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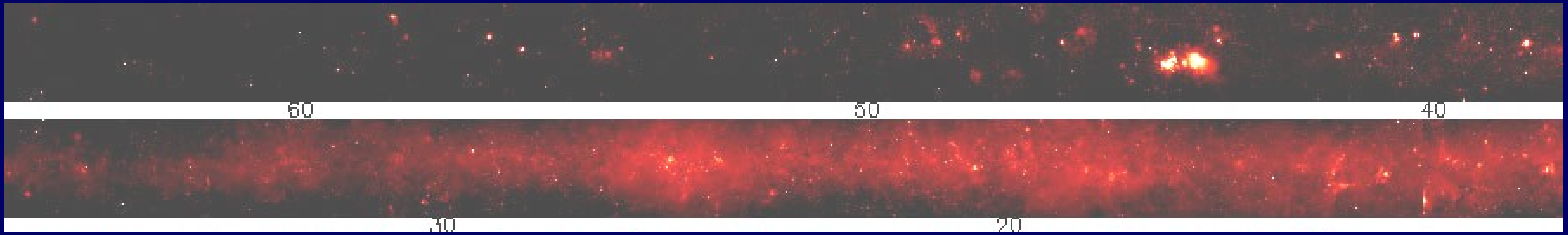
Radio Jets and Evolution of Massive Protostars

Stuart Lumsden



+ in particular;
+ Simon Purser, Willice Obonyo (radio)
+ Heather Cooper, Jake Ward, Rob Pomohaci (IR spectra)
+ the whole RMS Team over the years...

What was known?

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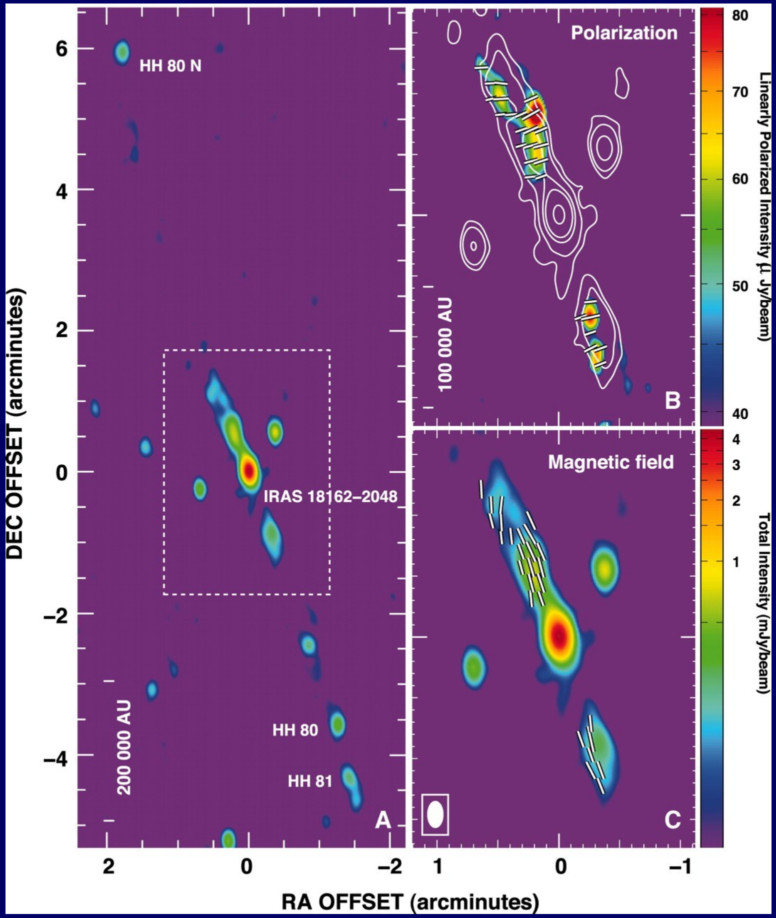
Relatively few well studied examples -



HH80/81 (GGD27) – Carrasco-Gonzalez et al – only current detection of magnetic field from a massive protostellar jet. Proper motions show a decelerating jet (600-1400km/s near core, ~250km/s in more distant knots).

Science, 2010, 330, 1209

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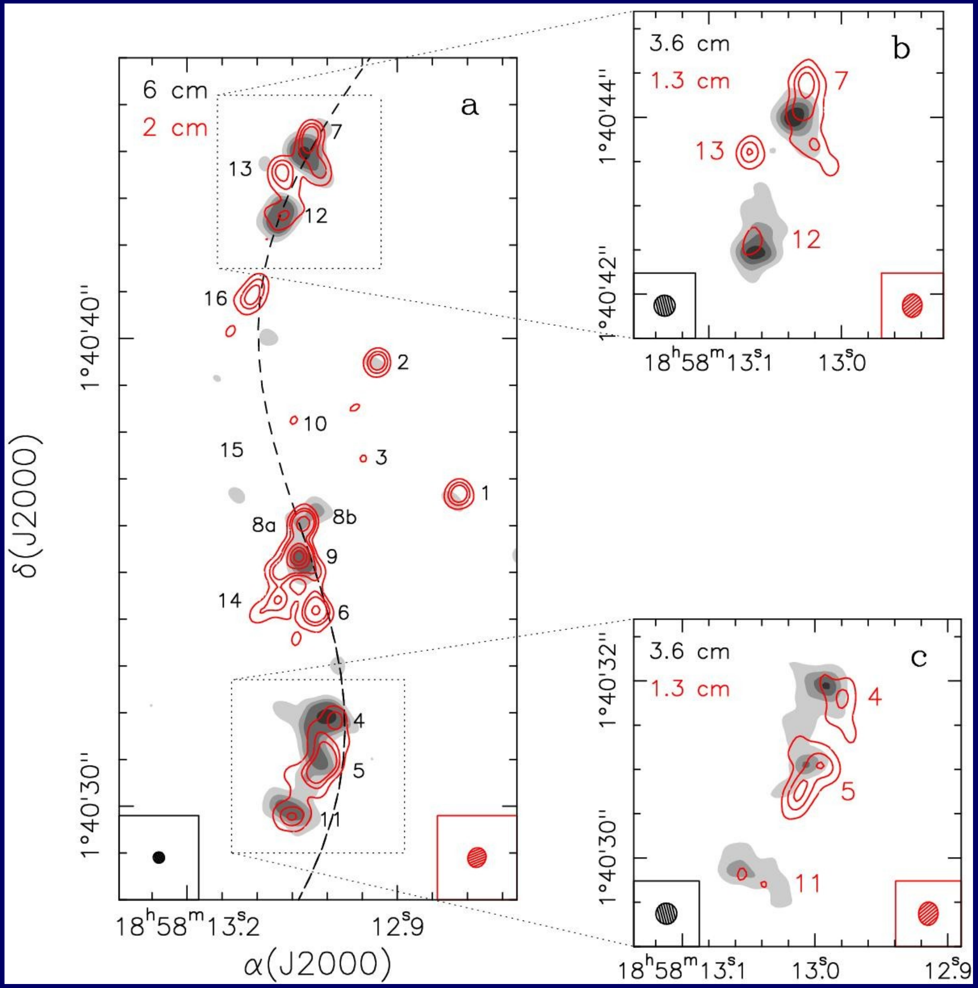
What was known?

Relatively few well studied examples -



G35.2N - precessing jet but much lower velocity ~300km/s (Beltran et al)

A&A, 2016, 593, 49

What was known?

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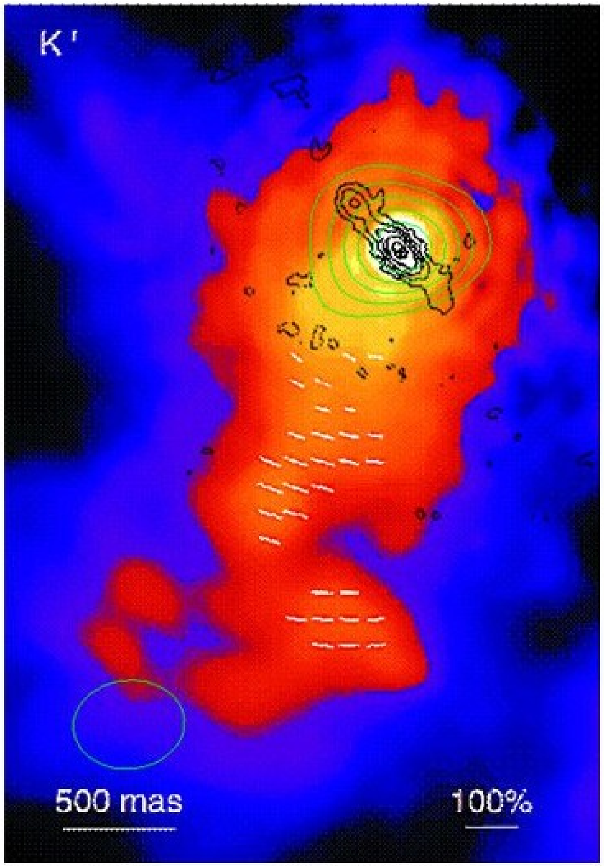
Relatively few well studied examples -



S140 IRS 1 (Hoare 2006)

S140 – Hoare found the radio emission perpendicular to the cavity axis – a disc/wind.

