Modelling the molecular content in galaxy formation simulations

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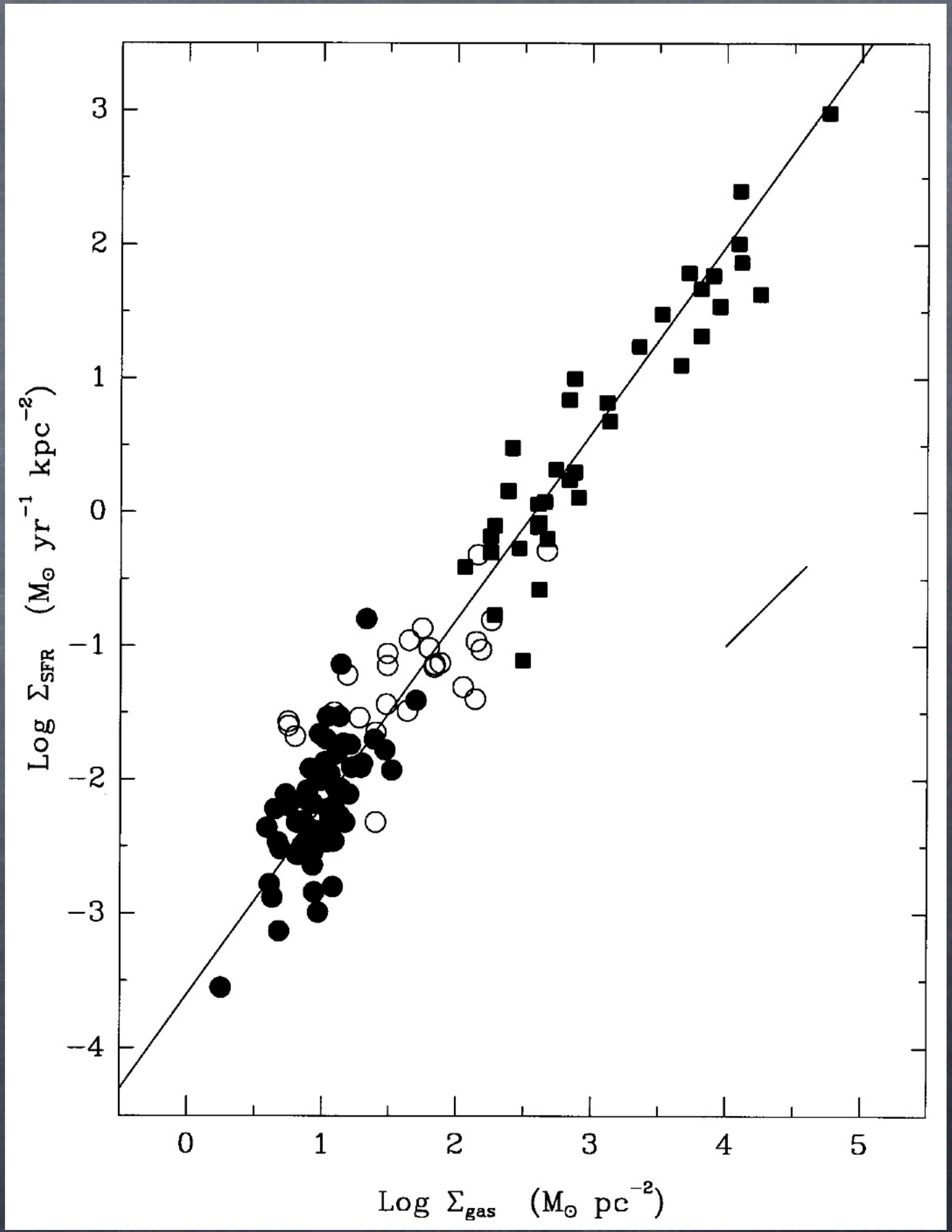
Star Formation

- Kennicutt-Schmidt (K-S) relation

$$\Sigma_{SFR} \propto \Sigma_{gas}^{n}$$

- n = 1.4
- => systems with high average gas surface densities more efficiently convert gas into stars.



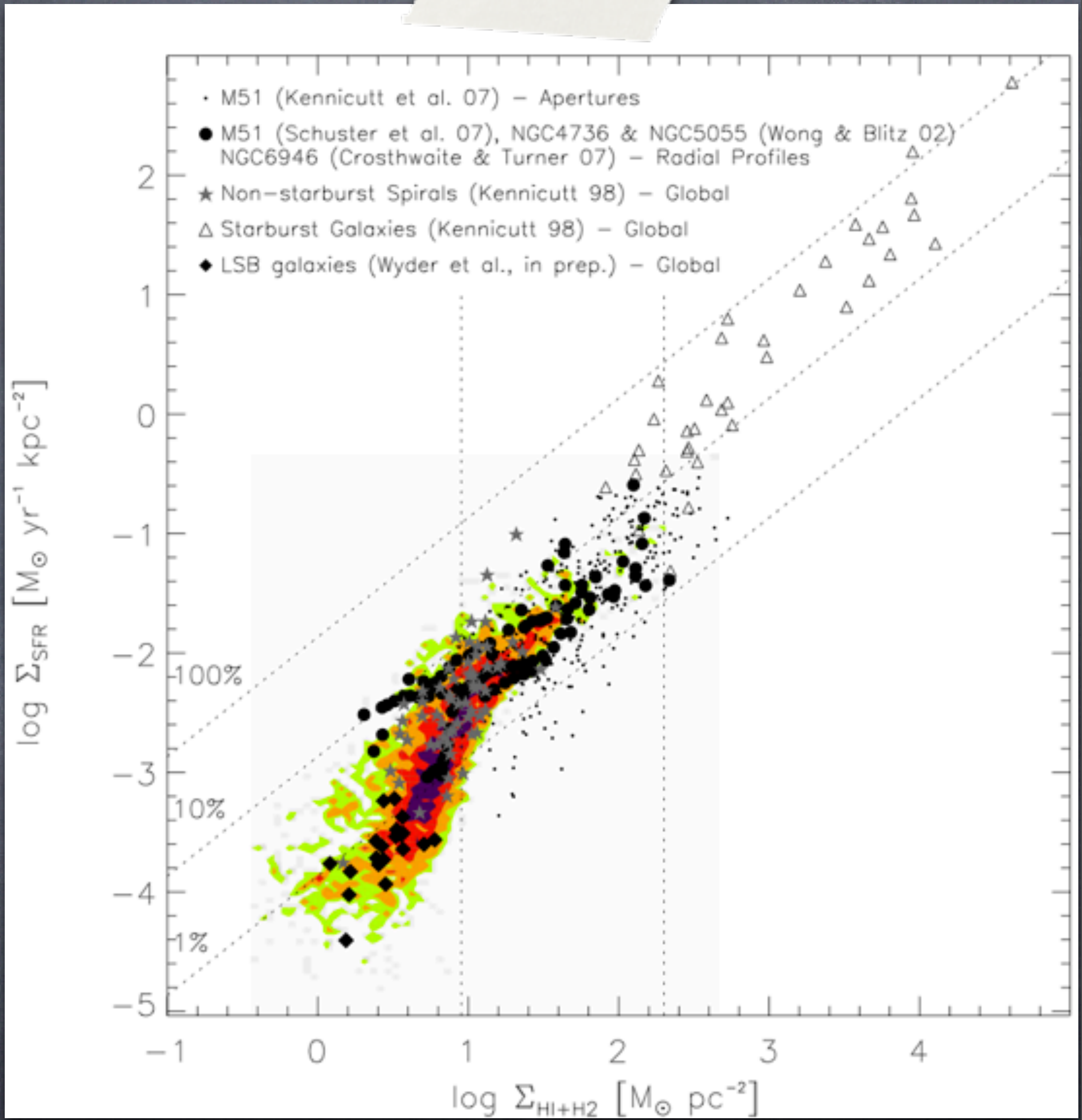
Kennicutt 98

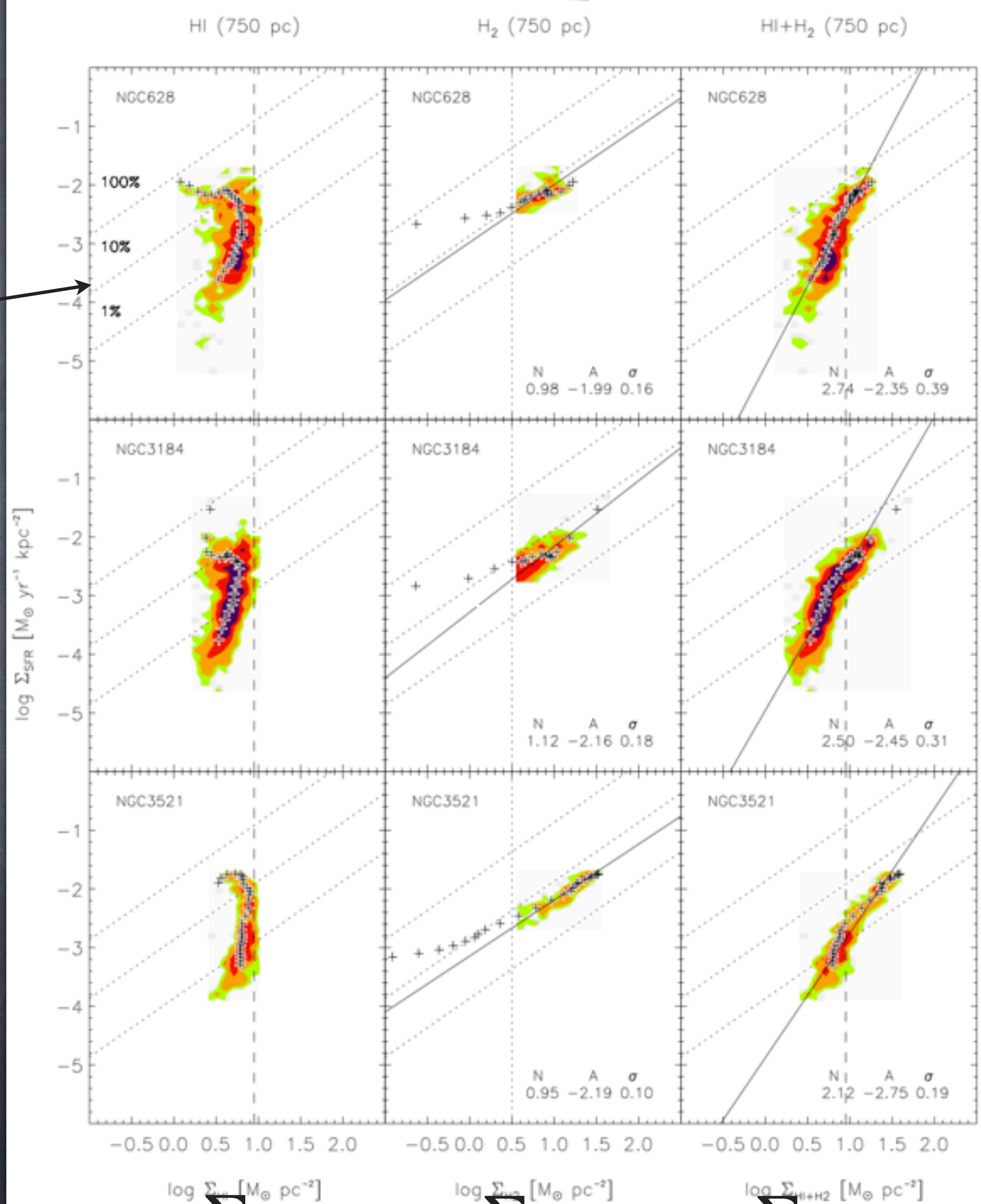
However...

- multi-wavelength maps show discrepancies (Bigiel +2008, Leroy+2010, etc)

- Σ_{H2} traced by CO intensity the X-factor

$$X = \frac{N_{H_2}}{W}$$

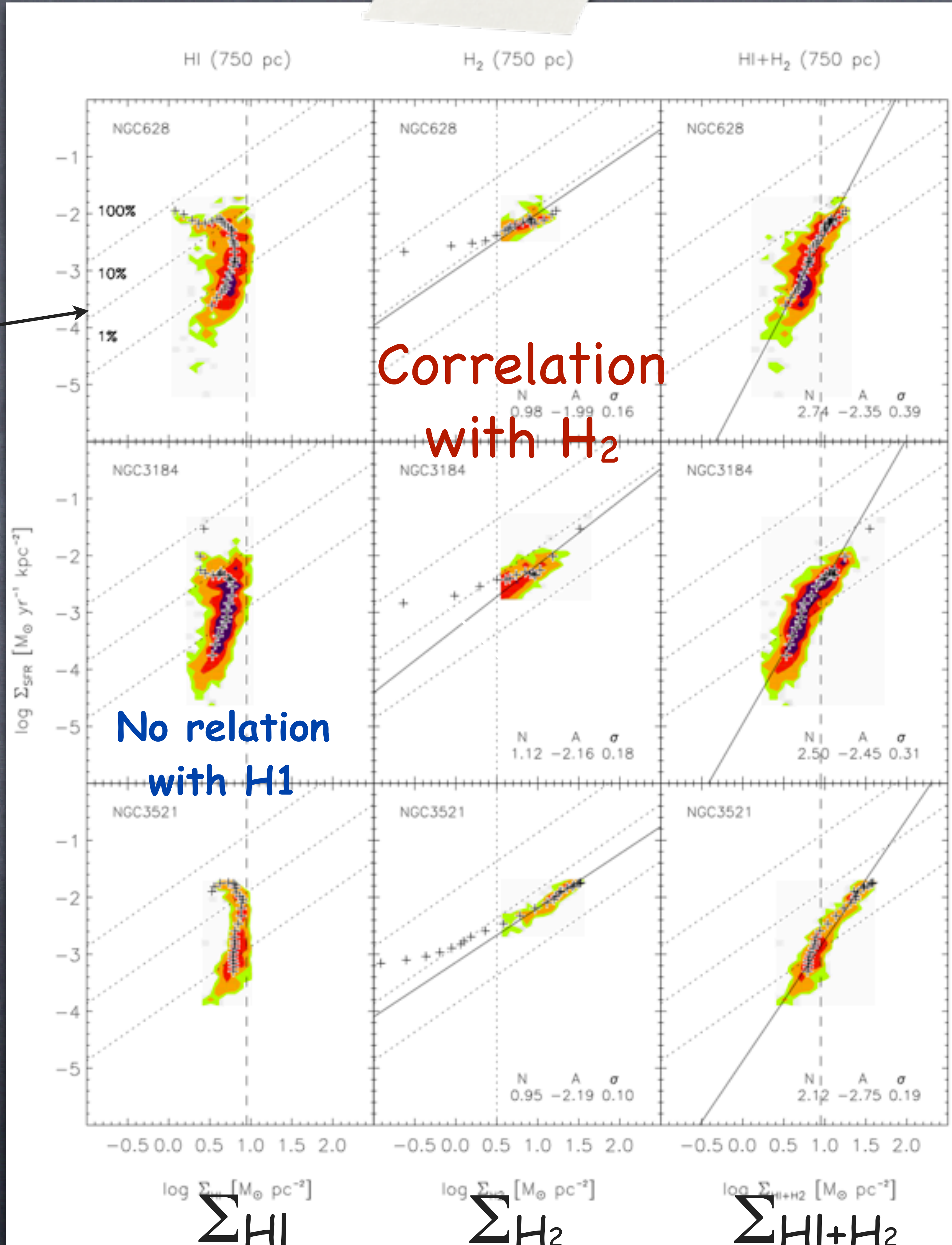




Σ_{HI} Σ_{H_2} Σ_{HI+H_2}

Bigiel+2010

Wednesday, June 20, 12



HI (750 pc)
H2 (750 pc)
HI+H2 (750 pc)
NGC628
NGC3184
NGC3521
100%
10%
1%
K-S
Correlation with H2
No relation with H1
N A σ
0.98 −1.99 0.16
2.74 −2.35 0.39
1.12 −2.16 0.18
2.50 −2.45 0.31
0.95 −2.19 0.10
2.12 −2.75 0.19
log ΣSFR [M⊙ yr⁻¹ kpc⁻²]
ΣHI
ΣH2
ΣHI+H2

