# An Update on the FIRE (Solar Probe) Mission

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## Abstract

A joint U.S.-Russian mission to the sun named FIRE is currently being planned. The mission consists of two spacecraft, one U.S. built and the other Russian built, Both spacecraft will be launched from a single vehicle, separate after launch, travel to jupiter for a gravity assist that will maneuver the spacecraft into highly elliptical polar orbits about the sun. The U.S. spacecraft will have a perihelion of 4 Rs and the Russian 10Rs. A full complement of in situ fields and particles instruments are planned for both spacecraft to measure acceleration mechanisms and other characteristics of the solar wind. The strawman payloads and expected science return will be discussed.

## Introduction

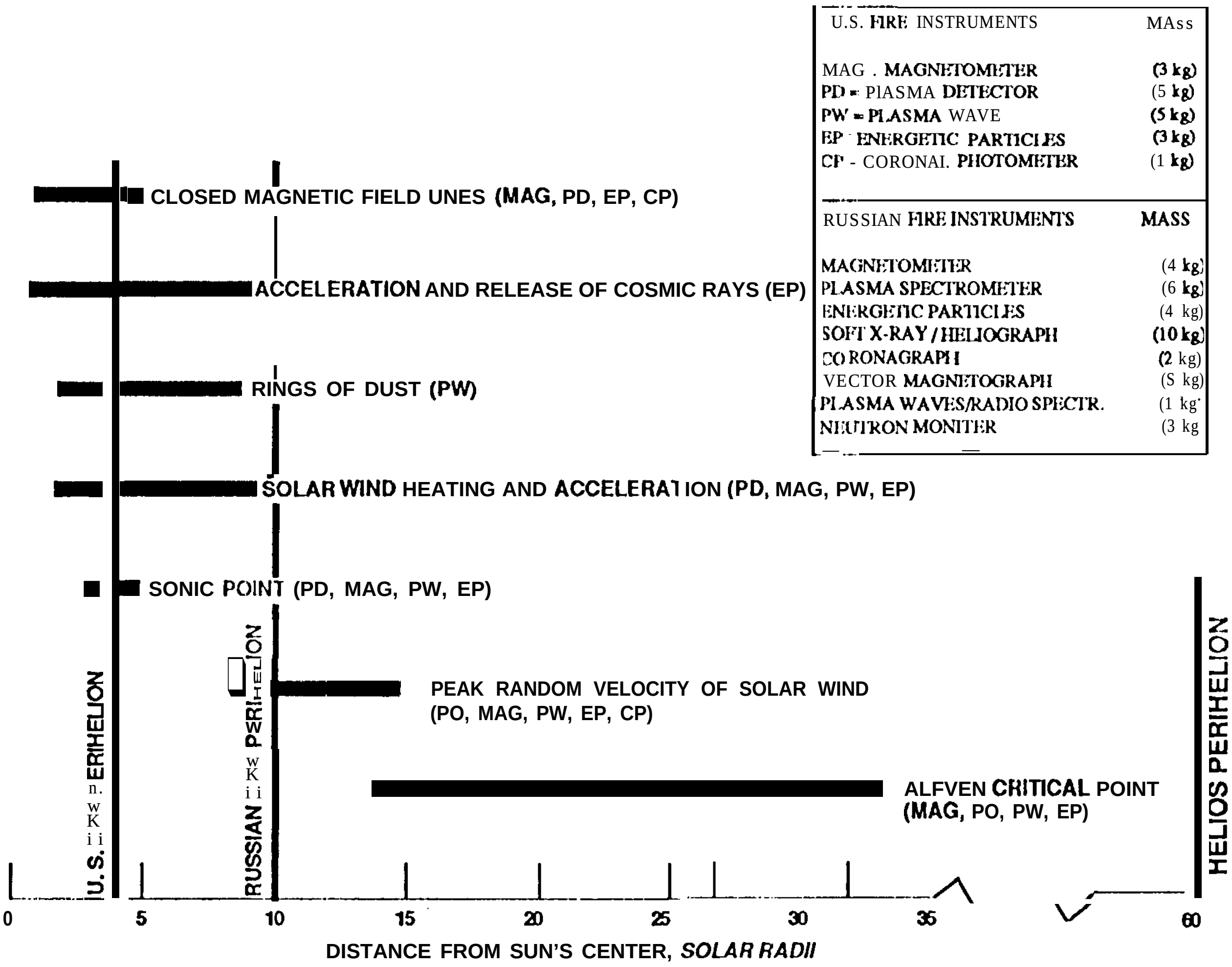
The FIRE program was conceived in 1994 to develop a joint U.S. and Russian mission to travel to the vicinity of the sun. It was planned to use a single launch of a Russian Proton launch vehicle in 2001. The program promises to yield new data about the local environments around the sun and specifically will reveal new information about the birth and acceleration of the solar wind. Miniaturized instruments will be developed that can be accommodated on small high technology spacecraft from each country. The two small spacecraft will be stacked inside the Proton fairing and will be launched to Jupiter for a swingby that will place them on trajectories with perihelion radii of 4Rs (U. S.) and 10RS (Russian).

