Discussion:
The ISM and Star Formation Cycle in Galaxies




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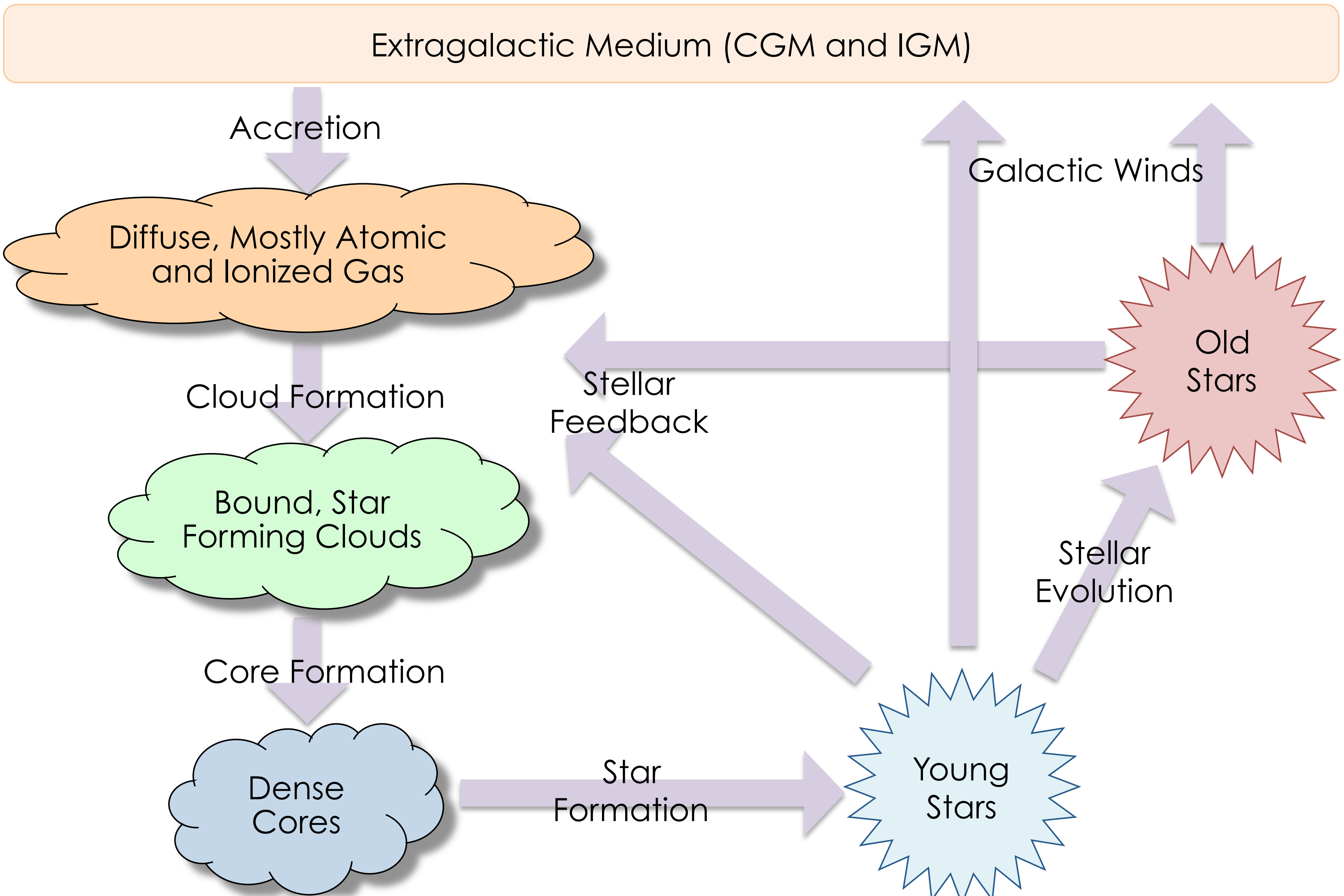
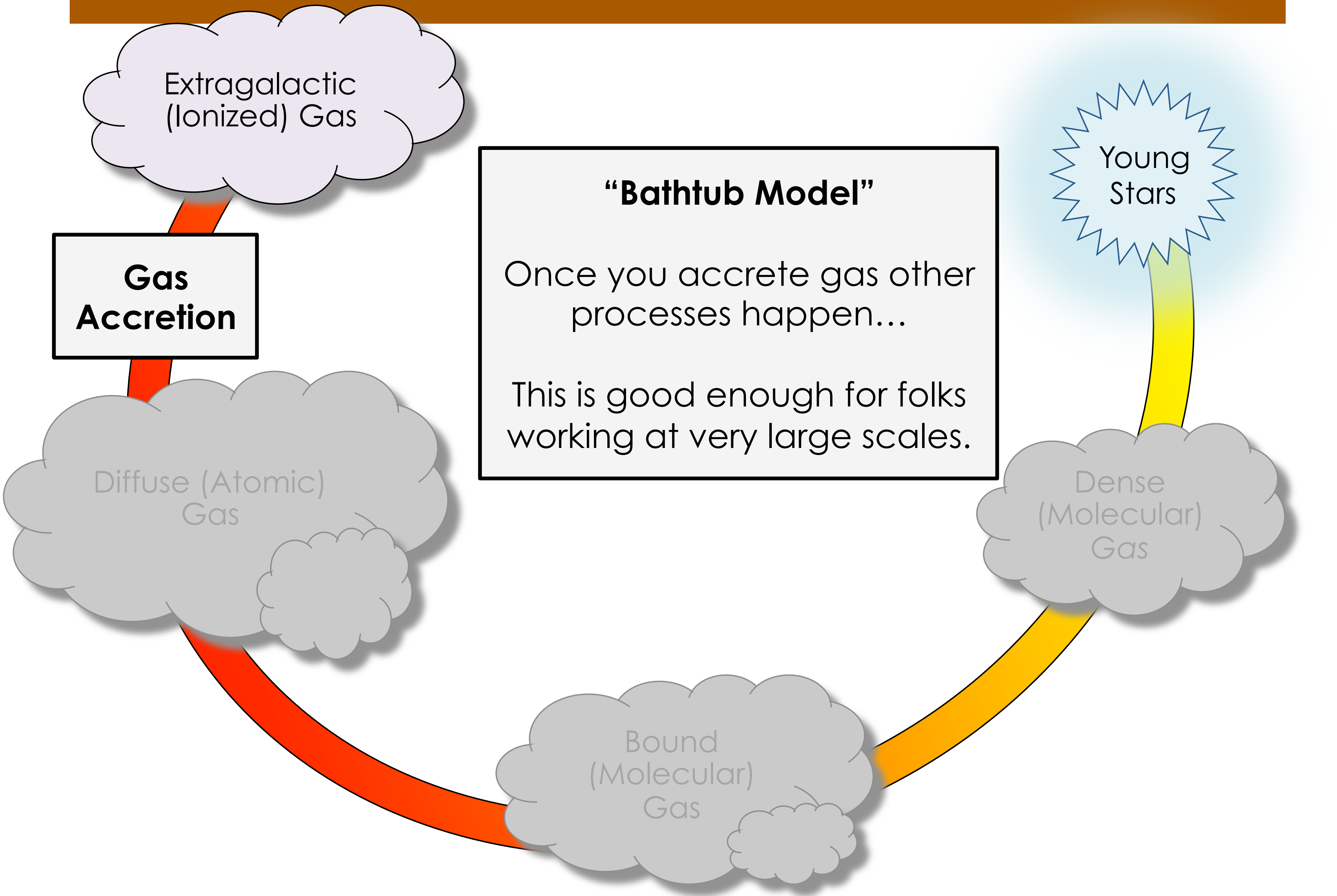
Multi-Process and Multi-Scale



If you zoom out enough

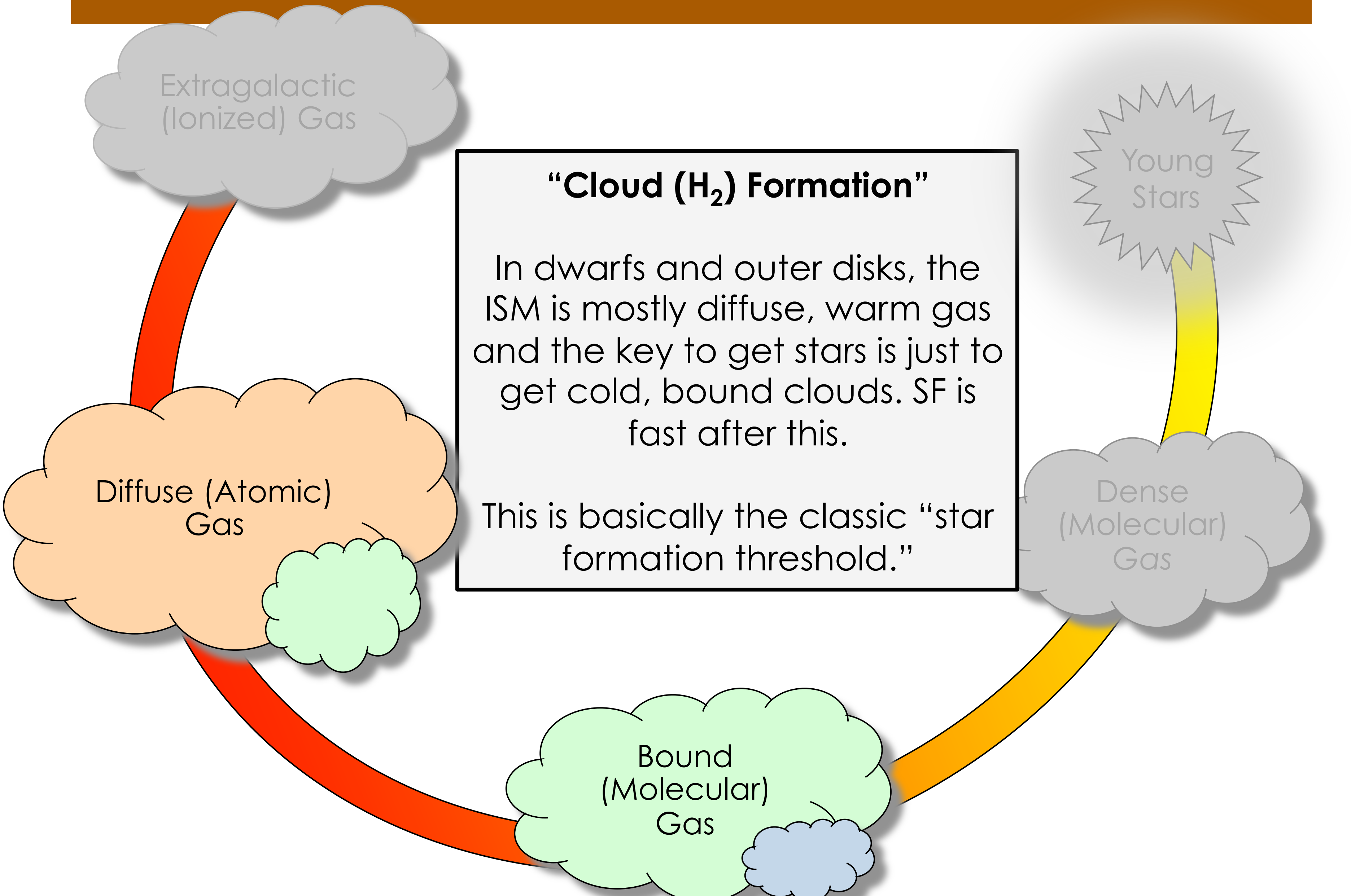


"Bathtub Model"

Once you accrete gas other processes happen…

This is good enough for folks working at very large scales.

A Molecular Bathtub

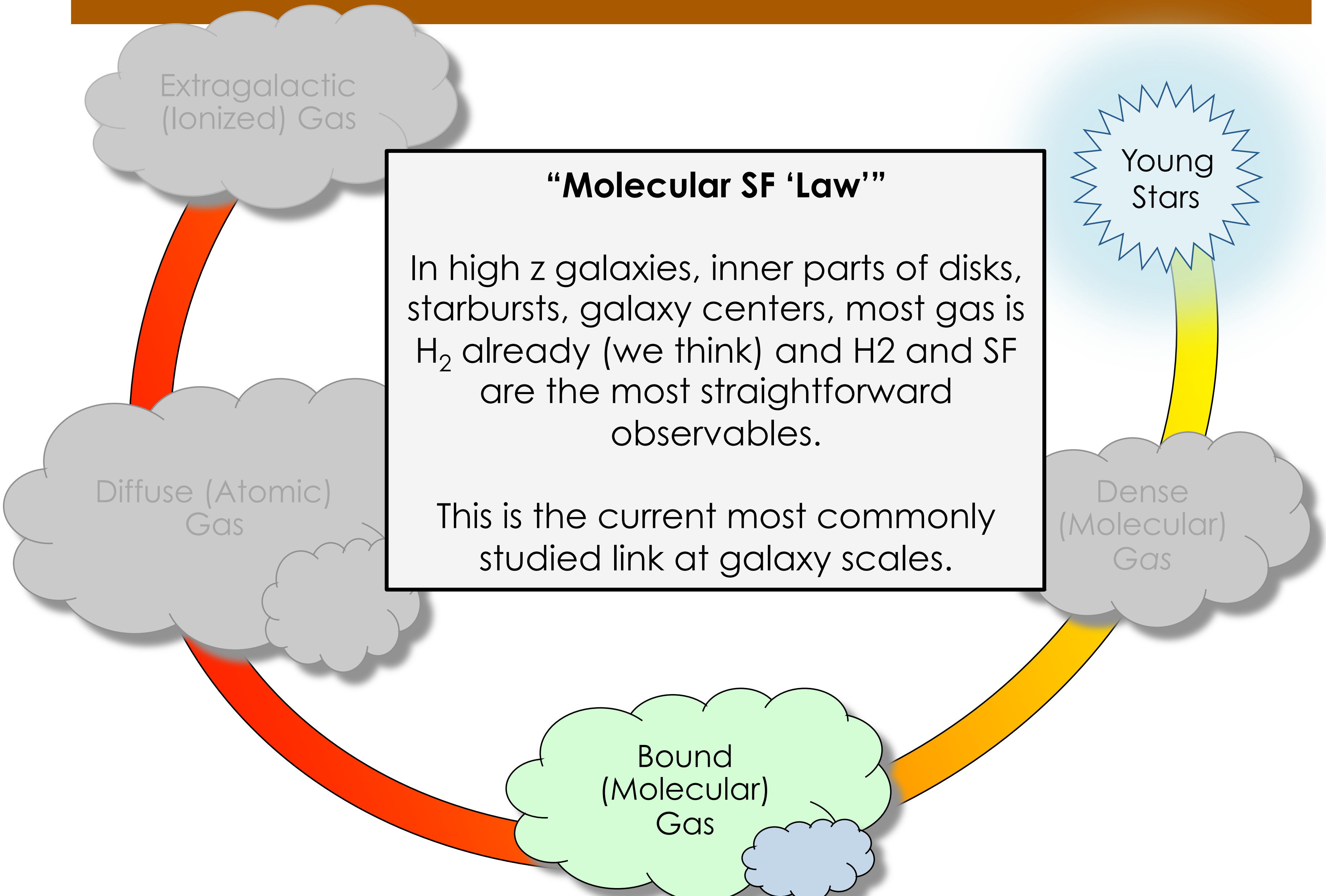


"Cloud (H_2) Formation"

In dwarfs and outer disks, the ISM is mostly diffuse, warm gas and the key to get stars is just to get cold, bound clouds. SF is fast after this.

