Polarimetric Observations of Jupiter's Atmosphere

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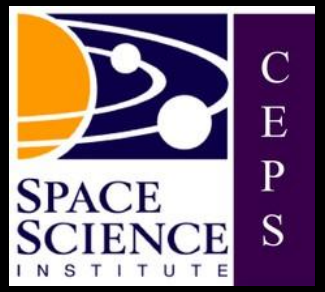
The PACA Project

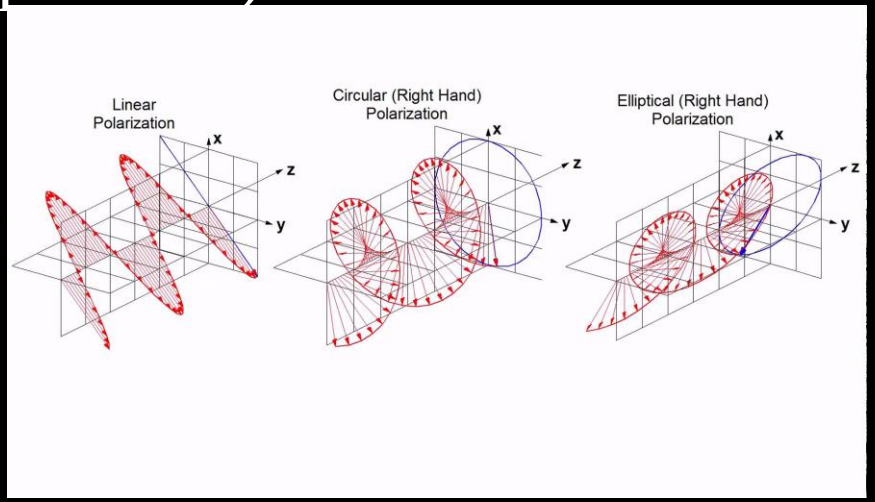


How is polarization produced?

Unpolarized light from star/sun is reflected by planetary atmospheres as partially polarized light

Modeling of polarized light provides information about the scatterers in the atmosphere (particle size, shape, composition)

Polarized light can be linear or circular



How does polarization probe the atmosphere?

Light scattering by atmosphere/scattering medium gives rise to polarization, seen in rainbows, clouds and haloes.

Rainbows are caused by reflection of sunlight by water droplets in the atmosphere and are highly polarized.

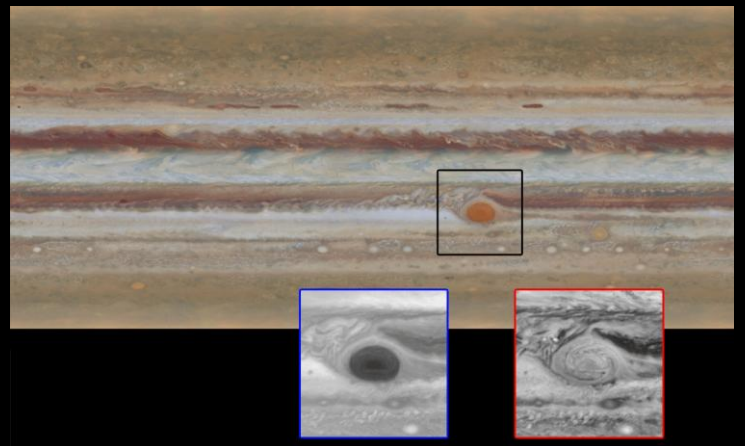
Haloes are produced by reflections/refraction by hexagonal ice crystals, as opposed to water droplets, and are mostly formed in colder climes. Glory can be either while (due to internal reflections in the hexagonal crystal) and highly polarized, whereas colored glory is slightly polarized due to the birefringence of the ice crystal.

