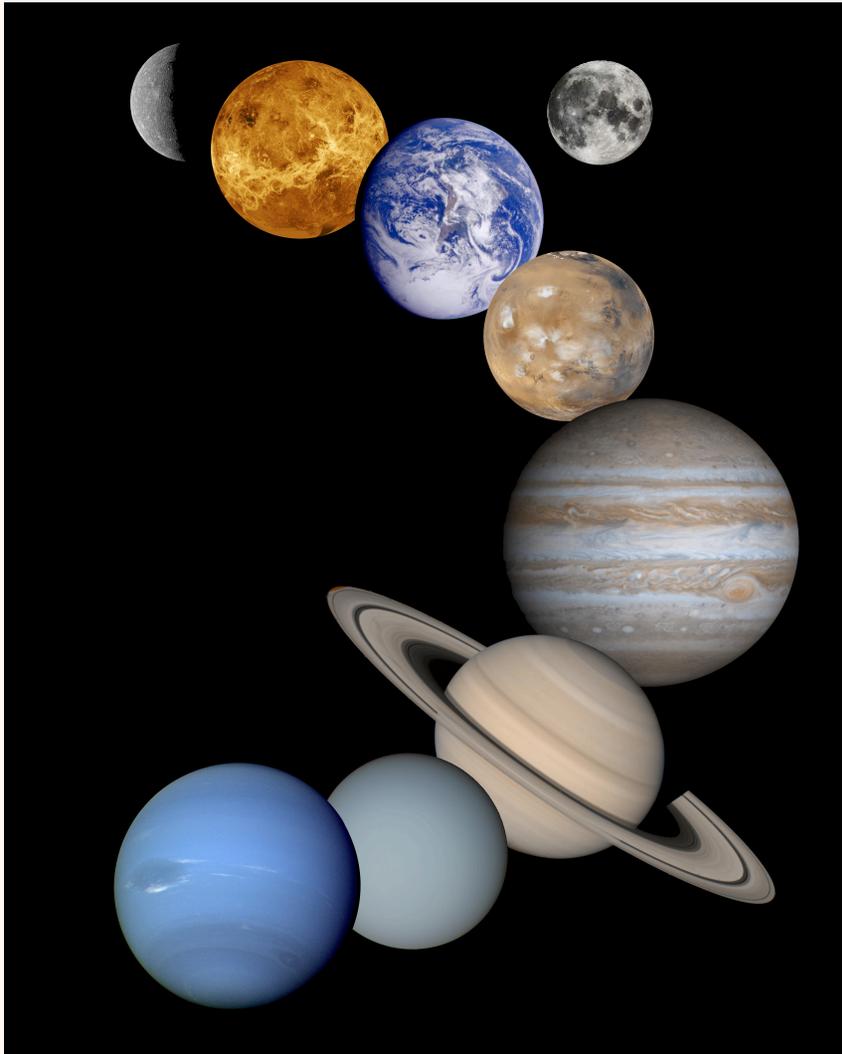


# **UV Polarimetry of Solar System**

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**Space Science Institute**

# The Solar System: Family Portrait



## Atmosphereless:

Moon, Mercury, Asteroids

## Atmospheres (terrestrial):

Venus, Mars

**Atmospheres (outer planets):** Jupiter, Saturn, Uranus, Neptune

**Ices :** Comets and Planetary

**Satellites :** Titan, Triton, Io, Ganymede, etc.

<http://photojournal.jpl.nasa.gov/catalog/PIA03153>

**All Solar System objects have unique polarimetric signatures, like fingerprints!**

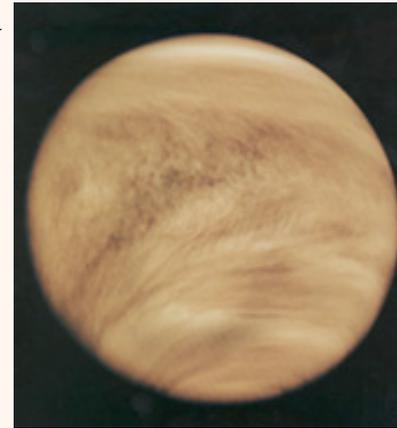
# What Polarization Reveals

Near-IR	Optical	UV
particle properties in planetary atmospheres, cometary comae; surface texture, refractive indices	particle properties in clouds/cloud tops (rainbows, haloes, etc.) to differentiate between liquid droplets vs. particles	particle properties of high-atmosphere processes: hazes, aurorae, species, etc.

