VARIATIONS OF THE ISM CONDITIONS ACROSS THE MAIN SEQUENCE OF STAR-FORMING GALAXIES

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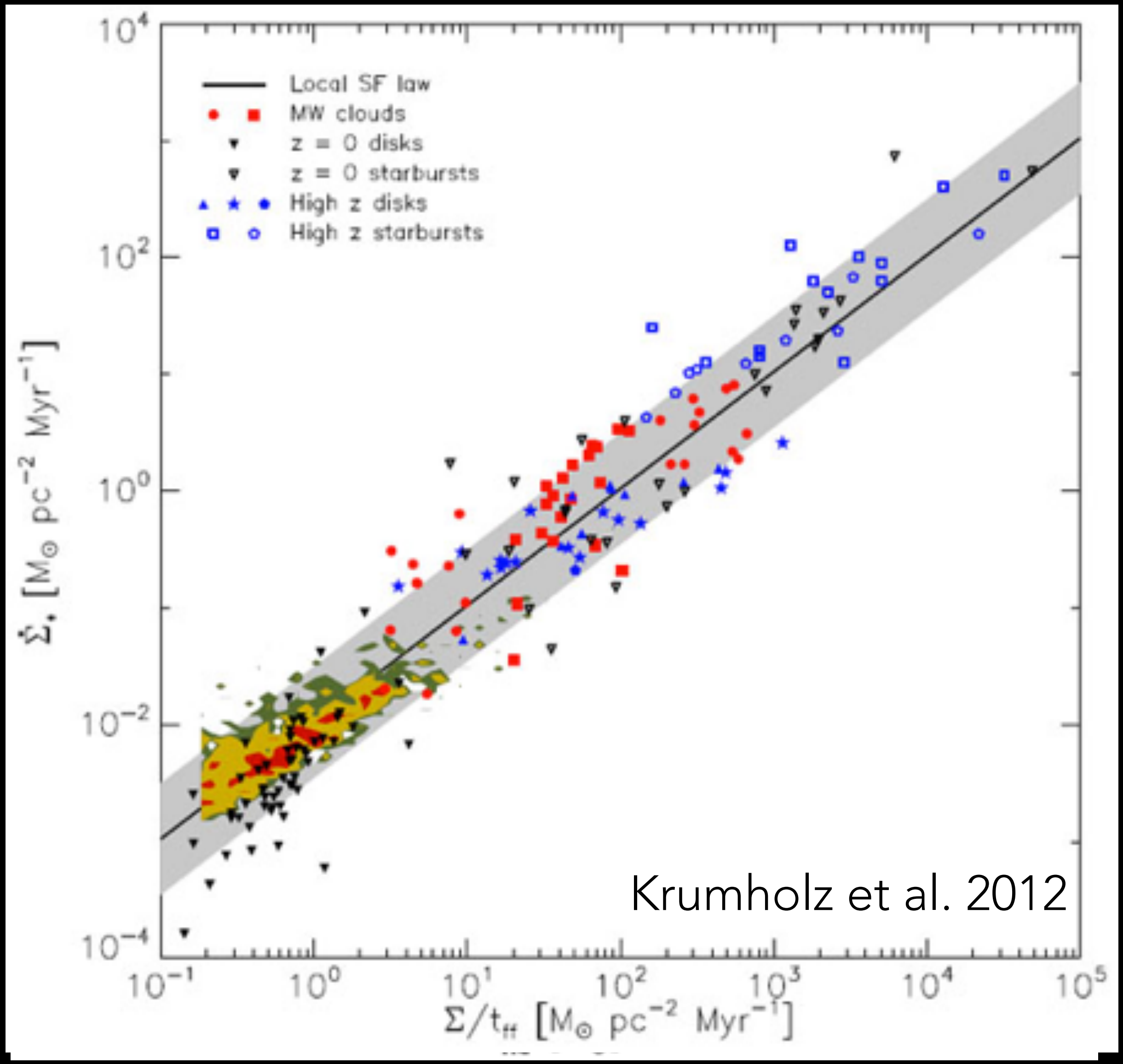
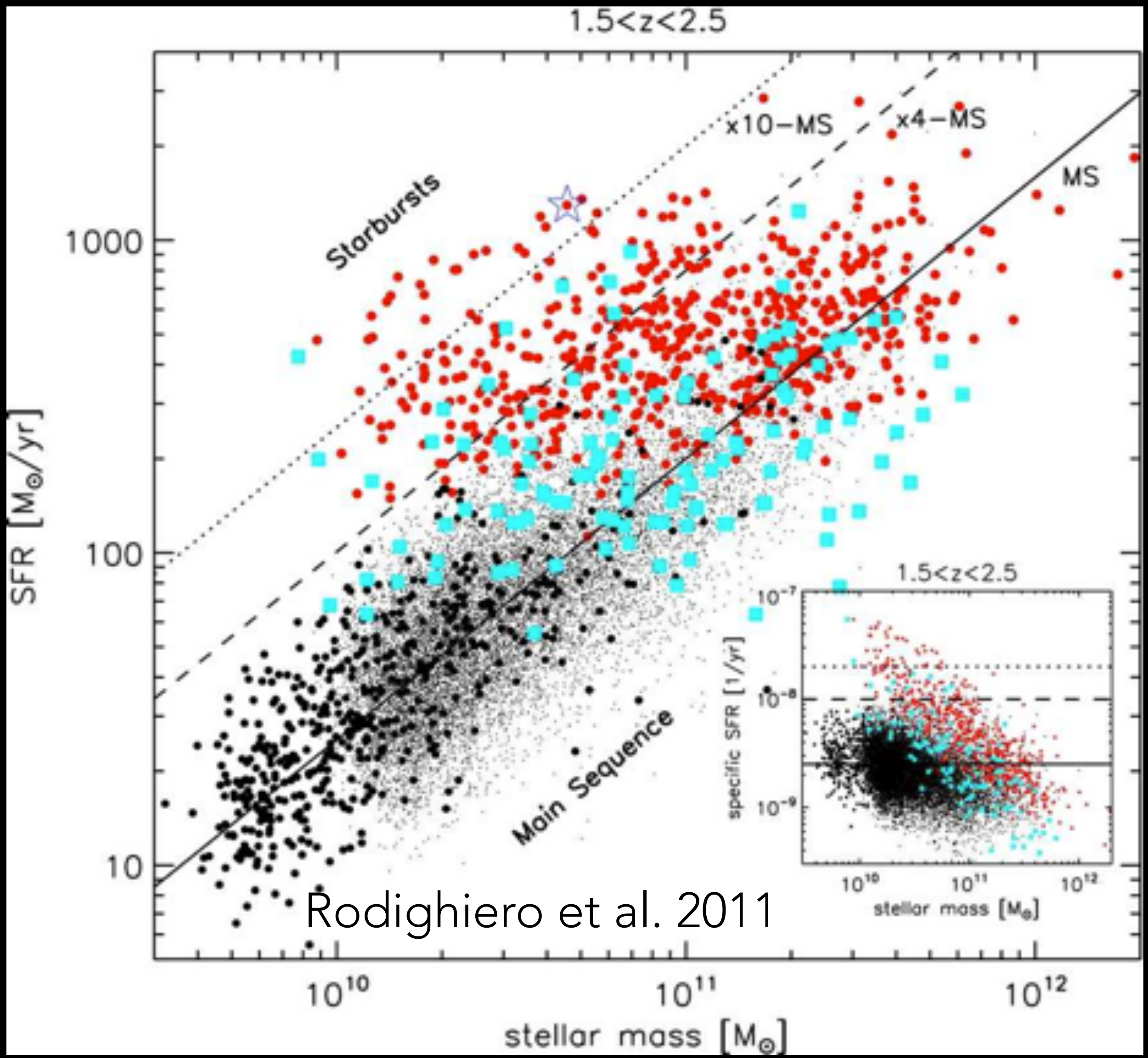
SCALING RELATIONS IN STAR-FORMING GALAXIES



Gas content-SFR relation



Main Sequence

In the merger paradigm, MS systems form stars secularly, in timescales that are long compared with their dynamical timescales. Outliers would be explained by starburst events driven by mergers.

A FEW OPEN QUESTIONS

- Two regimes or one regime of SF?
- Are the two regimes, if the exist, controlled by LOCAL or GLOBAL properties of galaxies?
- Do ISM conditions change along and across the MS?
- Are outliers of the KS law the same outliers of the MS?
- What is the role of mergers in shaping the MS?

WE NEED TO PARAMETRIZE THE ISM CONDITIONS ACROSS THE MAIN SEQUENCE

Stellar mass:

Top-heavy IMF?

More massive clusters in starbursts?

ISM gas:

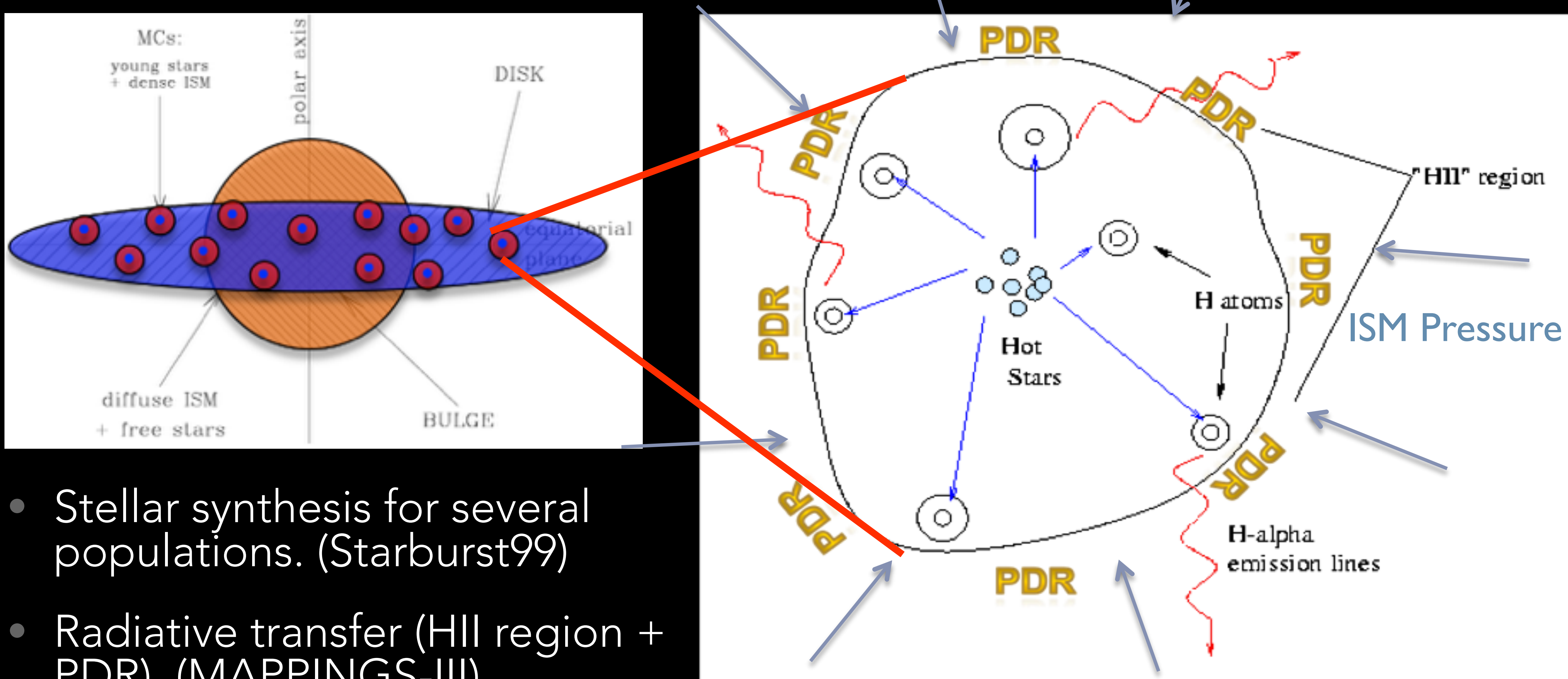
Different fractions of H_2?

