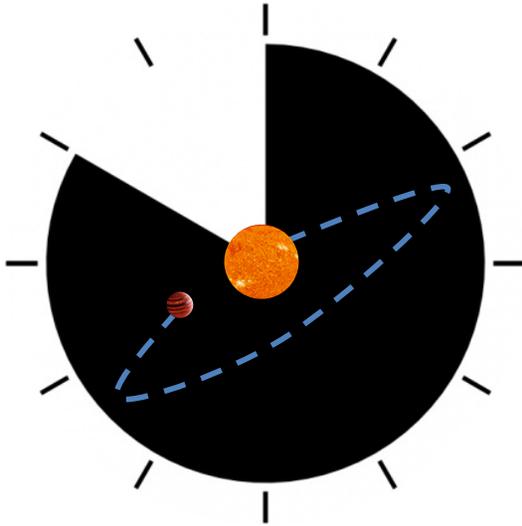


# ORBITS FOR THE IMPATIENT

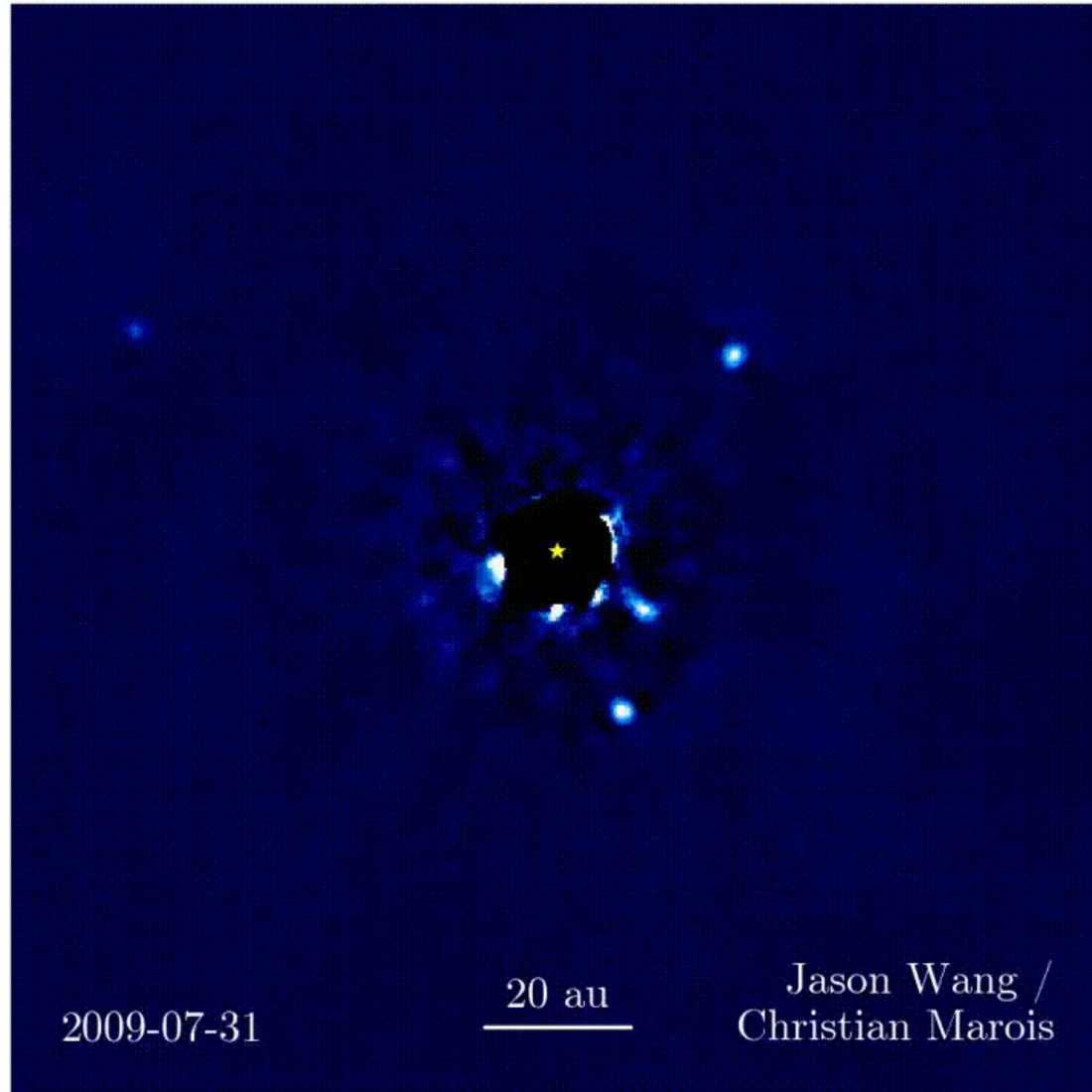


a Bayesian Rejection-sampling  
Algorithm for Rapidly Fitting the  
Orbits of Long-period Exoplanets

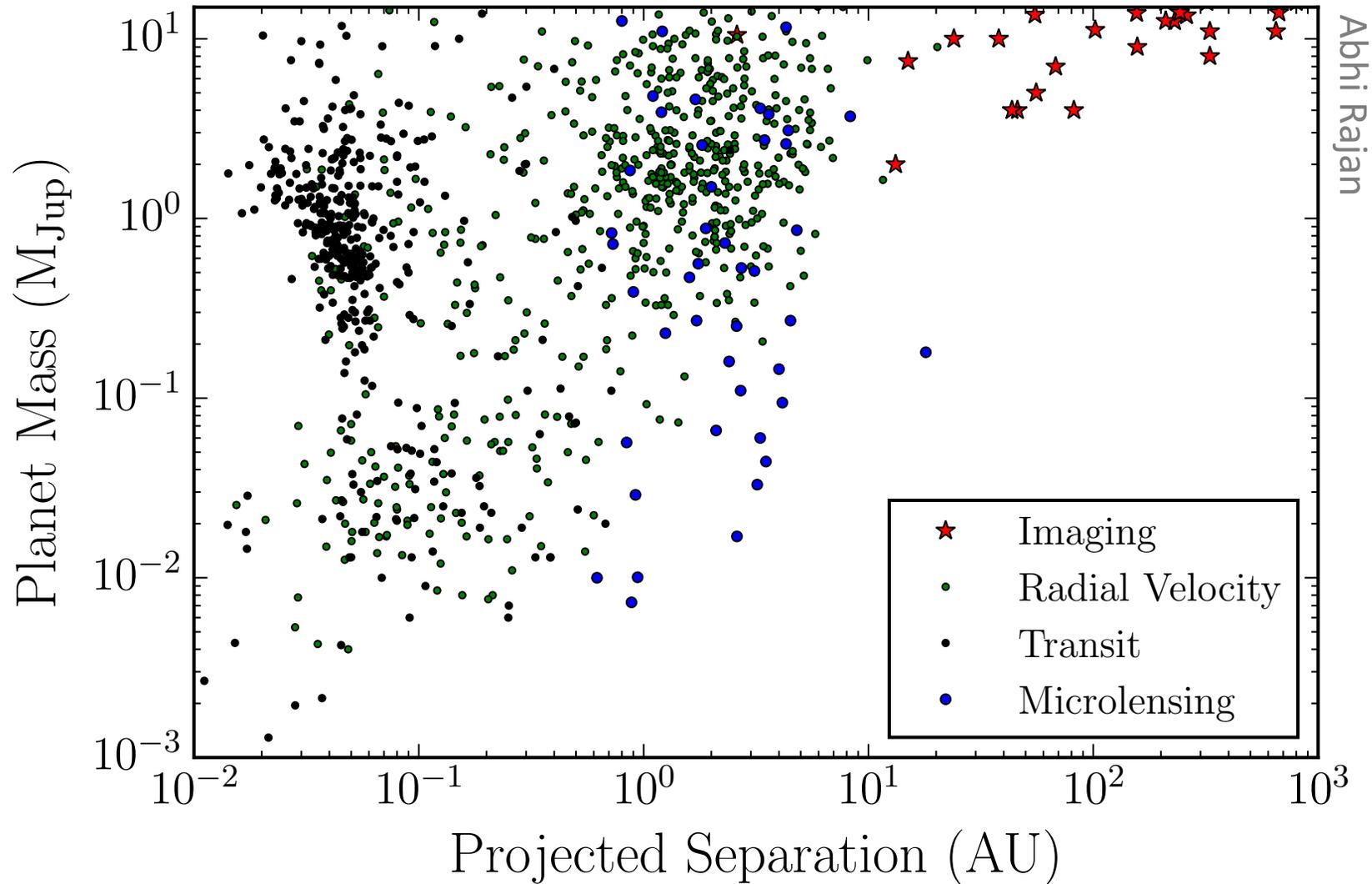
**SARAH BLUNT**

Eric Nielsen, Rob De Rosa, Quinn Konopacky,  
Dominic Ryan, Jason Wang, Laurent Pueyo, Julien Rameau,  
Christian Marois, Franck Marchis, Bruce Macintosh,  
James Graham, Gaspard Duchêne, & Adam Schneider

