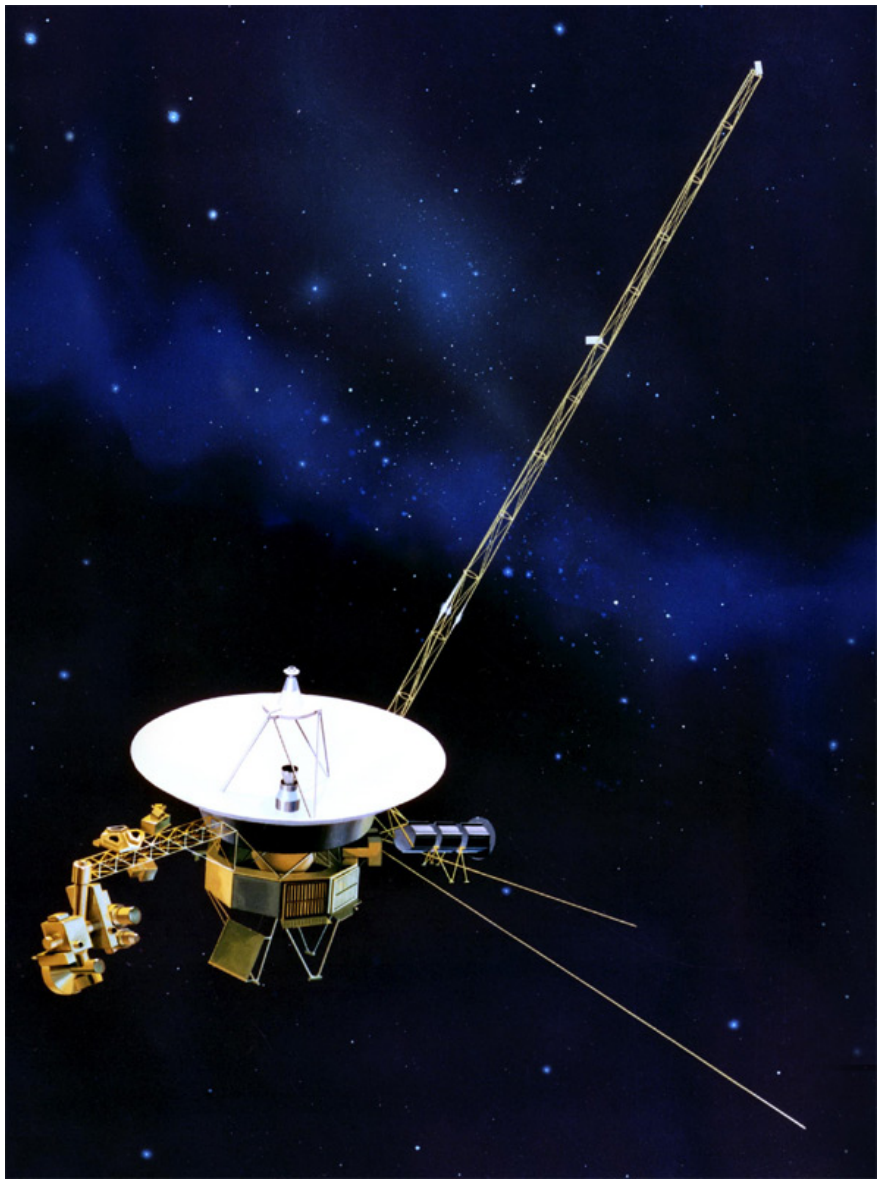


NORTHROP GRUMMAN

Astronomical Observations with the Voyager Spacecraft

The View from 5 AU

March 26, 2010

C. F. Lillie and R. S. Polidan

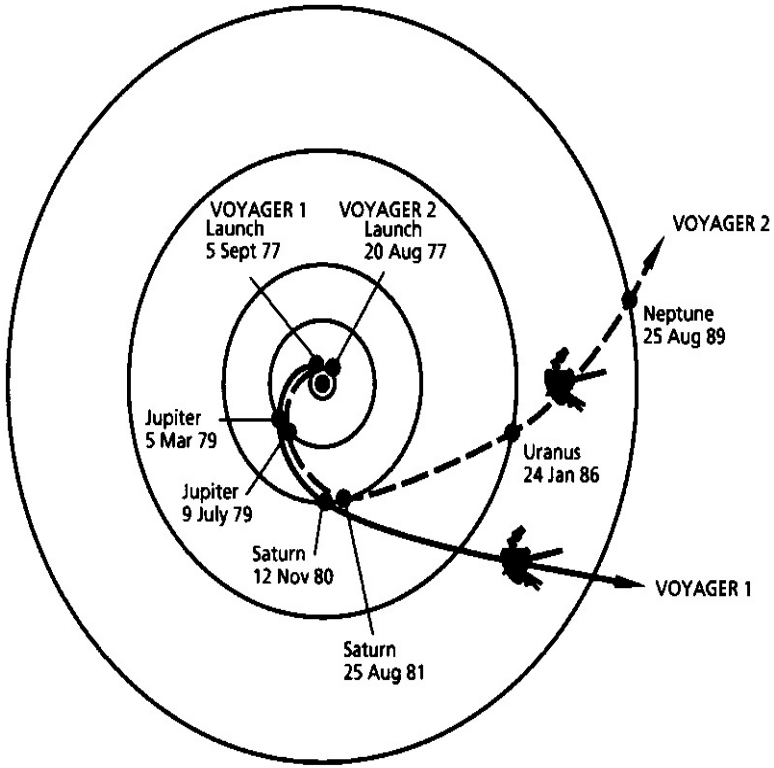
