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

- 2\textsuperscript{nd} most luminous stellar radio outburst
- Briefly, brightest object in nebula
- Magnetized T Tauri outburst \sim \text{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

- 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

HST Image of Orion Nebula
Pleiades distance controversy solved
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

\[ \lambda = 3 \text{ cm} \]
\[ D = 100 \text{ m} \]
\[ \Theta = 60 \text{ arcsec} \]

Expanded Very Large Array

\[ \lambda = 3 \text{ cm} \]
\[ D = 25 \text{ m} \]
\[ b = 35 \text{ km} \]
\[ \Theta = 200 \text{ milliarcsec} \]

Very Long Baseline Array

\[ \lambda = 3 \text{ cm} \]
\[ D = 25 \text{ m} \]
\[ b = 8000 \text{ km} \]
\[ \Theta = 1 \text{ milliarcsec} \]

Source localization is \[ \Theta / \text{SNR} = 0.1 \text{ milliarcsec} \]
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.

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?
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 pc 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
1000 m/s
planet
75 m/s
residuals
11 m/s

Donati et al 2016
PERIODGRAMS

- 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 AL. 2017)

340G dipole field with 22 degree 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
Magnetic topology: 70% poloidal, 30% toroidal, with time variations
due to the gap, 3 possible periods before the 2017 campaign

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. Granke$^6$,
<table>
<thead>
<tr>
<th></th>
<th>Tap 26</th>
<th>V830 Tau</th>
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<tbody>
<tr>
<td>age</td>
<td>17 My</td>
<td>2 My</td>
</tr>
<tr>
<td>mass</td>
<td>1 M$\odot$</td>
<td>1 M$\odot$</td>
</tr>
<tr>
<td>rotation</td>
<td>0.7 d</td>
<td>2.7 d</td>
</tr>
<tr>
<td>orbit</td>
<td>$\sim$12d</td>
<td>4.9d</td>
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</table>

Donati+2015,2016
Yu+2017

CFHT/ESPaDOnS

artist view by Michael Ho

VLA Detection of Radio Emission from V830 Tau
Emission is Variable

Table 1. VLA & VLBA Results for V830 Tau

<table>
<thead>
<tr>
<th>Tel.</th>
<th>Epoch</th>
<th>UT</th>
<th>Beam</th>
<th>RMS (µJy)</th>
<th>S (µJy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLA</td>
<td>25 Feb 2011</td>
<td>04:47</td>
<td>1.1” × 0.8”, 84°</td>
<td>22</td>
<td>&lt; 66</td>
</tr>
<tr>
<td>...</td>
<td>12 Apr 2011</td>
<td>02:37</td>
<td>1.6” × 0.8”, 86°</td>
<td>34</td>
<td>147 ± 34</td>
</tr>
<tr>
<td>...</td>
<td>01 May 2011</td>
<td>22:25</td>
<td>0.8” × 0.6”, -23°</td>
<td>26</td>
<td>919 ± 26</td>
</tr>
<tr>
<td>VLBA</td>
<td>31 Aug 2014</td>
<td>14:23</td>
<td>1.8 × 0.8 mas², -10°</td>
<td>39</td>
<td>&lt; 117</td>
</tr>
<tr>
<td>...</td>
<td>11 Sep 2015</td>
<td>13:42</td>
<td>1.8 × 0.8 mas², -11°</td>
<td>40</td>
<td>501 ± 75</td>
</tr>
</tbody>
</table>

Bower et al. 2016
VLBA Imaging
Radio Emission Looks Typical for T Tauri Star

- $L_x \sim 1 \times 6 \times 10^{30} \text{ erg s}^{-1}$
- Radio/X-ray correlation $\rightarrow 40 \sim 200$ uJy
- Synchrotron/Gyrosynchrotron
  - Flat spectrum
  - No detected circular polarization
  - $T_b > 3 \times 10^7$ K
  - $R < 50 \ R_{\text{sun}}$
  - Equipartition $\rightarrow B > 30$ G
Relation to Stellar Cycle

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

$\rightarrow$ Importance of simultaneous radio and ZDI monitoring
High Resolution Probes of V830 TauB

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

Massi et al 2007
Cyclotron Maser Instability Emission

Planetary B-field dominated by Stellar B-field
Mdot $\sim 3 \times 10^{-9} \, M_{\odot} \, yr^{-1}$

Max frequency $\sim 50 \ldots 250$ 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