INAF
ISTITUTO NAZIONALE
DI ASTROFISICA
OSSERVATORIO ASTRONOMICO
DI TRIESTE

ExaNeSt

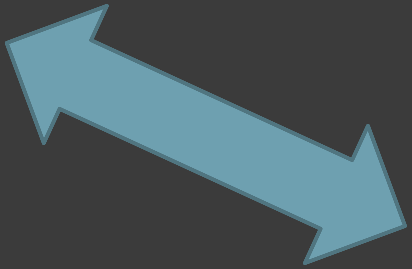
G. Murante – INAF OATs, with:

P. Barai – SNS Pisa
S. Borgani – Univ. Ts
A. Curir – INAF OATo
K. Dolag – Univ. Muenchen
R. Dominguez-Tenreiro – UAM, Madrid
D. Goz – Univ. Ts
G. Granato – INAF OATs
U. Maio – Univ. Posdam
P. Monaco – Univ. Ts
A. Ragagnin – Univ. Muenchen
C. Ragone-Figueroa - IATE, Argentina
L. Tornatore – INAF OATs
M. Valentini – SISSA. Ts
G. Yepes - UAM, Madrid
… and many others…

DISK GALAXIES WITH *MUPPI*

The idea…

trying to capture (some of) the interplay between large scale hydrodynamics and the physics of the ICM



..at moderate resolution
(SN blasts & GMCs not resolved)

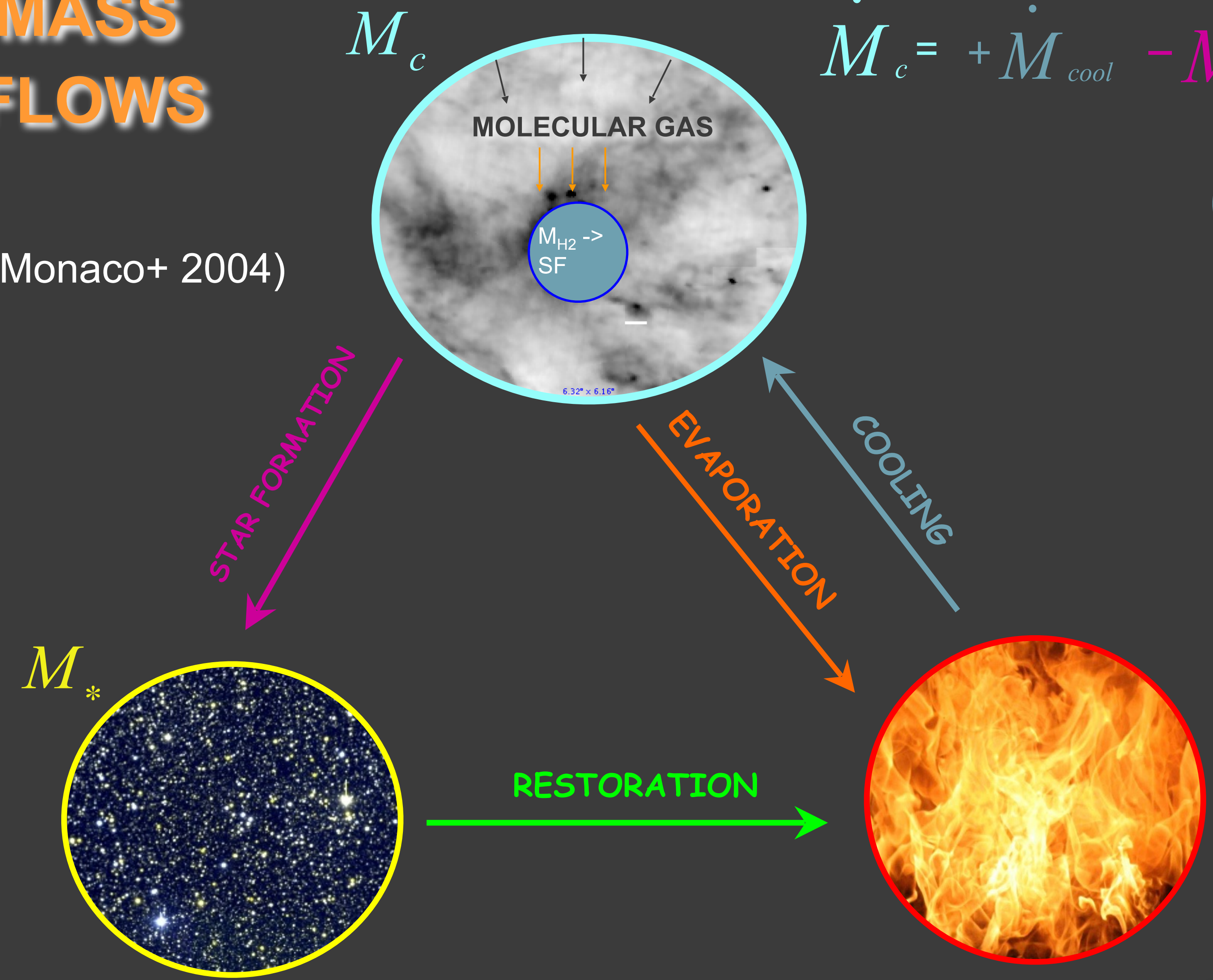
MUPPI: MUlti Phase Particle Integrator

Murante, Monaco, Giovalli, Borgani, Diaferio, 2010, MNRAS, 405, 1491

- Star formation & feedback algorithm
- Implemented in GADGET-3
- Integrates ISM equations for **each** particle at each SPH time step
- Thermal energy not radiated away immediately
- Obtains SK relation without imposing it
  (See Monaco, Murante, Borgani, Dolag, 2012, MNRAS, 421, 2485)
- Gives ISM characteristics (averaged! – no details on outflow)
- *Works in a given range of resolution scales*!

MASS FLOWS

(Monaco+ 2004)



$$\dot{M}_c = +\dot{M}_{cool} - \dot{M}_{sf} - \dot{M}_{evap}$$

$$\dot{M}_{cool} = \frac{M_h}{t_{cool}}$$

$$\dot{M}_{sf} = f_{star} \cdot \frac{M_{H2}}{t_{dyn}}$$

$$\dot{M}_{rest} = f_{rest} \cdot \dot{M}_{sf}$$

$$\dot{M}_{evap} = f_{evap} \cdot \frac{M_{H2}}{t_{dyn}}$$

On **hot** **phase!**

On **cold** phase!

$$\dot{M}_* = +\dot{M}_{sf} - \dot{M}_{rest}$$

$$\dot{M}_h = -\dot{M}_{cool} + \dot{M}_{rest} + \dot{M}_{evap}$$

ENERGY FLOW(S..)

Hot phase energy

$$\dot{E}_h = \dot{E}_{SN} - \dot{E}_{cool} + \dot{E}_{hydro}$$

ENERGY RELEASED BY SNe

$$\dot{E}_{SN} = E_{51} \cdot f_{fb,in} \cdot \frac{\dot{M}_{sf}}{\beta_{sf}}$$

ENERGY LOSS DUE TO COOLING

$$\dot{E}_{cool} = \frac{E_h}{t_{cool}}$$

ENERGY CONTRIBUTION DUE TO HYDRODYNAMICS

$$\dot{E}_{hydro} = \frac{1}{dt} \frac{\Delta S_{SPH}}{(\gamma - 1)\rho^{\gamma - 1}}$$

this is the ENTROPY variation due to SPH hydrodynamics

PRESSURE-DRIVEN SF

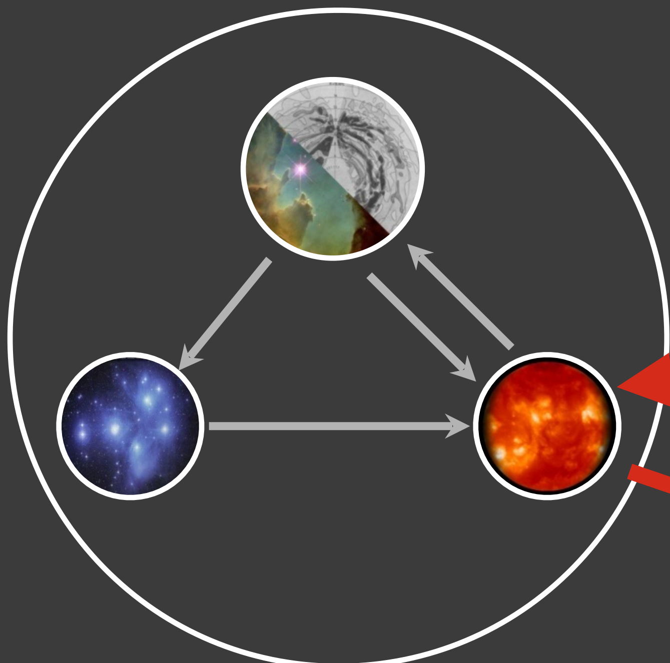
$$M_{H2} = f_{coll} \cdot M_c$$

$$f_{coll} = \frac{1}{1 + 4\left(\frac{P_0}{P_{ext}}\right)}$$

Phenomenological
(Blitz & Rosolowsky 2006)
$P_{ext} \approx P_{therm}$ with $P_0 = 35000$
(this parameter is tuned in our sims)