Information re: particles/process at different altitudes in atmospheres, surfaces, comets and solar-planetary interactions.

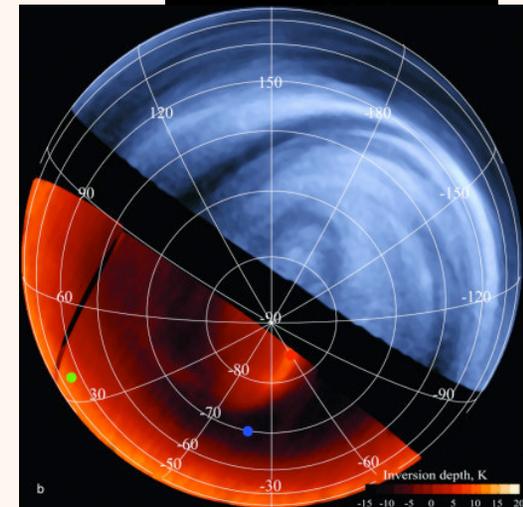
# Venus

- Very dense atmosphere; complex cloud system
- Details not revealed s/c; polarimetry
- Hansen and Houvenier (1974)
- Linear polarization
- Spherical droplets of  $(\text{H}_2\text{SO}_4 \cdot \text{H}_2\text{O})$
- Narrow size distribution; high
- Detailed views by new missions:
- Clouds variable and complex



