The Impact of Binary Companions on Planet Survival

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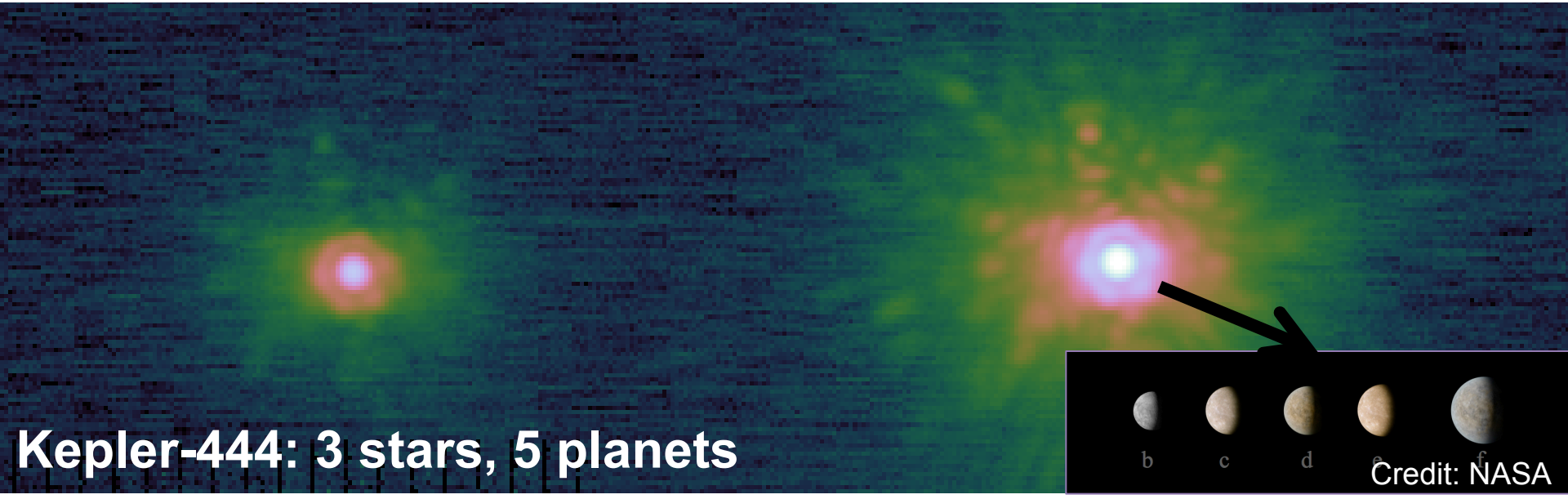
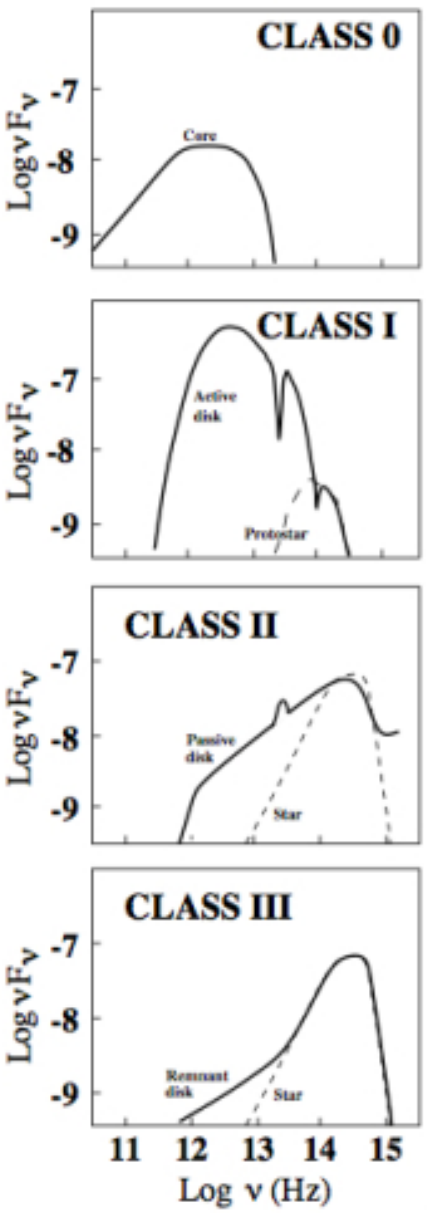
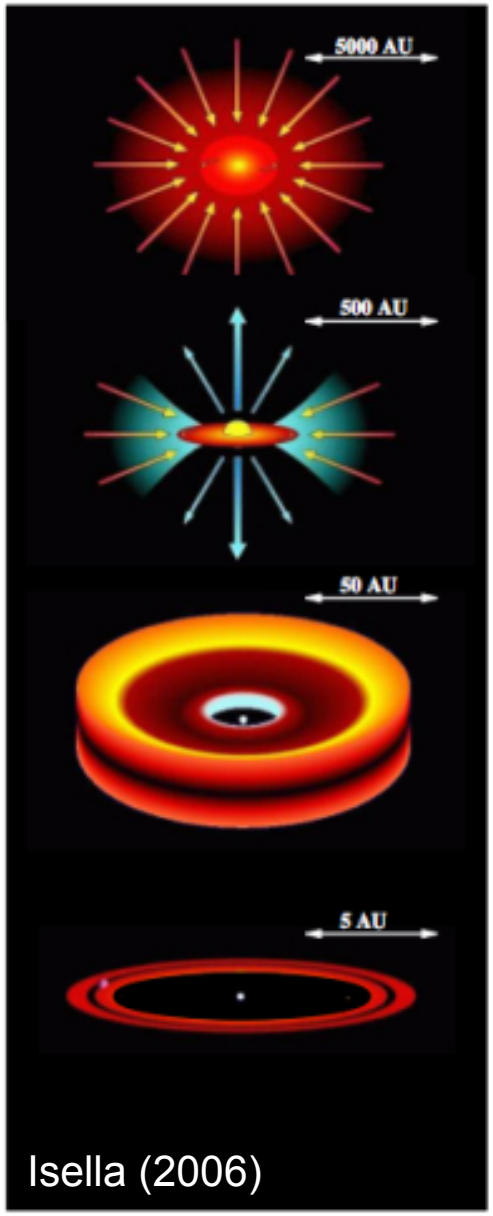
See: Kraus et al. (2016), Dupuy et al. (2016)



Obstacles to Planet Formation





References Include:
Alexander, Beust, Haghighipour, Lissauer, Lubow, Martin, etc etc

Disk Truncation

Planetesimal Stirring

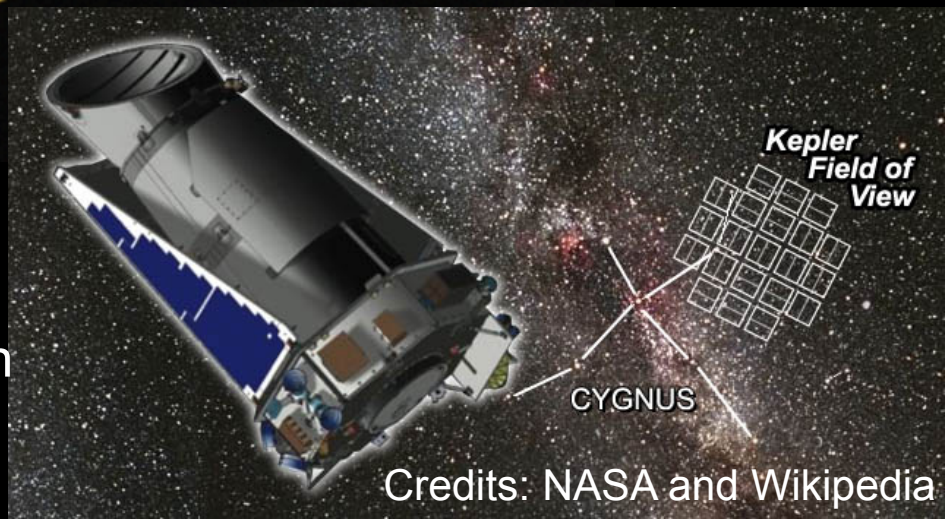
Enhanced Evaporation

Ejections

KOIs Are (Mostly) Unbiased For Multiplicity

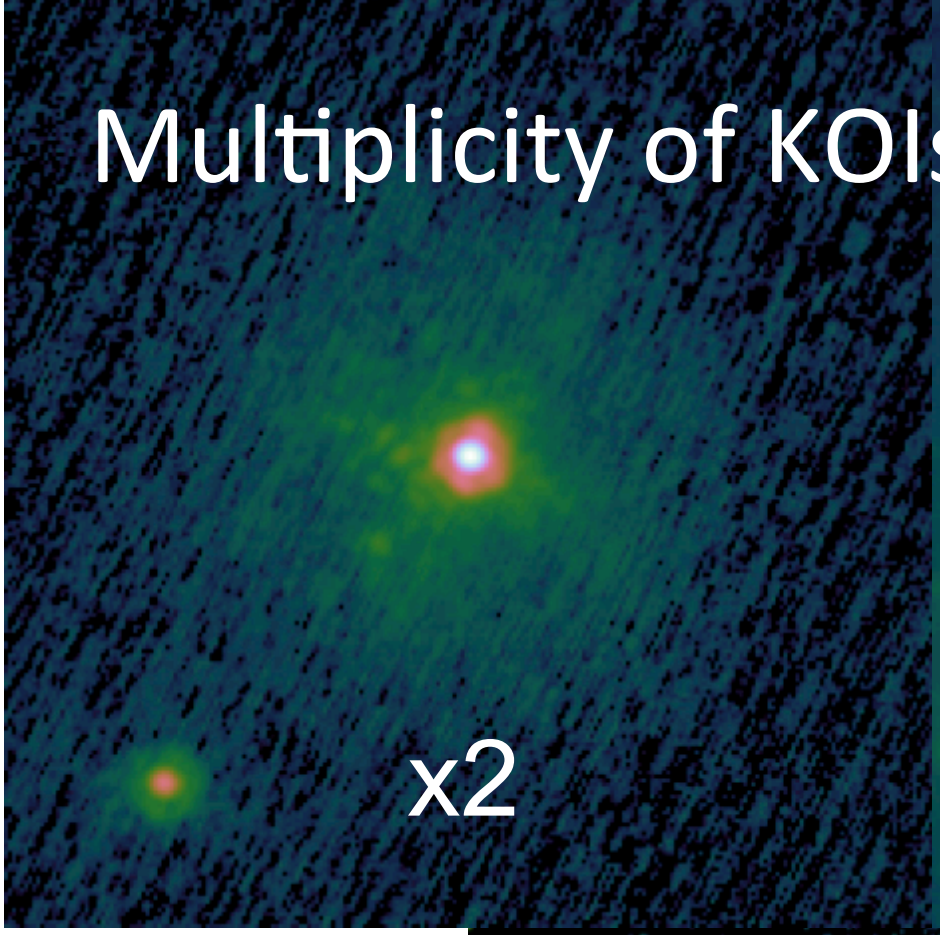
Due to low spatial resolution, Kepler is (mostly) indifferent to multiplicity status – though I'll discuss caveats.

