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SCIENCE OPPORTUNITIES THROUGH NUCLEAR POWER IN SPACE

Henry M. Harris
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena CA 91109-8099
(818) 354-2533

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Author to whom correspondence should be sent: Henry M. Harris

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Abstract

With the downsizing or outright elimination of nuclear power capability in space in progress, it is important to understand what this means to science in terms of capability lost. This paper is a survey of the scientific possibilities inherent in the potential availability of between 15 to 30kW through electrical nuclear power in space. The approach taken has been to interview scientists involved in space-research, especially those whose results are dependent or proportional to power availability and to survey previous work in high-power spacecraft and space-based science instruments. In addition high level studies were done to gather metrics about what kind and quantity of science could be achieved throughout the entire solar system assuming the availability in the power amounts quoted above. It is concluded that : (1) Sustained high power using a 10-30 kW reactor would allow the capture of an unprecedented amount of data on planetary objects through the entire solar system. (2) High power science means high quality data through higher resolution of radars, optics and the sensitivity of many types of instruments. (3) In general, high power in the range of 10-30 kW provides for an order-of-magnitude increase of resolution of synthetic aperture radars over other planetary radars. (4) High power makes possible the use of particle accelerators to probe tbc atomic structure of planetary surface, particularly in the dim, outer regions of the solar system. (5) High power means active cooling is possible for devices that must operate at low temperature under adverse conditions. (6) High power with electric propulsion provides the mission flexibility to vary observational viewpoints and select targets of opportunity.

INTRODUCTION

For more than two decades the advantages of the availability of high power for science exploration have been promoted in the literature. Various studies have examined the applicability and benefits of Nuclear Electric Propulsion on high priority NASA science missions. This study assumes a high power source in the range of 15 to 30kWe and examines the science objectives and instruments that are unique to this capability. Scientists involved in space-research, especially those whose results are dependent or proportional to power availability were interviewed and previous work in high-power spacecraft and space-based science instruments was surveyed .

There are five guiding concepts for using high power to the advantage of planetary science:

- Higher data rates (Mbps) are possible resulting in increased quantity of all kinds of science data.
- Increased signal to noise ratios are possible resulting in increased instrument sensitivity and better science.
- Increased mission opportunities and flexibility result from using electric propulsion from an on-board power source in the 15 to 30kWe range.
- Longer stay times are inherent in high power nuclear electric propulsion capability which provides better science.
- Some types of science instruments may only be practical when high power is available.

This study considered missions to all of the outer planets, Mars, all satellites of these bodies and asteroids as candidates for the benefit of high power science, With high power it is feasible to orbit all of these bodies and perform continuous, long-term studies with a variety of instruments. In addition, it is possible to perform long-range studies in a single mission using the proven capabilities of Earth-based radar and have the significant advantage of being located closer to interesting objects such as those found in abundance in the outer Solar System.

The major scientific disciplines that can benefit from higher power are atmospheric science, geology, geophysics, and space physics. The surface and internal characteristics of planetary bodies can be modeled and studied. Atmospheres can be probed and analyzed. The properties of rings can be determined. The relativistic effect of the large masses of the outer planets can be used to investigate theories of the nature of space-time.

Instruments can benefit from high power in several ways. Some instruments such as radar and particle beam accelerators require high power to work effectively. Most instruments, especially those that produce images can benefit from the higher data rate. Some instruments such as radio experiments can benefit from the increased sensitivity that comes with high power, Other instruments require cooling and can benefit from active cooling that is available when power is plentiful.

DATA RATE

The chart below shows the actual data rates used by planetary probes from 1966 to the present and the rates projected to the year 2020. The data rate shown, in bits/second is the equivalent imaging data rate capability at Jupiter distance (750 million kilometers). The chart shows how the need for increased data rate has dramatically risen with parallel increases in the technology of transmitters, antennas, and software.