Northrop Grumman Corporation

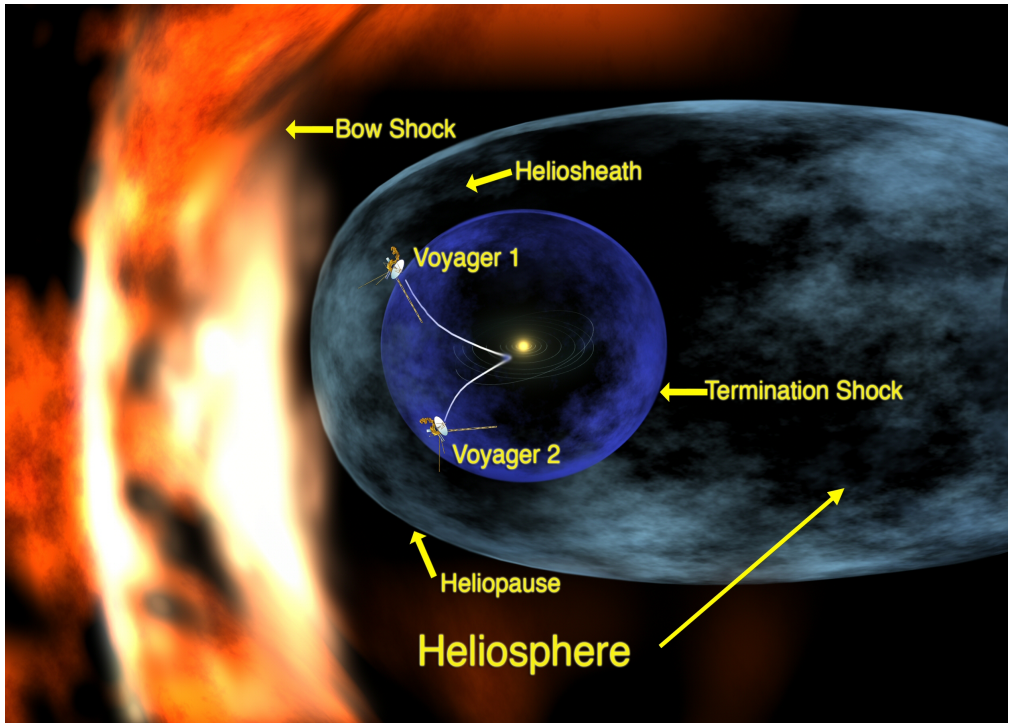
Topics

NORTHROP GRUMMAN

- The Mission
- The Spacecraft
- The Instruments
- Observations
- Guest Observer Program
- Lessons learned
- Conclusions

