How to bridge the gap between studies of small- and large-scale star formation physics?

Discussion session, 28 June, 2013


or Friday
B.L.U.E.S.
BEST NEON

Agora

Sculpture in downtown Chicago

Agora

Also the name of new galaxy formation code comparison project

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Project AGORA: High-resolution Galaxy Simulation Comparison

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2. Project Details

Here we detail Project AGORA: Assembling Galaxies Of Resolved Anatomy (formerly known as Santa Cruz High-resolution Galaxy Simulation Comparison Project). It summarizes the consensus made during the Starting Workshop, and explains the working groups formed.

Contents

1 Intro: 1st Workshop Summary
2 Goals of the Project
3 Working Groups
3.1 Task-oriented Working Groups
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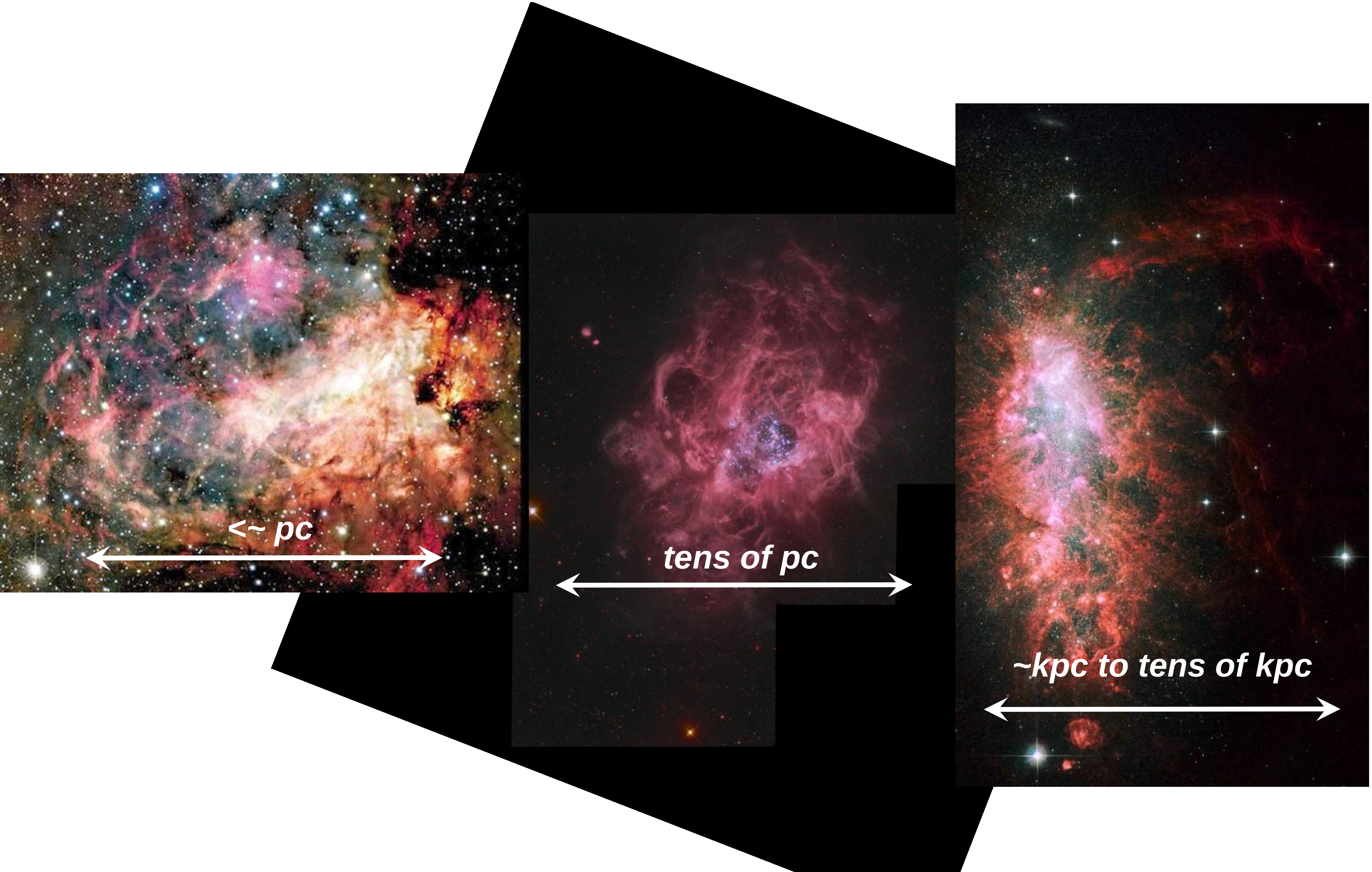
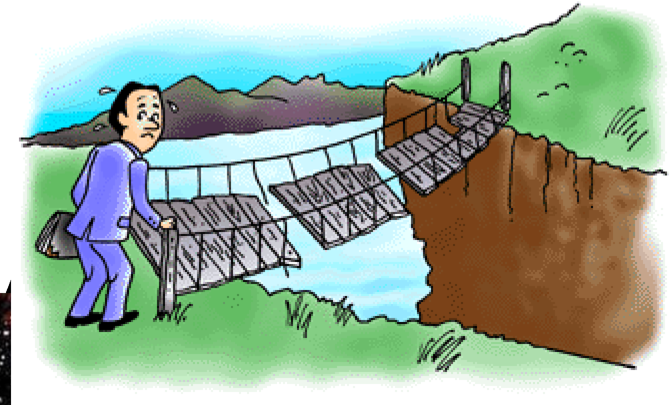
https://sites.google.com/site/santacruzcomparisonproject/details

What is small?

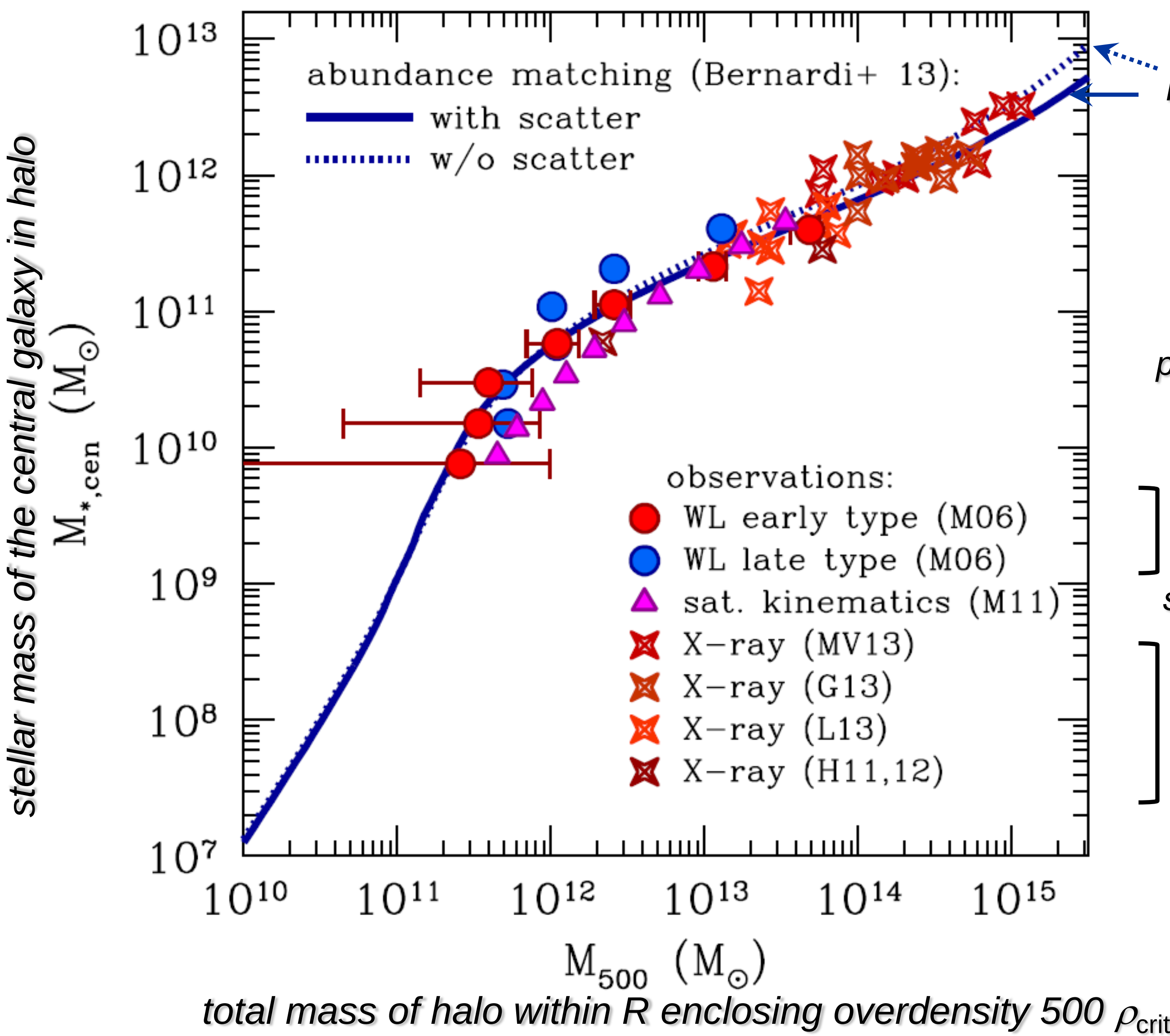


Why do we care about bridging scales?



Why do we care about bridging scales?

