Recent ALMA results in the field of (high-mass) star formation

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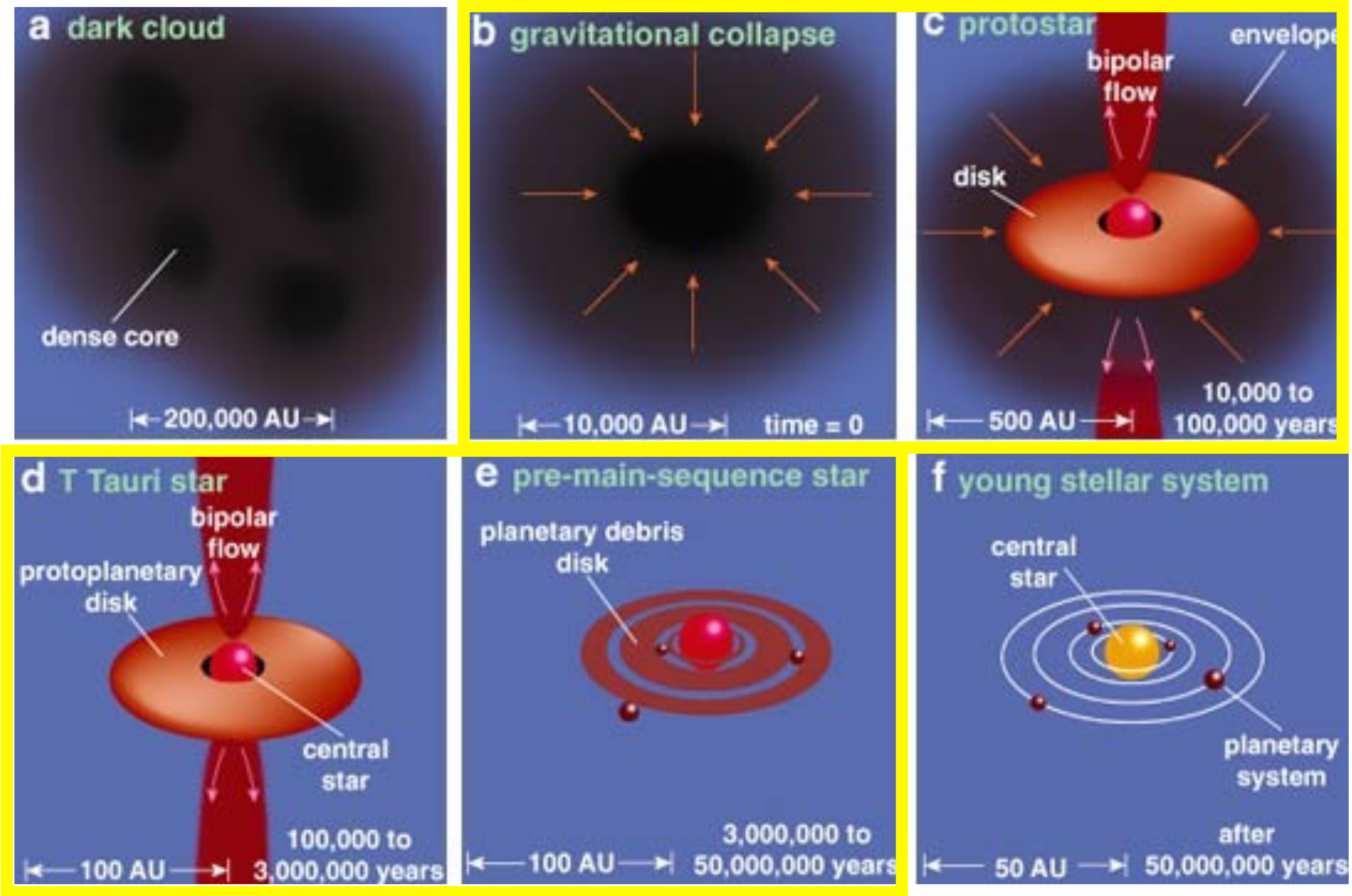
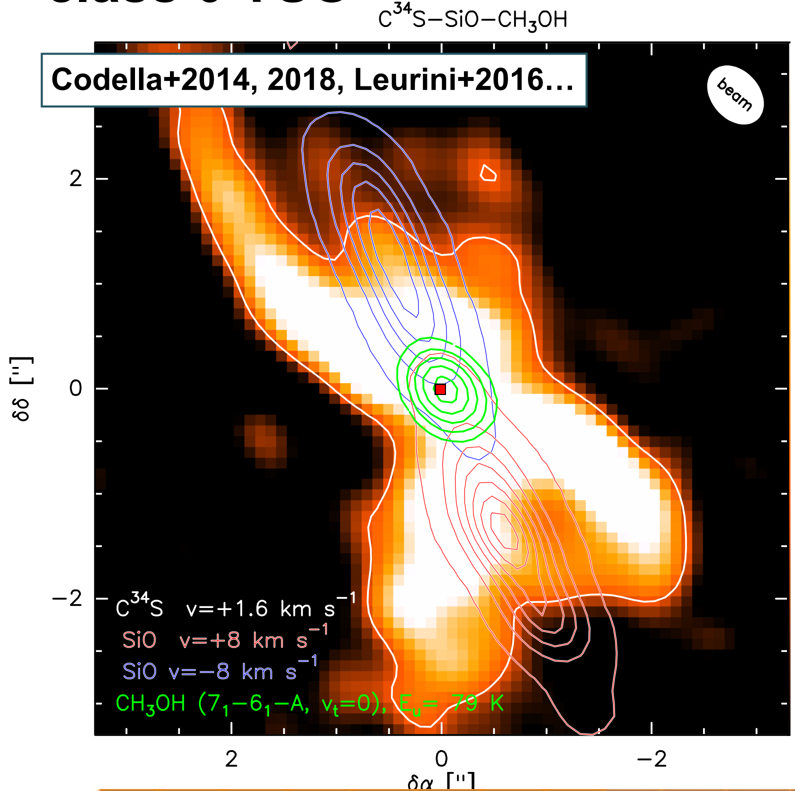
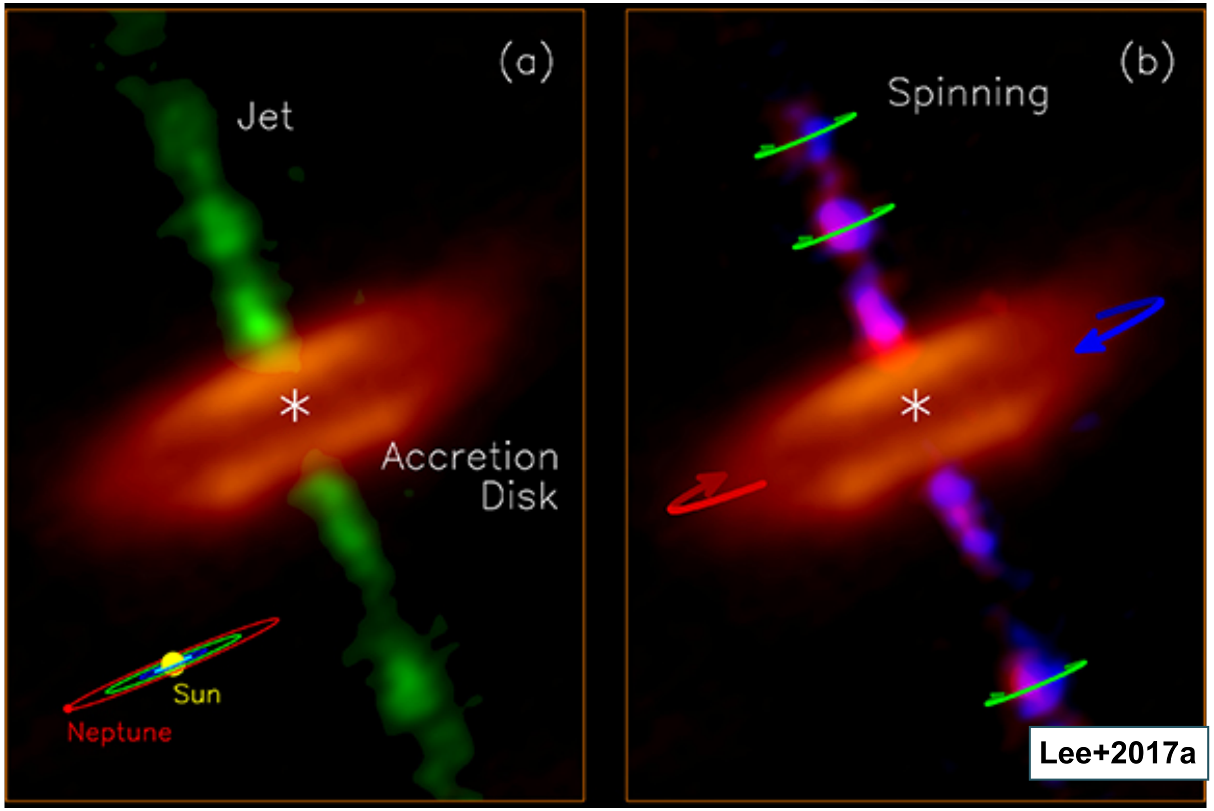
Standard paradigm of SF of a sun-like star

