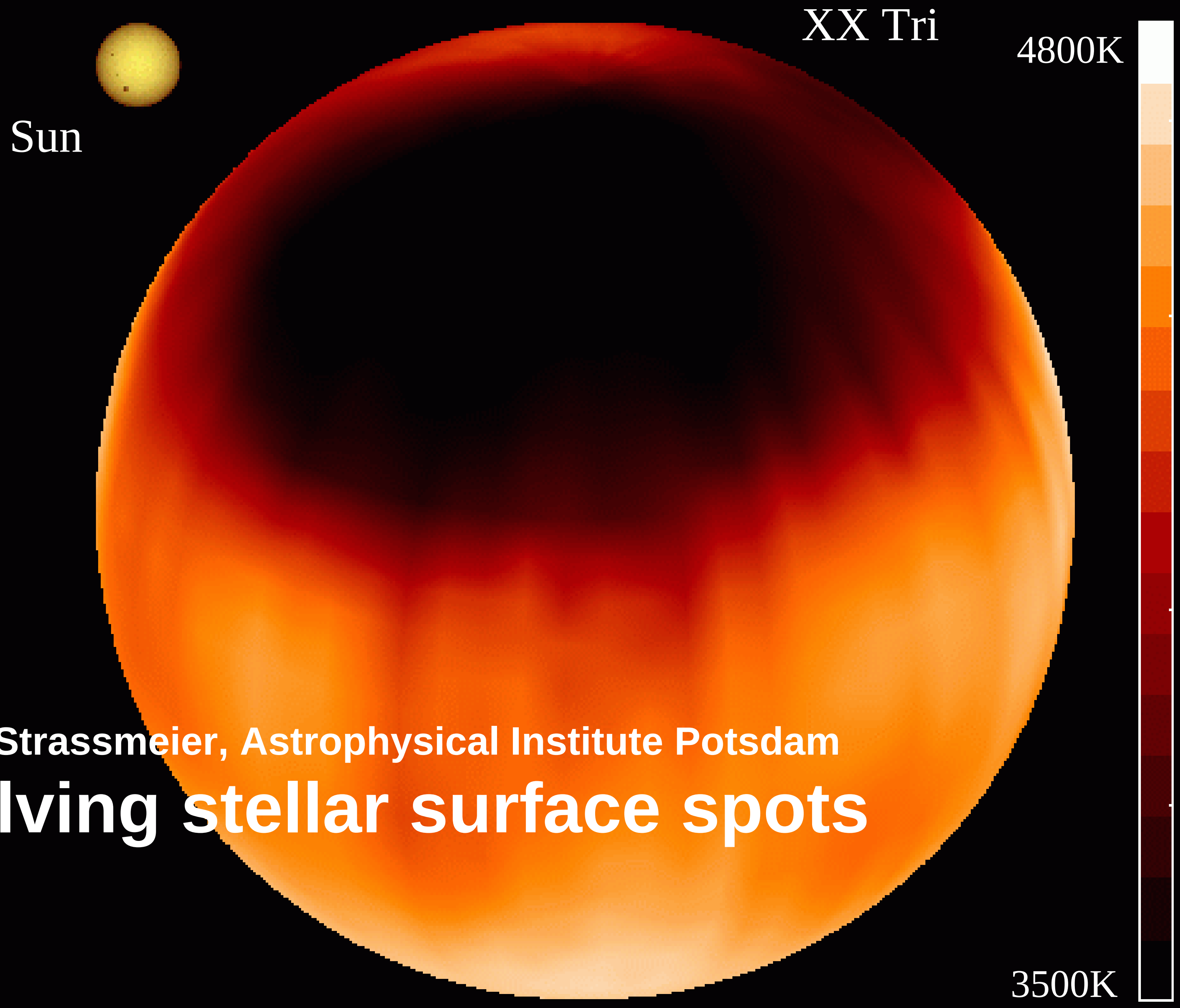
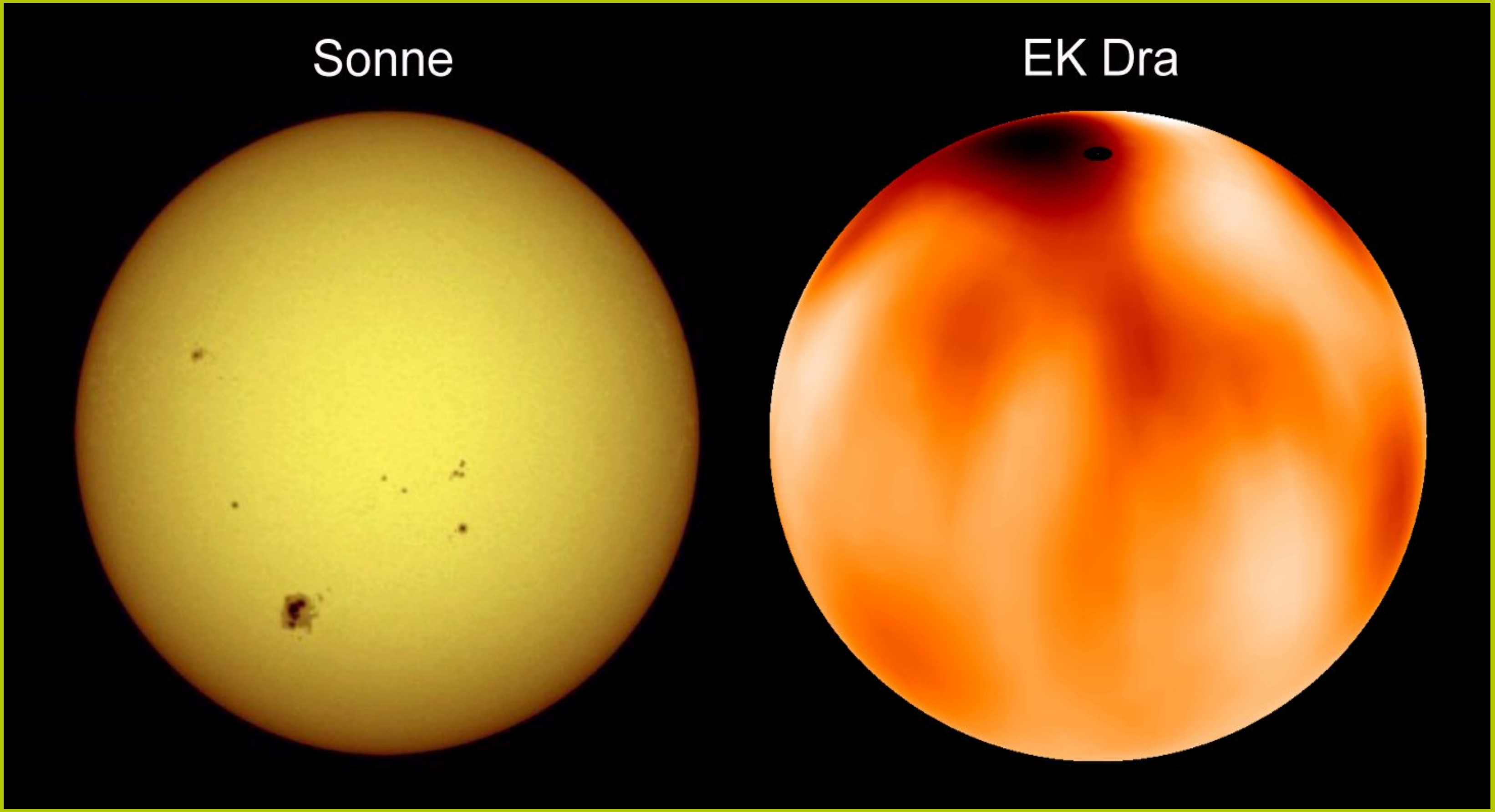
Resolving stellar surface spots

Klaus G. Strassmeier, Astrophysical Institute Potsdam



Why observing stellar spots?