This is basically the classic "star formation threshold."

From Cold (Bound?) Gas to Stars

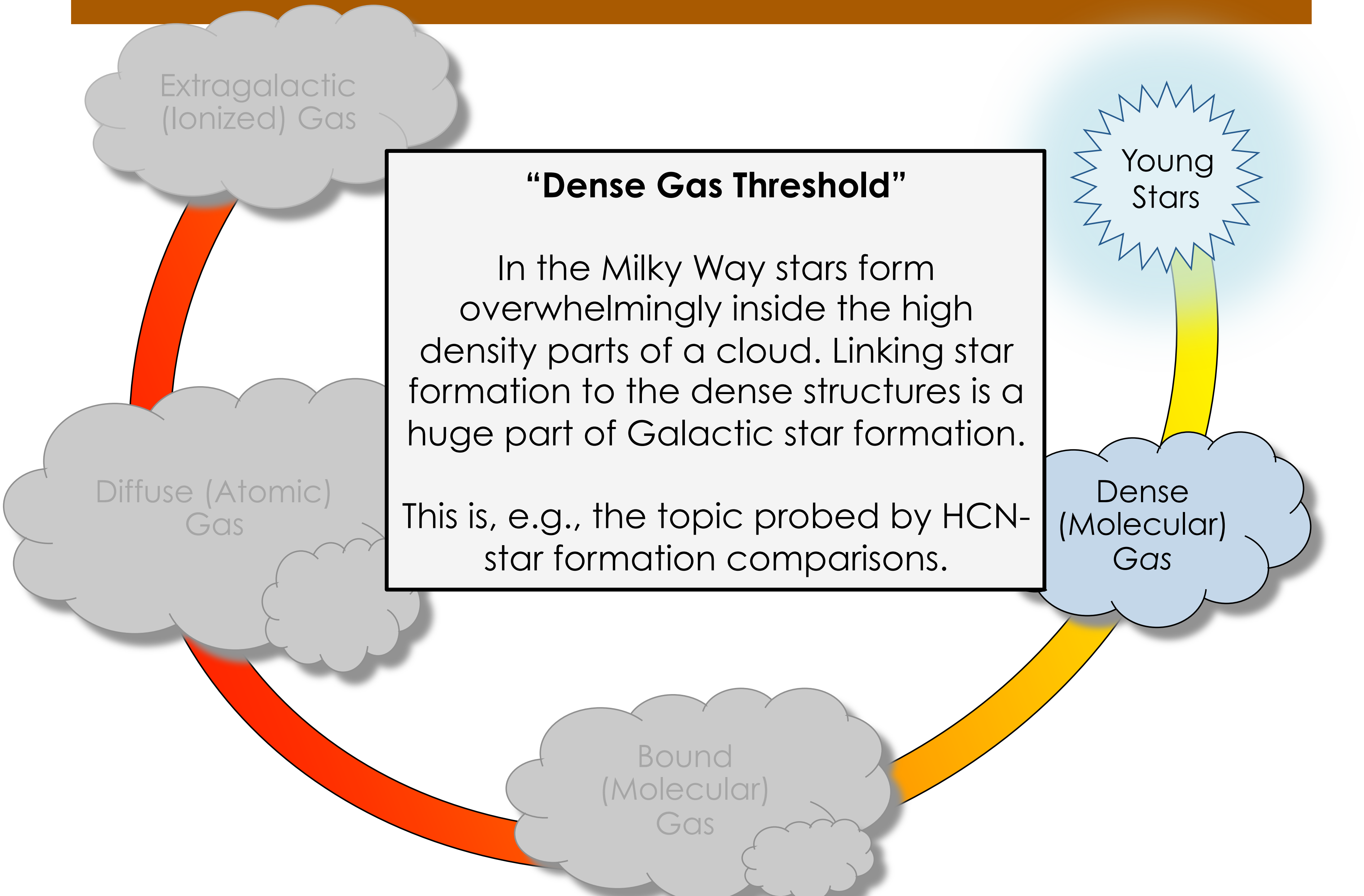


“Molecular SF ‘Law’”

In high z galaxies, inner parts of disks, starbursts, galaxy centers, most gas is H_2 already (we think) and H2 and SF are the most straightforward observables.

This is the current most commonly studied link at galaxy scales.

But Only Dense Gas Forms Stars

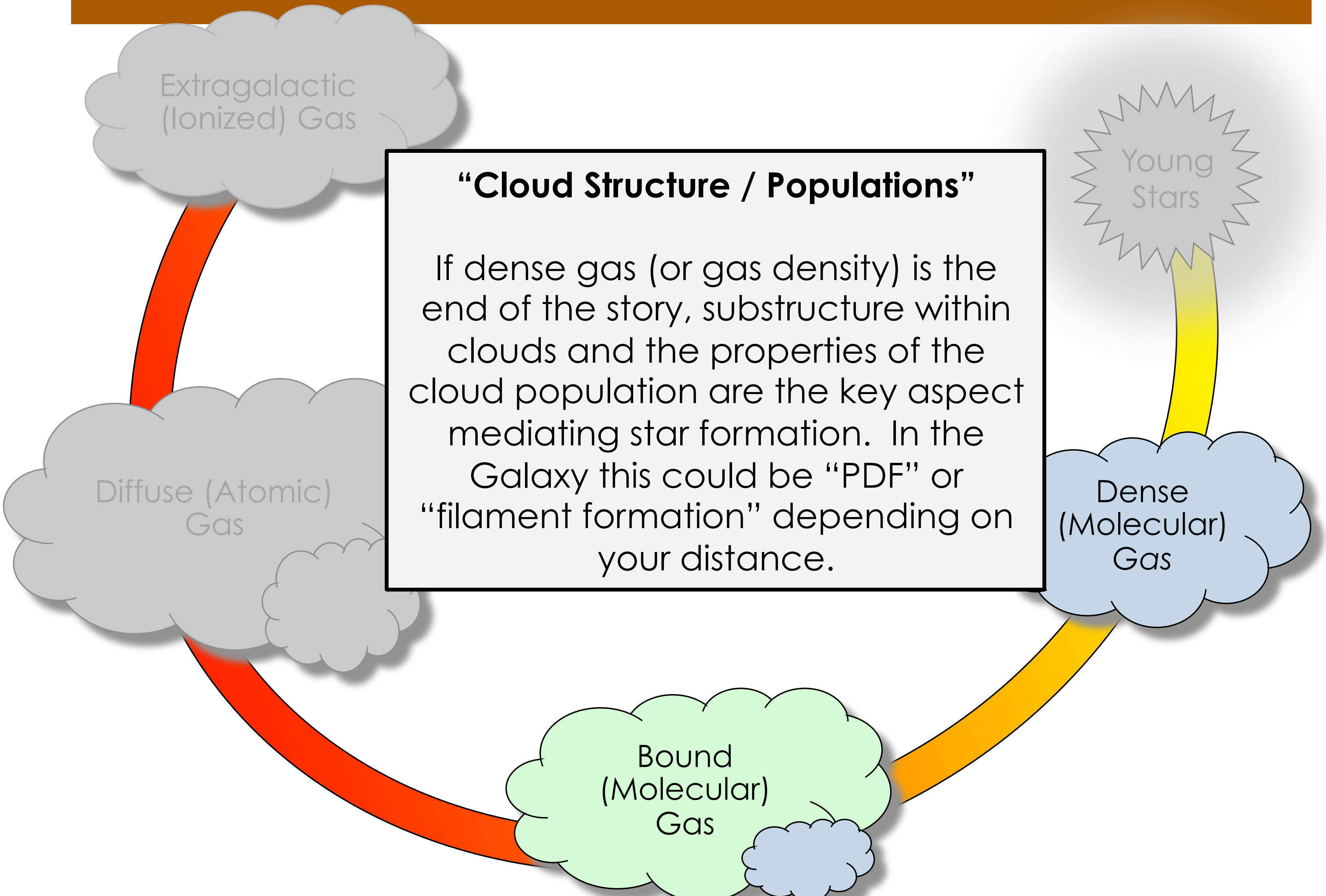


“Dense Gas Threshold”

In the Milky Way stars form overwhelmingly inside the high density parts of a cloud. Linking star formation to the dense structures is a huge part of Galactic star formation.

This is, e.g., the topic probed by HCN-star formation comparisons.

Linking Clouds to Galaxies

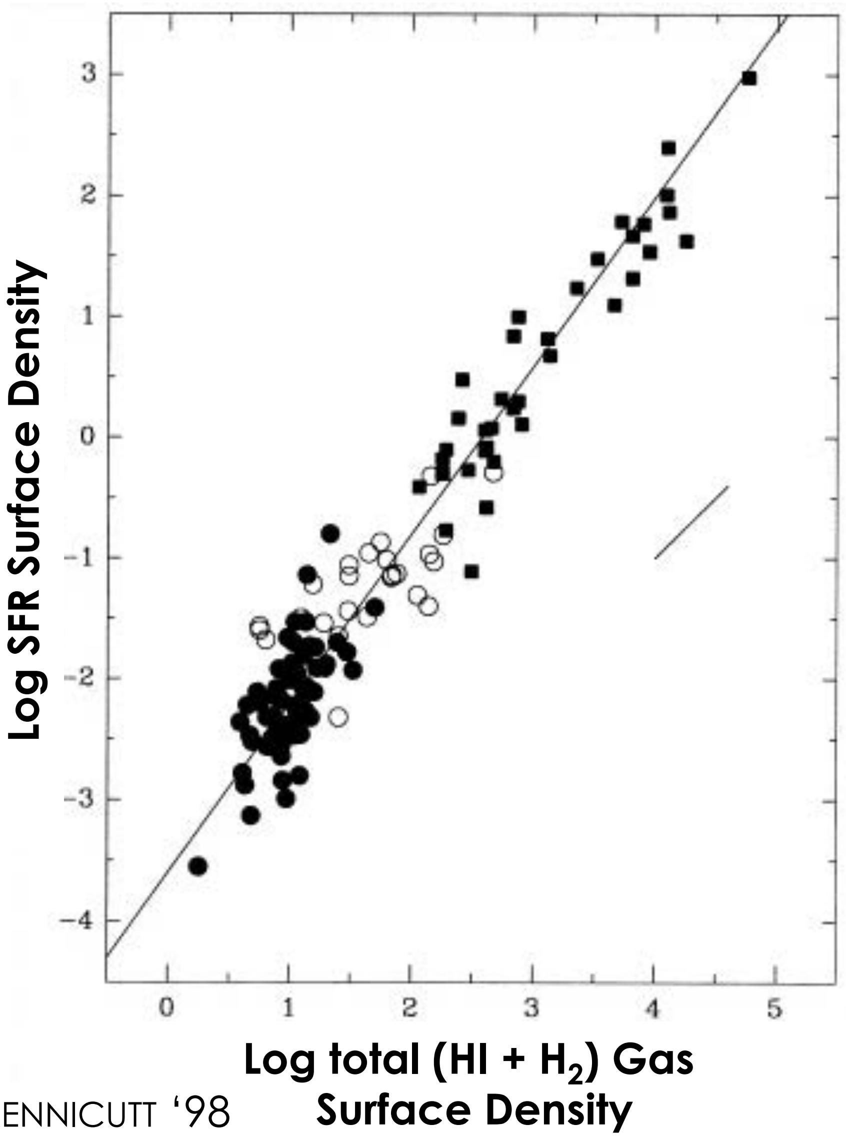


"Cloud Structure / Populations"

If dense gas (or gas density) is the end of the story, substructure within clouds and the properties of the cloud population are the key aspect mediating star formation. In the Galaxy this could be "PDF" or "filament formation" depending on your distance.

