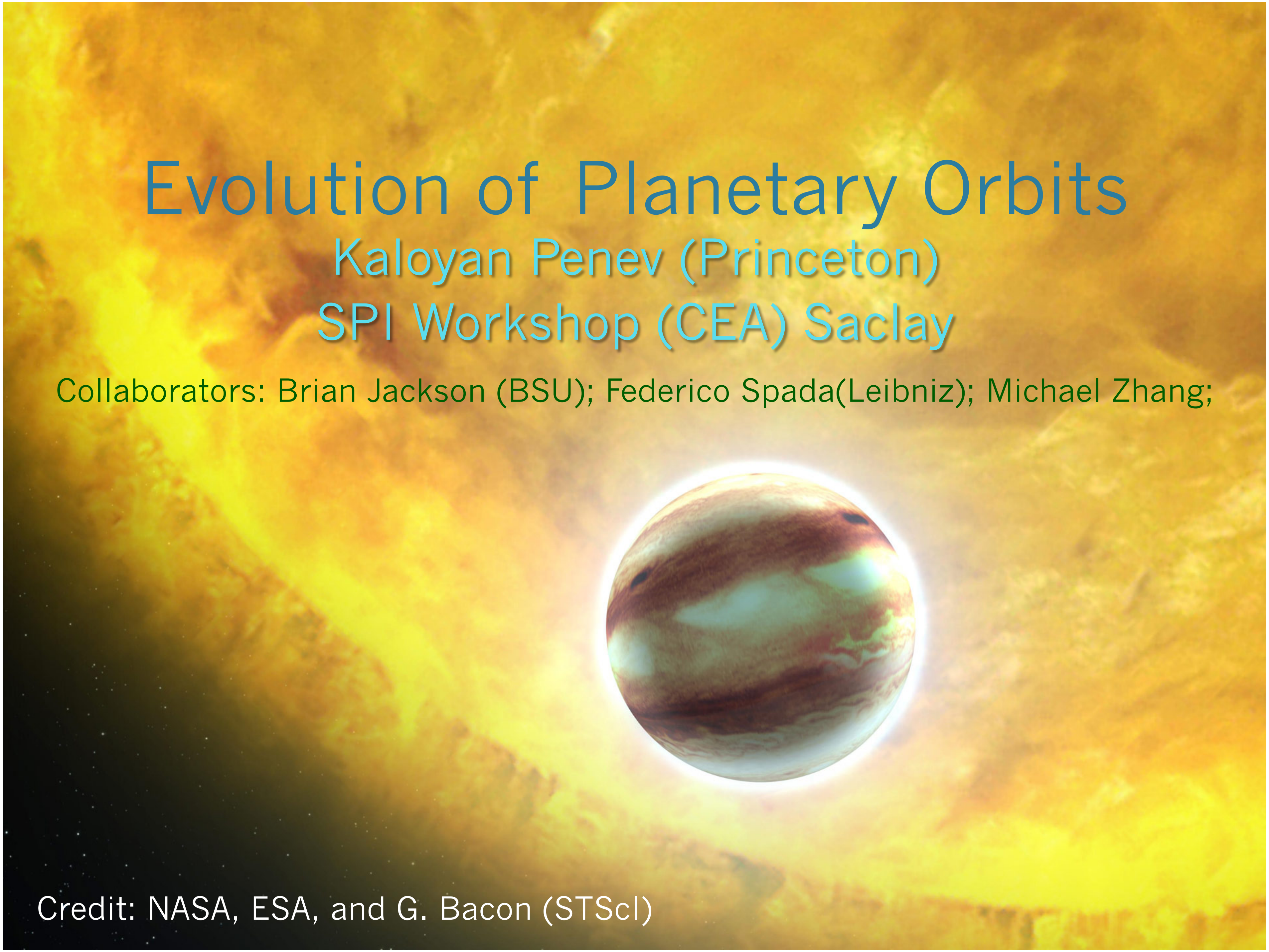
Evolution of Planetary Orbits

Kaloyan Penev (Princeton)

