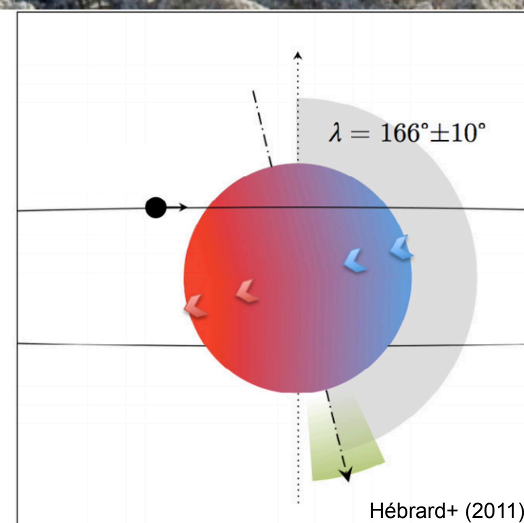
Orbital Obliquities of Small Planets from CHARA Stellar Diameters

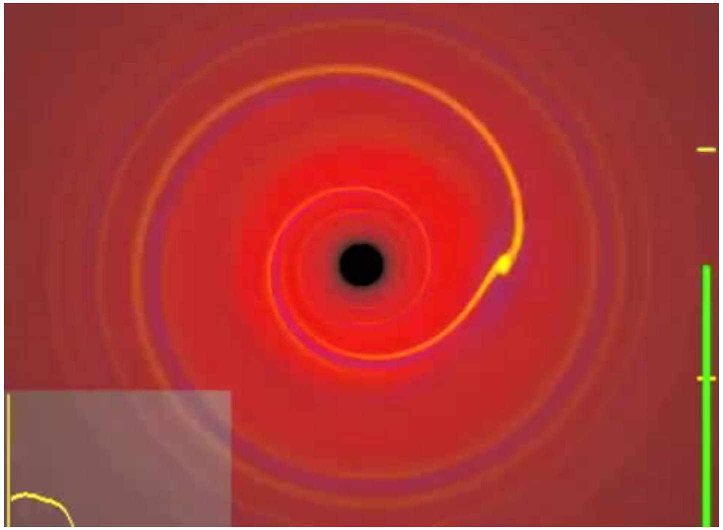


Samuel Quinn & Russel White
Georgia State University
CHARA Meeting
March 19, 2015

How do planets migrate?

Giant planets may migrate through the gas disk (Type II) or via interactions with other bodies (planet-planet scattering, Kozai cycles)

