Deep Space C^3: High Power Uplinks

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RF 2003 Workshop
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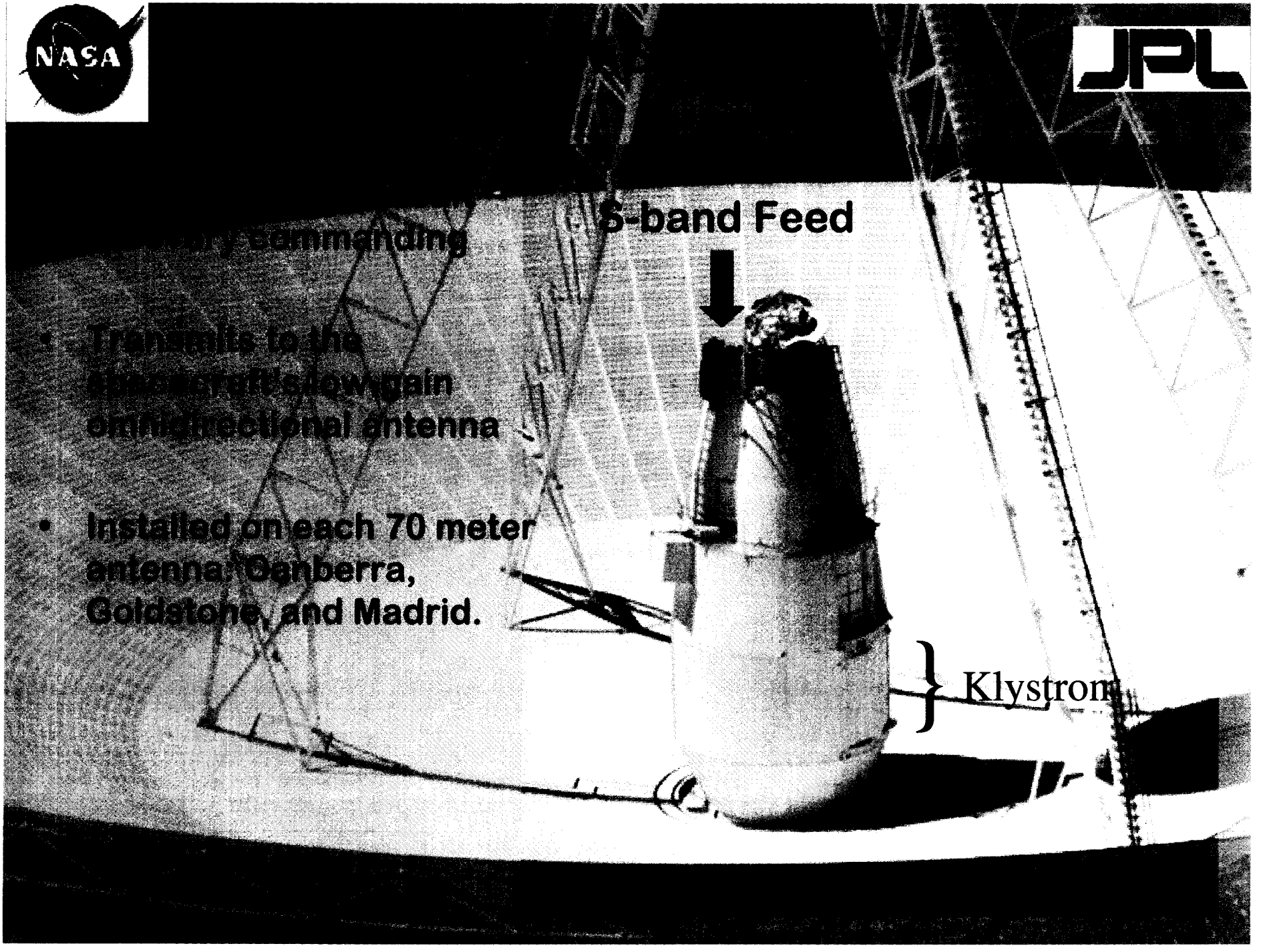


- [illegible] commanding
- Transmits to the spacecraft's low gain omnidirectional antenna
- Installed on each 70 meter antenna: Canberra, Goldstone, and Madrid.

CW Uplink Power Transmitters

S-band

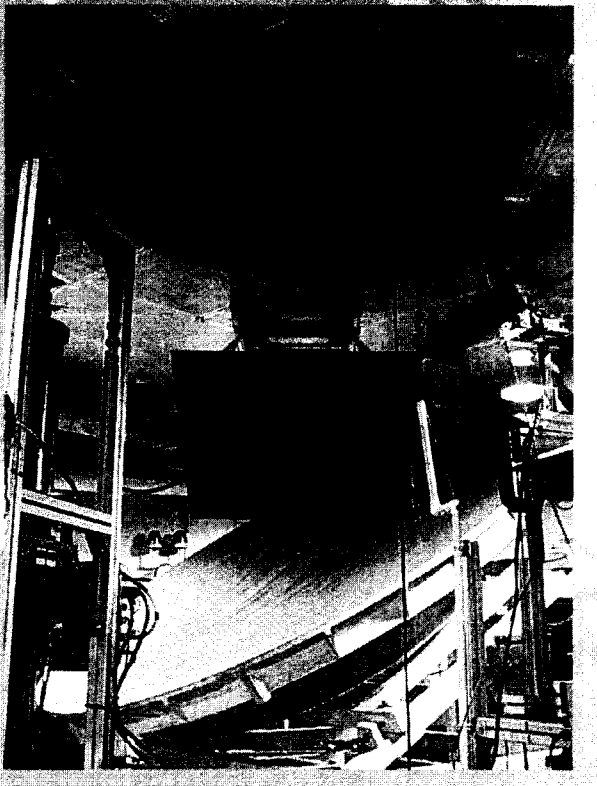
- 200W on 34m (LEO)
- 2 kW on 26m antenna (only DSN klystron not red)
- 20kW on 26m, 34m & 70m
- 400kW on 70m

Ka-band

- 800W on 34m (demonstration)
- Proposed 5-10kW on 34m antenna

X-band

- 4kW on 34m antenna (Decommissioning)
- 20kW on 34m & 70m
- 400kW on 70m (radar ONLY)

