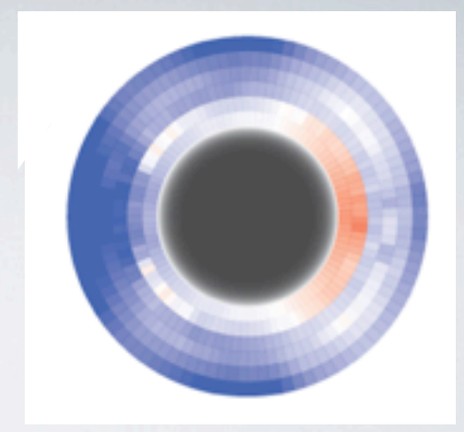
MEASURING WIND SPEEDS IN THE ATMOSPHERES OF HOT JUPITERS

Eliza Kempton[1] (formerly: Miller-Ricci)
&
Emily Rauscher[2]

arXiv: 1109.2270



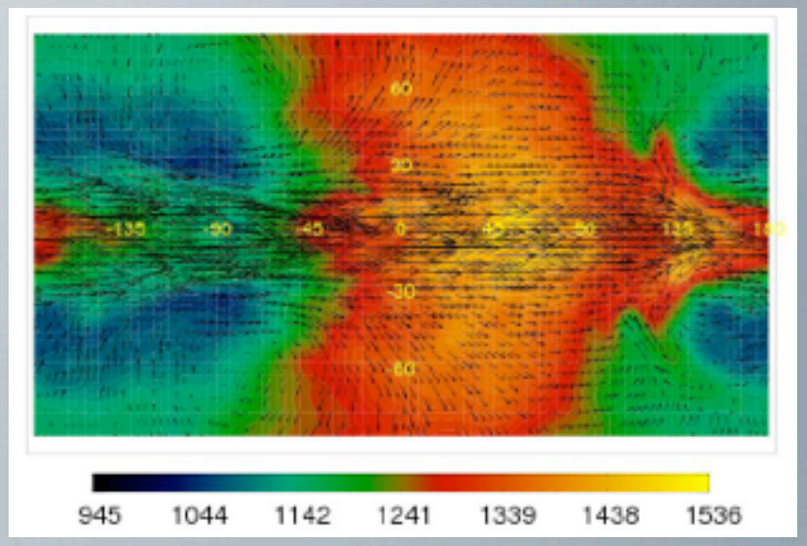
1: Sagan Fellow, U.C. Santa Cruz, 2: Sagan Fellow, University of Arizona / LPL

3 Predictions of 3-D Amospheric Dynamics Models for Hot Jupiters:

1. Equatorial jet at pressures of ~1 bar moving in the direction of the planet's rotation

2. Hot spot on planet is shifted away from the substellar point in the direction of the planet's rotation

3. Day-to-night winds at pressures of ~1 mbar



Rauscher & Menou., *ApJ,* 2010

e.g. Cho, Dobbs-Dixon, Heng, Menou, Rauscher, Showman, Thrastarson

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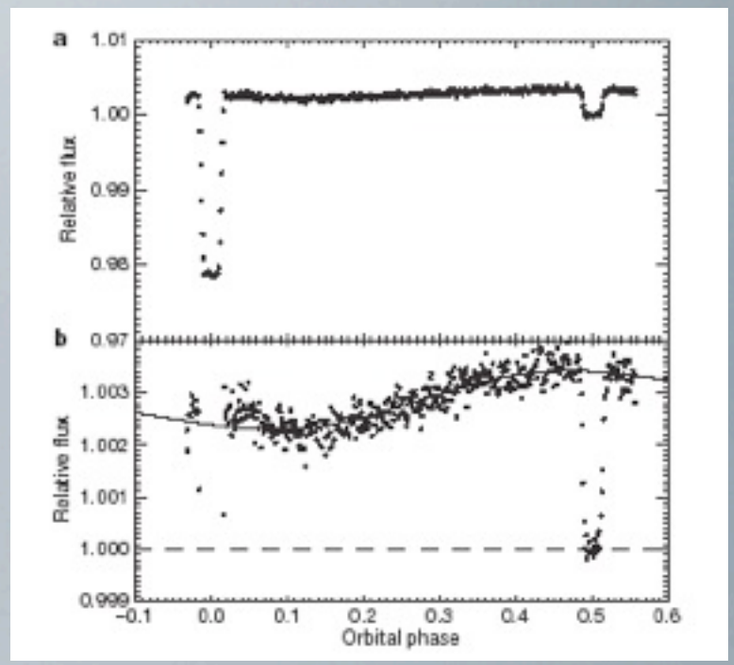

Knutson et al., *Nature,* 2007

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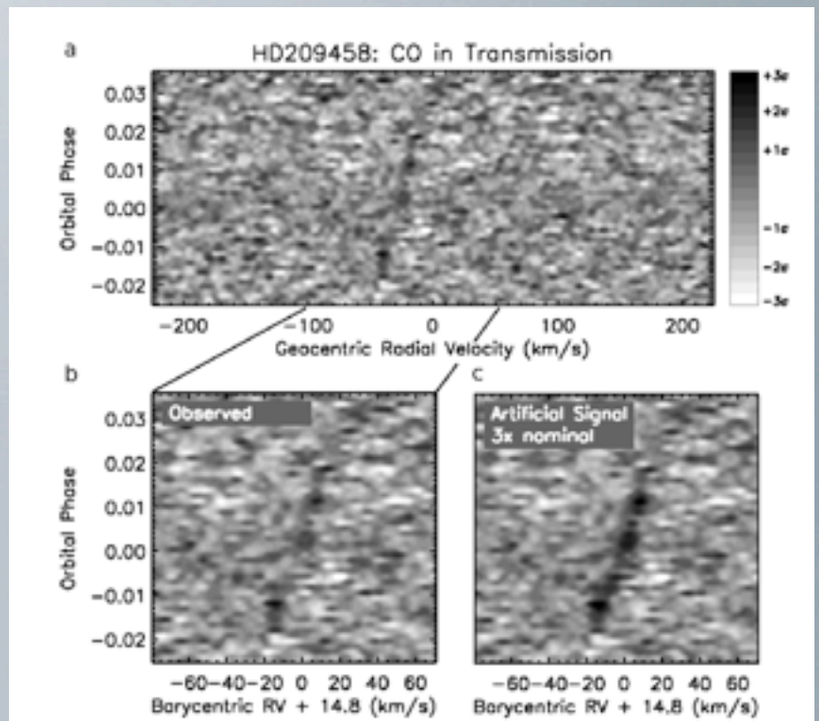