Simplicity out of complexity



lines = abundance matching results with and without scatter

lognormal scatter of 0.2 dex was assumed for scatter of M at a fixed Mhalo*

points = observational estimates of halo mass for galaxies of different stellar mass:

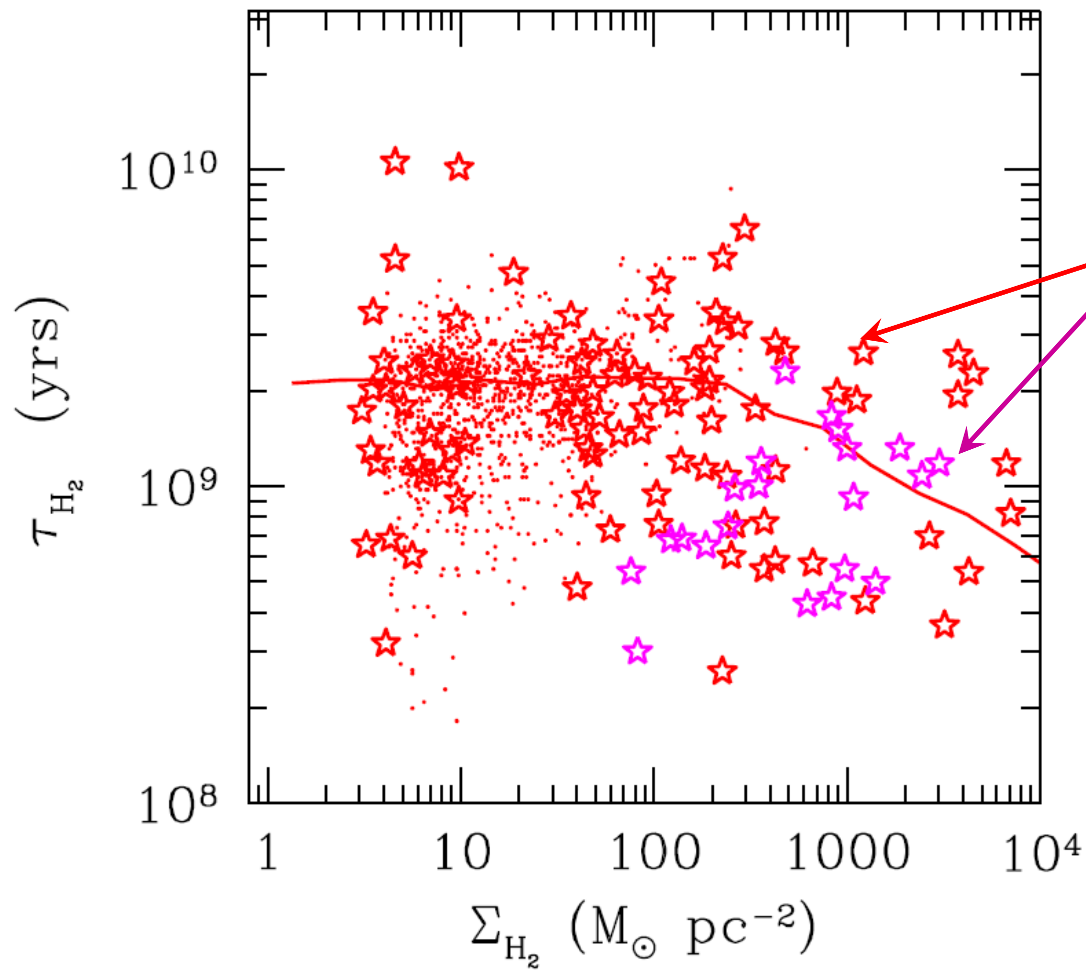
stacked weak lensing (Mandelbaum et al. '06)

satellite kinematics (More ea. '11)

Halo masses for groups and clusters measured from X-ray data and assuming hydrostatic equilibrium (Mescheryakov & Vikhlinin '13; Gonzalez et al. '13; Lagana et al. '13; Humphrey et al. '11, '12)

molecular gas depletion time due to star formation

$$\tau_{H_2} \equiv \frac{\Sigma_{H_2}}{\Sigma_{HI+H_2}} \sim 1 - 2 \text{ Gyr}$$



red (z~0) and magenta (z~1-2) points: τ_{H_2}

stars: Genzel et al. 2010, MN **407**, 2091

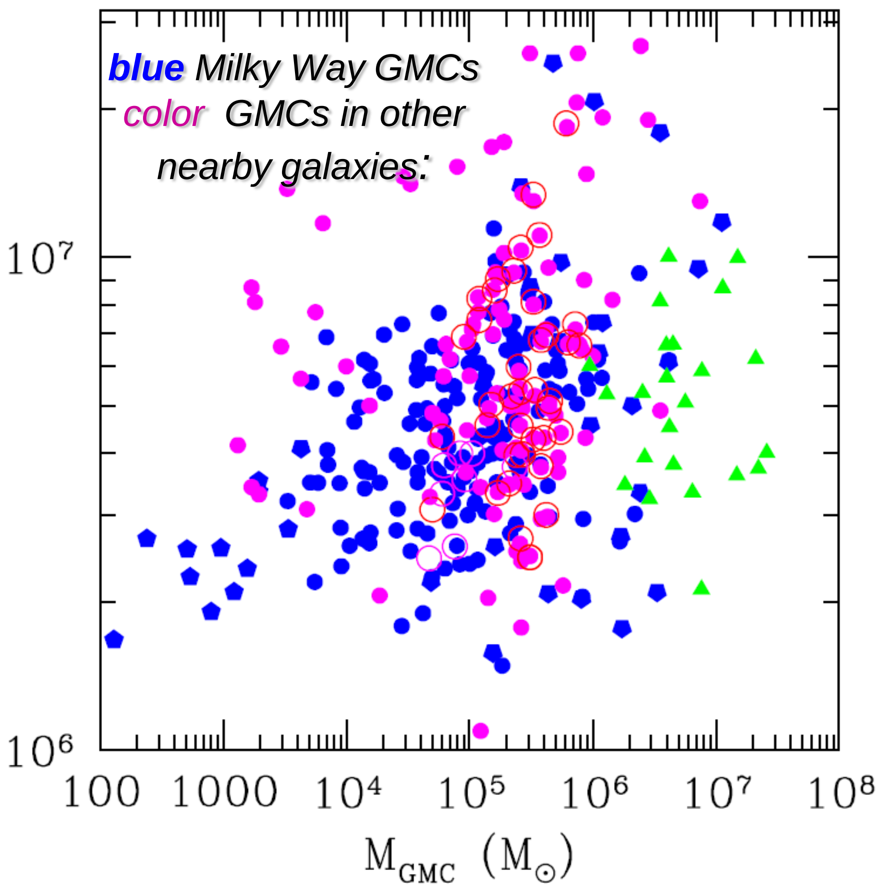
dots: Bigiel et al. 2010, AJ **140**, 1194

Compare this to the free-fall time of GMCs

$$t_{\rm ff} = \sqrt{\frac{3\pi}{32 G \bar{\rho}_{\rm GMC}}} \sim 5 \times 10^6 \ {\rm yrs} \qquad \tau_{\rm H_2} \sim 2 \times 10^9 \ {\rm yrs}$$

$$\epsilon_{\rm ff} \equiv \frac{t_{\rm ff}}{\tau_{\rm H_2}} \sim \frac{5 \times 10^6}{2 \times 10^9} = 0.0025$$

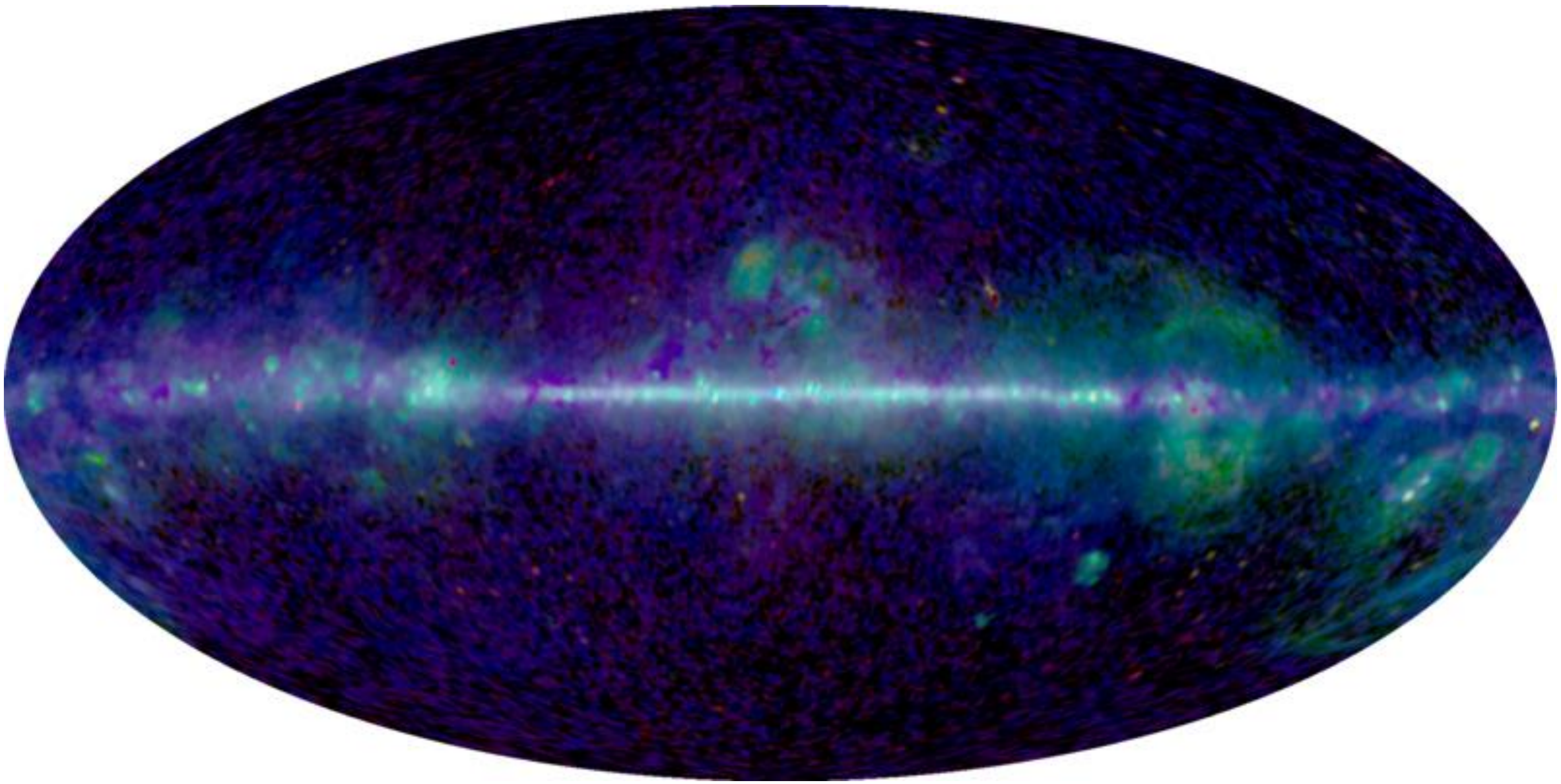
molecular gas is on average extremely inefficient in making stars