SPI Workshop (CEA) Saclay

Collaborators: Brian Jackson (BSU); Federico Spada(Leibniz); Michael Zhang;



Credit: NASA, ESA, and G. Bacon (STScI)

Outline

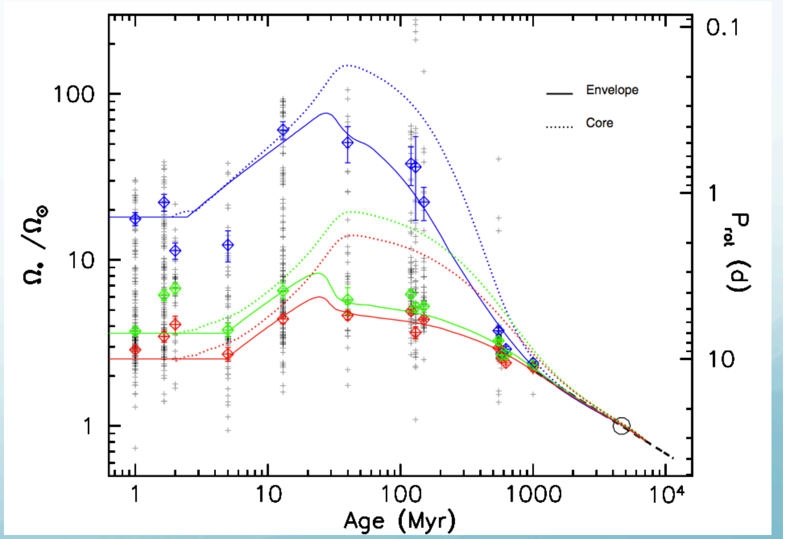
- POET orbital evolution code
- Constraining Q* from exoplanet population
- Extreme stellar rotation after engulfing a planet
- Tidal alignment explanation for observed obliquities
- Forming hot Jupiters in globular clusters

Planetary Orbital Evolution due to Tides

- Evolve two bodies orbiting one another
- Arbitrarily large eccentricity and inclinations
- Multiple, coupled layers in each body
- Bodies evolve, possibly in response to tidal heating
- Loss of angular momentum by magnetic wind

Some Details

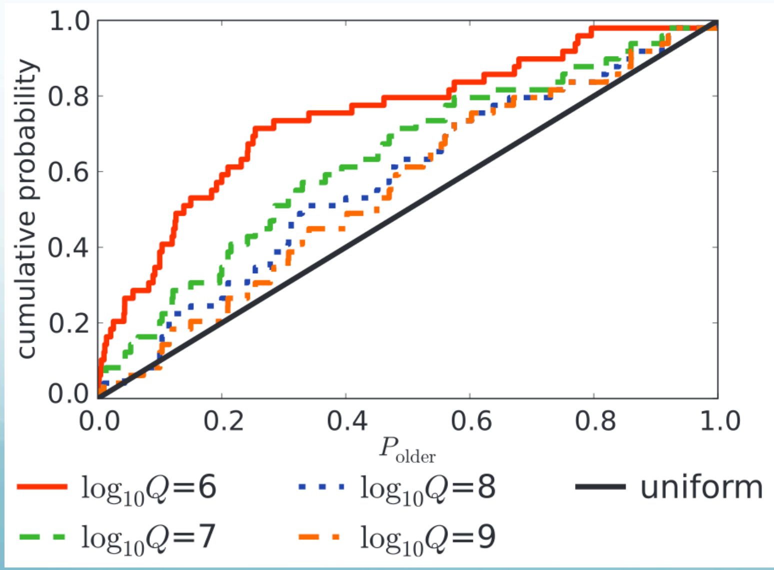
- Tidal disspation Model:
  - Equilibrium tide formulation assumed
  - Energy dissipation and torque can be discontinuous and depend on age, tidal frequency, tidal component, ...
  - Adaptive eccentricity expansion order
- Rotation model:
  - Surface angular momentum loss:
    $$K\Omega \min(\Omega,\Omega_{sat})^2 \sqrt{\frac{R_*}{M_*}}$$
  - Neighboring zone coupling:
    $$\vec{T} = \frac{I_1\vec{L}_2 - I_2\vec{L}_1}{\tau(I_1 + I_2)}$$
  - Evolving zone boundaries bring the shrinking zone's spin
  - Fits rotation observed in open clusters