Energy exchanges

Multi-Phase particle



Hydro

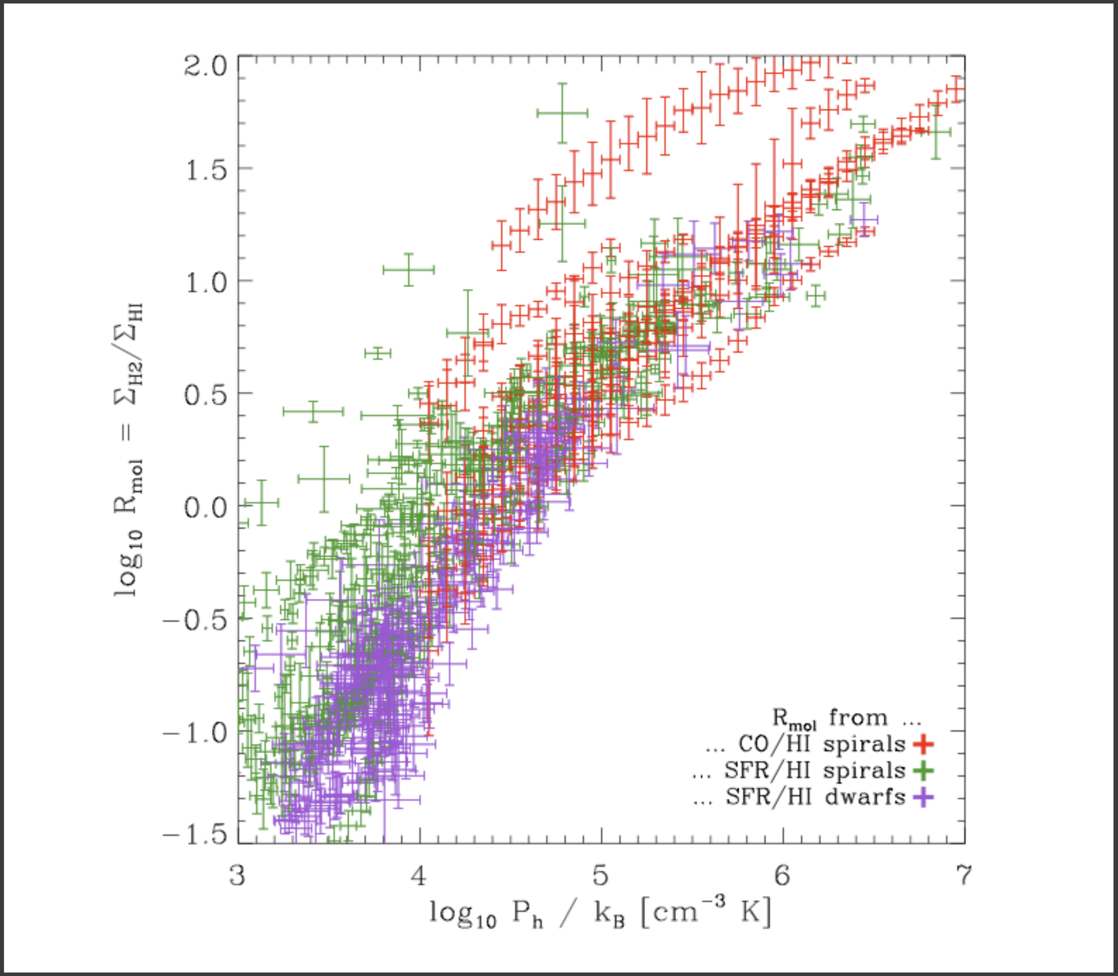
Δt, ΔS

$$\dot{E}_{hydro} = \Delta S/(\gamma-1)\rho^{(\gamma-1)}\Delta t$$

$$\dot{E}_{hot} = -\dot{E}_{cool}+\dot{E}_{sn}+\dot{E}_{hydro}$$

new ΔS

etc...



Inspired by Blitz & Rosolowsky, we scale the molecular fraction with SPH pressure

(NOT the same quantity the observers use!)

Note. This phenomenomenologically includes a number of astrophysic processes and feedbacks (turbulence, magnetic fields, cosmic rays, early stellar feedback…) PROS: it's the reality. CONS: local, kpc-averaged (…but… resolution…)

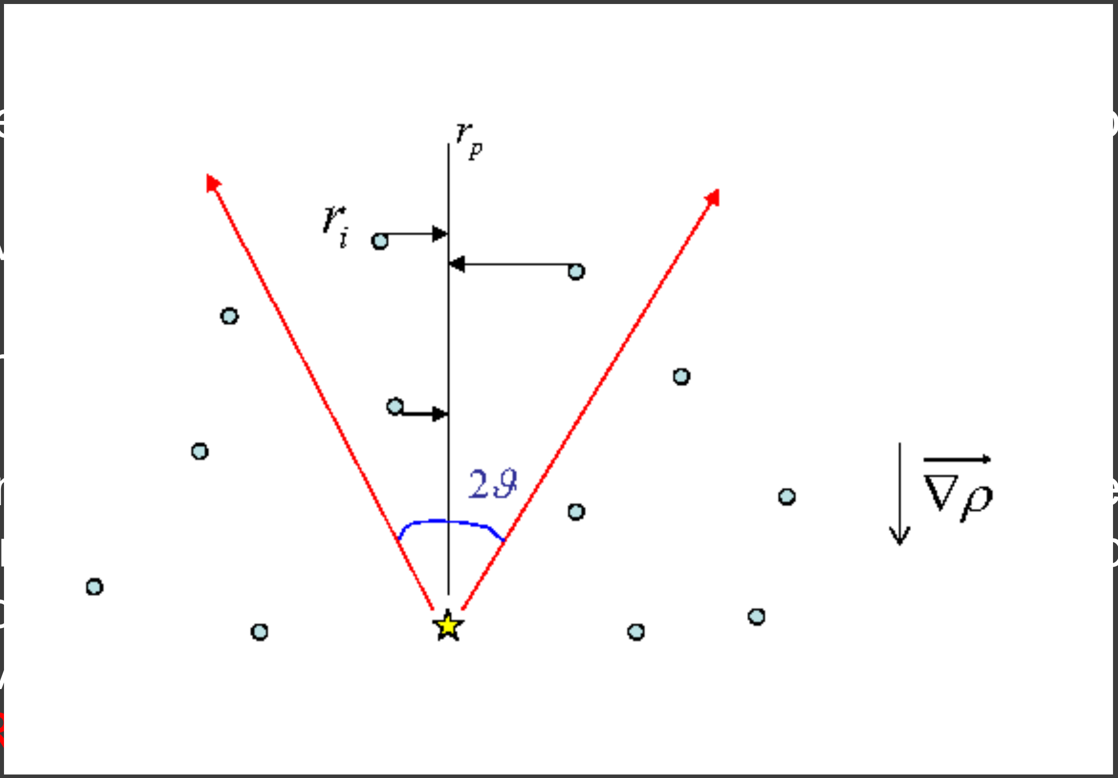
More characteristics

• Thermal ene[…]nal way

• Chemical ev[…]

• Metal deper[…]

• Stocastic kir[…]eceive also kinetic er[…]ble from the gas. Winc[…] simulations, v[…] WORK IN PR[…]



• Note: at these resolution, the form of the coupling of E_{fb} with the gas is very important.

Cosmological disk galaxy simulations

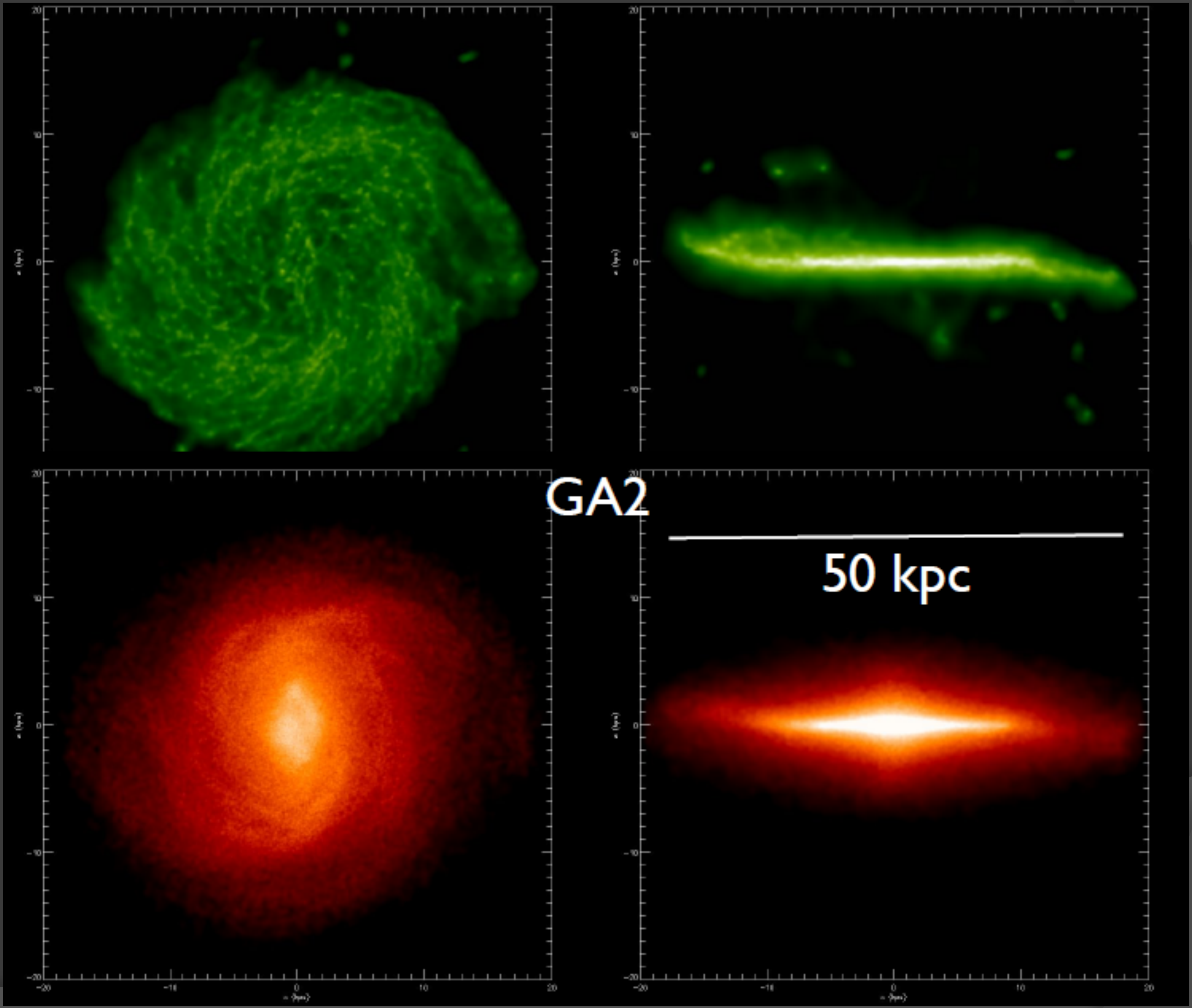
Simulation	$M_{\rm DM}$	$M_{\rm gas}$	$\epsilon_{\rm Pl}$	$M_{\rm Vir}$	$R_{\rm Vir}$	$N_{\rm DM}$	$N_{\rm gas}$	$N_{\rm star}$
GA0	$1.4 \cdot 10^8$	$2.6 \cdot 10^7$	1.4	$2.69 \cdot 10^{12}$	212.17	13748	6907	26612
GA1	$1.5 \cdot 10^7$	$2.8 \cdot 10^6$	0.65	$2.72 \cdot 10^{12}$	214.74	133164	63232	281685
GA2 (R1)	$1.6 \cdot 10^6$	$3.0 \cdot 10^5$	0.325	$2.70 \cdot 10^{12}$	211.37	1201310	628632	2543495
GA3 (R2)	$1.7 \cdot 10^5$	$3.2 \cdot 10^4$	0.155	-	-	-	-	-
Aq-C-6	$1.3 \cdot 10^7$	$4.8 \cdot 10^6$	1.0	$2.21 \cdot 10^{12}$	169.80	87340	43605	187823
Aq-C-5	$1.6 \cdot 10^6$	$3.0 \cdot 10^5$	1.0	$2.26 \cdot 10^{12}$	171.51	694617	355056	1585276

