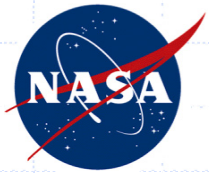
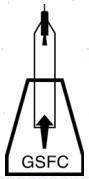


EPOXI

EPOXI/EPOCh Observations of Transiting Extrasolar Planets

Drake Deming
February 20, 2009



JPL

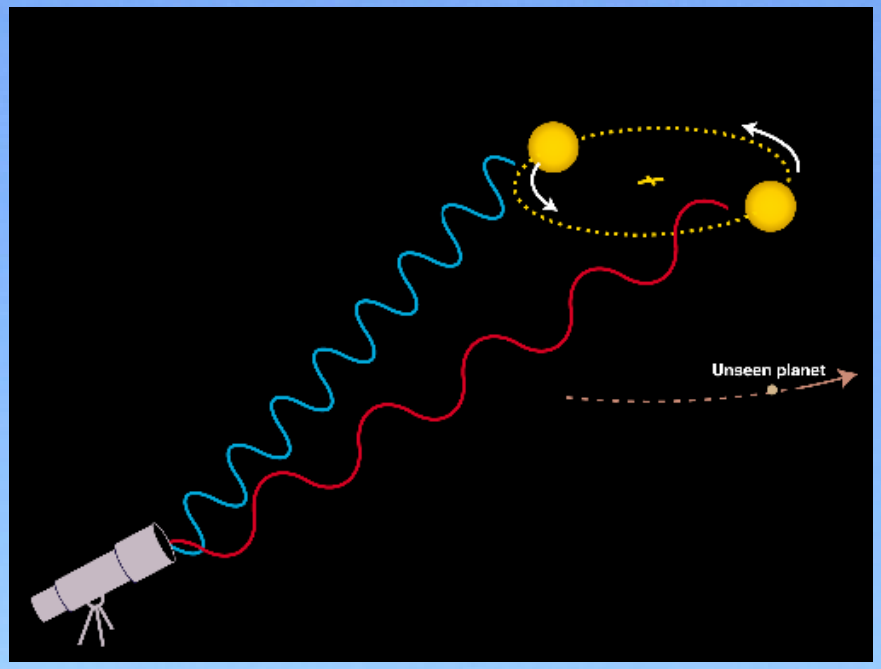
Ball

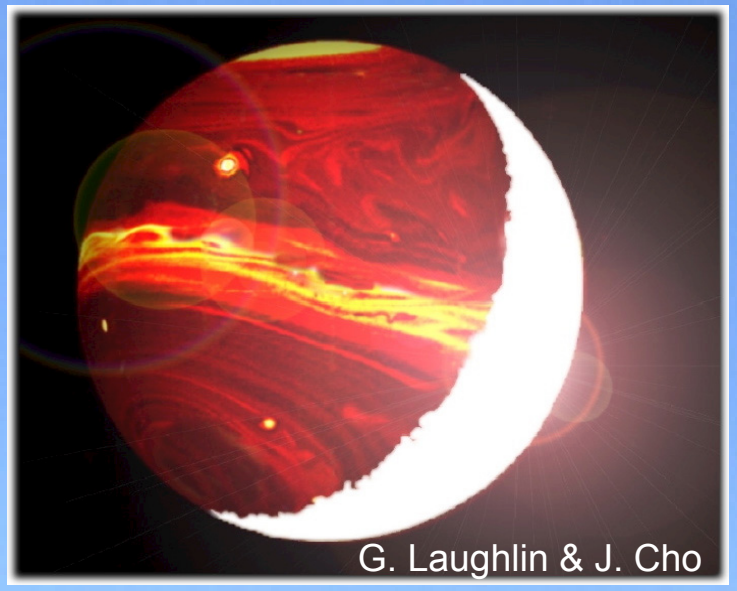
What I'm Going to Discuss.....

EPOXI

- Science value of transiting planets
- History of EPOXI - why the funny name
- Quality of our data, and what we will learn
- Earth-as-an-extrasolar-planet

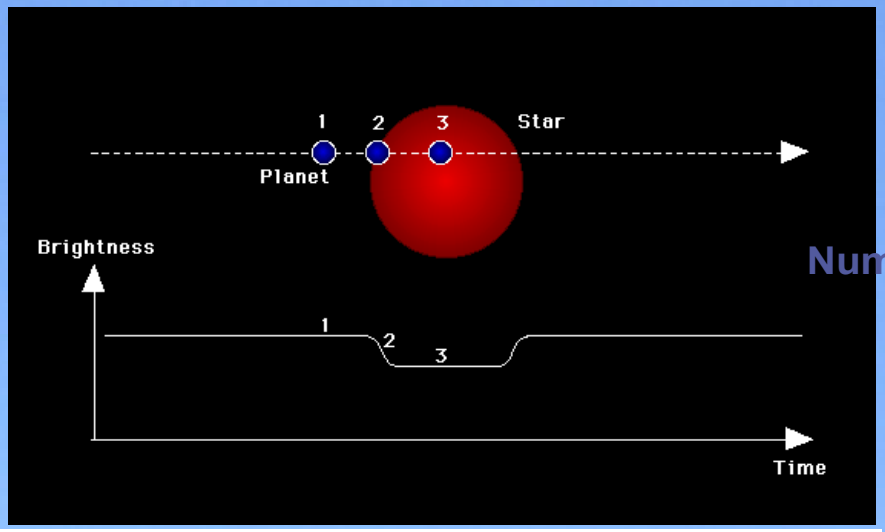
Since 1995, more than 300 extrasolar planets have been discovered - most by radial velocity (indirect detection)

