Statistical validation of PLATO 2.0 planet candidates

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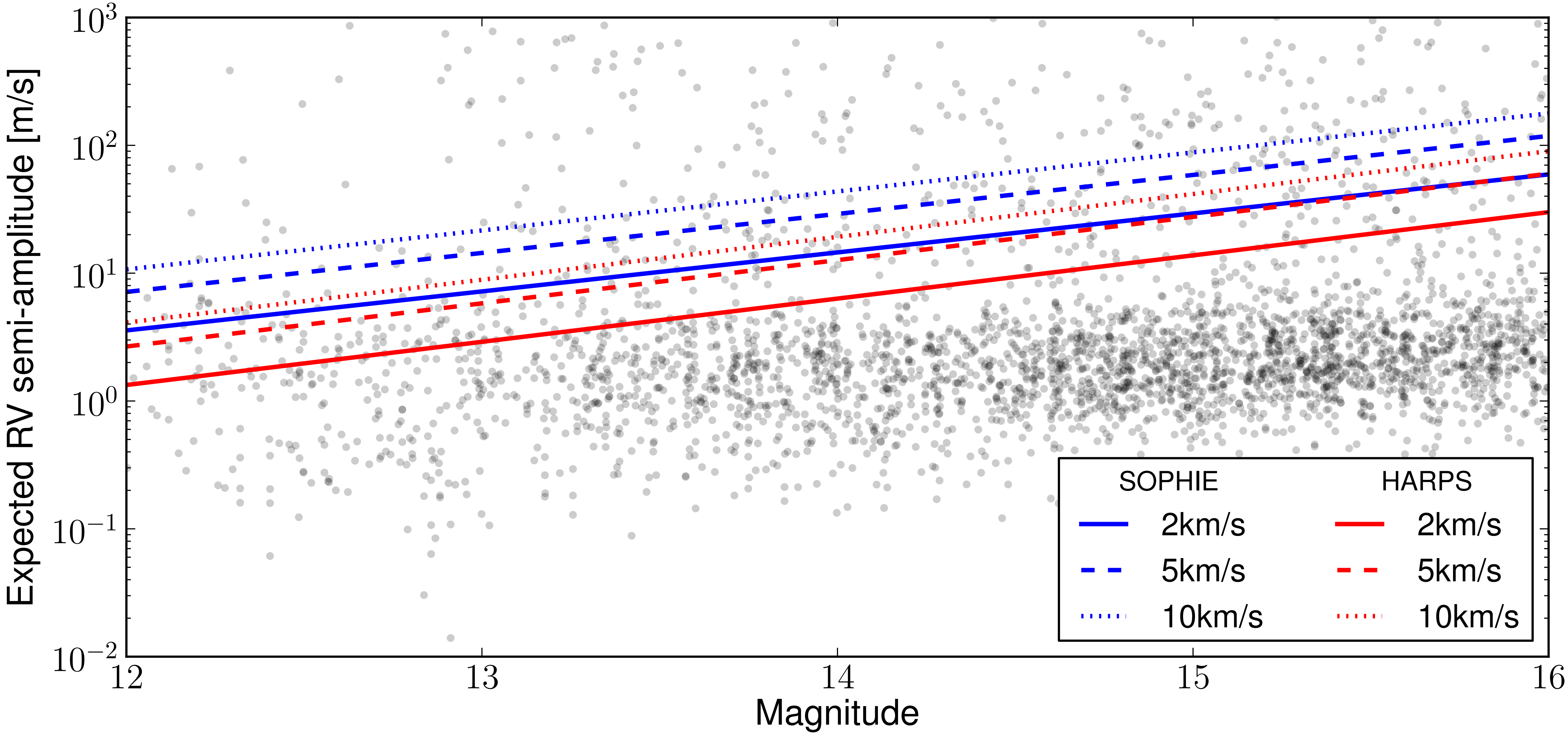
Outline

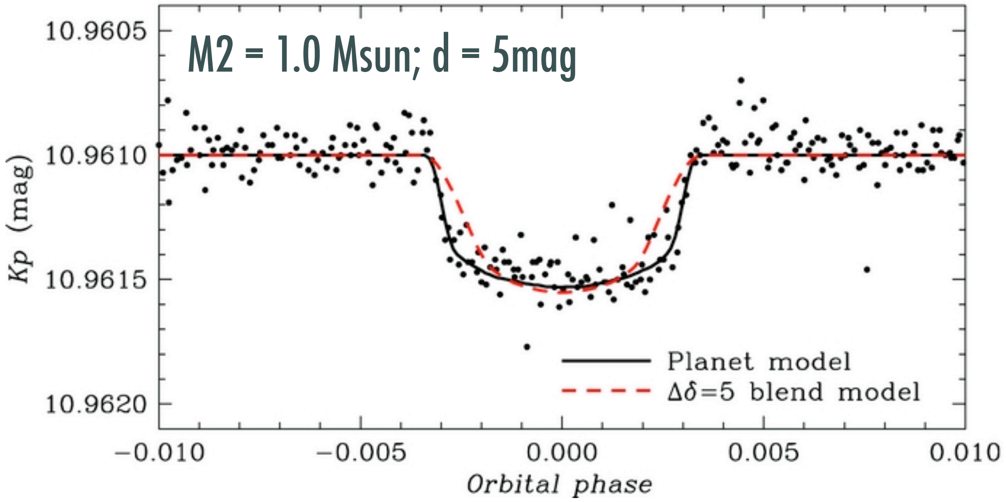
- Planet Validation.
- Motivation in the context of PLATO 2.0
- The Planet Analysis and Small Transit Investigation Software (PASTIS).
- Testing PASTIS on synthetic data.
- The radial velocity contribution.



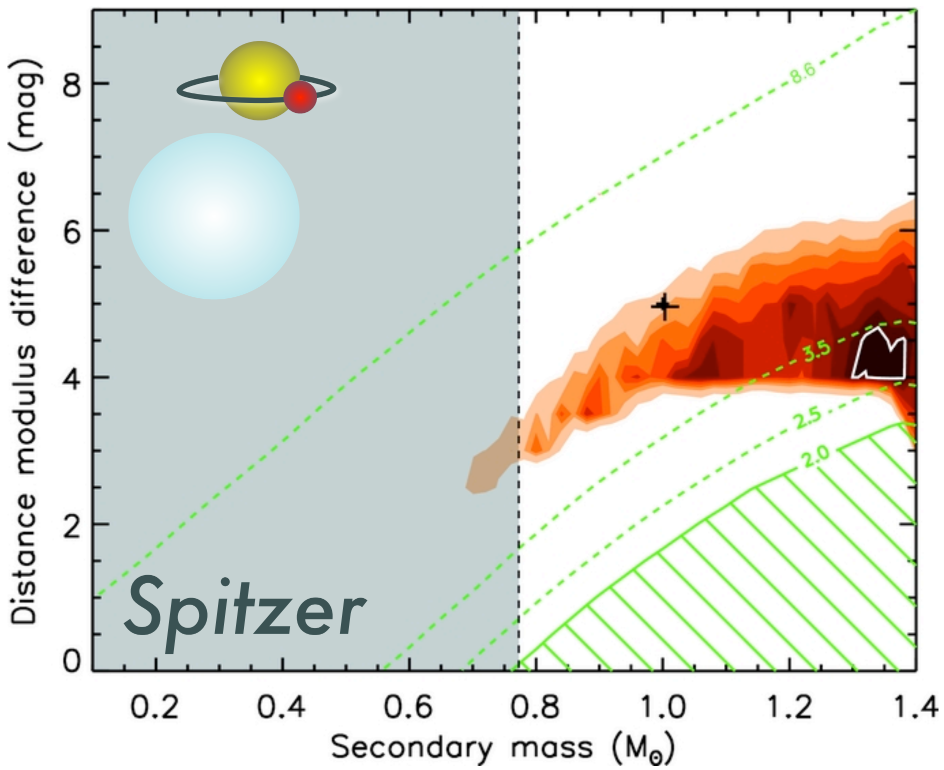
Talks by F. **Bouchy** and A. **Santerne**

