The Trieste galaxy formation group

P. Monaco, F. Fontanot, G. De Lucia, G. Murante, S. Borgani,
G. Granato, L. Silva

- Semi-analytic models (De Lucia, Fontanot, Monaco + Xie, Zoldan)
- Hydro simulations of galaxy formation (Murante, Monaco, Borgani + Viel, Mongardi, Villaescusa-Navarro)
- Hydro simulations of galaxy clusters (Borgani, Granato + Rasia, Biffi)
- Radiative transfer on a dusty ISM (Granato, Silva)

Semi-analytic models vs Herschel SFR functions

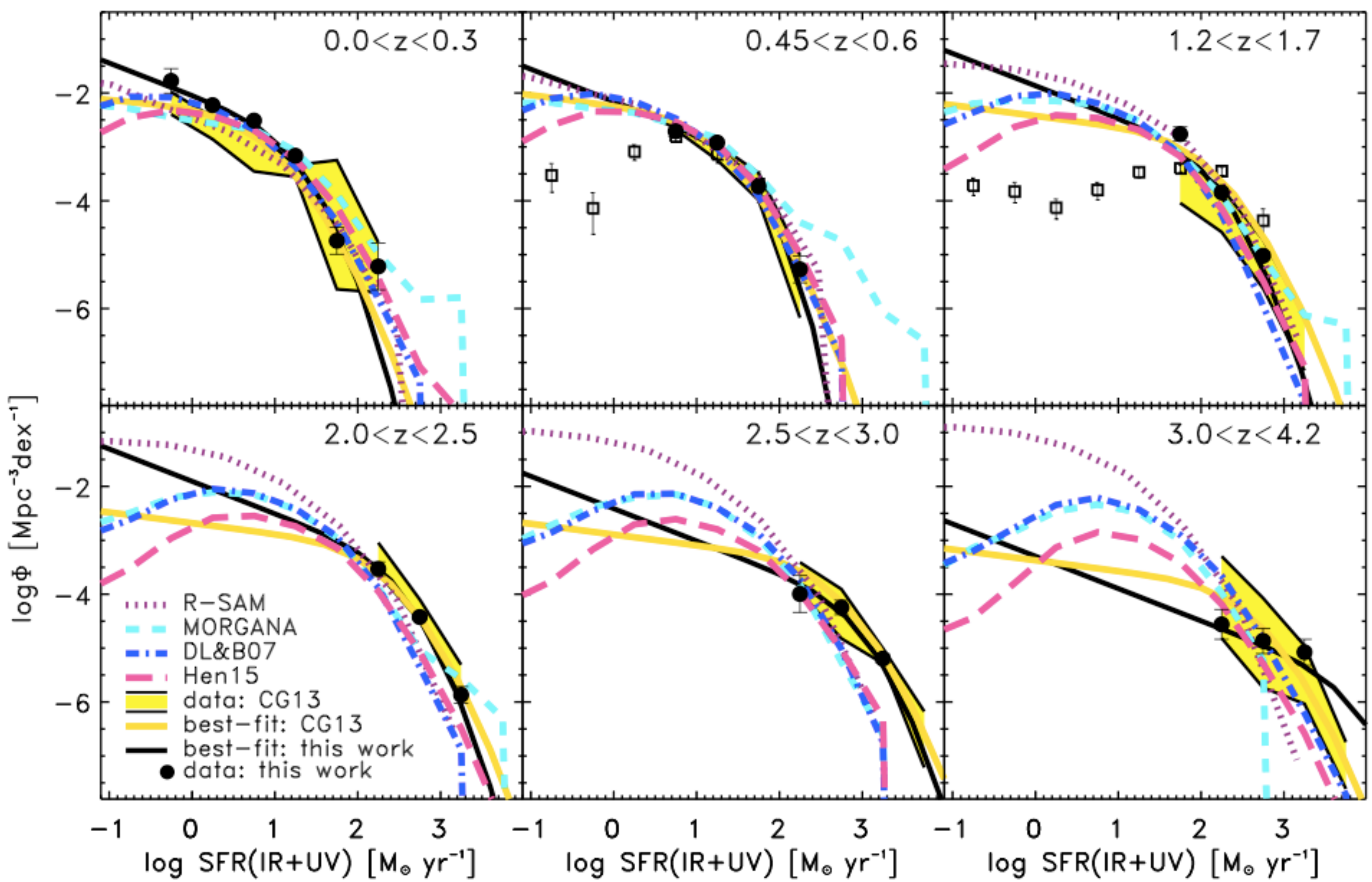


Figure 1. IR+UV SFRF estimated through the $1/V_{max}$ method in six representative redshift bins, by combining the data from the PEP GOODS-S and COSMOS fields using the Avni & Bahcall (1980) technique (black filled circles). The black solid line represents our best fit to our data with a modified Schechter function, while the yellow solid line is the total IR LF (without excluding AGN contribution through SED decomposition) obtained by Gruppioni et al. (2013), converted to an SFRF. The SFRFs of 24 μm sources with $\log(M/M_{\odot}) > 10$ in the GOODS-S by Fontanot et al. (2012) are plotted for comparison as black open squares. The SAMS predictions are shown as purple dotted (R-SAM), sea-green short-dashed (MORGANA), blue dot–dashed (De Lucia & Blaizot 2007) and deep-pink long-dashed (Henriques et al. 2015) coloured lines.

Gruppioni et al 2015, MNRAS 451, 3419

Predicting the Far IR SEDs of simulated galaxies

P. Monaco, University of Trieste and INAF-OATs

with: G. Murante, D. Goz, P. Barai, S. Borgani, K. Dolag, G. De Lucia, M. Viel, A. Ragagnin, A. Curir

Papers:

- Murante, P.M., Giovalli, Borgani & Diaferio, 2010, MNRAS 405, 1491
- P.M., Murante, Borgani & Dolag, 2011, MNRAS 421, 2485
- Murante, Calabrese, De Lucia, P.M., Borgani & Dolag, 2012, ApJ 749, L34
- Murante, P.M., Borgani, Tornatore, Dolag & Goz, 2015, MNRAS 447, 178
- Goz, P.M., Murante & Curir, 2015, MNRAS 447, 1774
- Barai, P.M., Murante, Ragagnin, Viel, 2015, MNRAS 447, 266
- Goz, P.M., Granato, Murante, Dominguez-Tenreiro, Obreja, Annunziatella, Tescari, 2016, submitted to MNRAS

A problem of resolution

galaxy formation	feedback	star formation
> 1 kpc	1 pc - 1 kpc	< 1 pc

Formation of star-forming (molecular) clouds

physics that can be resolved in cosmological simulations

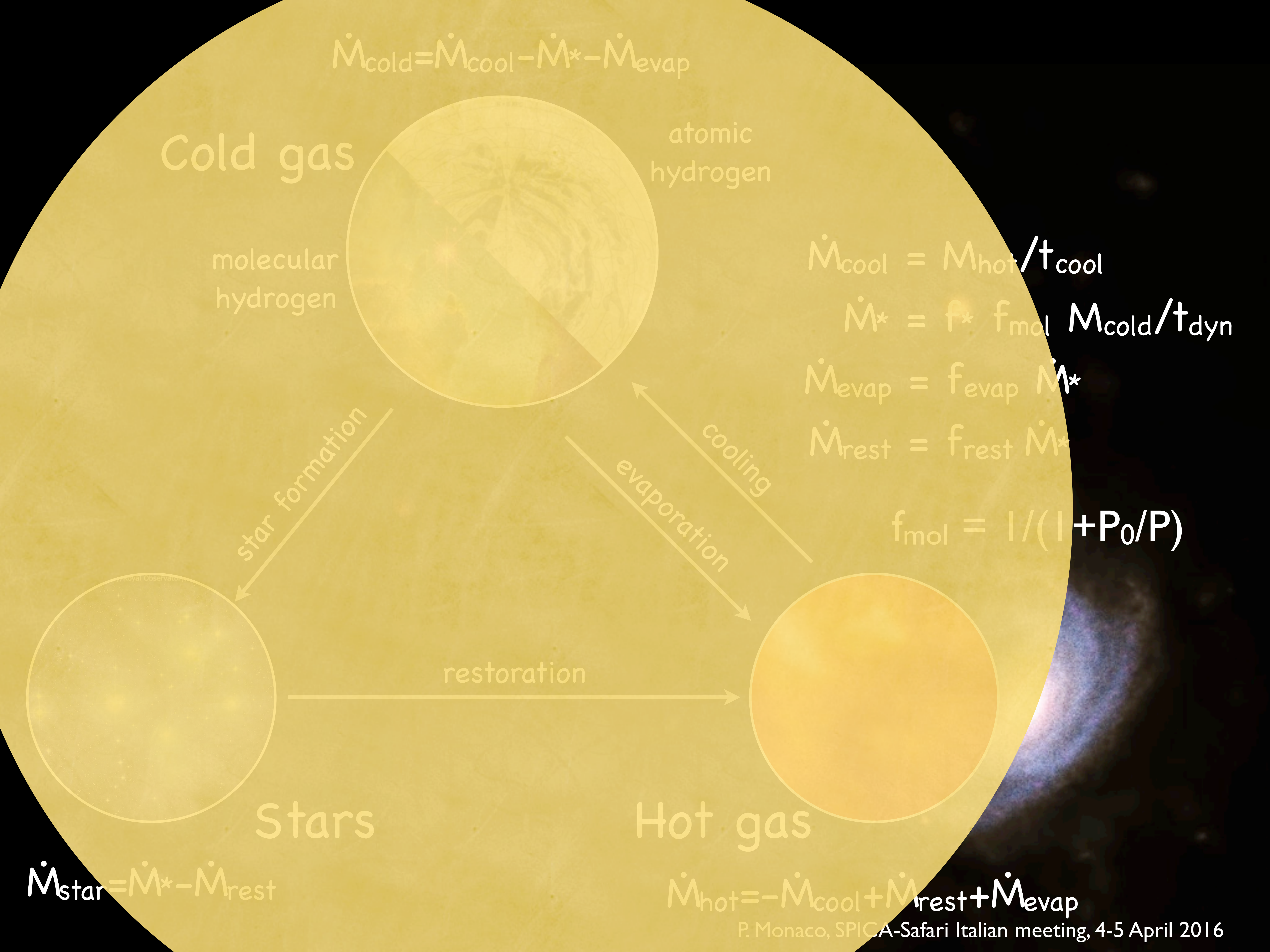
physics that can be addressed with stellar evolution and an assumption on the IMF

Emergence of energy through shock waves (and radiation pressure, cosmic rays, magnetic fields...)