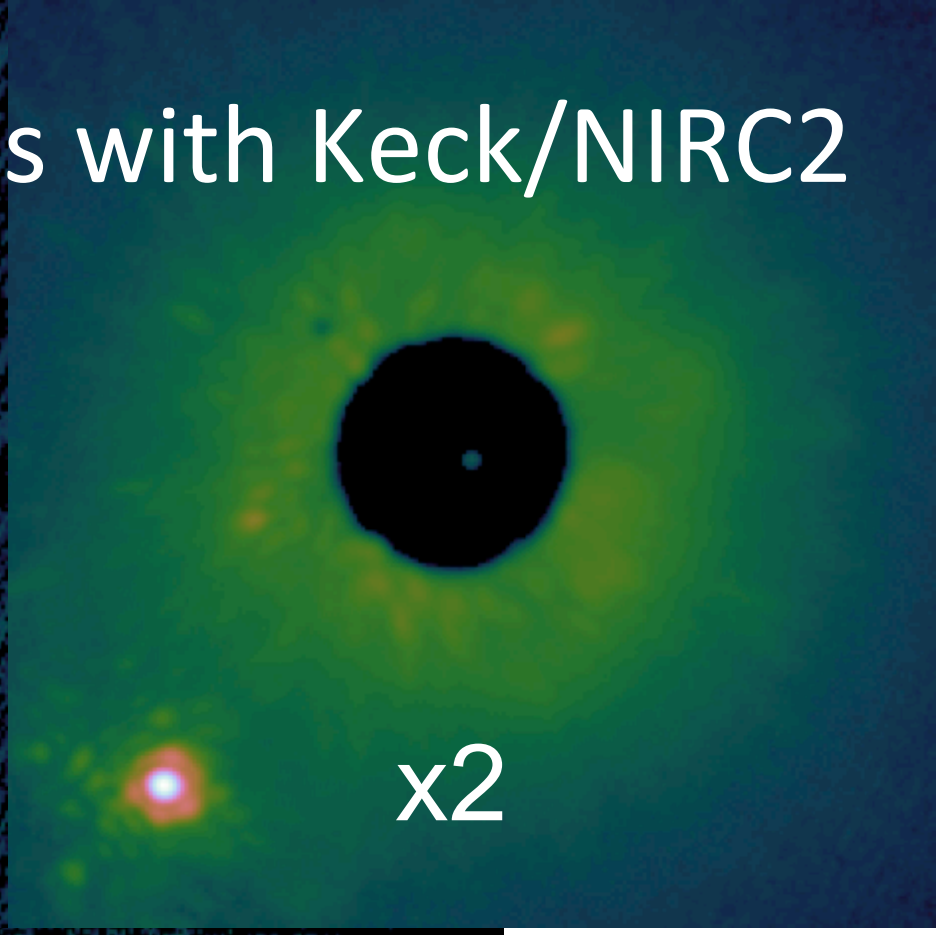
Also see observing campaigns or analyses by Howell, Adams, Lillo-Box, Horch, Dressing, Wang, Law, Kolbl, Gilliland, Everett, Teske, Baranec, Atkinson, Ziegler, Furlan, Hirsch, Deacon