Different pressures?

Geometry:

Where is the ISM dust with respect to the stars?

A SIMPLE PHYSICAL MODEL FOR STAR-FORMING GALAXIES



- Stellar synthesis for several populations. (Starburst99)
- Radiative transfer (HII region + PDR). (MAPPINGS-III)
- Dynamical evolution as an expanding bubble.
- Parameters are: f_{PDR}, SFR, M_*, Compactness.

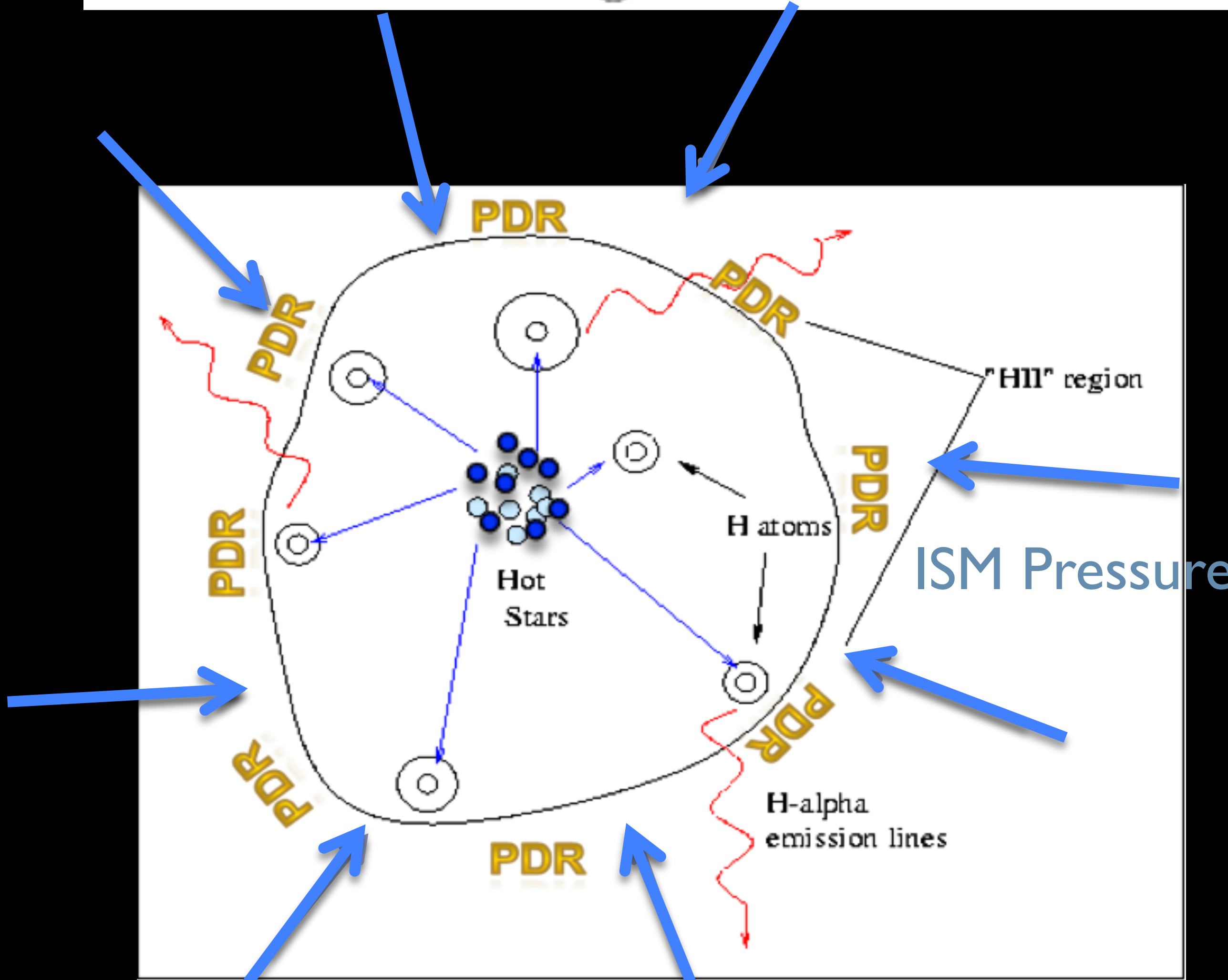
Resulting SED is a luminosity-weighted average of HII regions of different ages over 0-10 Myr, plus contributions from older populations.

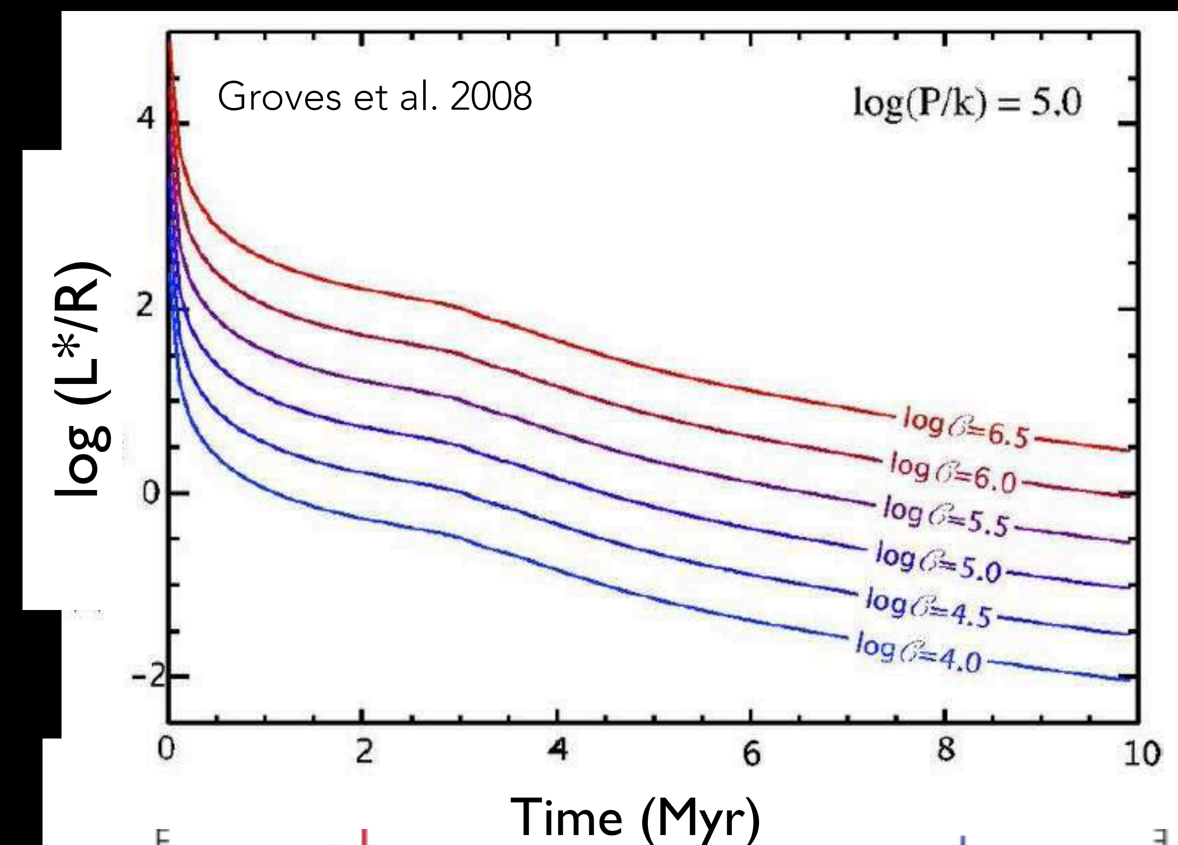
THE COMPACTNESS PARAMETER

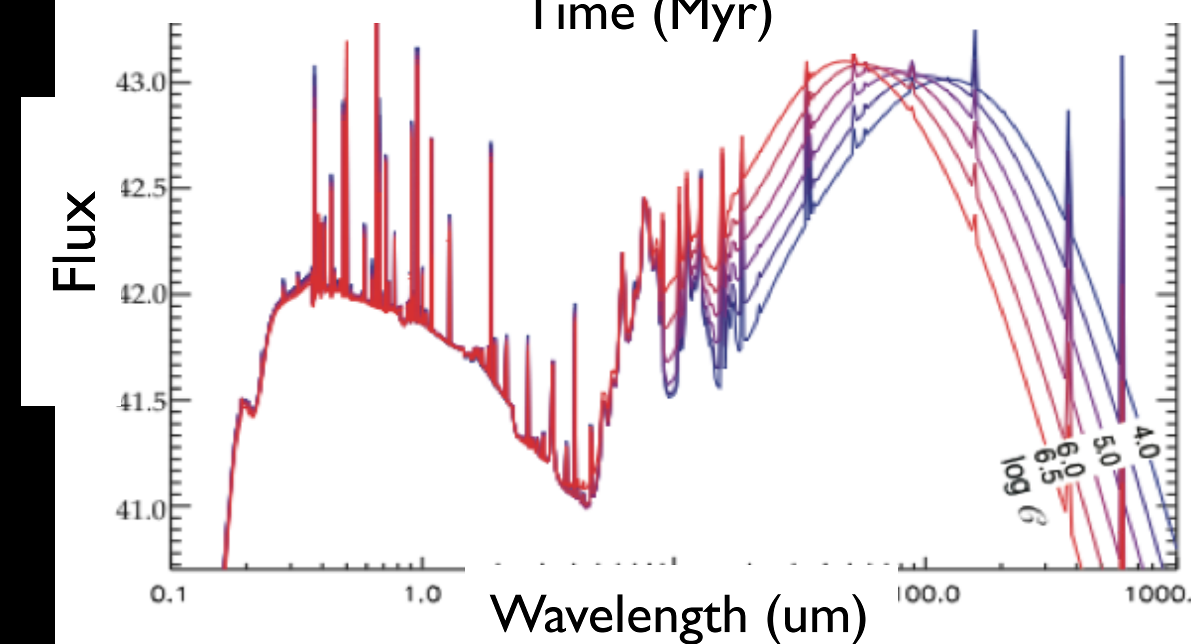
Instead of a single T_{dust}:

$$C \propto \frac{< L_\star(t) >}{< R(t)^2 >}$$

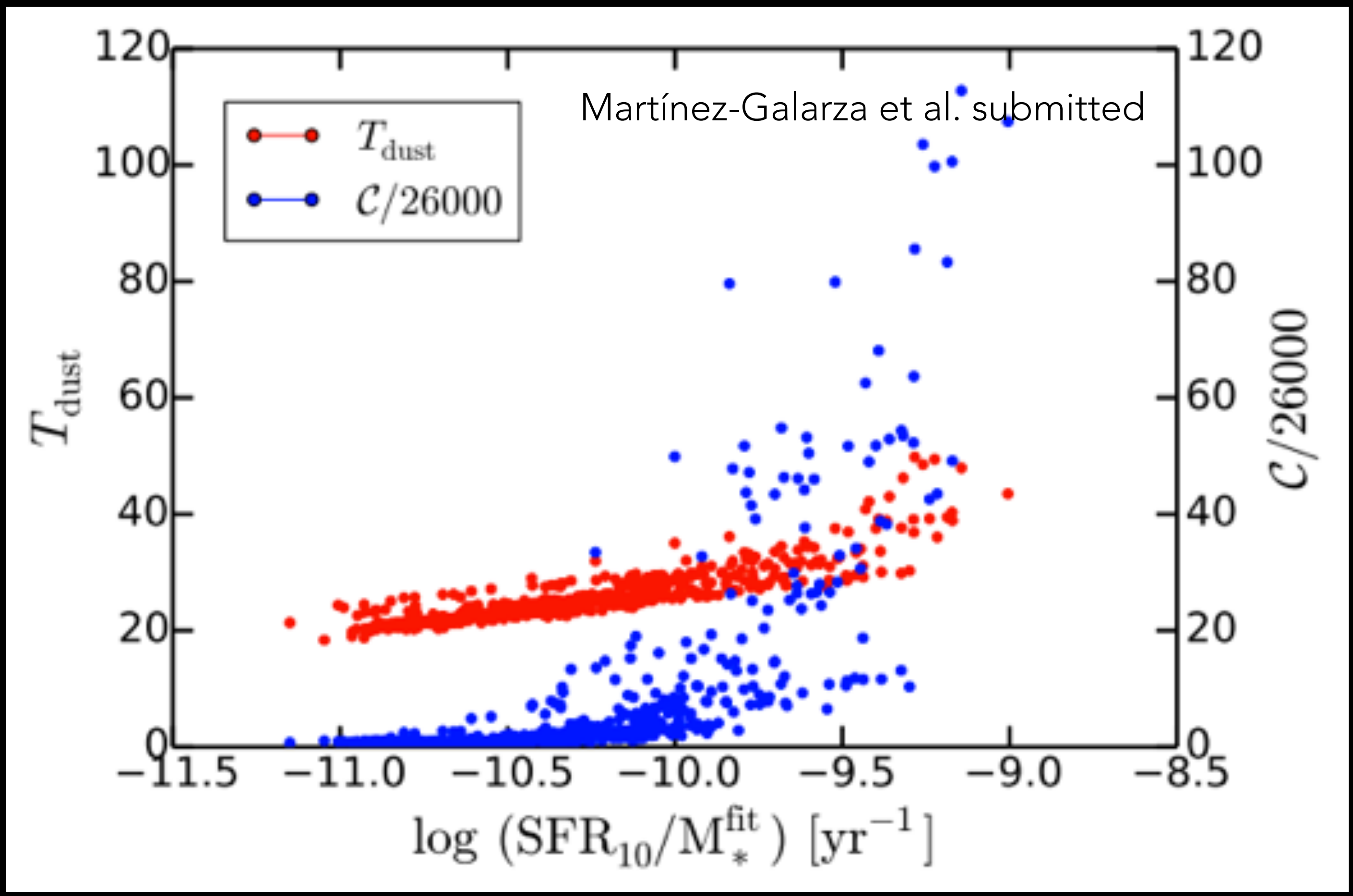
$$\log \mathcal{C} = \frac{3}{5} \log \left(\frac{M_{\rm cl}}{M_\odot} \right) + \frac{2}{5} \log \left(\frac{P_0/k}{\rm cm^{-3}\,K} \right)$$







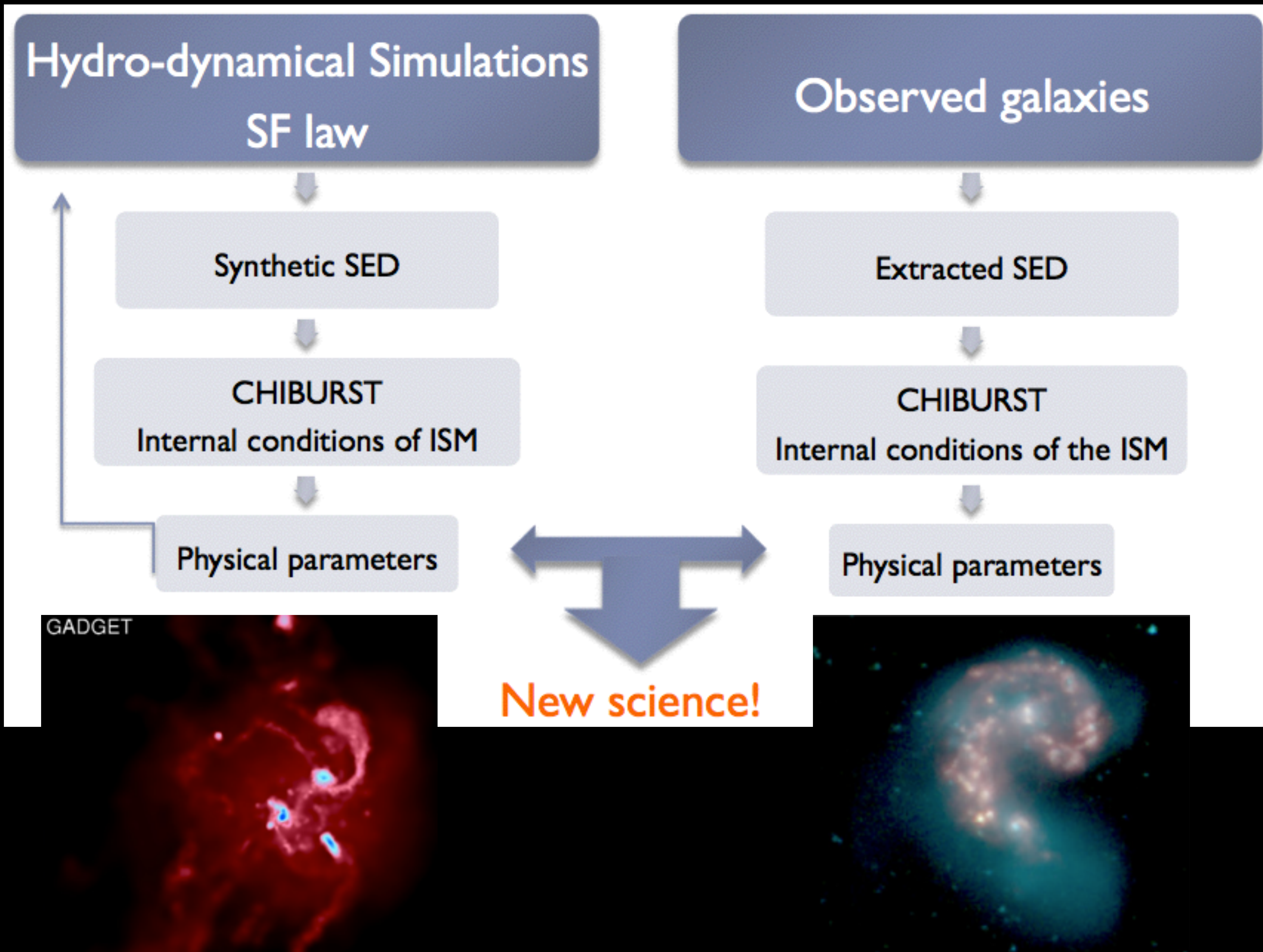
WHY CARING ABOUT COMPACTNESS?



- Although related, compactness and T_{dust} provide different information
- Compactness is a *parametrization* of the dust geometry in SF regions, whereas Tdust is an *effect* of this parametrization, but also of other things.
- Tdust is affected in a different way by other heating sources (not massive stars in HII regions). See Groves et al., 2012.

Compactness is more sensitive than T_{dust} to changes in sSFR, specially for sSFR>-10 yr^{-1}. In our simulations, this corresponds to the near-coalescence phases of massive mergers.

COMBINING SIMULATIONS AND OBSERVATIONS



SIMULATED INTERACTIONS

- Hydrodynamics: GADGET-3 (Springer et al. 2005).
    - Hierarchical tree method to compute gravitational interactions.
    - Gas dynamics via smoothed particle hydrodynamics.
    - Schmidt-Kennicutt law above $n \sim 0.1\ cm^{-1}$. $SFR \sim \rho_{gas}^{N}$, $N=1.5$
- Radiative transfer: SUNRISE (Jonsson et al., 2006).
    - 3-D polychromatic Monte Carlo dust radiative transfer code.