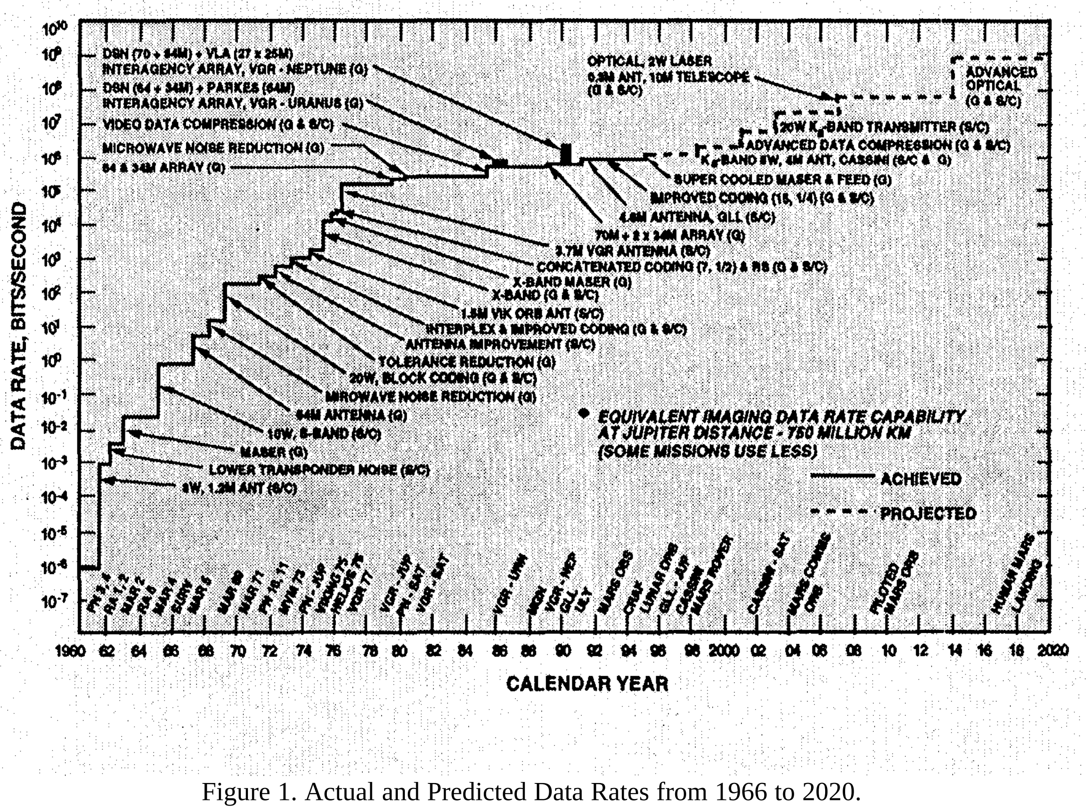

Figure 1. Actual and Predicted Data Rates from 1966 to 2020.

As an example of a high data rate option that is available with high power consider a CCD multispectral imager in orbit about a planet. Details of atmospheric dynamics can be obtained by taking a image of a hemisphere with 10 spectral channels, using 5 by 5 km pixels repeated every 500 seconds. This translates to a data rate of 156 Mbps. The table shows the predicted DC power input at the transmitter necessary to downlink data to Earth for an average Earth-planet distance.

TABLE 1. Predicted DC Power necessary to transmit 156 Mbps at average Earth-body distance.

MARS	(2 AU)	36 kW
ASTEROIDS	(3 AU)	81 kW
JUPITER	(5 AU)	225 kW
SATURN	(IO AU)	900 kW
URANUS	(20 AU)	3600 kW
NEPTUNE	(30 AU)	8100 kW
PLUTO	(35 AU)	11025 kW

Figure 2. compares the total data volume from all pre-Magellan planetary mission, the Magellan imaging data volume for one mission cycle and the data volume that would be obtained from a 30KWe nuclear-powered spacecraft for a mission orbiting a typical Galilean satellite.

