Radio Continuum Observations of Low Mass Young Stars Driving Outflows

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Radio Stars and Their Lives in the Galaxy
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Overview

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- Spectral Energy Distributions
- Radio Luminosity Correlations
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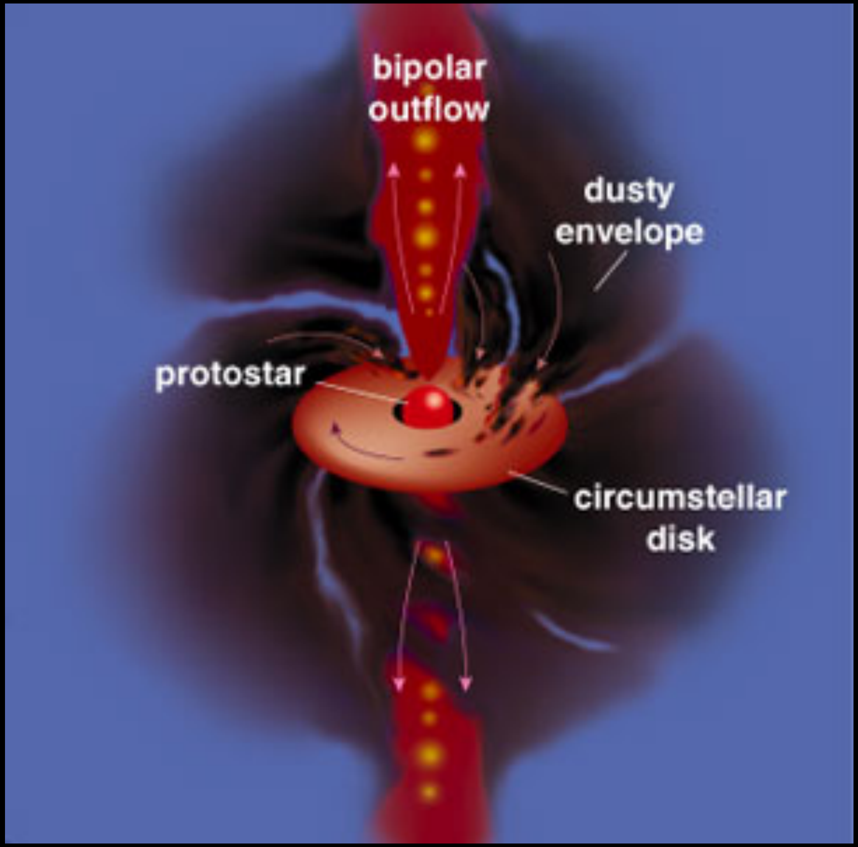
- Future Work: eMERLIN