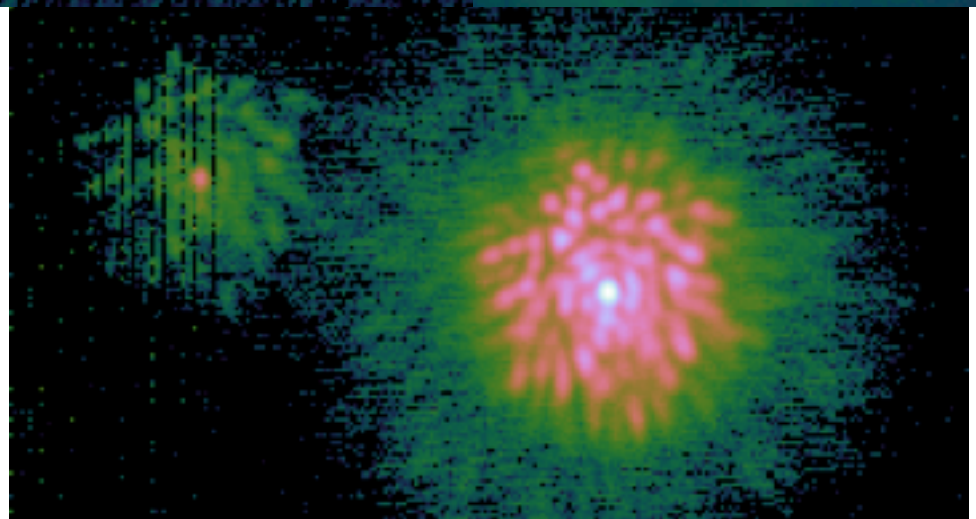
Credits: NASA and Wikipedia

Multiplicity of KOIs with Keck/NIRC2



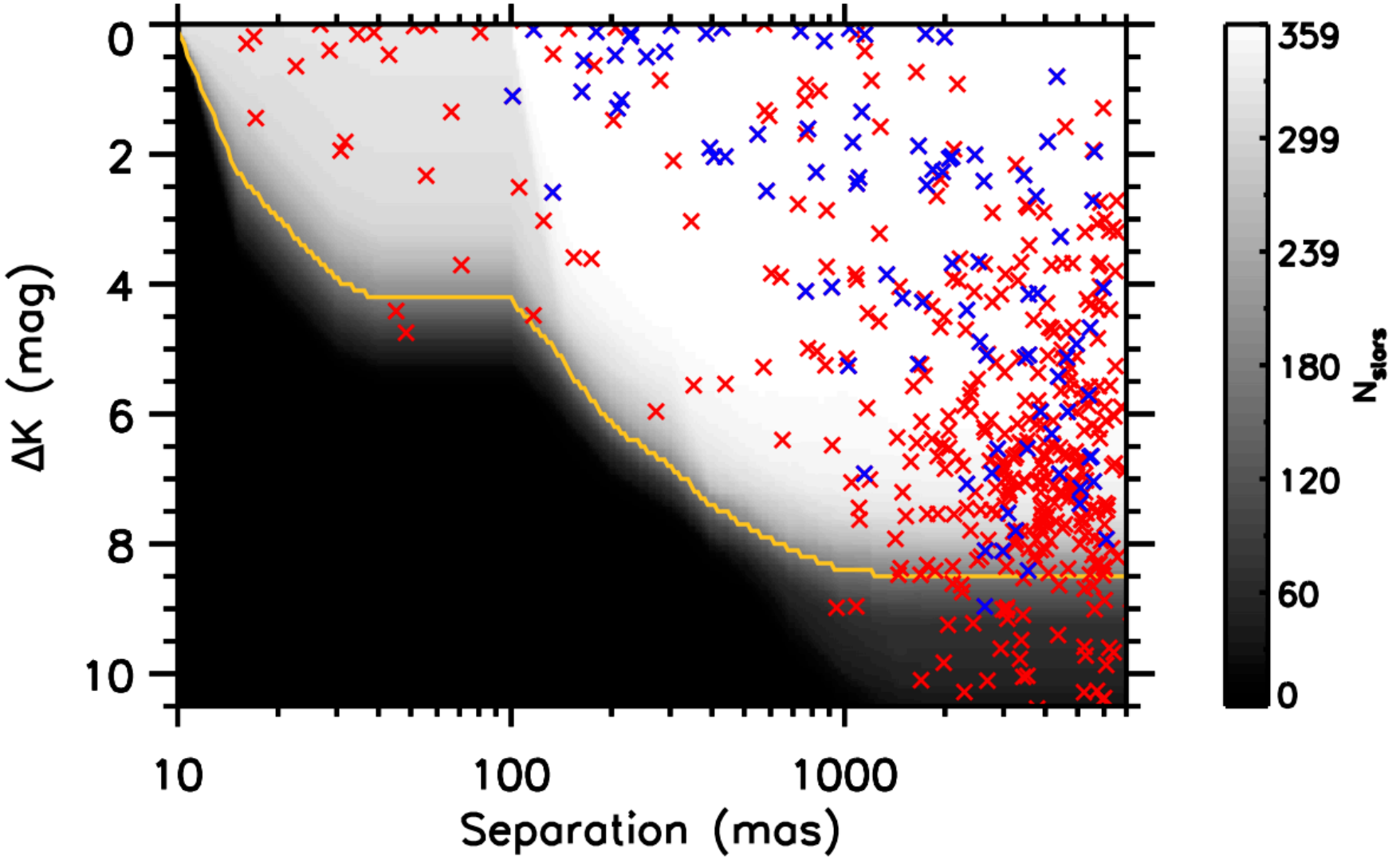


x6



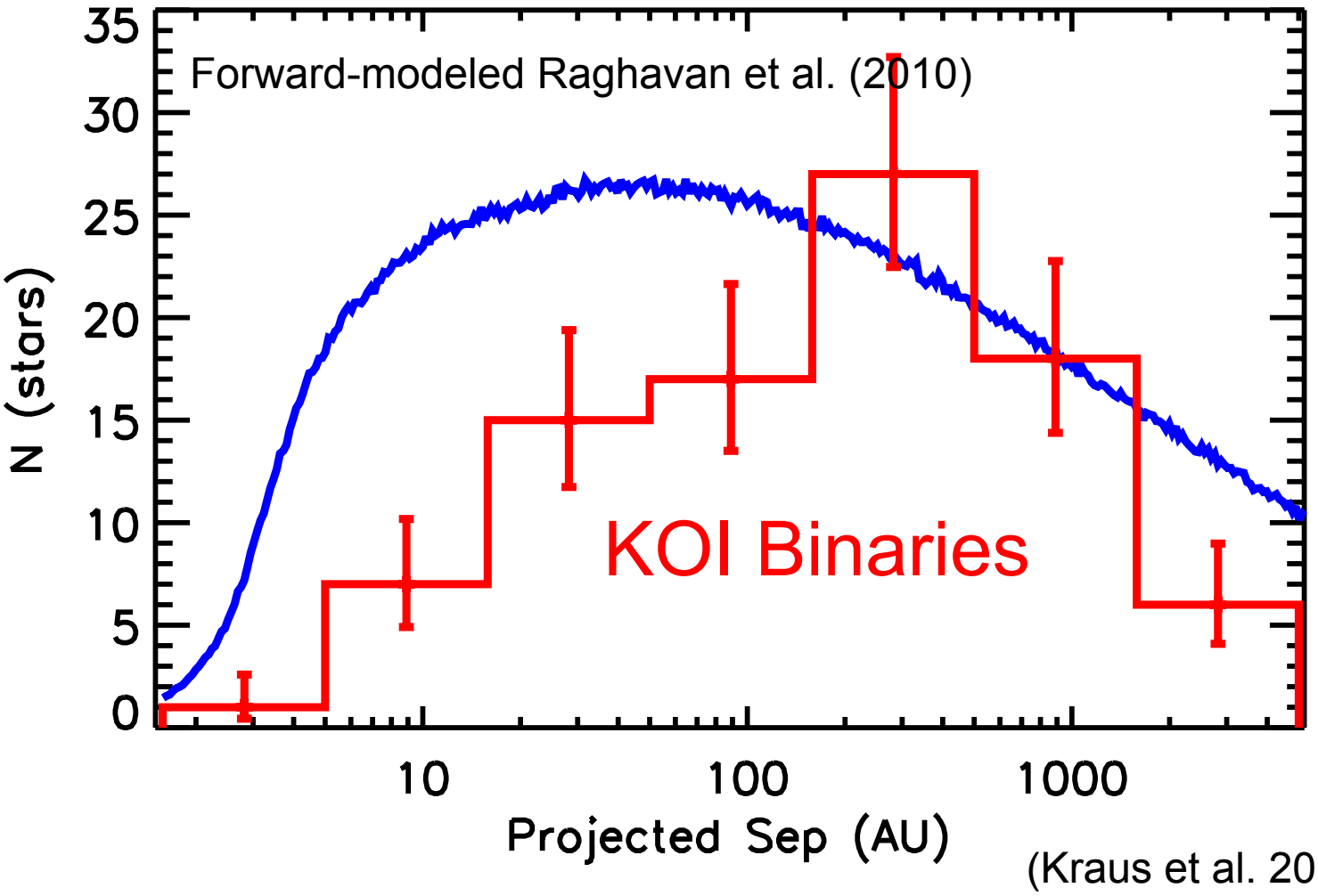
Sample:
430 KOIs,
~100 2nd
epochs

Detections and Detection Limits



Blue: Previously known. Red: New detections.
Grayscale: Sensitivity (fraction of sample)

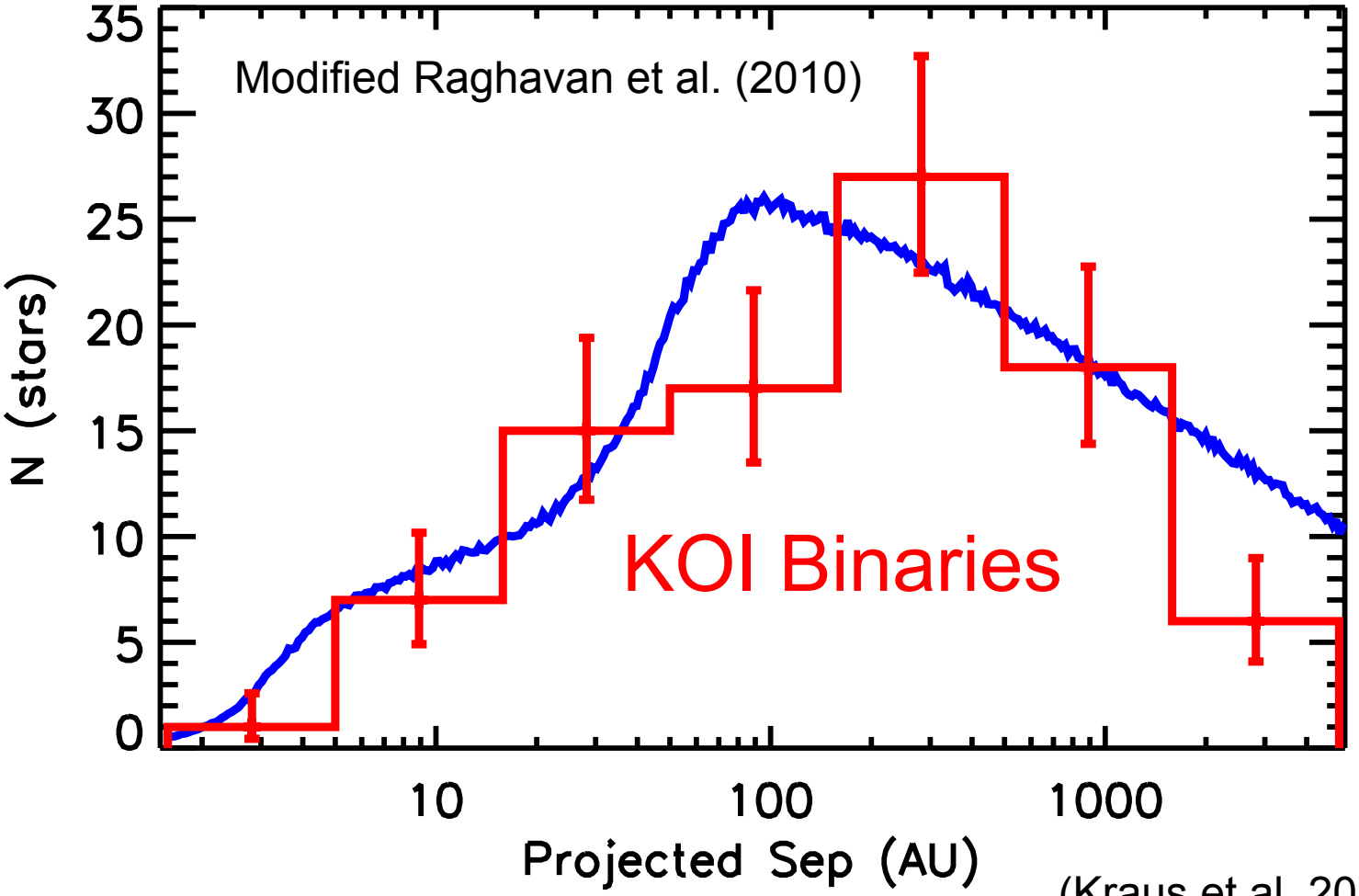
Detections: Observed vs Predicted



(Kraus et al. 2016)

Red = Observed, Blue = Simulation of known binary occurrence rate with Malmquist bias + detection limits included

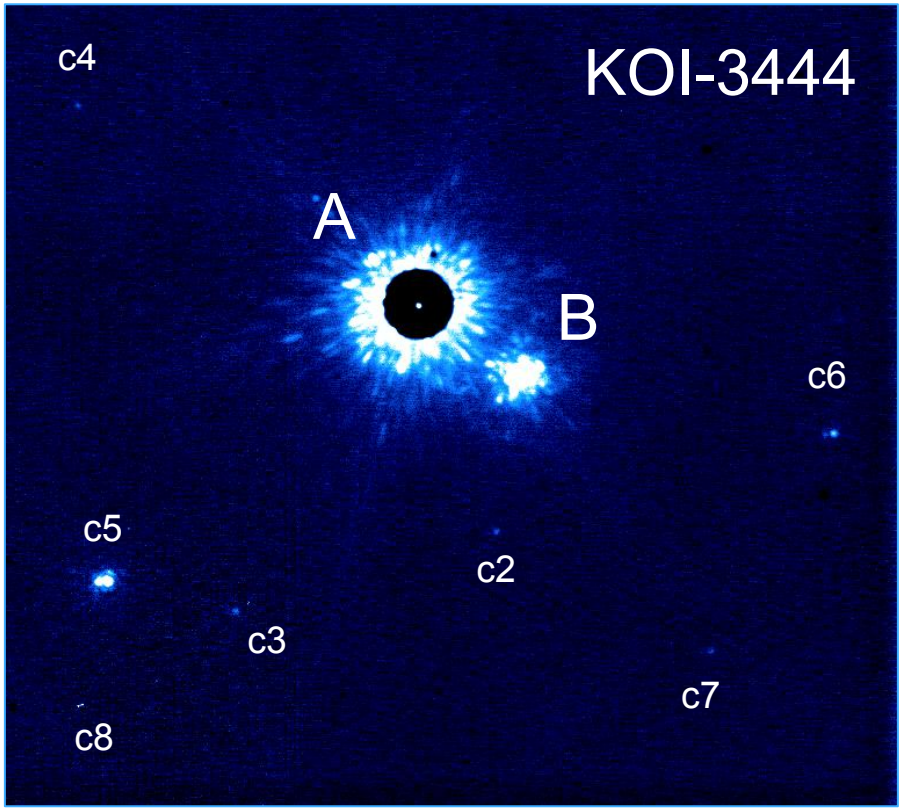
Toy model: Suppress Close Binaries

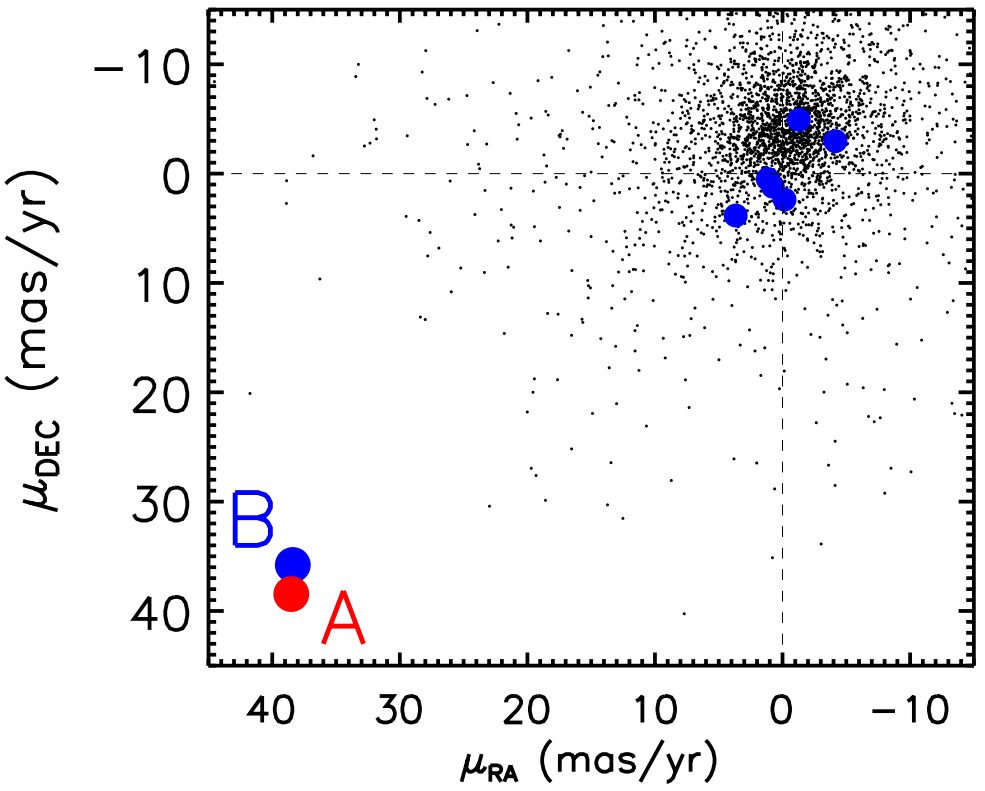


(Kraus et al. 2016)