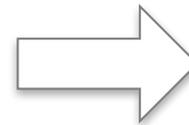
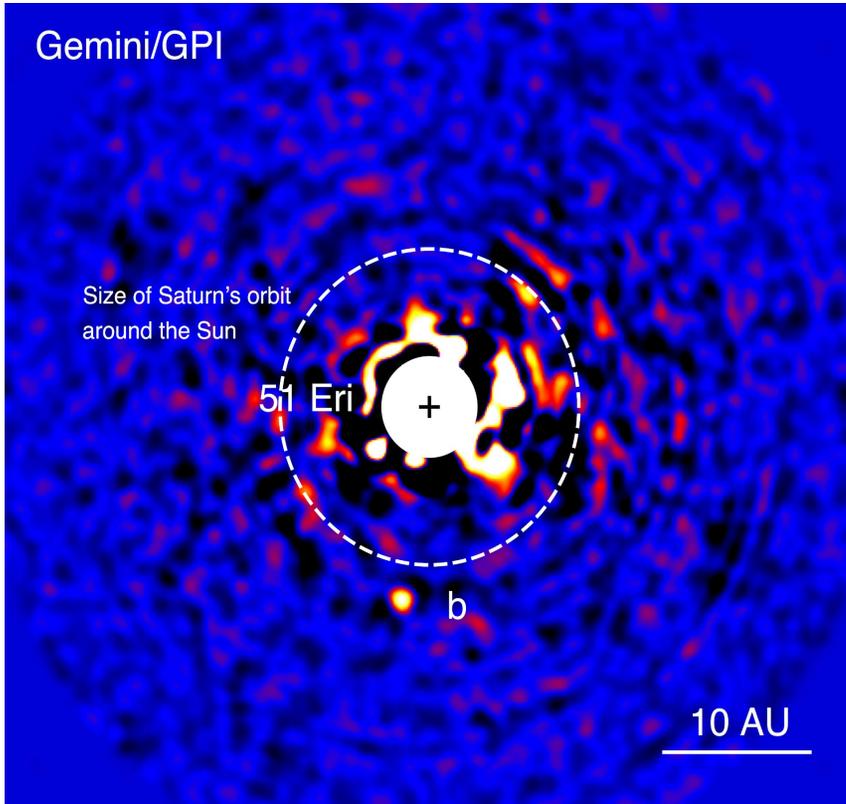
# Direct Imaging Reveals Orbital Motion



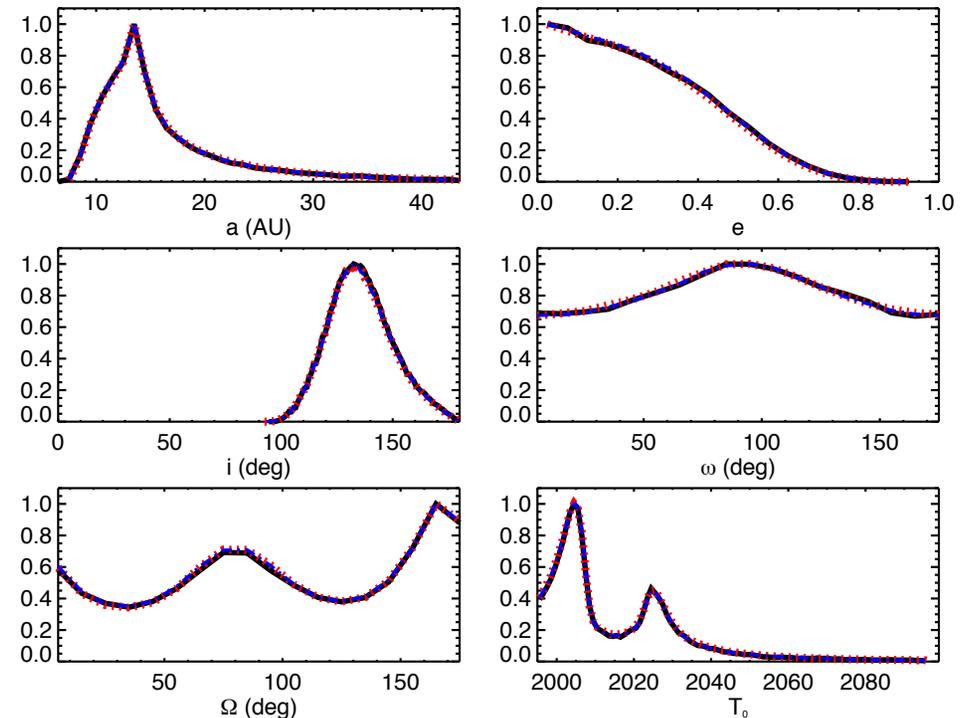
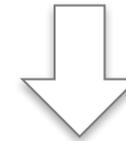
# Direct Imaging Probes New Regions of Parameter Space



# Orbit Fitting Lets Us Study Planets & Planet Formation

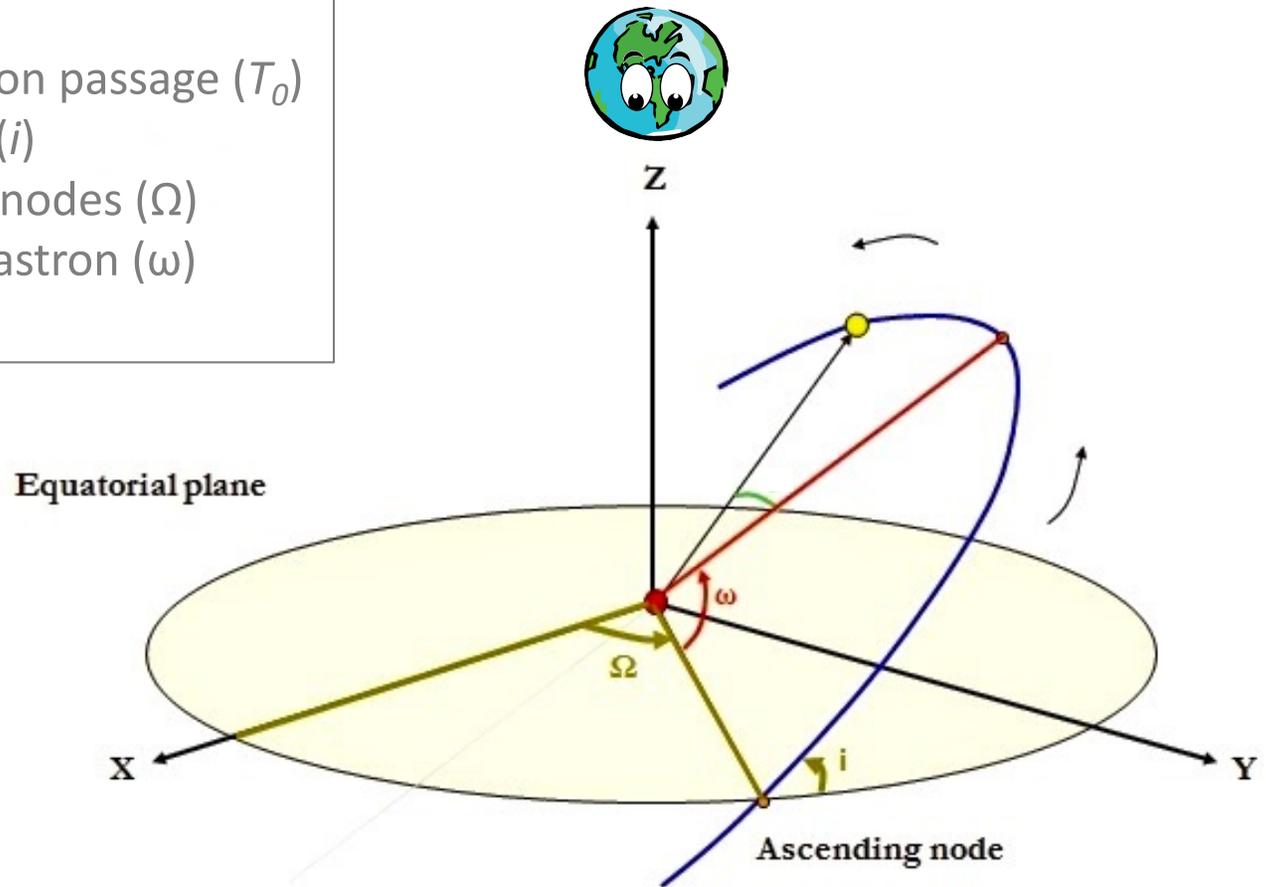


ASTROMETRY



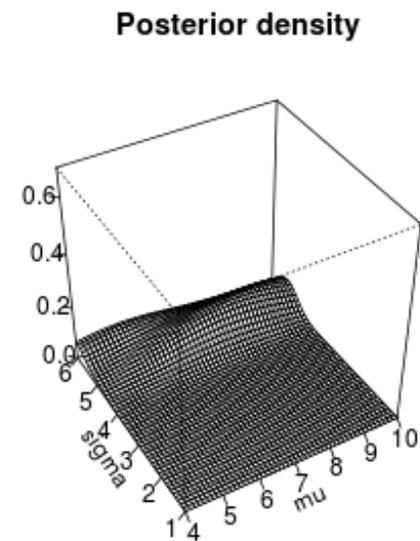
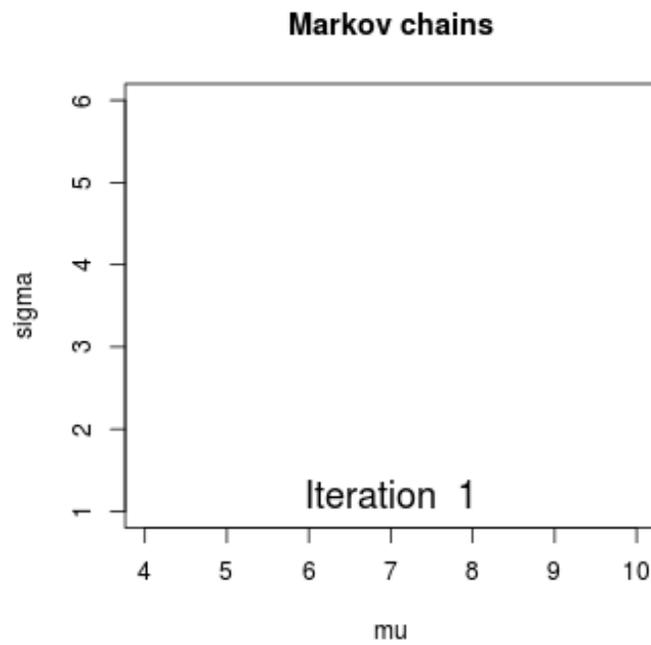
# Orbital Parameterization

