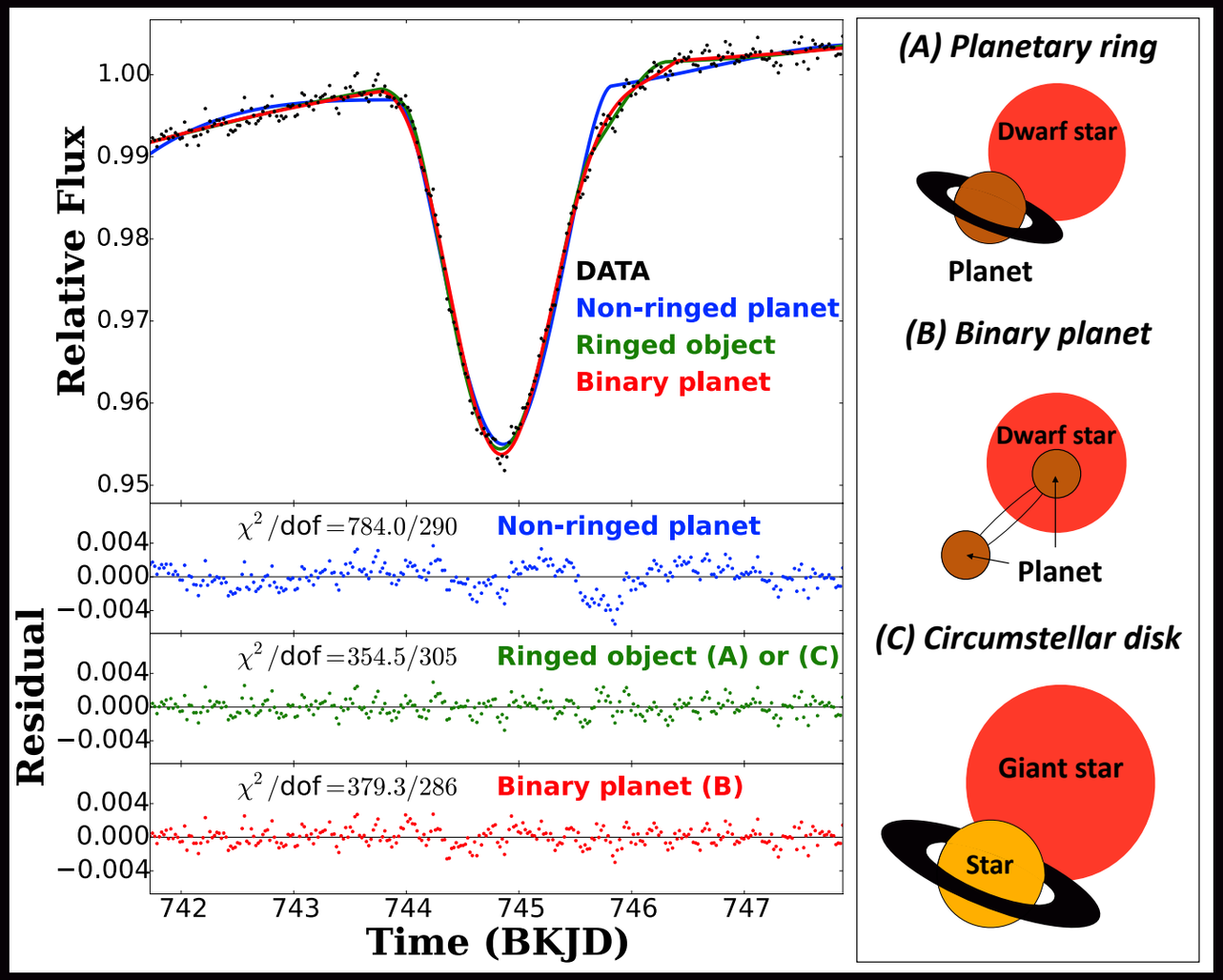
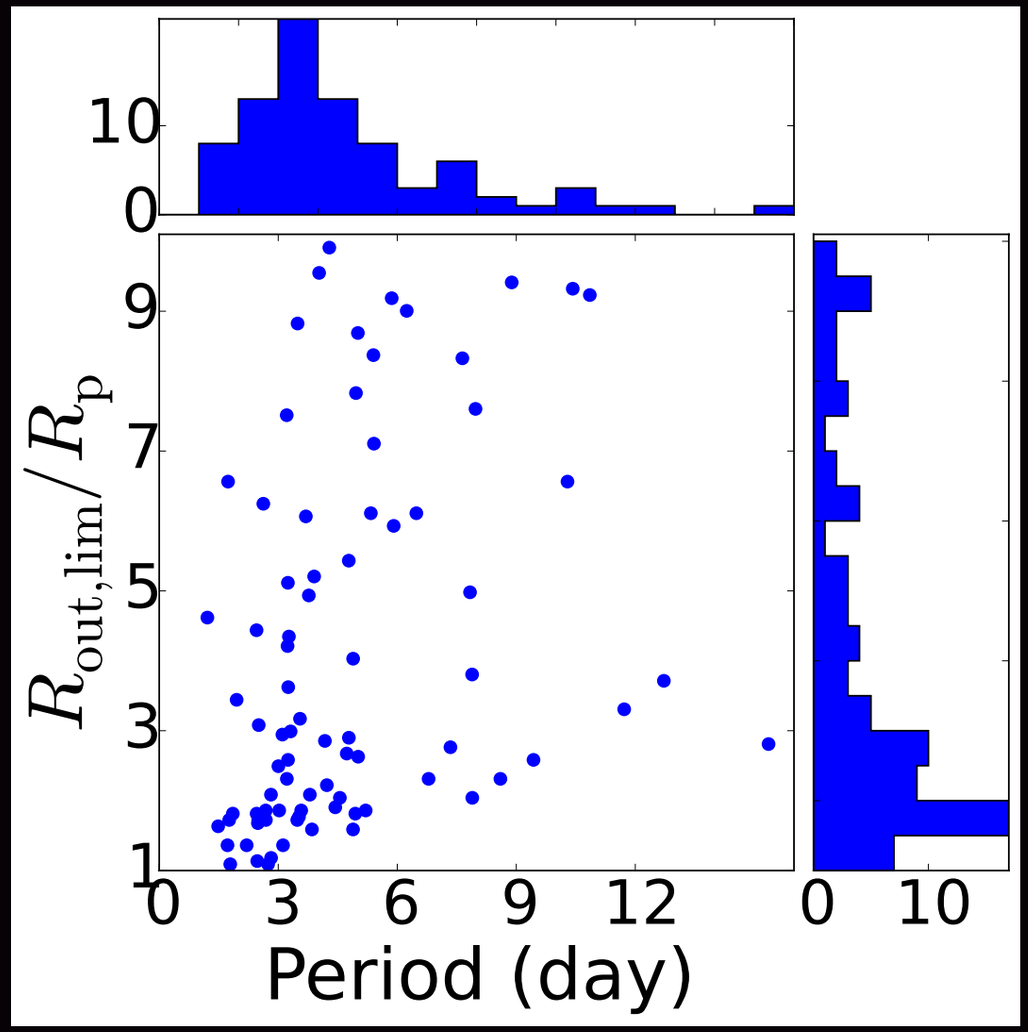
# Search for ringed planets using the Kepler data




**Masataka Aizawa** (3rd-year graduate student)

The University of Tokyo Theoretical Astrophysics

Collaborators: Kento Masuda, Hajime Kawahara, Yasushi Suto

**10th RESCEU/Planet$^2$ Symposium (11/28-30, 2017)**

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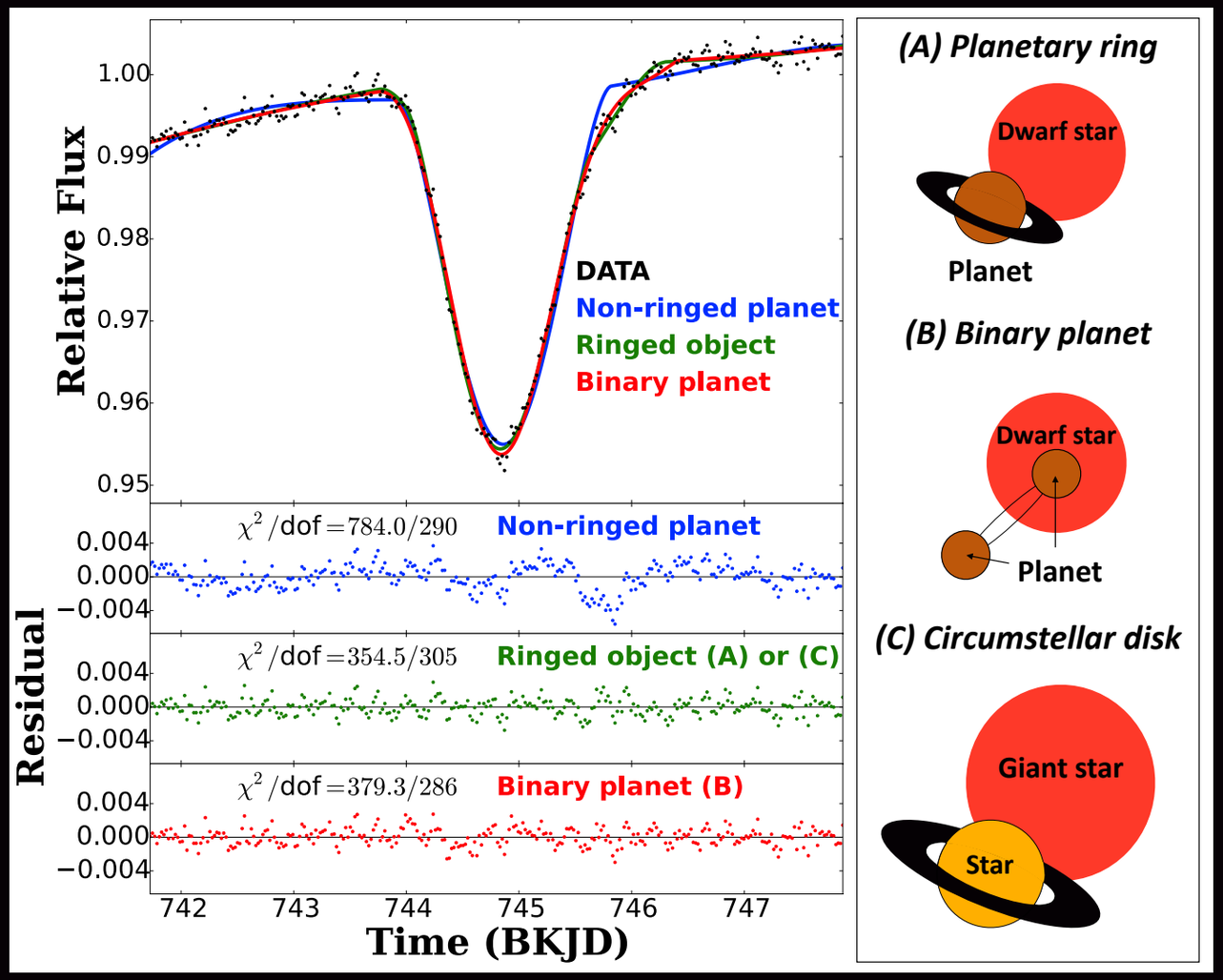


