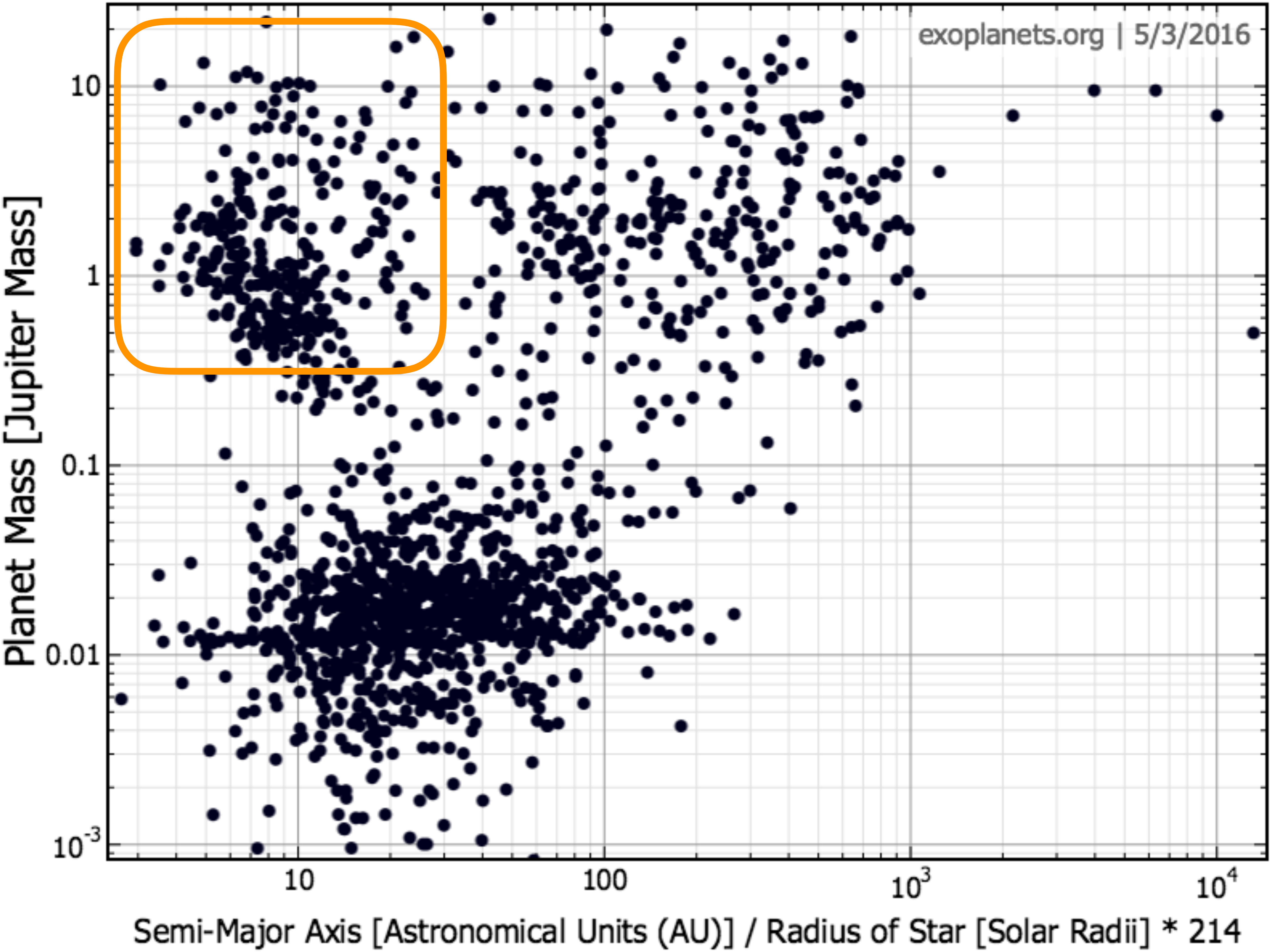
YOUNG HOT JUPITERS

CLAIRE MOUTOU
(CFHT/CNRS)

artist view by Mark Garlick


exoplanets.org | 5/3/2016
Planet Mass [Jupiter Mass]
10
1
0.1
0.01
10^{-3}
10
100
10^3
10^4
Semi-Major Axis [Astronomical Units (AU)] / Radius of Star [Solar Radii] * 214

HOT JUPITER FORMATION

PREVIOUS ATTEMPTS TO FIND YOUNG HOT JUPITERS

THE CFHT/ESPADONS MATYSSE PROGRAM

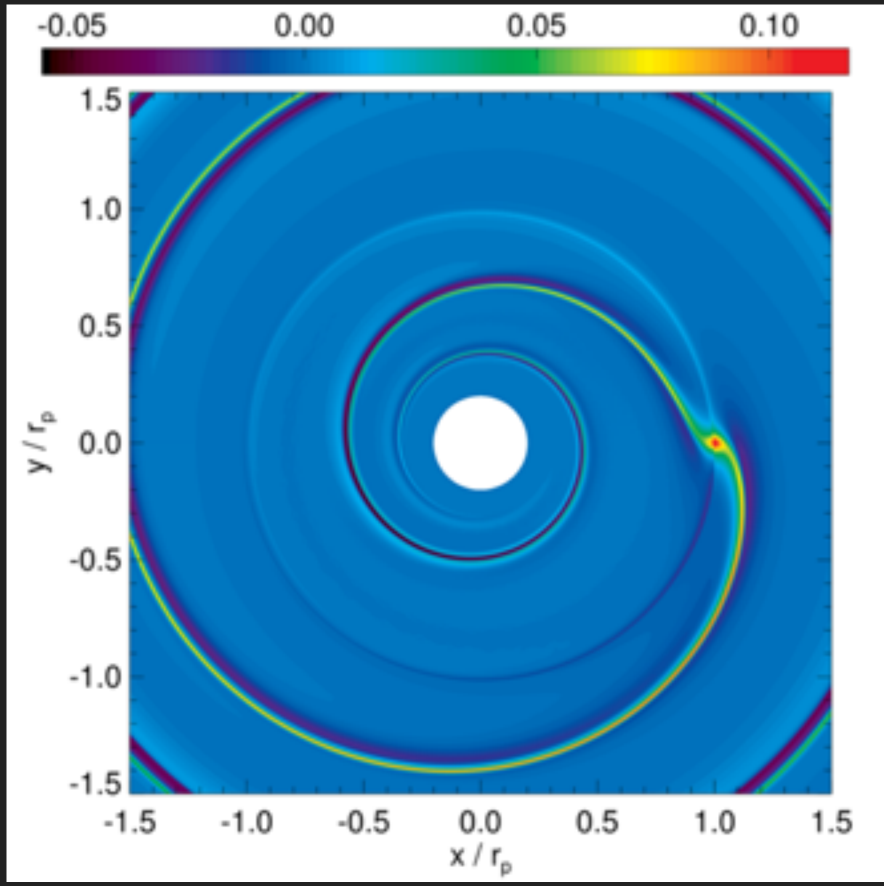
V830 TAU DATA AND DETECTION

INTERACTIONS WITH THE STAR?

FIND PLANET SIGNALS INTO THE ACTIVITY JITTER

HOT JUPITER FORMATION

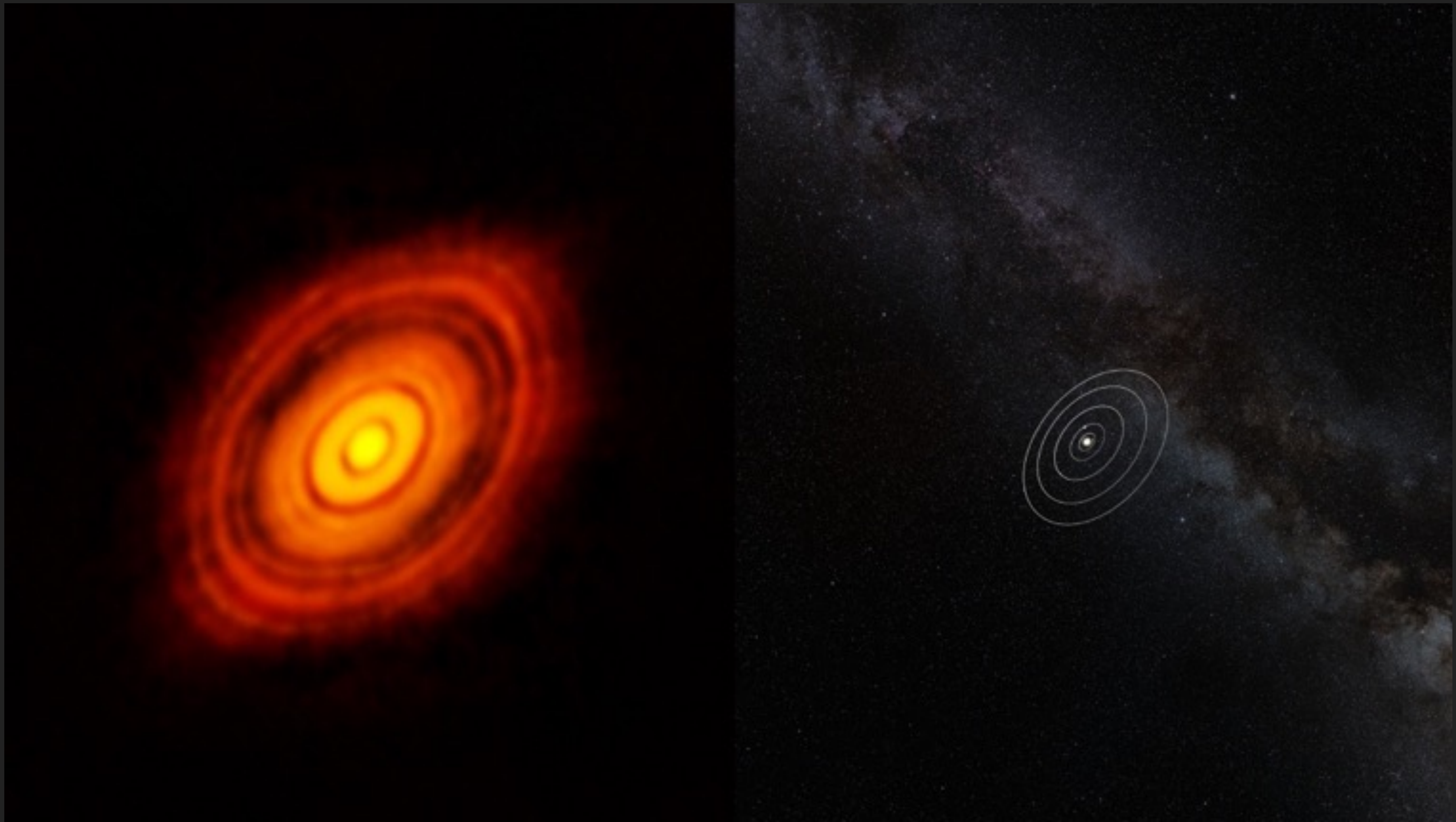
- jupiter-size planets need material to form, far from the star
- if formed early, they're dragged by the disk & spiral in
- inward migration within My
- stop at magnetospheric cavity
- later dynamical interactions possible
- in/out migration, tilts, eccentricity



Baruteau et al 2015

PLANETS DO FORM QUICKLY (HL TAU, 1 MYR)

- early evidence of disk clearing in young systems, e.g. revealed by ALMA



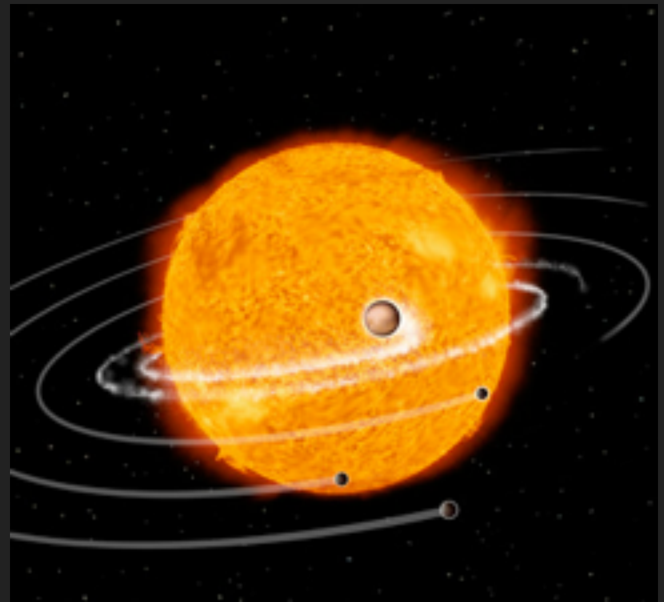
credits: ESO

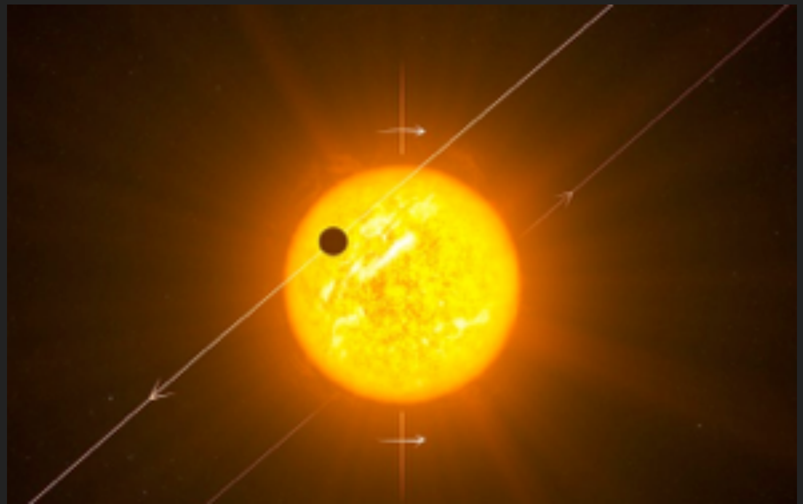
Nov 2014

HL Tau

SOME SYSTEMS HAVE A MORE VIOLENT HISTORY

- migration may not stop
- final orbits may be disturbed by dynamical interactions
- many hot jupiters are in binary systems
- binarity seemingly not related to misalignment (Ngo 2015)
- still being investigated, very active research ongoing





HOT JUPITERS ARE EASY TO FIND

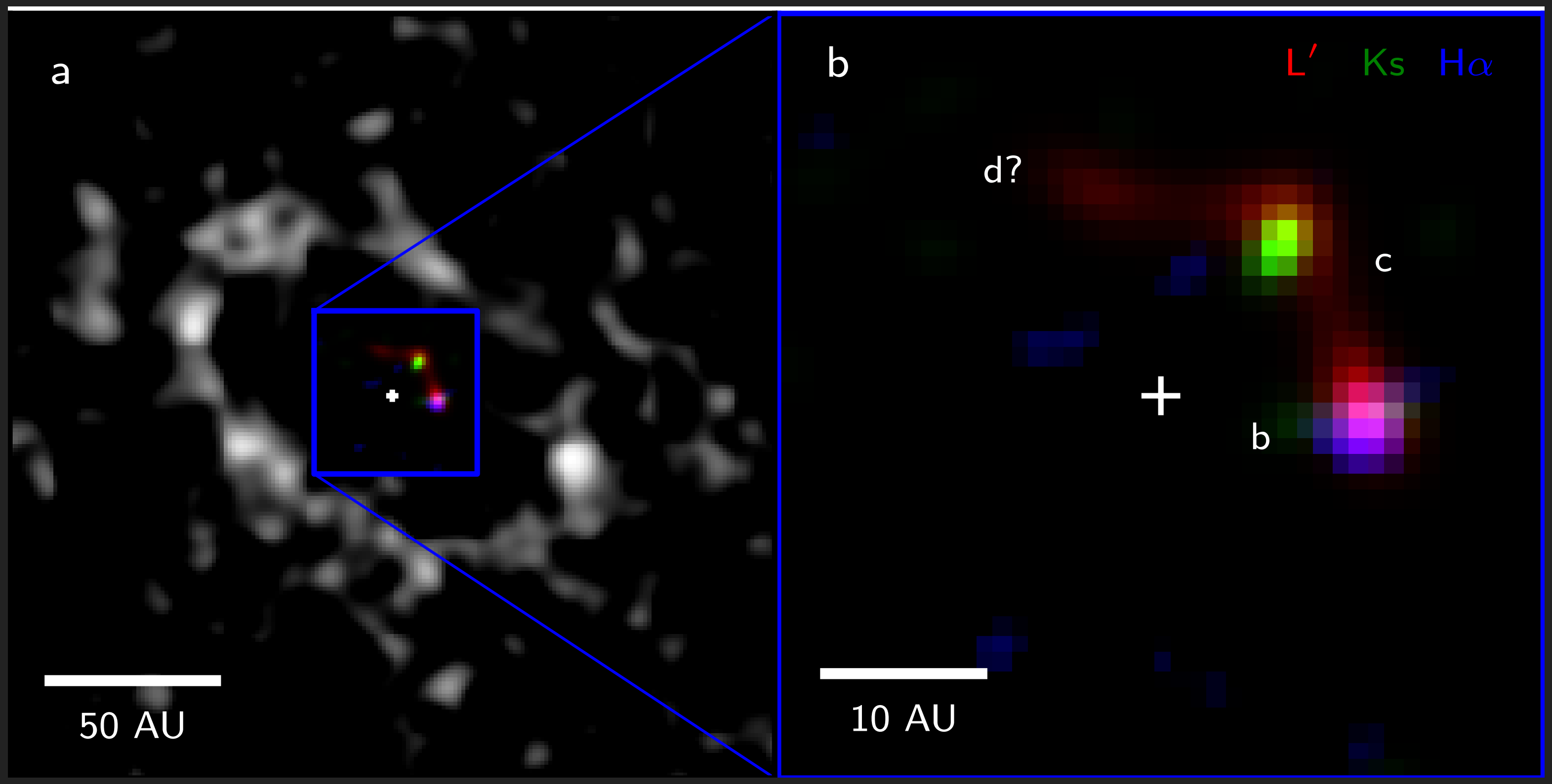
- strong bias of indirect methods:
  - Radial velocity: signal ~ Mp/sqrt(a)............100 m/s
  - transit: signal ~ Rp^2, proba ~ 1/a.............1%, 10%
- 30m/s RV accuracy sufficient: most echelle spectrographs
- mostly HJup found in the first years of planet surveys
- yet they are only present around 1% main-seq stars
- Kepler, and long-term RV surveys agree on that

