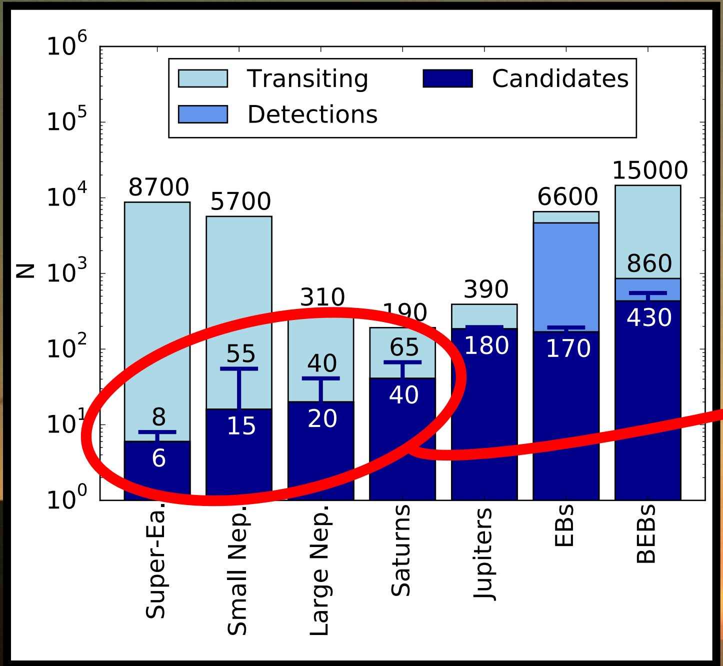
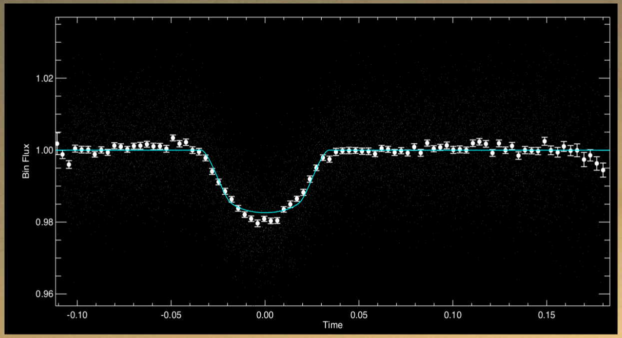
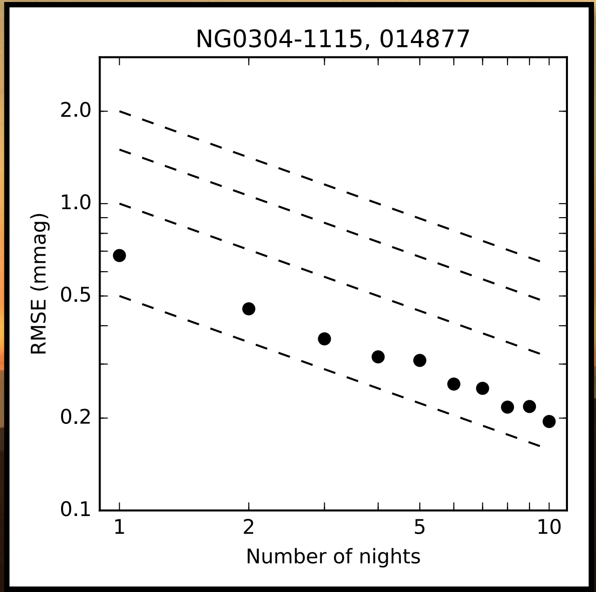
NGTS: High Precision Photometry

0.5 – 1 mmag red noise



Günther+, submitted to MNRAS

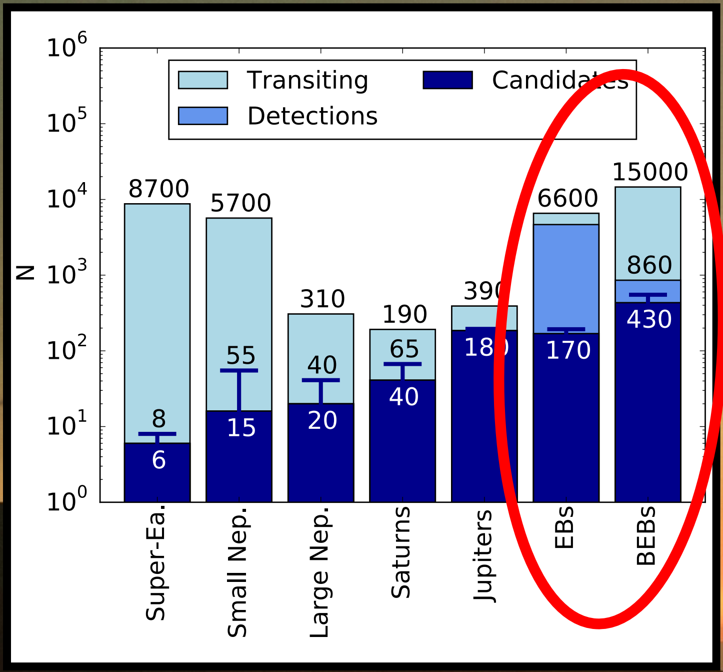




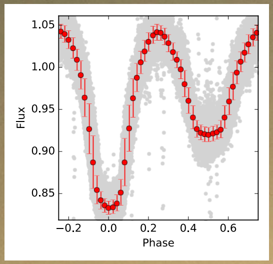
NGTS objects of interest from June 2016

NGTS: Identifying False Positives

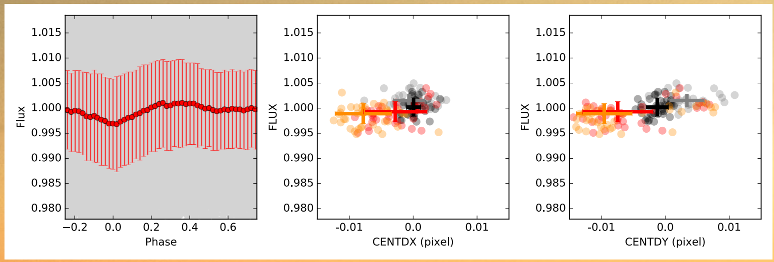
0.5 – 1 mmag red noise

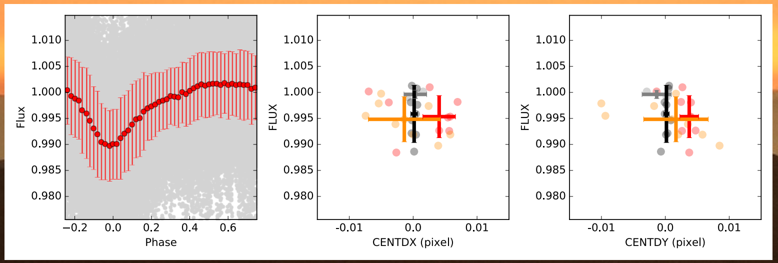


Günther+, submitted to MNRAS



Transit depth / duration
Secondary Eclipses
Ellipsoidal Variations
Centroiding
Pixel-level photometry





NGTS objects of interest from June 2016

Combining ground- and space-based transmission spectroscopy

Lorenzo Pino
(*Università degli studi di Padova, Université de Geneve*)

PhD supervisors and co-supervisors:
G. Piotto, V. Nascimbeni (Padova), F. Pepe, D. Ehrenreich (Geneva)

In collaboration with:
Geneva exoplanets group, ESPG, PlanetS

PyETA (done)

What: One dimensional (plane parallel) radiative transfer code with $R \sim 10^6$ (extending ETA, Ehrenreich et al., 2006).