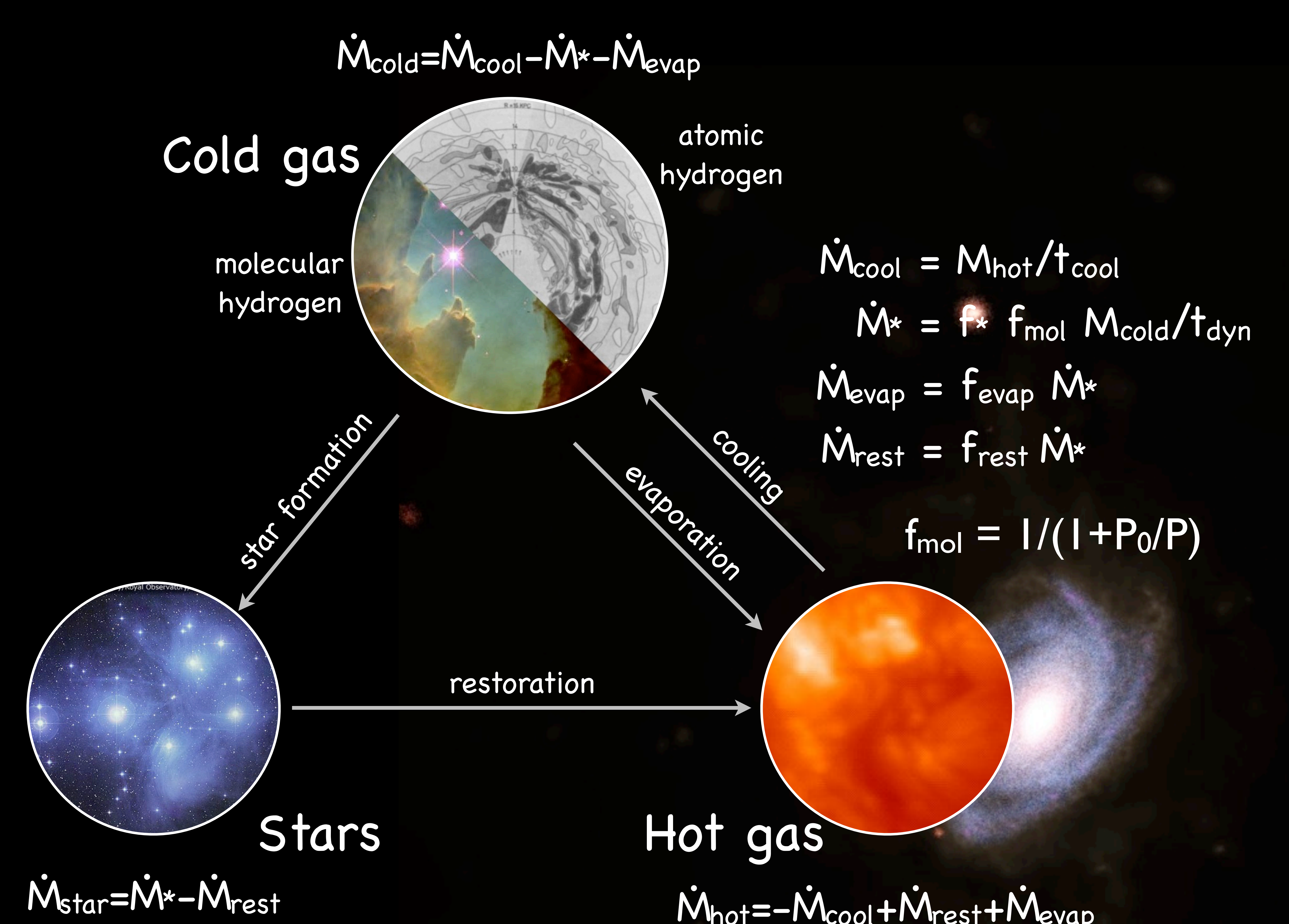
MUlti-Phase Particle Integrator (MUPPI):
a novel sub-resolution model for star formation and feedback in SPH simulations with Gadget-3

Murante, PM et al (2012); loosely following PM (2004, MNRAS 352, 181)

- gas in multi-phase particles is composed by two phases in thermal pressure equilibrium, plus a stellar component;
- gas molecular fraction is scaled with pressure;
- the evolution of the multi-phase ISM is described by a system of ODEs;
- the system of ODEs is numerically integrated within the SPH time-step (NO equilibrium solutions);
- energy from SNe is injected into the hot diluted phase; SPH hydro is done on this phase
  - ...entrainment of the cold phase...
- particles respond immediately to energy injection



$\dot{M}_{cold}=\dot{M}_{cool}-\dot{M}_{*}-\dot{M}_{evap}$
Cold gas
atomic
hydrogen
molecular
hydrogen
star formation
cooling
evaporation
restoration
Stars
Hot gas
$\dot{M}_{cool} = M_{hot}/t_{cool}$
$\dot{M}_{*} = f_{*}\, f_{mol}\, M_{cold}/t_{dyn}$
$\dot{M}_{evap} = f_{evap}\, \dot{M}_{*}$
$\dot{M}_{rest} = f_{rest}\, \dot{M}_{*}$
$f_{mol} = 1/(1+P_0/P)$
$\dot{M}_{star}=\dot{M}_{*}-\dot{M}_{rest}$
$\dot{M}_{hot}=-\dot{M}_{cool}+\dot{M}_{rest}+\dot{M}_{evap}$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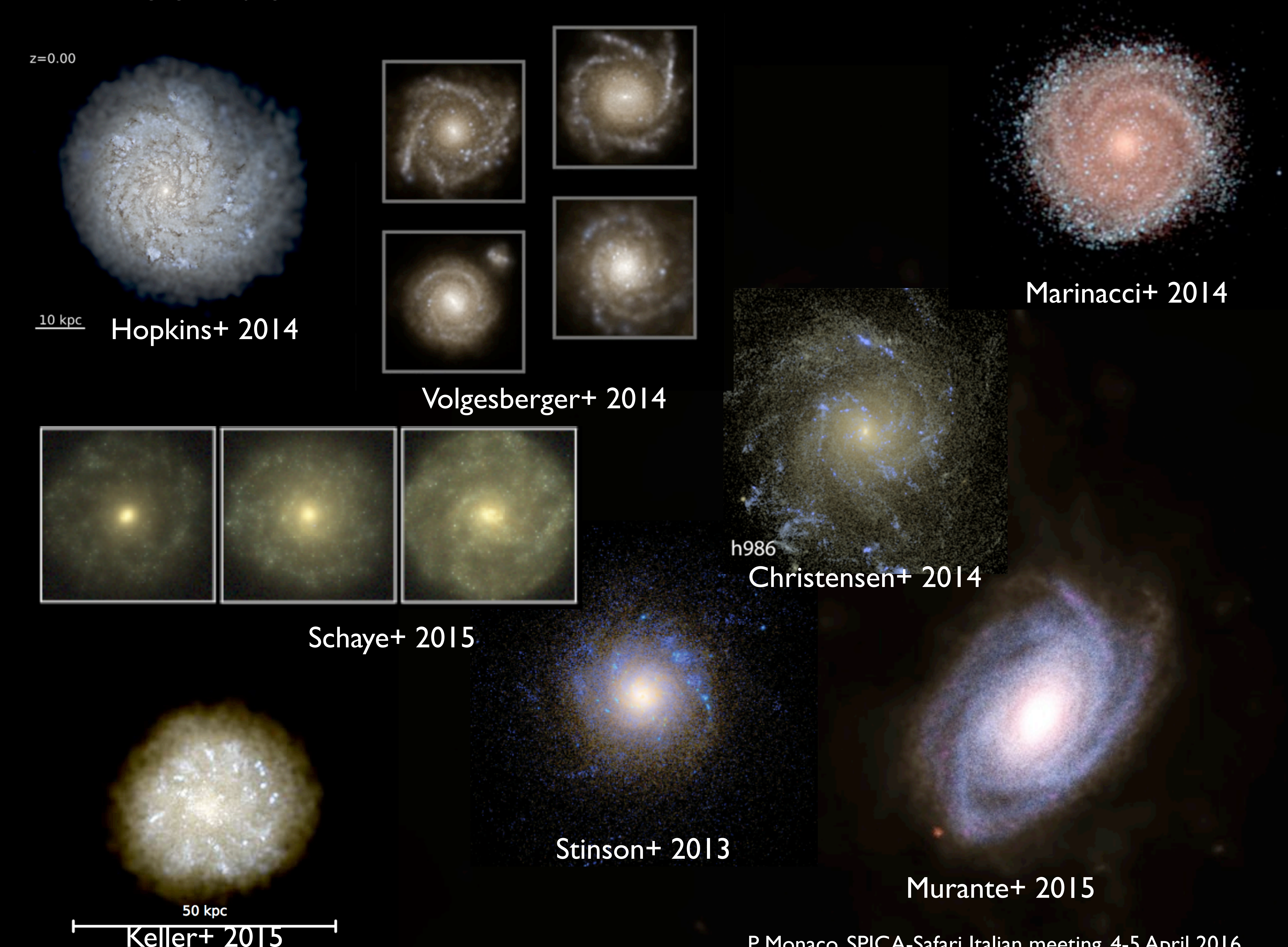
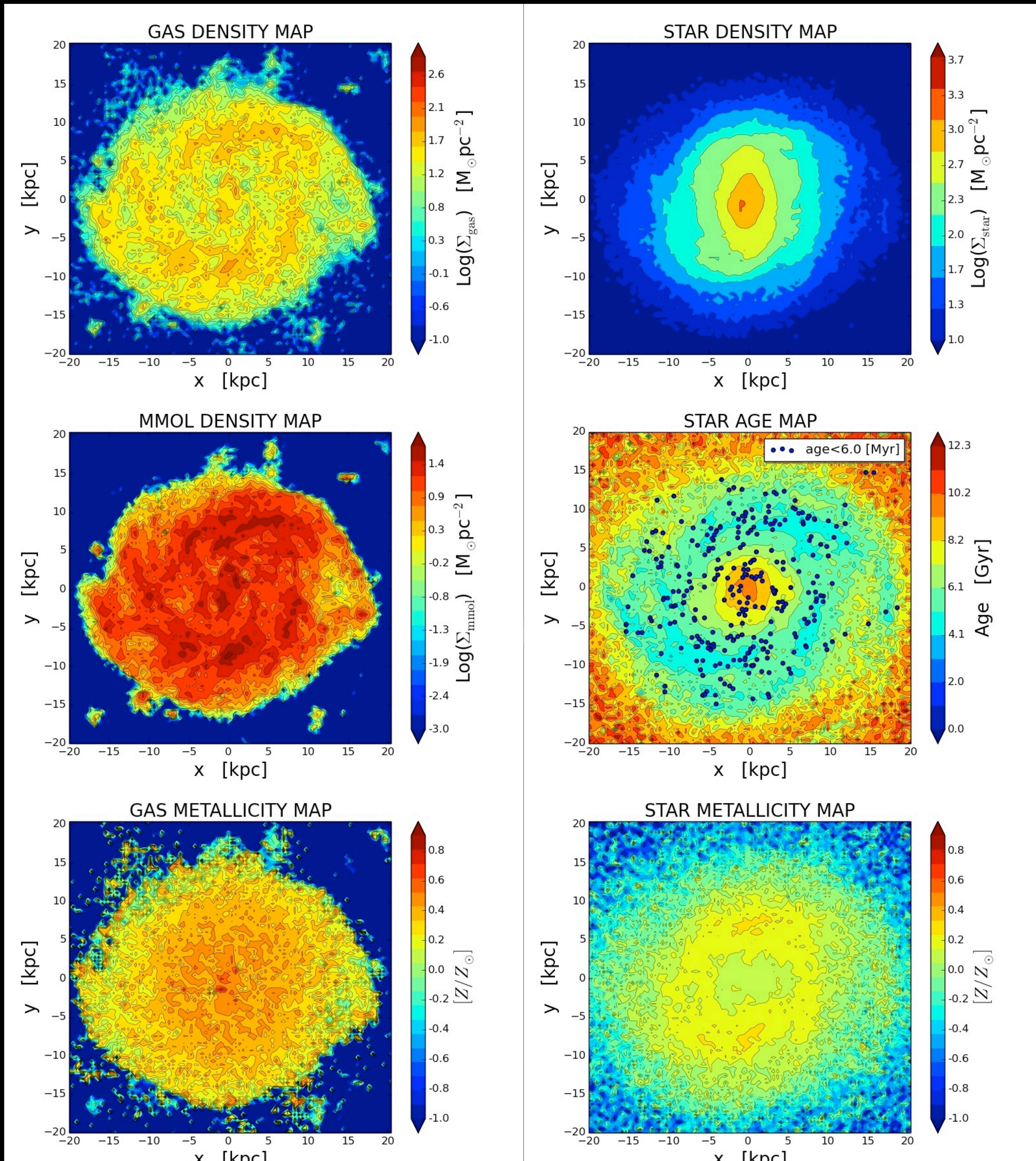

