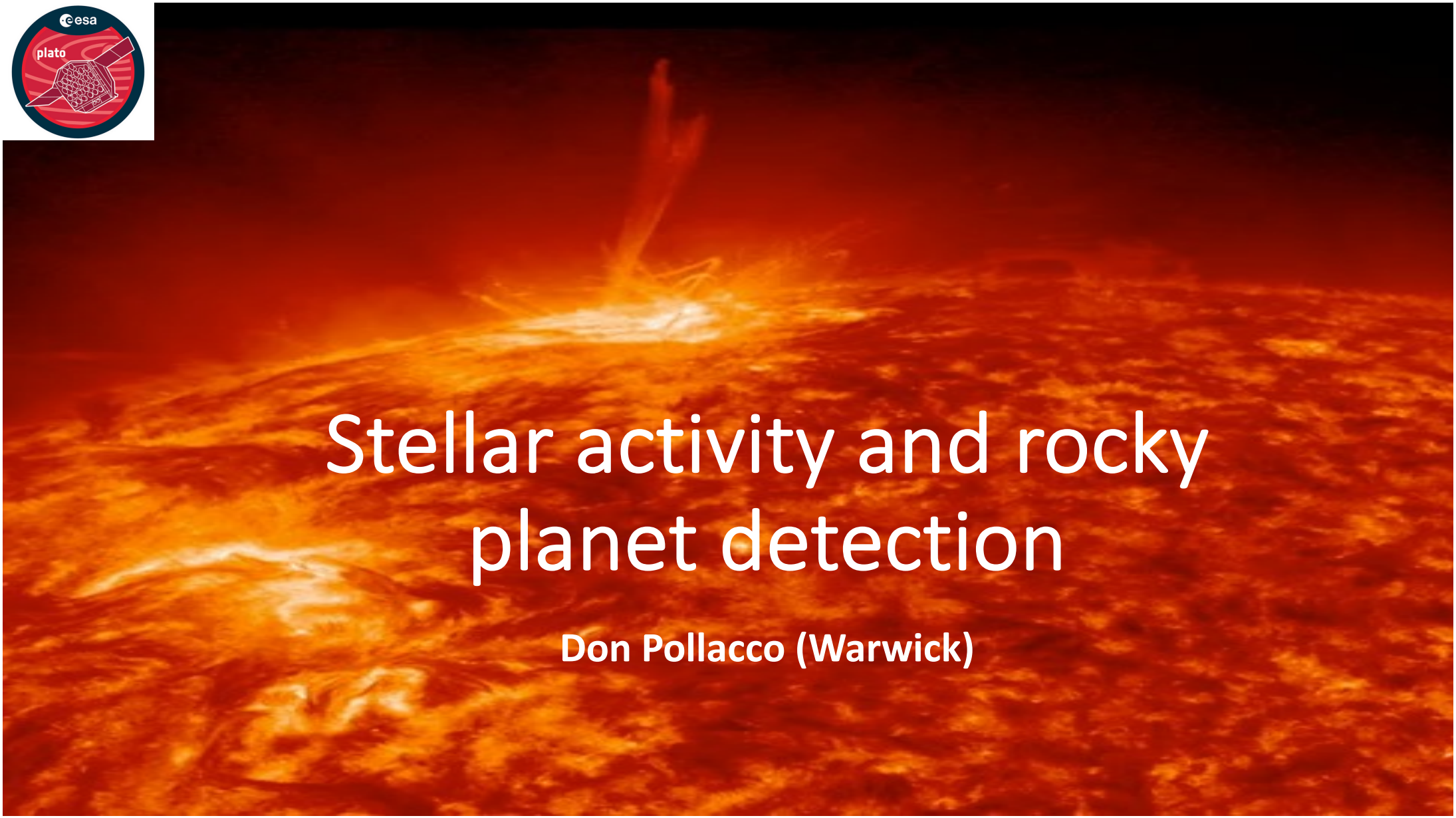


Stellar activity and rocky planet detection

Don Pollacco (Warwick)

Remember

The effects we are trying to measure are always small.

Planet detection and characterization is never trivial and prone to large errors

The measurements get more difficult for smaller and lower mass planets

As measurements are made relative to the host star then if the star varies the planet measurements are less well defined (implications for atmospheres)

Knowledge of the host is vital: “Know your star, know your planet.”

To put it bluntly, the devil is in the detail – as you will see…

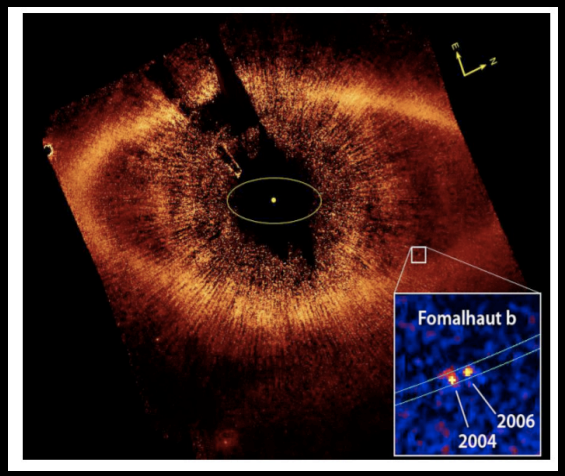
Keyword: MOTION

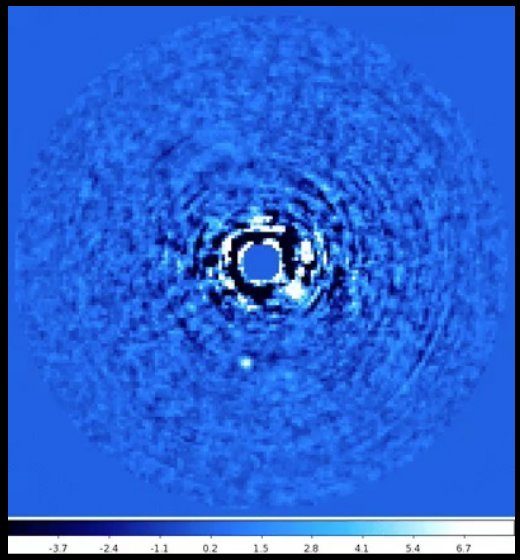
Outline

- Very quick summary of discovery methods
- Spectroscopy and absorption lines
- Radial velocity / doppler measurements – expected signals
- An aside: the RM effect
- Solar activity
- Observed activity effects in photometry & spectroscopy
- Causes of activity
- Prospects for 10cm/s…
- Implications of activity to the future of exoplanet bulk characterisation

Methods of Exoplanet Detection - Summary

1) Direct Imaging

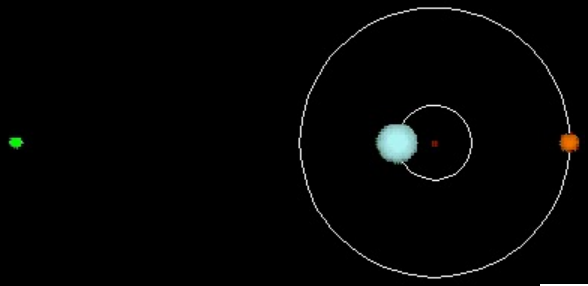


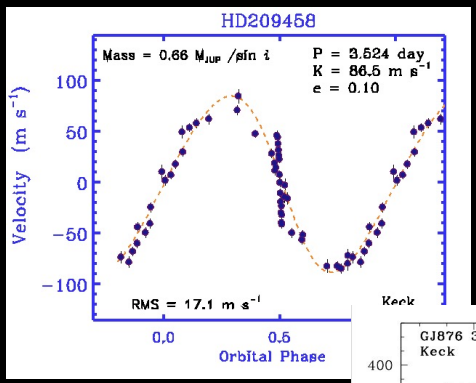


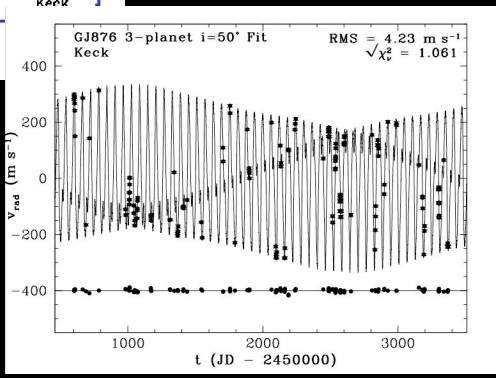
Methods of Exoplanet Detection - Summary

1) Direct Imaging

2) Radial Velocity







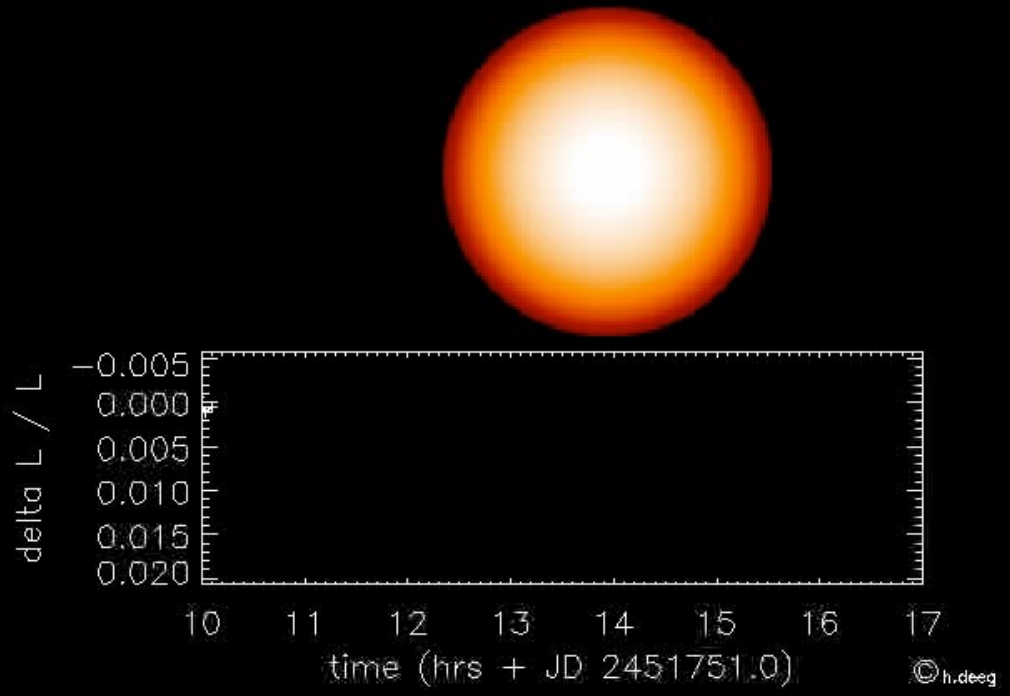
Measure Msini
ie lower limit for mass

Methods of Exoplanet Detection - Summary

1) Direct Imaging

2) Radial Velocity

3) Transit detection



Measure R_p/R_* & I Orbital inclination

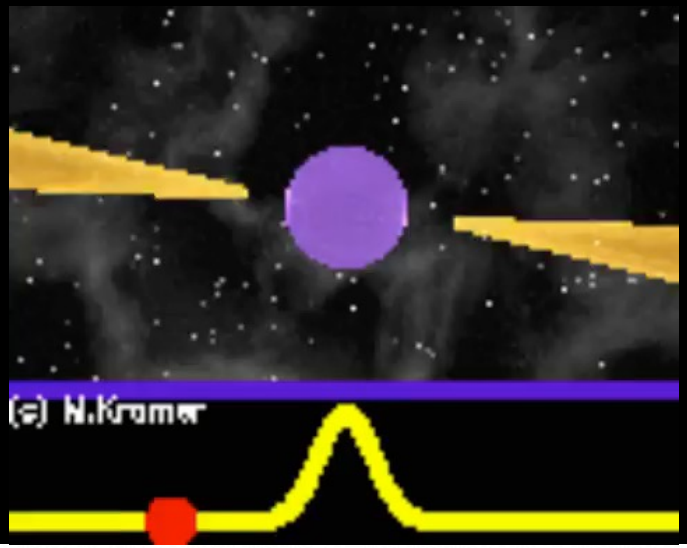
Methods of Exoplanet Detection - Summary

