Imaging Planets in the Thermal Infrared

Phil Hinz
University of Arizona

Outline:
- Observations of HR 8799 and Fomalhaut
- Survey of FGK stars in the thermal infrared
- LBTI status and plans
Exoplanets: Where are we?

Dunhuang Star Map 700 AD

- We are at the point of "mapping out" exoplanetary systems.
- Direct Imaging contributes by probing the wide-period planets.
Direct Imaging of a 3 planet system

Marois et al. 2008, JHK imaging

- Relatively massive planets (7, 10, and 10 MJ)
- Planets in wide or orbits.
Marois et al. 2008, Keck image

MMT observations of the planets around HR 8799 b c d 1 arcsec

3.8 µm observation with Clio

All three planets detected at L'.

Upper limits of M=14.7 set for all three objects.

c is detected at 3.3 µm.

Data broadly consistent with Marois results.

Hinz et al. 2009, submitted
Objects appear bluer than expected from equilibrium models. Vertical mixing can explain the colors.

- Planets do not look anything like blackbodies at 3-5 \( \mu \text{m} \)!
- Non-equilibrium models are needed to explain c.

Hinz et al. 2009, submitted
Fomalhaut Constraints

Kenworthy et al. 2009
Motivation for Imaging in Thermal IR

Theoretical models from Baraffe et al. 2003

Model spectrum from Sudarsky, Burrows and Hubeny (2003)

Conventional AO systems have focused on H band detection. The anomalous brightness of gas giant planets at 4-5 microns allows for improved contrast.

$10^{-3}$

$10^{-8}$

$10^{-10}$

Wavelength [microns]

$55$ Cnc d

10 Jupiter mass planet contrast

Theoretical models from Baraffe et al. 2003

$10^{-3}$

$10^{-4}$

$10^{-5}$

$10^{-6}$

$10^{-7}$

$10^{-8}$

$10^{-9}$

$10^{-10}$

Magnitude

$0.1$ $1$ $10$ age (Gyr)

planet/star contrast ratio
Cold Start Models suggest young planets may be fainter.

- Less of a discrepancy at older ages.
- Smaller effect at L' and M.

From Fortney et al. 2008
AO in the thermal IR

- AO is integrated into the telescope.
- 2 mm glass shell deformed by 336 actuators
- Unlike conventional AO, no reimaging optics are needed.
- Good for thermal background
- First light in 2002
- Routine operation begun in 2005
Thermal IR surveys with the MMT

- Survey of 54 FGK stars lead by Ari Heinze
- Survey of 32 M star lead by Daniel Apai
- Survey of 25 A stars lead by Eric Mamajek

See Heinze et al. 2008 and Kenworthy et al. 2009 for example results
We can extrapolate RV results to test whether the populations are the same. Suggests planet systems have outer cutoffs of < 100 AU.

Heinze et al. 2009, submitted
Model-Independent Limits

Less than 8% of FGK stars have planets similar to HR 8799

Heinze et al. 2009, submitted
High Contrast Improvement

Phase Apodization Coronagraphy has been demonstrated to achieve $10^{-5}$ at $3\lambda/D$.

Matt Kenworthy is leading a survey to explore the ice line region around nearby stars with this technique.

Kenworthy et al. 2007

Full observation

Inner Working Angle is half that of direct Imaging results
The Large Binocular Telescope

- Wavelength (µm)
- Lb'
- M
- MN
- LBTI
- MMT
- 2x8.4 m apertures on a 14.4 m baseline
- Adaptive Secondary Mirrors
- Interferometers are mounted on telescope
- Simple optical arrangement
- Low background
Telescope Status

- Fixed secondary installed on left side.
- AO secondary will be commissioned in Spring 2010.
- Two AO secondaries planned for late 2011.
LBT Interferometer

Light from left telescope

Cryogenic Beamcombiner

Light from right telescope

Nulling and Imaging Camera (NIC)
3-5 micron camera (UVa)
8-13 micron camera (UA)
"Planet Semi-Major Axis" vs "Planet Mass" (228)

Current Capability
LBTI

Planet Semi-Major Axis (AU)
Planet Mass (Mj)

exoplanet.eu (23/07/09)
The 3-5 $\mu$m range is a useful region for constraining the physical conditions of cool objects. - HR 8799 planets appear to have significant chemical non-equilibrium, similar to brown dwarfs. - FGK star survey has constrained outer planets around more mature, nearby stars, relative to NIR surveys. - Wide period, massive planets are not common - Consistent with NIR surveys (and a good cross-check) - LBTI will probe similar systems to ~1-3 MJ planets at 1-3 AU.