Bigiel+2010

- Direct detections of molecules: CO, C+ (ALMA, mm and submm range)

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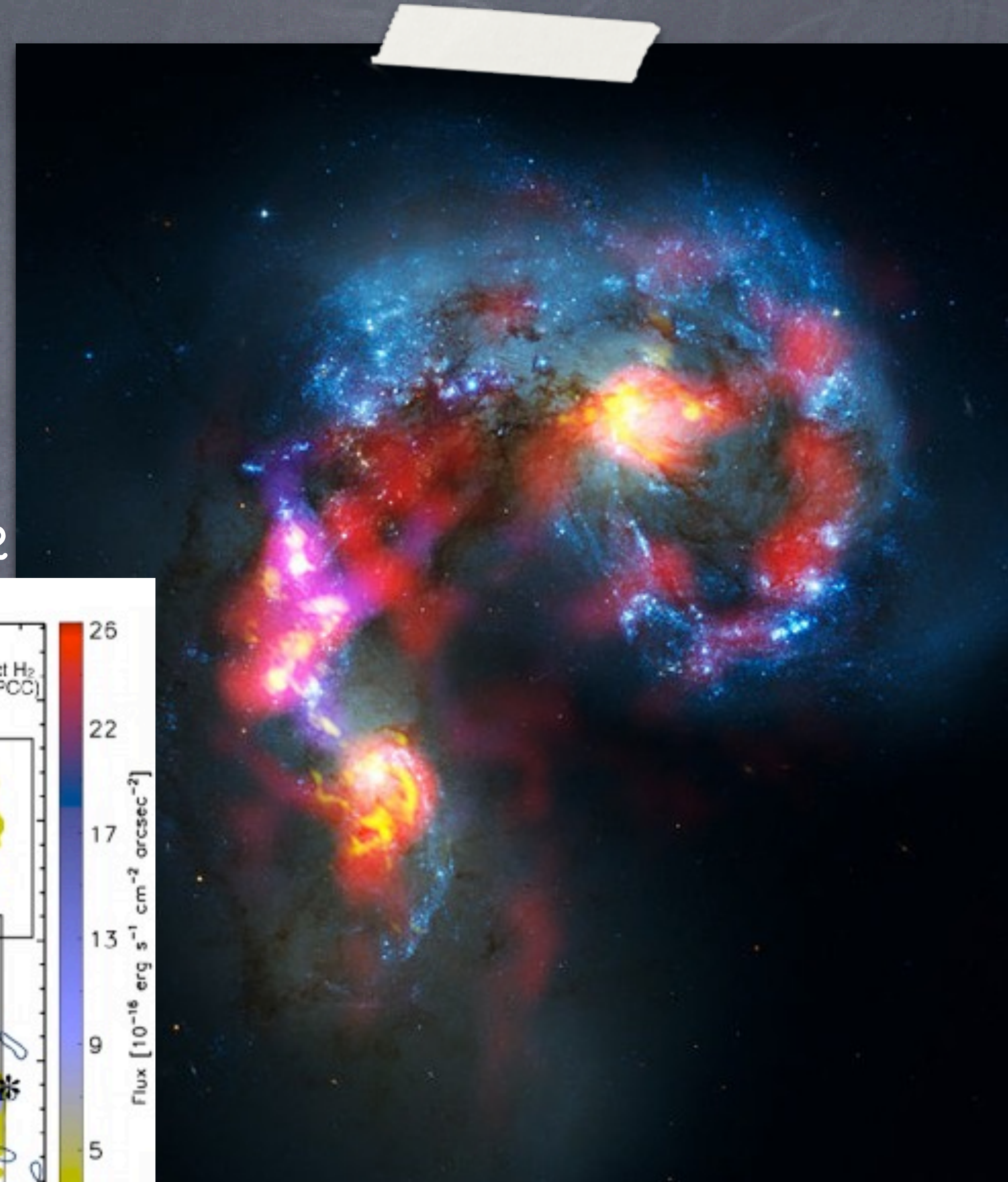
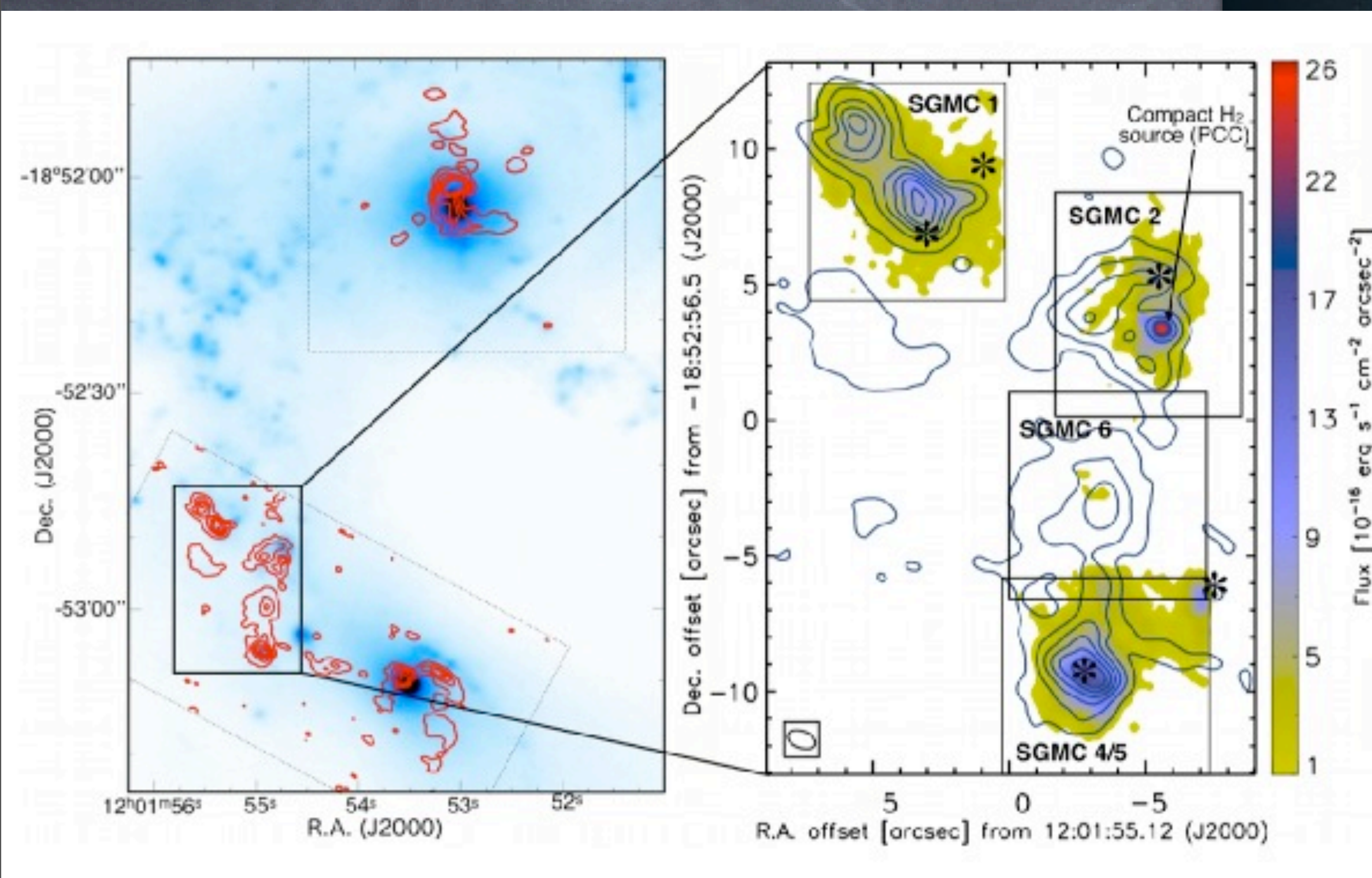
Herrera+2012





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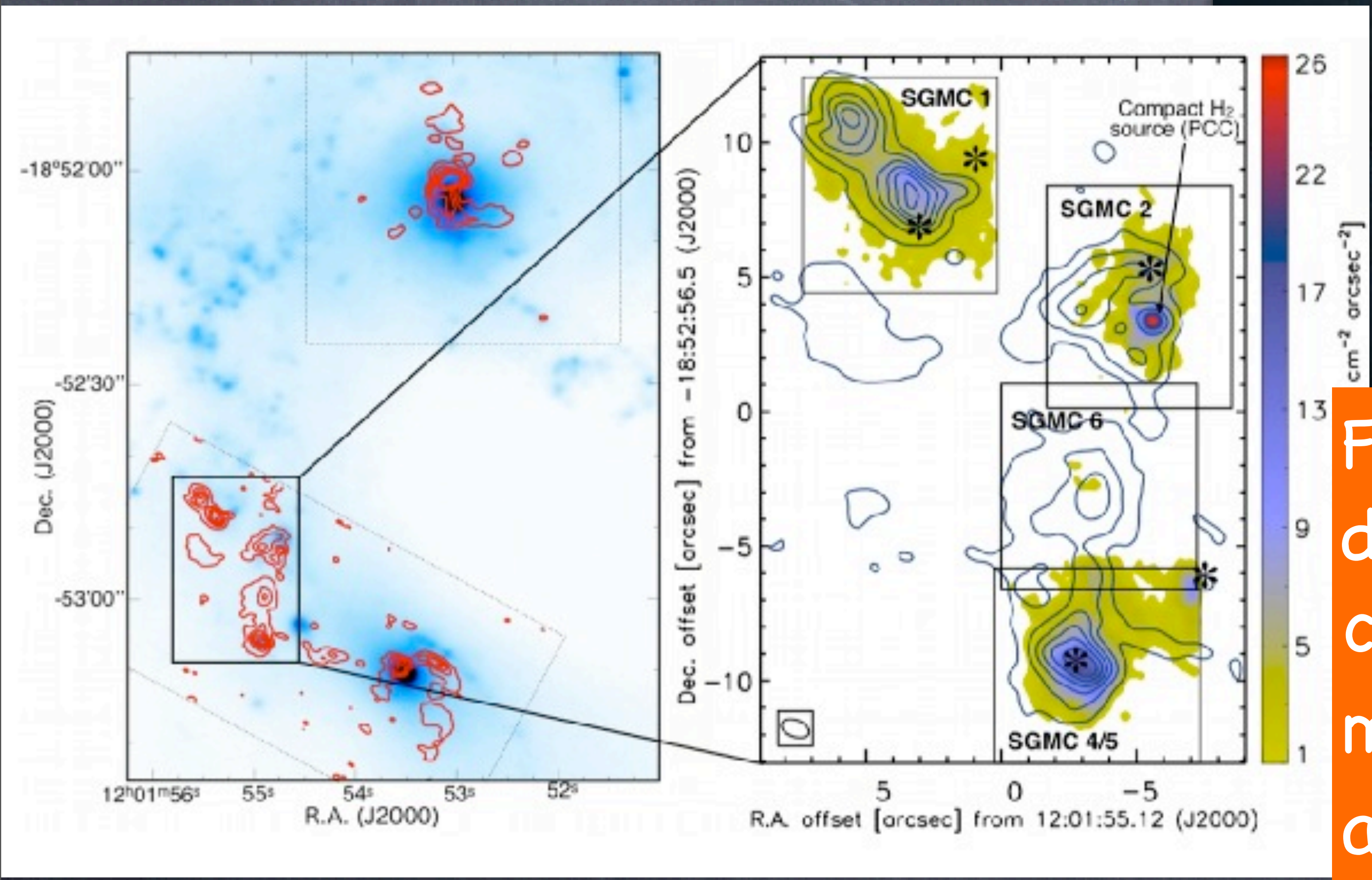

