Star formation and feedback in the multi-phase interstellar medium

Stefanie Walch

I.Physics Institute, University of Cologne

D. Seifried, F. Dinnbier, S. Haid (University of Cologne)

T. Naab, T.-E. Rathjen (MPA Garching)

P. Girichidis (AIP Potsdam)

R. Wünsch (Czech Academy of Sciences, Prague)

R. Klessen, S. Glover (ITA Heidelberg)

P. Clark (Cardiff University)

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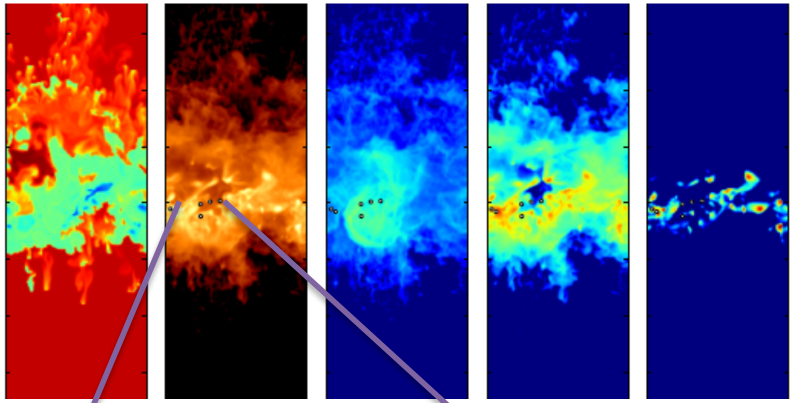
The life-cycle of gas in the multi-phase interstellar medium: A schematic view

Multi-phase ISM in a galactic disk

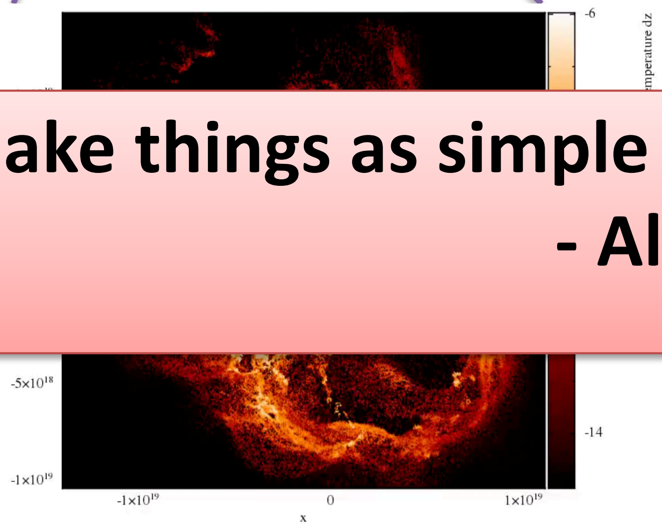


Molecular cloud hosting dense filaments

Compression & Cooling

1. Self-gravity
2. Magnetic fields
3. Chemistry

Collapse & Fragmentation

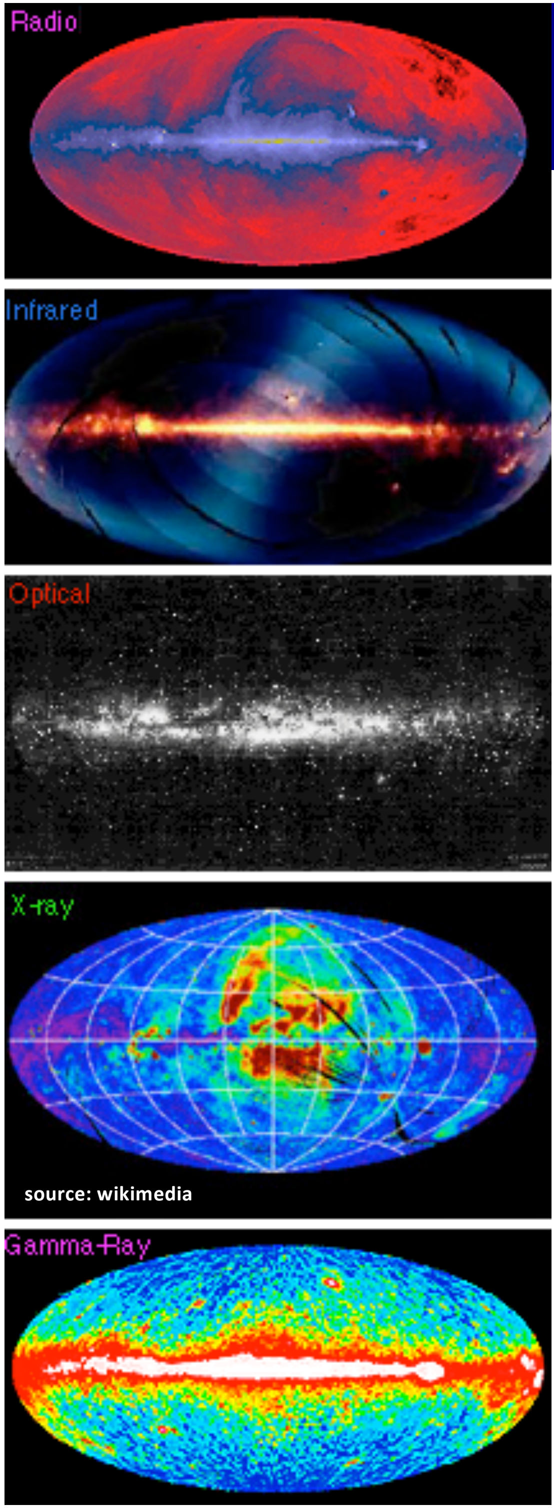


Bubbles on different spatial scales

"Make things as simple as possible, but not any simpler"
- Albert Einstein

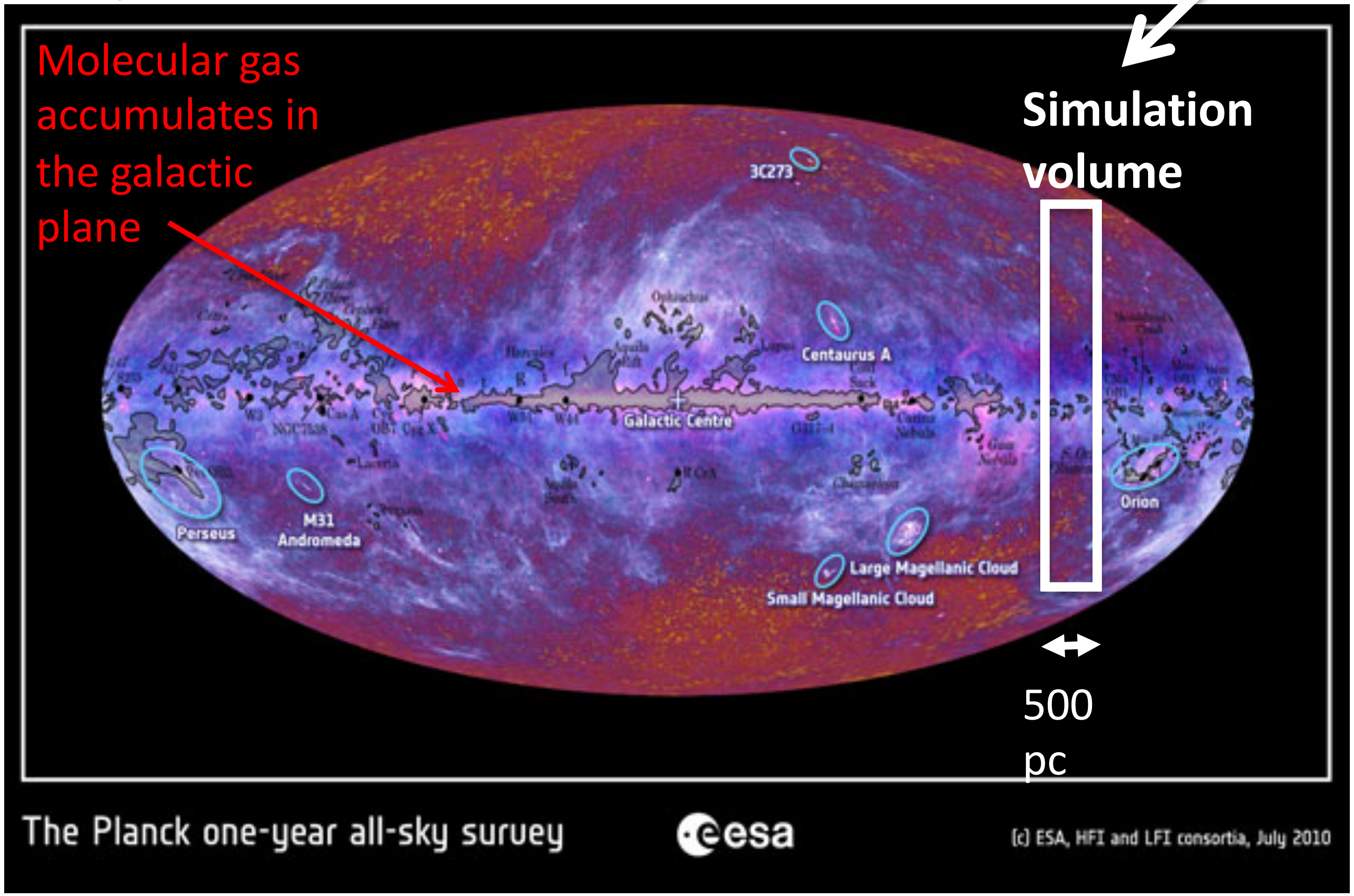
1. Radiation
2. Radiation pressure
3. Stellar winds
4. Supernovae
5. Cosmic Rays