1. semi-major axis ( $a$ )
2. eccentricity ( $e$ )
3. epoch of periastron passage ( $T_0$ )
4. inclination angle ( $i$ )
5. position angle of nodes ( $\Omega$ )
6. argument of periastron ( $\omega$ )
- (( 7. period ( $P$ ) ))



# Commonly Used Orbit Fitting Algorithms

## 1. Markov Chain Monte Carlo (MCMC)

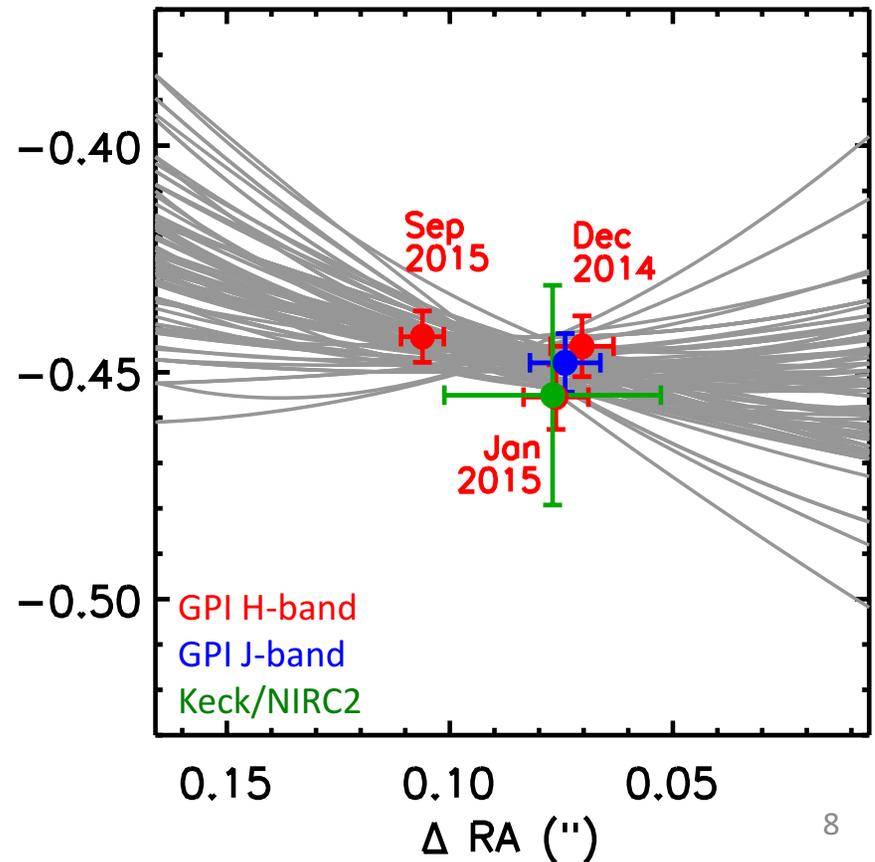
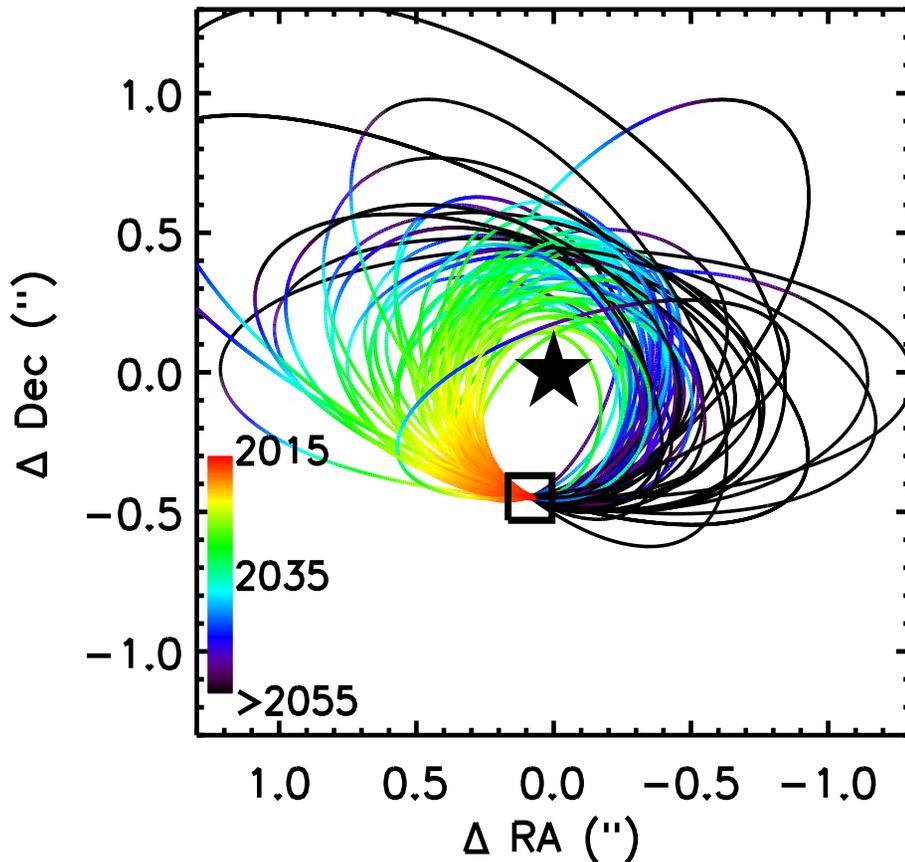


# Commonly Used Orbit Fitting Algorithms

(( 2. Least Squares Monte Carlo (LMSC) ))

