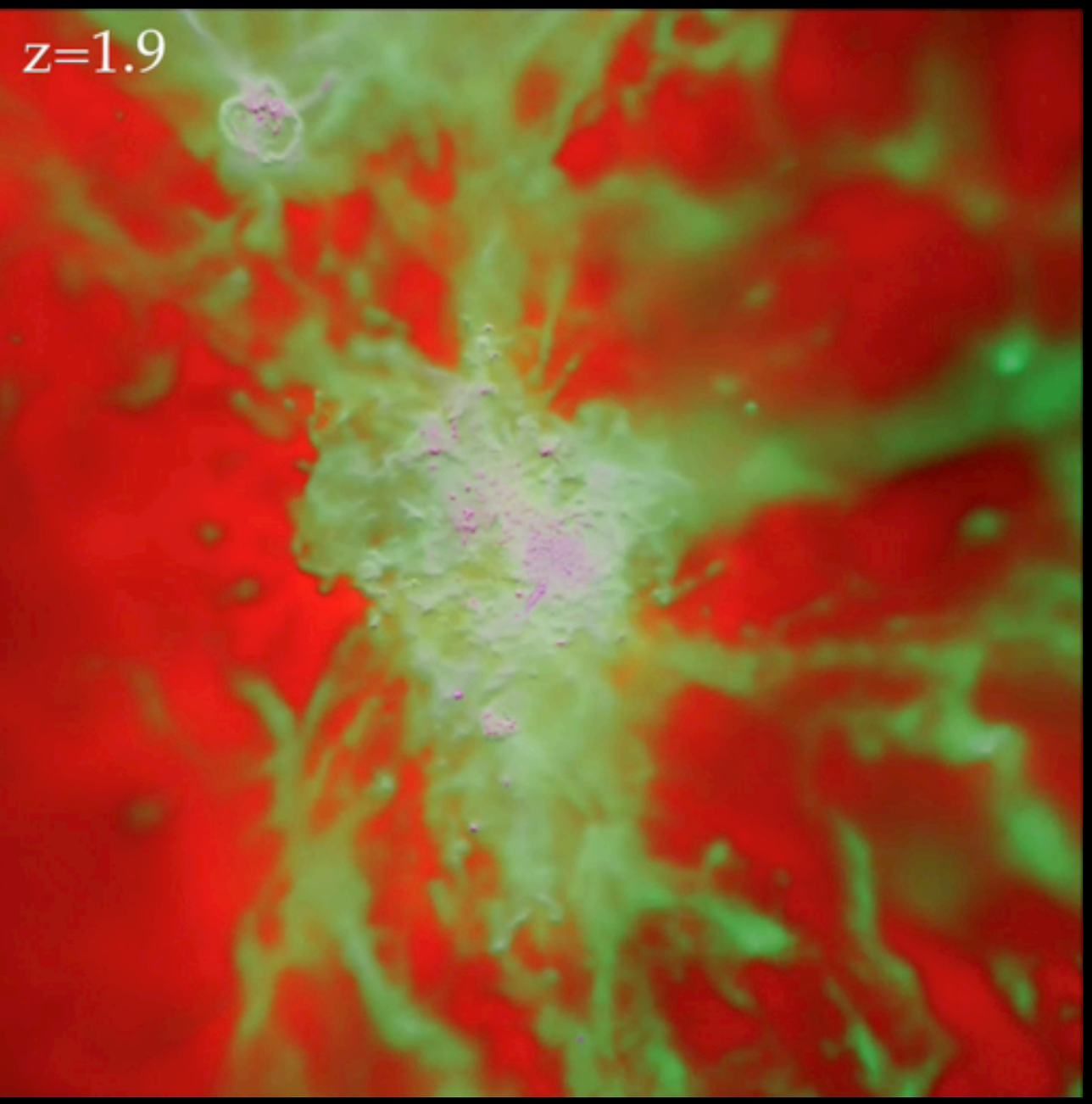
The star formation-AGN connection: a theoretical perspective

