Pre-transit signatures around hot planets: probing the circumplanetary material

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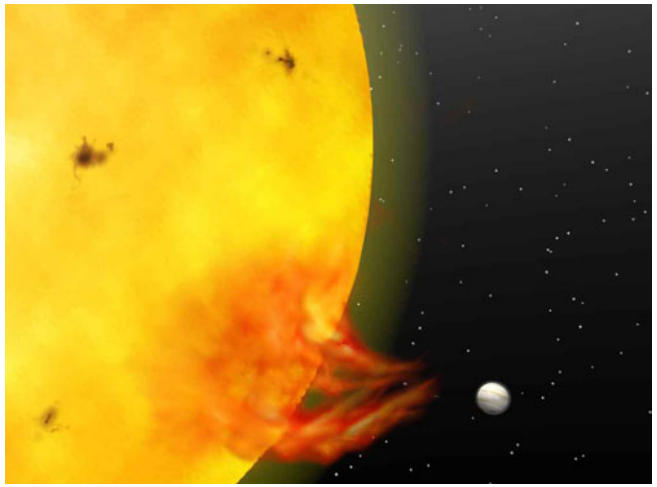
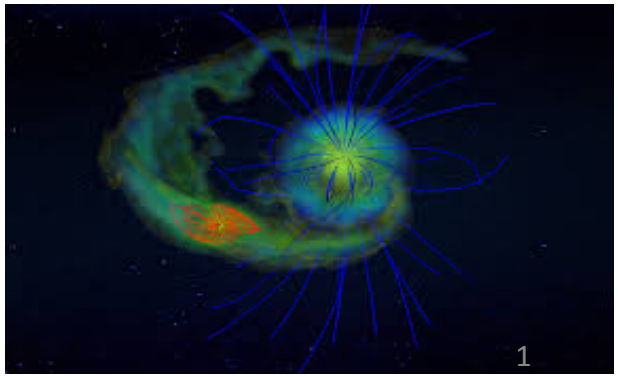
Collaborators: Seth Redfield, Adam Jensen, Michael Endl, Bill Cochran, and Travis Barman
Wesleyan University

SSI Friday Talk
01-22-16

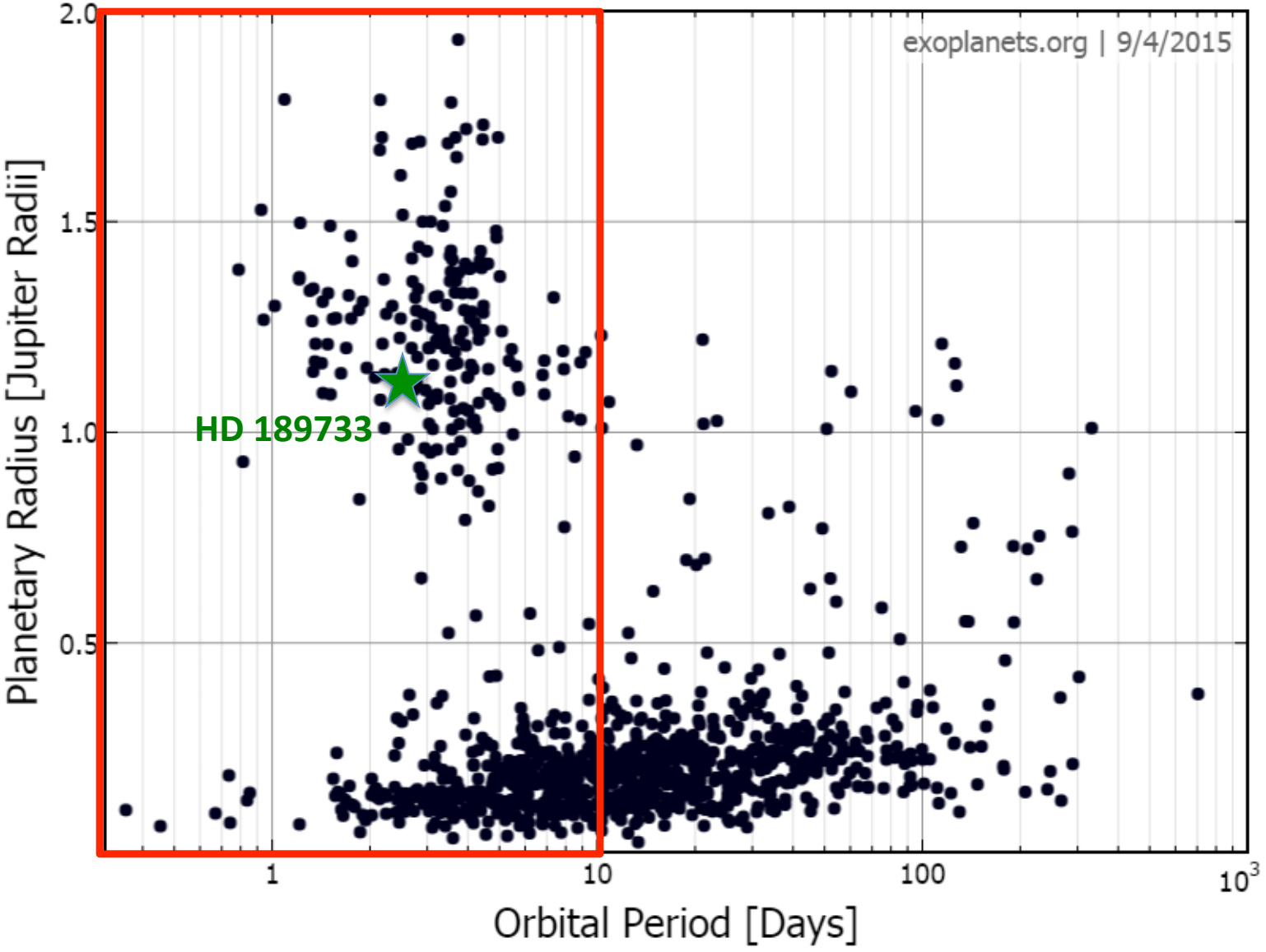




Overview

1. Why search for these signatures?
2. Types of star-planet interactions
3. Evidence of star-planet interactions (SPIs)
4. Pre-transit absorption: physical scenarios
5. Specific examples
6. Current and future work

Hot planets


exoplanets.org | 9/4/2015
HD 189733
Planetary Radius [Jupiter Radii]
2.0
1.5
1.0
0.5
1
10
100
10^3
Orbital Period [Days]

Atmospheric transmission spectra

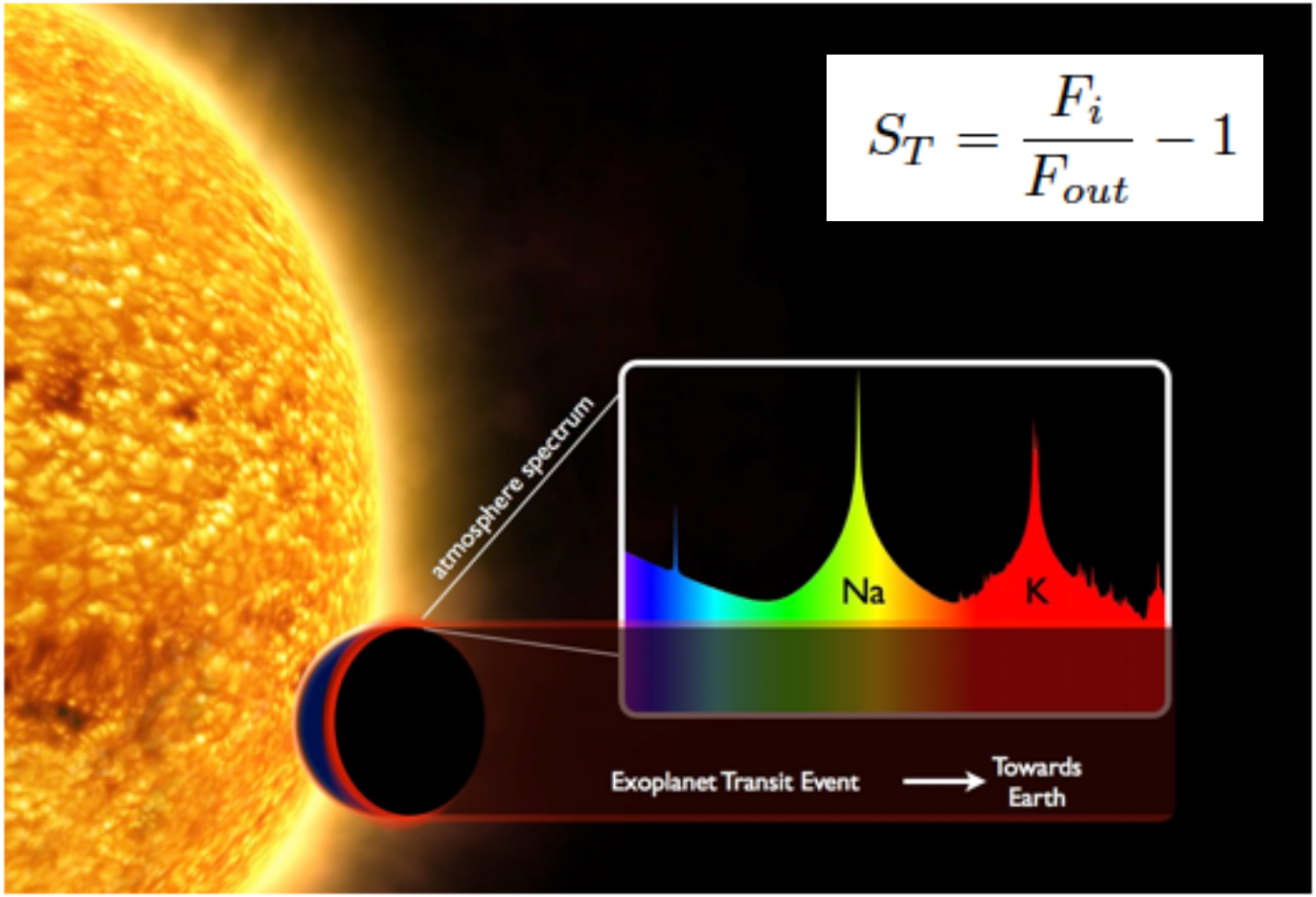


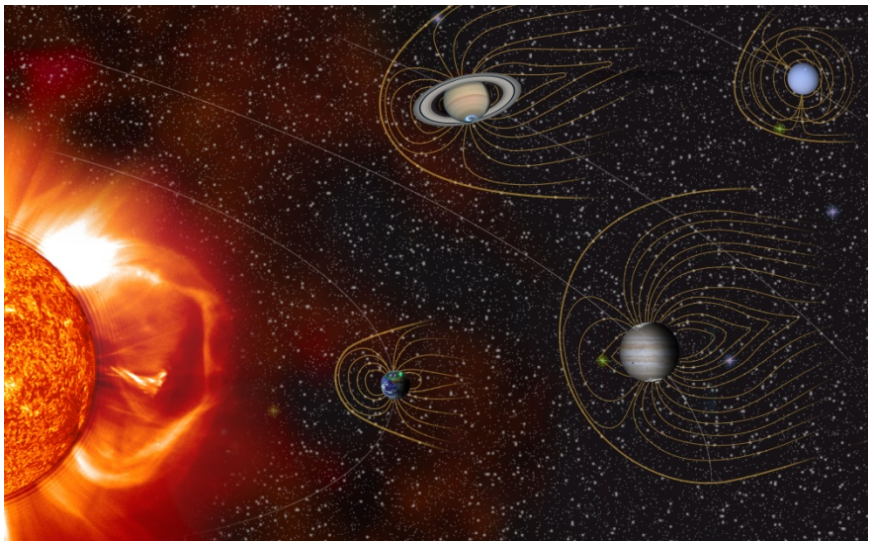
Image courtesy of Exoclimes 2012

Why bother with pre-transit signals?