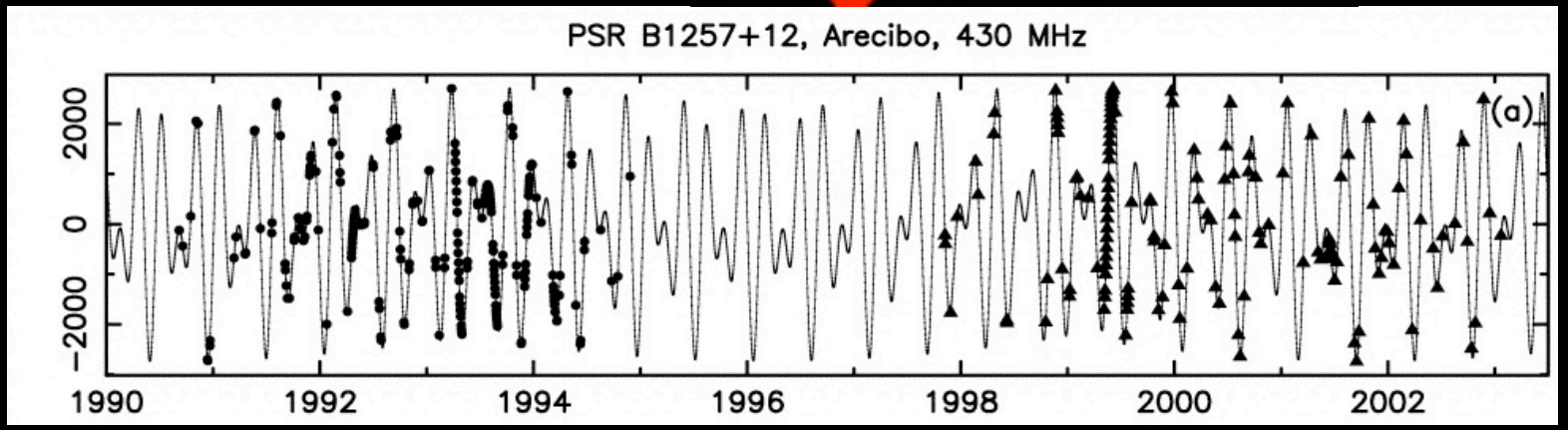
1) Direct Imaging

2) Radial Velocity

3) Transit detection

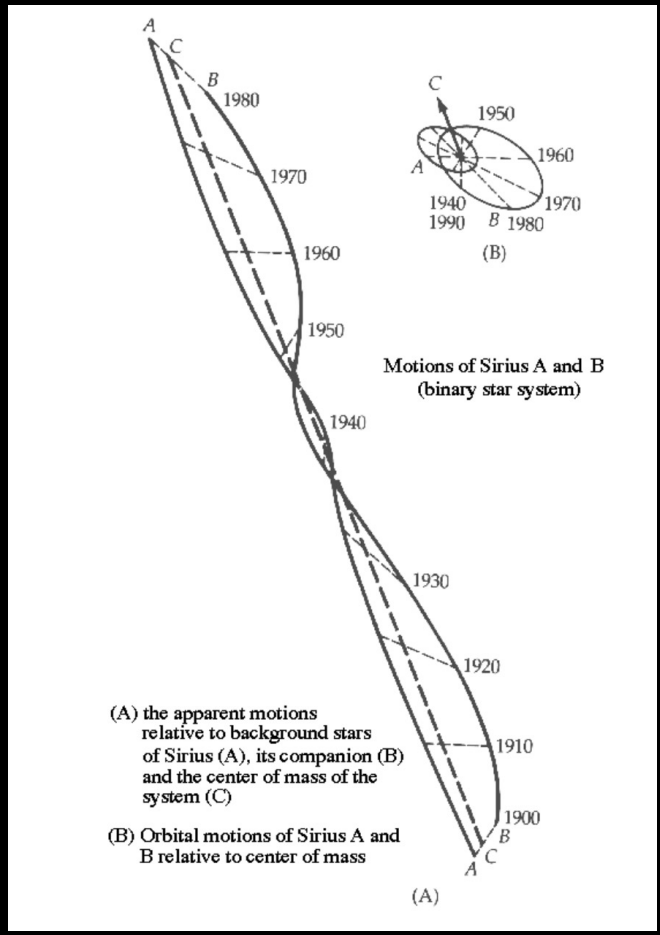
4) Timing





Methods of Exoplanet Detection - Summary

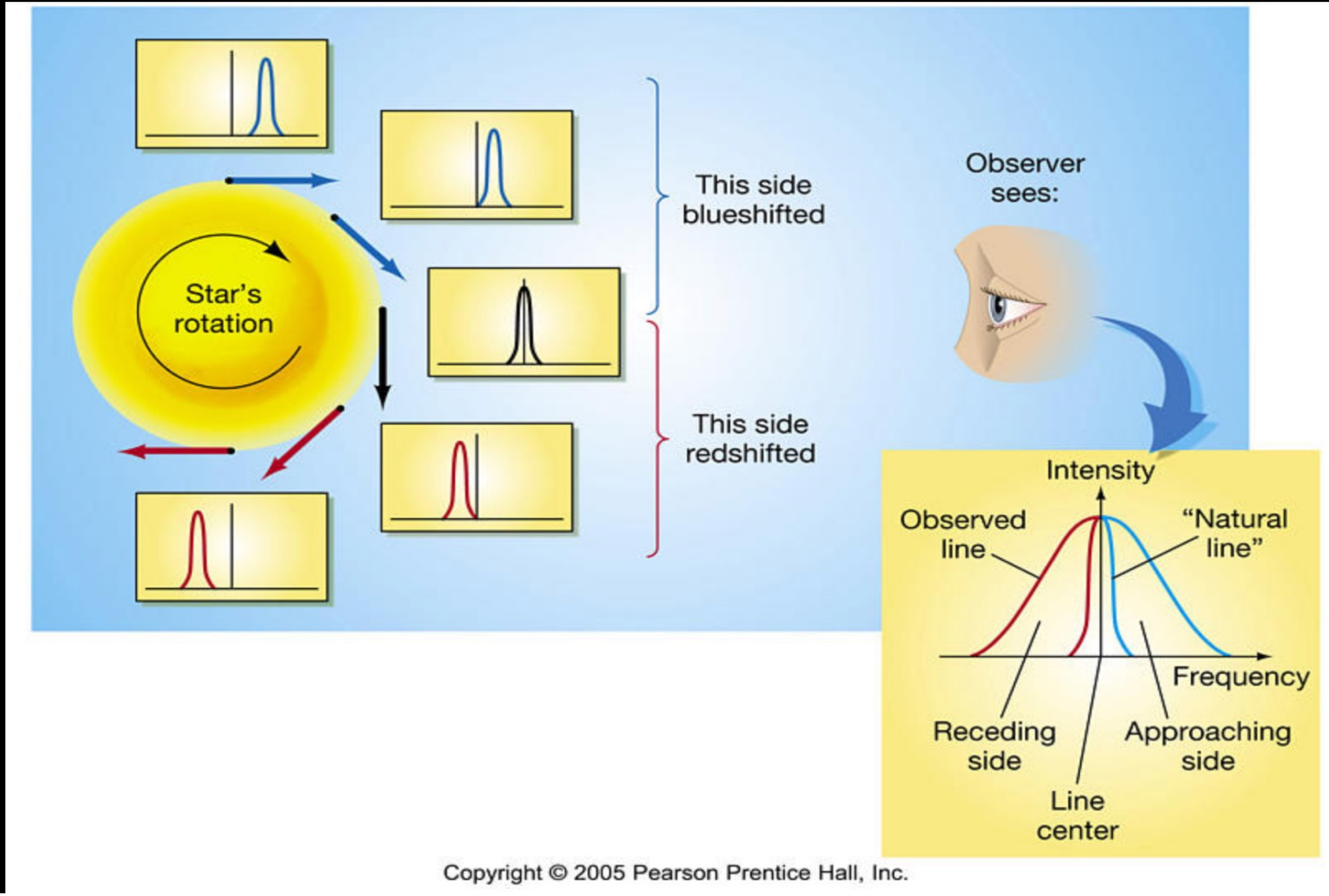
1) Direct Imaging
2) Radial Velocity
3) Transit detection
4) Timing
5) Astrometry



Radial Velocity in more detail

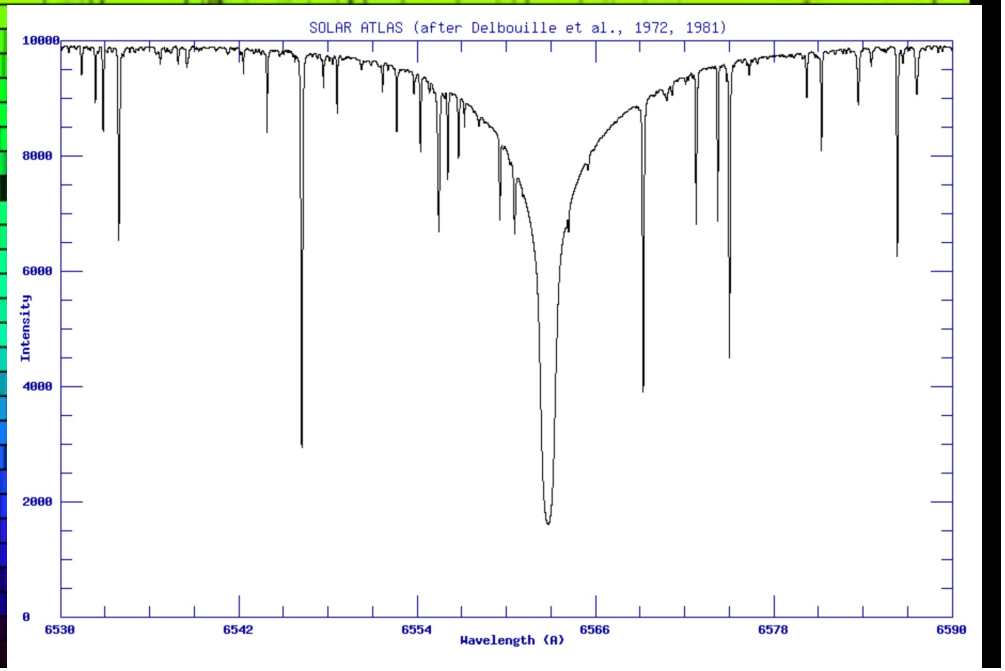
How is the radial velocity signal produced?

Think about an individual absorption line.



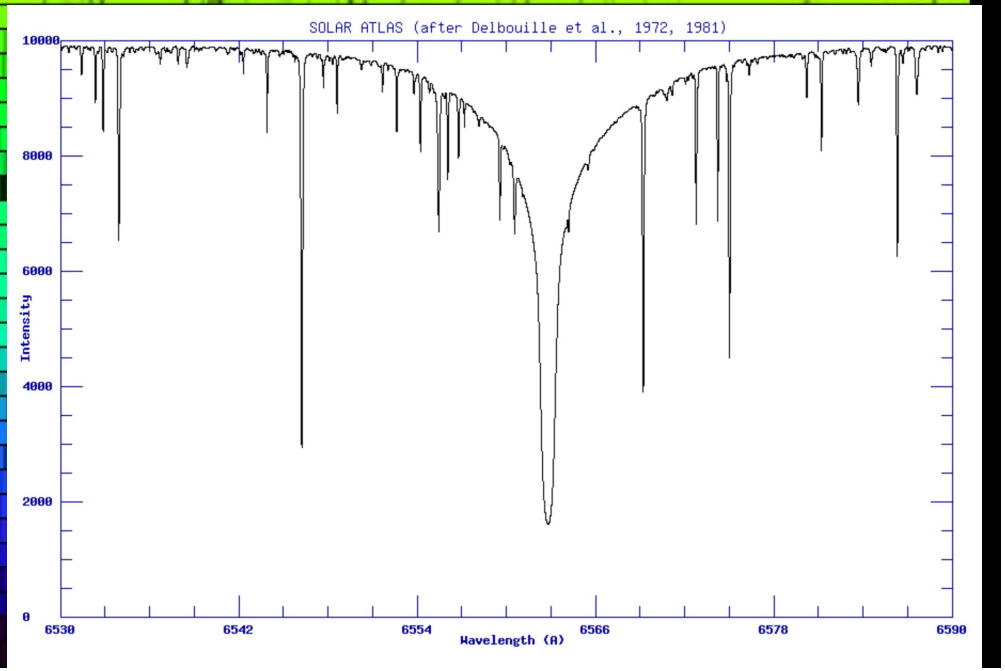
Radial Velocity in more detail

- **How is the radial velocity signal measured?**



Radial Velocity in more detail

- **How is the radial velocity signal measured?**
- **Typical spectrograph 2pixels on detector = 5 km/s**