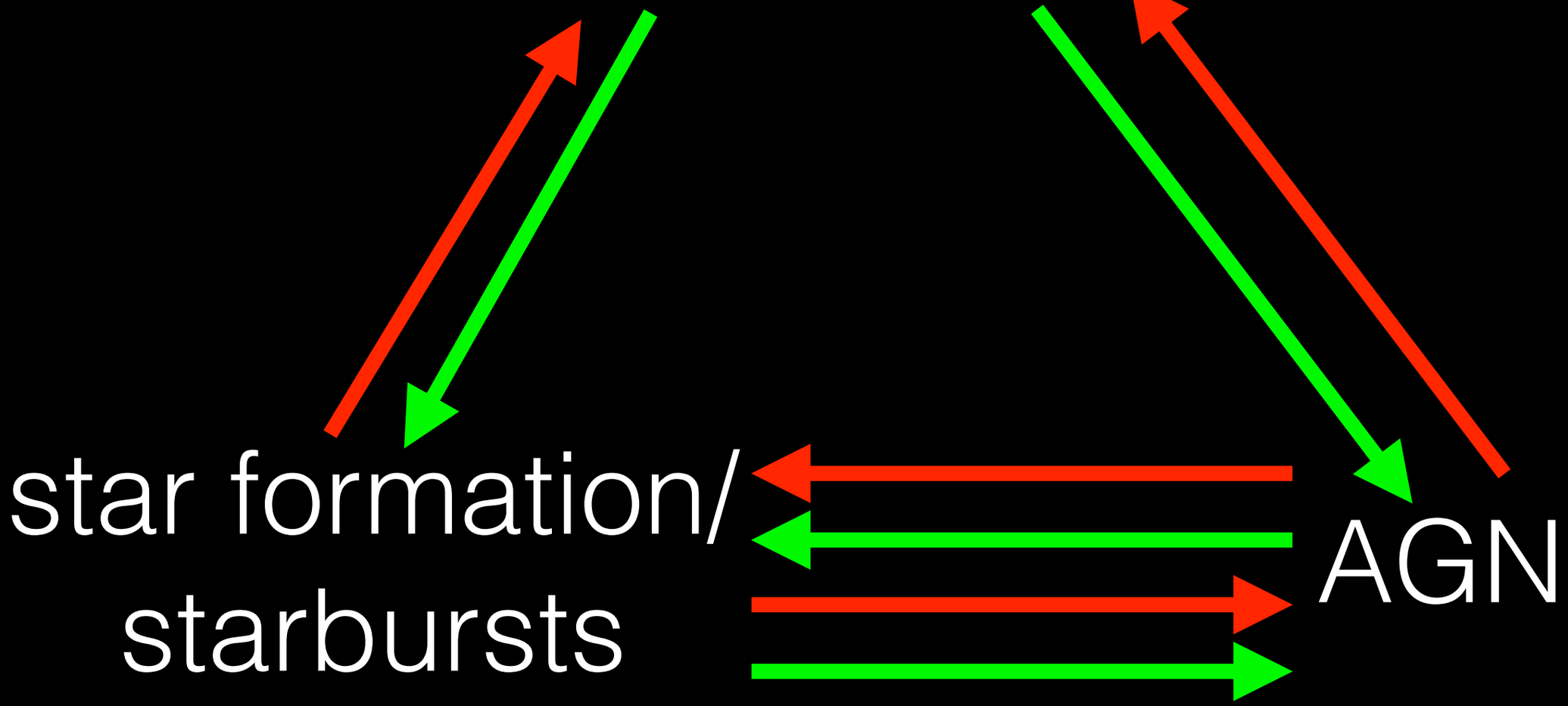


Chris Hayward, Caltech

FIR Surveyor Workshop, Pasadena, 4 June 2015

SF-AGN connection

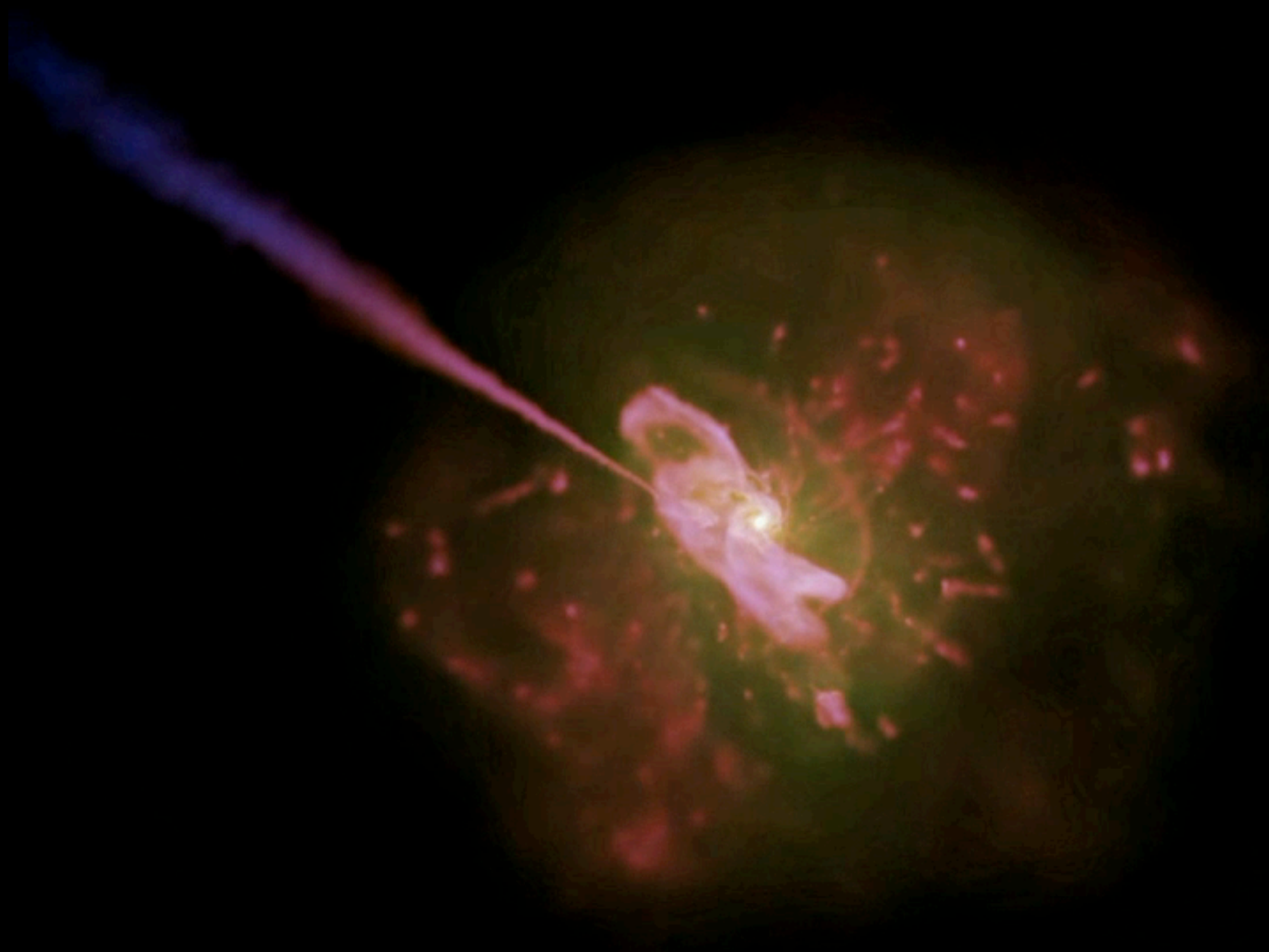
gas supply



SF-AGN connection c. 2005

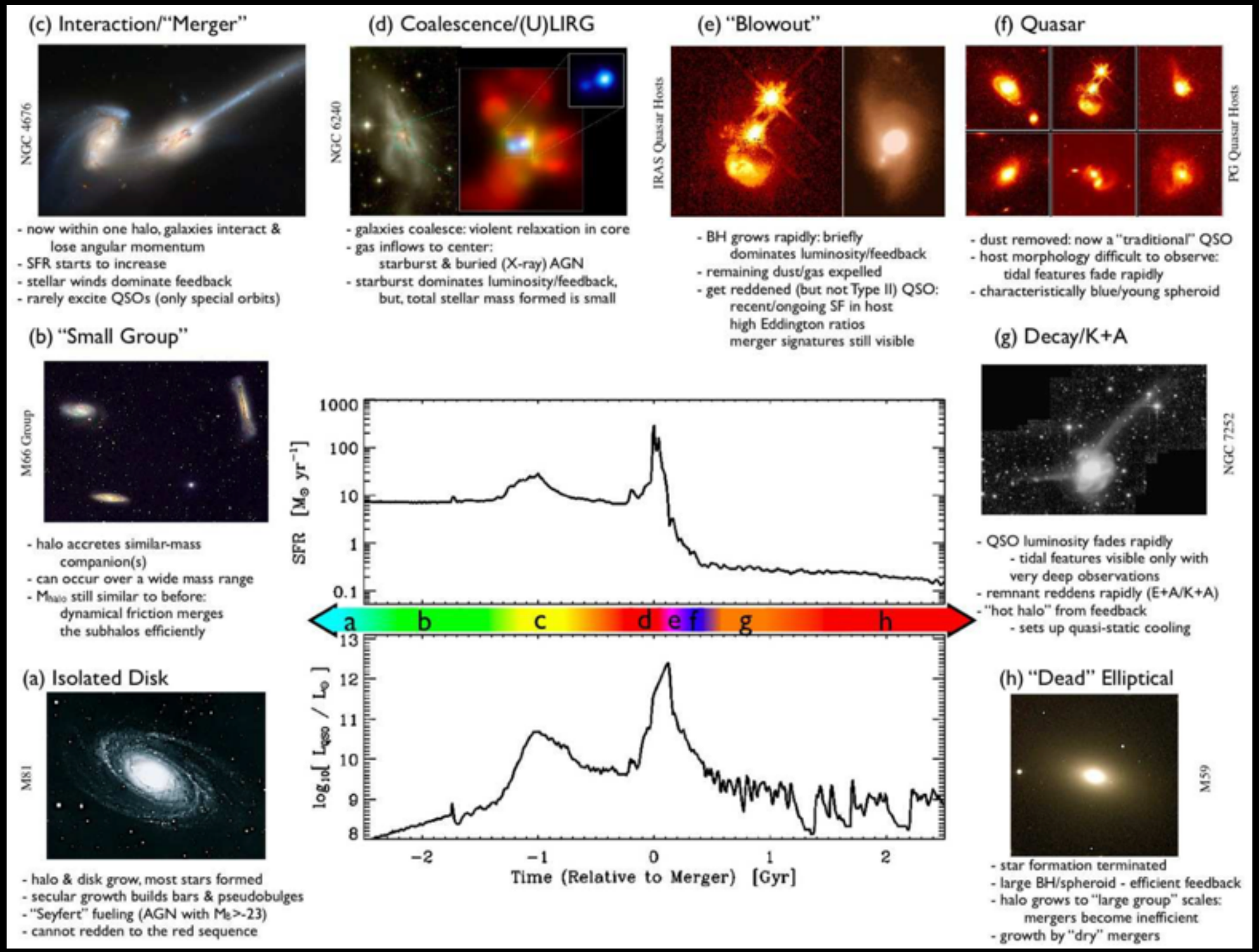
T = 1460 Myr

Gas



Springel, Di Matteo & Hernquist 2005

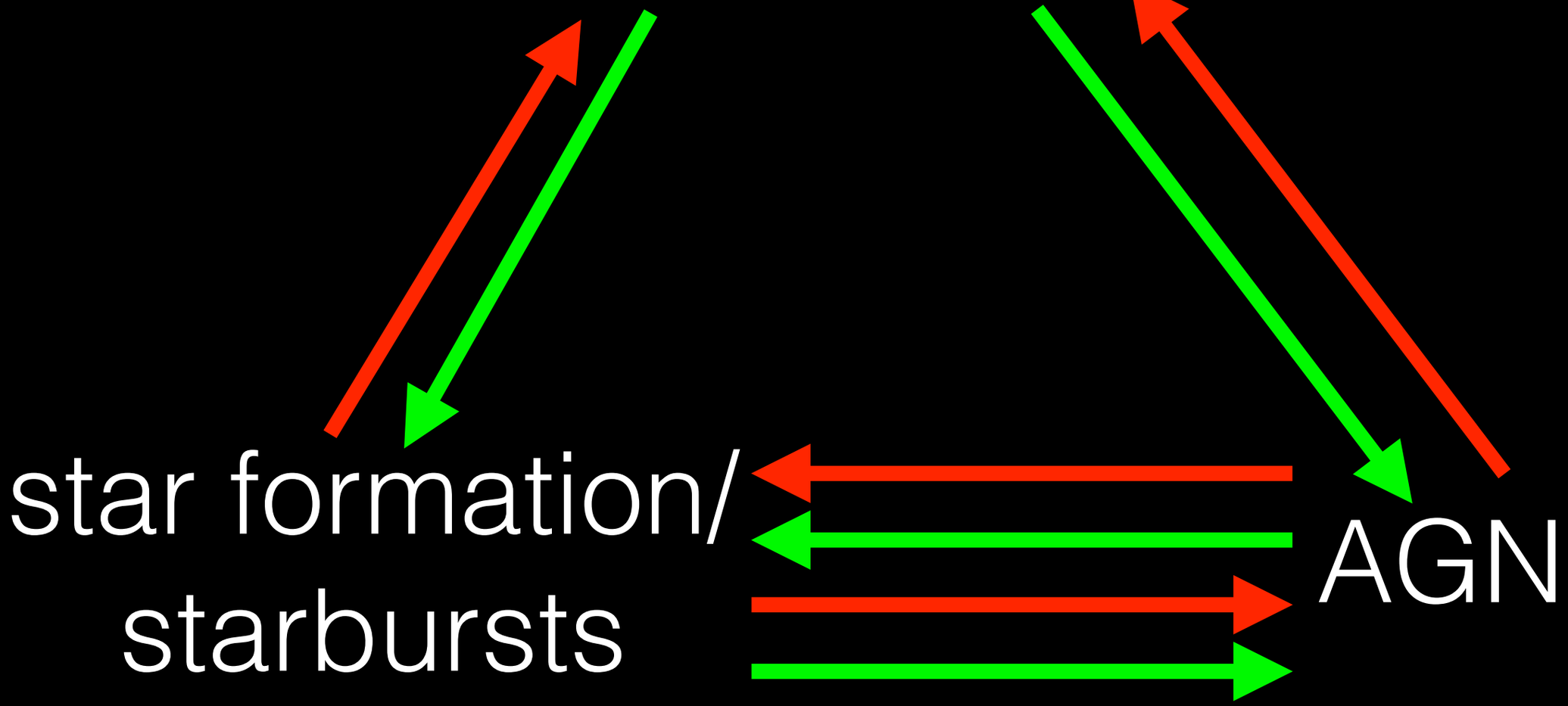
SF-AGN connection c. 2005



Hopkins et al. 2008

SF-AGN connection

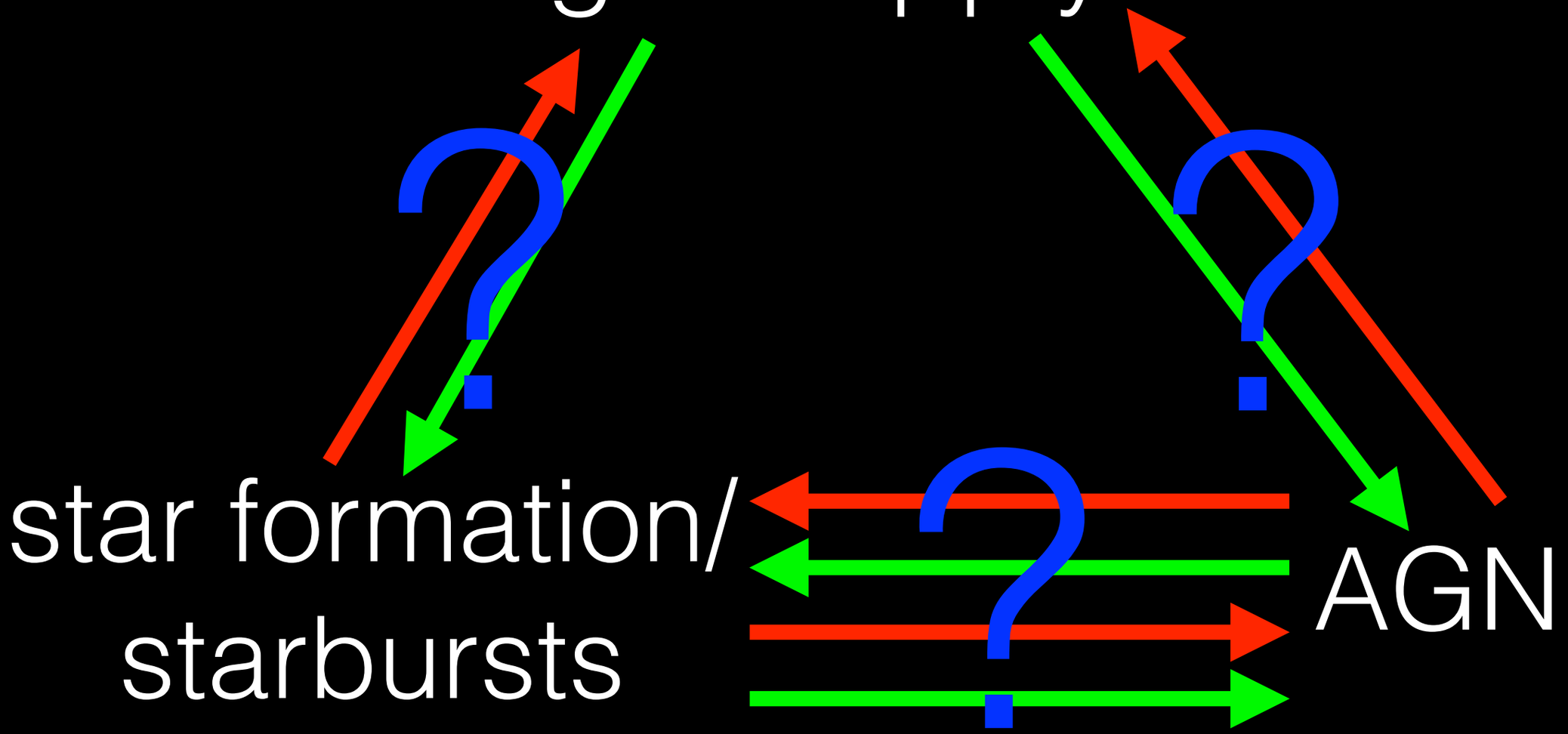
gas supply



SF-AGN connection

(a realistic) status of the theory

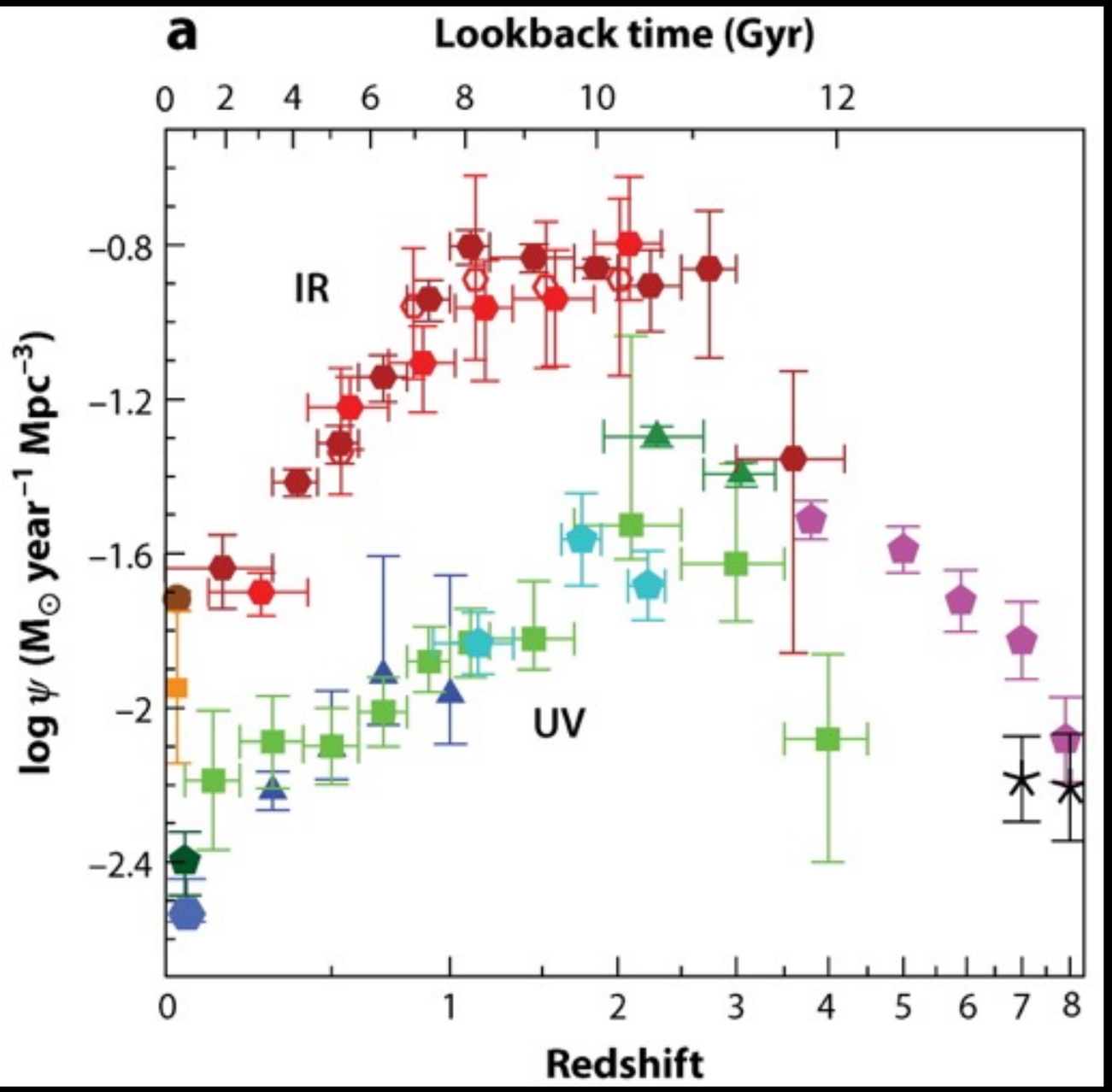
gas supply



How have things changed?

- ‘Old’ (and many current) simulations used effective ‘sub-grid’ treatments for e.g. stellar feedback-driven winds; involved kinematic decoupling or turning off cooling
- ISM structure unresolved
- Eddington-limited Bondi-Hoyle accretion with resolution >> Bondi radius
- Numerical inaccuracies potentially affected results
- Missing potentially important physics (e.g. B fields, CRs)
- Multiple groups are now doing better, and the conclusions can change qualitatively

Why the IR?

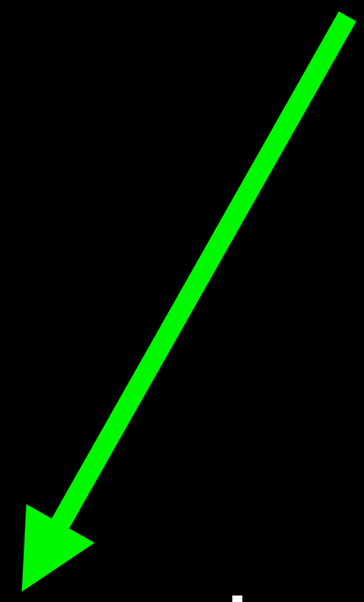


Madau & Dickinson 2014

- Observational: the bulk of star formation in the Universe is directly probed via the IR
- Physical: both star formation and AGN growth are associated with dense gas; thus, high obscuration is expected

