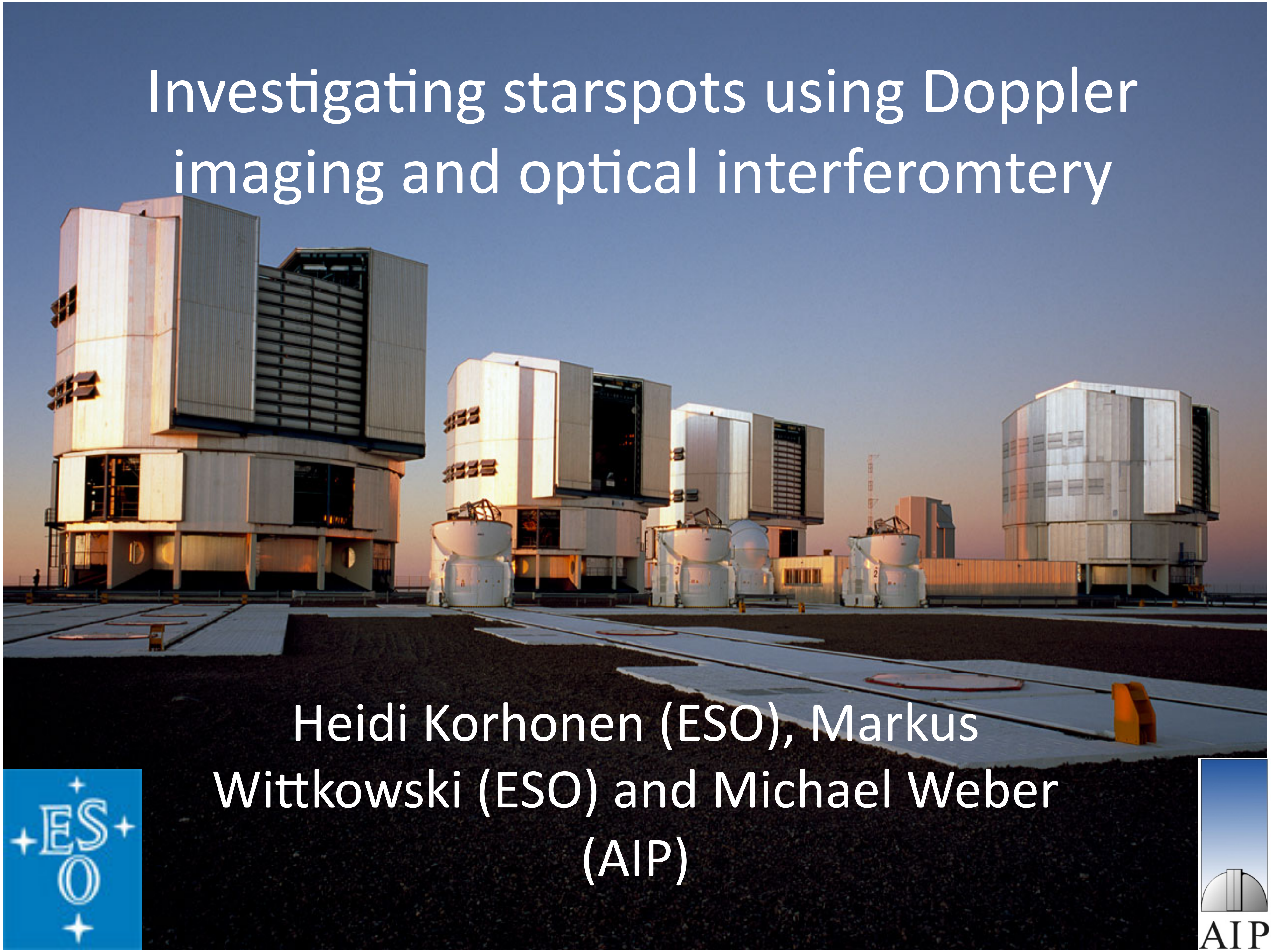
Investigating starspots using Doppler imaging and optical interferomtery