## The Science Context

The FIRE science objectives were defined early in the joint study (ref. 1) and provided the context for the science observational requirements of the mission.

One of the fundamental mysteries in the universe is why ordinary stars like our Sun have extremely hot outer atmospheres (approximately one million degrees), while their surface temperatures are only thousands of degrees. Near-Earth observations have provided information on the thermodynamics and flow parameters of the solar corona. However, all of the important physical processes thought to be the source of the heating involve small scale phenomena which cannot be resolved from line-of-sight integrated observations. Only in-situ measurements actually taken from inside the corona, combined with imaging of these extremely fine structures undertaken by a spacecraft traveling very close to the Sun, will provide the data to help researchers understand what causes the extreme heating in the corona. The FIRE mission proposes such first-time measurements from distances closer to the Sun than any other spacecraft has ever approached.

The predicted processes that heat the solar corona and thus provide energy and momentum that accelerate the solar wind, occur over an extended radial distance, from tenths of a solar radius above its surface to about 30 solar radii above as illustrated in figure 1. In addition, these processes may be quite different over the polar and



| U.S. FIRE INSTRUMENTS | MASS |
|---|---|
| MAG . MAGNETOMETER | (3 kg) |
| PD = PLASMA DETECTOR | (5 kg) |
| PW = PLASMA WAVE | (5 kg) |
| EP - ENERGETIC PARTICLES | (3 kg) |
| CP - CORONAL PHOTOMETER | (1 kg) |
| **RUSSIAN FIRE INSTRUMENTS** | **MASS** |
| MAGNETOMETER | (4 kg) |
| PLASMA SPECTROMETER | (6 kg) |
| ENERGETIC PARTICLES | (4 kg) |
| SOFT X-RAY / HELIOGRAPH | (10 kg) |
| CORONAGRAPH | (2 kg) |
| VECTOR MAGNETOGRAPH | (5 kg) |
| PLASMA WAVES/RADIO SPECTR. | (1 kg |
| NEUTRON MONITER | (3 kg |

Figure 1 FIRE Program Science Objectives and Payloads ( from Ref. 1)

the equatorial regions, partly due to the different local magnetic field characteristics in the two regions. It is also highly probable that the heating and expansion of the solar corona are dynamic processes, continuously changing with time and space. In order to understand the extended coronal heating and acceleration of the solar wind at different solar latitudes, and in order to understand how the dynamics of the corona change with time and place, in situ measurements must be made at a variety of altitudes above the surface of the. Sun and at different latitudes.

The U.S. Solar Probe mission consists of a single spacecraft placed on an elliptical encounter trajectory, traveling from 8 $R_S$ over the poles to 4 Rs (0.()19 AU) at the equator (where the solar wind becomes supersonic and is the closest that shield technology would allow ). The Solar Probe would be the first spacecraft to acquire in-situ measurements from within the solar corona at multiple ranges and latitudes together with imaging of the surrounding coronal region.

The FIRE mission consists of two spacecraft. The inner spacecraft duplicates the Solar Probe trajectory while the outer spacecraft (the Russian "Plamya") will travel from 20 Rs over the poles to 10 Rs at the equator. The FIRE mission will achieve, for the first time, simultaneous measurements by two spacecraft from multiple altitudes and latitudes in the solar corona, together with imaging of the underlying and surrounding coronal region. This data will enable researchers to determine both the 3-dimensional structure of the corona and identify the regions on the Sun that are responsible for the particular solar wind flows. These flows eventually reach the Earth and cause disturbances in the Earth's magnetosphere. Additionally, in-situ measurements will enable researchers to identify mechanisms responsible for coronal heating and the solar wind acceleration, thus answering the question of why the solar corona exists.