The Voyager Mission

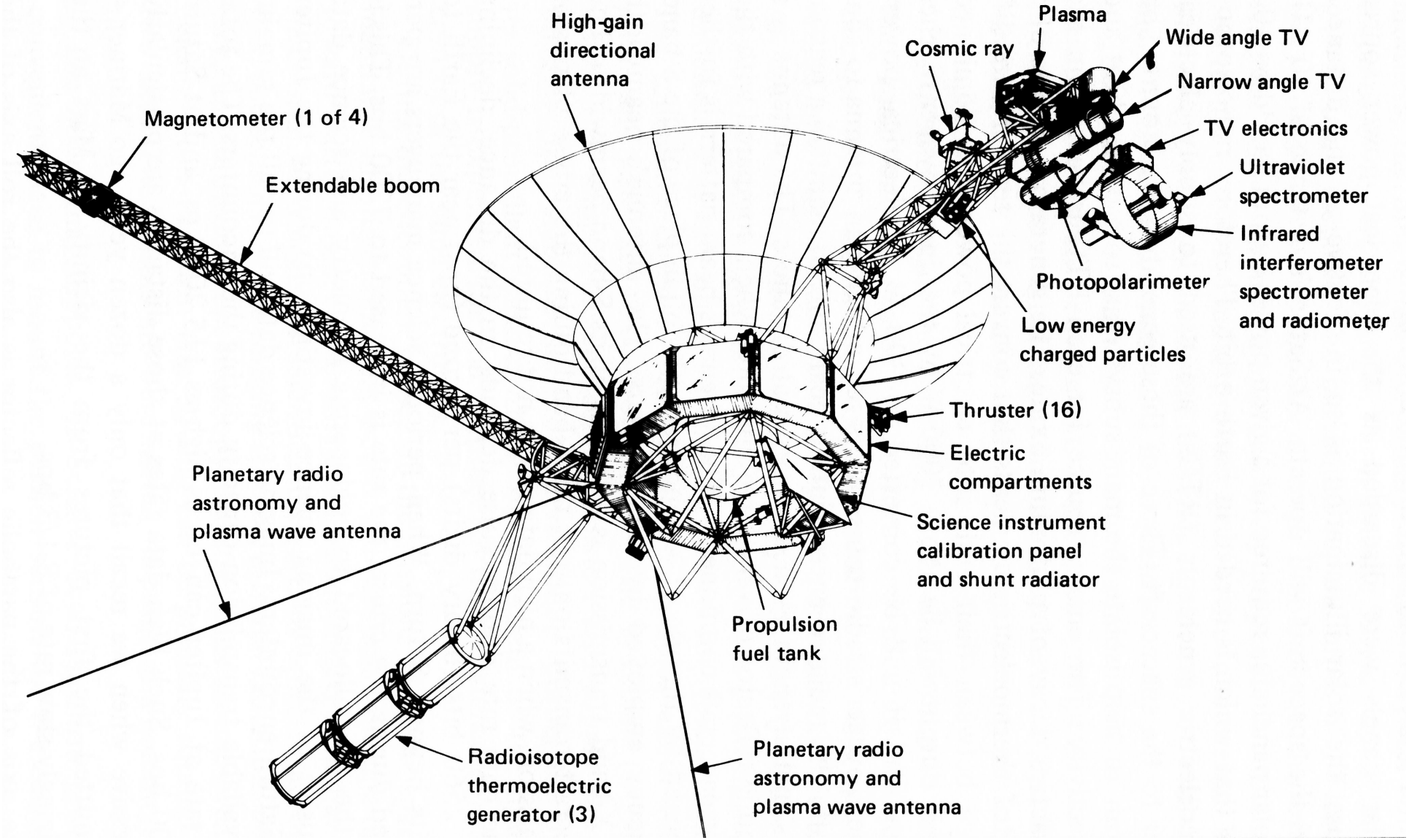




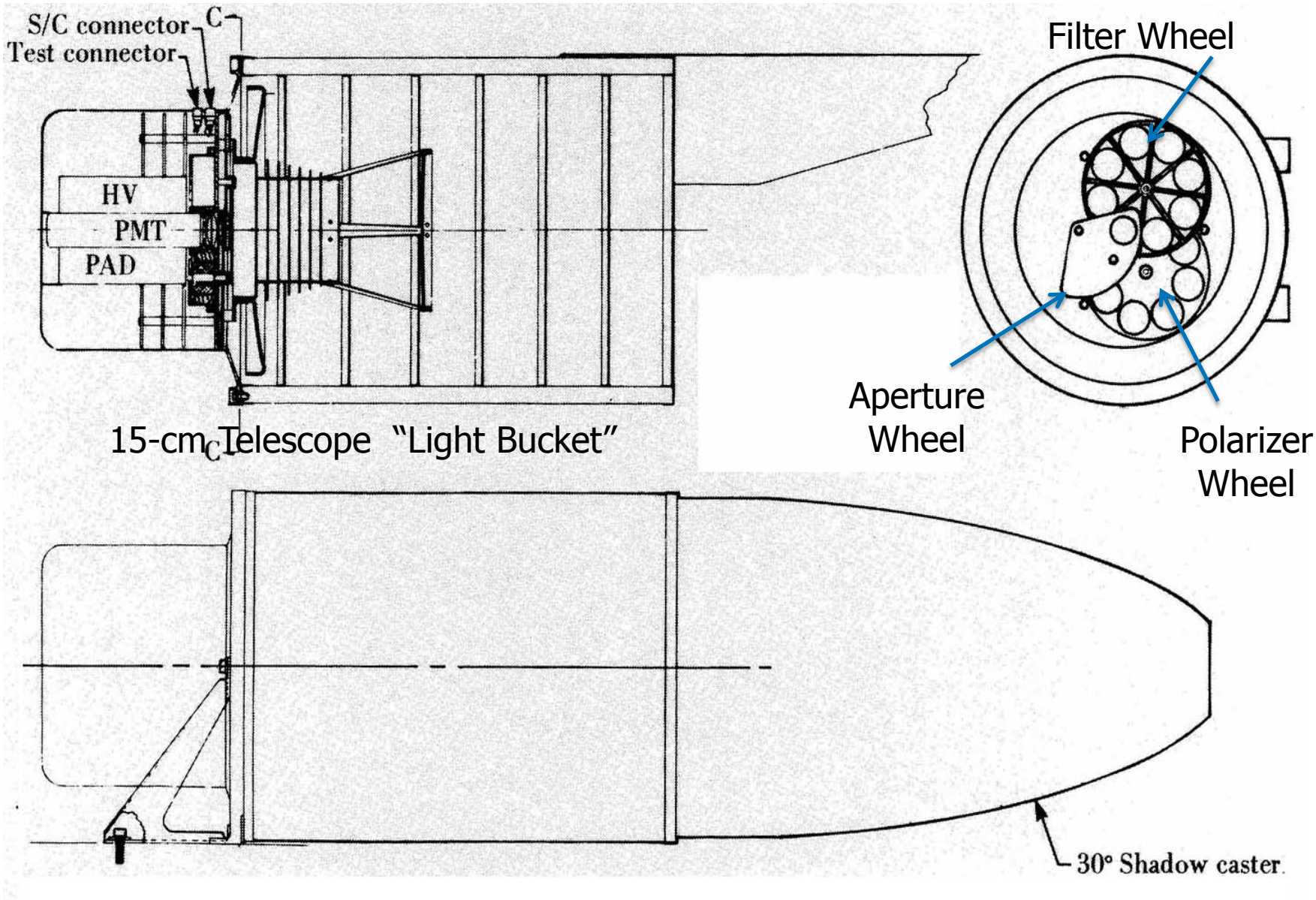
- Exploratory investigations of the Jupiter and Saturn planetary systems and the interplanetary medium from Earth to Saturn
- An extended mission for the first flyby investigation of Uranus and it's rings and interplanetary studies beyond 20 AU
- The first flyby of Neptune, and the Voyager Interstellar Mission

