SN and HII-region feedback: cloud formation, support, or destruction?

Enrique Vázquez-Semadeni
Instituto de Radioastronomía y Astrofísica, UNAM
México

Universidad Nacional Autónoma de México

IRyA

Collaborators:

Christian Alig (LMU, Munich)

Andi Burkert (LMU, Munich)

Pedro Colín† (IRyA)

Gilberto Gómez (IRyA)

Alejandro González-Samaniego (UAM Lerma)

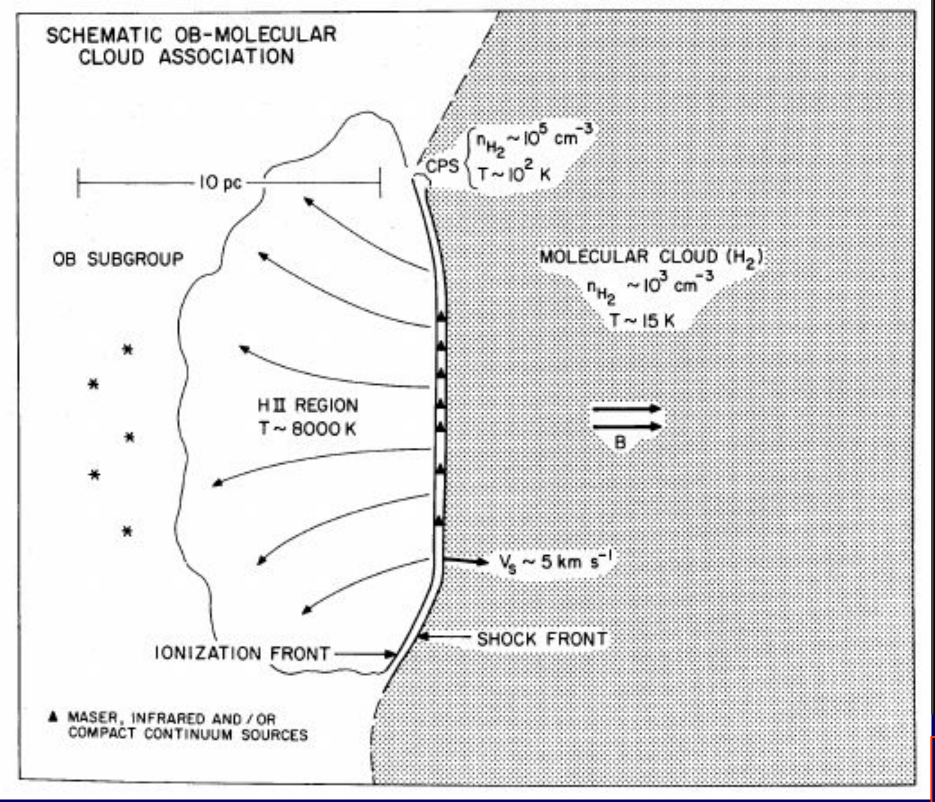
David Whitworth (IRyA)

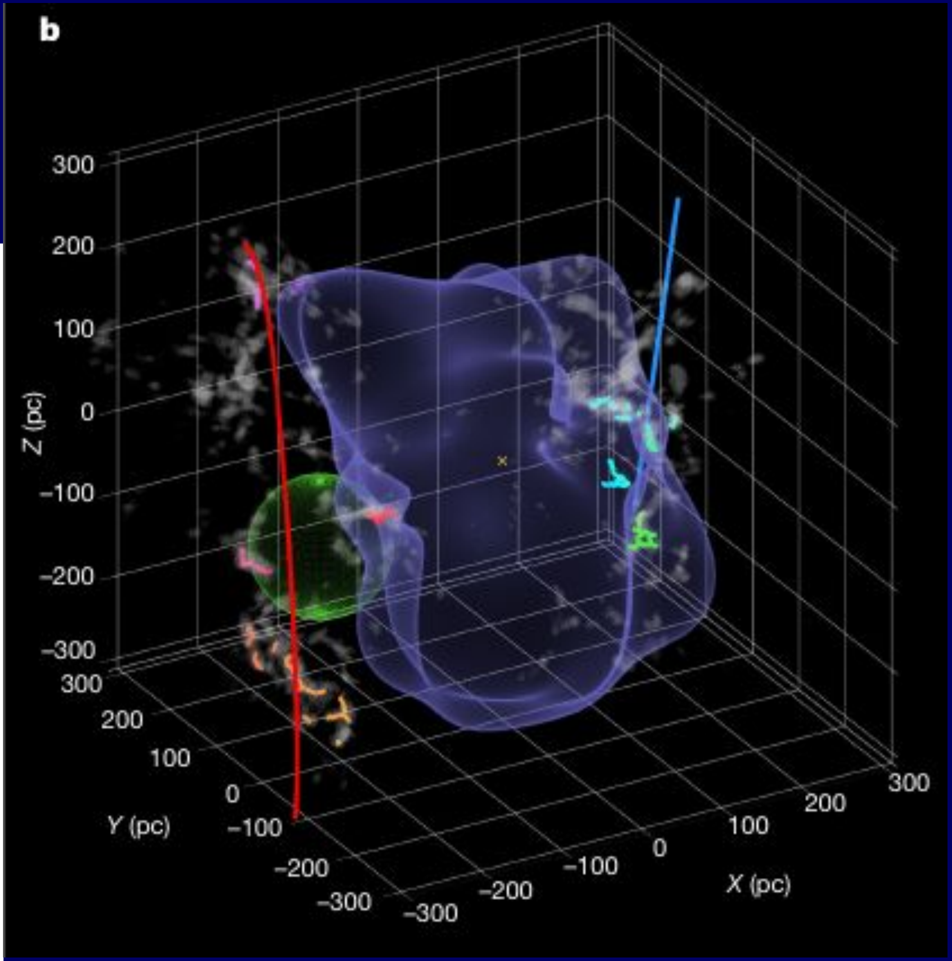
Manuel Zamora-Avilés (INAOE/LMT)

I. The many tasks we demand from HII-region and SN feedback

– Massive-star feedback (mainly photoionizing radiation and SN driving) has been blamed for:

1. Cloud ***formation*** by compression:





Elmegreen & Lada 77
"Collect & collapse."

Zucker+22: "We find that nearly all of the star-forming complexes in the solar vicinity lie on the surface of the Local Bubble... providing robust observational support for the theory of supernova-driven star formation."

– Massive-star feedback (mainly photoionizing radiation and SN driving) has been blamed for:

1. Cloud formation (e.g., Elmegreen & Lada 77: “Collect and collapse”; Zucker+22: solar neighborhood clouds lie on surface of Local Bubble).

2. Driving of clouds’ internal turbulence by nearby SNe (e.g., Mac Low & Klessen 04, Padoan+16; although see Seifried+18).