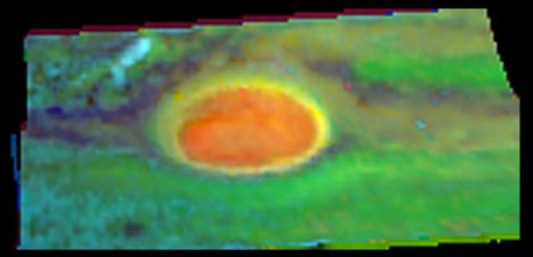
Mode	Application	Spectral	Temporal
Unpolarized	Inactive	Maybe	None
Linear	Particles/hazes	Size/ shape/ compositio nal effects	Seasonal changes
Circular	Organic molecules? Anisotropies in fields?	Near-IR UV	Biological activtiy; magnetic activity?

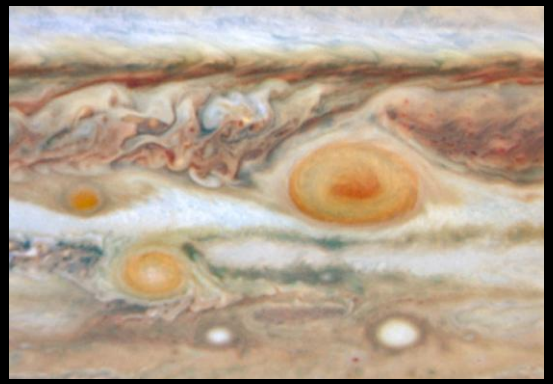
Timeline of Polarimetric Studies of Jupiter

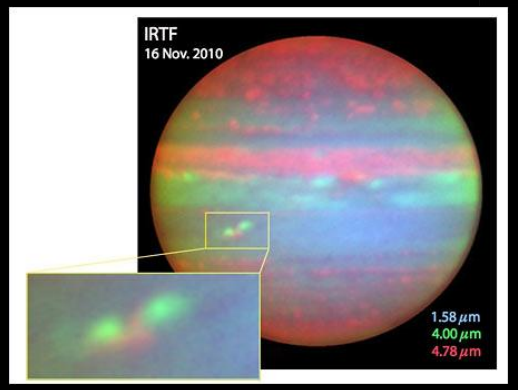
- First measured by Lyot (1929) Detection of polar asymmetry
- Hall and Riley (1971) Linear polarization of poles
- Kemp et al. (1978) Circular polarization of Jupiter
- Victor Teijfel (1981 – 1995) Seasonal asymmetry of polar polarization
- Pioneer: Blue/Red polarization at large phase angles
- Voyager: Jupiter/Saturn/Titan polarization
- Galileo: PPR polarimetry: laboratory work on ammonia ice crystals
- Smith and Tomasko (1984) and West (1991) :Models of polarization Jupiter/Titan; auroral
- Schmid et al. (2011): ZIMPOL Limb observations of methane bands of Jupiter/Saturn
- Stam et al. (2001): Vector RT – including polarization; models exoplanets
- West, Yanamandra-Fisher and Korokhin (2015): Review in Polarimetry of Stars and Planetary Systems

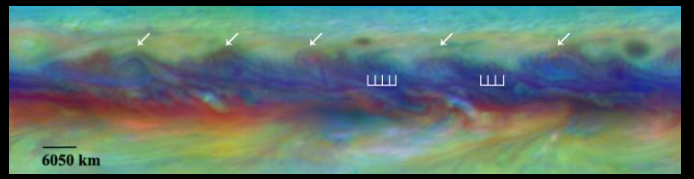
Jupiter's Atmosphere: Intrinsic Changes (Seasonal/Temporal Changes; Oval Interactions)