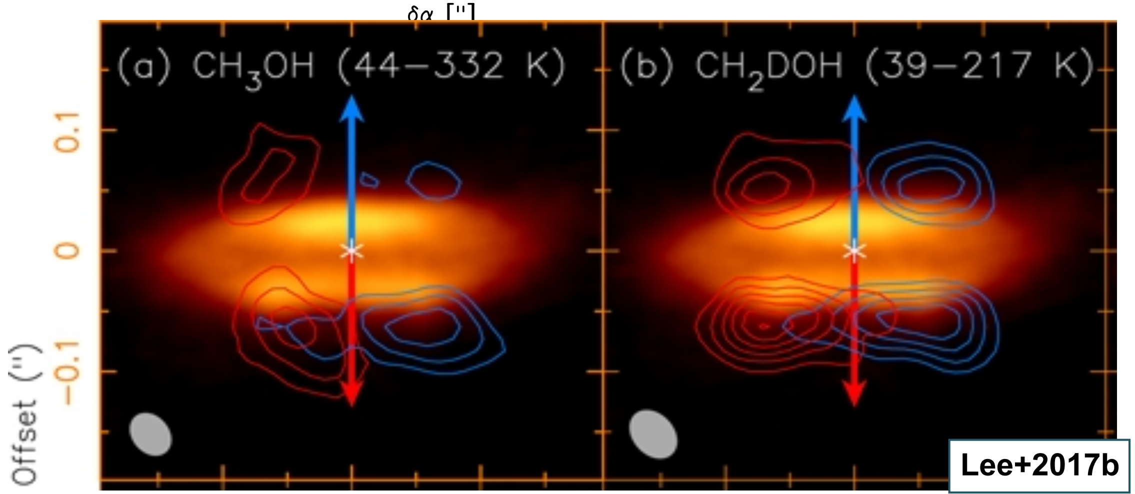


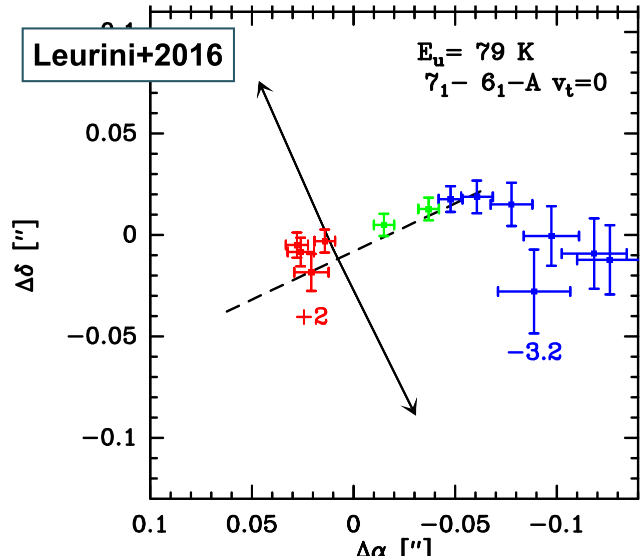
ALMA contribution to low-mass SF

HH212
class 0 YSO

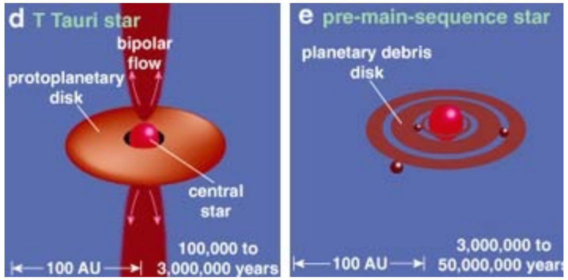


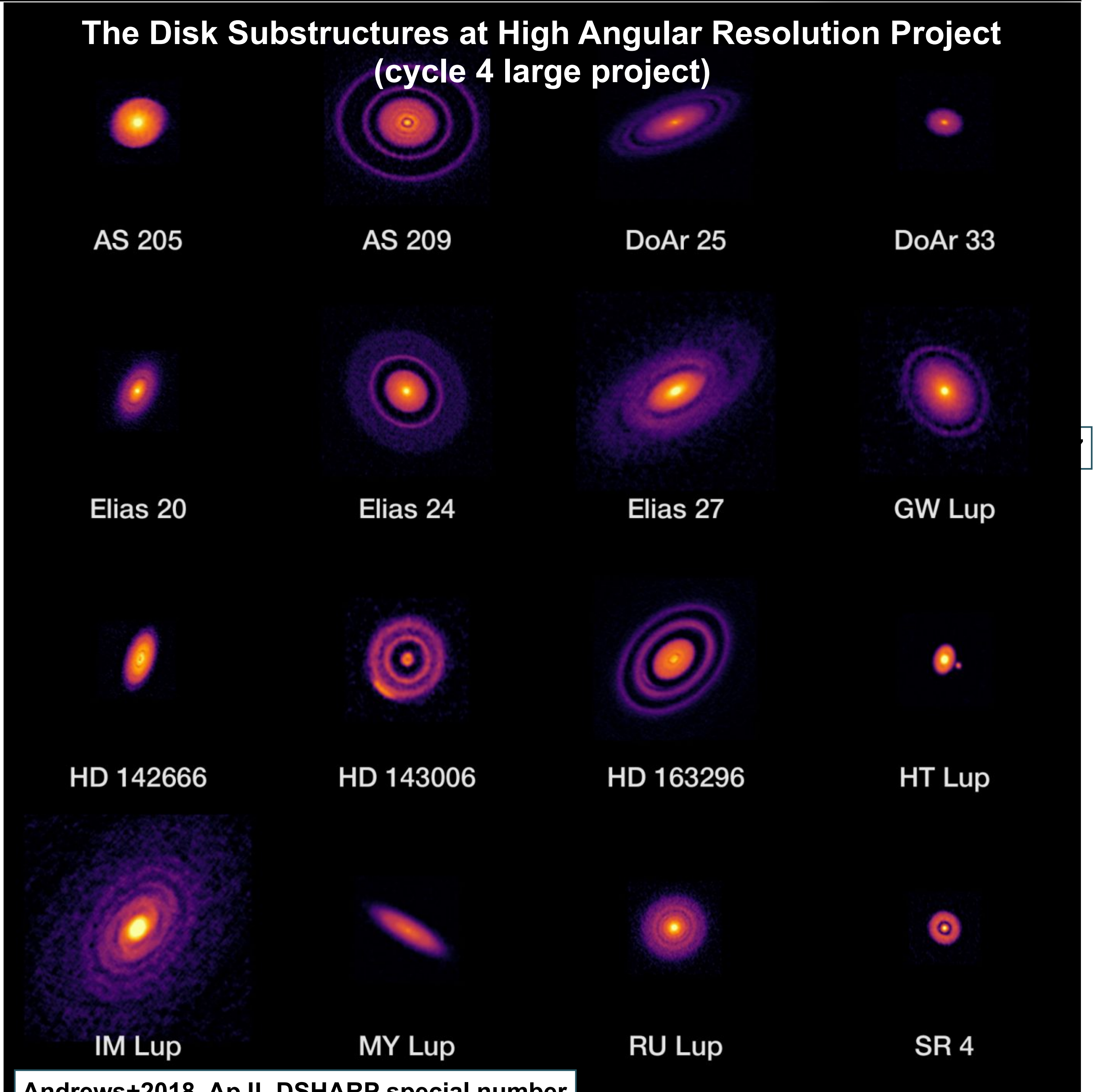






ALMA contribution to low-mass SF



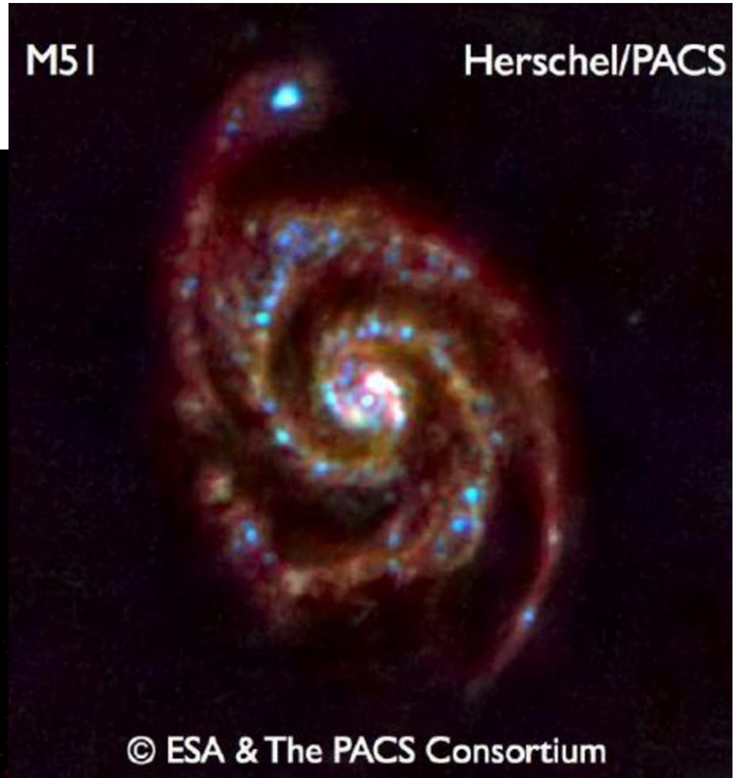


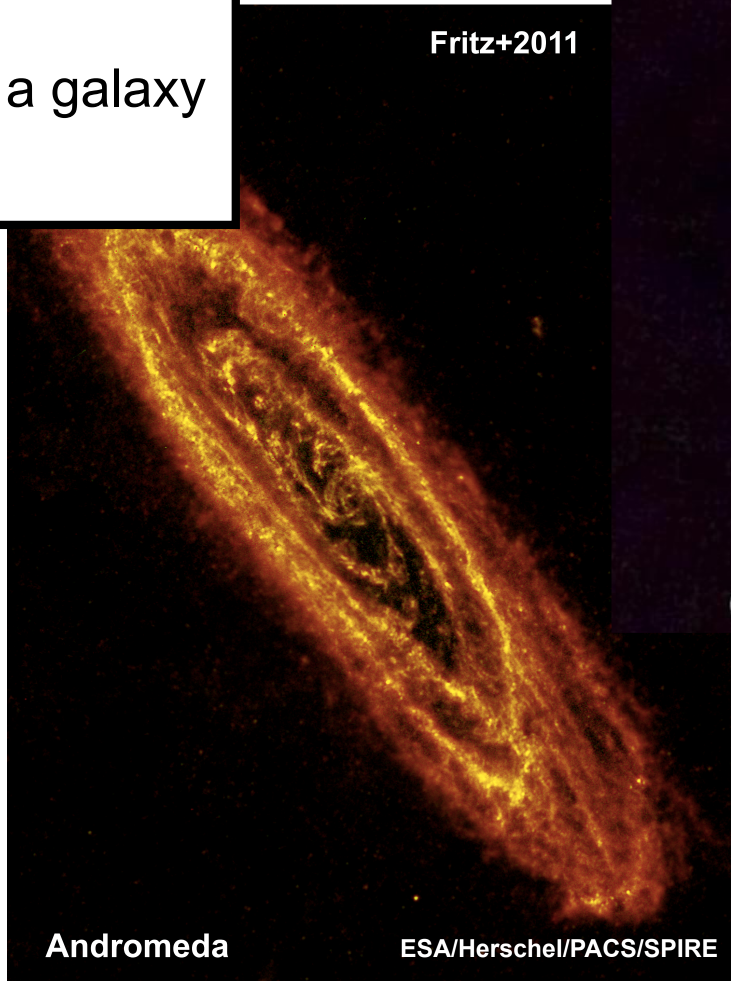
Andrews+2018, ApJL DSHARP special number

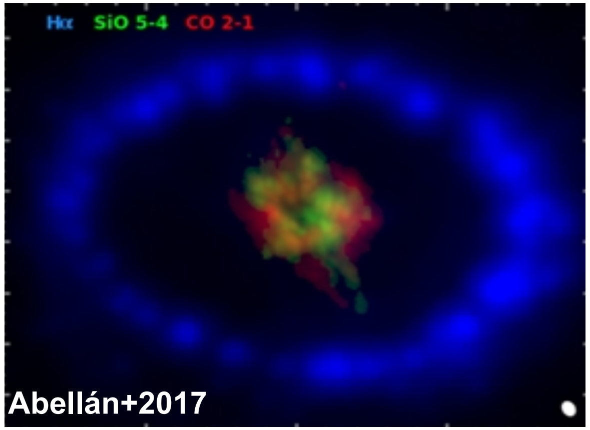
Massive (young) stars

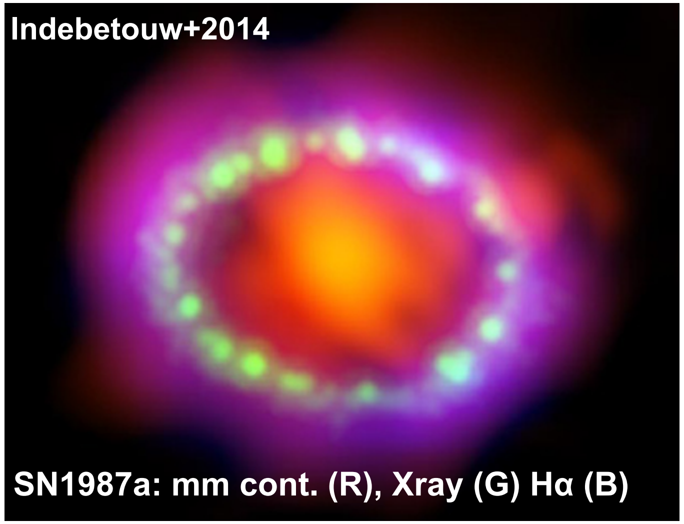
Massive (young) stars:

- enrich the ISM of metals
- dominate the energetics of a galaxy
- strong source of feedback