z=0.00
10 kpc
Hopkins+ 2014
Volgesberger+ 2014
Marinacci+ 2014
h986
Christensen+ 2014
Schaye+ 2015
Stinson+ 2013
Murante+ 2015
50 kpc
Keller+ 2015

Goz et al. (2016):
Radiative transfer in a dusty ISM

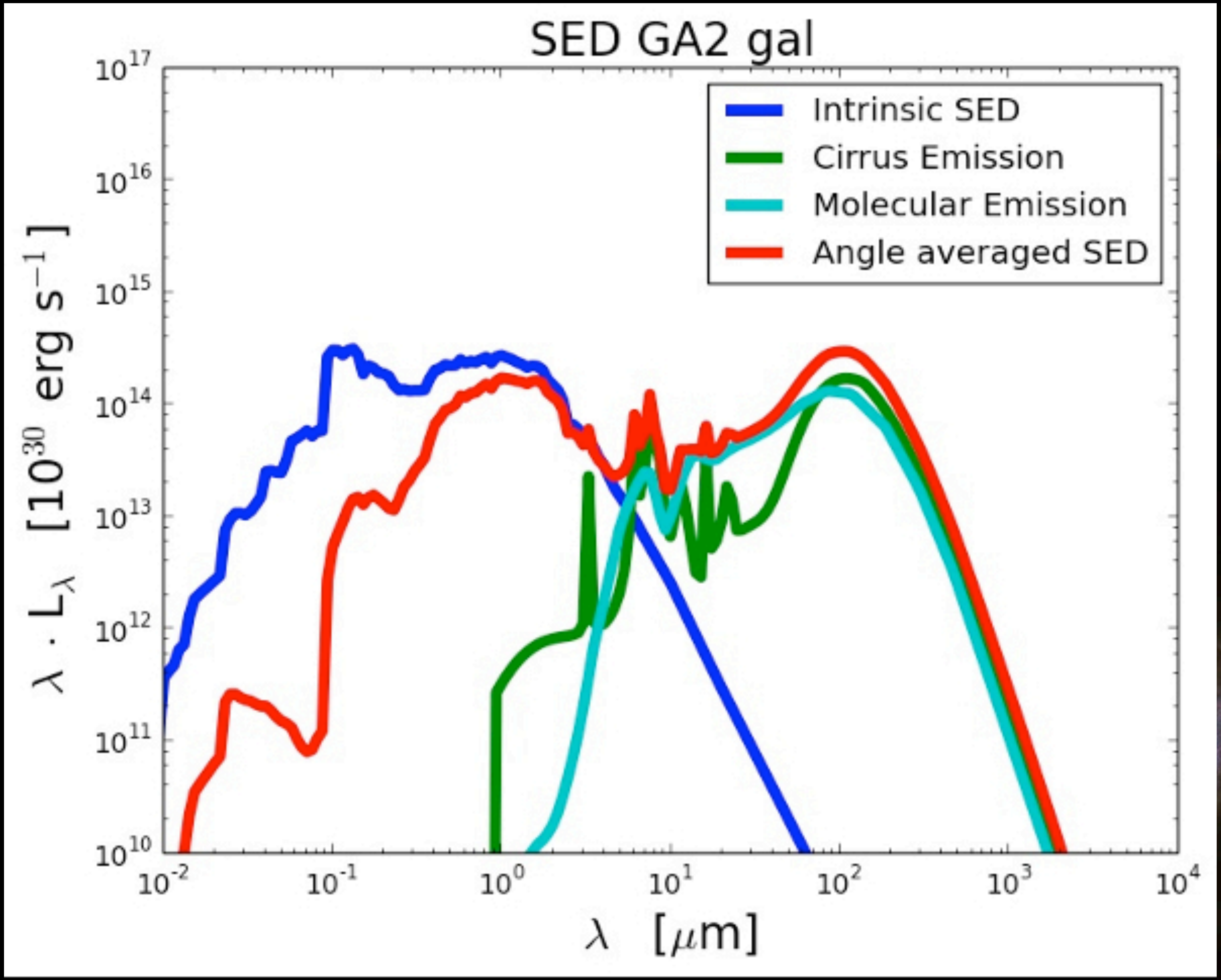
GRASIL3D (Silva et al. 1998; Dominguez-Tenreiro et al. 2014)

- Massive stars reside in highly opaque molecular clouds
- They exit the clouds after some time t_{esc}
- Radiative transfer is computed on the “cirrus” (diffuse) component
- Stellar emission follows Padova tracks
- Dust temperature is computed self-consistently
- Results depend on the line of sight



Input to GRASIL3D:

- star & gas surface densities
- star & gas metallicities
- star ages
- H_2 fraction


SED GA2 gal
Intrinsic SED
Cirrus Emission
Molecular Emission
Angle averaged SED
$\lambda \cdot L_\lambda$ [10^{30} erg s^{-1}]
λ [μm]
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}

Post-process with GRASIL-3D

Cosmological volumes

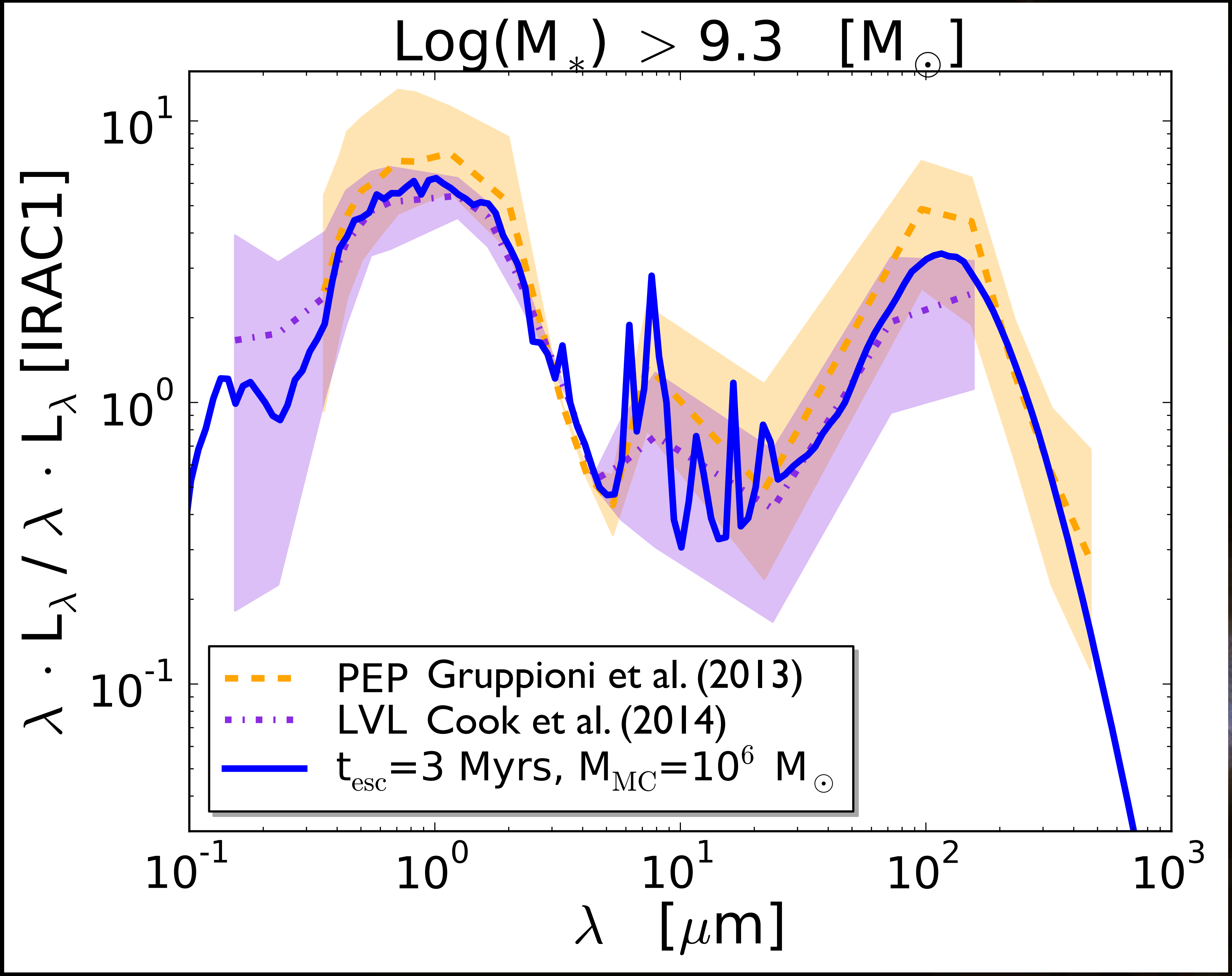
Box size: 25 Mpc (H_0=72 km/s/Mpc), N. particles: 2 x 256^3

