How to slow down star formation in dwarf galaxies

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Local Gas Conference

with Mark Krumholz, Nathan Goldbaum, Avishai Dekel

Outline

- Dwarf galaxies are inefficient at forming stars
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- We find that grain photoelectric heating has a much stronger effect(!)

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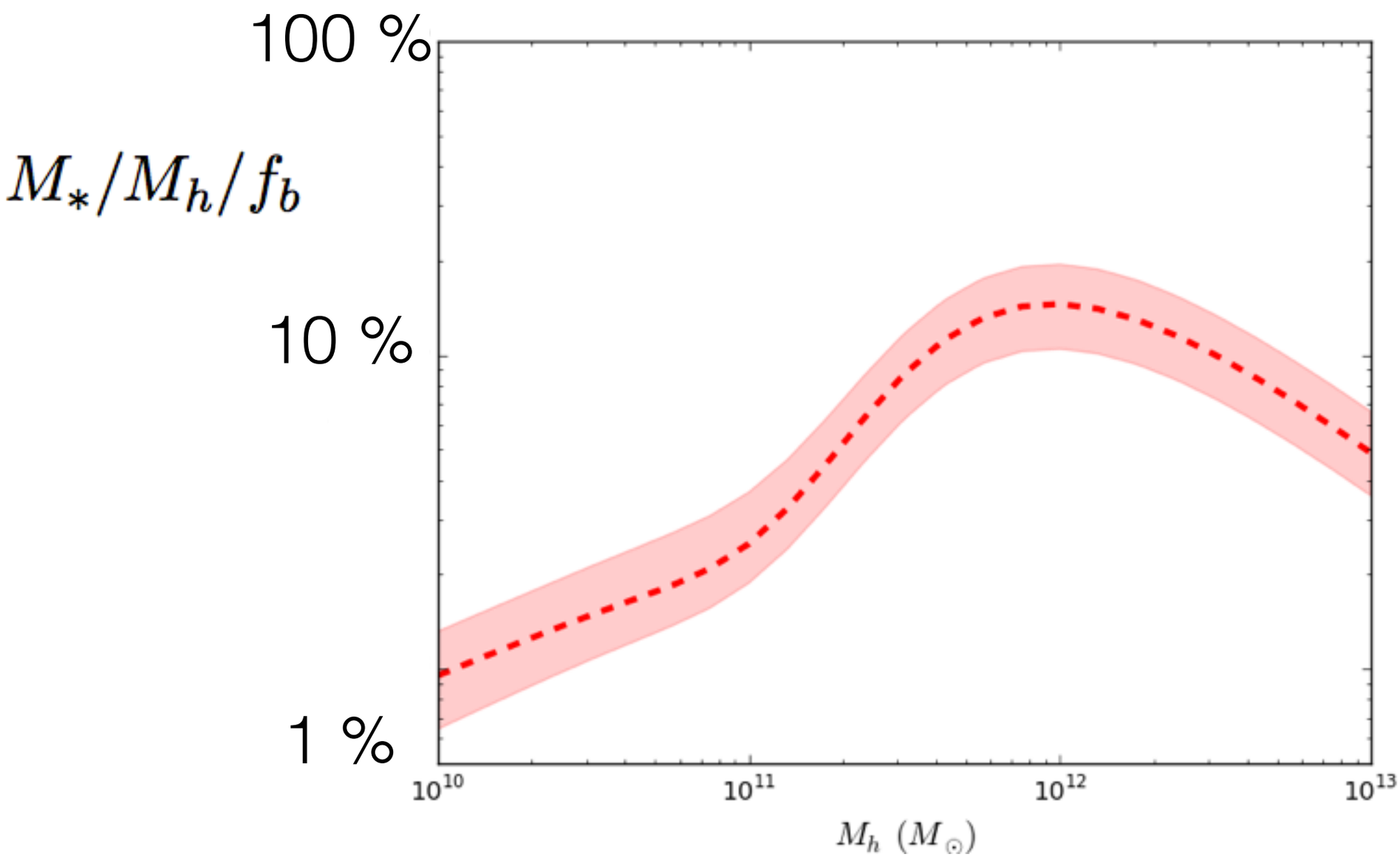
What is a galaxy?

Outflows

Gas

Stars

Dwarf galaxies are bad at their jobs



Behroozi+ (2013a,b) model

Three possibilities

Outflows

Gas

Stars

Three possibilities

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Three possibilities

Outflows

Gas

Stars

Three possible explanations

- Option 1: **Ejective** Feedback:
  - SNe: e.g. Dekel 1986, Stinson+ (2006), Governato+ (2010), Creasey+ (2013,2014), Keller+ (2014), FIRE
  - Radiative: e.g. Murray+ (2005), Hopkins+ (2012), FIRE
  - CRs: e.g. Socrates+ (2008), Jubelgas+ (2008) Salem+ (2013)
  - Prescriptive: Dave+ (2008,…), Illustris, SAMs
- Option 2: **Preventative** Feedback:
  - e.g. Cantalupo (2010), Lu, Mo and Wechsler (2015)
- Option 3: **“Parking Lot”** Feedback
  - e.g. Krumholz & Dekel (2013)