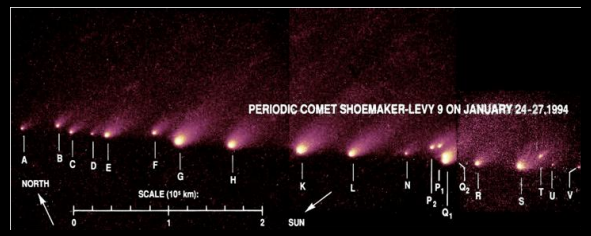


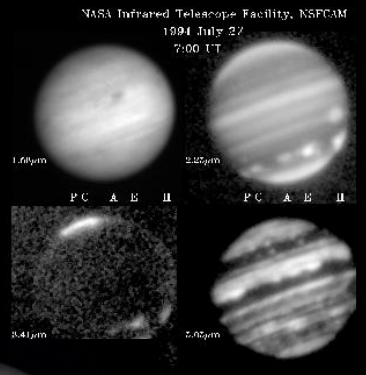


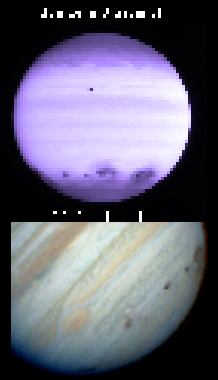


Ref: Simon-Miller, Baines, Go, Trujillo, Orton, Wong

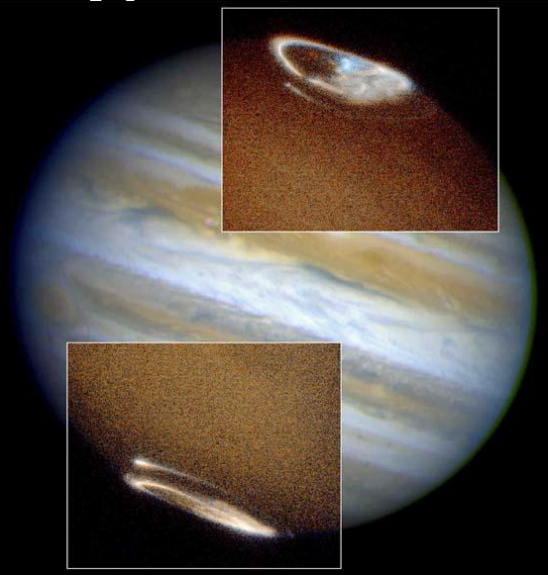
Jupiter's Atmosphere: Extrinsic Changes (Impacts, Aurorae, etc.)



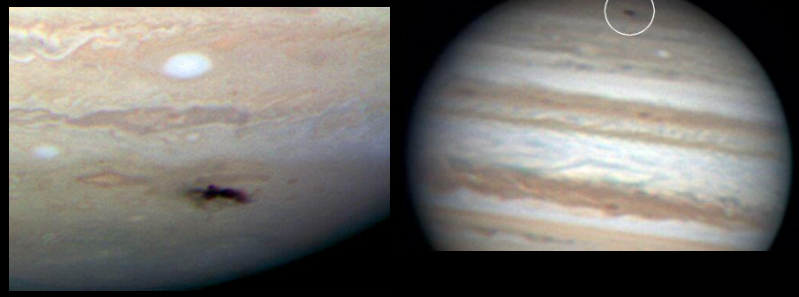


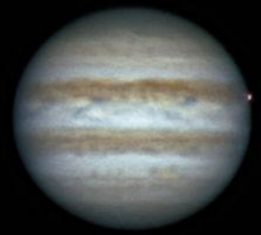


Aurora in UV
(HST; Clarke)



Aurora in Xray
(Chandra; 2011)





Ref: Weaver et al., Orton et al., Hammel et al., Clarke et al., Wesley, McKeon

What is the polarization of Jupiter?