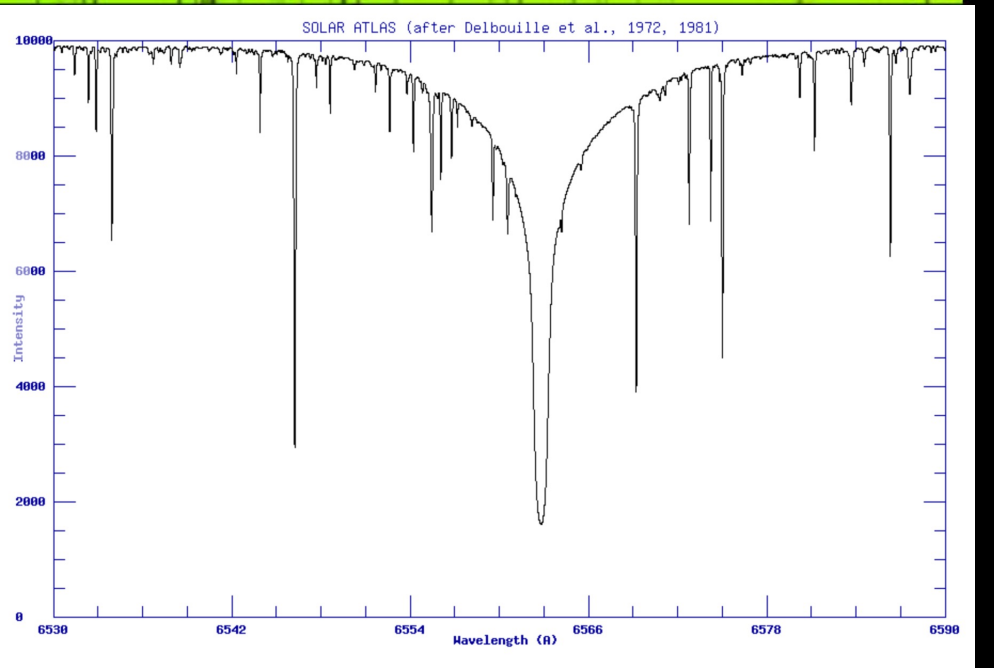


Radial Velocity in more detail

- **How is the radial velocity signal measured?**

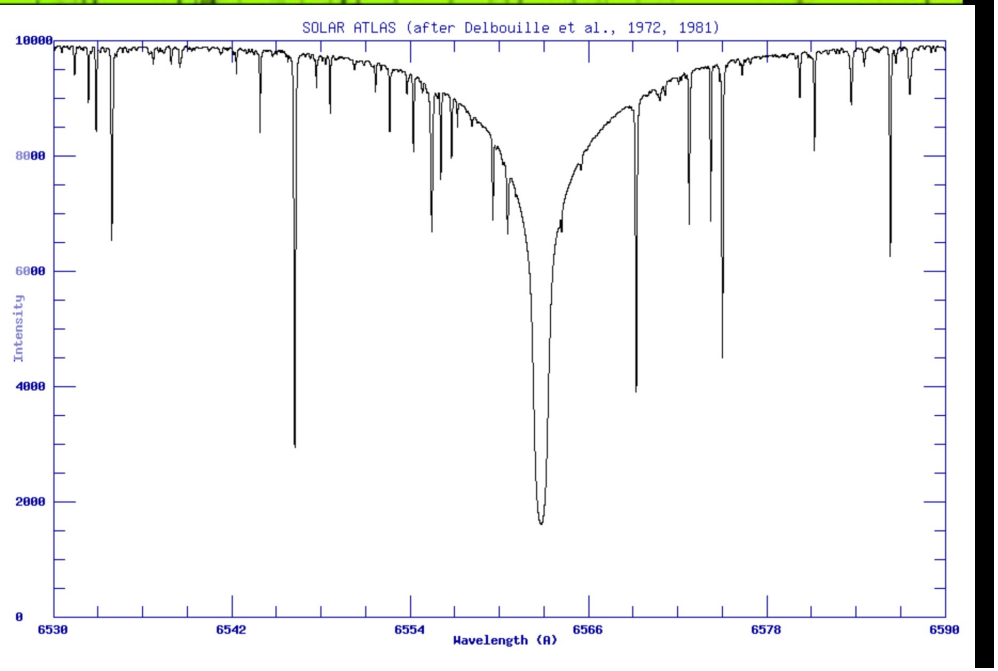
- **Typical spectrograph 2pixels on detector = 5 km/s**

- **To reach planet detection accuracy needs measurement of velocity to 1/1000 pixel**



Radial Velocity in more detail

- **How is the radial velocity signal measured?**
- **Typical spectrograph 2pixels on detector = 5 km/s**
- **To reach planet detection accuracy needs measurement of velocity to 1/1000 pixel**
- **Solution – measure thousands of absorption lines at once**



Radial Velocity in more detail

We are measuring the motion of the star as it orbits the centre of mass if it has a planet

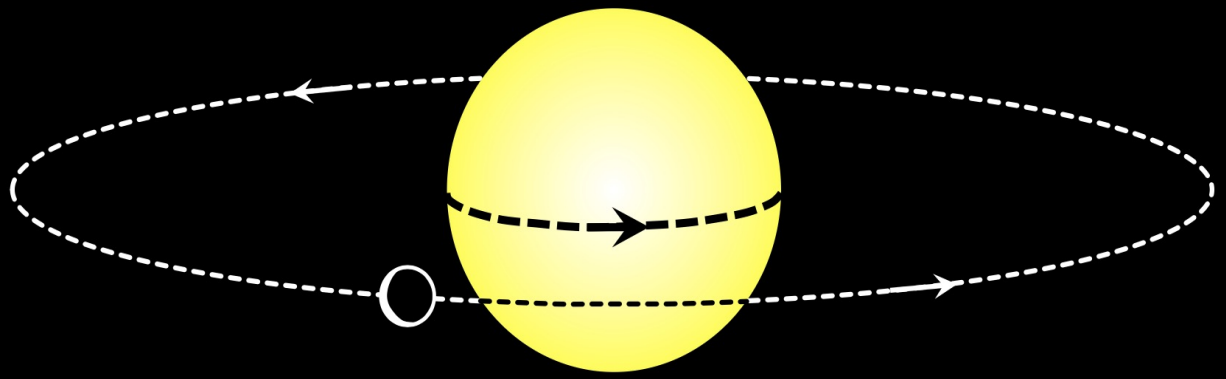
What is the radial velocity amplitude of a star for different kinds of planets (Sun-like star)?

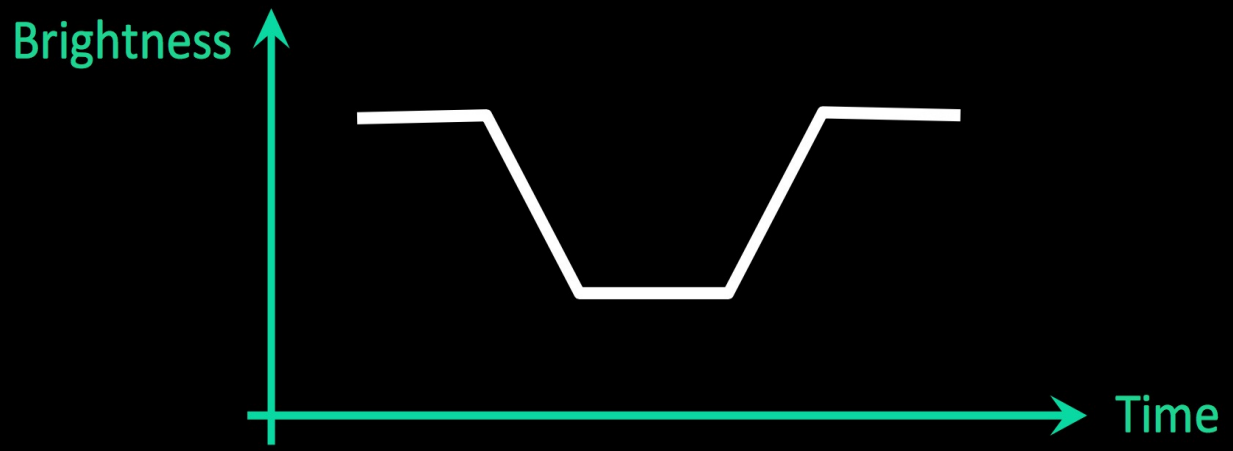
Example Object	a (AU)	k_* (m/s)		
Jupiter	1	28.4		
Jupiter	5	12.7	3-5m/s	
Neptune	0.1	4.8		
Neptune	1	1.5		
Super-Earth ($5M_E$)	0.1	1.4	1m/s	
Super-Earth ($5M_E$)	1	0.45		
Earth	1	0.09	Not feasible	

Radial velocity – RM an interesting aside

Light curve variations during a transit

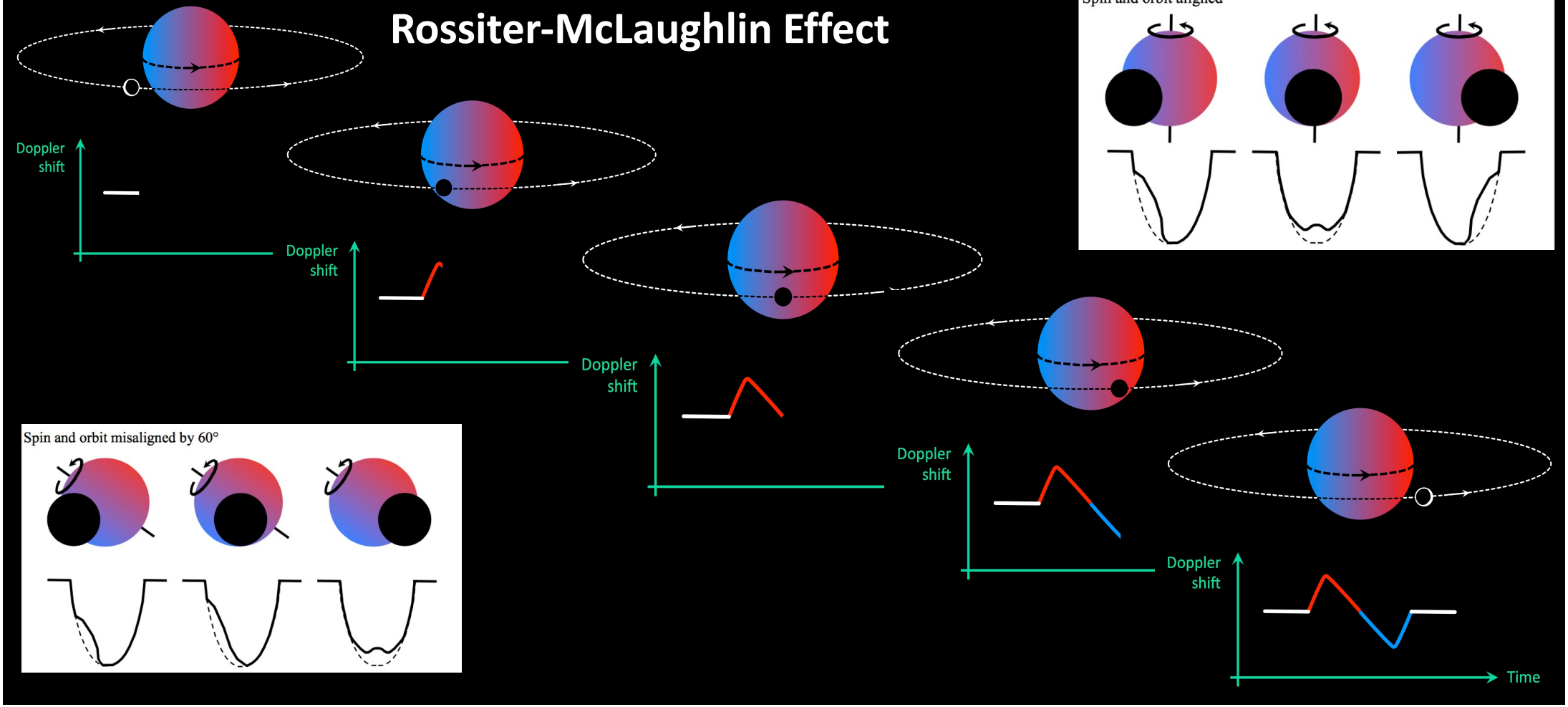
But what happens to the radial velocity of the star during this time





