Dust Is Interesting:

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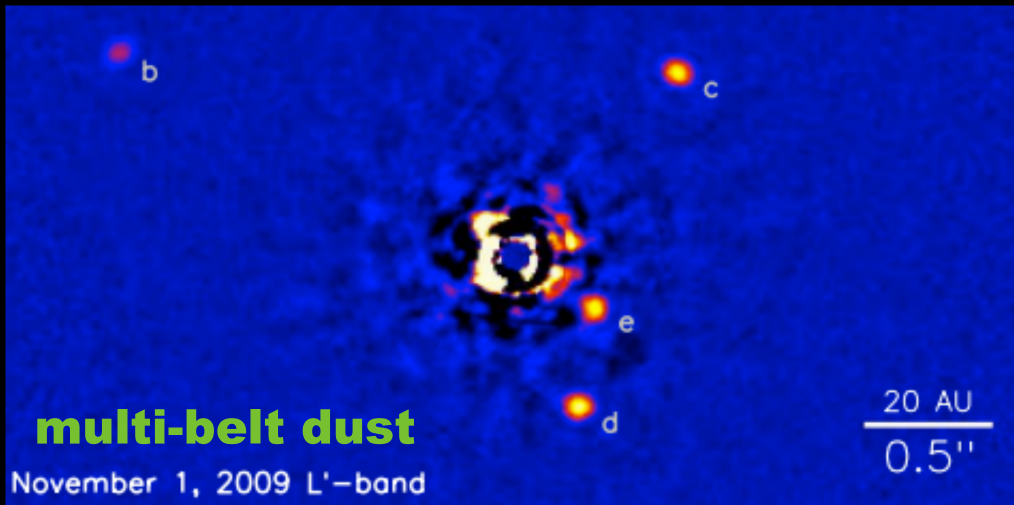
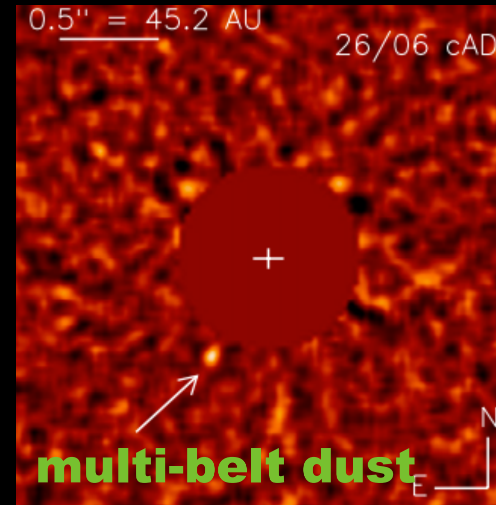
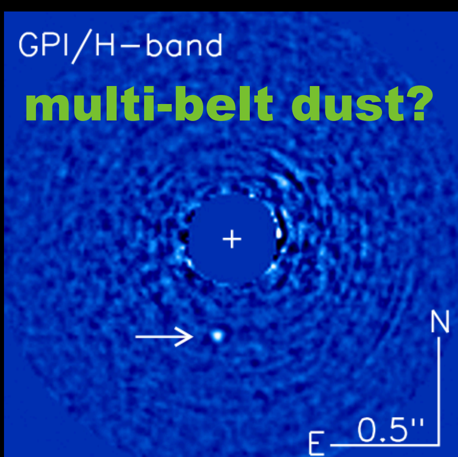


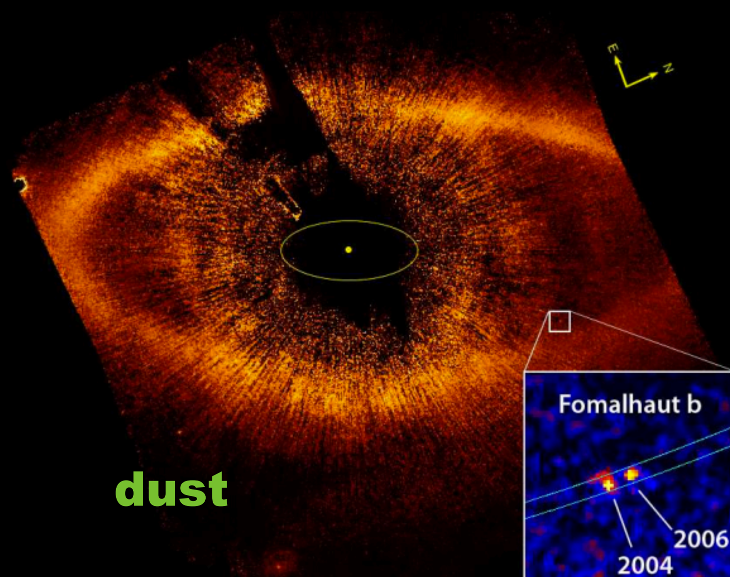
Marois+ 2010

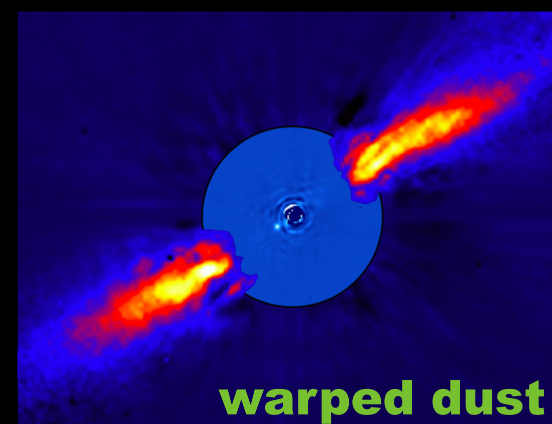


Rameau+ 2013



Macintosh+ 2015





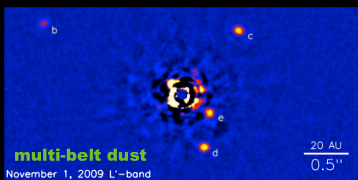
Lagrange+ 2009

Kalas+ 2008

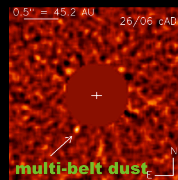
Is Multibelt Dust Interesting?

Is Multibelt Dust Interesting?

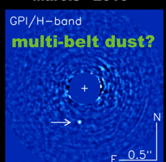
a signpost for planets?



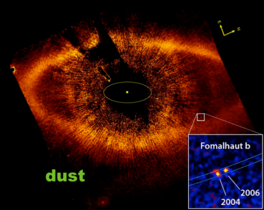
Marois+ 2010



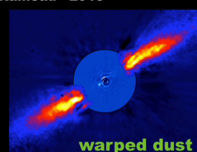
Rameau+ 2013



Macintosh+ 2015



Kalas+ 2008



Lagrange+ 2009

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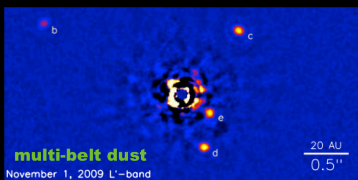
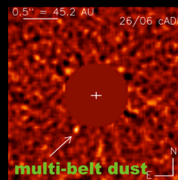
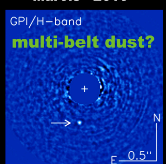


