New VLA Observations of Massive Protostars: A Search for Jets

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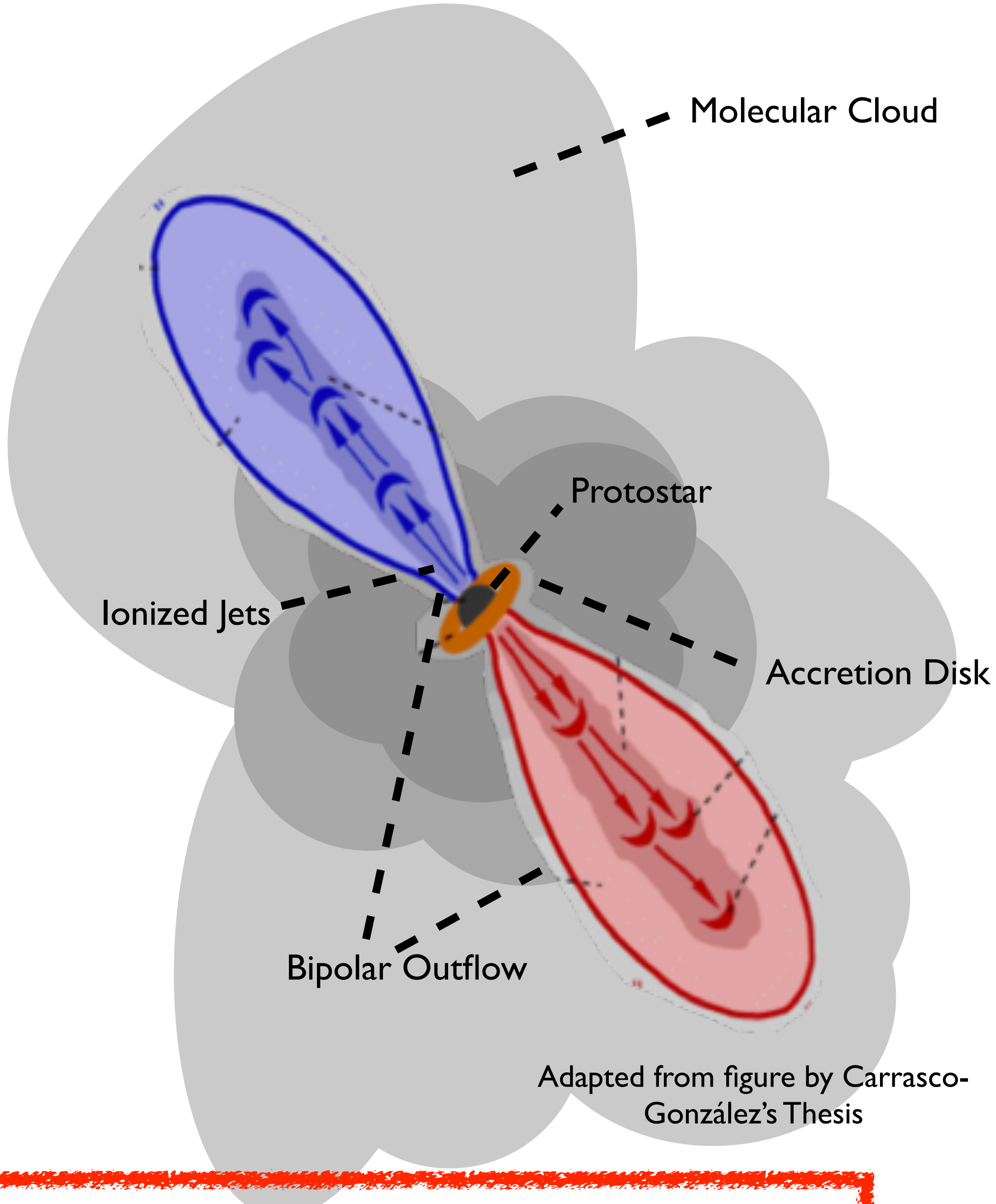
Introduction

- *Ionized* jets are predicted to occur at the base of the molecular outflow
- Small number of *ionized* jets from young massive objects (YMOs) detected to date
- Detections of *ionized* jets and disks help to complete the picture of massive star formation



Adapted from figure by Carrasco-González's Thesis

See poster by **Adele Plunkett**: Outflows and clustered star formation on scales of cores clouds

Thermal Jets

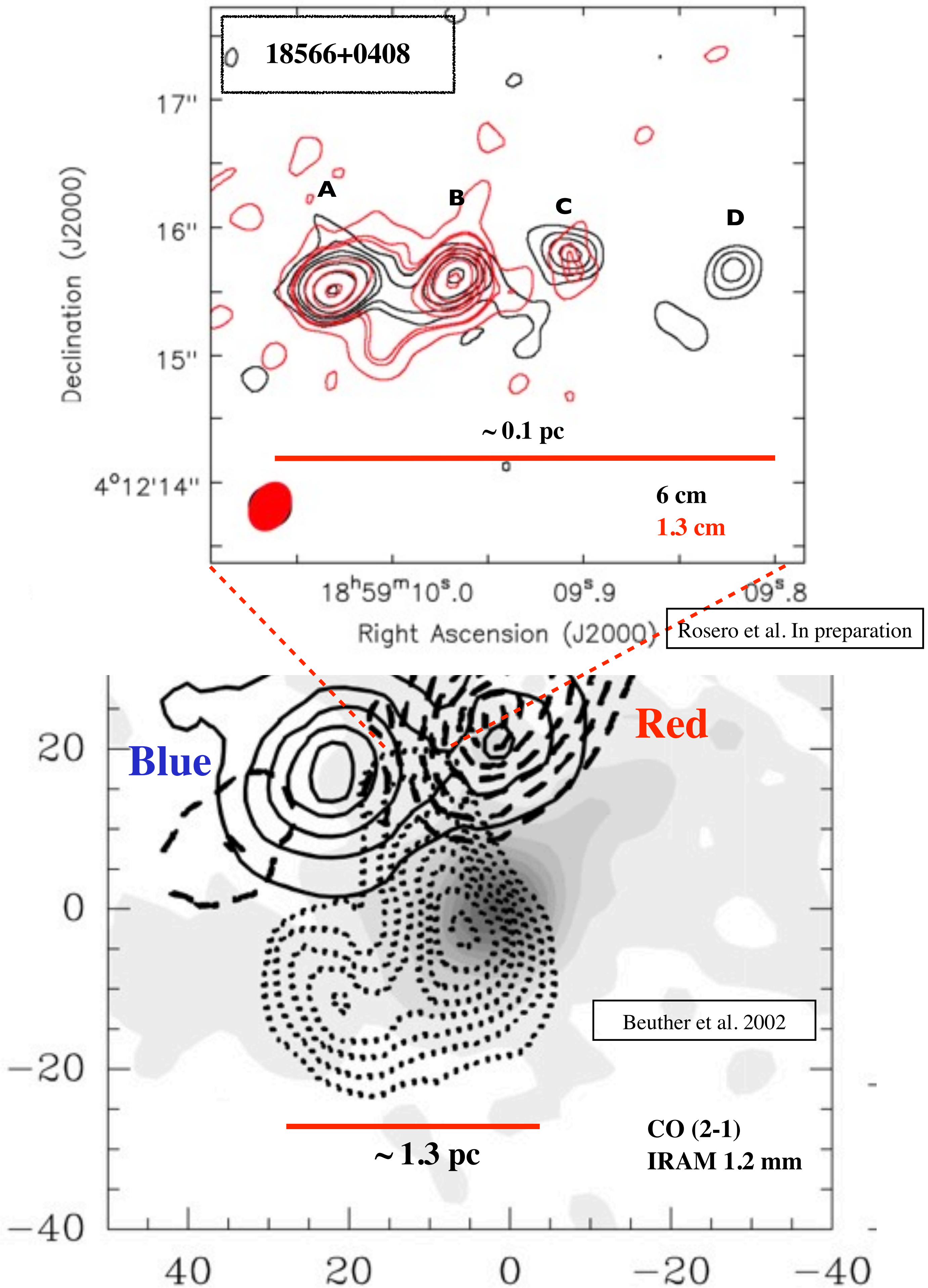
Weak radio continuum sources (~ μJy- mJy)

String-like morphology aligned with large scale outflow

Radio detection associated with FIR, mm and sub-mm counterparts

Positive (or flat) spectral index (-0.1 < α < 2)

Observed flux and size dependence with frequency (Reynolds 1986)



Motivation

- Previous work suggest evolutionary sequence of IR sources and their association (or not) with radio continuum (e.g., Molinari et al. 1996, 1998, 2000; Rathborne et al. 2006; Chambers et al. 2009)
- Jets occurrence rate towards YMOs of $L > 2 \times 10^4 L_\odot$ is ~38% (Guzmán et al. 2012)
- We want to measure the jet occurrence rate as a function of evolutionary type