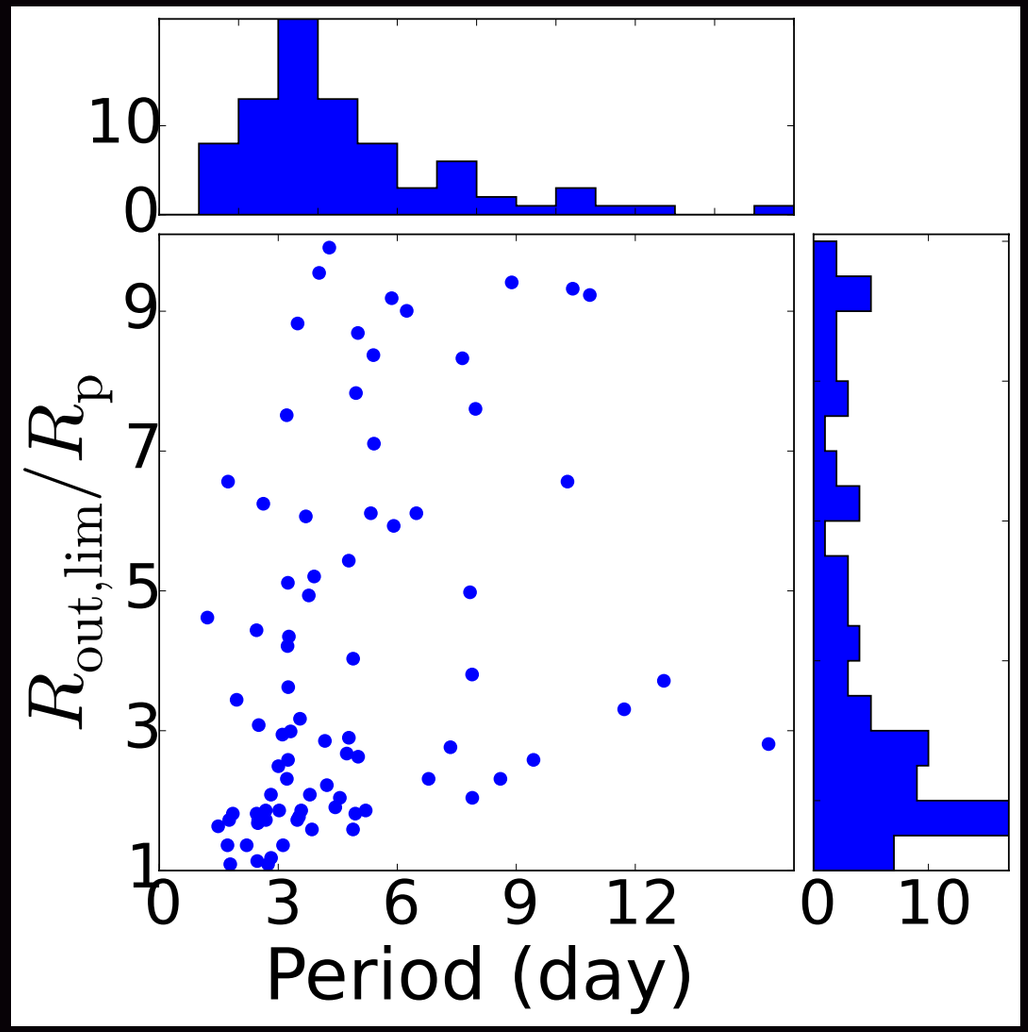


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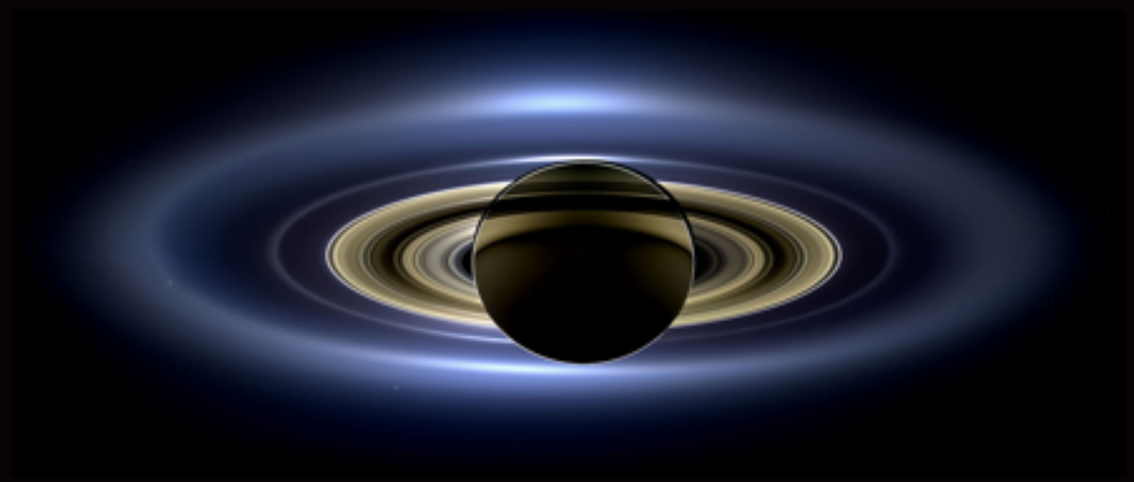
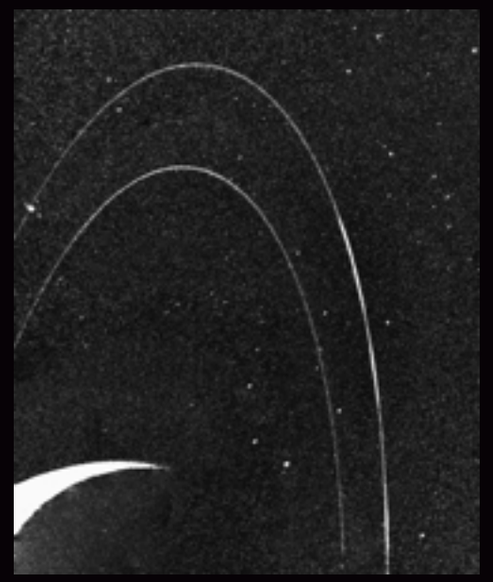
“Table of Contents”

# “Rings are common in Solar System”

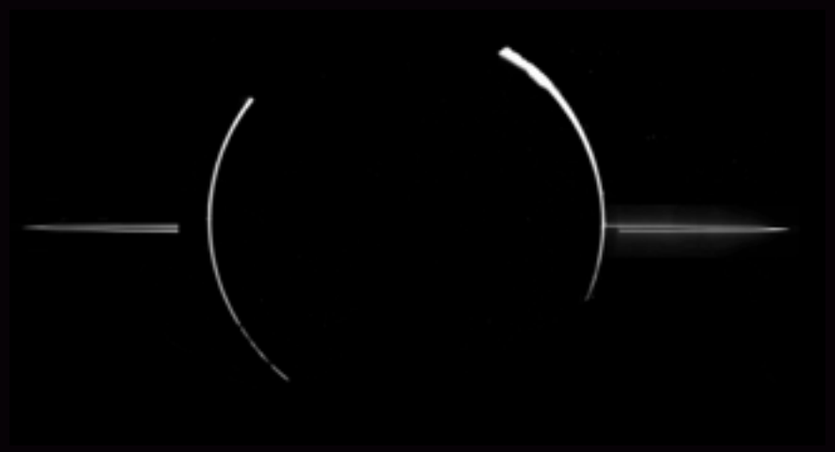
Saturn



Neptune



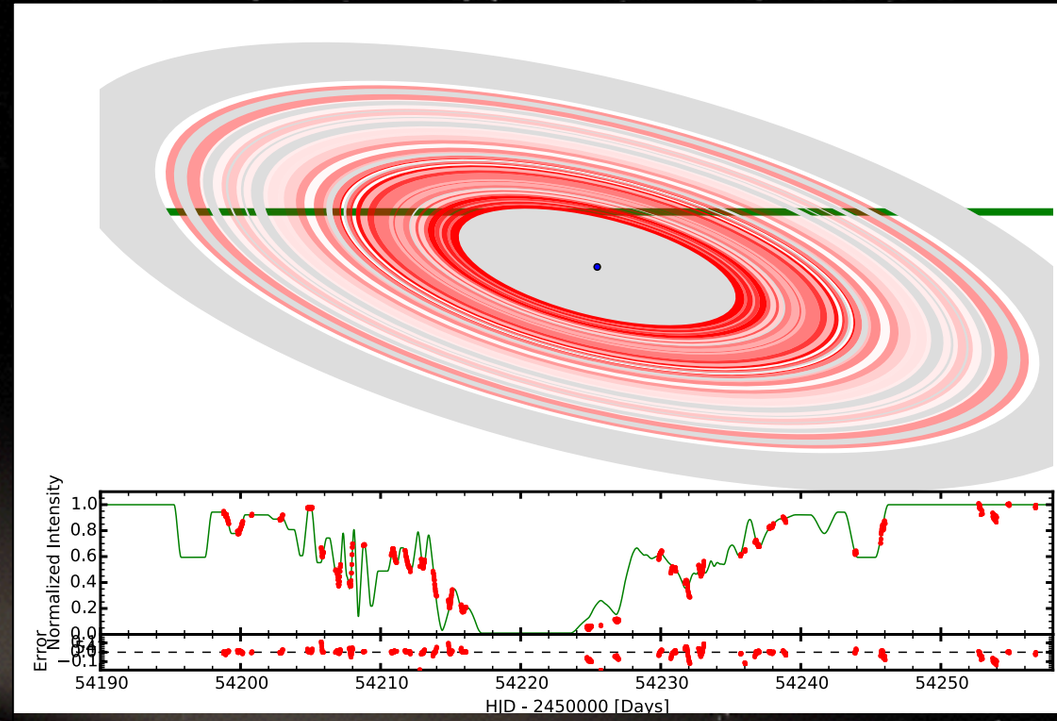
Jupiter



Uranus

“Exo”planetary rings would also be common!!

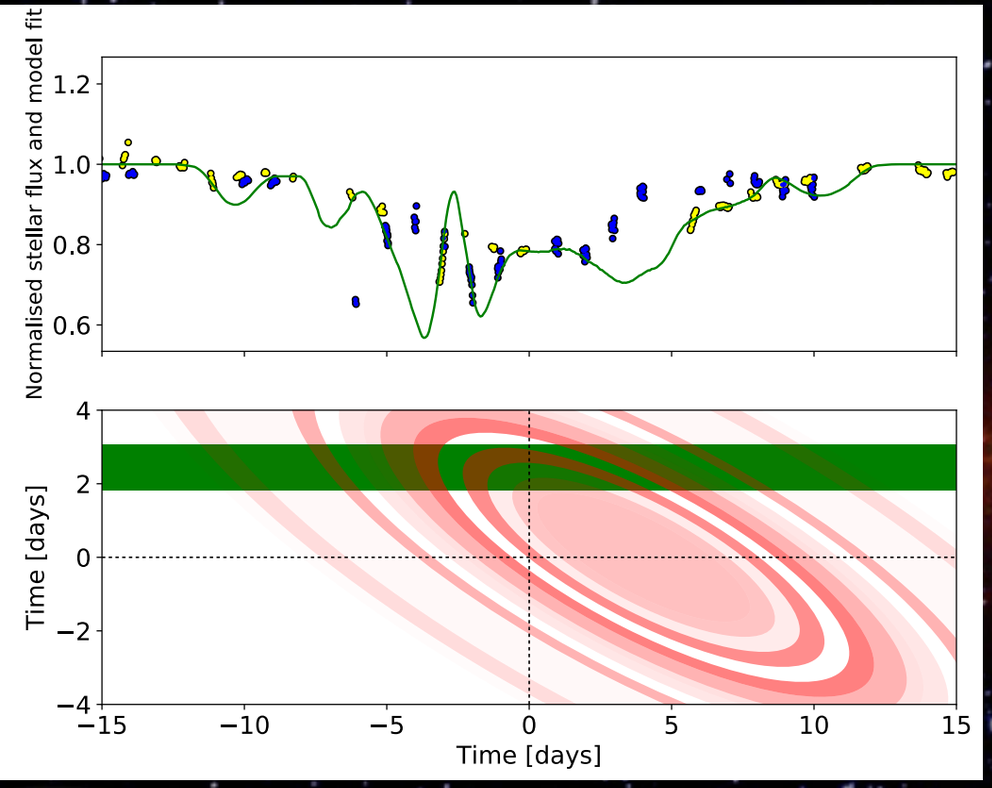
# Possible Circumplanetary disk J1407 b (~16Myr)