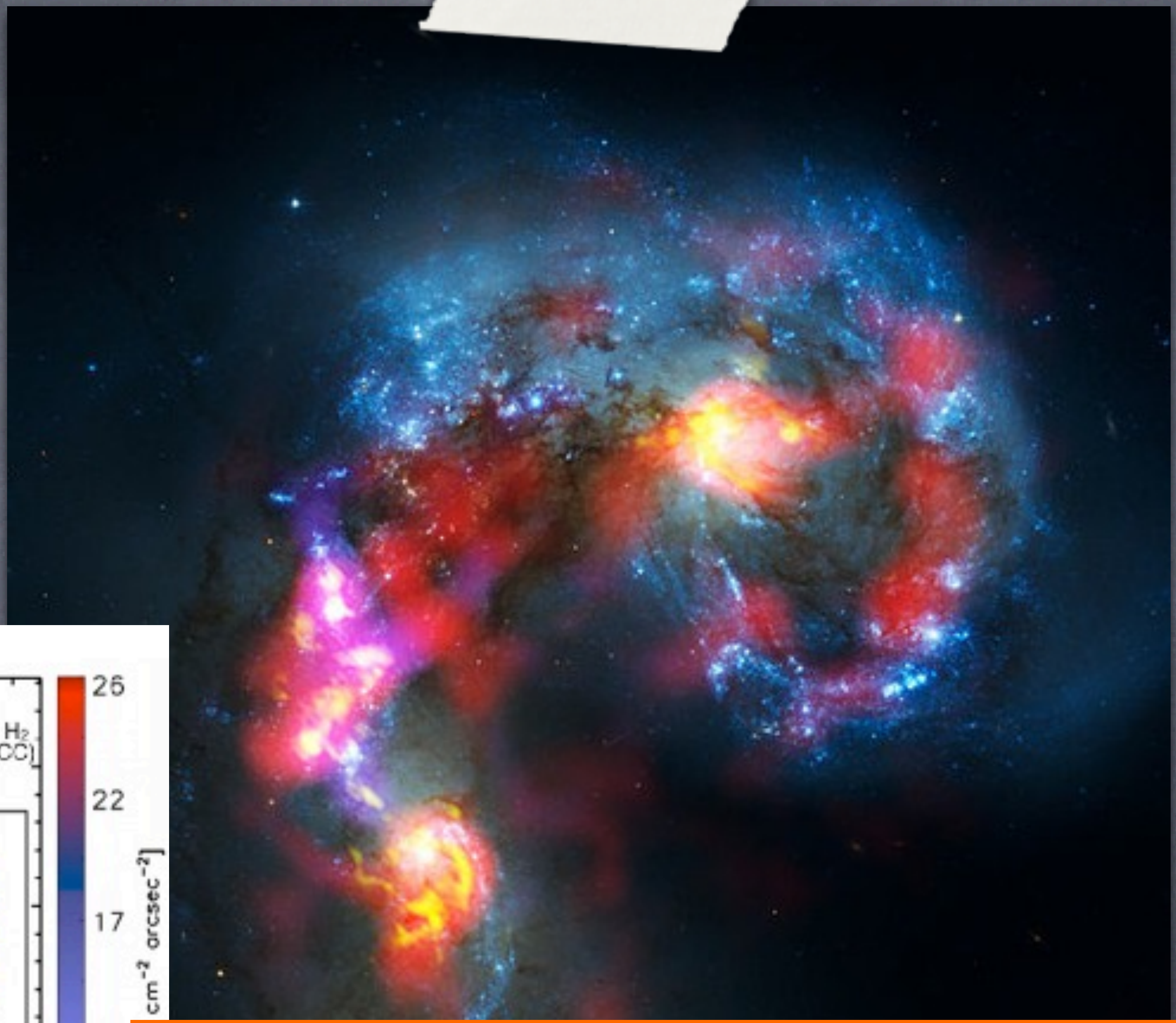

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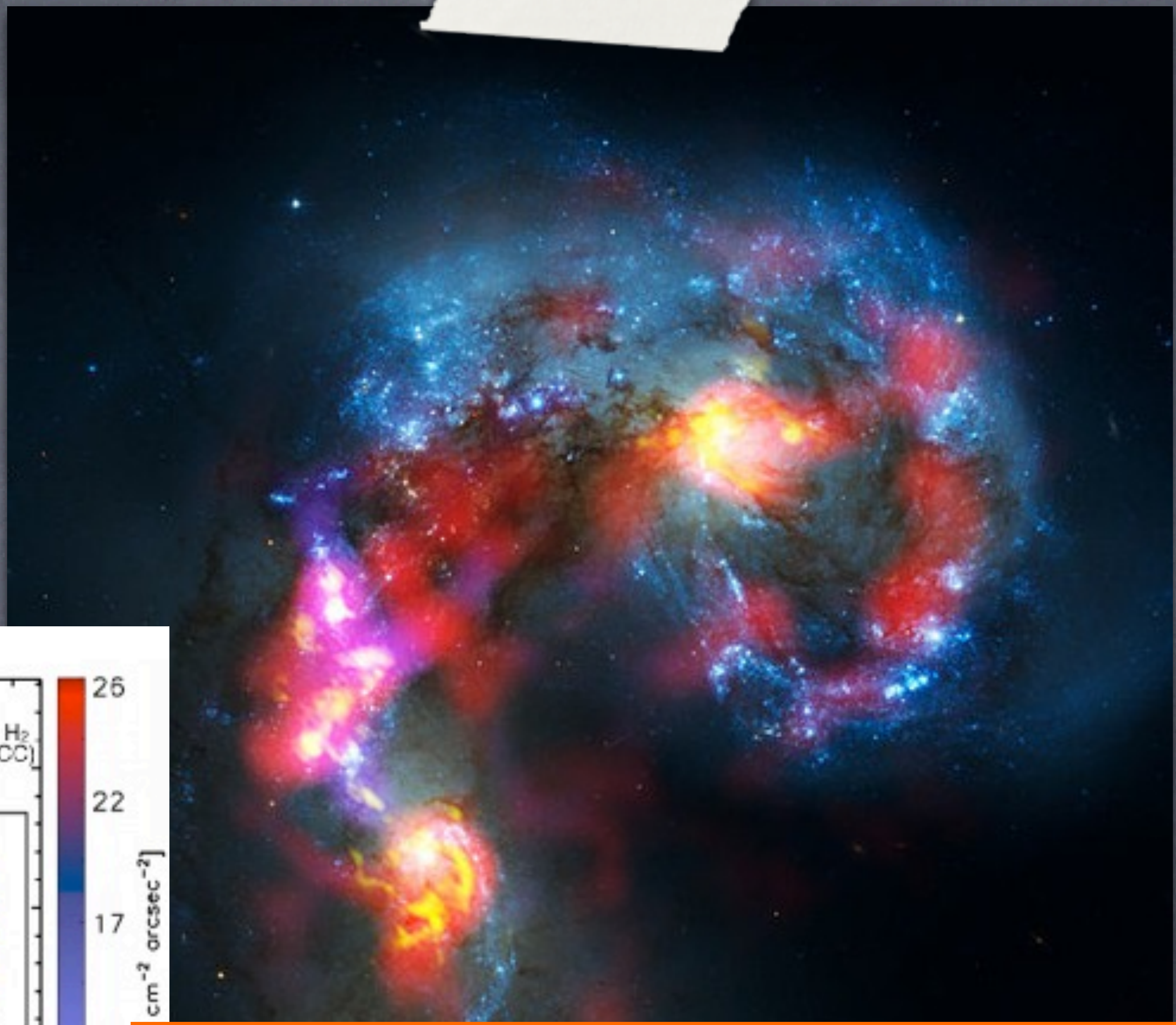

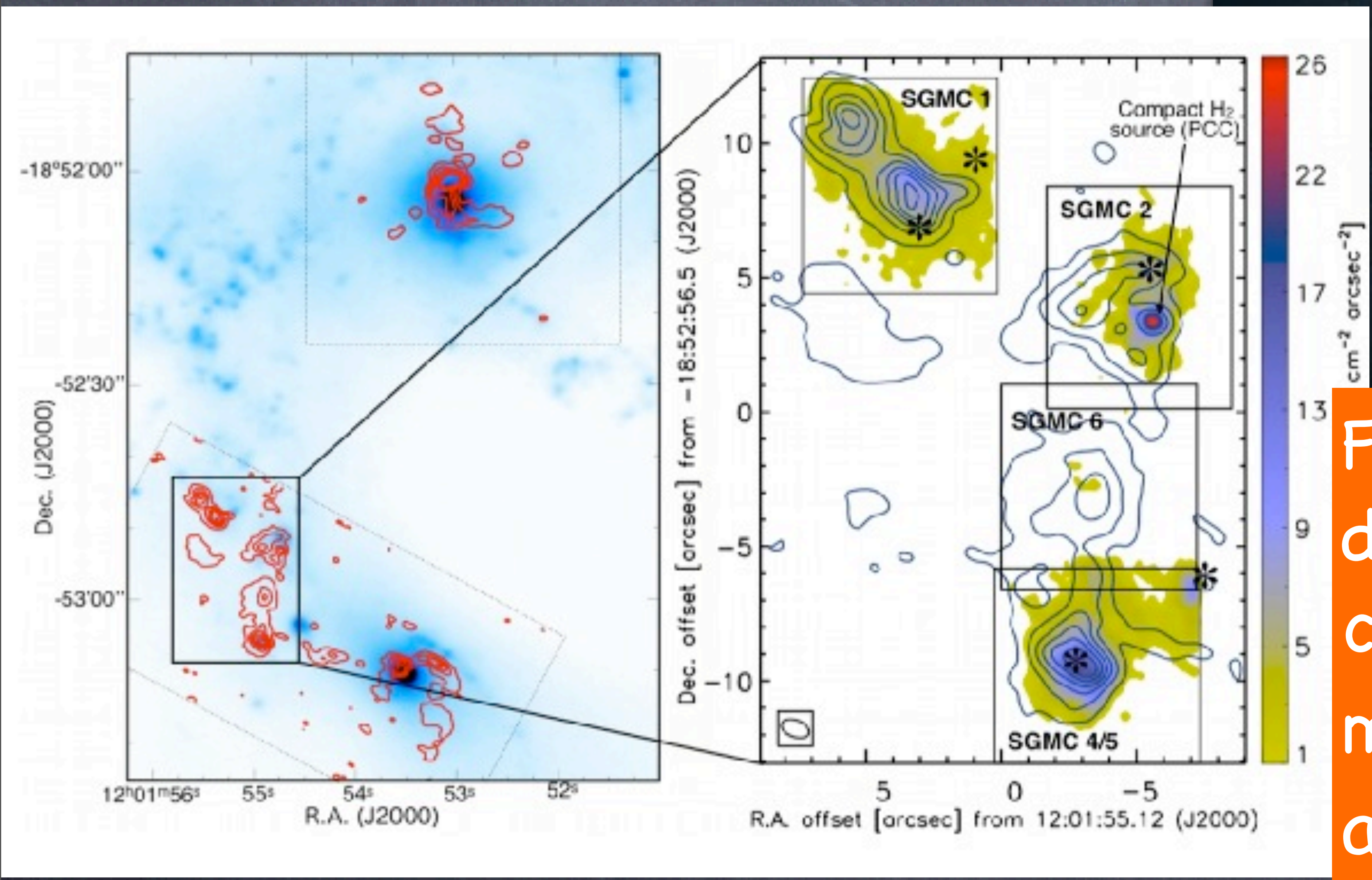

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(Glover+09,10)

But is this connection casual or causal?

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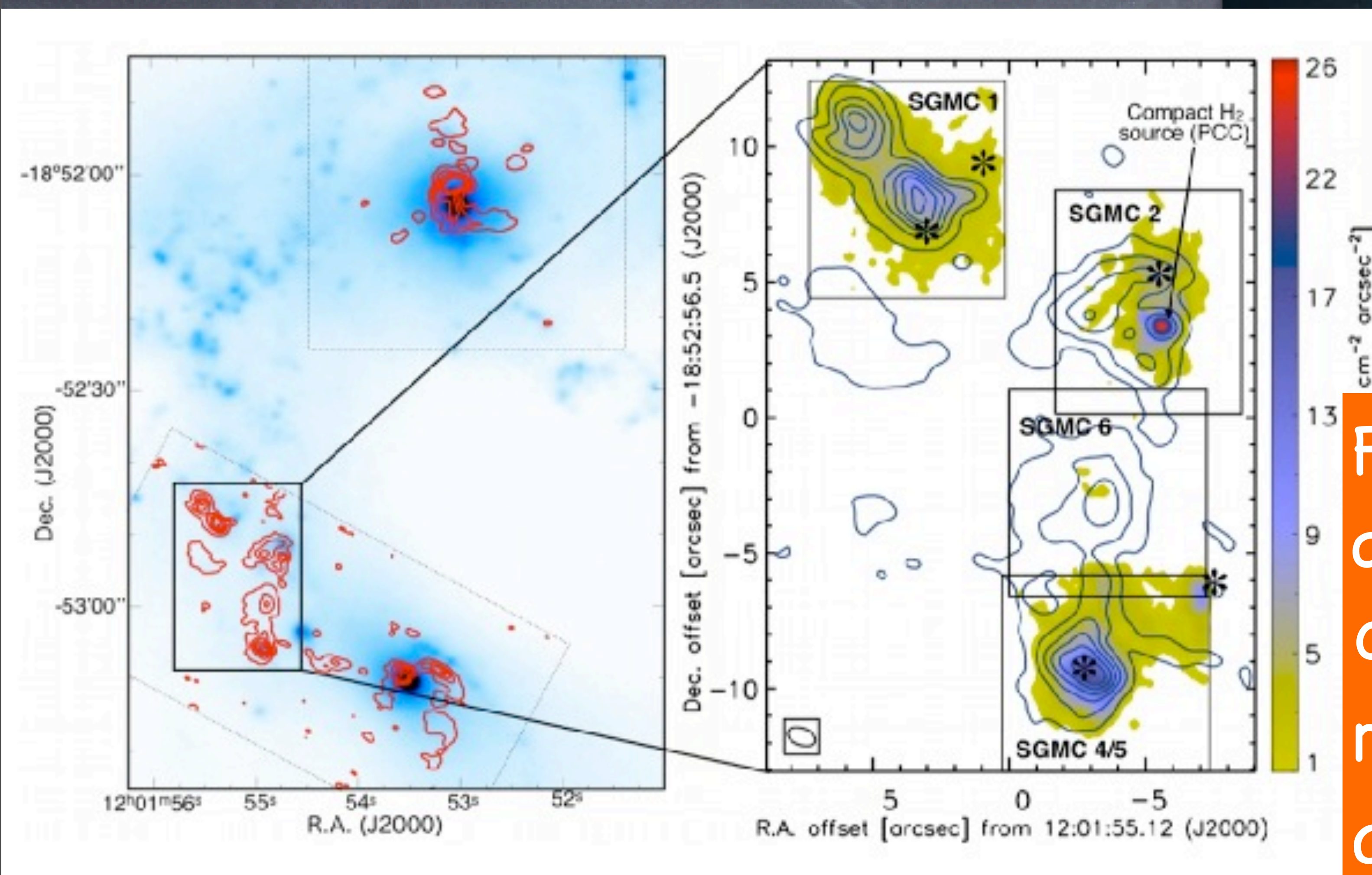