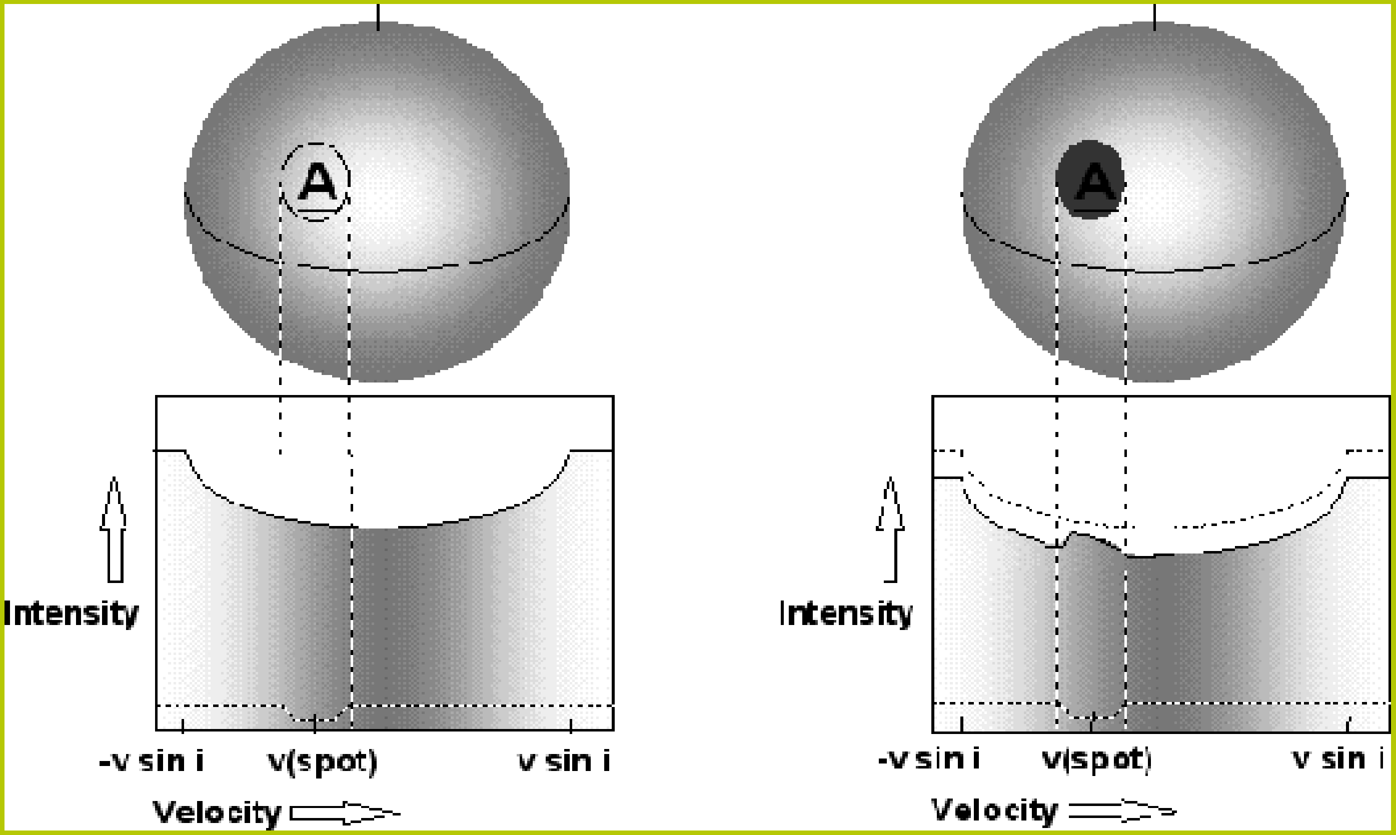
- **Magnetic fields**
  - affect the evolution of structure in the Universe and
  - drive stellar activity which is key to life's origin and survival
- **But our understanding of how magnetic fields form and evolve is currently very limited**
  - Our close-up look at the Sun has enabled the creation of approximate dynamo models, but none predict the level of magnetic activity of the Sun or any other star
- **Major progress requires understanding stellar magnetism in general and that requires a population study**
  - we need maps of the evolving patterns of magnetic activity, and of subsurface flows, for stars with a broad range of masses, radii, and activity levels
- **This understanding will, in turn, provide a major stepping stone toward deciphering magnetic fields and their roles in more exotic, complex, and distant objects**



Theoretical resolution limit of a telescope = *1.22 λ / D* = ***0.04”***
(without AO ***0.4”-1.0”***, *with AO* ***0.1“)***

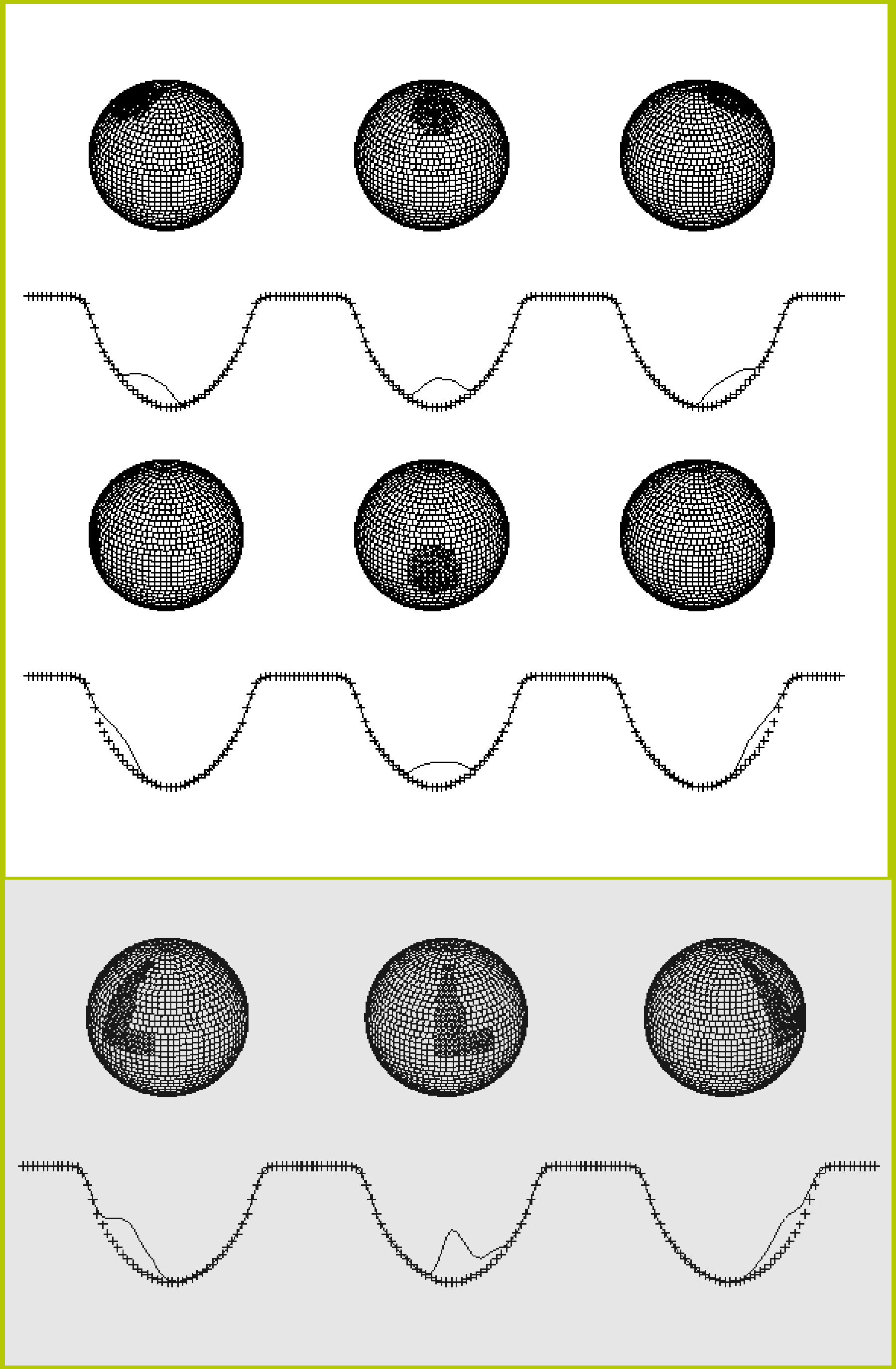
Indirect resolution with Doppler Imaging ≈ 4 Δt / P_{rot} = 1-10° on the stellar surface, e.g. for EK Dra (above) ≅ 9° or ***0.000003”*** with CFHT/Gecko

How does Doppler imaging work?



Collier Cameron 2002

Missing flux (in case of a dark spot) leaves a characteristic bump in the spectral line profile.