SF-AGN connection

gas supply



star formation/
starbursts

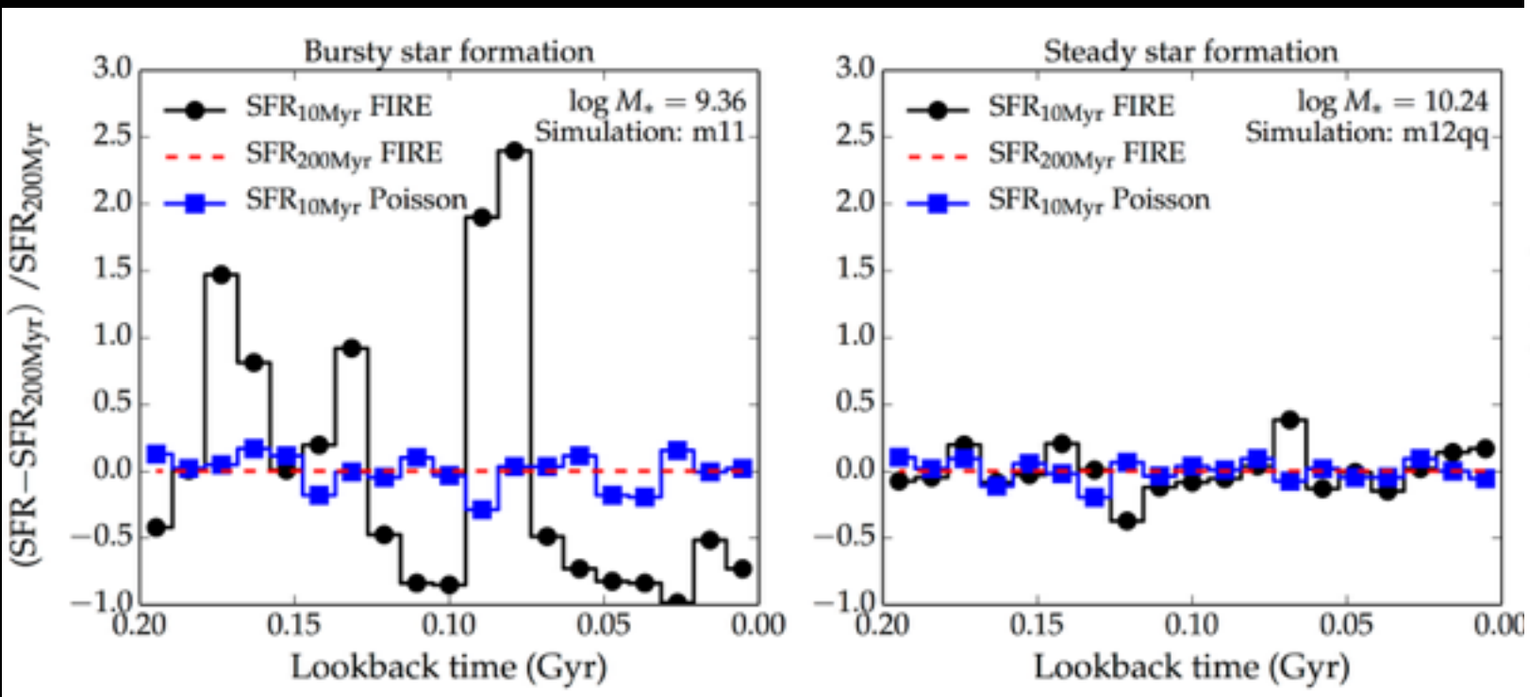
AGN

The definition of ‘starburst’

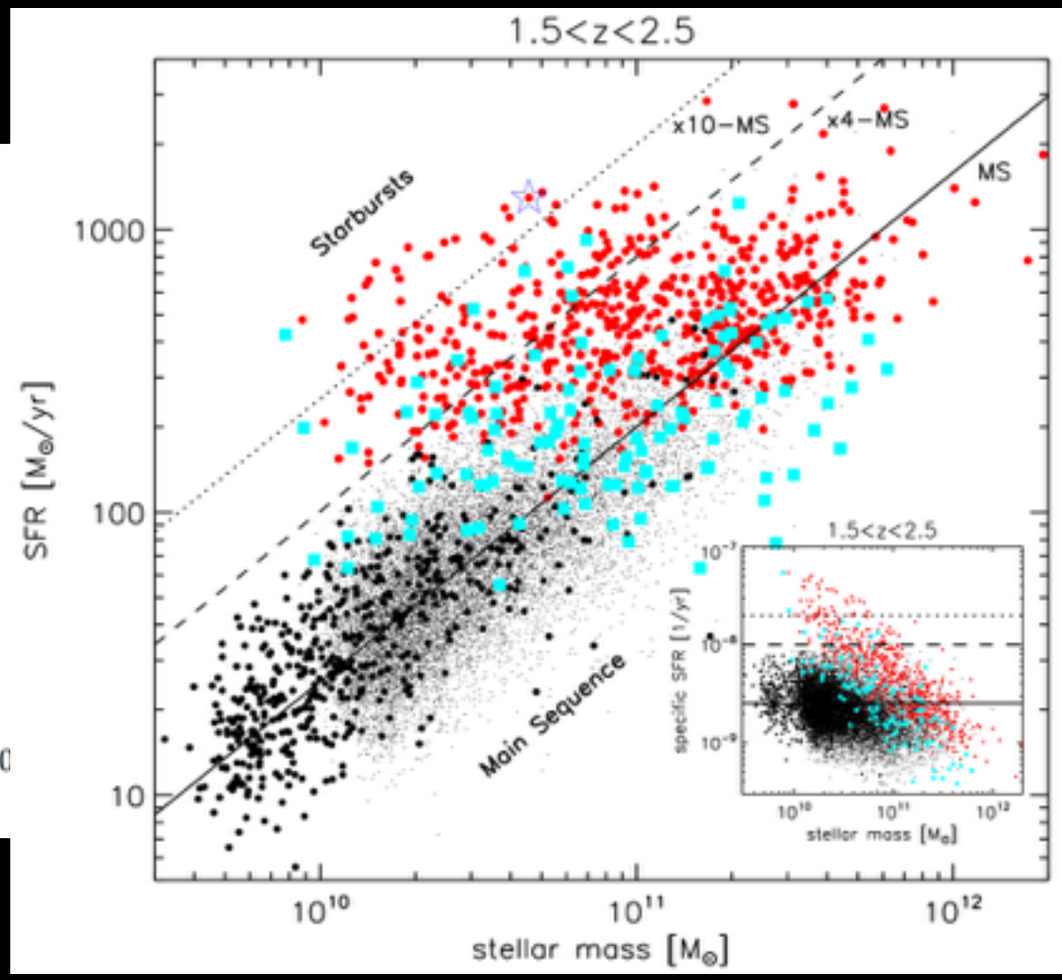
“We conclude that no one starburst definition can be devised that is objective and generally discriminant… the term will continue to be used for a heterogeneous and wide-ranging collection of objects with no physical basis for their classification as starburst.”

— Knapen & James (2009)

The definition of ‘starburst’

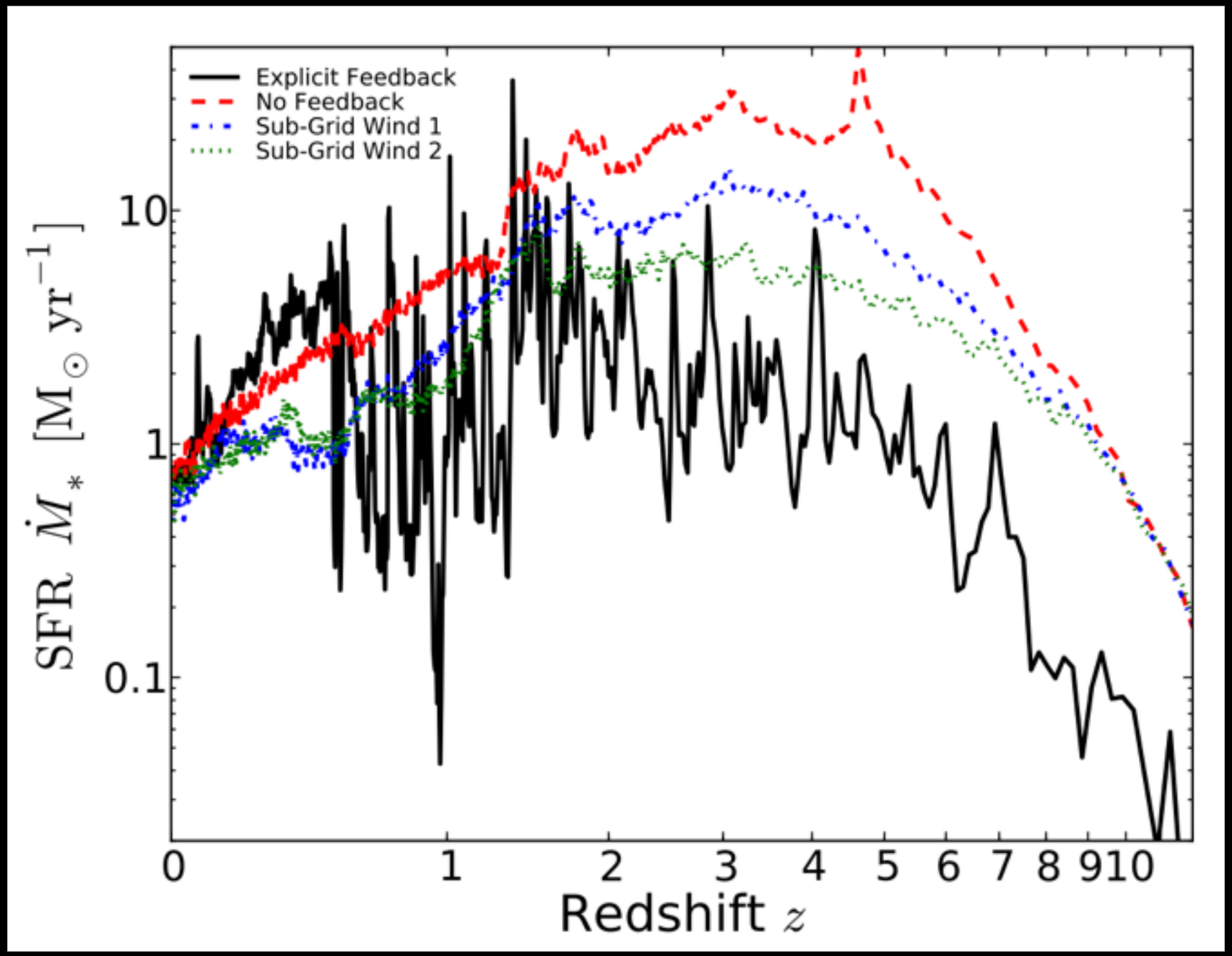


Sparre, CCH et al., in prep.



Rodighiero et al. 2011

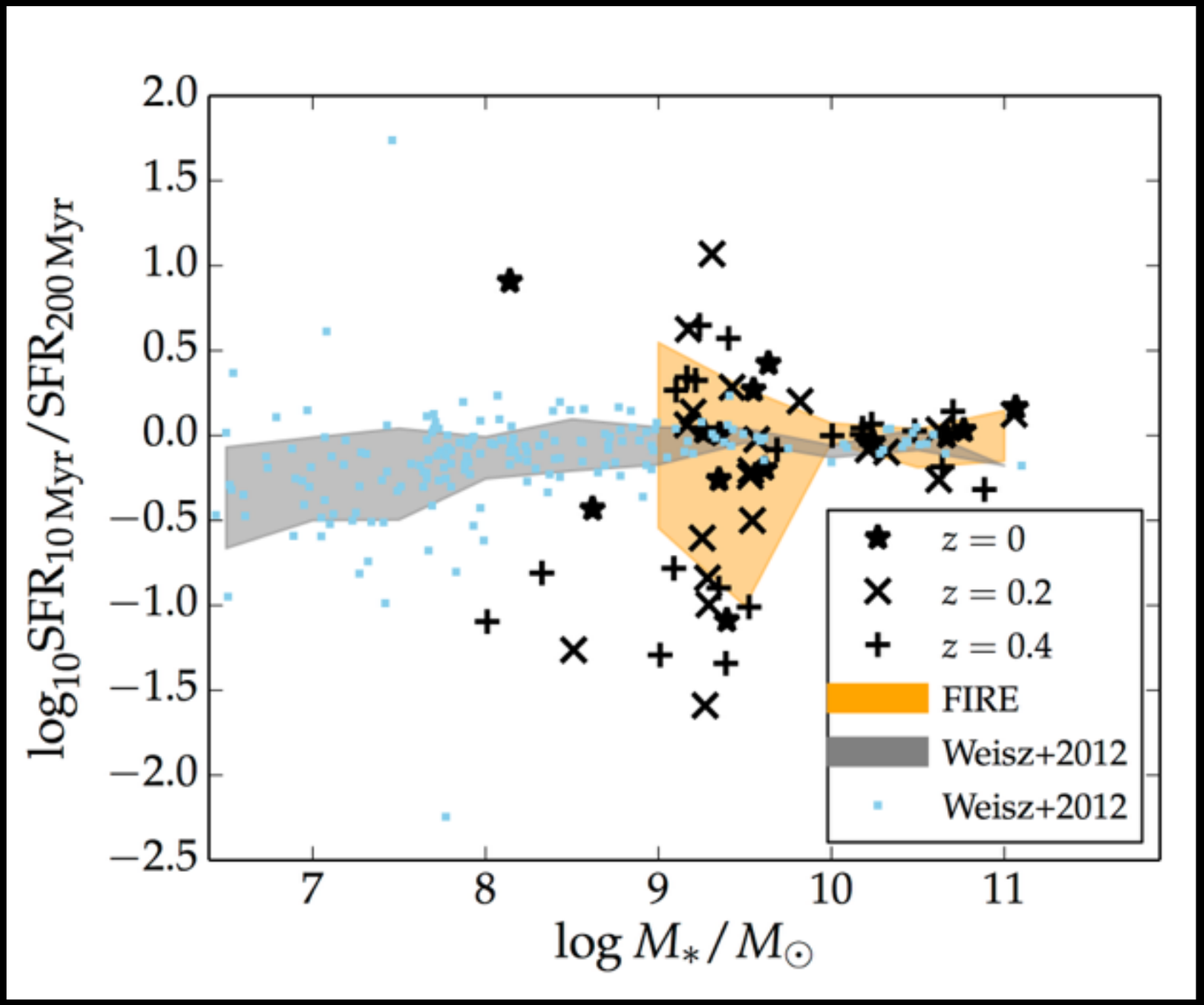
Are all galaxies ‘starbursts’?