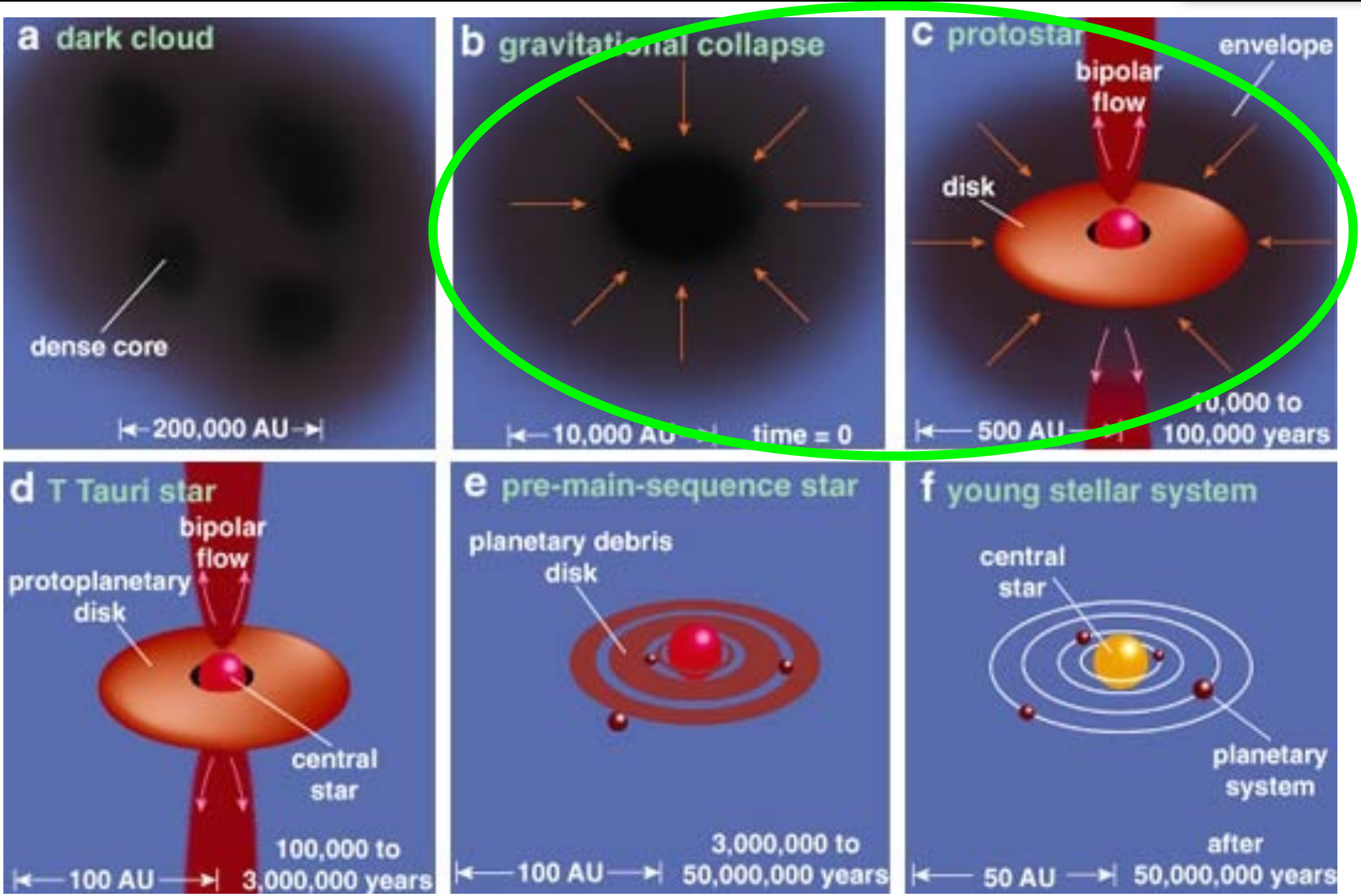








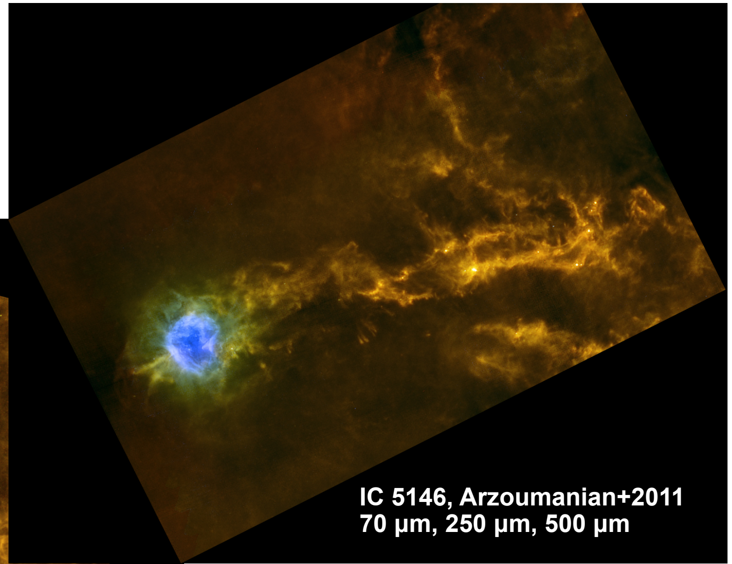
Massive SF in the standard paradigm



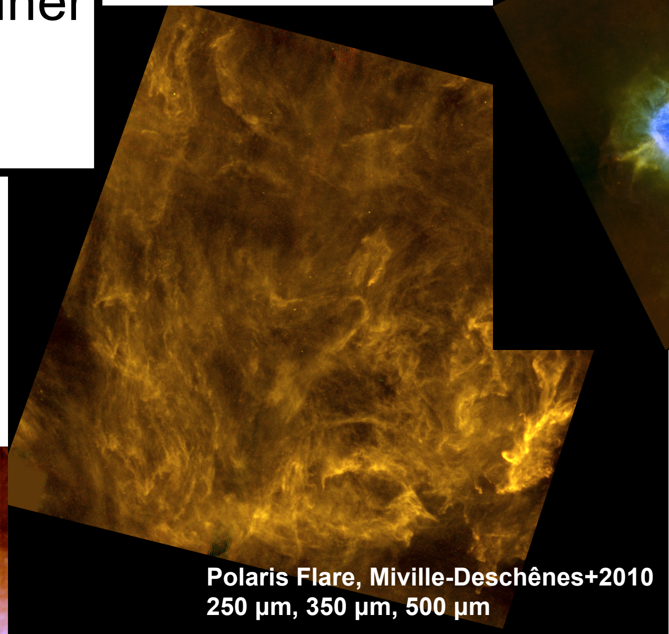
Herschel view of star formation

e.g. Ward-Thompson+2010, Konyves+2015, Schisano+2014/2019, Arzoumanian+2019

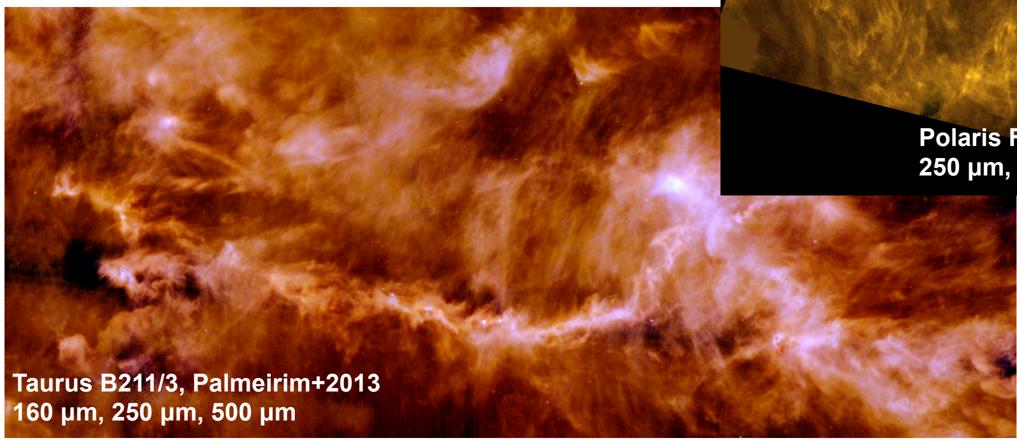
- *Herschel* revealed a "universal" filamentary structure in the cold ISM
- filaments are ubiquitous (~60 object per square degree in the inner Galaxy)
- filaments exist prior to SF



IC 5146, Arzoumanian+2011
70 μm, 250 μm, 500 μm



Polaris Flare, Miville-Deschênes+2010
250 μm, 350 μm, 500 μm

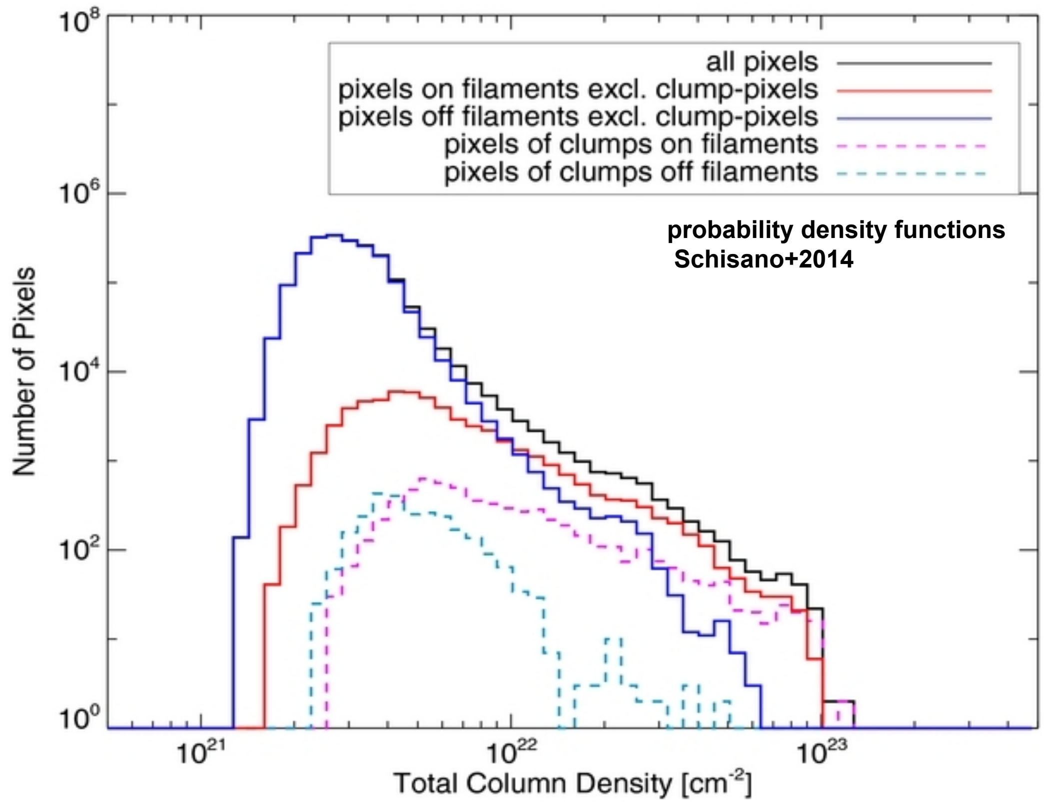


Taurus B211/3, Palmeirim+2013
160 μm, 250 μm, 500 μm

Herschel view of star formation

e.g. Ward-Thompson+2010, Konyves+2015, Schisano+2014/2019, Arzoumanian+2019

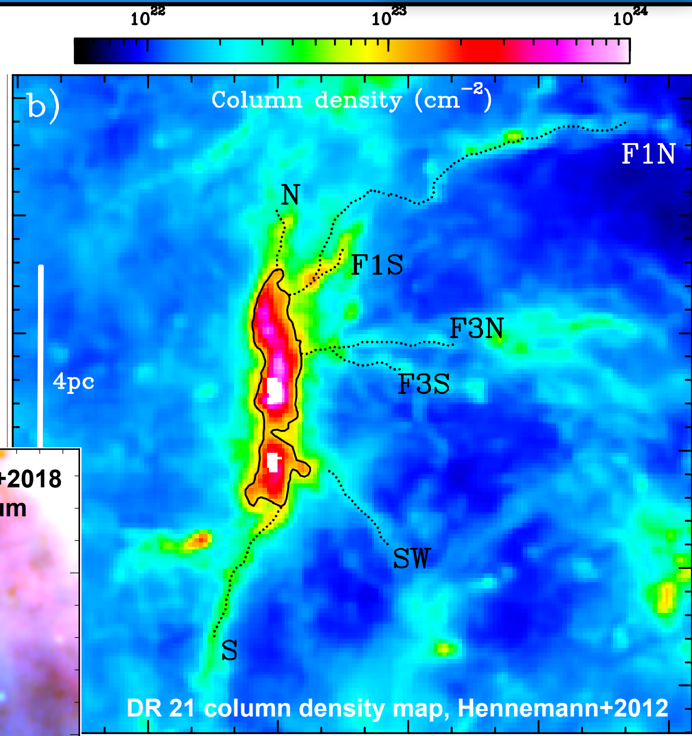
- more ~ 50% of the entire Hi-GAL source population is spatially correlated with filaments
- in 8 nearby clouds (<500 pc): 15% of the total gas mass, and more than 80% of the dense gas mass, is in the form of filaments

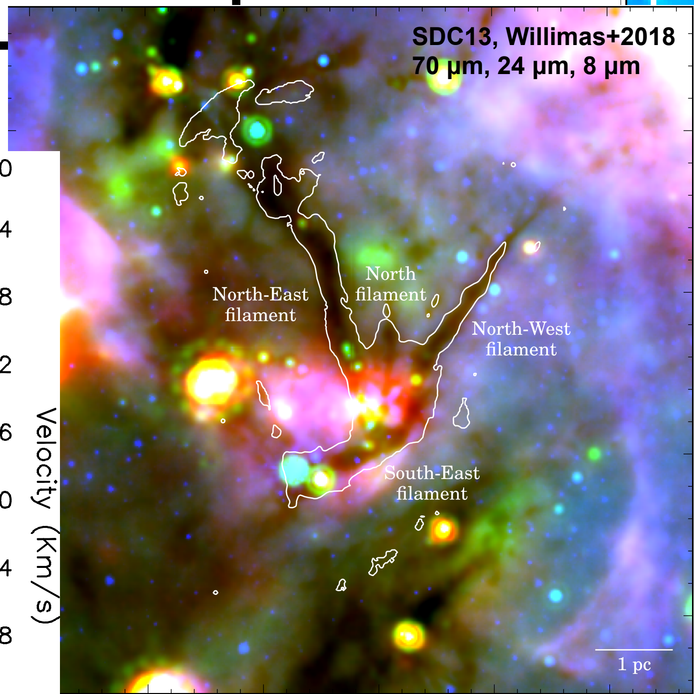


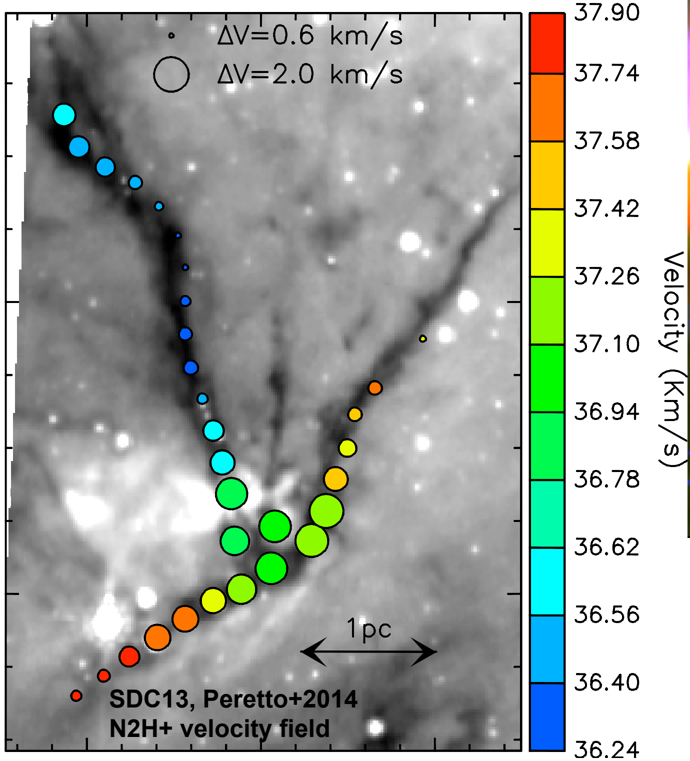
Proposed new paradigm: SF occurs in 2 main steps
1) Filaments form first in the cold ISM;
2) The densest filaments then fragment into prestellar cores via gravitational instability above a critical threshold

