Massive Galactic Star Formation: A Far-IR Wish List

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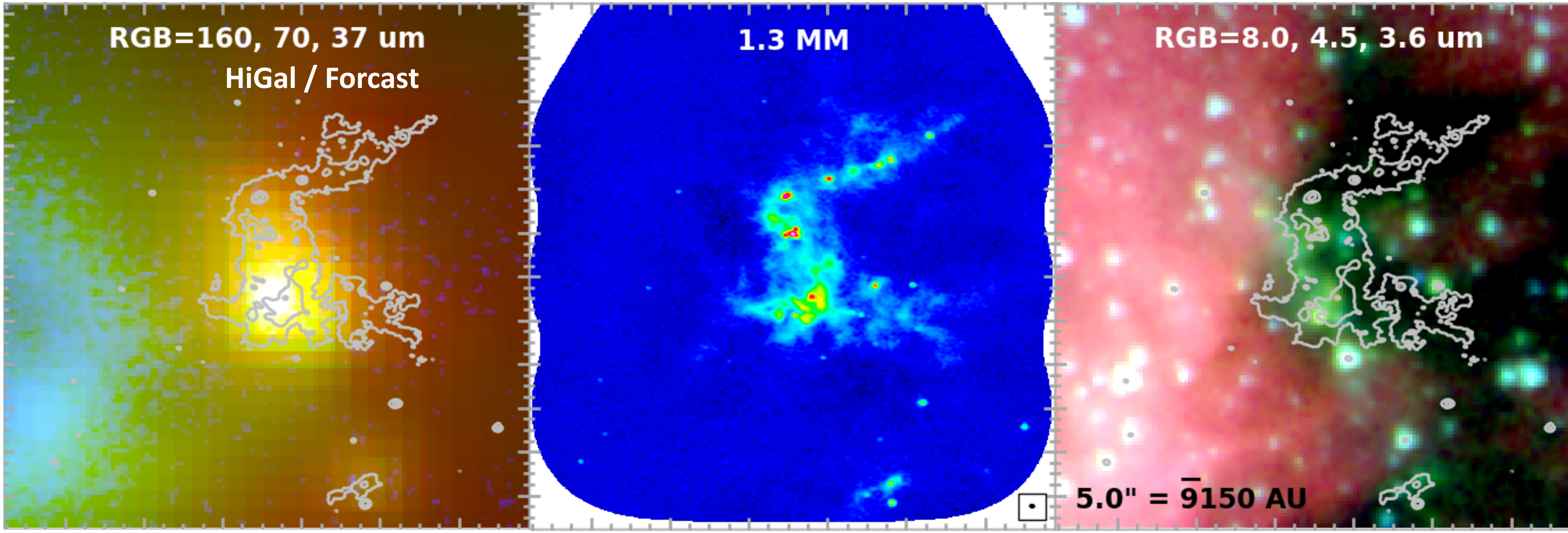
AAS 2018 Splinter Session -- Charting the Course:
The Present and Future of Far-Infrared and Sub-mm Space and Airborne Astronomy

Mid-IR Signposts of Galactic Massive Star Formation: Extended Green Objects – G14.63-0.58 (D = 1.83 kpc)



Herschel PACs Resolution ~6-12”
SOFIA FORCAST Resolution ~3”

ALMA Resolution ~0.8”

Spitzer IRAC Resolution ~2”

ALMA from 3000 to 350 micron has exquisite sensitivity coupled with high angular resolution

- Sample full circum-protostellar mass reservoir
- Explore predictions of high mass star formation: birth order, mass segregation etc