(assuming a four-level Jovian model, with stratospheric aerosol layer)

Linear

Polar asymmetry: increasing from equator to poles

Seasonal asymmetry: possible several causes

Caused by stratospheric haze/aerosols

Circular

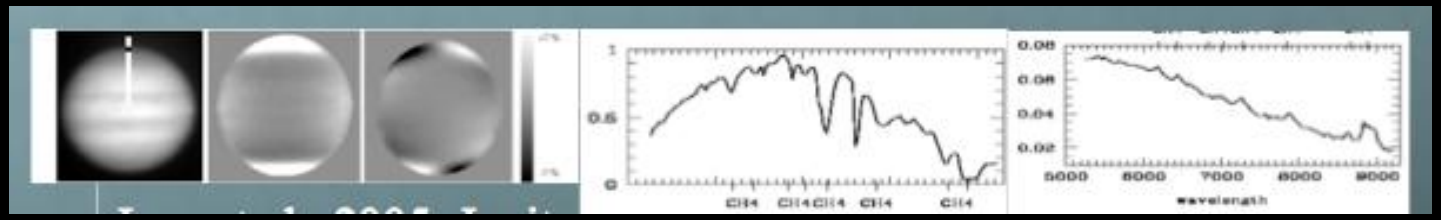
- Two effects: polar : nearly equal magnitudes and opposite signs

  q_N (alpha) ~ - q_S (alpha)

- and opposition:
- q_N (alpha) = - q_N (-alpha) ;
- q_S (alpha) = -q_S (-alpha)

- multiple scattering and/or (Rayleigh + secondary scattering)

Recent Polarimetric Observations of Jupiter and Ganymede



- Optical spectrophotopolarimetry probes the atmosphere in methane bands via limb polarization (Joos and Schmid, 2006/2007); (Schmid et al., 2011)
- Auroral H_3^+ line circularly polarized (Bartholemy et al., 2011)
- Ganymede exhibits aurora (oxygen line) – anisotropies in local magnetic field?

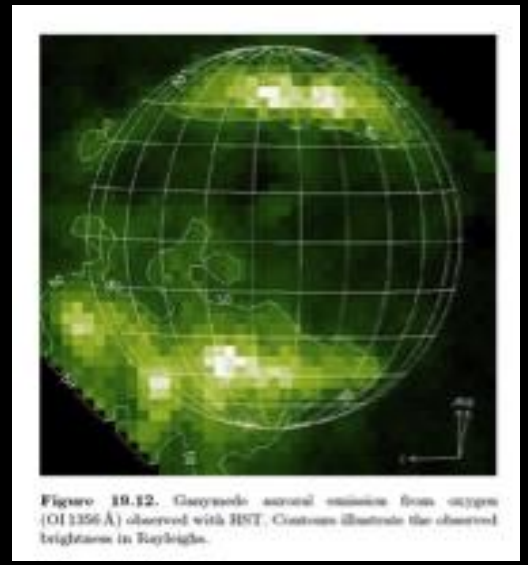
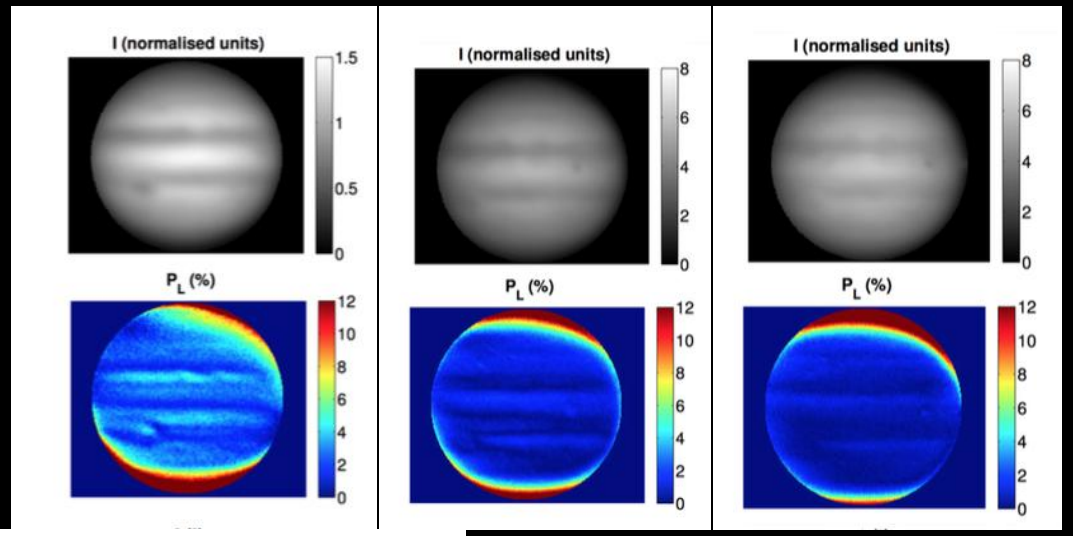