Hopkins et al. 2014

Simulations with resolved stellar feedback are very bursty

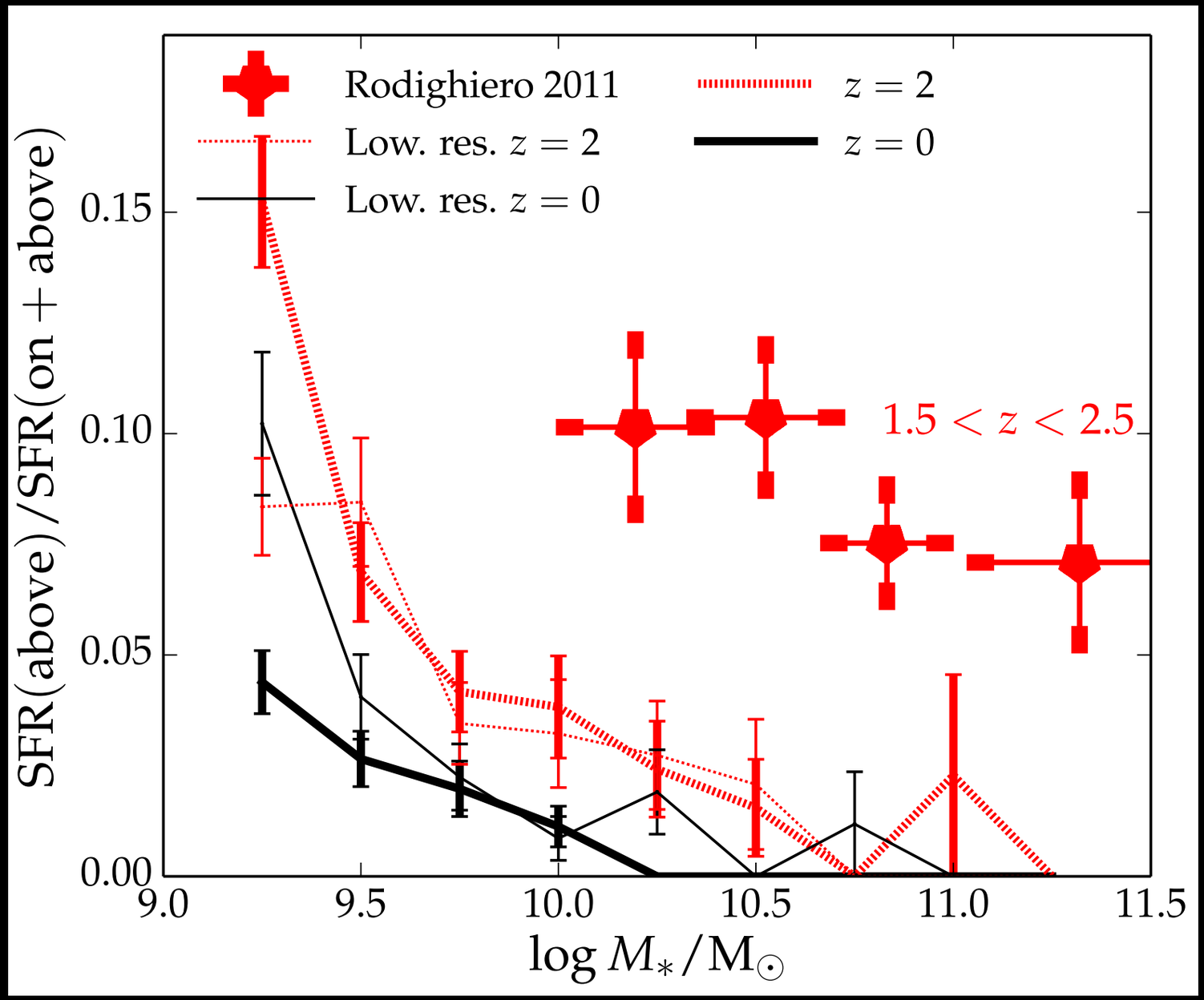
Are all galaxies ‘starbursts’?



Sparre, CCH et al., in prep.

…but may be more bursty than real galaxies

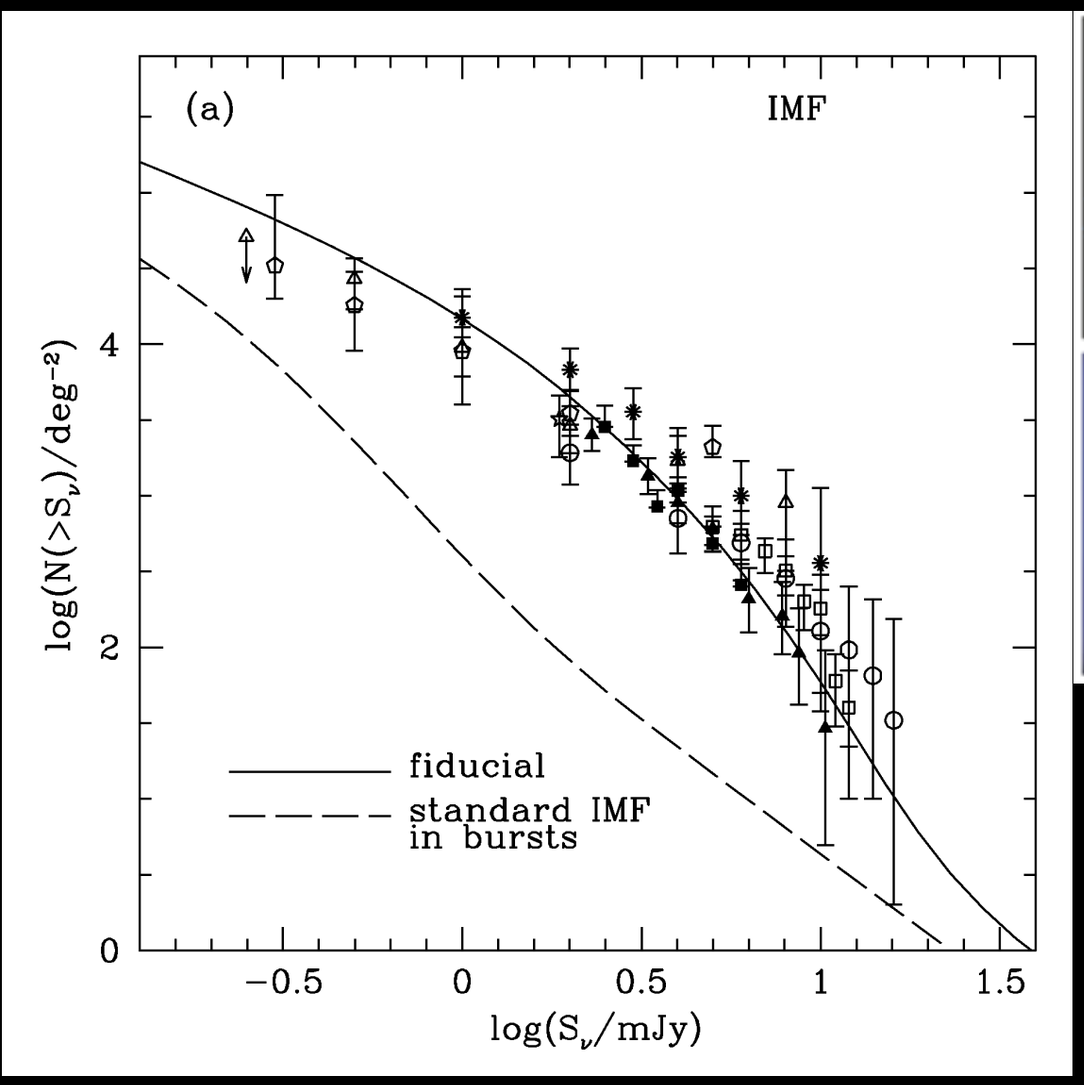
Are (almost) all galaxies not ‘starbursts’?



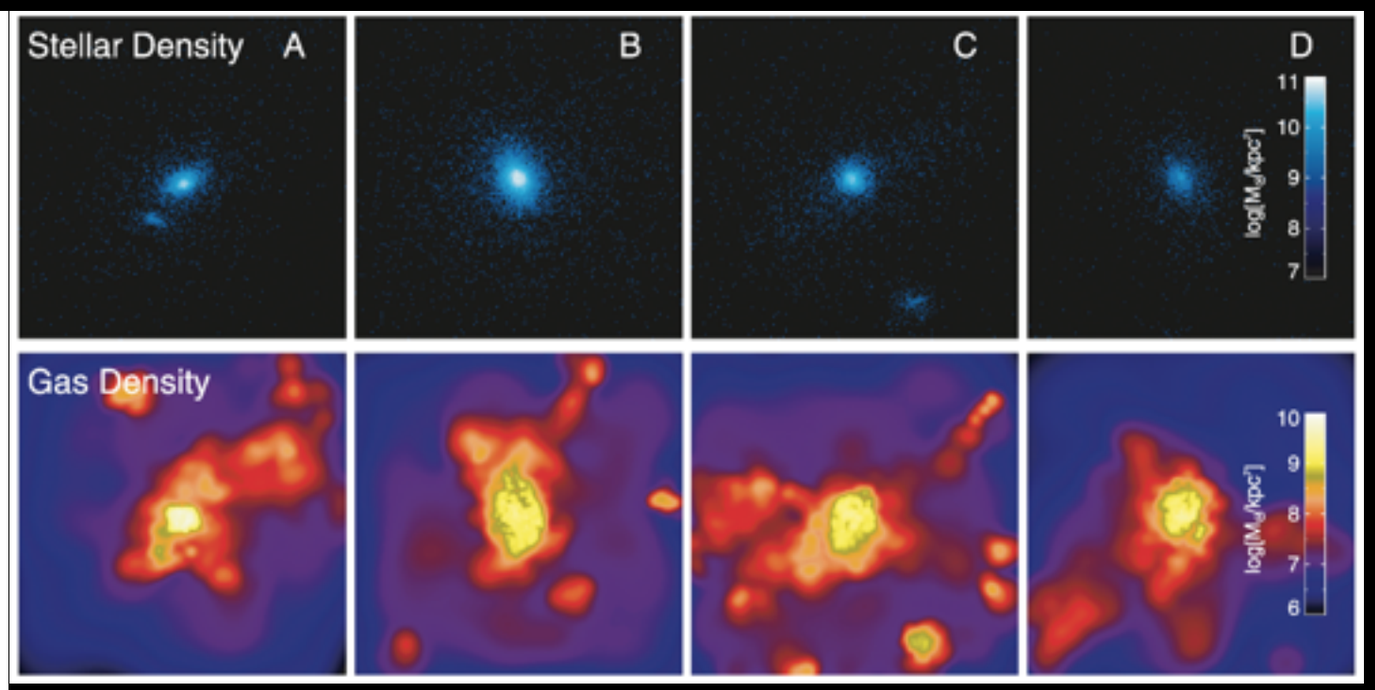
Sparre, CCH et al. 2015

Galaxies in state-of-the-art large-volume cosmological simulations are not very bursty — tension with reality?

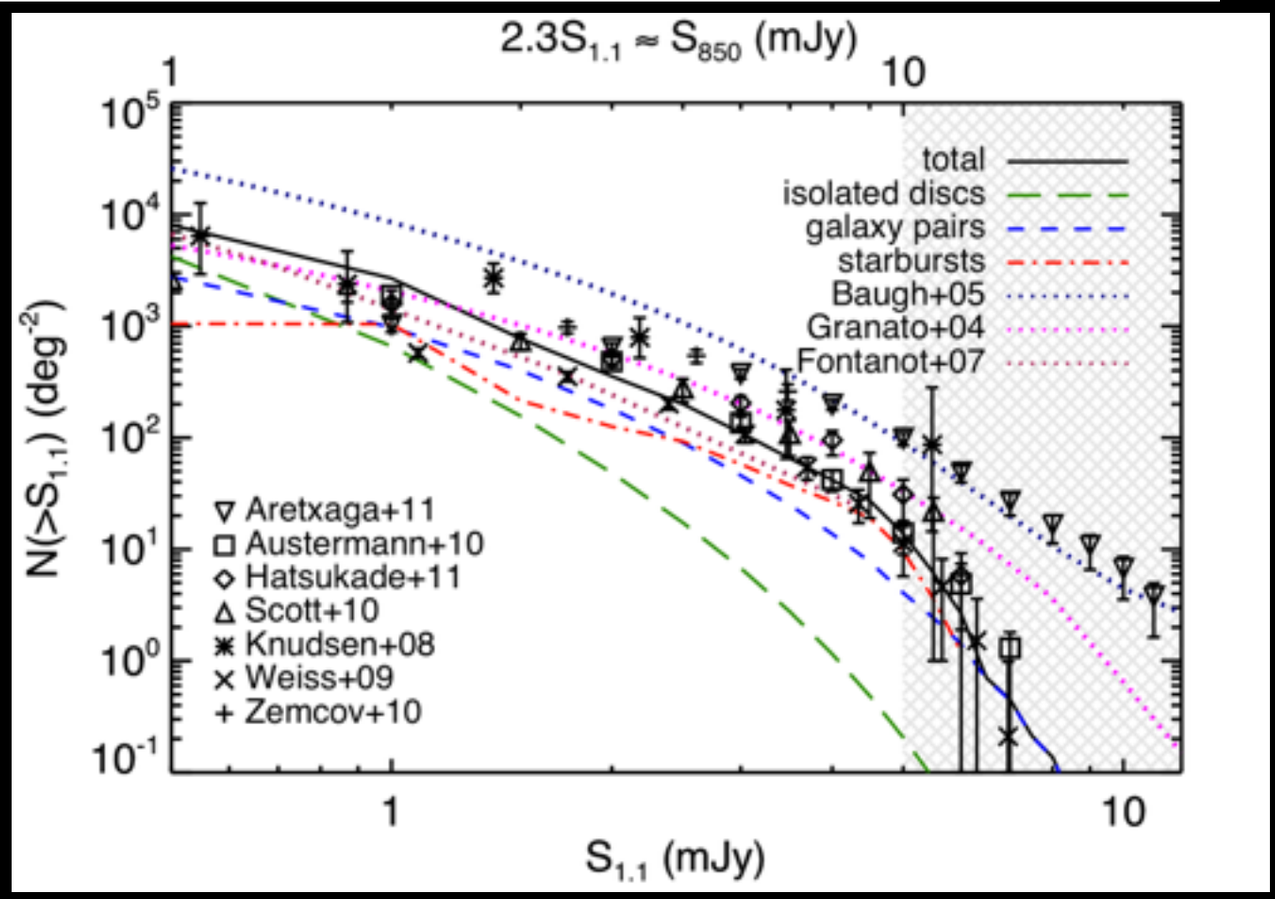
What powers high-z ULIRGs?