1. Interesting and novel astrophysics

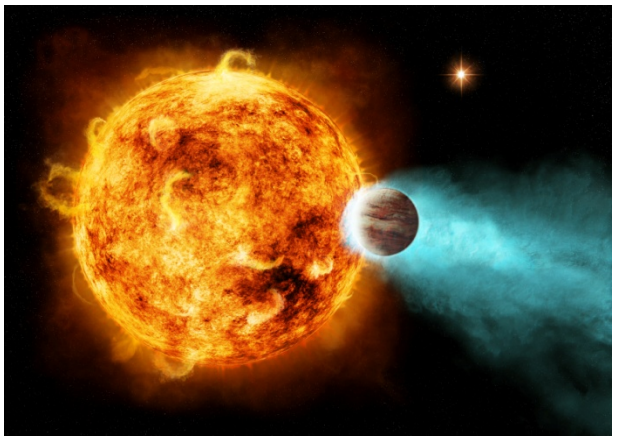
2. Probing stellar winds

3. Painting a complete picture of exoplanets



4. Constraining exoplanetary magnetic fields

Types of interactions



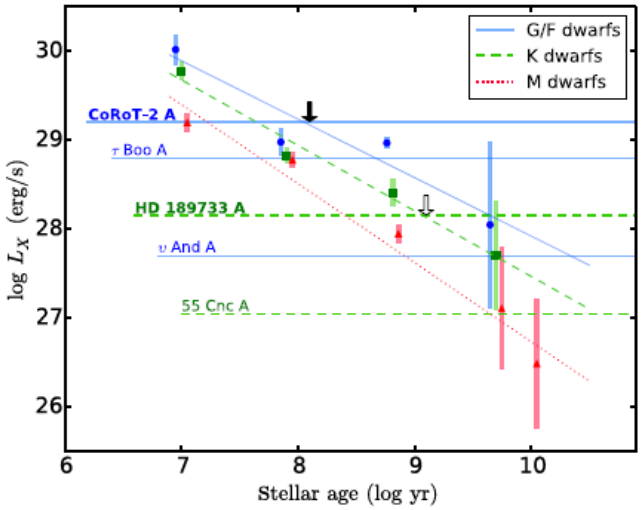
- Tidal interactions
- Direct magnetic interactions
- Accretion and outflows
  - Wind-wind
  - Wind-magnetosphere

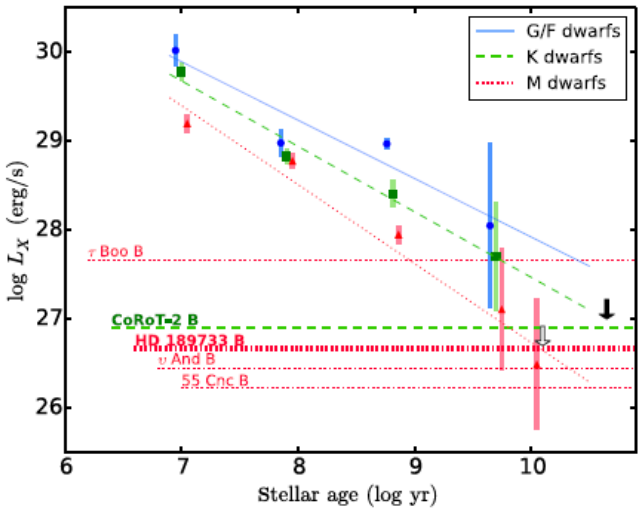
Bow shocks , pre-transit absorption

  - Accretion flows **Hot spots, pre-transit absorption?**
  - Photoevaporative outflows **Blue-shifted absorption, pre-transit absorption**

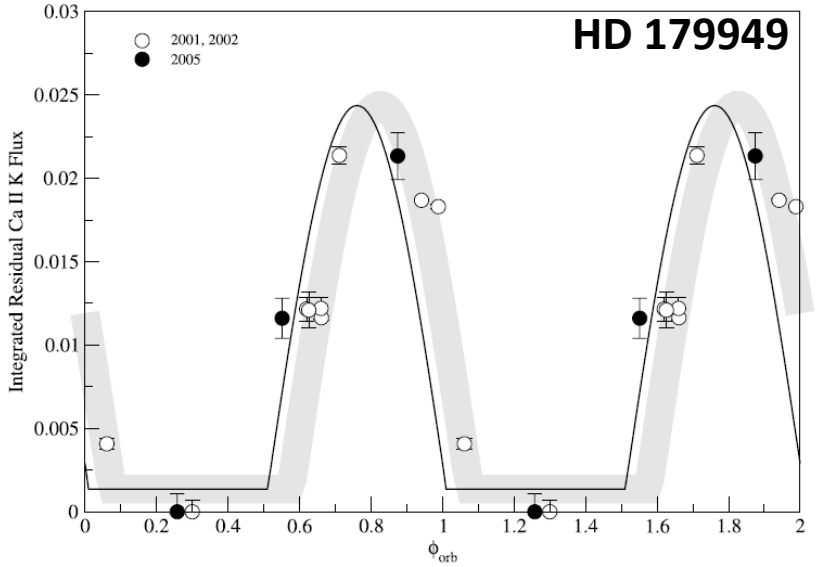
No broadband detections! (Turner et al. 2013, 2014)

Evidence of star-planet interactions

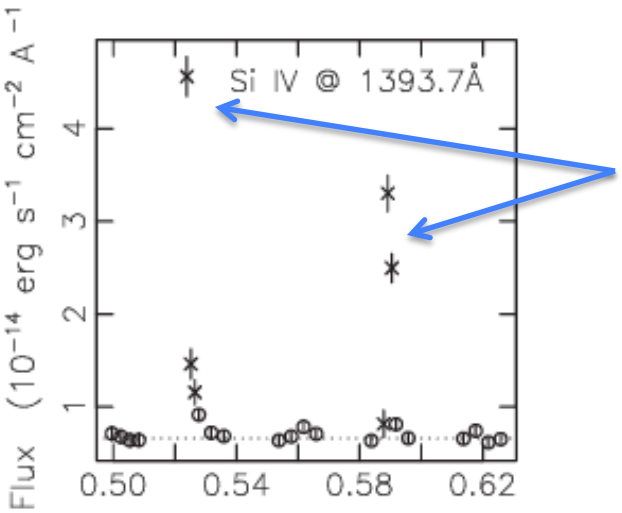




Poppenhaeger & Wolk 2014



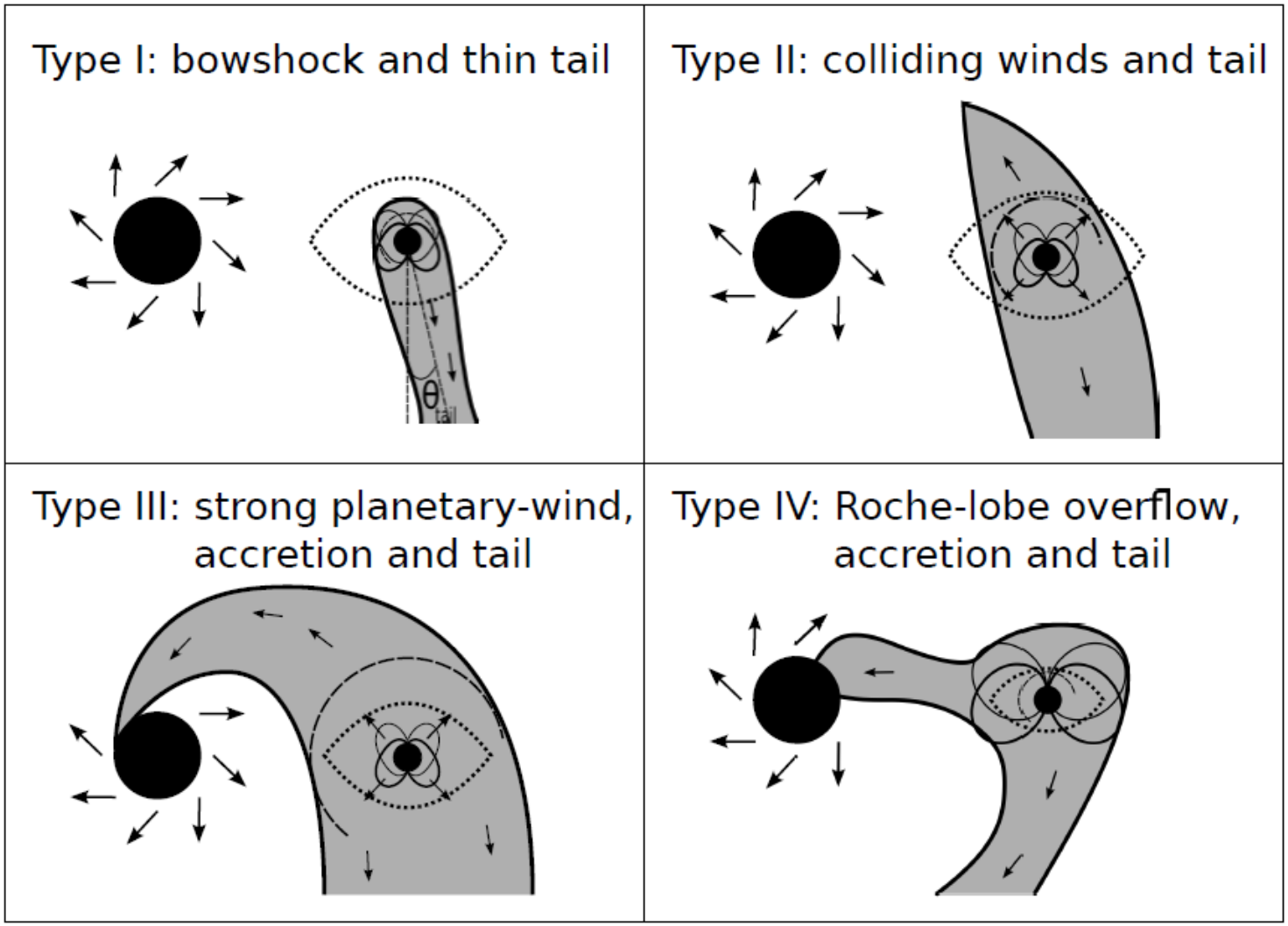
Shkolnik et al. 2008



Flares!