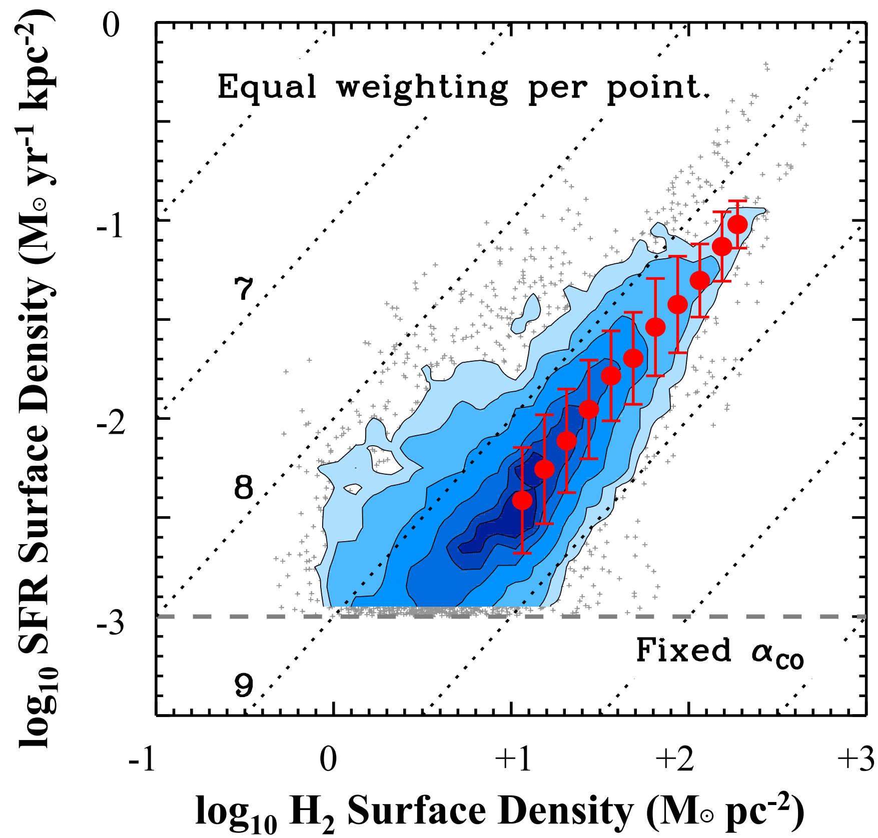
Global Scaling Relations

1 point = 1 galaxy



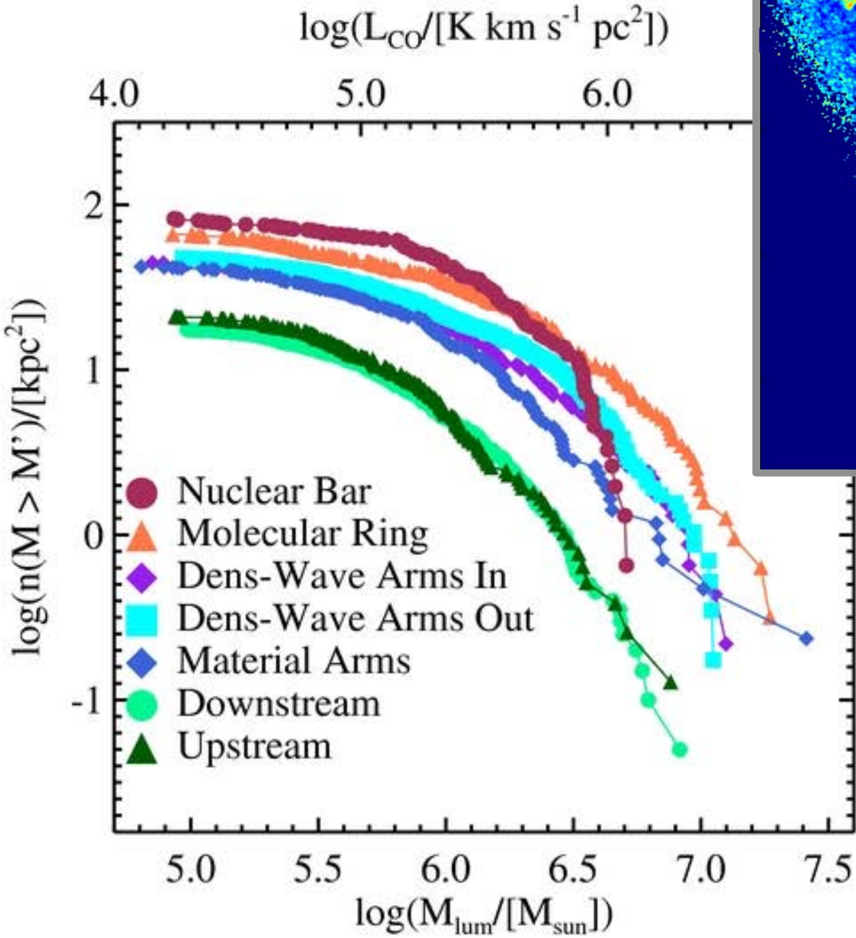
KENNICUTT '98

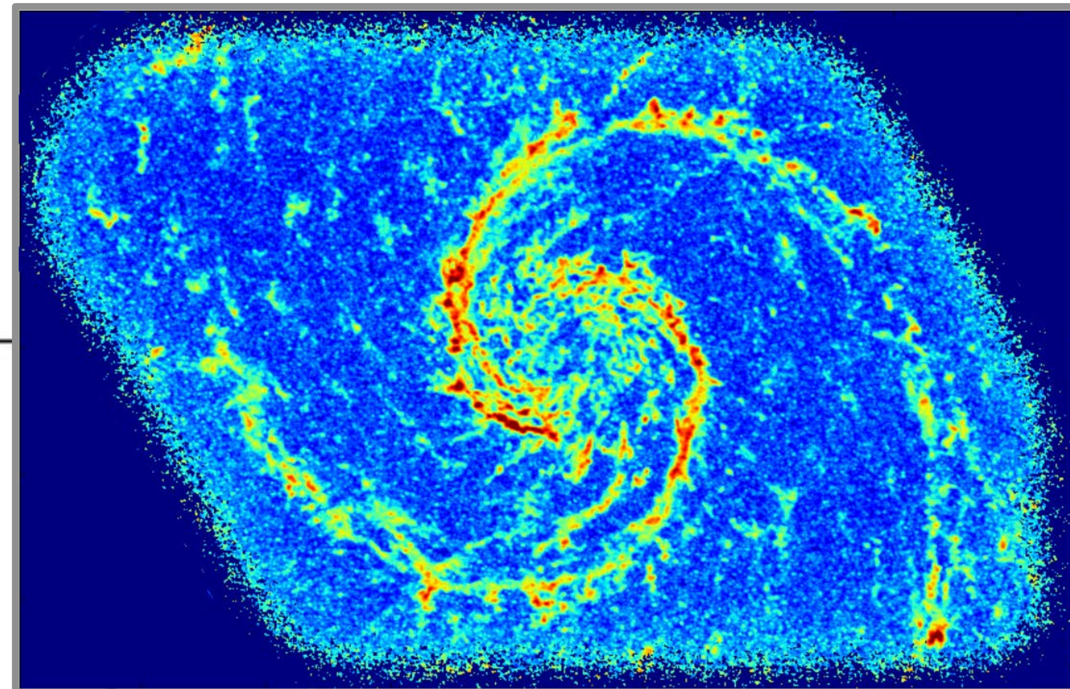
30 galaxies, 1 point = 1 kpc region



LEROY '13

Beyond Global Scaling Relations



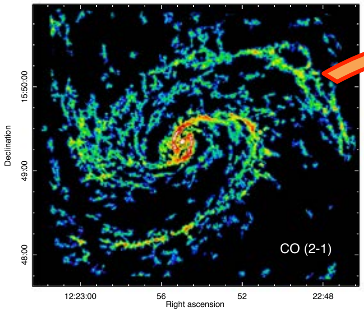


PAWS, Schinnerer+ '13

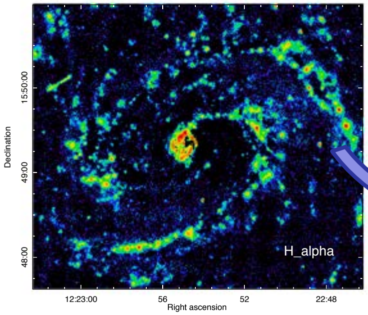
COLOMBO '14

Modeling KS Law Scatter

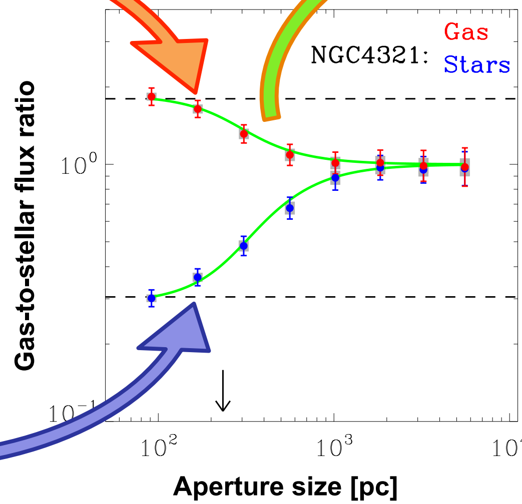
Measure of the **gas-to-stellar flux ratio** focussing on:



gas peaks



stellar peaks

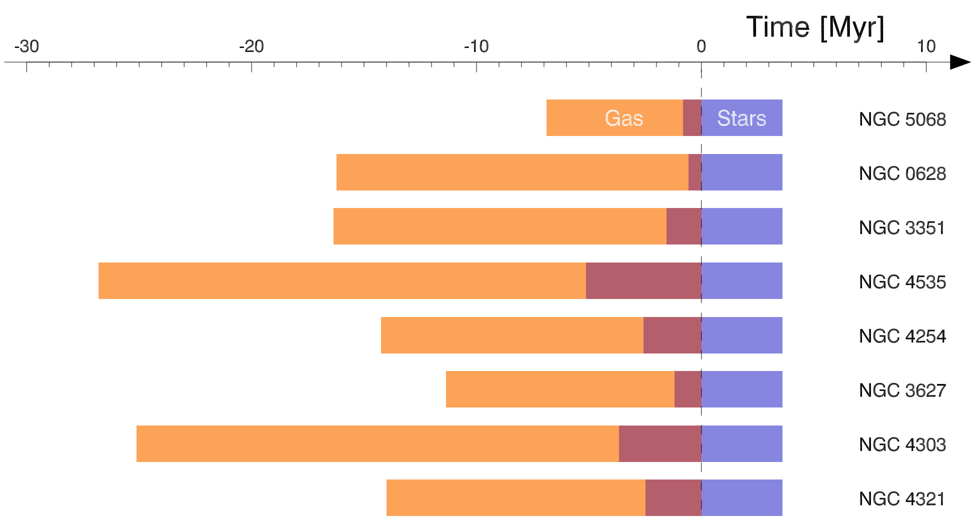


Fit depends on:

- **Cloud lifetime**
- **Separation scale**
- **Feedback timescale**

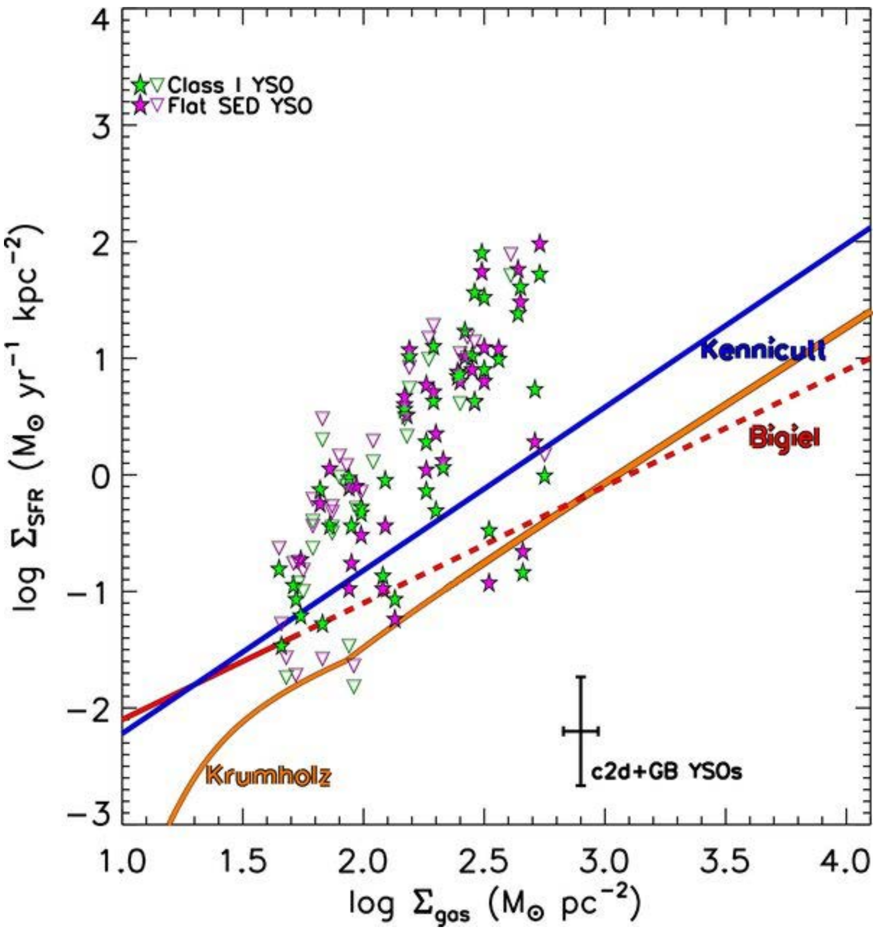
These provide:

- Feedback velocity and efficiency
- Mass loading factor
- Star formation efficiency
- Diffuse gas fraction

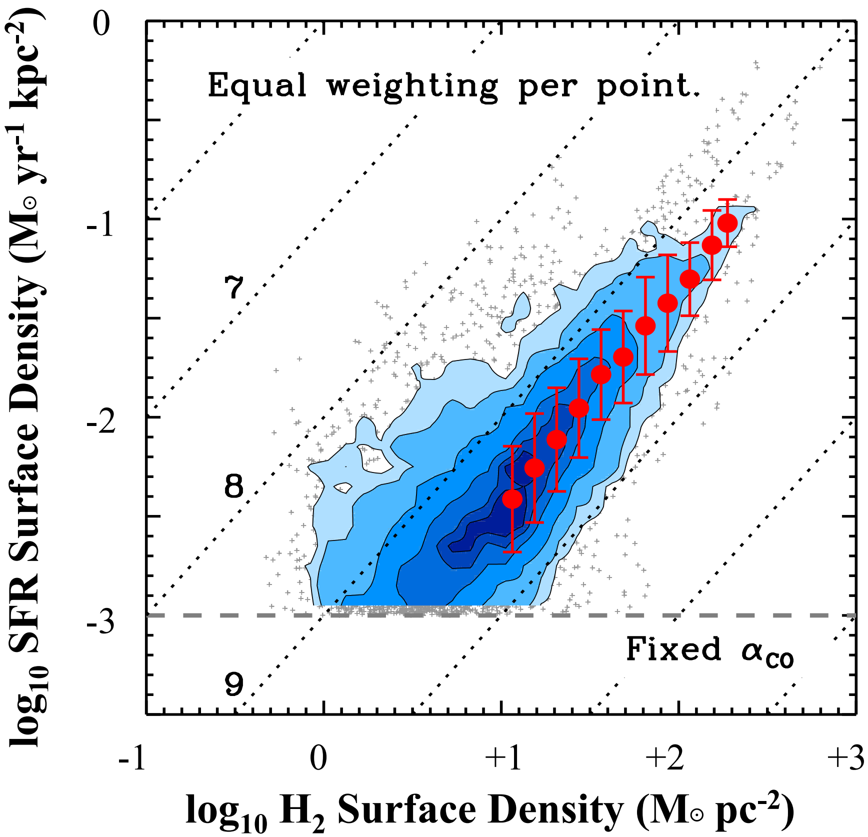


Fit: *Kruijssen et al. 2018*
Cf. Schruba+ '10, Onodera+ '10,
Kruijssen & Longmore '14,
Chevance+ in prep.