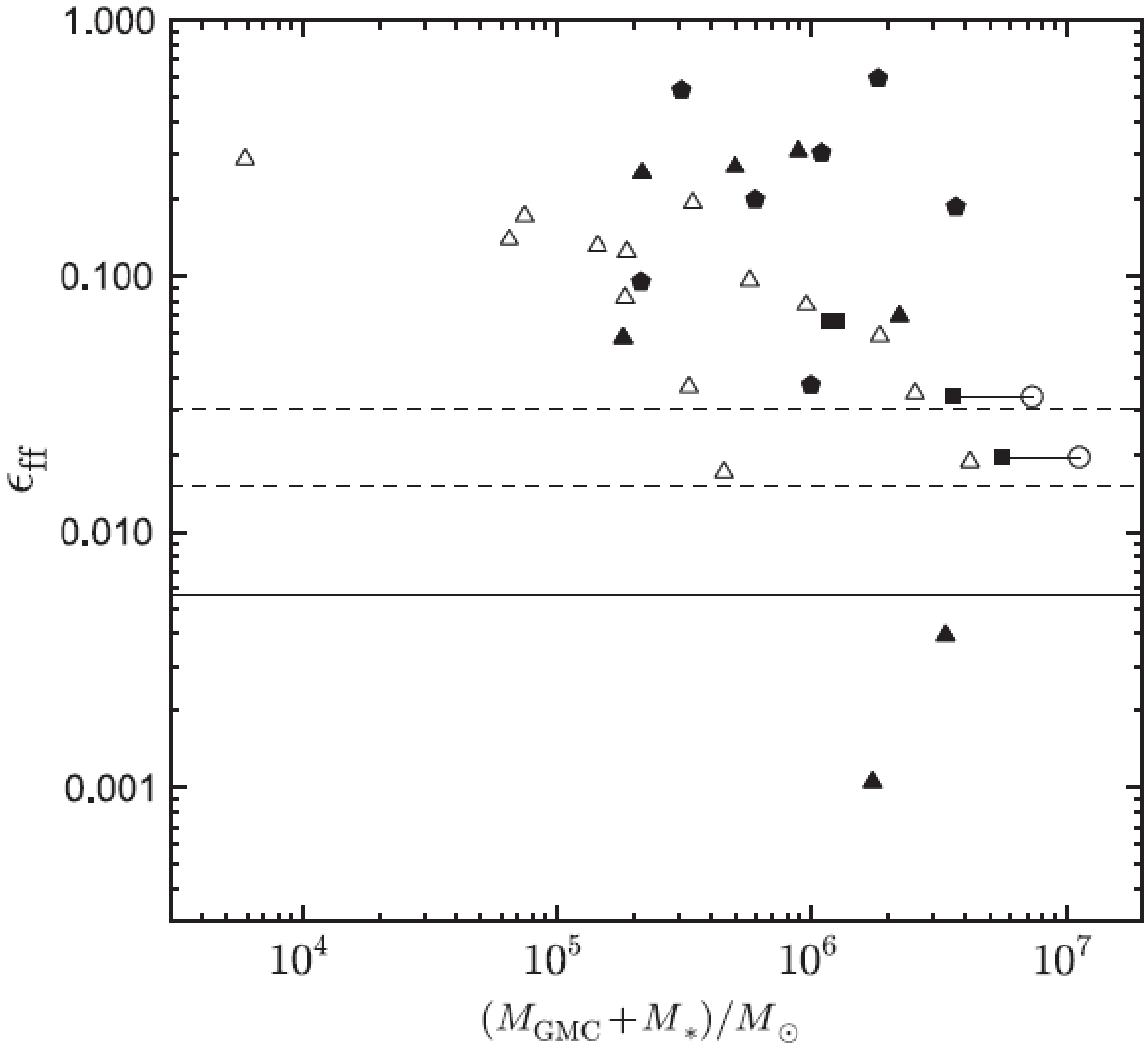
But many observed star forming regions seem to convert up to ~10% of their gas mass into stars, which would require up to $40t_{ff}$ GMC lifetime

N. Murray 2011, ApJ 729, 133

"We select the most rapidly star-forming GMCs in the Galaxy: <u>the 32 GMCs we select are responsible for 31% of the star formation in the Galaxy."</u>

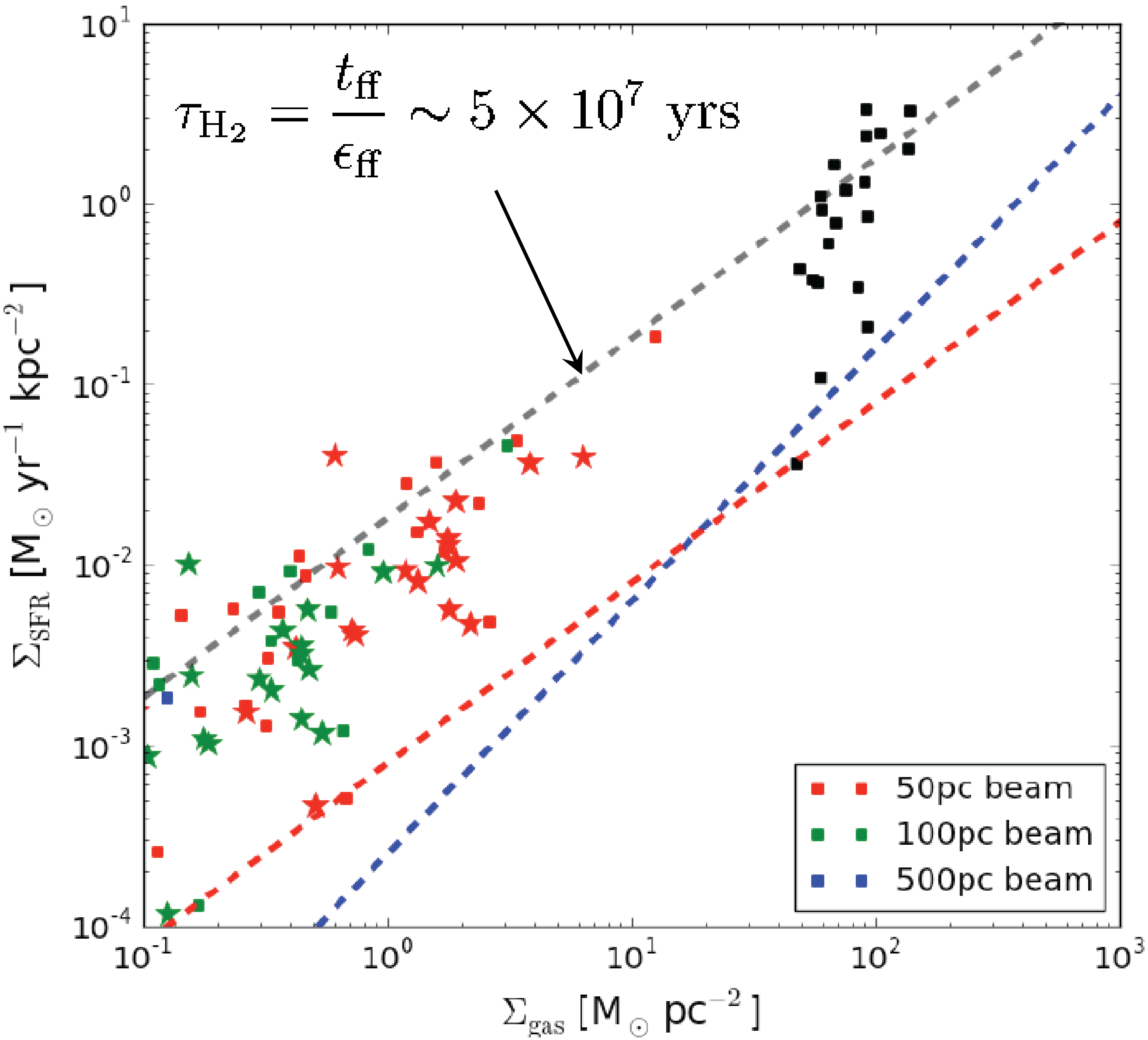


Depletion time in massive, star forming GMCs in the Milky Way



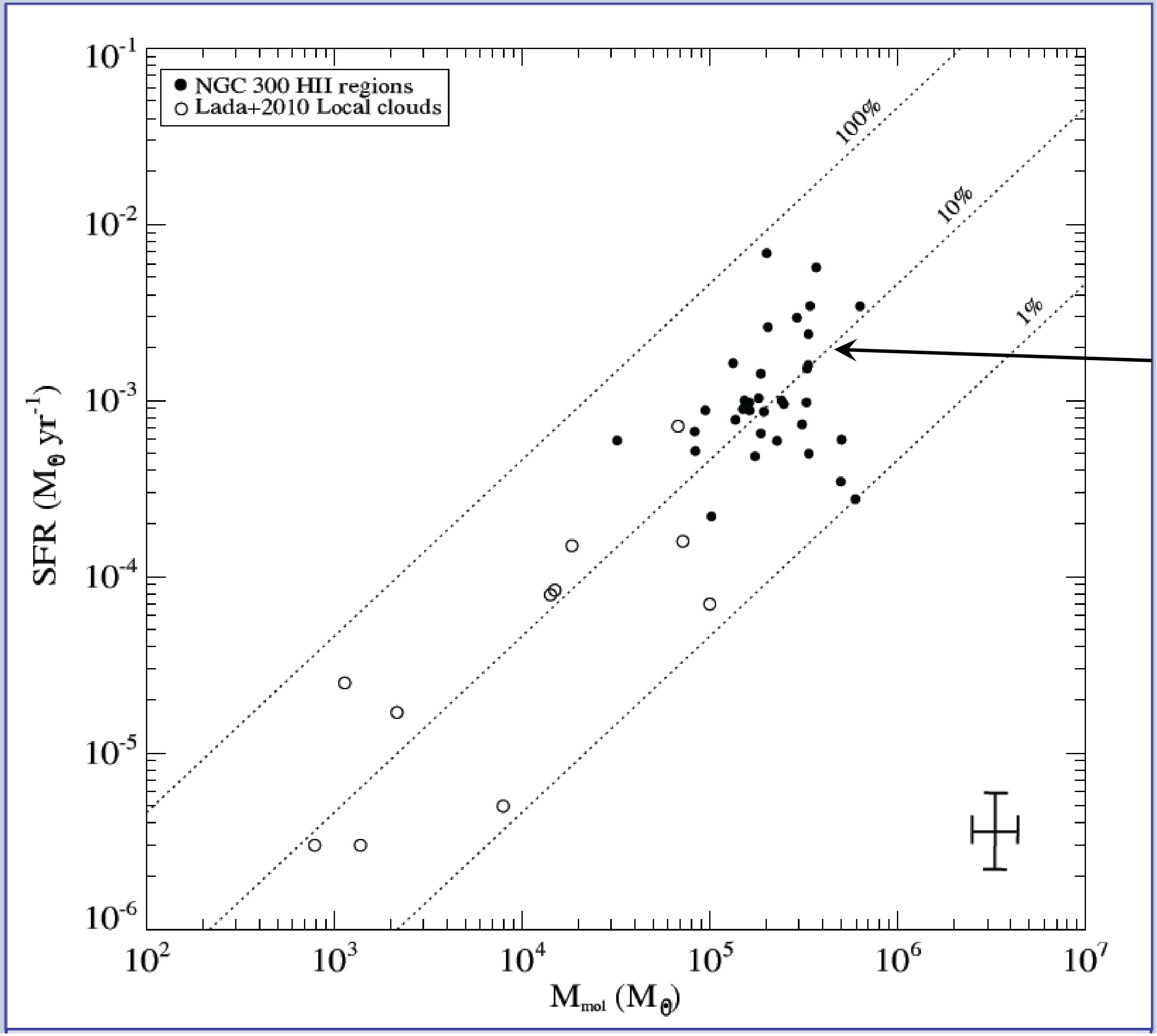
$$\tau_{H_2} = \frac{t_{ff}}{\epsilon_{ff}} \sim 5 \times 10^7 \text{ yrs}$$