HST, 1995

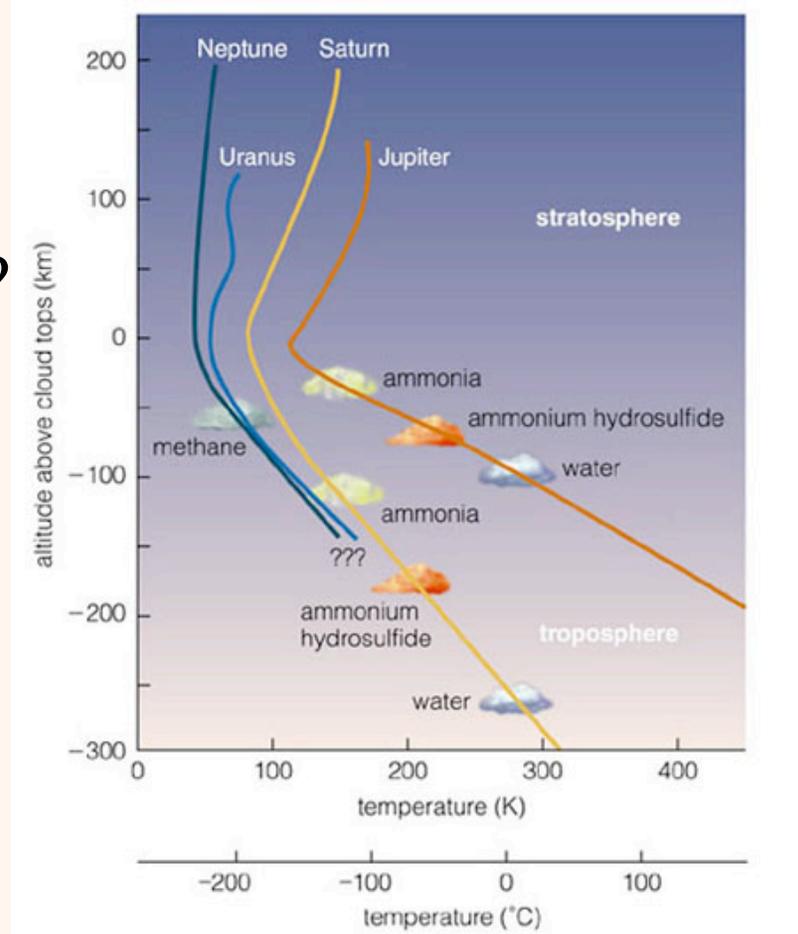
Pioneer Venus



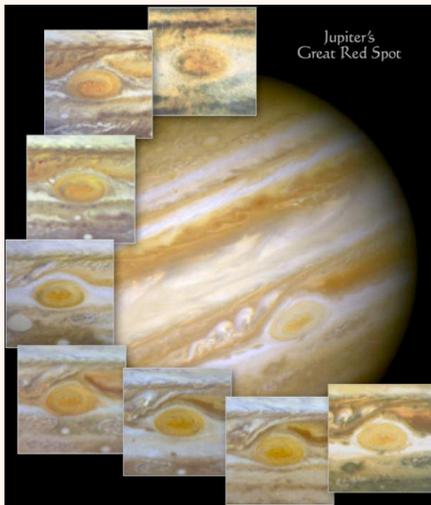
Venus Express/VIRTIS

# Outer Planets: Science Drivers

- Banded structure and Color?
- How deep are the storms?
- 3-D structure of atmosphere?
- Interior – Core?
- Aurorae
- Temporal changes
- Seasons
- Episodic events



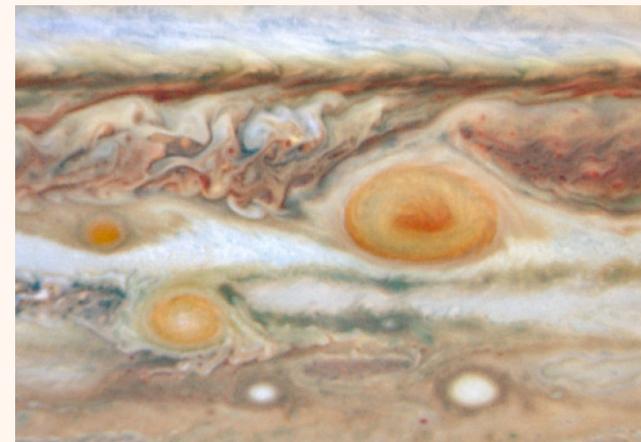
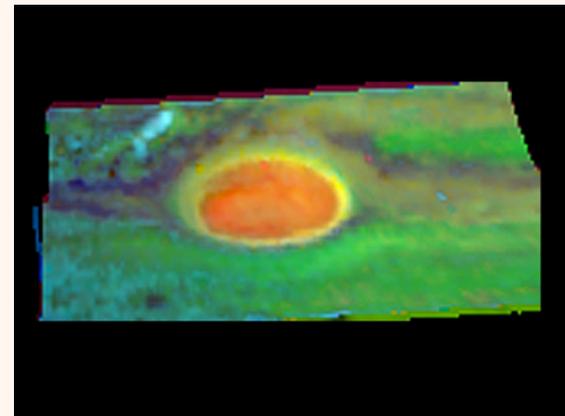
# Intrinsic Polarization: Changes in Atmospheric State



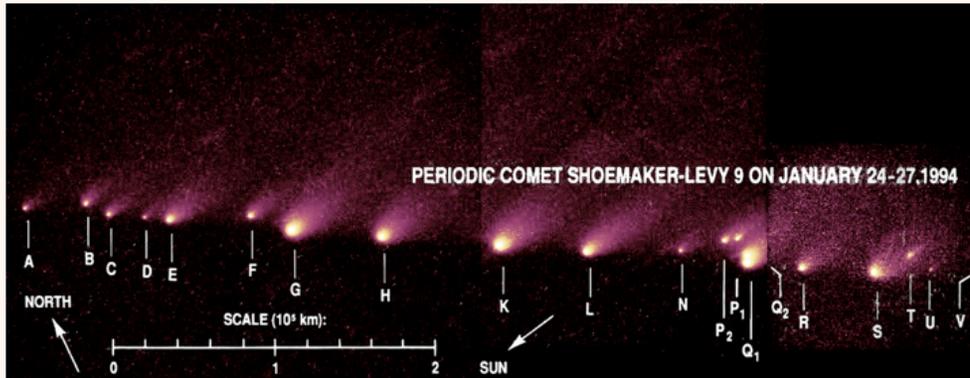
**Left: Changing shapes of vortices like Great Red Spot.**