Global Scaling Relations & Milky Way Measurements



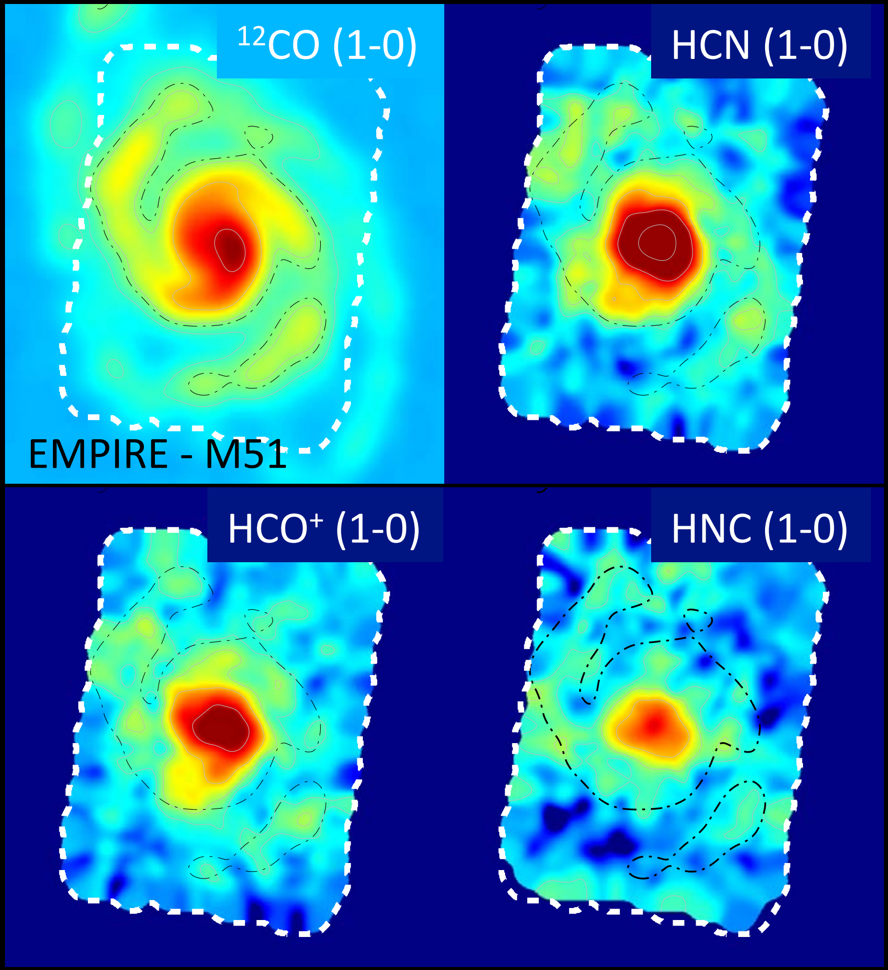
HEIDERMAN '10



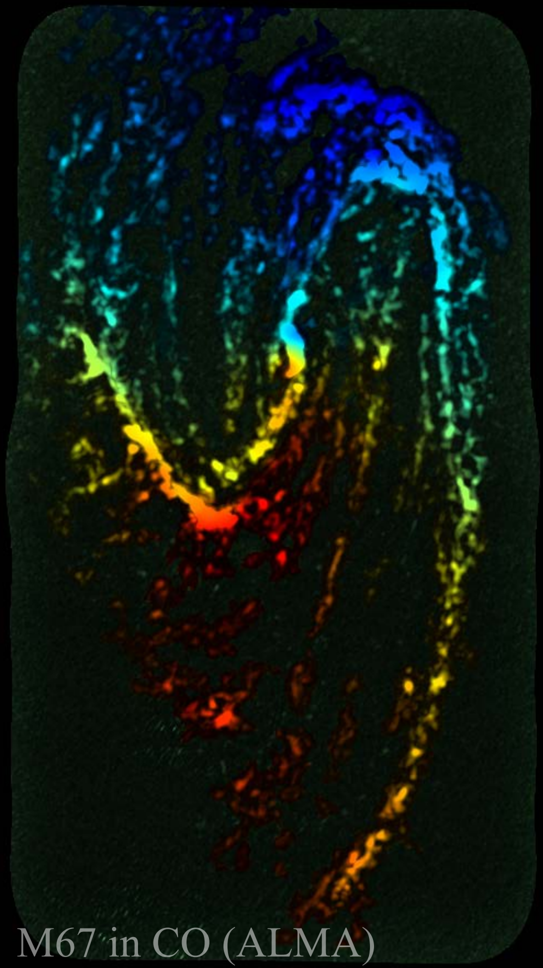
LEROY '13

Full Disk, Molecular Gas Spectroscopy

Full Disk, Cloud Scale (1") Molecular Gas Mapping

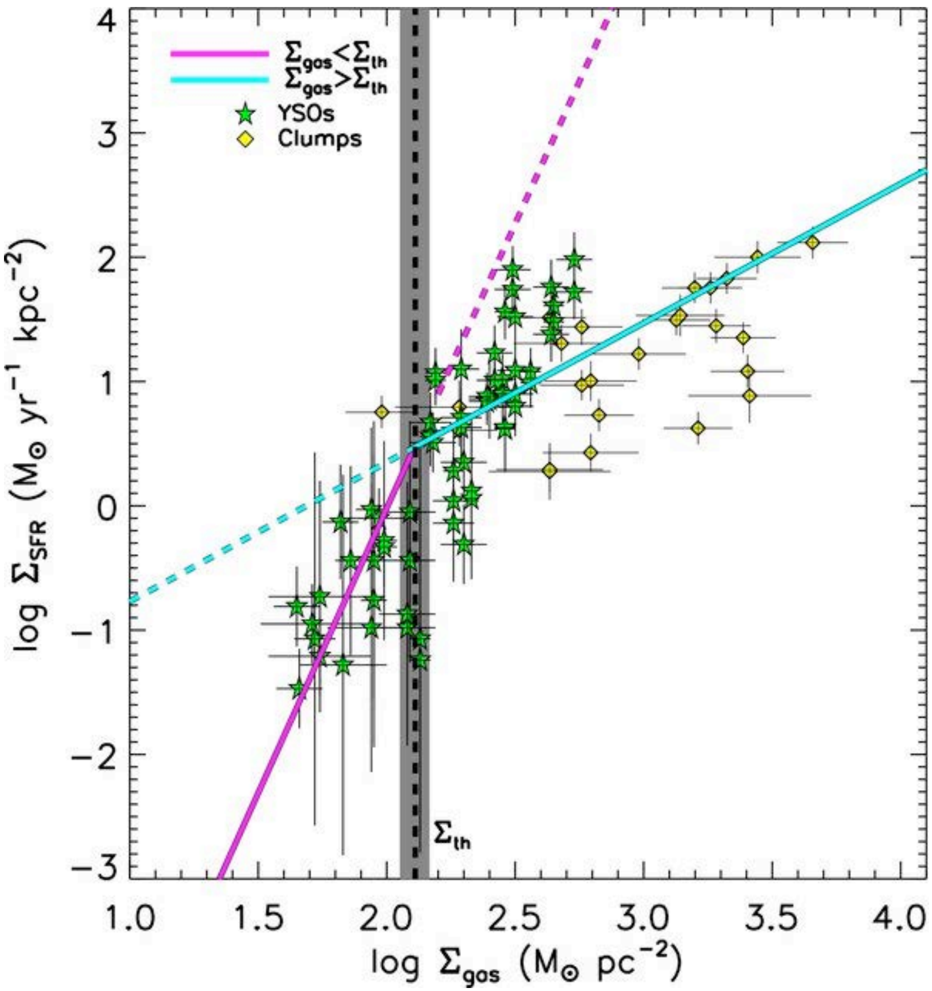


EMPIRE Survey, Bigiel+ '16, Jimenez-Donaire+ '17a,b, Cormier+ '18, Gallagher+ '18

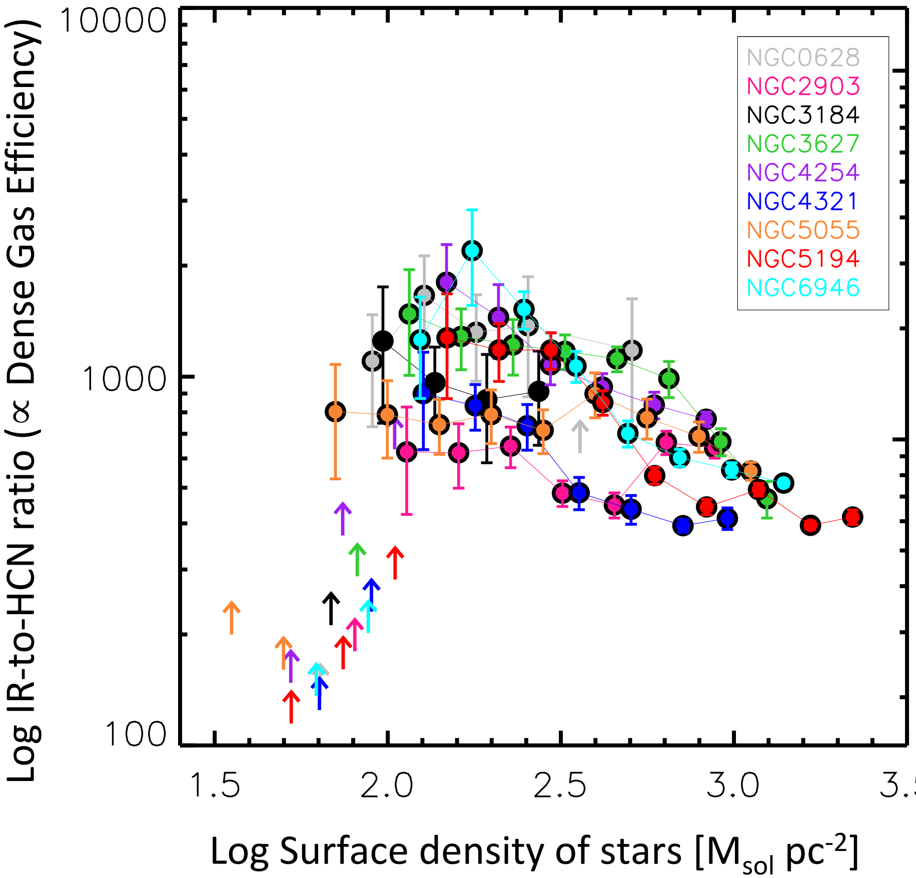


PHANGS Collaboration, Leroy+ in prep., Schinnerer+ in prep.

Star Formation Thresholds in the MW and Beyond

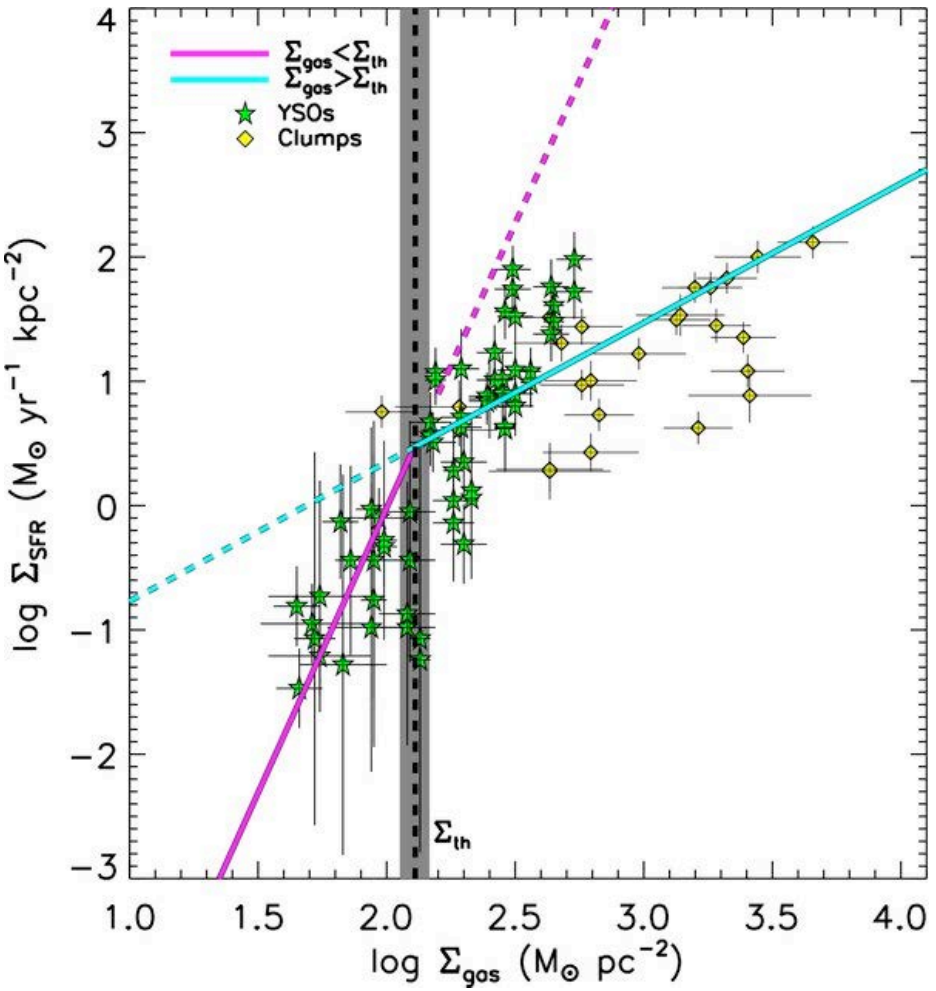


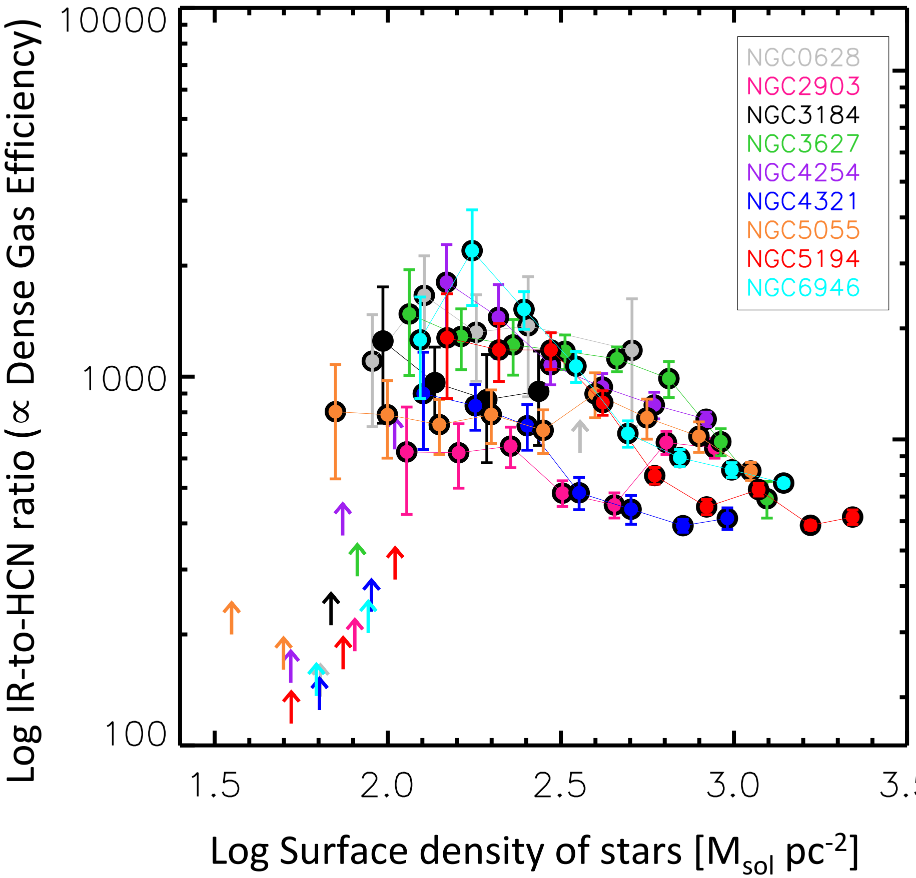
HEIDERMAN ET AL. (2010), EVANS ET AL. (2014), LADA ET AL. (2010, 2012) – C.F. FILAMENTS IN ANDRE ET AL. (2014)



EMPIRE: JIMENEZ-DONAIRE, BIGIEL+ IN PREP.