Murray 2011, ApJ 729, 133



Sarah Ragan's talk

SFR scaling law at 250 pc scales



$\tau_{H_2} \approx 2 \times 10^8$ yrs

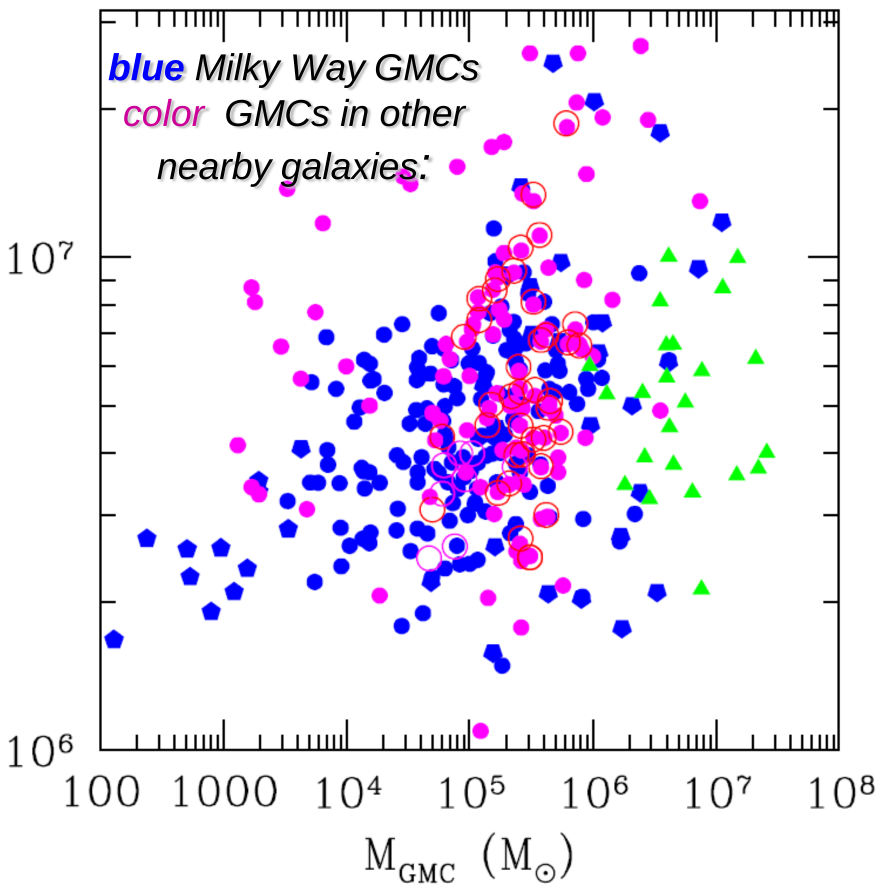
Faesi, Lada + poster

Compare this to the free-fall time of GMCs

$$t_{\rm ff} = \sqrt{\frac{3\pi}{32 G \bar{\rho}_{\rm GMC}}} \sim 5 \times 10^6 \text{ yrs} \qquad \tau_{\rm H_2} \sim 2 \times 10^9 \text{ yrs}$$

$$\epsilon_{\rm ff} \equiv \frac{t_{\rm ff}}{\tau_{\rm H_2}} \sim \frac{5 \times 10^6}{2 \times 10^9} = 0.0025$$

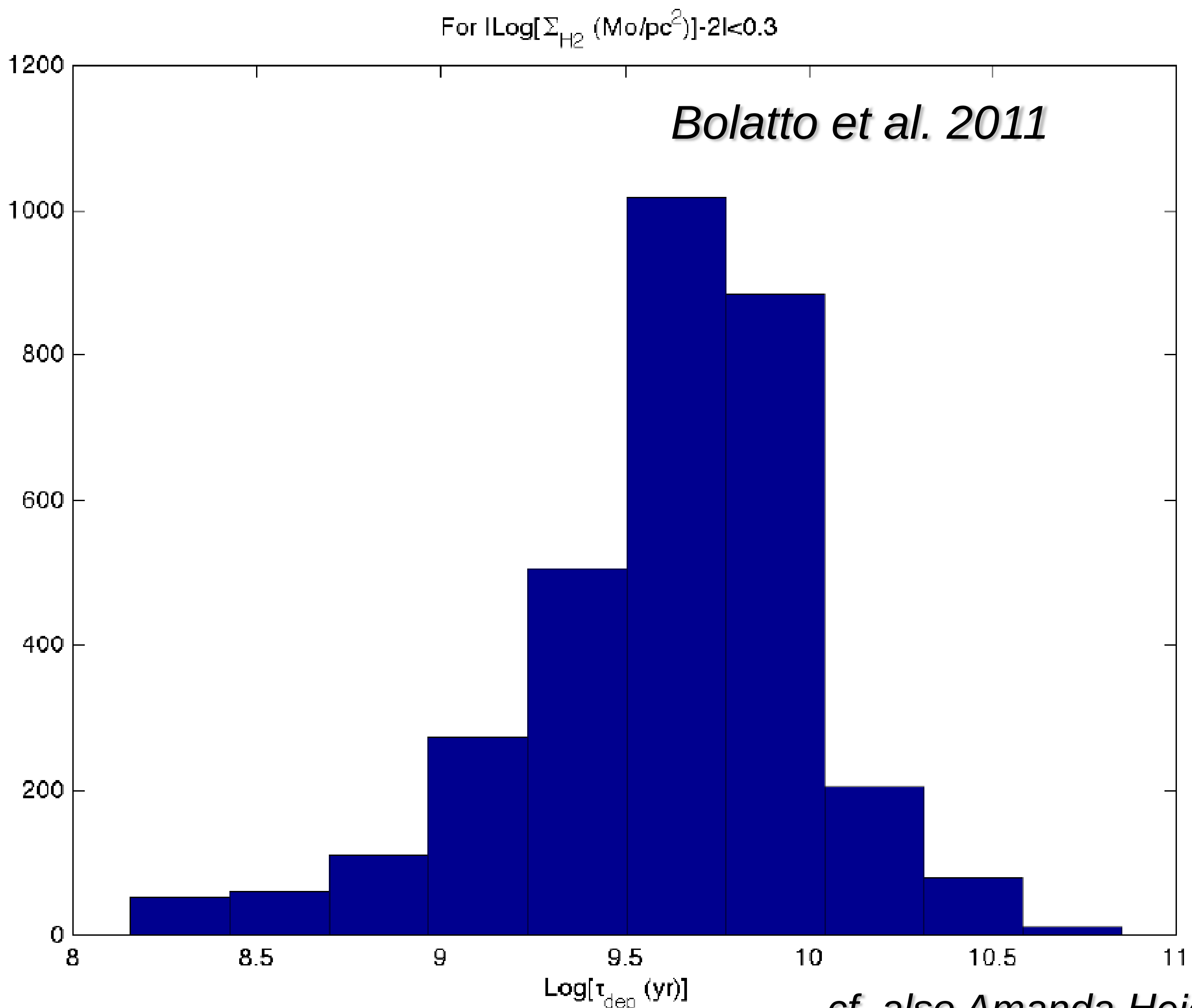
→ *molecular gas is on average extremely inefficient in making stars*



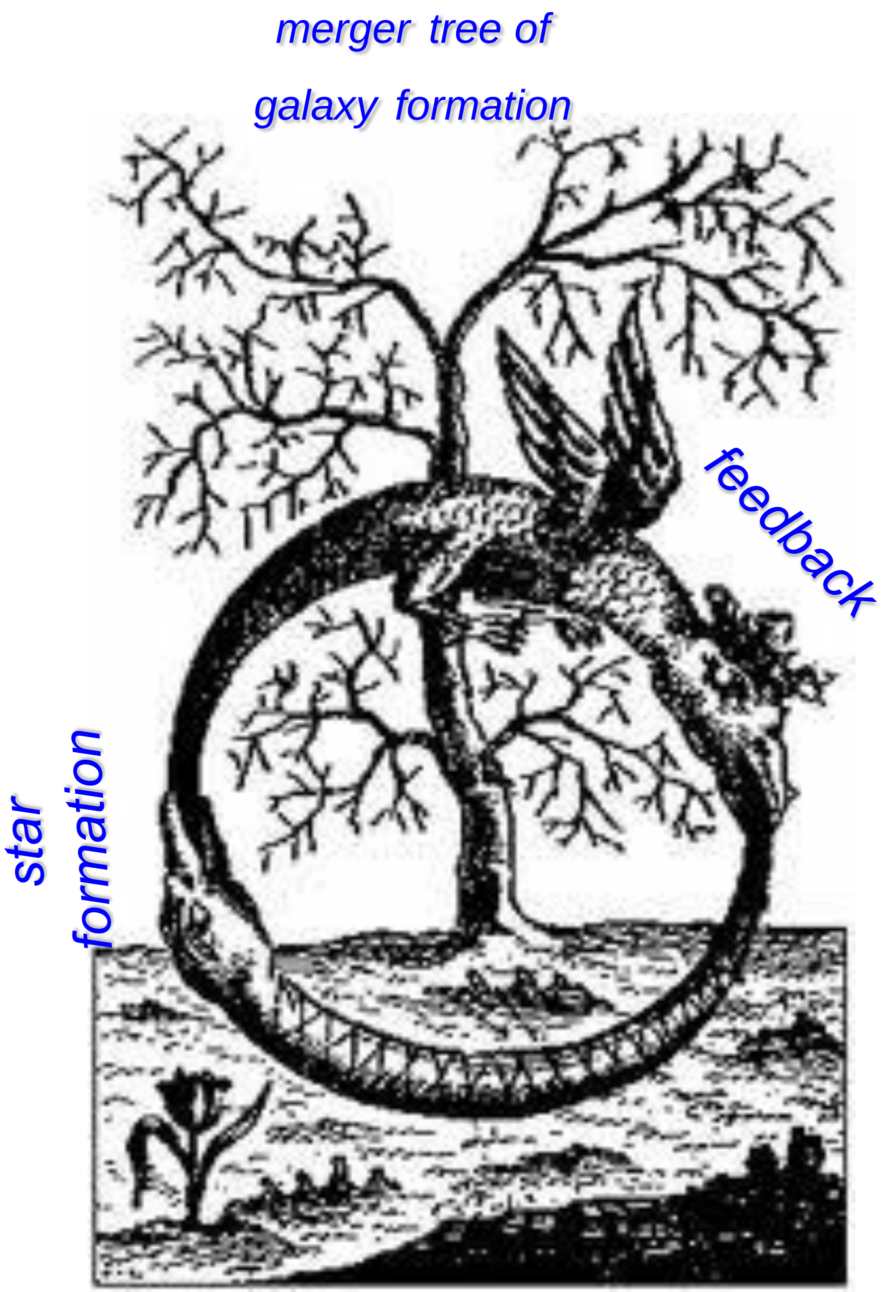
But many observed star forming regions seem to convert up to ~10% of their gas mass into stars, which would require up to 40t_{ff} GMC lifetime

What's going on???