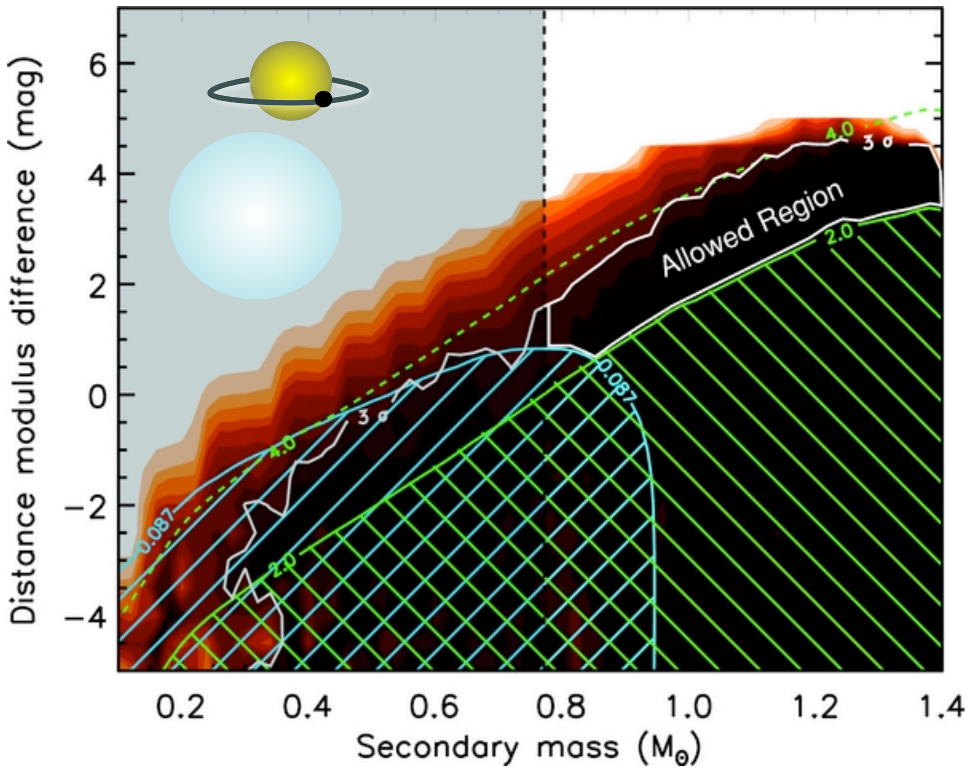
Planet Validation (*alla* BLENDER)

- Use all the information in the transit LC to constrain possible false positives (FPs).
- Add additional constrains from other datasets: RV, AO, multi-band photometry, ...
- Evaluate relative occurrence of planets to surviving blends (use Galactic models, current knowledge on mult. systems, etc.)



Fressin et al. (2011)





Planet Validation (the Bayesian way)

Model comparison: based on the computation of the odds ratio.

$$O_{ij} = \frac{p(\mathrm{H_i}|\mathrm{D},\mathrm{I})}{p(\mathrm{H_j}|\mathrm{D},\mathrm{I})} = \frac{p(\mathrm{H_i}|\mathrm{I})}{p(\mathrm{H_j}|\mathrm{I})} \cdot \frac{p(\mathrm{D}|\mathrm{H_i},\mathrm{I})}{p(\mathrm{D}|\mathrm{H_j},\mathrm{I})}$$

$\mathrm{H_i}$: hypothesis i
D: data
I: prior information

Model prior ratio

Bayes' factor

- Hypotheses must be described by a model **M** with parameter vector $\boldsymbol{\theta}$.
- The Bayes' factor is the ratio of the *evidence* for each model, defined as:

$$p(\mathrm{D}|\mathrm{H},\mathrm{I}) \equiv p(\mathrm{D}|\mathrm{M}) = \int d\theta\; p(\theta|\mathrm{M})p(\mathrm{D}|\theta,\mathrm{M})$$

- The evidence is a *k*-dimensional integral, generally intractable!

Motivation in the context of PLATO 2.0

- PLATO is expected to detect thousands of small-size planet candidates.
- Validation *will* be needed (unless reliance on Galactic priors is acceptable).
- RV confirmation is in principle be possible, but very time-demanding (see HARPS RV survey; talk by S. Udry). RV facilities likely limited to perform intense follow-up.
- Some stars will not be easily measured (fast rotators, hot stars, ...).
- High S/N of many candidates (e.g. S/N ~ 150 for a single Earth-size planet transit on 1-yr orbit around a mV = 8 star).
- Possible strategy: focus on validated planets to complete characterization (mass, eccentricity, bulk density, ...).

PASTIS

Planet Analysis and Small
Transit Investigation Software

Rigorousness (fully-Bayesian approach)

Flexibility (in the definition of FP scenarios)

Speed (to be able to apply it to large samples)

The PASTIS data models

GIE (Amores & Lepine)
LDC (Claret)

Light curves
(Kepler, CoRoT, Spitzer, ...)

Spectral Energy Distribution
(SDSS, 2MASS, WISE, ...)

Radial velocities
RV, Bisector, FWHM
(HARPS, SOPHIE)

SET (Dartmouth, Padova, Geneva, ...)
SAM (PHOENIX, ATLAS)