This Project

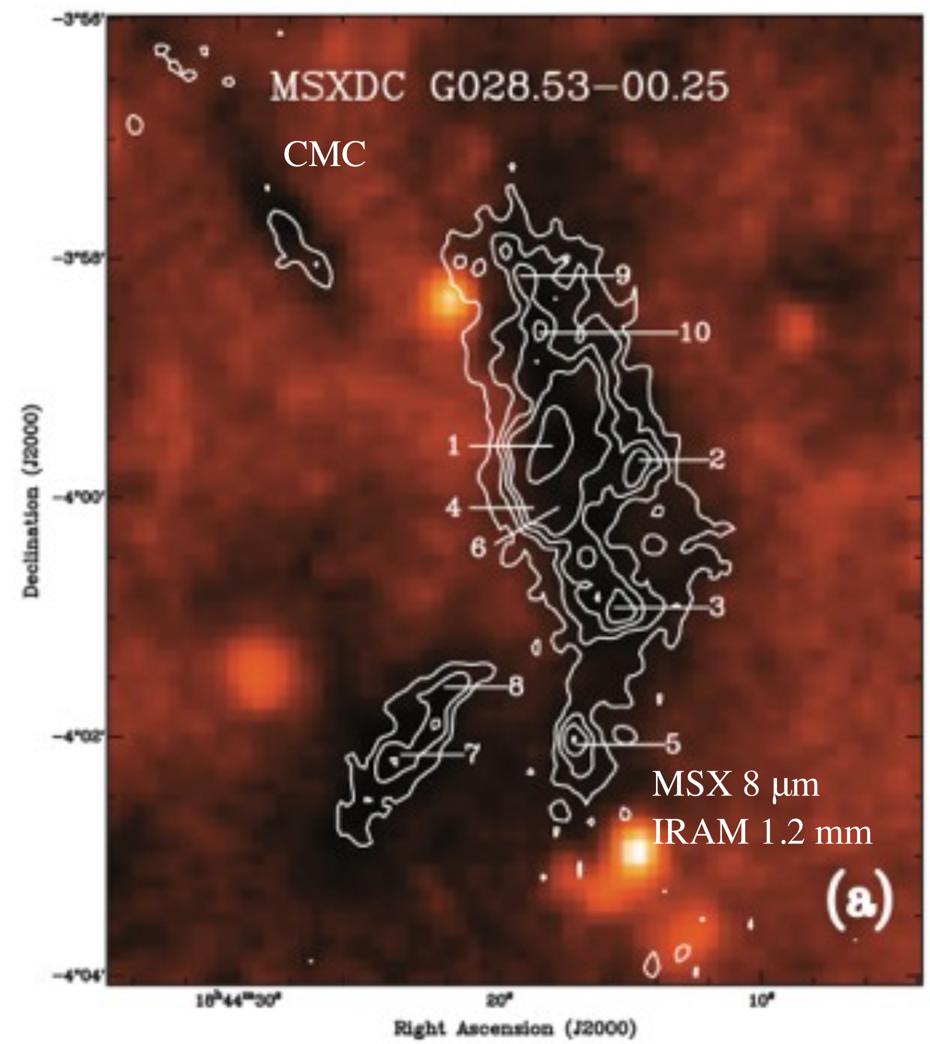
- Study of IRDC cores (CMCs: starless; CMC-IR: protostars still in the process of accumulate their mass) and hot molecular cores (HMCs; contain formed highly embedded protostar)
- Deep search for cm continuum emission from a sample containing the earliest stages of massive star
- Measure the physical structure and radio spectrum

Sample Selection

- **CMCs**: mm compact cores in IRDCs (Rathborne et al. 2006)
- **CMC-IR**: mm compact cores in IRDCs associated to 24 μm point source (Rathborne et al. 2006 and Chambers et al. 2009)
- **HMCs**: Heated by luminous, embedded protostar (Sridharan et al. 2002)

In addition some cores are associated with:

- Maser (CH_3OH and H_2O) emission
- Outflows activity



Rathborne et al. 2006

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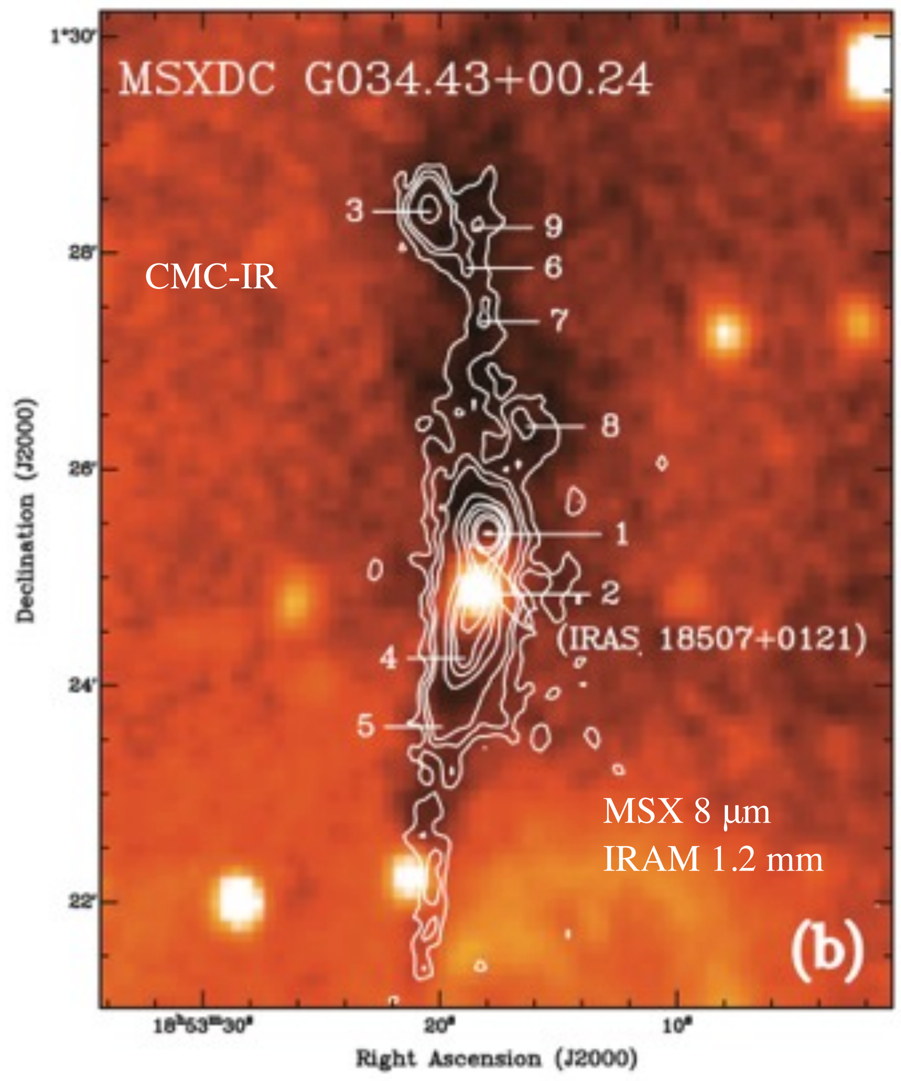