YOUNG HOT JUPITERS, NOT SO EASY TO FIND…

- the most variable stars: spots, accretion clumps, outbursts, strong magnetic fields, fast rotation
- a challenge for indirect exoplanet methods, watching the star
- very advanced data analysis or multi-techniques required
- direct imaging: young planets are brighter, but method limited in angular separation, not adequate for HJup

LKCA 15 (2MY)

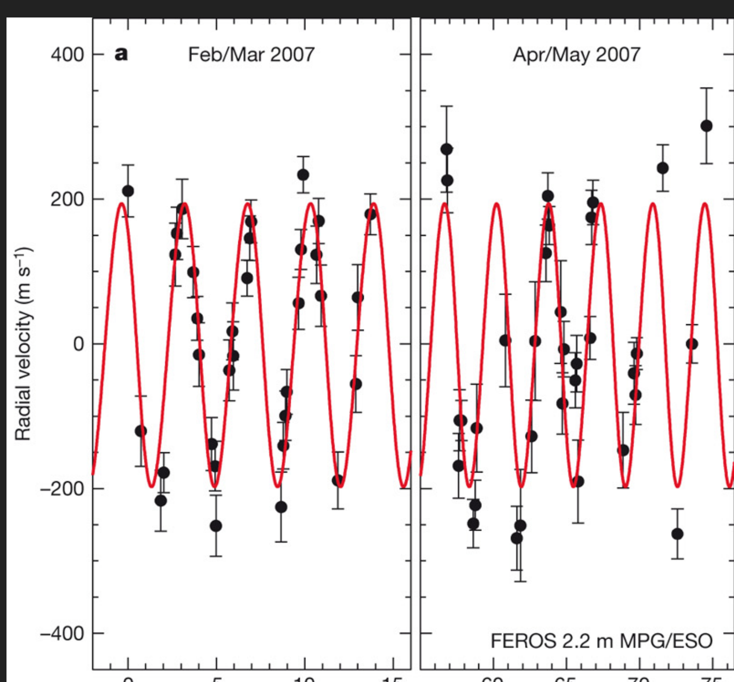
- direct imaging
- 2-3 massive planets in 15-20 AU range
- accretion still ongoing, planet still forming



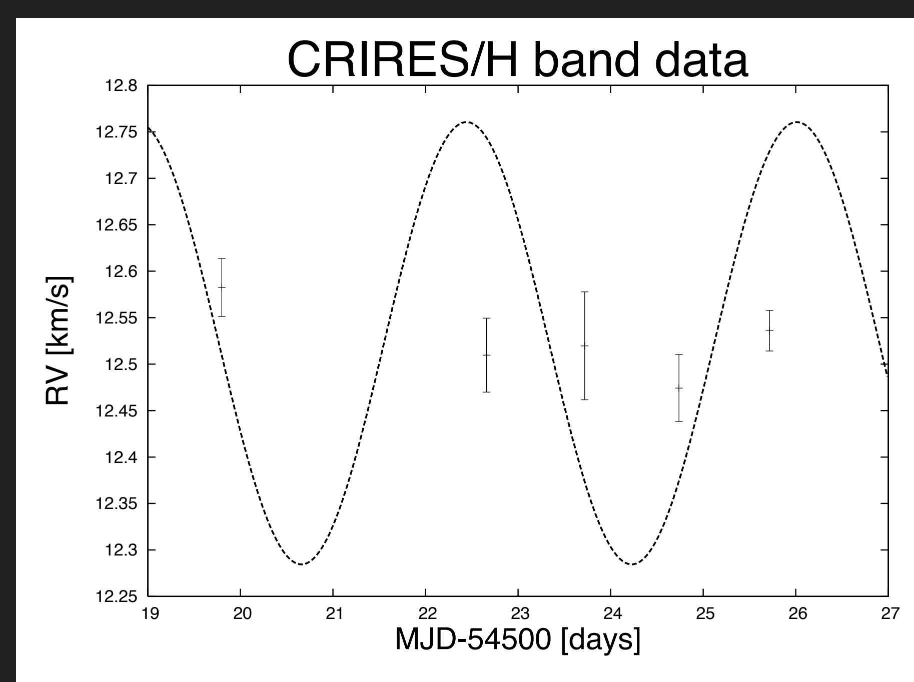
Kraus & Ireland 2011, Sallum et al 2015

TW HYA (5–10 MY)

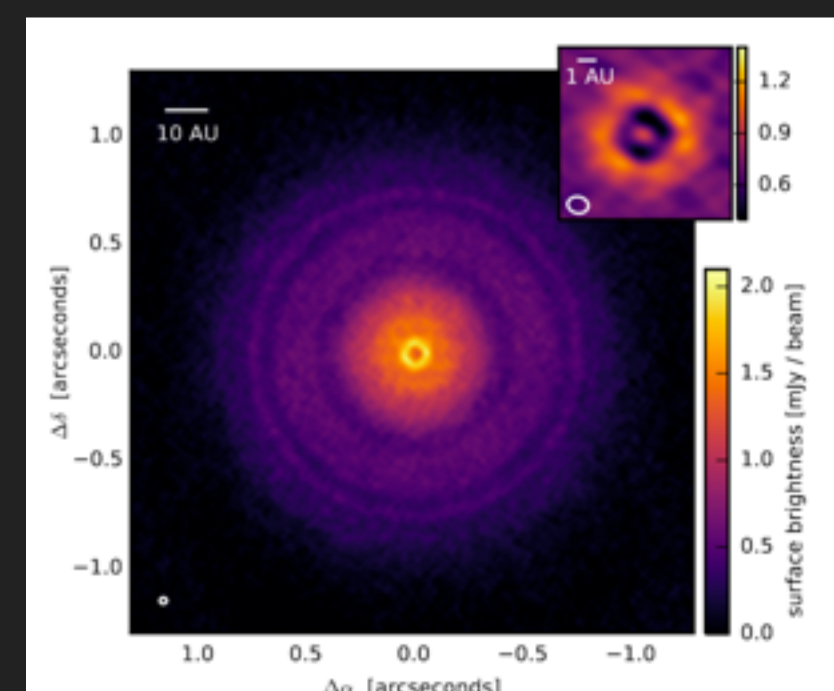
- HJup announced in 2008, optical RVs
- face on: 10MJ at 3.5d orbit
- nIR RVs and bisector slope deny this scenario
- gaps & structures at AU scale



Setiawan et al 2008

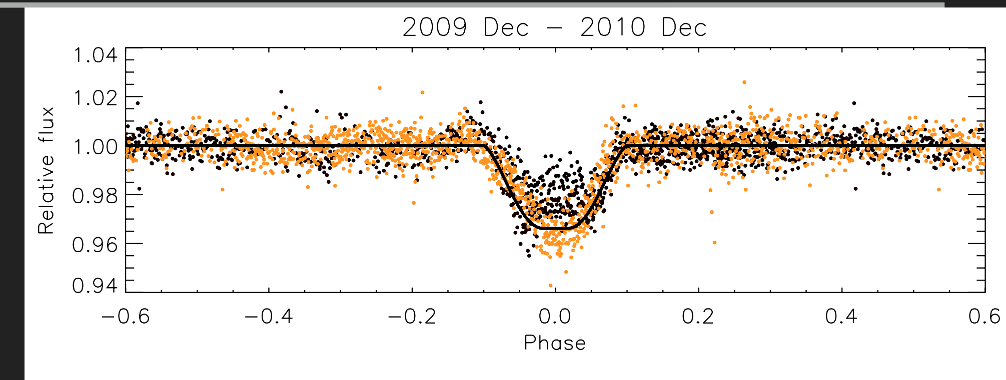


Huelamo et al 2008

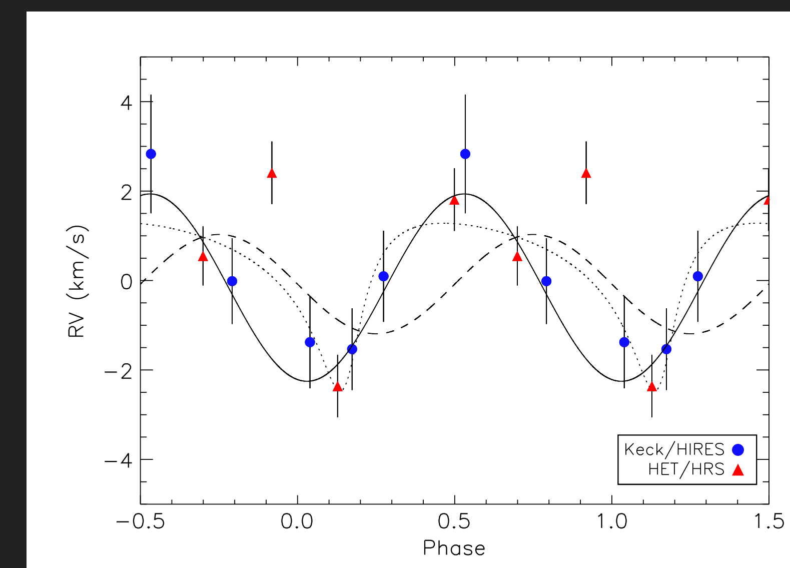


ALMA -Andrews et al 2016

PTFO 8-8695 (3 MY)



- planet candidate 0.45d period, 1.9RJ
- co-rotating star
- but transits are chromatic
- non-planet scenarios more probable

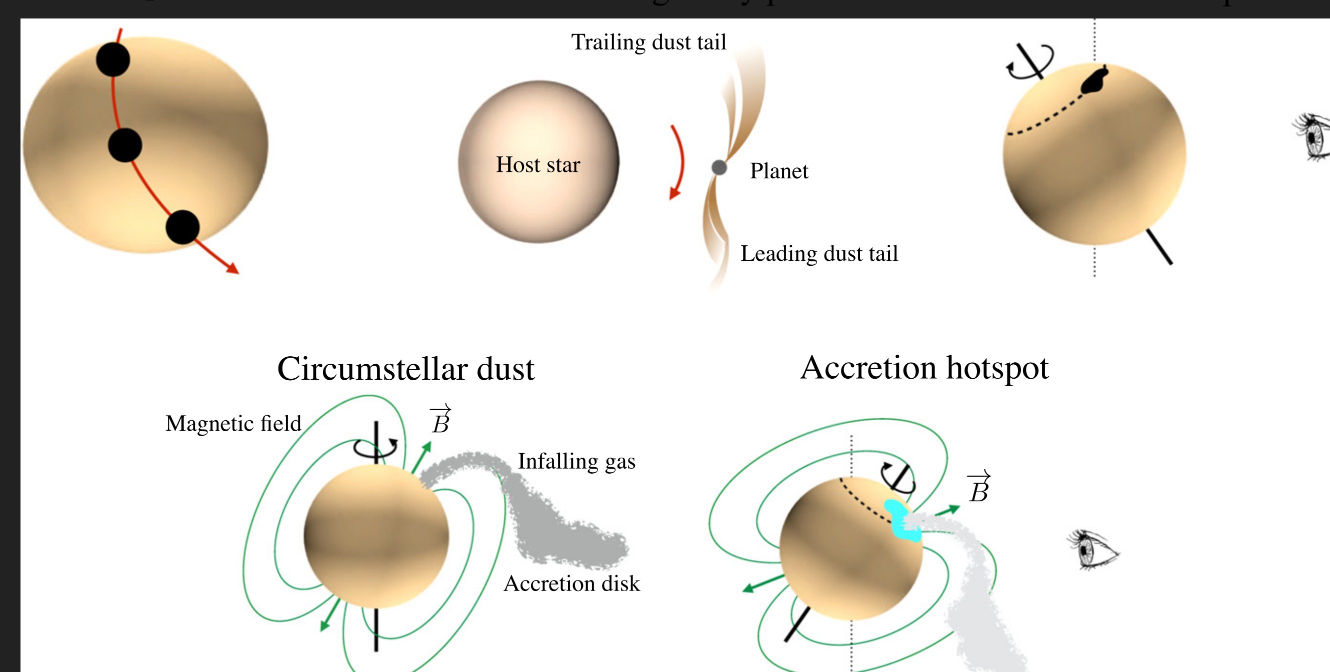


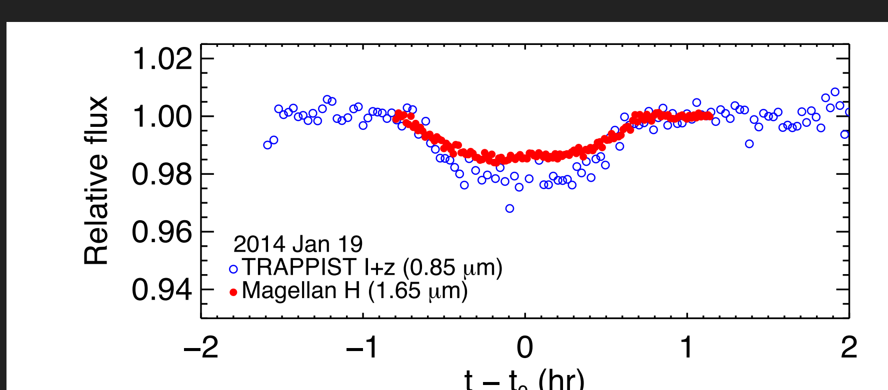
van Eyken 2012

Giant planet

Dust-emitting rocky planet

Cool starspots



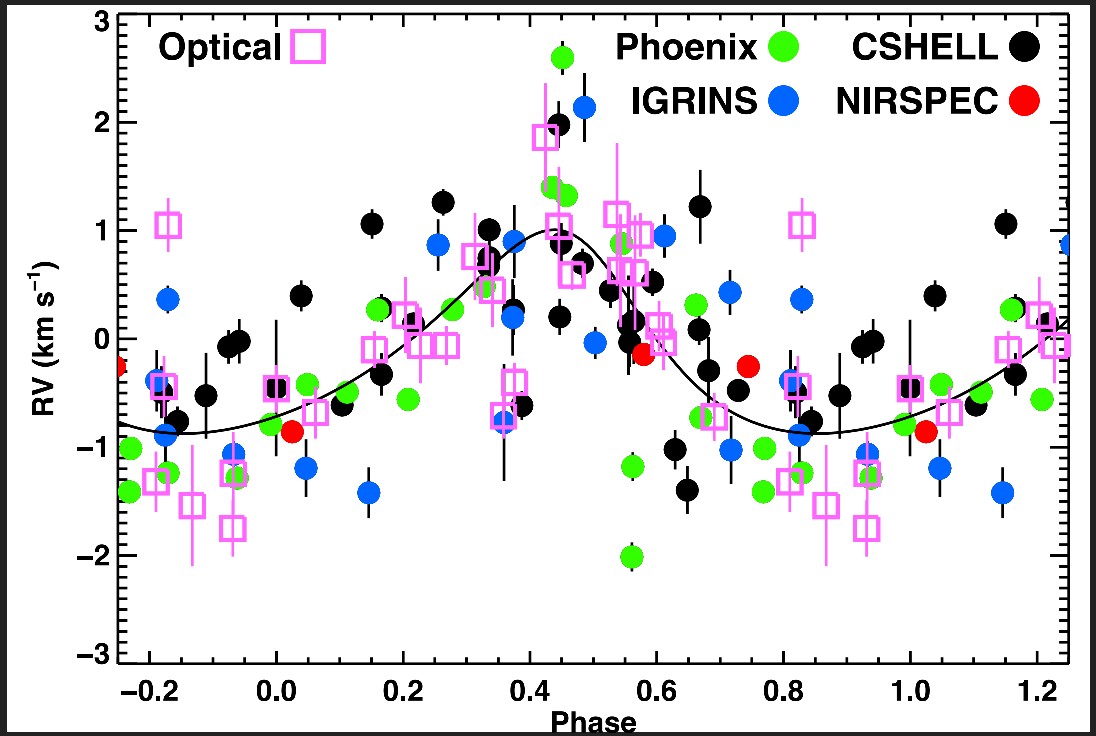


Liang Yu et al 2015

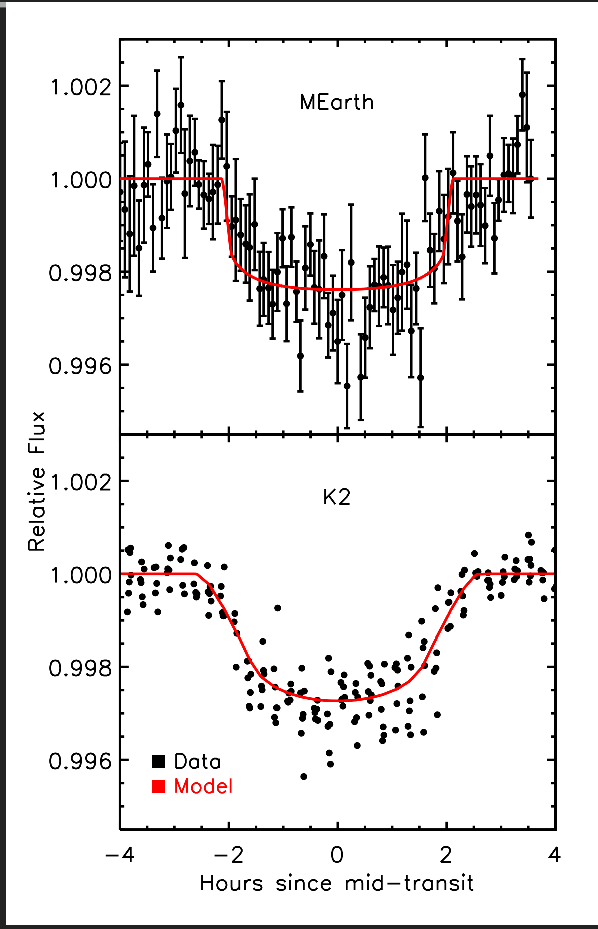
CI TAU (2 MY)