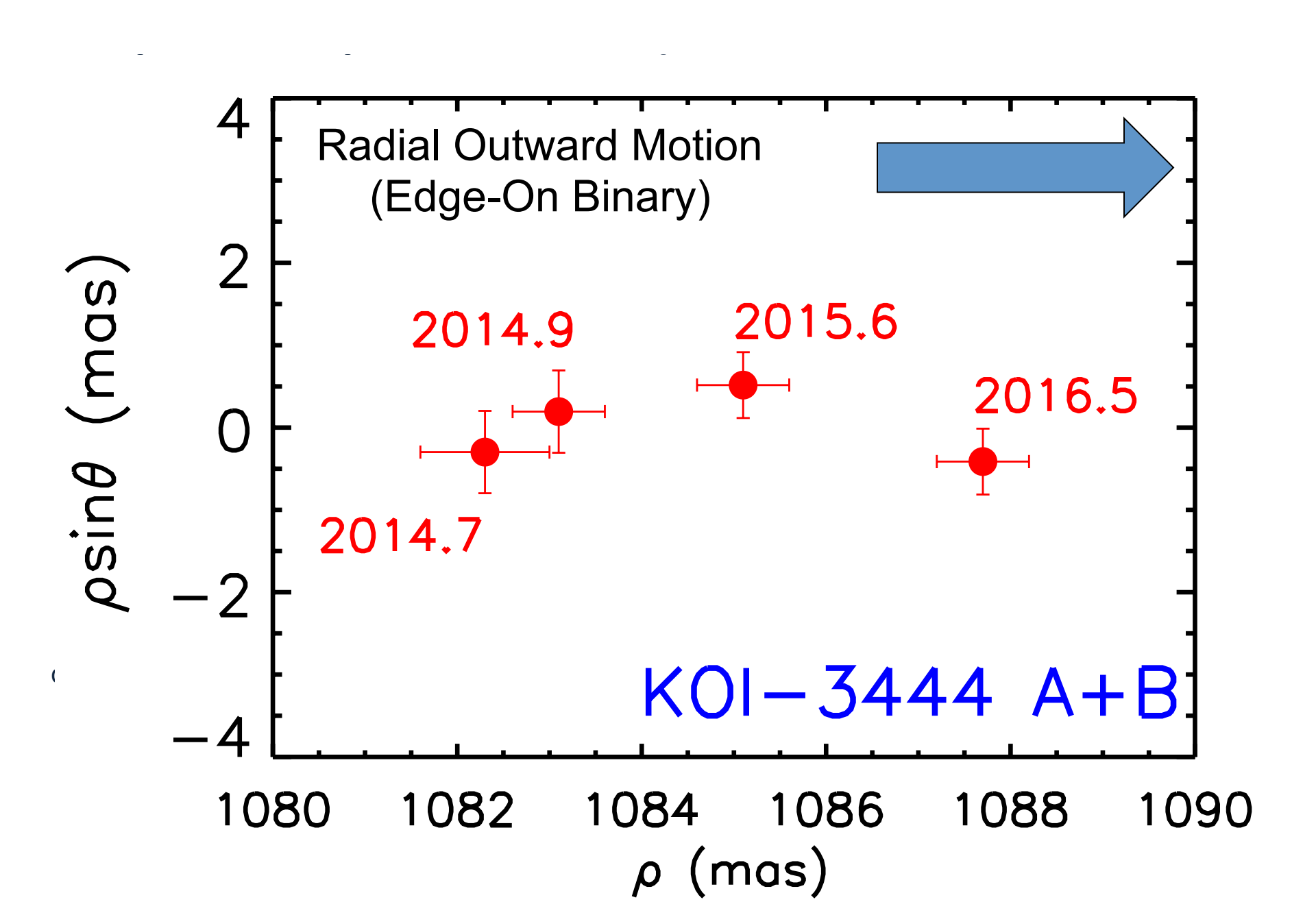
Model: Suppress close binaries (a < 50 AU) by a factor of 3. This is 20% of all stars.

The Path Forward: Proper Motions



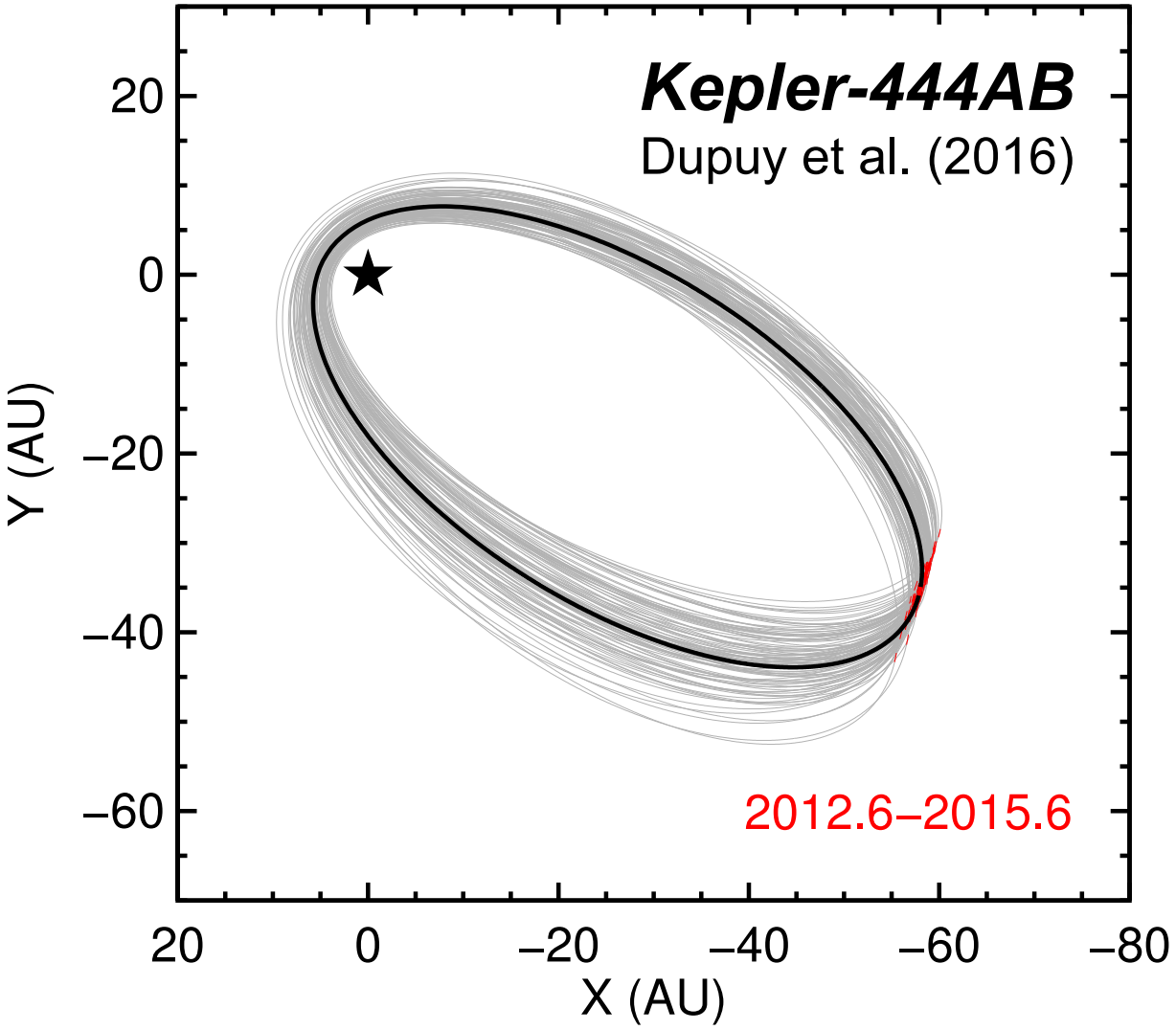


NIRC2 relative astrometry is calibrated to ~1 mas precision (e.g., Yelda et al. 2010), yielding proper motions good to <1 mas/yr across multi-year baselines. *We're resolving out the orbital motion of companions and the intrinsic velocity dispersion of interlopers.*



Dupuy et al. (2017, in prep)

