

PRINCIPIUM

The Newsletter of the Initiative for Interstellar Studies

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STARSHIP ENGINEER

The Initiative for Interstellar Studies (I4IS), in collaboration
with the British Interplanetary Society,
Saturday 25th and Sunday 26th November 2017.

To be held i4is HQ,
Bone Mill, New Street, Charfield, Wotton-under-Edge, Gloucester,
GL12 8ES, UK

This course is being delivered by the Initiative for Interstellar Studies (a not-for-profit organisation incorporated in the UK in 2014).

We aim to help raise the skill levels of participants so that they can use some of the tools to start assessing deep space exploration concepts and even designing interstellar vessels. Two one day courses have been arranged, and you can either attend one or both, each will be different and important in their own way.

Starship Engineer

Starship Engineer - Saturday 25th November (1030-1730)

This course aims to give you a basic grounding in interstellar studies. We go from considering the essential requirements to giving you an overview of different spacecraft systems. We then take you on a journey through several actual starship design studies, and show you how to calculate and evolve an interstellar machine. We will give a broad set of examples from the literature, but focus on two specific case studies, that of fusion propulsion and laser-sail propulsion, as plausible ways by which we may someday reach the distant stars.

Science Fiction Starships

Science Fiction Starships - Sunday 26th November (1030-1730)

The works of science fiction literature have produced many fascinating starship concepts, but how realistic are they? In this one day course we will examine texts such as laser-sails in “The Mote in God’s Eye” (Larry Niven and Jerry Pournelle), Torch Ships in “Time for the Stars” (Robert Heinlein), Quantum Ramjets in “The Songs of Distant Earth” (Arthur C Clarke) and other inspirational examples of interstellar vessels. This course will teach you how to evaluate these ideas from the imagination and how to perform a physics and engineering assessment of their feasibility.

Education Requirements:

The courses are open to everyone and anyone is welcome to attend, but to participate in the design workshops it is recommended that you have some familiarity with basic mathematics and algebra.

Principal Lecturers:

Kelvin F. Long is a physicist and aerospace engineer, founder of i4is, until recently Chief Editor Journal of the British Interplanetary Society, author of the book “Deep Space Propulsion: A Roadmap to the Stars”, and a member of the Breakthrough Starshot advisory committee.

Rob Swinney is a former RAF Squadron Leader aerosystems engineer, Deputy Director and founder of i4is. Rob & Kelvin have been involved in creation and running of recent starship design projects using fusion and laser sails, Project Icarus and Projects Dragonfly & Andromeda.

Pricing:

Normal rate: £180 per day or £280 for the two days.

Discounted rate (students and senior citizens): £90 per day or £140 for the two days; includes students and senior citizens. Lunch and coffee will be provided on the day for all.

Contact Rob Swinney via info@i4is.org for details and how to pay.

Getting there:

Charfield is 10 minutes from M5 Junction 14, 30 minutes of Bristol Parkway station on the Great Western line and within one hours drive of Bristol (and its international airport) and Swindon. Accommodation options in the neighbourhood will be available.

Editorial

Welcome to Principium, the quarterly newsletter about all things interstellar from i4is, the Initiative for Interstellar Studies - and our US-based Institute for Interstellar Studies. And a special welcome if you are a new reader. If you were at SpaceUK 2017 in Manchester you may remember Rob Swinney, Tishtrya Mehta or John Davies - or at NEAS Starfest 2017 in Colchester, Marc Casson or John. Please tell us if we have your details incorrect (info@i4is.org).

Our Guest Introduction for Principium 18 is *Aridopolis : Project for a Sustainable Earth / Mars Desert Settlement* by an old friend and contributor to Principium, Stephen Ashworth. Stephen considers an incremental approach to prototyping off-earth human habitation. Much food for thought - if you will forgive a pun!

We bring you the second instalment of the major new work by Dmitry Novoseltsev, *Engineering New Worlds: Creating the Future*. This is a vision of the massive prospect of Interstellar Engineering. This month Dmitry examines the gigantic concept of the Shkadov thruster, "star machines" and the architecture of galaxies. The final parts will appear in our November issue.

Interstellar News this time has much to report including UK Space 2017 and other outreach work by i4is, recent results on earth-like planets, relevant items in the most recent editions of the Journal of the British Interplanetary Society, this year's interstellar elective at the International Space University, Strasbourg, events coming up in the next few months - and more.

Andreas Hein and Robert Kennedy report from the Foundations of Interstellar Studies Workshop which took place at the City University of New York in New York City in June. Next time we will have the first of a series of technical reports from the workshop by Kelvin Long. The Workshop was also the venue for a *Statement of Solidarity for The Interstellar Vision* agreed by consensus at the end of the Workshop.



Credit: Arianespace - ESA - NASA

The News Feature on our new HQ also announces a very distinguished guest for our opening in October.

The feature, Art for Interstellar 2017, reporting the visual art event at the NYC Workshop, is postponed to our next issue so we can give it proper space.

Our front and back covers once more reflect very different aspects of our outward urge.

Our front cover, C Bangs' painting, *Fusion Pulse Starship*, is a new vision

of a Daedalus-like craft at first-stage departure. C Bangs' art investigates frontier science combined with symbolist figuration from an ecological feminist point of view. More about her work in our next issue.

Our back cover is the 80th successful launch of the Ariane 5 heavy launcher. Its reliability gives us cause for hope when it lofts the James Webb Space Telescope next year - but we will nevertheless have our fingers crossed in superstition. Launching to space is not yet the safe and routine matter we must achieve if we are to take genuine steps to the stars.

Next time we will have -

- » Opening of the i4is HQ, The Mill
- » Technical Report on Foundations of Interstellar Studies Workshop
- » Art for Interstellar - NYC June 2017

And we will have the final instalment of Dmitry Novoseltsev's visionary *Engineering New Worlds: Creating the Future*.

Comments on i4is and all matters interstellar are always welcome. Write to me!

John I Davies, Editor, john.davies@i4is.org

Keep in touch!

Join in the conversation by following the i4is on our Facebook page www.facebook.com/InterstellarInstitute

Become part of our professional network on LinkedIn www.linkedin.com/groups/4640147

And take a look at the i4is blog, The Starship Log www.i4is.org/the-starship-log

Follow us on Twitter at @I4Interstellar and seek out our followers too!

Contact us on email via info@i4is.org.

Back issues of Principium, from number one, can be found at www.i4is.org/Principium

The views of our writers are their own. We aim for sound science but not editorial orthodoxy.

Aridopolis : Project for a Sustainable Earth / Mars Desert Settlement

Stephen Ashworth

“Waste is worse than loss. The time is coming when every person who lays claim to ability will keep the question of waste before him constantly. The scope of thrift is limitless.”

– Thomas Edison

In this article, Stephen Ashworth, one of our most visionary interstellar thinkers, turns his mind to human existence in off-earth environments with an idea based on earlier research and experiment, to move incrementally towards a self-sufficient settlement in a succession of increasingly alien environments. Stephen suggests i4is should address this as part of the space economy we need to fulfil our interstellar vision.

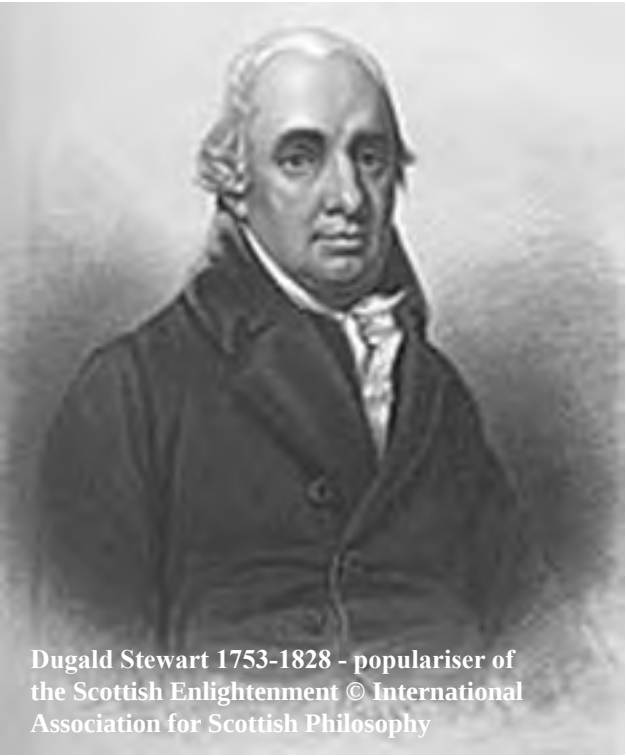
Sustainability and the human future

With the i4is now addressing the question of how to achieve a sustainable space economy that can act as a launchpad for interstellar exploration, the time has come to fill a major gap in sustainability research so far.

Human development over the past 10,000 years has taken our species far from its primordial state in which nomadic tribes supported themselves by hunting, gathering, scavenging and beachcombing. The neolithic agricultural revolution introduced a settled village lifestyle based on subsistence farming, while in Central Asia and North America a new kind of nomadic lifestyle developed on the basis of animal husbandry. Eventually many of the nomads too settled in villages, and a minority of the population built and occupied the first cities. Today’s cities remain dependent upon their agricultural hinterland, which is, however, highly mechanised, so that in developed countries the majority of the population is now urban. This overall picture of human development has been understood since the 18th century, when it first appeared as the “four stages theory” of the Scottish Enlightenment.

If human settlements are to arise on Mars or at any other extraterrestrial locations, they must of necessity include within their built structures all

the life-support provisions for food production and recycling of organic and other wastes. They will therefore represent a further stage of development, one which is totally urbanised with no agricultural hinterland. Given the high cost of creating surface conditions favourable to plant and animal life at such locations, the food production system will need to be more efficient than that in present-day use on Earth in



Dugald Stewart 1753-1828 - populariser of the Scottish Enlightenment © International Association for Scottish Philosophy

terms of both land use and energy consumption.

The same applies to worldships on multi-generational interstellar voyages. Such vehicles represent extreme space colonies, and their practicality will therefore depend upon a mature space colony industry having already grown up in the Solar System.

Meanwhile on Earth the population continues to grow in both absolute numbers and per capita wealth, and the resulting demands on the agricultural, mineral, oceanic and atmospheric hinterlands threaten ultimately to overwhelm the capacity of Earth's natural resources to supply them. Therefore the long-term solution for the maintenance of industrial civilisation on Earth itself is the same as that required on Mars and elsewhere in and between the planetary systems of the Sun and other stars: the materially self-contained city.

It should therefore be of wide interest to develop more self-contained ways of living

applicable both on Earth and beyond it. It is assumed here that, because of its relatively benign surface conditions and its closeness to Earth, Mars will be the first extraterrestrial location at which permanent human settlements will be established. If the low Martian gravity turns out to pose an insuperable health hazard then the alternatives are an [aerial settlement on Venus as described by Geoffrey Landis](#), or rotating O'Neill space colonies, but the need for a materially self-contained mode of life still applies.

This reasoning leads one to consider a project for developing and demonstrating the necessary recycling of life support consumables and hardware products through local processing and manufacturing, as well as social structures conducive to an attractive, growth-capable lifestyle. This should be achieved on Earth first; only once the system is mature can its extension to Mars or elsewhere in the astronomical universe be

realistically contemplated.

From time to time a wealthy individual or organisation is looking for an outlet for their surplus energies and resources. A project with direct application to the long-term sustainability of human civilisation both on Earth and at any and all extraterrestrial locations would use that surplus in a highly efficient way, and this is what is discussed here.

Earlier attempts

The Biosphere-2 experiment was intended to demonstrate a lifestyle which could be used in extraterrestrial colonies on Mars. It was designed to provide full recycling of air, water and food for a crew of eight people for two years. While the goal of enclosure of the eight bionauts in a biosphere independent of Earth for two years was largely met, with only one major outside intervention required during that time, several problems were revealed which will need to be addressed before further progress can be made.



Biosphere 2 - Credits: bio.ed.ac.uk/jdeacon Wikimedia
Johndedios

Chief among these problems were the division of the crew into opposing factions, the amount of manual labour required for them to maintain themselves through subsistence agriculture, and the Spartan nature of the resulting diet. Despite these adverse circumstances the crew toughed it out for two years. But they were only too happy to leave at the end of that period. No growth in either population size or duration of the biospherian lifestyle was planned or possible in practice, due not only to the hardships encountered in practice, but also to the high costs of maintaining the experiment, on the order of \$15 million per person per year (including both capital and running costs). No local manufacturing was attempted. Thus a sustainable lifestyle was not in fact achieved in terms of psychology, economics or hardware production, and only marginally achieved in terms of biology and food production. The various Mars simulation habitats operated by the Mars Society, by NASA and by ESA in collaboration with Roskosmos since the turn of the millennium are conceived as representing short-term missions, not permanent places to live, again with no capability for growth. While modest experiments in greenhouse food production are taking place, extending them to full recycling of the food supply does not seem to be a significant goal. All the Mars simulation experiments known to me which have been carried out so far are listed at the end of this article. There is therefore a need for a new Mars simulation experiment to be set up in order to address these shortcomings before any genuine settlement on Mars or beyond becomes possible.

Basic principles

Aridopolis is the name used here for a type of desert research community on Earth which develops systems for recycling, local manufacture and long-term sustainability and growth. It would be a successor to the Biosphere-2 and Mars simulation hab projects, picking up where they left off.

Aridopolis should be seen as the precursor to a new kind of urban living which has never existed before: the materially self-contained city, which does not require the support of an agricultural hinterland or a surrounding global economy. It will of course interact with the rest of the world as part of the global media network, will exchange knowledge and information, and will be able to purchase luxury items not essential for survival.

I intend Aridopolis to adhere to two fundamental principles:

- (1) It starts out with minimal recycling and makes incremental, step by step progress towards the kind of totally enclosed system envisaged by Biosphere-2.
- (2) It starts out small, with a population of perhaps a dozen individuals (depending on initial investment), and aims for long-term permanence and growth.

An ambitious growth rate of 7% per annum would see an initial 12-person settlement grow to several hundred after 50 years, 10,000 within a century, and millions after two centuries of growth.

These two principles define gradients of progress: cumulatively greater material independence through recycling, and cumulatively greater population size, allowing a cumulatively greater local skill

base to develop. While progress along these gradients continues, Aridopolis will be successful; if progress stops short of a fully self-contained city, then at that point it will fail.

The basic principles suggest development in three practical phases, with a preliminary phase zero as the planning phase:

- (0) Planning and design.
- (1) Small community, accessible location in developed country.
- (2) Move to remote desert location, settle in and begin expansion.
- (3) Adopt enclosed architecture.

A substantial initial investment of perhaps several million pounds will be required in order to start the first practical phase. The cost of starting phase 2 will depend upon how far local desert construction can be made independent of outside support at the outset, to be determined during phase 1.

The question is whether it would be worth starting on the planning phase in the absence of any firm prospect of financial backing. It would be preferable to engage the interest of potential sponsors first, and proceed on the basis that the preliminary studies, if successful, were likely to lead directly on to practical implementation.

