Challenges for connecting small scale and large scale simulations

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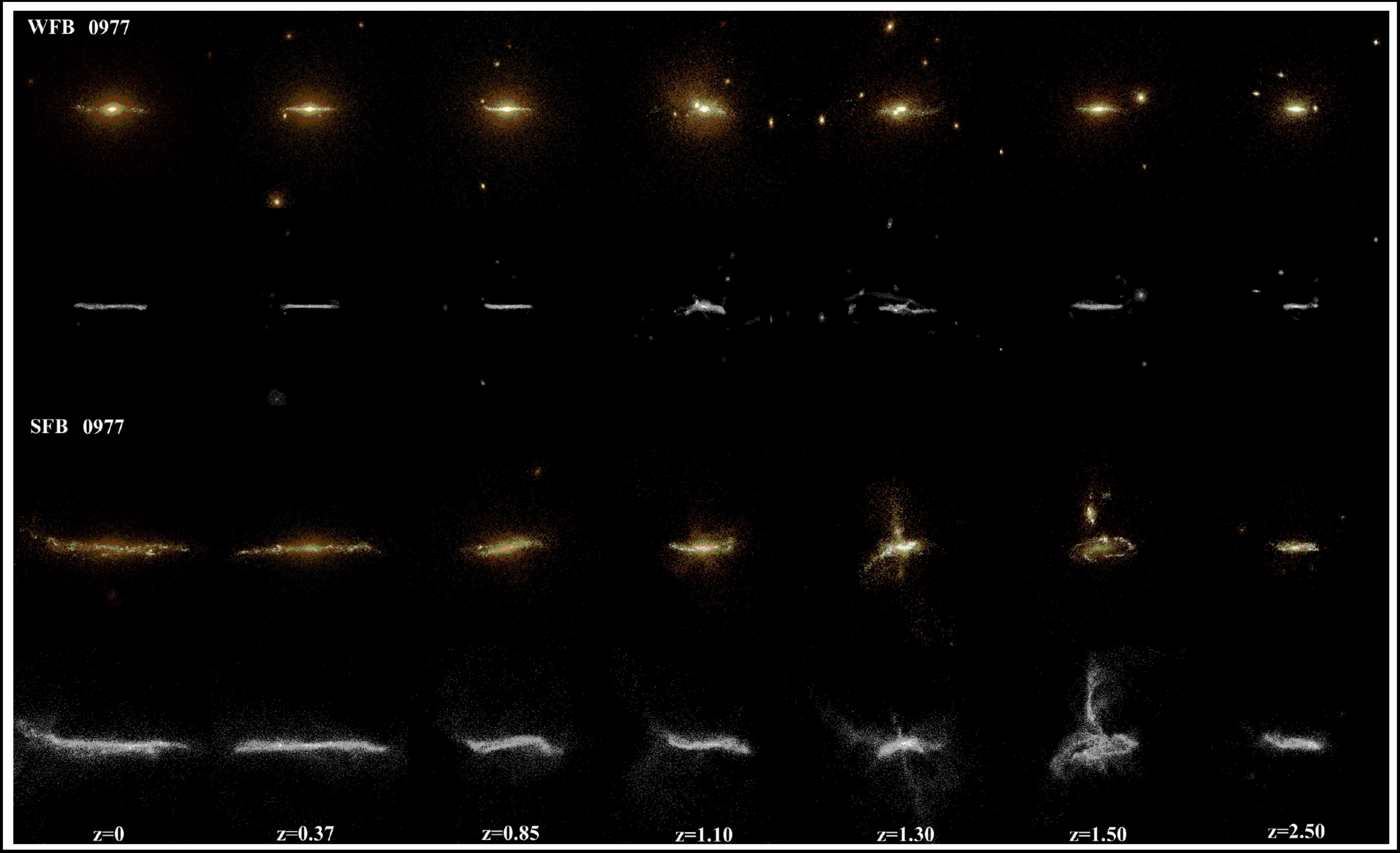
Feedback from massive stars promote the formation of spirals