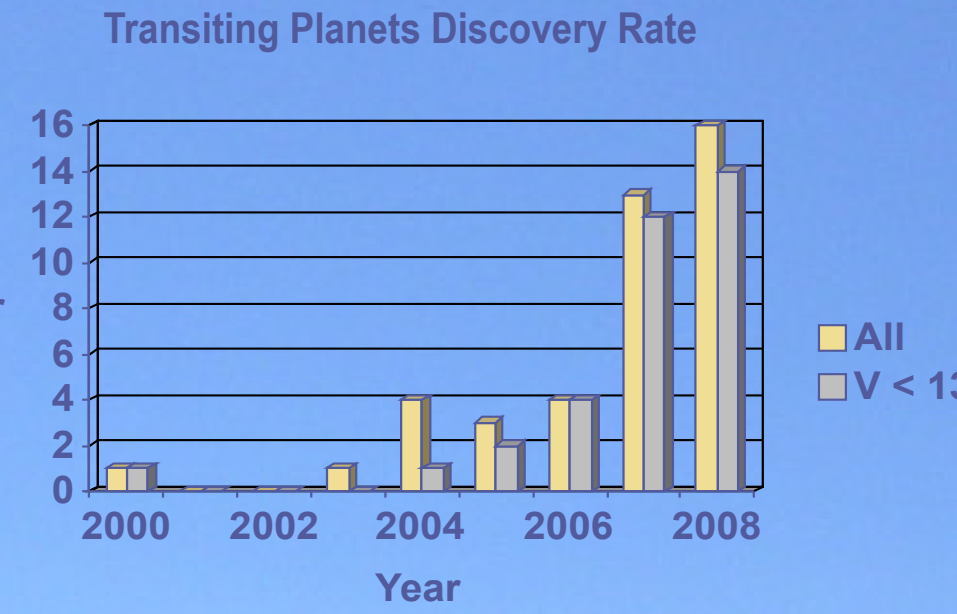


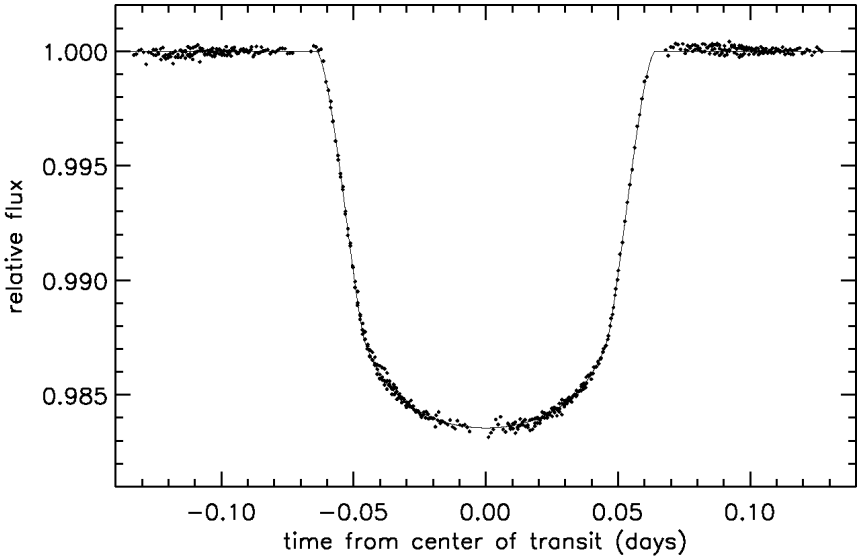


Many of these planets are close to their stars (0.05 AU) - the "hot Jupiters"

Close-in planets have a high probability to *transit*



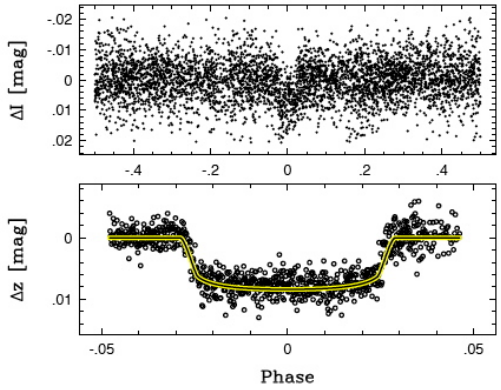




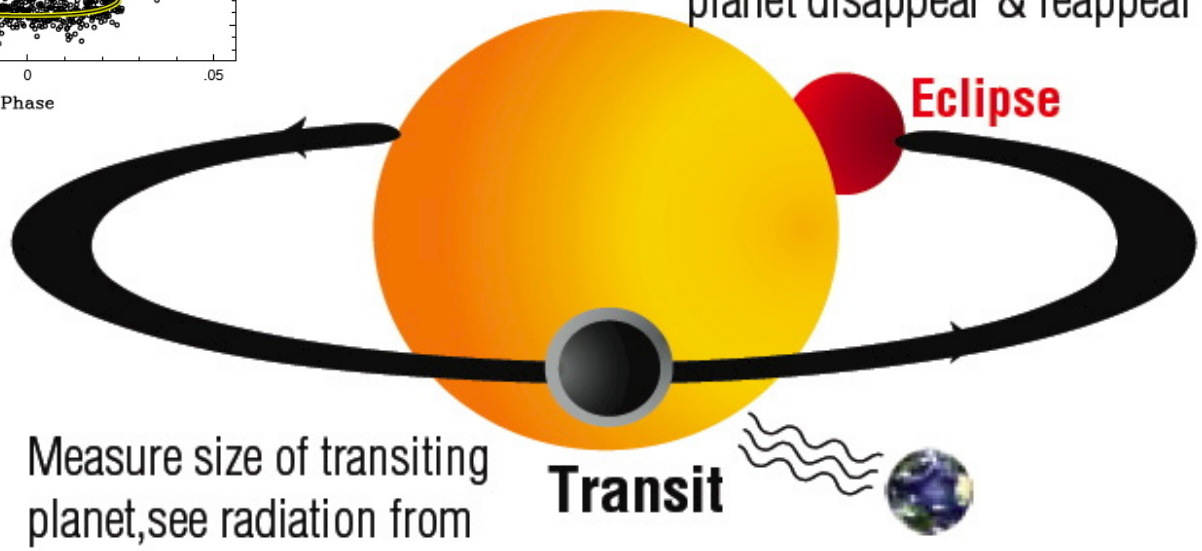
36* exoplanets are now known transiting bright solar-type stars & discovery rate is *accelerating