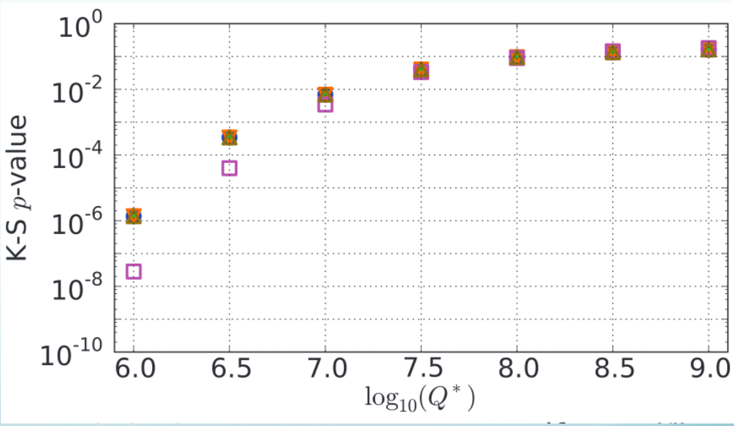


Gallet & Bouvier 2013

Constraning Q*

- Use transiting extrasolar planets detected from the ground
- After correct for survey and astrophysical biases, resulting planets should be caught with uniform probability at any moment in their lifetime