The Path Forward: Orbits



$a = 36.6 \pm 0.8$ AU

$e = 0.864 \pm 0.023$

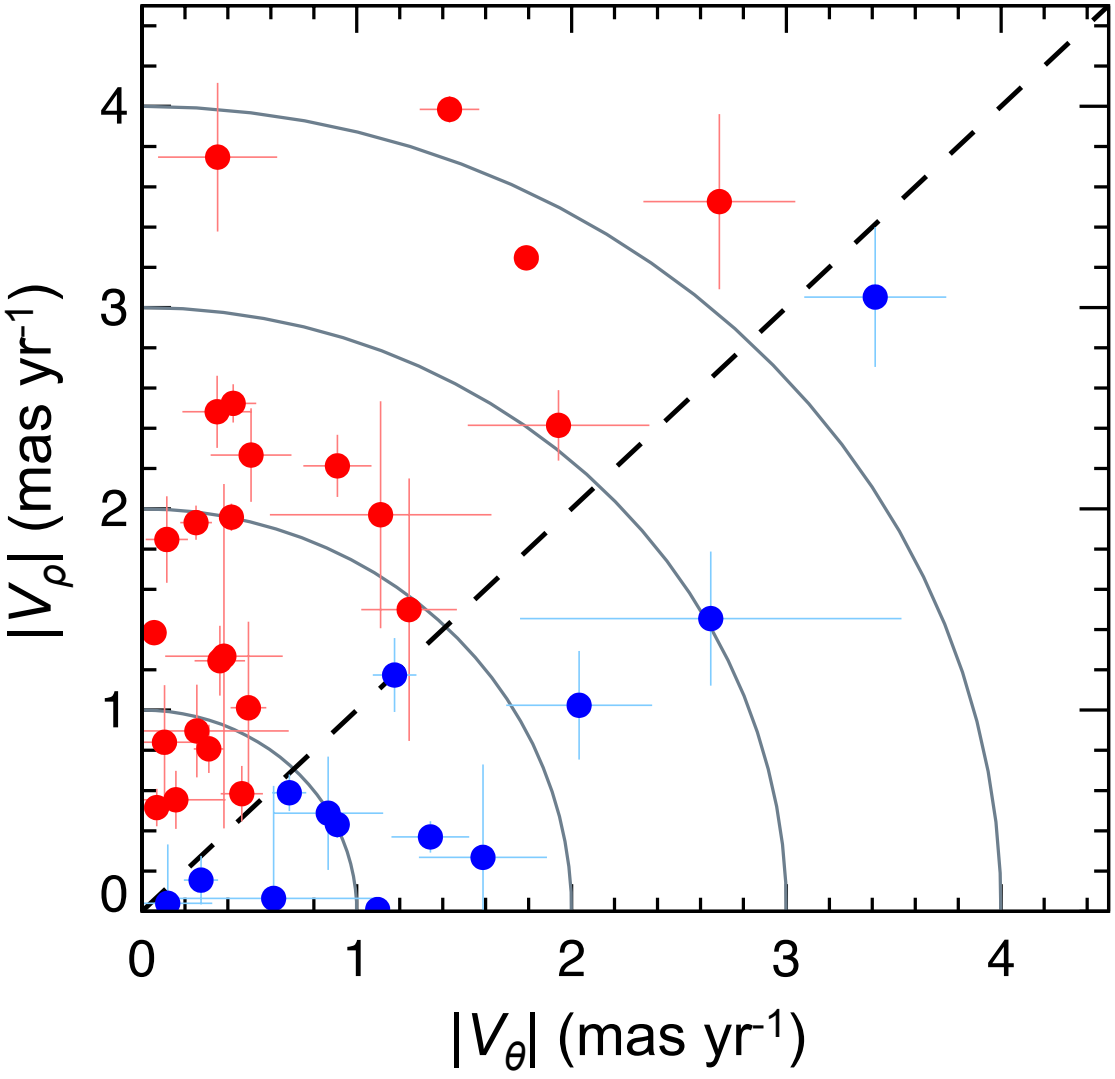
binary periastron

5.0 ± 1.0 AU

Small planets, born in a truncated disk

In collaboration with the CPS team for Keck/HIRES followup.

The Path Forward: Orbits



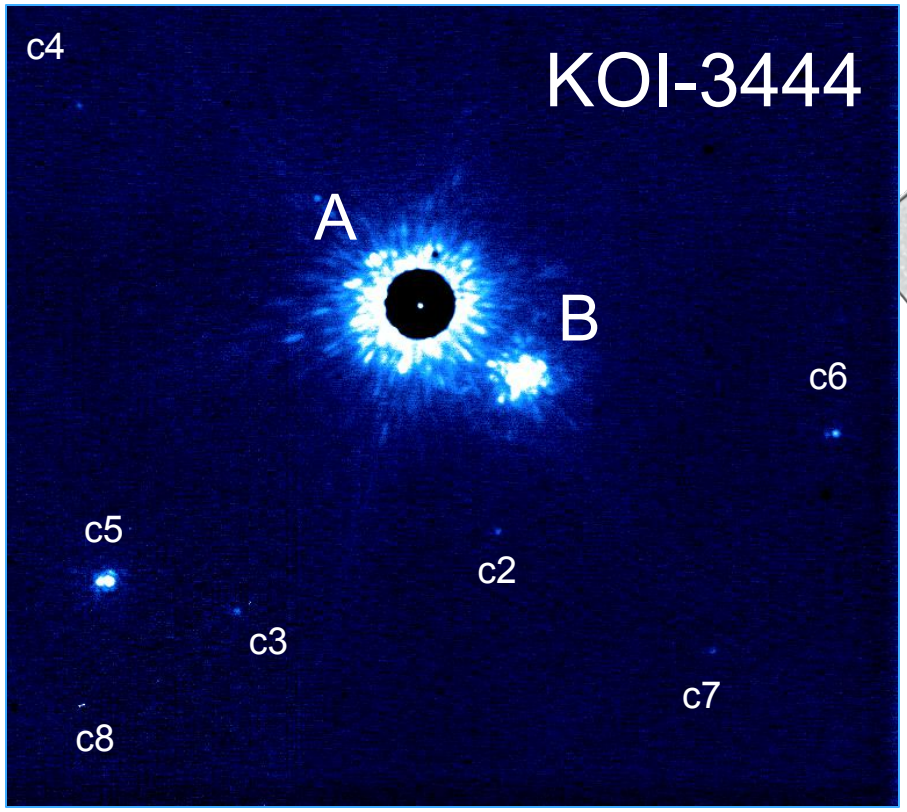
64% of sample has $V_\rho > V_\theta$

For Isotropic,
$p_{K\text{-}S} = 0.003$

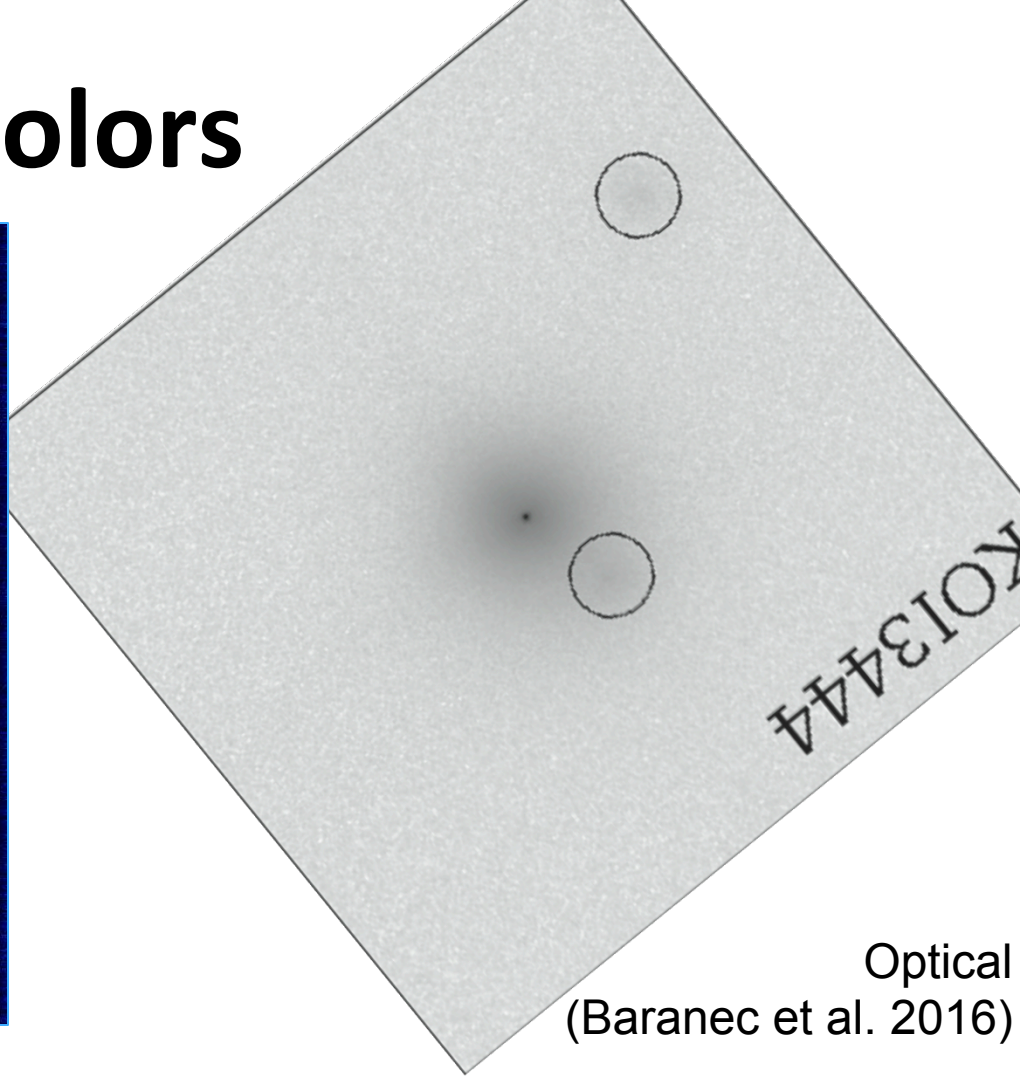
Planets + Stars are dynamically connected

(Dupuy et al. 2017, preliminary)

Path Forward: Colors



NIR (Kraus et al. 2016)



Optical
(Baranec et al. 2016)

~100/500 candidate companions have optical counterparts from Robo-AO or DSSI, mostly bright/wide candidates that could plausibly be bound or background. See upcoming talk by Carl Ziegler for Robo-AO sample (all KOIs), plus Hirsch et al. (2017).