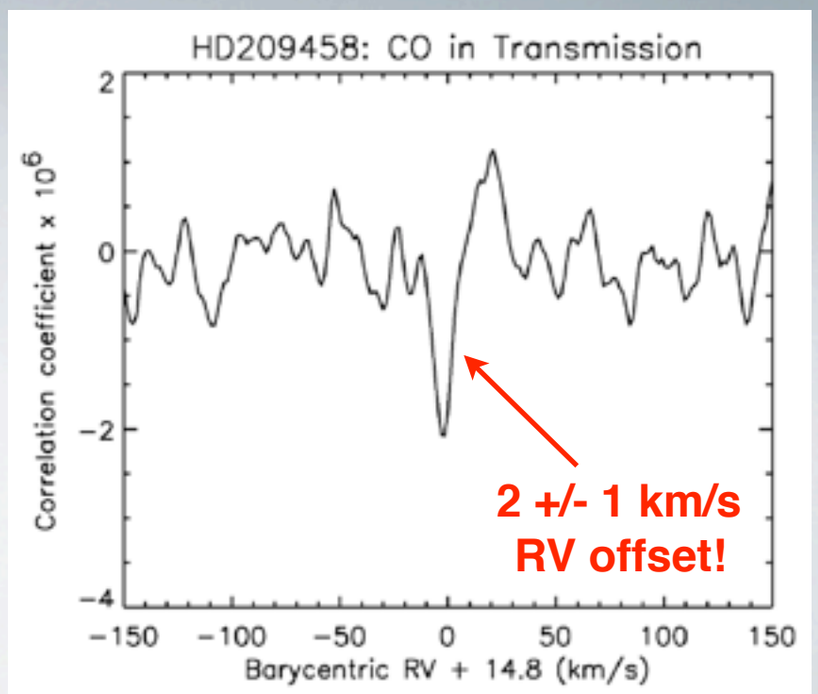

Snellen et al., *Nature,* 2010

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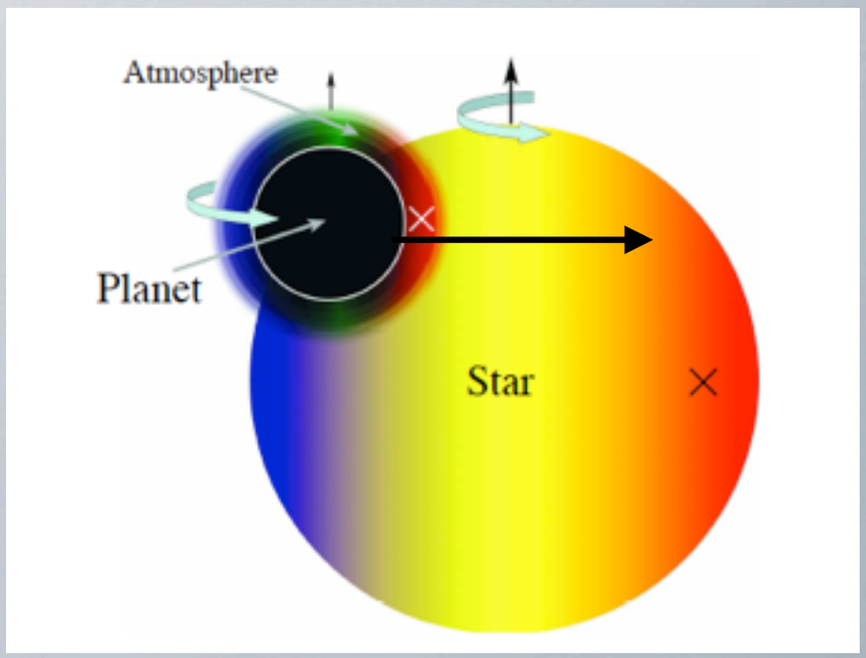
Causes for Doppler Shifts in Exoplanet Transmission Spectra:

1. Orbital Motion
2. Winds
3. Rotation



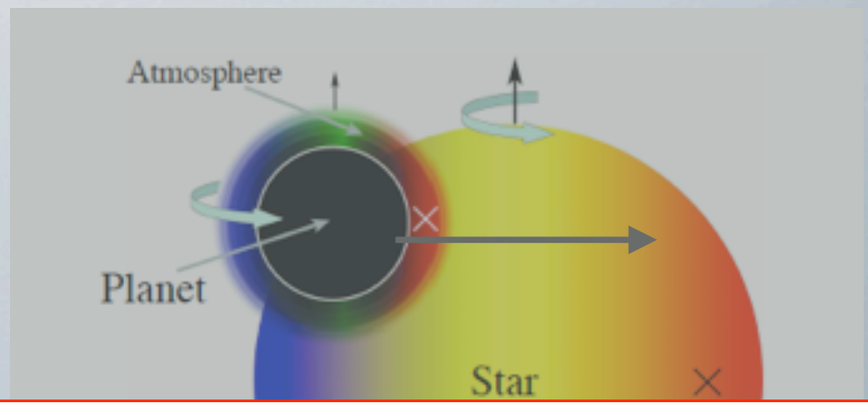
Spiegel et al., *ApJ,* 2007

Also, stellar Doppler shifts from:

- Radial velocity induced by orbiting planet
  &
- Rossiter-McLaughlin effect

Causes for Doppler Shifts in Exoplanet Transmission Spectra:

1. Orbital Motion
2. Winds



Coupled 3-D atmospheric circulation model

(Rauscher & Menou 2010, Perna et al. 2010)

+ transmission spectroscopy radiative transfer

(Miller-Ricci (Kempton) et al. 2009, Miller-Ricci & Fortney 2010)

→ Self-consistent treatment of 3-D T-P and wind structures in transmission spectra

- Radial velocity induced by orbiting planet

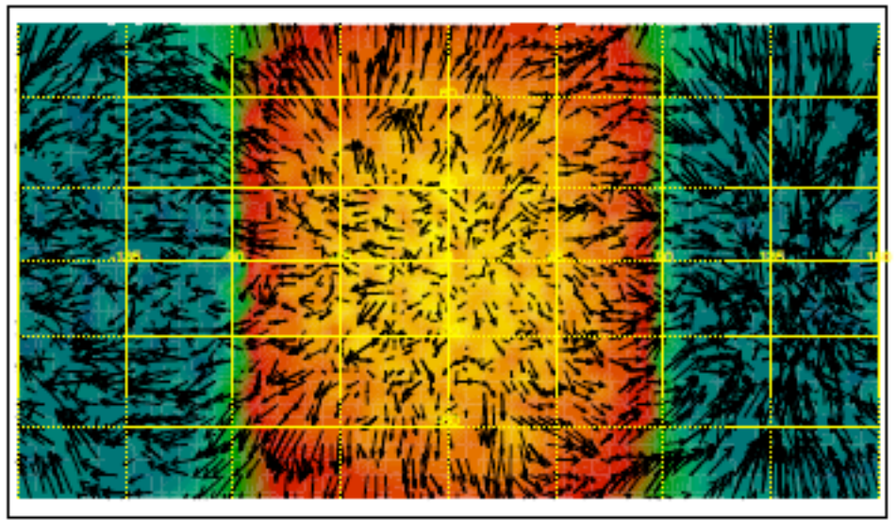
&

- Rossiter-McLaughlin effect

What Role Does Magnetic Drag Play?

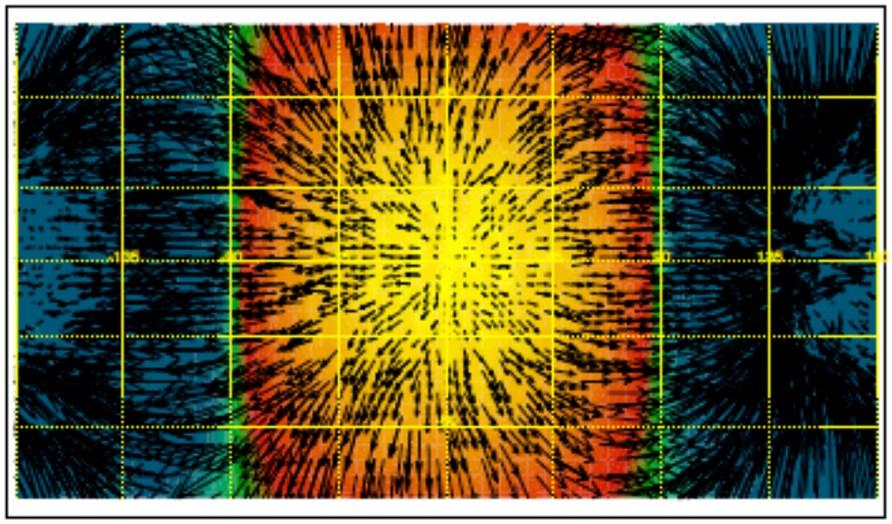
60 **u**bar:

Drag-Free



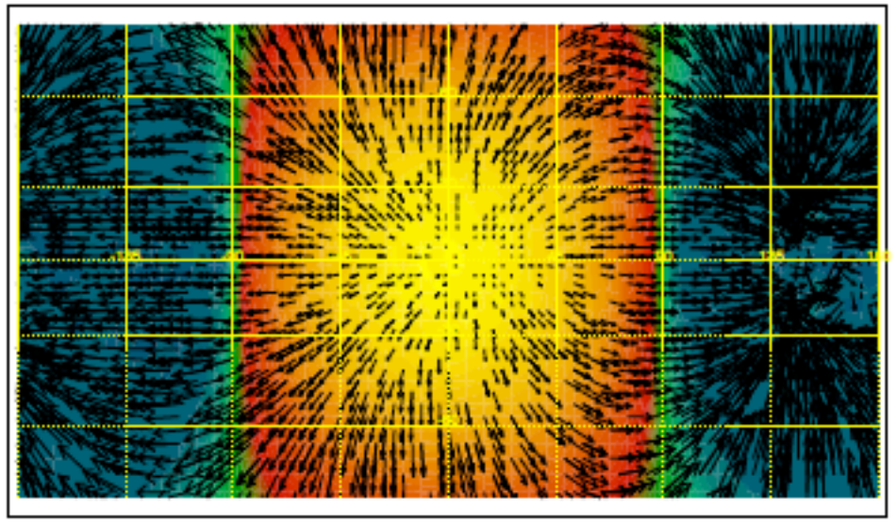
272 471 671 870 1070 1269 1469

Magnetic Drag (a)



