
thanks for …
… bringing us to such a beautiful place

thanks to …

... people in the star formation group at Heidelberg University:

Bhaskar Agarwal, Carla Bernhard, Daniel Ceverino, Sam Geen, Simon Glover, Dimitrios Gouliermis, Lionel Haemmerle, Sacha Hony, Ondrej Jaura, Ralf Klessen, Besma Klinger-Araifa, Kiwan Park, Eric Pellegrini, Daniel Rahner, Stefan Reißl, Claes-Erik Rydberg, Anna Schauer, Mattia Sormani, Robin Treß, Katharina Wollenberg

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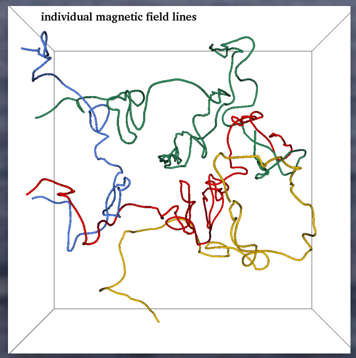
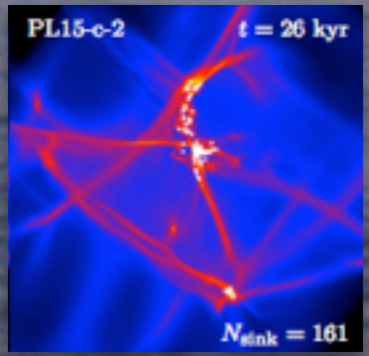
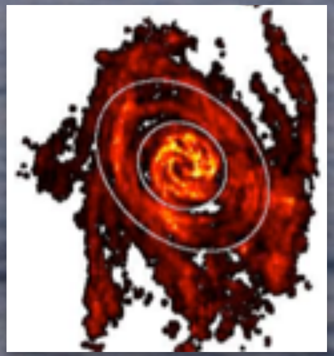
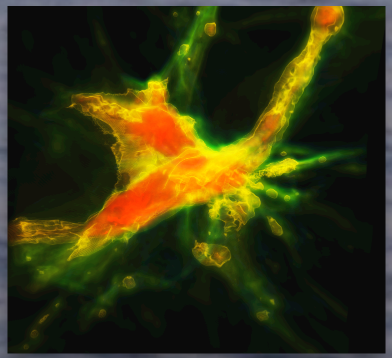
Deutsche Forschungsgemeinschaft DFG
ISM-SPP
BADEN-WÜRTTEMBERG STIFTUNG Wir stiften Zukunft
STARLIGHT
erc European Research Council

theoretical perspectives



Ralf Klessen

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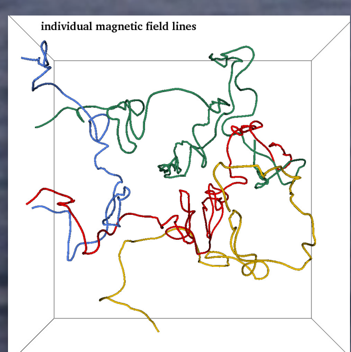
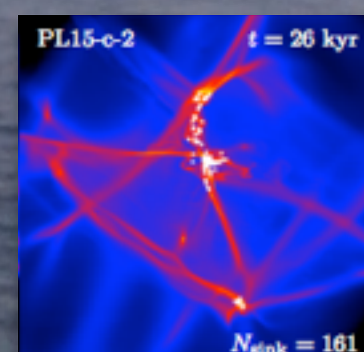
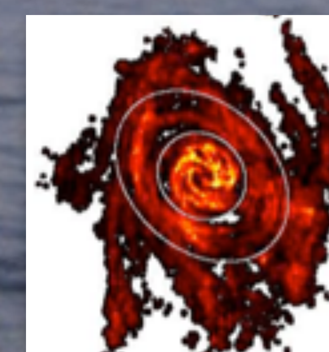
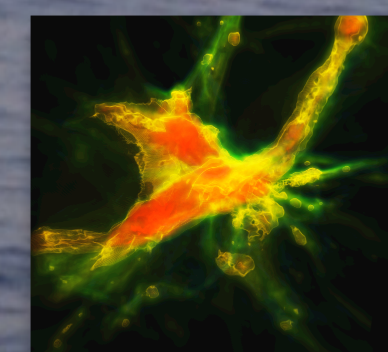
ISM dynamics & star formation