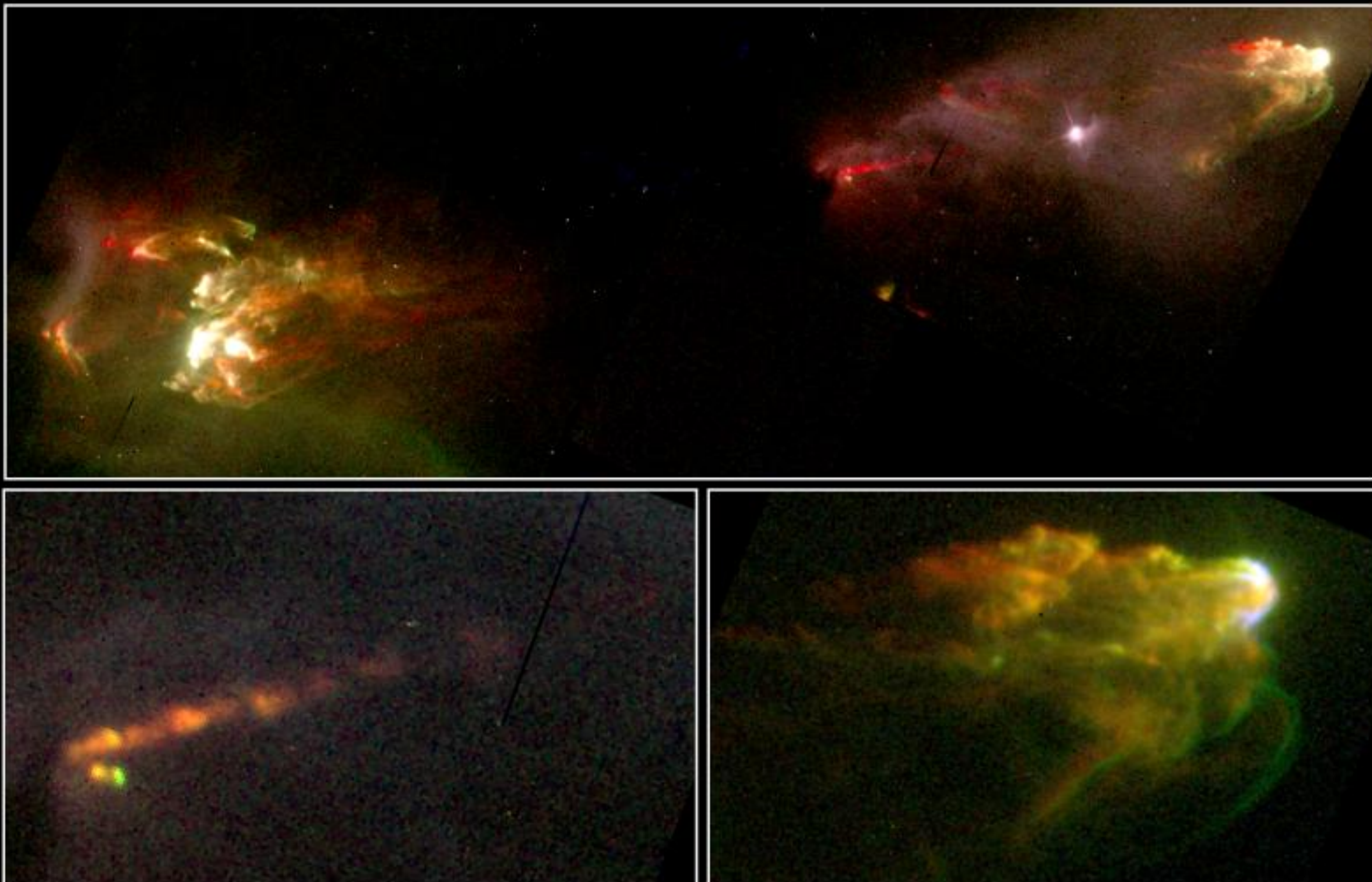
Star-Forming Region in the Carina Nebula HUBBLESITE.org

YSO Classification



Green, T., 2001, AS, 89, 316.

- Class 0
  - $M_{env} > M_*$
  - Powerful outflows
  - $L_{rad} \propto \boldsymbol{M}^{4/3}$
- Class I
  - $M_{env} < M_*$
  - Circumstellar disc
  - Less powerful outflows than Class 0
- Class II
  - CTTS
  - Accumulated >90% mass
  - Optically thick disc