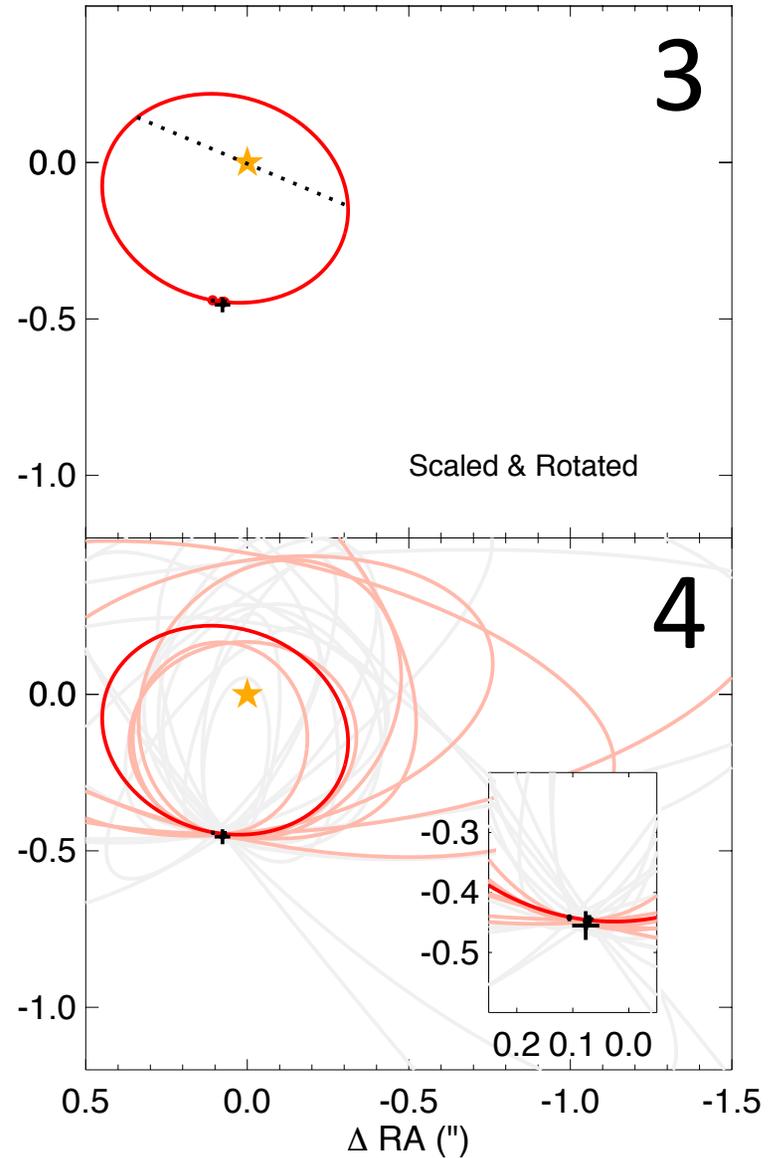
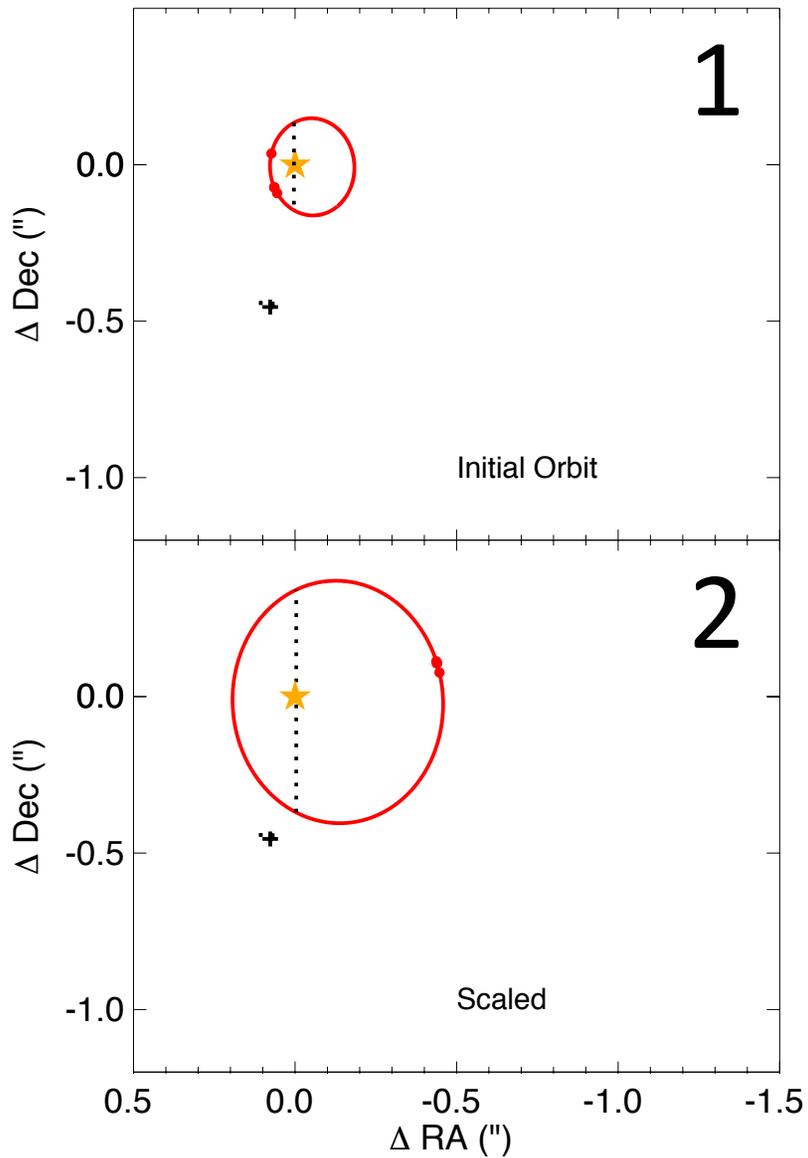
# The Problem

MCMC algorithms take too long to converge when accessible astrometry covers a short fraction of the total orbit.



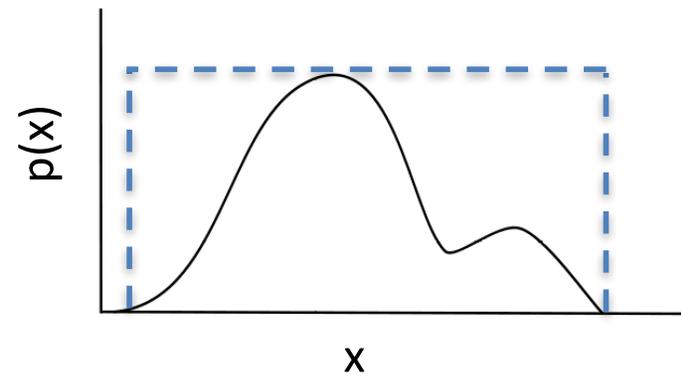
# The Solution

## Orbits for the Impatient (OFTI)

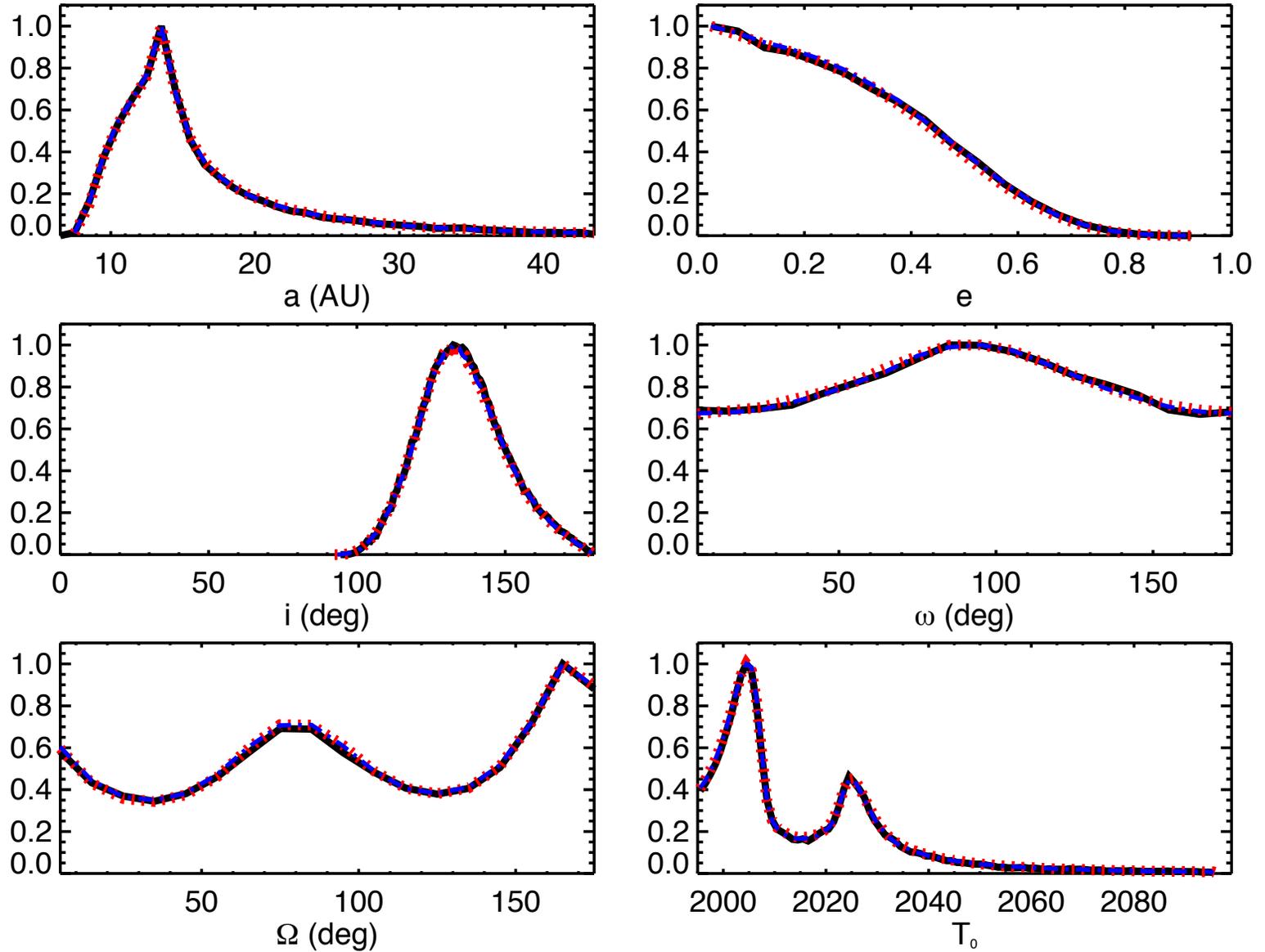


# Speedups & Tricks

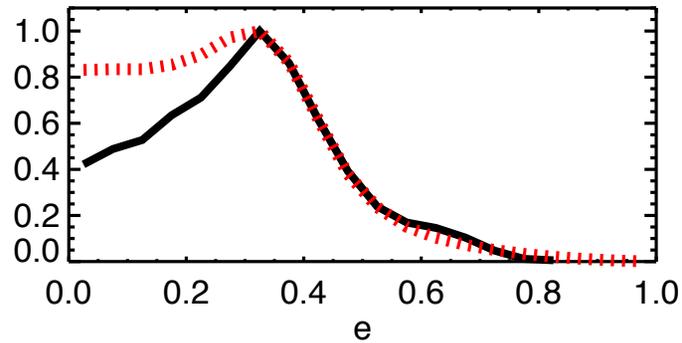
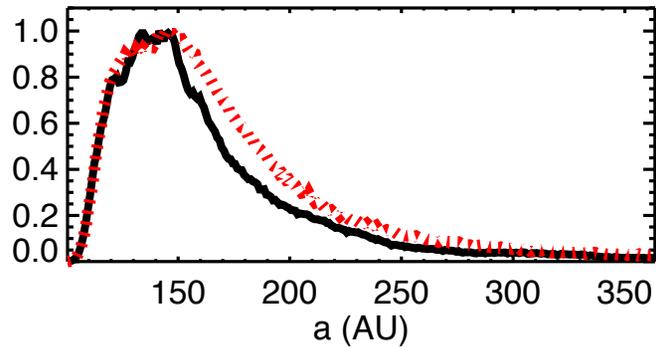
- Vectorized array operations instead of loops
- Runs in parallel
- Minimum  $\chi^2$  estimation
- Range restriction