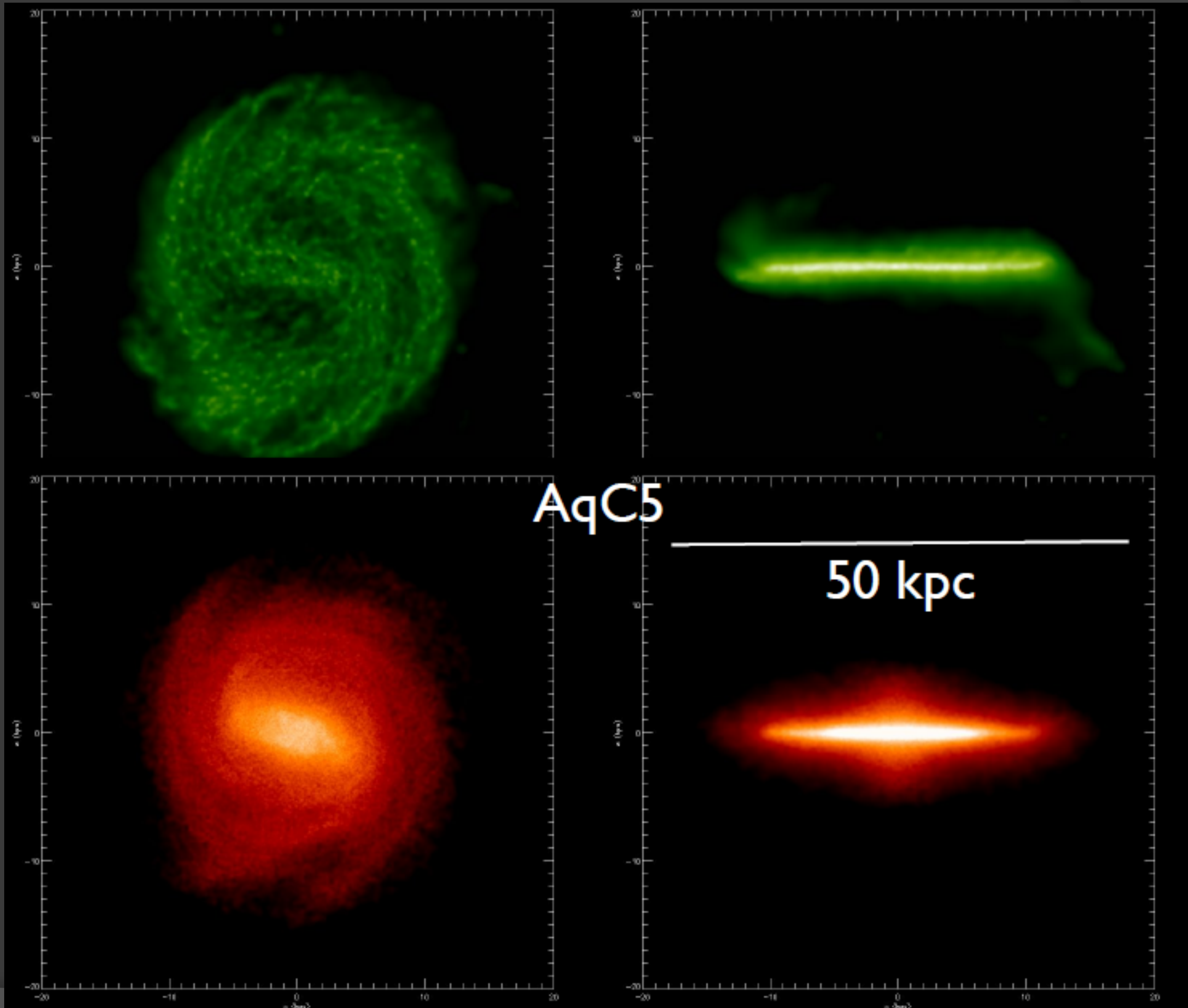
- (Stoehr+, 2002, MNRAS, 355, 84)
- (See *The Aquila comparison project*, Scannapieco+, 2012, MNRAS, 423, 1726)

