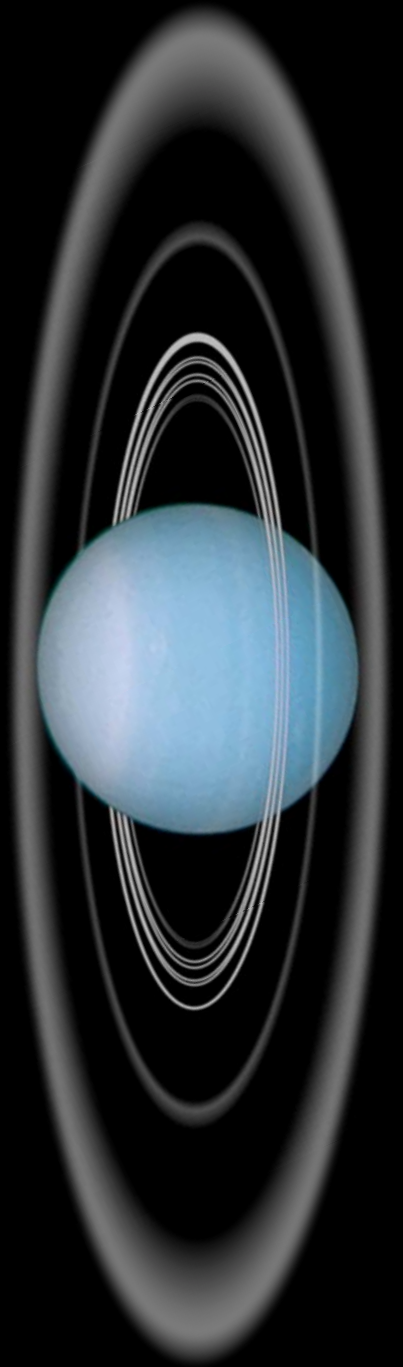


Report to OPAG on the Uranus at Equinox

Planning Workshop

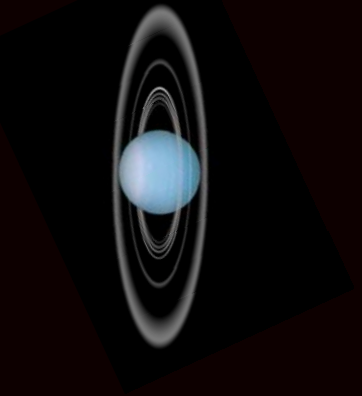
Pasadena, CA

3-4 May 2006

Co-Conveners:
Heidi Hammel (SSI) &
Mark Hofstadter (JPL)

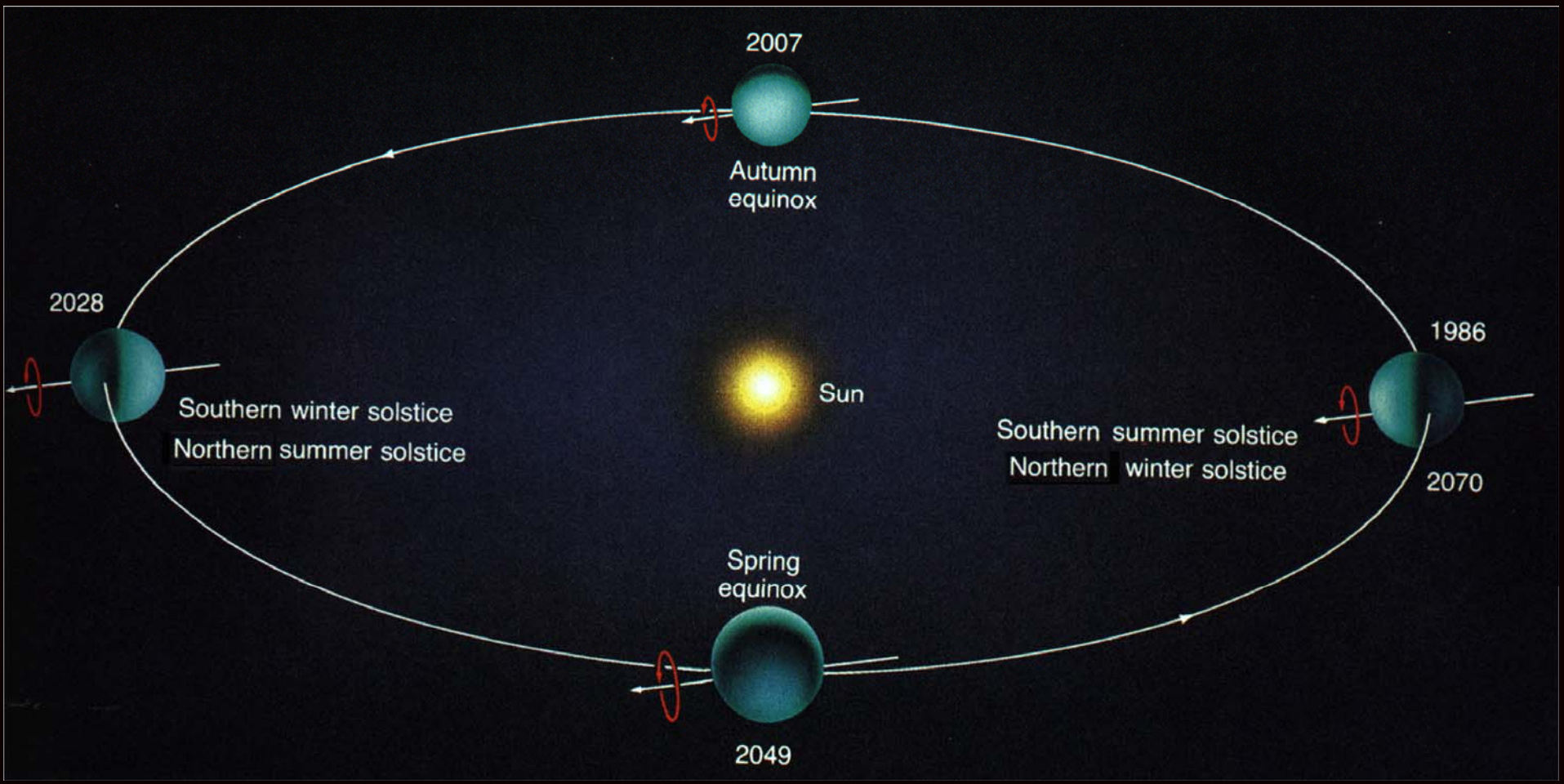
Sponsored by NASA

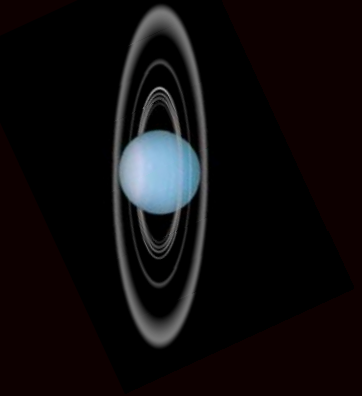
Presented by Heidi B. Hammel, 5 May 2006



Equinox of Uranus

- Equinox late 2007 - last 1965, next 2049
- Ring Plane Crossings (two in 2007, one in 2008)



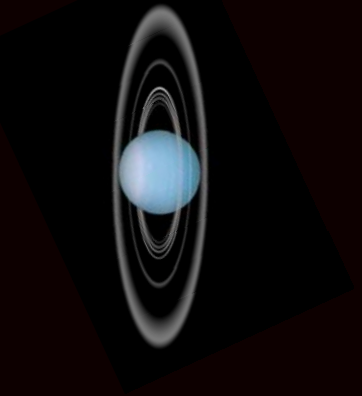


Workshop Goals

- Review Uranus equinoctial calendar
- Understand discipline-specific science goals
- Formulate cross-discipline strategies to optimize facility use
- Identify missing science
- Initiate actions and assignments

Uranus Equinoctial Calendar

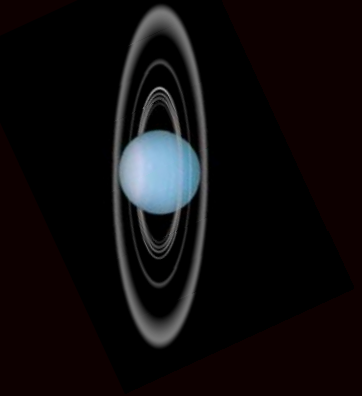
Event	Calendar Year / Quarter / Date	2007 1 Jan-Feb-Mar	2007 2 Apr-May-Jun	2007 3 Jul-Aug-Sep	2007 4 Oct-Nov-Dec	2008 1 Jan-Feb-Mar	2008 2 Apr-May-Jun	2008 3 Jul-Aug-Sep	2008 4 Oct-Nov-Dec
Equinox	7-Dec-07				EQ				
Ring Plane Crossing 1	2-May-07		RPX1						
Ring Plane Crossing 2	16-Aug-07			RPX2					
Ring Plane Crossing 3	20-Feb-08					RPX3			
Sub-Earth Lat (deg)		-4.1	0.5	0.0	-3.0	-0.3	4.4	4.2	1.2
Sun-Earth-Uranus Angle (deg)			54	155	90	16			
DPS Meeting	Oct				DPS				DPS
AAS Meeting	Jan, Jun	AAS	AAS			AAS	AAS		
AGU Meeting	Dec				AGU				AGU
LPSC Meeting	Mar	LPSC				LPSC			
VLA Proposals	Feb, Jun, Oct	A-Array	B-Array		C-Array	D-Array	A-Array		B-Array
VLA configuration		DDD	DAA	AAB	BBB	CCC	CDD	DDA	AAA
SMA Proposals	Mar and Aug?	?		?		?		?	
Hubble Proposals	Jan (to observe > July)	Hubble				Hubble			
NOAO Proposals									
Keck	Sep, Mar	Keck		Keck		Keck		Keck	
Gemini (N and S)		Gemini		Gemini		Gemini		Gemini	
For observing		Jan-Feb-Mar	Apr-May-Jun	Jul-Aug-Sep	Oct-Nov-Dec	Jan-Feb-Mar	Apr-May-Jun	Jul-Aug-Sep	Oct-Nov-Dec
IRTF Proposals	Apr, Oct		IRTF		IRTF		IRTF		IRTF
For observing		Jan-Feb-Mar	Apr-May-Jun	Jul-Aug-Sep	Oct-Nov-Dec	Jan-Feb-Mar	Apr-May-Jun	Jul-Aug-Sep	Oct-Nov-Dec
Spitzer Proposals	Feb (to observe > May)	Spitzer				Spitzer			



Goals: Discipline-Specific

- List scientific objectives
- Identify observational requirements
  - Wavelength
    Spatial Resolution
    Spectral Resolution
    Timing
- Discuss future discipline-specific meetings

Decadal Survey Key Scientific Question:
How do the processes operate that shape the contemporary nature and physical characteristics of Solar System bodies?