- 8 MJ, 9 day period in K-band radial velocities
- disk still present
- star rotation ~5-7 d (TBC)
- Halpha in phase with planet: accretion?
- maybe 10-12 MJ
- needs more observations

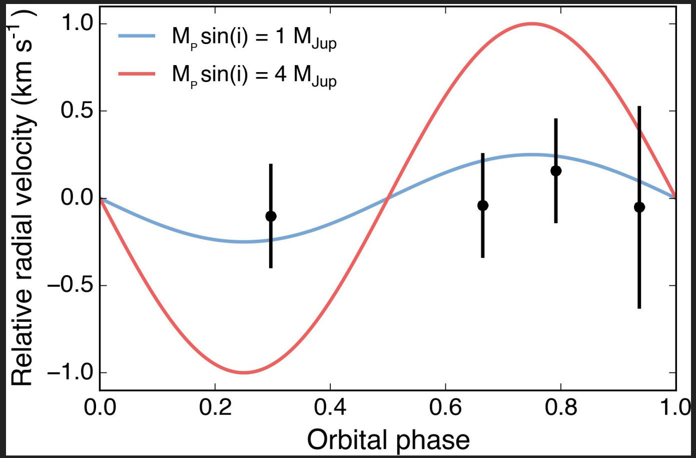
Johns-Krull et al 2016

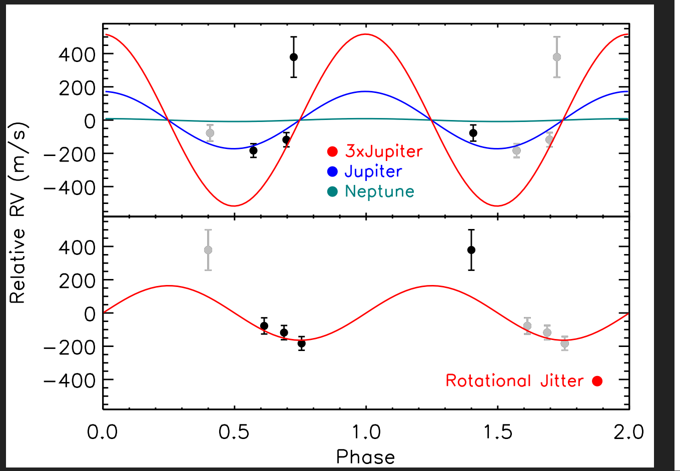


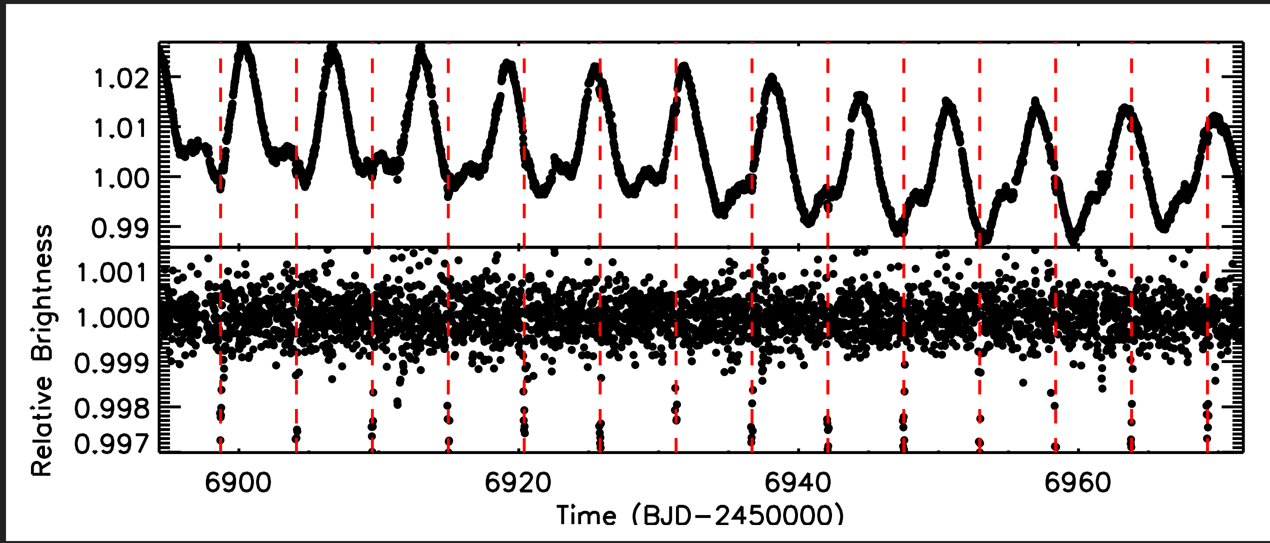
K2-33 / EPIC 205117205 (10 MY M STAR)



- orbital period 5.4d
- 5 Earth radii, no mass (K~20m/s expected)
- star rotation 6.3d
- false positives scenarios discarded







David et al 2016

Mann et al 2016, subm

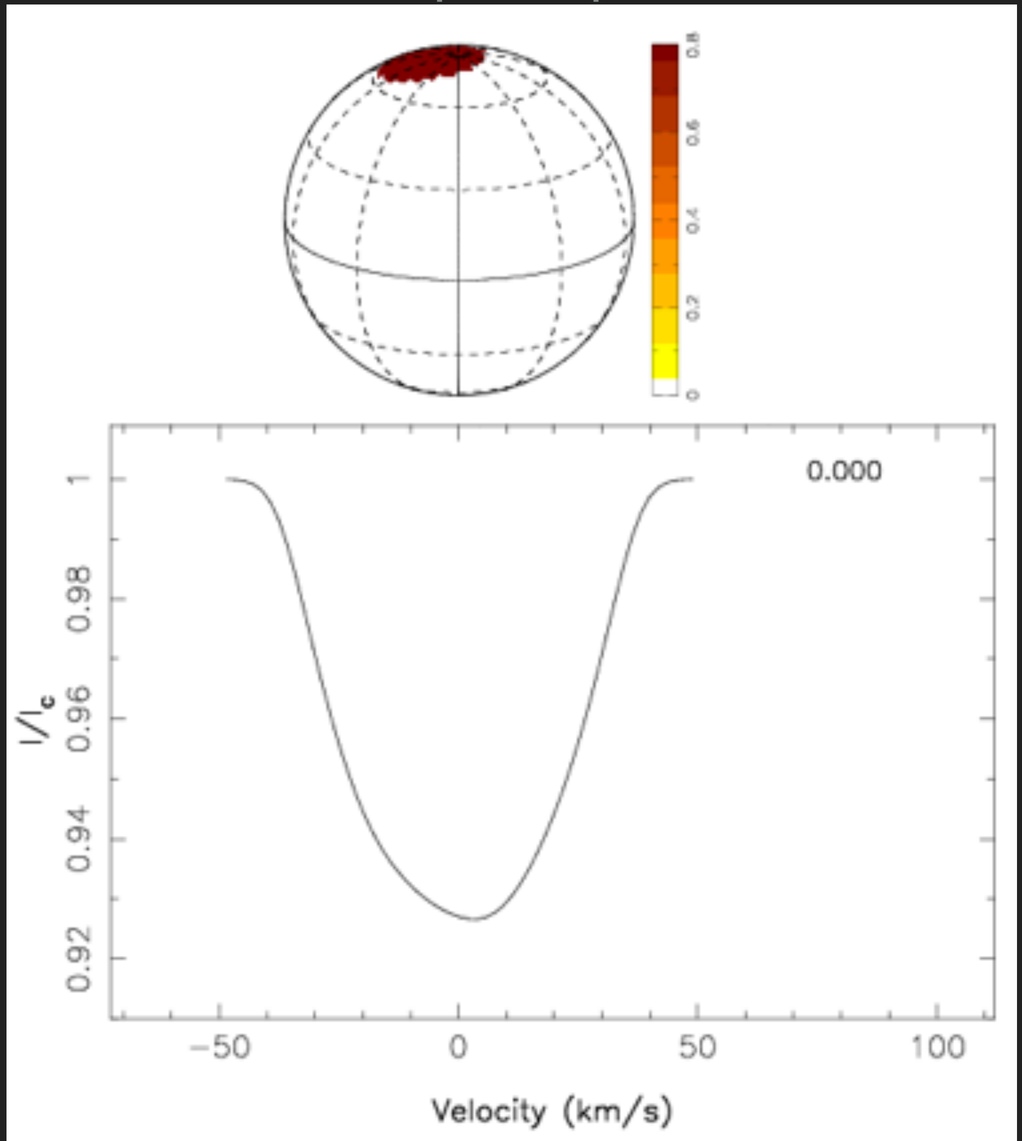
THE CFHT/ESPADONS MATYSSE PROGRAM

- uses CFHT/ESPaDOnS, TBL/NARVAL, HARPS-POL
- formation of Sun-like stars and their planetary systems
- role of the magnetic field in early stages
- large-scale magnetic topology of low-mass protostars
    - are these similar in cTTS and wTTS?
    - migration in disk, gaps, winds, and their time evolution, wrt planet formation and survival

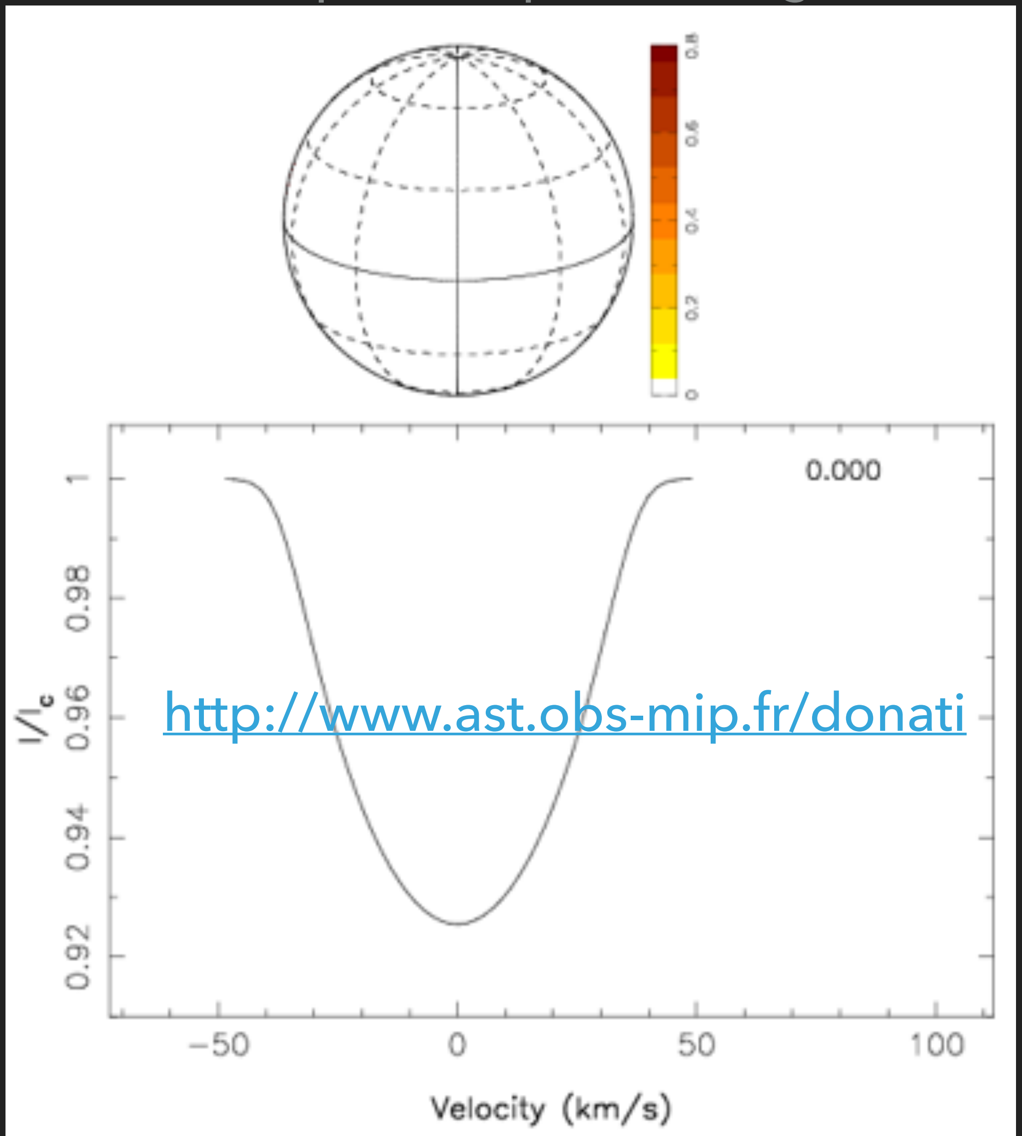
USING TOMOGRAPHY TO CORRECT FOR STELLAR ACTIVITY

- Intensity profile: latitude and longitude of spots
- mean star profile averaging 1,000s lines

spot at pole: core



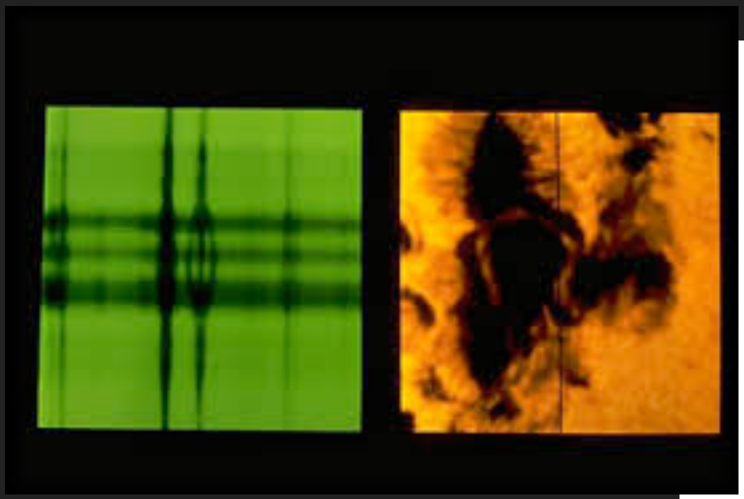
spot at equator: wings



http://www.ast.obs-mip.fr/donati

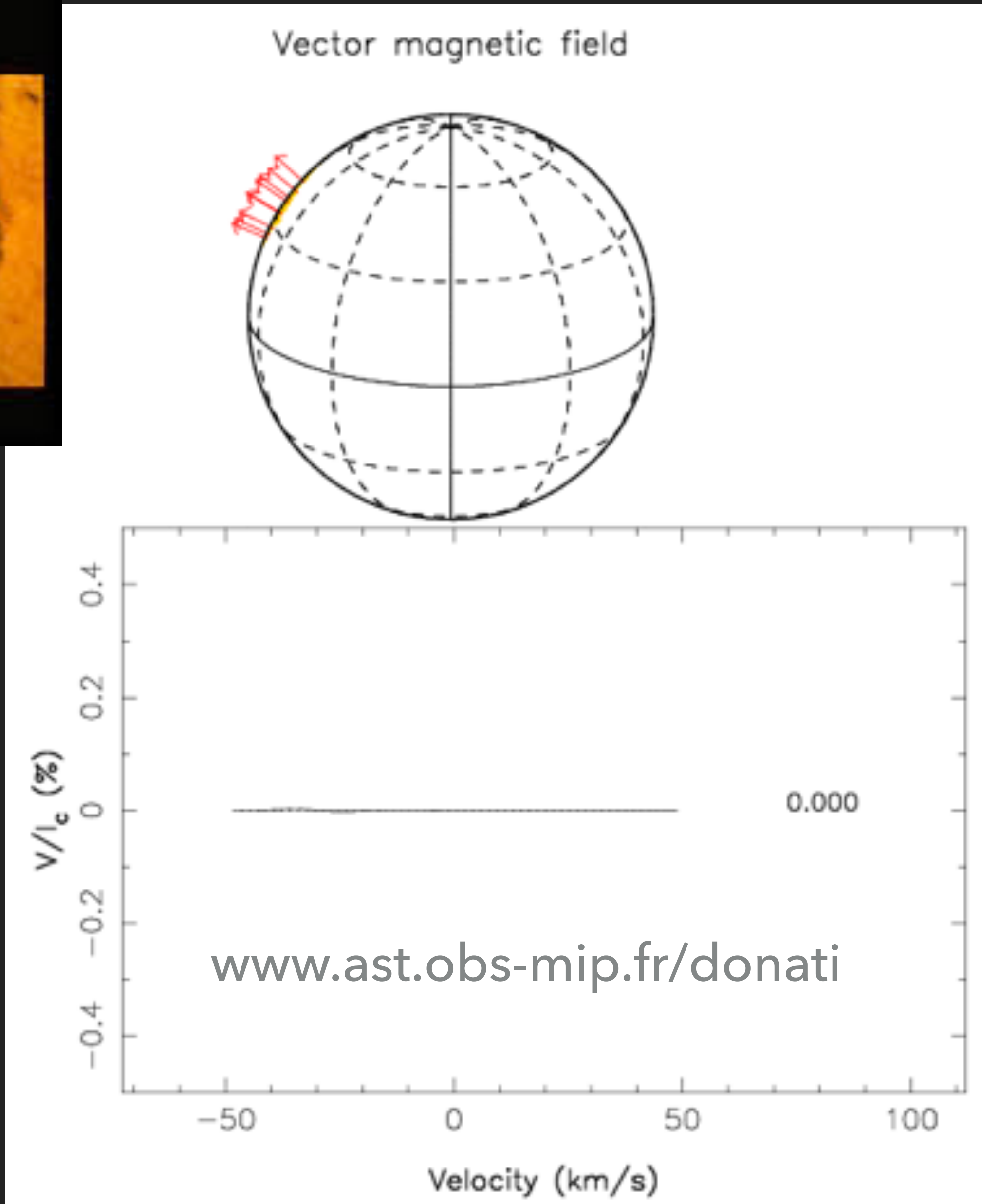
SPECTROPOLARIMETRY: MAGNETIC FIELD TOPOLOGY

- circular polarization is sensitive to the B field along l.o.s.



