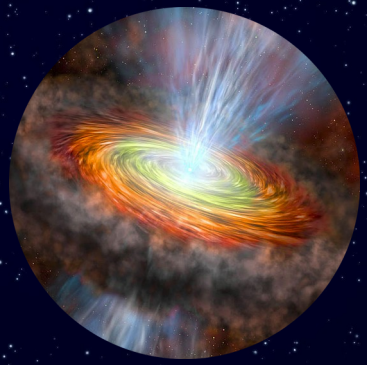
# Unique Case of IRAS 18162-2048:

## A massive protostar driving the largest scale jet in our Galaxy




*Sarita Vig*

**Indian Institute of Space science and Technology (IIST)**

**Trivandrum, INDIA**

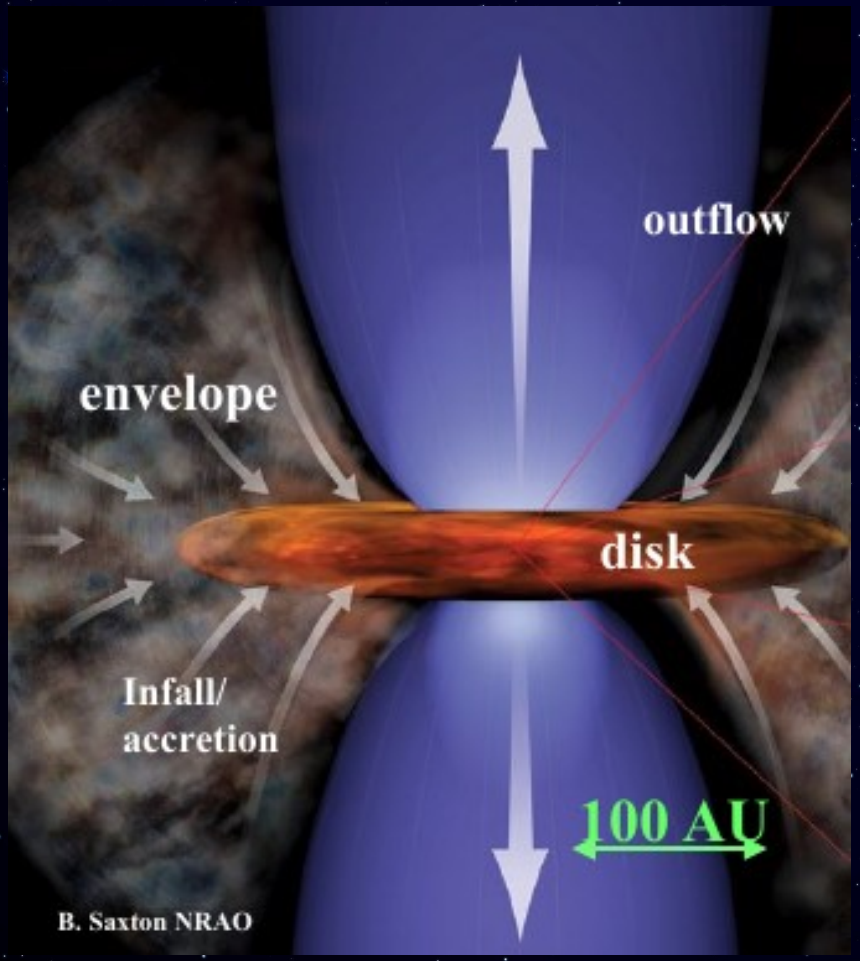

**Forging Giants: Massive Stars and their disks, 05 May 2026**

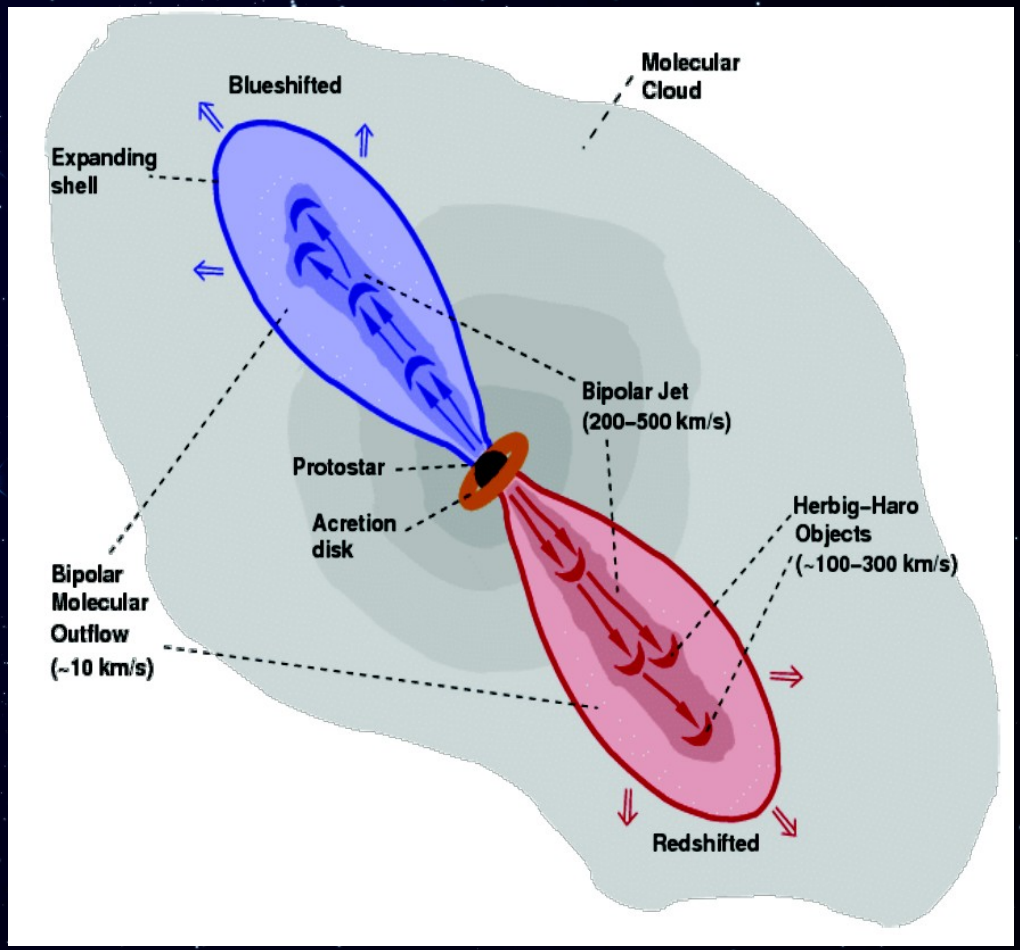
# Plan of the talk

- Star formation and Protostellar jets and outflows
- HH80-81 system
- Radio continuum emission
- NIR emission in lines of $H_2$ and [FeII]
- Circular polarisation from the massive YSO
- Summary

# Protostellar Jets and Outflows

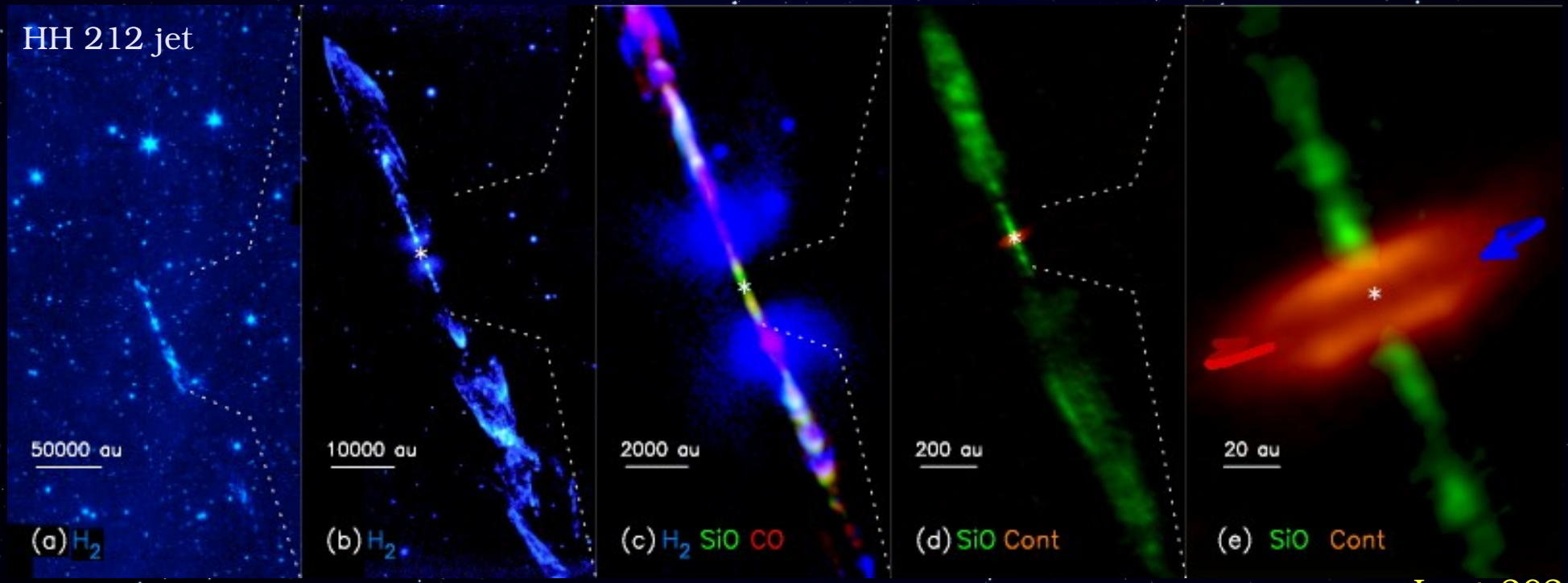
Material ejected and entrained from a protostellar system



# Protostellar Jets: Launch and Collimation

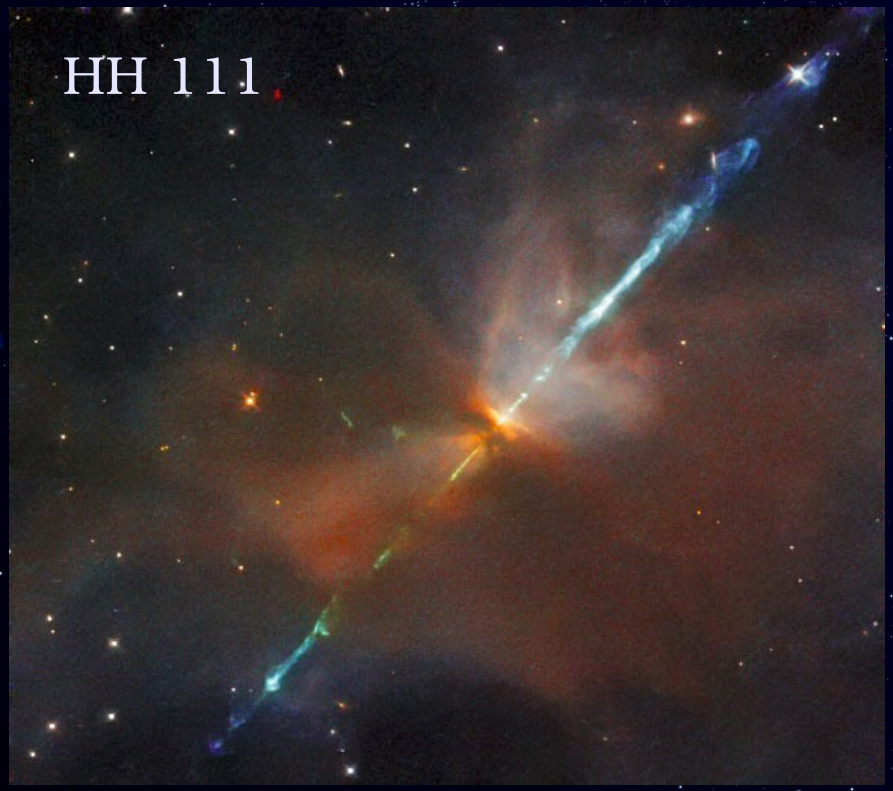
- Accretion disk and Magnetic field are essential
- Rotation + Magnetic field = twisted magnetic fields
- Helical Magnetic field confines the material
- Appears as jet at large distances
- Mechanism invoked for all jets: AGN, Microquasars, PNe, YSOs
- **Protostellar jets - Opportunity to study jets from close quarters**