Rathborne et al. 2006

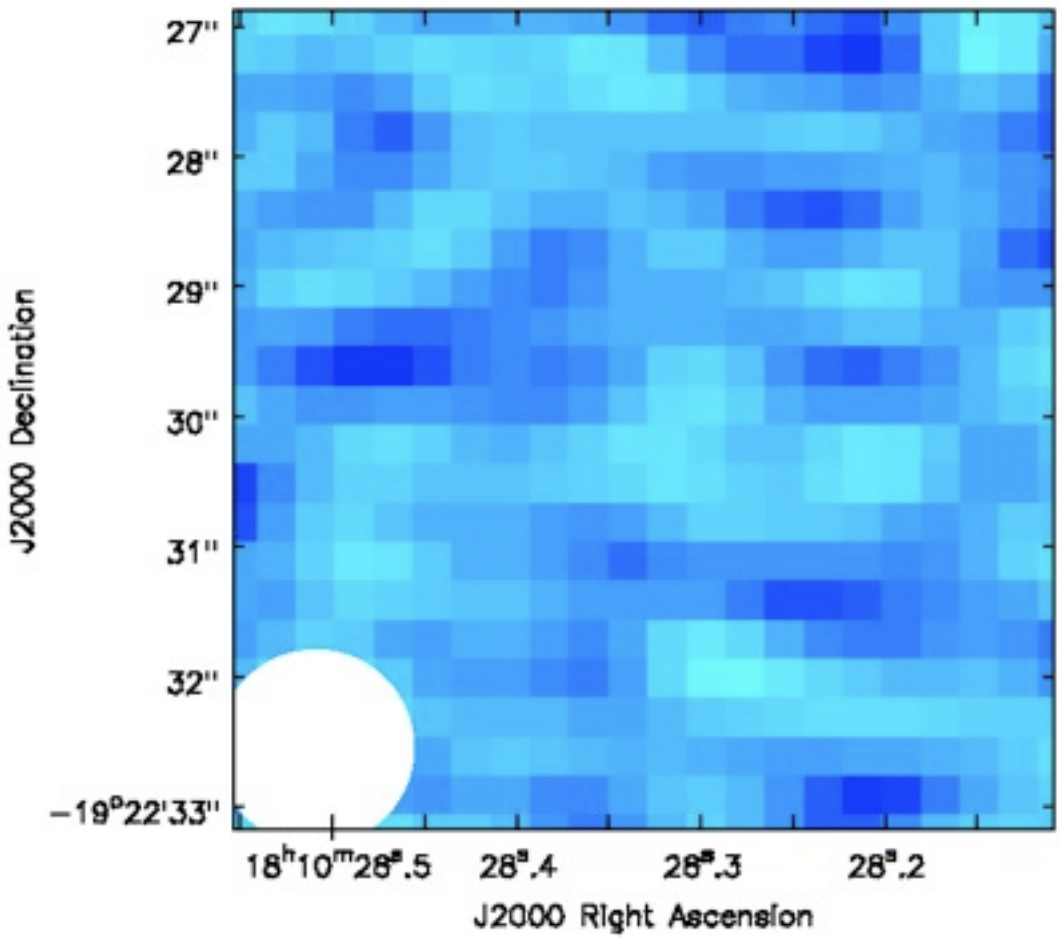
Observations

New VLA provides the high sensitivity and resolution required to study these weak young high mass objects

	K-Band	C-Band
λ (cm)	1.3	6.0
Center Frequency (GHz)	20.9, 25.5	4.9, 7.4
Bandwidth	2×1GHz	2×1GHz
Observations	2011 Spring/2013 Fall	2011 Summer
Configuration	B	A
# Objects Observed	56	59
Primary Beam (arcmin)	2	7
Resolution (arcsec)	0.5	0.4
rms (μJy/beam)	∼8	∼5