Murante, Monaco, Borgani, Tornatore, Dolag, Goz, 2015, MNRAS, 447, 178

Goz+, 2015, MNRAS, 447, 1774

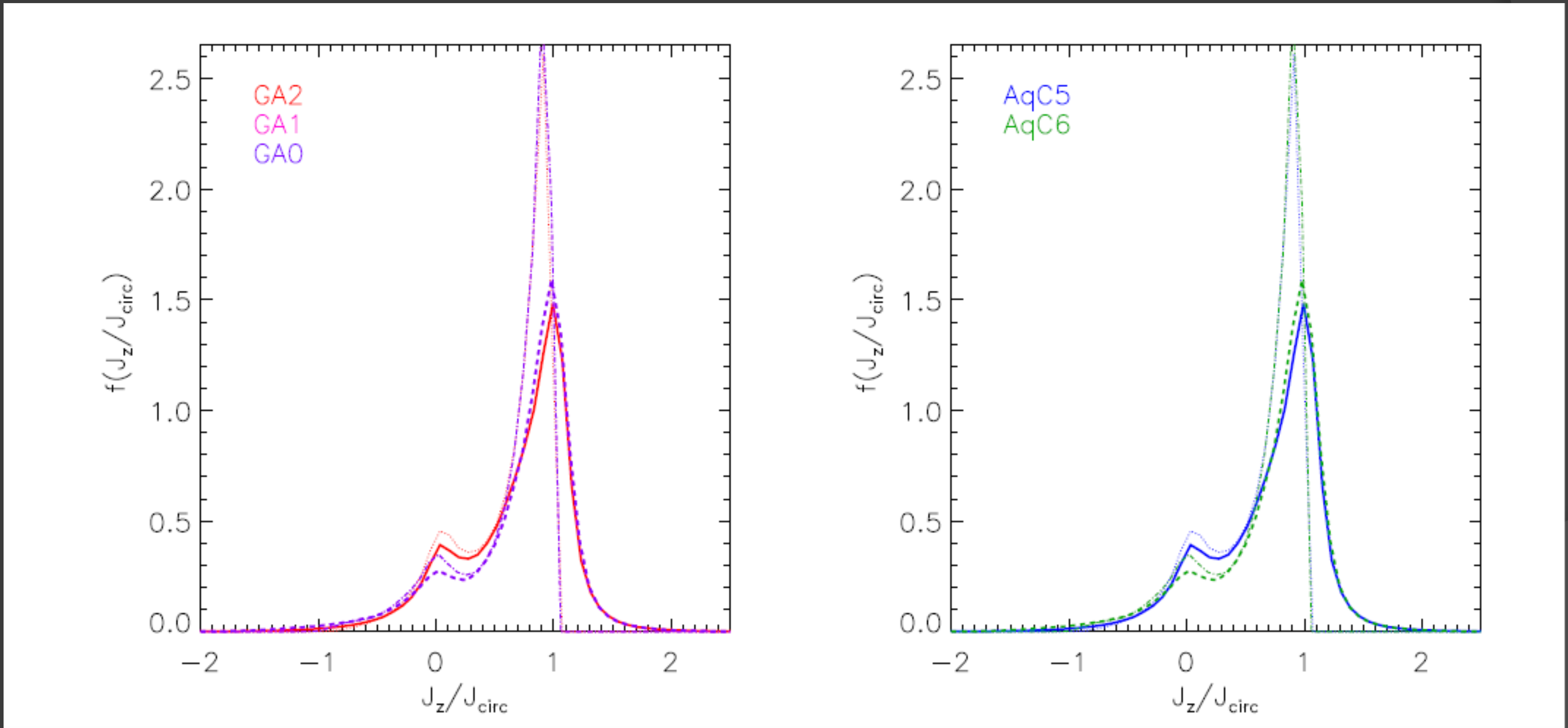
Monaco+, 2012, MNRAS, 447, 1774


GA2
50 kpc

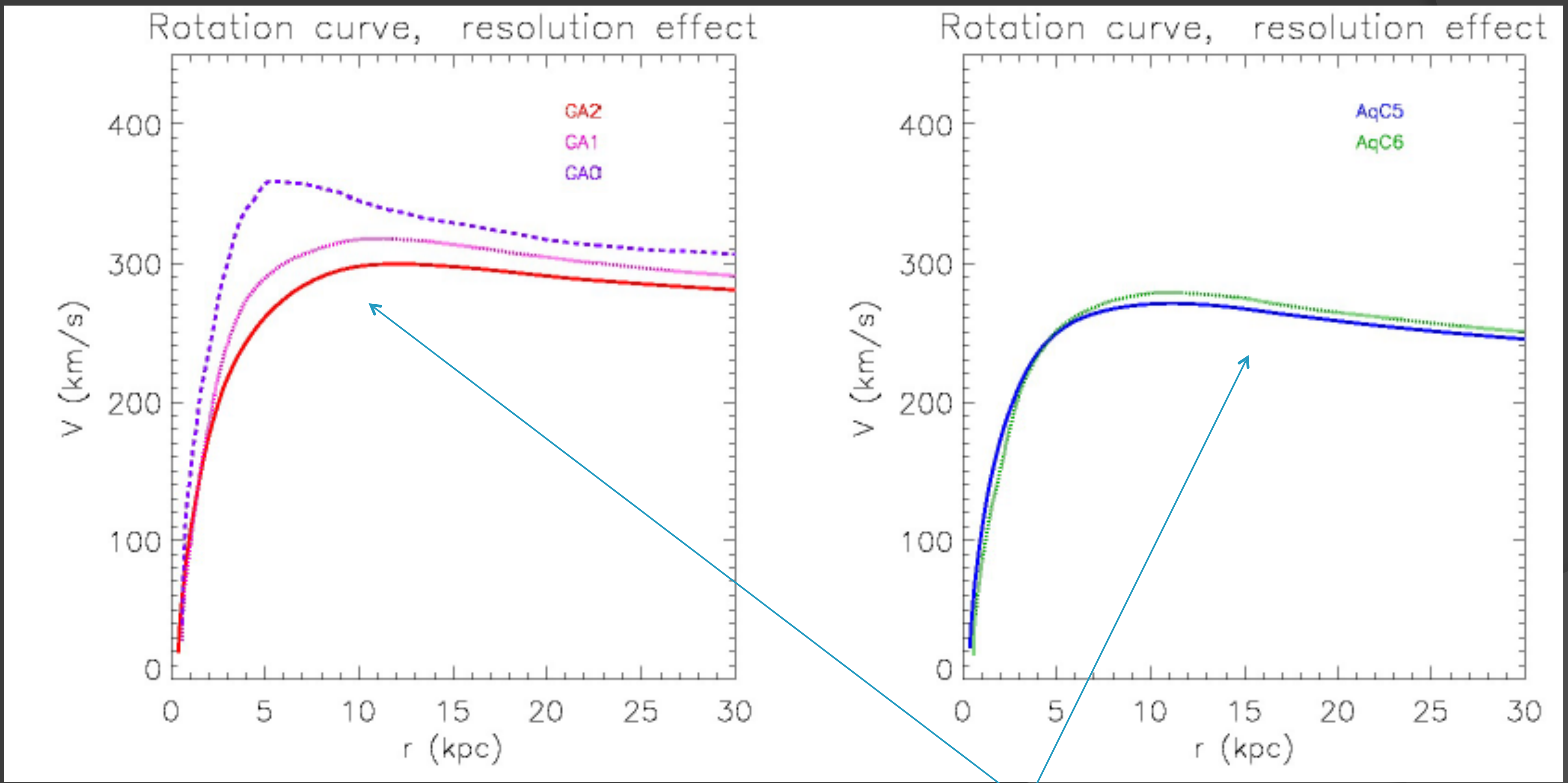

AqC5
50 kpc

Circularity Histograms

B/T=0.30 (GA0), 0.22 (GA1), 0.20 (GA2)   B/T=0.24 (Aq-C5), 0.23 (Aq-C6)