Mgas: 5.4×10^6 M_{sun} , Mstar: 1.3×10^6 M_{sun} , softening: 0.5 physical kpc

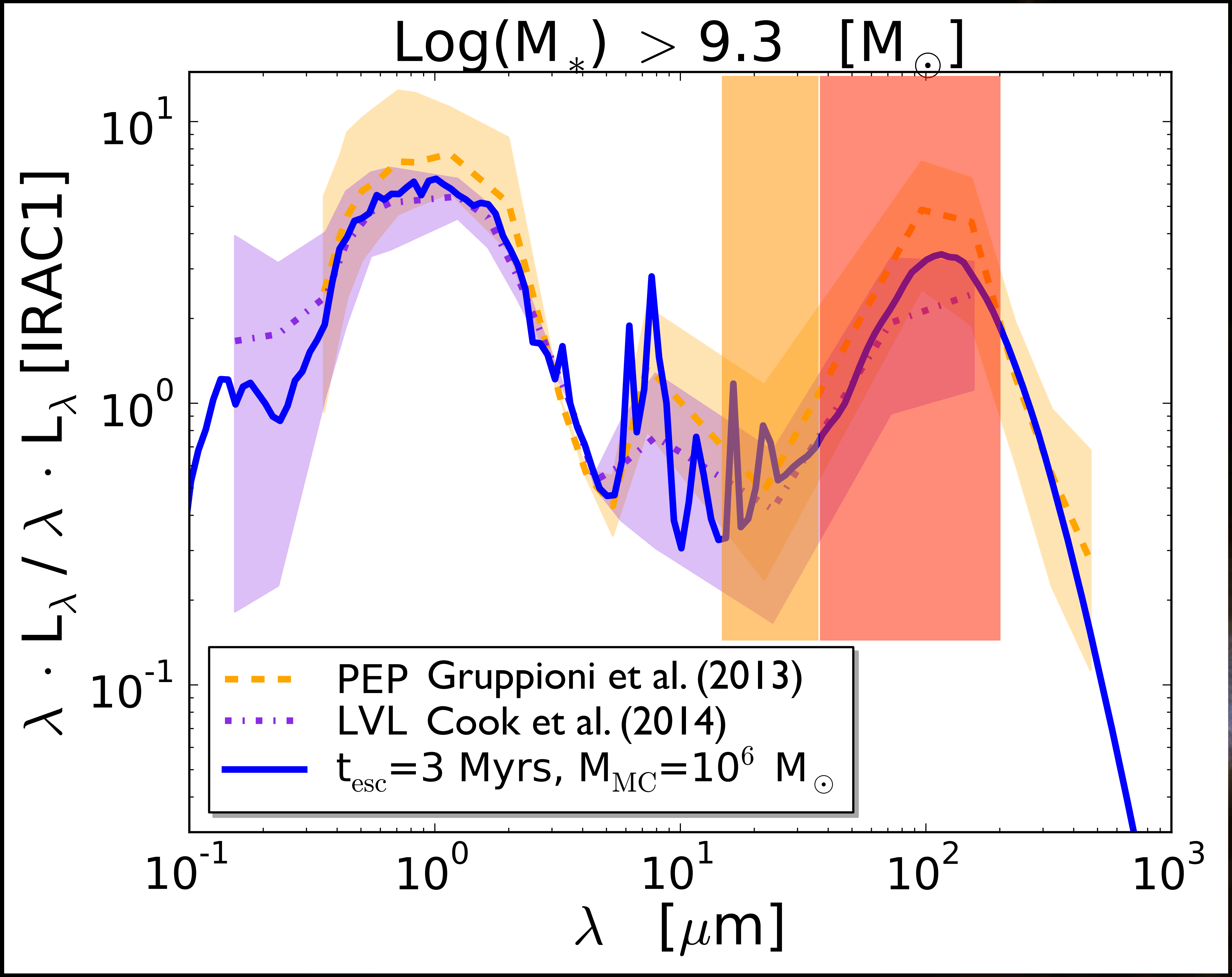
MUPPI: phenomenological model for molecular fraction, resolved hydro at ~kpc scale

GRASIL-3D: semi-analytic modeling of molecular clouds, resolved radiative transfer calculation for the cirrus

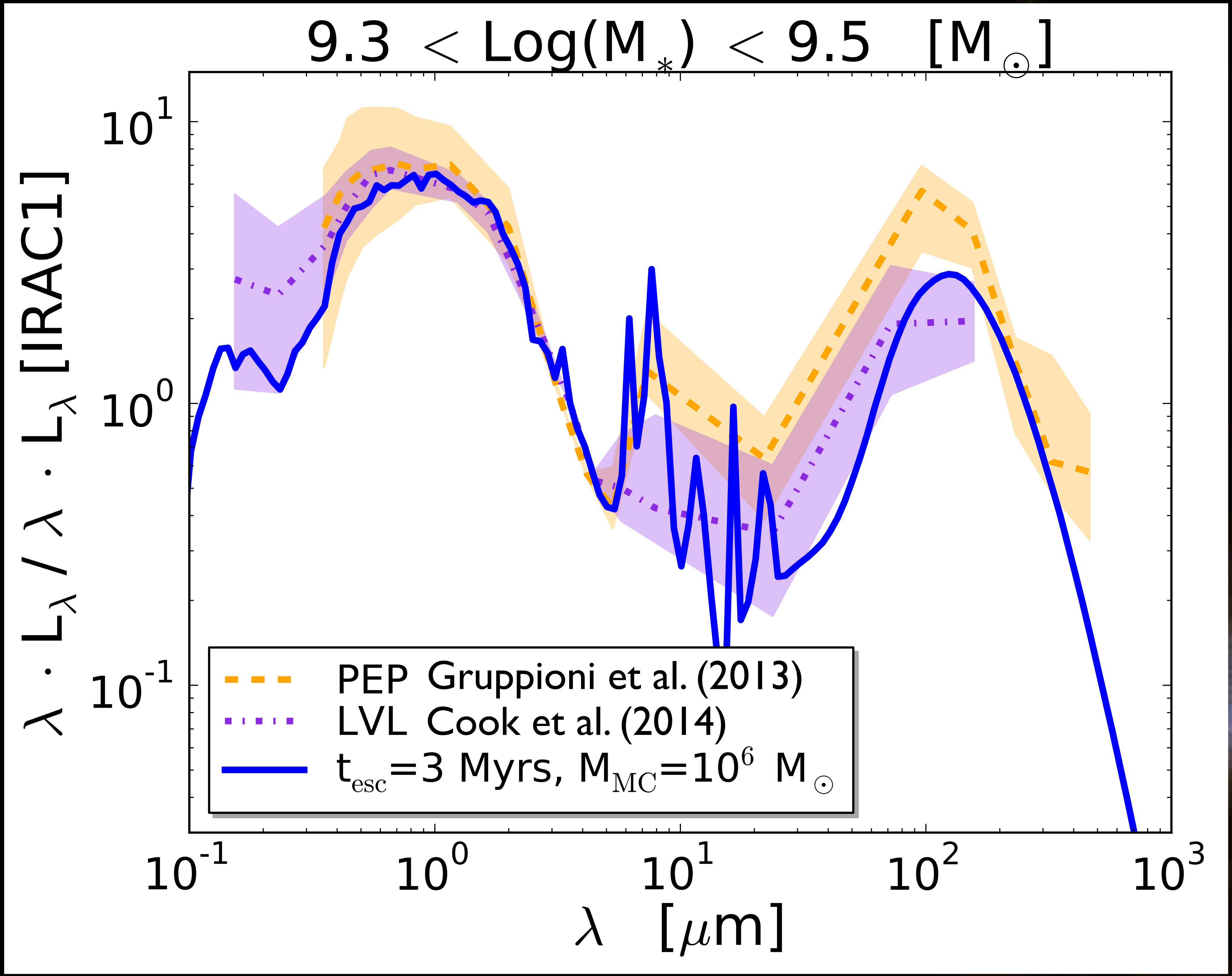
Panchromatic SEDs normalized at 3.6 μm



Panchromatic SEDs normalized at 3.6 μm



Panchromatic SEDs normalized at 3.6 μm



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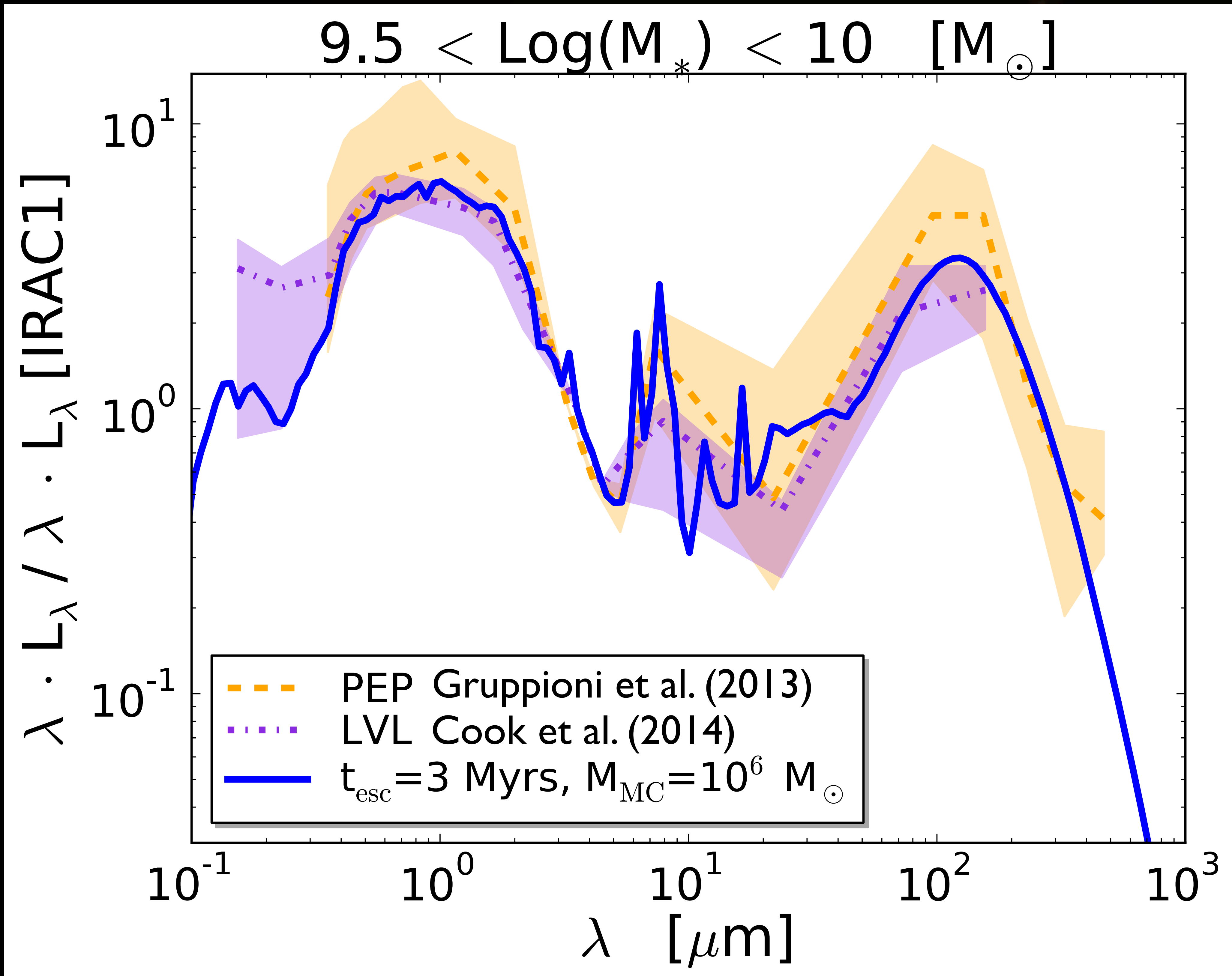