Star Formation Thresholds in the MW and Beyond



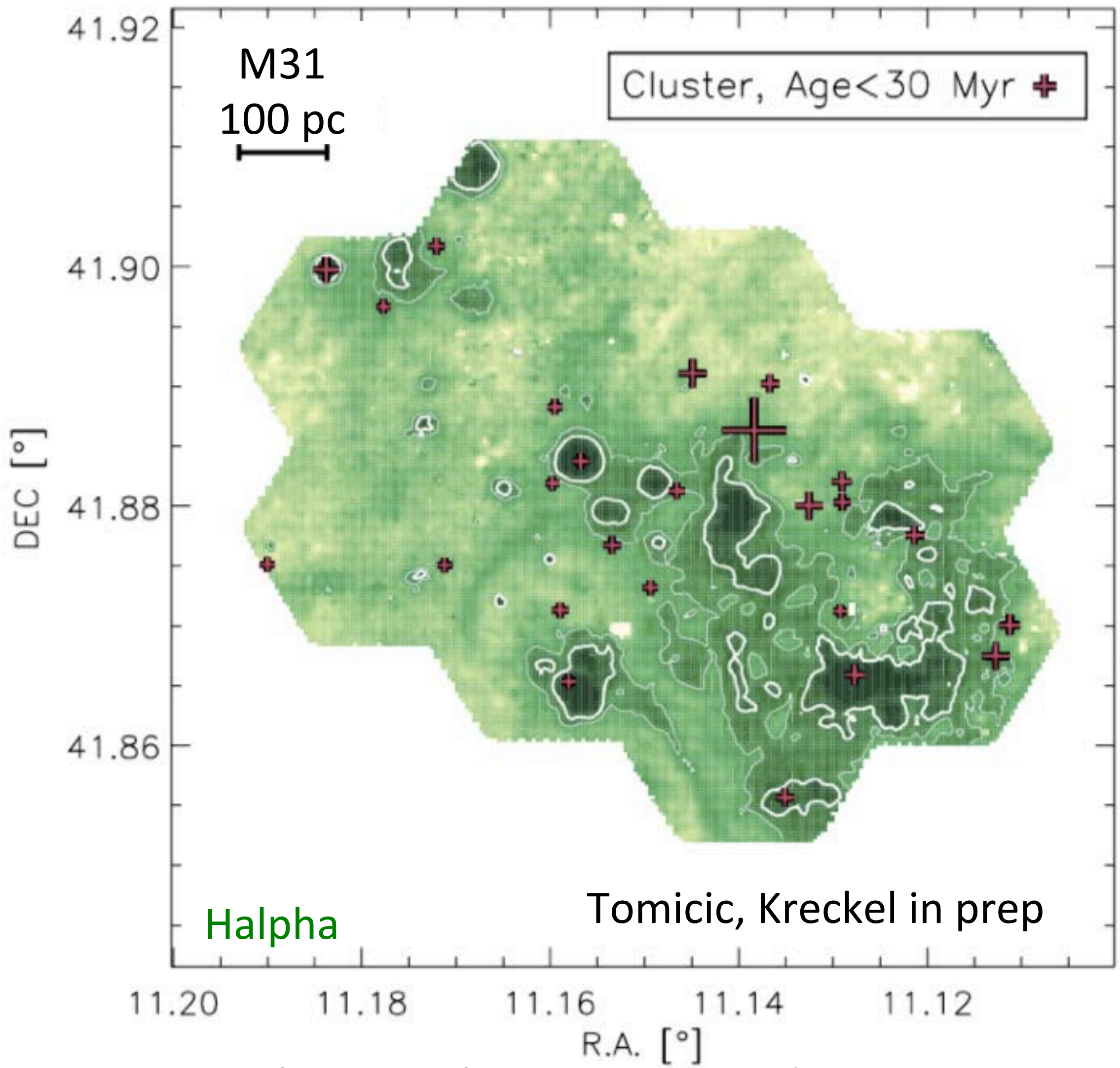


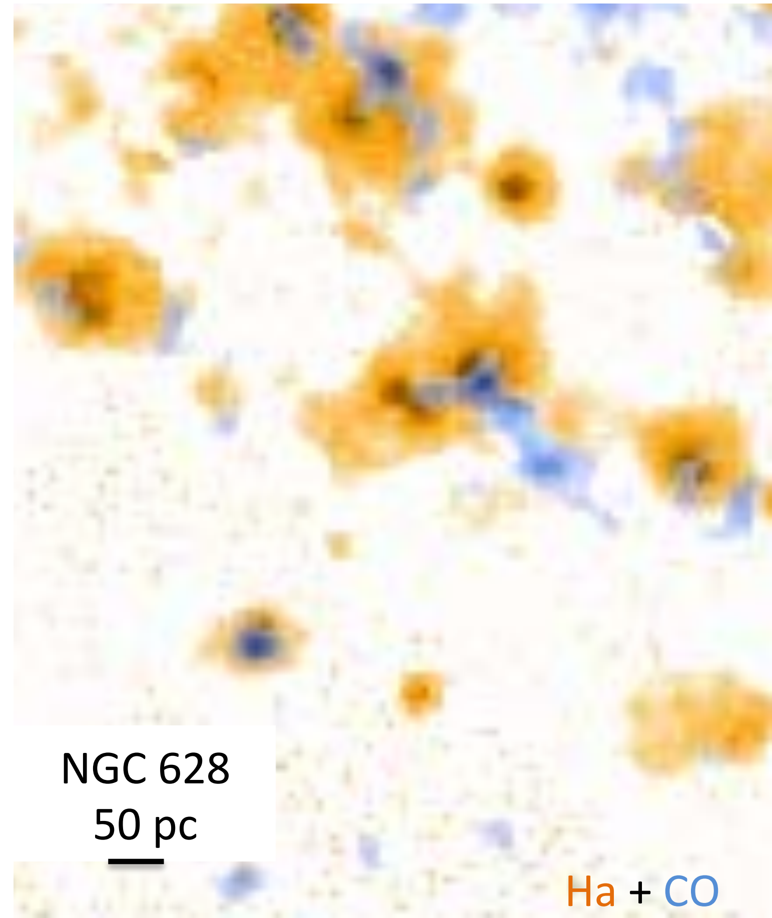
EMPIRE: Jimenez-Donaire, Bigiel+ in prep.

Heiderman et al. (2010), Evans et al. (2014), Lada et al. (2010, 2012) – c.f. Filaments in Andre et al. (2014)

Ionized ISM: High resolution CO/Halpha/Star cluster comparisons

Ongoing/future work: PHAT, LEGUS, PHANGS, SDSSV/LVM



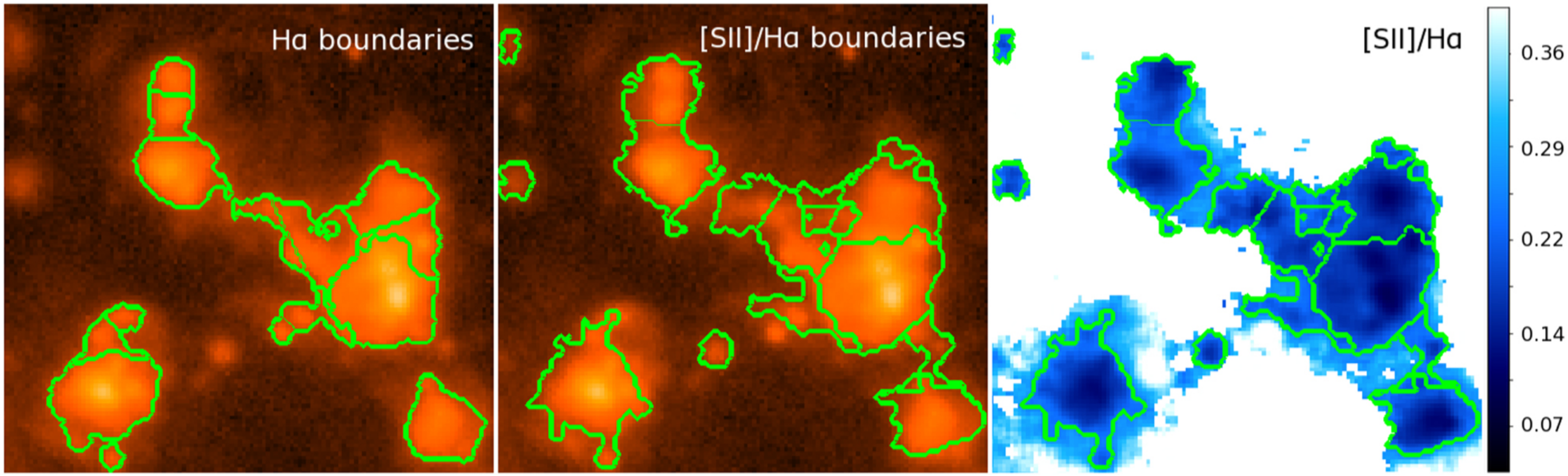


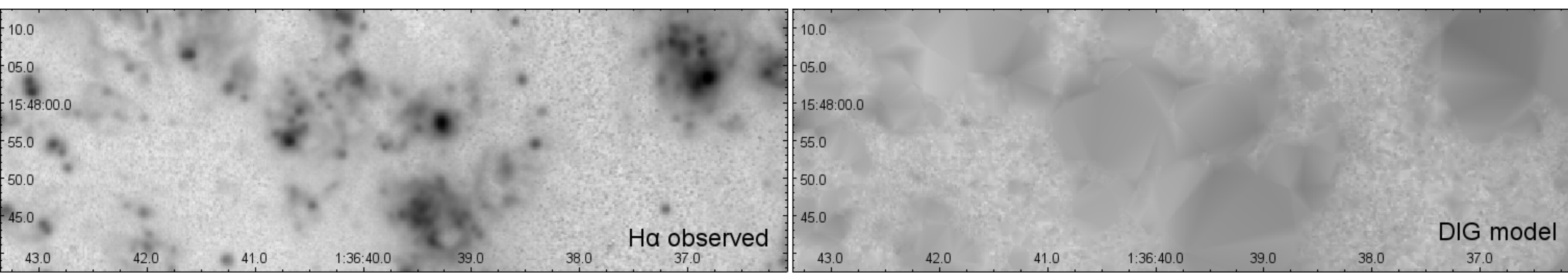
Kreckel+2018

- Time evolution makes interpreting direct comparisons on small (<50pc) scales challenging
- How to link the small scale (feedback) physics across different tracers? (stars/clusters, HII regions, H_2)

Ionized ISM: Diffuse Ionized Gas

Ongoing/future work:
MaNGA, CALIFA, PHANGS, SDSSV/LVM



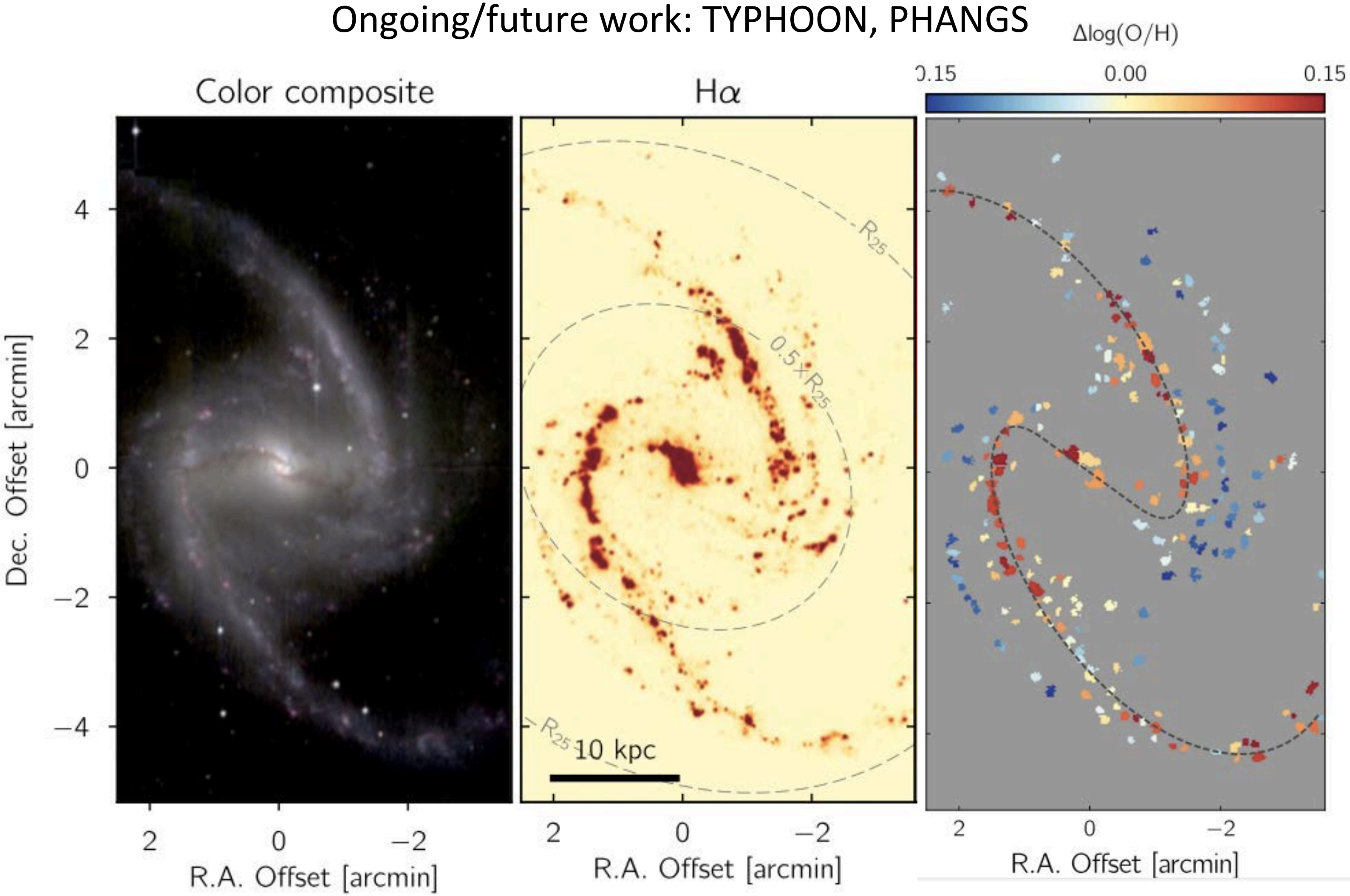


Kreckel+2016, Kreckel+2018

- Characterized by extended morphology, higher temperature, lower density than HII regions.
- Ionized by leaky HII regions? old hot stars? shocks? (Zhang+2017)
- ~50% of Halpha emission, should it be accounted for in SFR? How?