Massive SF in this new paradigm

- Intersecting filaments (*hubs*) seem to be the preferred environment for massive star and cluster formation
- hubs are likely collapsing on pc scales gathering matter at their centre

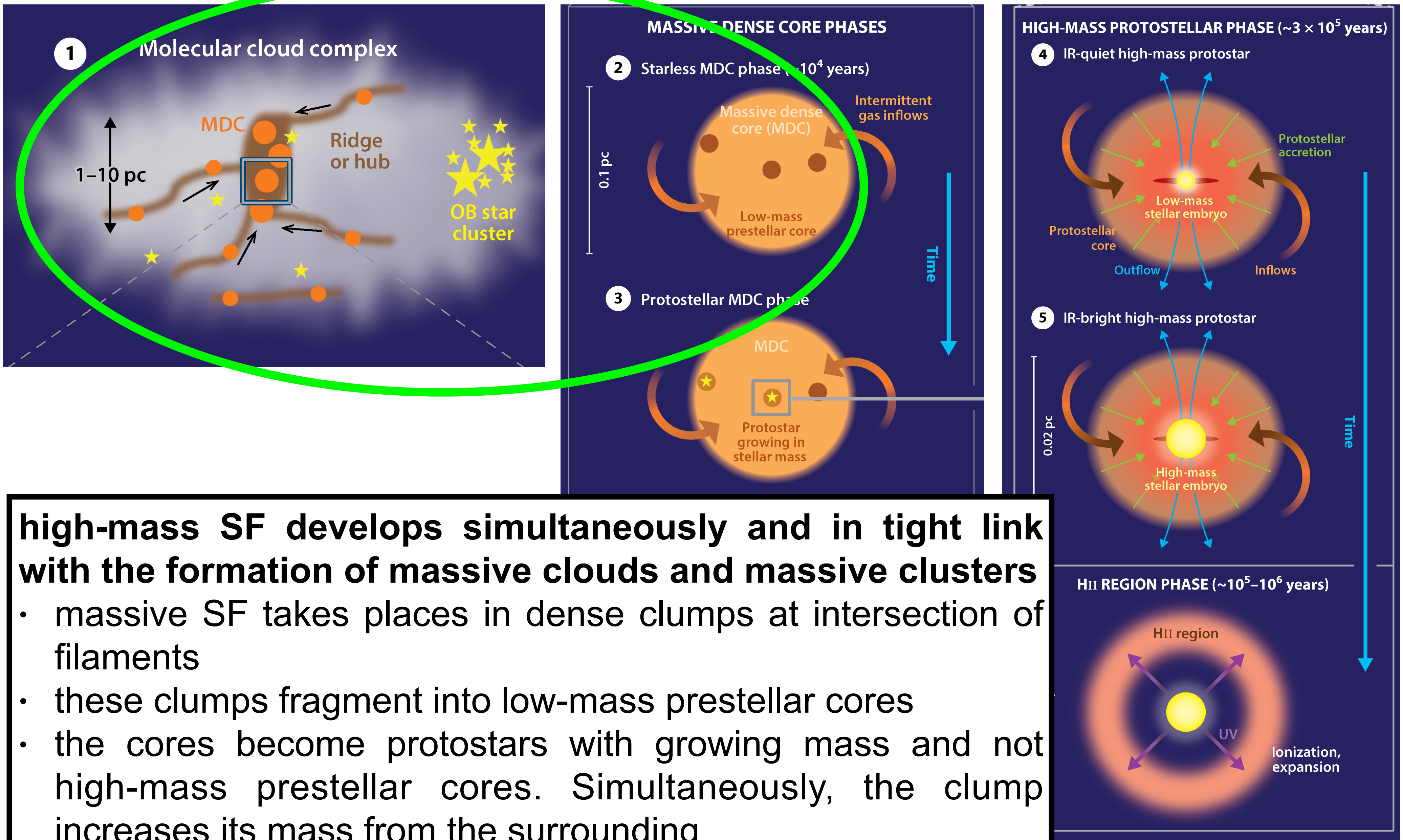






see Eugenio Schisano's talk

Massive SF in this new paradigm



high-mass SF develops simultaneously and in tight link with the formation of massive clouds and massive clusters

- massive SF takes places in dense clumps at intersection of filaments
- these clumps fragment into low-mass prestellar cores
- the cores become protostars with growing mass and not high-mass prestellar cores. Simultaneously, the clump increases its mass from the surrounding

Motte+2018

Open questions on massive SF

- **How can massive YSOs accrete their mass within short lifetime against strong feedback?**

  ➡ **do circumstellar disks exist around O-type YSOs?**

  ➡ **indirect evidences of disk accretion**

  ➡ ***does global collapse of the cloud happen? is it universal?***

- **do massive prestellar cores exist? do massive clumps fragment in a population of low-mass cores?**

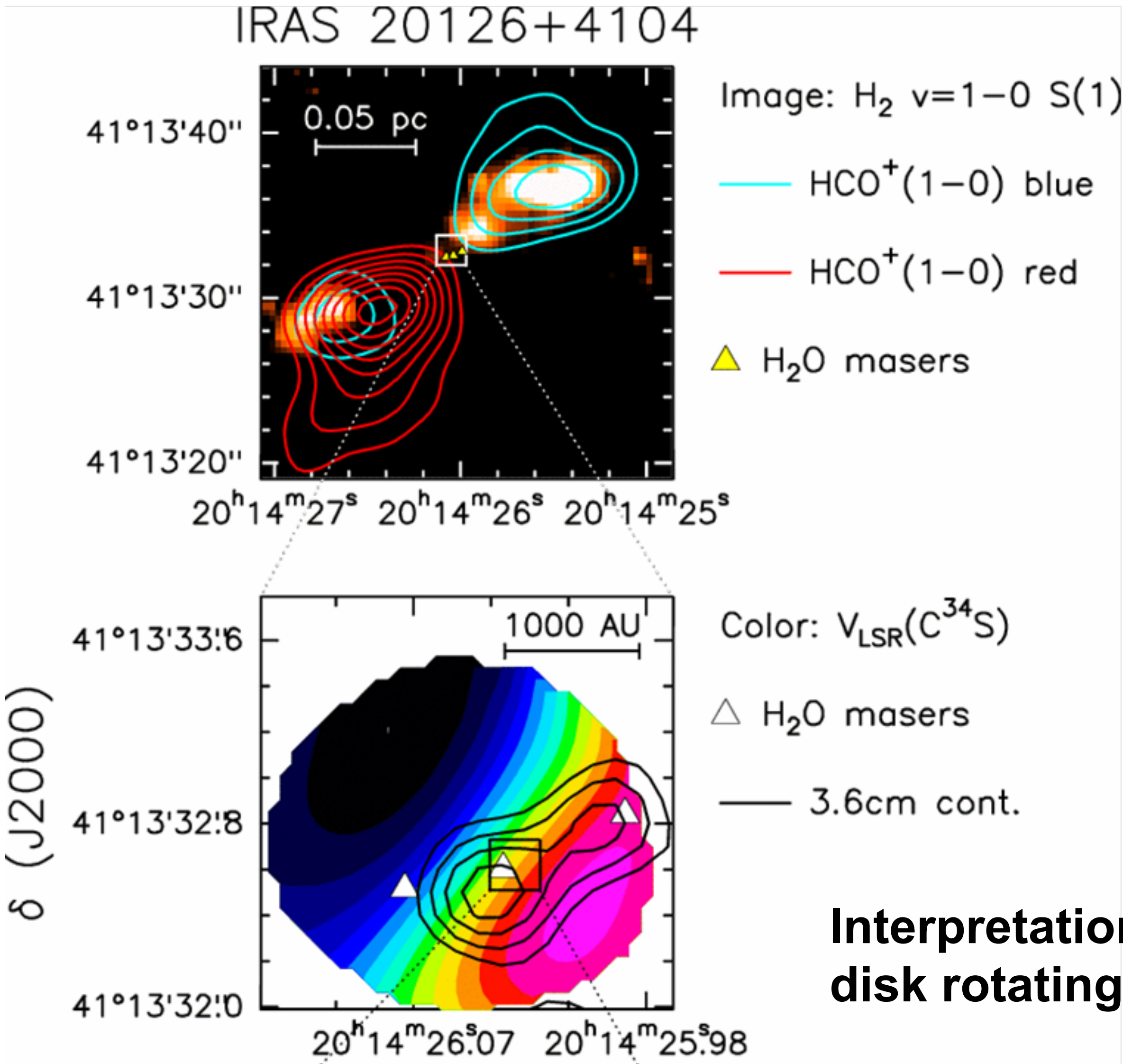
Open questions on massive SF

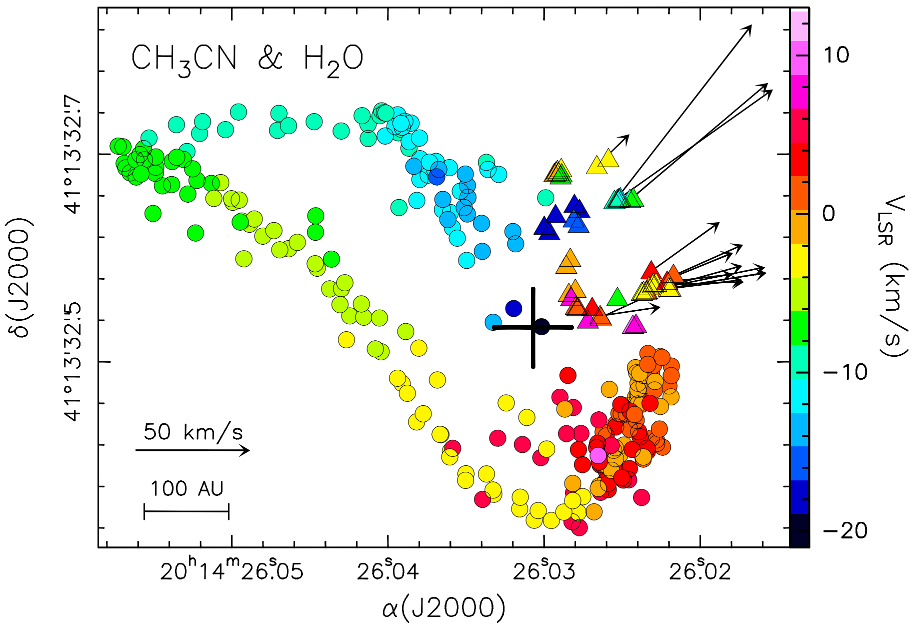
do circumstellar disks exist around O-type YSOs?

Do circumstellar disks exist?

Disk(-like) structures discovered even before ALMA era….