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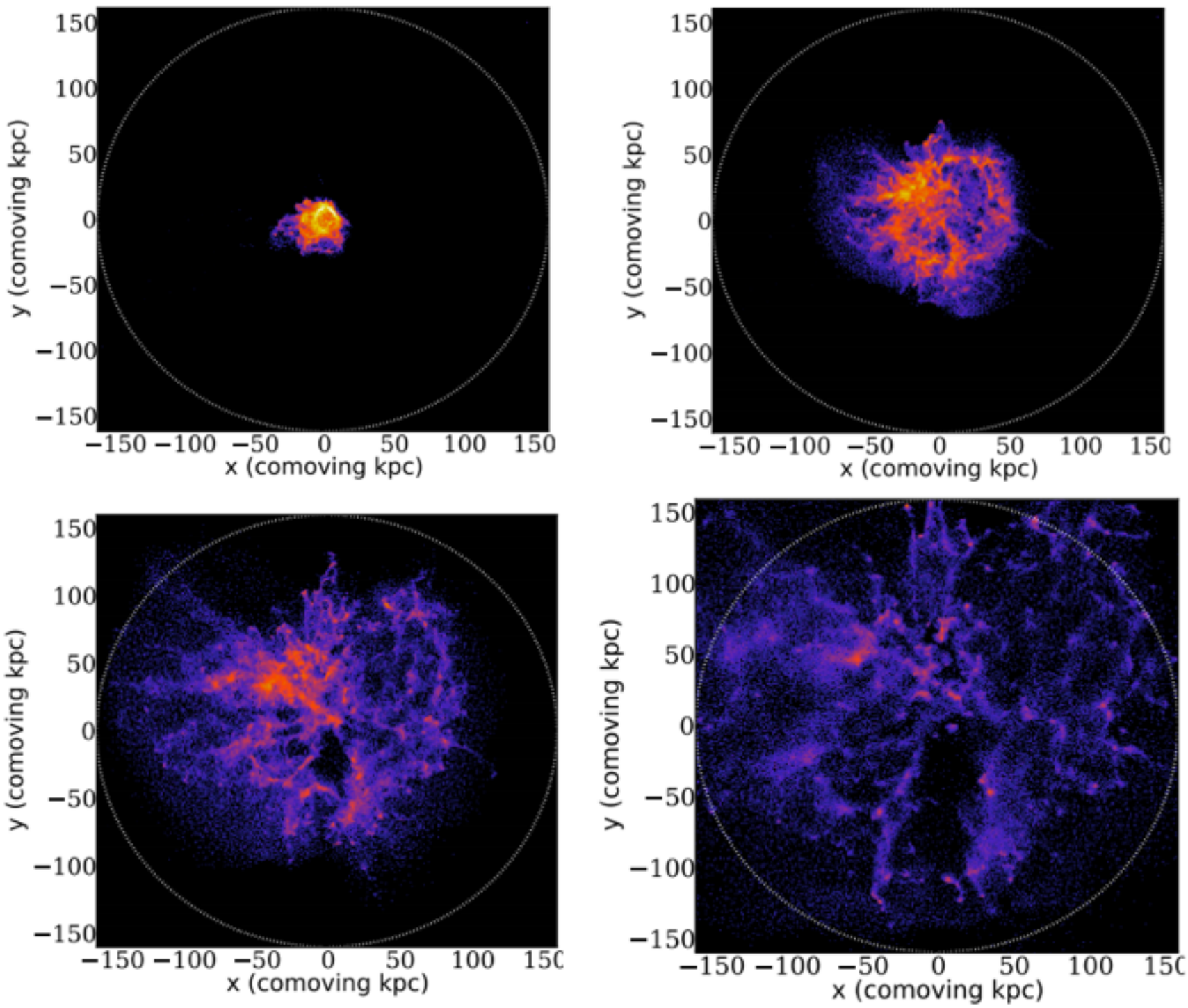
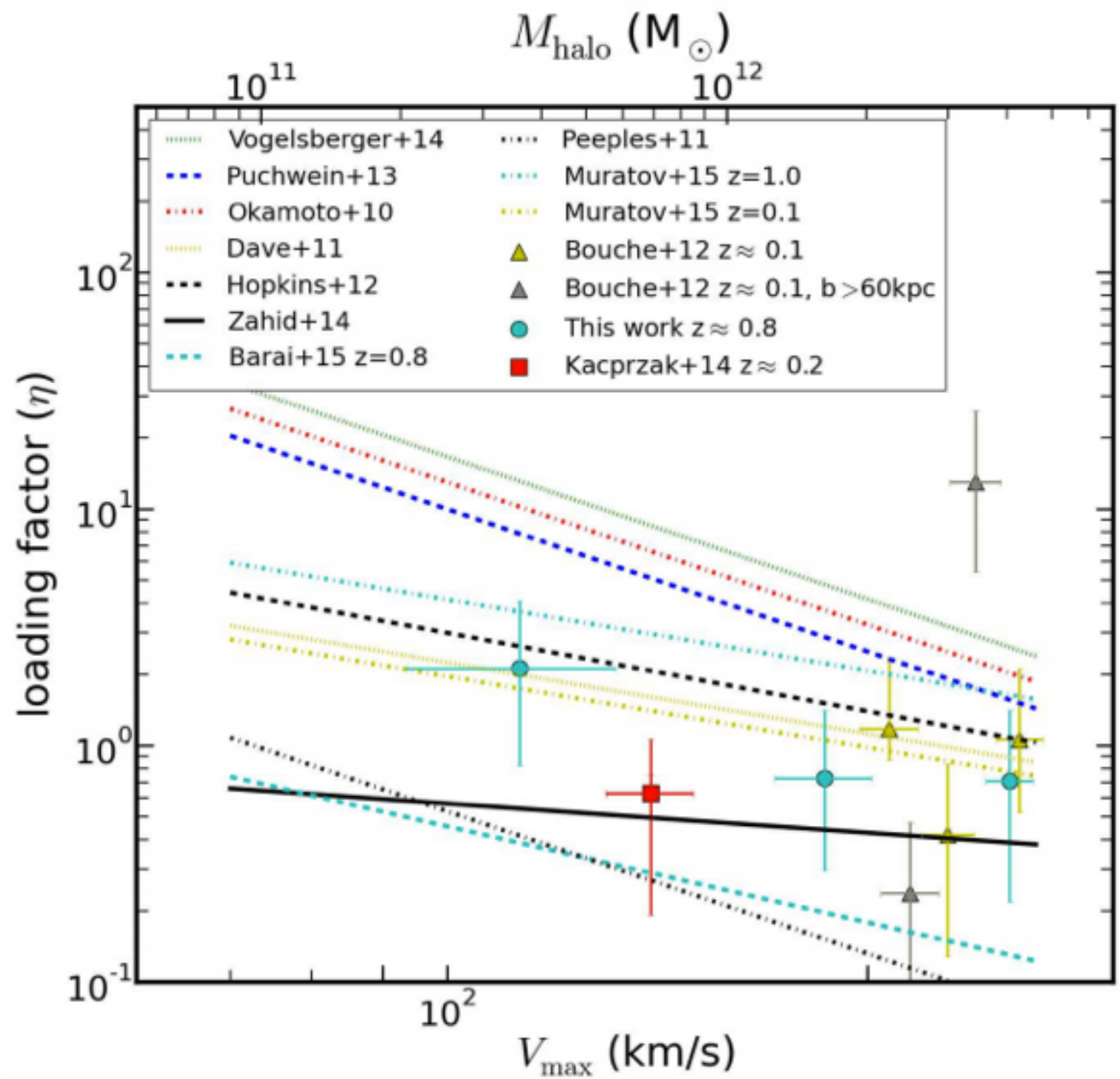
Option 1: Remove the gas



FIRE
Muratov+ (2015)

Theorists are divided



Schroetter+ (2015)

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The Simulations

- **Big questions:** Are dwarfs in or out of equilibrium? I.e., is there dramatic ejective feedback? Why have dwarf galaxies formed so few stars?

