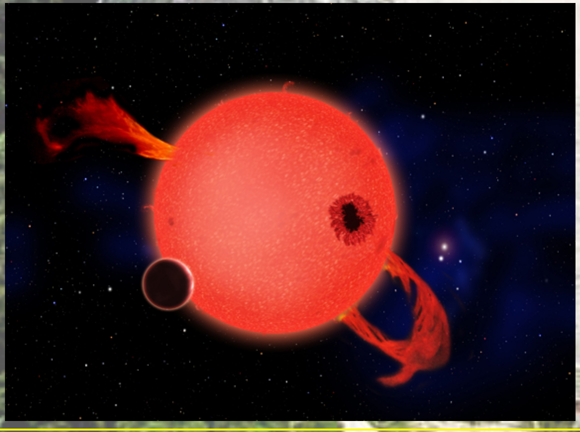
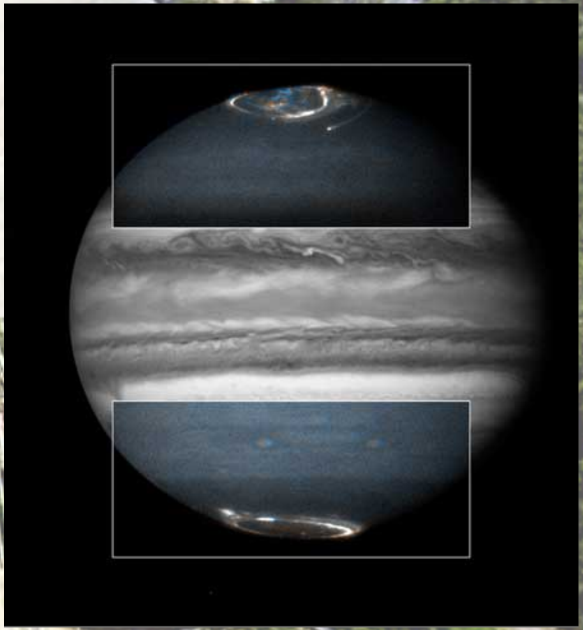
Arecibo observations of low-mass stars, brown dwarfs, and exoplanets





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Center for Exoplanets and Habitable Worlds

This meeting was co-sponsored by:

- Created in 2008
- 16 interdisciplinary researchers
- 10 postdocs and research associates
- 17 graduate students
- Huge range of research areas

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Radio astronomy vs. exoplanets