Pillitteri et al. 2015

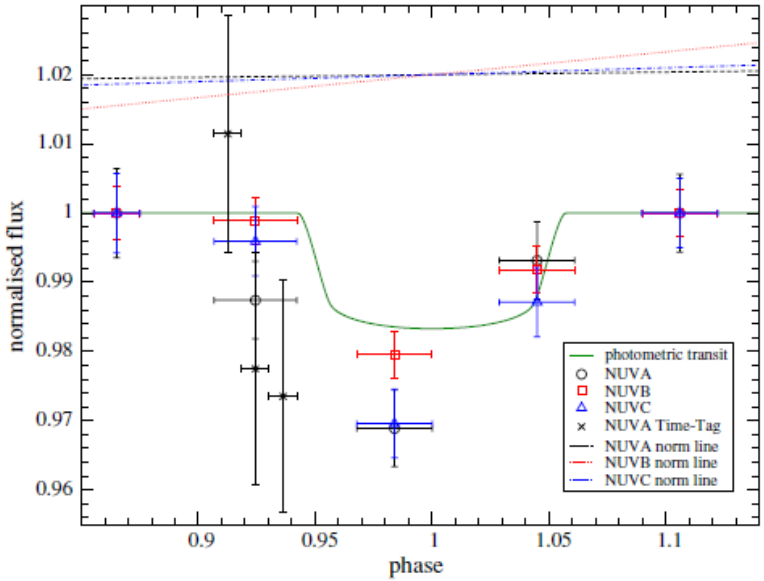
Pre-transit absorption scenarios

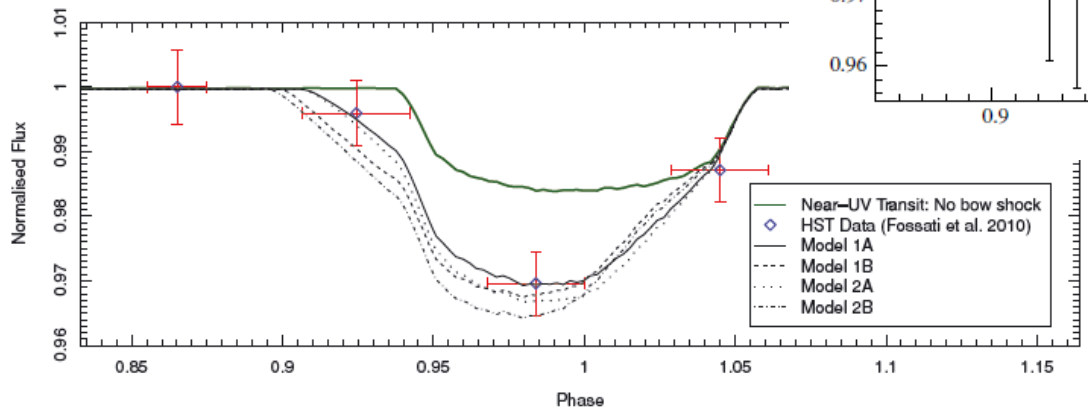


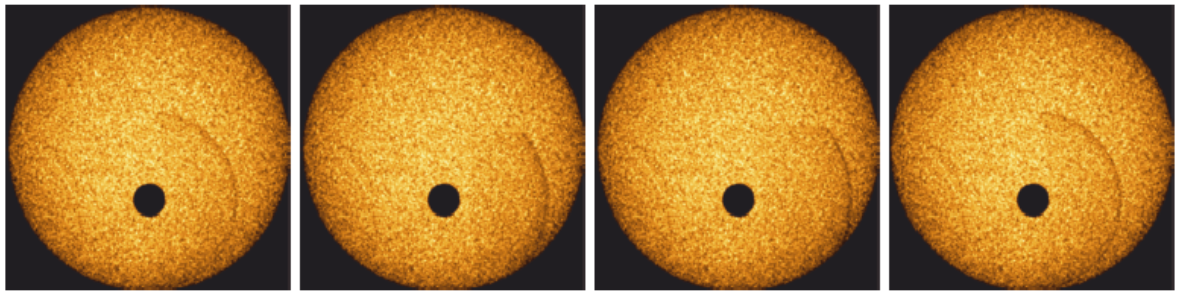
Matsakos et al. 2015

Pre-transit detections: specific cases

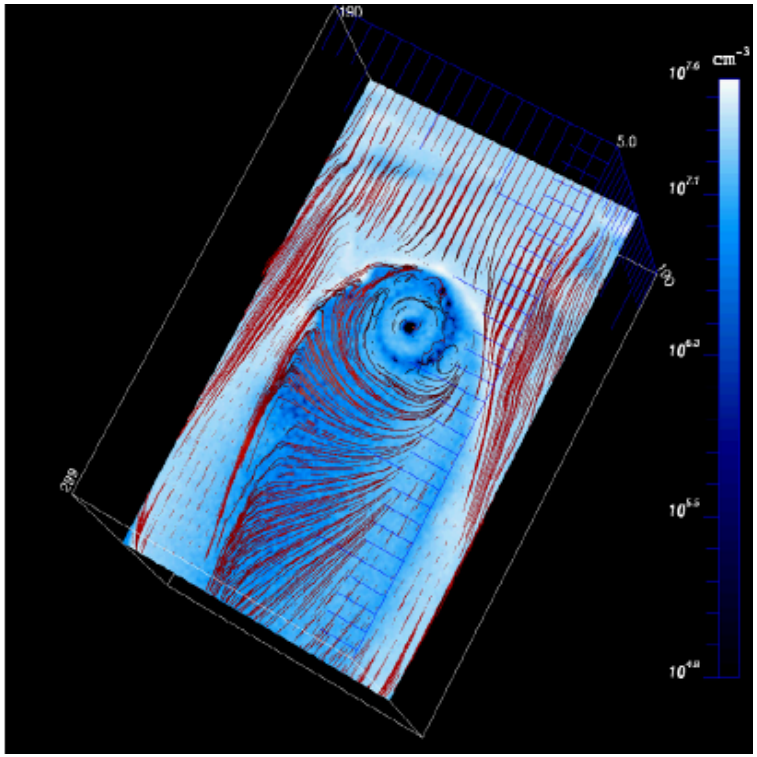
- Fossati et al. 2010: NUV flux in WASP-12b
- Modeled by Llama et al. 2011 as a bow shock

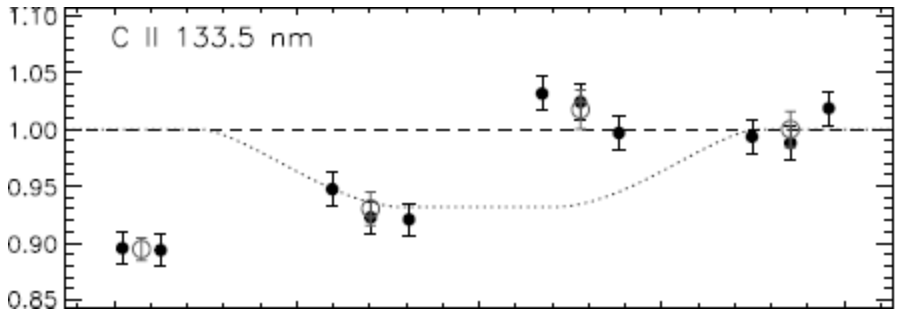


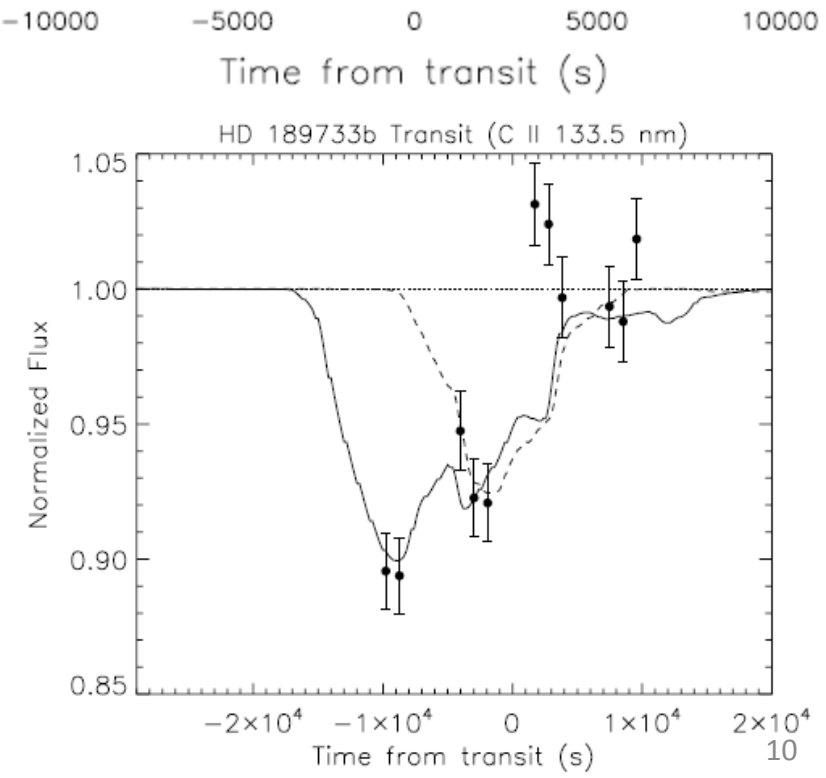




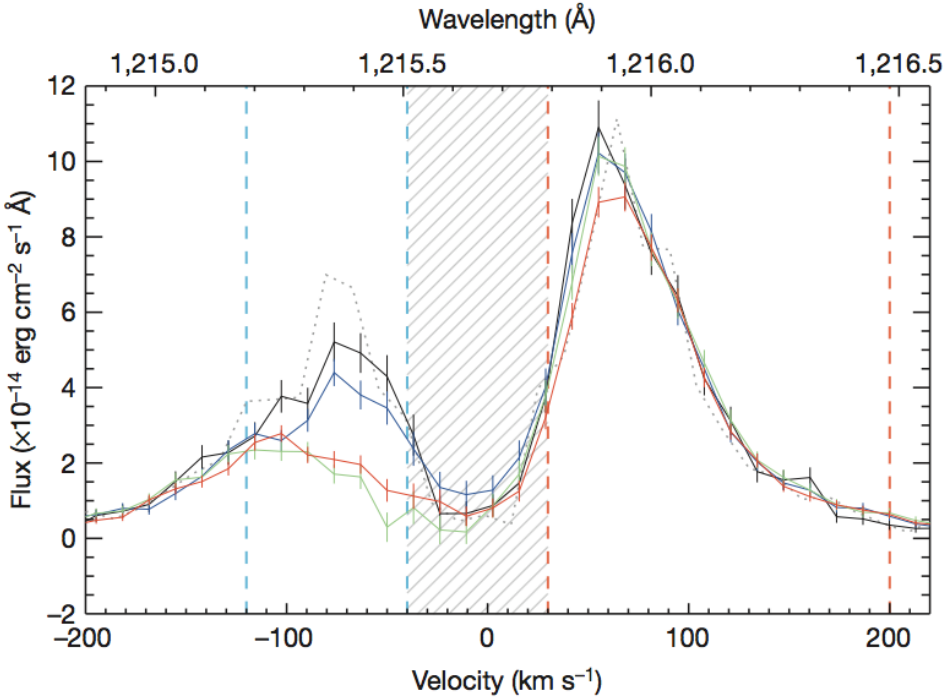
•Ben-Jaffel & Ballester (2013) and Bourrier et al. (2013): C II and Si II in HD 189733 b