Ionized ISM: Metal Enrichment & Mixing

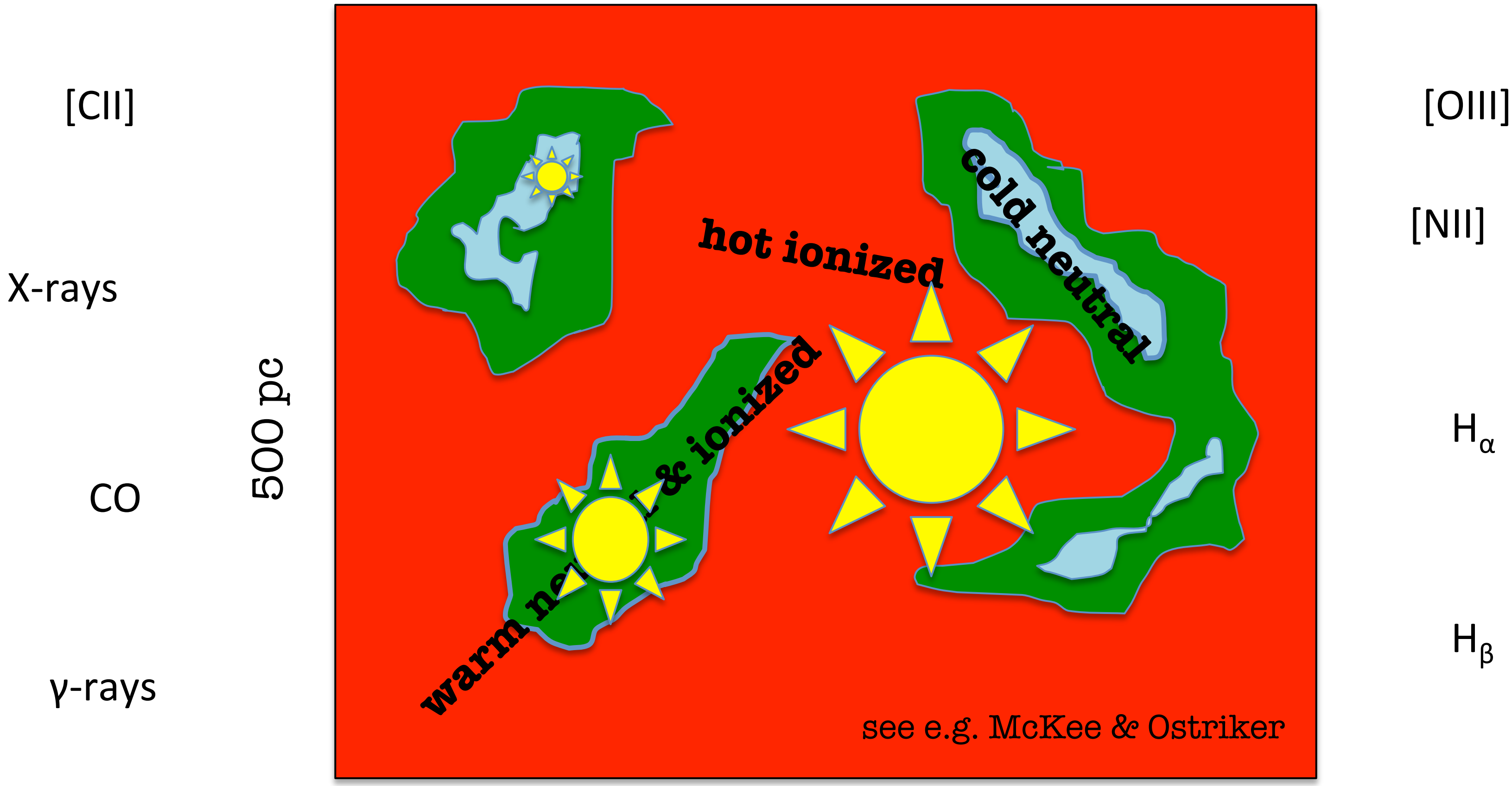
Ongoing/future work: TYPHOON, PHANGS



- Chemical enrichment Intimately related to the feedback (Emerick's talk)
- How does localized enrichment along spiral arms impact future generations of star formation?

Ho+2017

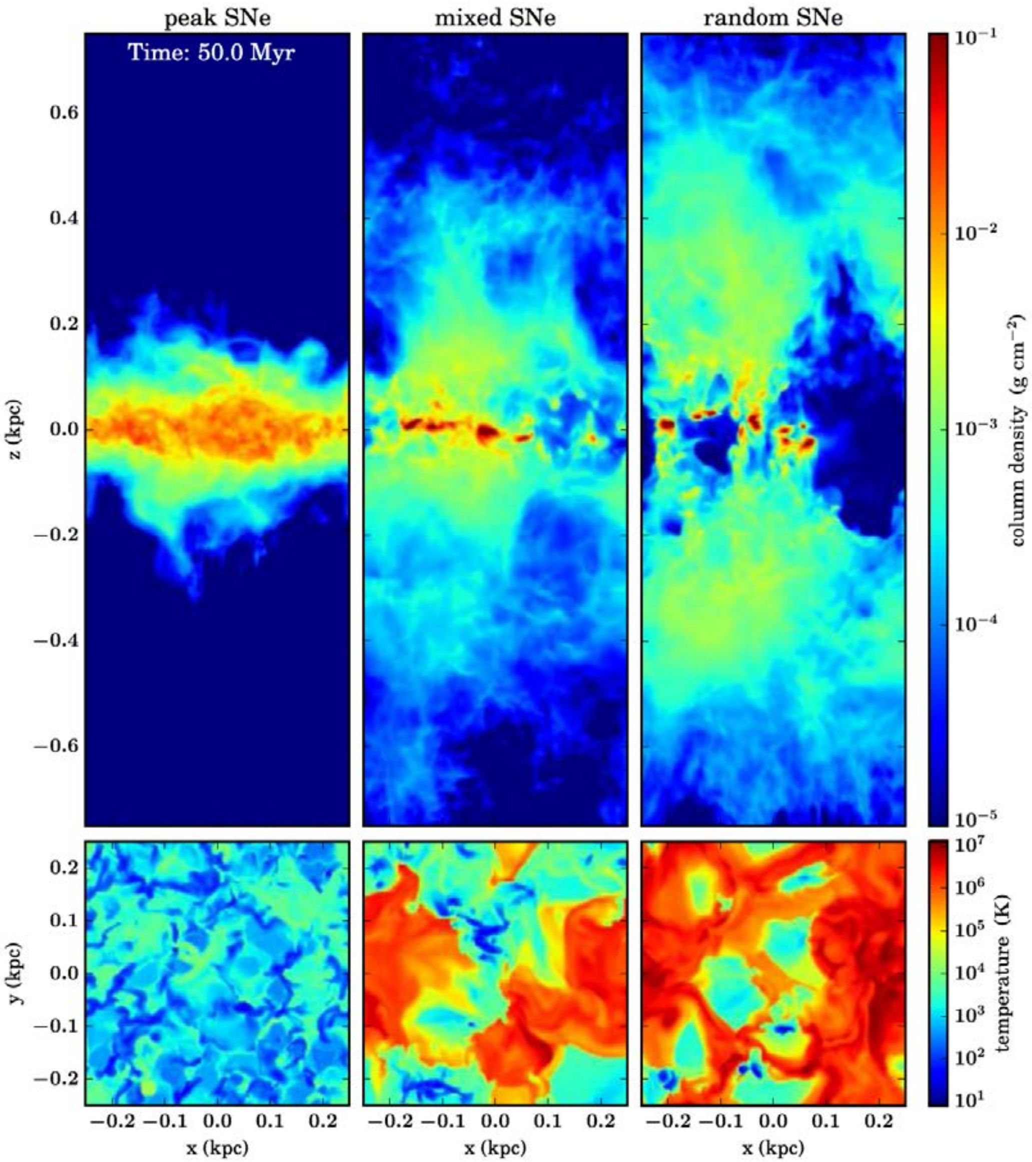
The multi-phase ISM drives galaxy evolution



- Volume in the ISM is filled with hot ionized, warm ionized & neutral gas
- Mass is mostly in warm/cold & molecular medium
- Ambient density of supernova explosions determines their impact
- Stable hot volume filling phase drives outflows

The impact of SN location on ISM properties (SILCC)

Walch et al. 2015, figure from Naab & Ostriker 2017

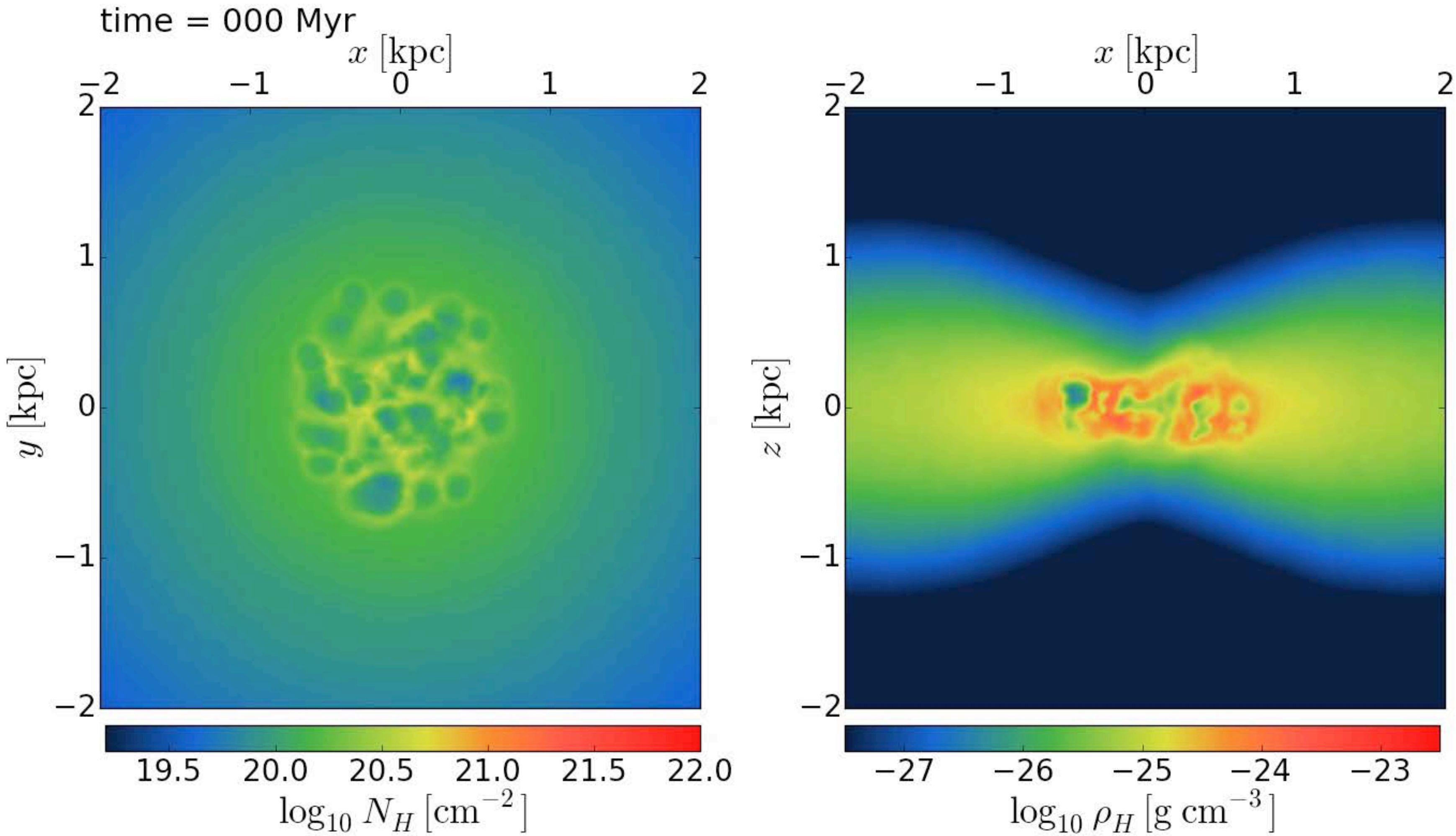


The ambient density of supernova explosions determines the fate of the ISM and outflows (Girichidis et al. 2016, Gatto et al. 2016)

Various physical processes impact ISM structure & ambient densities of SNe: walkaway/runaway OB stars, stellar winds, radiation, clustered SNe (Mac Low+, Hennebelle+, Ostriker+, Martizzi+ etc.)