ApJ, 2006, 649, 856

What was known?

But…

How many are jets? How many are disc-winds?

What evolutionary stage?

Can we derive wider proper motion/precession estimates?

RMS selected volume and luminosity limited sample in the South with ATCA; RMS+IRDC (from Rathborne et al 2006, ApJ, 641, 389) sample in the north with eVLA and eMERLIN. All defined as “radio-weak” (<few mJy).

Evolutionary Outline

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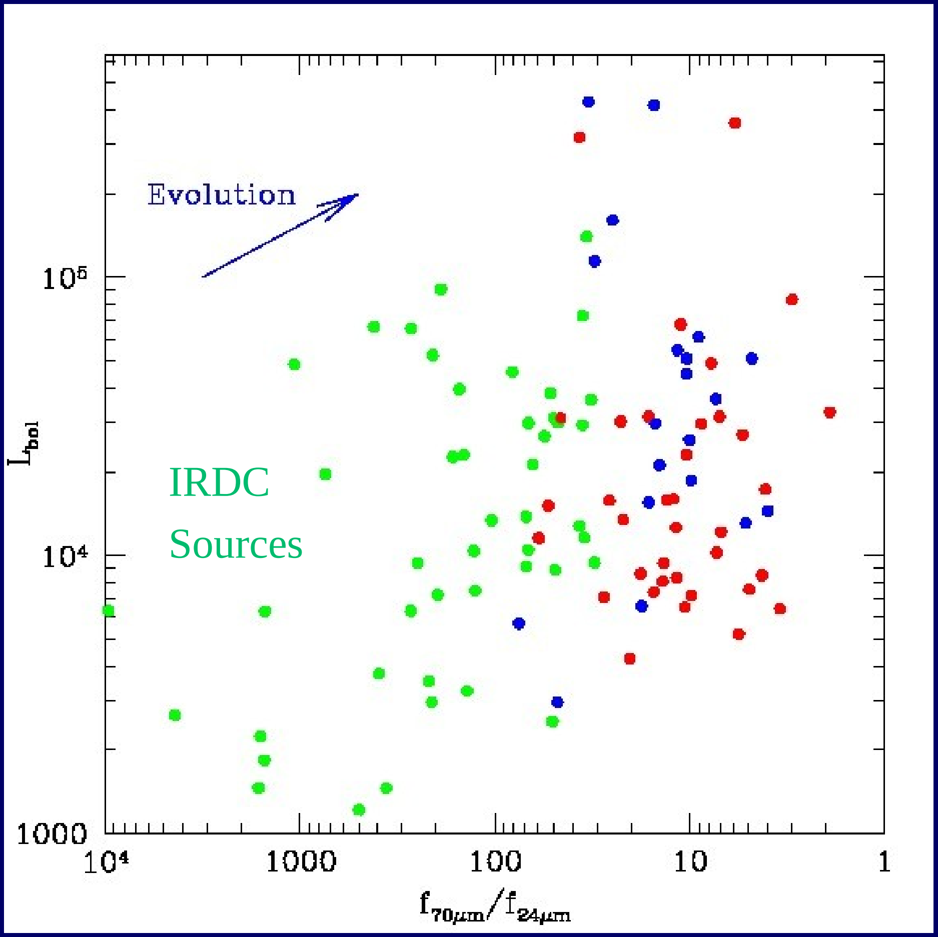

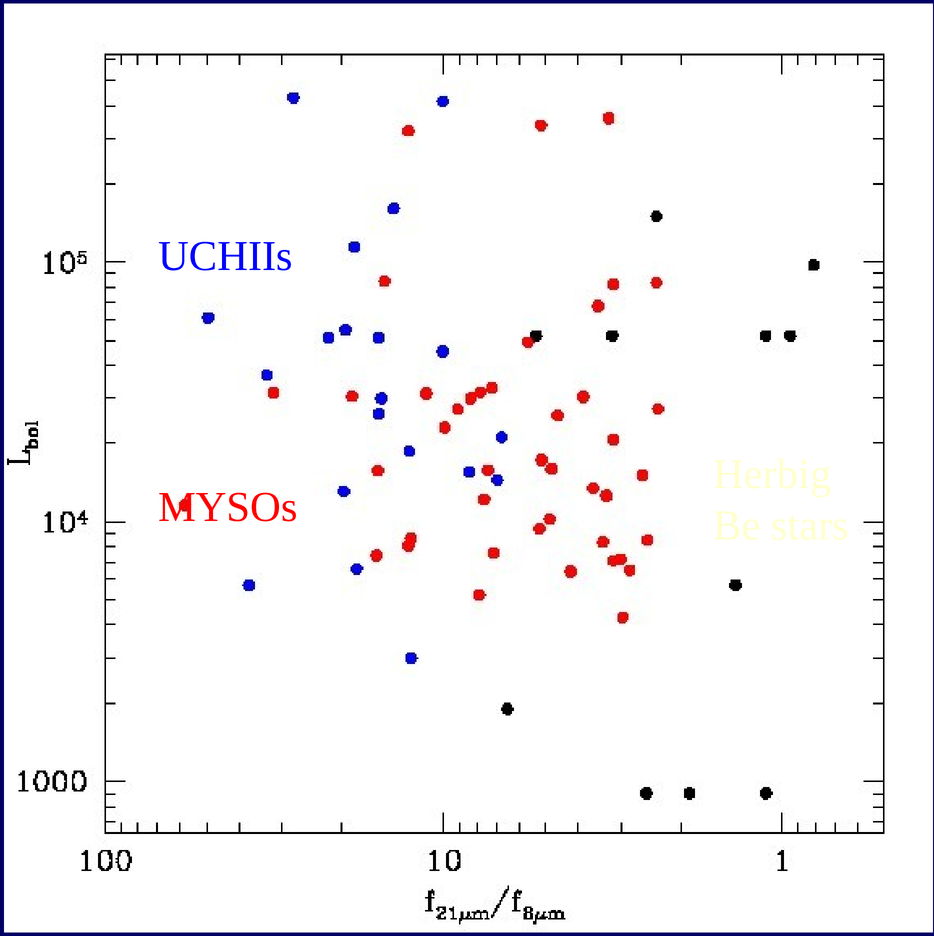

Observations

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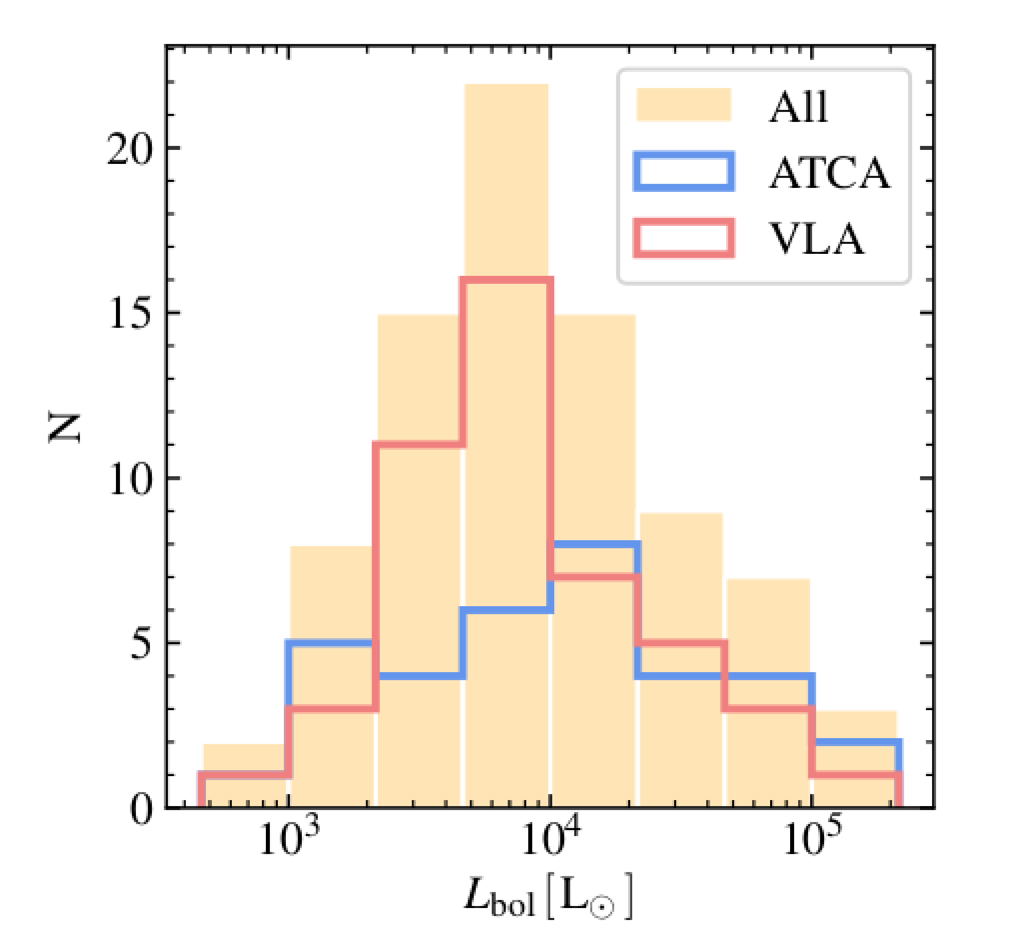
ATCA: 5+9+17+22GHz;   EVLA: 5+44 GHz