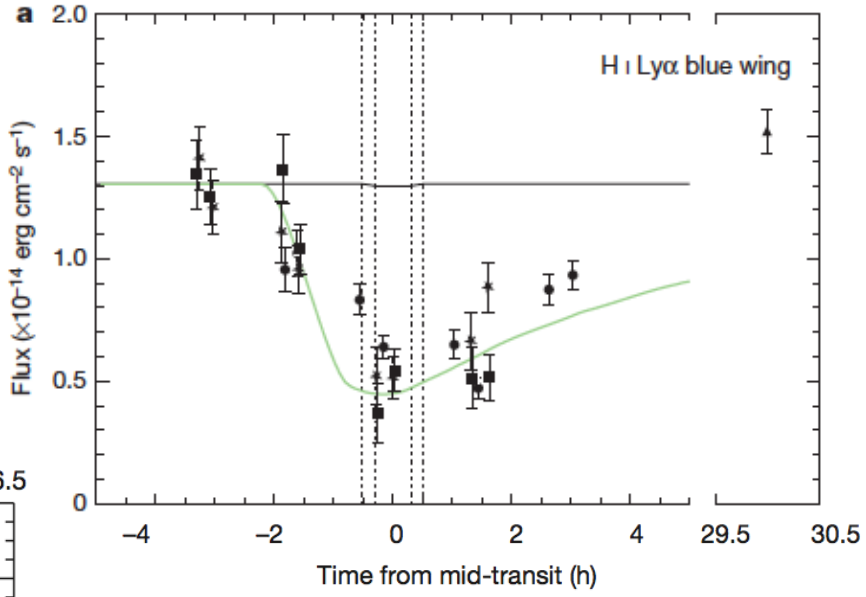


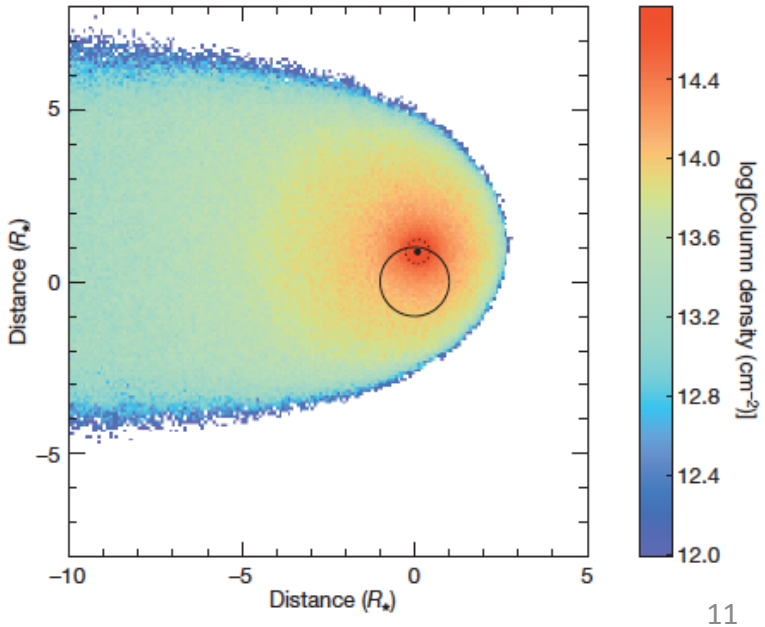




•Ehrenreich et al. 2015: Lyman-α absorption in GJ 436 b





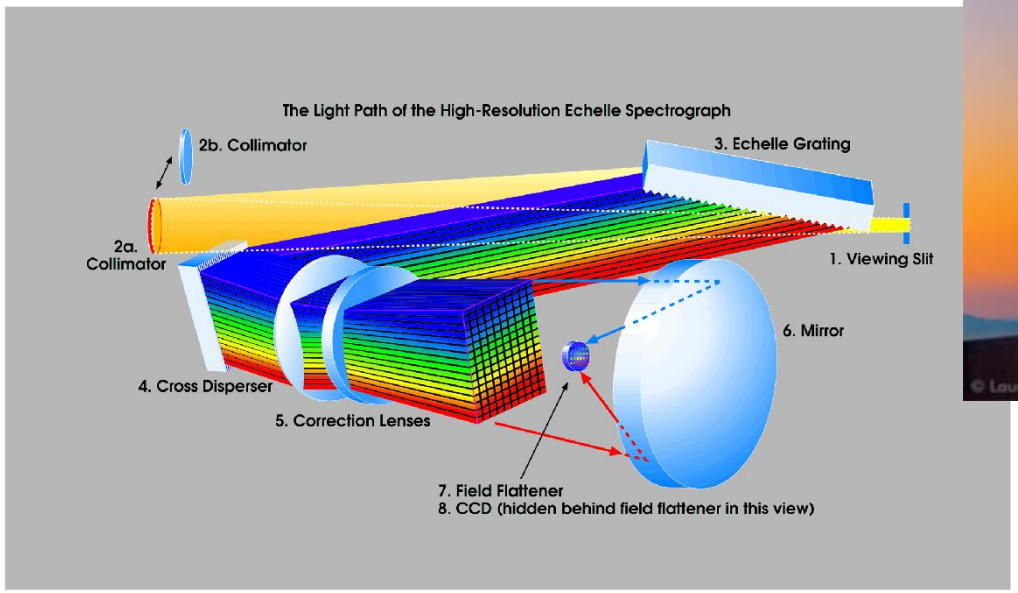


Bottom line: Pre-transit absorption must be common around very hot planets, UV observations are expensive

Potential solution: Search for these signatures in the optical

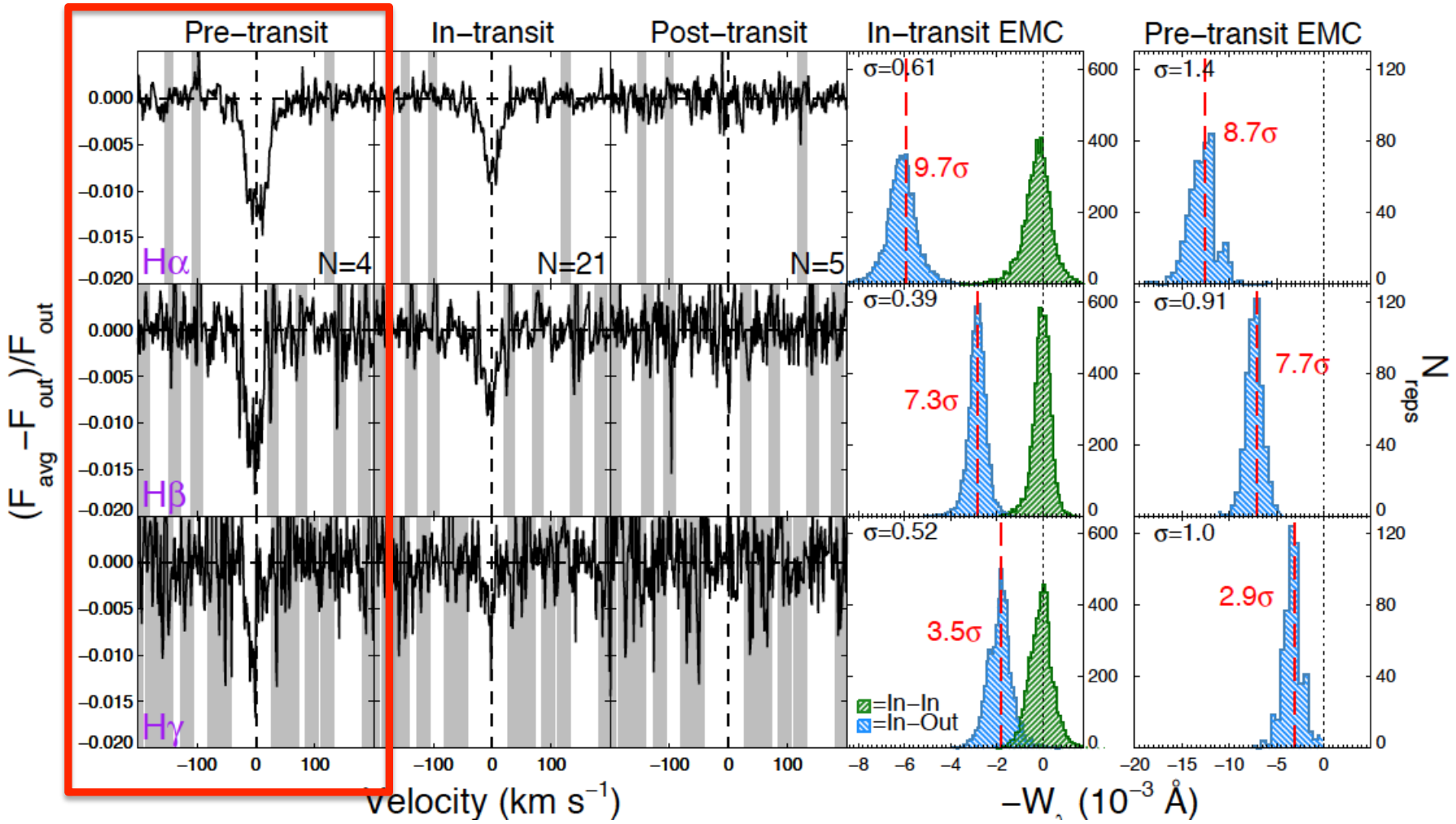
Optical pre-transit absorption: HD 189733 b

- Need a few things:
  1. Very high signal-to-noise
  2. Large wavelength coverage
  3. High observation cadence

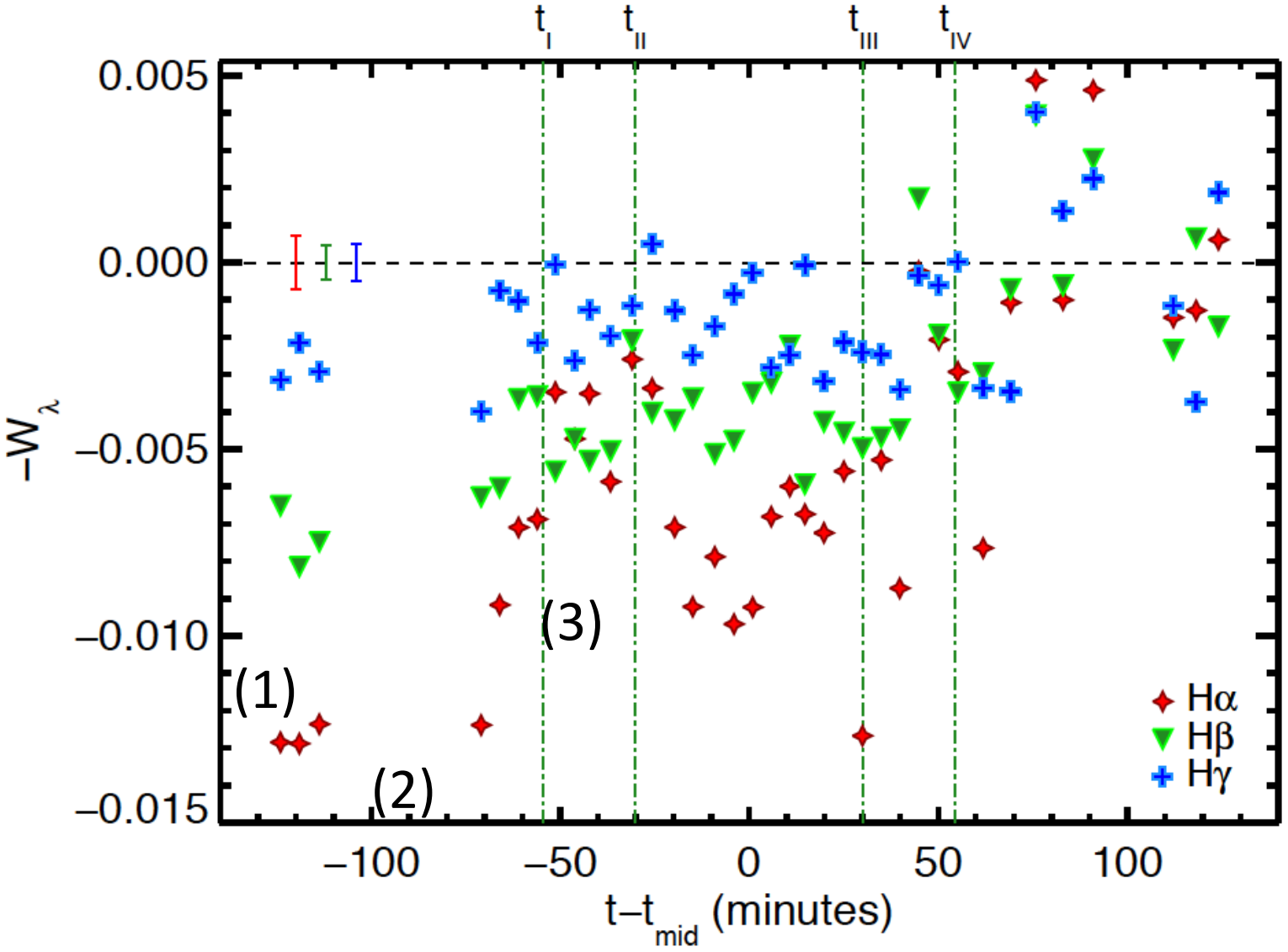


Transmission spectra

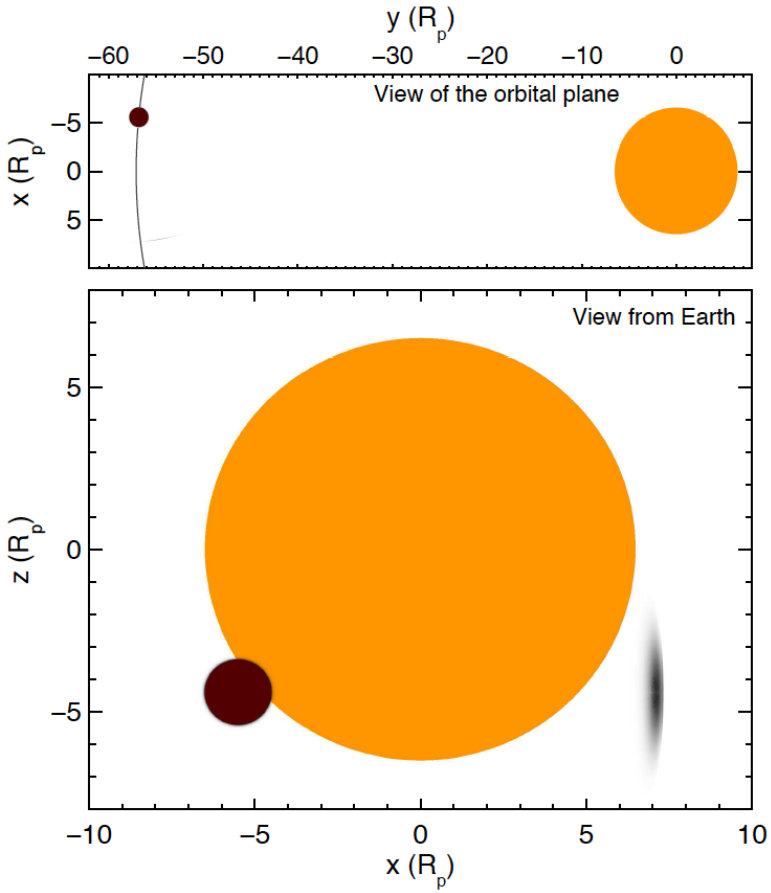
$$W_\lambda = \sum_{v=-200}^{+200} \left(1 - \frac{F_v}{F_v^{out}}\right) \Delta\lambda_v$$