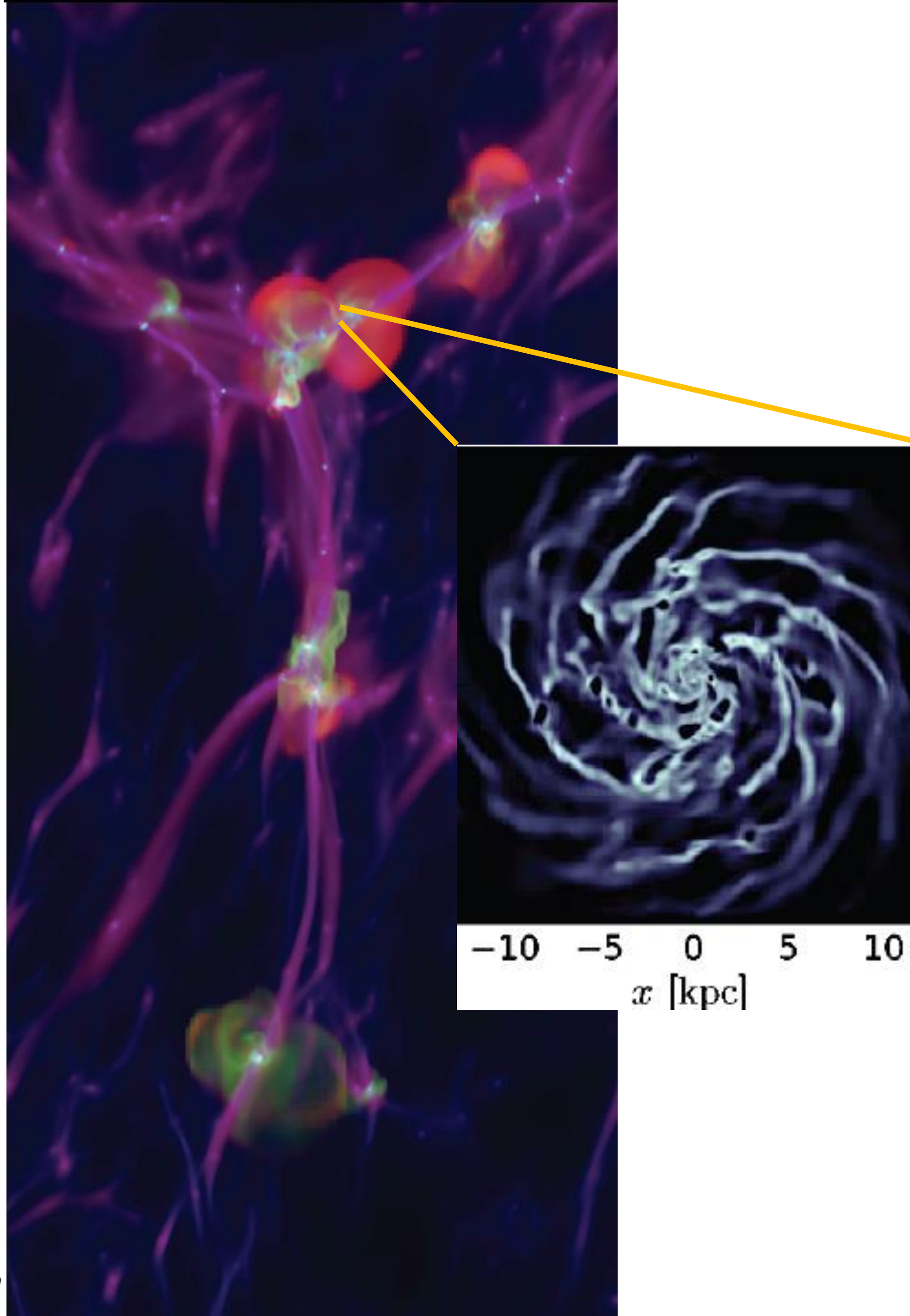
Distribution of molecular depletion times in the SMC on 12 pc scales



cf. also Amanda Heiderman's talk



the Cosmic Ouroboros: star formation,
feedback and the merger Tree of Galaxy Formation



What do you know about how star formation is done in galaxy formation simulations?

"Prescriptions for star formation in galaxy formation simulations are terrible…"
- Laura Lopez

Star formation in galaxy formation simulations

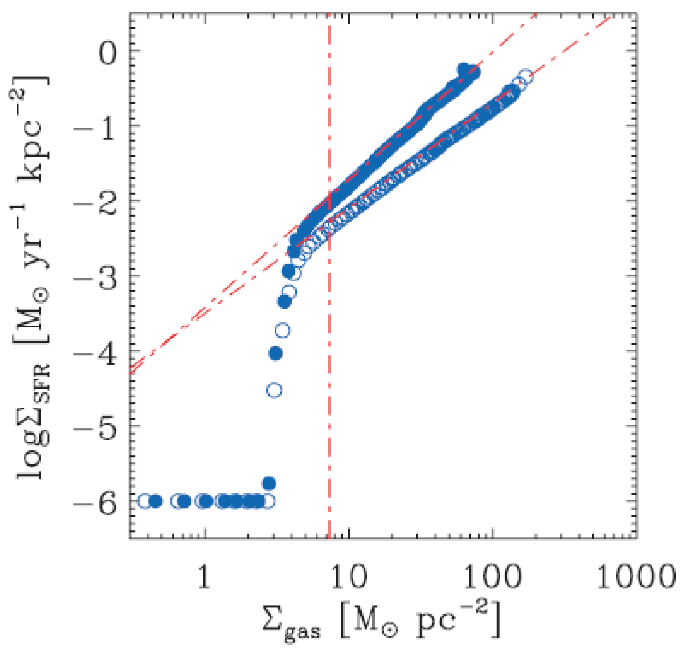
$$\rho_{\rm gas,SF} = \rho_{\rm gas} > \rho_{\rm SFthreshold}$$

$$\tau_{\rm SF} = \sqrt{\frac{3\pi}{32G\rho}}$$

the local SF rate → $$\dot{\rho}_* = \varepsilon_{\rm SF}\frac{\rho_{\rm gas,SF}}{\tau_{\rm SF}}$$

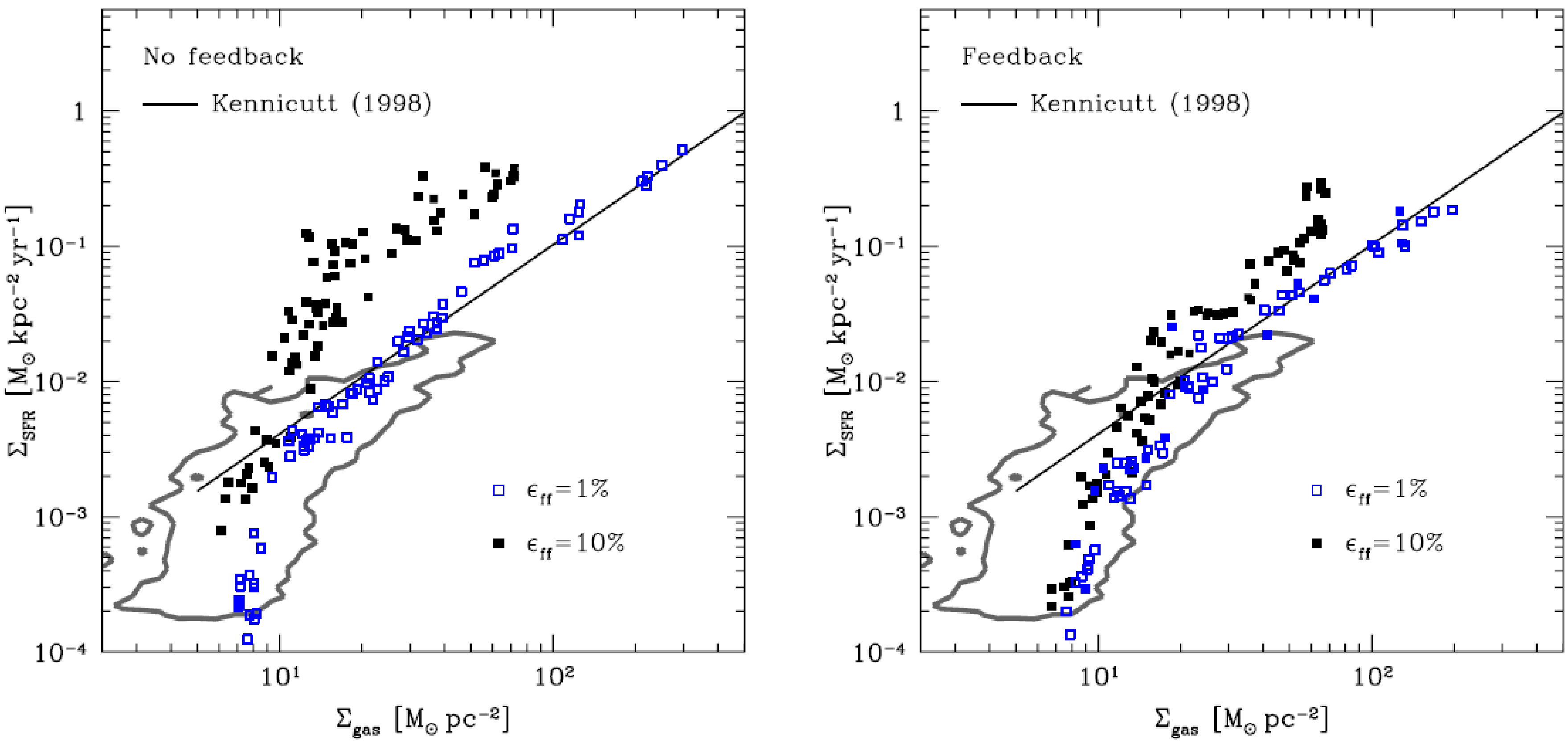
is used to "spawn" a star particle of mass → $$m_* = \dot{\rho}_* \Delta t_{SF}$$