Star and star cluster formation

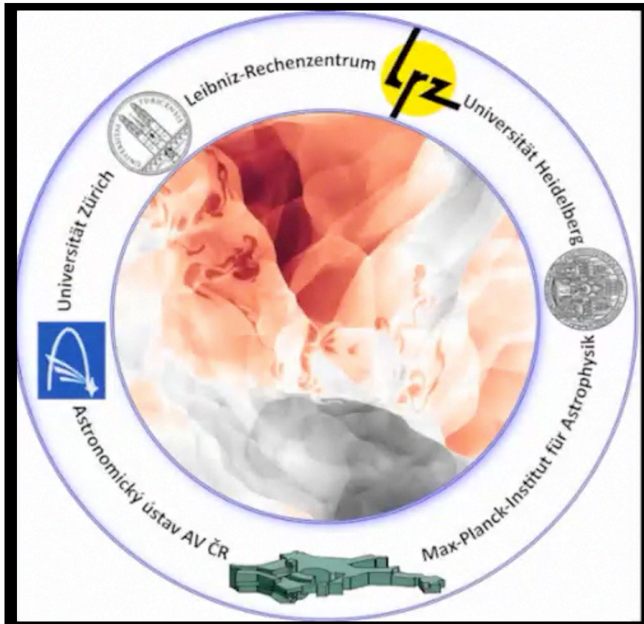


Multi-wavelength Milky Way

superimposed contours: CO survey (Dame et al. 2001):



Volume filling fractions:
Mihalas & Binney (1981); Kulkarni & Heiles (1988)



SILCC Project

SImulating the LifeCycle of Molecular Clouds

University of Cologne: S. Walch, D. Seifried, F. Dinnbier, S. Haid
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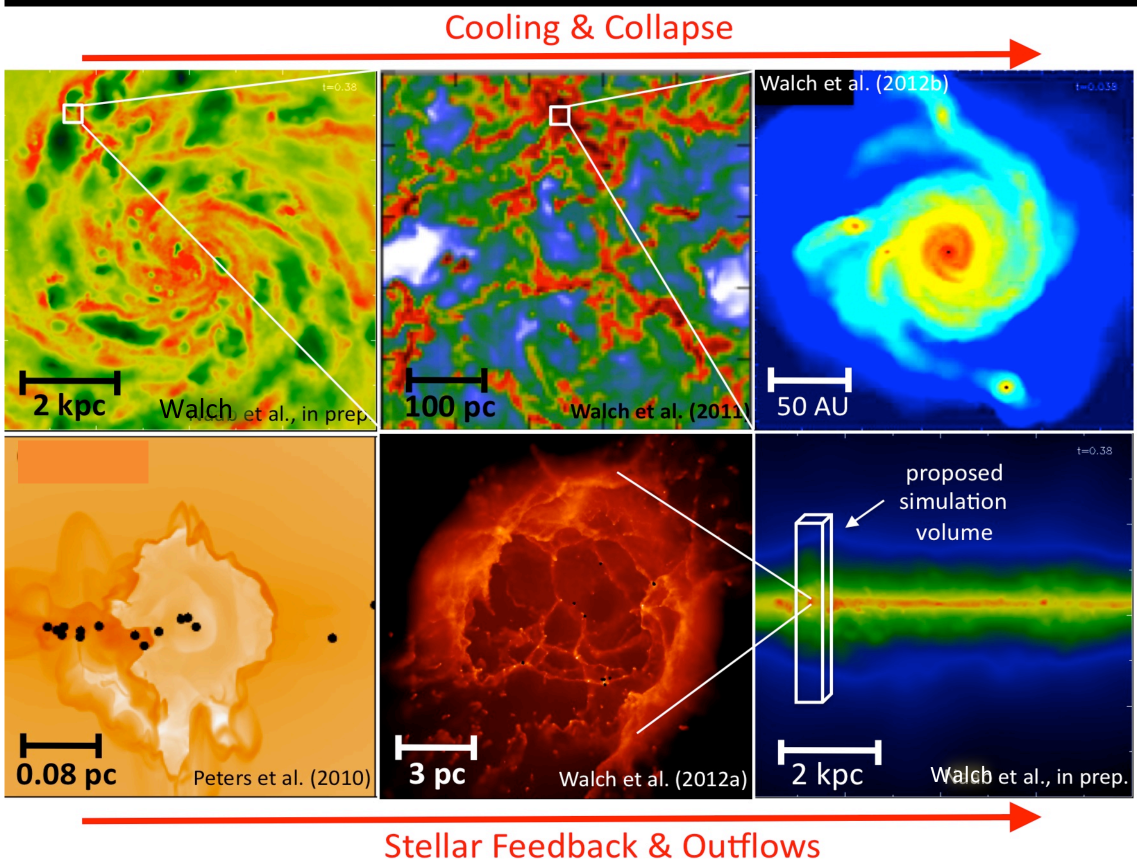

AMR code FLASH 4 with...

- Self-gravity
- External galactic potential
- ideal MHD
- Heating & Cooling and
- Molecule Formation
- TreeRay (diffuse radiation for shielding + radiative transfer from point sources)
- Sink Particles with subgrid cluster model/massive star model
- Supernova Feedback
- Wind
- Cosmic Rays

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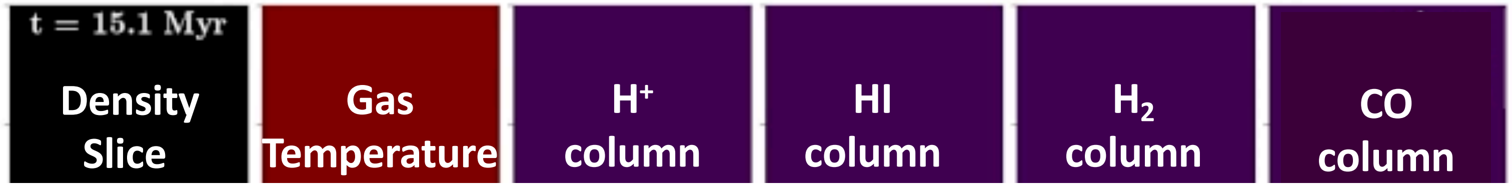
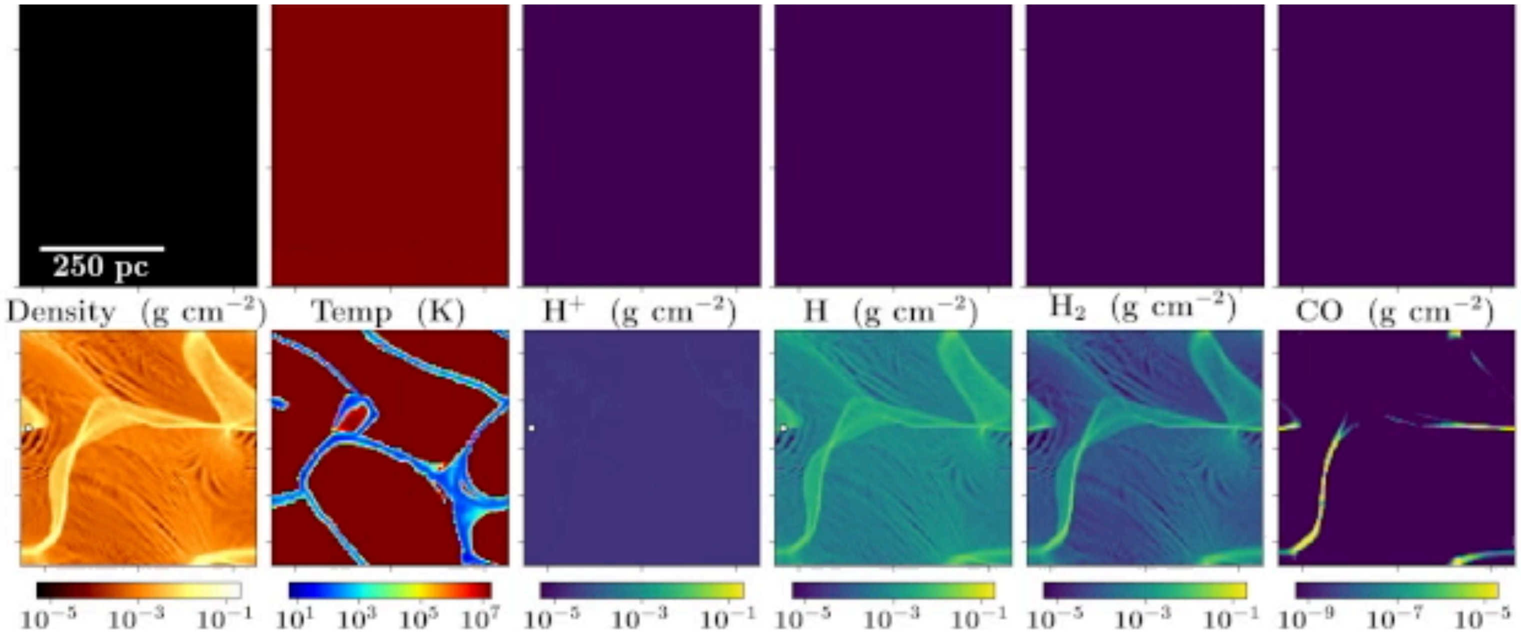
Walch +15, Girichidis +16