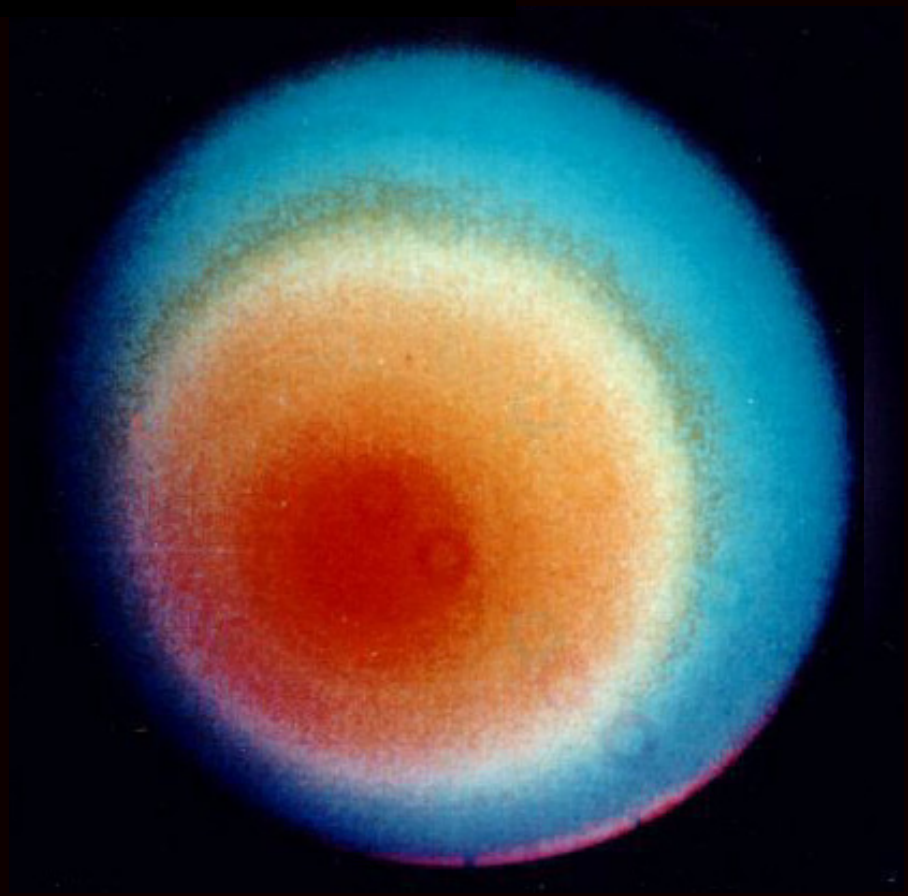
Discipline-Specific Breakout Sessions

Atmosphere

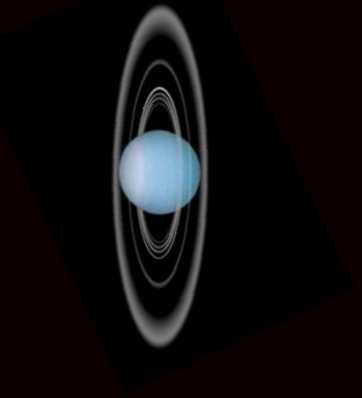
Satellites

Ring system

Enhanced Uranus



Voyager in 1986 - Uranus at Solstice

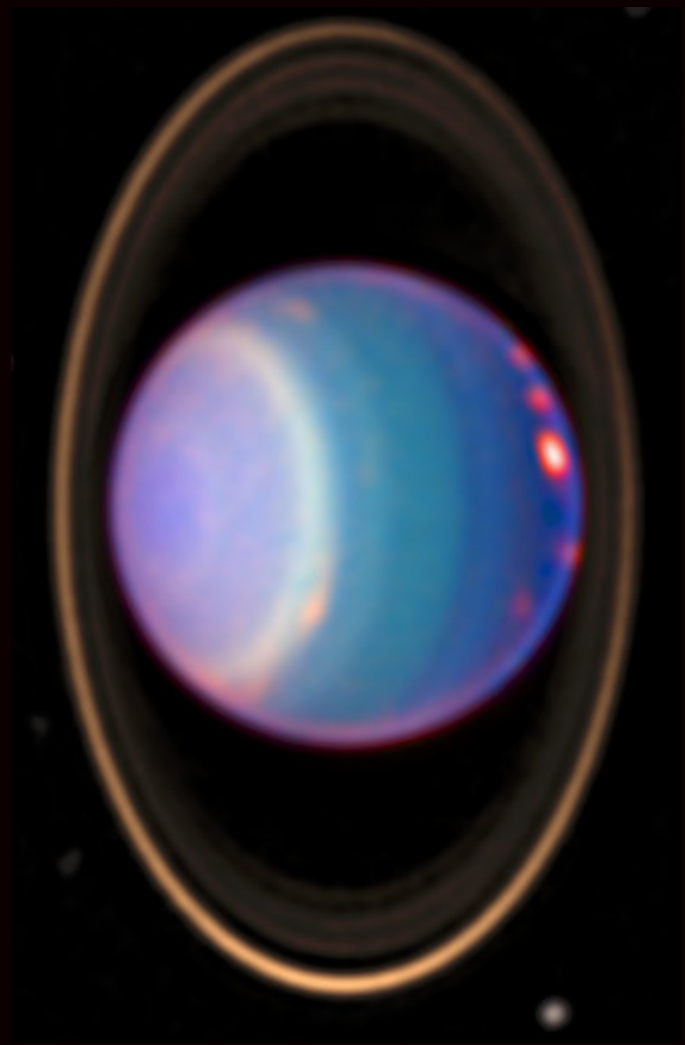


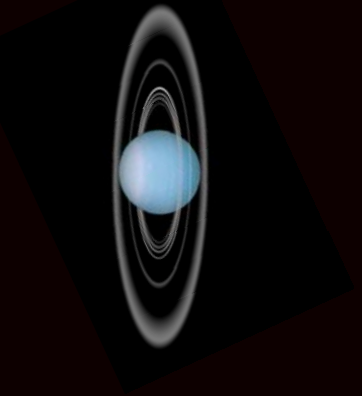
Uranus with Hubble

1994

1997

2000





Uranus with Keck

Keck 10-m

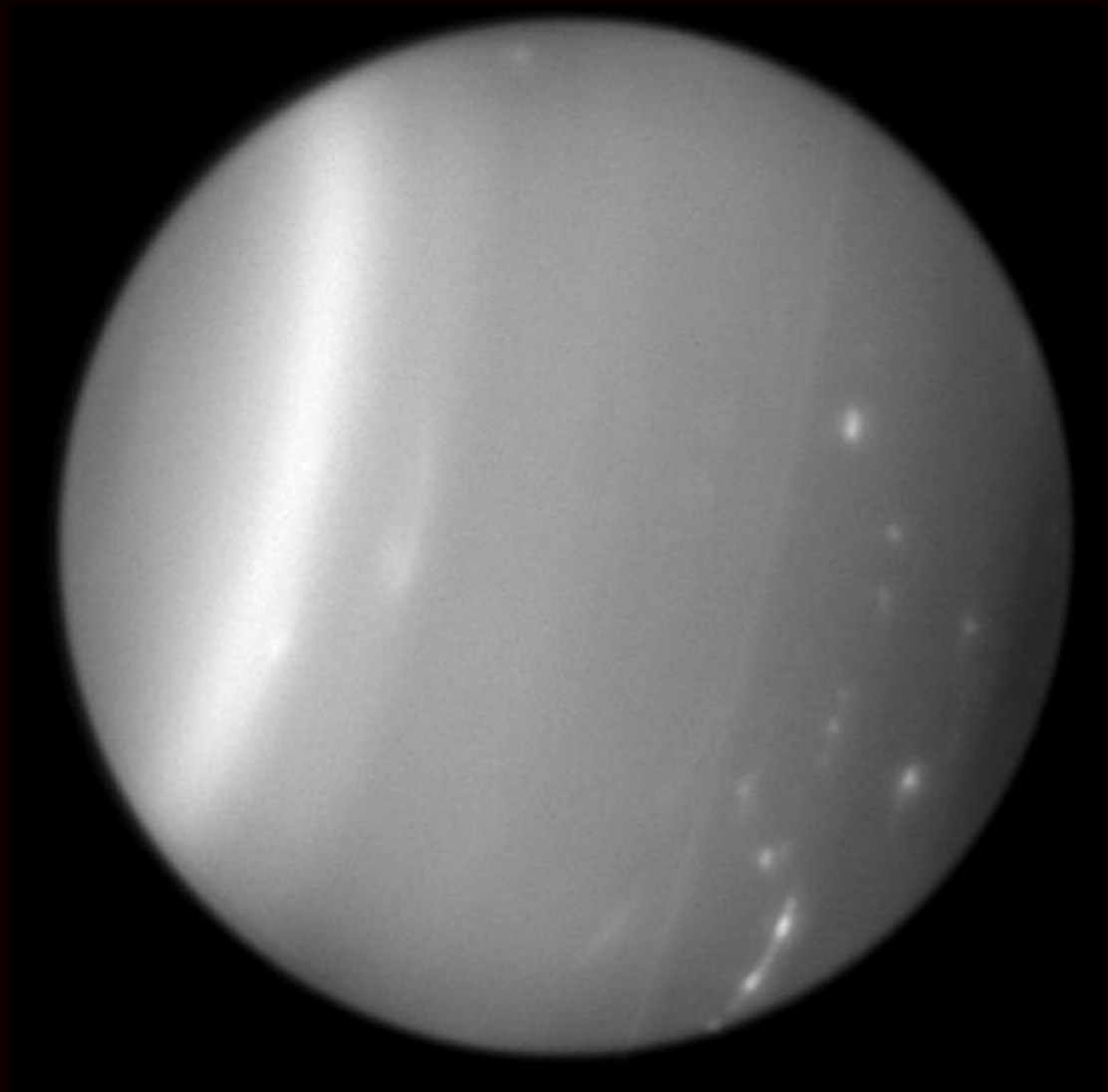
Mauna Kea

9 July 2004

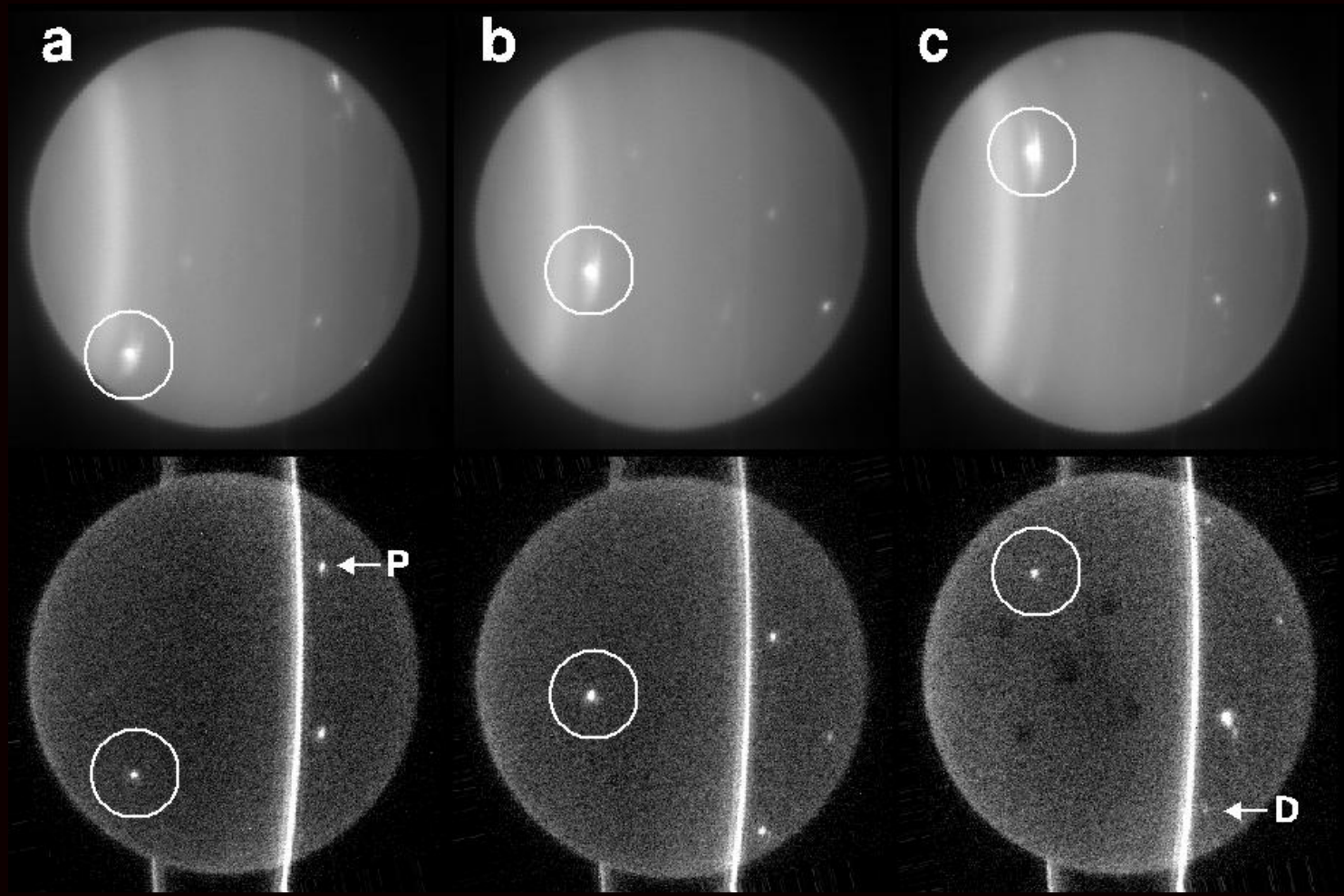
Hammel & de Pater

H (1.6 μm)

AO ON



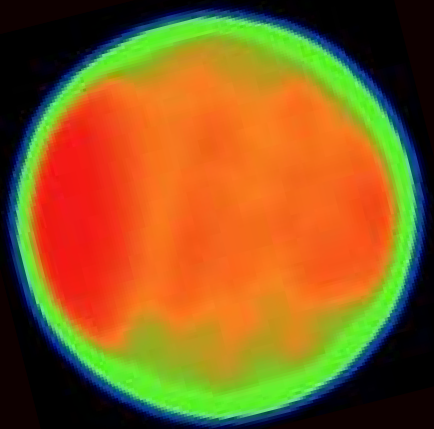
4th of July “fireworks” in 2004