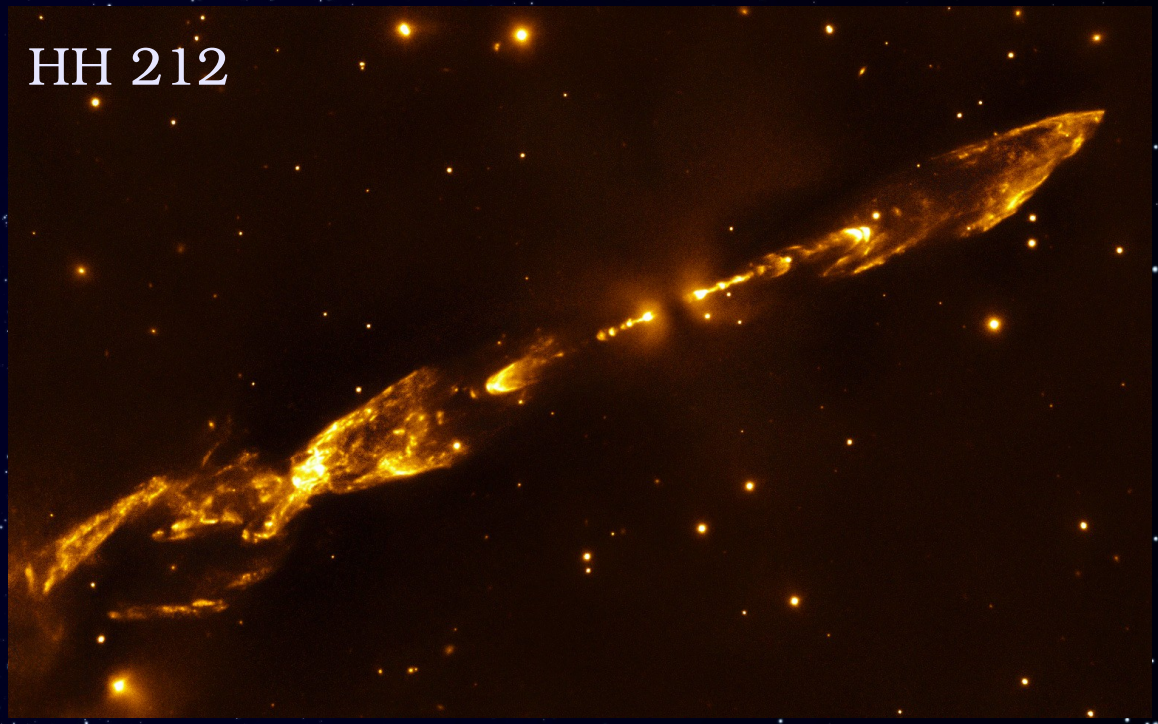



Lee+ 2020

# Protostellar jets: Herbig Haro Objects

Knots of emission (Optical / NIR) where jet interacts with ambient medium



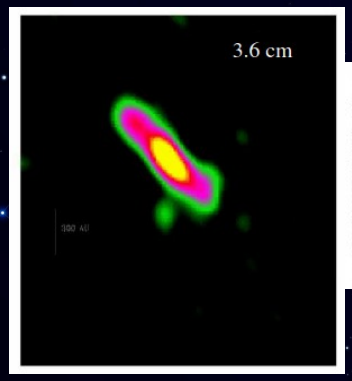


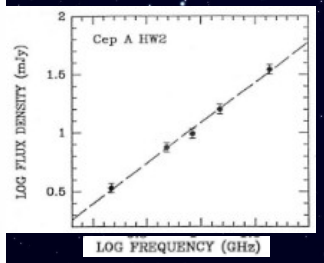
Credit: HST, VLT

# Protostellar jets: Interaction with ISM

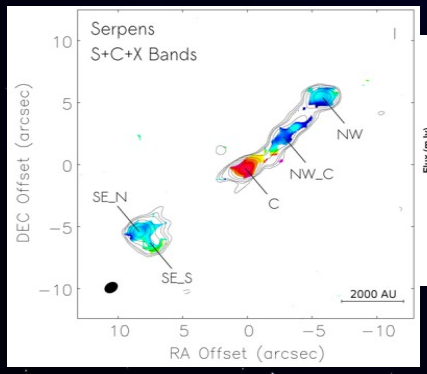
**Protostellar Jets**

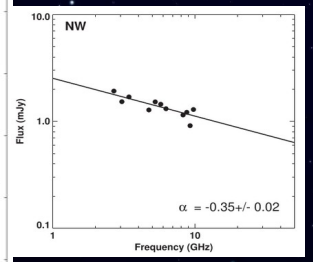
- Ionized Jets
- Molecular Jets
- HH Objects — X-Rays
  - At low extinctions: optical lines eg. Hα, [O II], [N II], [S II]
  - Moderate extinctions: near-IR lines eg. $H_2$ and [FeII]



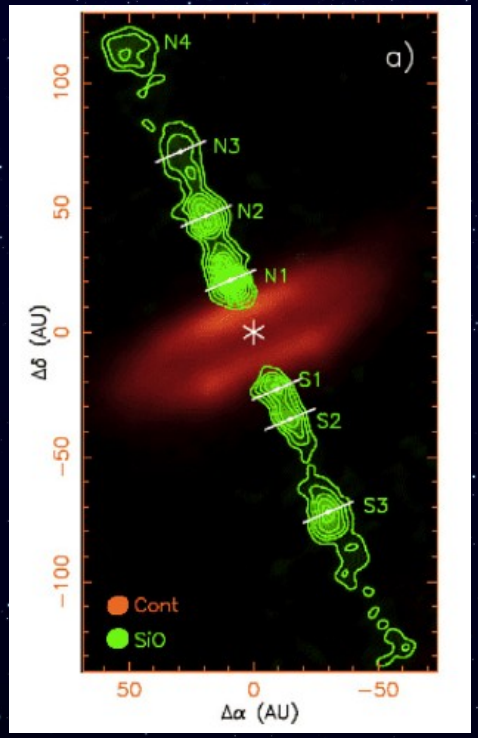




Curiel et al. (2006)

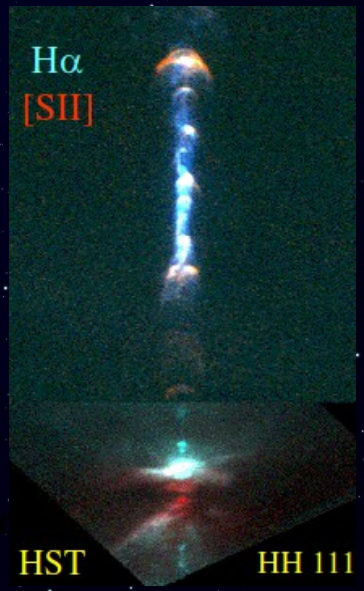


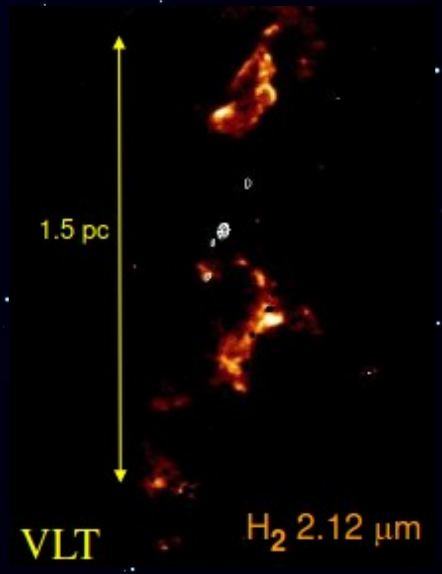




Serpens et al. (2016)




Ray et al.



# Protostellar jets: Interaction with ISM

**Protostellar Jets**

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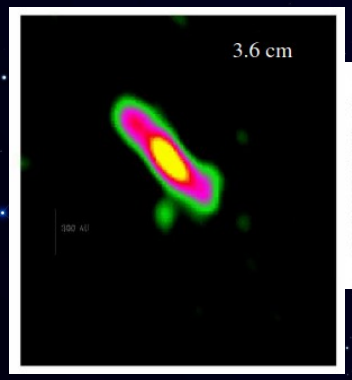
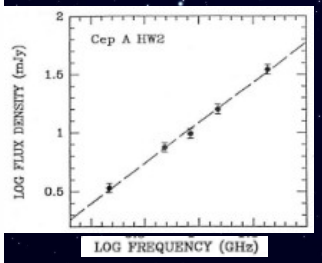
- HH Objects — X-Rays

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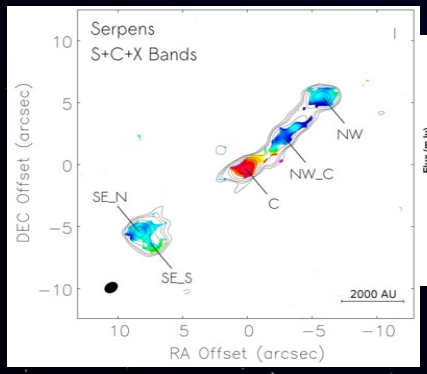


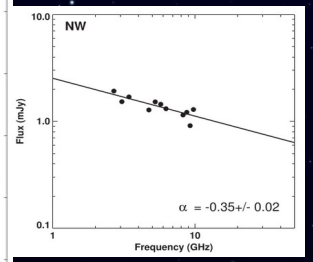


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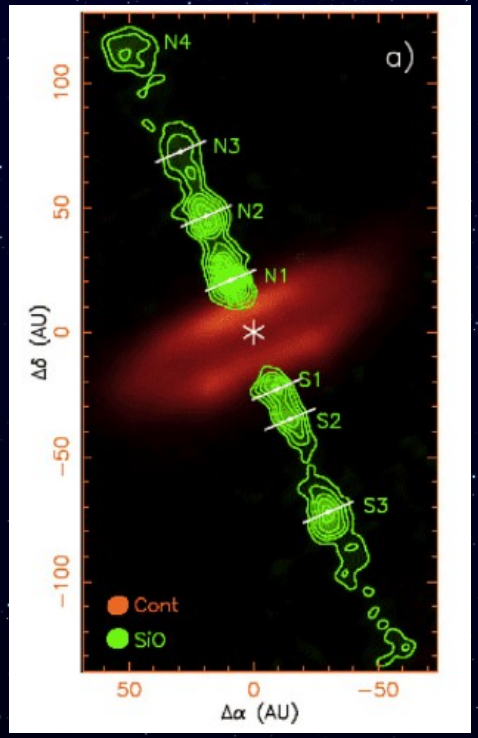


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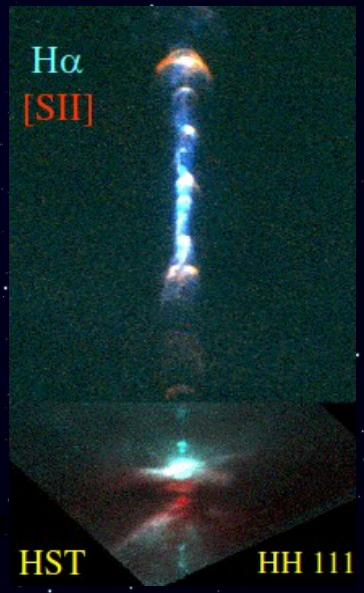