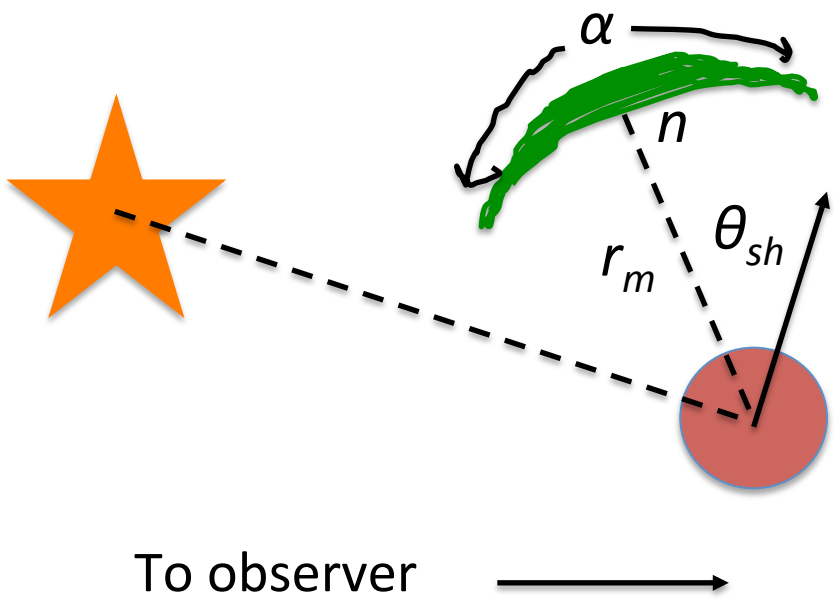
Absorption time-series

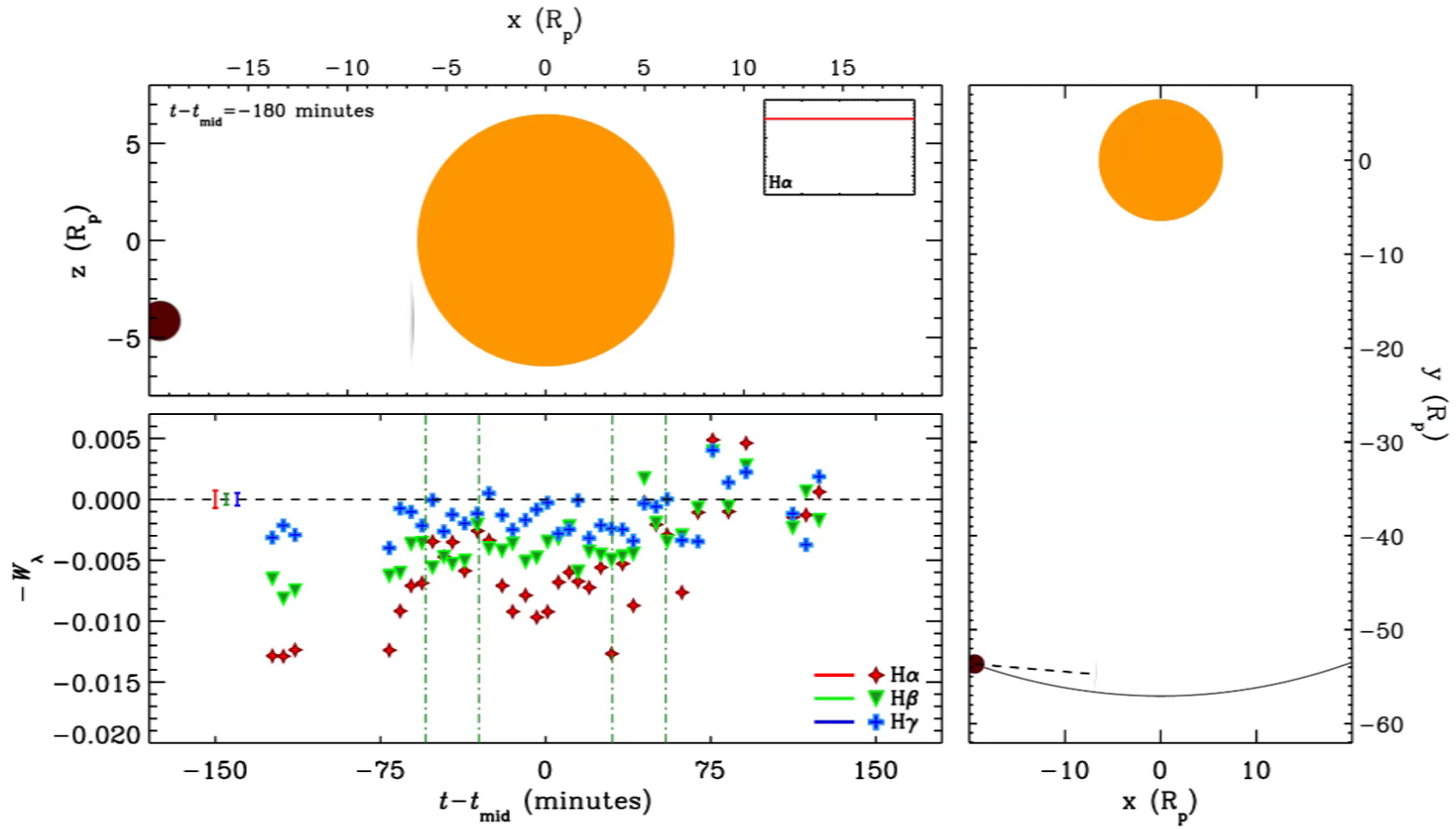


Geometric bow shock model

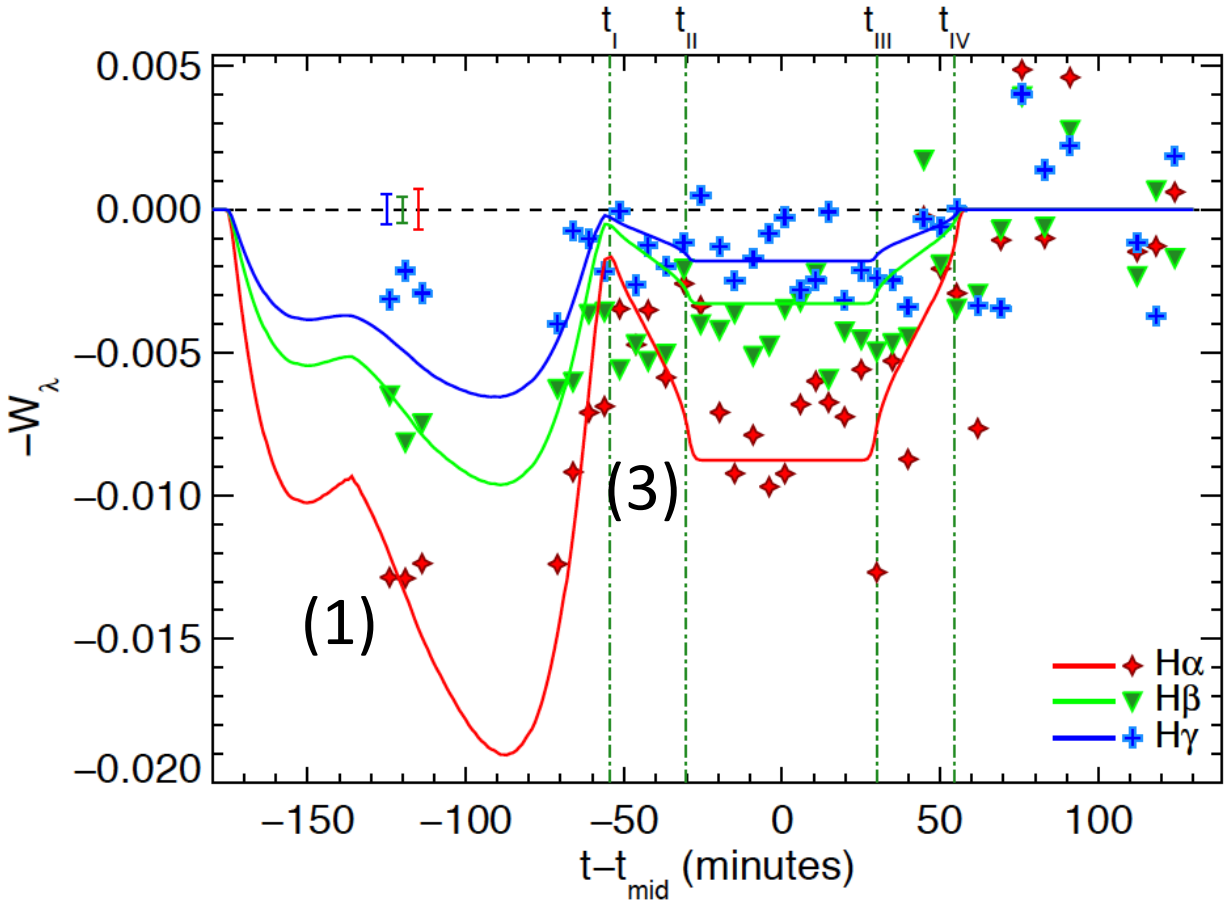


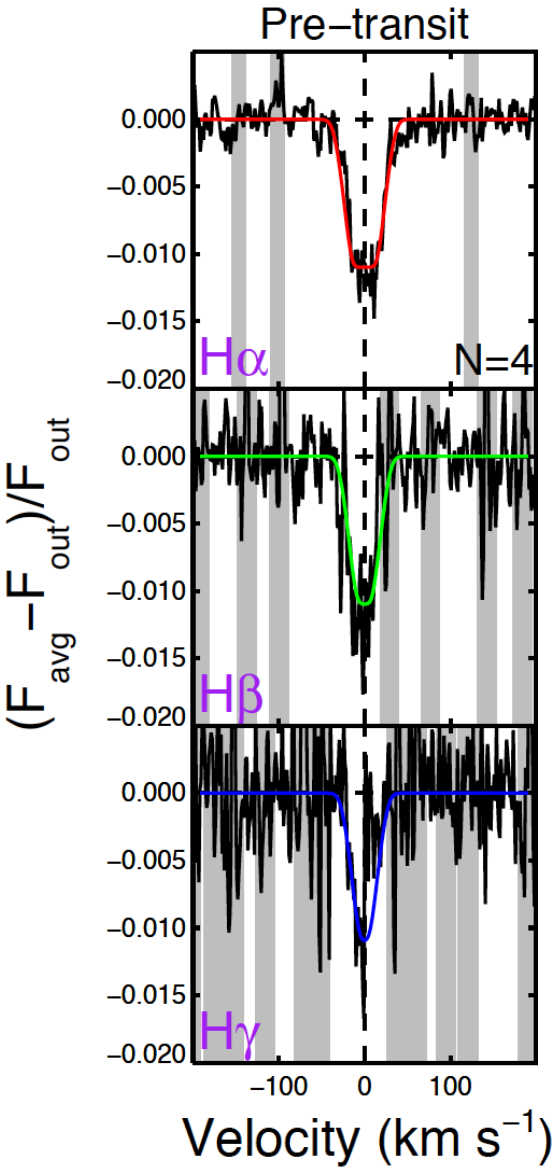
Model cartoon:




x (R_p)
−15 −10 −5 0 5 10 15
t−t_mid=−180 minutes
Hα
z (R_p)
5 0 −5
0.005
0.000
−0.005
−0.010
−0.015
−0.020
−W_λ
Hα
Hβ
Hγ
−150 −75 0 75 150
t−t_mid (minutes)
0 −10 −20 −30 −40 −50 −60
y (R_p)
−10 0 10
x (R_p)