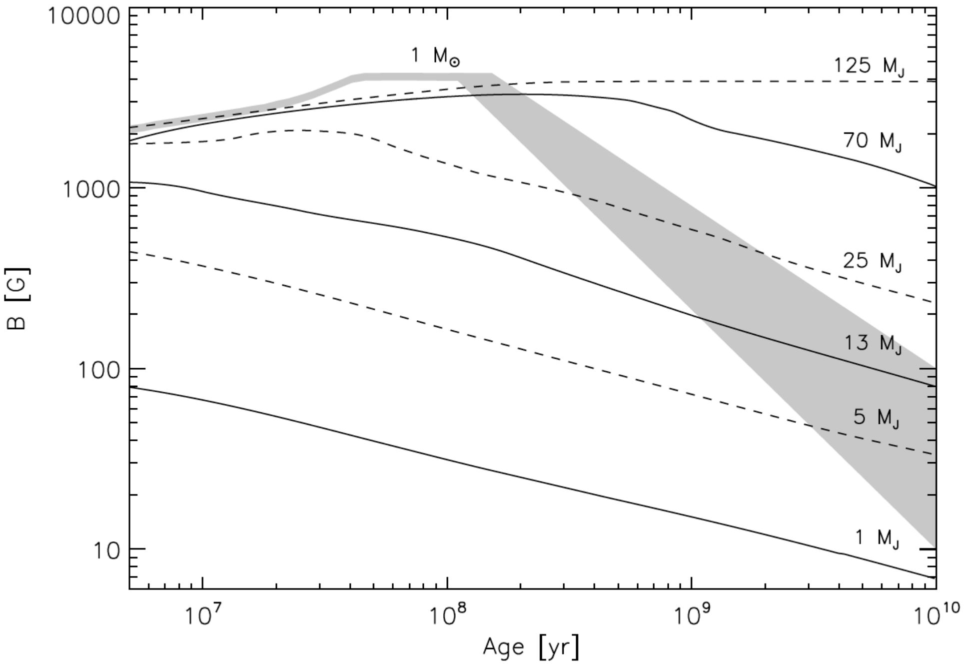
◆ Planet detection

- Planets around very low mass (VLM) stars, brown dwarfs (BD), white dwarfs (WD) via the unipolar (Jupiter-Io) emission mechanism
- Hot jupiters via stellar wind – planet interaction
- Timing of periodic flares from VLM stars/BDs (very few, limited precision)
- Pulsar timing (planets possibly extremely rare and/or low-mass, close-in)

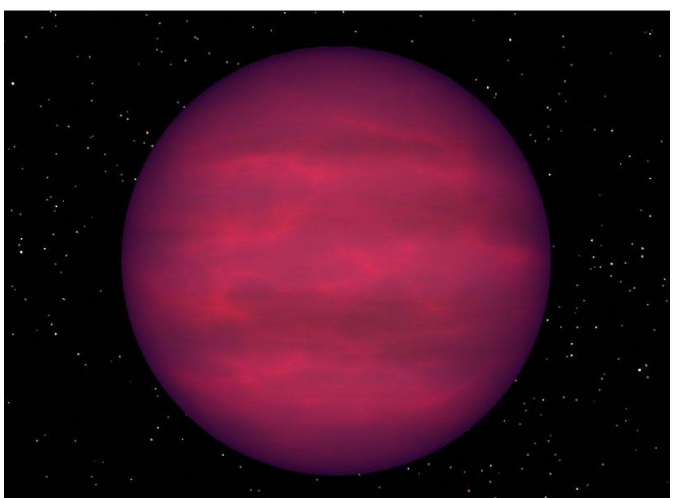
◆ Planetary habitability

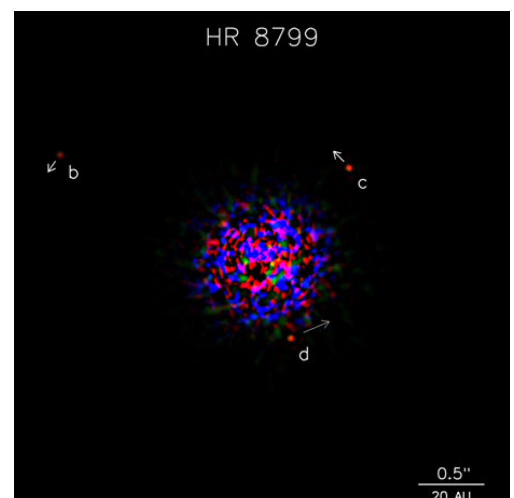
- Monitoring of M-dwarf flaring activity (focus on upcoming targets of RV surveys)
- Detection of planetary magnetic fields (old, hot jupiter systems → low frequencies/ young systems → GHz frequencies)
- Protoplanetary disk chemistry, broadband search for prebiotic molecules

From cool BDs to hot exoplanets?