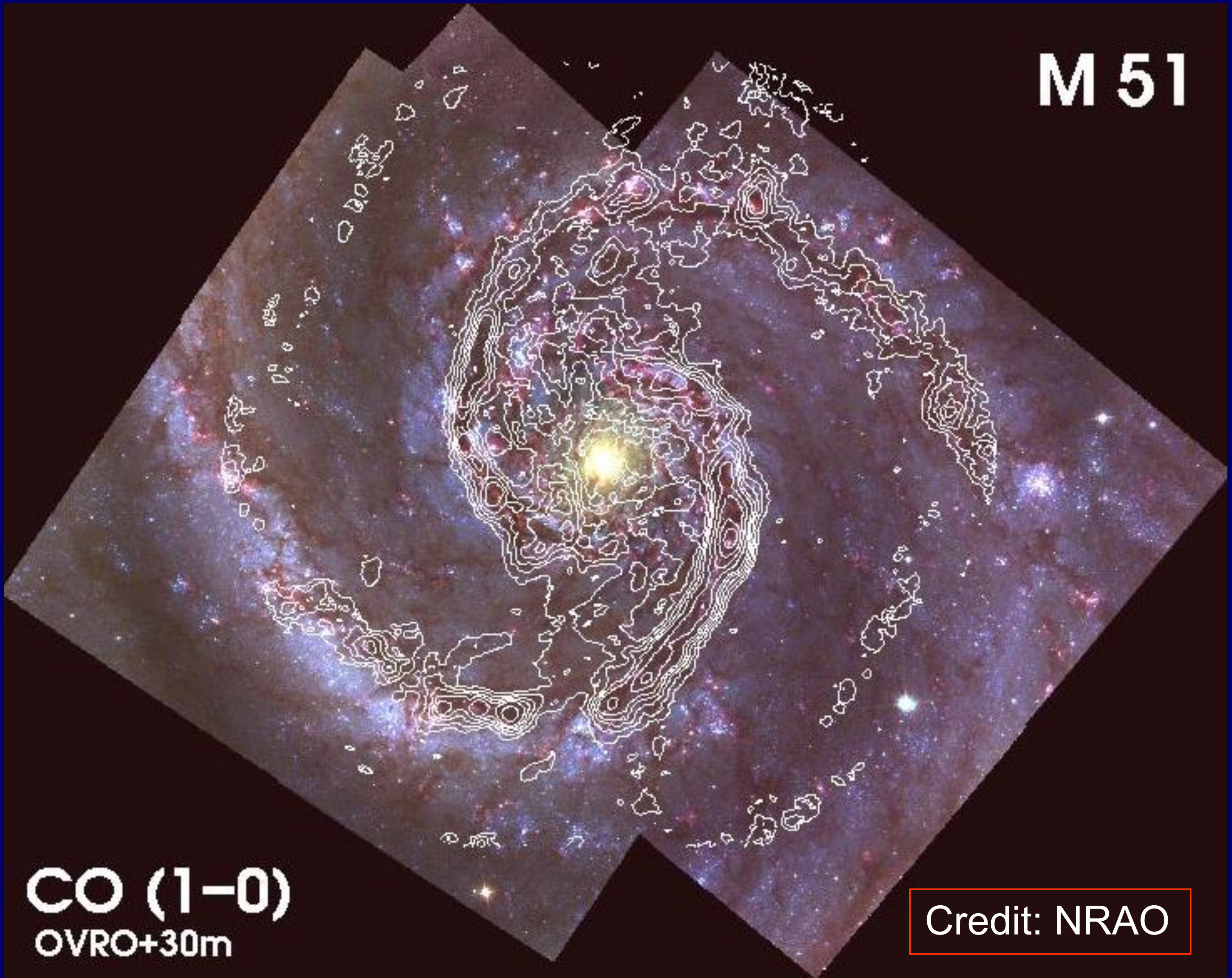
3. Cloud dispersal and regulation of the SFR (by HII regions; e.g., Matzner 02; Colín+13; Mac Low+17; Haid+19).

- So, how do all three of these effects combine, and what is the net result?

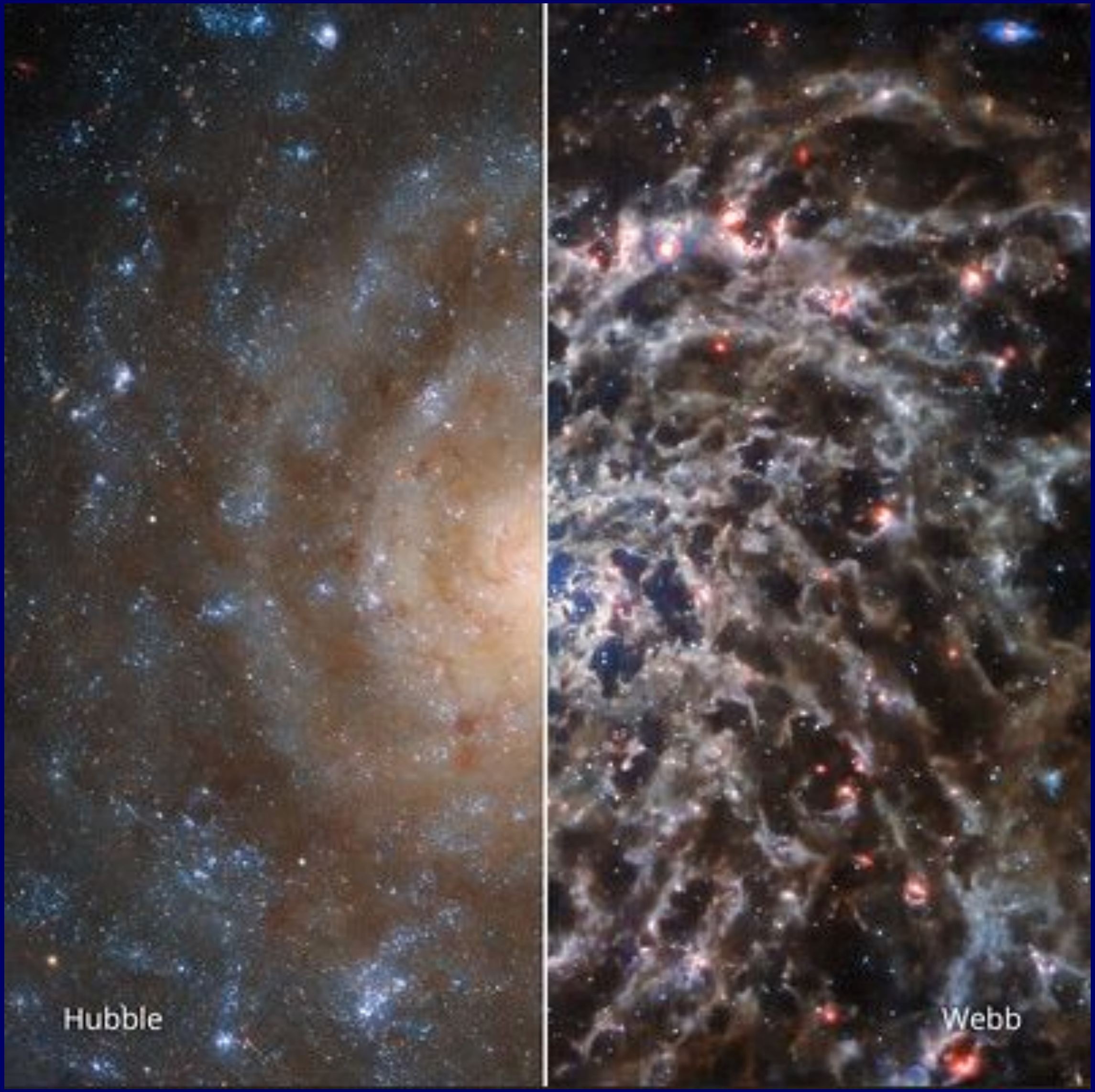
- Does feedback (and which kind) promote or inhibit SF?