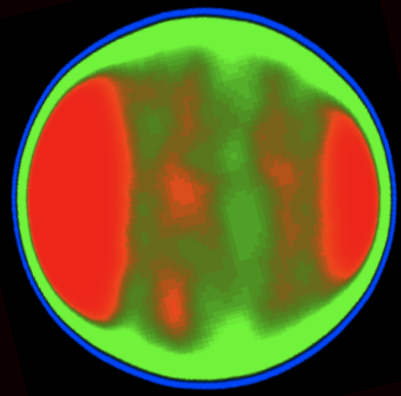
First southern feature ever seen on **Uranus** >2 µm (including HST NICMOS)

Hammel et al. 2005, Icarus **175**, 284

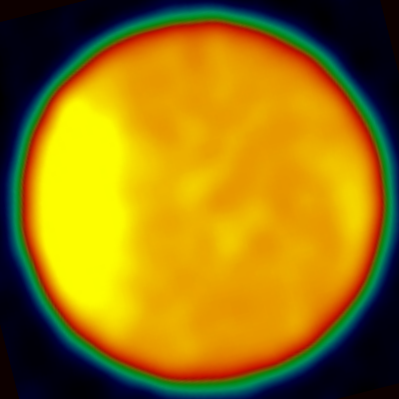
Uranus with VLA



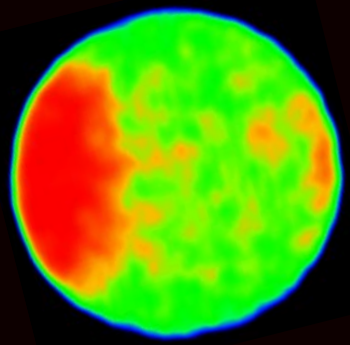
0.7 cm June 2005



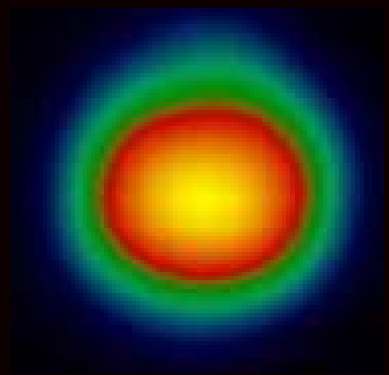
1.3 cm May 2005



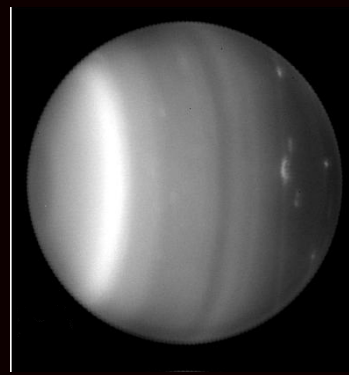
2.0 cm Dec 2005



6.0 cm July 2003



20.0 cm Nov 2004

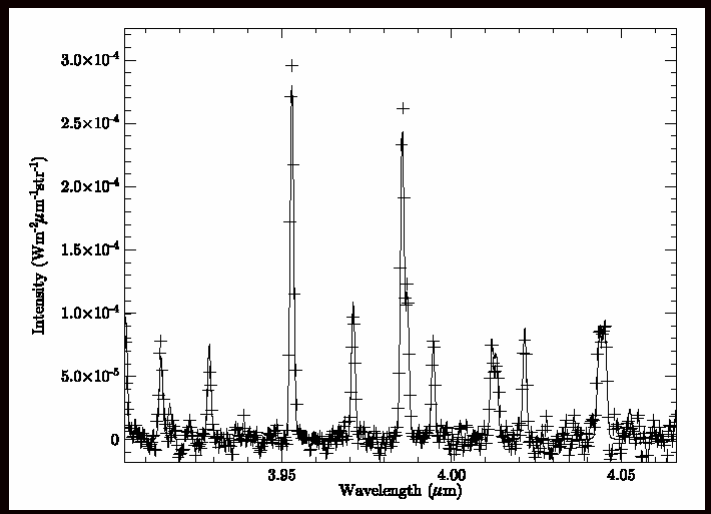


1.6 µm July 2004

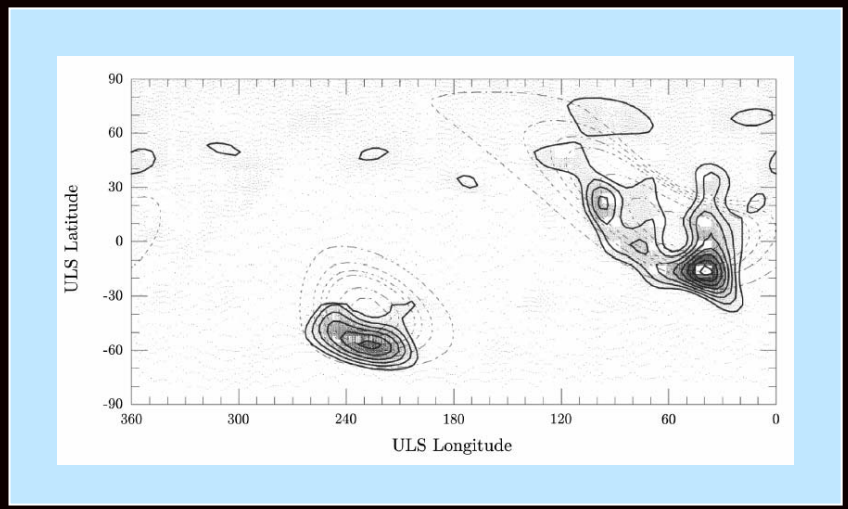
VLA maps courtesy M. Hofstadter

Hammel et al., Icarus 2005

Uranus H_3^+ (Ionosphere)