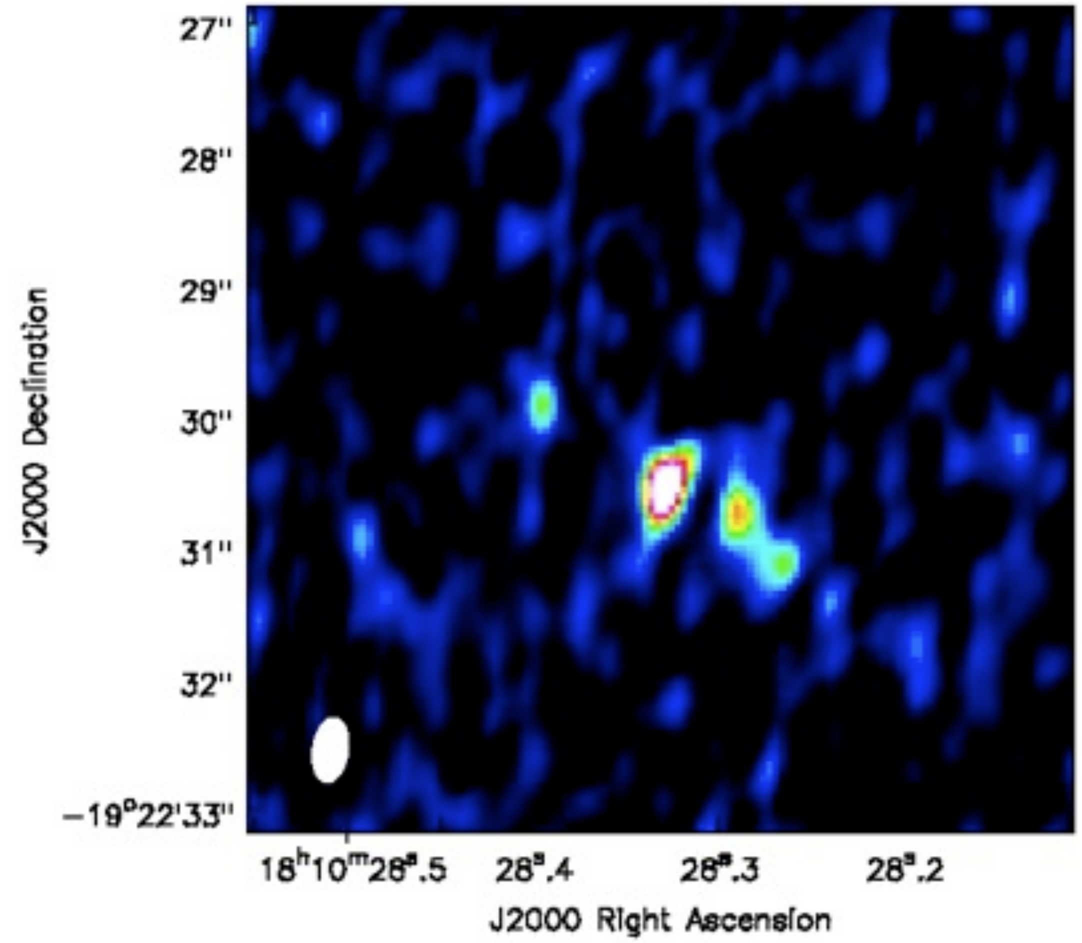
Sensitivity Improvement

Previous Studies



5 GHz
rms~ 0.4 mJy/bm
Resolution ~ 1.5''
B configuration

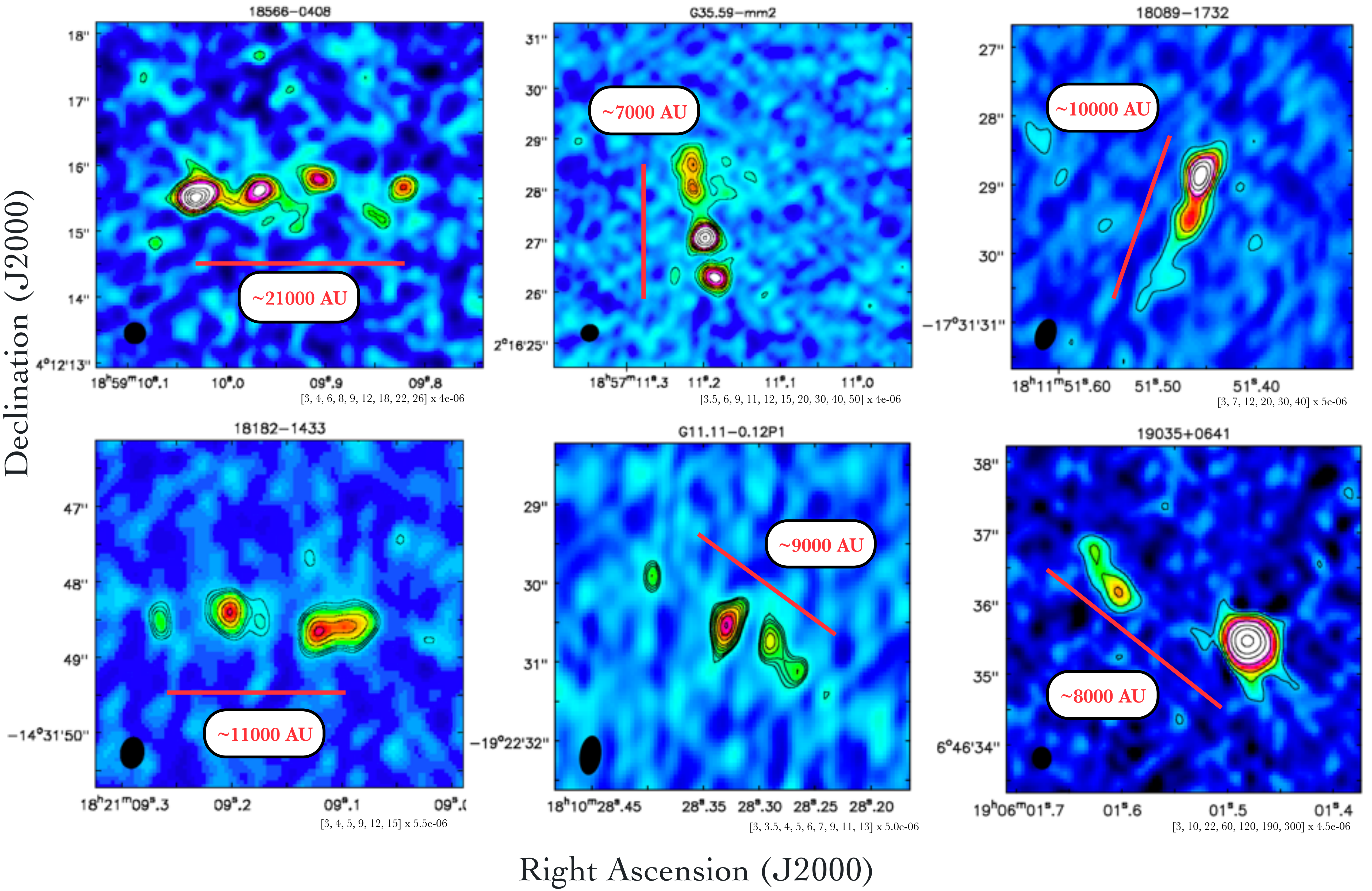
This Survey



4.9, 7.4 GHz
rms~ 5 μJy/bm
Resolution ~ 0.4''
A configuration

Examples from VLA Massive Protostar Survey: Jet candidates

C-band images, ~5 µJy/beam rms, ~0.4” angular resolution

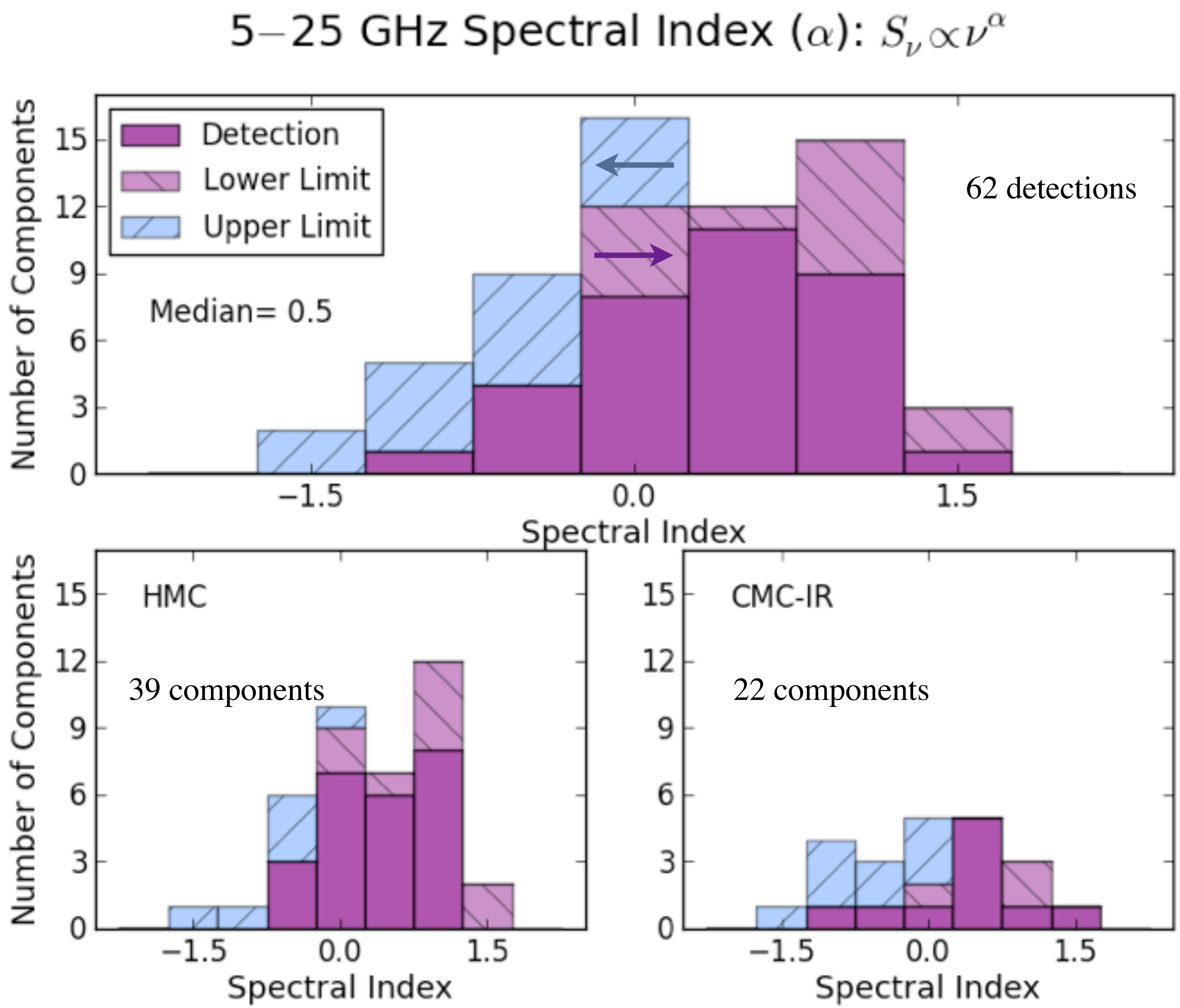


Survey: Preliminary Results

- 29 sources
- Detection criteria: 4σ
- Detections at both bands:
    - 1/9 CMC: 11%
    - 10/10 CMC-IR: 100%
    - 10/10 HMC: 100%

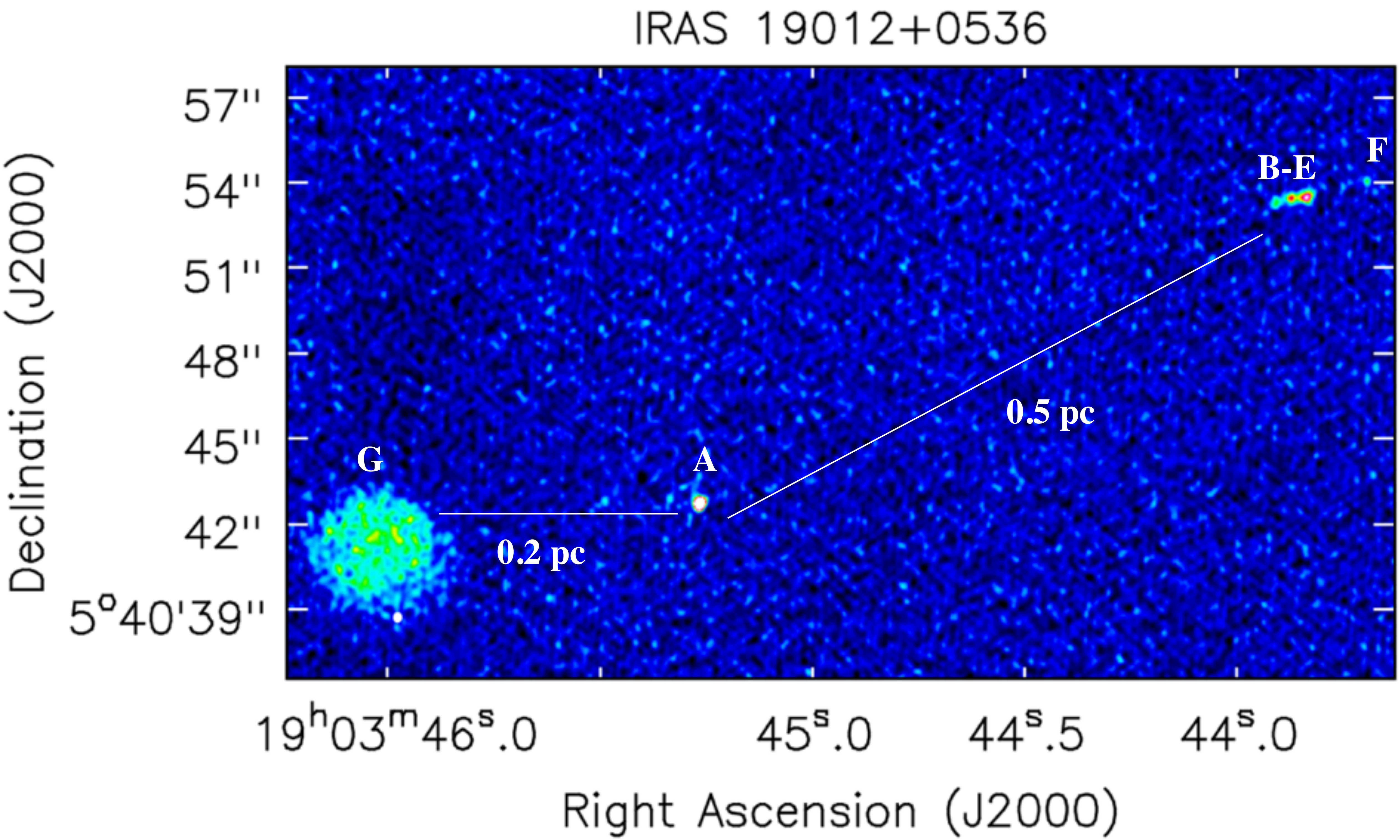
Age?