PASTIS

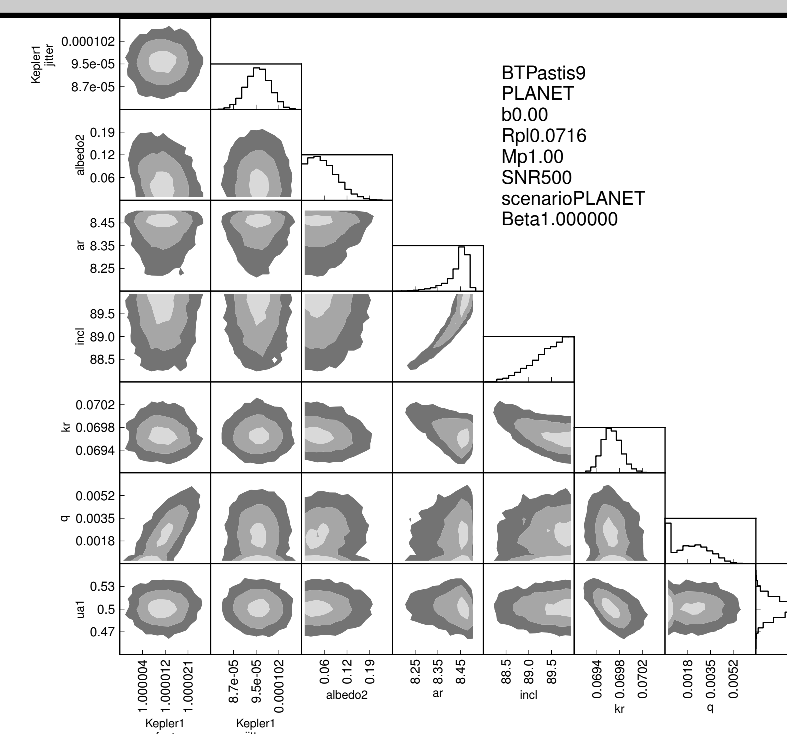
MCMC

Full parameter posterior

Bayes' factor

$$O_{ij} = \frac{p(\mathrm{H_i}|\mathrm{D},\mathrm{I})}{p(\mathrm{H_j}|\mathrm{D},\mathrm{I})} = \frac{p(\mathrm{H_i}|\mathrm{I})}{p(\mathrm{H_j}|\mathrm{I})} \cdot \frac{p(\mathrm{D}|\mathrm{H_i},\mathrm{I})}{p(\mathrm{D}|\mathrm{H_j},\mathrm{I})}$$

Model priors
(Binary prop., planet prop., ...)

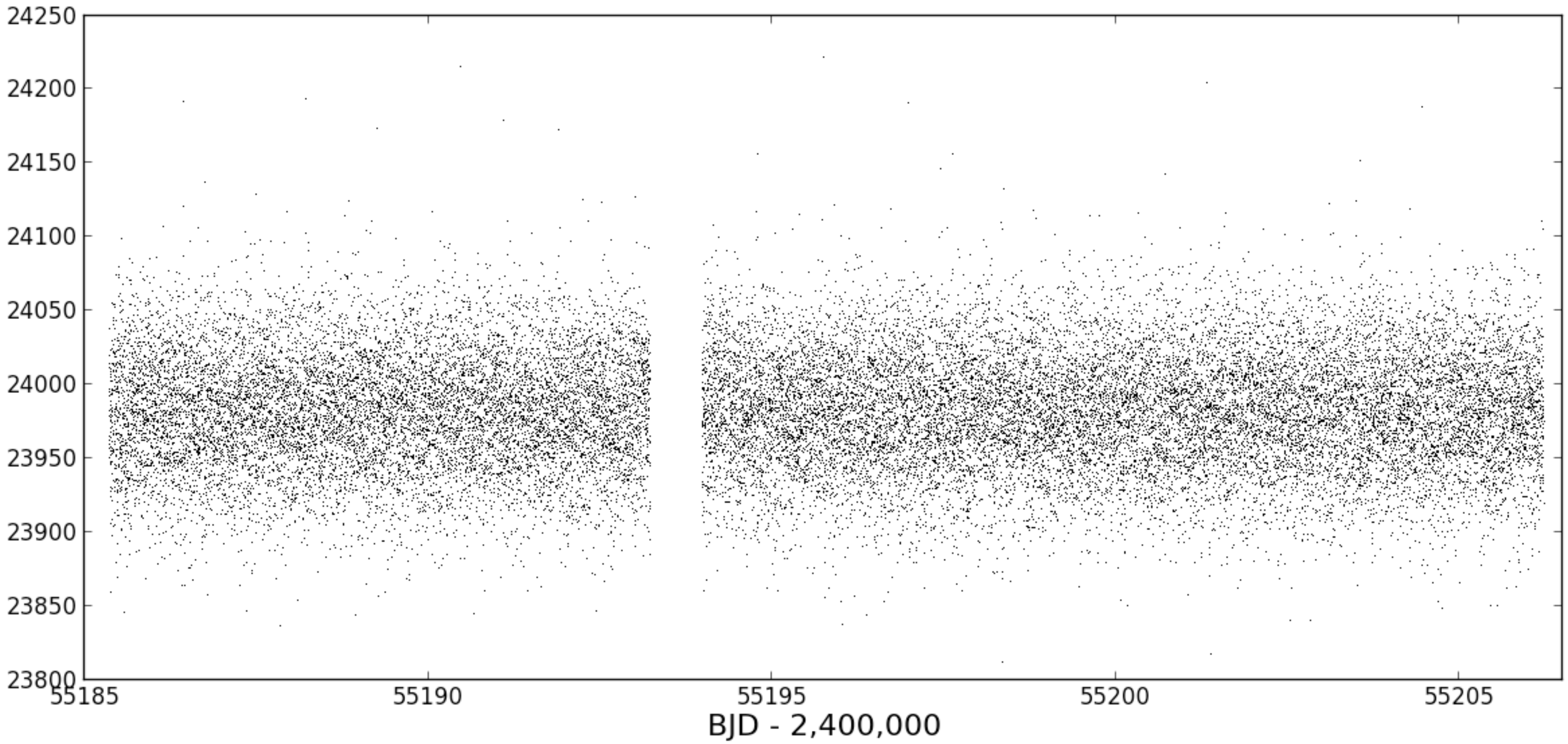


Full details in Díaz et al. (2013, in prep.)

