The Activity Cycle of HAT-P-11

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University of Washington

with
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The Activity Cycle of HAT-P-11

What would happen to the **solar dynamo** if you took away **20%** of the Sun's mass?

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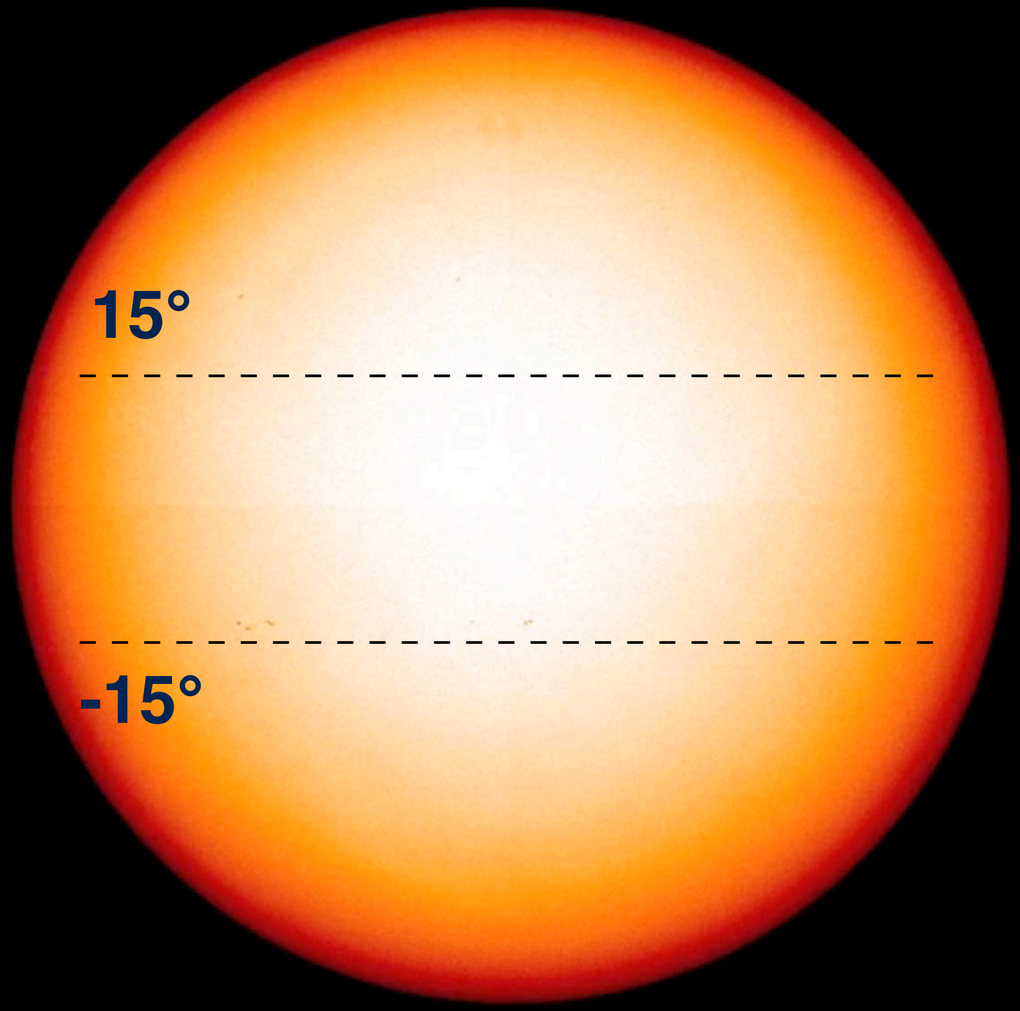
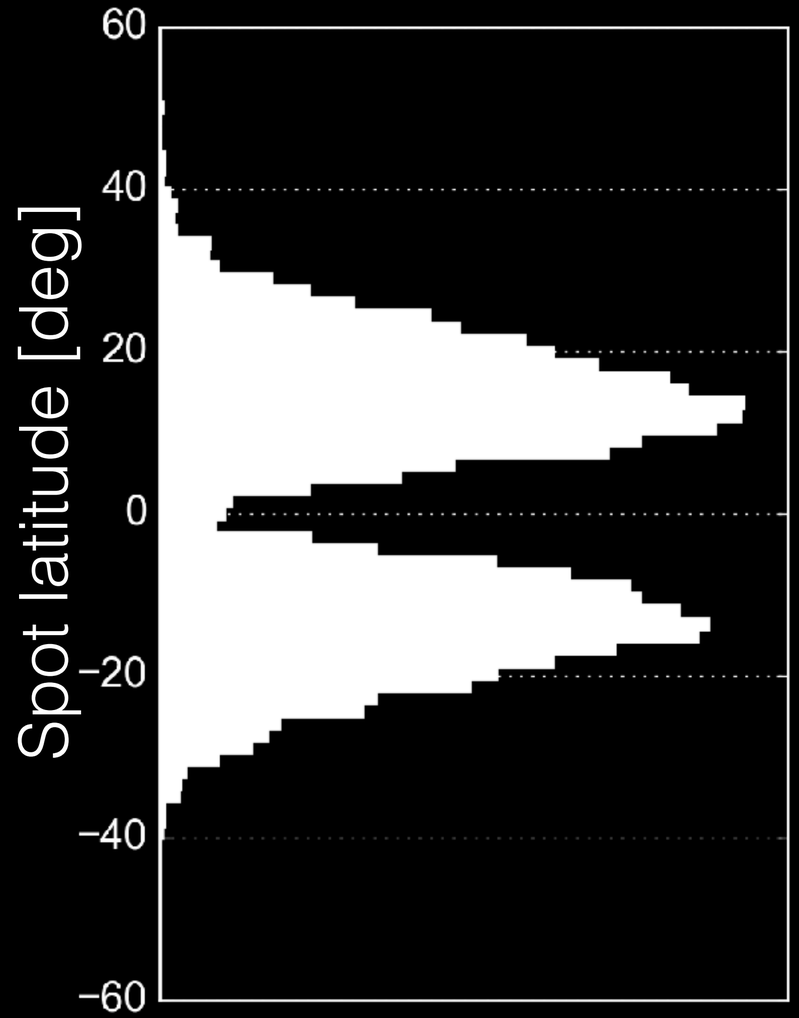
@brettmor

The Activity Cycle of HAT-P-11

1) Intro: brief review of solar cycle
2) Transiting planets for stellar activity
   - Properties and positions of starspots
3) Ground-based additions to Kepler results

Solar Cycle: Active latitudes



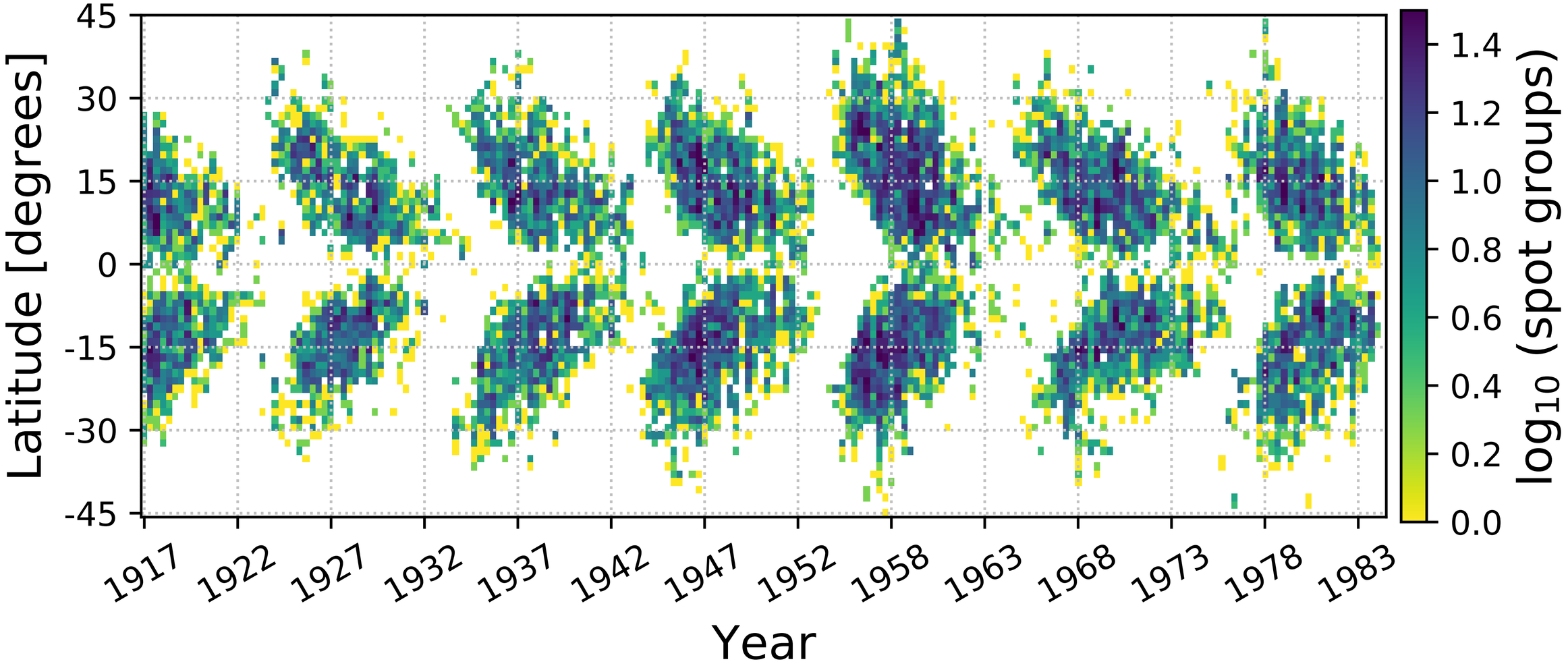


Howard et al. (1984), Morris et al. (2017a)

NASA/SDO

4

Solar Cycle: Active latitudes



Howard et al. (1984), Morris et al. (2017a)

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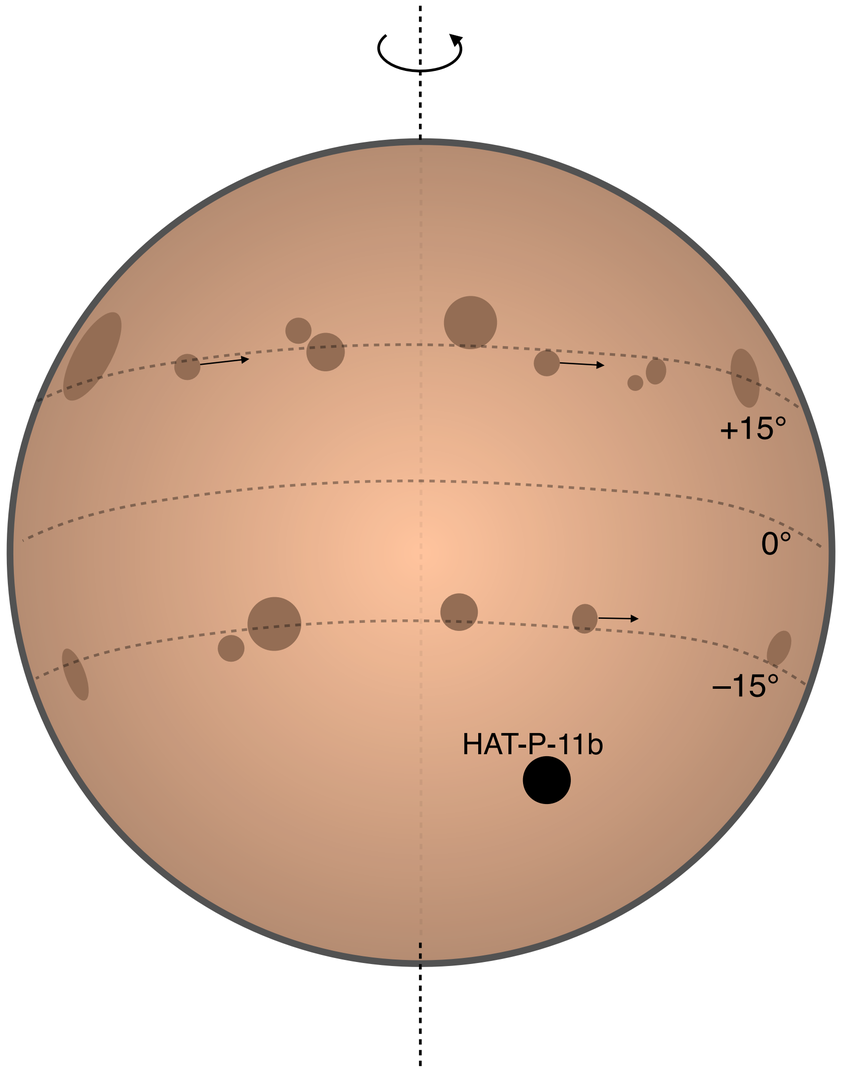
HAT-P-11: a scaled down Sun



- K4V
- $M_\star = 0.8\ M_\odot$
- $P_{rot} = 29$ d (like Sun!)
- Hot Neptune $P_{orb} = 5$ d