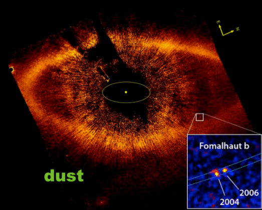
Marois+ 2010



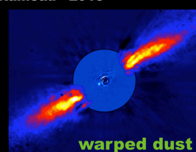
Rameau+ 2013



Macintosh+ 2015

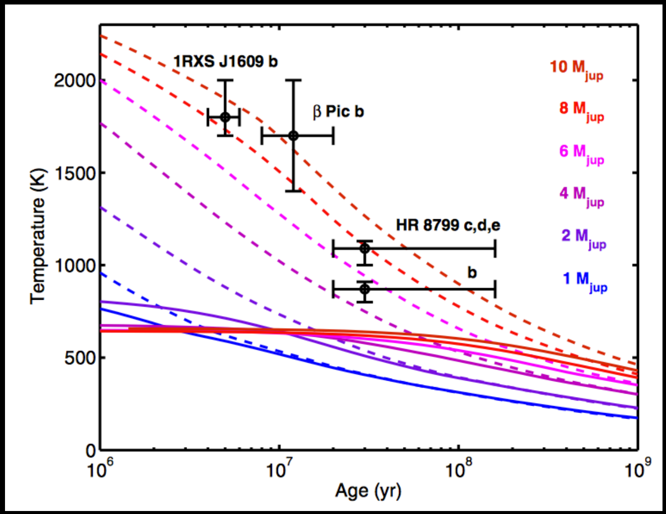


Kalas+ 2008



Lagrange+ 2009

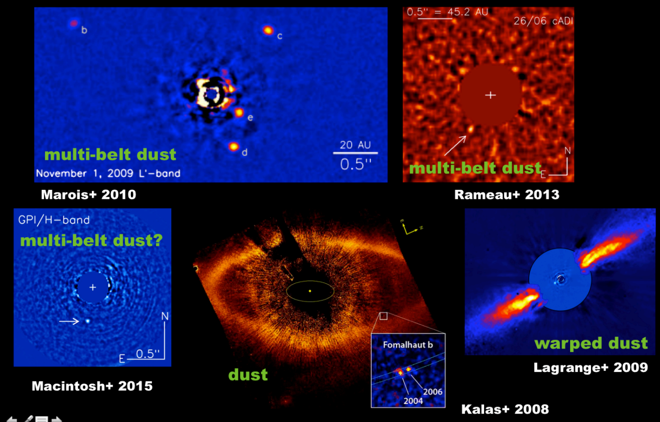
dynamical constraints



hot vs cold models: Janson+ 2011

Is Multibelt Dust Interesting?

a signpost for planets?



Marois+ 2010

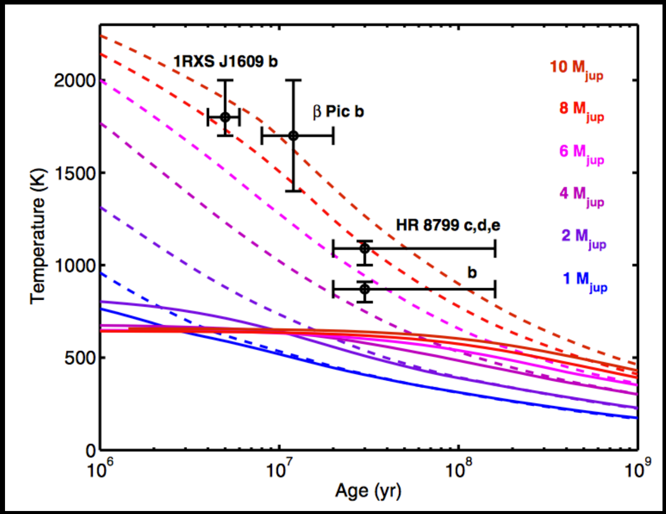
Rameau+ 2013

Macintosh+ 2015

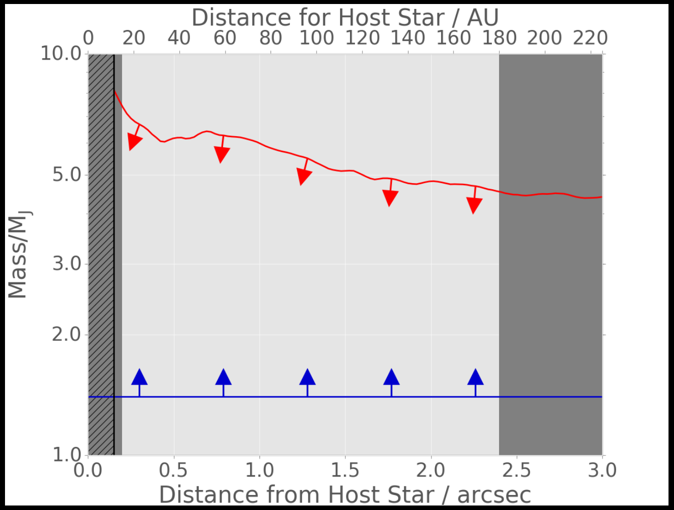
Kalas+ 2008

Lagrange+ 2009

dynamical constraints



hot vs cold models: Janson+ 2011



further constraints from dust

lower mass limits: Shannon+ 2016, accepted

Is Multibelt Dust Interesting?

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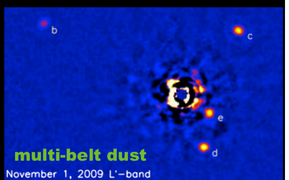
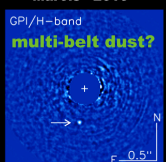
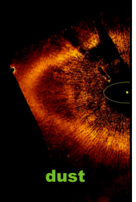


Marois+ 2010



Macintosh+ 2015



Searching for Planets in Two-Temperature Debris Disks with VLT/SPHERE

UNIVERSITY OF EXETER

Elisabeth Matthews*[,1], Sasha Hinkley[1], Arthur Vigan[2], Dimitri Mawet[3], Grant Kennedy[4], Andrew Shannon[4], Mark Wyatt[4]

1 - Astrophysics Group, University of Exeter 2 - Laboratoire d'Astrophysique de Marseille
3 - Department of Astronomy, California Institute of Technology, 4 - Institute of Astronomy, University of Cambridge

*ematthews@astro.ex.ac.uk

Abstract: Direct Imaging allows us to detect the youngest, widest separation planets that are inaccessible to the Radial Velocity (RV) and transit methods. Direct Imaging also gives the option of detailed spectroscopic follow-up analysis. In this work, we are particularly interested in two-temperature debris disks, which are thought to indicate that the debris disk is segregated into multiple separate rings. The gap between these dusty rings is believed to have been carved by the gravitational influence of one or several massive planets. We are performing a survey of 37 nearby, young stars with two-temperature debris disks using VLT/SPHERE. Our data reduction process, and some of the constraints we are able to place on the systems, are discussed below.

Introduction: We are carrying out a survey of 37 nearby, young stars. For each target, the infrared excess emission is thought to indicate that the star hosts a dusty debris disk, segregated into two distinct belts with an intermediate gap [1]. We believe that this gap is likely to be caused by the gravitational influence of giant planets, as has been observed for targets such as HR8799 [2] and β-Pic b [3].

As well as being a likely indicator for the presence of planets, the multi-belt nature of our targets will allow us to calculate dynamical masses for any companions we detect. For systems where candidates are *not* detected, we attempt to place both upper and lower limits on the possible mass of planets residing in the debris disk.

For this survey, our targets are imaged with VLT/SPHERE [4] in IRDIFS mode, which allows simultaneous imaging through two subsystems, namely IRDIS (InfraRed Dual Imaging Spectrometer) [5] and IFS (Integral Field Spectrometer) [6]. On this poster we present our data reduction & analysis for one example target: a young, ~15 Myr star at ~140 pc.