Disk migration

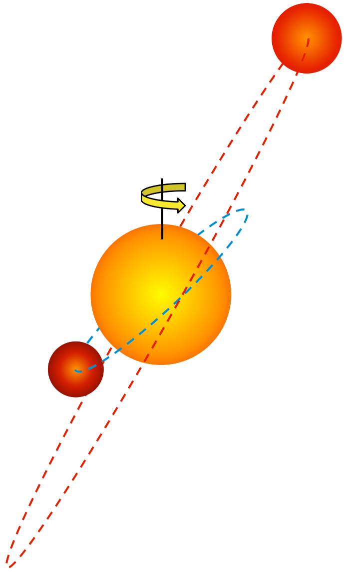


P. Armitage

P-P scattering

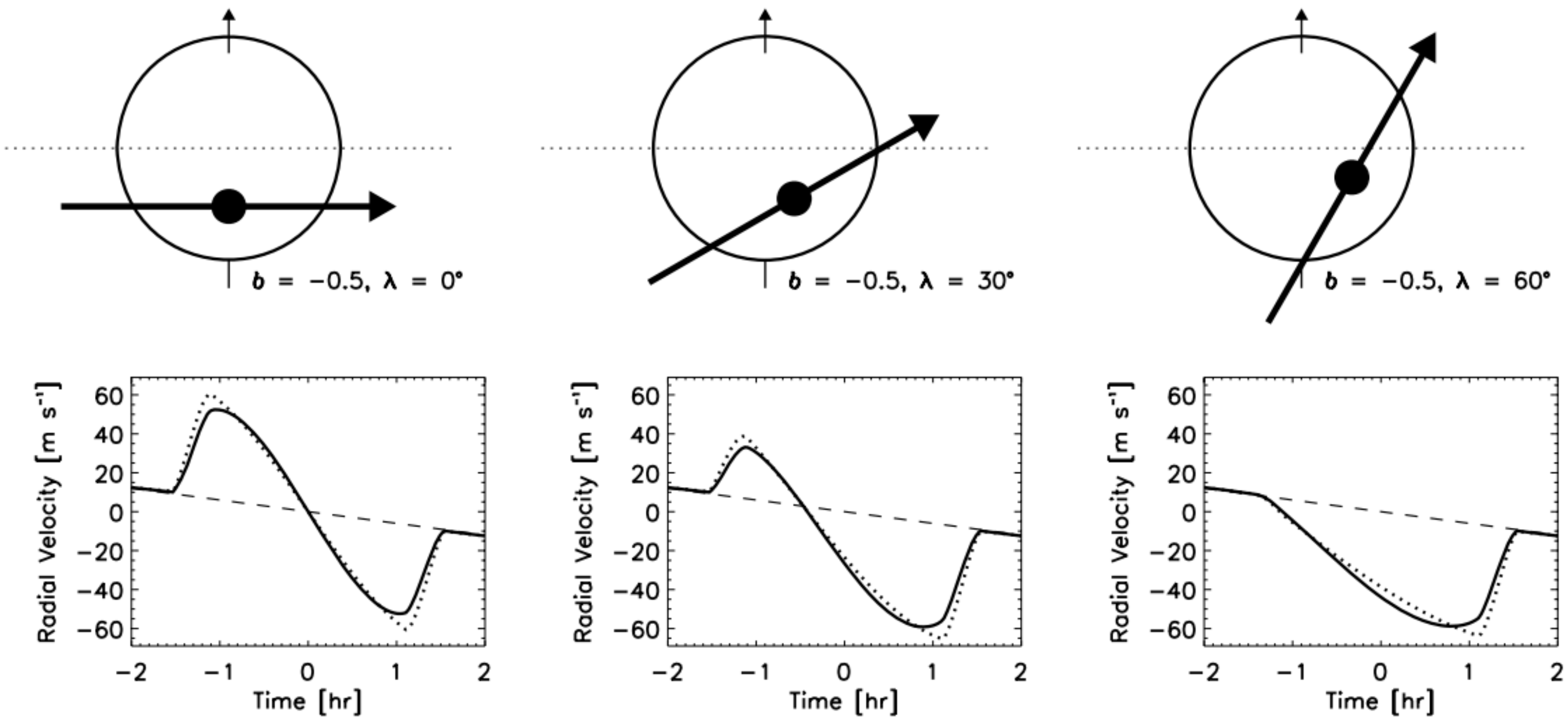
Ford & Rasio

Kozai



Obliquities hold clues to migration history

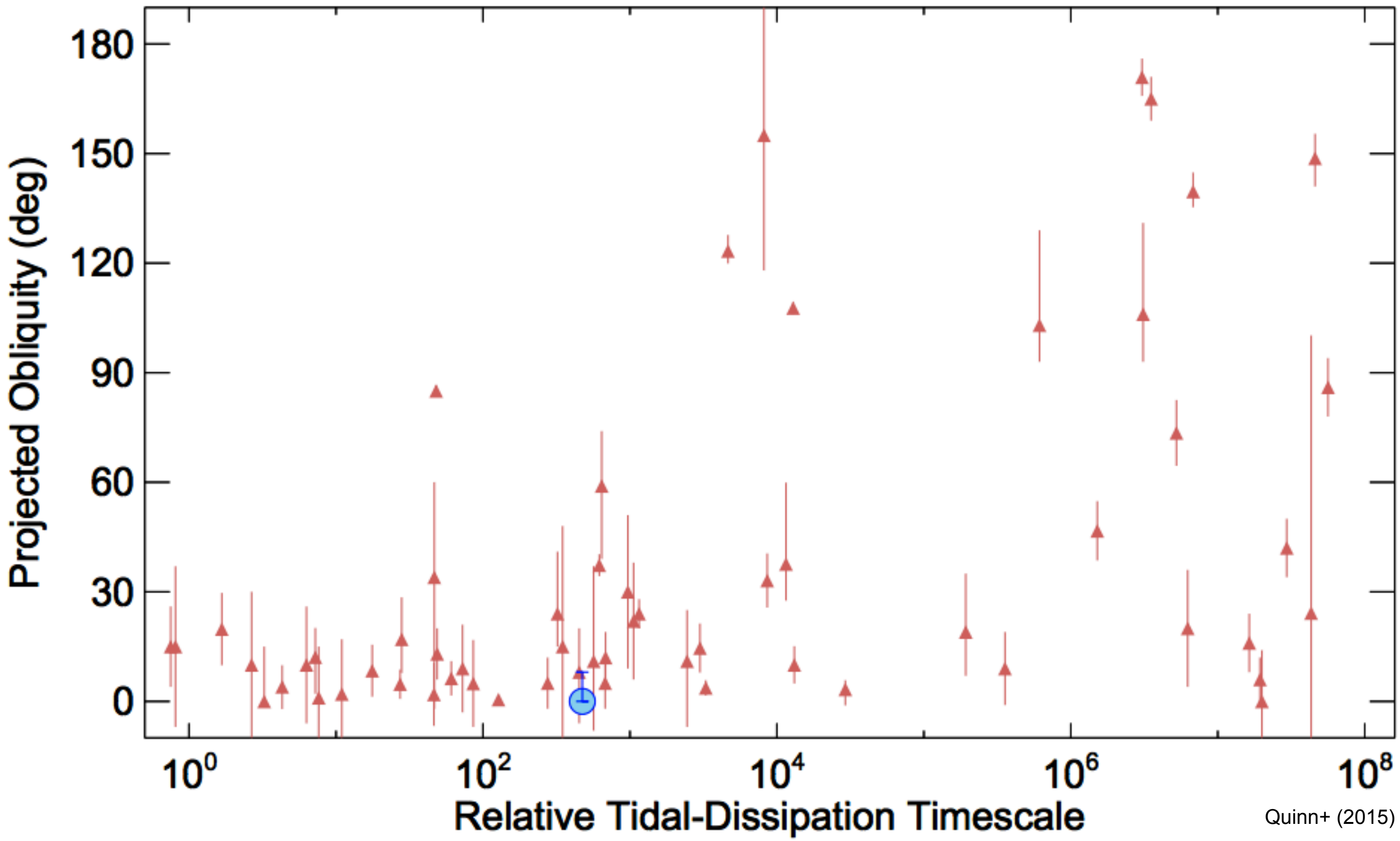
Lessons from giant planets



Winn (2006)

