P1155

Polarimetric Remote Sensing of Planetary Systems

Padma A. Yanamandra-Fisher

Space Science Institute (SSI)

Boulder, CO, USA

padma@spacescience.org

Polarimetic Method: Direct Detection and Characterization

DETECTION

◆Reflected starlight is linearly polarized by planetary bodies upon scattering by atmospheres or surfaces, unique to the scattering body (UV, optical and Near-Infrared)

CHARACTERIZATION

◆Changes in the scattering properties of object cause changes in the polarimetric signatures

◆Changes can be caused by seasonal effects; episodic events like storms; external processes such as collisions and impacts; surficial/ textural changes

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 high-atmosphere processes: hazes, aurorae, species, c

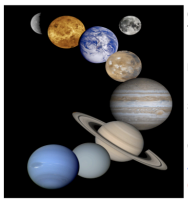
Information re :particles/process at different altitudes in atmosph surfaces, comets and solar-planetary interactions.

Types of Polarization

Mode	Application	Spectral	Temporal
Unpolarized	Inactive	Maybe	None
Linear	Particles/hazes	Size/shape/ compositional effects	Seasonal/ Episodic changes
Circular	Organic molecules? Anisotropies in fields?	Near-IR UV	Biological activity? Solar-magnetospheric

Two goals for exploration: Characterization and Habitability

Our Solar System



Our diverse solar system exhibits all flavors of polarization:

✧Atmospshereless (ASSBs) :Moon, Mercury, Asteroids
✧Atmospheres (rocky): Venus, Mars
✧Atmospheres (gas giants): Jupiter, Saturn, Uranus, Neptune
✧Ices : Comets and Planetary Satellites
✧Processes: Aurorae; Seasonal Changes; Storms; Impacts

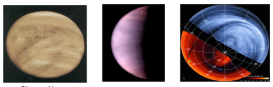
Two goals for exploration: Characterization and Habitability

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

Observed Polarization of our Solar Systen

Object	LP	CP	Characteristics
Sun	Yes	Yes	Second Solar Spectrum; Magnetic field chan
Mercury	Yes	?	changing regolith
Venus	Yes		clouds; spherical H2SO4 droplets
Earth	Yes	Yes	Earthshine; chlorophyll red edge
Moon	Yes	Possibly	Heterogeneous regolith
Mars	Yes	??	dust and ice crystals; organic?
ar Planets (J, S, U, N)	Yes	Yes	Seasonal/episodic changes
lanetary Satellites	Yes	??	Regolith nature; optically active species; ma fields (aurorae)
Planetary Rings	Yes	Yes	Primarily water ice; phase changes?
Comets	Yes	Yes	Coma particles; organic species
Asteroids	Yes	??	changing regolith; optically active species?

Atmospheres: Venus

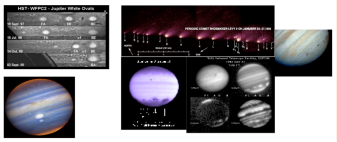


Pioneer Venus | HST, 1995 | Venus Express/VIRTIS

- Very dense atmosphere; complex and variable cloud system
- Details not revelaed s/c; polarimetry Hansen and Houvenier (1974)
- Linear polarization due to Spherical droplets of (H_2SO_4,H_2O)
- Narrow size distribution; high
- Detailed views by new missions and s/c, but no polarimetry

Jupiter: Interacting Giant Vortices and External Impacts

- Interactions of Giant Vortices
- External Impacts: D/SL9

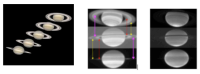


Saturn: Seasons/Clouds

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/ISSI; vis (amateur astronomer), mid-ir (ESA/VLT); 5-micron (IRTF/NSFCAM2)

Polarization of Outer Planets

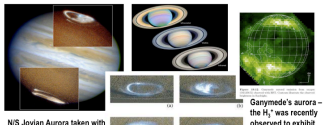
◆Atmospheric polarization signature small (approx. 3%) and increases polewards

◆Variable due to changing morphology of clouds, and other dynamic processes (intrinsic) and external (collosions)

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

◆ Near-IR polarization senses tropospheric/stratospheric aerosols/hazes (Yanamandra-Fisher et al. 2007/8)

Aurorae

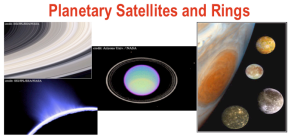


N/S Jovian Aurora taken with HST/STIS (Clarke 1997)

HST/STIS images of Saturn's s. auroral oval (top); HST/WF

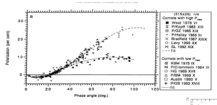
Ganymede's aurora – the H_2 was recently observed to exhibit both linear and circular polarization (Barthelemy et al., 2003

Planetary Satellites and Rings



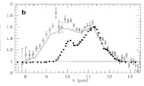
Gas giants form outside the frost line (where ices condense), and so their satellites (moons) and ring systems exhibit signatures of water ice and clathrates, non-ices (Si, C, Fe) in their NIR spectra – influences linear and circular polarization.

Comets



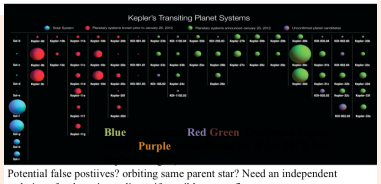
Polarization observations constrain the particle size and shape (Levassuer-Regourd et al., 1996)

Thermal emission constrains the composition (Hanner et al. 1994; open circles: C/Mueller; solid line: C/Halley; filled circles: crystalline livine)



Yanamandra-Fisher and Hanner (1999)

Multiple-Planetary Systems ("Multis"; Kepler 2012)



Potential false postives? orbiting same parent star? Need an independent technique for detection – direct, if possible, to confirm.

Life on Earth: Clues to Habitability

The Red Edge Effect

- Chlorophyll exhibits strong absorption in the red/blue wavelengths –
- Circularly polarized

Chirality or Handedness

- Asymmetry property of an object that is not identical to its mirror image is chirality or handedness
- Biological molecules/activity on earth exhibits left handedness or left-chirality (or homochiral)
- Detect via circular polarization

SUMMARY: SCIENCE DRIVERS

- solar-magnetospheres interactions – UV (aurora)
- identification of compositional species in comets, atmospheres – NIR
- atmospheric aerosols/hazes and satellite surface properties - VIS/ NIR
- two growing subfields(exoplanetary systems and habitability) – spectral and temporal

SUMMARY: NEEDED OBSERVATIONS

- Linear Polarization: separation of refleted and thermal cmponents flux, direct detection (optical polarimetric observations of Neptune like exoplanet; Berdyugina et al., Sept 2011)
- Differential Polarization: model changes in atmospheres and cloud on exoplanets
- Circular Polarization: sensitive to biologic activity necessary for habitabilty

SUMMARY: PARALLEL DEVELOPMENTS

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; imaging polarimeters and in-situ ellipsometers w/negligible instrumental polarization; low mass and power
- Laboratory Measurements: Water ice (phases); clathrates, etc. and models