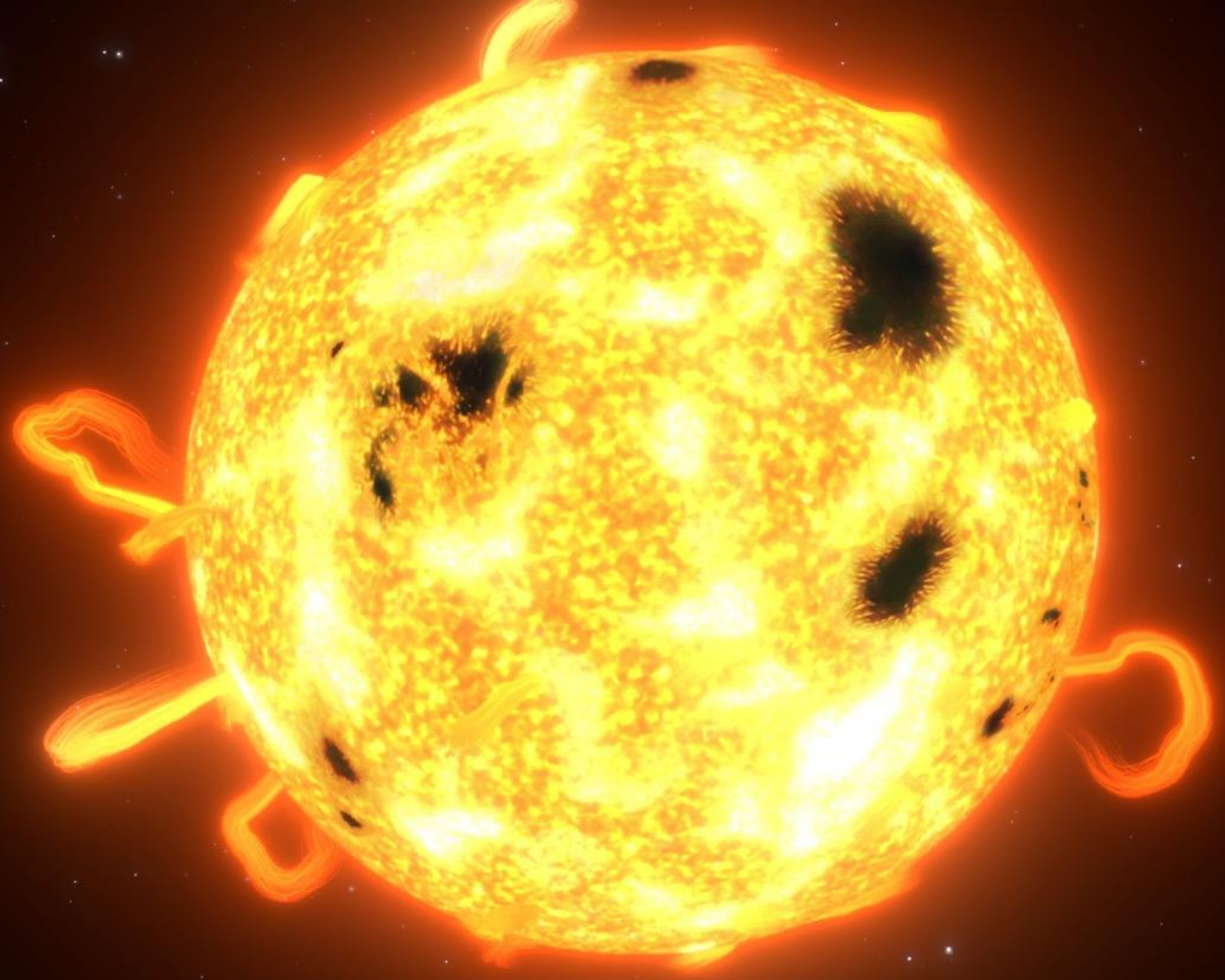
Variable Radio Emission from the Young Stellar Host of a Hot Jupiter



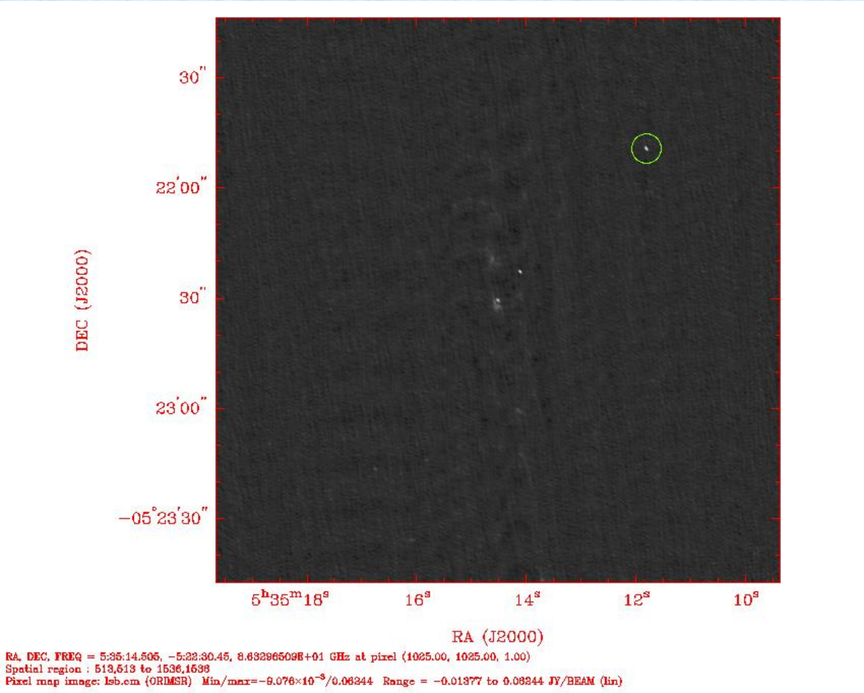
Geoffrey C. Bower

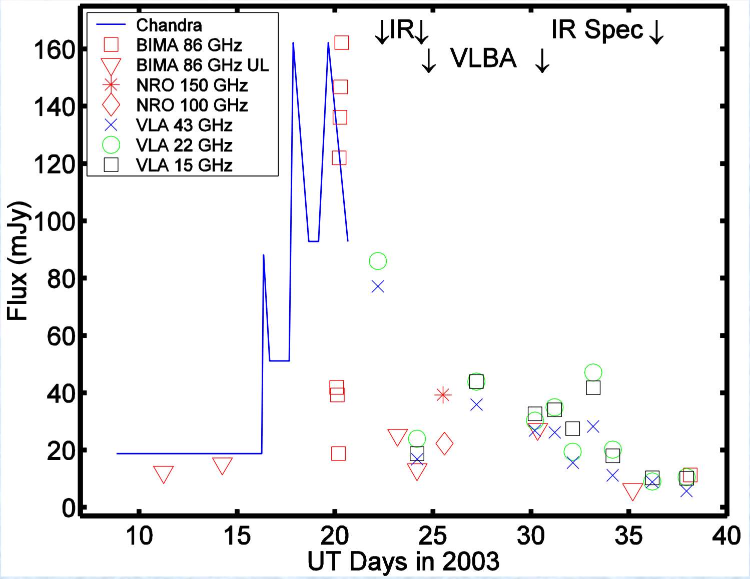
ASIAA, Hilo

Optical: Donati, Moutou
Radio: Loinard, Dzib, Galli, Ortiz-Leon
Meter-wave: Lamy, Zarka, Griessmeier, Loh, Turner, Briand, Girard, Tasse, Janvier, Enriquez
Theory: Vidotto

MM Wavelength T Tauri Outburst in Orion

- 2nd most luminous stellar radio outburst
- Briefly, brightest object in nebula
- Magnetized T Tauri outburst ~ kG fields
- Contemporaneous with X-ray outburst
- Many such objects likely to be found by ALMA

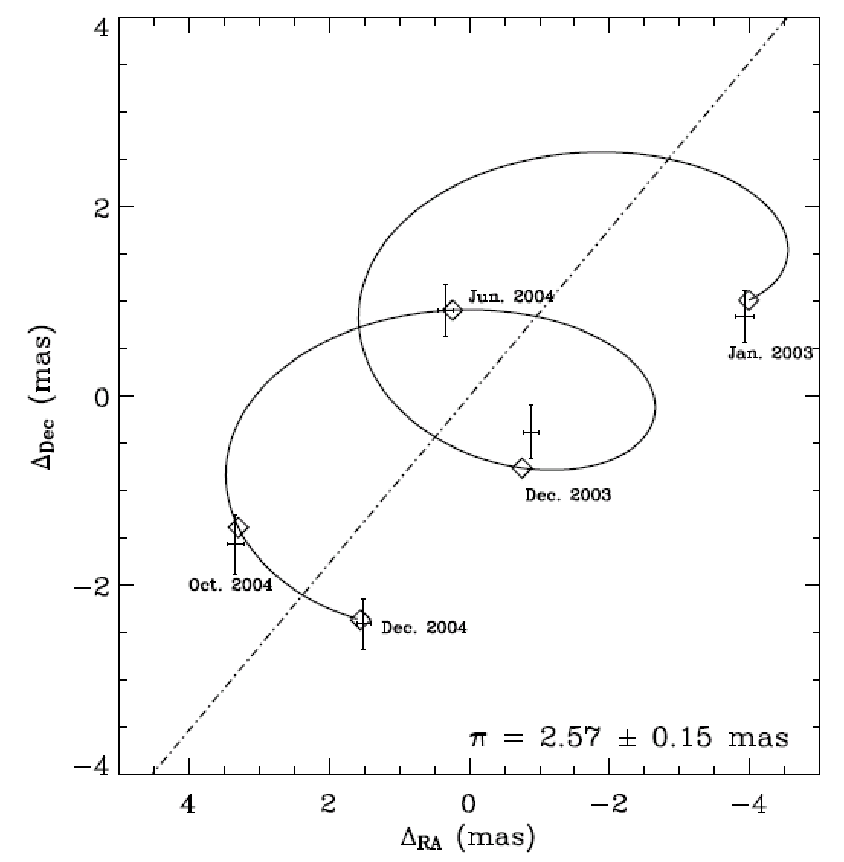




BIMA A configuration images

(Bower, Plambeck, Bolatto, Graham, de Pater, McCrady, Baganoff 2004)