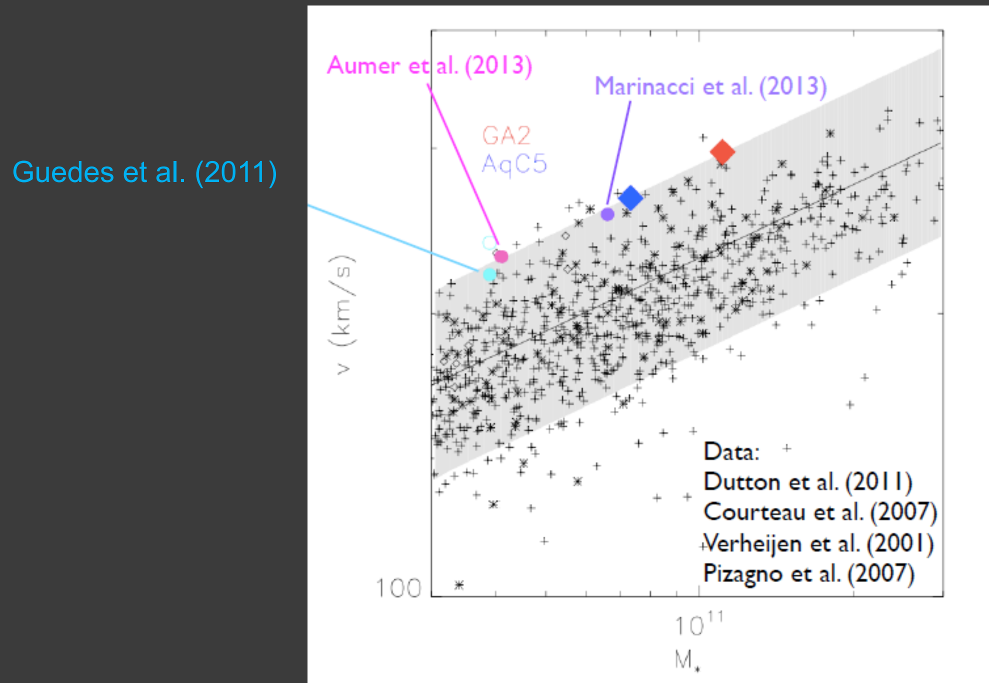


Circular Velocity Profiles

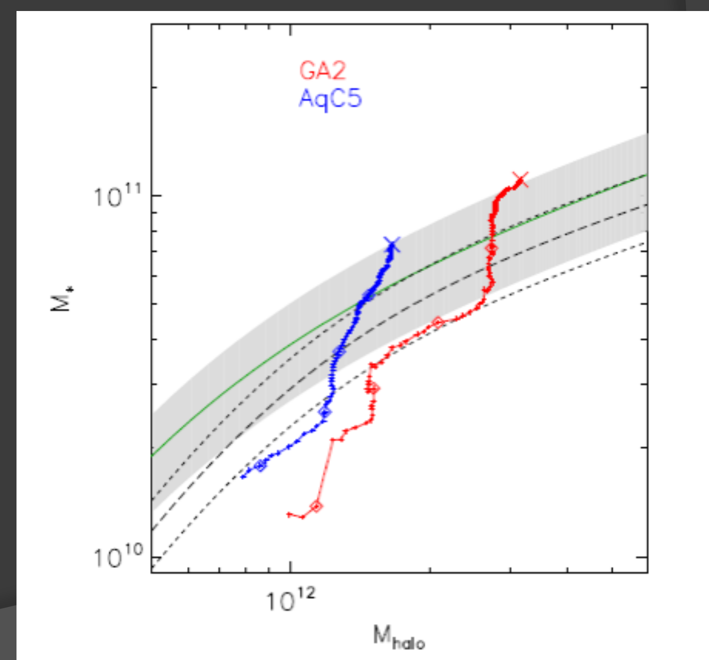


"weak convergence" wrt resolution…

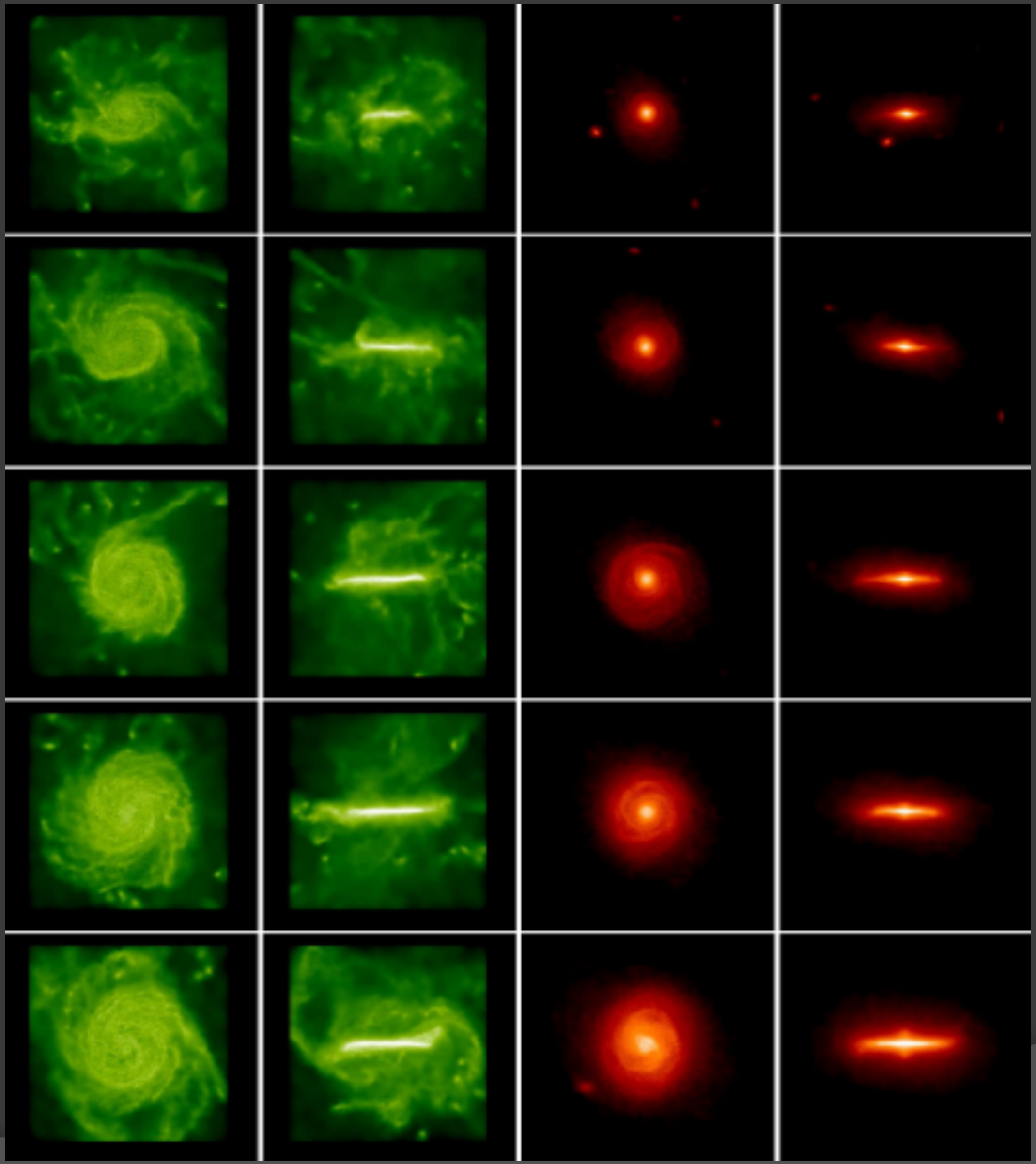
Tully-Fisher



Barion conversion efficiencies



Redshift evolution (AqC5)