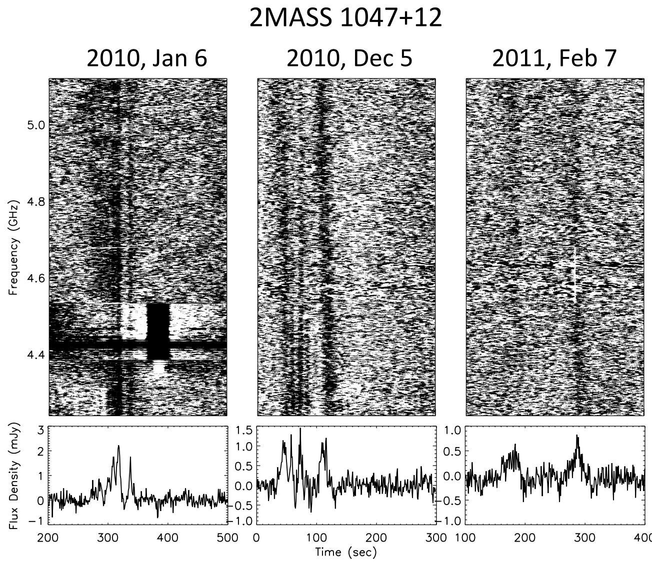


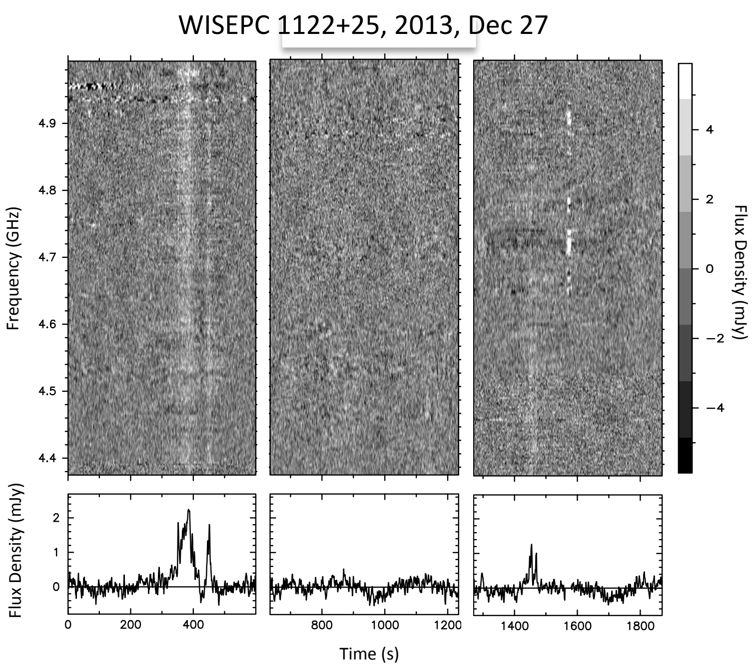
- Models of magnetic field evolution over time (e.g. Reiners & Christensen 2010) suggest that young, hot exoplanets could be detectable at higher frequencies → $B \sim (ML^2R^{-7})^{1/6}$ for objects rotating rapidly enough
- The same could work for older, inflated hot Jupiters (Trammell, Arras & Li 2011)
- Detection of the coolest BDs in the radio could provide "proof of concept" for this idea





Detection of T-dwarfs, 2MASS 1047+12 and WISEPC 1122+25





- Two Arecibo, C-band surveys of ~60 late L and T dwarfs, 2010-2014
- ν_c = 4.8 GHz, G = 6-8 K/Jy, T_{sys}~ 30 K
- Mock spectrometer: 20 kHz, 0.1 s resolution, 7 x 172 MHz frequency coverage → 1GHz BW
- Sensitivity for bandpass integrated signal ~0.15 mJy for Δt=0.9 s
- Four Stokes parameters, 600 s scans separated by 2 x 10 s cals