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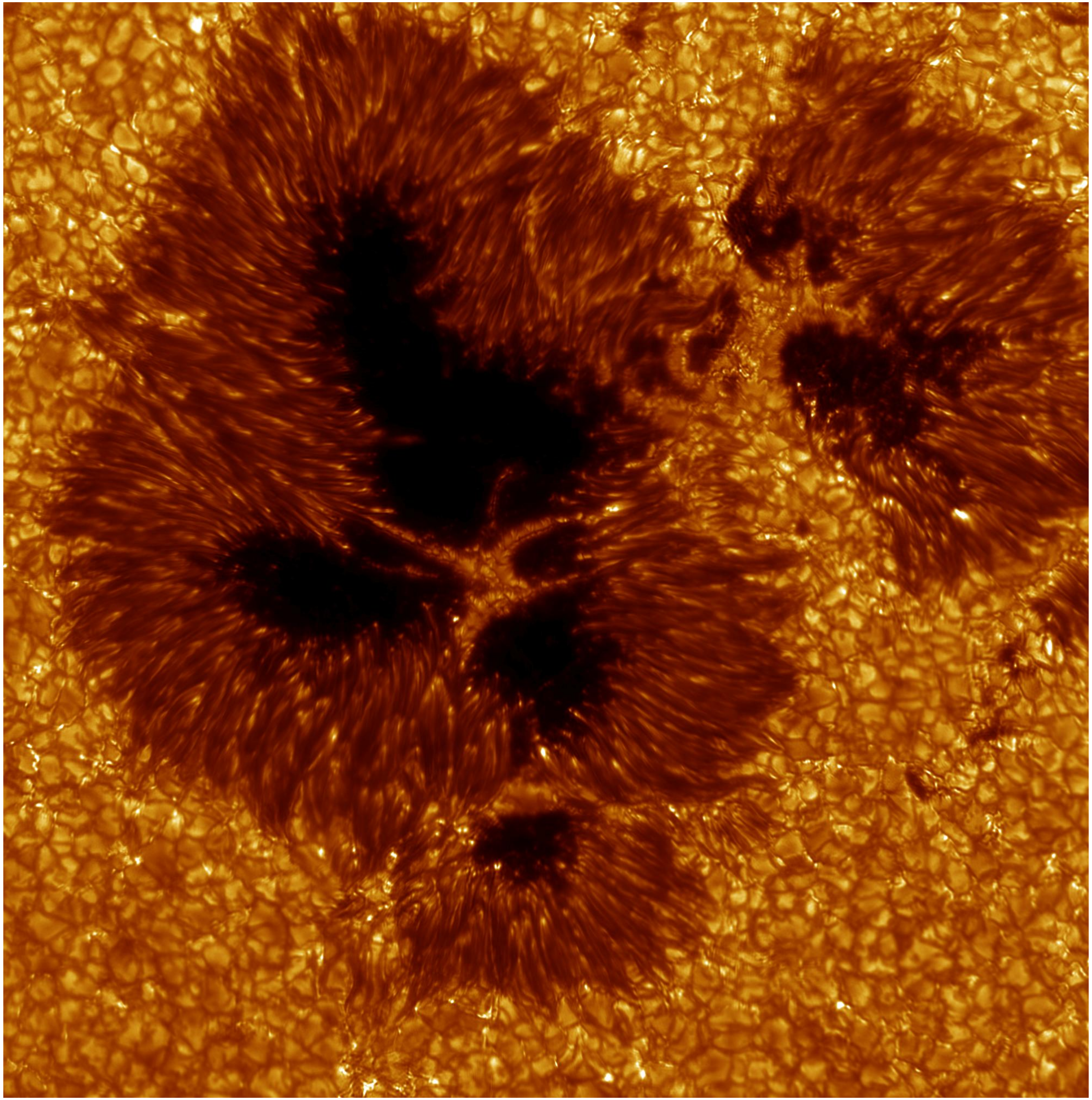
Why to study starspot?