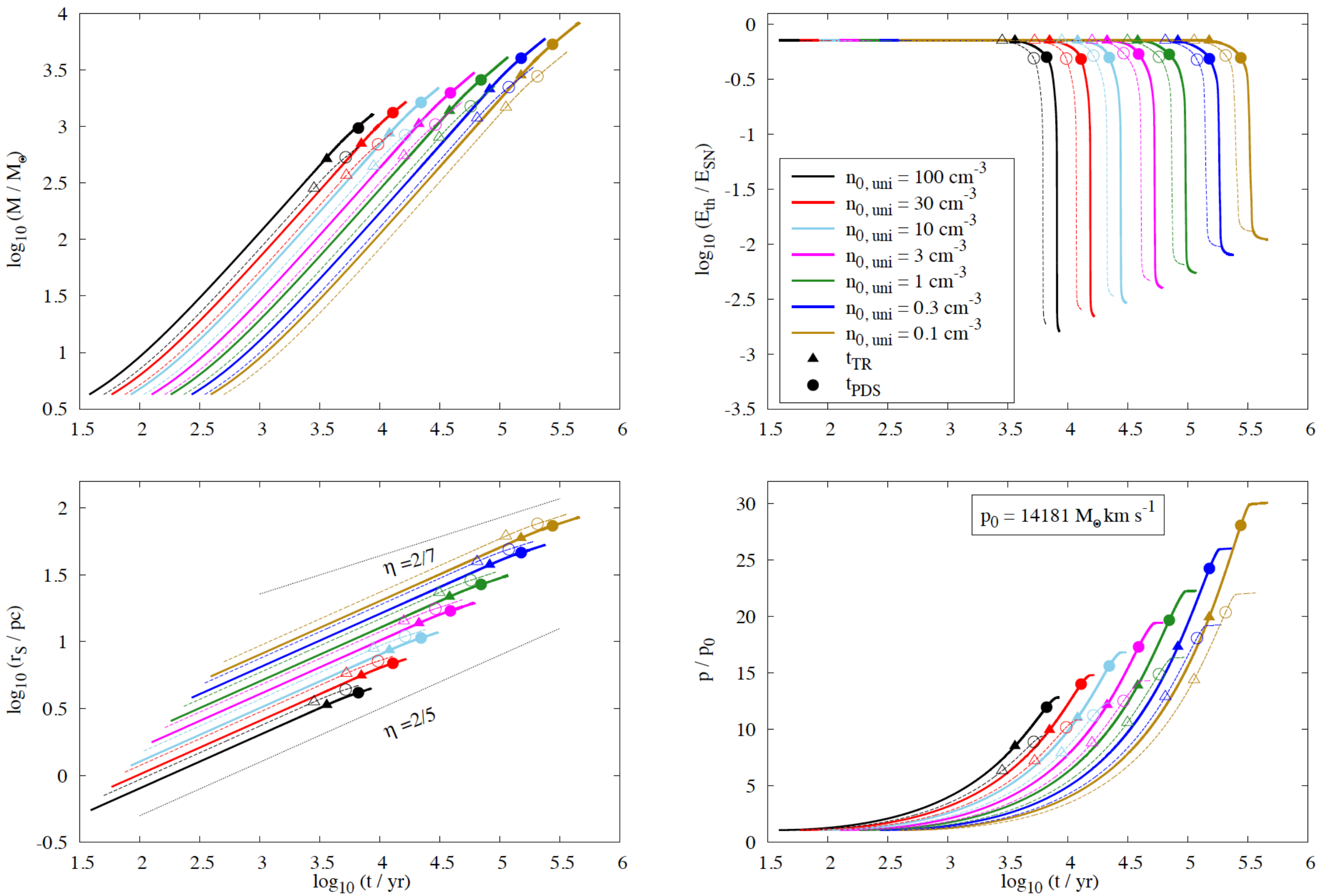


Übler et al. 2014

The challenge

- Many different ‘feedback’ models get qualitative similar results using sub-grid models on 100 - 500pc scales
- Successful modeling of galaxy populations in cosmological
- Most physical ‘feedback’ processes are unresolved
- How does the ISM get its multi-phase structure?
- How are galactic outflows launched?
- Can we use small scale simulations at higher resolution and physical complexity to ‘construct’ sub-resolution models?

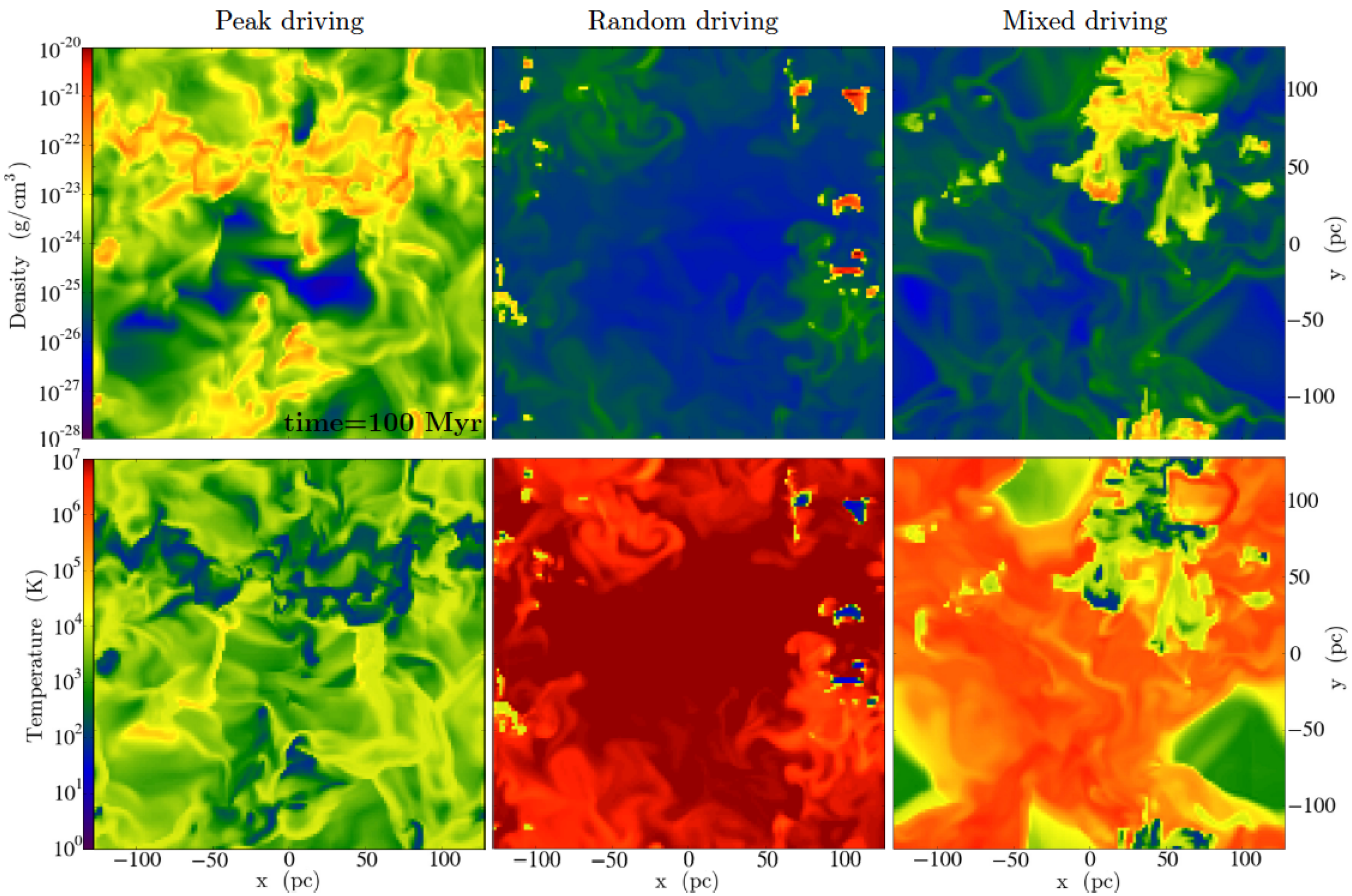
Supernova blast wave – homogenous medium



Momentum injection a homogenous ambient medium – larger variations in turbulent media!!!

