Astrometry of Directly Imaged Exoplanets after PSF Subtraction using MCMC Forward Modeling

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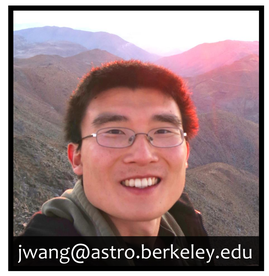

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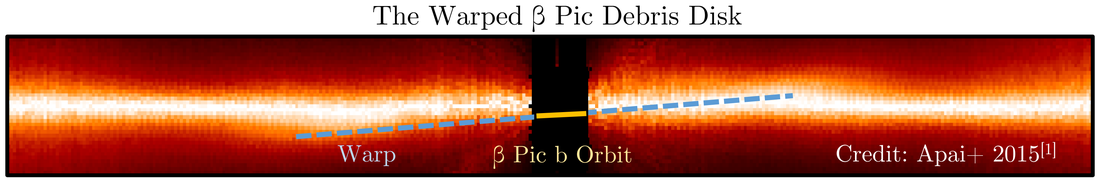
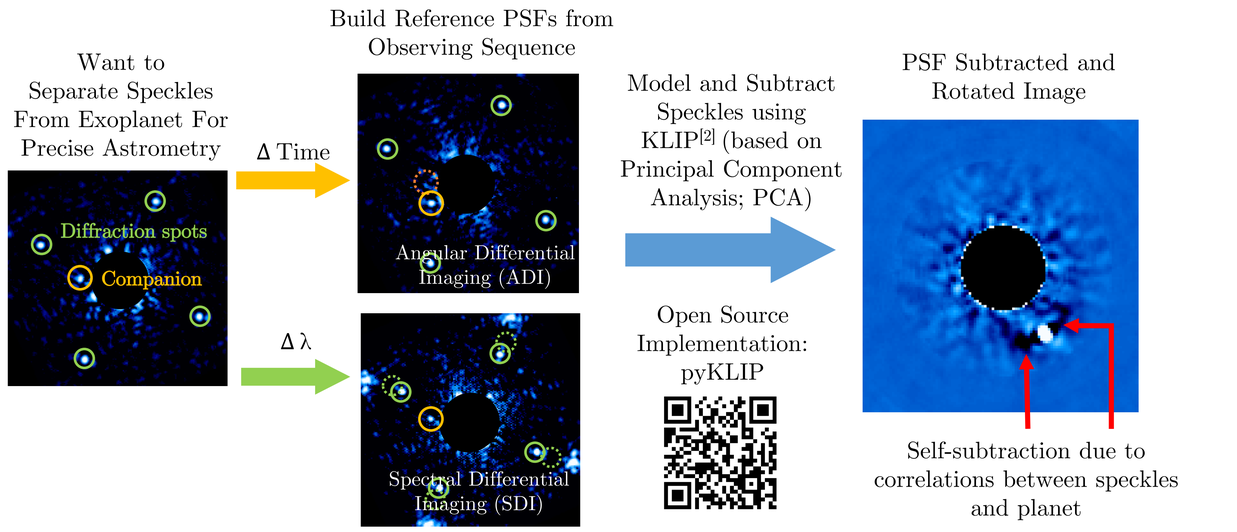
The β Pictoris System

The Warped β Pic Debris Disk



- β Pictoris b (~10 M_{Jup}) is likely inducing a warp in the debris disk
- Planet's orbit gives insight on disk dynamics, dynamical history, and possible unseen planets
- Possibly the first directly-imaged exoplanet to also transit
- Gemini Planet Imager (GPI) astrometric monitoring program (PI: Graham) to constrain orbit of β Pic b so far has two years of data

