How to prevent star formation in dwarf galaxies

John Forbes (University of CA, Santa Cruz)
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IGM50

with Mark Krumholz, Nathan Goldbaum, Avishai Dekel

Outline

- Dwarf galaxies are inefficient at forming stars
- The most popular way to explain this is with strong feedback from SNe.
- We are running simulations with well-resolved SNe feedback to verify or reject this scenario.
- So far we find that grain photoelectric heating has a stronger effect.

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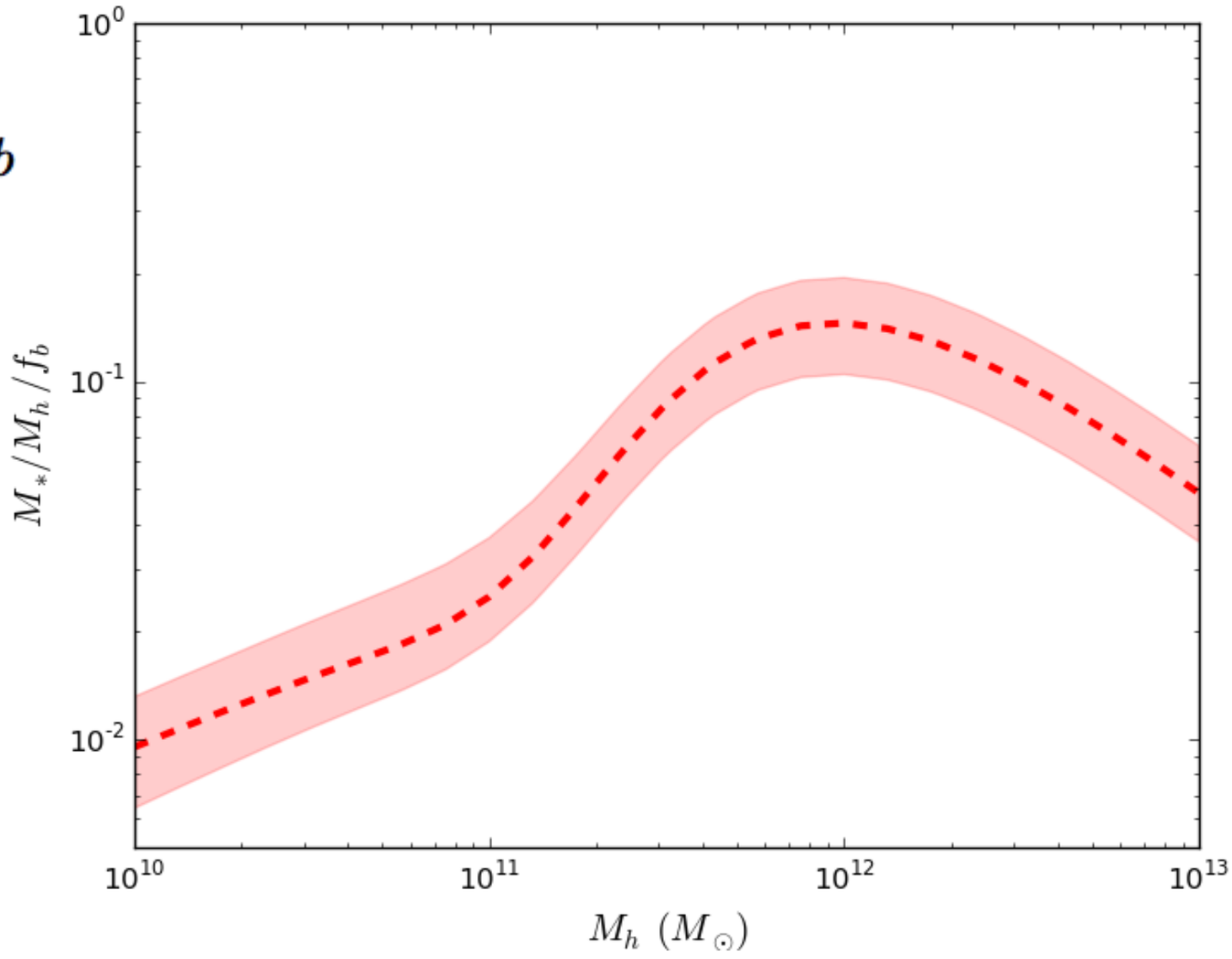
What is a galaxy?

Outflows

Gas → → **Stars**

Dwarf galaxies are bad at their jobs

$M_*/M_h/f_b$



Three possibilities

Outflows

Gas → → **Stars**

Three possibilities

Outflows

Gas

Stars

Three possibilities

Outflows

Gas

Stars

Three possible explanations

- **Ejective** Feedback:
    - SNe: e.g. Dekel 1986, Stinson+ (2006), Governato+ (2010), Creasey+ (2013,2014)
    - Radiative: e.g. Murray+ (2005), FIRE
    - CRs: e.g. Socrates+ (2008), Jubelgas+ (2008) Salem+ (2013)
    - Prescriptive: Dave+ (2008,…), Illustris, SAMs
- **Preventative** Feedback:
    - e.g. Lu et al (2013,…)
- **“Parking Lot”** Feedback
    - e.g. Krumholz & Dekel (2013)

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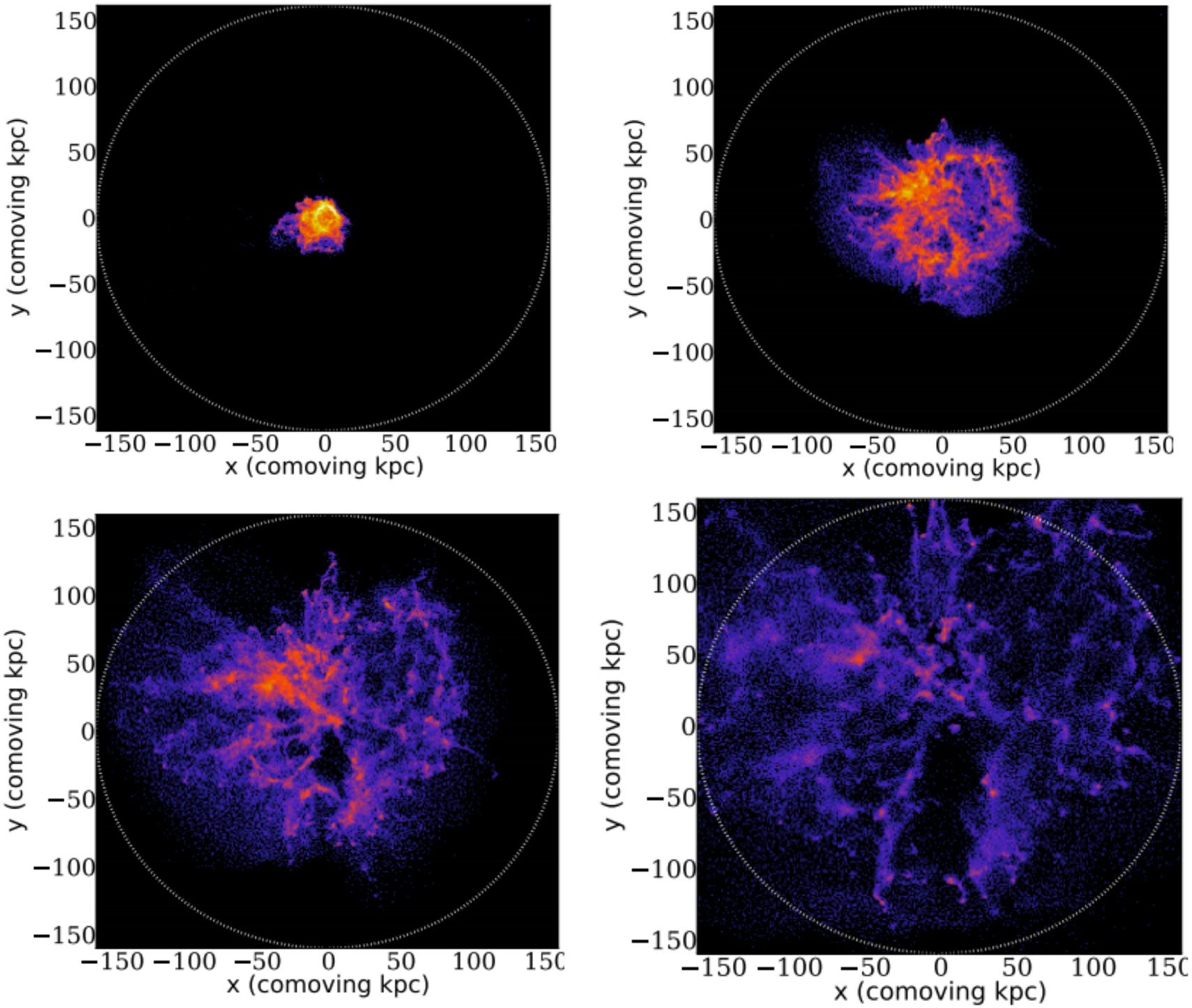
Option 1: Remove the gas



FIRE
Muratov+ (2015)