Tests on synthetic data

Synthetic data

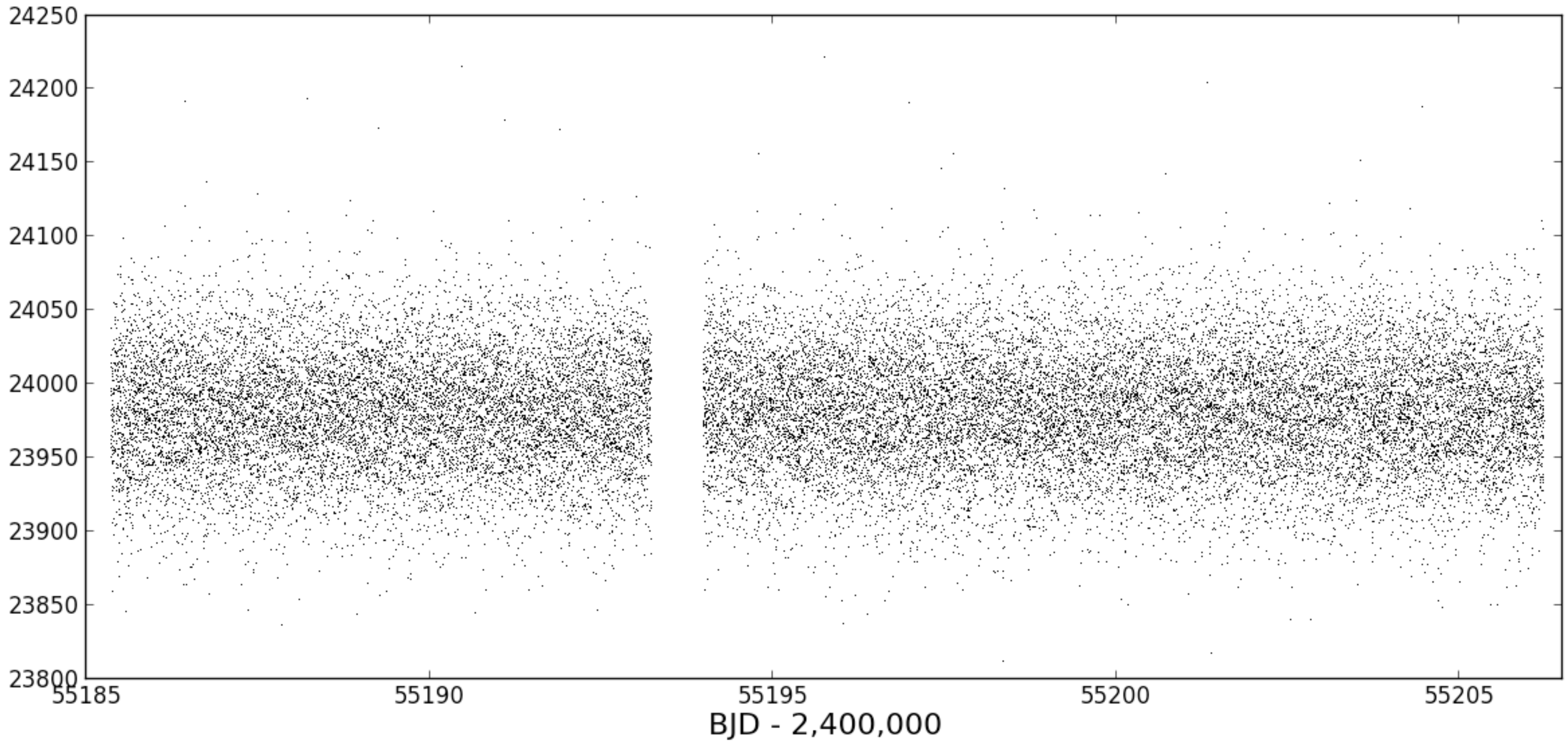
Kepler data
KIC11391018
KOI189
Q4; SC



- Noise level near the median for SC targets of Q4.
- Planet transiting candidate. Already checked.
- For simplicity, just use light curve. In some cases the other observables dominates (cf. CoRoT-16, Ollivier et al. 2012).

Synthetic data

Kepler data
KIC11391018
KOI189
Q4; SC



Model **P**: *“the signal is produced by a transiting extrasolar planet”*.

Model **B**: *“the signal is produced by a background eclipsing binary”.*

+ *data model: “jitter is an additional source of Gaussian error.”*

Synthetic data

Transiting Planets

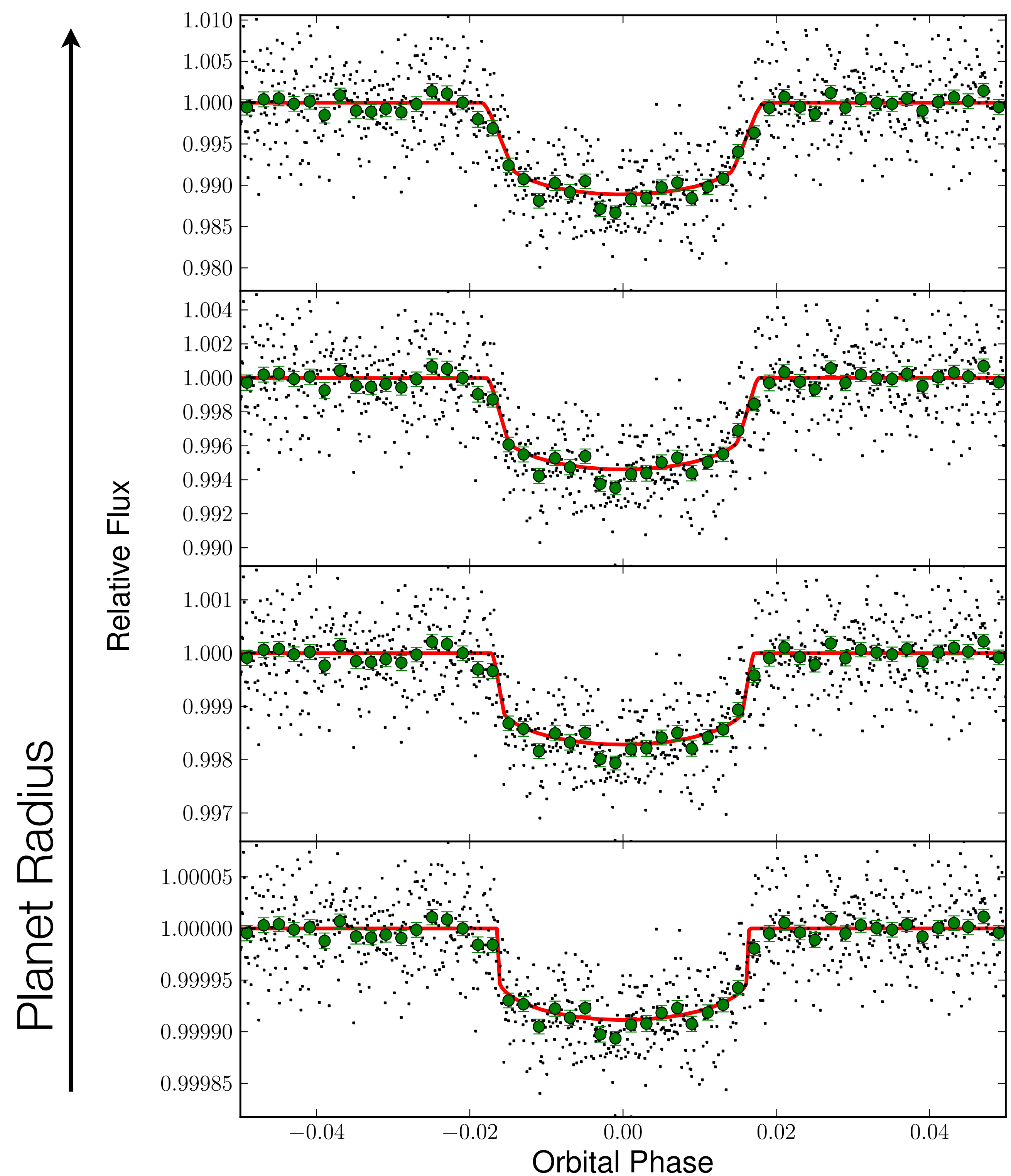
Studied parameters

Transiting Planet	
Planet Radius [$R_\oplus$]	{1.0; 4.4; 7.8; 11.2}
Impact Parameter b	{0.0; 0.5; 0.75}
Transit S/N	{20; 50; 150; 500}

Transit S/N independently varied from planet radius.

b = 0.75 near median of KOI distribution.