II. What is the main mechanism of molecular gas formation?

– Molecular gas in galaxies is distributed in large, kpc-long complexes. Along spiral arms in grand-design ones:

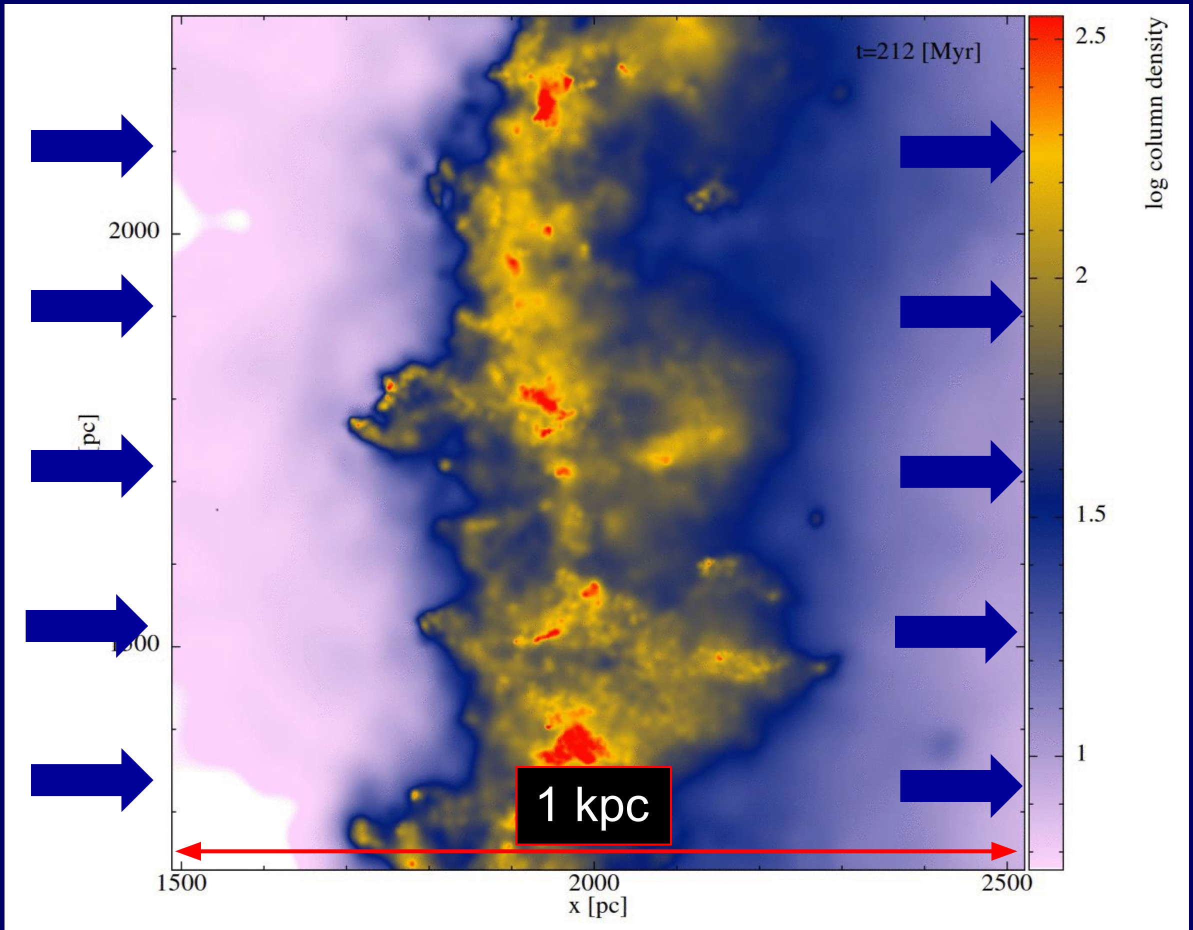


– SNe explode there.



– A simplified, rotation-less simulation (VS+25, subm., by C. Alig and A. Burkert):

- A 4-kpc GADGET3 simulation with a straight-arm potential in the middle.
- Gas enters on the left with v = 15 km s^{-1}, n = 0.2 cm^{-3}. Outflow conditions on the right.



SNe tend to explode outside MCs (Mélanie's talk), so they mainly *rearrange and destroy* part of the dense gas *initially formed by the arm potential*.

"Sculpting" the gas (Joao's talk), not *forming* it.

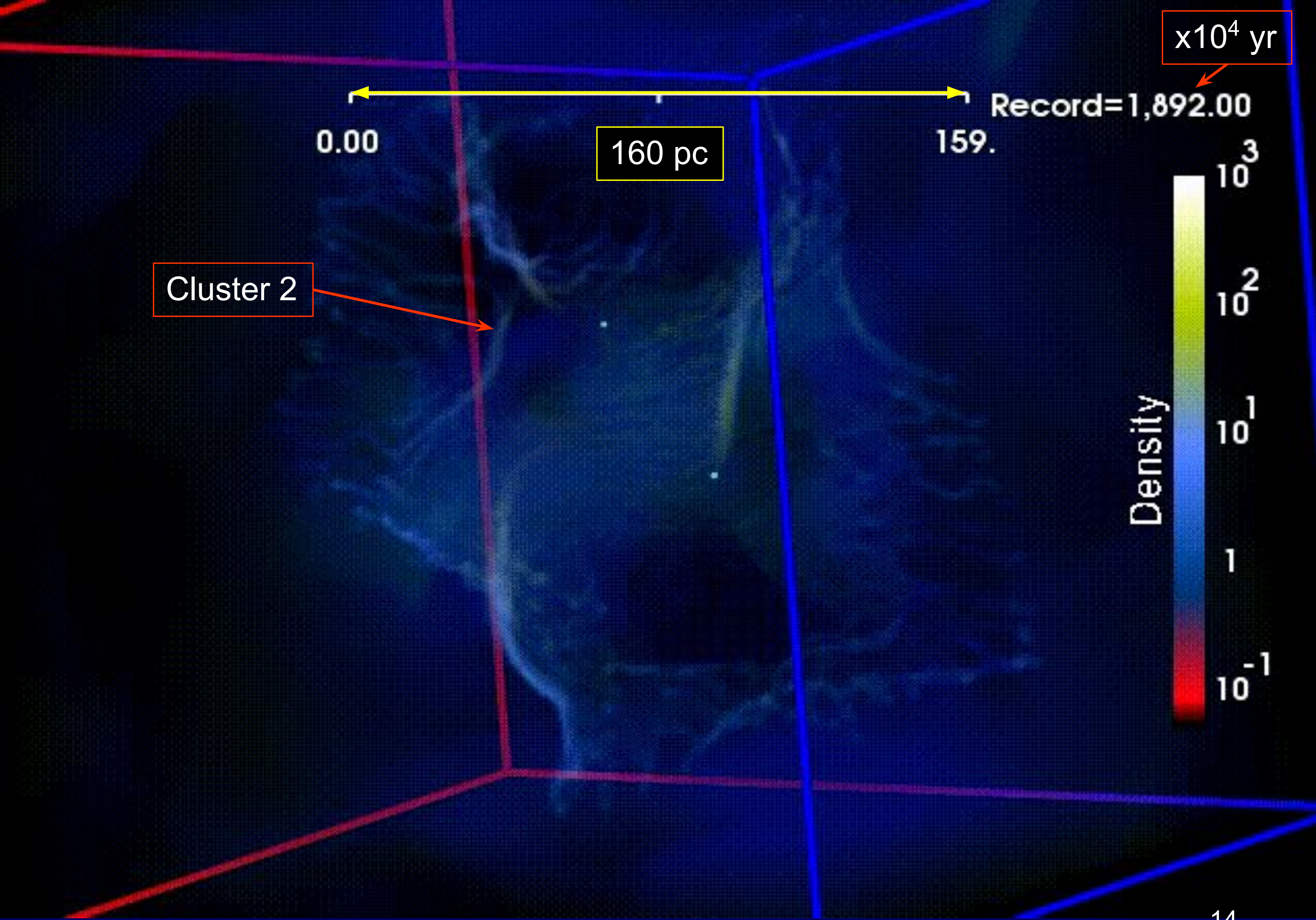
(The destructive effect of SNe in this simulation is exaggerated because the SNe explode *inside* the clouds.)

III. The effect of HII regions inside molecular clouds

– Inside the clouds, the dominant effect is that of the HII regions (Matzner 02; Colín+13; Haid+19; Steffi’s and Angela’s talks).
  - How does stimulated SF compare to “primordial”?
  - Is the net effect to induce or suppress SF?

– González-Samaniego & VS (2020, MNRAS, 499, 668): a comparison of two simulations, with and without UV feedback:

  - H-ART code (Kravtsov 2003).
  - 256-pc box, colliding flows, multiphase.
  - Stellar-mass sink particles, Salpeter IMF.
  - Simplified radiative transfer UV radiation.
  - Self-consistent turbulence (driven by instabilities of compressed, cold layer).