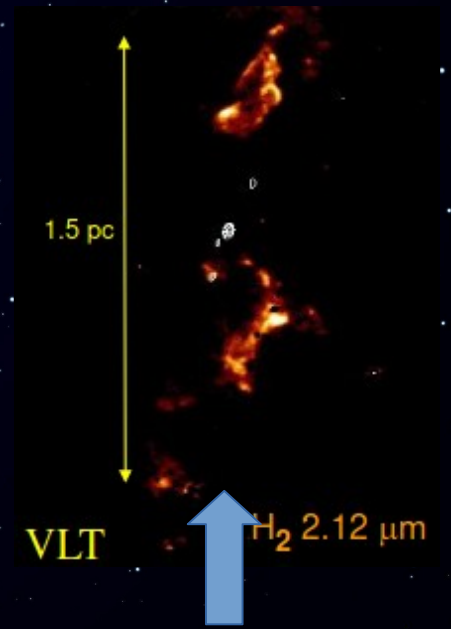

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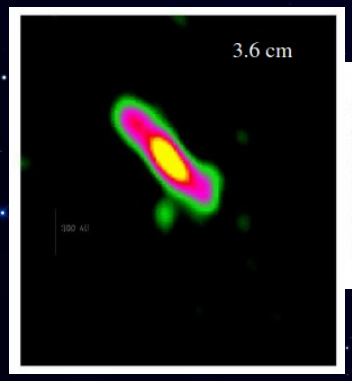


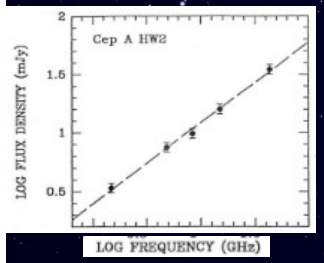


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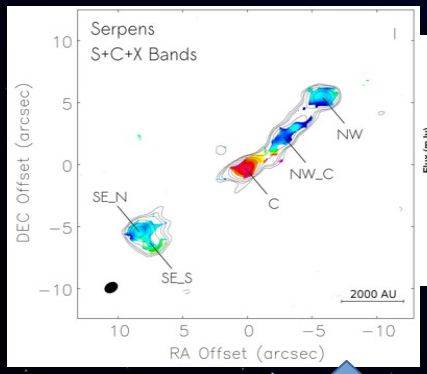


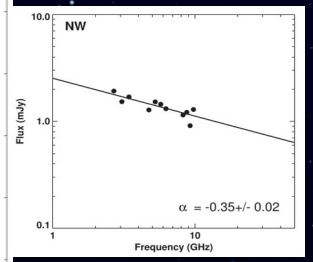


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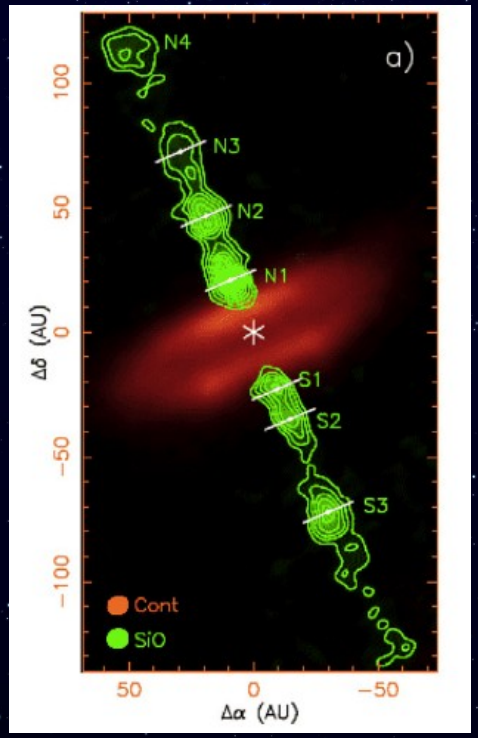


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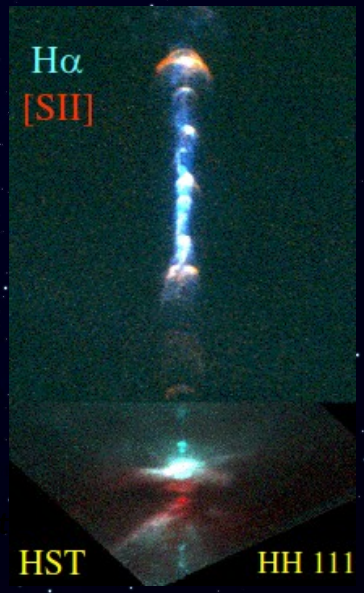
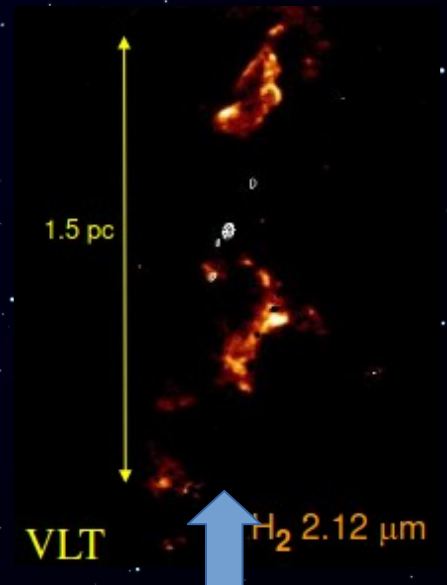
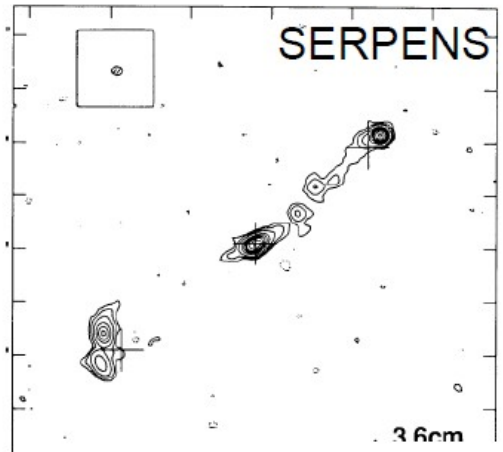
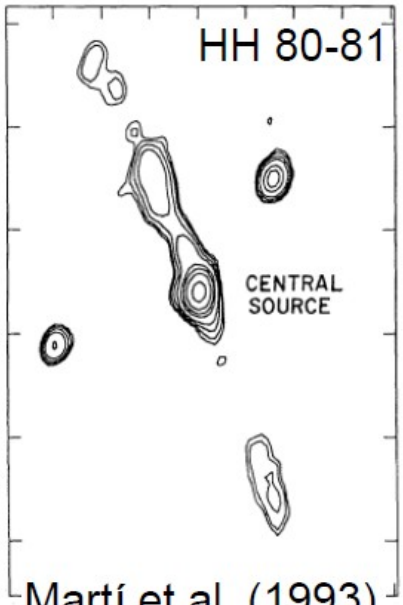


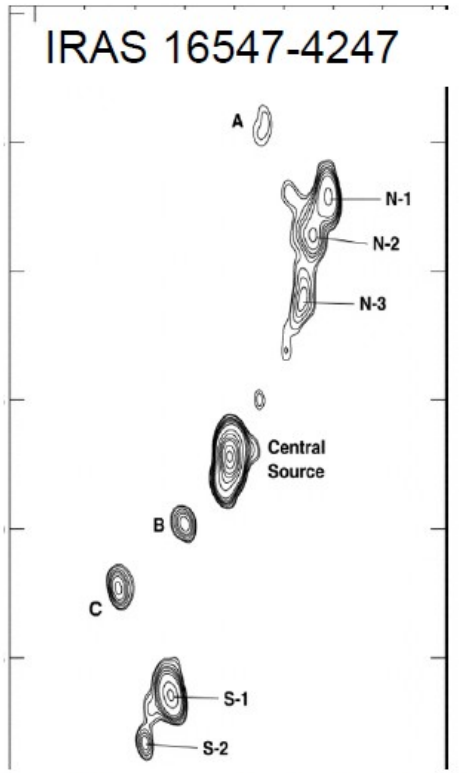
# Massive Protostellar Jets: Radio



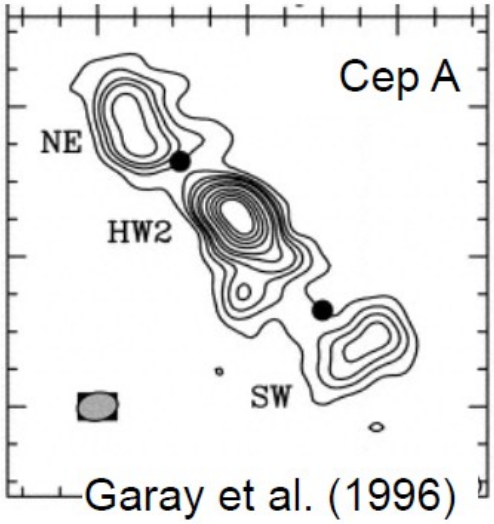

Rodríguez et al. (1989)



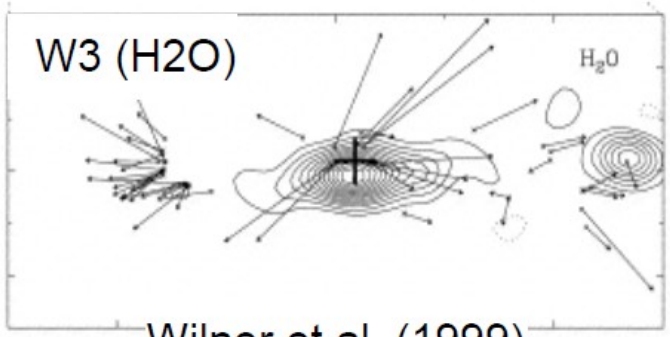

Martí et al. (1993)




Rodríguez et al. (2005)




Garay et al. (1996)

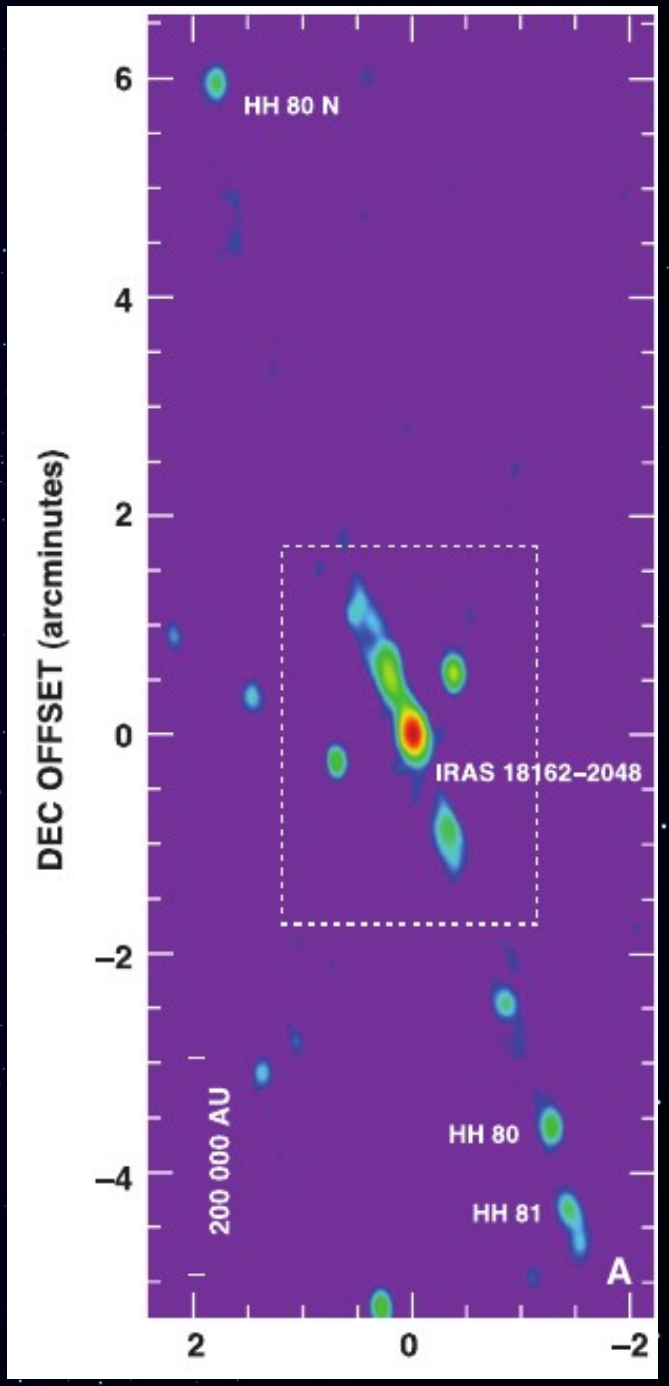



Wilner et al. (1999)