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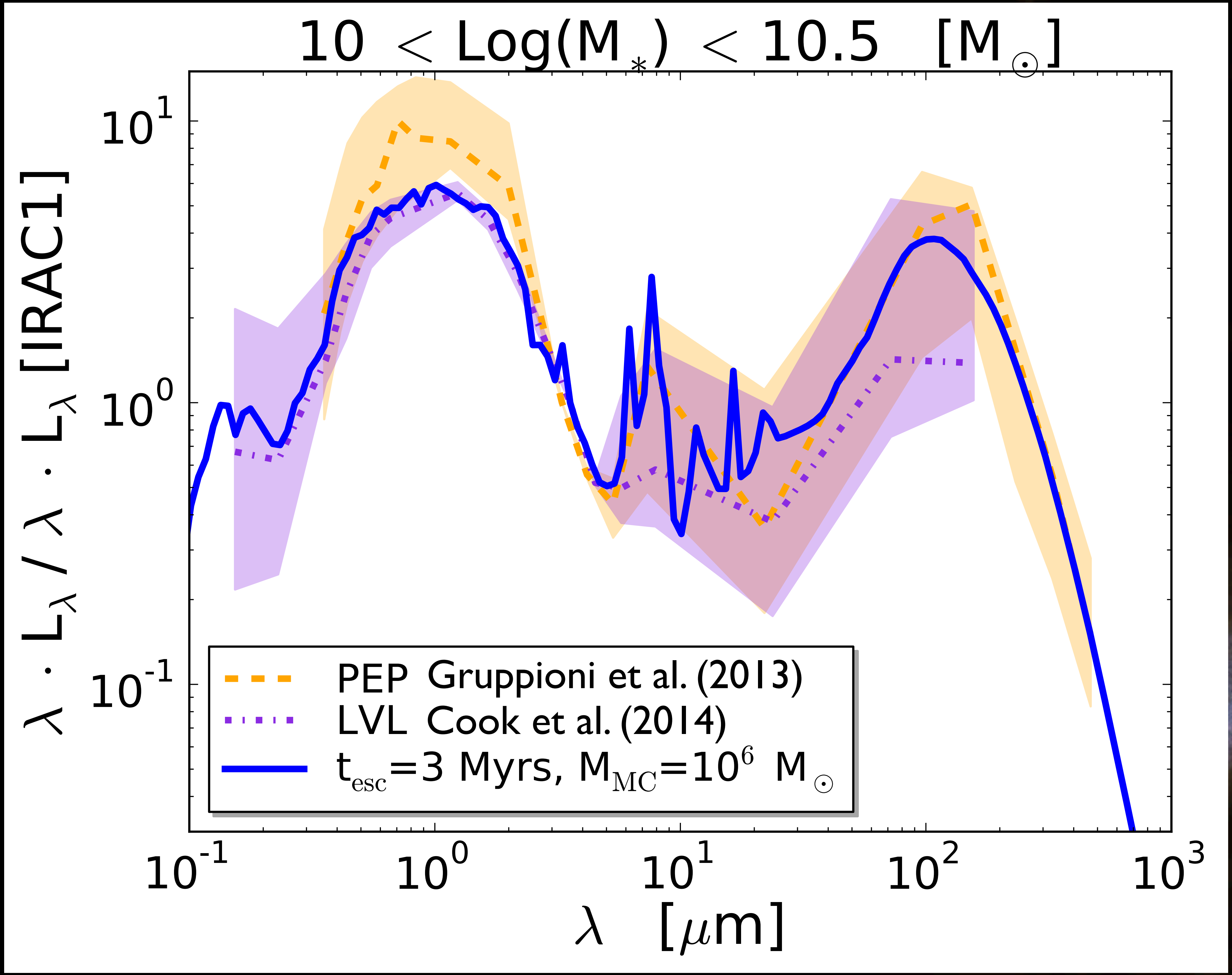
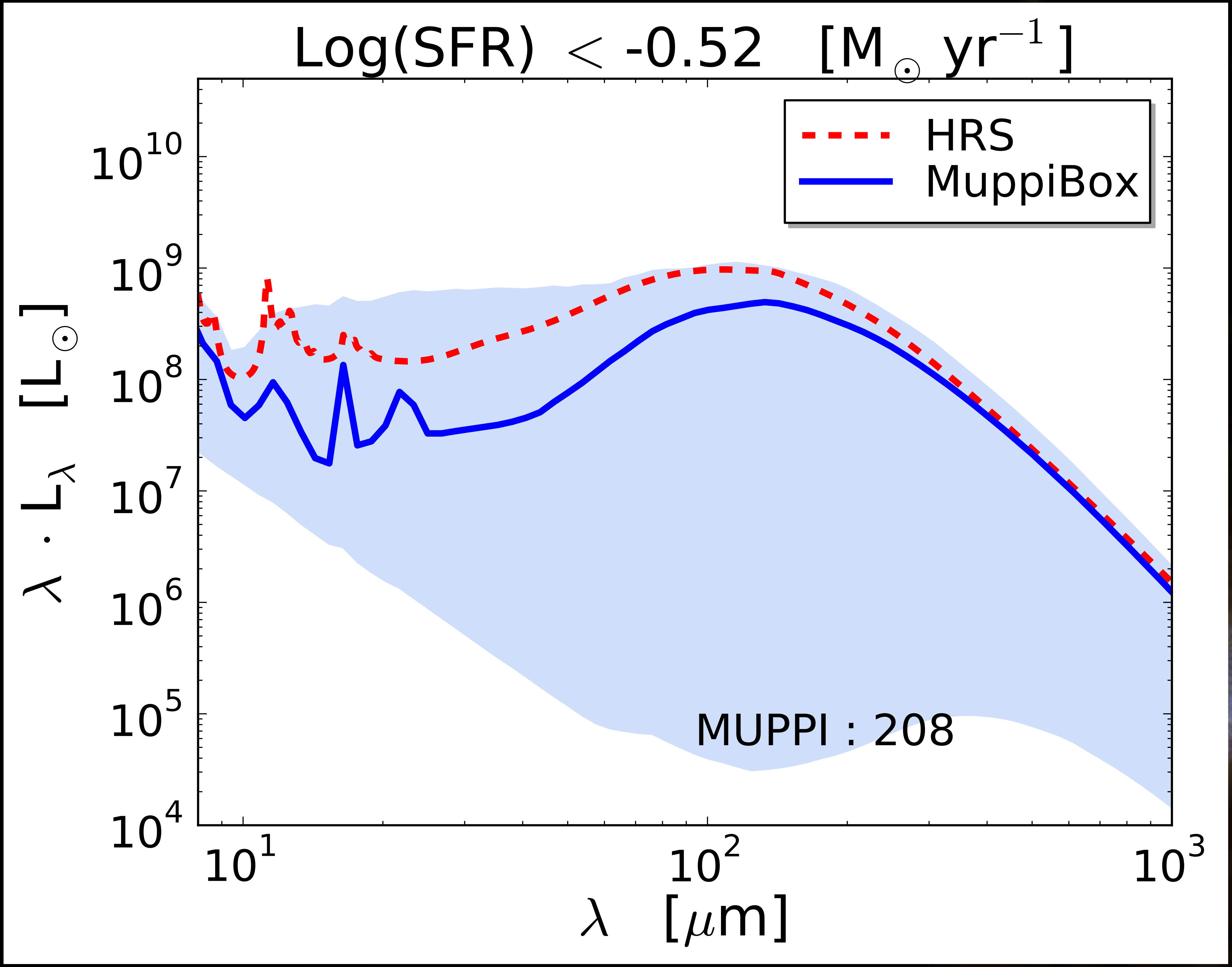


Comparison with Herschel Reference Survey



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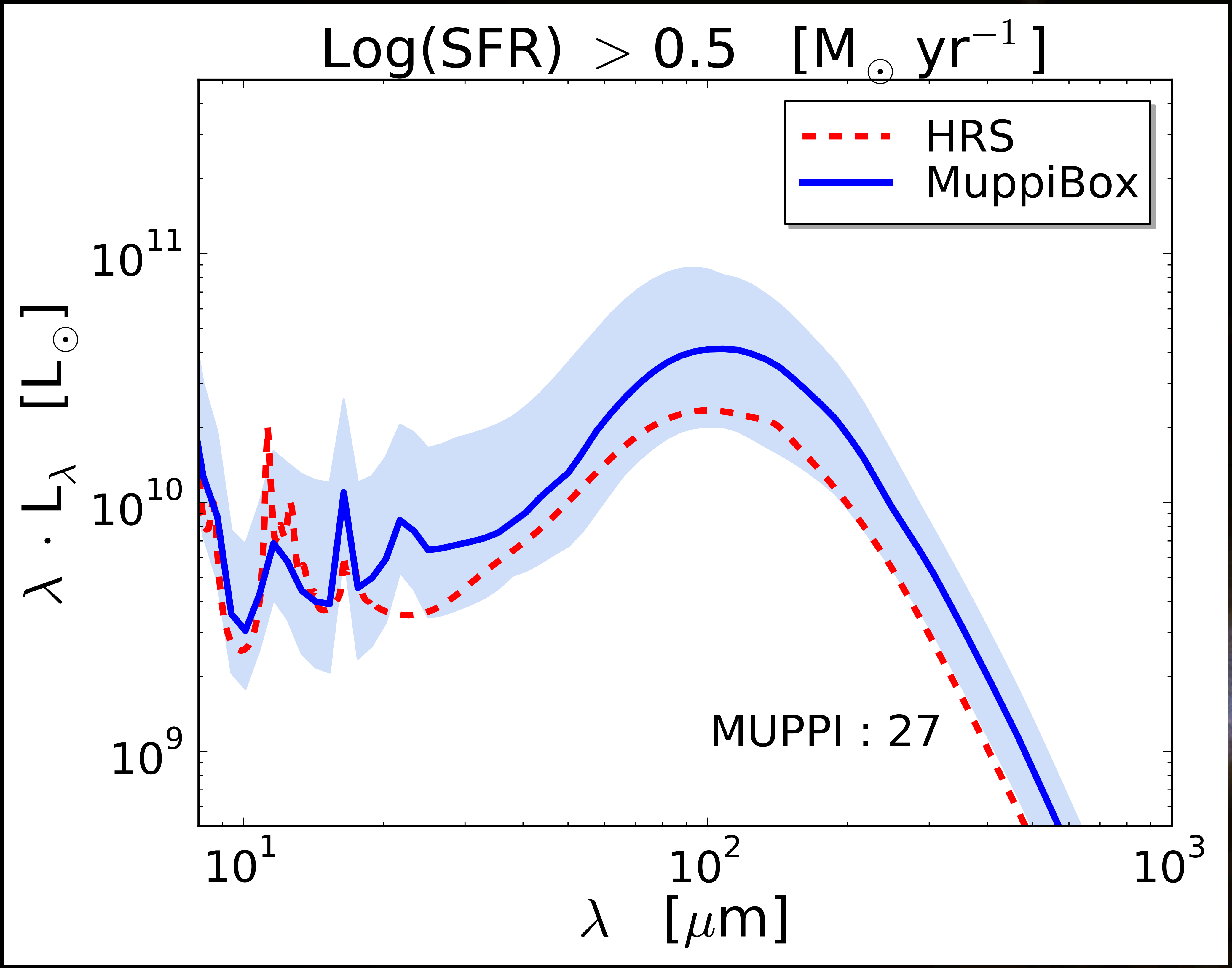