Jets from Young Stars · HH1/HH2 HST · WFPC2

PRC95-24c · ST ScI OPO · June 6, 1995 · J. Hester (AZ State U.), NASA

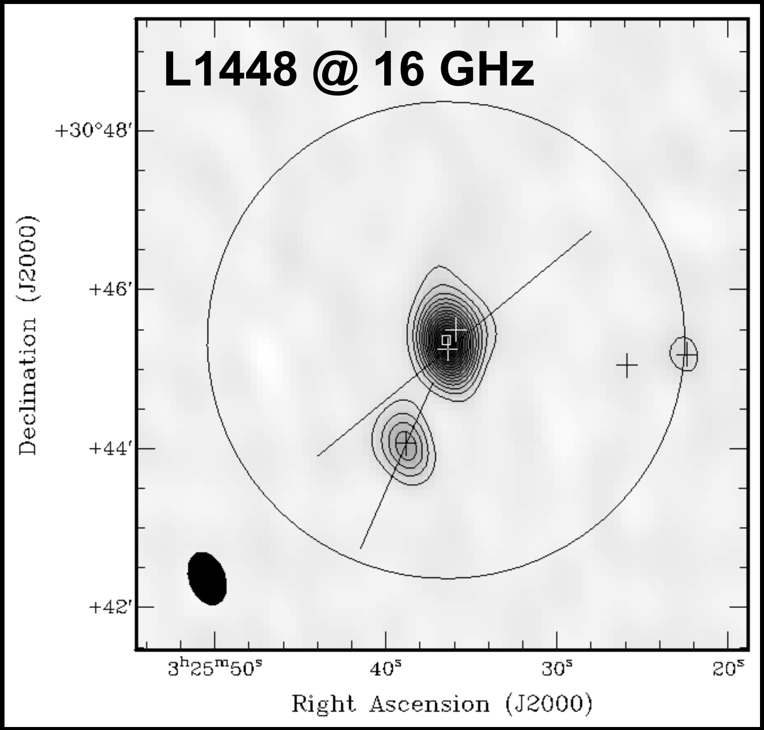
Radio Continuum Observations

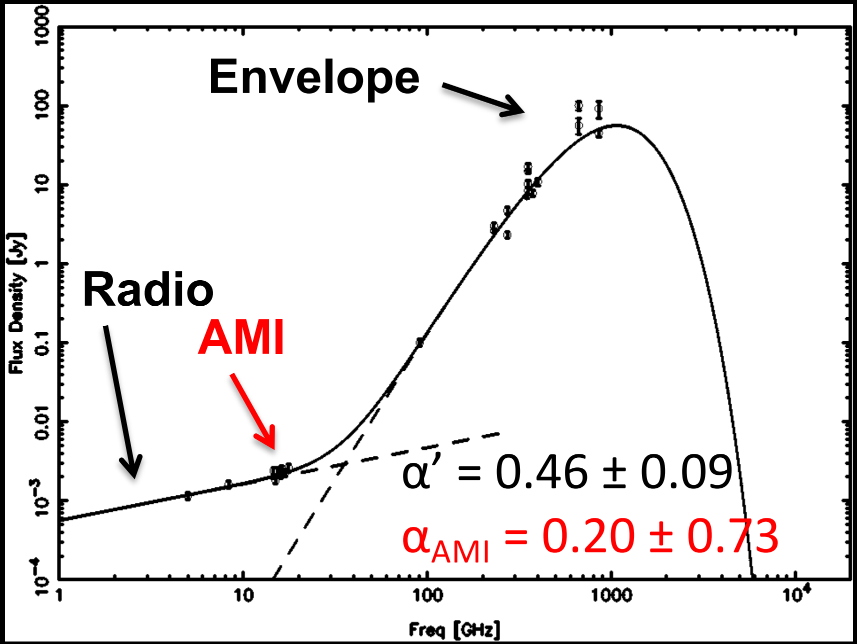
- Thermal bremsstrahlung radiation
  - $S_\nu \propto \nu^\alpha$, where $-0.1 < \alpha < 2$ and $\alpha = 0.6$ for a canonical jet (Reynolds 1986)
- Non-thermal emission
  - $\alpha < -0.1$ (e.g. Carrasco-González et al. 2010)

The Arcminute Microkelvin Imager

- AMI Large Array comprises eight 13 m dishes
- Operates between 13.5 and 17.9 GHz with eight 0.75 GHz bandwidth channels
- Primary beam at 16 GHz ≈ 6 arcmin

Results





- 16 GHz radio continuum observations for 16 YSOs with optical outflows
- Power-law spectral indices were fitted to the AMI channel data

$$S_\nu \propto \nu^{\alpha_{AMI}}$$

- SEDs were compiled and fitted with a combined radio power-law and modified blackbody model

$$S_{total} = K_1 \left(\frac{\nu}{\nu_1}\right)^{\alpha'} + K_2 \frac{\nu^\beta B_\nu(T_d)}{\nu_2^\beta B_{\nu_2}(T_d)}$$

(i) Fixing T_d based on evolutionary class
(ii) Allowing T_d to vary

SED Results

- 78% of the target sample had $-0.1 < \alpha^{AMI} < 2$
  - Average $\alpha^{AMI} = 0.4 \pm 0.6$
- 80% of the target sample had $-0.1 < \alpha' < 2$
  - In both T_d Scenarios
  - Average $\alpha' = 0.2 \pm 0.4$
- Remaining sources have spectral indices < -0.1

These results suggest that free-free radiation is the dominant mechanism for producing the radio emission.