Haid et al. 2016

Random vs. peak SN explosions



Supernovae exploding at random positions may push the system to thermal runaway – volume completely filled with hot gas

Gatto et al. 2015, see also Li et al. 2015

Stratified disk – peak driving

SILCC: **SI**mulating the **L**ife**C**ycle of molecular **C**louds

Stefanie Walch
Philipp Girichidis
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Paul C. Clark
Thomas Peters
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Christian Baczynski

Walch et al., MNRAS 454, 238 (2015)
Girichidis et al., arXiv:1508.06646

KS SN rate, peak driving

Walch et al. 2015

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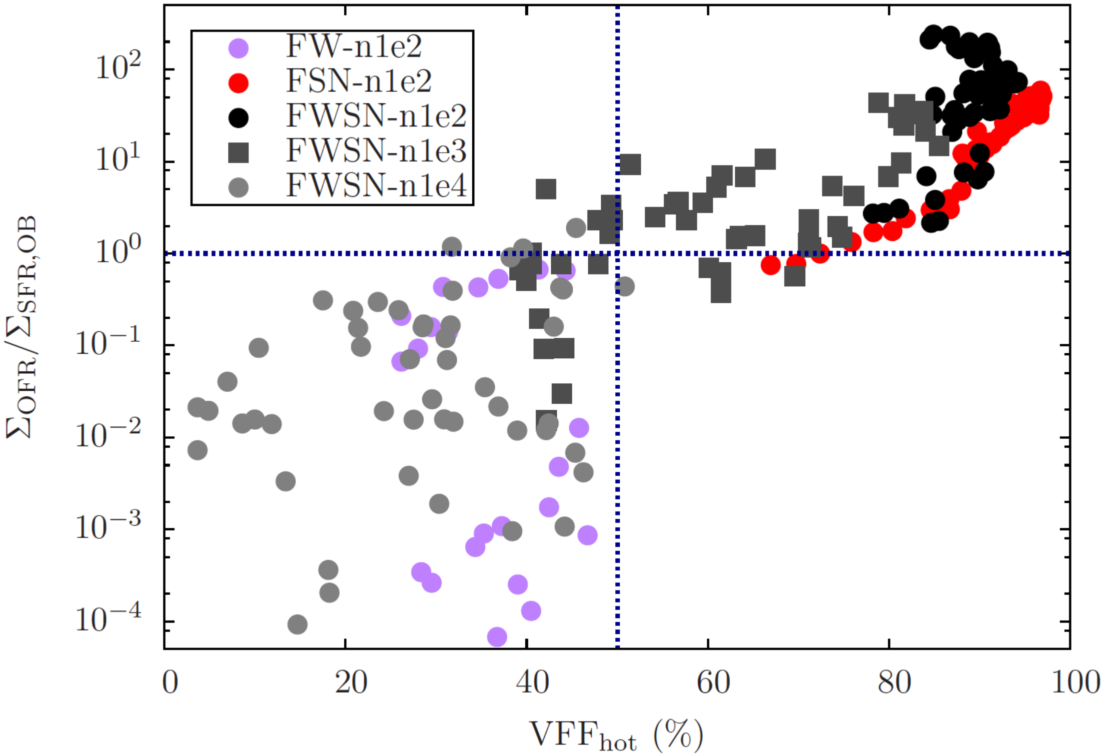
KS SN rate, clustered driving, $B_0 = 3\,\mu\mathrm{G}$

Hot volume filling ISM drives outflows



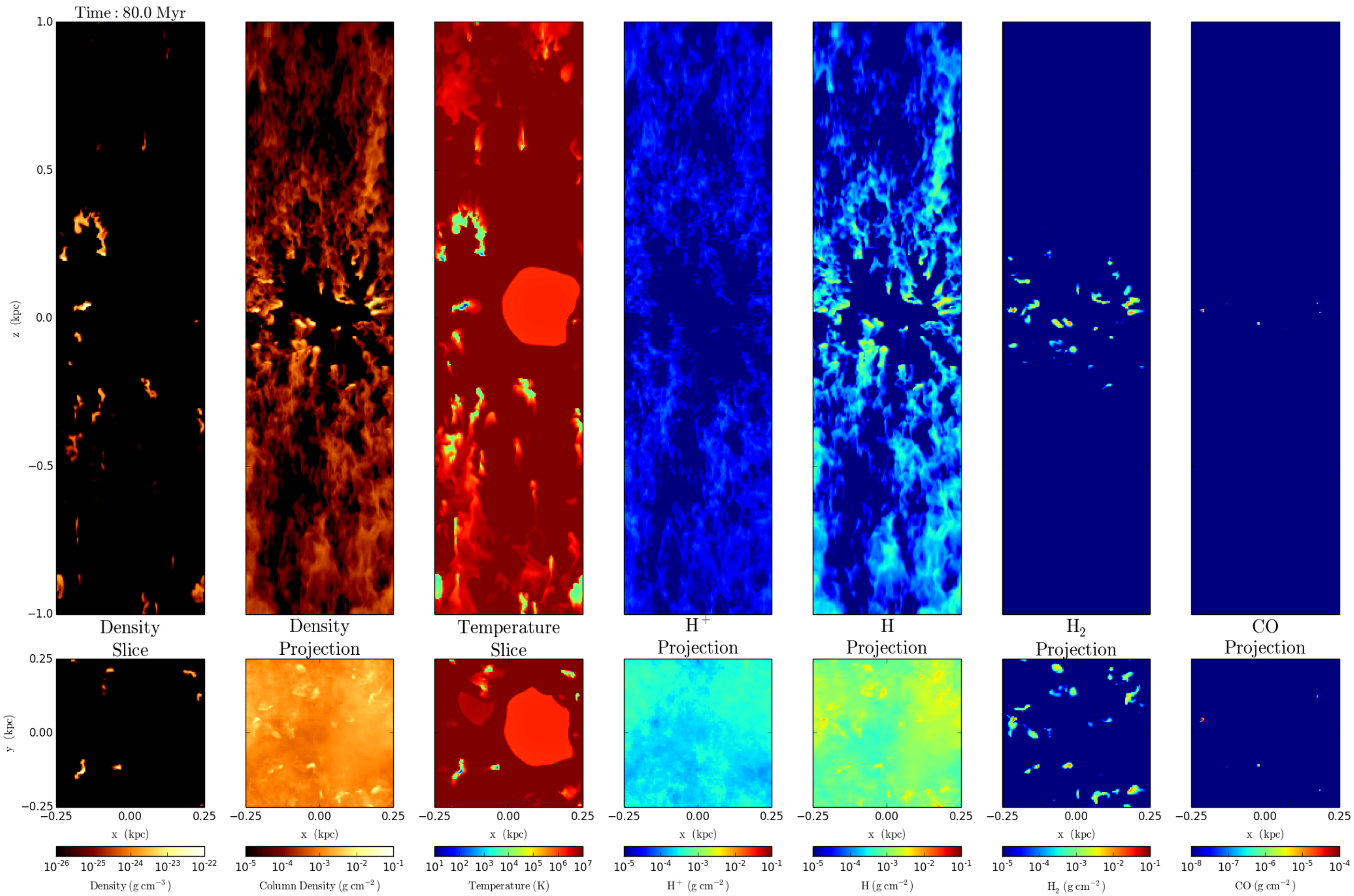
- Models with high star formation rates generate volume filling hot gas
- Volume filling hot gas drives outflows with significant mass loading
- This process is mainly driven by star formation rate which is regulated by supernovae and winds

Gatto et al. submitted

What sets the structure of the ISM?