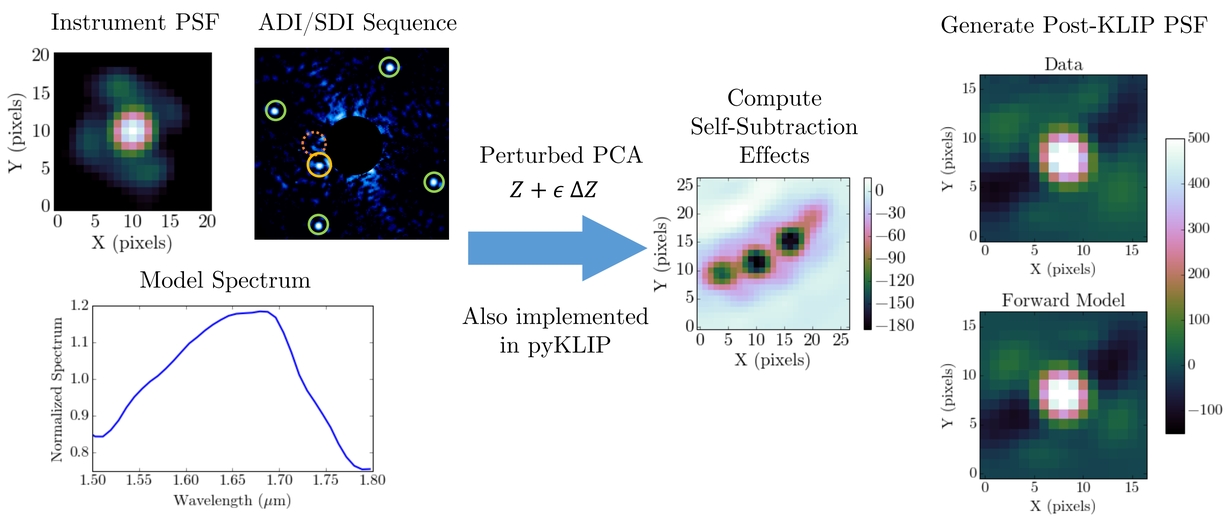
Problem: PSF Subtraction Distorts Planet's PSF



- Traditionally, distortion of the planet PSF is a nuisance term that needs to be calibrated by repeating the analysis with fake planet injections

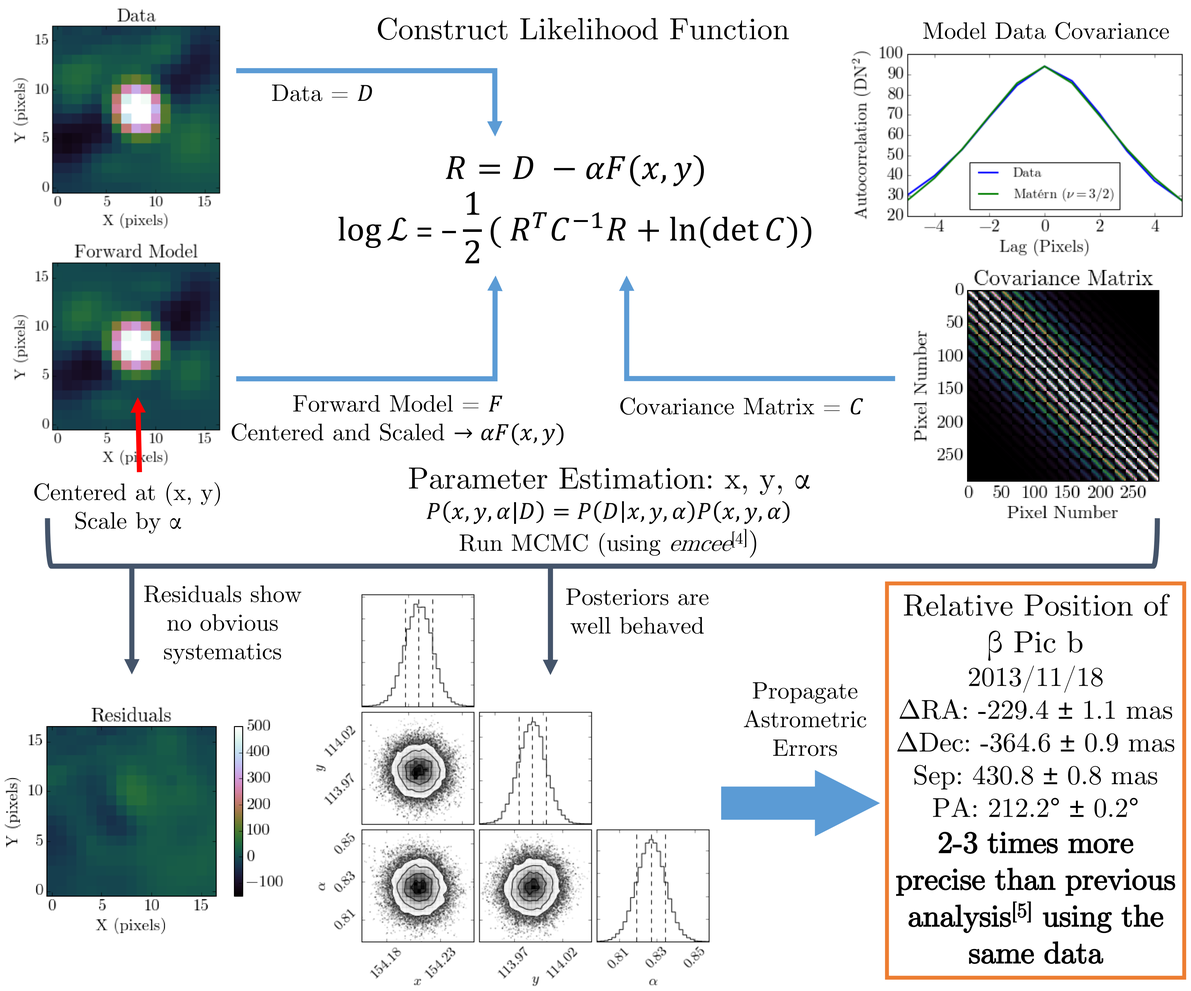
KLIP-FM Computes the Distorted PSF

- The existence of the planet PSF in the reference PSFs will cause the planet to appear in the model and subtract itself
- Effect can be calculated analytically with KLIP-FM developed by Pueyo[3] (see poster 138.01)
- pyKLIP: Open-source implementation of KLIP and KLIP-FM