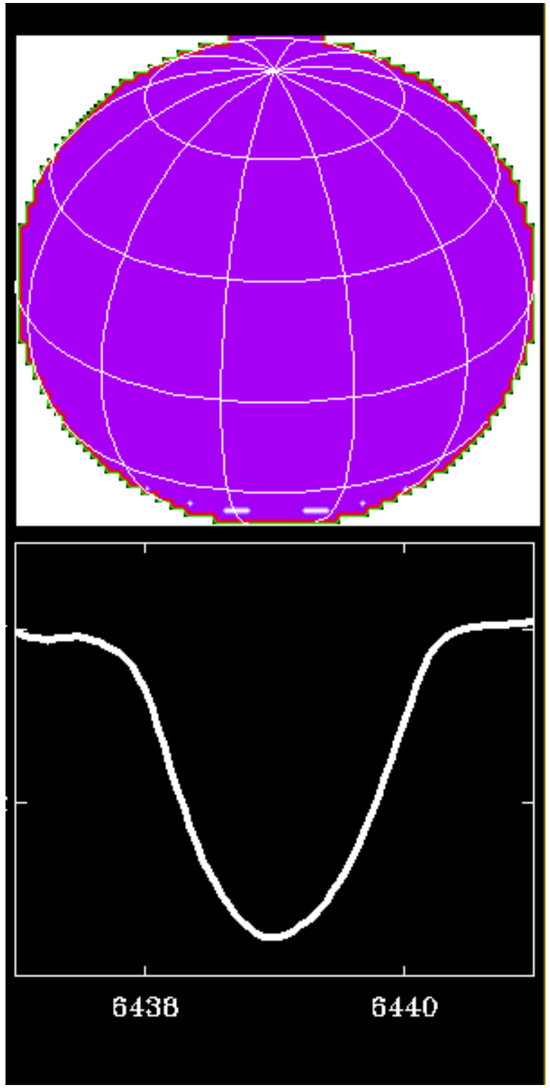
- Starspots are the most visible sign of stellar magnetic fields
- The stellar magnetic field is created by dynamo operating in the stellar convection zone, but its detailed location and operation is not well understood
- To understand the creation of the magnetic fields in stars one has to understand the underlying dynamo
- Strong stellar magnetic activity created by vigorous dynamo has implications to the planets forming and orbiting these stars



Sunspots imaged using the Swedish Solar Telescope on La Palma

Starspots with high resolution, Doppler imaging

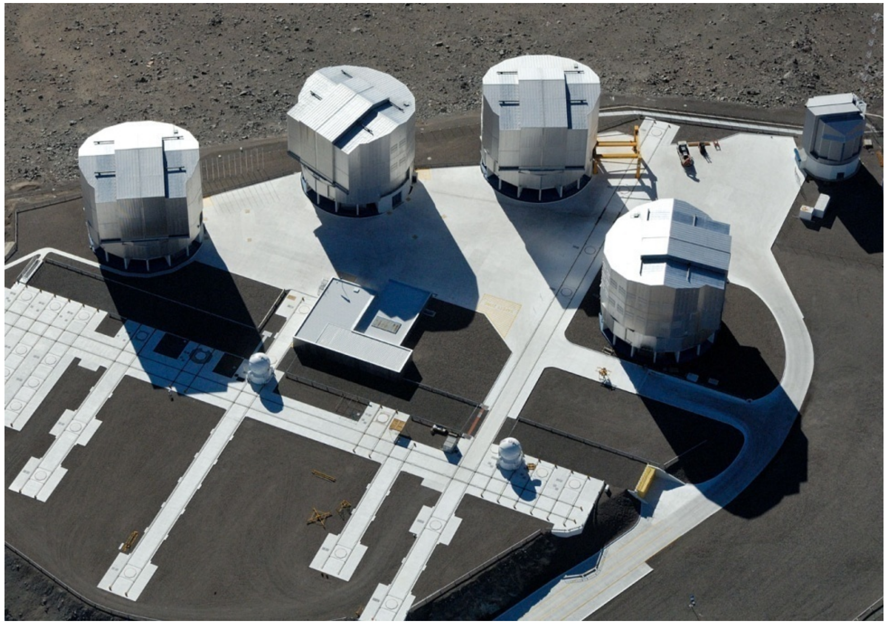
- In Doppler imaging the distortions appearing in the observed line profile due to the presence of spots and moving due to the stellar rotation
- Ill-posed inversion problem
- Many methods for solving: aximum Entropy Method (e.g., Vogt et al 1987), Tikhonov Regularization (e.g., Piskunov et al 1990), Occamian Approach (Berdyugina 1998), Principal Components Analysis (Savanov & Strassmeier 2005)



From Svetlana Berdyugina

Starspots with interferometry

- Another method for studying starspots is to use near infrared interferometry
- Unfortunately most active stars are apparently small, and spots naturally even much smaller
- Possibly indirect methods can still be used for studying starspots?