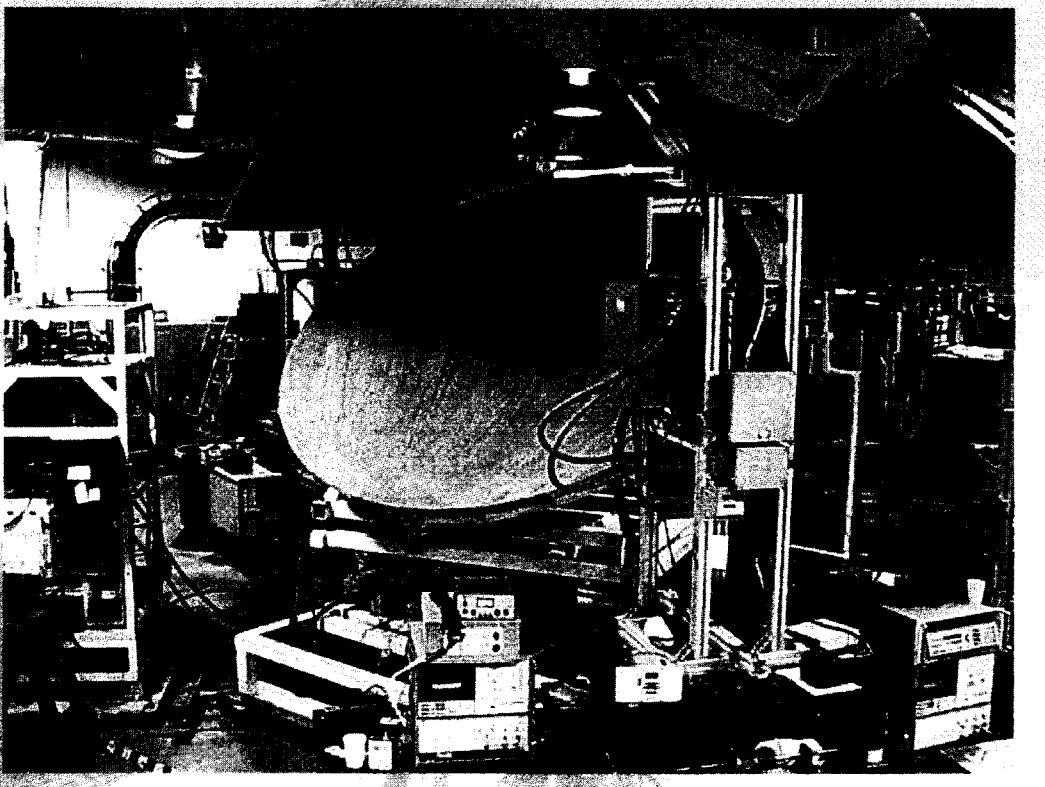


Dichroic Filter

$$\frac{\text{Transmit Power}}{\text{Receive Power}} \leq 10^{24}$$

T/R Diplexers

- Separate 7.2GHz, 20kW uplink from 8.4GHz, femtowatt downlink

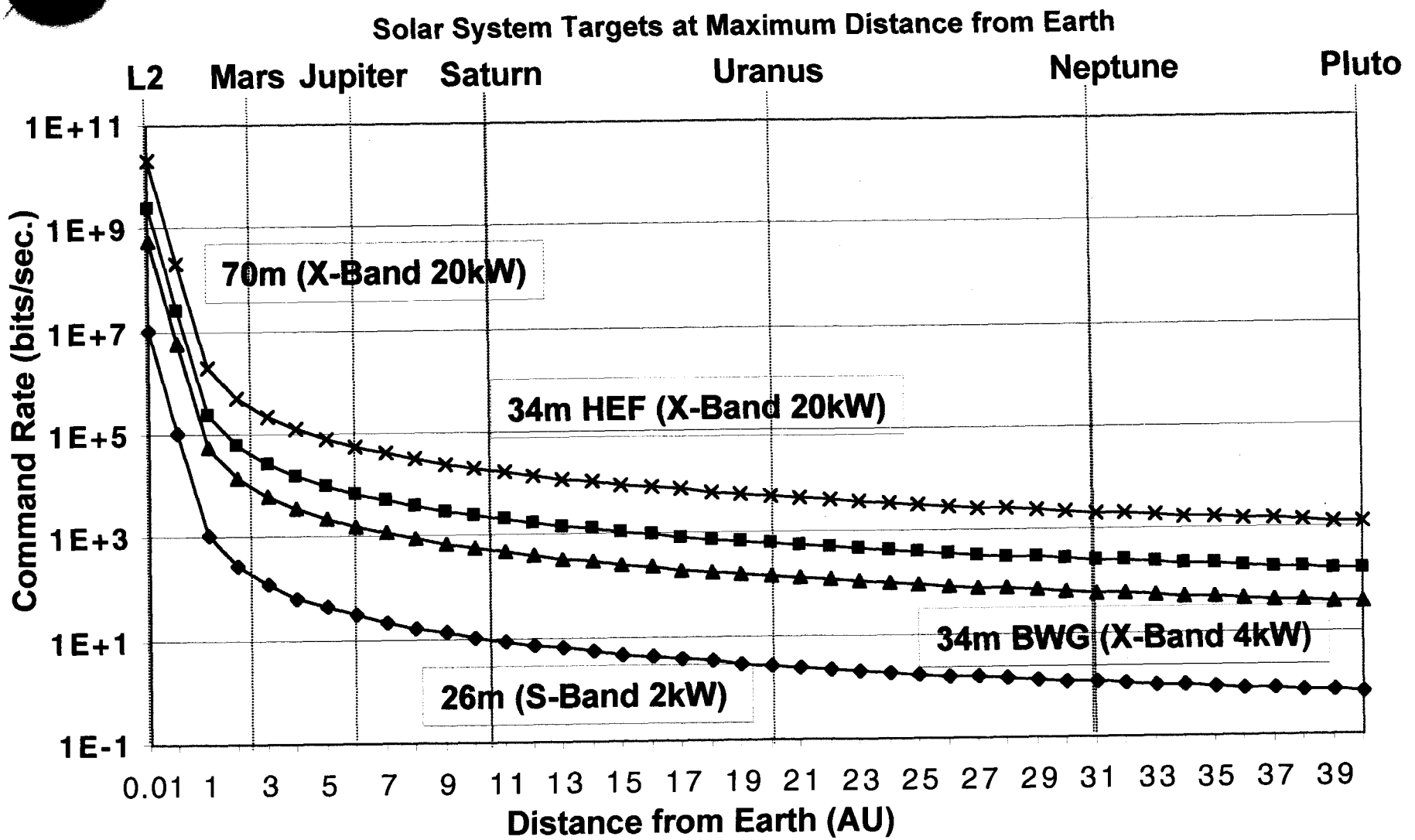


Dichroic Filters

- Allow simultaneous Ka downlink and X-band uplink/ downlink.

http://csoc-dsn-web.jpl.nasa.gov/PAGES/13_shrd_1.jpg

Uplink Power Transmitters



Note: Plots assume uplink to a 1.0m spacecraft HGA and a 400K spacecraft receiving system noise temperature. Supporting link calculations include 3dB margin. This 2002 data is subject to revision and should be regarded as ROM. Slide courtesy of Douglas S. Abraham

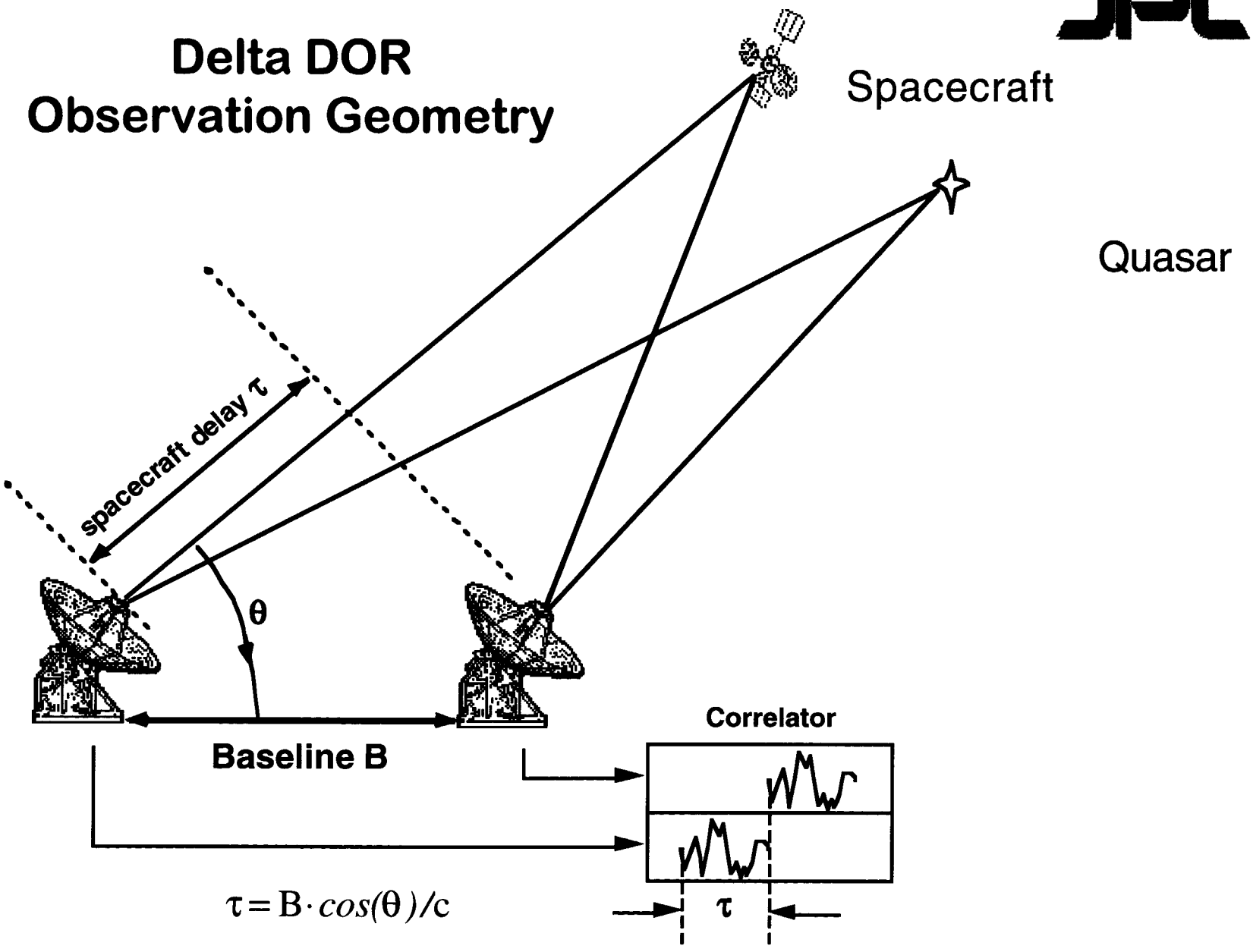
Command, Control, and Communications in Deep Space