Morris et al. 2017a

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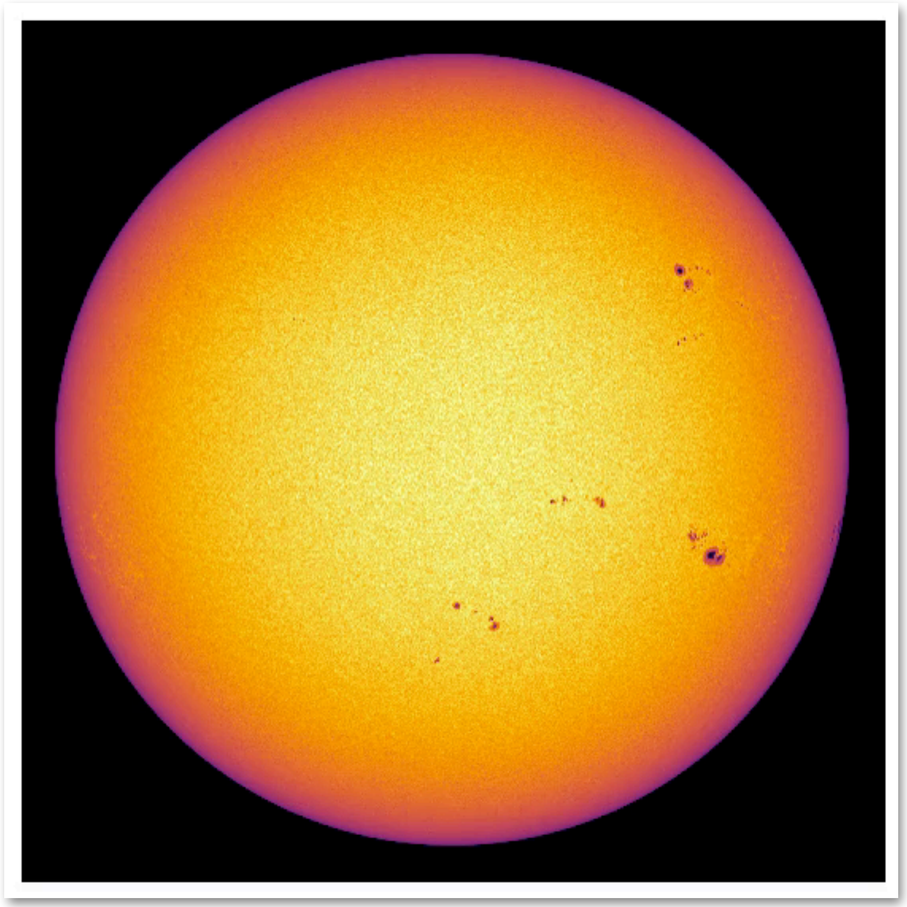
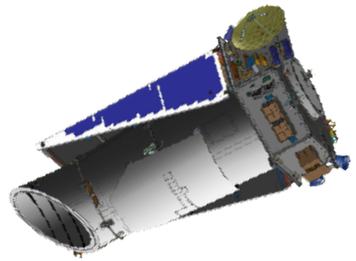
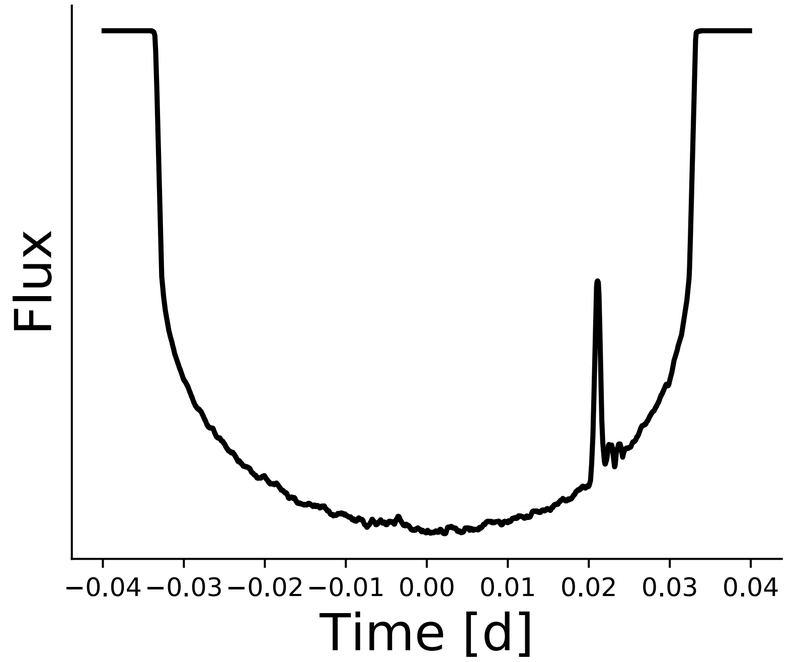
Transiting exoplanets reveal starspots

- Timing encodes spot position
- Amplitude encodes spot contrast



NASA/SDO/HMI





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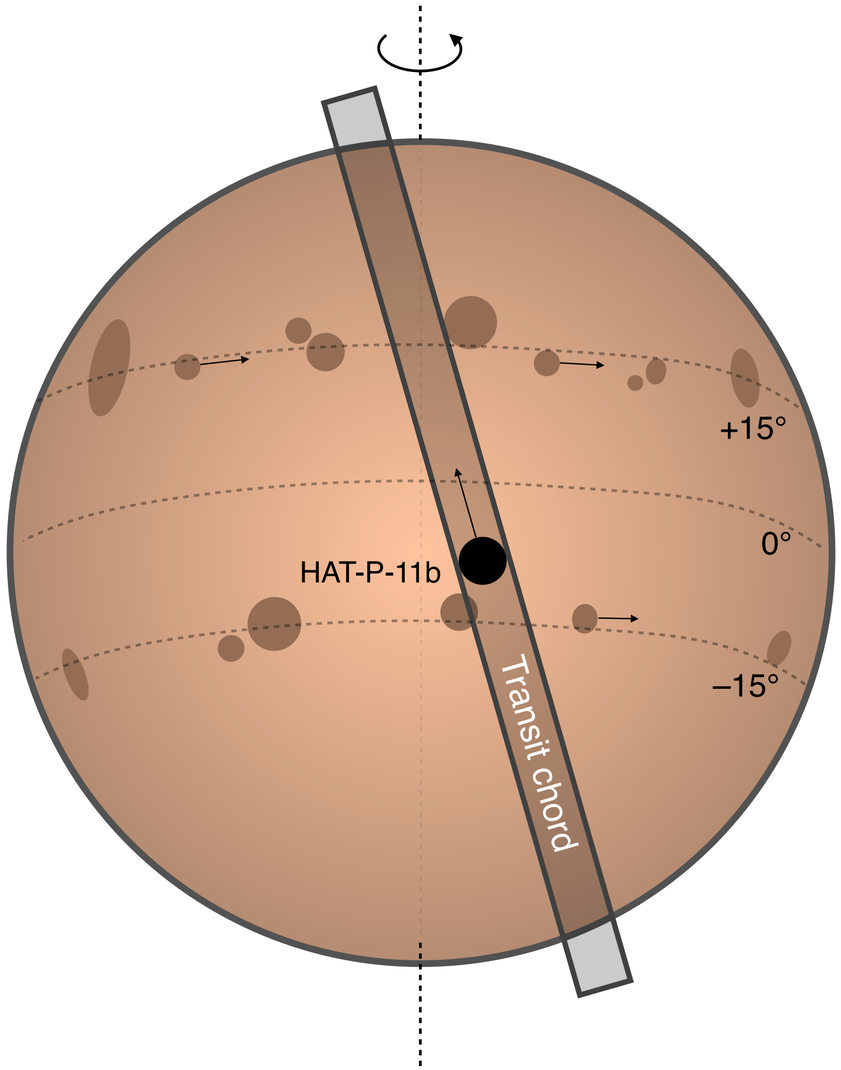
HAT-P-11: a scaled down Sun



- $M_\star = 0.8\ M_\odot$
- $P_{rot} = 29$ d (like Sun!)
- Rossiter-McLaughlin effect yields orientation

Sanchis-Ojeda et al. 2011
Morris et al. 2017a

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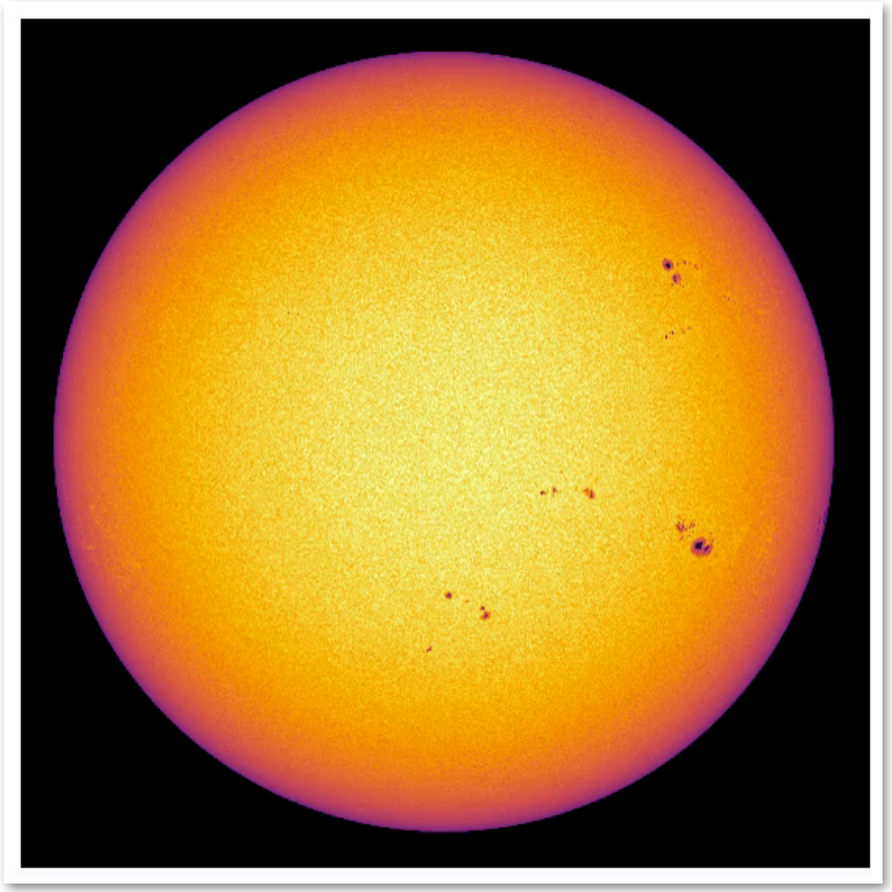
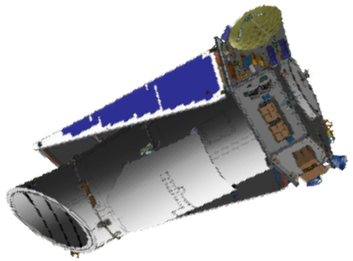
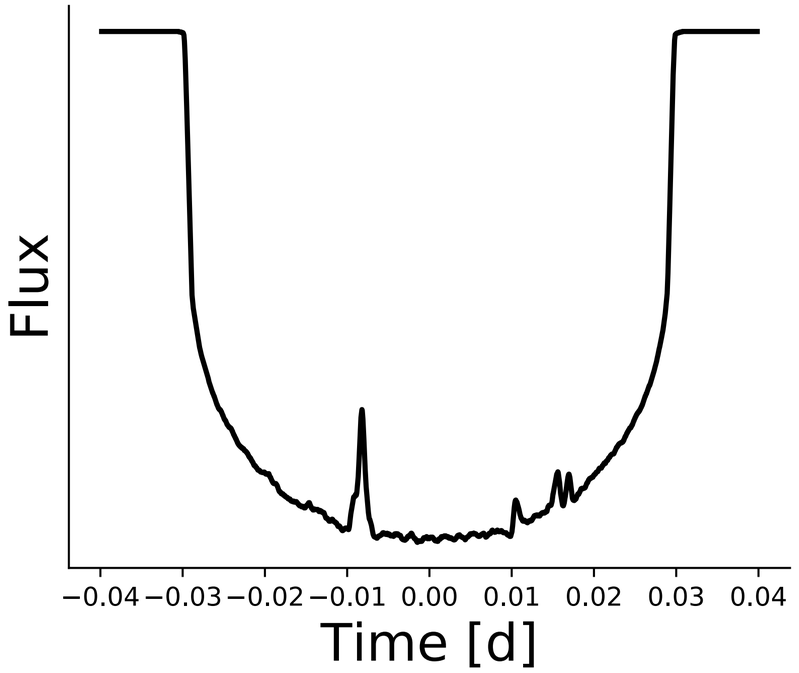
Misaligned exoplanets reveal active latitudes

- Timing encodes active latitude positions
- Amplitude encodes spot contrast



NASA/SDO/HMI





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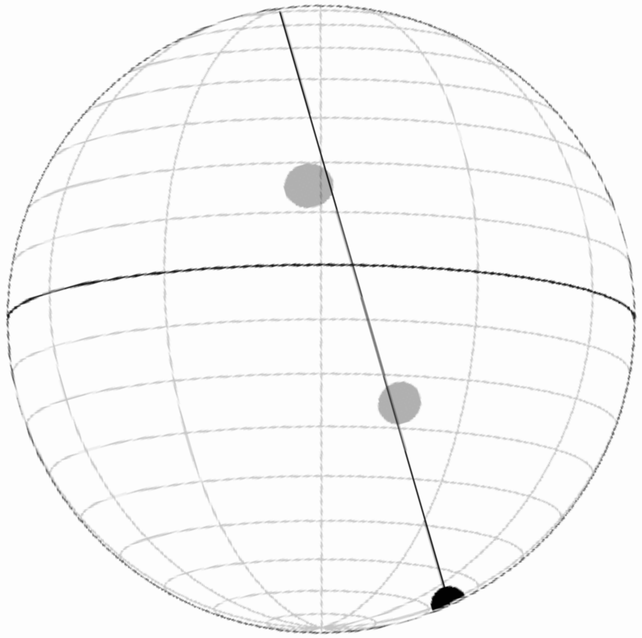
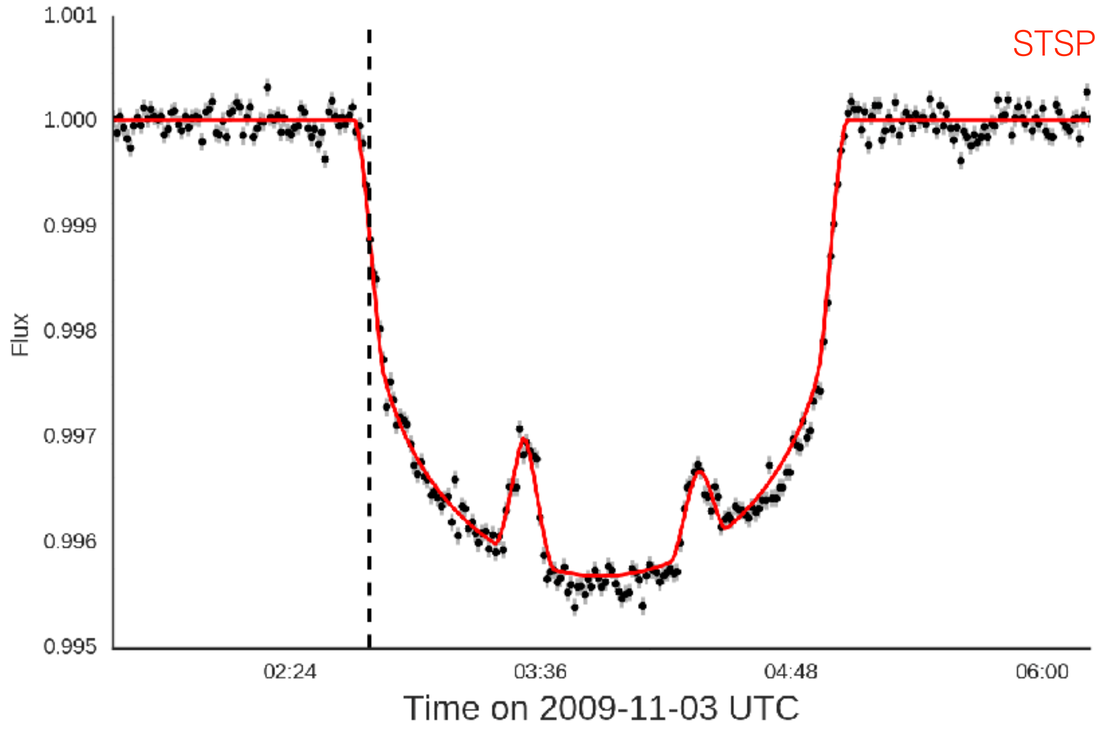
HAT-P-11: Sun-like active latitudes