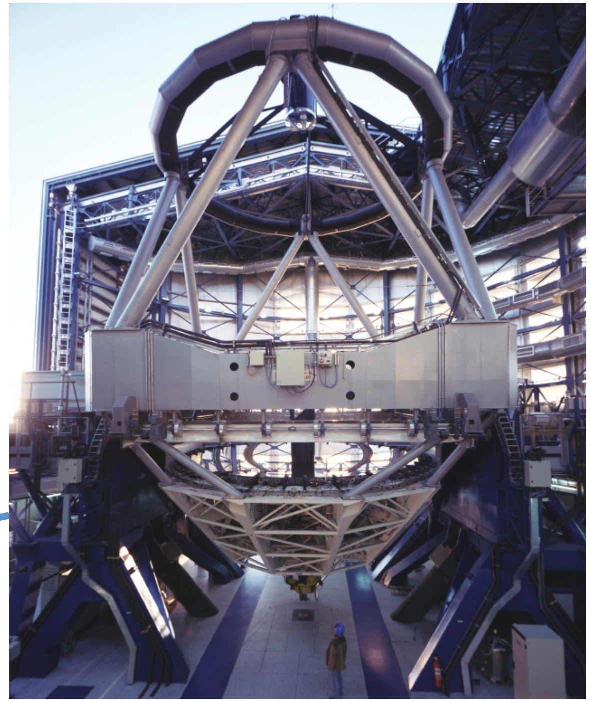
ESO VLTI (above): current resolution ~3mas (planned highest resolution ~1mas)
CHARA array: resolution ~0.5mas

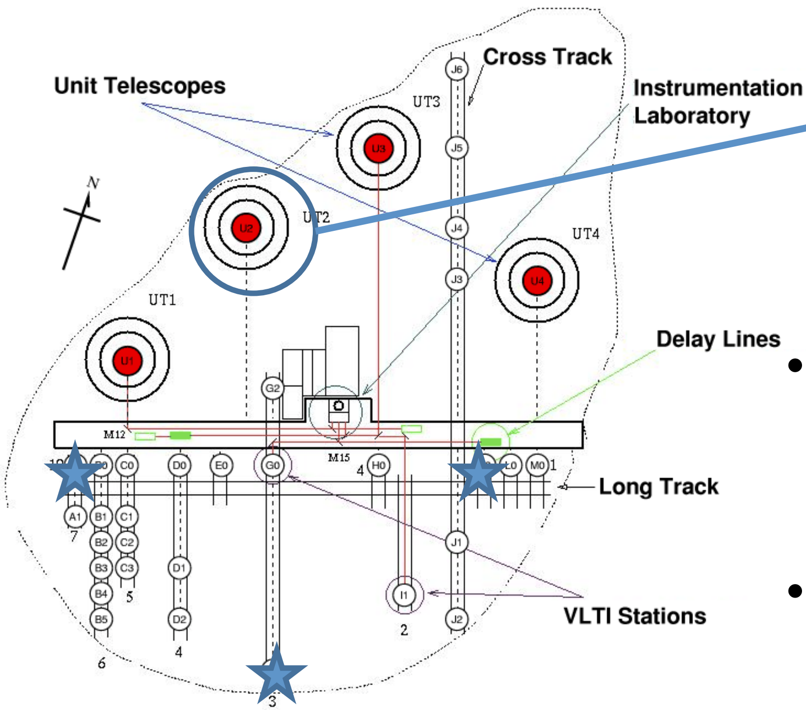
Differential phase technique

- If the position of the photocentre of the object depends on the wavelength differential phase measurements can be used to derive information on the object brightness distribution
- Starspots are ~1000-1500K cooler than the rest of the stellar surface
- Due to the low temperature starspots have more molecules than the surrounding stellar atmosphere
- Sunspots show signatures of molecules: MgH, CO, Sill, NH, CN, CH, H_2O, TiO, etc.
- From observations across the K band in medium resolution the differential phase between CO line and the continuum can be calculated
- The calibrated differential phases can be converted into differential astrometric shifts of the photocentre

