What is There?

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There are two historical models for space missions beyond the Solar System. I call the models Atlantic and Pacific. The Atlantic model has big ships with big money, crossing the ocean from continent to continent in one jump. The purpose was to explore new continents. The Pacific model was Polynesian canoes, carrying families with children, pigs and chickens, hopping from island to island, not trying to reach new continents. The purpose was to find new places to live.

The future of interstellar missions must follow the Pacific model for at least the next hundred years. The Atlantic model needs huge resources of power and industry in space. For example, a single mission with 1 ton payload traveling at one tenth light-velocity has kinetic energy 10^{18} Joules. The space-craft will take a week to accelerate to this velocity at $3g$ acceleration, requiring a launch system delivering a Terawatt of power even if the efficiency is a hundred percent. Space engineering on this scale is certainly possible, but it will take a century or two to grow.

For the Pacific model, the big question is: What is There? Where are the islands for us to explore in the ocean of space? The immediate task for the next ten or twenty years is to find them.

Here is the hypothesis to be tested. Planets of all kinds from Jupiter to Earth are kicked out of stellar systems with high probability, so there is a population of free planets as abundant as stars floating around our galaxy. Evidence for the existence of orphan planets in our galaxy is provided by micro-lensing observations using modest optical telescopes. There are also populations a thousand times larger of objects with diameters of hundreds of kilometers, dwarf planets like Pluto, satellites like Enceladus, asteroids and Kuiper Belt objects. There are populations a billion times larger of comets in the Oort Cloud, loosely attached to the Sun with diameters of a few kilometers. We know that the population of the Oort Cloud is at least a billion because new long-period comets have been coming by the sun at a rate about one per year for billions of years.

How do we find these objects at distances beyond 100 AU? They are easy to find if they are warm. Warm means 100 Kelvin rather than 10 Kelvin. I am proposing an observational program to find warm objects. I am a theoretical physicist, knowing little about observational instruments. In spite of my ignorance, I propose a specific instrument and explain why I think it can do the job. After I am finished, I hope that people in the audience, who know more about instruments than I do, will tell us how to do the job better.

Warm objects can be seen in thermal infra-red. A black body radiating at temperature 100 Kelvin has the maximum of the Planck spectrum at wave-length 30 microns. The practical limit to visibility is set by the radiation background. There are three components of background, solar, galactic and cosmic. The solar component is mostly zodiacal light, smoothly distributed and well studied. The galactic component is mostly due to warm dust in star-forming regions of our own galaxy, and is heavily concentrated in the galactic plane. It includes "infra-red cirrus", more extended emissions at longer wave-lengths. The cosmic component is from extra-galactic sources and extends over the whole sky. It is given the name CIB for Cosmic Infra-red Background. I will talk only about the CIB, which sets the limit for detectability of foreground objects over most of the sky.

A good picture of the observed CIB spectrum is shown in a review article by G. Lagache, J.-L. Puget and H. Dole, Annual Reviews of Astronomy and Astrophysics, 43, 727-768 (2005), page 733. The intensity of the CIB around 30 microns is 3.10^{-9} Watts per square meter per steradian. Since an arcsecond is 5.10^{-6} radians, the CIB at 30 microns is 10^{-19} Watts per square meter per square arcsecond.

I like to think in astronomical magnitudes rather than Watts per square meter. Here is the conversion factor. A standard source of bolometric magnitude 20 is 2.10^{-16} Watts per square meter. I call magnitude 20 a standard source because this is a typical brightness for faint objects detectable with modern instruments. For wave-lengths around 30 microns, a standard source is 4 photons per square centimeter per second. So the observed CIB is 5.10^{-4} standard sources per square arcsecond. This looks good. Sources down to magnitude 20 are considerably brighter than the average background.

To find the warm foreground objects, we have to do a rapid all-sky survey with an orbiting telescope in the 30 micron band. To achieve second-of-arc resolution at 30 micron wave-length needs a ten-meter diffraction-limited telescope. This is possible but not for the next decade. A practical instrument for the next decade is a one-meter telescope with resolution 10 arcseconds. Then a pixel is roughly 100 square arcseconds, and the CIB is .05 standard sources per pixel. A standard source is still above the average background.