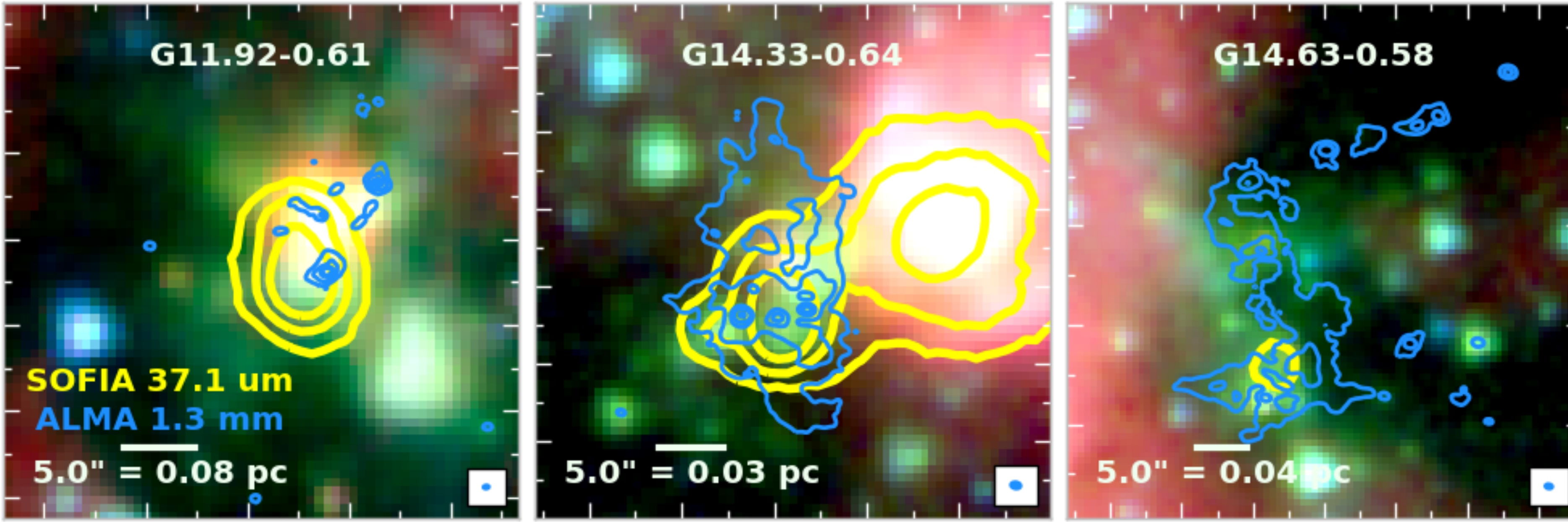
However, without comparable resolution anchors for the mid to far-IR portions of the SED, we CANNOT *easily* assess:

- Individual protostellar luminosity
- Individual protostellar mass
- Mass accretion rate

ALMA: Brogan+2018, in prep.; SOFIA: Towner+2018, in prep.