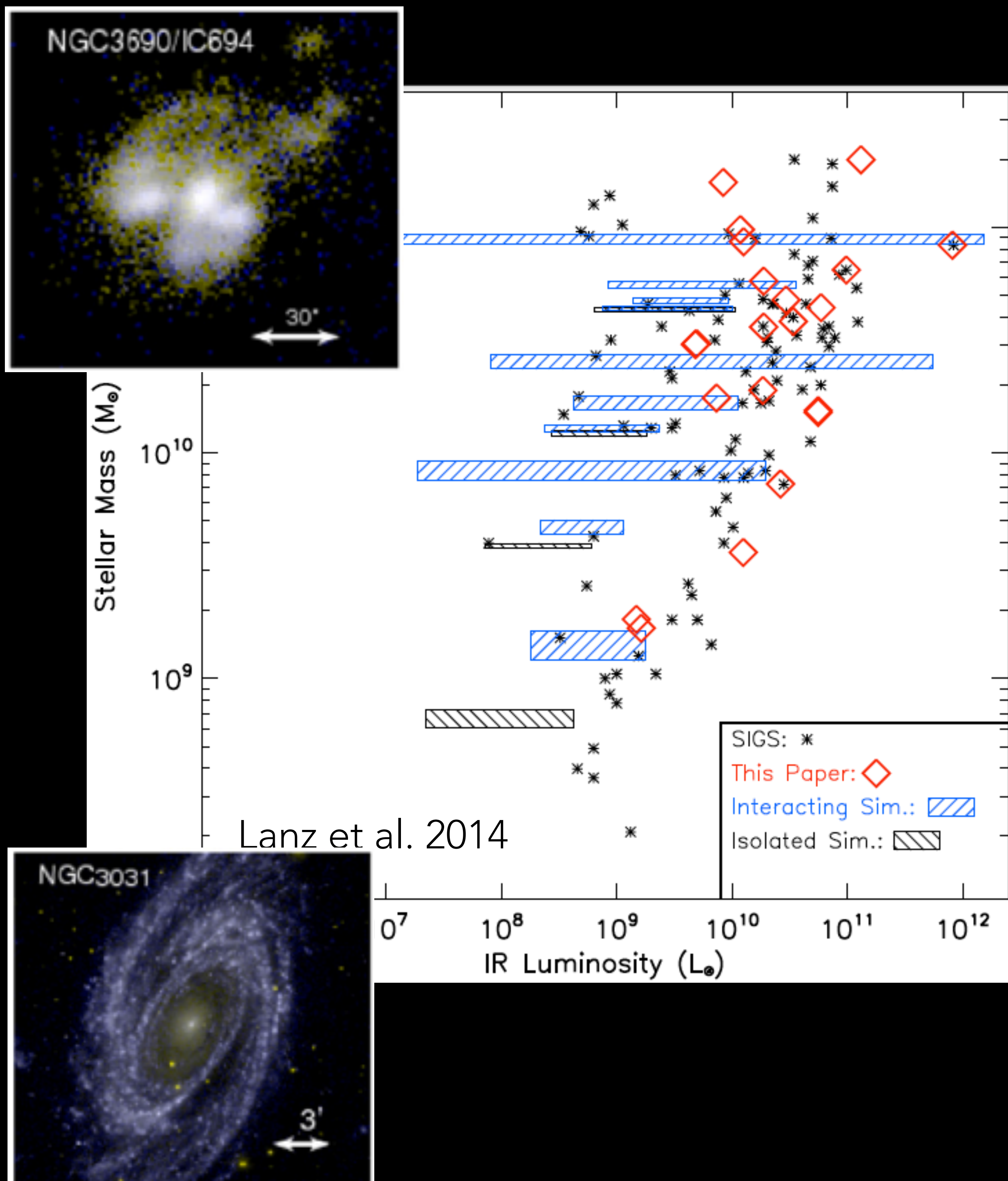
SIMULATED PROGENITORS

TABLE 1
GALAXY MODELS FOR THE SIMULATIONS

	M0	M1	M2	M3	SMG
M_* (10^{10} $M_\odot$)	0.061	0.38	1.128	4.22	16.0
M_{tot} (10^{10} $M_\odot$)	5.0	20.0	51.0	116.0	940.0
M_{gas} (10^{10} $M_\odot$)	0.035	0.14	0.33	0.80	24.0
N_{DM}	30000	50000	80000	12000	60000
N_{gas}	10000	20000	30000	50000	48000

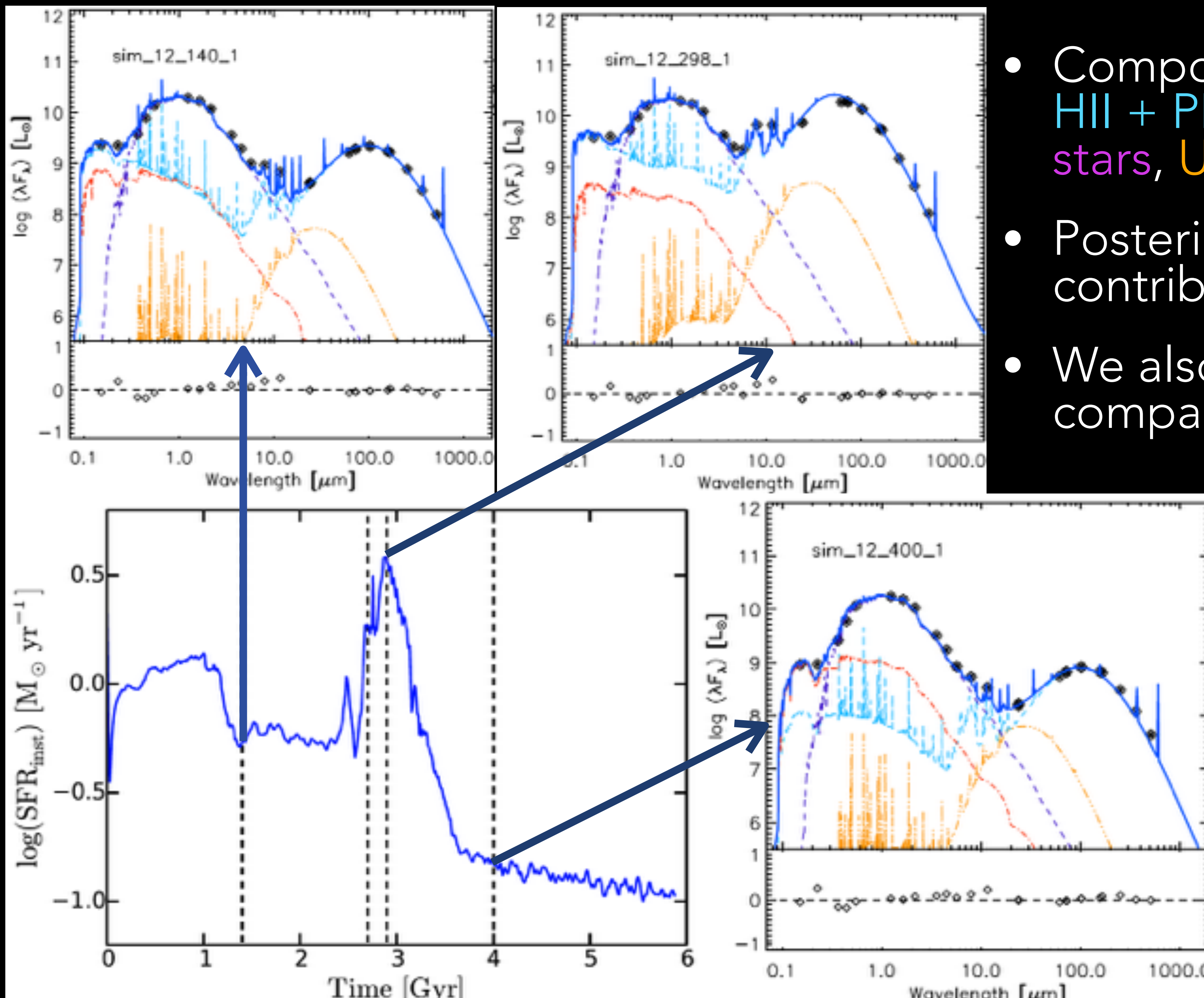
Simulated galaxies have a broad range of gas content, with f_{gas} in the range (0.16-0.36). For the SMS simulation, f_{gas} = 0.6.

MATCHING SIMULATIONS TO OBSERVATIONS



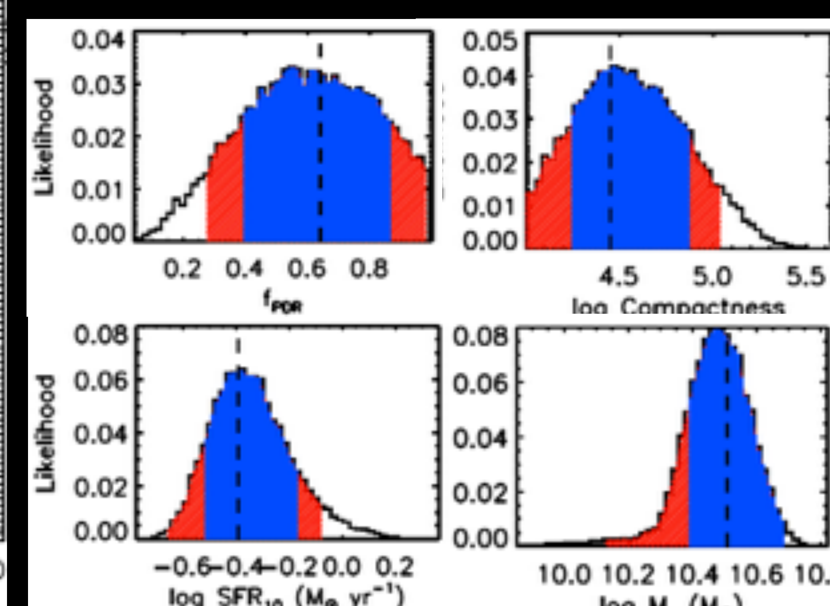
- ~120 interacting systems at several stages (about 40 included so far).
- From early stages to near-coalescence phases.
- We also have data from about 20 local and z~0.3 Herschel-selected LIRGs ($L>10^{11}L_{\odot}$) from Magdis +2014.

