Transiting Extrasolar Planets
discovered by the XO Project
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XO data distilled

The special star’s …

• Position (RA, DEC)

• Time

• Depth

• Width

• Period

Approximately 10 bytes of information!
Each clear night, XO gathers…
- as much data as HST
- 1 billion pixels
- 1000 images
- 100 epochs of 10000 stars suitable for transit detection

XO observes each target for months.
Each clear night, XO gathers…
• 1 billion pixels
• 2 Gbytes
• the equivalent of 1,000,000 printed ASCII pages

After operating for 4 years, XO has accumulated the equivalent of a forest of 4000 stacks of paper like the one under Bill Gates.

If printed, XO data would cost, at $0.01/page, $10,000 per night.
Summary of Transiting Extrasolar Planets

1 year ago, May 2007: N = 17

- “Traditional” RV surveys
  - Marcy et al (HD 209458)
  - Hot-Neptunes (GJ436)

- Photometric surveys:
  - HAT: 2.5 bright (V=8-12)
  - XO: 3 bright (V=10-11)
  - TrES: 2.5 bright (V=11.4, V=11.8)
  - WASP: 2 bright (V=11.8, V=12.0)
  - OGLE: 5 faint (V ~15) (10b, 56b, 111b, 113b, 132b)
  - Others 2 faint (Lupus, SWEEPS)
  - Others (in process)

- Metallicity-filtered RV surveys
  - N2K (HD 149026, V=8)
  - OHP (HD 189733, V=8)
Summary of Transiting Extrasolar Planets

May 1, 2008: N=46

- "Traditional" RV surveys
  - Marcy et al (HD 209458)
  - Hot-Neptunes (GJ436)
  - TransitSearch.org (HD 17156)

- Photometric surveys:
  - HAT: 7 bright (V=8-12)
  - XO: 3 bright (V=10-12), (more, May 20)
  - TrES: 4 bright (V=11-12)
  - WASP: 5[+10] bright (V<13)
  - OGLE: 7 faint (V ~15)
  - Corot: 2 faint (V=12.6, V=13.6)
  - Others: 3 very faint (Lupus, SWEEPS)
  - Others (in process)

- Metalicity-filtered RV surveys
  - N2K (HD 149026, V=8)
  - OHP (HD 189733, V=8)
XO targets Bright Stars that allow ...

- **Absorption Spectra of Planetary Atmosphere**
- **Precise photometry and timing of transits**
  - Oblateness (rotation rate) of planet
  - Rings, Satellites of planet
  - Perturbations from TP: \( \delta(\text{TOA}) \sim \text{many seconds} \)
  - Limb darkening and star spots
- **Secondary Eclipse**
  - Temperature, \( \delta f/f \sim \left( \frac{T_p}{T_s} \right) \left( \frac{R_p}{R_s} \right)^2 \sim 0.4\% \text{ in IR} \)
  - Map of IR brightness of planet’s “surface”
  - Eccentricity better than RV method
  - Albedo, \( \delta f/f \sim 0.02\% \times \text{optical albedo} \)

- Key: **done** and feasible but not demonstrated yet
Haleakala's typical weather
XO Cameras and Robotic mount

Unique aspects:
1) Two cameras (pilot & copilot)
2) 0.4-0.7 micron bandpass
3) Powered drift scanning (like SDSS)
XO-N telescope parade:
XO Extended Team

- Ron Bissinger
- Mike Fleenor
- Cindy Foote
- Enrique Garcia
- Bruce Gary
- Paul Howell
- Franco Mallia
- Gianluca Masi
- Tonny Vanmunster
XO’s Extended Team:

- E.T. = Advanced Amateur Astronomers
  - (Olympic athletes are amateurs too...)
- Global longitude coverage
- More and Better photometry (next slide)
- “A spectrum saved is a spectrum earned.”
XO Planet 1 a.k.a. XO-1b

- **Location**
  - 16h +28deg
  - Corona Borealis

- **Star**
  - V = 11.2 mag
  - Sp. Type = G1 V
  - D = 200 pc

- **Planet**
  - Period = 3.94 days
  - Mass = 0.9 M_Jupiter
  - Radius = 1.3 R_Jupiter

- Additional planets in system? Not yet...
Title: XO-2b: A Transiting Hot Jupiter in a Metal-rich Common Proper Motion Binary


Abstract: XO-2b, the second transiting extrasolar planet from the XO Project (McCullough et al. 2005), is approximately Jupiter-size and 0.6 Jupiter-mass with an orbital period of 2.6 days. The stellar host, XO-2, is a V=11, early K dwarf which is metal rich, [Fe/H]=+0.44. XO-2 has a high proper motion and has a common proper motion stellar companion. The two stars are nearly identical twins, with very similar spectra and apparent magnitudes. The global network of amateur and professional astronomers organized by the XO project confirmed the XO-2b transit light curve two days after being notified that it was a high-priority candidate, and radial velocities confirmed its planetary mass eight days after that.
Abstract: We report the discovery of a massive planet ($\approx 12 \, M_{\text{JUP}}$) in an eccentric orbit ($e \approx 0.2$) around the F6 star XO-3. This planet transits the 10th magnitude star every 3.19 days. This system is unusual for a number of reasons. XO-3b is one of the most massive planets discovered around any star for which the orbital period is less than 10 days. The mass is near the deuterium burning limit of $13 \, M_{\text{JUP}}$ which is a proposed boundary between planets and brown dwarfs. Burrows et al. (2001) propose that formation in a disk or formation in the interstellar medium in a manner similar to stars is a more logical way to differentiate planets and brown dwarfs. Our current observations are not adequate to address this distinction. XO-3b is also unusual in that its eccentricity is large given its relatively short orbital period. Finally, the star XO-3 is somewhat metal poor, with $[\text{Fe/H}] \approx -0.25$. We will present our observations leading to this discovery and discuss the implications of this system for models of planet formation.
Radius versus Mass --- expanded scales

Transiting hot Jupiters

M dwarfs

Planet-sized brown-dwarf edge

Rare here
XO Constellation, Phase 1 = 3 units

Operational 2003-2007
  Haleakala

Operational 2008-
  Haleakala

1 unit ($50k) = 2 lenses, 2 CCDs, 1 mount, 3 computers
Further Reading

- **Websites:**
  - XO Project: http://www-int.stsci.edu/~pmcc/xo/
  - Pont’s site: http://www.inscience.ch/transits/
  - Exoplanet Encyclopedia: http://exoplanet.eu/

- **XO Publications**
  - XO-3 arXiv:0712.4283
  - XO-2 arXiv:0705.0003
  - Search Technique:

- **Articles about XO:**
  - Sky & Telescope Sep 2006 issue
  - (Knutson popular article on E.T.)