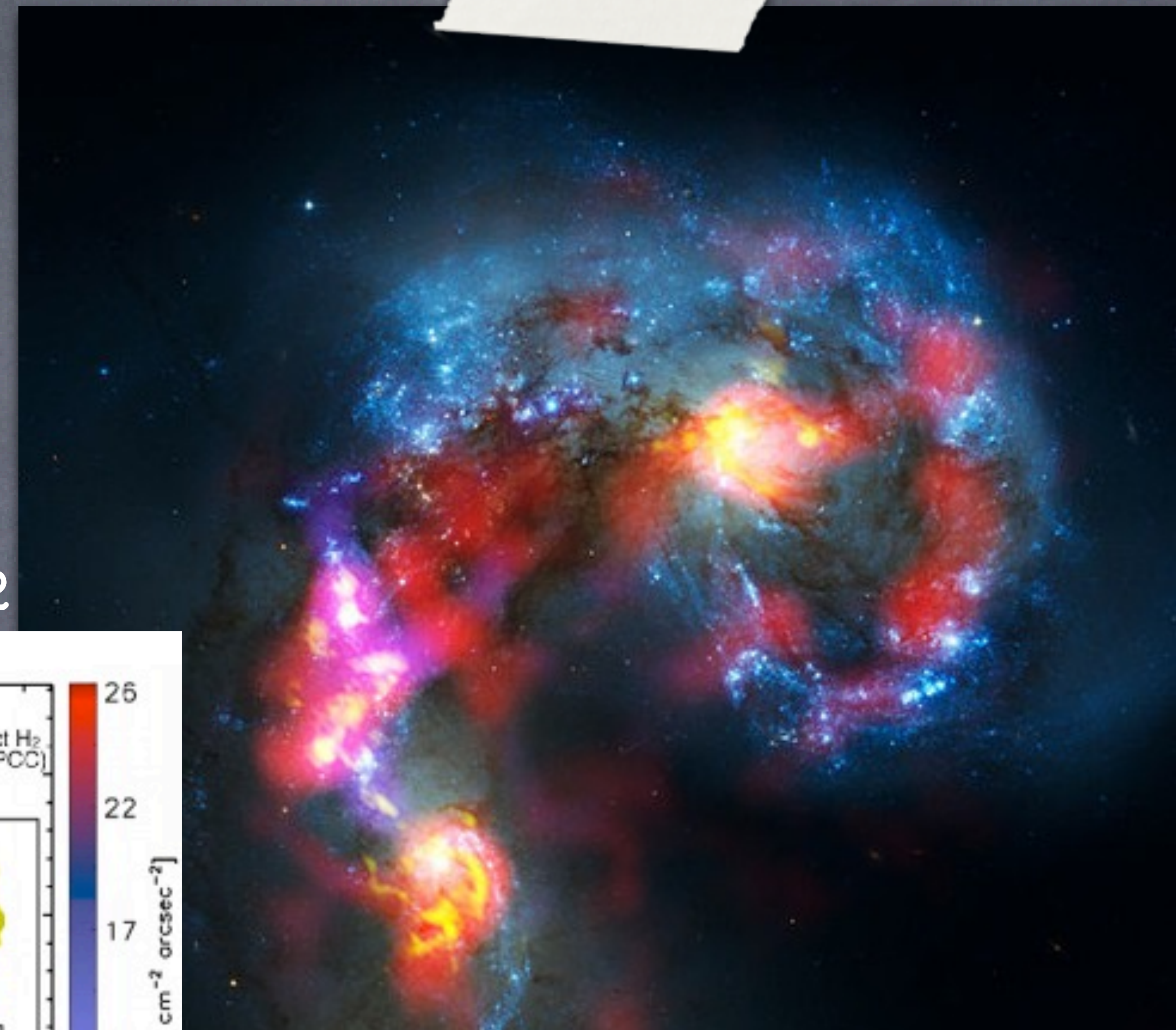

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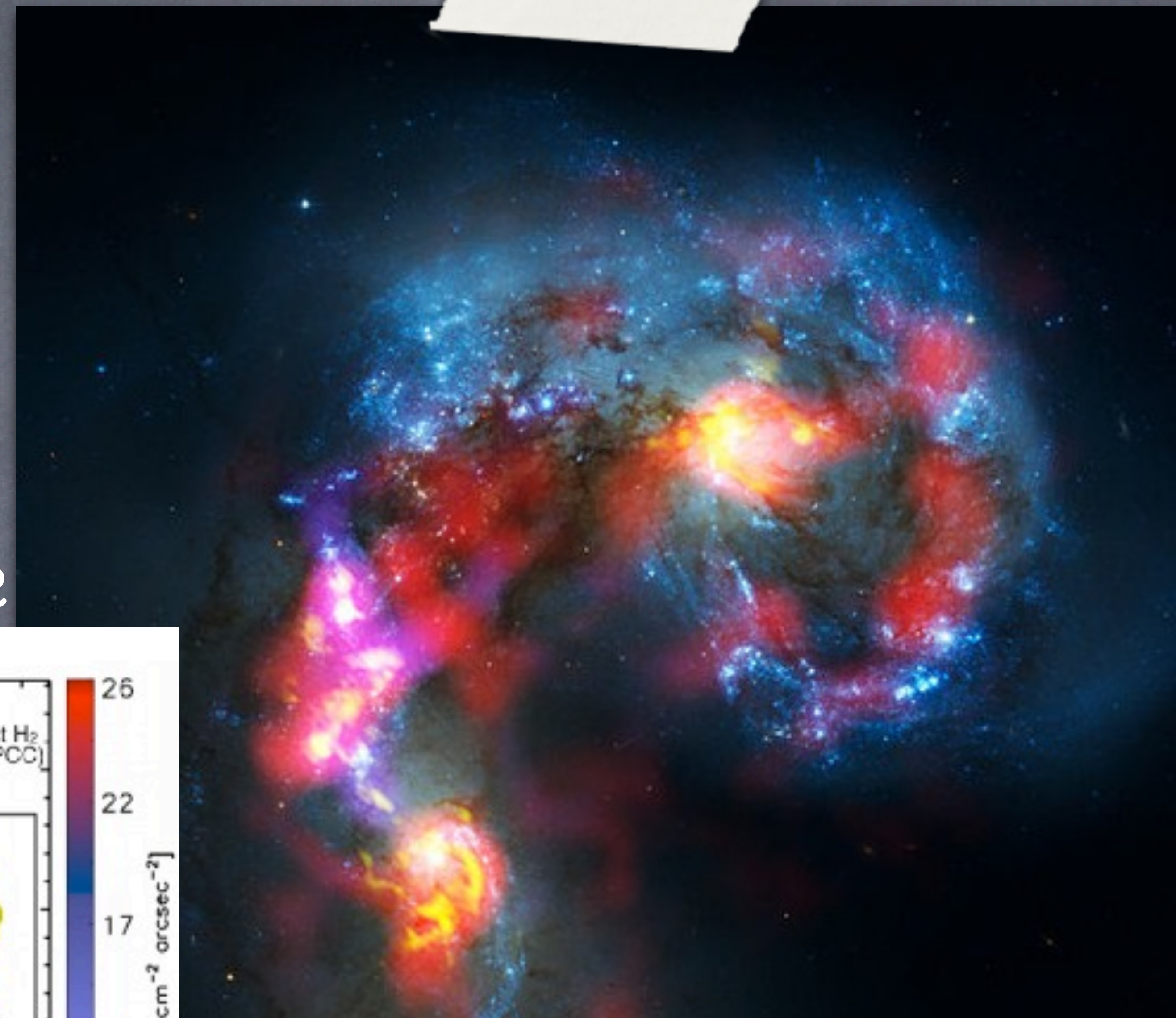

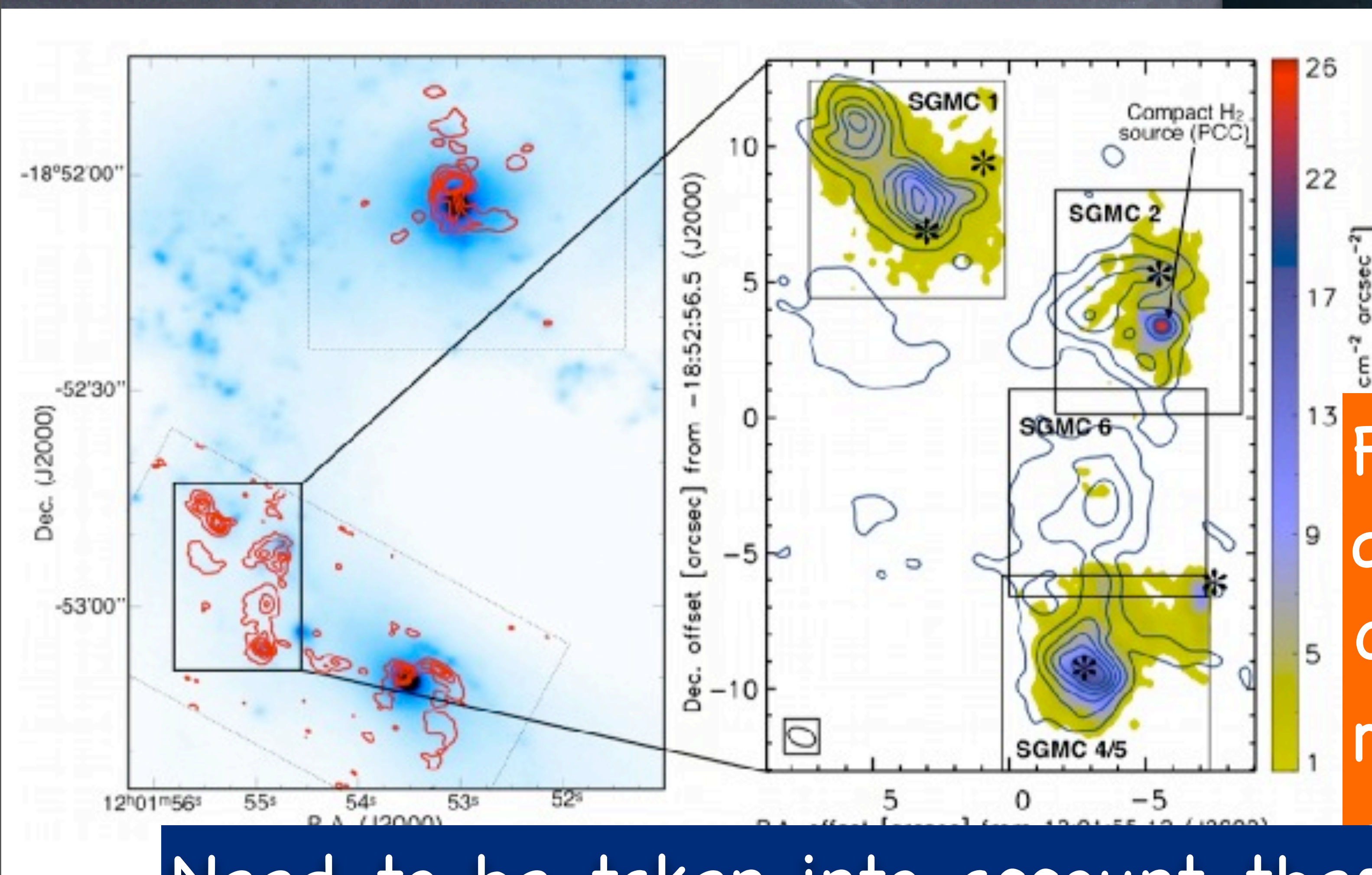

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(Glover+09,10)

Need to be taken into account these phenomena in our theoretical and numerical models for star formation

causal?

- Recent theoretical work has been done as to include molecules: Krumholz+09,+10, Narayanan+12, Wolfire+10.
- Numerical simulations including a SF-molecule dependence: Pelupessy & Papadopoulos 06,+09, Wada+12, Tassis+09, Gnedin+09,+11, Kuhlen+12.
- But most of the work done for isolated galaxies (Pelupessy+, Wada+); short periods of time (Gnedin+,Tassis+); or low numerical resolution (Kuhlen+)

Our goals:

- Link SF and the molecular content (Krumholz+09) in cosmological simulations of galaxy formation (resolution down to 100pc)
- Understanding how to relate the observed CO line flux to the quantity of interest: H_2 gas mass
- Reproduce observational properties for galaxies (H_2, CO, C^+, X maps) and make predictions for ALMA at high-redshift (2,3)

Star formation

$$\dot{\rho}_g = \epsilon \frac{\rho_g}{t_{ff}} \qquad (\rho > \rho_0) \qquad\qquad m_* \propto \rho_0 \Delta x^3$$

$$\propto \epsilon \rho_g^{3/2}$$

- few 100pc resolution, ``enough" to resolve GMC
- ε~0.01 (Krumholz & Tan 07)

Star formation: H_2 regulated

$$\dot{\rho}_g = \epsilon \frac{\rho_{H_2}}{t_{ff}} \propto \epsilon f_{H_2} \rho_g^{3/2}$$

(Krumholz+08,09,10, Mckee+10)

- Based on a R-T calculation of idealized spherical giant atomic-molecular complex, subject to a uniform & isotropic LW radiation field

- ISM: two-phase equilibrium between a cold neutral medium (CNM) and a warm neutral medium (WNM, Wolfire+03)

$$f_{H_2} \sim 1 - \frac{3}{4}\frac{s}{1+0.25s} \qquad s = \frac{ln(1+0.6\chi+0.01\chi^2)}{0.6\tau_c}$$

$$\chi = 2.3\left(\frac{\sigma_{d,-21}}{R_{-16.5}}\right)\frac{1+3.1(Z/Z_{SN})^{0.365}}{\phi_{CNM}}$$

- Krumholz & Gnedin 11, ϕ_{CNM}=3, and (σ/R)=1.

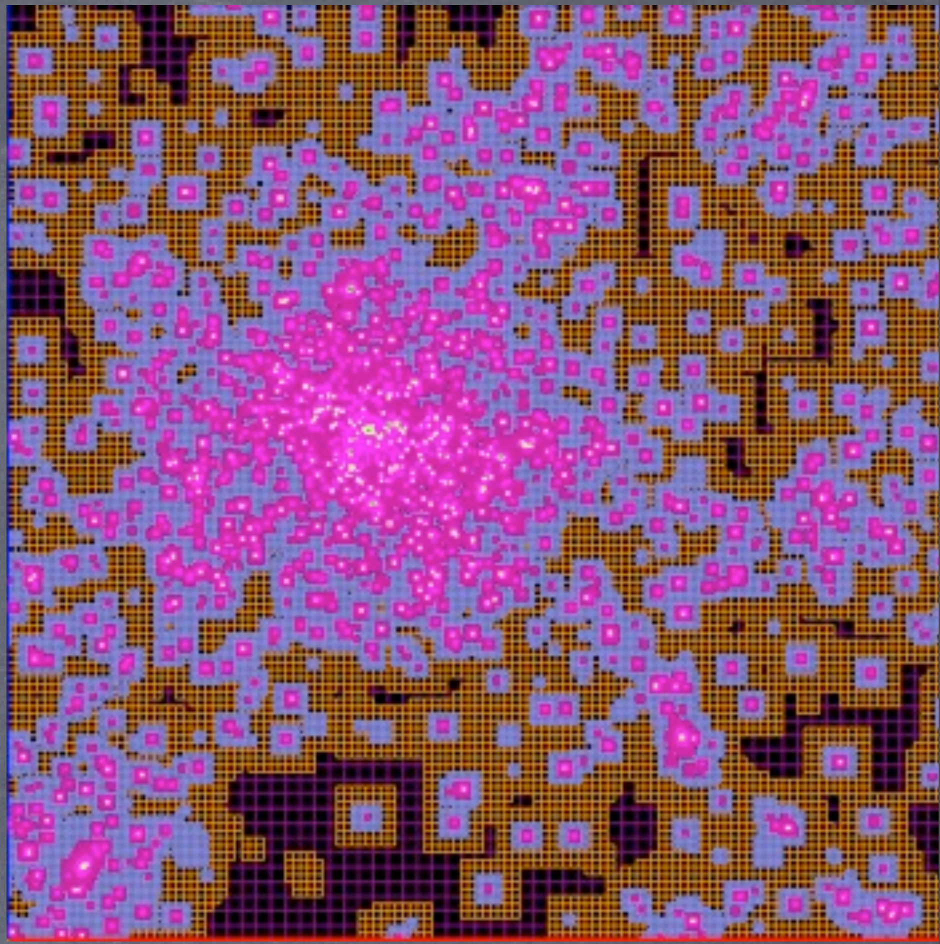
CO-H_2 conversion

(Wolfire+10, Glover+11)

$$f_{CO} = f_{H_2} \times e^{-4(0.53-0.045 ln \frac{G'}{n_h/cm^{-3}} - 0.097 ln Z')/A_v}$$

