Dynamical interactions in young stellar clusters

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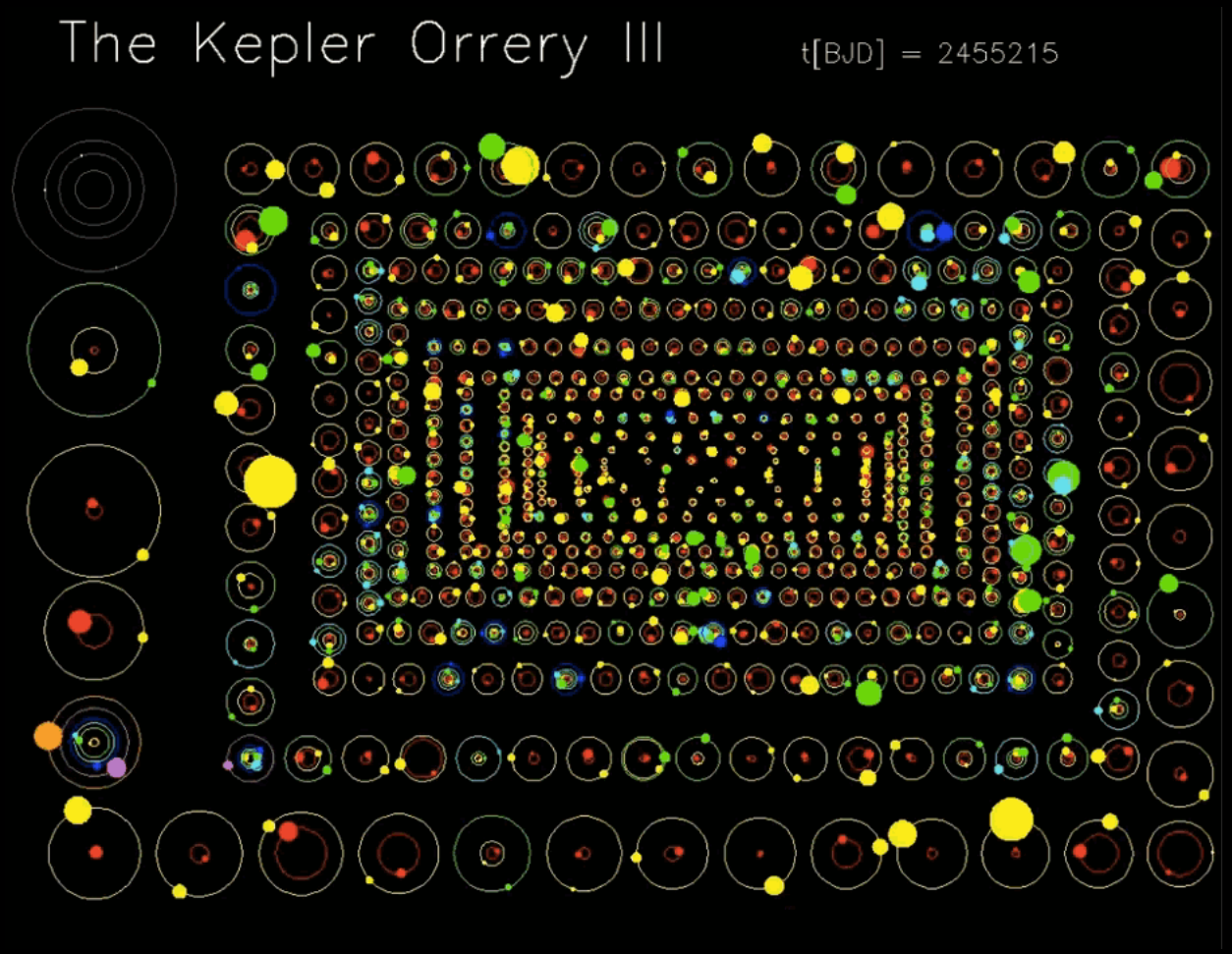
h & χ Persei: Volker Wendel, Josef Popsel, Stefan Binnewies

Birth environment affects many aspects of planetary systems: architecture, stability, composition, …

- Most stars – and therefore most planets – form in clusters *(e.g., Adams et al. 2006, Flammini Dotti et al. 2019, Li et al. 2020, …)*
- Orbital architectures *(e.g., Spurzem et al. 2006, Malmberg et al. 2011, Parker & Quanz 2012, …)*
- Stability of multiplanet systems in clusters *(e.g., Hao et al. 2013, Cai et al. 2017, Hamers et al. 2017, …)*
- Free-floating planets *(e.g., Bonnell et al. 2001, Hurley & Shara 2002, Spurzem et al. 2009, …)*
- Connect formation environment to observed field population *(e.g., Cai et al. 2018, Portegies Zwart 2019, Winter et al. 2020, …)*



NASA / Dan Fabrycky (2015)

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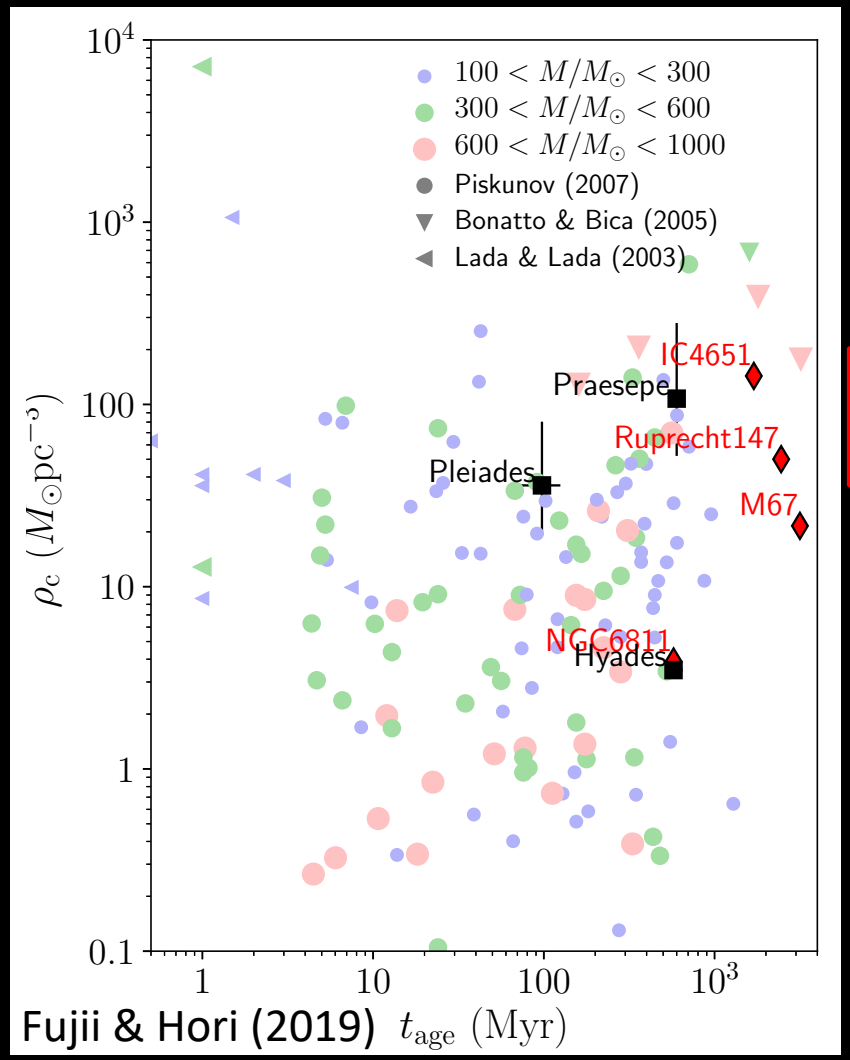


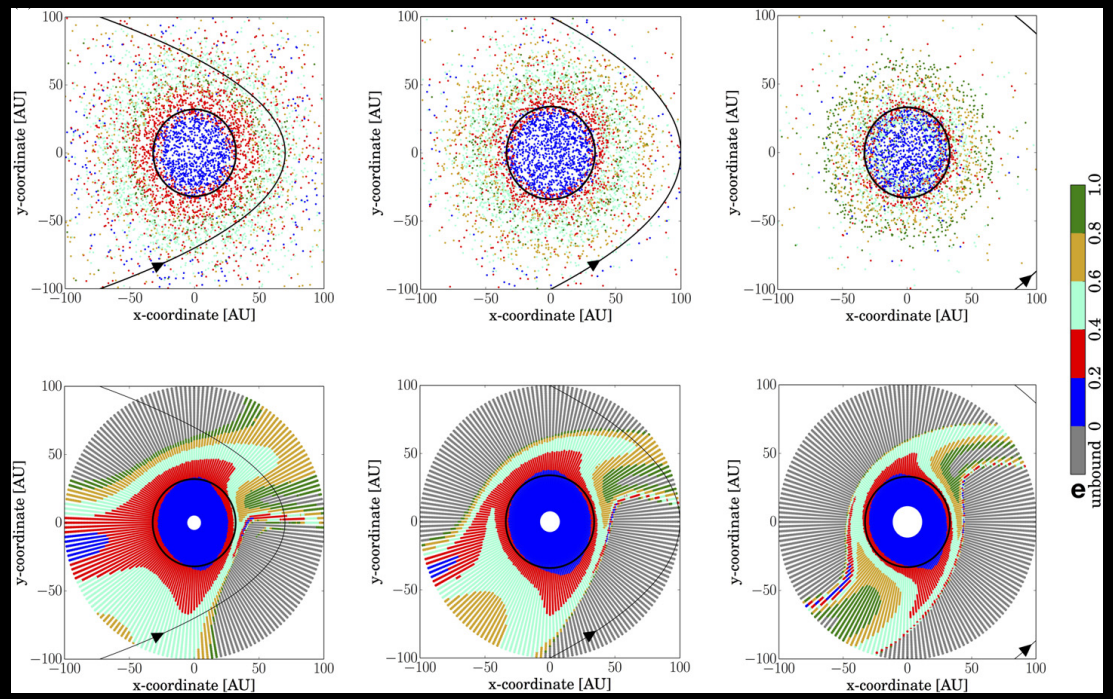
Fujii & Hori (2019)

♦ planets detected

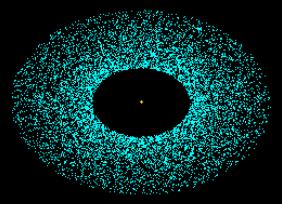
Dynamical interactions in young clusters affect disks directly and indirectly by changing the environment.

Direct:

flybys excite the outer disk and may contribute minor planets



Pfalzner et al. (2018)

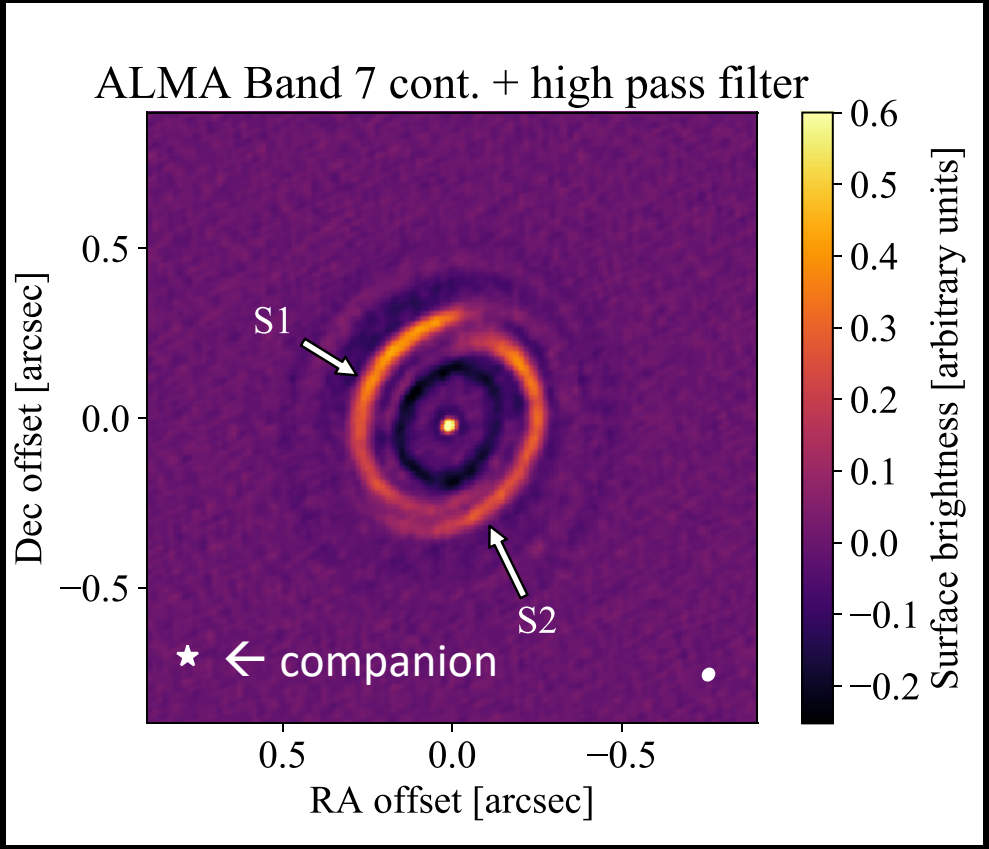


Bromley & Kenyon

Dynamical interactions in young clusters affect disks directly and indirectly by changing the environment.

Direct:

binary interactions may truncate the disk, drive spiral arms, perturb kinematics, …



Rosotti et al. (2020)

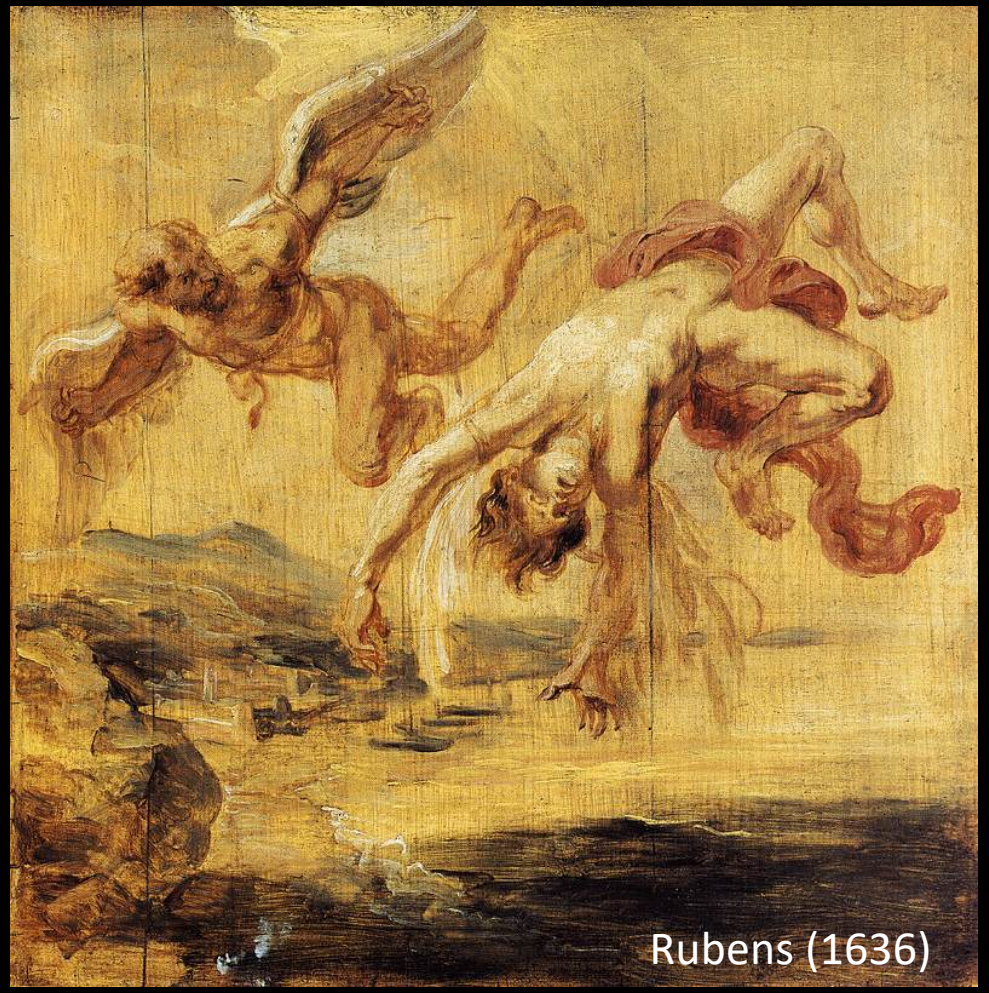
See posters:

- **Rota** – gas and dust disk radii in Taurus multiples
- **Nealon** – spirals, shadows and precession in HD 100453
- **Maureira** – gas and stellar kinematics of young binary IRAS 16293-2422 A
- **Aly** – warps in dusty disks