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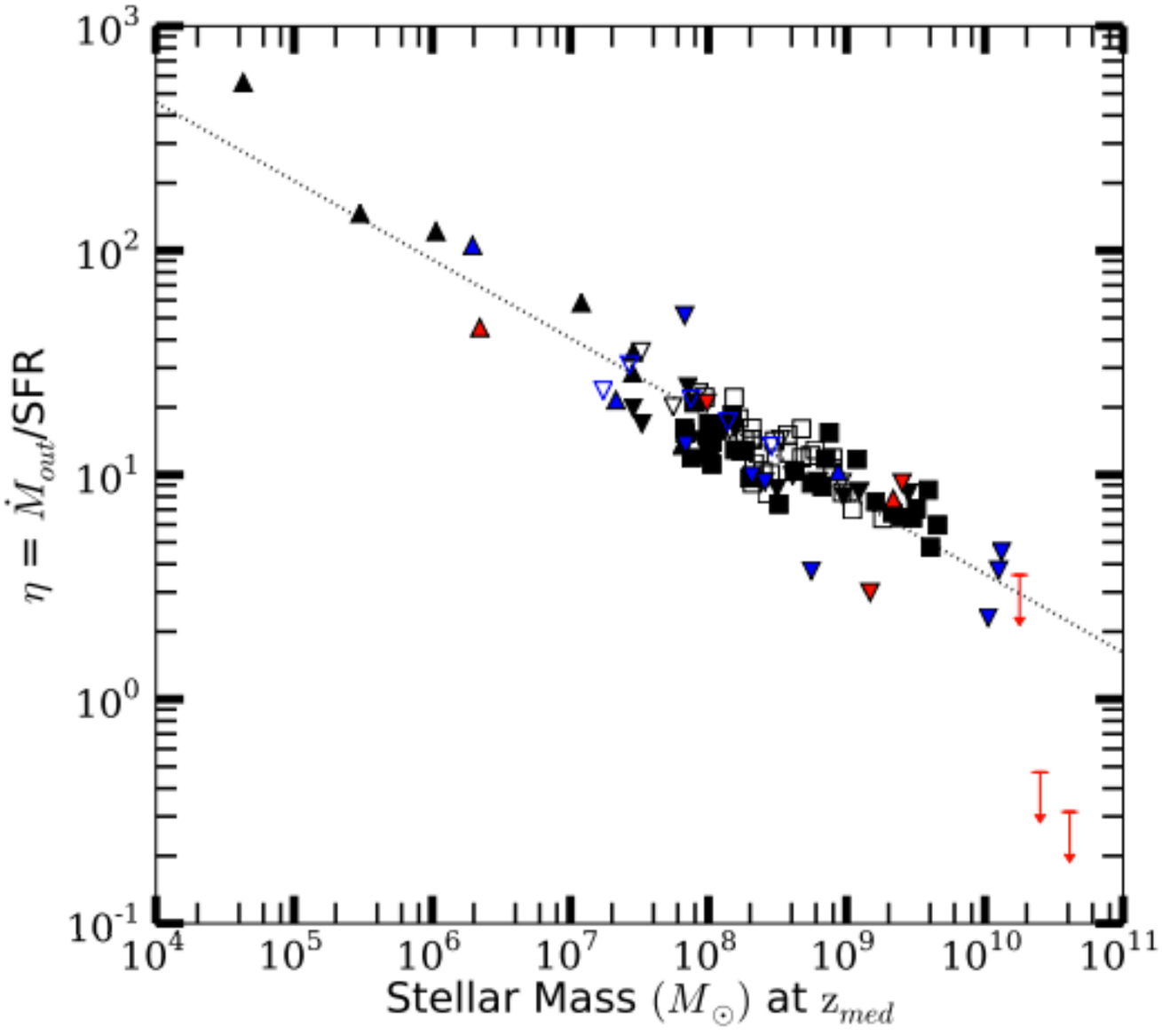
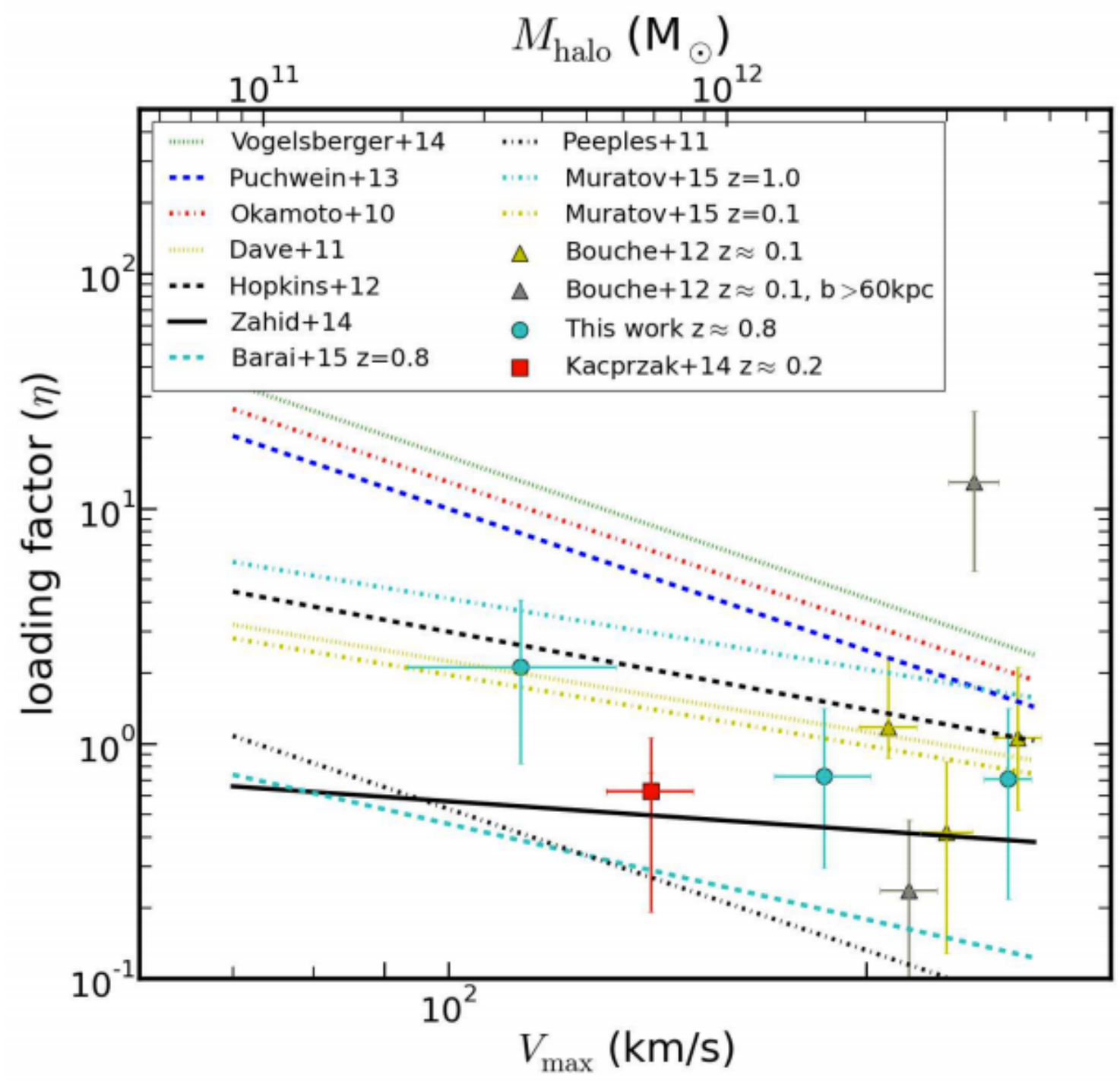


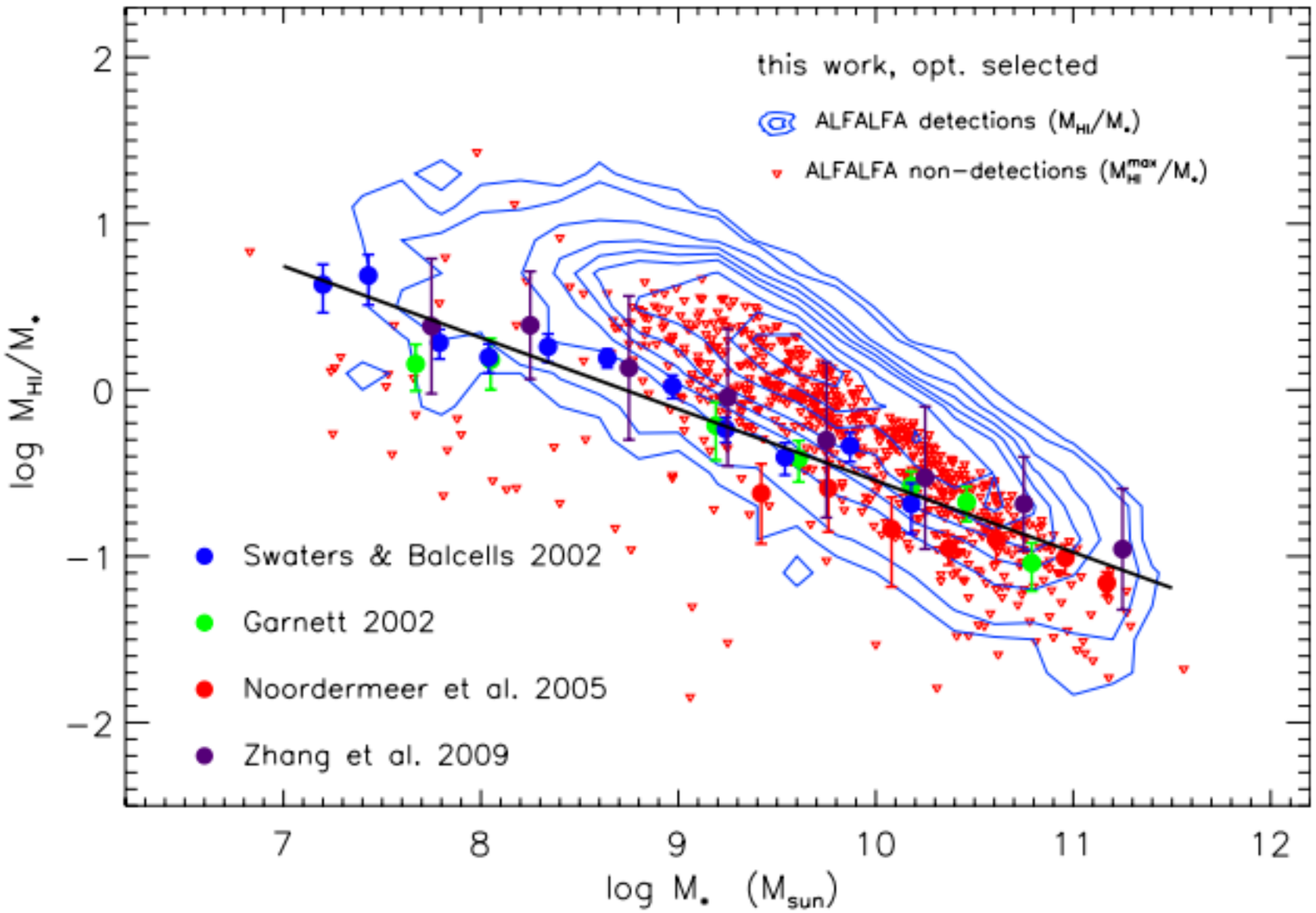
FIRE
Muratov+ (2015)

Is this feasible?