Pilot study at VLT/VLTI to combine Doppler imaging and interferometry

- We have obtained high resolution spectra of two active K giants with UVES (resolution 110 000, S/N ~300)
- The UVES spectra are used for Doppler imaging





- Contemporaneous VLTI AMBER observations in low and medium resolution modes using 90-128 meter baselines (A0-G1-K0)
- The AMBER observations are for studying the stellar surface using differential phase technique

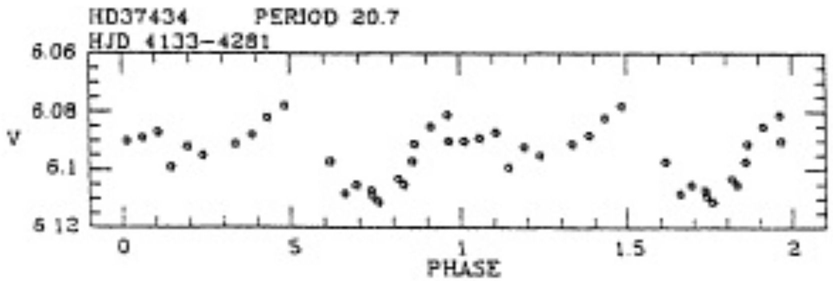
Target selection

- Requirements:
  – Apparently large -> close-by giants
  – Rapid rotator for Doppler imaging to work
  – Bright to enable VLTI observations (limits choice)
  – Visible from Paranal
- We looked at the Hipparcos catalog to find near-by bright giants visible from Paranal
- Estimated their diameters from V and K magnitudes
- Checked the vsini from Glebocki et al. 2000

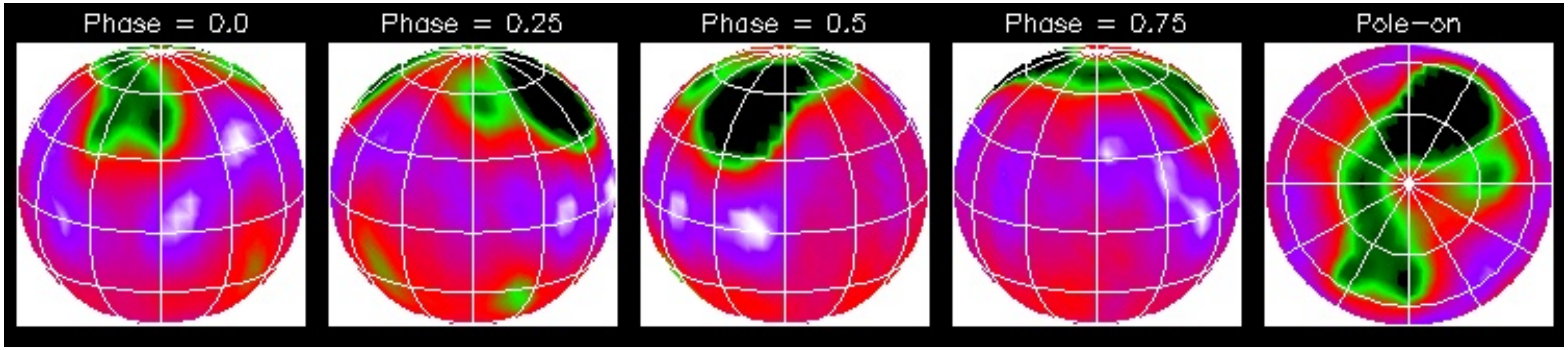
Selected targets

- IM Peg: K2III, V=5.9, K=3.3,
  P=24.45 days vsini=28km/s
- TX Pic: K2III, V=6.1, K=2.8,
  P=~20.7 days, vsini=65km/s
- Estimated diameter 1.5mas (for both)