Cesaroni+1997, 1999, 2014

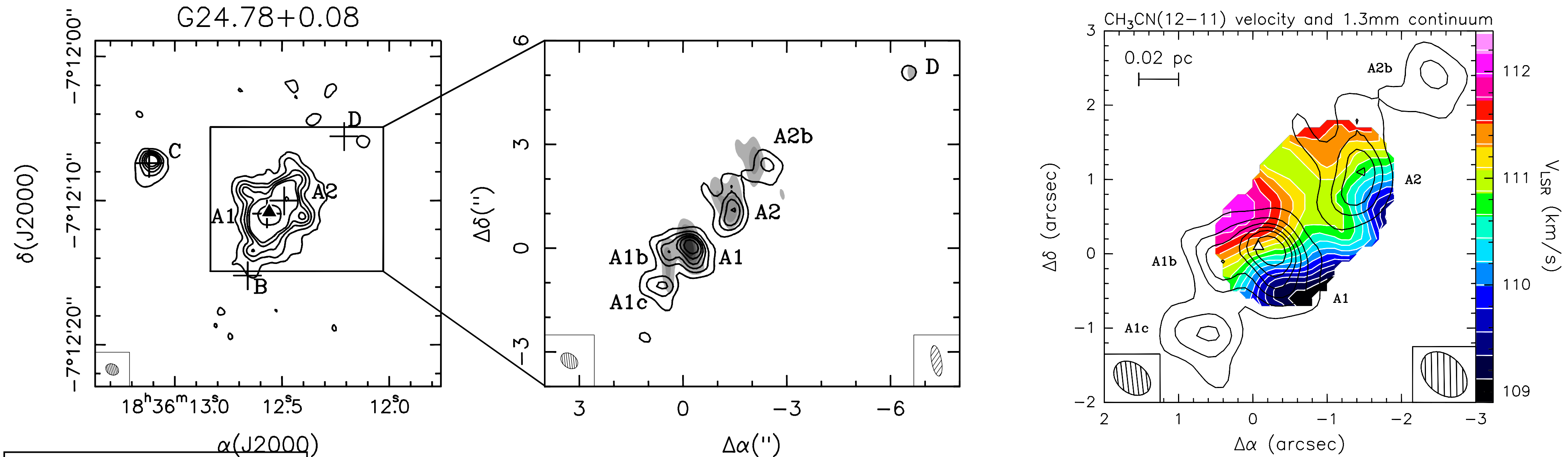




Interpretation: CH_3CN traces a (quasi-)Keplerian disk rotating about a 7−10 $M_\odot$ protostar

Do circumstellar disks exist?

ALMA seems to confirm this picture…

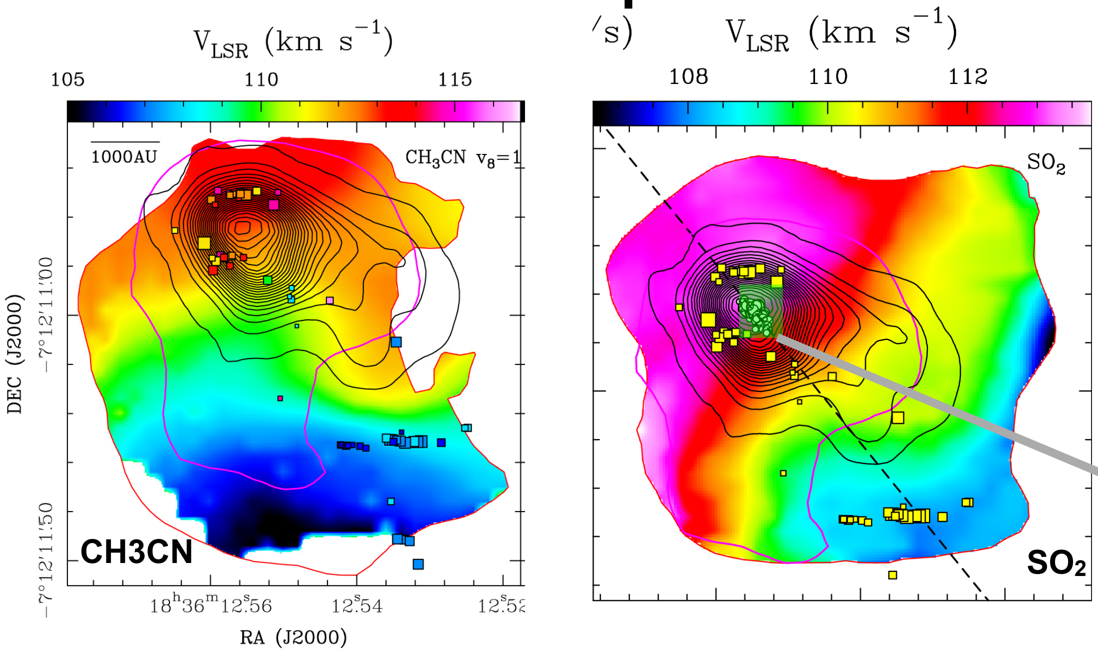


Beltran+2011 (SMA data)

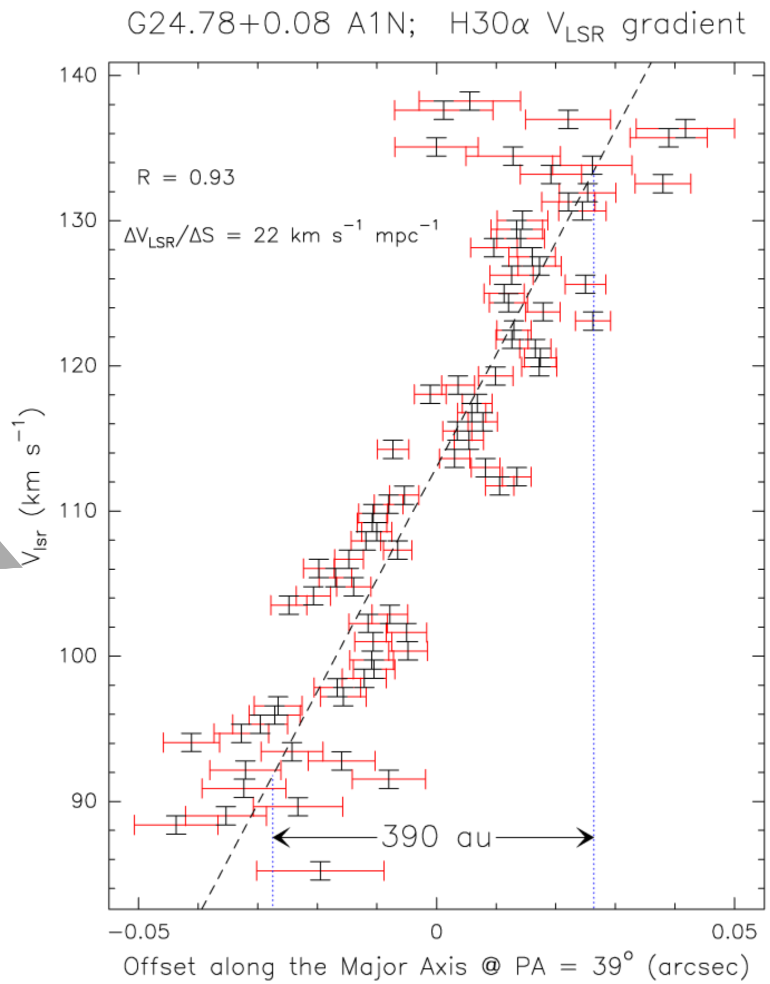
Interpretation: circumcluster disk/toroids

Do circumstellar disks exist?

…but make it more complicated!



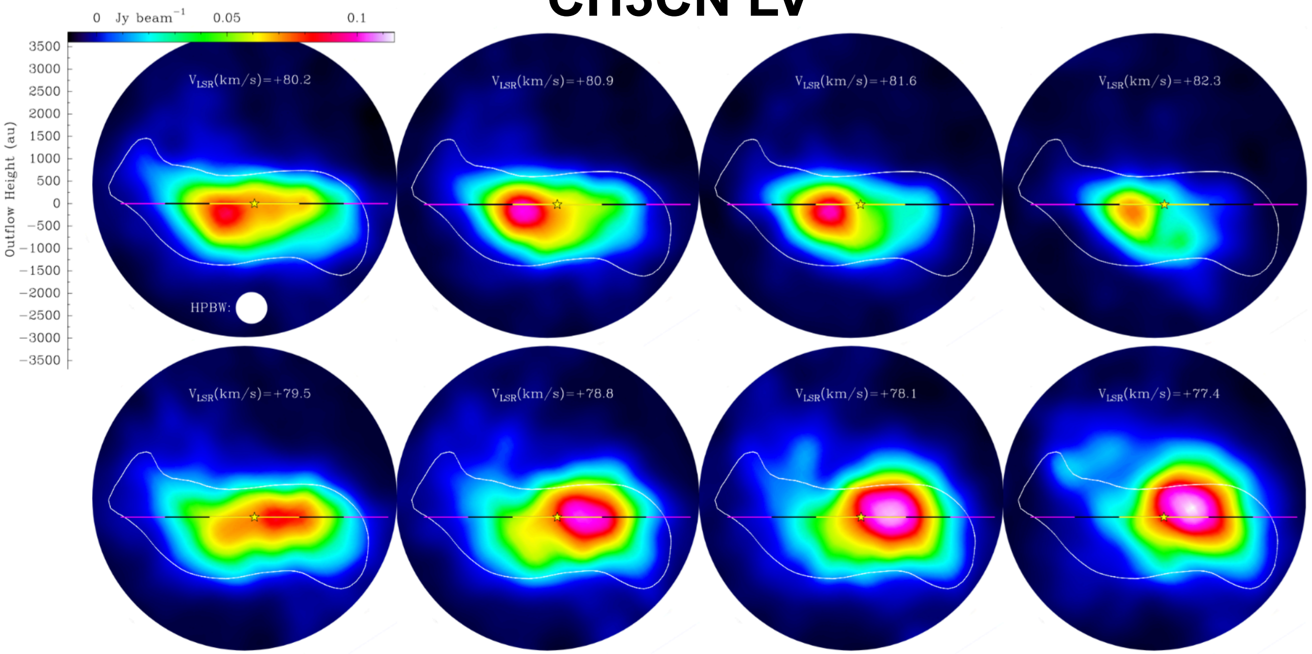
Moscadelli+2018



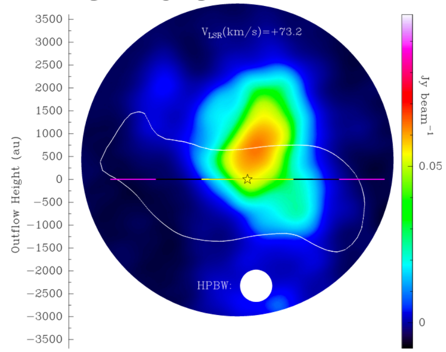
Interpretation: the H30*α* line reveals a fast bipolar flow in the ionized gas ⇒ *the velocity gradient in CH_3CN traces, in this case, a fast flow*

Do circumstellar disks exist?

CH3CN LV

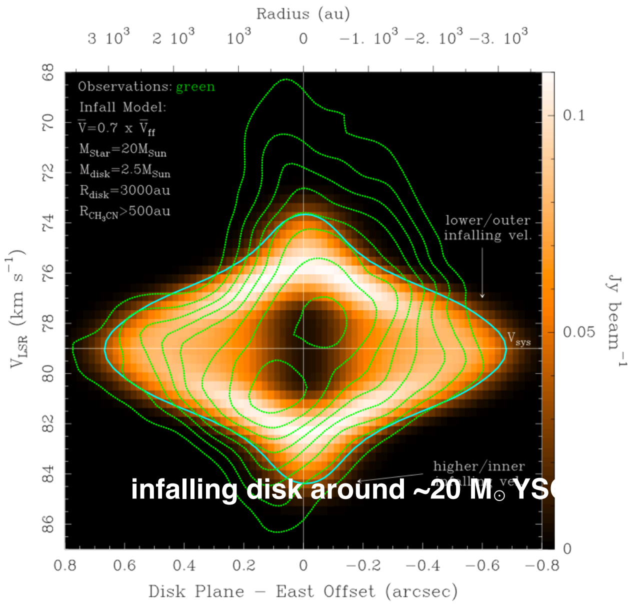


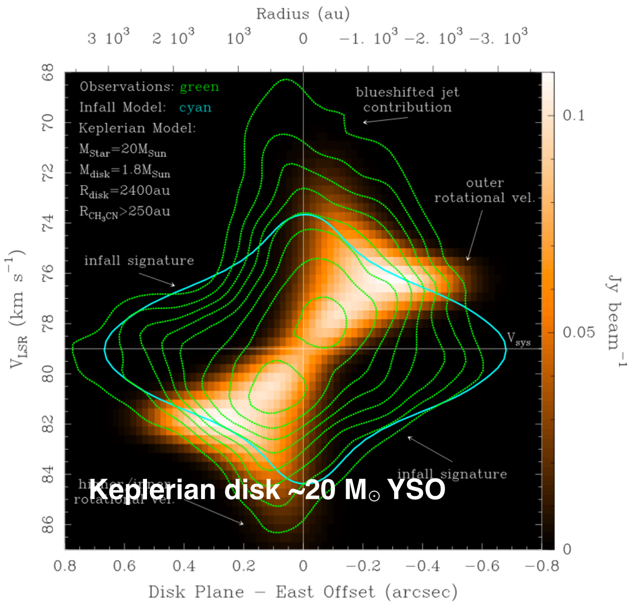
CH3CN HV



Sanna+2019

G023.01−00.41



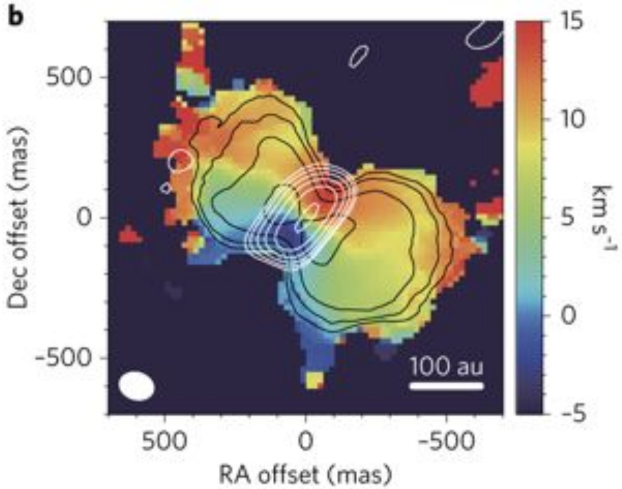


Interpretation:

- **molecular jet from the inner disk**
- **molecular disk which rotates and undergoes infall around a 20 $M_\odot$ star**
- **centrifugal equilibrium does not hold r>500 au, where the velocity field ia a combination of sub-Keplerian rotation and infalling motion.**

Do circumstellar disks exist?