Preparatory research

The following areas of research all need to be addressed in the preliminary planning phase, before phase 1 can begin:

- * Utopian societies: why they fail / how to prevent failure
- * Small-scale food production
- * Small-scale recycling of liquid and solid human waste
- * Small-scale recycling of material products (clothes, furniture, hardware items)

- * Small-scale power supply
- * Drawing up an overall financial plan

* Choice of a location for phase 1.
During phase 1 the following research areas will be added:

- * Choice of a location for phase 2, and obtaining permission from the local political authorities
- * Small-scale resource extraction from the types of rock to be found in phase 2.

More needs to be said on the financial plan. It is clear that such a project cannot begin without philanthropic sponsorship. At the same time, the ultimate objective must be to have a self-sustaining, thus independently profitable, community. Since development of Aridopolis on a timescale on the order of a century will be needed before all essential skills and manufacturing capabilities are present within the community, it will need to transition as soon as possible to earning its keep in the existing global economy through exports of some description. Some care needs to be devoted to designing this aspect of its activities.

First phase: an experimental station

Phase 1 entails occupation of an estate consisting of a large house with garden in some rural location in the developed world, thus the typical kind of location for a utopian society. Here a small number of people, perhaps starting at half a dozen and building up from there, install and develop basic recycling procedures for food and for whatever other consumables and material items lend themselves most readily to recycling. An electrical power system independent of the national grid must be set up. Ease of access from the global

industrial economy is more important than isolation from it at this point, because life-support systems are still being developed. But looking ahead, once a desert location for phase 2 has been decided upon, techniques for mining, refining and manufacturing from the rock types that will be available there must be developed.

Specialists will need to be recruited in a number of technical disciplines, each of which will have its own team. The project should be funded sufficiently to allow all the people involved to draw full salaries for their work. At this stage, the community is still part of the wider economy and people can come and go as they please or as their contracts allow.

Second phase: the move to the desert

Once the estate has been functioning smoothly for a few years and has made sufficient progress to act as a basis for the next step, a new community is set up in a more remote location. This will be Aridopolis proper. Its location will still inevitably lie within the jurisdiction of one or another nation state, and will therefore need the political acquiescence of that state.

The requirements for isolation from the global economy and politics, and for relevance to Mars and space colonisation, suggest a location in one or other of the major world deserts. A moderately high-latitude location would provide a realistic Mars analogue environment in terms of cold, lack of vegetation, reduced sunlight, cost of access and general unattractiveness as a place to live permanently. The ultimate challenge of a Mars colony would be to turn its initially unattractive,

hostile environment into a highly desirable one.

An initial settlement would consist of a number of buildings, as in any normal town. Each building is exposed to the general desert environment, and roads and open areas will still be part of that environment.

The move to the desert will only make sense if the food is as tasty, nutritious and economic to produce as the best and cheapest food that can be made under normal conditions. Therefore there is an opportunity to use the food production technologies developed in phase 1 to produce food which can be marketed globally by a separate branch of the organisation.

Third phase: creating a micro-environment

Once a substantial local economy has been built up, with large-scale production, using local resources, of construction materials such as glass, plastics, fibre-reinforced composites, metals and concrete, the third phase consists of enclosing the entire settlement under a transparent roof with a ceiling height of several tens of metres. Thus a worldhouse is formed containing a micro-environment more hospitable than the surrounding desert: warmer and moister, and if at high altitude then also holding a higher atmospheric pressure, as would be needed on Mars. Existing analogues include enclosed shopping malls, the Biosphere-2 structure, and the multi-dome Eden Project in Cornwall.

There is interesting work being done on biological processes for making building materials and eventually entire buildings, and these need to be explored to the full (see for example: www.fastcodesign.com/3068583/)

[the-quest-to-grow-cities-from-scratch](#)).

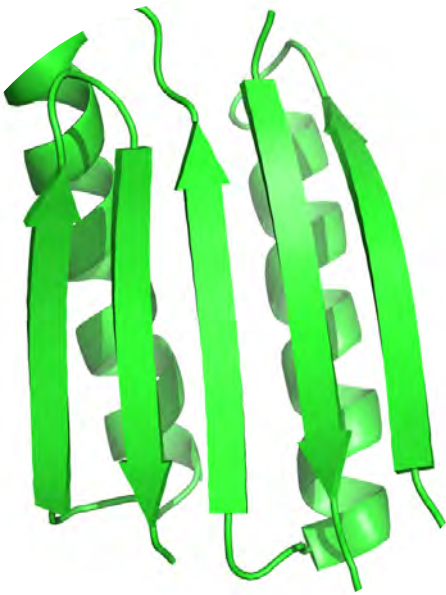
The ceiling need not necessarily be a dome, which is a geometrically inefficient shape. It would more probably be flat, either completely level or else built of sloping segments to form a low, multi-faceted pyramid. The outer walls might be 10 to 20 metres high, the central peak 50 to 100 metres high, in a structure hundreds of metres to a kilometre across. The open space between individual buildings can be landscaped and planted to create parkland with trees, bushes, birds and other wildlife.

The worldhouse developed in the Aridopolis project is a semi-sealed environment in which, to all the other recycling mechanisms in use, recycling of air is added. Full atmospheric recycling is not necessary for terrestrial surface living, but is essential for extraterrestrial colonies. While it may appear to be a trivial matter of converting carbon dioxide back to oxygen and scrubbing out impurities, the sealing off of a low-buffer environment from the global atmospheric circulation introduces issues of microbiology and accumulation of trace gases which may not be so easy to solve. The worldhouse can approach this problem gradually with an air-conditioning system which makes progressively less use of the external desert air.

Thus Aridopolis is intended both for its own sake, and as a stage that leads in due course to its Martian equivalent: Areopolis. Two major differences are that on Mars fully hermetic sealing is essential, and a ceiling thickness of several metres necessary in order both to balance the pressure difference and to

provide shielding from galactic cosmic radiation. In a Martian worldhouse, it is envisaged that a roof consisting mainly of locally manufactured glass lets in a certain amount of daylight, supplemented by internal electric lighting.

Once hermetically sealed environments on this scale have been qualified to support permanent human occupation on Earth, they are then ready for adaptation for extraterrestrial use. If by this point in time progress in space technologies has brought down the cost of transport to the point that access to Mars is practical, then a Martian colony may be set up. This is not realistically likely to happen before the middle of the 21st century, as the cost of access



to orbit still has to fall by two to three orders of magnitude from its present level.

Meanwhile the first desert settlements on Earth need to grow into true cities with thousands of permanent residents in order to demonstrate the attractiveness of the lifestyle. A number of individual worldhouses could be built adjacent to each other, with connecting tunnels or bridges making it possible to move from

one to another without going out into the desert, as one would do on Mars. Permanent settlement of Mars cannot realistically proceed until the worldhouse lifestyle has been demonstrated to be sufficiently civilised and attractive that comfortable family life is possible there.

In addition to the requirement for material recycling, any small-scale sustainable industrial society has to innovate in two further major areas:

- * Governance: social systems for decision-making and conflict management
- * Maintaining professional expertise: education and division of labour.

The importance of the first of these is emphasised by the conflict-ridden history of Biosphere-2. The second point (and in the longer term the first as well) will be strongly affected by developments in artificial intelligence ongoing at present.

All the trends necessary for

computationally designed protein,
Credit Pablo.gainza/wikimedia

Aridopolis are already in progress: urbanisation of the world's population, food supply from urban vertical farms, full air-conditioning in skyscrapers and shopping malls, use of vegetable protein as a meat substitute, automating of construction through robotics and biological production methods, lowering of the cost of access to space, and experimenting with independent habitable space on the sea surface. The challenge of Aridopolis is to bring all of these disparate trends together into a single settlement.

[Desert location](#)

The requirements for a Mars-analogue desert colony are:

- * Stony landscape, free from vegetation
- * High altitude above sea level
- * Plentiful sunshine in generally cloud-free skies
- * Negligible precipitation of rain or snow
- * Subsurface water available
- * Cold climate
- * Physical isolation
- * Sympathetic government
- * Local geology suitable for extraction of raw materials.

Subtropical deserts (eg Sahara, Kalahari, Great Victoria) are at first sight unsuitable, being too hot to serve as Mars analogues. As settlement locations in their own right they would be difficult to keep cool. But note that Sundrop Farm in Australia has solved this problem, which might bring subtropical deserts back into consideration (www.newscientist.com/article/2108296-first-farm-to-grow-veg-in-a-desert-using-only-sun-and-seawater/).

Polar deserts in the Arctic and Antarctic are unsuitable since they have little or no sunshine in winter. Their settlement would require a more advanced power technology, thus nuclear fission or fusion, or else some means of transmitting power, which certainly rules them out for the time being.

Of the temperate zone deserts, and taking into account the preference for a European political presence in the region, the best candidates might then be the Great Basin and Colorado Plateau deserts in the USA, the Namib desert in South Africa, and the Atacama and Patagonian deserts in South America. As noted above, an efficient cooling system would bring the hot Australian deserts back into contention. If it proves possible to work with Central

Asian governments, the Kara-Kum, Kyzyl-Kum and Gobi deserts would also be worth consideration. It is assumed that China and especially Iran would be too difficult to work with.

If the zero vegetation requirement is relaxed, the world's semi-arid steppe regions come into play. While not simulating the look of Mars, these would be equally valid test locations for sustainable closed-cycle technologies.

Sparsely populated regions in the UK such as the Scottish highlands and islands might be attractive, in places where local hydroelectric power is available. One notable possibility, with or without local vegetation, is Iceland, due to the availability of geothermal power. Since the present-day population of Iceland is only a third of a million, there may be more of a political constraint on the growth of an Icelandic Aridopolis than on one in say Australia or the USA. On the other hand, having created one settlement in Iceland, the project can then well set up others at other locations.

Aridopolis should not be thought of as a unique experiment, but rather as a prototype for a whole new class of cities, whose technologies and social structures will also find application in existing cities. The name will not necessarily be used for an actual settlement, since particular locations may suggest names more in keeping with the local terrain or culture.

Language

If an Aridopolis settlement is created in a non-Anglophone country, it will be necessary for the official language of that community to be the local national one. This is required both as a courtesy to the local government and population, and

as a statement of permanence. Since the citizens of Aridopolis will certainly be drawn from around the world, as is usual in experiments of this type, a certain amount of language learning will be going on in any case.

In my own view, this increases the attractiveness of Iceland. Others may disagree, preferring the Gobi desert because the Mongolian language sounds like a softer version of Klingon.

Neither the cultural identification with Vikings, nor that with Mongols/Klingons, is likely to reassure those on the Left who worry about imperialist stereotypes.

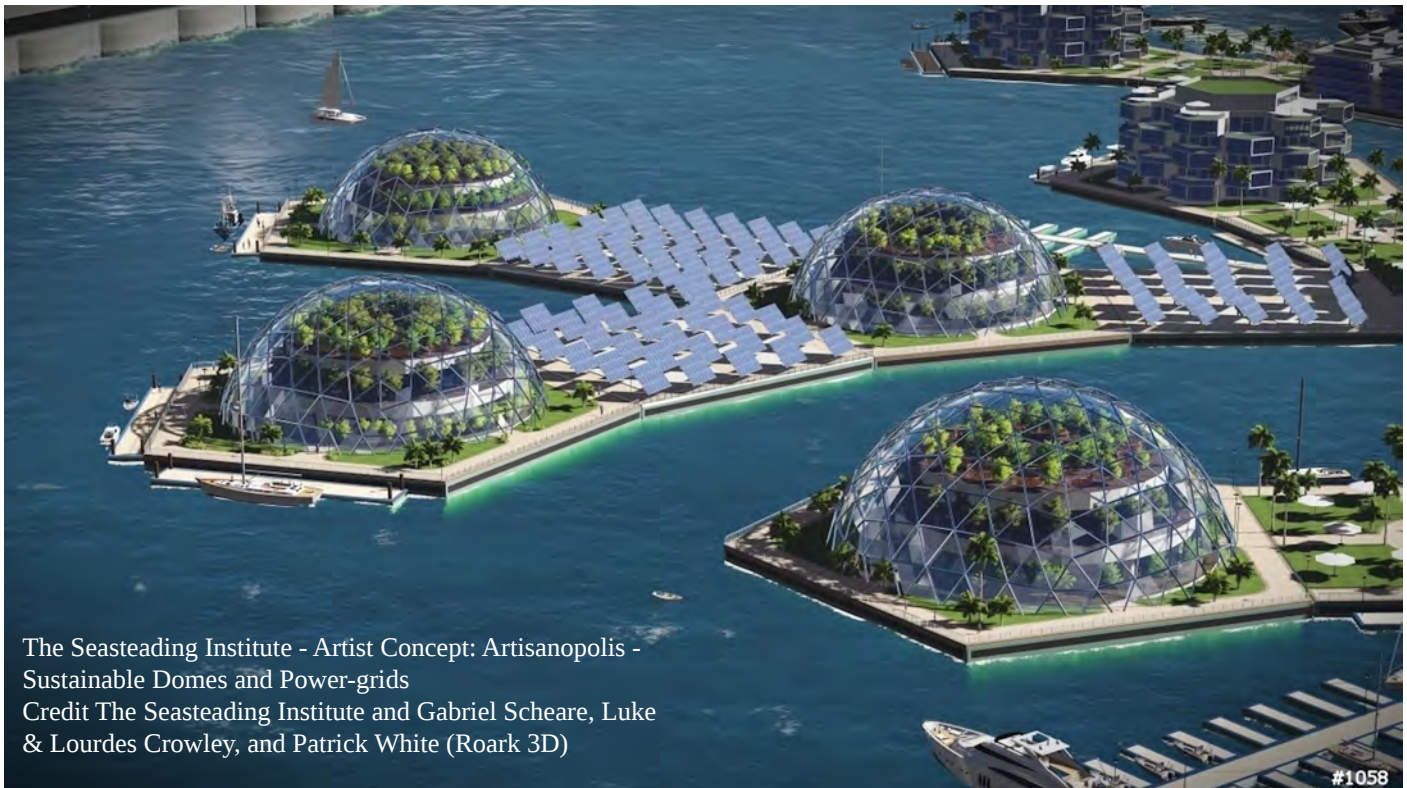
Long-term developments

Assuming that the first Aridopolis functions successfully, after some years political constraints are likely to begin to interfere with its growth, even at a desert or semi-desert location. What is ultimately needed, if political independence is to be assured, is a terrestrial location outside the jurisdiction of any nation state, where growth can continue into the millions. The only location which satisfies that criterion is the surface area of the tropical oceans, drawing upon Marshall Savage's plan in his book *The Millennial Project* to construct floating islands by pulling calcium carbonate out of seawater to make sea-derived cement.

An attempt to realise this vision is now proceeding under the auspices of The Seasteading Institute (www.seasteading.org/). Again, it will be at least some decades before Seasteading has become a mature technology.