S/N = 50; *b* = 0.5



Synthetic data

S/N = 150; *b* = 0.5

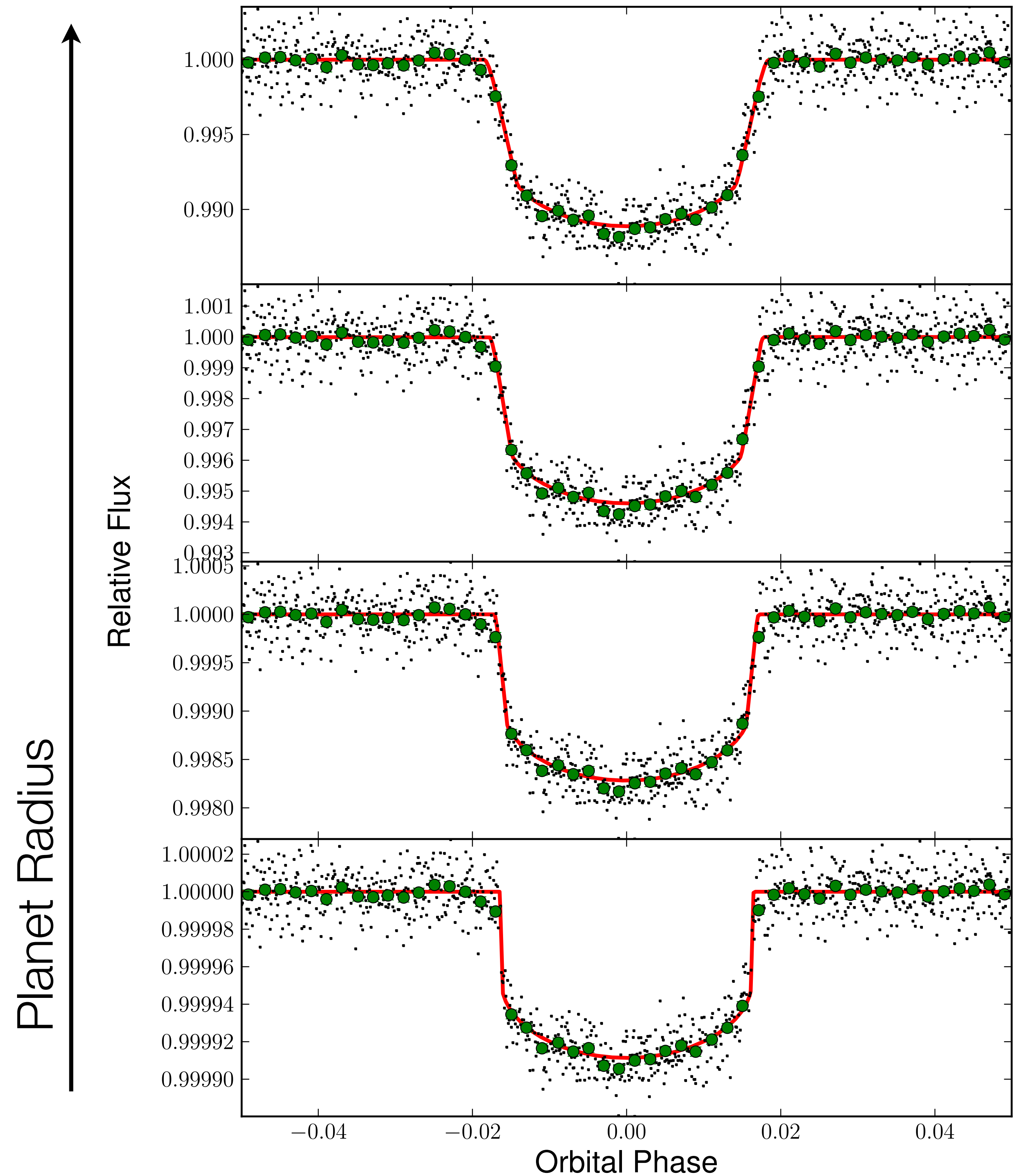
Transiting Planets

Studied parameters

Transiting Planet	
Planet Radius [$R_\oplus$]	{1.0; 4.4; 7.8; 11.2}
Impact Parameter *b*	{0.0; 0.5; 0.75}
Transit S/N	{20; 50; 150; 500}

Transit S/N independently varied from planet radius.

b = 0.75 near median of KOI distribution.