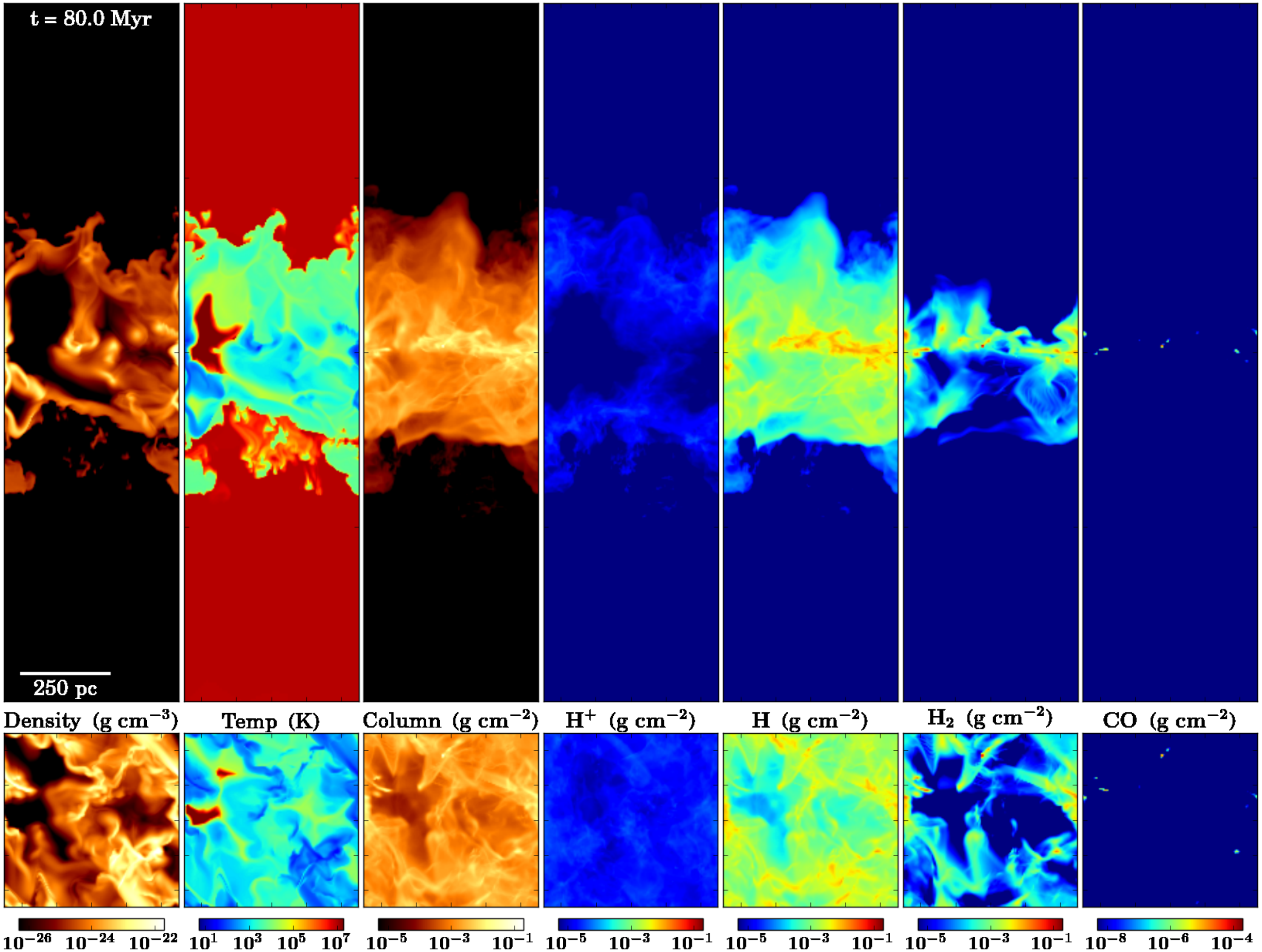
- ISM structure is set by the ambient density of supernova explosions
- Ambient density is set by supernovae (see Mac Low et al.), stellar winds, ionization, walk-away and run-away stars exploding in low density regions, supernovae Ia
- A proper treatment of the dense phase is required – filamentary structure
- "overlapping" supernova remnants can generate a stable hot phase which drives an outflow
- Any subgrid model has to capture the ability of the ISM to generate a volume filling hot phase with most of the mass in a cold phase
- A possible natural scale for this might be star clusters (10^3 – 10^4 stars)

What sets the structure of the ISM?



