Systems of Planets
with the Great Observatories

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Scope of this review:
our solar system (some)
extrasolar planets (mostly)
... planets and small bodies
... not disks
Physical characterization of small bodies in the outer solar system (KBOs, comets)

volatile-rich objects develop comae in the inner solar system

The Kuiper Belt: Swarm of primitive objects orbiting beyond Neptune - *relic of the Sun’s accretion disk*
HST can measure radii for the largest KBOs

Brown & Trujillo 2004

Spitzer IR photometry yields albedo & radii

Stansberry et al. 2006

Binary KBOs give masses, densities...!

1999 TC_36
Trujillo et al.

Multi-wavelength observations (HST/Chandra) can clarify complex phenomena

Jovian aurora: excited by solar energetic particles - direct - secondary

X-ray, UV, visible, IR
time-variable, spatially complex
role of electrons vs. ion precipitation

induces poorly-understood chemistry in the neutral atmosphere
**Episodic Phenomena:**

Jupiter’s “white oval” turns red!

HST high resolution and photometric precision needed to quantify the color change (via PCA)

Believed related to dredge-up of deeper atmosphere

Simon-Miller et al. 2006

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**Extrasolar planets (> 160 known)**

most discovered by the Doppler surveys
Transits: probability $\sim R_{\text{star}}/a \sim 0.1$

duration $\sim 3$ hours

depth $\sim (R_p/R_{\text{star}})^2 \sim 0.015$

yield $M$, $R$ for the planet
Primary Eclipse (transit)

Secondary Eclipse

See thermal radiation and reflected light from planet disappear and reappear

Primary vs. Secondary Eclipse

Primary Eclipse (transit)

See radiation from star transmitted through the planet’s atmosphere
Spitzer secondary eclipse observations: direct detection of light from the planets

eclipse depth \sim \left( \frac{R_p}{R_{\text{star}}} \right)^2 \left( \frac{T_p}{T_{\text{star}}} \right)

yields $T \sim 1100$K

Expect the shape of the planet’s spectrum to be shaped by water absorption; but: clouds, high-Z, C/O (?)
many additional Spitzer photometry points will soon be available... and more bright systems

Spectroscopy from Spitzer, HST & ground

atmospheric composition

= related to bulk composition?

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Hot Jupiter rotation will be tidally locked so one side receives all of the stellar irradiation

Circulation & dynamics: how efficiently is heat transported to the night side?

*can be determined from full Spitzer IR light curves*
A dynamics-based approach to extrasolar planet finding/characterization ... including Earth-like planets

- Almost all planet detection & characterization to date has come from dynamical methods - Doppler & transits
- Bulk properties (M, R) are readily derived from transits, and spectra can be measured using both transits and secondary eclipses
- Imaging separates the light from the planet from that of the star spatially; the transits/eclipses do so temporally. The former is conceptually simpler but technologically daunting.

\[
\text{eclipse depth } \sim \left(\frac{R_p}{R_{\text{star}}}\right)^2 \left(\frac{T_p}{T_{\text{star}}}\right)
\]

\[
T_p \sim T_{\text{star}} \Delta^{0.5}
\]

*lower main-sequence stars allow high S/N planet detection

HD 189733b (K3V)

32\(\sigma\) detection at 16 \(\mu m\)

Deming et al.
Several super-Earth mass planets are known to orbit close to M-dwarfs, e.g. Gliese 876d (7.5 Earth-masses)

- M-dwarfs are the best candidates for habitable-planet detection:
  - they are the most numerous
  - microlensing & Doppler surveys suggest they harbor rocky planets
  - Doppler survey sensitivity can extend to rocky planets if the star is low-mass
  - transits by rocky planets can yield an accurate density (e.g., Earth transiting M3V = 0.1% transit, density to ~ 10%)
  - transiting planets will be close to the habitable zone
  - favorable contrast ratio for secondary eclipse
- This approach is much more practical than TPF-like high technology methods
  - Neptune-class planets are directly detectable by Spitzer
  - JWST can take us to warm Earths, orbiting K- and M-dwarfs
Suggested priorities:

1. Detect the transit and eclipse of a “hot Neptune” using HST/Spitzer, continuing toward detection and characterization of a close-in “extrasolar Earth” orbiting a nearby lower main sequence star (by JWST).

2. Composition and dynamics of close-in hot Jupiters.

3. Physical characterization (masses, radii, albedos, composition) of Kuiper Belt Objects

Honorable mention: Episodic phenomena on our giant planets (e.g., Jupiter's white oval turning red)

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