Mamajek+ 2012

1 AU

# “PDS110” (~11Myr)



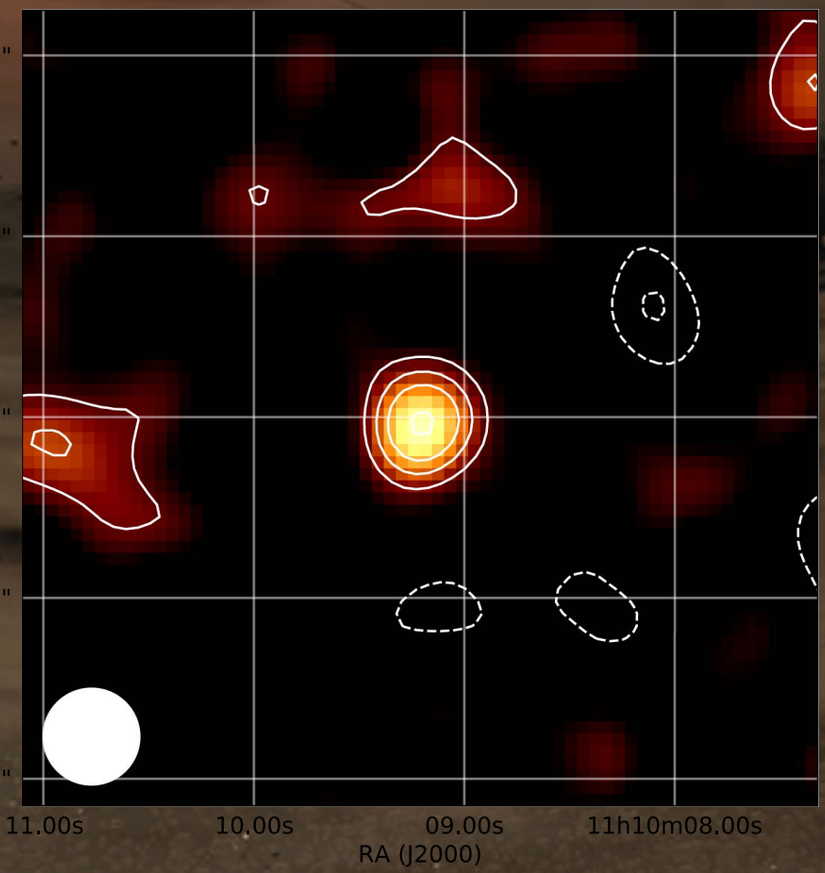

Osborn+ 2017

0.3 AU

©University of Warwick

# Direct Imaging of Circumplanetary Disk by ALMA

**OTS 44 (~2Myr, 12 $M_J$)**



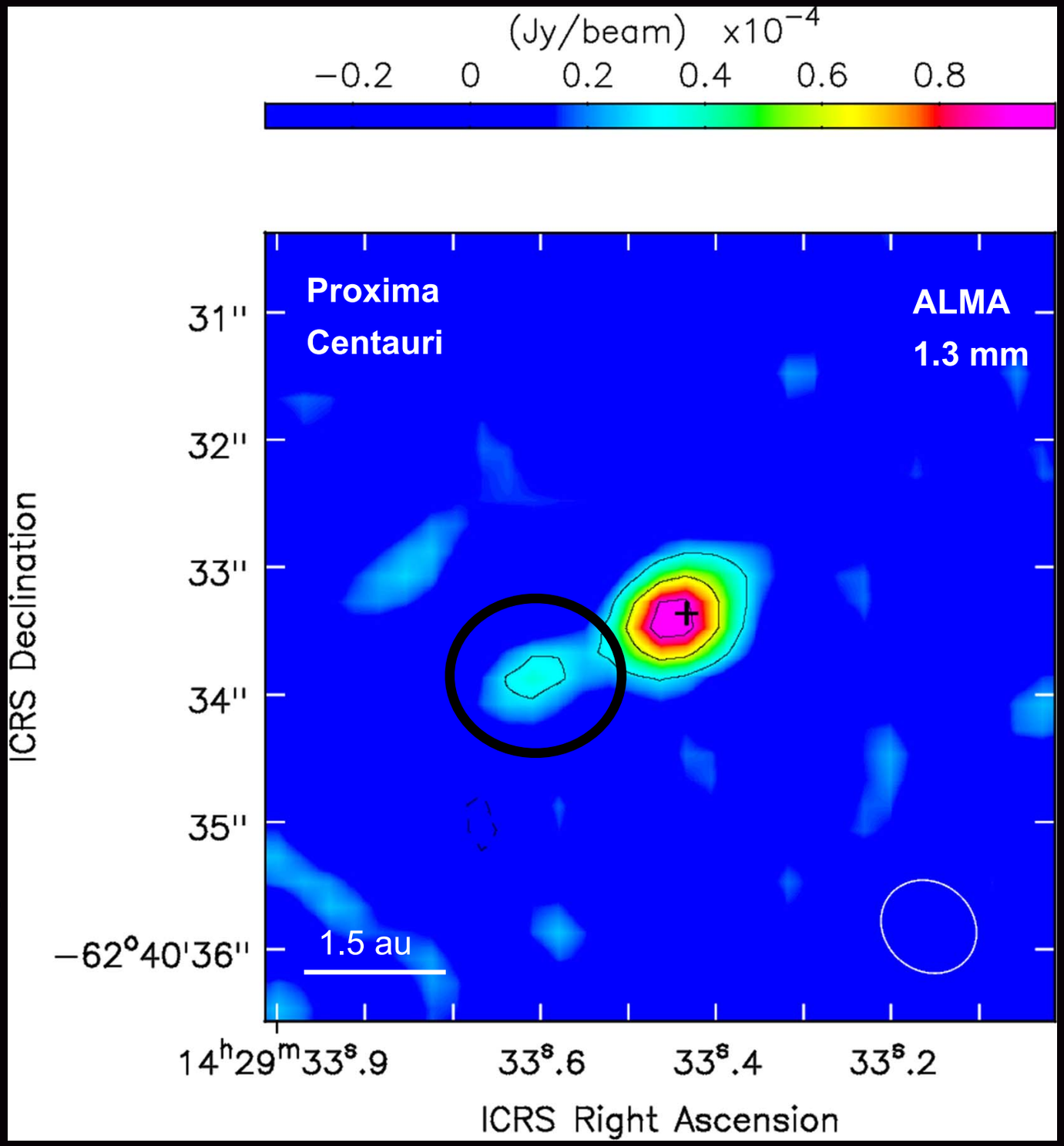

©NASA

Bayo+ 2017

# Mysterious radio emissions of Proxima Centauri

- 4σ signal at few au

- Thermal emission from planet with “large ring”?

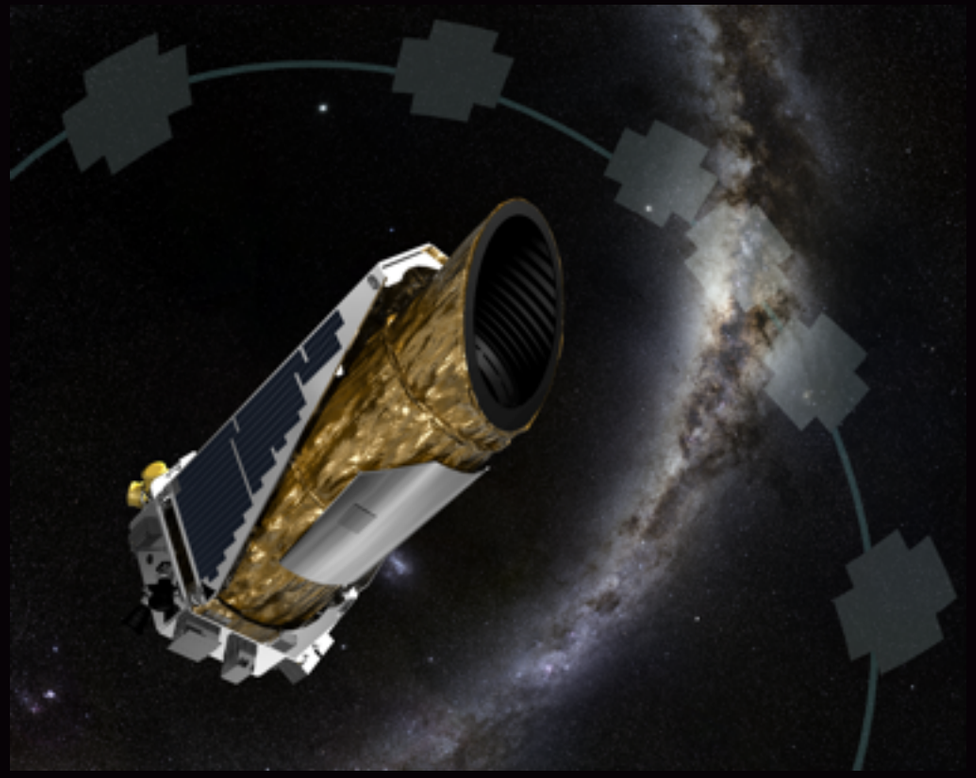



Anglada+ 2017

# Previous search for “Saturn”-like rings

HST ©NASA

- Constraint on ring size for HD 209458 (Brown+ 2001)



Kepler ©NASA

- No signals among 21 Kepler planets (Heising+ 2015)

No evidence for exo-Saturn!

# TO DO

- Detection of “first” Saturn-like exorings
- Derivation of frequency & size of exoplanetary ring
- Every possible analysis now

# Observation strategy

- Direct imaging (ALMA, Coronagraphs)

  - Low detectability of Saturn rings

  - Comparatively small sample of direct imaged planets

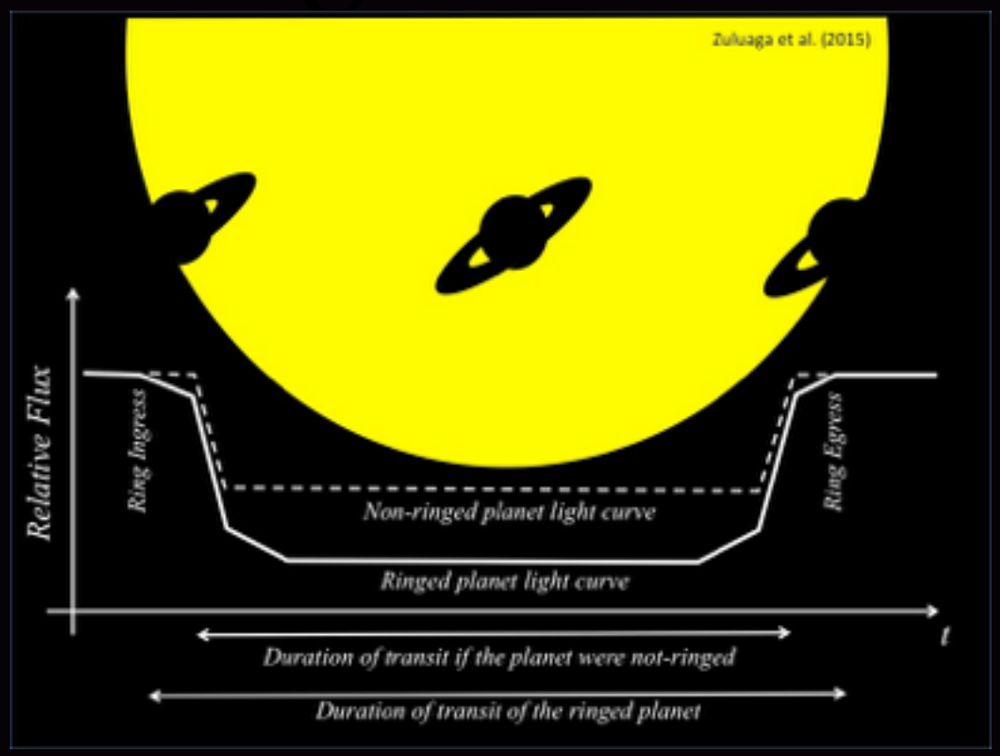
- Indirect method (Transit)