Transit Science

EPOXI



See thermal radiation from planet disappear & reappear



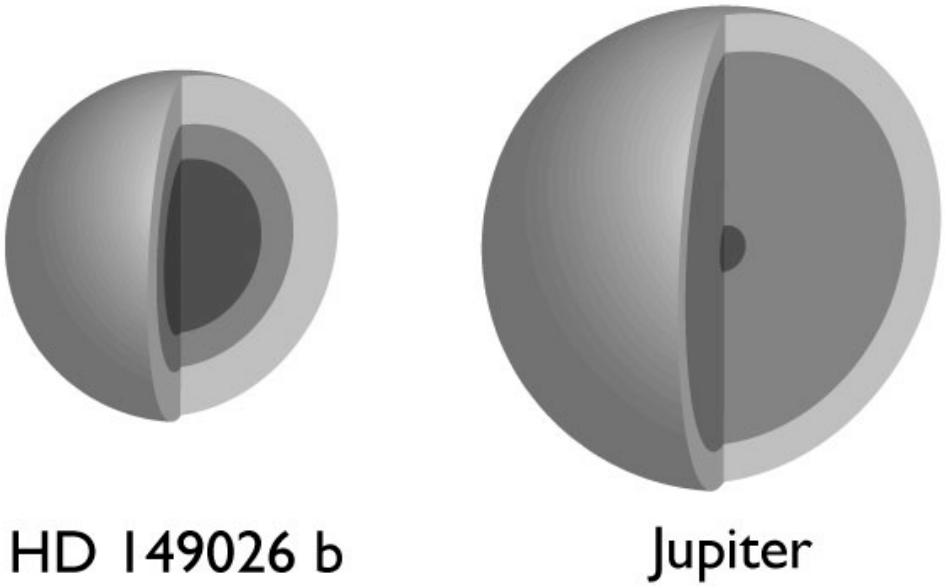
Measure size of transiting planet,see radiation from star transmittedthrough the planet's atmosphere

Gravitational tug of unseen planets alters transit times

TRA0009

Mass & Radius from transits inform us of the planet's average interior structure

EPOXI



History of EPOXI

- Deep Impact Prime mission impacted Comet Tempel-2 in July 2005, then the flyby spacecraft entered a storage orbit
- 2006 Discovery AO, solicited re-use as Mission-of-Opporunity. Selections included:
  - Extrasolar Planet Observations and Characterization (EPOCh, D. Deming et al.)
    - Use the CCD imager to acquire high-precision transit photometry
    - Known, bright, transiting systems (follow-up, not discovery)
  - Deep Impact eXtended Investigation (DIXI, M. A'Hearn et al.)
  - Selection Letters dictated a combined investigation for Step-2
  - EPOCh + DIXI = EPOXI.....voila!
  - EPOXI was confirmed for Step-2 in October 2007

    "Nice acronym....." - Alan Stern

EPOCh Science Team

EPOXI

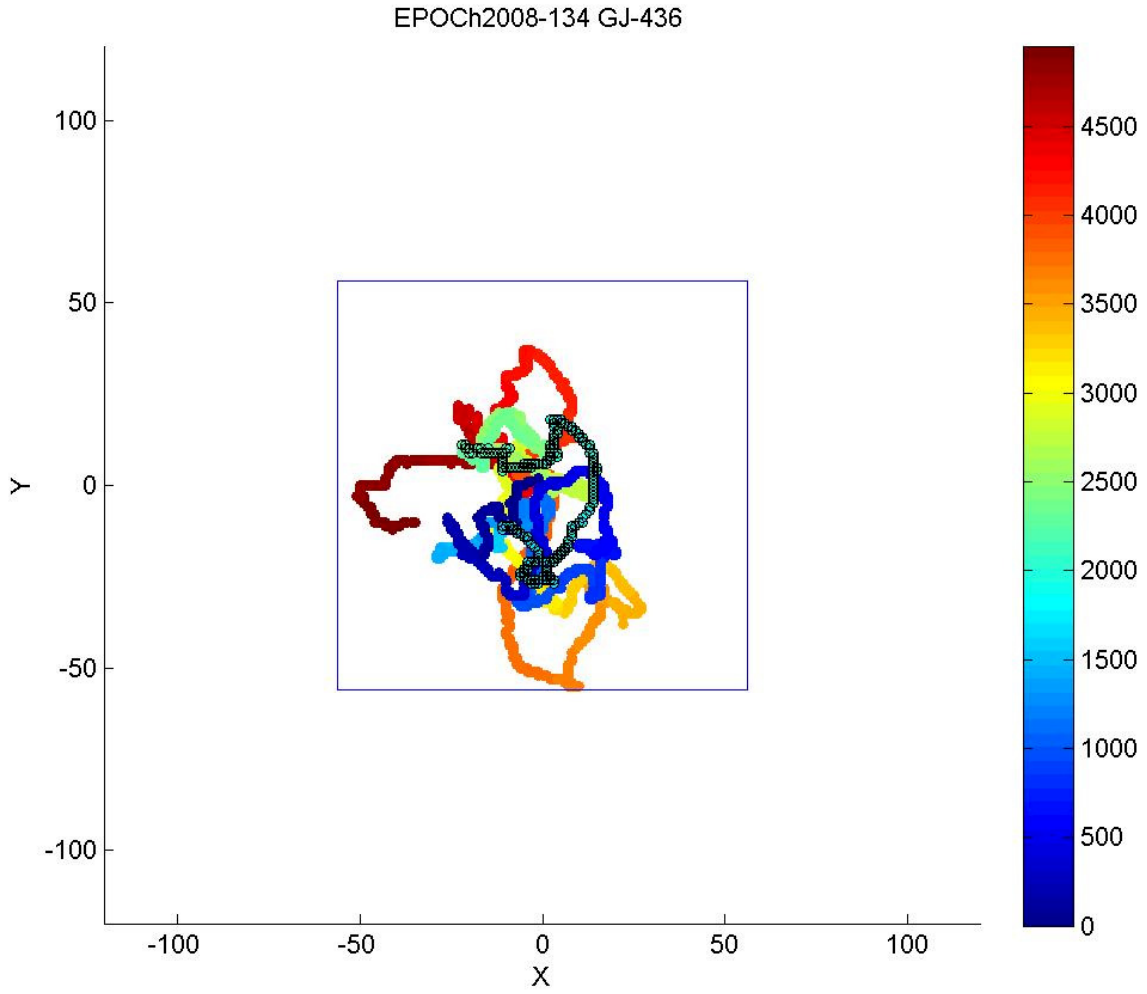
Drake Deming (GSFC), Principal Investigator
David Charbonneau (Harvard), Deputy P.I.

