High-contrast imaging of exoplanet Beta Pictoris b with Magellan AO: Simultaneous 0.9-5µm observations with VisAO and Clio

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Jupiter’s atmosphere

- Reflecting by Aerosols/Clouds (~4.9)
- Incoming Solar Flux
  - UV+Visible: ~13.5
  - Near-IR: Reflected <0.01
  - Mid-IR: ~4.2
- Troposphere
  - Absorbed by Aerosol and CH₄: ~0.6-0.7
  - ~8.5
  - ~0.9 Absorbed by CH₄
  - ~3.3

- Stratosphere
  - Absorbed by Aerosol and CH₄: ~4.2
  - ~1.5-1.7
  - Emitted by CH₄, C₂H₂, C₂H₆, H₂-H₂ CIA, H₂-He CIA

- Internal Heat Flux ~5.4 W/m²

Zhang 2013

Marley et al 2009
Jupiter-like exoplanet atmospheres

Marley et al 2009

Burrows et al 2005
Models vary in opacities, abundances, clouds, metallicity, chemistry, dynamics

Allard et al 2013
Models require more data with increased wavelength coverage
Adding thermal IR: Equilibrium chemistry models underpredict the HR 8799 planets’ 3.3um fluxes

Skemer et al 2012
Thermal IR is critical for constraining cooler-effective-temperature planets
Andy Skemer
LBT AO

Skemer et al 2013 in prep

Poster #1.37
MagAO is on the 6.5-m Magellan Clay telescope at Las Companas Observatory, Chile
Team of astronomers from Steward Observatory (University of Arizona, Tucson), Arcetri Observatory (INAF, Florence), and Carnegie Observatories
MagAO

- **NGS Modulating Pyramid WFS**
  - 21-378 modes
  - 100-1000 Hz
  - Limiting mag:
    - $R \approx 14 \, @ \, <1\mu m$
    - $R \approx 16.5 \, @ \, 2-5\mu m$
- **Adaptive-Secondary Mirror**
  - 561 illuminated actuators
  - $d = 23 \, \text{cm}$
- **Control**
  - Modal gain: tip/tilt, low-order, high-order
  - Selectable subap. size via pix. binning
MagAO has two co-mounted science cameras: VisAO for r’, i’, z’, Y_5 and Clio for J H K_5 L’ M’

VisAO:
8 mas pixels, 8x8” FoV
Imaging, SDI

Clio:
16 mas pixels, 16x8” FoV
27 mas pixels, 28x14” FoV
Imaging, NRM, APP, Prism

Information for Observers:
magao.as.arizona.edu/observers
VisAO: 0.55 – 1.1 μm science

r', i', z', Y_s

Hα, [SII], [OI]

open

ND 3 spot
R ~ 0.1"

ND 3.22
VisAO PSF

Lab

On Sky
Clio: 1 – 5 µm science

Wide camera 28x14”

NRM 6

NRM 3

Narrow camera 16x8”

M’ APP

L’ APP

prism
Pupil and theoretical PSF
Clio
3–5 μm
PSFs

Model

Data
Extreme AO around the world

- Palm3k
- LBTAO
- SCExAO
- SPHERE
- GPI
- MagAO
\( \beta \) Pictoris b

Lagrange et al 2009
Clio – βPic – M’

Morzinski et al 2013 in prep
Clio – βPic – 3.3 μm

Data

Morzinski et al 2013 in prep

Model
Clio – βPic – 3.3 μm

Morzinski et al 2013 in prep
Clio – βPic – L’

Morzinski et al 2013 in prep
Clio – βPic – 3.1 μm

Morzinski et al 2013 in prep
β Pic b imaged simultaneously on a CCD & HgCdTe, from 0.98–5 μm
Estimated mass of Beta Pic b ranges from 9–13.7 \( M_{\text{Jup}} \) depending on formation mechanism assumed.
Luminosity peaks during maximum accretion of solids onto core

Bodenheimer et al 2013
VisAO SDI Mode – Disk imaged in Hα silhouette

Kate Follette, Laird Close, Jared Males & the MagAO team

A − B = C

Poster #3.14
Kate Follette
Summary

• Detailed characterization of exoplanets
  – Models are crucial to interpreting data
  – More data is needed to constrain degeneracies
    • Within models
    • Between models

• MagAO: Unique 0.55–5μm capabilities to characterize exoplanets
  – Diffraction-limited deep imaging in O/IR
  – High-contrast imaging via SDI, ADI, APP
  – 20 mas resolution at Hα
  – Thermally optimized for 3–5μm
  – Simultaneous visible and IR imaging

• Beta Pic b
  – Mass, age, atmosphere composition, clouds

MagAO is commissioned and will be available in 2014A

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magao.as.arizona.edu