Orion Nebula Parallax w/Star GMR-A

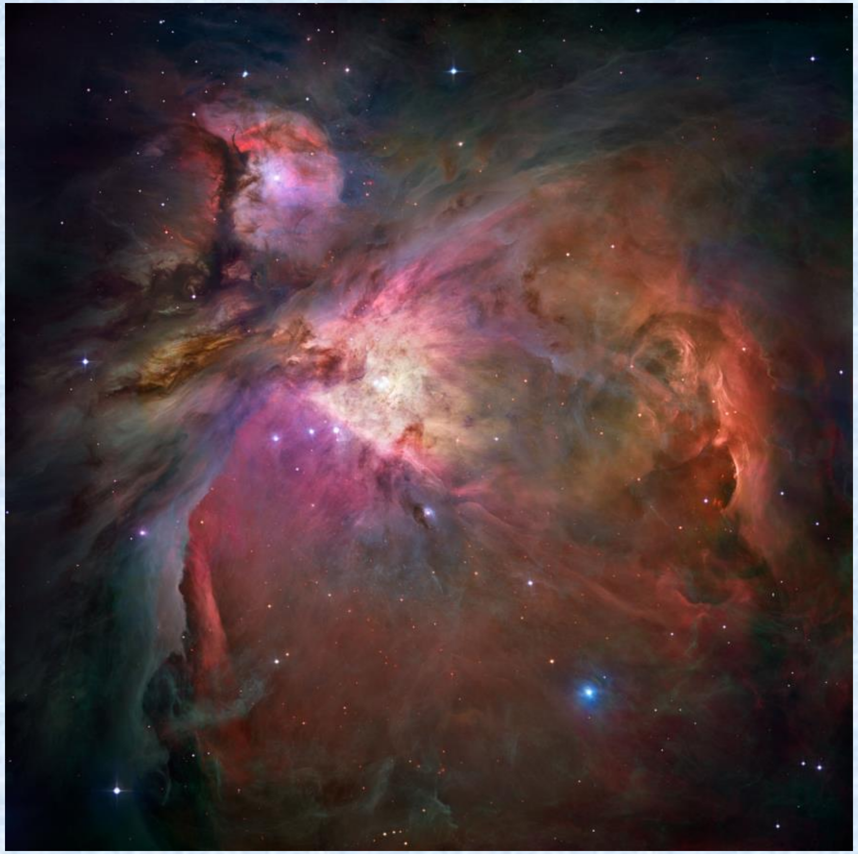


D=389 pc +/- 5%

<0.1 mas/epoch

Sandstrom, Peek, Bower, Bolatto, Plambeck 2007
Astro-ph/0706.2361

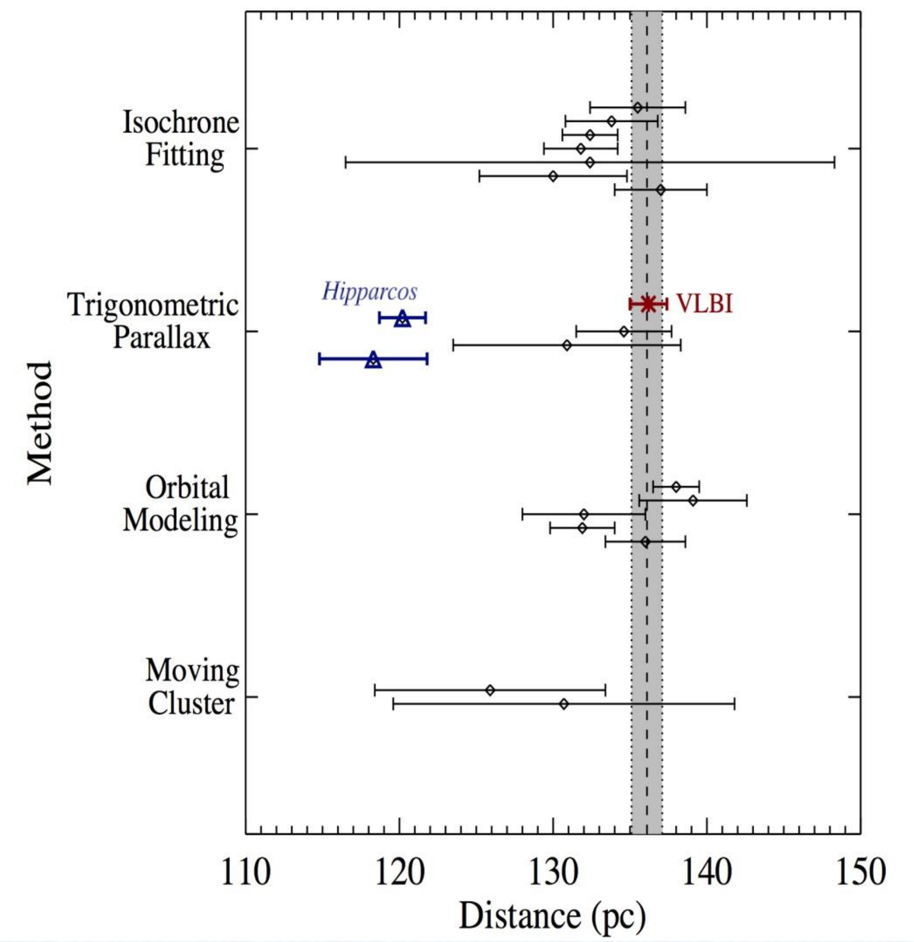
Implications of Orion Parallax



HST Image of Orion Nebula

- Factor of 4 improvement over previous parallax measurement
  - 480 +/- 80 pc (Genzel et al 1981)
- Lower distance reduces stellar luminosities by 40%
  - Resolves problem of overluminous massive stars
  - Indicates greater age spread of pre-main sequence stars → process of continuous star formation rather than single episode

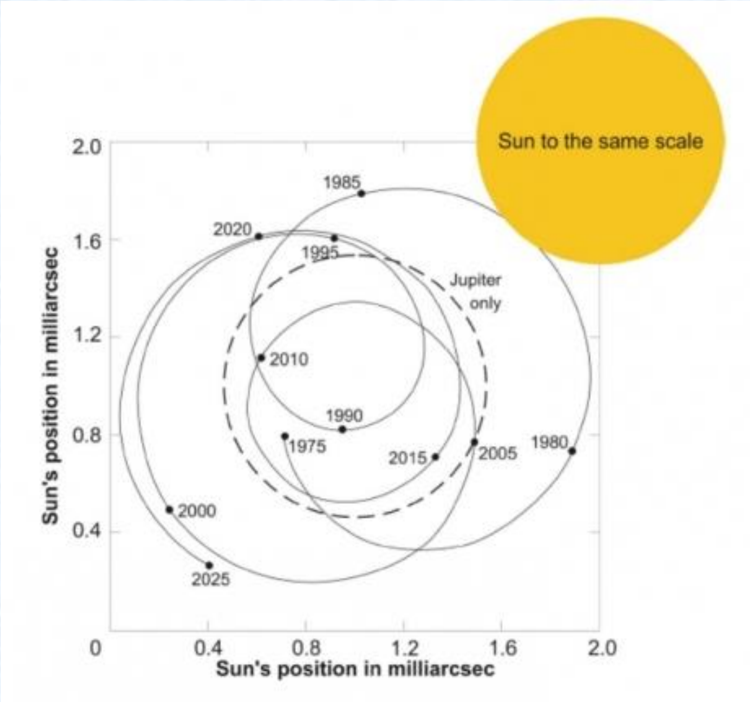
Pleiades distance controversy solved



Melis et al 2015

Astrometric Searches for Extrasolar Planets

- Seek the wobble on the sky of the position of the star
  - Analogous to the Doppler velocity method
- Wobble of the Sun is approximately 1 milliarcsecond @10 pc
- Provides complete characterization of the orbital parameters



Jones 2008

Radio Telescope Resolution

Greenbank Telescope

λ=3 cm
D=100 m
Θ=60 arcsec

Expanded Very Large Array

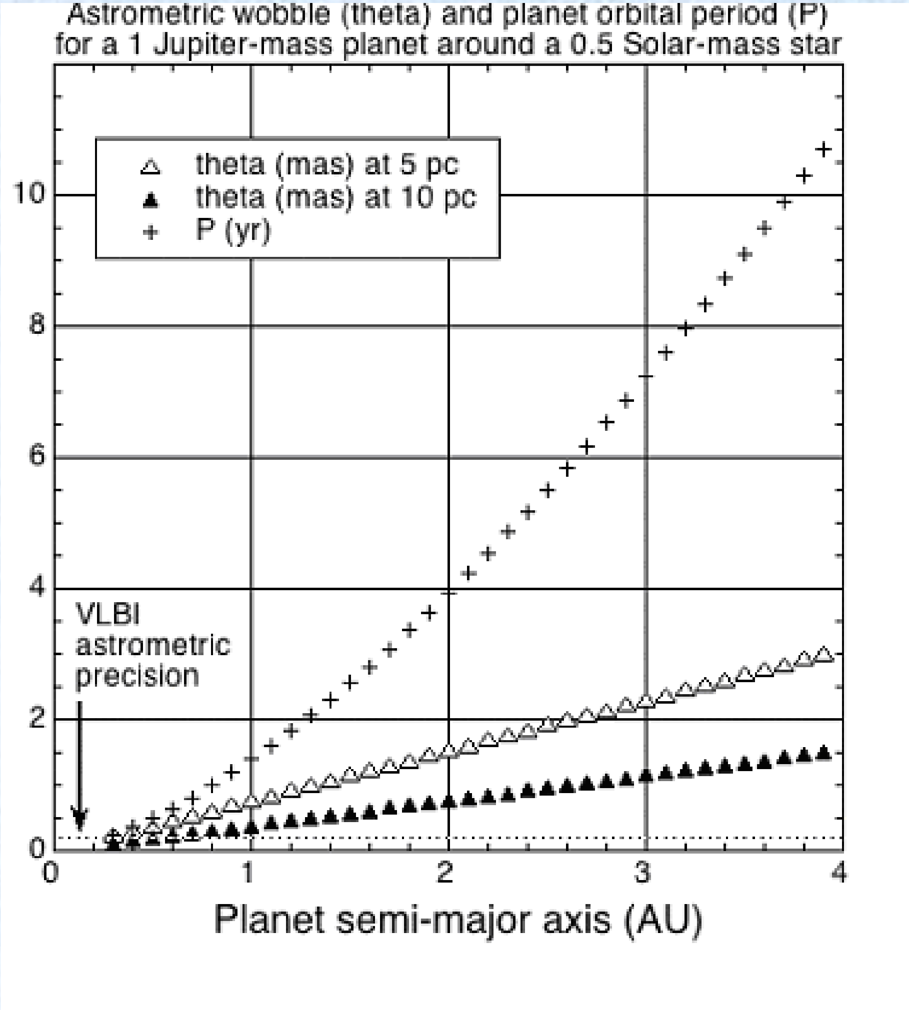
λ=3 cm
D=25 m
b=35 km
Θ=200 milliarcsec

Very Long Baseline Array

λ=3 cm
D=25 m
b=8000 km
Θ=1 milliarcsec

Source localization is Θ/SNR = 0.1 milliarcsec

Planets are Easy to Detect with Radio Astrometry!?

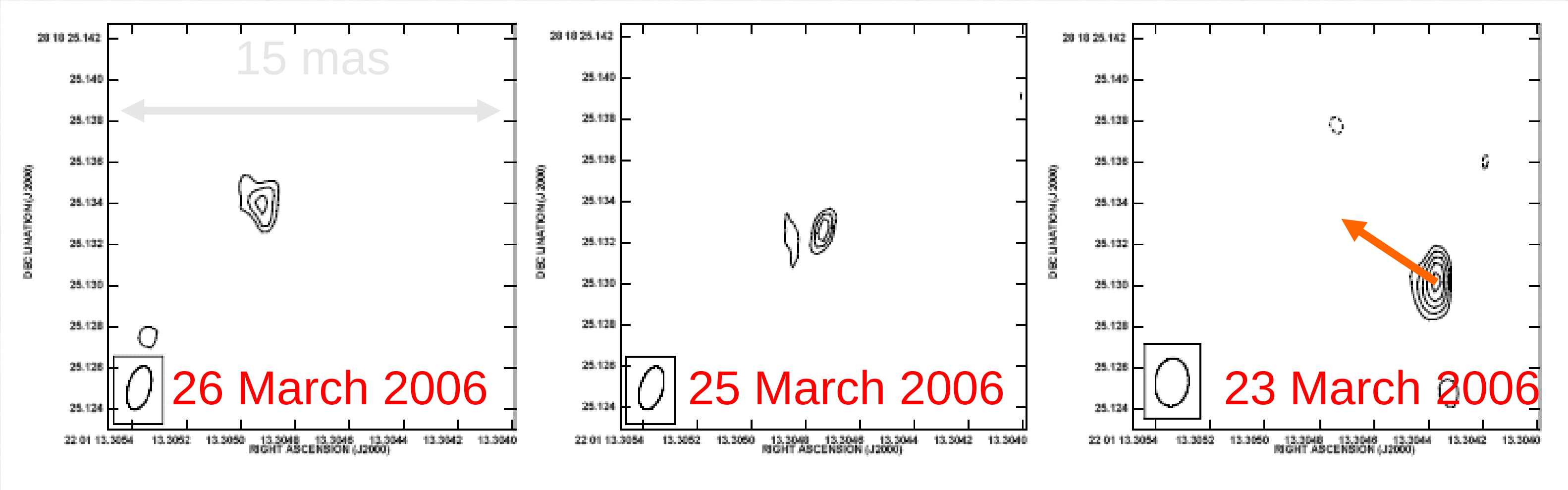


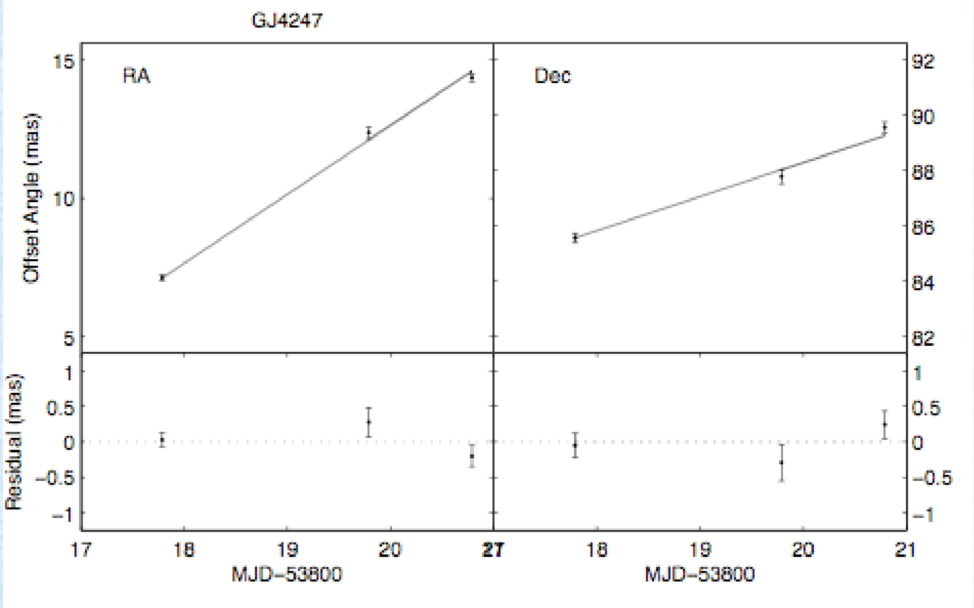
RIPL
Radio Interferometric Planet Search

- 30 stars
  - Low mass dwarf stars
  - All within 10 parsecs
  - All faint, requiring maximum sensitivity
- VLBA + GBT
- 4 year project

Key question: *What is fraction of long-period planets around low mass stars?*

Initial Results:
Apparent Motion of GJ 4247



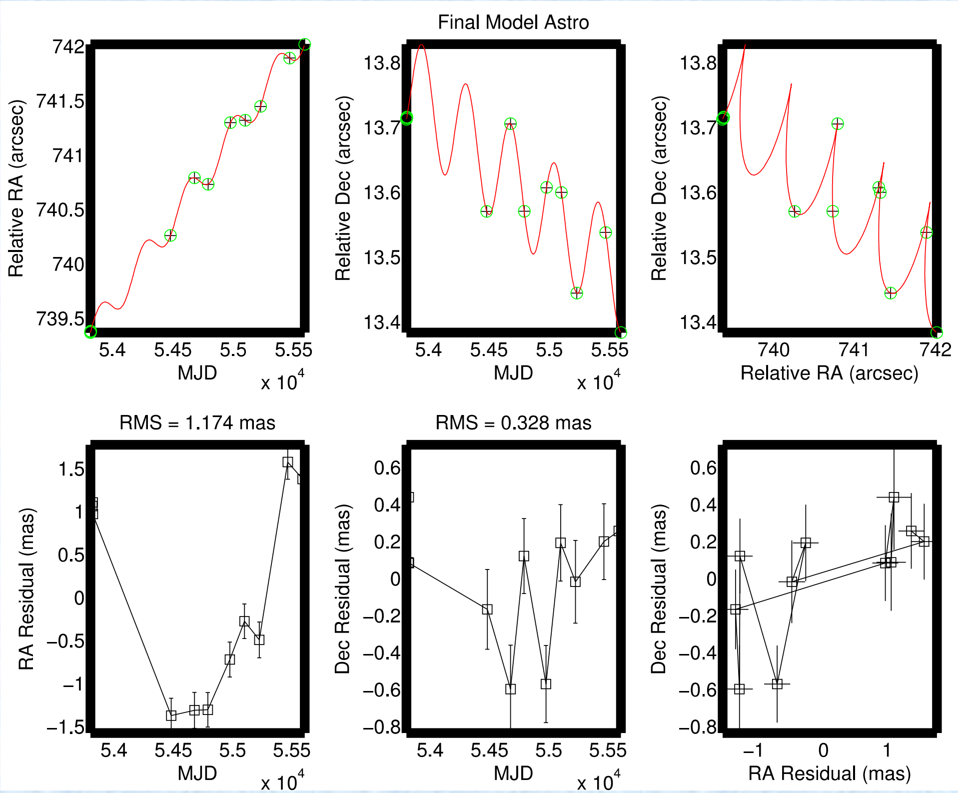


Comparison of radio positions (points) with predictions from Hipparcos astrometry (solid line) reveal noise-limited rms residuals ~0.1 milliarcseconds, approximately 1 stellar diameter.