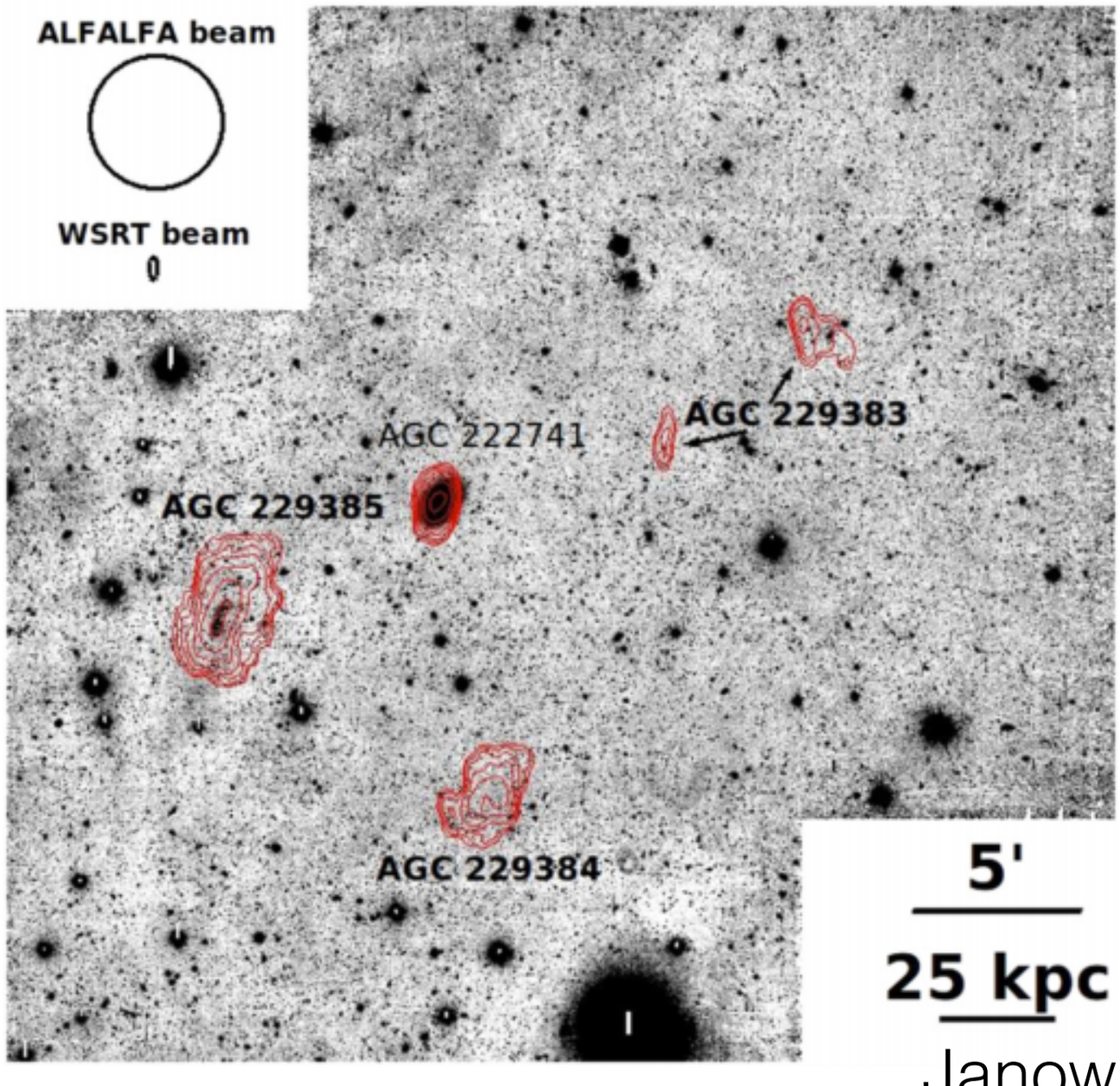
Schroetter+ (2015)

Dwarf galaxies have plenty of gas



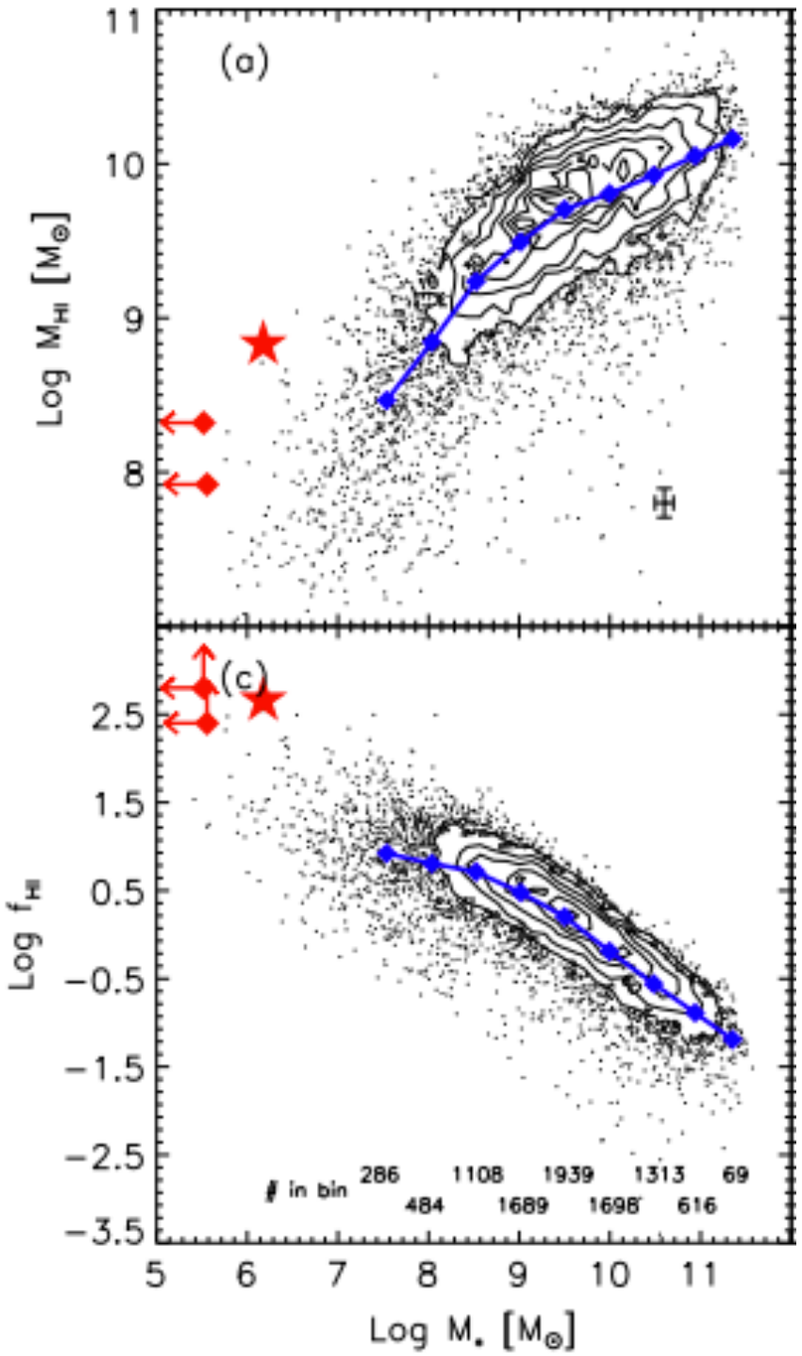
Papastergis+ 2012

Extreme case



Janowiecki+ (2015)

Extreme case



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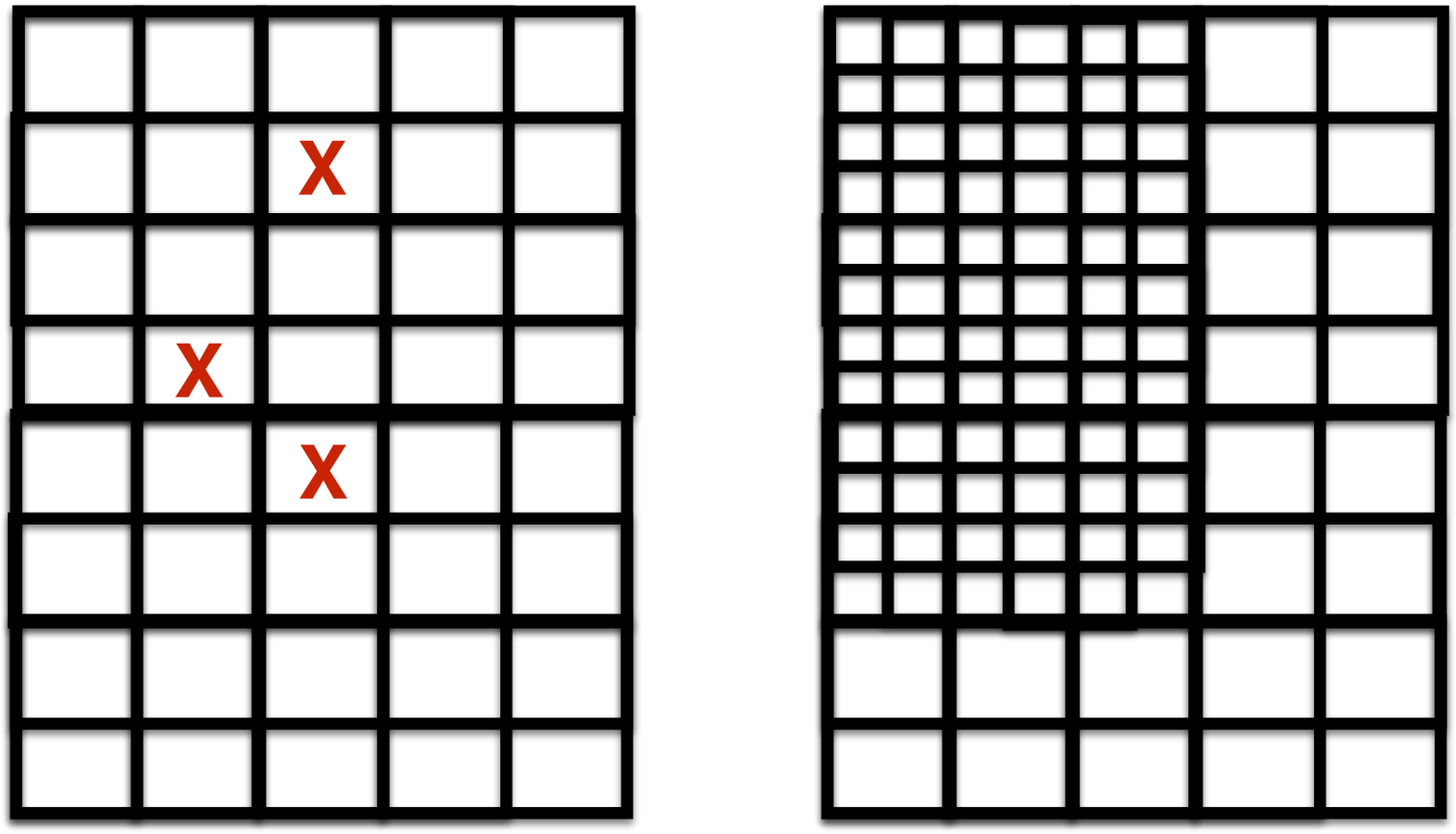
The Simulations

- **Big question:** Is a mass loading factor of 30 feasible?
- **Testing ground**: dwarf galaxies
  - Large predicted mass loading factors
  - Small sizes -> computational affordability