Z=2.48

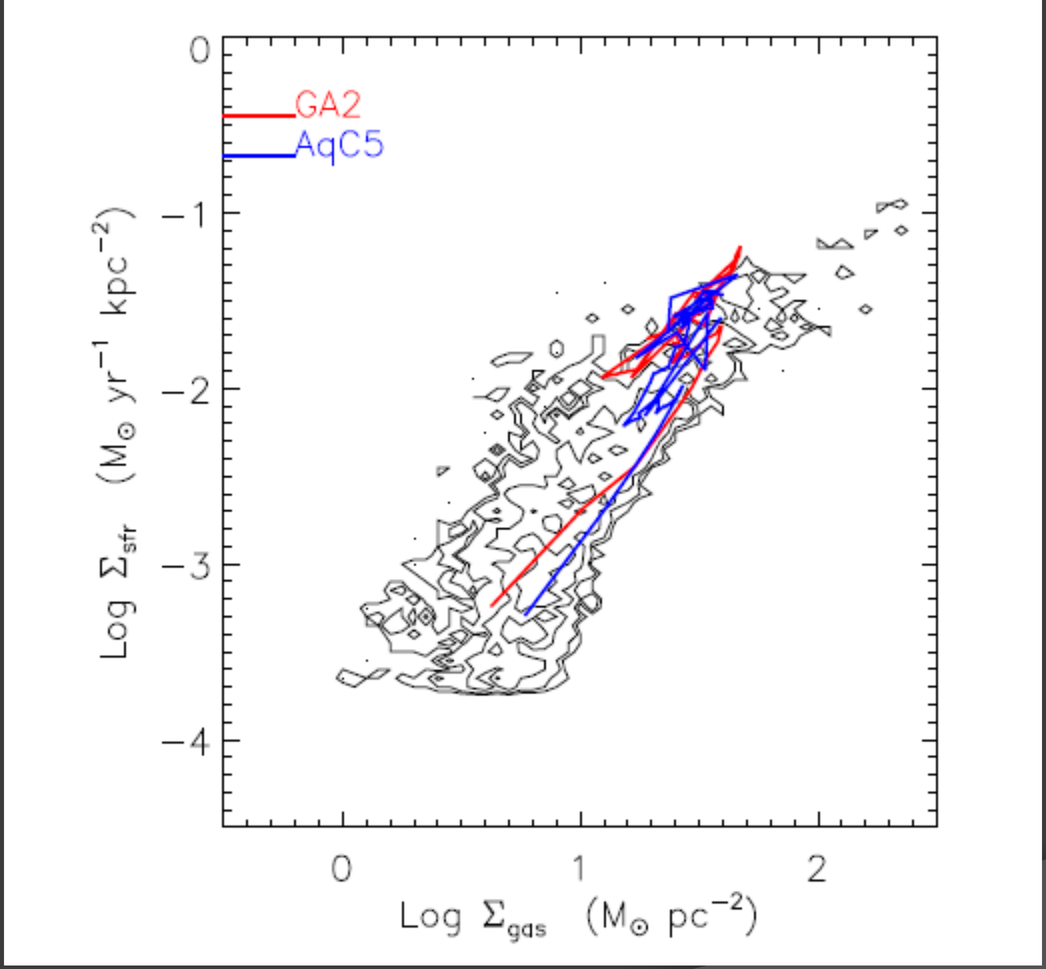
Z=2.02

Z=1.50

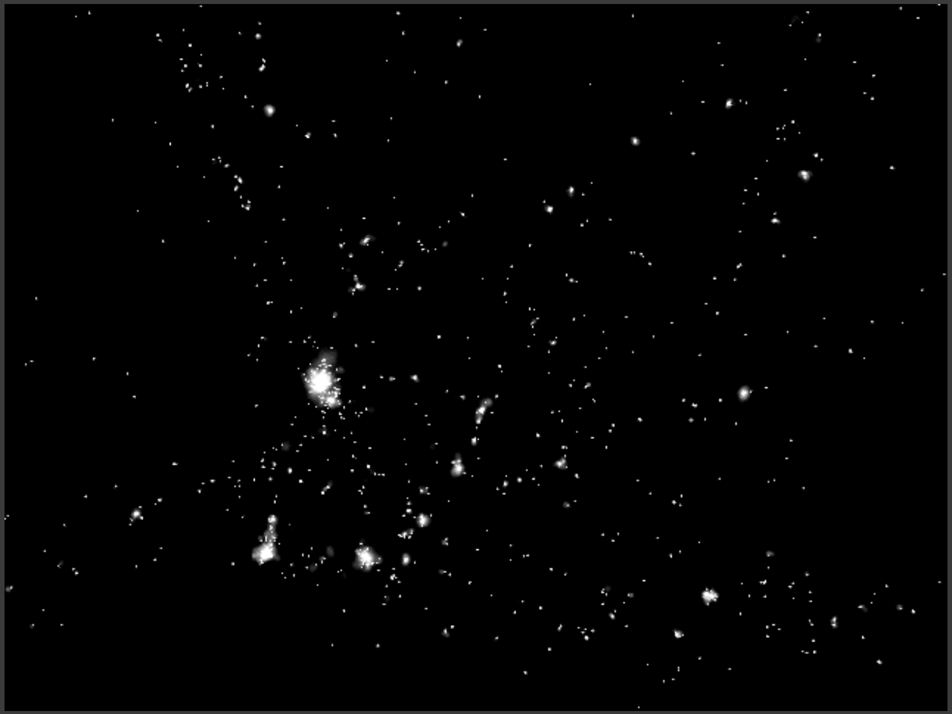
Z=1.01

Z=0.49

Schmidt-Kennicutt relation



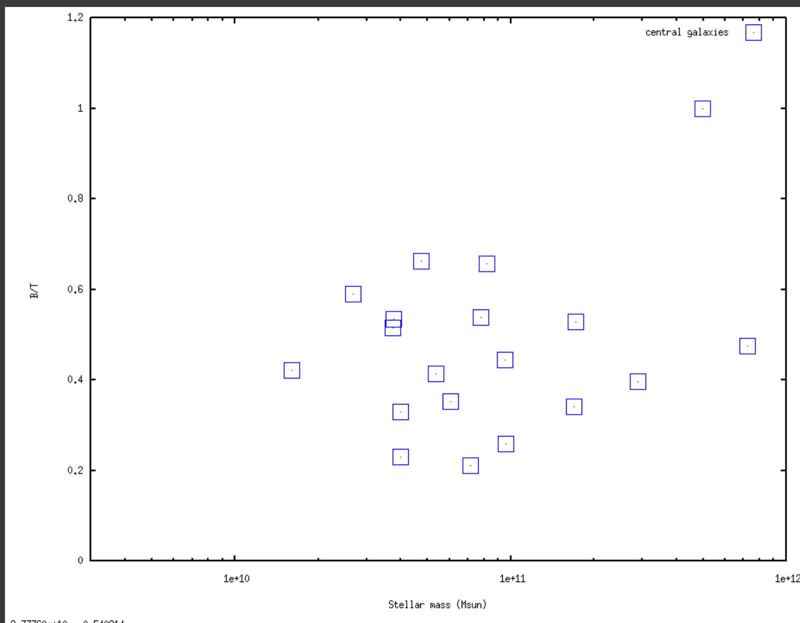
MUPPI Boxes

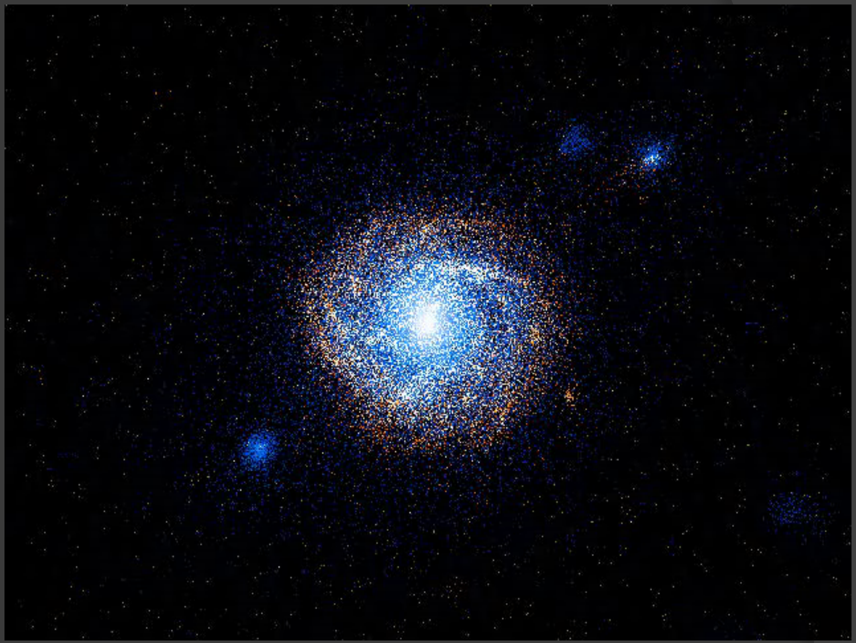


- **MEDIUM** resolution:
  force: 0.5 kpc/h
  mass (gas): $5x10^6$ Msun/h
- About 20 galaxies more massive than 10^{10} Msun/h

18 Mpc/h, **$2x256^3$** particles

Bulge/Total mass ratios





A range of morphologies is present

Not all observables well fitted (e.g., z=0 mass function not satisfactory)

Mass: stars, 7.2x10^{10} Msun; gas, 3.4x10^{10}

f_{bar}: 0.075 (galaxy) 0.12 (halo)

B/T: 0.21; mass of stellar disk: 5.65x10^{10}

approx. 10^5 baryon particles in the galaxy

Galaxy SED with GRASIL3D

Dominguez-Tenreiro+ 2014; Goz+, MNRAS submitted

Comparison with observed emission in various bands

- Radiative Transfer post-processing code
- Particular attention to dust reprocessing
- Arbitrary geometry
- Modified to be used with MUPPI (e.g., H_2 given by the simulation)

GRASIL3D parameters calibrated againts PEP and LVL samples

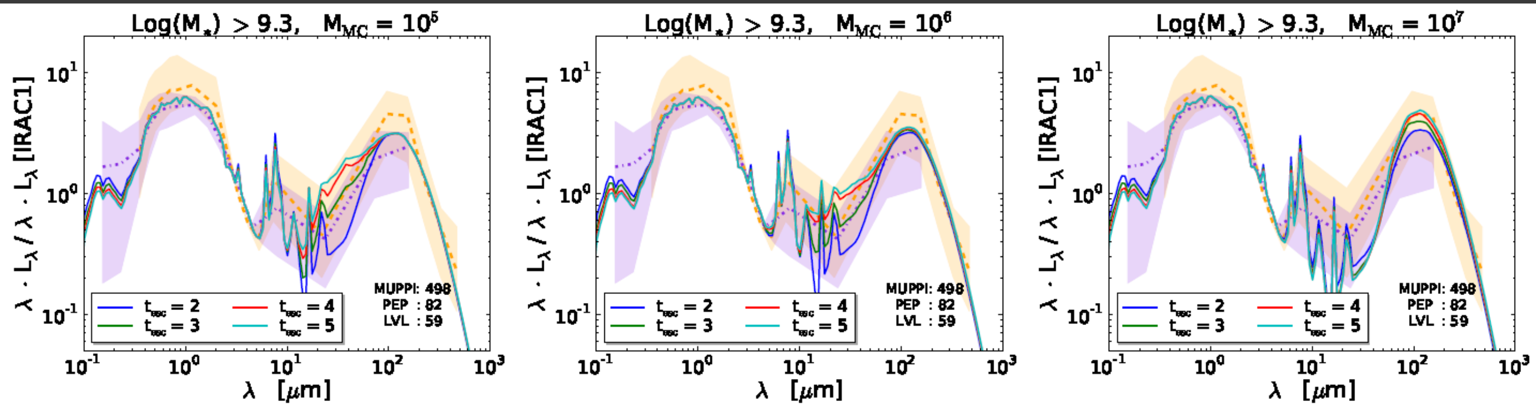


Figure B2. Calibration of GRASIL-3D parameters. In all plots only galaxies with $\mathrm{Log}(M_*) > 9.3\,M_\odot$ and $M_{MC} = 10^5\,M_\odot$ (left), $M_{MC} = 10^6\,M_\odot$ (middle), $M_{MC} = 10^7\,M_\odot$ (right) are taken into account. In each plot all the SEDs are normalized to the IRAC1 band (3.6 μm), continuous colour lines show the median values for different t_{esc}, while orange and violet dot-dashed lines represent the median value for PEP and LVL samples respectively, and finally the corresponding filled regions give the 1σ uncertainty. Every plot reports the number of galaxies in the MUPPIBOX, PEP and LVL samples.

Example: calibration of M_{MC} and t_{esc}

Galaxy SED with GRASIL3D: results

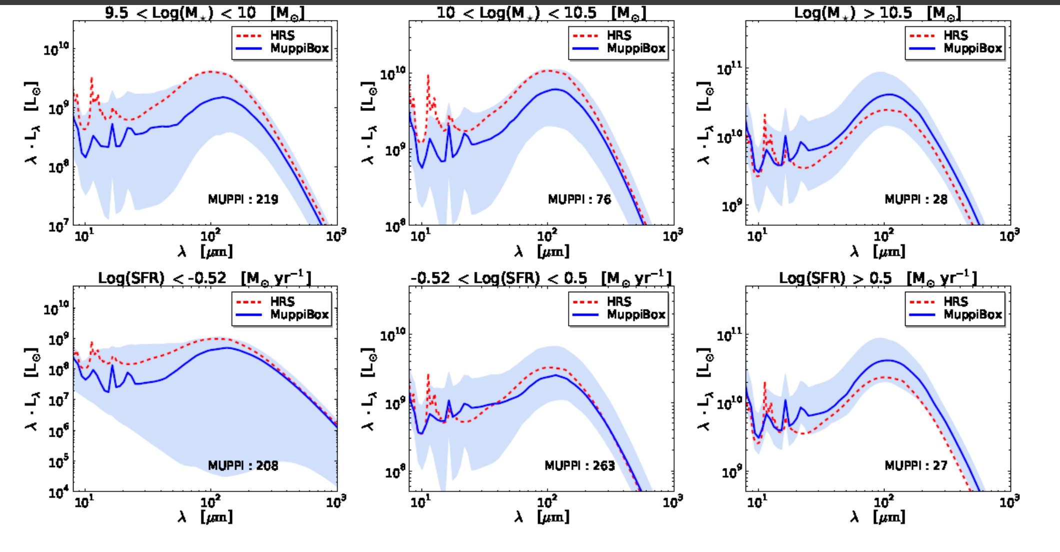


Figure 5. Comparison between median SEDs of simulated galaxy sample (blue continuous lines) and HRS (red dashed lines) for galaxies in various bins of stellar mass (first row) or SFR (second row). The blue filled region marks the 1σ uncertainty of the simulated sample, defined by the 16th and 84th percentiles. Above each panel we report the selection criterion used to define the subsample, while the number of simulated galaxies (MUPPI [number]) is reported in each figure.

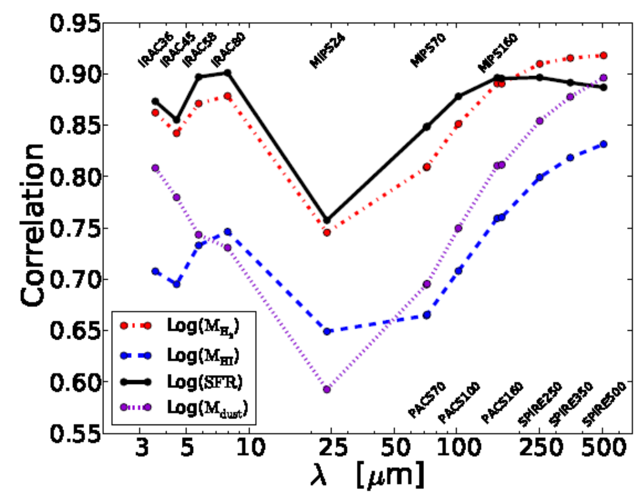


Figure 6. Spearman Correlation coefficients of IR luminosity in *Spitzer* (IRAC and MIPS) and *Herschel* (PACS and SPIRE) bands with $M_{\rm H_2}$ (dot-dashed red line), $M_{\rm HI}$ (dashed blue line), SFR (continuous black line) and $M_{\rm dust}$ (dashed violet line).