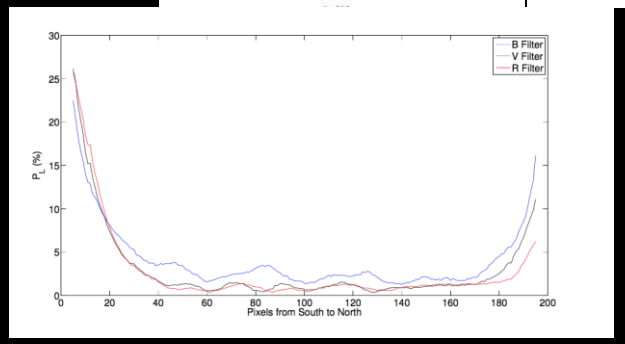
Figure 19.12. Ganymede auroral emission from oxygen (OI 1356 Å) observed with HST. Contours illustrate the observed brightness in Rayleighs.

New Generation of Polarimeters

- Large Facilities: (driven by explanet studies, but also study solar system objects)
- PlanetPOL – WHT (La Palma)
- SPHERE – VLT (Chile)
- HIPPI – AAT (Australia)
- use 3D printing for parts; building prototype for amateurs/small apertures (with appropriate filters, polarizers)

- 1-m telescope: Ex: Calpern Observatory, France (McLean, Pvt Comm.)