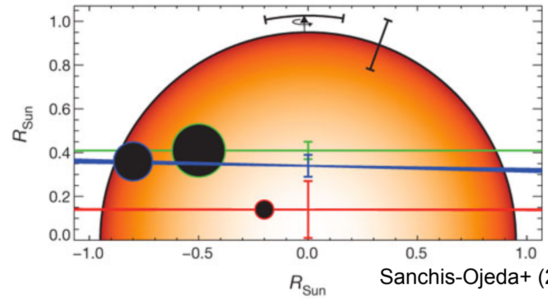
Obliquities determined mainly via the Rossiter-McLaughlin effect

Lessons from giant planets



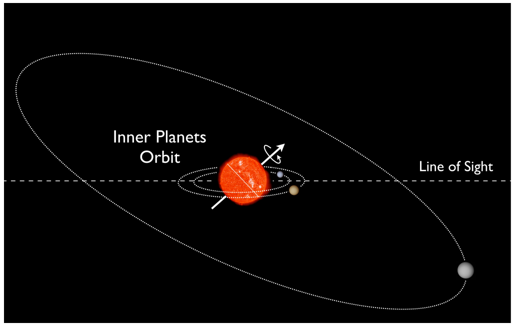
Lessons from *Kepler*

Systems of small planets tend to be mutually coplanar



Sanchis-Ojeda+ (2012)

Some of these systems may still be misaligned with the stellar spin (e.g., Kepler-56)



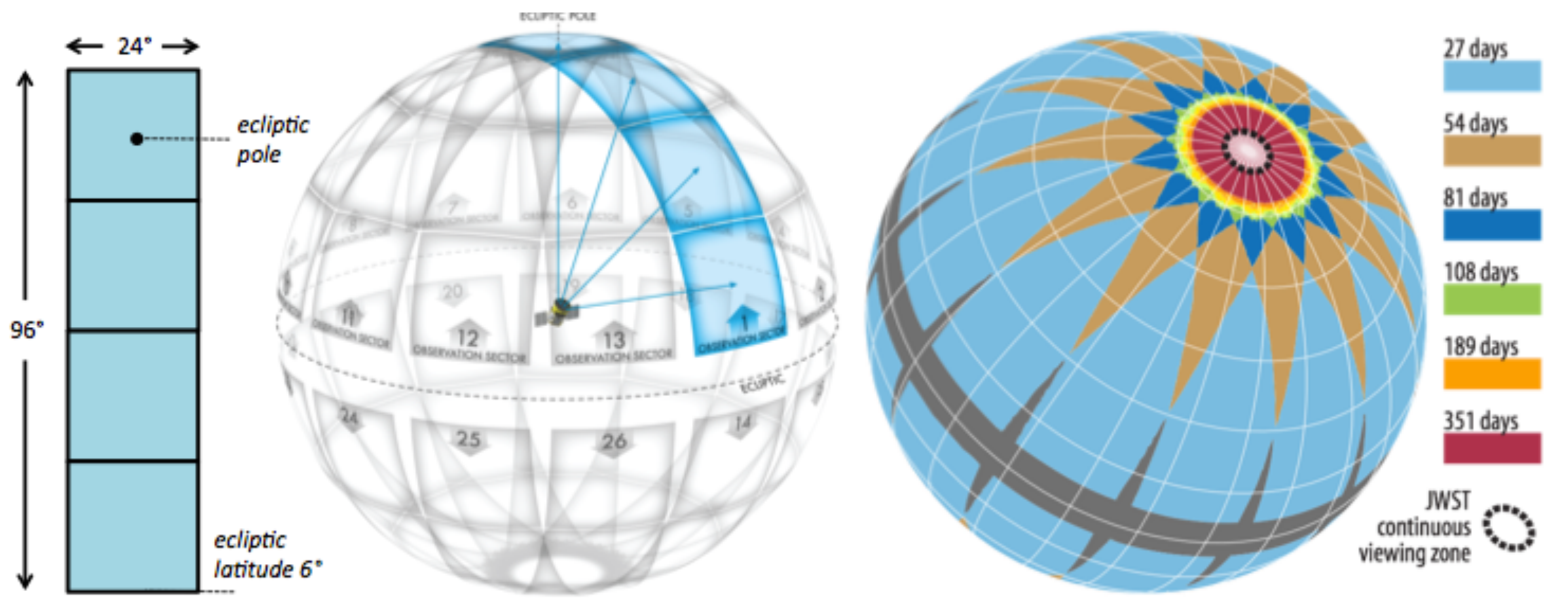
Huber+ (2014)

Can sometimes determine obliquities photometrically:

- (Repeated) starspot crossings
- Gravity darkened transits
- Full photodynamical models
- Asteroseismology

Most techniques work best for big planets (R-M, tomography, spots, grav. dark., etc.) or only special cases (seismology, grav. dark., spots, etc.)