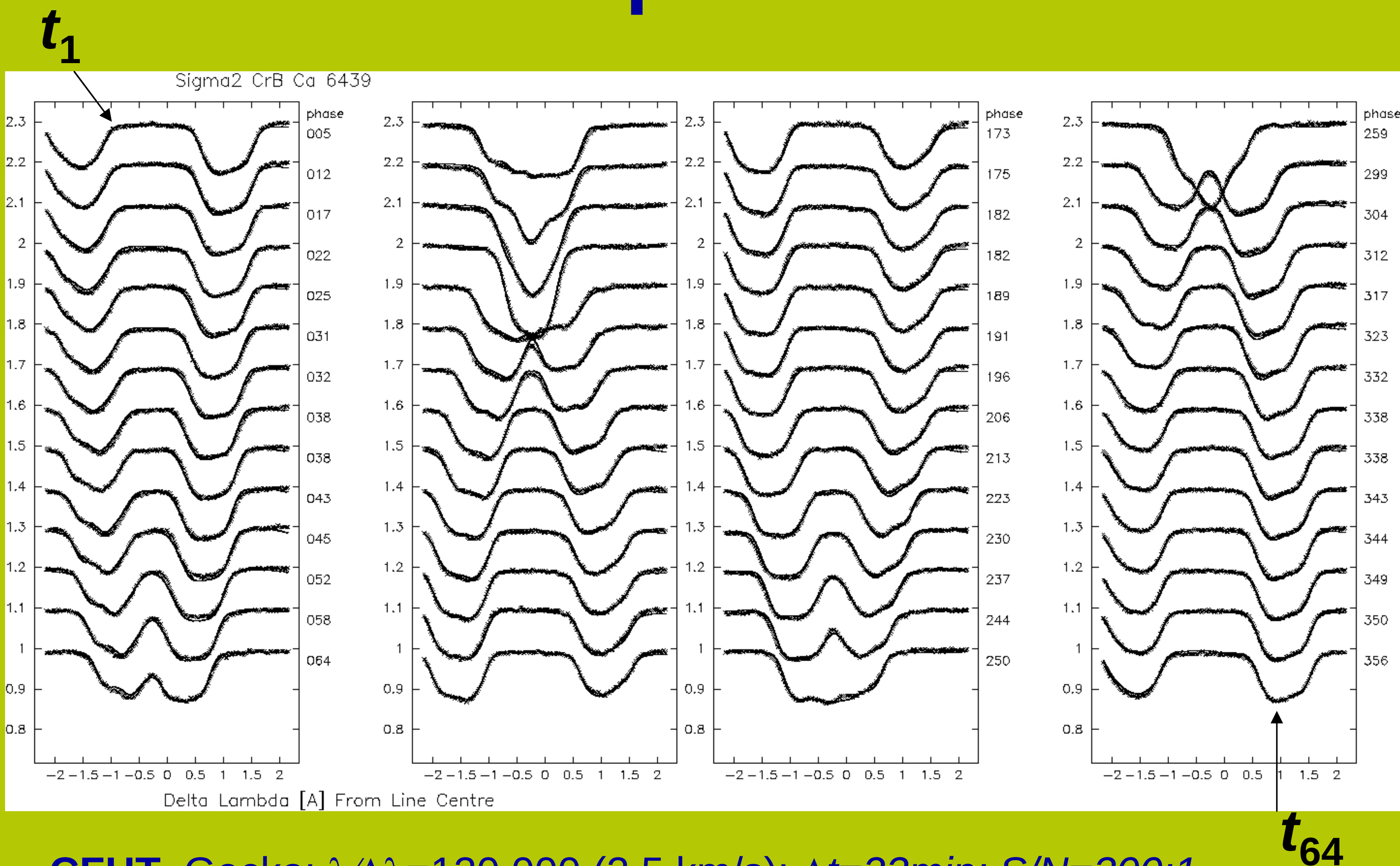
Line profile deformation due to spots at

high latitudes

low latitudes

and of complex shape.

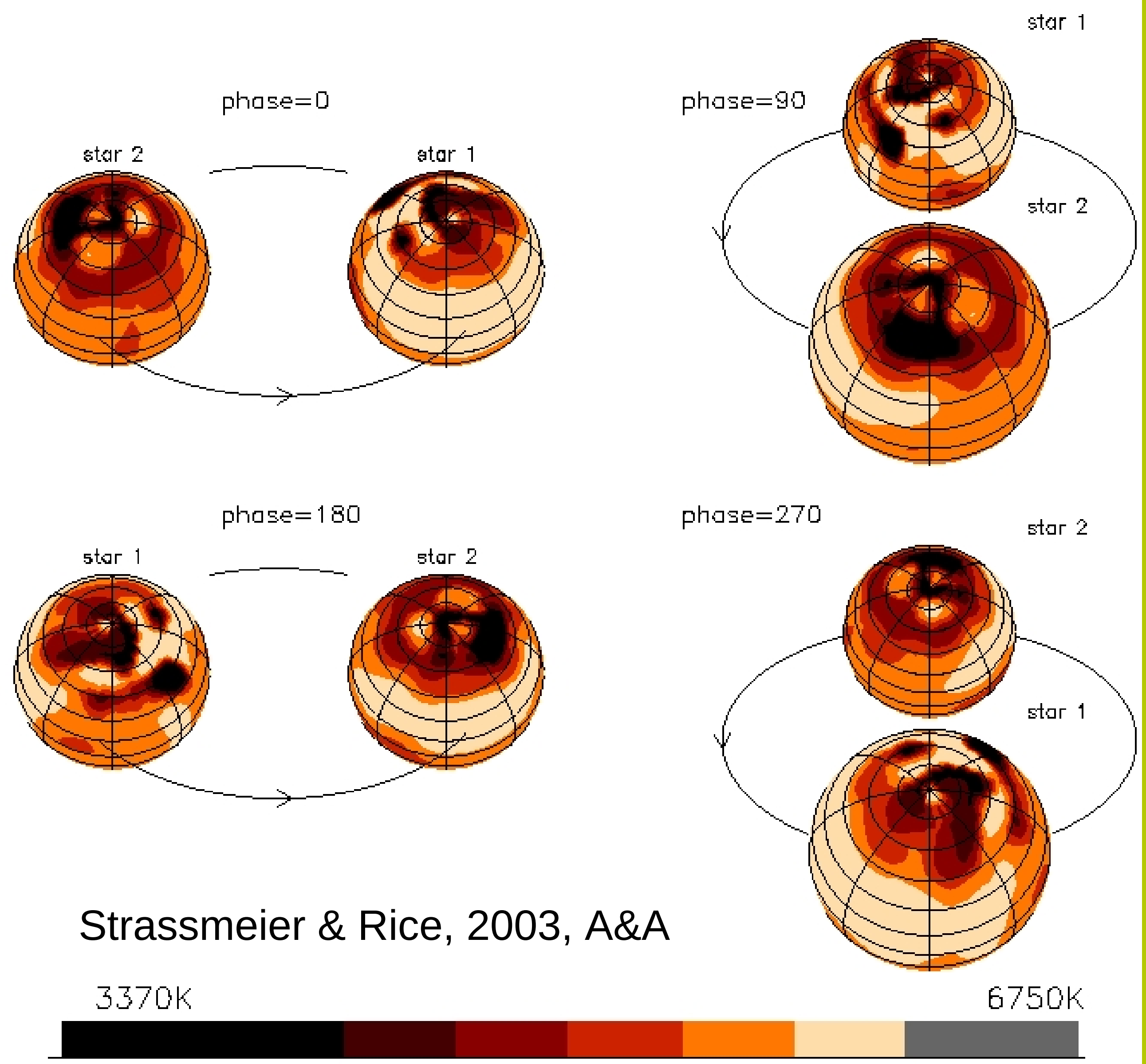
Time series spectra of σ^2 CrB



CFHT, Gecko: $\lambda/\Delta\lambda$=120,000 (2.5 km/s); *Δt=23min; S/N=300:1*

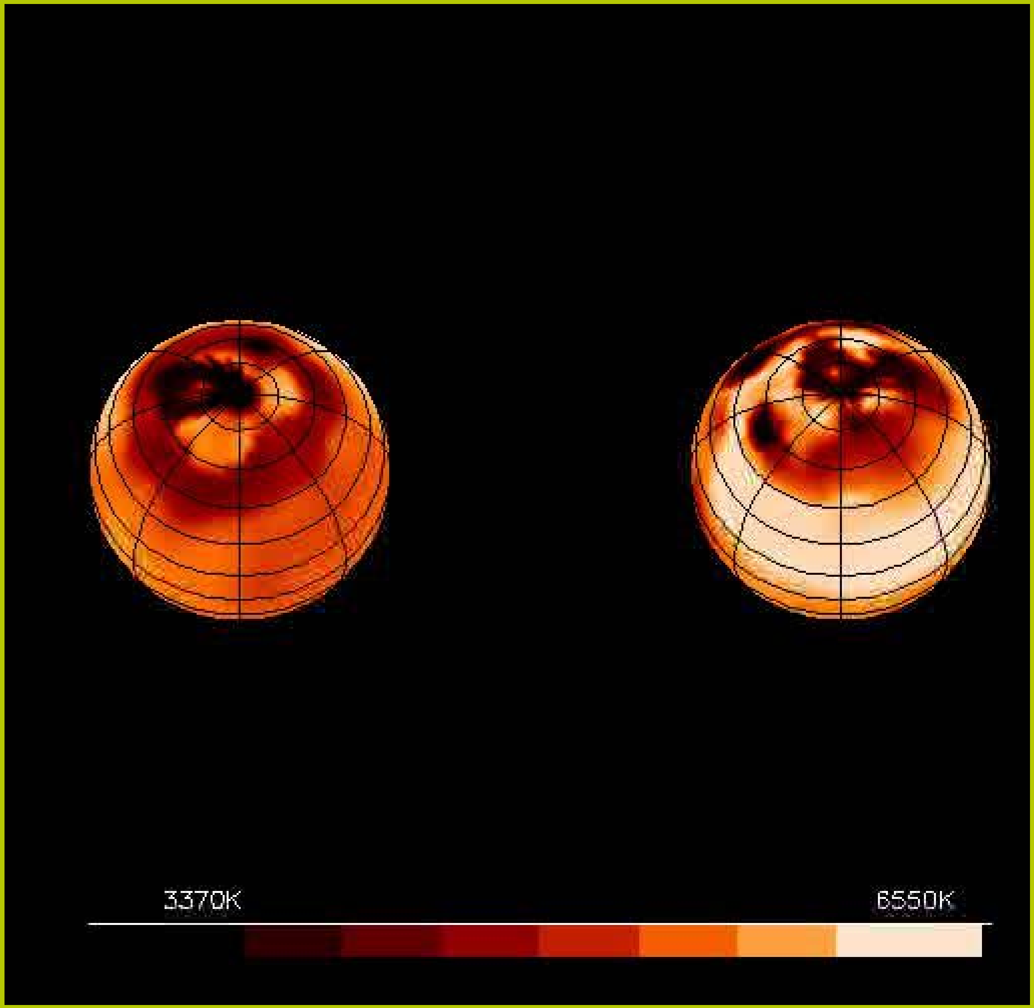
K. G. Strassmeier
Stellar Coronae, MPIfR, December 2006