- **Testing ground**:

  - Halo Mass ~ 10^{10} $\mathrm{M}_\odot$

  - 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 10 K, UVB, Photoelectric heating
- Non-cosmological
- Maximum resolution between 2.5 pc and 10 pc
- Effective mass resolution ~10 $\mathrm{M}_\odot$ / cell at SF threshold

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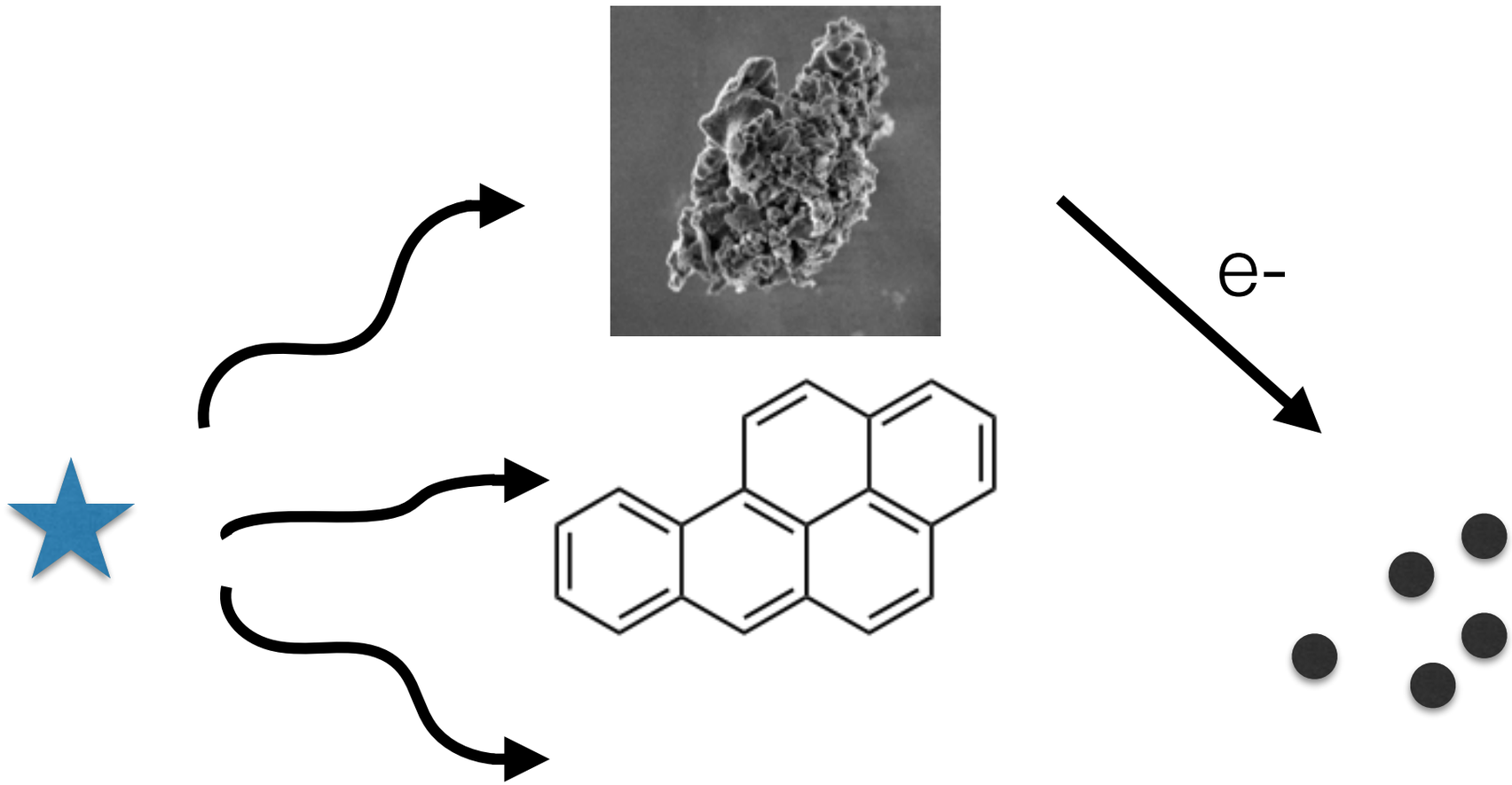
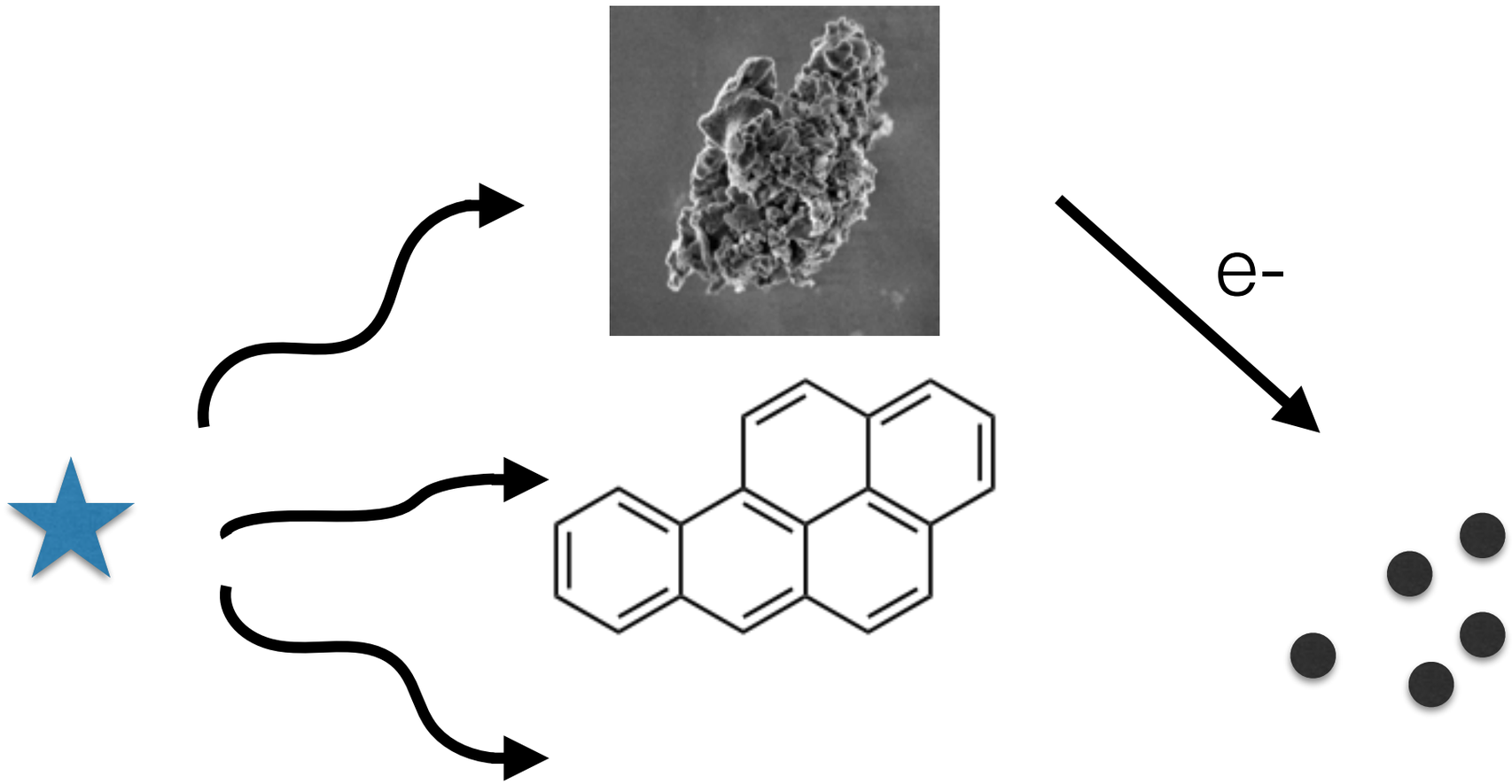
Photoelectric Heating



