A Spectral Approach to TTVs

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ApJ submitted

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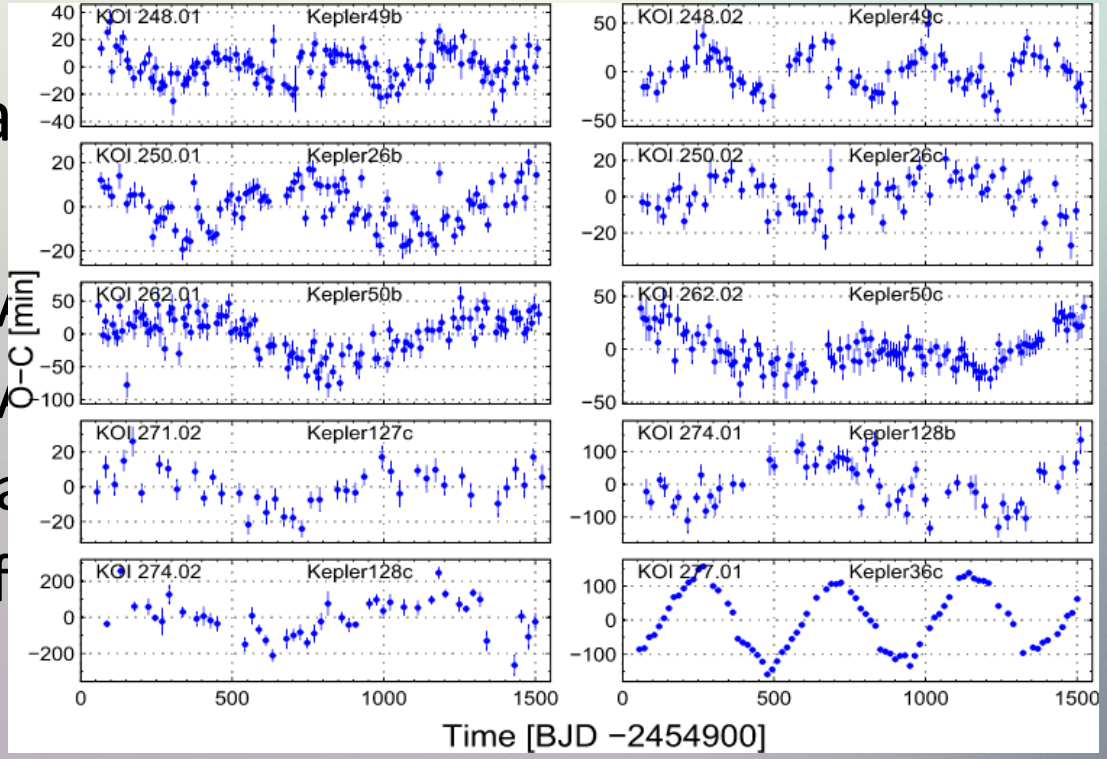
“Classical” approach

- Fit planetary parameters and all $T_{mid,i=1..N}$ simultaneously.
  - Recent major work: Kepler TTVs catalog by Holczer+2016
- Limitations of cla
  - Strong Biases:

    Deep transits (A

    Long periods (A
  - Blind to short-tra
  - Large number of



Spectral approach to TTVs

Lessons learned:

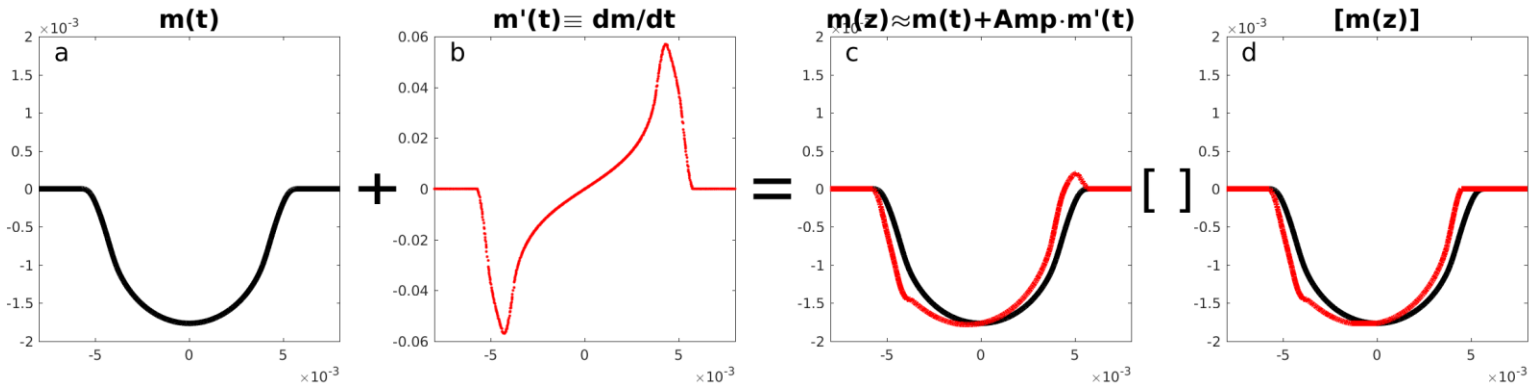
- Linear ephemeris means: $T_{mid,i}=T_0+iP$
- TTV information approx. sinusoidal

A new way to look for TTVs:

- $T_{mid,i}=T_0 + iP + A_{TTV}\cdot\sin[2\pi t f_{TTV} - \varphi_{TTV}]$
- Check: did it improve χ^2 relative to χ^2_{linear}?
- Scan over A_{TTV}, f_{TTV}, φ_{TTV}
- WORKS! But…. Problematic search space.

Perturbative Approximation (PA)

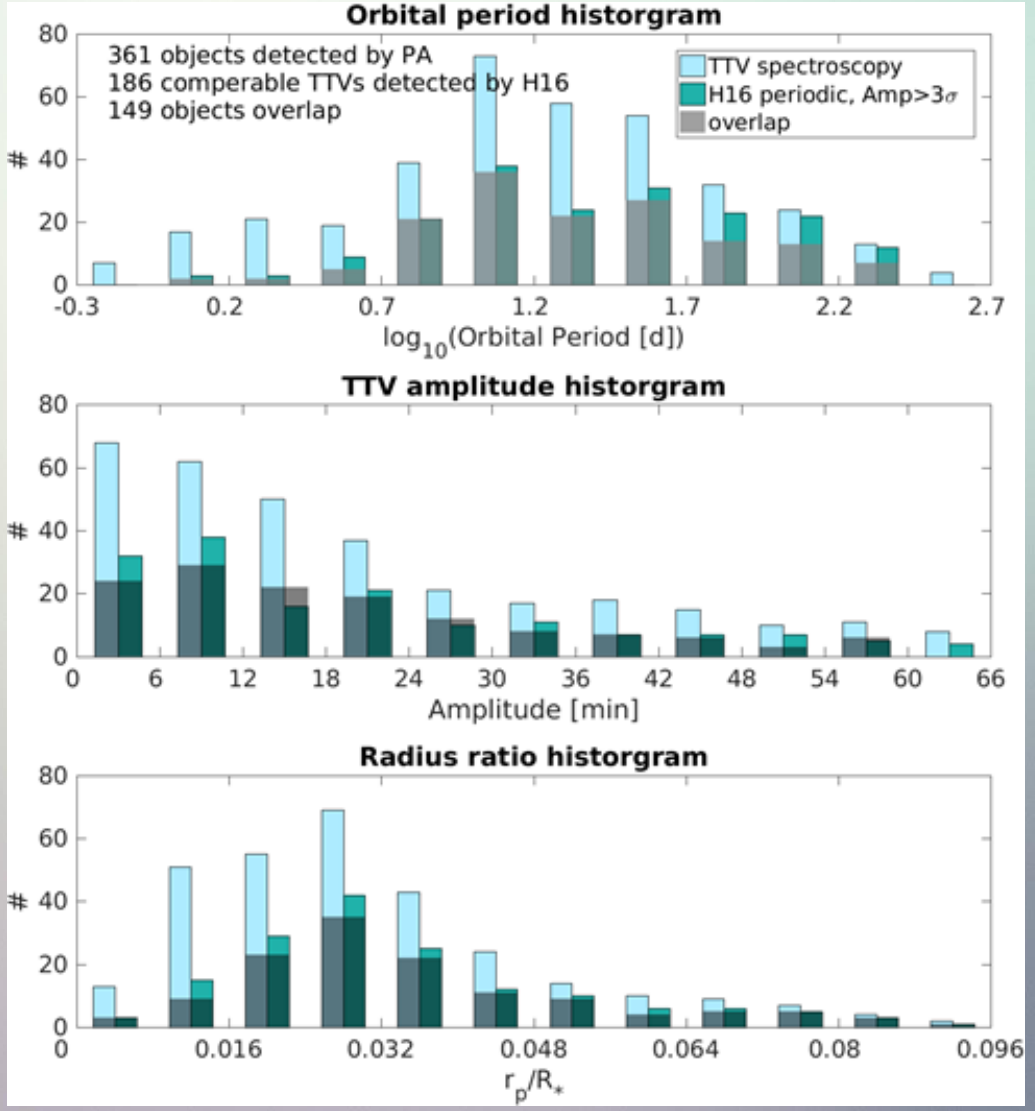
- Large-amplitude TTVs probably already found