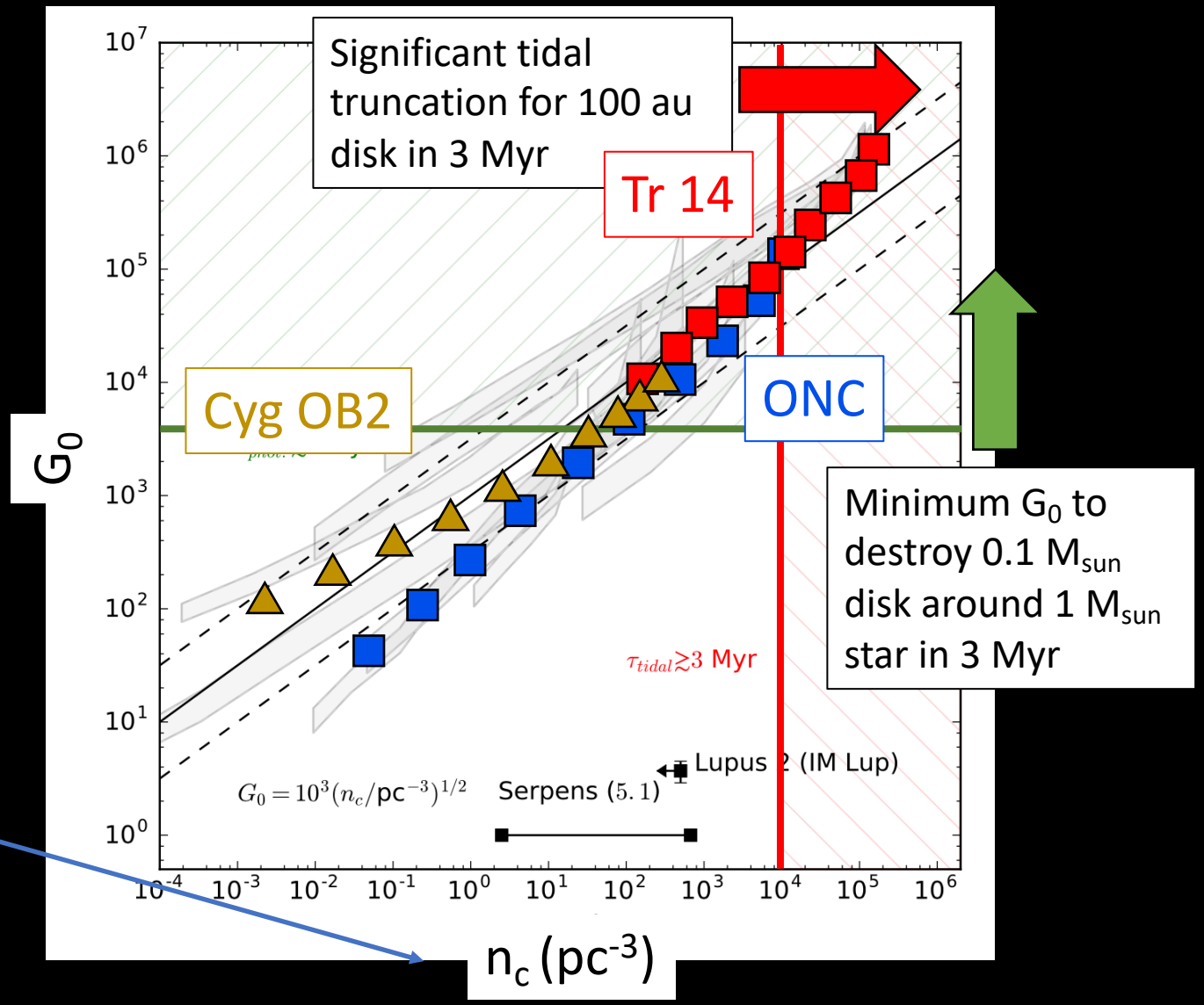
Dynamical interactions in young clusters affect disks directly and indirectly by changing the environment.

Indirect:

stellar motions regulate the distance between stars and thus the incident flux



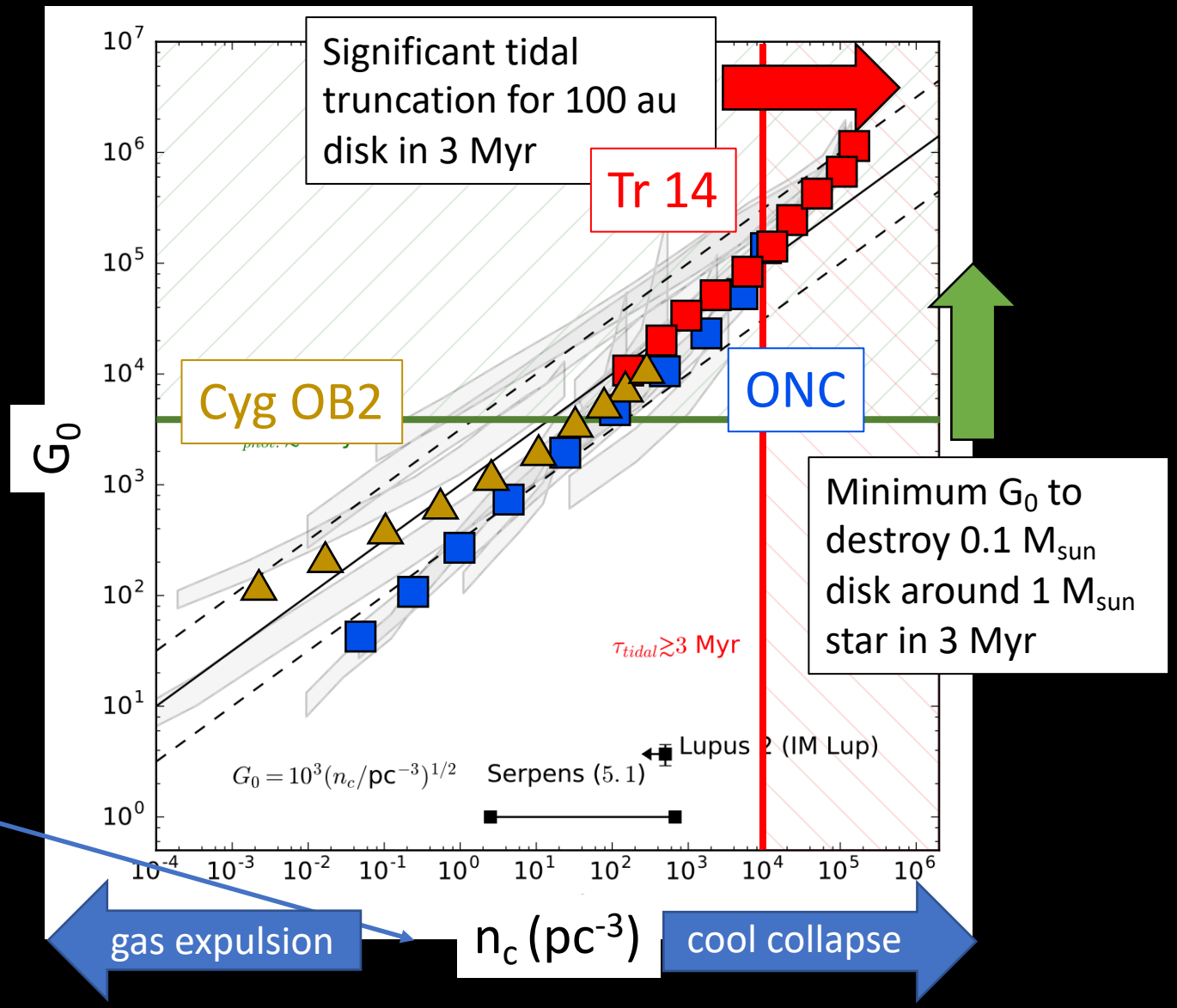
The density of star-forming aggregates evolves with time.



Dynamical evolution means density changes with time

Winter et al. (2018)

The density of star-forming aggregates evolves with time.



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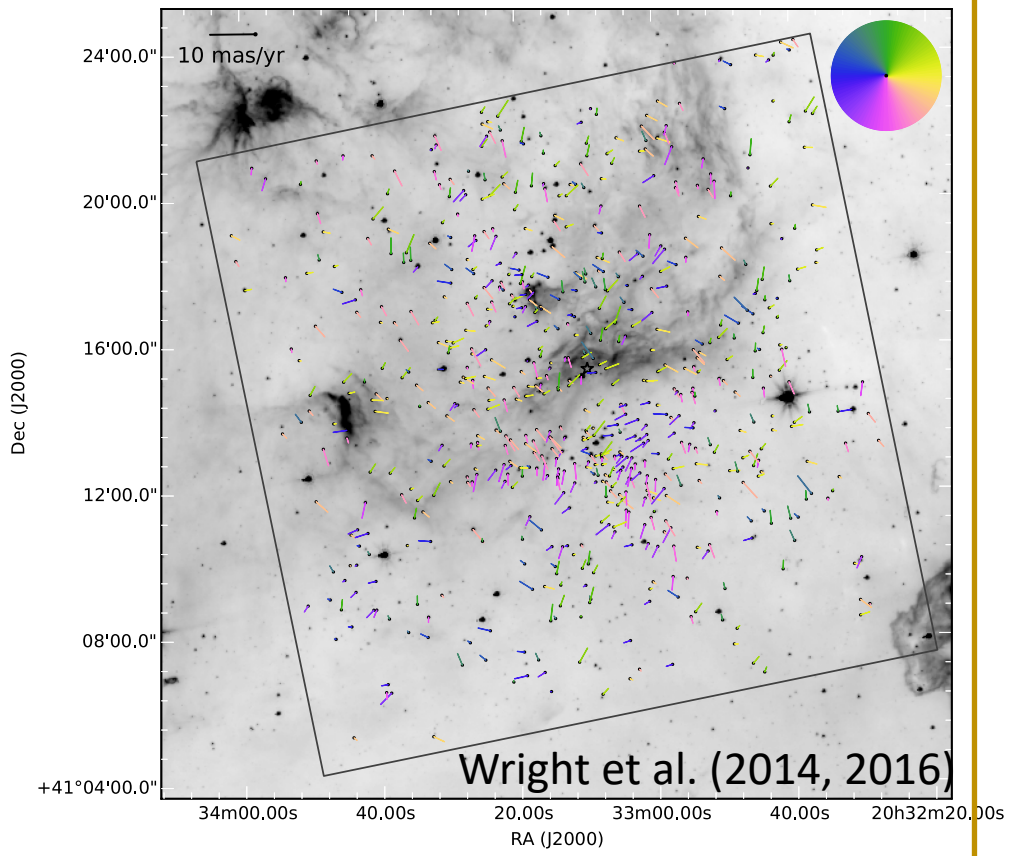
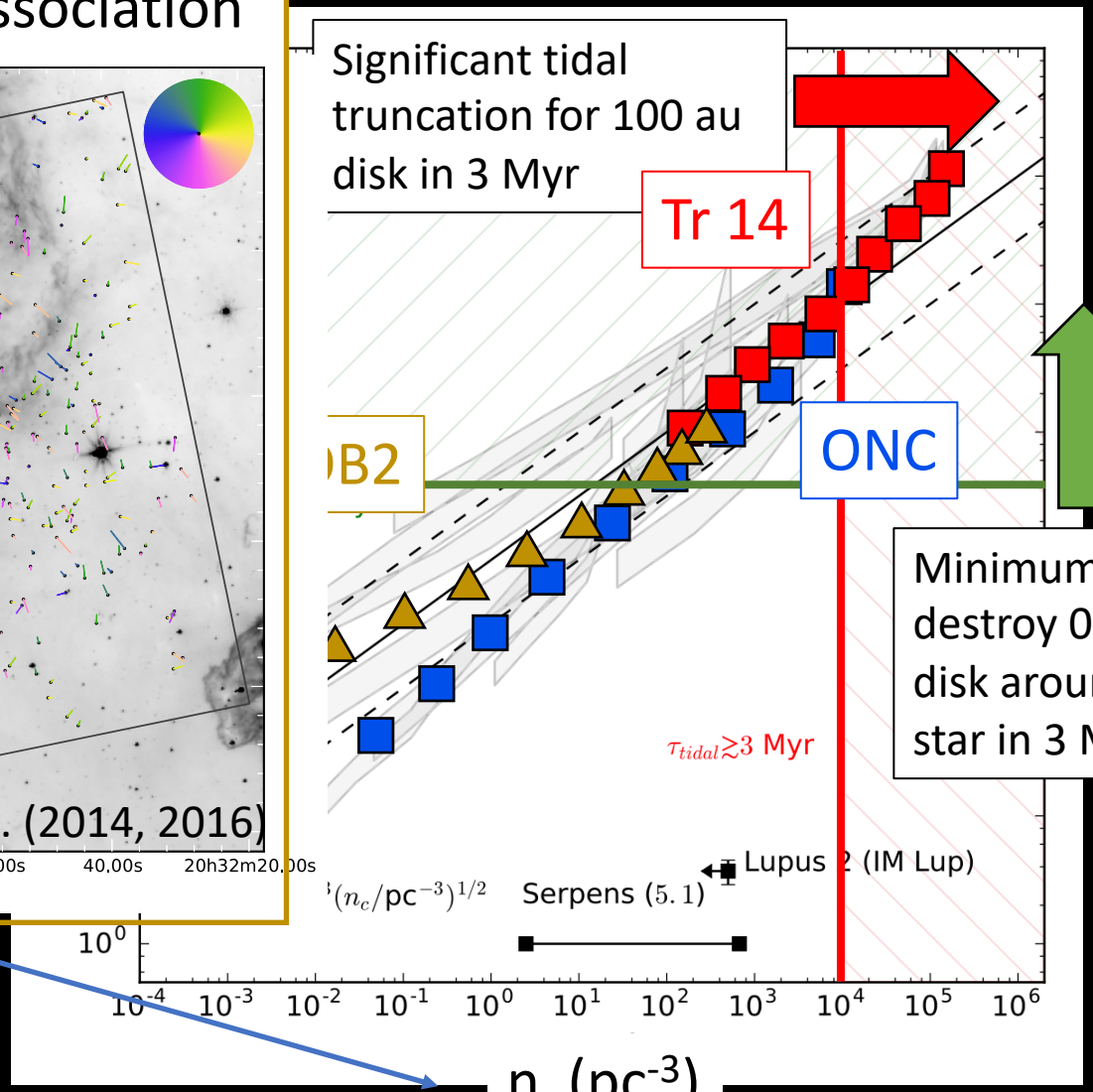
Winter et al. (2018)

The density of star-forming aggregates evolves with time.

Cyg OB2 was always an association



means density changes with time



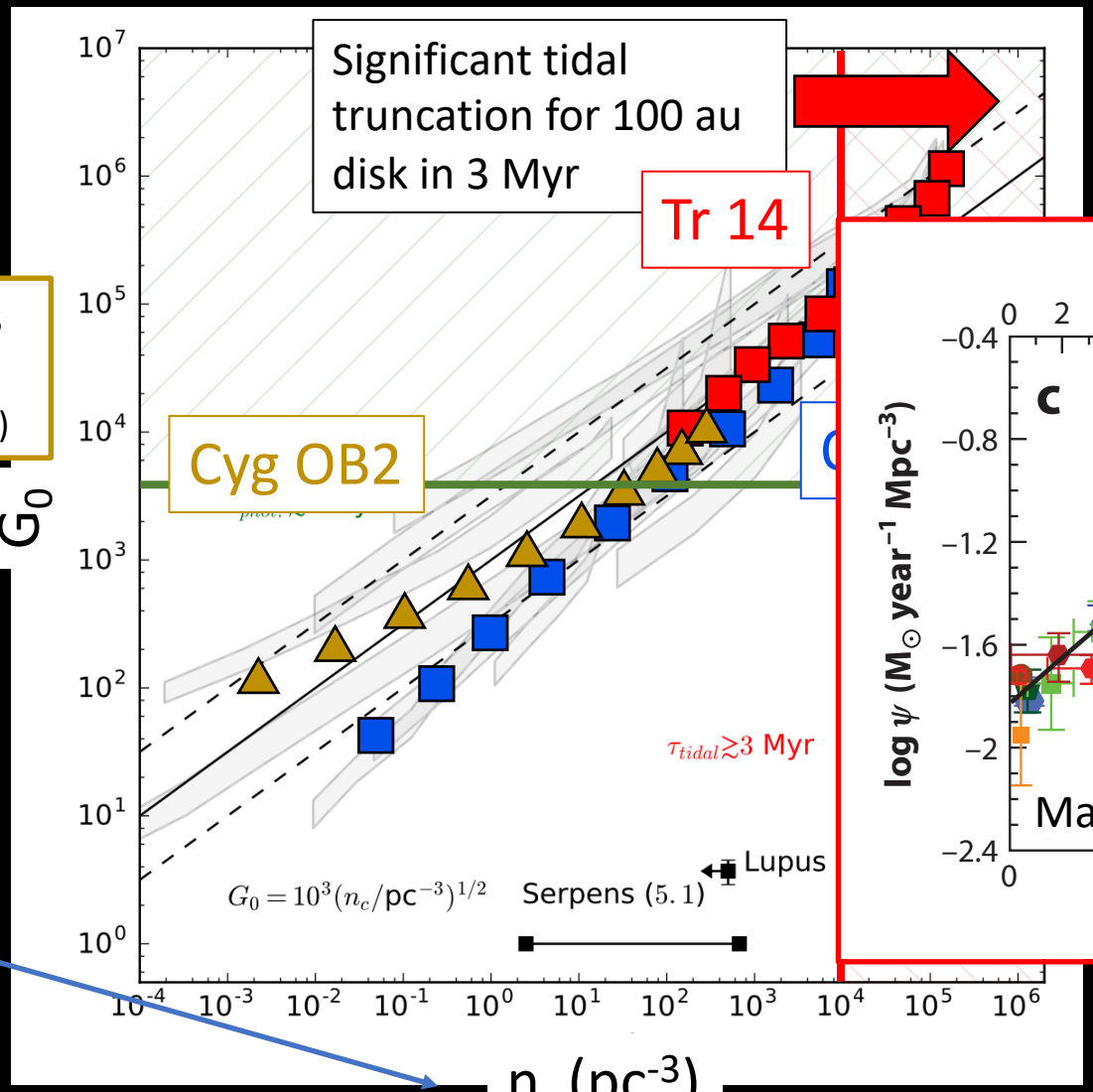
Minimum G_0 to destroy 0.1 M_{sun} disk around 1 M_{sun} star in 3 Myr

Winter et al. (2018)

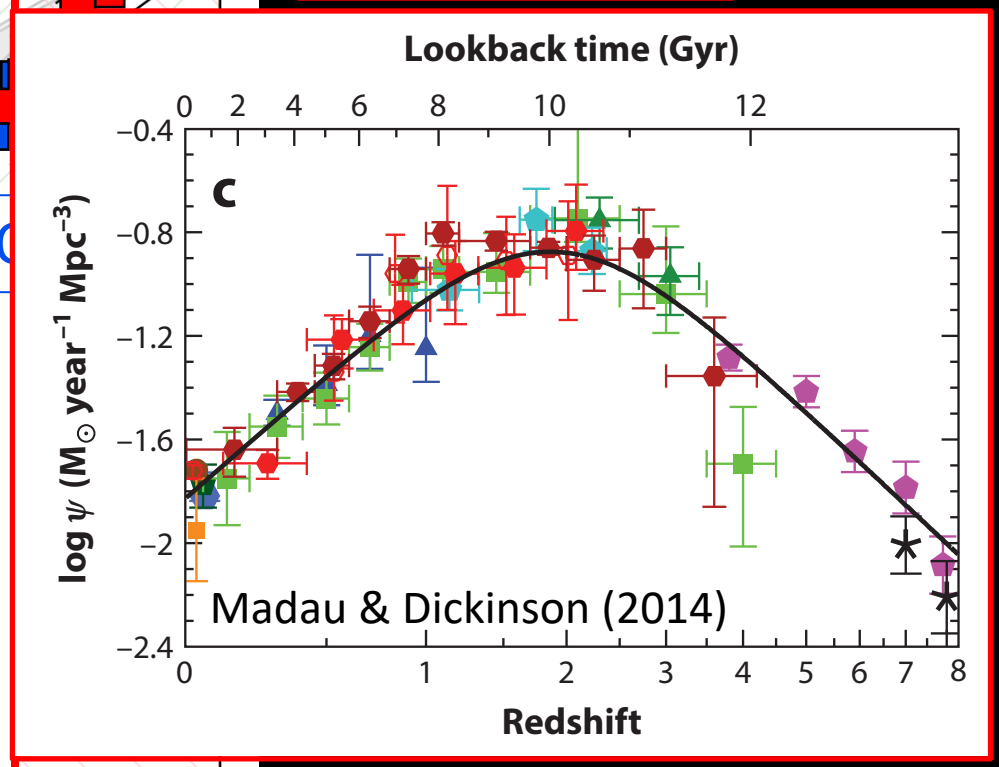
The density of star-forming aggregates evolves with time.