Zeeman splitting

radial field



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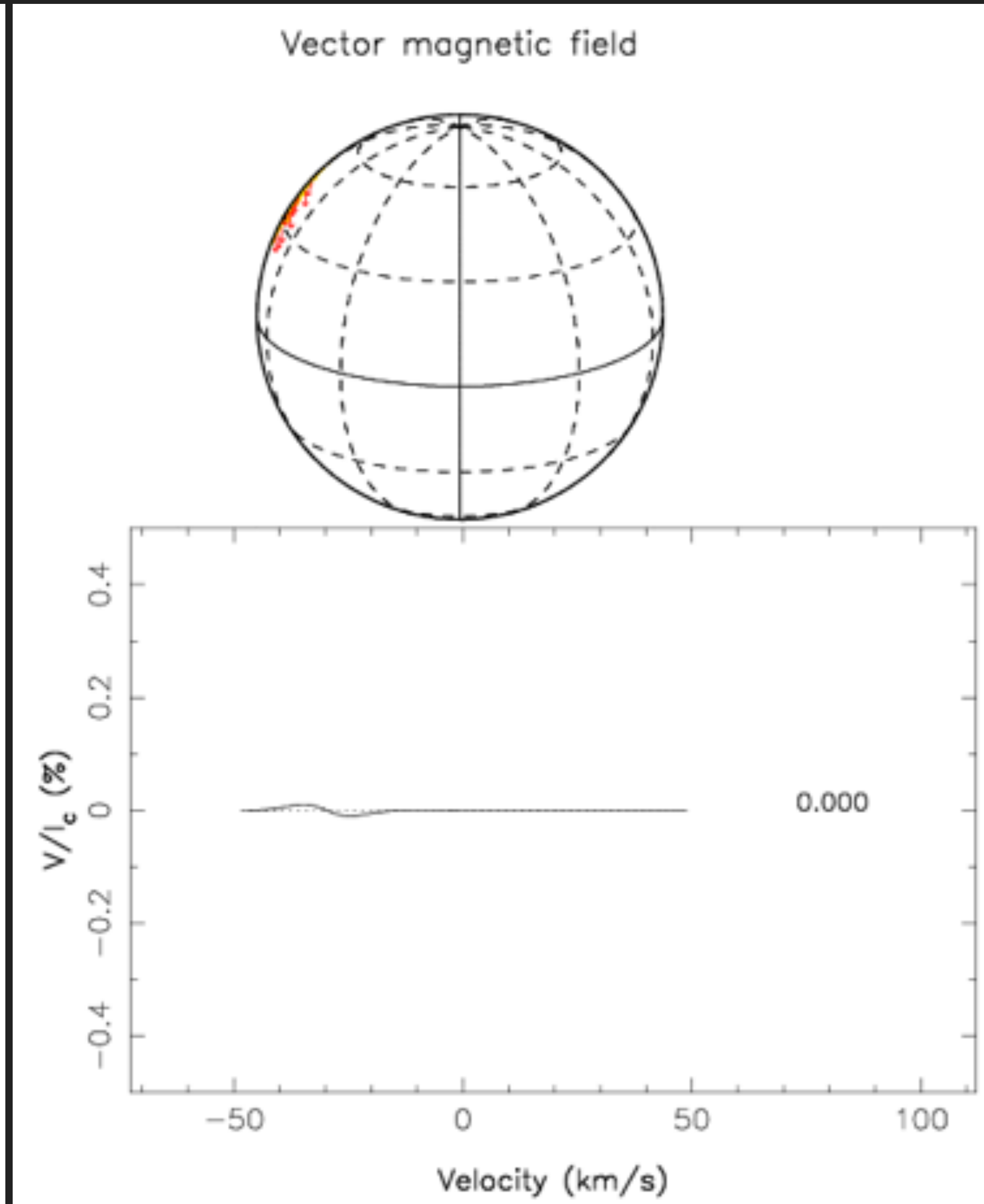
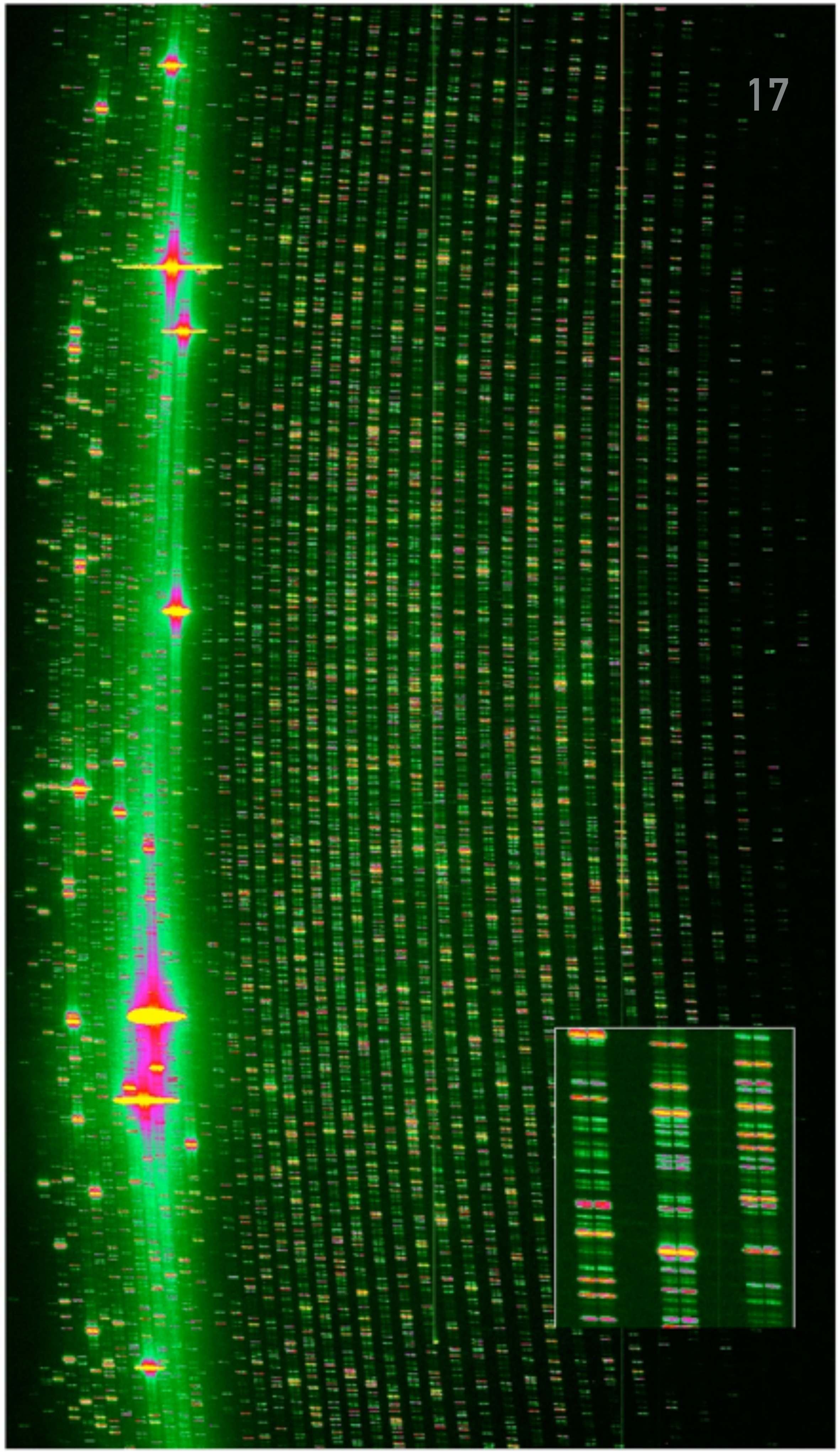
azimutal field



CFHT/ESPADONS

- Xdisp échelle 370-1050nm
- 65-80k resolution
- polarimetric/spectro mode
- 20m/s RV accuracy
- operated in queue mode
- ~8 runs / 80 n per year

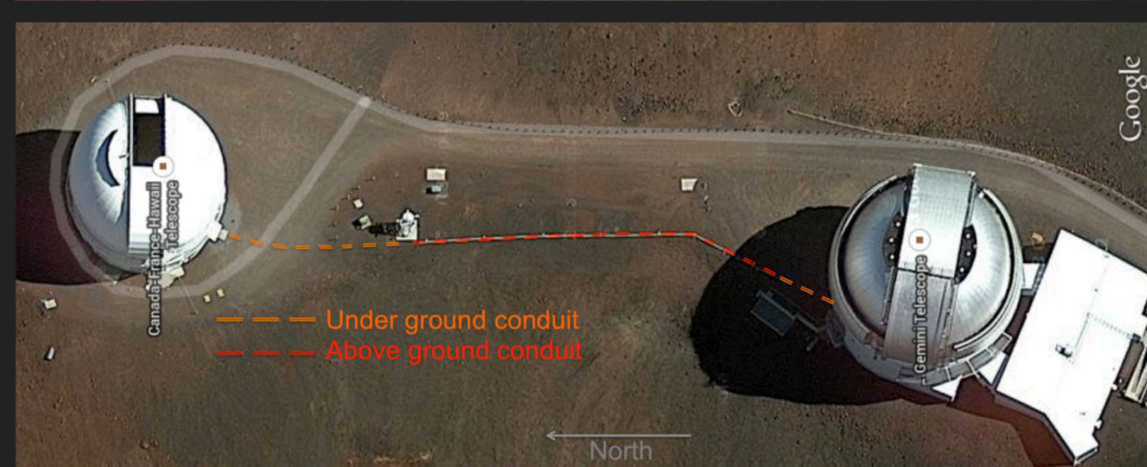


TBL/NARVAL

- NARVAL is a twin of ESPaDOnS
- TBL 2m in the Pyrénées, South France
- same pipeline, same RV accuracy, data can be mixed

GEMINI/ESPADONS = GRACES

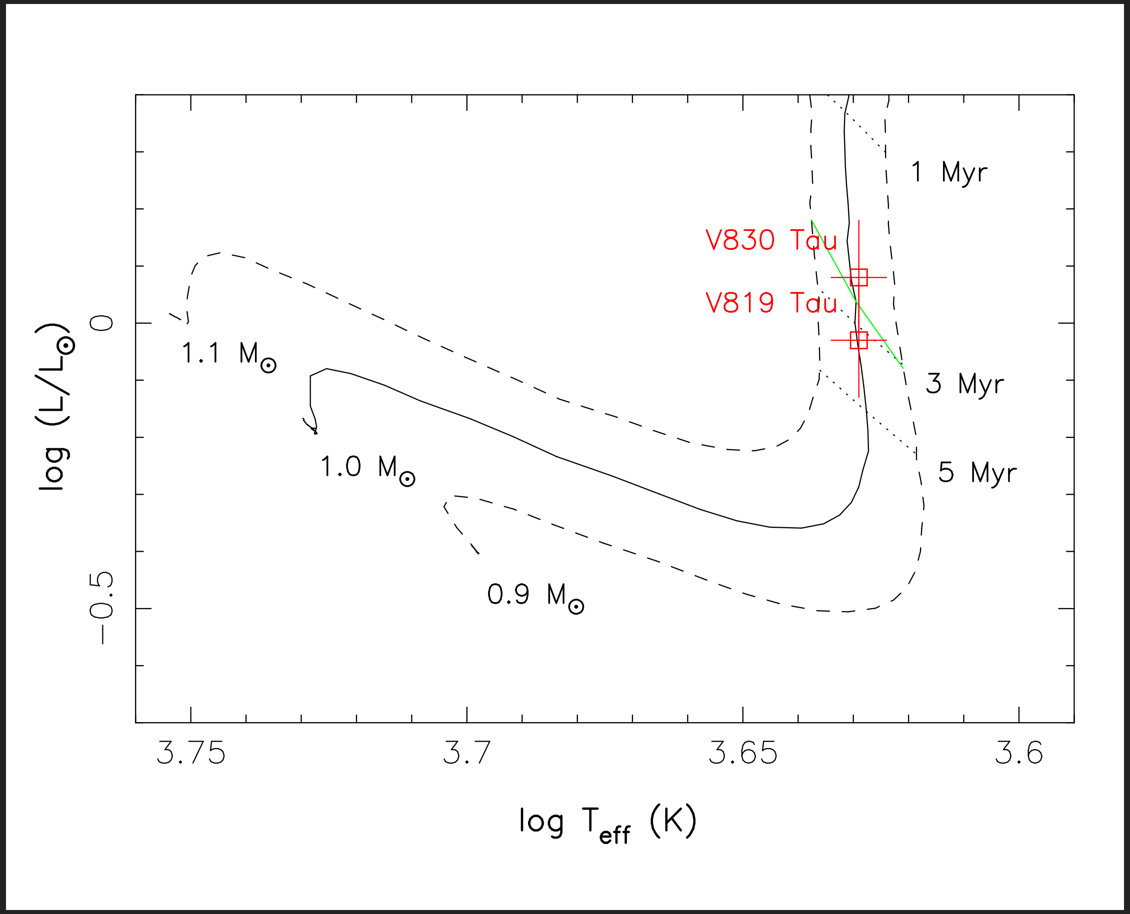
- uses Gemini telescope, a 270m fiber link, and ESPaDOnS, in operation since May 2014
- spectral range 400-1050nm (less blue), R 40-65k
- NO polarimetry, ~ same RV accuracy



courtesy A.-N. Chene

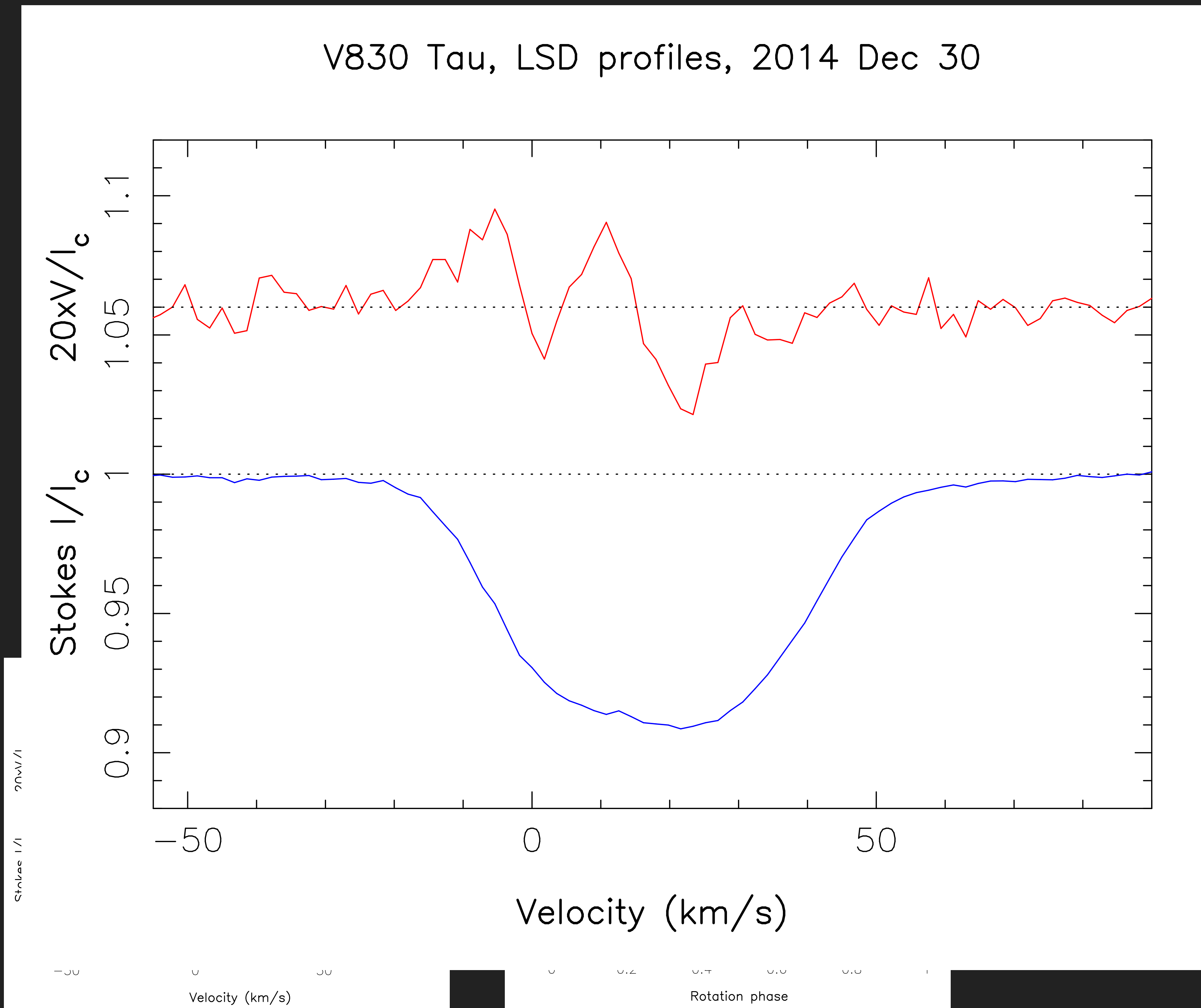
V830 TAU

- 131 parcsec in Taurus
- a solar-type star 1 Msun
- ~2 My, inflated radius 2 Rsun
- 8% solar luminosity, V=12.1
- 2.741 d rotation period (precise from ZDI)
- inclination 55 degrees (from ZDI)
- projected rotational velocity 30 km/s