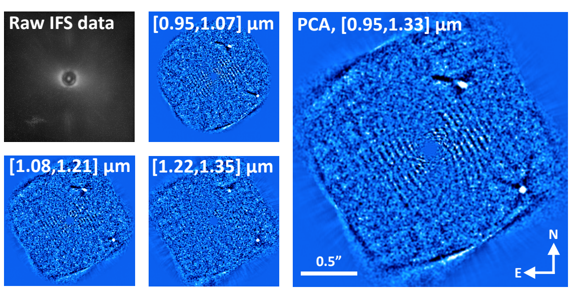


Fig 1: Example data from the SPHERE/IFS instrument. We use the YJ mode, allowing data collection at 39 spectral channels between 0.95 and 1.33 µm. The raw data consists of a series of spectra, at each point in the image. We first perform basic calibrations: dark and flat field corrections, and IFS spectra position & wavelength calibrations. We then use a custom routine (see [7]) to convert the data into 4-d (x,y,λ,t) cubes. After further calibration, we perform a Principle Component Analysis on the full sequence of images. For the above images, one candidate is observed at a separation of 0.8", in the SW quadrant,

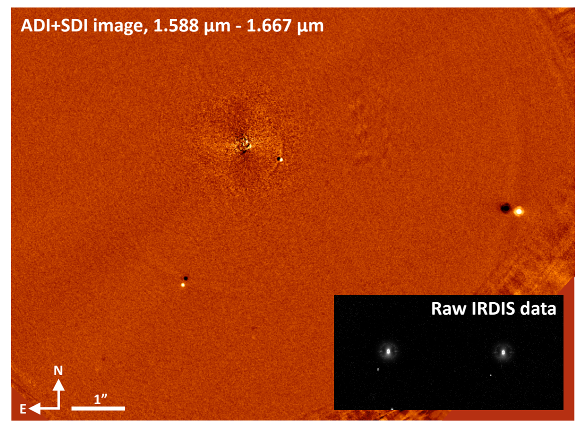
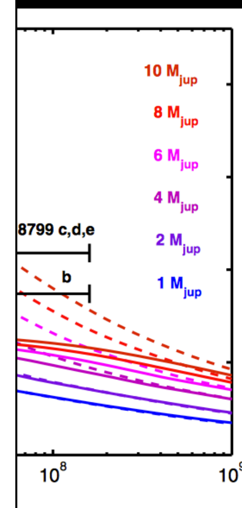


Fig 2: Example data from the SPHERE/IRDIS instrument. Images are taken simultaneously with two filters at 1588.8 nm and 1667.1 nm and exposure times of 2-32 s, with the full sequence consisting of roughly 100 images. After standard pre-processing steps, we apply both Angular and Spectral Differential Imaging routines, whereby we remove speckle noise based on both its wavelength and rotational properties. This reduction process causes each candidate to appear as a 'dipole' in the final image. For this target, we observe three candidate companions at separations of 0.8", 2.8" and 5.3". Two very faint candidates are observed, at 3.6" and 5.0", both at lower than 5σ significance. Note that the reduced image has been cropped to the show only the region containing candidate companions.

Analysis: The above target is typical of our survey results: we have identified several candidate companions and are in the process of collecting follow-up data which will be used to confirm whether each target is a companion or a background star.

We are also studying the relationship between dust gaps and the planets that are



anson+ 2011

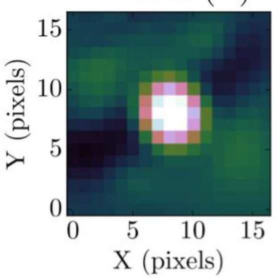
aints

2016, accepted

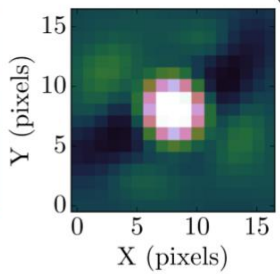
One Milliarcsecond Astrometry of β Pic b with the Gemini Planet Imager

Jason Wang, James Graham, Laurent Pueyo, Paul Kalas, Maxwell A. Millar-Blanchaer, Jean-Baptiste Ruffio, and the GPIES Team

Data (D)



Forward Model (F)



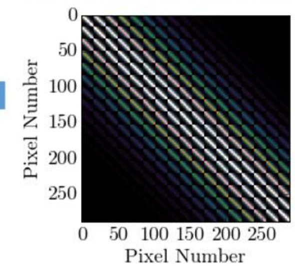
Centered at (x_p, y_p)
Scaled by α

Construct Likelihood Function

$$R = D - \alpha F(x_p, y_p)$$

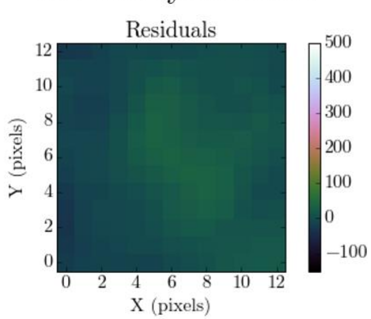
$$\log \mathcal{L} = -\frac{1}{2}\left(R^T C^{-1} R + \ln(\det C)\right)$$

Covariance Matrix $= C$



Matérn Kernel ($\nu = 3/2$)
Correlation length l

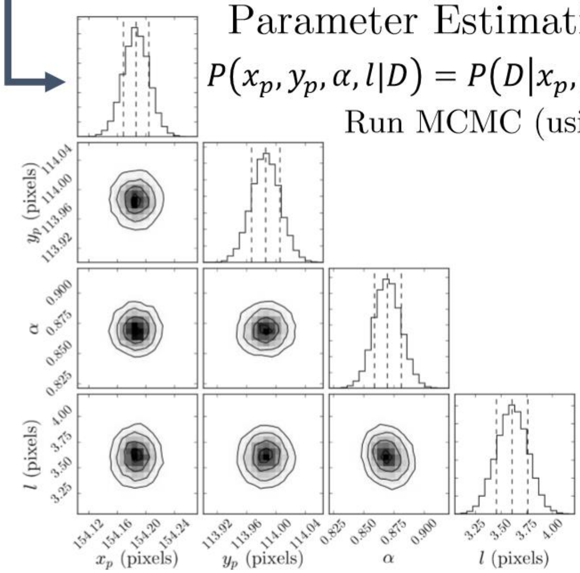
Residuals show no obvious systematics



Parameter Estimation: x_p, y_p, α, l

$$P(x_p, y_p, \alpha, l | D) = P(D | x_p, y_p, \alpha, l) P(x_p, y_p, \alpha, l)$$

Run MCMC (using *emcee*)