Cyg OB2 has always been low density (Wright et al. 2014, 2016)

Dynamical evolution means density changes with time



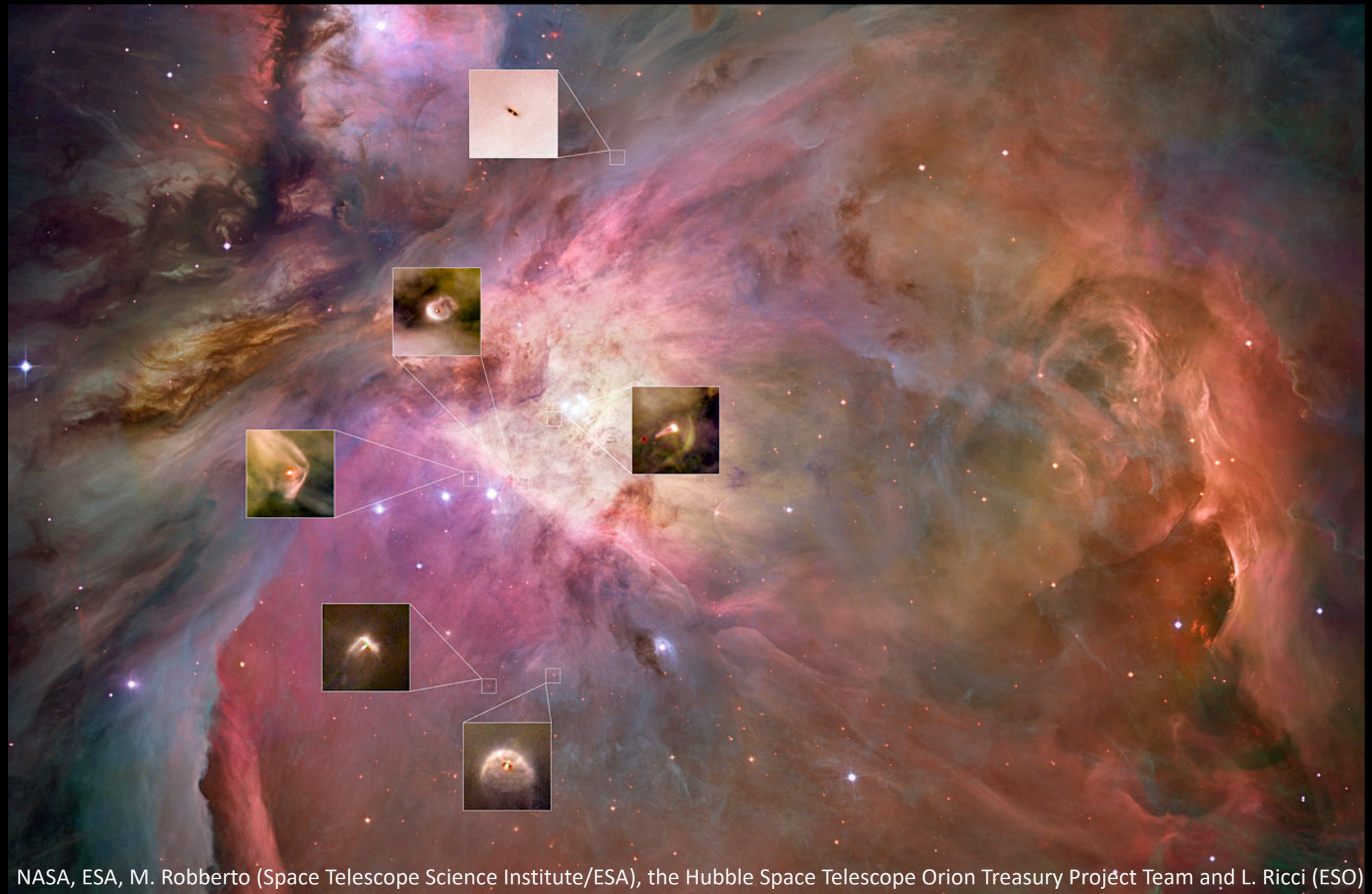
Closer to conditions at peak of cosmic star formation (z~2)



Winter et al. (2018)

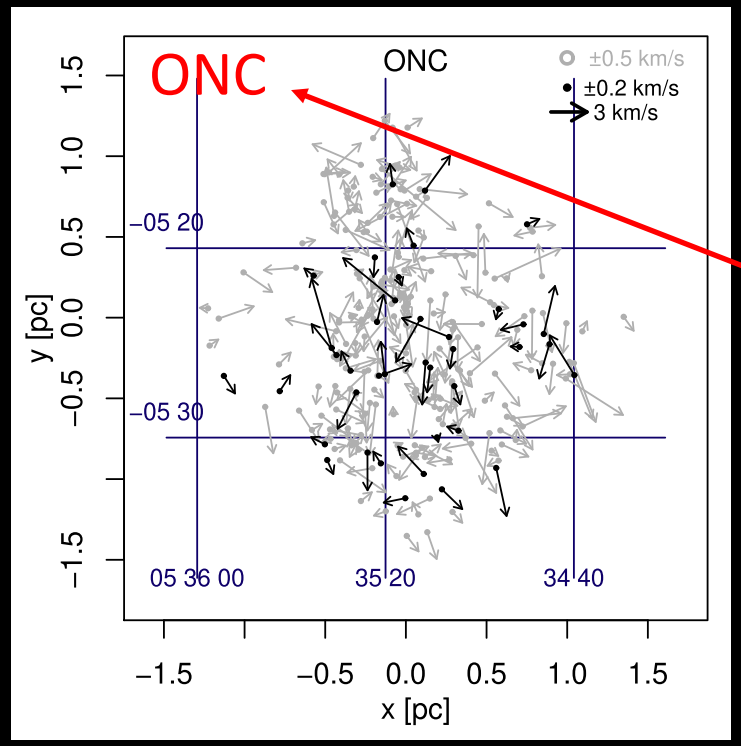
Observations provide static snapshots of a dynamic process.

At 1 km/s, a star will move 1 pc in 1 Myr (h/t M. Bate).

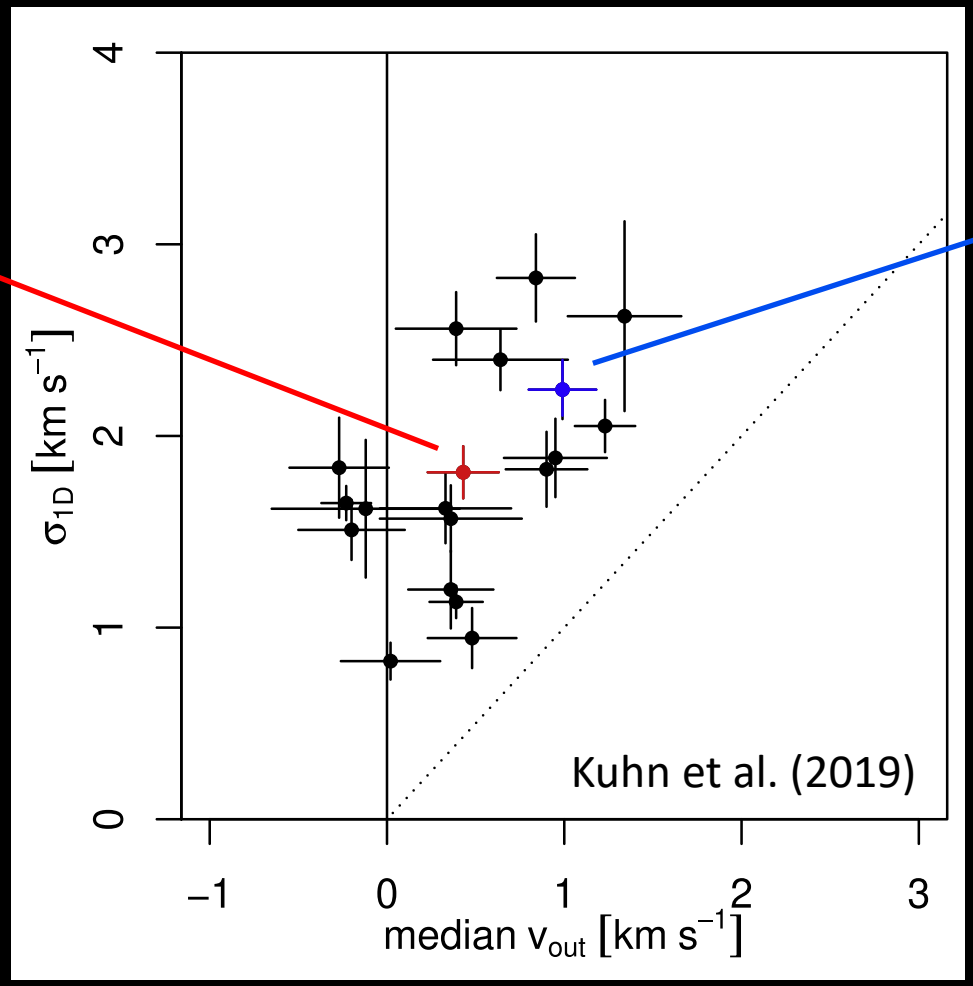


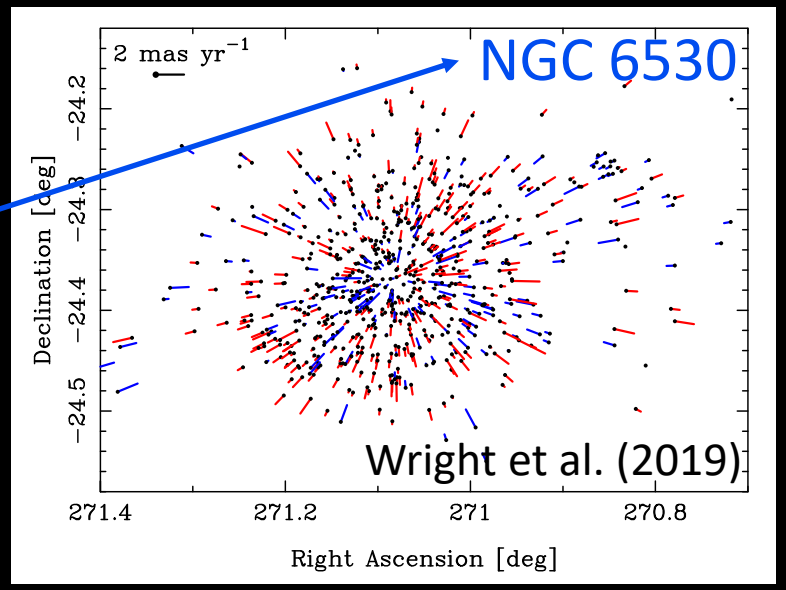
NASA, ESA, M. Robberto (Space Telescope Science Institute/ESA), the Hubble Space Telescope Orion Treasury Project Team and L. Ricci (ESO)

Kinematic data from the *Gaia* mission suggests that many clusters are expanding.



→ radial velocities consistent with cold collapse (Tobin et al. 2009)

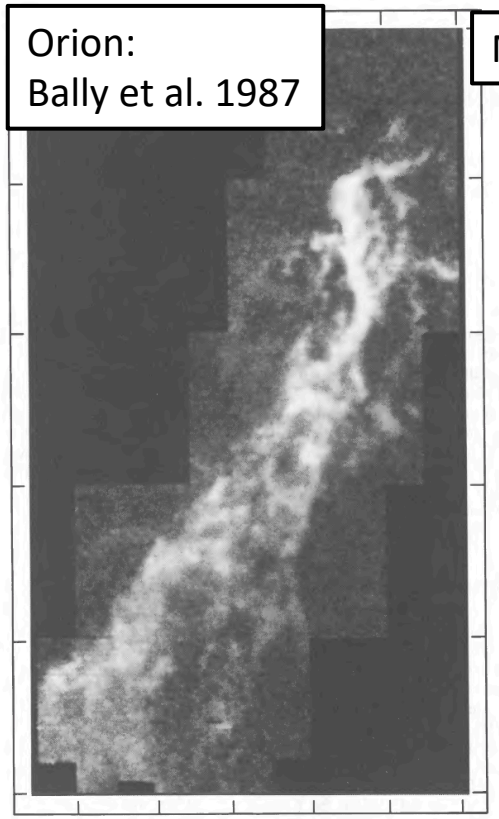


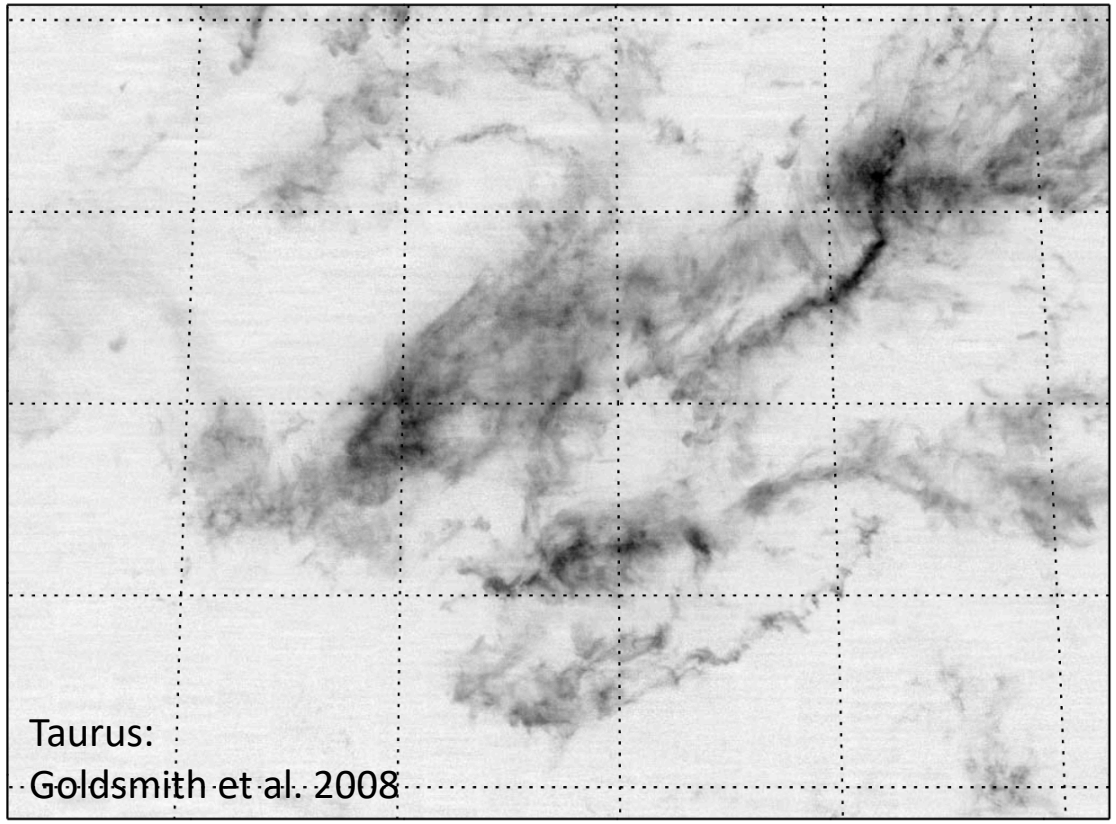


→ velocity dispersion as a function of mass → kinematic evidence for cool collapse (Wright & Parker 2019)