Sarah Ballard (CfA)
Nick Cowan (Univ. Wash)
Don Hampton (U. Alaska)
Matt Holman (SAO)
Carey Lisse (APL)
Vikki Meadows (U. Wash.)
Alfred Schultz (GSFC)
Joseph Veverka (Cornell)
Dennis Wellnitz (U. MD)

Richard Barry (GSFC)
Jessie Christiansen (CfA)
Tilak Hewagama (U. MD)
Marc Kuchner (GSFC)
Timothy Livengood (NCESSE)
Tyler Robinson (U. Wash)
Sara Seager (MIT)

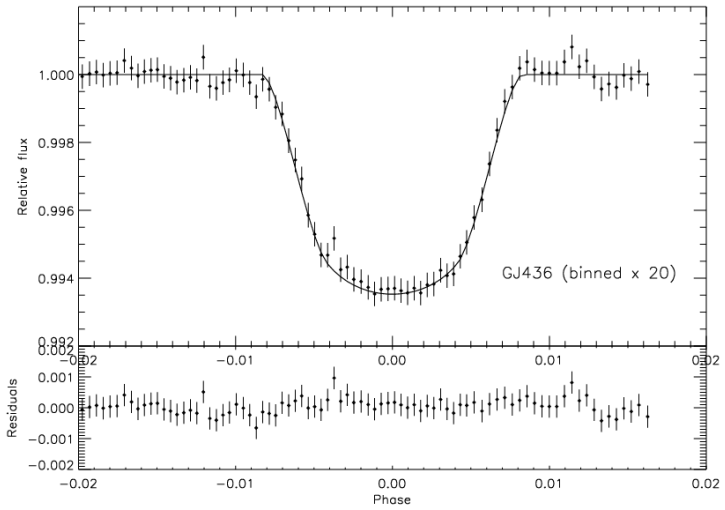
Spacecraft pointing (in)stability is our principal challenge

EPOXI

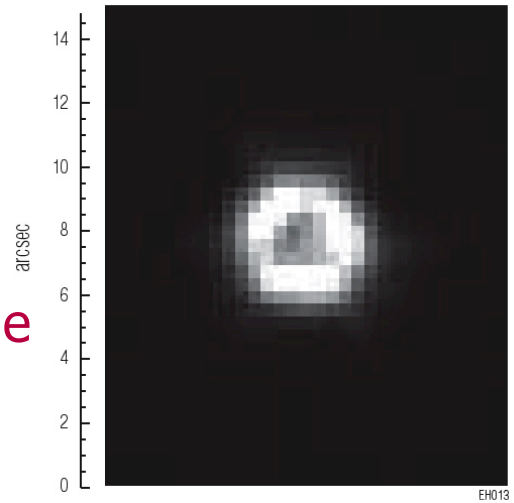


Why we need spaceborne data...

- For higher S/N photometry
  - improved radii for the giant planets
  - reflected light - or thermal emission
  - rings and moons
  - detection of even smaller planets
  - transit timing to ~ seconds precision
- Continuous coverage
  - discovery of smaller planets
  - Trojan planets?



EPOCh transit of a Neptune-sized planet in GJ 436



Capitalize the defocus...!