The Voyager Spacecraft

NORTHROP GRUMMAN

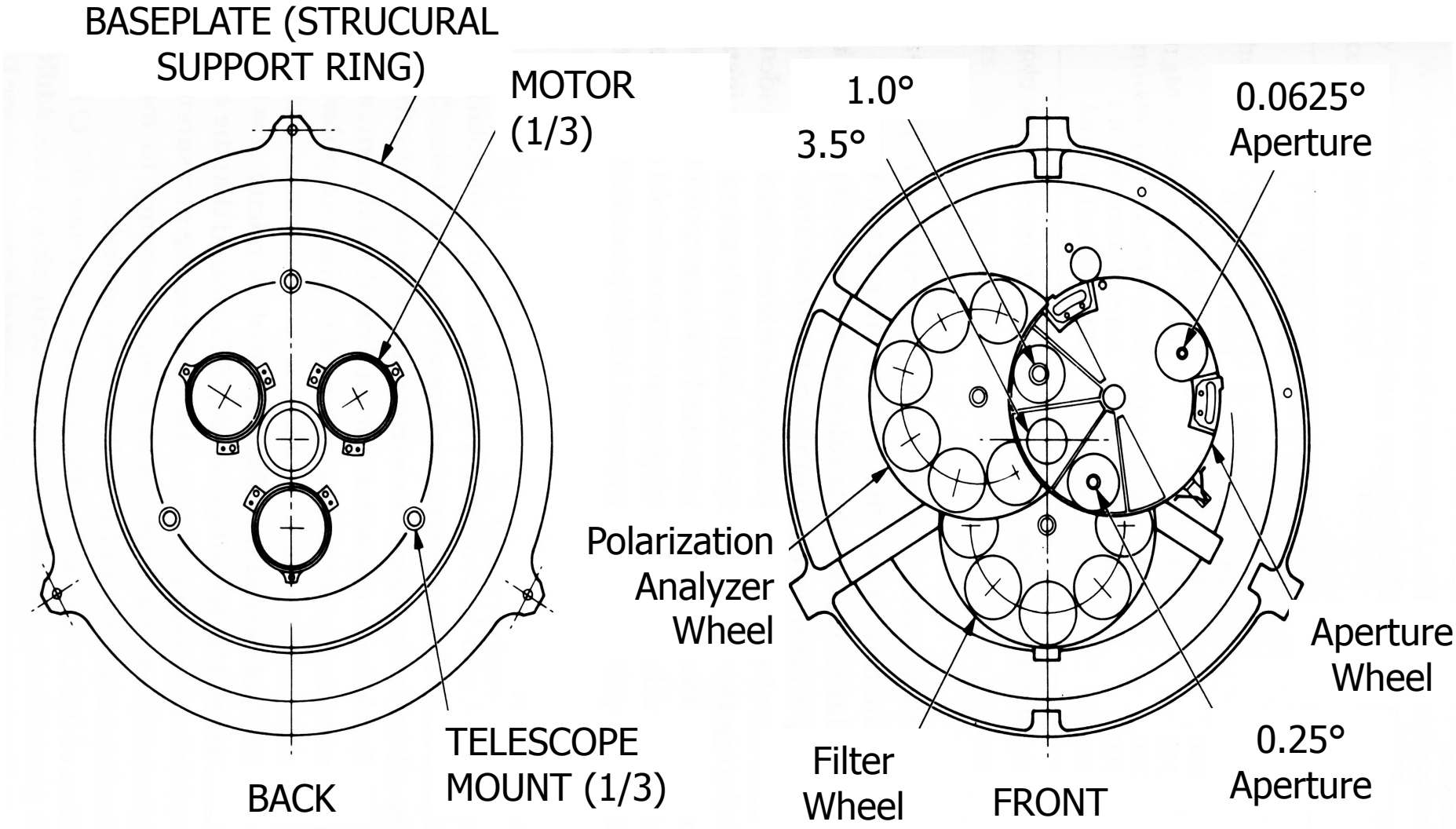


Voyager Photopolarimeter Experiment (PPS)



PPS Mechanisms

NORTHROP GRUMMAN



Photopolarimeter Filter Characteristics

NORTHROP GRUMMAN

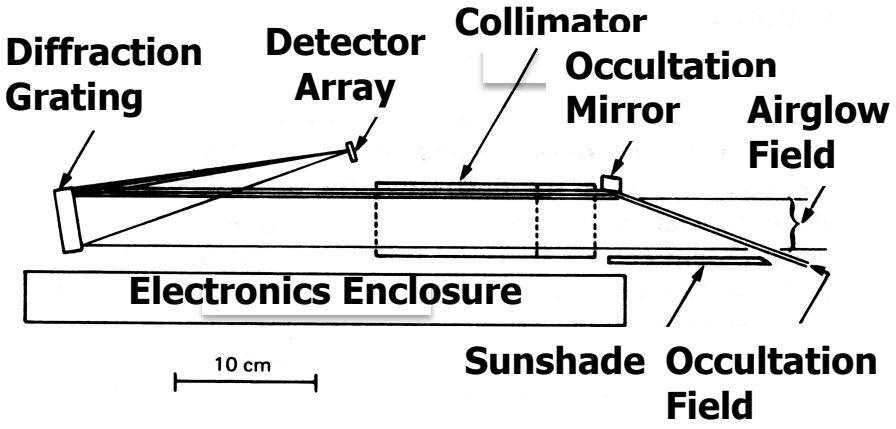
Position number	Spectral wavelength (Angstroms)	Effective bandwidth (Angstroms)	Half-power sensitivity*	Nominal features
0	5900	100	30	Sodium D
1	4900	100	50	H beta
2	3900	100	45	He I, Ca II
3	3100	300	40	OH Emission
4	2650	300	25	O3, Mg II, Chromophore
5	2350	300	20	Si I, Rayleigh scattering
6	7500	300	8	K I, Aerosol scattering,
7	7270	100	4	CH4 absorption