Stars form in molecular clouds

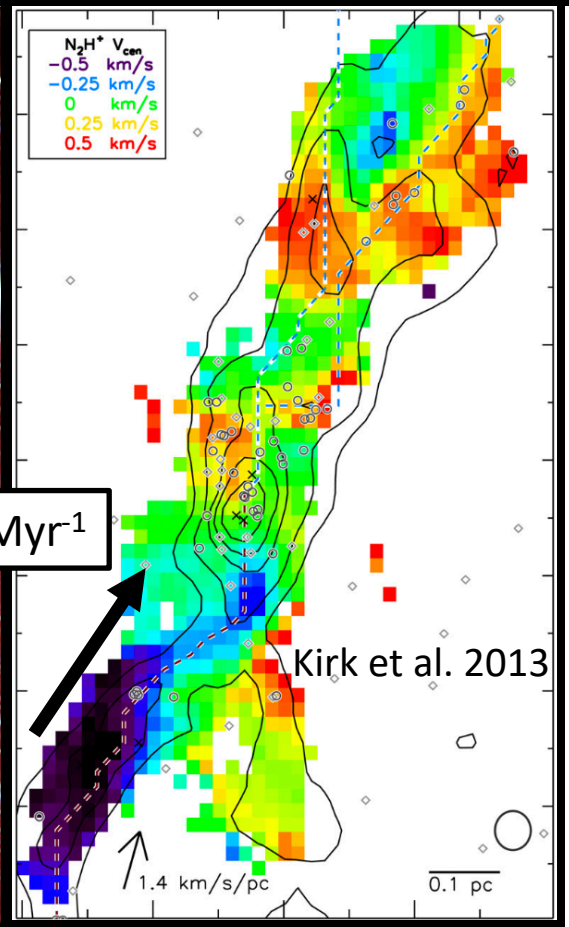
Stars form in molecular ~~clouds~~ filaments

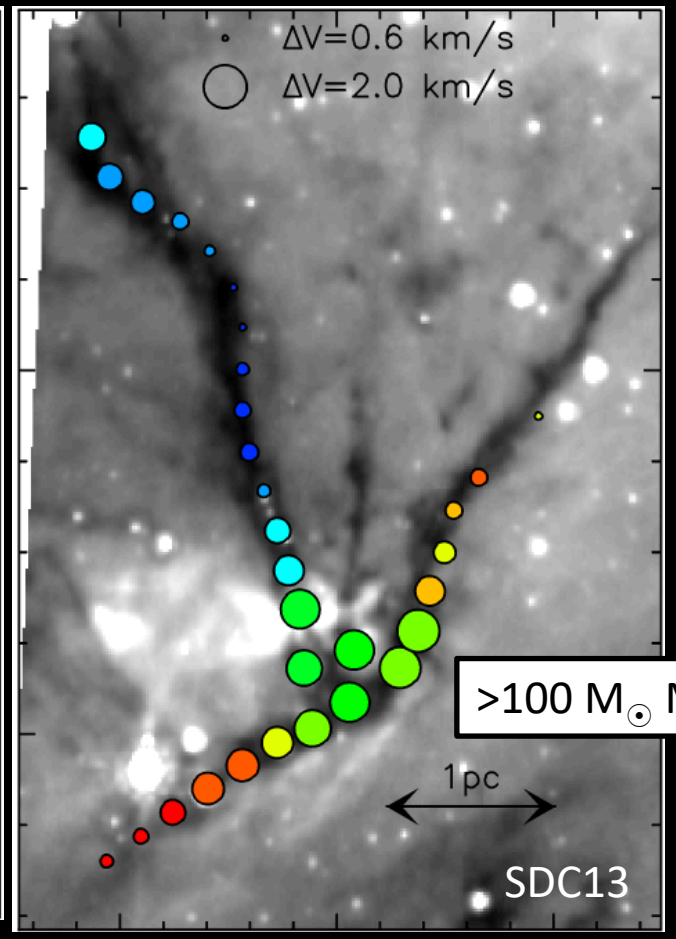


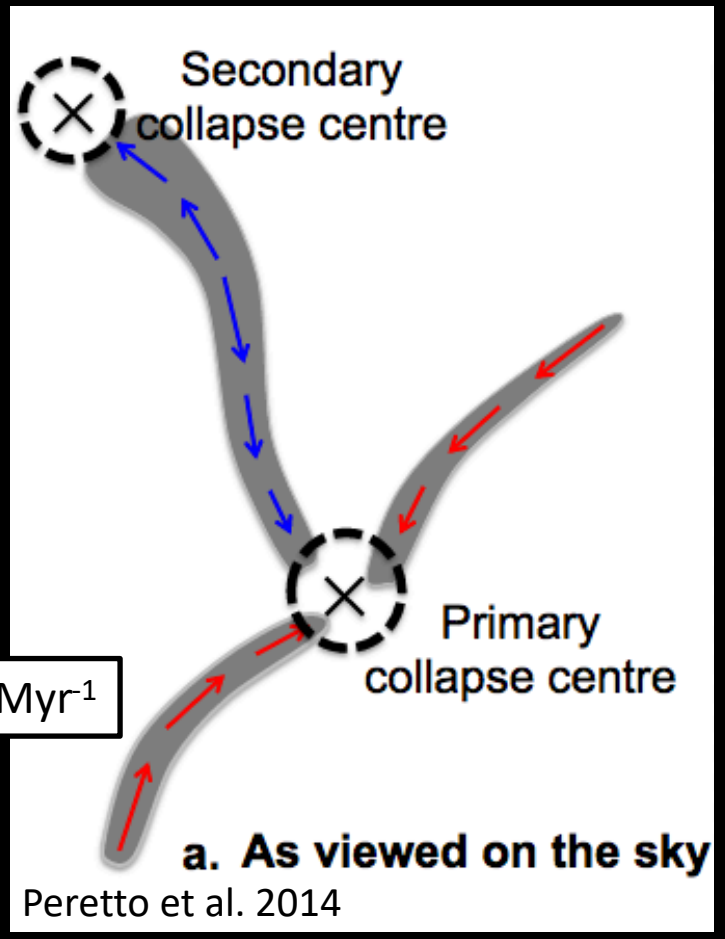


Filaments are dynamic structures

low mass



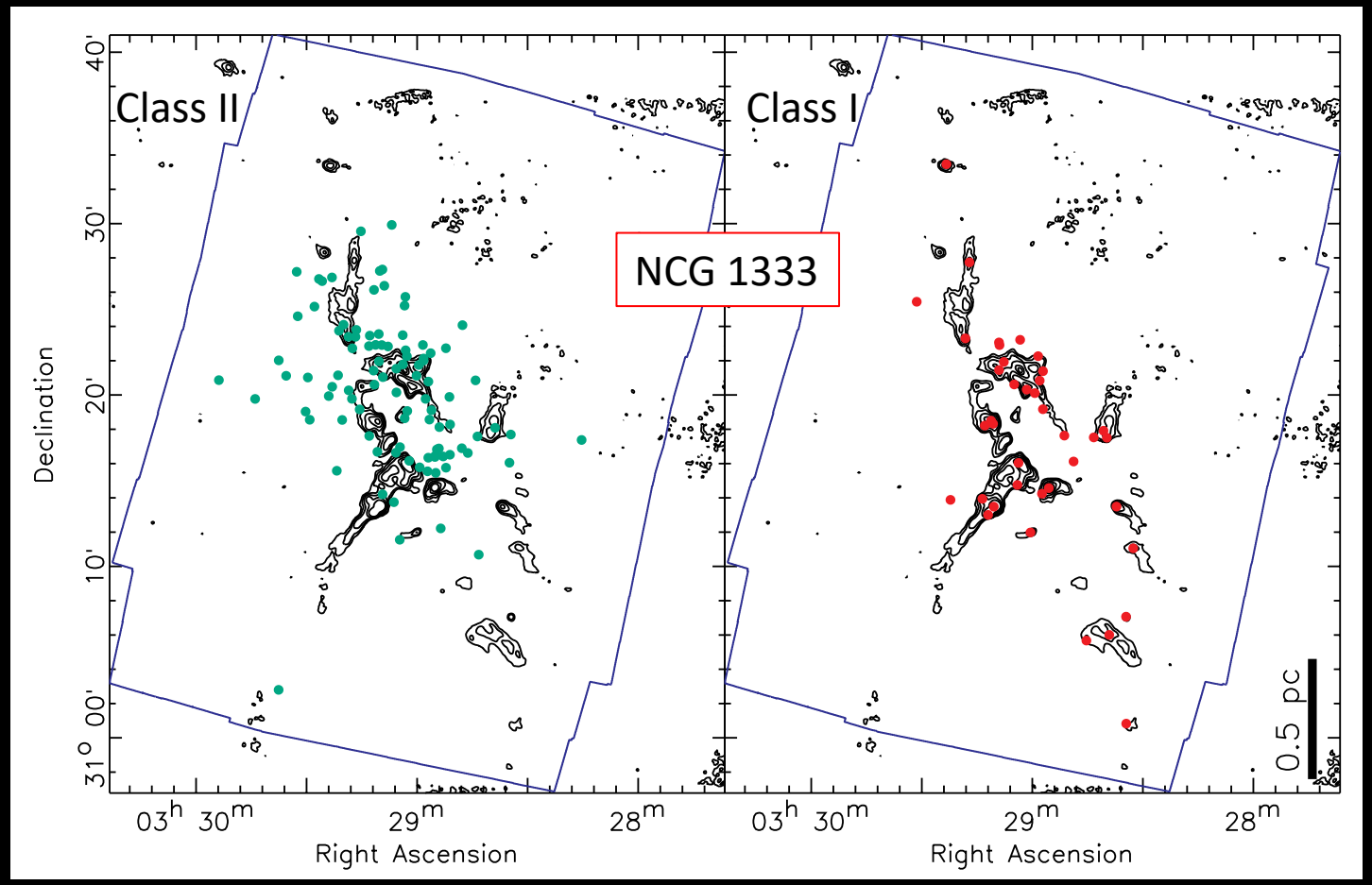




high mass

Stars form in filaments, following the spatial and velocity structure of the gas.

e.g., Larson 1995,
Walsh et al. 2004,
Gutermuth et al. 2008,
Tobin et al. 2009,
Foster et al. 2015, …



Gutermuth et al. (2008)

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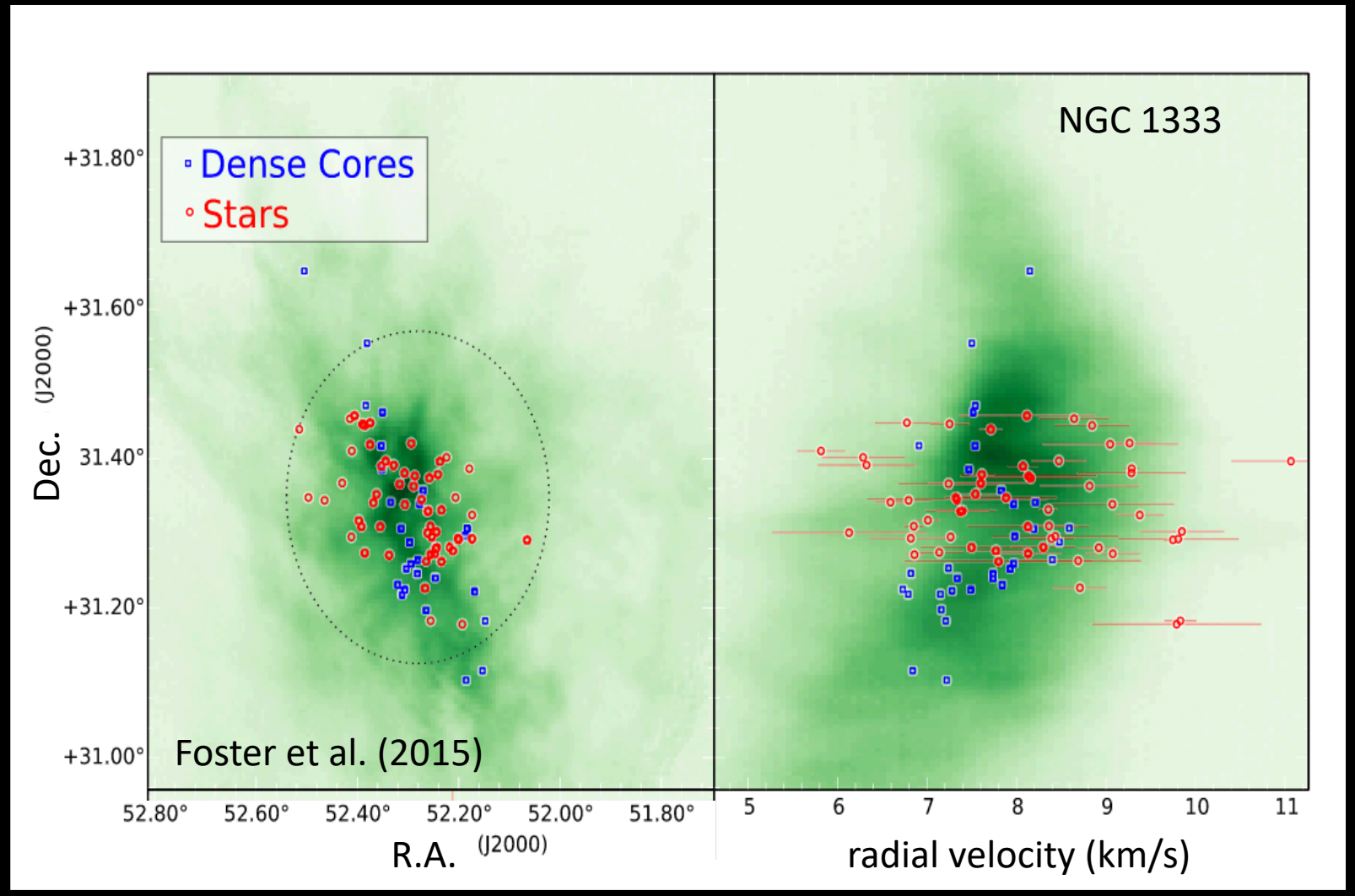
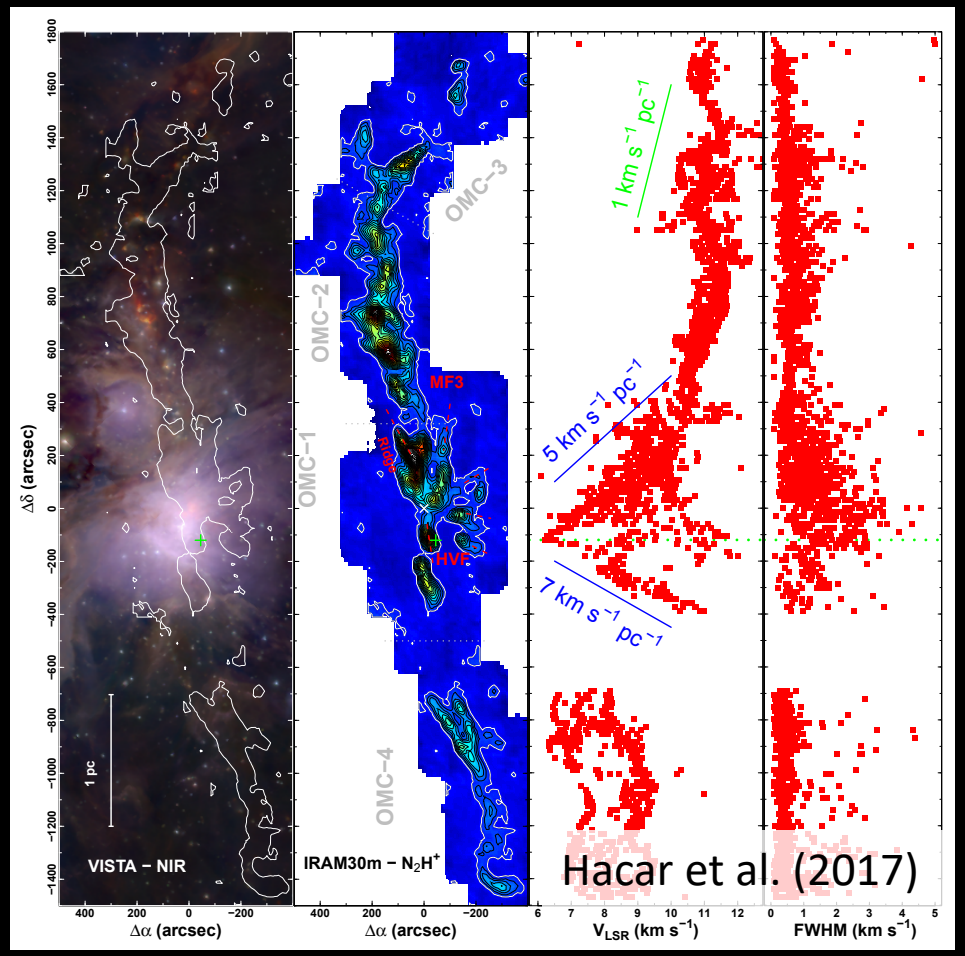
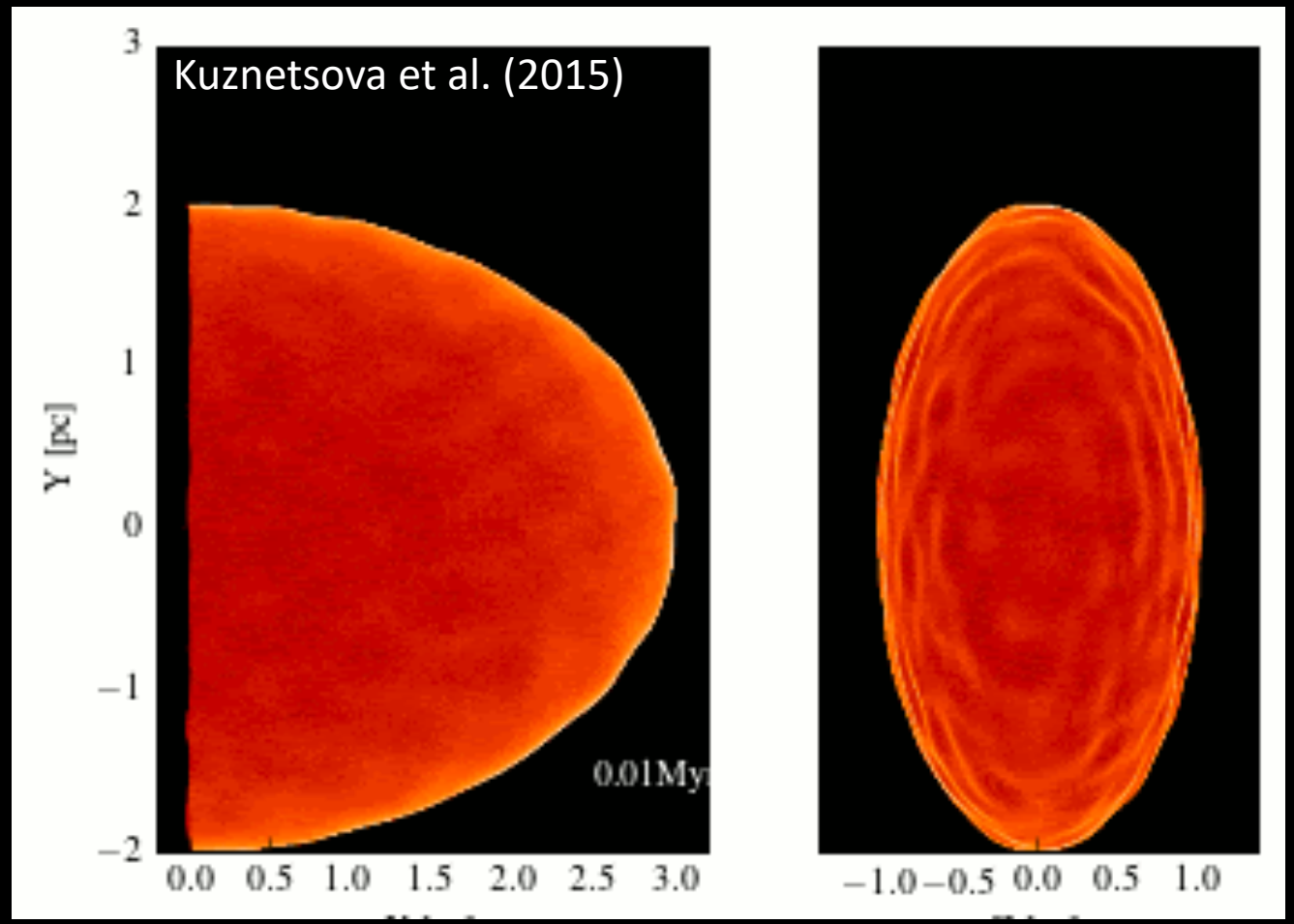