The Path Forward: Model Upgrades

- **Systematics Include:**
  - **Drawing from Realistic Binary Population**
  - **Simulations Match Sample Distances**
  - **Malmquist Bias (+binaries)**
  - **Random Orbital Phase (-binaries)**
  - **Planet Detectability/Flux Dilution (-binaries)**
  - **Two Stars to Host the Planets (+binaries)**
  - **Stellar Mass-Dependent Planets (-binaries)**
  - **Biases in KIC and Kepler Target List? (-binaries)**

The Path Forward: Model Upgrades

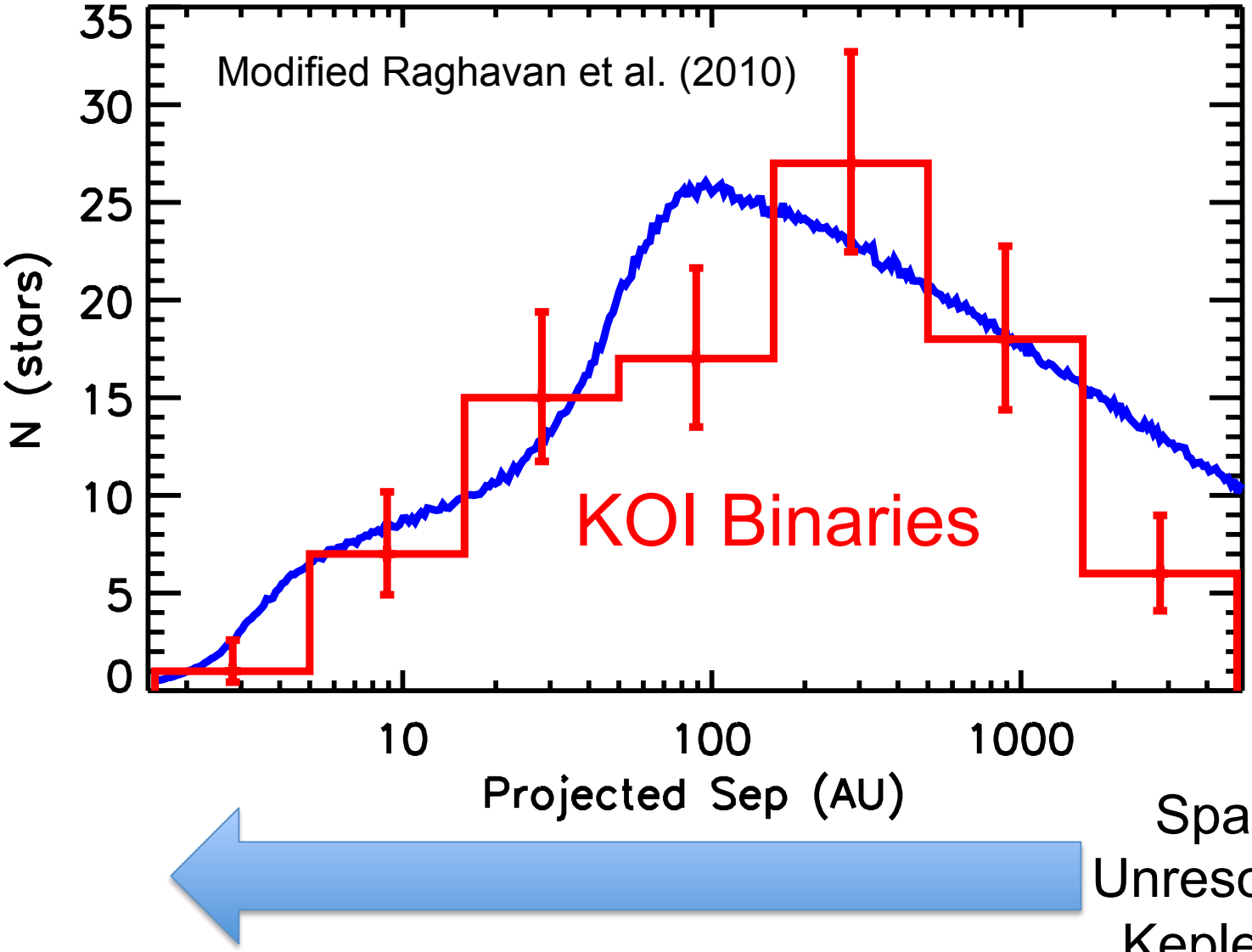
- Systematics Include:
  - Drawing from Realistic Binary Population
  - Simulations Match Sample Distances

First simulate a binary population, try to detect binaries.

Then simulate realistic planets around both stars,
and try to detect those too.

  - Two Stars to Host the Planets (+binaries)
  - Stellar Mass-Dependent Planets (-binaries)
  - Biases in KIC and Kepler Target List? (-binaries)

Note: Differential Signal is Robust

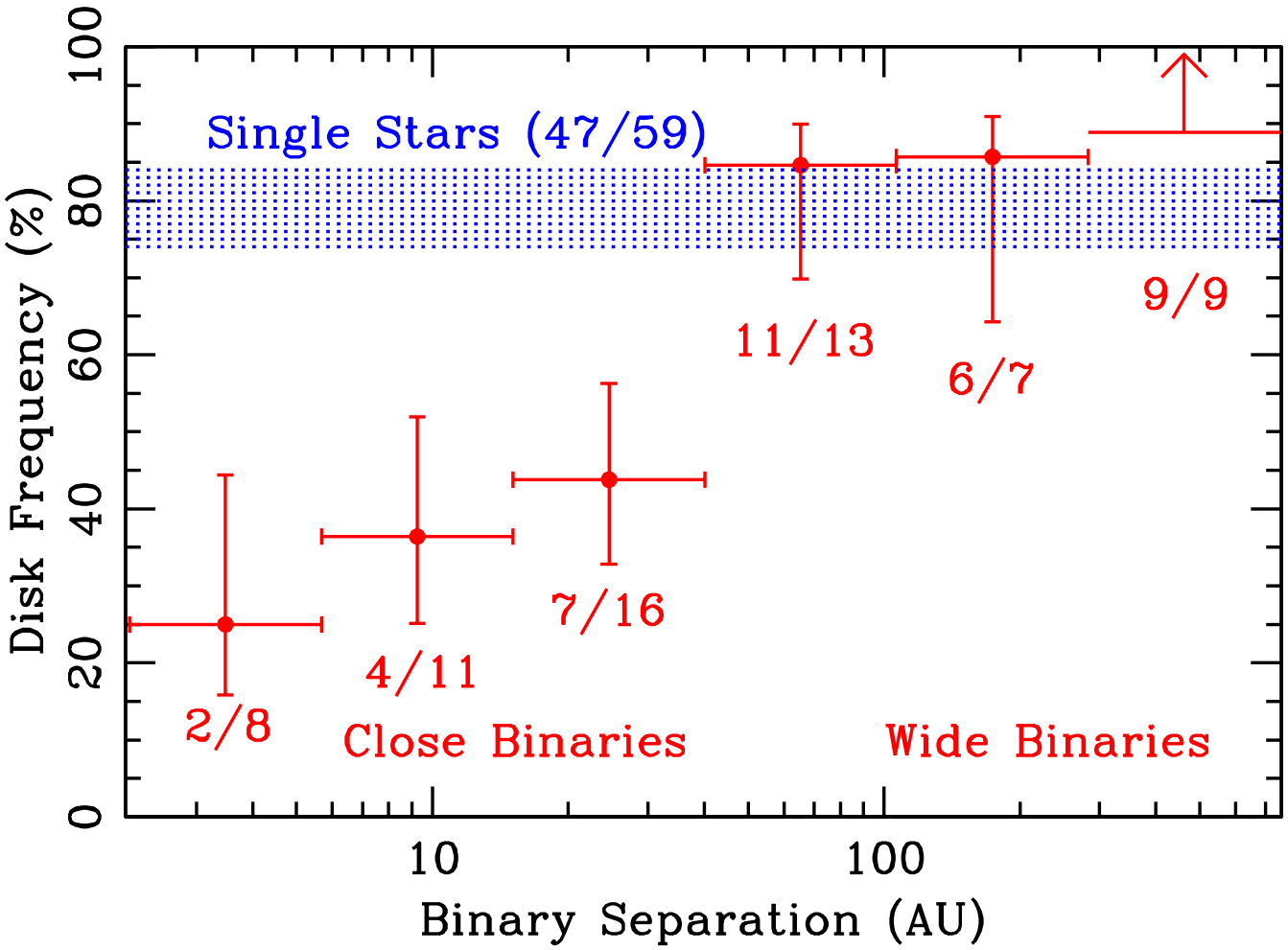


Spatially Unresolved in Kepler Data

Takeaway Points

- Inside ~50 AU, ~2/3 of binary systems don't form planets. Wider binaries are fine. This affects 1/5 of all stars.
- Why do some close binaries succeed at planet formation/survival? Unclear. Suspects include binary eccentricity or disk/binary mutual inclination, but some very odd systems survive.
- The binary+planet surveys are no longer difficult; controlling for systematics is probably the largest remaining challenge.

For Context: Disk (Non)Survival



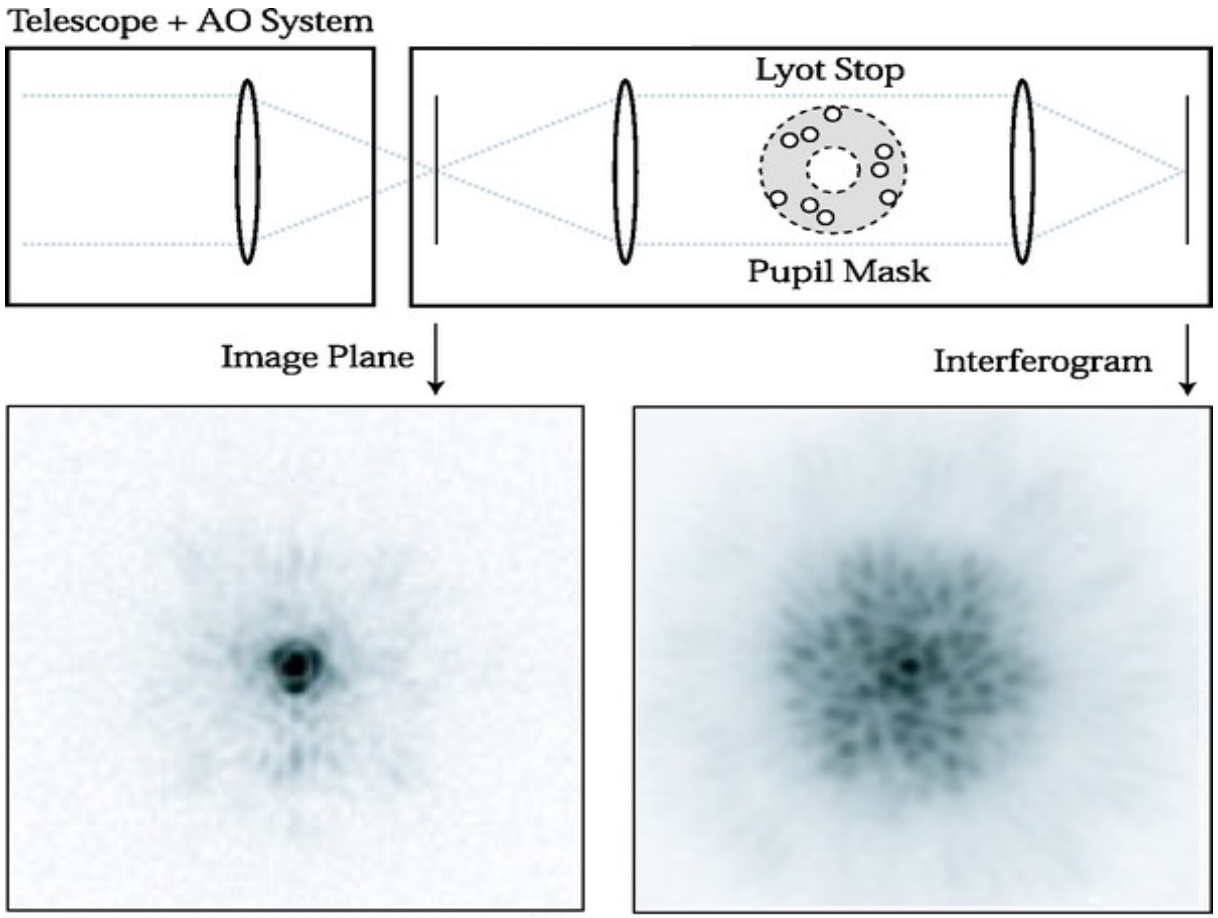
Kraus et al. (2012)
(Non)Occurrence of Disks in Young Binary Systems

This pattern is set by an age of ~2 Myr.