Peters+17, Gatto+17, Seifried+17, +18

New SILCC simulations:
stellar winds + ionizing radiation (TreeRay) + supernovae



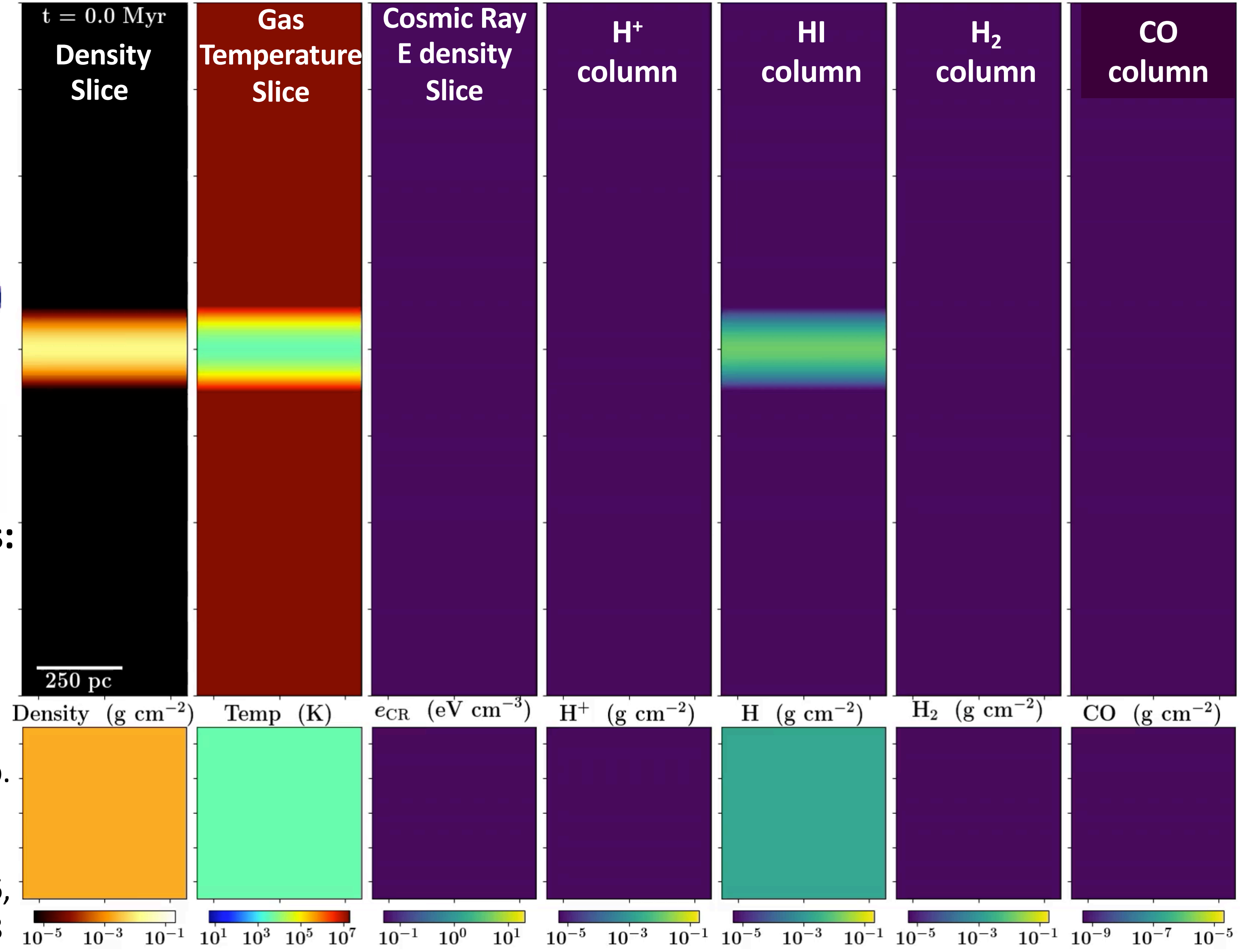
See also:
Kannan+2019, Kim & Ostriker (2018, 2017, etc.), Hill +2018,
Iffrig & Hennebelle (2017), Safranek-Shrader +2017,
Martizzi +2016, Sur+2016, Gent +2013a,b,
Hill & MacLow (2006), deAvillez & Breitschwerdt (2005)



Cluster mass:
- $10^2\ M_\odot$
- $10^3\ M_\odot$
- $10^4\ M_\odot$

Gatto et al. (2017)
Peters et al. (2017)
Wünsch, SW+ in prep.
Dinnbier, SW+ in prep.

New SILCC simulations: winds + ionizing radiation + supernovae + Cosmic Rays



Cluster mass:

- 10^2 $M_\odot$
- 10^3 $M_\odot$
- 10^4 $M_\odot$

Rathjen+in prep.

CR description:
Girichidis +2016,
Girichidis +2018

A quick word on Cosmic Rays...

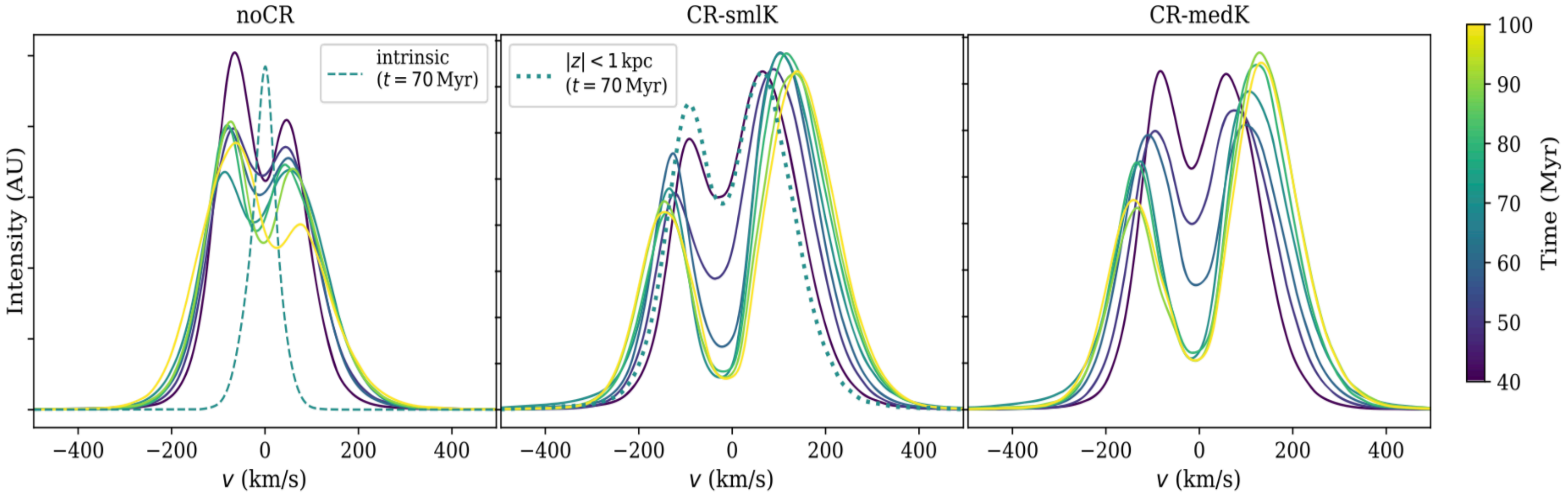
Outflows become cooler and smoother

(Girichidis +2018)

Lyman-alpha line profiles become in agreement with observations only with Cosmic Rays:

Low intensity at line center and asymmetric wings

(Gronke+2018)