The Simulations

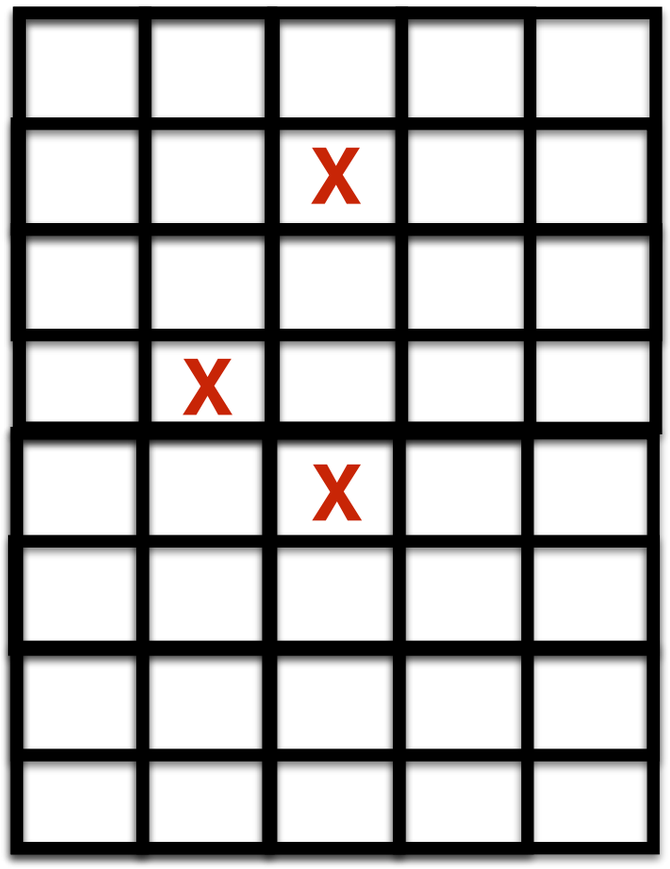
- AMR hydrodynamics and gravity with Enzo
- Detailed SNe Feedback + Stellar winds, HII regions
- Grackle cooling to below 100 K, UVB, Photoelectric heating
- Non-cosmological
- Maximum resolution between 2.5 pc and 20 pc
- Halo Mass ~ 10^{10} $\mathrm{M}_{\odot}$

Jeans instability and star formation

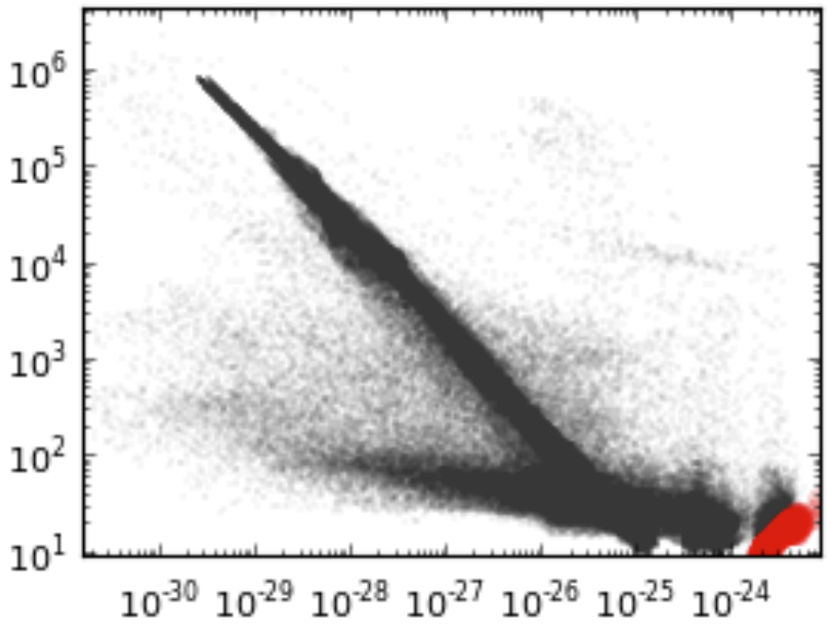


$$\Delta x < \left(\frac{\pi \gamma k_B T}{N_J^2 G \rho \mu m_p} \right)^{1/2}$$

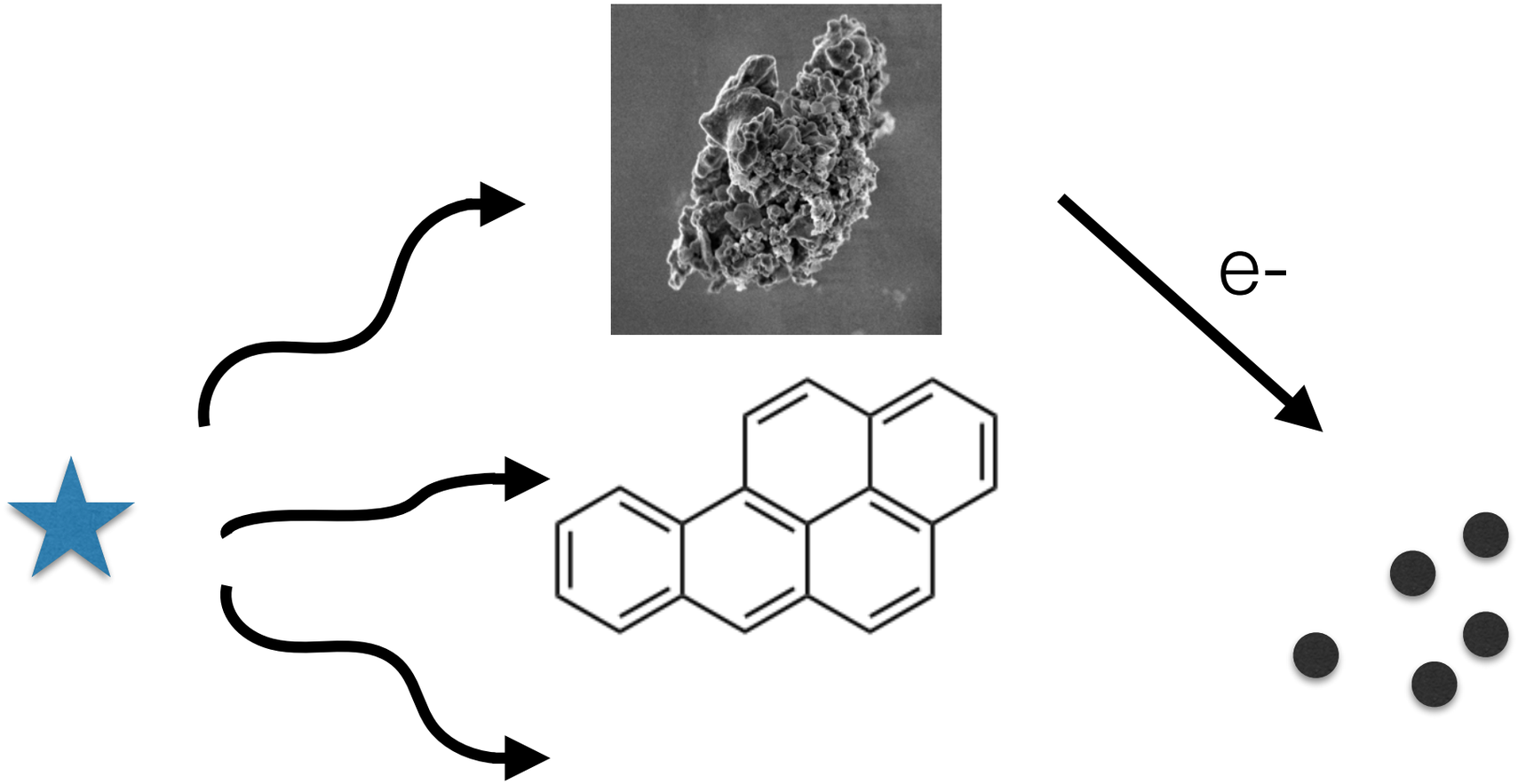
Jeans instability and star formation



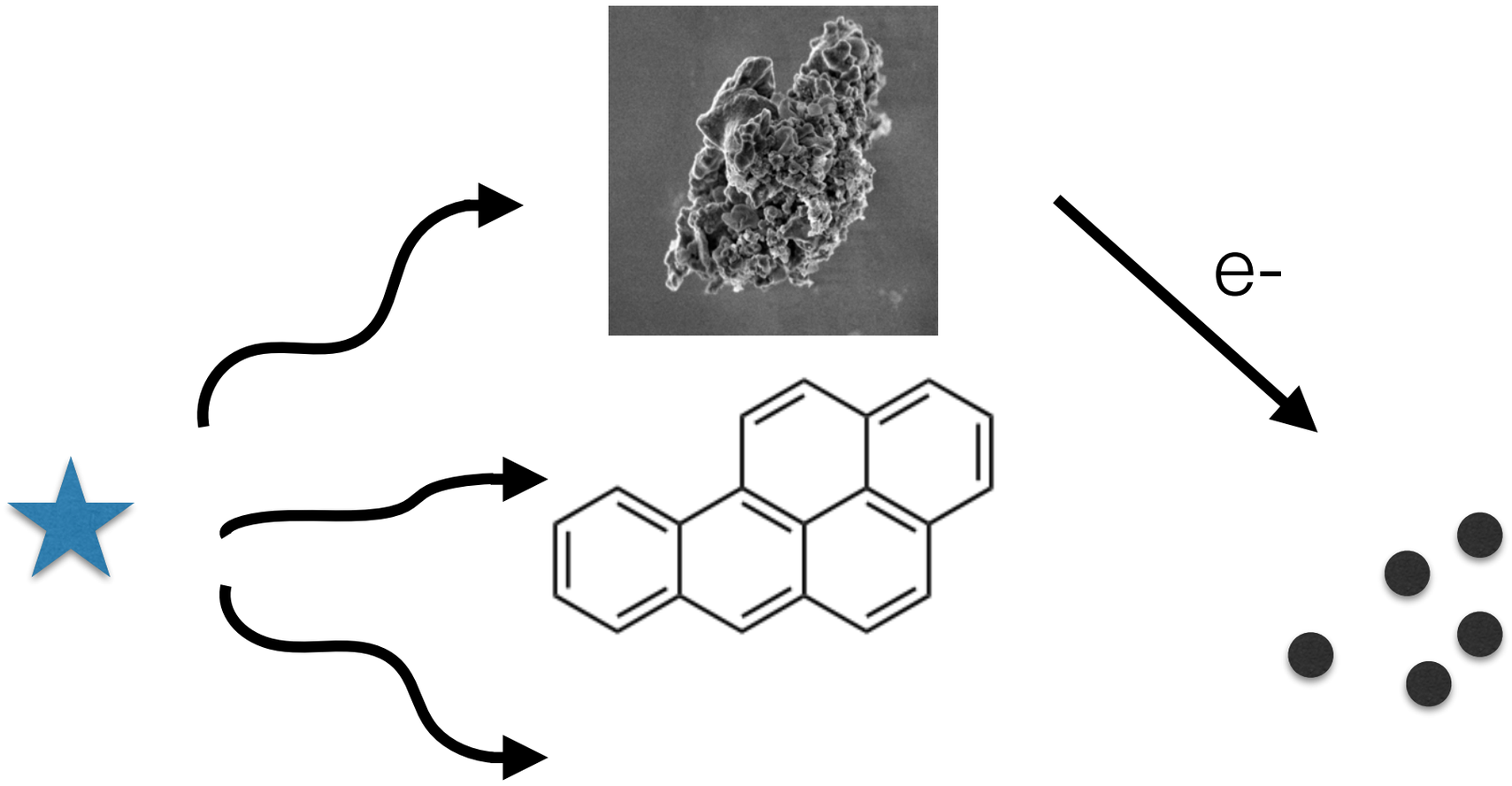
$$E(\mathrm{SFR}) = \epsilon_{\mathrm{ff}} \frac{\rho}{t_{\mathrm{ff}}}$$