**Right: Short-lived fresh ammonia clouds (white).**

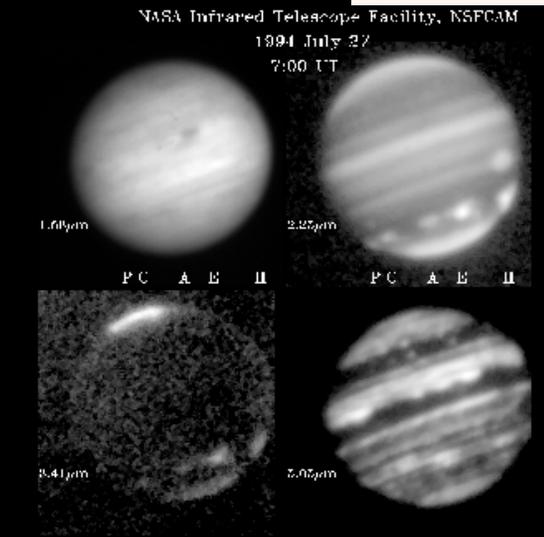
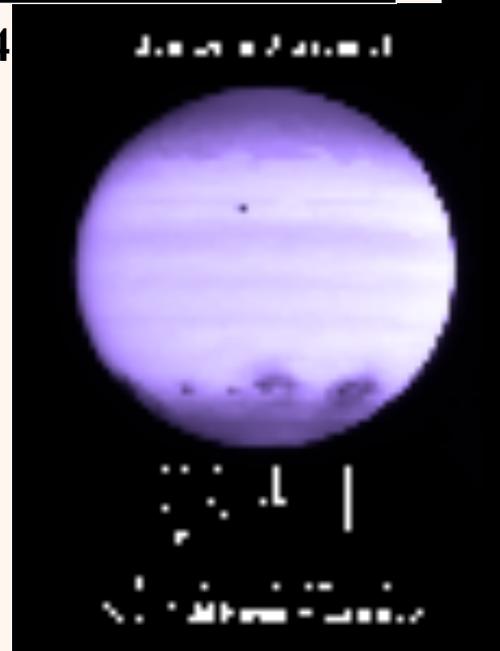
**Bottom: Interaction of vortices**



# Extrinsic Polarization: Multiple Collisions between Celestial Bodies

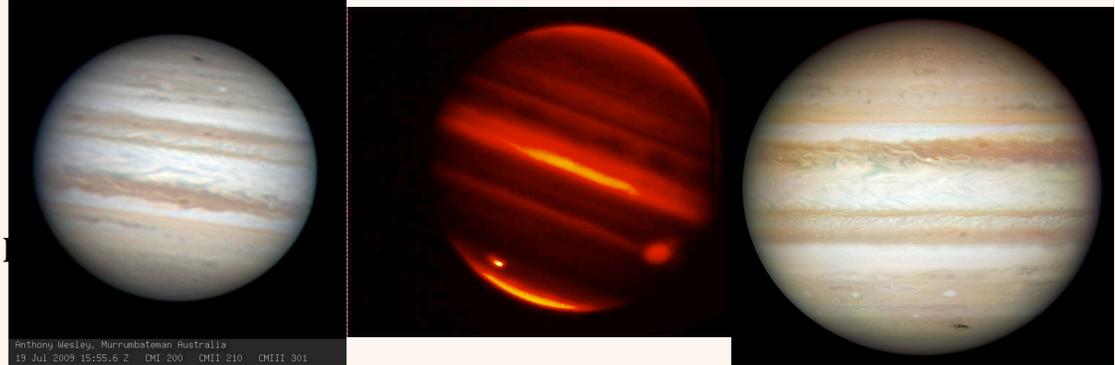


- 🌍 D/Shoemaker-Levy 9, 1994
- 🌍 Impacted Jupiter in southern hemisphere
- 🌍 Exhumed/lofted material from deep atmosphere/ deposited impact material
- 🌍 Frequency: 1/300 yrs?