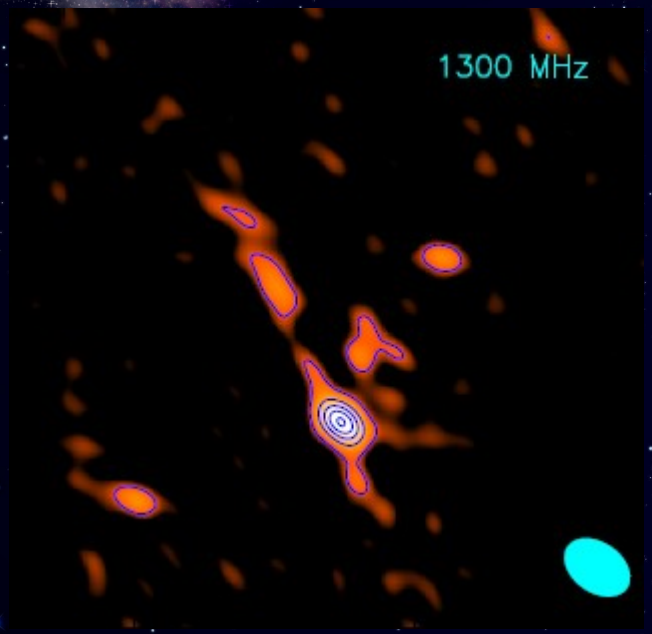

IRAS 18162-2048: HH80-81 Jet

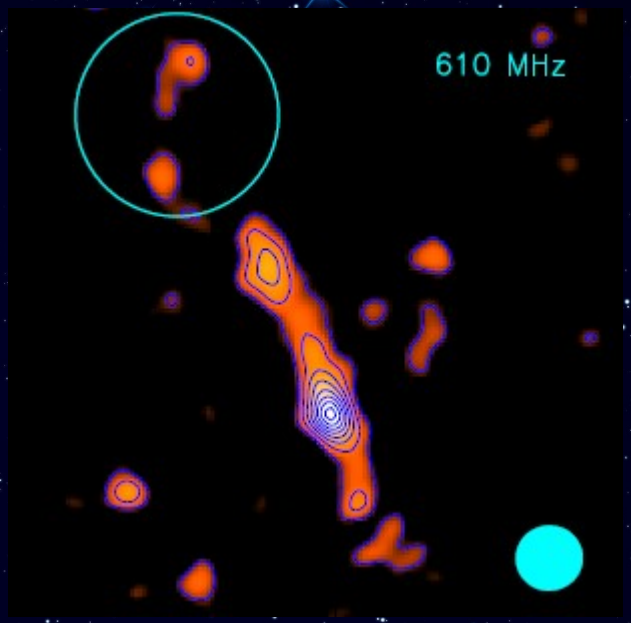
# Massive Protostellar Jet: HH80-81

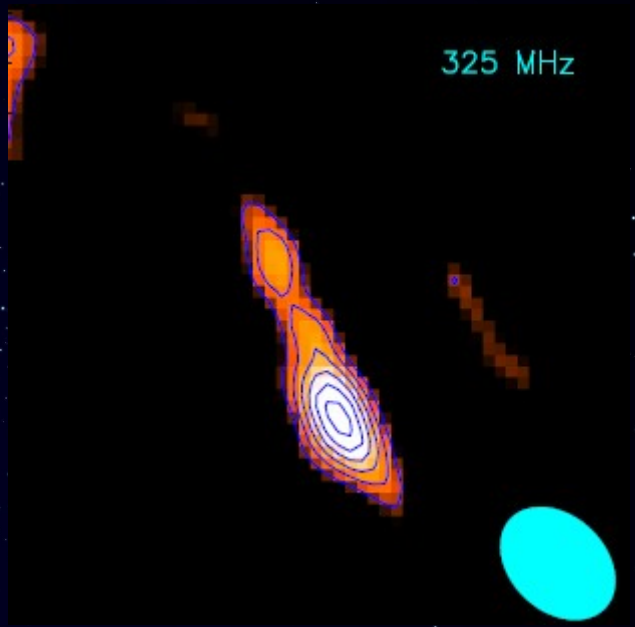
- Protostar IRAS 18162-2048, Also GGD27-28
- Distance ~ 1.4 kpc
- Jet detected in radio wavebands
- Radio spectral type B0 ZAMS
- **Most collimated protostellar Jet:** Upto ~ 18.1 pc
- **Fastest known jet:** Velocities ~ Upto 1000 km/s
- ALMA: 25 mm cores, MM1 & MM2 most massive
- HH80-81 excited by MM1
- Multiple outflows – CO, SiO
- Radio Spectral indices ~ -0.3 (Non-thermal)
- **Synchrotron emission:** Magnetic field mapped
- X-ray emission: Close to base of jet and HH objects



# HH80-81 Massive Protostellar Jet in Radio

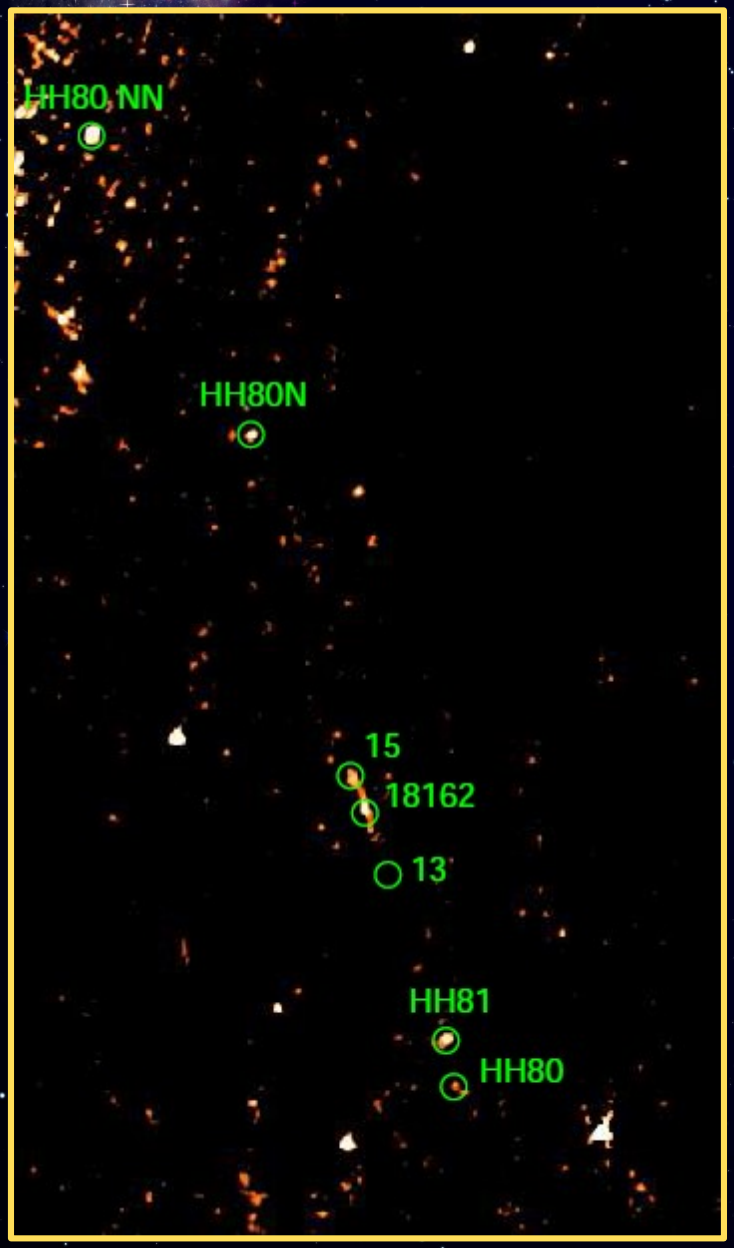


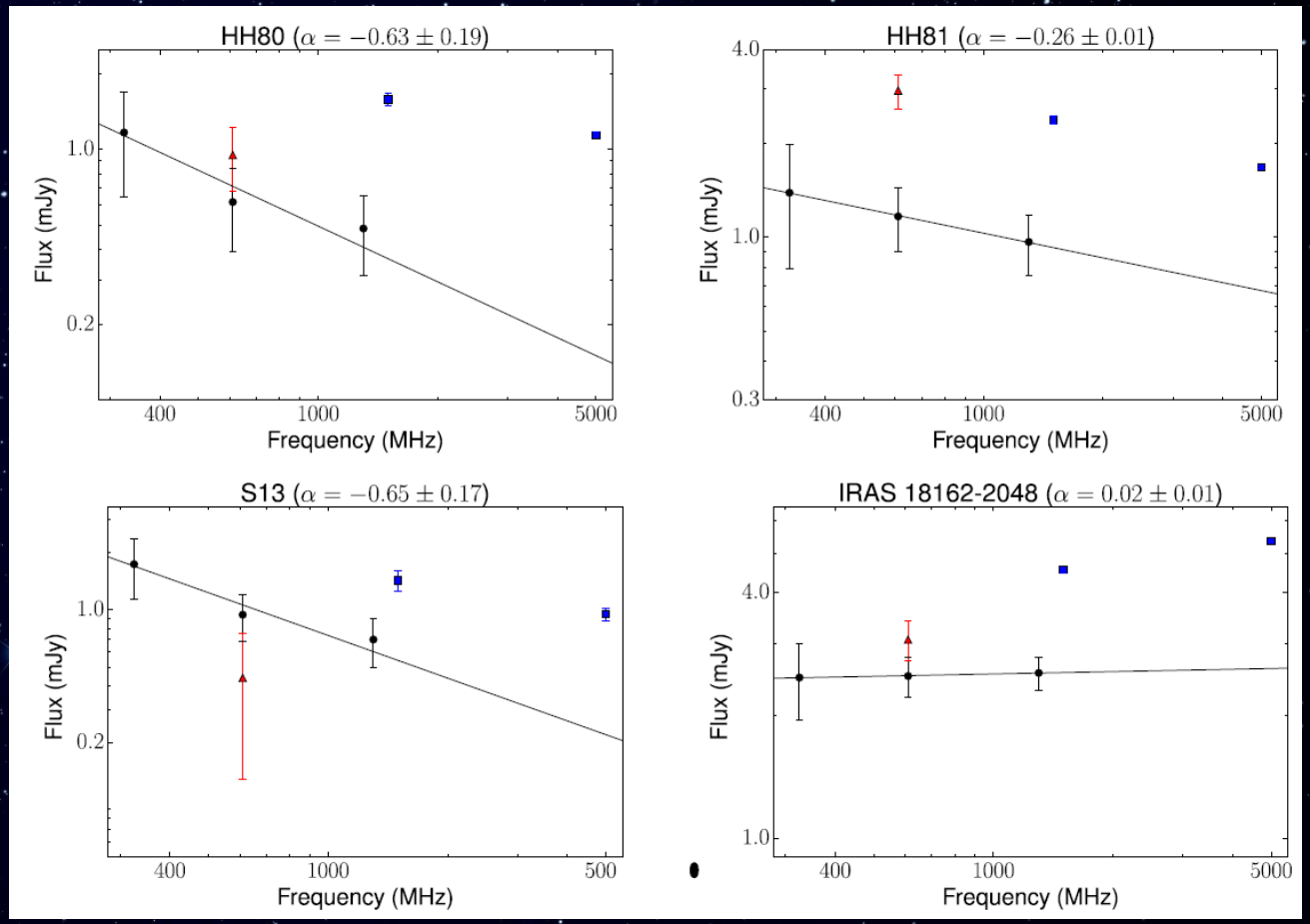




- Low radio frequencies – jet detected out to ~18 pc
- Confirmation of non-thermal emission using spectral indices - most knots