Power supply

Geothermal power is available at certain locations on Earth (notably Iceland), and probably also at specific locations on Mars



(Zubrin, *The Case for Mars*, chapter 7). But, unless nuclear power is available, the only power source which is generally accessible in desert environments on these planets is solar. This has the advantages of long-term sustainability of the power source (the Sun), and of a well-developed existing technology base. The disadvantages on planetary surfaces are that large land areas are needed for power capture, and that batteries, fuel cells or some functional equivalent must be used to convert the intermittent input into an output that is constantly available over the day/night and seasonal cycles.

Nuclear power is high-tech and politically controversial. It is therefore assumed here that the power supply for Aridopolis will be drawn from some sort of batteries, which are recharged during the day from solar photovoltaic arrays.

On Earth's surface the insolation, averaged over day/night and seasonal cycles, is on the order of 150 W/sq metre. Assuming this is passed to the power grid at

20% efficiency, the power system has an output of 30 W/sq metre. If waste heat from the batteries can be used for space heating, the photovoltaic cell efficiency would then dominate the overall efficiency.

The industrial power requirement per person in the UK is around 5 kW. If we apply this to Aridopolis then each person will need 170 square metres of solar arrays. A town of 10,000 people will need 50 MW generated from 1.7 million square metres, or a square 1.3 km on a side. (Sundrop Farm generates up to 39 MW, so averaging presumably less than that.) At a moderate urban population density of 2000 people per square kilometre, the solar arrays would represent 34% of the land area required.

The solar arrays and power storage systems need to be manufactured from local resources, thus basically surface rocks, in order to allow the city to grow without having to import large quantities of material resources. Designing them, and their manufacturing plant, will

require its own research project.

Another question is the power supply required per person. A figure of 5 kW for the present-day UK was used above, but this is for industrial power consumption only. In addition, that person eats plant-derived foodstuffs which have used free solar power which is not accounted for in their industrial power allowance. It is not yet clear exactly how much industrial power per person will be needed to manufacture the equivalent mass of food through artificial means within the colony. A reliance on solar power would force the phase 2 settlement site to be well outside the Arctic and Antarctic circles. As noted above, an exception would be a settlement in Iceland based on geothermal power, which is in use in Reykjavik.

List of biosphere / Mars simulation experiments

The following information is from Wikipedia and from the Mars Society website. The first two listed, BIOS-3 and Biosphere-2, were focused on closed-cycle biospherics. The remaining projects focus on the traditional space agency Mars mission with little interest in closed-cycle living, though the Mars Desert Research Station does operate a greenhouse and carries out experiments in crop-growing.

BIOS-3: 1965-1984, Institute of Biophysics, Krasnoyarsk, Russia. Activities resumed in 2005 in collaboration with ESA. BIOS-3 facilities were used to conduct ten manned closure experiments with a one to three man crew. The longest experiment with a three-man crew lasted 180 days (in 1972-1973).

Biosphere-2: 1991-1994, private venture by Space Biosphere Ventures. Facility at the base of the Santa Catalina Mountains (elevation 1.2 km above sea level) in Arizona, USA. Missions:

- (1) 1991-1993: 8 people for 2 years
- (2) 1994: 7 people for 6 months.

Flashline Mars Arctic Research Station: constructed 2000, missions 2001 onwards, private venture by the Mars Society. Facility at Devon Island, Canada. Crews of 6 to 7 individuals live and work there for typically one month during the Arctic summer.

Mars Desert Research Station: 2001 onwards, private venture by the Mars Society. Facility at San Rafael Swell, Utah, USA. Crews of 6 to 7 individuals live and work there for 2-3 week

missions during the December to May period (the summer months are inconveniently hot for Mars simulation experiments).

Mars-500: 2007-2011, Russian/European/Chinese space agency collaboration. Facility set up at the Institute of Biomedical Problems in Moscow. Missions with six crew members in each case:

- (1) 2007: 15 days
- (2) 2009: 105 days
- (3) 2010-2011: 520 days.

Hi-SEAS: 2013 onwards, NASA/University of Hawaii/University of Cornell collaboration. Facility on the Mauna Loa volcano in Hawaii. Missions:

- (1) 2013: 8 people for 4 months
- (2) 2014: 6 people for 4 months
- (3) 2014-2015: 6 people for 8 months
- (4) 2015-2016: 6 people for 1 year
- (5) 2017: 6 people for 8 months (continues at time of writing)
- (6) 2018: an additional 8-month mission is planned.

The Edison quote at the head of this article is from: Forbes (1958), p.170; also in American Opinion, vol.22 (1979), p.41; also in T D MacGregor, The Book of Thrift: Why and how to Save and what to Do with Your Savings; a Book of Inspiration and Practical Help (1915), p.344 (according to izquotes.com/quote/55889).



Facility on the Mauna Loa volcano in Hawaii.
Credit: Hi-SEAS NASA/University of Hawaii

About the Author

Stephen Ashworth has been a BIS member since the 1980s, and associated with i4is since its foundation. He has written numerous articles for Spaceflight magazine (most recently one on Mars settlement in the April 2016 issue), and several of his technical papers have appeared in the Journal of the BIS. He is the author of a full-length science fiction novel, The Moonstormers, available online (www.smashwords.com/books/view/260248); a novelette, "Half-way There!", in the collection Visionary, published by the BIS and available on their website; and a short story, "The Marchioness", inspired by the recent movie The Martian. He blogs at Astronautical Evolution (www.astronist.co.uk/astro_ev/ae_index.shtml). He works in academic publishing at Oxford University and plays jazz saxophone.

Interstellar News

John Davies and Patrick Mahon with the latest interstellar-related news



Rob Swinney addressing secondary school teachers at UK Space 2017



John, Marc and Terry at NEAS Starfest 2017

i4is Outreach

The bi-annual **UK Space conference** was in Manchester this year - 30 May - 1 June. i4is was in the Outreach section of the conference. Rob Swinney, Tishtrya Mehta and John Davies enjoyed talking to visitors of all

ages and meeting colleagues from other organisations, especially of course, the British Interplanetary Society.

The North Essex Astronomical Society held its annual **Starfest** on 15 July, Marc Casson and John Davies met many amateur

astronomers and acquired new friends for i4is. This year we were pleased to be next to Terry Regan, our favourite model maker, who is a long term NEAS member.

More about Terry and his magnificent models in *Principium* issues 13-15.

Interstellar Workshop, NYC, June 2017

The Foundations of Interstellar Studies Workshop, June 13 – 15, 2017, is extensively reported elsewhere in this issue. We will be featuring more in our next issue. There is also a day by day summary by the co-chair, Kelvin Long, in i4is.org/blog/ - *Foundations of Interstellar Studies: Monday 12 June 2017 (social-cultural night & art exhibition) / Tuesday 13 June 2017 / Wednesday 14 June 2017 / Thursday 15 June 2017* ending with *Foundations of Interstellar Studies: Solidarity for the Interstellar Vision* (see the **Statement of Solidarity** in this issue) plus a final *Foundations of Interstellar Studies: Post Workshop Wash-Up*.

JBIS News

The Journal of the British Interplanetary Society (JBIS) continues to feature significant work in interstellar studies. Since the last issue of Principium in May 2017 we have seen -

JBIS vol 69 No 9/10, received May 2017

Staggered Launch Sequences for Fleets of Interstellar Worldships by our friend and colleague, Stephen Ashworth, also featured elsewhere in this issue. Stephen addresses the problem for worldships that fleets are necessary for mutual support but which, due to their high cost, are constructed and launched individually from the Solar System. He considers three scenarios by which such a fleet rendezvous may be achieved.

JBIS vol 69 No 11, received June 2017

Navigation to the Alpha Centauri Star System by Roderick A Smith, Suneel Sheikh and i4is Deputy Director, Robert W Swinney considers that ancient method, navigation by measuring angles to known stars which, even for the relatively close case of an Alpha Centauri journey requires refinement since parallax errors occur. Distances to the stars

cannot be treated as infinite, as in terrestrial stellar navigation.

Granularity and Ambiguity in Navigating the Void by Roderick A Smith and Robert W Swinney is a companion paper considering the issues of navigating within the generic interstellar void explaining aspects of autonomous interstellar navigation peculiar to interstellar missions - such that existing techniques will need to be adapted or re-designed.

Examination of the Biefeld-Brown Effect for the Case of a Symmetric Parallel Plate Capacitor by Curtis L Promislow and Andre P Mazzoleni of North Carolina State University considers whether an effect traditionally used to describe the force created by an asymmetrical capacitor might have a similar effect in parallel plate capacitors, potentially leading to propulsion systems that could revolutionise space travel.

That is not Dead Which can Eternal Lie: The Aestivation Hypothesis for Resolving Fermi's Paradox by Anders Sandberg, Stuart Armstrong and Milan Ćirković of the Future of Humanity Institute, Oxford, and the Astronomical Observatory of Belgrade considers that the reason we are

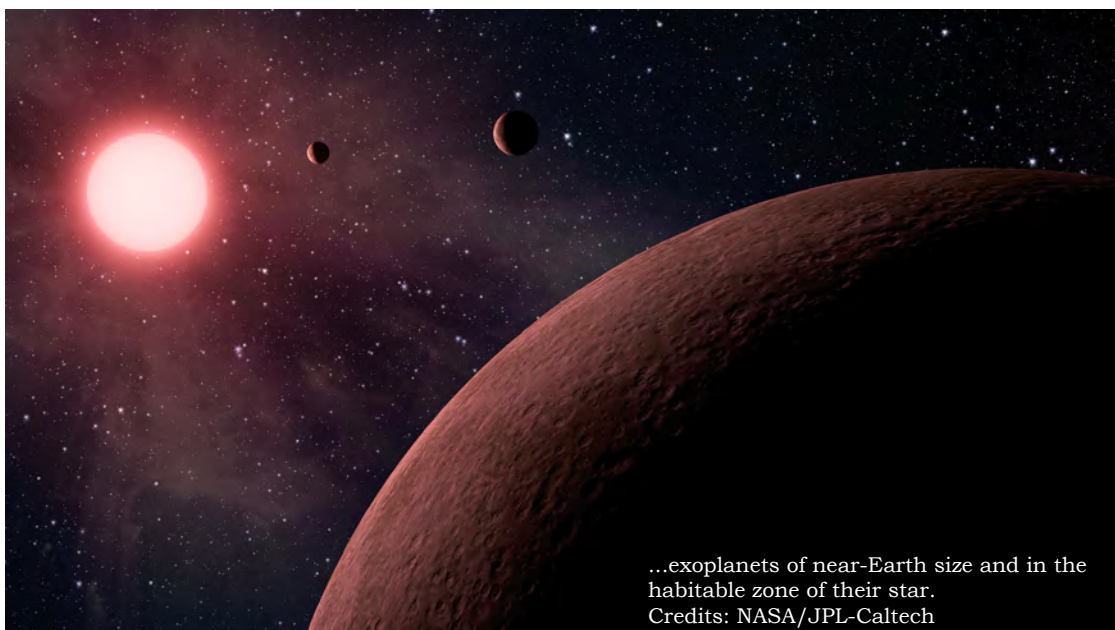
not observing manifestations of alien civilizations is that they are currently (mostly) inactive, patiently waiting for future cosmic eras.

JBIS vol 69 No 12 received July 2017

Quantifying the Assumptions Behind the METI Debate also by Stephen Ashworth sets the debate about whether or not it is acceptable to transmit speculative messages to nearby stars in the hope of attracting the attention of their hypothetical inhabitants in a probabilistic context.

The Oculus Project: Gravitational Lensing, Earth-Like Exoplanets and Solar Sailing by P Murzionak and Prof Chris Welch of the International Space University and Gregg Matloff of City University, New York describes a conceptual study to design a solar sailing interstellar precursor mission using gravitational lensing of the Sun to study Earth-like exoplanets at the centre of the Milky Way.

All the founding members of i4is are long-established members of the BIS. Why not join this, the world's longest-established space advocacy organisation (www.bis-space.com/eshop/why-join)?



...exoplanets of near-Earth size and in the habitable zone of their star.
Credits: NASA/JPL-Caltech

Ten new 'candidate Earths' identified in data from NASA's Kepler telescope

On 19 June, NASA announced the publication of the final catalogue of exoplanets identified by the Kepler telescope during the first four years of its mission, between 2009 and 2013, when it was focused on a small patch of sky in the constellation of Cygnus. Preliminary results from this data have previously been announced, but the final publication includes 219 new exoplanets, of which 10 have been calculated to be roughly the size of the Earth and orbiting at a distance from their parent star that puts them within its habitable zone, where temperatures would be suitable for the presence of liquid water, a likely pre-condition for life to exist.

In total, the catalogue includes data on 4,034 exoplanets identified by Kepler, of which 50 are potential Earth analogues. Over half of these candidates have been verified by subsequent observations. Such a large dataset will help exoplanet researchers to better understand the statistical distribution of exoplanets in the galaxy, in terms of the average number of planets per star, their distribution of sizes, from small, rocky planets like Mercury or the Earth to large gas-giants like Jupiter or Neptune, and the proportion that might have the potential to harbour life.

The Kepler telescope identified these exoplanets using the transit method, where minute but regular dips in the amount of light received from a star indicate the presence of a planet whose orbit round the star is aligned such that



Artificial Intelligence in Interstellar dramatisation by Holly Spence at ISU

the planet passes between the star and the Earth periodically. The Kepler mission continues, but after problems emerged with the ability to point the spacecraft at a specific target, since 2014 the telescope has been focused on new areas of the sky in the plane of the ecliptic, looking in particular for exoplanets around smaller, dimmer, red dwarf stars.

More details can be found at www.nasa.gov/press-release/nasa-releases-kepler-survey-catalog-with-hundreds-of-new-planet-candidates.

ISU elective 2017

The relationship between i4is and the International Space University, Strasbourg, dates back to the foundation of i4is. In recent years we have added a two-week elective for the Masters of Space Studies students to our ongoing supervision of Masters projects. This year we updated the programme from 2016 and delivered new elements. Modules on Advanced Propulsion Systems were expanded adding - M8-ISR-L15 Advanced EP Systems for Interstellar Precursor Missions (delivered by Angelo Genovese). We added M8-ISR-L19 An Introduction to Radiation Shielding (Sam Harrison) and M8-ISR-L20 The Local Interstellar Medium (Professor Ian Crawford, UCL). We also added M8-ISR-L21 Artificial Intelligence in Interstellar

(John Davies with a dramatisation by Holly Spence, East 15 Acting School, University of Essex) and M8-ISR-L05 Infrastructure and Next Steps (Richard Osborne).

Red Dots Project aims to find further nearby Earth-like planets

In August 2016, the Pale Red Dot project announced through the journal Nature that they had found the nearest potentially habitable exoplanet to our Sun. Proxima Centauri b, as it has been labelled, is an Earth-sized planet orbiting within the habitable zone of the red dwarf star Proxima Centauri, 4.2 light years away.

As a follow-up to this work, the Red Dots project has been set up to search for further terrestrial exoplanets orbiting other red dwarfs near our Sun. During 2017, the project will focus on three

nearby stars: Proxima Centauri again, where they are looking for further planets; Barnard's Star, some 6 light years away, where the search is on for any planets at

nearest neighbours as it develops. If you'd like to know more, they are on Twitter and Facebook at @RedDotsSpace, or their website is at reddots.space.



all; and Ross 154, 9.7 light years away, where the rapid rotation of the star makes exoplanet detection very challenging.