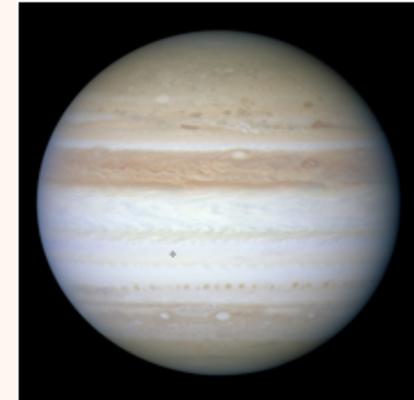
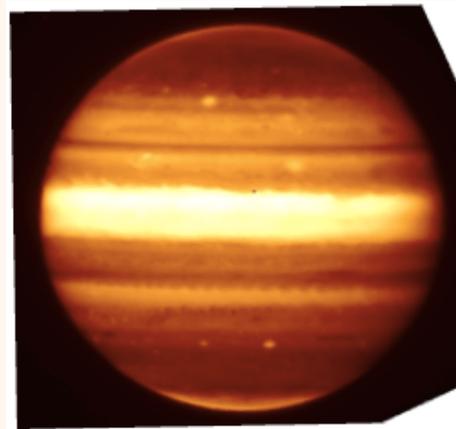


# Extrinsic Polarization: Single Collision (Deep and Shallow)

- **Deep Impact 2009 possibly asteroidal**
- **Discovered by amateur astronomer, A. Wesley**



- **Shallow Impact 2010**
- **Discovered by A. Wesley**
- **a superbolide/meteor, high in atmosphere**



# Saturn: Seasons/Clouds

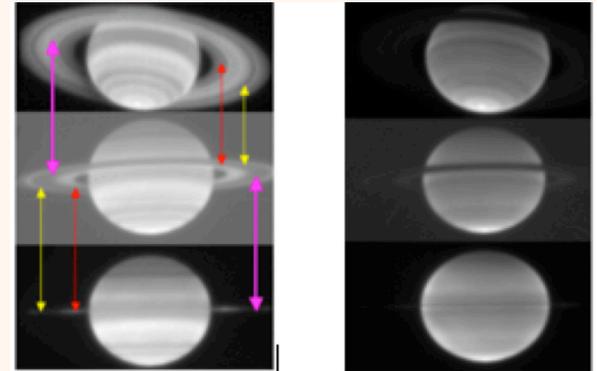
Changes occur due to season and big storms (once every Saturnian year (~ 30 years, but unpredictable))

Current 2010 Dec. GWS still raging

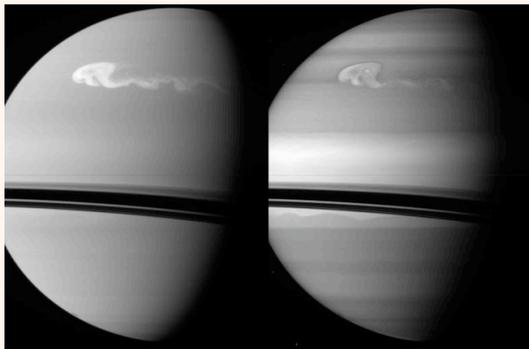
Transport energy/material into stratosphere (like beacons) and dispersed by the winds