(Also see Jensen et al. 1996, Ghez et al. (1997), White & Ghez (2001), Cieza et al. (2009), Duchene et al. (2010), and many many others…)

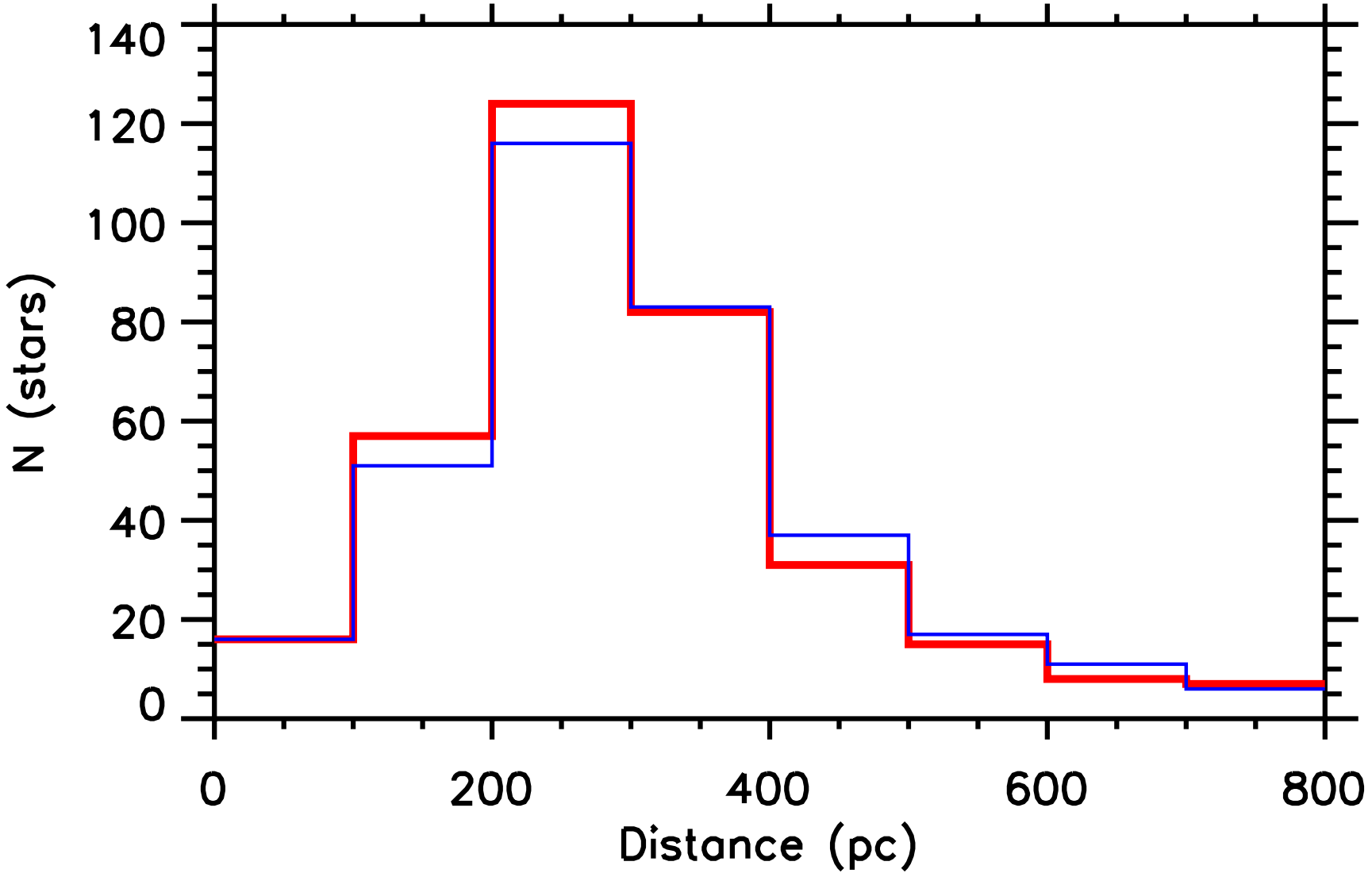
Non-Redundant Aperture Masking

Used Keck/NIRC2 to observe >400 KOIs out to d=400 pc with imaging, coronagraphy, and non-redundant aperture masking (NRM).

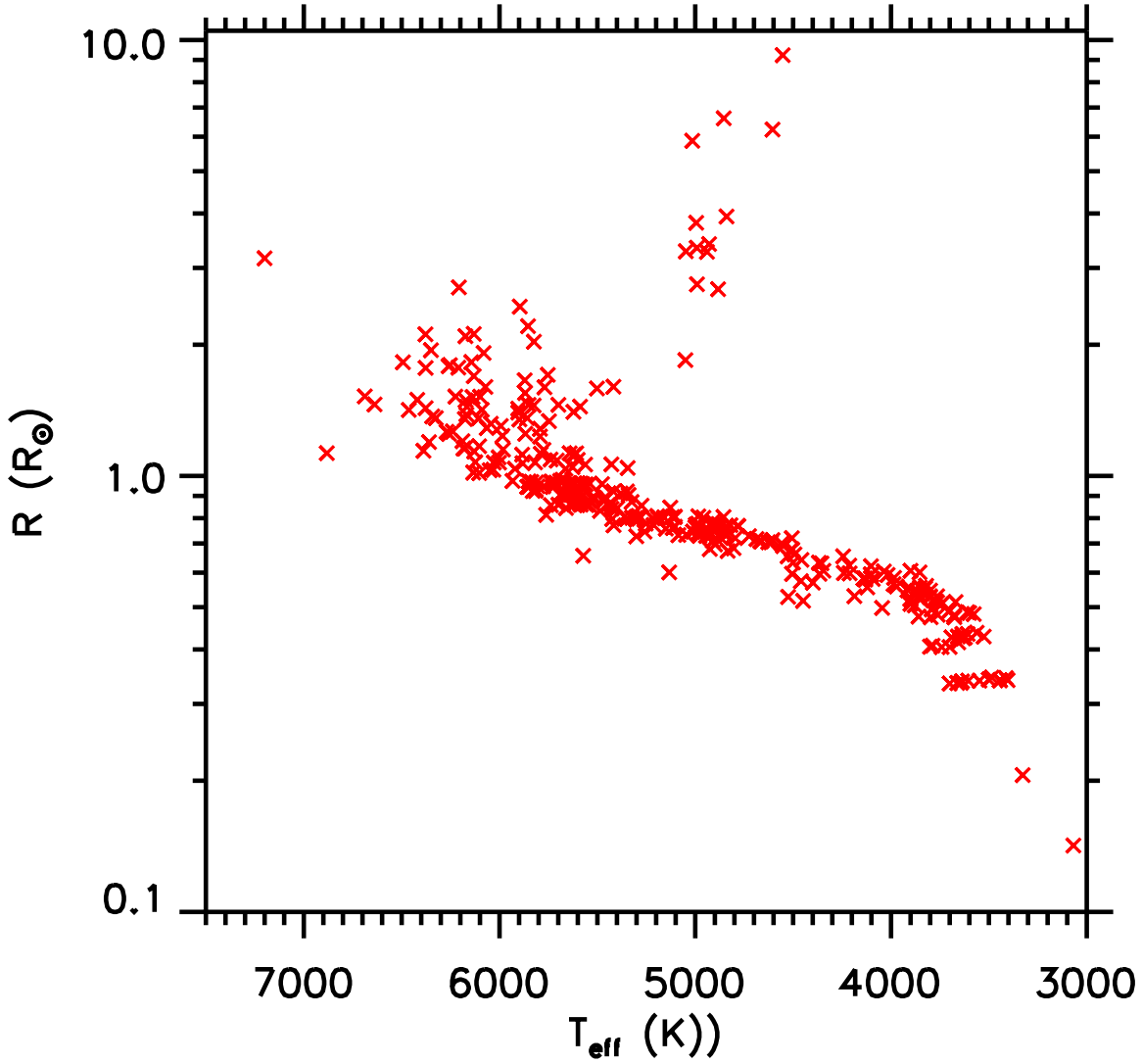


(NRM): Place a mask in the pupil plane, turning the single mirror into a sparse array. Fourier analysis techniques filter most remaining noise from atmosphere