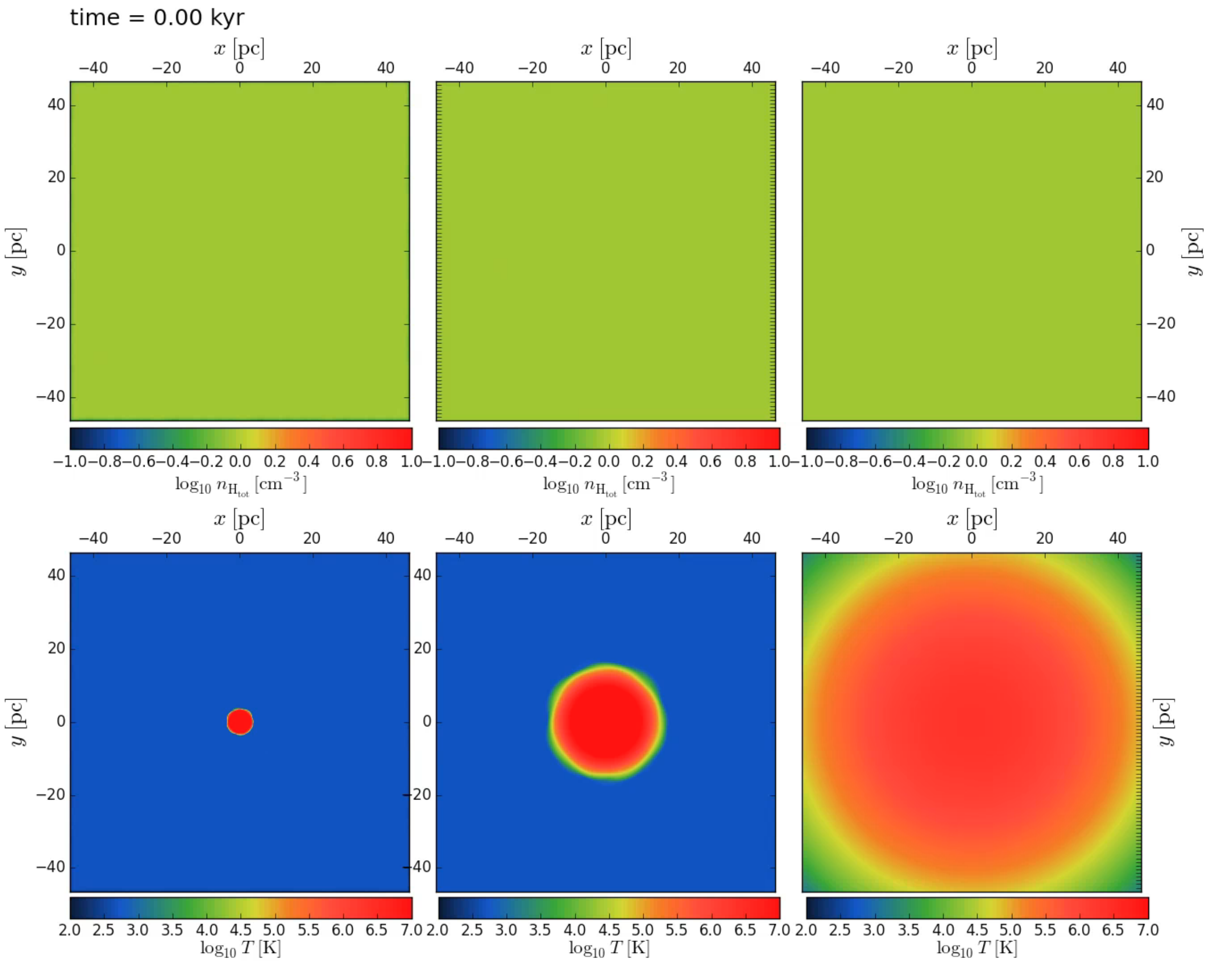
Spatially and temporally correlated supernovae

What sets the structure of the ISM?



"Schmidt type" star formation

Resolving blast waves in the ISM of galaxies



M_*/M_{gas}=100 M_*/M_{gas}=10 M_*/M_{gas}=1

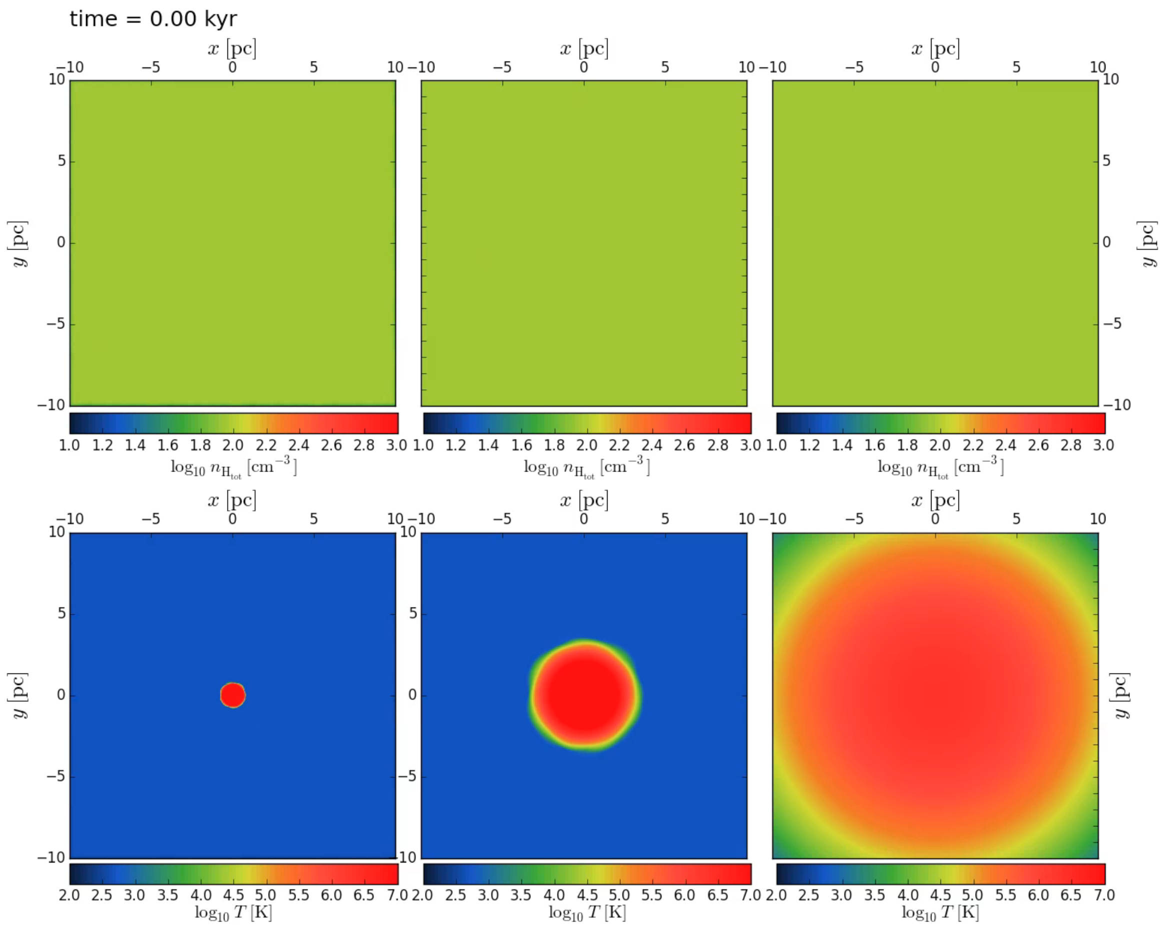
SN blast waves are typically unresolved in galaxy-scale simulations
- many phenomenological models

Cooling time shorter than sound crossing time – no proper blast wave evolution (della Vechia & Schaye 2012)

This problem also exists for high resolution galaxy simulations if mass resolution in the stellar phase and gas phase is comparable!