- Part 1: Navigation
  - Toughest job is Entry, Descent, Landing (EDL)
  - Predict upgrades to spacecraft and receivers
- Part 2: Command Uplink
  - Toughest job is Rover Operations
  - Predict upgrades to ground transmitters
- Part 3: Emergency Recovery
  - Toughest job is a spacecraft tumbling out of control ("unknown rotational state")
  - Predict upgrades for X-band transmitters and for antenna array systems

Part 1: Navigation Measurement Techniques

- Angular Position
  - Antenna Main Lobe Angular Width
  - Delta Differential One-way Range (Delta DOR)
- Range
  - One way (spacecraft to ground)
  - Two way (gnd to spacecraft to gnd)
  - The uplink and downlink frequencies differ by 5% to 25%, depending on the band.
  - Regenerative ranging with pseudorandom code (gnd to spacecraft, spacecraft to gnd)
- Range Rate
  - Doppler, one way or two way
- Advanced spacecraft navigation makes demands on the ground receivers and the spacecraft, NOT the uplink transmitter.

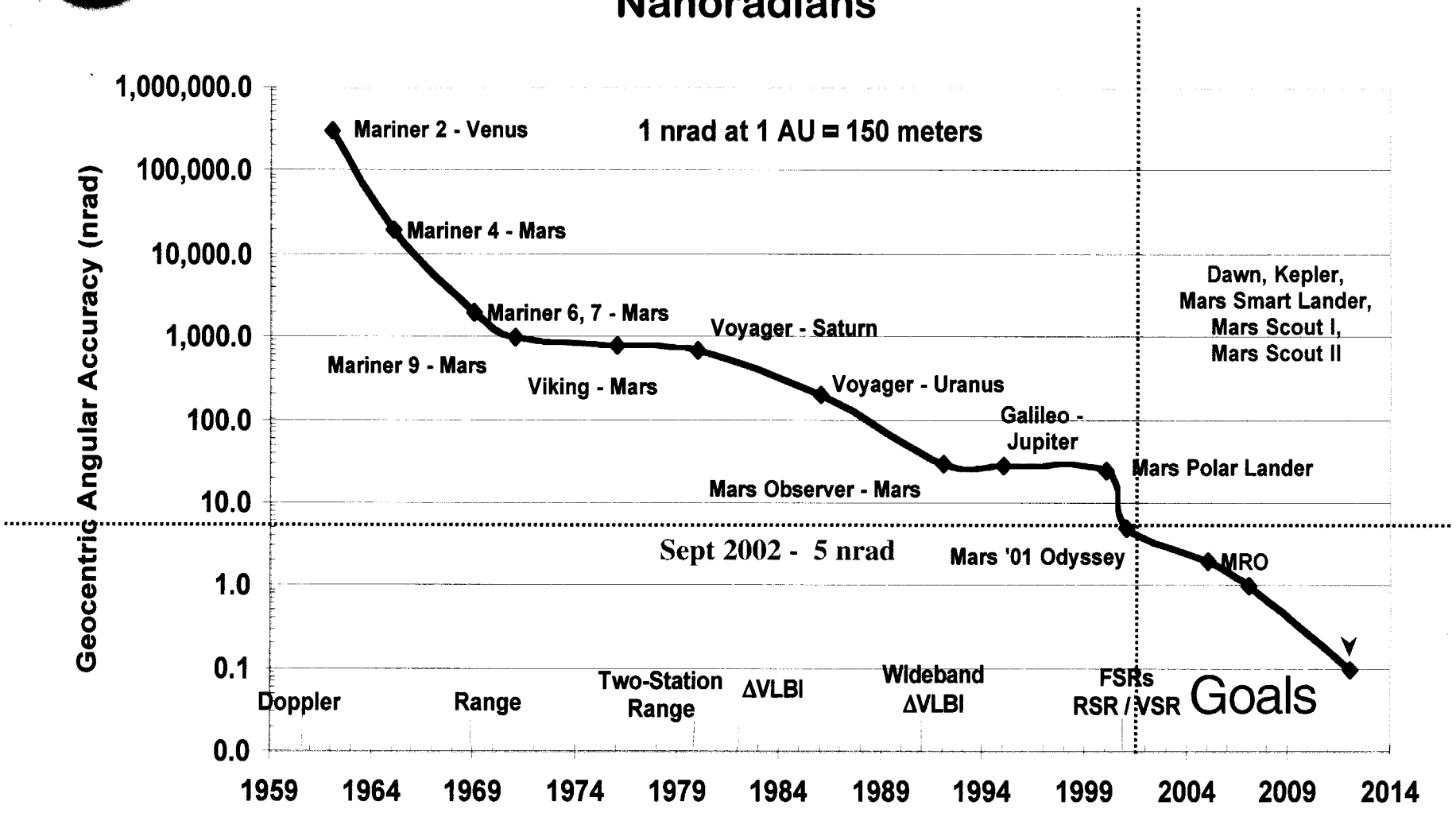