SPITZER is a one-meter infra-red telescope covering the 30 micron band. It has done an excellent job of observing fine details of known objects in the sky. But it is no good for doing an all-sky survey because it has a tiny field of view, about 10 arcminutes at 24 microns. It takes pictures with about 10000 pixels. To survey the whole sky quickly, we need a camera with wider field and far more pixels. A wide-field camera with ten degree field of view will give us about 10 megapixels. It will need to point to only about 500 frames to cover the sky. It can cover the sky repeatedly within a few years.

After the first one-meter telescope mission is flown, the next step would probably not be a ten-meter telescope. A ten-meter telescope would increase the cost of the mission by a large factor. A more cost-effective second step would be a simple interferometer, with two or more one-meter telescopes linked by ten-meter base-lines. The interferometer would help to distinguish small foreground objects from more extended objects in the background.

As an example of a hypothetical source, consider an earth-like planet with no sunlight. The gravitational energy of condensation radiated away over 5 billion years gives an average luminosity of 2.10^{15} watts with a Planck spectrum at temperature 100 Kelvin. This has the bolometric magnitude 20 of a standard source at distance $D = 6000 AU$, one tenth of a light-year. Earth-like planets should be well above CIB background out to a distance of 6000 AU. Younger, warmer and bigger planets should be detectable at much greater distances.

As another example, consider a Jupiter-like planet with no sunlight. This will have roughly 10^4 times the luminosity of the earth-like planet, and will have bolometric magnitude 20 at 10 light-years distance. If orphan Jupiters are as abundant as stars, we should be able to see many of them above the CIB background.

For objects much smaller than the earth, the main source of radiated infra-red energy will be incident sunlight rather than internal energy. For these objects, infra-red detection may be useful if they have very low optical albedo, but they will only be detectable at distances below 500 AU.

The CIB is highly non-uniform, being dominated by emission from star-burst galaxies with dense dust converting visible to infra-red luminosity. A distant high-luminosity galaxy will appear in the CIB as a point source, similar to the hypothetical foreground objects which we are trying to identify. To identify the foreground objects with certainty, we must verify that they have non-zero parallaxes or proper motions. For objects at distances out to 6000 AU, parallaxes are of order 30 arcseconds or greater, easily measurable with a one-meter telescope at 30 micron wavelength. For objects not gravitationally bound to the sun, proper motions will be of the order of 10 arcseconds per year at 1 light-year distance, and will be easily detectable at distances out to 1 light-year. Objects that are gravitationally bound to the sun and further away than 6000 AU, or gravitationally unbound and further away than 1 light-year, may require observations extending over several years to identify.

A sky-survey should be done at several wave-lengths to see differences between different types of object and to distinguish different components of background. With four or five wave-bands in the thermal infra-red region, foreground objects could be diagnosed in some detail. After the foreground objects have been located and studied remotely, the planning of missions to explore them can begin. I leave it to the engineers at this workshop to design the space-craft and the payloads to do the job of exploring.

The big remaining problem is to find ways of detecting cold objects. The Polynesians detected islands beyond the horizon by observing clouds forming over the islands and by observing birds traveling to and from the islands. We have to find the celestial equivalents of clouds and birds.

Speculative topics for discussion. Contrast Russian and American space cultures. Russian started by Tsiolkovsky ("Dreams of Earth and Sky," 1895), American by Goddard. Tsiolkovsky saw two big problems, how to get into space and how to live in space, engineering and biology. The easy problem was engineering, solved by rockets. The hard problem was biology, solved by aliens with green wings. Goddard was only interested in engineering and rockets.

For high-velocity missions, rockets fail. The energy-source must not travel with the payload. Energy-source stays put and generates laser-beam or microwave beam. Payloads in small space-craft travel along the beam. System becomes cost-effective when launches are frequent, payloads small.

What are payloads for Pacific style missions? Noah's arc egg, carrying genetic information for entire planet ecosystem, microbes, plants, animals. Total 1 Petabyte of information, a few micrograms of DNA. After hatching, life-support provided by viviparous plants, growing greenhouses around themselves with mirrors concentrating starlight, providing warm environment for whole ecosystem. Sowing the seeds of life on cold objects far from the sun. After the ecosystem is established, it could provide a home for humans too.