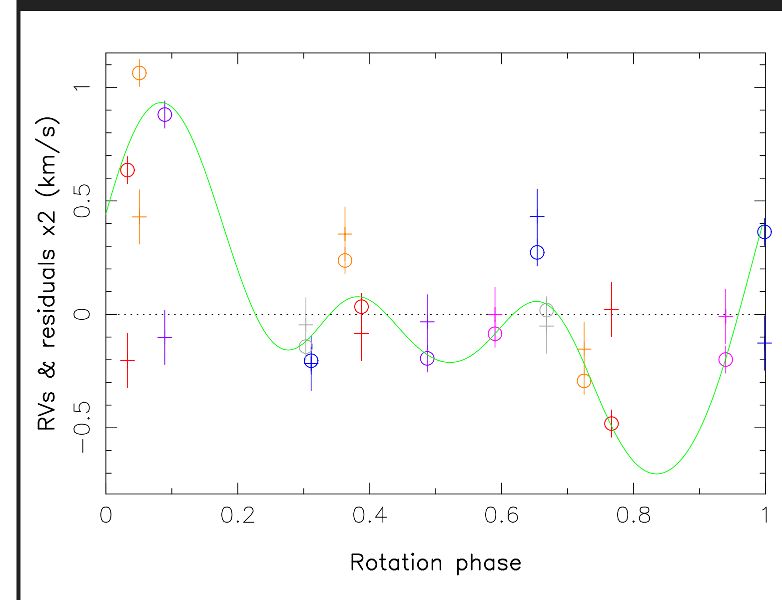


Donati et al 2015

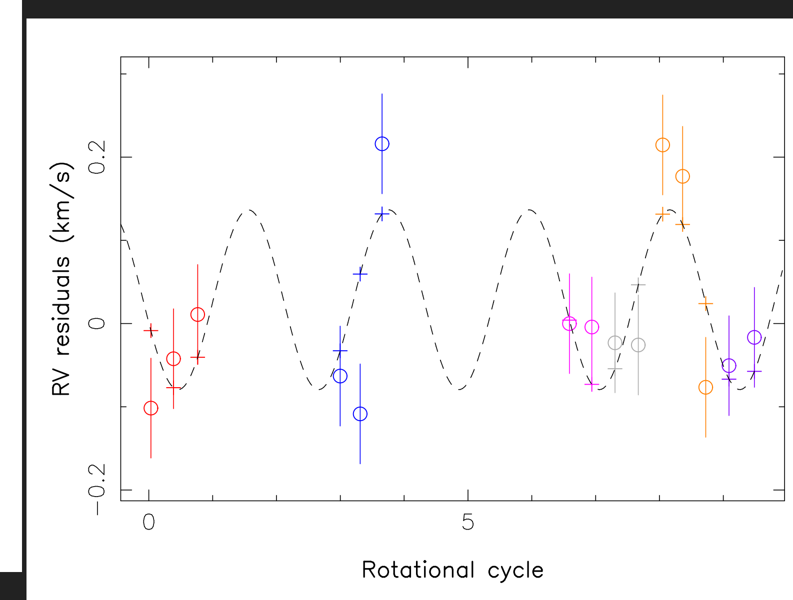
PRE-DETECTION IN DEC2014



sequences

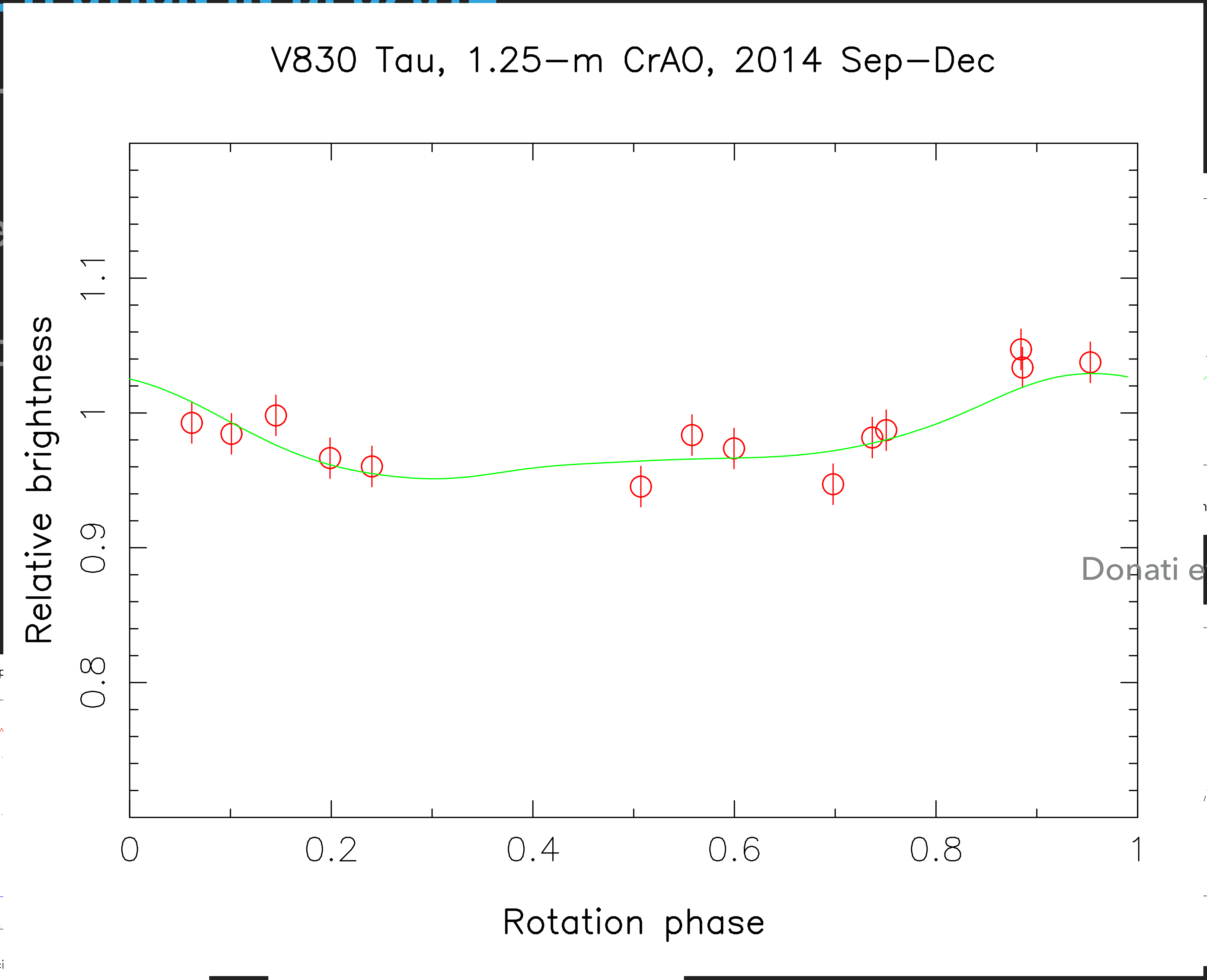


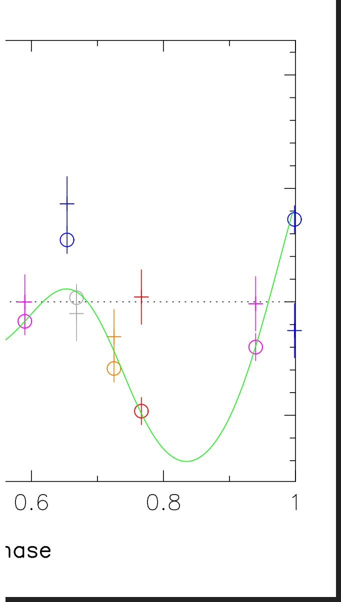
Donati et al 2015



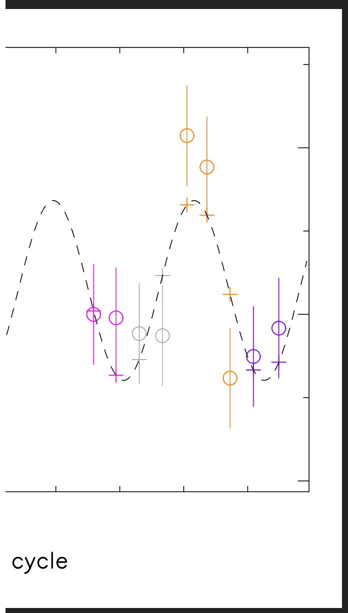
PRE-DETECTION IN DEC2014

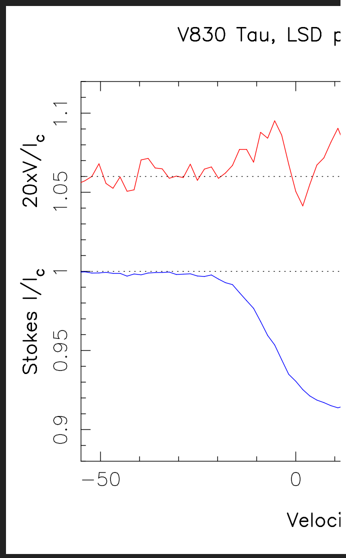
- CFHT
- wide
- phot





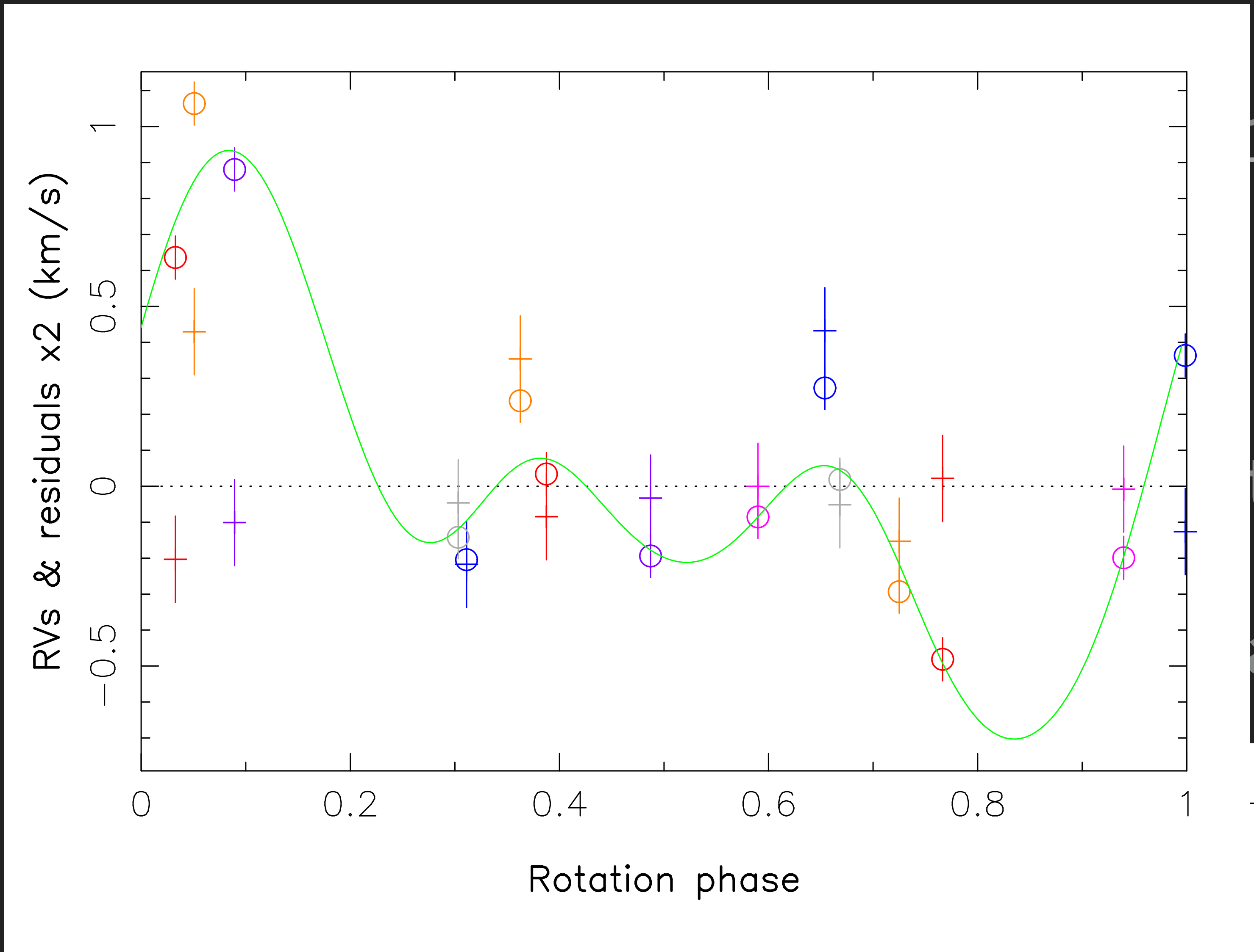
Donati et al 2015



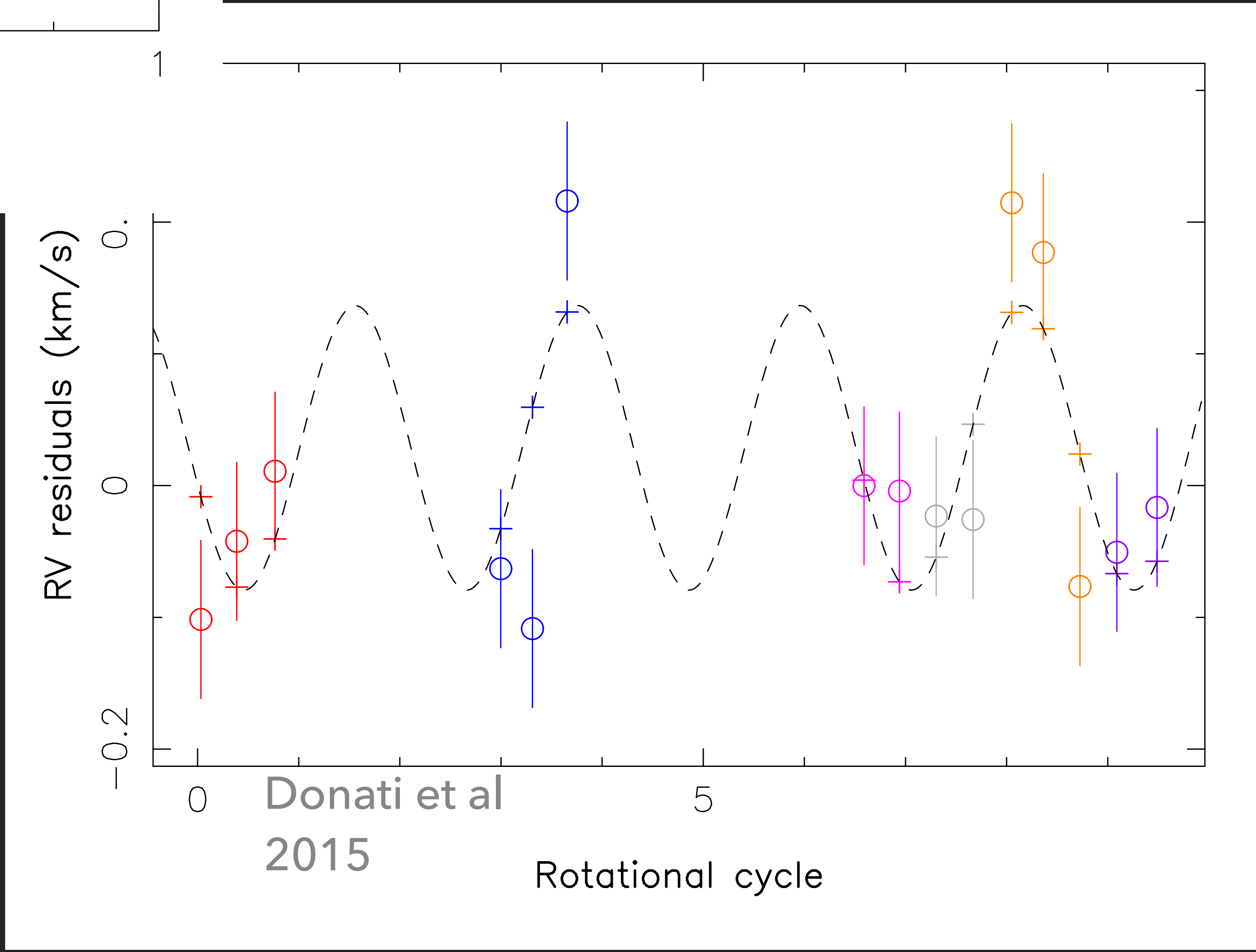


tro-polar sequences

ariations



- RV indicate an additional

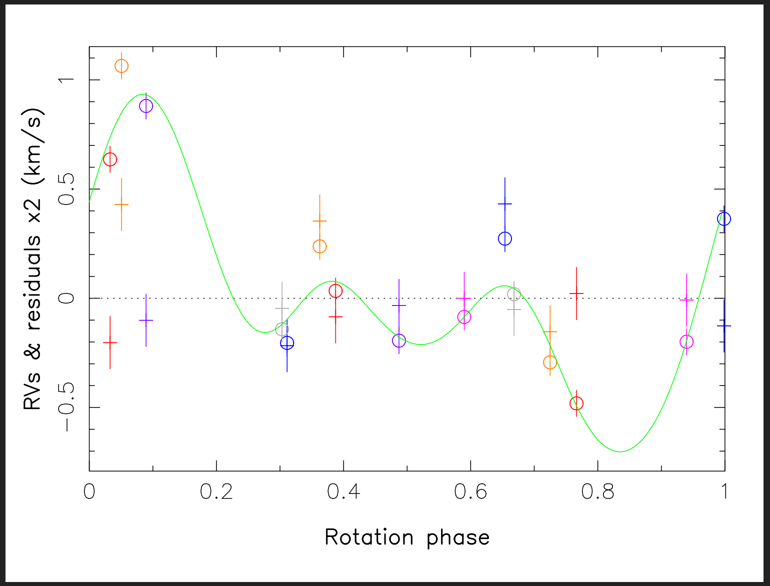


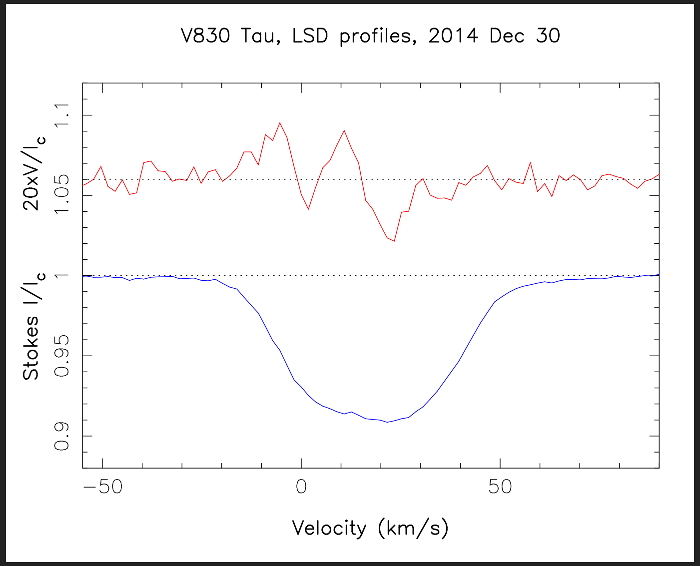
Donati et al 2015

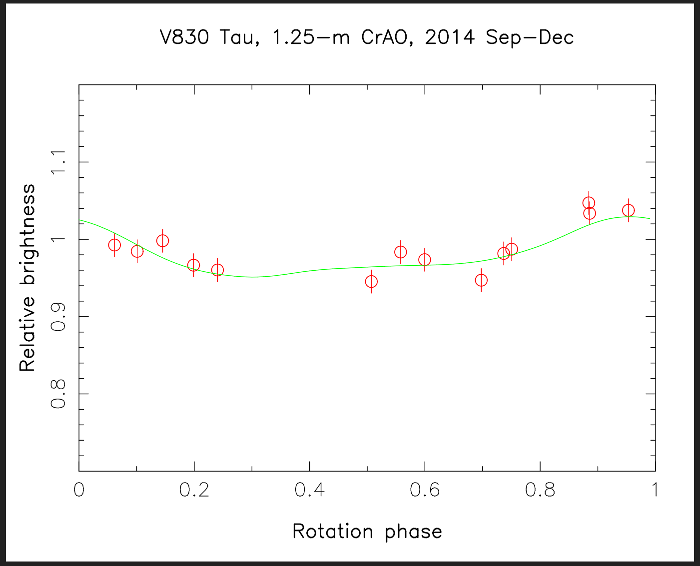
Donati et al 2015

PRE-DETECTION IN DEC2014

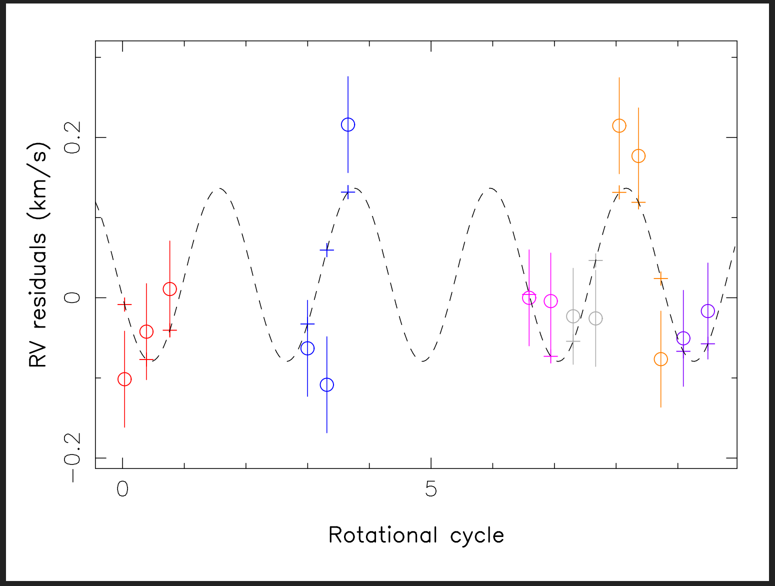