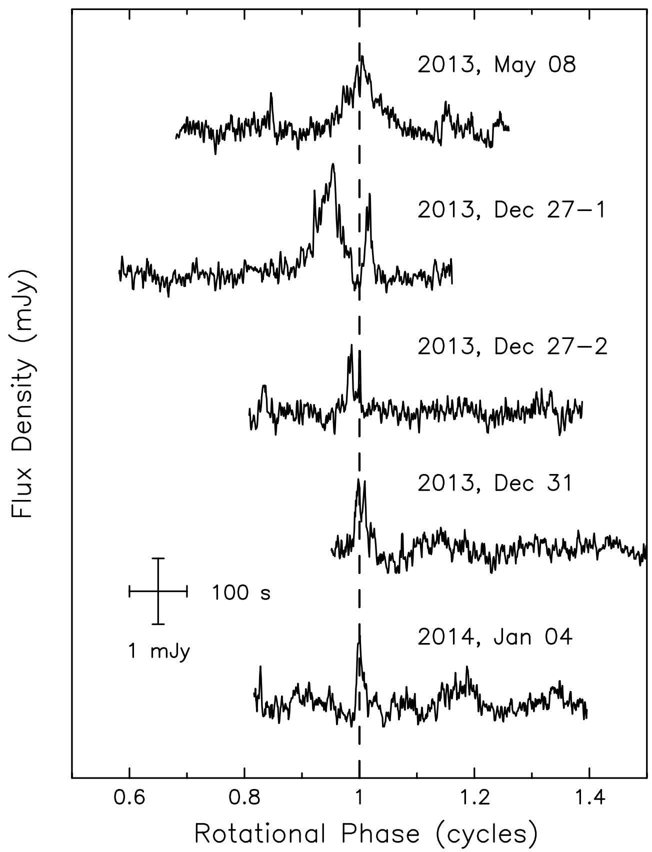
Detected two BDs: 2MASS 1047+12 (T6.5; Route & Wolszczan 2012) and WISEPC 1122+25 (T6; Route & Wolszczan 2016)

Follow-up work by Kao et al. (2015) produced four additional LT-dwarf detections, Williams & Berger (2014) measured 2MASS 1047+12 period to be 1.77 hours

These detections demonstrate that massive, young gas giants could indeed be radio detectable. Our attempts to detect the HR8799 system with Arecibo at L-band have not been successful so far (< 1 mJy peak for Stokes V bursts)

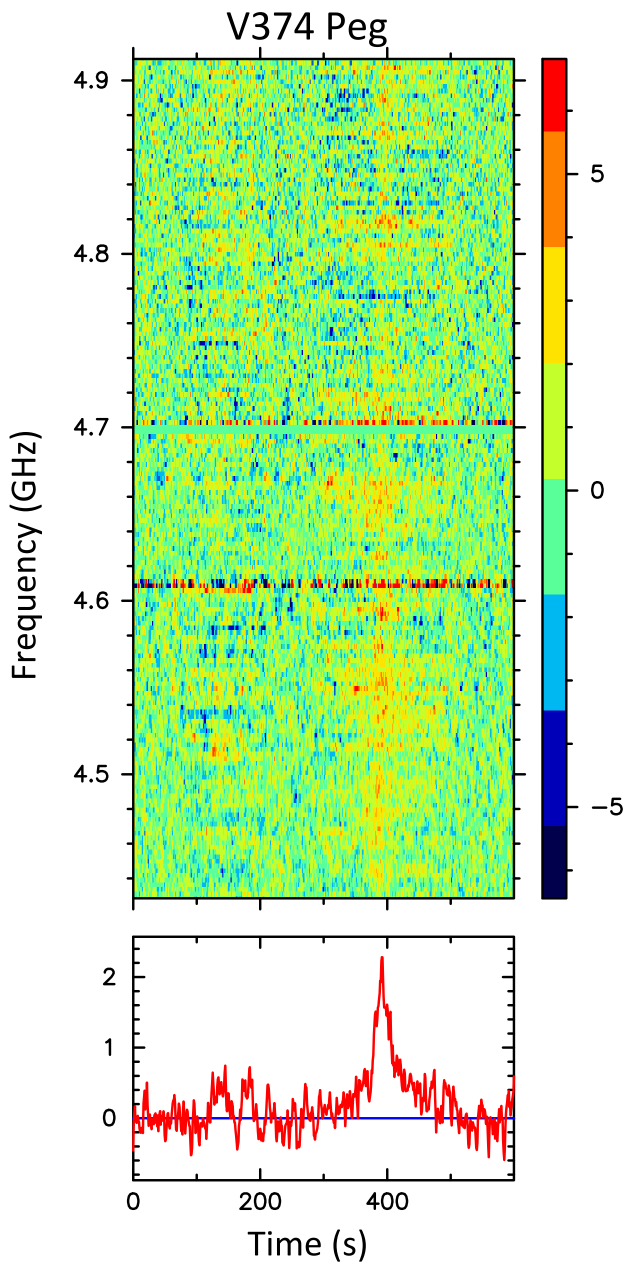
WISEPC J1122+25: a rapidly spinning T6-dwarf?