Radial velocity – RM an interesting aside

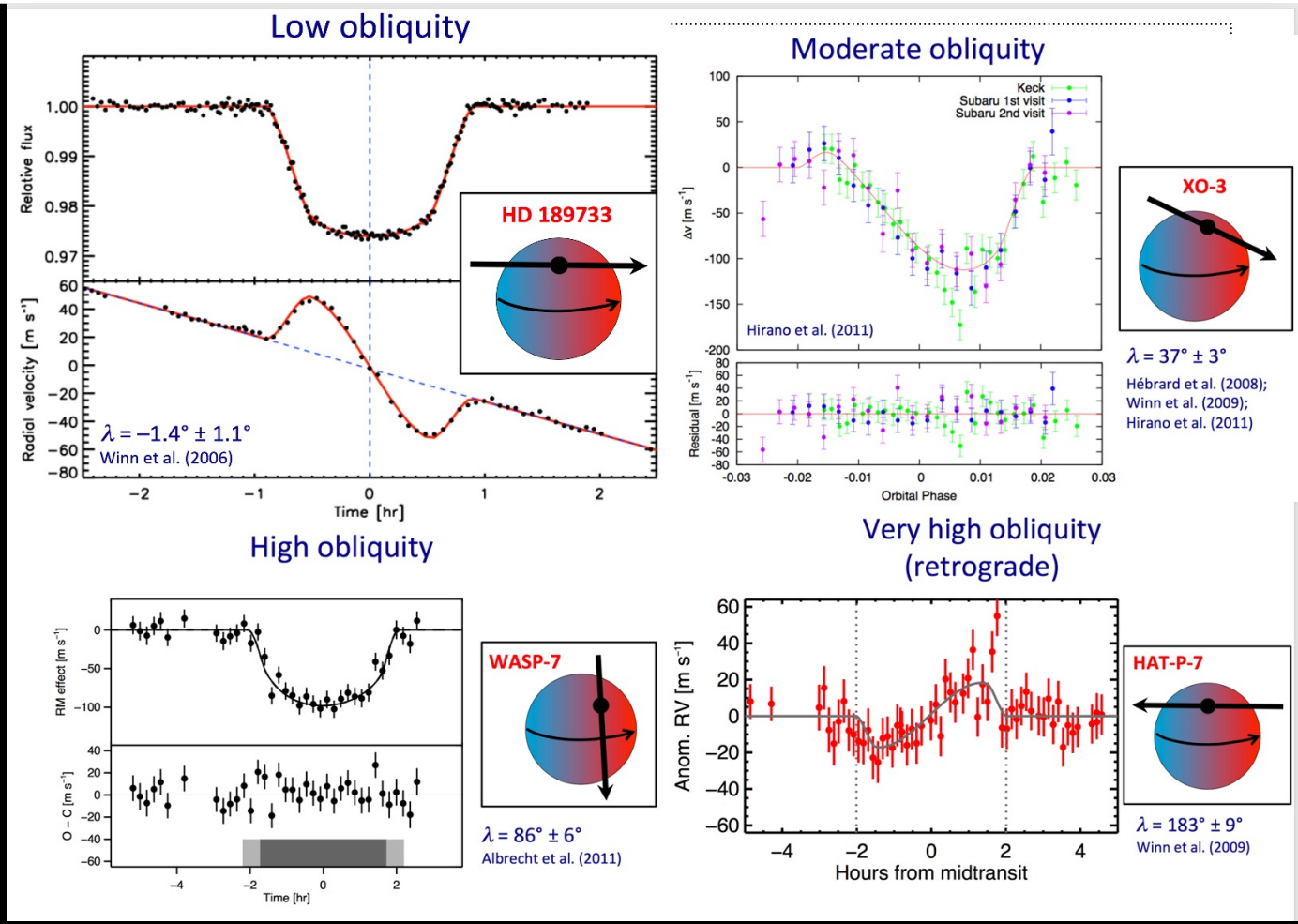
Rossiter-McLaughlin Effect



Radial velocity – RM an interesting aside

Planets moving in inclined orbits

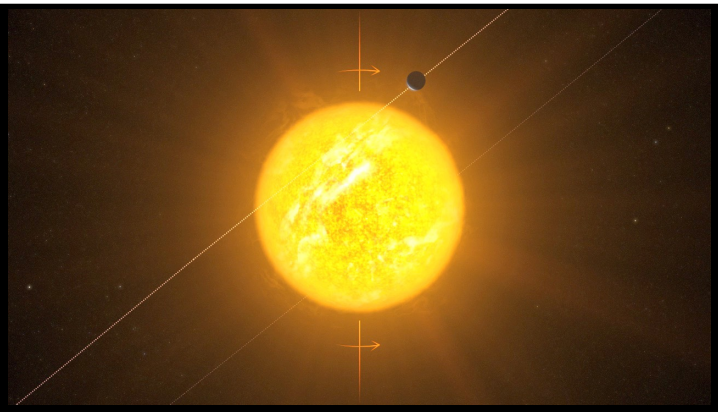
Very different to the solar system

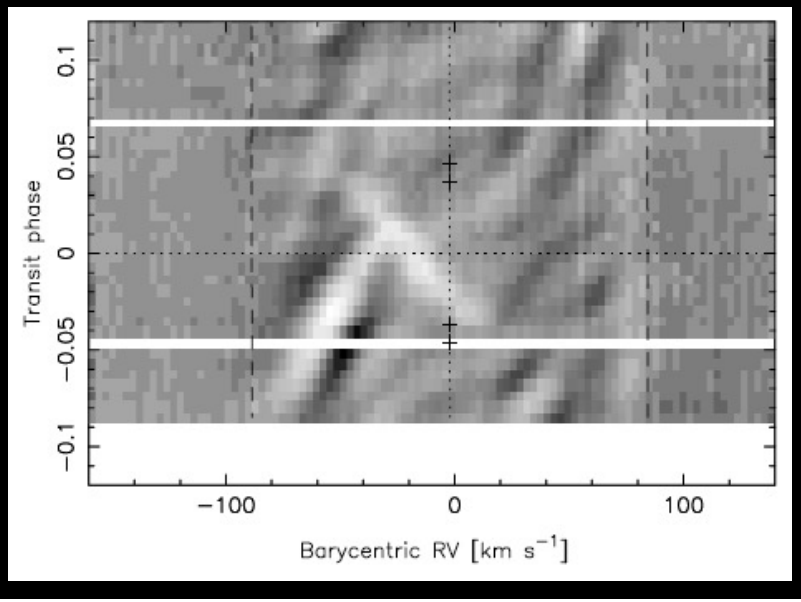


Radial velocity – RM an interesting aside

- Maybe 85% hot jupiters mis-aligned orbits!
- E.g. WASP-33b (A5V):
- Winn et al 2010: strong misalignments more common in planets orbiting hot stars.

Remember Gas giants must have formed at great distance from the host and somehow migrated inwards. Clues to planet-planet scattering.

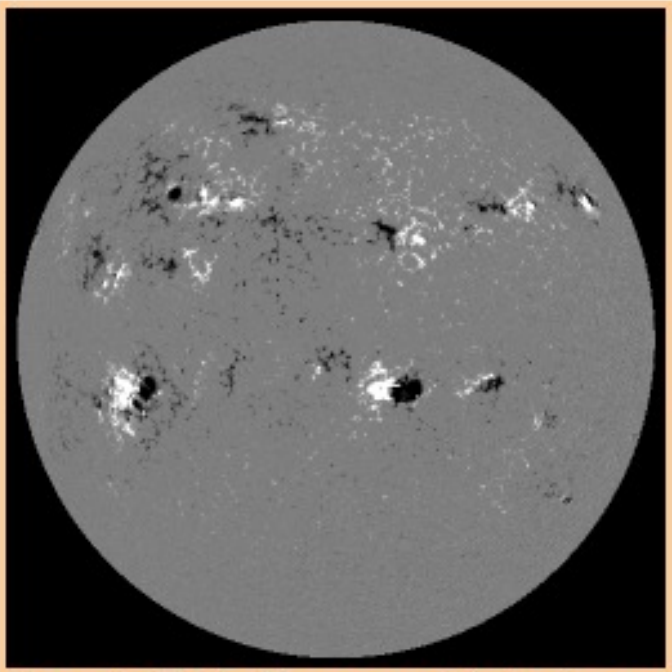




Activity in the Sun

Activity in the Sun (ccf Keith Strong's talk)

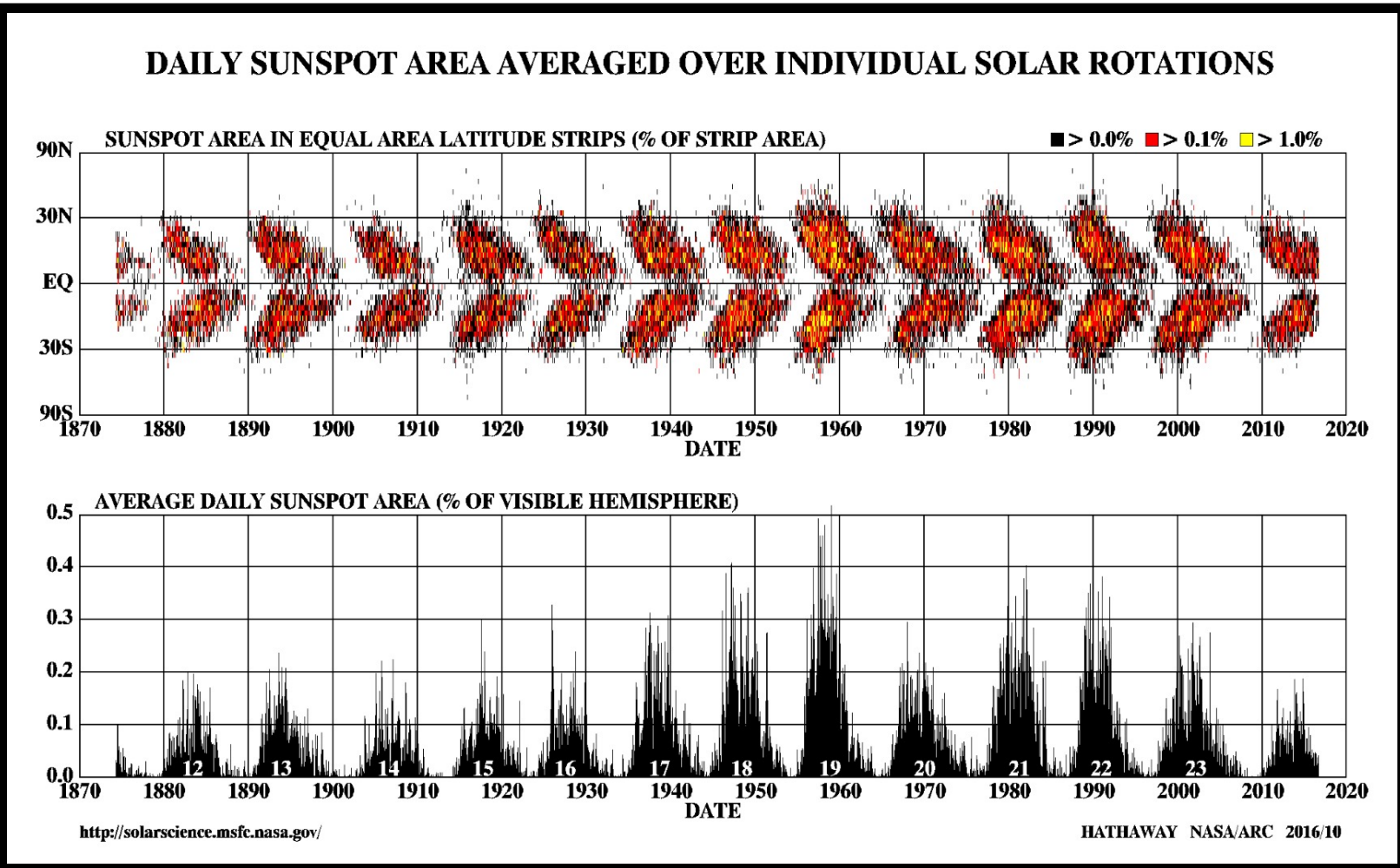
Sunspots and other activity are signs of magnetic fields



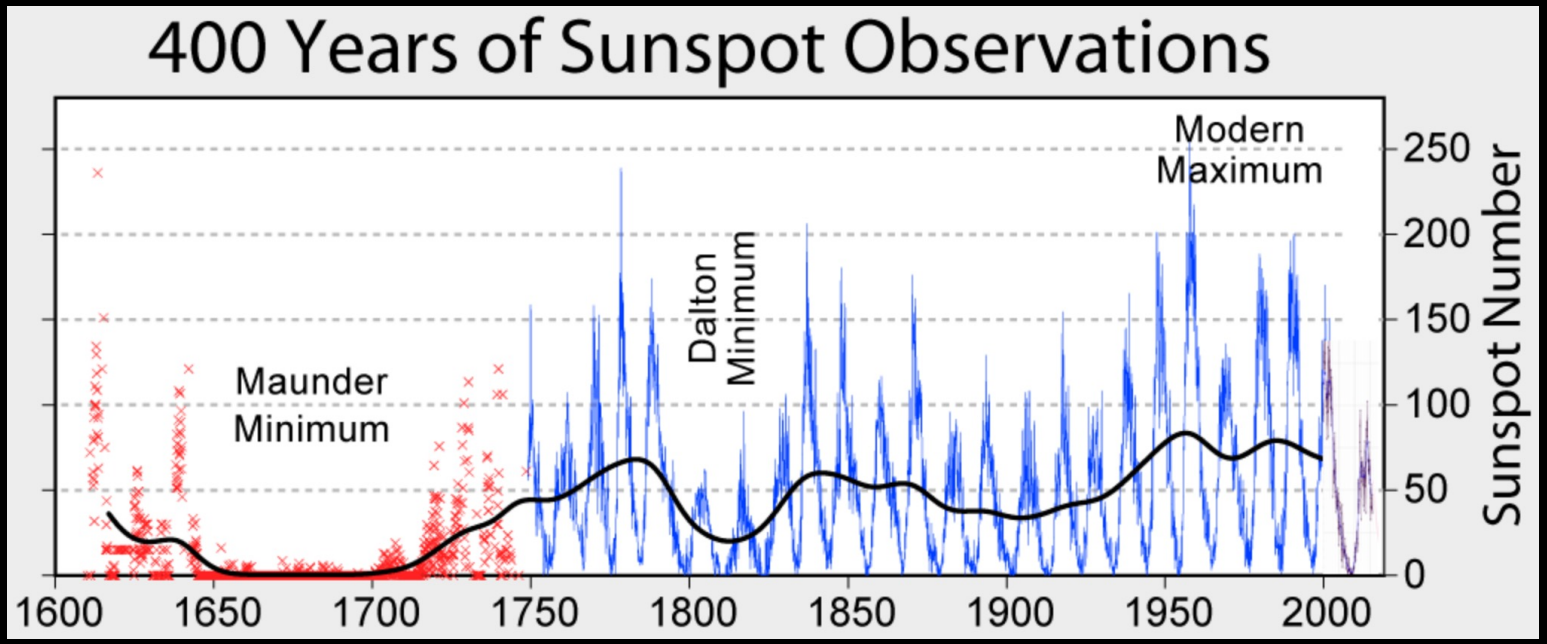
Magnetic Fields: The sunspots in the image at right are revealed to be areas of strong, opposite polarity magnetic fields, which extend to even larger areas than the spots themselves.

Notice the lighter areas, called faculae, which are found near sunspots and are also areas of strong magnetic field.