Doppler images σ^2 CrB



Strassmeier & Rice, 2003, A&A

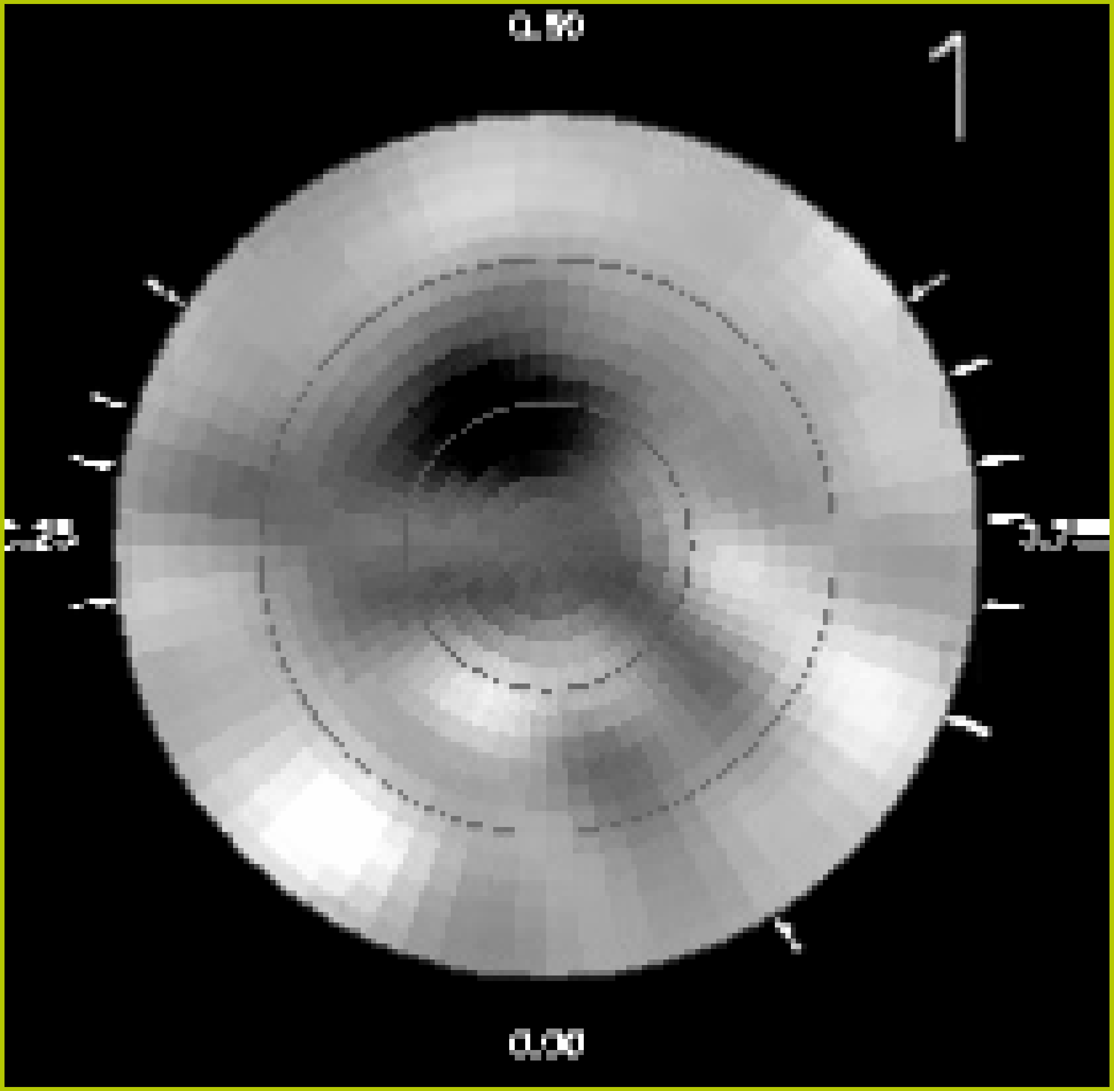
AIP



“Following” hemispheres appear warmer than “leading” hemispheres! Plasma in magnetic flux tubes moves away from places of largest curvature due to tidal effects (see models by V. Holzwarth et al.).

Stellar surface as *f*(time)

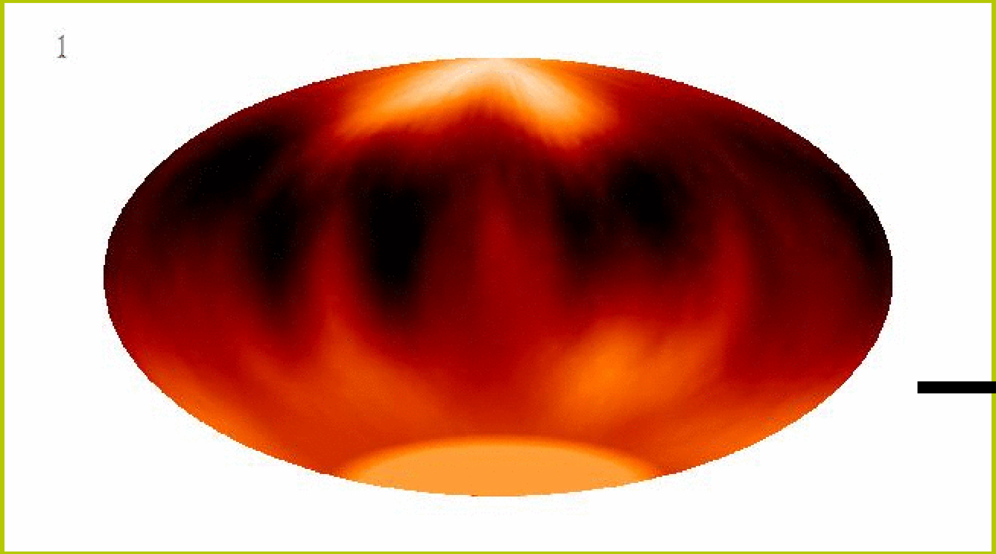
Bartus & Strassmeier 2000, A&A

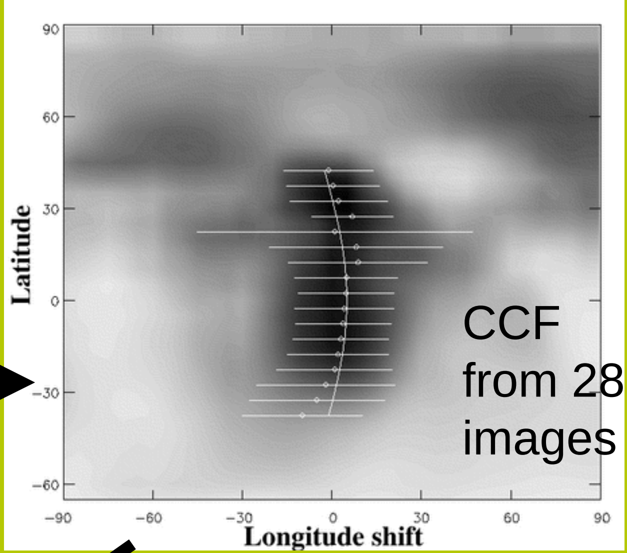


Animation:
HR 1099=V711Tau
Prot=2.7 days
70 consecutive nights
in 1996
with NSO/McMath

Some spots travel
to pole!