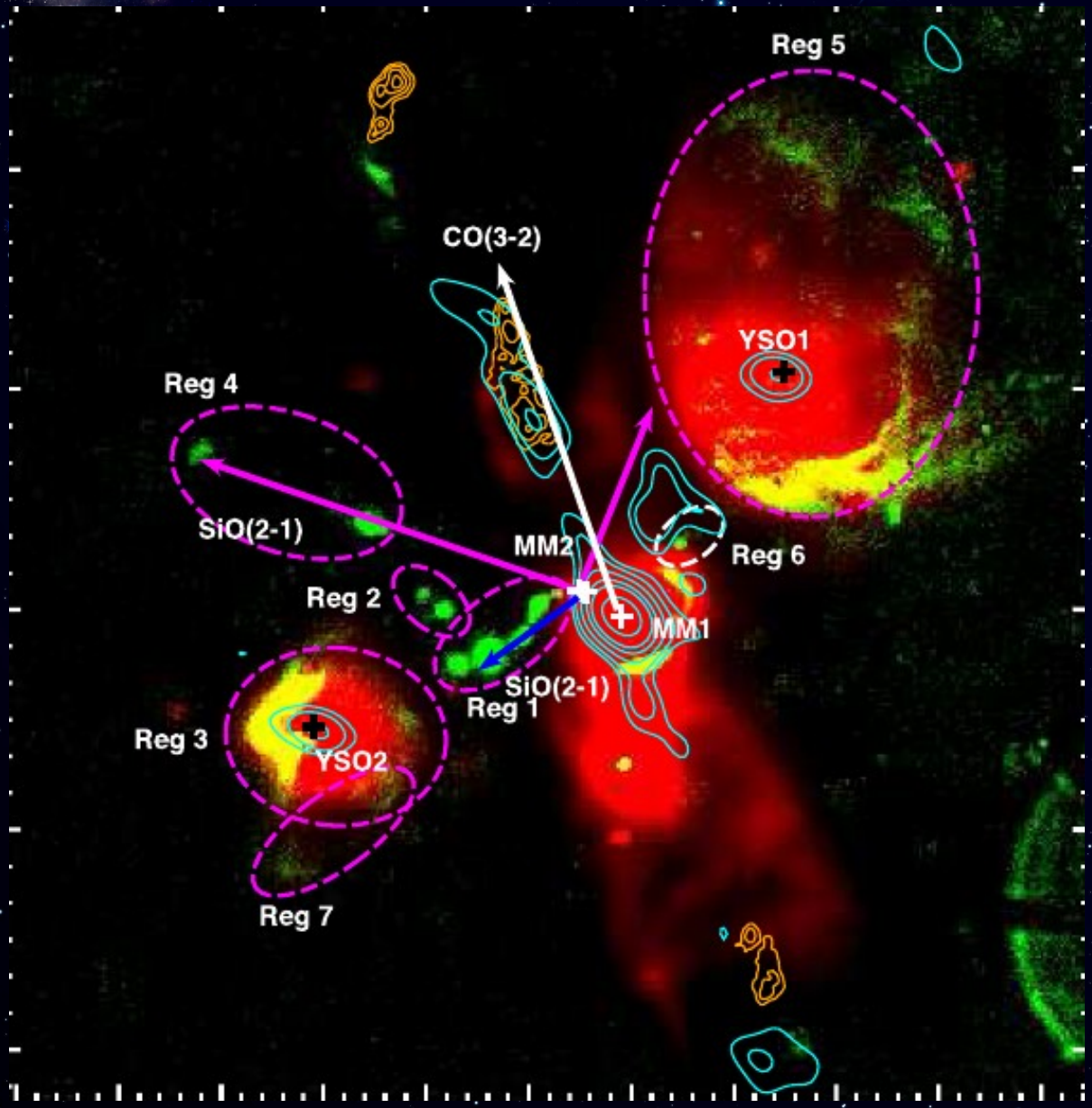
# HH80-81 Massive Protostellar Jet in Radio



# Massive Protostellar Jet: HH80-81

## Green - $H_2$ emission, Red – 8 μm Spitzer--IRAC



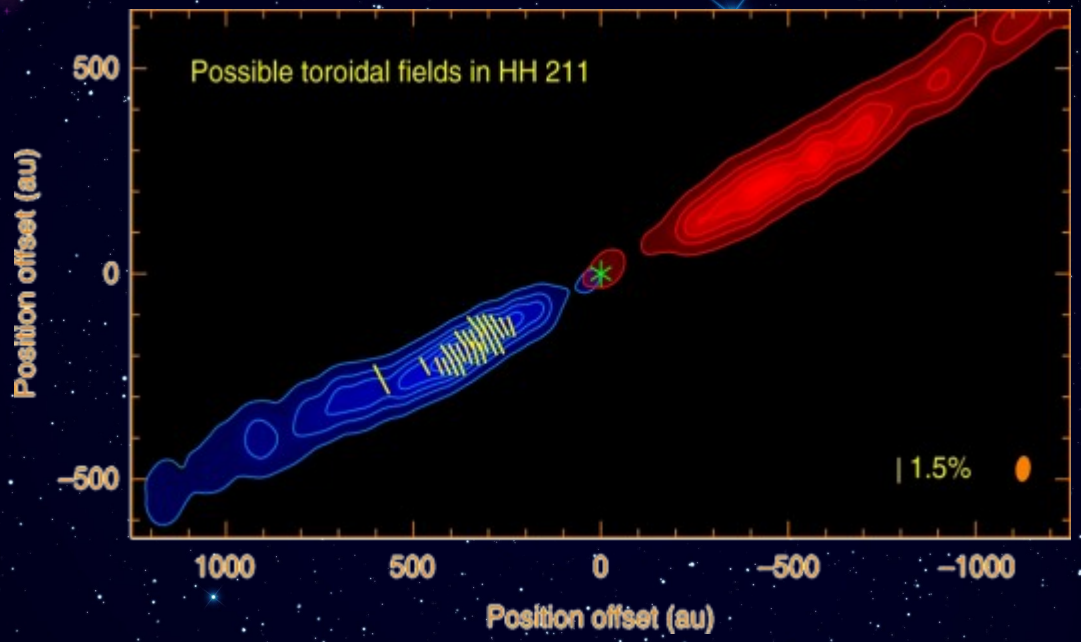

Arrows – Outflow directions

Cyan contours – Radio continuum emission

Orange contours – [FeII]

Ellipses – Regions with $H_2$ emission

# Magnetic field near protostars

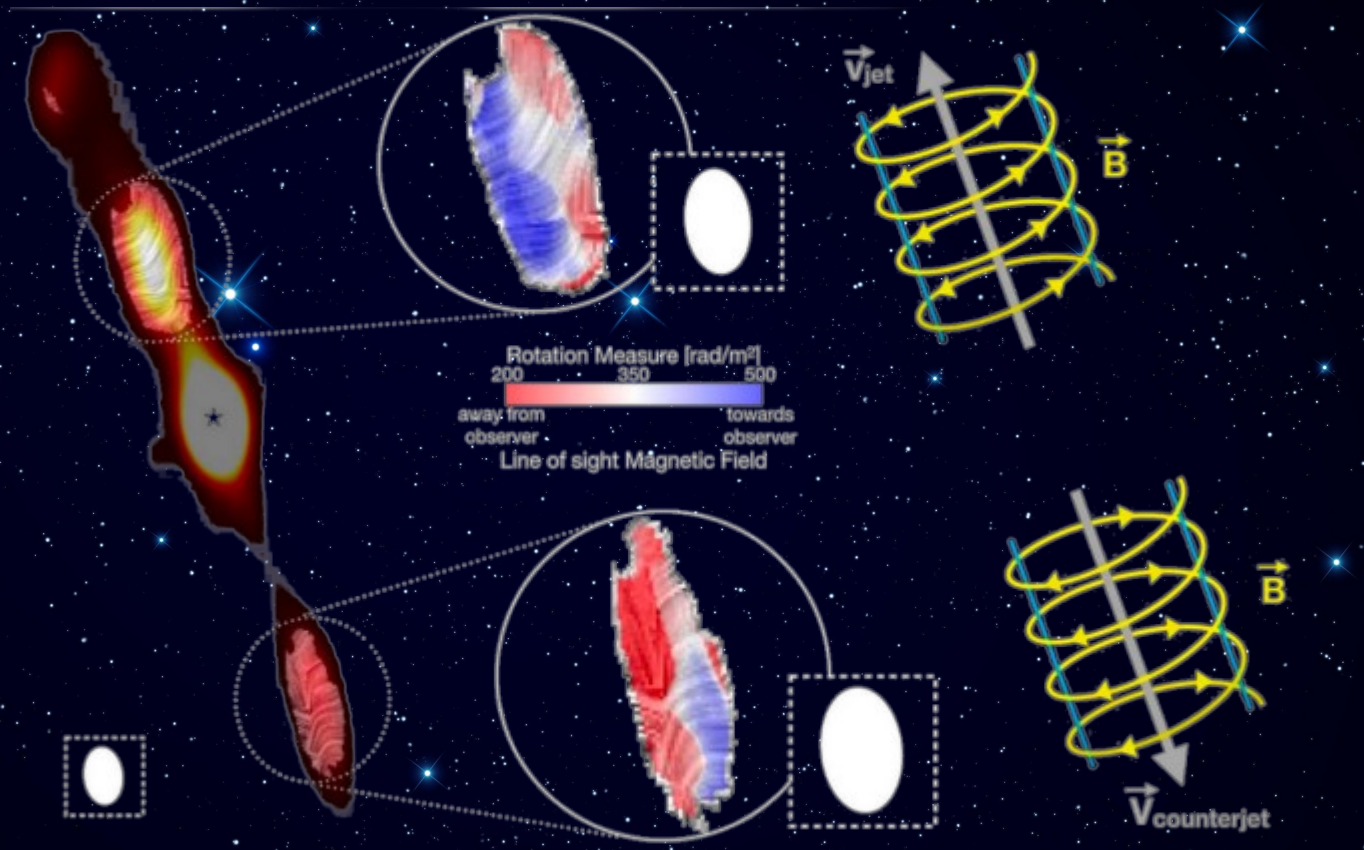



Possible toroidal fields in the HH 211 jet. Yellow line segments indicate the possible toroidal fields (Lee + 2018)

Low-mass protostars: surface magnetic fields several kiloGauss (Guenther 1999)

- Massive protostars: magnetic field estimates in the dense cores and/or disk-jet
  - Dust polarization measurements ~ 1 mG
  - Polarization measurements employing masers ~ 0.6 G
  - Linear polarization of HH 80 81 jet ~ 0.2 mG