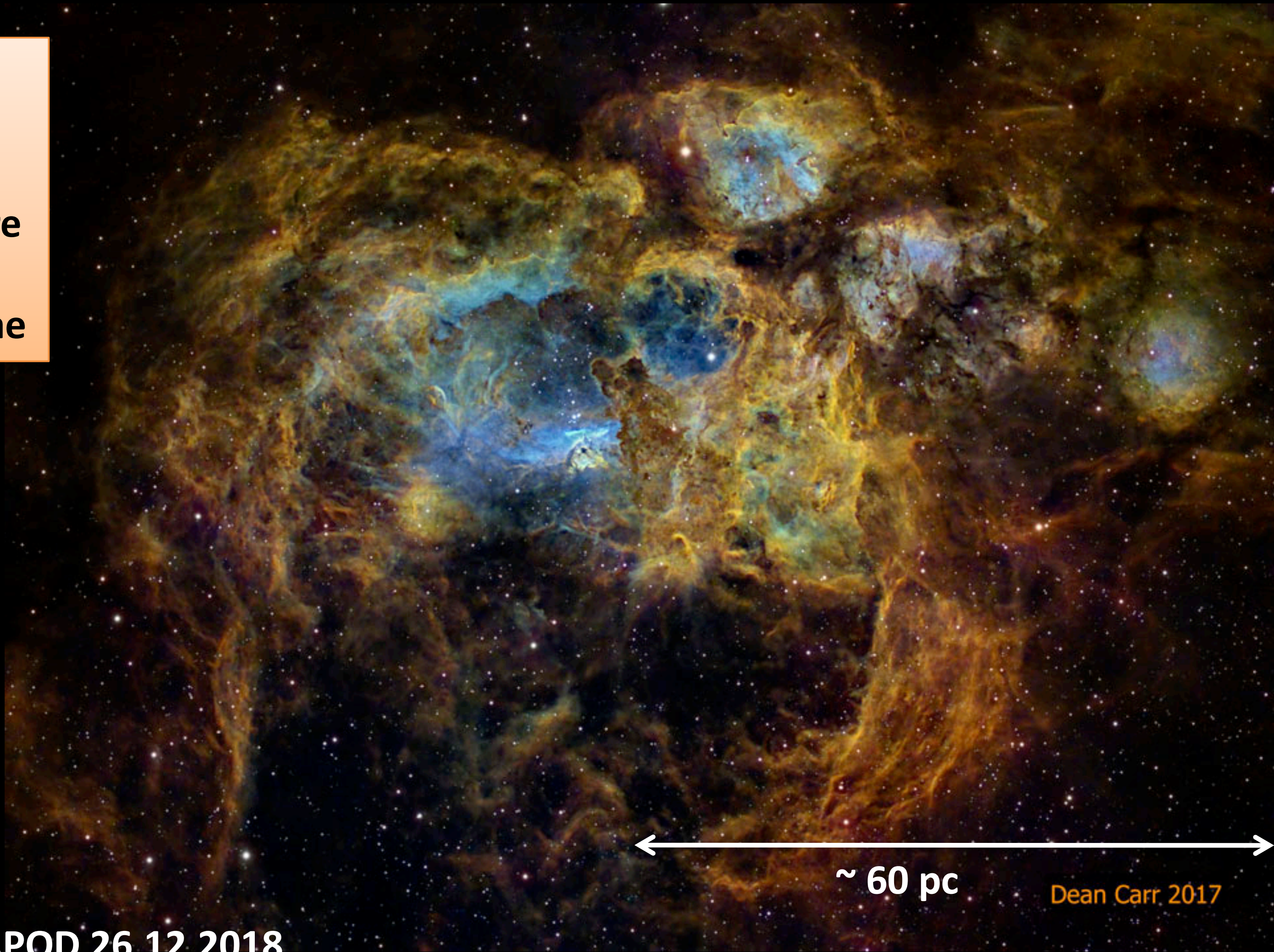


The impact of star formation:
The signatures of stellar feedback are ubiquitous in the ISM

Stellar feedback driven bubbles in the Lobster Nebula (NGC 6357)

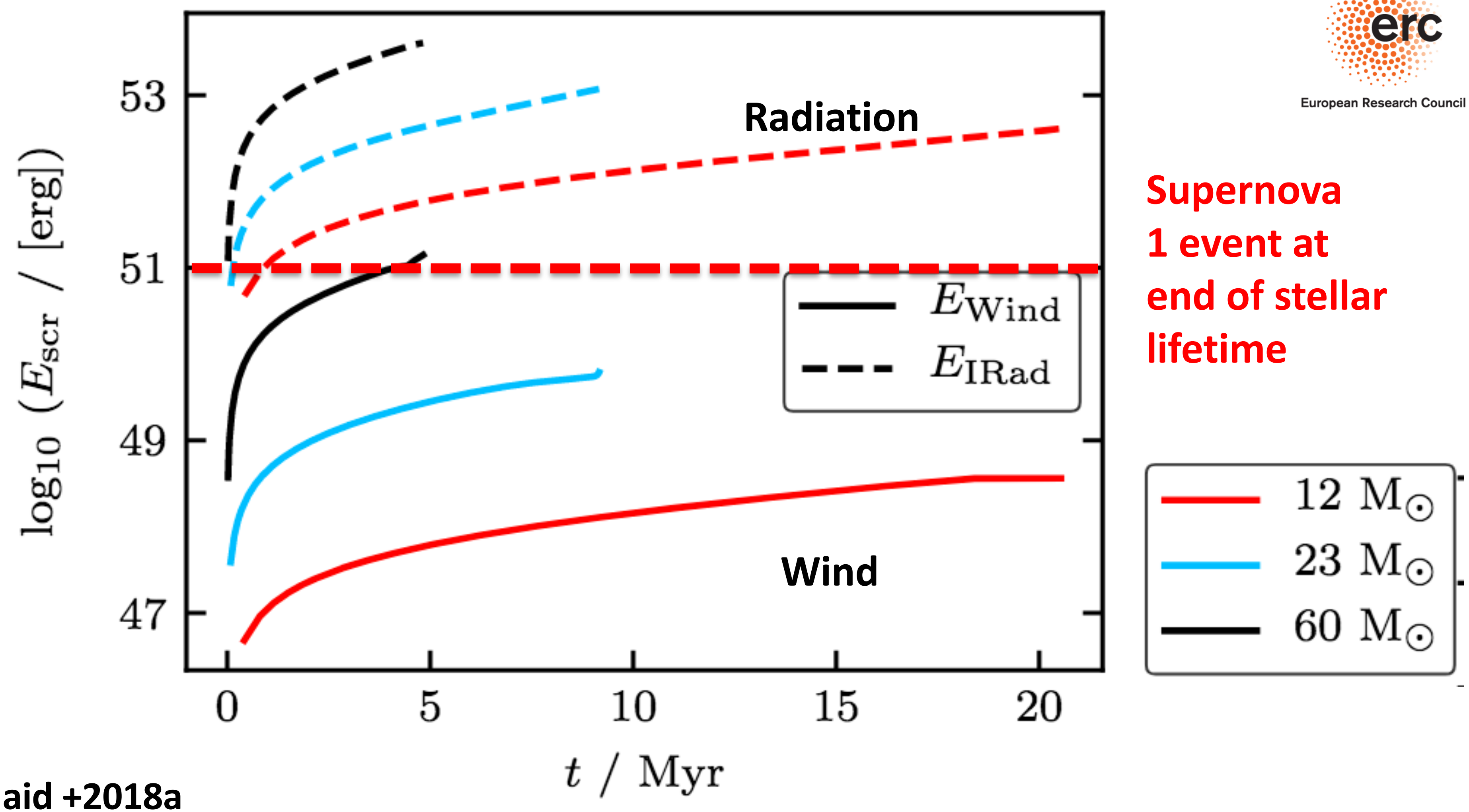
Stellar feedback:

- -UV radiation
- -Radiation pressure
- -Stellar winds
- -Type II Supernovae



Blue: ionized gas
Red: dust
Image taken from: APOD 26.12.2018

Comparing the energy input: Stellar winds, ionizing radiation & Supernovae: How is this energy coupled to the ISM?



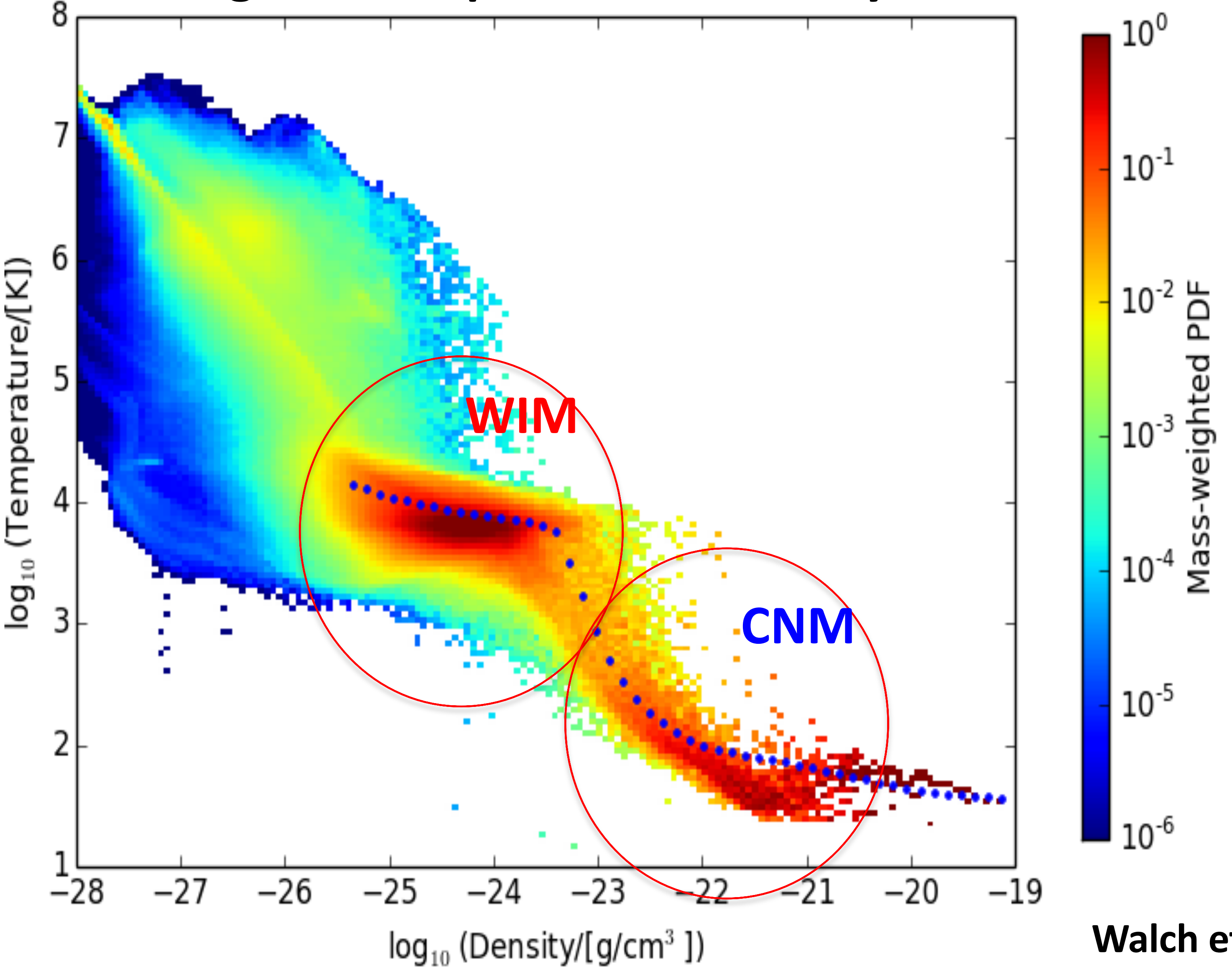
Supernova
1 event at
end of stellar
lifetime