Photoelectric Heating

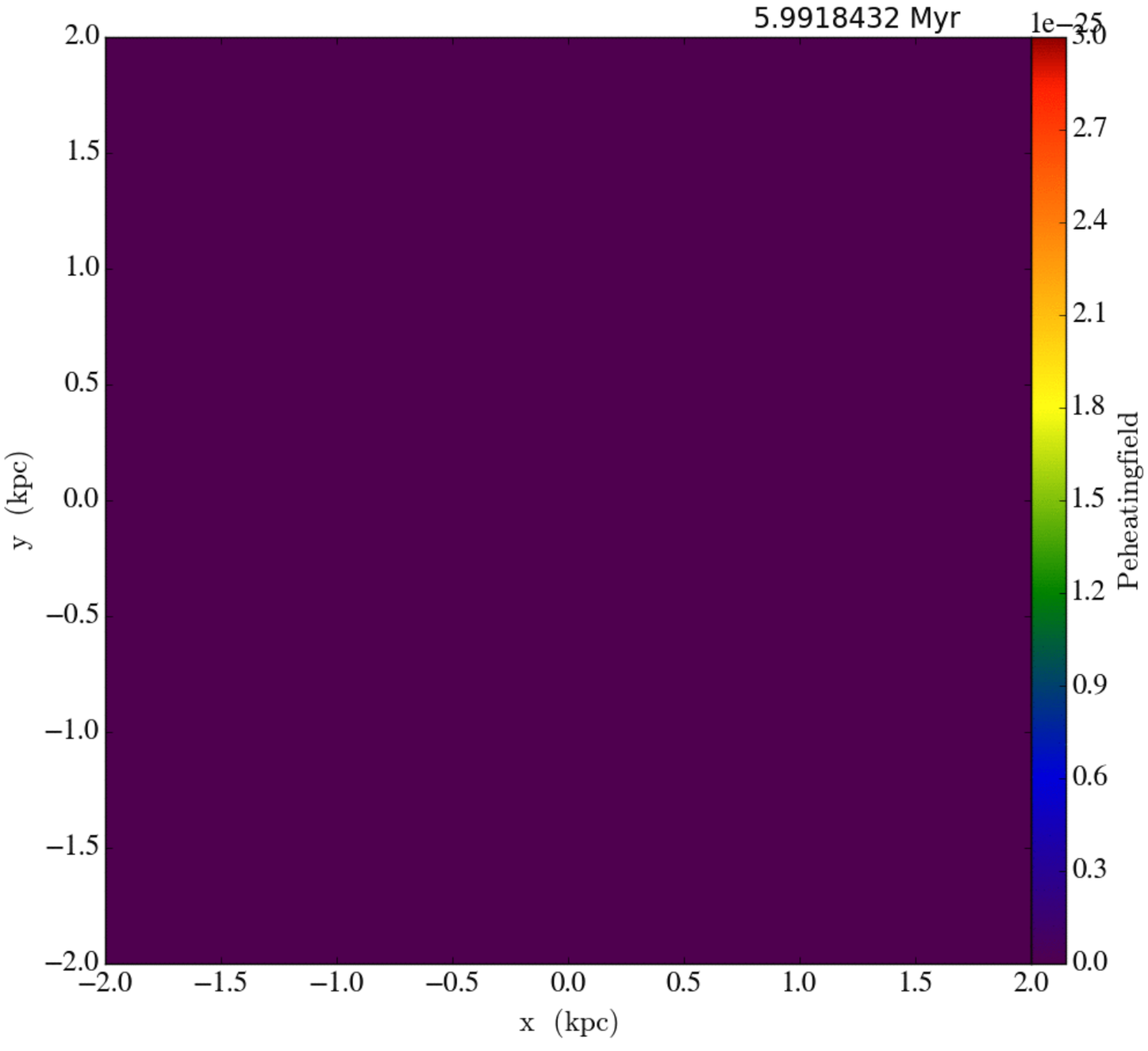


Photoelectric Heating



$$\mathcal{G} \propto F_{\mathrm{FUV}} Z n$$

Photoelectric Heating



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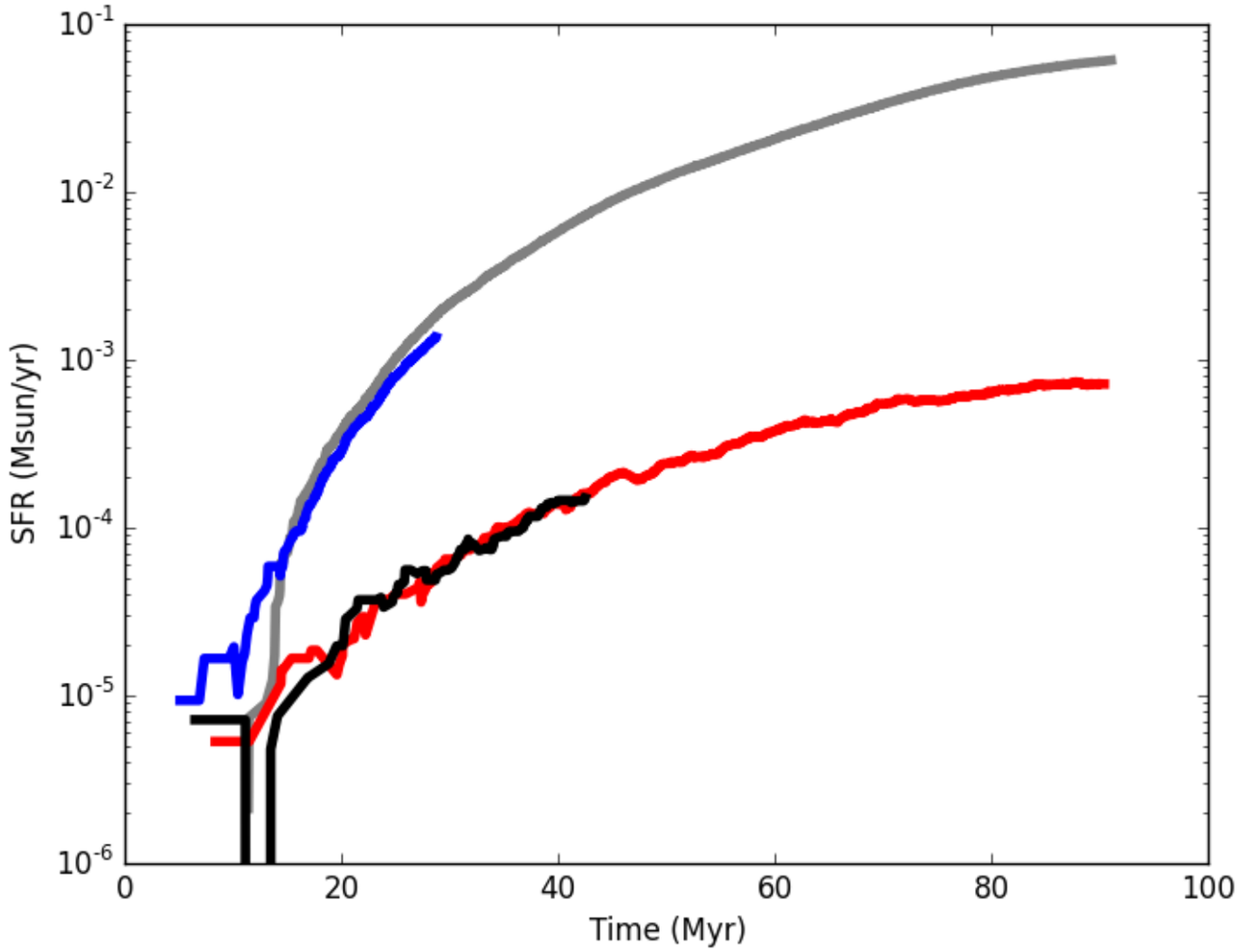
Photoelectric heating alone suppresses SFR by 10