Purser et al 2016 MN 460 1039;
Purser et al 2018 in prep;
Obonyo et al 2018 submitted.

Observations of IR bright protostars

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Class.	ATCA	VLA	All-sky
DW	1	1	2
H II	6	3	9
N/D	3	3	6
U/K	2	2	4
Jet	3	4	7
Jet(C)	9	21	30
Jet(L)	7	10	17
Jet(L,C)	3	3	6
	34	47	81

… but true IR dark cores show nothing.

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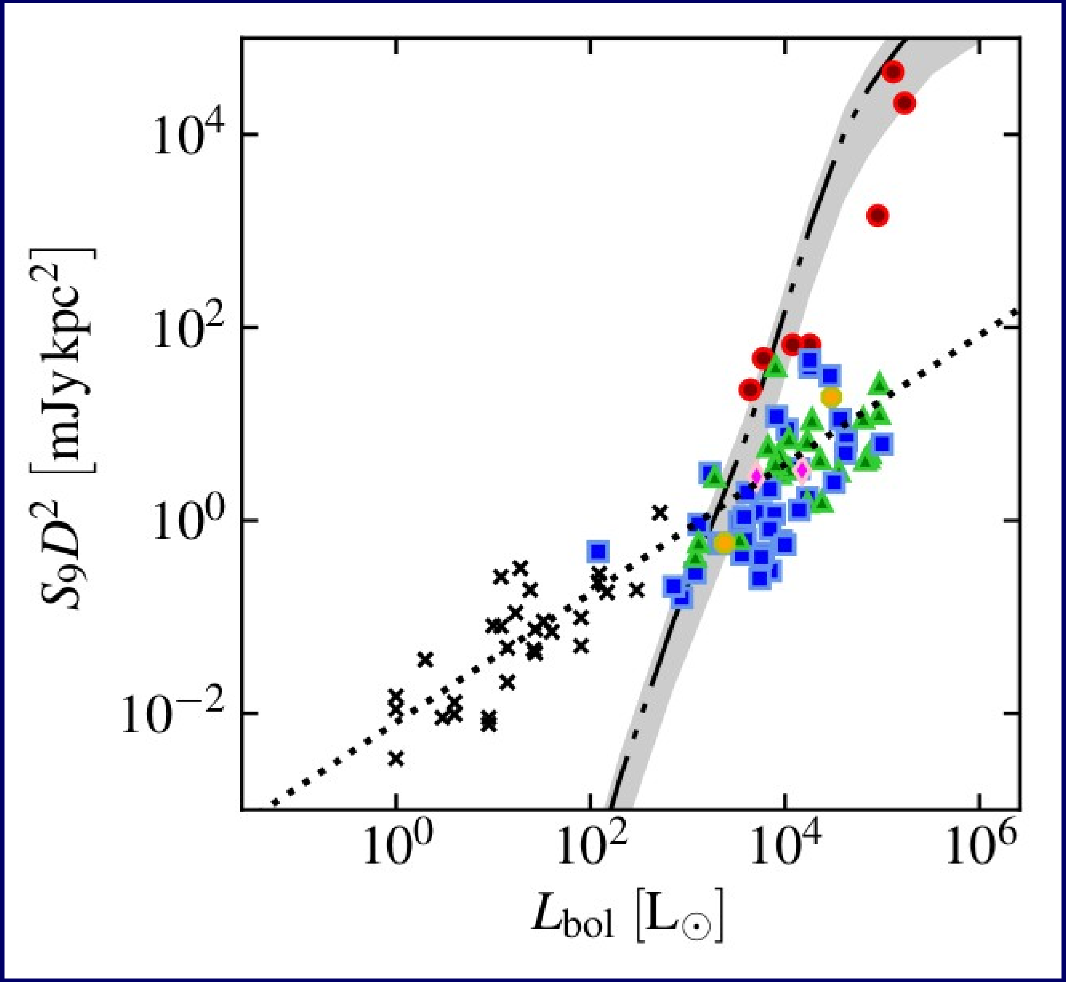
Observations

DW
HII
N/D
U/K
Jet
Jet(C)
Jet(L)
Jet(L,C)



+ low mass sources from Anglada 1995
RMxAA conf series v1, p67

ATCA: Spectral Indices

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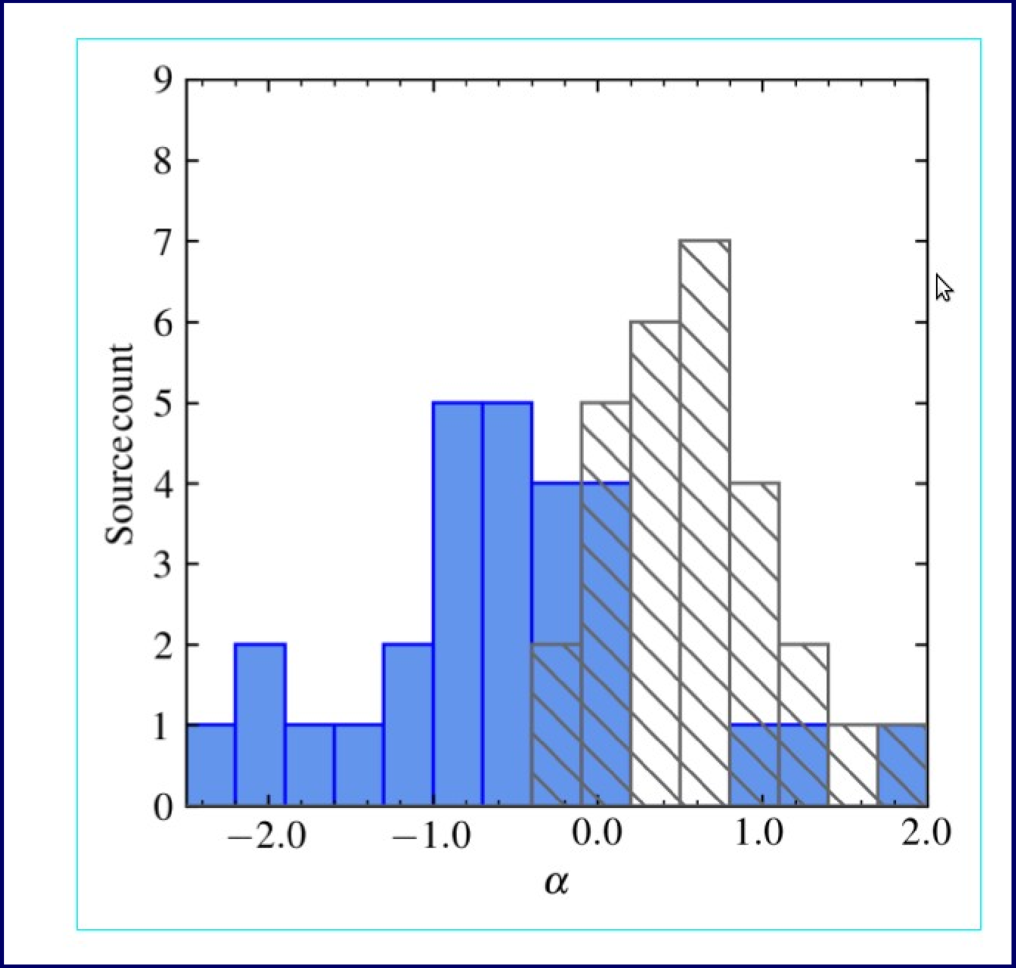


