Feedback and accretion toward proto-O-stars

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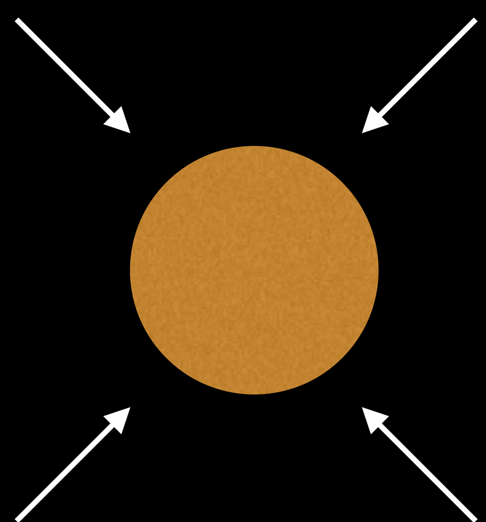
https://github.com/keflavich/W51_ALMA_2013.1.00308.S

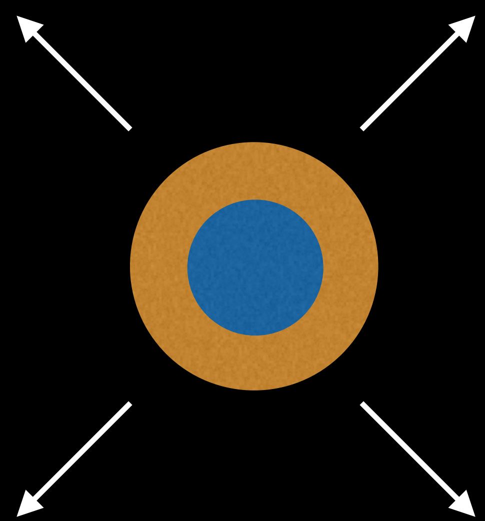
A short history of high-mass star formation theory

thanks to Schilke 2016 and Tan+ 2014 reviews

Spherical Accretion

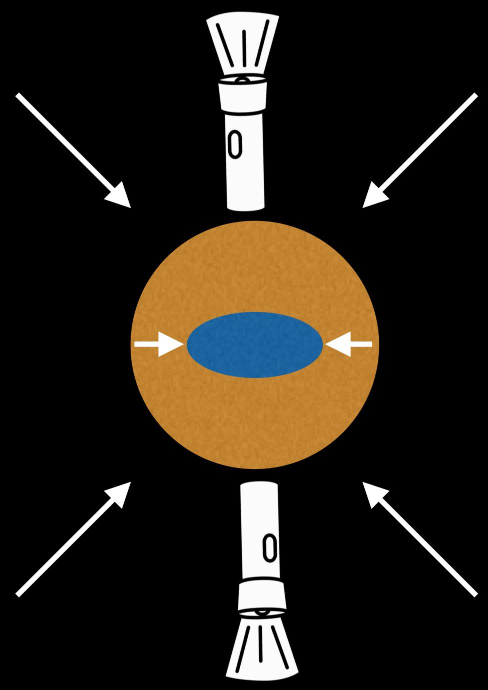


Short KH timescale: feedback stops accretion



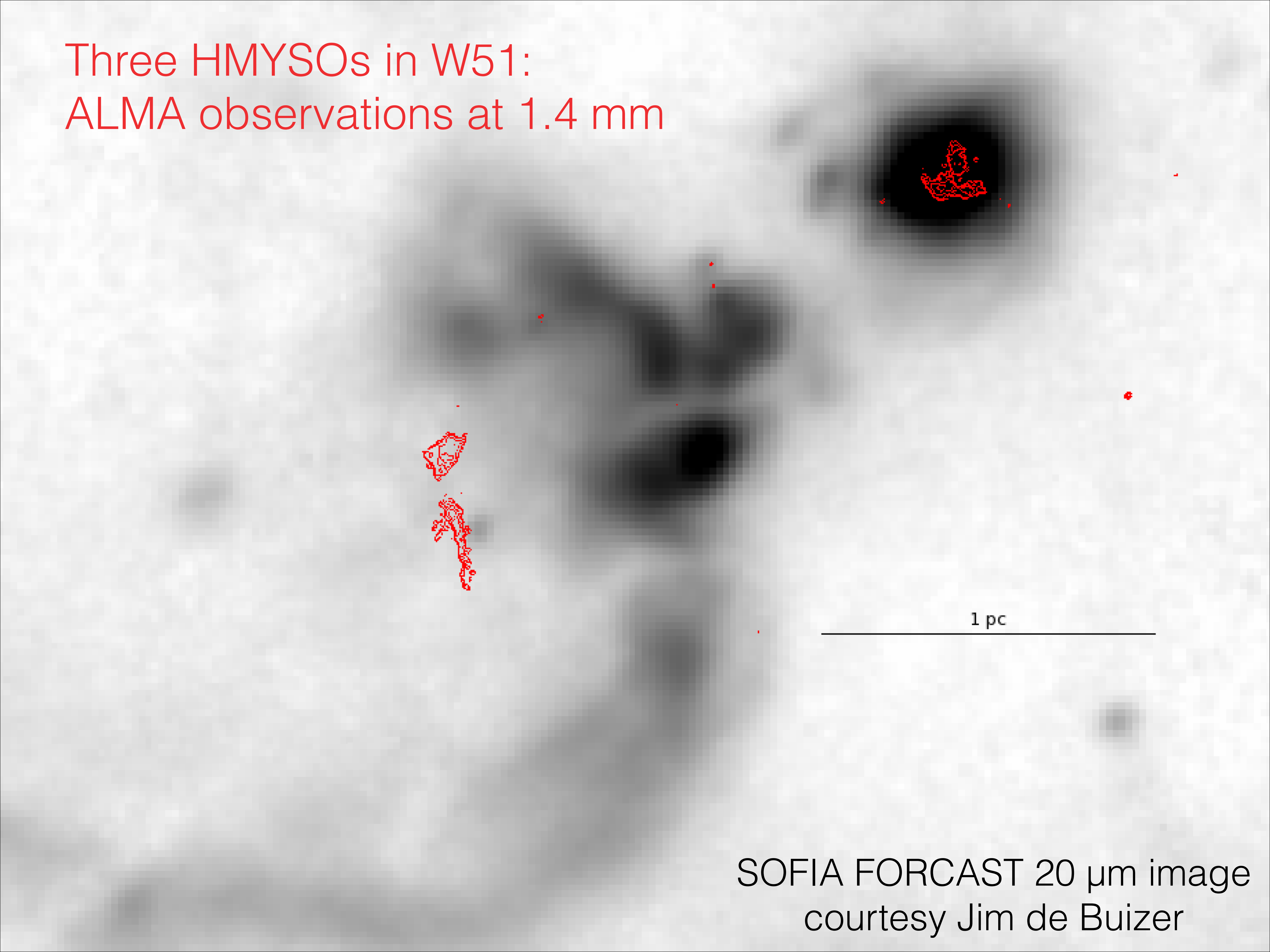
Larson 1969, Shu 1977, Kahn 1974 ->
Wolfire & Casinelli 1987

Flashlight effect: Outflows let light out, disks let mass in

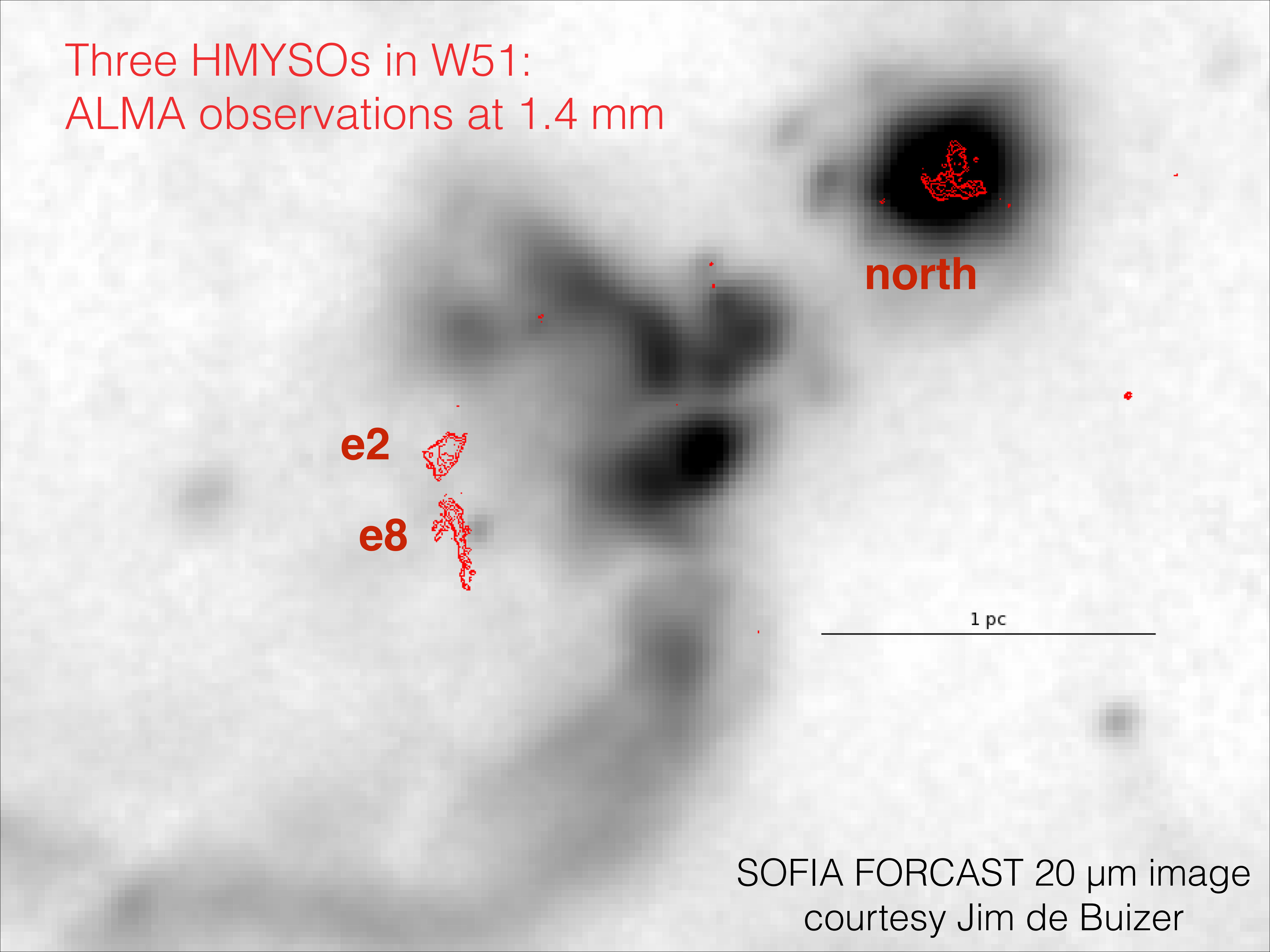


Yorke & Sonnhalter 2002
Kuiper+ 2012, 2013, 2015, 2016
Krumholz+ 2005, 2009
Rosen+ 2016