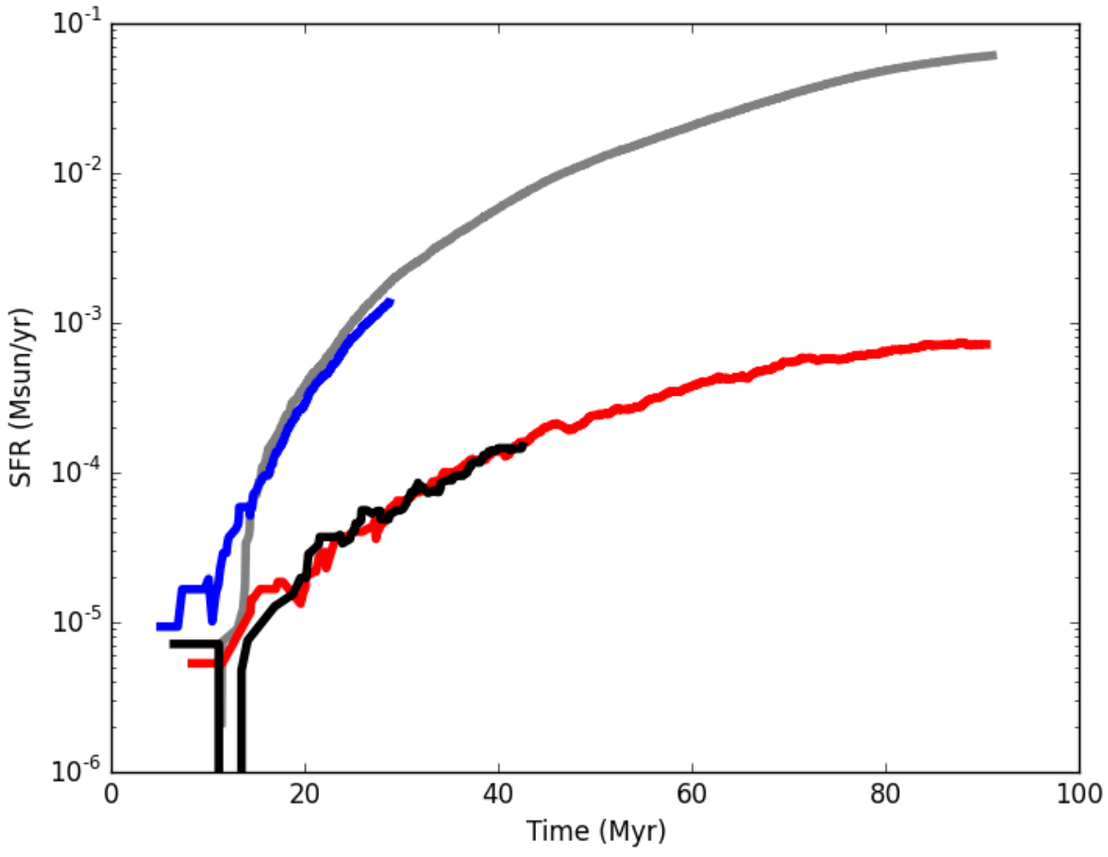
No feedback

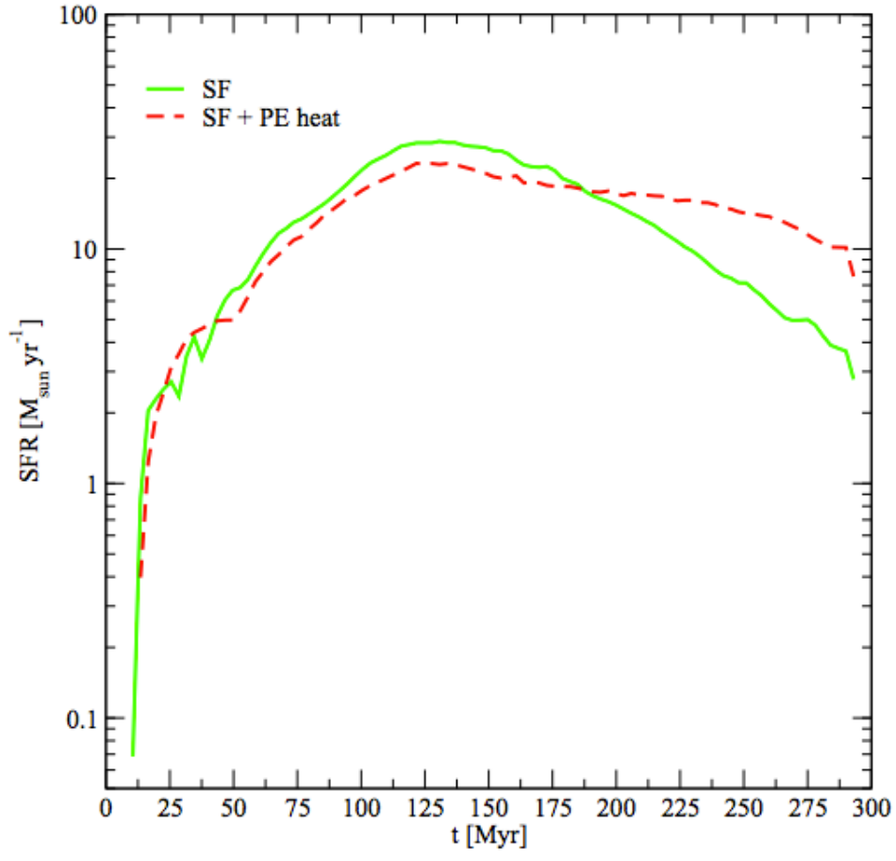
SNe, no PE

PE, no SNe

PE + SNe

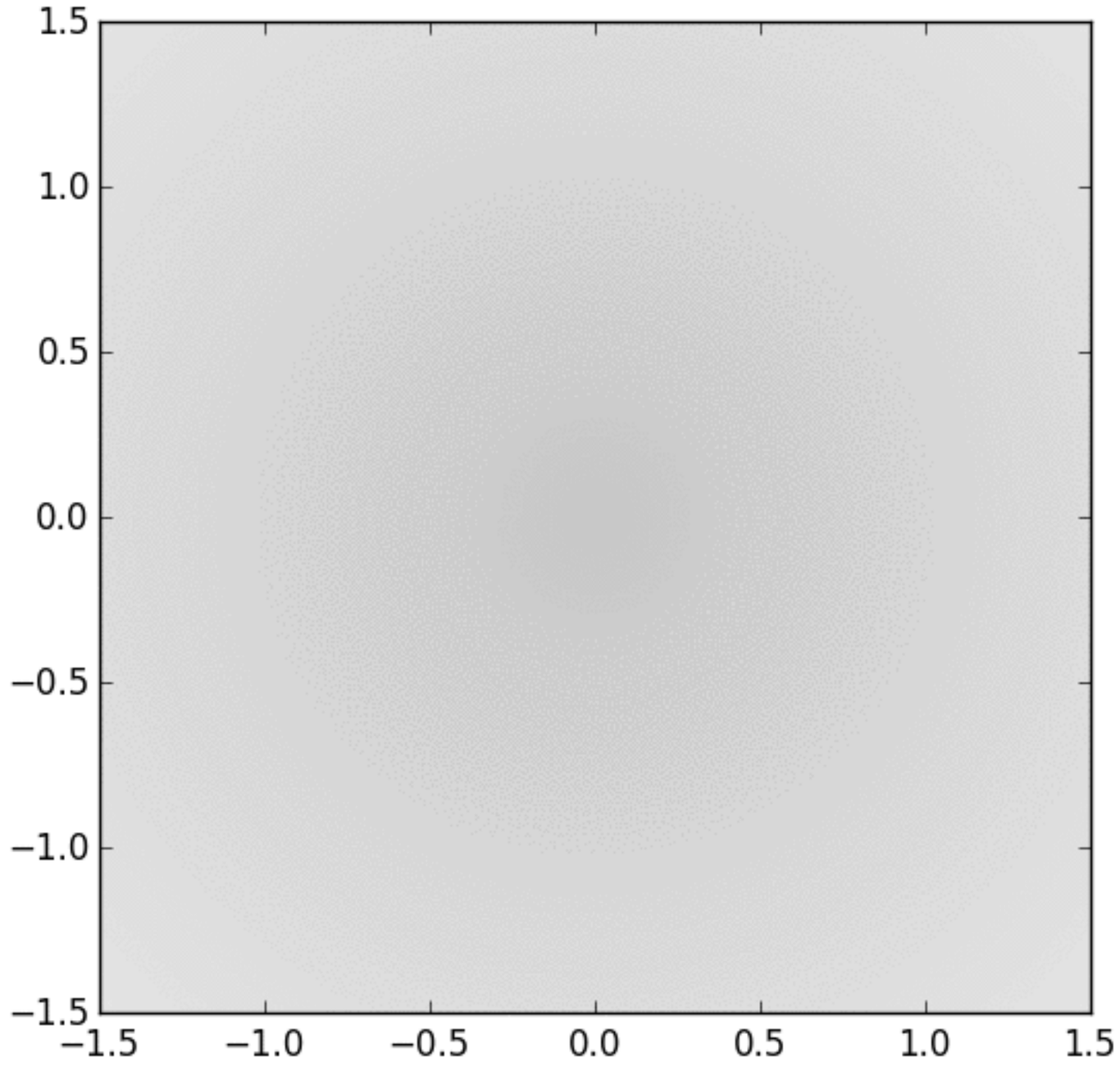
Photoelectric heating alone suppresses SFR by 10





Tasker+ (2011)