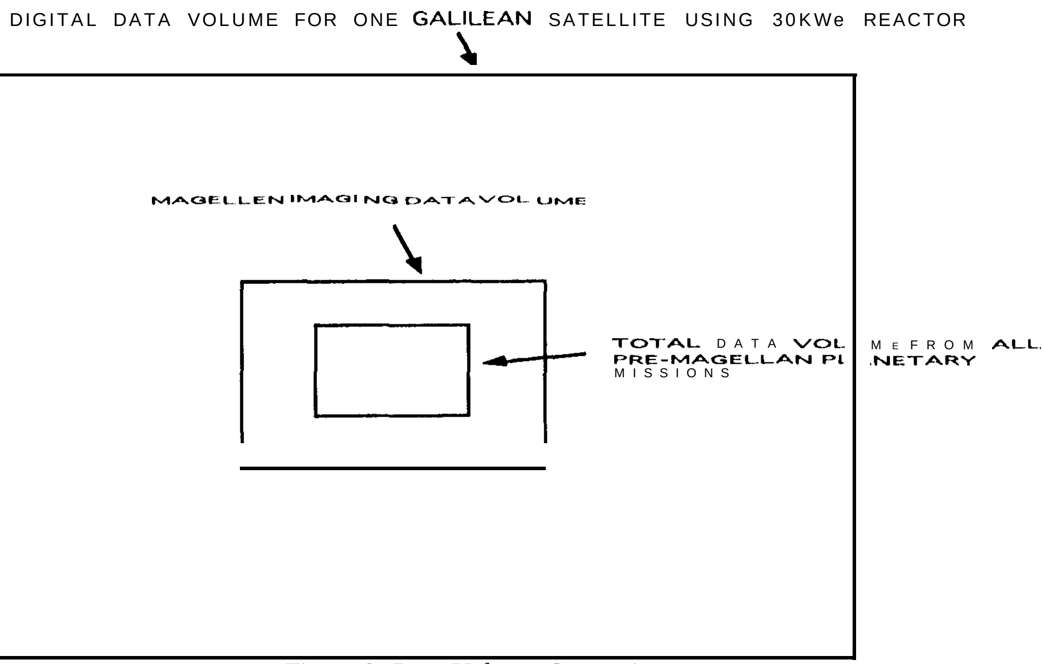

Figure 2. Data Volume Comparison

ACTIVE EXCITATION WITH A PARTICLE BEAM

Figure 3,' shows a proposed space-based particle accelerator capable of gathering important elemental composition data from the surface of a satellite, This concept has advantages over the current method of remote analysis of elemental composition using background cosmic-ray particles in that the integration time required to achieve useful scientific data is much shorter. (How much shorter depends on the specific orbit parameters. Current methods take about 10 months.)

Figure 4. shows how active excitation can be used to gather elemental composition data from a satellite. 5Mev proton bombardment induce fluorescence in the surface material which is recorded by the detectors on the spacecraft. Analysis of the emitted signature can provide data on the species and amounts of atomic composition of the surface material including magnesium, aluminum, silicon, titanium and iron.

Figure 5. is a proposed spacecraft that would use a particle beam for active investigation of the elemental composition of the surface of a satellite. The beam is targeted with the aid of optics mounted parallel to the beam output. Science data is gathered using the X-ray sensors shown mounted on the composite structure.