  - Kepler  is sensitive to Saturn rings

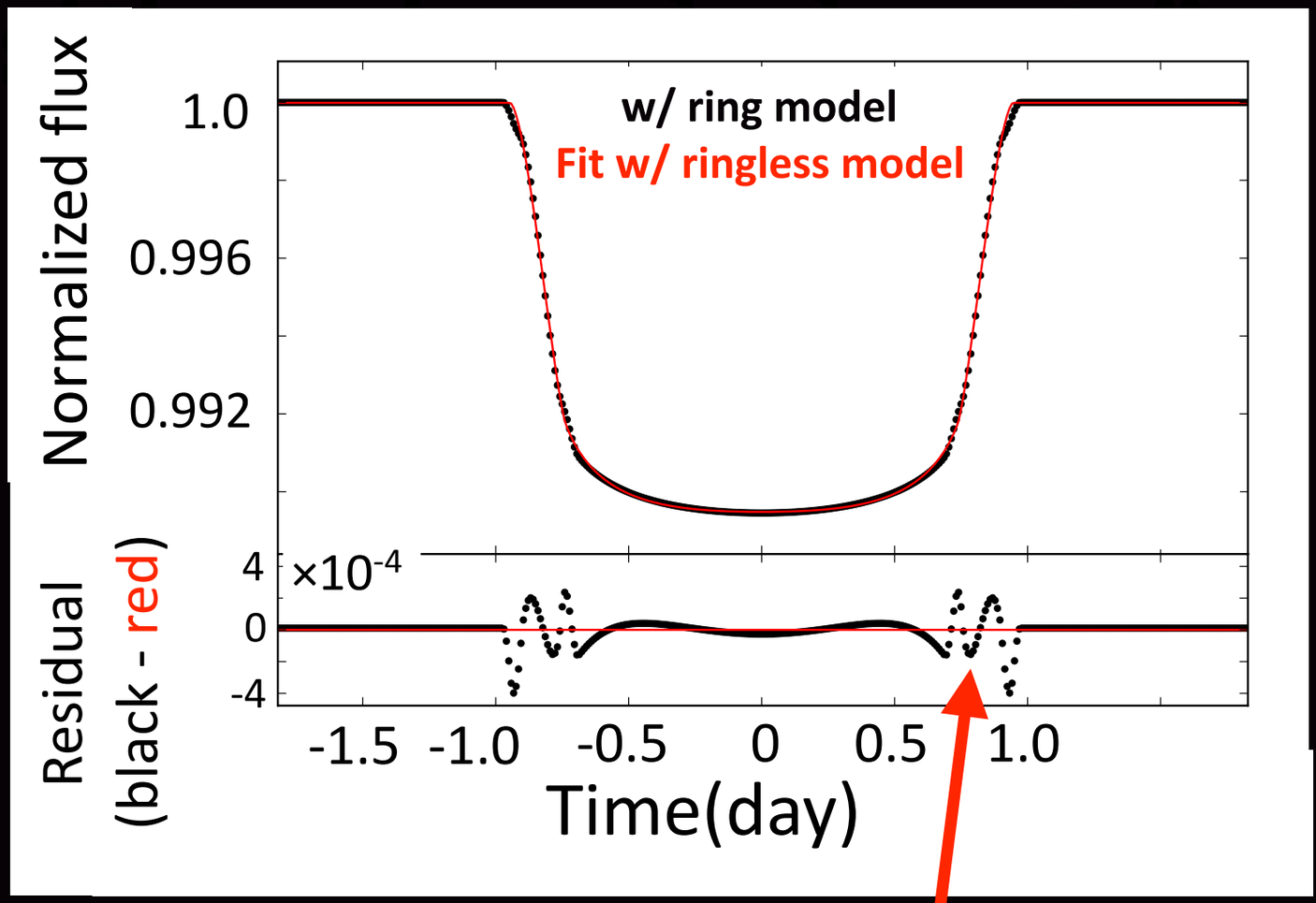
  - Large sample of Kepler planets

Kepler planets are best targets for search

# How Transiting Ringed Planets look like?




Zuluaga+ 2015




- Longer transit duration & larger depth
- Residual obtained from ringless fitting

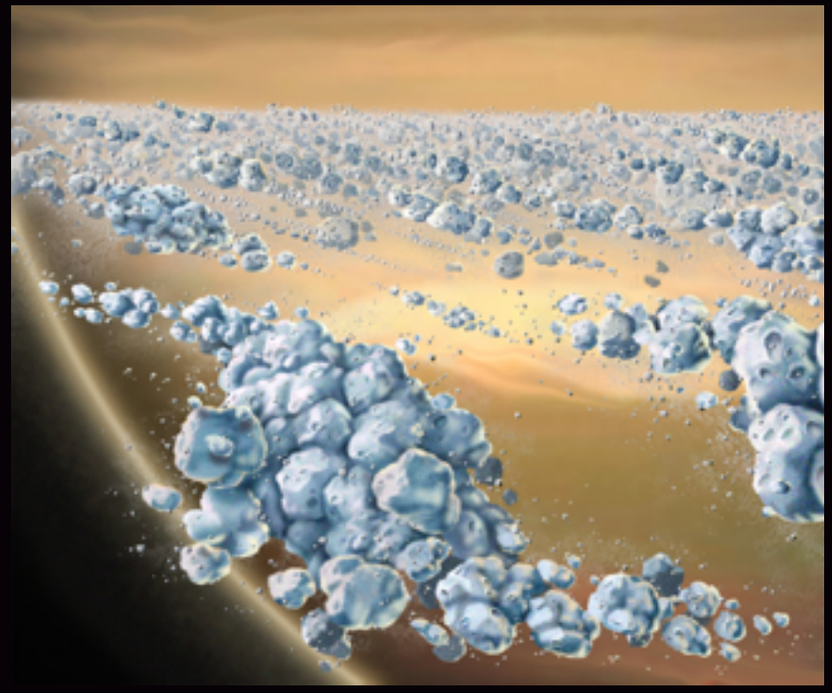
We will seek for such tiny signatures

# “Table of Contents”

# “Search around long-period planets”

- Saturnian rings are composed of **ice**
- Rings are stable around cold (long-period) planets

**Let’s search for rings around cold planets!!**



Aizawa, Uehara, Masuda, Kawahara & Suto AJ, 153 (2017) 193 (23pp)

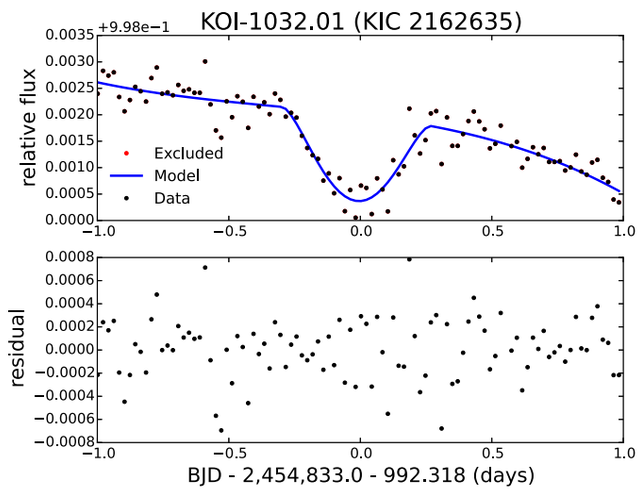
# Targets: Long-period planets

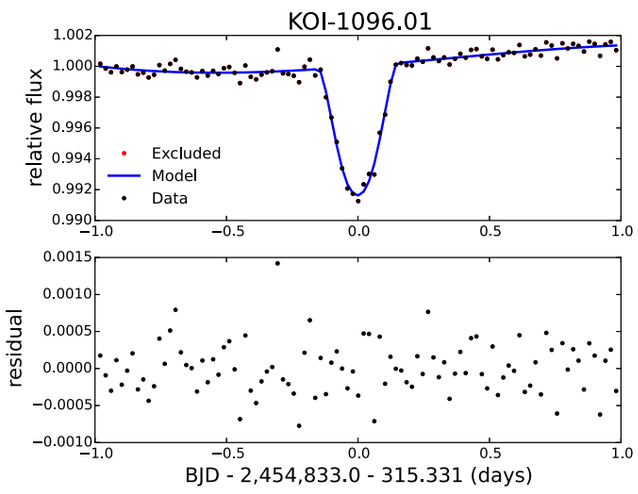
- **89** long-period transiting planets chosen from
  - KOIs (T<200K)
  - Few transits systems (Wang+ 2015, Uehara+ 2016)
- LC data (29.4 mins)
- Small number of transits (long period and cold)

↓

Fitting w/ ringless model and visual inspection

# Example (1)


KOI-1032.01 (KIC 2162635)
+9.98e−1
relative flux
Excluded
Model
Data
residual
BJD - 2,454,833.0 - 992.318 (days)


KOI-1096.01
relative flux
Excluded
Model
Data
residual
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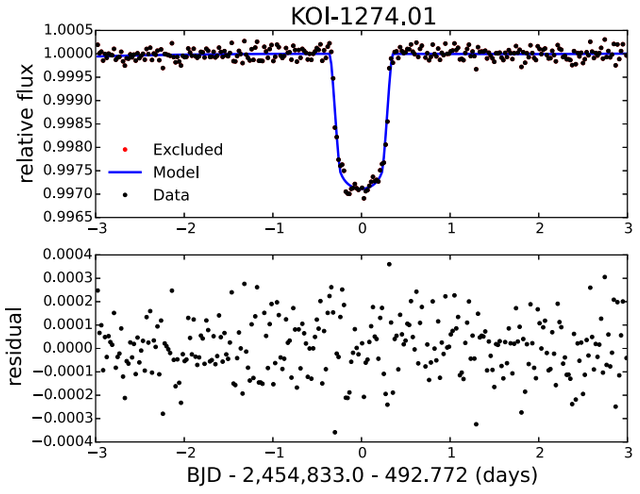
KOI-1274.01
relative flux
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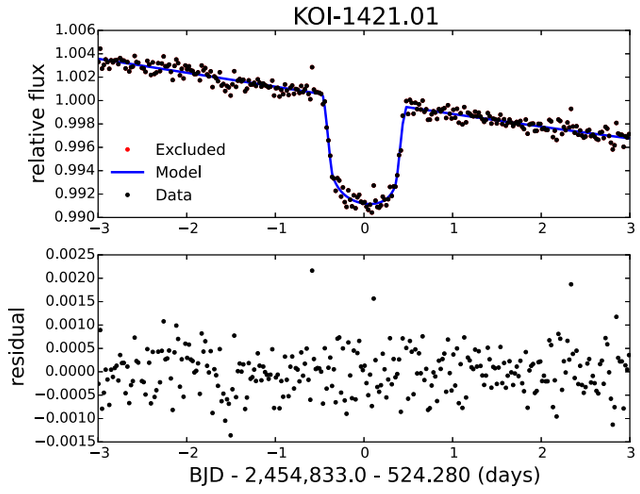
Model
Data
residual
BJD - 2,454,833.0 - 492.772 (days)


KOI-1421.01
relative flux
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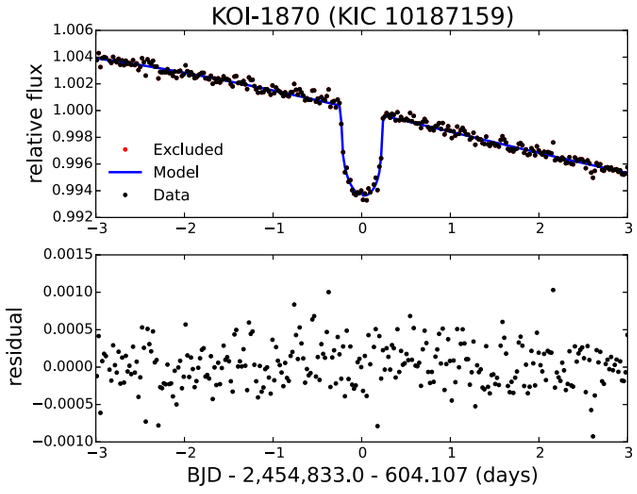
Data
residual
BJD - 2,454,833.0 - 524.280 (days)