Delta DOR Observation Geometry



$$\tau = B \cdot cos(\theta)/c$$

Slide Courtesy of Charles Naudet

Angular Position Accuracy: Nanoradians



FSR: Full Spectrum Recorder

Slide Courtesy of Charles Naudet

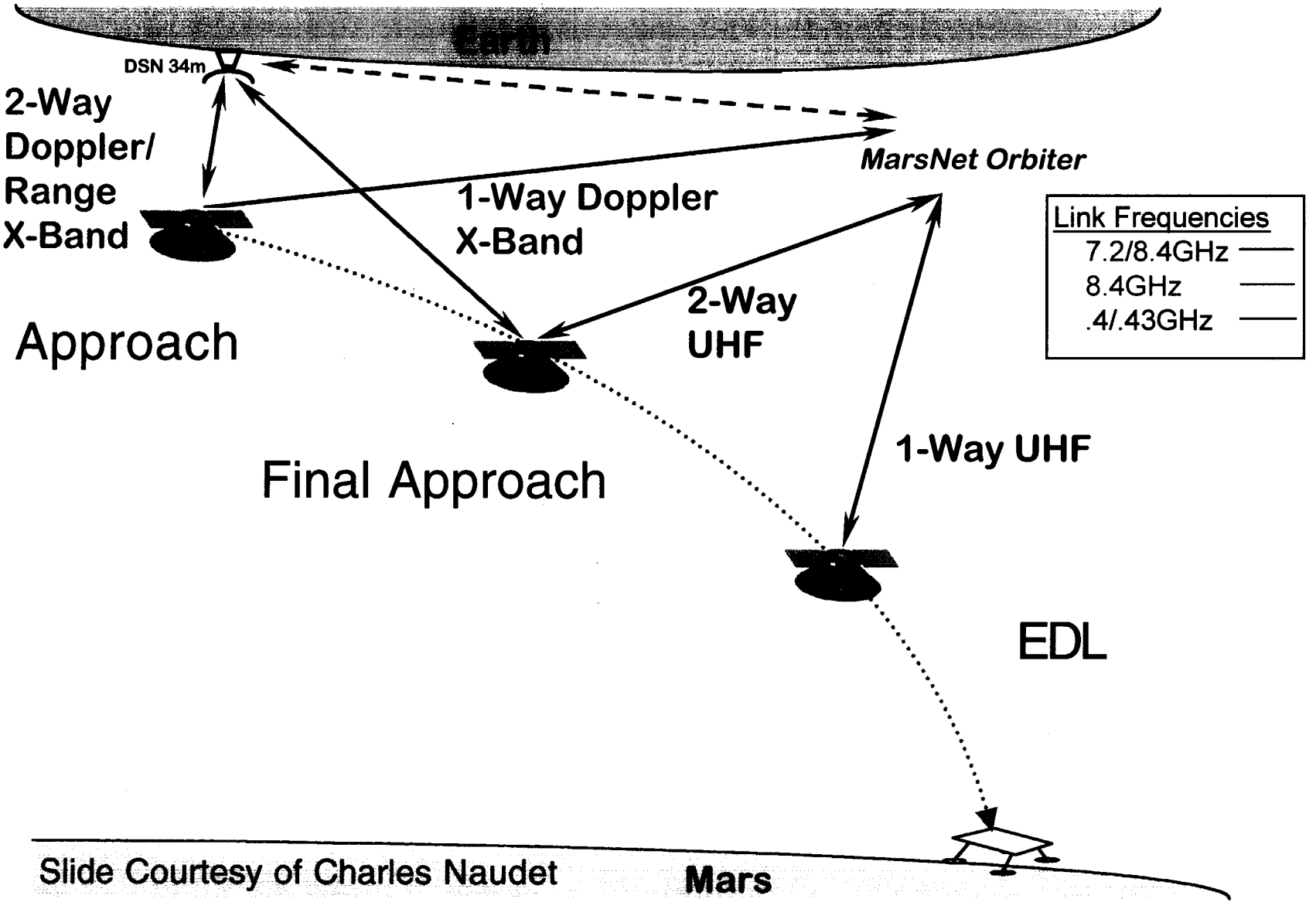
Range and Range-Rate Accuracy

- The range is the transmission delay (Round Trip Light Time, RTLT) earth-spacecraft-earth.
- Accuracy:
  - Near lunar orbit (up to 644,000 km): 1 meter
  - Near Mars, Jupiter orbits (150 million km): <1 km

- The range rate, or spacecraft velocity vector toward or away from Earth, is the Doppler shift of the downlink frequency.
- Accuracy:
  - 30 minute integration time: 0.1 mm/sec (1-sigma uncertainty) for the larger antennas.
- The derivative of the range rate, or spacecraft acceleration vector, is also calculated.

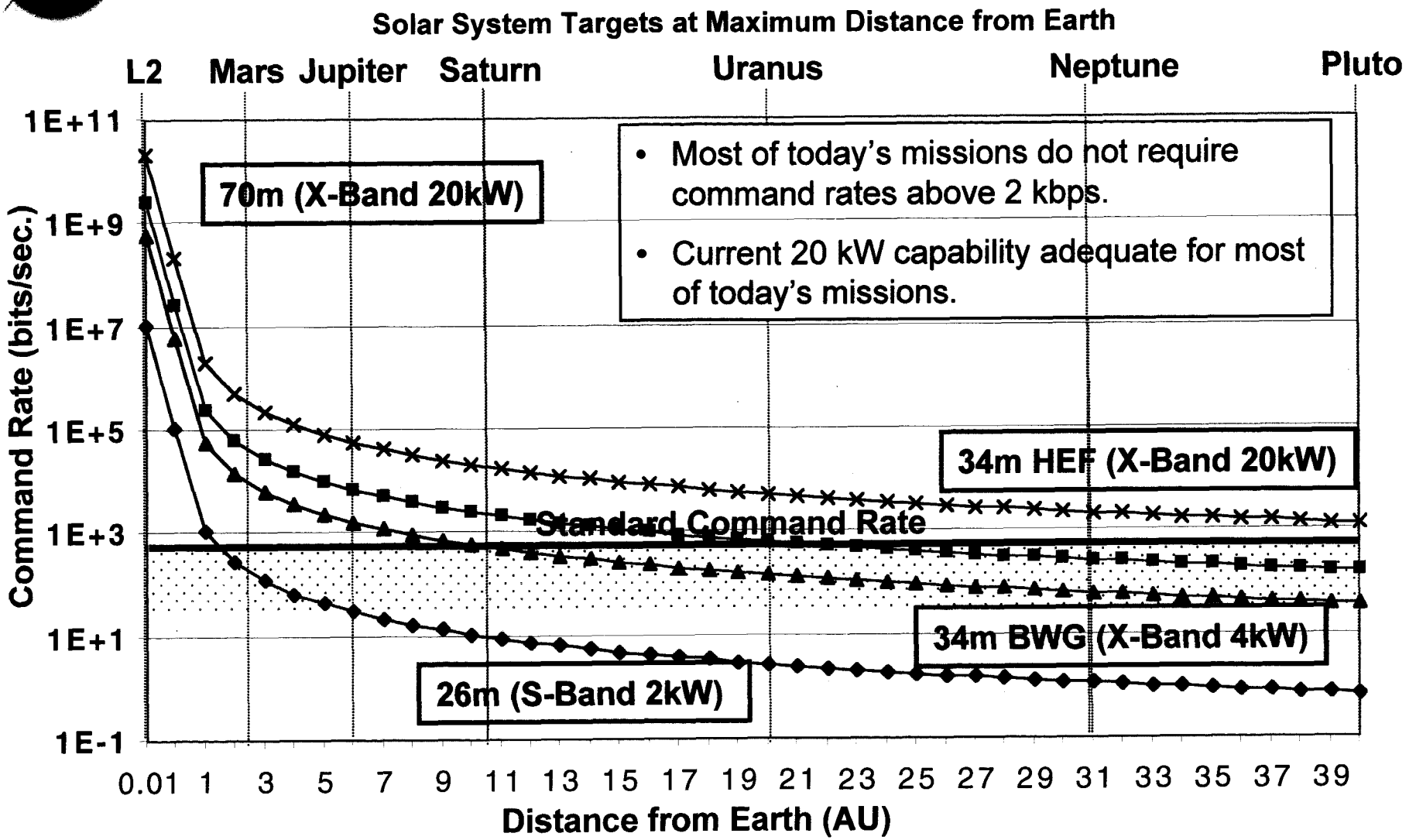
Charles J. Ruggier, DSMS Telecommunications Link Design Handbook, (Document 810-005, Rev. E, November 30, 2000) and Charles J. Ruggier, personal communication