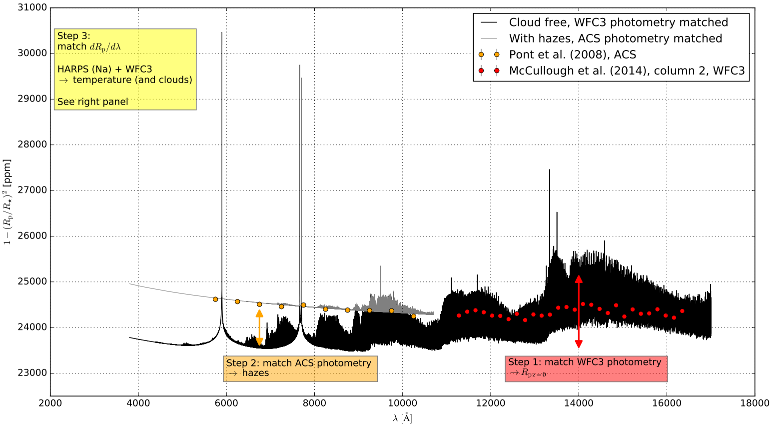
Why: To "rapidly" produce thick grids of models for the interpretation of data from different sources (e.g., ground and space).

How: Simple physical assumptions.

Simplification vs. Accuracy

Where is the compromise?

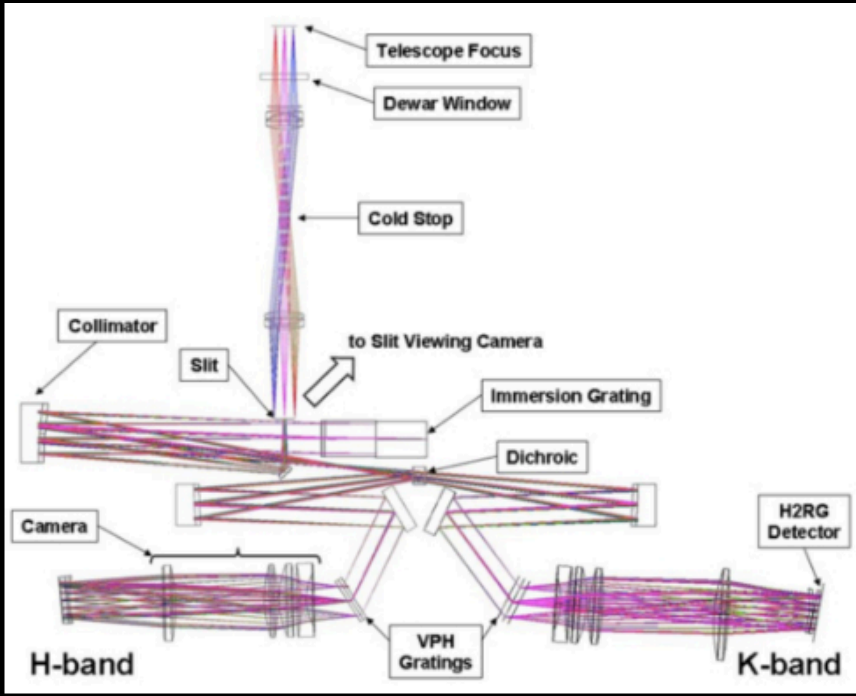
HD189733b (in progress)

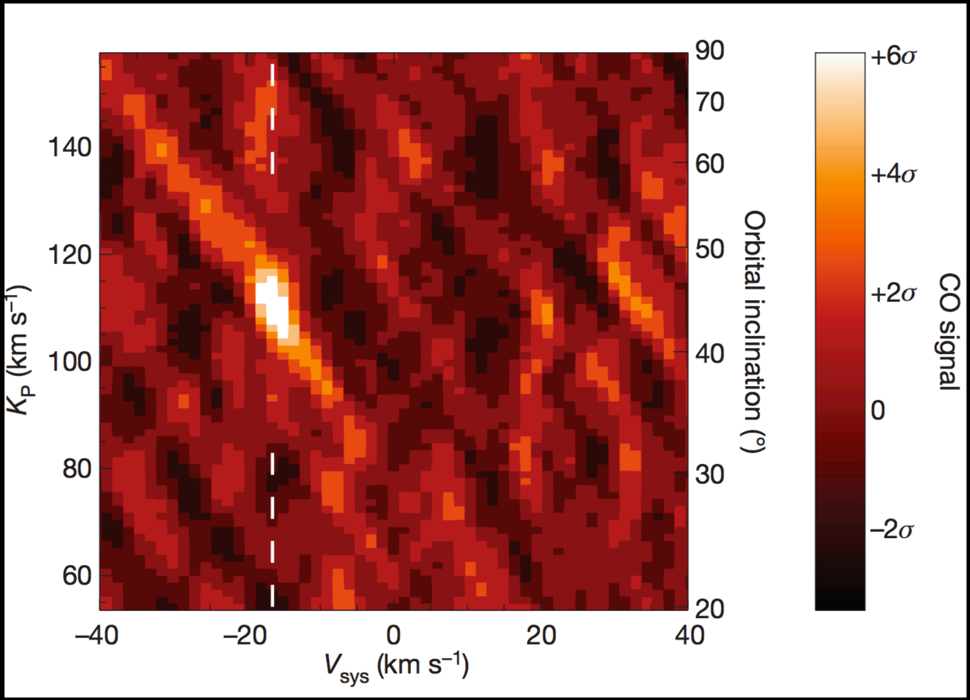


And scheduled observations with:
HARPS/HARPS-N, LBT, HST, . . .

Detecting Molecular Absorption using IGRINS for the Exoplanet Tau Boötis b

Jessica Luna, UT Austin





<u>IGRINS</u>:

R≈45,000

1,500 - 2,500nm

<u>Brogi et al. (2012)</u>:

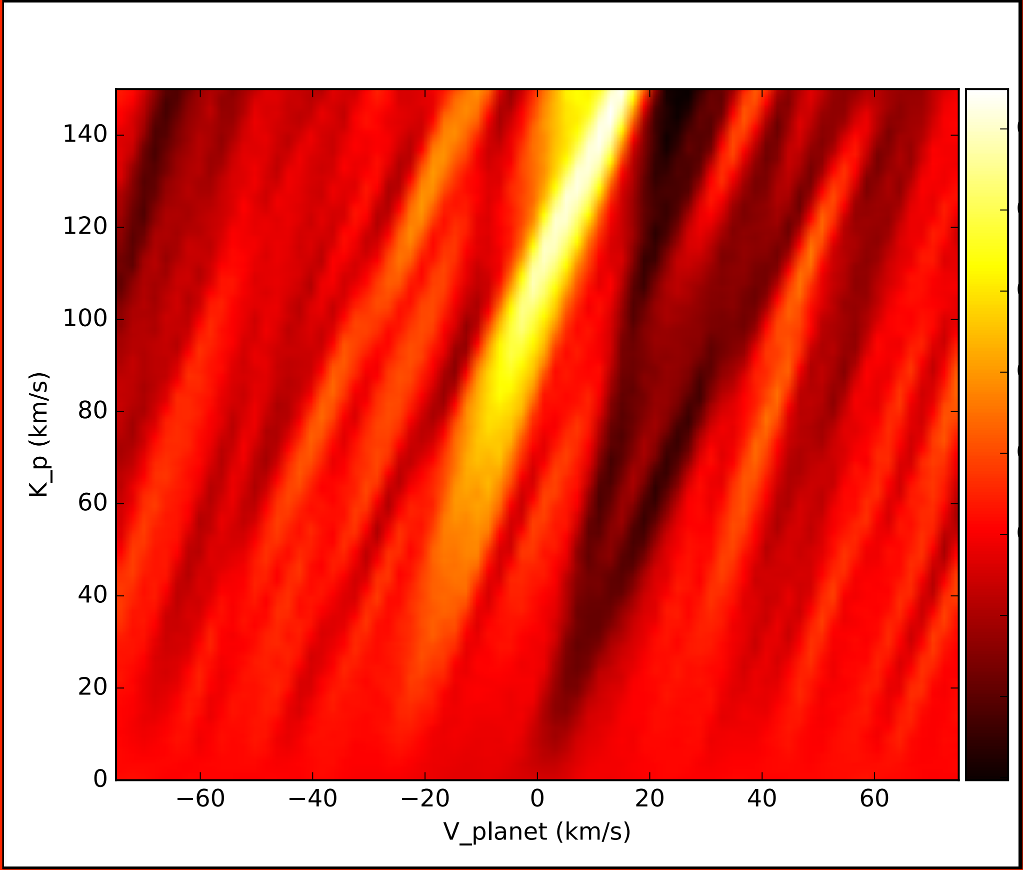
3 nights using CRIRES on VLT

2,287-2,345nm

6σ detection of CO

Preliminary Work: Injected Signal

Injected CO signal with IGRINS :



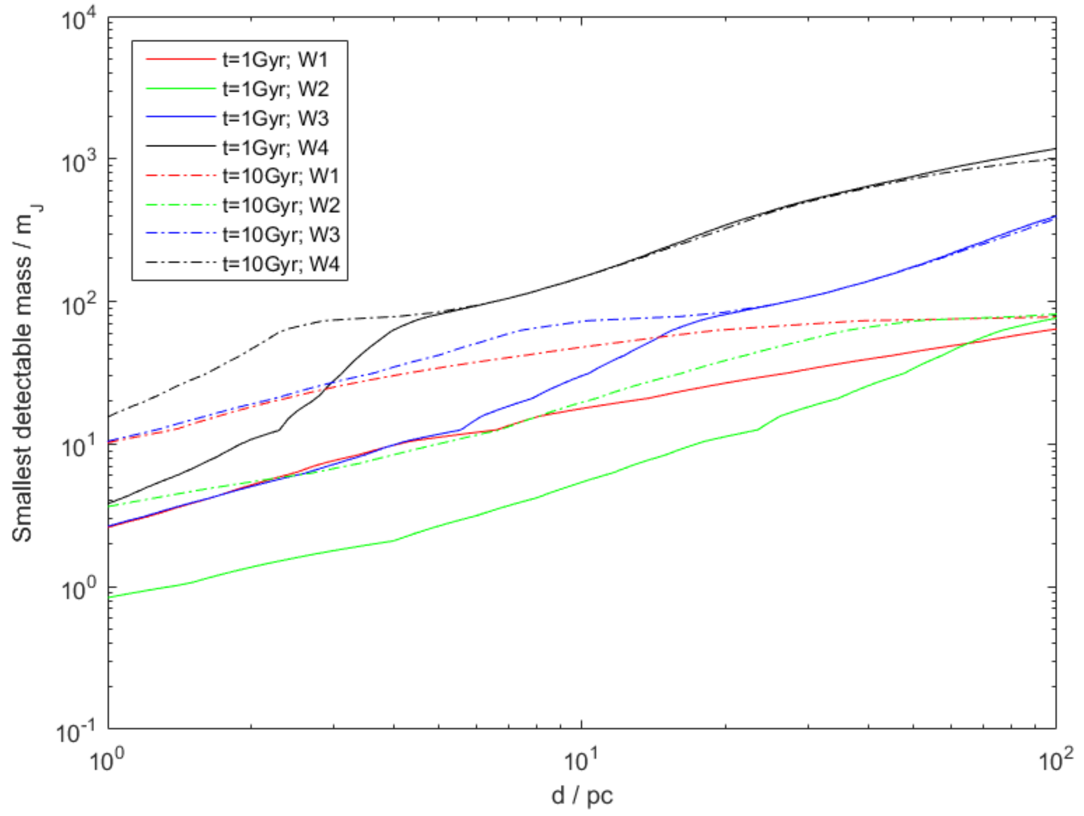
Signal will Increase by:

- Using full IGRINS spectral range (30x CRIRES)
- Reducing all 24 nights of full phase coverage with, 9 nights at optimal phases

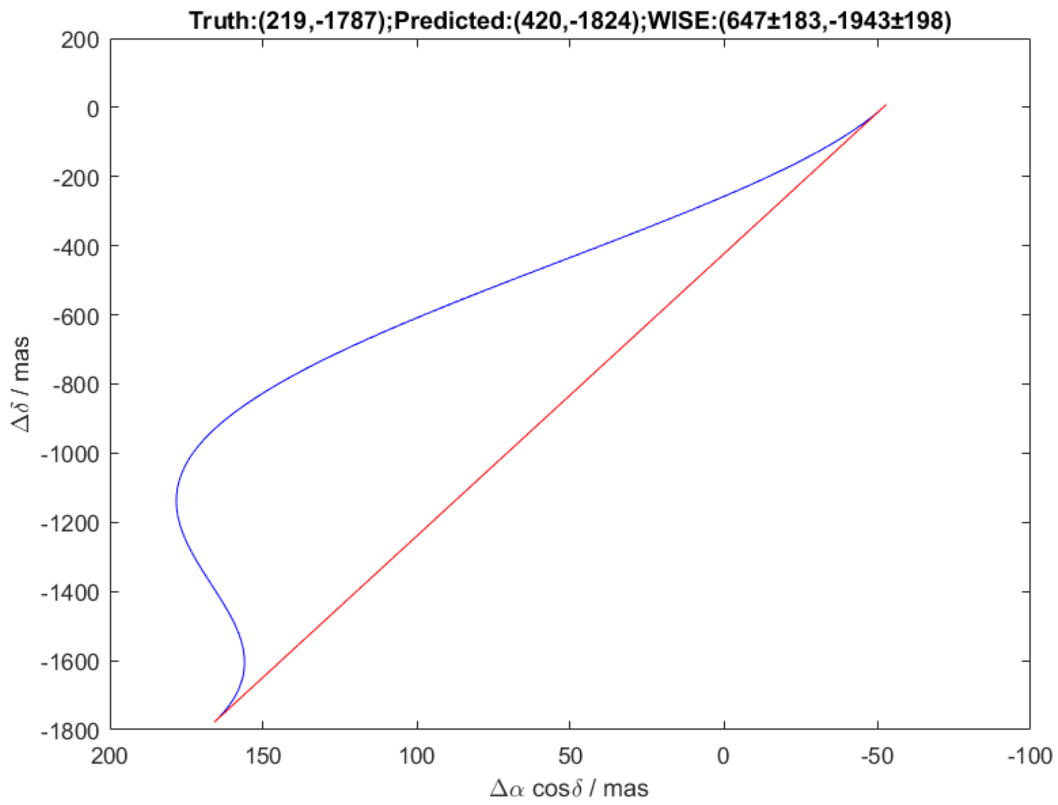
Future work will look for methane, water etc…

Searching for low-mass companions to high proper motion stars with WISE

Ben Yelverton, Mark Wyatt & Grant Kennedy (IoA, University of Cambridge)