KOI-1870 (KIC 10187159)
relative flux
Excluded
Model
Data
residual
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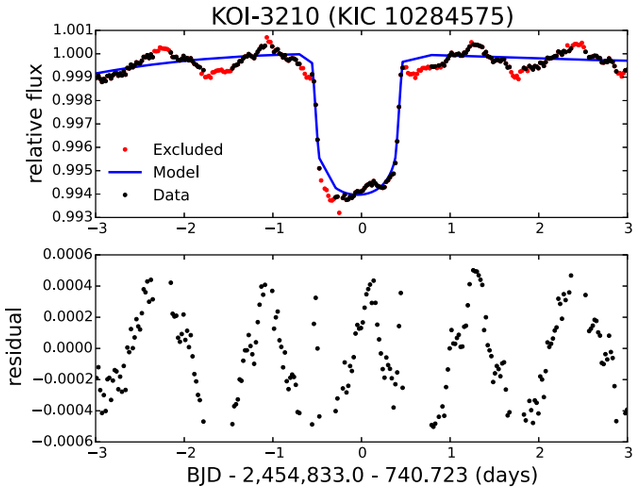
KOI-3210 (KIC 10284575)
relative flux
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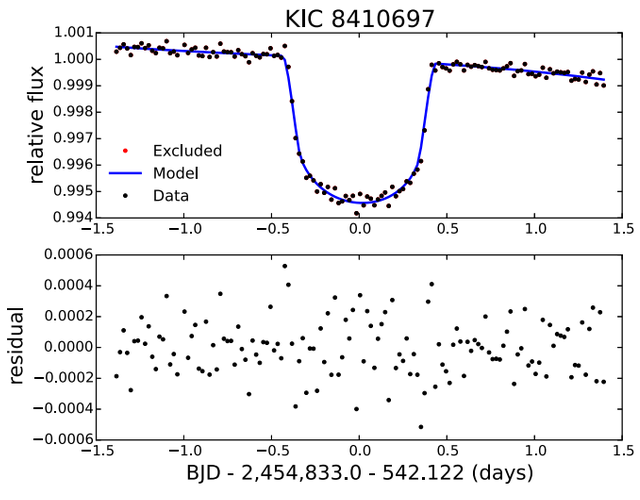
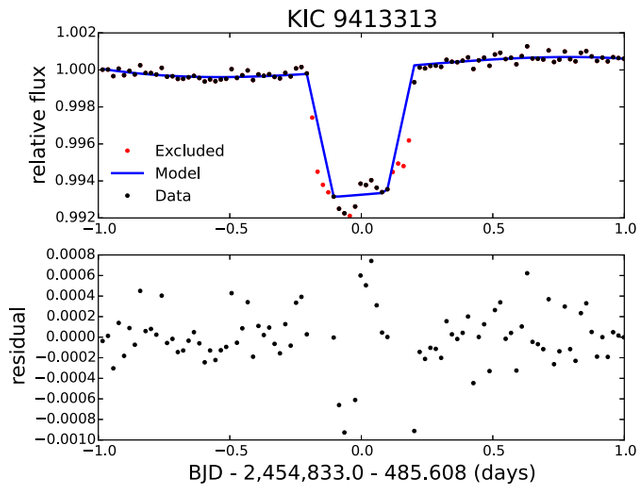
Model
Data
residual
BJD - 2,454,833.0 - 740.723 (days)


KIC 8410697
relative flux
Excluded
Model
Data
residual
BJD - 2,454,833.0 - 542.122 (days)


KIC 9413313
relative flux
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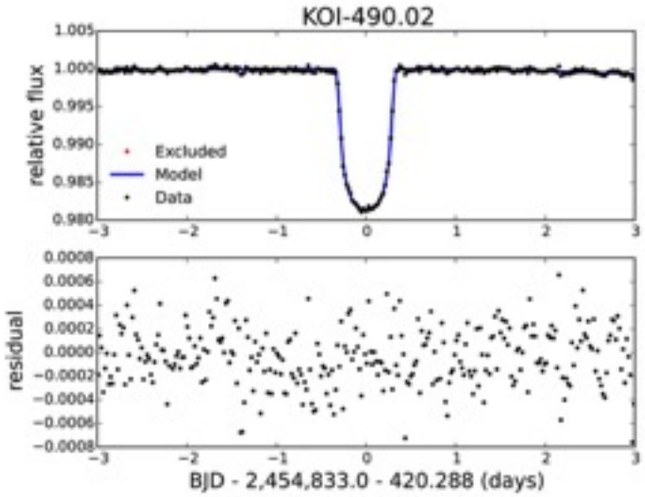
residual
BJD - 2,454,833.0 - 485.608 (days)

# Example (2)


KOI-490.02
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residual
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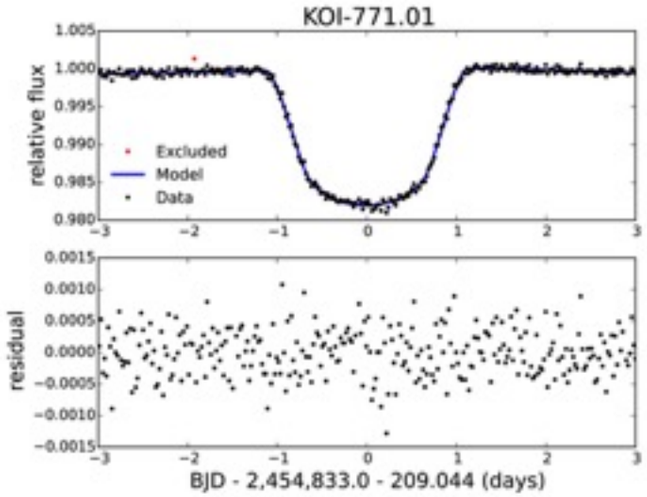
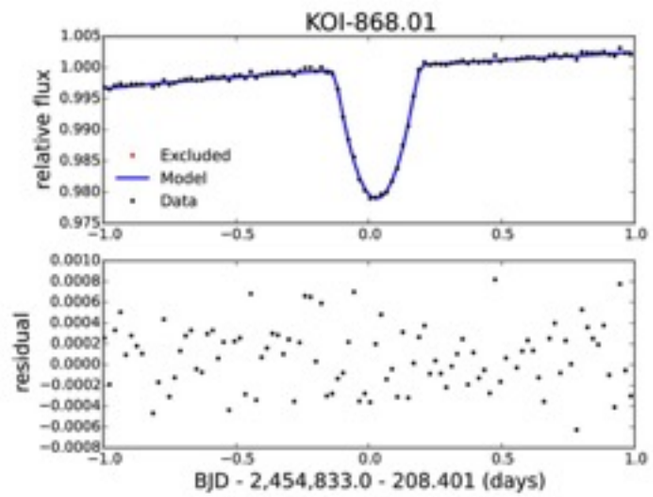
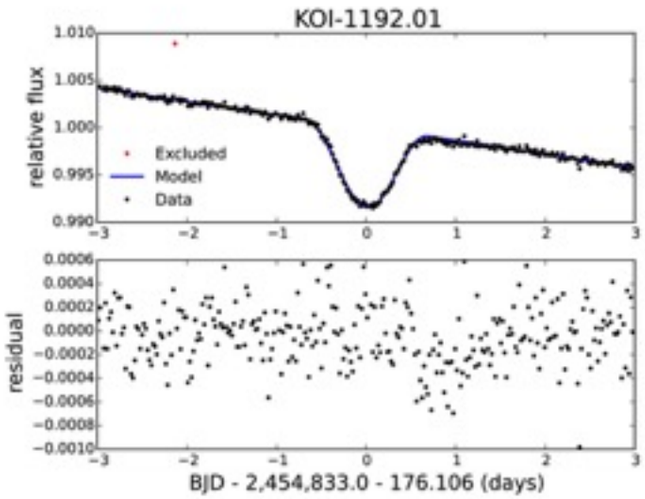
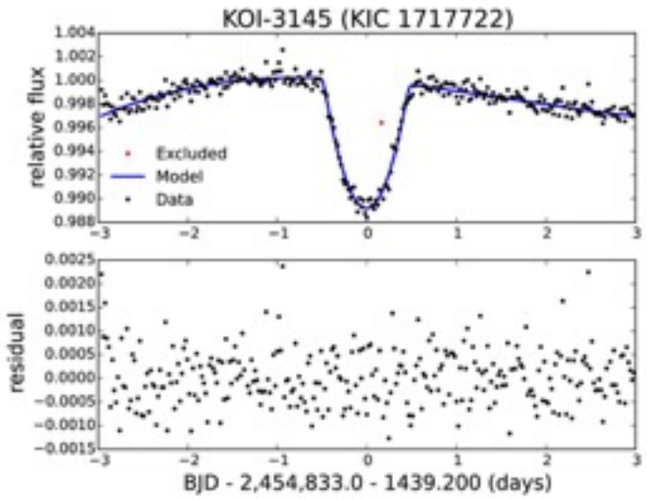
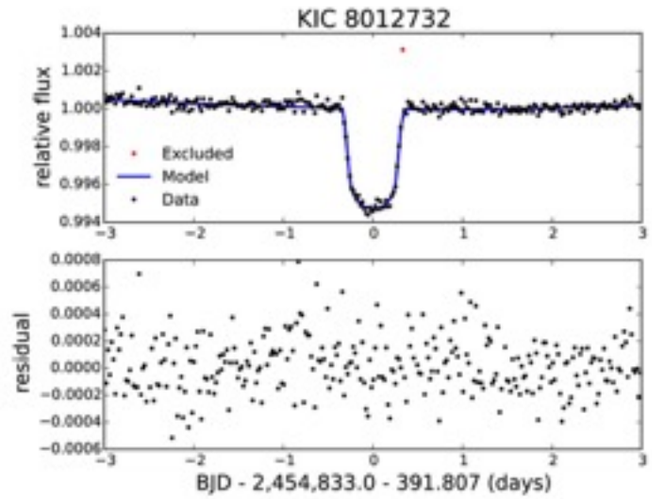
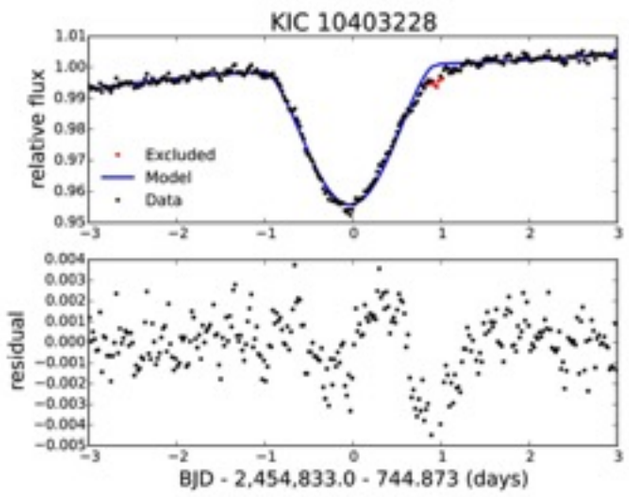

KOI-771.01
relative flux
Excluded
Model
Data
residual
BJD - 2,454,833.0 - 209.044 (days)


KOI-868.01
relative flux
Excluded
Model
Data
residual
BJD - 2,454,833.0 - 208.401 (days)

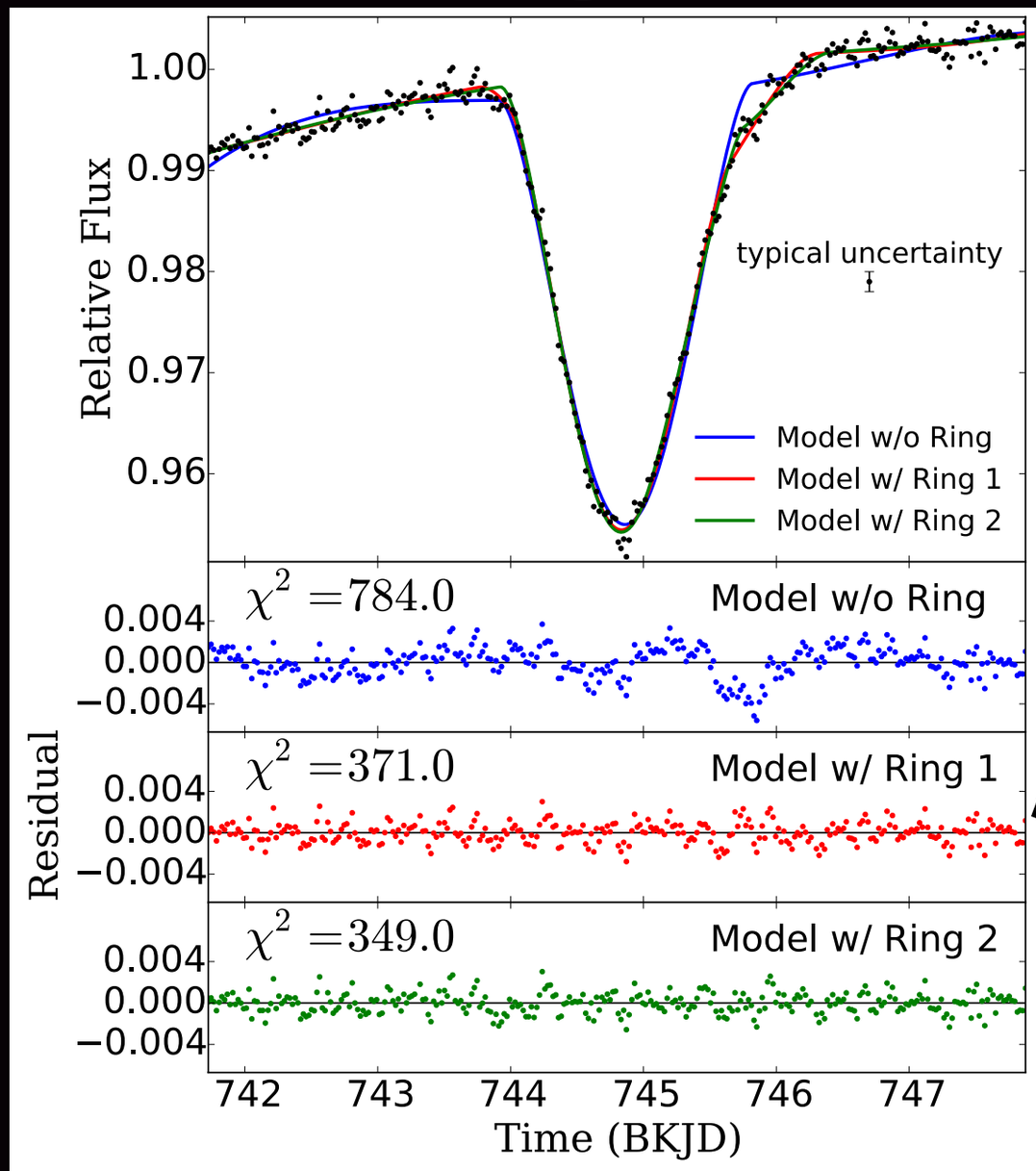

KOI-1192.01
relative flux
Excluded
Model
Data
residual
BJD - 2,454,833.0 - 176.106 (days)