The Test of Navigation: Entry, Descent, Landing



Slide Courtesy of Charles Naudet

Part 2: Command Uplink



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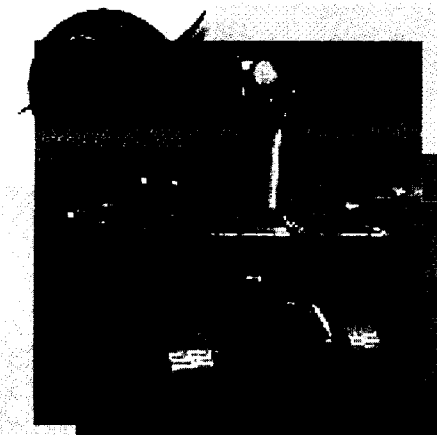
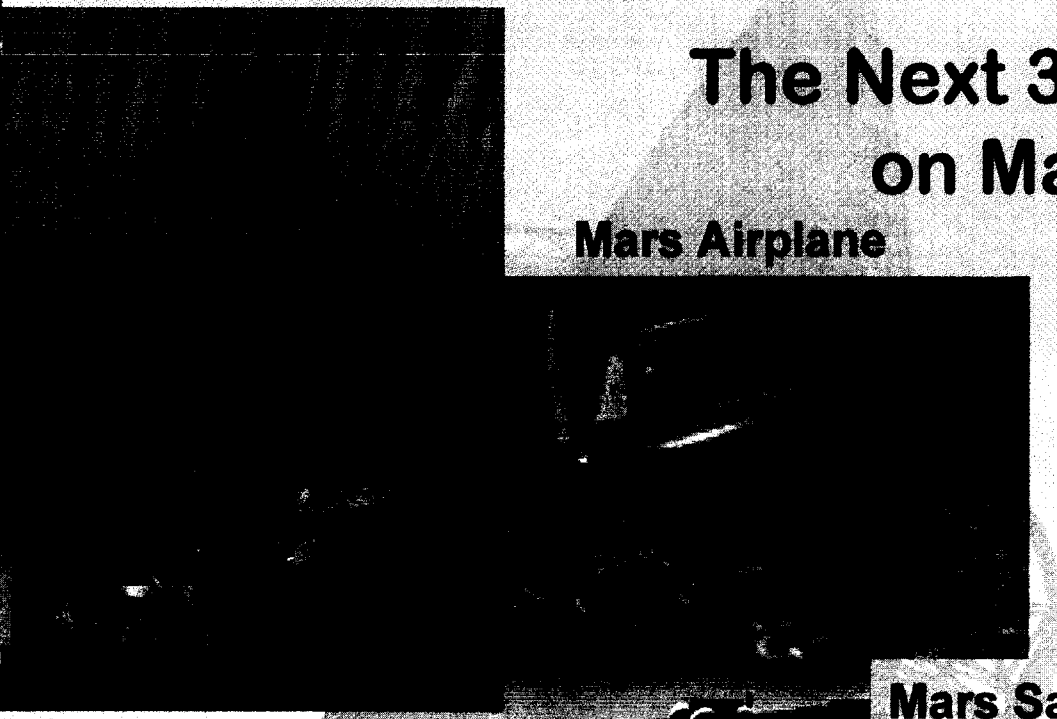
The Next 30 Years on Mars



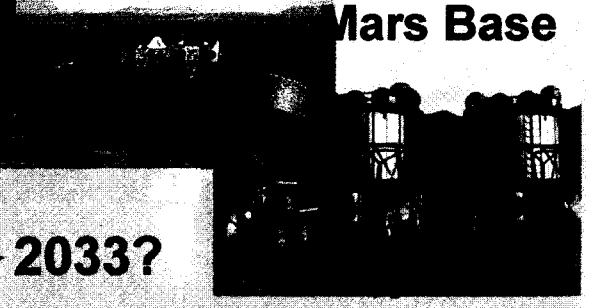
Mars Exploration Rovers

Mars Scout Aerobot



Mars Airplane

Mars Sample Return



Mars Base

Intelligent use of rovers requires navigation.

2003 → 2033?

Other Rover Missions

Titan Explorer Aerover

Intelligent use of mobile elements requires navigation.

Venus Aerobot and Venus Surface Sample Return

Europa Hydrobot

Again, all of these concepts involve or depend on mobile elements.

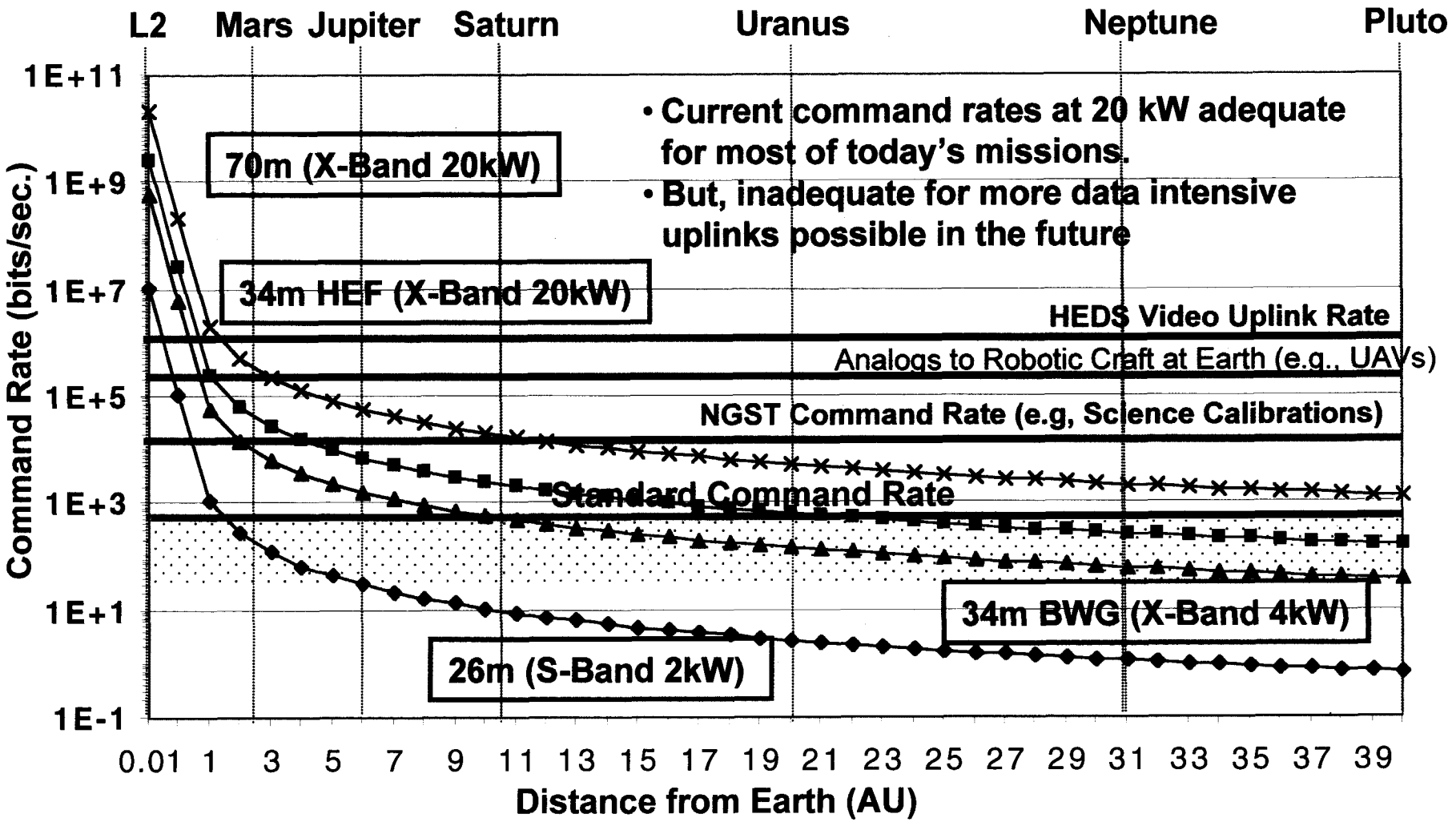
2013? → 2033?