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ISM dynamics & star formation

connecting theory with observations

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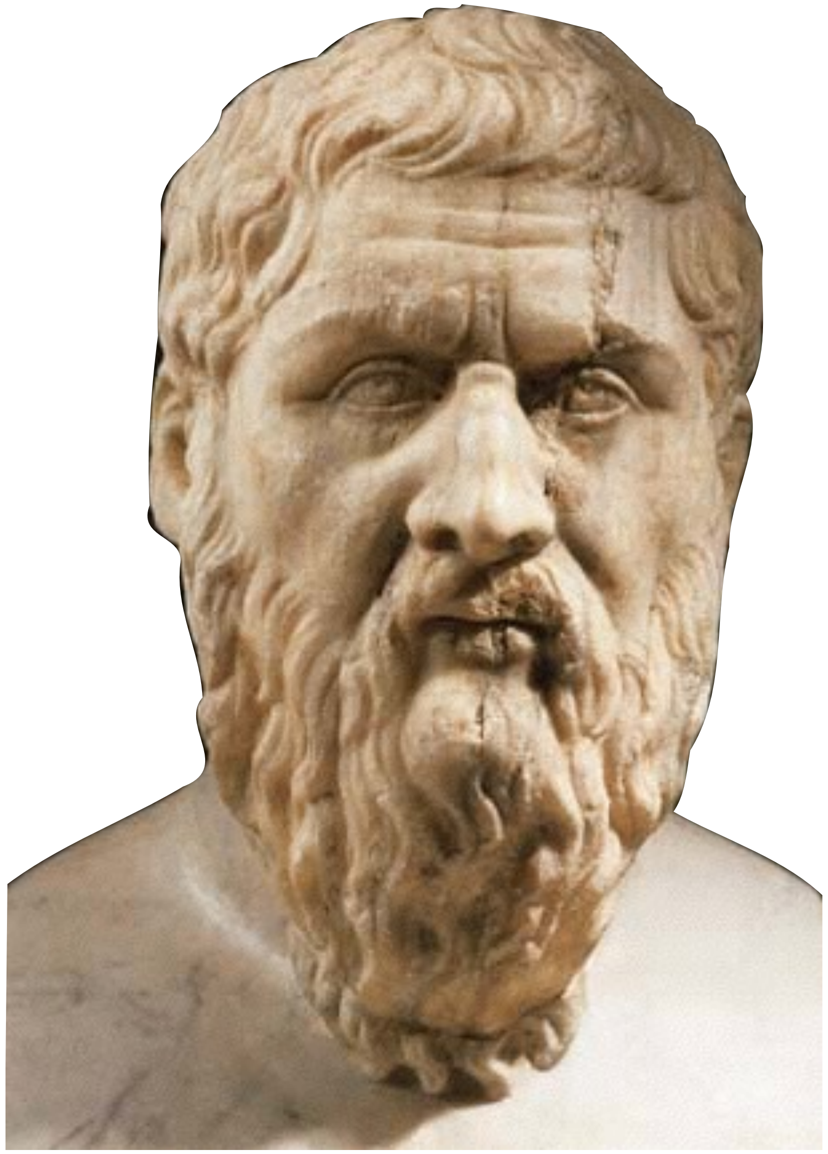
connecting theory with observations