+



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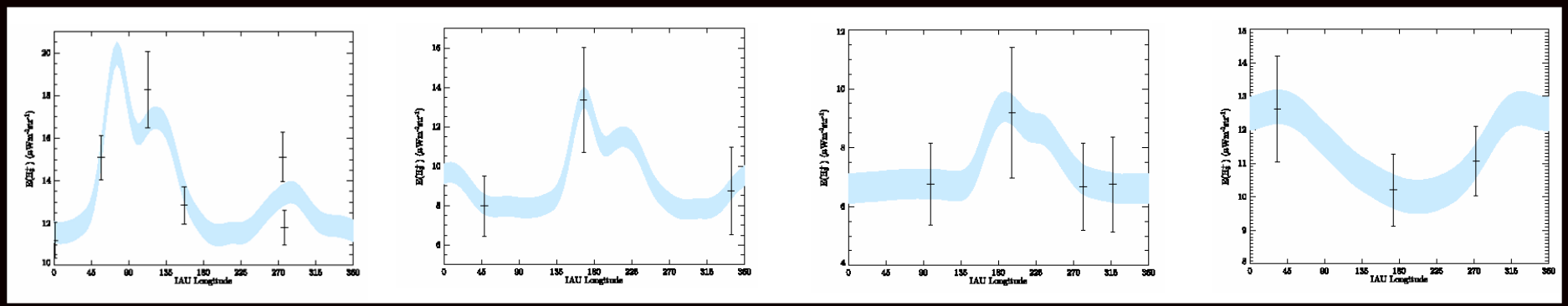
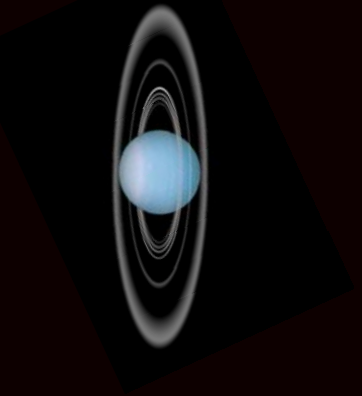
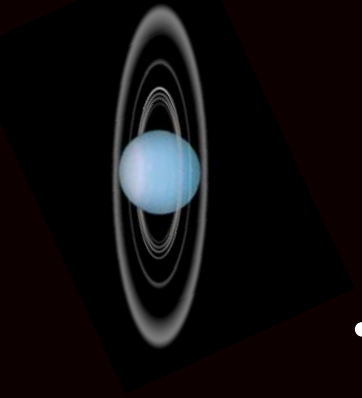




Atmosphere Science

- What is the effect of solar forcing on giant planet atmospheres?
  - Most extreme geometry for studying solar forcing
  - No internal heat source
  - Important for extra-solar planet studies
- What are the relative roles of dynamics and radiation in controlling atmospheric properties, and what are the timescales and phase lags?
- How does Uranus' tilt and offset magnetic axis affect magnetosphere/atmosphere/solar interactions?
- What is the temperature as a function of altitude (few bars to microbars) and latitude?

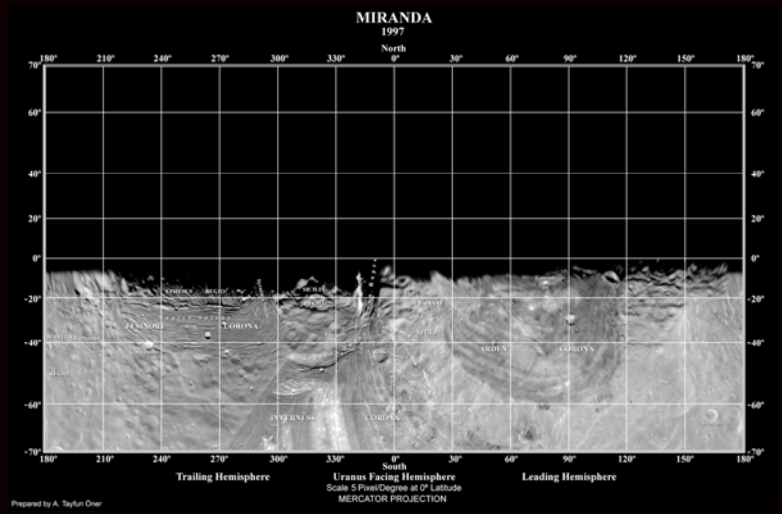


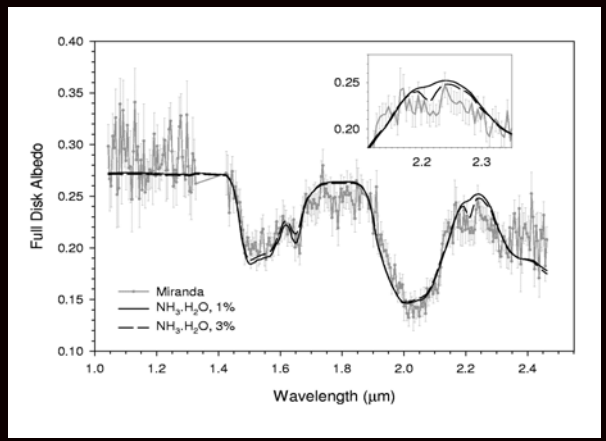
Atmosphere Measurements

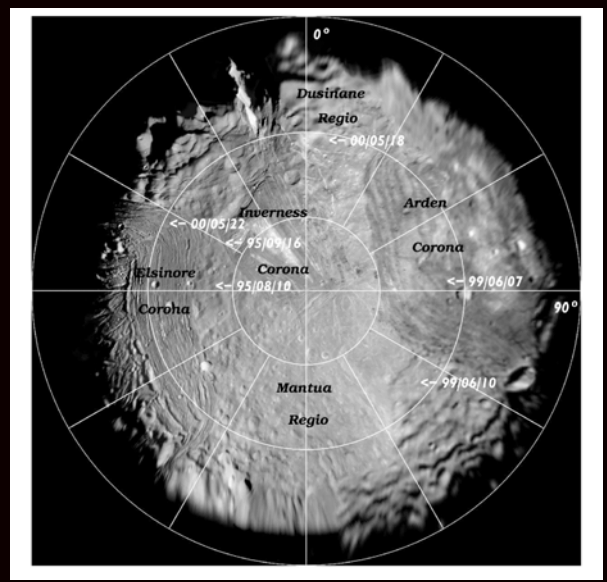
- Composition
  - Abundance variations (CH_4, C_2H_2, C_2H_6, oxygen compounds, complex hydrocarbons, ammonia, water?) with altitude, latitude, time
- Temperatures
  - Troposphere (100-400 mbar, 1 bar)
  - Stratosphere to thermosphere (stellar occs, thermal IR)
- Aurora and magnetosphere interactions
  - UV and/or IR
- Clouds and hazes
  - Altitude, optical properties, particle size
  - N polar cap formation, S polar cap dissipation
  - Confined convective events
- Winds
  - High northern latitudes
  - Potential for changes

Satellite Miranda

- Ridged terrain with Coronae
- r ≈ 235km, p_V~0.3 (Veverka et al. 1991)
- Opposition surge observed by Buratti (gb) & by Karkoschka (HST)
- Karkoschka et al. 2001 report darkening at higher sub-sol lat.
- Species: Xtal water-ice, $NH_3 \bullet H_2O$, plus a third component (Am Carb?, Murch. Extract?)

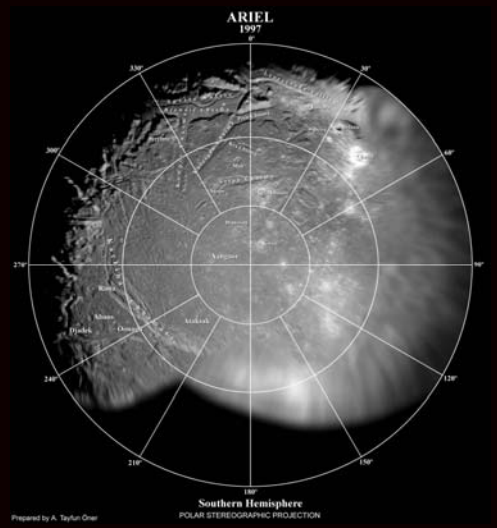


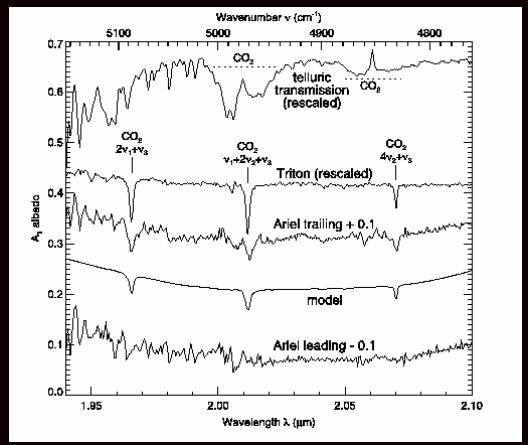


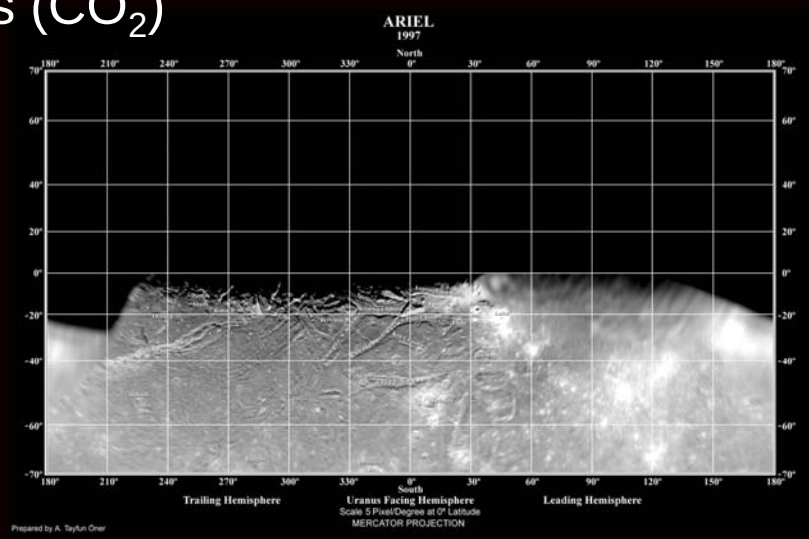


Satellite Ariel

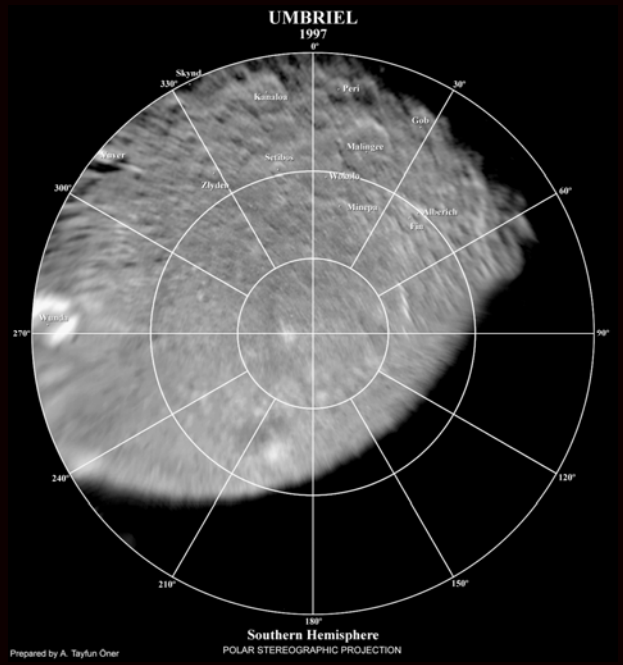
- Ridges/canyons higher reflectance in younger looking craters (~0.55)
- r ≈ 580km, *p*~0.34
- Opp. Surge: yes
- Species: Xtal Water-ice, CO_2, + third component (Grundy et al. 2003)
- Leading/Trailing Spectral asymmetries (CO_2)