Independently model each spot occultation

Morris et al. 2017a

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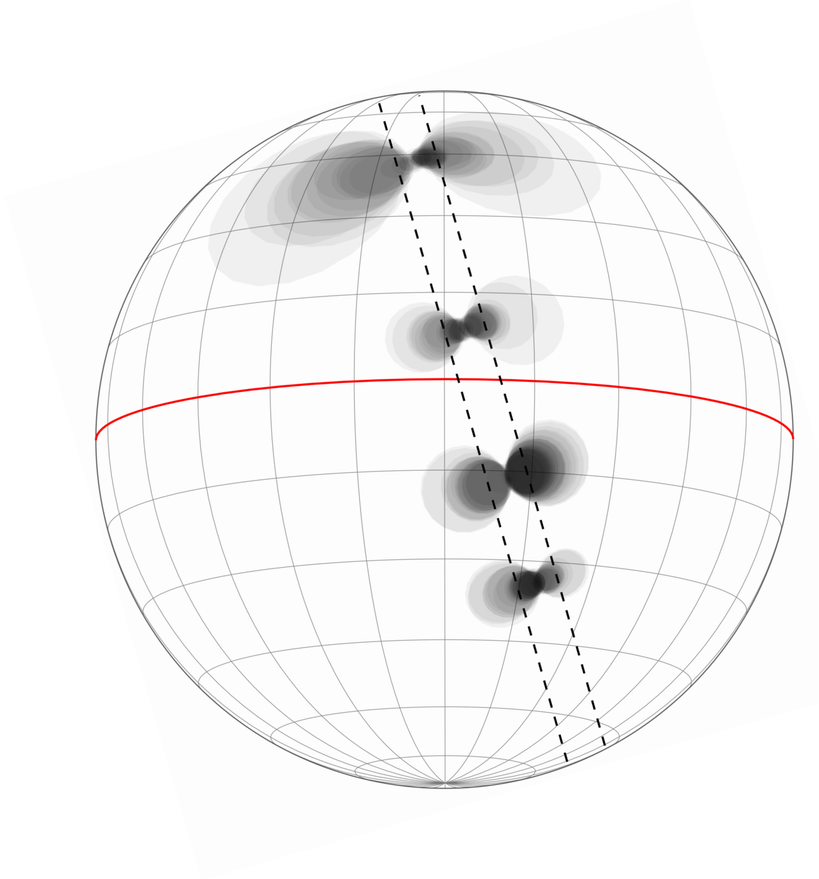
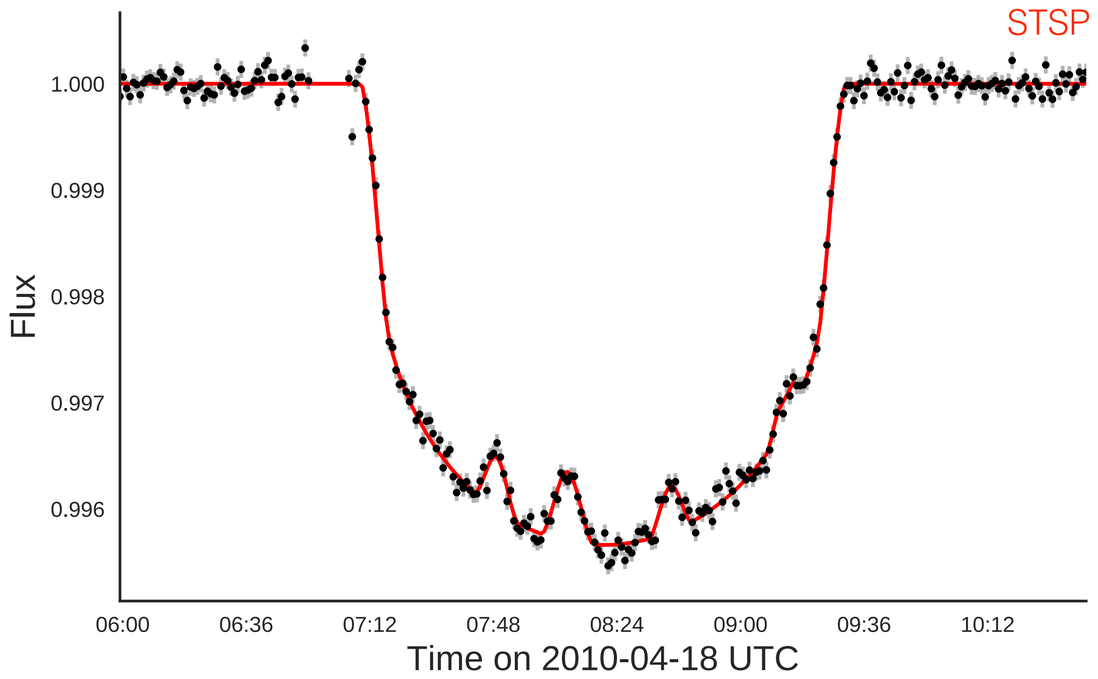
HAT-P-11: Sun-like active latitudes





Posterior positions, radii are degenerate

Morris et al. 2017a

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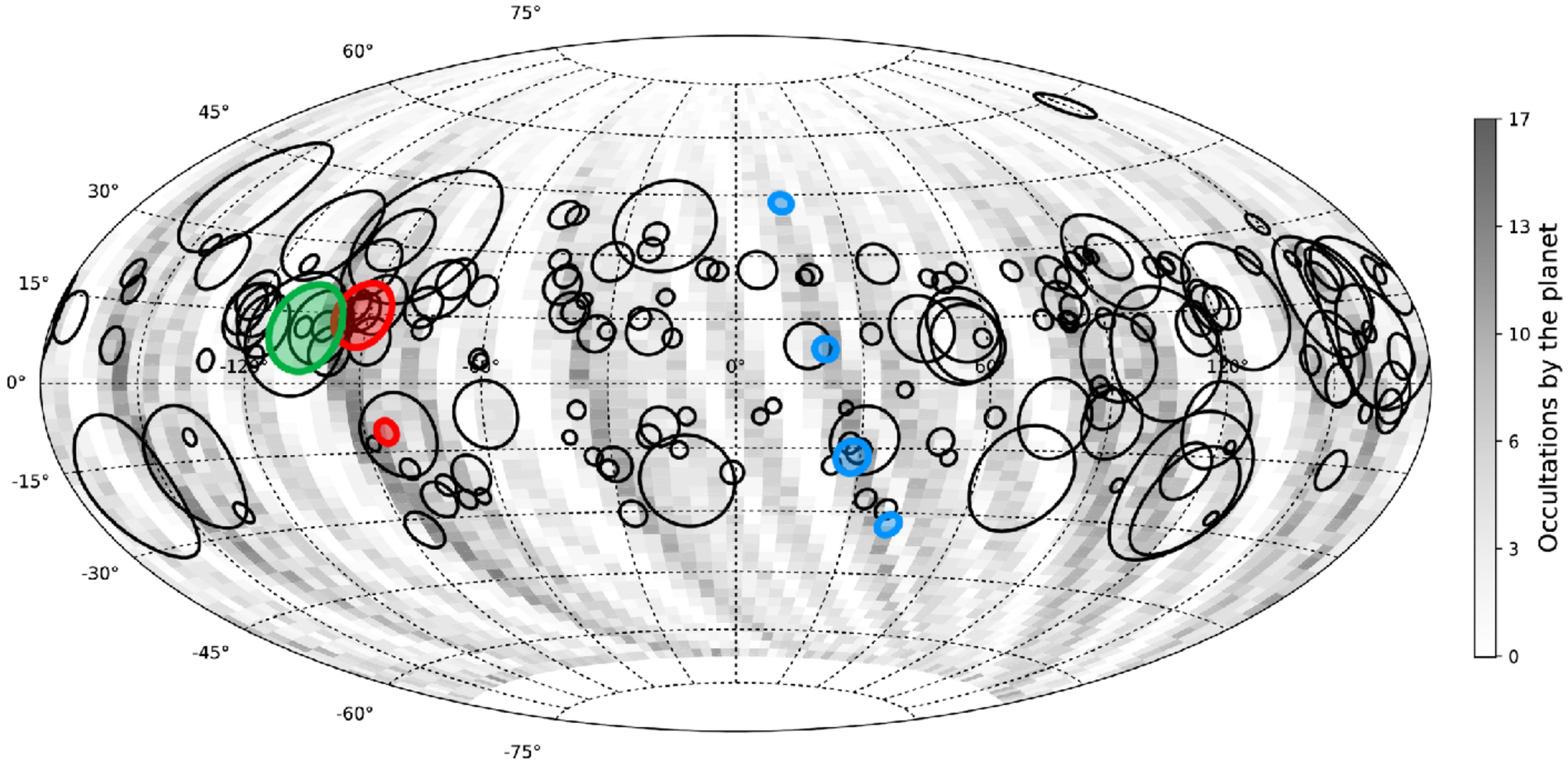
HAT-P-11: Sun-like active latitudes



Morris et al. 2017a

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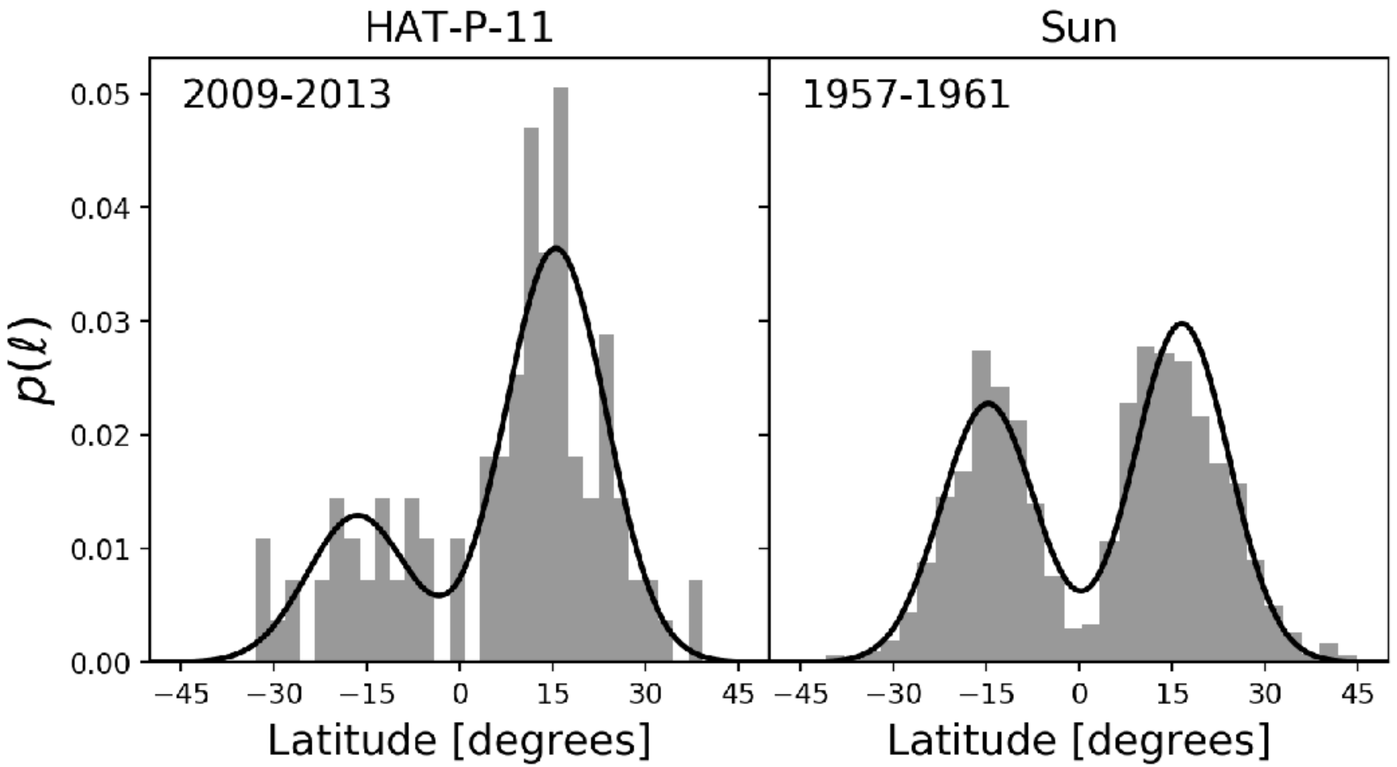
HAT-P-11: Sun-like active latitudes



Active latitudes: similar positions, widths to Sun's

Morris et al. 2017a

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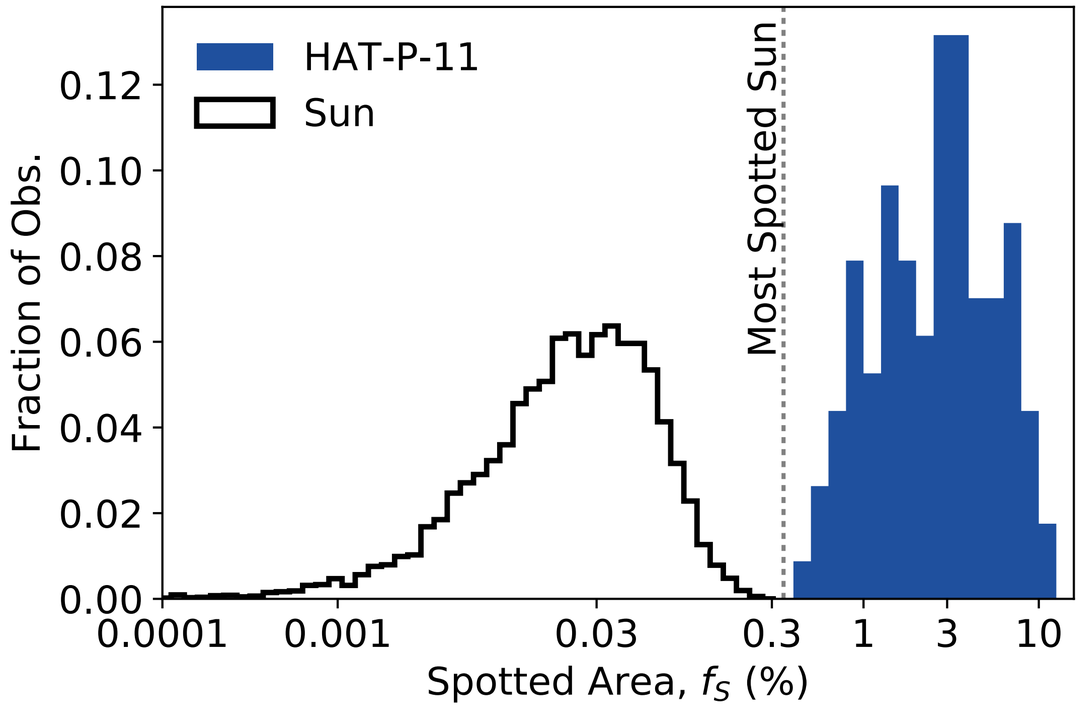
HAT-P-11: More spotted than Sun