- CFHT/ESPaDOnS data, 14 spectro-polar sequences
- wide, rich stellar profile and V variations
- photometric LC modeled by ZDI
- RV indicate an additional short P signal
- better sampling needed!
- B mainly poloidal, dipole 350G + 100G toroidal







Donati et al 2015

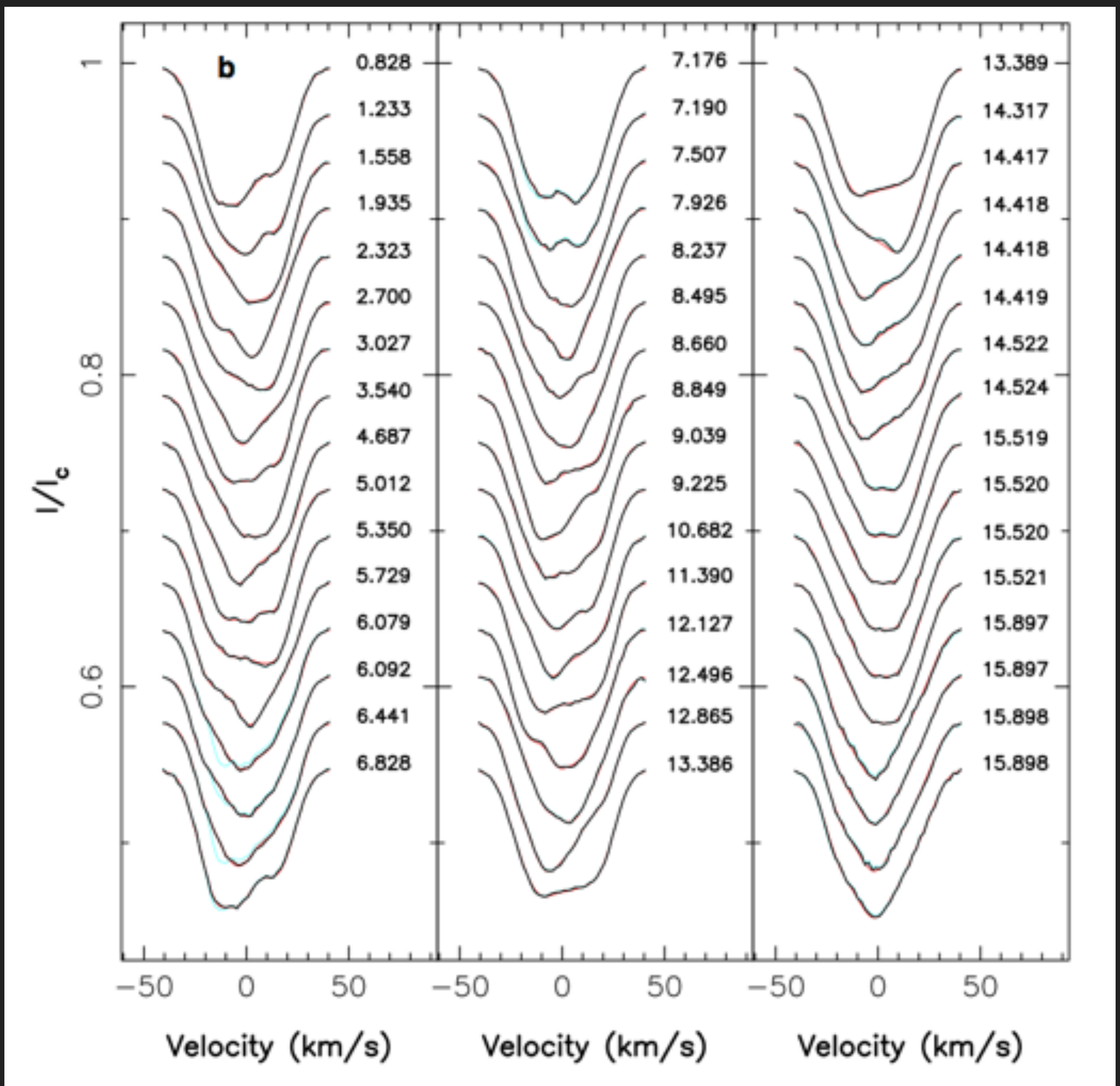


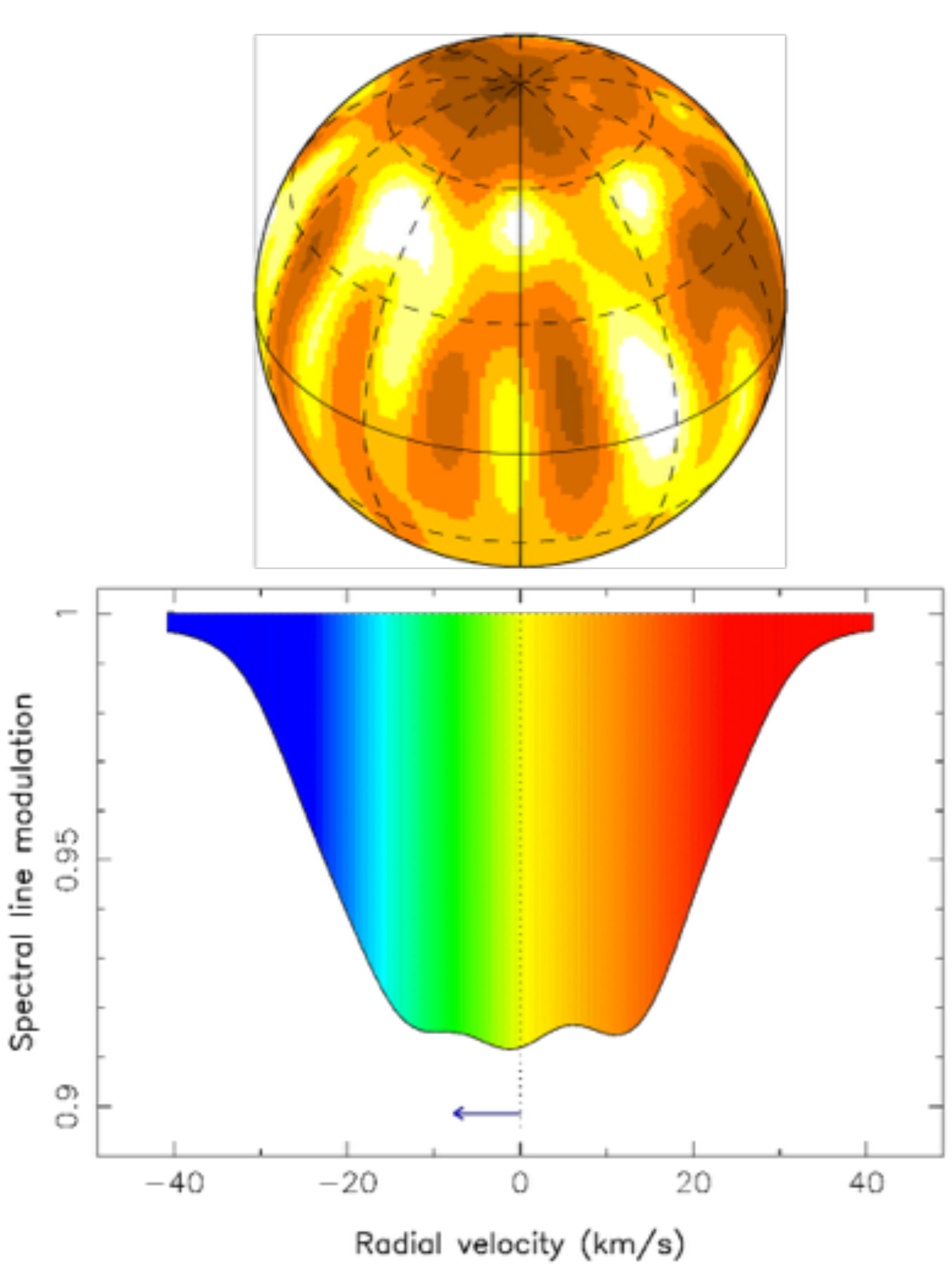
THE FINAL DETECTION

- 47 hours of telescope time over 1.5 month
- CFHT/ESPaDOnS, GRACES, NARVAL
- Unique pipeline and homogeneous data analysis
- Tomographic techniques to remove the stellar jitter
- The signal is consistent in several sub-data sets
- V stokes profiles not even used yet

TIME SERIES OBTAINED IN NOV-DEC 2015

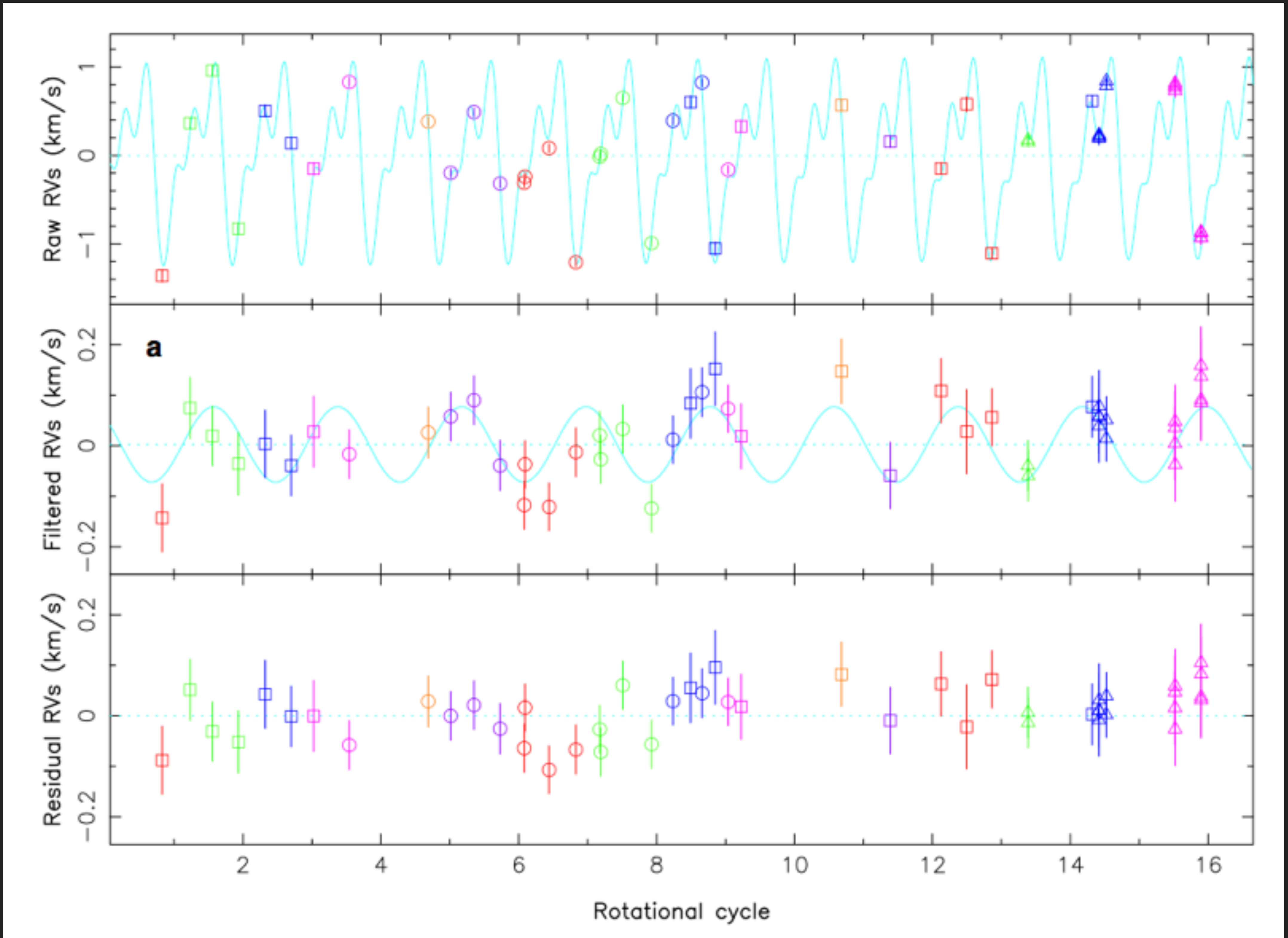
Multi-line Intensity Profiles with time ESP/NARVAL/GRACES + Model