Hu et al. 2016

Resolving blast waves in the ISM of galaxies



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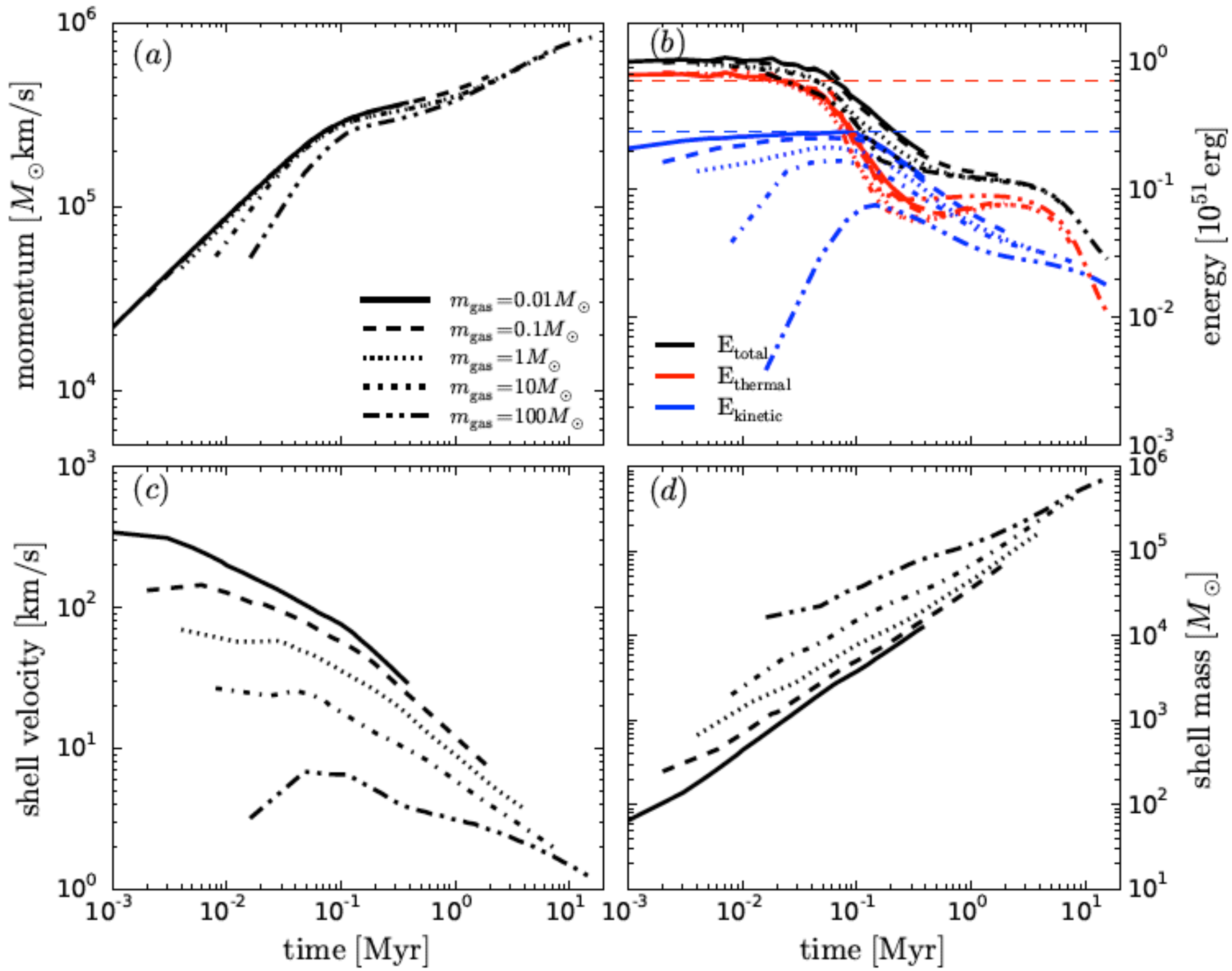
Star formation in dwarf galaxies