Ionized accretion flow (Keto 2002, 2003)


Three HMYSOs in W51:
ALMA observations at 1.4 mm
1 pc
SOFIA FORCAST 20 μm image
courtesy Jim de Buizer

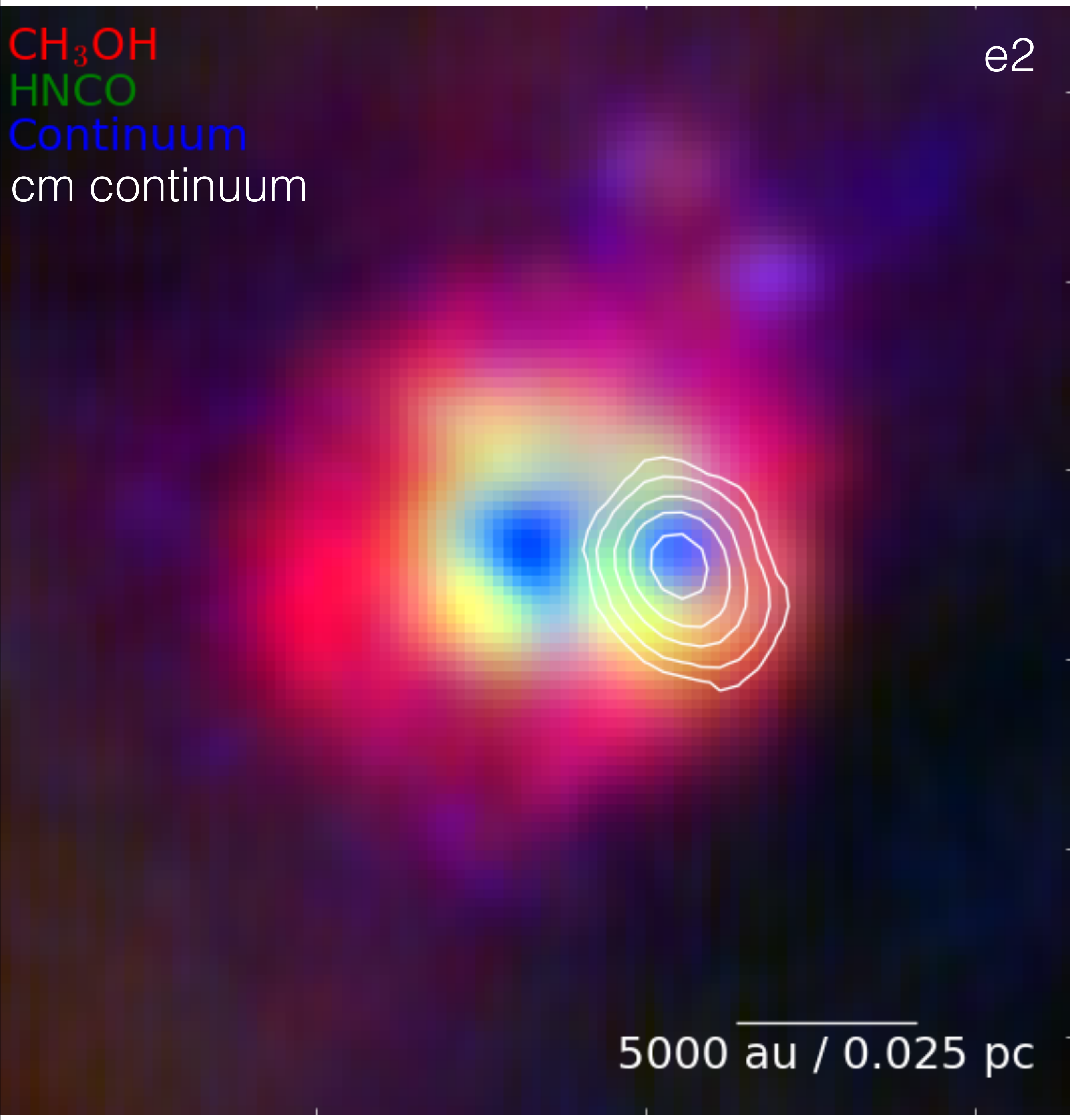
Three HMYSOs in W51: ALMA observations at 1.4 mm

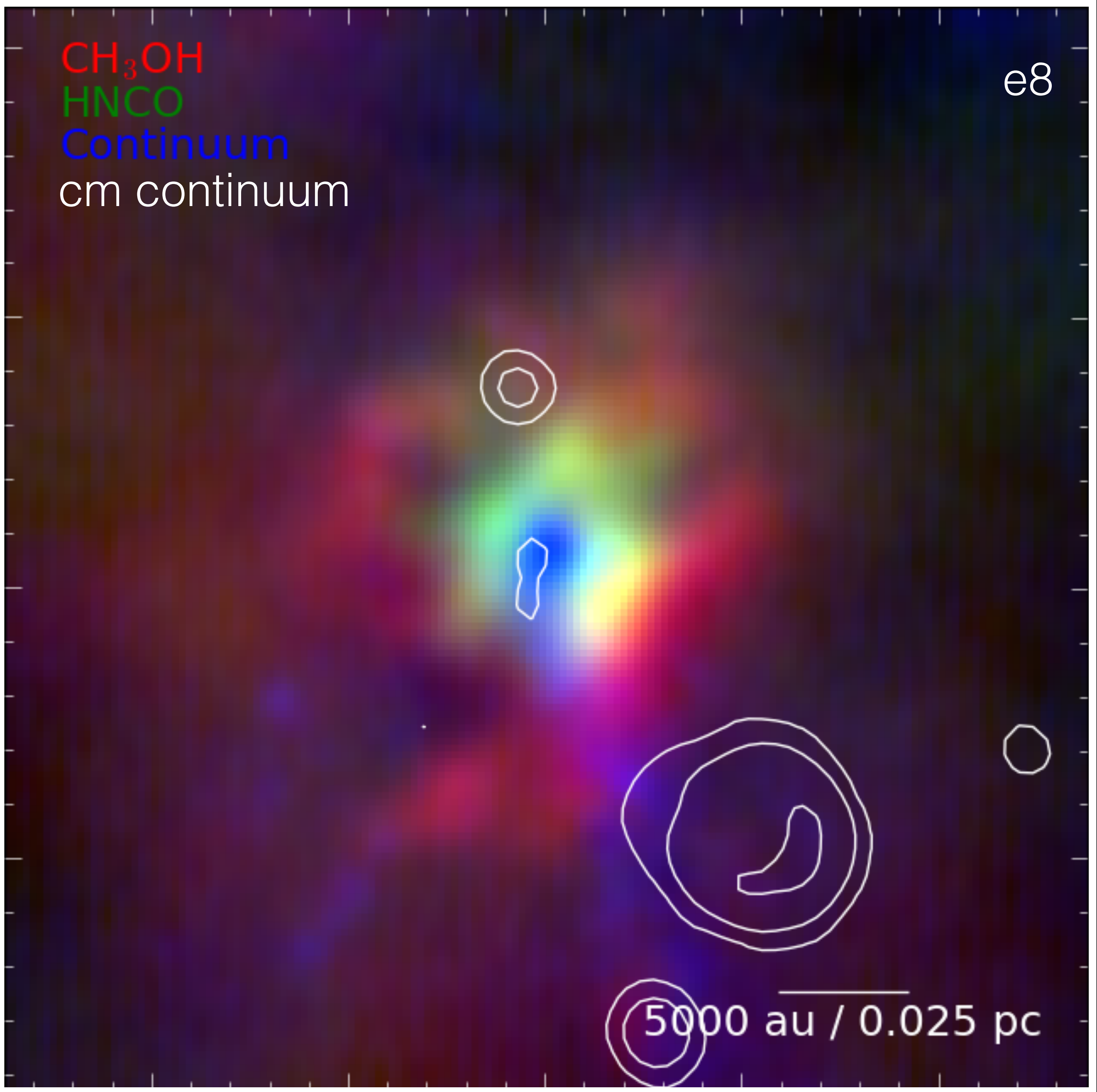


SOFIA FORCAST 20 μm image courtesy Jim de Buizer

Part 1: Cores & Feedback

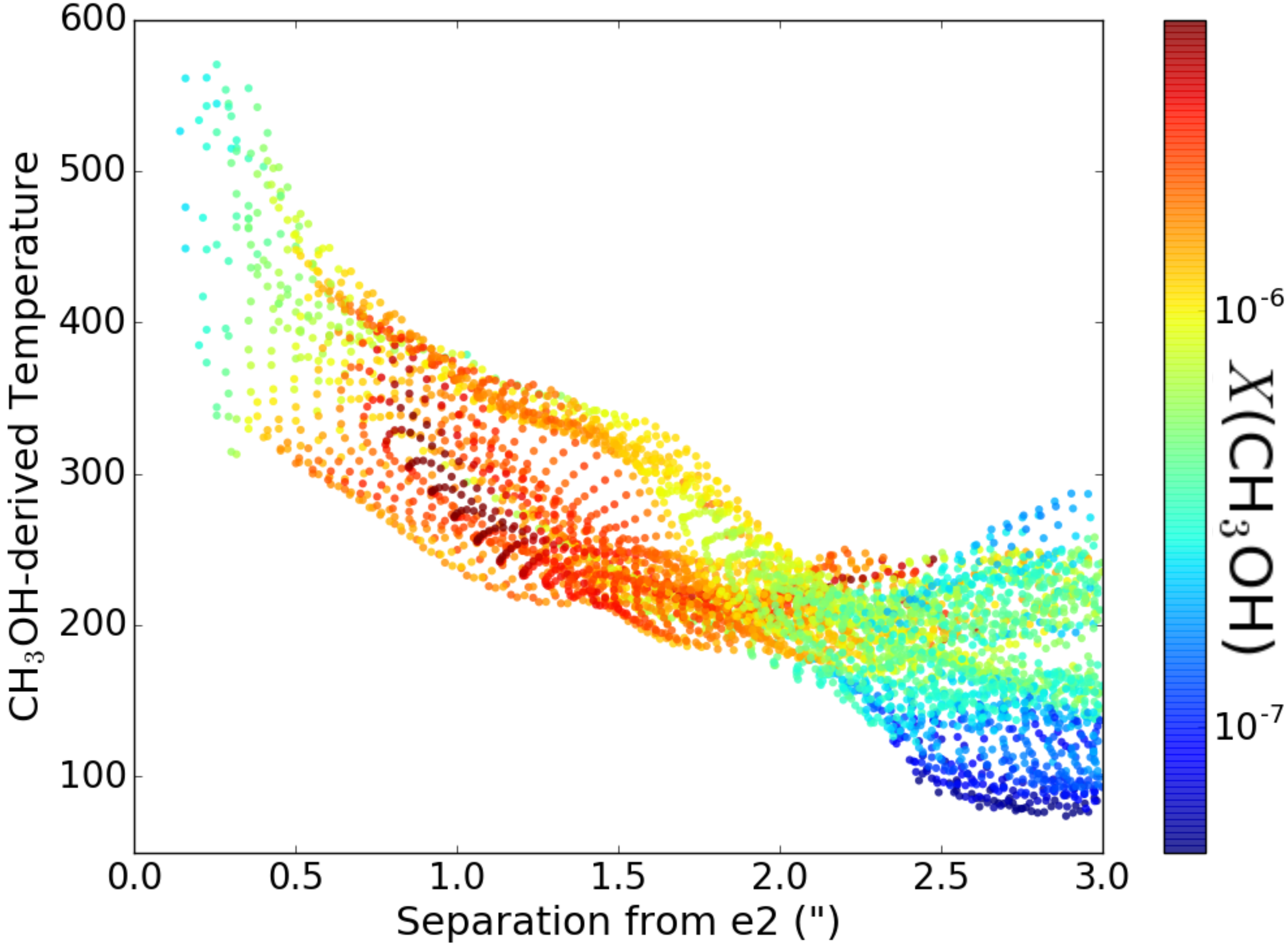
- HMYSOs are near HCHII regions
- Warm gas (enhanced complex molecule abundance) surrounds HMYSOs
- The gas around HCHII regions is not generally warm (or dense)