TRACING SF IN AN INTERACTING SYSTEM (M2/M3)

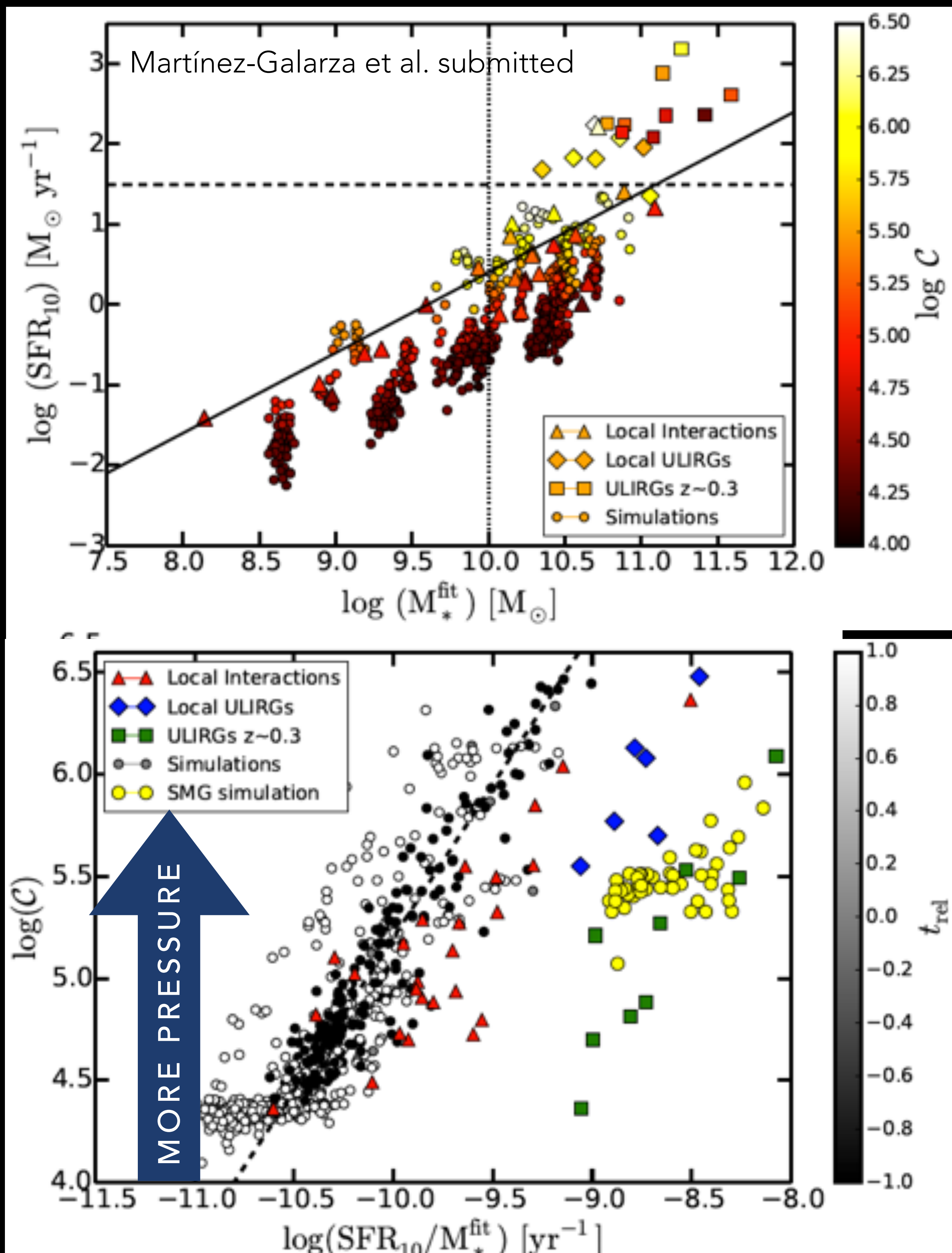


- Components shown are: HII + PDR, <100Myr stars, <5Gyr stars, UCHII regions
- Posterior PDFs give the most likely contribution from each of them.
- We also infer the most likely compactness in each case.

Example PDFs



BUILDING THE MAIN SEQUENCE OF GALAXIES



- Slope and scatter of the MS reproduced by the evolution in time of a set of interacting galaxies.
- ISM conditions (P/k, G_0) change across the MS.
- Changes in f_{gas} don't significantly affect the normalization of sSFR-logC.
- If outliers of the MS are mergers, they have to be more massive than $10^{11} M_\odot$, or have more gas ($f_{gas}>0.6$)
- Not all outliers of the MS have SEDs consistent with late-type mergers.

A POSSIBLE INTERPRETATION (OBS)

Assume polytropic equation for the ISM gas:

$$P \propto n_{\mathrm{gas}}^{\gamma}$$

And a volumetric KS law that depends on free-fall time of the gas only (Krumholz 2012):

$$\frac{SFR}{V} = f_{\mathrm{H_2}} \epsilon_{\mathrm{ff}} \sqrt{\frac{32G}{3\pi}} n_{\mathrm{gas}}^{3/2}$$

$$t_{\mathrm{ff}} = \sqrt{\frac{3\pi}{32 G n_{\mathrm{gas}}}}$$

This implies:

$$\frac{SFR}{V} \propto P^{3/2\gamma}$$

$$P_{\mathrm{upper}}/P_{\mathrm{lower}} = 10^{\gamma}$$

And since $\mathcal{C} \propto P^{2/5}$, for reasonable values of γ the change of pressure only partially explains the change in compactness.

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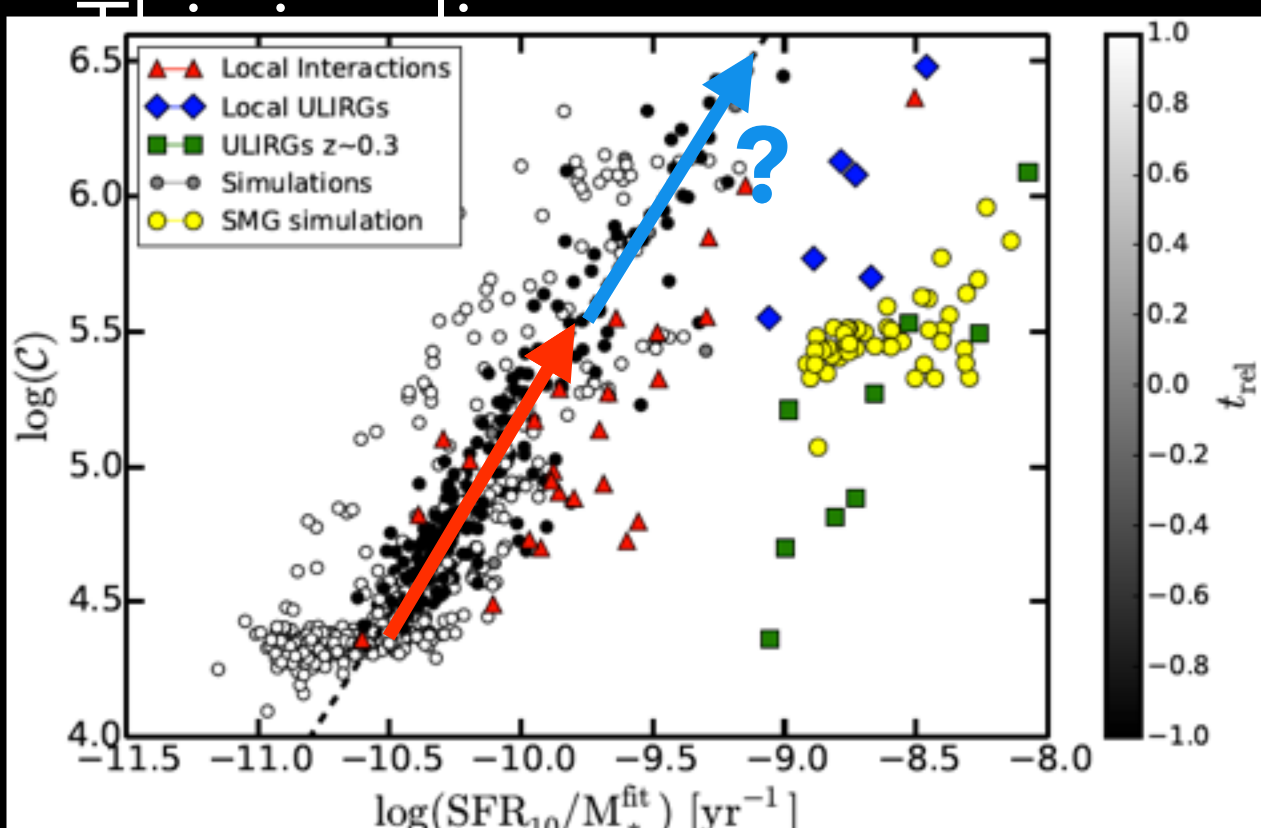