connecting theory
with observations
more on observations
in Charlie Lada's talk

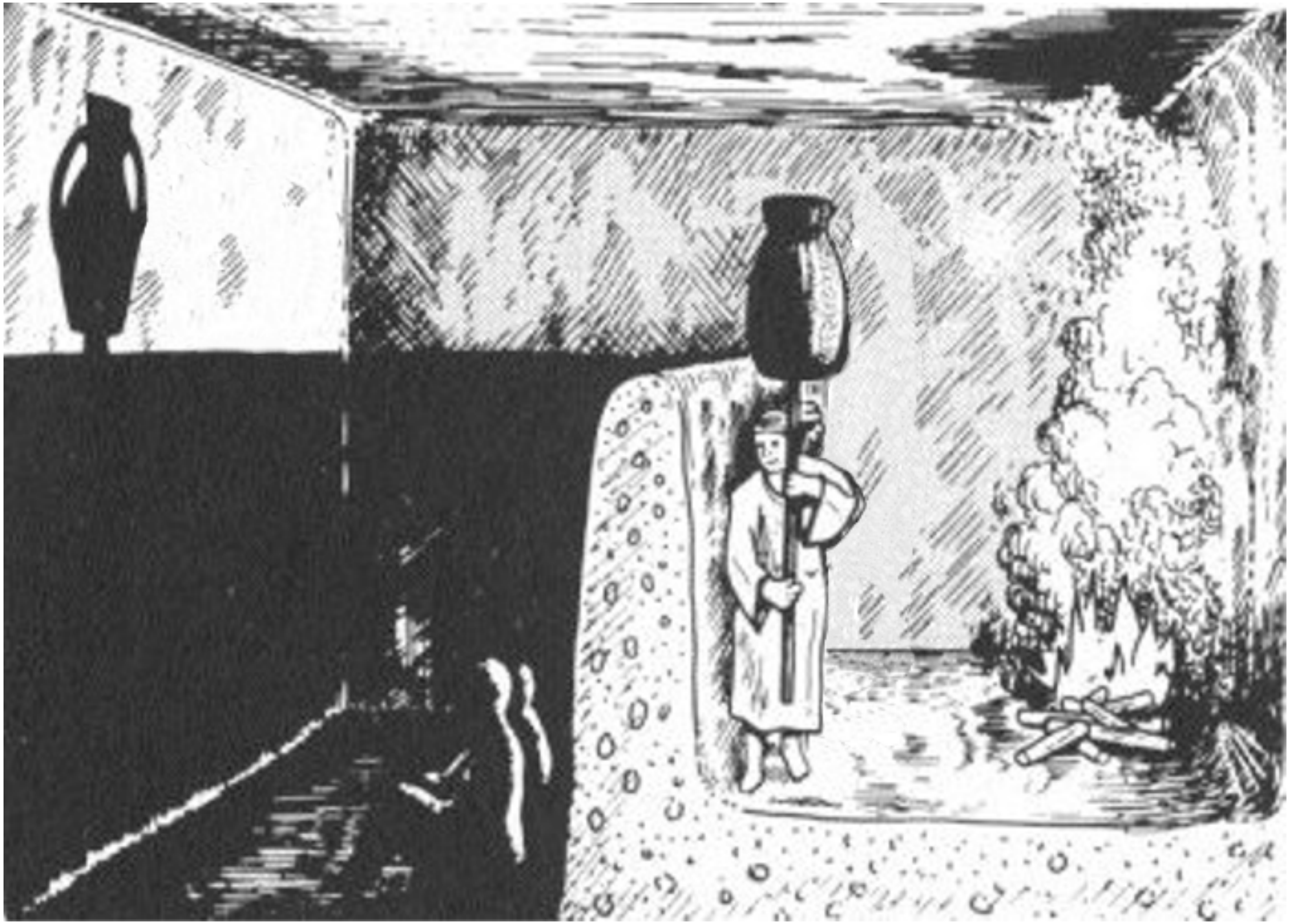

prolegomenon



Platon
428/427–348/347 BC

Capitoline Museum, Rome.