Spot coverage 100x greater than Solar

Morris et al. 2017a

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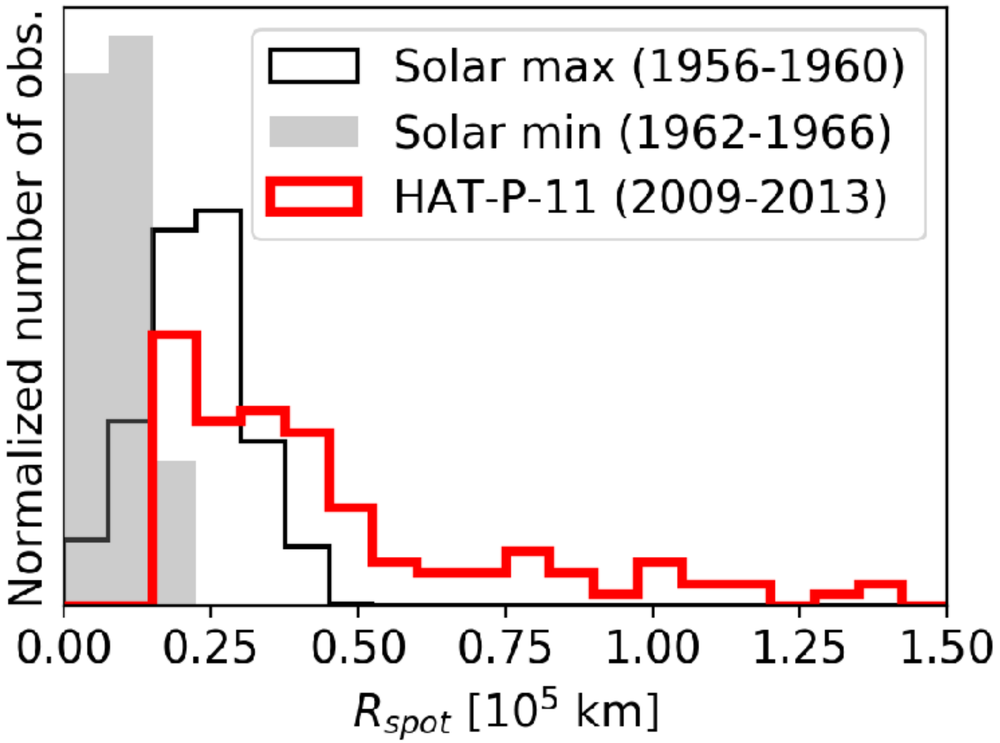
HAT-P-11: Sunspot-like sizes



Most spots have similar sizes to the largest spots on the Sun at solar max

Morris et al. 2017a

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Lessons from Kepler

- The spots of HAT-P-11 are like the Sun's
  - Similar latitude distribution
  - Similar physical radii
- However: they cover 100x more fractional surface area
- **Solar-like dynamo**

Lessons from ground-based follow-up

Morris et al. 2017a

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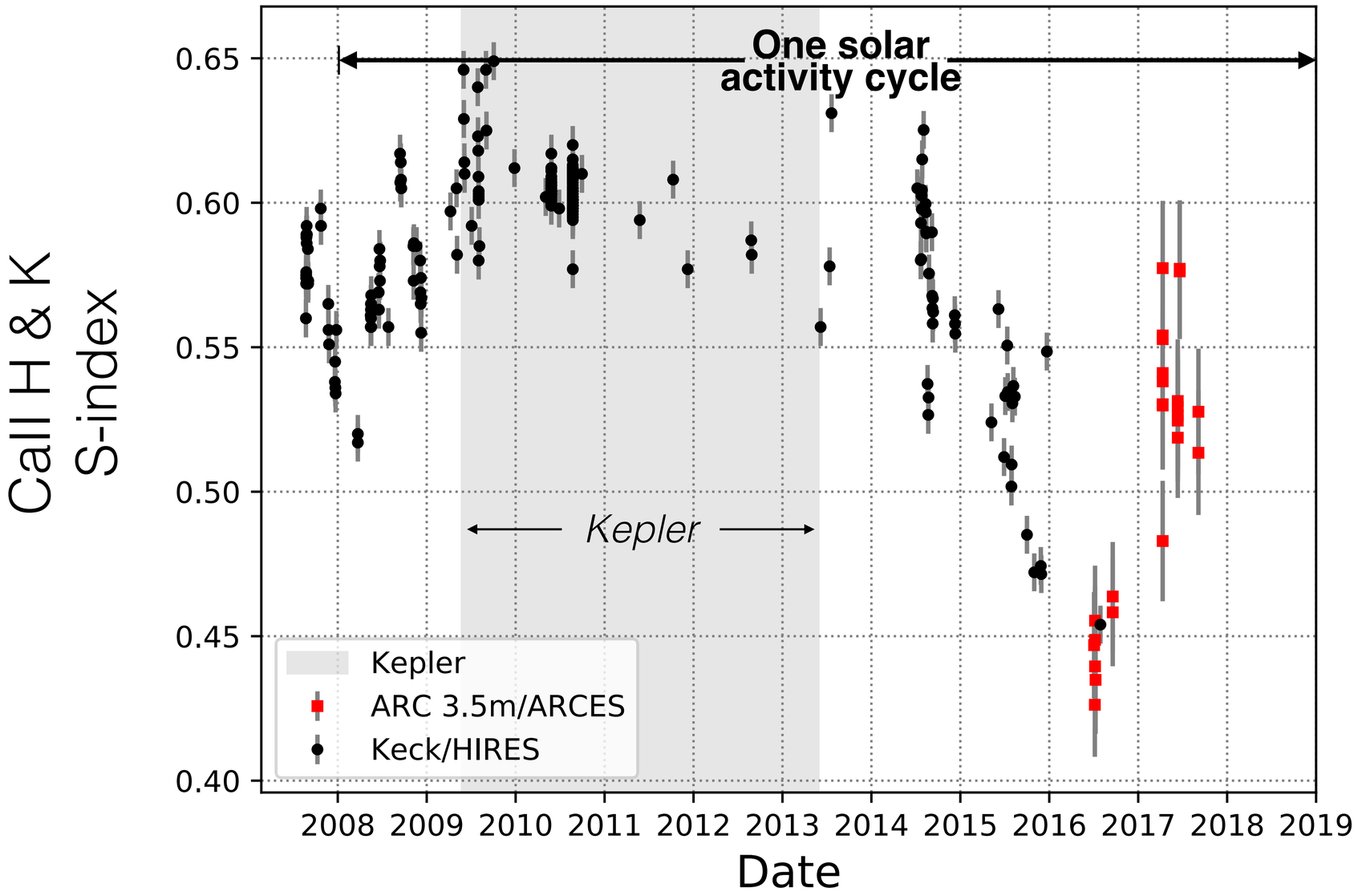
HAT-P-11: Chromospheric activity



Morris et al. 2017b

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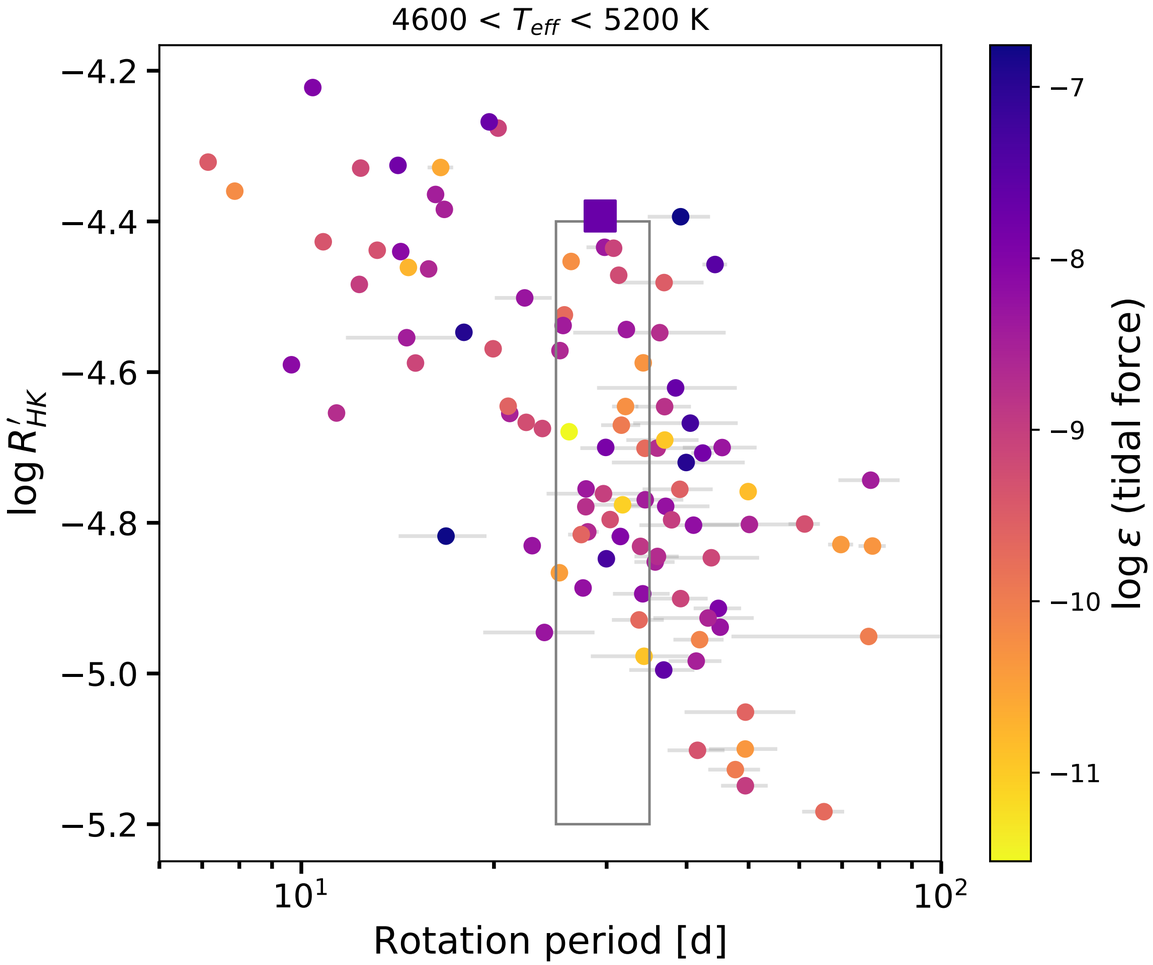
HAT-P-11: Star-planet interaction?



HAT-P-11 is more active than its peers in temperature and P_{rot}

Morris et al. 2017b
California Kepler Survey (Howard et al.)

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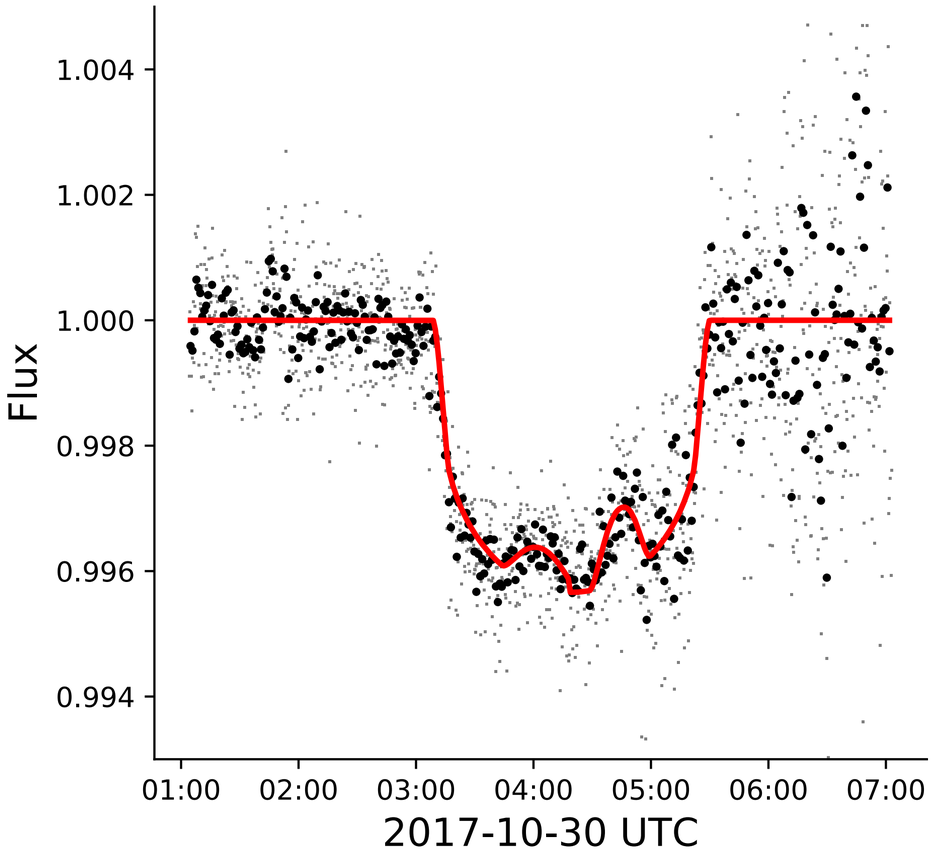
Holographic Diffuser-Assisted Photometry