$$P_{\rm upper}/P_{\rm lower} = 10^{\gamma}$$

$$M_{\rm cl} \propto n_g^{\beta}$$

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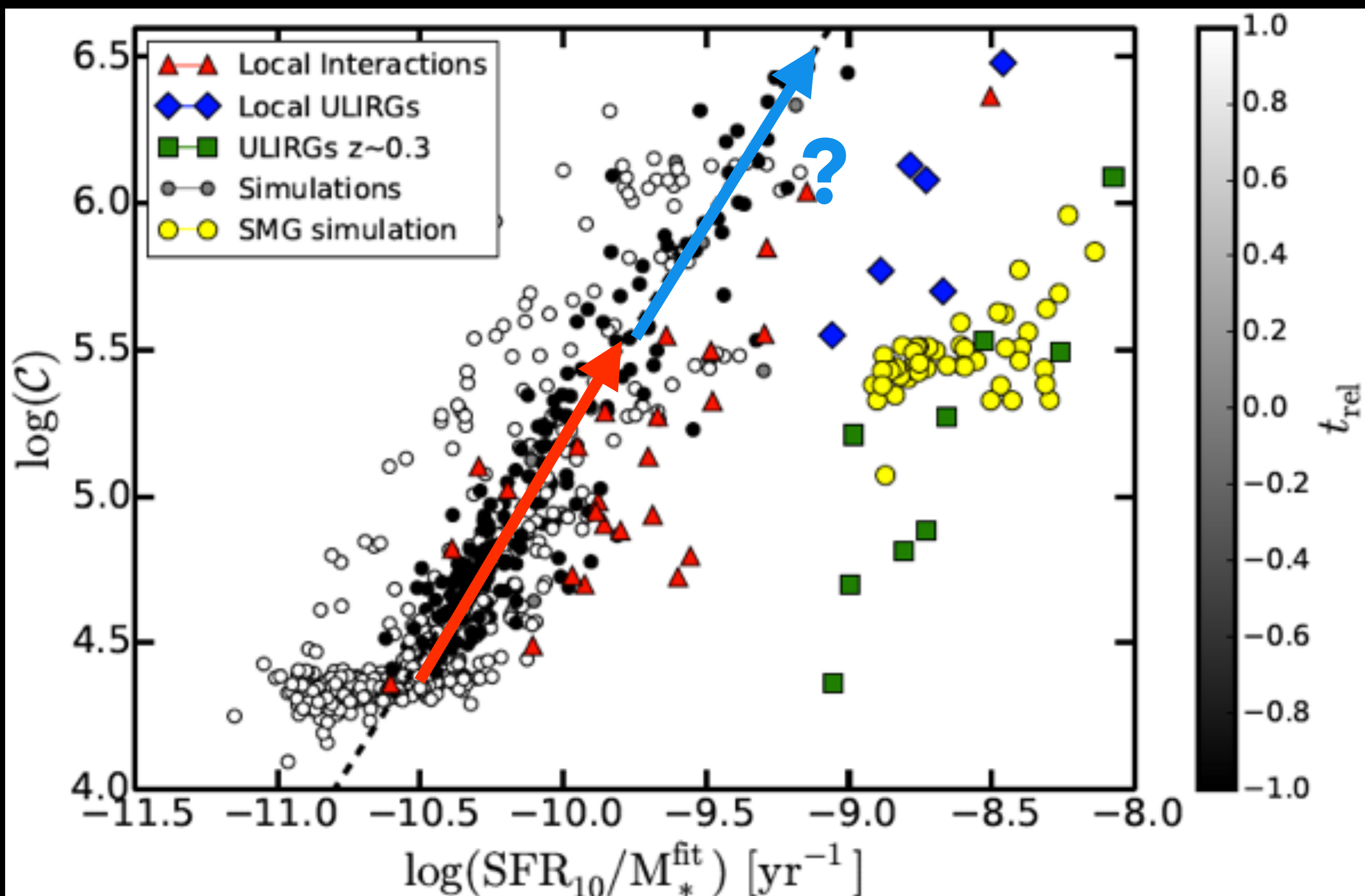
SUMMARY

- Compactness is a useful quantity to characterize the ISM of star-forming galaxies.
- Not all outliers of the MS have SEDs consistent with late-type mergers.
- Compactness evolves smoothly across the MS. Variation translates into an increase of a few orders of magnitude P/k, assuming invariance of the radiation field.
- If outliers of the MS are strong starbursts driven by mergers, they must have total stellar masses above $10^{11} M_{\odot}$, or have more gas (f_{gas}>0.6).
- In real systems, pressure changes might only partially explain the observed range of compactness. Variations in the average radiation field (Mcl?) are needed to explain the remaining.

THANK YOU!

COMPACTNESS AND STAR FORMATION



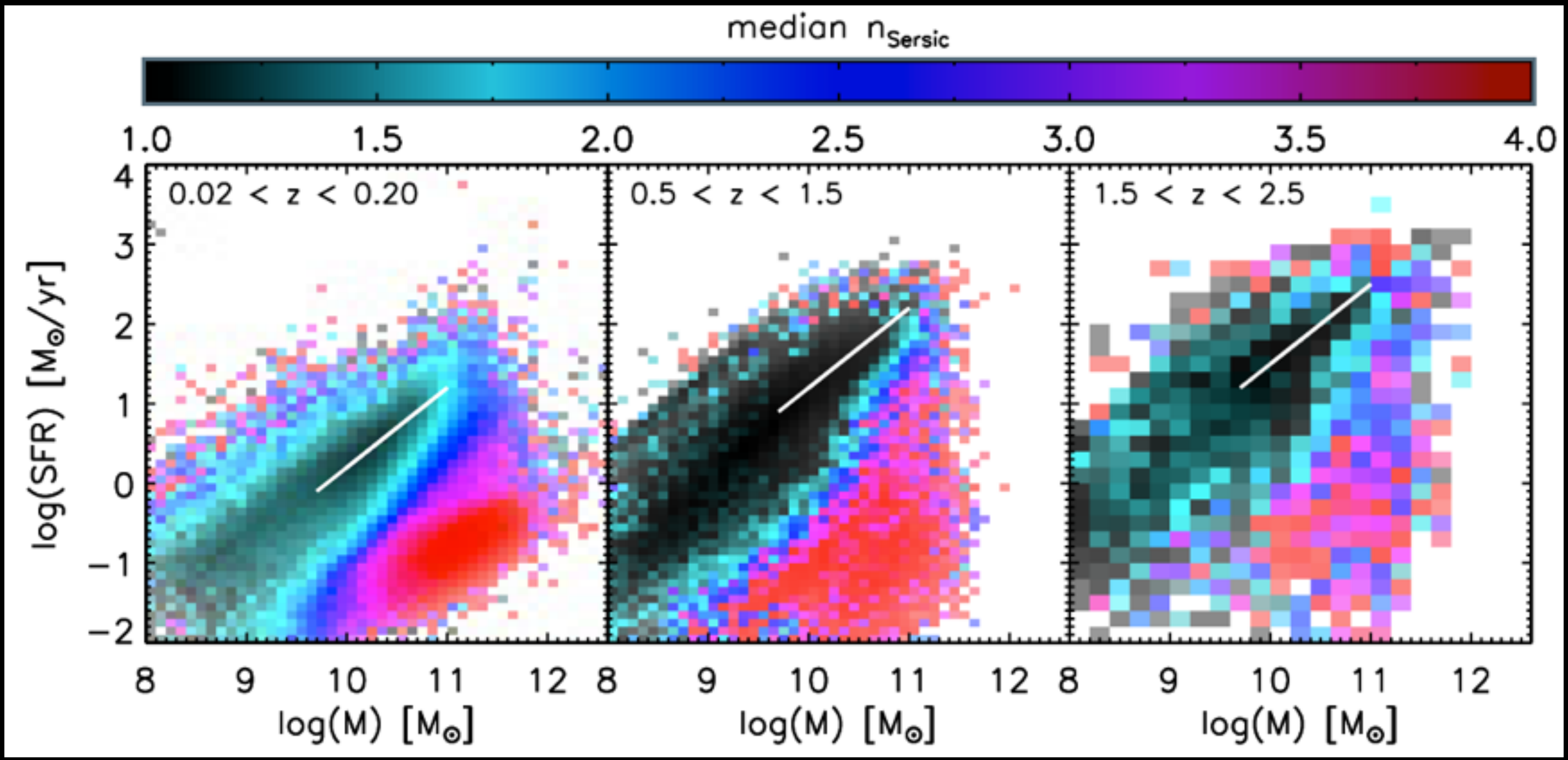
$$\frac{SFR}{V} \propto P^{3/2\gamma}$$

$$P_{\rm upper}/P_{\rm lower} = 10^{\gamma}$$

$$M_{\rm cl} \propto n_g^{\beta}$$

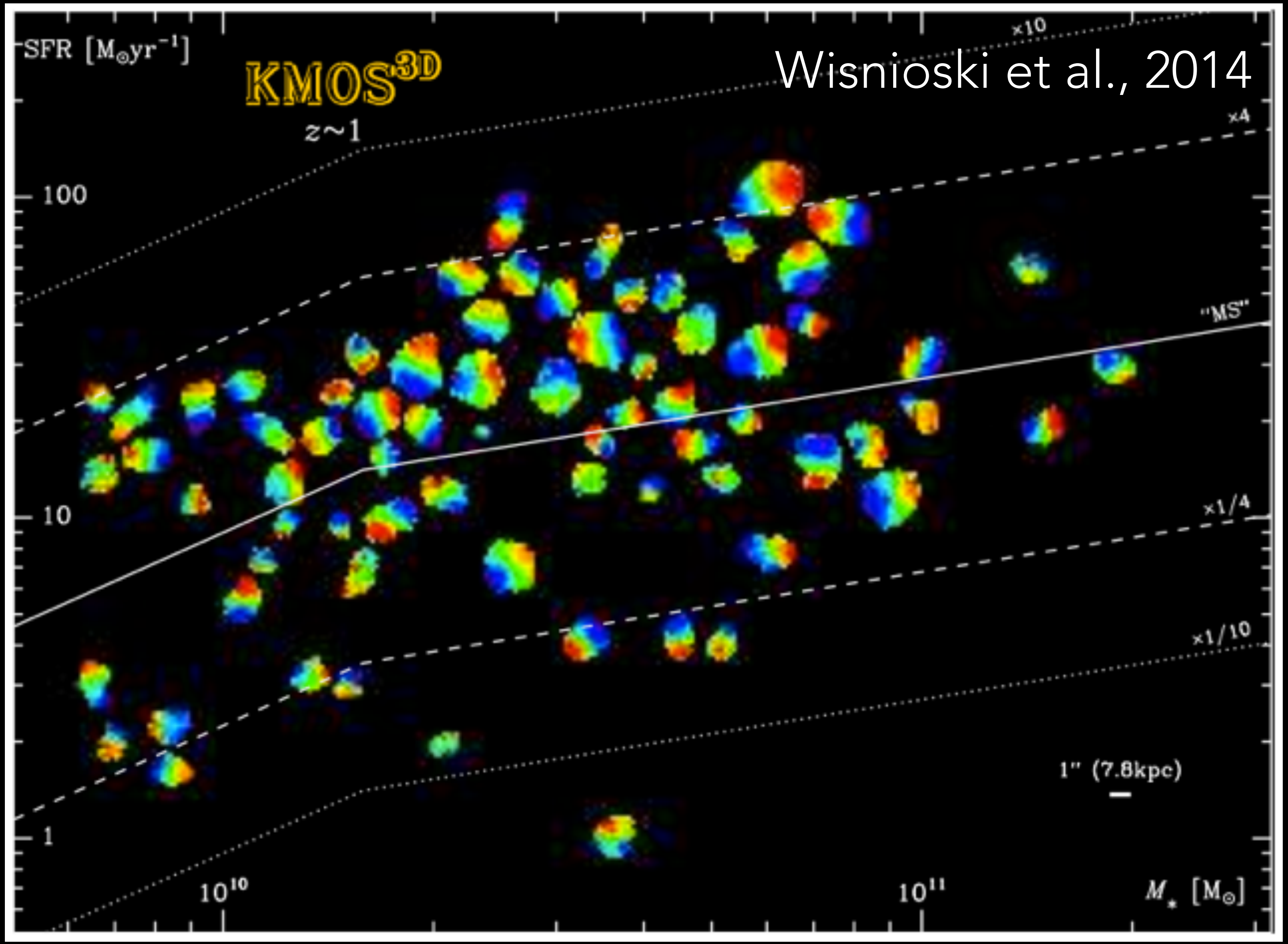
Assuming a volumetric SF law, pressure changes only partially explain the observed range of compactness. Variations in the average radiation field (Mcl?) are needed to explain the remaining.