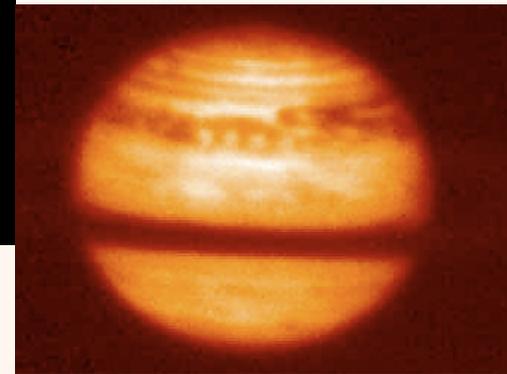
HST 1996 – 2003



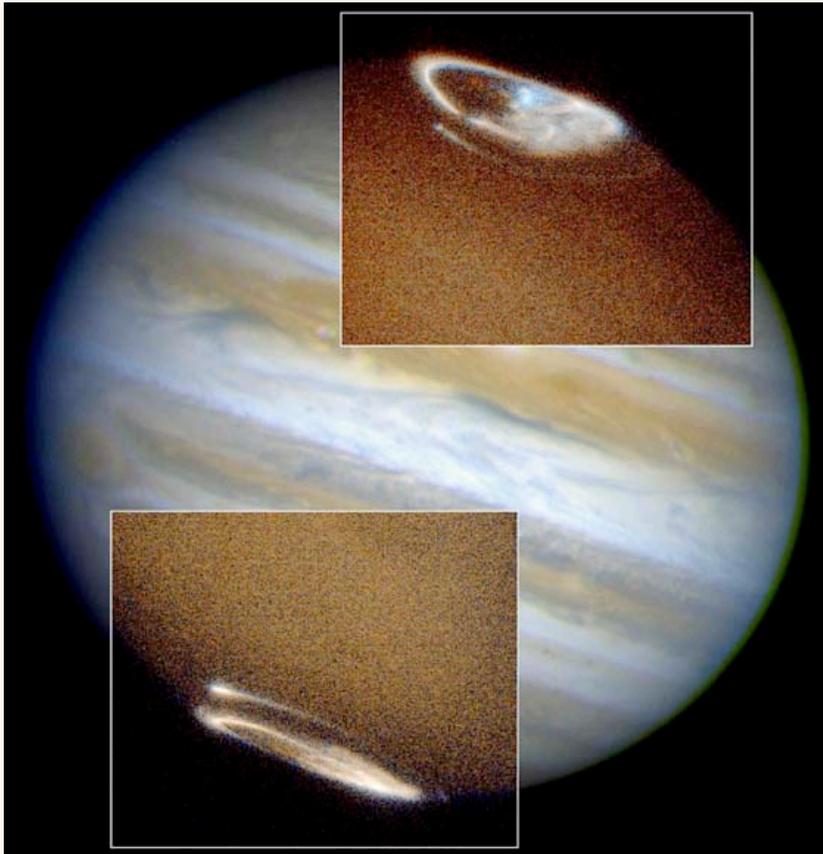
Mid-IR changes, 2005 - 2008



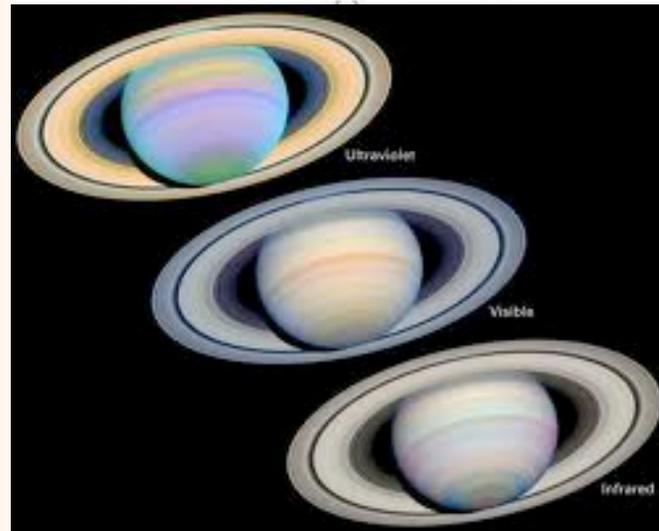
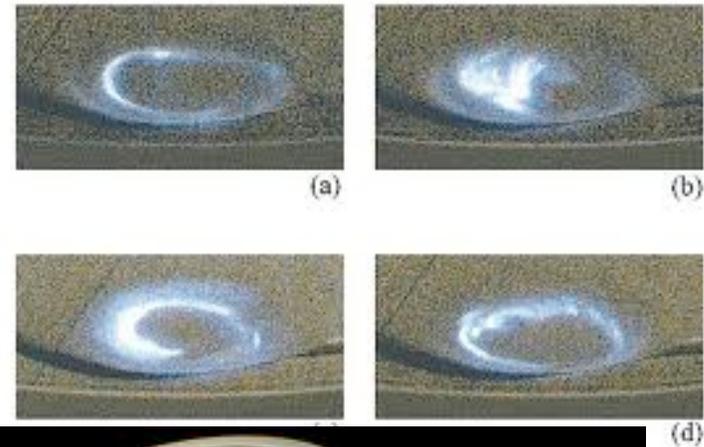
2010 GWS on Saturn:  
views from Cassini/SSI;  
vis (amateur astronomer),  
mid-ir (ESA/VLT); 5-mic  
(IRTF/NSFCAM2)



