The role of Ridges in high mass star formation

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1. High-mass SF and filaments
2. Massive filaments or Ridges
3. Kinematics and large scale infall
4. Open issues
How high-mass stars form?

Theoretical views:

- Slow evolution of turbulence supported (massive) dense cores (McKee & Tan 2003; Krumholz & Mckee 2005; …).

- Fast dynamical evolution and turbulent support (Padoan & Nordlund 02; Hennebelle & Chabrier 08, 09): high-mass stars from large scale, low density regions (large $M_{\text{Jeans}}$).

- Fast gravo-turbulent low-mass fragmentation ($\sim t_{\text{ff}}$) and competitive accretion in proto-clusters (Bate et al. 2003; Bonnell et al. 2003).
Surveys for high-mass protostars

- Masers: samples of high-mass SFRs Molinari et al. (1996), Plume et al. (1997), all refs in Kurtz et al. (2000)
- pre-UCHII regions: IRAS sources, no cm Sridharan, Beuther et al. (2002)
- MM continuum: IRAS samples Muller et al. (2002), Faundez et al. (2004), …
- IRDCs: not only high-mass Simon, Rathborne et al. (2006); Pillai et al. (2006); Peretto & Fuller (2009).
- MM complete imaging: W43, Cygnus X Motte et al. (2003, 2007)
Fragmentation in massive clumps/cores

High-spatial resolution observations:

- Beuther et al. (2007); Leurini et al. (2007); Brogan et al. (2010); Rathborne et al. (2007, 2009), Zhang et al. (2009), Bontemps et al. (2010); Wang et al. (2011); Palau et al. (2014); Beuther et al. (2013, 2014).

Need to reach ~ 2000 AU scale
High-mass Class 0 and Super-Jeans cores

Local (thermal) Jeans Mass of < 1 $M_{\odot}$.

How can we get such massive cores?

Here we have cores up to ~50 x Jeans Masses.

They collapse and actually form high-mass stars.
Short statistical lifetime for massive clumps

Motte et al. (2007)
ATLASGAL - Csengeri et al. (2014)

- 7.5 \times 10^4 \text{ yr} \text{ for } 0.3 \text{ pc} \text{ leads to } 4 \text{ km/s typical accretion speed.}
- Formation of massive clumps is supersonic.

Fraction of clumps with HMSF (for more than $\frac{1}{4}$ of the Galaxy): 75% at high mass

Galaxy-wide statistics on $\sim 0.3$ pc clumps
How high-mass stars form?

Observations:
- Super-Jeans cores exist and they form high-mass stars.
- Fast massive core formation.

Theoretical views:
- Large effective Jeans masses?
  - To get $M_{\text{Jeans}} = 20 M_\odot$ one needs $T_{\text{gas}} \sim 200 \text{ K}$ or $\Delta v_{\text{FWHM}} \sim 3 \text{ km/s}$.
  - Pre-stellar phase has to be dynamical (formed by supersonic motions).
- High-mass star formation requires “special conditions”.
- Dynamical, and large (effective?) Jeans conditions.
Filaments and low-mass star formation

Palmeirim et al. (2013)  Arzoumanian et al. (2011)

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What about high-mass star formation?

- Massive filaments with coalescence of cores.
- Cloud collisions to form massive networks of filaments?

- (small-scale) Flows, most probably convergent (e.g. Vazquez-Semadeni et al. 2009)
What about high-mass star formation?

Cygnus X - North

W75N
2,000 $M_{\text{sol}}$

DR21
20,000 $M_{\text{sol}}$

5 pc

100 $M_{\text{sol}}$

B213 – 40 $M_{\text{sol}}$
Palmeirim et al. (2013)

HOBYS survey (Motte et al.)
Hennemann et al. (2012)
A number of ridges in nearby GMCs

Cygnus X (1.4 kpc)
HOBYS survey
Hennemann et al. (2012)

Vela (700 pc)
HOBYS survey
Hill et al. (2011, 2012), Minier et al. (2013)

Orion A (420 pc)
Gould-Belt survey
André, Polychroni, Roy et al.
Some IRDCs are ridges in distant GMCs

G35.39-0.33 (Nguyen-Luong et al. 2011), G32.03+0.05 (Battersby et al., 2014)
Teyssier et al. 2002; Simon et al. 2006; Kainulainen, Alves et al. 2011

Schneider, Csengeri et al., 2014
... but also massive hubs

Cygnus X (1.4 kpc)

Rosette (1.7 kpc)

MonR2 (800 pc)

Clusters @ filament junctions

Schneider et al. (2012)

HOBYS survey

Rayner et al. in prep.

Hennemann et al. (2012)
High-density ridges under dynamical influence …

DR21 Ridge
\(~ 20,000 \, M_\odot\)

20% of the total mass of dense gas in the whole CygNUX complex!

Schneider et al. (2010), Csengeri et al. (2011), Hennemann et al. (2012).
Dynamical features

- Infall / contraction \((10^{-2} \, M_{\odot}/\text{yr})\) see Schneider et al. (2010).
- “Refill” from large scales \((2 \, \text{Myr timescale})\).
- Short crossing times but long-living … (such as MCs in the colliding flow view).
- see Schneider et al. (2010), and Csengeri et al. (2011), Peretto et al. 2014, Louvet et al. 2014).

Hierarchical fragmentation

- The clump splits into 3 massive clumps.
- Dynamic dominated \((\tau_{\text{cross}} > \tau_{\text{ff}})\).
- Individual protostars at 0.02 pc scale.
Other evidences in massive filaments/ridges

Peretto et al. (2013, 2014)

Tackenberg et al. (2014)
Open Issues

- Do all high-mass stars form in ridges ... it does not seem so, how? Two modes?

- What is the relationship with lighter filaments? Are they just massive filaments or do they form differently? What is the formation scenario for ridges?

- Relation between ridge formation and SF (different IMF?), different mode of SF?
Most ridges should form by cloud global collapse

- Forced-fall (pressure-driven infall) of the DR21 ridge further fed by filaments.
  - Gas flows along sub-filaments.
  - 13CO(1-0) 0.2-1 km/s infall speeds
  - Global infall

Hennemann, Motte, Schneider et al. 2012

- Similar kinematics and SiO shocks for the W43-MM1 & MM2 ridges (Nguyen Luong et al. 2013; Louvet et al. in prep.)

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Other evidences in massive clumps/cores

Velocity Discontinuities in massive dense cores:
- Peretto et al. (2006); Rodon et al. (2008); Galvan-Madrid et al. (2010)

[Images of diagrams showing velocity discontinuities in massive dense cores]

Peretto et al. (2006)

Galvan-Madrid et al. (2010)
Origin of Super-Jeans cores

Large effective Jeans masses?
- To get $M_{\text{Jeans}} = 20 M_\odot$ one needs $T_{\text{gas}} \sim 200 \text{ K}$ or $\Delta v_{\text{FWHM}} \sim 3 \text{ km/s}$.

How to avoid fragmentation at later stage?
- Cooling and turbulence dissipation decrease $M_{\text{Jeans}}$ on short timescales at such high densities (of the order of $10^7 \text{ cm}^{-3}$).
- Driven turbulence?
- Magnetic field?
- Radiation from the protostar?

RMHD simu. with RAMSES
- Magnetic field braking.
- Increases accretion on 1st core.
- Enhances $T_{\text{gas}}$.
- Prevents fragmentation.

See also Palau et al. (2014) for other evidences