see Haid +2018a

The SILCC project (www.astro.uni-koeln.de/silcc):

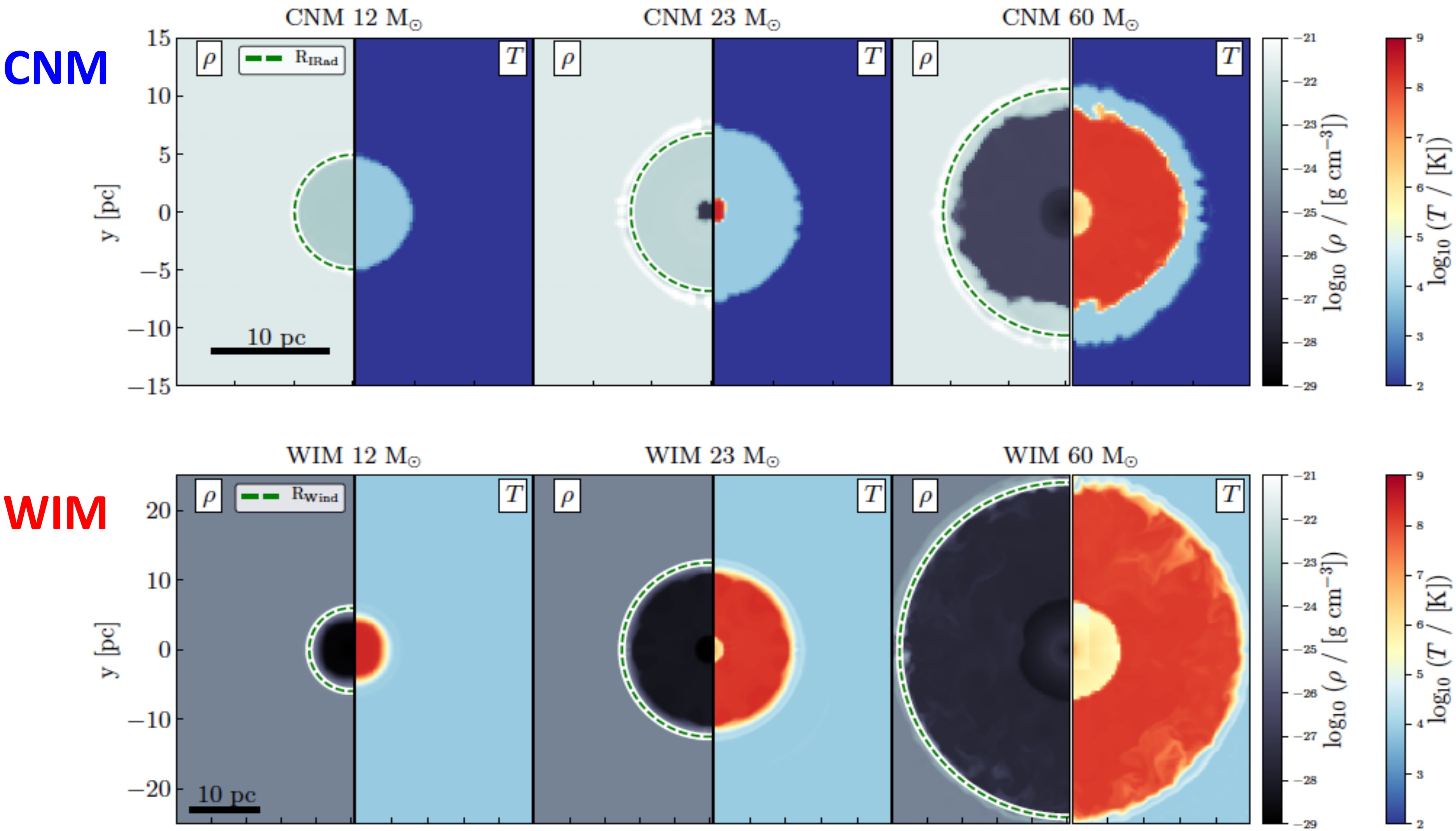
Typical mass distribution in the multi-phase ISM in a star forming galactic disk

Mass-weighted temperature – density PDF



Walch et al. (2015)

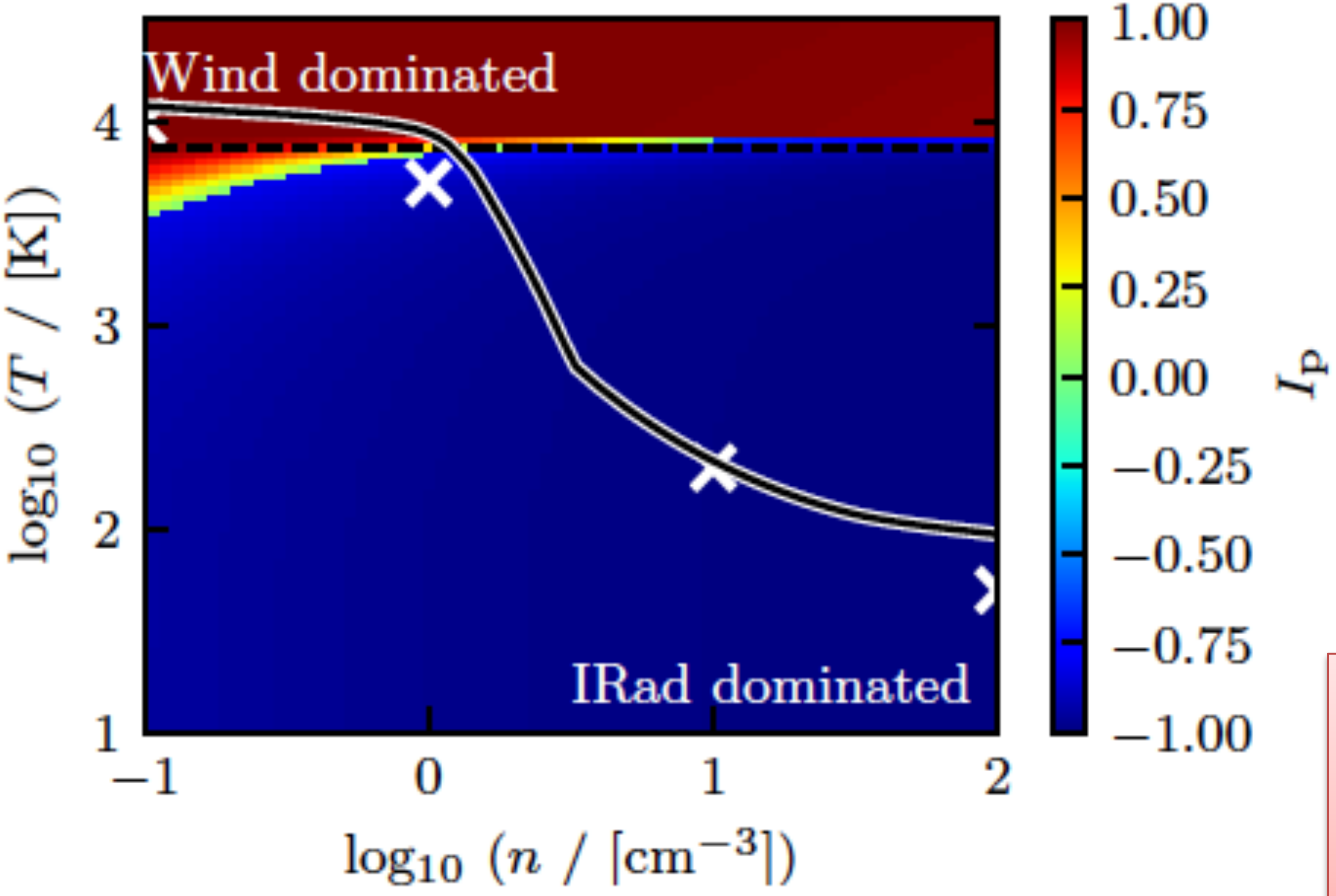
Stellar winds vs. ionizing radiation:
Simulations with FLASH + TreeRay + Chemical Network