The near-Sun scientific objectives require two generic classes of measurements and can be summarized as follows:

1) coordinated in-situ observations using a complement of particle and field experiments;

2) imaging experiments, consisting of coronal imaging on the Solar Probe and the disc imaging on the Plamya spacecraft;

The range of objectives and scientific payloads are shown in Figure 1. Here each major objective is identified as a horizontal line plotted on a scale of distance from the Sun in solar radii. Note that the Solar Probe travels to 4 Rs and the Plamya travels to 10 Rs. This can be compared to the only other "Solar Probe" mission, Helios, which had a perihelion of 60 Rs as shown.

The perihelion trajectories for the FIRE program are shown in figure 2 as an overlay to a magnetic field model (from Ref. 2). Note the nearly radial (open) field lines over the polar regions that are consistent with the regions of high speed solar wind confirmed by recent observations from the Ulysses spacecraft, As the spacecraft approaches lower latitudes, the field will become more dipole-like but will probably be more unstructured than this simple model suggests in this region.

Tables 1 and 2 contain the details of payload for the Solar Probe and PLAMYA spacecraft. The emphasis for the Solar Probe payload is on fields and particle measurements close to the sun with only a small photometer that observes the. coronal features above the limb of the sun. The Plamya payload carries three large remote observational insturments that will view closer to the sun (coronagraph) and view the solar disk for magnetography and x-ray observations.

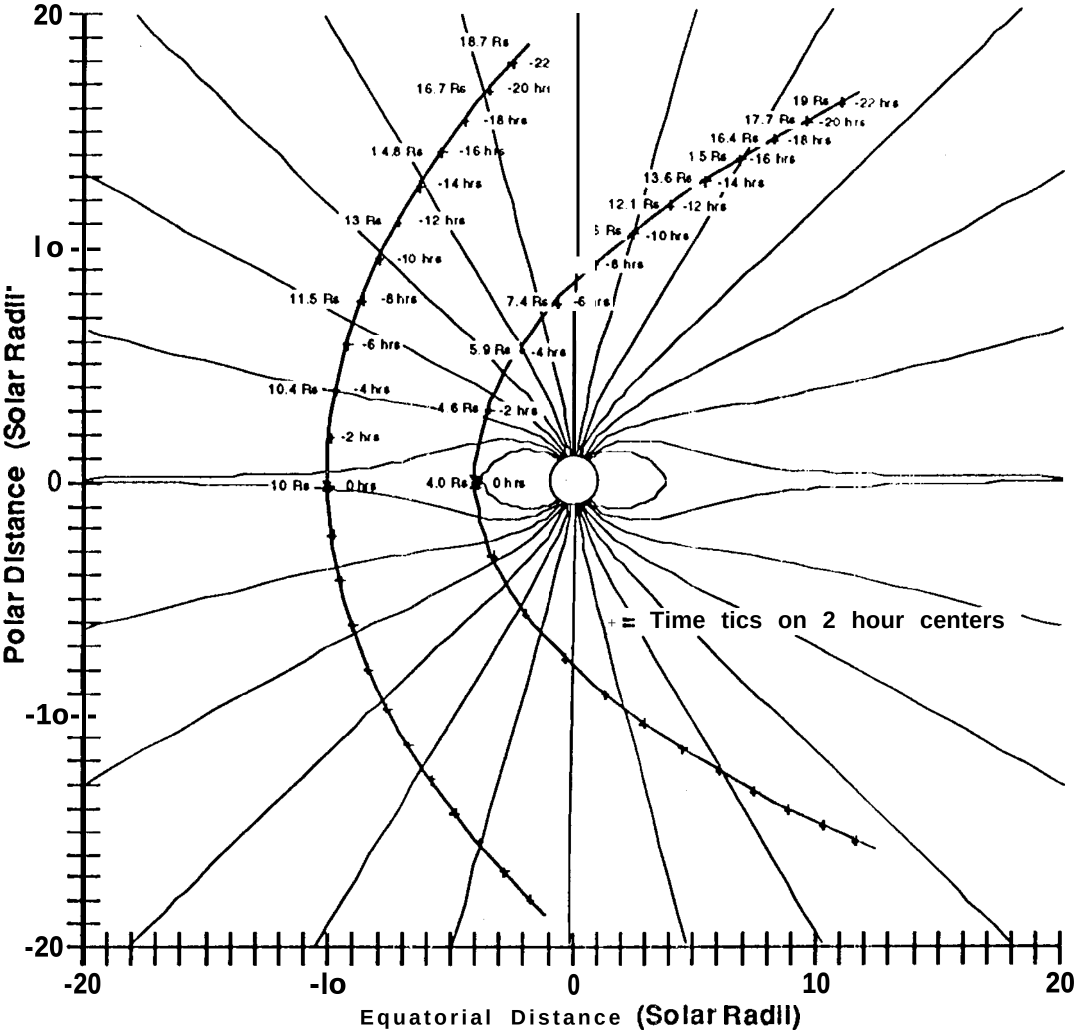


Figure 2 FIRE Trajectories Over a Solar Magnetic Field Model

Table 1 Solar Probe Payload Characteristics (from Ref. 3)