Mid-IR Signposts of Galactic Massive Star Formation: Extended Green Objects

Poster: Allison Towner #449.01

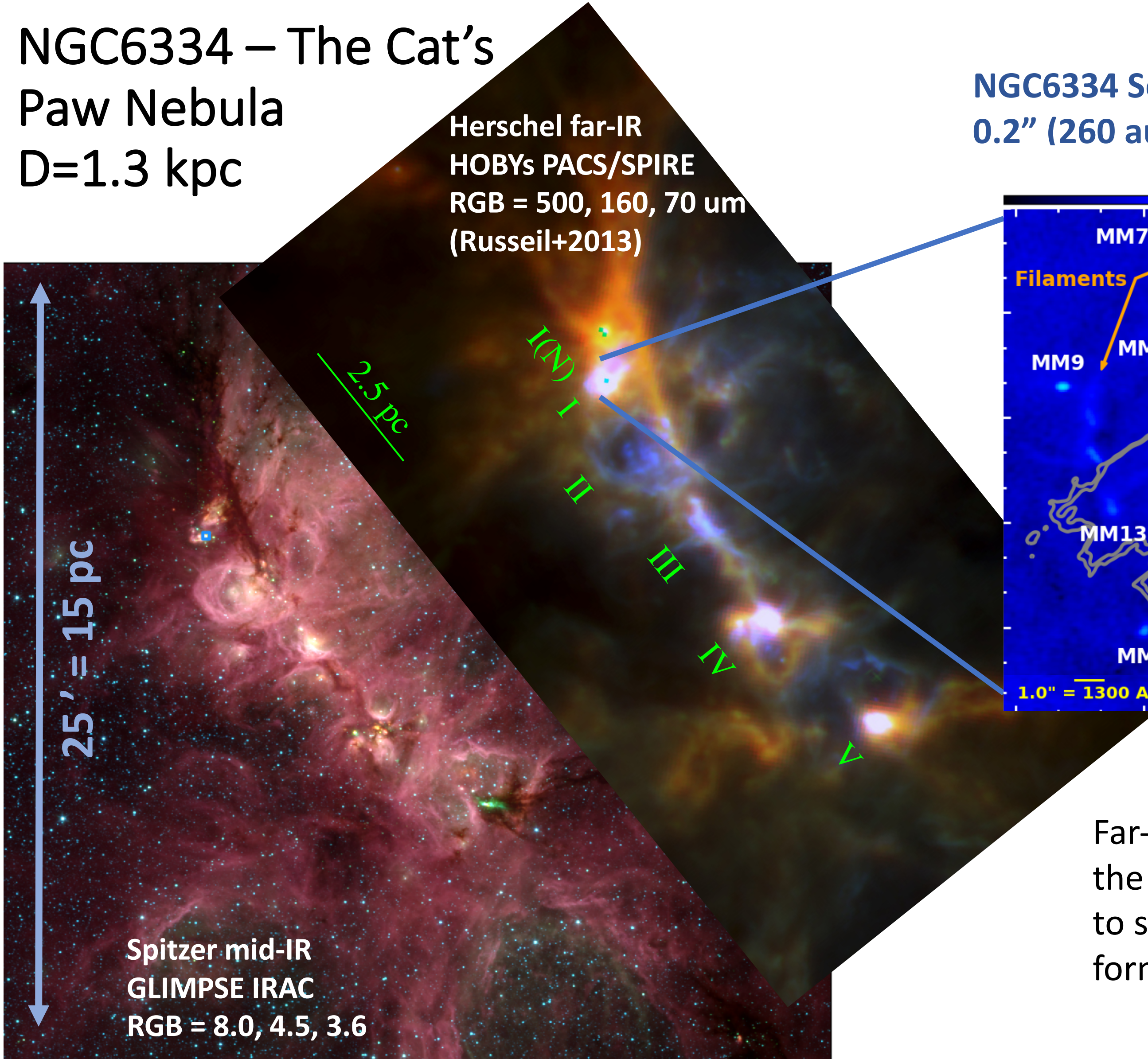


Better far-IR angular resolution (< 1”) is absolutely essential, but it must be coupled with:

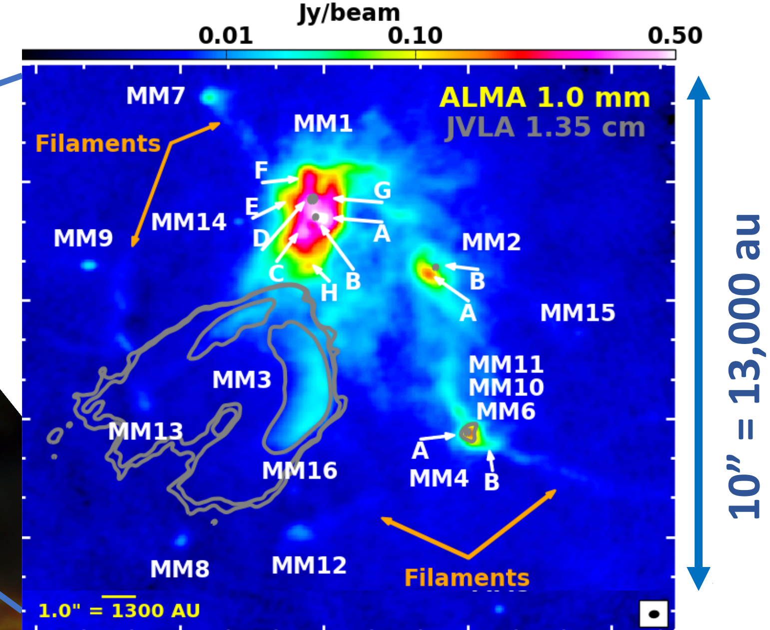
- Not only high sensitivity but **very high dynamic range** ⇒ saturation is serious problem due to more evolved objects / highest mass protostar (i.e. Spitzer at 24 um / JWST largely unusable)
- Better native **Astrometry (< 0.3“)**
- High quality PSFs and robust, public deconvolution software

ALMA: Brogan+2018, in prep.; SOFIA: Towner+2018, in prep.