Radio Luminosity

The greybody contribution at 16 GHz:

$$S_{\mathrm{gb},16} = f(K_2, \beta, T_{\mathrm{d}}) = K_2 \frac{\nu_1^\beta B_{16}(T_{\mathrm{d}})}{\nu_2^\beta B_{300}(T_{\mathrm{d}})}$$

$$\sigma_{S,16}^2 = \left(\frac{\partial f}{\partial K_2}\sigma_{K_2}\right)^2 + \left(\frac{\partial f}{\partial \beta}\sigma_\beta\right)^2 + \left(\frac{\partial f}{\partial T_{\mathrm{d}}}\sigma_{T_{\mathrm{d}}}\right)^2$$

– The dominant source of error is the uncertainty on β

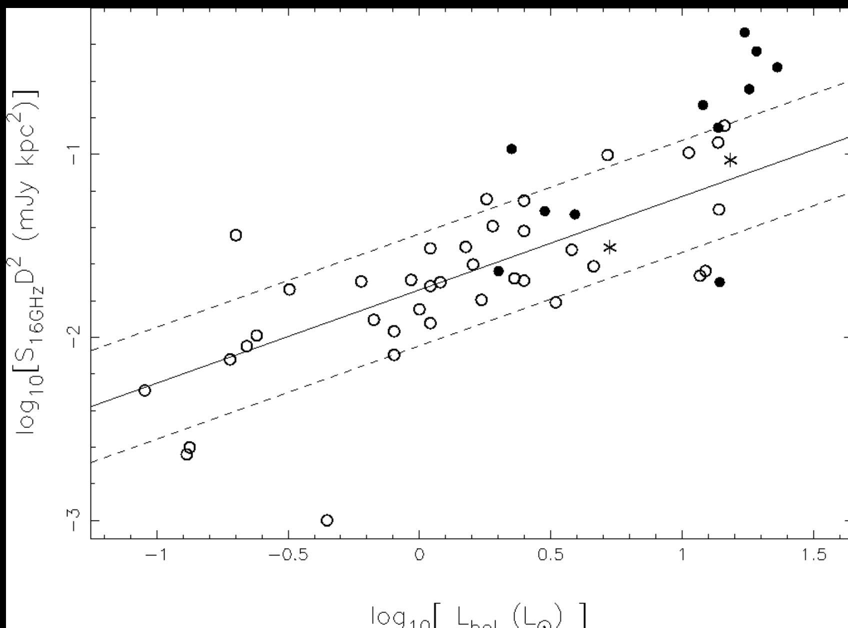
– For L1448: $S_{\mathrm{gb},16} = 145.74 \pm 77.31$ μJy, where

