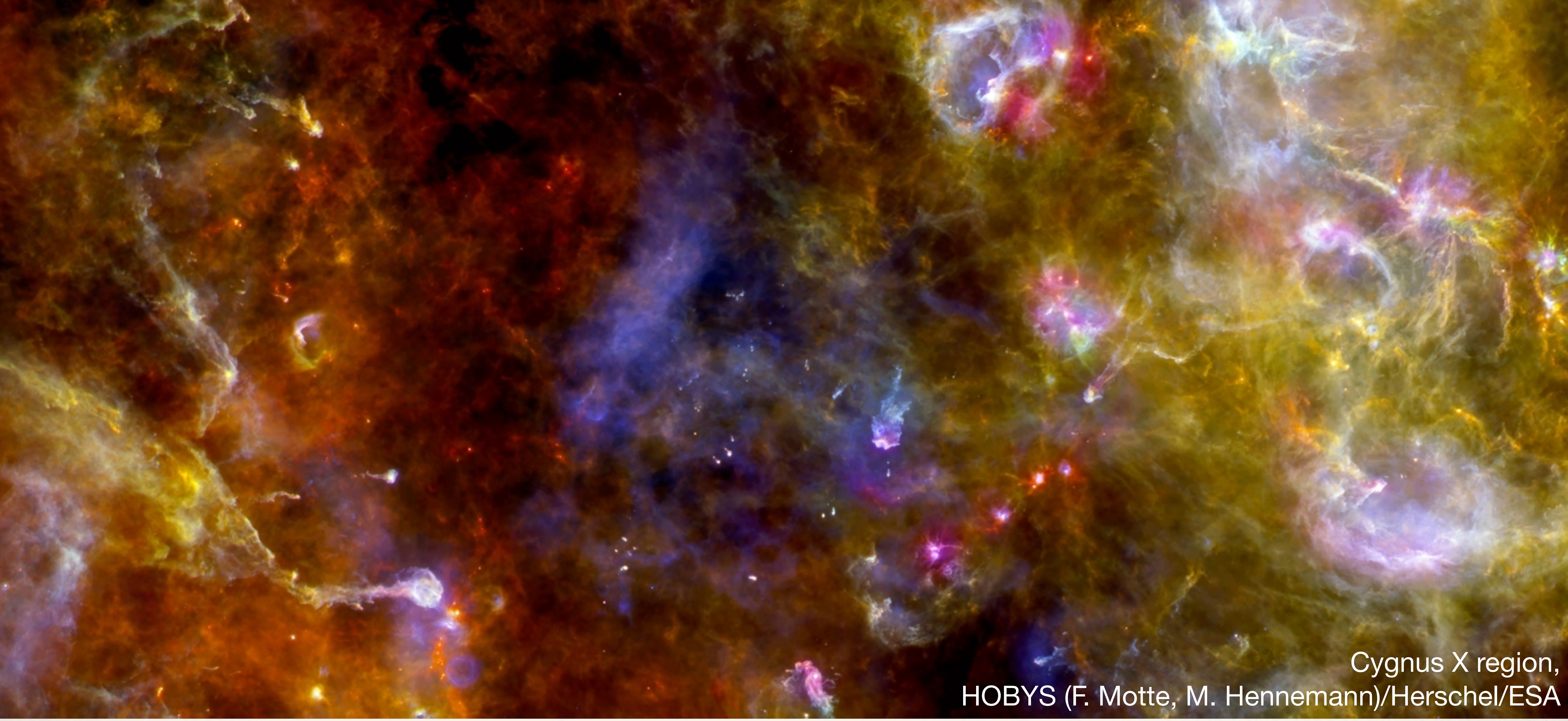


Understanding the tracers of star formation

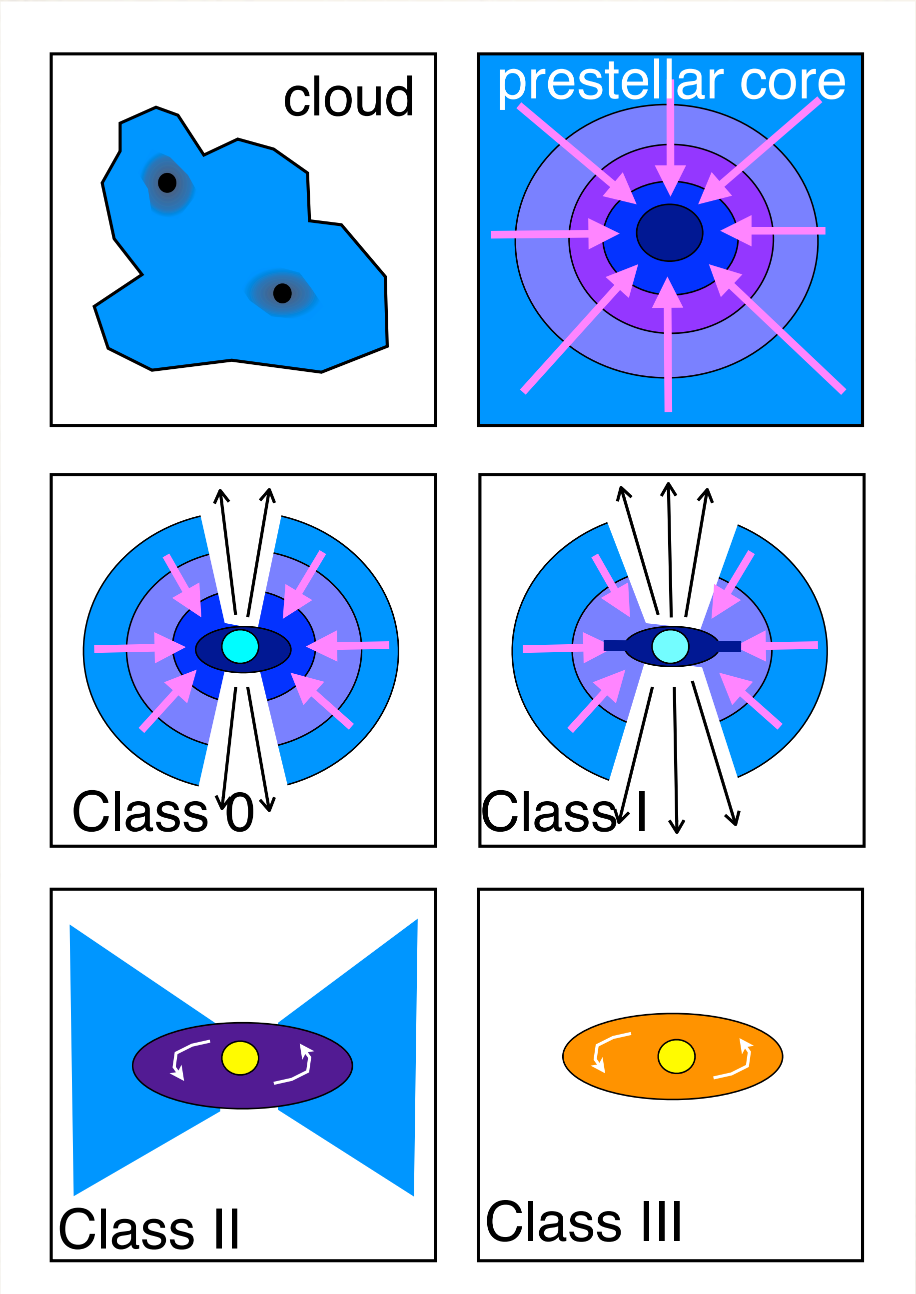
Kazi Rygl (ESA-ESTEC)