The promise of TESS



Ricker+ (2014)

- Similar performance to *Kepler*, but all-sky and bright, nearby stars
- Follow-up observations more feasible: RVs, atmospheres, DIAMETERS
- However, shorter timespan of observations make obliquities hard:
  - asteroseismology is difficult
  - fewer transits, spot crossings

New life for an old idea

Stellar inclination can be crudely estimated from estimates of the stellar radius, a rotation period, and a spectroscopically measured vsin(i).

$$\sin i_\star = \frac{v \sin i_\star P_{\rm rot}}{2\pi R_\star}$$

Schlaufman 2010 used predicted rotation periods and radii with vsin($i_\star$) measurements to identify possible misaligned hot Jupiters, and found consistency with emerging Rossiter-McLaughlin results for misalignment.

But with rotation periods from TESS, angular diameters from CHARA, and (soon!) distances from Gaia, we can directly observe all terms in the equation, with most sources of error significantly reduced.

$$\sin i_\star = \frac{v \sin i_\star P_{\rm rot}}{\pi \Theta d}$$

Is this technique feasible?

How precisely can we determine the inclination?

What are error sources (and magnitudes of error)?

$$\left(\frac{\sigma_{\sin i_\star}}{\sin i_\star}\right)^2 = \left(\frac{\sigma_{v \sin i_\star}}{v \sin i_\star}\right)^2 + \left(\frac{\sigma_{P_{\rm rot}}}{P_{\rm rot}}\right)^2 + \left(\frac{\sigma_\Theta}{\Theta}\right)^2 + \left(\frac{\sigma_d}{d}\right)^2$$

Ex.: $0.055^2 = 0.05^2 + 0.01^2 + 0.02^2 + (\sim 0)$

How many obliquity measurements can we expect to make?

How many TESS stars can CHARA resolve?

How many of those will have (transiting) planets?

How many will have detected rotation periods?

$$N_{\rm obliq} = N_{\rm CHARA} f_{\rm pl} f_{\rm tr} f_{\rm rot}$$

Can we determine the underlying obliquity distribution of small planets?

Simulation: Stellar Population

The TRILEGAL stellar population synthesis code (Girardi+ 2005) allows us to generate realistic galactic populations with known properties (e.g., radius, distance, age, (B-V), effective temperature, etc.)

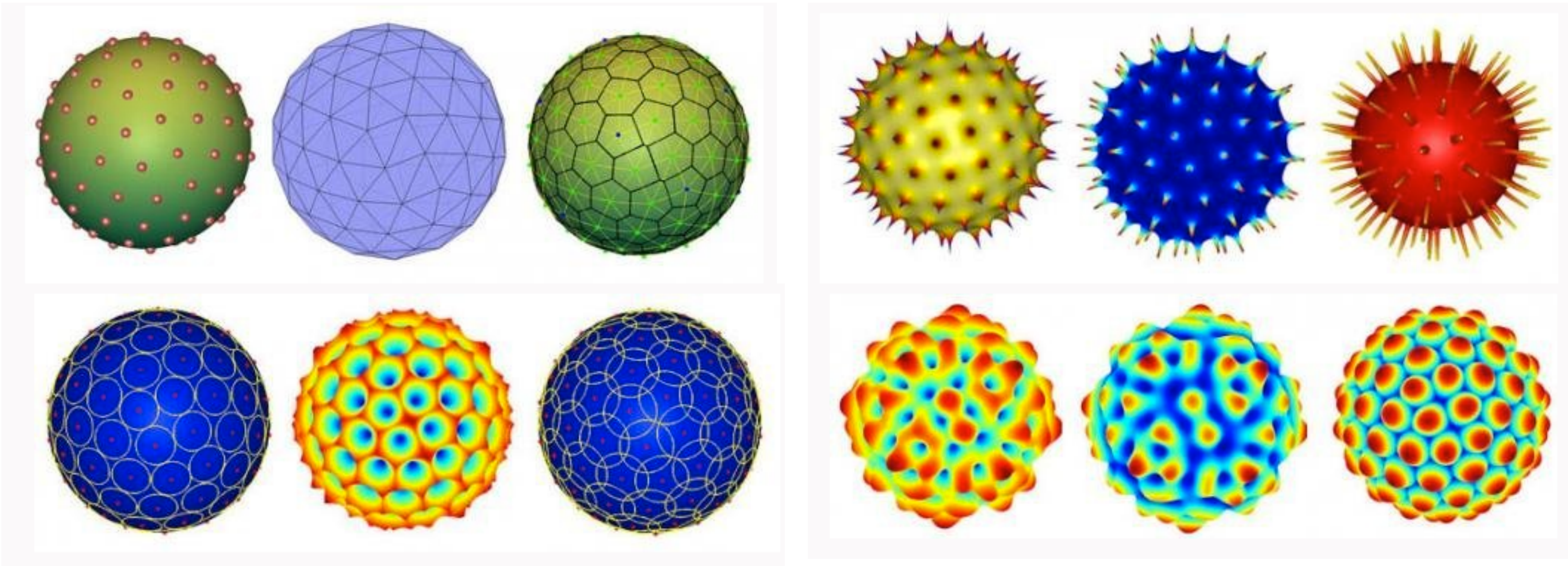
We run TRILEGAL for ~1/10th of the sky (400 10 deg^2 pointings), and can scale final numbers up to all-sky.