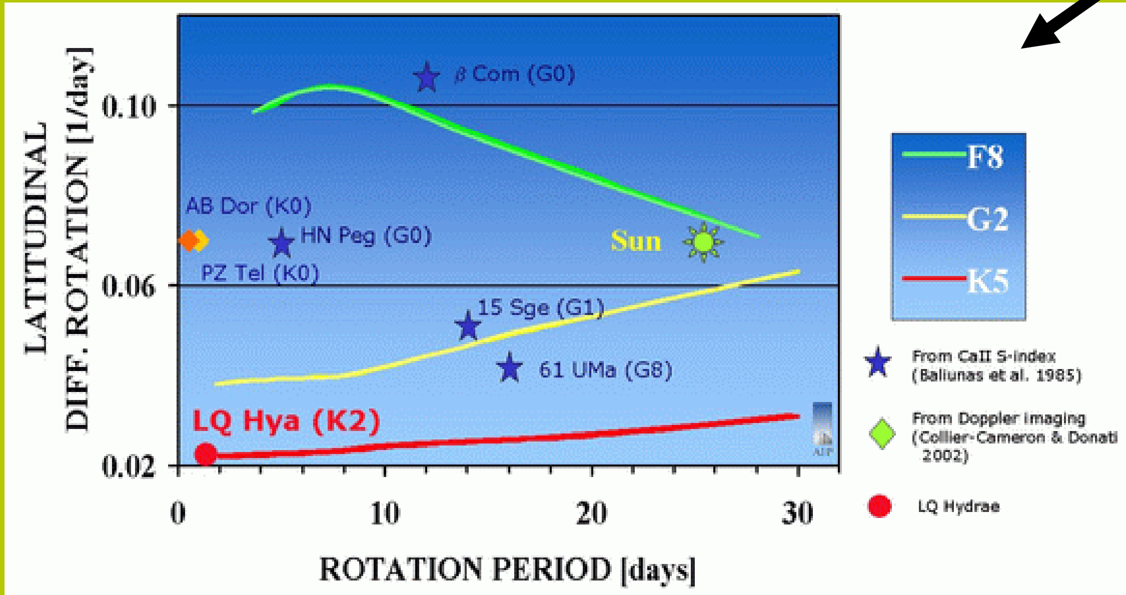
LQ Hya (K2V, 120Myr, 15Ω_{sun}): latitudinal shear roughly a factor of 3 weaker than on the Sun



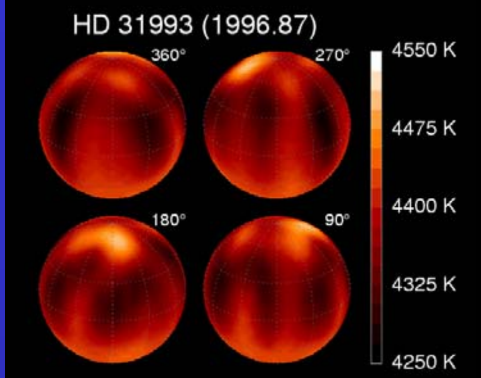


CCF from 28 images

Kövari, Strassmeier, Granzer, et al. 2004, A&A

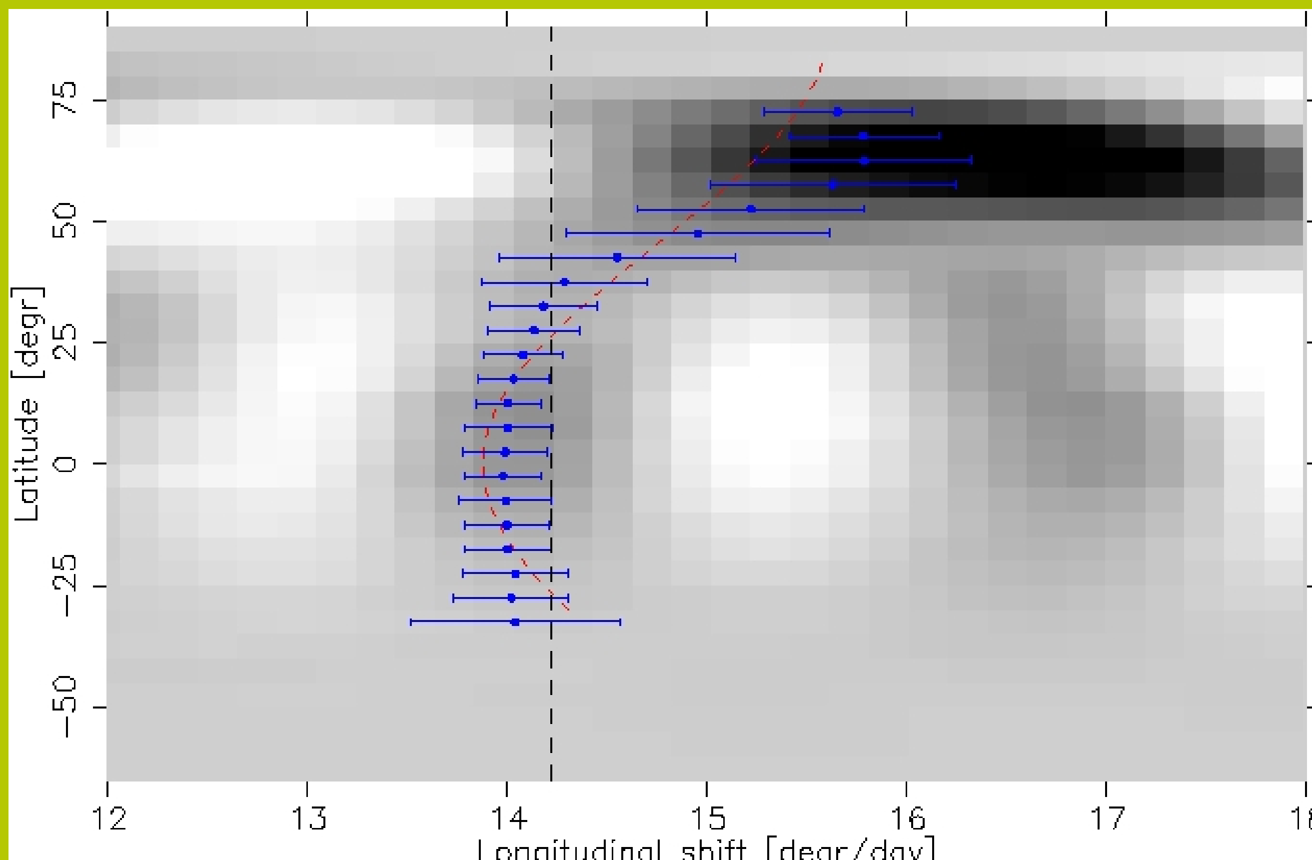


Comparison with models



HD31993 (K2III, 1-2Gyr, 1Ω_{sun}): poles rotate faster than equator !