22 Jan 2015, Bologna

Overview

- Evolutionary phases of star formation
- Age determinations: W48A Hii region
- Methanol masers as a tracer of a precise evolutionary phase?
- Accepted Effelsberg proposal: do all methanol masers pinpoint objects with already formed stars?

Phases of low-mass star formation



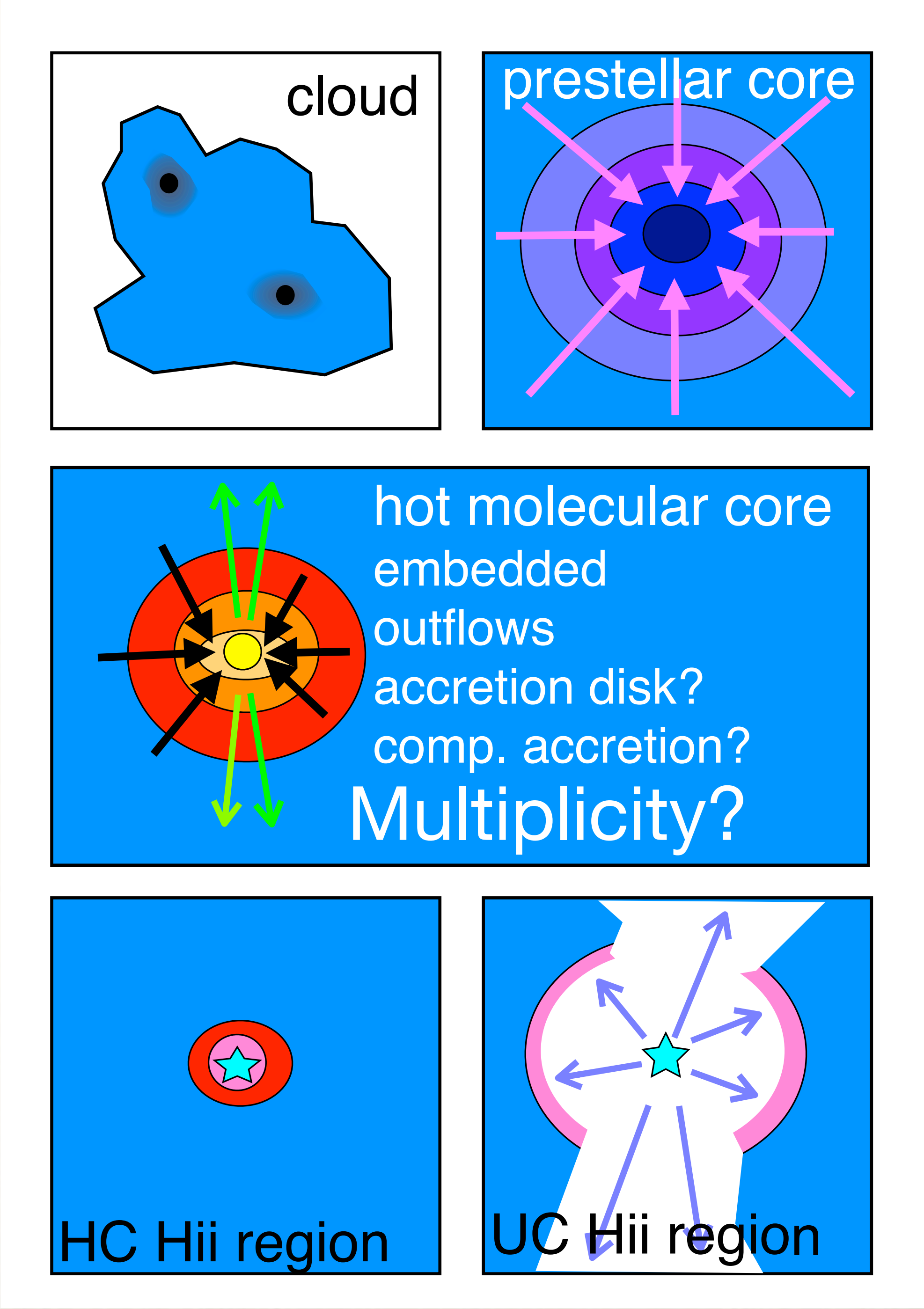
Rygl+ 2014, after Hogerheijde 1998

- From observations of nearby (100-400 pc) Gould Belt clouds in mm, submm, IR, near infrared
- Rough idea of lifetimes of each phase
- Evolution of low mass stars, disks, acceleration/deceleration of star formation, causal relations with surrounding etc. etc.