Rovers Navigate a Complex Space

- Terrain obstacles and associated decision points may occur in time frames much shorter than the two-way light time with Earth. Possible solutions:
  - **Live with the delay by allowing the rover to move only short distances between commands**
  - **Use orbiters and/or ground-based beacons to provided limited GPS-like capability**
  - **Use inertial navigation in combination with star/sun sightings and/or above techniques.**
  - **Apply autonomous navigation visual-cuing techniques.**
- Hence, rover mission planning usually assumes autonomous navigation and reduced low-level commanding from Earth. JPL has a large program in artificial intelligence.
- Unfortunately, the rover will usually lack the resources to process its own photographic and/or radar data into a 3-D map.
- The rover observations must be downloaded to Earth, processed, and uplinked. That is a high volume uplink 100X anything previously required.
- **Uplink utilization may be transitioning from low-level commanding to software and data upload requests from largely autonomous rovers.**

Uplink Data Rates: Current Capabilities and Future Needs

Solar System Targets at Maximum Distance from Earth



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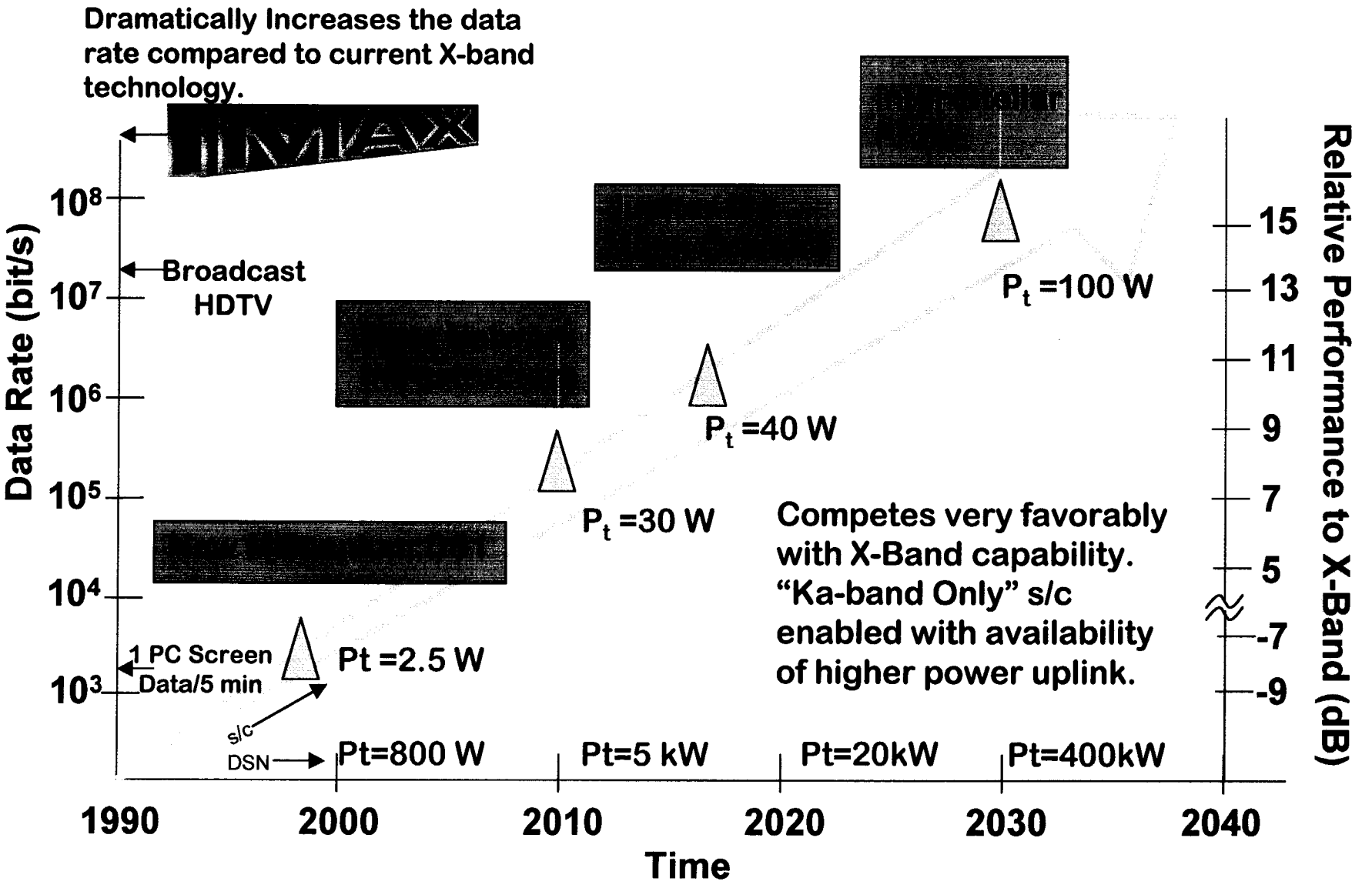
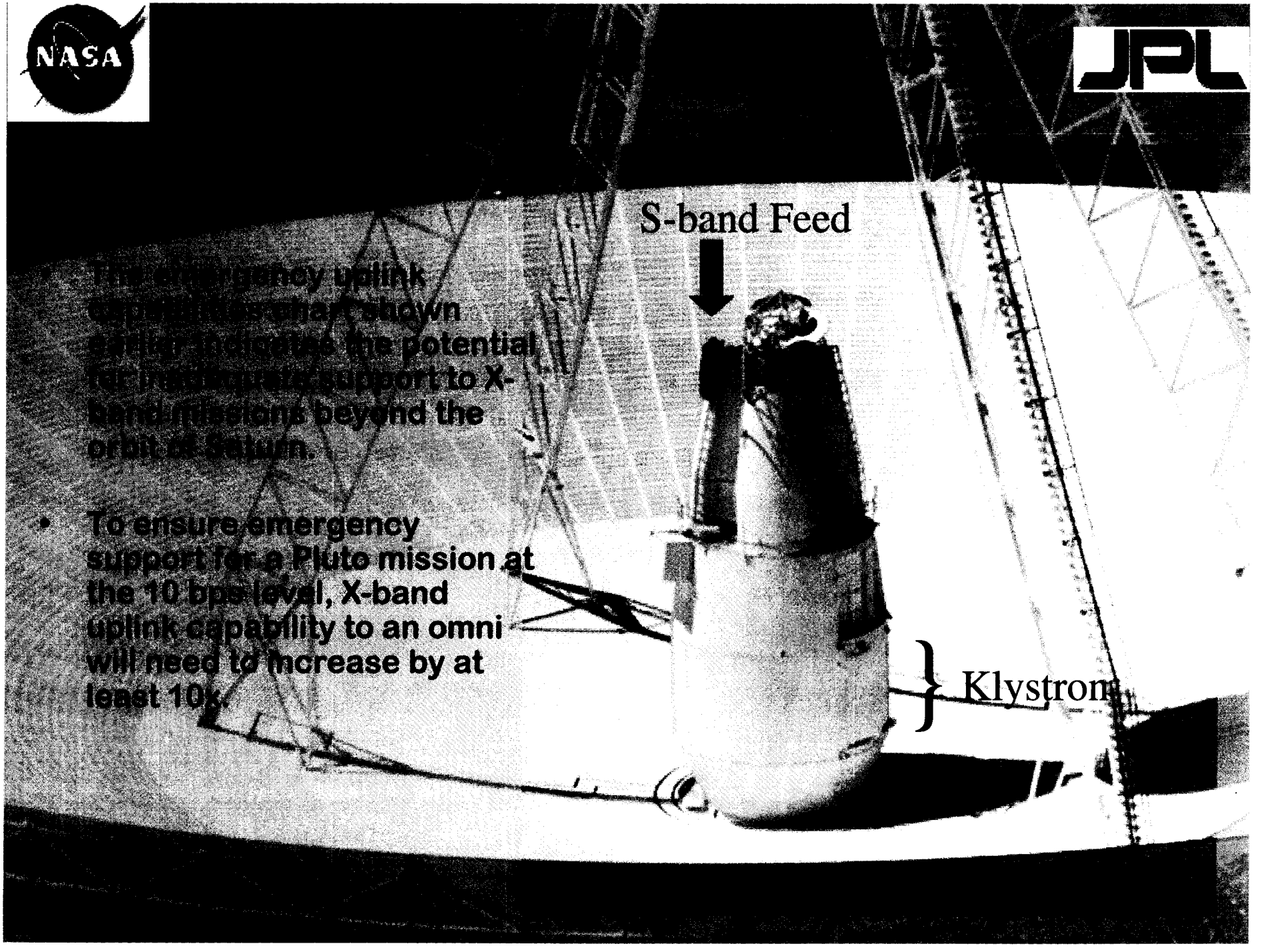
Ka-Band Technology: Enabling Advanced Comm for the Future