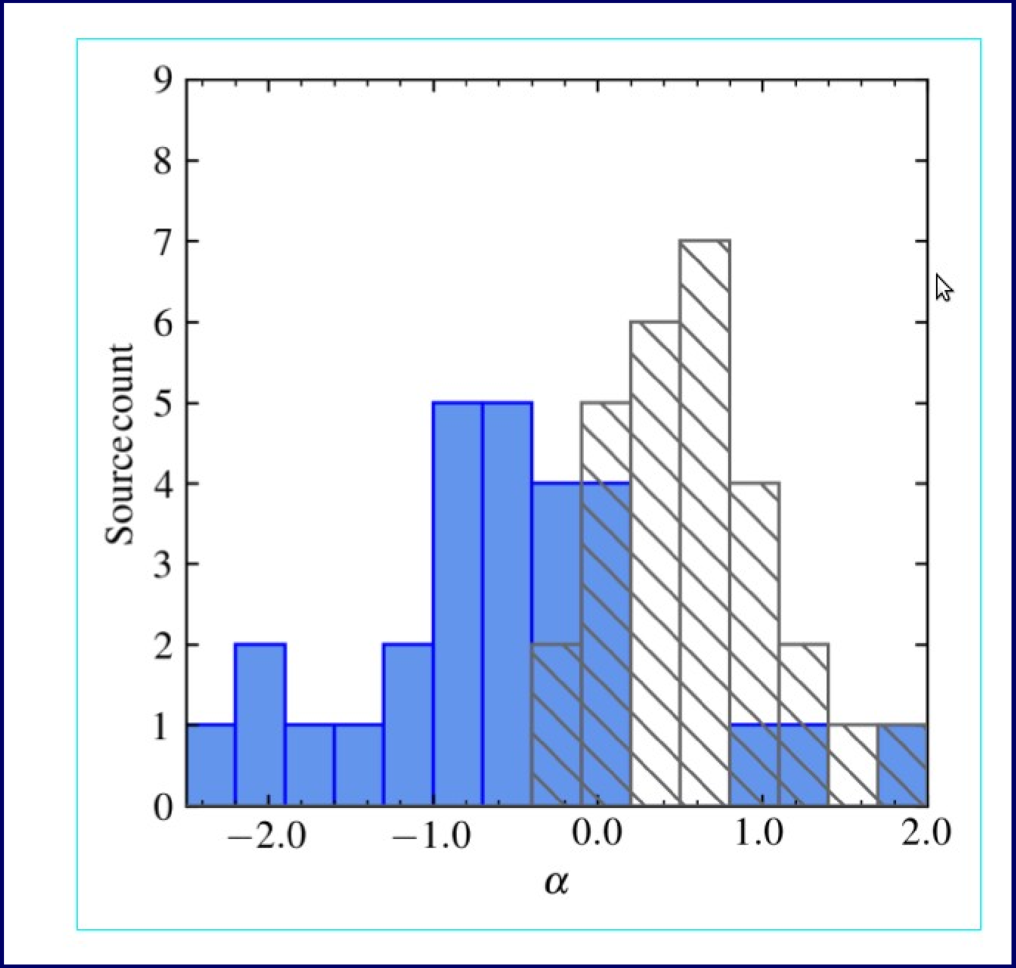
Hatched – cores
Solid - lobes

1.4GHz eVLA obs show no additional non-thermal emission in northern sample.

Cores are thermal.

Same seen in class 0 low mass sources in Serpens – Scaife et al 2012 MN 420 1019.

ATCA: Spectral Indices



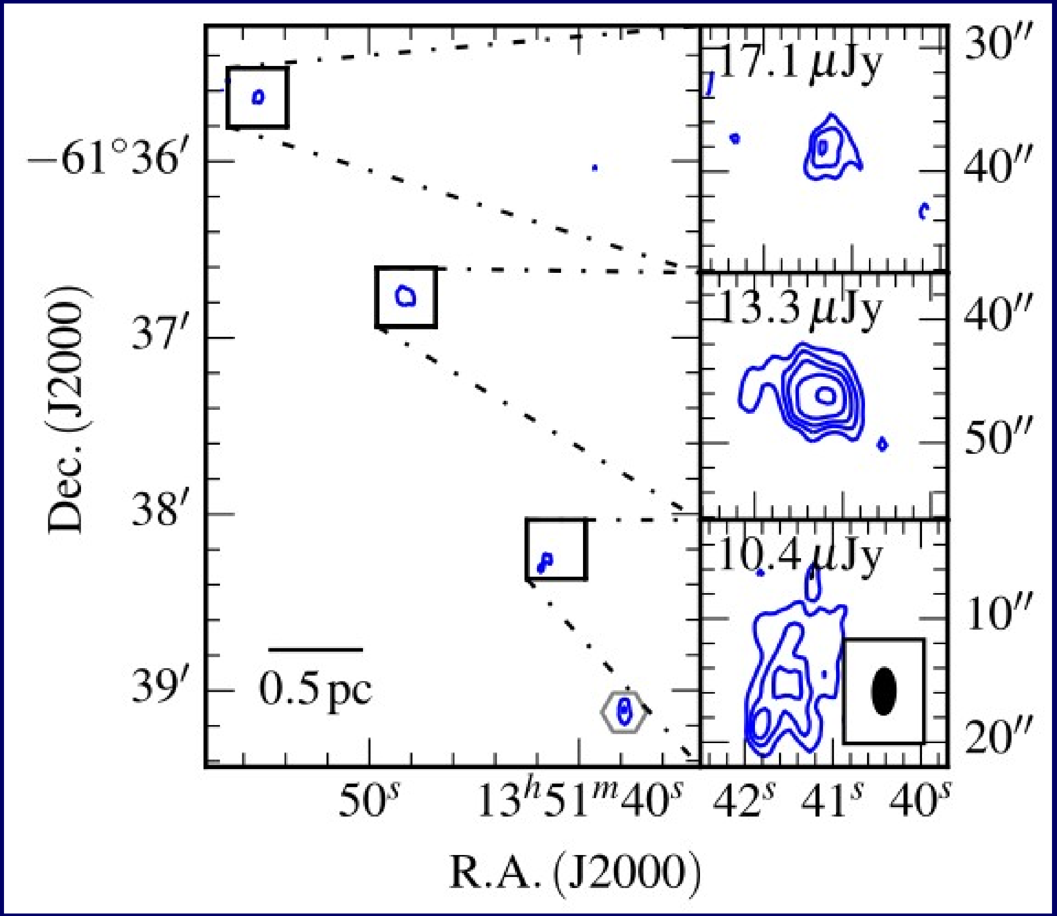
Hatched – cores
Solid - lobes

Lobes more indicative of non-thermal – likely due to magnetic field in ambient medium.

Lobe separation typically 10^4 au.

Extended Emission

Radio HH objects ~ 4pc from core.
~8000 years at 500km/s



Stellar Evolution Model

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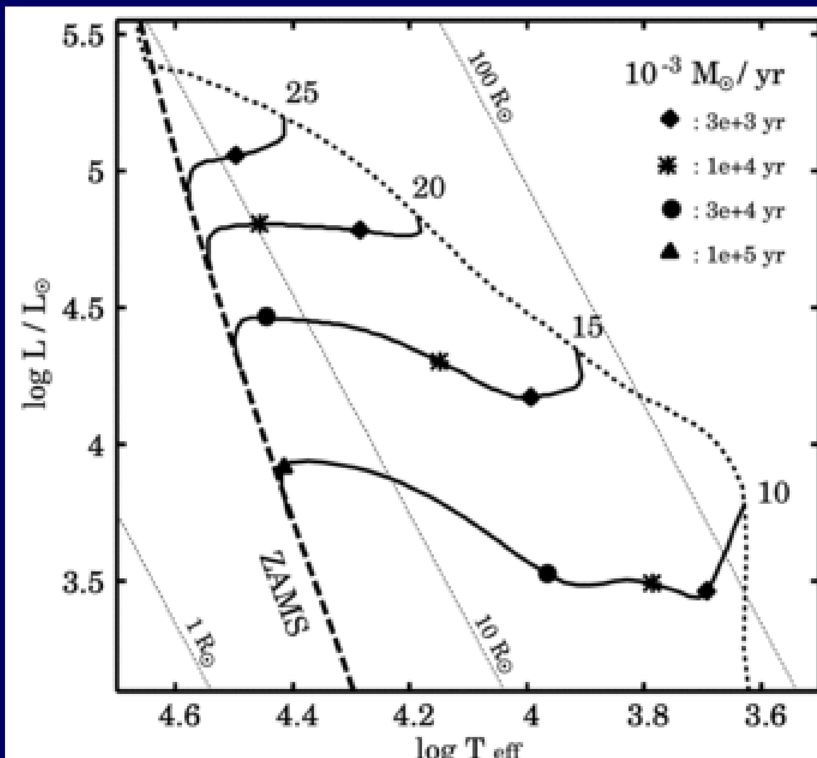