Survey: Preliminary Results



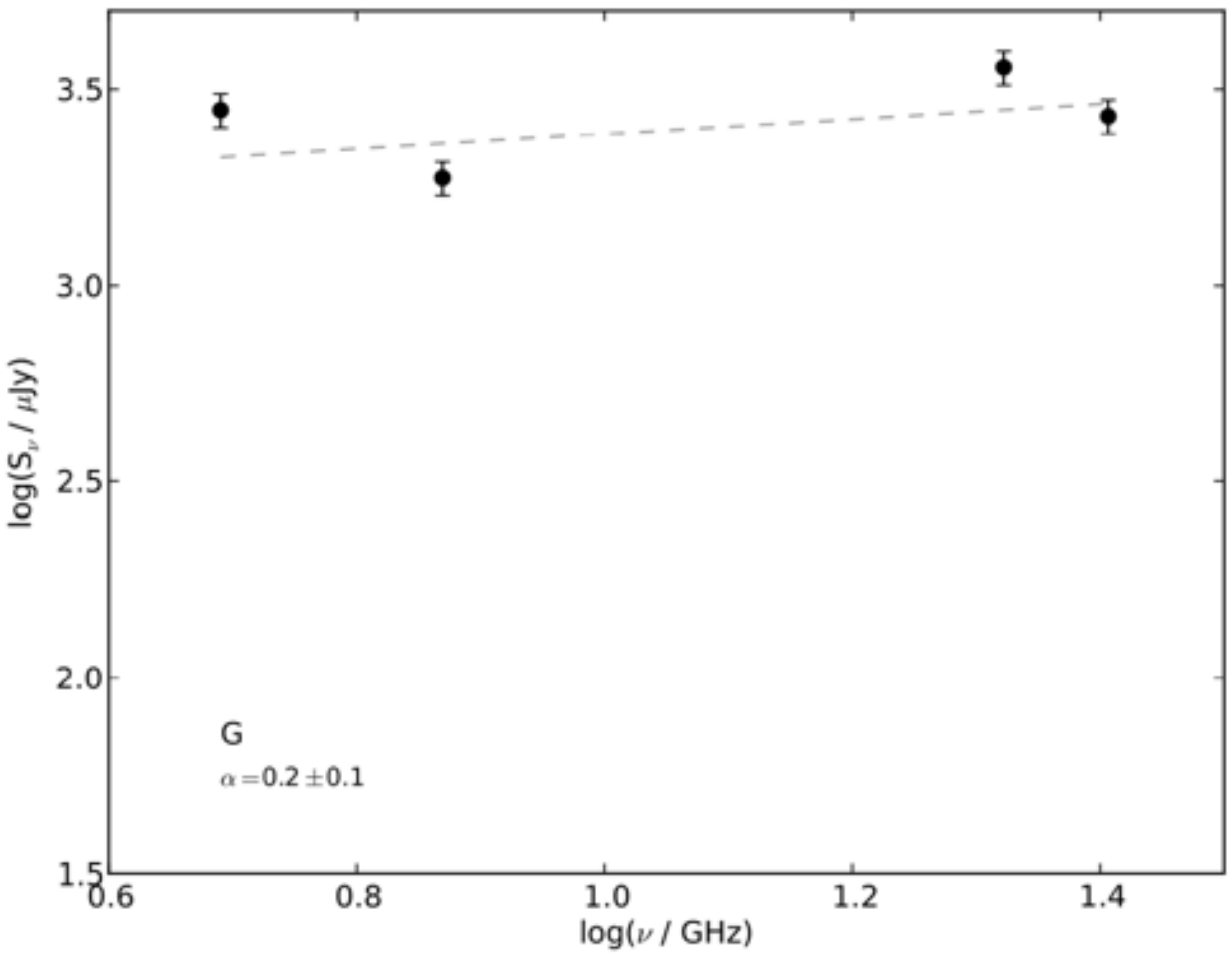
Lower Limit ⇒ not detection at 5 GHz

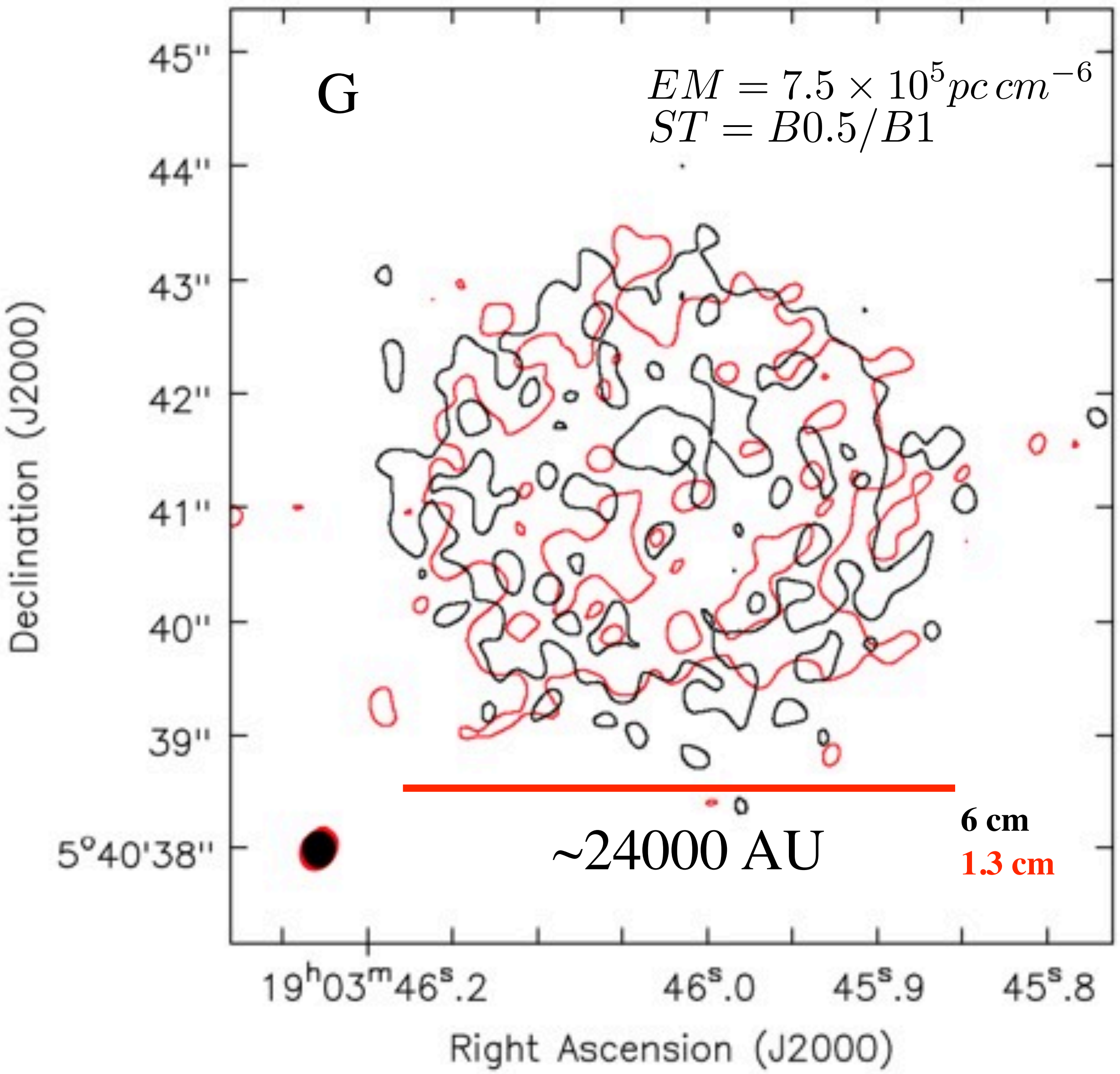
Extended Sources: UCHII Regions?



Extended Sources: UCHII Regions?