Transmitter Upgrade Schedule

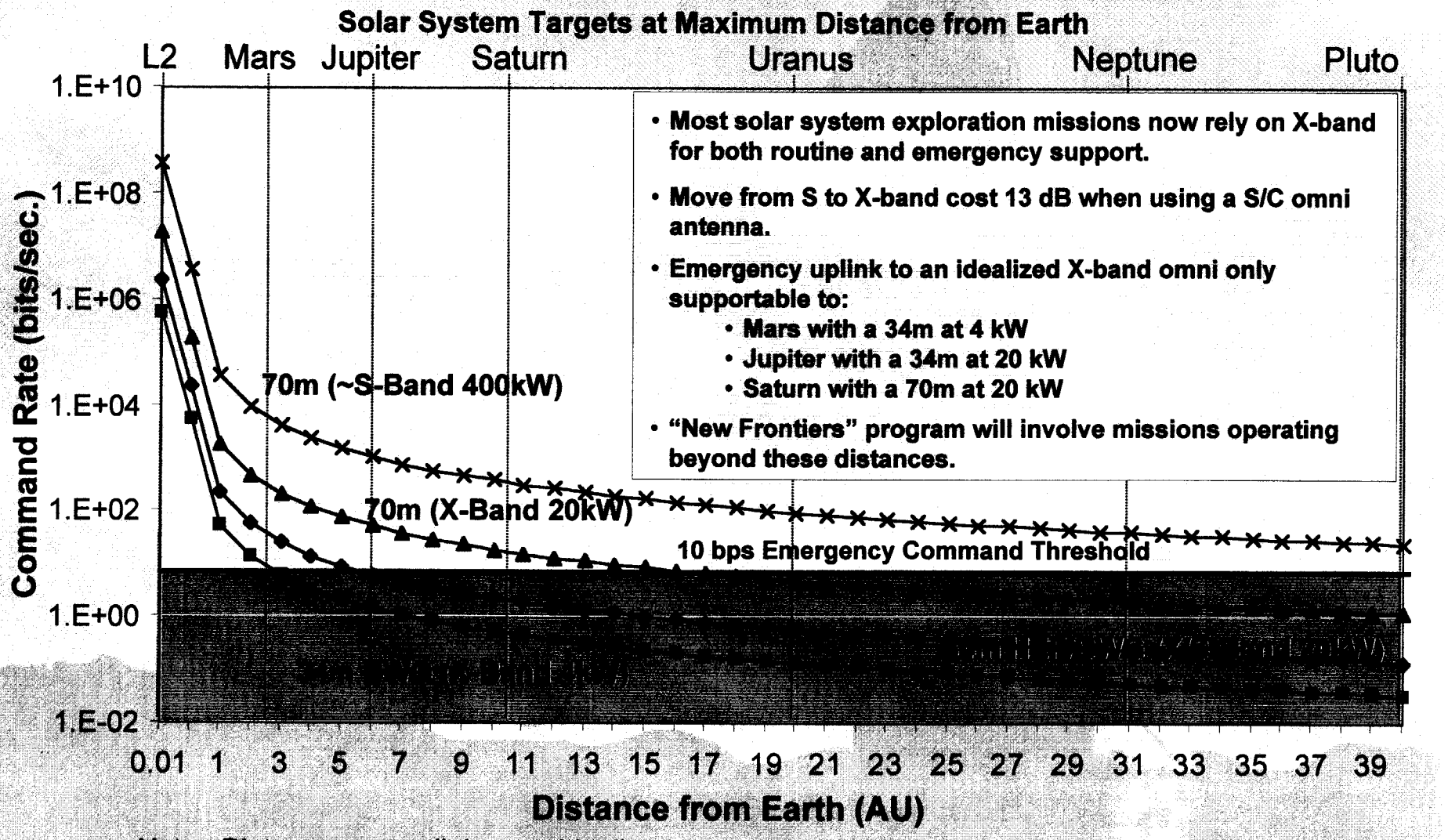
- The Deep Space Network is a service organization committed to the support of NASA and international space exploration.
- Upgrades will be funded as missions that require them are funded.
- Therefore, upgrade schedules are typically challenging and can involve short lead times.



- The emergency uplink capability as shown earlier increases the potential for transmission support to X-band missions beyond the orbit of Saturn.

- To ensure emergency support for a Pluto mission at the 10 bps level, X-band uplink capability to an omni will need to increase by at least 10x.

Problem:
Many Recent Spacecraft Don't Receive S-Band



- Most solar system exploration missions now rely on X-band for both routine and emergency support.
- Move from S to X-band cost 13 dB when using a S/C omni antenna.
- Emergency uplink to an idealized X-band omni only supportable to:
  - Mars with a 34m at 4 kW
  - Jupiter with a 34m at 20 kW
  - Saturn with a 70m at 20 kW
- "New Frontiers" program will involve missions operating beyond these distances.

Note: Plots assume uplink to an idealized omni and a 400K spacecraft receiving system noise temperature. Supporting link calculations include 3dB margin. Plot data is subject to 2003 updates and should be treated as ROM estimate only. Slide courtesy of Douglas S. Abraham