Propagate Astrometric Errors

Relative Position of β Pic b

2013 Nov 18

ΔRA: -229.1 ± 1.1 mas

ΔDec: -364.7 ± 1.0 mas

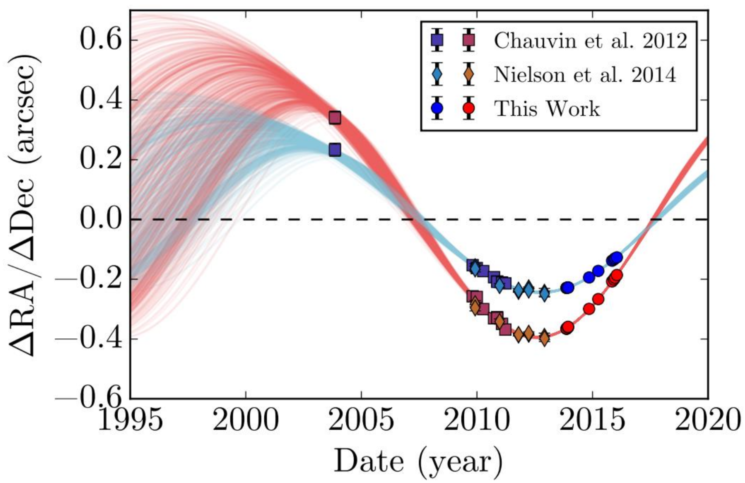
Sep: 430.6 ± 0.8 mas

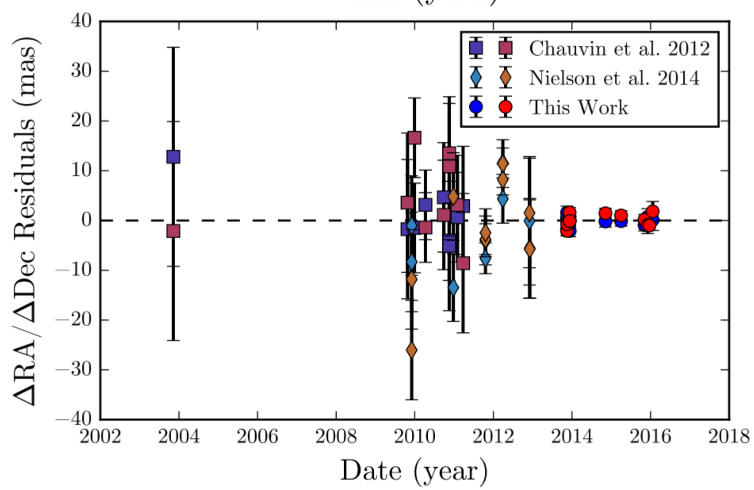
PA: 212.1° ± 0.2°

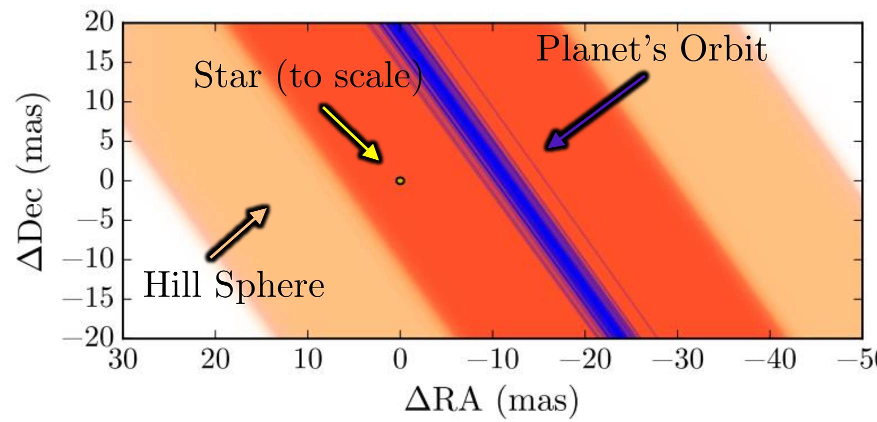
2-3 times more precise than previous analysis using the same data

β Pic b will not Transit! (But its Hill sphere will)

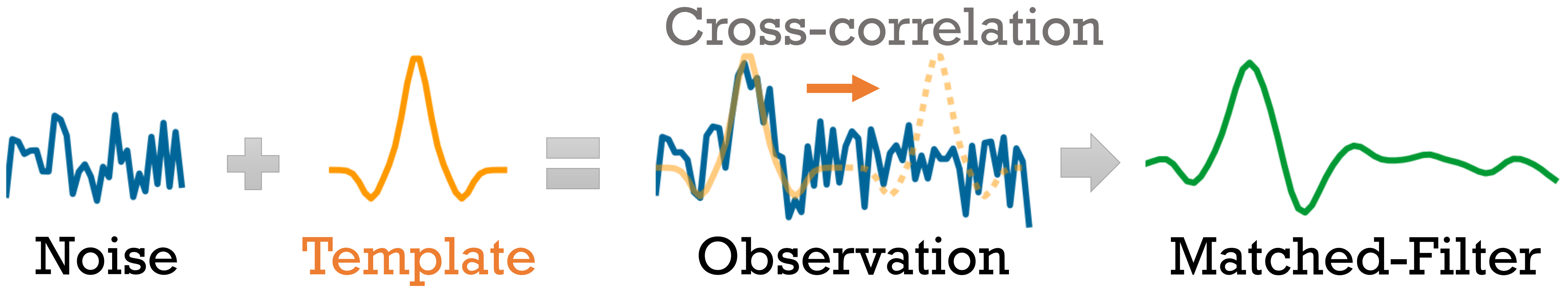
Jason Wang, James Graham, Laurent Pueyo, Paul Kalas, Maxwell A. Millar-Blanchaer, Jean-Baptiste Ruffio, and the GPIES Team