Activity in the Sun: Sunspot Butterflys

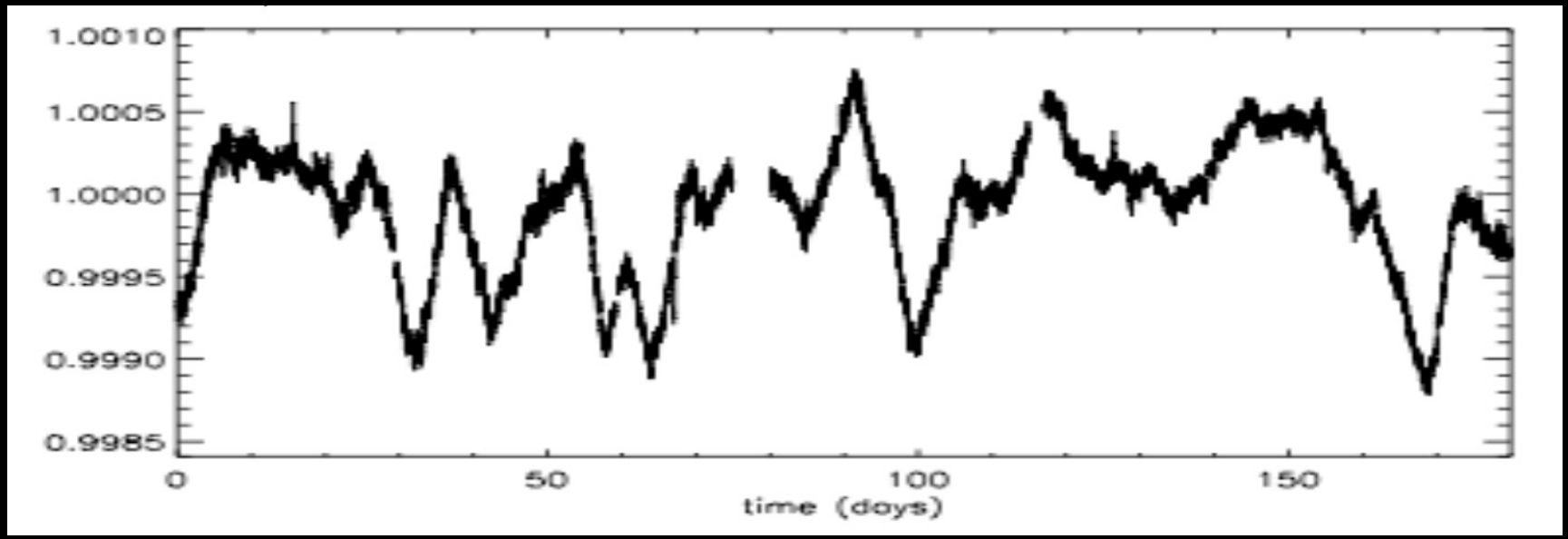


Activity in the Sun: Sunspot Numbers



A real effect – corresponds with a period of extreme winters (eg River Thames froze over) => lower solar luminosity

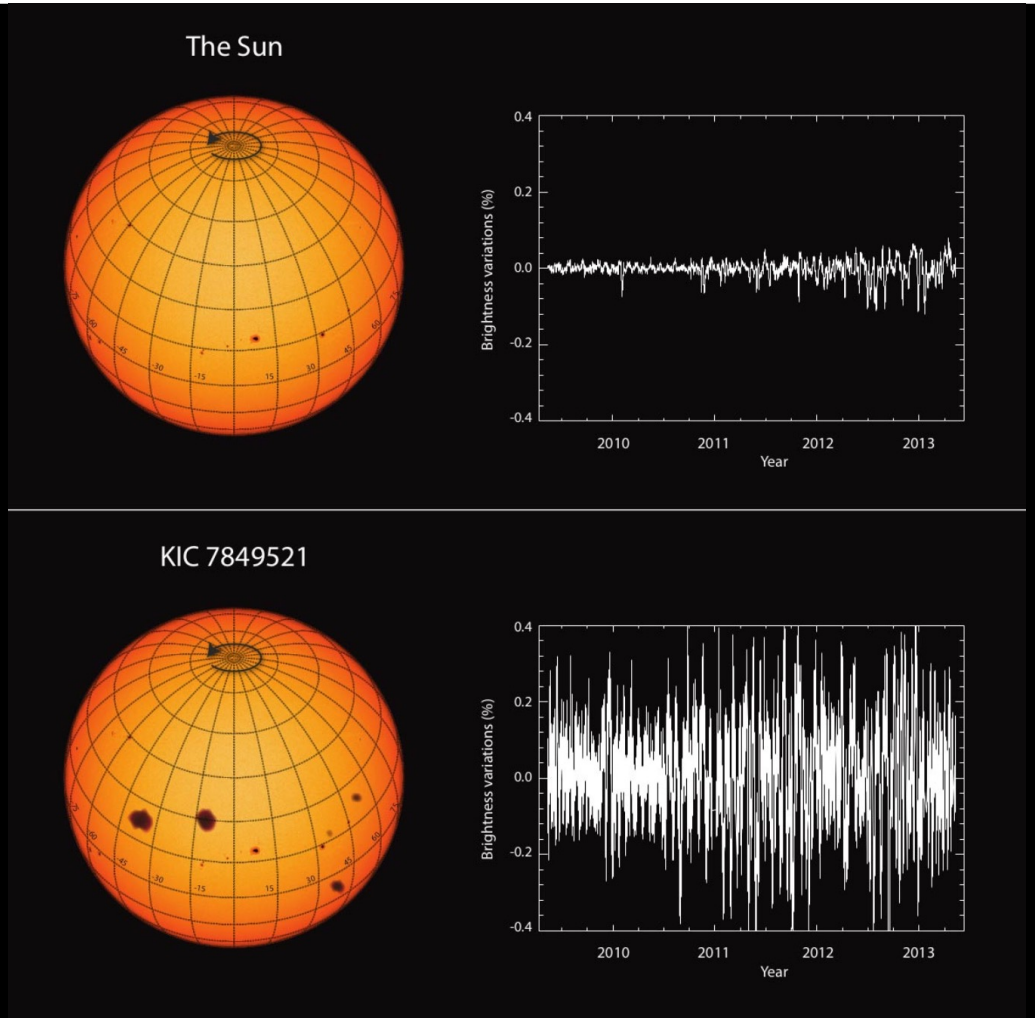
Activity in the sun: Brightness variations



Photometric variations in the suns brightness over 6 months

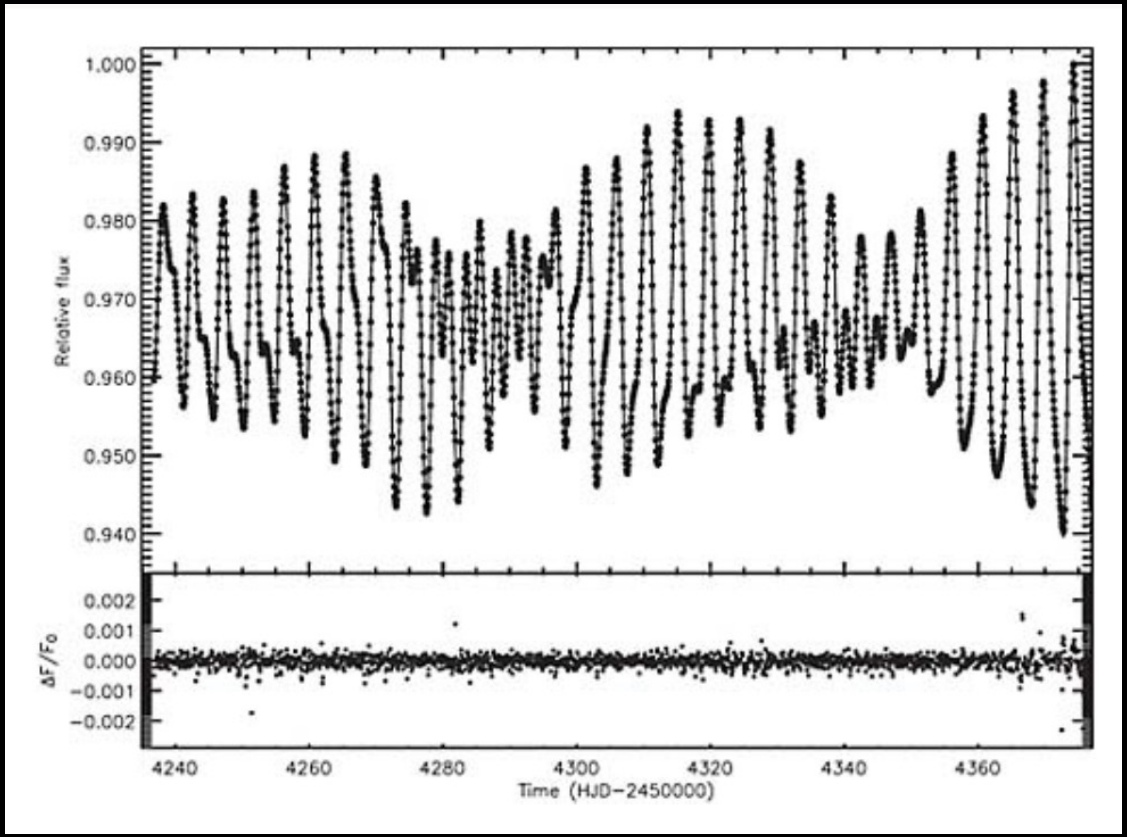
Activity in the sun

The relative effect on brightness of activity



Signs of Photometric activity in stars

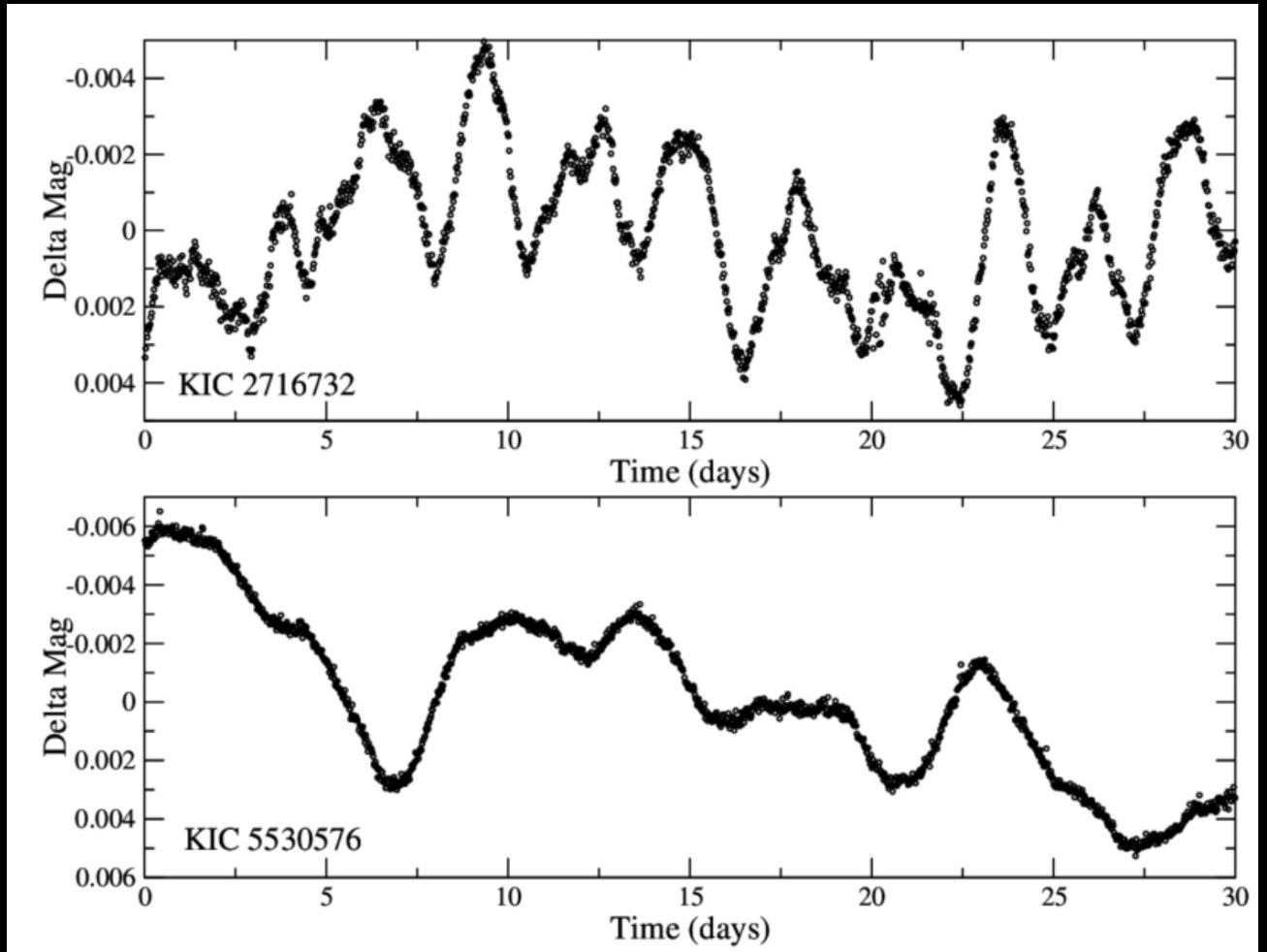
Light curve of a Sun like star fitted with model with 2 spots