- Add two perturbation: f=sine & g=cosine:
  $m_i(z_i) \approx m_i(x_i) + Af_i m_i' + Bg_i m_i'$
- Would fit both φ_{TTV} and A_{TTV} analytically
- Sensitive, nearly unbiased, fast

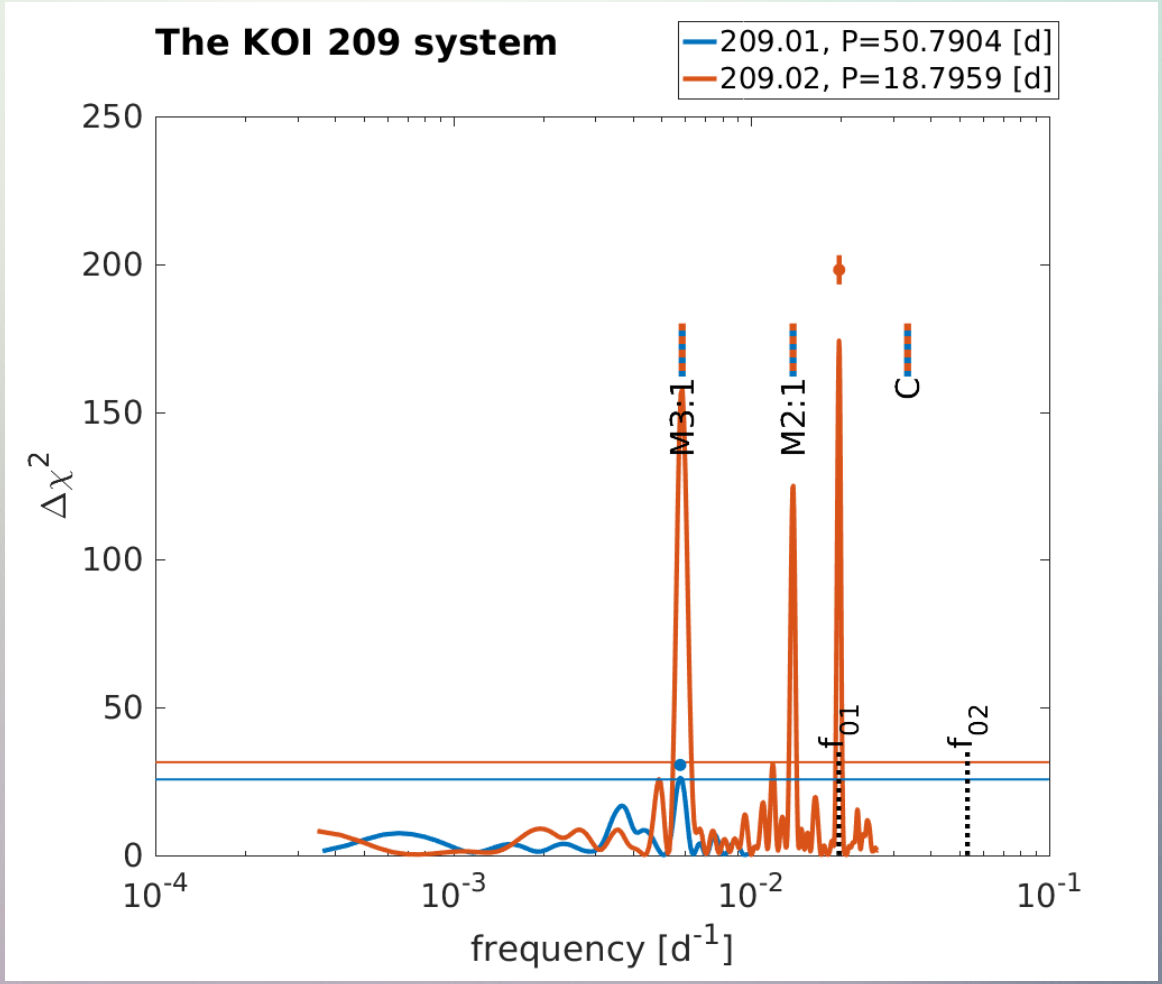
Kepler Results - statistics

- Required Bootstrap confidence ≥0.999
- 131 new TTVs in (+2/3 over H16*)
- Depth:
  - All KOIs: 428ppm
    PA: 458ppm
- Period:
  - All KOIs: 9.5d
    PA: 10.8d