| Instrument | Mass (kg) | Power (W) | Data (kbit/s) |
|---|---|---|---|
| Magnetometer | 3.3 | 1.9 | 0.5 |
| Thermal Plasma | 4.8 | 3.4 | 1.2 |
| Energetic Particles | 3.3 | 3.1 | 0.5 |
| Plasma Waves | 5.5 | 5.0 | 0.5 |
| Coronal Photometer | 1.0 | 0.6 | 0.1 |
| **Total** | 18 | 14 | 3 |

Table 2 Plamya Payload Characteristics (from Ref. 4)

| Instrument | Mass (kg) | Power (W) | Data (kbit/s) |
|---|---|---|---|
| Plasma Spectrometer | 6 | 6 | 5 |
| Magnetometer | 4 | 3 | 8 |
| Soft X-ray Telescope/Heliograph | 10 | 8 | 5 |
| Energetic Particles Spectrometer | 3.5 | 3 | 1 |
| Chronograph | 1.5 | 2 | 5 |
| Vector Solar Magnetograph | 8 | 8 | 5 |
| Plasma Waves/Radio Spectrometry | 1.5 | 2 | 2 |
| Neutron Monitor | 3.5 | 3 | 0.1 |
| Total | 38 | 35 | 31 |

## Launch Configuration

The latest launch configuration of the U.S. and Russian spacecraft on the Proton is illustrated in figure 3. Note that the Proton vehicle has high performance upper stage (STAR 48 ) to provide the high injected mass capability required for the high launch energies of a Jupiter gravity assist mission. The launch mass of the U.S. spacecraft is expected to be about 200 kg while the Russian spacecraft is expected to be about 300 kg. With the launch adapters and other supporting hardware. The launch mass of about 600 kg should be well under the performance of the Proton /STAR 48 which is over 750 kg at the launch energy of 120 $km^2/sec^2$ required for the 2001 joint launch.

## Russian Spacecraft

The Russian spacecraft or Plamya (from Ref. 4) shown in Figure 4 is characterized by a wide angle cone for a thermal shield that provides sufficient spacecraft thermal protection for the perihelion of $10R_S$. The shield will reach a temperature of about 1900K at 10Rs and will have holes (not shown) in it to allow for imaging of the. solar surface at perihelion. A unique. characteristic of the Plamya spacecraft is the radioisotope (RTG) power system which provides 150W of power continuously throughout the mission including at perihelion. The radio system will operate at X-band in order to have tracking compatibility with NASA's Deep Space Network as well as the Evpatoria and Ussurisk tracking stations in Russia. The RF power amplifier will provide 5W of power through the 1 m antenna shown in the figure to achieve the required 30 kilobits/s telemetry rate at the 10Rs perihelion. Science instrument accommodation will include apertures through the shield to allow solar viewing at perihelion, plasma and particle instruments in the central bus area behind the antenna, and a magnetometer on a long boom below the RTG as shown.