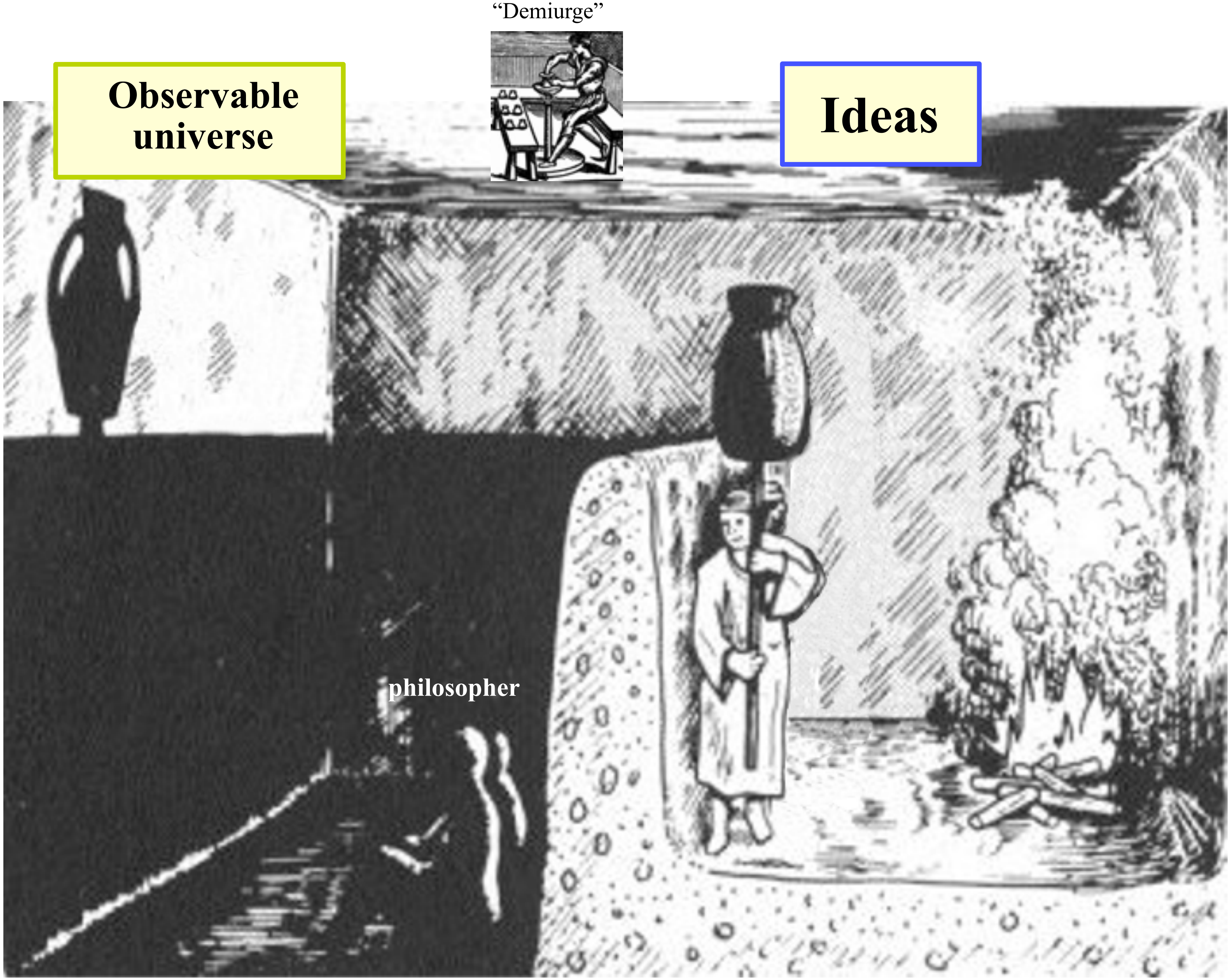
Plato's allegory of the cave*



Laszlo Szücs, image from criticalthinking-mc205.wikispaces.com

* The Republic (514a-520a)