Synthetic data

S/N = 500; b = 0.5

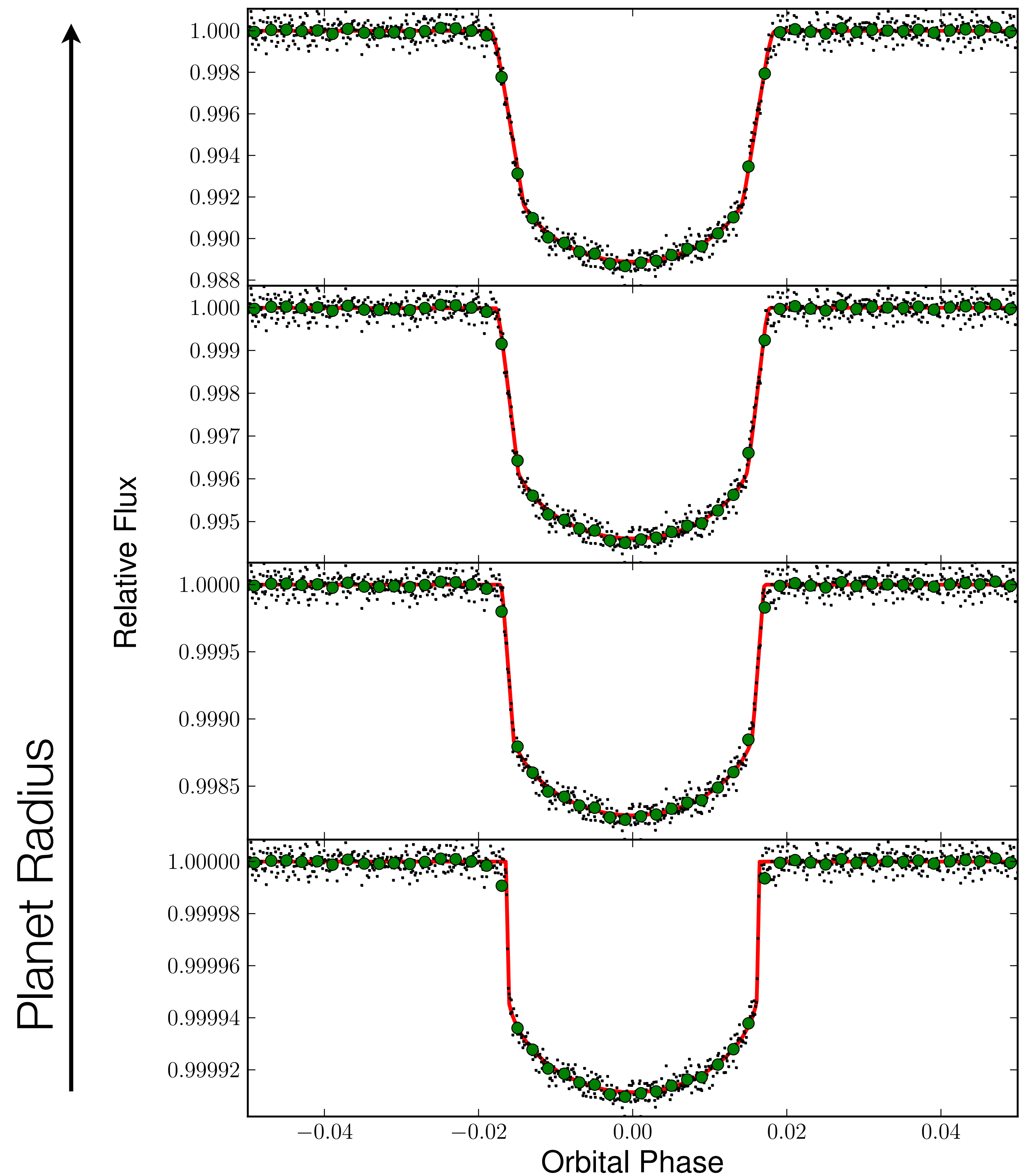
Transiting Planets

Studied parameters

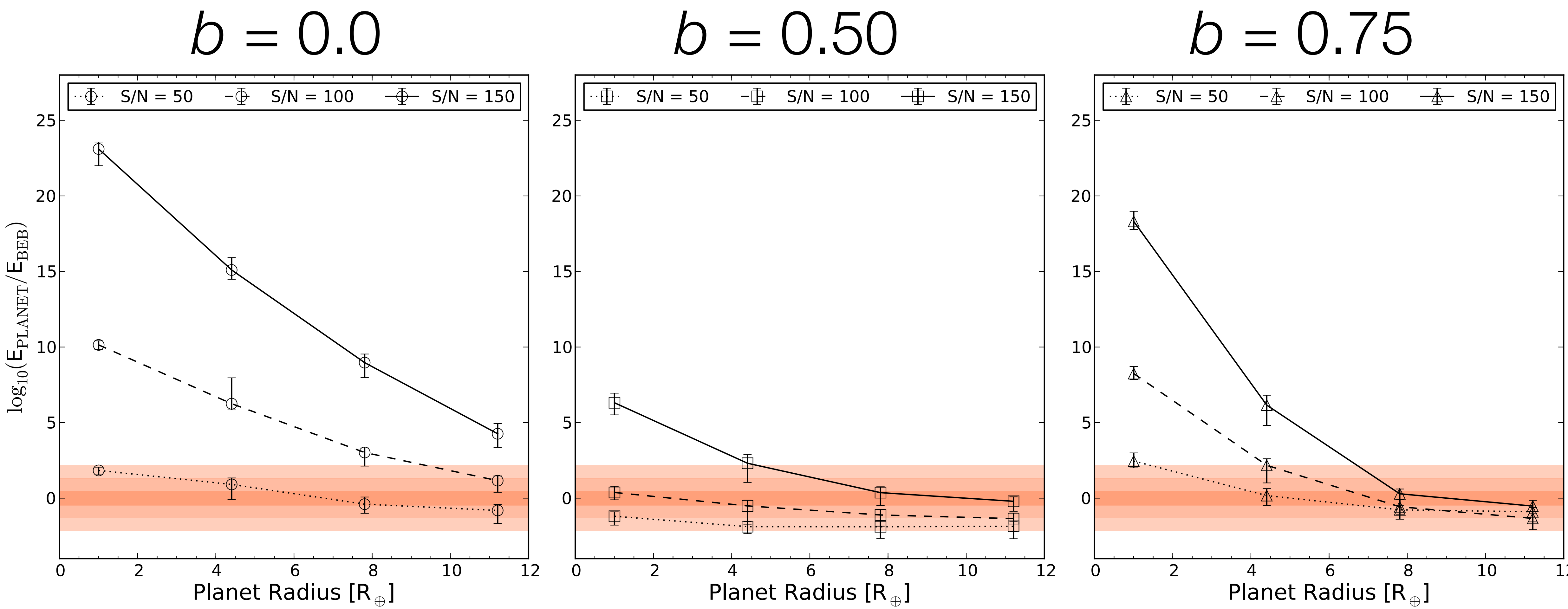
Transiting Planet	
Planet Radius [$R_\oplus$]	{1.0; 4.4; 7.8; 11.2}
Impact Parameter b	{0.0; 0.5; 0.75}
Transit S/N	{20; 50; 150; 500}

Transit S/N independently varied from planet radius.

b = 0.75 near median of KOI distribution.



Results (I: PLANET simulations)