Kim, Kim & Ostriker 2011, Hennebelle & Iffrig 2014, Walch et al. 2015, Girichidis et al. 2016, Naab & Ostriker 2017, Gatto et al. 2016, Li et al. 2016

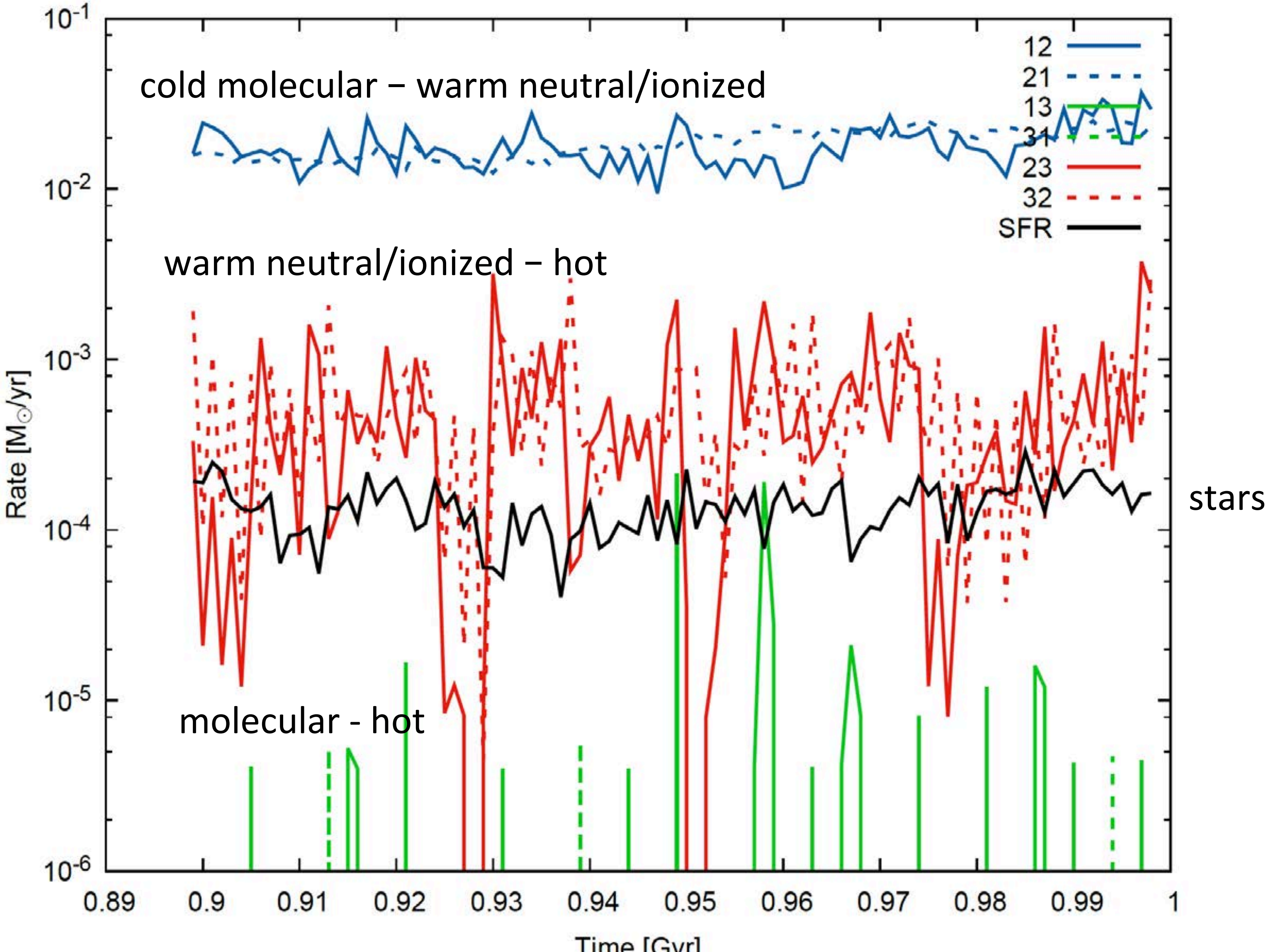
Star formation in dwarf galaxies



Simulations with chemical network, radiation and feedback from individual stars (individual tracks), see Emerick

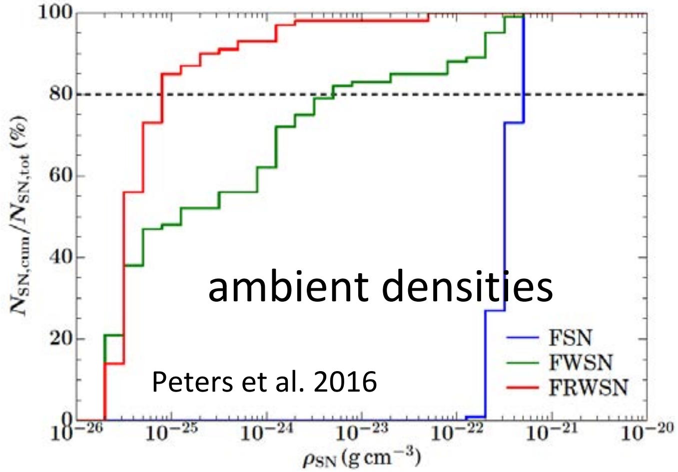
Hu, Naab et al. 2017

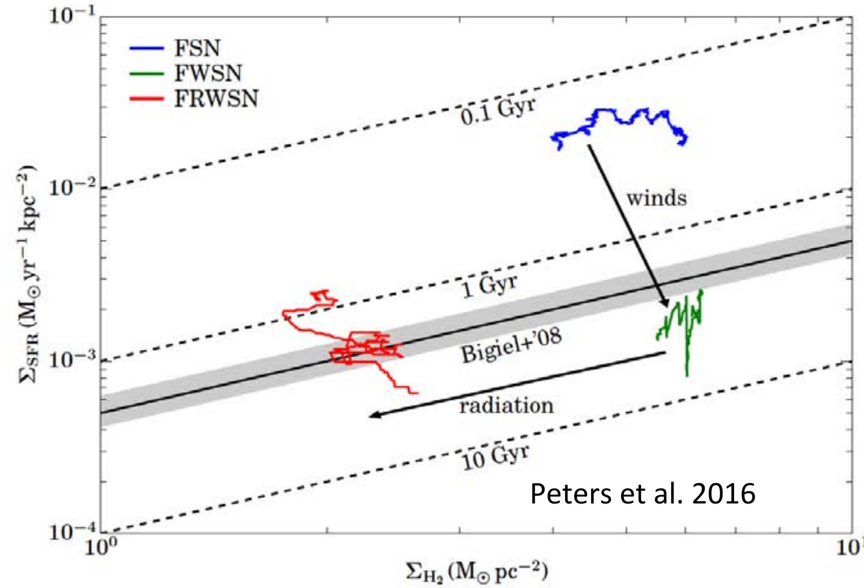
Follow the feedback driven matter cycle

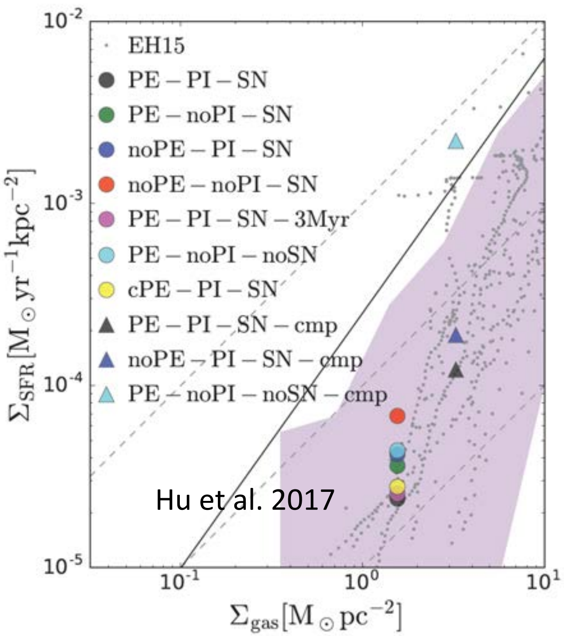


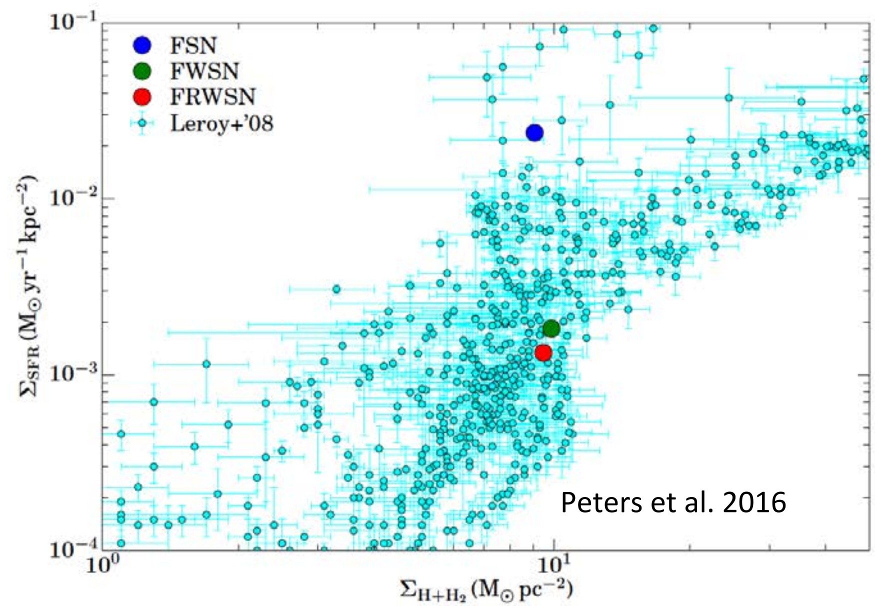
Zhukovska et al.. In prep.

Comparison to observations at different wavelengths



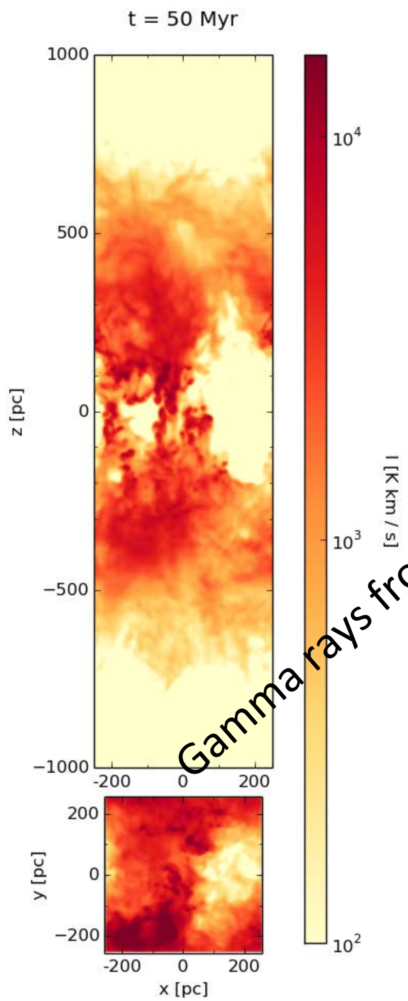






see also ATHENA, RAMSES & AREPO efforts!!!

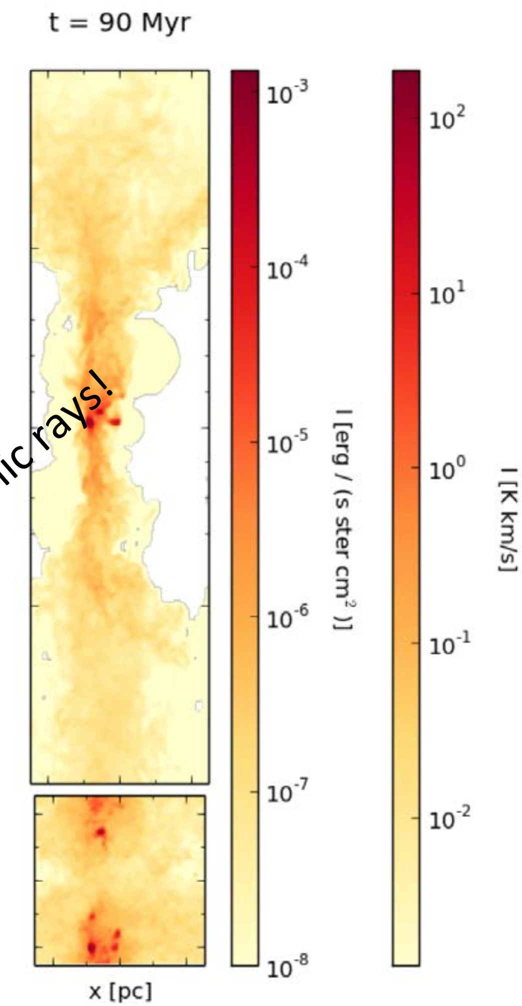
Comparison to observations at different wavelengths



HI emission

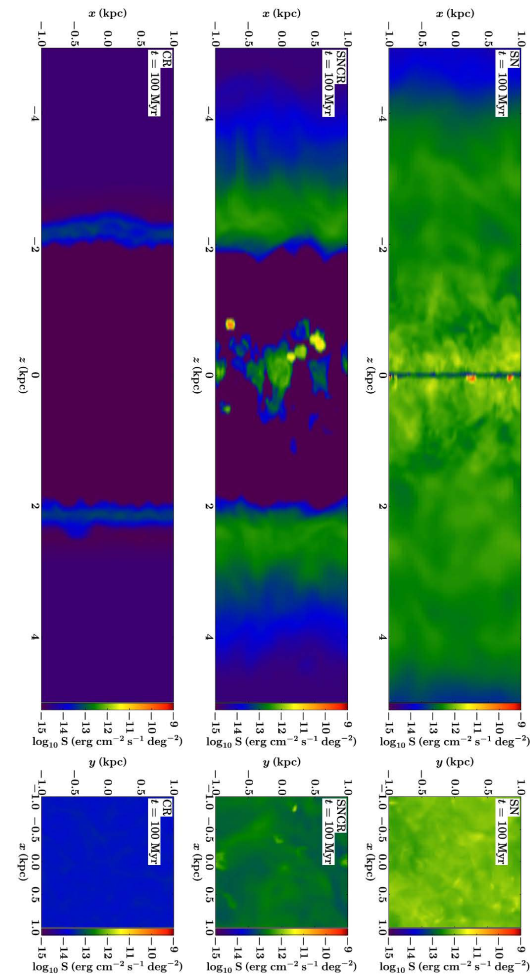
Franneck, Walch et al., in prep.

Gamma rays from cosmic rays!