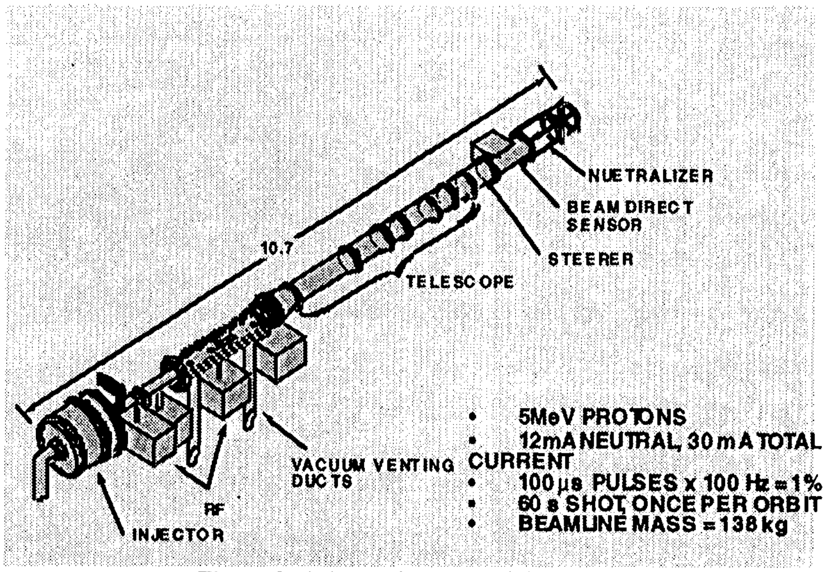

Figure 3. A Space-based Particle Accelerator

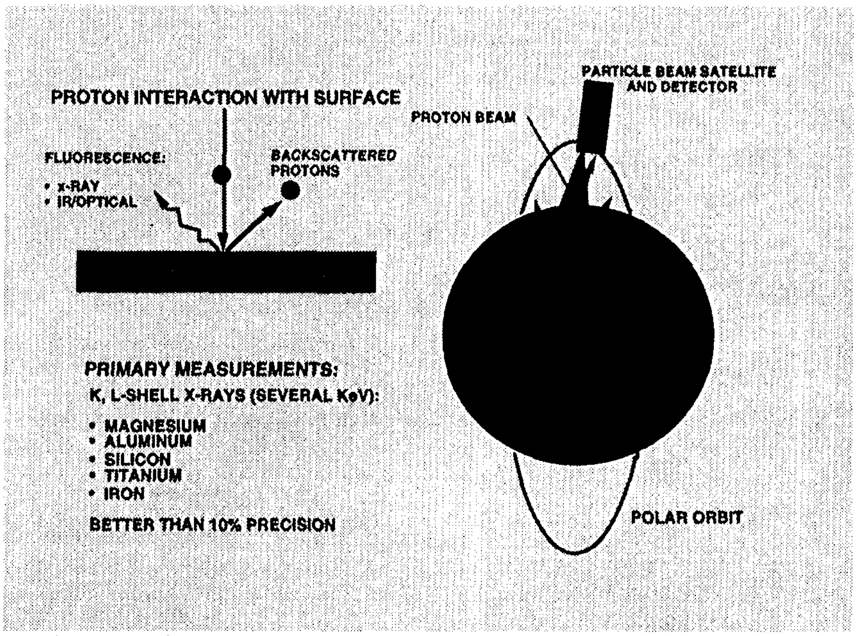

Figure 4. Elemental Composition Determination using Active Excitation

RADAR

Radar and sounding instruments have increased effectiveness when high power is available. The science possibilities of high-powered radar can be realized in both imaging and search modes. Multi-mode radars can have a long wavelength mode that would be able to penetrate into certain types of materials as much as kilometers in depth,

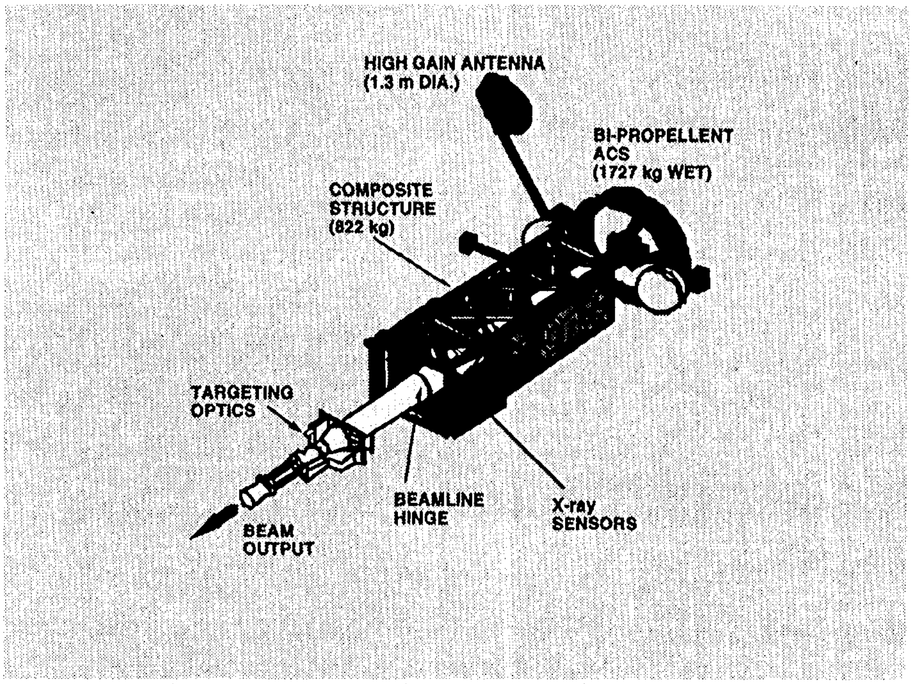

Figure 5. A proposed Space-based Particle Accelerator.