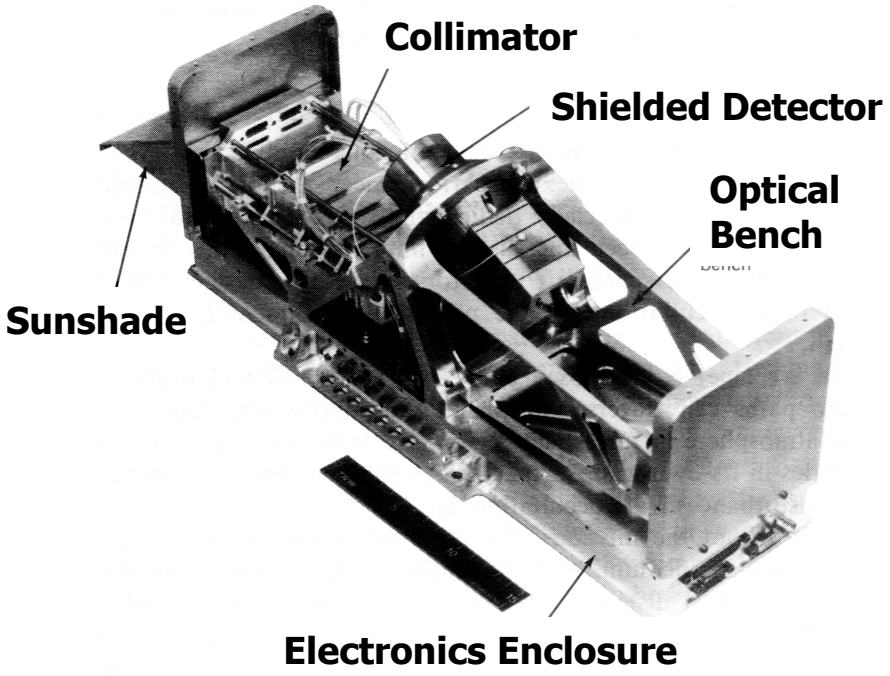
* For a point source in counts accumulated during an 0.4 second integratio per incident photon /cm^2/s/Angstrom

Voyager Ultra Violet Spectrometer (UVS)

NORTHROP GRUMMAN

- Pi Lyle Broadfoot – U. of Arizona
- 128-Channel Wadsworth Spectrometer
- ~1200Å Bandpass (500Å to 1700Å)
- ~20Å spectral resolution (pt source)
- 2 fields of view (FWHM):
  - Airglow: 0.10° x 0.87°
  - Occultation: 0.25° x 0.87°
- Located on scan platform
- Spacecraft pointing limit cycle ~1°