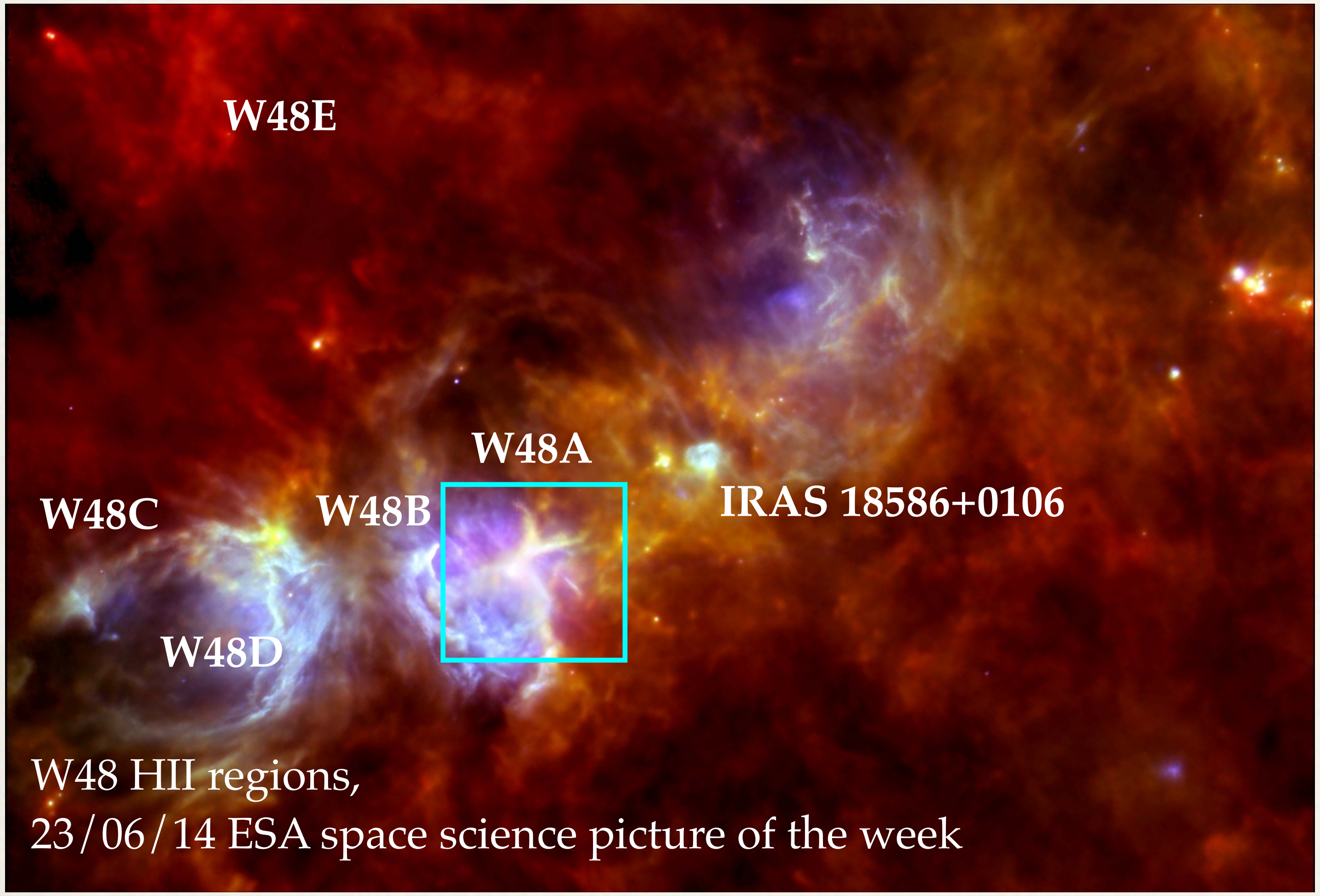
prestellar core	0.5 Myr	Enoch+ 2008
Class 0	0.05 Myr	Froebrig+ 2006
Class I	0.84 Myr	Evans+ 2009
Class II	2 Myr	Evans+ 2009
Class III	10 Myr	Andre+ 2002

High-mass star formation ($> 8M_{sun}$)

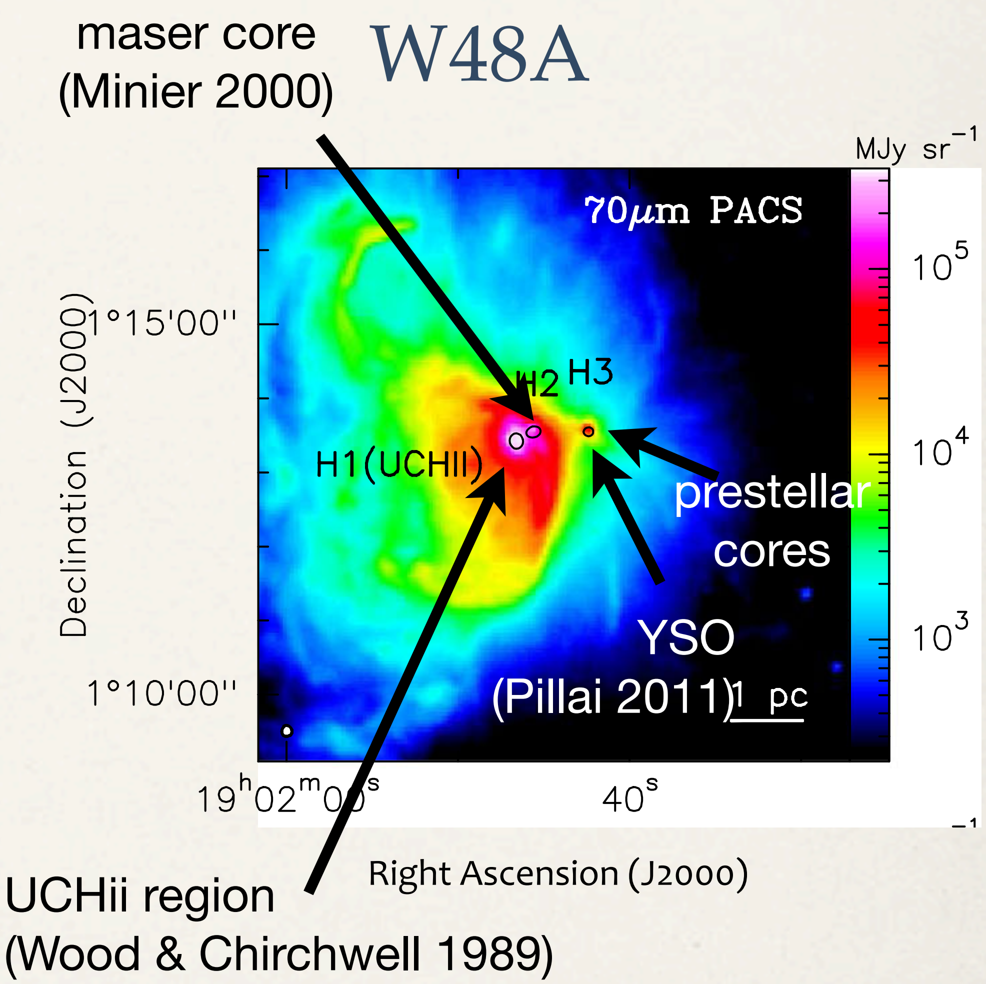
- Many open questions
- Form deeply embedded, few, far away (>kpc)
- Difficult to observe (resolution, sensitivity)
- Rough age of final star few Myr, so all stages must have short (< Myr) lifetimes. UC Hii regions have ages of 10^5yr (Wood & Churchwell 1989, Motte+ 2007).
- Age estimation through models (mass, luminosity), statistics (counting), and chemistry