SF rate as a function of gas surface density in a controlled simulation of a gas disk (Schaye & Dalla Vechia 2008)



But the agreement with the observed KS relation may be misleading…

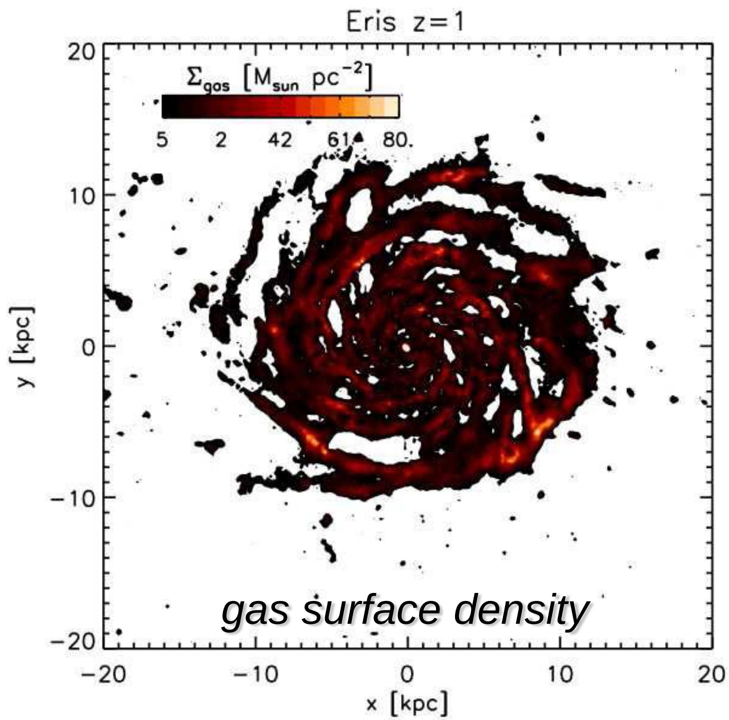
THE ASTROPHYSICAL JOURNAL, 770:25 (26pp), 2013 June 10 AGERTZ ET AL.



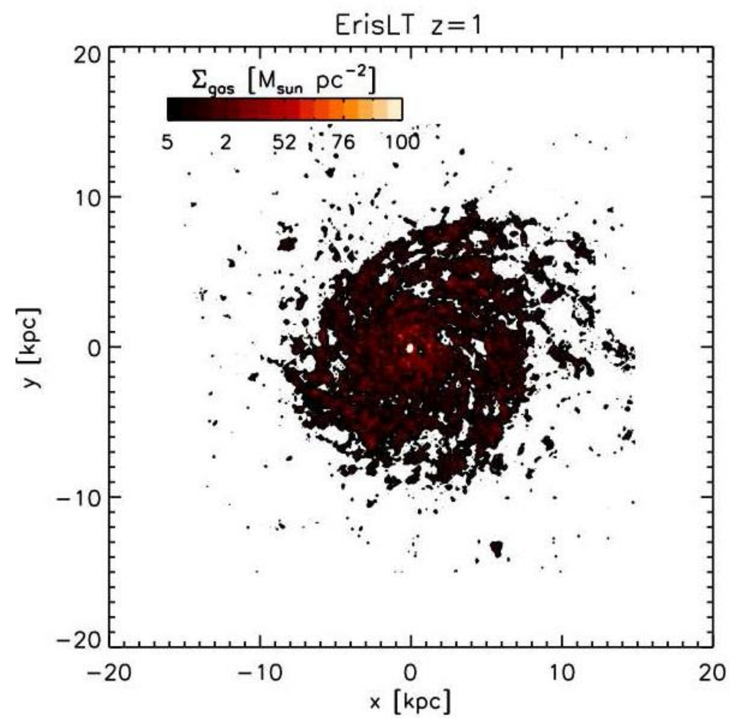
Results are highly sensitive to adopted density threshold for star formation

cold gas distribution in two simulations from identical initial conditions
(Guedes et al. 2011, arXiv/1103.6030; cf. also Governato et al. 2010, Nature)

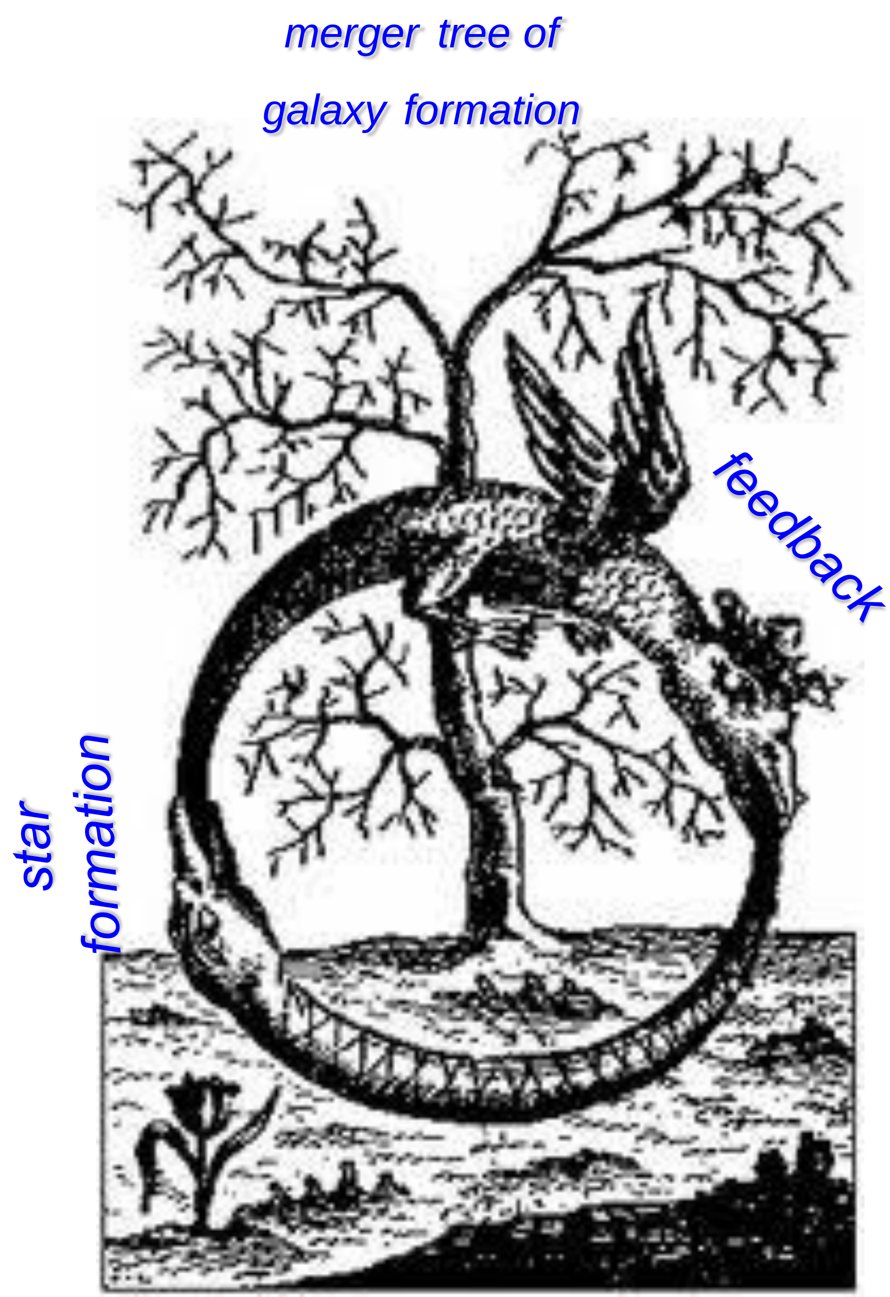
this simulation forms stars at densities $n > 5\ cm^{-3}$ -> realistic gas disk



this simulation forms stars at densities $n > 0.1\ cm^{-3}$ -> small disk, little gas



-> we need a better physical model for star formation in galaxy formation simulations!



the Cosmic Ouroboros: star formation, feedback and the merger Tree of Galaxy Formation

What's going on?

- *with low density threshold, star formation occurs in lots of small events spread more or less uniformly within a disk*

- *with high density threshold, the same mass of stars may be formed, but in fewer locations, so that each star formation site forms a much larger stellar mass*

- *feedback is thus also more concentrated for high density threshold and is more efficient*

this example highlights the intricate relation between the mode of star formation and efficiency of stellar feedback. Both need to be modelled carefully!

A nonuniform star formation efficiency

$$\dot{\rho}_* = \frac{\rho_g}{t_{SF}} \text{ for } \rho > \rho_*,$$

$$t_{SF} = t_{ff}/\epsilon_{ff},$$

$$t_{ff} = \sqrt{3\pi/32G\rho}$$

4. STAR FORMATION TIMESCALES

4.1. *A bimodal star formation timescale*

We assume that the star formation times scale t_{SF} follows a bimodal distribution. A fraction f of all star formation events belong to population 1, and $(1-f)$ to population 2 such that