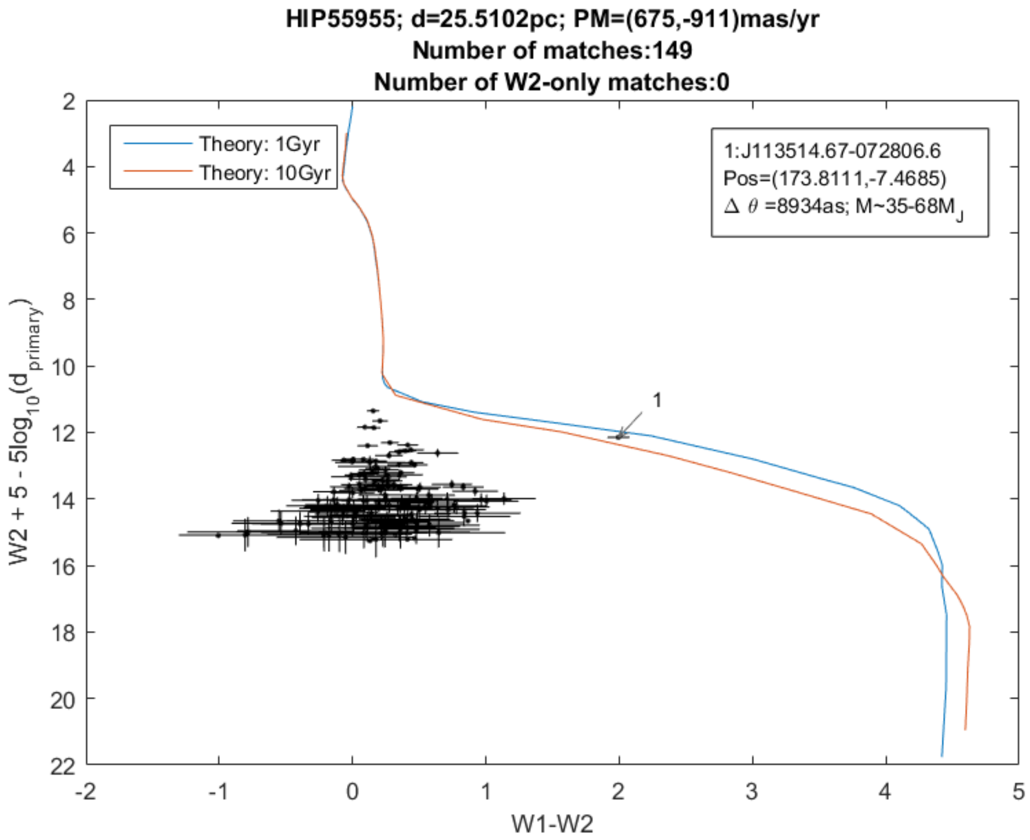
Mass of lightest objects detectable by WISE as a function of distance, within the PHOENIX AMES-Cond model (Allard et al 2001)



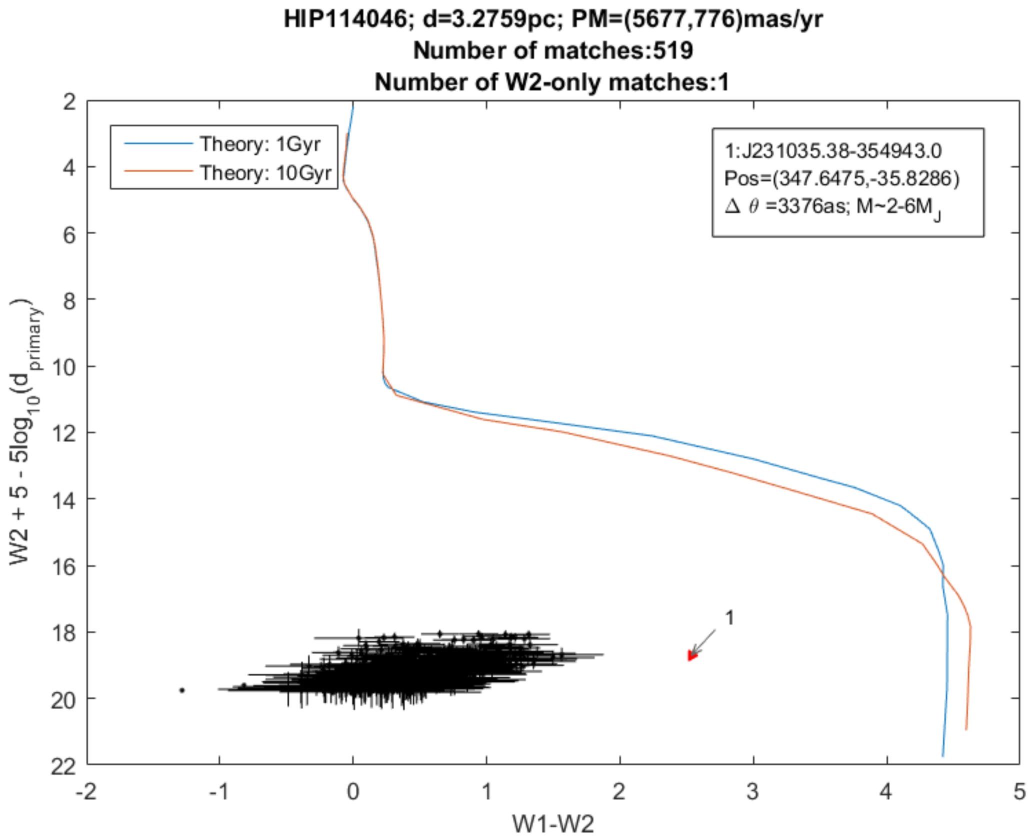
Path across the sky (proper motion + parallax) traced out by LHS 239

Searching for low-mass companions to high proper motion stars with WISE

Ben Yelverton, Mark Wyatt & Grant Kennedy (IoA, University of Cambridge)



Wide CPM brown dwarf at 2.48°
(2.2x10^5AU) from HIP55955?



A very red, W2-only CPM
object around HIP114046

Searching for Wide, Low-Mass Planetary Companions in Archival Spitzer IRAC Data

Raquel Martinez, Adam Kraus
The University of Texas at Austin

Wide, Planetary Mass Companions Challenge Formation Theories

Over the past decade, a growing population of planetary-mass companions (<20 M_{Jup}; hereafter PMCs) orbiting young stars have been discovered at wide separations (100-500 AU) from their hosts. While this indicates these objects are a normal end result of star and planet formation, it is unclear whether these systems represent the low-mass extreme of the stellar binary model, or instead are the end result of a high-mass and wide-orbit extreme of planet formation theories. The final determination of which theory adequately describes how these objects form requires a statistically robust sample of PMCs from which general properties and demographics can be obtained.