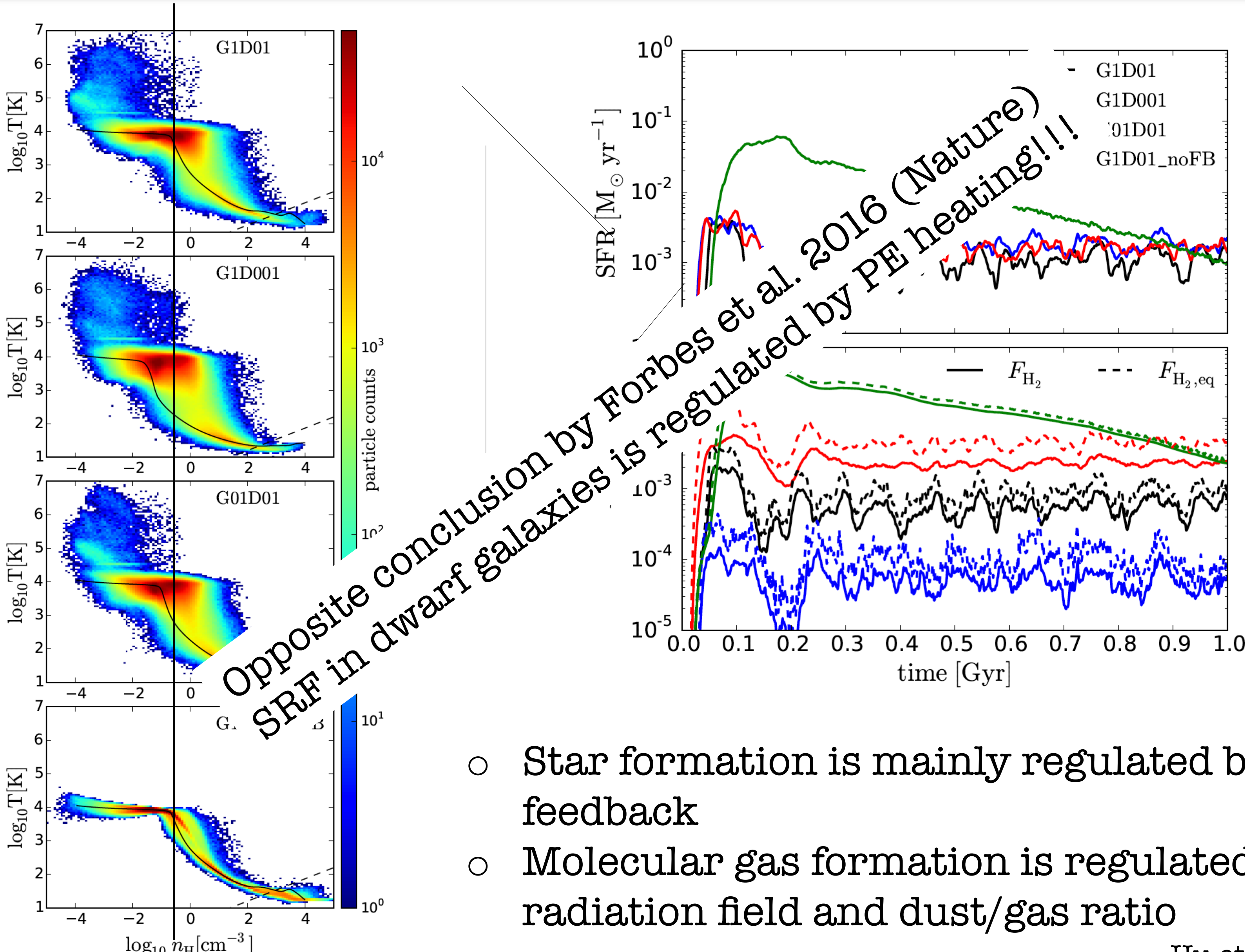


How well do we resolve blast waves in simulations?

(see e.g. dalla Vecchia & Schaye 2012)

Hu et al. 2016

Star formation in dwarf galaxies



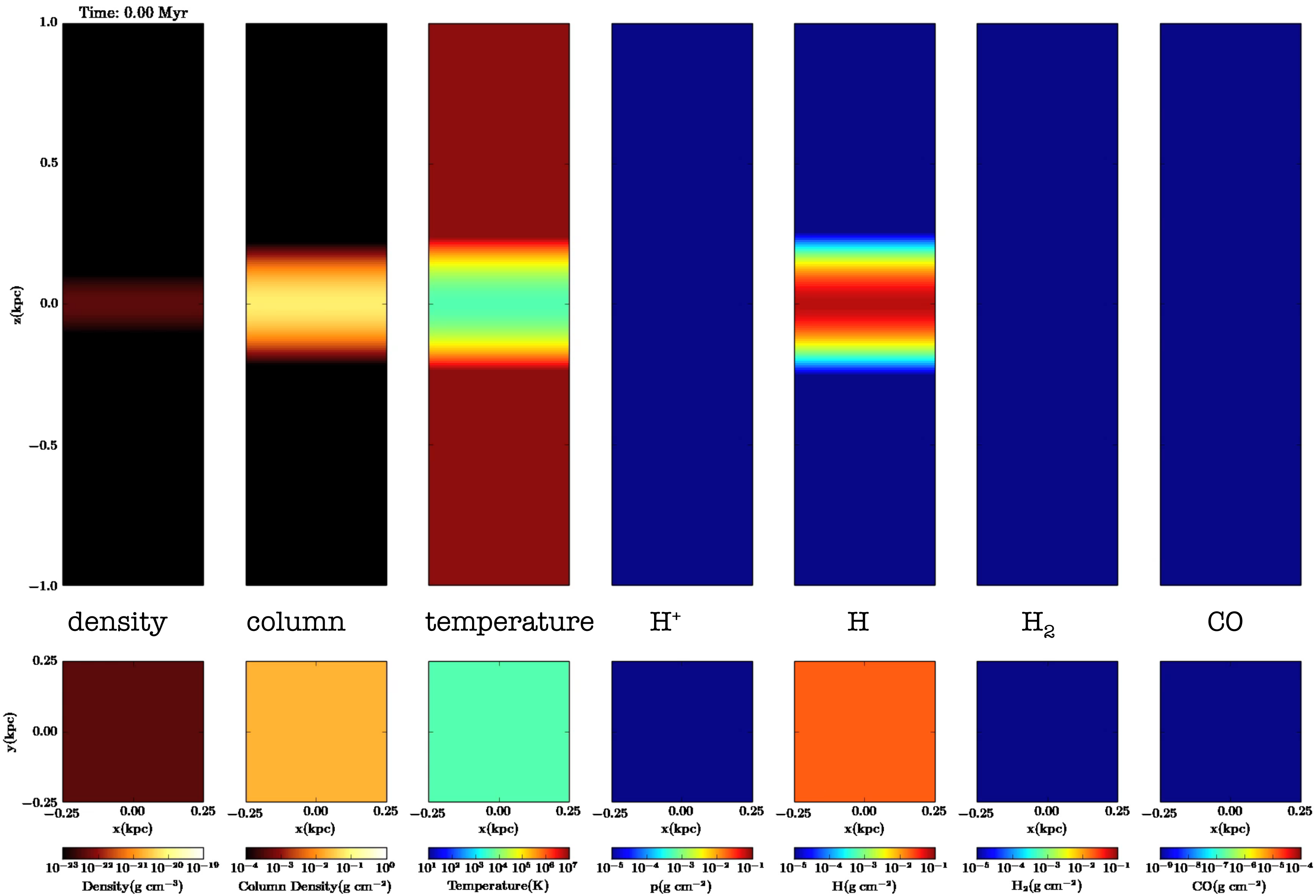
- Star formation is mainly regulated by feedback
- Molecular gas formation is regulated by radiation field and dust/gas ratio

Hu et al. 2016

Which resolution is required?

- Star clusters might be a natural scale:
- Spatially and temporally correlated explosions, wind and ionization models possible, star kinematic can be accounted for - super-bubbles
- Individual supernova explosions (individual massive stars) might be the next natural scale:
- Clustering is automatically accounted for and lower mass stars are possibly less relevant?!
- Gas phase resolution has to be sufficient to follow blast waves AND to follow the dense gas (100 p/ccm)