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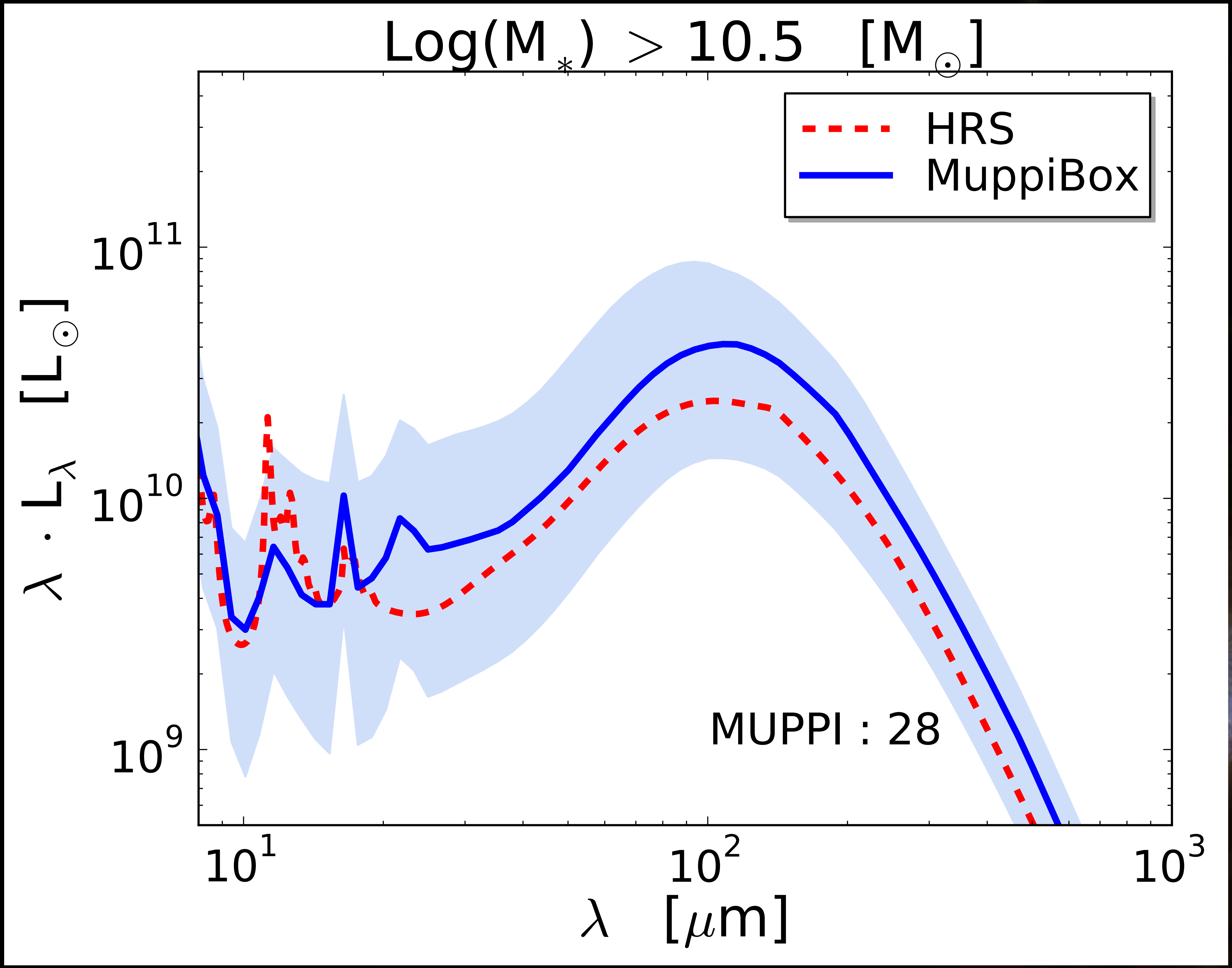
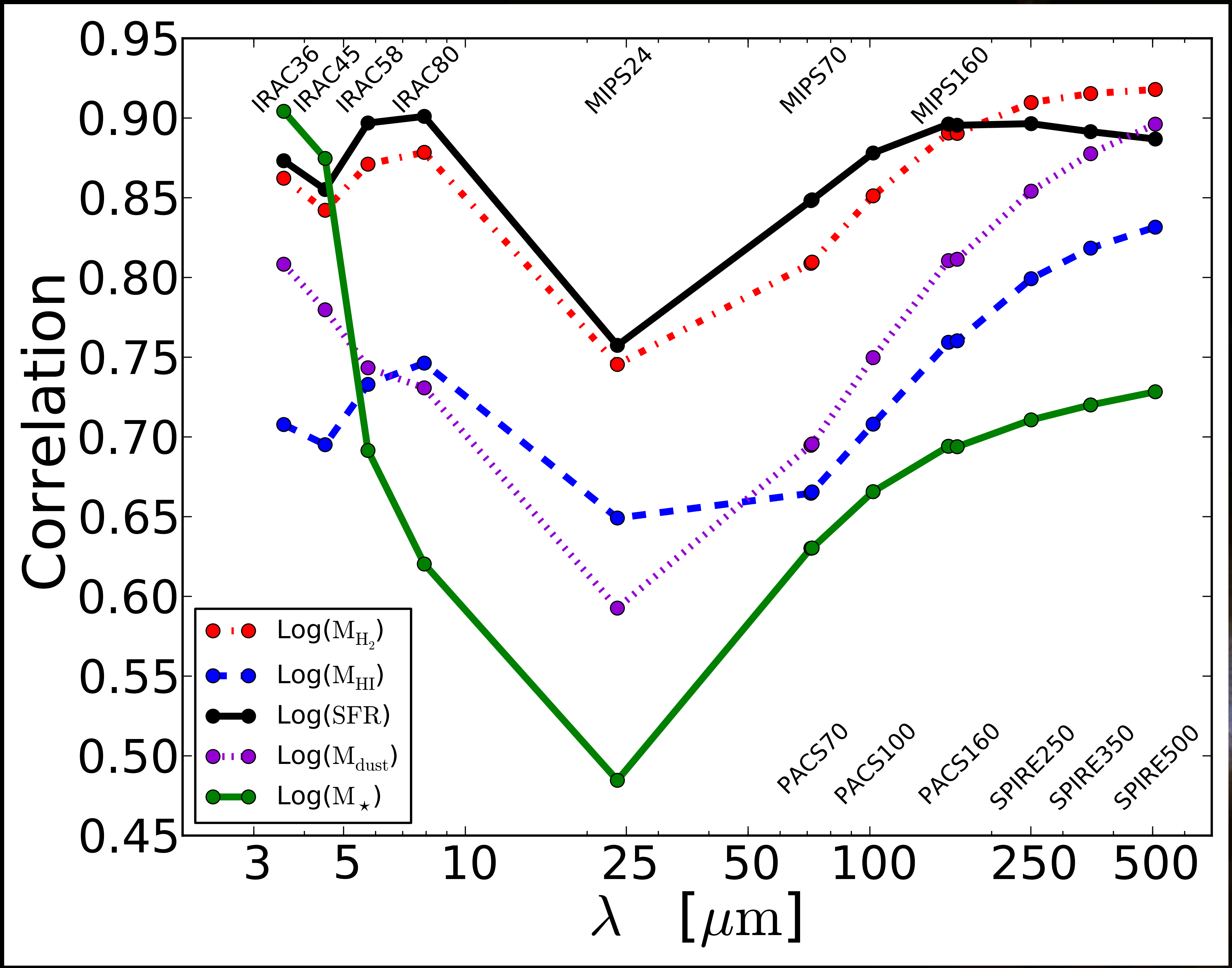