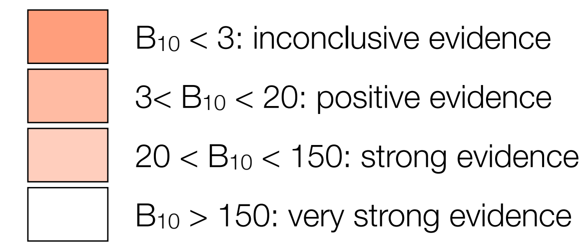
$B_{10} < 3$: inconclusive evidence

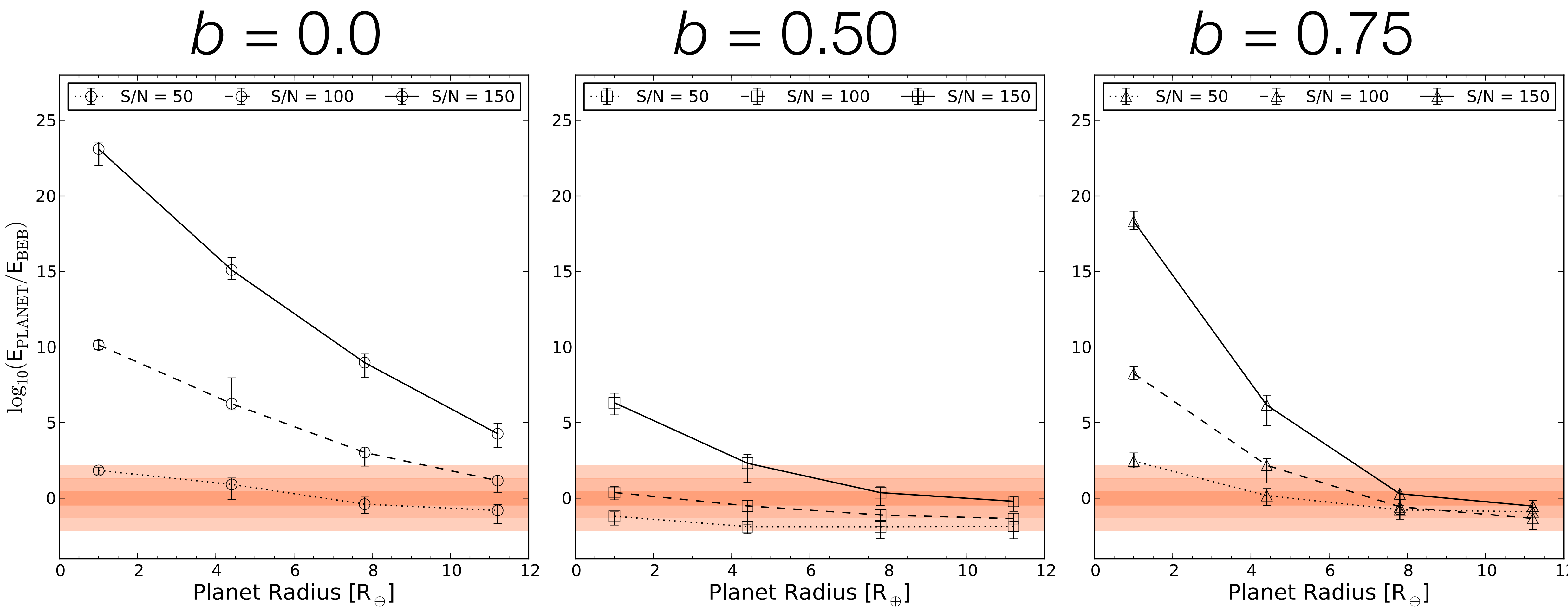
$3 < B_{10} < 20$: positive evidence

$20 < B_{10} < 150$: strong evidence

$B_{10} > 150$: very strong evidence

Results (I: PLANET simulations)





- Monotonic decrease of B_{PB} with planet radius, and S/N of transit.
- Minimum B_{PB} for *b* = 0.5.
- For *b* = 0.75, highest value of B_{PB}.
- S/N = 20 and 500 (not plotted) are completely inside and outside of shaded are, respectively.

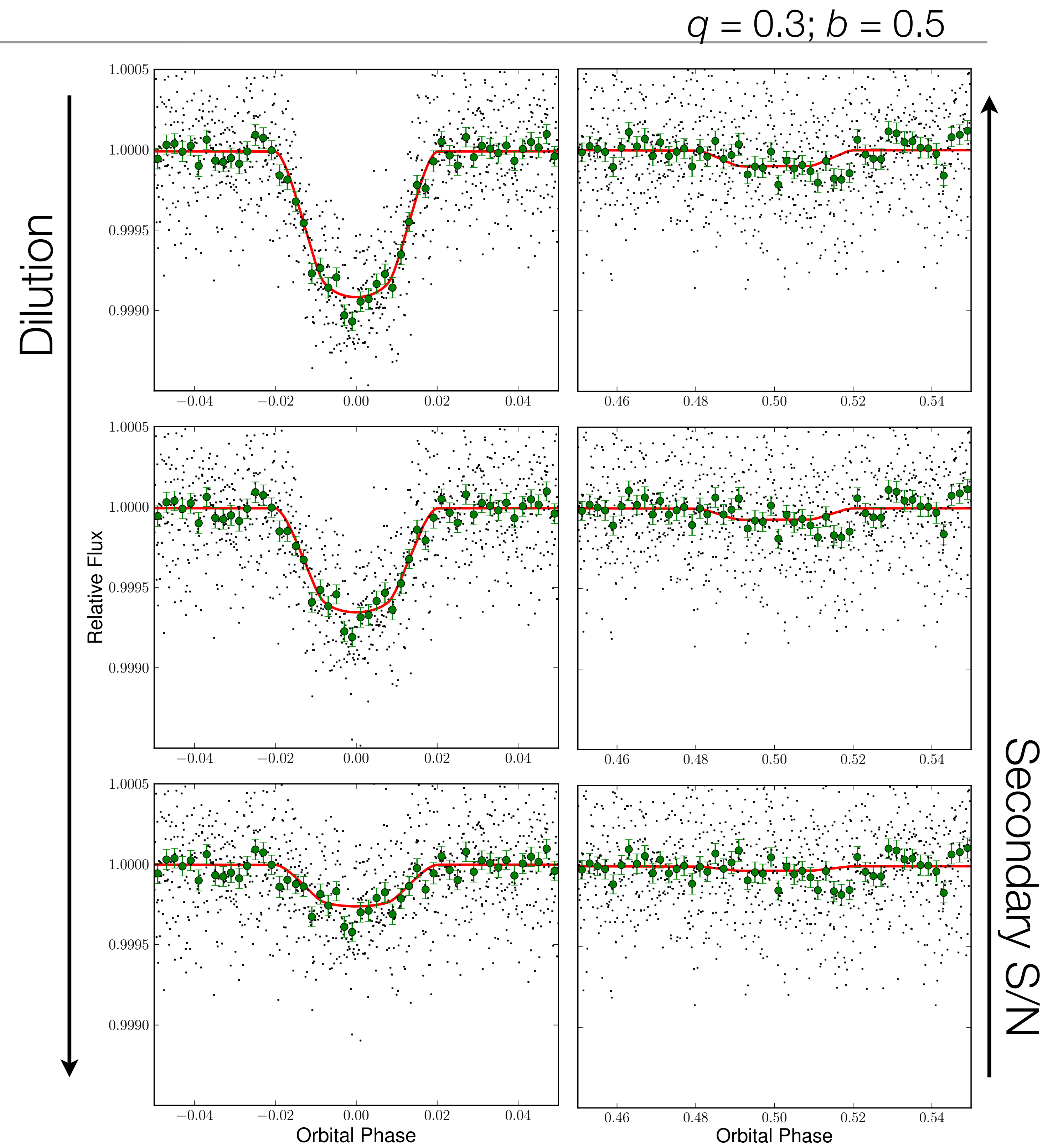
Synthetic data

Background eclipsing binaries

Studied parameters

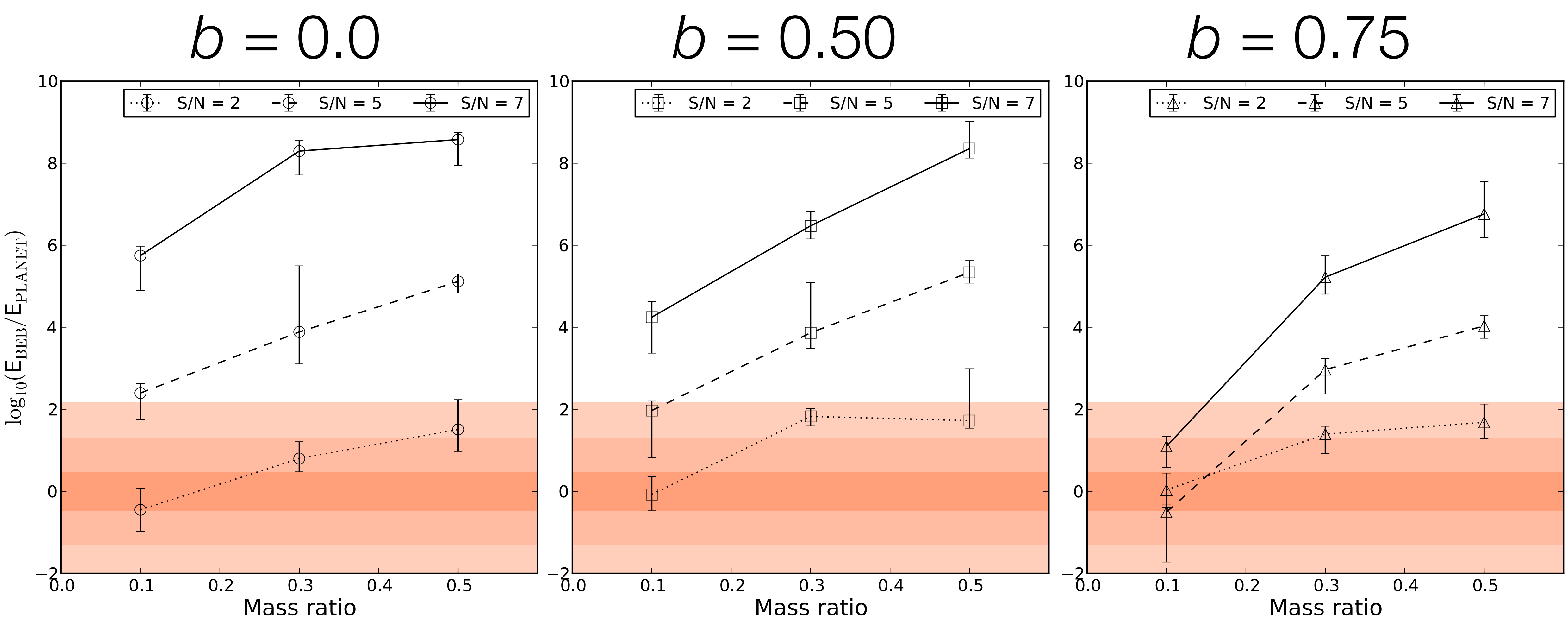
Background Eclipsing Binary	
Mass Ratio	{0.1; 0.3; 0.5}
Impact Parameter b	{0.0; 0.5; 0.75}
Secondary S/N	{2; 5; 7}