Signs of Photometric activity in stars

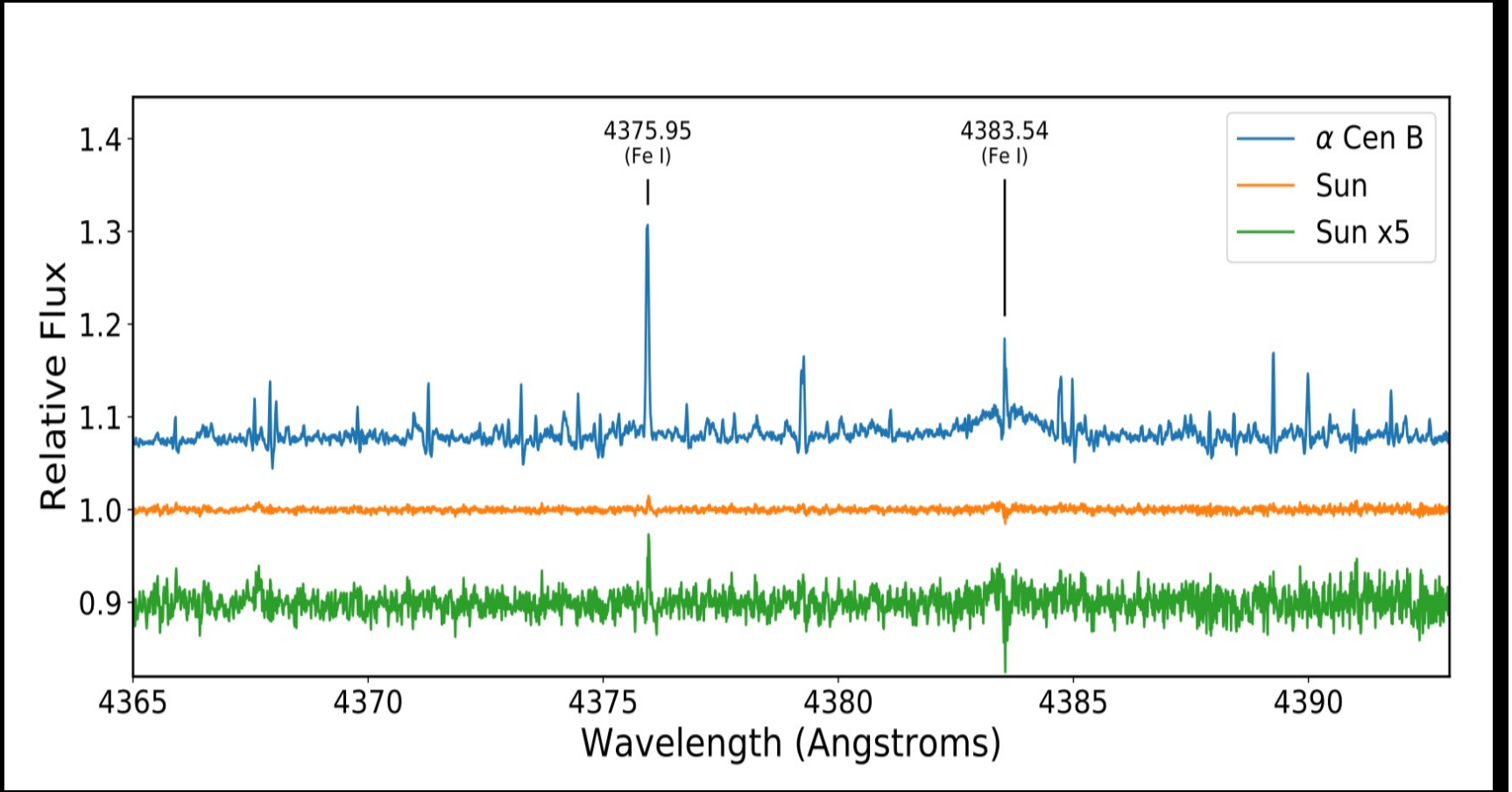
Lots of different rotation periods…

Are there any “quiet” stars?



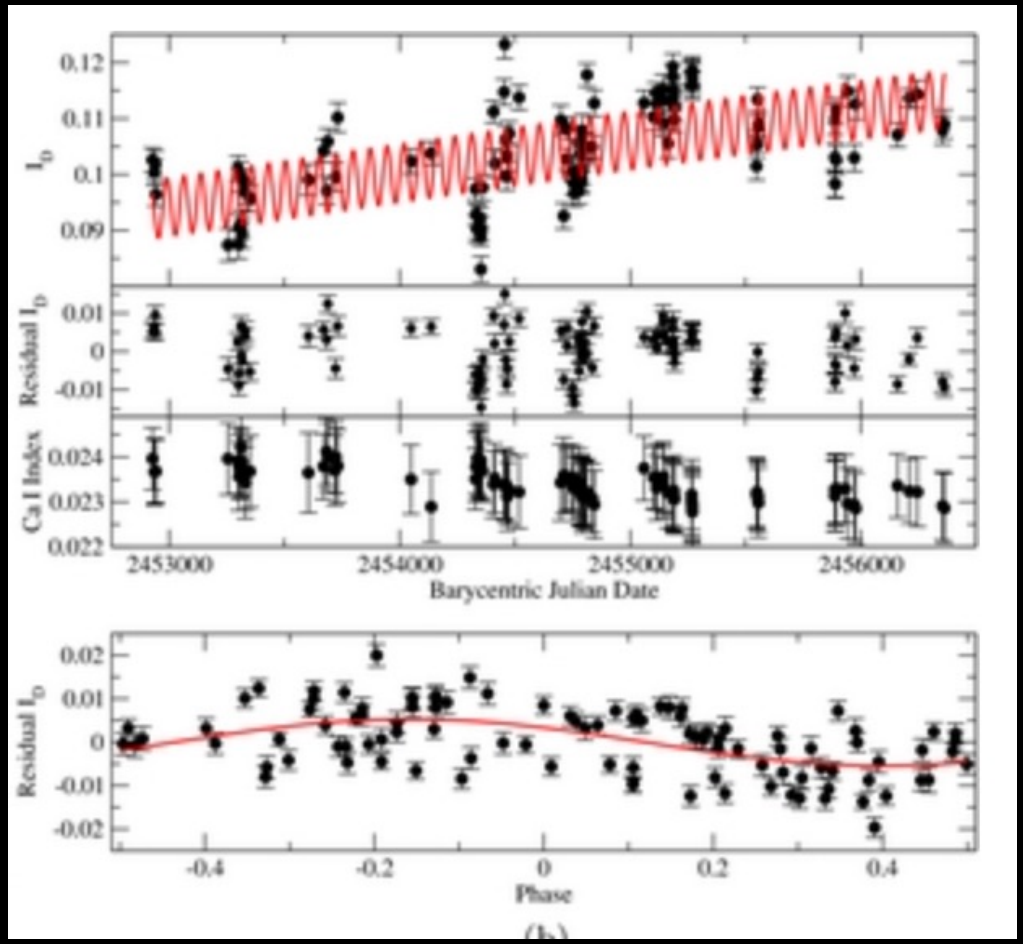
Activity in the sun: spectroscopy

Signs of activity in solar spectrum compared to star of known activity



Activity – spectroscopic signs

Activity signals introduce variations in the spectrum and contaminate the radial velocity measurement.



What are the effects on the spectrum of different activity?

- Convection
- Spots
- Magnetic fields

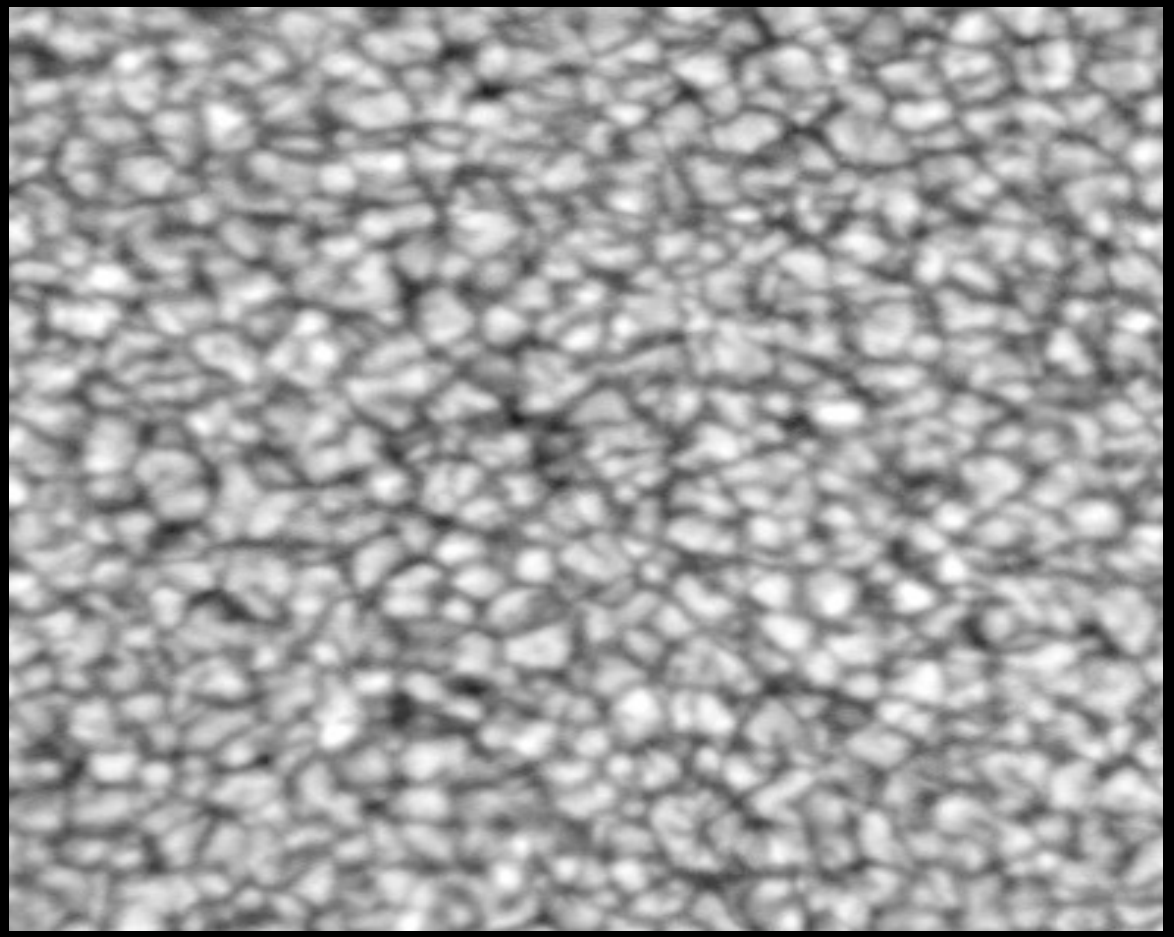
Spectroscopic effects: Convection

Time lapse of a 1000x1000km region of the Solar surface for 1 hr

Hot material comes up from deeper areas (bright areas)