To match TESS targets, select only F5V-M0V with I<12 and M0V-M9V with J<13.

Calculate angular size from (known) $R_\star$, d

A Mathematical Aside

Determining evenly-spaced points on a sphere for TRILEGAL pointings. Not as easy as one might think…



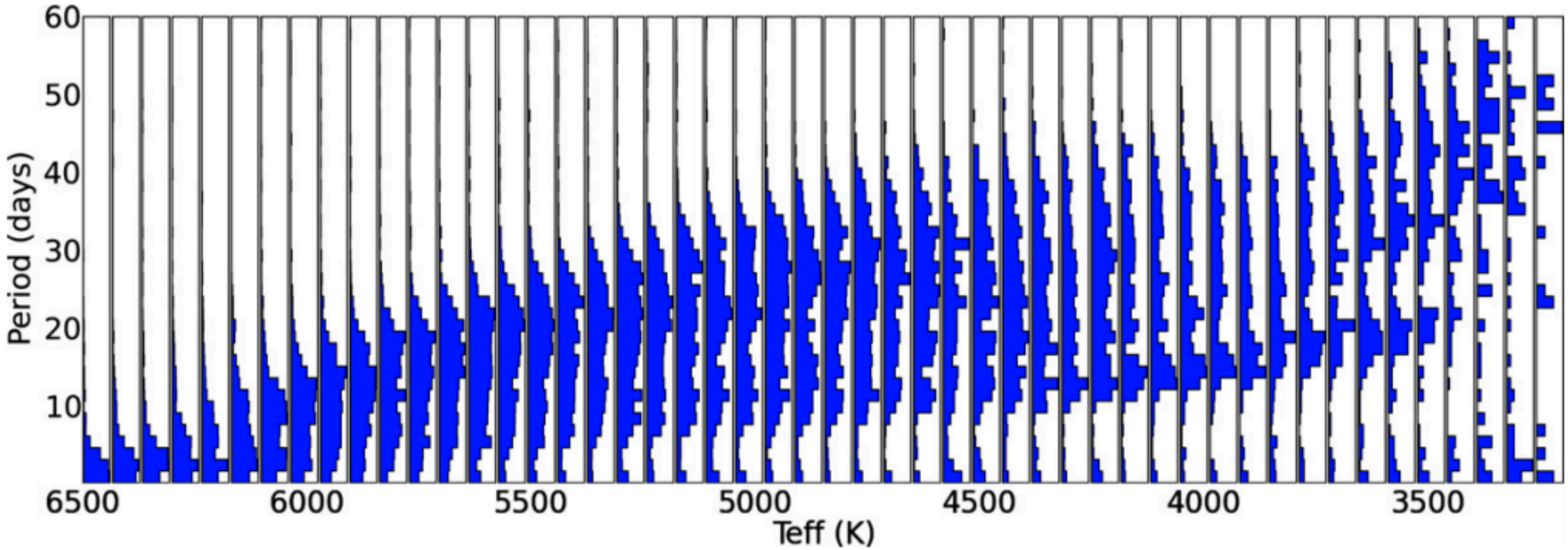
No (known) analytical solution! Coolest one? e^- constrained to a sphere.

Simulation: Rotation Periods

Mamajek & Hillenbrand (2008) gyrochronology relation:

$$P_{\mathrm{rot}} = 0.407\,[(B-V)-0.495]^{0.325}\,t^{0.566}$$

McQuillan+ (2014) *Kepler* rotation periods:



Simulation: Projected Rotational Velocities

Choose underlying distribution of stellar spins (3 cases):

i. isotropic (suitable for a random sample of stars with no priors)

ii. nearly edge-on (what we'd expect if all planets have low obliquities)