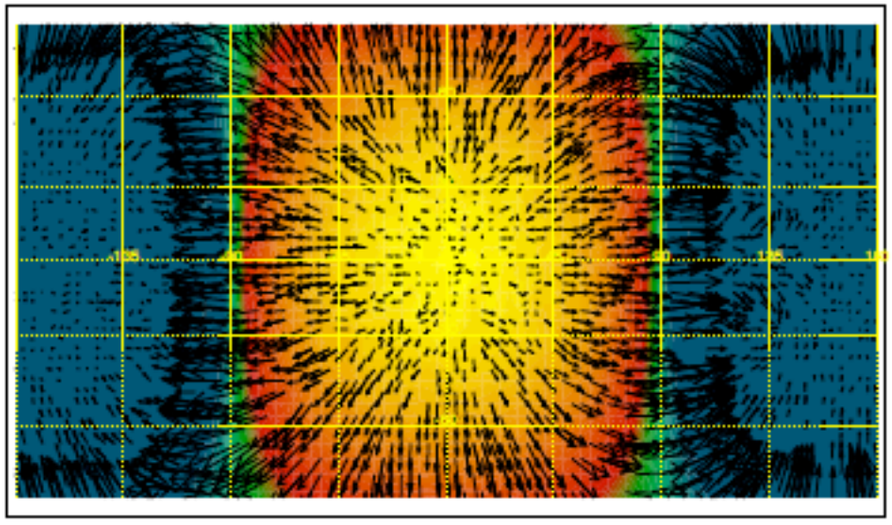
334 505 676 847 1017 1188 1359

Drag-Free + Hyperdissipation



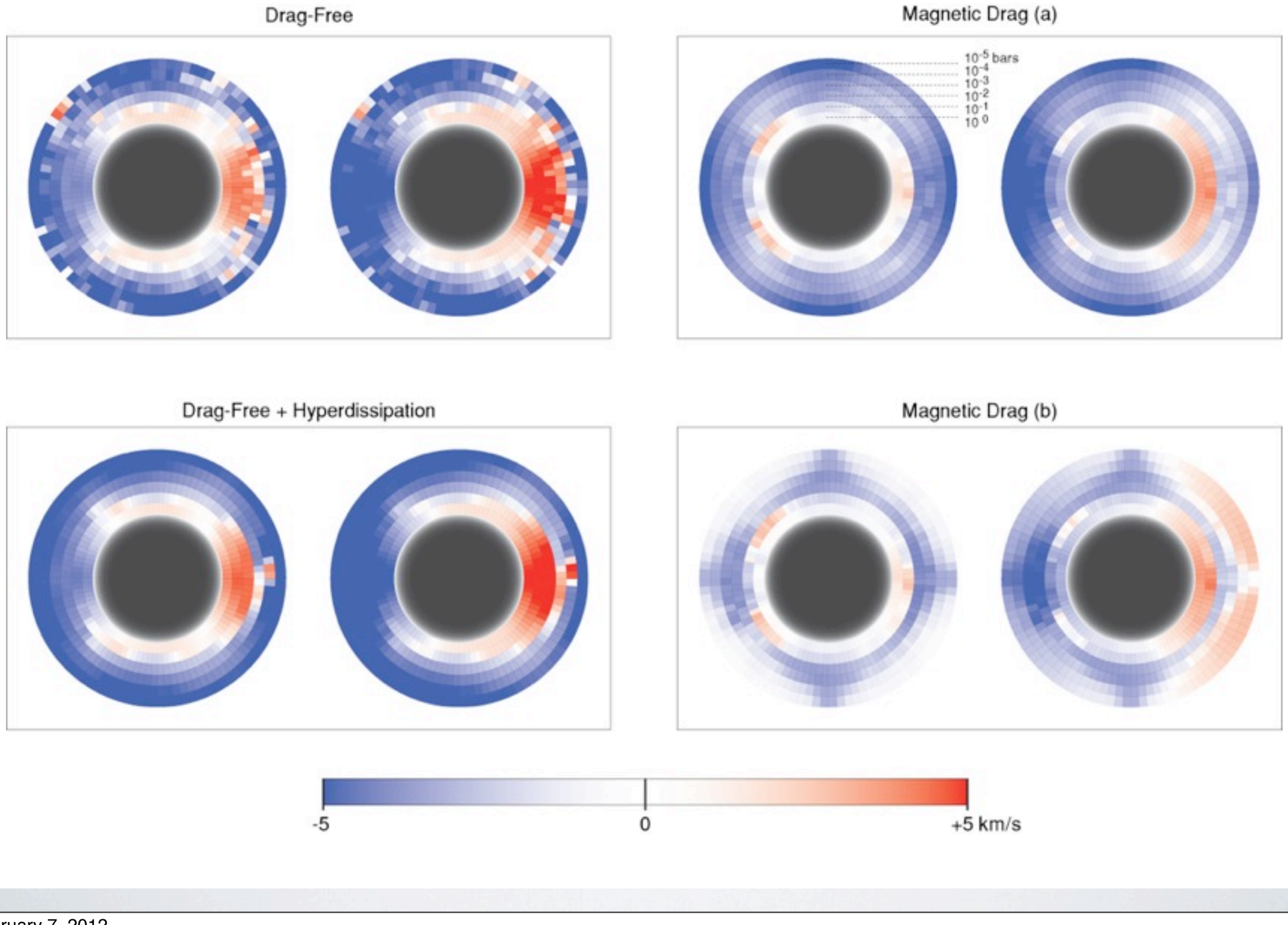
326 495 665 835 1004 1174 1344

Magnetic Drag (b)

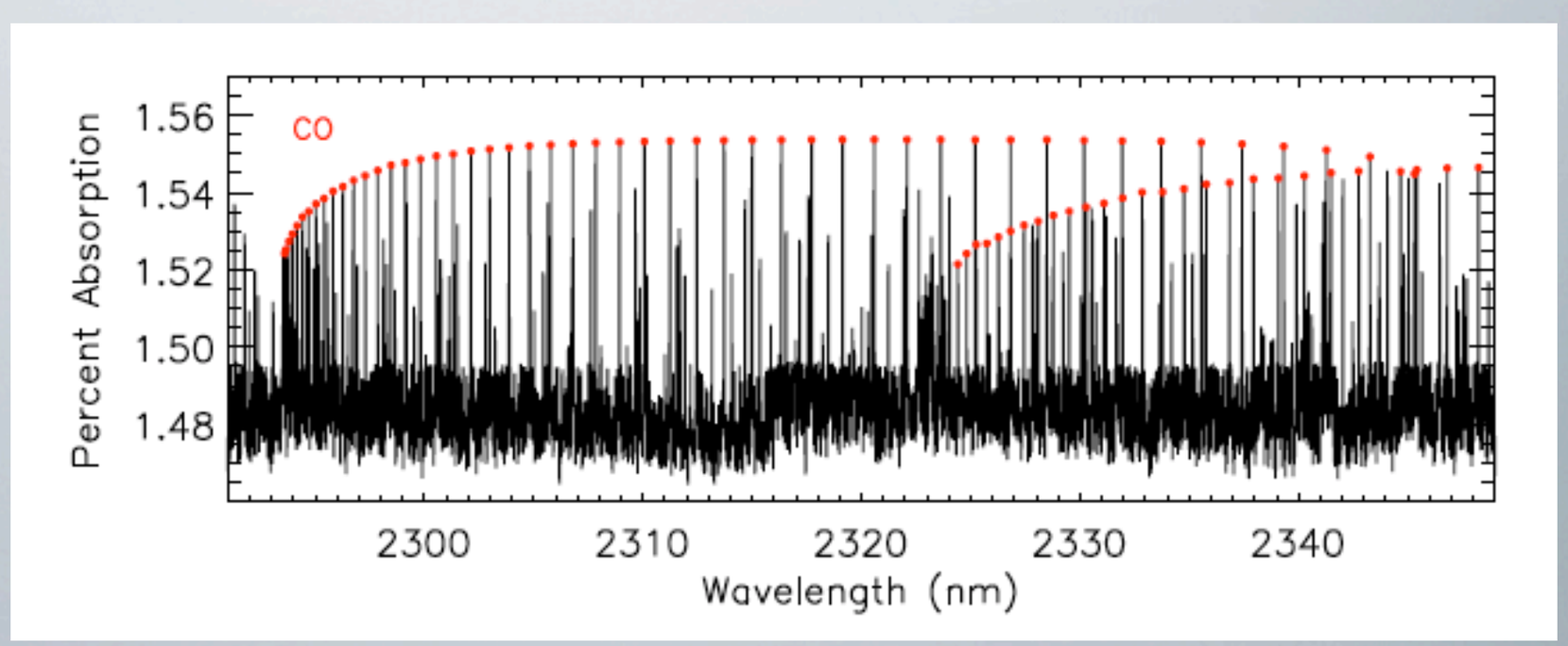


339 510 680 851 1022 1193 1363

What Role Does Magnetic Drag Play?