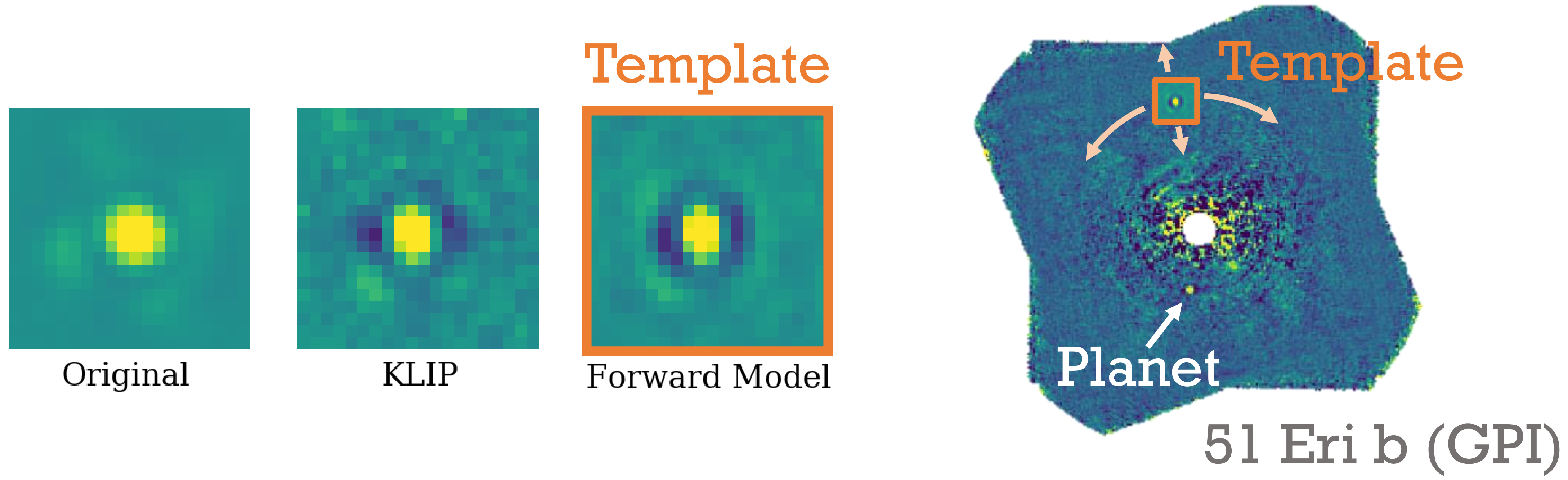




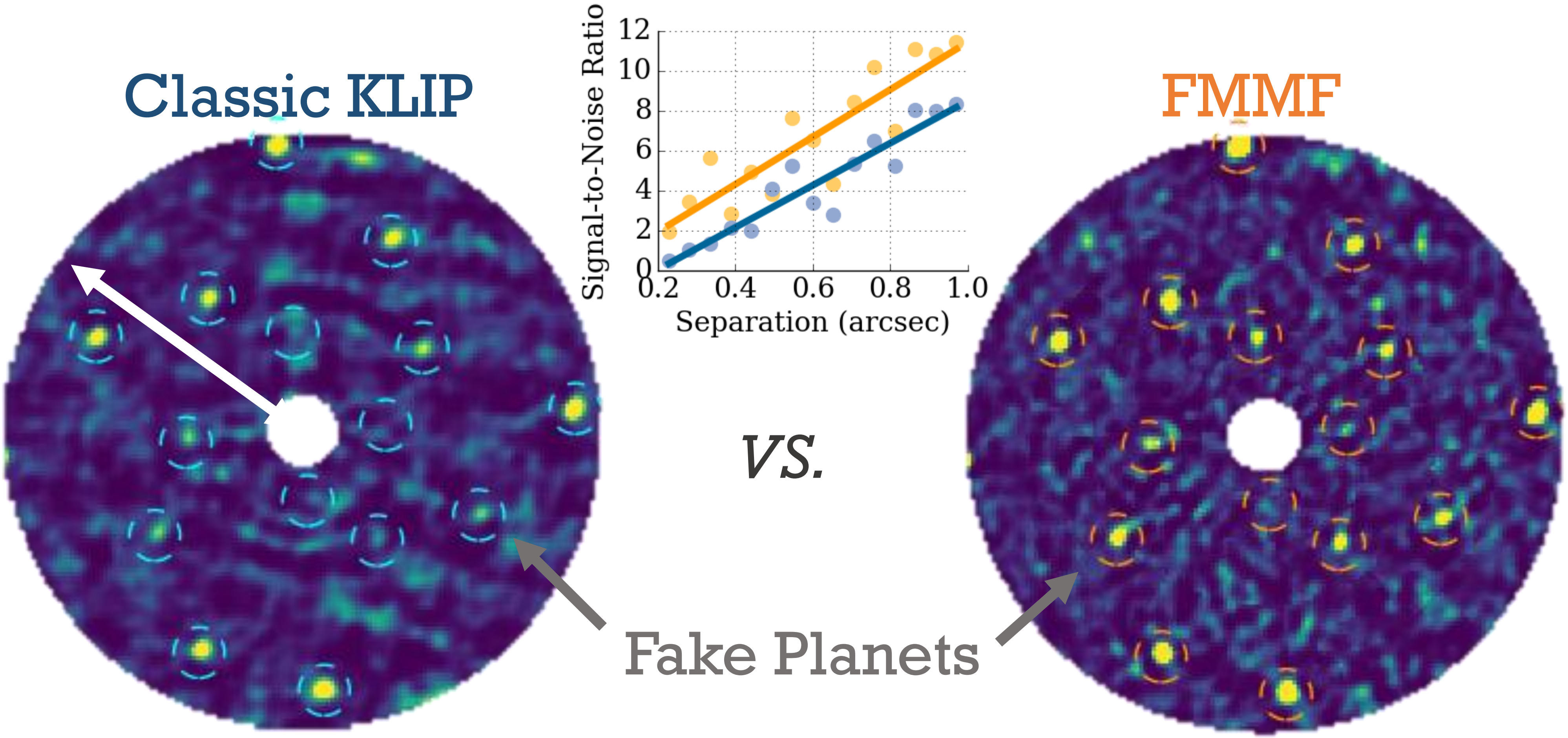


Detecting Planet using Direct Imaging





Forward Model Matched Filter (FMMF)

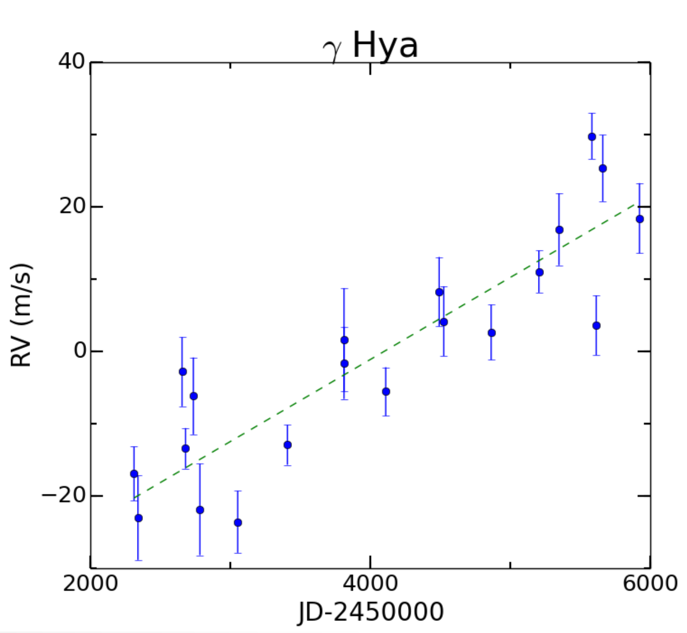


Jean-Baptiste Ruffio

High-Contrast Imaging of Giants with RV Trends (Ryu+16)

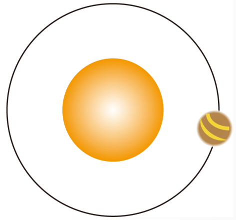
Tsuguru Ryu
(SOKENDAI/NAOJ)

RV trends suggest the presence of companions.

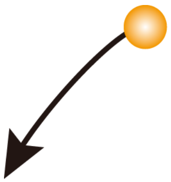


Okayama Planet Survey Results

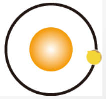
distant(10AU) planet



cause same RV trend



distant(100AU) companion stars

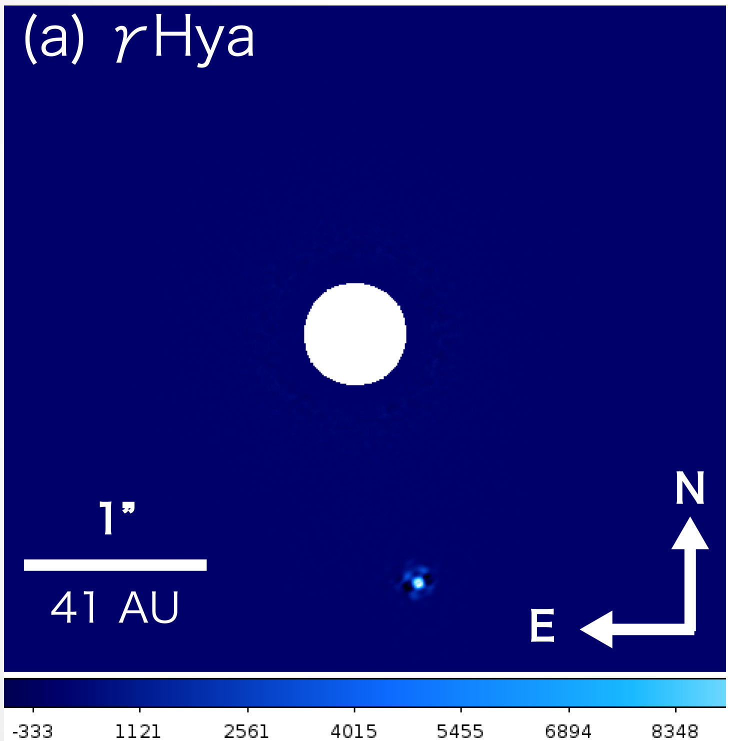


Direct imaging is crucial to reveal such companion(s)

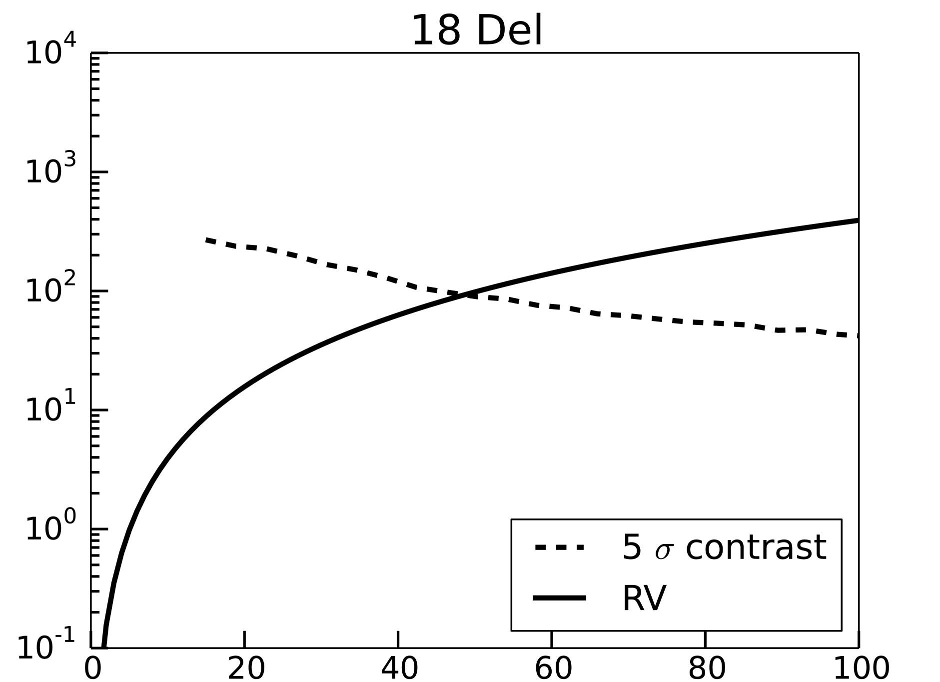
If companions are detected, we can derive various parameters from imaging data.

or

Even if not detected, we can constrain the RV trend source.