Baugh et al. 2005



Davé et al. 2010

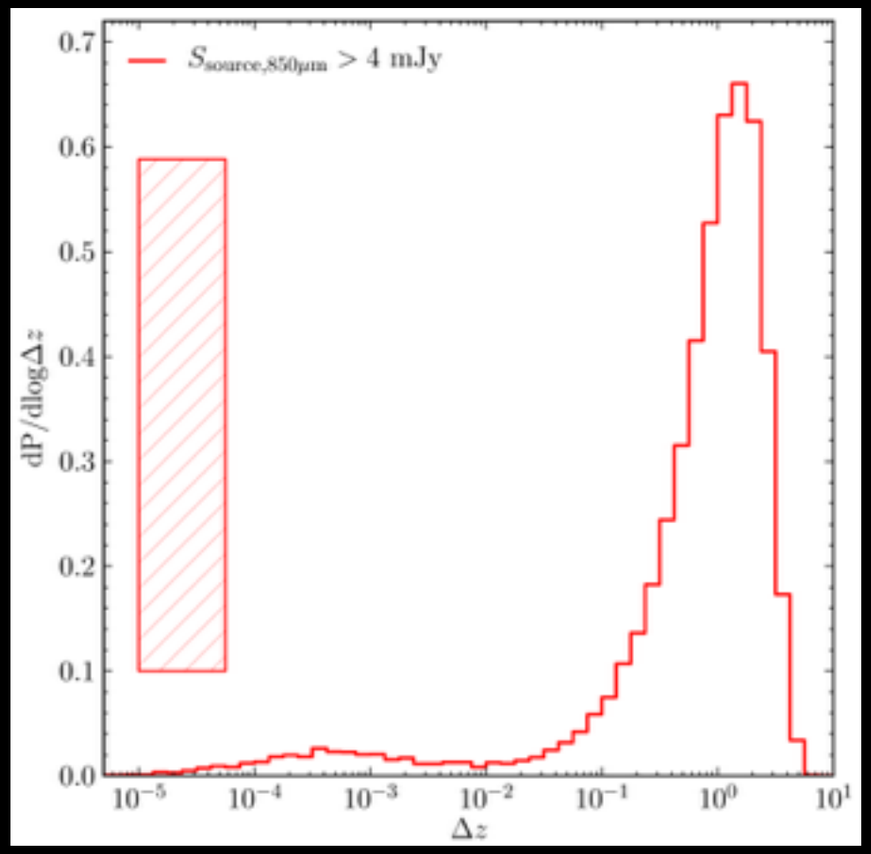


CCH et al. 2013a

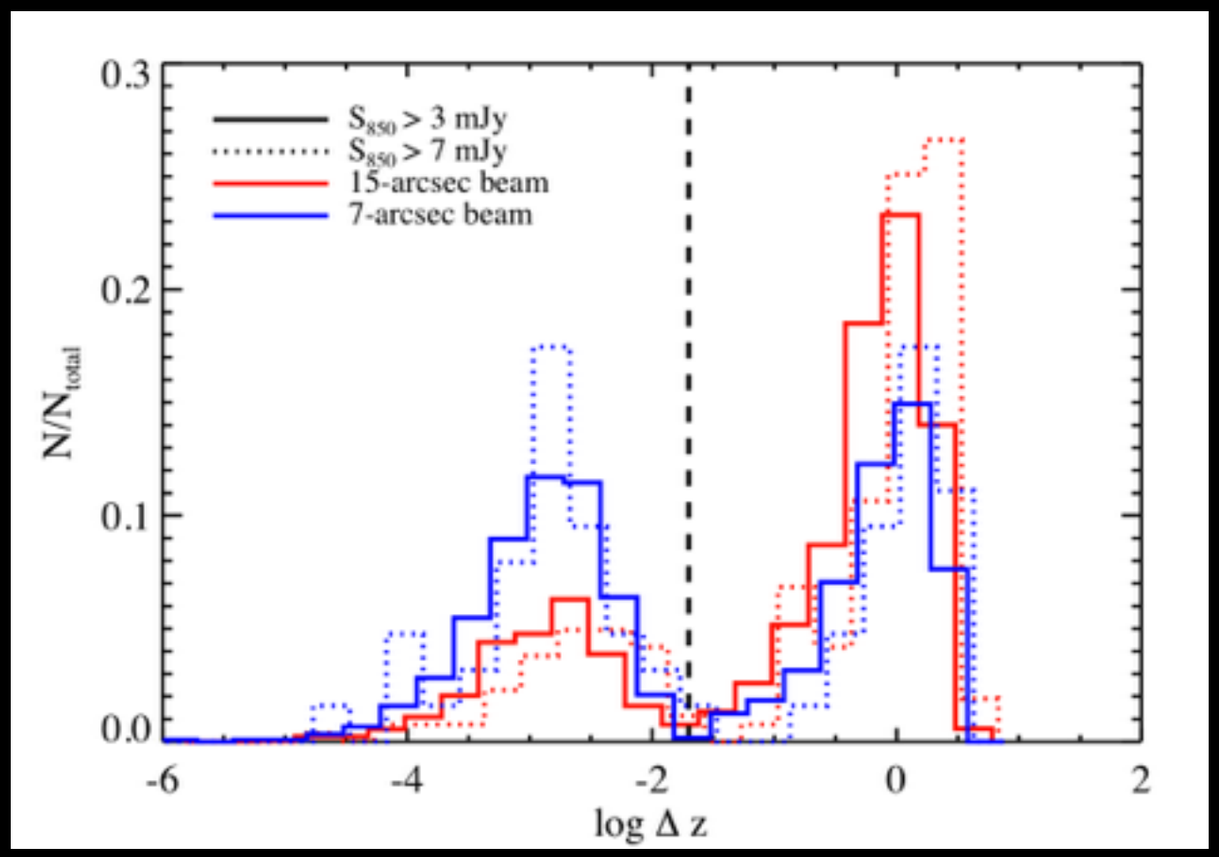
Physical nature of most IR-luminous galaxies still hotly debated by theorists

Confusion very important for interpreting IR sources

CCH et al. 2012



Cowley et al. 2015

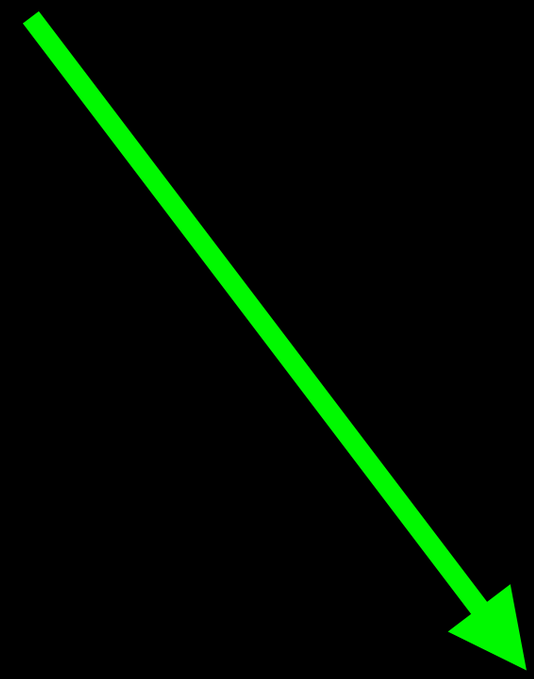


CCH et al. 2013b

Single-dish-selected SMG population significantly affected by blending even above the ‘confusion limit’