Results - Examples

- KOI-209 (Kepler-117): text-book example

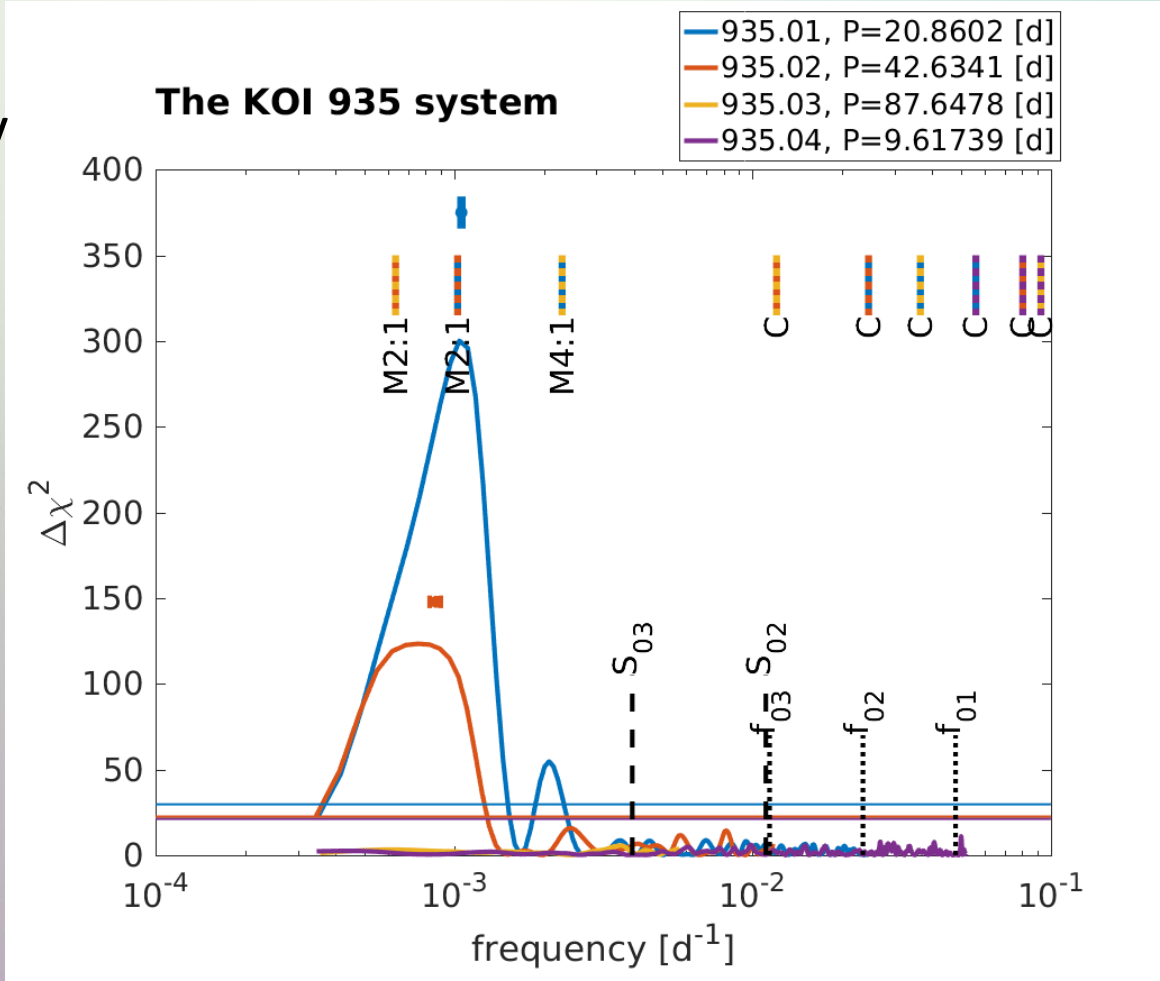


Results - Examples

- KOI-935 (Kepler-31)