Donati et al 2016

FROM STAR TO PLANET



activity

planet

residuals

Donati et al 2016

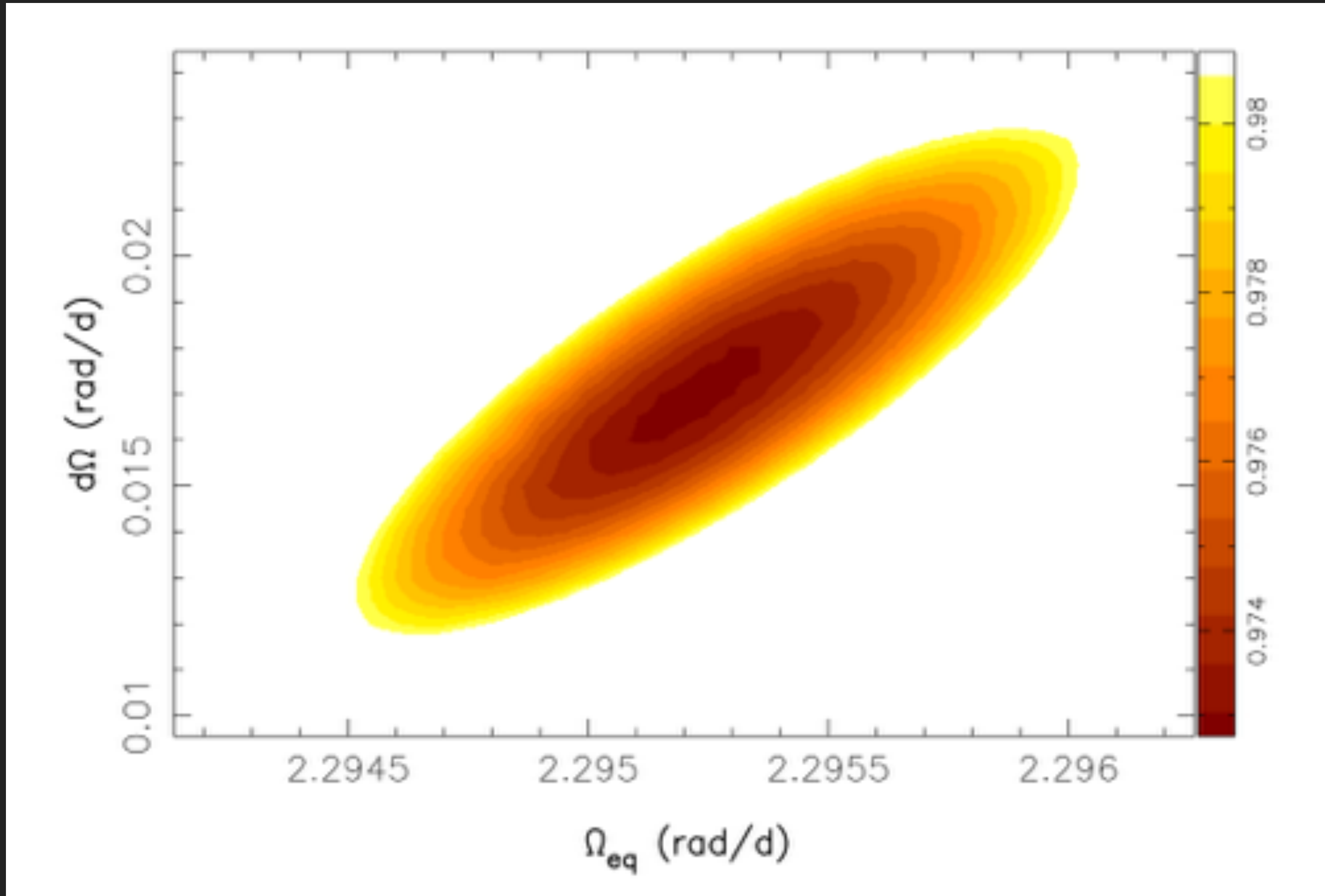
PERIODOGRAMS

- a clear peak at 4.94d
- stable in various subsets
- not present in activity tracers
- Prot clearly identified

Donati et al 2016

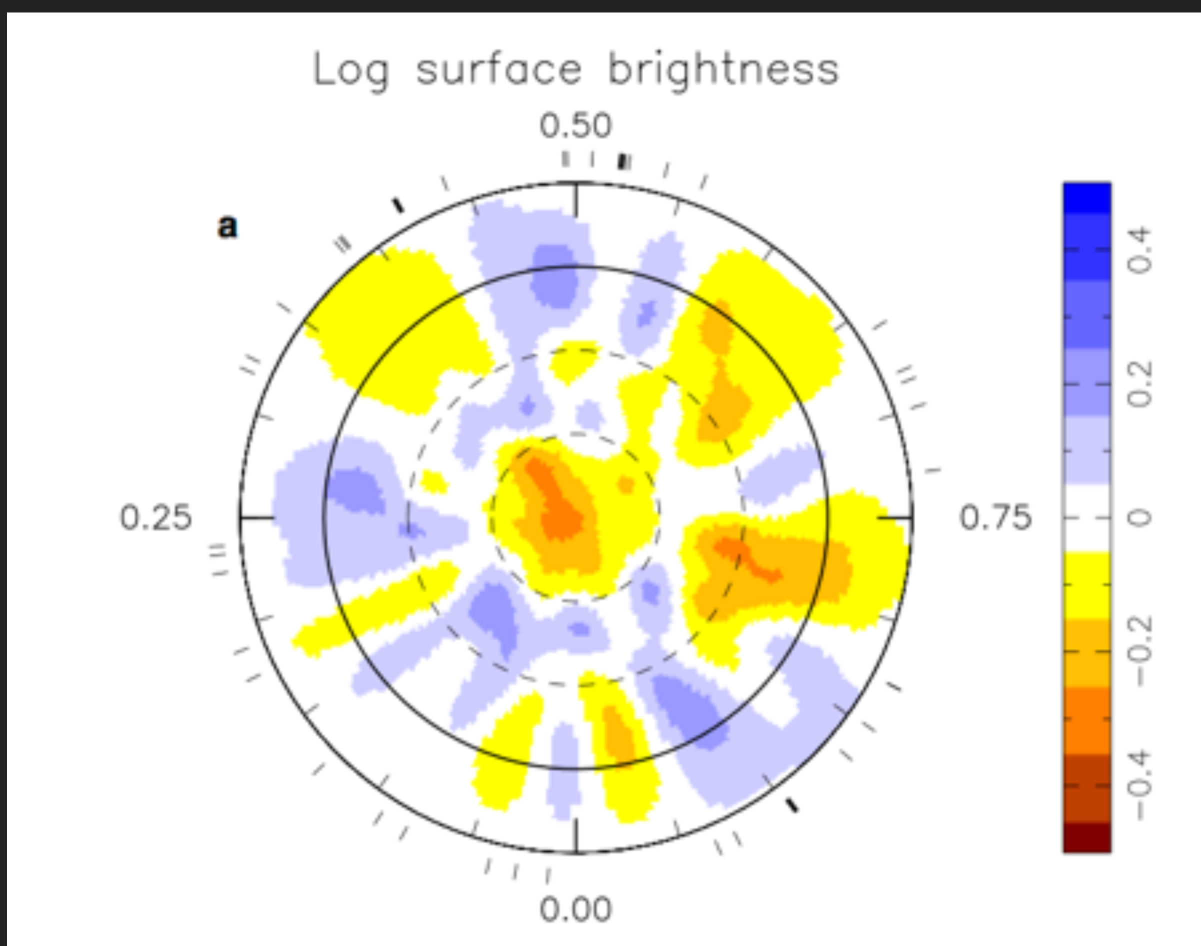
BY-PRODUCT: THE ROTATION PROPERTIES OF THE PARENT STAR

- rotational period is very well constrained by ZDI
- differential rotation can be added to the model and leads to a better result
- 3x weaker than the Sun
- largely/fully convective star

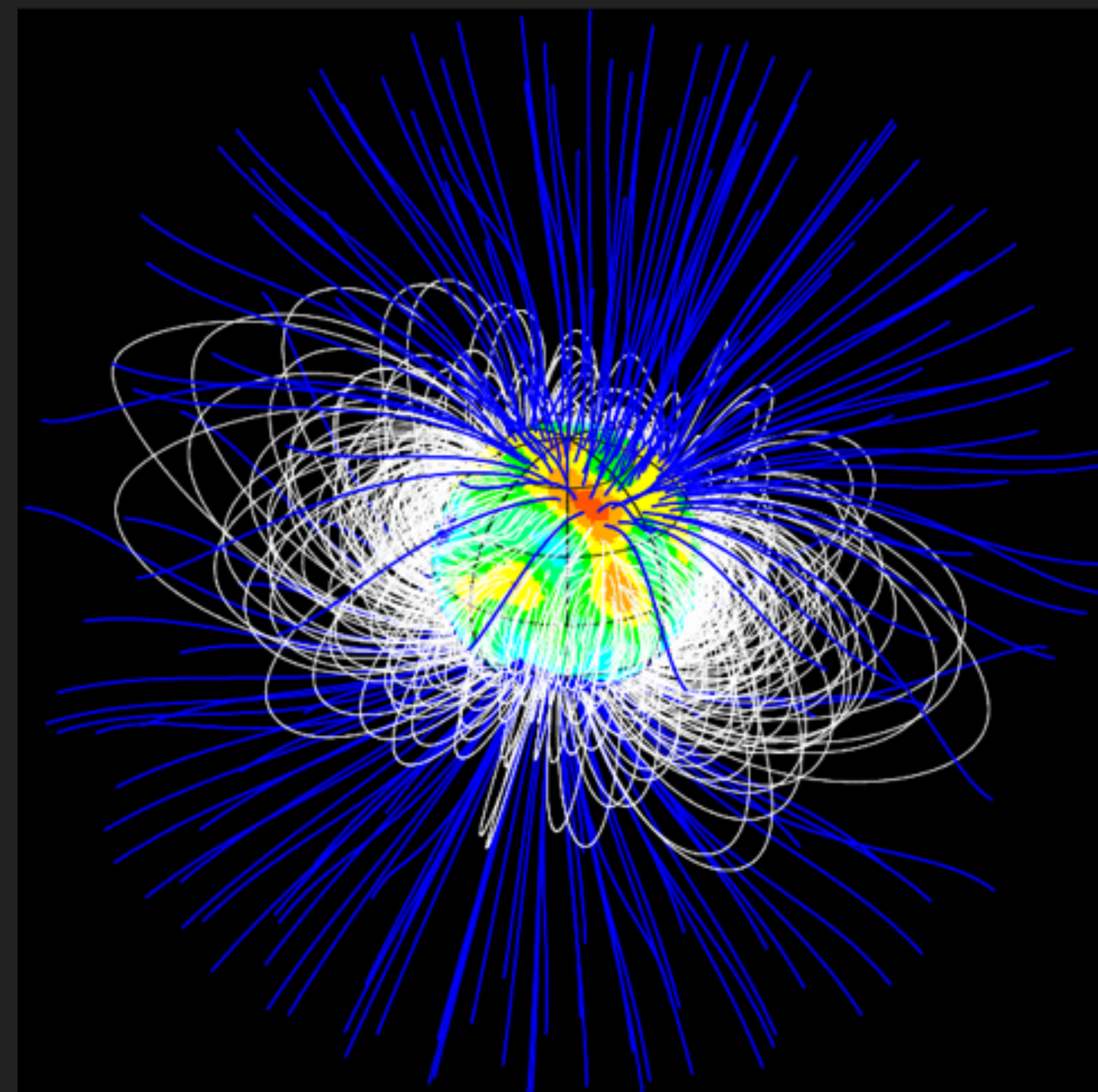


Donati et al 2016

A COMPLEX STELLAR SURFACE



surface features modeled by differential rotation



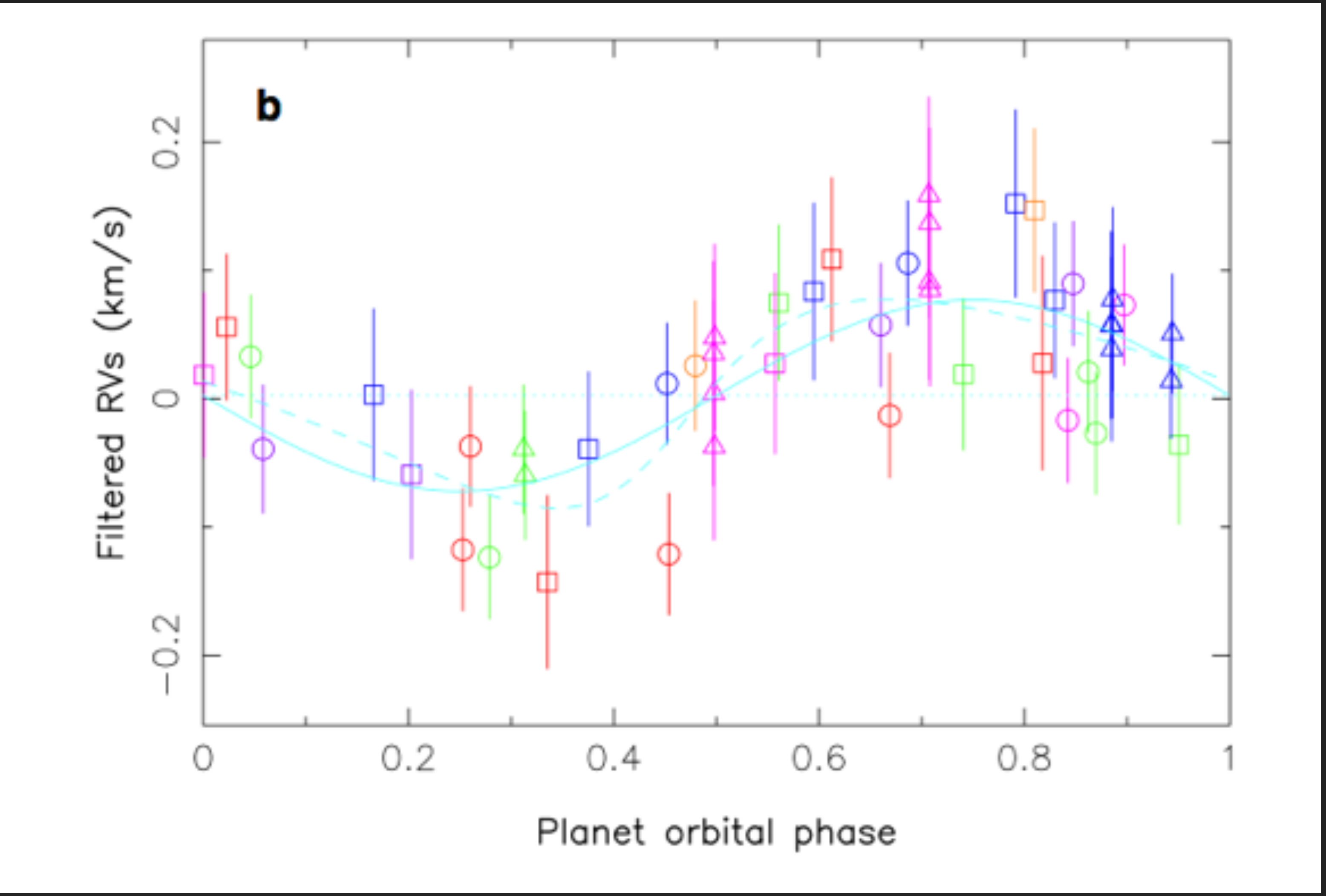
Donati et al 2016

PLANET

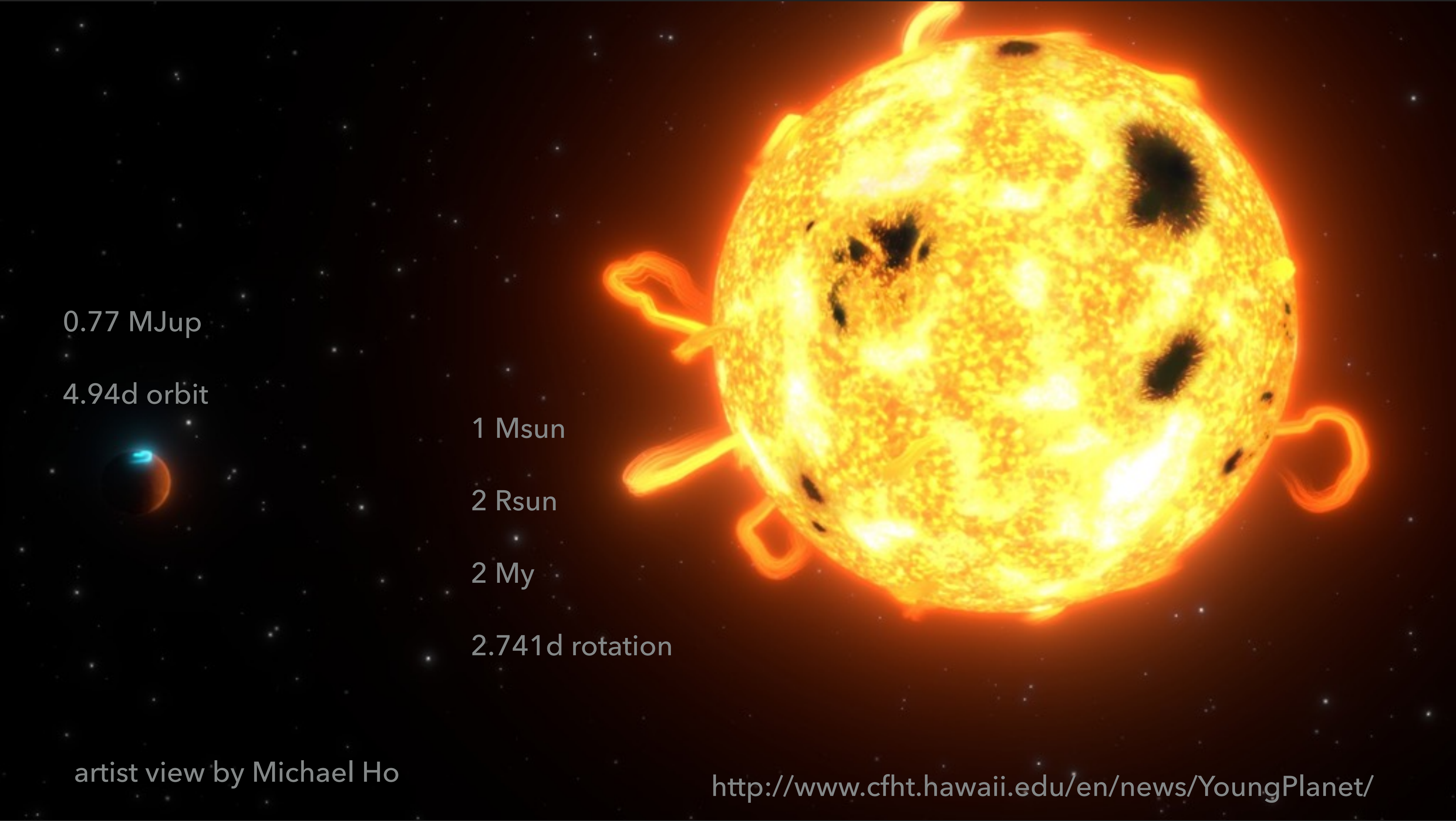
- corrected RVs phased at 4.94d orbit
- eccentricity is not constrained; residual e or circularized?
- 0.77 MJup
- 0.057 AU