CNM: T=20 K, n=100 cm^{-3}; WIM: T=10^{4} K, n=0.1 cm^{-3}

Haid et al. (2018a)

Momentum input:
Stellar winds vs. ionizing radiation:



Relative impact of wind and radiation

Here: for 23 $M_\odot$ star

$$I_p \equiv \frac{p_{\mathrm{Wind}} - p_{\mathrm{IRad}}}{p_{\mathrm{Wind}} + p_{\mathrm{IRad}}}$$

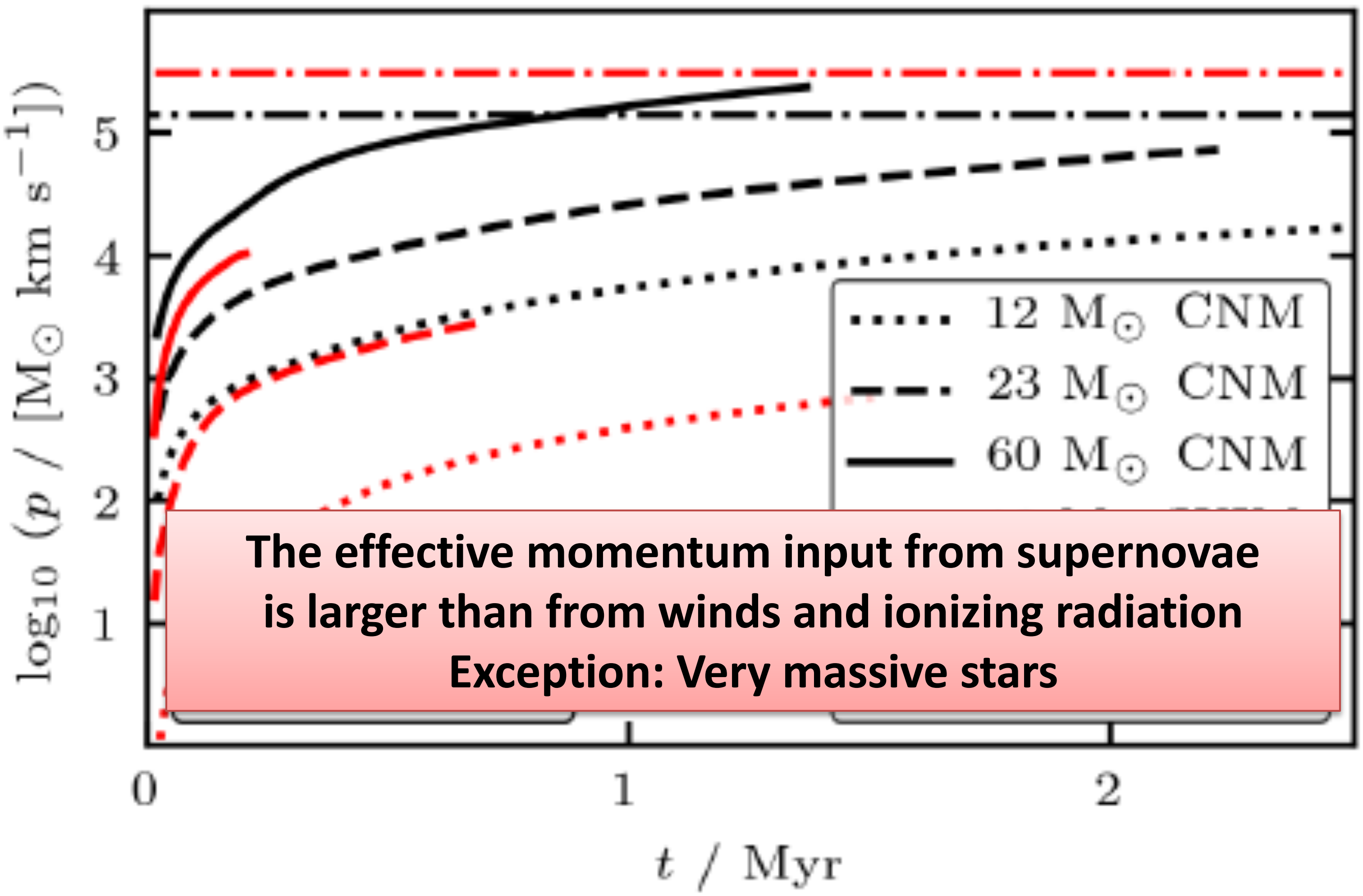
Radiation does not couple in low density/ warm ambient medium $\Rightarrow$stellar winds become dominant there!

Haid et al. (2018a)

CNM: T=20 K, n=100 cm^{-3}; WIM: T=10^4 K, n=0.1 cm^{-3}

Momentum input:
Stellar winds, ionizing radiation and Supernovae:
Coupling of radiation is inefficient!

European Research Council



Supernova
1 event at
end of stellar
lifetime in
the same gas

The effective momentum input from supernovae is larger than from winds and ionizing radiation
Exception: Very massive stars

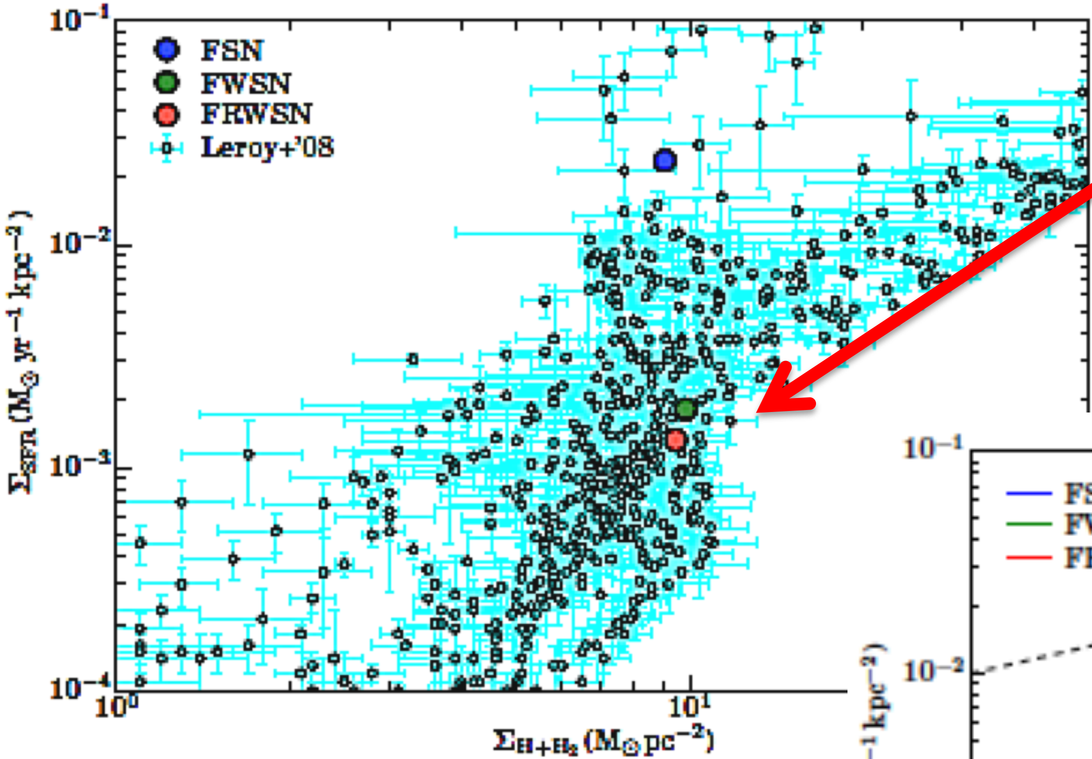
Stellar winds are more important than radiation in a warm environment (WIM)

CNM: T=20 K, n=100 cm^{-3}; WIM: T=10^4 K, n=0.1 cm^{-3}

Haid et al. (2018a)