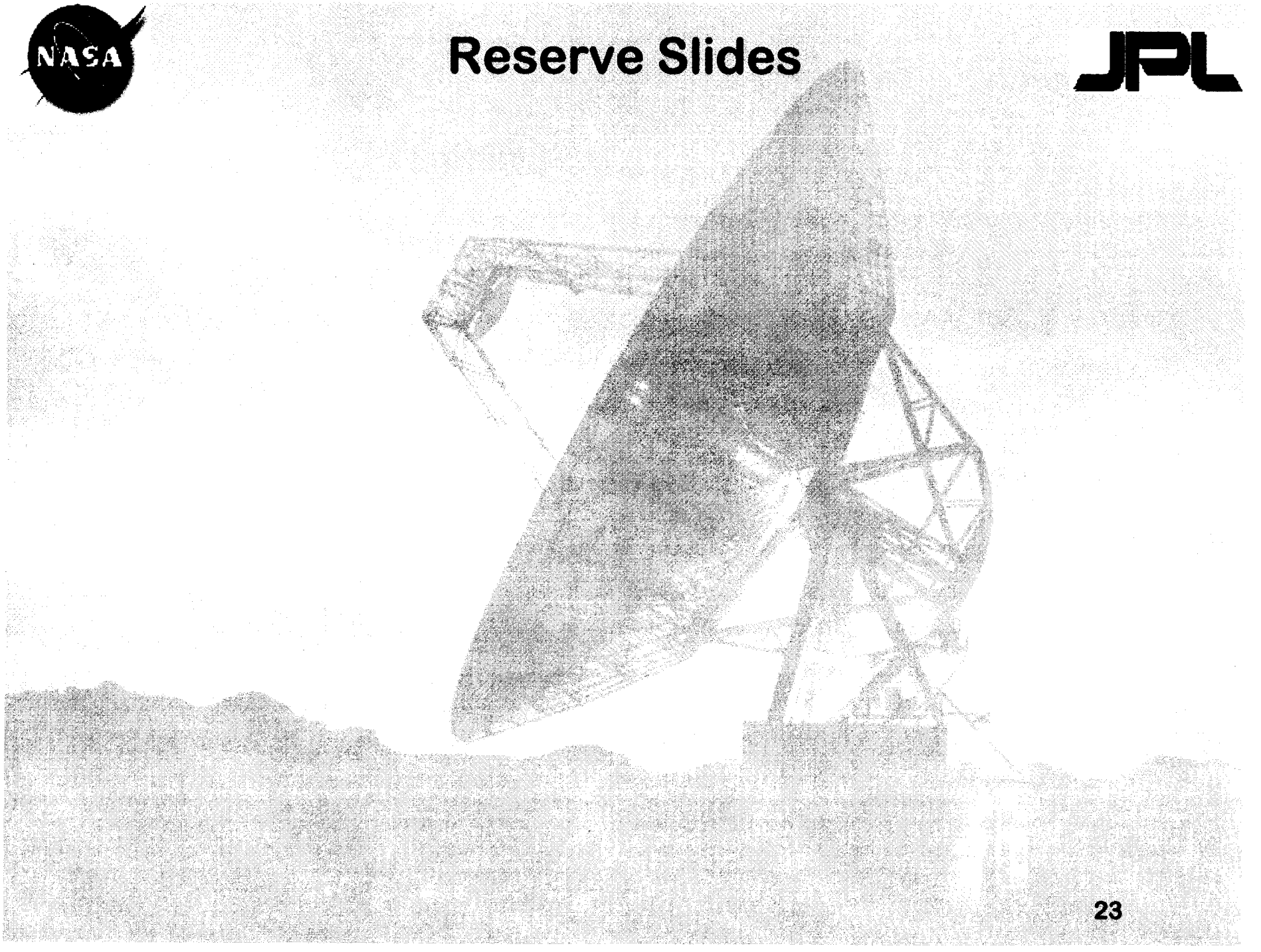
X-Band Emergency Uplink

- Need 10X present power to reach Pluto.
- One proposal is converting the high power S-band transmitter to 400kW CW X-band as S-band missions go away in 2003 to 2005.
- In-Phase Arrayed Uplink has been tested with 34m antennas in Apollo Valley, Goldstone. The "spot" where multiple signals are in phase is much smaller than the single-signal illumination area. It precesses about as the signal's phase difference varies. The phase coherence requirement is beyond the present capability of the DSN's communication links.

Conclusions

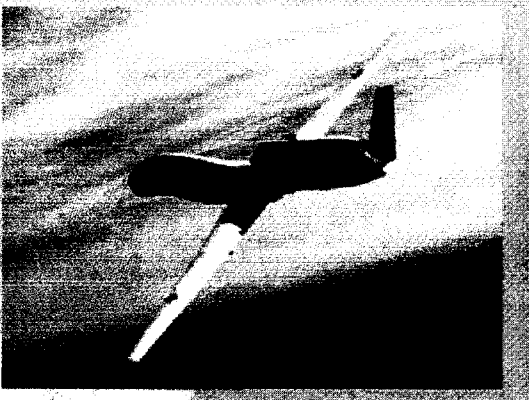
- The DSN ground transmitters are presently in transition from S- and X-band to X- and Ka-band.
- Current X-band emergency uplink capability is inadequate beyond Saturn. To support this capability at Pluto will require ~10x improvement to maintain 10bps emergency rate.
- While most missions currently can be satisfied at the 2 kbps rate, there may be a science calibration-driven requirement for ~10x higher rates in 10 years, from 2kbps to 20kbps.
- Comparisons of rover navigation with UAV/UGV navigation requirements at Earth suggest that an additional 10x improvement, to 200kbps will be needed to support navigation-related uploads of orbital remote sensing data.

Reserve Slides



Data Req'ts of Earth-based Rovers Are High

Tomahawk

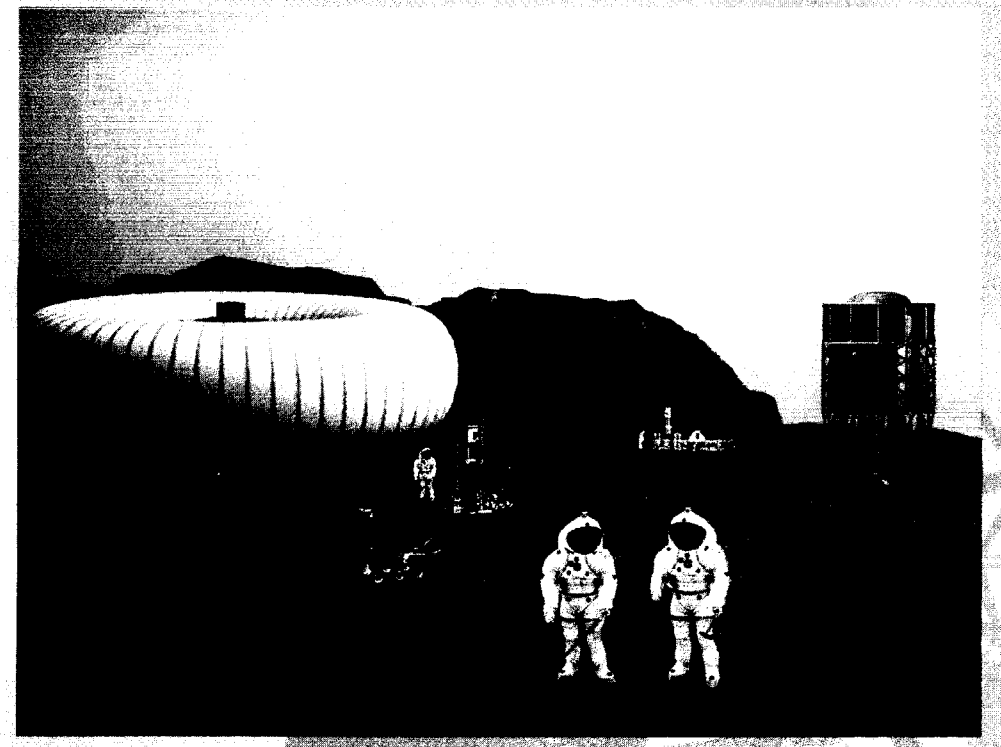


Global Hawk

Autonomous UGVs

- While these systems are highly autonomous and require very little commanding, some of their uplink data rate requirements are very high (e.g., 200 kbps). Why?
- Re-targeting and uploading of target recognition signatures are significant contributors.
- **Earth robotic mobility elements are consumers of Earth remote sensing data!**

Looking Beyond Robot Exploration



- The Human Exploration and Development of Space uplink rate requirement is between 0.5 Mbps and 1 Mbps.
- 1 Mbps would support near-real-time video communication.
- **Human exploration begins to necessitate symmetric communication.**