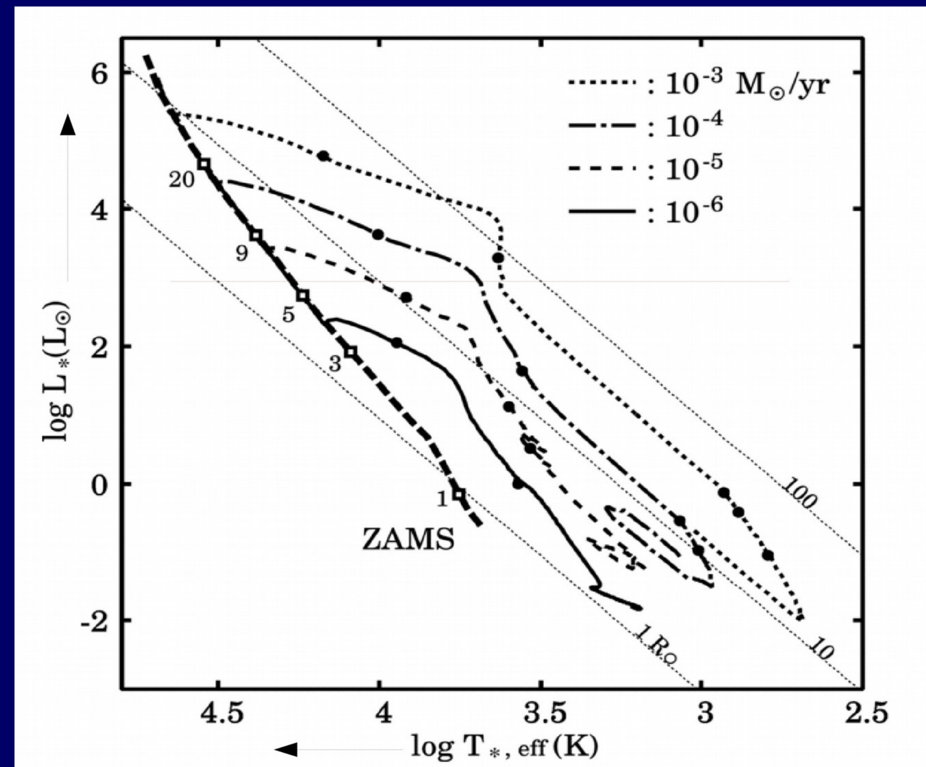

Model from Hosokawa and Omukai (2009 ApJ 269 823) for spherical accretion - dotted line is the birth line for stars with the indicated initial mass. (See also Hosokawa, Yorke and Omukai 2010 ApJ 721 428 for disc accretion)

Protostars versus UCHIIs

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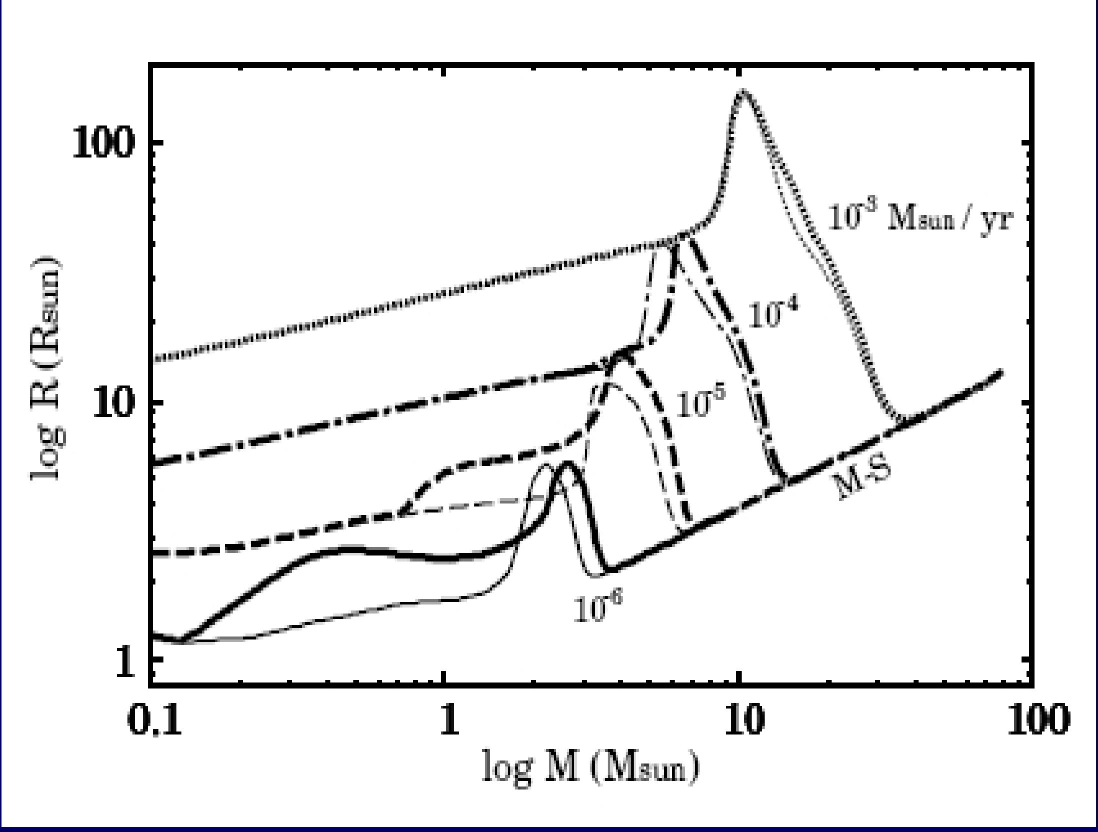
- Protostars may be swollen by accretion
- => T_{eff} < 30000K - no ionized H II regions
- BUT - No protostars seen above $L \sim 10^5 L_\odot$ ($M \sim 30 M_\odot$);
- They rapidly contract to MS so => T_{eff} >30000K
- These are HII from near “birth”



Hosokawa & Omukai (2009)

Protostars versus UCHIIs

- Agrees with the sustained radio jets where we see them.
- But why not in IRDCs?
- And does any other property agree?