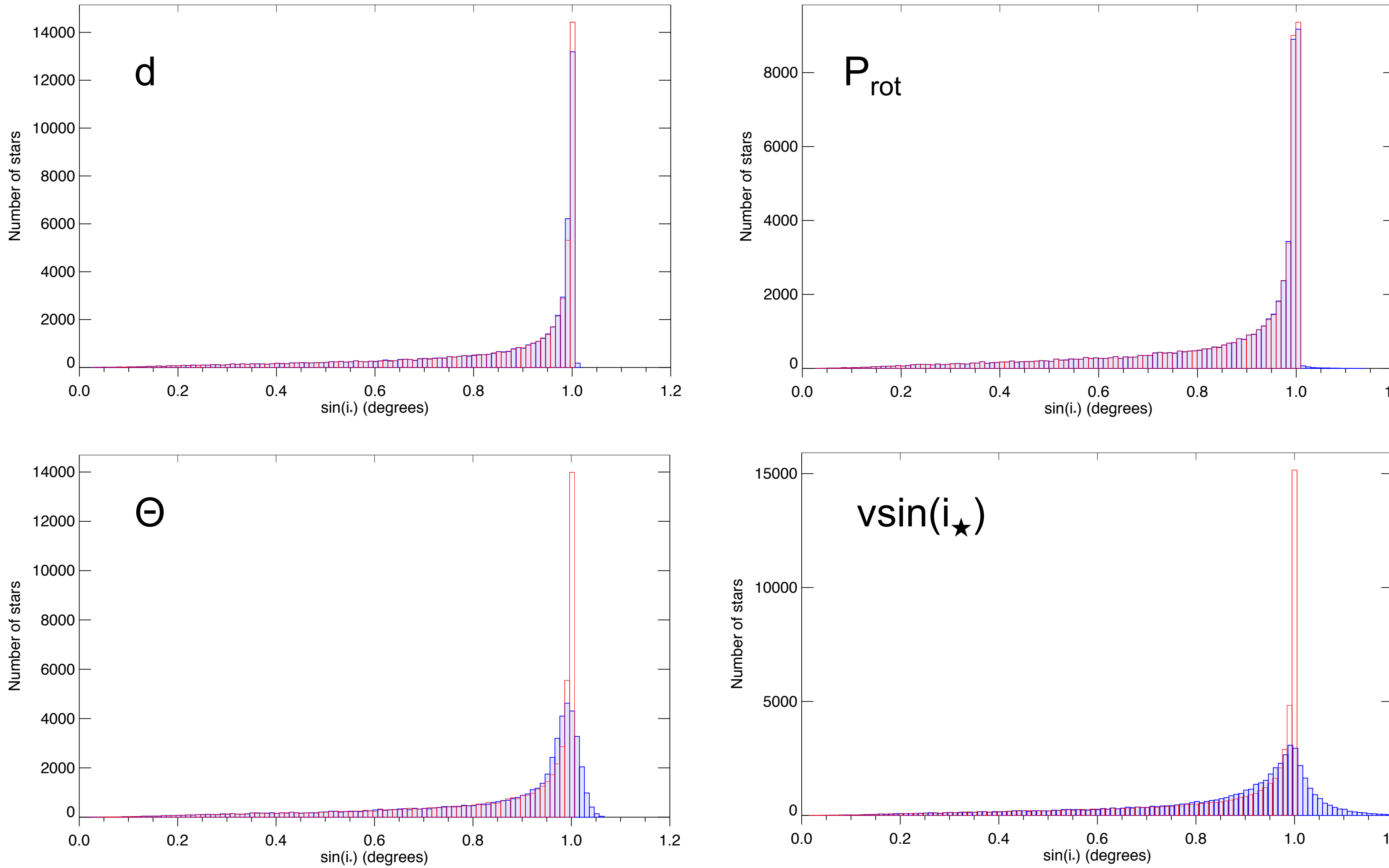
iii. a mix of i. and ii. (as expected from multiple migration channels/ effects of outer bodies/primordial disk misalignment)

Draw inclinations, calculate vsin($i_\star$) from $R_\star$, P_{rot}, $i_\star$.

Estimate error as ~0.25 km/s

(Further assume (σ_Θ/Θ)~2% and σ_d~0.7 μas)

How do errors affect derived $i_\star$?



Simulation: Transiting Planets

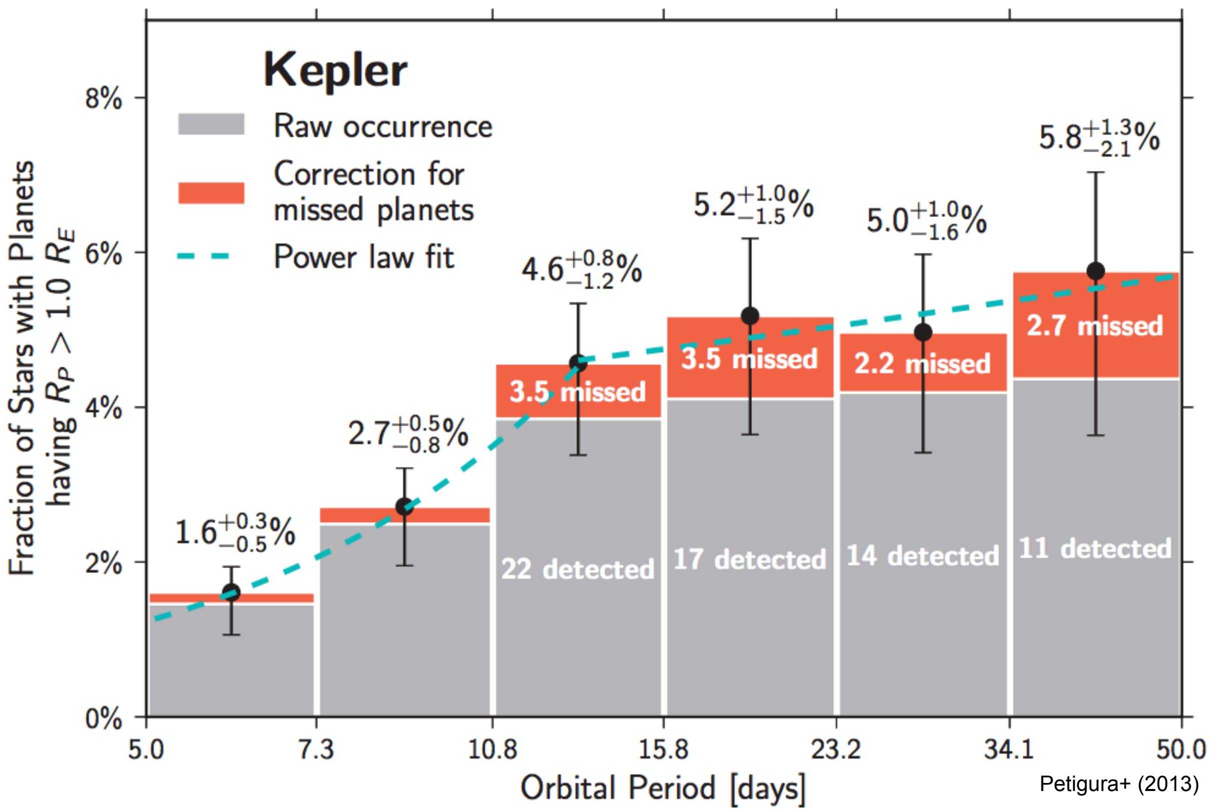
Kepler occurrence rates are fairly well known