Synthetic Aperture Radar (SAR) can benefit greatly from availability of high power. A good example of this is to compare the high data volume of Magellan which only had a few hundred watts of power but collected a staggering 3x1012 bits of data through one cycle of data taking. At best, Magellan had only about 300 meters of resolution. SIR-C, on the other hand, had 8 kW of DC input and, as a result, 30 meter resolution--an order of magnitude increase in resolution. SIR-C is an example of what can be done with high power. Unfortunately, SIR-C was tied to the Shuttle's power system and had only a few days to take data. A nuclear power-based radar imaging system could have the advantage of both approaches and collect high resolution data over a long period of time, A 30 kW nuclear system would allow 10 meter resolution for global coverage of a planetary surface.

RELATIVITY INVESTIGATIONS

Although to date no gravity waves have been detected, most scientists believe that it is only a matter of time. Produced by cataclysmic events, such as a star falling into a black hole at the center of the galaxy, gravity waves will provide an entirely new way of viewing the universe. Gravity wave signature detection require extremely sensitive communications that can theoretically be enhanced by the availability of high power. If gravity wave signature detection is successful, weaker sources could theoretically be detected with higher power.

In addition to the study of gravity waves, the effect of gravity on the space-time continuum can be measured more effectively using high power. Large masses such as Jupiter distort space-time enough that relativistic effects can be detected using sensitive electronics that take advantage of the availability of high power. Relativistic effects that can be detected are the slowing of time frame of photons passing through the gravity well, frequency displacement of light (red-shift) and the precession of orbits,