Most spotted transit light curve of HAT-P-11 observed to date

Morris et al. 2018
Stefansson et al. 2018

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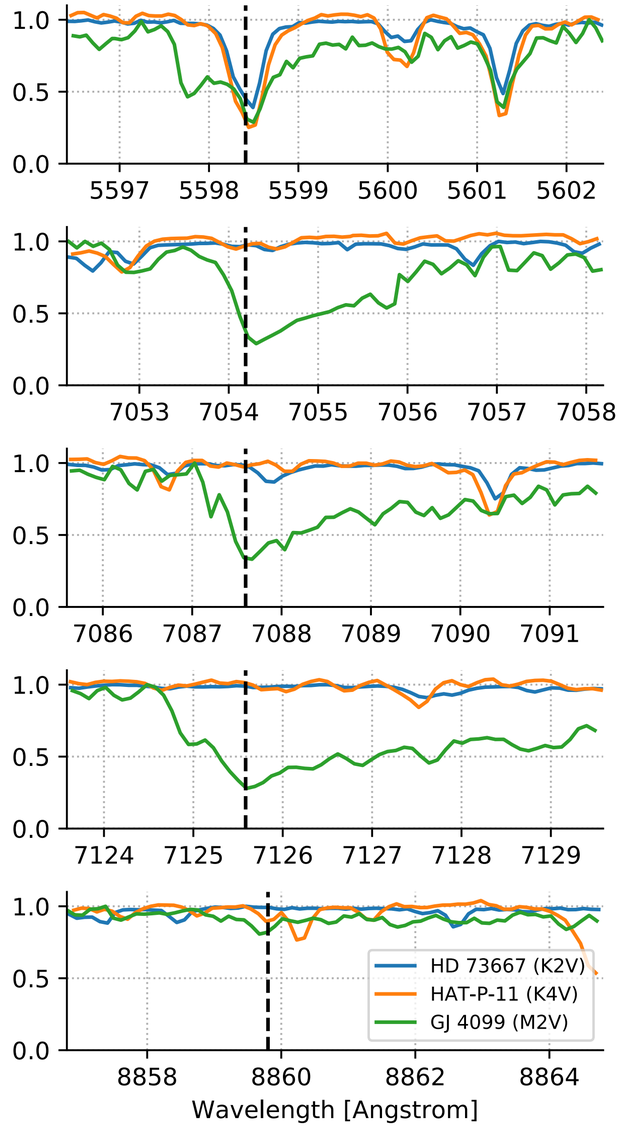
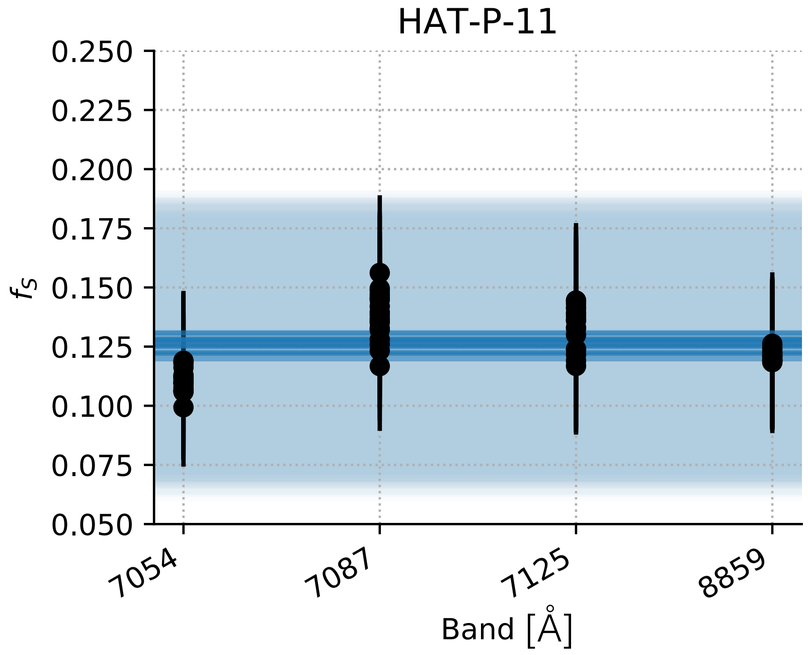
HAT-P-11: Molecular band modeling



Spot coverage inferred from TiO band modeling consistent with spot coverage in transit



Morris et al. 2018 (in prep)

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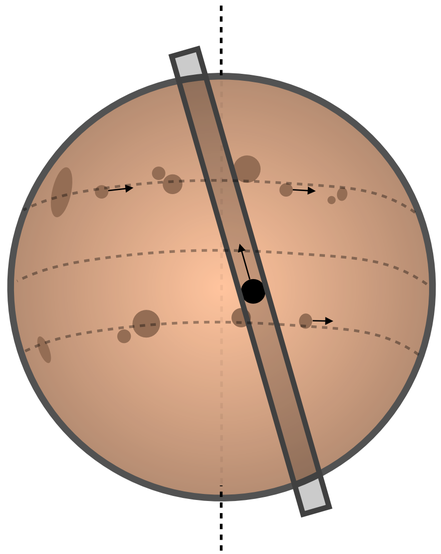

Lessons from Kepler

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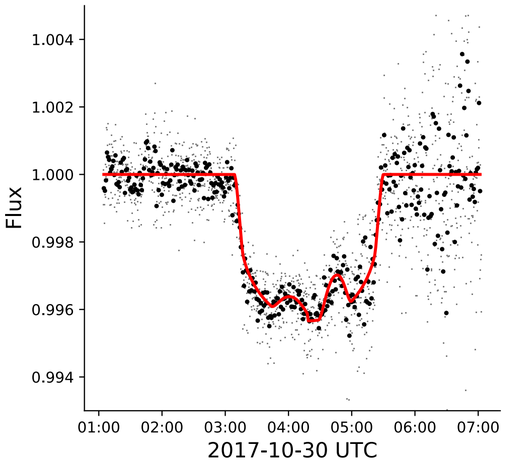
  - Similar latitude distribution
  - Similar physical radii
- However: they cover 100x more fractional surface area
- **Solar-like dynamo**



Lessons from ground-based follow-up

- Chromosphere: activity cycle P ≳ 11 years
- Diffuser: Perhaps more spotted than ever in 2017
- TiO: corroborates large spot coverage

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Recent Works

http://brettmorr.is
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HAT-P-11

The Starspots of HAT-P-11: Evidence for a Solar-like Dynamo
Morris, B.M., Hebb, Davenport, Rohn & Hawley, ApJ (2017)

Chromospheric Activity of HAT-P-11: an Unusually Active Planet-Hosting K Star
Morris, B.M., Hawley, Hebb, Sakari, Davenport, Isaacson, Howard, Montet & Agol, ApJ (2017)

Large Starspot Groups on HAT-P-11 in Activity Cycle 1
Morris, B.M., Hawley & Hebb, RNAAS (2018)

TRAPPIST-1

Non-detection of Contamination by Stellar Activity in the Spitzer Transit Light Curves of TRAPPIST-1
Morris, B.M., Agol, Hebb, Hawley, Gillon, Ducrot, Delrez, Ingalls & Demory, ApJL (2018, in review)

Possible Bright Starspots on TRAPPIST-1
Morris, B.M., Agol, Davenport & Hawley, ApJ (2018)

Photometric Analysis and Transit Times of TRAPPIST-1 b and c
Morris, B.M., Agol & Hawley, RNAAS (2018)

But wait there's more!

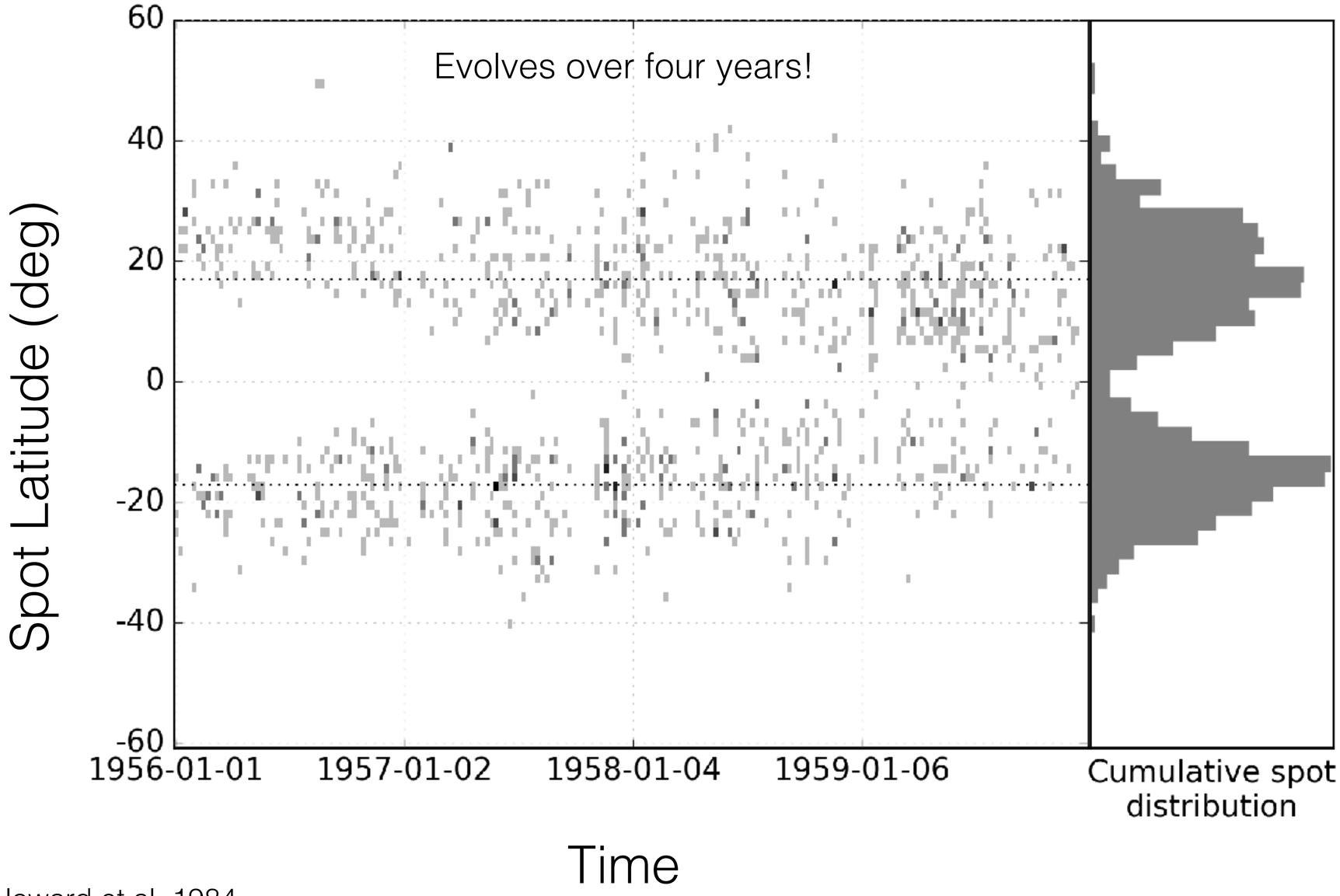
Spotting Stellar Activity Cycles in Gaia Astrometry
Morris, B.M., Agol, Davenport & Hawley, MNRAS (2018)

astroplan: An Open Source Observation Planning Package in Python
Morris, B.M. Tollerud, Sipőcz, Deil, Douglas… et al. AJ (2018)

Robust Transiting Exoplanet Radii in the Presence of Starspots from Ingress and Egress Durations
Morris, B.M., Agol, Hebb & Hawley, AJ (2018)

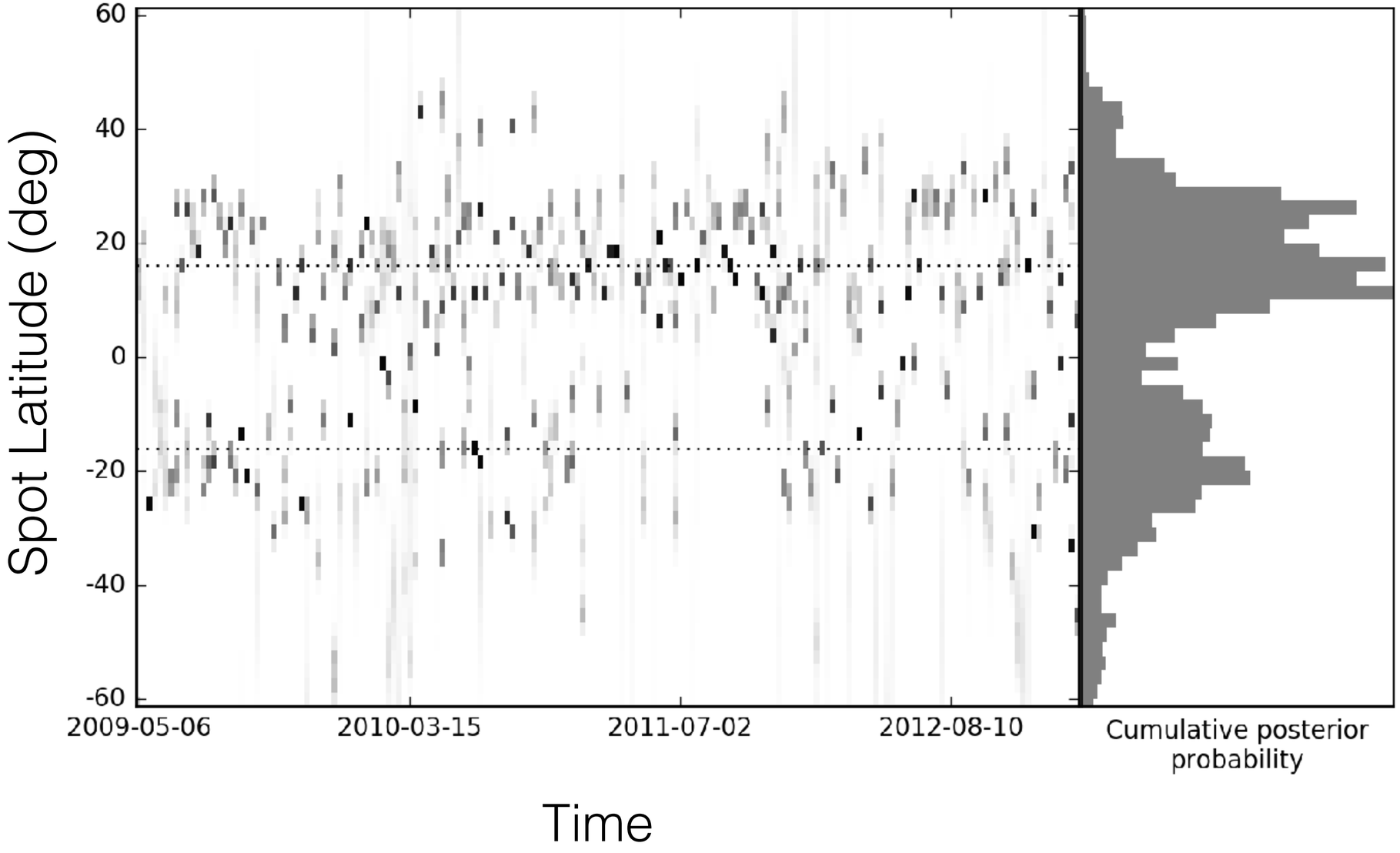
Are Starspots and Plage Co-Located on Active G and K Stars?
Morris, B.M., Curtis, Douglas, Hawley, Agüeros, Bobra, Agol, AJ (2018, in review)