The Red Dots project has chosen to focus on smaller red dwarf stars, rather than those more like our own Sun, because the lower mass of these stars – as an example, Proxima Centauri has a mass only around one-eighth that of our own Sun – means that it is easier to detect the signal of a small, rocky planet orbiting them using the chosen radial velocity method, which looks for periodic Doppler shifts in the light from the host star.

One of the most exciting aspects of the Red Dots project, as with its predecessor Pale Red Dot campaign, is that the team of scientists will be sharing their observational data over social media in real time, so that the entire community can get involved with the search for our

"When will we go to the stars?" - William Perkin High School anniversary

John Davies returned to William Perkin High School in west London for their annual Founder's Day. He talked to two year 9 (age 13 to 14) groups and one year 8 (age 12 to 13) group asking *When will we go to the stars?* Founders Day always has a famous guest and this year we heard much history and wisdom from Dame Jocelyn Bell-Burnell, the pulsar pioneer and powerful advocate for women in science - an inspiring speaker! And there were presenters from the Royal Observatory, Imperial College and from the Mullard Space Science Laboratory of University College London (UCL) so we were in good company.

Interstellar Challenge 2017

As we have reported earlier, the second running of the i4is Interstellar Challenge for Schools is planned for 2017. However, our planned venue has experienced some internal difficulties so we are looking for an alternative. London is just one option but the venue does need to be an easy day-trip for schools. Please get in touch if you have a venue suitable for 6-8 teams of 6-8 school students later this year - john.davies@i4is.org is the best route.

Dame Jocelyn Bell-Burnell opens a new lab carrying her name at William Perkin High School Founders Day Friday 12 May 2017, Credit: William Perkin High School

RI Space and New Scientist live

i4is will be at two very different events in the next 3 months:

ReInventing Space (rispace.org), organised by the British Interplanetary Society, is an annual conference and exhibition dedicated to low cost access and utilisation of space. It is the largest conference worldwide in this important sector. This year it runs 24-26 October at Strathclyde University's Technology and Innovation Centre, Glasgow, Scotland. i4is will be there. Look for us in the Exhibition space.



Logo of ReInventing Space

New Scientist Live (live.newscientist.com) is the major science outreach event from New Scientist magazine. This year it is at ExCel in London's Docklands, 28 Sep - 1 Oct. We aim to be there alongside guests ranging from novelist Margaret Atwood to Apollo 15 Astronaut Al Worden featuring at the BIS stand.

Congratulations to Icarus Interstellar

Icarus Interstellar raised their crowd-funding target of USD 15,000 (EUR 12,700/GBP 11,300). Their 2017 event (www.icarusinterstellar.org/pages/starship-congress-2017) has a very distinguished cast list including Miguel Alcubierre, most recently mentioned in our last issue. i4is wishes Icarus Interstellar all the best for the show!

Awards for i4is Technical Director

Dr Andreas Hein, Technical Director of i4is and currently Acting Executive Director, has received the "Willy Messerschmitt Award" from the Technical University of Munich (TUM) for the best aerospace engineering PhD thesis this year. His thesis entitled "Heritage Technologies in Space Programs – Assessment Methodology and Statistical Analysis" presents a statistical analysis of heritage technologies, the “carry-over parts” so often employed in risk reduction for complex space programmes. Andreas' work yields empirical relationships between these heritage technologies and the performance of space programs. Prof. Vogel Heuser gave the laudatio, saying, "The next PhD thesis literally takes us to the stars." And Andreas' thesis (www.researchgate.net/publication/310478449_Heritage_Technologies_in_Space_Programs_-_Assessment_Methodology_and_Statistical_Analysis) has numerous references to chipsat system design, highly relevant in his leadership of our i4is work on Project Glowworm (i4is.org/what-we-do/technical/project-glowworm).

Project Glowworm is currently working on a functional prototype for its attosat (<10 gram spacecraft). The team is also producing a technology roadmap for attosats to serve as a baseline for the project and also for the attosat community.

Andreas has also received the International Systems Engineering Honor Society award for an Exemplary Systems Engineering Doctoral Dissertation (omegalpha.org/se-dissertation-showcase).



Andreas (right) receiving his award at Technical University of Munich (TUM):

Left: **Prof Dr-Ing Birgit Vogel-Heuser**, Chair of the Institute of Automation and

Information Systems, Department of Mechanical Engineering Technical University of Munich (TUM)
Centre: **Prof Dr-Ing Nikolaus A Adams**, Dean of the Faculty of Mechanical Engineering and Chair of the Institute of Aerodynamics and Fluid mechanics, Department of Mechanical Engineering, TUM

Photo credit: Tobias Schubert



Vehicle static firing stand at Spadeadam, Cumbria

images: John Davies

Social

A group of **old and young rocketeers got together in Cumbria** in July to discuss and reminisce about a time when the UK built moderately big rockets. Organised by the BIS History Committee and Executive Secretary Gill Norman, the visit to the former static firing site at Spadeadam was led by [Alan](#)

[Bond](#) who provided a substantial briefing based on his experience with rocket engine development for Rolls Royce, who ran the site, also featured in the latest BIS Spaceflight (*A visit to Spadeadam* in Spaceflight Vol 60 September 2017).

Pictures from John Davies, who also remembers *Bluestreak*, *Europa* and *Spadeadam*.



Alan Bond (left) reminiscing with Gerry Webb (umbrella)



And finally, when in Berlin drop in and see the Cosmonaut encountered on a recent trip.

NEWS FEATURE - Headquarters of the Initiative for Interstellar Studies

John I Davies

The new headquarters of the Initiative for Interstellar Studies is in the English county of Gloucestershire. Informally known as the Mill, it was part of the early industrial revolution. Let's take a look at this historic building before its formal opening on 8 October 2017 featuring Apollo 15 Astronaut Al Worden.



Credit: Kelvin Long

A headquarters building needs to be iconic, accessible and practical. The Mill fulfils these criteria with ease.

[History and Architecture](#)

The Mill was built around 1812; the Napoleonic Wars (Guerres Napoléoniennes) were still raging and Britain even had some unpleasantness with the young

United States ("rockets red glare" and all that) - all these long since forgiven we hope!

The industrial revolution had yielded cast iron but not yet mass-produced steel. Steam power was in its infancy and industry needed water power as a reliable motive force. The small cluster of mills to the north

of the village of Charfield were presumably built there because of the presence of the Little Avon river. The mills included the Pin Mill and the Bone Mill, the latter being our new HQ building. The construction mixes brick-enclosed rubble for the external walls, cast iron columns for the vertical structure internally and large oak



The mill race
Credit: Kelvin Long

beams supporting the 4 floors - apart from one with what must be very early RSJs - or a later replacement. A milestone building bringing industry to a formerly rural area. Unlike the major towns and cities further north, industry has not persisted in Charfield and you approach the small cluster of mills through a short stretch of countryside north of the main village. The motive power for the mills came from a mill wheel which no longer exists but the mill race and associated sluice are still there.

Transport

The Mill is 3.5 miles from Junction 14 on the M5 motorway with connections to all major centres in the UK. This brings it within less than 30 minutes drive from Bristol Parkway station and thus the main line from London Paddington station. And it's 45 minutes from Bristol Airport and multiple direct flights per day from Paris, Frankfurt, Brussels, Amsterdam and Munich.

Practical

The Mill has four office-style floors with no fixed divisions, including three floors with 3 m ceilings and so it is very practical. i4is also has use of the basement which will be adapted as lab, workshop and storage space.

i4is in the Mill

i4is volunteers and local contractors have already been busy preparing our new HQ at the Mill. The meeting space and library is already in use - though the shelves are not yet populated. The HQ will be ready for the formal opening on 8 October by NASA Project Apollo 15 astronaut Al Worden. He famously said "Now I know why I'm here. Not for a closer look at the Moon, but to look back at our home, the Earth".

Watch our blog, Facebook page and Twitter for news of this. Naturally it has to be an invitation-only event and invitations will be going out soon. The presence of an Apollo astronaut will naturally create wide interest but we can only accommodate limited numbers.

Contact us on info@i4is.org if you have any questions about the opening.



Library and meeting space

i4is & CUNY, NYC June 2017

Report from Foundations of Interstellar Studies Workshop

Andreas Hein

i4is Technical Director Dr Andreas Hein was at this historic event. Here are his impressions of the first two days.

Opening dinner:

The workshop started with the opening dinner at the Harvard Club of New York City in Manhattan, a prestigious venue. Entering the Harvard club and making my way to the dinner ball room, Sonny White, who is currently working on warp mechanics at NASA is handing me the conference badge and Elena Ancona, who has been basically responsible for the conference administration hands out the conference package. Entering the ball room, a crowd of well-known interstellar people has already gathered, including Louis Friedman, one of the co-founders of the Planetary Society, Phil Lubin and Greg Matloff. Various art pieces have been set up in the room, featuring artists such as David A Hardy, Adrian

Mann, Alex Storer, C Bangs, Kari Weatherbee and others. Last but not least Kelvin has brought with him the original Cosmos starship drawings of Rick Sternbach, who has also been a concept artist for Star Trek.

Musicians played classical music in the background which contributed to a relaxed atmosphere that resembled a vernissage. More and more people from the interstellar community arrive, such as Al Jackson, Robert Freeland, Robert Kennedy, Ryan Weed and small groups of people gather in the room, engaging in conversations.

Dinner is served and people enter into conversations around their table. At the end of dinner, the official part of the evening begins. Two i4is awards are handed out:

Greg Matloff was awarded the i4is Alpha Centauri Pegasus Award for his long-term contributions to the interstellar field. C Bangs, who contributed for many years with illustrations to Greg Matloff's books, has been awarded the Alpha Centauri Prometheus Award for her artistic contributions to the interstellar field. Overall, the opening dinner foreshadowed the days to come: An intense exchange of ideas around interstellar travel by some of the key people of the community.

Day 1: Energetic reaction engines

The first day of the workshop was opened by the Dean of the City University of New York, the organizing committee and the session chairman Kelvin Long. The first talk, given by the



President of i4is-US, **Robert Kennedy III**, dealt with the different sources for fusion fuel in the solar system. Using plenty of historical analogies and examples, Robert presented the prospects and challenges of obtaining fusion fuels in space. To illustrate his point about the difficulty of synthesizing nuclei in industrial quantities as opposed to mining them he brought with him and passed around the room a transmutation rod that he designed for a nuclear reactor. It is filled with plutonium, americium and curium, which ends up



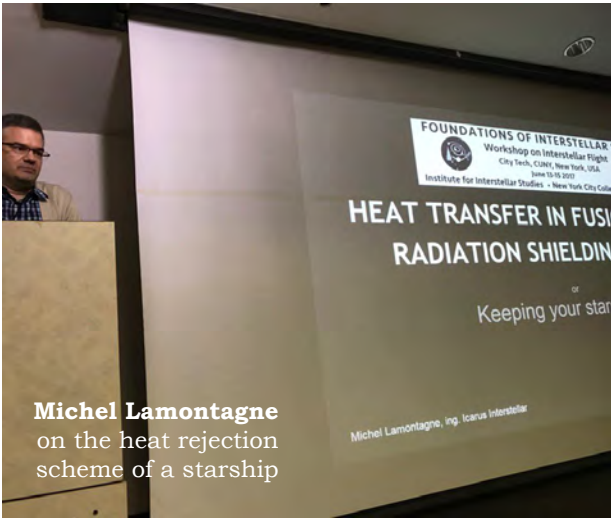


The company at the opening dinner.
Credit Elena Ancona

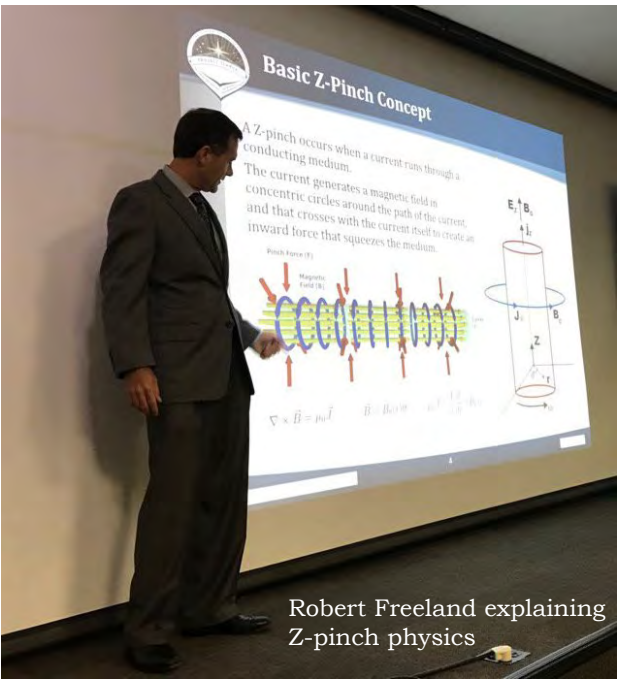
back row: Robert Kennedy III, Ron Litchford, Masataka Nishi, Ryan Weed, John Hartley, Harold ‘Sonny’ White, Andreas Hein (specs), Ralph McNutt, Robert DeBiase, Louis Friedman, Al Jackson, Andrew Higgins, Robert Freeland, Peter Ness (back), Phil Lubin (front, behind Greg), Jeremy Munday, Roman Kezerashvili, Eric Malroy, Glen Robertson, Kelvin F Long
front row: Helene Condat, Bridgette Hyde, Carmela Tal Baron, C Bangs, Elena Ancona (in front), Greg Matloff, Alexandra Limpert, Kari Weatherbee, Stephanie Thomas

as californium-252 (plus tiny amounts of einsteinium-254 and fermium-257) that the Department of Energy sells for US\$50 million per gram. He then passed around a box of inexpensive laundry borax, wherein resides his favorite fusion fuel (because it’s aneutronic): boron-11. In the Q&A session, Phil Lubin remarked that fusion propulsion systems are inherently limited in their efficiency due to the physics of rocket propulsion

systems, compared to beamed propulsion systems. **Michel Lamontagne’s** talk featured the latest results from Project Icarus and more specifically the heat rejection scheme of the starship, which is crucial for the ship not to get molten. Michel presented a high-level design



Michel Lamontagne on the heat rejection scheme of a starship



Robert Freeland explaining Z-pinch physics

along with necessary technologies and heat exchange medium for rejecting the huge heat loads that are generated by a fusion propulsion engine. He furthermore presented a new design for a fusion-propelled precursor probe “L’Espérance” (Hope), beautifully illustrated by himself.

Project Icarus’ **Robert Freeland** gave a talk on the plasma dynamics in a Z-Pinch fusion engine, which is the propulsion system for the Icarus Firefly starship. Robert presented the basic physics of the Z-Pinch fusion engine that essentially quenches the plasma to levels where fusion occurs in it. **Regina Sullivan** presented the latest results from Lockheed Martin Skunk Works’ compact fusion reactor program that has received a lot of attention in the media. The talk described the



Regina Sullivan on high beta cusps, a path to compact fusion

concept and initial analysis results for using magnetic cusps for confining the plasma.