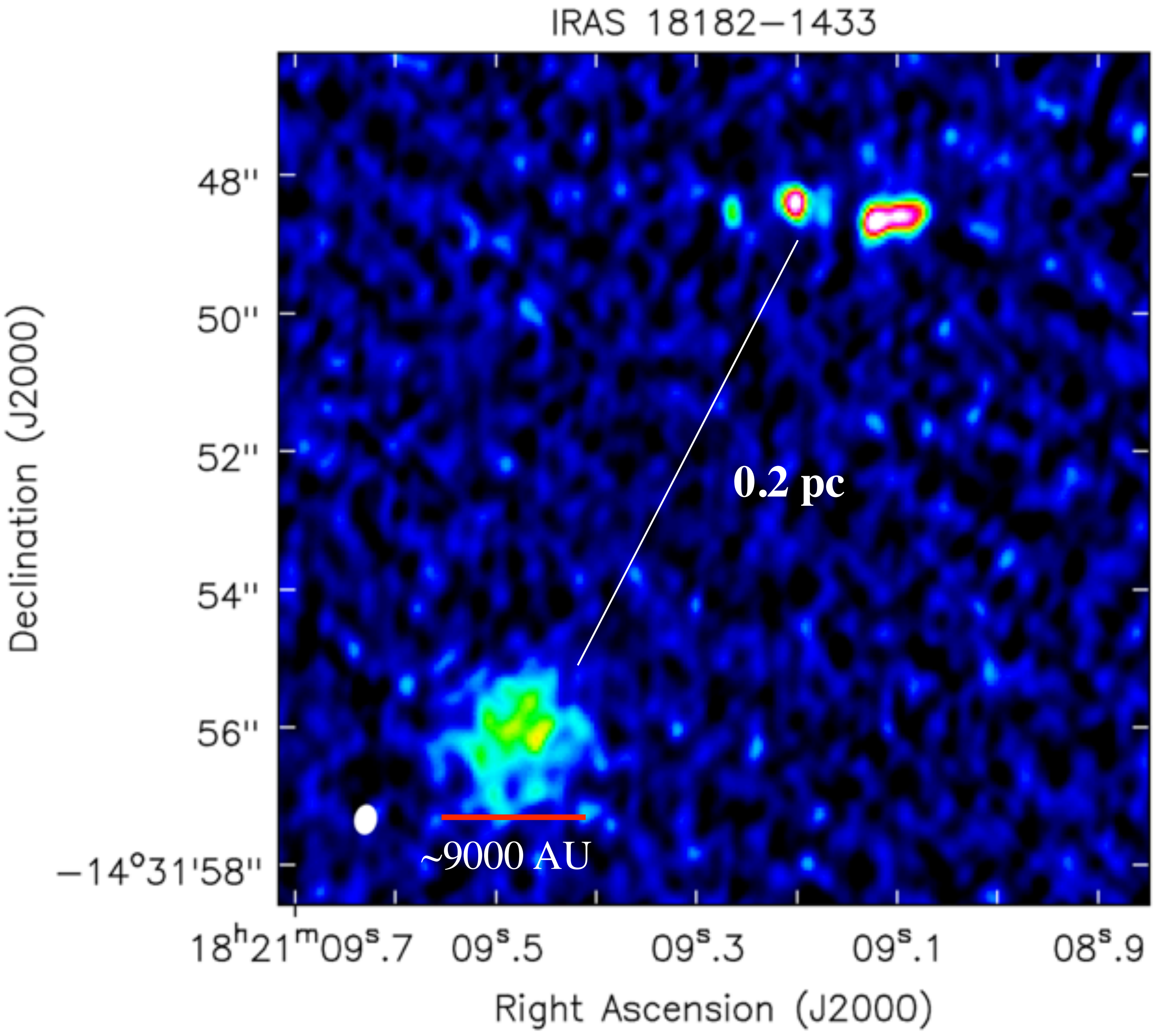
Spectral Index IRAS 19012-0536





Rosero et al. In preparation

Extended Sources: UCHII Regions?

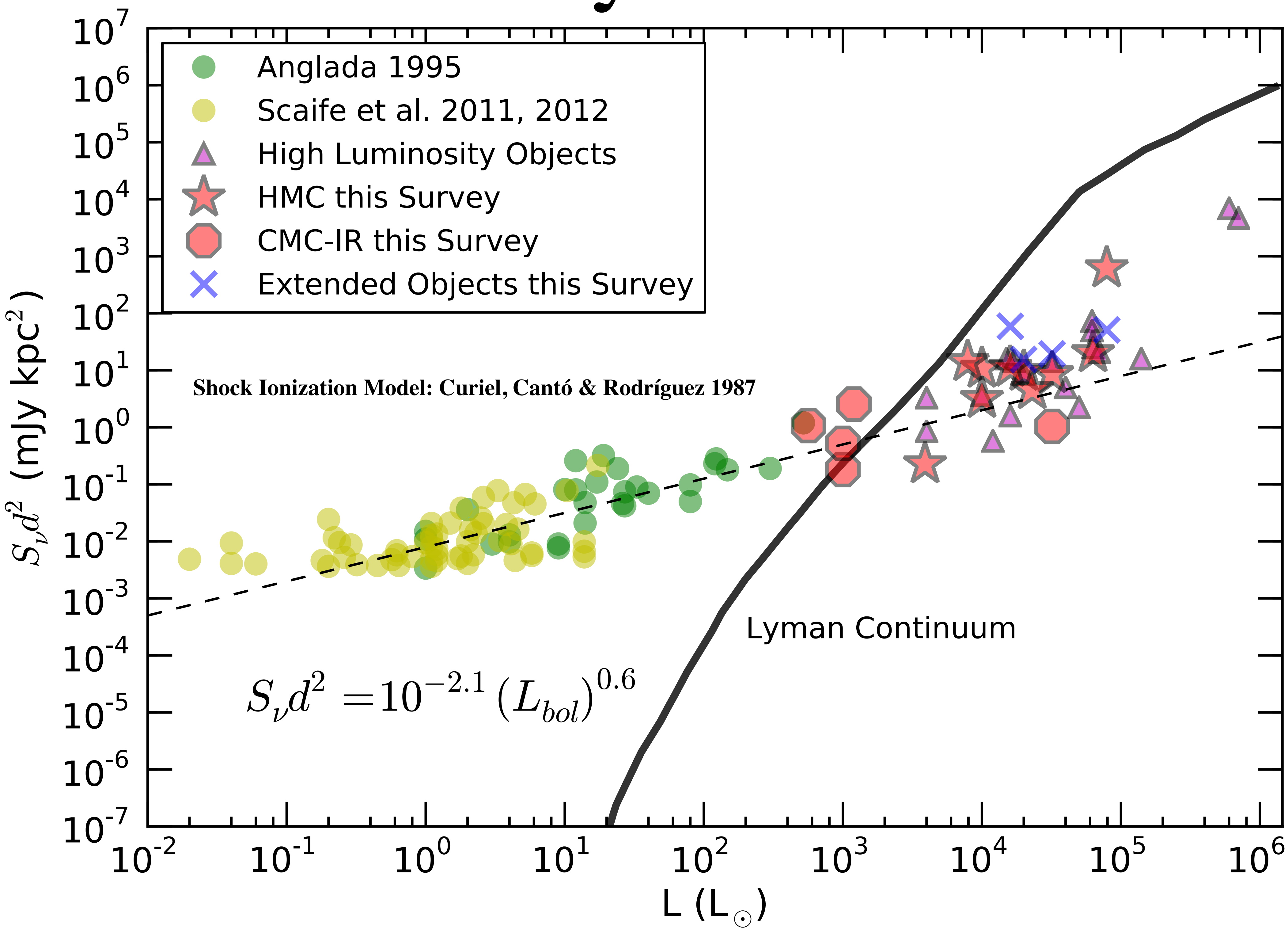


Extended Source:

$EM = 2.1 \times 10^5 pc\, cm^{-6}$

$ST = B2$

Radio continuum - Bolometric luminosity correlation



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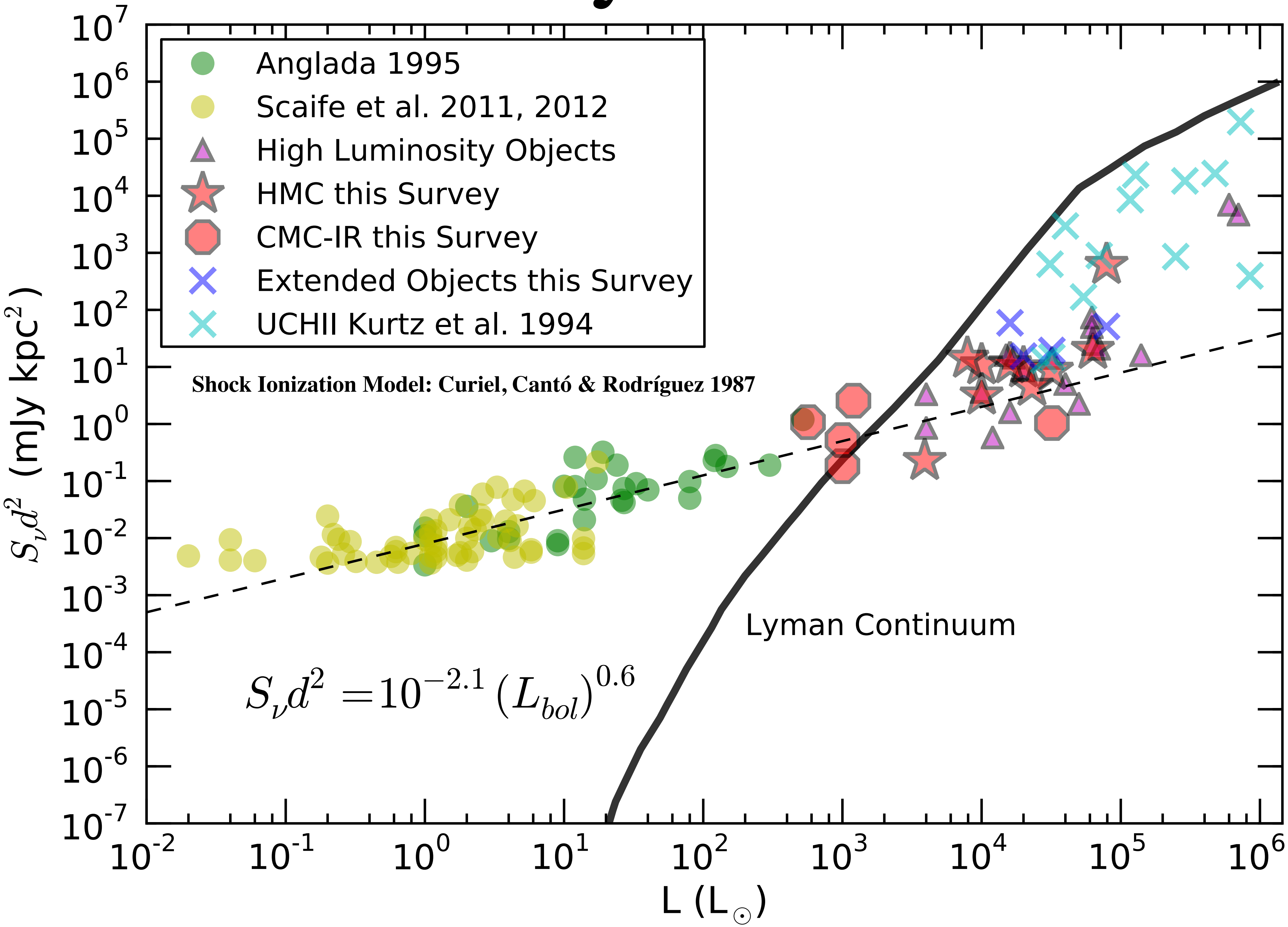
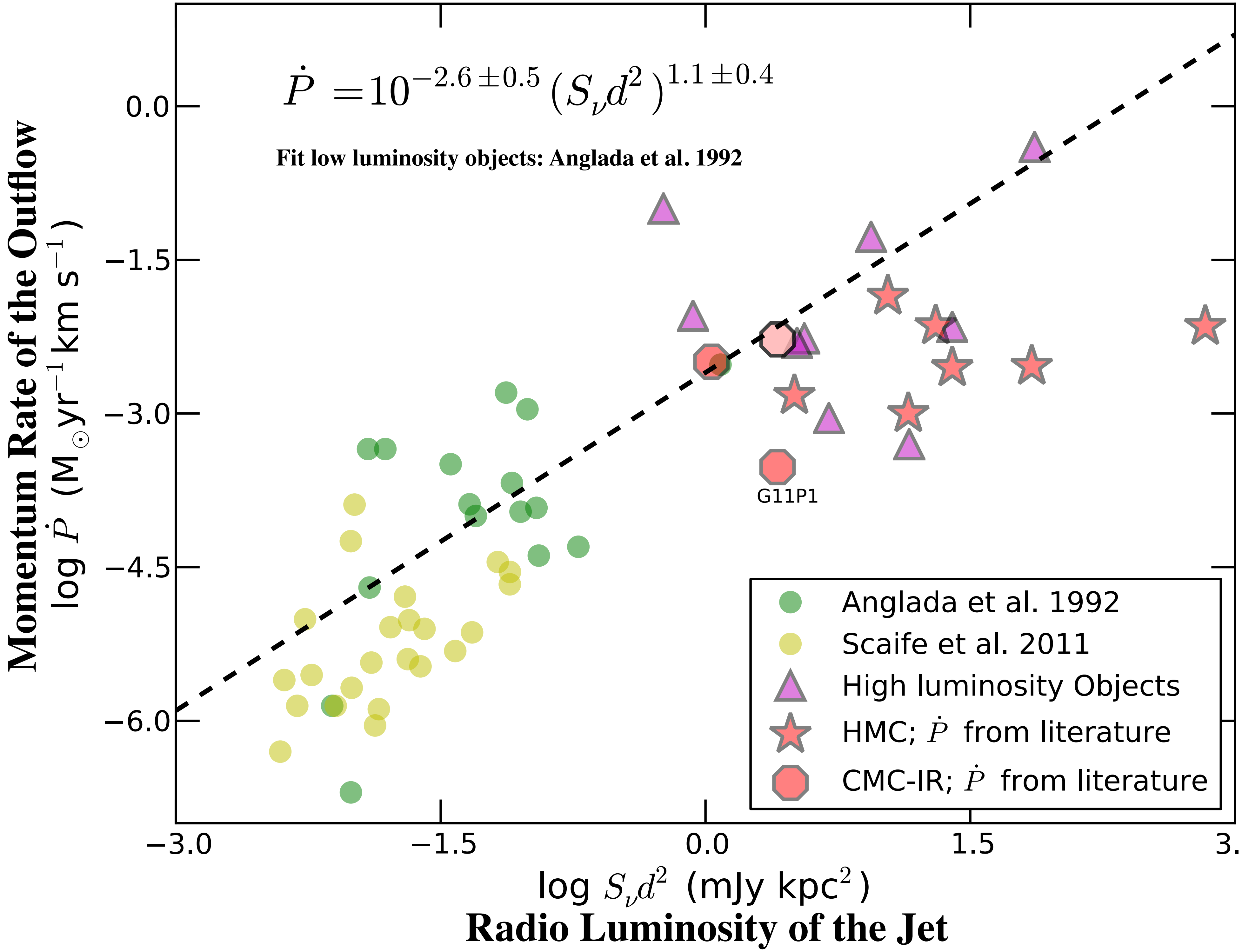


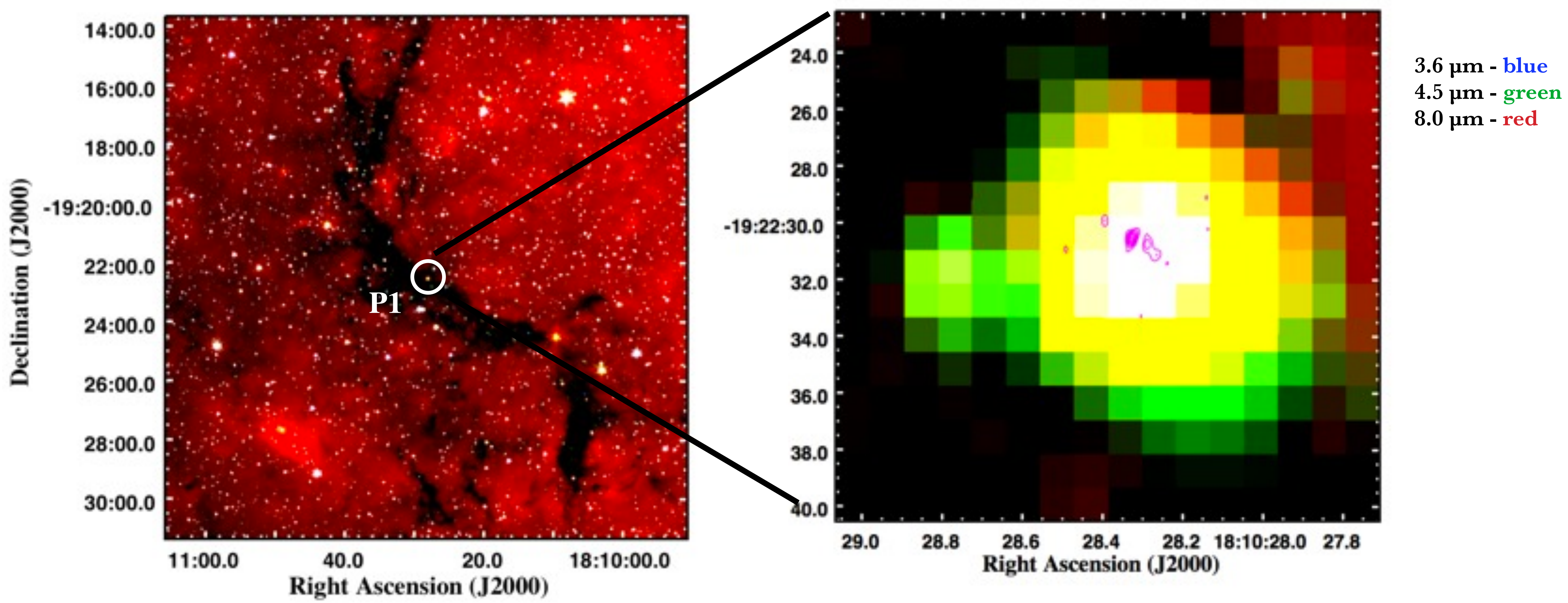
Radio continuum - Molecular outflow correlation