Sun: Mt. Wilson Observatory



Howard et al. 1984

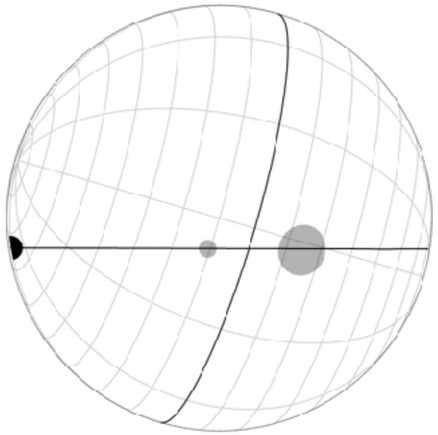
HAT-P-11: *Kepler*



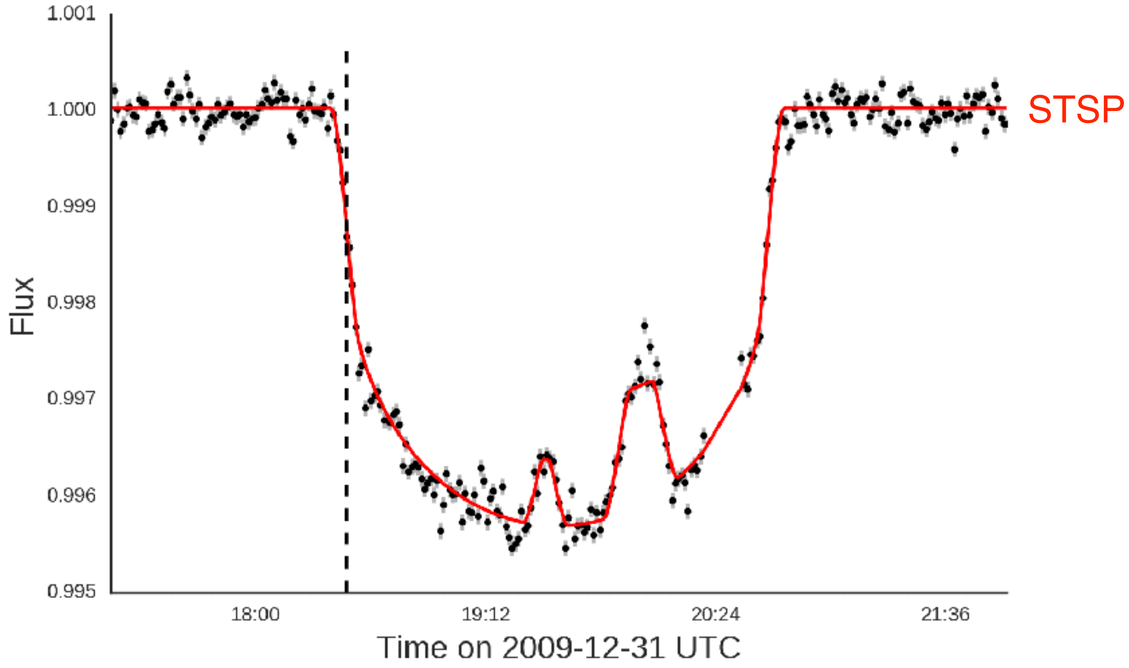
Morris et al. 2017a

HAT-P-11:

Kepler photometry +
STSP model

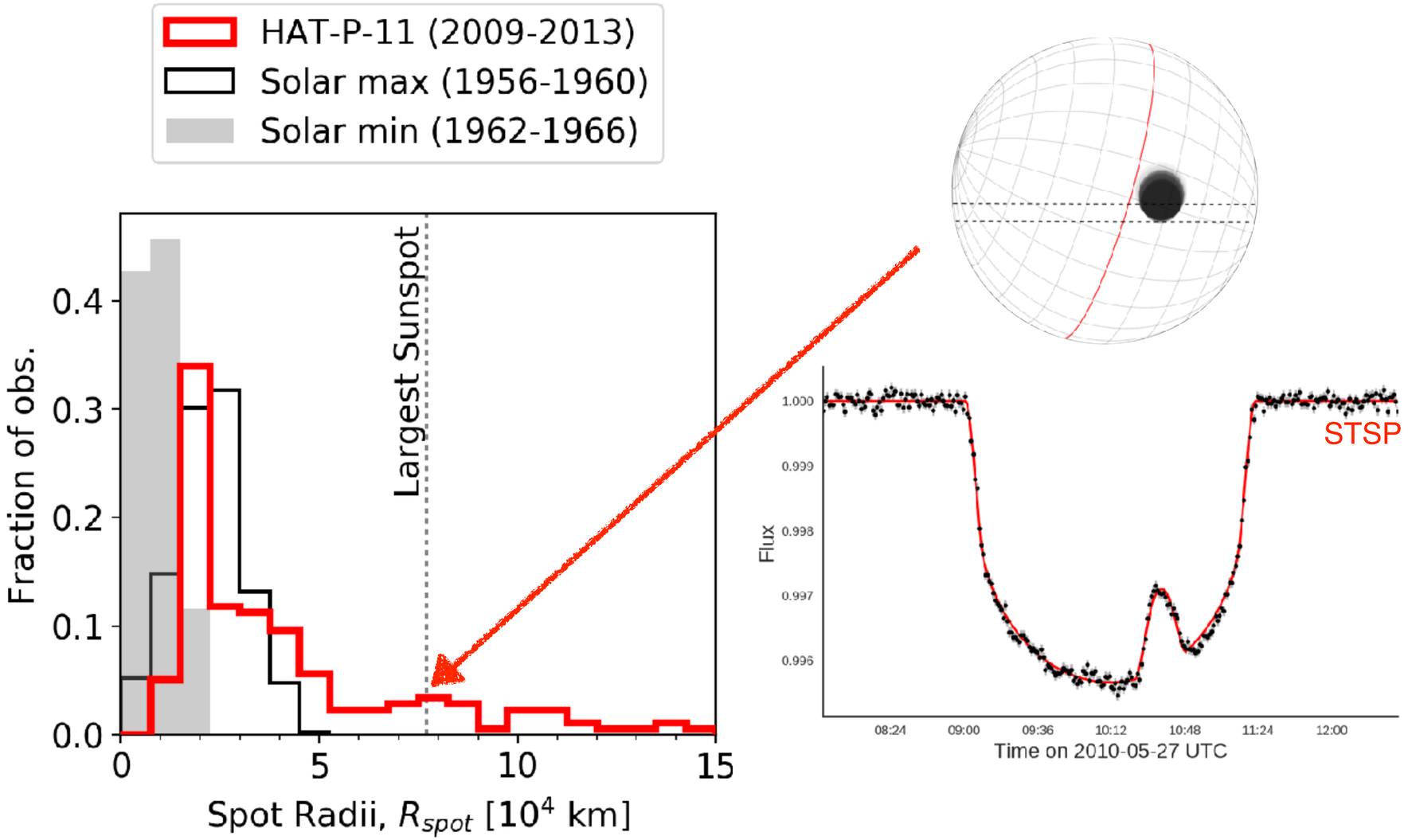


Spot occultation amplitude, duration, shape describe spot



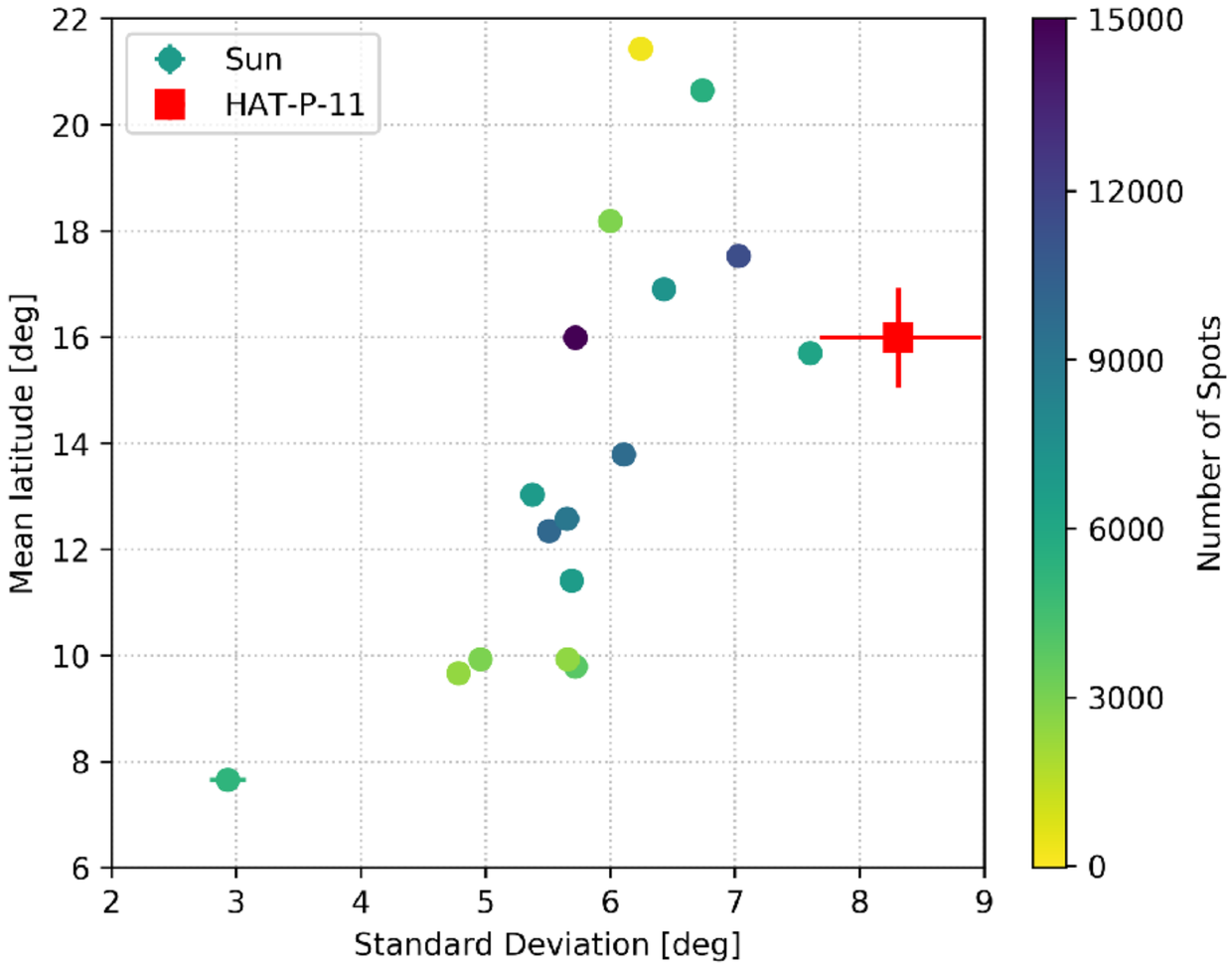
Morris et al., in prep.
Hebb et al., in prep.

Spot radii similar to sunspots

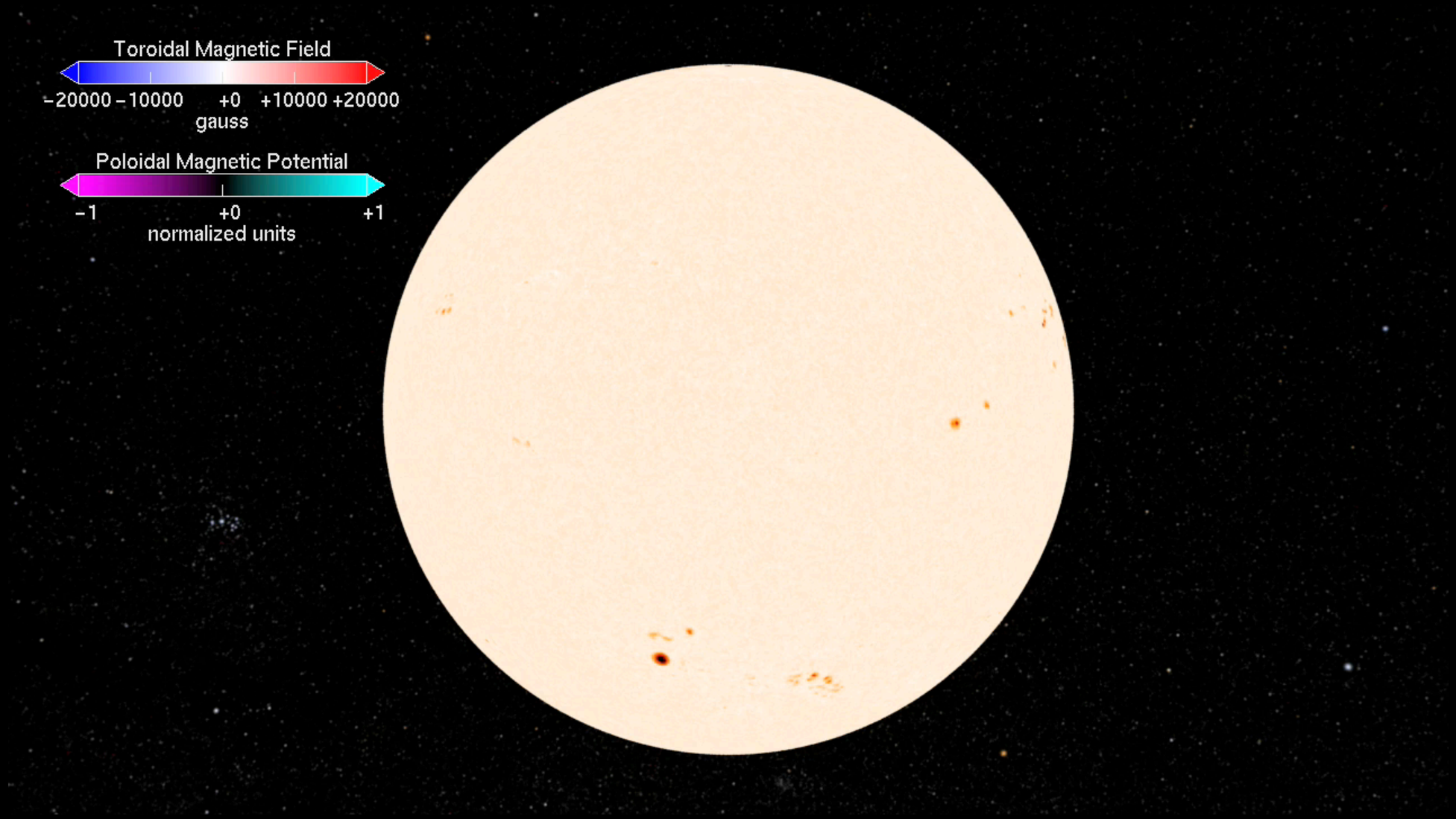


HAT-P-11: K4 star with solar-like dynamo

Morris et al. (2017)