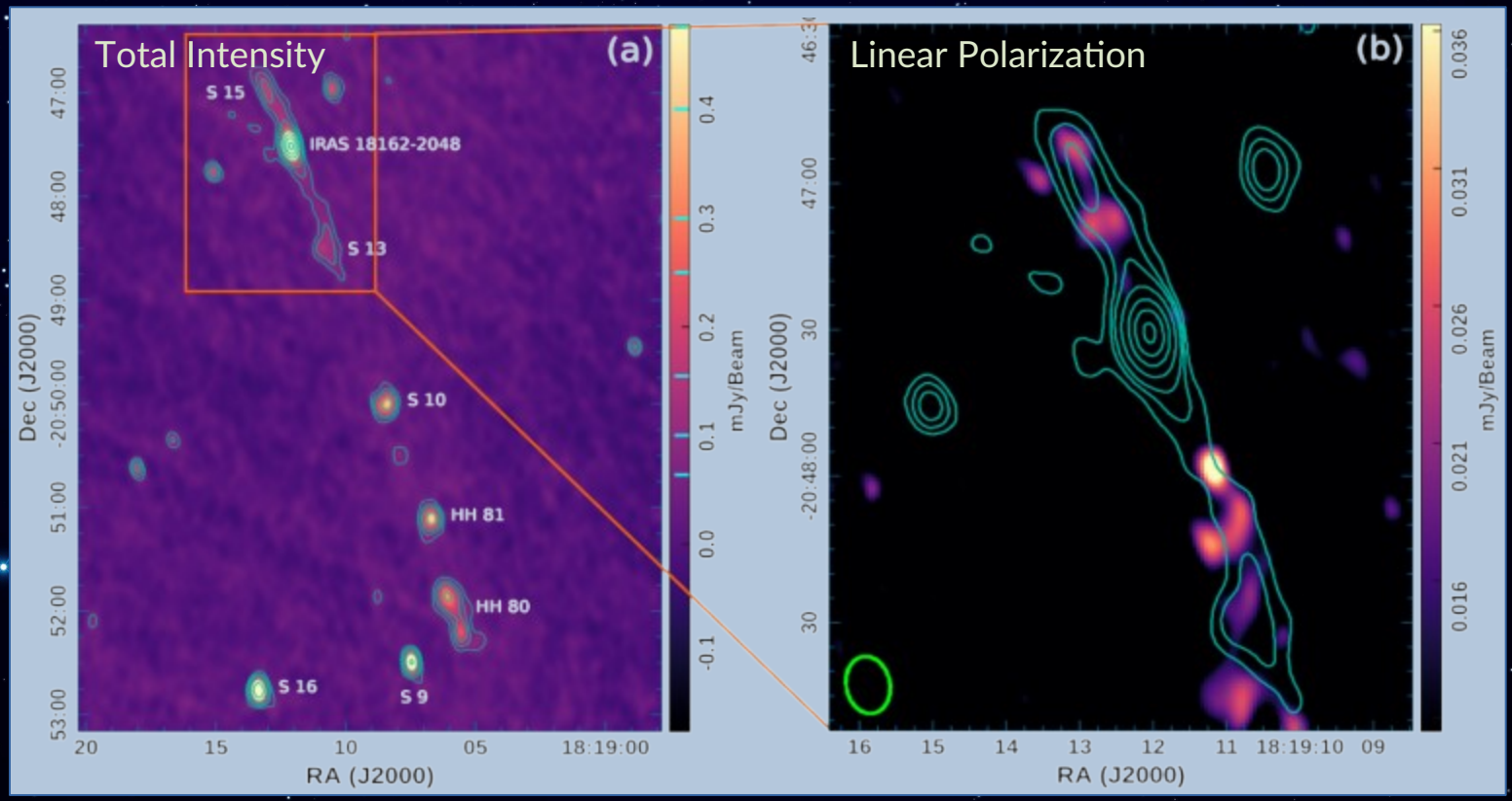
# Magnetic field of massive protostar



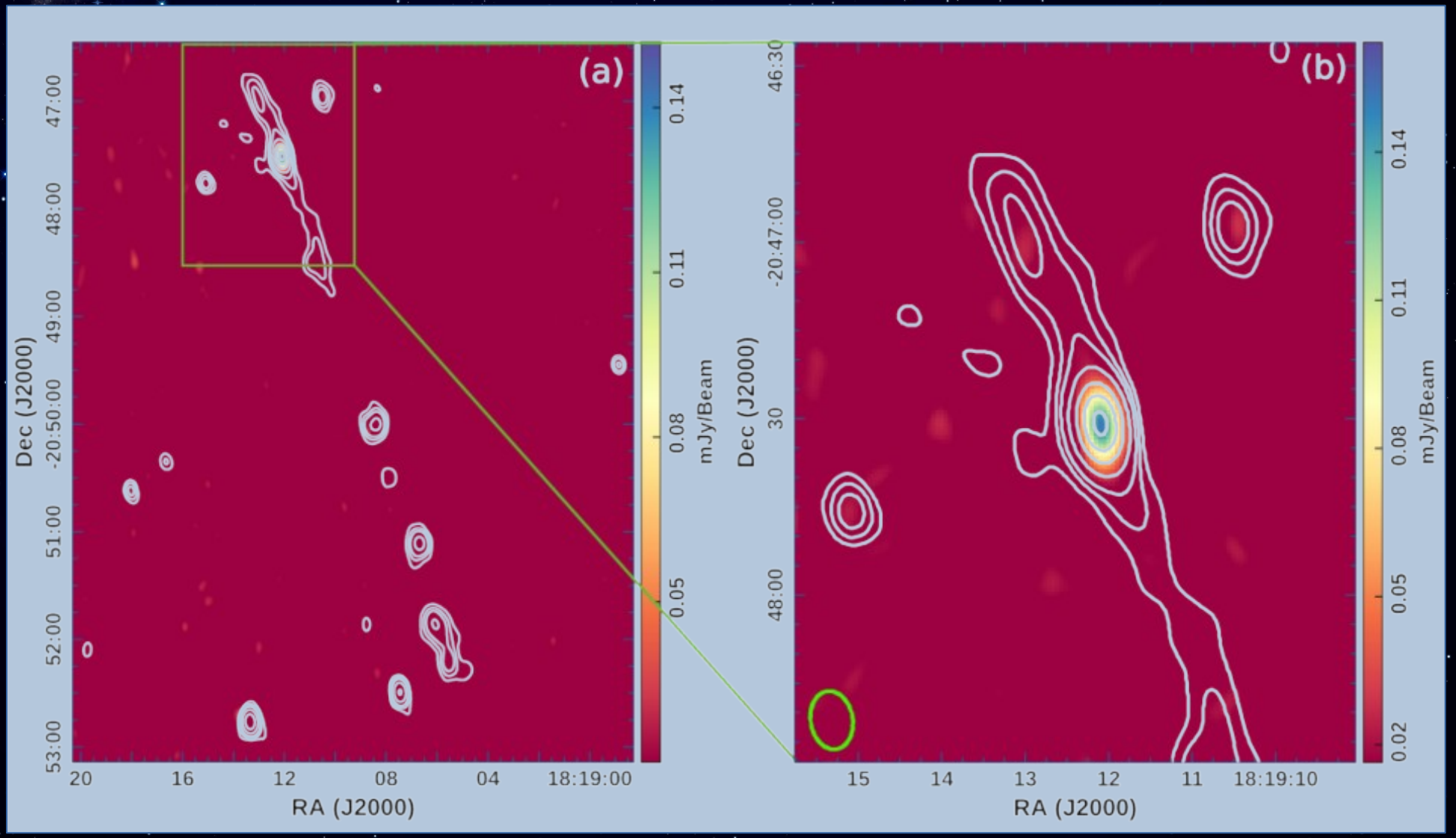

Results of the Rotation Measure analysis in the HH80-81 jet. The left image shows the streamline image of the component of the magnetic field parallel to the plane of the sky. In the middle panel, the colour scale of the RM indicates the direction of the magnetic field along the line of sight. The right panel shows a scheme depicting the 3D configuration of the magnetic field, exhibiting a helical topology (Rodríguez-Kamenetzky + 2025).

# Polarization observations of IRAS 18162-2048

- Karl G Jansky, Very Large Array (USA) 27 antennas,
- C band (4-8 GHz), B configuration
- 32 Spectral windows, 64 Channels, 2 MHz channel width, 128 MHz bandwidth
- 21, 22 Dec 2018, Time ~ 10 hrs
- rms noise : 6 µJy/beam



# Circular Polarization of IRAS 18162-2048



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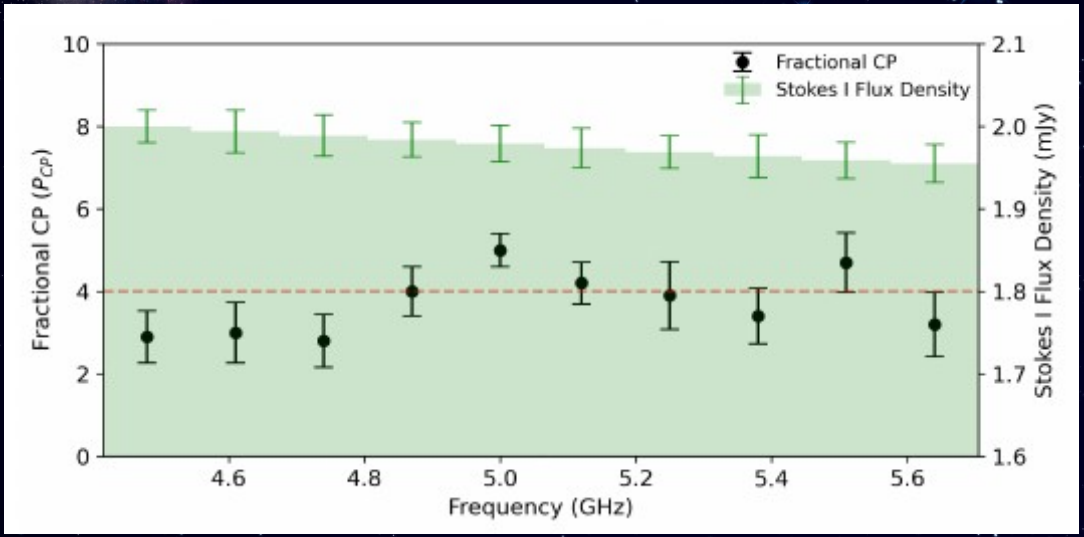



- Relatively flat spectral index α ~ −0.10 ± 0.02
- CP fraction, varies between 3 – 5 %
- No discernible trend with frequency

Main mechanisms explored:

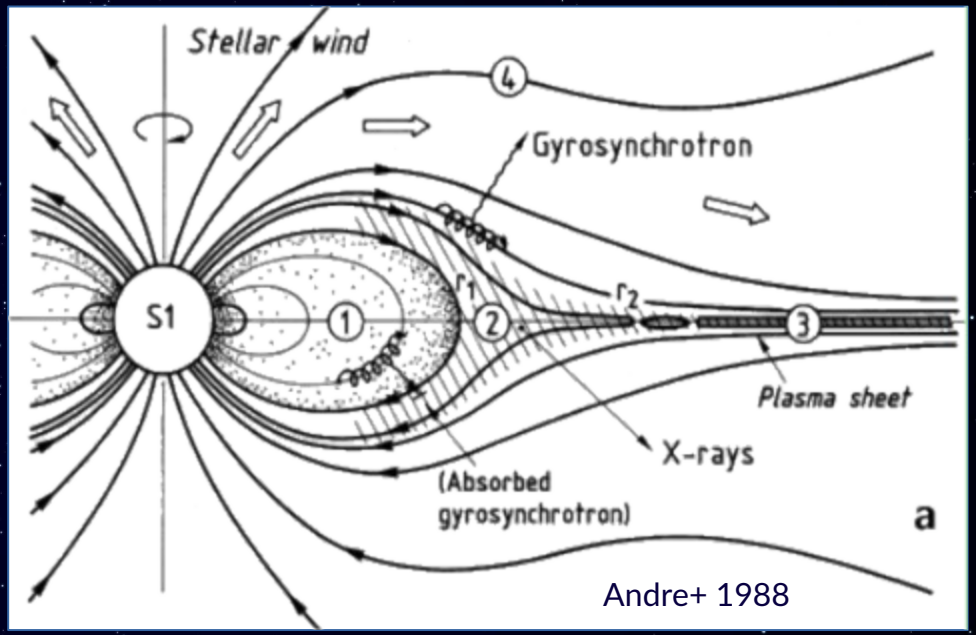
1. Gyrosynchrotron emission: Arises from mildly relativistic electrons (Legg & Westfold 1968), line of sight is close to the direction of the magnetic field