Leveraging *Spitzer* to Increase Number of Known PMCs

The *Spitzer* mission (Werner et al. 2004) has obtained a wealth of wide and deep imaging of nearby molecular clouds and cores, including complete Infrared Array Camera (IRAC) maps of every major star-forming region within 300 pc (e.g., Evans et al. 2009) across its four channels (3.6, 4.5, 5.8, and 8 μm). By spanning a wide range of mid-infrared wavelengths, *Spitzer* allowed astronomers to peer inside obscured regions of the sky and gain more knowledge regarding the characteristics of star-forming regions in the solar neighborhood. Properties such as stellar association membership, binary frequency and disk populations are only a few examples of the science enabled by the mission. The extensive IRAC data set of nearby star-forming regions and associations has great potential to be mined for as yet undiscovered wide companions to stars. The instrument can resolve companion separations above 240 AU at the distances of Taurus or Upper Scorpius (145 ± 15 pc; Torres et al. 2009). Thus, IRAC is able to resolve these systems with projected separations greater than 1-10". It is also sensitive enough to detect the photospheres of proto-brown dwarfs and protoplanets (M_{lim} = 1 M_{Jup} at 1 Myr and 2 M_{Jup} at 5 Myr, according to the DUSTY models of Chabrier et al. 2000). IRAC's limits are even deeper for hosts of circumplanetary disks, which would add substantial infrared excesses. In an effort to increase the numbers of wide PMCs, we are developing an automated pipeline that searches for these objects in archived IRAC images utilizing point spread function (PSF) subtraction.

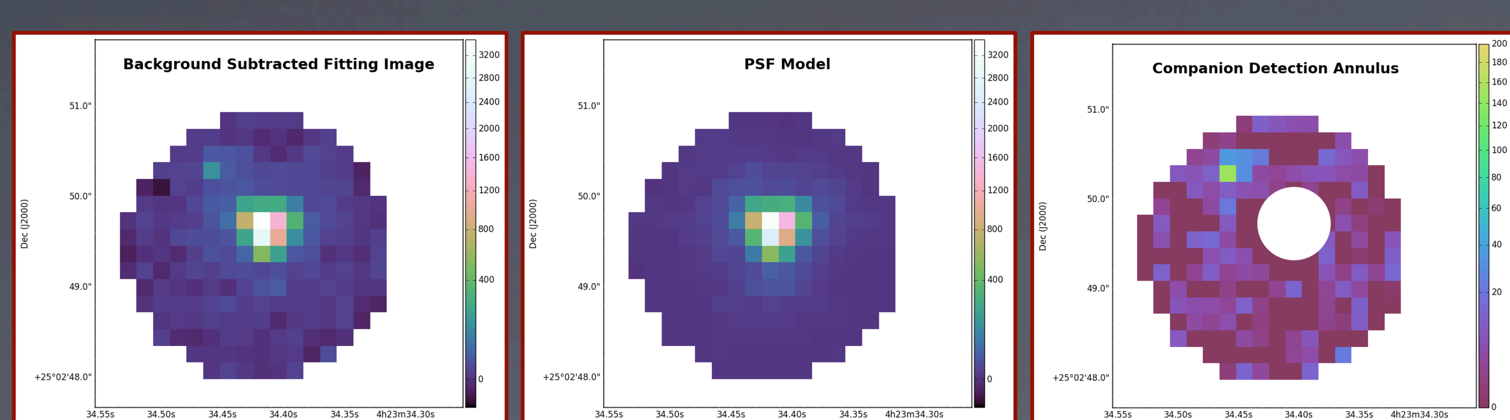


Fig. 1 (Above): Example pipeline output for FU Tau. The leftmost panel is the portion of the IRAC image that is sent through the pipeline to be fit. The middle panel is the best-fit PSF model. The rightmost panel is the residual image with problematic central pixels for the PSF-subtracted primary masked.

Automated PSF-Fitting Algorithm Workflow

- Query IRSA/SHA with object coordinates from command line
- Download all publicly available IRAC "corrected basic calibrated data"
- Generate IRAC PSF utilizing "effective PSFs" provided by *Spitzer* Science Team
- Model IRAC PSF via Markov Chain Monte Carlo (MCMC) algorithm (Metropolis-Hastings fitter with Gibbs Sampler)
  - Four parameters allowed to vary; x-pixel of primary centroid, y-pixel of primary centroid, sky background, and flux)
  - Initial sky background estimated from 8 pixel wide annulus of inner radius equal to 12 pixels, centered on the initial centroid estimate. Annulus undergoes sigma-clipping to find its median pixel value, ensuring cosmic ray hits and nearby sources do not heavily influence the estimate.
  - Initial flux estimate determined by summing pixel values in a 10 pixel radius centered on the initial centroid guess, then subtracting previously determined background estimate.
- Subtract χ^2-minimizing PSF to produce residuals image
- Ascertain presence of a potential companion within residuals image (see Figure 1)

This single component fitter was easily generalizable to a two-component fitter by introducing three more free parameters; x-pixel position of companion, y-pixel position of companion, and Δmag in the IRAC Channel. The two-component subtraction results for an image of USco 1910-2502 are shown in Figure 2.

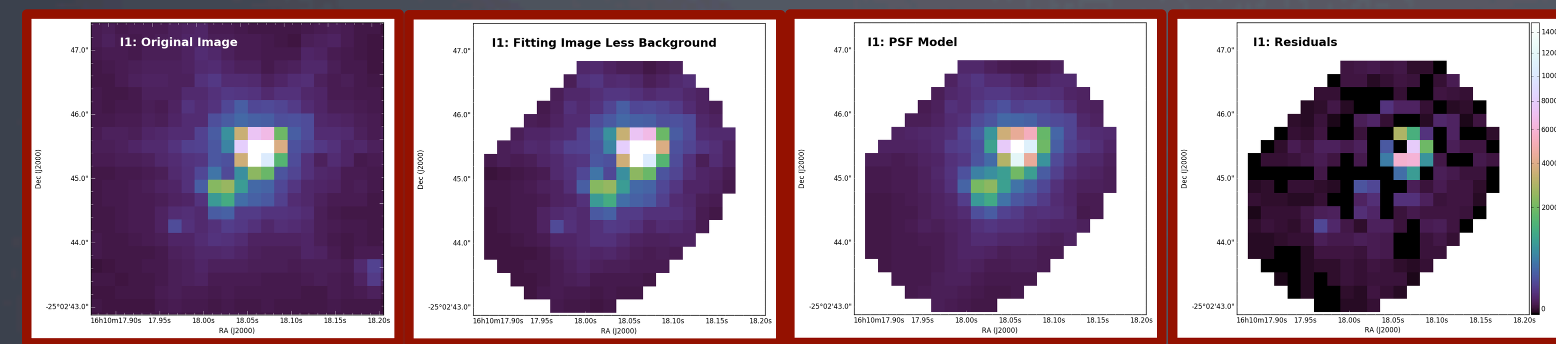


Fig. 2 (Above): Output Channel 1 images of USco 1610-2502 as it goes through the pipeline. Leftmost panel is the original image downloaded from IRSA/SHA. Second panel is the background subtracted fitting image. Third panel is the best-fit PSF model. Fourth panel are the residuals left over after the PSF model is subtracted.

Signaling of Potential Companion

"Potential companion detection" images are automatically created after the MCMC runs. We zero out problematic central pixels and create a circular cut out of the residuals image with an 8 pixel radius of the best-fit centroid. The median value for the annuli "potential companion detection" images are found via sigma-clipping. Finally, the user is notified of a potential companion if 5 pixels in the annulus are greater than 3σ above the sigma-clipped median value. Detection images are also vetted visually. Example images of the pipeline output are shown in Figure 1 while "potential companion detection" images are shown in Figure 3.