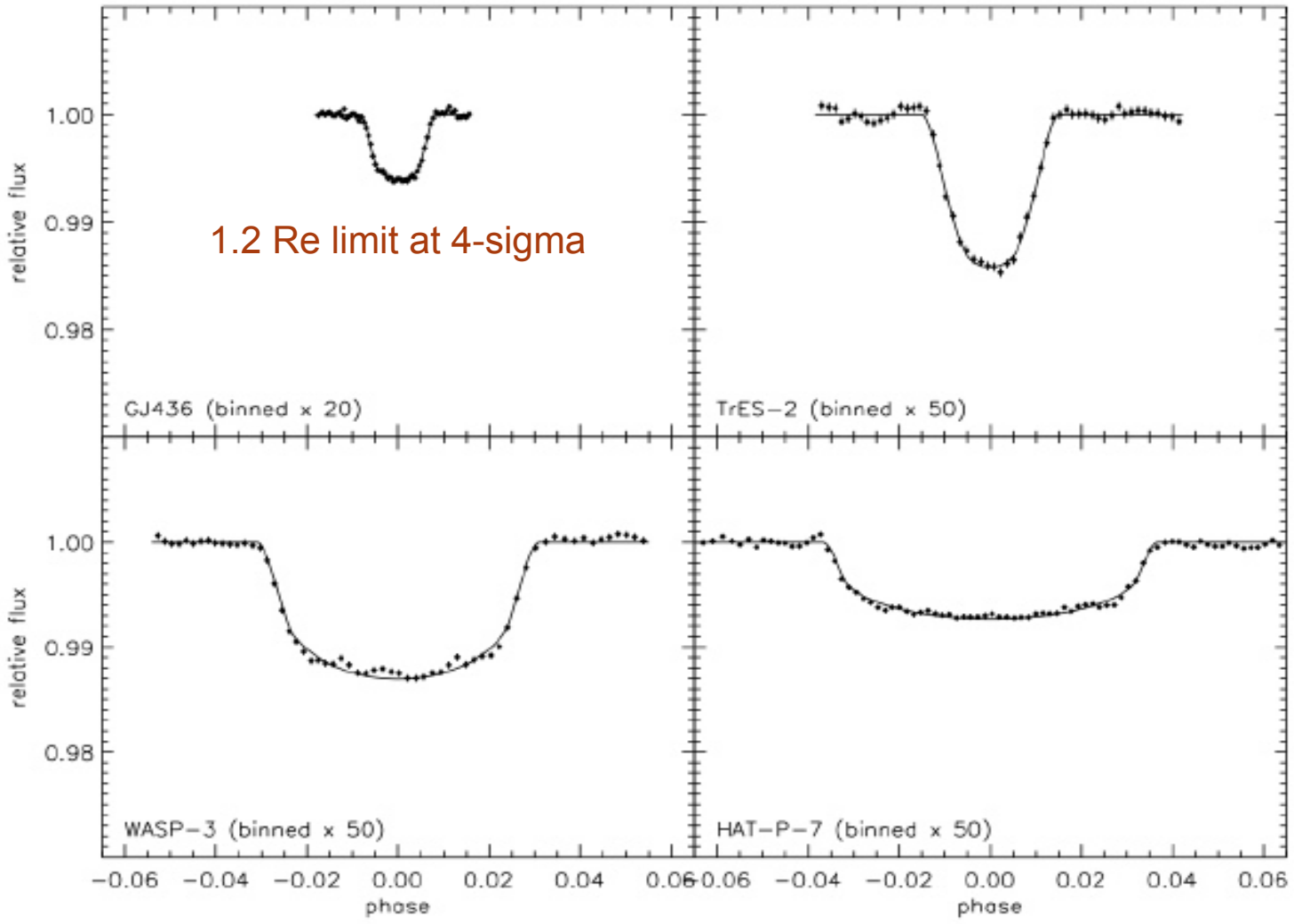
Our targets... observed Jan-Aug, 2008
EPOXI in "follow-up mode", unlike Kepler

EPOXI

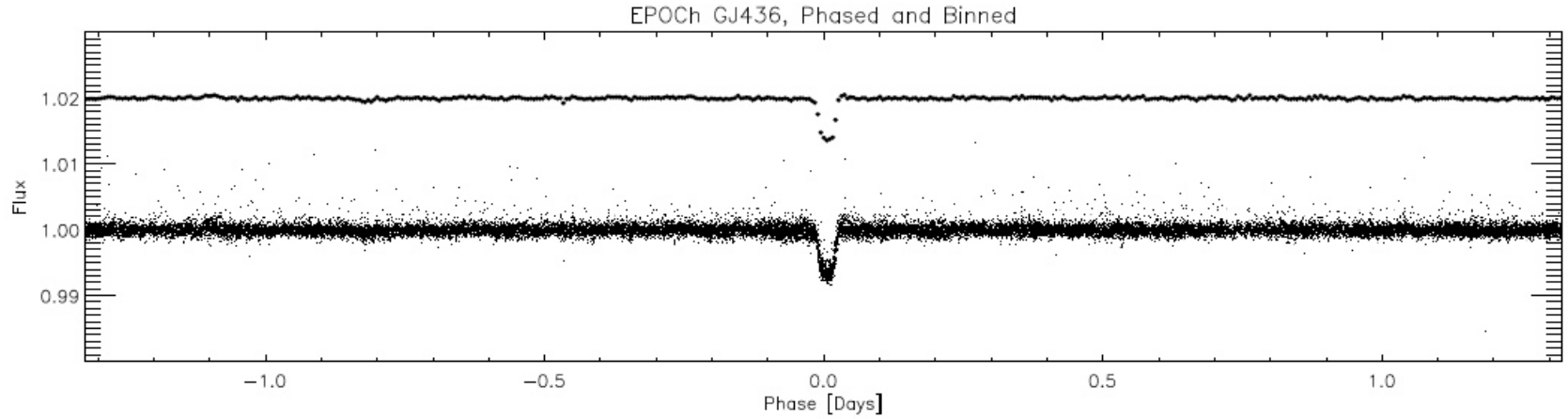
- HAT-P-4
  - a "puffed up" giant planet, R~1.3 times Jupiter, M~0.7 times Jupiter
- TrES-3
  - a giant planet in a 31-hour orbit!
  - potential for large reflected light signal (0.1%)!
- WASP-3
  - a strongly heated giant planet - thermal emission in the visible?
- TrES-2
  - a giant planet in the Kepler field... can combine with Kepler data
- HAT-P-7
  - even more strongly heated than WASP-3; also in Kepler field
- GJ 436
  - Smallest known transiting planet (Neptune-sized); M-dwarf star
  - Super-earths are predicted! We covered out to the *habitable zone!*