$$\frac{1}{t_{SF}} = \frac{f}{t_{SF,1}} + \frac{1-f}{t_{SF,2}}. \quad (2)$$

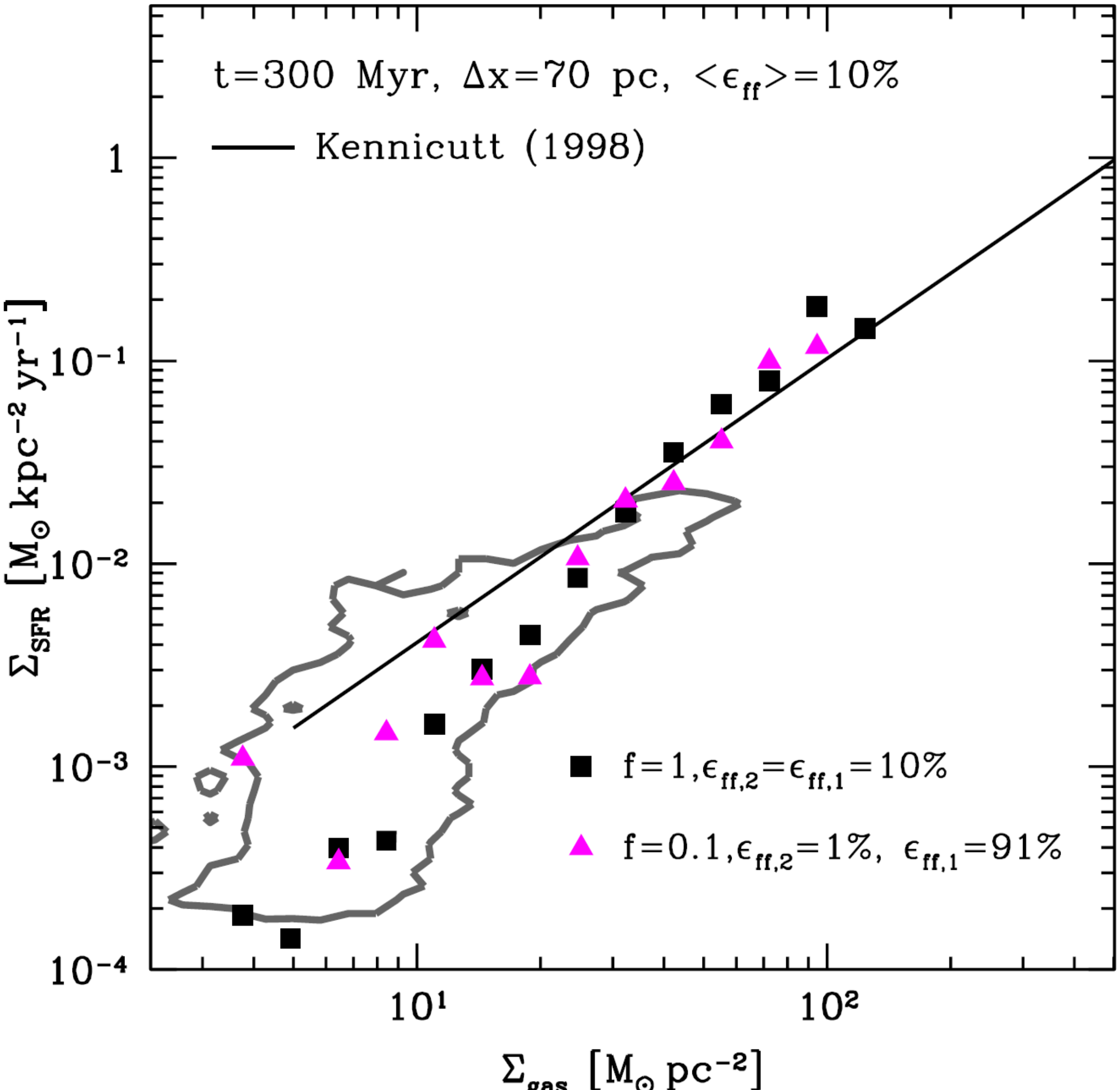
As we assume $t_{SF} = t_{ff}/\epsilon_{ff}$ in the adopted star formation law (Equation 1), we can write the free-fall efficiency of population 1 as

$$\epsilon_{ff,1} = \frac{\epsilon_{ff} - (1-f)\epsilon_{ff,2}}{f}. \quad (3)$$

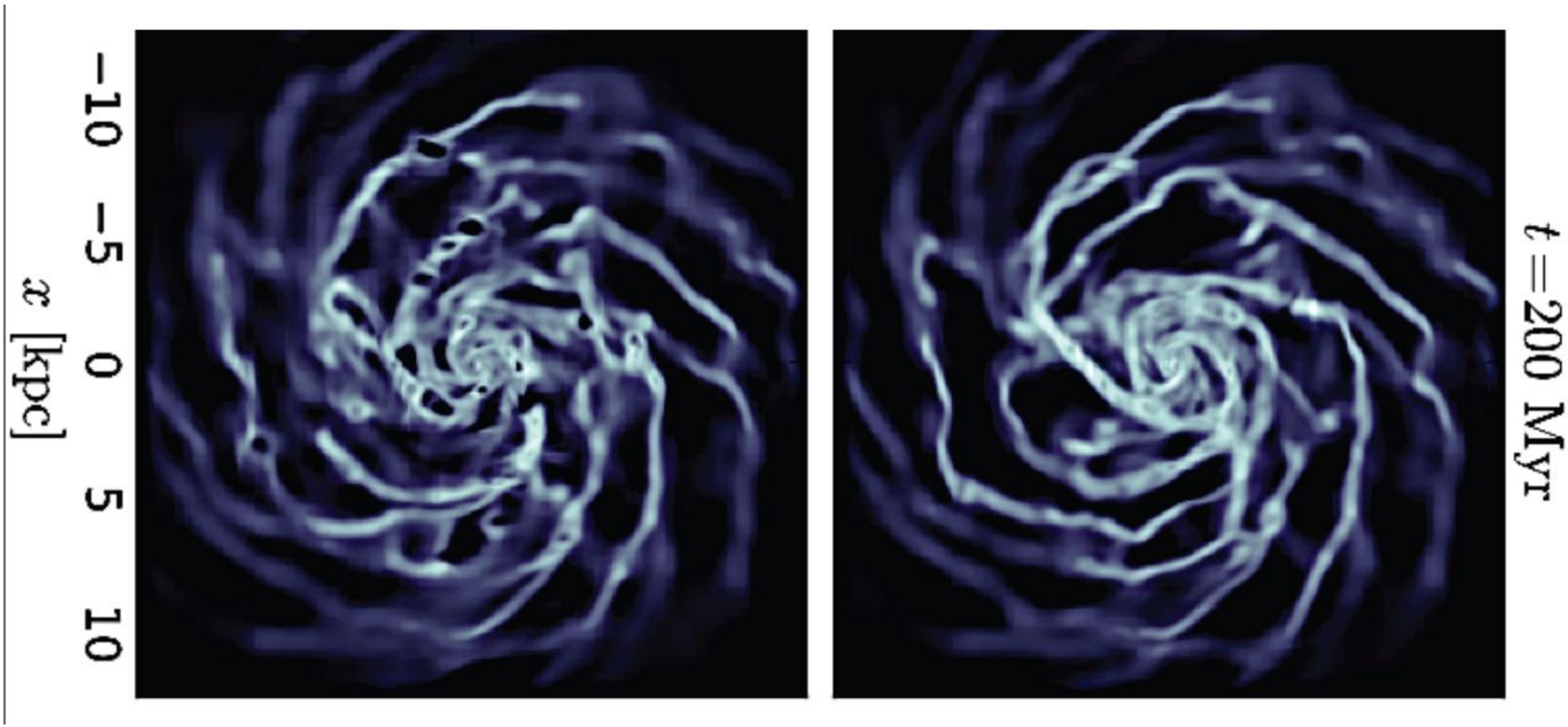
As an example, by setting $f = 0.1$, $\epsilon_{ff} = 1\%$ and $\epsilon_{ff,2} = 0.1\%$ we arrive at $\epsilon_{ff,1} = 9.1\%$.

Agertz et al. 2013, in prep.