2. Faraday Conversion: Presence of varying magnetic field due to turbulence along line-of-sight (Jones et al., 1977, Beckert et al., 2002)

# Magnetic field of massive protostar

## Gyrosynchrotron mechanism

- Arises from mildly relativistic electrons (Legg & Westfold 1968)
- Emission from individual electrons is circularly polarized
- The line of sight is close to the direction of the magnetic field
- Electrons streaming perpendicular to the magnetic field lines
- Maximum fractional CP



Andre+ 1988

$$P_{\mathrm{CP,max}} = \frac{\cot\theta}{3}\left[\frac{\nu}{3\nu_B \sin\theta}\right]^{-1/2} f(\alpha).$$

(Melrose, 1971)

θ: inclination angle of the jet with respect to the observer

f(α): weakly dependant function of spectral index α

values 0.6 - 2 for α = 0 - 2

$\nu_B$ = eB/mc: electron gyrofrequency

Magnetic field strength, B ~ 20 – 35 G

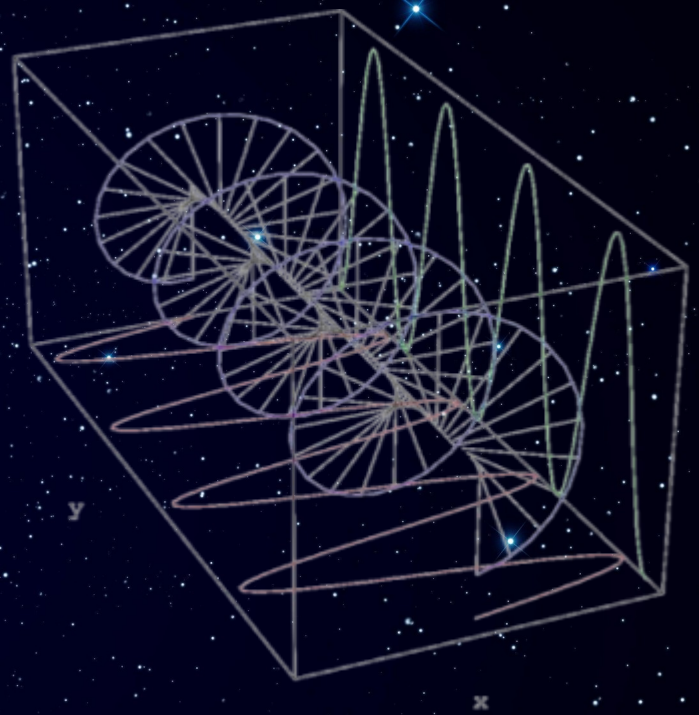
Lorentz factor $\gamma = 0.1915\ (\cot\theta) \times P_{CP}$ , $\gamma \sim 5 - 7$

**First estimation of magnetic field towards a massive protostar!**

# Magnetic field of massive protostar

## Faraday Conversion

- LP at source gets converted to CP
- Presence of varying magnetic field due to turbulence (Jones+ 1977, Beckert+ 2002)
- Leads to flat or mildly positive spectral indices
- Has been used to explain CP and lack of LP near Sgr A* at GC (Bower+ 1999)



$$P_{\rm CP} \approx 0.5 \quad \frac{s+1}{s+7/3}\left(\frac{1}{K_{\rm out}R}\right)\frac{\tau_C}{\tau_F} \quad \frac{B_z}{B_0} \quad \cos\theta.$$

$s = 2\alpha + 1$

$K_{out}$ - inverse length of a single turbulent cell

Bz cos θ is the source magnetic field along line of sight

B0 is the sum of ordered field from source and turbulent field

τc and τv represent the Faraday conversion depth, and Faraday rotation depth

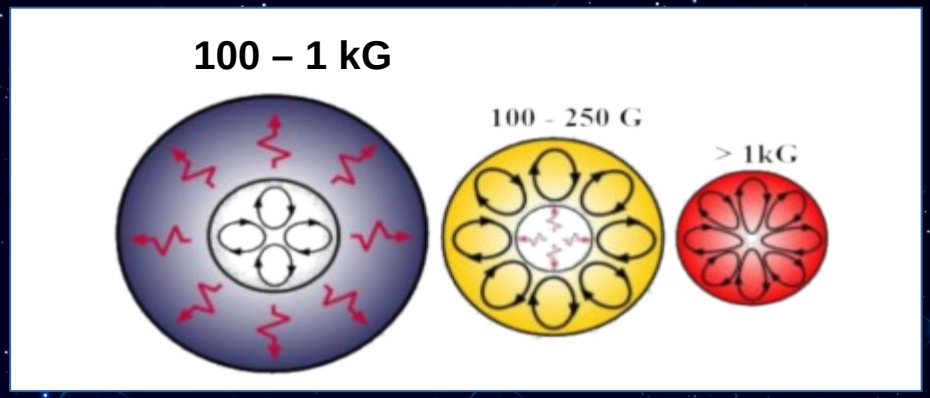
No. of tubulent cells ($K_{out}$ R) ~ 6 – 8

Min Lorentz factor $\gamma_{min}$ ~ 80 – 100

Observed CP: 1 ≤ Bo /Bz ≤ 1.25

Bo ~ 50 – 65 G

# Fossil Magnetic fields for massive MS stars

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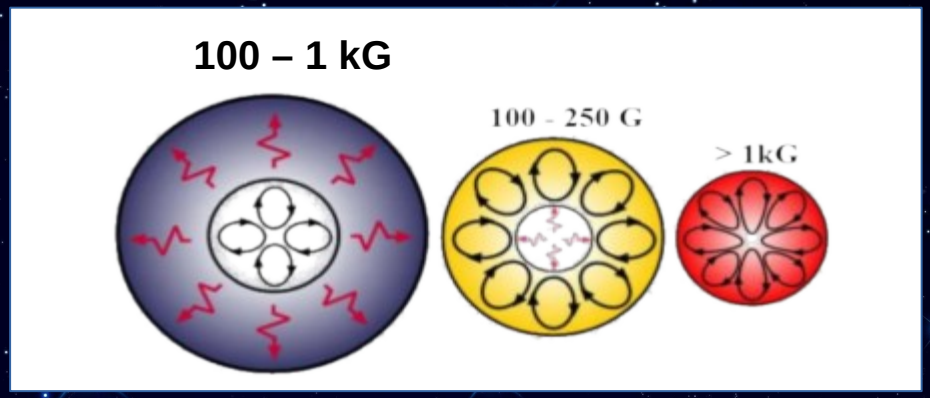
# Fossil Magnetic fields for massive MS stars



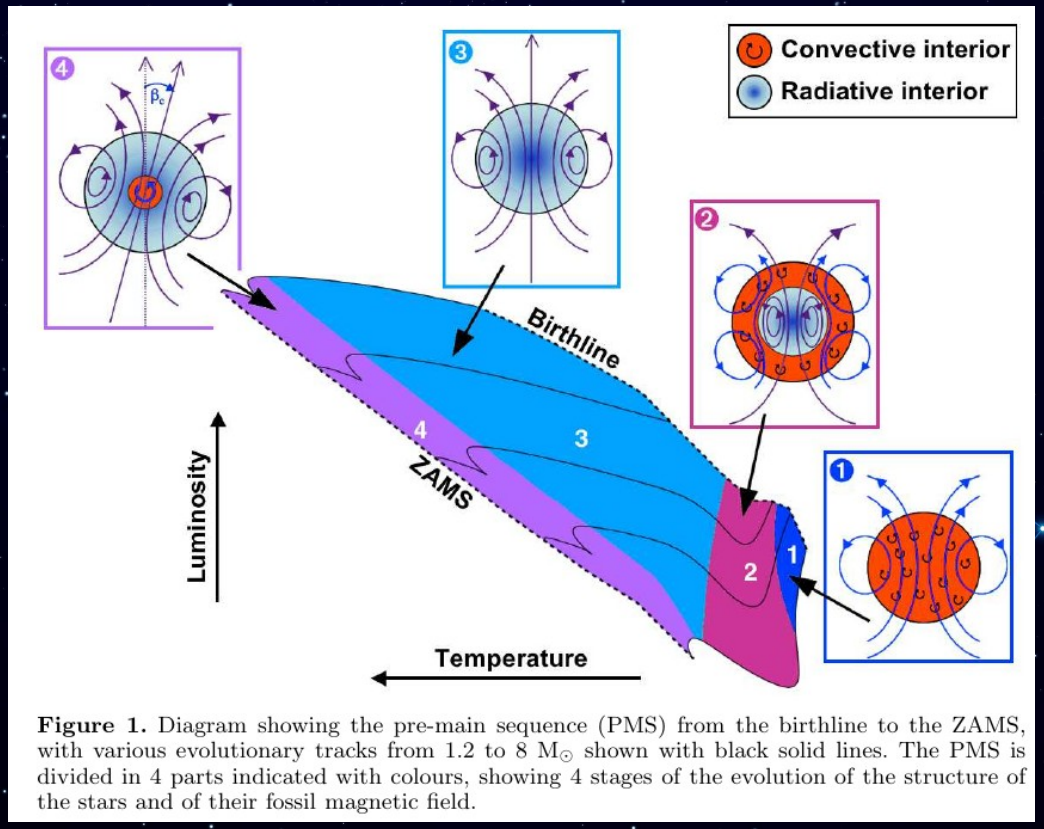




**Figure 1.** Diagram showing the pre-main sequence (PMS) from the birthline to the ZAMS, with various evolutionary tracks from 1.2 to 8 $M_{\odot}$ shown with black solid lines. The PMS is divided in 4 parts indicated with colours, showing 4 stages of the evolution of the structure of the stars and of their fossil magnetic field.

(Neiner+ 2015)

# Summary


- Protostellar jets – Beacons of embedded protostellar phase
- IRAS 18162-2048 drives HH80-81 - Largest most collimated jet from massive protostar
- Non-thermal synchrotron emission from jet knots
- Circular polarisation from massive YSO for the first time ~ 50G
- Possible mechanisms: Gyrosynchrotron emission, Faraday rotation
- Likely precursor to magnetic OB star

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## First Detection of Circular Polarization in Radio Continuum Toward a Massive Protostar

A. G. Cheriyan[1], S. Vig[1], Nirupam Roy[2], Samir Mandal[1], C. Carrasco-González[3], A. Rodríguez-Kamenetzky[4], and A. Pasetto[3]