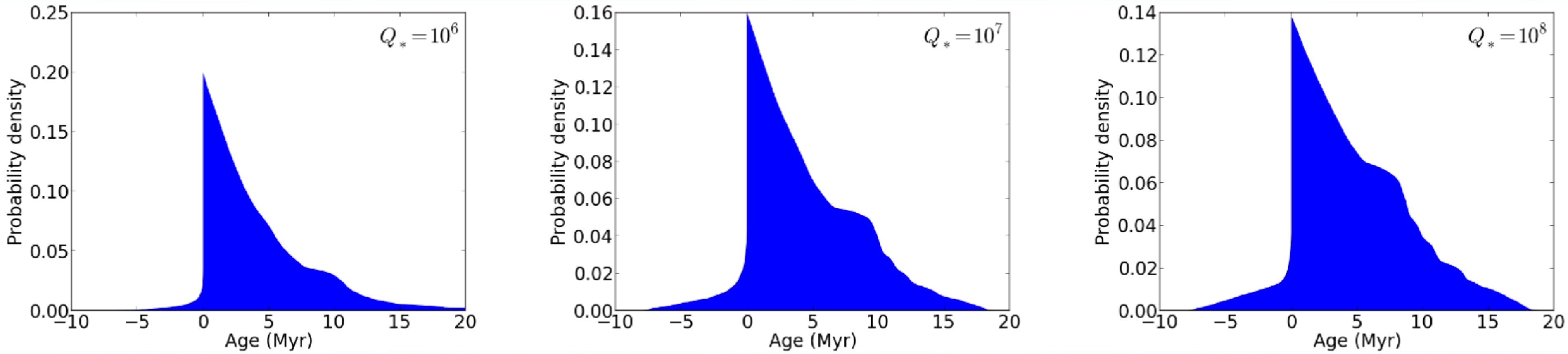




Penev, Jackson, Spada & Thom 2012

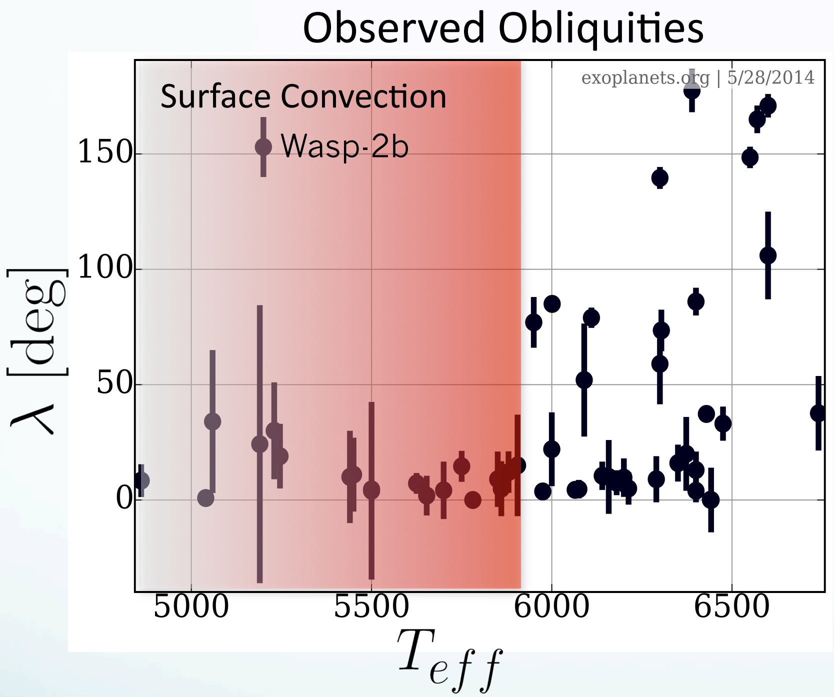
Stellar Spin-Up by Planet Engulfment

- Hot Jupiters contain sufficient angular momentum to spin up the star to extreme periods if engulfed
- Spindown is fast => signal recent accretion event
- Detectable by transit surveys
- Unclear how engulfment can be confirmed
  - Exclude other possibilities
  - See remnant of planet core
  - See anomalous element abundances in the star



From Zhang & Penev 2014

Tidal Alignment Explanation for Observed Obliquities

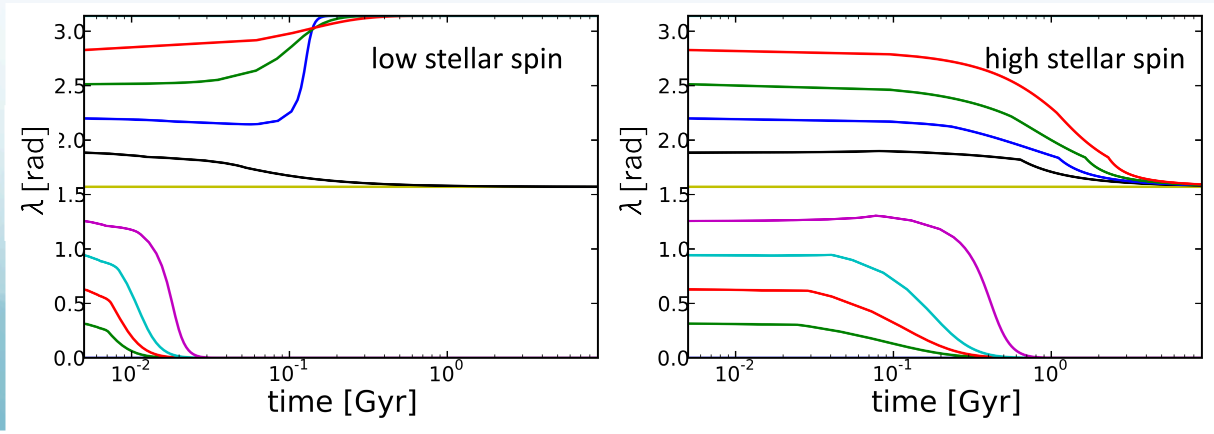


- Low/high obliquities for planets around cool/hot stars
- Cut-off coincides with disappearance of surface convection
- Exceptions are long period or low mass planets

