Probe Radio Science in the Next Generation Deep Space Network

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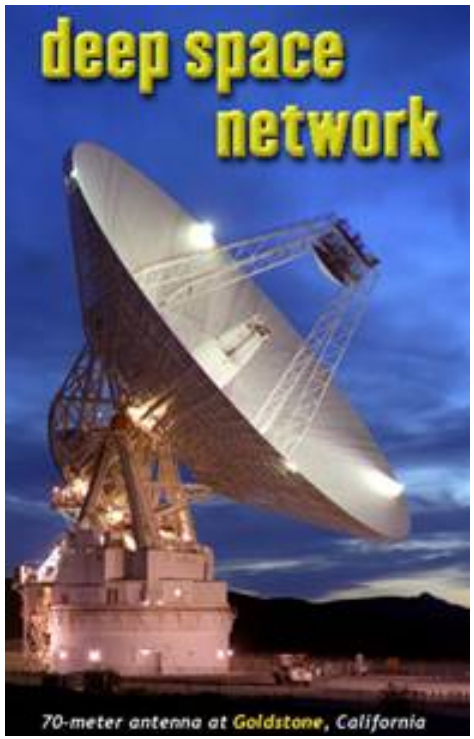
Overview



- Radio science experiments that use radio links between planetary spacecraft and NASA's Deep Space Network (DSN) provide important science discoveries for most solar system missions, including probes.
- The next generation DSN will have greatly enhanced radio links to significantly improve performance for spacecraft communications & navigation
- This future DSN may also offer significant new advantages to radio science experiments (e.g., increased received signal-to-noise ratio), but there are also some concerns.

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Radio Science Investigations

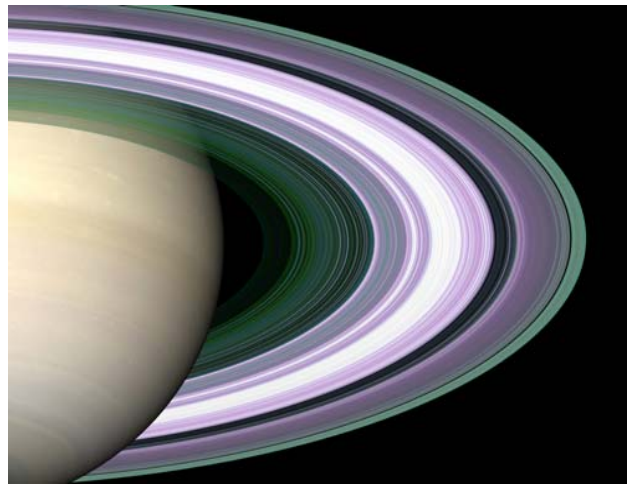
Utilize the telecommunication links between spacecraft and Earth to examine changes in the phase/frequency, amplitude, and polarization of radio signals to investigate:

- **Planetary atmospheres**
  - Temperature-pressure profiles
  - Composition of ionospheres
  - Winds speeds and directions
  - Scintillations & magnetic fields
- **Planetary shapes**
- **Planetary interiors**
  - Mass distribution
- **Planetary rings**

- **Planetary surfaces**
- **Solar corona and wind**
  - Electrons density
  - Scintillation
  - Magnetism
- **Comet mass flux**
- **Fundamental Physics**
  - Search for gravitational waves
  - Relativistic time-delay

Limiting Noise Sources for Radio Science Measurements

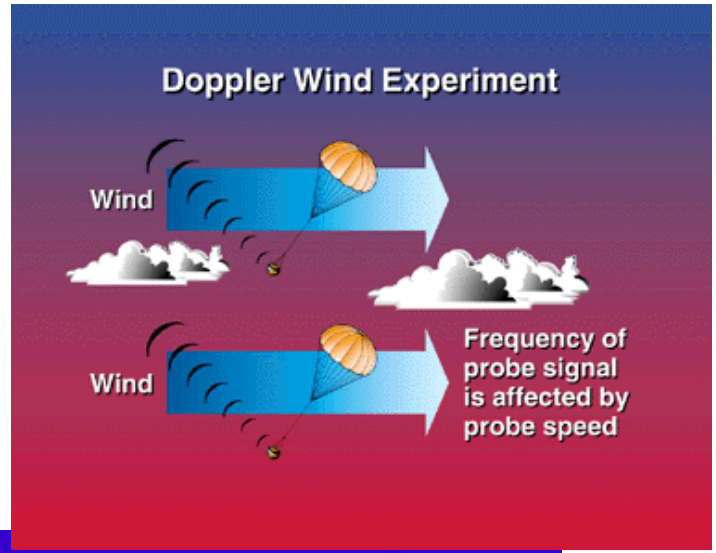
- Instrumental: random errors by spacecraft or ground
  - Signal-to-noise ratio
  - Electronic components
  - Un-modeled spacecraft motion
  - Frequency standards
  - Antenna mechanical motions
- Propagation media:
  - Interplanetary plasma
  - Earth ionosphere
  - Earth troposphere
- Systematic errors
- **Current DSN can provide good calibration for ground instrumentation and propagation media for precision radio science experiments**