Plato's allegory of the cave*



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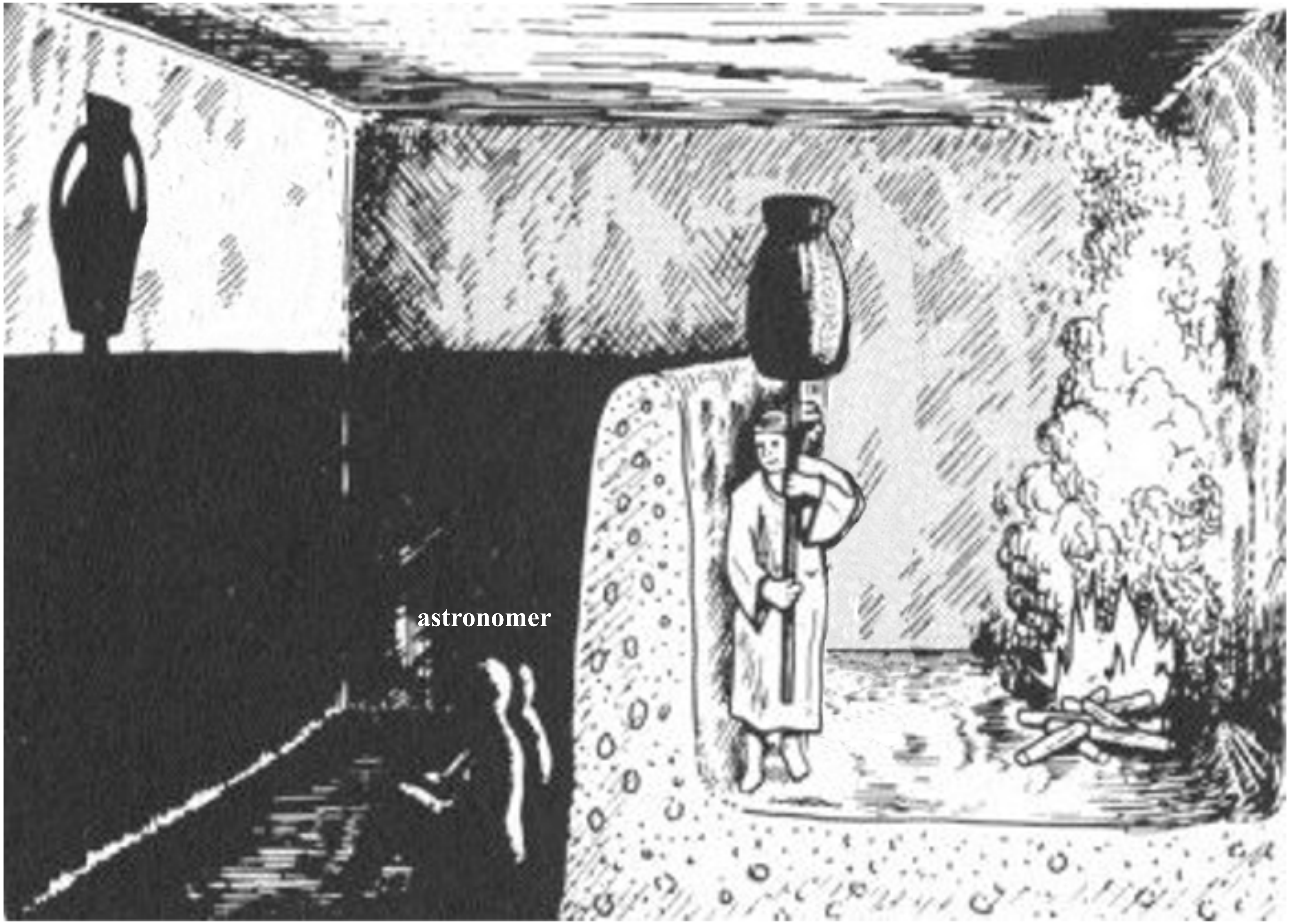
Laszlo Szücs, image from criticalthinking-mc205.wikispaces.com