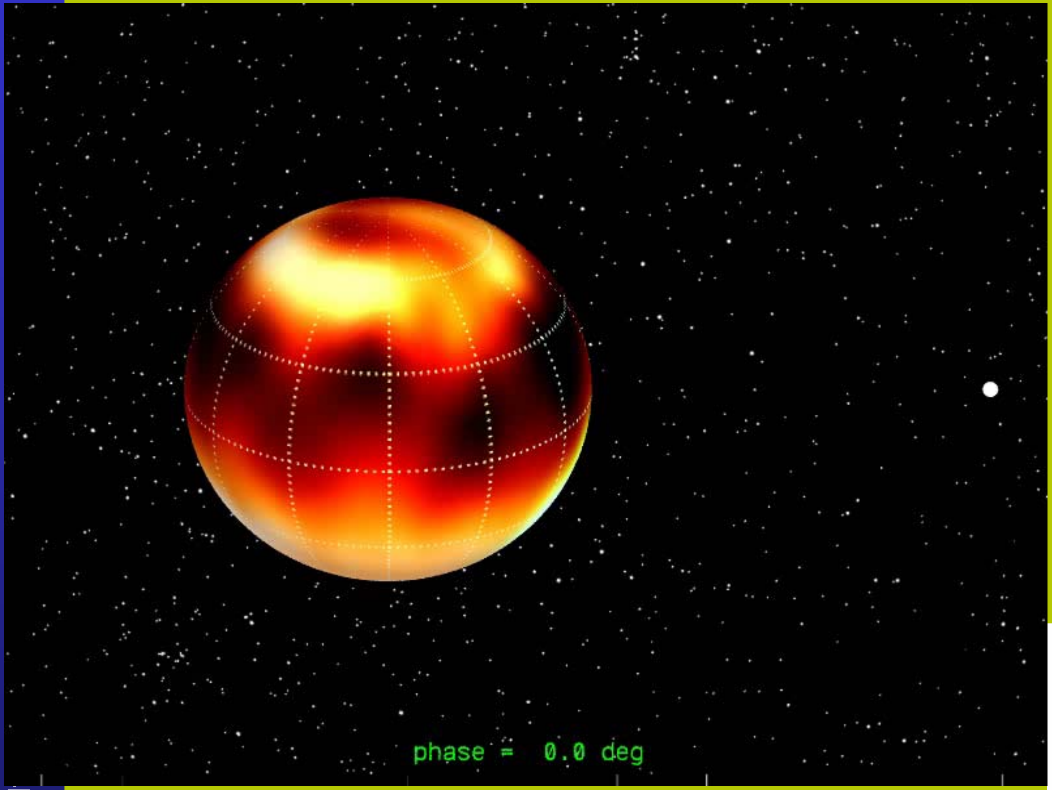
Lap time ≈ 200 days

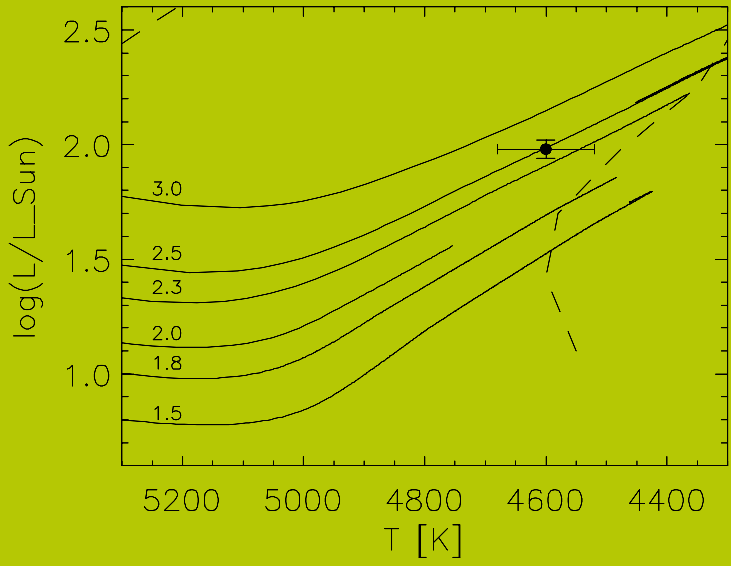


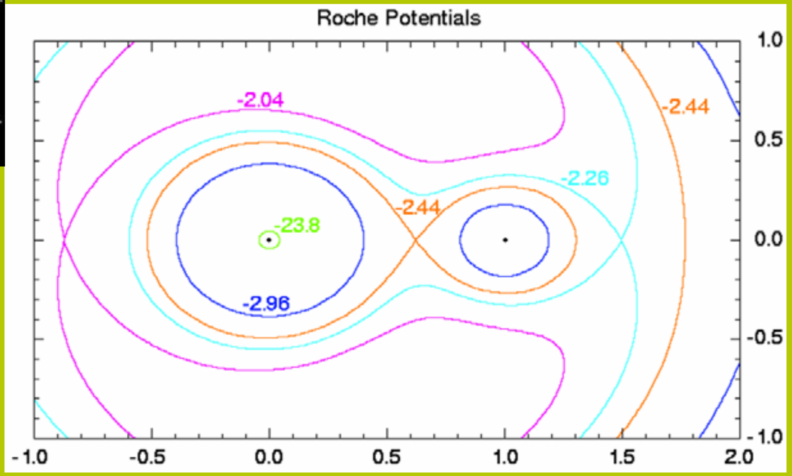
Strassmeier, Kratzwald, Weber 2003, A&A

The evolved binary ζ And: (KV) + K1 III

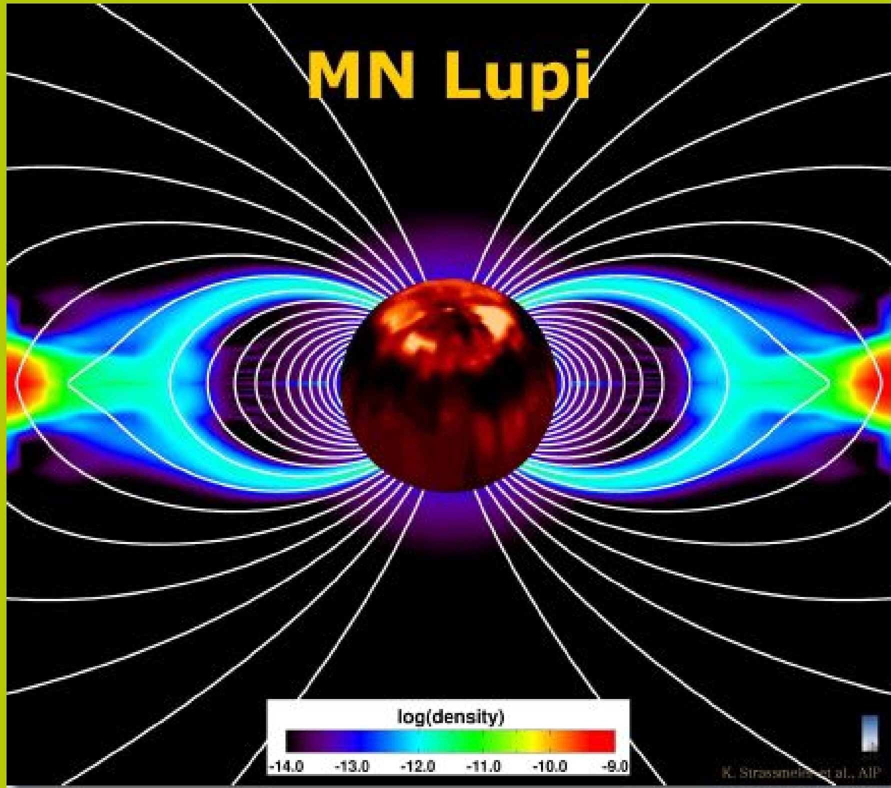
Kövari, Bartus, Strassmeier et al. 2006, A&A, in press