No Photoelectric Heating

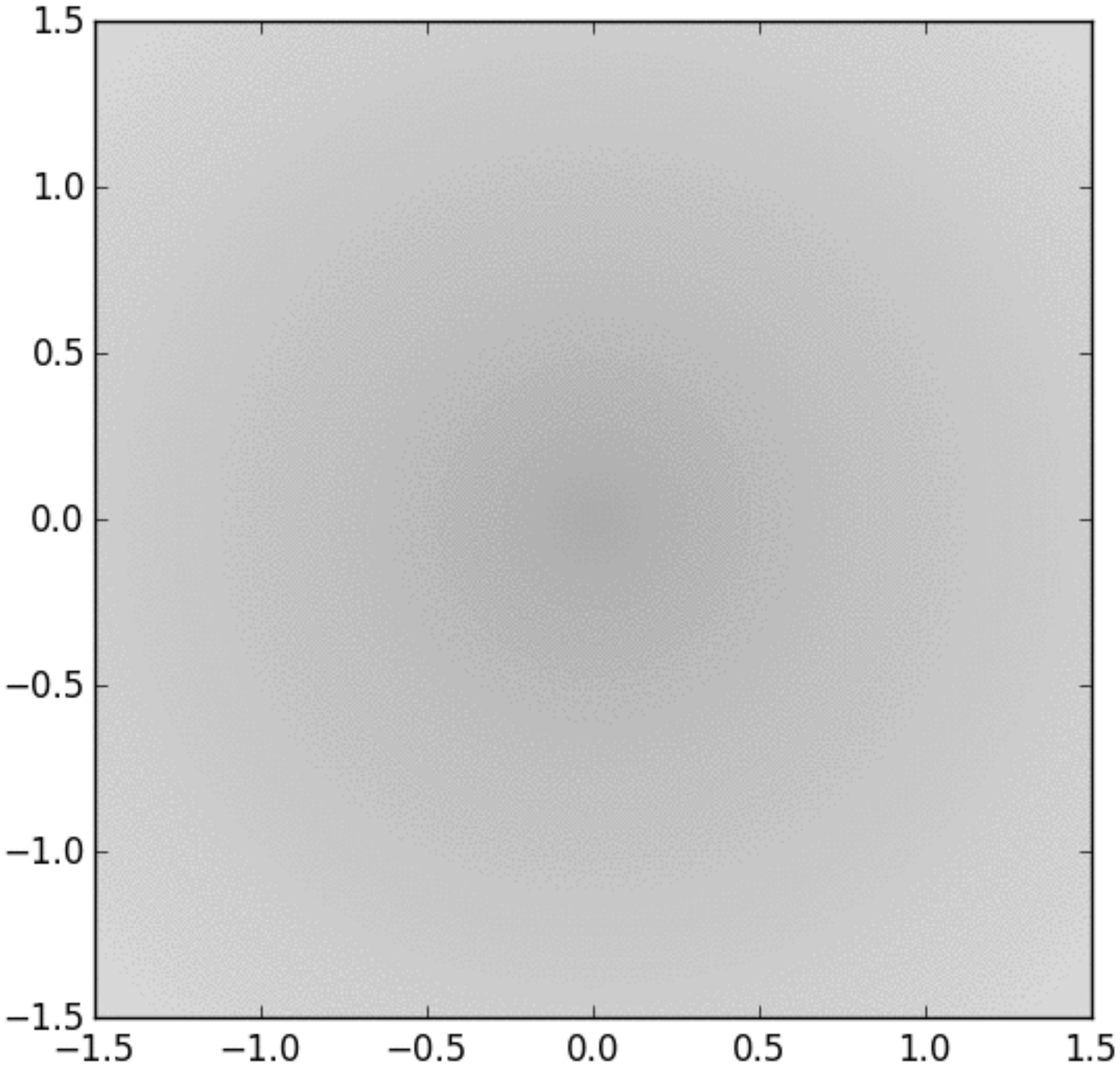


Gas Surface Density

Jeans Unstable Gas

Newly formed stars

Photoelectric Heating + SNe



Gas Surface Density

Jeans Unstable Gas

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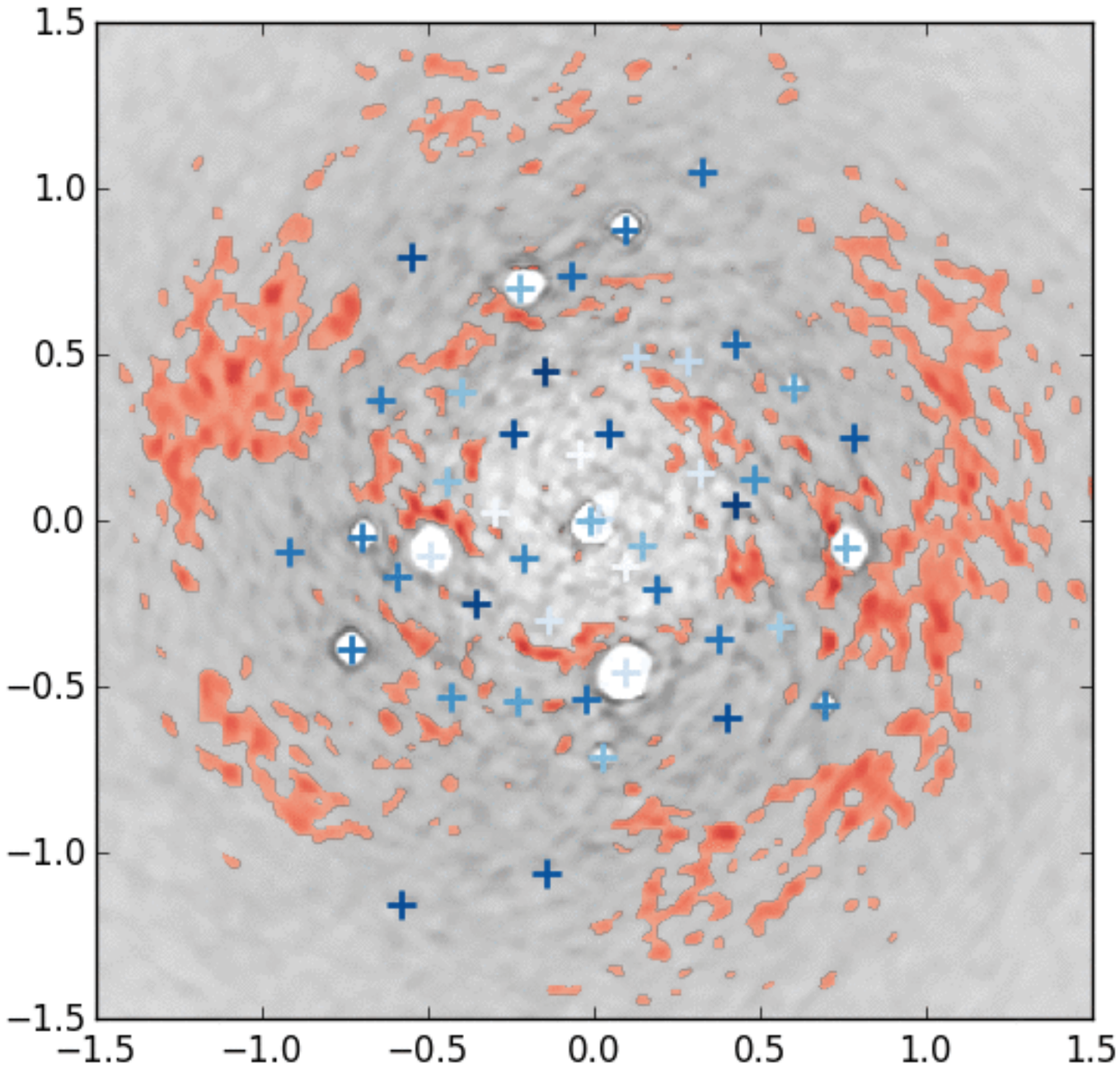
Photoelectric Heating shuts down SF in large swathes



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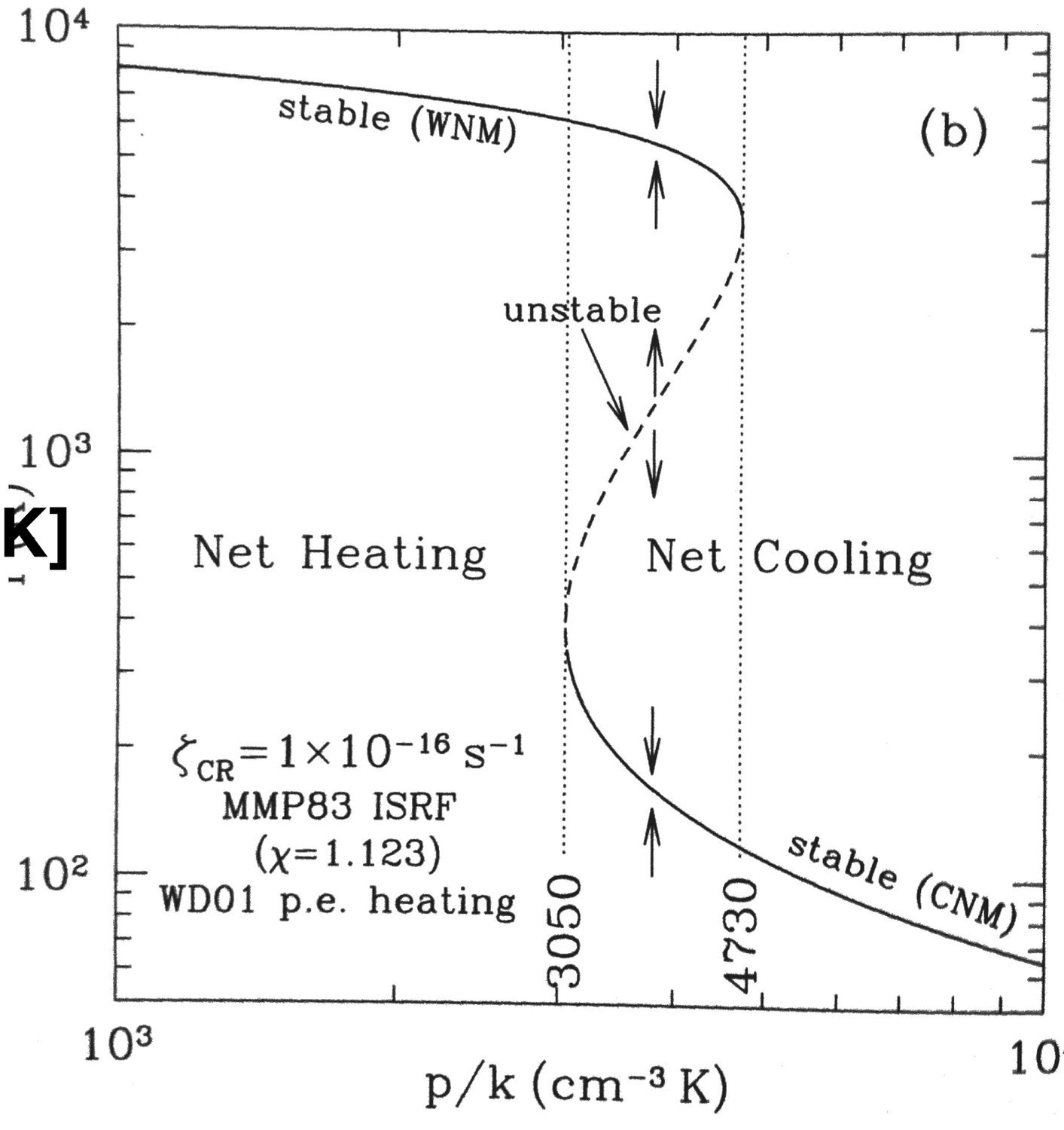
The multi-phase ISM

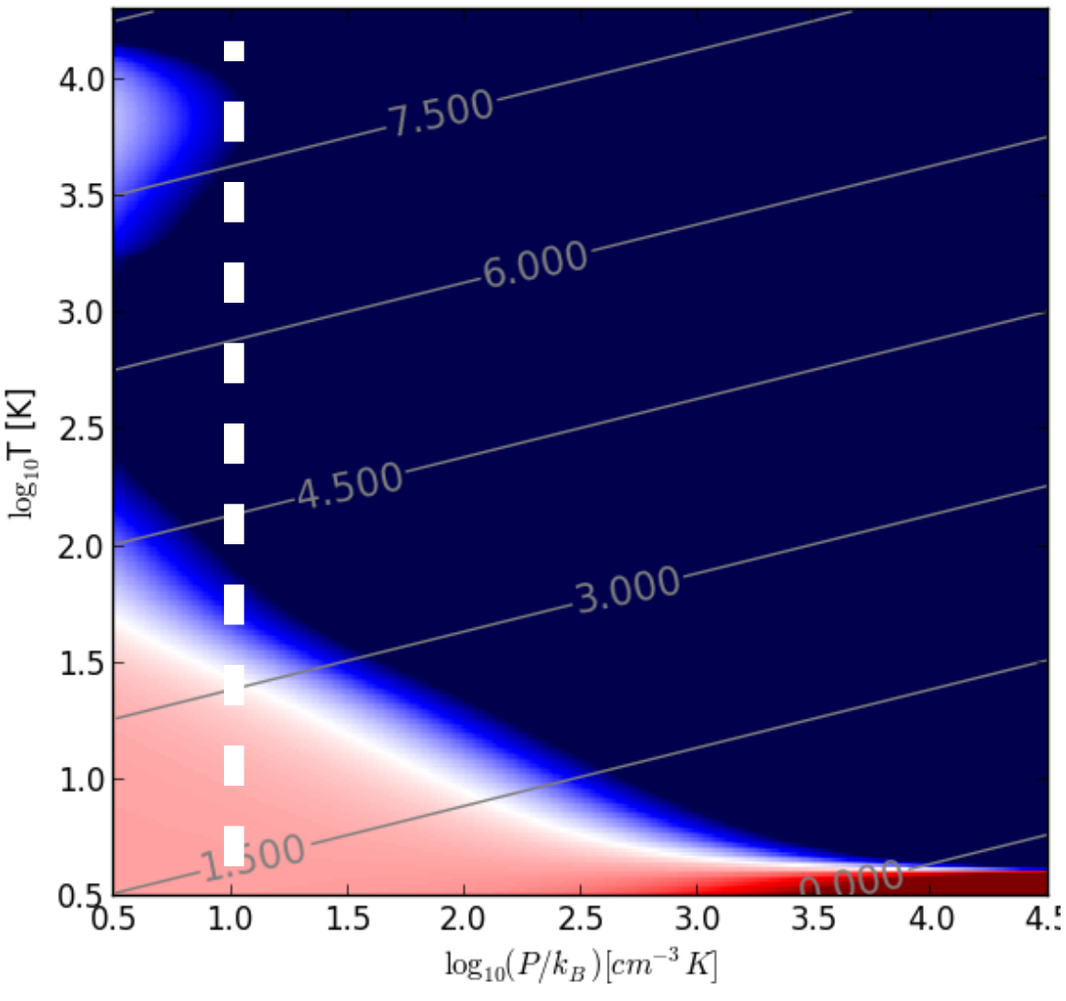


Draine (2011)