W48A: Age gradient real?

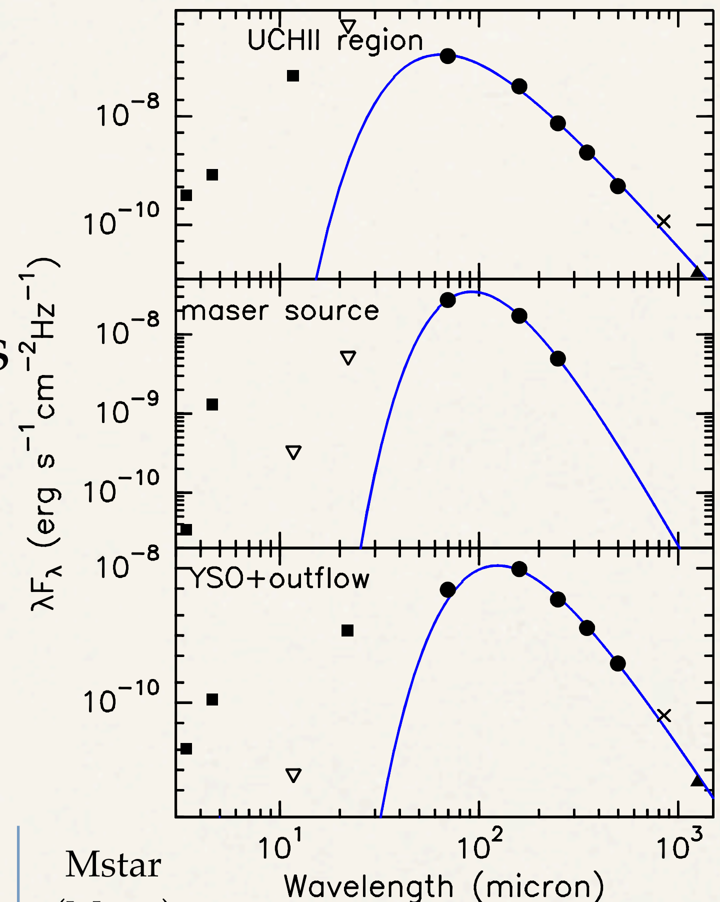


Part of the *Herschel* Imaging suvery of OB young stellar objects (HOBYS, PI: F. Motte)

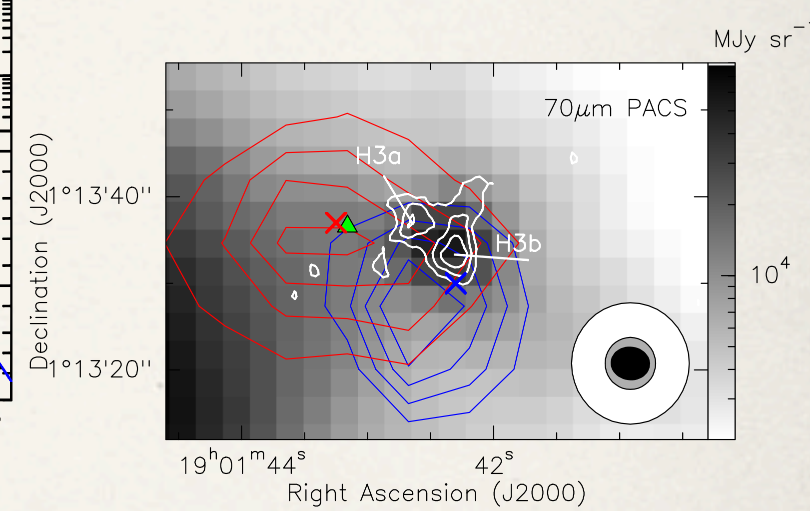


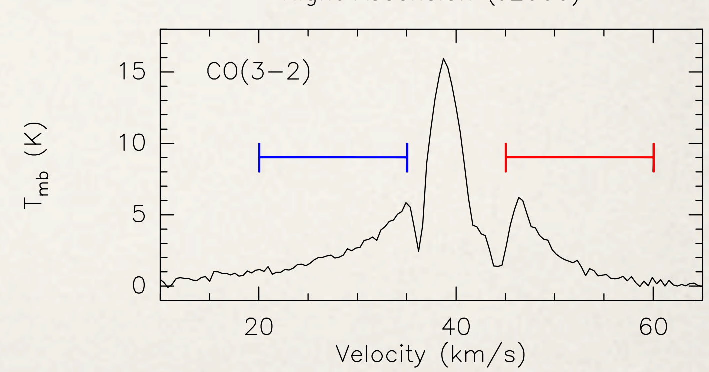
Age estimations in W48A

- from SED (M_{env}, L_{bol}) compared to model prediction (Molinari+ 2008)
- using chemistry and kinematics: masers, $[CH_3CN]/[NH_3]$, CO outflows
- Indicative age gradient found, though uncertainties are large
- Objects similar mass: evolutionary gradient most likely age gradient