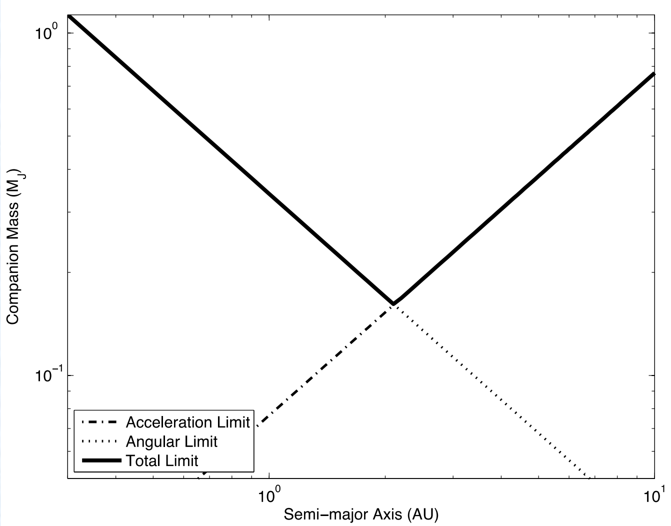
Bower, Bolatto, Ford, Kalas 2009, ApJ, in press

Radio Interferometric Planet Search II: Constraints on sub-Jupiter-Mass Companions to GJ 896A

Bower, Bolatto, Ford, Fries, Kalas, Sanchez, Sanderbeck, Viscomi

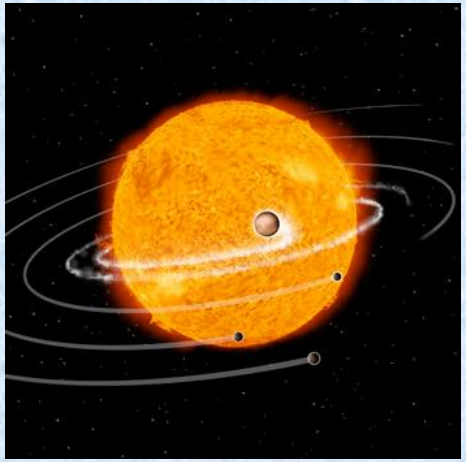


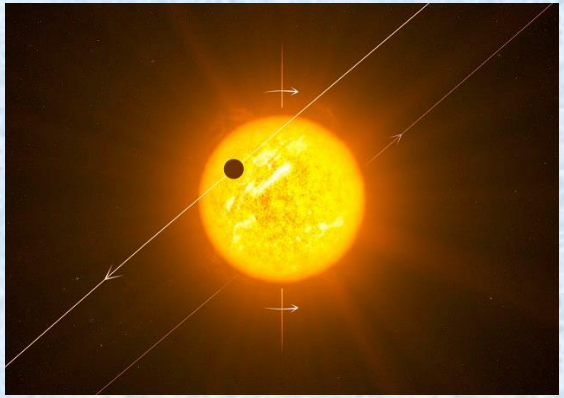
- GJ 896A = EQ Peg A
- M_min = 0.15 M_Jup @ 2 AU
- Δ(pos) = 0.3 mas epoch^{-1}
- π = 160.010 ± 0.182 mas
    - → 0.1% accuracy
- Δμ = 0.01 mas/y = 30 cm/s

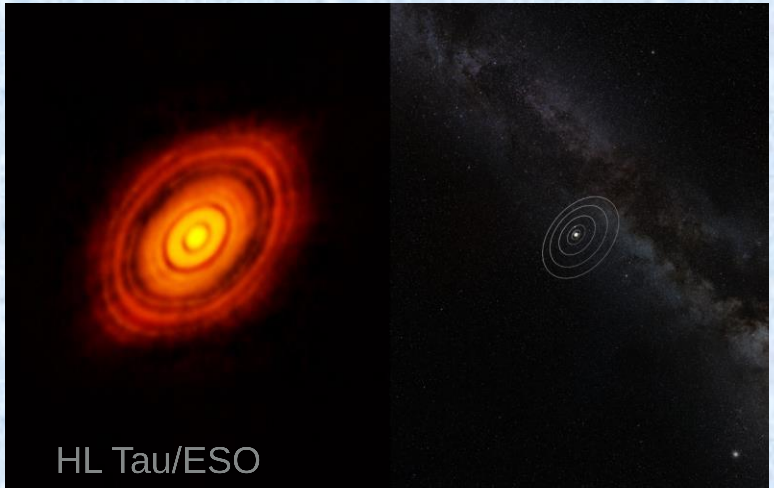


HOT JUPITER FORMATION

- giant planets need material to form: far from the star
- they're then dragged by the disk & spiral in (~few My)
- tend to stop at magnetospheric cavity
- more violent scenarios, binaries, planet collisions...
- are there hot Jupiters in the first My of a systems?







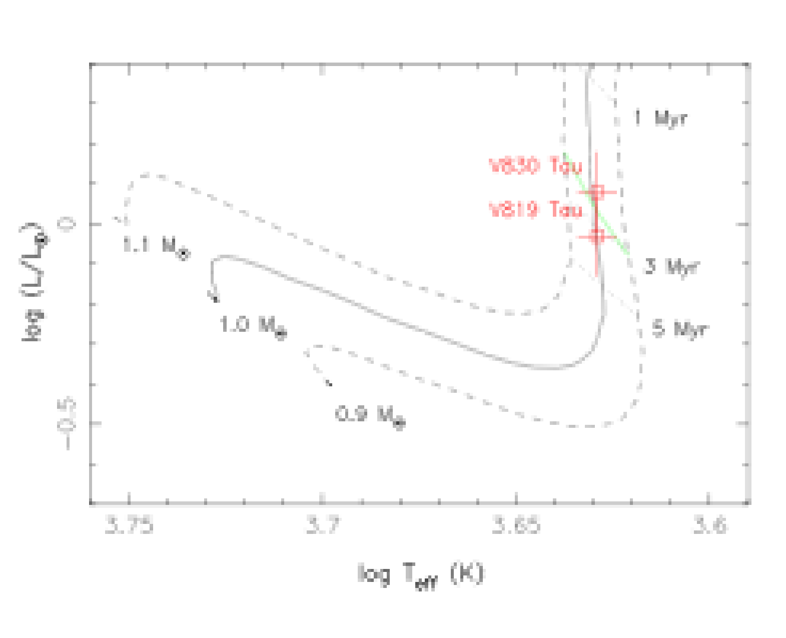
HL Tau/ESO

THE CFHT/ESPADONS MATYSSE PROGRAM (DONATI ET AL)