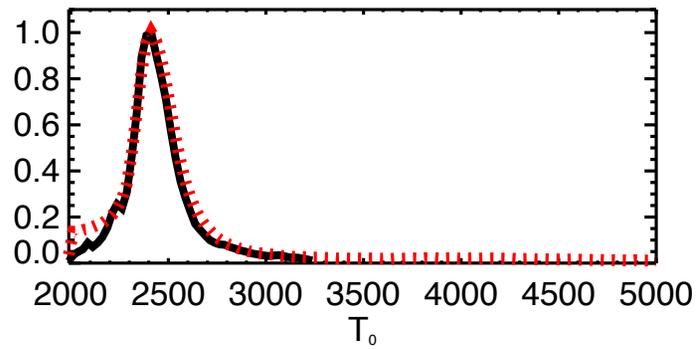
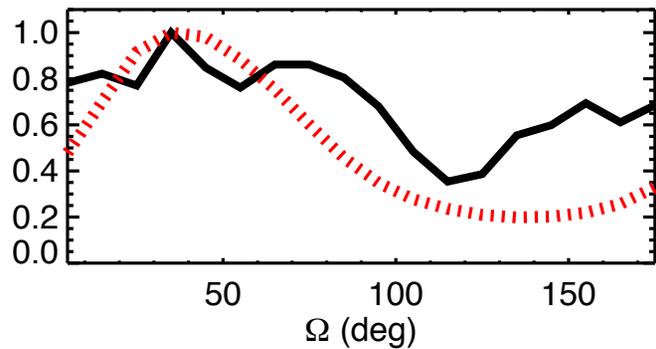
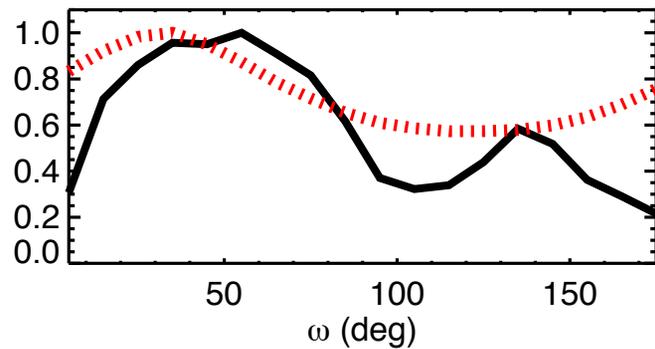
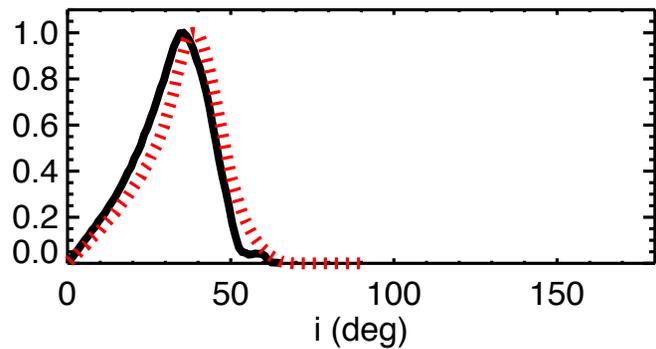
# Validation with MCMC