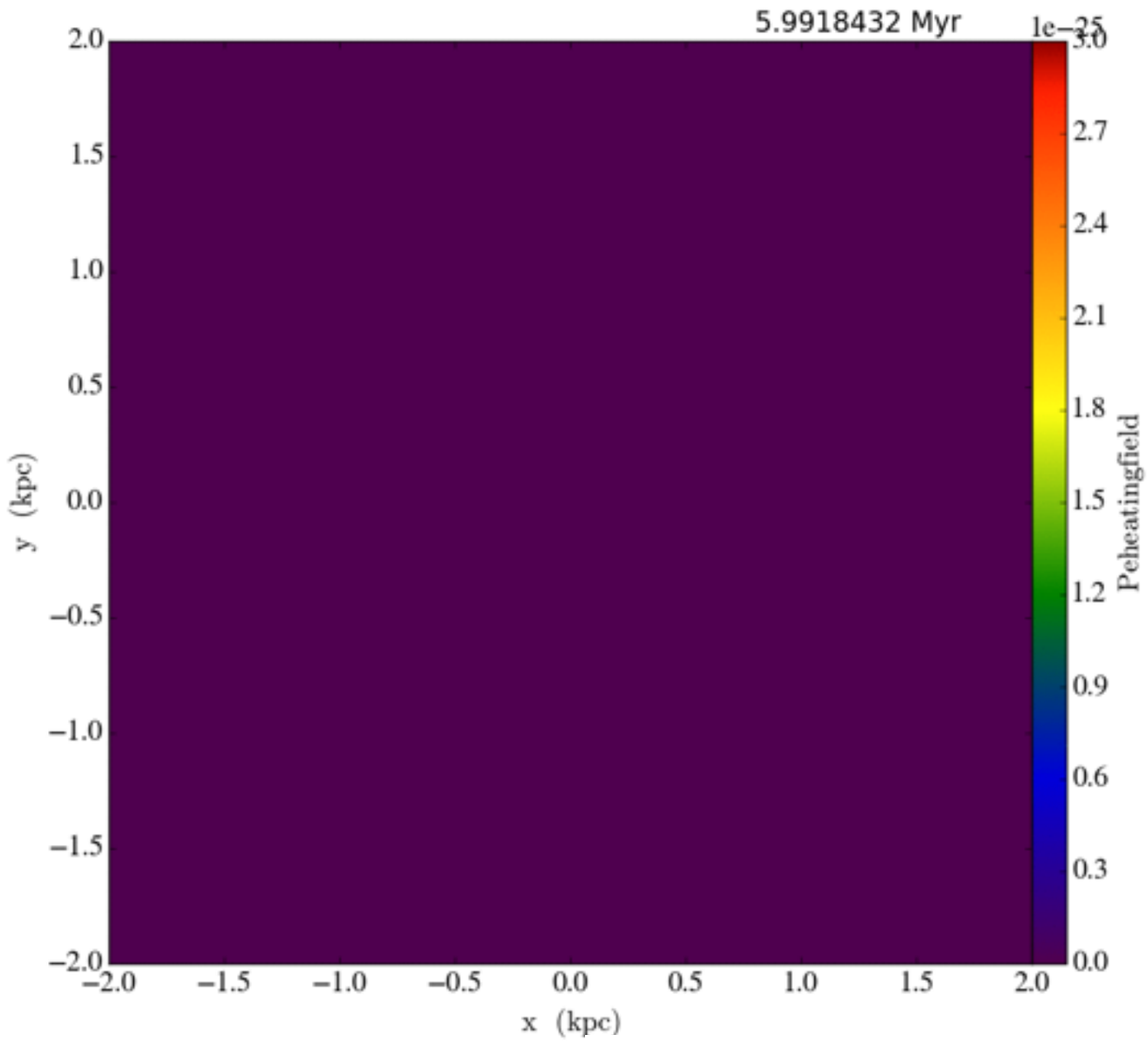
8-13.6 eV
non-ionizing

Photoelectric Heating



$$\mathcal{G} \propto F_{\mathrm{FUV}}\, Z\, n_H \quad \left[\mathrm{erg/s/cm^3}\right]$$

Photoelectric Heating



$$\Gamma_{\rm p.e.} = \frac{\mathcal{G}}{n_H} \propto F_{\rm FUV} Z \ [{\rm erg/s}]$$

Movie available:
https://www.dropbox.com/s/pfdk3l120p98yr4/m10r402_ProjectionDensJeans.gif?dl=0