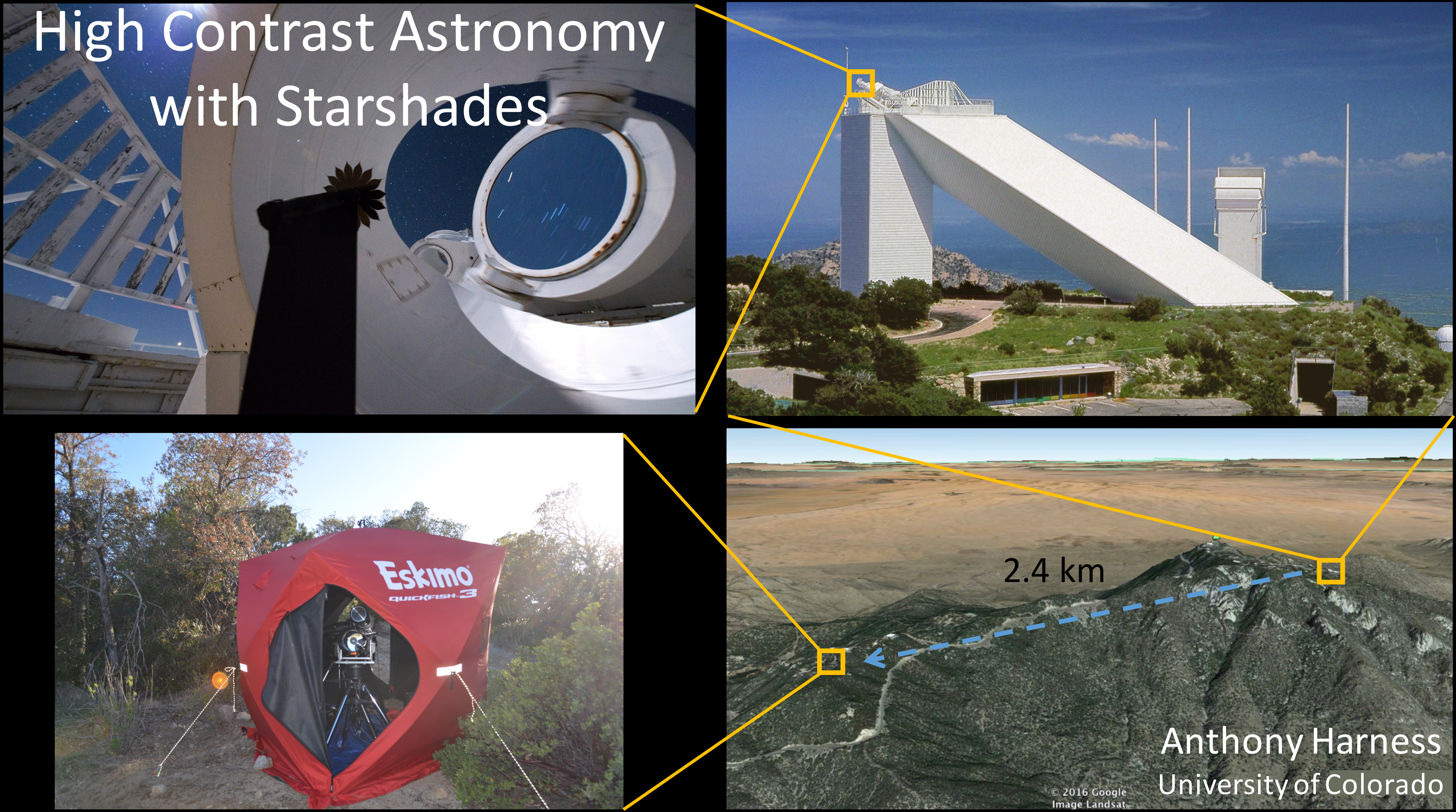


Subaru/HiCIAO+AO188

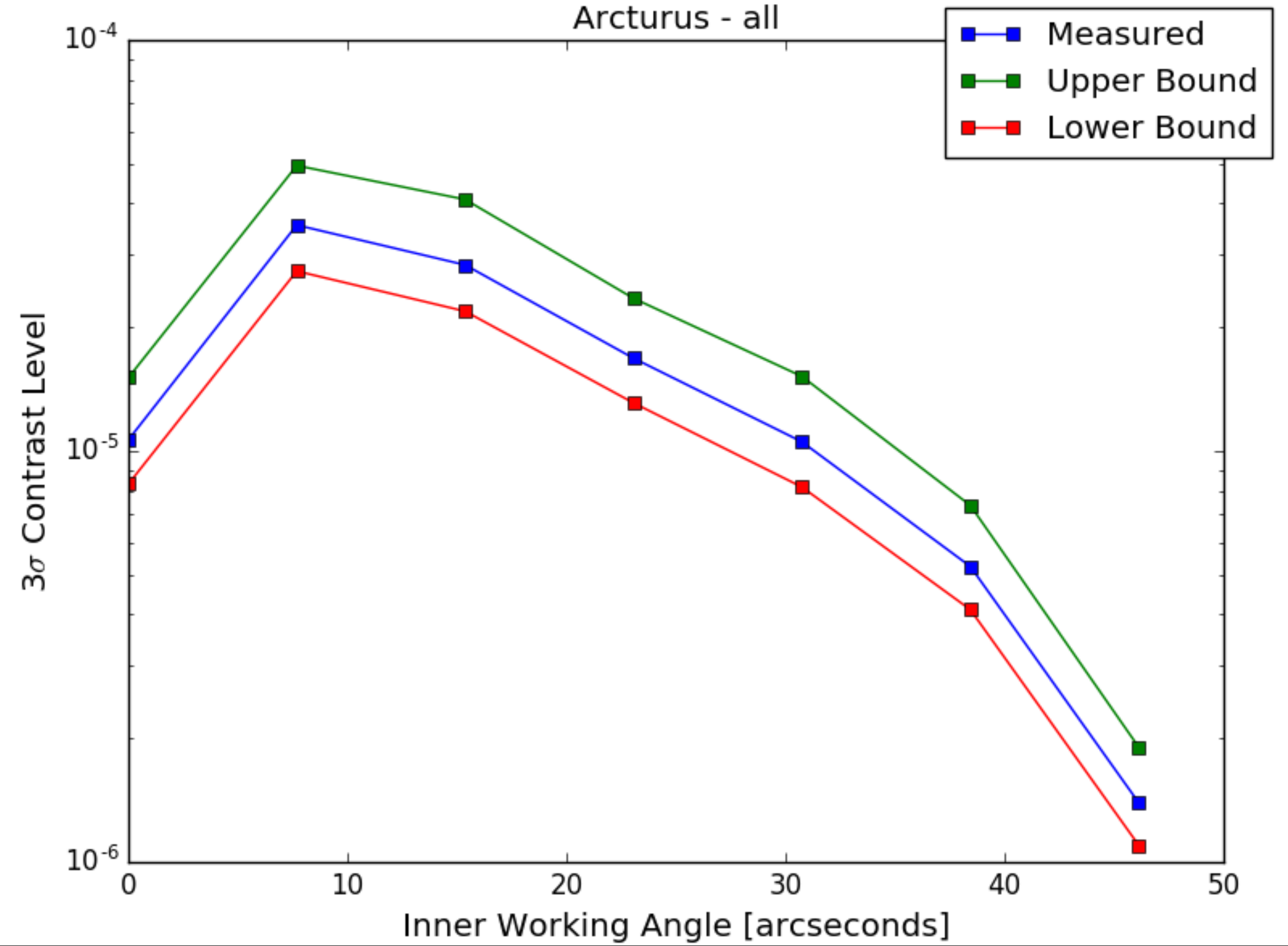


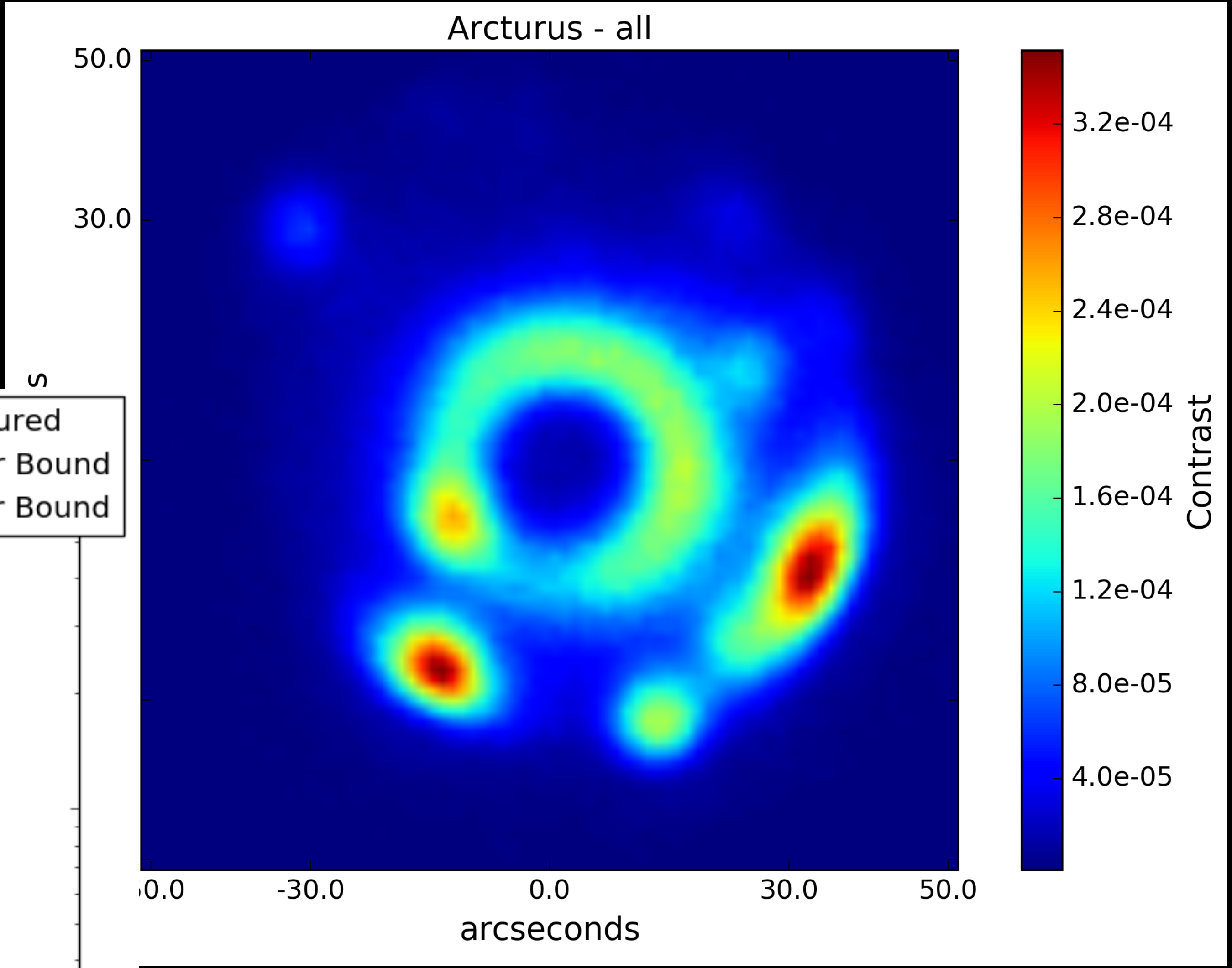
dash line: upper limit by direct-imaging
solid line: lower limit by RV trend

Revealing the sources of RV trends enables us to estimate frequency of distant planets.



High Contrast Astronomy
with Starshades
Eskimo
QUICKFISH 3
2.4 km
© 2016 Google
Image Landsat
Anthony Harness
University of Colorado


Arcturus - all
Measured
Upper Bound
Lower Bound
3σ Contrast Level
Inner Working Angle [arcseconds]
10^-4
10^-5
10^-6
0
10
20
30
40
50


Arcturus - all
50.0
30.0
-30.0
0.0
30.0
50.0
arcseconds
Contrast
3.2e-04
2.8e-04
2.4e-04
2.0e-04
1.6e-04
1.2e-04
8.0e-05
4.0e-05

Uncovering System Architectures Near the 2:1 Resonance

John H. Boisvert and Jason H. Steffen

- RV signal of a planet with an eccentric orbit,
  $V_{RV} \sim m_1 \cos(\omega_1 t) + m_1 e \cos(2\omega_1 t)$