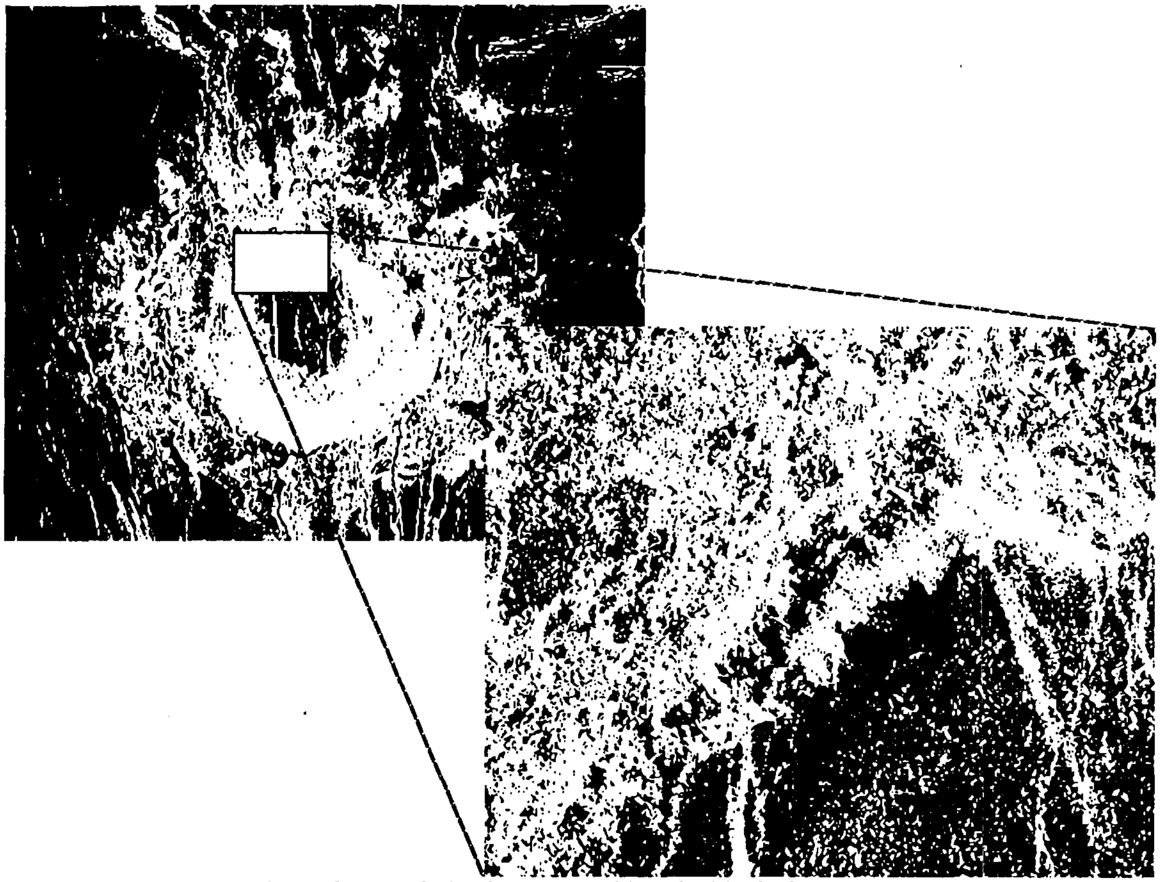

Figure 6. Resolution Increase Achieved with Nuclear Power

ACTIVE COOLING

Active cooling has not been available on planetary spacecraft in the past because of power constraints and the lack of reliable long-life active coolers. Future high-technology experiments may require cryogenic temperatures. Extremely sensitive superconducting electronics will require active cooling as will high-powcred radars and high data-rate electronics. Cooling of sensor elements such as CCD arrays that are used for imaging and optical navigation is used to repair radiation damage which may be necessary to insure long-term operation while using a nuclear generator for power.

Missions that require data acquisition at Mars or closer to the sun may require active cooling if thermal characteristics of the spacecraft prevent effective passive cooling.

The elemental composition of an airless body can be investigated by bombarding the surface with protons generated by an on-board particle accelerator. The impact of the protons results in induced gamma ray emission that can be detected by a gamma ray spectrometer. This is similar to the way a cosmic ray gamma spectrometer experiment works except the source of the exciting radiation is well-controlled and can be much stronger. In general, the number of elements that can be discriminated is proportional to the strength of the beam.

ATMOSPHERIC SCIENCE

The capability for long-term orbiting and repeated viewing angles will allow the study of atmospheric characteristics that change slowly with time such as Jupiter's Red spot. Laser sounding can provide spectrographic analysis while radio atmospheric occultation can provide deep penetration of planetary atmospheres.

Short-term dynamic processes can also be studied using the high data rate capability to transmit time-varying measurements. Imaging can study the movement of dust and vapor clouds in the Martian atmosphere. Occultation experiments can provide insight into changing pressure gradients and the depth of methane and ammonia clouds in the atmosphere of gas giants.

On previous missions, transmitter power has limited the depth of temperature-pressure profiles of the outer planets. Increased power allows deeper penetration, Profiles produced by radio occultation provide the only direct measure of the interior of the atmospheres of the outer planets and they provide significant clues to create more realistic atmospheric and planetary interior models. Global coverage that can be obtained with the long stay time afforded by high power can further constrain these models.

GEOLOGY AND GEOPHYSICS

The geology and geophysics of the surface and subsurface of planetary objects can be studied with multi-mode radar imaging. Mineralogy data can be obtained by imaging at different frequencies and multi-polarizations can further characterize the surface. Elemental composition can be obtained by exciting the surface with high-powered lasers or by impact with spacecraft-fired projectiles (Impact Flash Spectrometry).

CONCLUSIONS

Nuclear power in space gives a number of capabilities that are not easily achievable or impossible with other types of power sources for many types of mission and science objectives. Although NASA dots not currently plan any nuclear power-based missions nor plan any missions that would require nuclear power, that may not always be true if scientific and mission requirements increase in the future. The following summarizes the benefits of high power in space.

(1) Sustained high power using a 10-30 kW reactor would allow the capture of an unprecedented amount of data on planetary objects through the entire solar system.

(2) High power science means high quality data through higher resolution of radars, optics and the sensitivity of many types of instruments.

(3) In general, high power in the range of 10-30 kW provides for an order-of-magnitude increase of resolution of synthetic aperture radars over other planetary radars.

(4) High power makes possible the use of particle accelerators to probe the atomic structure of planetary surface, particularly in the dim, outer regions of the solar system.

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