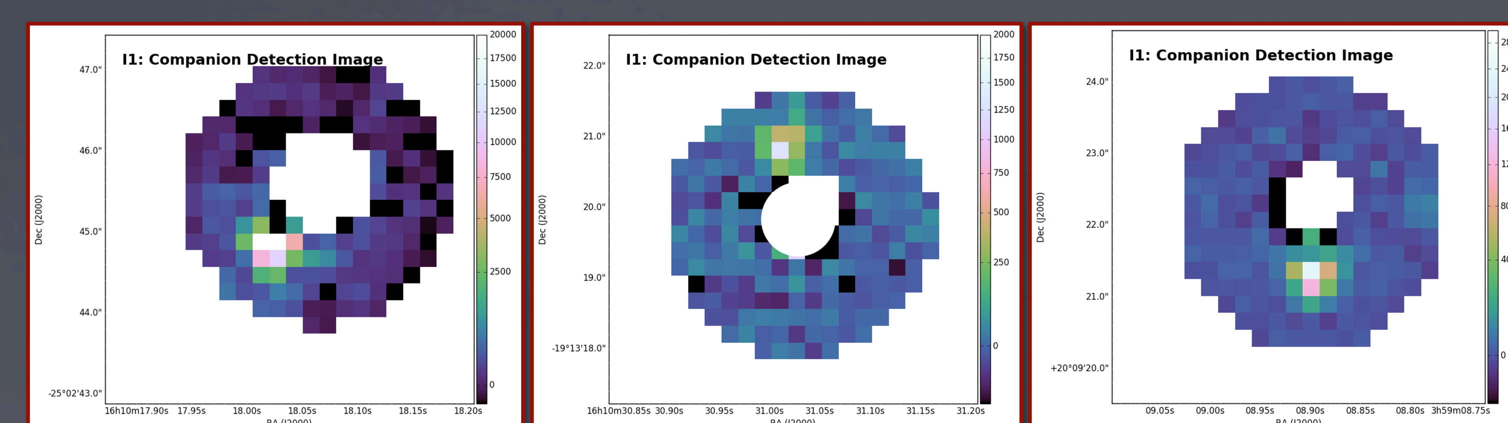


Fig. 3 (Above): "Potential companion detection" images for (from left to right) USco 1610-2502, USco 1610-1913, and SJ0359+2009.

Known PMC System Test Cases

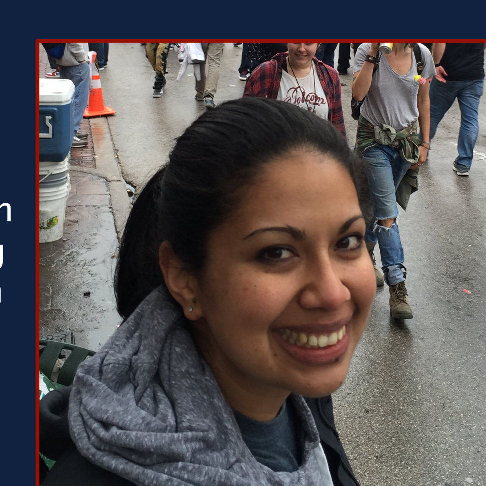
Name	Separation (arcsec)	Position Angle (deg)	ΔK_s (mag)	Ref.
SCH J0359099+2009362	4.660 ± 0.005	264.275 ± 0.003	1.965 ± 0.005	1
FW Tau	2.295 ± 0.003	295.0 ± 0.5	5.15	2
FU Tau	5.72 ± 0.1	123.2 ± 1.0	4.12 ± 3.88	3
2MASS J04554970+3019400	7.313 ± 0.007	129.15 ± 0.02	1.770 ± 0.05	2
SCH J0537385+2428518	1.684 ± 0.008	152.84 ± 0.14	7.27 ± 0.13	2
CHXR 28 Aa+B	1.818 ± 0.003	115.9 ± 0.0	0.32 ± 0.04	4
T51	1.977 ± 0.001	162.5 ± 0.1	2.35 ± 0.03	4
USco 1610-1913	5.820 ± 0.009	114.01 ± 0.10	3.83 ± 0.05	5,6
USco 1610-2502	4.896 ± 0.002	241.24 ± 0.02	2.9	5,6
SCH J16111711-22171749	4.207 ± 0.004	344.41 ± 0.02	5.66 ± 0.05	1
SCH J16151115-24201556	5.100 ± 0.005	141.03 ± 0.01	4.74 ± 0.02	1

NOTE. — System properties obtained from the following references: (1) Kraus & Hillenbrand (2012); (2) Kraus et al. (2014); (3) Luhman et al. (2009); (4) Lafrenière et al. (2008); (5) Kraus & Hillenbrand (2009); (6) Aller et al. (2013).

In an attempt to quantify the detection limits of our novel PSF-fitting routine, we chose a handful of objects from binary and multiple frequency surveys in the literature to build a sample of test cases. They have a variety of projected separations (~ 1.7″– ~ 7″) and K_s band contrasts (0.3 – 7.2 mag), as listed in the table above.

Initial tests of the algorithm were performed on *Spitzer*/IRAC archival images of 11 young, low-mass (0.044-0.88 M⊙; K3.5-M7.5) stars in 3 nearby star-forming regions (Chameleon, Taurus, and Upper Scorpius) known to have faint, low-mass companions orbiting them. The PSF-fitting routine is currently able to recover 7 low-mass companions out of the 11 of the systems tested (see Figure 4).

About the Author



Raquel Martinez is a 3rd year graduate student at the University of Texas after having received her B.S. in Astrophysics from Caltech, then her M.A. in Astronomy from Wesleyan University. Her research interests include studying the stages of star and planet formation, and high-resolution imaging of exoplanets. When not searching for PMCs, she enjoys all that Austin, TX has to offer. Hook 'em!
Email: ram@astro.as.utexas.edu

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THE UNIVERSITY OF TEXAS AT AUSTIN