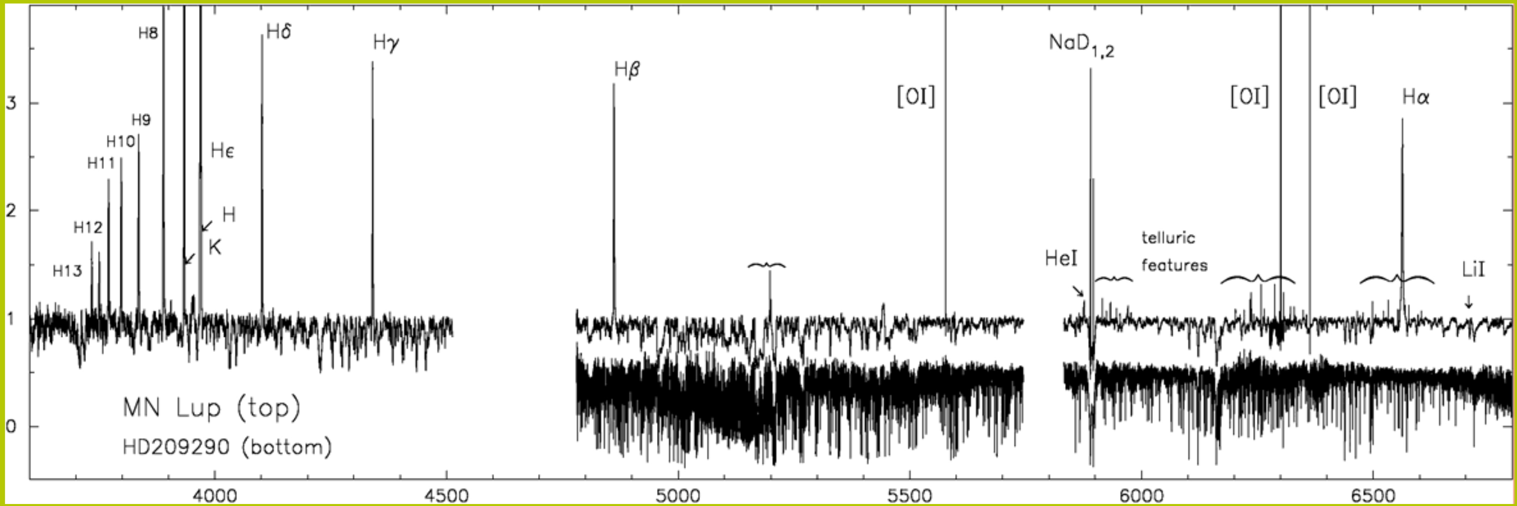


AIP

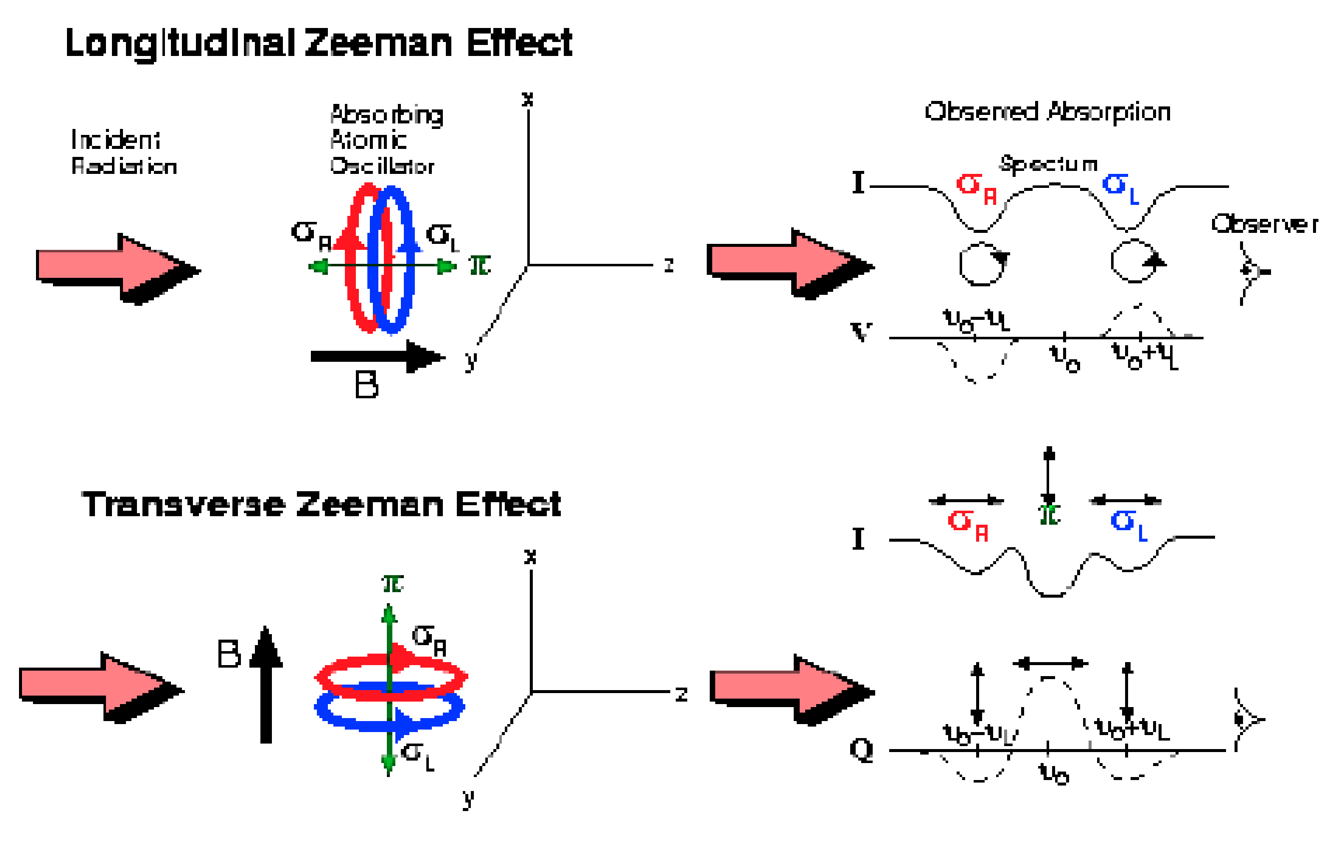


- Magnetospheric accretion model fits Doppler images and predicts a polar field of 3 kG
- Hot spots are the heating points of accretion shocks (the shock itself is evident in emission lines like HeI, Balmer, H&K ...)
- Warm cap is the trailed and redistributed impact energy
- Cool spots are likely of local magnetic origin
- „Cool“ hemisphere is obscuration due to the inner rim of the disk

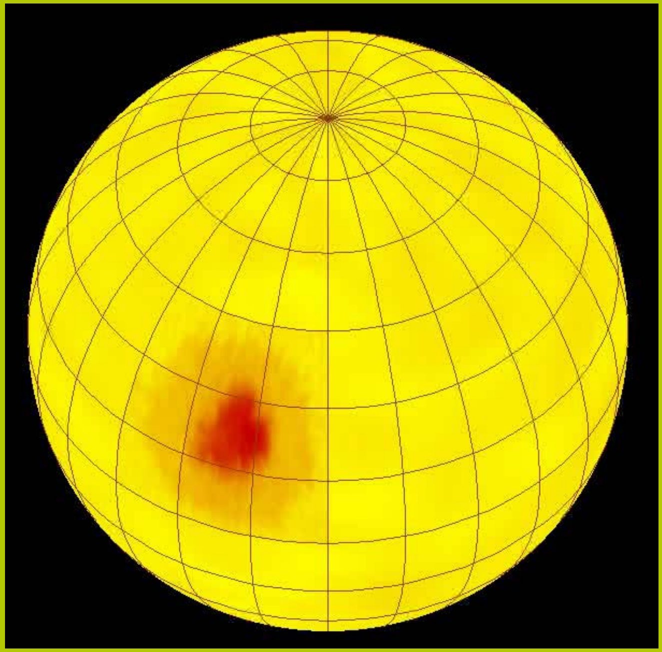
Strassmeier, Rice, Ritter, Kueker, Hussain, Hubrig, Shobbrook, 2005, A&A 440)



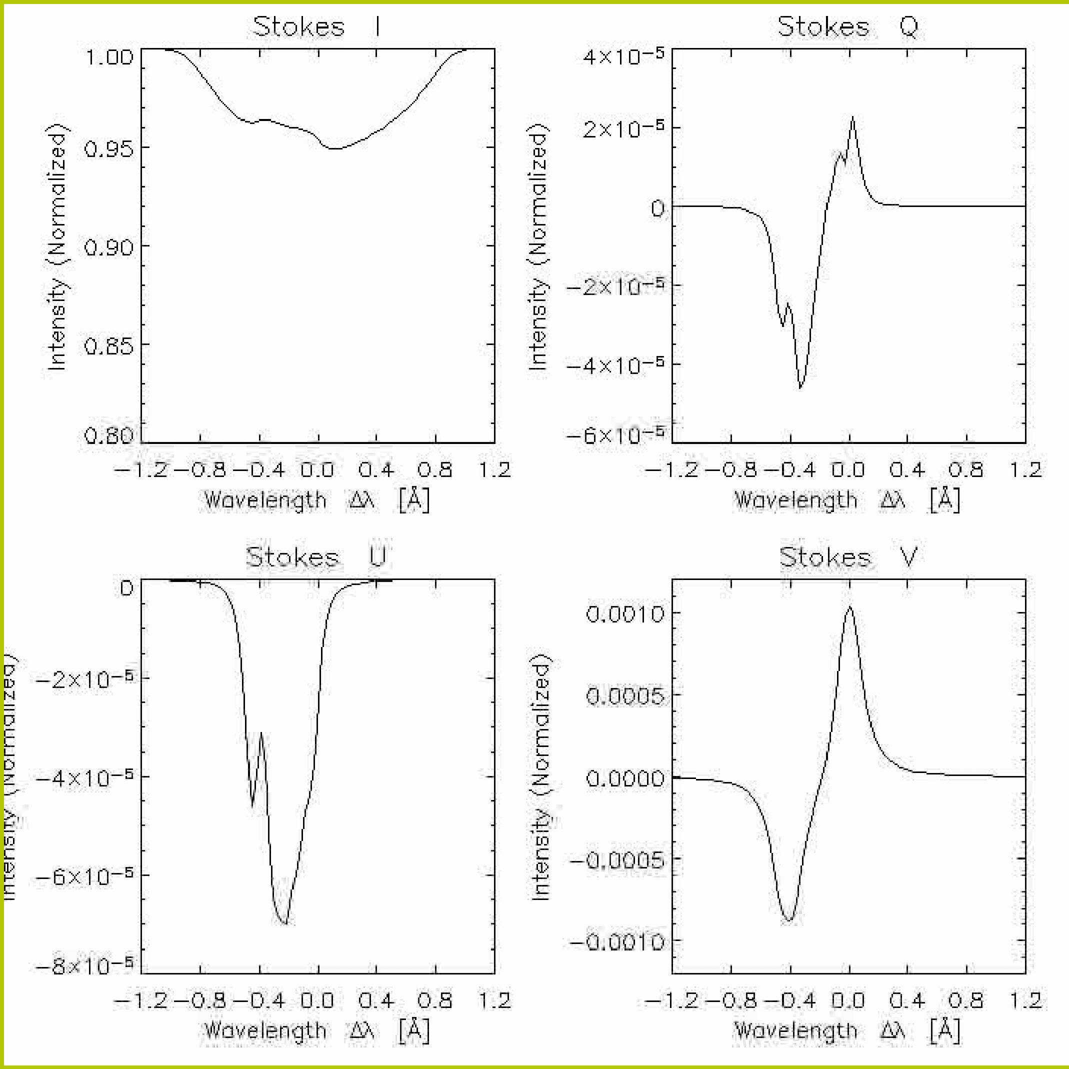
„The holy grail“
... full-Stokes Zeeman-Doppler imaging



4-Stokes simulation with two Sunspot vector-magnetograms



Kopf, Carroll & Strassmeier 2006



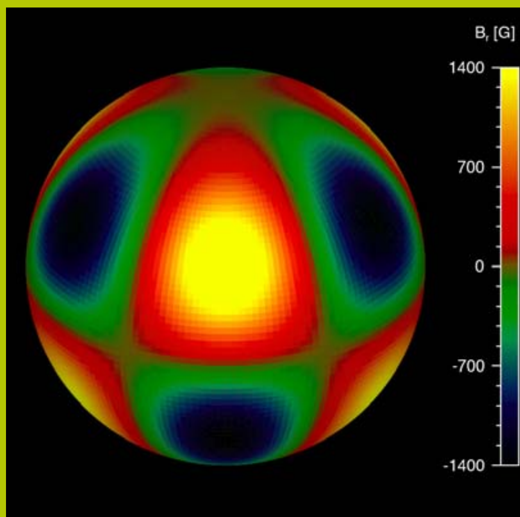
Zeeman-Doppler imaging (numerical requirements)