The role of photo-ionization and stellar winds on few 100 parsec scales

Kennicutt-Schmidt relation

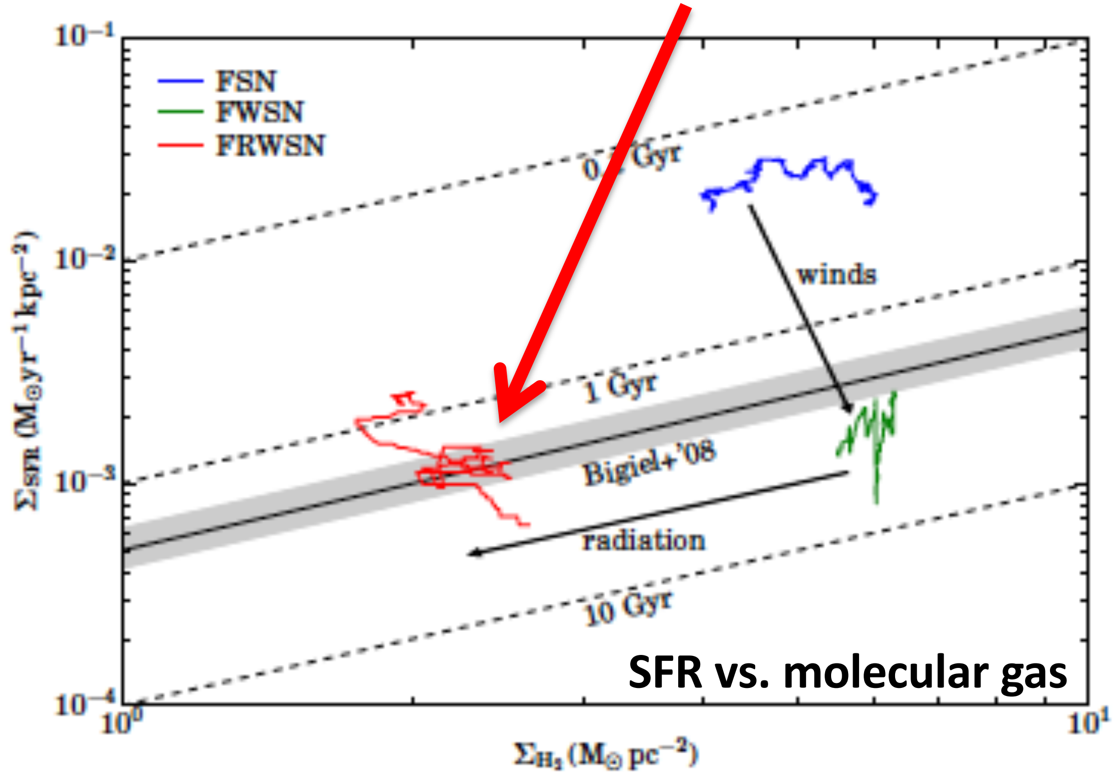


SILCC scales: few 100 pc

Wind+Supernova already regulate star formation: Σ_{SFR} on KS relation

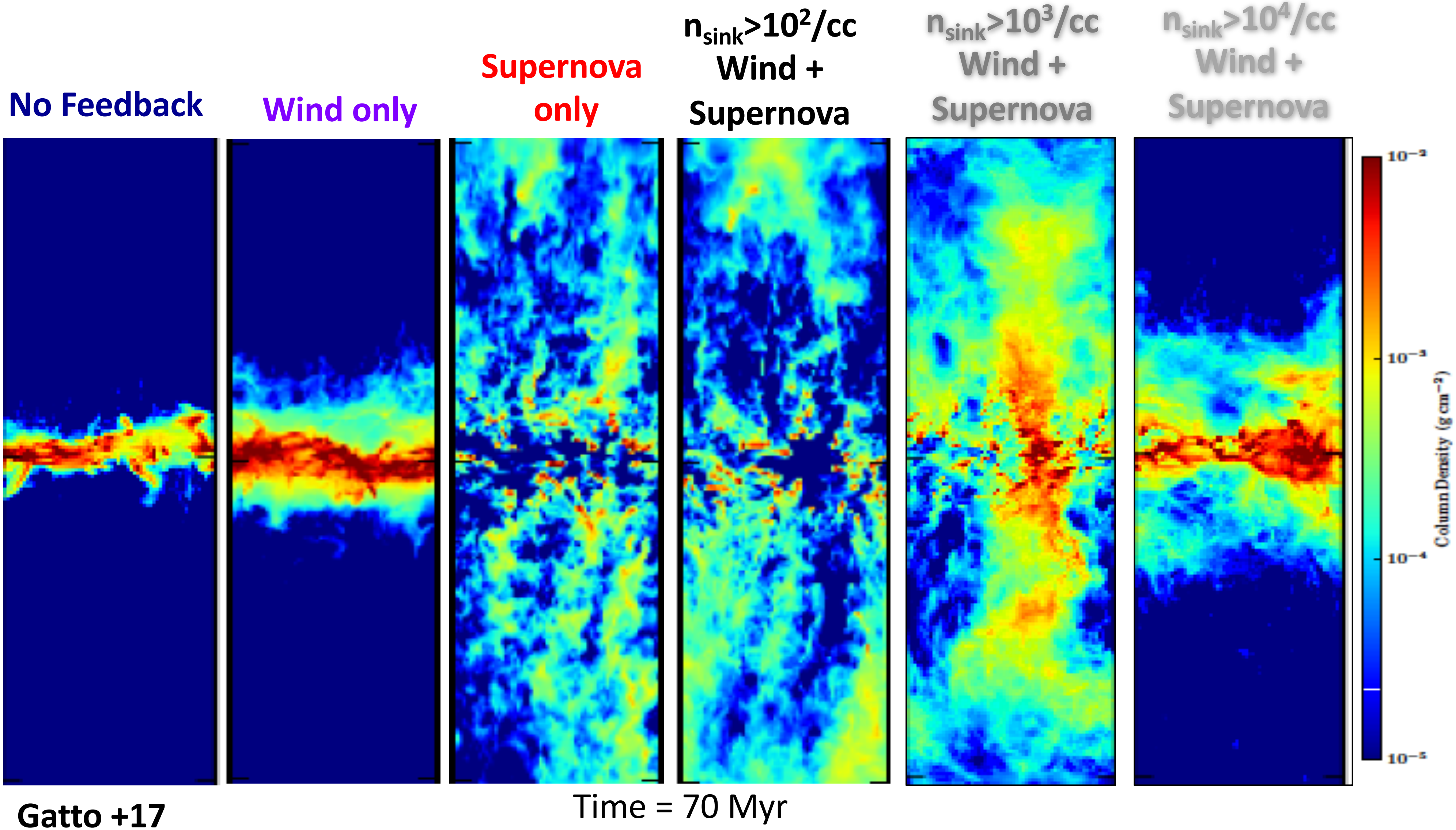
⇒Role of radiation?

⇒Shift to lower Σ_{H2} at similar Σ_{SFR}



Peters+SILCC, MNRAS, 2017

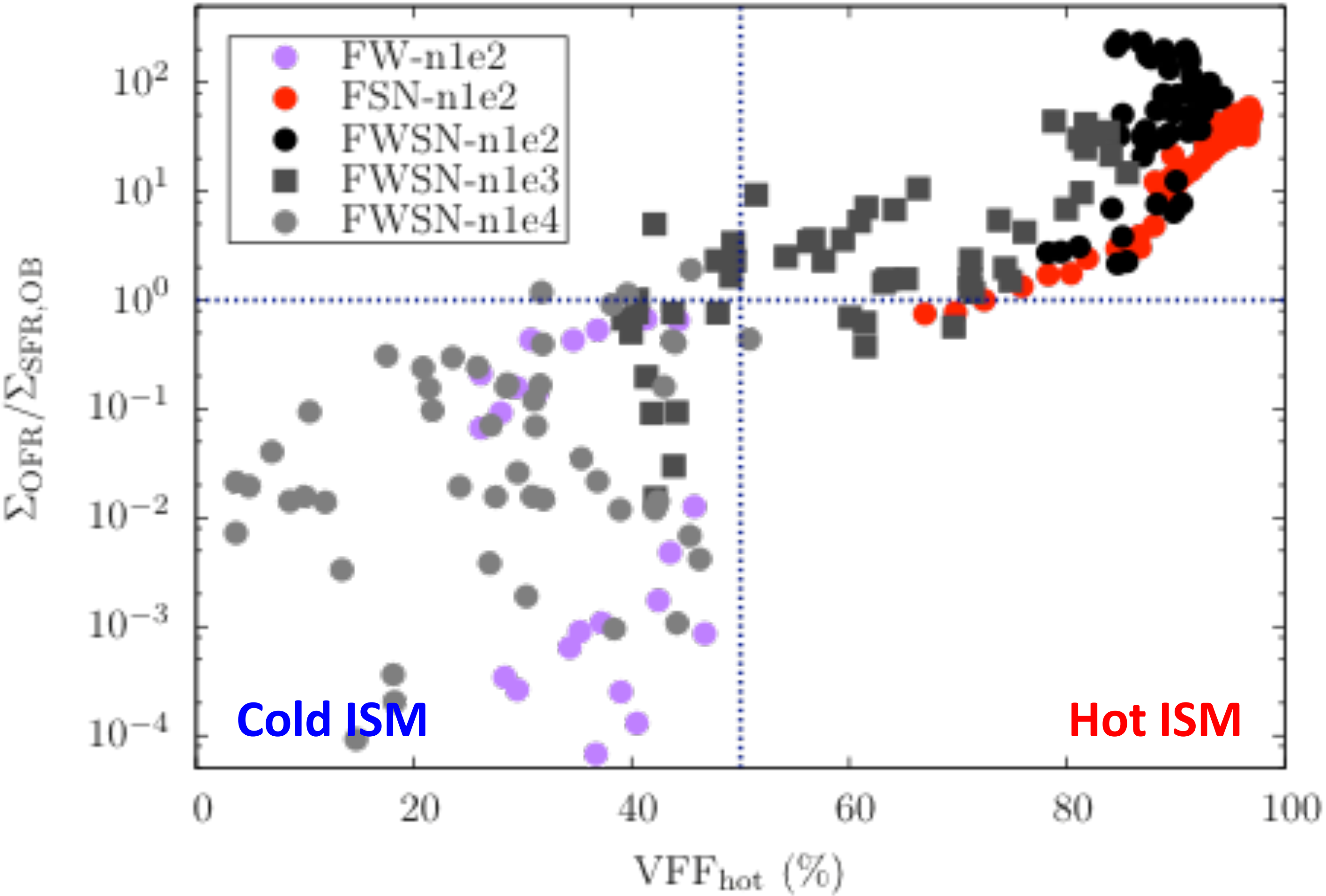
Outflows are only launched if there is a hot, volume-filling phase: Supernova driving