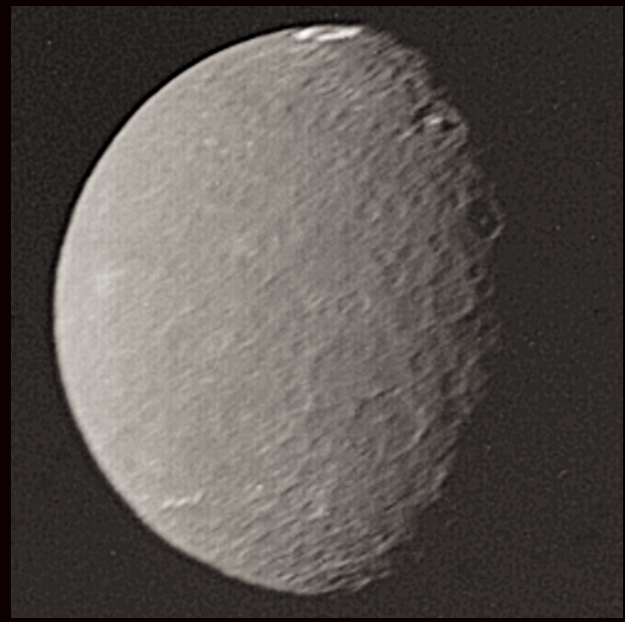






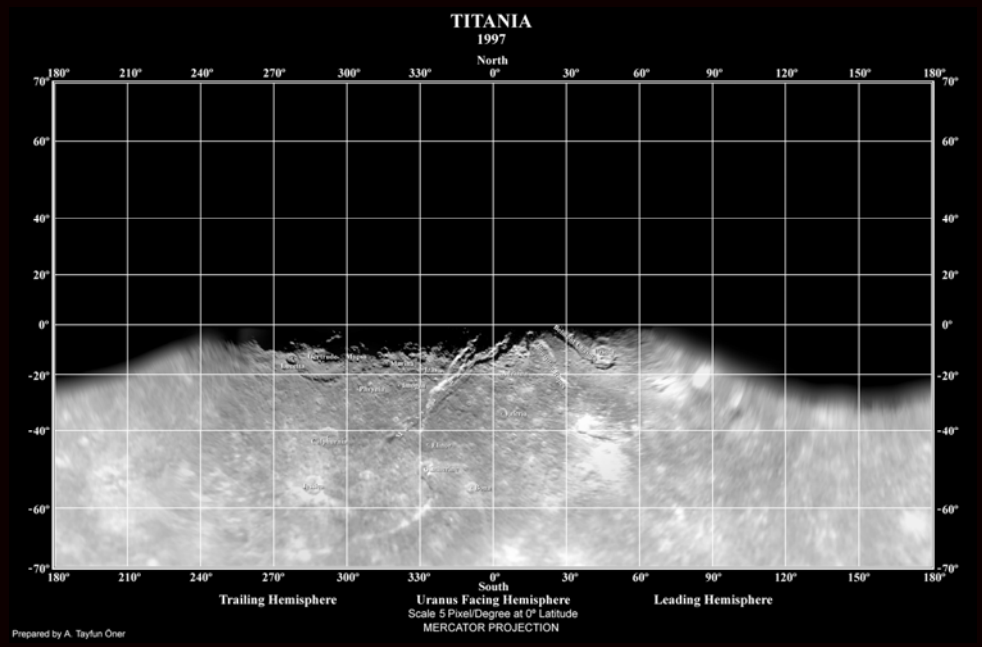
Satellite Umbriel

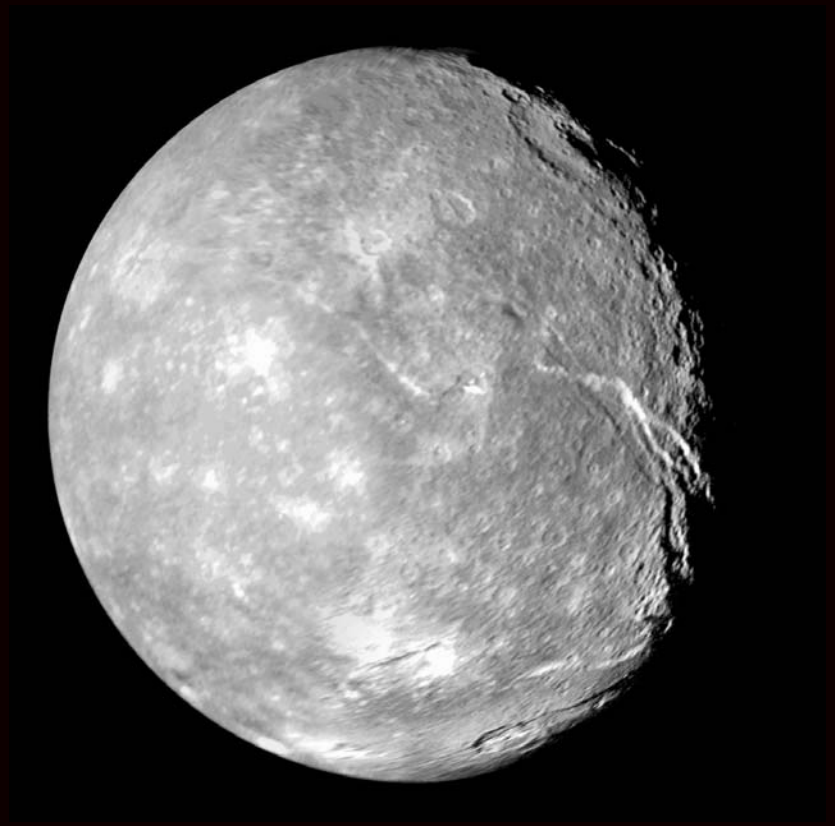




- Heavily Cratered, more uniform albedo
- r ≈ 585km, *p*~0.2
- Opp. Surge: likely
- Species: Xtal Water-ice, +other (Am. Carbon?) (Grundy et al. 1999)

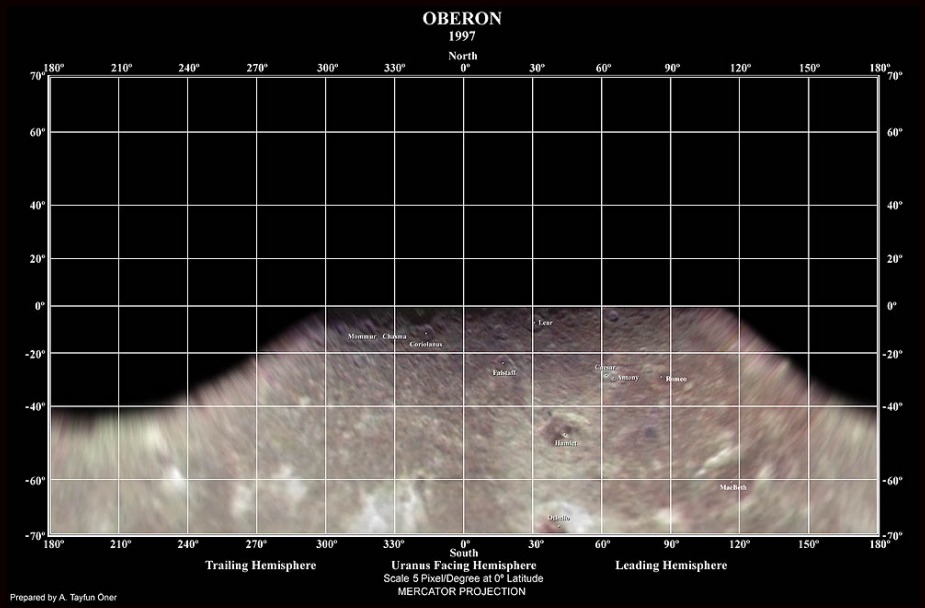
Satellite Titania

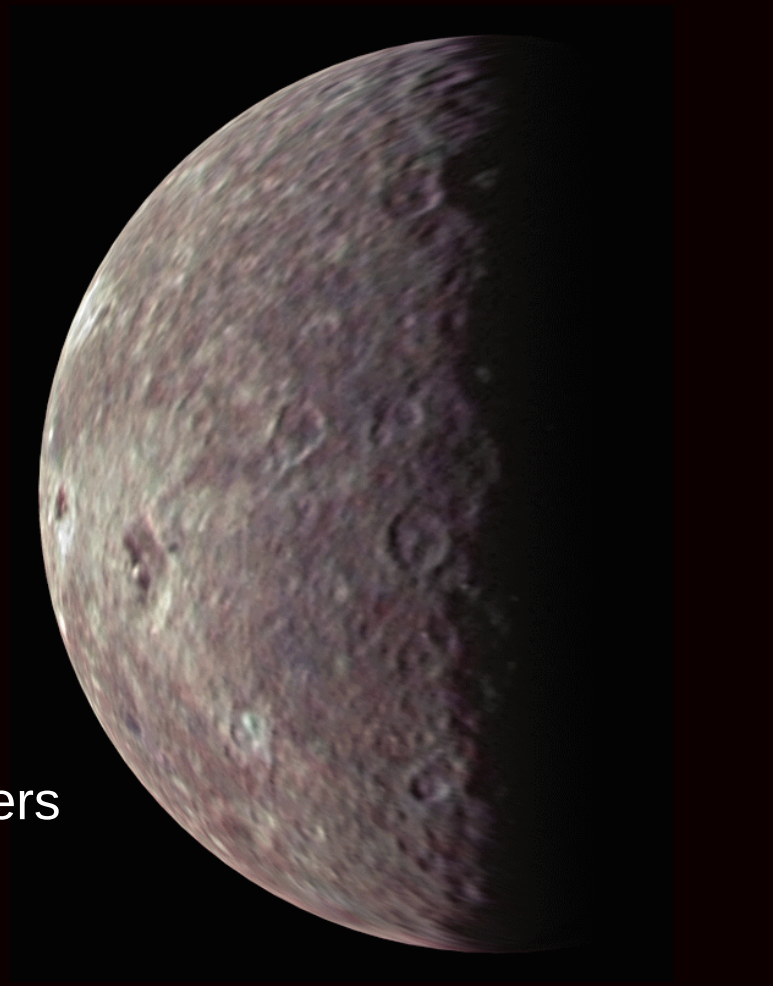




- Canyons + many small craters
- r ≈ 789km, *p*~0.3
- Opp. Surge: yes
- Species: Xtal Water-ice plus OH, Am. Carbon,Tholins? (Roush et al. 1998)