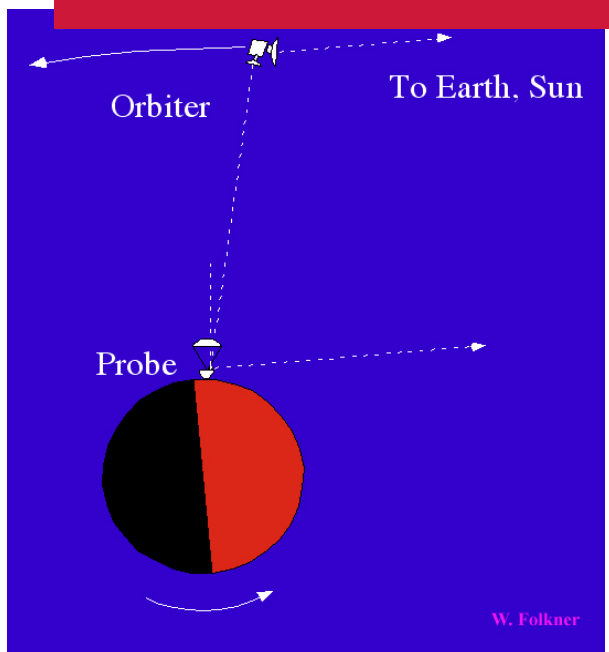


Example of recent experiment with Cassini: radio "image" of Saturn's rings

Probe Radio Science Example: Doppler Wind Experiments

- Deduce wind speed and direction from Doppler shift when probe descends into atmosphere of planet or satellite
  - Russian probes at Venus
  - Galileo Probe at Jupiter
  - Huygens Probe at Titan
- Observables: Doppler shifts on probe-Earth links and/or probe-to-orbiter/flyby links
- **Galileo probe wind experiment successful using both links to Earth and an orbiter**
- **Huygens probe wind experiment successful on link to Earth**