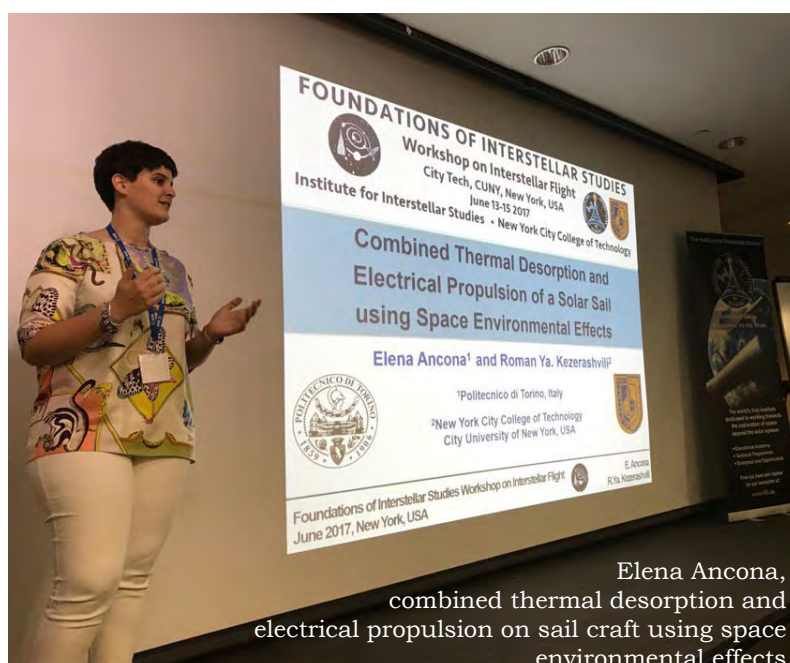
Ryan Weed, the CEO of Positron Dynamics, presented some highly interesting results for positron-induced fusion and ultra-dense deuterium that led to a lot of discussions among workshop participants. Positron Dynamics, which is now funded by venture capital, has succeeded in generating positrons from nuclear material. Using a moderator, the positrons are decelerated to thermal positrons. The positrons are then stored as thermal positrons and can be used for propulsion. Ryan presented two propulsion concepts. The first is a CubeSat demonstrator, in collaboration with Cornell University, which will

of such a rocket would be its scalability, compared to existing inertial confinement fusion schemes where a large infrastructure is needed for compressing the fusion fuel. Another interesting result that Ryan presented was some initial experiments to confirm the creation of Ultra Dense Deuterium (UDD). The creation of UDD has been claimed by a group of researchers in 2012. However, it remains to be seen if these claims are justified. The final talk of the

demonstrate day was given by **Elena Ancona**, the propulsion Spacecraft Controller at European Space Operations Centre (ESOC) for Telespazio-Vega GmbH, a joint piece with **Roman Kezerashvili**. The talk looked at enhancing the acceleration of solar sail spacecraft that pass close to the Sun by exploiting solar radiation heating and charged particles. Solar radiation heating can be used for evaporating coating material on the sail, creating a thrust. As a second mechanism, the sail can be charged and repels particles of the Solar Wind, creating additional thrust. An optimal combination of these mechanisms



Ryan Weed on positron dynamics



Elena Ancona, combined thermal desorption and electrical propulsion on sail craft using space environmental effects

could result in a velocity of 0.001 c for the sailcraft.

One feature of the workshop was extended discussion sessions throughout the day, which were deliberately started by statements that would be controversial, in order to spur a lively debate. The Day 1 discussion focused on whether or not it would be beneficial to concentrate all work on interstellar propulsion systems on one technology, instead of working on different schemes. Phil Lubin commented that certain technologies could be excluded right away. For example, solar sails could not be used for interstellar travel.

Greg Matloff argued that they can and it depends on how interstellar travel is defined. If trip times can exceed the lifespan of a human, solar sails would be a viable option. Furthermore, he remarked that a dying star which expands before its collapse would provide ideal conditions for a civilization to leave its star system using solar sail.

Ralph McNutt remarked that the question which interstellar propulsion system would be most promising is a “flight over napkins”. Using the historical

Sonny White remarked that one cannot stop people working on the propulsion system they advocate. He added that the commercial sector matured electric propulsion systems and he can imagine that Lockheed develops its fusion reactor, which is then used in submarines and airplanes and would then be used in space. A further comment from the audience remarked that in the semiconductor industry roadmaps are defined in which technology options are identified and then narrowed down and important

as sail areal density and laser power. Furthermore, it presented some preliminary analysis that was conducted in collaboration with the Planetary Society for demonstrating laser sail propulsion (EBEX), using the LightSail 2 mission. Two options were presented, based on laser guiding stars of large astronomical telescopes and a tactical laser of the US Army. He also presented the results of several parametric trade studies of Earth Orbit, Solar System, and interstellar solar and laser sail missions.



example of electric propulsion, he argued that electric propulsion systems were shown to be advantageous for interplanetary missions for a long time but only with getting electric propulsion systems on Deep Space 1 and Dawn provided the proper proof of concept of its advantages, leading industry to jump on the technology. The problem is rather that NASA first raids the technology budget if there are issues with a flight program such as cost overruns, making technology programs vulnerable to budget cuts.

Louis Friedman commented that solar sailing is somewhat not attractive for agencies as solar system missions can be done with alternative propulsion systems such as electric propulsion. Only laser sailing would have unique capabilities.

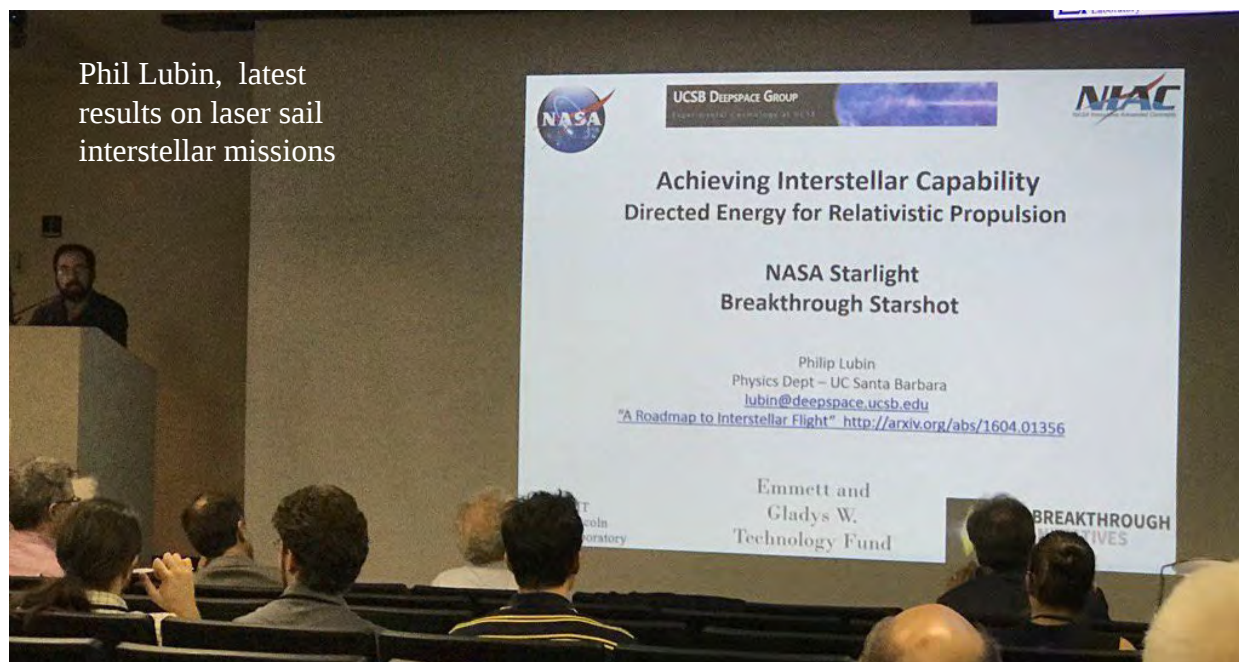
stakeholders agree on this roadmap.

Day 2: Sails and beams

Before the talks started, Roman Kezerashvili gave a short introduction to the historical roots of solar and laser sail propulsion, notably Maxwell, Tsiolkovsky, Tsander, and Perelman who provided the theoretical and conceptual basics for such systems in the 19th and early 20th century.

The first talk of the day was given by **Richard Montgomery**, who presented a solar sail roadmap from today to interstellar missions, in collaboration with Les Johnson. Les is well known in interstellar circles but unfortunately could not attend the workshop. The presentation clearly identified the key parameters for sail-based propulsion systems such

The second talk was given by **Phil Lubin**, who is well known for his contributions to Project Starshot. He presented his latest results on laser sail interstellar missions, funded by a NASA NIAC grant. He mentioned that NASA has recently received the objective from US House of Representatives’ John Culbertson to launch an interstellar mission by NASA’s 100th anniversary in 2069. At the same time, no specific budget was provided for this purpose. Throughout his talk, Lubin stressed the principal physics that constrains the performance of certain propulsion systems such as rocket-based propulsion systems. Except for antimatter propulsion and laser sail propulsion, he does not see promising candidates for an interstellar mission. After these propulsion basics, he



Phil Lubin, latest results on laser sail interstellar missions

presented a range of new results and technologies such as thin-film electronics, a concept for a Moon-based laser infrastructure on the far side of the Moon etc. Interestingly, the Moon-based laser infrastructure has been previously proposed by the Project Dragonfly team from the Technical University of Munich.

In the third talk, i4is Director **Andreas Hein** presented the results of the Andromeda study that was conducted in March 2016 for Breakthrough Starshot prior to its announcement in April 2016. Andreas presented potential technology options for three key areas of a laser-propelled interstellar probe:

Communications, power generation, and laser optics. For communications he concludes that optical communication is clearly the winner, although an antenna size of at least 1 m will be needed on the spacecraft. For power generation, either an external source such as beamed laser power or thermo photovoltaic cells are the most promising options. For the laser optics, large membrane lenses could be an interesting option near term but more advanced concepts such as the "Orbital Rainbow" based on aerosol lenses could also be promising.

After the coffee break, **Jeremy Munday** gave a talk on the

theoretical and experimental determination of photon pressure on dielectric materials. He also presented an experimental setup that is capable of measuring photon pressure on dielectric materials in the picoNewton ($\text{pN} \equiv 10^{-12}$ Newton) range that he and his team have developed at the University of Maryland.

The discussion session started with an exchange of ideas on sail materials. Eric Malroy from NASA Johnson Spaceflight Centre remarked that he and his team had developed a prototype of a sail material that uses graphene as a substrate and a reflective metal coating. He further proposed to use carbon nanotubes as a



Andreas Hein on the Andromeda study of March 2016



Jeremy Munday on the theoretical and experimental determination of photon pressure on dielectric materials

secondary structure for absorbing shear stress in the sail. Phil Lubin remarked that the requirements for solar and laser sails would differ fundamentally. Whereas thicknesses of 100 nm are fine for laser sails, solar sails would require thicknesses of ~10 nm. A shared view was that graphene would be attractive for absorbing stress in the sail structure and it is necessary to coat it by a reflective material. From sail materials the debate moved on to alternative propulsion systems. Kelvin Long remarked that sail propulsion systems are fine for unmanned

space probes but would not be scalable to manned missions. He argued that any advanced civilization would likely develop fusion propulsion as they would have their star as a “proof of concept” of nuclear fusion. Phil Lubin countered that the same argument could be used in favour of sail propulsion. Andreas Hein countered that there would be no reason in principle why sail propulsion could not be scaled up as Robert Frisbee and Robert Forward have proposed in their publications.

After the lunch break **Gregory Matloff** presented his results on using enhanced graphene sails for interstellar arks. He examined how different optical values for the sail would influence the final cruise velocity of the ark. To conclude, the combination of presentations and extended discussions, and long breaks proved to be ideal for pondering new ideas. I would like to use this occasion to thank the organizing committee at CUNY / i4is-US, and of course all the presenters and participants for making this truly remarkable event possible!



Greg Matloff on sun launched interstellar arks

About the Author

Dr Andreas Hein is Acting Executive Director of i4is and Chairman of the Technical Research Committee. He was joint leader with Kelvin F Long, of 2016's Project Andromeda, a very rapid study of a laser propelled interstellar probe presented to Breakthrough Starshot in March 2016. He has a PhD "Heritage Technologies in Space Programs - Assessment Methodology and Statistical Analysis" from the Technische Universität München / Technical University of Munich (TUM) and a degree in Aerospace, Aeronautical and Astronautical Engineering, also from TUM.

Statement of Solidarity

The following statement was issued at the Workshop on Foundations of Interstellar Studies

FOUNDATIONS OF INTERSTELLAR STUDIES



Workshop on Interstellar Flight

City Tech, CUNY, New York, USA

June 13-15 2017



Institute for Interstellar Studies · New York City College of Technology

STATEMENT OF SOLIDARITY FOR THE INTERSTELLAR VISION

Declared Consensus by participants of the Foundations of Interstellar Studies Workshop on interstellar flight, 13-15 June 2017 in the City of New York.

The firmest foundation for interstellar studies is a community united by a common goal, to travel to and explore space beyond the Solar System, but committed to the mastery of their individual fields and interests. We have assembled here in the great city of New York to advance the state of interstellar studies, especially in regard to the type of engines to propel our future vessels across the stars. We educated ourselves, shared knowledge and wisdom with one another, and learned new things — some of which were profound. We observe that many great questions remain unanswered, and we suspect that others are yet unasked. We know that our field is young, and therefore it is premature to close off any avenue of scientific inquiry, or settle on just one approach. Whilst we embrace a spirit of friendly competition to advance all conceptual methods and advance the capabilities critical to achieving interstellar flight, we also observe the need for constructive collaboration that enhances our shared aim. Realizing these things, we must foster the closest co-operation among practitioners, because no one effort will be able to solve all of the problems necessary to conquer one of the most awesome challenges in human history by itself. The interstellar community will succeed in claiming humankind's place in the stars. Together our open exchange of ideas has also revealed the vital relationship between the sciences and the arts, and we will continue to promote the key visual projects that benefit our aspirational goals. Examining the developments in popular culture within just the last seven years, we have observed that the public mind has changed noticeably in regards to the feasibility and potential for interstellar travel. Our consciousness has been raised thanks to organizations and individuals that anticipated the future and worked towards its fulfillment, as we will continue to work towards the astounding possibilities of existence that await our promising future.

The Foundations of Interstellar Studies Workshop on interstellar flight was organized by City University of New York and the Institute for Interstellar Studies. The declaration was made at CUNY City Tech New York, USA on Thursday June 15 2017.

i4is & CUNY, NYC June 2017, the final 24 hours Report from Foundations of Interstellar Studies Workshop

Robert G Kennedy III, PE

i4is USA President and New Yorker Robert Kennedy gives us his very personal impressions of the final 24 hours of the Workshop.