Satellite Oberon

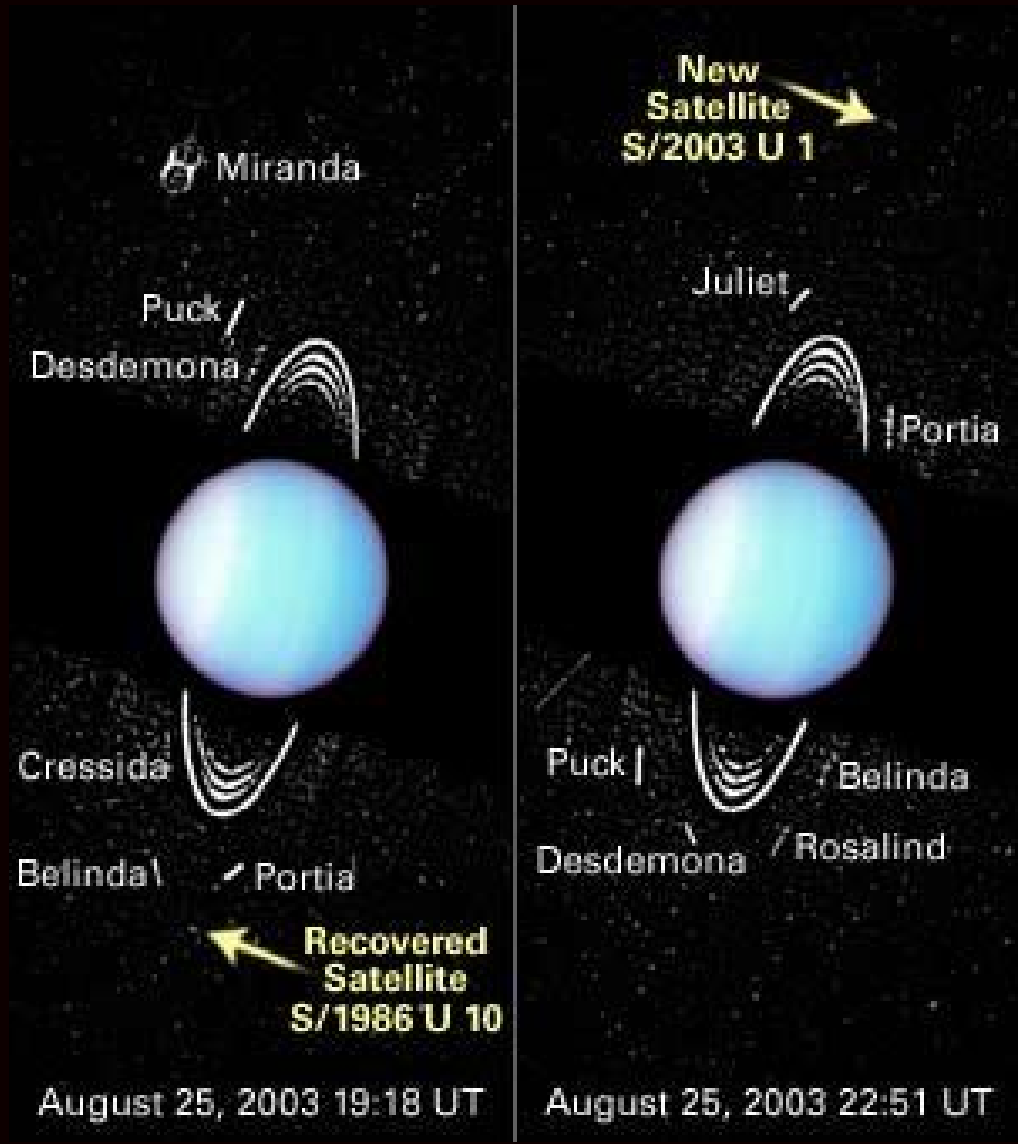




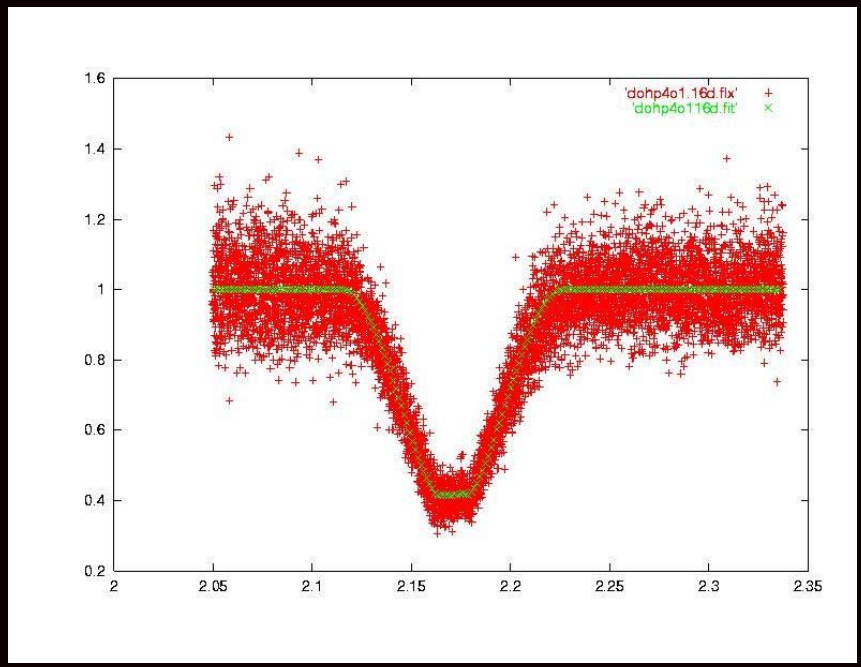
- Some canyons + many large & small craters
- r ≈ 761km, *p*~0.25
- Opp. Surge: yes
- Species: Xtal Water-ice plus OH, Am. Carbon,Tholins? (Roush et al. 98)
- $T_{water\text{-}ice}$~72K (others ~60K; Grundy et al. 1999)

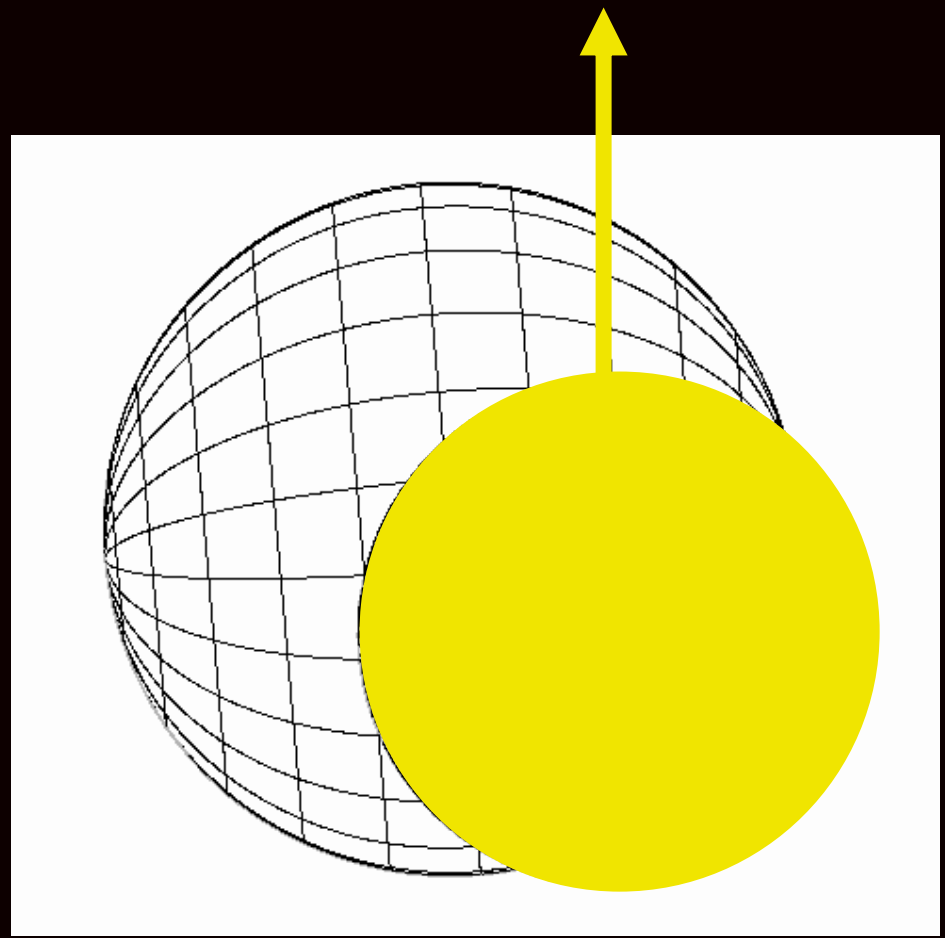
Other satellites

In addtion to the five "MAUTO" satellites (Miranda, Ariel, Umbriel, Titania, and Oberon), Uranus has dozens more moons, including the recently discovered "Mab" and "Cupid"