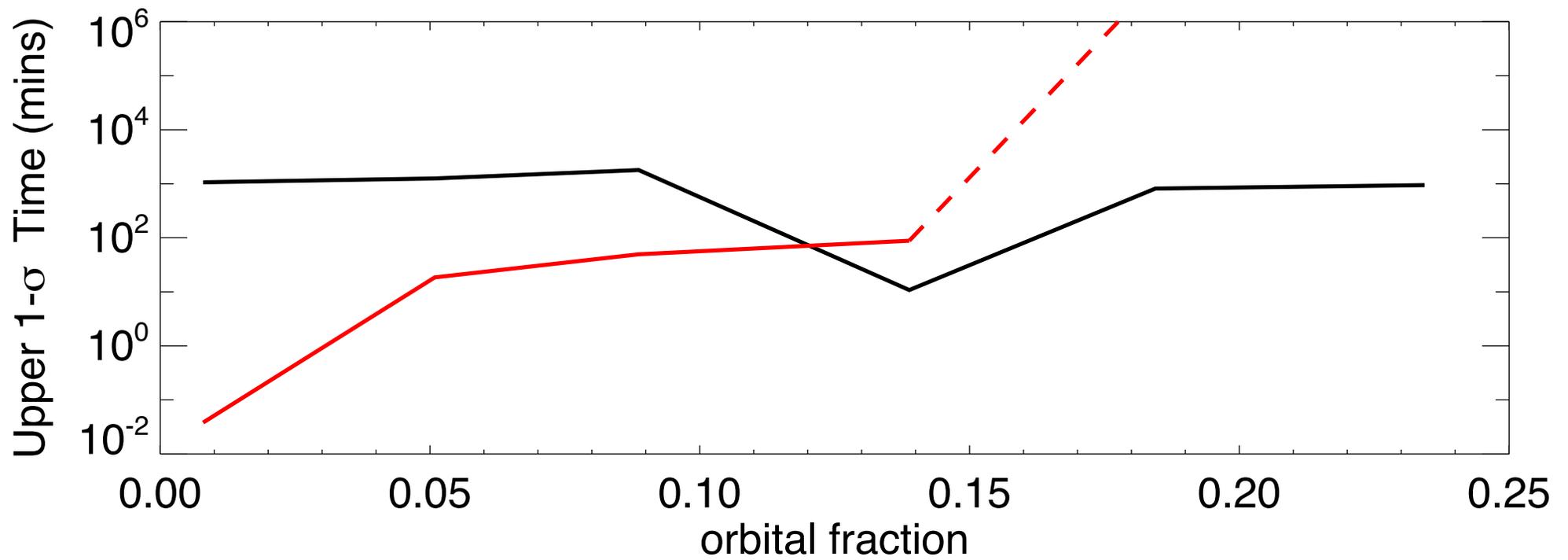
# Advantage Over MCMC



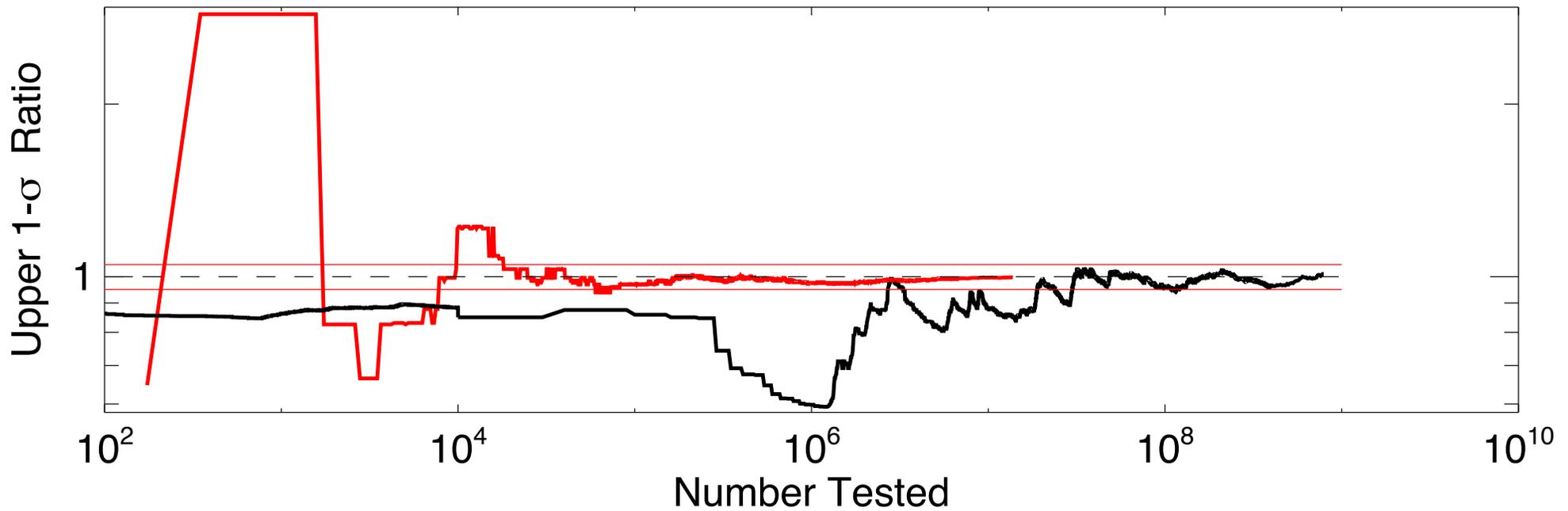
OFTI: 136 mins  
MCMC: 10 hours



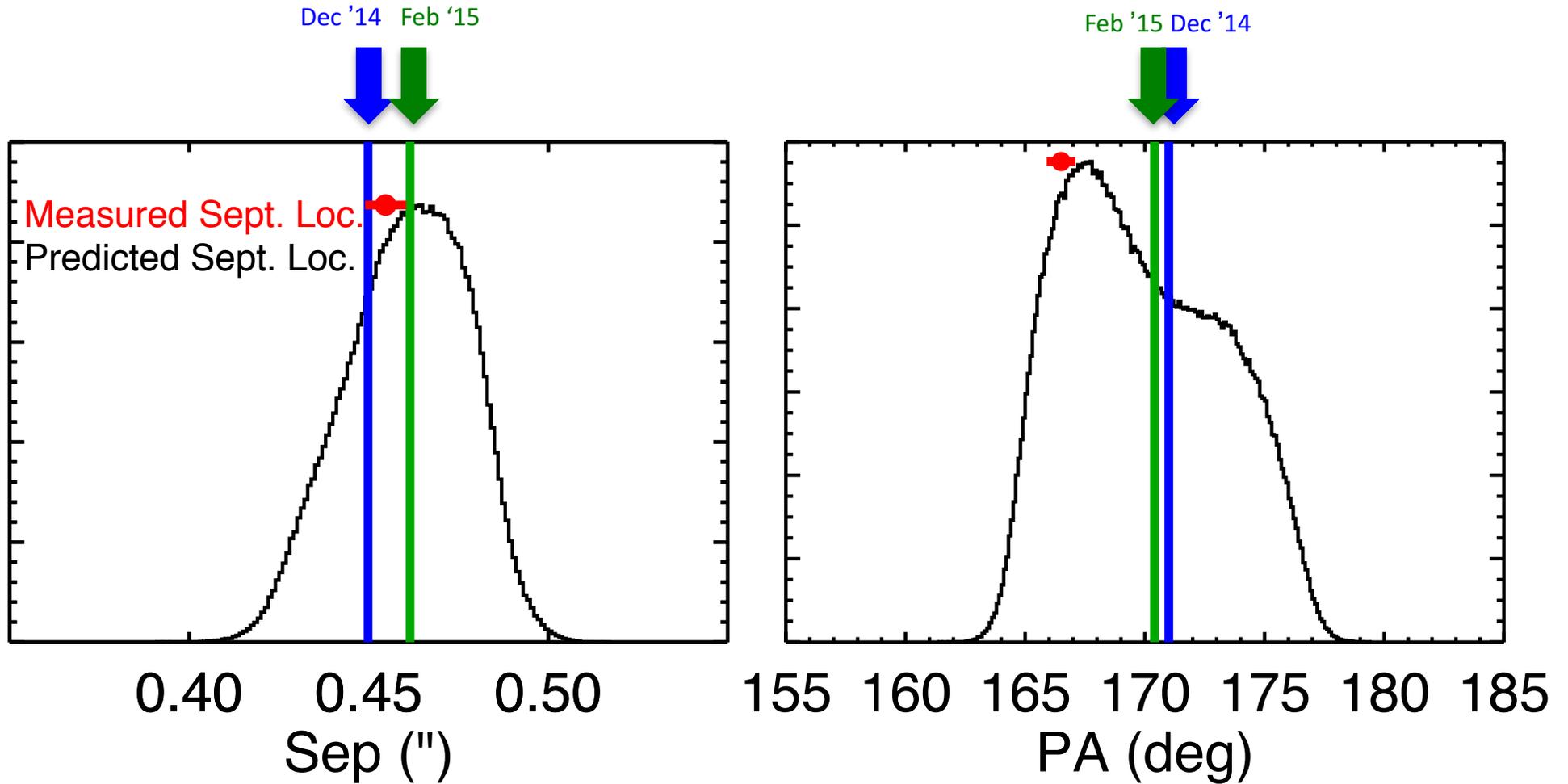
# OFTI > MCMC... But not Everywhere



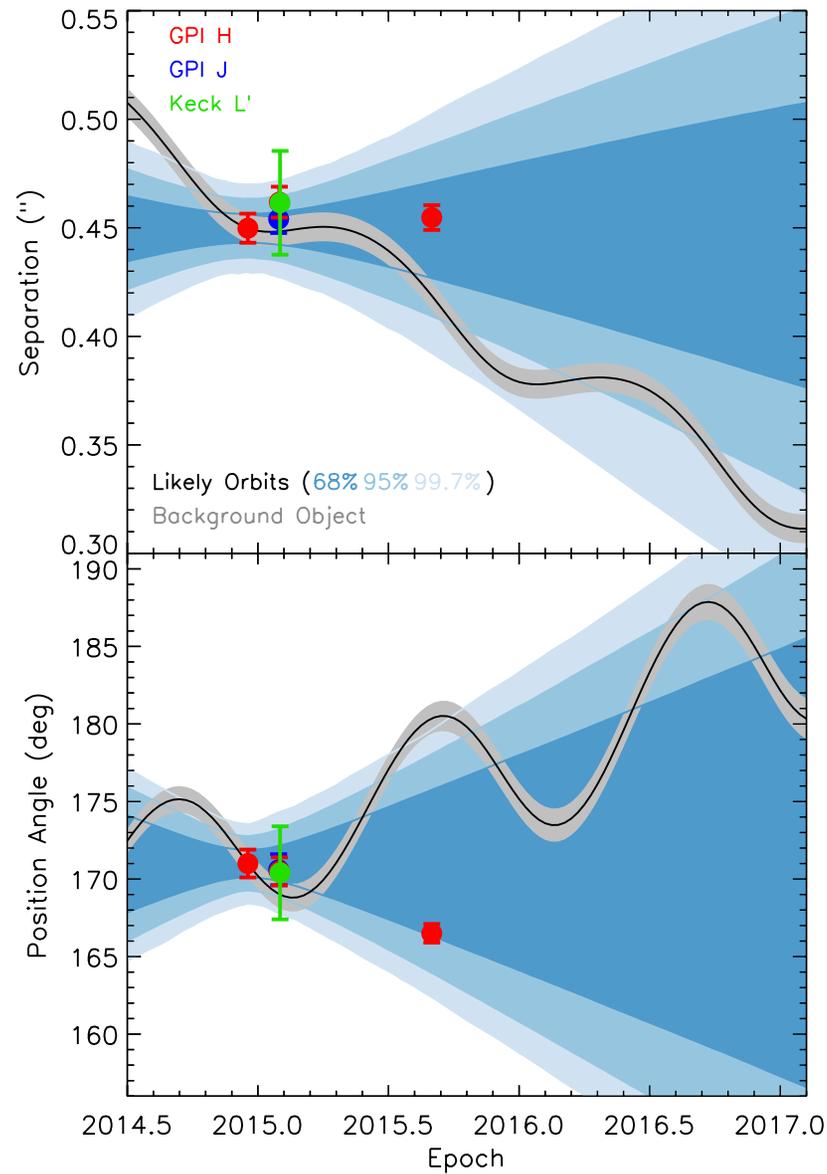
**OFTI** uses Independent Steps, while  
MCMC uses Correlated Chains