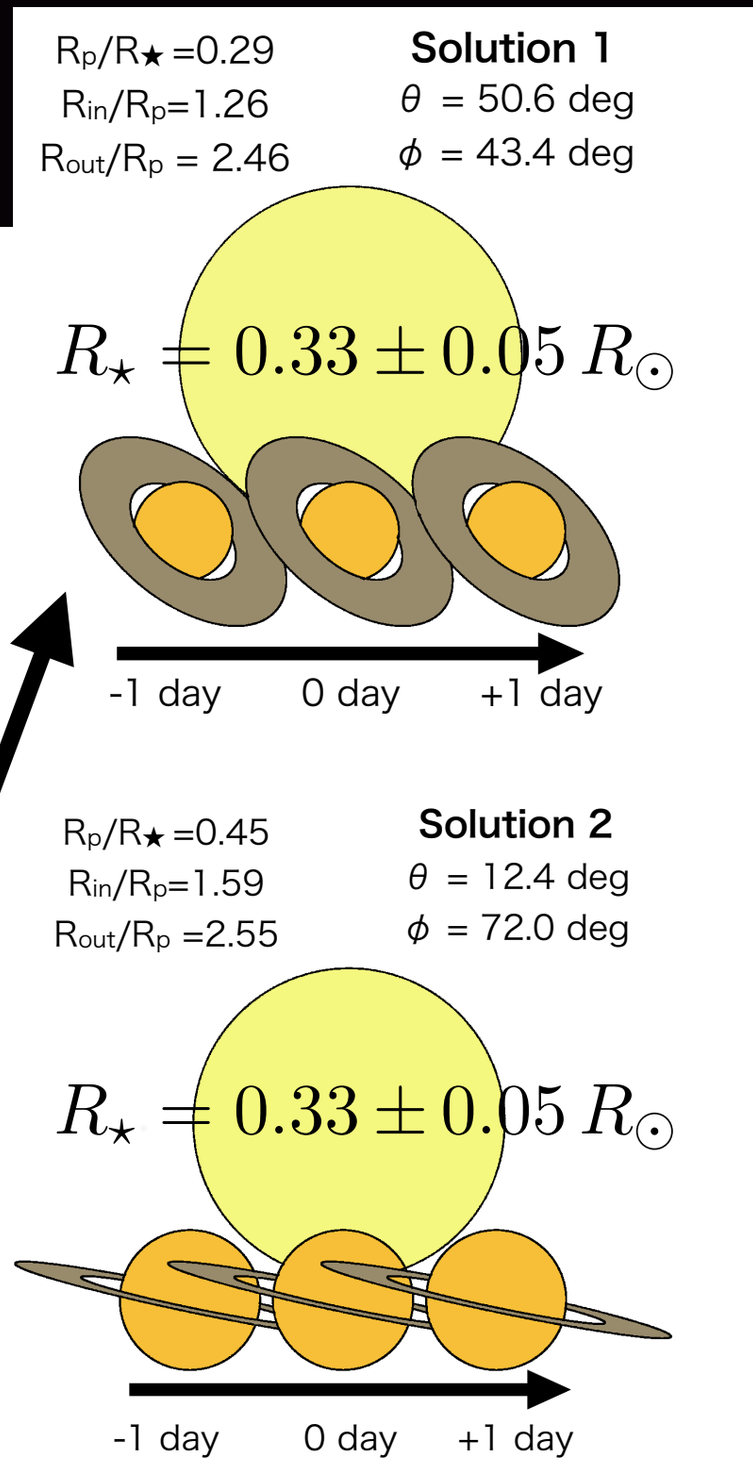

KOI-3145 (KIC 1717722)
relative flux
Excluded
Model
Data
residual
BJD - 2,454,833.0 - 1439.200 (days)


KIC 8012732
relative flux
Excluded
Model
Data
residual
BJD - 2,454,833.0 - 391.807 (days)


KIC 10403228
relative flux
Excluded
Model
Data
residual
BJD - 2,454,833.0 - 744.873 (days)

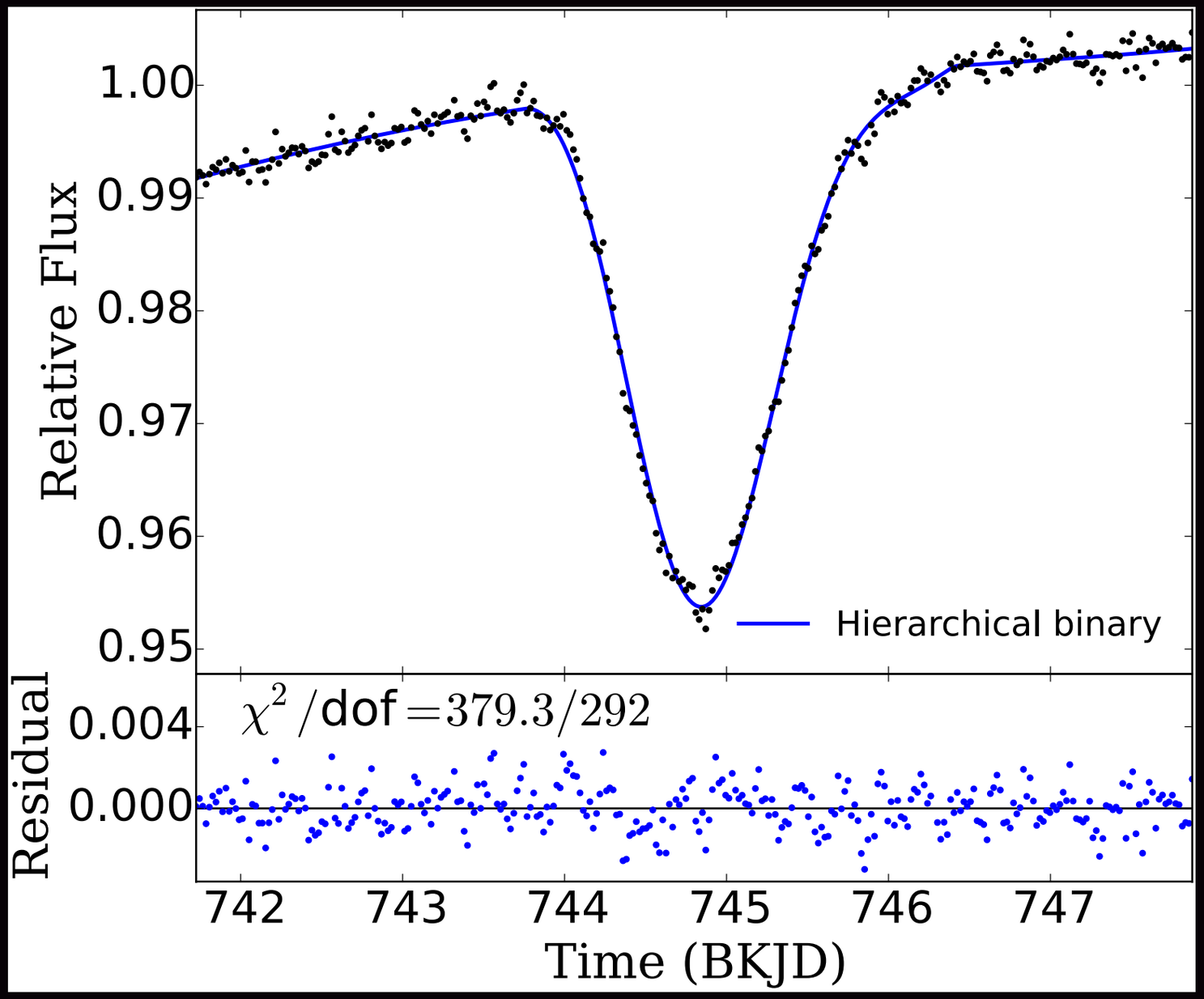
# “KIC 10403228”
# Fit with ring model

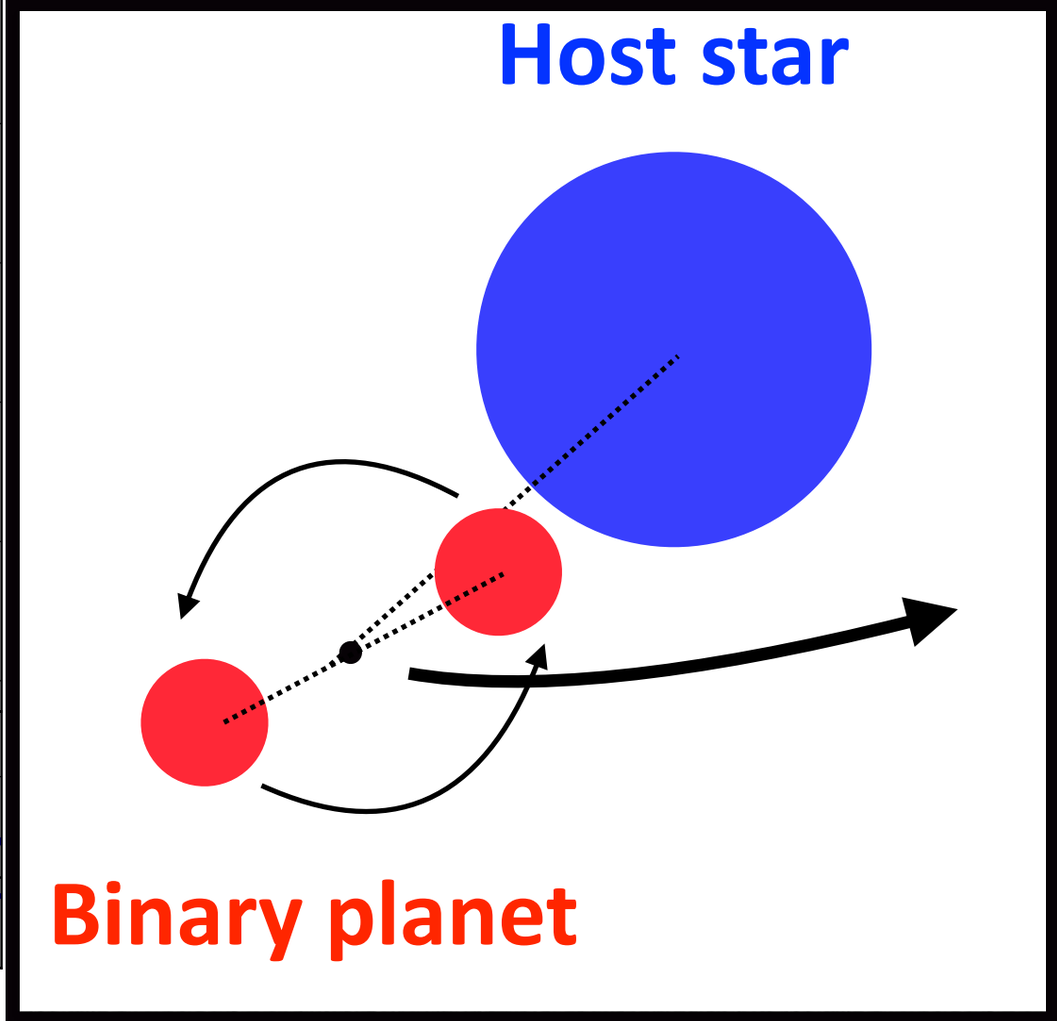



- Two possible solutions for ring models
- Stellar model and current data -> dwarf star