Route & Wolszczan (2016)



- We have investigated a possibility that the five flares are phased up at some period
- Assuming that the Dec 27 flares, 17 min. separation is actually the period, one gets an excellent fit to all five of them with a ~0.8 s post-fit residual!
- If either one of the two is not in phase with the rest, the periods of 34 and 51 min. are also possible
- Stability of the periodicity (if real) suggests its rotational origin
- An > 1 Gyr, ~30-60 M_J, ~0.8 R_J, log(g) > 5 dwarf looks plausible
- Williams et al. (2017) have detected the source, did not confirm these periodicities

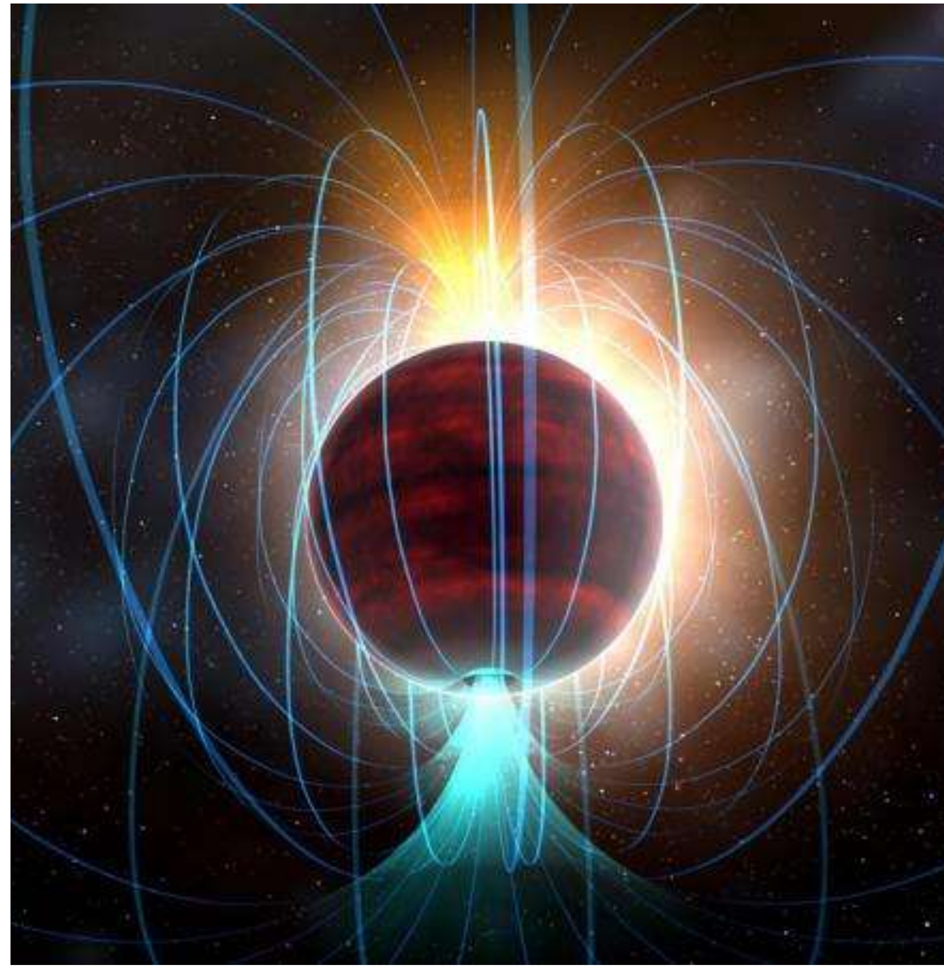
The Arecibo M-dwarf monitoring project



- A pilot program of bi-weekly monitoring of six active dwarfs of M4-M9 spectral types at L, S, and C-bands
- This is in preparation for a larger project to characterize activity of M-dwarfs that are targets of the HPF and CARMENES NIR-RV surveys
- Arecibo sensitivity will allow detection and monitoring of low-level activity
- Observations will be coordinated with radio interferometry and optical photometry