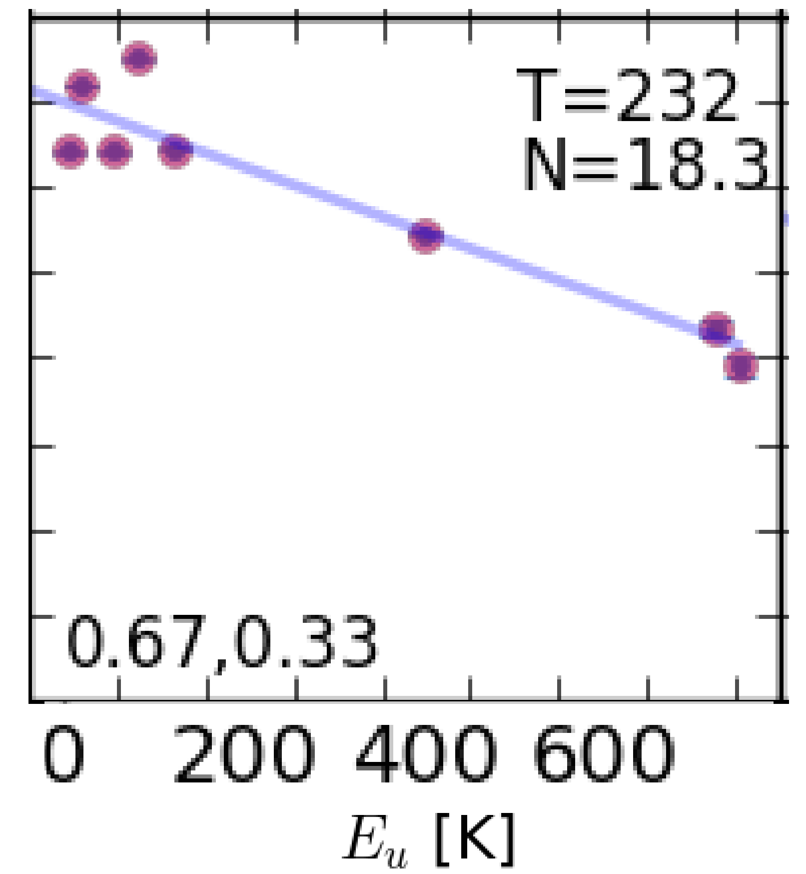


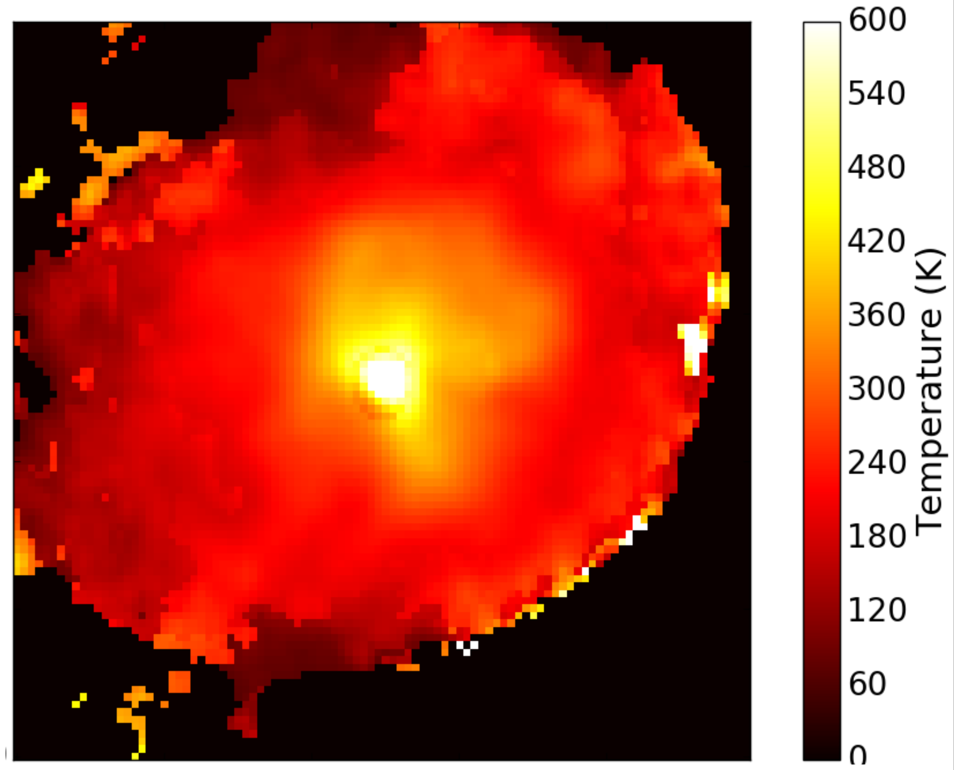


The gas around the HYMSOs is warm, 200-600 K out to $r<10^4$ au

(resolution ~1000 AU)