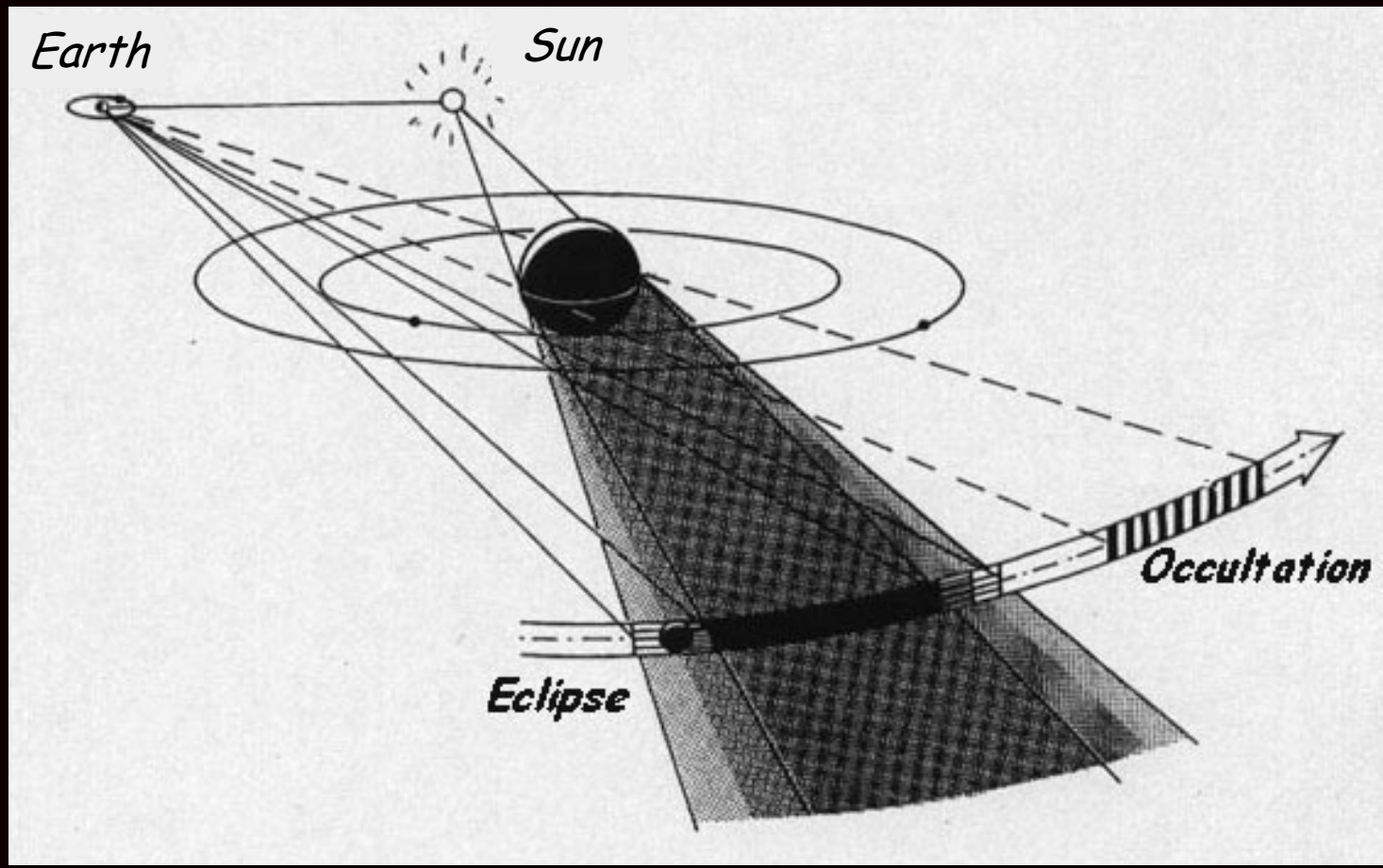


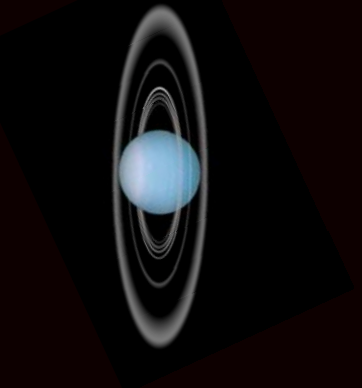
Satellite Mutual Events





Satellite Eclipses





Satellite Science

Do seasonal insolation variations trigger large-scale migration of volatile species on MAUTO satellites?

assess timescales of variability; detection of post-eclipse brightening

Are there apparent variations across the MAUTO satellite surfaces as a function of latitude?

detectable as changes in the amplitude of the phase curve

Do the MAUTO moons exhibit hemispheric variations of composition? of albedo?

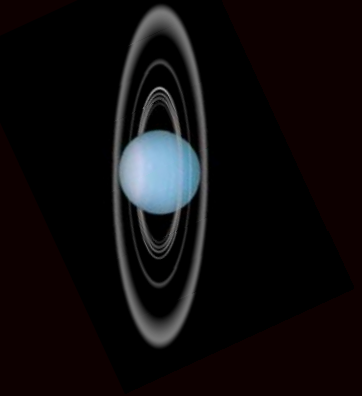
repeated secular observations; "mapping" by transits of smaller moons

What internal physics can be elucidated by much more accurate position determinations of the smaller moons?

timing of both mutual events and eclipses:Tidal effects, planetary precession, secular precession of satellite orbits, other perturbations, satellite masses

What are accurate sizes for smaller moons?

determined via mutual event



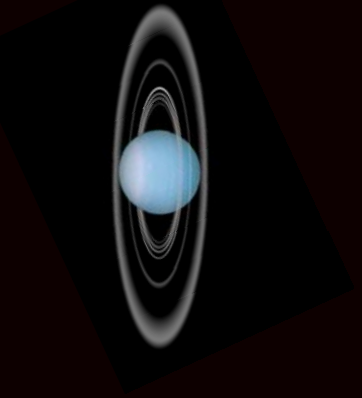
Satellite Measurements

Non-Event observations

- Spectral reflectance at visible wavelengths
- Spectral reflectance at near-infrared wavelengths
- Surface composition and characteristics
- Phase curves

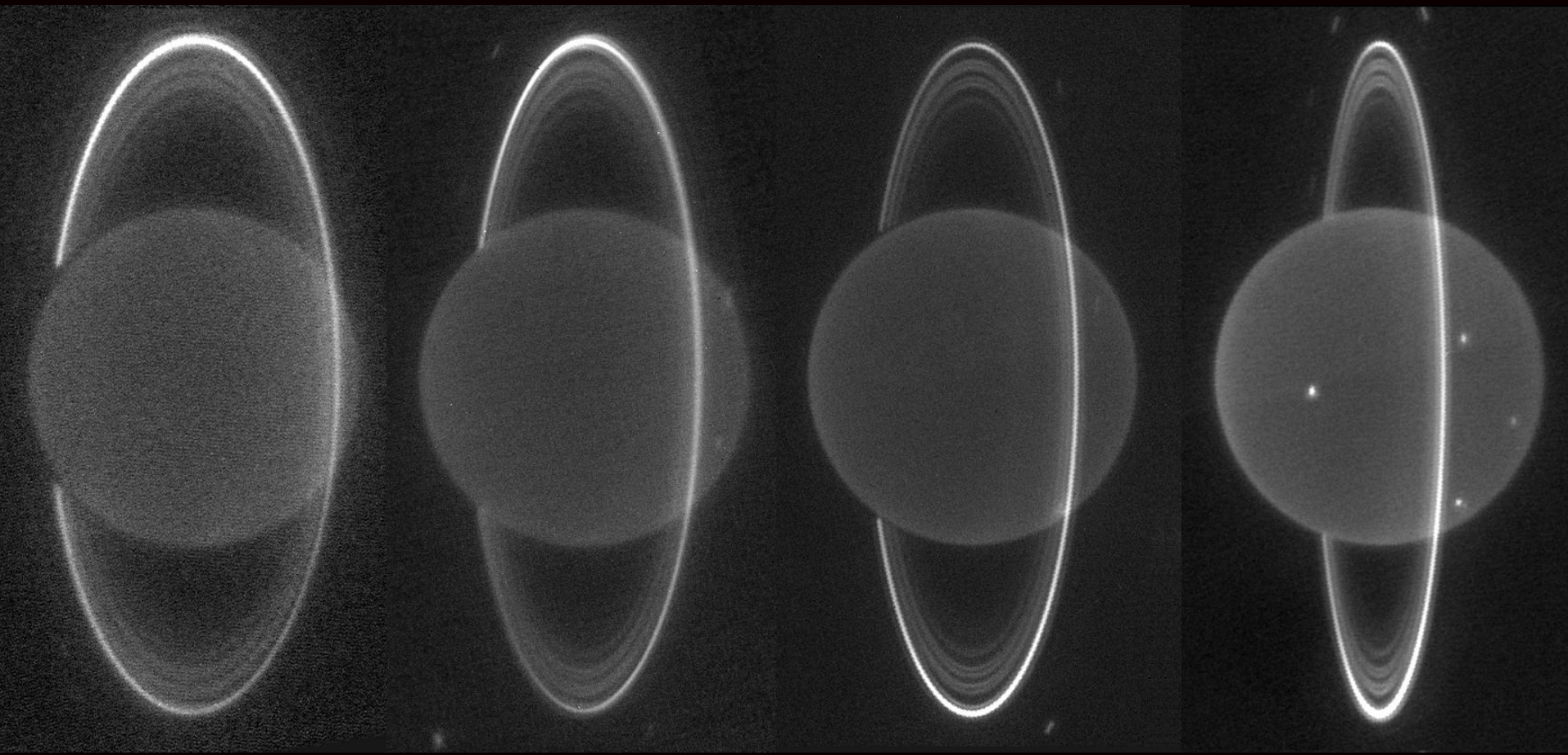
Eclipse and Mutual Event observations

- Orbital parameters
- Spatially-resolved albedo variations (single channel)
- Spatially-resolved composition (spectra)



Rings by Keck

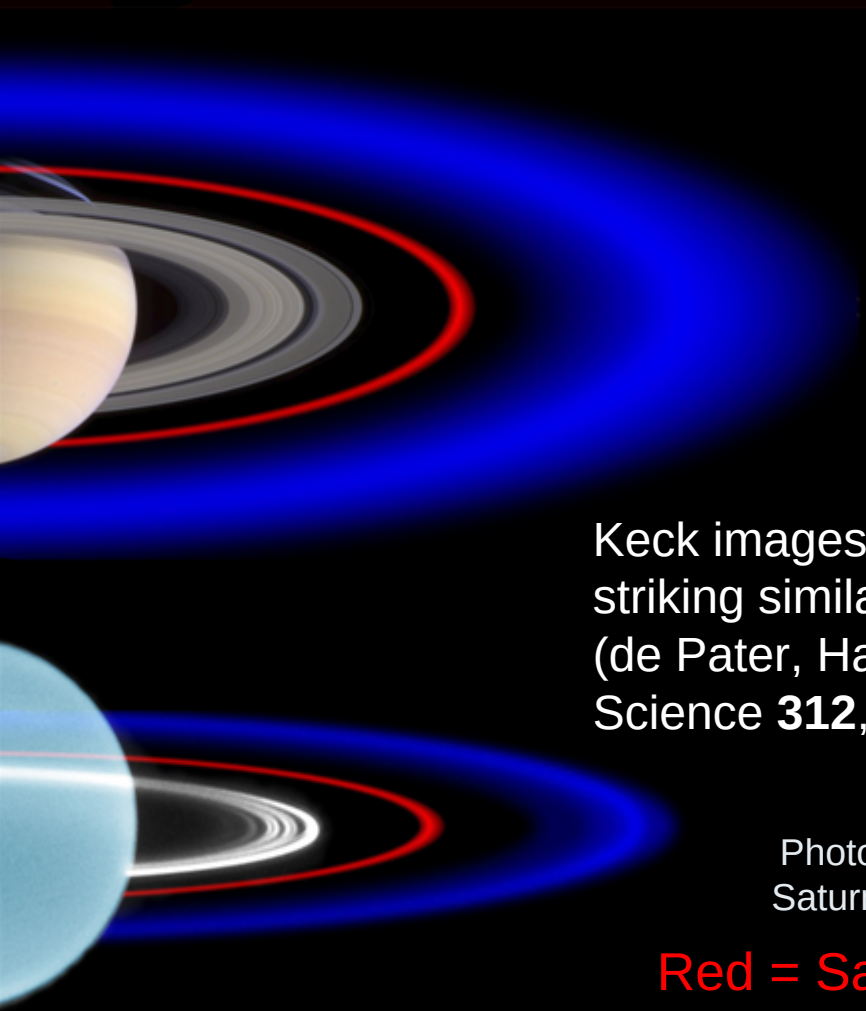
2001 2002 2003 2004



New Rings by HST and Keck

Two new rings discovered with HST and Voyager by Showalter and Lissauer (2006, Science **311**, 976)