SF-AGN connection

gas supply

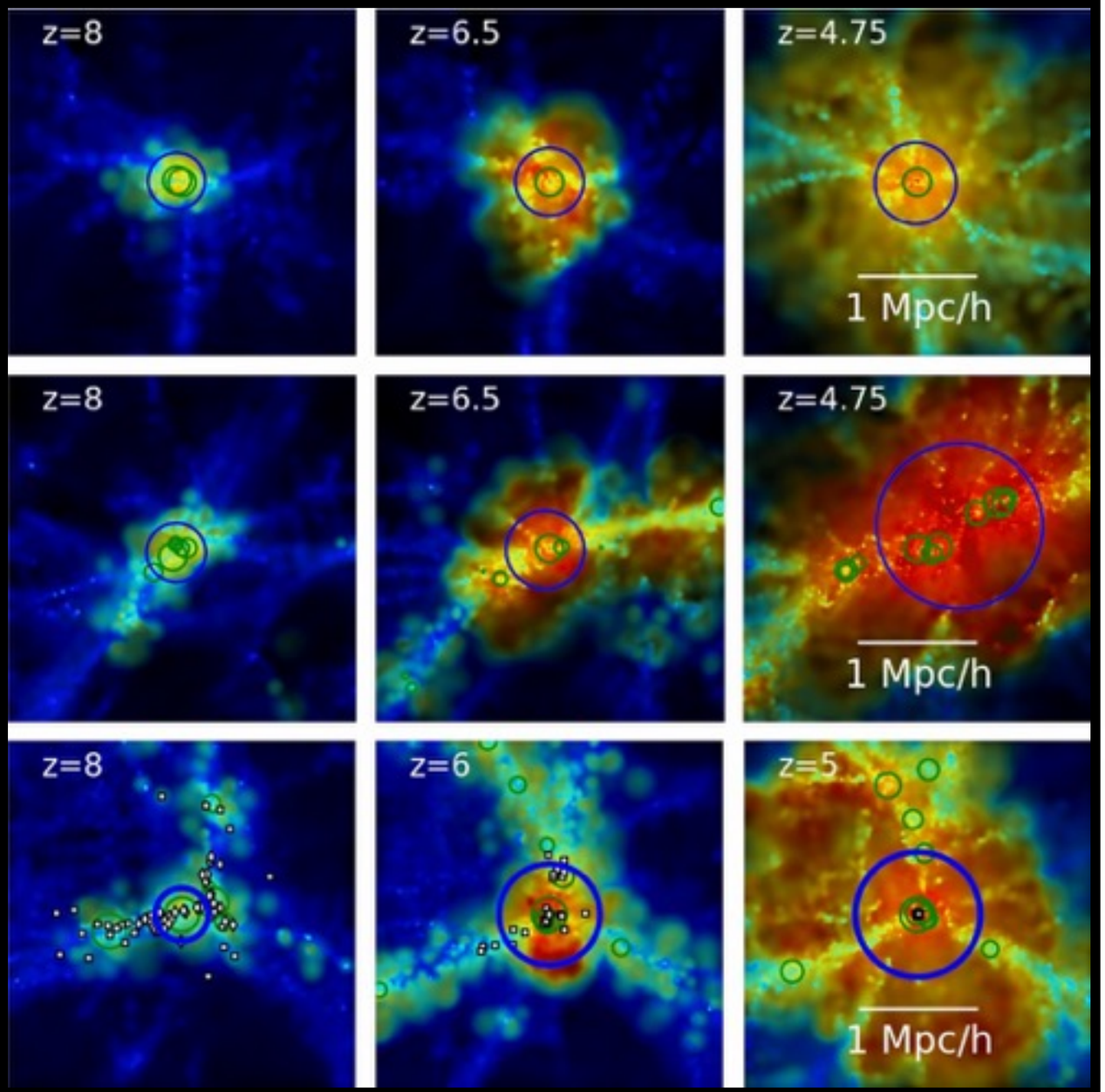


star formation/
starbursts

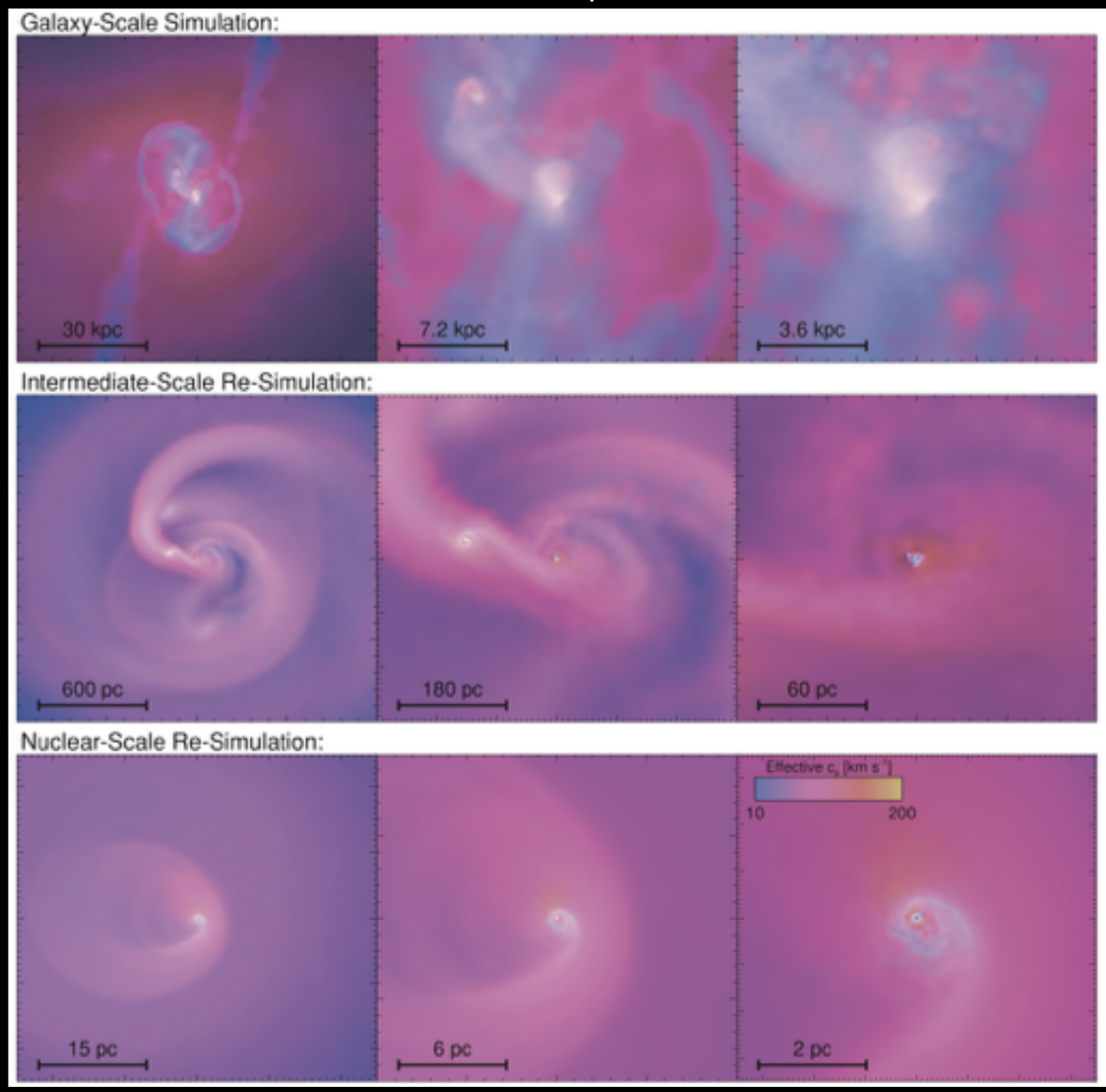
AGN

AGN fueling

DiMatteo et al. 2012



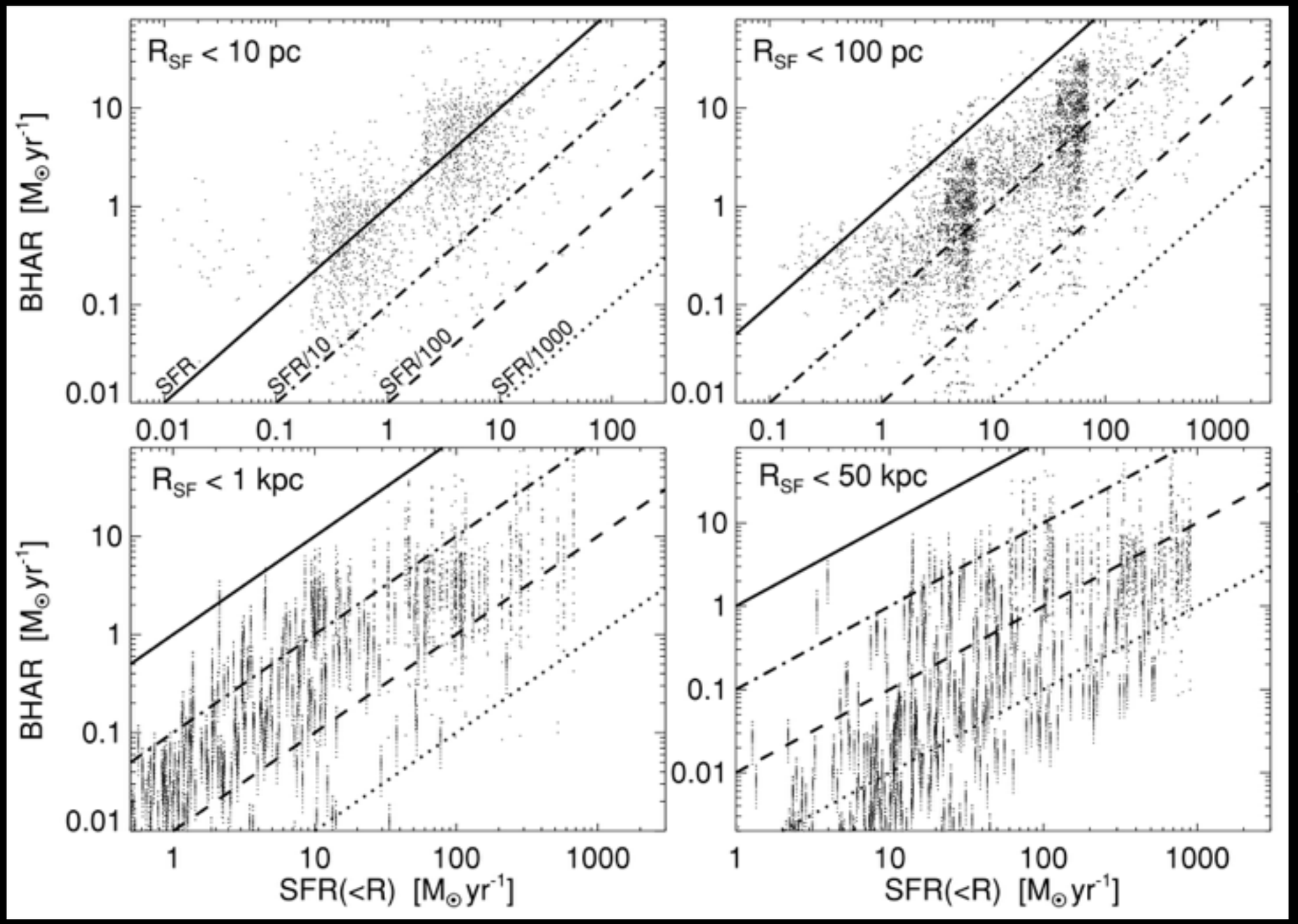
Hopkins & Quataert 2010



Hierarchy of scales/instabilities responsible for fueling AGN

Chris Hayward (Caltech) — FIR Surveyor Workshop — 4 June 2015

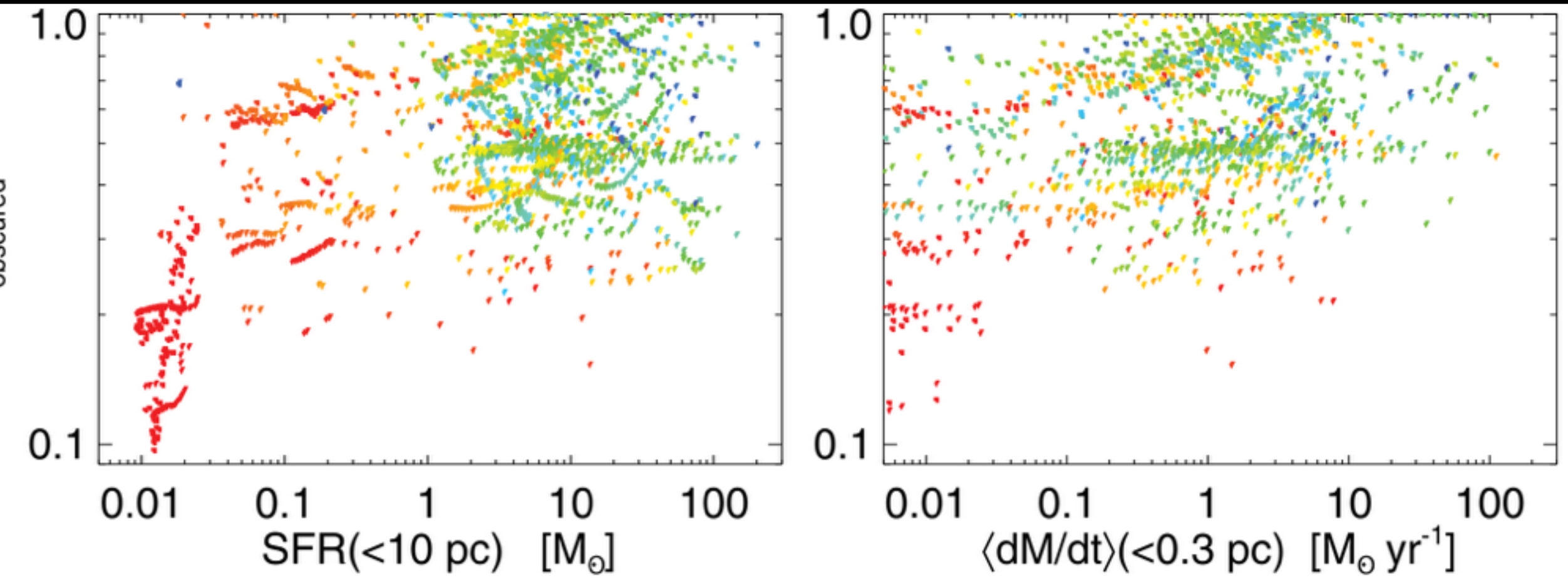
Connection with SF/SBs



Hopkins & Quataert 2010

BH growth and SF (both nuclear and galaxy-scale) are correlated because of common fuel (dense gas)

Utility of IR

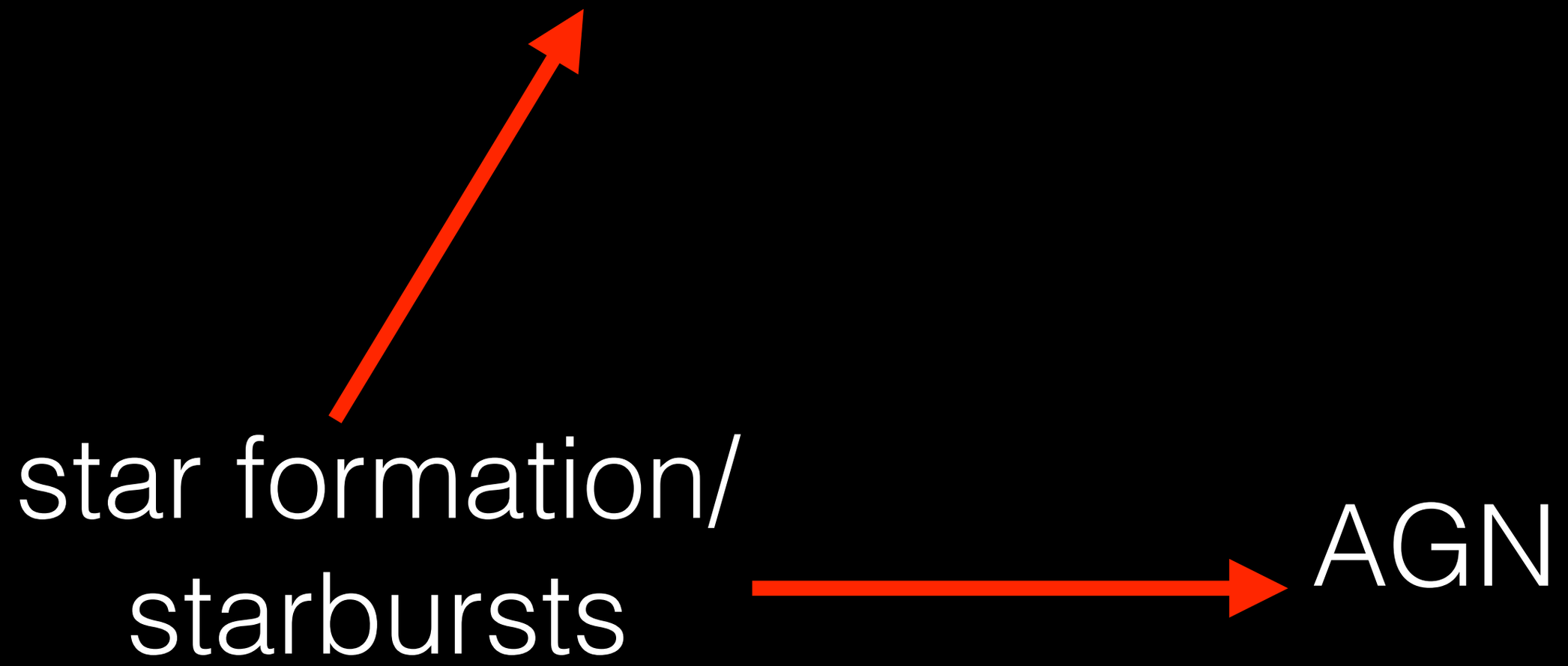


Hopkins, CCH et al. 2012

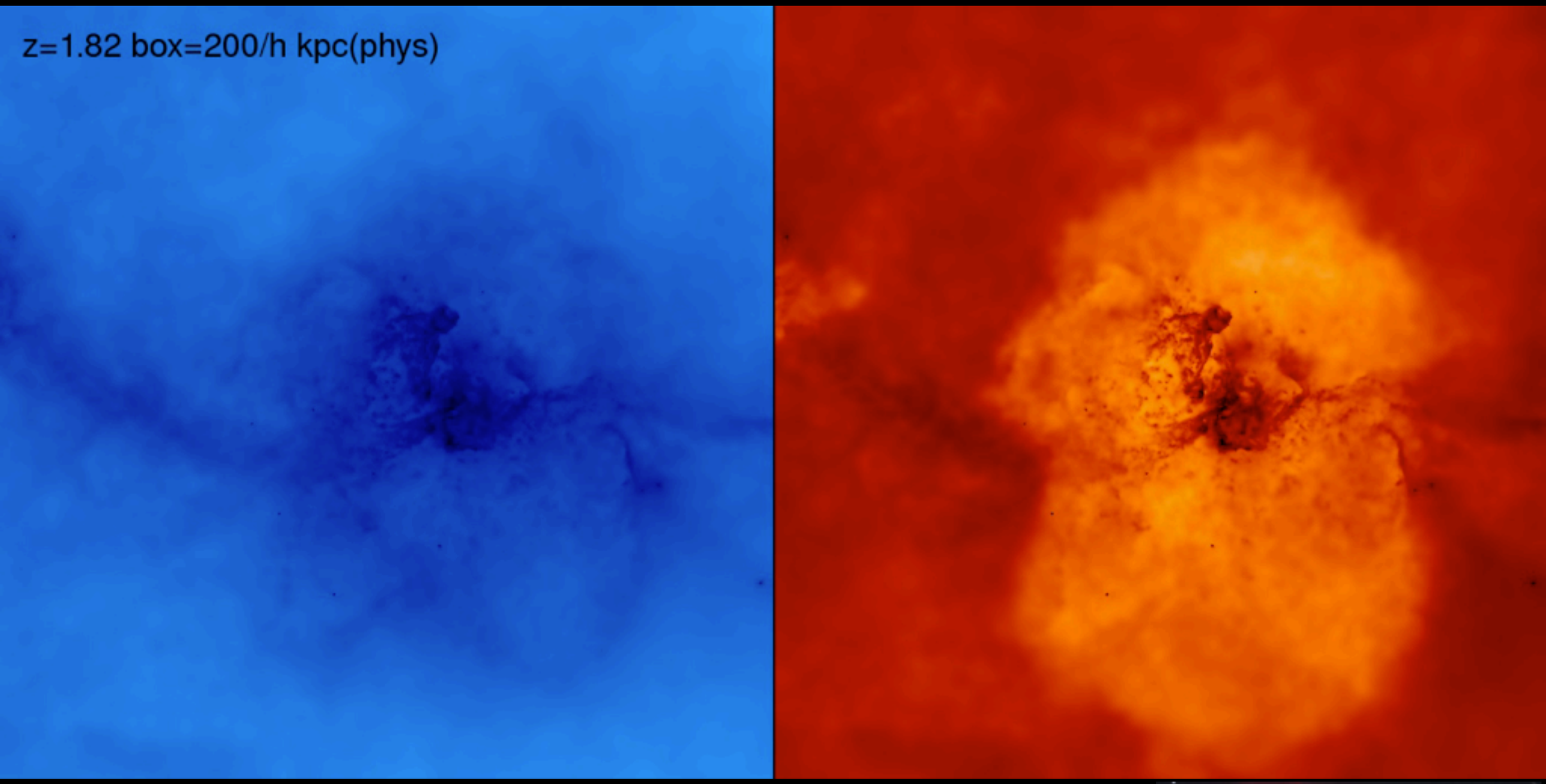
Most of the action happens in obscured regions; IR enables both penetrating through dust obscuration and mapping inner gas/dust structures