Orion as a case study:

evidence for gravitational collapse

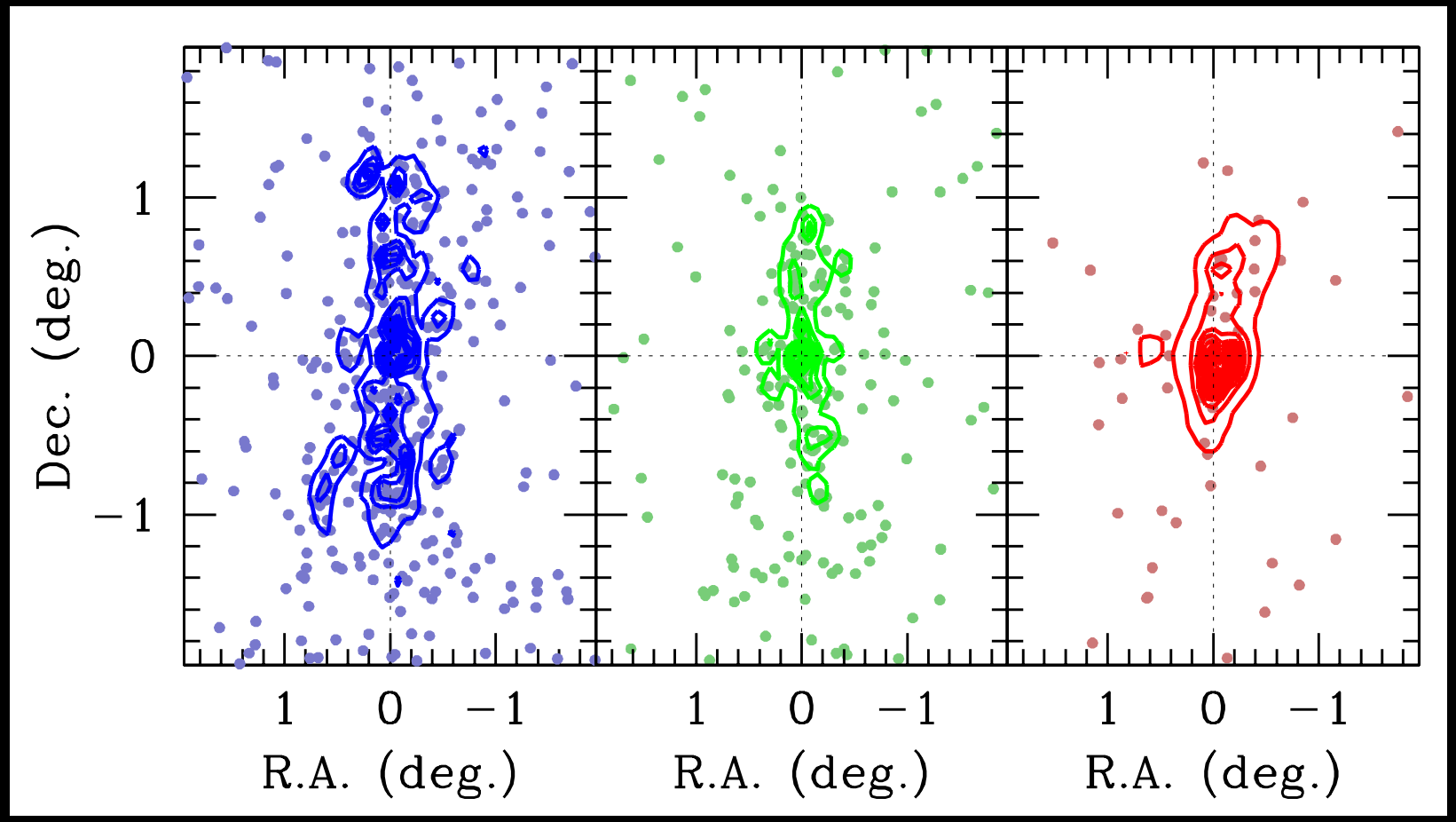


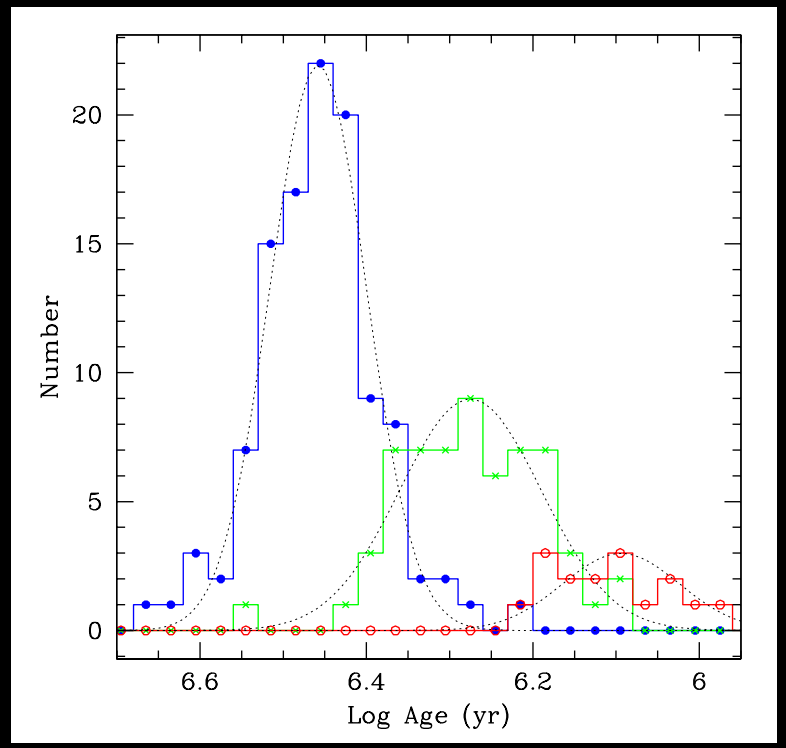
kinematics consistent with cold collapse



Orion as a case study:

three pre-main-sequences tracing three populations of different ages?

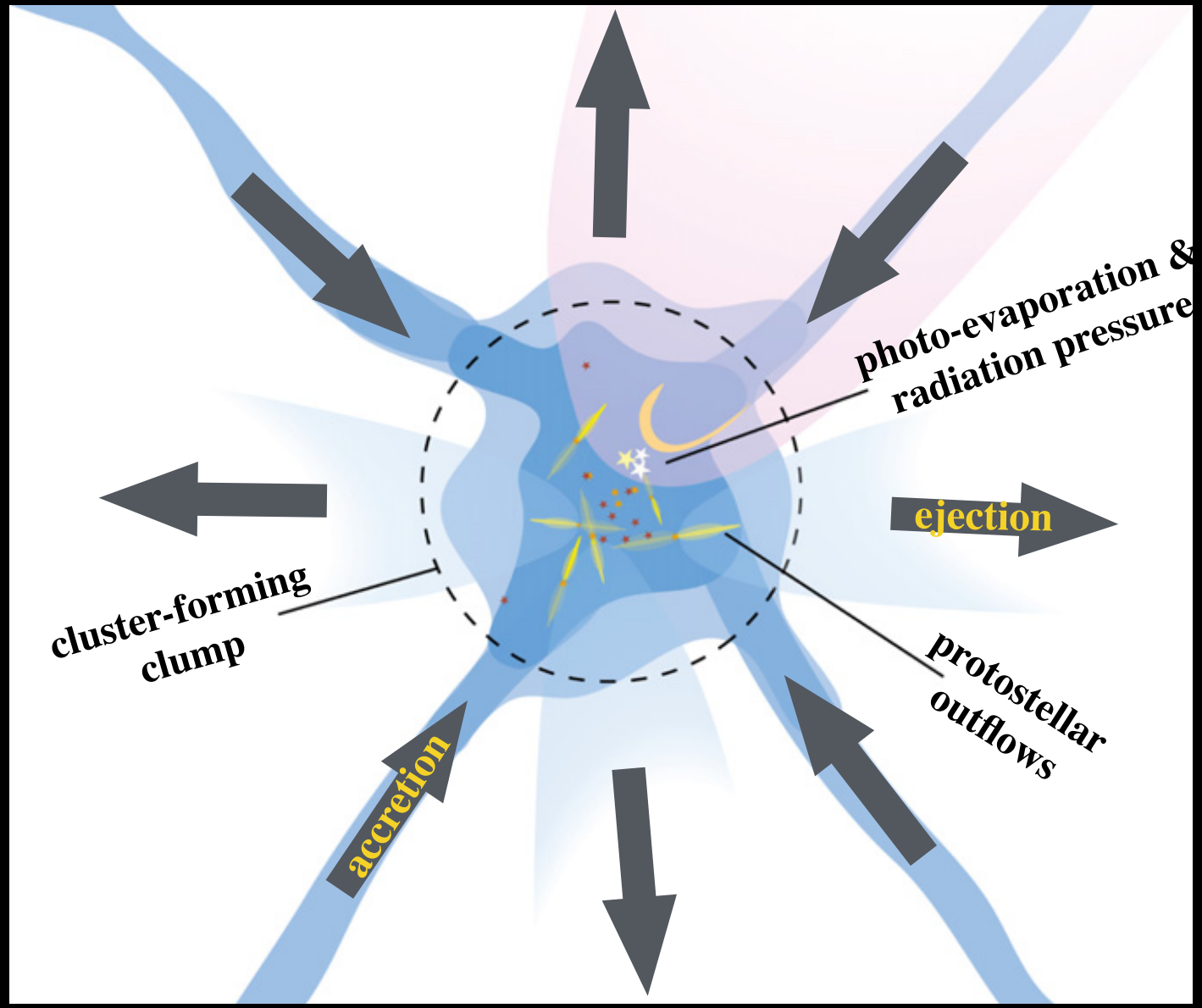




Beccari et al. (2017)

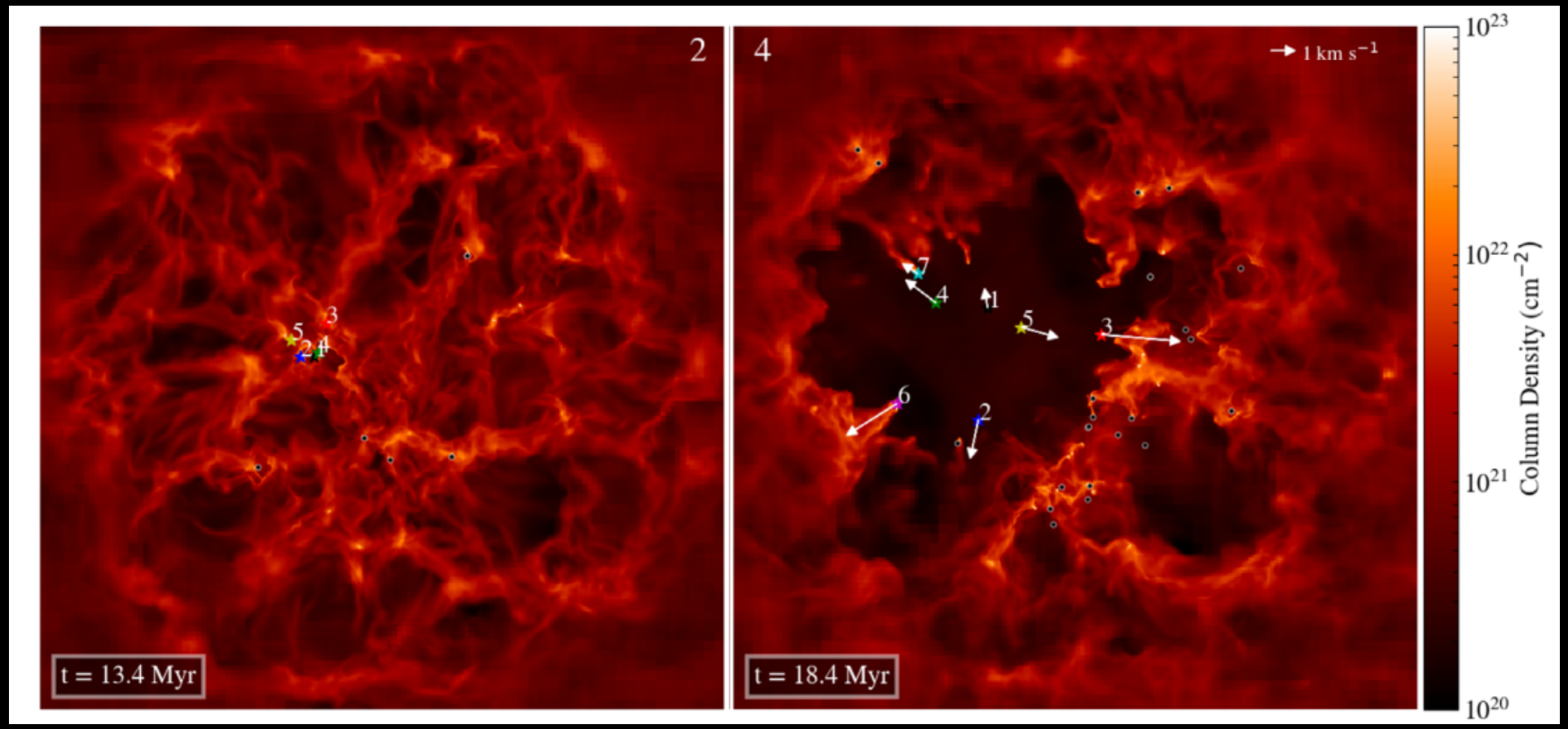
The star/planet-forming environment:

- Begin with hierarchical, fractal initial stellar distribution followed by dynamical evolution
- Gas affects stellar dynamics assisting both cluster assembly and dispersal (note gas also absorbs ionizing radiation)
- Structure in gas and stars affects distribution of feedback – affects enrichment models