- 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

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



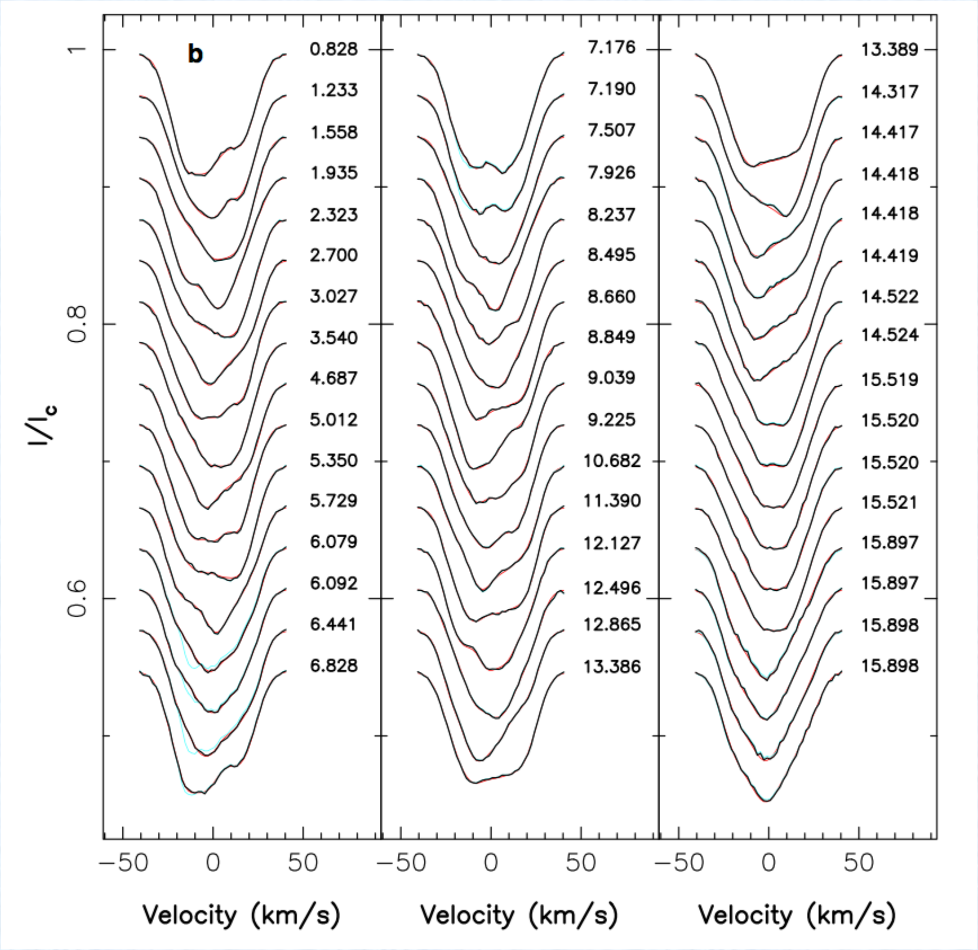
Donati et al 2015

STRONG SPECTROPOLARIMETRIC CAMPAIGN TO CONFIRM PLANET

- 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

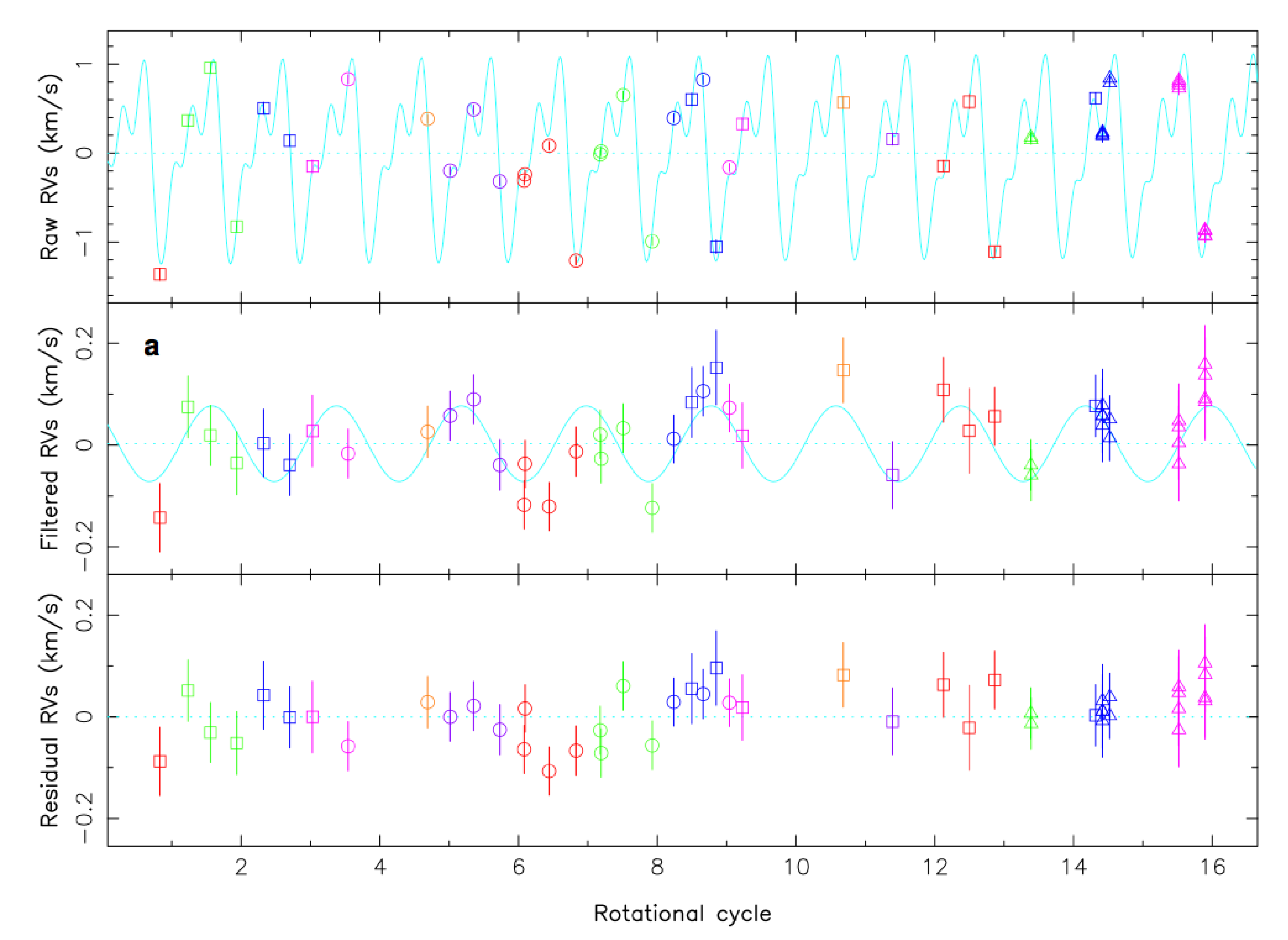
TIME SERIES OBTAINED IN NOV-DEC 2015

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



Donati et al 2016

FROM STAR TO PLANET



activity

1000m/s

planet

75m/s

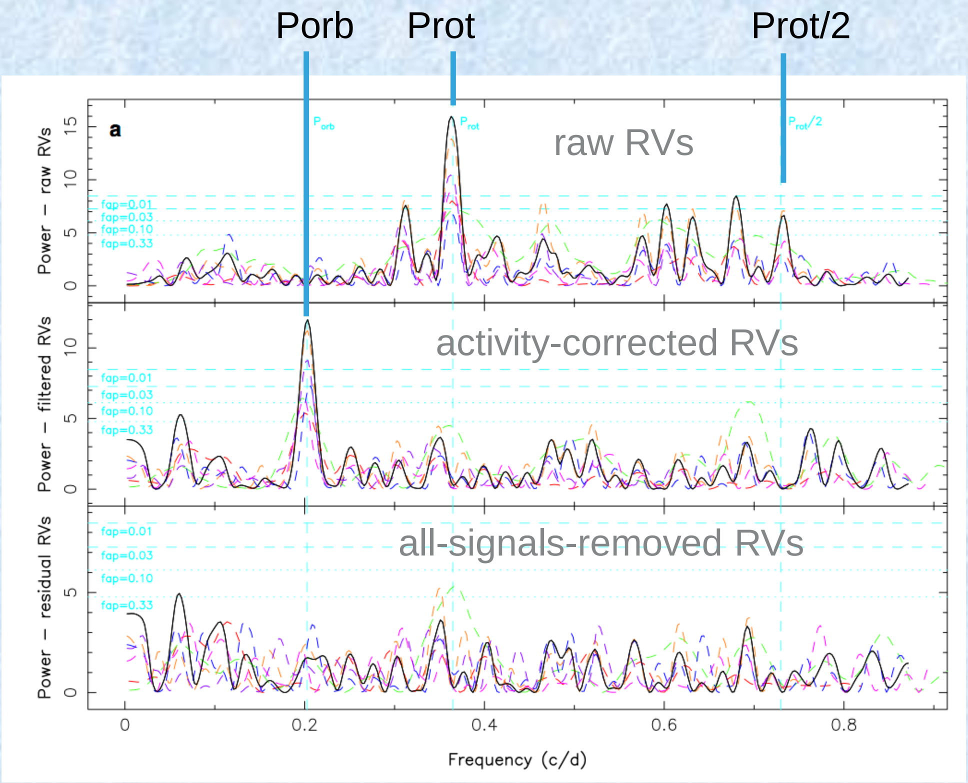
residuals

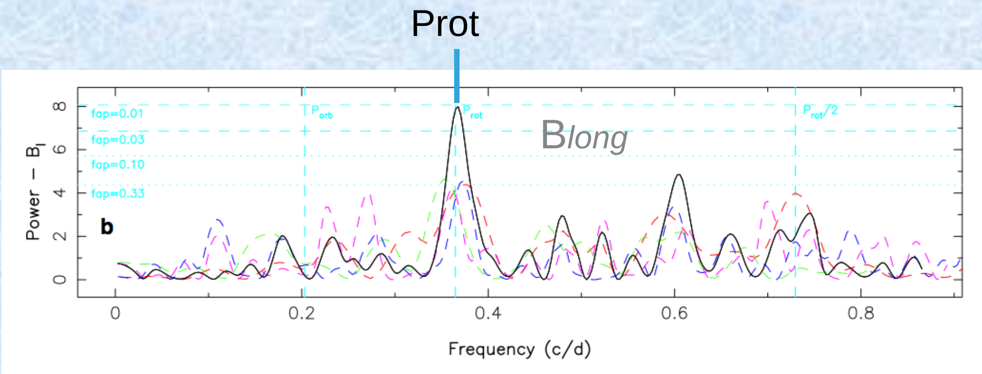
11m/s

Donati et al 2016

PERIODOGRAMS

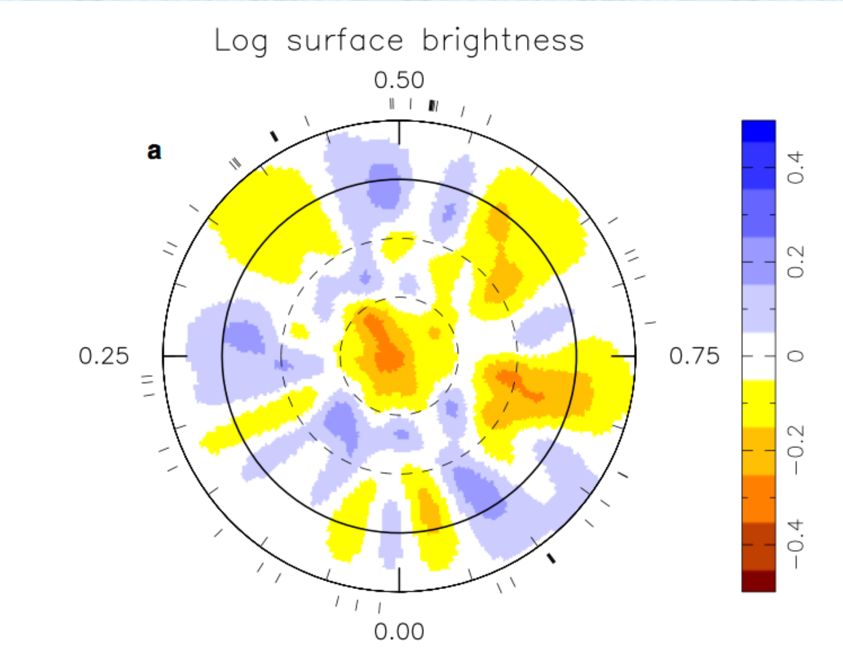
- a clear peak at 4.94d
- stable in various subsets
- not present in activity tracers
- Prot clearly identified



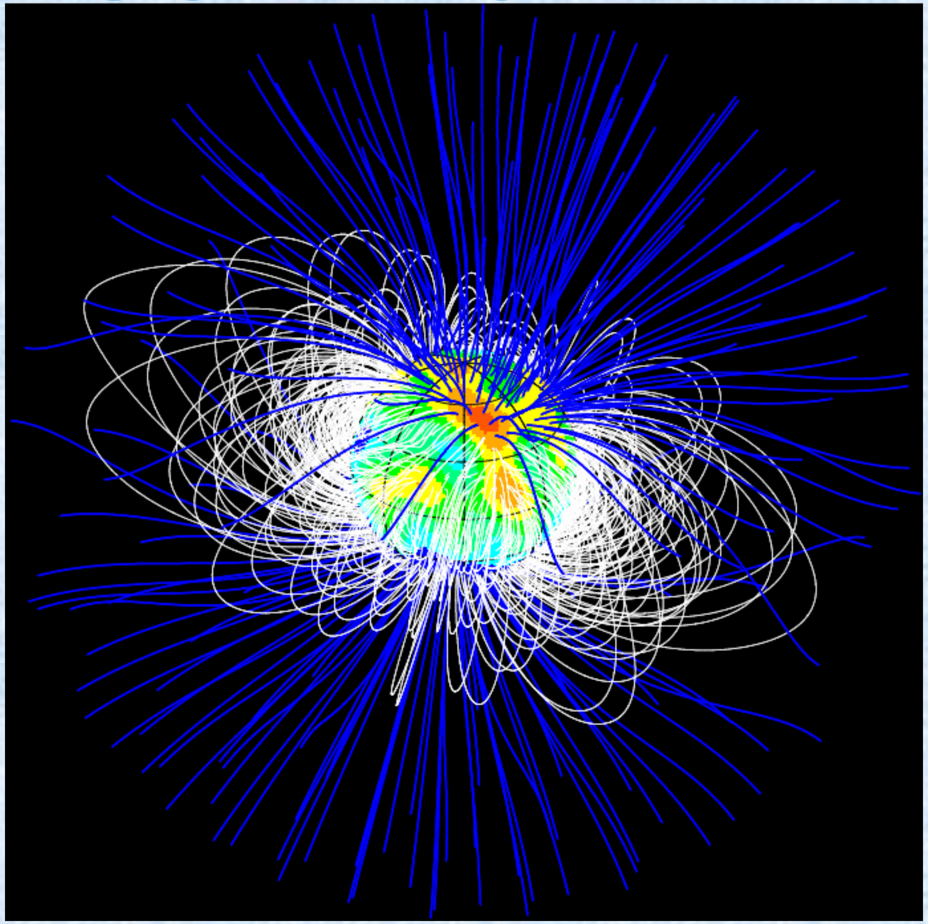


Donati et al 2016

A COMPLEX STELLAR SURFACE



surface features modeled by differential rotation



from Stokes V profiles (circular polarization)

and potential field extrapolation

Donati et al 2016

MAGNETIC CONFIGURATION OF V830 TAU (DONATI ET

Jan 16

Nov 15

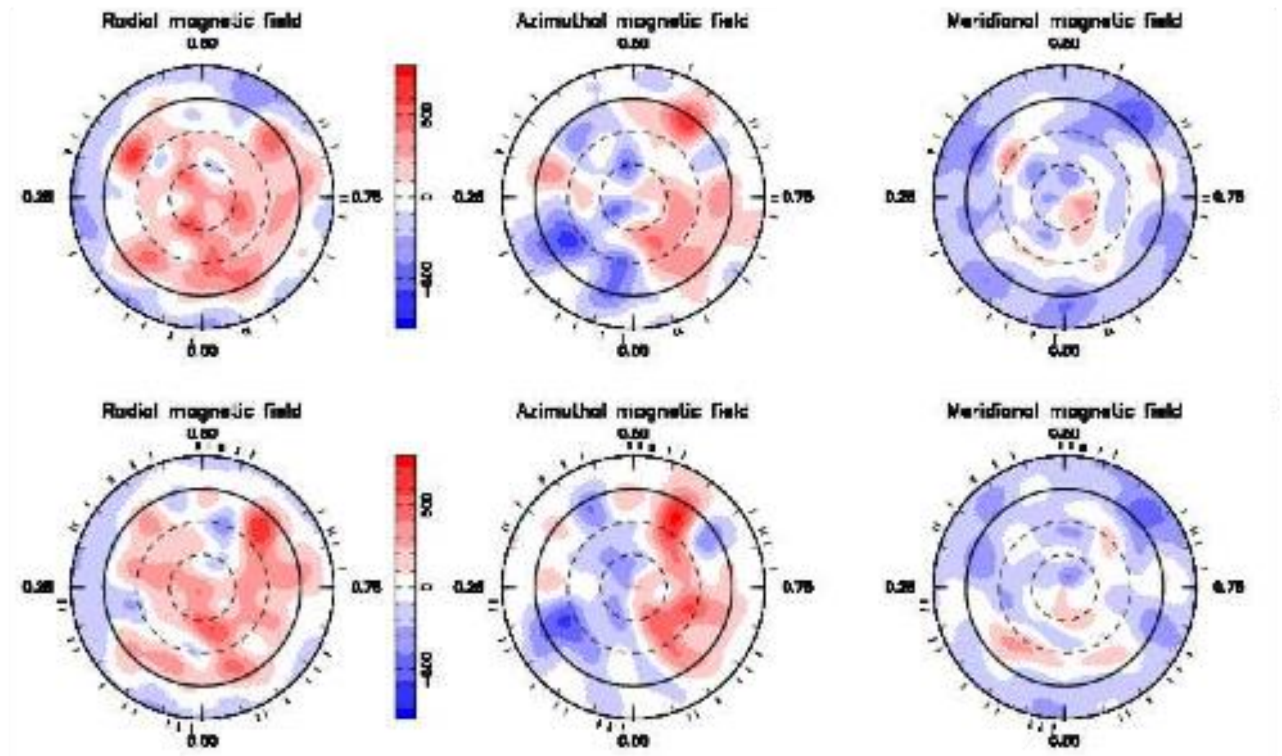


Figure 5. Maps of the radial (left), azimuthal (middle) and meridional (right) components of the magnetic field **B** at the surface of V830 Tau in early 2016 (top) and late 2015 (bottom). Magnetic fluxes in the color lookup table are expressed in G. The star is shown in flattened polar projection as in Fig. 3.