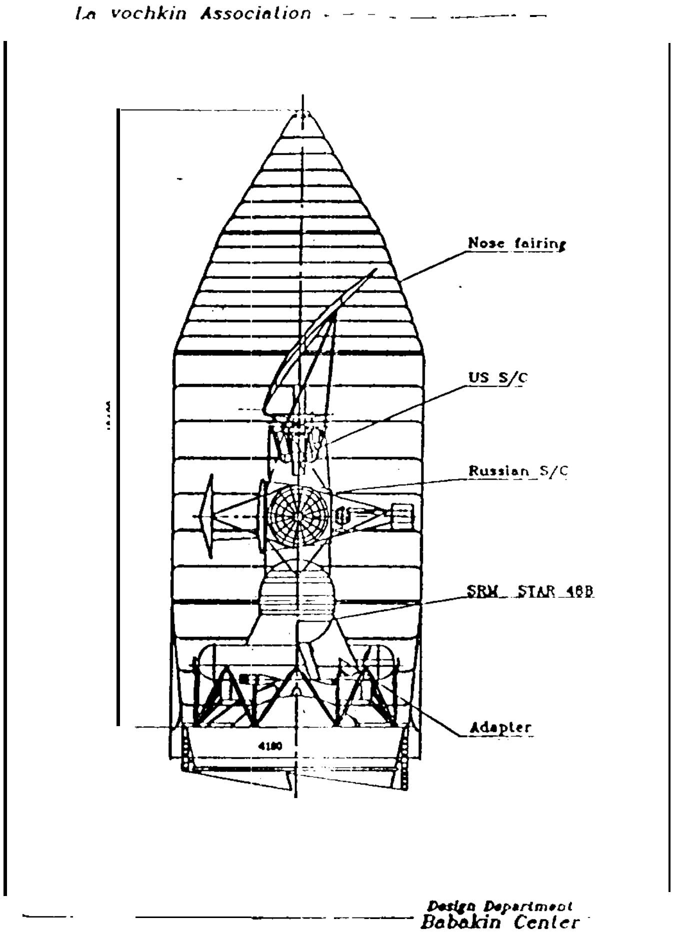


Figure 3 FIRE Launch Configuration: PROTON/Star 48

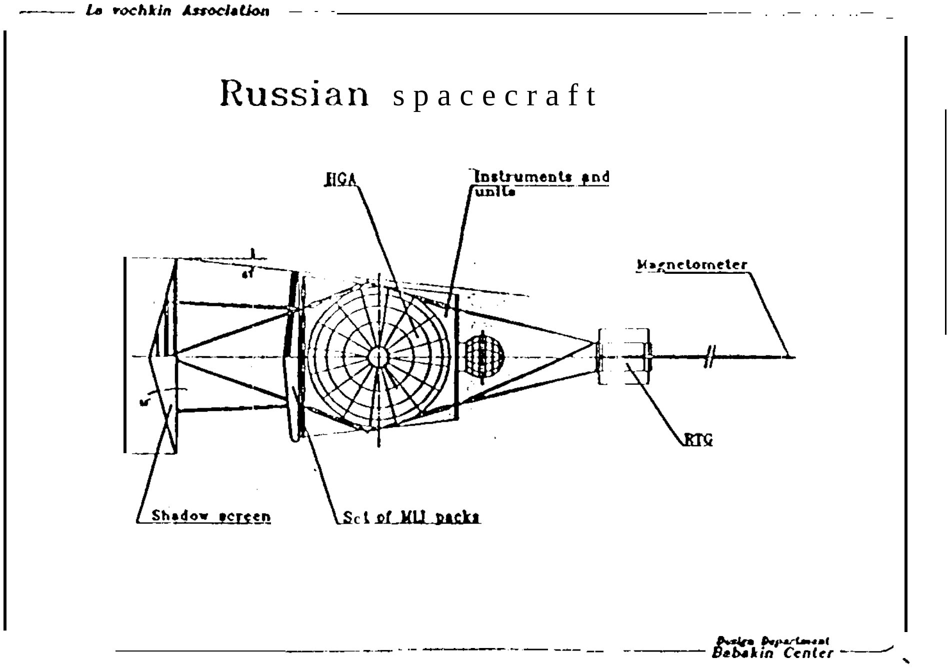
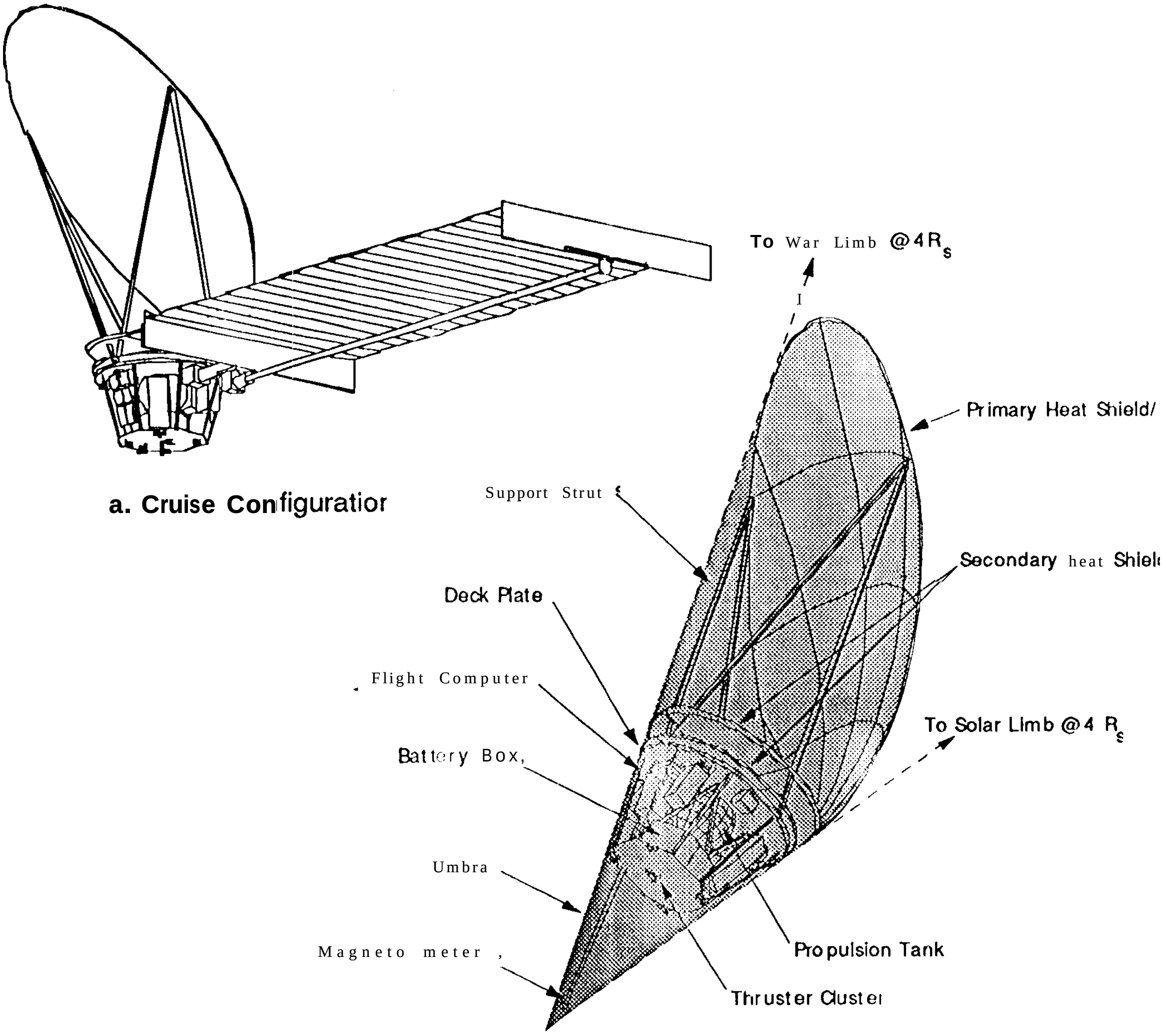