SEDs using BIMA, SCUBA, Herschel, WISE data





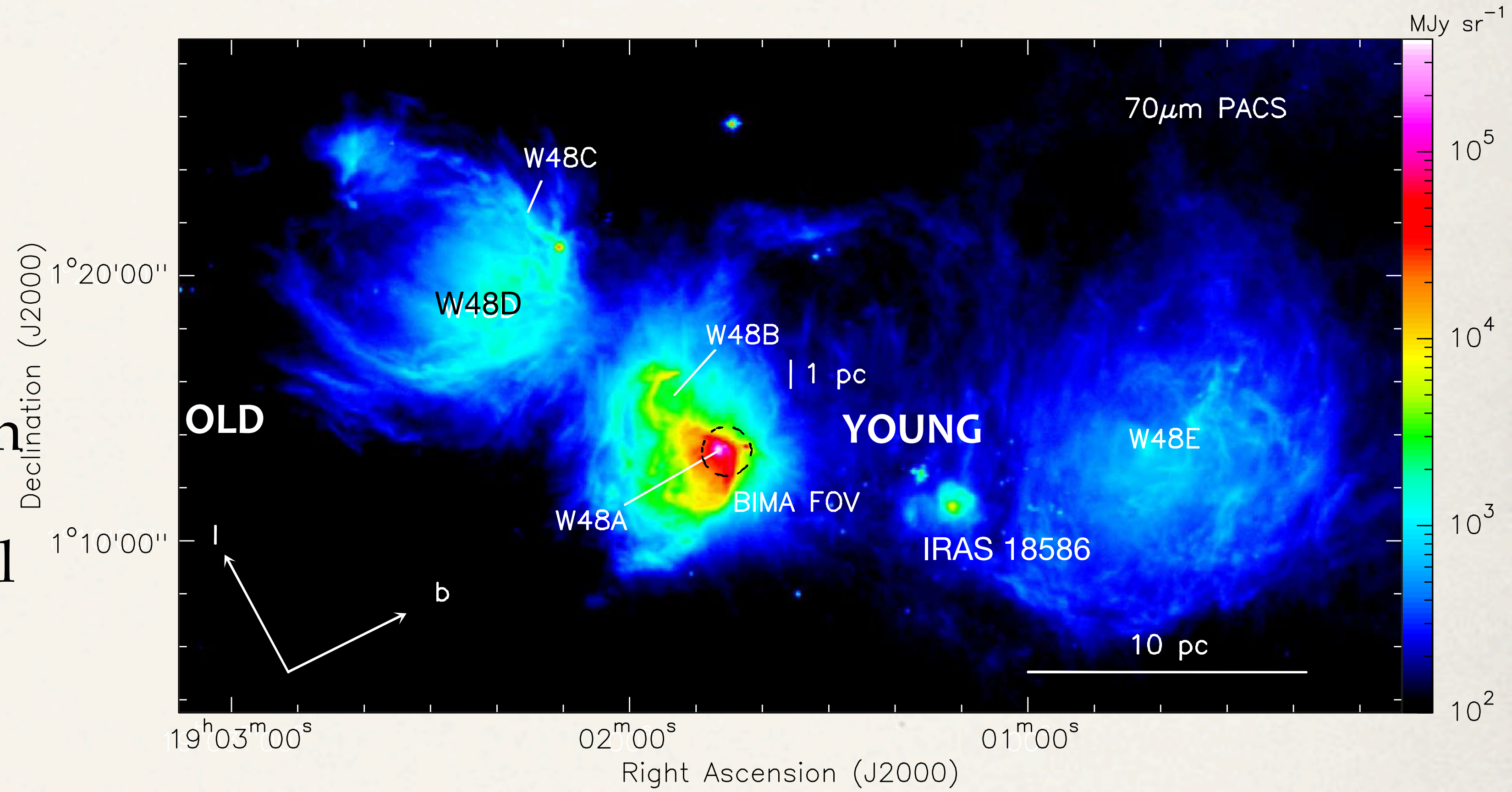
Object	L/M diagram (10^5 yr)	Lit	Mstar (Msun)
UCHii region	7.5 (2-13)	~10^5 yr (W&C 1989)	18-28
maser core (CH3CN core, no radio)	8.0 (6.5-9.5)	~<10^5 yr (Walsh 1989)	8-13.5
YSO (CH3CN core, outflow)	1.5 (1-2)	5x10^4 yr (Cazeaux 2003), 6x10^4 yr (Charnley 1992)	13.5-18
massive prestellar cores		Deuteration (Pillai 2011)	

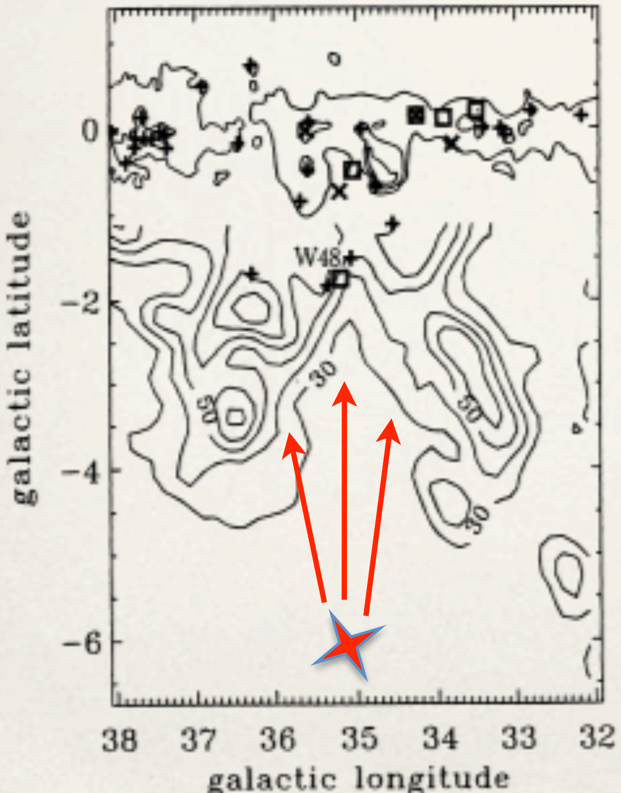
Outflow in YSO

Rygl+ 2014

Origin of this age gradient?