Molecular outflows in starburst disks

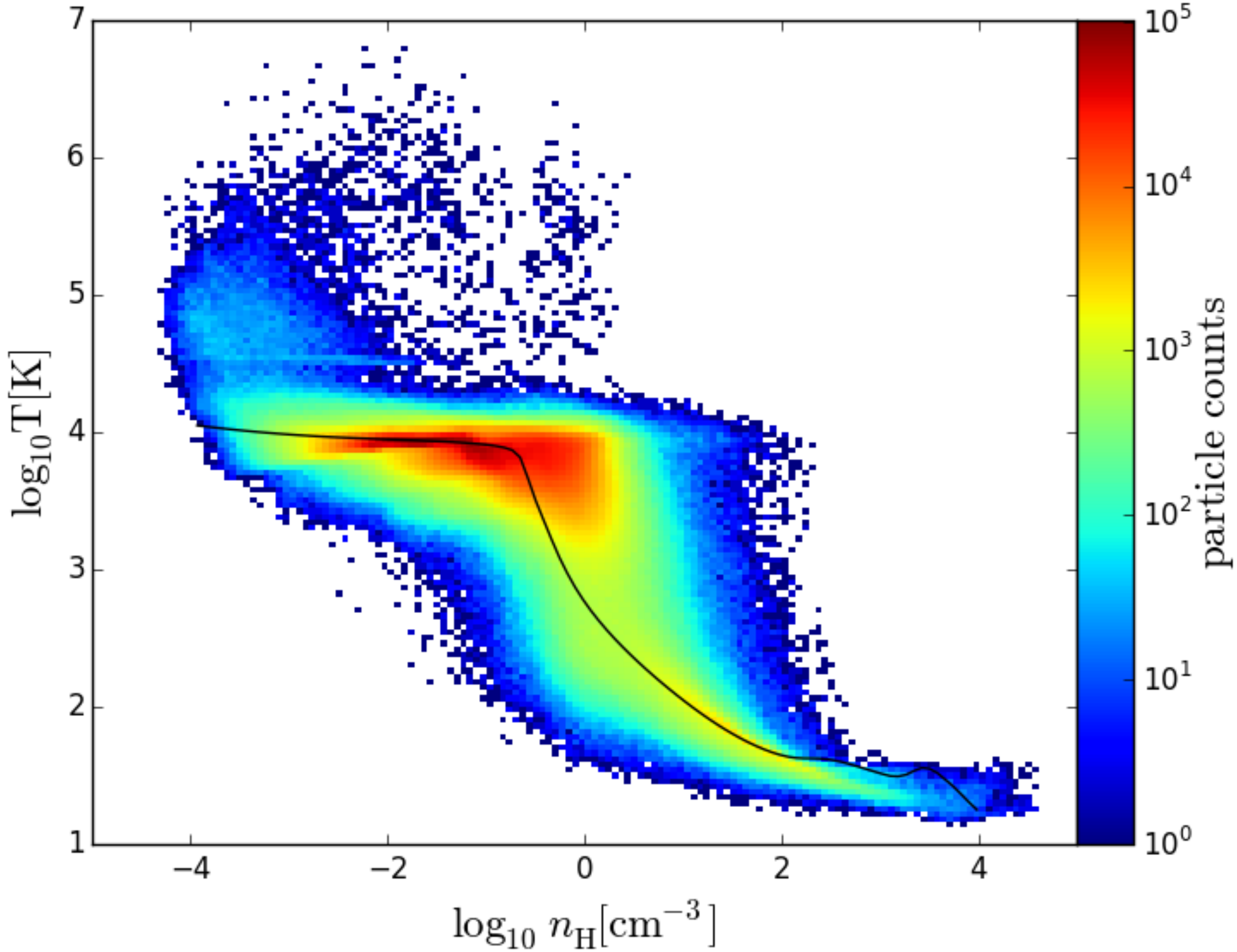


Naab et al. in prep.

Mixing of cold gas in a hot outflow

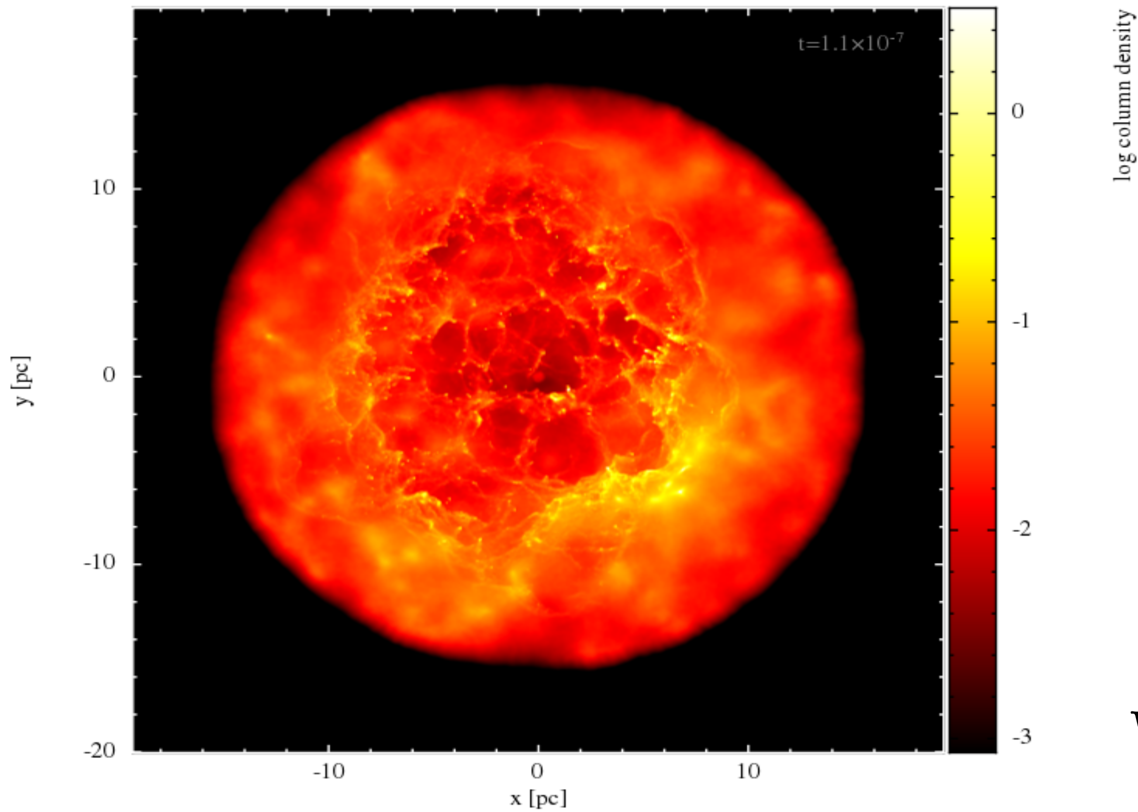
Girichidis et al. in prep.

Star formation in dwarf galaxies



Hu, Naab et al. 2016

Sedov-Taylor blast waves



Walch & Naab 2015

- Sedov-Taylor blast waves (28% kinetic energy, 72% thermal energy) are well studied (e.g. Chevalier 1974, McKee & Ostriker 1977, Ostriker & McKee 1988)
- Significant fraction of the SN energy is radiated early – rapid onset of the snow plough phase – inefficient feedback, but pre-ionisation and cloud structure matters (Walch & Naab 2015)