Unshifted Transmission Spectrum:



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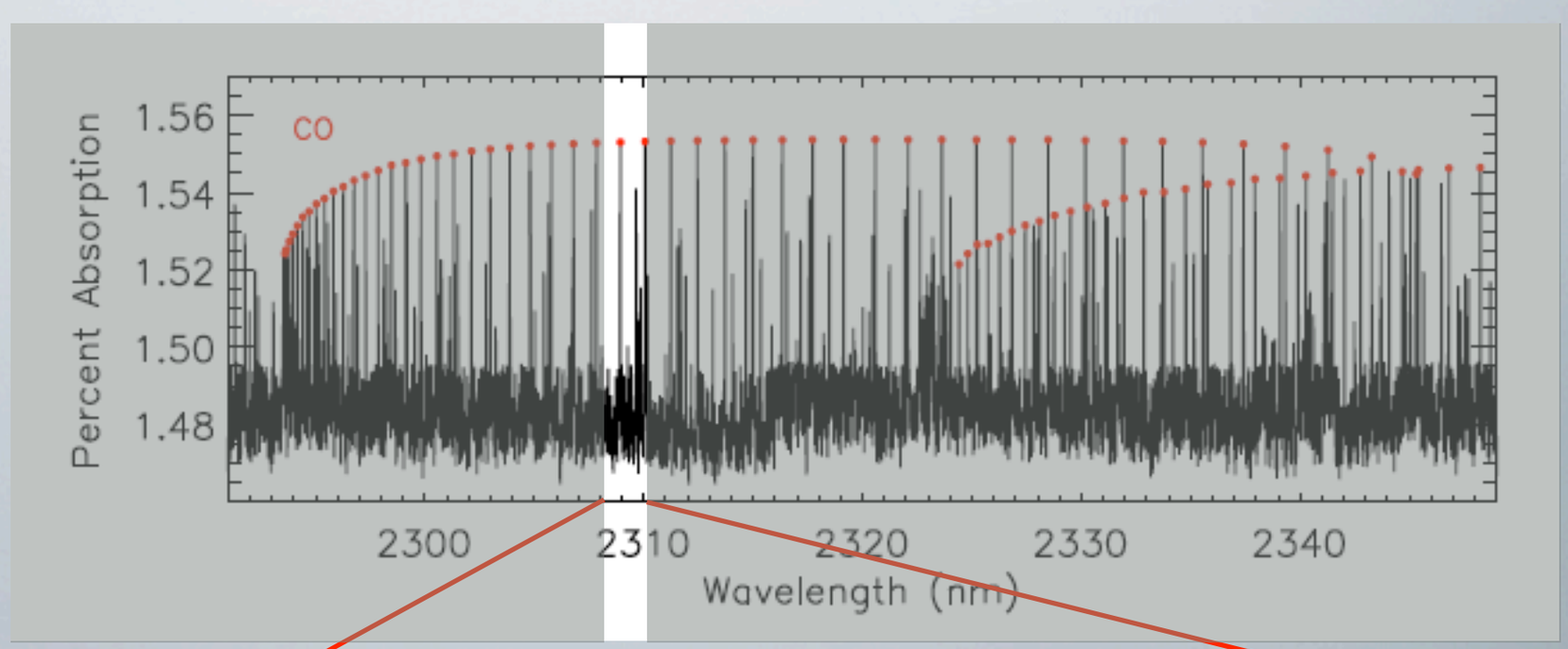
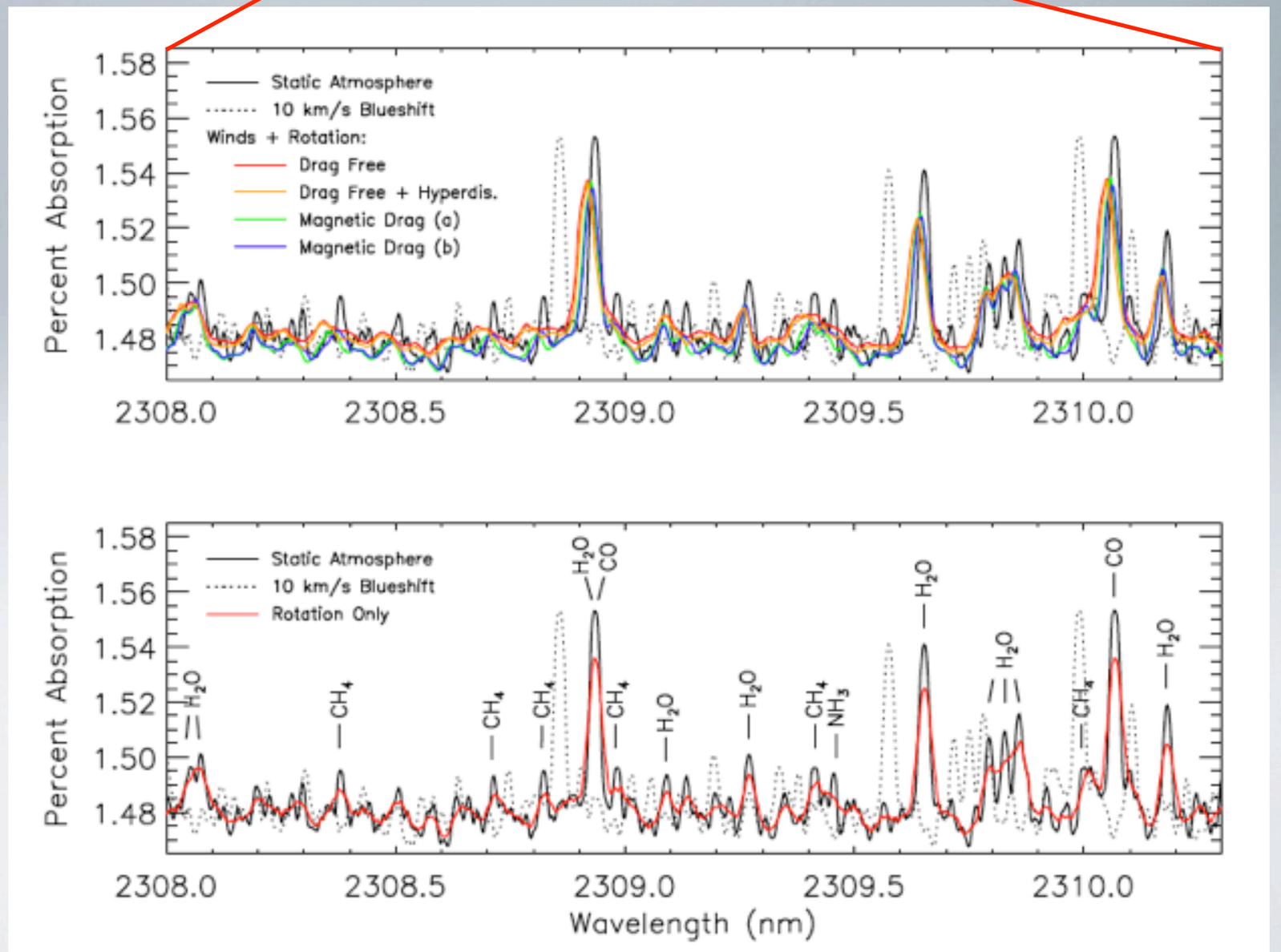


Doppler-Shifted Transmission Spectrum:

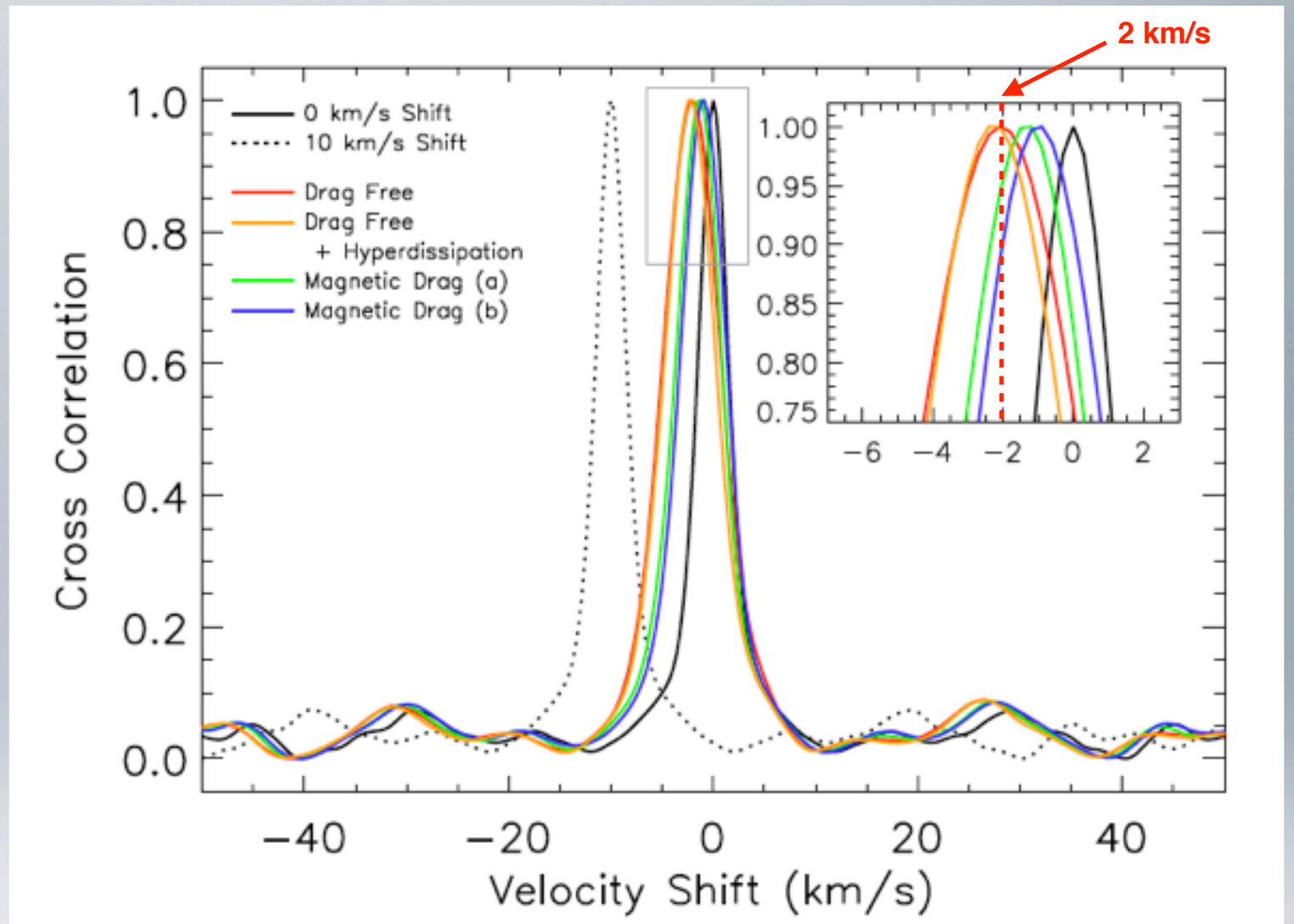


Miller-Ricci Kempton & Rauscher, *ApJ*, submitted

Cross-Correlation Functions for Doppler-Shifted Spectra:

- Drag-free models
  → 2 km/s blueshifts
- Magnetic drag models
  → 1 km/s blueshifts
- All models consistent

w/ Snellen et al. 2 km/s blueshift for HD 209458b



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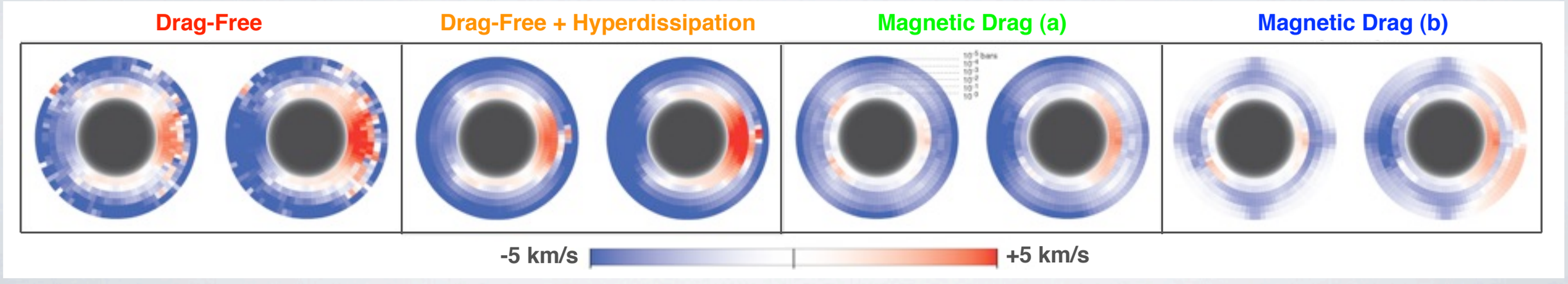
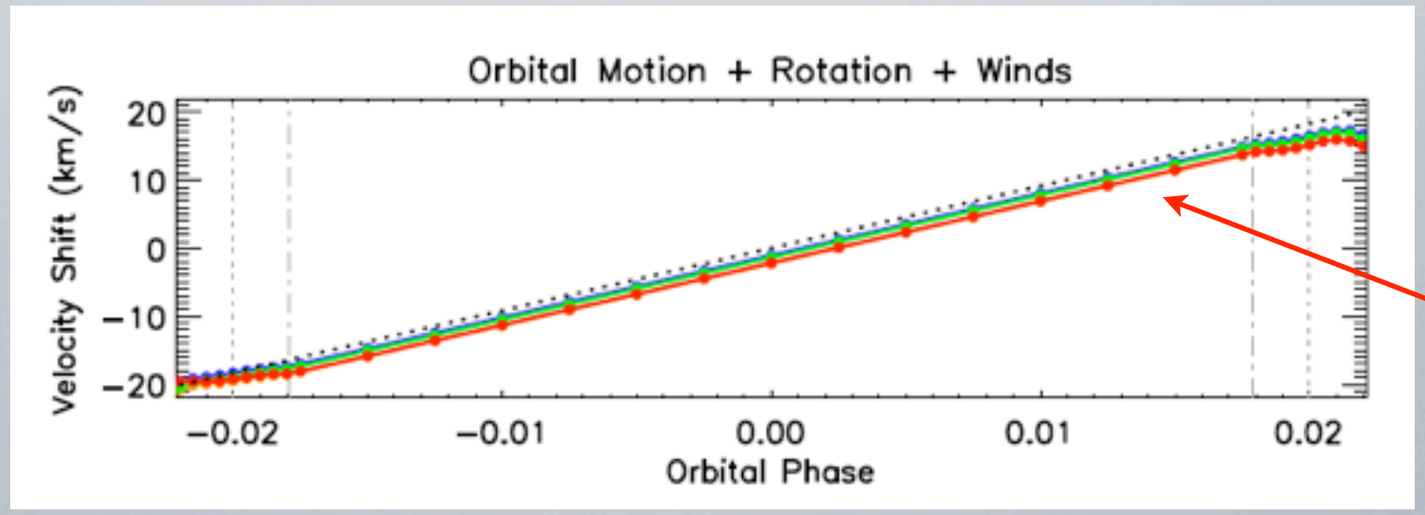
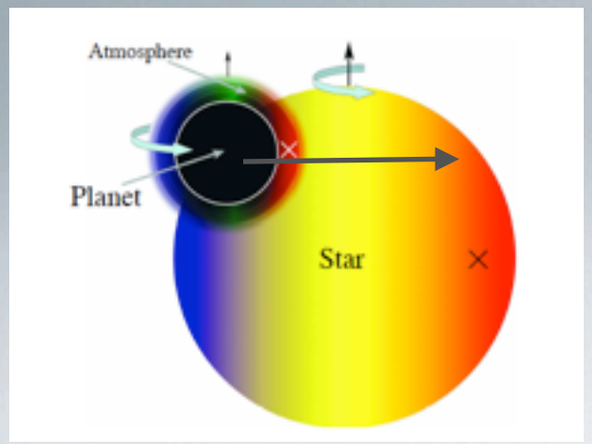


Doppler Shifts vs. Orbital Phase:

- Drag-Free
- Drag-Free + Hyperdissipation
- Magnetic Drag (a)
- Magnetic Drag (b)