- W48A: not triggered, age spread too small
- Large scale: evolutionary estimations of W48 Hii regions from compactness 21 cm emission
- W48 formed by Aquila supershell





Aquila supershell
Maciejewski+ 1996

Table 5. 21 cm emission properties of the W 48 H II regions.

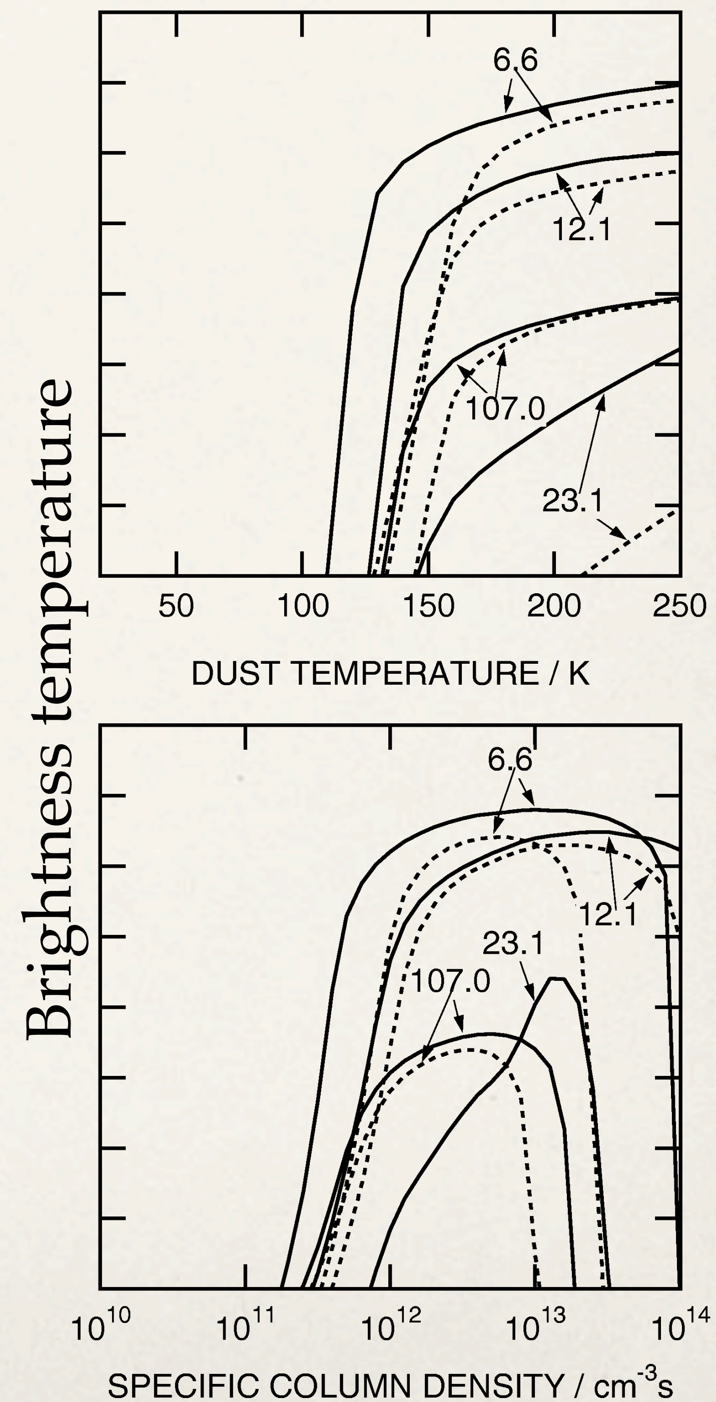
H II region	Size (arcsec, arcsec)	Peak flux (Jy beam^{-1})	Int. flux (Jy)	I/P
W 48A	74, 72	4.9	12.8	2.6
W 48B	118, 84	0.12	0.6	5.0
W 48C	50, 49	0.16	0.2	1.3
W 48D	221, 169	0.097	1.8	185.5

Notes. Columns are (from left to right): name; size in major and minor axis at FWHM; peak flux; integrated flux; ratio of integrated to peak flux.

Rygl+ 2014

Methanol as a tracer

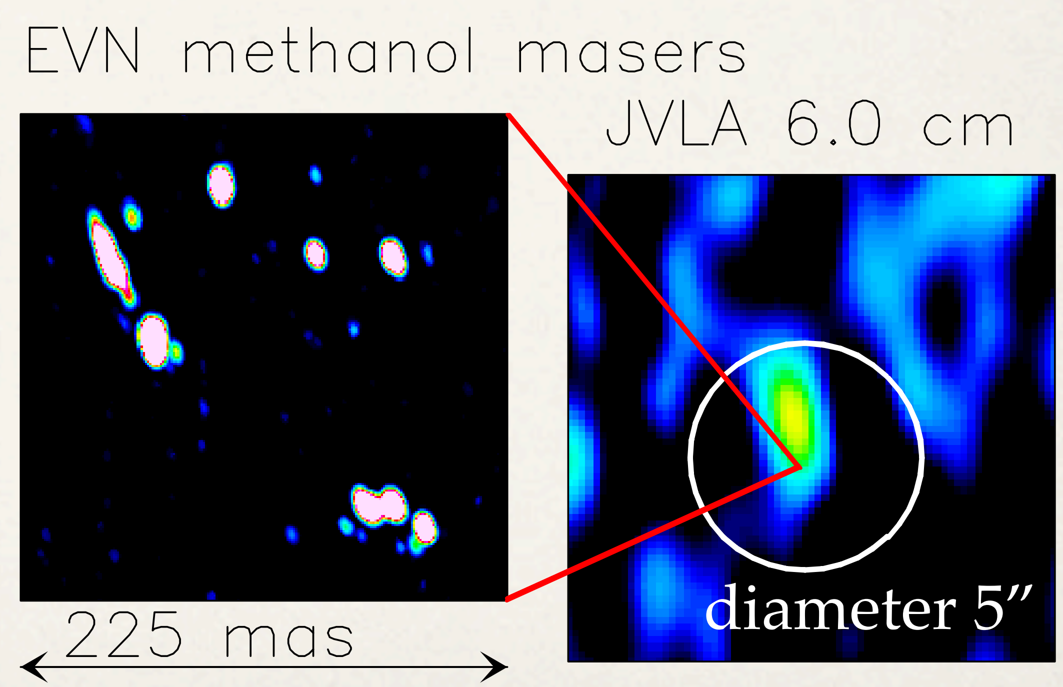
- 6.7 GHz methanol masers (class II) might be an excellent timer
- lifetime short enough ~4x10^{4}yr (van der Walt 2004) with respect to the lifetimes of HC and UC Hii regions (10^5 - 10^4 yr)
- Bright, many known sources (Pestalozzi+ 2005, Green+ 2012, and more)
- Exclusive tracers of high-mass forming objects (Breen+ 2013)
- mostly pumped by IR radiation from warm dust (Sobolev & Deguchi 1994) > forming star or star inside



Cragg+ 2005

What phase traced by 6.7 GHz masers?