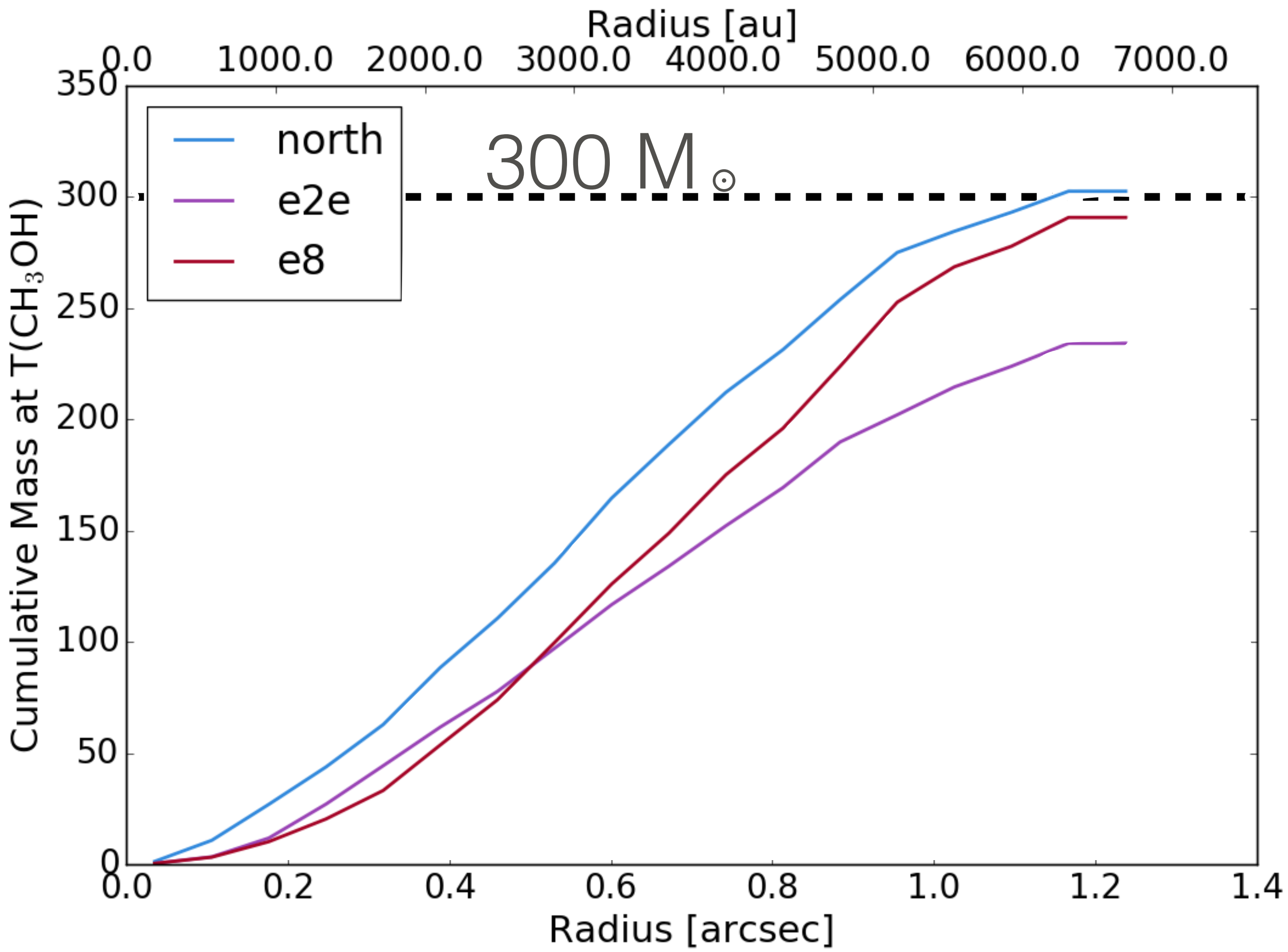




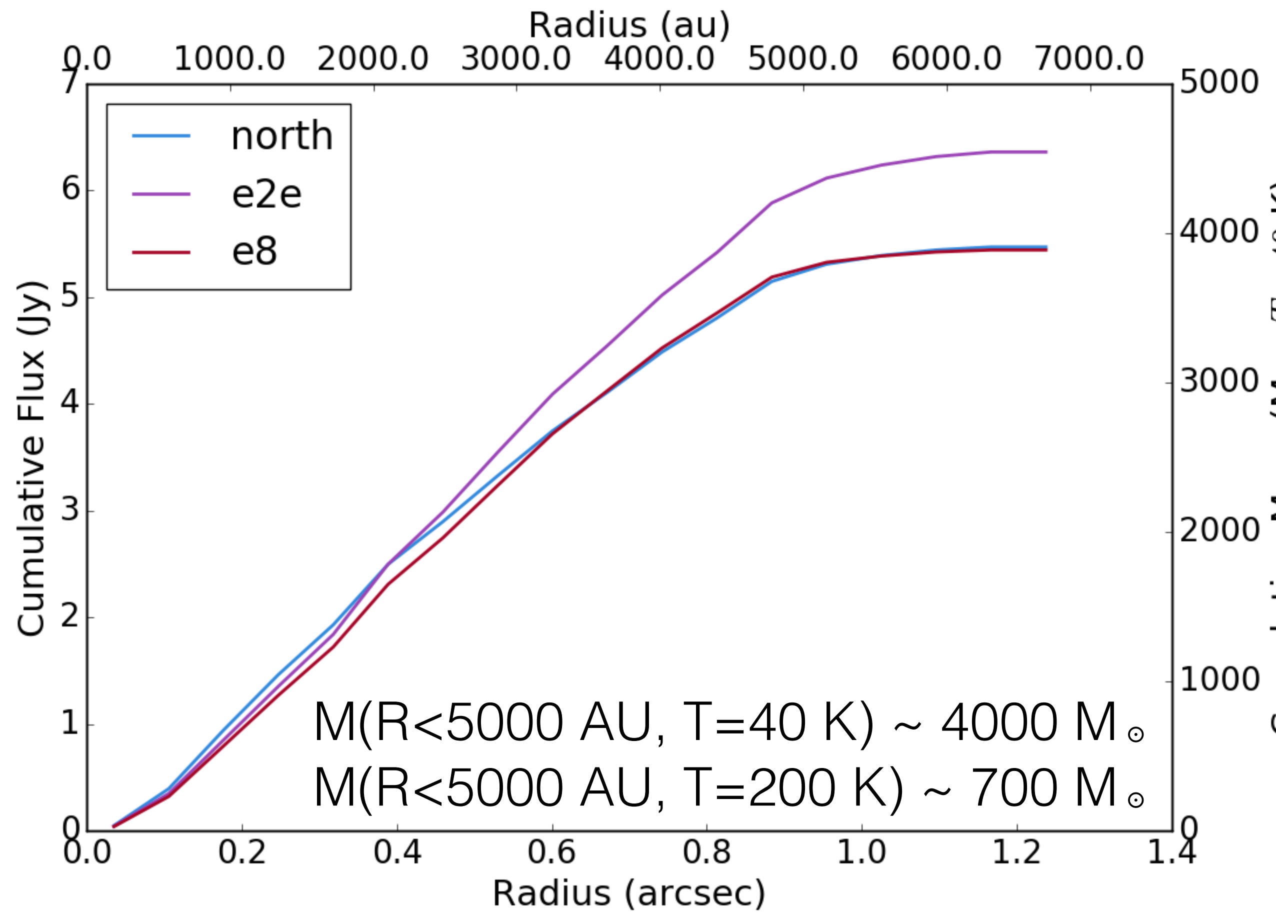


The warm gas mass is large, at least hundreds of $M_\odot$

Conservative



"Standard" assumptions



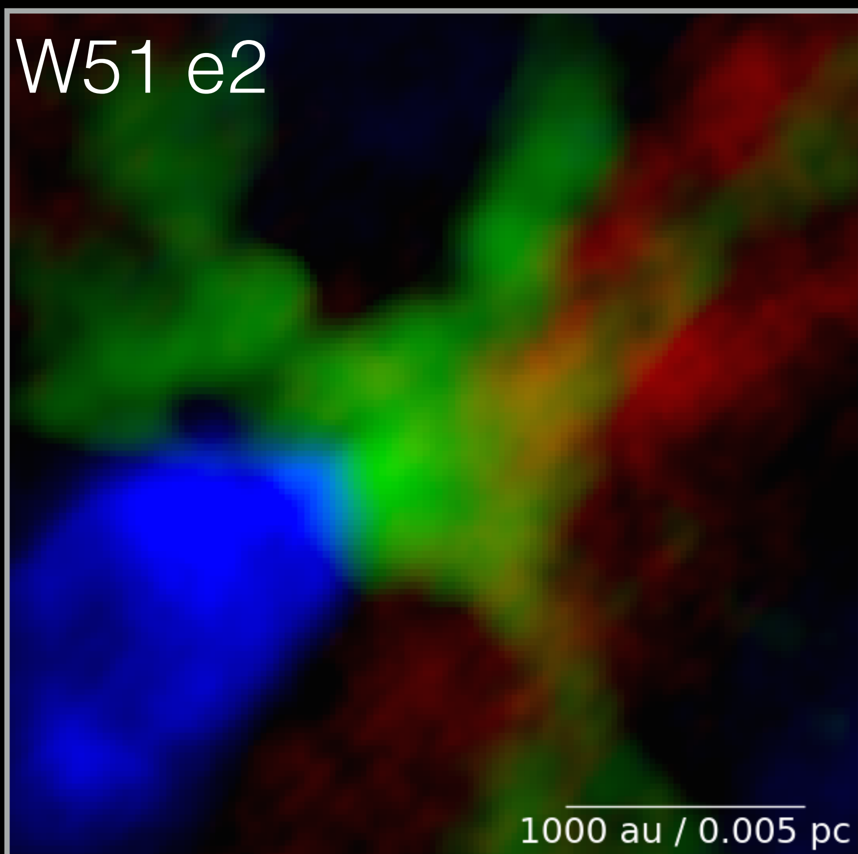
Forming MYSOs can heat enough of their surroundings to suppress fragmentation and keep a "food source" available

Part 2: Disks & Outflows

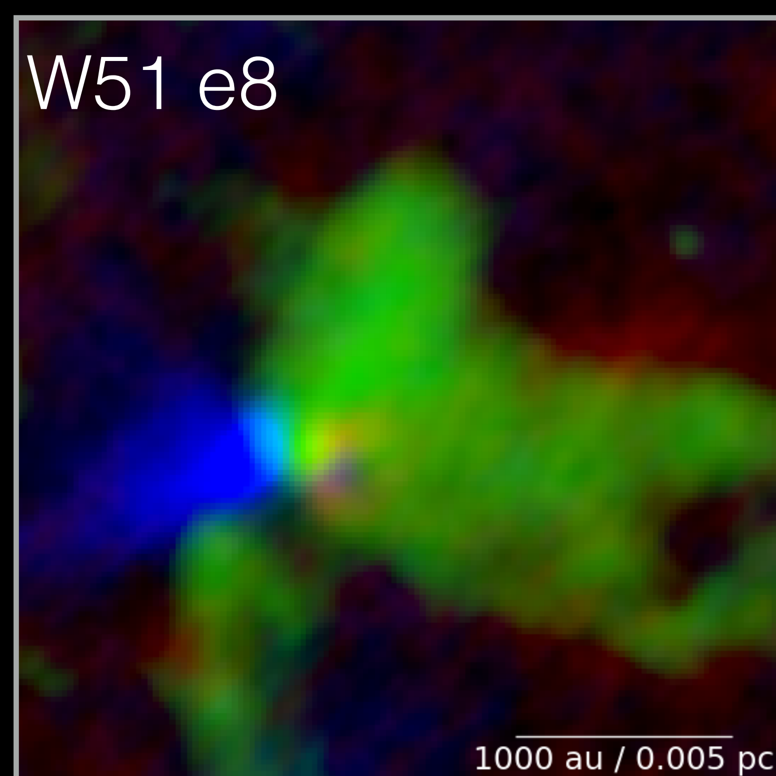
- SiO outflows reveal the presence of disks on <200 AU scales
- But there are no 1000+ AU scale disks