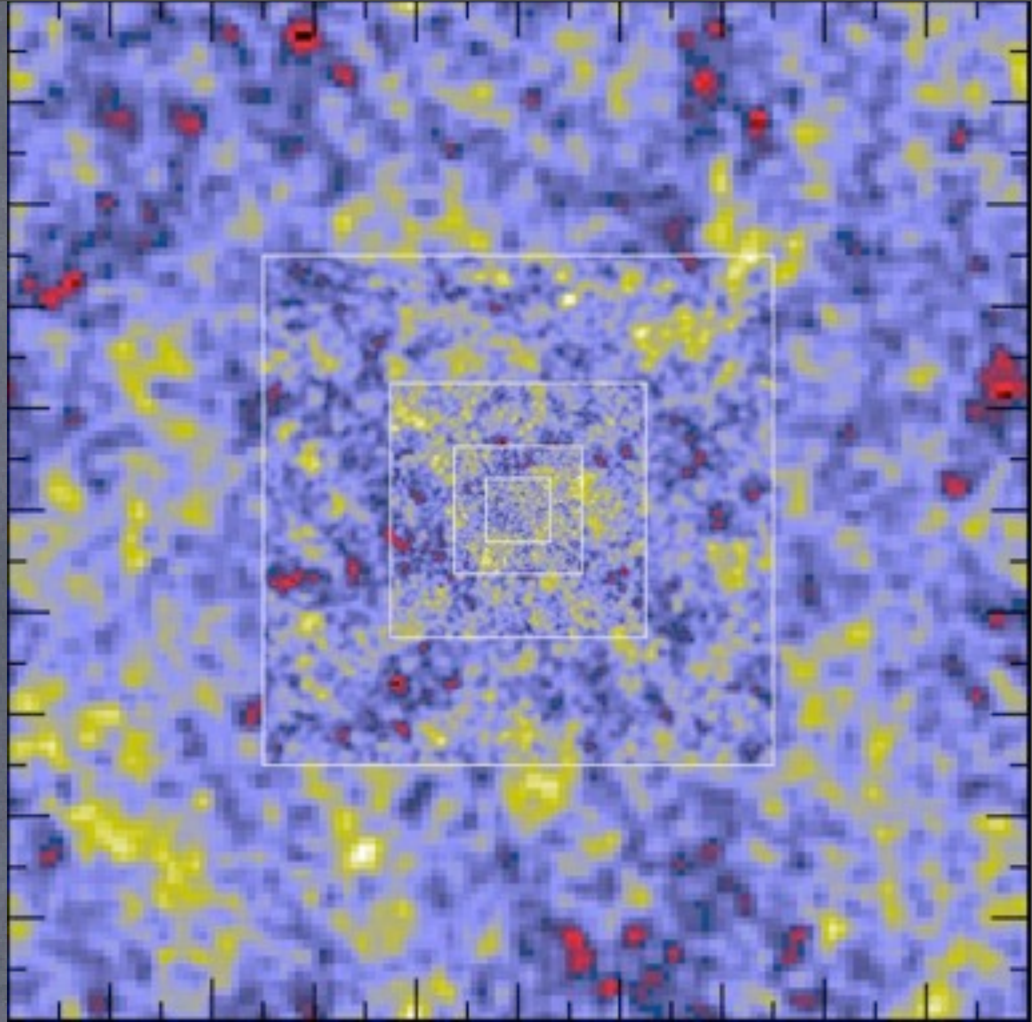
- CO: historically has been one of the most commonly used tracers of physical conditions in the molecular ISM
- XCO may be lower in regions of high molecular surface density, ie starburst galaxies, galactic center, high-z submm galaxies (Hinz & Rieke 06; Meier +10)

The Simulations: the code



- RAMSES (Teyssier 02): Nbody+hydro
- AMR technique, achieve high resolution.
- SF, UV (Hardt-Madau 06); Feedback SNII & enrichment (Duboius +08), (SNIa Agertz+11); Winds.
- Cooling (Sutherland&Dopita 93) down to 10^4K, extended cooling down to 50K (metals), (H2,CO,CII cooling, Smith +09)

The Simulations: ICs



- MUSIC (Hann+11)
- WMAP7 cosmology, E-H (98) TF, Box 50Mpc/h
- Unigrid 128 grids/1D (res ~390 Kpc/h)
- DM halo M~10^{12} Msun/h
- TESTS: 3 extra levels of refinement (48 kpc/h)
- Production Runs: +6levels: 6kpc/h

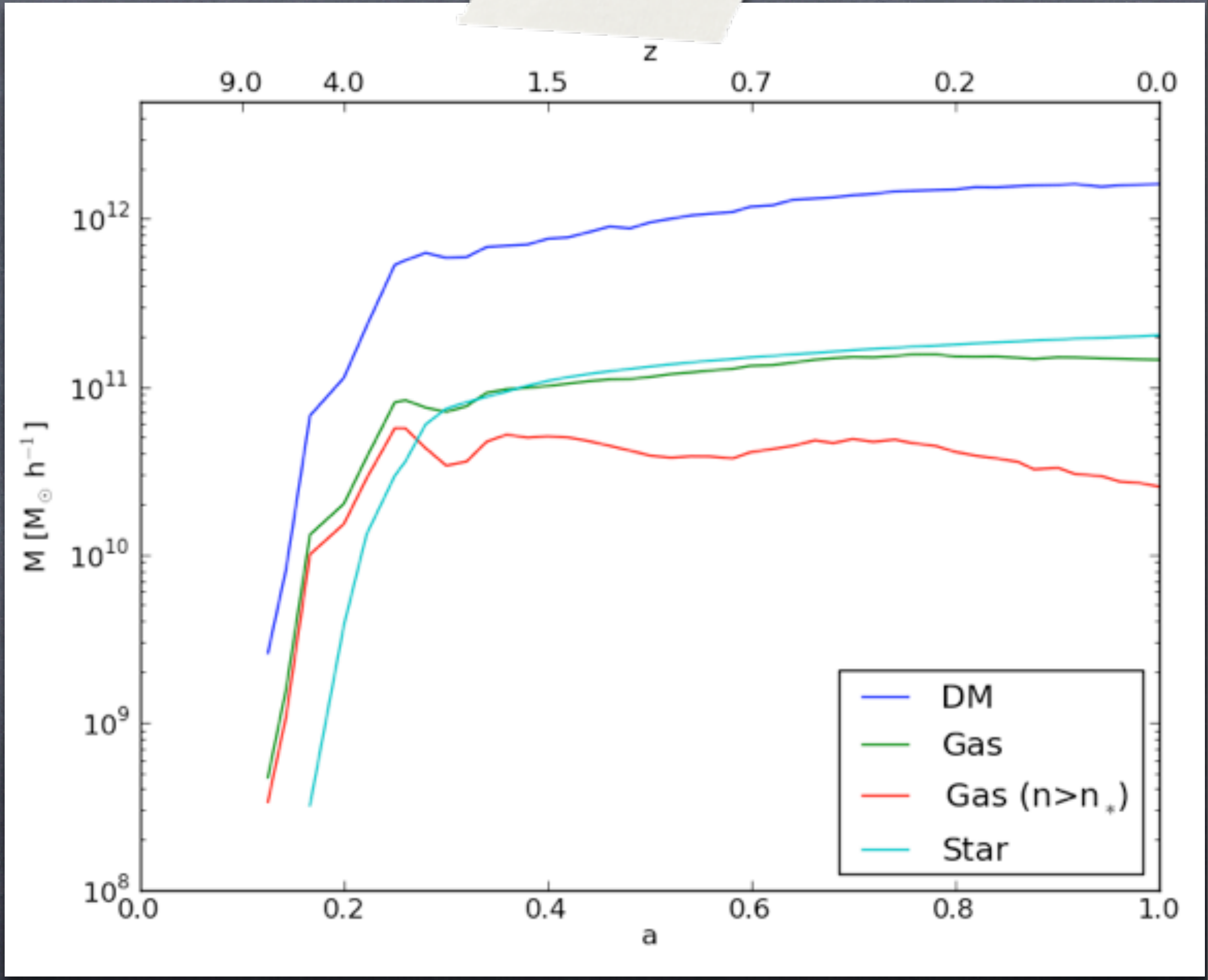
The simulations

- The ICs: 1) DM only; 2) DM + baryons
- Identify a halo
- Resimulate Zoom-in technique, max-level refinement
- Resimulate + baryons
- 2 Simulations, same object: Standard-SF, Molecular-SF
- hope for the best...

Results:

- halo M~2X10^{12}Msun/h
- max-resolution ~200pc (~40pc)
- Last major merger z~3
- Simulations down to z~1
- Disk gal. in both models

MAH



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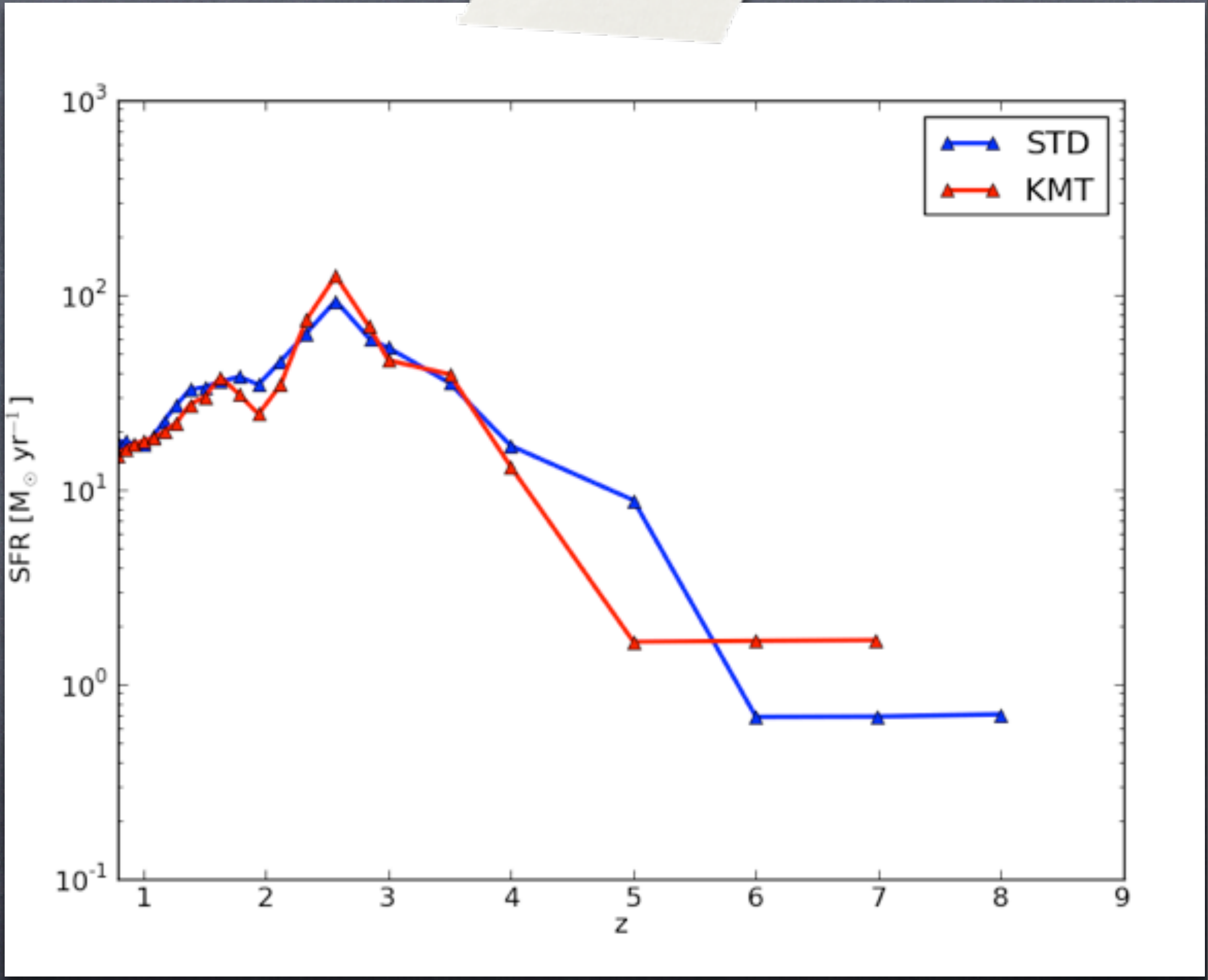
SFR