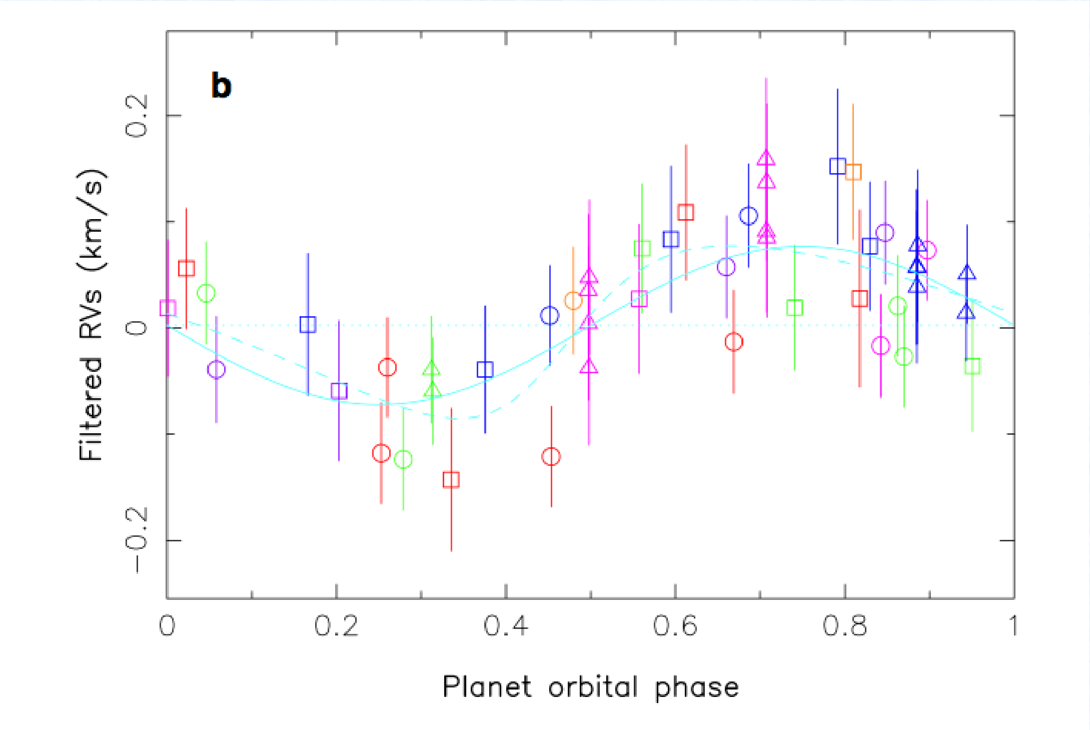
340G dipole field with 22degree inclination
weaker quadrupolar and octupolar components + weak and complex toroidal field

PLANET

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

activity amplitude
reduced by x10

K=75+-11m/s

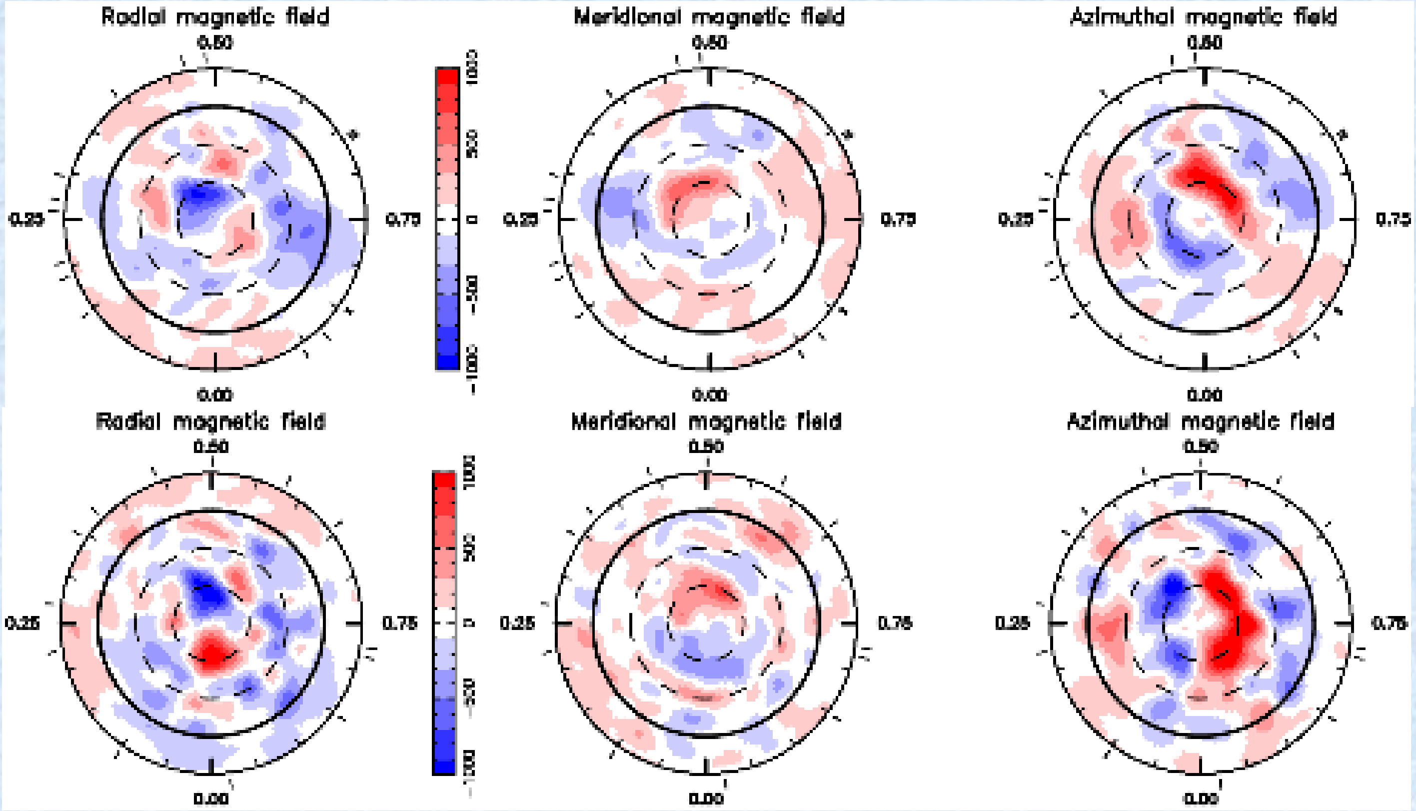


TAP 26

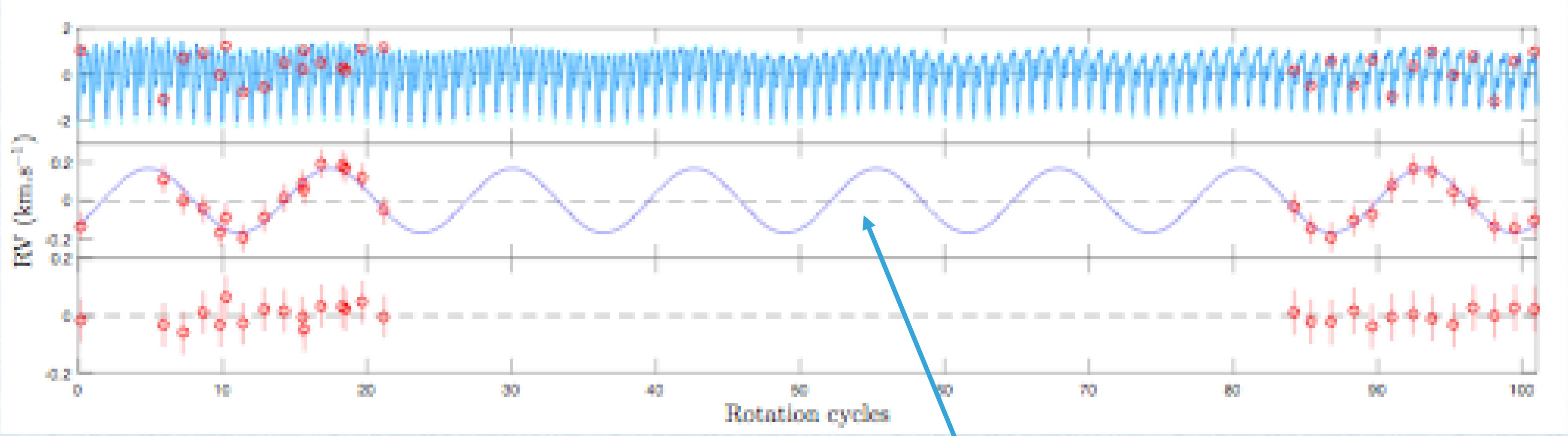
- Magnetic topology: 70% poloidal, 30% toroidal, with time variations

Nov15

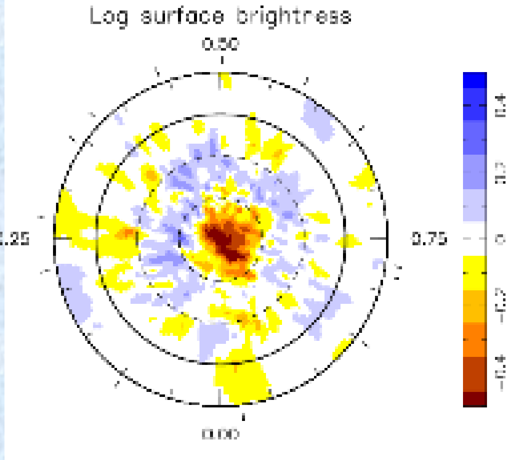
Jan16



TAP 26



due to the gap, 3 possible periods before the 2017 campaign

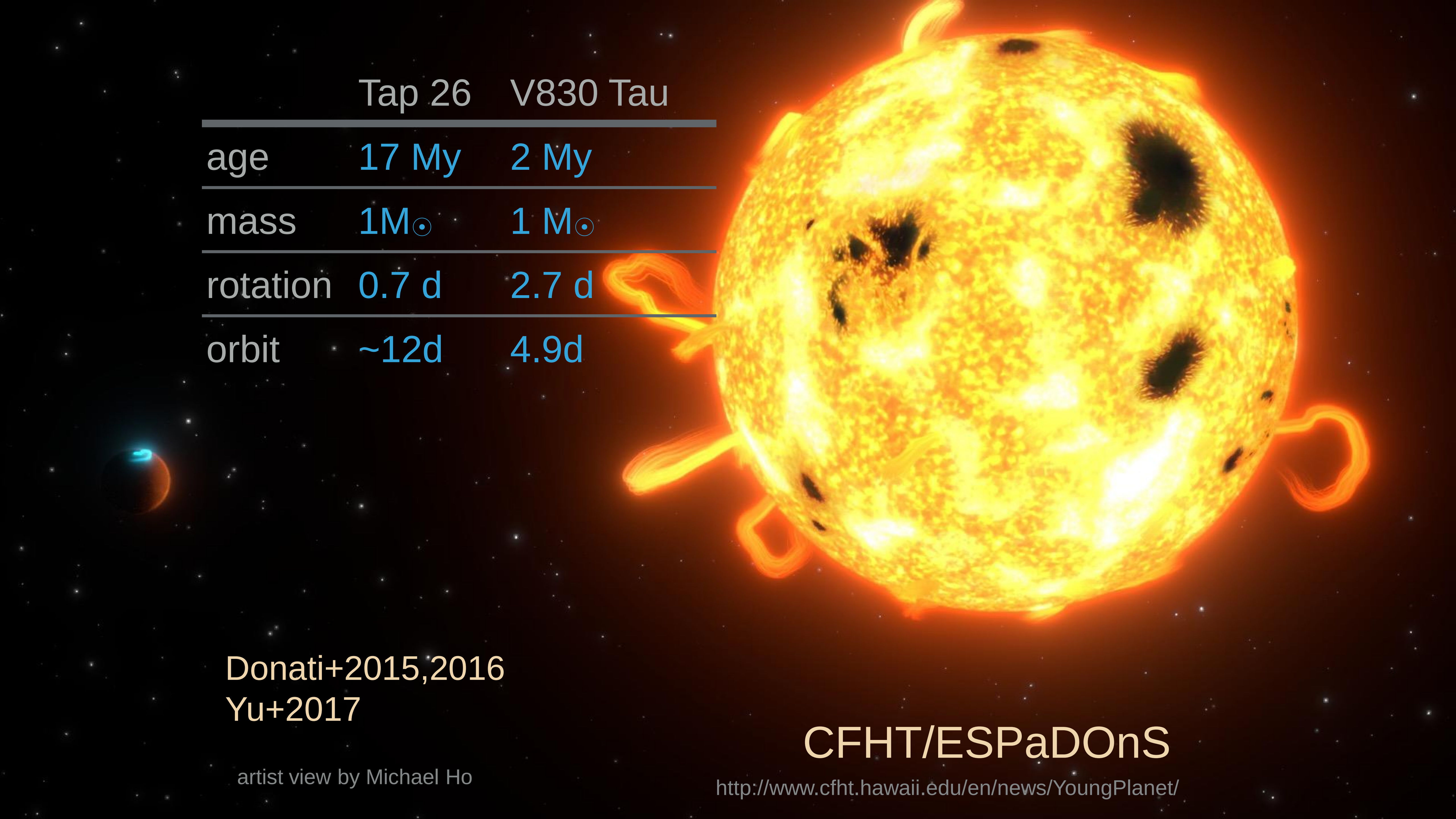


brightness map

A hot Jupiter around the very active weak-line T Tauri star TAP 26

L. Yu[1,2]*, J.-F. Donati[1,2], E. M. Hébrard[3], C. Moutou[4], L. Malo[5], K. Grankin[6],

Yu et al, 2017



	Tap 26	V830 Tau
age	17 My	2 My
mass	$1M_\odot$	$1\ M_\odot$
rotation	0.7 d	2.7 d
orbit	~12d	4.9d