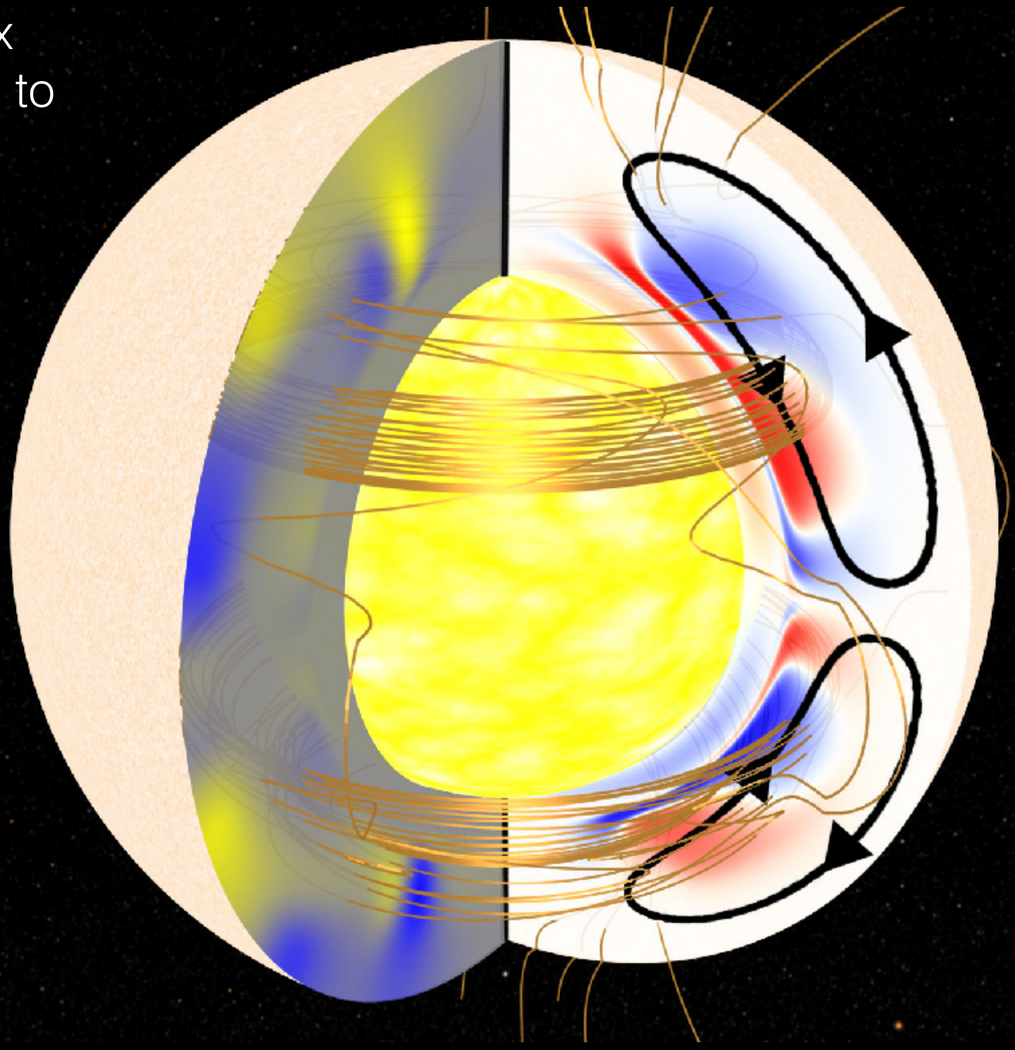


Rotation period = 29 d,
M = 0.8 M_{sun},
active latitudes quite
similar positions,
widths to Sun's


Toroidal Magnetic Field
−20000 −10000 +0 +10000 +20000
gauss
Poloidal Magnetic Potential
−1 +0 +1
normalized units

Flipping the polar field: Babcock-Leighton Mechanism

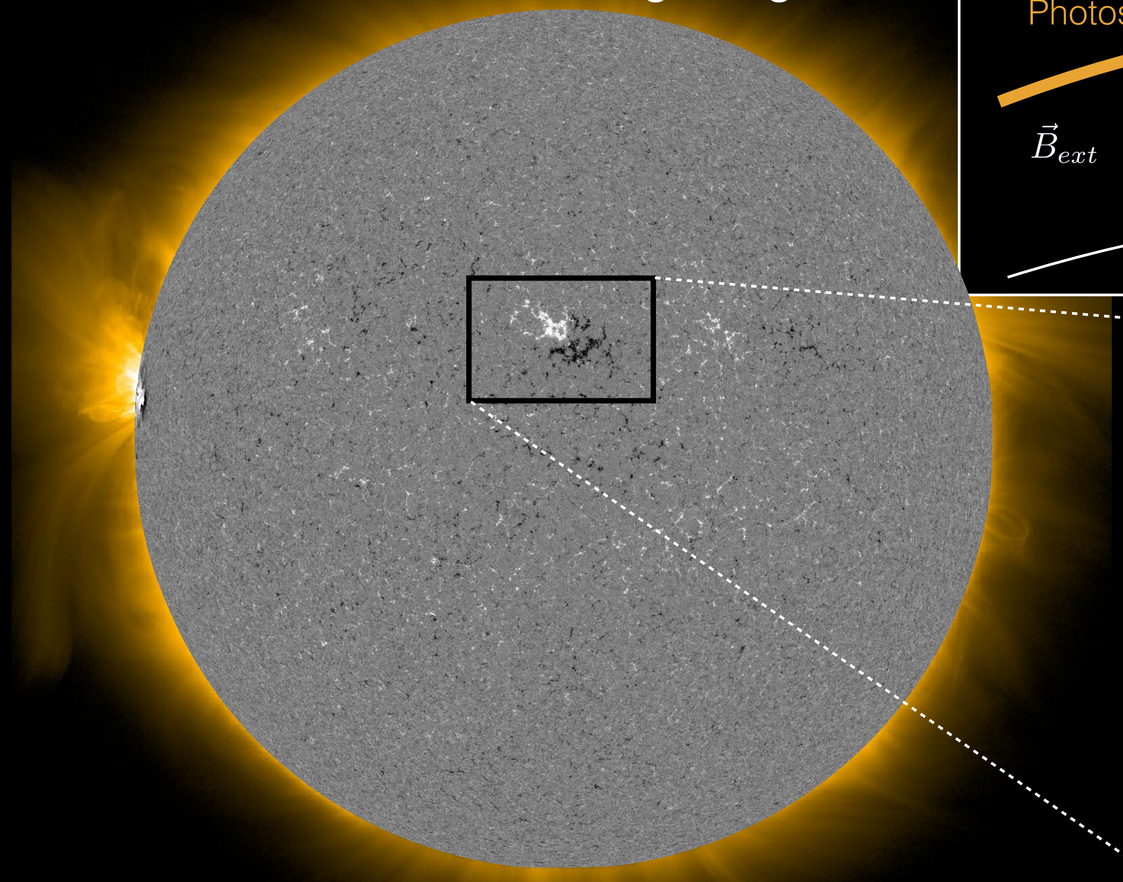
Meridional flow drags surface flux from low latitudes to higher latitudes

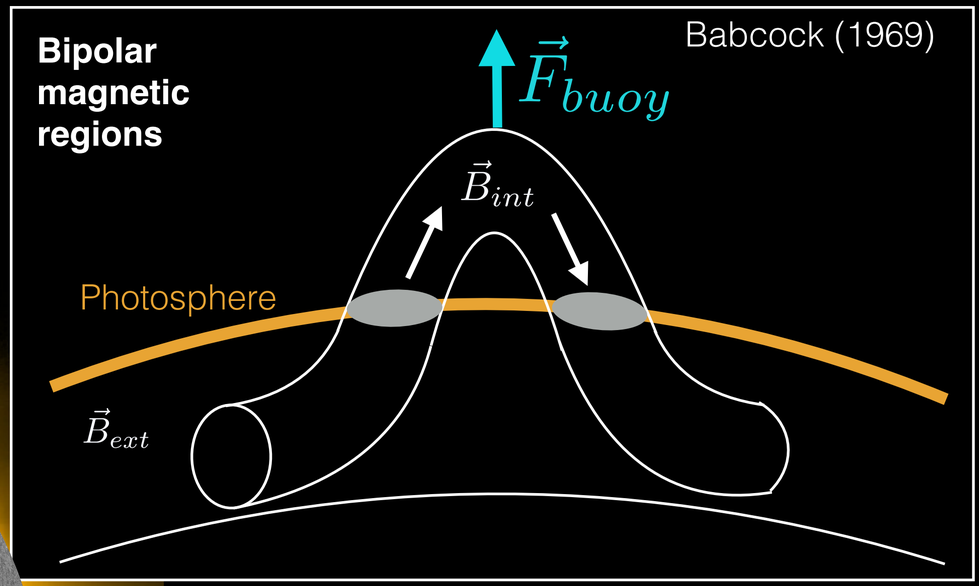


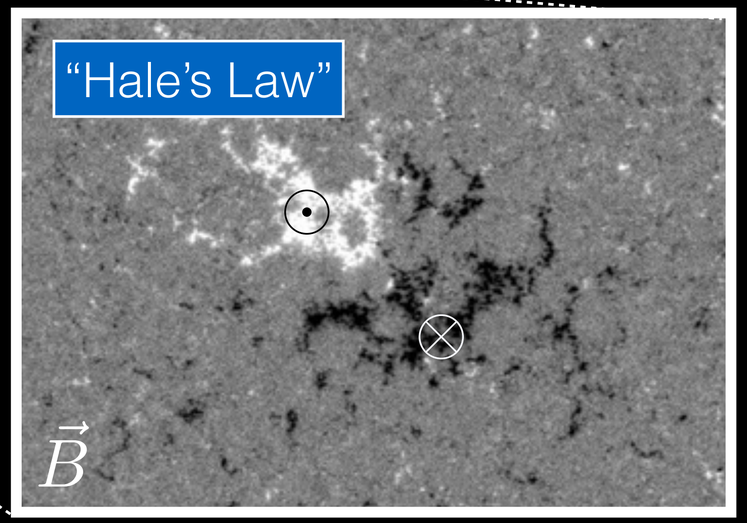
NASA/Holly Zell

Spot bipolarity arises naturally

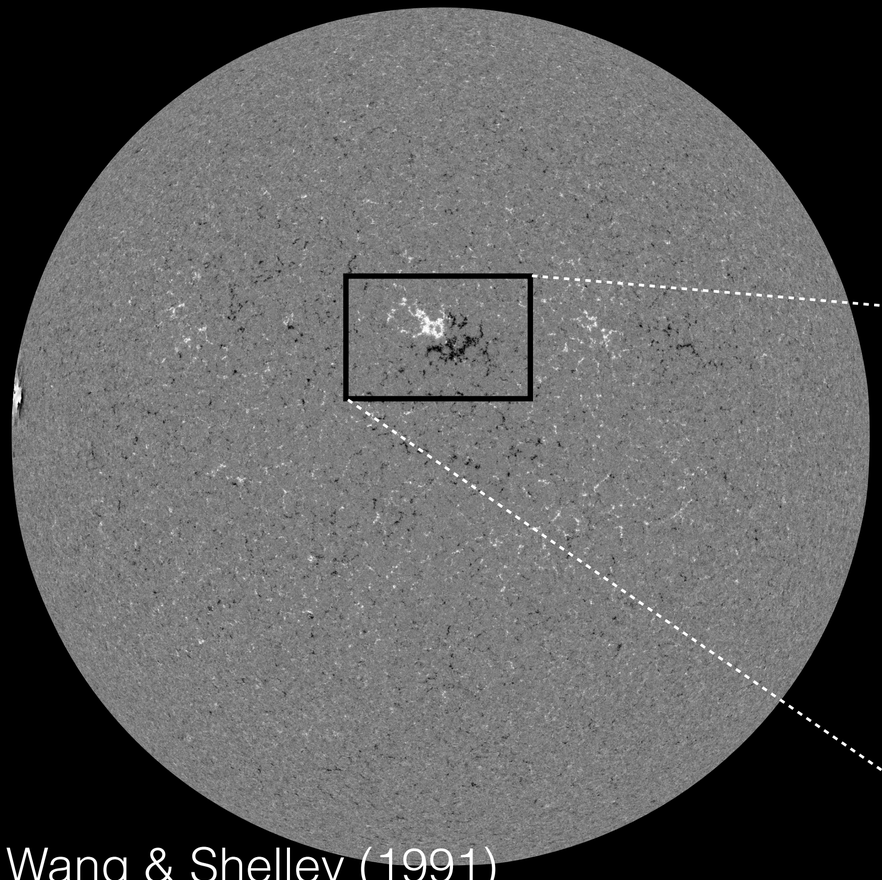
May 31, 2017
NASA/SDO 171nm, Magnetogram