# Planetary Aurorae



N/S Jovian Aurora taken with HST/STIS (Clarke 1997)



HST/STIS images of Saturn's s. auroral oval (top); HST/WFPC2 images (bottom) taken in 2003

# Polarization of Outer Planets

Atmospheric polarization signature small (approx. 3%) and increases polewards

Galileo data (Houvenier et al.) and ground based observations of Jupiter/satellites (Rosenbush, Dulgach, Shalygina)

Variable due to changing morphology of clouds, and other dynamic processes

Optical spectrophotopolarimetry probes the atmosphere in methane bands (Joos and Schmid, 2006/2007)

Important to identify material brought up by various events; and local photochemical state of the atmosphere

# Planetary Satellites and Rings

Outer planets from outside the frost line – where ices condense; evidenced by observational data

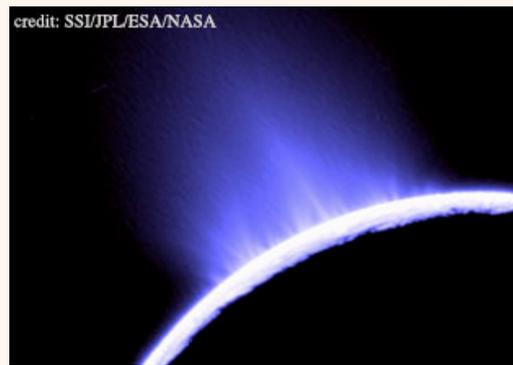
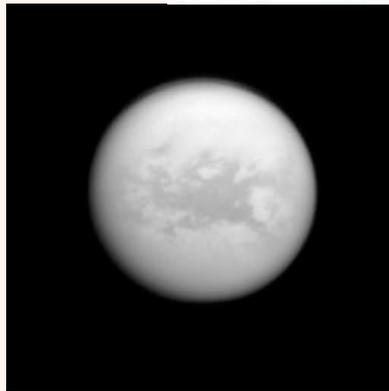
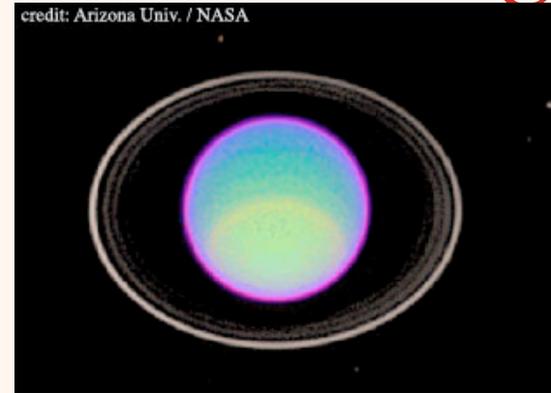
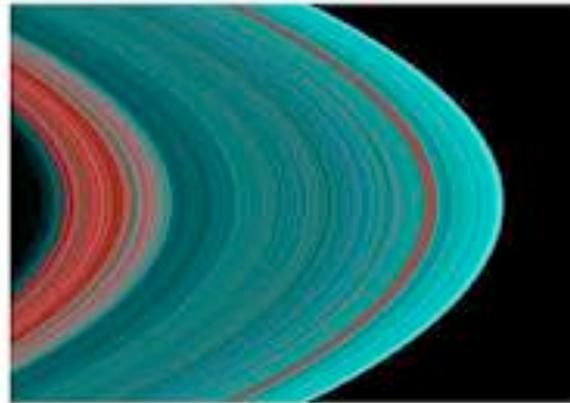
Jupiter: Galilean Satellites