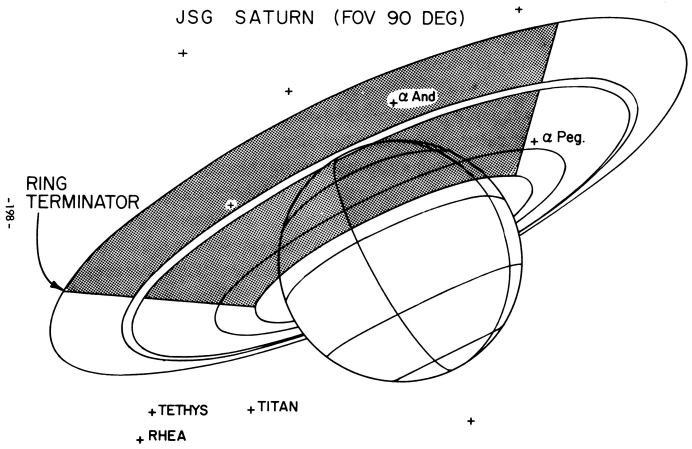
Observations

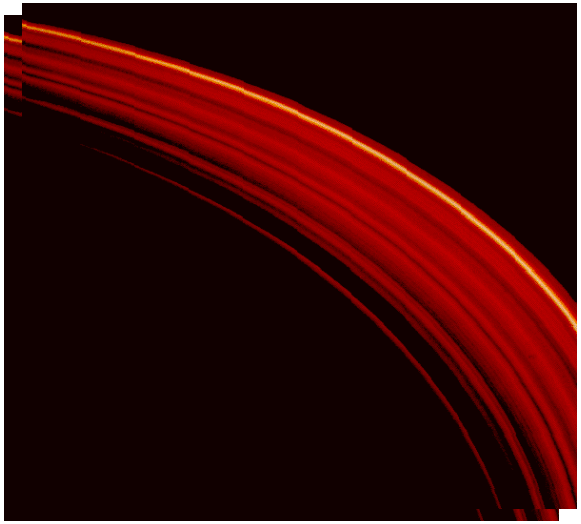
NORTHROP GRUMMAN

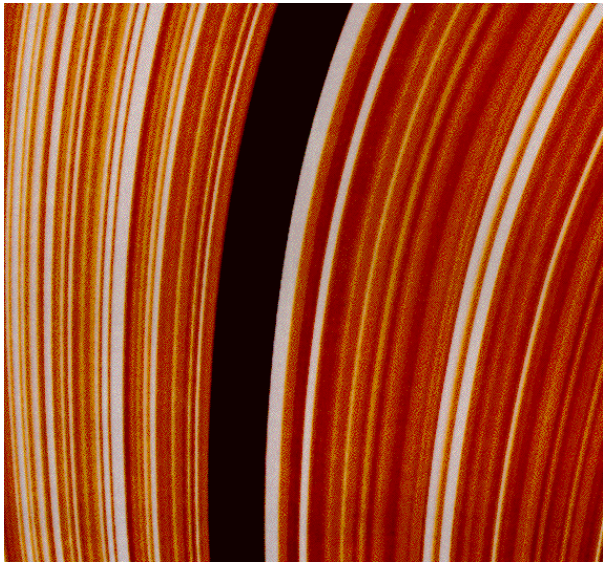
- Cruise Science
  - Stellar calibration
  - Small body observations
  - Sky Background
- Encounter Science
  - Planetary and Satellite Photopolarimetry
    - Surface properties
    - Cloud particle size, distribution
    - Atmospheric scale height, temperature
  - Stellar Occultation's
    - Ring particle size, composition, distributions, dynamics
    - Atmospheric scale height, temperature
- Extended Mission
  - Uranus Neptune flybys
  - EUV Stellar, Sky Background Observations