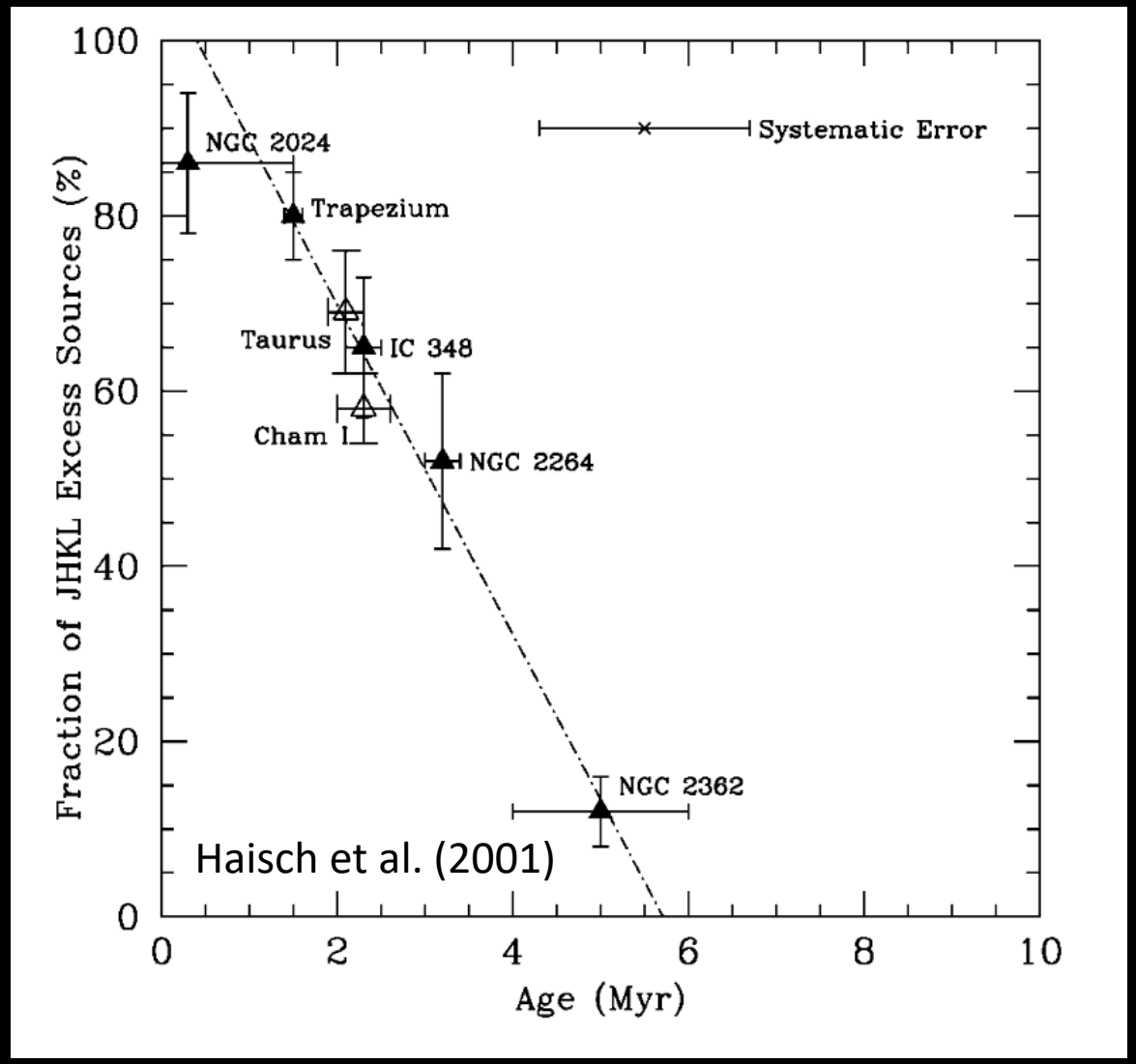
Matzner & Jumper (2015)

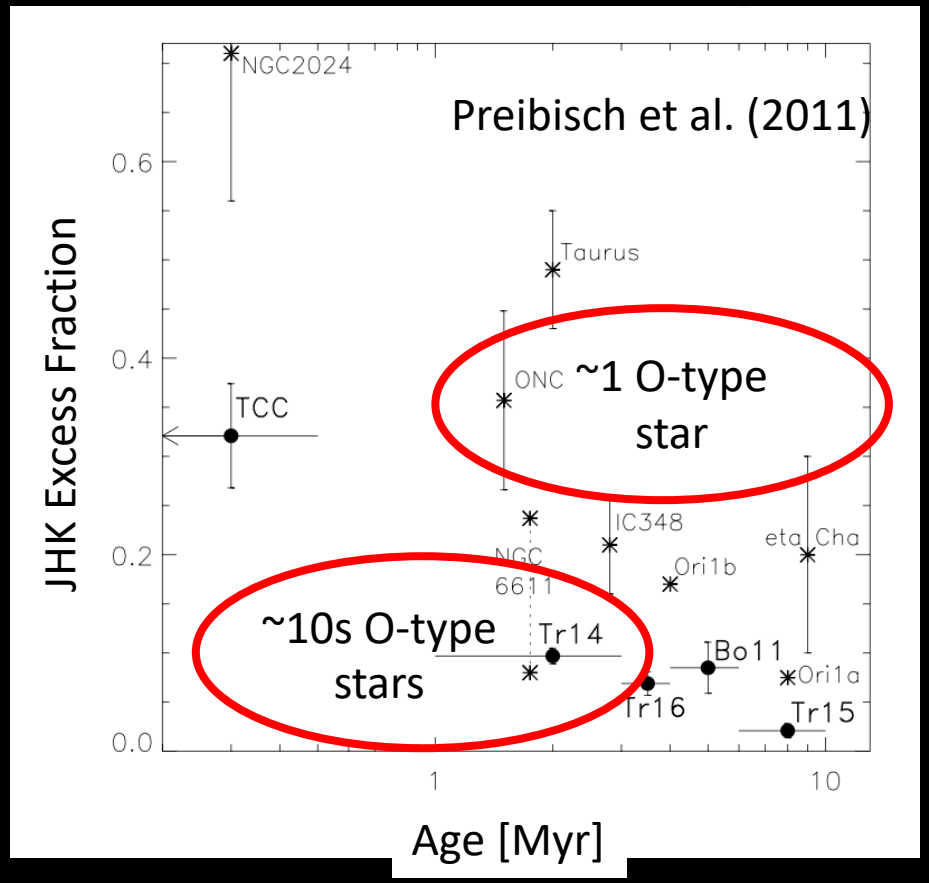
Gas affects dynamical evolution by changing the potential, may produce ’gravitational feedback.’



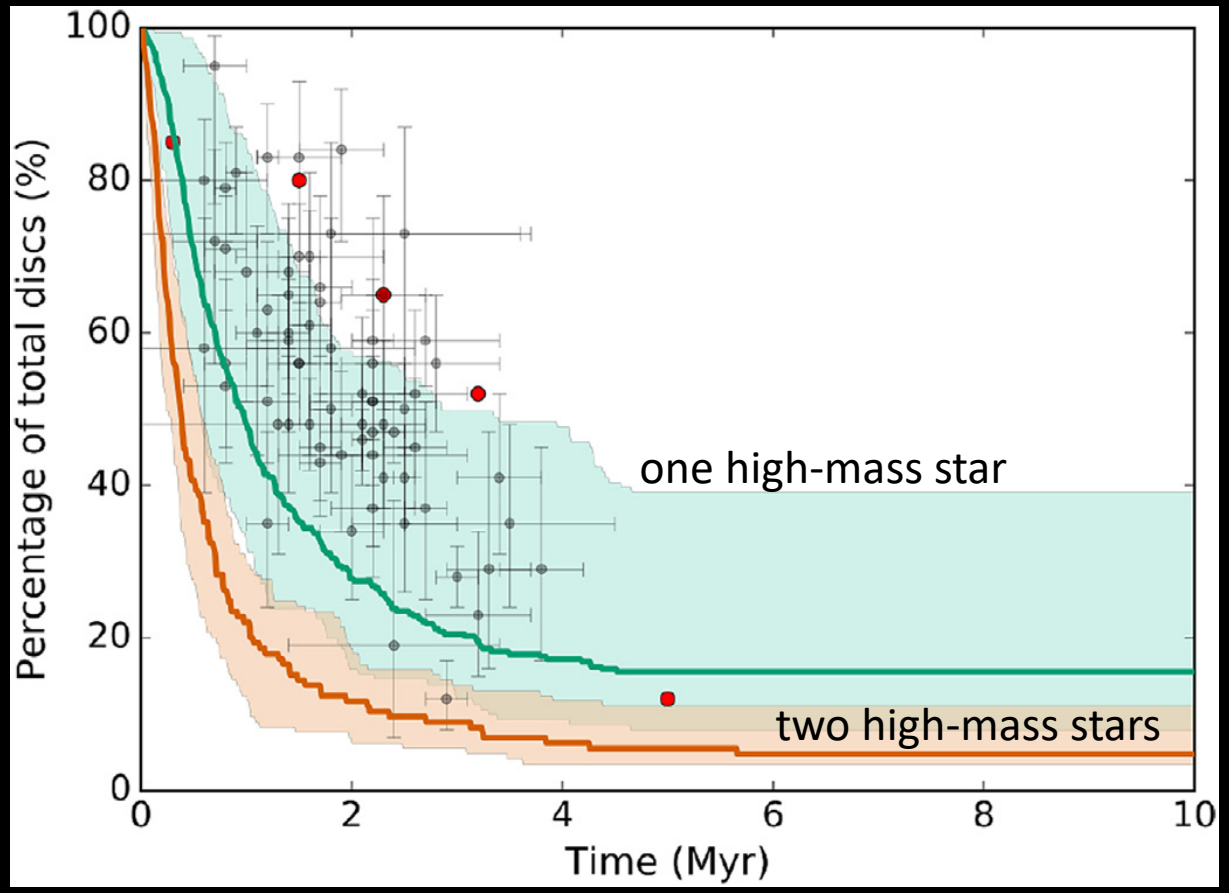
λ Ori –like cluster from Zamora-Aviles et al. (2019)

Disk lifetimes estimated from snapshots assuming a single-age population.





Disk lifetime varies with environment – density, dynamical evolution, and radiation field can all shorten disk lifetimes.



Nicholson et al. (2019)

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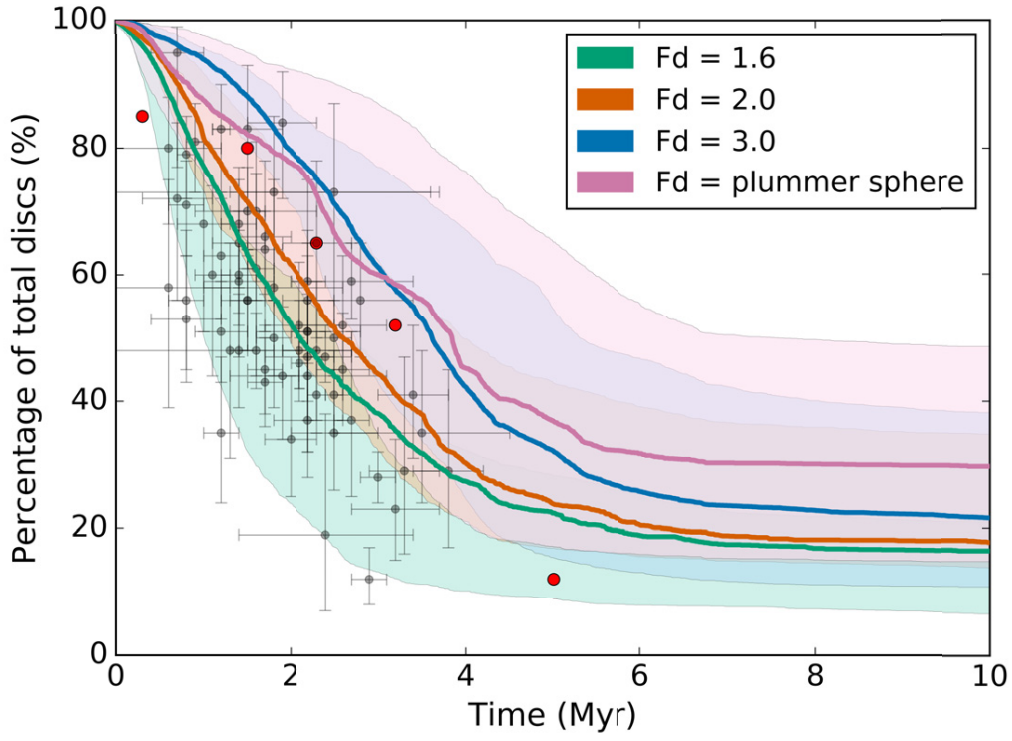
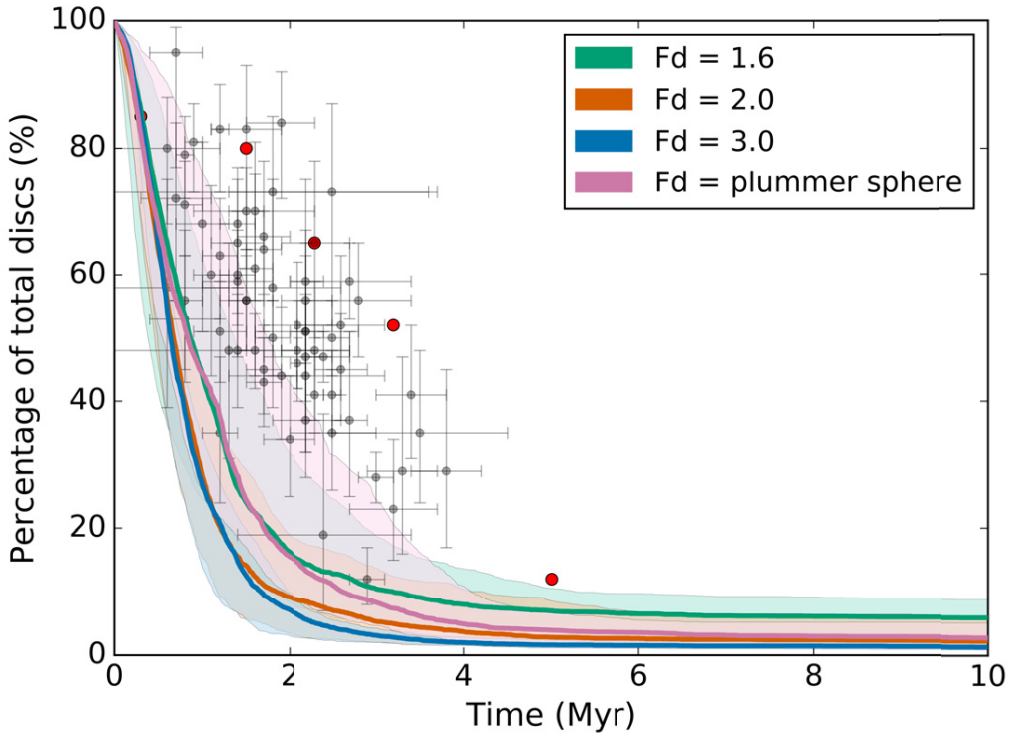