- Up to know, 6.7 GHz excited before or in early stage of UC Hii region phase (Walsh+ 1998) due to few detections of radio cont. toward masing sources
- New JVLA data (Hu in prep.) for BeSSeL observation show a high percentage (37%) of continuum (free-free) using 20s snapshots (3σ 0.15 mJy/beam)
- **Do all 6.7 GHz masing sources contain weak free-free emission? Do they all contain an embedded high-mass star?**

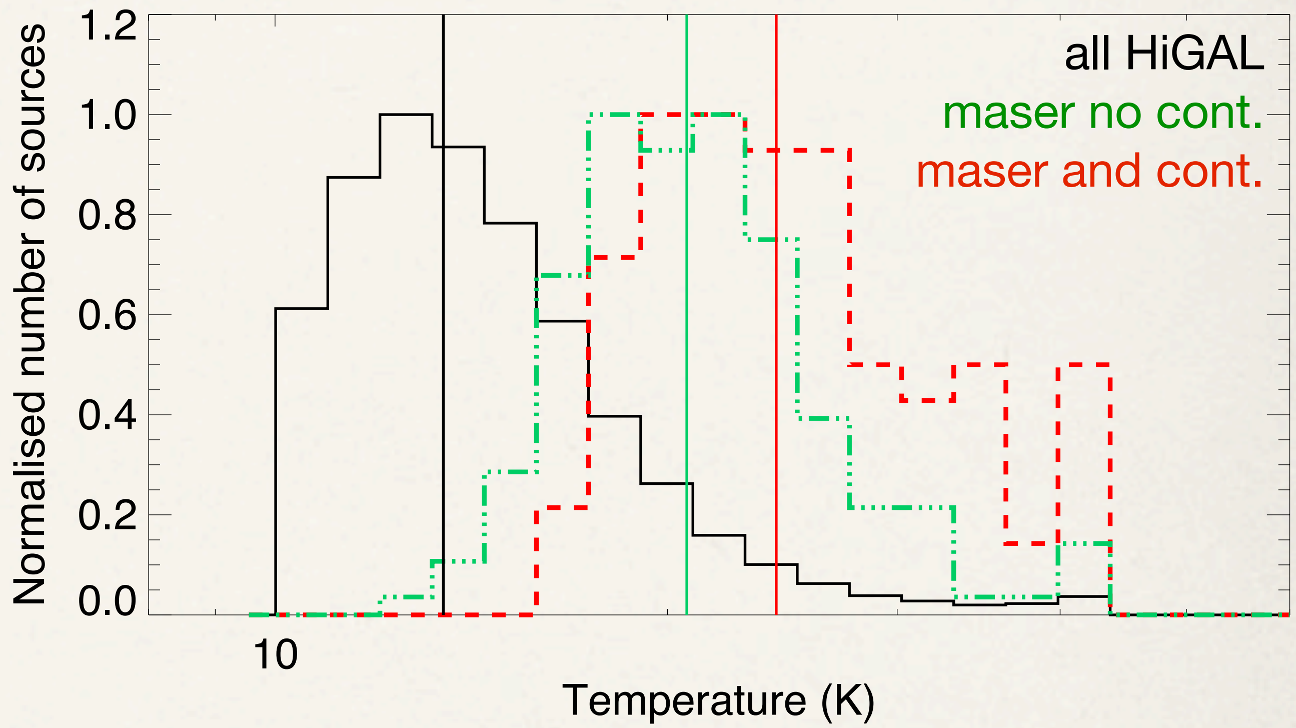


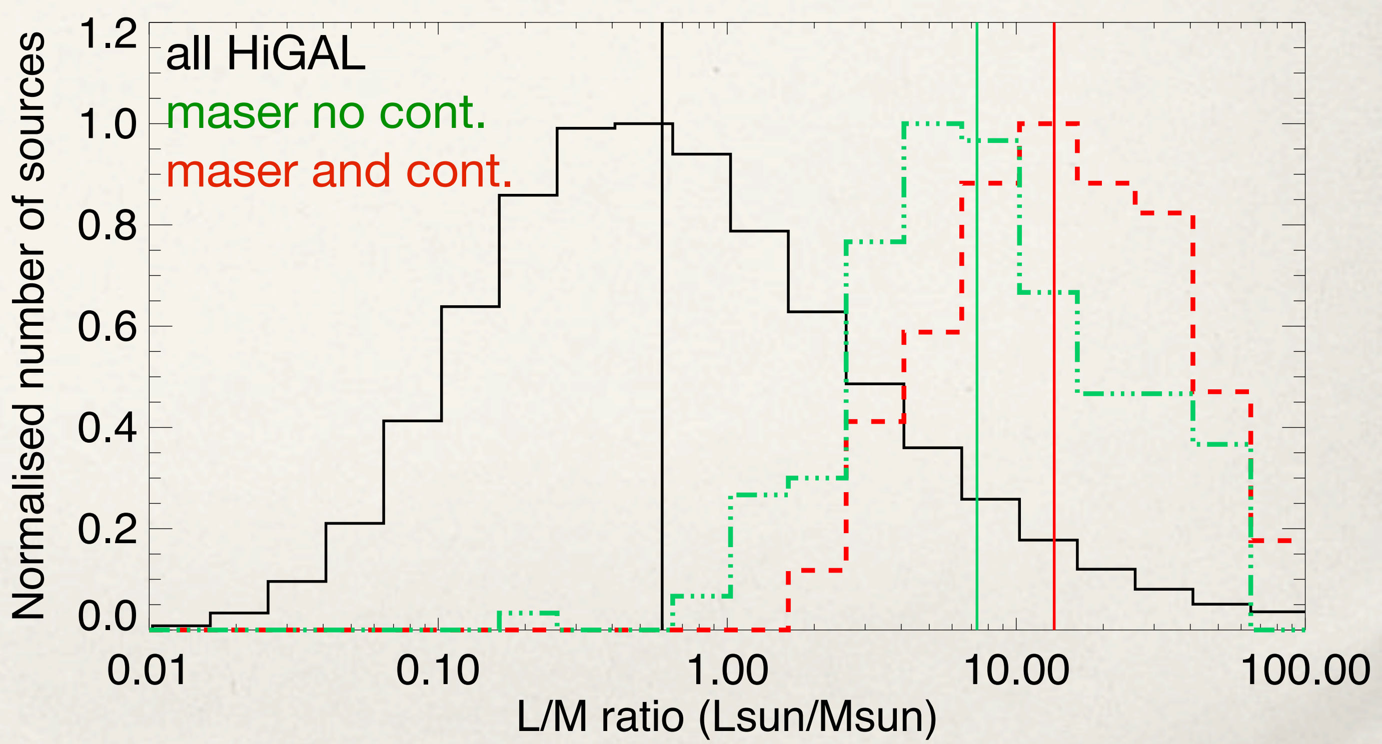
Bartkiewics et al 2009, no continuum emission
Hu in prep, 0.25 mJy/beam detection