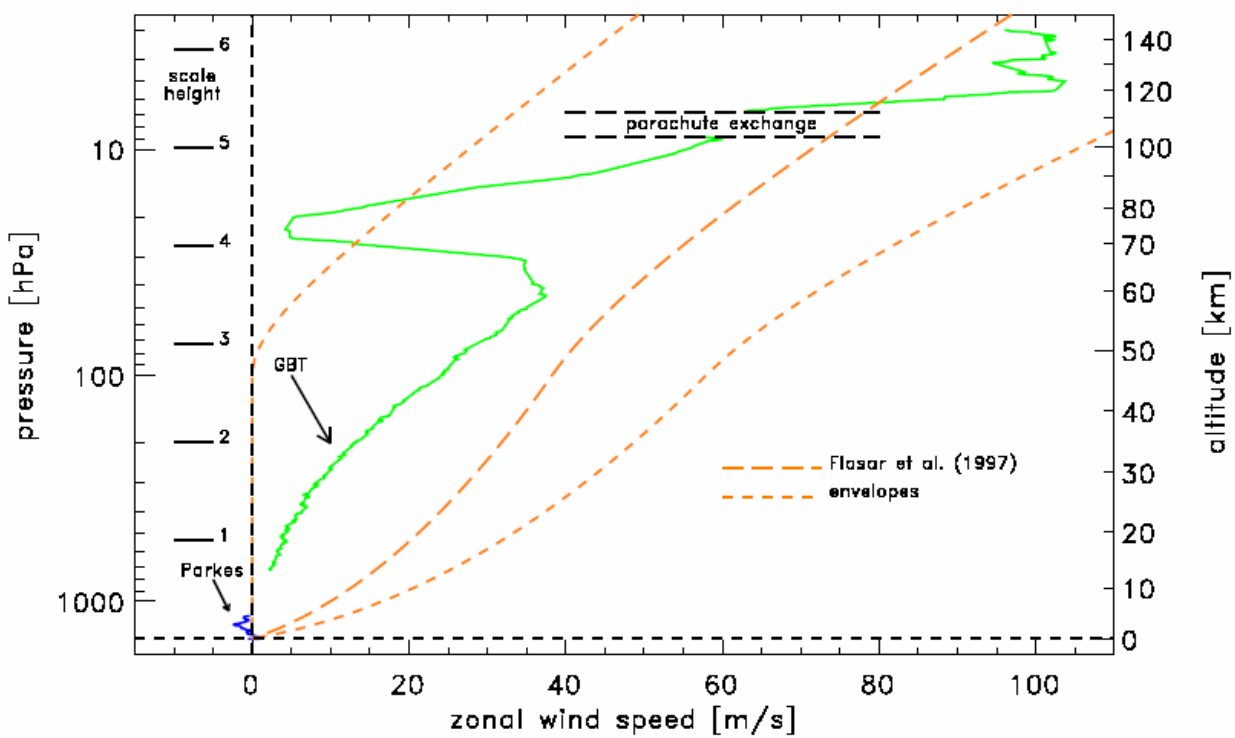




Huygens Probe Results

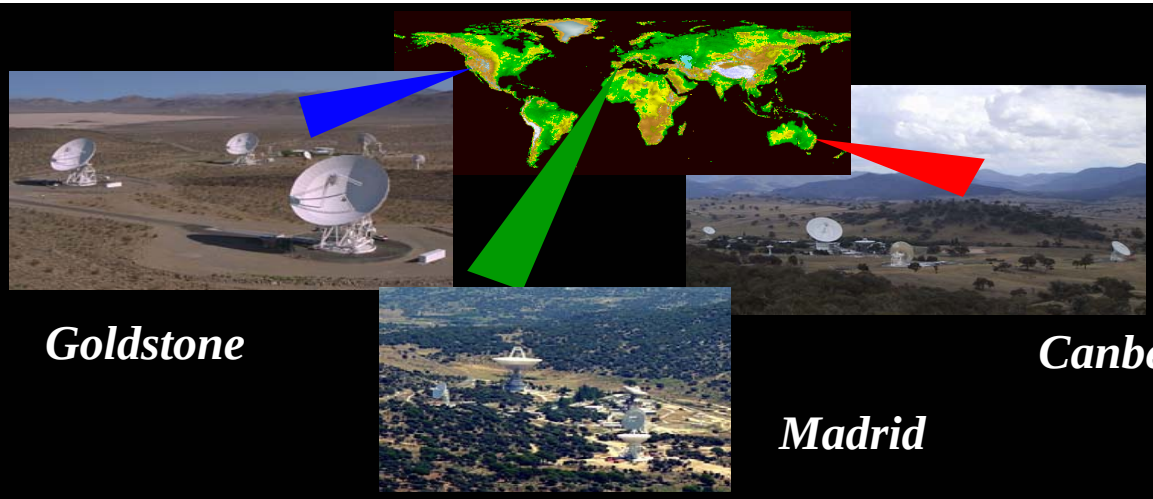
- Frequency outside DSN band but used DSN Radio Science Receivers
- Green Bank and Parkes Telescopes received USO-referenced signal carrier

Zonal Wind Height Profile

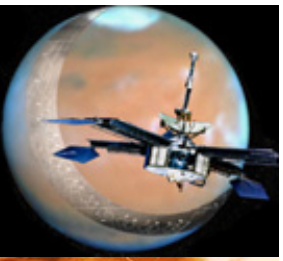


DSN Today

- **Three major tracking sites around the globe, with 16 large antennas**
- **Provides continuous S-, X-, and Ka-band communication and navigation** support for deep space missions
- **Currently services ~ 35 spacecraft** both for NASA and foreign agencies
  - Includes planetary, heliophysics, and astrophysical missions
- **Spigot for science data** from most spacecraft instruments exploring the solar system
- **A $2B infrastructure that has been critical to the support of 10's of $B of NASA spacecraft** engaged in scientific exploration over the last few decades
- **The DSN is an essential element of radio science instruments**



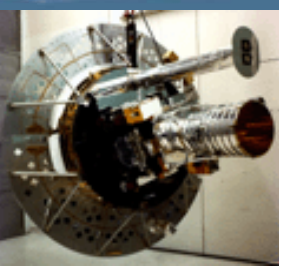
NASA's Science Missions Are Changing



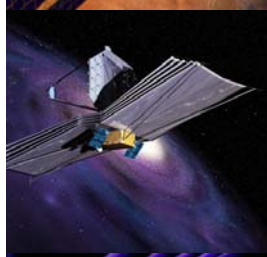
Preliminary solar system reconn. via brief flybys. → Detailed Orbital Remote Sensing.