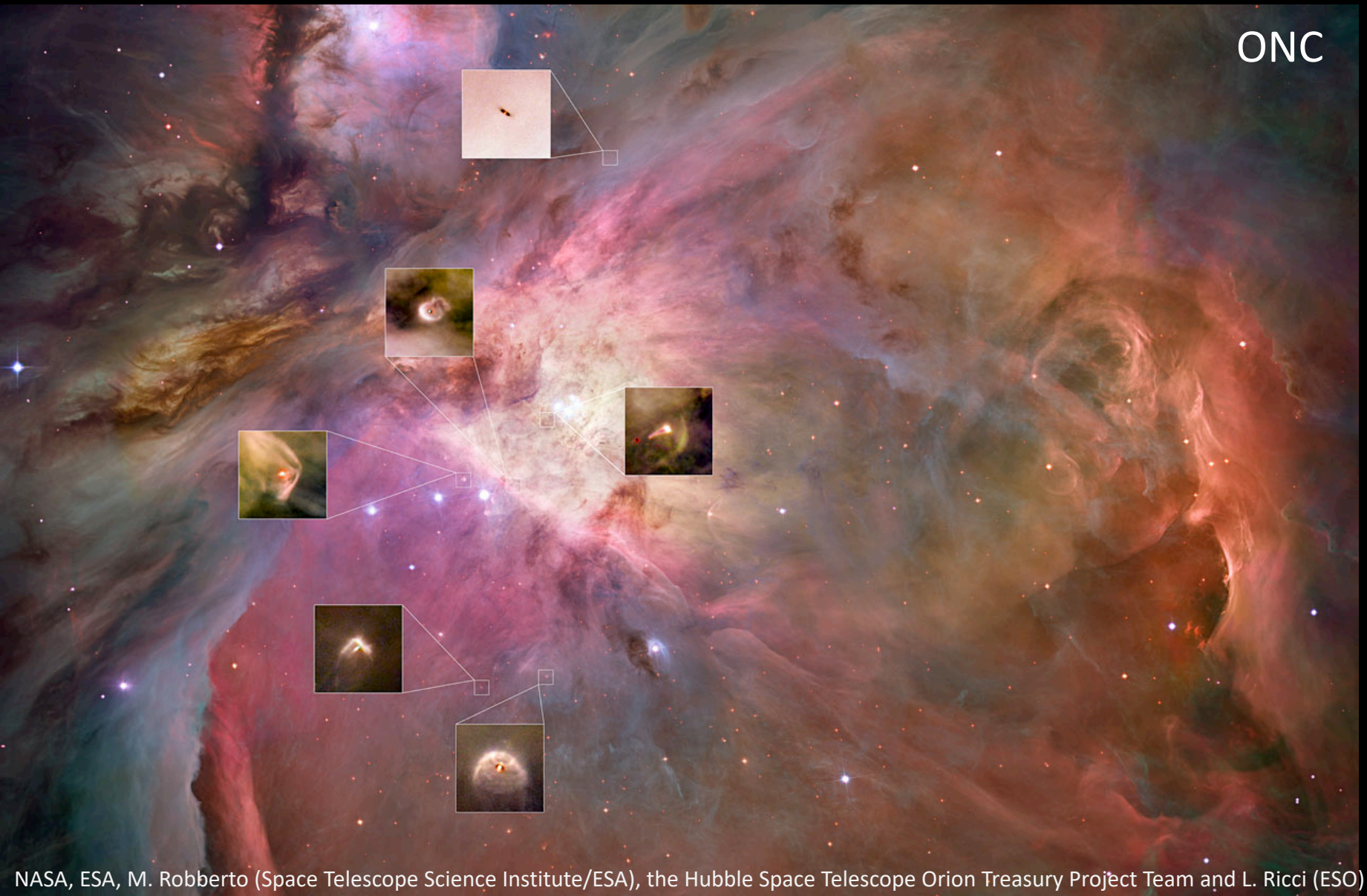
(a) Density = 10 $M_\odot$ pc^{-3}



(b) Density = 100 $M_\odot$ pc^{-3}

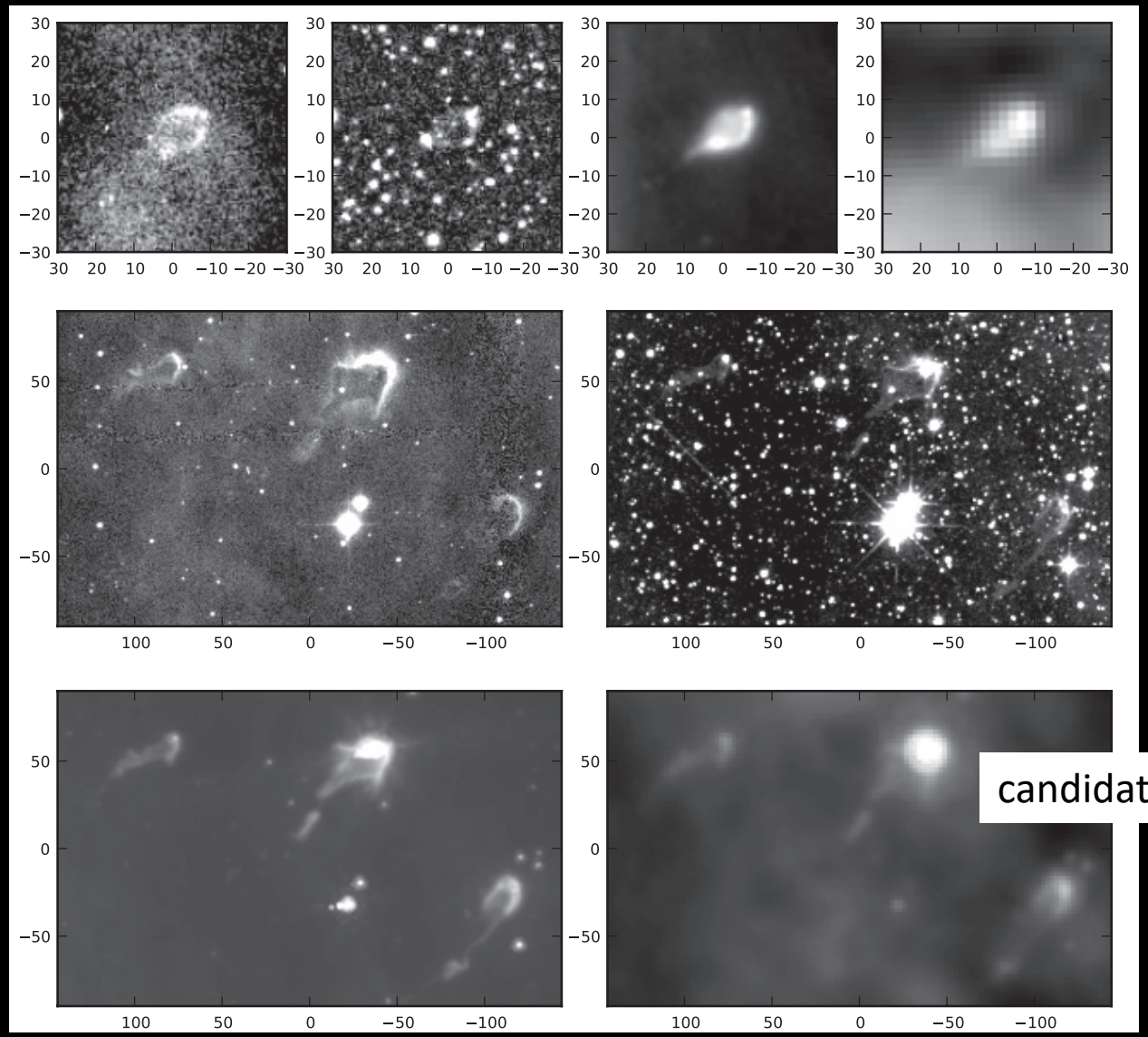
Nicholson et al. (2019)

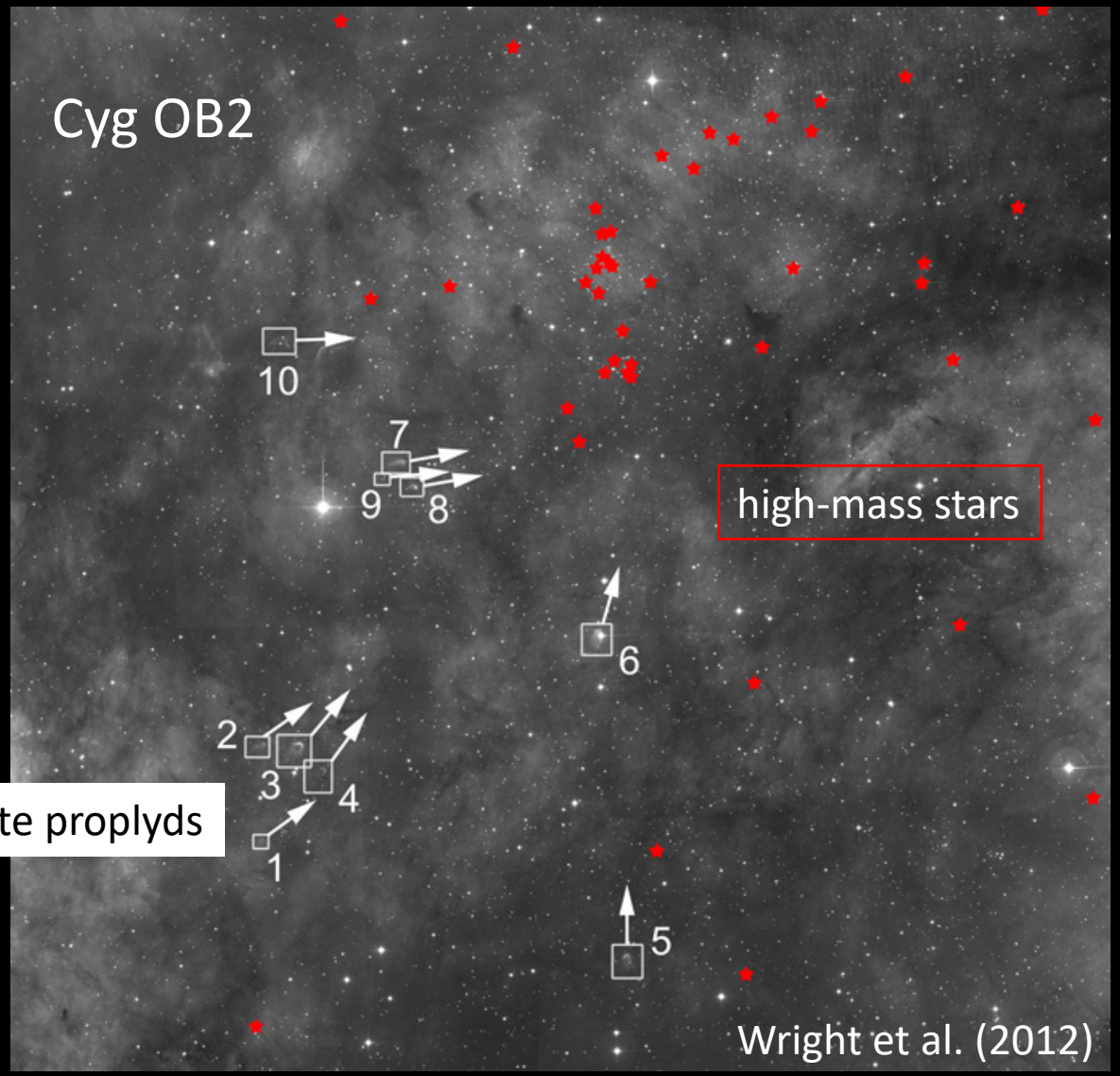
Observational evidence of disk destruction



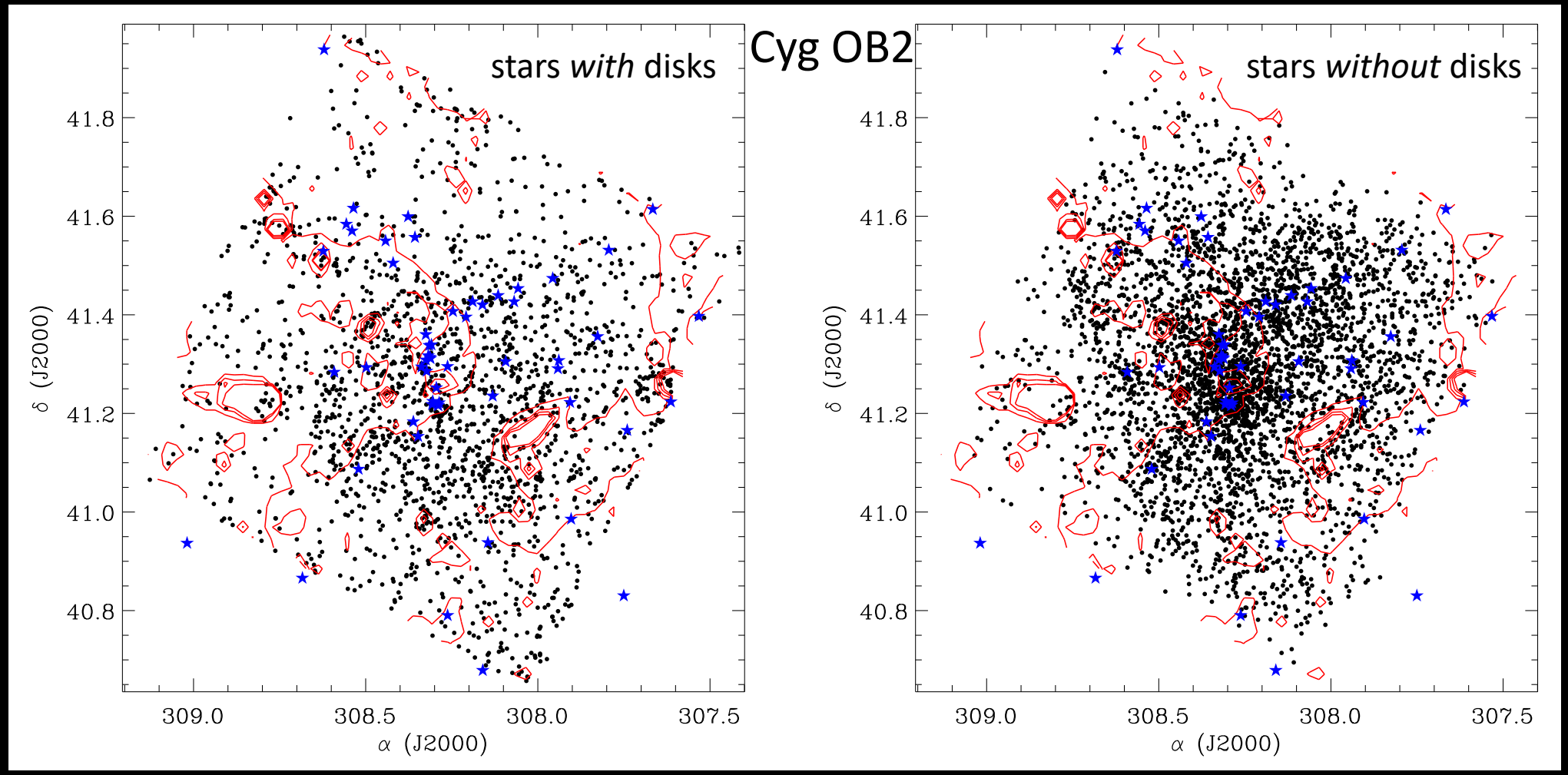
NASA, ESA, M. Robberto (Space Telescope Science Institute/ESA), the Hubble Space Telescope Orion Treasury Project Team and L. Ricci (ESO)

Observational evidence of disk destruction: Hα morphology





Structure in the observed distribution of disks (near-IR excess)



Guarcello et al. (2016)

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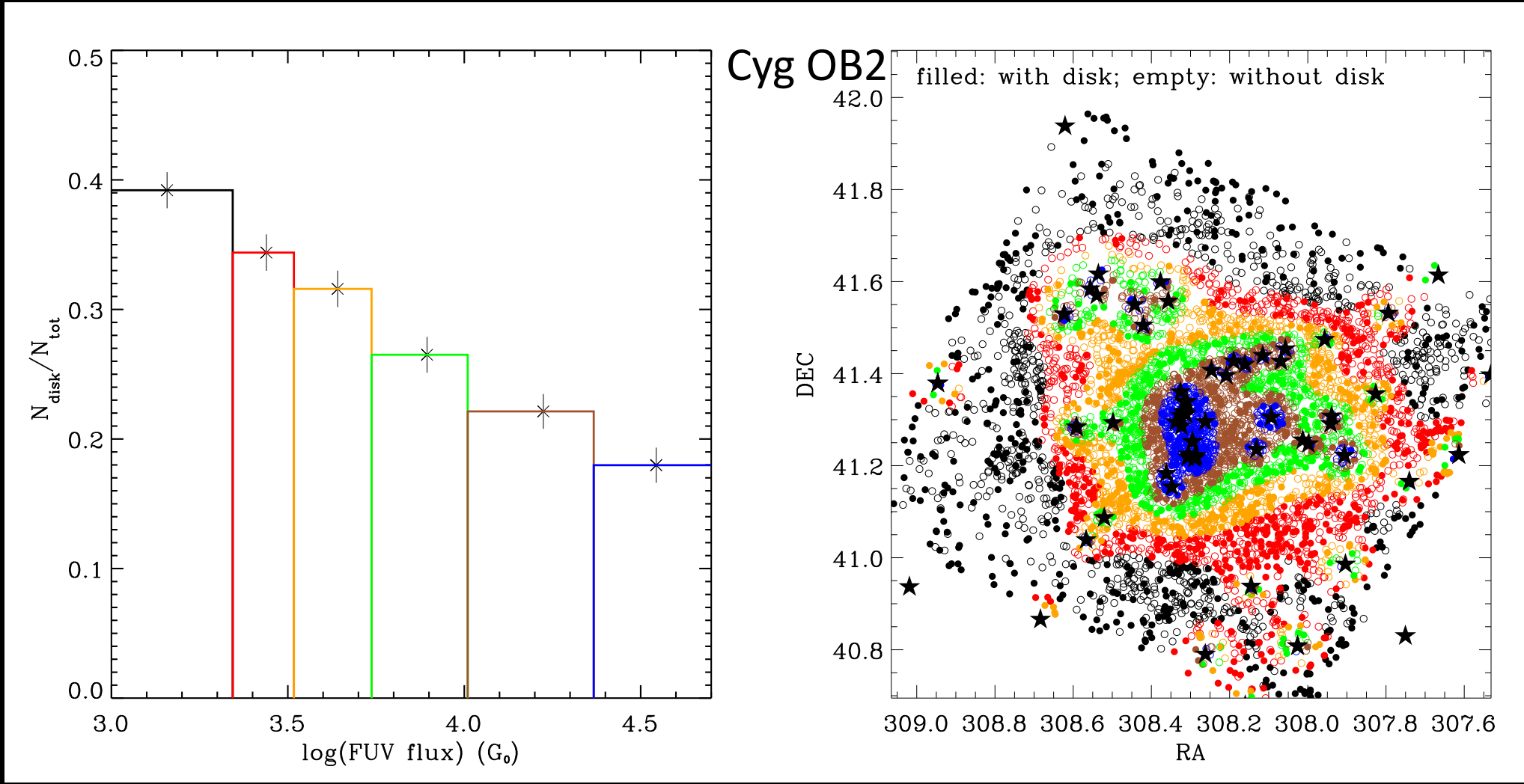
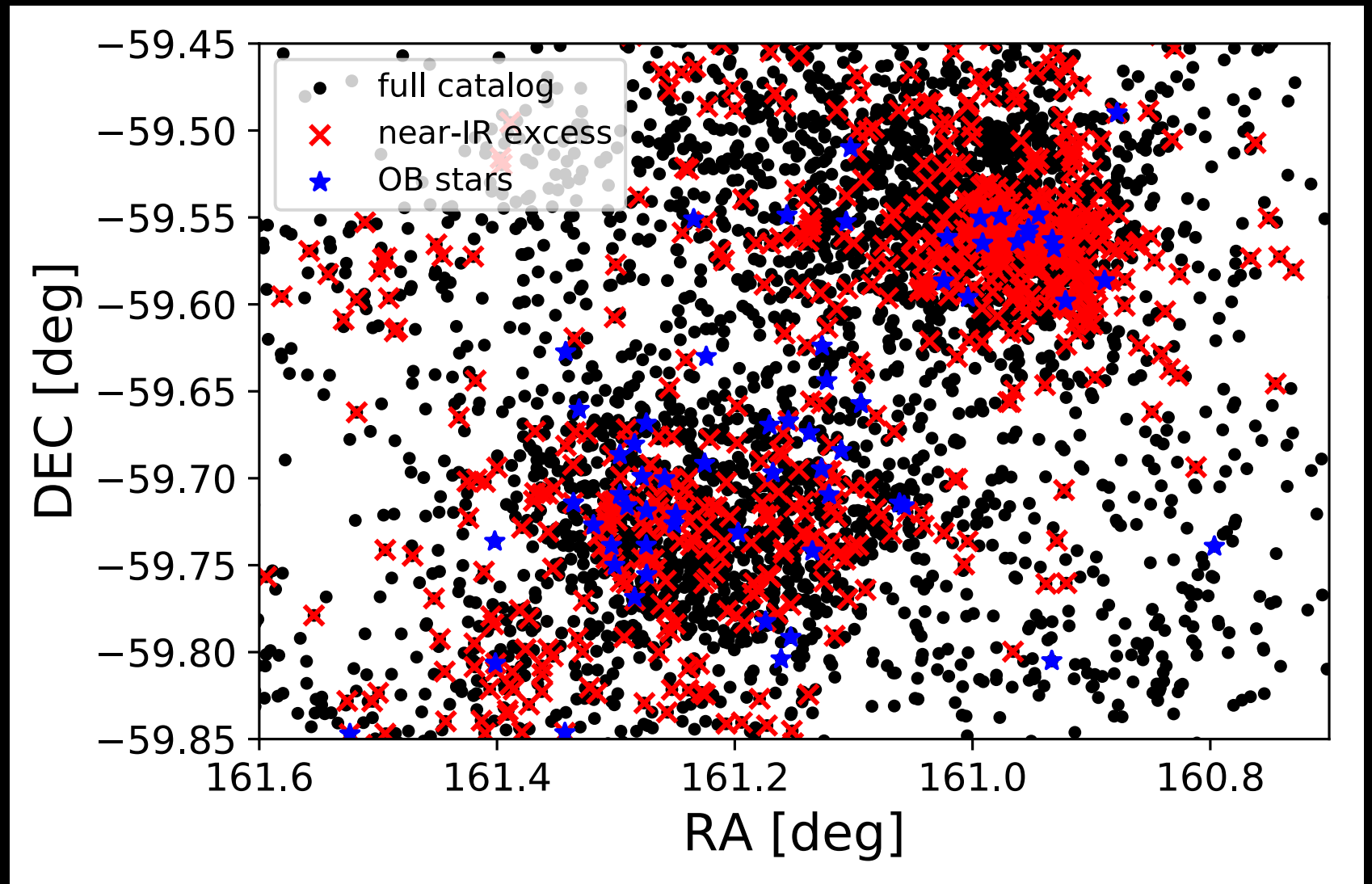


Guarcello et al. (2016)

Ongoing dynamical evolution will mix stars with/without disks; unclear what structure to expect for multiple HM stars.