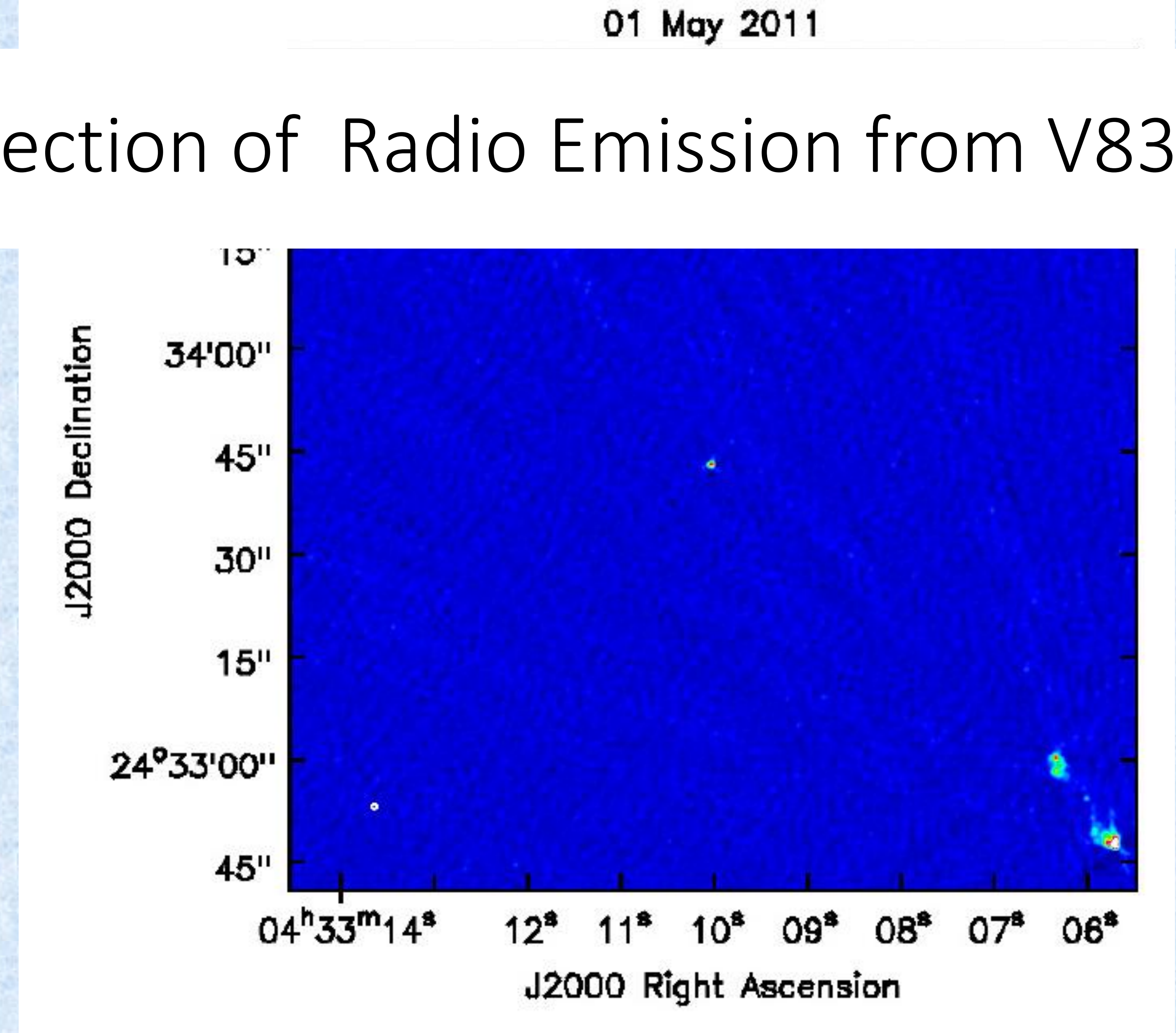
Donati+2015,2016
Yu+2017

artist view by Michael Ho

CFHT/ESPaDOnS

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

VLA Detection of Radio Emission from V830 Tau



4.5 & 7.5 GHz

Emission is Variable

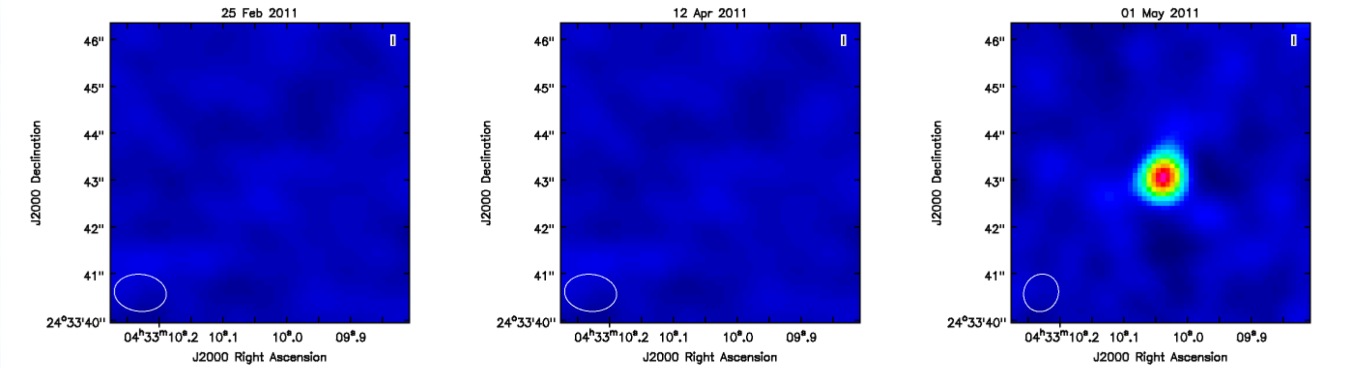
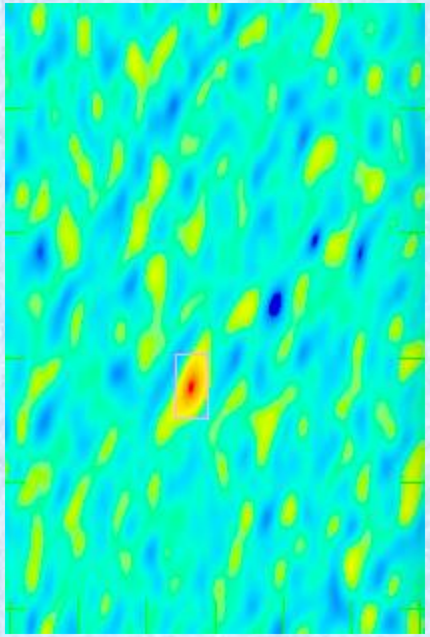


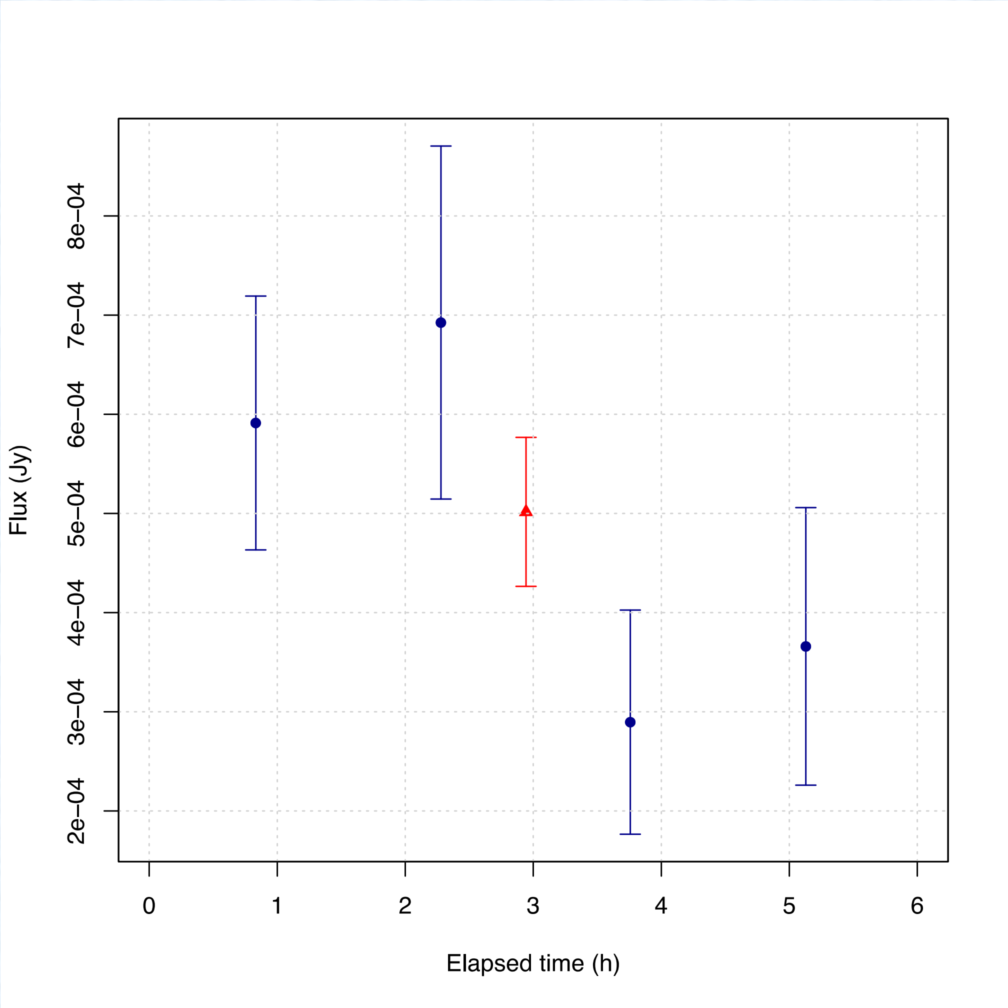
Table 1. VLA & VLBA Results for V830 Tau

Tel.	Epoch	UT	Beam	RMS (μJy)	S (μJy)
VLA	25 Feb 2011	04:47	1.1” $\times$ 0.8”, 84°	22	< 66
...	12 Apr 2011	02:37	1.6” $\times$ 0.8”, 86°	34	147 ± 34
...	01 May 2011	22:25	0.8” $\times$ 0.6”, -23°	26	919 ± 26
VLBA	31 Aug 2014	14:23	1.8×0.8 mas^2, -10°	39	< 117
...	11 Sep 2015	13:42	1.8×0.8 mas^2, -11°	40	501 ± 75