Almost no difference in the KS relation

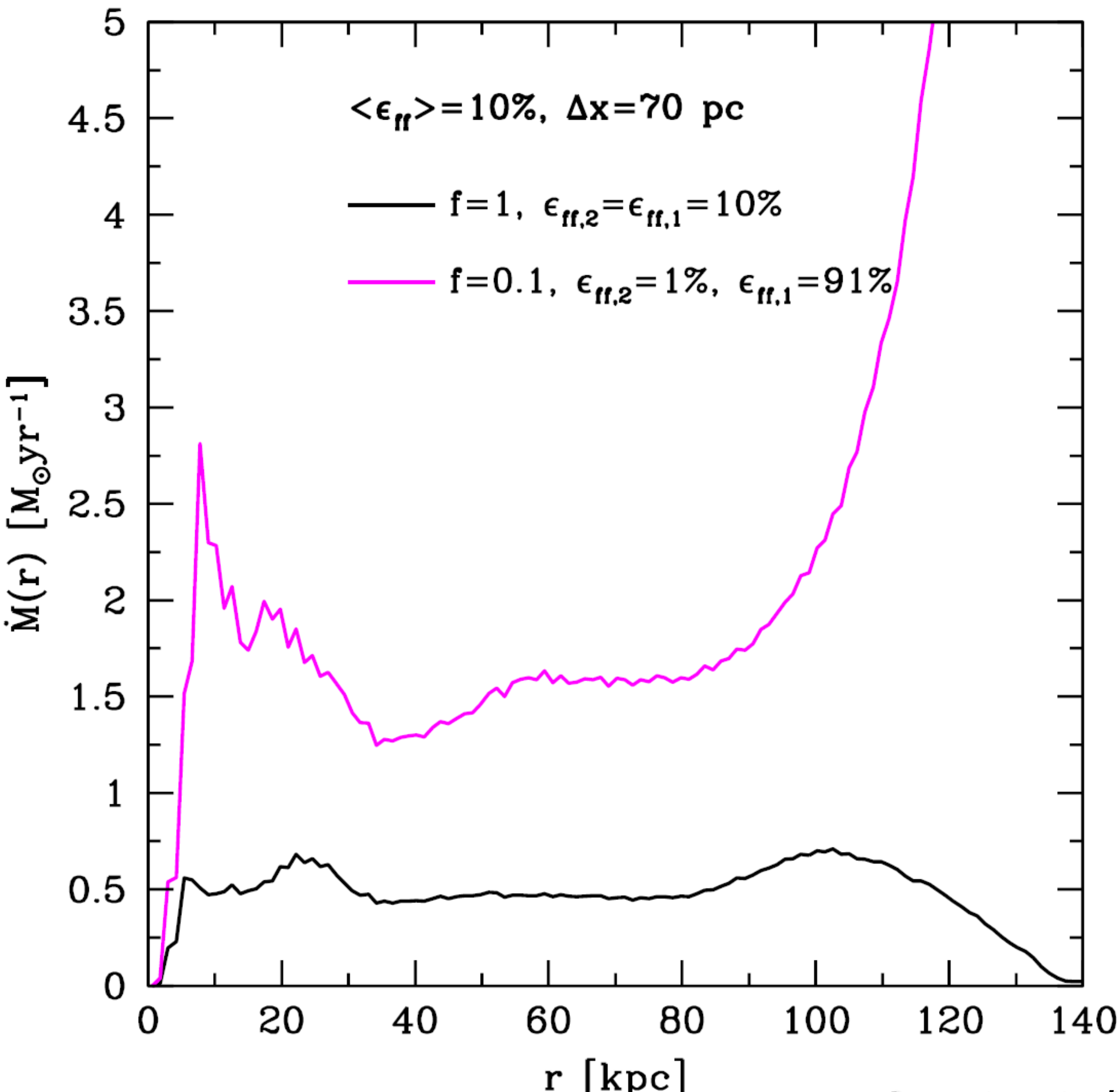


Stochastic vs. uniform star formation efficiency



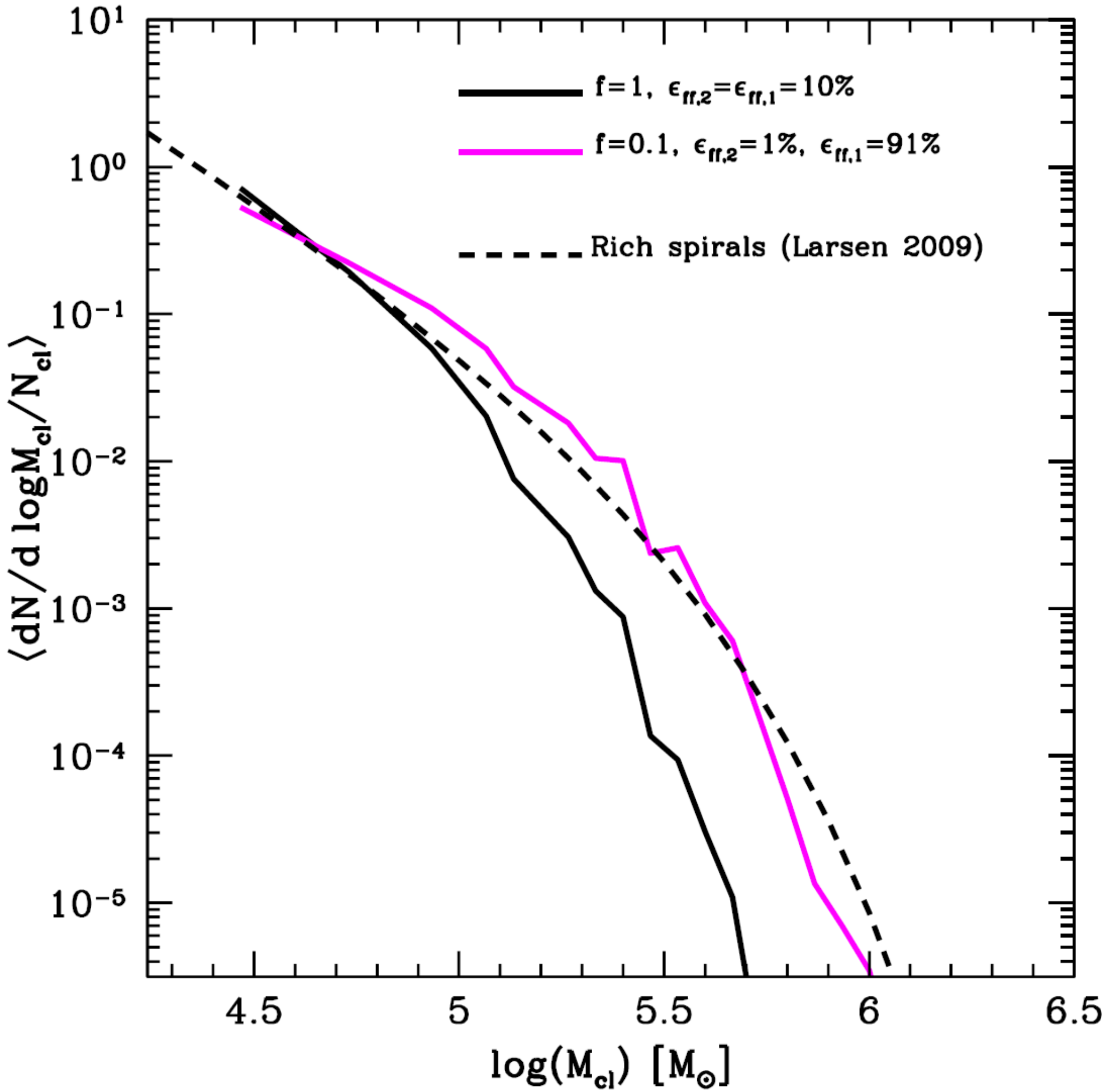
Agertz et al. 2013, in prep.

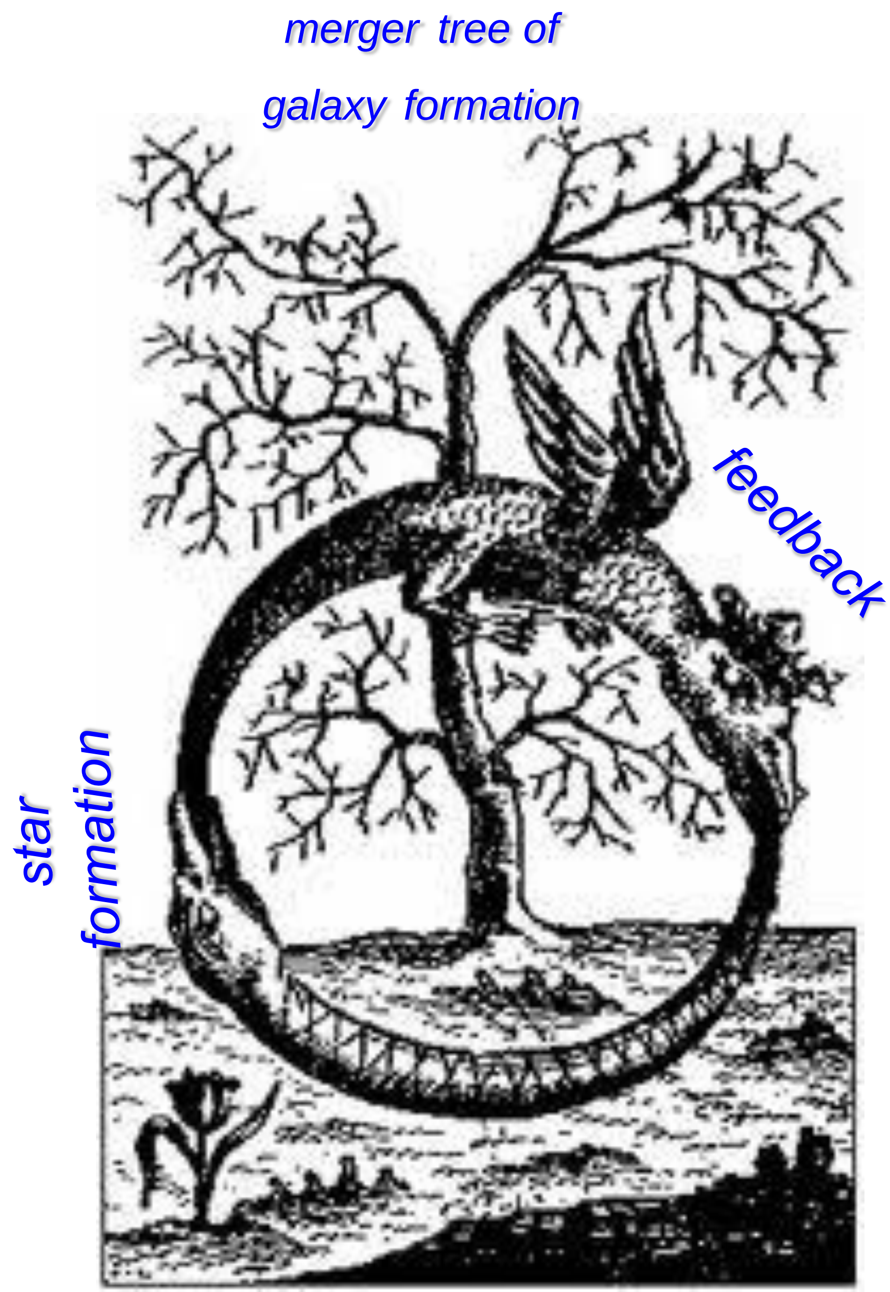
Outflow mass rate



Agertz et al. 2013, in prep.

Possible additional test of star formation in simulations





the Cosmic Ouroboros: star formation, feedback and the merger Tree of Galaxy Formation

Discussion points

- ❑ *what is the scale on which we should focus our calibration of depletion time or SF efficiency?*

- ❑ *Can we measure statistical PDF of depletion time distribution for molecular regions of a given scale/mass?*

- ❑ *can we robustly identify the amount and properties of molecular gas that is not forming stars actively (long depletion times)?*

- ❑ *can we measure the total energy and momentum in a statistically representative sample of regions of this size at the end of star formations (i.e., when region is in the last stages of disruption – think 30 Dor)?*

Alyssa's pyramid (or mandala)

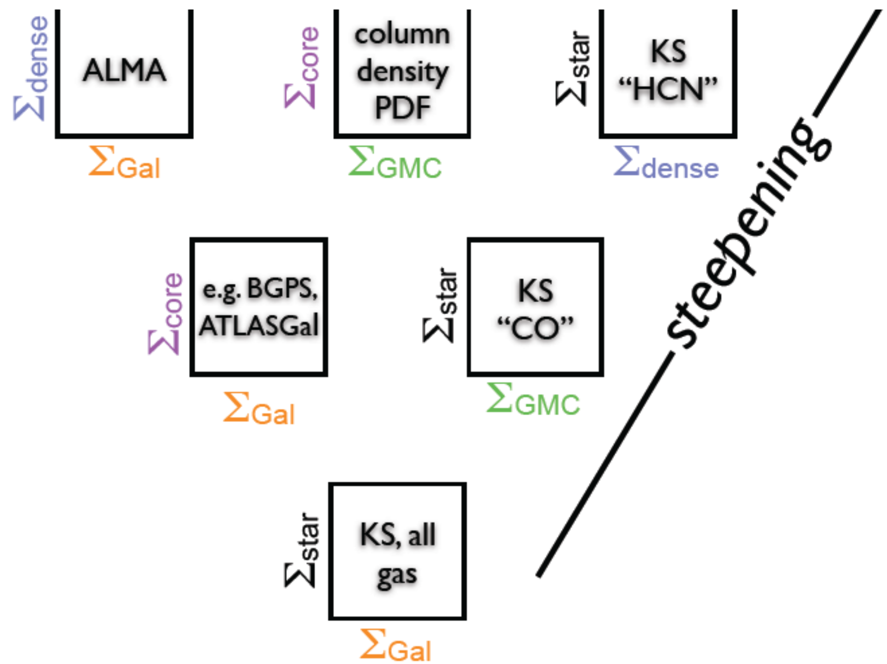
Mandala

From Wikipedia, the free encyclopedia

For other uses, see Mandala (disambiguation).

Mandala (Sanskrit: मण्डल *Maṇḍala*, 'circle') is a spiritual and ritual symbol in Hinduism and Buddhism, representing the Universe.[1] The basic form of most mandalas is a

Star
Formation
Efficiency
Pyramid
Scheme



Alyssa's pyramid (or mandala)

Universe → Galaxy → "GMC" → Dense Gas → Dense Core → Star

time dependent mass fractions

Galaxy	GMC	Dense Gas	Dense Core	Star
Universe	Galaxy	GMC	Dense Gas	Dense Core

Star Formation Efficiency Pyramid Scheme