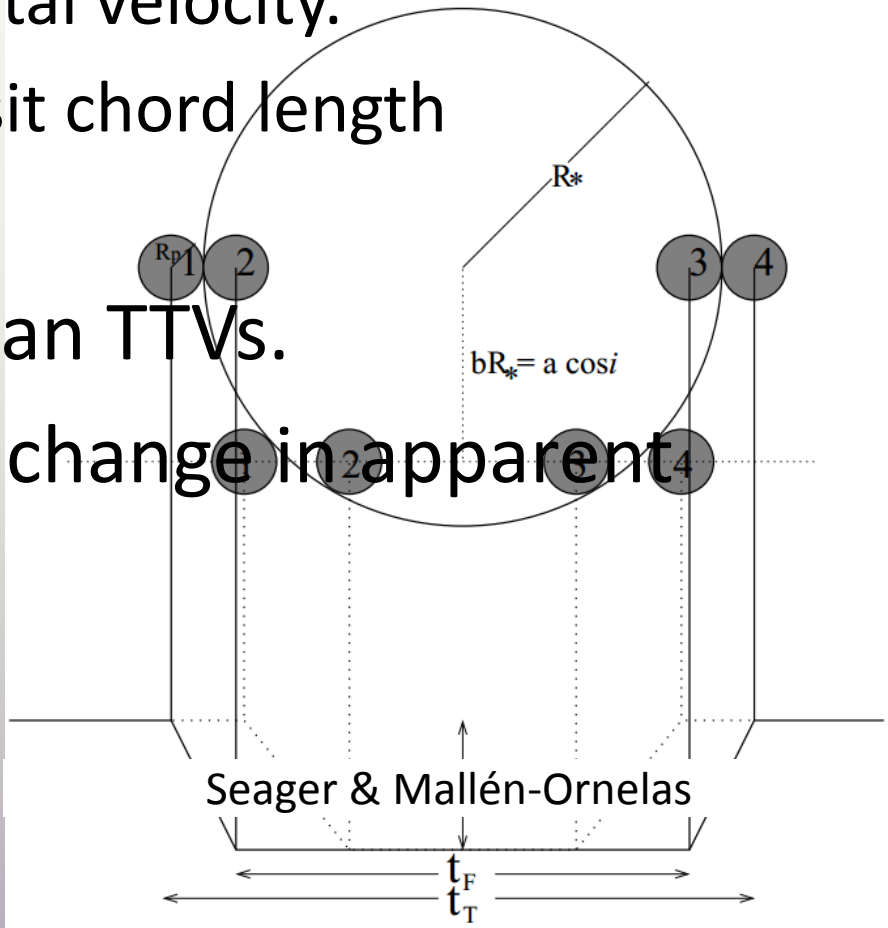
- .01-.02: main .01 peak
- .01-.03: new secondary
- .02-.03: wide .02 peak

1:2:4 resonant chain w/masses?