# NGC6334 – The Cat's Paw Nebula
D=1.3 kpc

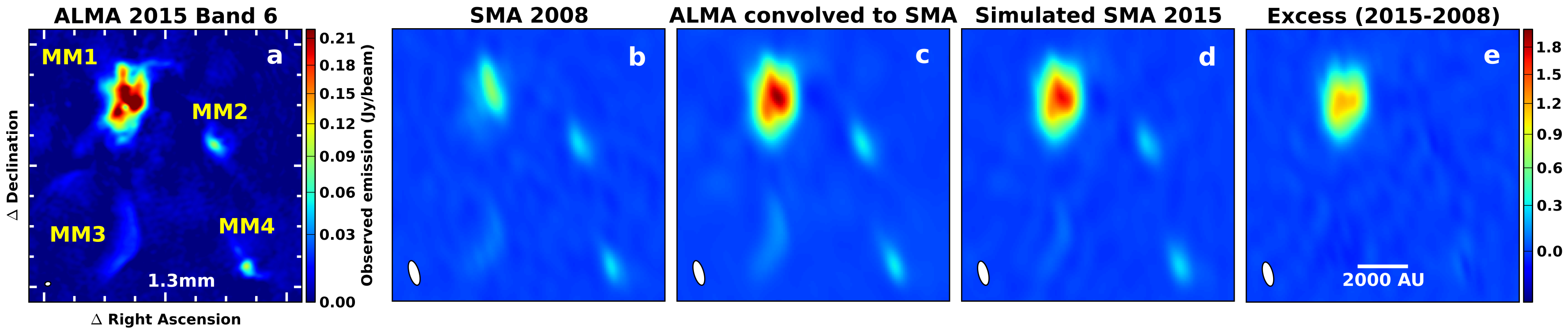


NGC6334 Source "I" with ALMA at 1 mm 0.2" (260 au) resolution (Brogan+2018, in prep.)



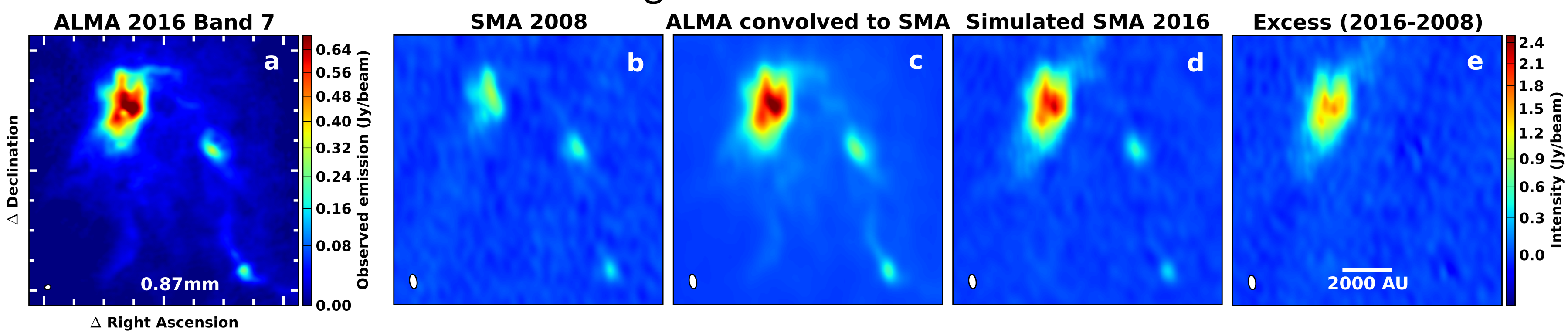
Far-IR does not not currently have the **Resolution** and **Dynamic Range** to study massive *protocluster* formation

An extraordinary brightening at 1.3 and 0.87mm (2008-2015)



MM1 Band 6 (1.3 mm) flux density: 2008.6 SMA: 2.34 Jy versus 2015.6 ALMA: 10.8 Jy

- Simulation: SMA could have recovered most of the ALMA flux (9.4 Jy)
- Increase = factor of 3.9! No change in other 3 sources.