Bower et al. 2016

VLBA Imaging

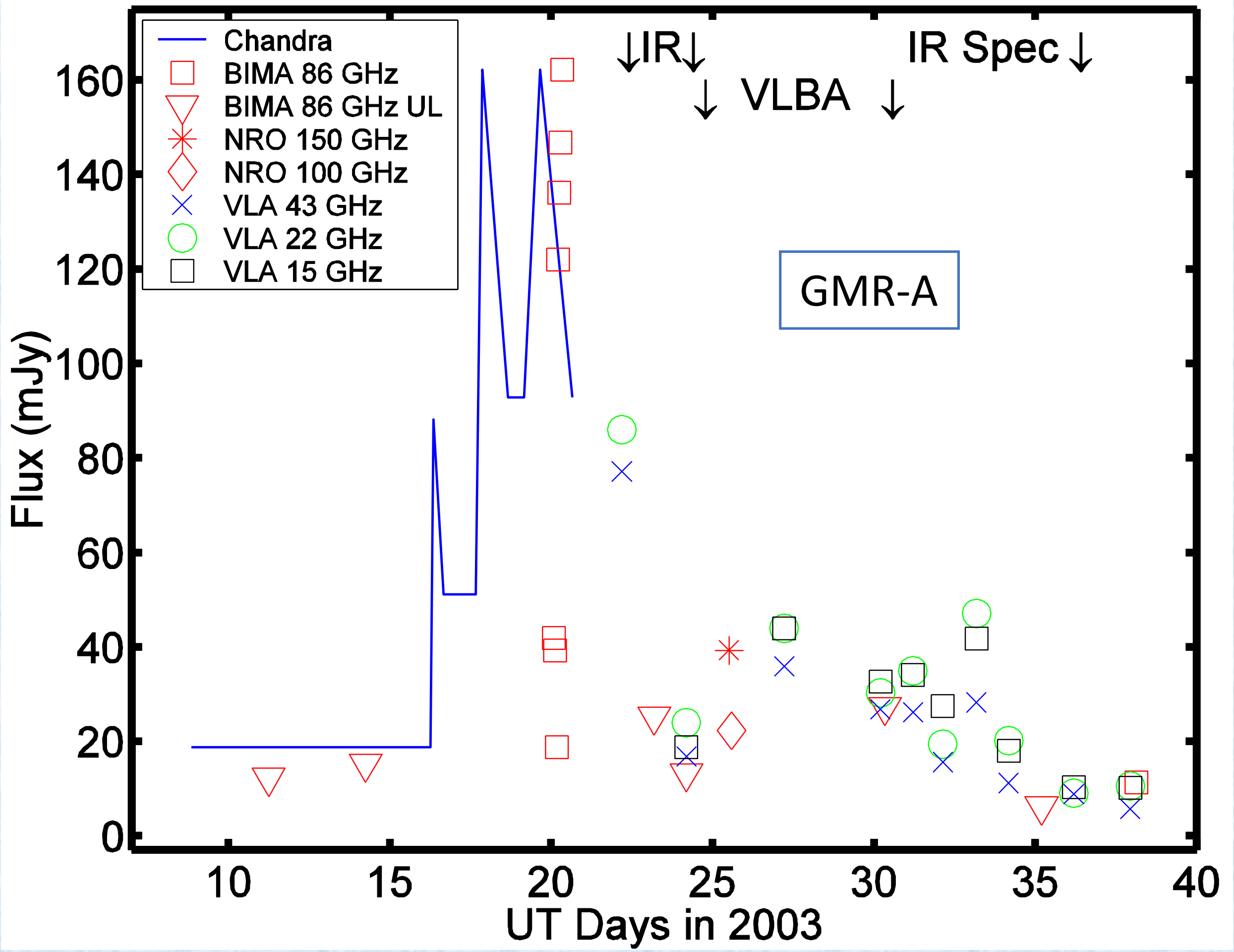




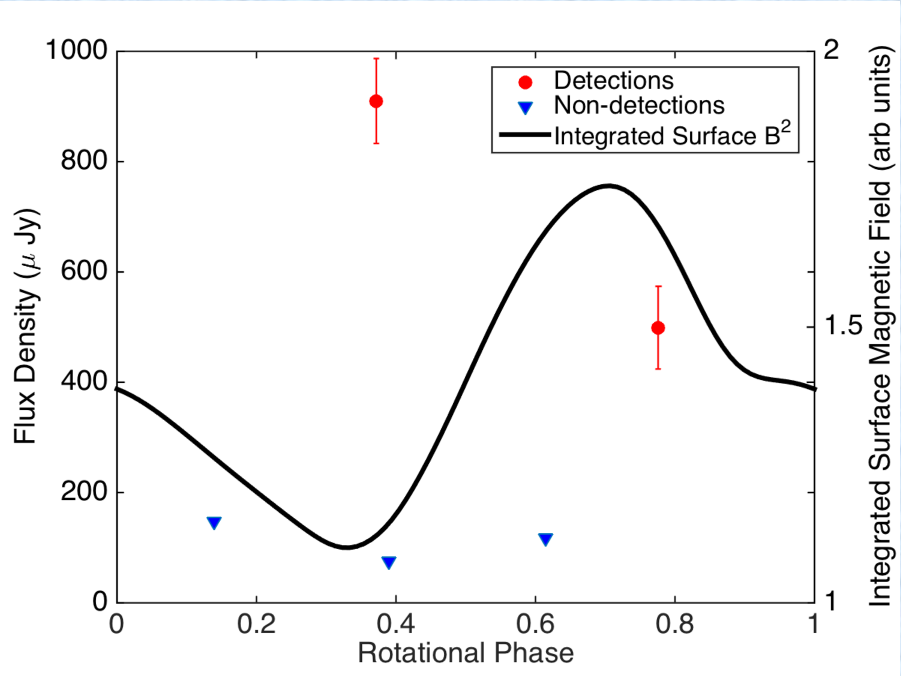
RMS [Jy]	S/N	DETECTION	RA [h:m:s]			DEC [d:m:s]			eRA [sec]	eDEC [arcsec]	EPOCH_START	EPOCH_END
3.92E-05	---	NO	---	---	---	---	---	---	---	---	31-aug-2014/11:30:08	31-aug-2014/17:16:13
3.78E-05	---	NO	---	---	---	---	---	---	---	---	23-mar-2015/22:02:55	24-mar-2015/03:48:58
2.80E-04	---	NO	---	---	---	---	---	---	---	---	16-jun-2013/16:29:10	16-jun-2013/19:04:43
3.98E-05	6.7	YES	4	33	10.03886986	24	33	42.92381	0.00000262045	0.0000702342	11-sep-2015/10:48:49	11-sep-2015/16:34:54
2.38E-05	---	NO	---	---	---	---	---	---	---	---	25-mar-2016/21:55:48	26-mar-2016/03:41:51
2.49E-05	---	NO	---	---	---	---	---	---	---	---	29-sep-2016/09:36:07	29-sep-2016/14:51:16

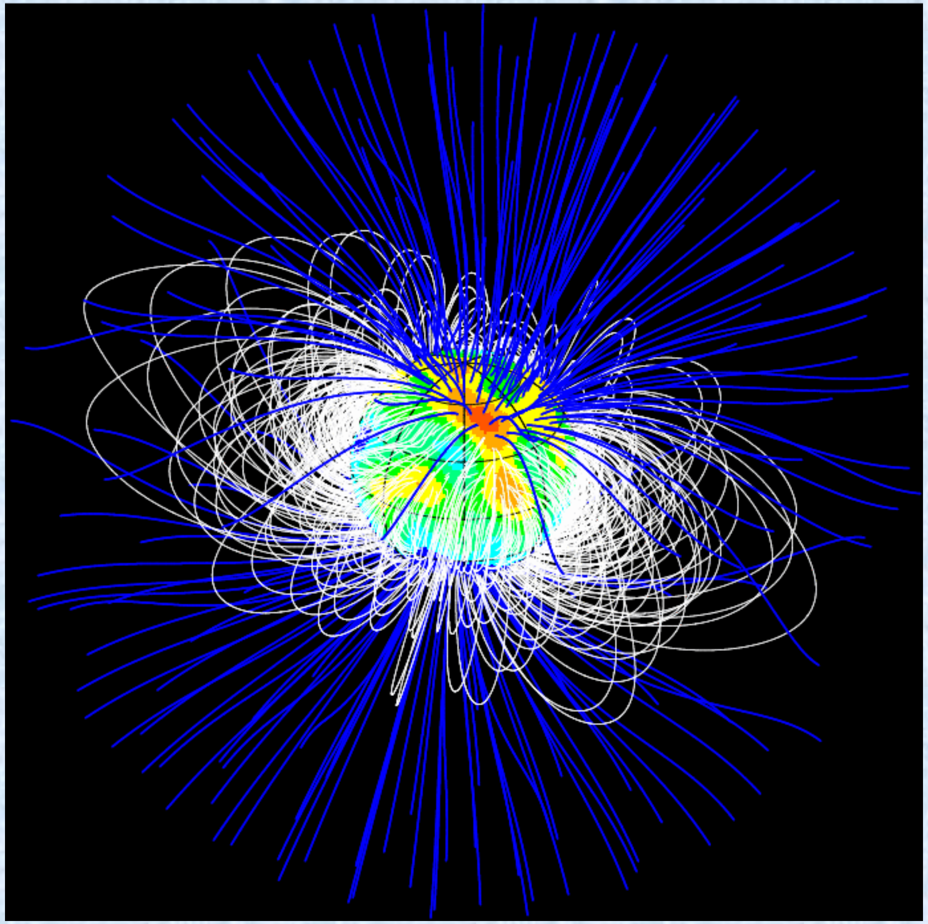
Radio Emission Looks Typical for T Tauri Star

- $L_X \sim 1$ --- 6×10^{30} erg s^{-1}
  - Voges et al 1999, Scelsi et al 2007
- Radio/X-ray correlation → 40 --- 200 uJy
- Synchrotron/Gyrosynchrotron
  - Flat spectrum
  - No detected circular polarization
  - $T_b > 3 \times 10^7$ K
  - $R < 50\ R_{sun}$
  - Equipartition → $B > 30$ G



Relation to Stellar Cycle



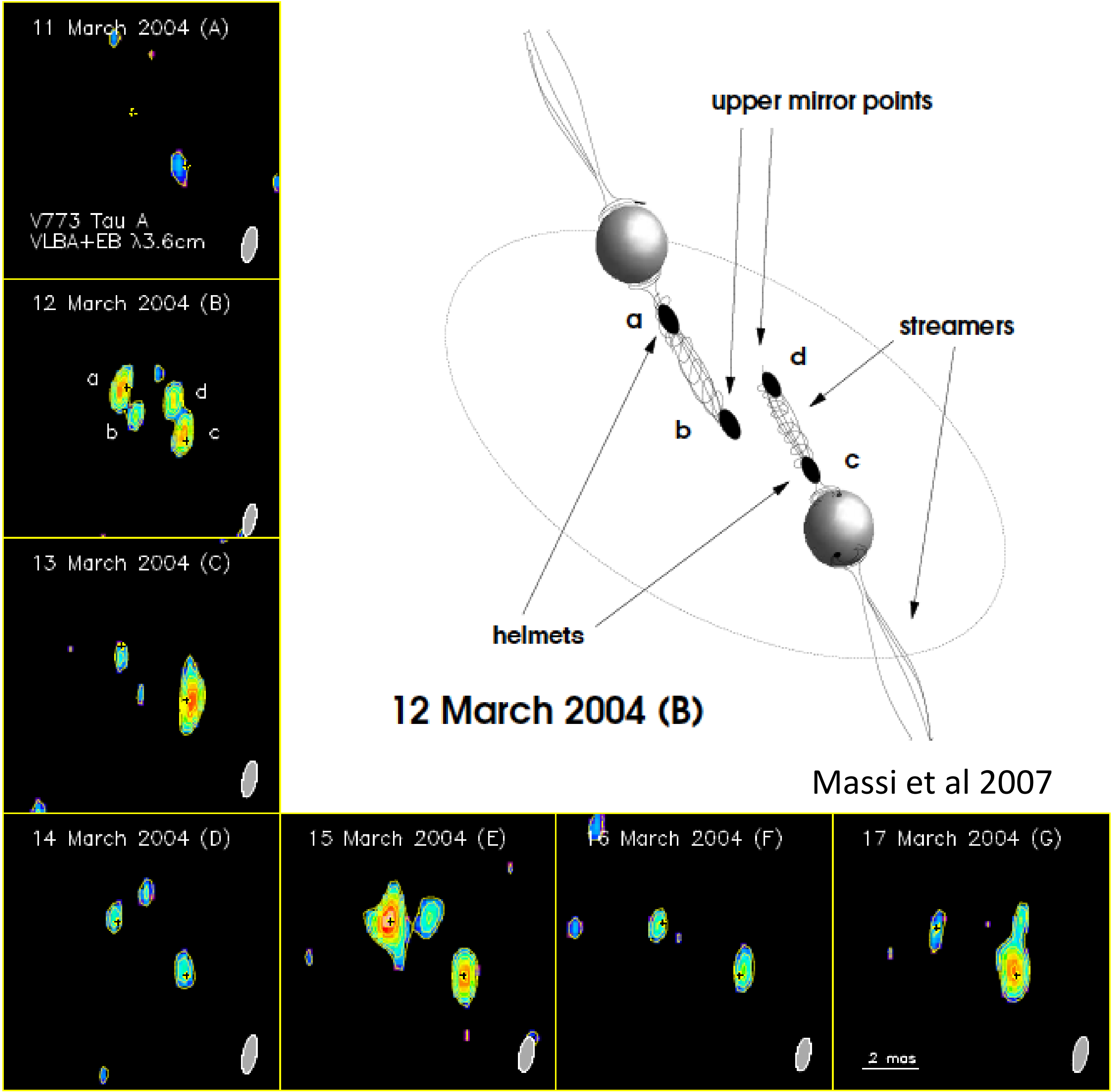


But note that $\Delta P/P$ ~ 1% → Magnetic field coherence is not expected over years

→ Importance of simultaneous radio and ZDI monitoring

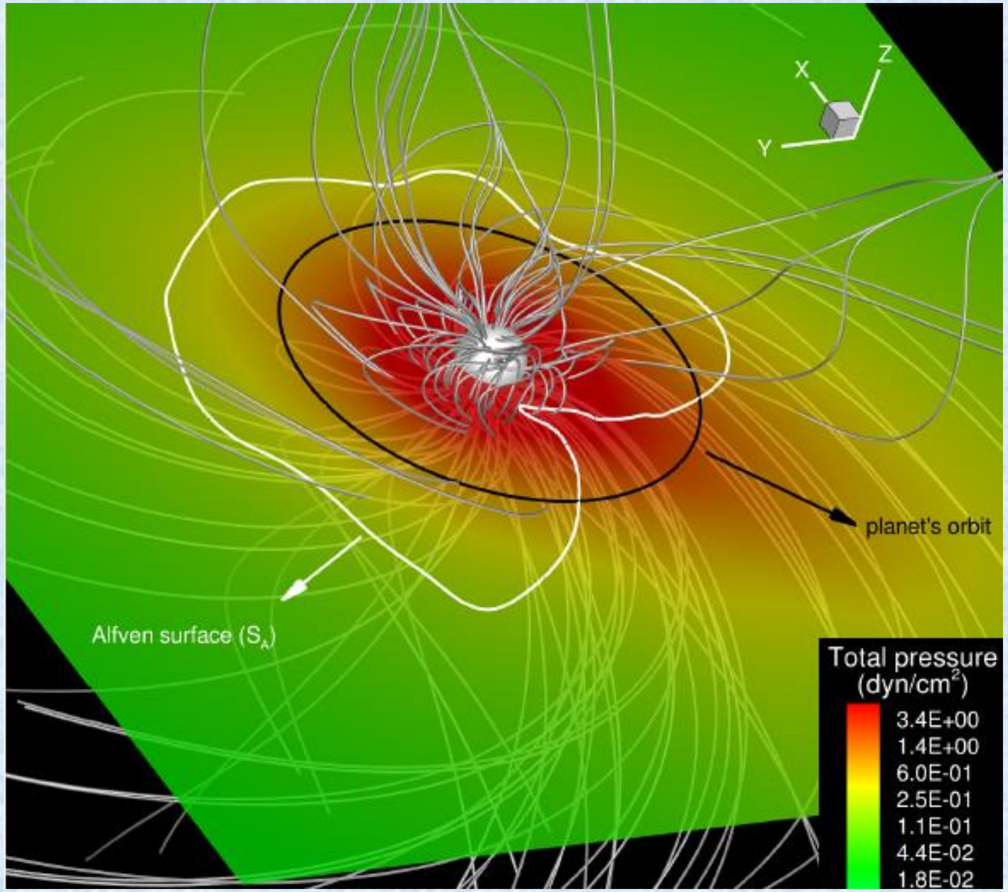
High Resolution Probes of V830 TauB

- Astrometric Detection of the Companion?
  - Reflex Motion ~ 0.35 microarcsec -→ Impossible
  - Other companions?
- Image Star and Planet Interaction
  - ~0.44 mas separation
  - Possible with high SNR at 8 GHz or detected source at ~40 GHz