Detecting the first light of high-mass stars

Rygl, Hu, Bartkiewicz, Traficante, Elia, Molinari

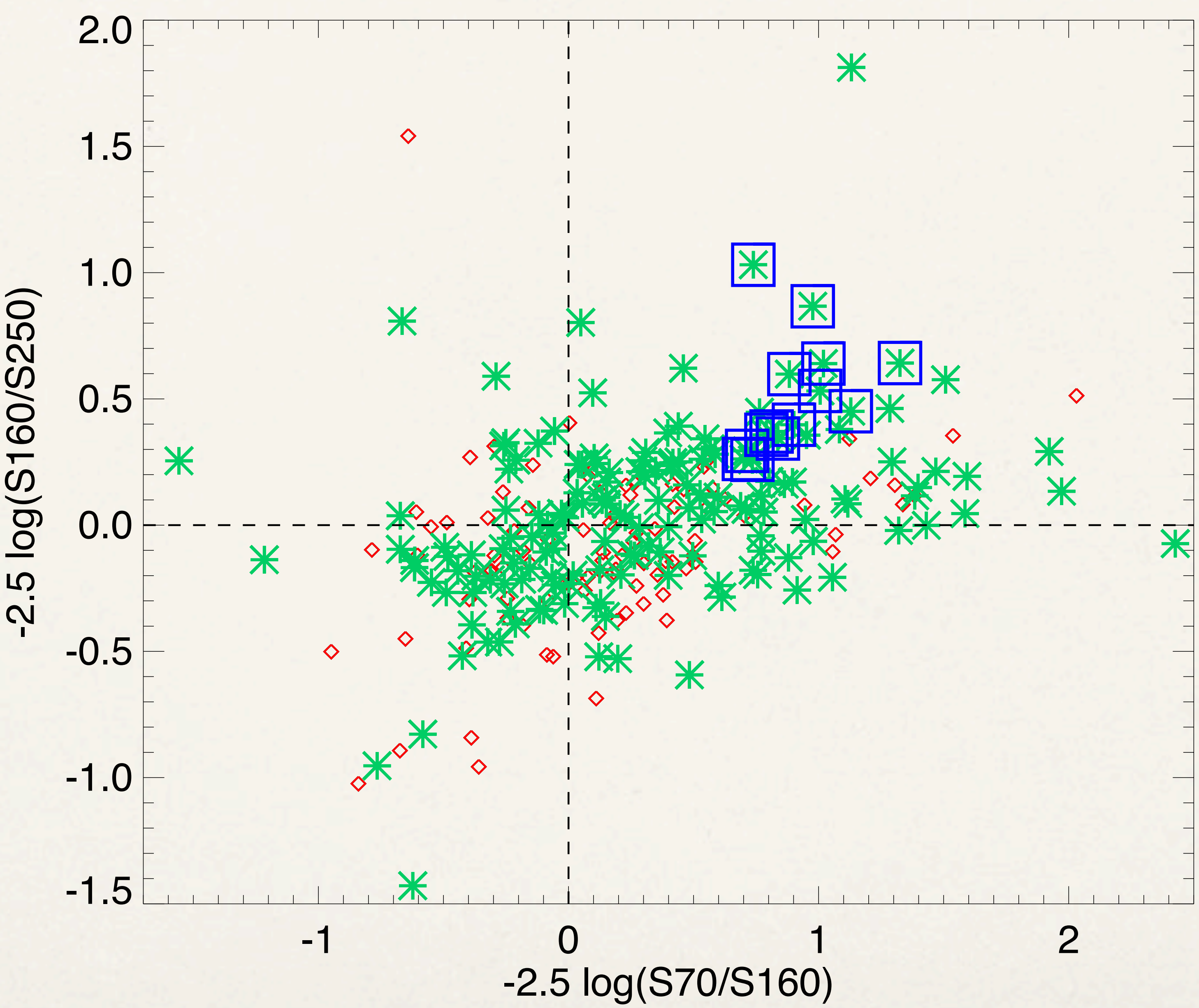
- Investigate 8 young 6.7 GHz methanol masing sources at 2.8 and 0.9 cm to detect radio continuum and measure the slope
- Targets: masers with no continuum, which are young based on *Herschel* colors
- Effelsberg observations expected to be done this winter/spring :)





Summary

- Age estimations are important for understanding star formation, and the relation of the star-forming object with the environment
- Various methods exist to estimate ages, all with their own uncertainties
- We are exploring the usage of 6.7 GHz methanol masers to trace the earliest stellar stages by trying to detect continuum emission toward young masing objects with the Effelsberg telescope



<Tdust>~ 17.5K

<L/M>~2.7 Lsun/Msun