SF-AGN connection

gas supply



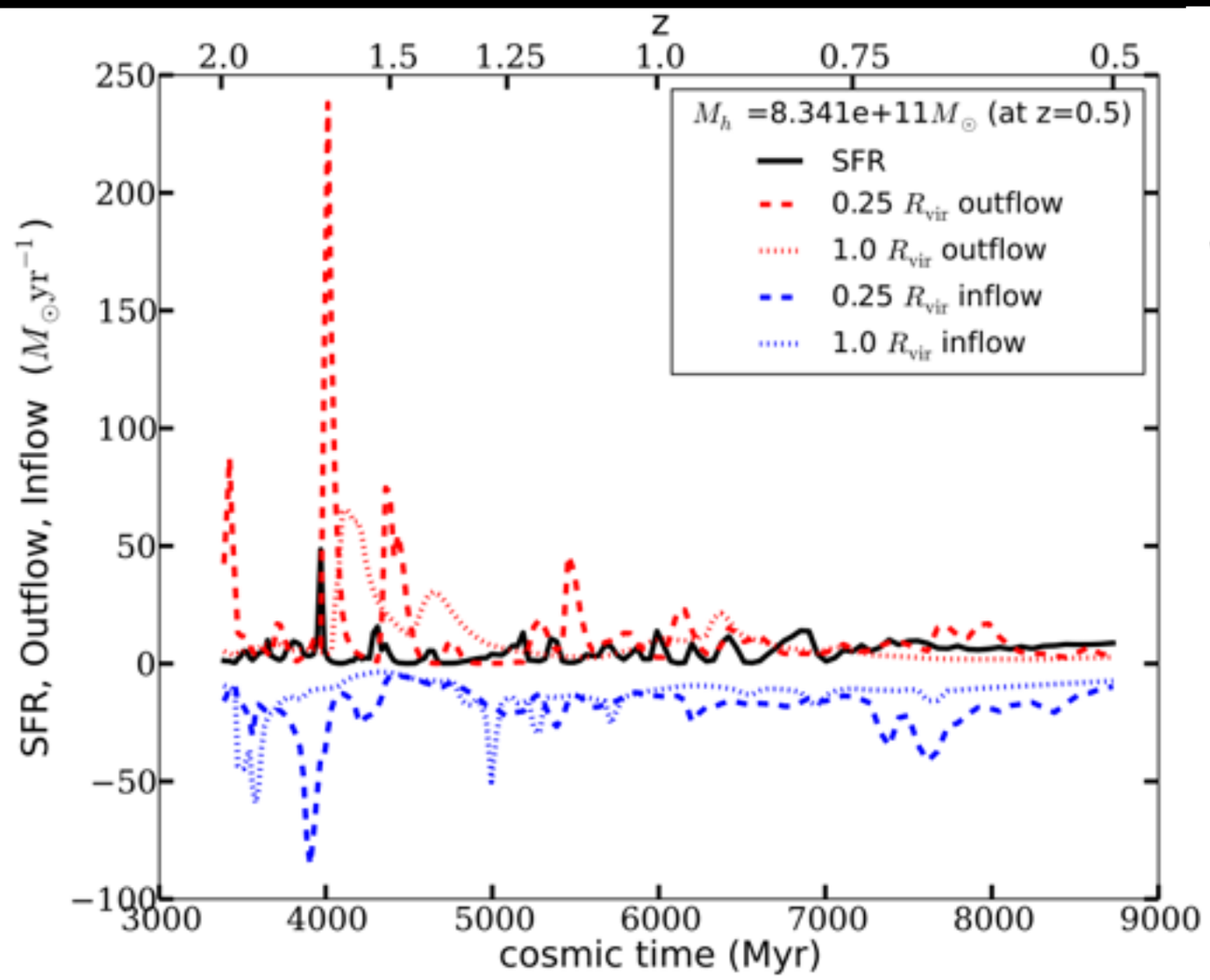
Stellar-feedback-driven outflows



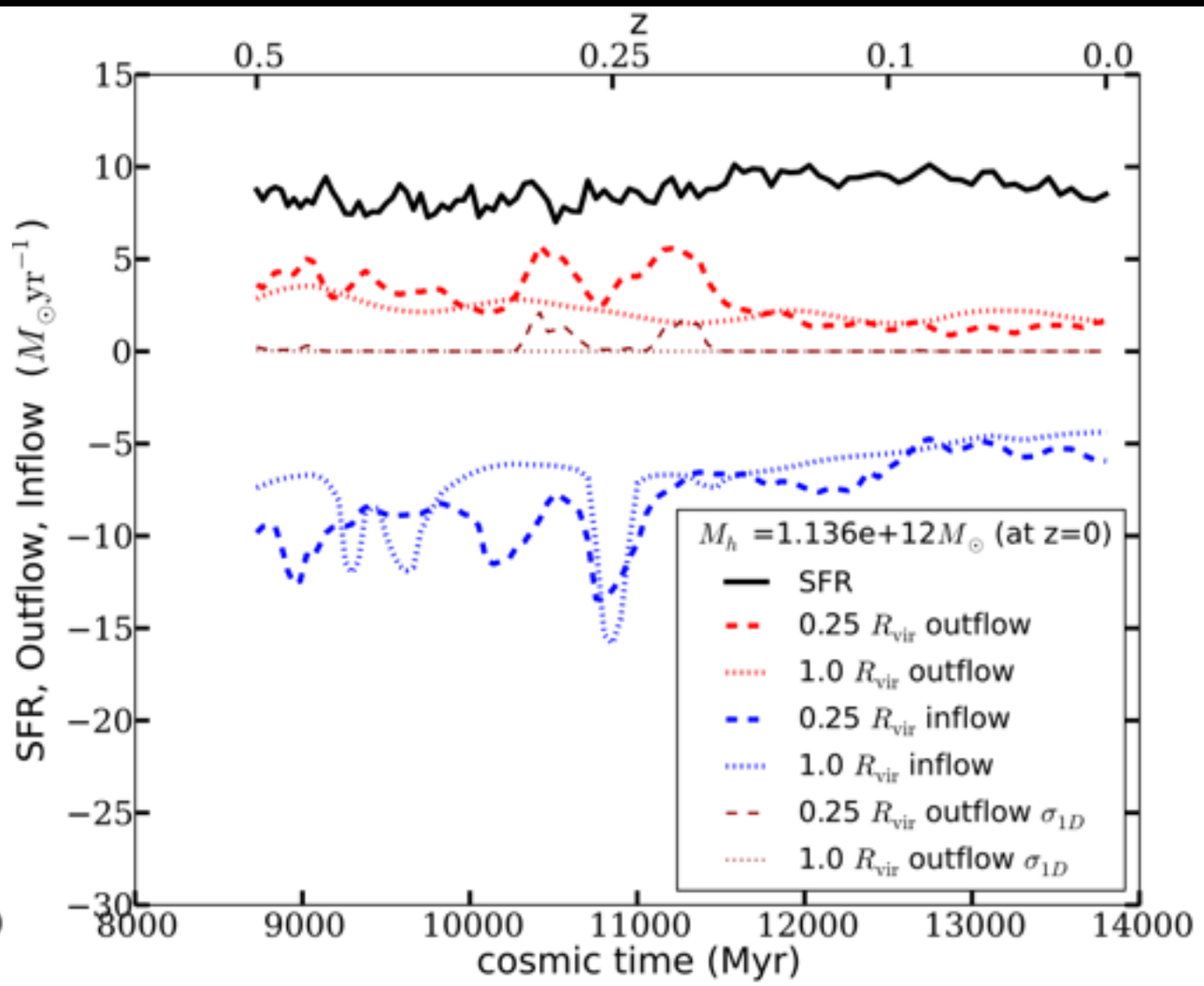
FIRE
Feedback In Realistic Environments

Stellar-feedback-driven outflows

z = 0.5-2



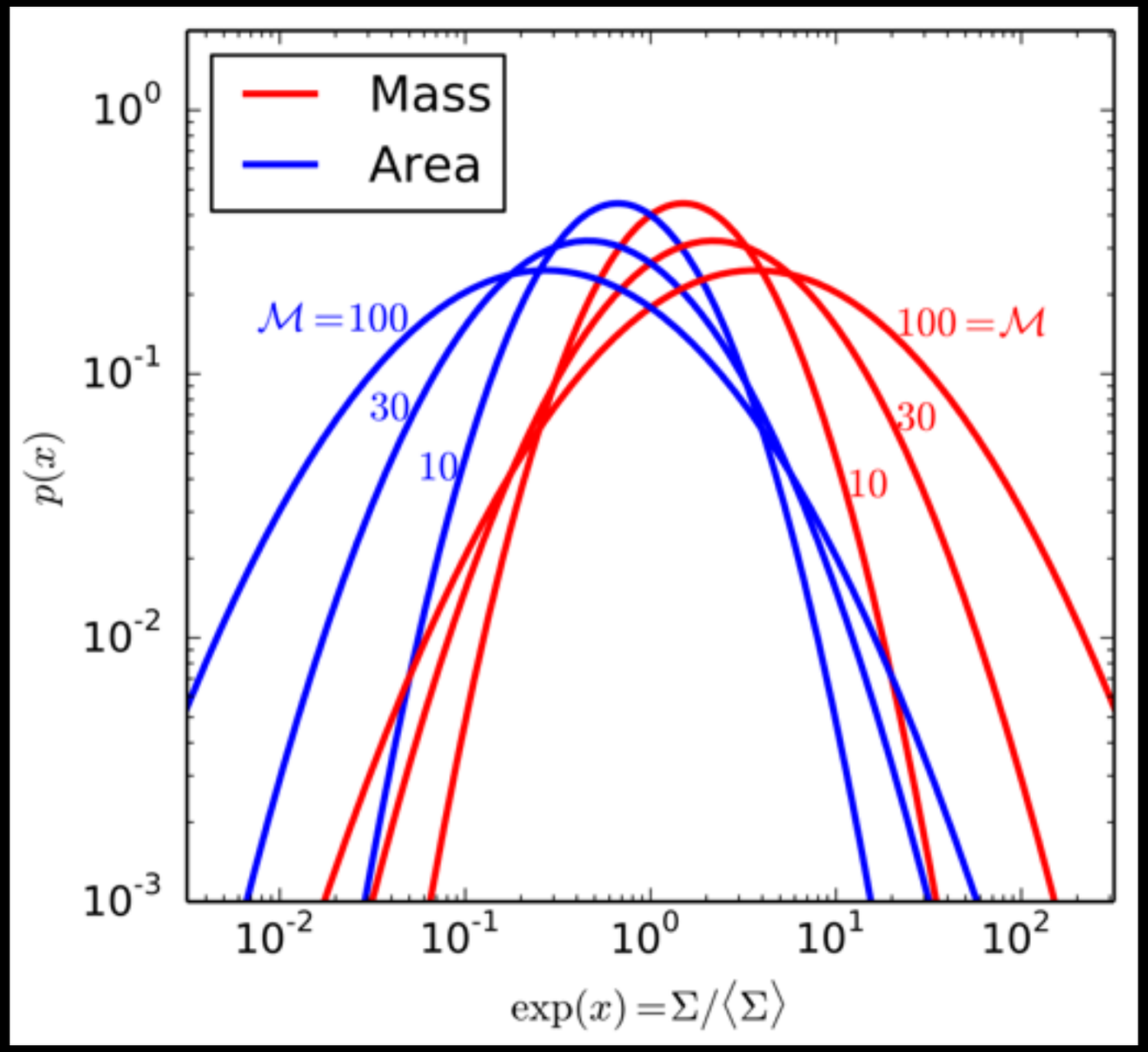
z = 0-0.5



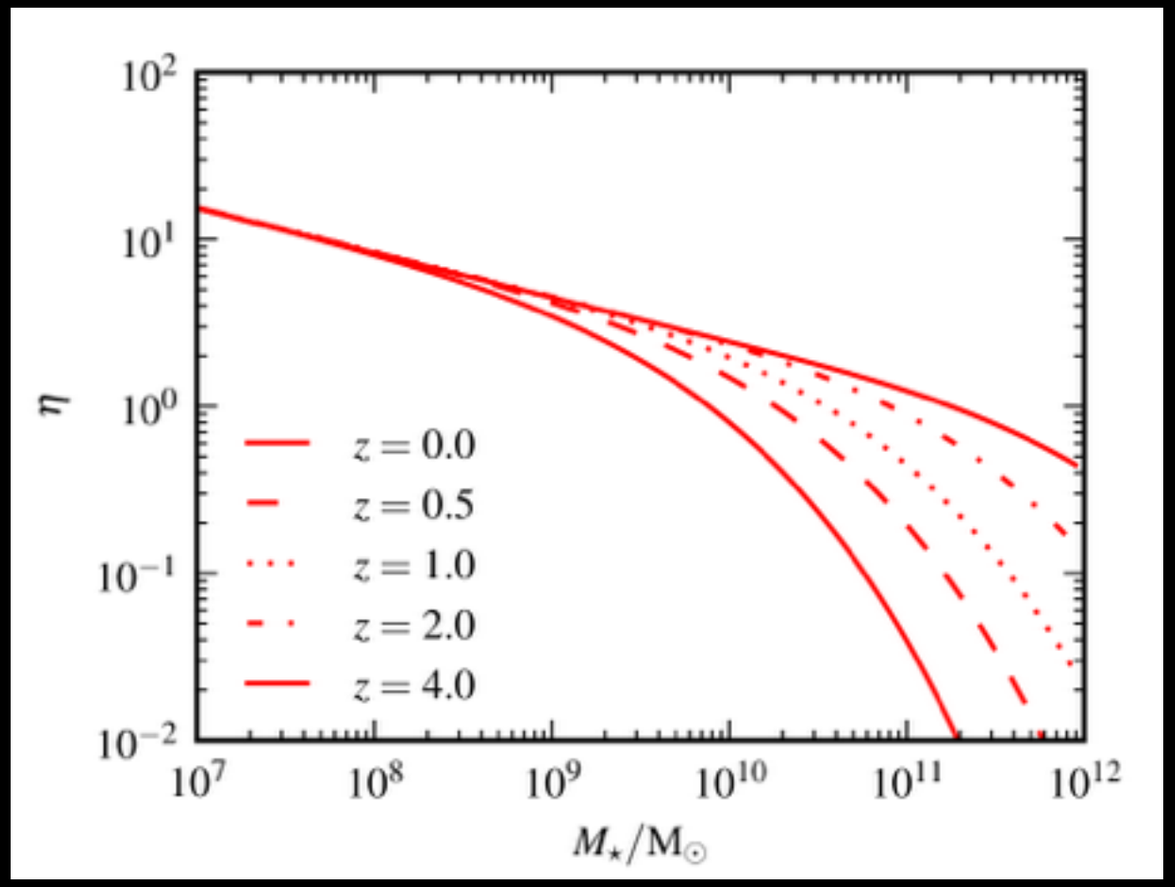
Muratov et al. 2015

High z: violent starbursts followed by strong outflows
Low z: steady star formation with weak outflows