# “Another possibility: Transiting binary planet”

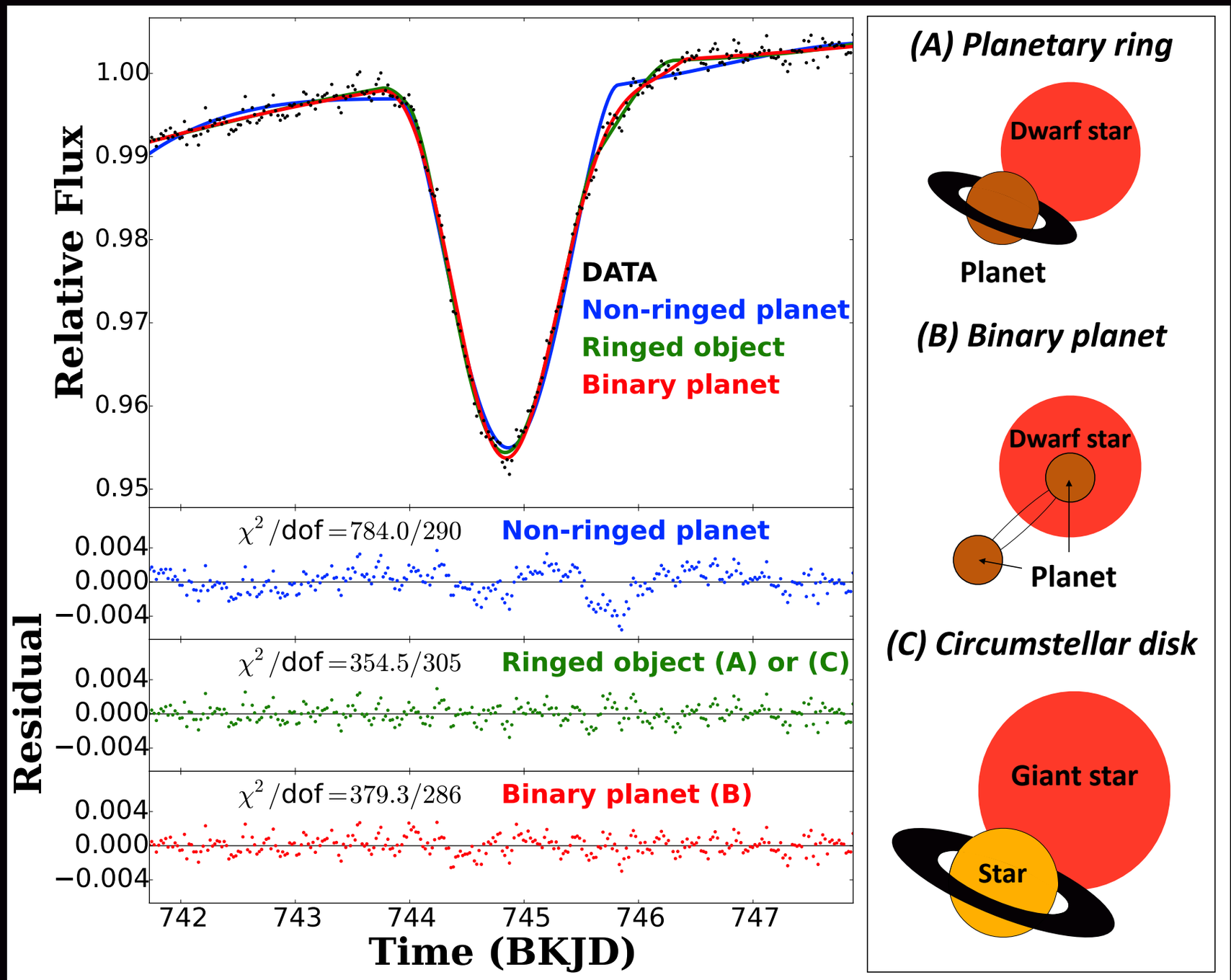



- Transiting binary planet also explains data

# “Third Possibility: Circumstellar disk”

- Host star can be giant
- Need for stellar spectrum

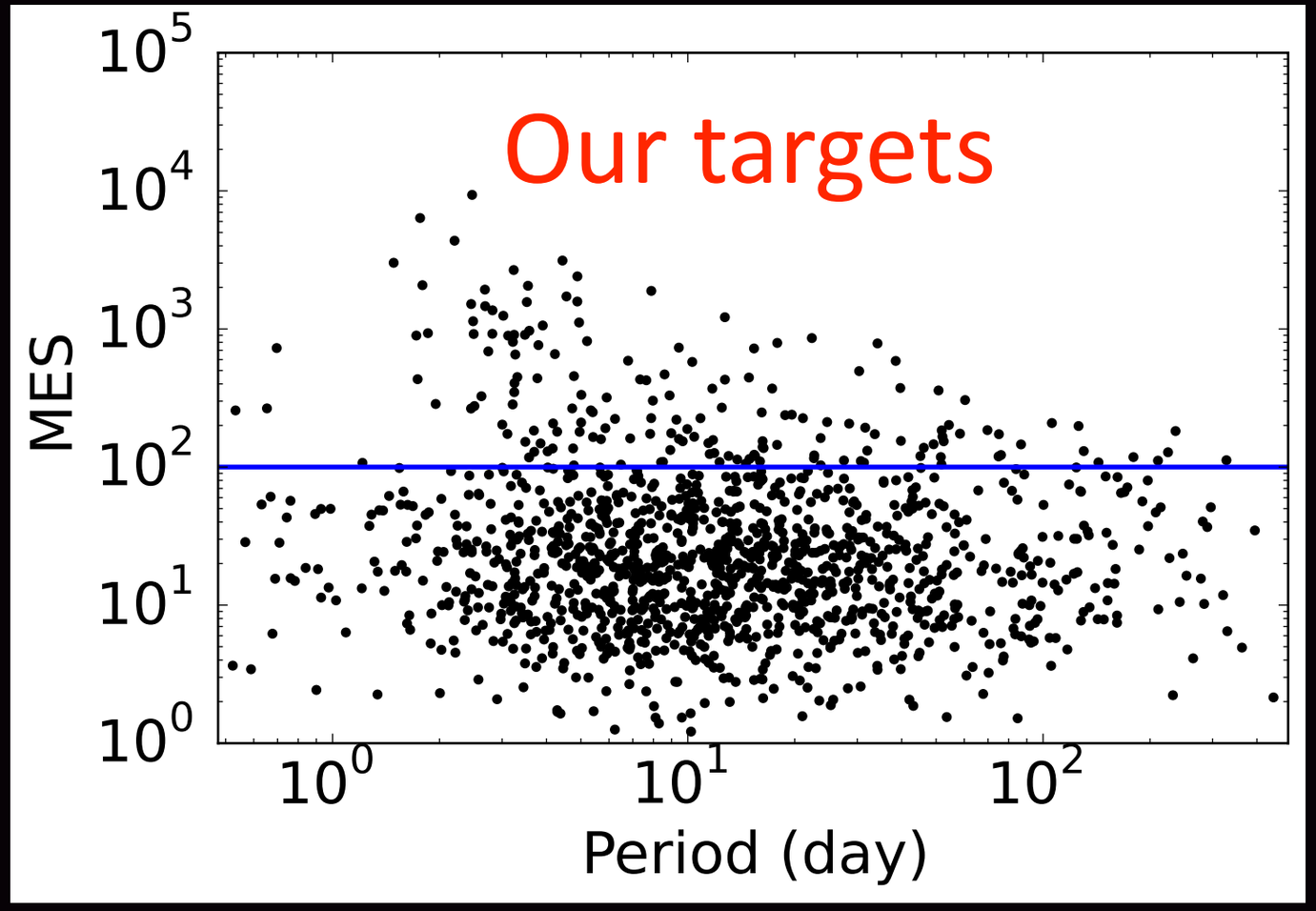


# “Table of Contents”

- Introduction and previous studies
- Search around long-period planets
- **Search around short-period planets**
- Summary

# “Search around short-period planets”

- High S/N & reproducibility (multiple transits)
- SC data (1min)
- **168 targets with MES>100 (1σ for Saturn)**




- MES is S/N of Transit

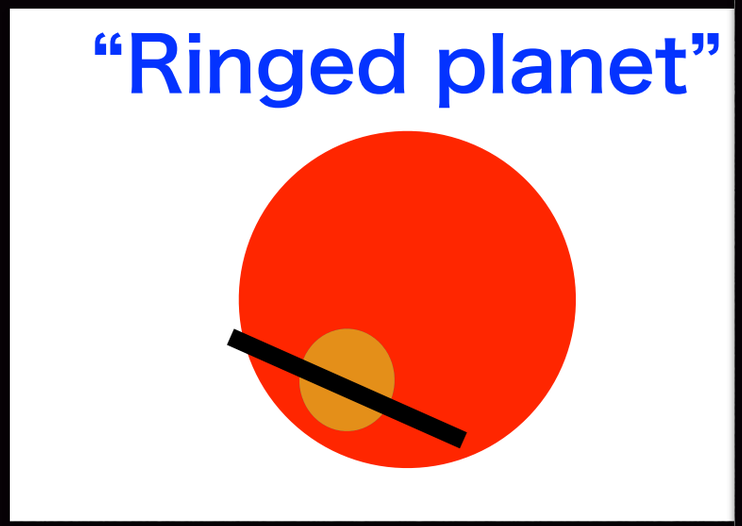
$$\mathrm{MES} = \sqrt{\frac{T_{\mathrm{obs}}}{P_{\mathrm{orb}}}} \frac{F_{\mathrm{depth}}}{\sigma(T_{\mathrm{dur}})},$$

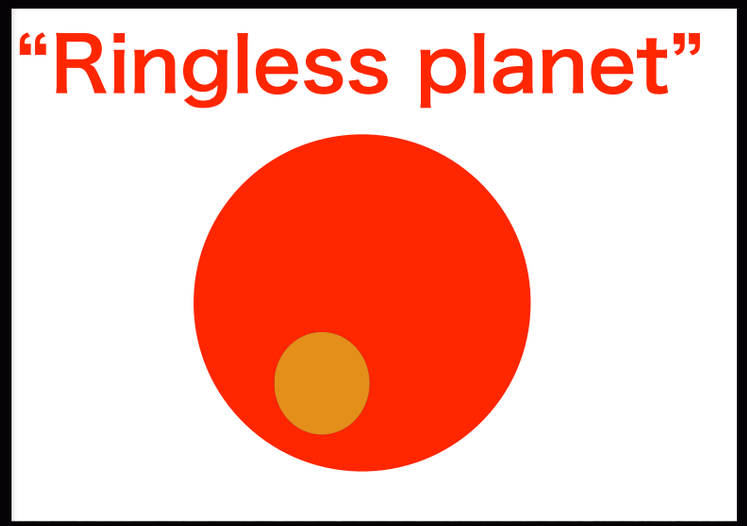
($T_{obs}$: length of sc data)