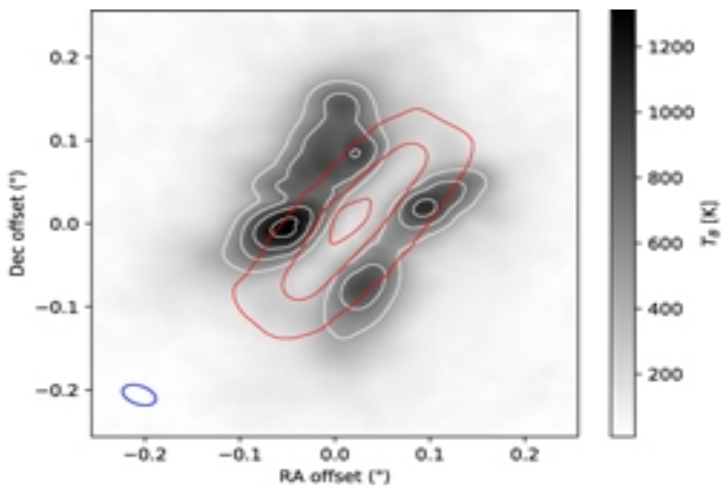
Orion SrcI



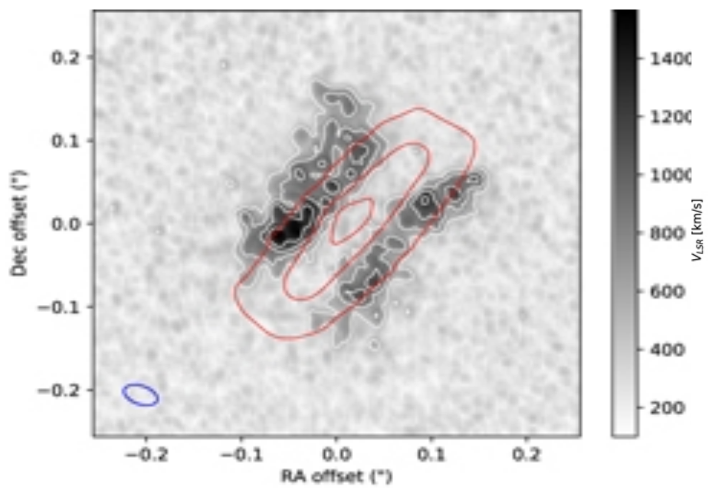
Hirota+2014

- **Rotation of the outflow in SiO**
- **Keplerian disk system, central mass of ~15 $M_\odot$**

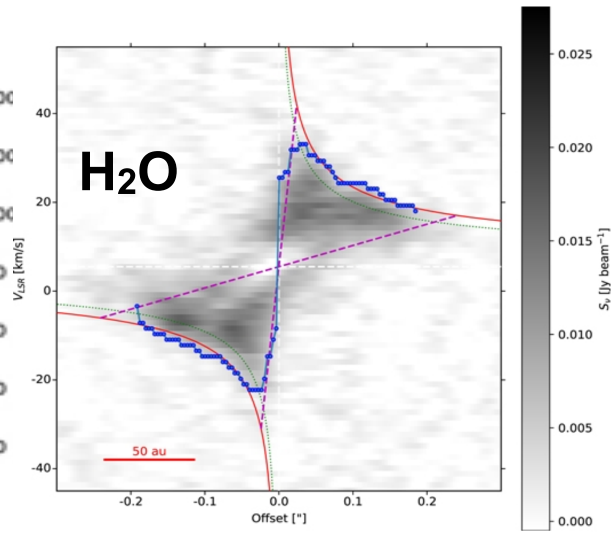
Ginsburg+2018



(b)



(c)

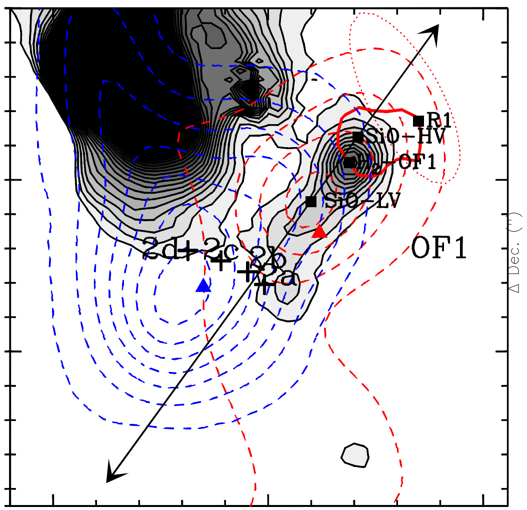


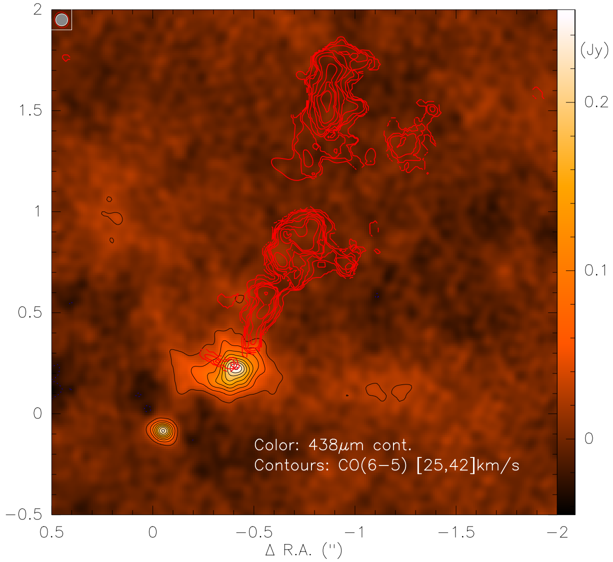
Open questions on massive SF

indirect evidences of disk accretion in massive YSO

Collimated jets in high-mass YSOs

G351.77-0.54, early B YSO

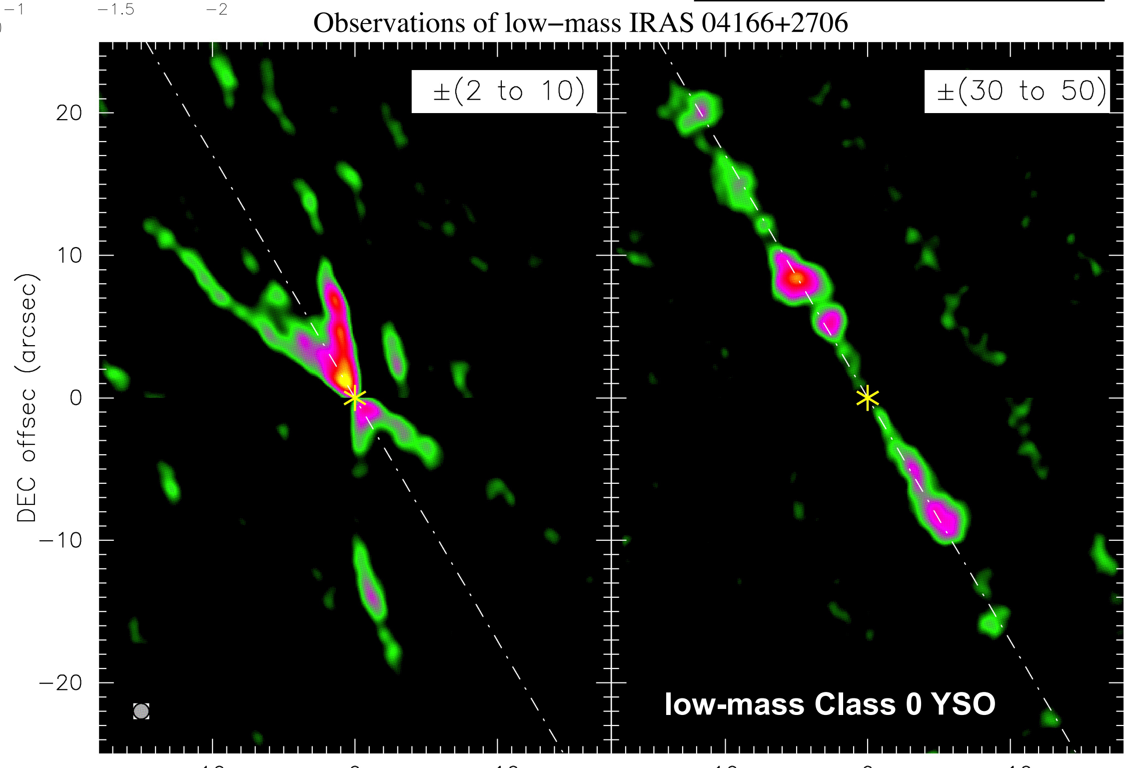




Leurini+2009; Beuther+2017

at least one collimated jet detected (plus radio jet with JVLA)

Wang+2014 (SMA CO(3-2))



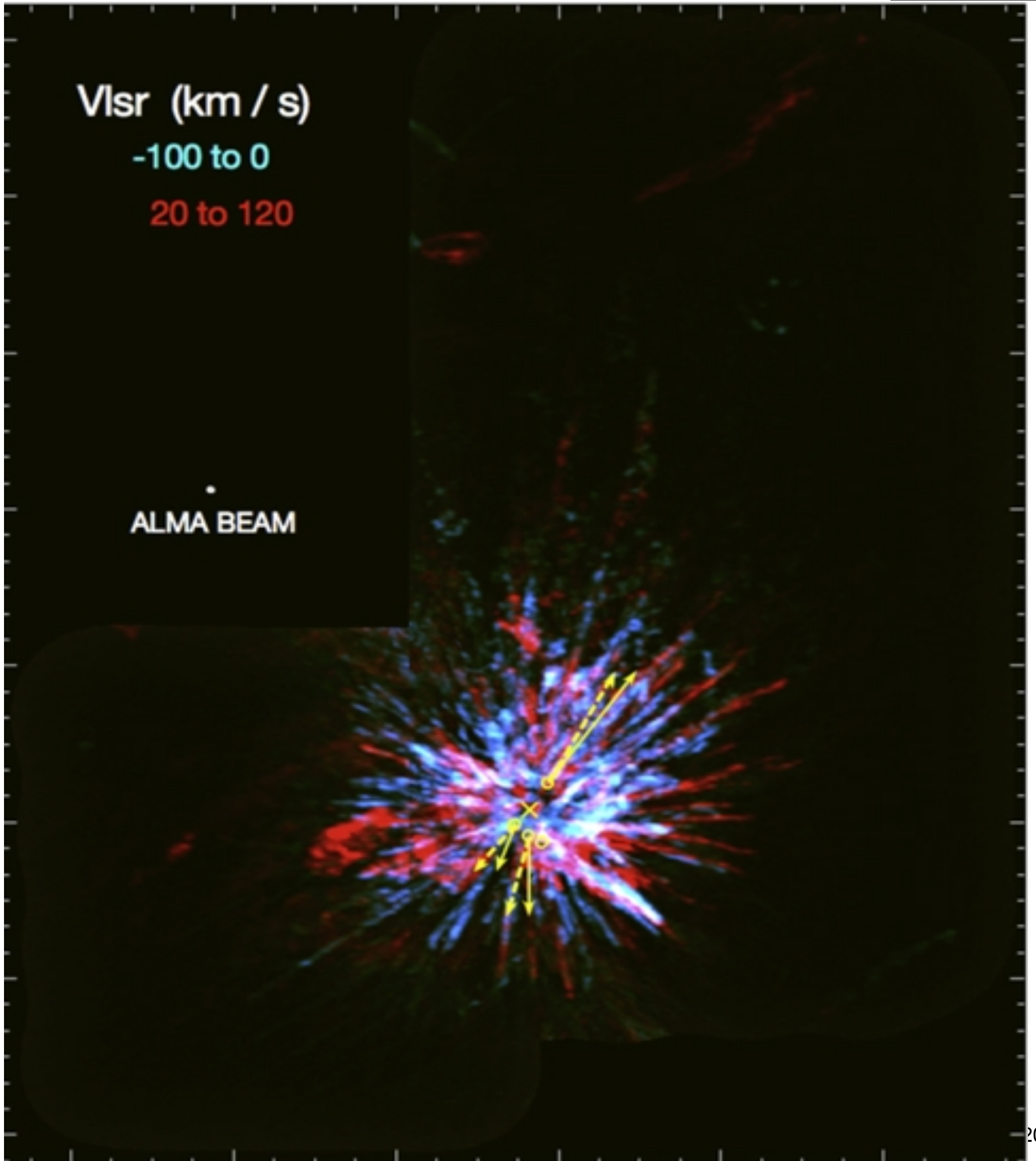
however, never towards more massive YSOs! plus we did not detected yet the kinematical structure seen in low-mass outflow/jet systems jet, LV outflow-cavities)

Collimated jets in high-mass YSOs

…but also explosive outflows associated with the formation of a compact binary or a protostellar merger (?)