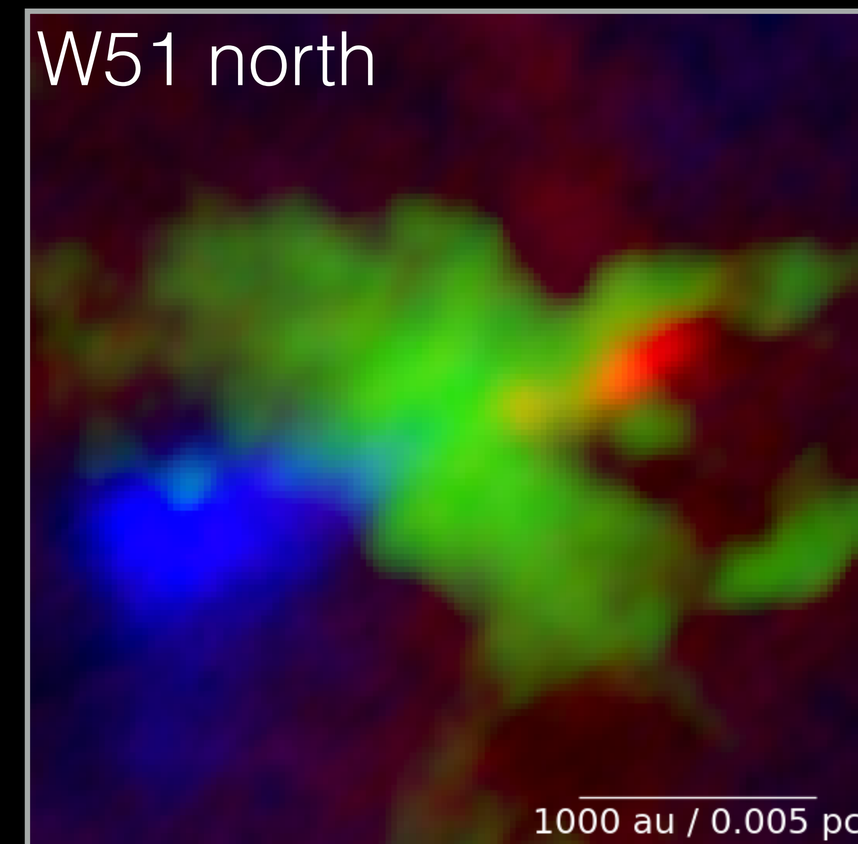
1.3 mm

SiO SiO

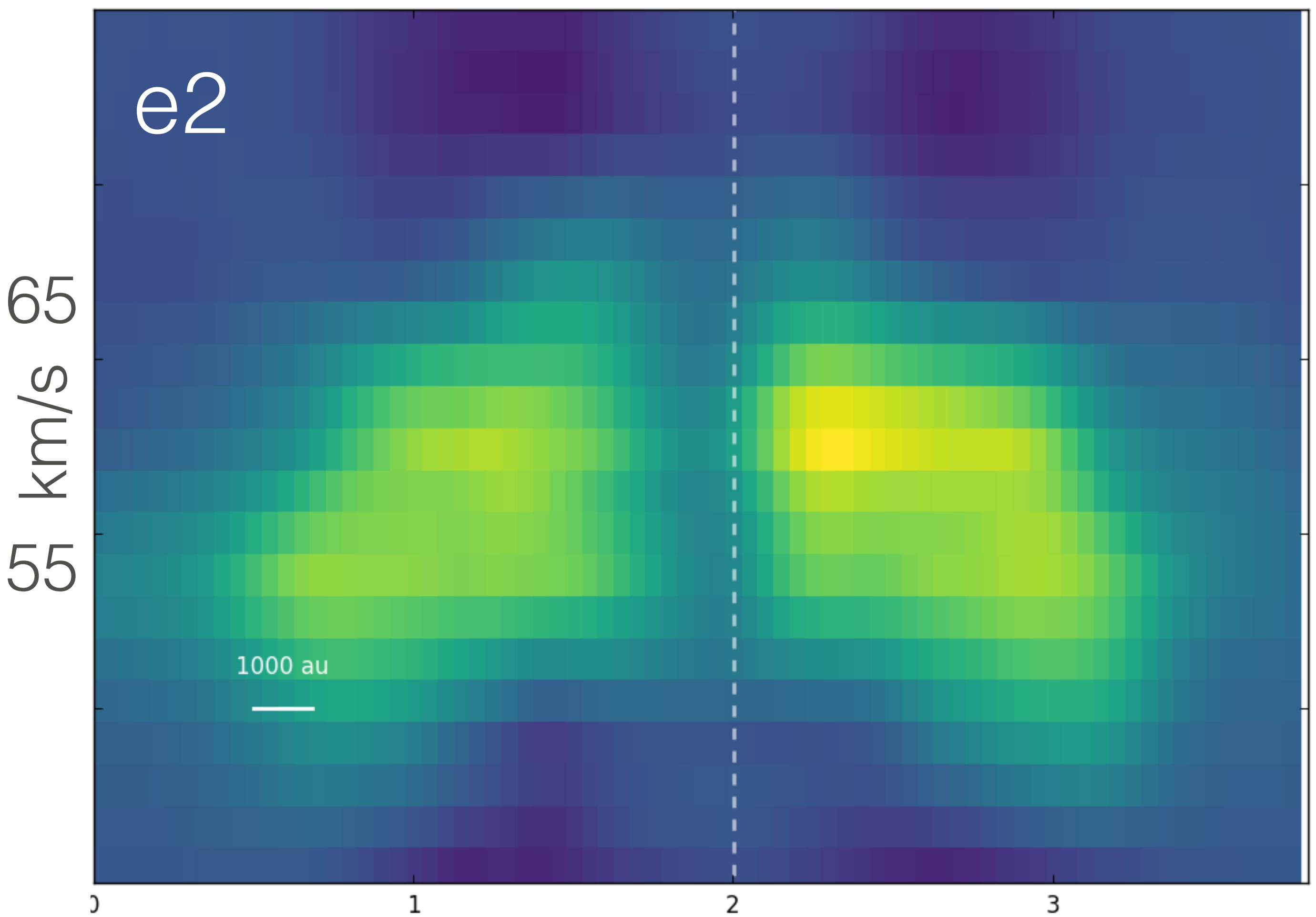


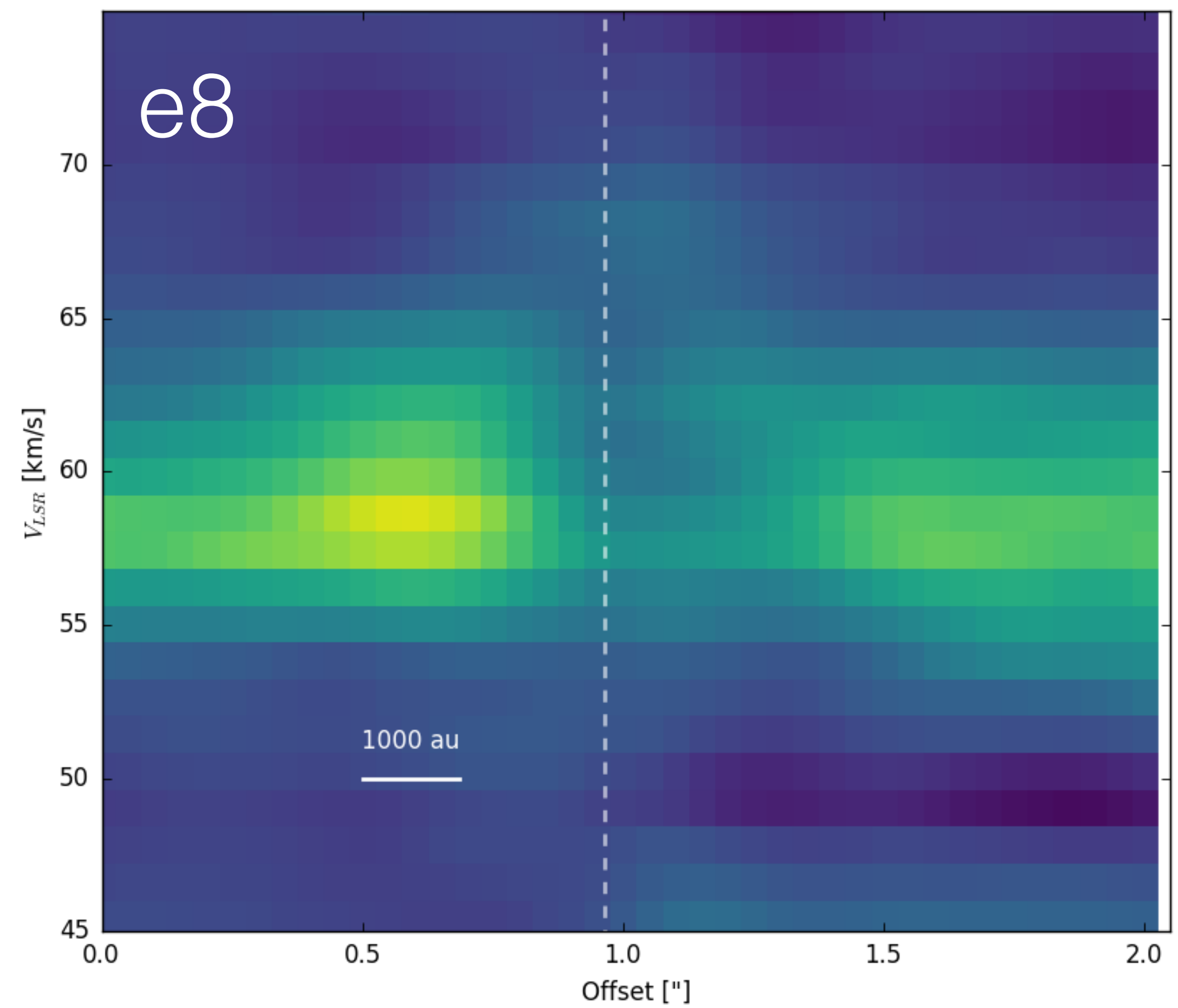
1000 au
0.005 pc

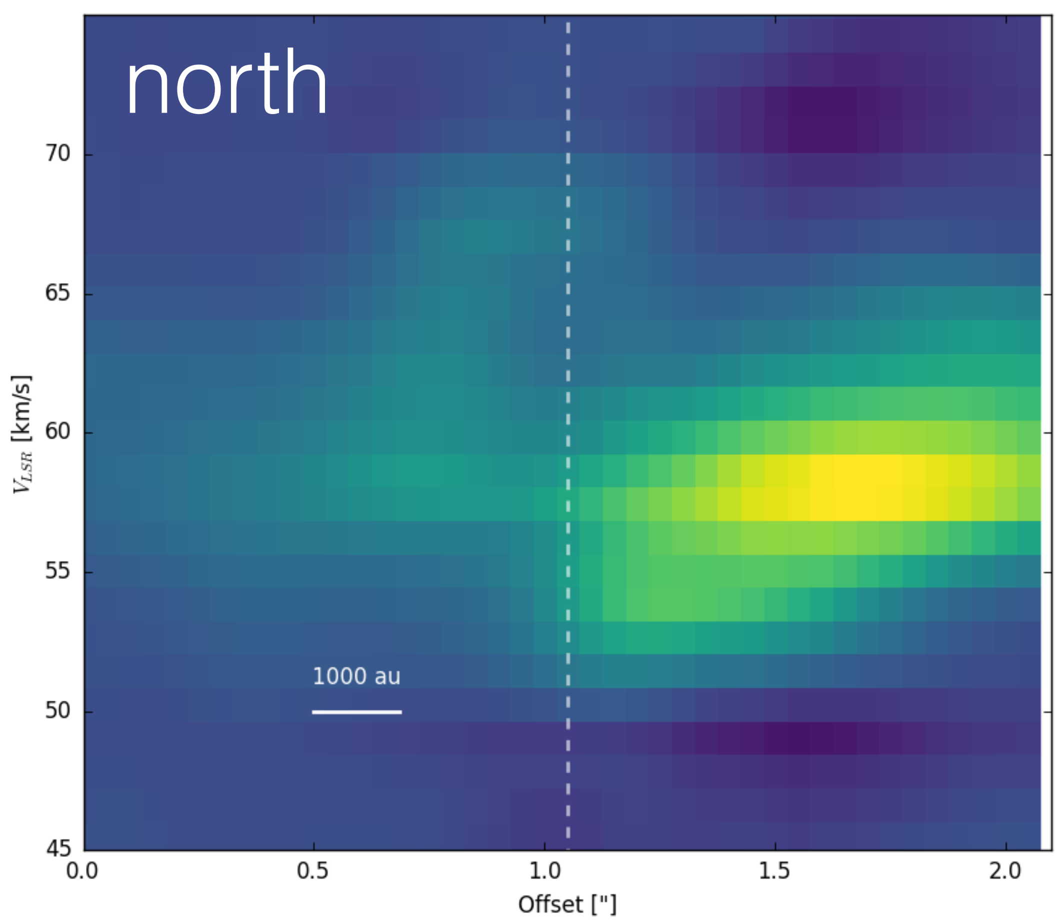




Resolution 200 au







The W51 MYSOs lack clear position-velocity gradients: there is no obvious sign of rotation