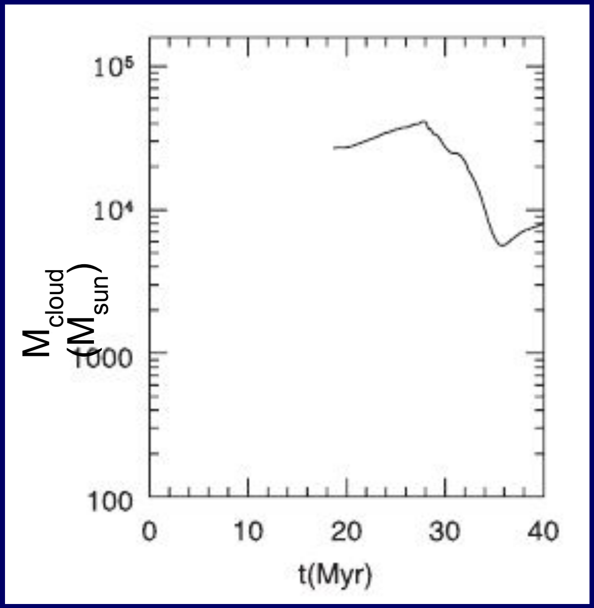


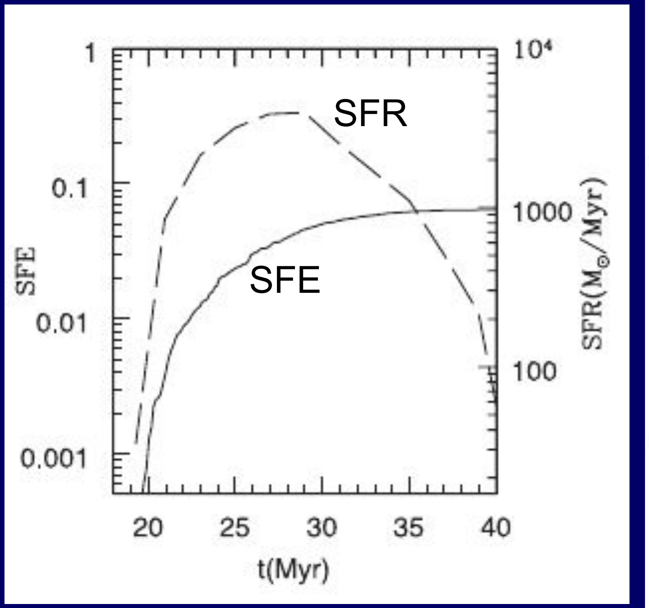
Colín+13, MNRAS, 435, 1701: run LAF1

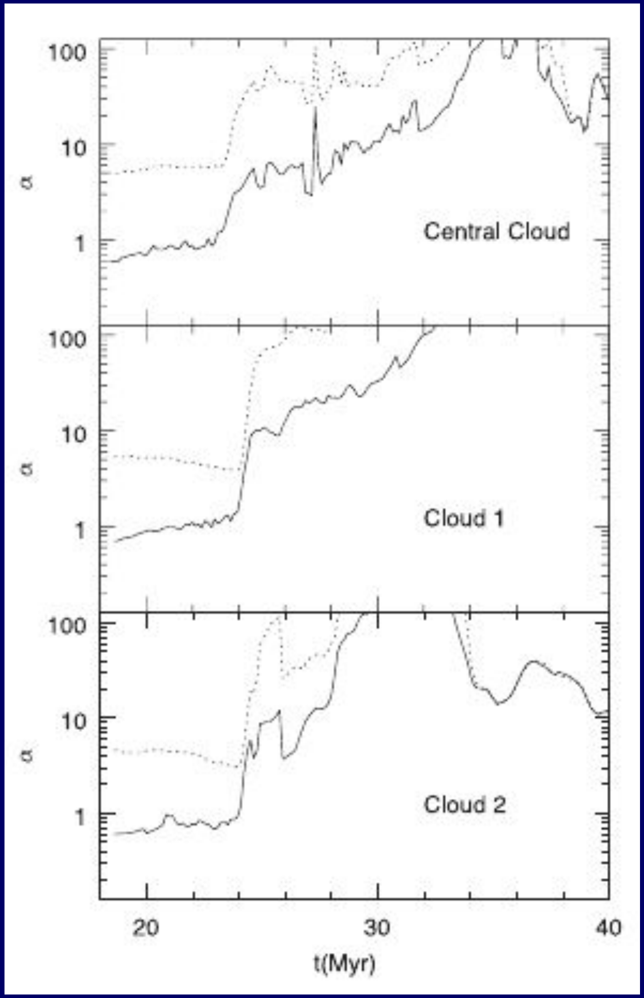
– Dense gas mass first increases by accretion, then decreases by *cloud erosion*.

– Similarly for SFR.

– Virial parameter ~ 1 *during collapse, increases during feedback stage.*

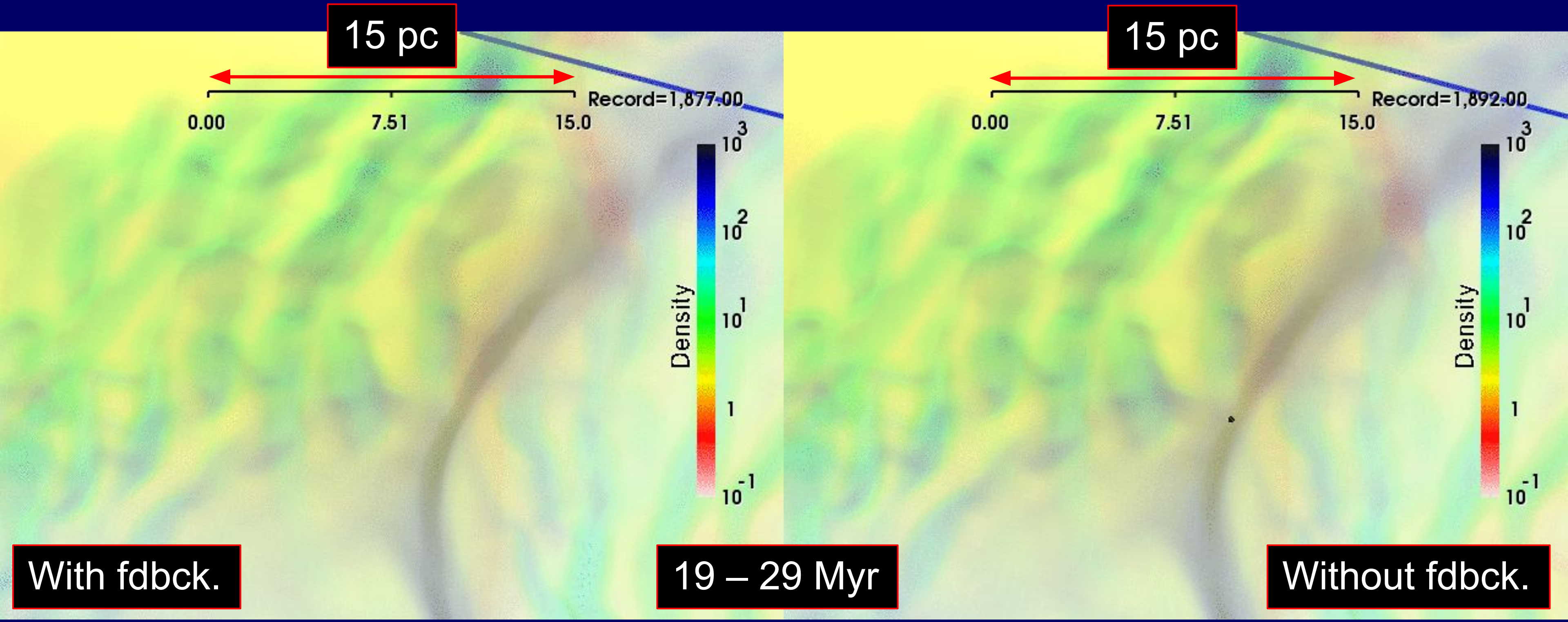






Colín+13, MNRAS, 435, 1701.