Gatto +17

Mass loading vs. hot gas volume filling fraction

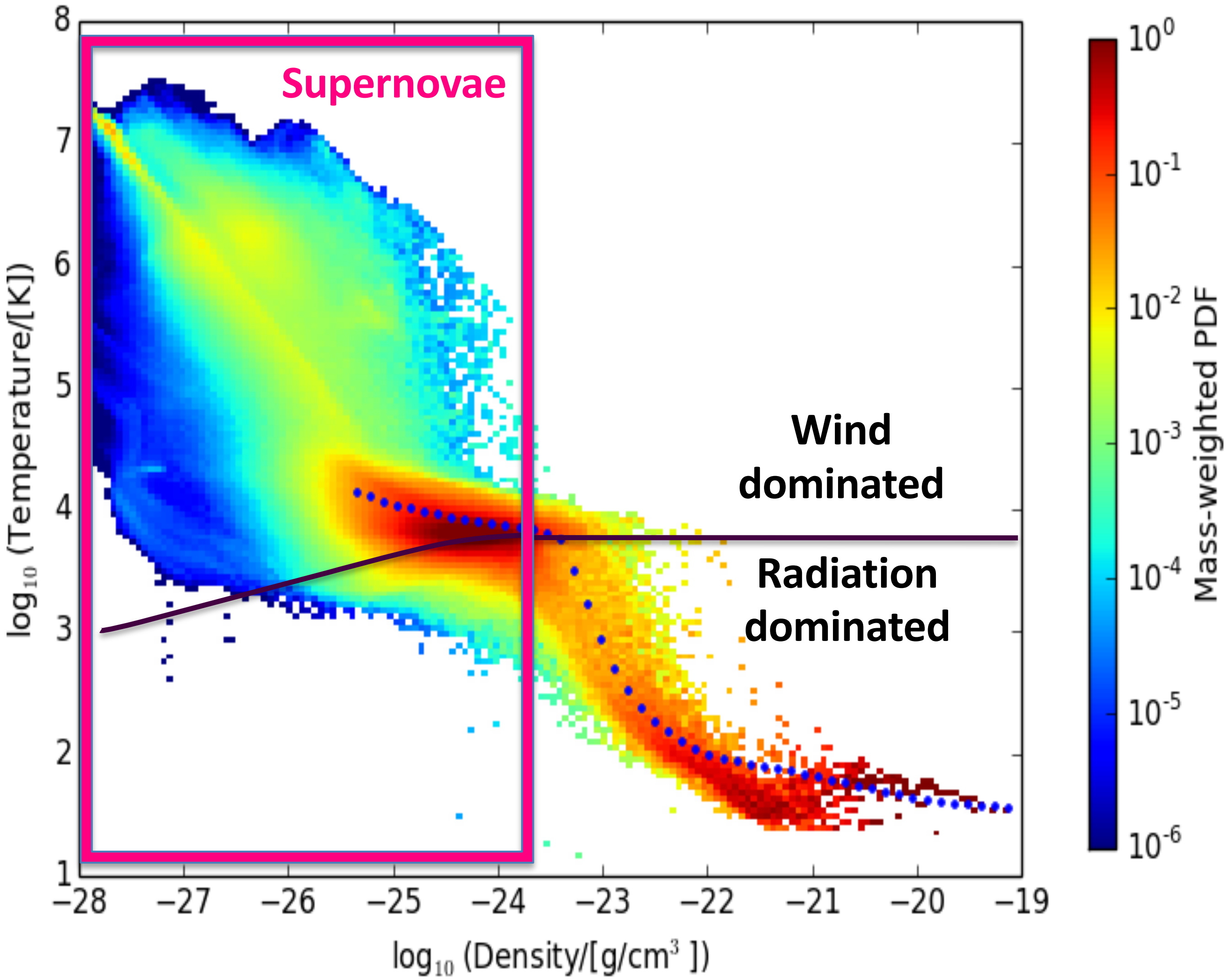
Gatto +17



Massloading at z=± 1 kpc is strongly correlated with the hot gas volume filling factor in the galactic midplane => fountain/outflow regulated by thermal feedback

See also:
Fielding +2018, Li, Bryan & Ostriker (2017), Creasey +2013, Tomisaka & Ikeuchi (1986)

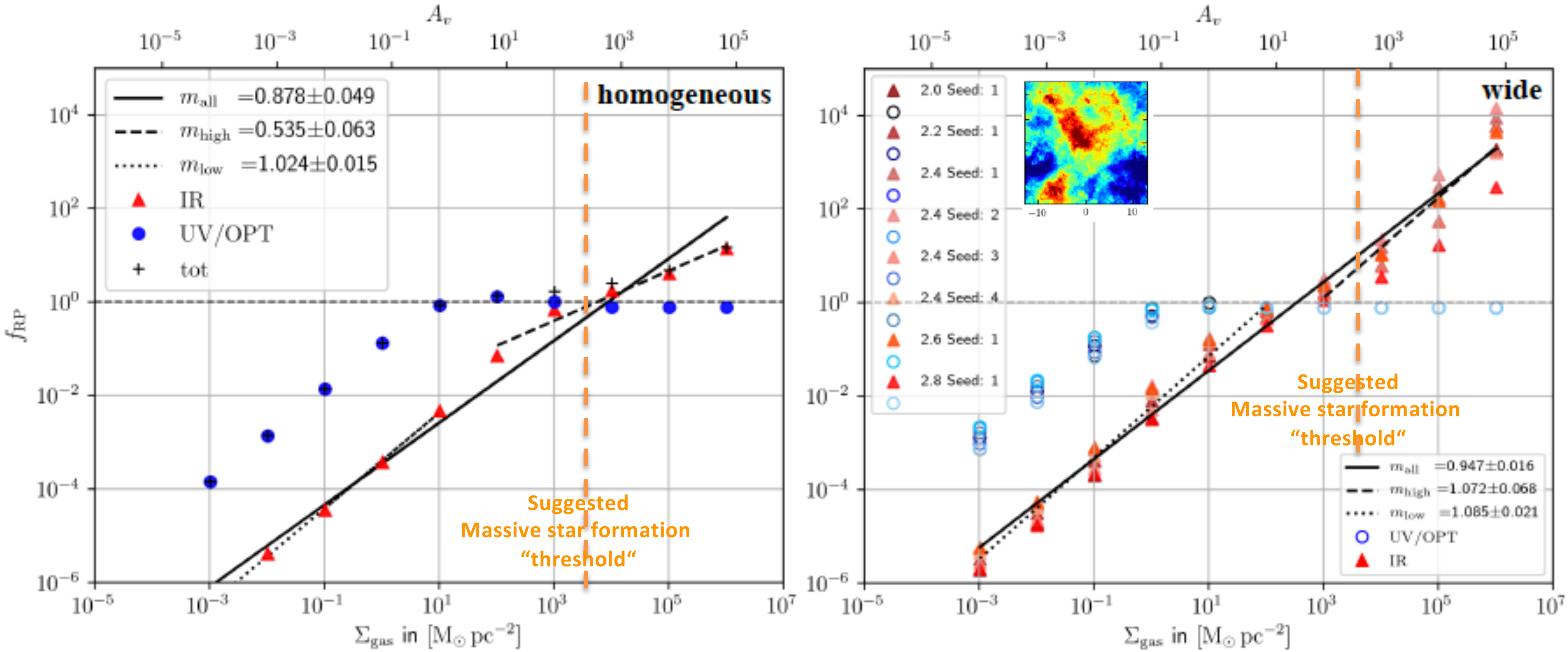
Not yet final… Conclusions:
Impact of stellar feedback in different ISM phases



Radiation Pressure on dust:
Active in dense clouds / early during the stellar feedback process

Walch et al., in prep.

Boost factor: f_{RP} = dp/dt $(L/c)^{-1}$ calculated using RADMC-3D



Prediction: Diffusion limit assuming a constant grey opacity and a uniform cloud: $f_{RP} \sim \boldsymbol{\Sigma}_{gas}$

However, in the uniform cloud case we find: $f_{RP} \sim (\boldsymbol{\Sigma}_{gas})^{0.5}$

$\Rightarrow$ wavelength of photon progressively becomes longer due to absorption / re-emission events

$\Rightarrow$ Fewer interactions than expected

In broad fractal case: Gas is locally heated up => Planck-mean opacity is increased => $f_{RP} \sim \boldsymbol{\Sigma}_{gas}$

Conclusions:
Impact of stellar feedback in different ISM phases