Figure 4 **PLAMYA** Spacecraft Configuration (from Ref. 4)

## U.S. Spacecraft

The U.S. Solar Probe spacecraft is **shown** in Figure 5 during two mission phases that are defined by the power source during that phase. RTGs will not be used on the U.S. spacecraft and it must depend on other power sources including solar arrays for power when it is away from the sun. As it approaches the sun, the arrays will be jettisoned and a battery will be required to complete the mission. Panel a in figure 5 shows the configuration after launch when a large (Low illumination -1 Low Temperature) solar array will provide power out to Jupiter and then on in to about 0.7AU. At that time, the large array is



**a. Cruise Configuratior**

b. **Perihelion Configuration**

Figure 7 U.S. Fire (Solar Probe) Spacecraft Configurate ions jettisoned and a smaller High Temperature Solar Array (not shown) will begin operation. At about 0.2AU, that array will also be jettisoned and a large primary battery will begin to supply power until just past perihelion when the battery will be depleted ending the mission.

A quadrature geometry will be designed for perihelion where the sun-spacecraft-earth angle will be exactl y 90 degrees to optimize the antenna geometry on the spacecraft at perihelion. This is fundamental to the spacecraft configuration allowing nadir pointed shields with simultaneous earth pointed antennas. Panel bin the figure illustrates the large parabolic shield that will function as a thermal shield as well as a high gain antenna at perihelion providing high telecommunications performance with a low power requirement. The X-band communications subsystem will have a 5 W power output and the antenna/shield will have a gain of about 40 dB. The estimated telemetry rate performance at the 4Rs perihelion is about 5 kilobits per second and is limited by the hot body noise in the tracking stations (when the sun will be in the beamwidth of the stations) and by the scintillation perturbations on the telecommunications link caused by plasma turbulence in the solar corona ( see Ref. 3).

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