- RV signal of two planets with near circular orbits, with inner-to-outer period ratio 2:1,
  $V_{RV} \sim m_1 \cos(\omega_1 t) + \ m_2 \ \cos(2\omega_1 t)$
- Kepler has revealed many adjacent planet pairs with this period ratio and a significant number at 2.17:1.
- 48 systems from Exoplanets Data Explorer (exoplanets.org, Han et al. 2014), reported as single planets, with mass < M_J, e > 0.045, S/N > 2
- Systemic 2 Console (www.stefanom.org/console-2)
- Same number of model parameters

Inner-to-Outer Period ratios of 2:1 and 2.17:1 from Kepler data (Steffen & Hwang 2015)

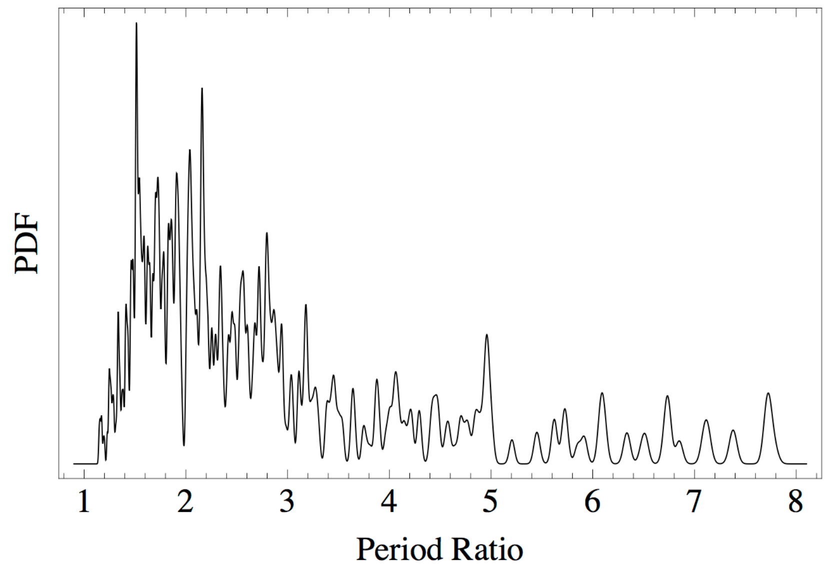


Figure 5. The period ratio distribution for *Kepler* planets using only adjacent planet pairs and correcting for geometric bias and pipeline completeness. The most prominent feature is the spike near the 3:2 MMR. Second to that is the excess of planet pairs near a period ratio of 2.2.