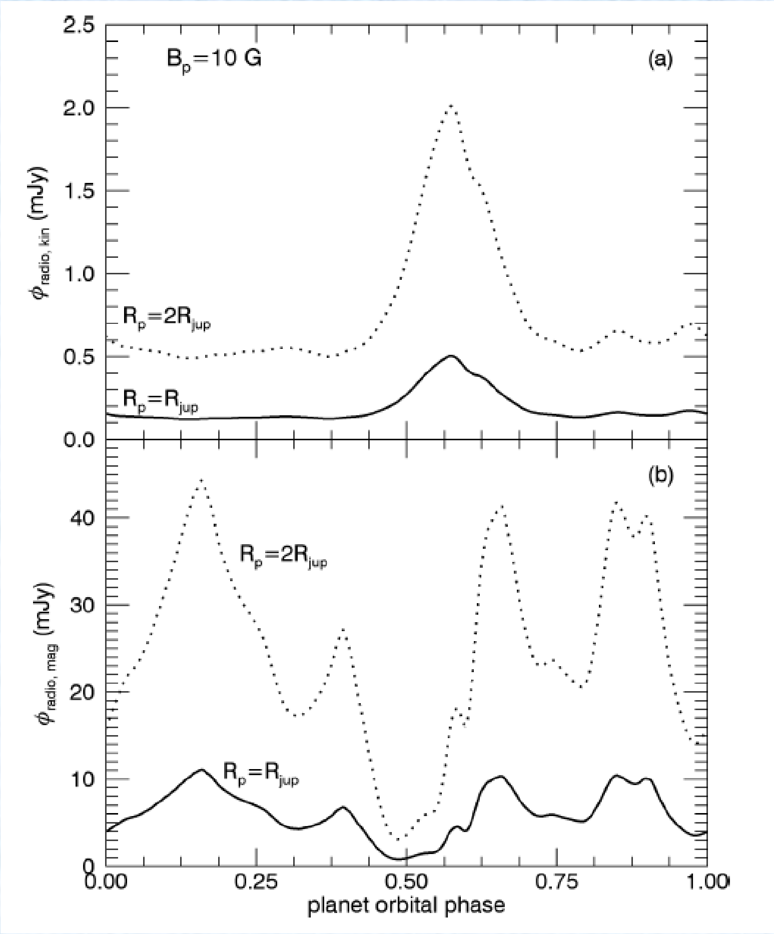
Massi et al 2007

Cyclotron Maser Instability Emission



Planetary B-field dominated by Stellar B-field

Mdot ~< 3 x 10^{-9} M_{sun} yr^{-1}



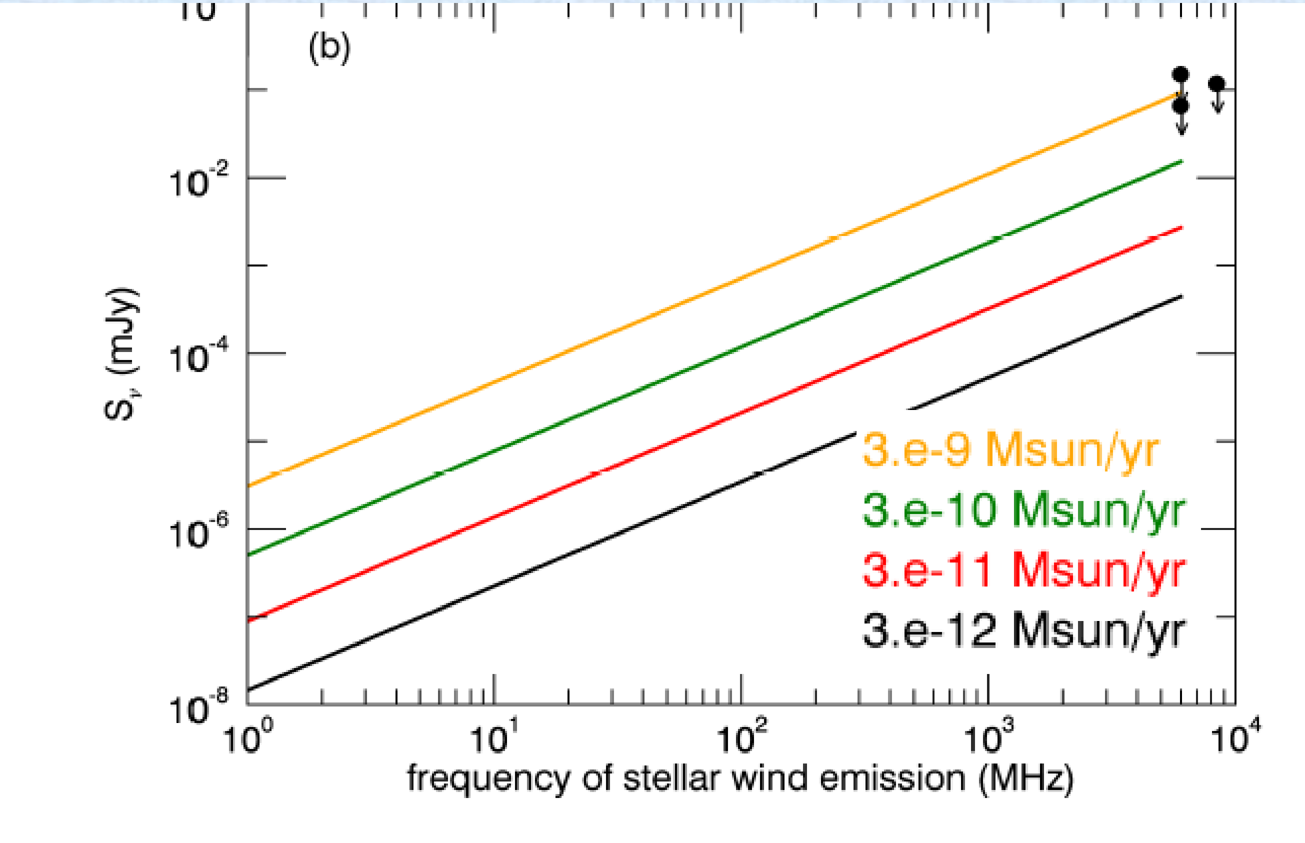
Kinetic Flux

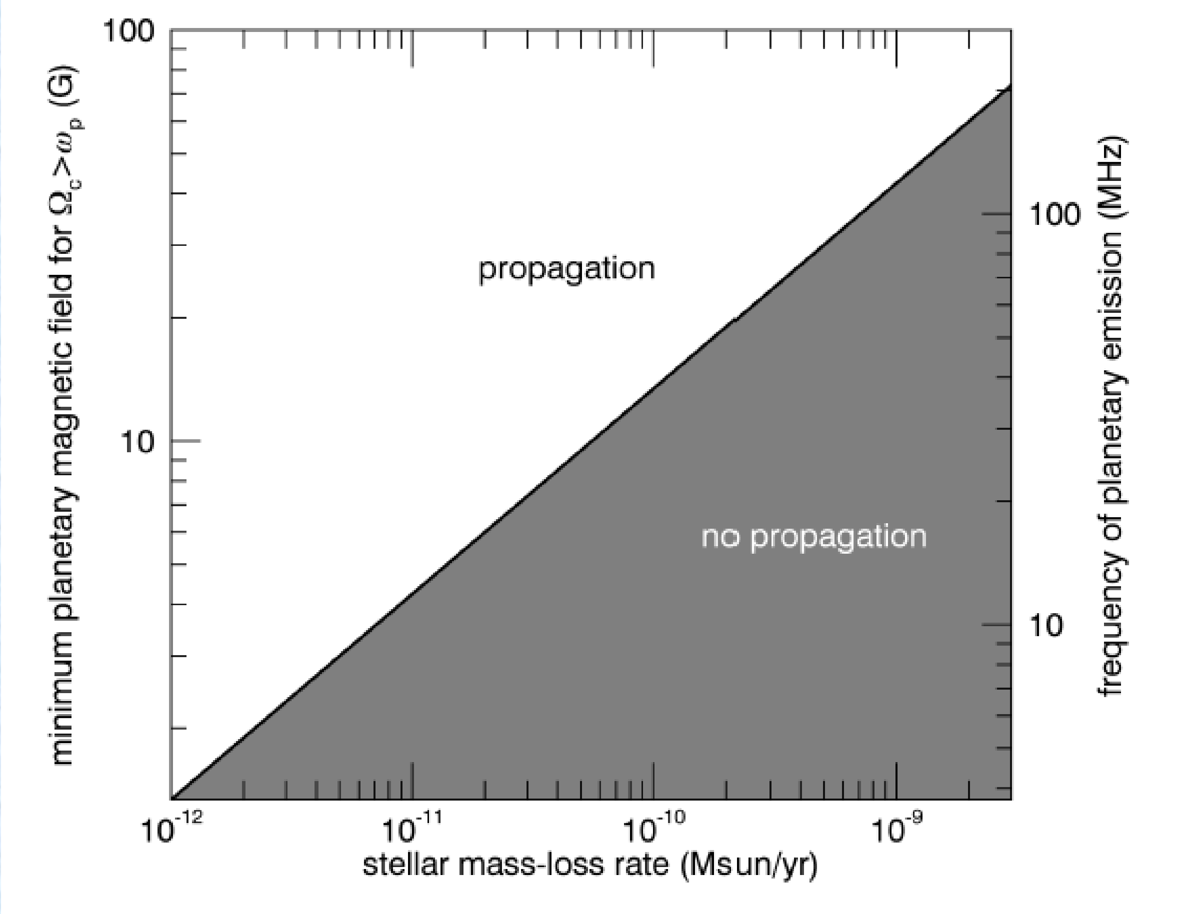
Magnetic Flux

Max frequency ~ 50 --- 250 MHz

Vidotto and Donati 2017

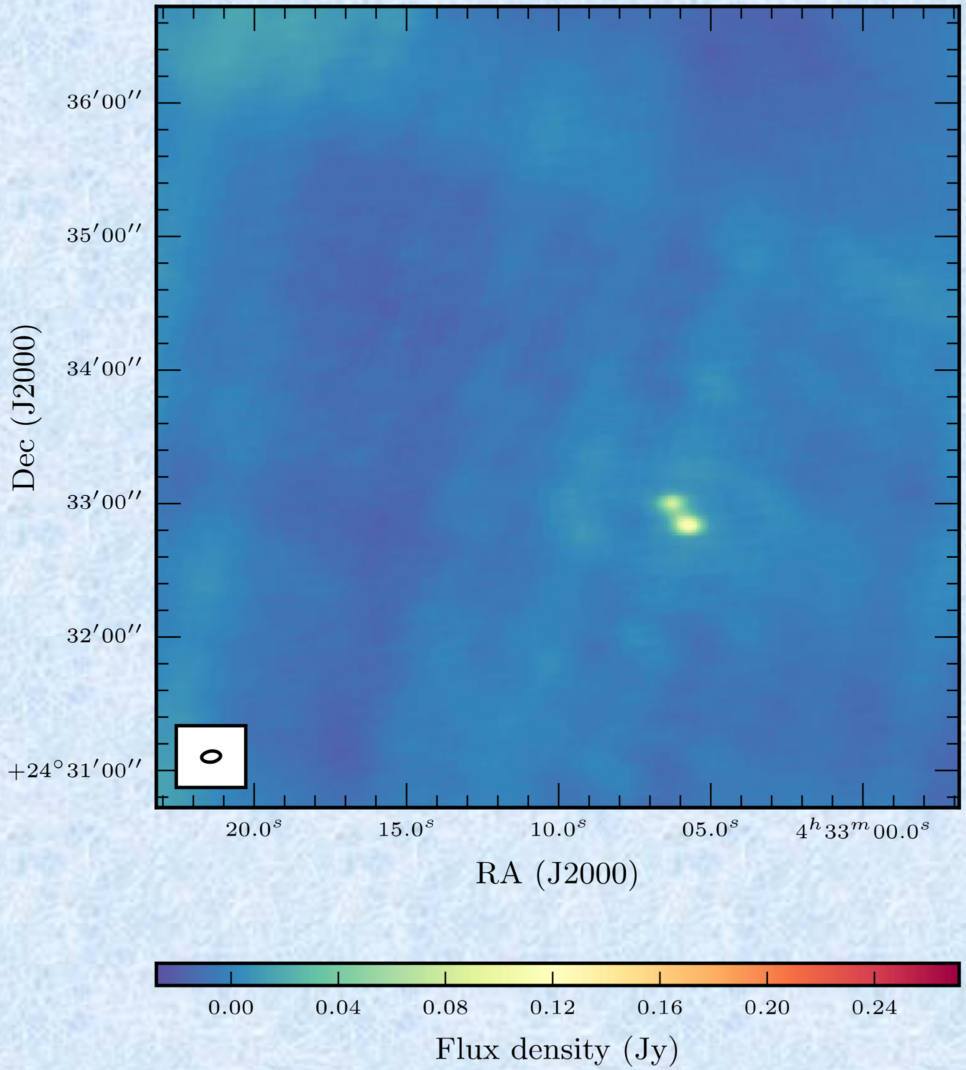
Stellar Wind Constraints





Vidotto and Donati 2017

LOFAR Search



- Preliminary Results
  - HBA imaging
  - ~few mJy rms
  - 195 kHz BW @ 173 MHz
- Expected Results
  - 100 microJy rms over full bandwidth
  - Need to search for short-term variations

Summary

- V830 Tau is youngest stellar host to an exoplanet
- The first (non-degenerate) star known to host an exoplanet with detected radio emission
- Prospects for further results
  - Orbital modulation of the radio flux
  - VLBI Imaging of the system
  - Low frequency detection of the CMI
- Strong B-fields on YSOs could be a guide towards radio characterization of exoplanets