– Zoom into Cluster 2, comparing two runs with and without feedback:

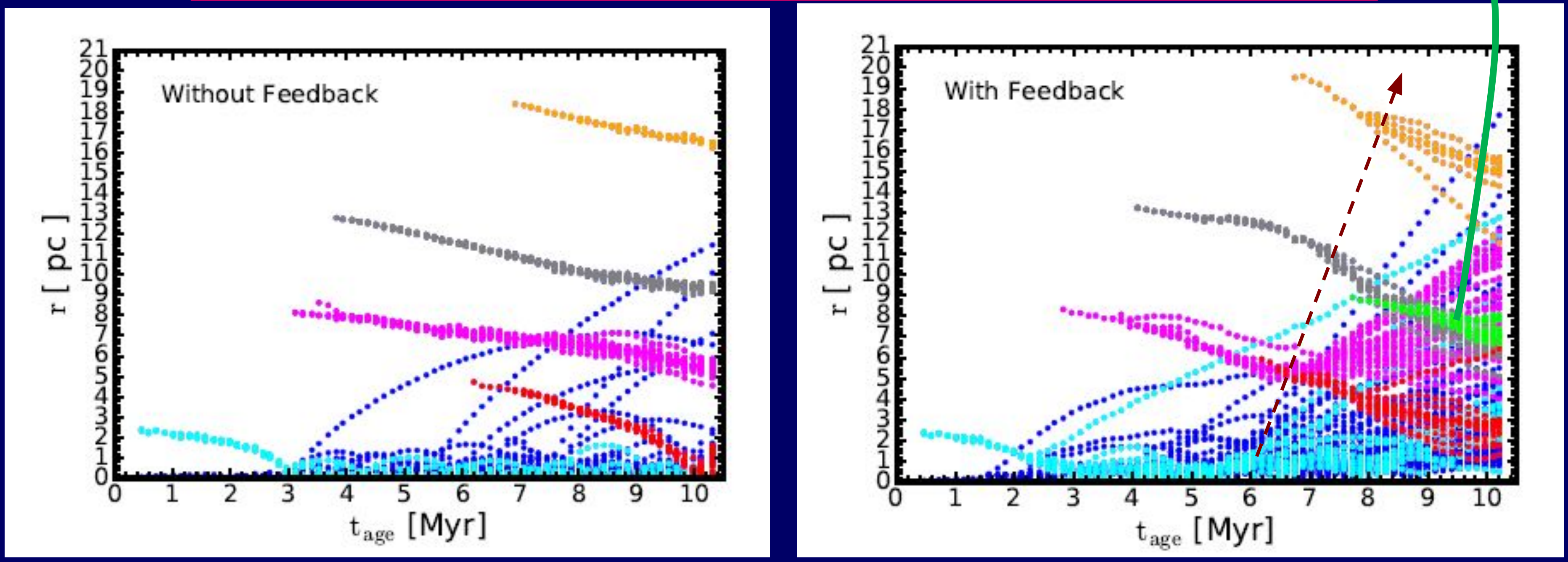


González-Samaniego & VS 2020, MNRAS, 499, 668

- HIGHLIGHTS:
  - A filament forms and grows by continued accretion from the cloud.
    - A main hub forms and grows roughly simultaneously.
    - Slow longitudinal inflow motion develops in the filament towards the central hub.
  - Several secondary stellar subgroups appear later in the filament.
    - As a consequence of the filament's line mass growth.
    - Cluster assembles *hierarchically* due to hierarchical collapse of parent cloud.
      - *"Conveyor-belt"* flow (Longmore+14).
    - Since they form in *both* simulations, their formation is *primordial.*

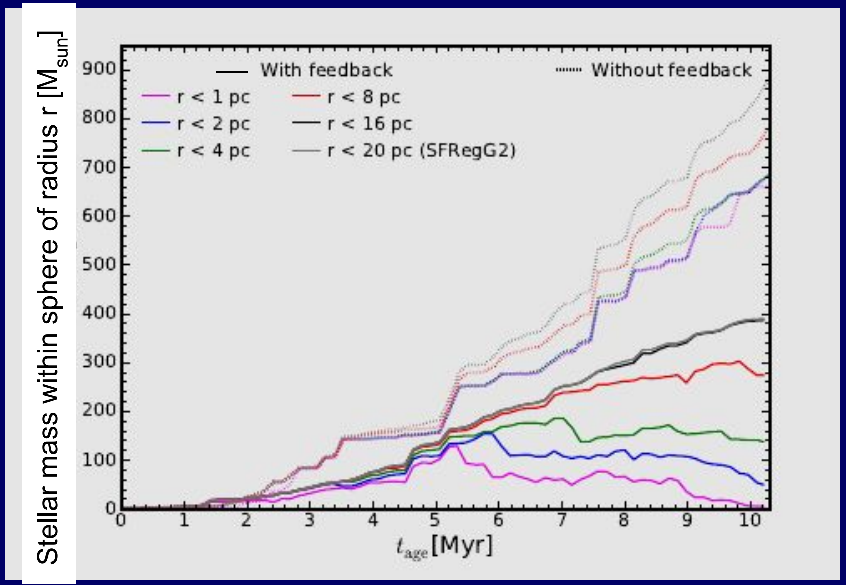
– However, *out of six* secondary subgroups, *one does* form in the run with feedback that does not form in the non-feedback run.

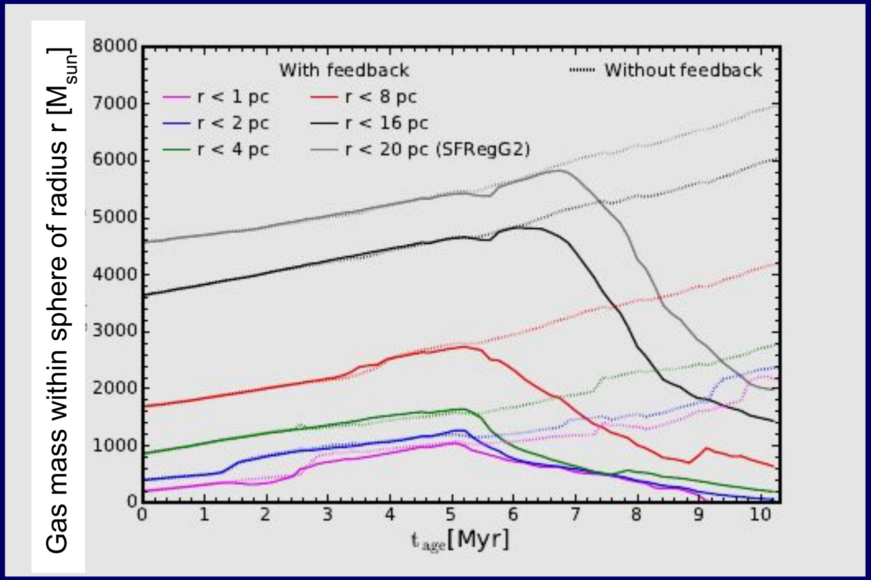
Distances of individual stars to cluster's center of mass vs. time.



– A case of *stimulated formation*.