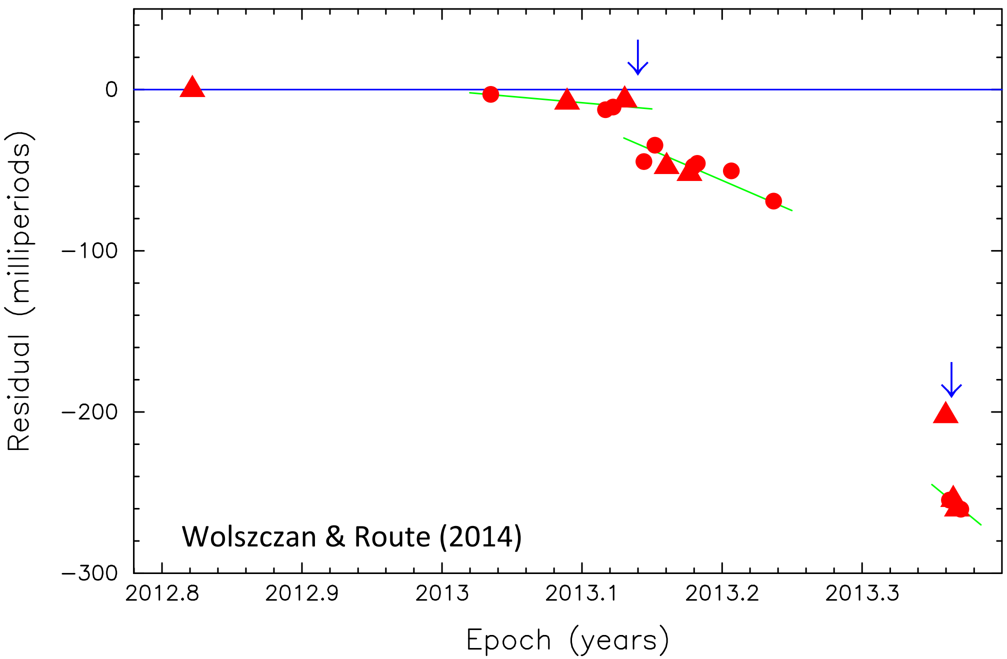
TVLM 513-46546

- M9 star at brown dwarf boundary
- Distance: 10.5 pc
- Mass: ~ 0.08 solar masses
- Surface temp ~2200 K
- Rapid rotation: 1.96 hr
- Flares at 5-12 GHz at the same period (Hallinan et al. 2006, many others later)
- Sinusoidal photometric variations at the same period in the optical (Littlefair et al. 2008)
- Periodic linear polarization (Miles-Paez et al. 2015)
- Detected with ALMA (Williams et al. 2016)
- Part of the monitoring program at Arecibo