Model results





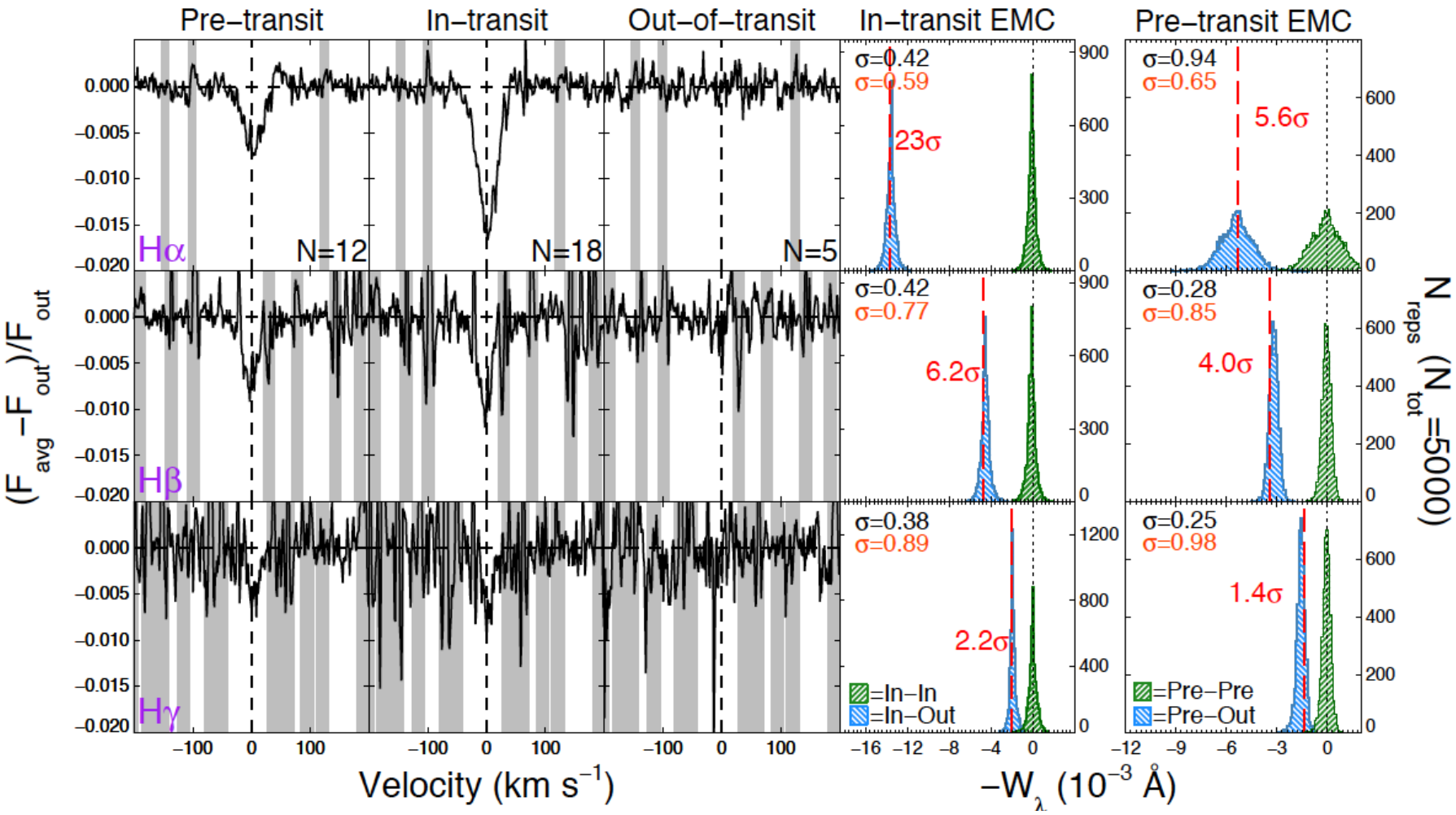
n=5.4x10^4 cm^{-3}, α=400, r_m=12.75 R_p, θ_{sh}=15°

$P_w = P_B \rightarrow B_{eq}$ = 28 G

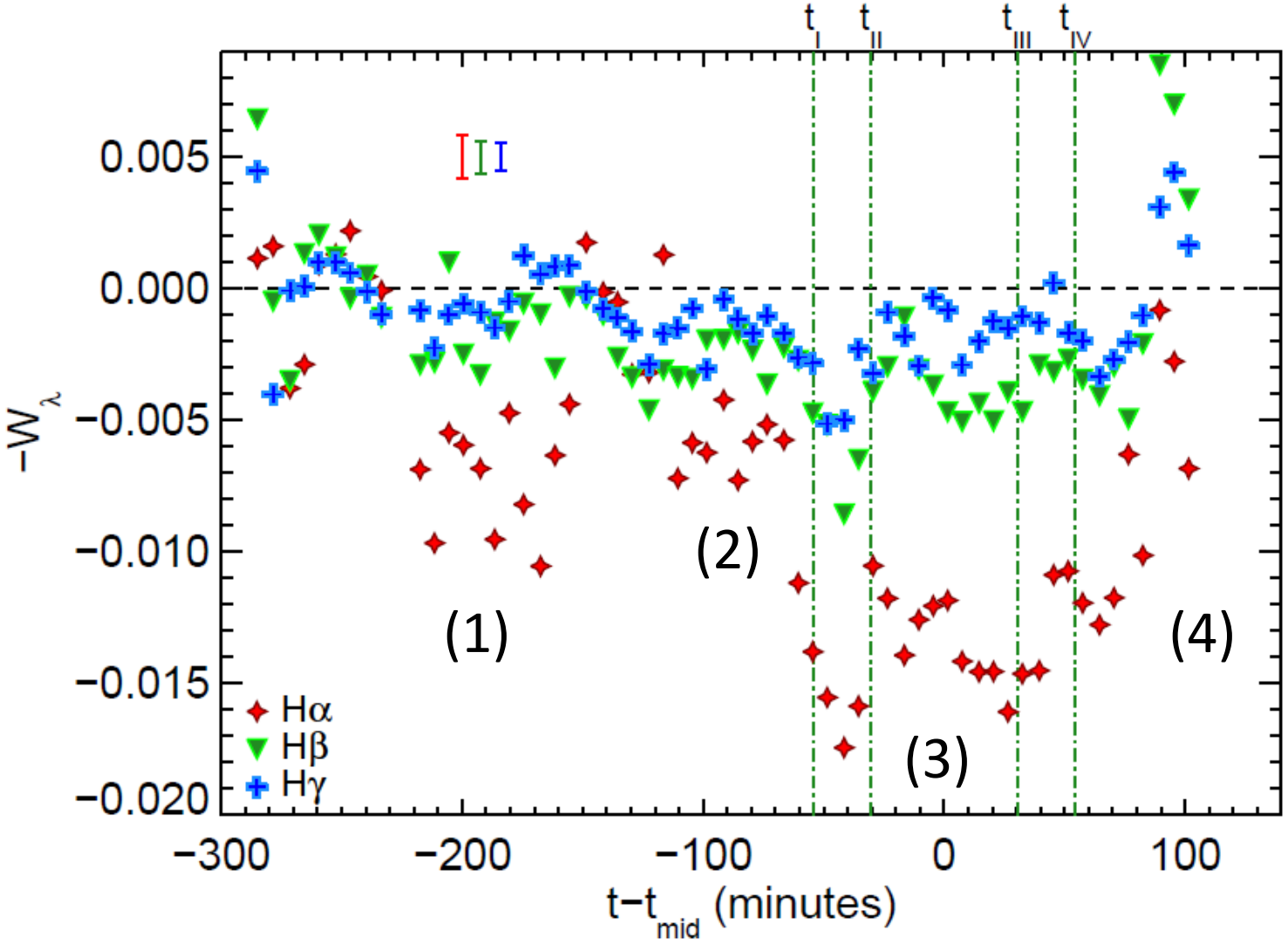
Follow up observations: a second transit

- If magnetic field strength is that strong, signal should be somewhat consistent*
- New observations fill in phase gaps of previous data
- Identical observing strategy and instrument setup
- ~4.5 hours pre-transit through ~1 hour post-transit

Transmission spectra

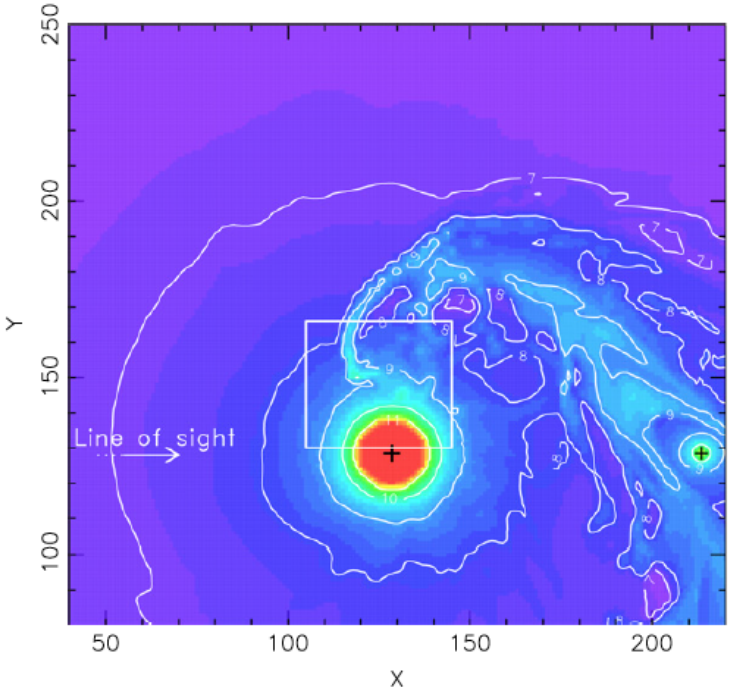


August 2015 transit



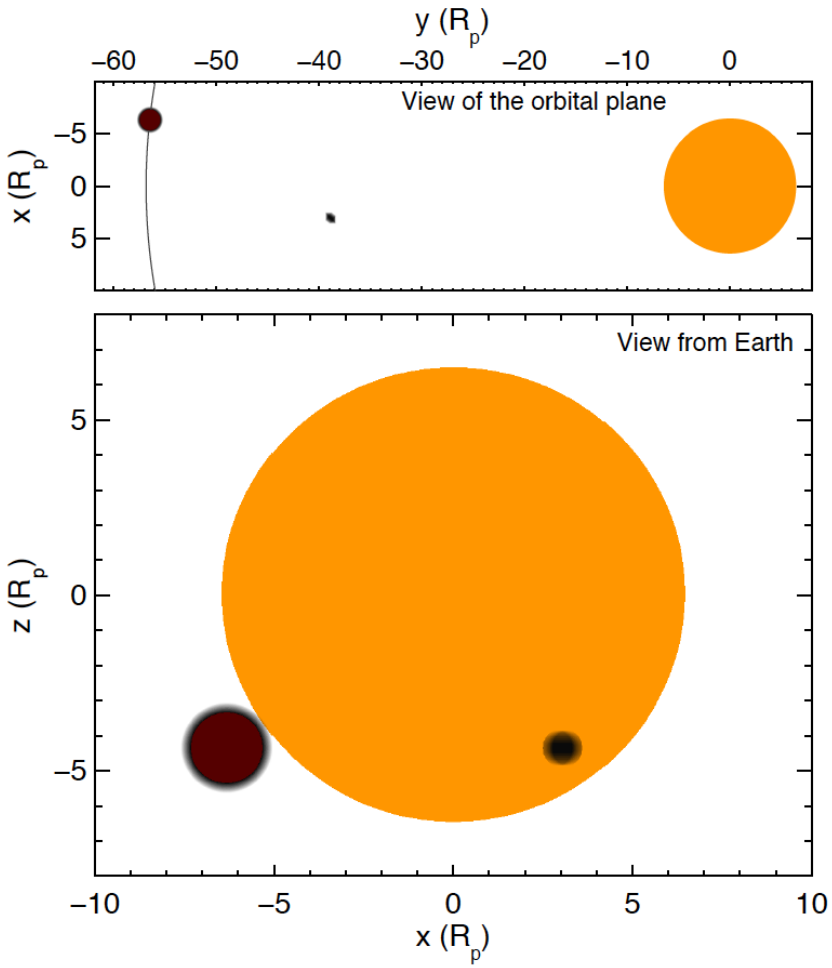
Clumpy accretion?