– Yet, the net SFR is always lower in the run with feedback:





– Hub gas mass increases by accretion onto cloud *faster than stellar mass!* (González-Samaniego & VS, 2020, 499, 668)

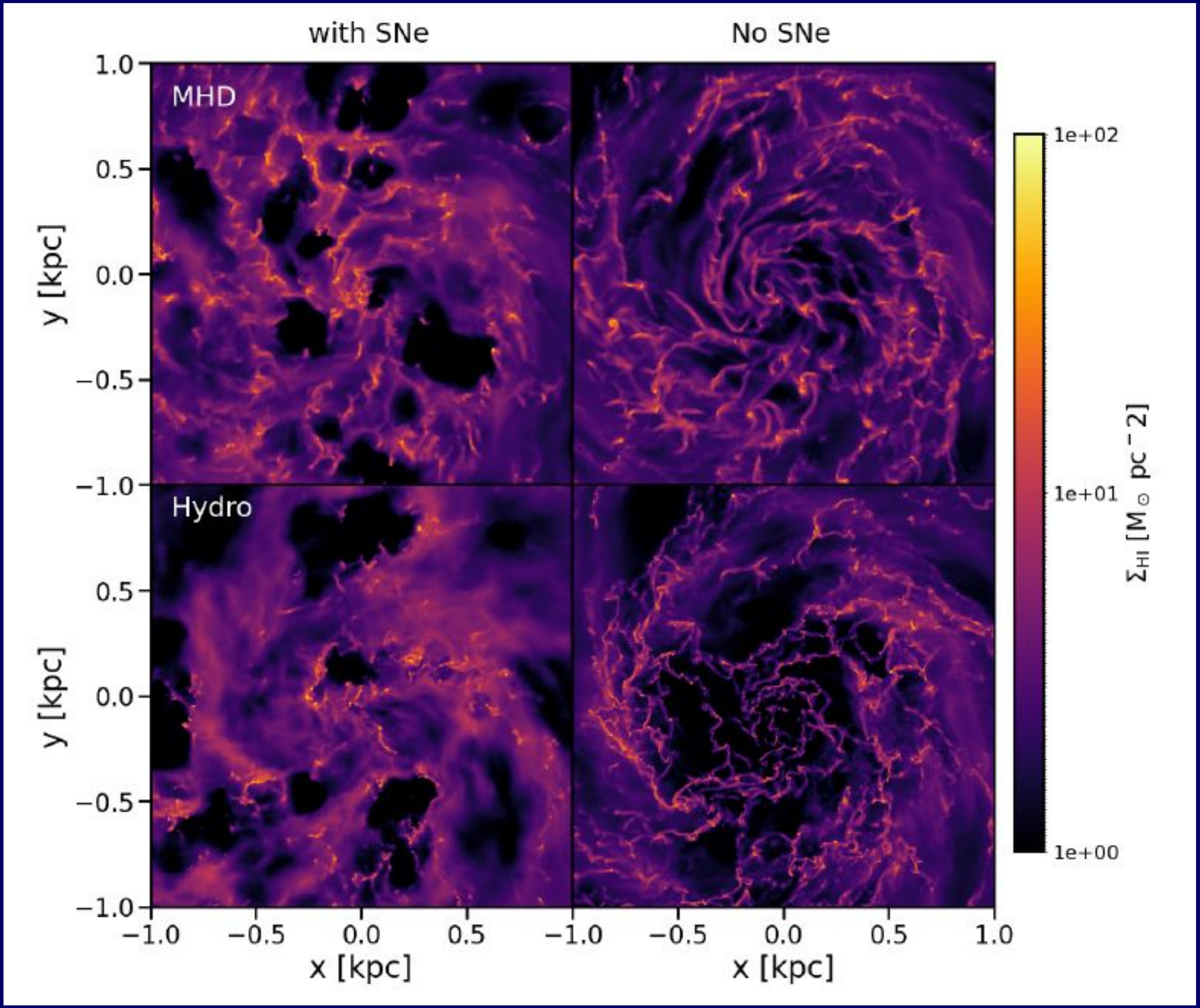
- *Maintains a low measured SFE* even before cloud dispersal.

$$\mathrm{SFE}(t) = \frac{M_*(t)}{M_g(t) + M_*(t)}$$

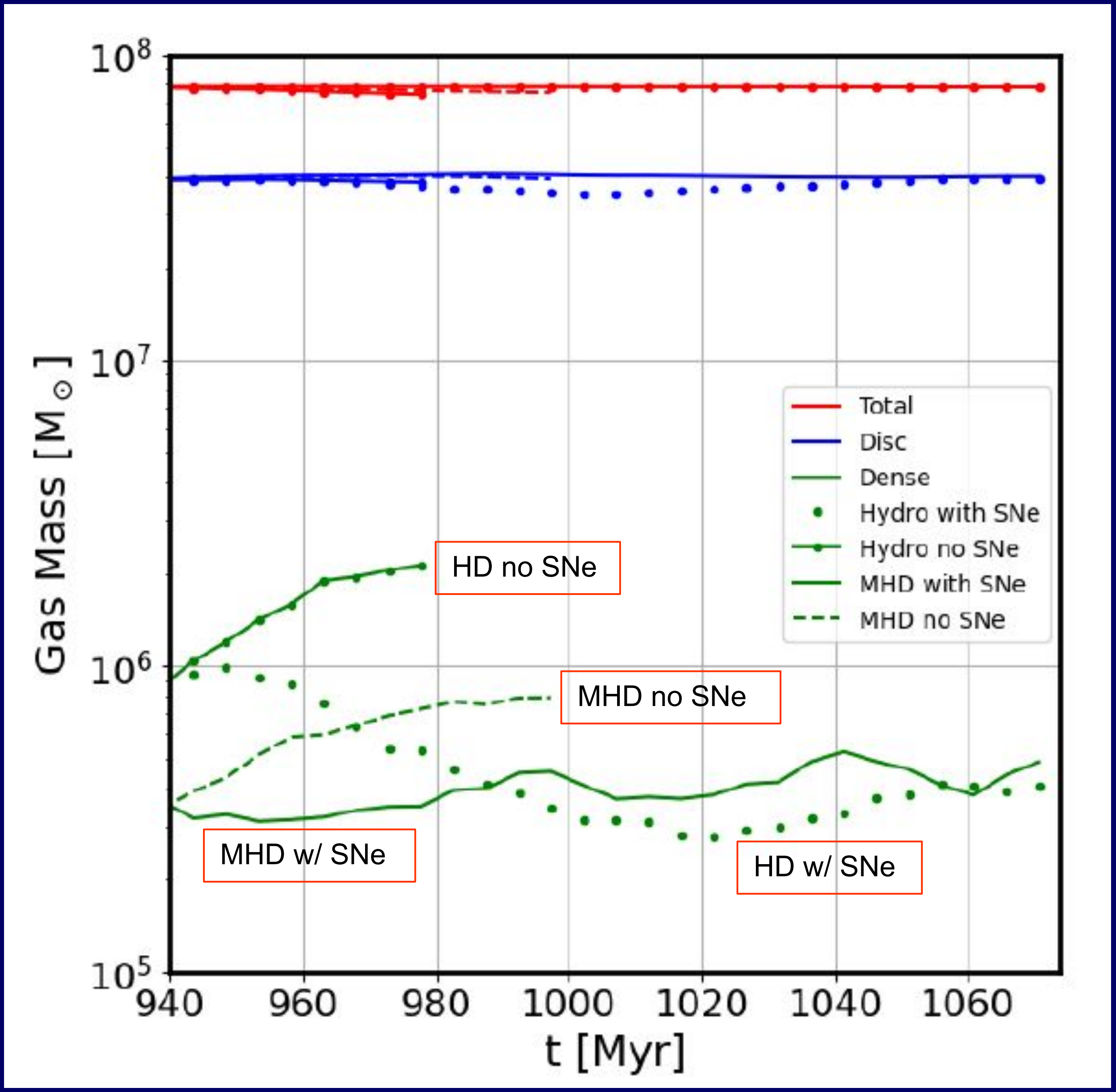
- At t_{age} = 7 Myr, $\mathrm{SFE}_{\text{no fbck}}$ ~ 6.5% $\mathrm{SFE}_{\text{fbck}}$ ~ 4%.
- *The SFE_{ff} becomes a competition of accretion rates!* (Zamora-Avilés+25, subm.)