Plato's allegory of the cave* ↔ Astronomical observations



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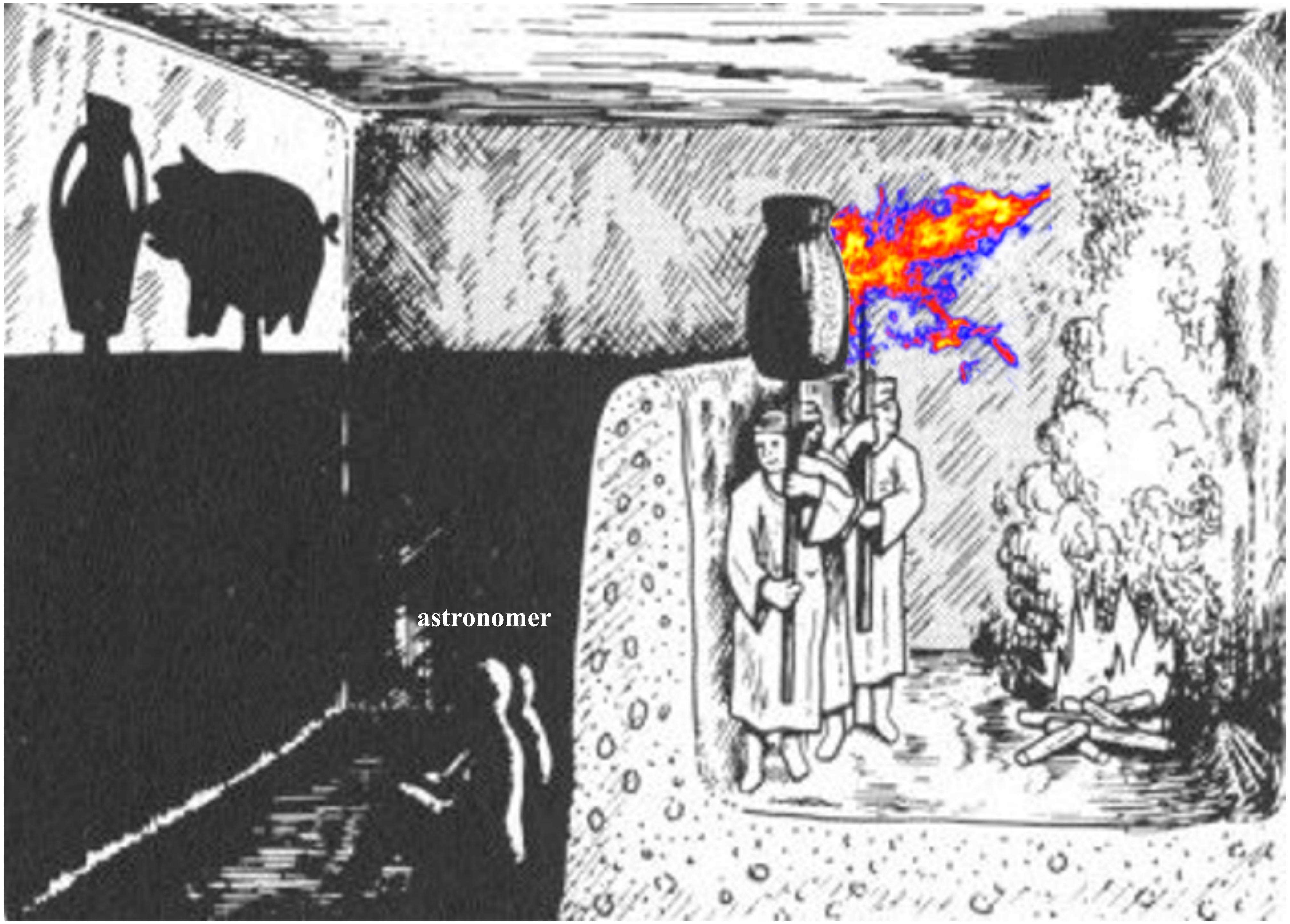