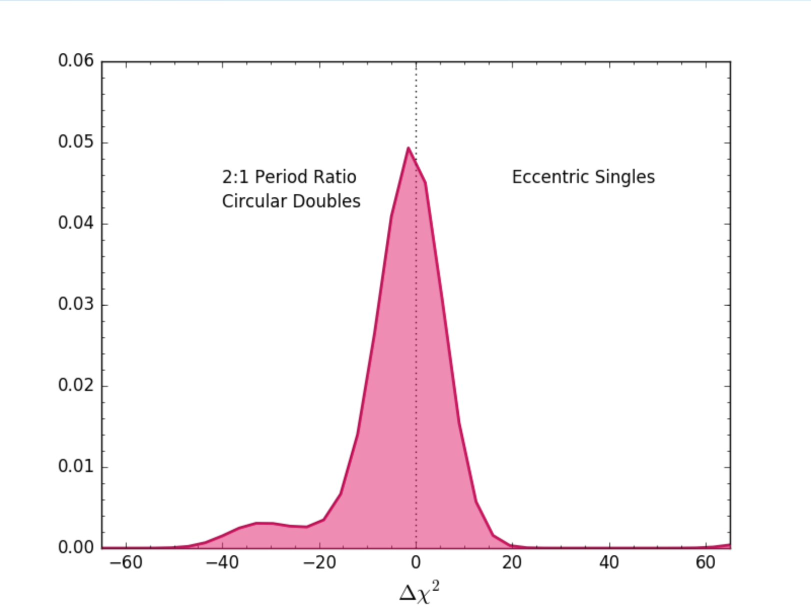
$$S/N \equiv \frac{K}{\sqrt{N_{obs} \times {\sigma_K}^2}}$$

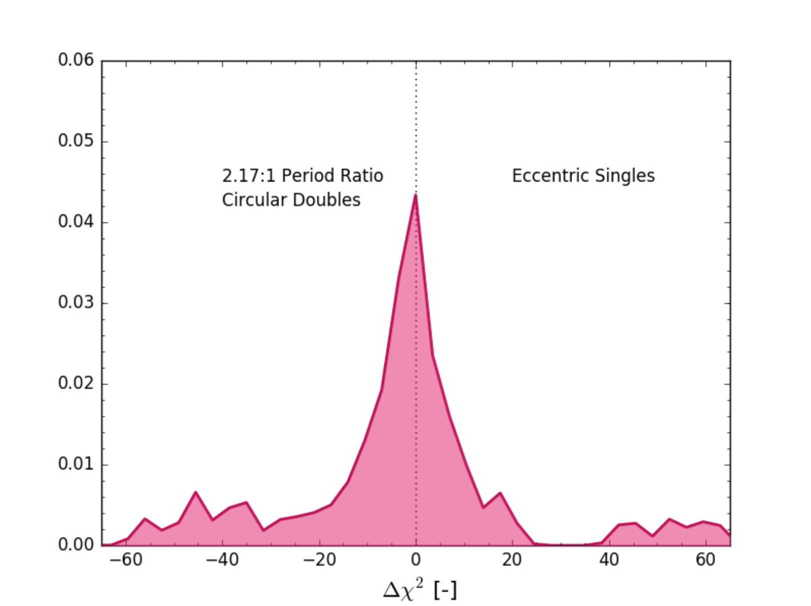
See my poster for more!

<u>Quick Results</u>

- 2:1 – 58.33% Double vs. 41.67% Single
- 2.17:1 – 62.5% Double vs. 37.5% Single

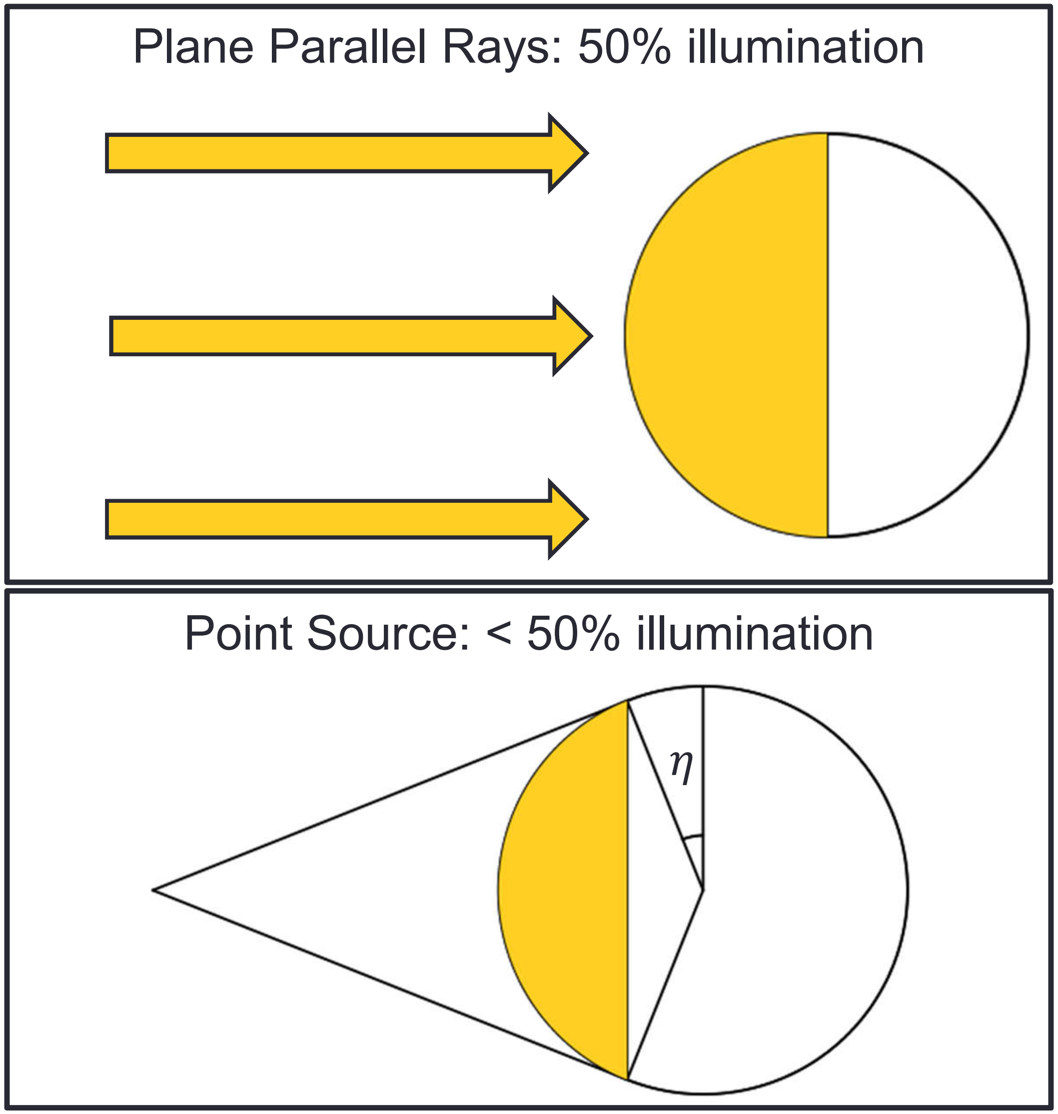
- We plan to investigate further using more sophisticated statistical approach.
- If those results are robust, then they will have major ramifications on the formation histories and abundance measurements of those systems.
  - Unique formation channel for eccentric singles and near circular doubles
  - Scattering vs. interacting with disk (removes eccentricity and drives planet pair into an orbital resonance)





Reflected Light of Extremely Close-In Exoplanets

Authors: Jennifer Carter & Kevin H. Knuth



UNIVERSITY AT ALBANY
State University of New York

Including the Angular Size of the Star