TX Pic lightcurve, Loyd Evans & Koen 1987

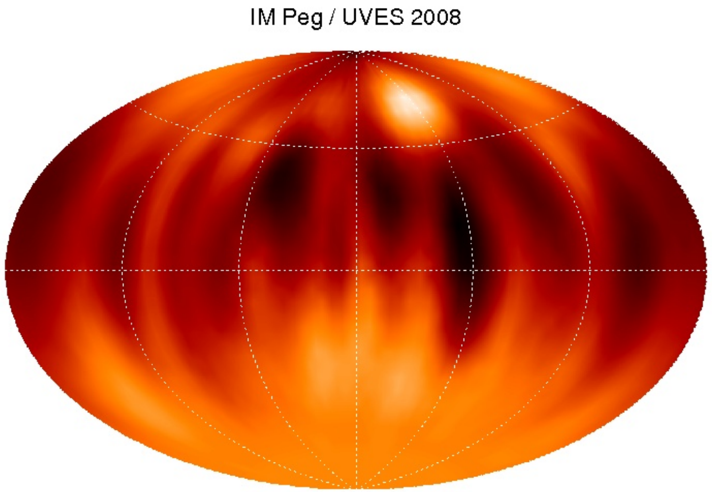


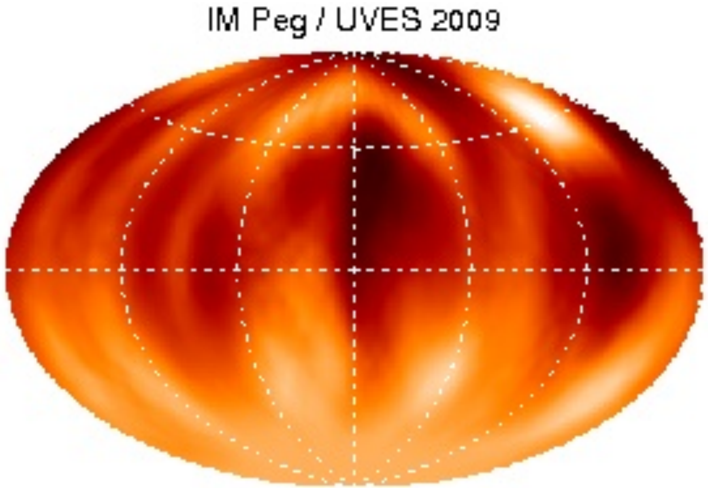
- Both have photometrically/ spectroscopically detected strong magnetic activity
- These stars are the best available targets to fulfill our strict requirements
- The angular diameters of our targets are too small to resolve them directly using near-IR interferometry, so we use the differential phase technique



Temperature map of IM Peg in 1998, Berdyugina et al. 2000

Doppler images of IM Peg

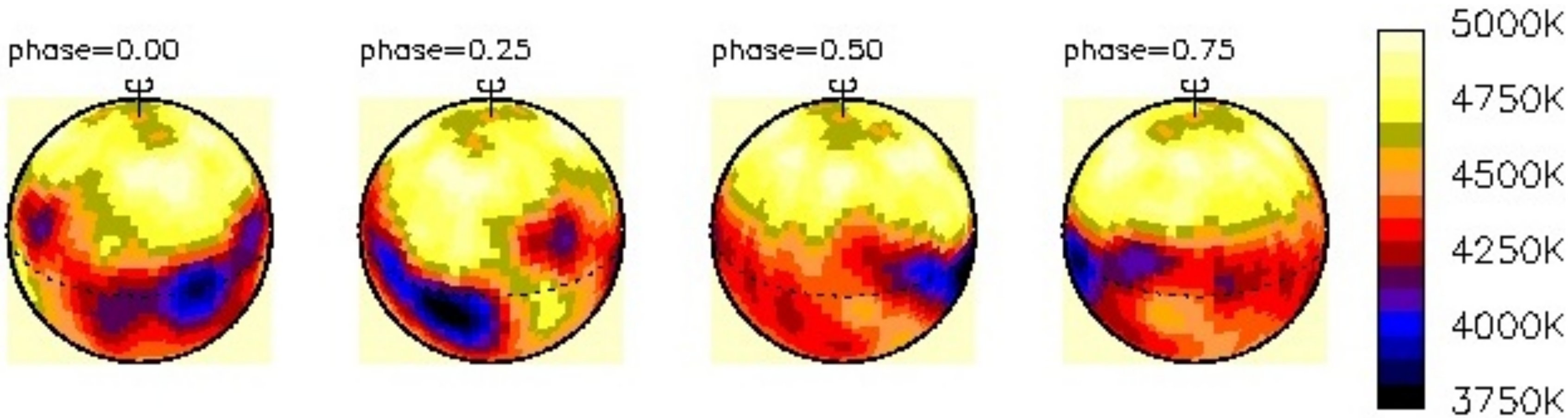




- IM Peg was observed with UVES on 10 nights in October-December 2008 and on 10 nights in August-September 2009
- Both maps show mainly equatorial and low latitude spots around longitude 0^{o} (see also the poster by Marsden & Berdyugina)
- The coolest temperature in the spots is 3500K