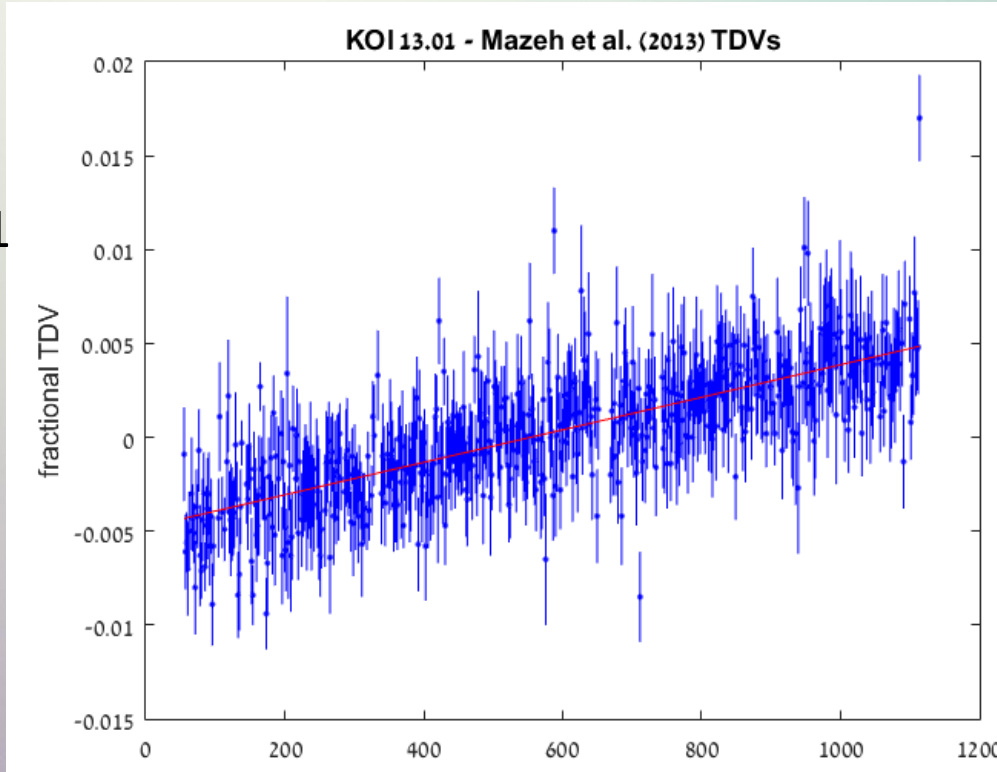
TDVs: Transit Duration Variations

- Origin of TDVs is:
  - Change in tangential orbital velocity.
  - Change in apparent transit chord length
  - Both simultaneously
- Noisier measurement than TTVs.
- TbVs are only caused by change in apparent transit chord length.
- PA: linearly perturb *b*



KOI 13.01 TDV/TbV

- Mazeh+13 catalog (Q1-Q12 data): fractional TDV of 0.00316±0.00012 yr^{-1}.
- Circular orbit→ TbV=$\frac{(1-b^2)}{-b}$(Frac. TDV)= = -0.00142 ± 6e-5 yr^{-1}
- PA gives TbV = -0.00130 ± 5.9e-5 yr^{-1} (Preliminary analysis)



Conclusions

- Spectral Approach is a new TTV detection technique, allowed many new detections.
- Its PA generalizable to other transit variations.
- Unbiased, sensitive, general, very fast.
- May contribute to M-R relation of small planets
- First-line detector of TTVs/TbVs/…: very suitable to short-baseline datasets like: TESS, PLATO, …

Thank you.