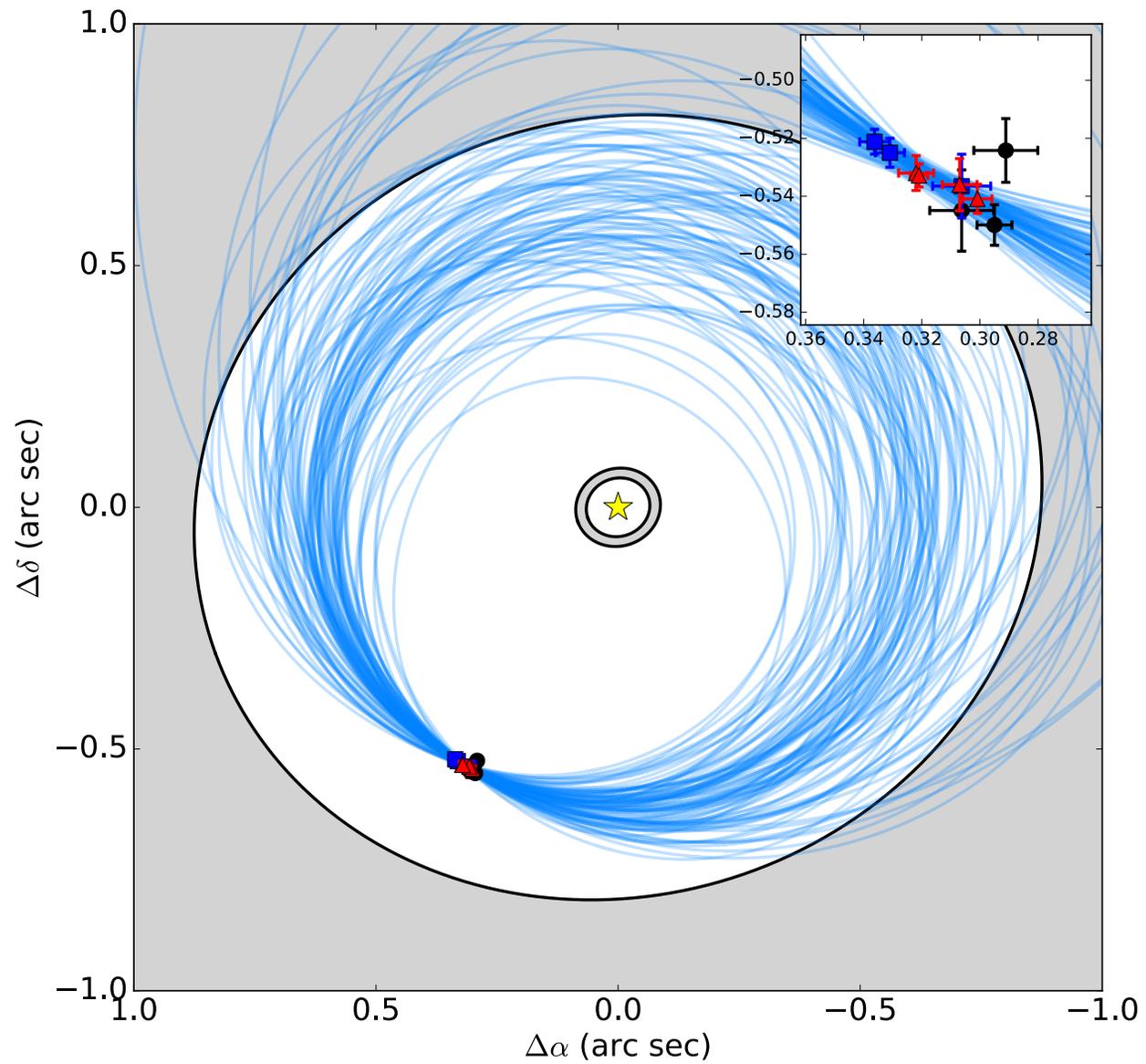
# Science with OFTI: 51 Eri b



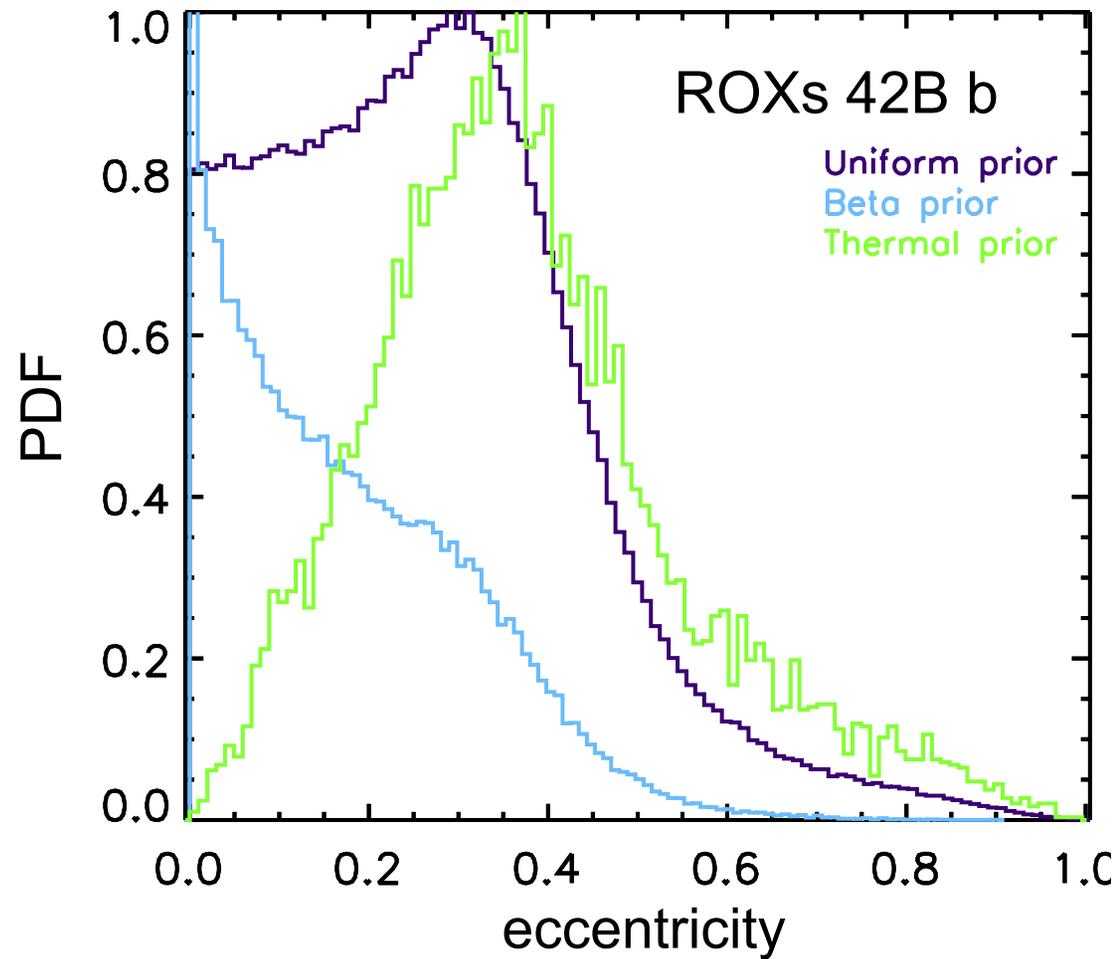
# Science with OFTI: 51 Eri b



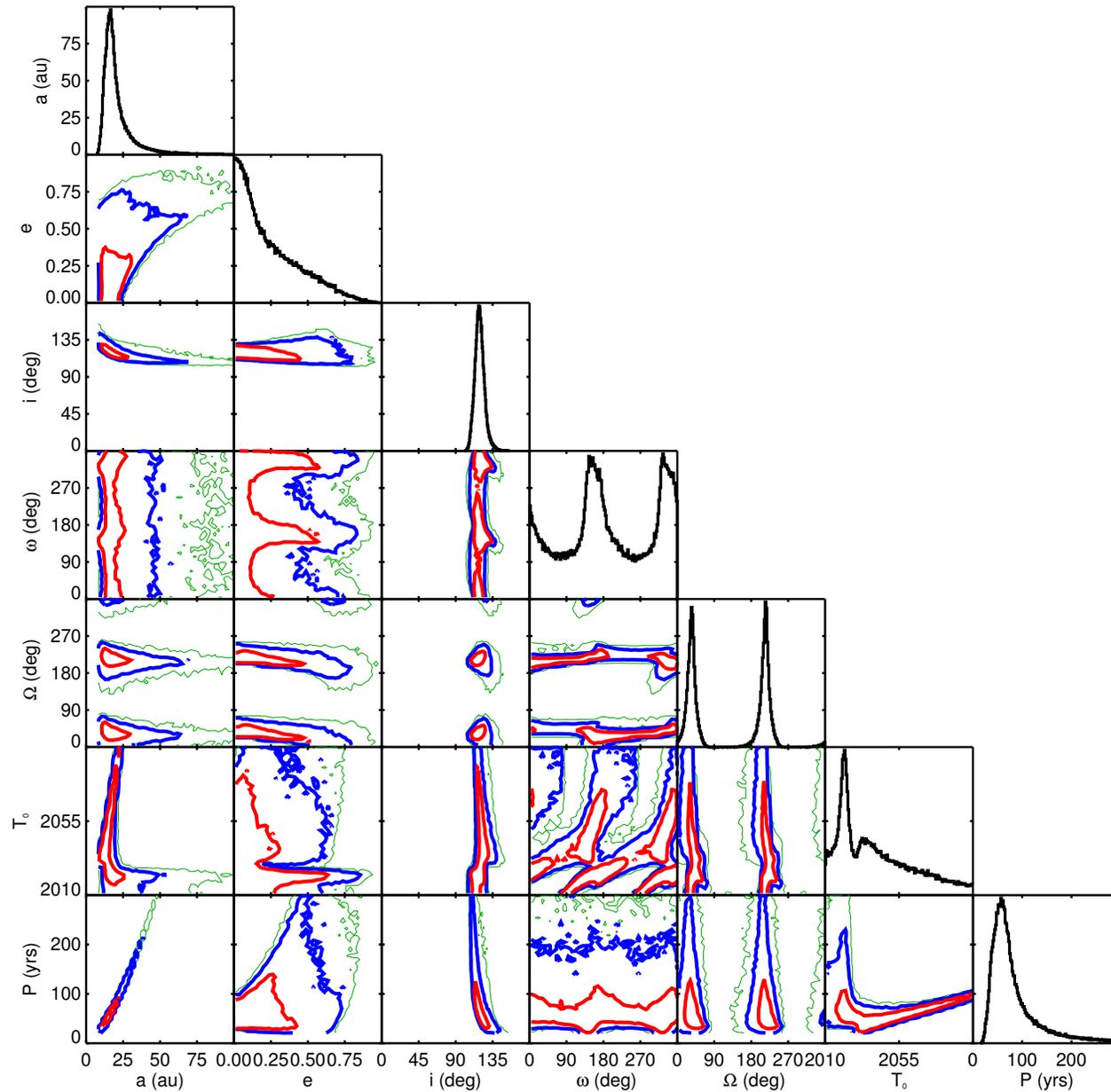
# Science with OFTI: HD 95086 b



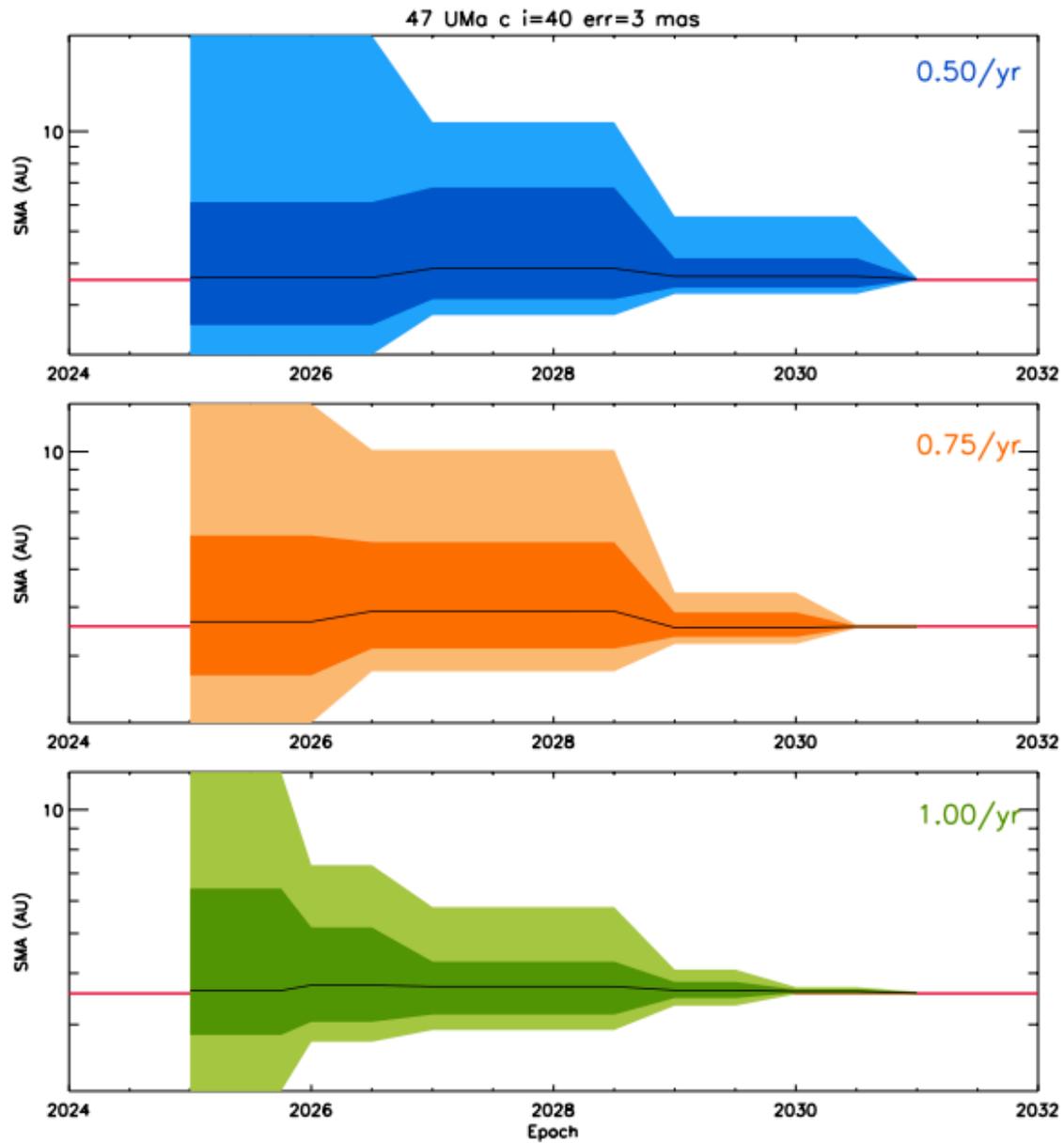
# Science with OFTI: Widely Separated Companions



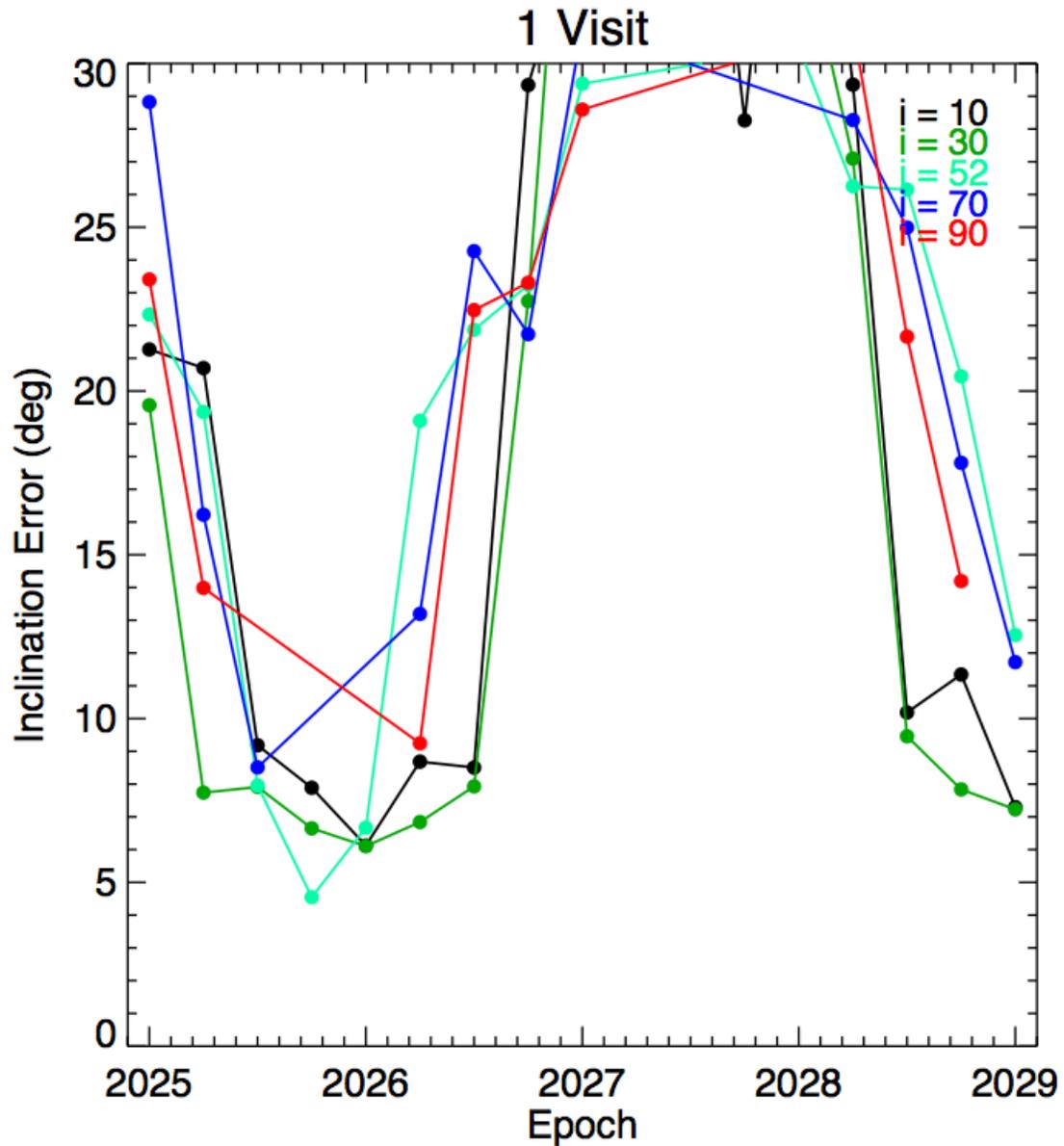
# Science with OFTI: HD 984 B



# Simulations with OFTI: WFIRST Discoveries



# Simulations with OFTI: WFIRST Re-Observations



# Future Hacks and Science

- more orbits
- more simulations
- the eccentricity distribution of Brown Dwarfs
- add systematics parameters
- fit radial velocity & imaging combined datasets
- explore Nyquist sampling problems for smaller orbital periods (Eric already working on this)
- ...and much much more!

What can OFTI do for you?

# References

## Overview:

- AJ, Blunt et al 2017

## Similar Techniques:

- ApJ, Konopacky et al 2016
- ApJ, Price-Wheelan et al 2017

## Science Papers:

- AJ, Nielsen et al 2017 (submitted)
- AJ, Ngo et al 2017
- AJ, Johnson-Groh et al 2017
- ApJ, Bryan et al 2016
- ApJL, Rameau et al 2016
- ApJL, De Rosa et al 2015

# Acknowledgments

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BROWN