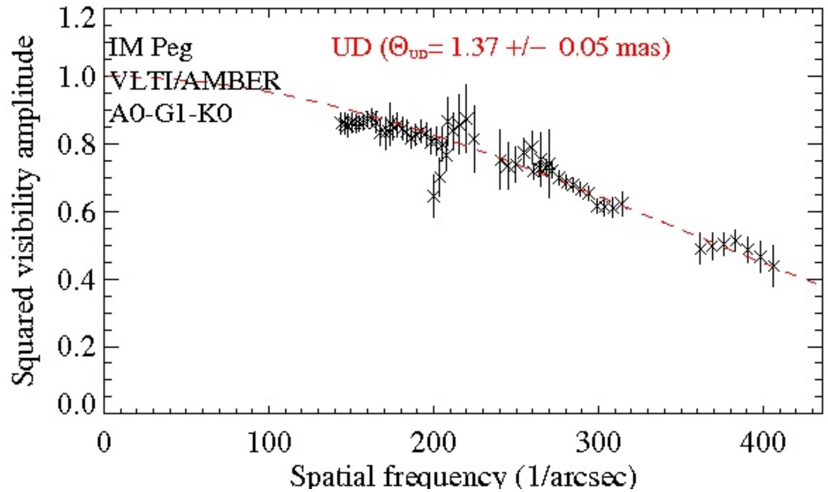
Doppler image of TX Pic

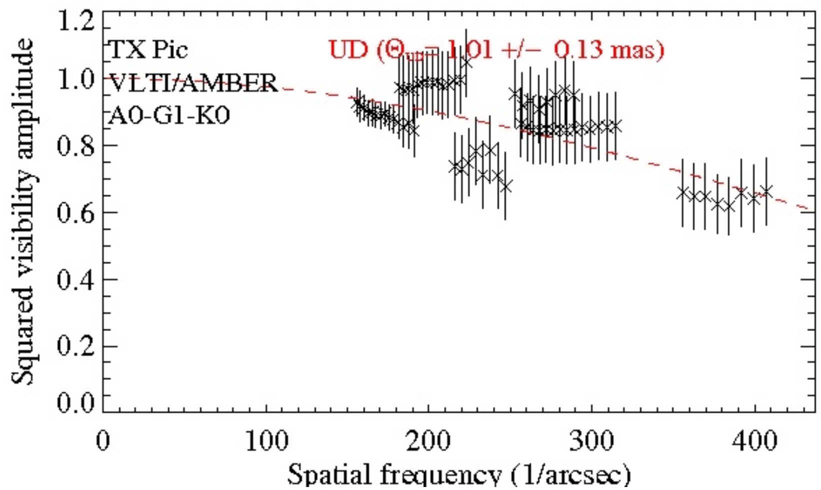
- The TX Pic observations were obtained in October-November 2008
- The spots occur at the equatorial region and concentrate to longitudes 0-180^{o}
- The coolest temperature in the spots is 3750K
- Problems because the rotation period is not very well defined