Vector RT modeling: polarization sensitive to particle shape, size, ref. index

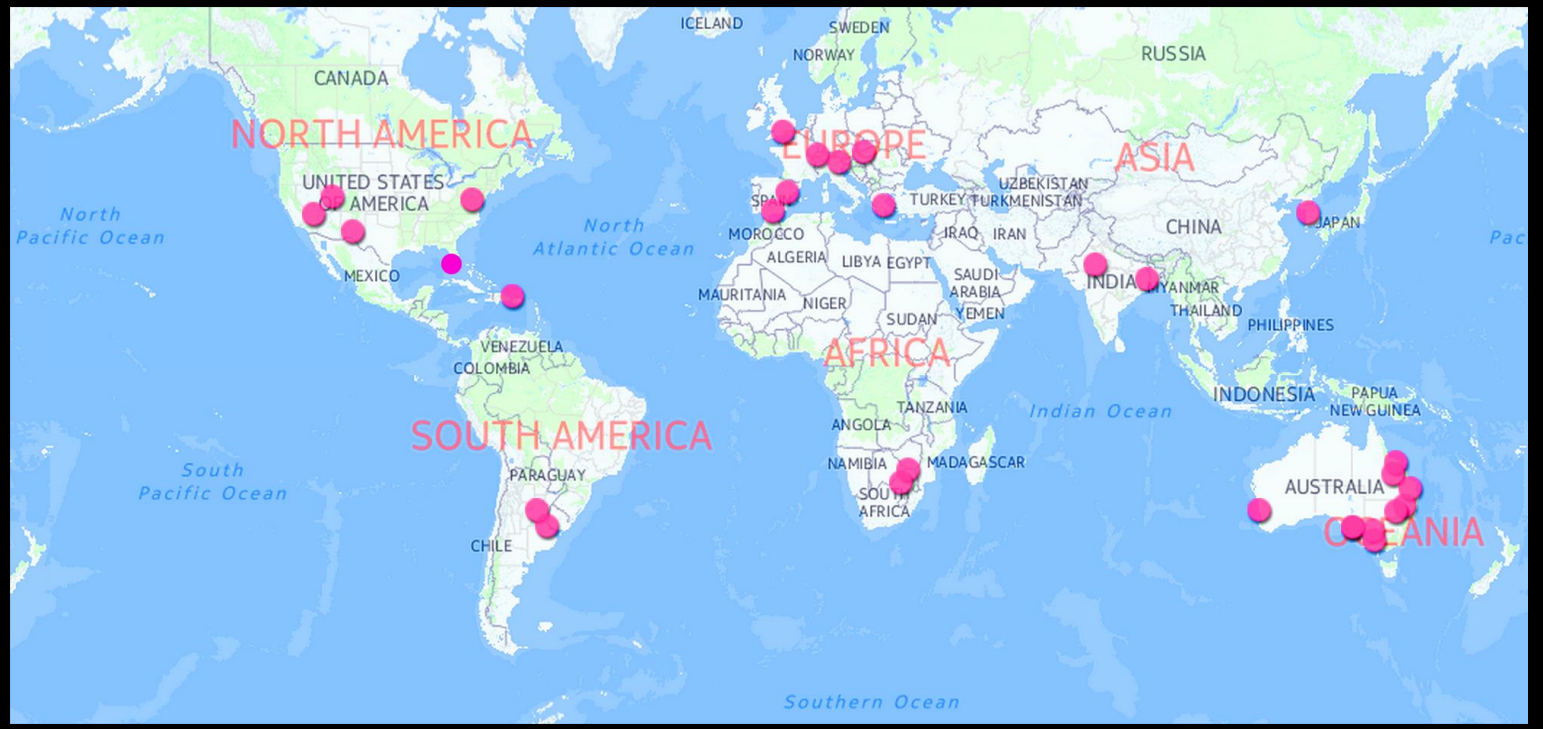
Tie-in to JUNO's Goals

Polarimetric observations/mapping can be helpful to study:

Changes in clouds, hazes: probe the high altitude haze layer (possible correlation with thermal measurements)

Map (…) magnetic fields, aurorae : probe anisotropies in local magnetic fields; correlate (possibly) with changing solar activity

PACA Global Network of Amateur Observers



Credit: T. A. Greiner

Challenges/Issues:

Coordinate observations
Consistent/standardized logs

Data collection/archival

Collaborate with scientists

Outreach/citizen science

Summary: Polarization of Jupiter

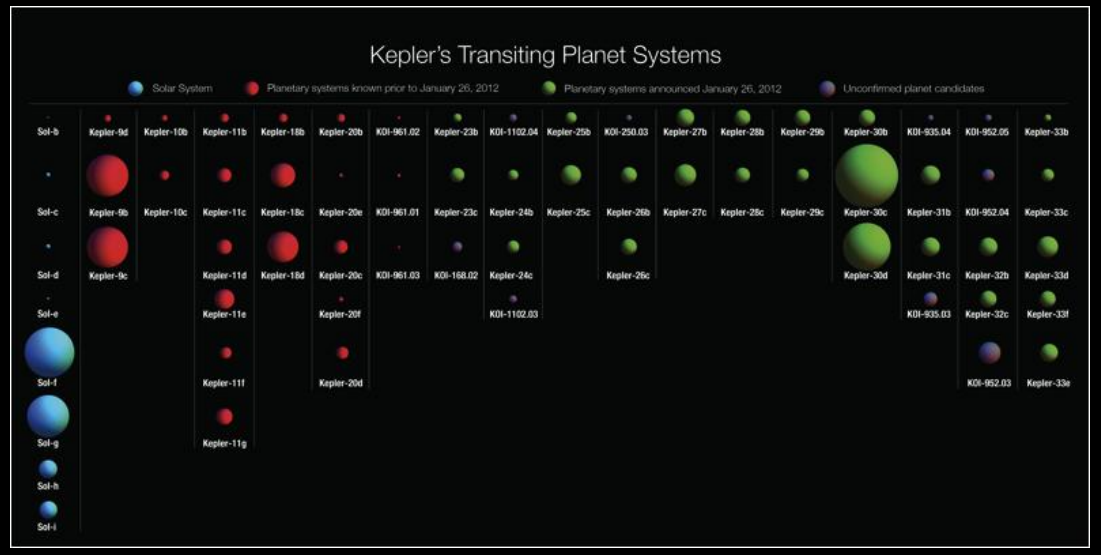
Probe aerosols/hazes – rejuvenation of a tested technique