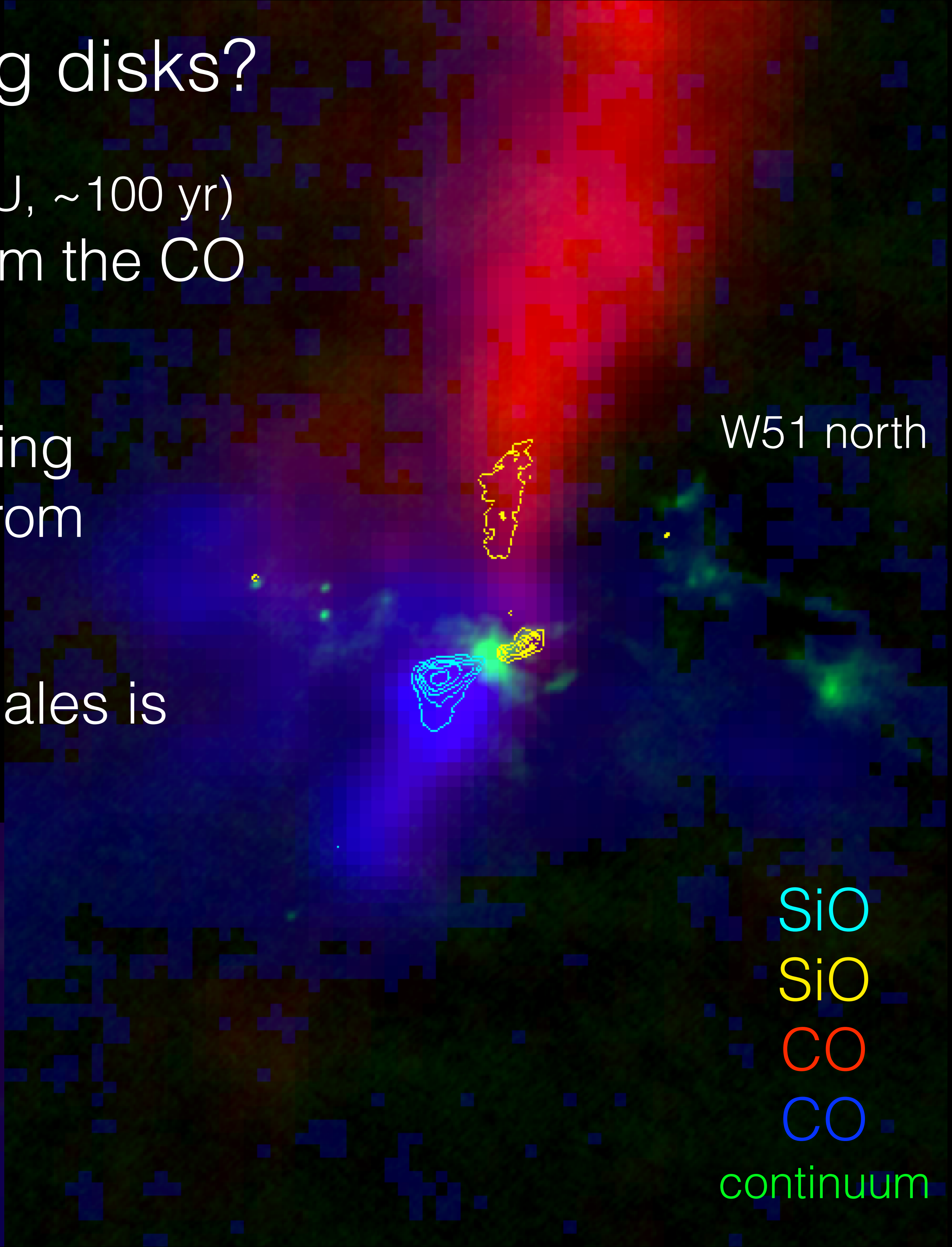
There are no 1000+ AU scale rotationally supported objects

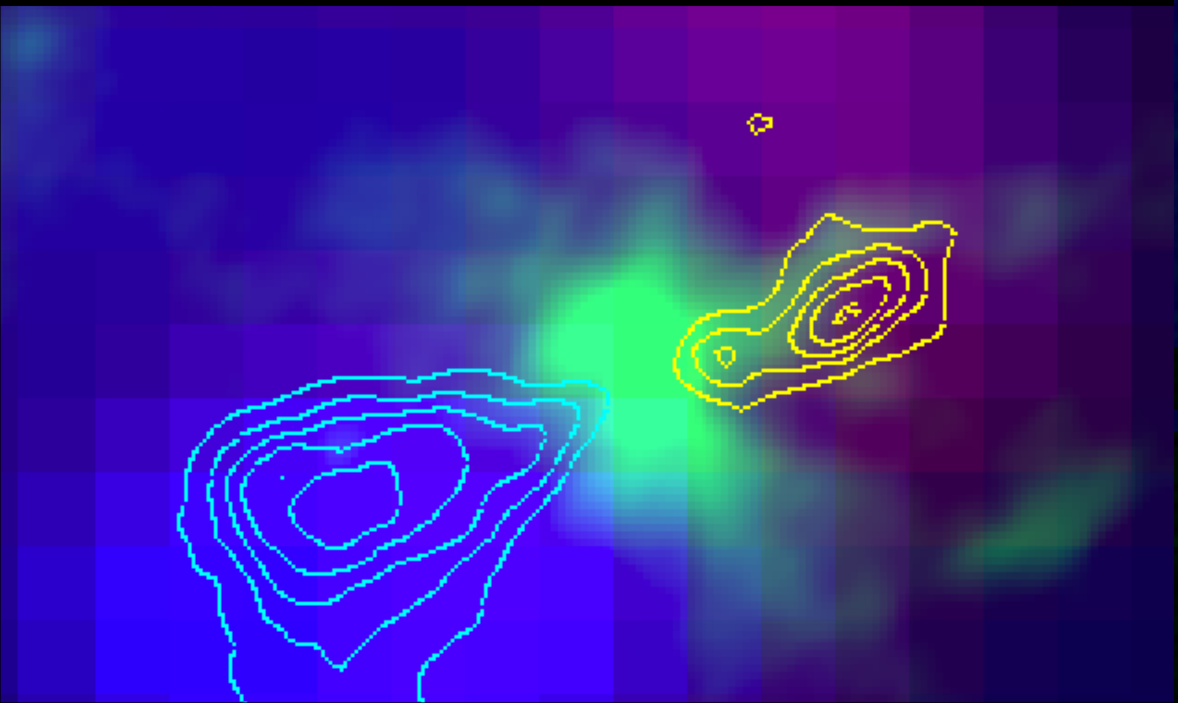
Why are there no big disks?

The SiO outflow (~2000 AU, ~100 yr) is ~50 degrees offset from the CO outflow (~0.1 pc, ~1000 yr)

High-mass, disk-destroying accretion events come from different directions

Accretion to ~100 AU scales is disordered and clumpy



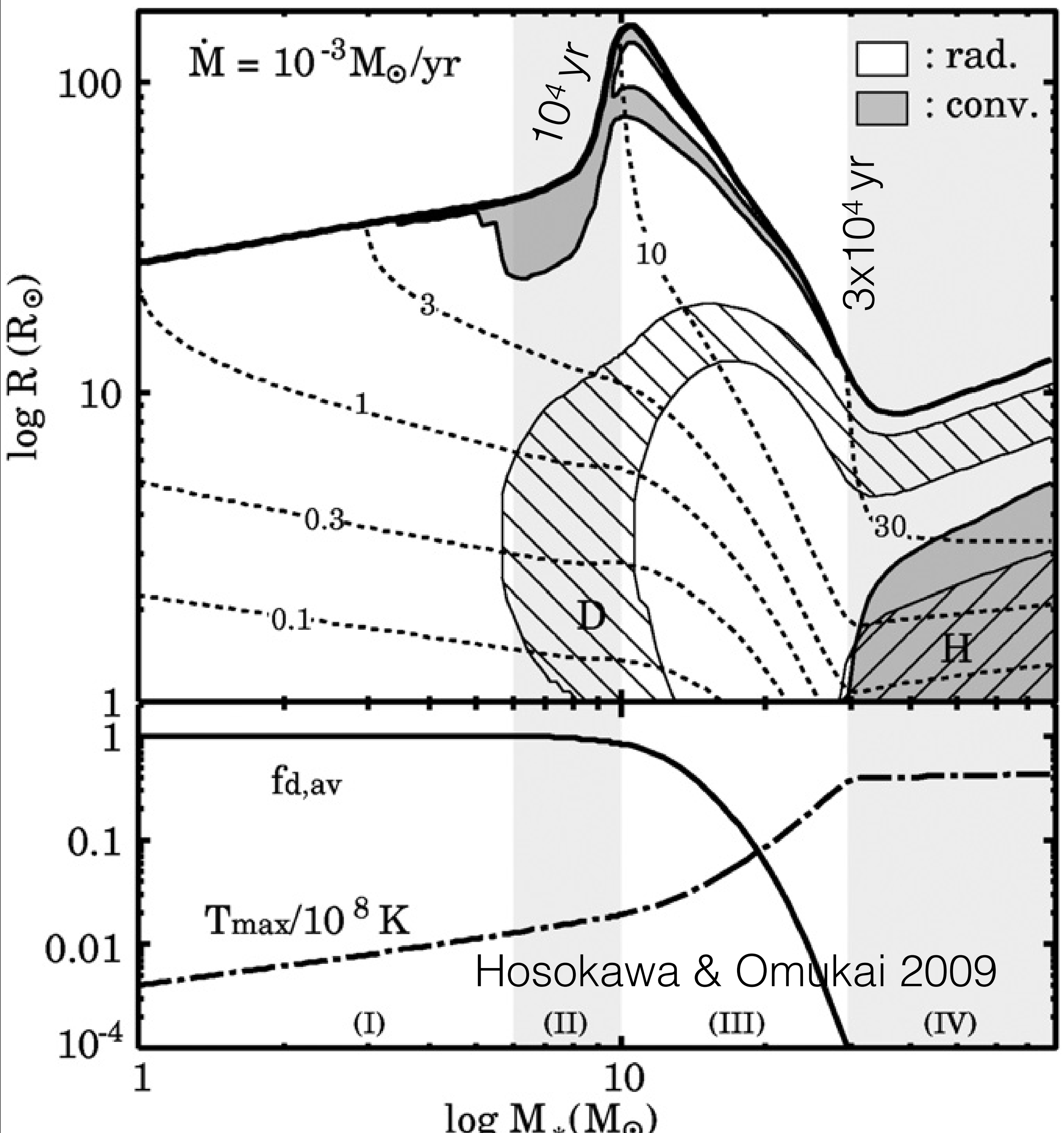


The story so far…

- MYSOs have massive cores
  - HCHII regions don't
- Accretion is rapid & sporadic