IV. The effect of SNe outside molecular clouds

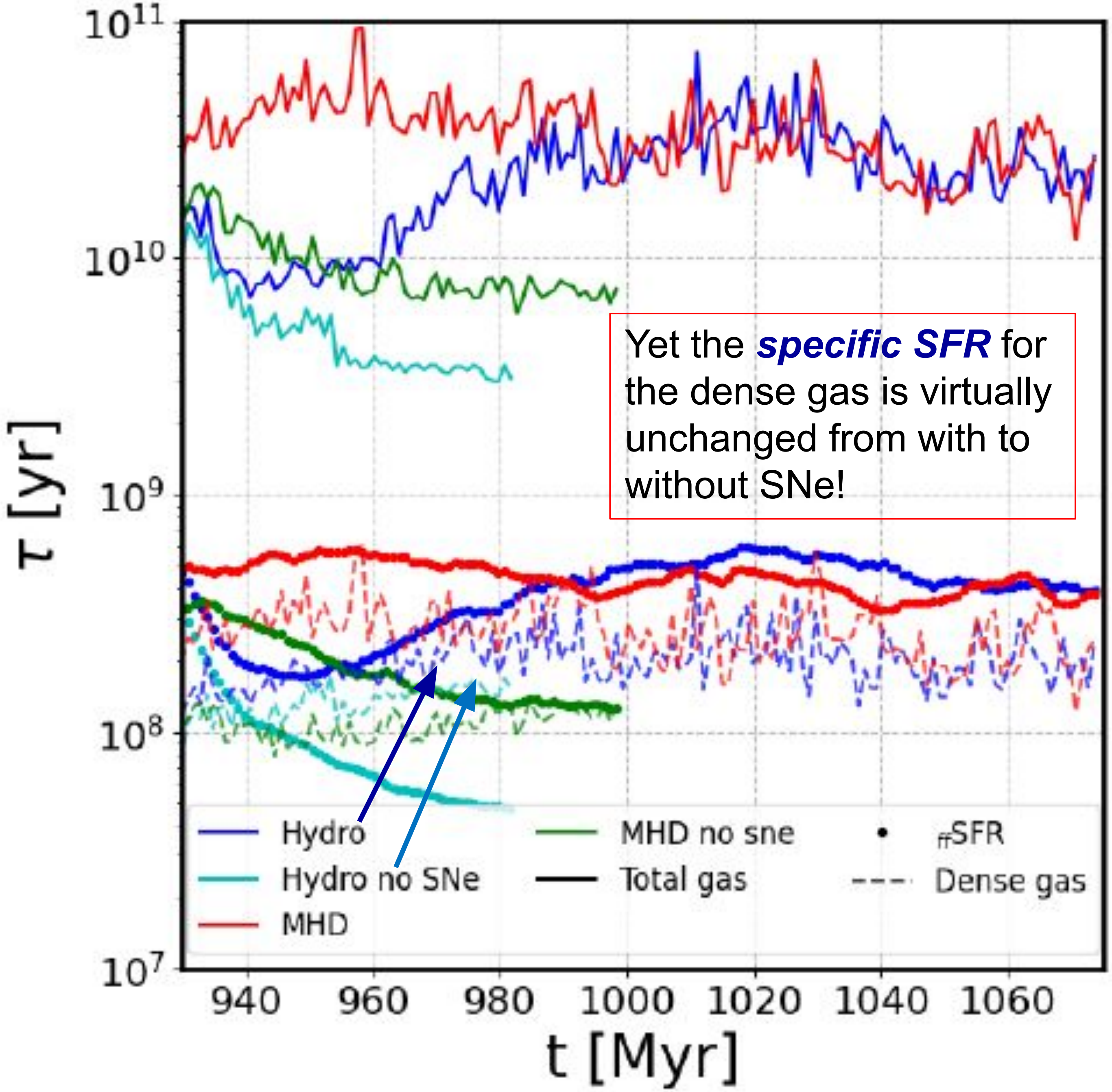
– Whitworth, VS, +25, in prep.: dwarf-galaxy simulations with and without SN feedback and B field:



- Result:



The dense (n > 100 cm^{-3}) gas mass is smaller in the runs with SNe...



Yet the ***specific SFR*** for the dense gas is virtually unchanged from with to without SNe!

- Conclusion:
  - SN feedback *prevents the formation* of dense gas, or destroys some of it, ...
  - ... but *the existing dense gas collapses at the same rate* as the case without SNe*.*

IV. Conclusions

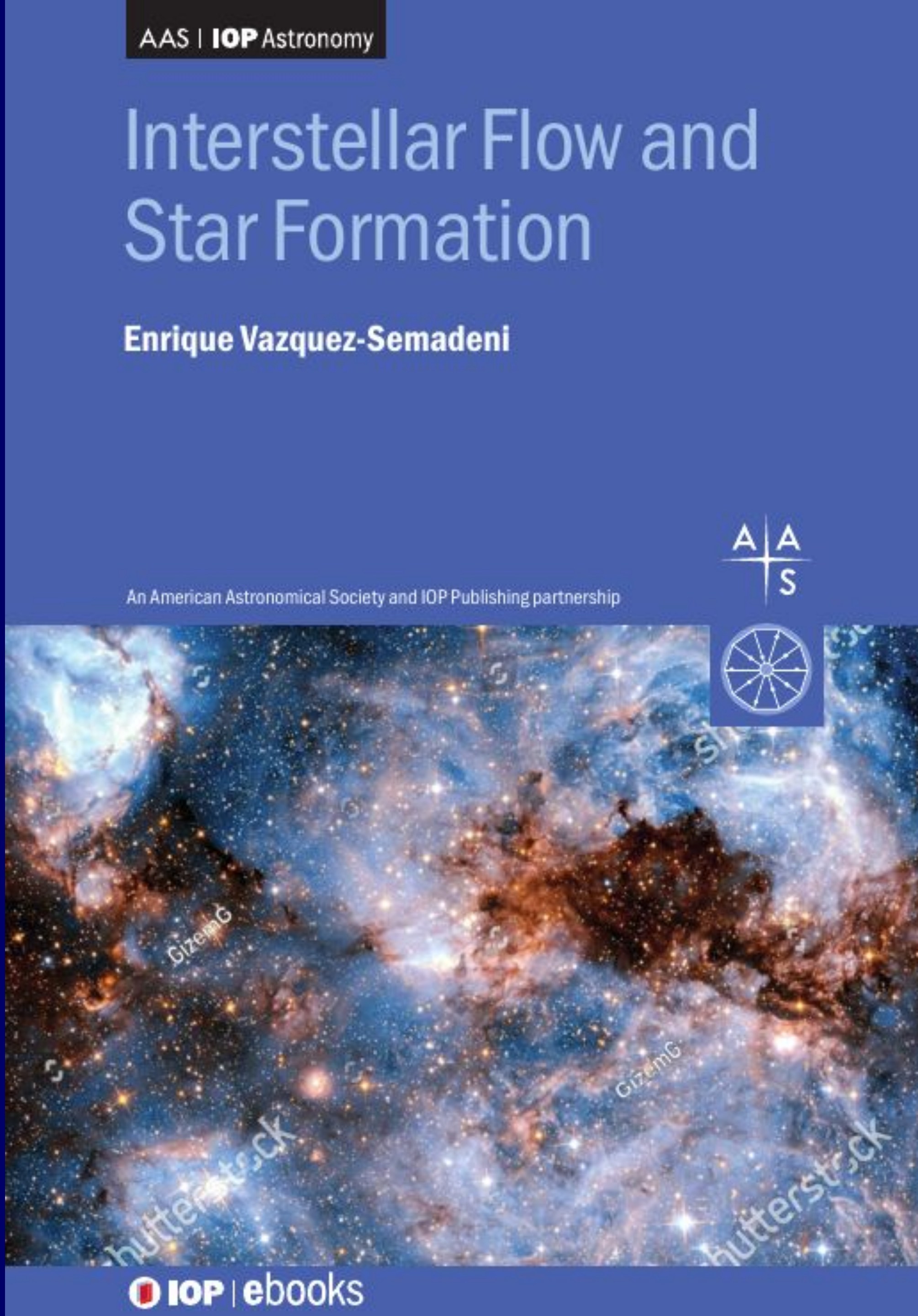
1. At least in grand-design spiral galaxies, most molecular gas is probably made by the arm potential.
   - SNe exploding outside of MCs mainly *rearrange or destroy* part of that gas.