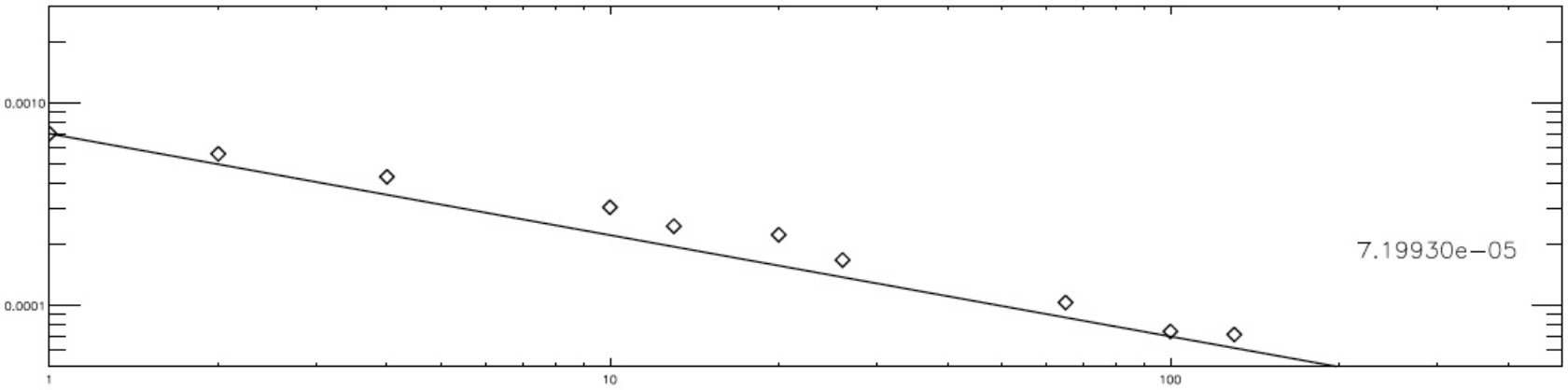
Family portrait

EPOXI



Nearly photon-limited precision....





Search for an Earth-sized planet (in GJ436)

EPOXI

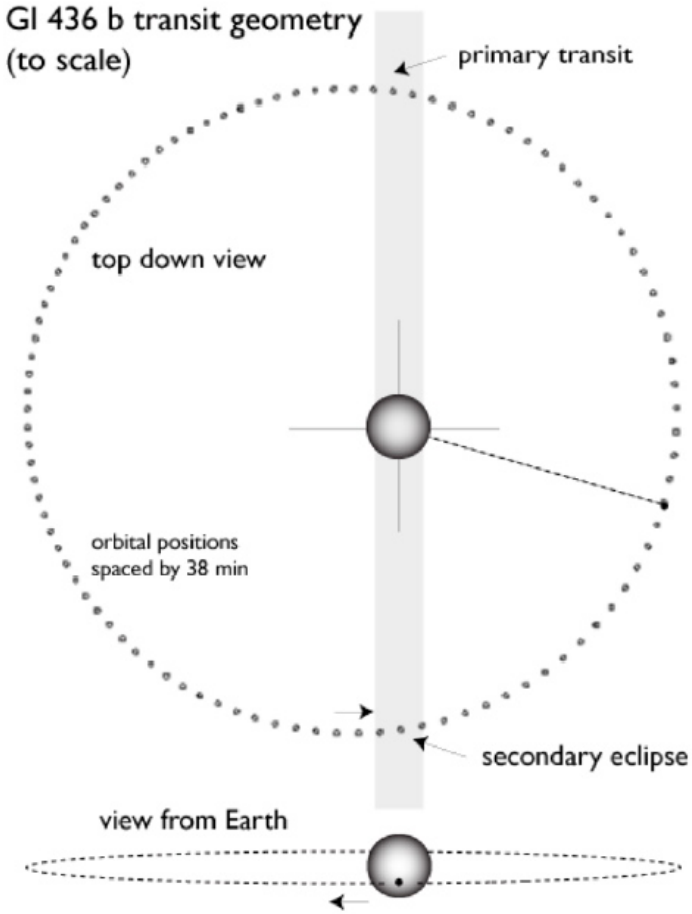


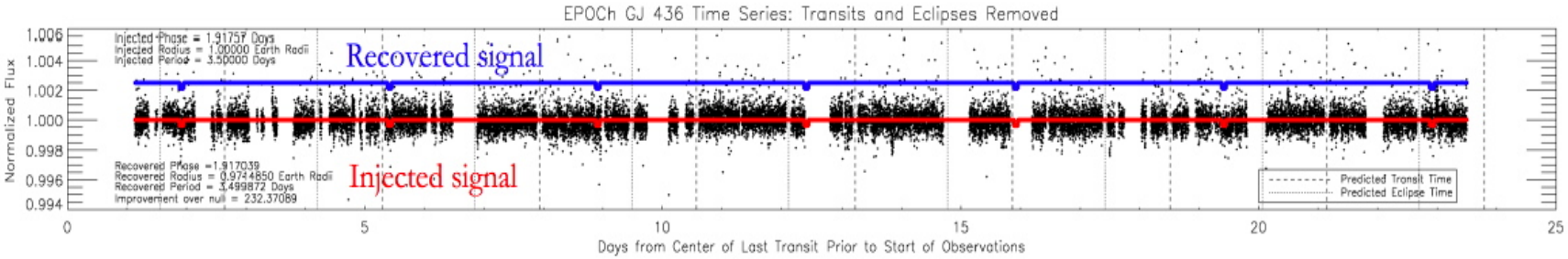
image credit: Greg Laughlin (oklo.org)