Spectroscopic Results

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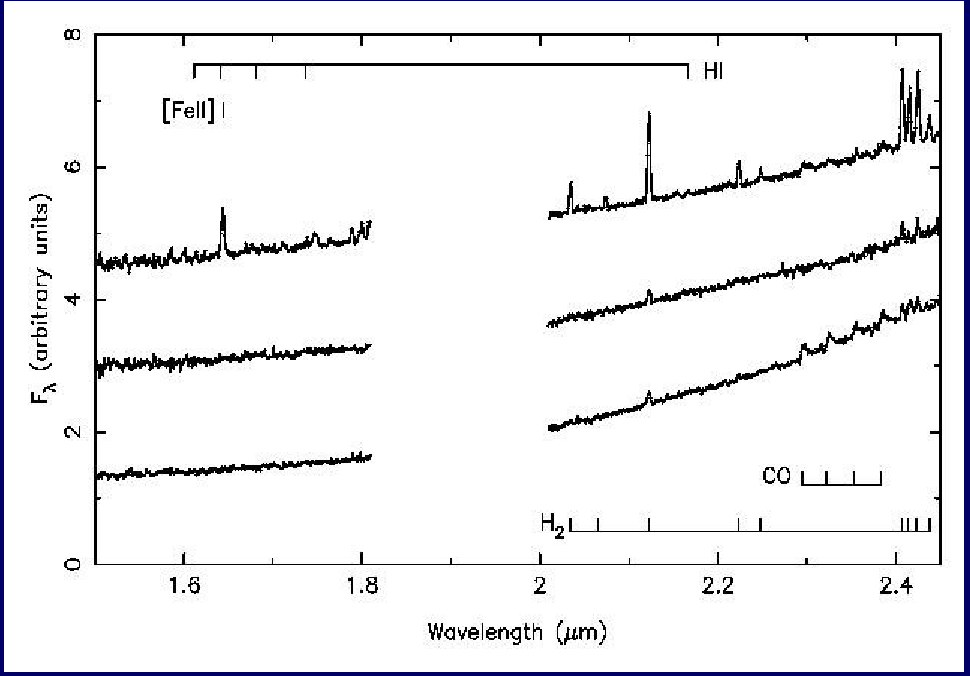
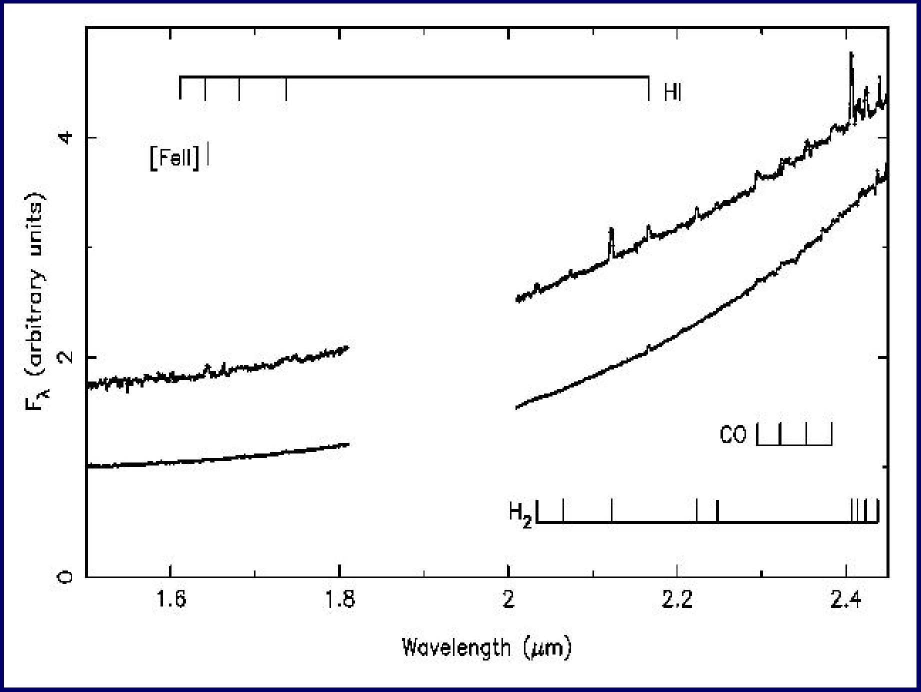
Type I - no ionised gas, molecular & shock signatures



Type II – weak ionised gas, still shocks and molecules



Spectroscopic Results

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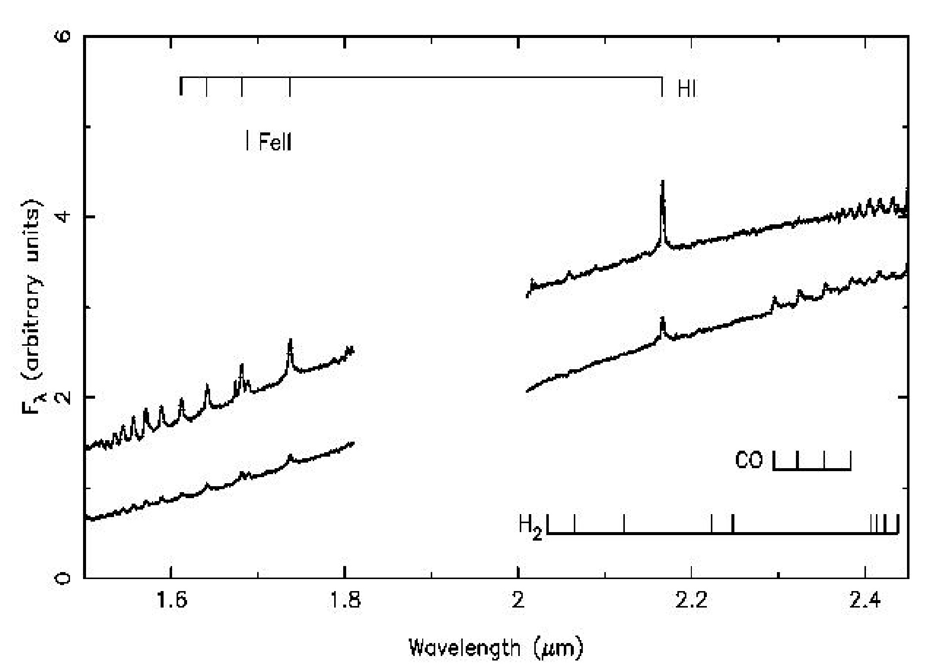
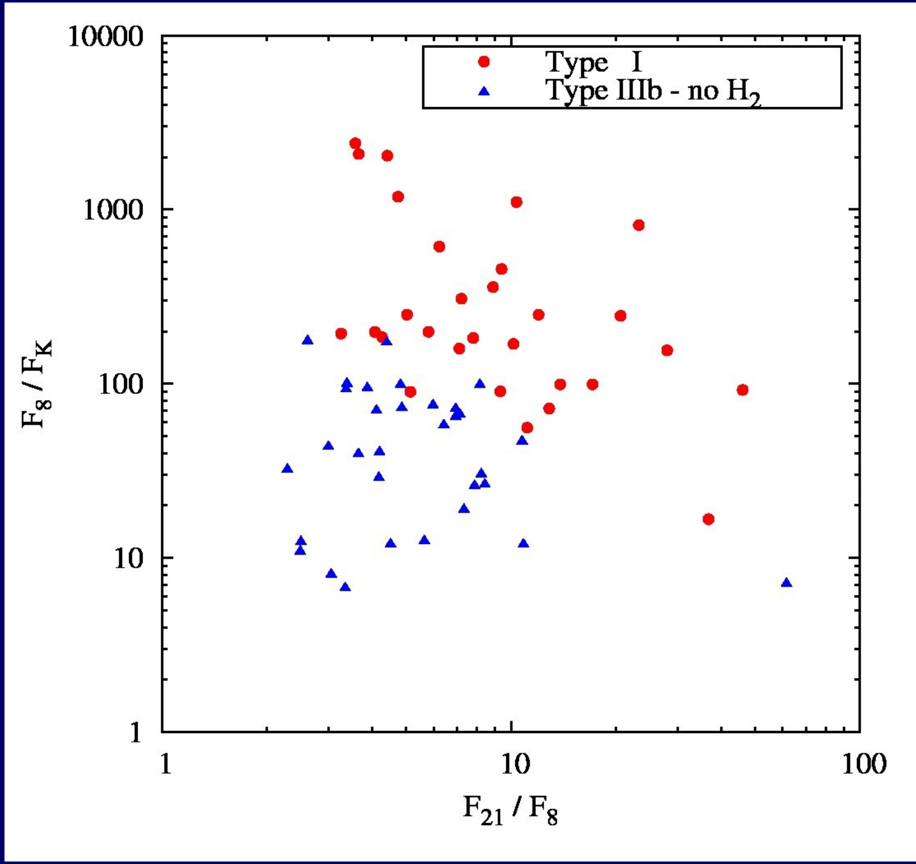
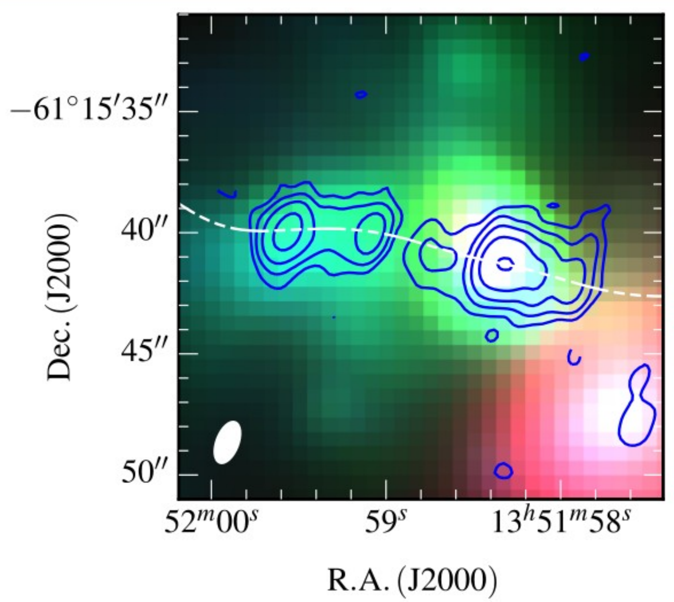
III & IV – strong Br series, weak or no H_2/CO etc.