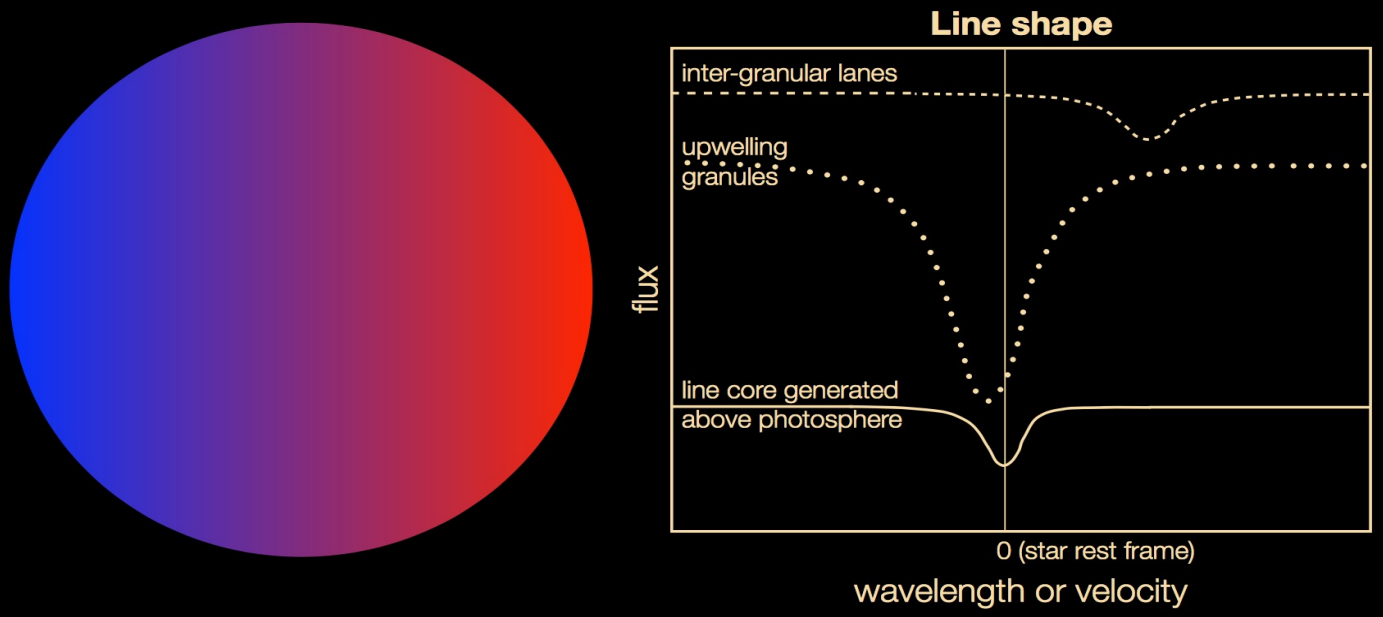
Cools and descends in dark lanes

=> CONVECTION Cells



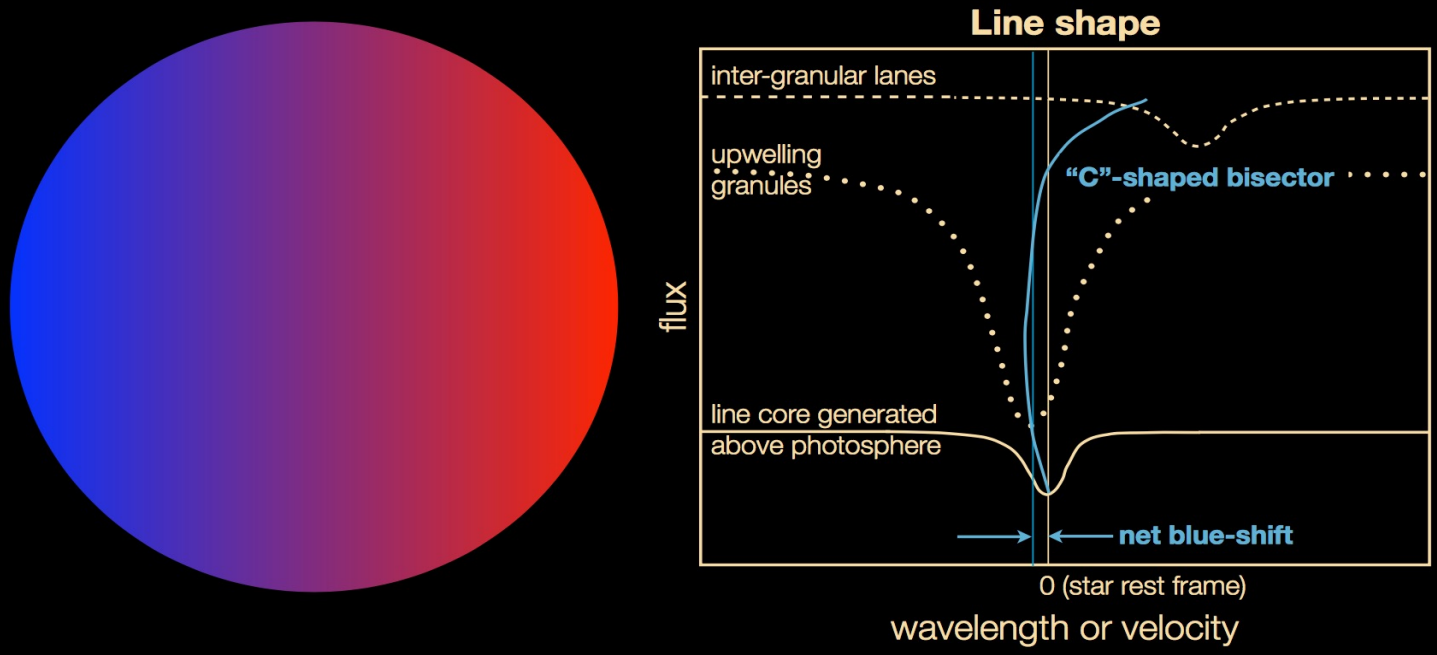
Spectroscopic effects: Convection

Spectral line in “normal” photosphere



Spectroscopic effects: Convection

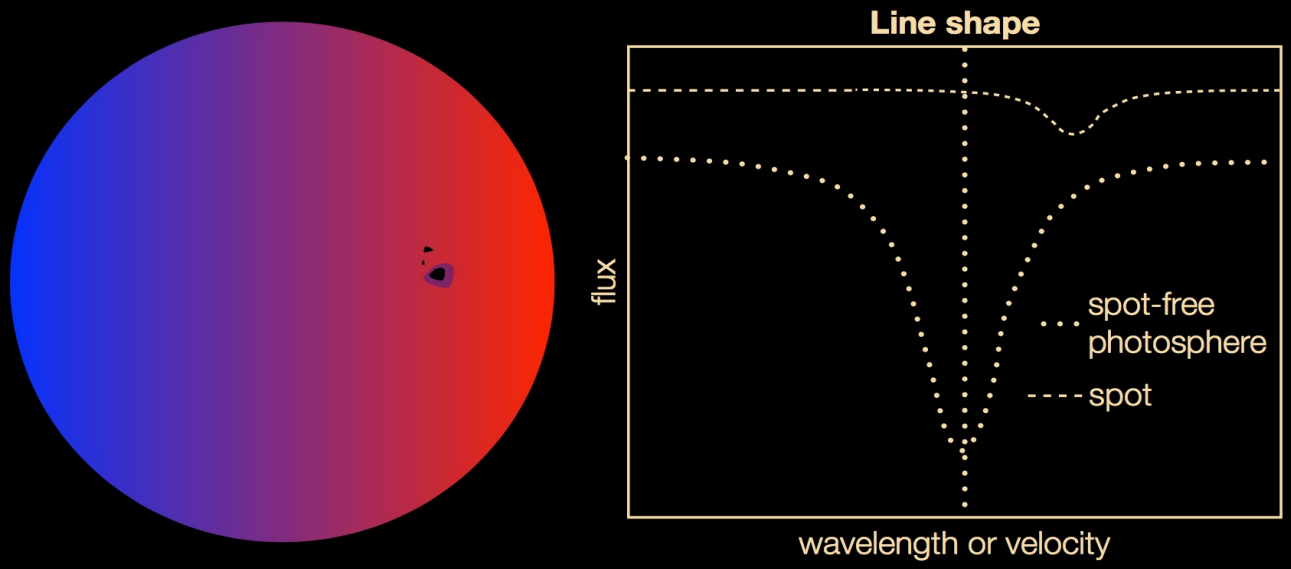
Spectral line in “normal” photosphere



Line shape and absolute convective blue-shift depend on line strength (Gray 2009)

Spectroscopic effects: Spots

RV effects of activity - 1:
distortion of rotation profile (a.k.a. photometric effect)



Spectroscopic effects: Spots

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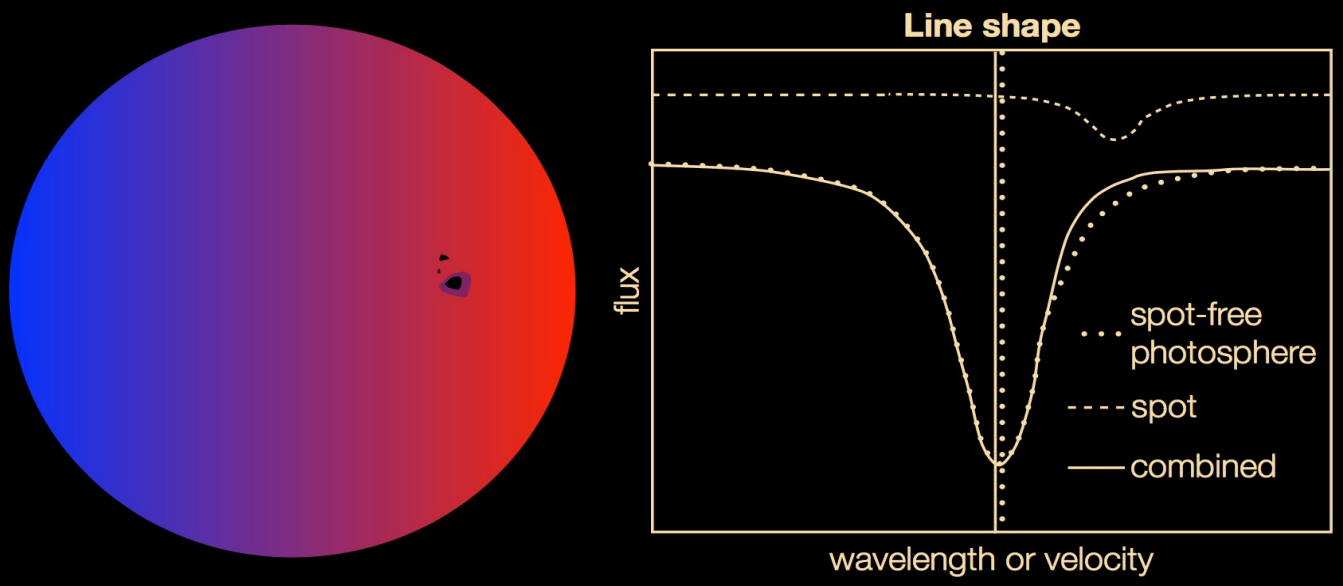
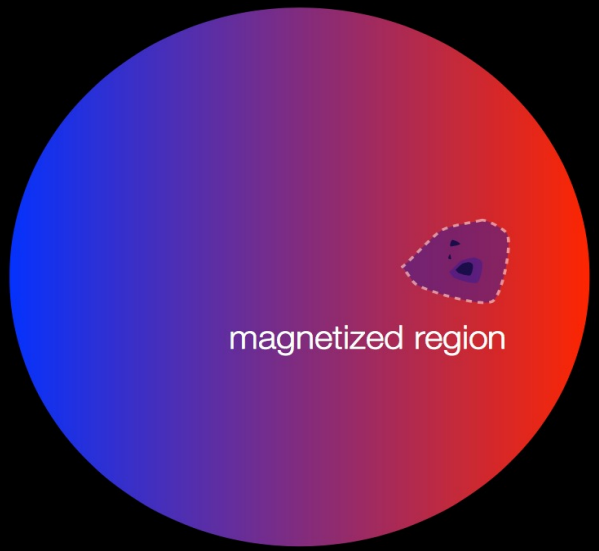


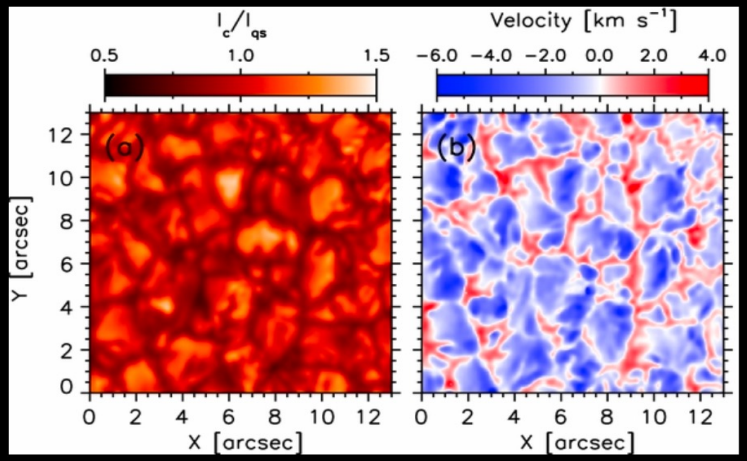
Spectroscopic effects: Spots

RV effects of activity - 2: convective blueshift suppression



Convection is partially suppressed in regions where surface magnetic field is large

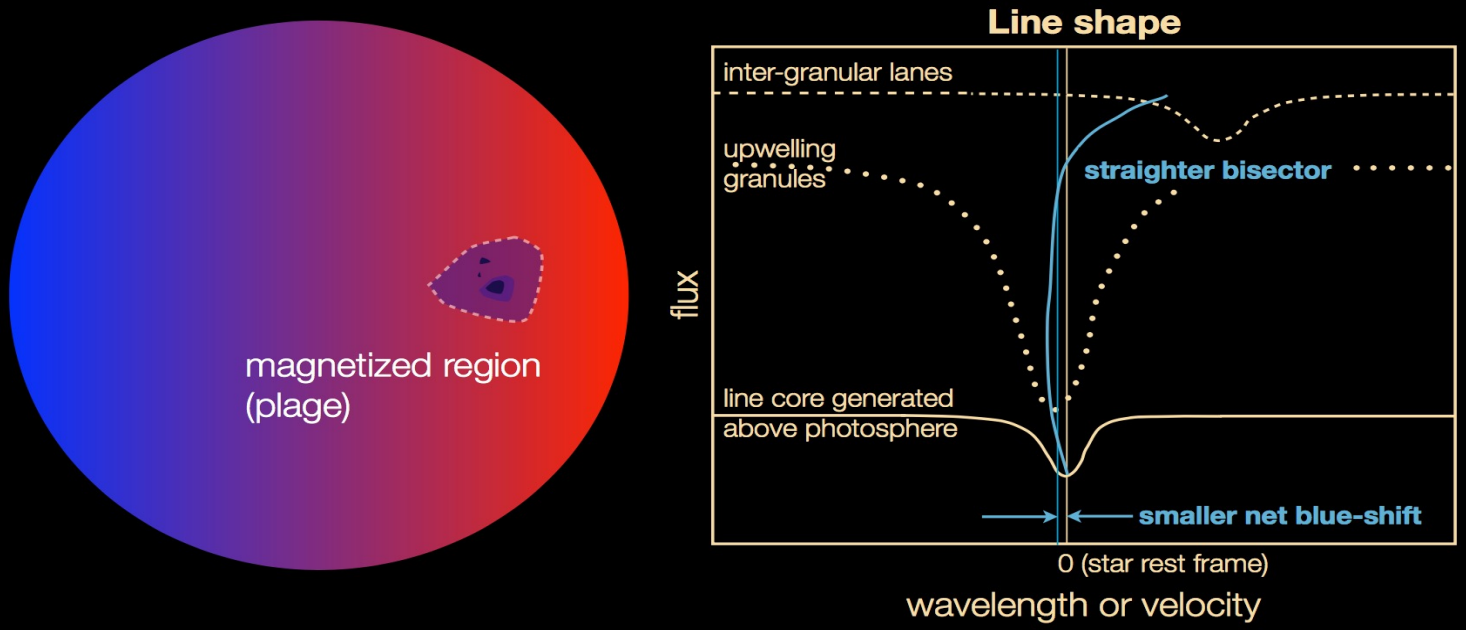
Why does this affect RVs?