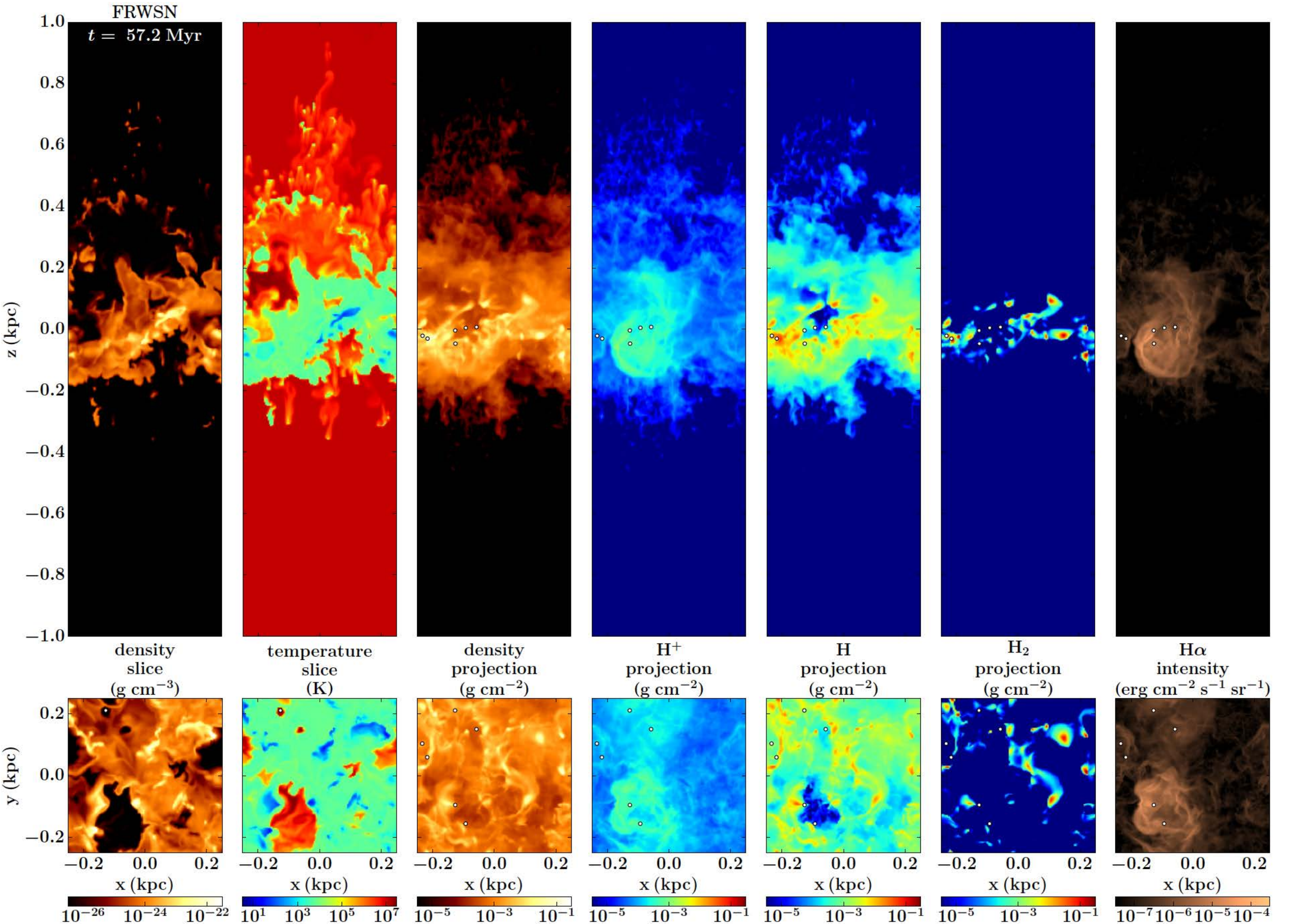
[CII] emission

Franneck et al., submitted



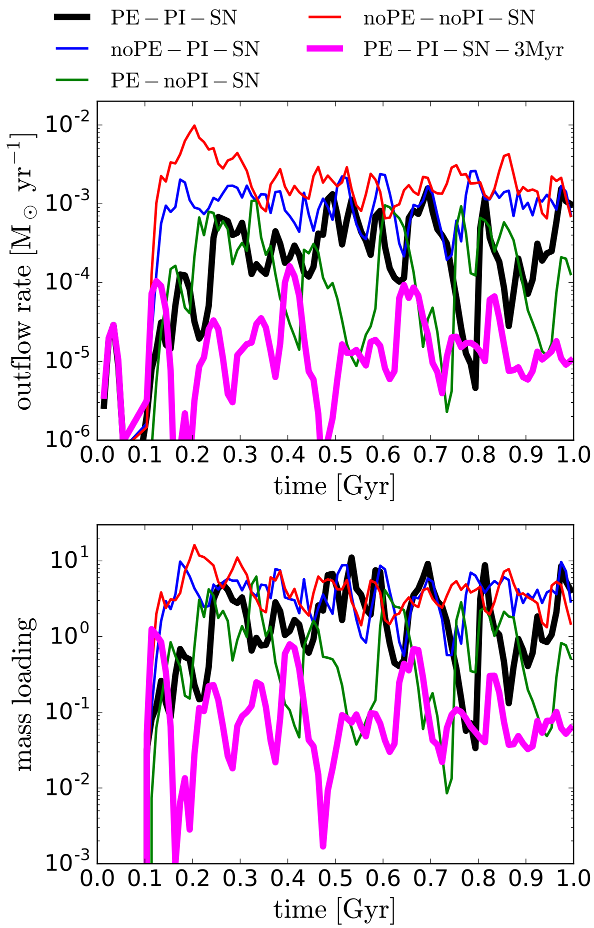
X-ray emission

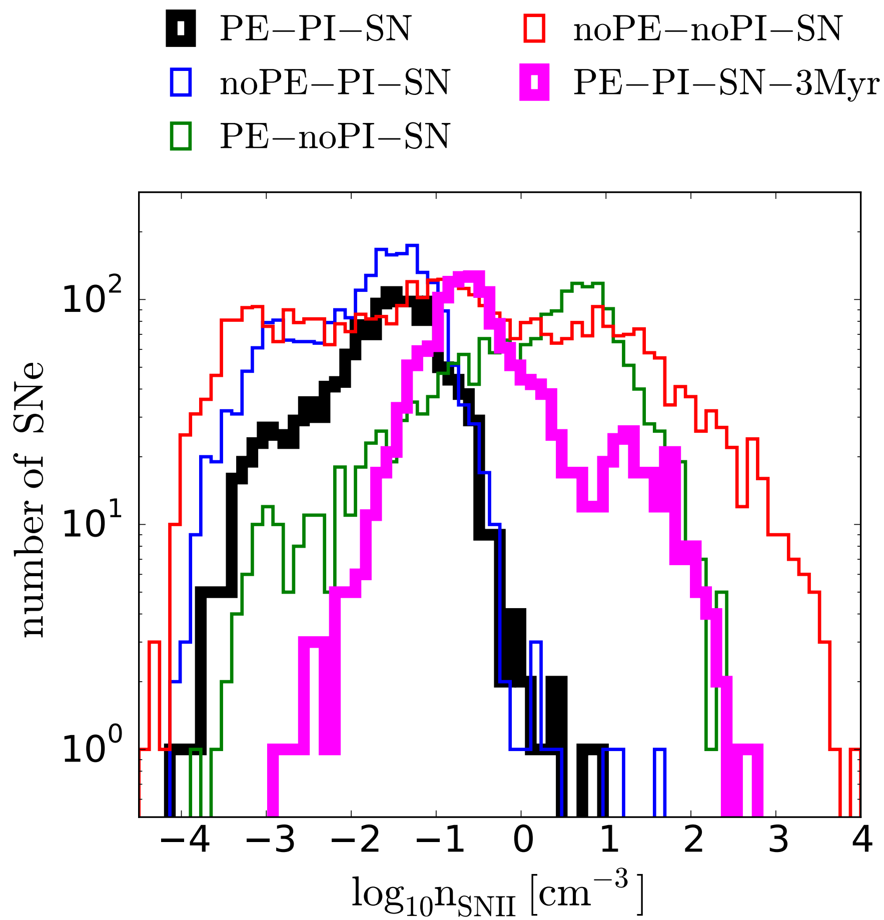
Peters et al. 2016



FRWSN
$t =$ 57.2 Myr
z (kpc)
y (kpc)
x (kpc)
density slice (g cm^{-3})
temperature slice (K)
density projection (g cm^{-2})
H$^+$ projection (g cm^{-2})
H projection (g cm^{-2})
H$_2$ projection (g cm^{-2})
Hα intensity (erg cm^{-2} s^{-1} sr^{-1})
10^{-26} 10^{-24} 10^{-22}
10^{1} 10^{3} 10^{5} 10^{7}
10^{-5} 10^{-3} 10^{-1}
10^{-7} 10^{-6} 10^{-5} 10^{-4}

Ambient densities of SNe are important

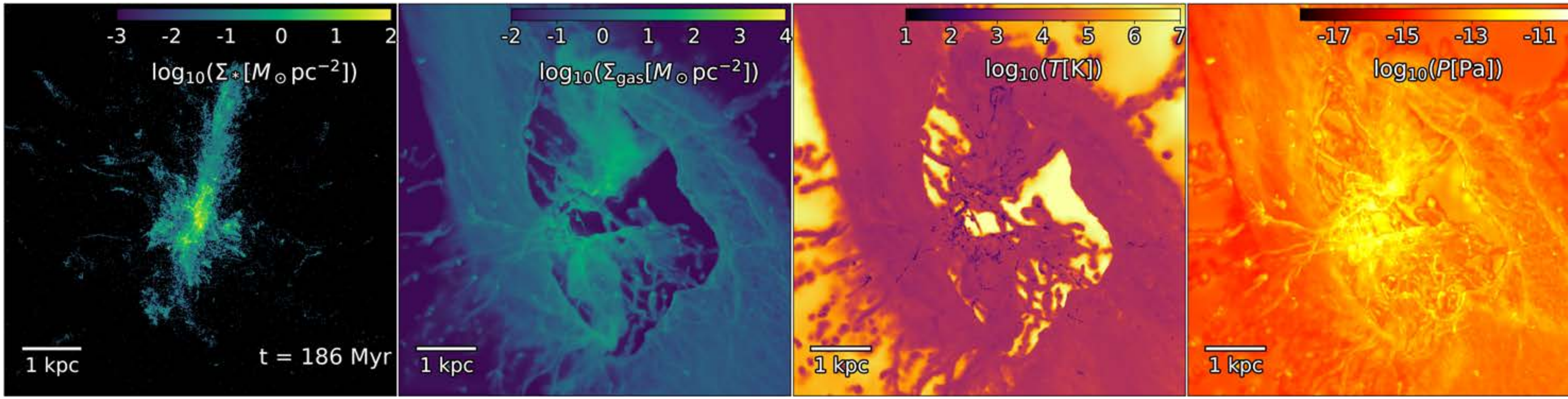


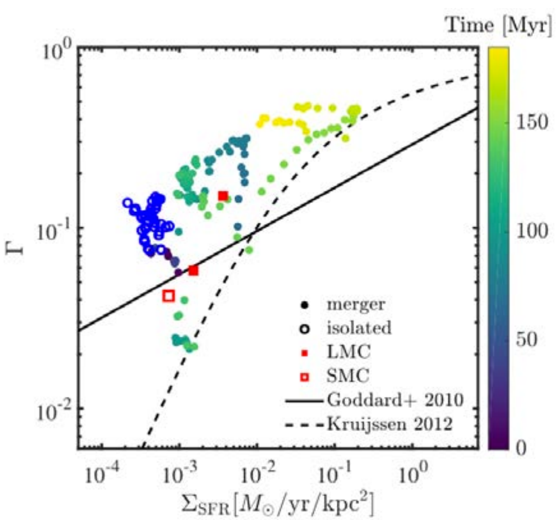


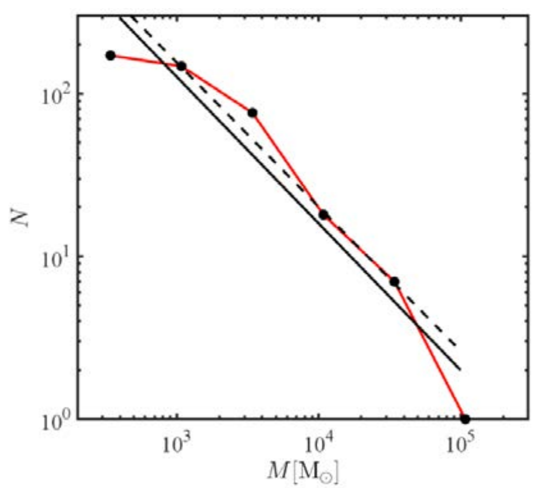
Hu et al. 2017

- Ambient densities are not only regulated by ‘feedback’ but also by ‘walkaways’
- Lower ambient densities – higher outflow rates

Star formation in dwarf starbursts







Starburst in interacting dwarf system results "naturally" in clustered star formation

4 $M_\odot$ mass, 0.1 pc spatial resolution, resolved SNe

Lahen et al., in prep., poster

Discussion points

How can we compare Galactic, sub-cloud-scale work to extragalactic measurements in a useful way (scales and tracer)?

The star formation efficiency in dense gas: is it constant, how is it regulated, formation thresholds, galaxy centers, etc.

How to link the small scale (feedback) physics across different tracers (star clusters, HII regions, H_2) that are uncorrelated via their time evolution?

How should we treat diffuse ionized gas? Does its distribution match simulations?

Does localized chemical enrichment impact future generations of star formation, or is it too quickly diffused/mixed?

Discussion points

Which feedback processes are required to get the right picture? And which picture? Is outflows all we care about?

Which spatial and time resolution is required to get a multi-phase ISM? Is 0.1 pc enough?

How important is thermal conduction?

How important is non-equilibrium chemistry?

Do magnetic fields change star formation − on galactic scales?

How do we assess uncertainties in the modeling?

Which observational diagnostics should we use for the validation/falsification of the model? How much freedom is there in post-processing?

How do we quantify the "success" of a model?

Discussion points

“Small scale” simulations will not reproduce galaxy populations? Is this a problem?

How do we quantify the “success” of a model?

Should theorists publish all material (code versions, analysis scripts, data) to make results reproducible?

What do we do with “numerically correct” simulations which give “wrong” results?

Do observers ask too much of the models? “Fitting” models are “promoted”