Simulated SEDs in classes of galay masses and SFR, compared with HRS

Correlation between IR luminosities and various physical quantities

Developments

- MUPPI with modern SPH (Beck+ 2015) (done; needs parameter tuning; **M. Valentini, Ph.D student**)
- Improve FB schemes (ongoing: **with M. Valentini**)
- Include AGN feedback in MUPPI (ongoing; using Steinborn+ new model)
- Include non-equilibrium chemistry (by U. Maio) with self-consistent formation of H_2 (1 PhD, D. Goz; 1 graduate, P. Di Cerbo; + U. Maio)
- Kinetic AGN feedback (ongoing; with P. Barai)

PRELIMINARY: H_2 chemistry

Umbero Maio's chemical network in MUPPI

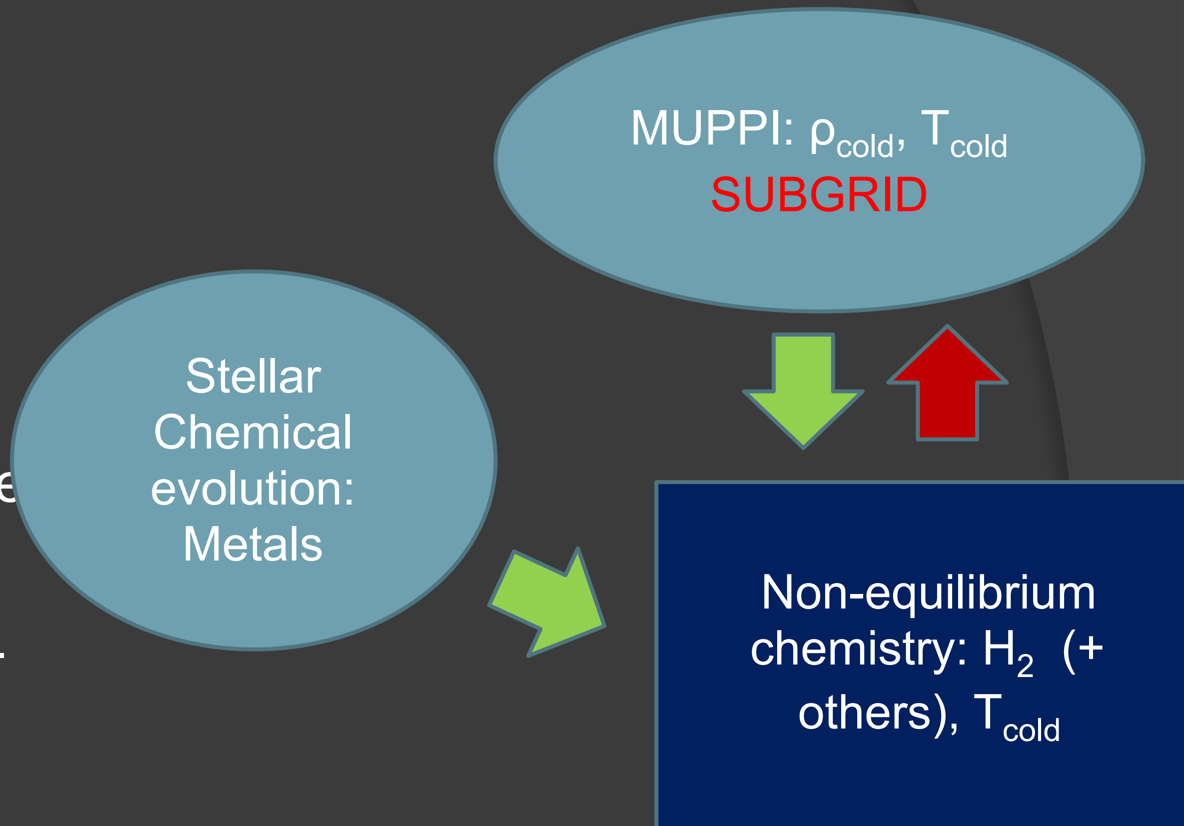
Reazioni	Referenze per i tassi di reazione
$H + e^- \longrightarrow H^+ + 2e^-$	A97/Y06
$H^+ + e^- \longrightarrow H + \gamma$	A97/Y06
$He + e^- \longrightarrow He^+ + 2e^-$	A97/Y06
$He^+ + e^- \longrightarrow He + \gamma$	A97/Y06
$He^+ + e^- \longrightarrow He^{++} + 2e^-$	A97/Y06
$He^{++} + e^- \longrightarrow He^+ + \gamma$	A97/Y06
$H + e^- \longrightarrow H^- + \gamma$	A97/Y06
$H^- + H \longrightarrow H_2 + e^-$	A97/Y06
$H + H^+ \longrightarrow H_2^+ + \gamma$	A97/Y06
$H_2^+ + H \longrightarrow H_2 + H^+$	A97/Y06
$H_2 + H \longrightarrow 3H$	A97
$H_2 + H^+ \longrightarrow H_2^+ + H$	S04/Y06
$H_2 + e^- \longrightarrow 2H + e^-$	ST99/GB03/Y06
$H^- + e^- \longrightarrow H + 2e^-$	A97/Y06
$H^- + H \longrightarrow 2H + e^-$	A97/Y06
$H^- + H^+ \longrightarrow 2H$	P71/GP98/Y06
$H^- + H^+ \longrightarrow H_2^+ + e^-$	SK87/Y06
$H_2^+ + e^- \longrightarrow 2H$	GP98/Y06
$H_2^+ + H^- \longrightarrow H + H_2$	A97/Y06
$D + H_2 \longrightarrow HD + H$	WS02
$D^+ + H_2 \longrightarrow HD + H^+$	WS02
$HD + H \longrightarrow D + H_2$	SLP98
$HD + H^+ \longrightarrow D^+ + H_2$	SLP98
$H^+ + D \longrightarrow H + D^+$	S02
$H + D^+ \longrightarrow H^+ + D$	S02
$He + H^+ \longrightarrow HeH^+ + \gamma$	RD82,GP98
$HeH^+ + H \longrightarrow He + H_2^+$	KAH79, GP98
$HeH^+ + \gamma \longrightarrow He + H^+$	RD82, GP98

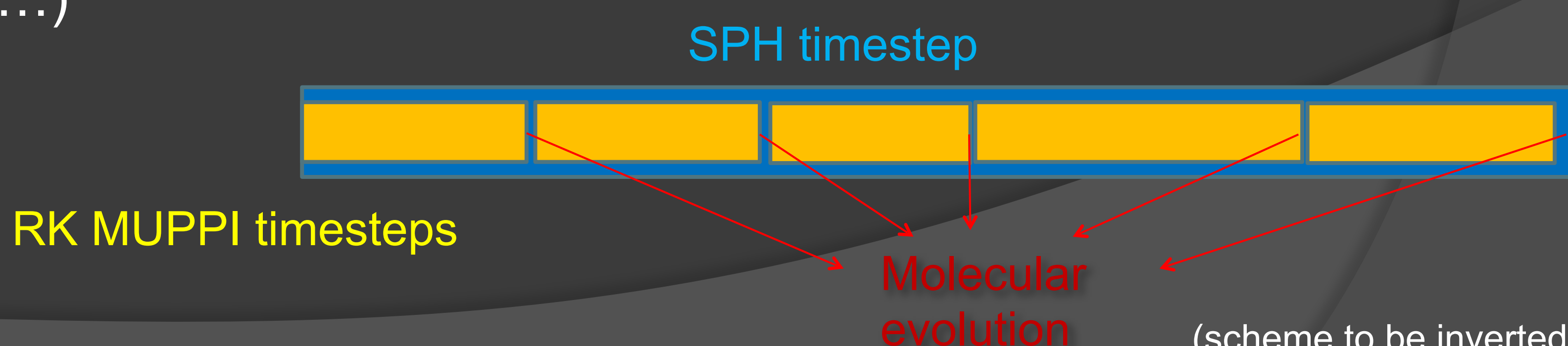
What the network does

Given ρ_{cold}, T_{cold}:
Given Metals:
Given T_{cmb}, UV background:

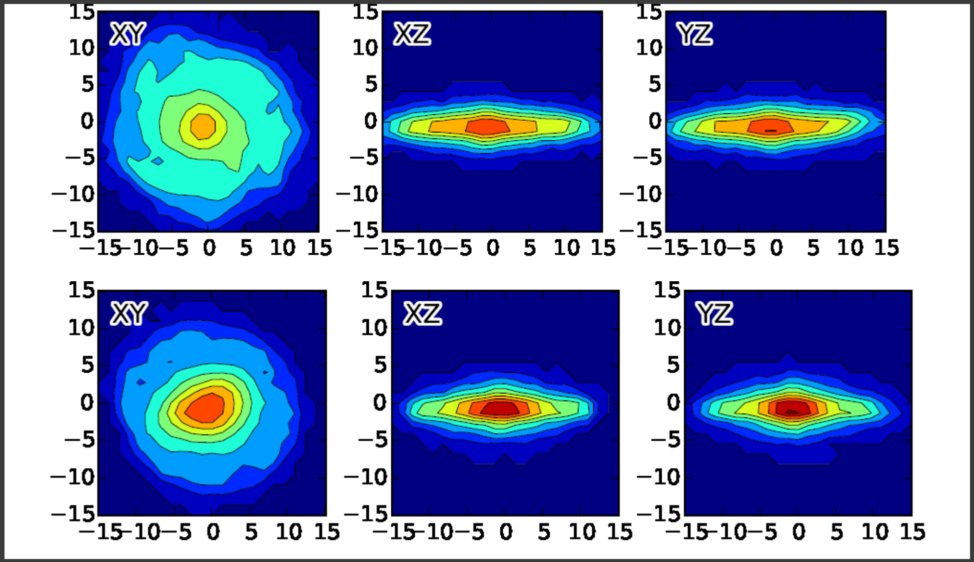
- Calculates new abundances in Δt
- Gives new temperature in Δt