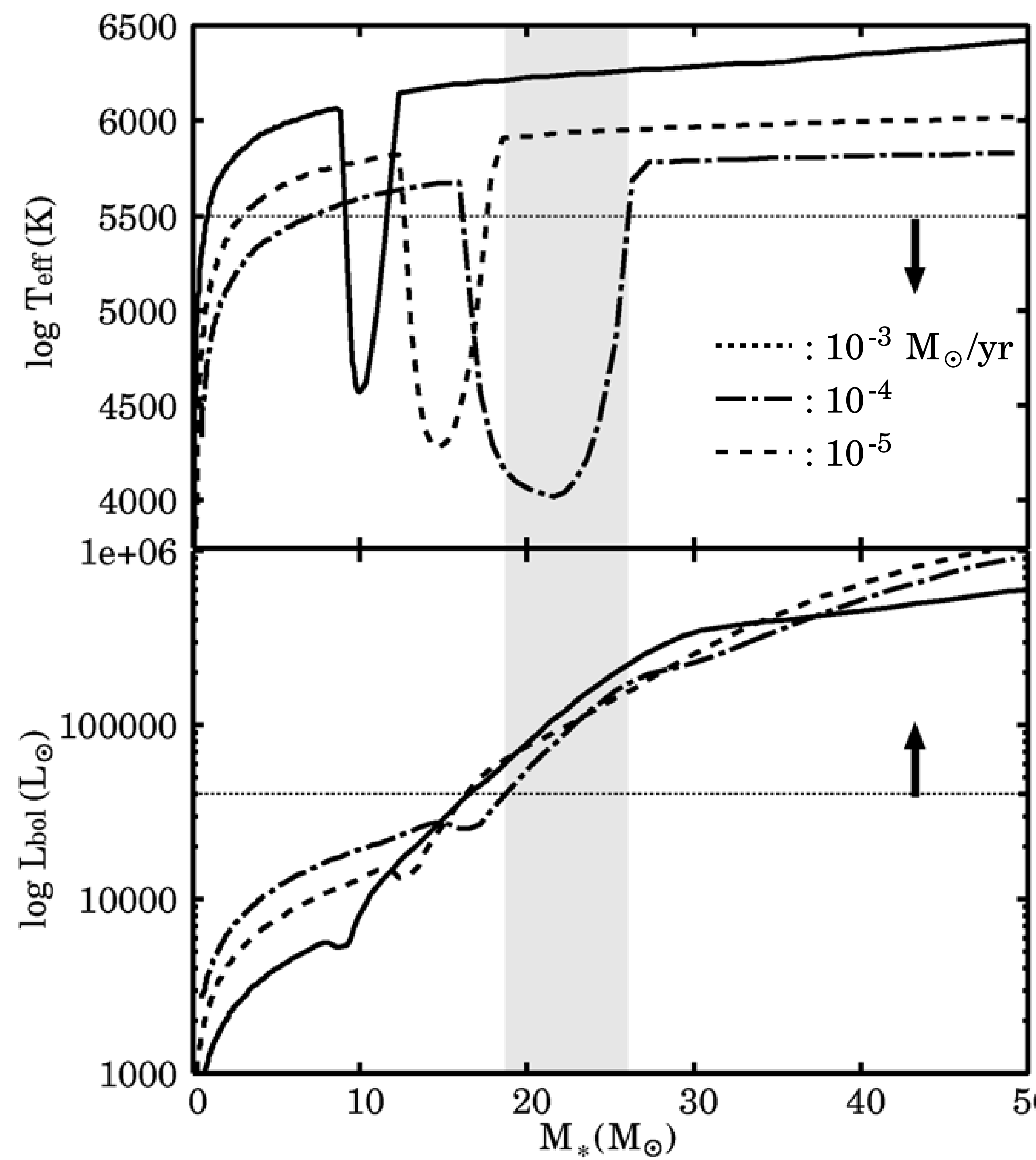
Disordered Accretion

- Disk-destroying accretion events can remove angular momentum and dump mass on the star
- Major accretion events should trigger infrared and millimeter variability (Kumar+ 2016, Brogan+ 2016 & Hunter+ in prep, Johnstone+ 2013, Stecklum+ yesterday)
- Major accretion events affect the star…



High accretion rates cause massive stars to bloat: photospheric temperatures stay low

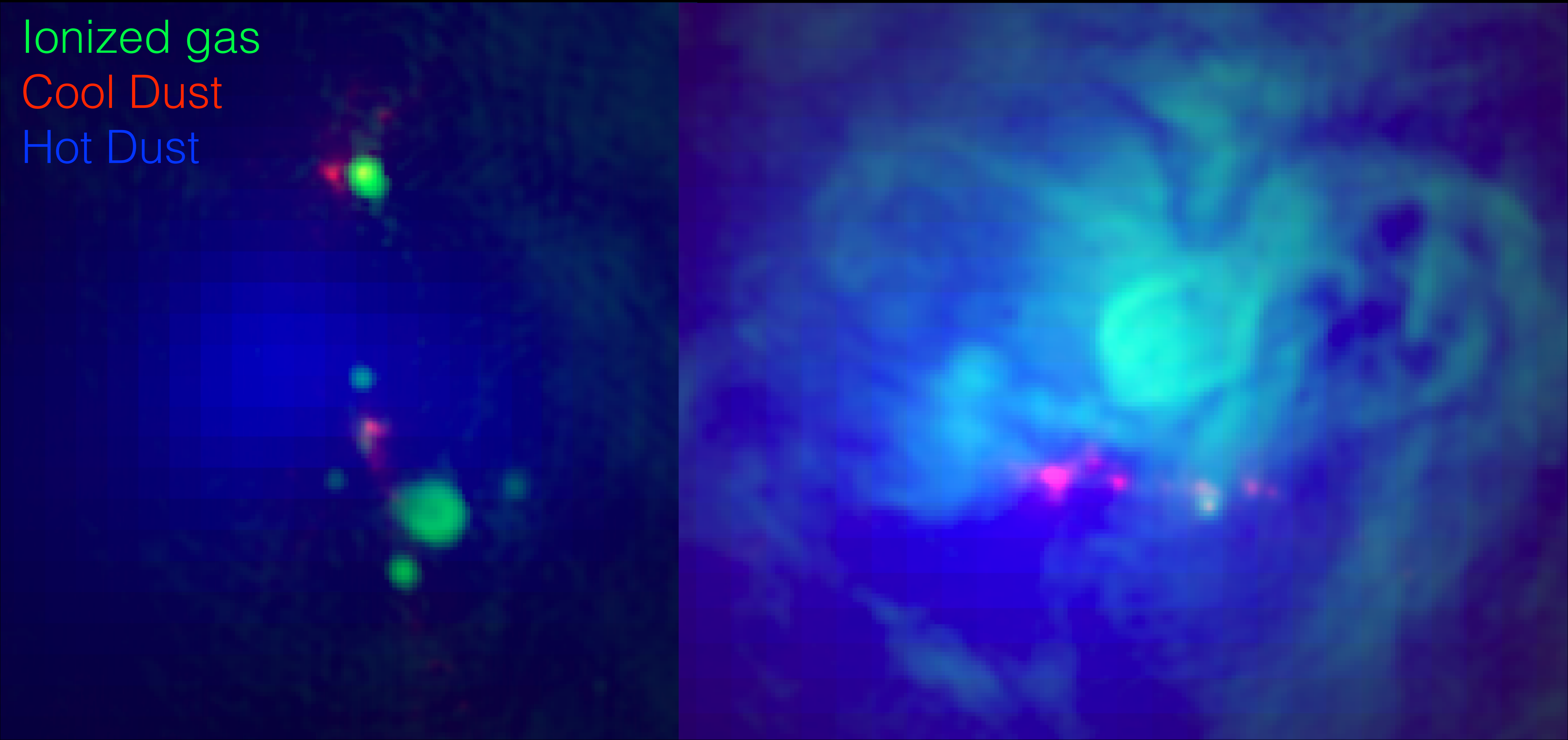
(high & variable works even better)



High accretion rates *suppress ionizing photon generation*

Observations in favor of bloated stars:

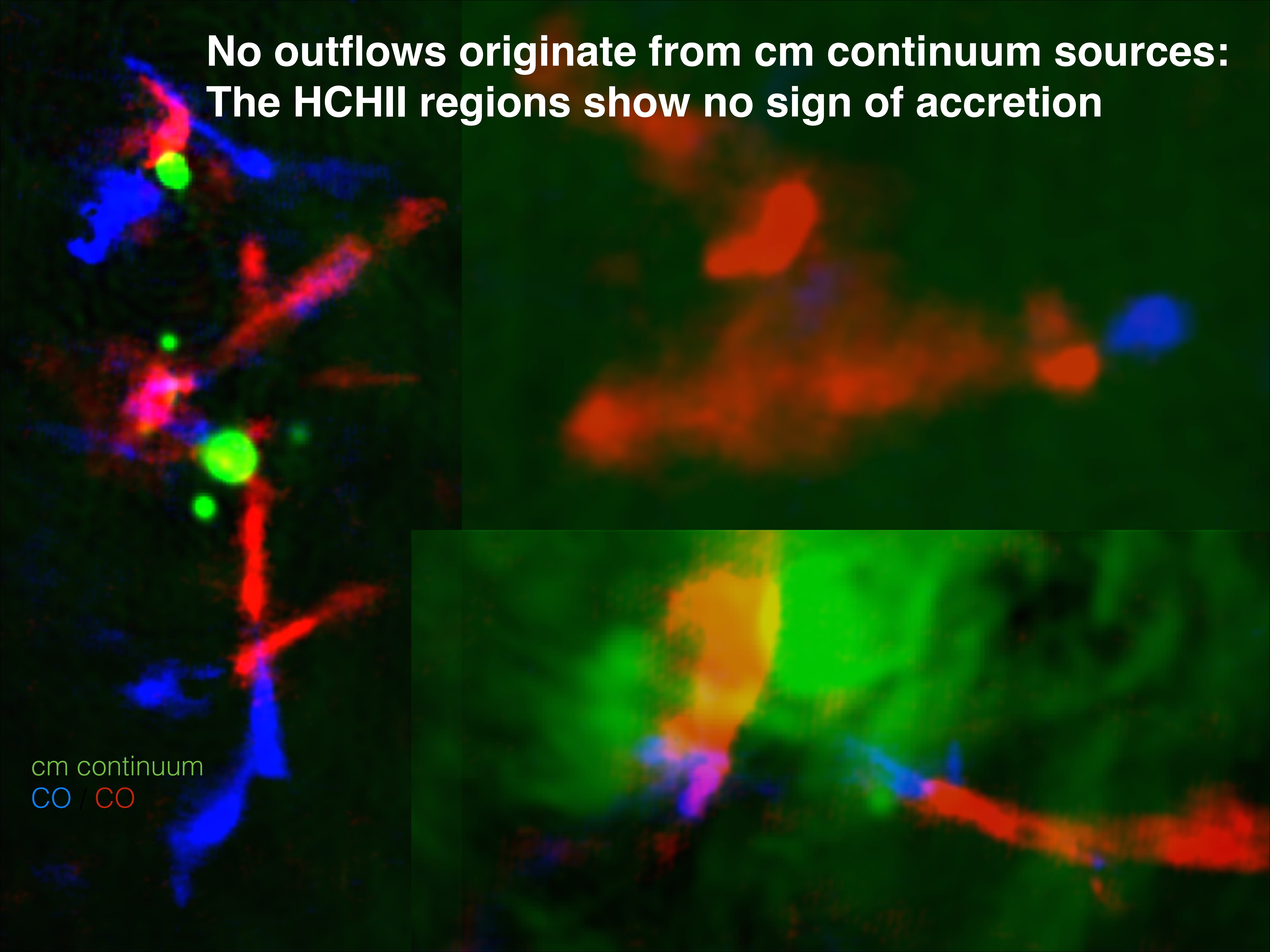
- Cores are warm
- Centers of cores exhibit no free-free emission
- Centers of cores (red dots) are optically thick at 1mm



Optically thick at 1mm

- T_B >225 K over at least a 200 AU beam
  - Implied luminosity is at least $\sigma_{sb}T^4\,4\pi r^2 > 1000\ L_\odot$
    - (usually thick area ~5-10 beams, so $L > 0.5\text{-}1\times10^4\ L_\odot$)
- The central source is *luminous*, but not ionizing