Saturn: Titan, Enceladus, Rings

Uranus/Neptune: Classical satellites; Triton

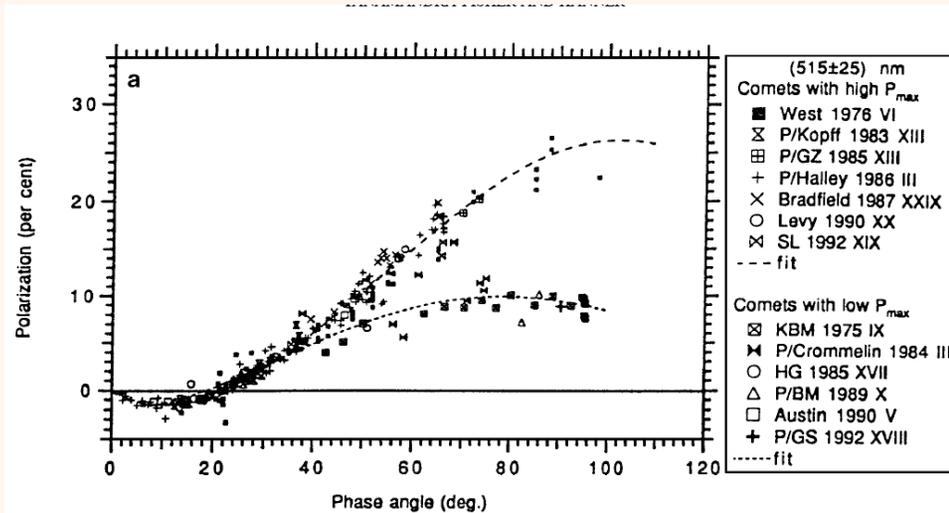
All exhibit water and/or other ices (clathrates) in their spectra; however, very little is known about the phase of water ice and contaminants – uv, optical, near-infrared polarimetry would be useful to identify these materials

# Planetary Satellites and Rings



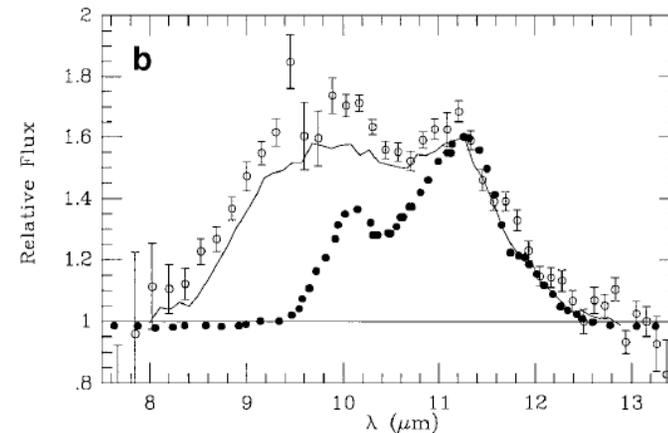
Various objects composed of small particles, source of polarization: Saturn's rings in UV , Uranus rings, Titan, Enceladus jets; Galilean satellites

# Comets



Polarization  
(Levassuer-Regourd  
et al., 1996)

Thermal Emission from C/  
Mueller (Hanner et al. 1994), C/  
Halley (Ryan and Campins, 1989)  
and crystalline olivine (Stephens  
and Russell, 1979).



# Other Subfields

## Exoplanets

- Detection and characterization by various means: most recent technique: polarization (optical; Berdyugina et al., Sep 2011)
- Able to model atmospheres and clouds on exoplanets
- (where there are clouds => polarization) and separate thermal and reflected components of flux
- (Polarimetric) transit spectroscopy now possible in near-, mid-ir;  
**extend to UV**

## Chirality

- Search for habitability using circular polarization
- Examples: vegetation. associated red edge (chlorophyll) at visible (700nm) and fluorescence in UV
- Earthshine studies as templates for exoearths (vegetation, oceans, etc.)
- Biological activity in the SS

# Summary

**Future UV astronomy drivers:** solar-magnetospheres interactions; variety of aurorae and coronae in the solar system; identification of compositional species in comets, atmospheres, etc. and feed two growing subfields( exoplanetary systems and habitability)

**Need interdisciplinary collaborations:**

- **Observations:** polarization (UV – NIR) of solar system objects is sporadic at best; need sustained full Stokes matrices as function of geometry, seasons, etc.
- **Missions and Sub-Orbital Facilities:** Dedicated missions; in-orbit and balloon-borne telescopes
- **Instrumentation:** Spectrophotopolarimeters, differential polarimeters; negligible instrumental polarization
- **Laboratory Measurements:** Water ice (phases); clathrates, etc. and models