Correlation coefficient of IR light with galaxy properties



P. Monaco, SPICA-Safari Italian meeting, 4-5 April 2016

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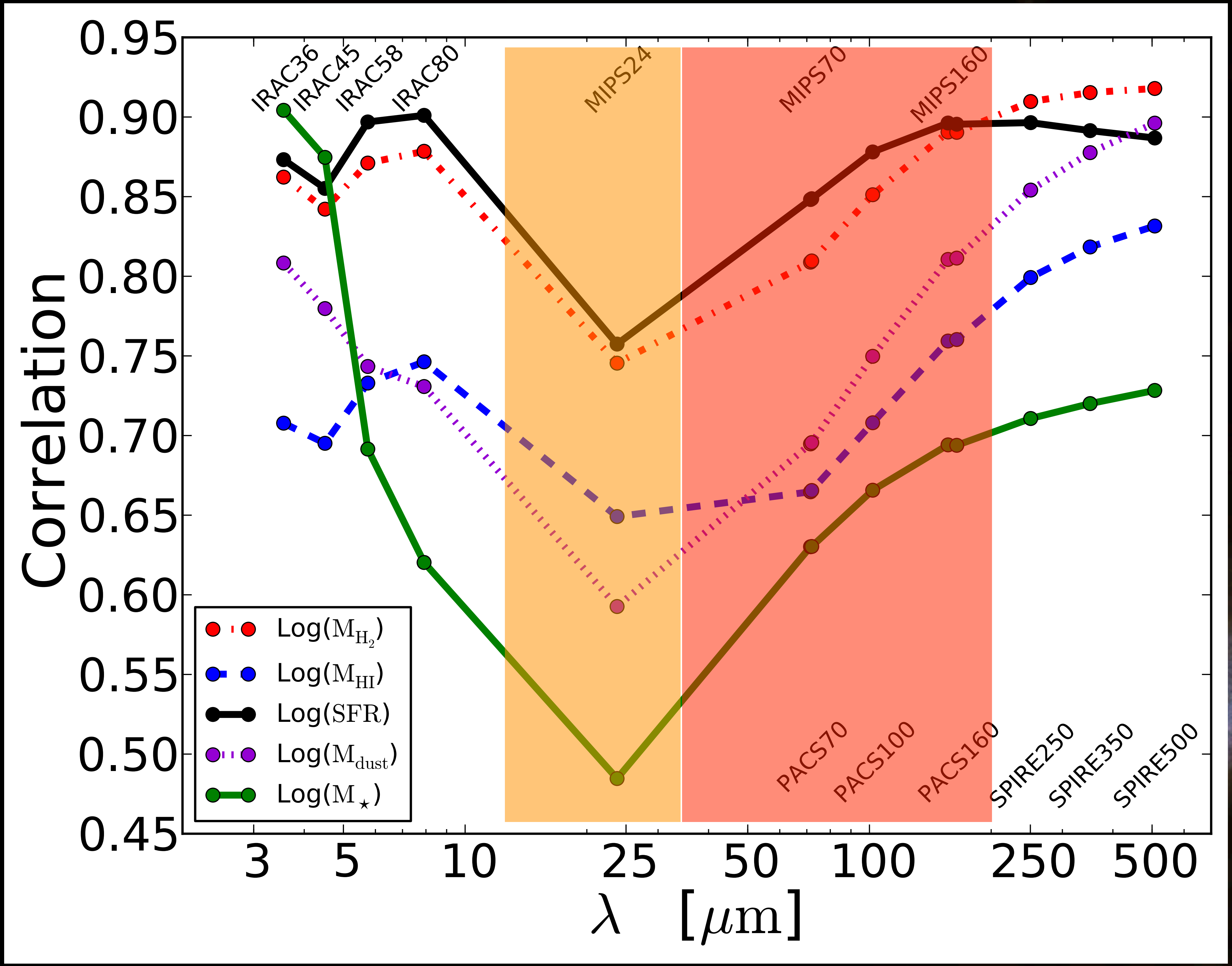
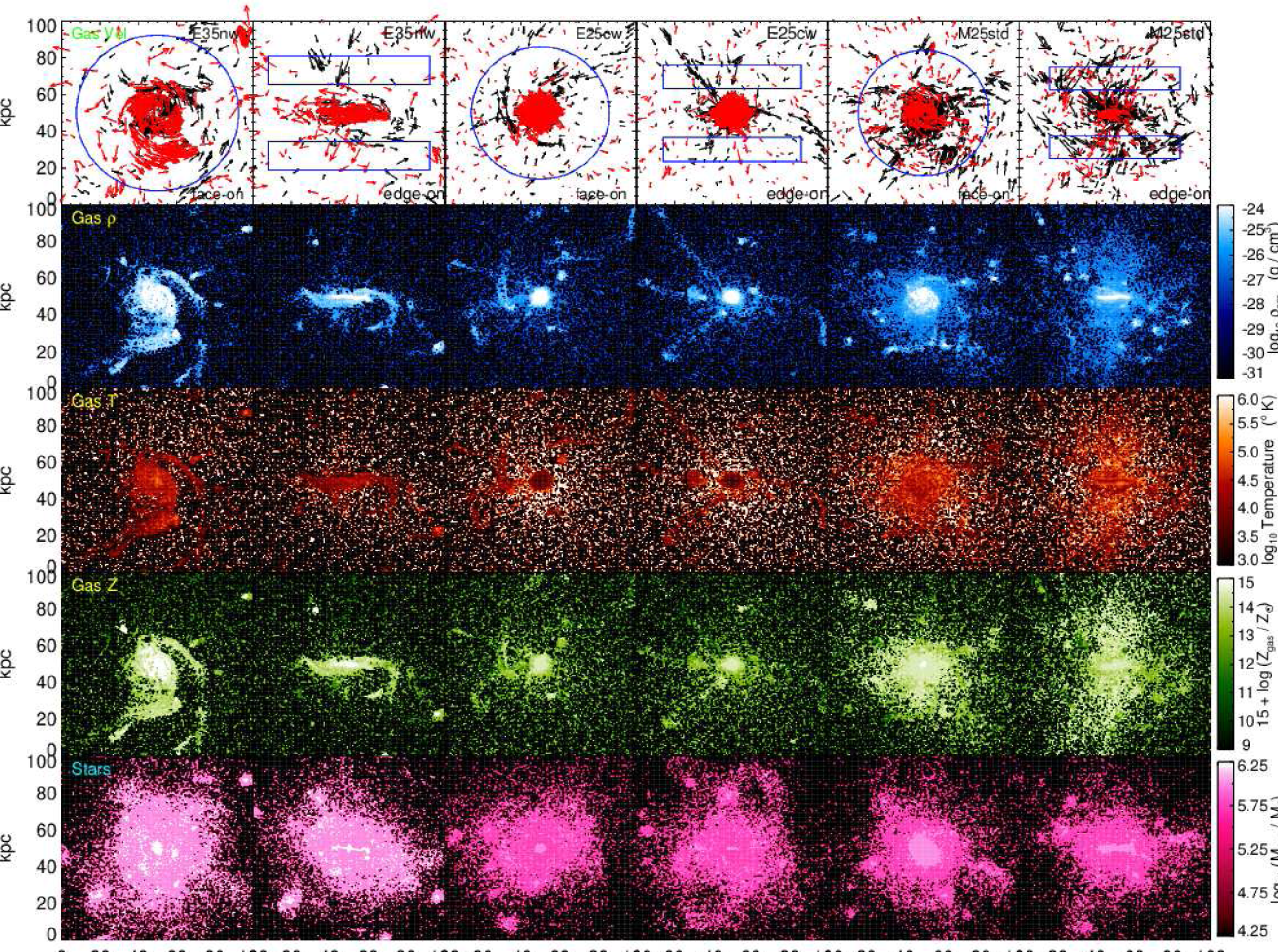
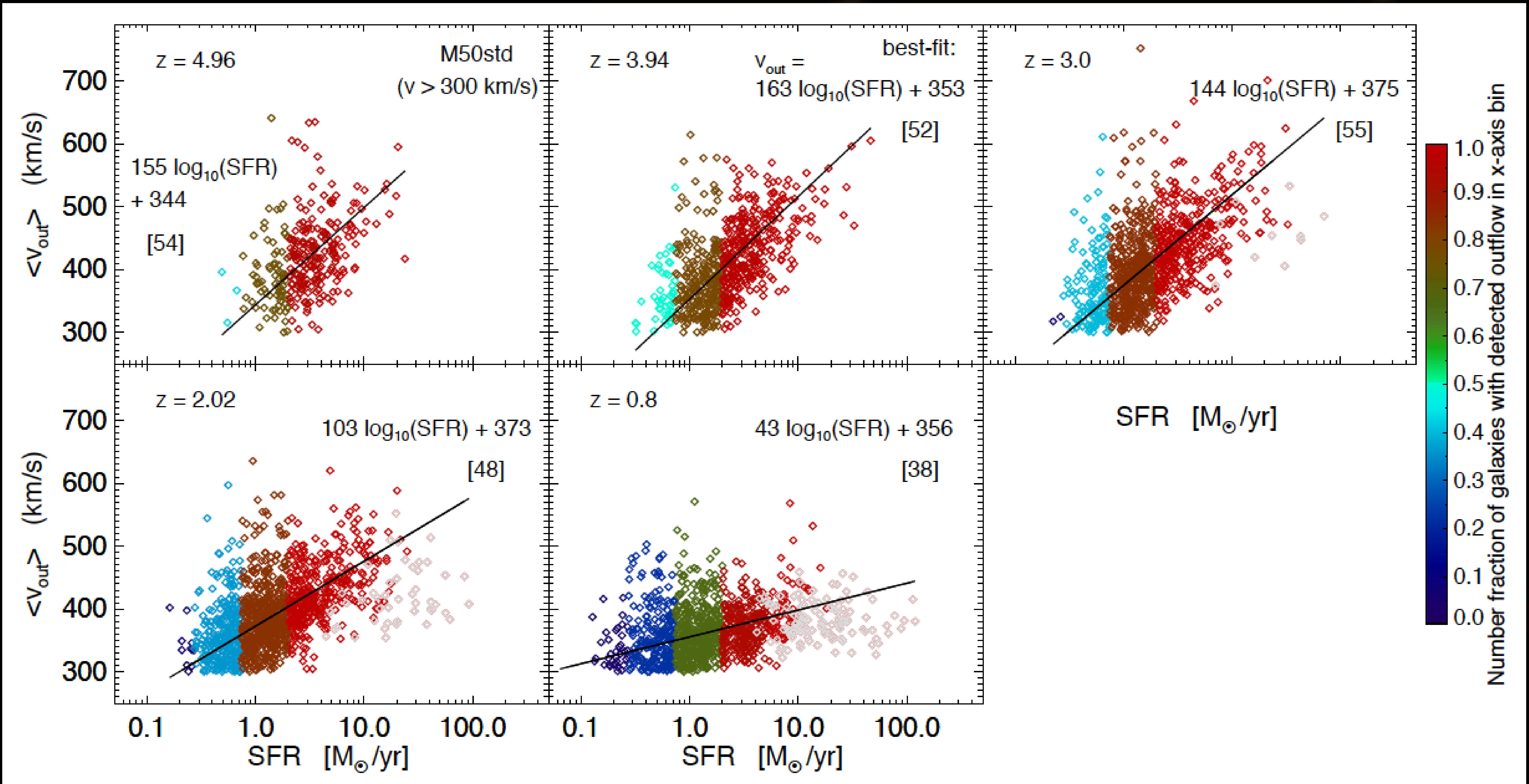




Gas Vel
E35nw
E35nw
E25cw
E25cw
M25std
M25std
face-on
edge-on
face-on
edge-on
face-on
edge-on
Gas ρ
Gas T
Gas Z
Stars
kpc
$\log_{10} \rho_{gas}$ (g / cm^3)
$\log_{10}$ Temperature (° K)
15 + log (Z_{gas} / $Z_\odot$)