$\sigma^2 = 4.39^2 \pm 75.8^2 \pm 14.3^2$ μJy

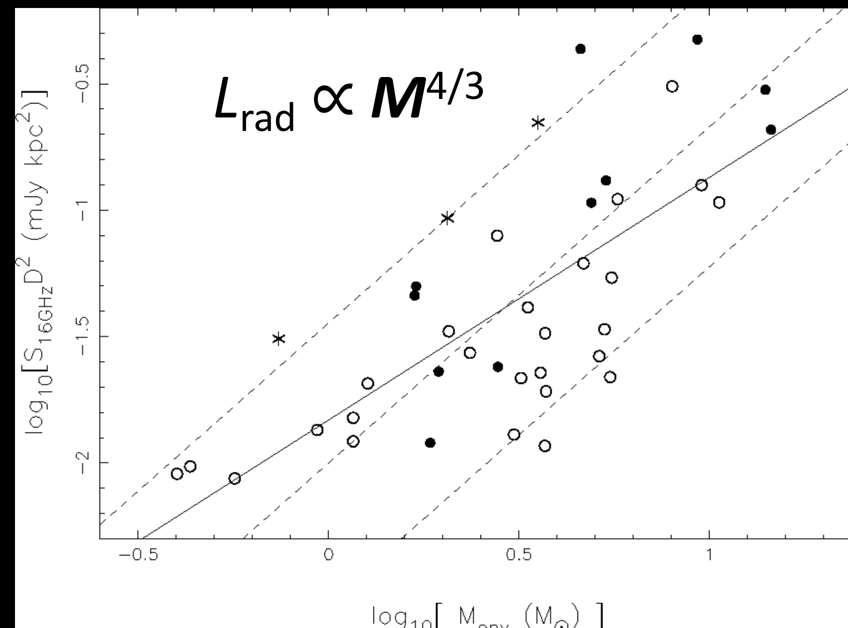
The radio luminosity:

$$L_{\mathrm{rad}} = S_{\mathrm{rad},16} d^2 = (S_{16\ \mathrm{GHz}} - S_{\mathrm{gb},16}) D^2$$

Radio Luminosity Correlations



Correlation with Bolometric Luminosity



Correlation with Envelope Mass

Best fit from Scaife et al. 2011:
$\log[L_{rad}$ (mJy kpc^2)] = - (1.74 ± 0.18) + (0.51 ± 0.26)$\log[L_{bol}$ ($L_\odot$)]

Best fit from Ainsworth et al. 2012:
$\log[L_{rad}$ (mJy kpc^2)] = - (1.83 ± 0.25) + (0.96 ± 0.41)$\log[M_{env}$ ($M_\odot$)]

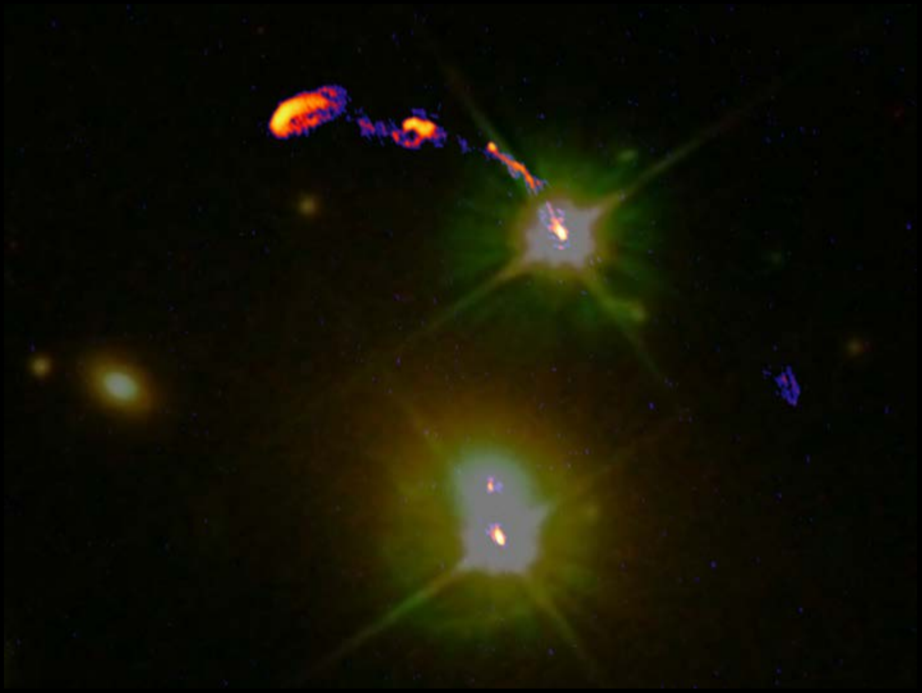
Summary of AMI Results

- Provided total radio emission at 16 GHz for a relatively large sample of YSOs with outflows
  – 16 GHz observations constrain the boundary between the radio and sub-mm
- Shown dominance of thermal emission in outflow
- Shown that dust emissivity is important even at radio wavelengths