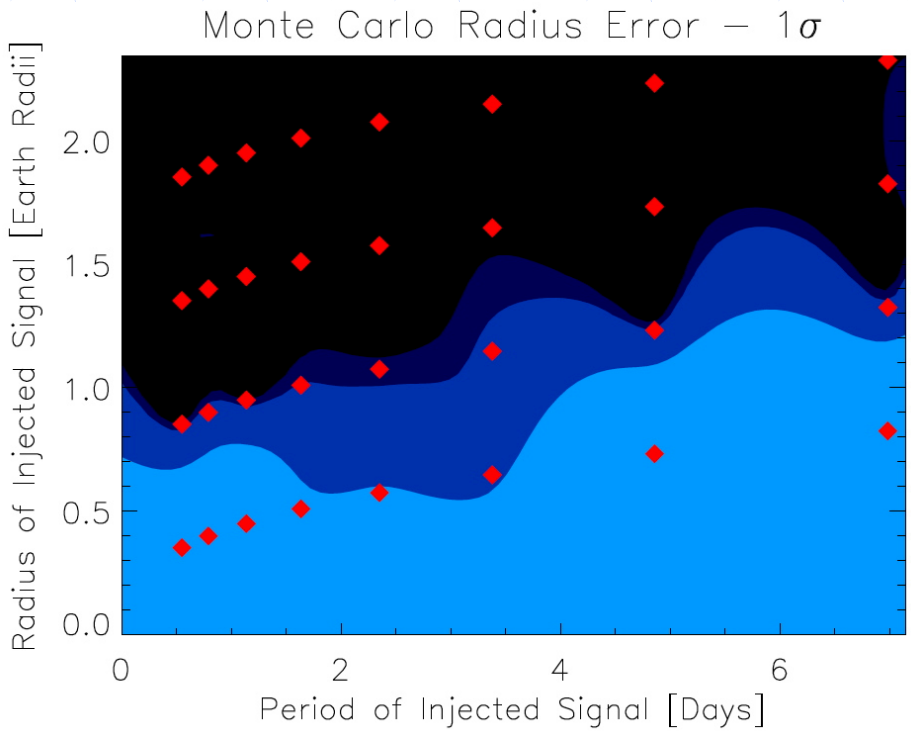
Eccentric orbit requires perturbation by a second planet ... so the theorists say

If the second planet lies in the same plane, it should transit also....

EPOXI observed the system for 22 days...

Results of our search.....





Results show that no other planets transit, down to about 1.5 Earth radii

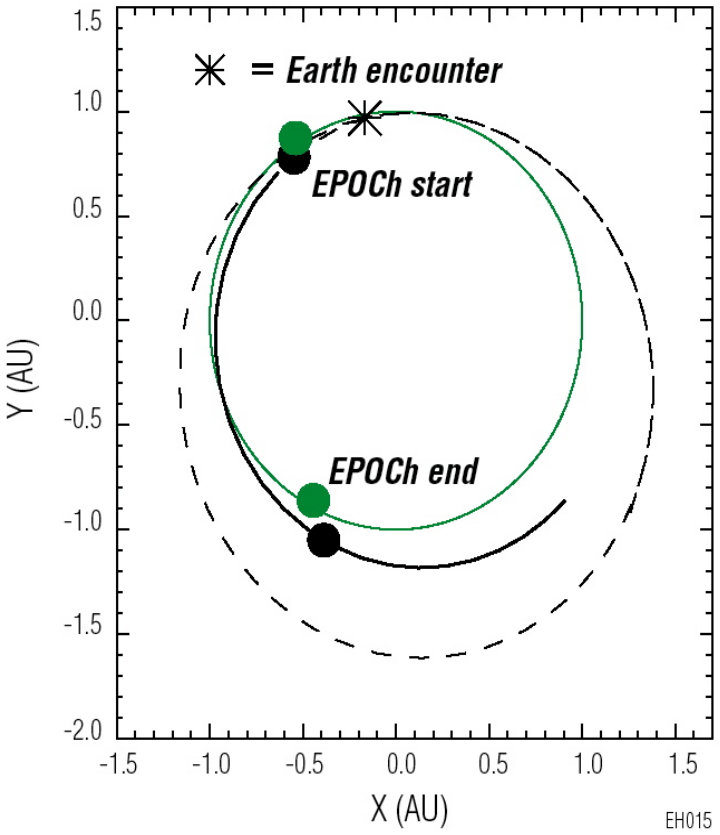
...how is *e* for GJ436b maintained?

EPOCh Earth Observations

EPOXI

Imaging in all HRI filters hourly, (some at 15 min cadence)
IR spectroscopy twice hourly

Study the Earth-as-an-exoplanet:
rotational light curves
inversion mapping
calibrated astronomical colors
model-independent spectroscopy
validation of the VPL