- Structure is different from 2013
- Bow shock model doesn't work
- Two distinct events = two transits?

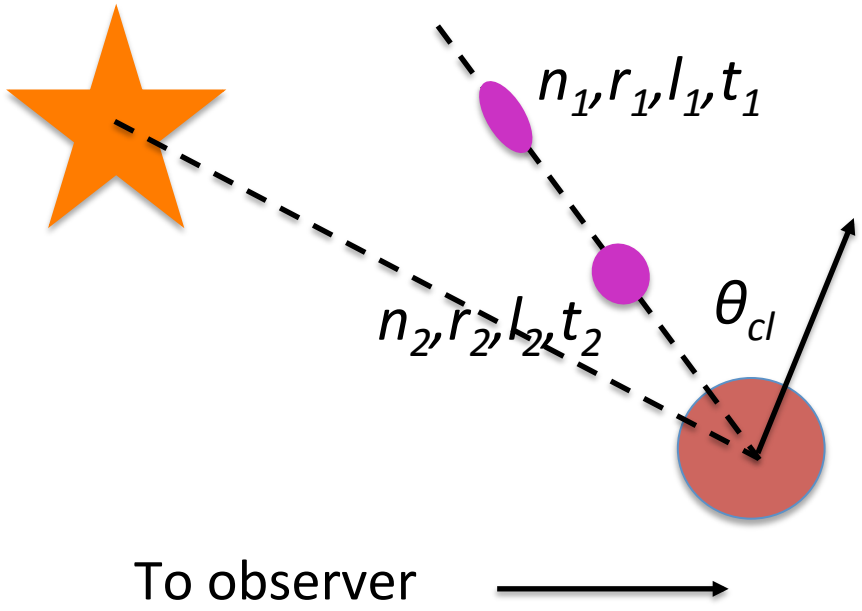


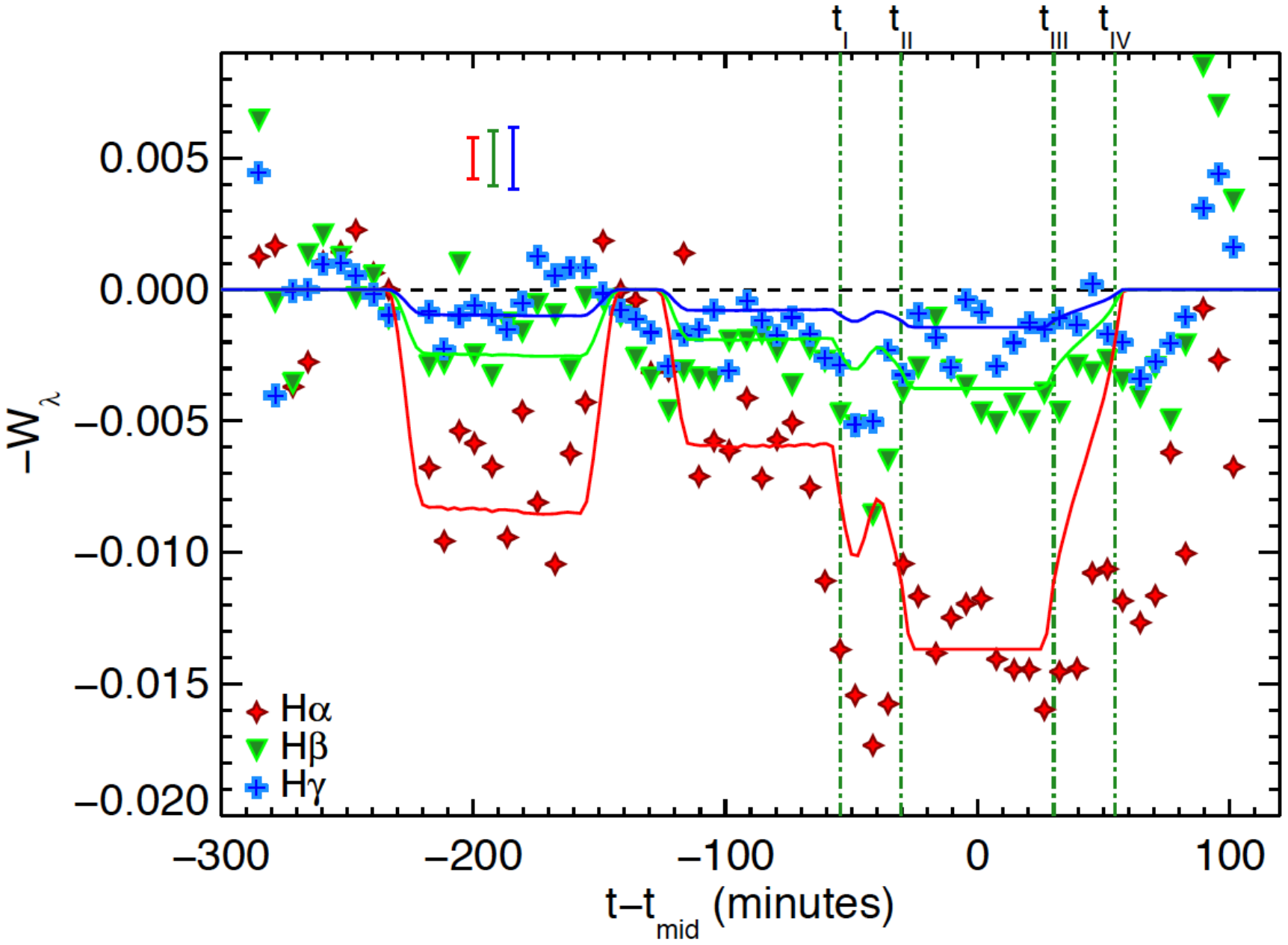
Pillitteri et al. 2015

Accretion clump model



Model cartoon:

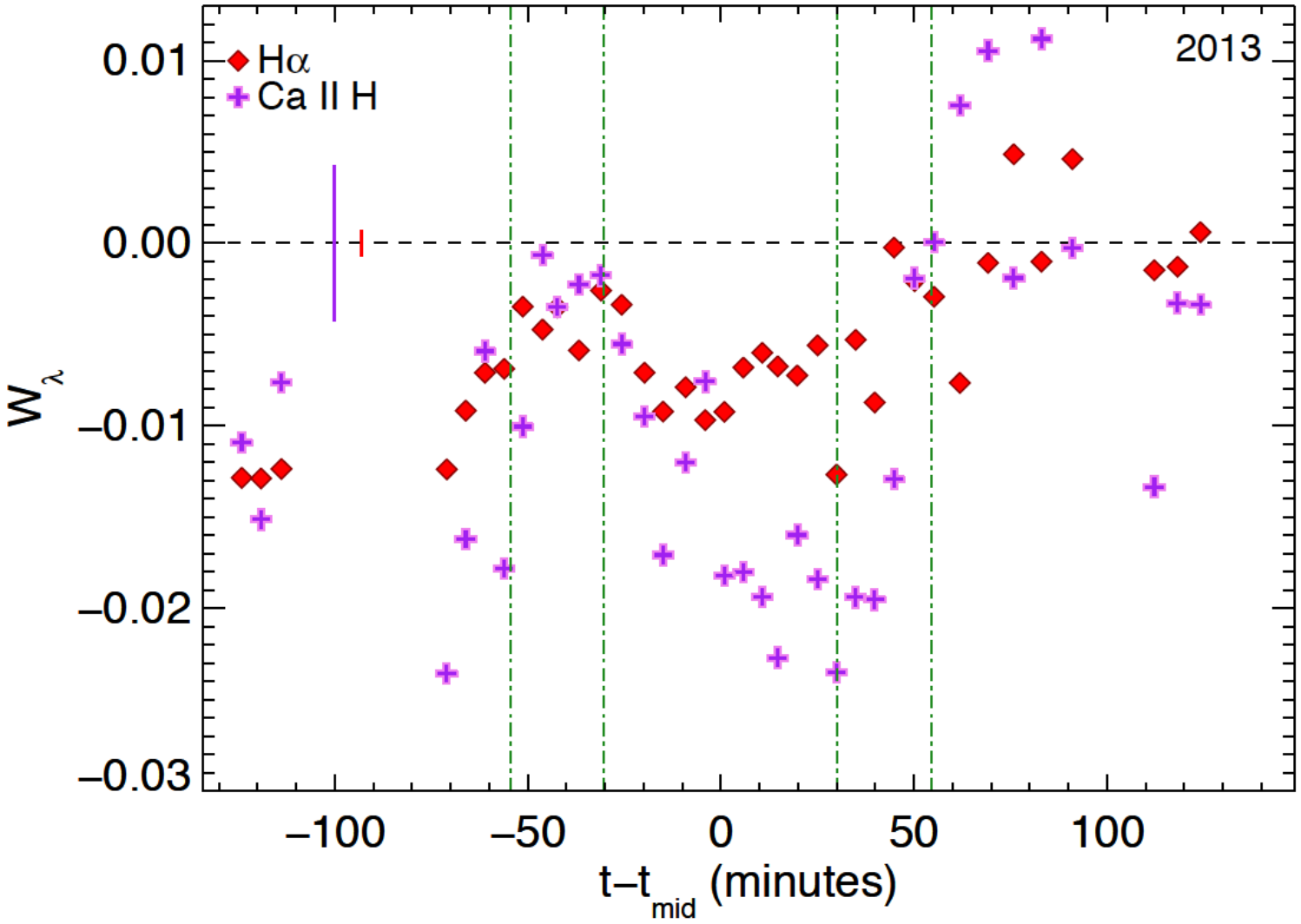


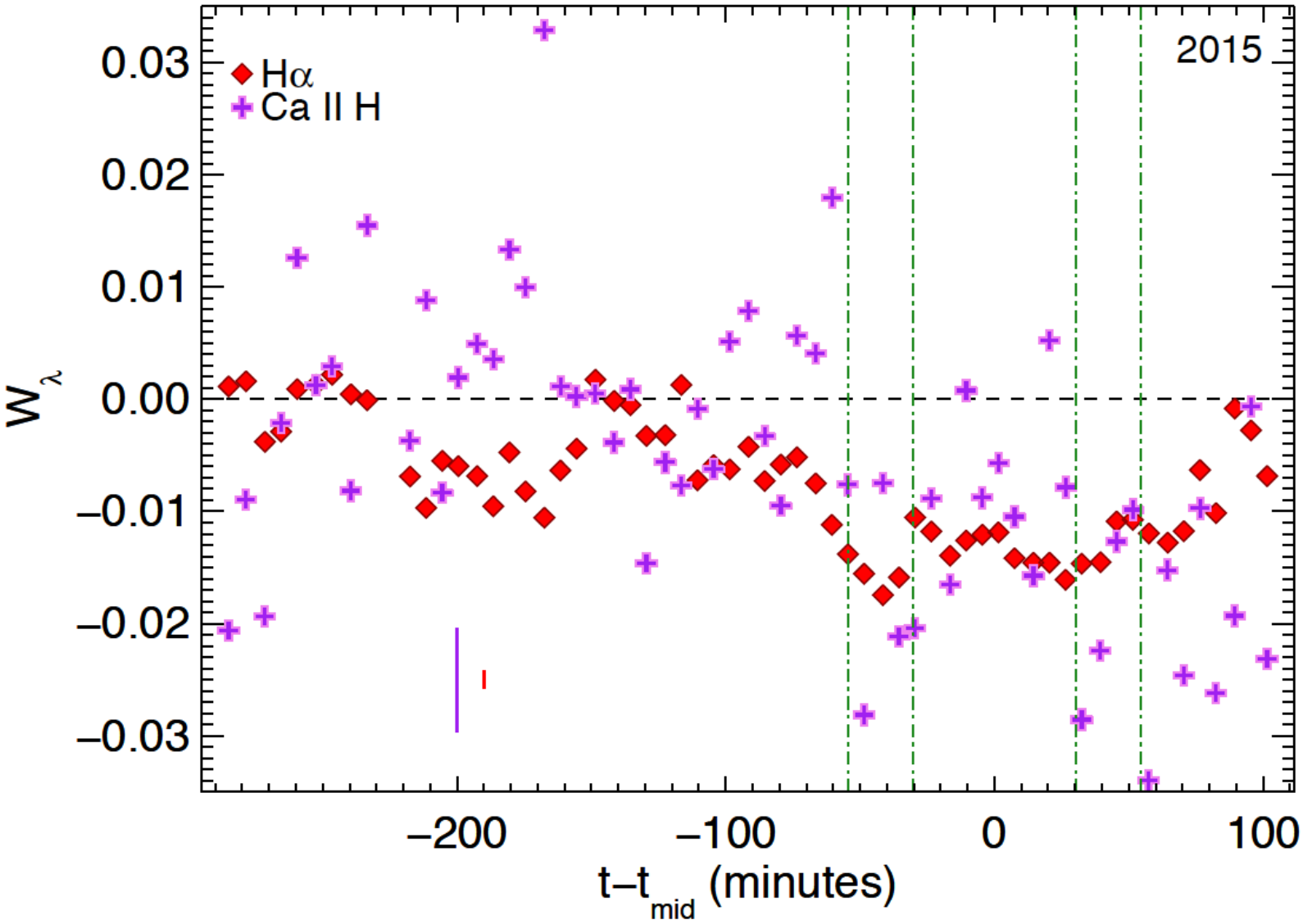

t I
t II
t III
t IV
I
II
III
0.005
0.000
−0.005
−0.010
−0.015
−0.020
−Wλ
Hα
Hβ
Hγ
−300
−200
−100
0
100
t−t mid (minutes)

Alternatives to pre-transit material?

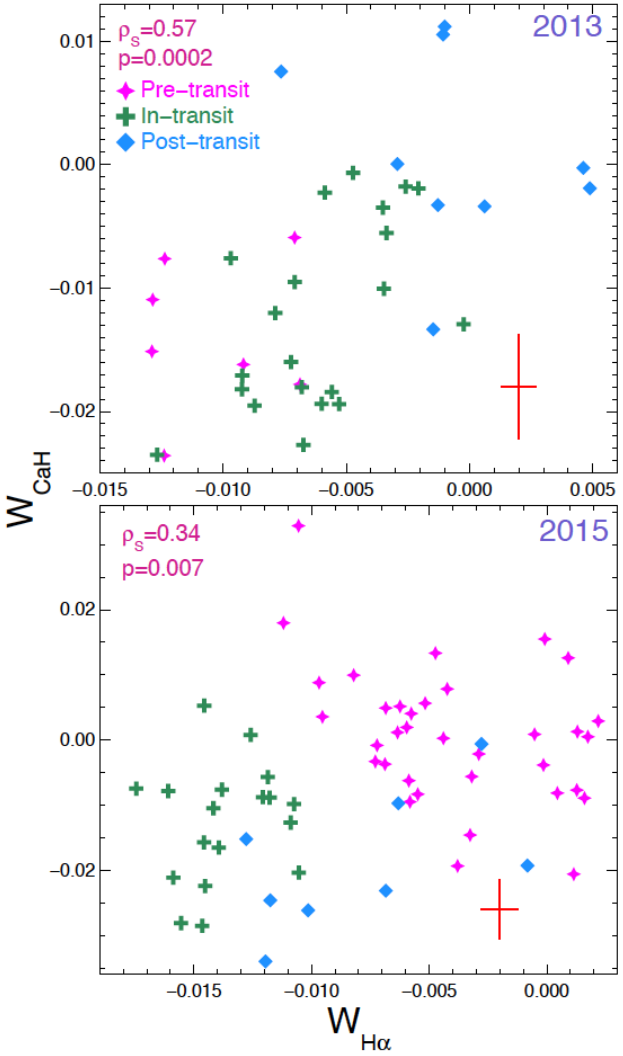
Yes! Varying levels of activity in the Balmer lines.

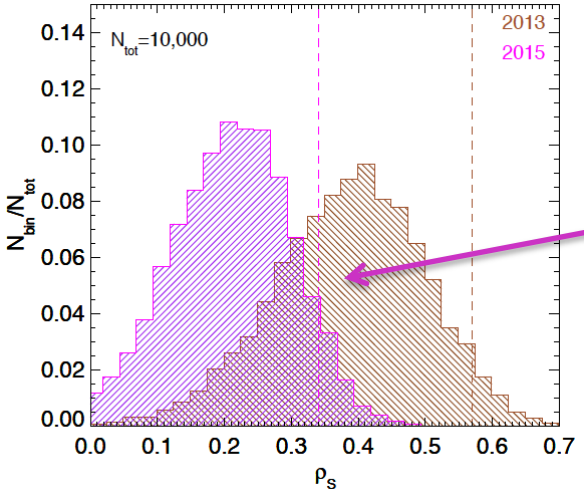
Stellar variability



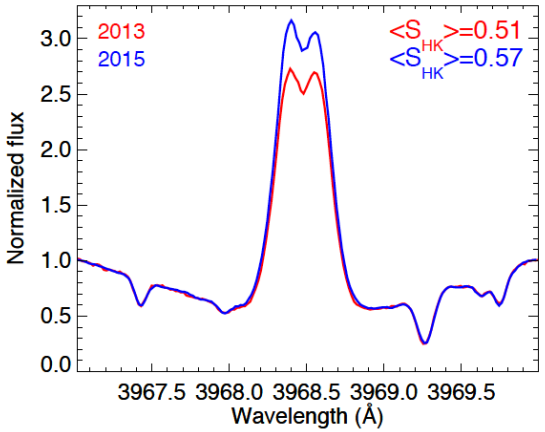

Hα
Ca II H
2015
0.03
0.02
0.01
0.00
–0.01
–0.02
–0.03
W_λ
–200
–100
0
100
$t–t_{mid}$ (minutes)

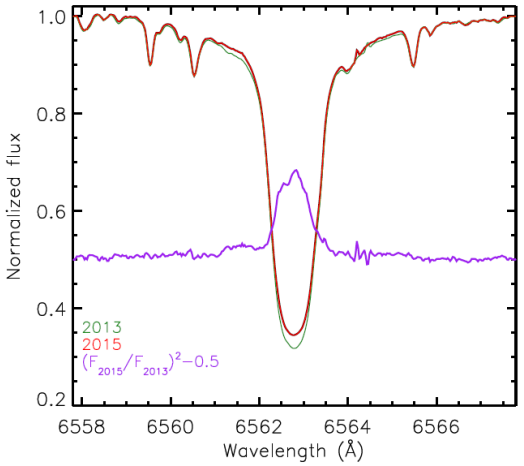
Stellar variability



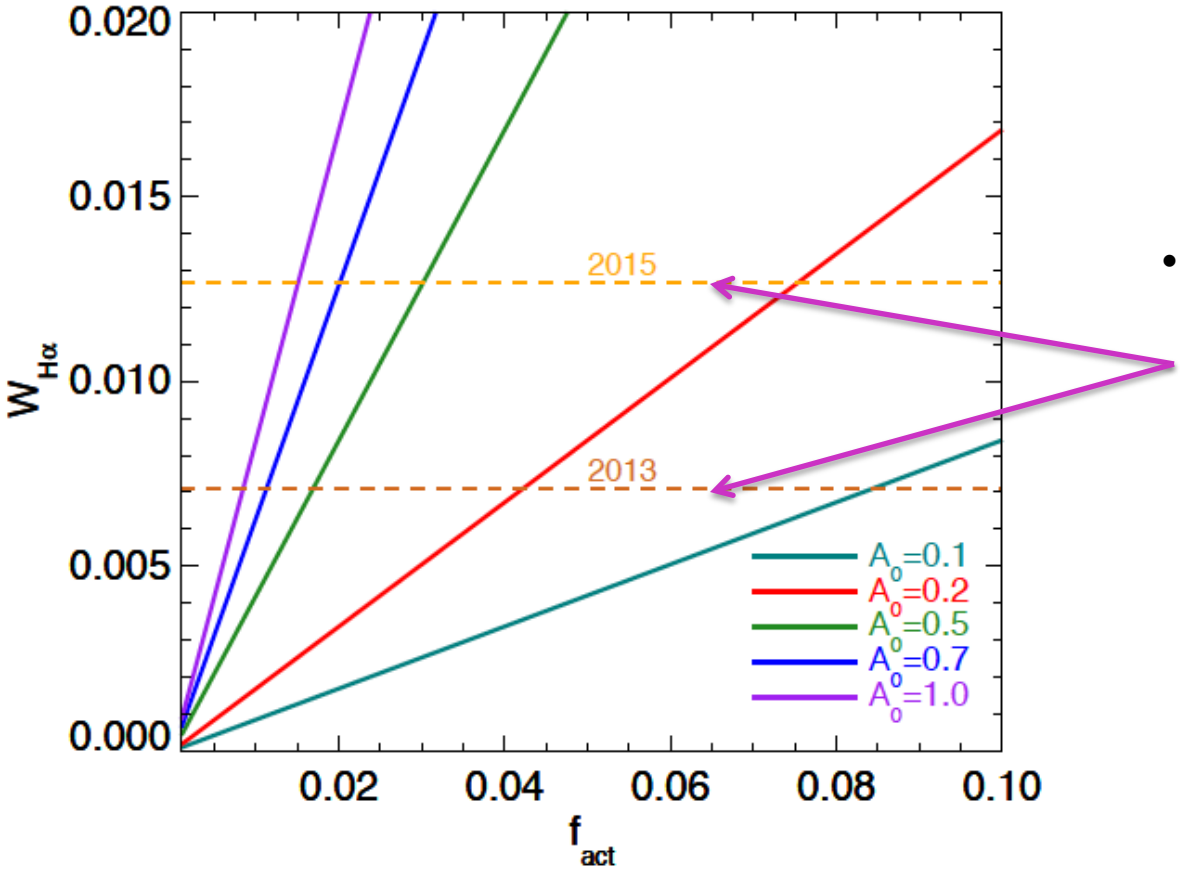


- Correlations are fairly weak, no strong relationships





Stellar activity contamination



- Levels of pre-transit absorption easily reproduced by stellar activity!

- Vary surface coverage of active regions (f_{act}) and strength of active region emission (A_0)

Conclusions

- New data probably not consistent with model from previous observations
  - More transits
- Pre-transit signal is consistently detected but variable
  - Variations in stellar wind? Need to explore other physical scenarios
- Atmospheric signal is variable, much stronger in 2015 data
  - Similar to absorption measured by Jensen et al. 2012
- Need to carefully consider stellar variability!

Future work

- Follow-up current detections
  - Variability, true structure of pre-transit material
  - Stellar wind variability?
- Search for pre-transit absorption around new hot planets
  - Hydra WIYN
  - Narrowband Hα filter photometry?
- Use observations to inform models of star-planet interactions