2. Inside MCs,
   - SF appears driven by *primordial, hierarchical* collapse.
   - A minority of cases of triggered SF, but main effect of HII region feedback is cloud destruction/dispersal and SF suppression.
   - SFR first increases by accretion onto cloud, then decreases by destruction/dispersal.
     - α_{vir} ~ 1 during collapse, jumps to >>1 during cloud dispersal.
   - *Accretion onto clouds causes always-low measured SFE.*
     – A matter of *accretion rate competition* between cloud and stars.

4. Outside MCs, SNe:
   - Reduce global SFR by reducing the net amount of dense gas...
   - ...not by retarding its collapse.

5. In no case are nearly hydrostatic, turbulence-supported clouds observed.

A commercial…



Coming soon:

- Part I: Expanded views on basic physics:
  - turbulence,
  - thermodynamics
  - *out-of-equilibrium* virial theorem,
  - anisotropic and outside-in collapse.
- Part II: An account of molecular cloud formation and evolution.

THE END

- Outline:
  - The many tasks we demand from HII-region and SN feedback.
  - Who's the main driver of molecular gas formation in galaxies?
  - Does feedback...
    - promote formation, support, or destruction of molecular clouds?
    - promote or reduce star formation?

3. Cloud ***turbulence driving*** by SNe:

Padoan+16

SUPERNOVA DRIVING. I. THE ORIGIN OF MOLECULAR CLOUD TURBULENCE

PAOLO PADOAN[1], LIUBIN PAN[2], TROELS HAUGBØLLE[3], AND ÅKE NORDLUND[3]

[1] ICREA & Institut de Ciències del Cosmos, Universitat de Barcelona, IEEC-UB, Martí Franquès 1, E08028 Barcelona, Spain; ppadoan@icc.ub.edu

[2] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA; lpan@cfa.harvard.edu

re for Star and Planet Formation, Niels Bohr Institute and Natural History Museum of Denmark, University of Copenhagen, Øster Voldgade 5-7, DK Copenhagen K, Denmark; haugboel@nbi.ku.dk, aake@nbi.ku.dk

Received 2015 September 15; accepted 2016 March 1; published 2016 April 27

ABSTRACT

Turbulence is ubiquitous in molecular clouds (MCs), but its origin is still unclear because MCs are usually assumed to live longer than the turbulence dissipation time. Interstellar medium (ISM) turbulence is likely driven by supernova (SN) explosions, but it has never been demonstrated that SN explosions can establish and maintain a turbulent cascade inside MCs consistent with the observations. In this work, we carry out a simulation of SN-driven turbulence in a volume of $(250\,\mathrm{pc})^3$, specifically designed to test if SN driving alone can be responsible for the observed turbulence inside MCs. We find that SN driving establishes a velocity scaling consistent with the usual scaling laws of supersonic turbulence, suggesting that previous idealized simulations of MC turbulence, driven with a random, large-scale volume force, were correctly adopted as appropriate models for MC turbulence, despite the artificial driving. We also find that the same scaling laws extend to the interiors of MCs, and that the velocity–size relation of the MCs selected from our simulation is consistent with that of MCs from the Outer-Galaxy Survey, the largest MC sample available. The mass–size relation and the mass and size probability distributions also compare successfully with those of the Outer Galaxy Survey. Finally, we show that MC turbulence is super-Alfvénic with respect to both the mean and rms magnetic-field strength. We conclude that MC structure and dynamics are the natural result of SN-driven turbulence.

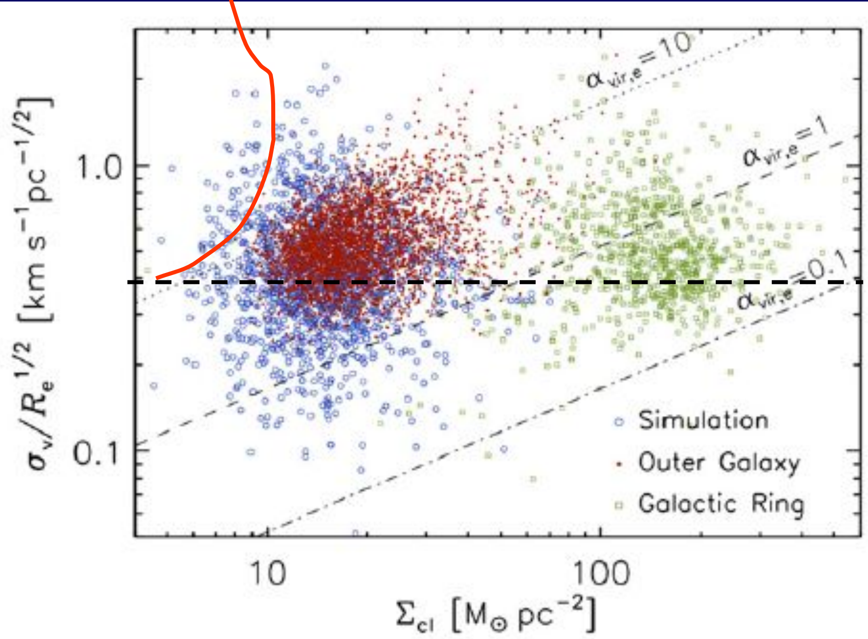
Key words: ISM: kinematics and dynamics – magnetohydrodynamics (MHD) – stars: formation – turbulence

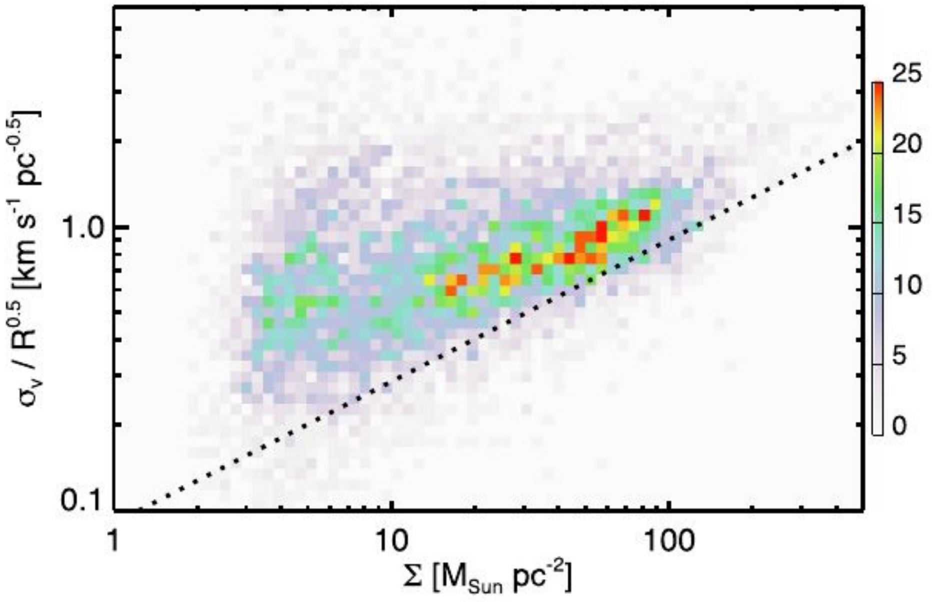
– Although see Seifried+18...

– Except that the usual scaling laws of supersonic turbulence are ***not*** consistent with observations!

Turbulence: $\sigma \propto R^{1/2}$

Molecular clouds: $\frac{\sigma}{R^{1/2}} \propto \Sigma^{1/2}$





Padoan+16

Miville-Deschênes+17