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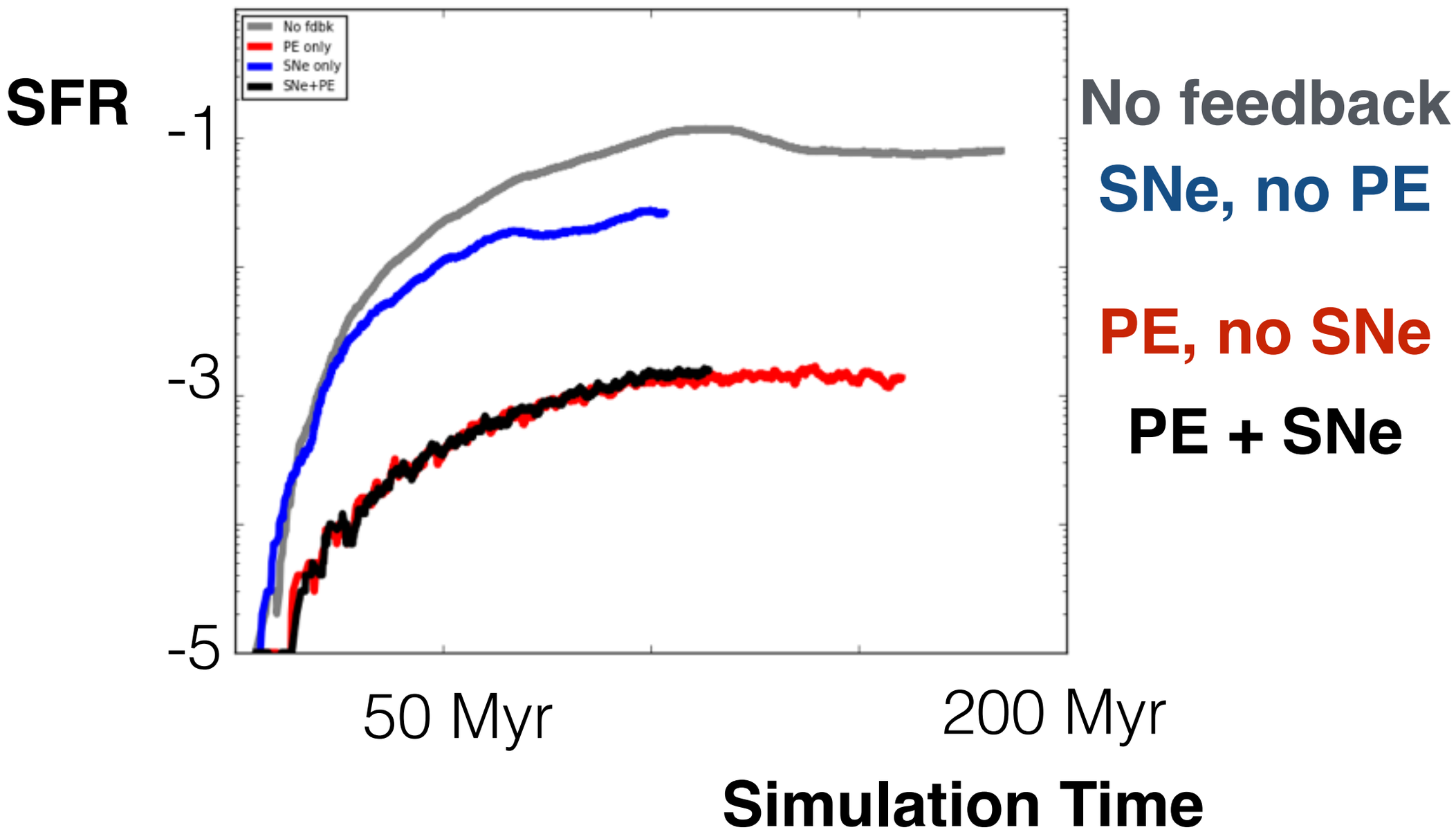
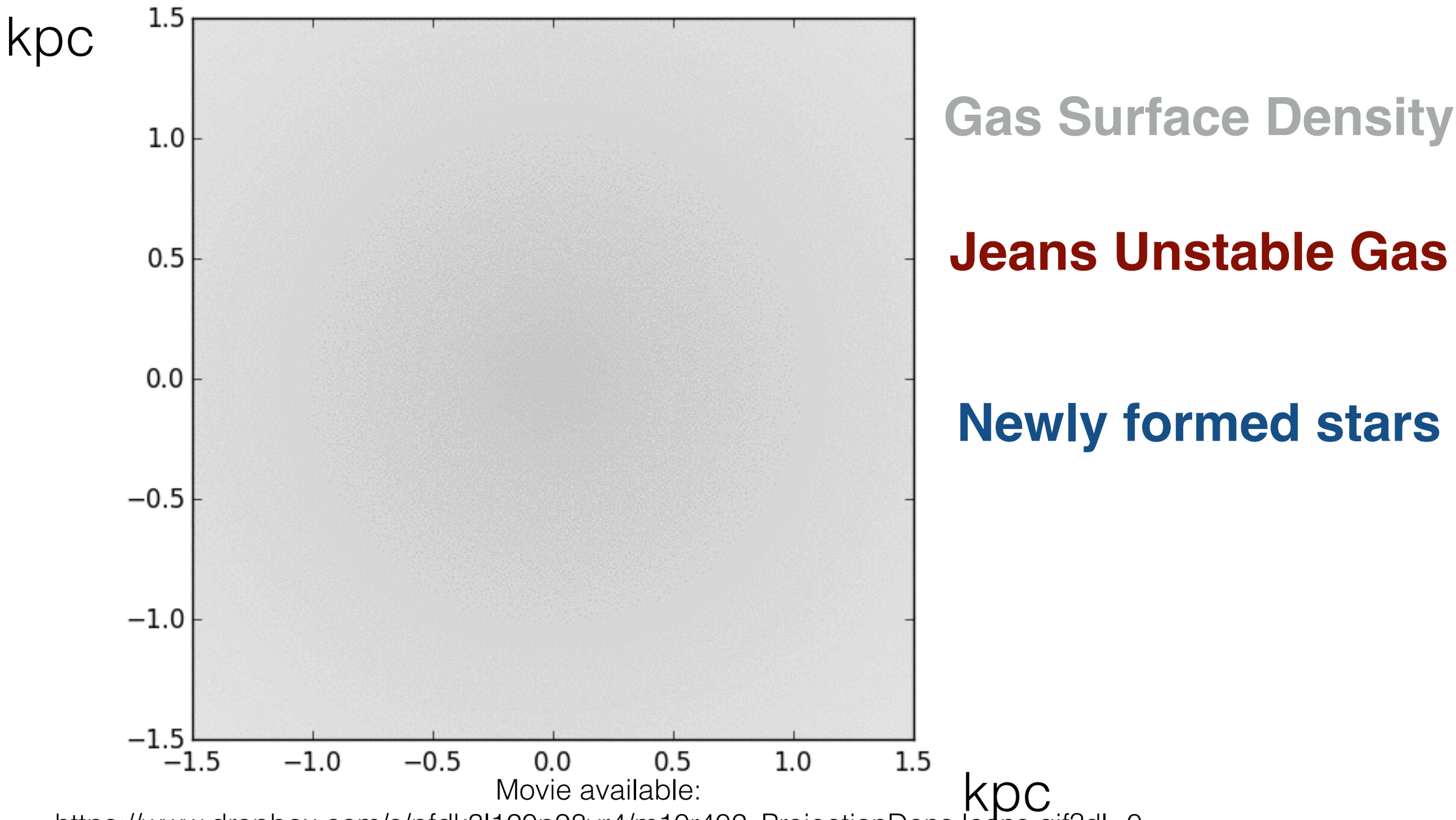
Photoelectric heating alone suppresses SFR by 10+