G11.11-12P1

- Cold molecular core located at 3.6 kpc (Carey et al. 2003)
- Luminosity ~1300 $L_\odot$ (Pillai et al. 2006; Henning et al. 2010)
- Maser emission: H_2O and CH_3OH (Pillai et al. 2006)
- Extended 4.5 μm emission: indication of shocked molecular gas
- SiO molecular outflow and ammonia detection (Wang et al. 2014)

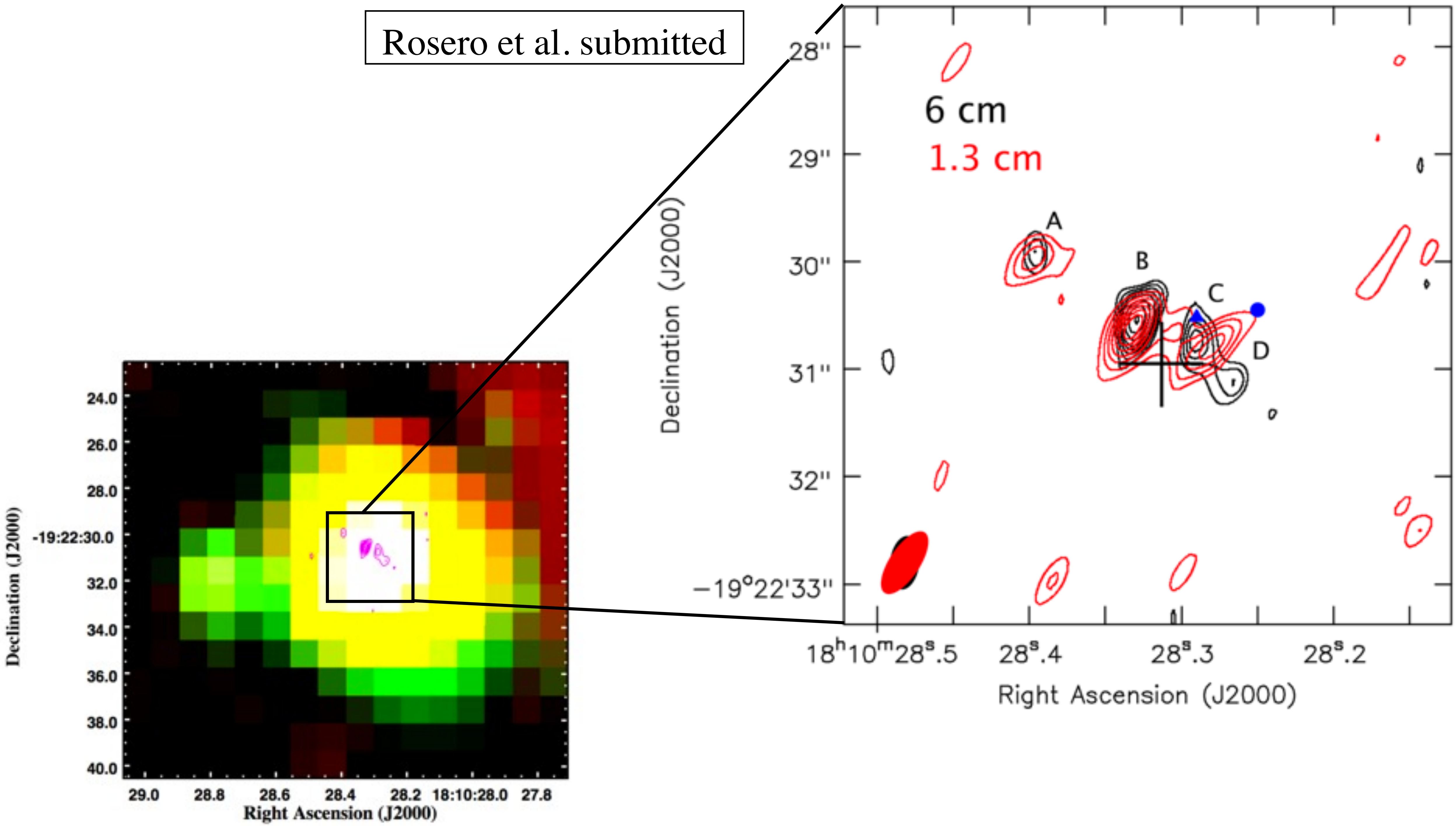
Rosero et al. submitted



See poster by **Ke Wang**: Fragmentation at the Earliest Phase of Massive Star Formation

G11.11-12P1: Results

Rosero et al. submitted



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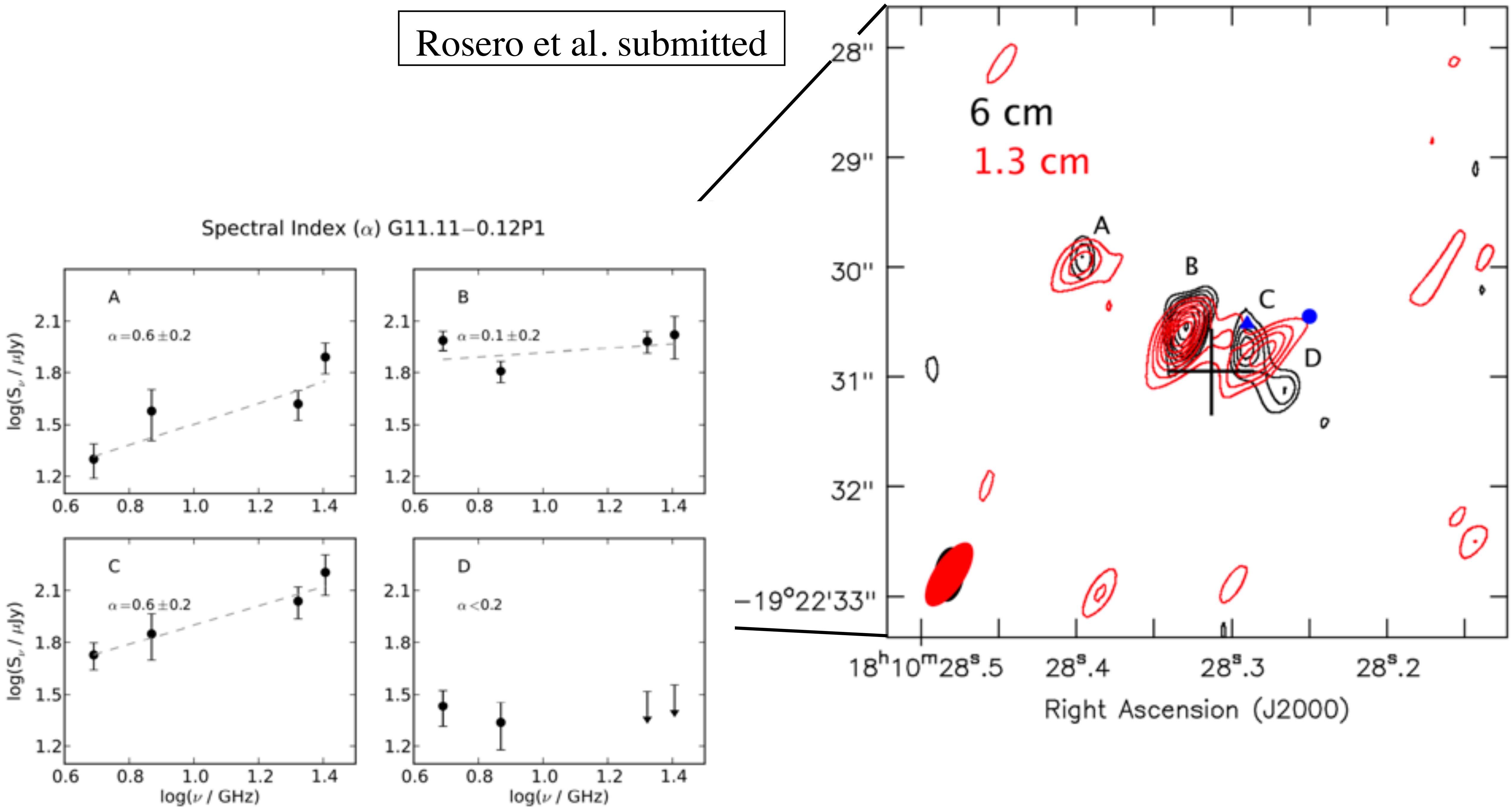

Summary

- Results indicate a high detection rate of radio continuum for HMC and CMC-IR, some with multiple radio components
- Jets seems to be a common phenomena among high mass protostars
- Sample provides suitable candidates to be observed in a search for accretion disks
- Sensitivity of the data allows detection of UCHII regions with spectral type later than B2
- Improve correlations (radio continuum luminosity vs bol luminosity)