activity amplitude reduced by x10

K=75+-11m/s



V830 TAU IN A NUTSHELL

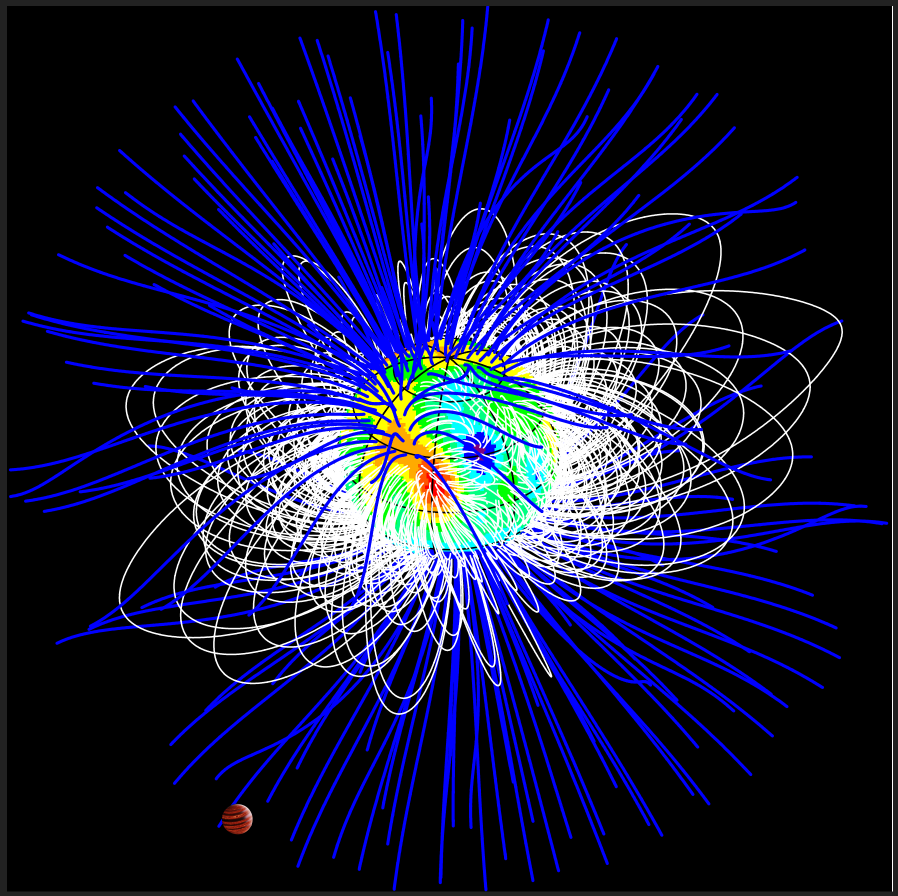


artist view by Michael Ho

http://www.cfht.hawaii.edu/en/news/YoungPlanet/

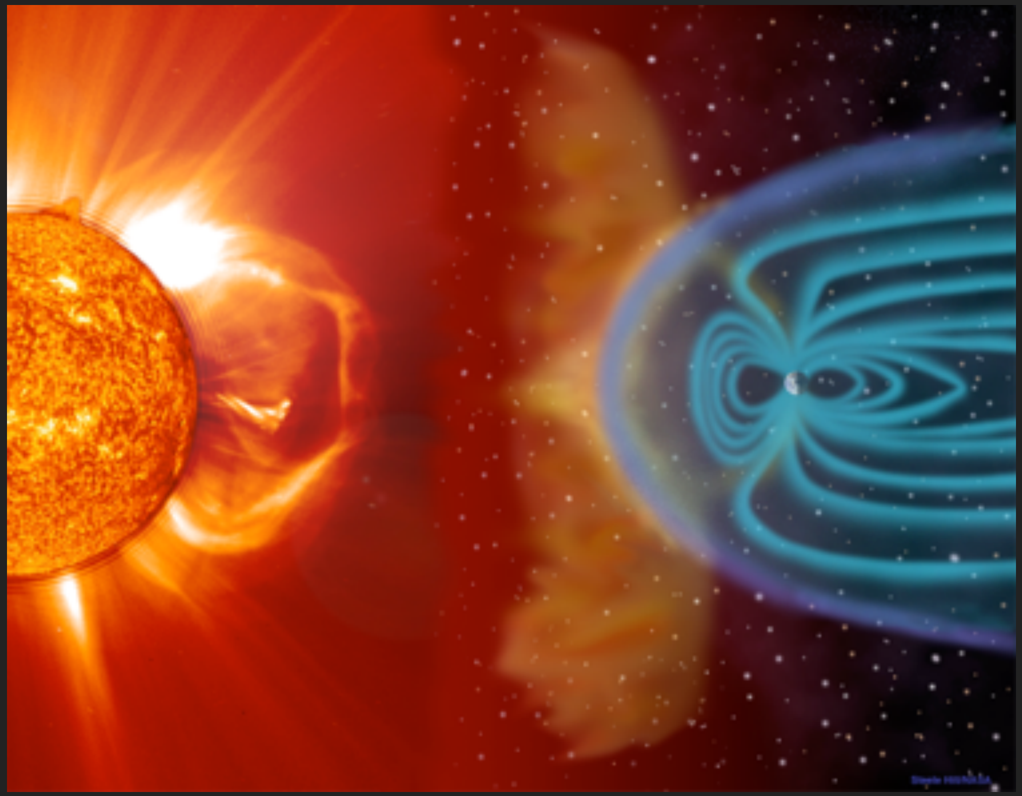
INTERACTIONS WITH THE STAR?

- why does the magnetic field matter in a hot Jupiter system?
- magnetospheric cavity has impact on migration
- migration timescale depends on stellar B topology, rotation, mass loss
- stellar wind, atmospheric corrosion
- radio emission of exoplanets
- close-in planet can induce activity
- or impact the stellar magnetic cycle?
- adds up to tides and irradiation interactions



SPI THEORETICAL STUDIES

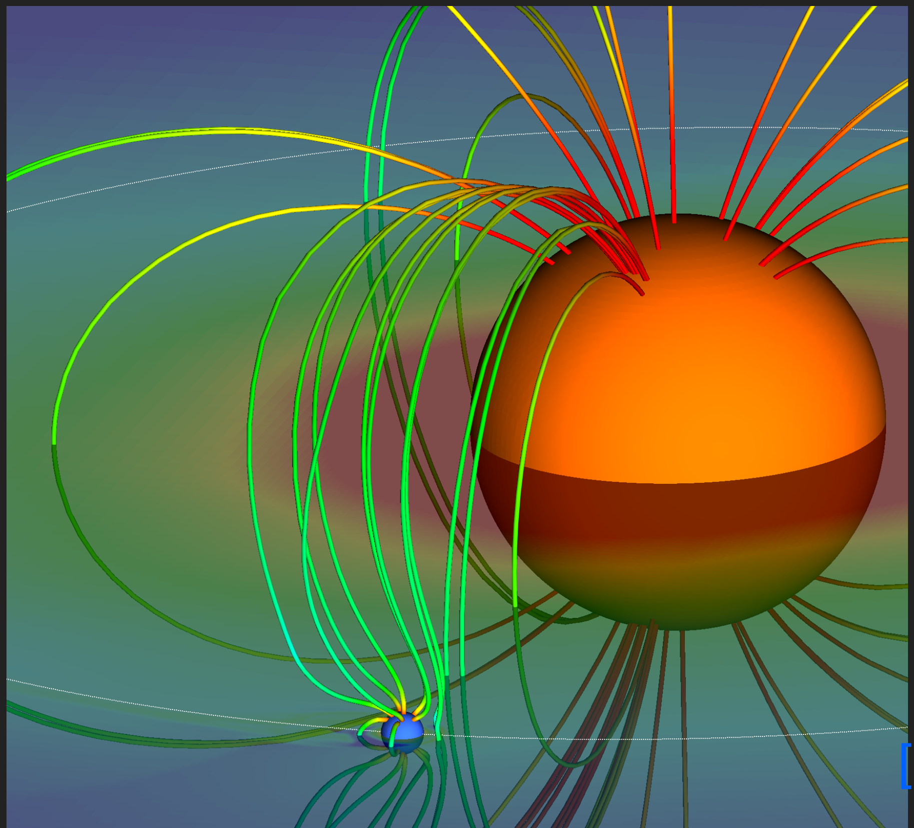
- case 1: super-Alfvenic interactions
  - formation of a bow shock
  - planet protected
  - interactions limited

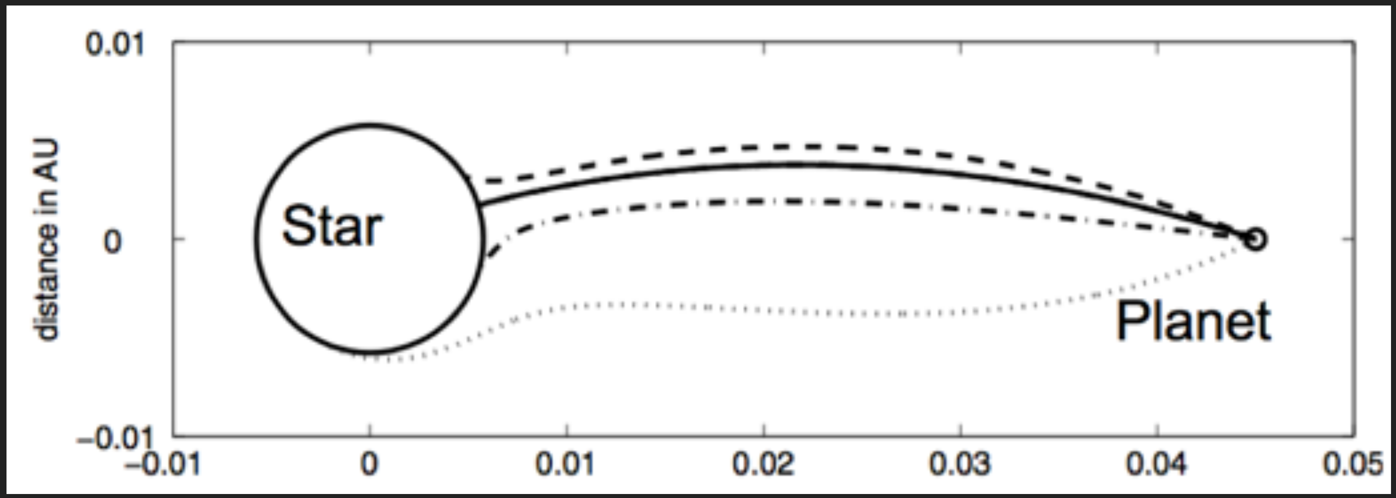


Gombosi et al 1998

SPI THEORETICAL STUDIES

- case 2: sub-Alfvenic connection
  - connection between the star and planet (Io-Jup like)
  - induced activity on star and planet, atm erosion



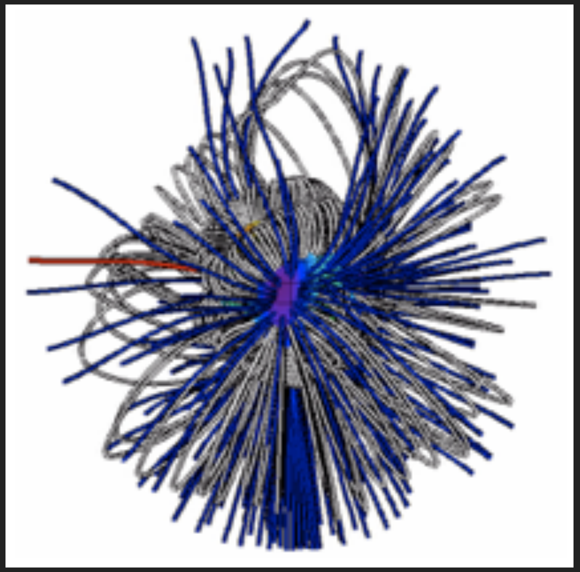


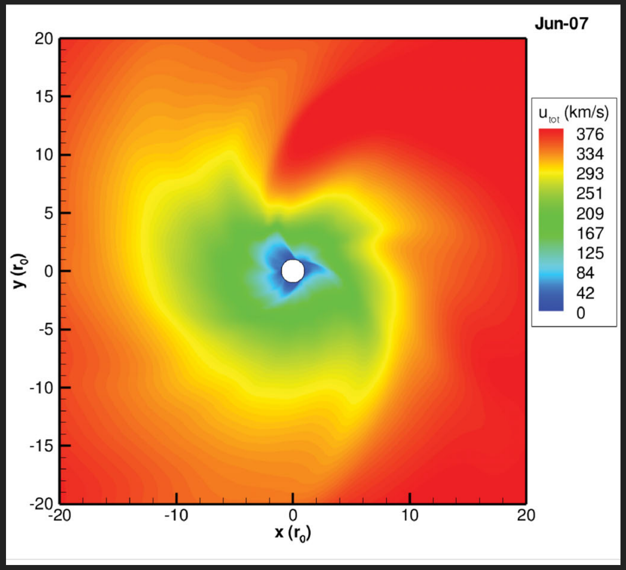
Preusse et al 2006, Saur et al 2013…

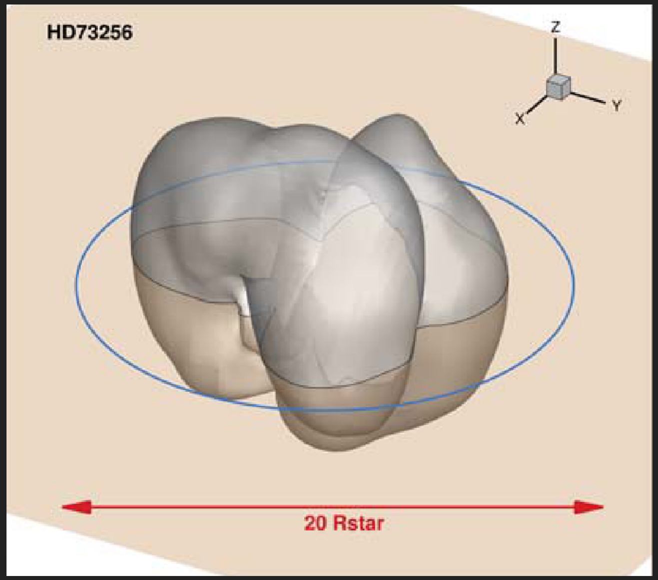
[Strugarek+ 2015]

WIND DENSITY AT PLANET ORBIT

- from surface topology to field extrapolation to mass loss and wind density
- size and structure of Alfven surface wrt planet
- predict radio emission from planet + its modulation
- important to measure the B topology







Vidotto et al 2012, 2015; See et al 2015

STELLAR ACTIVITY AND PLANET SEARCH

- spots' rotation, granulation, magnetic cycles: stellar magnetic activity perturbs the planet signals at many timescales
- mitigated by simultaneous monitoring of activity tracers and good sampling of all these periods
- spectropolarimetry + I profile analysis diagnostics
- in nIR domain, stronger Zeeman effect and lower T contrast

HOW SPIROU WILL HANDLE STELLAR ACTIVITY AND FIND PLANETS

- nIR spectropolarimeter YJHK, IVQU, 65k resolution, 1m/s
- monitor longitudinal B, RVs and activity tracers together
- large program: huge number of visits, many timescales
- focus on young systems and systems around cool stars
- observations start in 2018!

http://www.cfht.hawaii.edu/en/projects/SPIRou/

http://spirou.irap.omp.eu/

SUMMARY

- hot jupiter formation mechanisms: various
- very young close-in planets being discovered: 3!
- star-planet magnetic interactions: an ingredient to include in formation-migration-evolution models
- lessons learned in stellar activity correction will be needed in the next-generation RV surveys