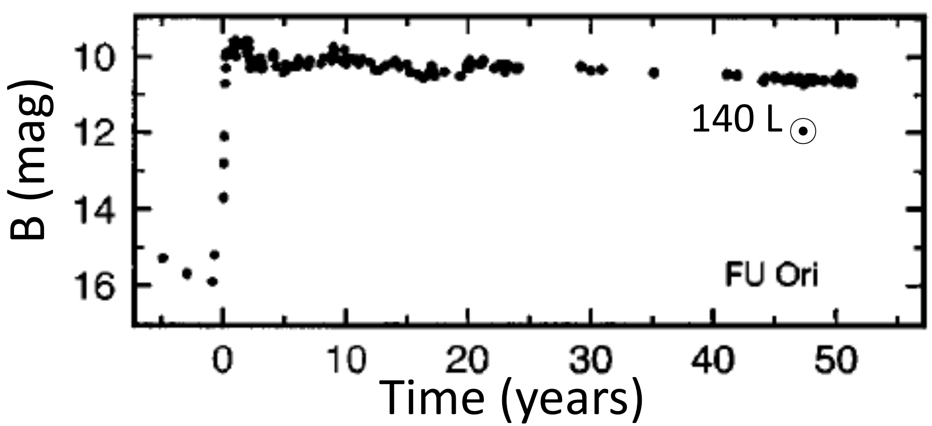
MM1 Band 7 (0.87 mm) flux density: Increase = factor of 4.2. No fading over a year.

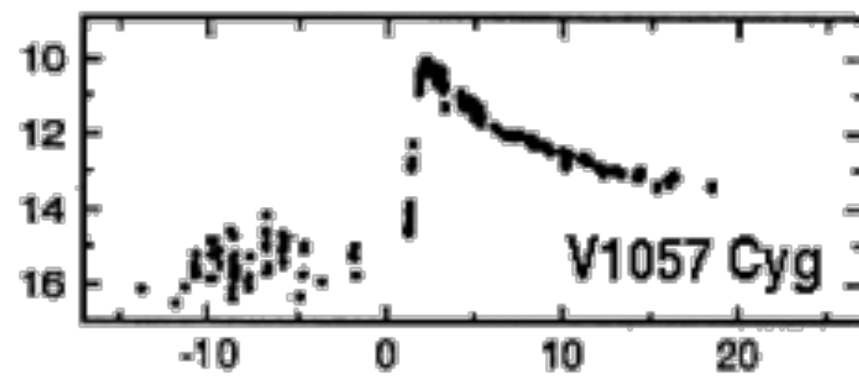
- Spectral index of excess is 2.6 – confirms it is dust
- Luminosity increased 70x likely due to episodic accretion event!

(Hunter, Brogan+ 2017)

Evidence for Episodic Accretion for Low Mass (Class I/II) Objects: Strong Time Variability Known as "Outbursts"

- Classical FU Ori stars: Kenyon & Hartmann (1996)
  >100x brightness boost lasting for decades





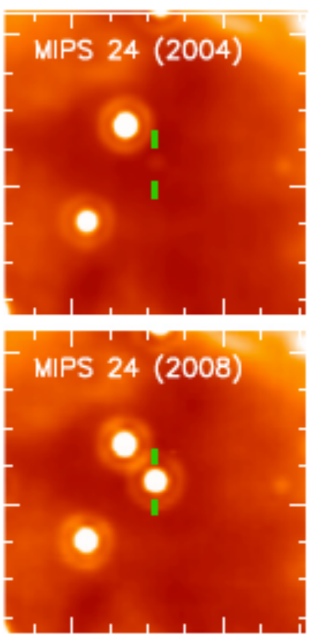
- Spitzer c2d Legacy results: most YSOs are underluminous relative to evolution models with a constant or decaying accretion rate (Evans+2009)
- UKIDSS & VVV surveys finding hundreds of Near-IR variable YSOs (Lucas+2017)