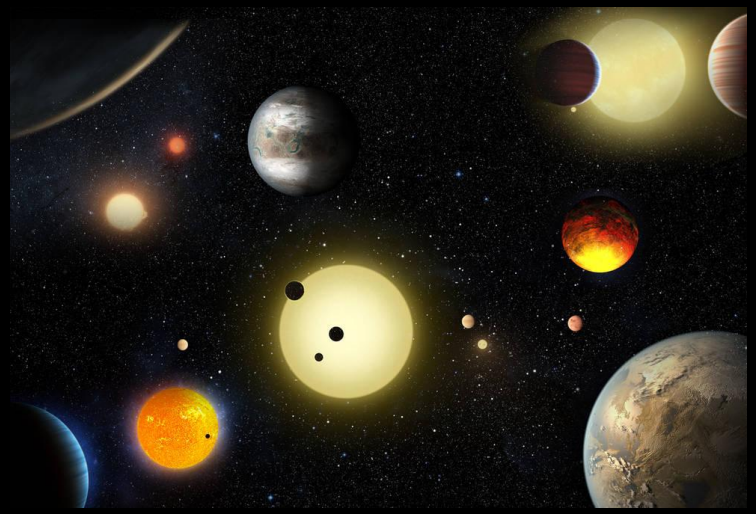
Observe at multiple wavelengths –blue/red wavelengths
Synergy between optical, thermal, imagers and polarimetrists modelers, amateurs
References for temporal studies of planetary atmospheres and exoplanets characterization

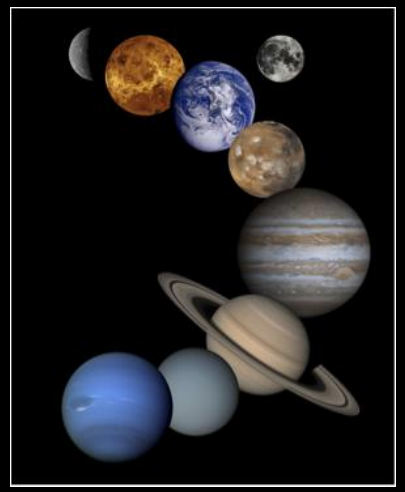
Support JUNO mission in near-term and provide long-term database for modelers, observers, future missions.

(Contact me for details: padmayf@gmail.com)

Variety of Planetary Systems







Top: The myriad of planetary systems (or multis) discovered by Kepler mission. **Left:** Our solar system, taken by Voyager; and **Right:** the sample of "hot" Jupiters studied in the search for water on extrasolar planets (Sing et al., 2015). The water signature is masked /hidden by the presence of clouds in the atmosphere

Future Directions

SUMMARY

- **Polarization** provides a complementary remote sensing approach to photometry and spectroscopy.
- **Linear Polarization** separation of reflected and thermal components of flux, direct detection of planetary atmospheres and surfaces.
- **Differential Polarization** changes in atmospheres; spectral characterization and compositional studies (nir)
- **Circular Polarization** biologic activity necessary for habitablity; anisotropies in magnetic fields (via aurorae).
- **Atmospheric phenomena** such as rainbows, haoles, glories provide insight to properties of scattering media.

ONGOING/FUTURE WORK

- **Observations**: polarization (UV – NIR) ois 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.
- **Vector RT methods:** Development of VRT; inclusion of non-spherical particles and aggregates