Keck images reveal rings' colors and striking similarity with Saturn's rings (de Pater, Hammel, et al. 2006, Science **312**, 92)



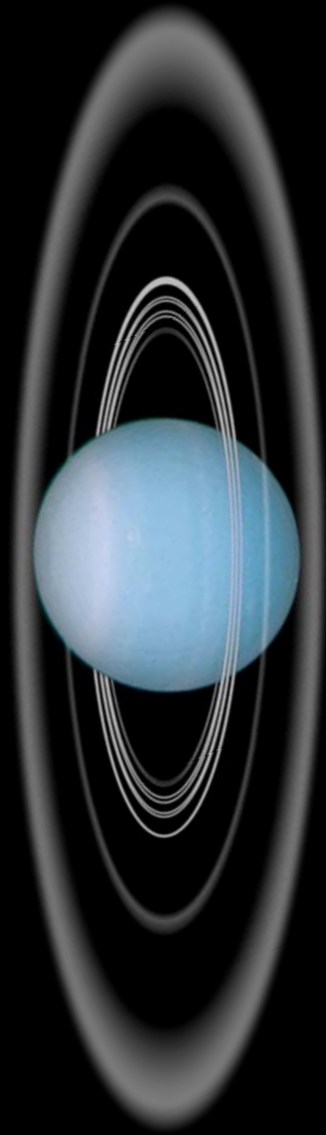
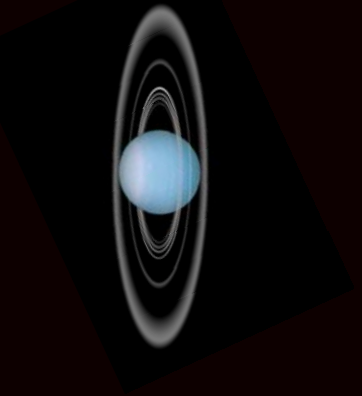


Photo-Illustration compares the Saturn and Uranus ring systems

Red = Saturn G ring, Uranus R2

Blue = Saturn E ring, Uranus R1



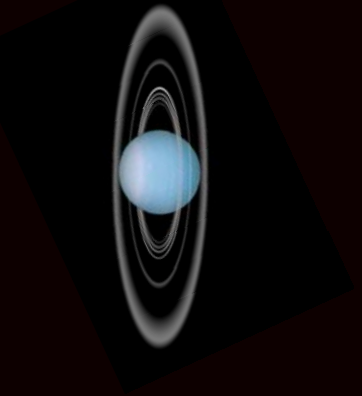
Ring Science

What processes drive the formation and evolution of rings and ring material?

Are the rings stable and long-lived?

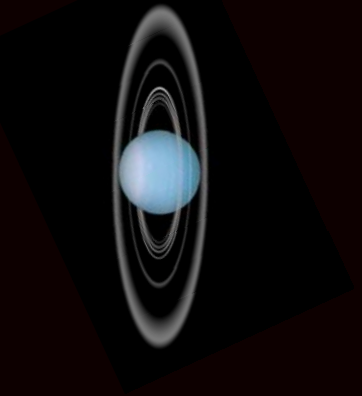
What are the physical and optical properties of the ring material?

How well can the faint outer rings and dust sheets be characterized?



Ring Measurements

- Ring thickness during RPX
- Structure of—and within—the rings
  - warps, waves, inclination, orientation
- Physical and optical properties of ring material
  - reflectivity as a function of viewing geometry
  - reflectivity as a function of wavelength
  - particle size distribution as inferred from colors
- Faint outer rings and dust sheets



Needed Laboratory Work

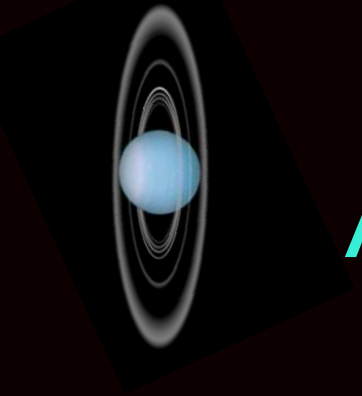
NEED actual line data down to 50 K to confirm models extrapolated from 100 K

NEED Hydrogen Ortho-Para conversion rates to be confirmed in the laboratory

NEED further work on the detailed line measurements of ethane in the mid-IR (12-μm) region.

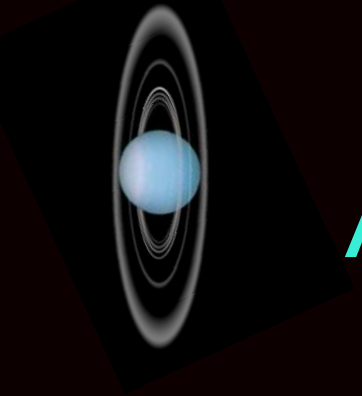
NEED further exploration of solid-state chemistry on hydrocarbon particulates as a result of UV irradiation ; spectral results

NEED low-temperature measurements of H_2-H_2, H_2-He absorption in the mid infrared between 7 and 14 μm



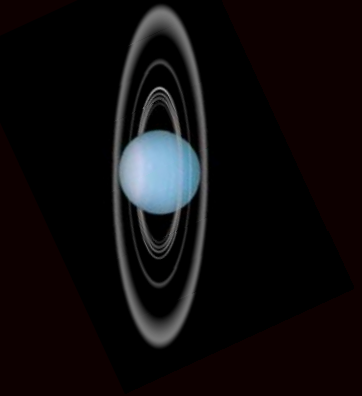
Actions (assignments) 1 of 2

- Science workshops
  - Atmospheres: DPS Pasadena, 8 October 2006 (Nancy Chanover)
  - Satellites: Observatoire de Paris, 16-18 Nov 2006 (Jean-Eudes Arlot)
  - Rings: TBD (Mark Showalter)
- Predictive work
  - Mutual events for small satellites (Valery Lainey)
  - Occultations (Julie Moses to contact the usual suspects)
- Contact Paul Steffes re laboratory data (David Huestis)



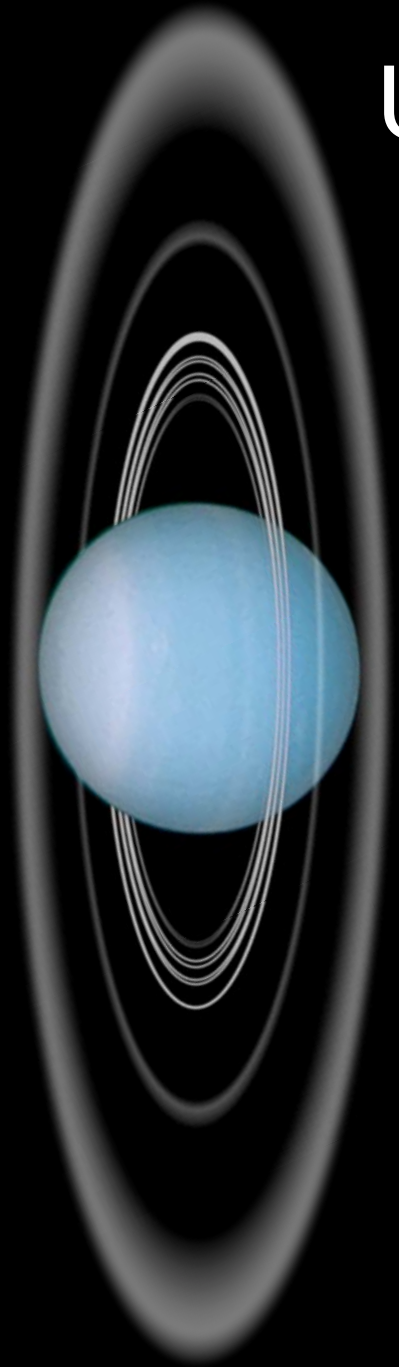
Actions (assignments) 2 of 2

- IOPW Uranus at Equinox Website (Tom Stallard)
  - Assemble list of existing data (Jim Norwood)
  - Assemble list of scheduled observations (Mark Hofstadter)
  - Bibliography (Kathy Rages)
  - Links to JPL Horizons, Ring Node tools, IMCCE satellites ephemerides
- Publication of "Uranus at Equinox" work (Heidi Hammel)
  - workshop: Chapman Conference or NASA-sponsored event
  - book: U. Arizona Press or Cambridge University press
  - special journal issue: Icarus or JGR-Planets
- Education and Public Outreach
  - GAVRT (Mark Hofstadter)
  - Publications: newsletters, magazines, websites (various)



Requested OPAG Action

- Brief Letter of Support for "Uranus at Equinox" Campaign
  - Addressed to H. B. Hammel
  - Will be used to inform observatory directors, funding agencies, TACs (etc)
- Contents
  - Acknowledgement of today's workshop report
  - Few sentences about unique opportunity and enabled science
  - Role of ice giants (intermediate class of giants; links to EGPs)
  - Statement about lack of flight opportunities
  - Voice of support for the Uranus at Equinox Campaign



Uranus at Equinox Workshop

Once every 42 years, we have an opportunity to see the planet Uranus and its moons from pole to pole, and to view its ring system edge on.
That opportunity comes in 2007.

By observing the Uranus system at equinox in 2007, we will explore an atmosphere that is changing rapidly. We will probe newly discovered faint rings.
We will use the rare opportunity of mutual satellite eclipses to map the brightness variations on large moons.

Observations at the equinoxes of Jupiter, Saturn, and Pluto provided fundamental insights.
The year 2007 is our chance to do the same for the Uranus system.

Uranus at Equinox Workshop