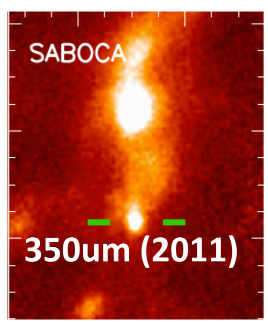
Outbursts recently identified in young protostars

Low-mass Class 0: HOPS 383

(Safron+2015)

- Flared by 35x at 24um between 2004-2008
- Luminosity rose by x30-50 (from 0.2 $L_\odot$ to 6-10 $L_\odot$), no significant fading over 6 years
- Similar to FU Ors, but 15x less luminous

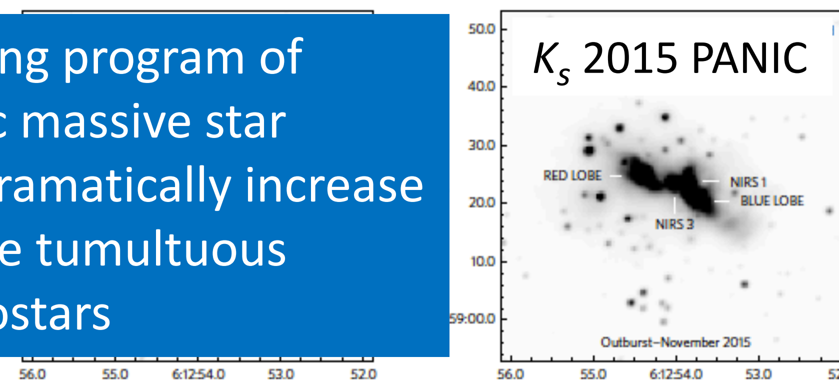




Massive YSO: S255IR-NIRS3

(Caratti o Garatti +2016)

- Flared by 30x at 60um between 2009-2015
- Luminosity rose 6x (from 2.9e4 to 1.6e5 $L_\odot$) with no fading evident over 1.5 years

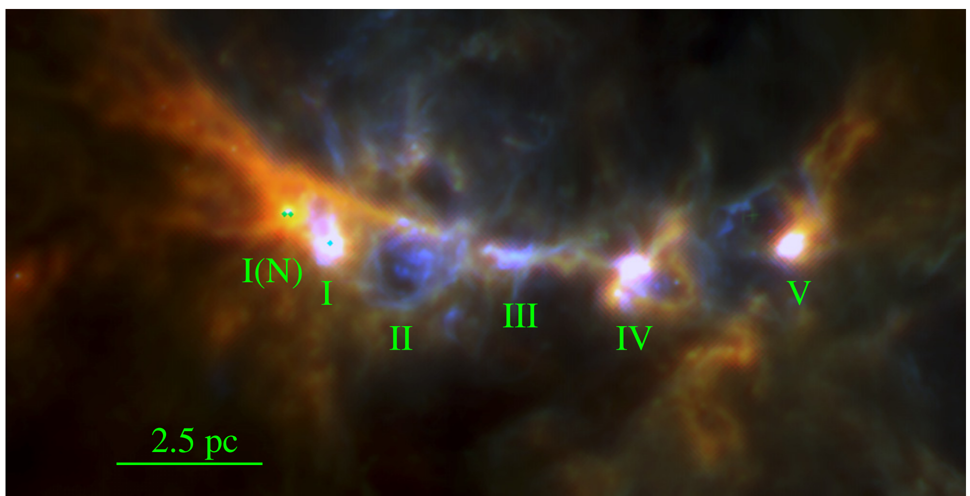


A future Far-IR monitoring program of several hundred galactic massive star forming regions could dramatically increase our understanding of the tumultuous growth of massive protostars

Dust in surrounding envelope is heated rapidly:
$t_{heating} = E_{abs}/L_{abs} \ll$ photon travel time
(Johnstone et al. 2013)
t_{photon} = 1200AU / c = **1 week**