Secondary S/N: a way to quantify the dilution provided by the foreground target star.



Results (II: BEB simulations)

- $B_{10} < 3$: inconclusive evidence
- $3 < B_{10} < 20$: positive evidence
- $20 < B_{10} < 150$: strong evidence
- $B_{10} > 150$: very strong evidence

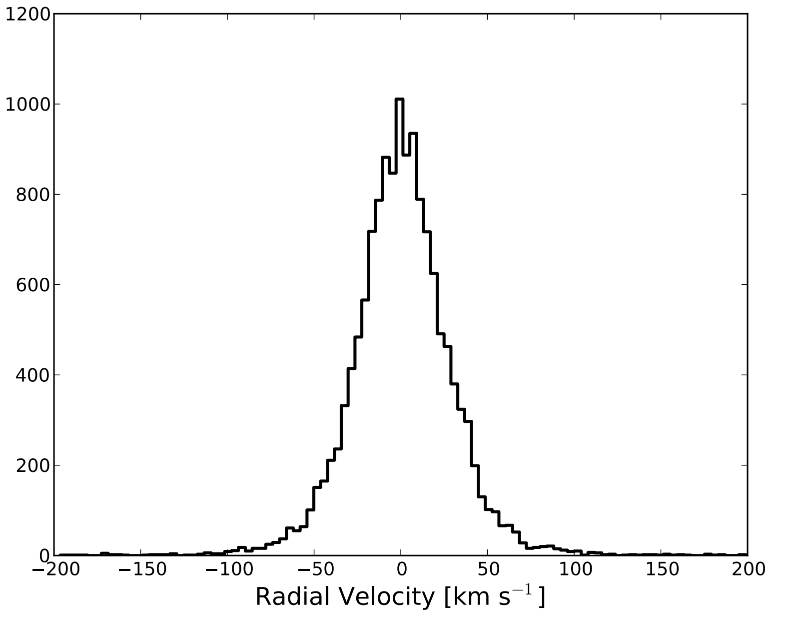


- Monotonic increase of B_{BP} with mass ratio *q*, snr of the secondary, and decrease with impact parameter.
- BEB model is not strongly chosen for *highest* dilution level at any *q* or *snr*.
- Secondaries with snr = 7 lead to strong evidence for the BEB hypothesis (except *q* = 0.1; b = 0.75)

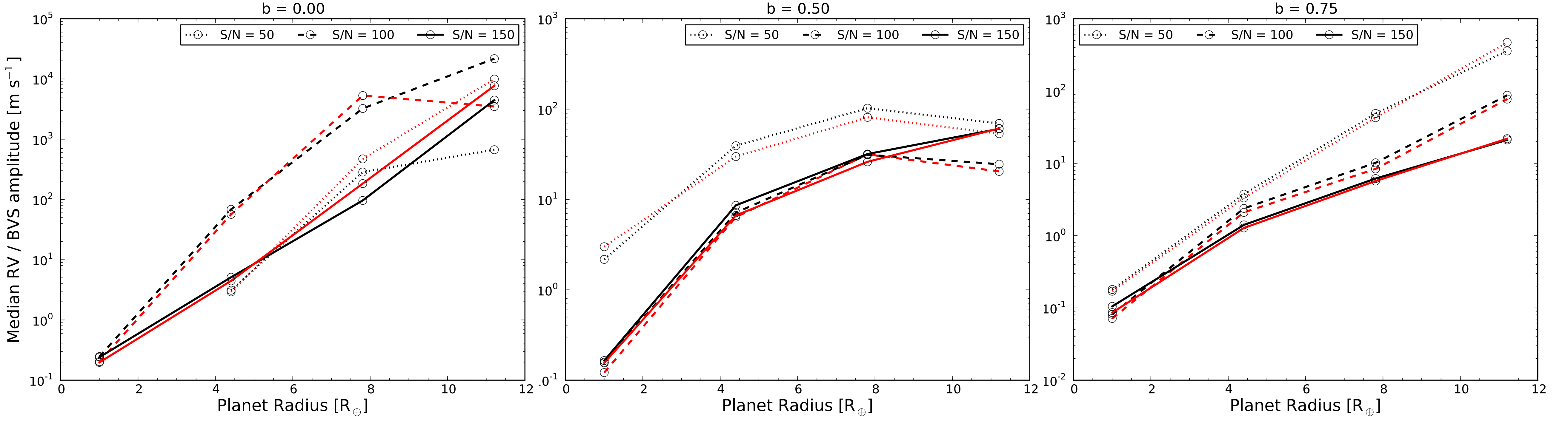
The radial velocity contribution

Could RV measurements help us decide on some cases?

- Nordström et al. (2004) distribution of RV measurements in the Solar neighborhood used to BEB velocity.
- Velocity and bisector amplitudes are computed.



- Best-fit BEB model to PLANET simulations; RV amplitude clearly detectable.



Summary and Conclusions

- Planet validation is the only technique to establish the planetary nature of the smallest transiting candidates from CoRoT and Kepler.
- PASTIS correctly identifies both transiting planets *and* false positives if the signal is sufficiently high.
- Simulations of synthetic data show that BEB with a modest dilution are easily detectable as such. However, if the dilution is such that the secondary eclipse has signal-to-noise ratio ~ 2, the data cannot say much.
- For simulated PLANETS, only data from very-high-S/N transits provides strong support for the planet scenario.
- For the unresolved cases, the model priors will be the deciding factor. Other observations: AO, etc.
- Radial velocities can contribute in this point. Apparently more so in the case of planets than BEBs.