- H_2 formation on metal-dependent dust
- H_2 destruction from a FIXED UV field (from stars…)





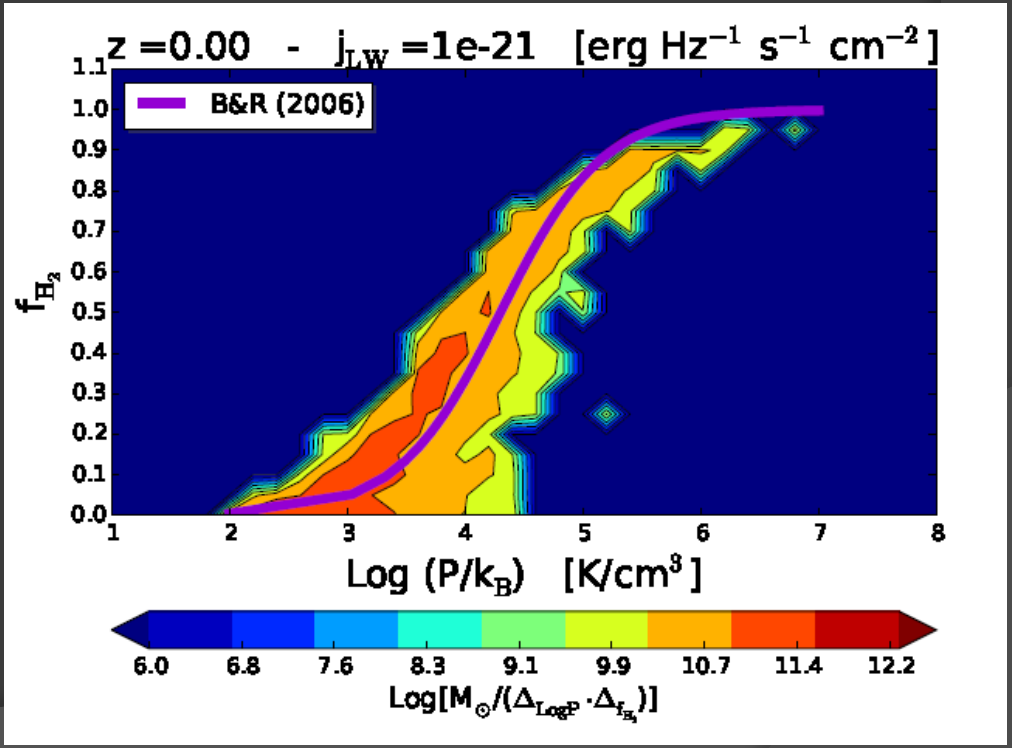
(scheme to be inverted)



AqC6, std

AqC6, H_2, fixed UV

Predicted Blitz-Rosolowsky



WHAT we do:

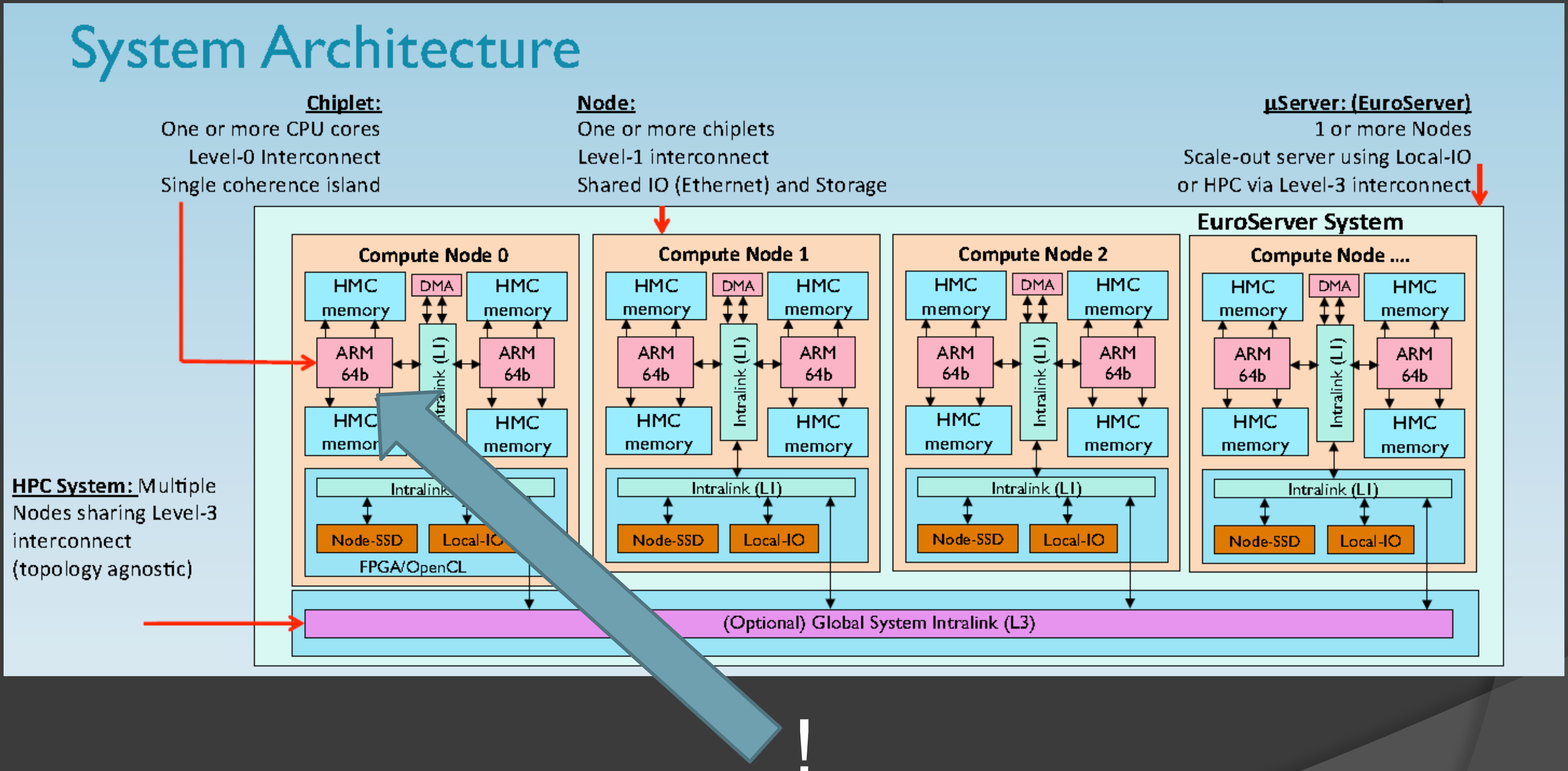
ExaNeSt develops and prototypes solutions for **Interconnection Networks**, **Storage**, and **Cooling**, as these have to evolve in order for the production of *exascale-level supercomputers* to become feasible. **We tune real HPC Applications**, and we use them to evaluate our solutions.

WHY we do it:

HPC is a precious tool for all of modern technology, science, and society. For the next generation of HPC systems, we need millions of low-power-consumption computing cores, tightly interconnected and packaged together and appropriately cooled, and with a new storage architecture.

www.exanest.eu

New technologies..



!

This project is supposed to be "application driven"

Hierarchy	Scale	Performance	DRAM	Storage	Maximum Power
Chiplet (Compute Unit)	Heterogeneous CPU/GPU compute unit	8 CPU 200 GFLOPS	Up to 6x 8GB	virtualized	15 W (16 GB)
Interposer (3D-IC)	4 × Chiplet	32 CPU 800 GFLOPS	64 GB	virtualized	70 W
Compute Node (Shared IO & Acceleration)	2 × Interposer, I/O + OpenCL FPGA	64 CPU 3.5 TFLOPS	128 GB	Host SSD 400-3400 GB	140 W + 20 W for I/O
Compute Element (daughter board PCB)	2 × Nodes	128 CPU 7 TFLOPS	256 GB	6.8 TB	320 W
Mezzanine (mother-board for Elements)	4 × Elements	512 CPU 28 TFLOPS	1 TB	27 TB	1.28 kW + 120 W Interconnect
Blade (deployment unit / hot-swap)	3 × Mezzanine	1536 CPU 84 TFLOPS	3 TB	81 TB	4.2 kW + 0.8 kW cooling
Rack (metal frame)	72 × Blades	110,592 CPU 6 PFLOPS	221 TB	5.8 PB	360 kW + 1 kW TOR switch
Example HPC System	100 × Racks	11 M CPU 600 PFLOPS	22 PB	58 PB	36 MW
ExaScale Level	167 × Racks	1 ExaFLOPS 18.5 M CPU	37 PB	1 ExaByte	60 MW

Required level of parallelism…

THIS MEANS THAT WE NEED TO RE-DESIGN OUR CODES!!

Conclusions

- Our sub-resolution star formation and feedback models produces realistic disk galaxies (at moderate resolutions)
- Key ingredient: SF -> effective (kinetic) feedback producing high-z galactic winds, gas reacts strongly to energy injection.
- Results do depend on details of the fb scheme…
- Bonus: ISM (sub-grid, average) properties
- Properties of our galaxy populations in cosmological volumes still not in perfect agreement with several observations
- …but promising halo mass dependance of winds mass-load and SEDs with GRASIL3D
- Sub-grid model useful at moderate resolution
- **New technologies will require a significant technical effort**