Barai et al. (2015): Redshift Evolution of Outflow Velocity vs SFR



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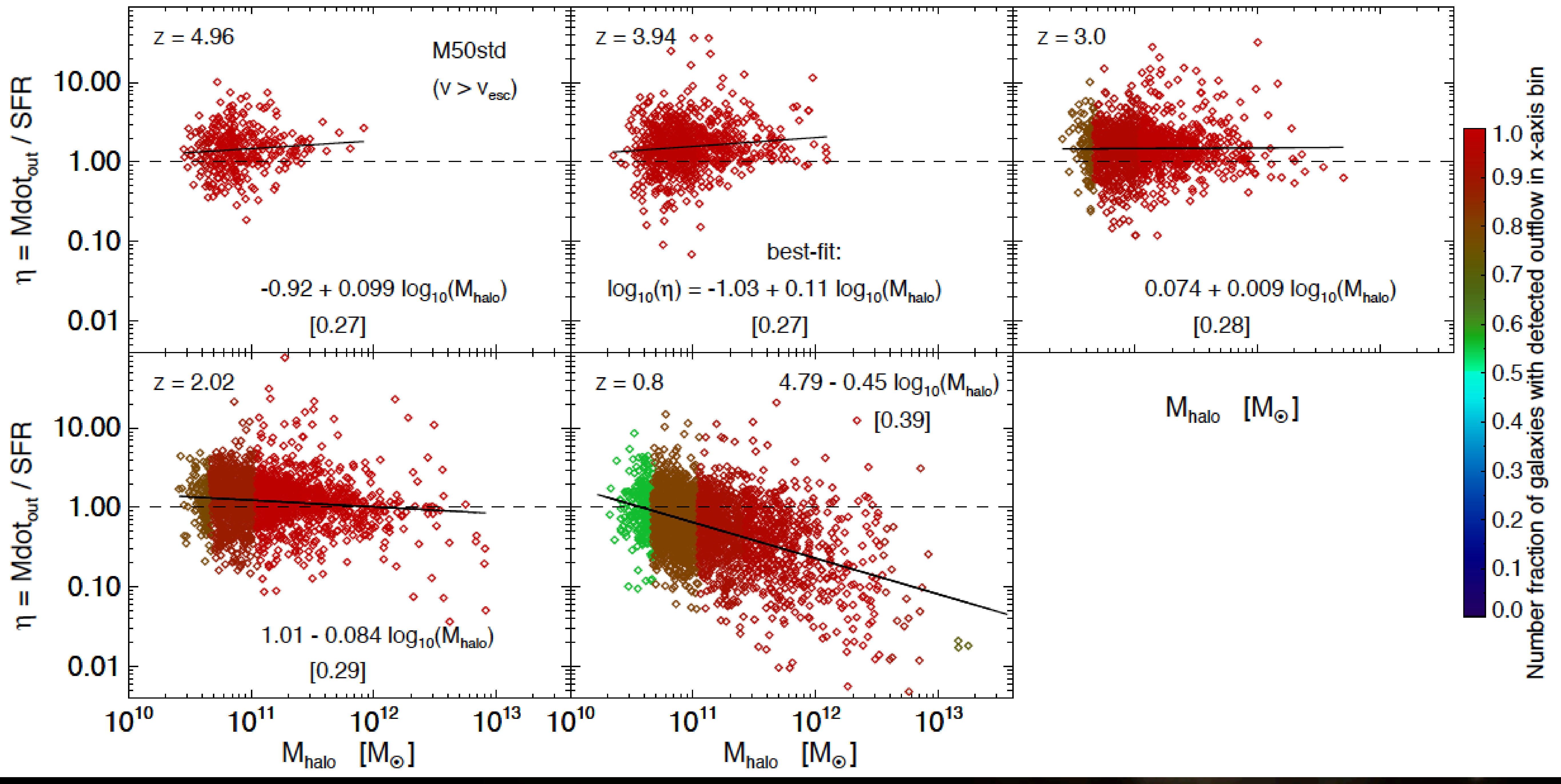
Redshift Evolution of Mass-Loading factor vs Halo Mass



How can we “measure” these outflows through gas lines?

Approximate procedure

Choose the three box axes as three (random) lines of sight

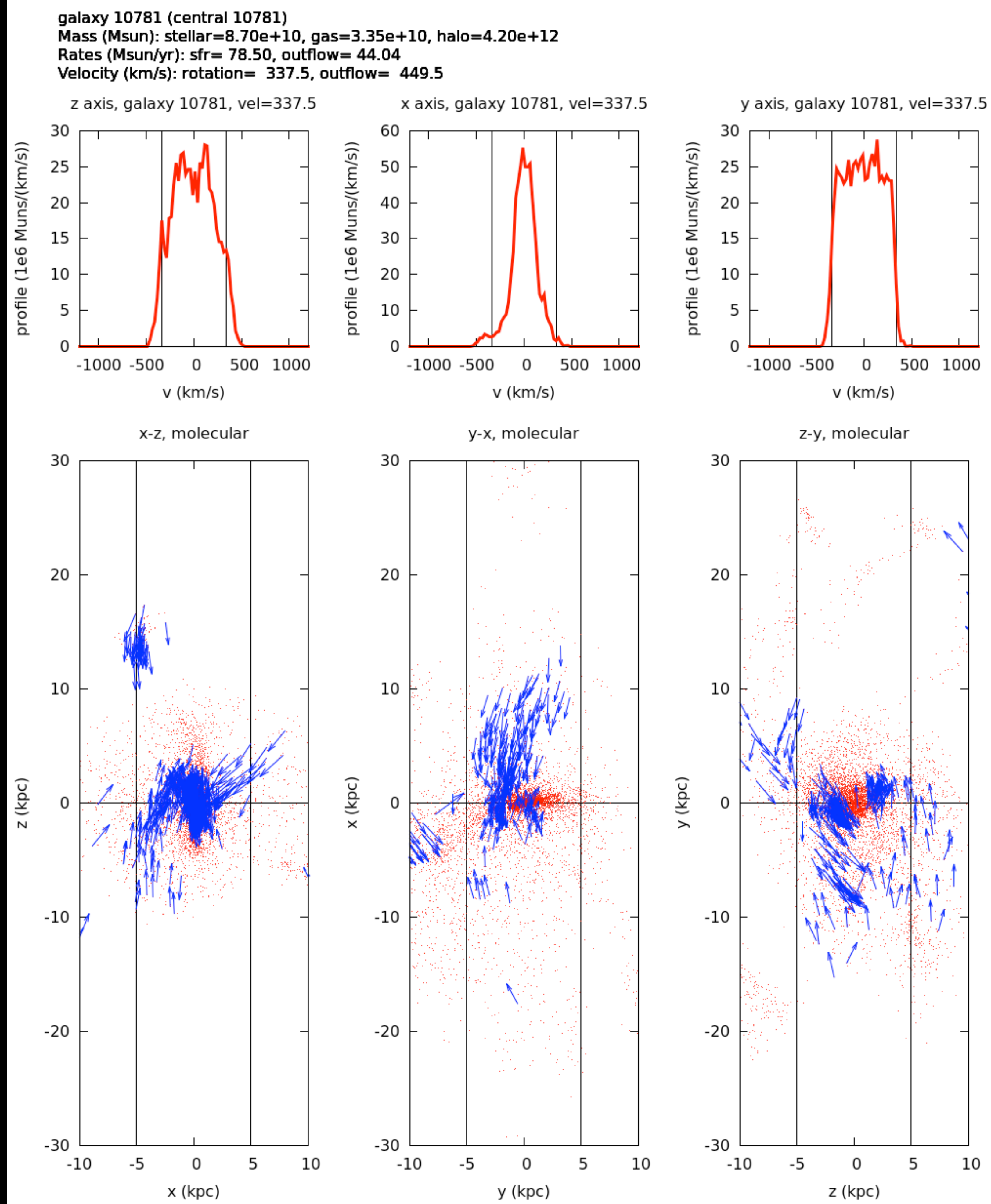
Select gas particles that would contribute to some line

- molecular phase of MP particles → molecular emission lines
- warm (<10^5 K) single-phase particles → atomic absorption lines

Draw histogram of velocities

- across the galaxy for molecular emission lines
- on one side of the galaxy for atomic absorption lines

Red: multi-phase particles
Blue: velocity of "fast" particles

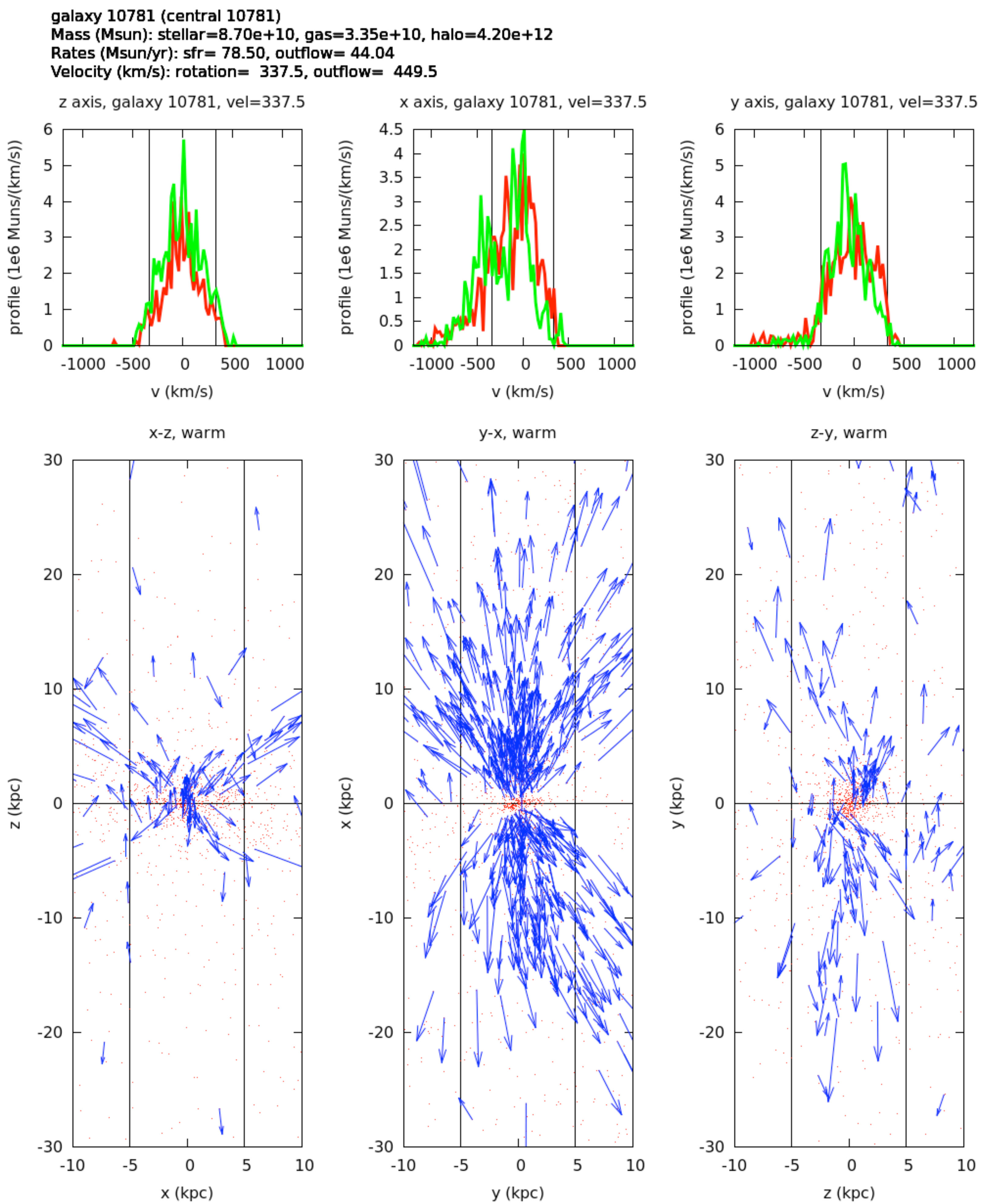


line of sight

molecular emission lines

Bologna, 2015

Red: single-phase particles
Blue: velocity of "fast" particles



line of sight

atomic absorption lines

Bologna, 2015

Open for collaboration with SPICA

Our tools for predicting galaxy populations:

- semi-analytic models
- hydro simulations (of small volumes)
- GRASIL and GRASIL-3D

We can provide:

- mock catalogs with multi-band photometry
- light cones (mostly from SAMs)
- resolved properties of galaxies (simulations)

We must improve in:

- sub-resolution modeling of the molecular phase (D. Goz, U. Maio, P. Di Cerbo et al., work in progress)
- modeling of emission lines