- Suggests tides are involved, however, alignment timescale ≈ orbital decay timescale

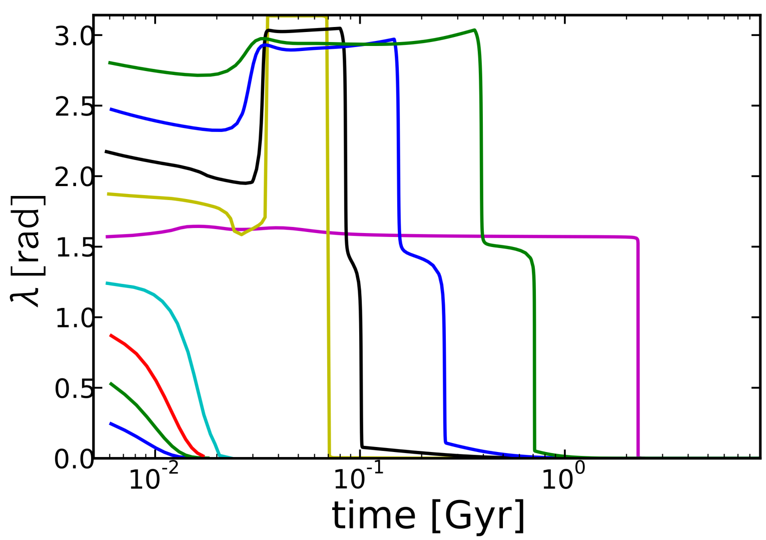
Realistic Tides to The Rescue

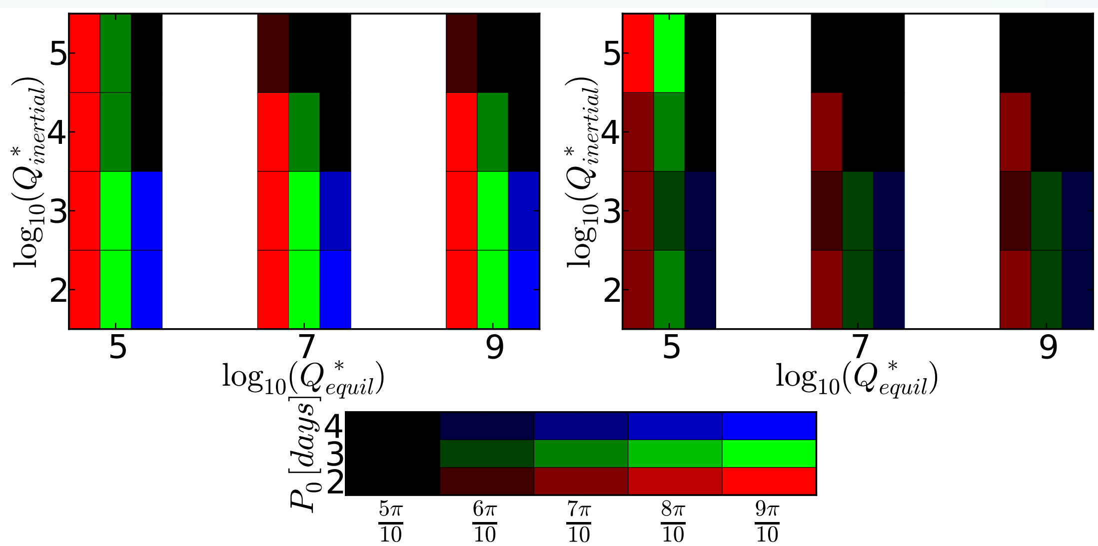
- The timescale argument only holds for Q*=const
- Variable efficiency of dissipating equilibrium tides
- Dynamical tides: resonance with inertial waves
  - Only possible for tidal frequencies ≤ twice orbital
  - For fast tides around slow stars, only alignment but not the orbit deacay (Lai 2012)
  - However, obliquities>90^o should converge to 180^o or 90^o (Rogers & Lin 2013)