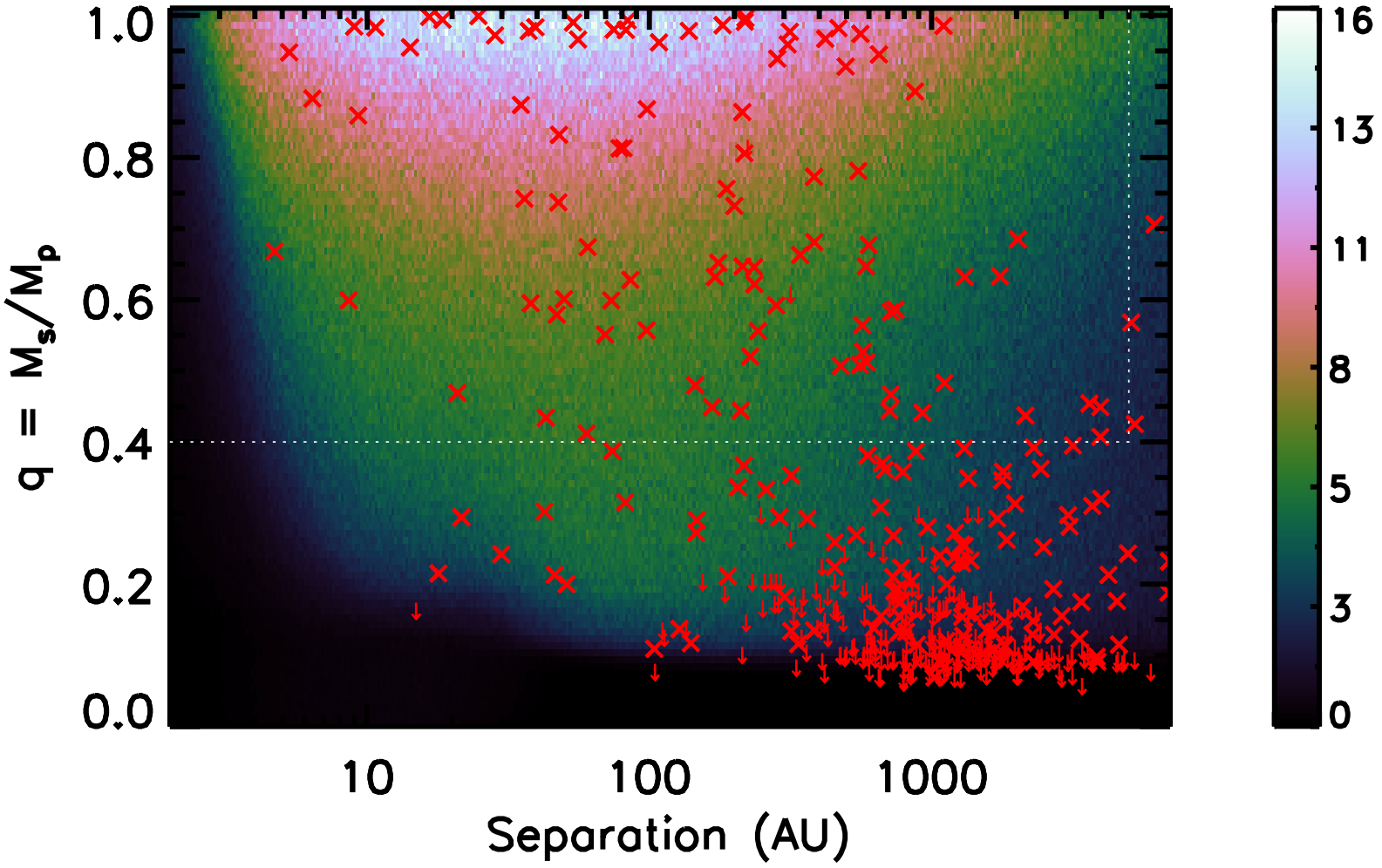
KOI Binary Search Sample



KOI Binary Search Sample

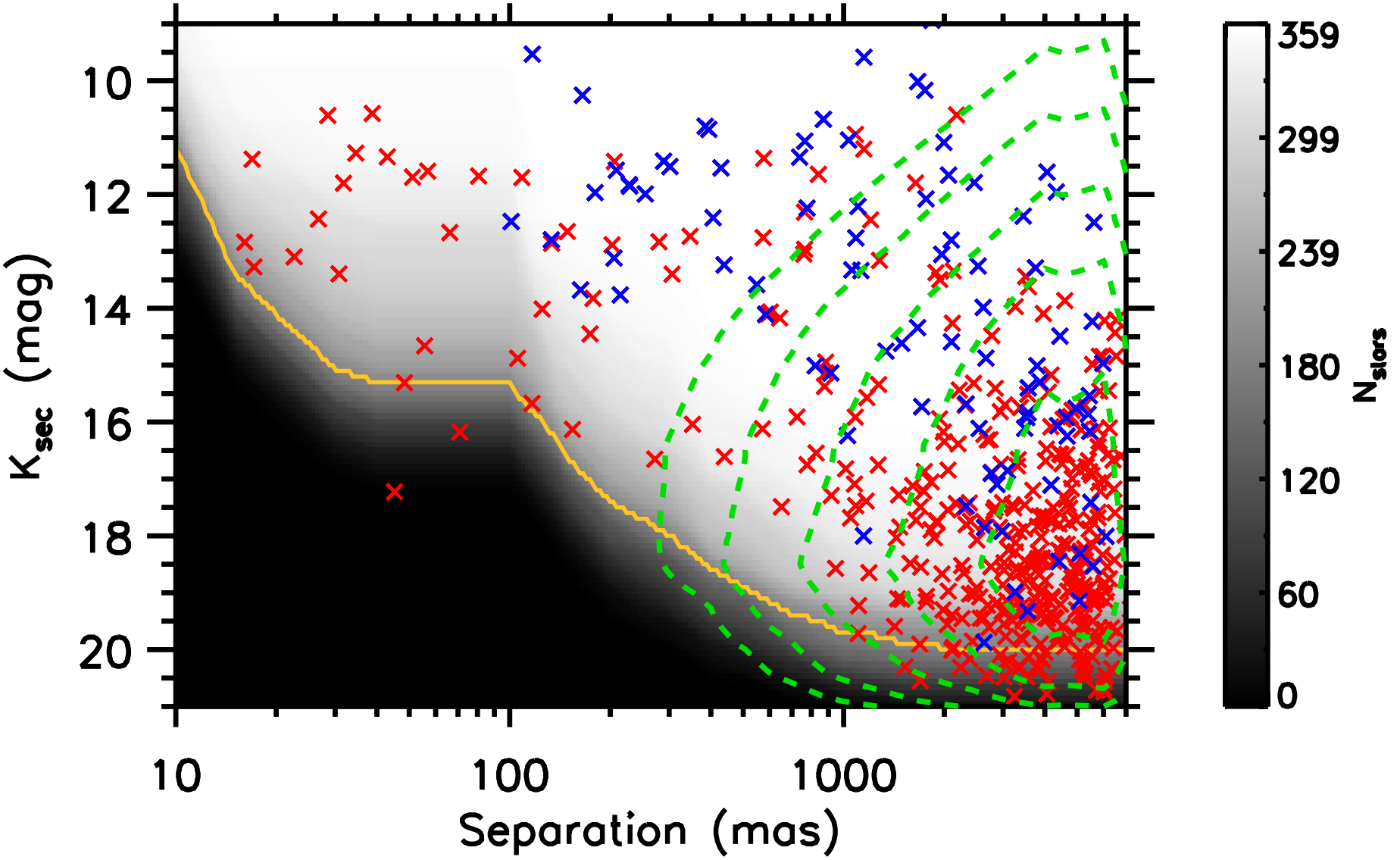


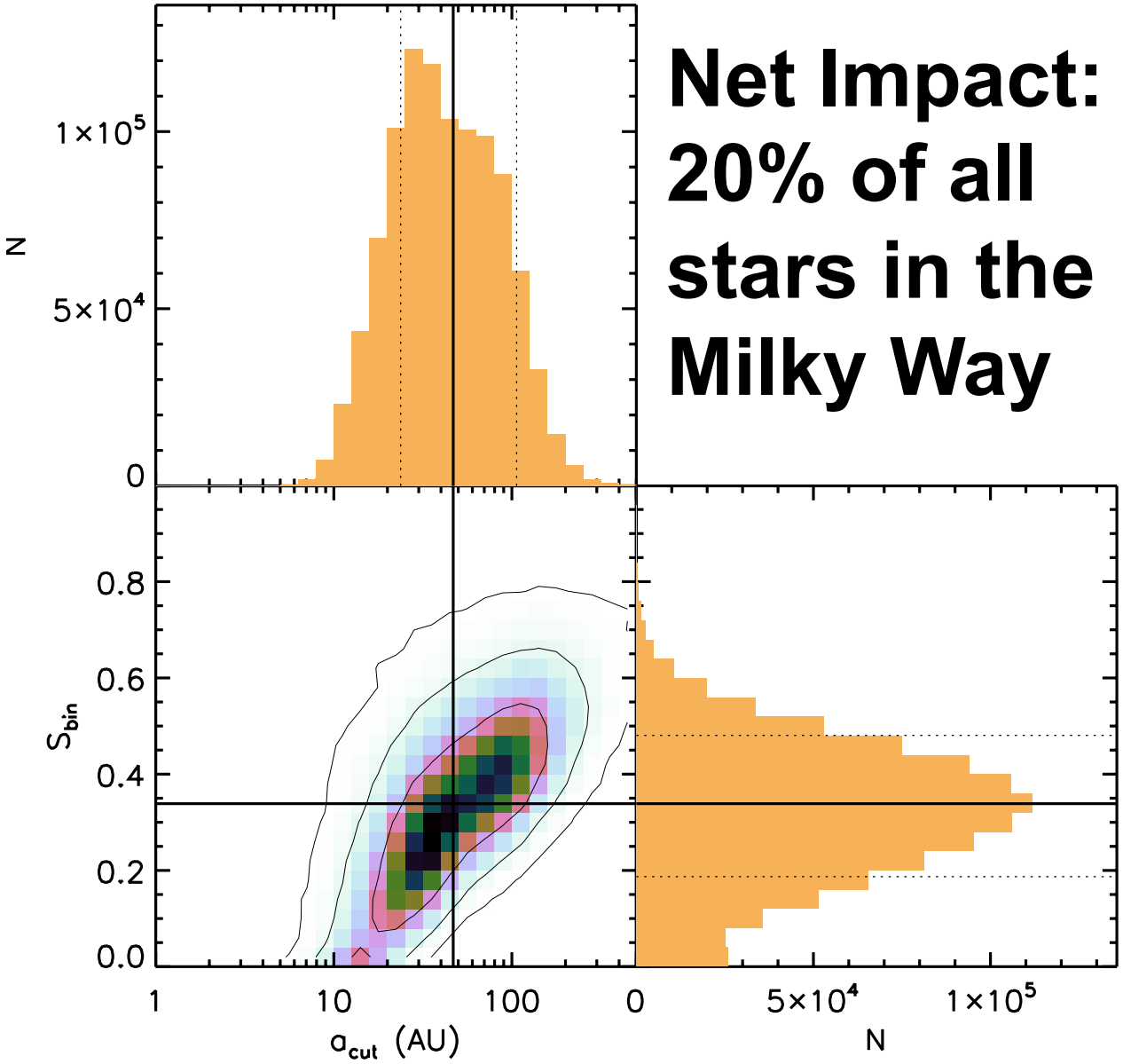
Detections: Observed vs Predicted



Background color: Simulation of known binary occurrence rate with Malmquist bias + detection limits included

Detections and Detection Limits





Net Impact: 20% of all stars in the Milky Way

…so far, survival does not correlate with planet size, planet multiplicity (16:10:3:1), or binary mass ratio.