Our story properly begins the night before (Wednesday the 14th of June), in the basement of the Hotel Sheraton Brooklyn, NYC. Having gotten over the “hump day”, Your Humble Narrator (YHN) and the rest convened in one of the basement ballrooms for drinks, good cheer, a sumptuous dinner buffet, fellowship, humorous presentation of awards especially to the indefatigable Workshop secretary Elena Ancona, and lots of laughter. Our table of worldshippers (flanked by the remarkable Robert Freeland and inimitable Michel Lamontagne) had endeared ourselves to the Albanian servers

by learning a bit of Albanian (ain’t smartphones wonderful?). This was because the entire crew of servers were Albanians, living in the borough where I grew up, Staten Island, NYC.

During dinner, “volunteers” YHN, Messrs Freeland and Munday and Alexandra Limpert) were tapped by Kelvin to start composing a draft closing statement. Maj Brent Ziarnick (USAF) chipped in via email. After shutting down the dinner, we re-located to some settees near a fireplace (fortunately non-functioning as New York hit 100° F that day) to finish our work. Thirsty, thirsty work. We did not wish to repeat

the sin of Monday night, wherein \$450 worth of wine at the Harvard Club went unconsumed. Towards midnight when the servers had finished clearing the big room, they were trundling a cartload of leftover food and wine back to the basement kitchen. Then one of the Albanians spotted us and said, “here – want this wine?” Physicists, artists, engineers, writers—what could go wrong? The resulting Statement of Solidarity for the Interstellar Vision was agreed by consensus of the workshop and published on the workshop’s website by the City University of New York (and in this issue of Principium).

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**Elena and Kelvin's
postcard from New
York**

**All other pictures
credit: Robert
Kennedy**

The downside of our lubricated approach to creative writing became apparent twice:

(1) once on the endless slog home to my borrowed (but free, see Rule #1**) digs in Bayonne across the Hudson River with as many wine bottles as I could conceal (Rule #1**) from the Port Authority Police in my satchel. The NYC subway never closes, but the tempo sure drops off after midnight. Luckily, I was able to pass the time with an immigrant couple on the PATH platform near where the World Trade Center used to be. Serbians or Slovenes or something. Her English was no better than my Russian, and he had none at all, but somehow we communicated just fine. Nice people.

(2) again in the morning when this poor engineer had to sit thru four presentations in a row chock-a-block full of general relativity on just one cup of coffee. Oy. Well, the third day was intended to be the most far-out, and it was. (I hope Dr. White, Fearn, Garattini, Kezerashvili, etc will forgive my characterization of a subject they clearly care a lot about.)

For several years I had only known of Harold “Sonny” White (who led off the morning’s talk) by reputation. It was a pleasure to finally meet him in person. In addition to his famous technical abilities he displayed a calm professionalism, supporting Kelvin and making the workshop work.

Actually, I was most surprised by Roman’s lecture, in which he showed that relativistic mechanics would apply meaningfully to my own field of geoengineering—as I recall it, there is a measurable frame-dragging effect on a radiated-levitated lightsail flying around the Sun-Earth L1 point

in a non-Keplerian orbit, which I would have to take into account. And here I thought the orbital mechanics of a solar sail the size of Texas would be purely Newtonian. Silly me. I sure hope Roman and I could follow up on that. Maybe get Greg involved in the paper too.

We then broke for the final lunch in the nearby cafeteria. No complaints about the lunches whatsoever. Elena found a fine caterer (who in turn managed to get a bunch of really cool workshop T-shirts ginned up at the last minute.) The chef was curious about our interstellar subject and engaged with everybody (my only culinary regret on this trip is that I did not manage to consume a hot dog

slathered with the unique onion relish you can only get from a New York City street cart. I’ve been trying to recreate that relish for 40+ years ever since moving away from the Big Apple, without quite hitting it).

Now, by Thursday the 15th, the inevitable cancellations and last-minutes changes had stacked up to create a large gap in the schedule. Rather than merely fill that hole with second-rate or extemporaneous talks, the organizers came together to produce a wonderful ad hoc thing: an hour-plus-long structured discussion of a few big questions. Sonny is an excellent facilitator, it was a pleasure to work with him and I look forward to working with him in future.



Roman and Kelvin in Roman’s office, lots of equations on blackboards, a bottle of Georgian cognac and a real Georgian friendship horn

Then the formal program resumed with a couple of very big closing presentations, one by Lou Friedman about the gravity lens 550 AU away, the other a broad survey by Ralph McNutt of the exploration of the solar system. I quite enjoyed those, especially the latter.

At some point, we took another group picture (which became *Postcard from New York* on the first page).

A few of us went up to Roman's office, crammed with all sorts of books, laboratory apparatus, gimcracks, tsotchkes, and of course lots of equations on blackboards. He opened a desk drawer and produced a bottle of Georgian cognac and a real Georgian friendship horn, as you will see on the previous page.

Before I head off to Africa again, I want to commend Roman for his excellent advice in particular

re: restaurants. I had wanted to convene some people from the TVIW Worldship tracks for a "thank-you" dinner and it worked like a charm. I took Michel and his family, as well as Cassidy Cobbs and her family, to "Teresa's" on Montague behind the Brooklyn Post Office. Excellent Polish food & drink, and very good prices! Dessert consisted of vodka, then a 100-meter stroll to take in all of Lower Manhattan at sunset. I hate driving in the Big Apple (Rule #2**), so this was the perfect end to a perfect event. Большой спасибо Roman! I've known of you for many years, almost as long as I've known Greg (1994), but I am so glad that contact is personal now.

Respectfully submitted by Your Humble Narrator,
Robert

** the two things you have to remember about me is that I'm cheap and lazy.
PS What New Yorker does not recognize the site of the immortal Algonquin Round Table? (en.wikipedia.org/wiki/Algonquin_Round_Table)



Michel & Cassidy overlooking Lower Manhattan on last day.

From L to R: Jean-Daniel, Michel & Diane's son, Your Humble Narrator, Michel Lamontagne, Diane Lamontagne, Cassidy Cobbs, Cassidy's mother, Cassidy's sister-in-law, Random photo-bomber



About the Author

Robert G Kennedy III, PE, is President of Ultimax Group Inc and of the Institute for Interstellar Studies - US (i4is-US). He is also Senior Systems Engineer VI at Tetra Tech. And he is current chair of the Asilomar Microcomputer Workshop, now in its 44th year (amw.org), "Celebrating Microprocessor Technology Since the Dawn of Sand!". He is also Vice-Chair of the Environmental Quality Advisory Board of the City of Oak Ridge, TN. He hold a degree in Mechanical Engineering from California State Polytechnic University-Pomona and a Special MA in National Security Studies of California State University-San Bernardino.

i4is & CUNY, NYC June 2017

The Social Side

Andreas Hein reported from the Foundations of Interstellar Studies Workshop, organised by the Institute/Initiative for Interstellar Studies and the City University of New York, but emphasised the value of the informal and sociable atmosphere at the workshop. Robert Kennedy added a mixture of the social and technical. Here are some images illustrating the opening evening, awards given emphasising the social side. All captured by co-organiser Kelvin Long.



Engineering New Worlds: Creating the Future - Part 3

Dmitry Novoseltsev

Dmitry Novoseltsev (Дмитрий Новосельцев) is Deputy CEO of the Siberian Mechanical Engineering, Non-Profit Partnership (www.npsibmach.ru). His article, which is appearing over three issues of Principium, considers a number of different approaches to increasing the likelihood of intelligent life developing anywhere else in the Universe. The first two parts were in the last issue. In Part 1, *The current state of play: an "uncomfortable" Universe* he pointed out that the structure of the Universe does not make it a particularly encouraging place to generate intelligent life. In Part 2, *"Catalysis": the spread of life*, he outlined a two-step project intended to increase the probability of intelligent life forming in the proto-planetary systems around stable stars in our galactic neighbourhood. In this issue he moves on to Part 3, discussing the Shkadov thruster, "star machines" and the architecture of galaxies. In the next issue, Part 4, *Cosmological Natural Selection*, he will discuss an engineering approach to the creation of a world and Part 5 will speculate on a history of the future we might desire – to create worlds.

All visualisations are by Dr Anna V Sedanova (Анна В Седанова)

Previously, [1] the author proposed a scheme for a modified solar sail: an electric solar sail (ESS) which combines the advantages of the classical photonic solar sail and the "electric sail" by P Janhunen [2], and could be used for propulsion by charged solar wind particles.

In the short term ESS is offered as an engine for spacecraft intended to study distant regions of the solar system, including small bodies in the Kuiper Belt. However, in the longer term objectives for space colonization, there is undoubted interest in the possibility of scaling up an ESS

to a size comparable to that of the orbits of the inner planets of the Solar system. For such huge engines, I have adopted the name "electric Shkadov thruster" (EST), as the concept originates with Shkadov [4]. Such an engine has the potential to solve some of the problems of SETI, which are not

only scientific but also ideological in nature. The conclusions about SETI which are presented in the article are largely speculative, due to problems of specificity. However, using them we can not only interpret the lack of positive results in a number of SETI projects - for example, [3] - but also clarify the signs to be expected of the possible activities



of cosmic civilizations (CC).

Schematic

The most ambitious example of the application of the classical solar sail is the Shkadov thruster (ST, or stellar thruster), attributable to the star machine of Class A (ie intended for direct propulsion) [4, 5, 6]. The classic ST is a huge (comparable to the size of the orbits of the inner planets in our Solar system) structure made in the form of a solar sail, where the light pressure is balanced by the gravitational attraction of the star. As the stellar radiation pressure as a result acquires an asymmetrical nature, it creates a pressure differential and so thrust, and the star will begin to accelerate in that direction, soaring above the sail. This thrust and acceleration will be very small, but such a system can remain stable for thousands of years. Any planetary star system will move together with its star. According to available data for the "photonic" ST, for a star like the Sun, with a luminosity of 3.85×10^{26} W and weighing 1.99×10^{30}

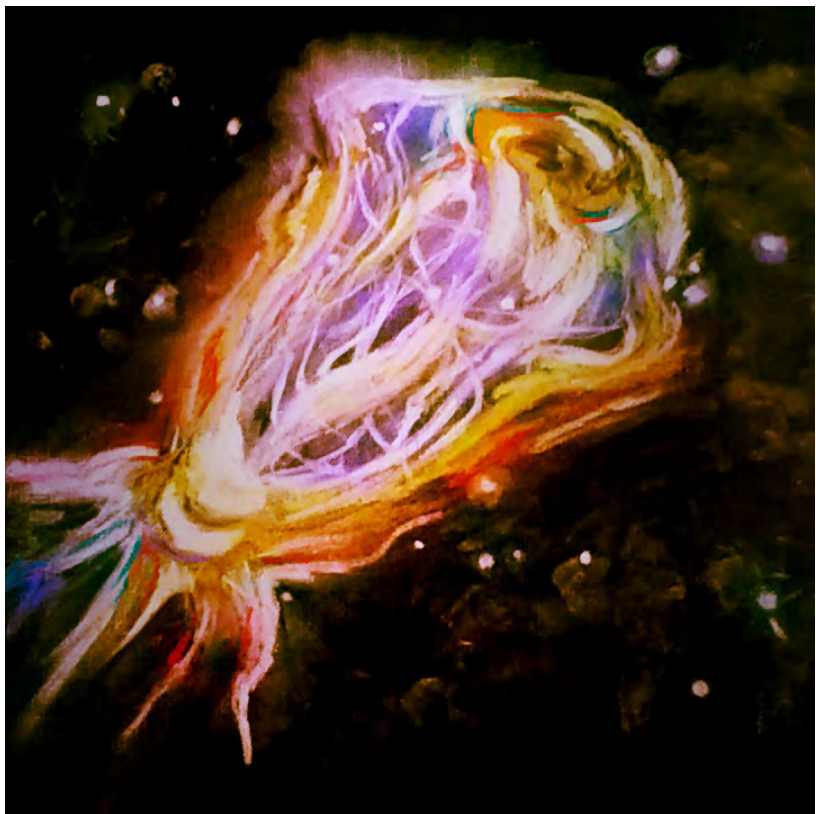
kg, the total thrust produced if half the solar radiation is reflected will be equal to 1.28×10^{18} N. Over a million years, this will give a change in velocity of 20 m/s and a distance from the starting position of 0.03 light years. After a billion years the velocity will be 20 km/s, and the distance from the initial position, 34,000 light years.

The obvious solution to increase the rate of velocity change and the reduction of travel time for the star is by accelerating ST by using reflection by the sail of not only light emission, but also the positively charged solar wind ions. This can be achieved by modifying ST into EST, by giving the sail an electric charge. Due to the fact that the expected mission requires EST to function for a long time, it would not be advisable to use beta-radioactive isotopes, as proposed by the author for small spacecraft [1], but placed on the outer side of the sail of electron guns, like the design by P Janhunen [2]. The power for the electron guns can be provided by utilizing the heat absorbed by the sail structure from the incident

radiation - for example, by using thermoelectric converters. In the case of manufacturing a sail cloth in accordance with [1], of pure metallized nanostructured films of the order of hundreds of nanometers thick, suitable integrated thermoelectric transducers can be bonded directly to the design sail fabric as a laminate of nanofilms of different composition. It is also possible to use thin-film solar cells of conventional design, while ensuring their sufficient resources.

A detailed discussion of the different types of possible sail design goes beyond the objectives of this article. One possible option could be considered as self-assembling (and subsequently self-repairing) canvas sails, creating relatively small, identical self-replicating robotic spacecraft - robots - with at least one flat reflective (working) surface. Primary production of such robots can be carried out in the plane of the ecliptic by utilizing the material of asteroids, with a further flight to the pole of the Sun (using an ESS integrated into the design of the robot), and the further maintenance of their numbers to repair sails by reusing the materials from faulty robots which cannot be repaired. Thus, the sail cloth that EST is formed of is a plurality of small identical interchangeable ESS, which ensures its high survivability. In contrast to the slow spacecraft for project "Catalysis" (see Part 2 of this article in Principium 17), for the moving of components of the sails of the Shkadov thruster during their flights from the asteroid belt to the pole of the Sun it would be permissible to use concentrated solar, laser or microwave radiation for acceleration.