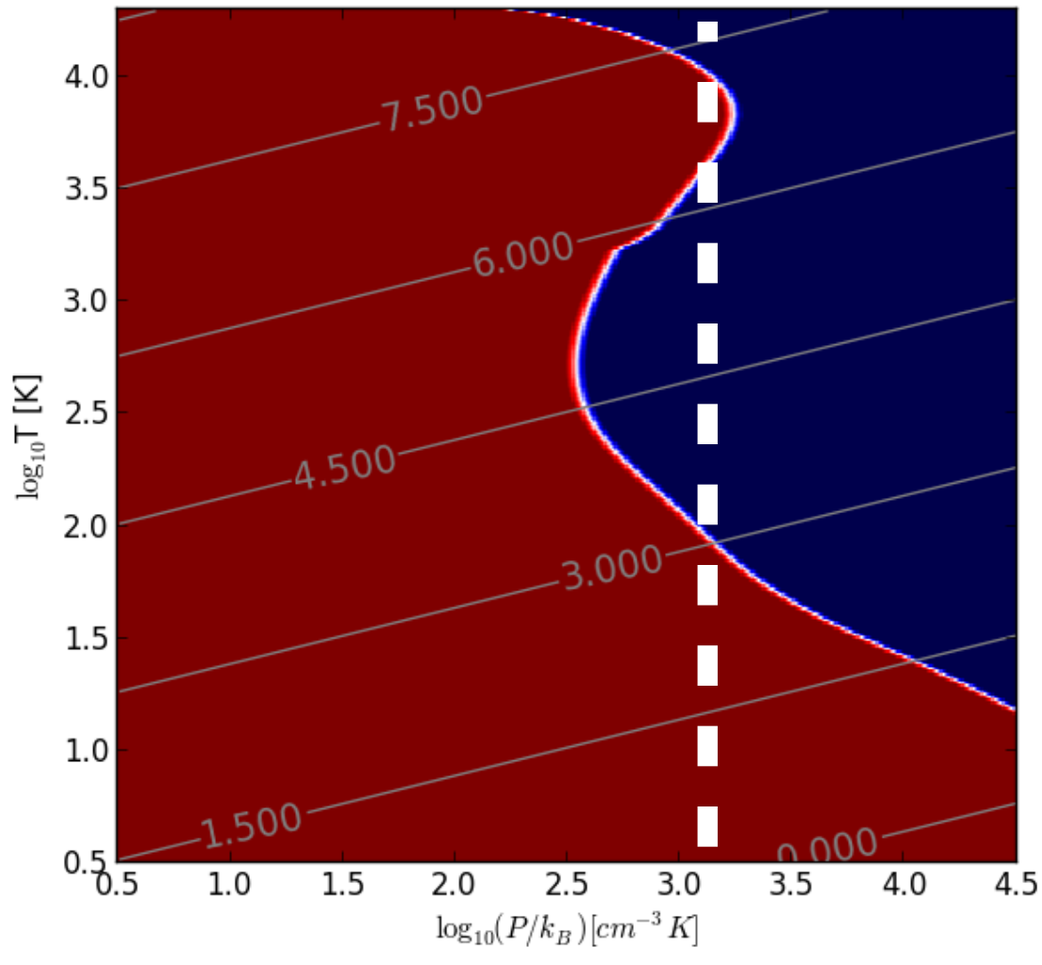
Field, Goldsmith, and Habing (1969)

Dwarf galaxies have a very different ISM

Dwarf

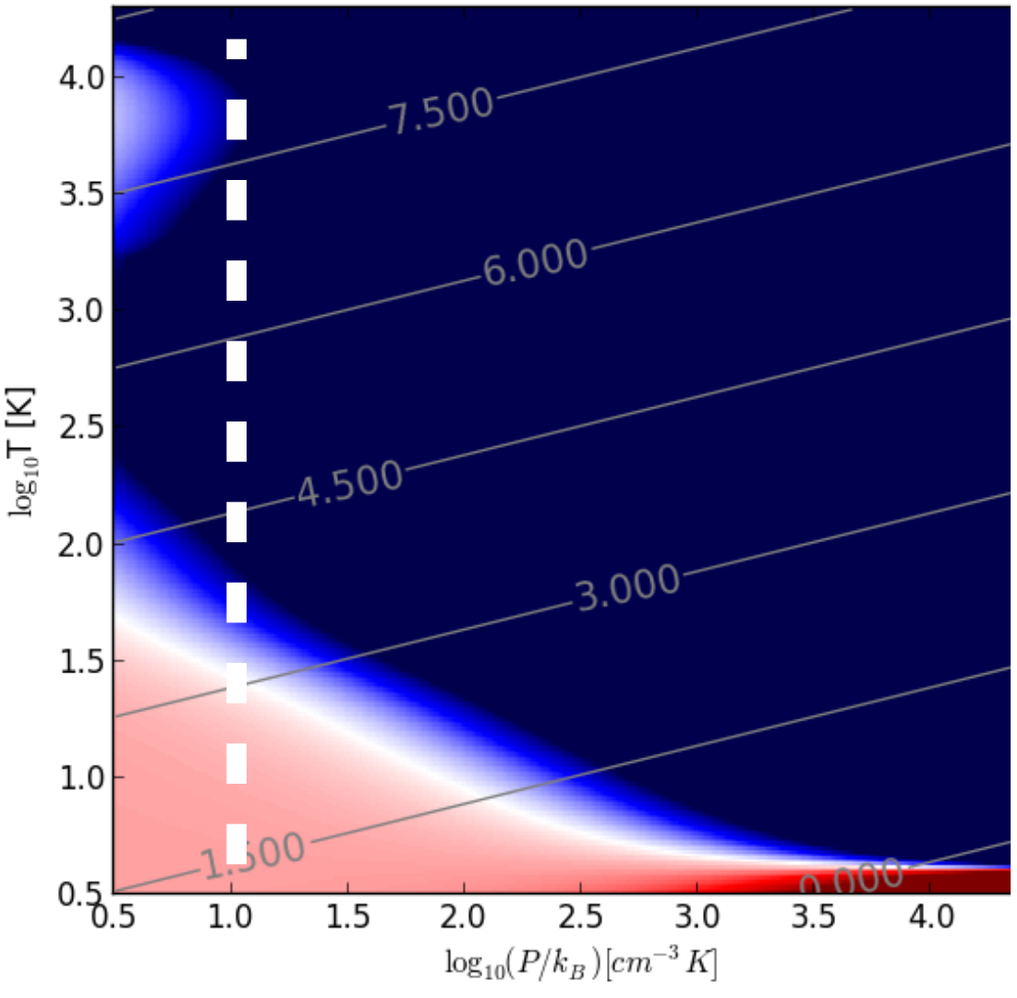


MW

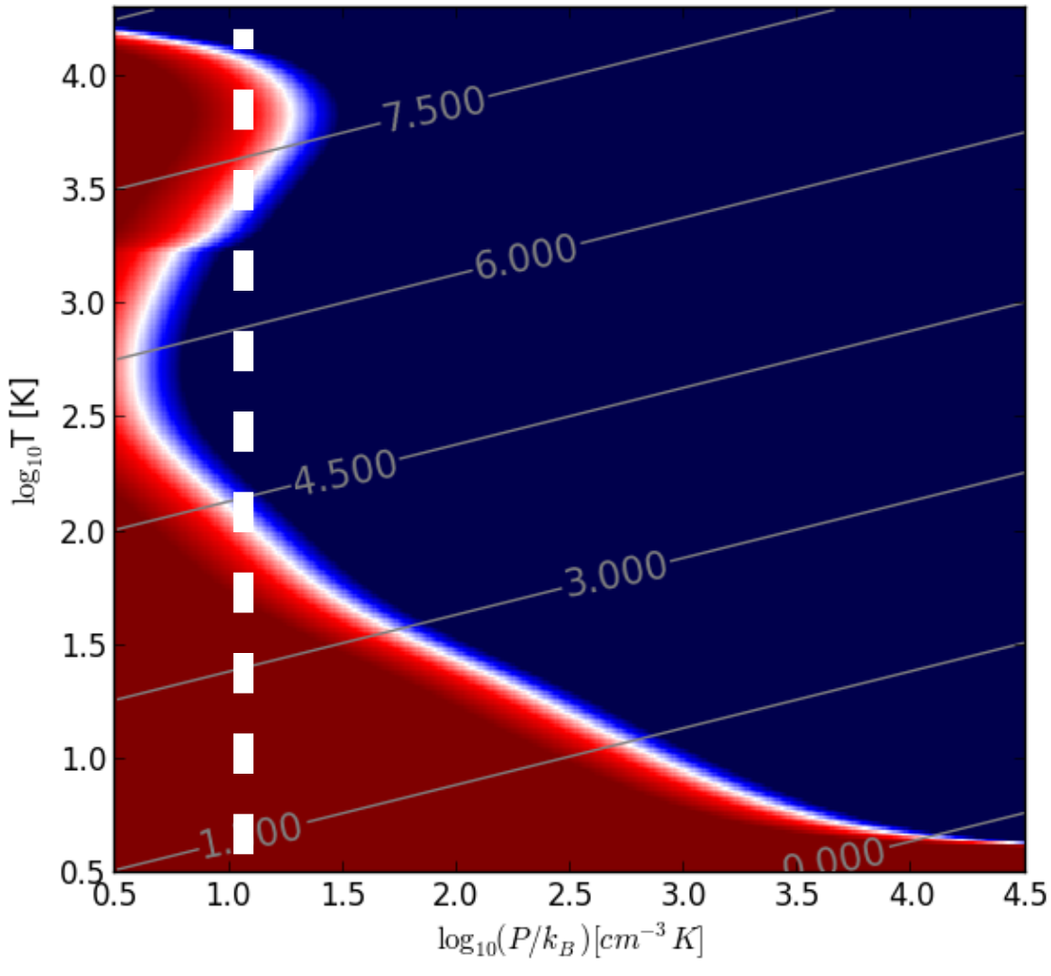


Dwarf galaxies have a very different ISM

Dwarf - Low P.E.



Dwarf - Large P.E.



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