Orion KL

Bally+2017

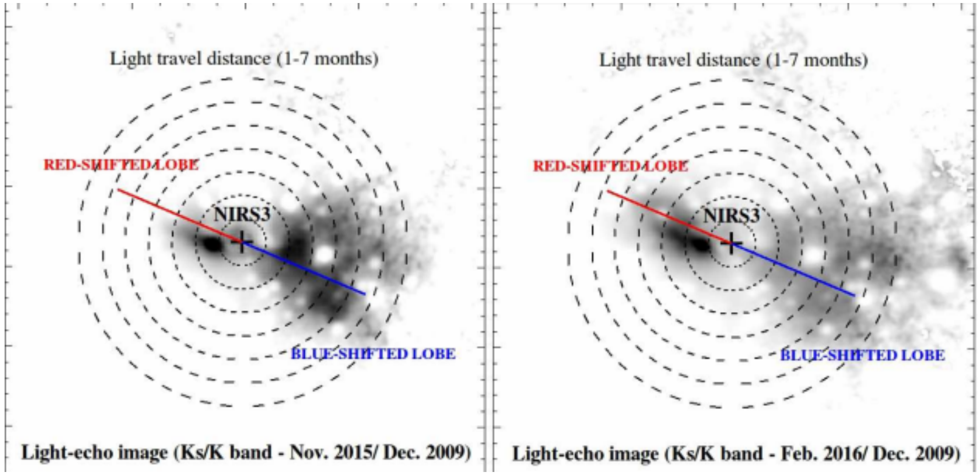


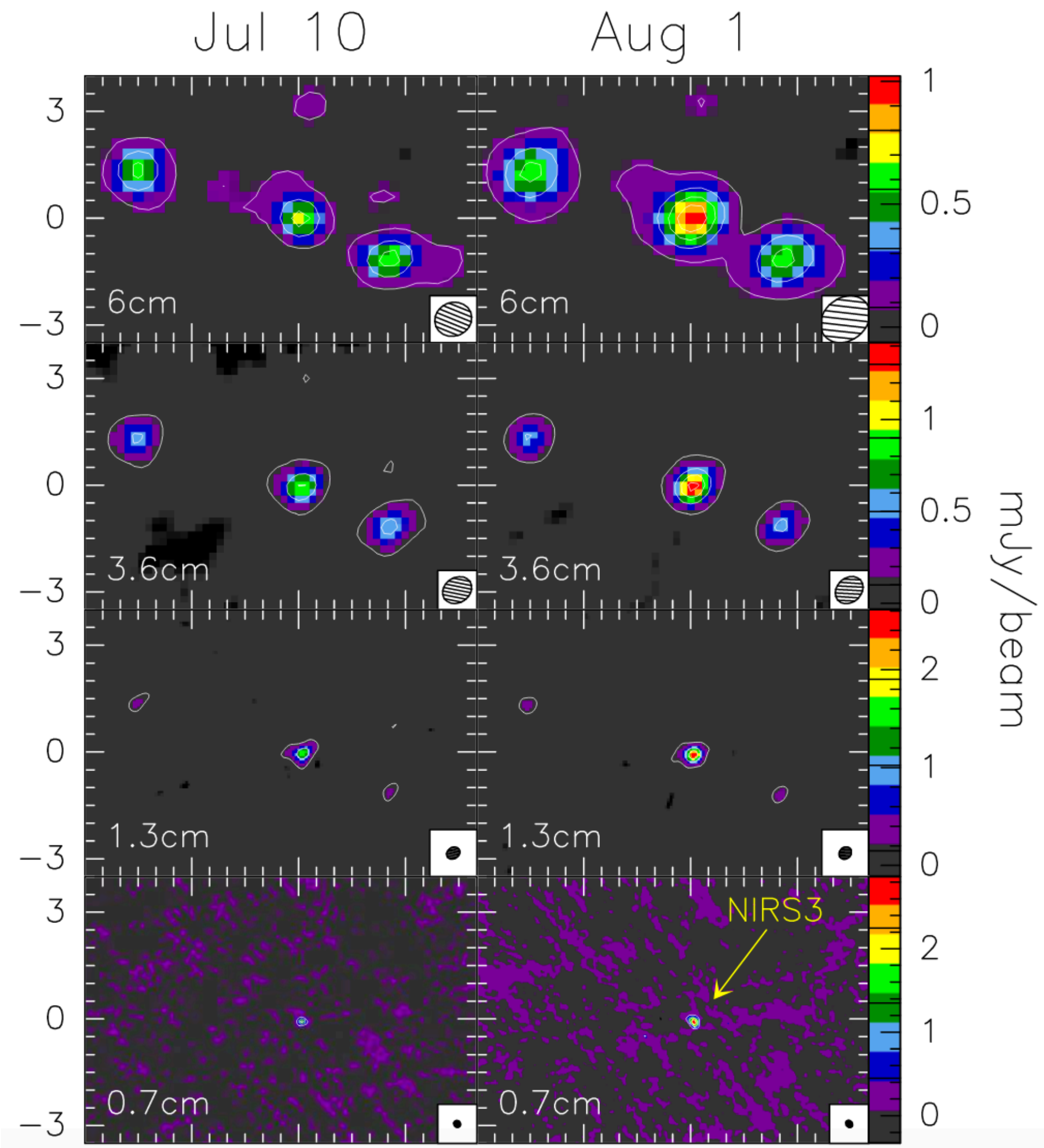
Accretion bursts in high-mass YSOs

Osservatorio Astronomico di Cagliari

Disk-mediated accretion bursts (as in low-mass YSOs)

20M⊙ S255 NIRS 3





exponential increase in the radio flux density from 6 to 45 GHz

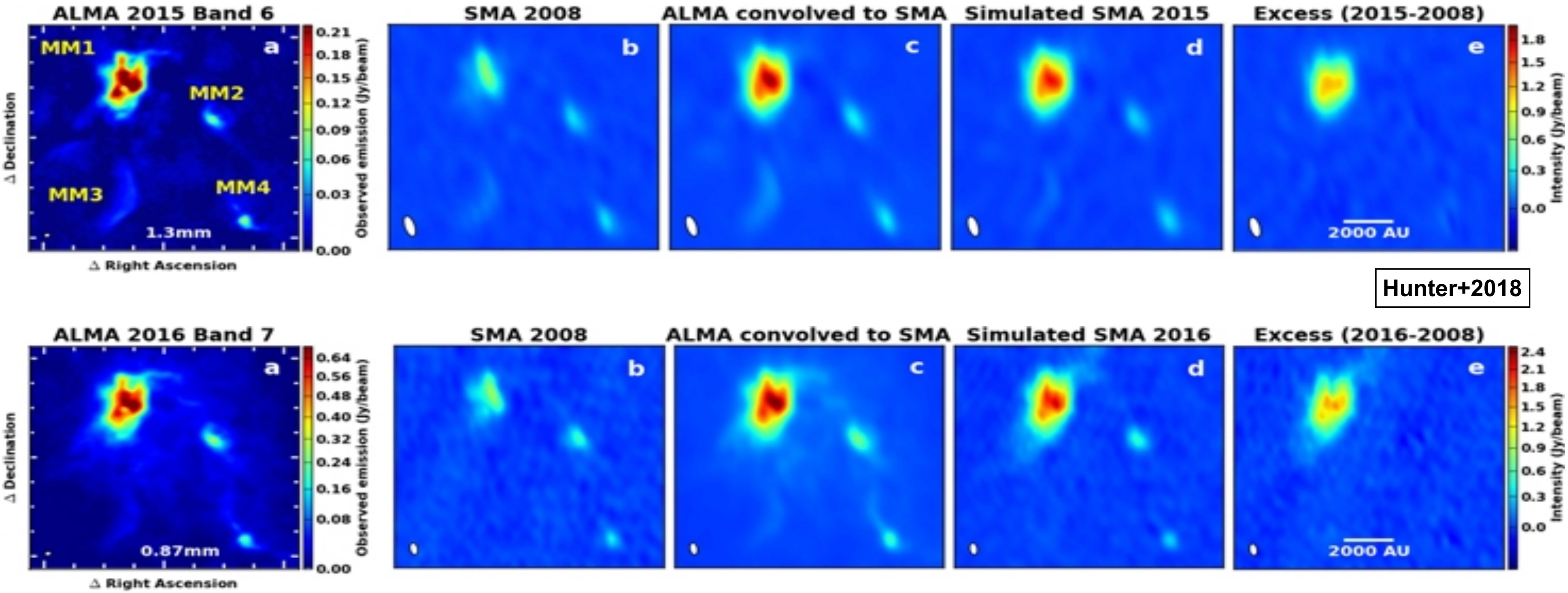
Caratti o Garatti+2017; Moscadelli+2017; Cesaroni+2018

Accretion bursts in high-mass YSOs

Osservatorio Astronomico di Cagliari

Disk-mediated accretion bursts

NGC 6334I



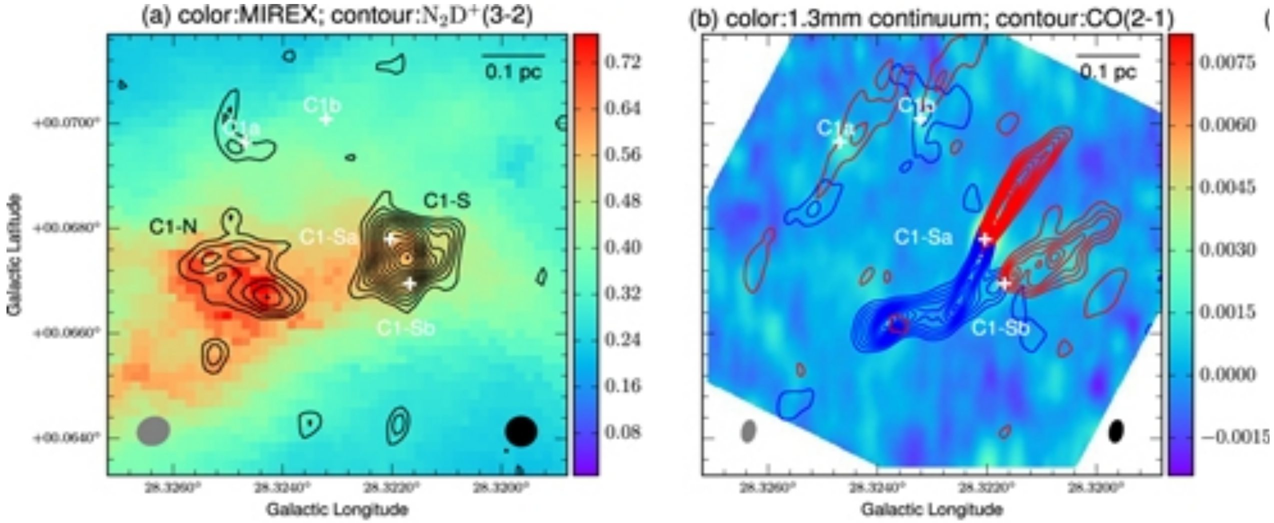
Hunter+2018

dust emission from MM1 has increased by a factor of 4.0 from 2008–2015

Open questions on massive SF

do massive prestellar cores exist?