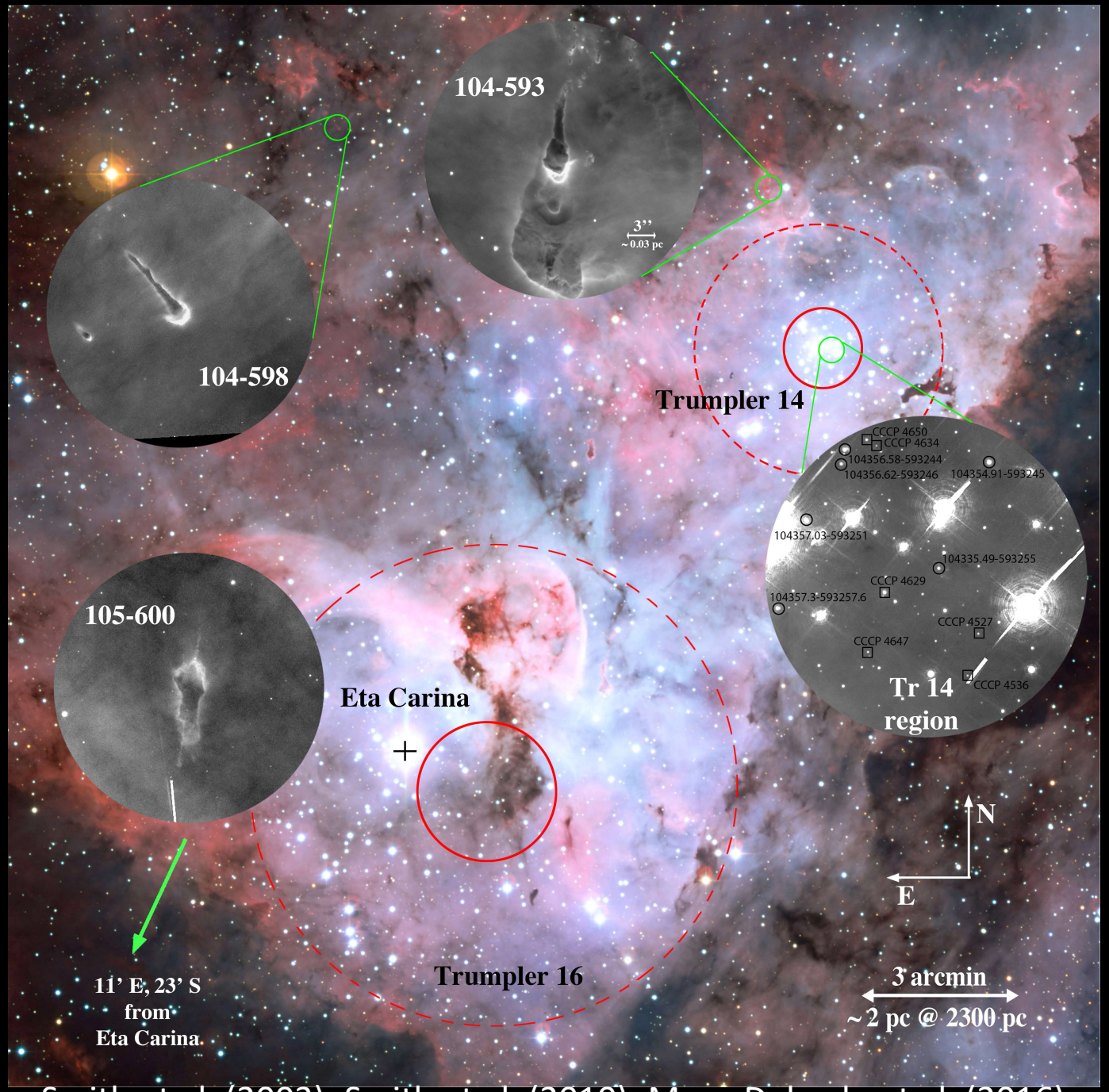


*also note that images provide a 2D projection of a 3D distribution

Reiter & Parker (2019) using near-IR data from Preibisch et al. (2011)

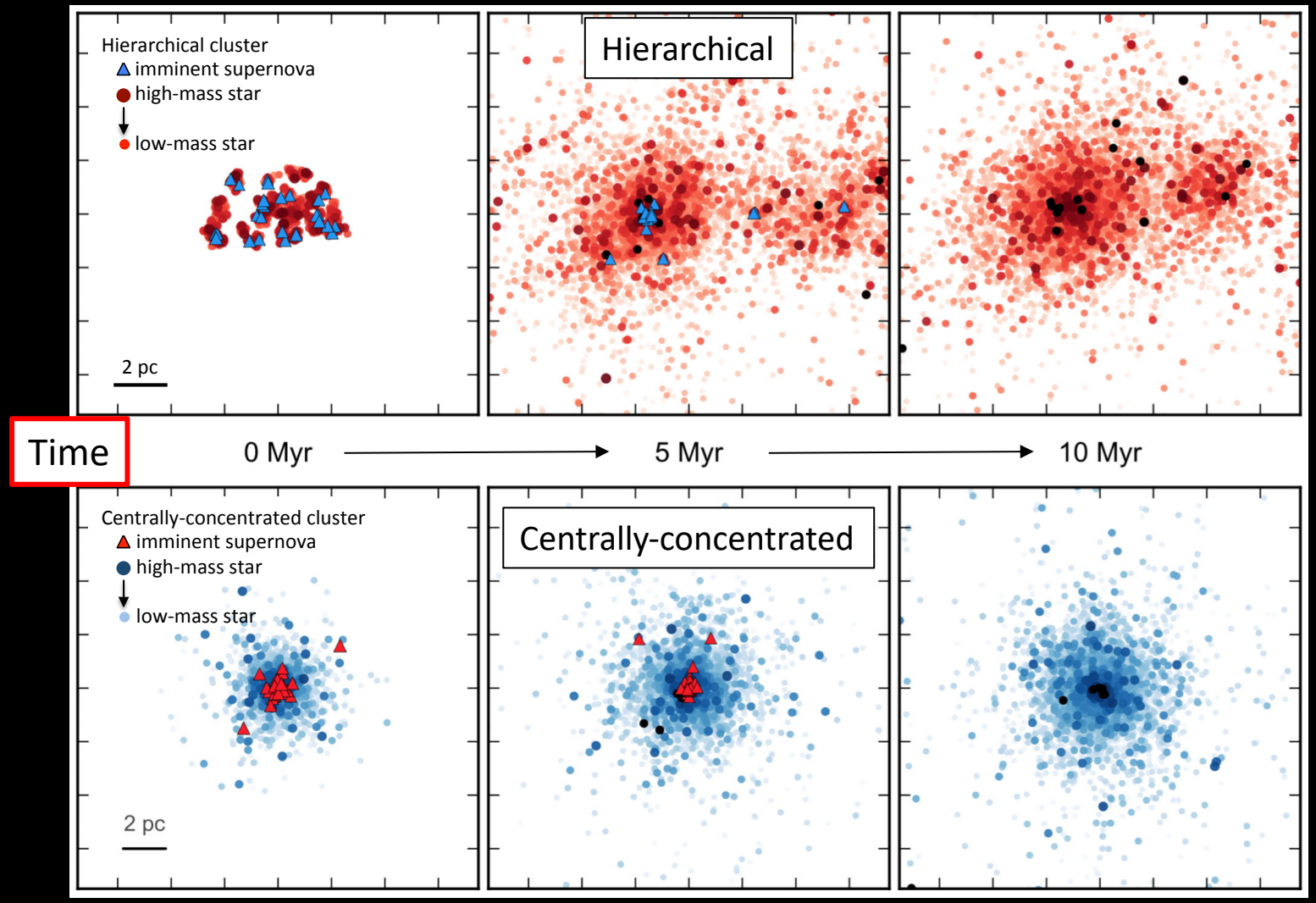
Difficult to identify signatures of disk destruction in regions with D >2 kpc.

- Many candidates turn out to be Evaporating Gaseous Globules (EGGs)
- Candidates in Tr14 identified in Hα images not detected in mm continuum



Smith et al. (2003); Smith et al. (2010); Mesa-Delgado et al. (2016)

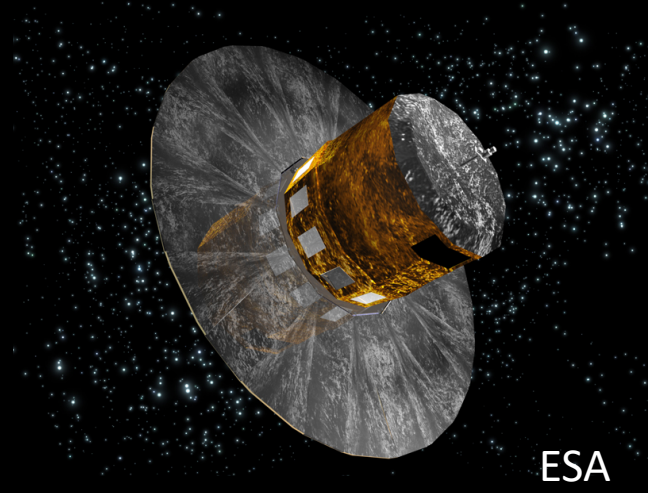
Cluster evolution ties together the themes of this meeting: dynamical interactions, photoevaporation, enrichment, ...



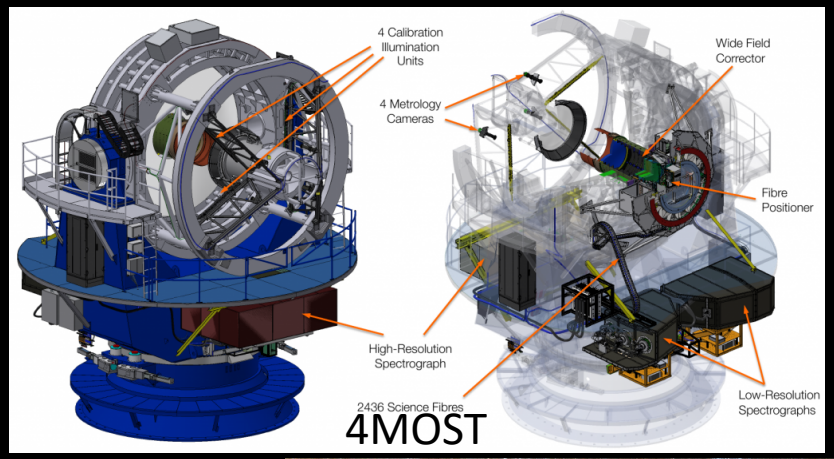
- dynamical evolution
- external photoevaporation
- supernova enrichment

Lichtenberg et al. (2016)

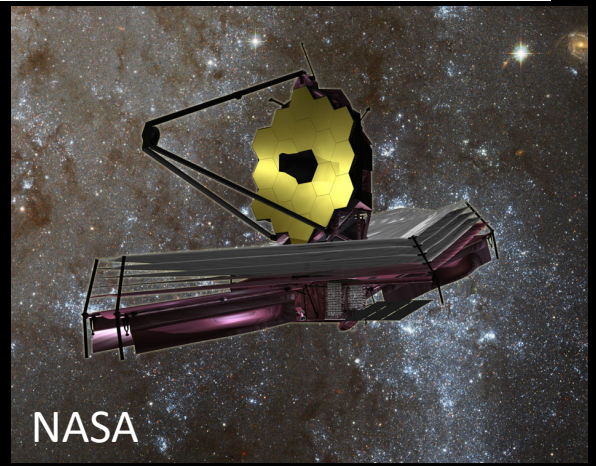
Future directions with future facilities



- Gaia – eDR3 expected 3 December 2020
  - parallaxes and proper motions
  - improve membership
  - kinematics for cluster evolution and dissolution studies

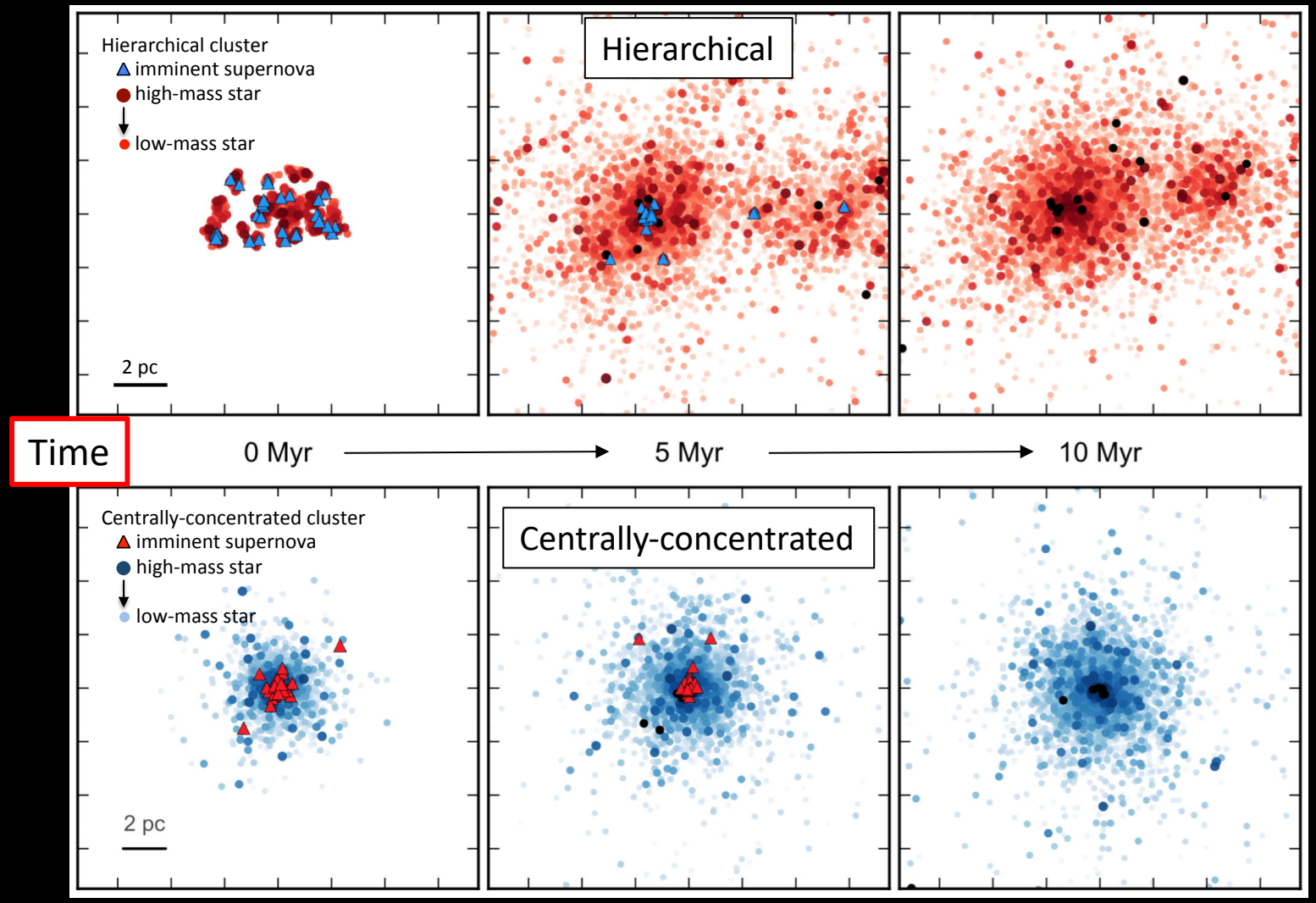


- Spectroscopic surveys: WEAVE, 4MOST, MOONS
  - radial velocities
  - age and accretion indicators



- IR instruments to probe younger, embedded regions

Cluster evolution ties together the themes of this meeting: dynamical interactions, photoevaporation, enrichment, …



Lichtenberg et al. (2016)