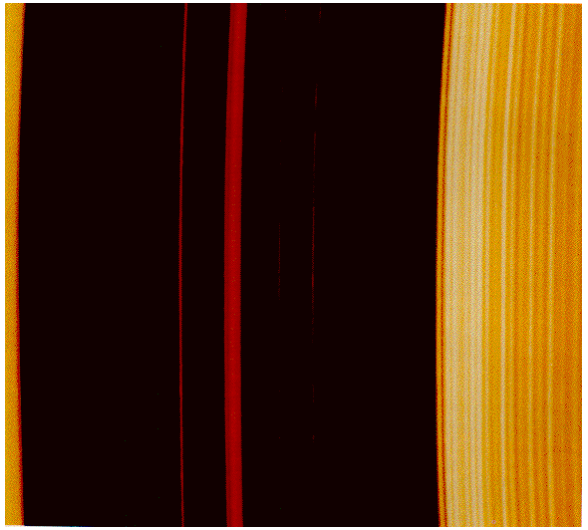
PPS – Saturn's Rings

NORTHROP GRUMMAN



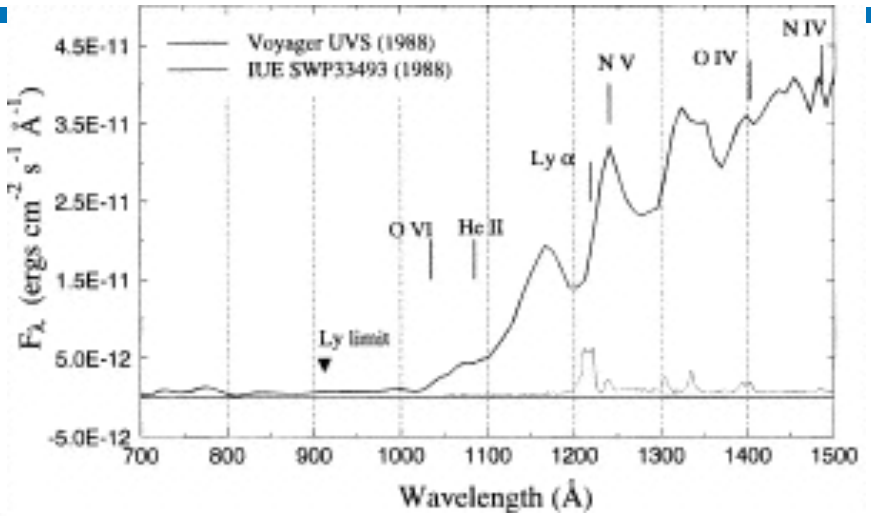






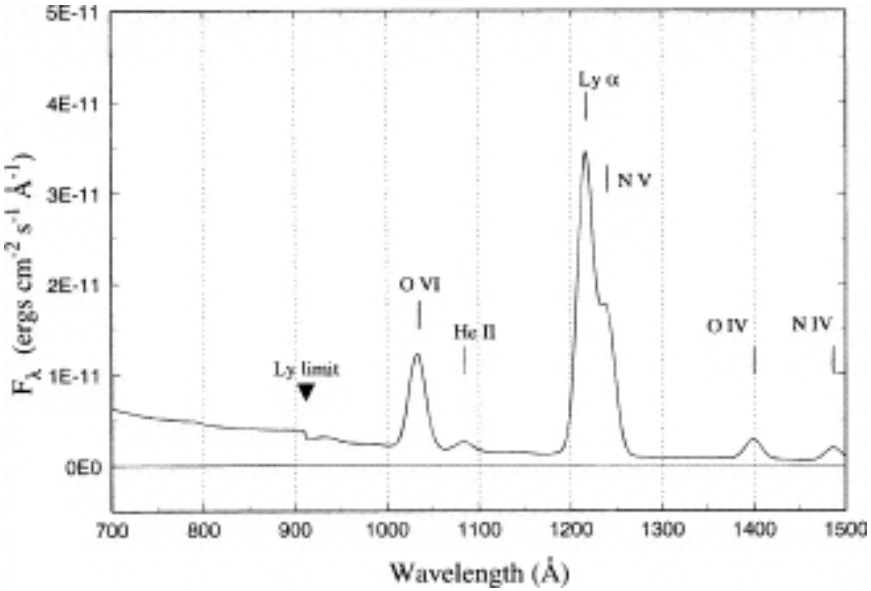
UVS Stellar Observaitons

NORTHROP GRUMMAN



CH Cyg+SAO 31651

RR Te



Voyager Guest Observer Program

NORTHROP GRUMMAN

- Voyager 1 and 2 both have small far-ultraviolet spectrometers (Broadfoot et al 1977, Space Sci Rev, 21, 183) as part of their instrument complement.
- Not long after both these missions launched in 1977 it was realized that these instruments could provide useful astronomical observations
  - Far-UV astrophysics was in its infancy
  - While the aperture was small (~ 0.75 cm^2), long integration times were easy
- Informal astronomical observations were performed in the early mission "cruise" phases (between planetary encounters)
  - Typical for planetary missions – astrophysics observation done in a non-interference mode
  - No funding supplied for data analysis/publication
- In the mid-1980's R. Polidan and J. Holberg made a concerted and successful effort to convince the Astrophysics Division at NASA HQ that a formal Guest Observer Program (i.e. scheduled observations and funding for analysis/publication) was both desirable and possible
  - Voyager Project approval of the astronomical program
  - The existence of the necessary infrastructure at U Arizona to support Guest Observers

Voyager Guest Observer Program

NORTHROP GRUMMAN

- In 1987 a formal Guest Observer Program was established by NASA and successfully ran for ~5 years
  - Program utilized both Voyager spacecraft, filling the long cruise periods between planetary encounters with astronomical observations
  - "The View for 30 AU": Started prior to the Neptune encounter in Aug 1989, continued post encounter
  - Proposals peer reviewed using standard NASA processes, time allocated, Guest Observers supported, papers published
  - Observations covered the range of UV bright targets
    - Nearby white dwarfs and other compact stars
    - Cataclysmic variables and related objects
    - UV Background
    - Supernovae remnants
    - Galaxies and QSOs (first Far-UV detection of a QSO – Reichert et al 1987)
- Formal GO Program was terminated due to funding pressure

Lessons Learned

NORTHROP GRUMMAN

- Outer planet missions offer unique Opportunities for Astronomy
  - Long cruise periods with low pointed instrument activities
  - Stable, low temperature thermal environment
  - Dark sky (minimal zodiacal light background)
- Many Challenges
  - Science politics is a major hurdle
    - Planetary science vs. Astrophysics
    - Uniqueness counts
  - Limited resources
    - Size, weight, power
    - Cruise operation support
  - Operations Constraints
    - Pointing accuracy
    - Cones of avoidance (Sun, planets, satellites)
    - Limited field of regard
    - Configured flight software

Conclusions: Beyond 5 AU

NORTHROP GRUMMAN

- Excellent location for astronomical Observations
  - Missions need to be a joint Planetary/Astrophysics activity
  - Pointing accuracy requirement defined by astronomical instruments
  - Cruise operations augmented for operations astronomical
    - Planning and scheduling team
    - Additional communications opportunities
  - Separate central processor for astronomical instruments
    - Allows software changes without impact on spacecraft subsystems, safety, reliability, etc.
- Unique location for Sky Background Observations
  - No (scattered) zodiacal light observed with the PPS beyond ~ 2 AU
  - Need to observe in the infrared (7 to 30 microns) to see thermal emission from the interplanetary dust particles
  - Tunable Fabre-Perot interferometers with large field of view deserve serious consideration


NORTHROP GRUMMAN