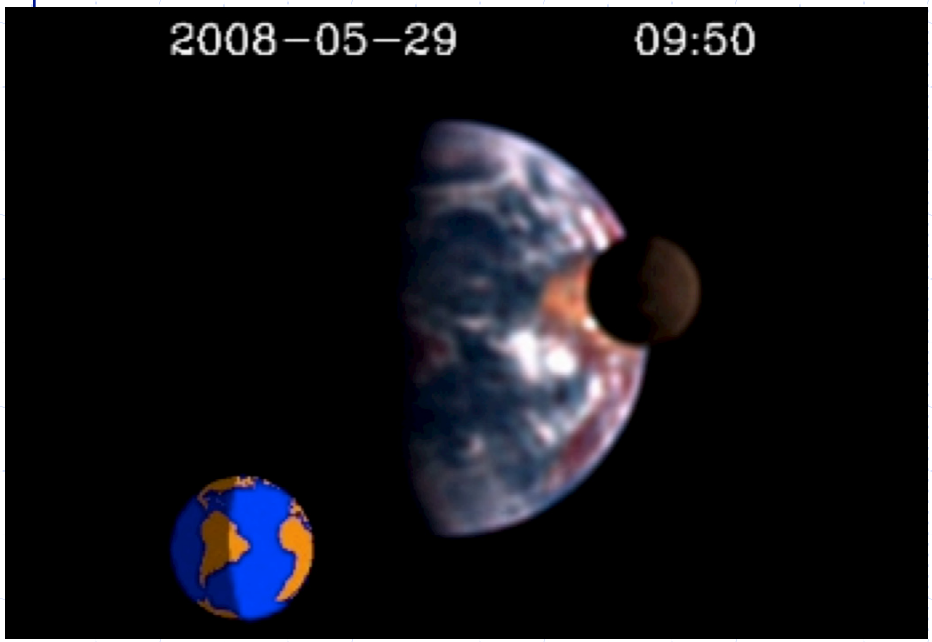


IR-green-blue vs. Red-green-blue

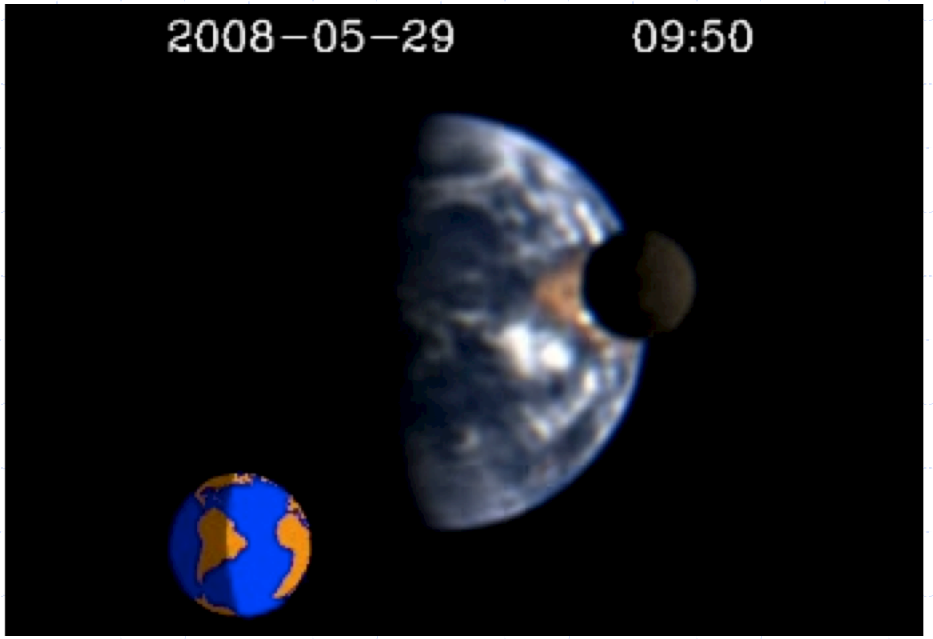
EPOXI

"let me be very clear: the following is just about the coolest thing I have ever seen"
- Phil Plait

Image deconvolutions by Don Lindler (GSFC)



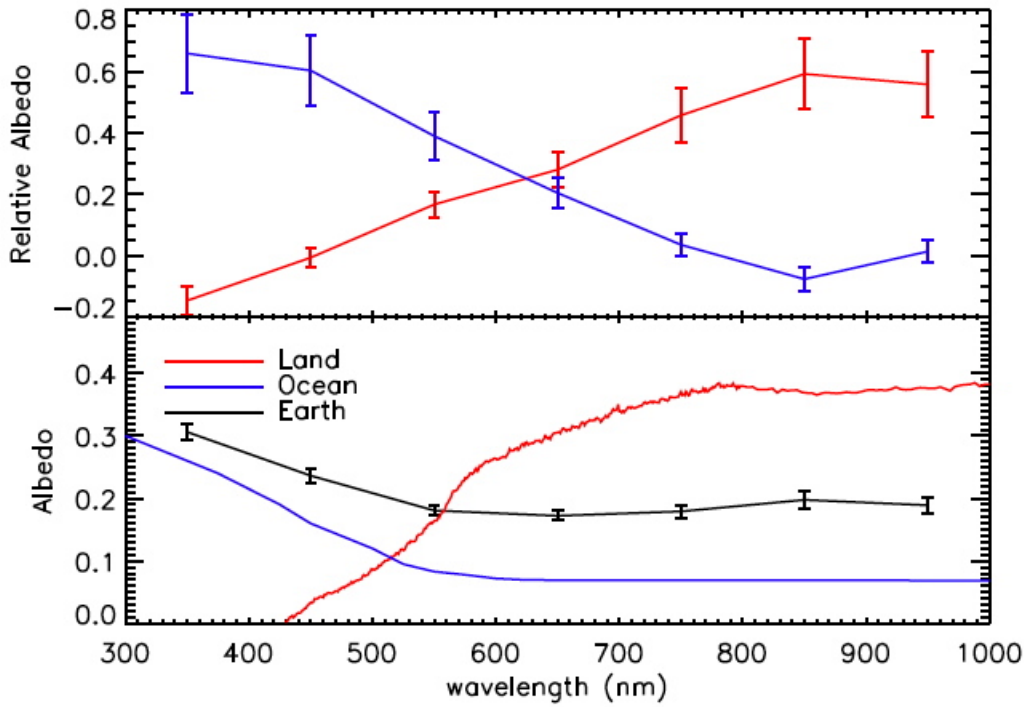
IR-green-blue
(still frame)



Red-green-blue
(still frame)

Inversion Mapping of Earth

- Sum the EPOXI data spatially - Earth as single pixel
- Use PCA to infer what spectral components are present
- ...then invert the time history of those components as the Earth rotates



Alien Maps of an Ocean-Bearing World

EPOXI

- Inversion maps show oceans and continents, but with no latitude resolution
- TPF will be able to infer the presence of oceans on Earth-like exoplanets

Alien Maps of an Ocean-Bearing World

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Timothy A. Livengood,[2,3] Drake Deming,[2] Michael F. A'Hearn,[3]
David Charbonneau,[4] Carey M. Lisse,[5] Tyler Robinson,[1†]
Sara Seager,[6] Dennis D. Wellnitz[3] and the EPOXI Team