MORPHOLOGICAL PROPERTIES OF THE MAIN SEQUENCE



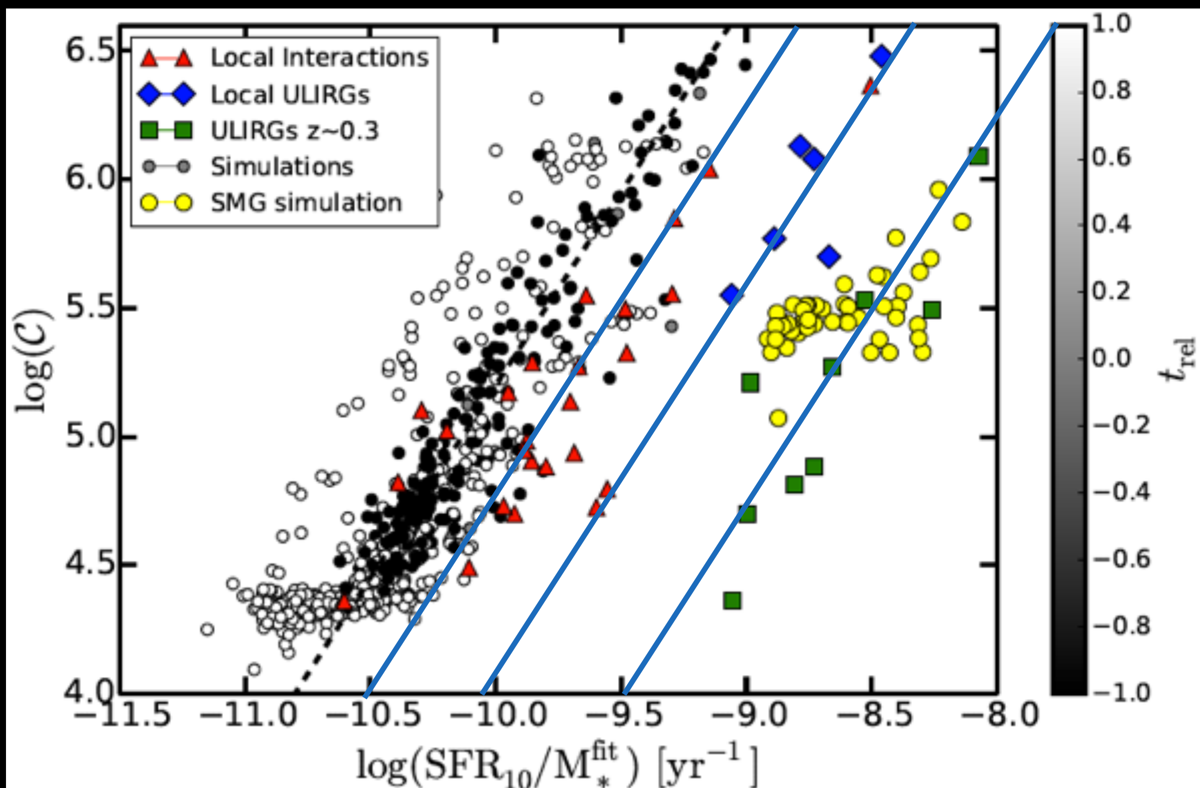
- Most galaxies in the MS are exponential disks.
- Outliers in the upper envelope have cuspier light profiles.
- However, are outliers really merger-driven starbursts?

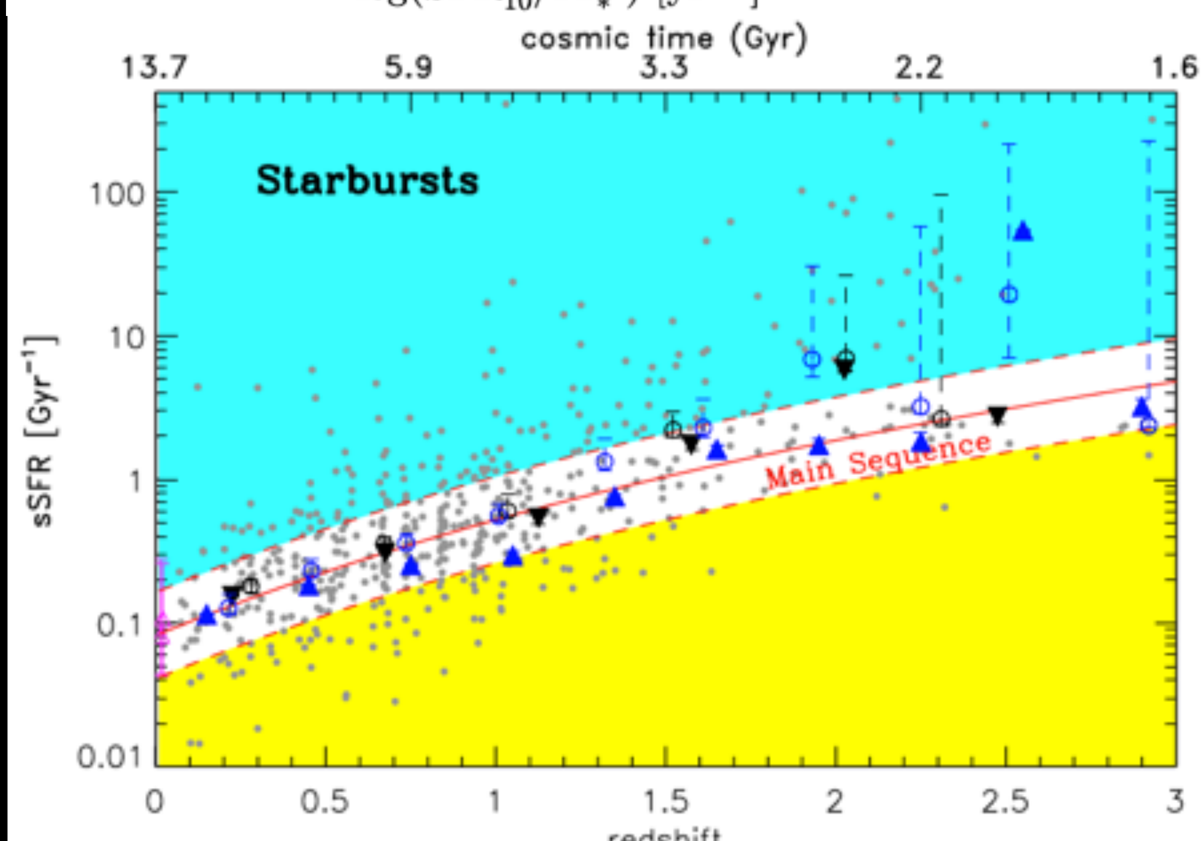
WHAT DO KINEMATICS TELL US?



- Are really all galaxies in the MS exponential disks?
- About 20% of galaxies in the MS are mergers (Hung et al. 2013)
- Issues: do disks re-form after coalescence?

WHAT ABOUT THE OUTLIERS?