The sail would be located on

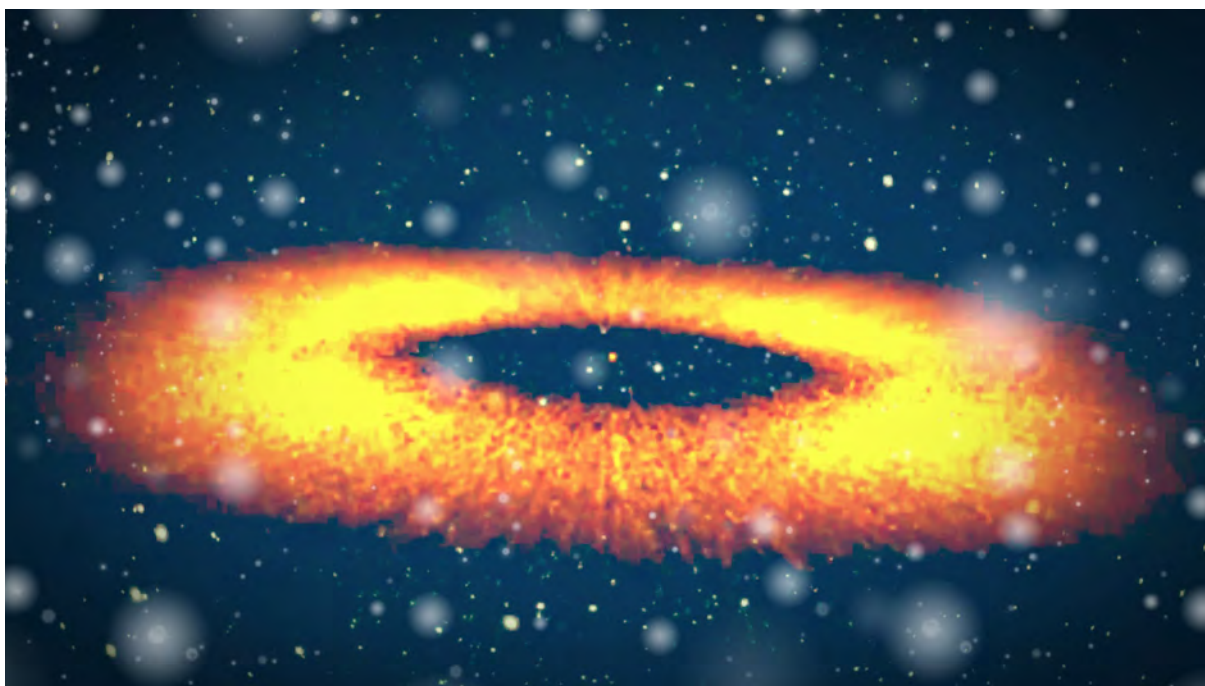


the side of one of the poles of the star (Sun), referenced to the planetary system's axis of rotation. Excluding the negative climate impact on a habitable planet of reflected sail light and ion radiation will require, for example, in the case of the Solar system, the sail to be positioned inside the orbit of the Earth (and in the case of detection of

rotating parts are "at the edge" of the elements of the sail - on the same principle as window blinds. In addition, the dynamic design of the individual elements will create some asymmetry in the sails and adjust the direction of the thrust vector. The photon and ion components of thrust on the EST sails should change little over time (due only to the evolution of

sufficient. "Exo-humanitarian" restrictions on the use of developed CC bodies in the planetary system for the extraction of construction materials (in [8]) can be bypassed, for example, by a priority waste facility, 'recycling' any celestial bodies on a potential collision course with a densely populated planet.

It is



even the simplest life forms in the upper, relatively cold layers of the atmosphere of Venus, as mentioned hereinafter as "exo-humanitarian" reasons - and inside the orbit of Venus, in contrast to the classical astro-engineering designs of type class B as a Dyson sphere. In this case, if the recycled heat is absorbed in the sail structure, it becomes a real challenge. Thus, in the existing classification EST is a stellar machine of class C, designed not only for propulsion, but also for the partial utilisation of the star's energy. It may be possible to control the lighting of any habitable planets with dynamic design of the sails by creating in front of them some windows, rotating with the same angular velocity. In the simplest case, the

the stars).

Despite the magnitude of the task of building the sails, it seems quite solvable. As the proposed sail design is dynamic and not rigid, its weight may be much lower than for more traditional astro-engineering designs. Thus, the volume of the hemispherical canvas sails, if the radius is about $1/3$ AU (5×10^9 m) with a thickness of 200 nm membrane, is 3.14×10^{13} m³. With an average density of the material of the membrane equal to that of iron (7800 kg/m³), its mass will be 2.448×10^{17} kg, which is comparable to the mass of the asteroids Vesta (2.67×10^{20} kg) and Eros (6.69×10^{15} kg). Thus, for the manufacture of these sails, at least 100 small asteroids or one large one would be quite

important that in using the EST the star becomes with a stable "tail" of relatively slow ions from the solar wind, reflecting by the sail, with typical composition according to the solar wind from the star (for example, for the Sun - at [7]) which distinguishes it from a typical star and is different from the characteristics of a number of astrophysical processes such as narrow relativistic jets. The search for such "exhaust jets" of EST could then be one of the independent tasks for SETI, in the same way as you can uniquely identify the fact that a jet aircraft has passed, not just by watching the actual flight of the aircraft at high altitude, but for quite a long time afterwards by locating the remaining vapour trail. When identifying such facilities, the

effects of the interaction of the ion flux with the magnetic field of the heliosphere where the flow is largely dissipated and loses its original direction should be considered. But in this case, due to the asymmetric heliosphere, the ion flow will be deformed in a characteristic manner, and this feature can be used to identify the star. It should be noted that the traditional photon ST also generates an asymmetric flow of neutral interplanetary gas whose formation mechanism is similar to the mechanism of occurrence of comet tails.

A possible variant (immediate term)

This part of the article contains speculation on the possible ways of development of the CC once it has reached level 2 on the scale of Nikolai Kardashev, including the ability to implement a design of EST type.

It is assumed that the fundamental idea of the limitation of the speed of information transmission to the speed of light in vacuum remains valid for the type 2 CC. This is the first reason for which, according to the author, the transition to

a Kardashev type 3 CC by the further colonization of space is not possible. As with systematic energy-intensive "quick" interstellar travel relatively small spacecraft, and in the slow movements of base for the CC star in the galaxy with simultaneous use of electromagnetic (radio, optical) communication channels, it is impossible to preserve the unity and coherence of CC at interstellar distances.

As one of the variants of the further evolution of organized matter, was proposed and convincingly demonstrated a model of the "galactic cultural field", as following after the technological civilisation level of organisation of matter, which can not be reduced to the sum of the individual CCs, its structural elements are organised similar to neurons [8]. One of the obstacles to the formation of a "galactic cultural field", in addition to the problems of identification of potential partners for CC for its formation through the traditional methods of SETI, is seen the comparative smallness of the velocity of light relative to interstellar distances. In addition

to the above-mentioned problems of the connectivity of the CC structure at the galactic scale, most of the processes, lasting a small amount of geological and cosmological time (eg the history of the Earth at the turning point of the XX-XXI centuries), the "galactic cultural field" is simply not able to register, not to mention reflect on them, since they will be completed before the information about them will reach the nearest of its elements.

It is proposed to designate this as the first (technological) reason for a ban on the existence of the type 3 CC. For this reason, according to author, the emergence of a CC exceeding the level of type 2, but not reaching the level of type 3 (which we will designate as a type 2+, corresponding to the level of energy use of a star cluster) is only possible in a fairly local scale, and not as a result of expansion of a type 2 CC, but as a result of the convergence of a group of CC. This will require a harmonized convergence of their base stars with designs such as ST or EST – and, apparently, the second option is energetically preferable. Importantly, the



process is self-organizing, ie it does not require a single control centre. Each type 2 CC directs its star to another star which it has identified, using the methods of SETI, as a base for another CC. As a result, over time, a sufficiently compact inhabited star cluster (with the distances between the stars of light weeks, possibly light days) forms, in which both the exchange of information on electromagnetic communication channels, and the flights of spacecraft may be realizable for CC, leading to the early formation of some type 2 CC into a single system – a CC of type 2+. For this artificial star cluster can be characterized by the ion "halo" in the form of individual segments of the ion "exhaust jets" that the ESTs leave behind. In the later stages of the convergence of the stars, when braking and positioning relative to each other, the "exhaust stream" of ESTs will be directed into the cluster, and an ionic "halo" then becomes continuous.

It can be assumed, and other signs of construction of artificial star cluster dynamics in the process of its completion (when the stars are already closer, but still continue to move). During construction, the cluster should include class G and K (stable, sun-like) stars, capable of providing for the long-term development of life. The nearest star to the observer, moving away from him, will be observed with a small red shift (corresponding to the speed of tens of km/s) and more vivid than in the typical "mass-luminosity" dependence (due to the reflected light from the sail). Looking more closely between them you will notice a group of stars flying towards the viewer. They will be visible as a weak infrared source (heated by radiation from the back side of the

sail) with a small blue shift.

At the final stage of construction, the stars will be much closer to each other, and they will carry out the braking manoeuvre, deploying the sail in the direction of movement (or rather, to remount them from the other poles of the star). At the same time the nearest star to the observer will look to that observer like an infrared source with a red shift, and counter to that - abnormally bright stars with a blue shift.

In this respect, very interesting results were obtained in 2007 in the framework of the GALEX project (www.galex.caltech.edu). When viewed in the ultraviolet range, images of the star Mira (Omicron Ceti, o Ceti) showed trace gases extending from the star for a few light-years; this was not observed in the optical range. A number of impressive images are presented on the GALEX project website [16, 17, etc]. Thus, the technical means to detect objects resembling the jet of an EST are currently already available.

As known, Mira is a double star, consisting of a red giant Mira A and a white dwarf star Mira B, and it has a relatively high rate of movement relative to the surrounding galactic clouds (130 km/s). Previously [18, 19, 20] in the selection of potential sites for SETI, stars with a spatial speed of 50-65 km/s or more have generally been excluded from consideration. This is based on the assumption by D Soderblom [19], that they would have a low metal content. According to L N Philippova ([16]) in the overwhelming majority (93%) of stars with exoplanets in the catalogue «Extra-solar Planets Catalog» as of March 2002, the radial velocities were less than 40 km/s.

But in the case of EST, on the other hand, a high velocity of the star's movements, in the tens of km/s and more, is exactly the purpose of such astro-engineering. It is characteristic that, given the above-mentioned values of traction, achievable for the ST and EST, for a sun-like star an acceleration to a speed of over 100 km/s will take several billion years, a period sufficiently long for its evolution into a red giant such as Mira A.

In [21] L N Philippova presented the hypothesis of creating radio-emitting CC "electromagnetic monuments" around subgiants or red giants evolved from former Sun-like stars. It can be assumed that the establishment of such a "monument" that can continue to operate in the conditions present during the further transformation of the star into a planetary nebula, and which has sufficient technical, energy and intellectual resources for the maintenance tasks necessary to communicate with other CCs is itself tantamount to the level of complexity of the preservation of the base CC - perhaps on other (non-biological) media. The latter, of course, is for CC a priority.

In this sense, further observation of Mira and other similar objects will be of interest - both in the interest of finding possible anthropogenic signals of CCs, taking the above assumptions into account, and to obtain criteria for the safe separation of "decoys" in the search from the signs of work processes of EST (in the case of an exhaustive verification of the natural character of the observed Mira processes).

It should also be noted that when the number of CCs simultaneously existing in the galaxy and able to create designs such as EST is small, and given the extremely

large distances between them, the duration of convergence of the stars via EST will significantly exceed the time of their lives on the main sequence. Then the artificial clusters which can be collected will not be stable class G and K stars, but red giants or white dwarfs. At one stage in the evolution of stars (of duration a few tens of thousands of years) in the presence of a severe planetary nebula, the value of the photonic component of traction for devices such as EST becomes negligible compared to the ionic component. In this case, the most effective device is not the EST (which degenerates into a pure power plant, the star machine Class B - for example, the Dyson sphere fragment), but a large (the size of a few AU), but in principle, the classic "electric sail» (E-sail) by P Janhunen as a web of thin elongated electrically charged components. This object should be well observed, including in the optical range, by how asymmetrical (due to the ion jet) a planetary nebula is. Acceleration of the object continues for several billion years, and the thrust of the "electric sail" in a planetary nebula due to high density of the working fluid is much higher than that of EST in normal conditions, all of which provides a high linear speed of the object. Thus, in combination with the high speed, the asymmetry of a planetary nebula can be a very promising sign for the search for artificial signals - all the more so as in this case we can talk about very old and stable CCs able to survive such catastrophic events as the explosion of a star.

Obviously, in any case, an artificial cluster is easily detectable and sufficiently attractive for the majority of the CC in the galaxy, with the result

that they ultimately will be also involved in its formation (the "urbanization" of the galaxy). It may be noted that such a process of localization of the "galactic cultural field" in a limited area, accompanied by its nonlinear complication, is similar to the process of cephalization in biological evolution, by which neuronal mass is not evenly distributed throughout the body but is localized in a small specialized organ – the brain – which ensures a much higher speed and intensity of their co-operation. In this case, any activity for SETI for CC type 2+ can be only extragalactic and quite formal in nature - in the form of one-way transmission with no prospect of an answer, only by "exo-humanitarian" reasons. It can to some extent be assumed that a type 2+ CC will have an introverted character, leading to the formation around an artificial star cluster of an "information barrier" - in the sense that the interaction of individual CCs in the cluster is for them an incomparably higher priority than any activities in the surrounding galaxy. According to the available evidence, this suggests that any type 2+ CCs are currently absent in the Milky Way, which corresponds to the general dynamics of its development ([8], [9], and others).

It is known that a sufficiently large-scale work to find evidence of the existence of the CCs type 3 - such as the recently completed research to find high-level mid-infrared radiation, which could be interpreted as a side-effect of technological activities in more than 100 thousands of galaxies made using an infrared telescope WISE [3] - have not yielded positive results.

Currently, a number of studies (eg

A D Panov in [8]) are justified by the potentially "exo-humanitarian" nature of any CCs type 1 and above, where "exo-humanism" is understood broadly as including "any form of control on the destructive power of technology." In turn, "exo-humanism" of CCs obviously follows from the law of techno-humanitarian balance by A P Nazaretyan [9].

Given the available detection methods, like that shown in [3], it is obvious that any large-scale astro-engineering activity of the classic type 3 CC would be catastrophic for the development of all lower-level CCs in the galaxy, and perhaps completely eliminate the possibility of preserving and developing some forms of life, which is clearly contrary to the principle of "exo-humanism". It is proposed to identify this problem as a second ("exo-humanitarian") ban on the existence of the CC type 3. Formation of the "information barrier", as noted above, at the same time removes this ban.

It may be noted that the construction of a group of CCs in an artificial star cluster, using technologies such as EST, to a certain extent can be a solution to the problem of B N Panovkin, according to which "... direct and prolonged contact between civilizations can develop a common view of the world and the common system of concepts. But outside of practical activity for world transformation, contact (in particular, only by the communication channels) can not be" [14]. Obviously, at the beginning of works on the construction of clusters for each CC type 2, the issue of the interpretation (and, in general, even the presence) of signals of other participants in the traditional electromagnetic channels is

irrelevant - it just determines by the known methods, directions for star movements, alleged CC partners and the presence in these stars of a number of signs that can be interpreted as the effects of EST. The total system of concepts can be developed in the future CC group in the final stages of building of clusters with intensive bilateral exchange of signals, and with a sufficient approximation of the stars, perhaps spacecraft. Favourable conditions for the possible accelerated joint development of the CCs group of "natural" star clusters has been discussed previously (eg [15]). The latter, of course, does not apply to the CC of "anthropogenic" origin, arising from the implementation of the project "Catalysis". As noted above in Part 2 of this article, they can use a common cultural code, provided by "Keepers" of the Fleet of Memory (functionally similar to, with some degree of approximation, the Roman culture in early medieval Europe).