Clear colour trend – at fixed L, type III should be near MS, type I on growth line – type I will become more luminous

Variability - Precession



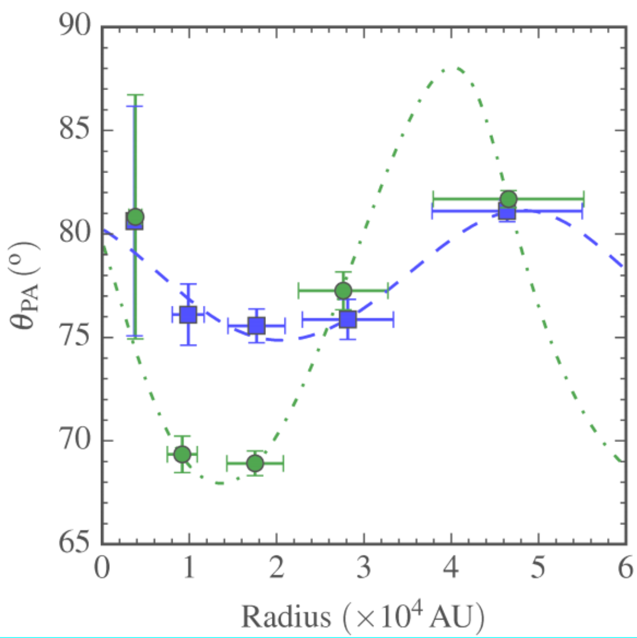


Figure 3.16: A plot of the radii and position angle of components A2, A3, A4, C and D relative to A1 during both the 2013 (green circles) and 2014 (blue squares) epochs with their fitted curves (green dot-dashed line and blue dashed line respectively). For 2013 and 2014 data θ_{PA} was fixed at 78° and values for P_{pr} of 515 and 725 yr, i of 19° and 17°, θ_{pr} of 19° and 6° and ϕ of −9° and −45° were derived for the 2013 and 2014 models respectively.

Binarity/Higher order systems.

Warped discs.

Variability - Intensity

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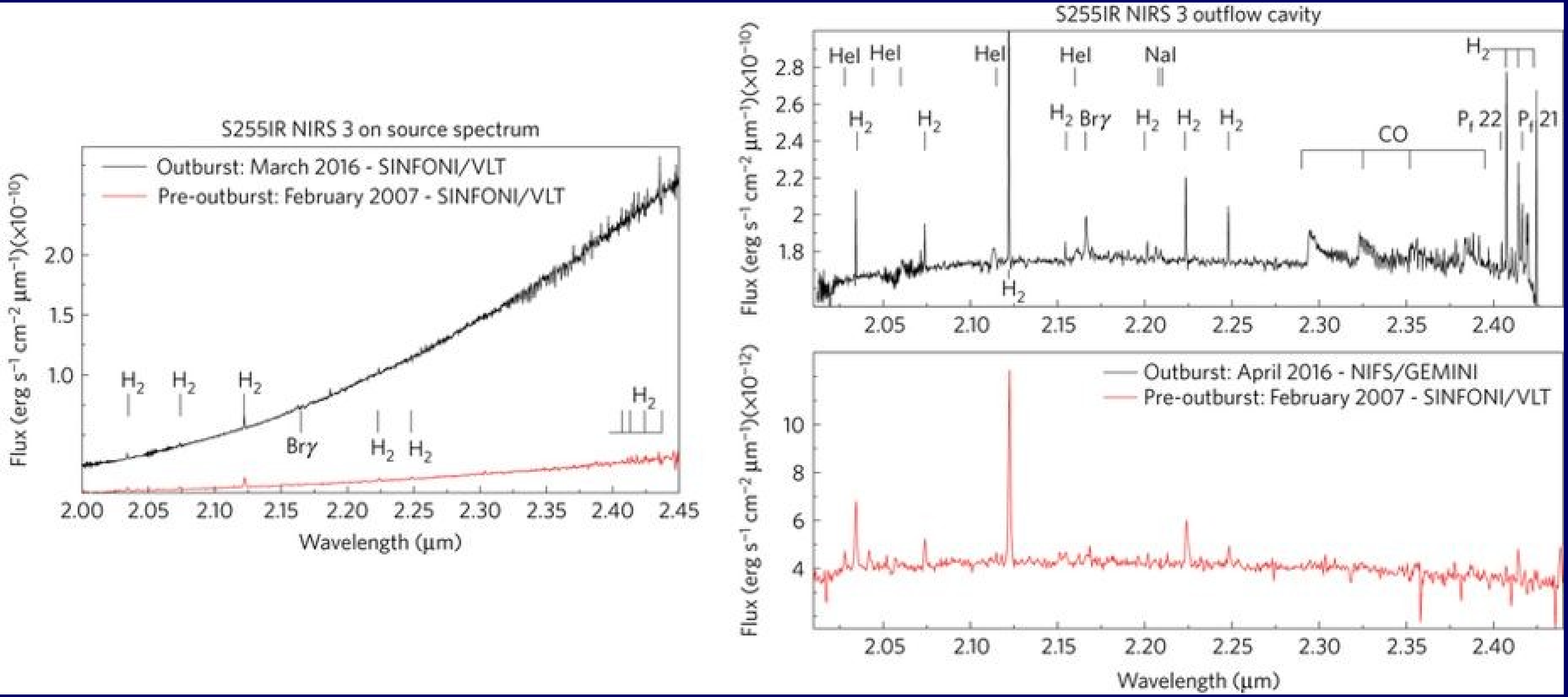
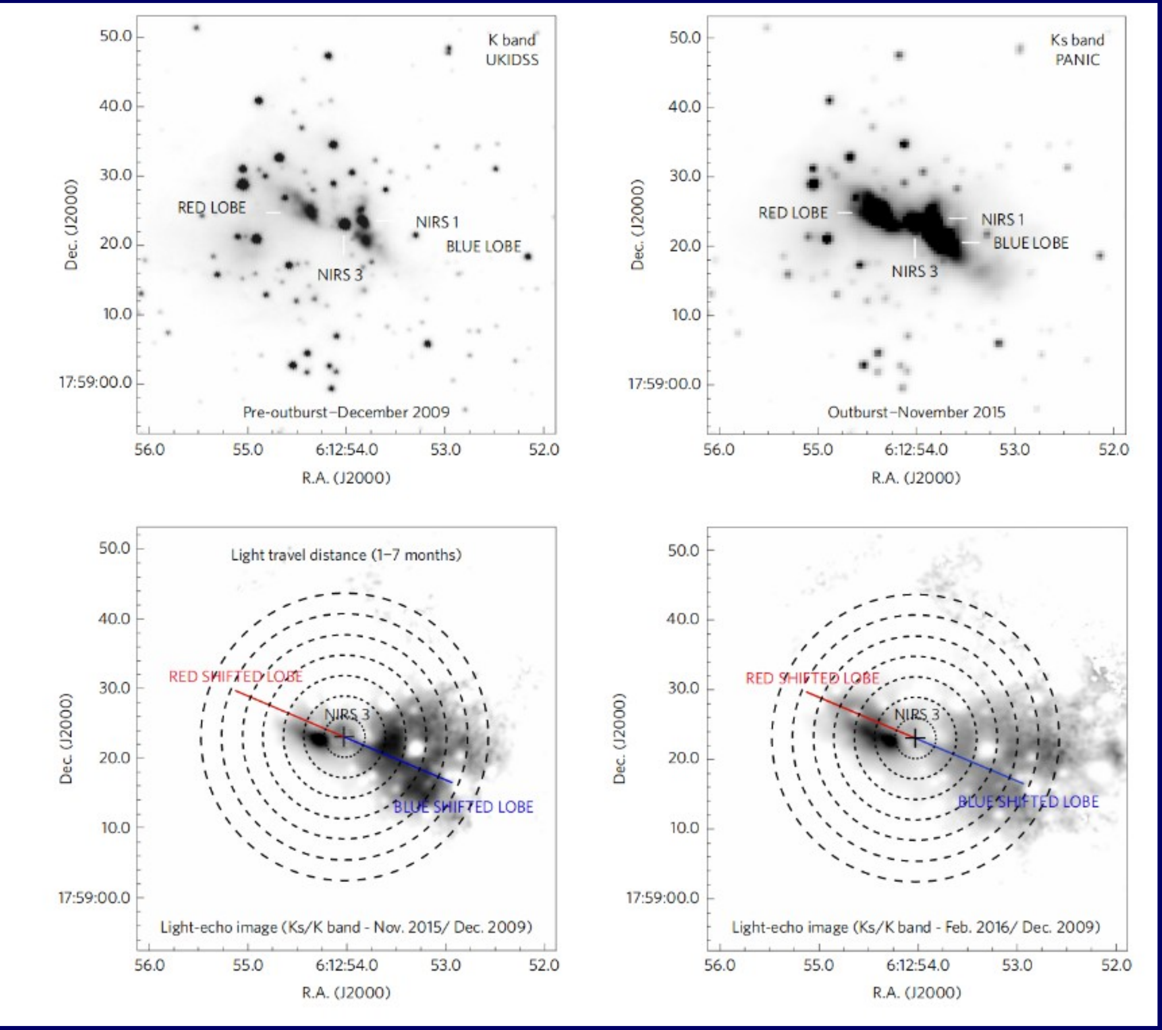
S255 IRS3