146 km/s orbital velocity



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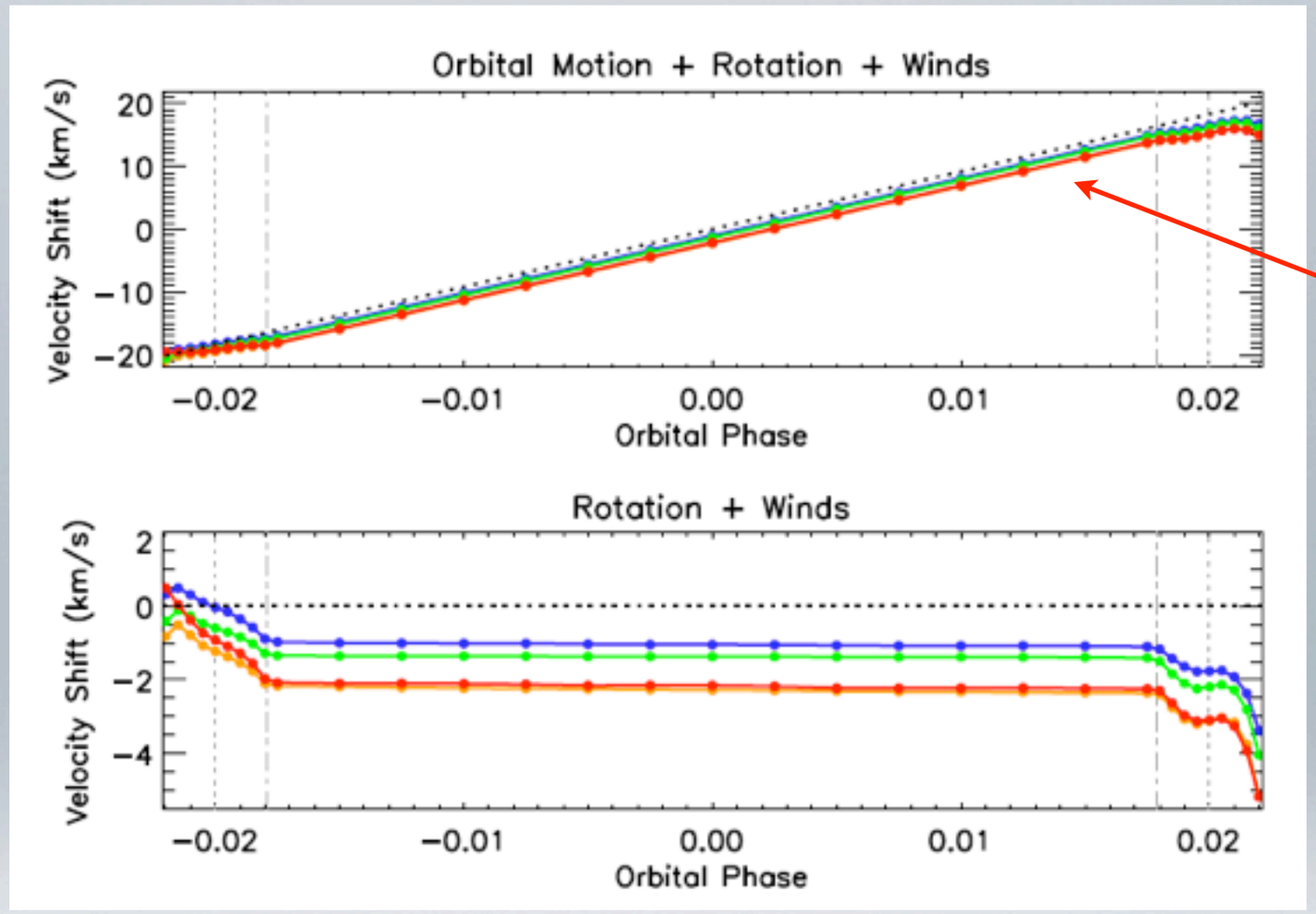

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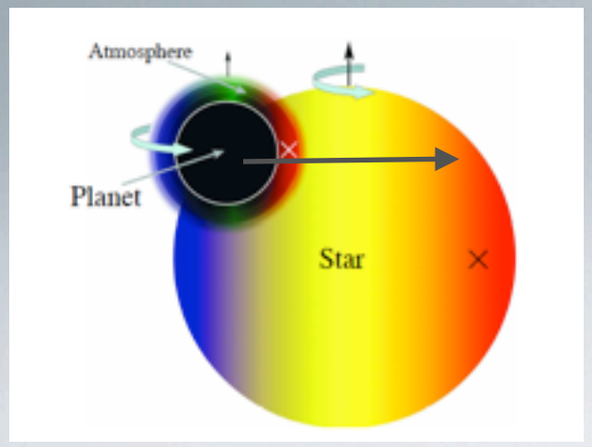

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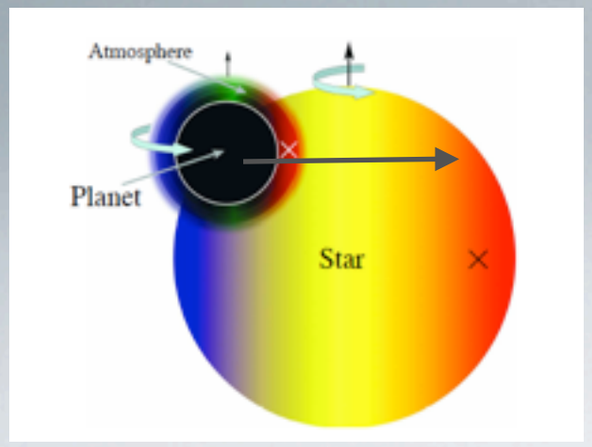

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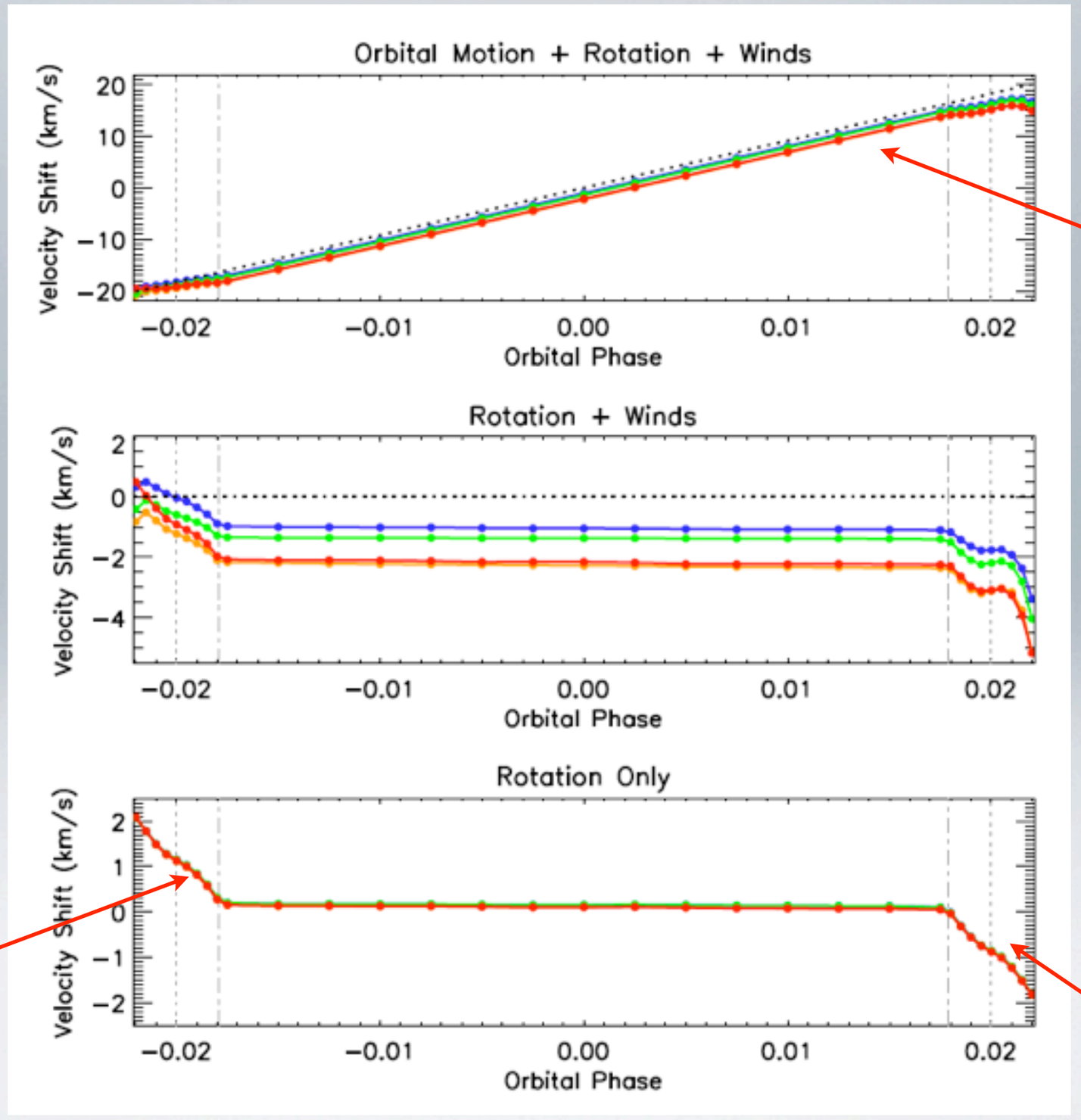