Future work: eMERLIN

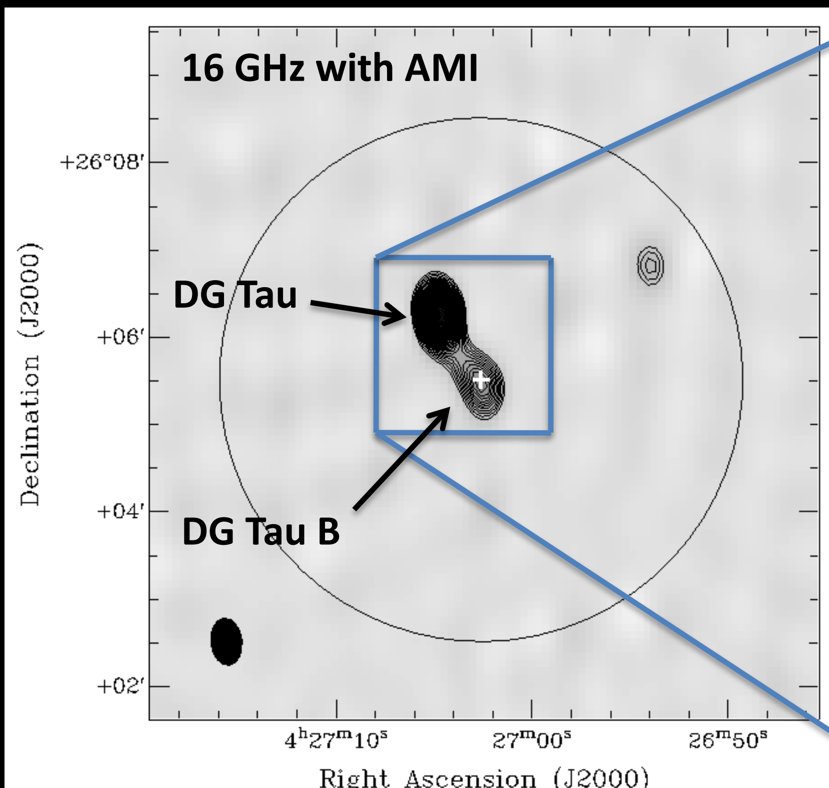
Capabilities include:

- Observing bands at
  1.3-1.8 GHz
  4-8 GHz
  22-24 GHz
- Resolution 10 to 150 mas
- Total bandwidth 4 GHz
- Sensitivity ~ 1 μJy
- Polarimetry
- Proper motions