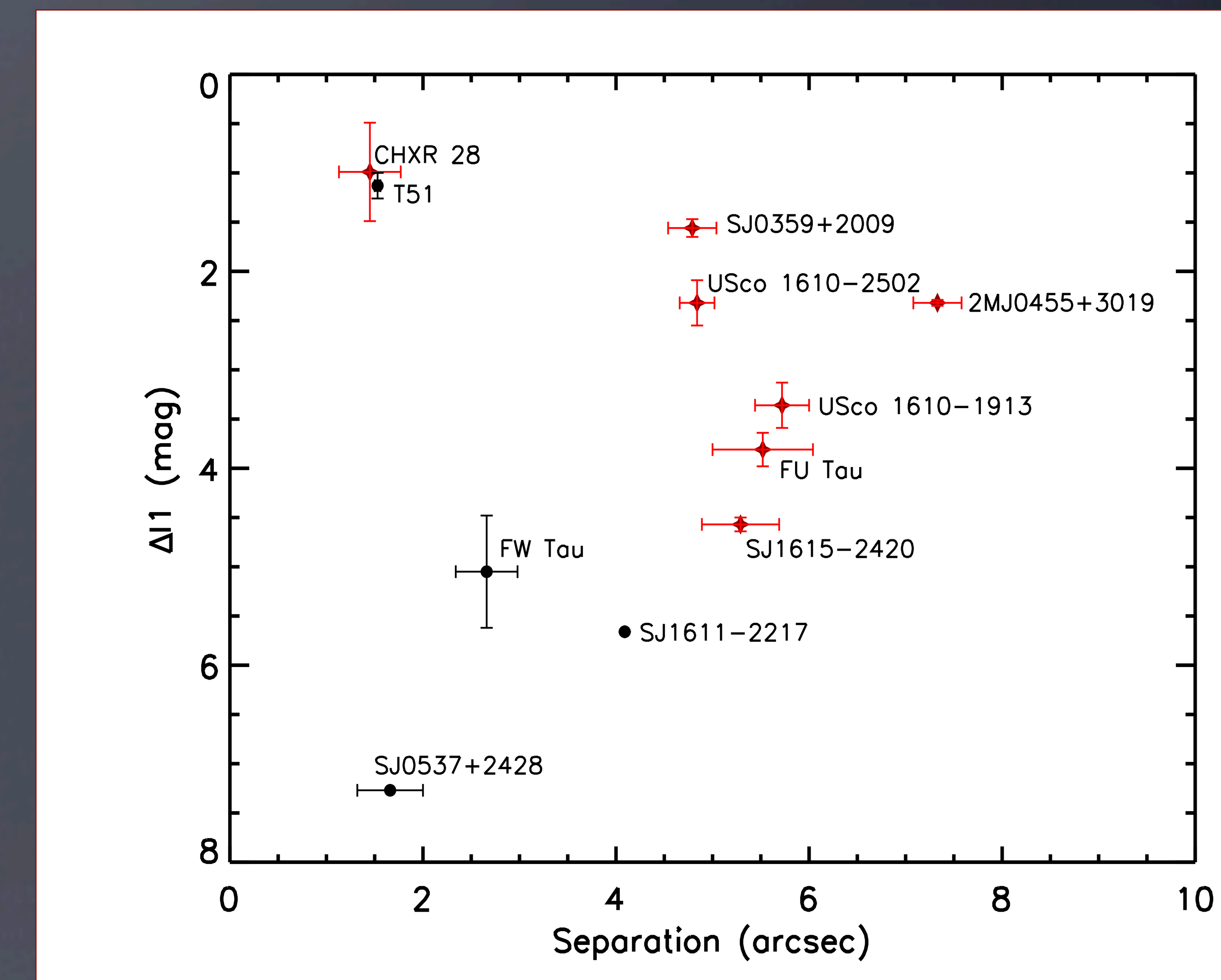


Fig. 4 (Above): Test case objects' Δ*I1* magnitudes versus separation. The moderately separated and brighter companions were recovered by the single component fitter (red stars) while the closer-in, fainter companions were not (black dots). Even so, the double two-component fitter was still able to measure reasonable IRAC photometry for most of our test sample.

Preliminary Results

Object	$[I1]-[I2]$ (mag)	$[I1]-[I3]$ (mag)	$[I1]-[I4]$ (mag)	$[I2]-[I3]$ (mag)	$[I2]-[I4]$ (mag)	$[I3]-[I4]$ (mag)
SCH J0359099+2009362	0.05 ± 0.38	0.15 ± 0.47	1.05 ± 0.67	0.10 ± 0.39	1.00 ± 0.62	0.90 ± 0.67
FW Tau	0.19 ± 0.82	-0.30 ± 0.60	0.37 ± 1.34	-0.49 ± 0.57	0.18 ± 1.33	0.67 ± 1.21
FU Tau	0.45 ± 0.18	1.93 ± 0.10	1.69 ± 0.21	1.48 ± 0.15	1.24 ± 0.24	-0.24 ± 0.19
2MASS J04554970+3019400	-0.01 ± 0.16	-0.10 ± 0.23	0.23 ± 0.30	-0.09 ± 0.27	0.24 ± 0.33	0.33 ± 0.37
SCH J0537385+2428518	...	...	...	...	...	0.88 ± 0.58
CHXR 28 Aa+B	0.01 ± 0.65	0.22 ± 0.54	0.32 ± 0.61	0.21 ± 0.64	0.31 ± 0.69	0.10 ± 0.60
T51	-0.65 ± 0.56	0.07 ± 046	0.17 ± 0.41	0.72 ± 0.68	0.82 ± 0.65	0.10 ± 0.57
USco 1610-1913	0.11 ± 0.29	...	0.34 ± 0.34	...	0.23 ± 0.22	...
USco 1610-2502	-0.02 ± 0.27	0.26 ± 0.30	0.83 ± 0.24	0.28 ± 0.21	0.85 ± 0.11	0.57 ± 0.18
SCH J16111711-22171749	...	...	...	...	...	...
SCH J16151115-24201556	0.49 ± 0.07	0.09 ± 0.40	...	-0.40 ± 0.39	...	...

NOTE. — Errors reported for the properties of each object were determined by calculating the standard error of the mean from images that reached a plausible minimum in each channel. The uncertainties are expected to decrease substantially once all of an object's IRAC images are fit. If an entry is missing, either no IRAC data existed for that object or no images were adequately fit in that IRAC Channel.

The two-component fit version of our pipeline measured astrometry and the infrared photometry of these systems across the four IRAC channels simultaneously (see above table). We find 3 of the companions in these systems to have non-zero [*I1*] – [*I4*] colors, signifying the potential presence of a circumstellar disk.

Future Work

This PSF-fitting algorithm has not only recovered known low-mass companions from the literature, but has also measured mid-infrared photometry for these multiple systems. The fact that companions with known disks were recovered by the pipeline speaks to the great promise this avenue of inquiry has for finding new PMCs. Even so, there is still room for improvement of the pipeline before it can be a fully automated, "hands-free" PSF-fitting routine. Such tasks include:

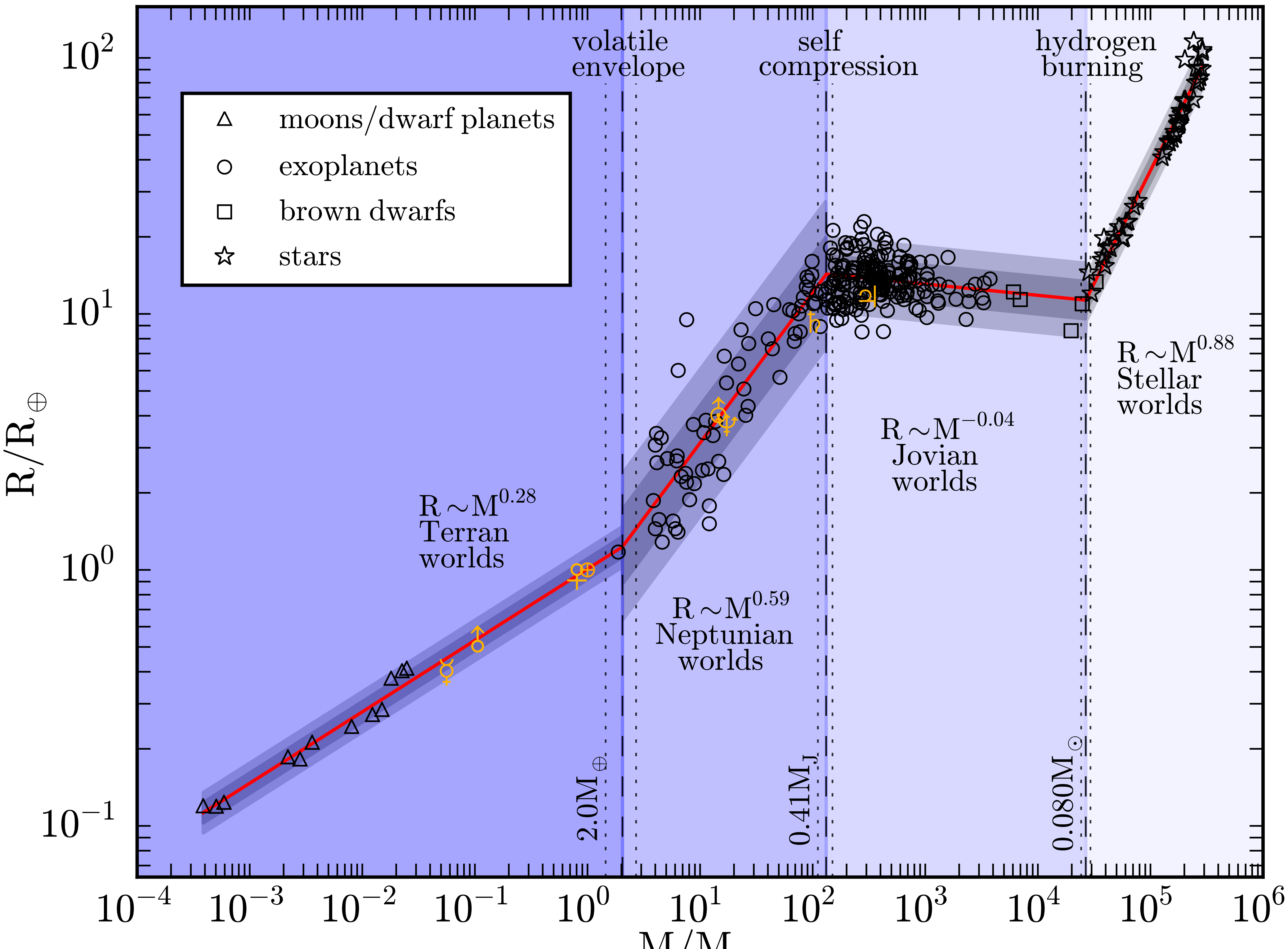
- Incorporate capability to adaptively adjust size of fitting image, allowing brighter stars to go through pipeline
- Recognize presence of comparably bright, nearby sources in fitting images
- Determine whether *Spitzer*/IRAC image artifact mitigation pipeline is adequately rectifying saturated pixels
- Utilize Source Extractor (Bertin & Arnouts 1996) for robust source identification, companion signaling, and bad/saturated pixel flagging (*in progress*)