Astrometry using Forward Models, MCMC, and Gaussian Processes

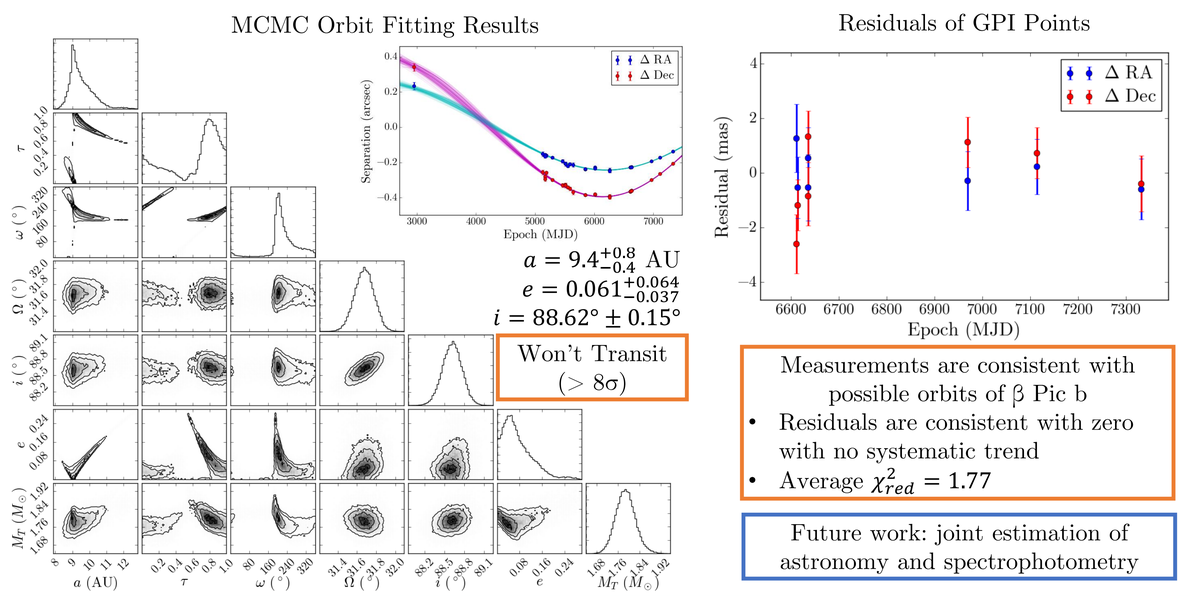
- Self-subtraction effects actually give us information on the location of the planet, so we can use our forward models to derive better astrometry
- Markov-Chain Monte Carlo (MCMC) gives the posterior of possible positions of the planet
- Gaussian processes necessary to model the correlated nature of the noise and for accurate estimation of the statistical errors



Relative Position of β Pic b
2013/11/18
ΔRA: -229.4 ± 1.1 mas
ΔDec: -364.6 ± 0.9 mas
Sep: 430.8 ± 0.8 mas
PA: 212.2° ± 0.2°
2-3 times more precise than previous analysis[5] using the same data

Technique Validation through Orbit Fitting

- We measure the position of β Pic b in seven GPI datasets, combine with previous astrometric data, and fit an orbit (following the analysis in Millar-Blanchaer et al.[5])
- Orbit should follow Keplerian motion, so residuals will reveal any potential systematic errors and validate our calculated uncertainties



References:

[1] Apai , D., Scneider, G., Grady, C. A., et al. 2015, ApJ, 800, 136.
[2] Soummer, R., Pueyo, L. , & Larkin, J. 2012, ApJ, 755, 2.
[3] Pueyo, L. 2015, submitted.
[4] Foreman-Mackey, D., Hogg, D. W., Lang, D. & Goodman, J. 2013, PASP, 125, 306.
[5] Millar-Blanchaer, M. A., Graham, J. R., Pueyo, L. et al. 2015, ApJ, 811, 18.
[6] Foreman-Mackey, D., Price-Whelan, A., Ryan, G. et al. 2014, triangle.py, v0.1.1, Zenodo.

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