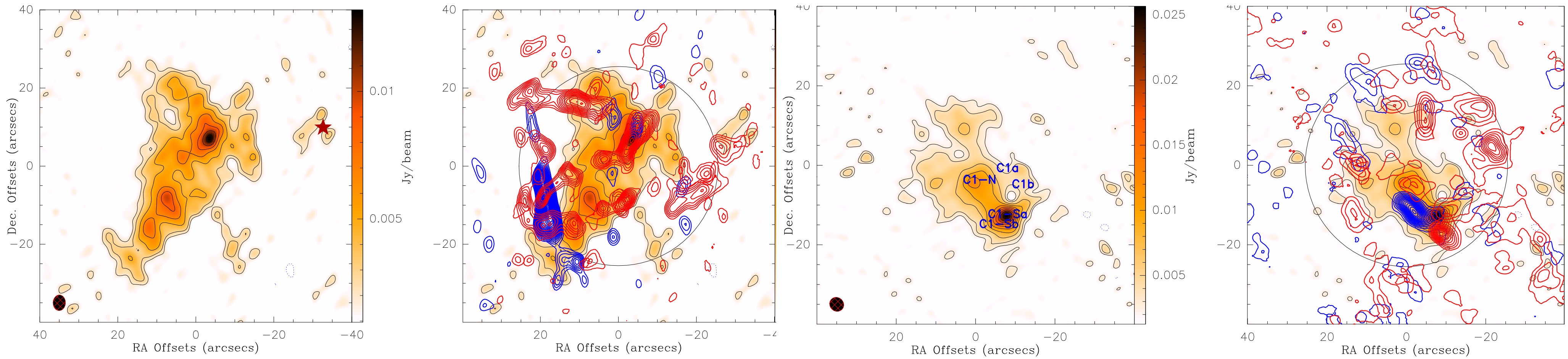
Do massive prestellar cores exist?



Tan+2016, Kong+2016

70 and 160 μm dark massive clumps (⇒ cold and dense)

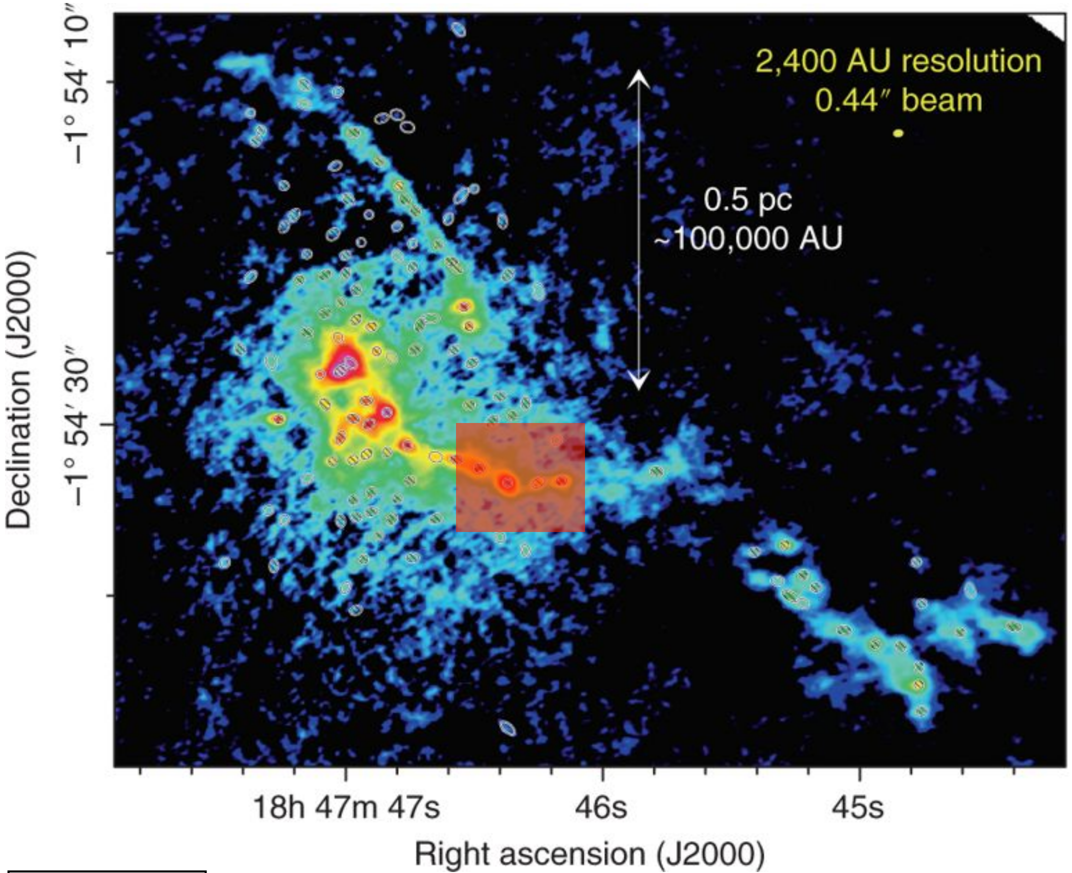
- **fragments in (few) massive cores**
- **host outflows from massive YSOs**
- **host outflows from population of low-mass YSOs (not detected in the continuum)**



Pillai+2019

⇒low-mass stars might form first or coevally with massive stars

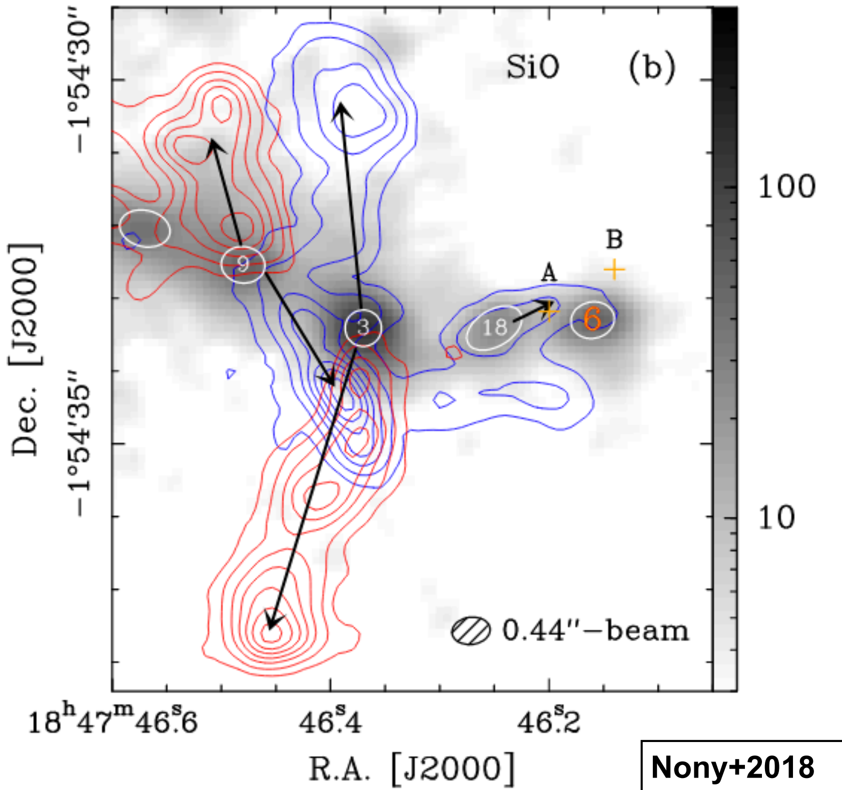
Fragmentation of massive clumps



Motte+2017

ALMA 1.3 mm dust continuum emission of W43-MM1 (2 10^4 M⊙)

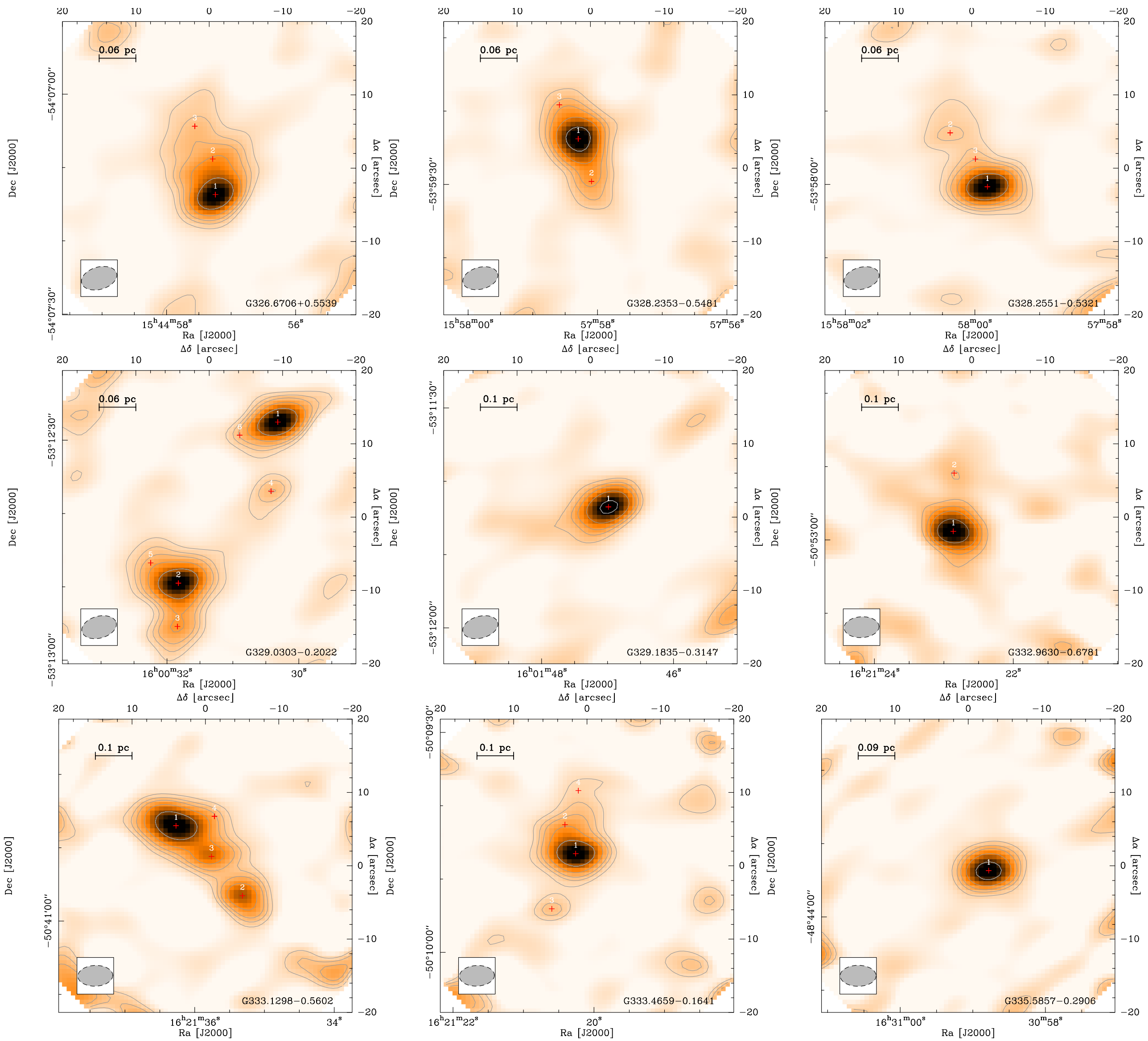
W43-MM1 seems to challenge the relationship between the CMF and IMF (shallower slope at high masses)



Nony+2018

prestellar ~60 M⊙ core?

Fragmentation of massive clumps



SPARKS: ALMA survey of 35 low-luminosity (L_{bol}< $10^4 L_{\odot}$) ATLASGAL clumps within $d \leq 4.5$ kpc

Results: Limited fragmentation

Csengeri+2017

more with ALMA-IMF cycle 5 large project, P.I. Motte

Summary

ALMA has opened a new window for HM-SF studies

- ✦ High quality cloud/filament structures
- ✦ High resolution disk/outflow systems
- ✦ High sensitivity datasets for clump fragmentation/ identification of starless massive cores

Higher resolution is definitely crucial

Large surveys are needed

ALMA2019: Science Results and Cross-Facility Synergies

14-18 October 2019
T-Hotel Cagliari
Europe/Rome timezone

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- Important dates
- Invited speakers
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:/789/

ALMA 2019 Conference.

The Atacama Large Millimeter/Submillimeter Array (ALMA) is the world's most sensitive facility for millimeter/submillimeter astronomical observations, and will soon be fully operational in all of the originally planned bands. Since its first observations, ALMA has routinely delivered groundbreaking scientific results that span nearly all areas of astrophysics.

https://indico.ict.inaf.it/e/ALMA2019