Credit: Dana Berry

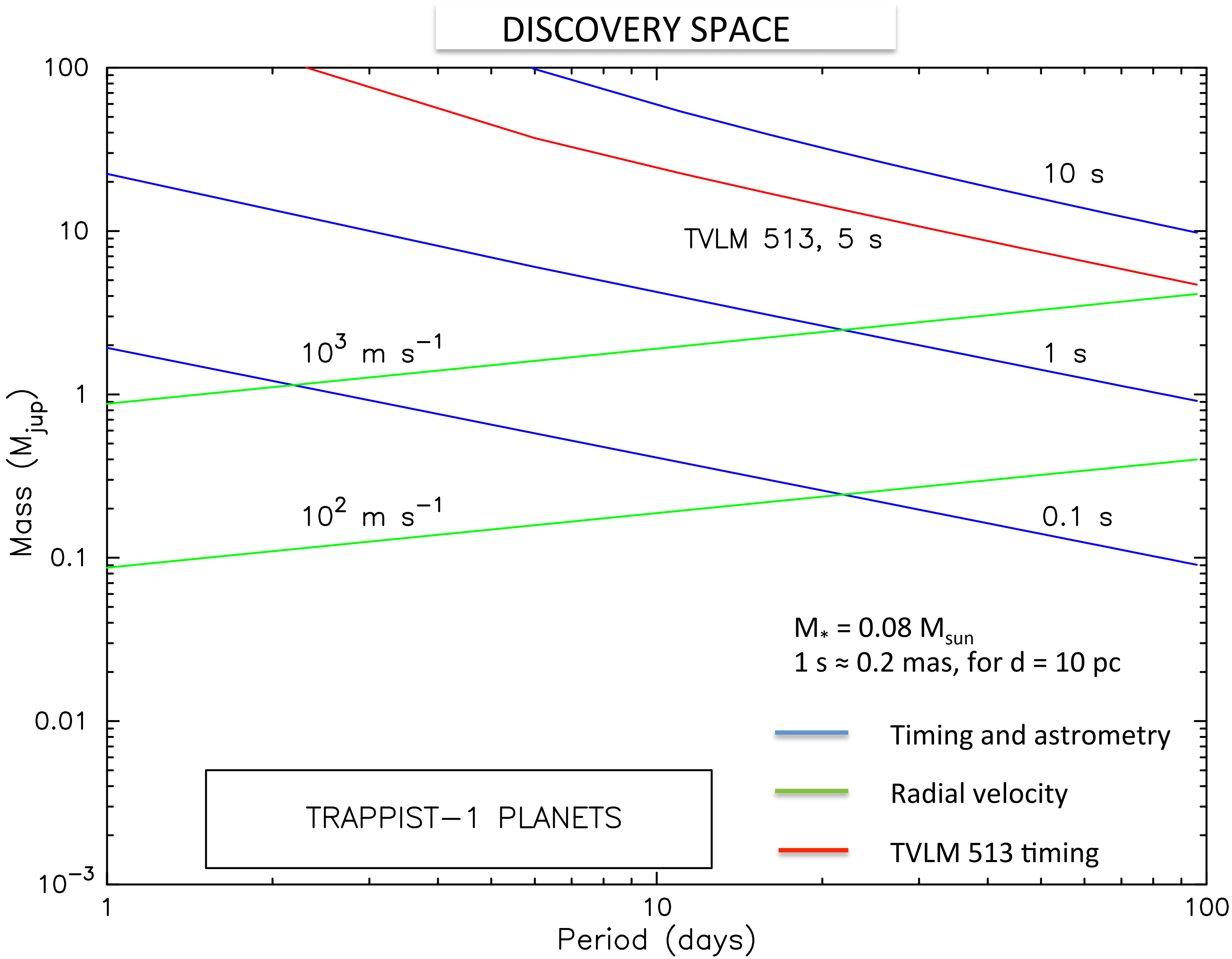
Long term timing and activity monitoring of TVLM 513



$$\phi_i = \phi_0 + \nu\, t_i + \frac{1}{2}\dot{\nu}\, t_i^2 + \frac{1}{6}\ddot{\nu}\, t_i^3 + \cdots$$

- In 2012-2013, flare period had been decreasing
- Phase drift up to ¼ of period in 200 days
- Phase jumps (arrows) followed by period decreases
- Period (~7054 s) became shorter by ~2 s
- In early 2015, bursts of emission were initially spread over the whole period
- Replaced in late May by single bright flares maintaining phase for ~6 months, intensity went up by a factor of ~10 at the time of transition (work in progress)
- A 5-10 s precision timing of flares with modeling of period changes and phase jumps is possible. May be useful for flare monitoring and companion detection (see next slide)

Detection of substellar companions to VLMs and BDs with timing of the periodic radio flares



Hi-res dynamic spectra offer insights into details of the physics of TVLM 513 bursts

Wolszczan et al., in prep.