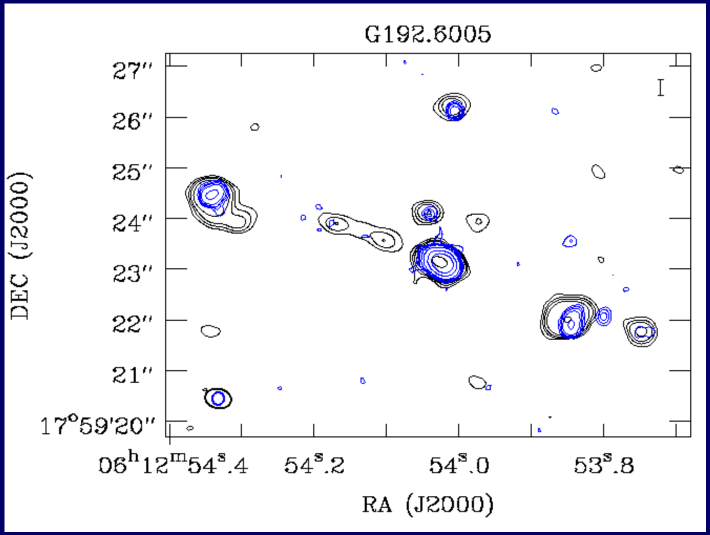
Caratti o Garatti et al 2017 Nature Physics 13 276

Variability - Intensity

S255 IRS3



Obonyo et al 2018 in prep



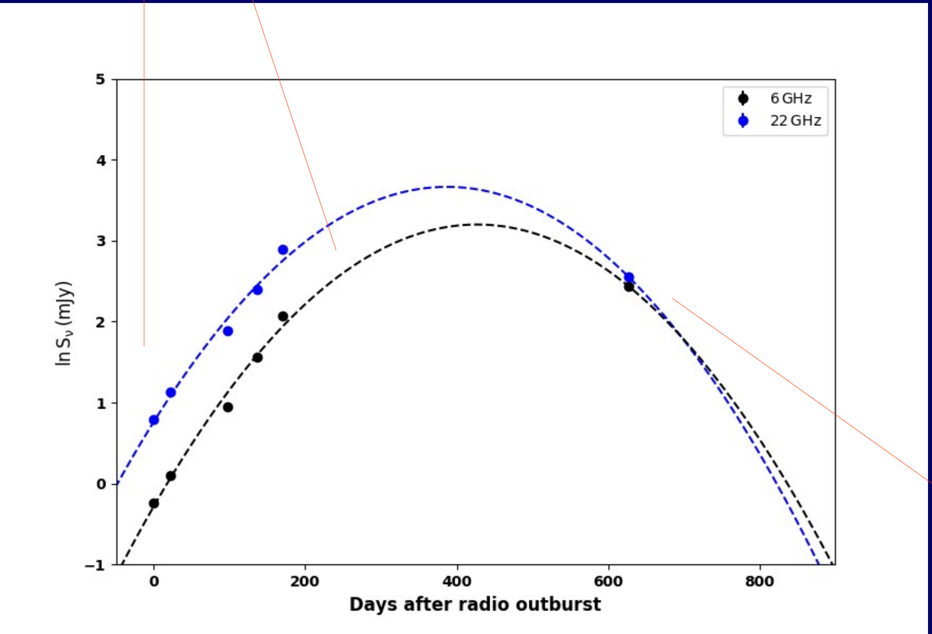
Caratti o Garatti et al

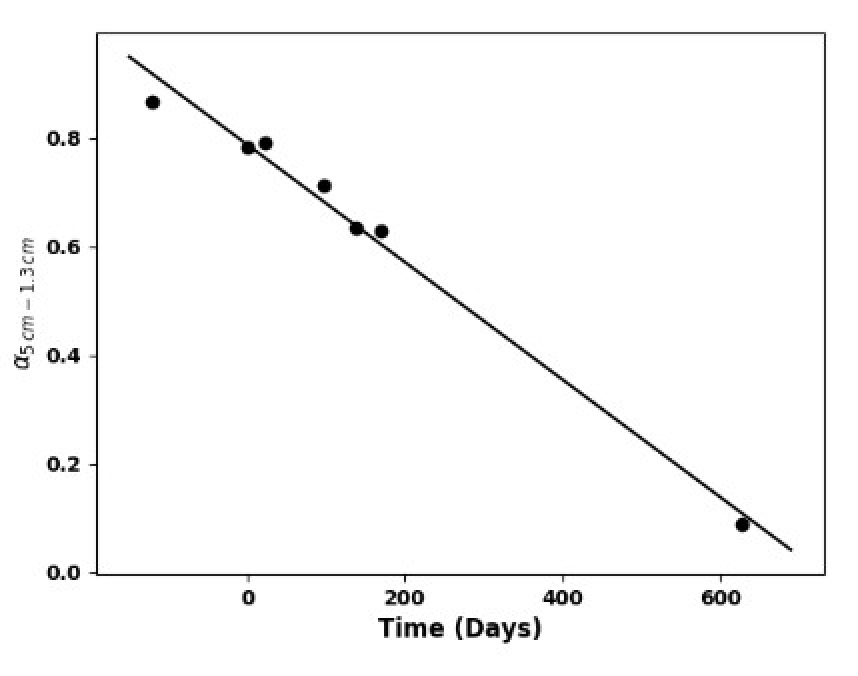
Variability - Intensity

S255 IRS3

Cesaroni et al 2018 A&A 612 103

Episodic accretion?





Obonyo et al 2018 in prep

Model – based on light curve in Meyer et al 2017 MN 464 L90

Massive Protostar Properties

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So, all looks consistent – but…

No correlation in jet properties and near IR properties.

Ditto ratio jets and high resolution sub-mm where it exists.

Massive protostars are complex regions!

Summary

We see thermal jet cores (or potential jets cores) in the vast majority of massive protostars (sorry disc-winds...)

Non-thermal lobes present in a significant fraction

Jet luminosity scales up from low mass case – clump mass the key factor??

IRDCs don't show much evidence of emission, and those that do are more evolved (ie not dark!).

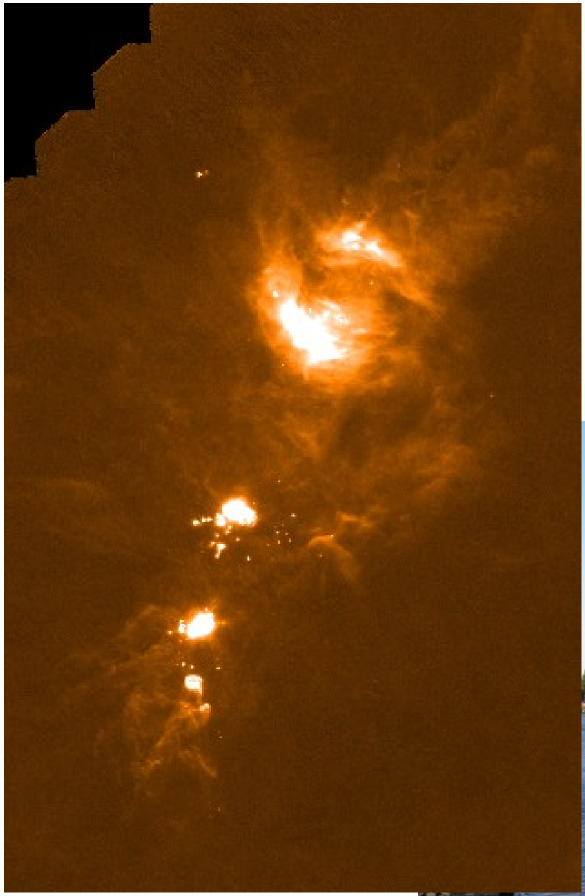
Conclusions pt 2

Near IR data suggests a simple evolutionary sequence, but this does not track to other wavebands.

Both precession and intensity variations seen.

S255 IRS3 suggests spectral type could be linked to present accretion rate as much as evolution.

From Gas to Stars – The Links between Massive Star and Star Cluster Formation,



York, 16th - 20th September 2019, by the river. First announcement due in the autumn.

This conference has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 687528.