Petigura+ (2013) provide power law approximation for Sun-like stars

Fressin+ (2013) suggest little dependence on stellar mass

We assign planets from this period distribution, and calculate transit probability:

$$P(transit) = \frac{R_\star}{a}$$



Petigura+ (2013)

$$\frac{df}{d\log P} = k_P P^{\alpha}$$

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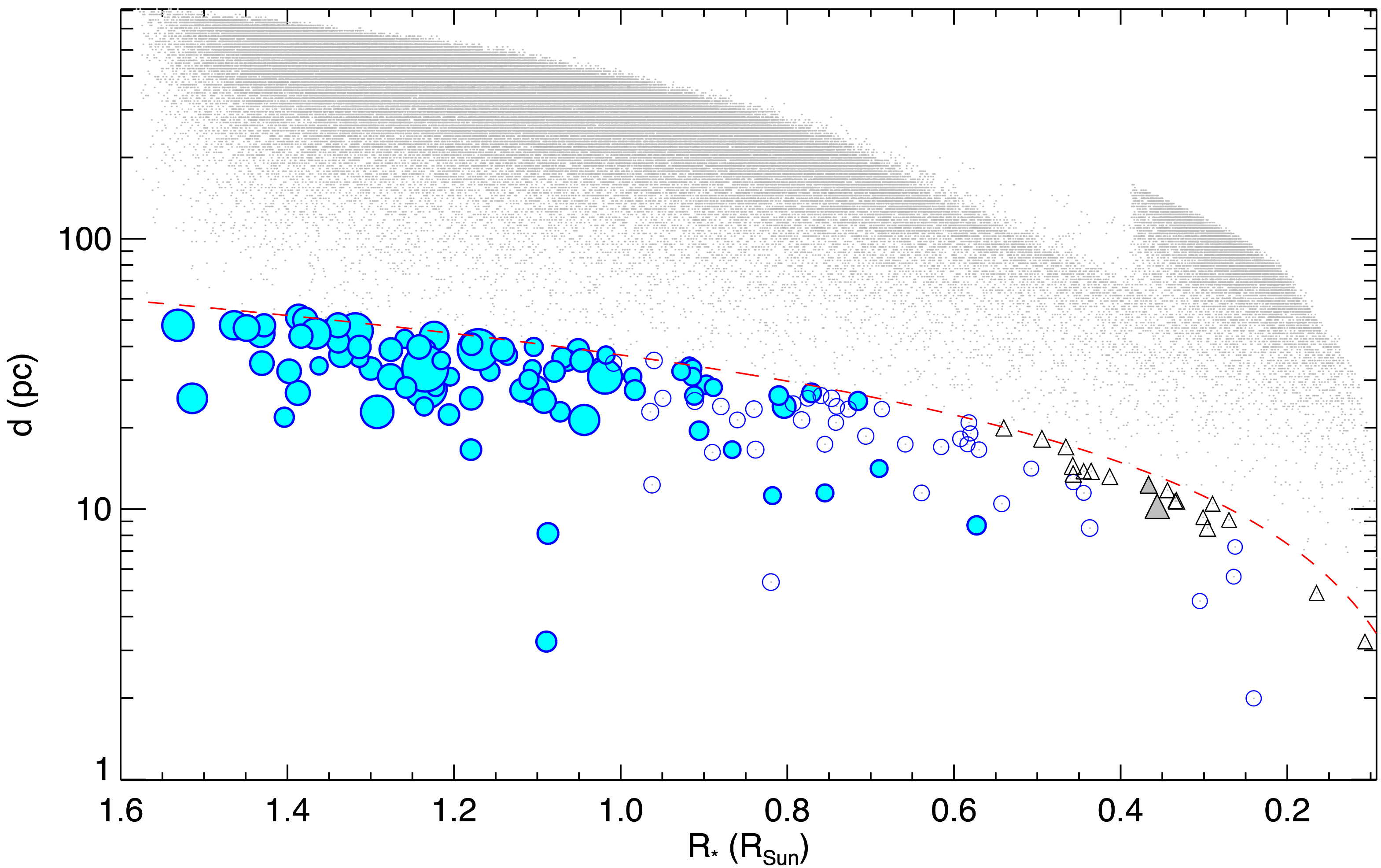
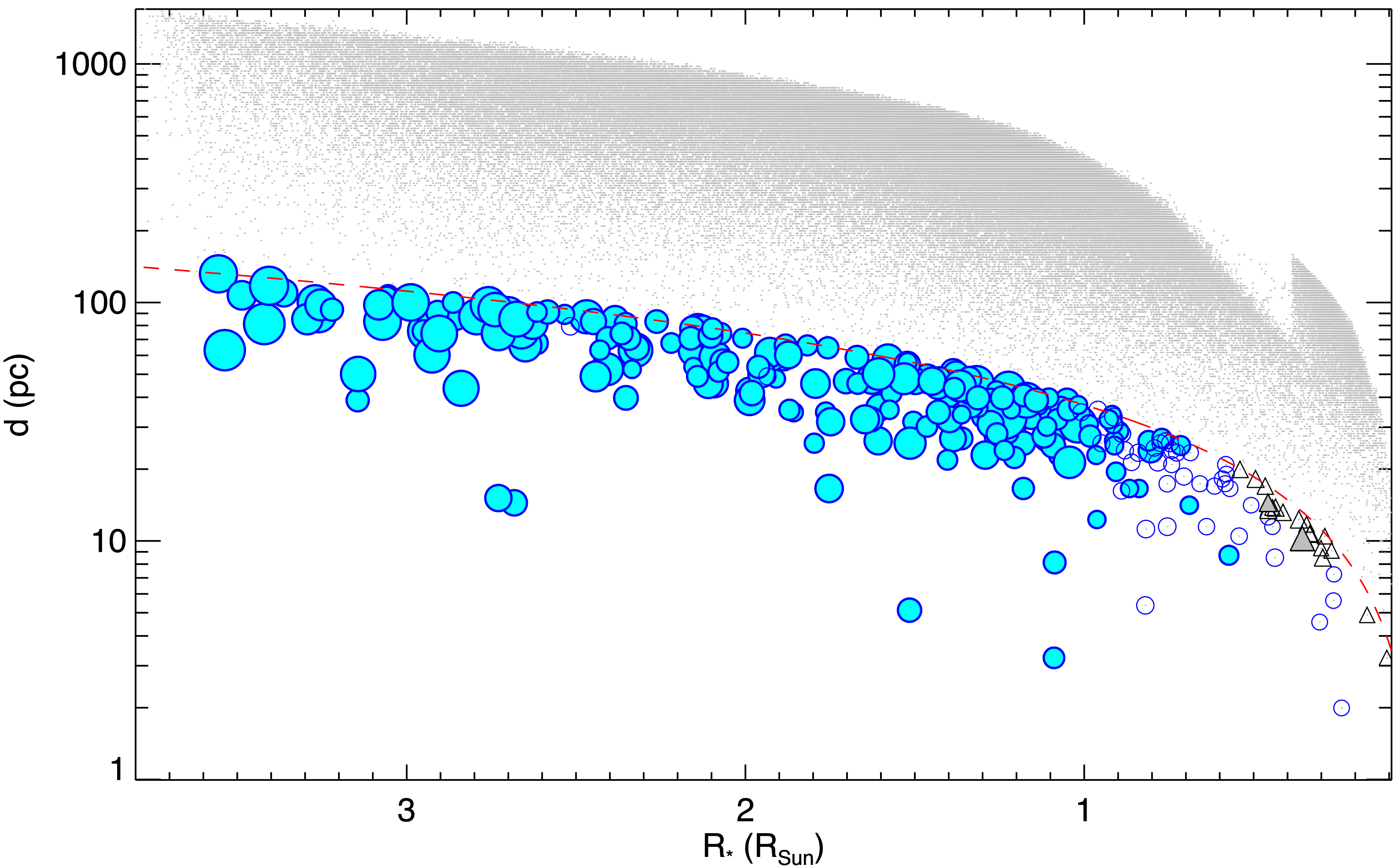
Results: Resolvable TESS Dwarfs



Should TESS observe subgiants?



Remaining Work

Estimate more precisely which stars will have detected rotation periods (use McQuillan distributions and frequencies of detection)

For three underlying obliquity distributions (isotropic, aligned, mixed):

- Calculate inclincations, errors, and distributions of those quantities for typical systems that survive all of our cuts (and have planets).
- Compare our simulated distributions to theoretical underlying distributions – how many detections do we need to distinguish between the three cases? (K-S tests)

Summary

Obliquities of small planets, which place constraints on the migration history and architecture of planetary systems, are difficult to obtain using current techniques

The synergy between TESS, CHARA, and Gaia will allow a new (old) method to be employed -- with very precise results in certain cases.

We estimate that a handful of TESS systems will be amenable to this technique (analysis is ongoing to determine overall impact of results)

The inclusion of CHARA-resolvable subgiant stars in the TESS sample would improve the results (and open up other valuable areas of stellar astrophysics research)