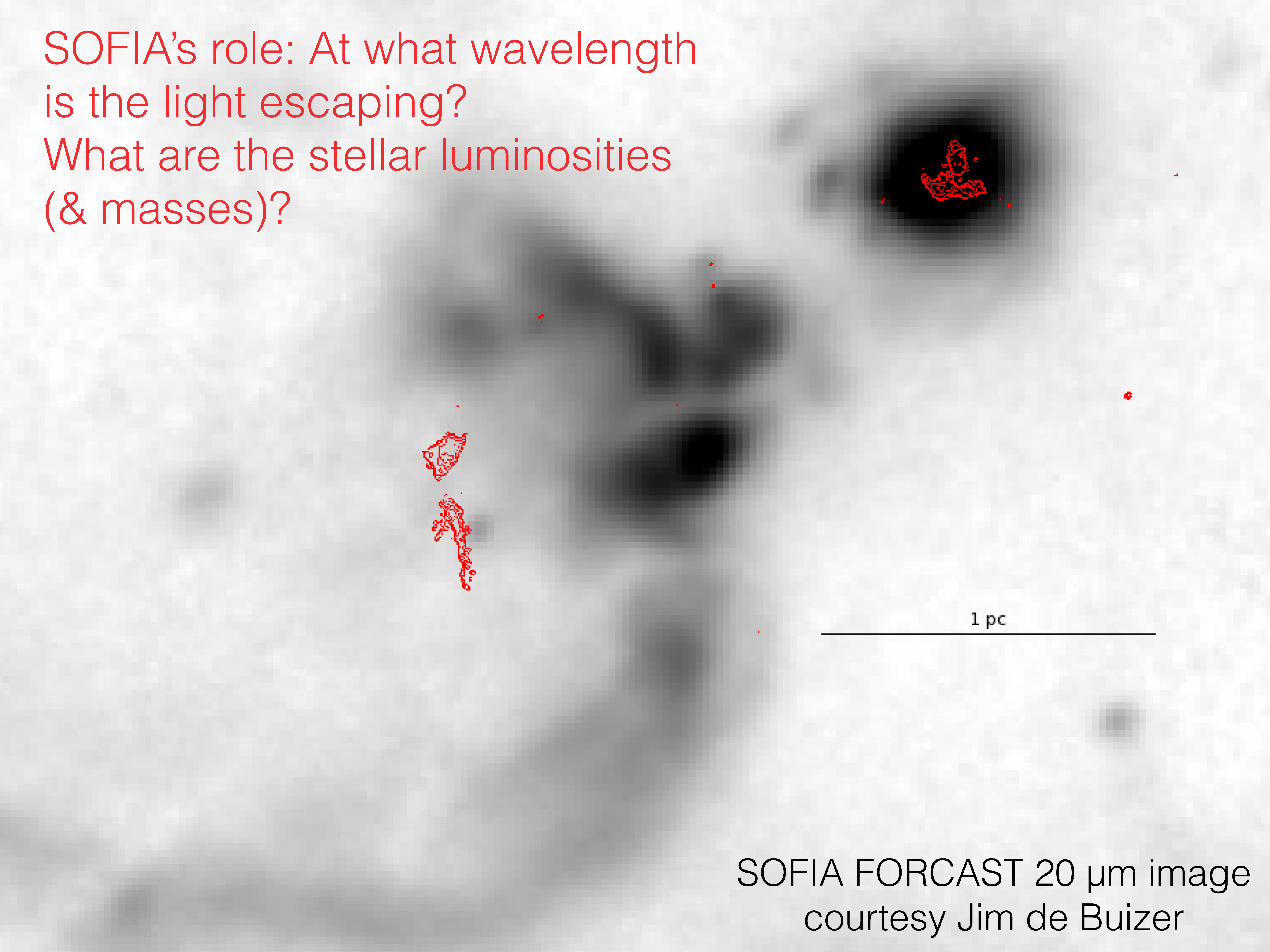
No outflows originate from cm continuum sources: The HCHII regions show no sign of accretion



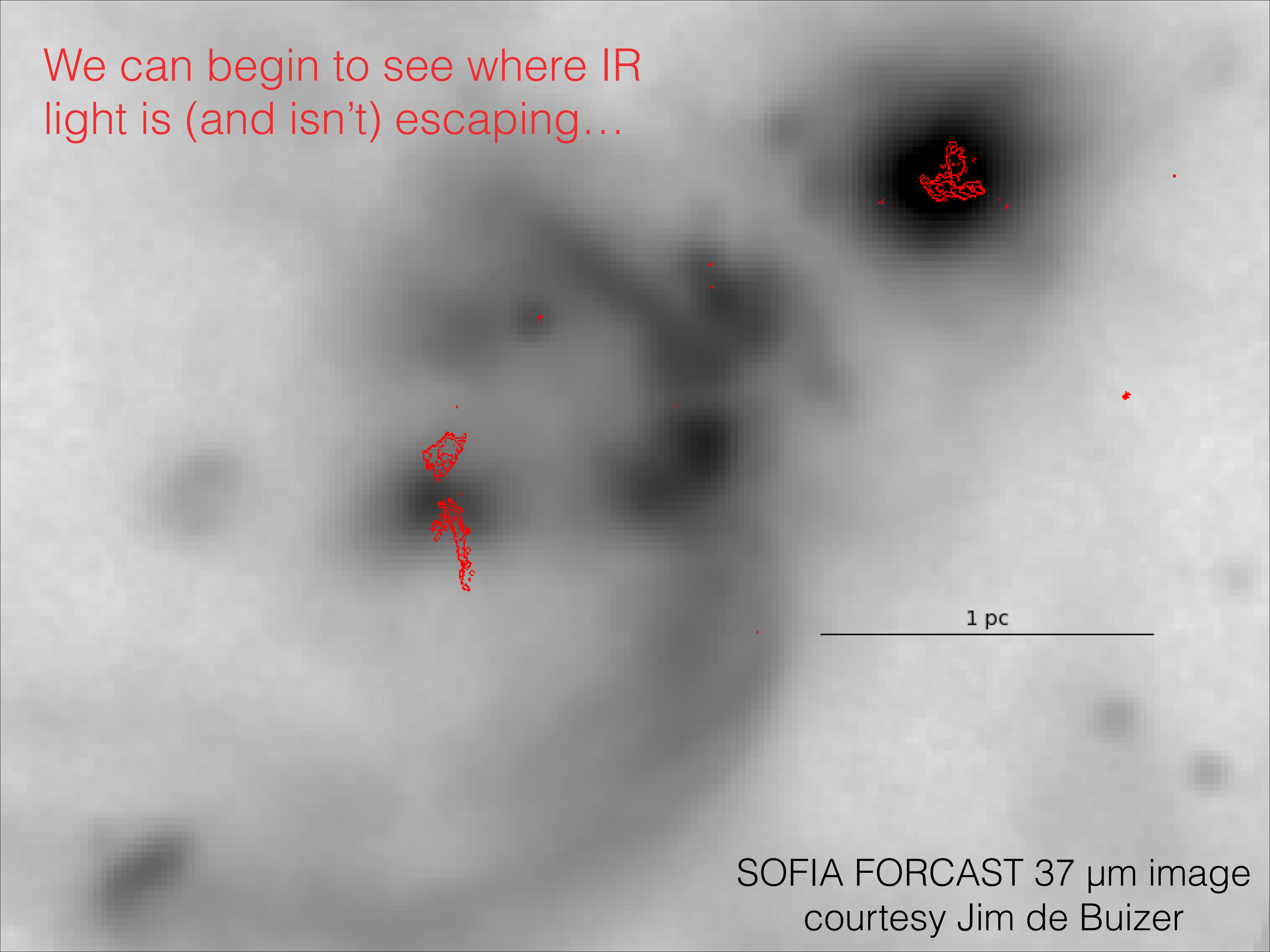
Evolutionary Story

- HMYSO forms as a seed
- Accretion proceeds very rapidly, *but* intermittently
  (100-1000 yr variability)
- Disks form during low phases of accretion
  (when there are disks, there are outflows)
- Disks are destroyed during, and re-form in different directions after, high phases of accretion
- Ionization starts when accretion has been low for long enough for the star to relax & shrink:
  Once ionization has started, accretion is (mostly) done

SOFIA's role: At what wavelength is the light escaping? What are the stellar luminosities (& masses)?

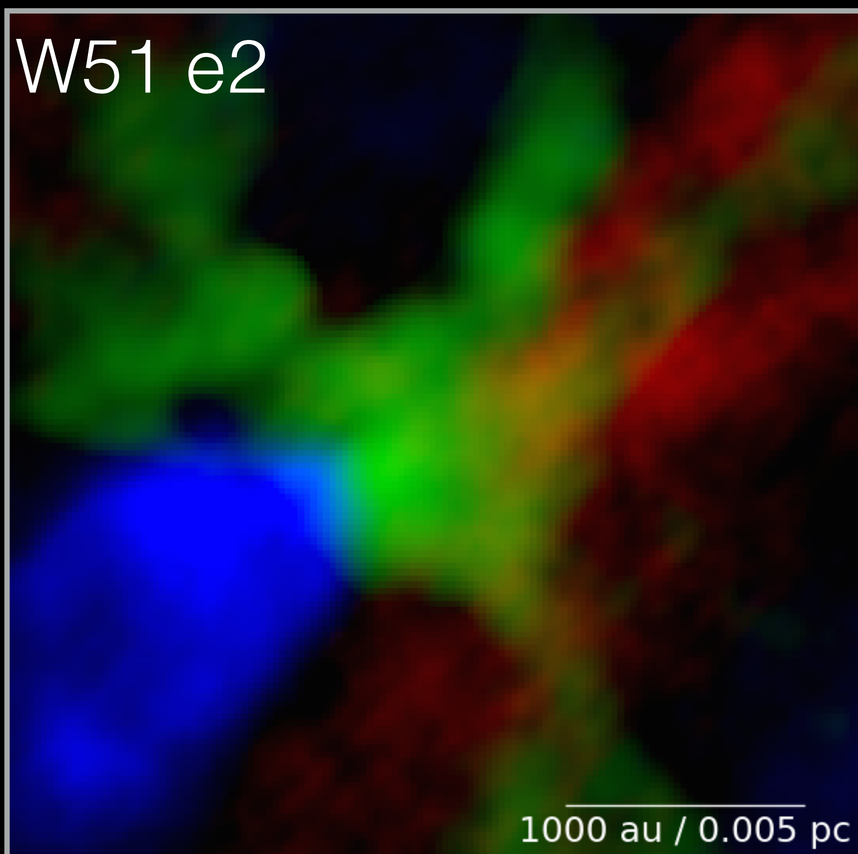


SOFIA FORCAST 20 µm image
courtesy Jim de Buizer


We can begin to see where IR light is (and isn't) escaping…
1 pc
SOFIA FORCAST 37 μm image
courtesy Jim de Buizer

Conclusion

- HMYSOs heat their own massive cores without ionizing them
- Lack of disks, twisting outflows hint at variable accretion



1.3 mm
SiO SiO