No Photoelectric Heating



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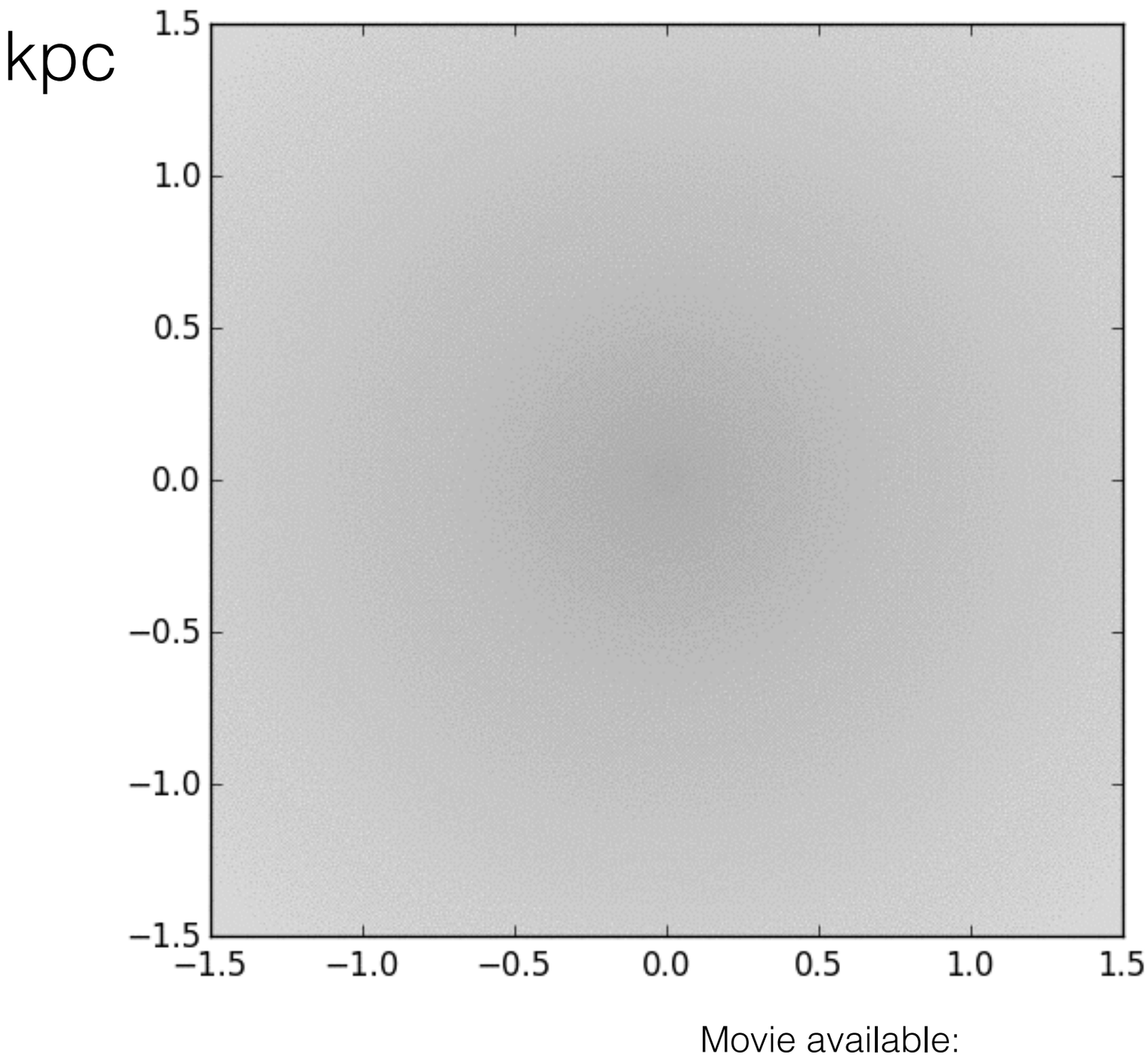
Photoelectric Heating + SNe