Massive Star Formation Wish List for the Future of Far-IR

- **Better far-IR angular resolution (< 1”) is absolutely essential**
- Not only high sensitivity but **very high dynamic range** $\Rightarrow$ saturation is serious problem due to more evolved objects / highest mass protostar (i.e. Spitzer at 24 um / JWST largely unusable)
- Better native **Astrometry (< 0.3“)**
- High quality PSFs and robust, public deconvolution software
- Fast survey speed coupled with **accurate absolute flux calibration** to study variability

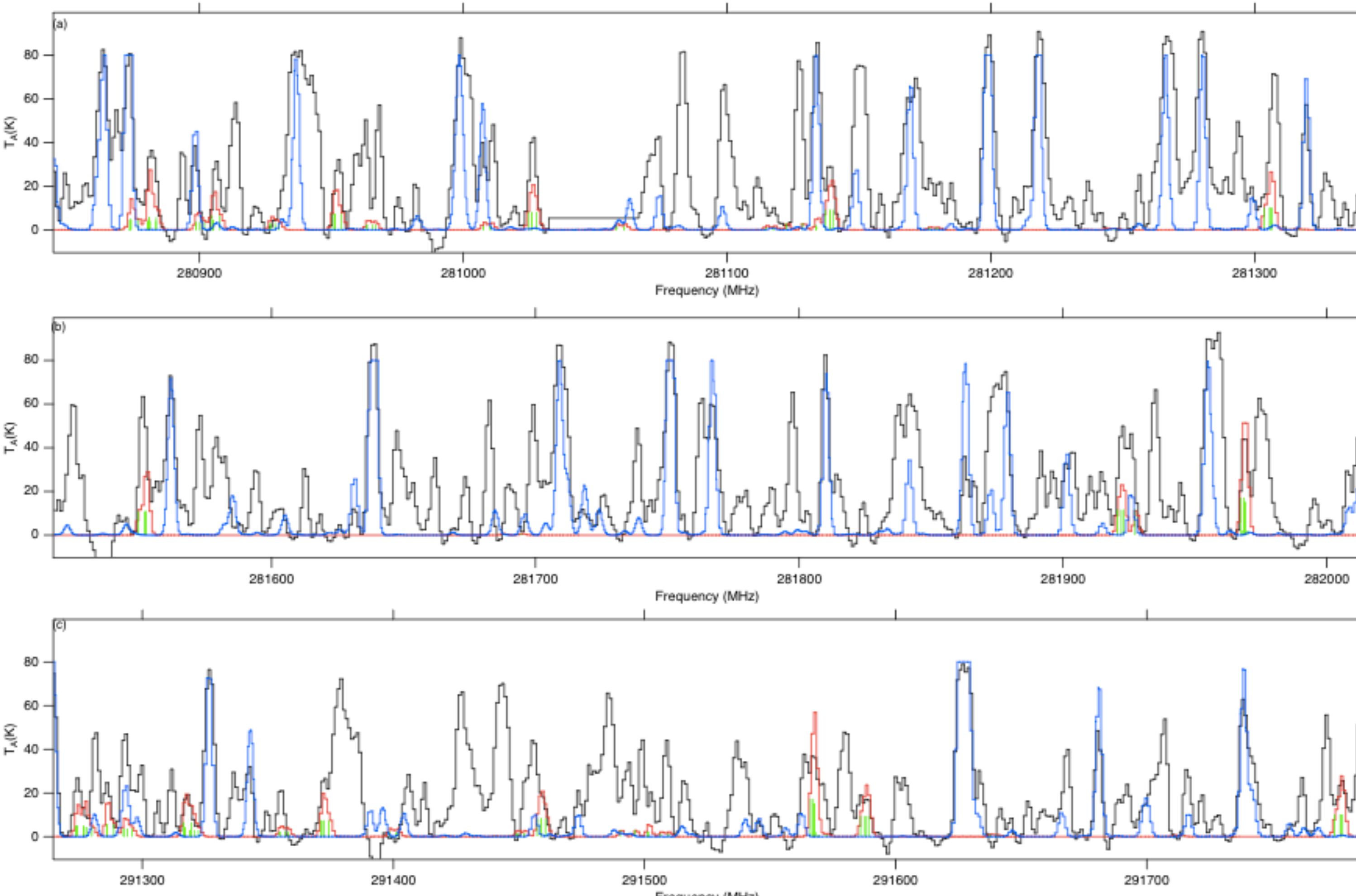


Extra slides

NGC6334I: Extraordinarily Rich Hot Core

First detection of interstellar Methoxymethanol (CH_3OCH_2OH)