In situ exploration via short-lived probes. → *In situ* exp. via long-lived mobile human & robotic elements.

Low-Earth-orbit solar and astrophysical observatories. → Observatories located farther from Earth. (e.g., Spitzer, JWST)



Single, large spacecraft for solar & astrophysics obs. → Constellations of small, low-cost spacecraft. (e.g., MMS, MagCon)

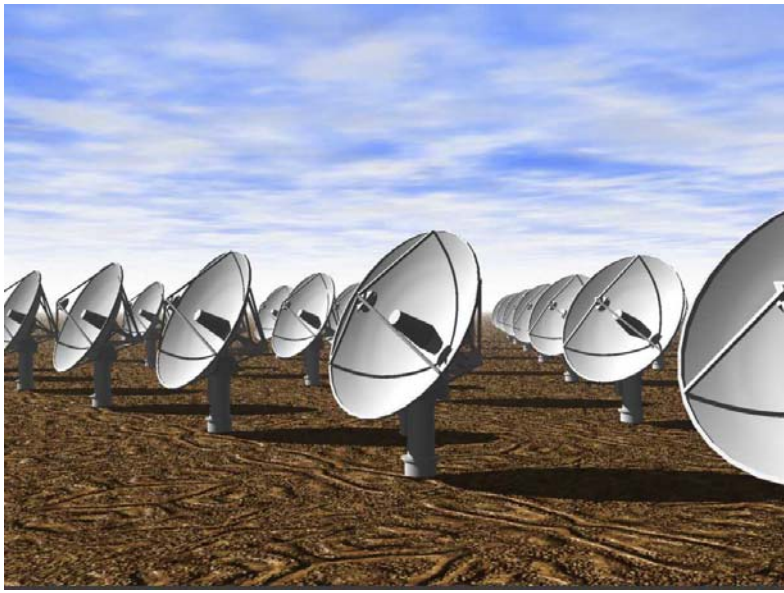


Future DSN

- **Future NASA mission requirements require a much more capable DSN**
  - 2-3 orders-of-magnitude increase in data acquisition
  - Double the number of supported spacecraft
  - More precise spacecraft navigation
  - Human mission support

- **To meet these needs NASA has recommended that the future DSN be composed of the following elements:**
  - Radio communication with large arrays of small antennas
    - Would serve all missions, large and small, new and old
  - Orbital data relays at the Moon, Mars, and perhaps other planets
  - Optical communication to allow transfer of extremely high data rates

Large Arrays of Radio Antennas



Advantages:

- Much greater data flow to and from spacecraft:
  - Especially when combined with spacecraft enhancements (e.g., higher power transmitters)
- Significant growth in the number of spacecraft that can be simultaneously tracked
  - Each with just the required aperture
- Higher precision spacecraft navigation

Properties:

- Mature and low-risk technology
- Easily scalable architecture when growth is required
- More resilient and redundant
- Improved cost-effectiveness

6-m DSN Array breadboard antenna

Probe Radio Science With The Future DSN

Potential radio science advantages:

- Greatly increased SNR could allow direct-to-Earth links and eliminate need of supporting (relay) spacecraft
- Deeper probing of atmospheres
- Hemispherical coverage of multiple probes
- Improved wind measurements

Challenges:

- Will array phase stability be sufficient for precision radio science experiments?
- Radio links for probes often require lower frequencies (e.g., 1-2 Ghz) than currently planned for the DSN arrays (8 and 32 GHz)
  - E.g., Atmospheres can absorb probe signals

The DSN is currently studying these challenges

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Read These Relevant Poster Papers in IPPW-4

- Douglas Abraham, Leslie Deutsch, Robert Preston, and Barry Geldzahler, **"Evolving the Deep Space Network: Implications for Planetary Probes."**

- David Atkinson, Thomas Spilker, Kevin Baines, Kamal Oudrhiri, Sami Asmar, Bernie Bienstock, Steve Sichi, **"Direct-to-Earth Communications for Outer Planets Entry Probe Missions."**