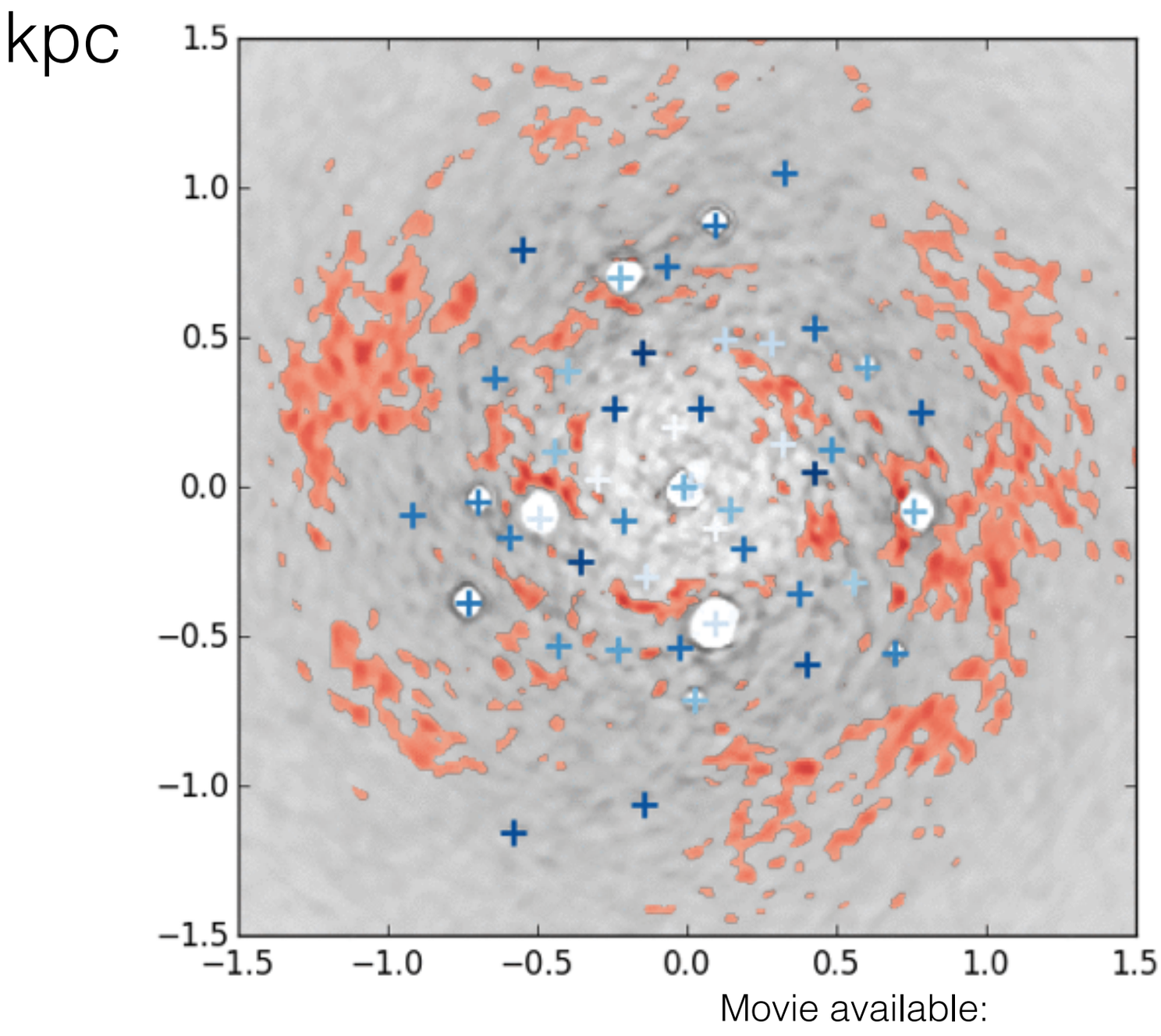
Gas Surface Density

Jeans Unstable Gas

Newly formed stars

Movie available:
https://www.dropbox.com/s/rol1euwpgjrqi3l/m10r431_ProjectionDensJeans.gif?dl=0

Photoelectric Heating shuts down SF in large swathes



Gas Surface Density

Jeans Unstable Gas

Newly formed stars

Movie available:
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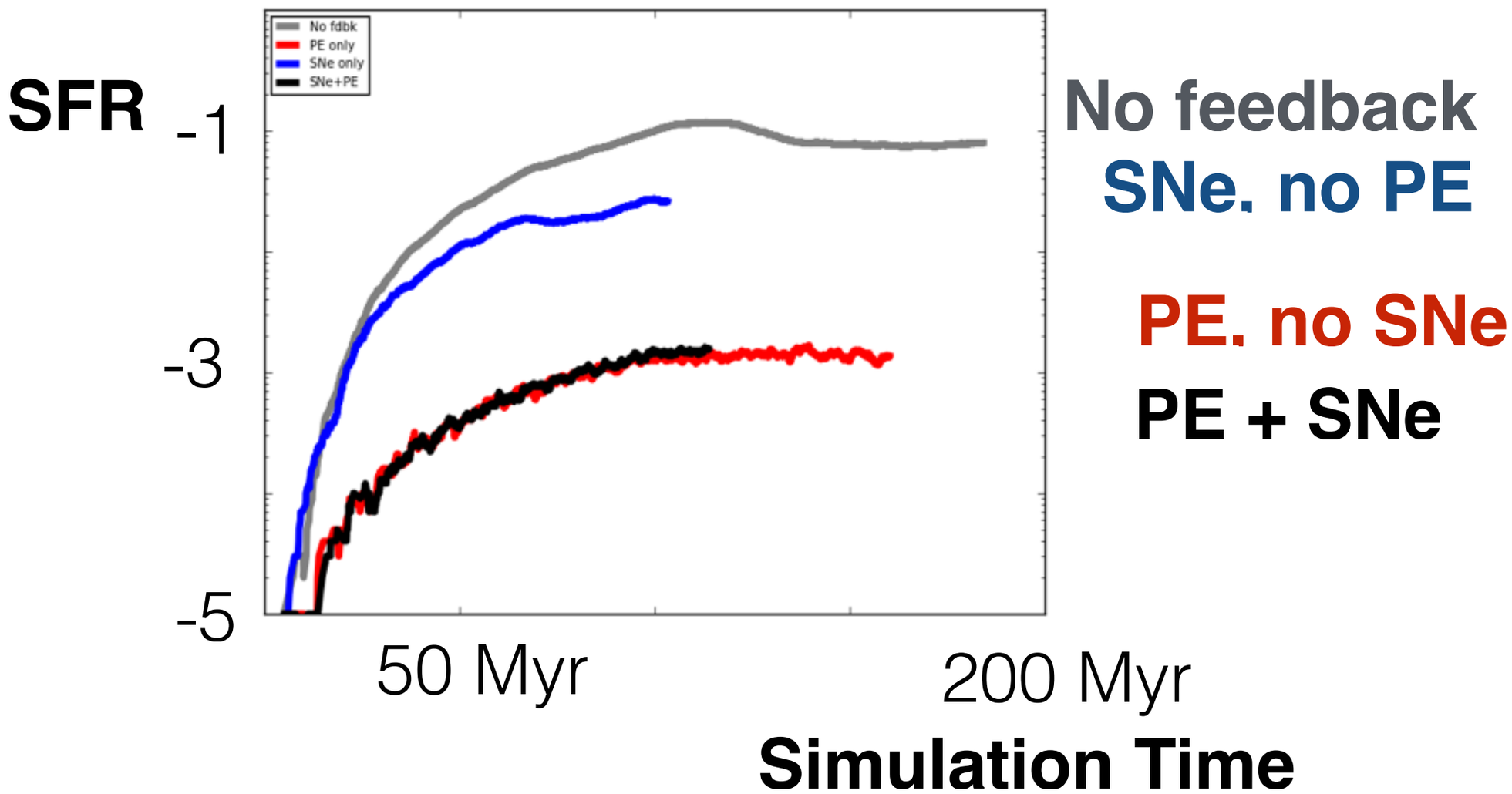
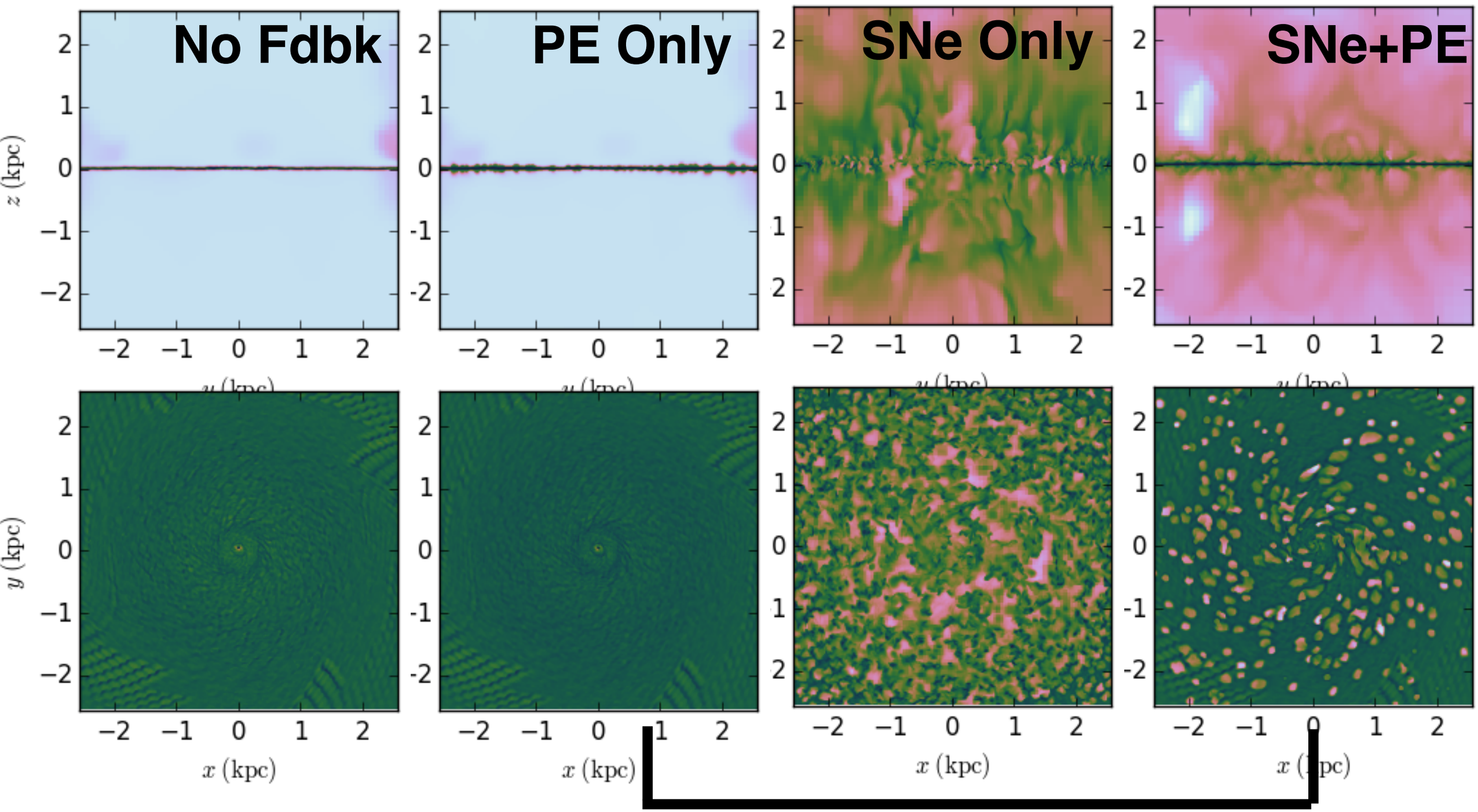
What about the SNe?!