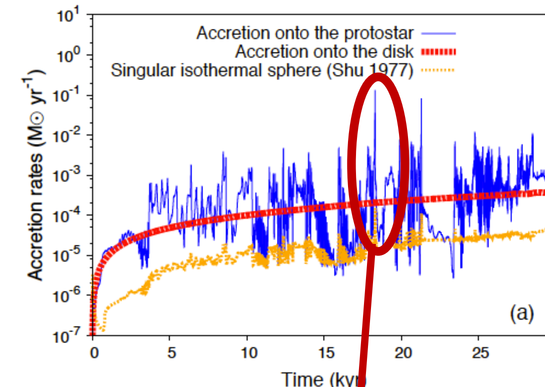
McGuire+2017, accepted ApJL

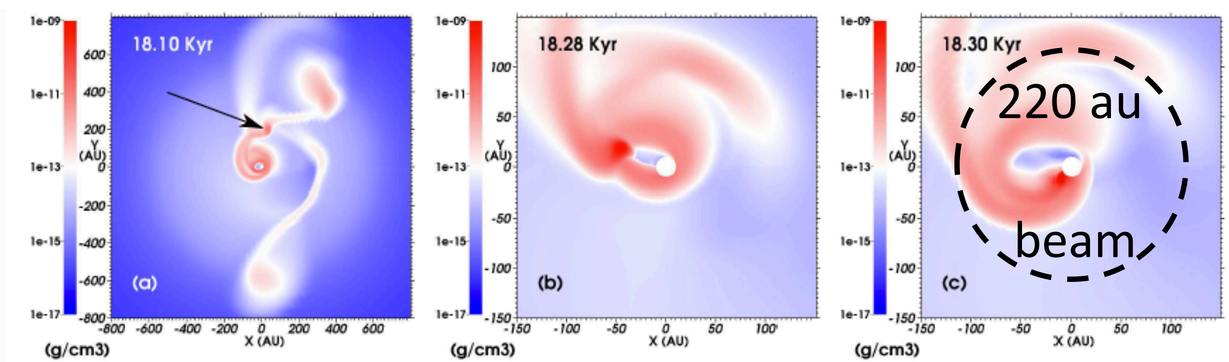


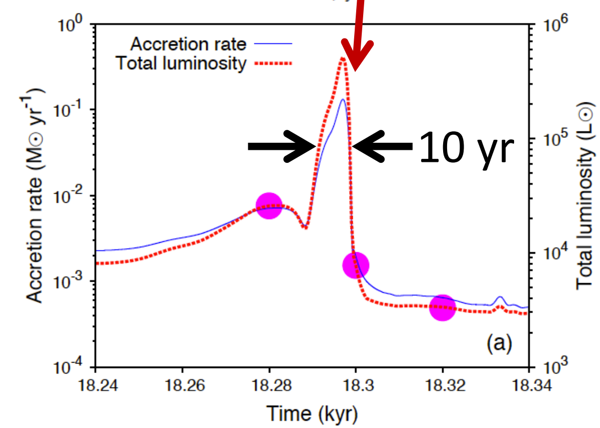
Large accretion events are expected

Example: Meyer et al. 2017: numerical radiation hydrodynamic simulations, including gas self-gravity & radiative feedback (Kuiper & Klessen 2013)

- Produces bursts in accretion rate of a factor of 100:
  - Yields x50 boost in luminosity for 10 yr
  - Large bursts separated by few 1000 yr
- MM1 outburst dust brightness temperature increase implies luminosity increase of 70+-20. Rare event!







Resolving these structures requires < 0.1" beam, even in nearby sources at 1 kpc