Even More Realistic Tides with POET

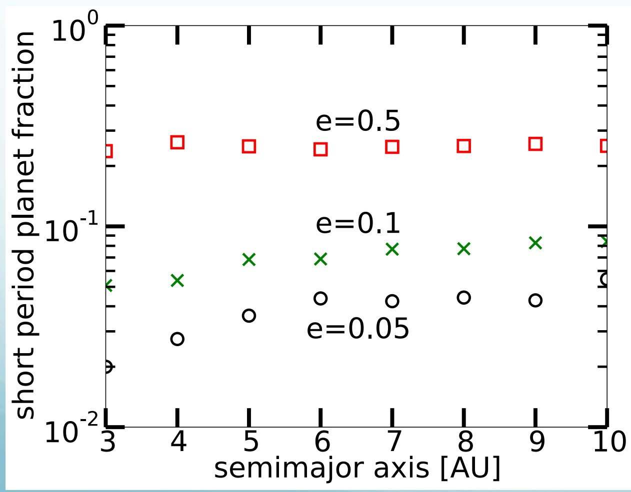
- Stars lose angular momentum over time:
  - Young systems converge to aligned and polar orbits
  - Equilibrium tides drive polar orbits to slightly prograde
  - Dynamical tides finish the job
- Need very efficient dissipation in the inertial range





Forming Hot Jupters in Globular Clusters

- Perturbations by close encounters induce high eccentricity, allowing tidal dissipation to make a HJ
- Flybys closer than tens of AU every ~10Myr
- With some simplifying assumptions a few percent of stars could end up with a HJ!

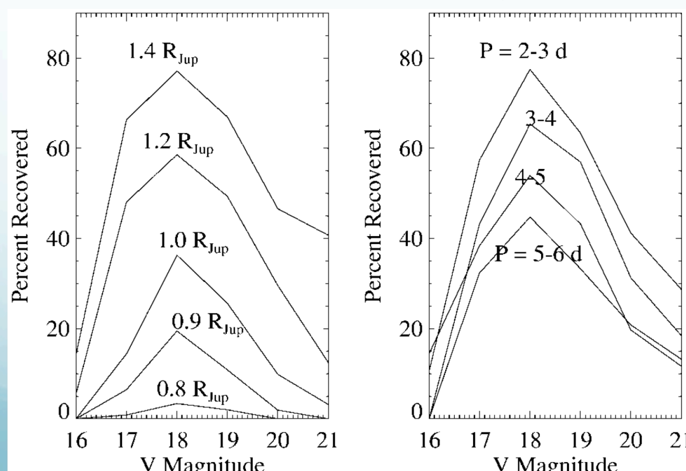


- Stellar density and veloctiy dispersion appropriate for the core of 47 Tuc
- King profile for the cluster
- 1 M_J planet around $0.9M_\odot$ star
- Instant circularization if perastron <0.1AU

Where are they?

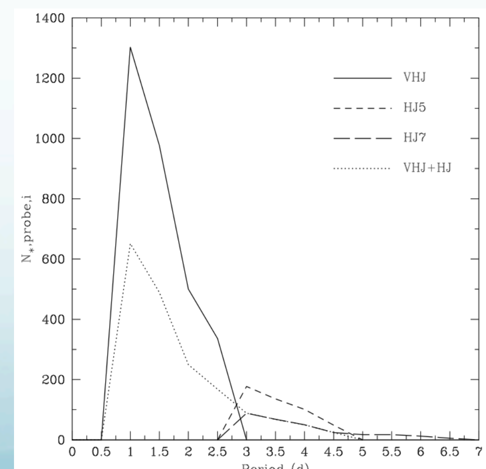
- No radial velocity searches (stars are too faint)
- Transit searches only sensitive up to ~5days
- Globular clusters are old and metal poor

Detection efficiency for 47 Tuc HST survey



From Gilliland et. al. 2000

Detection efficiency for ω-Cen survey



From Weldrake, Sackett & Bridges 2008

Thank You!
Questions/Comments?