146 km/s orbital velocity

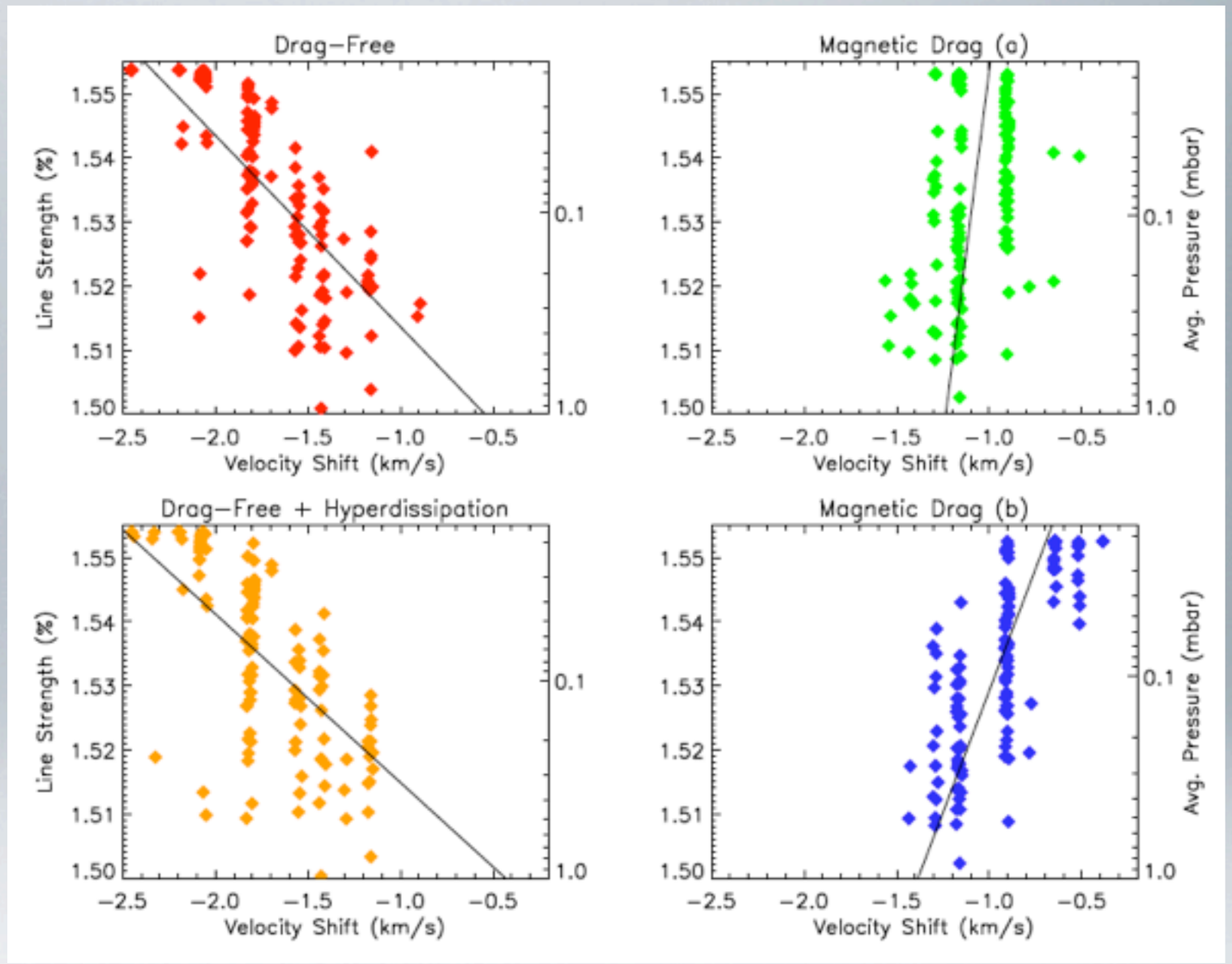
redshifted limb

blueshifted limb

Miller-Ricci Kempton & Rauscher, *ApJ,* submitted

Doppler Shifts for Individual Spectral Lines:

- Stronger lines originate higher in the atmosphere
- Weaker lines originate lower (deeper) in the atmosphere
- Slope in line strength vs. velocity shift → vertical wind shear



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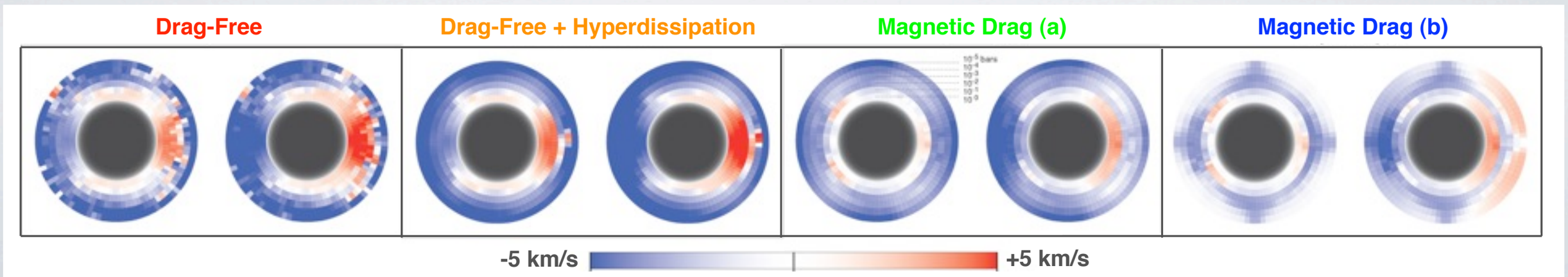
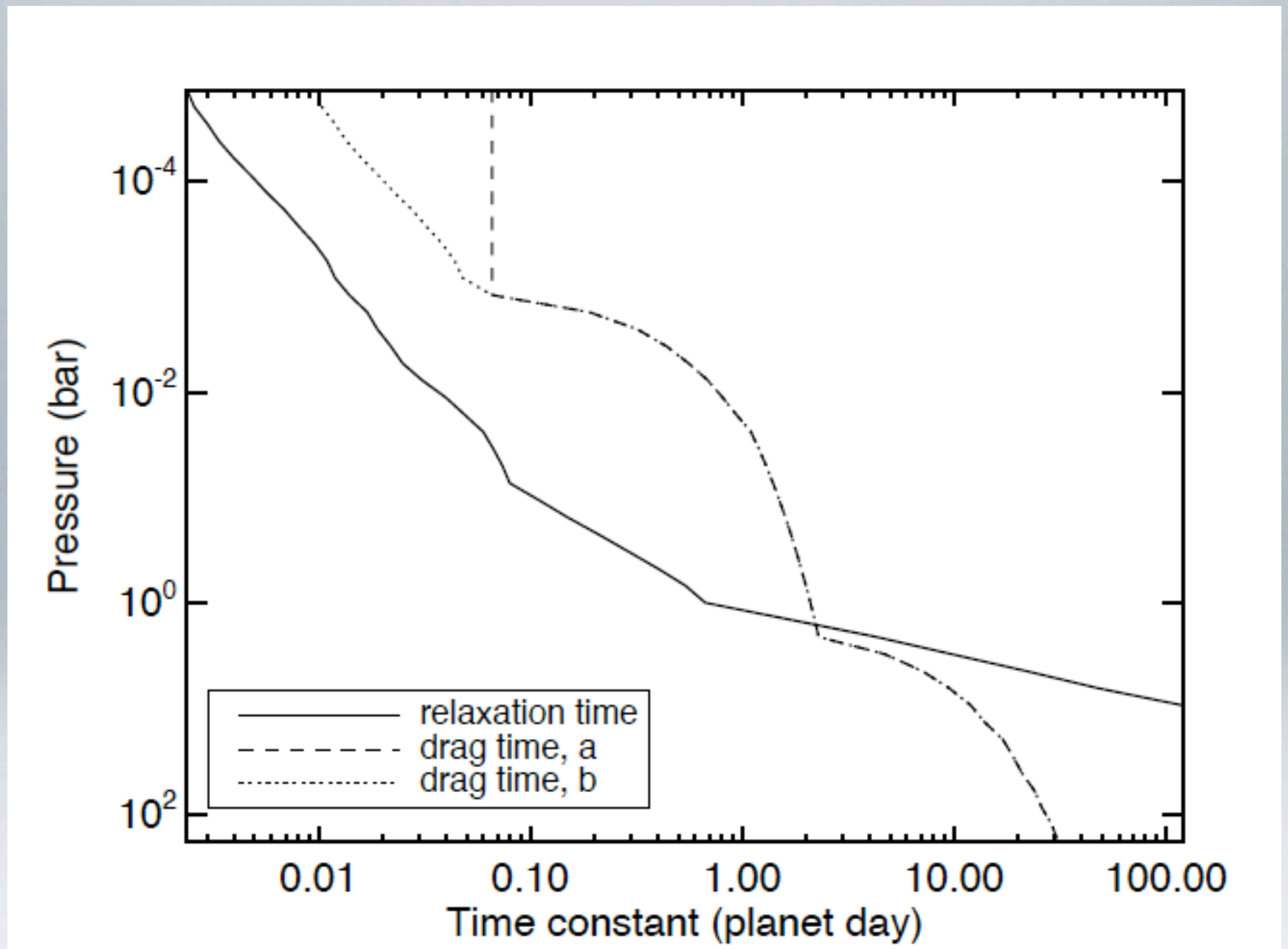