The role of turbulence



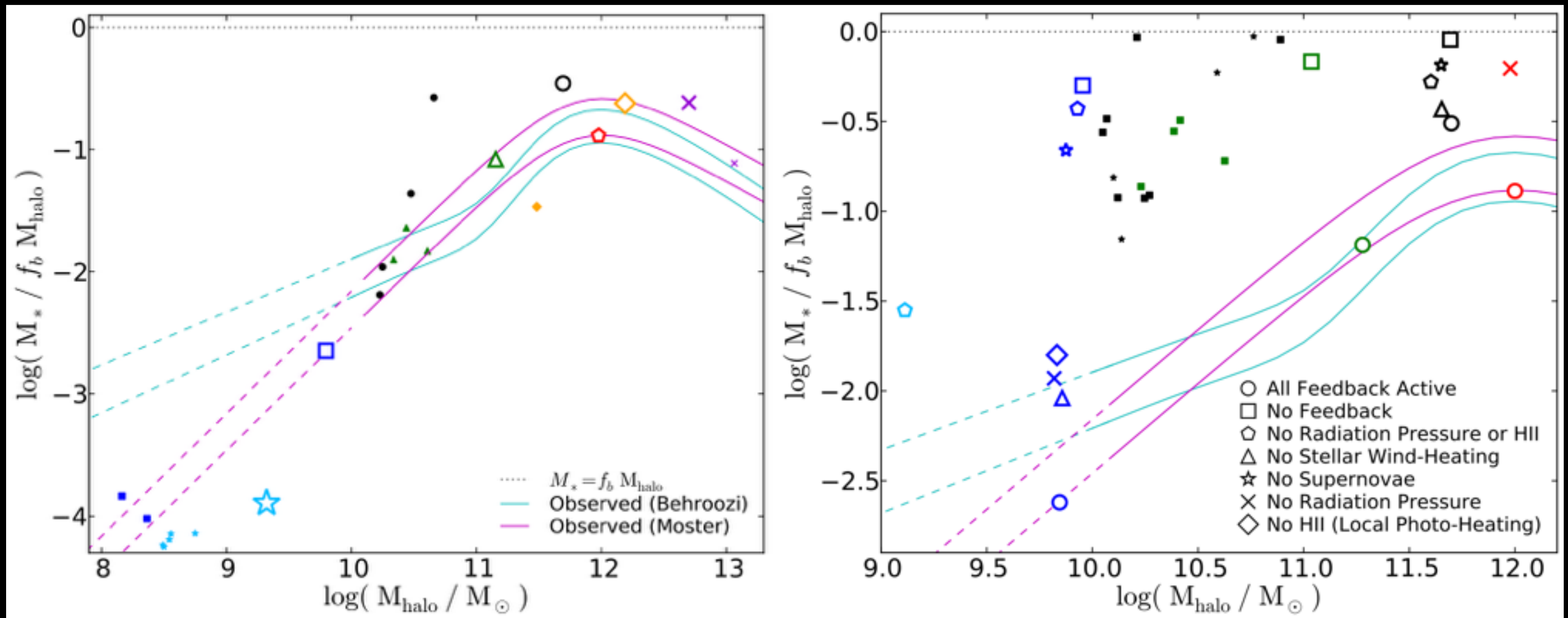
Thompson & Krumholz 2014



CCH & Hopkins, in prep.

Feedback drives turbulence; which regulates amount of low-surface density gas and thus how much can be blown out

Is stellar feedback enough?



Hopkins et al. 2014

Stellar feedback alone suppresses star formation sufficiently for galaxies with M_{halo} (z=0) <~10^{13} M_{sun}; the jury is still out for higher masses

SF-AGN connection

gas supply

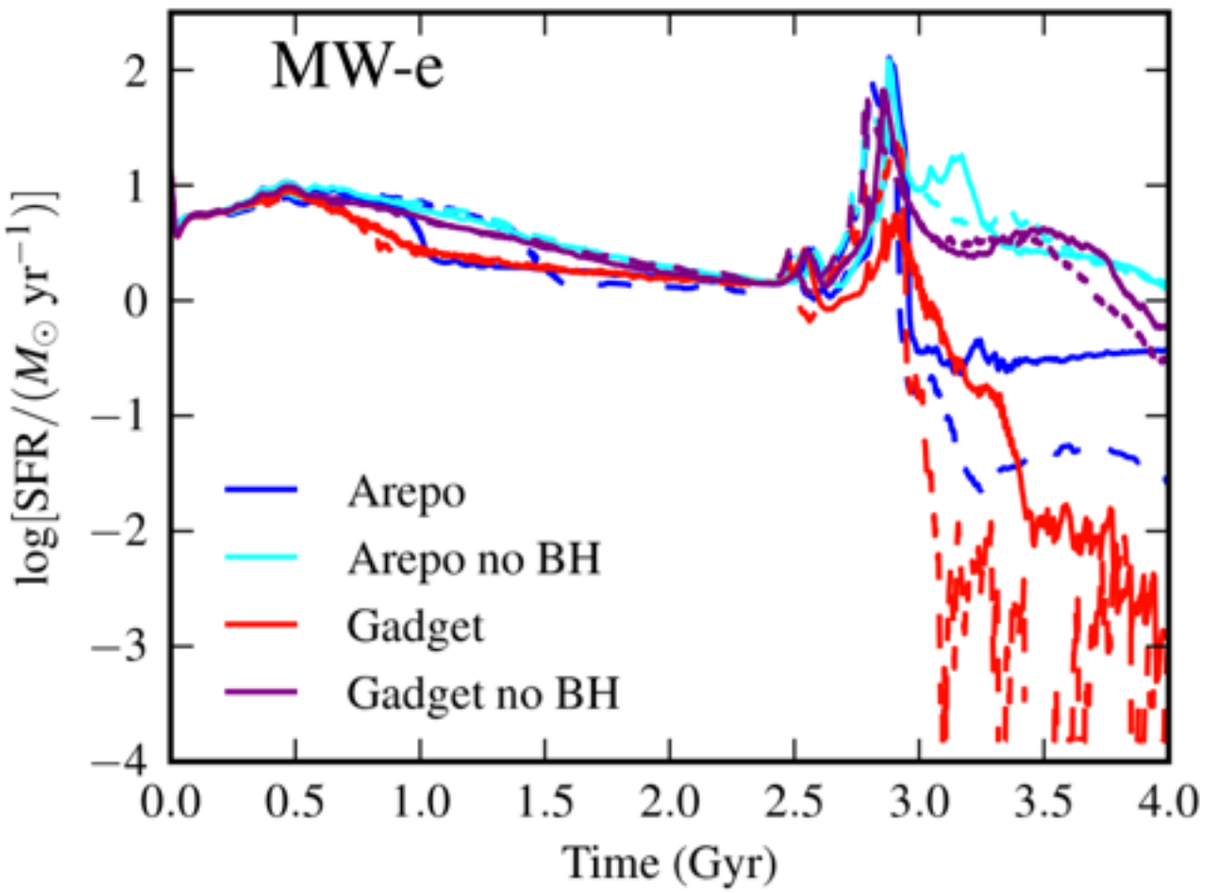
star formation/
starbursts

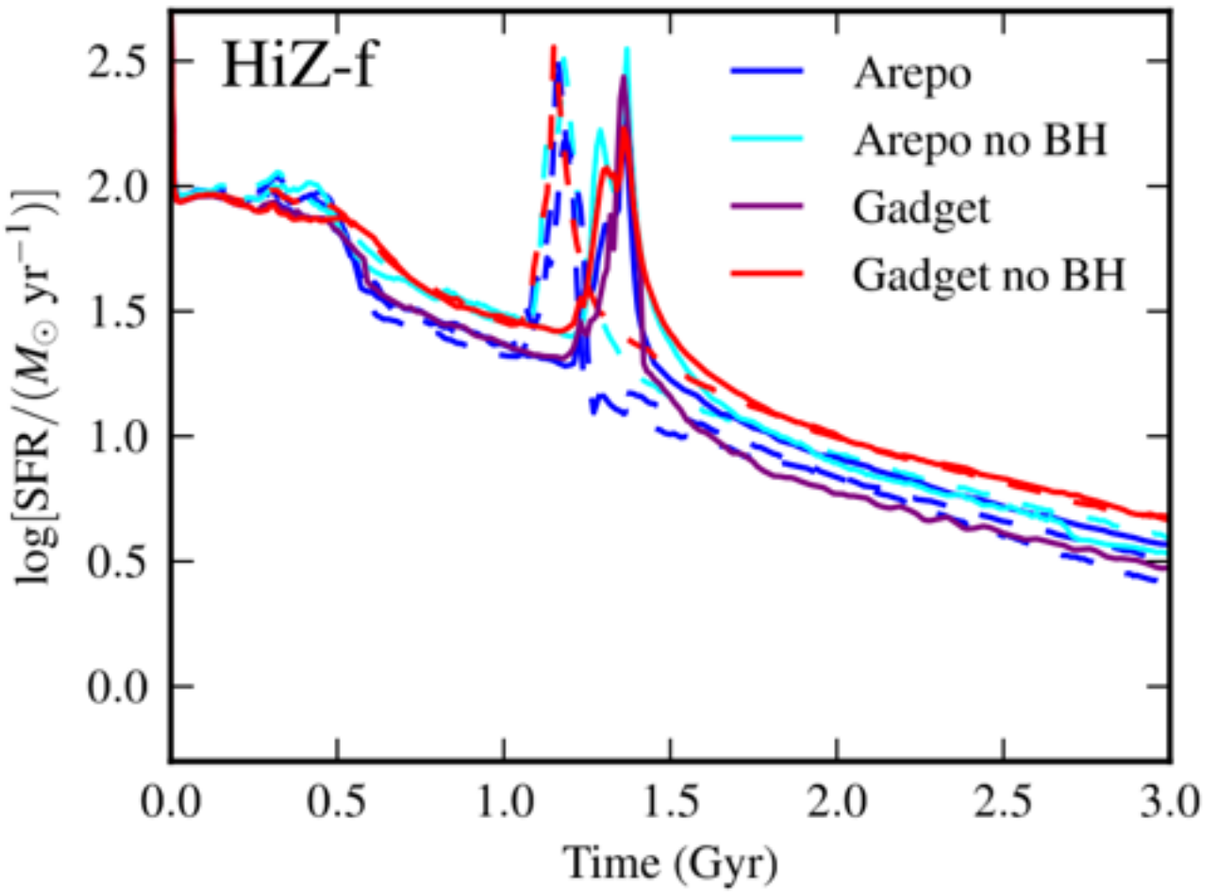
AGN

AGN feedback

Strong effect of AGN feedback

Weak effect of AGN feedback

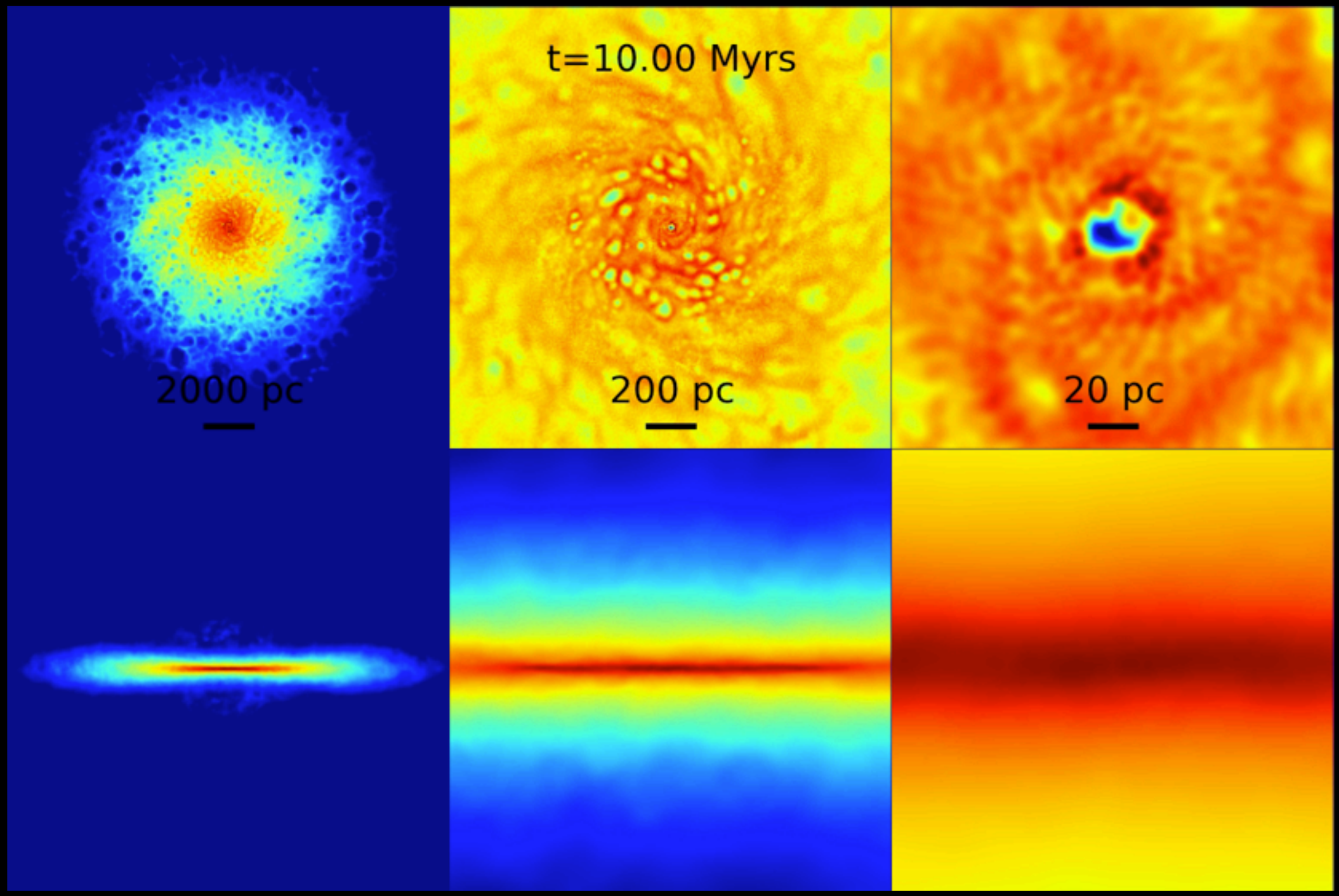




CCH et al. 2014

Only (sometimes) terminates ‘residual’ star formation; understanding has been (and still is) limited by missing physics and numerical challenges

AGN feedback



To fully understand (possible) AGN fueling & feedback, we need higher resolution & more physics

Open questions/needs

- Which feedback mechanism(s) are most important?
- Does SF (AGN) exert negative feedback on AGN (SF)? Positive feedback?
- What powers high-z (U)LIRGs?
- What drives outflows? Properties such as mass loading, velocity, phase structure are key
- How common/important are obscured AGN?

Open questions/needs

- What is role of turbulence in regulating SF and driving outflows?
- Unstable disks? high-res maps of Toomre Q
- Correlations between AGN activity and SF at high resolution and on short timescales
- Role of magnetic fields in galaxy formation — motivation for IR polarimetry
- …