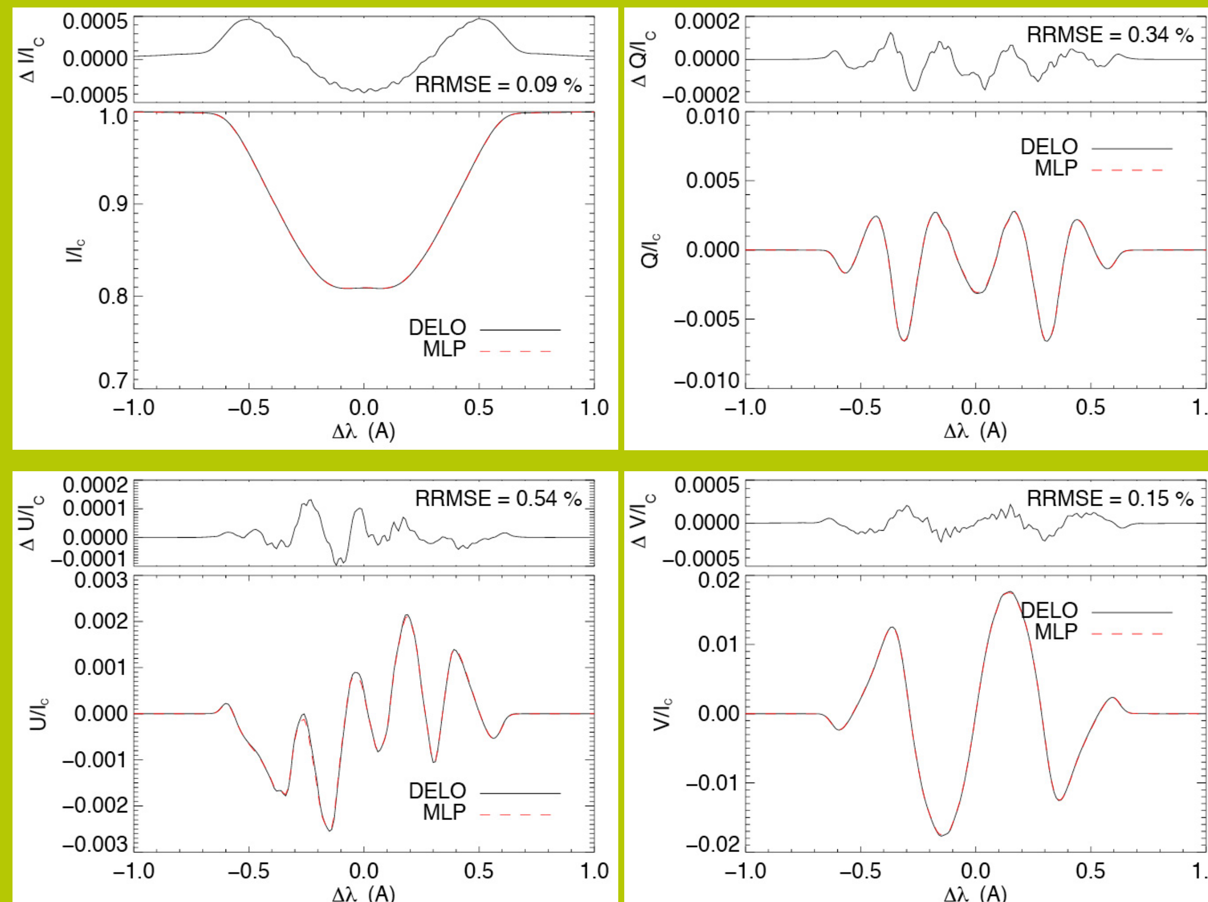
- pre-tabulation of local Stokes profiles unrealistic (too complex ***B***-structure)
- weak-field approximation does not provide the needed accuracy and is strictly valid only for Stokes V and <1kG (LSD problematic)

However, full problem is numerically not handable.

- ***PCA-MLP*** **ZDI code** (Kopf, Carroll & Strassmeier 2006, CS14):
- $\rightarrow$ use an approximation method based on Principal Component Analysis (PCA) and Multi Layer Perceptrons (MLP)
- decomposition of local Stokes profiles into their eigenspectra via PCA
- a set of MLPs is then trained to compute local profiles as f(θ), f(T), model atmosphere, and field configuration (B,γ,ϕ)
- compared to classic polarized radiative transfer solution with quadratic DELO (e.g. Kochukhov & Piskunov, IAU-JD8 poster): **speed-up of a factor 1000! Relative RMS** $\approx$ 0.1(I)-0.5(U)%.
- Currently requires 320-PC Cluster Sansoucci 700 Gflops/s

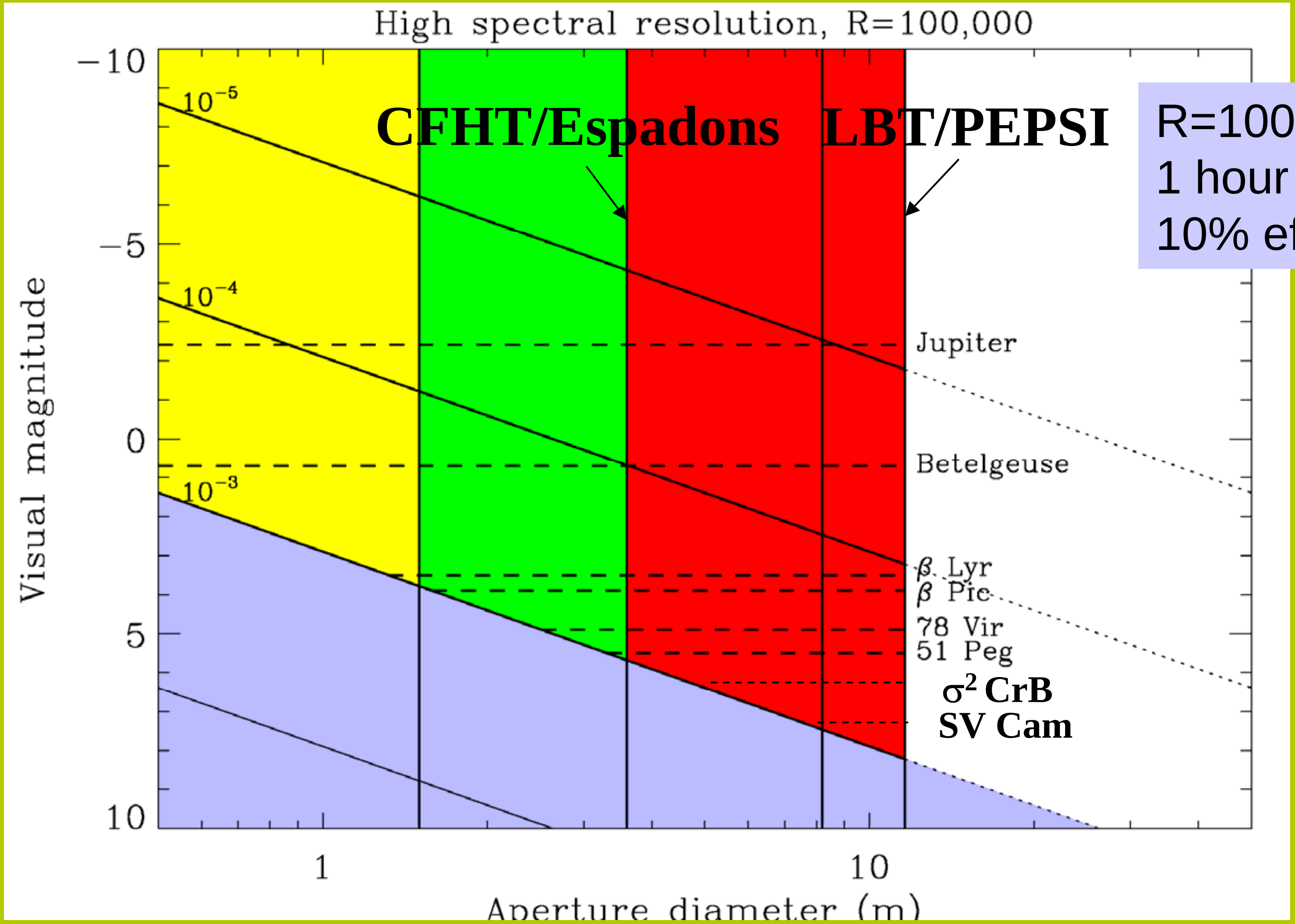
Zeeman-Doppler imaging (numerical requirements)





FeI6173

Zeeman-Doppler imaging (observational requirements)



R=100,000
1 hour exp.
10% efficiency


Size matters