[1] Department of Earth and Space Sciences, Indian Institute of Space Science and Technology, Thiruvananthapuram 695547, India; amalgeorgecheriyan@gmail.com, sarita@iist.ac.in
[2] Department of Physics, Indian Institute of Science, Bangalore 560012, India
[3] Instituto de Radiastronomía y Astrofísica (IRyA), Universidad Nacional Autónoma de México (UNAM), Morelia, Michoacán, México
[4] Instituto de Astronomía Teórica y Experimental (IATE), Universidad Nacional de Córdoba (UNC), Córdoba, Argentina
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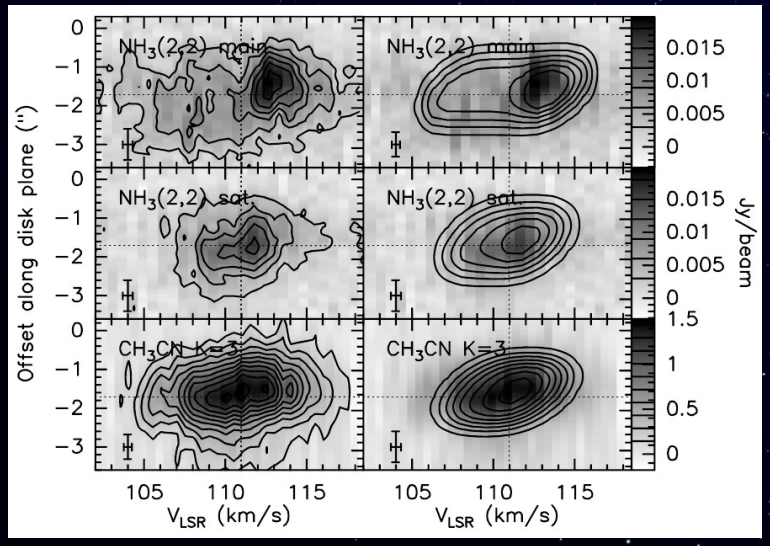
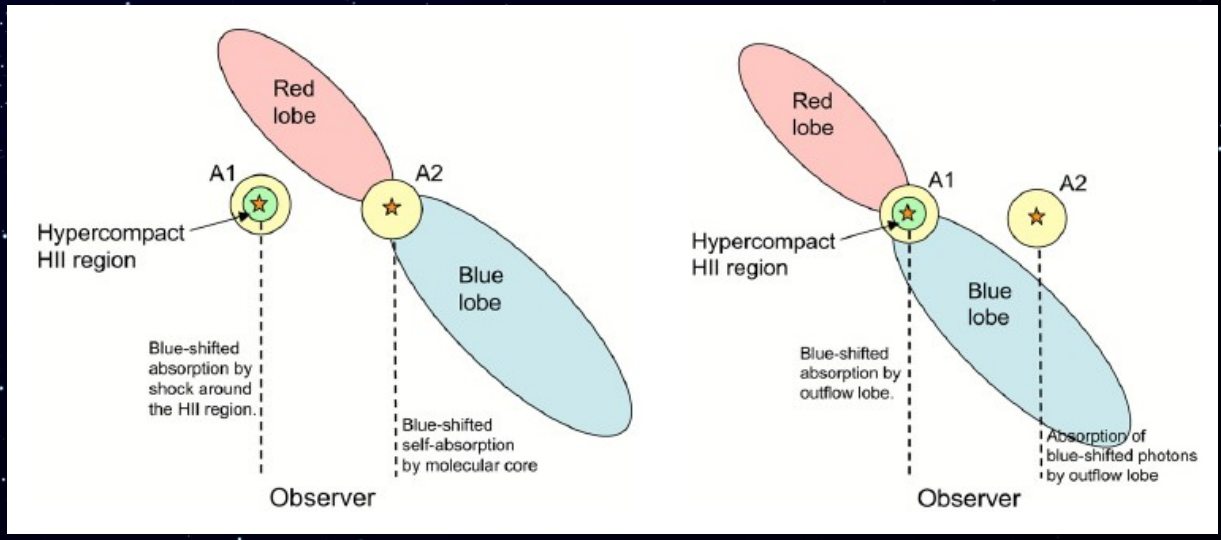
# My association with Riccardo Cesaroni

*Joined Arcetri in 2005*

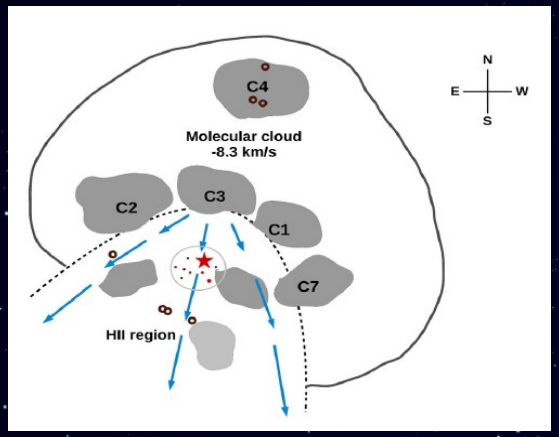
*Postdoc with Riccardo 2006 – 2008*

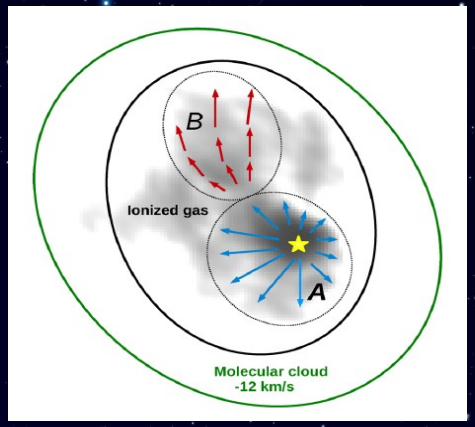
*Worked on G24.78+0.08 A2, later Mol75*

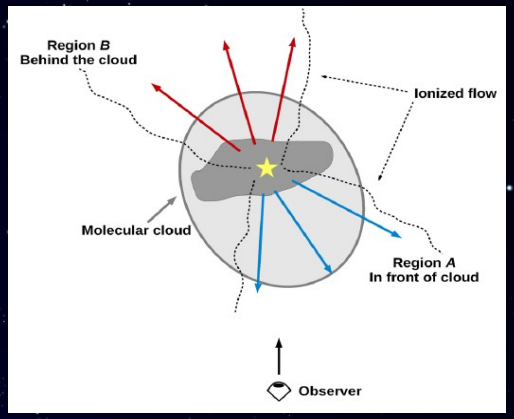


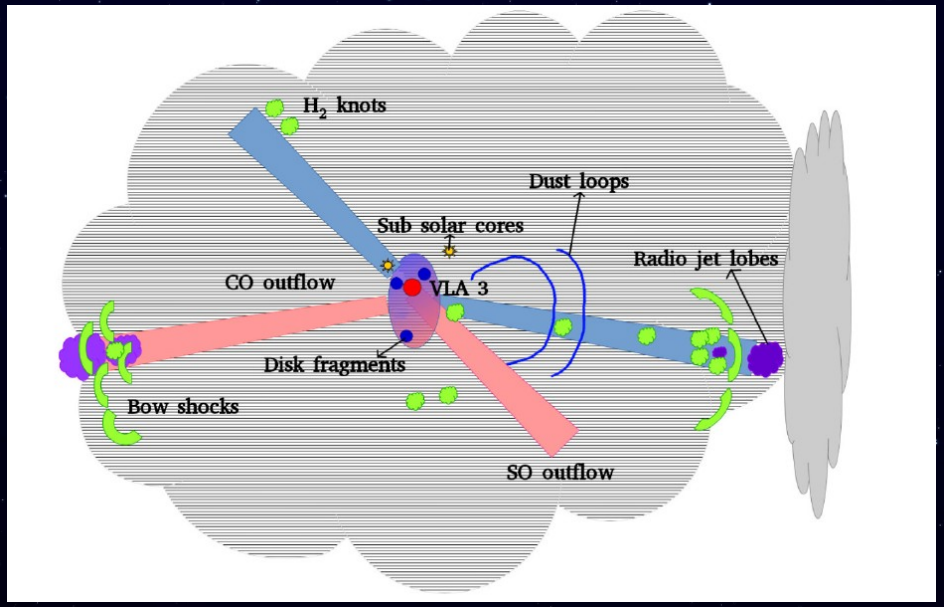
# My association with Riccardo Cesaroni




*Schematic models towards regions in G351.7-1.3 (Veena, Vig + 2017)*




*Schematic of RAFGL2591 (Cherian, Vig + 2023)*

# My association with Riccardo Cesaroni

*At Marcello's Villa in 2006 probably*

# My association with Riccardo Cesaroni

*At Pico Veleta in 2007.*

*Riccardo has been a friend, philosopher and guide.*

# My association with Riccardo Cesaroni

At Conference in honor of Malcolm, 2018

# My association with Riccardo Cesaroni

At Conference in honor of Malcolm, 2018

# आभार

ज़िस जिससे पथ पर स्नेह मिला

उस उस राही को धन्यवाद।

साँसों पर अवलम्बित काया

जब चलते-चलते चूर हुई

प्रोत्साहन के दो शब्द मिल गए,

मिली नव स्फूर्ति थकावट दूर हुई

इस पथ पर वे ही चलते हैं

जो चलने का पा गए स्वाद

जिस जिससे पथ पर स्नेह मिला

उस उस राही को धन्यवाद।

# *Thankfulness / Appreciation*

*I am grateful to the fellow travelers,*

*Who have walked some distance along the same path.*

*When this self, sustained only by breath,*

*grew weary and worn from the constant journey,*

*a few words of encouragement came my way —*

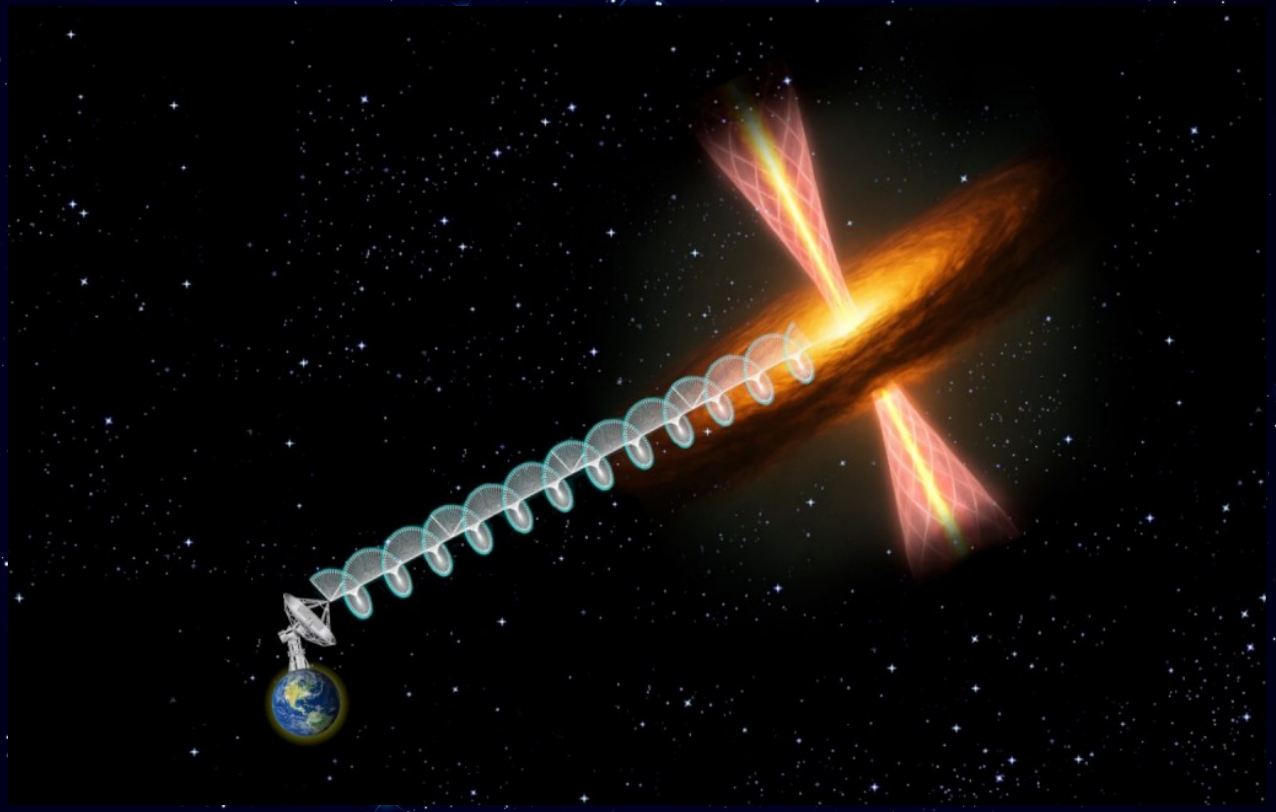
*Bringing renewed energy, and my weariness vanished.*

*Only those who have discovered the joy of walking*

*walk this path*

*I am grateful to those fellow travelers,*

*Who have walked some distance along the same path.*



*Thank-you for your attention!*