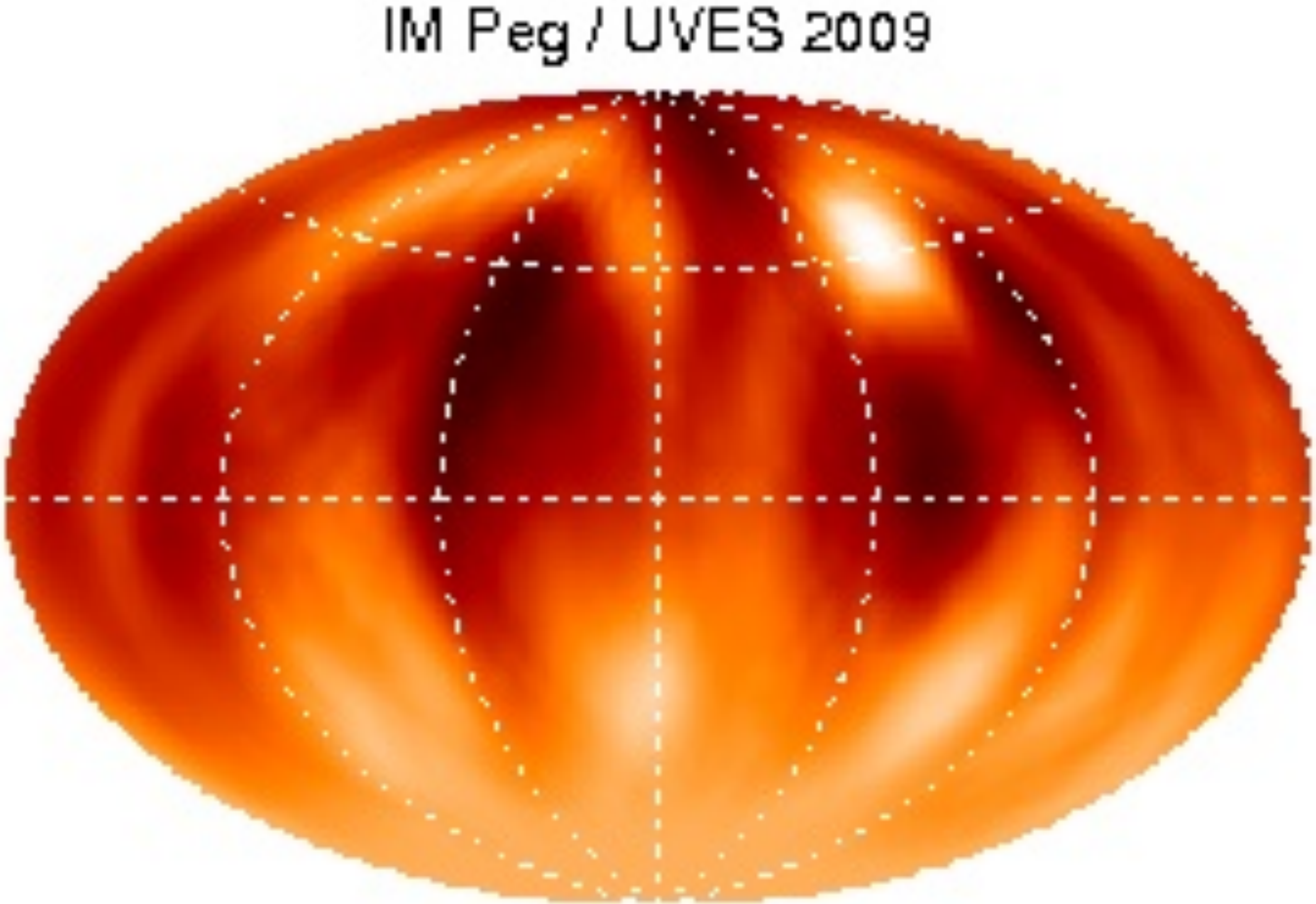
Results from interferometry

- The AMBER low resolution data give the diameter 1.01mas and 1.37mas for TX Pic and IM Peg, respectively
- The limb-darkened diameters are: 1.03 (TX Pic) and 1.41 (IM Peg)
- The differential phase signal is difficult to detect, and we are still in process of analysing the data
- Thus we have so far not been able to use the differential phase technique to study the spots





Phase of interferometric observations of IM Peg



Conclusions/outlook

- We have made the first attempt to use VLTI in studying starspots
- We have obtained Doppler images contemporaneous to our AMBER observations
- We have used interferometric data to measure the diameters of these stars, and we need to have another look at the data to see if it is still possible to do the differential phase measurements
- We will also investigate the chromospheric activity in these stars from UVES spectra using Hα-line and compare it to the photospheric activity seen in the Doppler images
- For the future studies we first have to investigate the near-IR spectrum of the target stars to find targets with strong CO lines
- We also need photometric observations to accurately determine the rotation period of TX Pic