Interestingly there is consideration of this process from the standpoint of Universal evolution (synonyms - Big History, Megahistory et al [8], [9]). Currently, a number of studies ([8], and others) allocated two sleeves (invariants) of Universal evolution -

- the development of a deceleration process according to intensity, close to logarithmic, from the earliest stages of the Universe before the beginning of the formation of elements heavier than iron in stars - the first sleeve, and
- the development accelerated by a power law with an acceleration factor of about 2.7 at this moment and until the middle of XXI century (for the Earth) - the second sleeve.

In [8] the possibility was

justified, at the beginning of the second half of the XXI century, of a third, "postsingular" or "exo-humanitarian" sleeve, with a non-linear deceleration of development, the basic content of which will enable the tasks of SETI; and the formation of a "galactic cultural field" is also proposed. Continuing the trend, we can assume the beginning of the fourth sleeve of Universal evolution once the CCs identify each other and the start of construction of stellar machines such as EST, ending a non-linear acceleration of the development of CC type 2+ in artificial star clusters on the scenario presented above.

A possible variant (long-term)

There are some interesting further possible ways of developing artificial CC star clusters of type 2+, in terms of interpreting the results of experiments to search for the CCs type 3 such as [3]. With a sufficiently large number of stars in the cluster, and if they approach each other closely for the activities of the CC type 2+ as a whole, as well as in the presence in the cluster of sufficiently massive dark matter not just an "information barrier", but also a physical event horizon might form around these cluster, leading to its isolation from the surrounding space. This accumulation might be seen from the outside as a hypothetical supermassive black hole. (It should be noted that the formation of a supermassive black hole with a billion times the mass of the sun with a low average density in the Milky Way is formally possible using about 1% of the stars, which based on a rather optimistic but plausible assumption about the possibility of the presence of CC, on average, in one out of 100 stars. The latest data on the detection of planets

such as "earths" and moderately massive "super-earths" in the "habitation zones" of a number of stars give hope for a concrete definition of this assessment in the foreseeable future.) Thus, at the same time this completely bypasses both of the above prohibitions - both technological and "exo-humanitarian" - because from that moment, no large-scale activities of the CC within the cluster can affect the environment of the event horizon.

It is very likely that, before finally being isolated from the outside world in this way, by "exo-humanitarian" reasons, such a type 2+ CC could position outside the 'dead zone' automatic transmitters ("beacons") to translate by the known channels of electromagnetic communication messages containing information about the development history of all its CCs type 2.

In principle, this is not a compulsory creation of object, which is a black hole. Solution of the problem of isolation from the environment is possible due to a sufficiently strong curvature of space around an artificial accumulations, similar to that observed in the immediate vicinity of the binary pulsar J1906, a system consisting of a pair of neutron stars [10].

It should be noted that existing black holes (eg in the cores of galaxies) definitely can not be used as a CC type 2+ for this purpose. Since the artificial cluster is a collection of dynamically balanced stars with planetary systems, moving at low thrust at speeds of the order of tens of km/s, the gravitational effects of a supermassive black hole would lead to its destruction long before it approached the event horizon. A supermassive black hole could only be artificially generated by

the purposeful movement of the stars and their interaction with dark matter.

The question of the possible existence of an artificial star cluster in a state of gravitational collapse, and some form of highly organized life within it, in the broadest interpretation, remains quite controversial. A number of papers ([11], [12]) discuss the possibility of the existence, inside the event horizon of black holes, of stable or quasi-stable orbits of a rather complex configuration, which could be positioned as the planets and stars with planetary systems (*see box*). It should be noted that a star equipped with EST engines can maintain its position indefinitely under certain conditions, even in quasi-stable orbits. The habitability (or rather, subjectivity) of black holes has been presented under a slightly different set of assumptions by other authors [13]. Nevertheless, the general attitude to such a possibility today is quite sceptical. Since the absence of any possibility of obtaining information about the internal processes of black holes is their fundamental property, these ideas are based solely on the results of theoretical modelling, and so it is risky even for the CC type 2+.

The more interesting question is, what can be the motive for such action? It is likely that, for all the complexity and diversity of connections in the cluster, like CC it will eventually face the problem of "exhaustion of knowledge" (in [8]), when the whole "exo-humanitarian" information within the galaxy is integrated and assimilated, and the possibility of bilateral contacts with similar CCs in other galaxies then tends to zero due to the unacceptably large time of signal transmission and also as a result of the presence

Life inside an artificial star cluster?

Obviously, the collapsed artificial star cluster is not required to be homogeneous.

In addition, this time the very form of intelligent life has to change. Initially, presumably, these were biological beings (as human), "intelligent animals" that need the same ecosystem in the biosphere. But then, during the evolution of stars, their stars have experienced a transformation into red giants, with the formation of planetary nebulae and white dwarfs. At this stage of the development of civilizations, they themselves had to be changed so that they no longer require a biosphere (and perhaps, they stay on the surface of planets, but only to harvest them as a source of energy), and can be much more compact.

Thus, a significant number of white dwarfs, the former "native" stars, are no longer needed for these CCs. They are collected in a primary supermassive black hole, the core of the new astroengineering construction at its central singularity. Its radius is relatively small.

The rest are white dwarfs, on which live sentient beings, which are sent to stable orbits around this core, as in model by V I Dokuchaev ([11], [12]), forming a very thin outer layer outside the event horizon of the primary supermassive black hole.

All this together forms a secondary, inhabited black hole and orbits of "inhabited" white dwarfs are inside of it.

A small portion of white dwarfs from the former artificial star cluster remains outside, as sources of energy for 'beacons'.

of "information barriers" (as noted above, all CCs type 2 + a likely consequence is deep introversion). However, relativistic effects observed in a significant distortion of the space around an artificial cluster could radically change the situation. Relativistic time dilation from the perspective of an outside observer to a type 2+

CC will match the acceleration of the time in the outer world. In this case, a response to signals sent by any other similar CC could be prepared in a very short time. When forming a full-fledged event horizon performing its CC to complete isolation from the surrounding universe can be obtained the maximum amount of "exo-humanitarian" information from all who wished to join with this CC in contact during the existence of the universe after this point, including the vaguely distant future. In this case, such a risky astro-engineering activity can certainly be justified. Within the framework of the Universal evolution that moment will correspond to the "singularity" of the hypothetical fourth sleeves – when the speed and intensity of information processing tends to infinity, followed by the CC completely disappearing from the observable Universe.

Obviously, this approach completely changes the relationship of a type 2+ CC to the SETI question. After taking the decision to conduct such an operation, it will be interested in establishing the maximum number of possible contacts, but are not limited duration of the period of the signals on intergalactic distances. The above-mentioned "beacons" in this case are very energy-intensive facilities, and, apparently, are the stars with EST, remains outside the artificial supermassive black hole at a significant distance from the event horizon on stable orbits. These objects, in addition to the signals supplied by them, with the growth in the future hardware capabilities of astronomical observations in the optical and infrared, may also be identified from time to time observed as infrared sources of stellar



scale (if the reverse side of the sail is pointed at the viewer) or as visible stars (if sideways to the observer) or disappearing from the observations of a supermassive dark body. Their signals with sufficient power for transmission to the intergalactic distances are likely to be fixed have modern radio astronomy facilities. It should be noted that, to be able to conduct a dialogue with alien CCs in the absence of an established base CC (which can only be one-way communication of data transmission over the event horizon), "beacons" themselves must have some capabilities - in the sense that is embedded in the present, in the concept of "artificial intelligence", ie they must be able to identify and decode the signal of "beacon" of other CC and reply to them. For those "beacons", used to maintain the operation and maintenance of power transmission of their own star, the existing formal

classification is itself as CC type 2. Thus, the system of intergalactic "beacons" may be the next hierarchical level of the "galactic cultural field", localized in artificial star clusters, and then in artificial black holes. We can assume that, by using the effect of gravitational lensing by objects weighing a million solar masses, "beacons" can effectively transmit and receive messages within the entire observable Universe. With the successful development of autocatalytic process of emergence of CCs, as initiated by the "Catalysis" project, a sufficient number of potential sources of information, as noted in Part 2 of this article, may occur in the nearest part of the Galaxy. Selecting the location of the artificial star cluster is generally determined by the initial distribution of CCs in the galaxy. In the case of our Galaxy, there seems an obvious need for the removal of the

artificial star cluster beyond in anticipation for 4-5 billion years of its upcoming merger with the Andromeda [24]. In this case, there is a particular problem for intelligent life with the unsteady gravitational interaction of the stars, but is still a big problem - a sharp increase in radiation flow at the confluence of the nuclei of galaxies. Along with choosing a location at a considerable distance from the interacting nuclei, the gravitational collapse of the artificial cluster could be an effective measure of protection. Thus, if the emerging type 2+ CC is observed as a star cluster with a number of anomalous features, but it is unlikely getting a targeted signal from it, but in the above hypothetical case at the final stage of development, such as the CC may be a supermassive dark object (probably a black hole) not located in the core of galaxies, but on its periphery, may be surrounded by a halo of typical

ionic composition at a distance disintegrating into individual streams of such relatively slow ions, which is a multi-band source of electromagnetic radiation, from which can be isolated presumably modulated signals. Obviously, the two-way contact with the type 2+ CC is not possible in principle, but derived from its "historical" signals in the event of at least partial decryption could be crucial - as "exo-scientific" (according to [8]) and ideological.

Feasibility variants of Earth civilization as CC

It should be noted that, in addition to the formation of the detection criteria for the activity of one of the hypothetical types of CC, the proposed considerations are practical in the future colonization of space, including the development of human civilization to the level of type 2, and then type 2+. If we have unlimited time, the beginning of the project to establish EST (and our subsequent participation in the formation of an artificial star cluster) seems feasible at the current scientific and technical level. This requires the solution of two problems: the choice of the stars - a potential target for the convergence with using of traditional methods of SETI, and to create and run to one of the asteroids a prototype of automated spacecraft (robot) with propulsion type ESS [1] and self-reproduction function (like von Neumann machines) using locally available materials, as a typical element of EST. Both problems can potentially be addressed in the first half of the XXI century, after which the EST project can be performed automatically without substantial human intervention - except the coordination of robots' activities, and may be, tasks of change of their generations. One

of the first steps towards solving the problem of the creation of robots could be the manufacturing and testing of the sail elements of the EST as the first experimental prototype of small "budget" spacecraft with ESS as [1] in the coming years in the framework of advanced space programs to study the outer Solar system.

It may be noted that the technical means for realization of the project could be created in the near future. The Japanese Space Agency JAXA announced a project to launch a solar sail-based spacecraft to the Trojan asteroids found near Jupiter [23]. The vehicle must be equipped with a solar sail with thin-film solar panels. An interesting option would send a similar craft to one body in the main asteroid belt, followed by going beyond the ecliptic plane and a flight to one of the poles of the Sun. Further, the device's work programme could be to find and study in the polar region of the Sun, among other things, the influence of non-stationary processes of solar activity on the device positioning, as well as an assessment of its requirement resource. The process of building a Shkadov thruster could thus be simulated.

Conclusion

Any forecast of the development of CC using a modified Shkadov thruster is largely speculative at this point, as it involves the "finality" of some modern ideas about the world and its laws. However, this forecast allows us to use a new approach to the problem of SETI on the basis of a number of specific properties of the desired objects.

The latter may be particularly important in the context of the July 2015 announcement by Yuri Milner of the Breakthrough

Initiative (Breakthrough Listen) under the supervision of Stephen Hawking to intensify of SETI [22] as the basis for the selection of promising future search objects. Positive identification of at least one of the observed objects as EST, artificial star cluster or an artificial black hole would have a very important philosophical significance, since it is an indirect confirmation of the non-exclusiveness of modern human civilization and the possibility of virtually unlimited development over cosmological eras, and would be an essential basis for social optimism. At the same time, the beginning of the creation of the design of EST as a set of fairly simple stand-alone machines with ESS is a practical engineering problem that can be solved in the foreseeable future.

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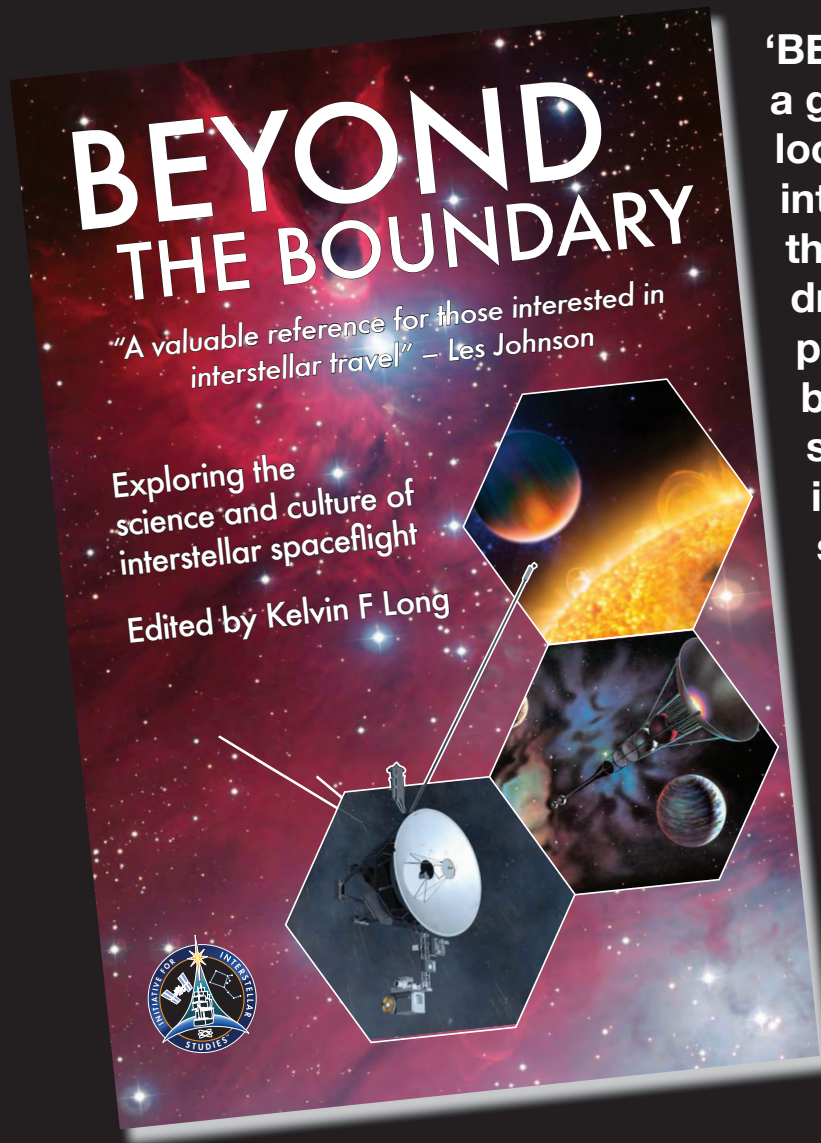
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