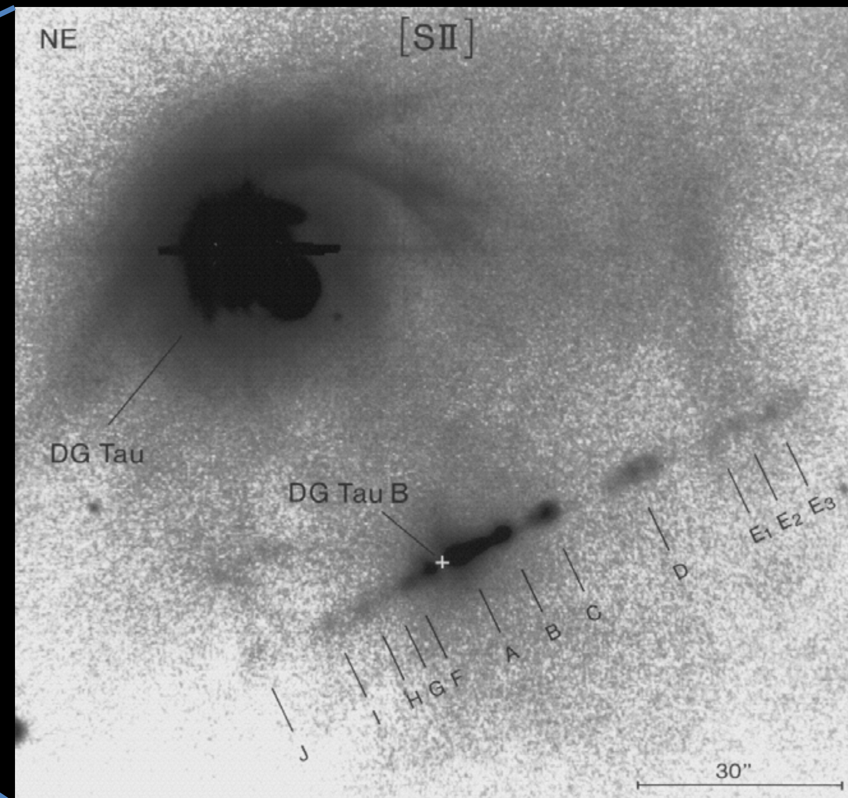


DG Tau

Scaife et al. 2012

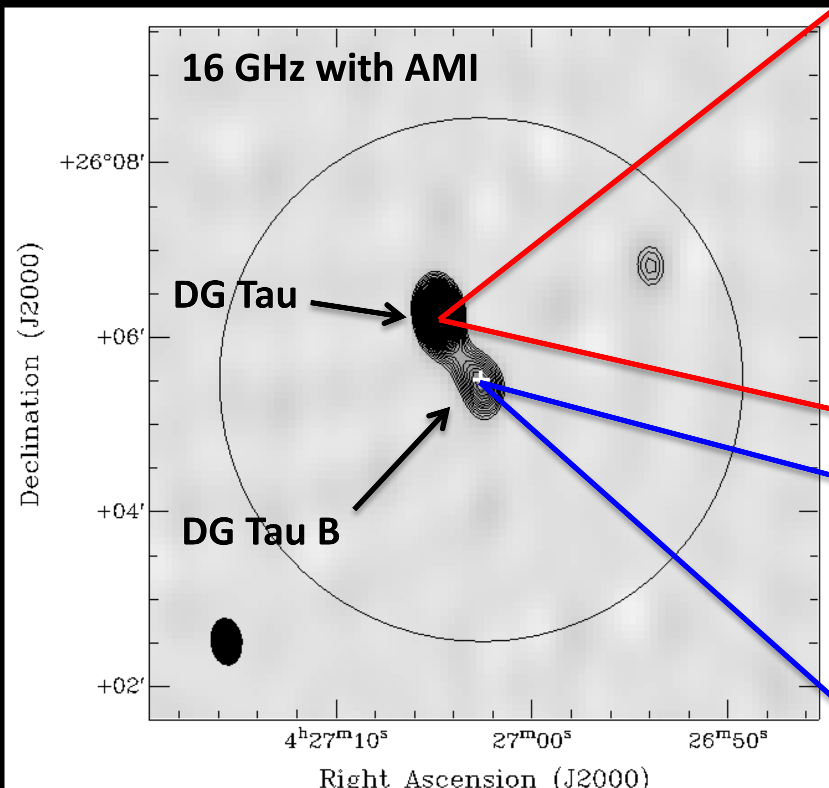


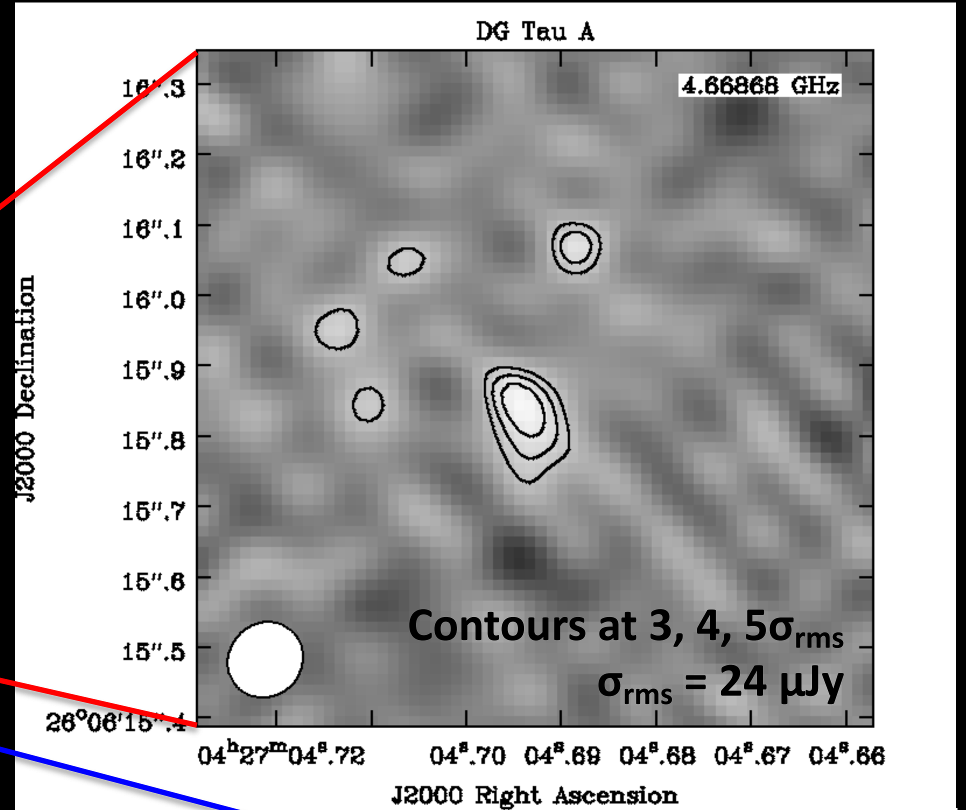
Eislöffel & Mundt 1998

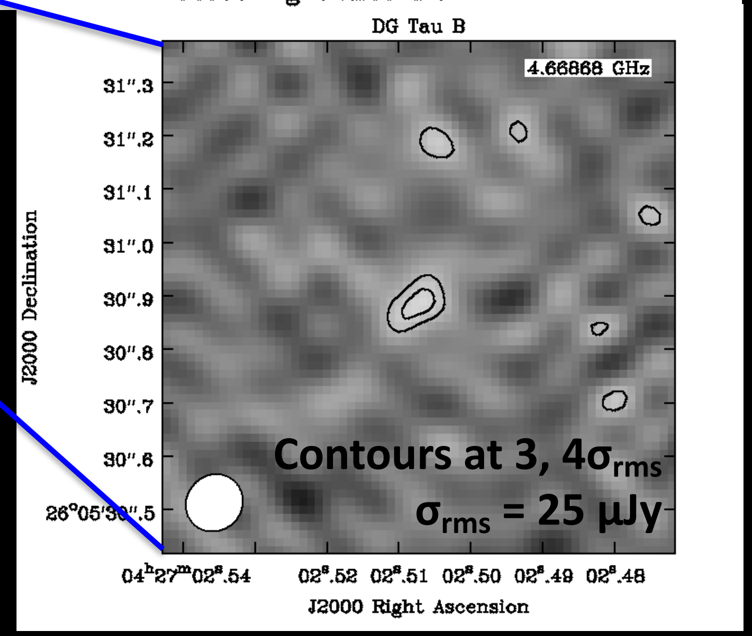


- DG Tau is a highly active CTTS in Taurus (*D* ≈140 pc) and was one of the first to be associated with optical jet (Mundt & Fried 1983)
  - The jet has onion-like structure within 500 AU of the star (Bacciotti et al 2000)
  - X-ray jet (Güdel et al 2005)
- DG Tau B is a CI source located 55” SW driving a bipolar jet (Mundt & Fried 1983)

DG Tau with eMERLIN







- Detect the central engine
- eMERLIN Θ_{FWHM} = 0.11x0.10 arcsec
- Jet collimation on scale of ≈ 14 au
- Mass loss rate ≈ 1.7 x 10^{-8} $M_{\odot}yr^{-1}$, consistent with recent optical results (Maurri et al. 2012, private communication)

Questions?

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For more information:

2012MNRAS.423.1089A