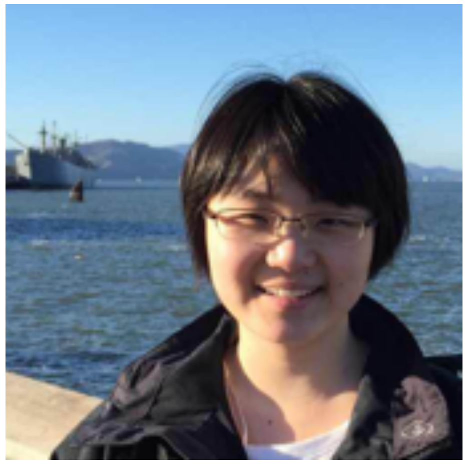
Known companions with unrecognized disks and candidate companion objects detectable in the *Spitzer*/IRAC data should easily be resolved with ground-based telescopes in good seeing. Photometric and spectroscopic follow-up in both the optical and infrared is valuable, especially if a disk around a low-mass companion is suspected.

Increasing the number of PMCs observed will allow us to explore the poorly populated parameter space of wide orbit and planetary mass companions, placing better constraints on the models of extreme binary star and planet formation. Ultimately, this will serve to better our understanding of how these systems originated and evolved.

PROBABILISTIC FORECASTING OF THE MASSES AND RADII OF OTHER WORLDS

Columbia University
In the City of New York



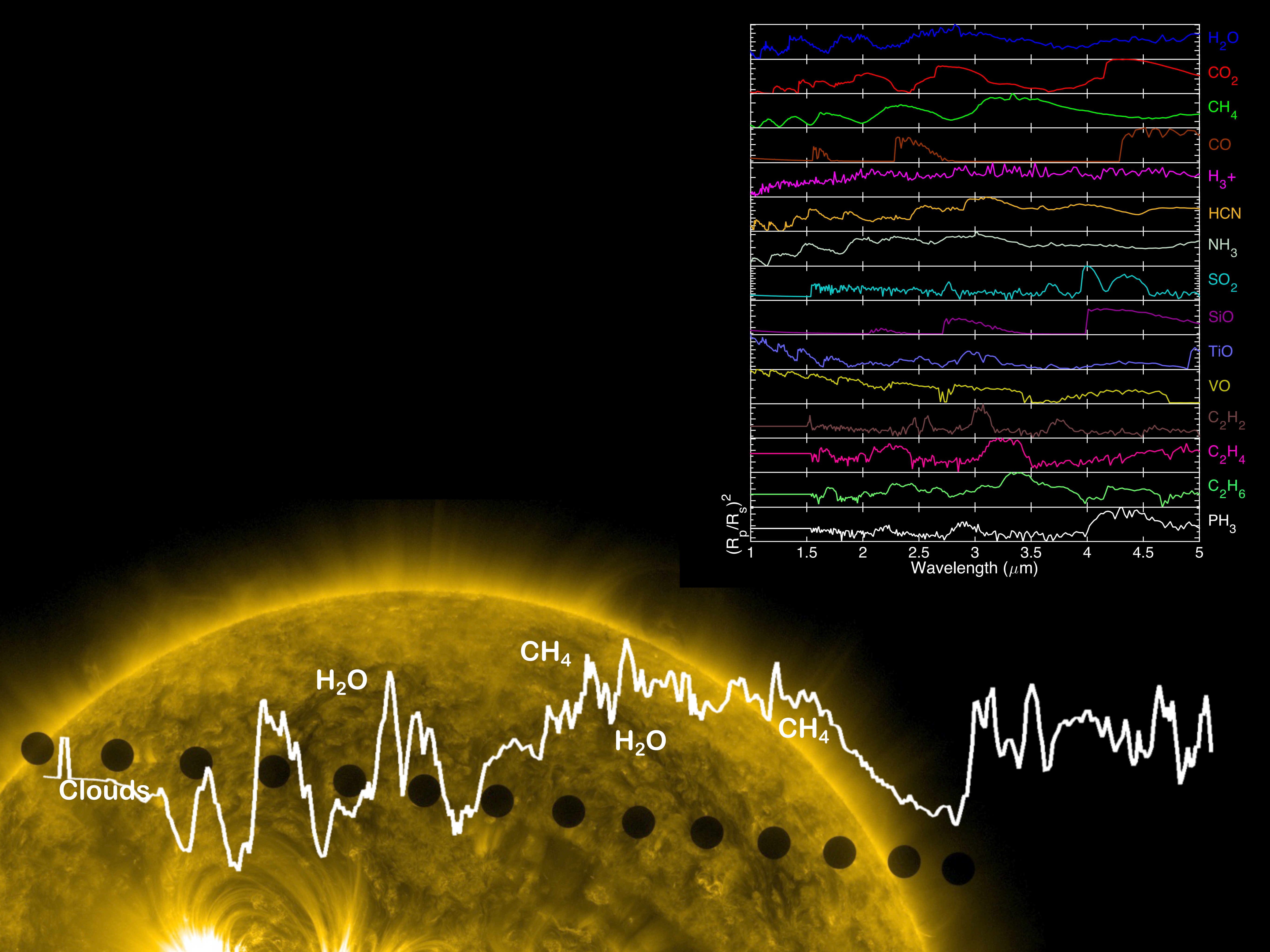


Jingjing Chen

arXiv:1603.08614

GitHub:chenjj2/forecaster

ORBYTS 2016



H_2O
CO_2
CH_4
CO
H_3+
HCN
NH_3
SO_2
SiO
TiO
VO
C_2H_2
C_2H_4
C_2H_6
PH_3
$(R_p/R_s)^2$
1
1.5
2
2.5
3
3.5
4
4.5
5
Wavelength (μm)
Clouds
H_2O
CH_4
H_2O
CH_4