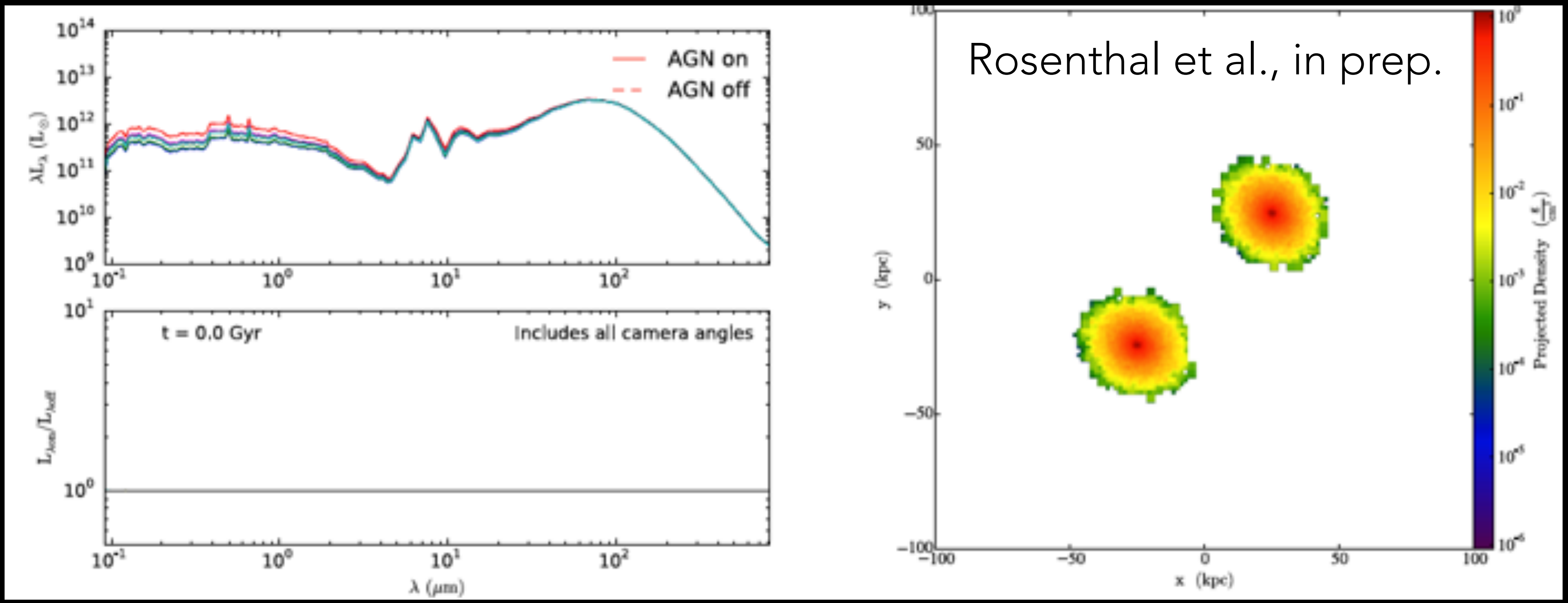




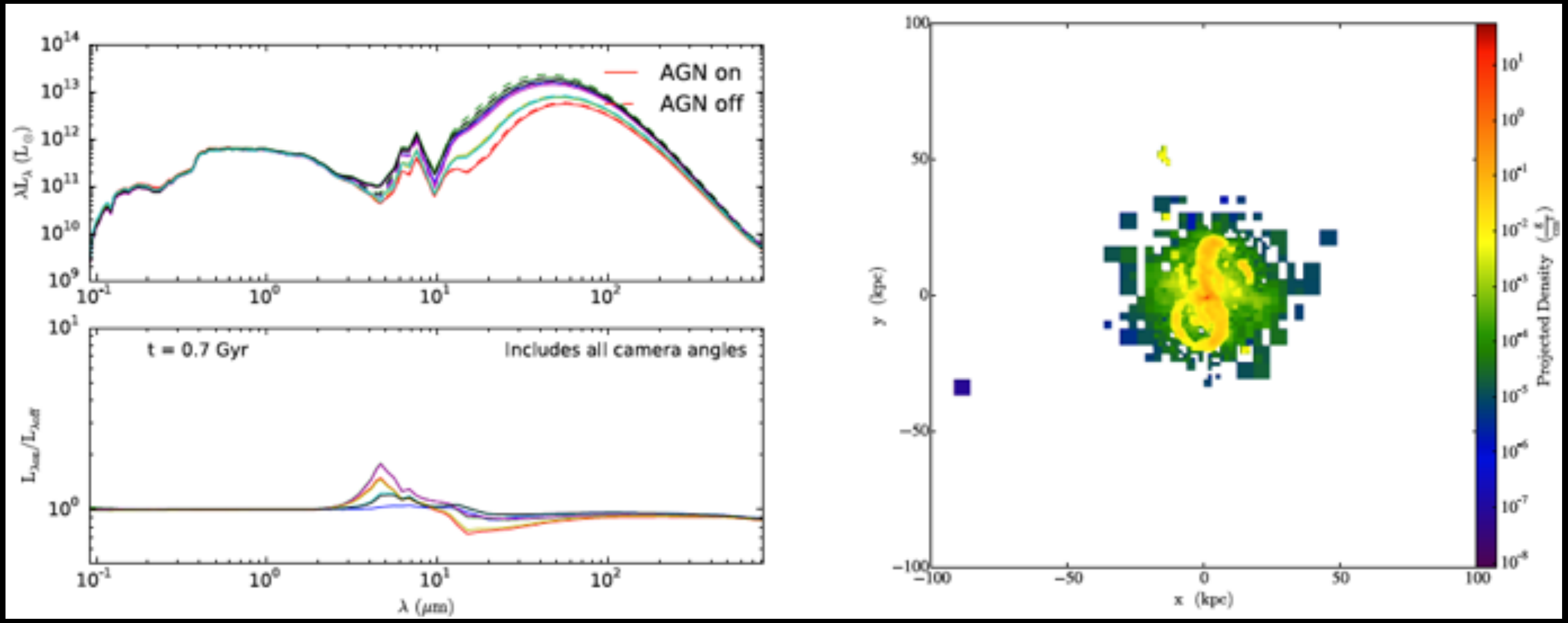
- The normalization of the MS evolves in time.
- Even after gas content effect has been taken into account, a population of MS outliers remains.
- They appear as systems whose compactness is too low for their high sSFRs.
- Outliers either:
  - Have larger SFEs (i.e., no universal SF law exists).
  - Have weaker radiation fields (notice that they are not necessarily outliers of the KS law).
- Certainly not all of them are compact.

BONUS1: EFFECT OF THE AGN ON THE SED

Before coalescence

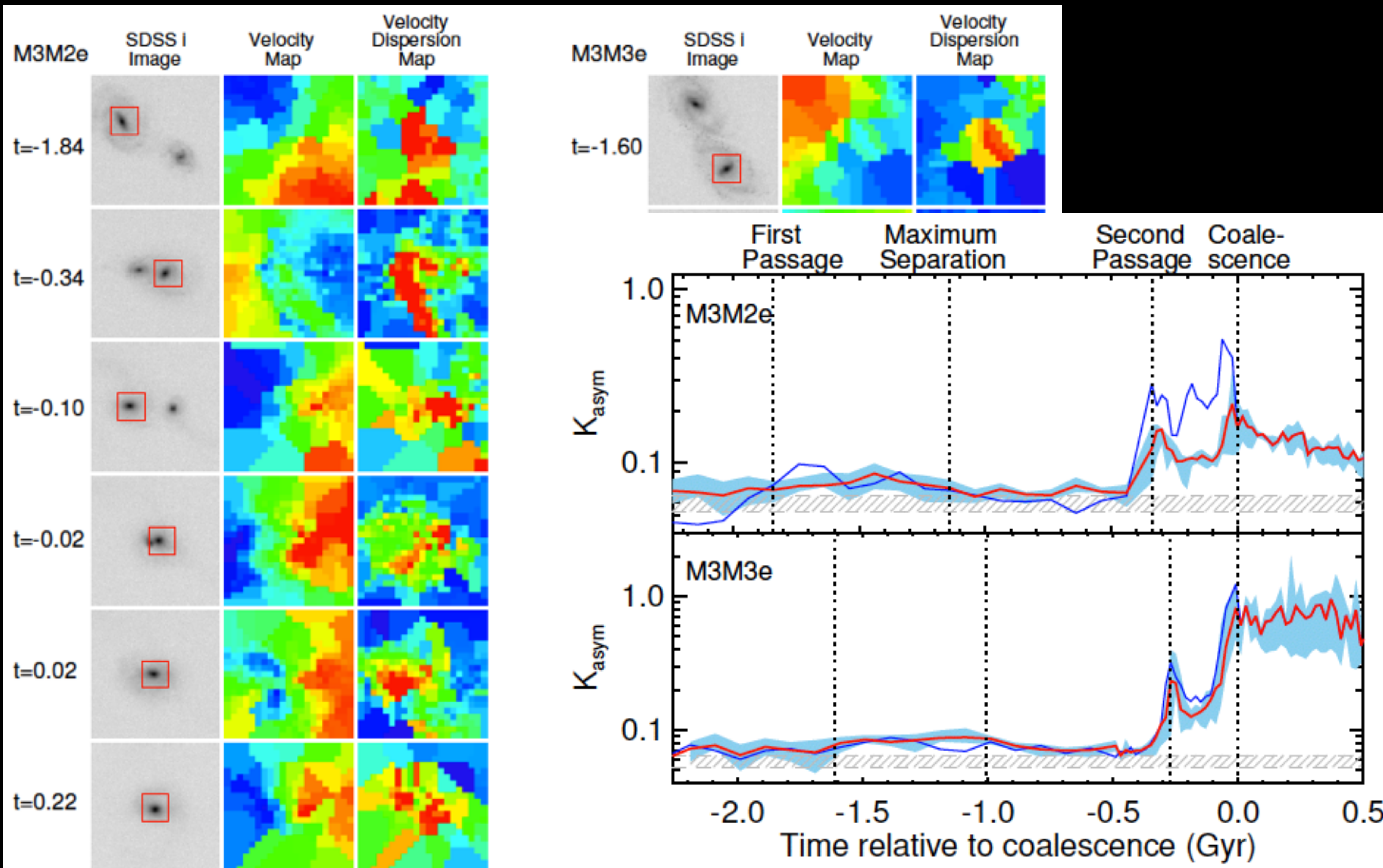


Right after coalescence

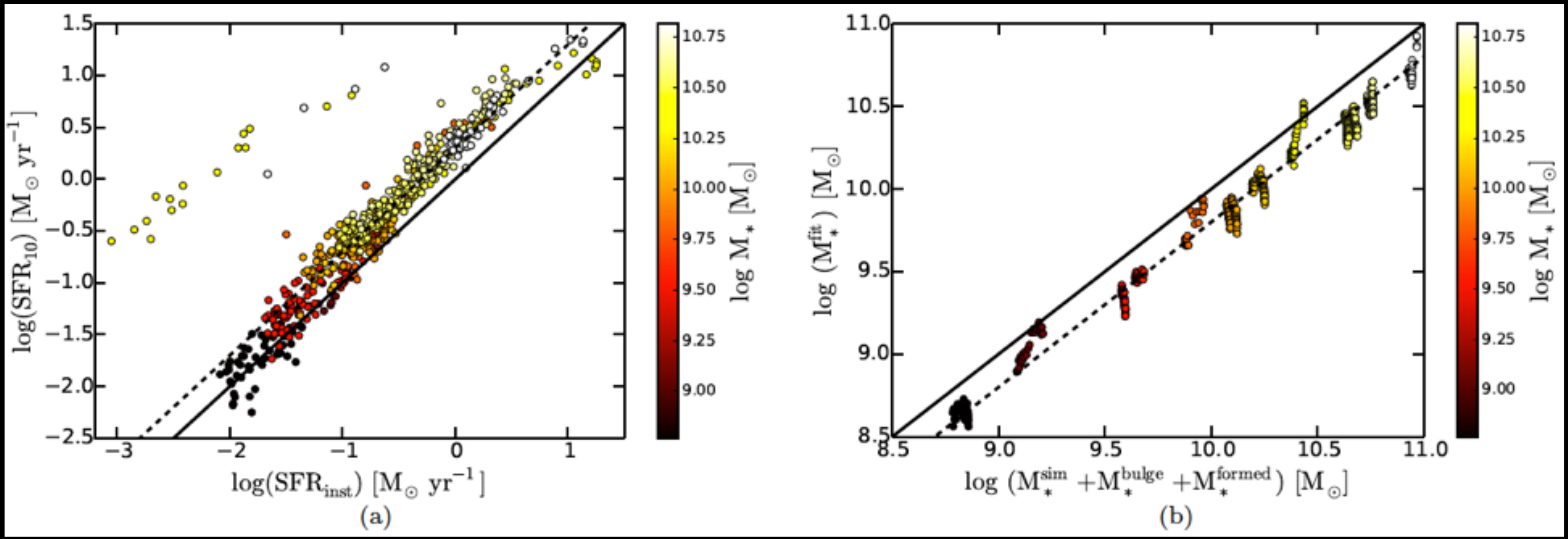


BONUS 2: DYNAMICS OF STAR-FORMING GAS

Hung et al., in prep



HOW WELL ARE WE DOING?



- Estimation of the sSFR is model dependent.
- Sources of error: assumptions on the feedback physics, different dust models used
- Method associated uncertainties are between 0.3 and 0.4 dex depending on total galaxy mass (Berhoozi et al., 2013).
- Our discrepancies with "true" values are within these uncertainties.