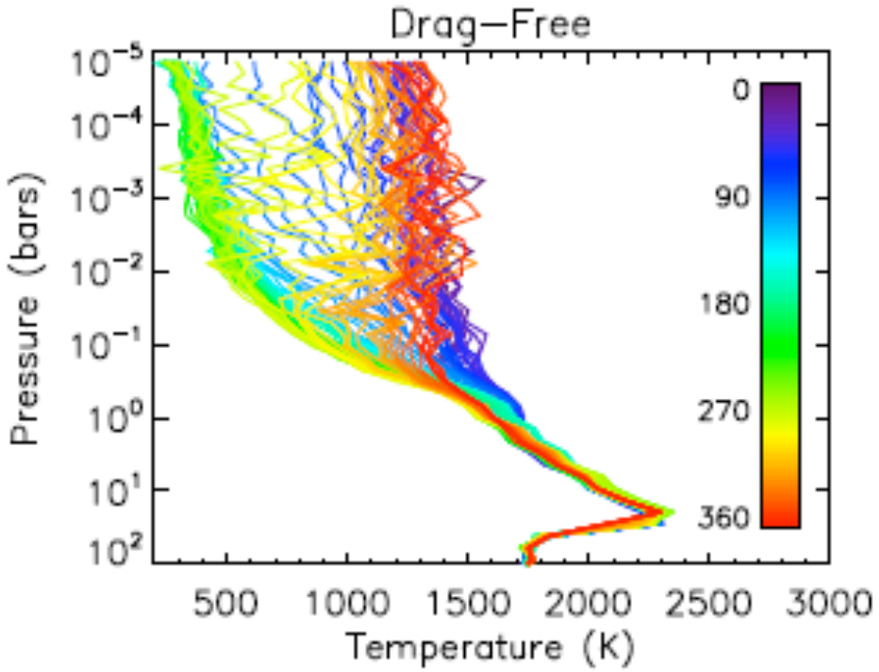
Implications:

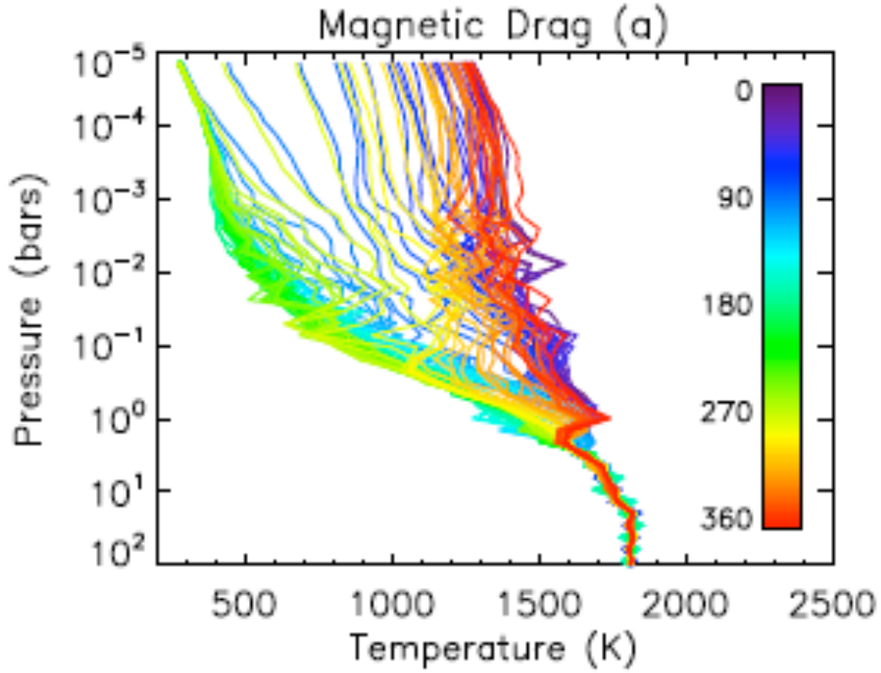
- Measuring wind speeds in hot Jupiter atmospheres via Doppler shifted transmission spectra helps to constrain atmospheric circulation patterns in a fundamentally new regime

- Day-to-night flow patterns in tidally locked hot Jupiters have important implications for the planets' global energy budgets

- The Snellen et al. observation of a 2 km/s blueshift in the transmission spectrum of HD 209458b is well-reproduced by models both with and without magnetic drag


Pressure (bar)
10^{-4}
10^{-2}
10^{0}
10^{2}
relaxation time
drag time, a
drag time, b
0.01
0.10
1.00
10.00
100.00
Time constant (planet day)


Drag−Free
Pressure (bars)
Temperature (K)
0
90
180
270
360


Magnetic Drag (a)
Pressure (bars)
Temperature (K)
0
90
180
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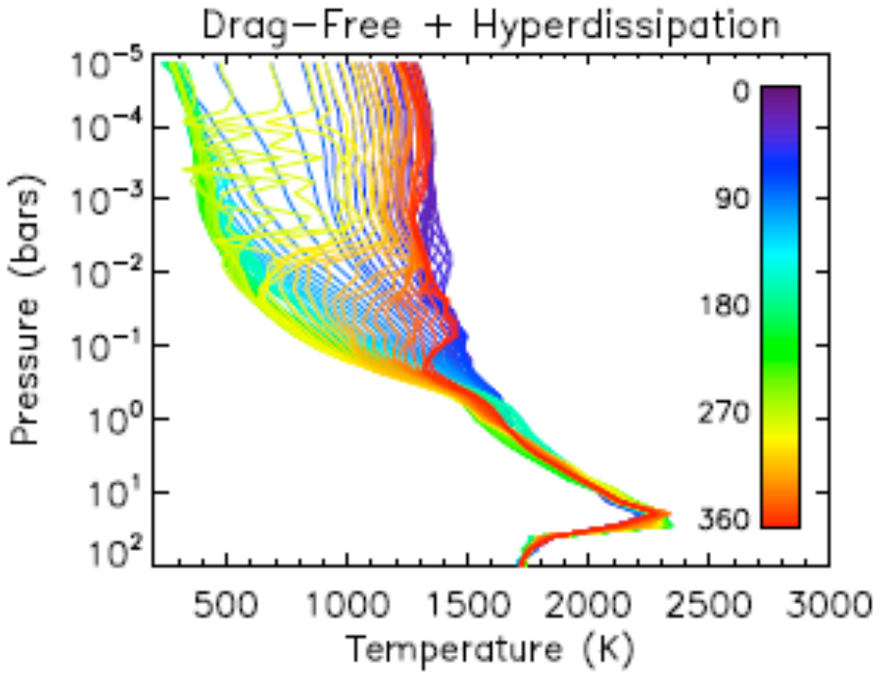
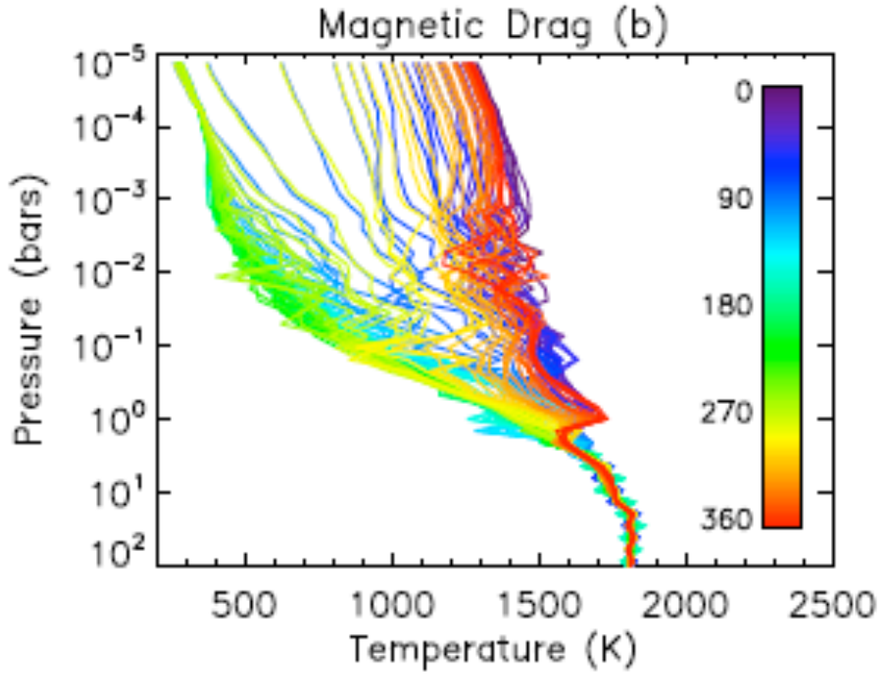
360


Drag−Free + Hyperdissipation
Pressure (bars)
Temperature (K)
0
90
180
270
360


Magnetic Drag (b)
Pressure (bars)
Temperature (K)
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90
180
270
360