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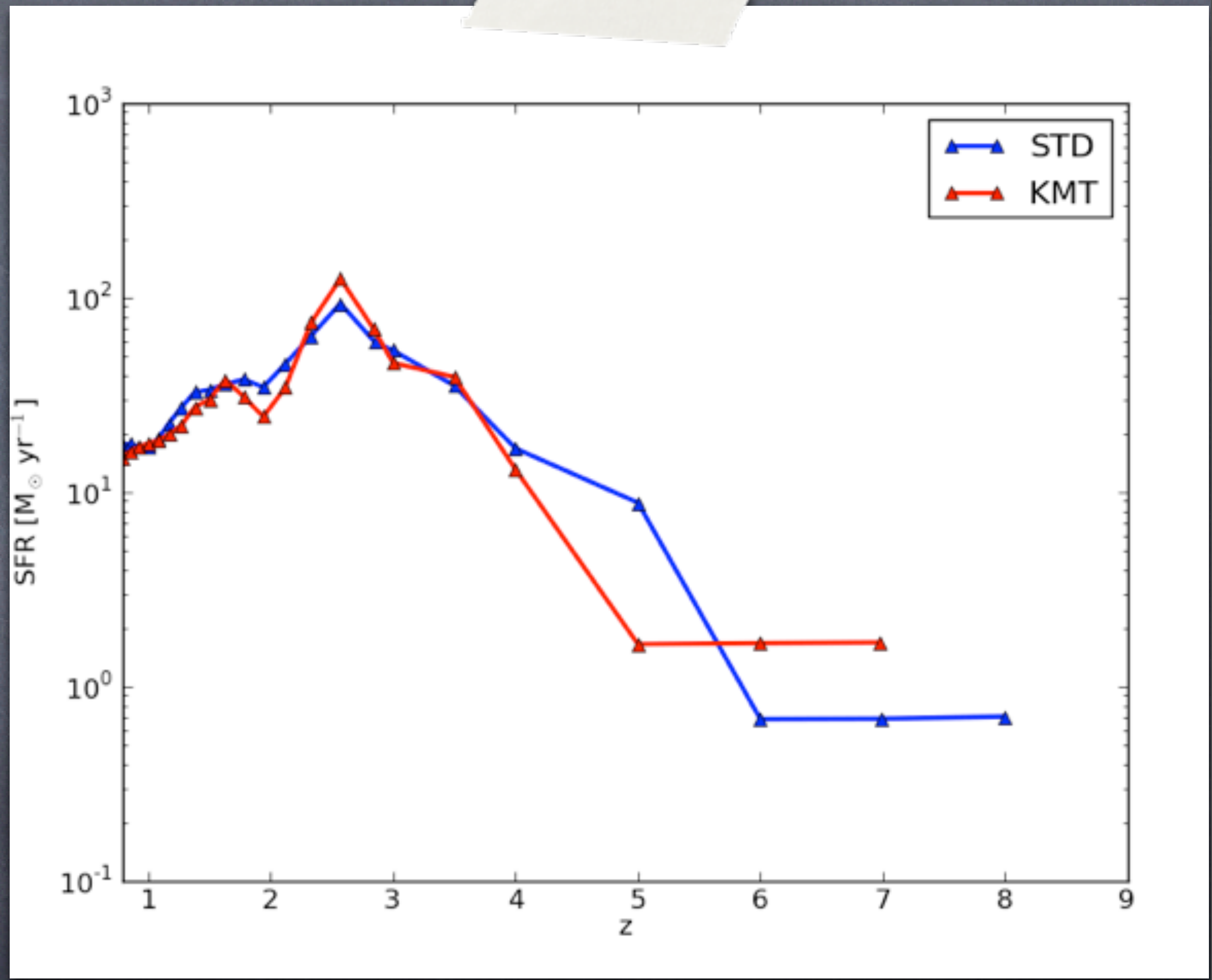
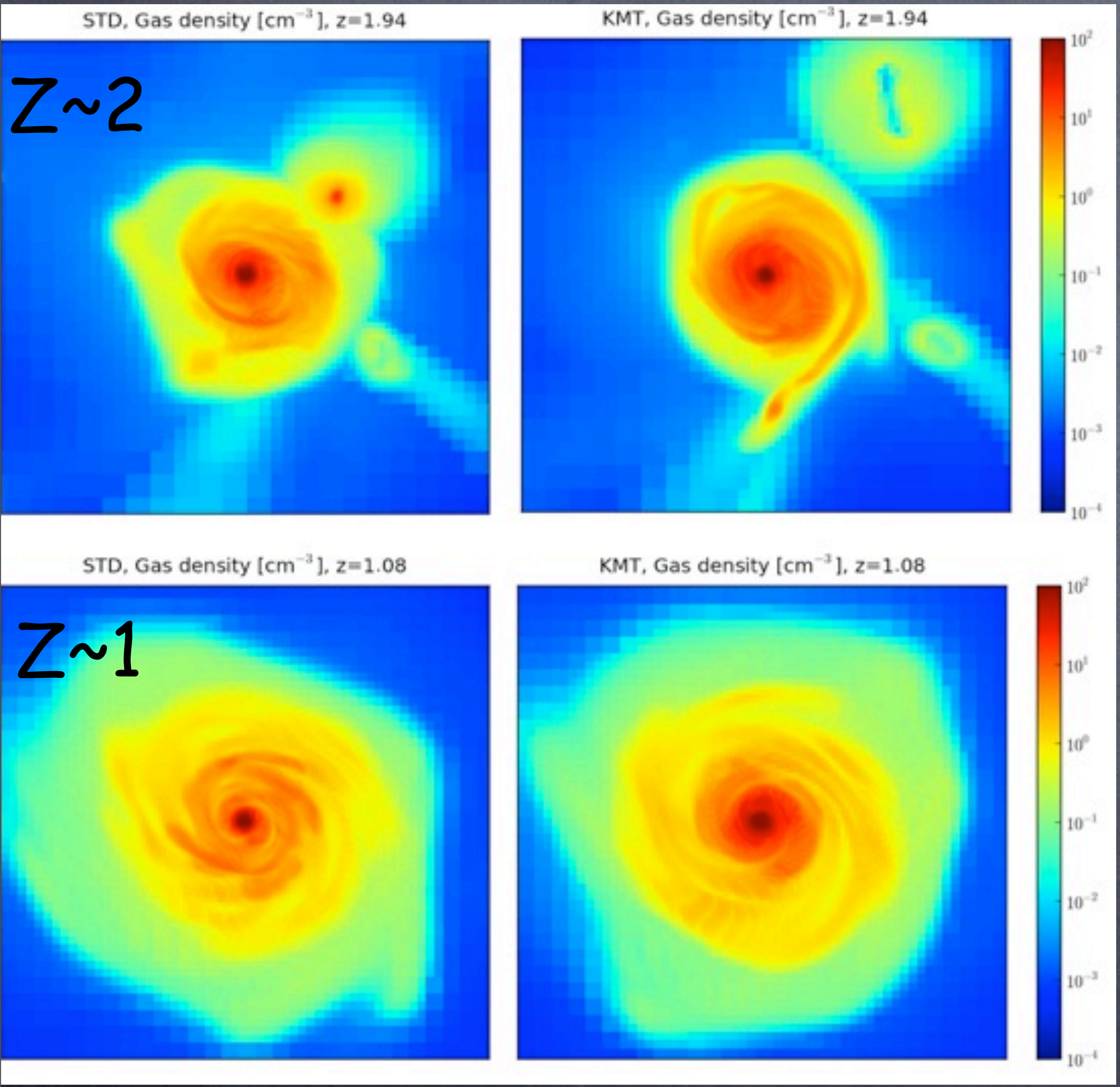


Delayed SF! (depends on resolution)

Disks:

STD KMT



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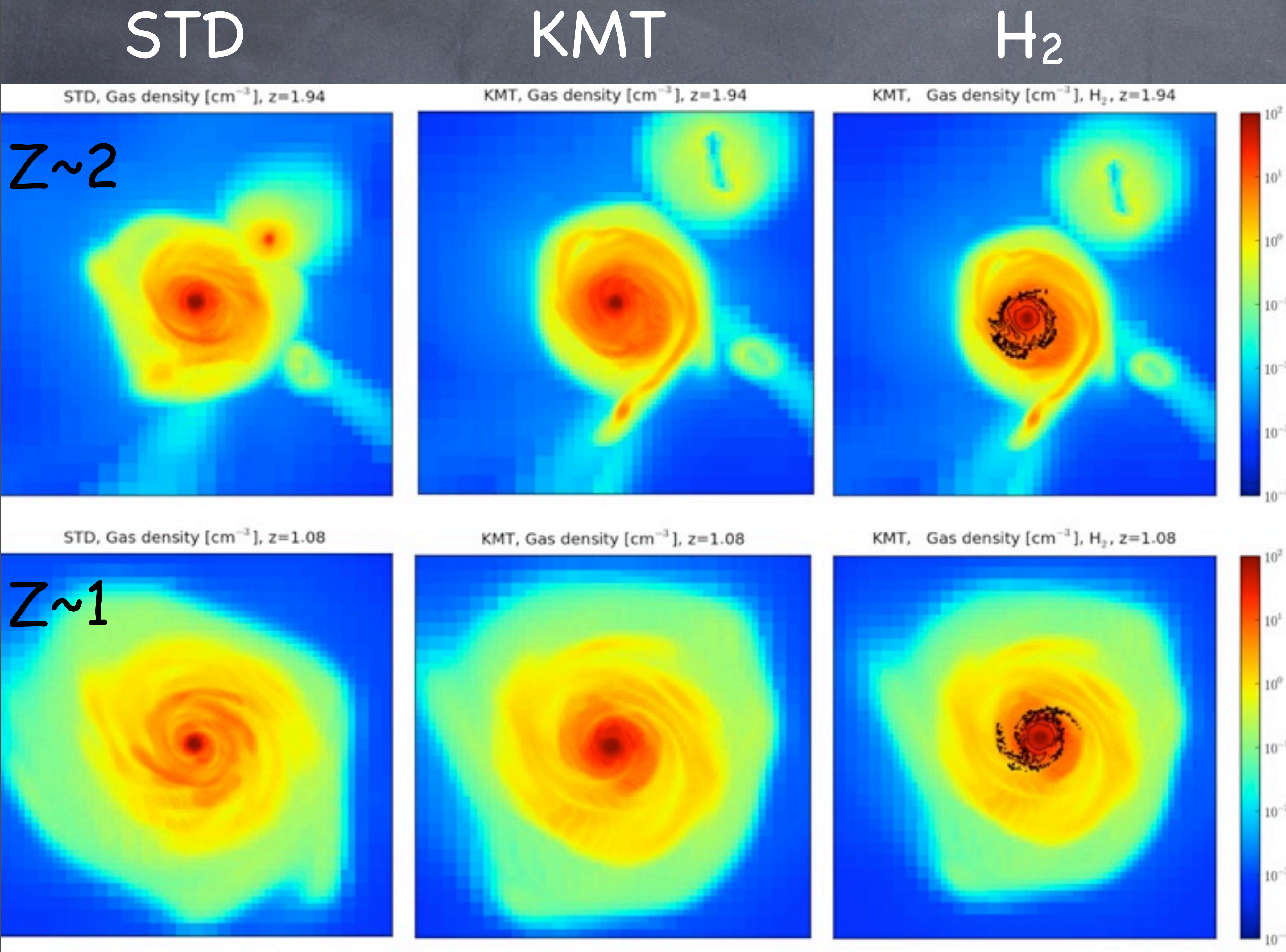
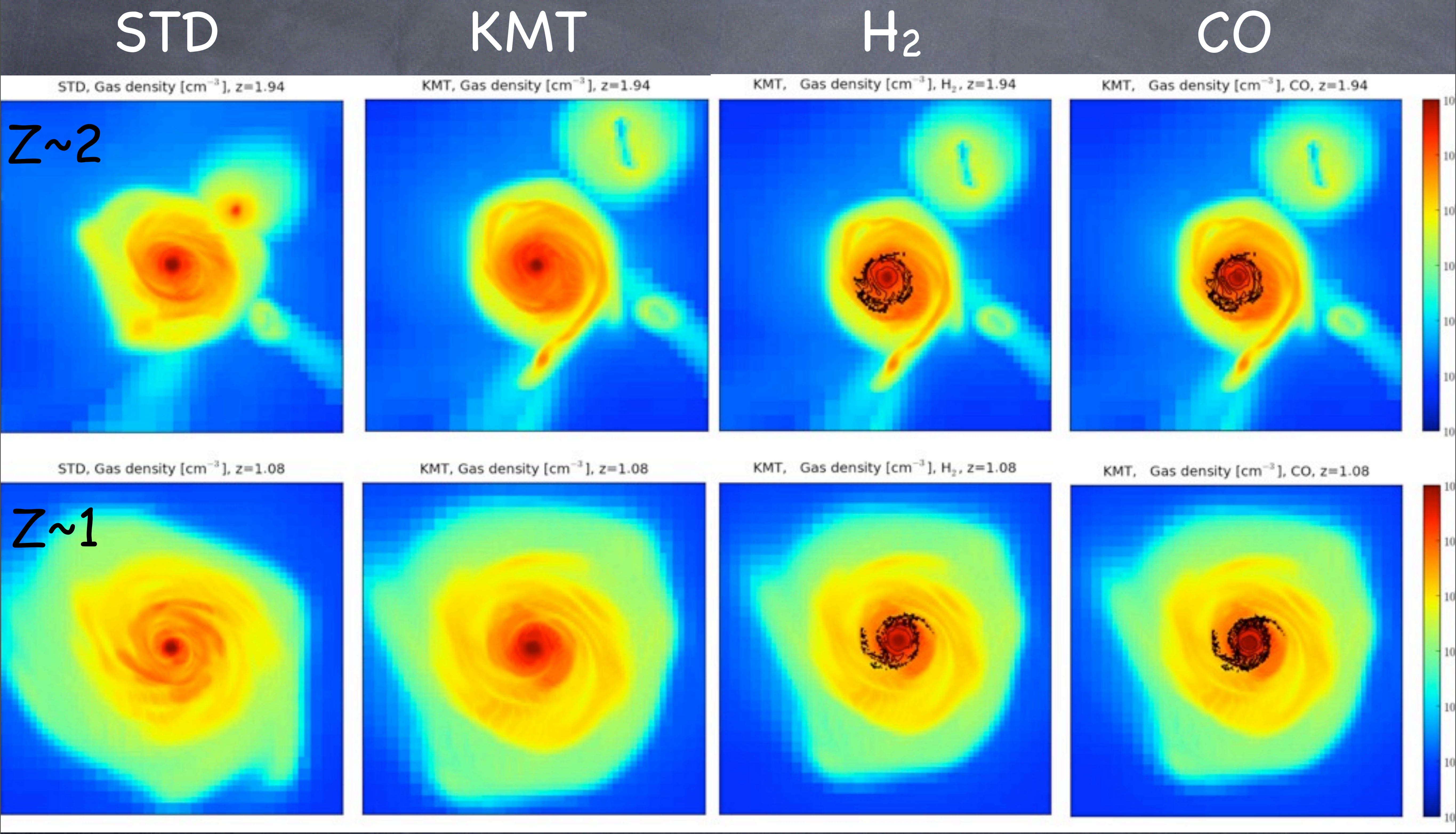

STD
KMT
H2
STD, Gas density [cm^-3], z=1.94
KMT, Gas density [cm^-3], z=1.94
KMT, Gas density [cm^-3], H2, z=1.94
Z~2
STD, Gas density [cm^-3], z=1.08
KMT, Gas density [cm^-3], z=1.08
KMT, Gas density [cm^-3], H2, z=1.08
Z~1

Disks:


STD
KMT
H_2
CO
STD, Gas density [cm^{-3}], z=1.94
KMT, Gas density [cm^{-3}], z=1.94
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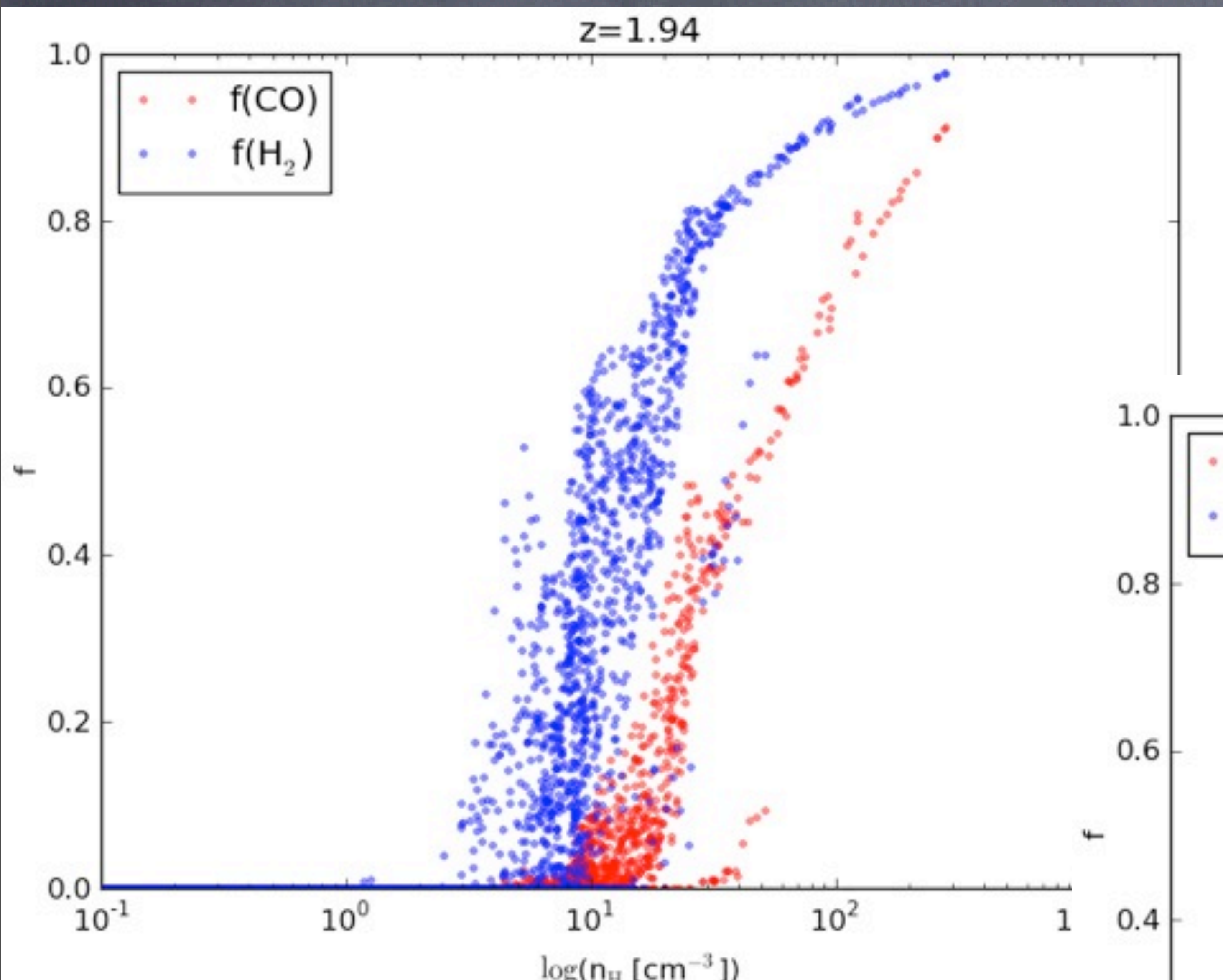
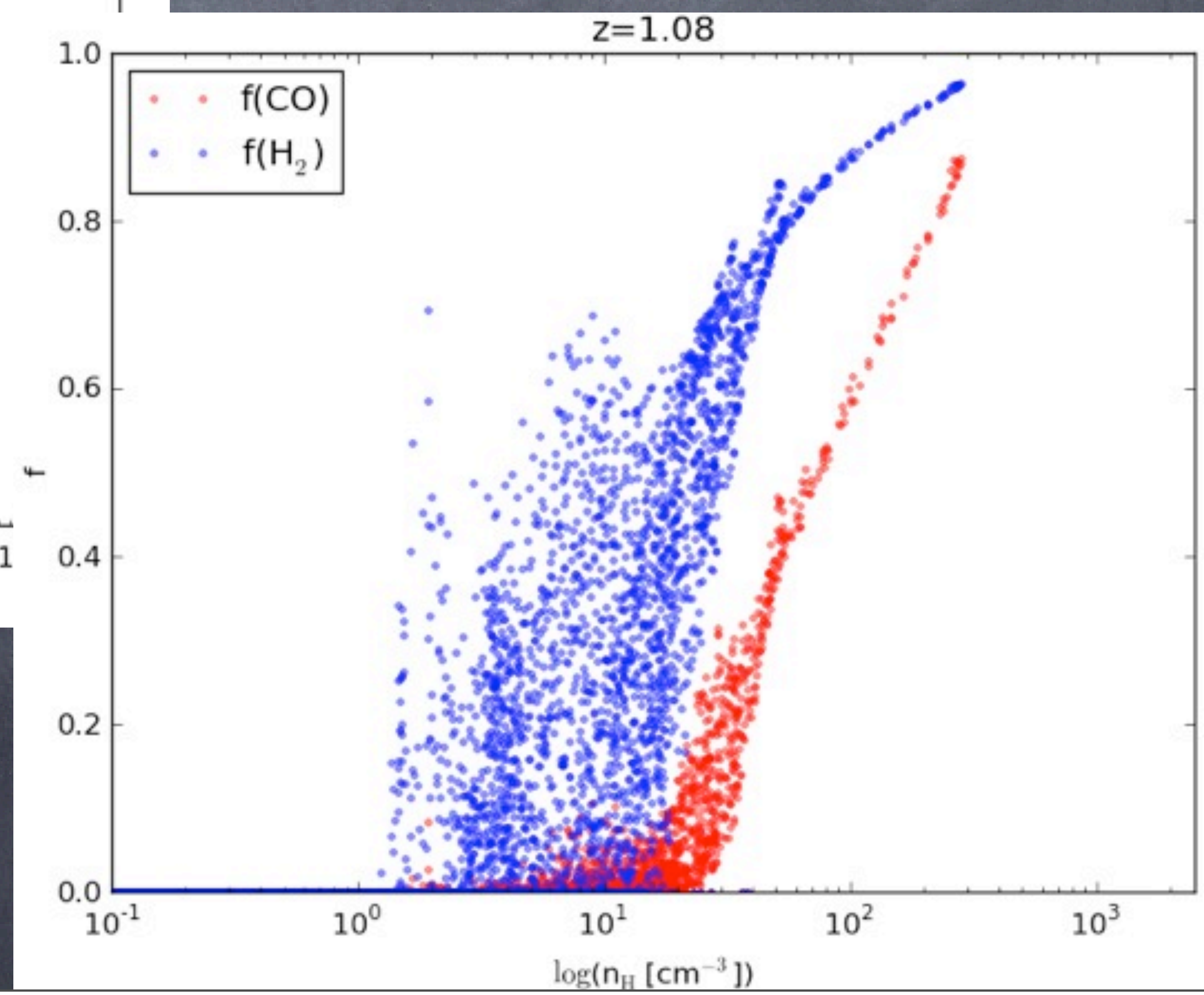
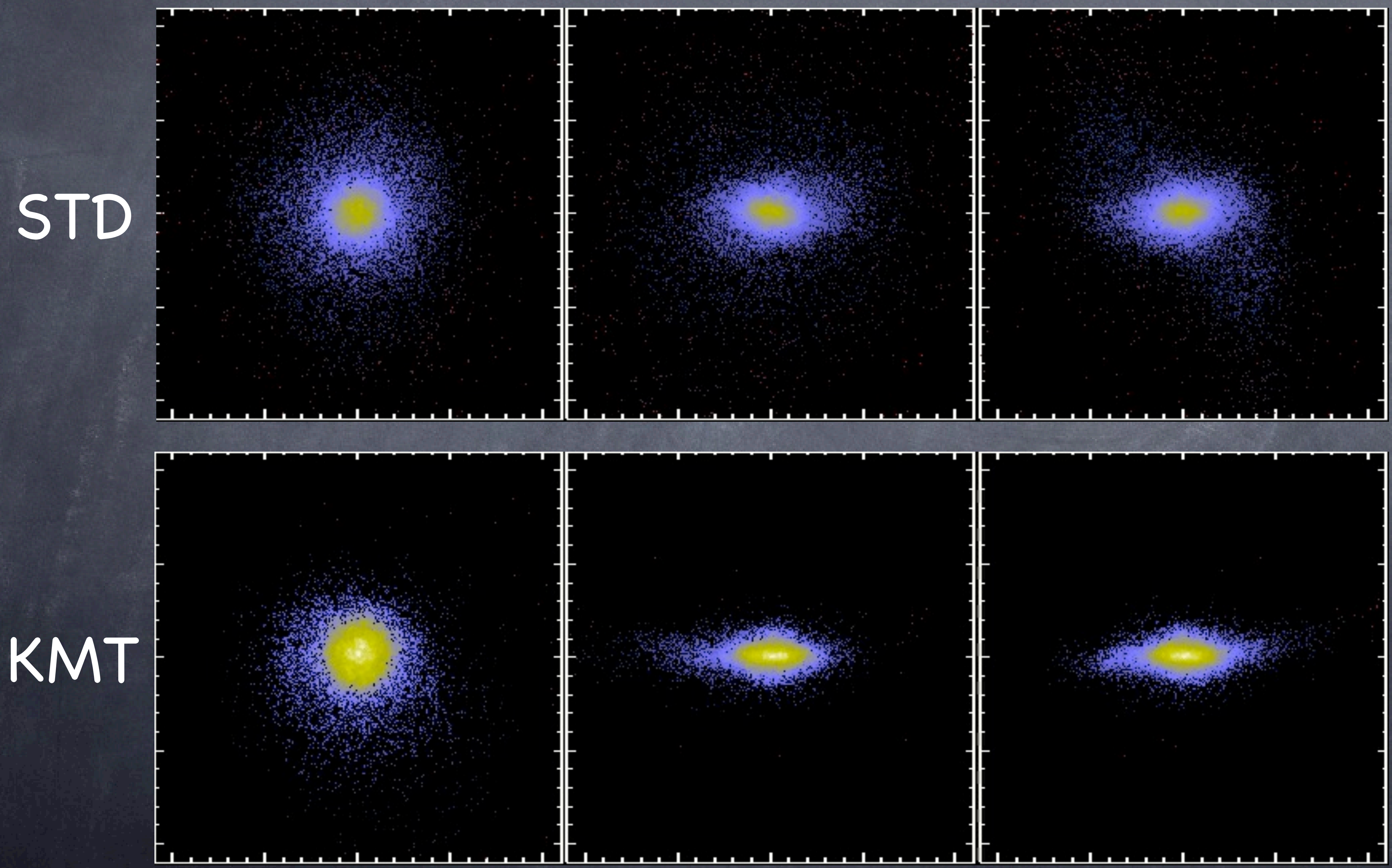
Z~2
STD, Gas density [cm^{-3}], z=1.08
KMT, Gas density [cm^{-3}], z=1.08
KMT, Gas density [cm^{-3}], H_2, z=1.08
KMT, Gas density [cm^{-3}], CO, z=1.08
Z~1

Molecular fractions





Stellar disks (z~3)



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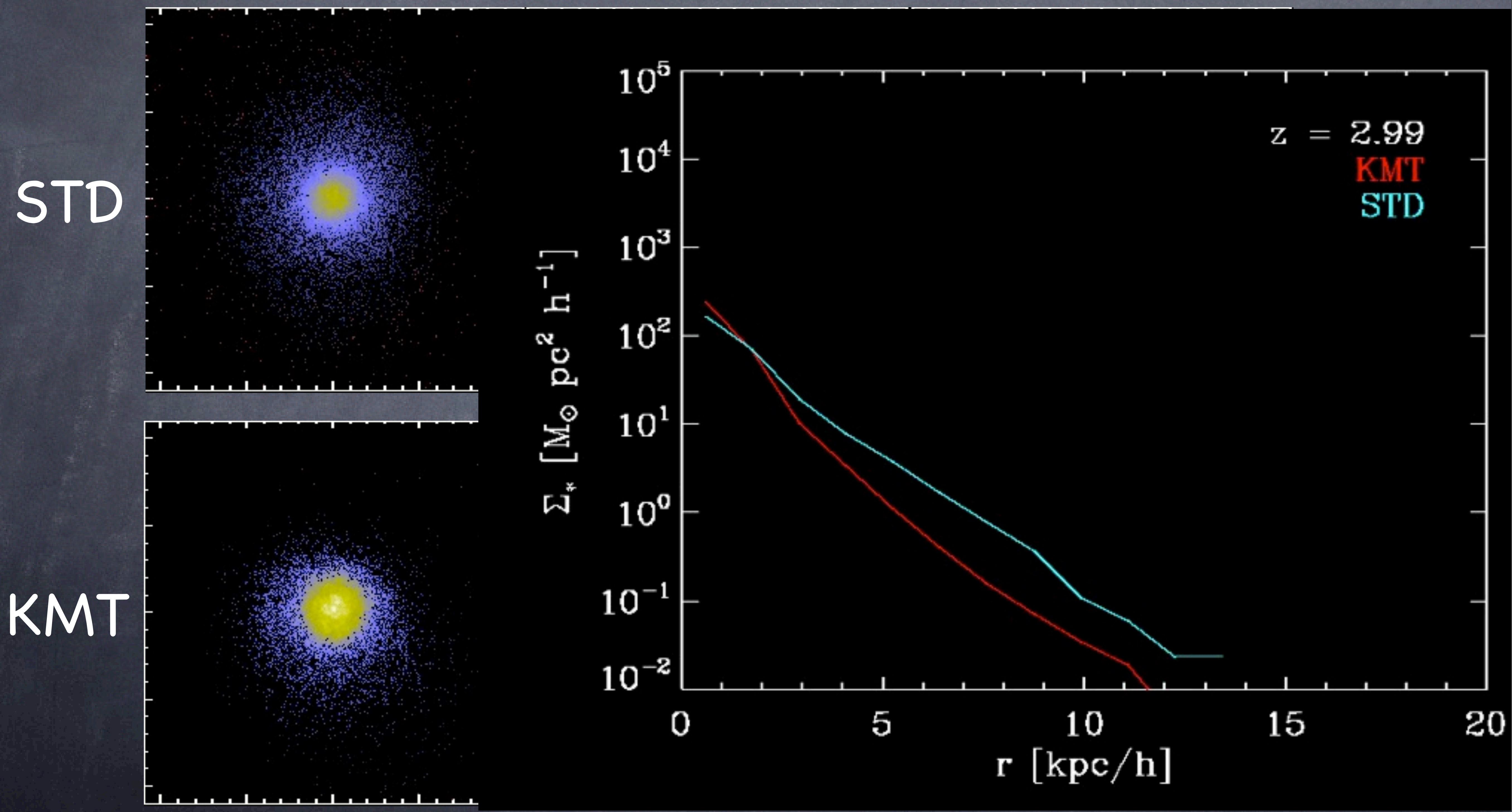
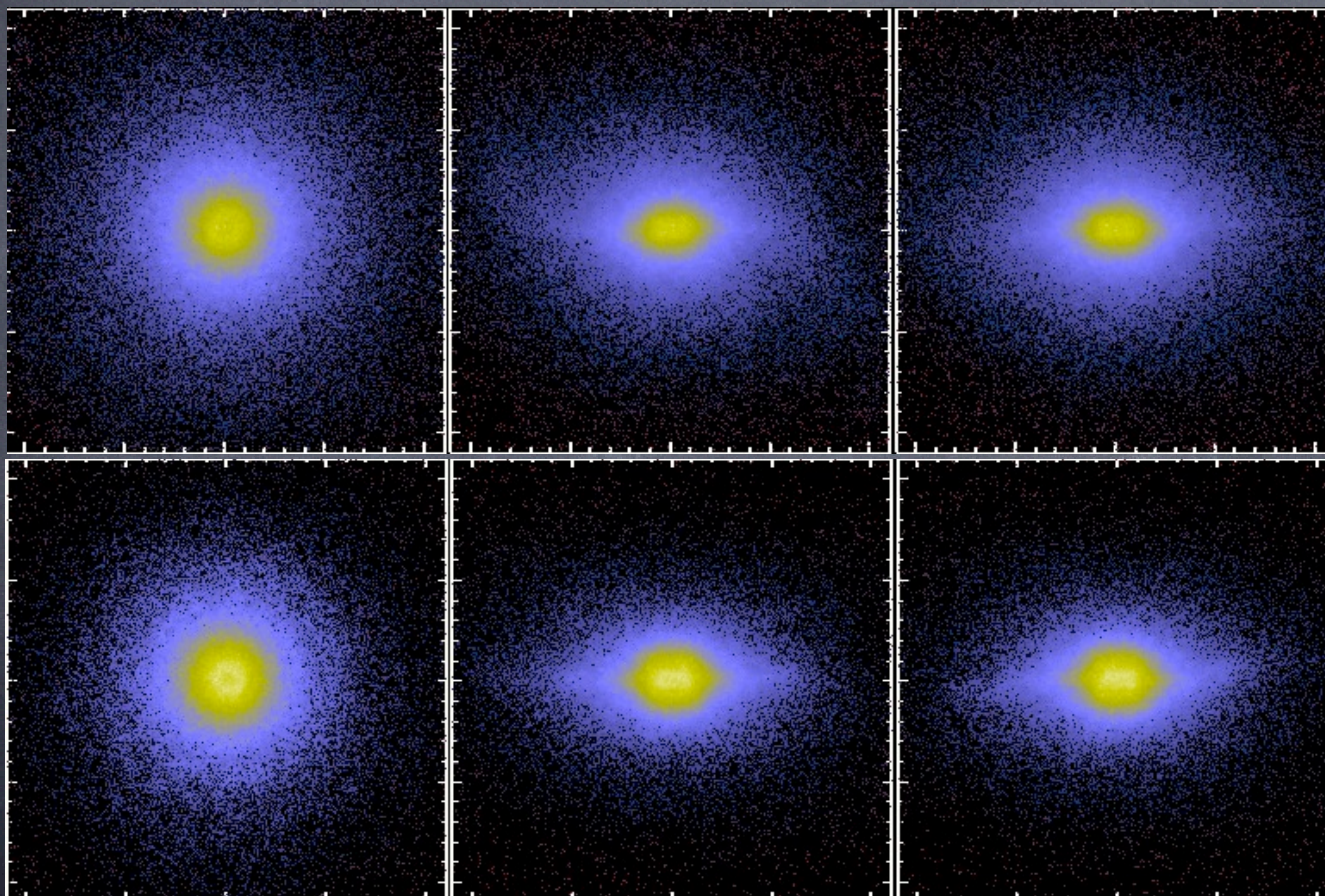