Joshi et al. (2011)

Spectroscopic effects: Spots

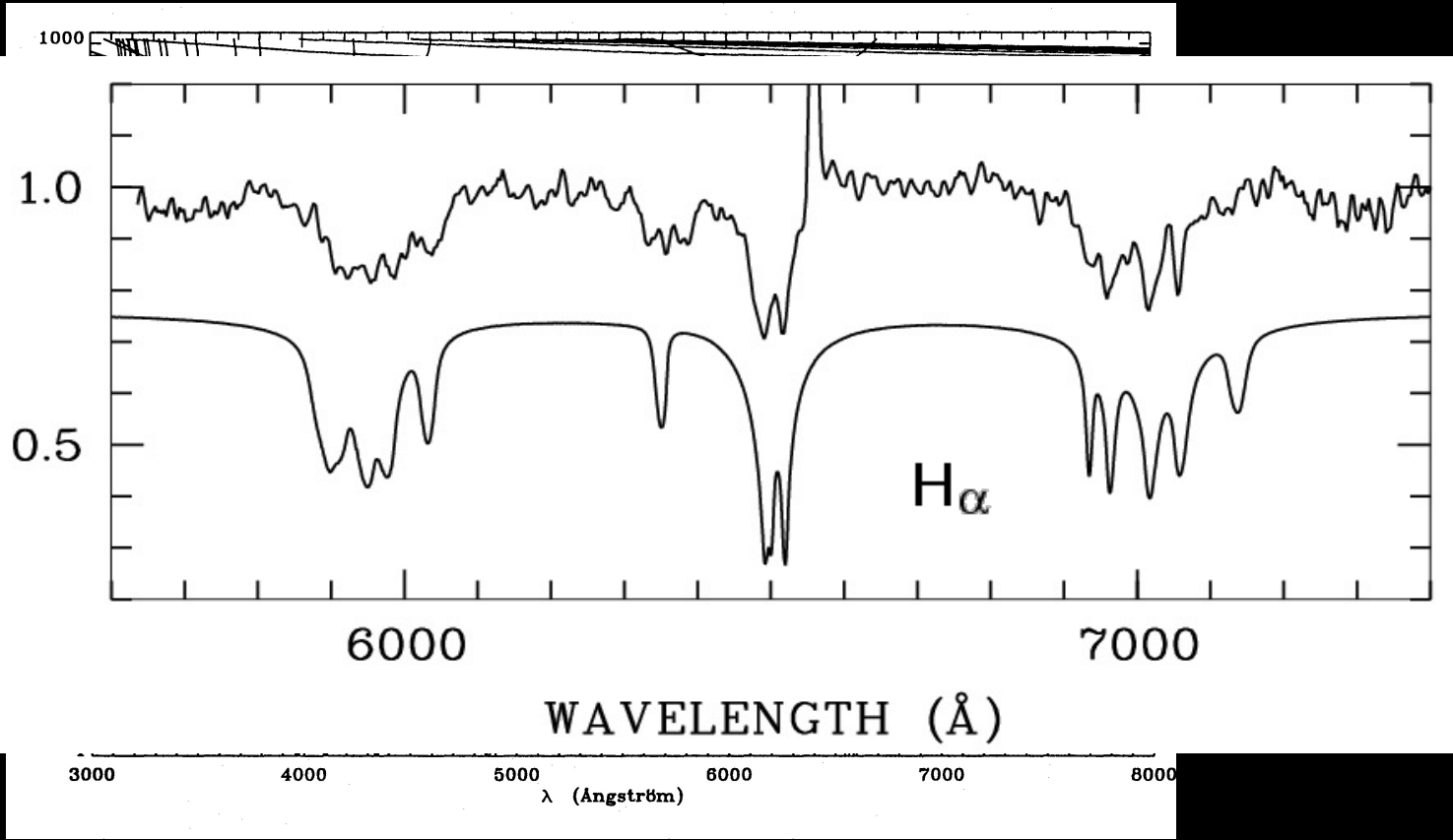
Effect of convective blueshift suppression on RV and spectral line shape



This dominates over the effect of spots for the Sun (Meunier et al. 2010)

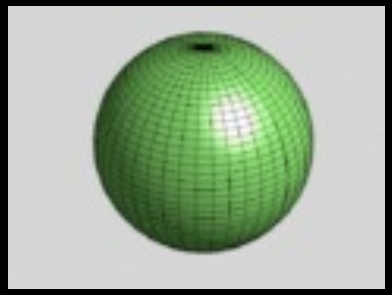
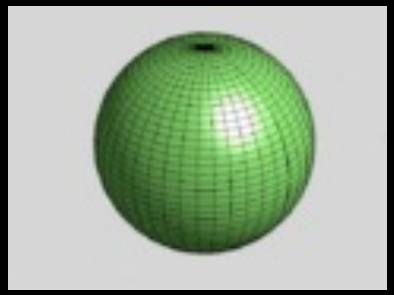
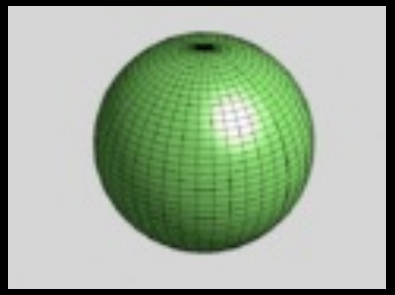
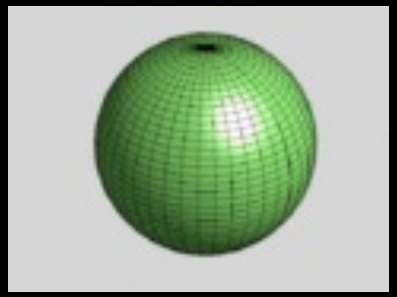
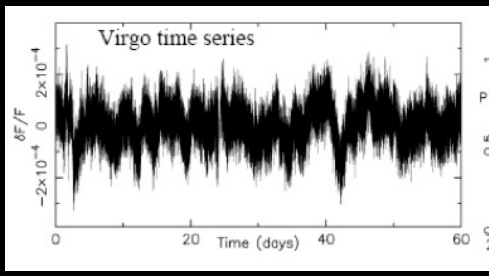
Effects of really strong magnetic fields

Zeeman Effect: wavelengths of hydrogen Balmer lines with increasing magnetic field strength



Spectroscopic effects: Pulsations

Sun-like stars Pulsate in complex ways (depends on internal conditions and mass/radius etc).
Parts of surface moving towards and away from observer – disturbs the absorption line profile

Implications for observation strategy ie sum observations over pulsation “period”

What does this mean for transit detection?

- Increased activity -> more difficult transit detection (for given planet size)
- For fixed activity level -> smaller planets more difficult to detect
- Activity can “mask” transits for small planets
- Solution: observe more transits!
- Places strong observation baseline pressures

What does this mean for RV measurements?

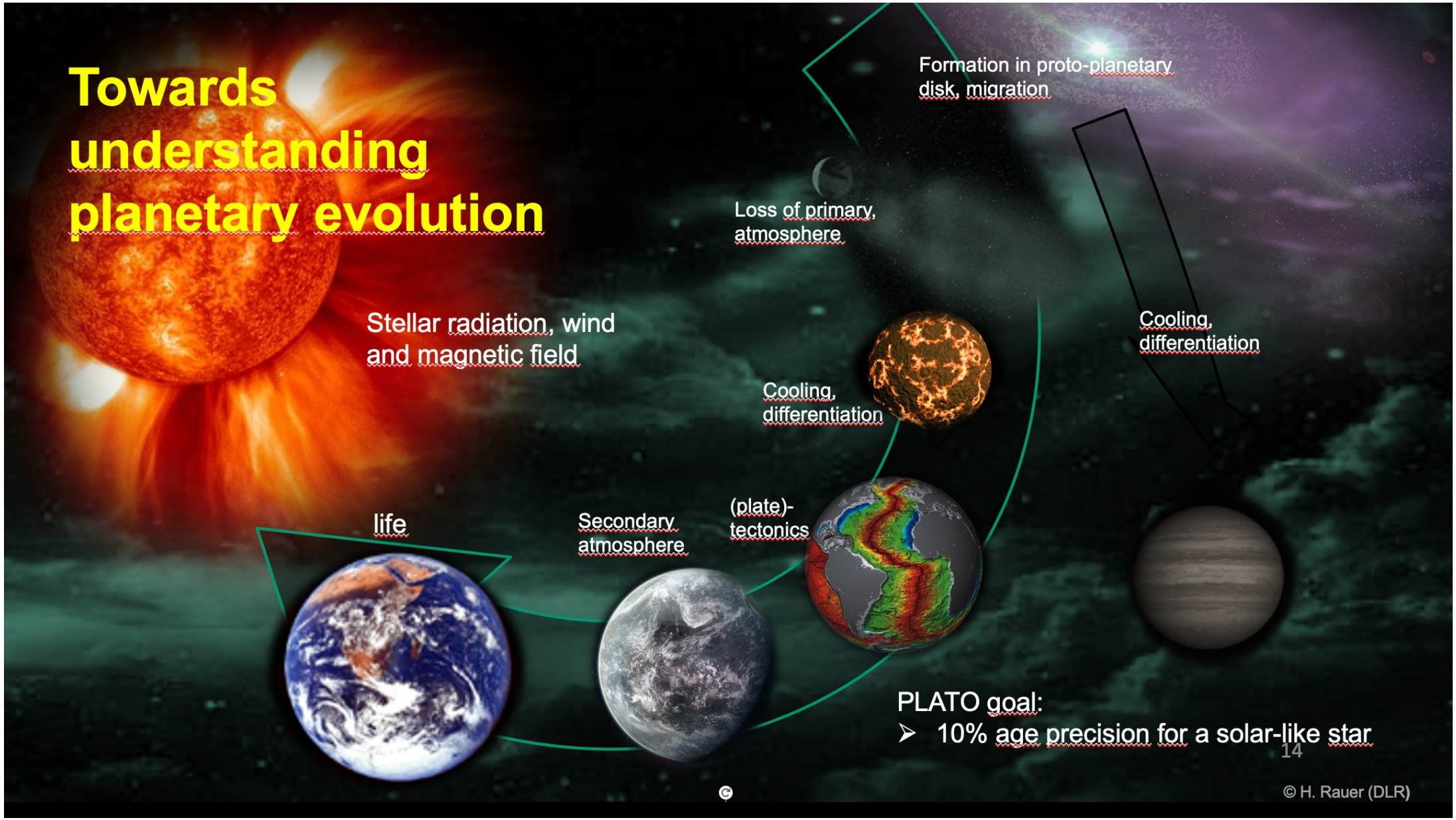
- Increased activity -> more distortions of *some* absorption lines
- For fixed activity level -> lower mass planets more difficult to detect
- Activity makes orbit determination more difficult
- Solution: Low activity stars – multiple observations combined into each RV point ie try and average out the activity signal
- Better, smarter solution: model the physics and correct the signal
- Activity timescales from minutes to much longer

Prospects for 10 cm/s….

- The first spectrographs with this level of stability are now entering service (ESPRESSO at the VLT/ESO), but there will be very few.
- The *averaging observations technique* needs a shed load of data eg for a bright Earth-Sun analog (V~9) about 33nights of VLT time needed.
- An immense amount of research trying to understand how to identify the activity signal (in spectra) and “correct” for it – really difficult problem.
- Lateral thinking – activity signals shown to be lower at IR wavelengths (I don’t understand why). However, RV signals increase in amplitude at longer wavelengths -> in principle easier to measure, in practice….

Summary & PLATO Requirements

- PLATO is the Habitable Zone rocky planet explorer – looking to characterise and compare 1-2$R_{\oplus}$ planets (accurate R, M, ρ, and Age).
- *Correcting for activity* will be vital to reach these aims.
- Current approach of averaging observations will work but is akin to using a hammer to crack a nut.
- Current discussions with ESO suggest that 400n of VLT maybe available ie ~10 Earth-Sun analogs.
- Expensive! (But should be seen against the back-drop of zero Earth Analogs currently characterized). (Priced at 50K euro/night).
- *Understanding activity* will lead to more efficiency – hence more characterized rocky planets.


Towards understanding planetary evolution
Formation in proto-planetary disk, migration
Loss of primary atmosphere
Stellar radiation, wind and magnetic field
Cooling, differentiation
Cooling, differentiation
life
Secondary atmosphere
(plate)-tectonics
PLATO goal:
➢ 10% age precision for a solar-like star
14
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