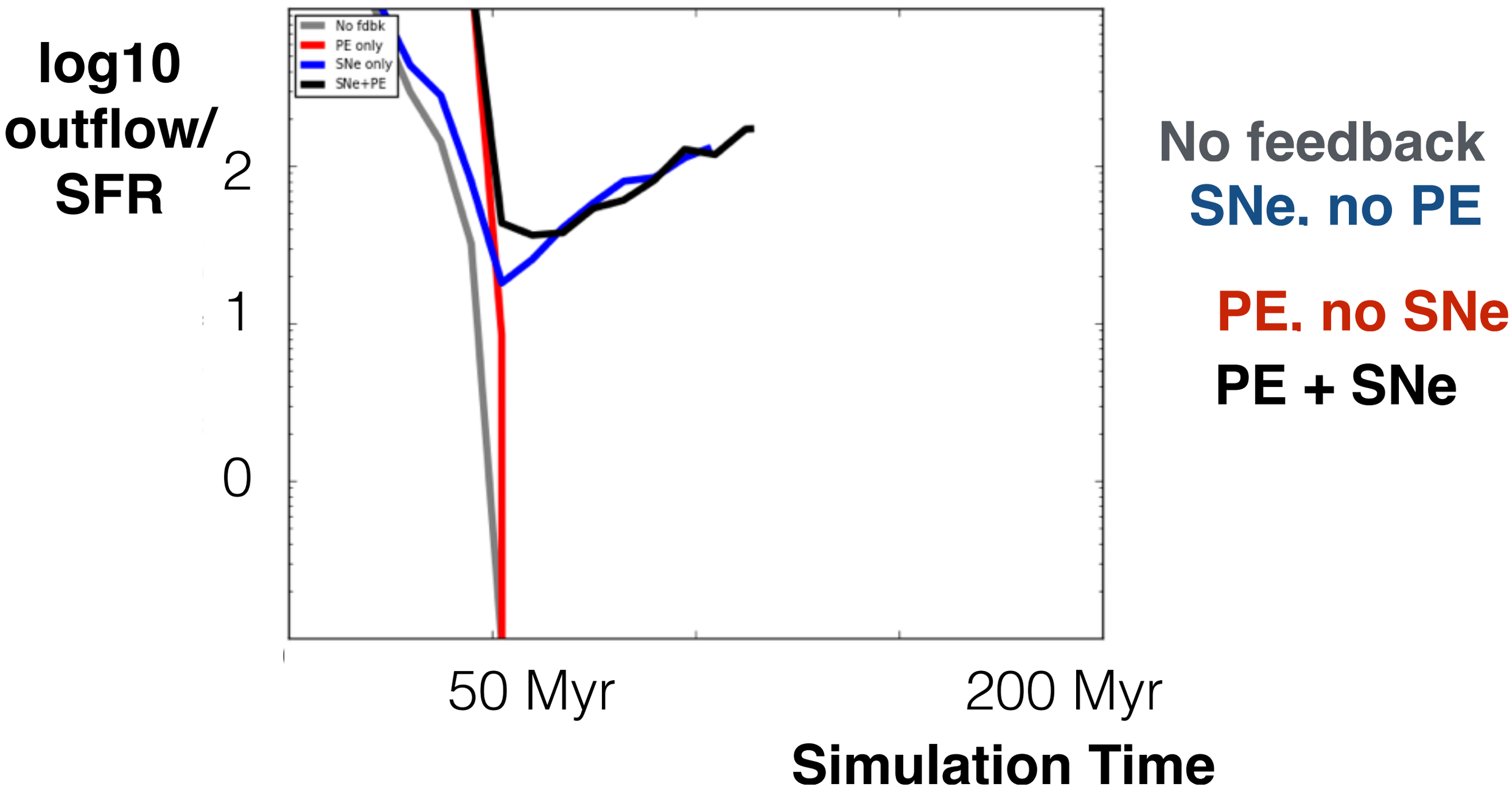
(Are they even on?)



SNe determine morphology



SNe determine the mass loading factor



Summary

- 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.
- **Photoelectric heating sets the depletion time in dwarf galaxies.**
- **Supernovae set the outflow rates in dwarf galaxies, but have remarkably little effect on the SF Law.**