Stellar disks (z~2)

STD

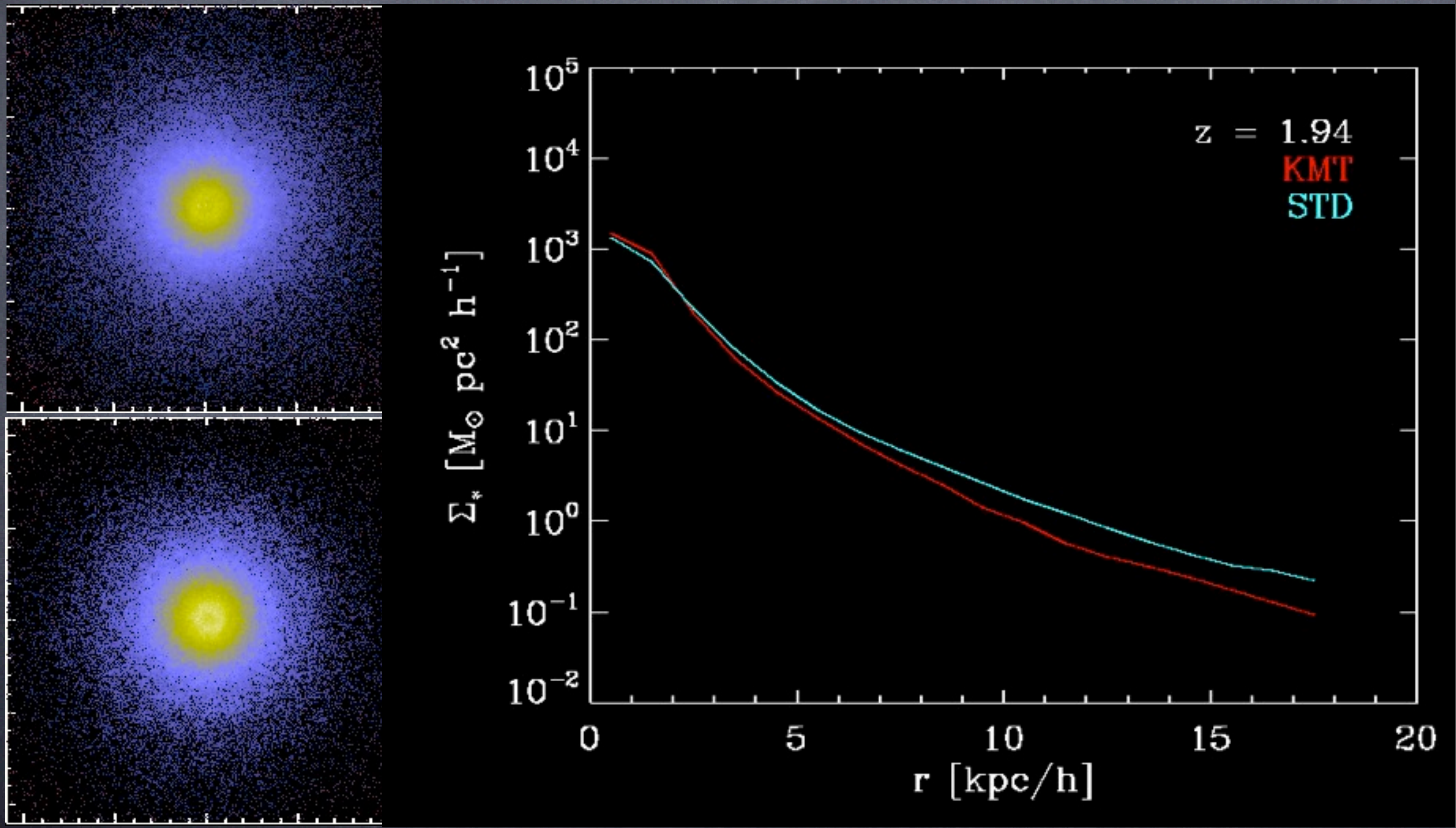
KMT



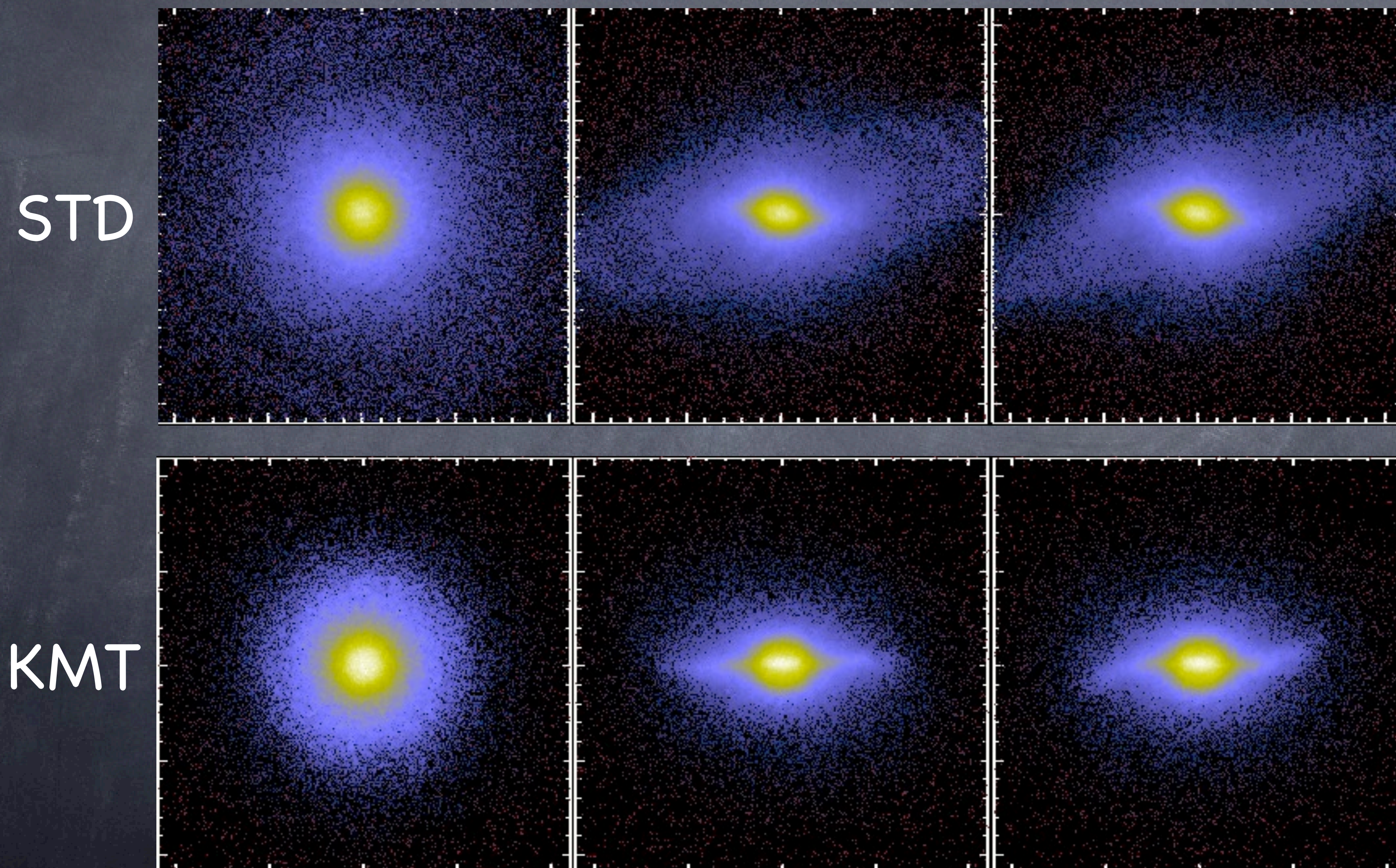
Stellar disks (z~2)

STD

KMT



Stellar disks (z~1)



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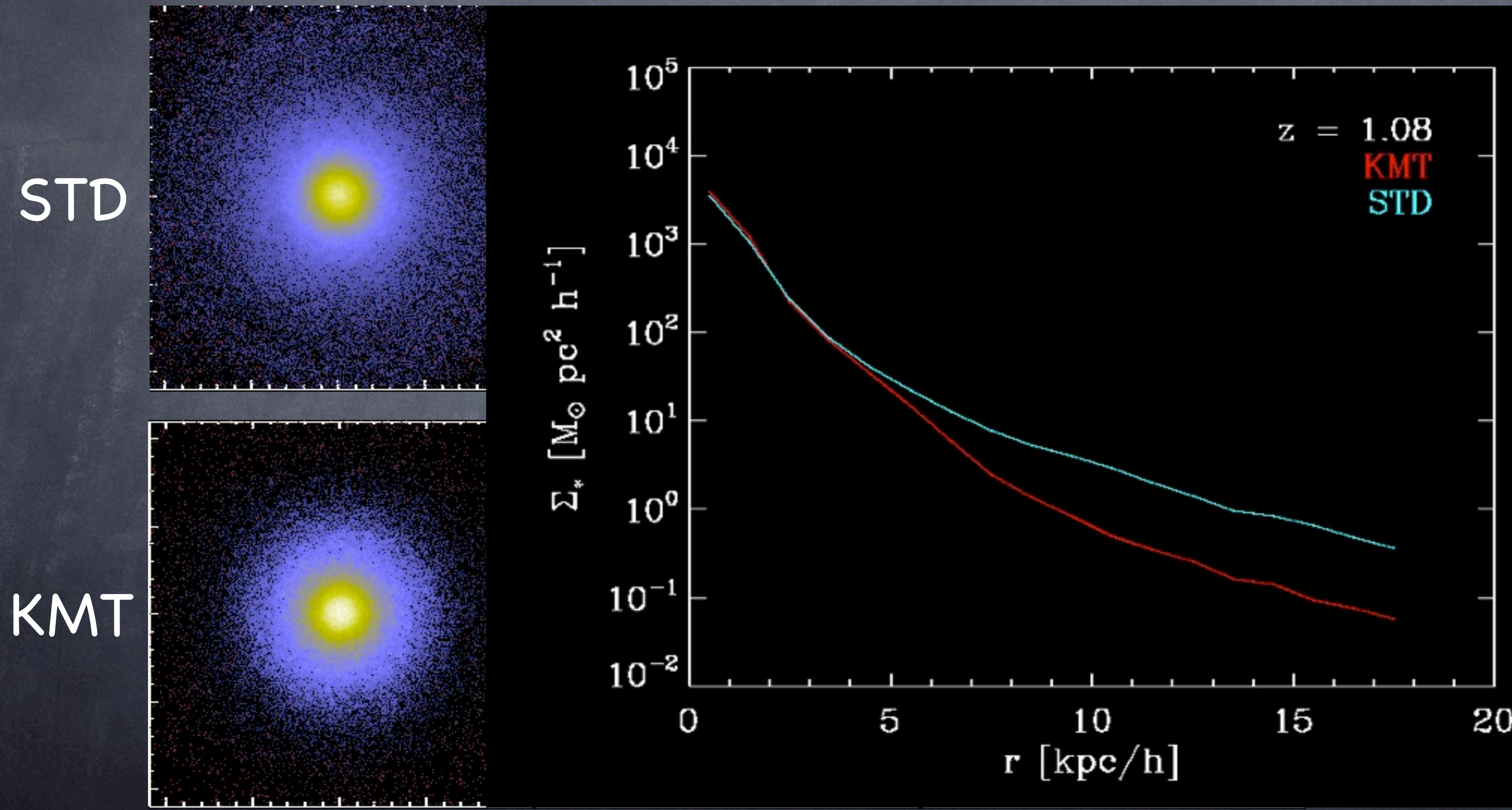

Conclusions

It makes sense to include molecules :D

Work to do...

- Increase resolution +3 levels in ICs, eff-max-res~30pc
- Include Stellar UV field
- Initial metallicity
- CO, CII cooling
- C+ calculation
- Time-dependent chemistry, formation of H_2, CO
- Different feedback mechanisms
- Spectral stellar properties, SEDs