Aizawa et al. in prep

# “Method: Search for signatures & constrains”

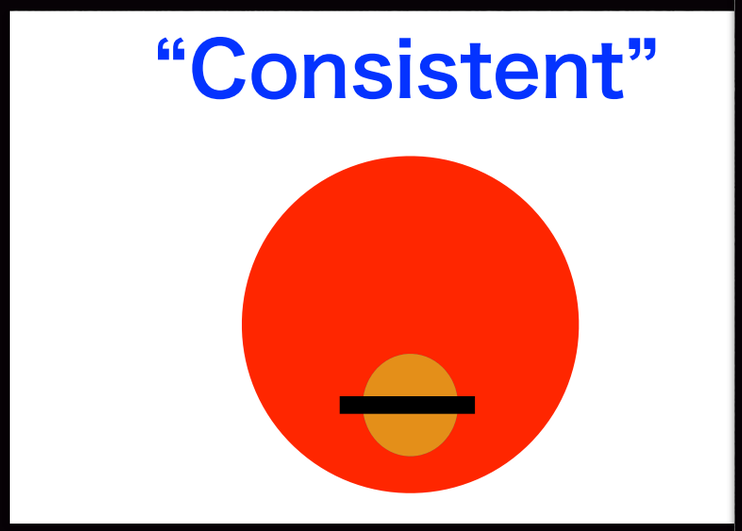
- **Search for ring signatures**

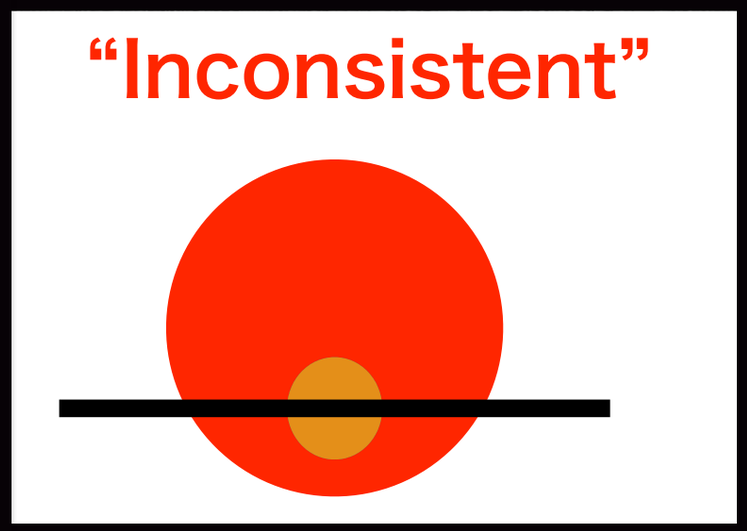



- Compare models w/ and w/o rings
- Consider full parameter space

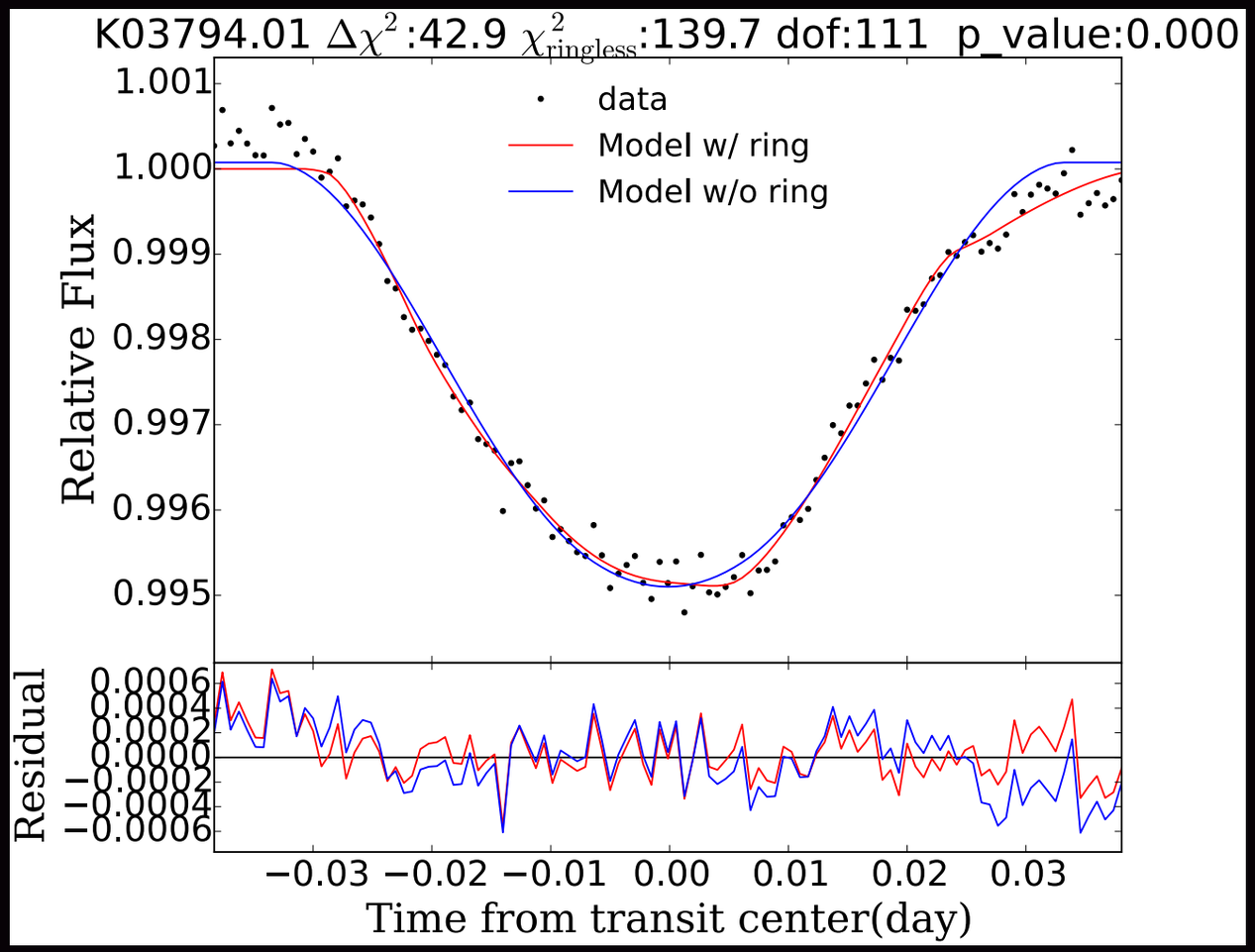
- **Upper limits on ring size**

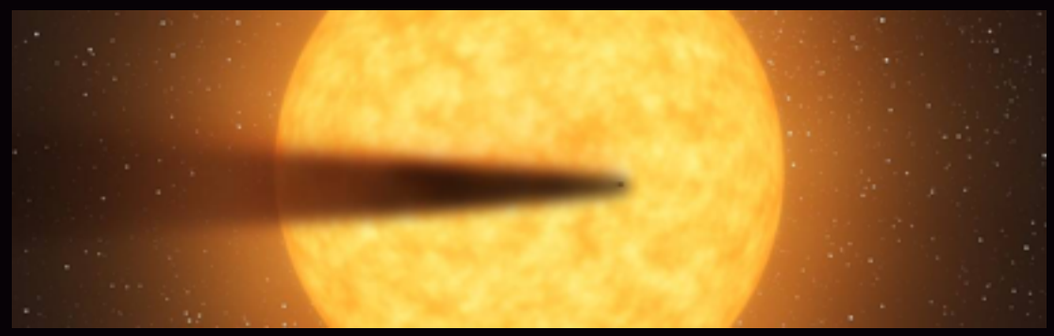



- Tidally aligned disk (Brown+2001)

# “False positive: Disintegrating planet”



- Dust tails are origins (Rappaport+ 2012)
- Quasi-periodic signals throughout light curves

# “33 planets w/ $2\sigma$ signals out of 168 planets”

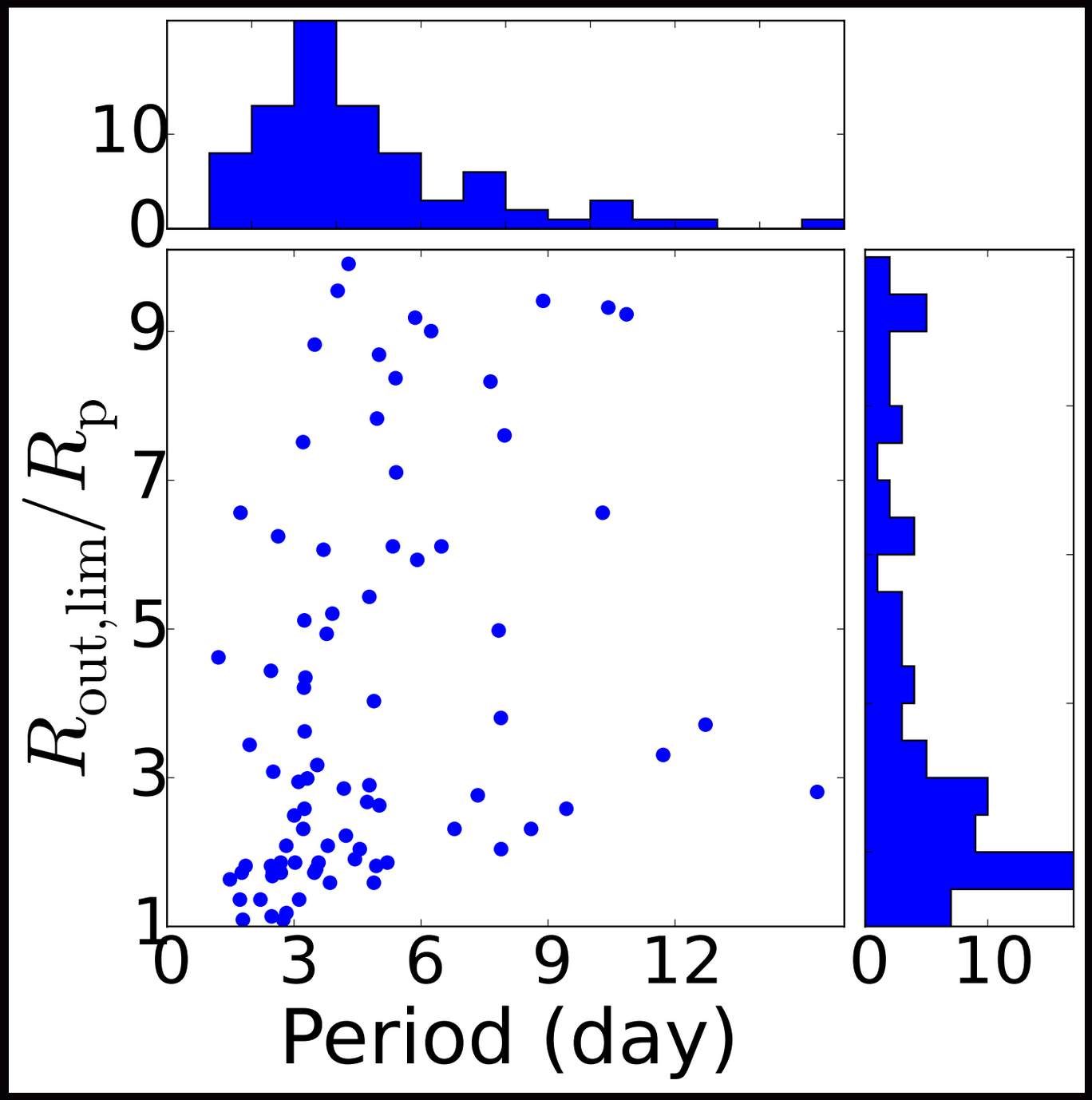
- But, other phenomena mimic ring-like signals

  - Gravity darkening (e.g. Masuda 2015)
  - Spot Crossing (e.g. Rabus+ 2009)
  - Evaporating planets (e.g. Rappaport+ 2012)
  - Stellar activities
  - 2σ> but very marginal signals

**No evident signatures among Kepler SC data**

# “Upper limits on ring size”

- Assuming rings to be tidally aligned with orbital axes (Brown+ 2001)

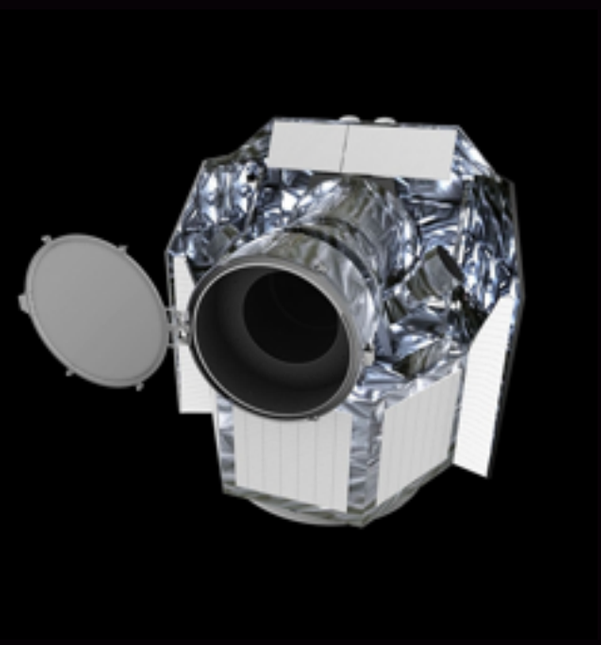



- **24 systems exlude rings larger than $2R_p$**
- First sample of ring size

# Summary & Future prospects

- Only KIC 10403228 is possible (though dubious) candidate
- There are no evident signals of rings in the Kepler short-cadence data
- First statistical samples of ring size
- Long-span data are needed to find Saturn-like rings

TESS



CHEOPS