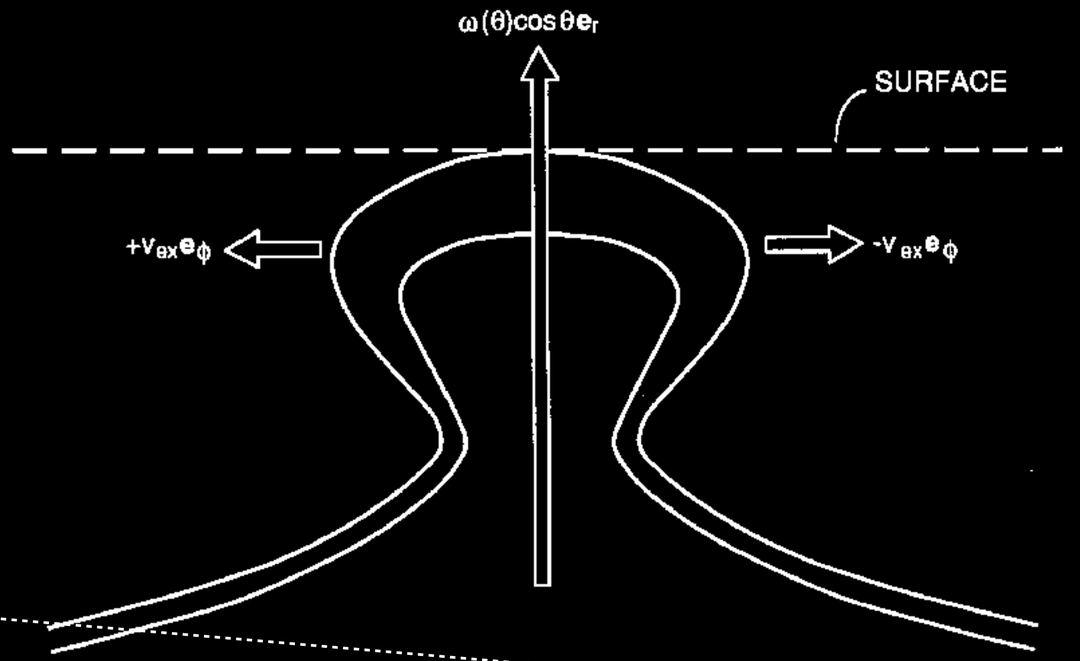


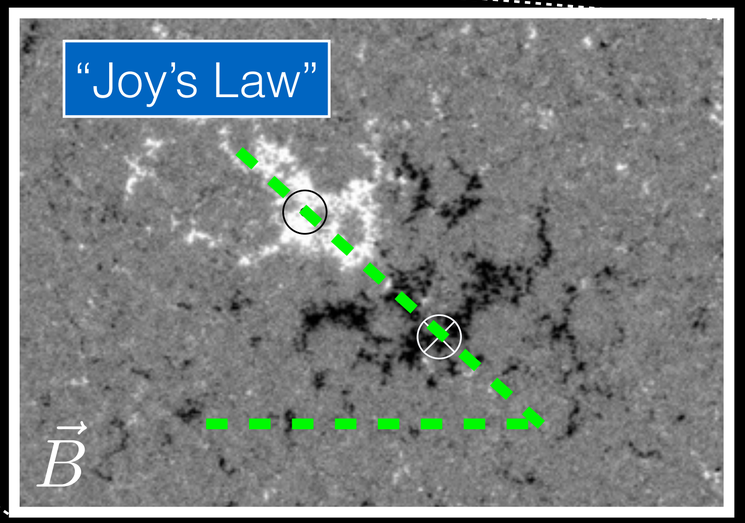




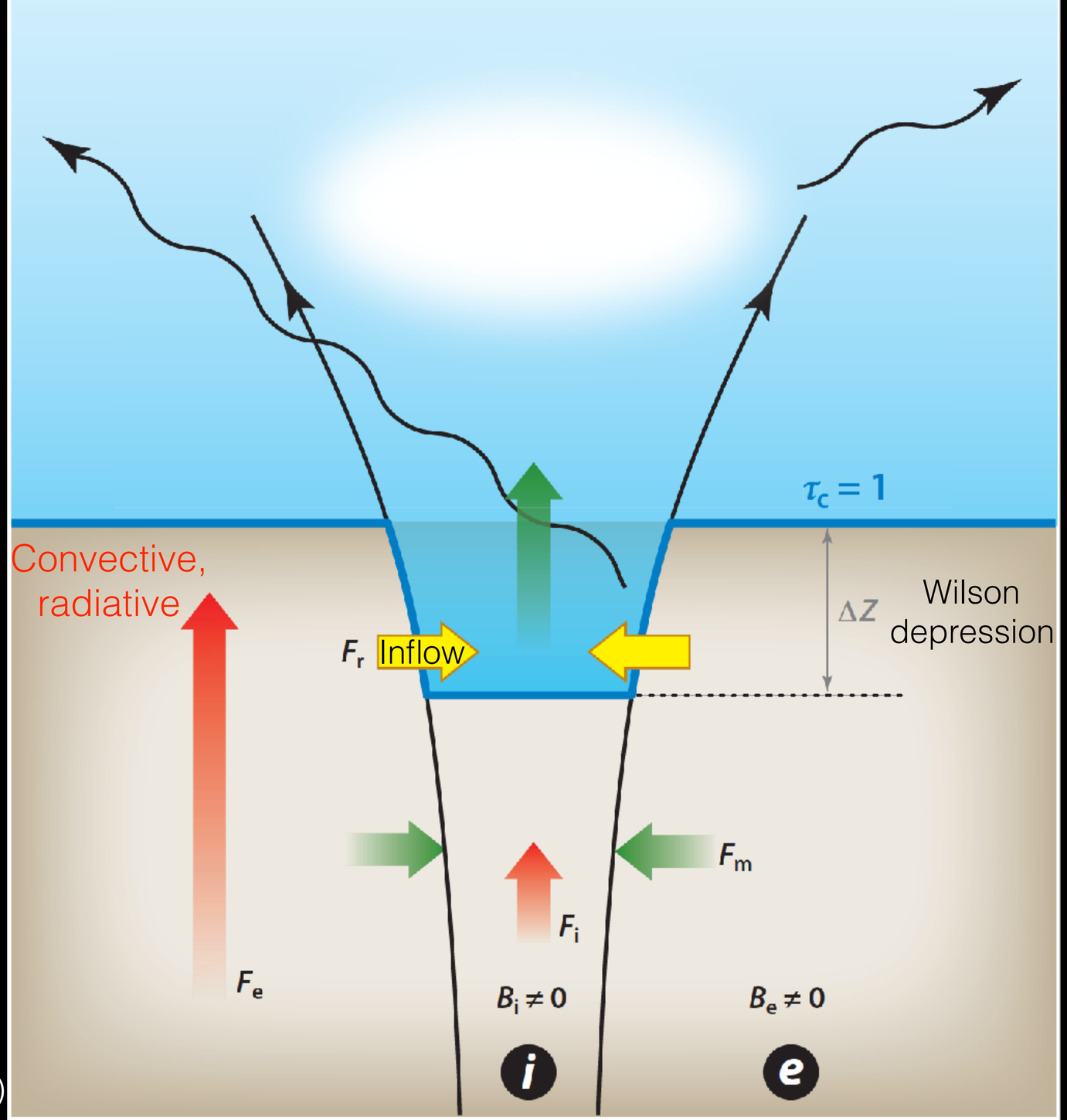
BMR tilt arises from Coriolis effect





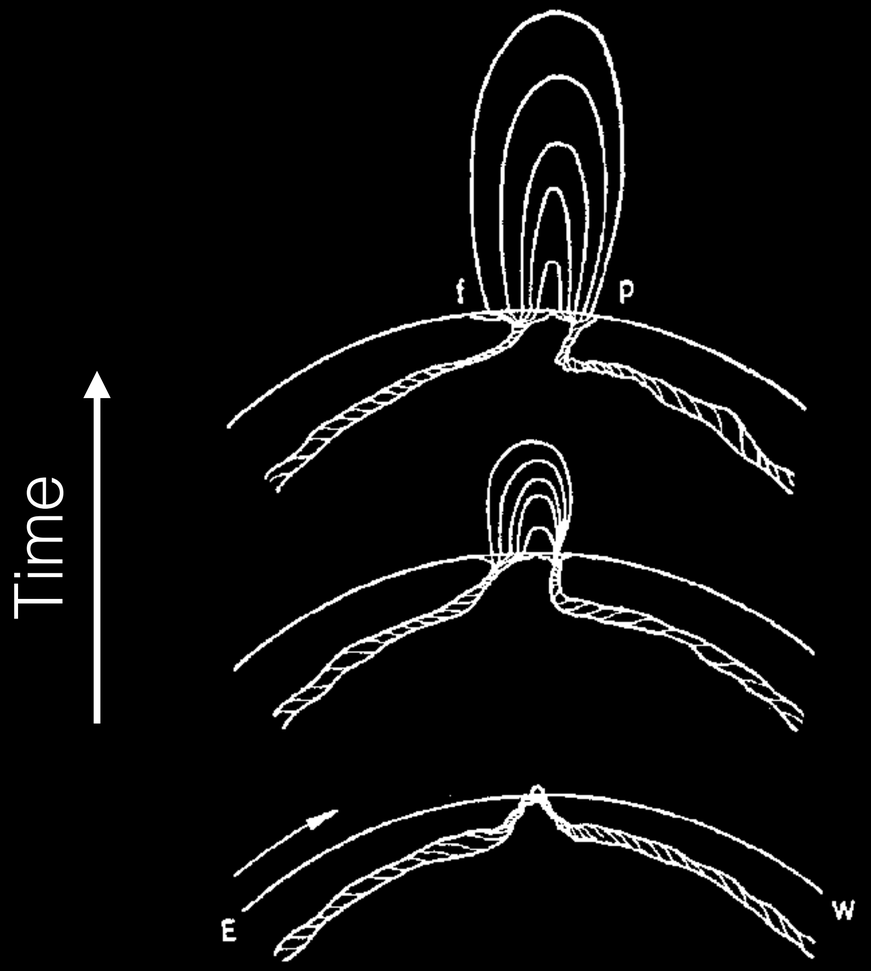


Wang & Shelley (1991)



Solanki (2013)

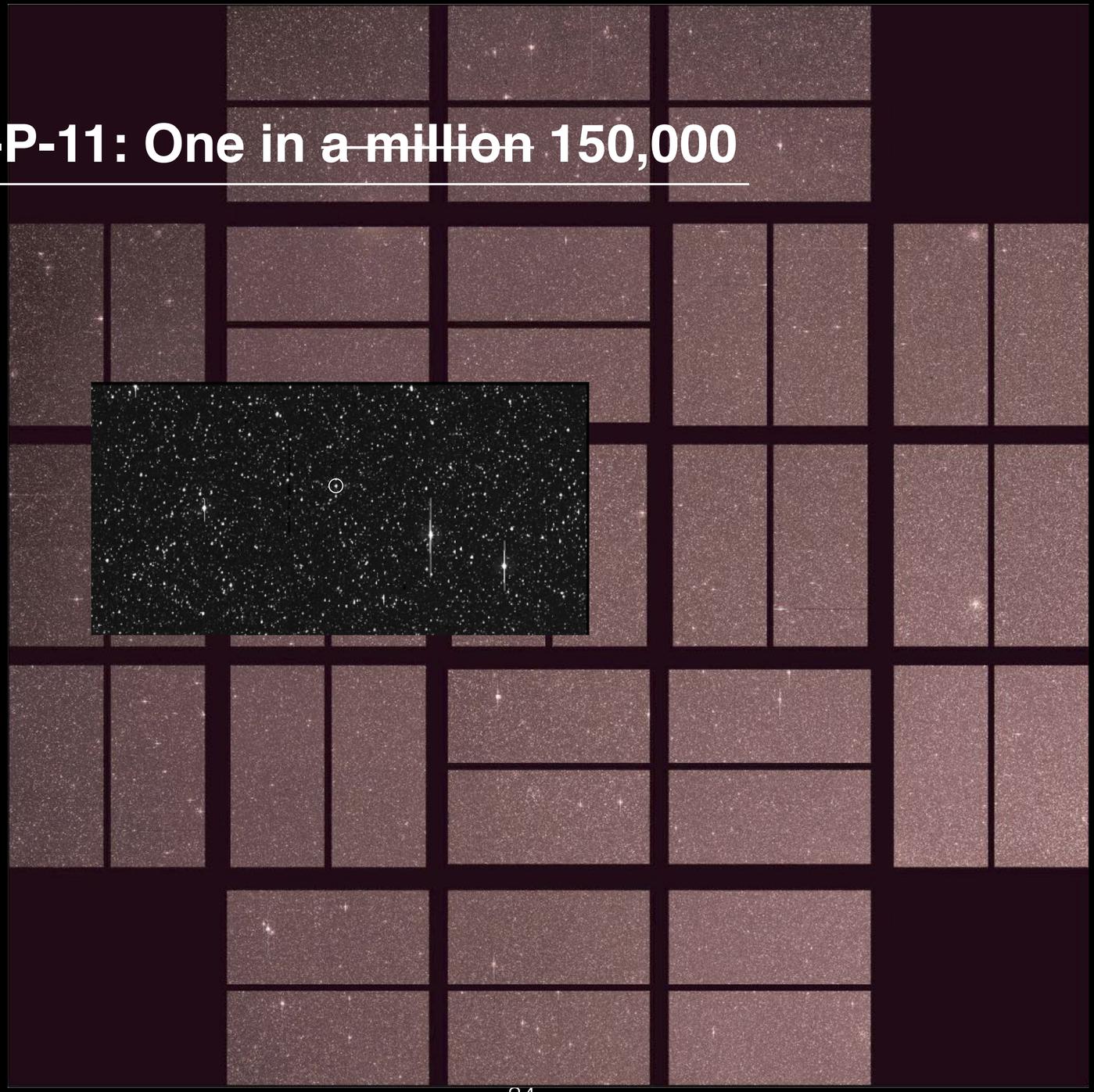
Leading spot dominates *B*-field



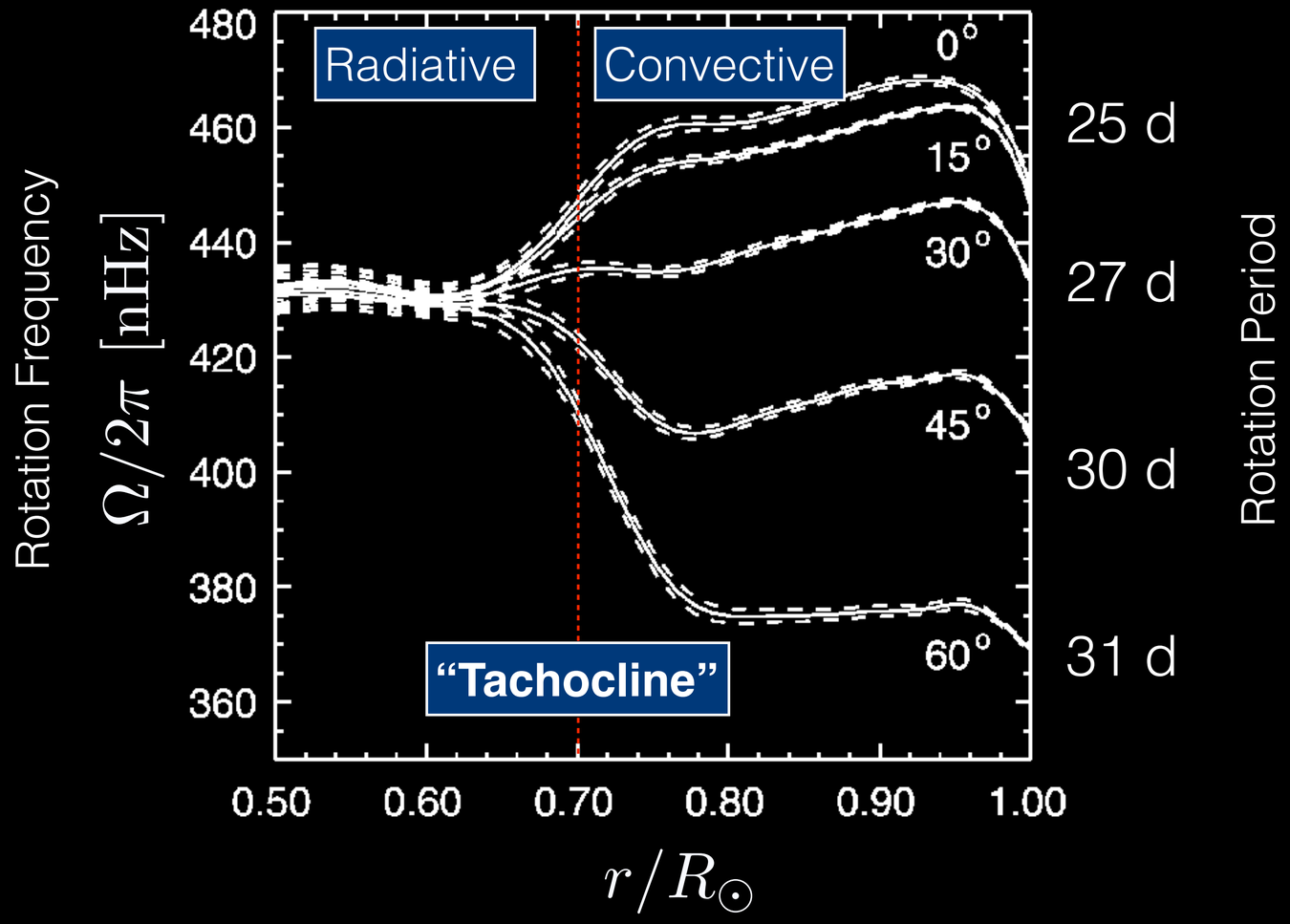
Near-surface rotates faster than sub-surface,
leading *B*-field dominates

Babcock (1961)

HAT-P-11: One in ~~a million~~ 150,000



Helioseismology saves the α-effect



Howe et al. (2000)

35