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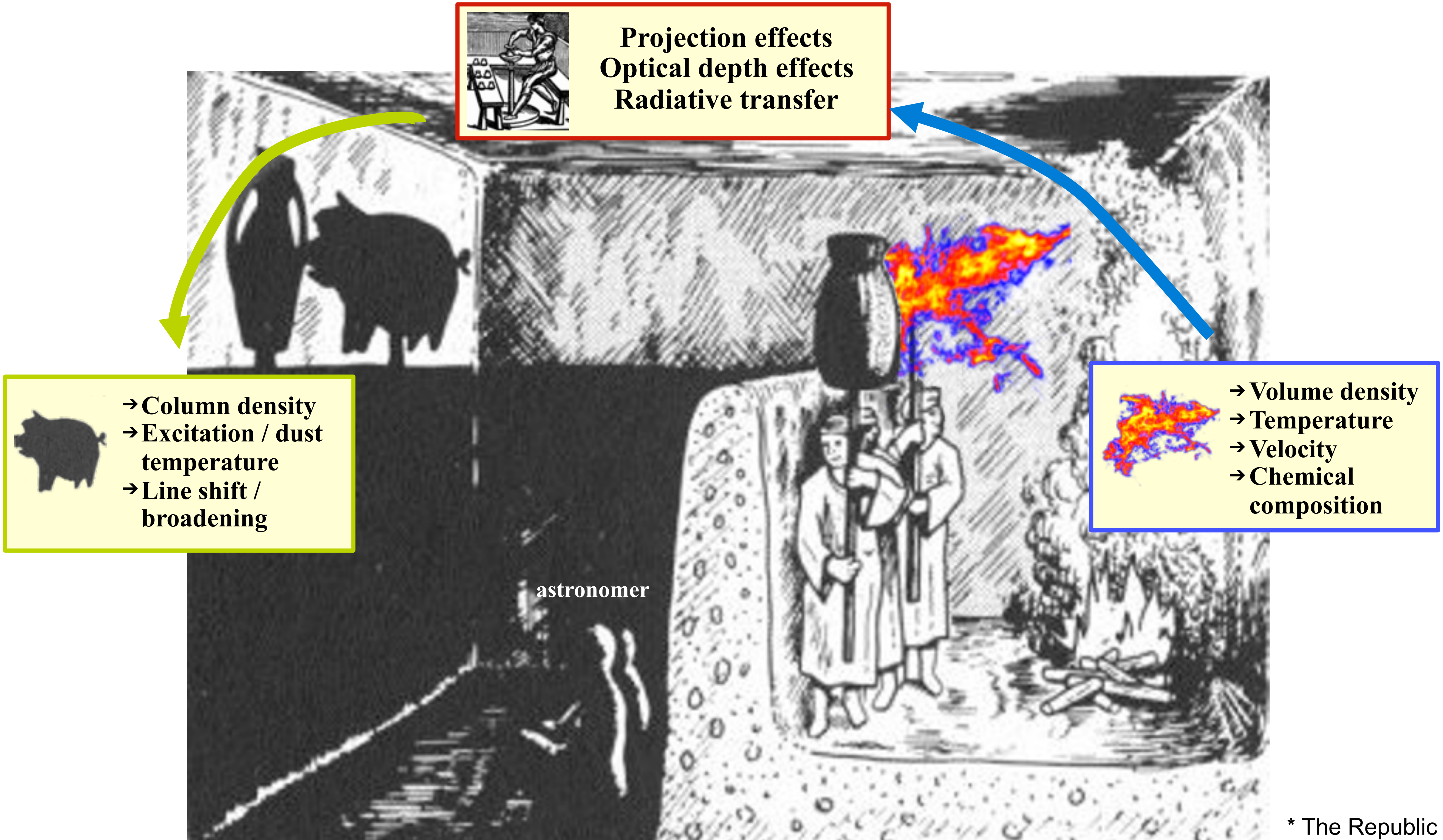

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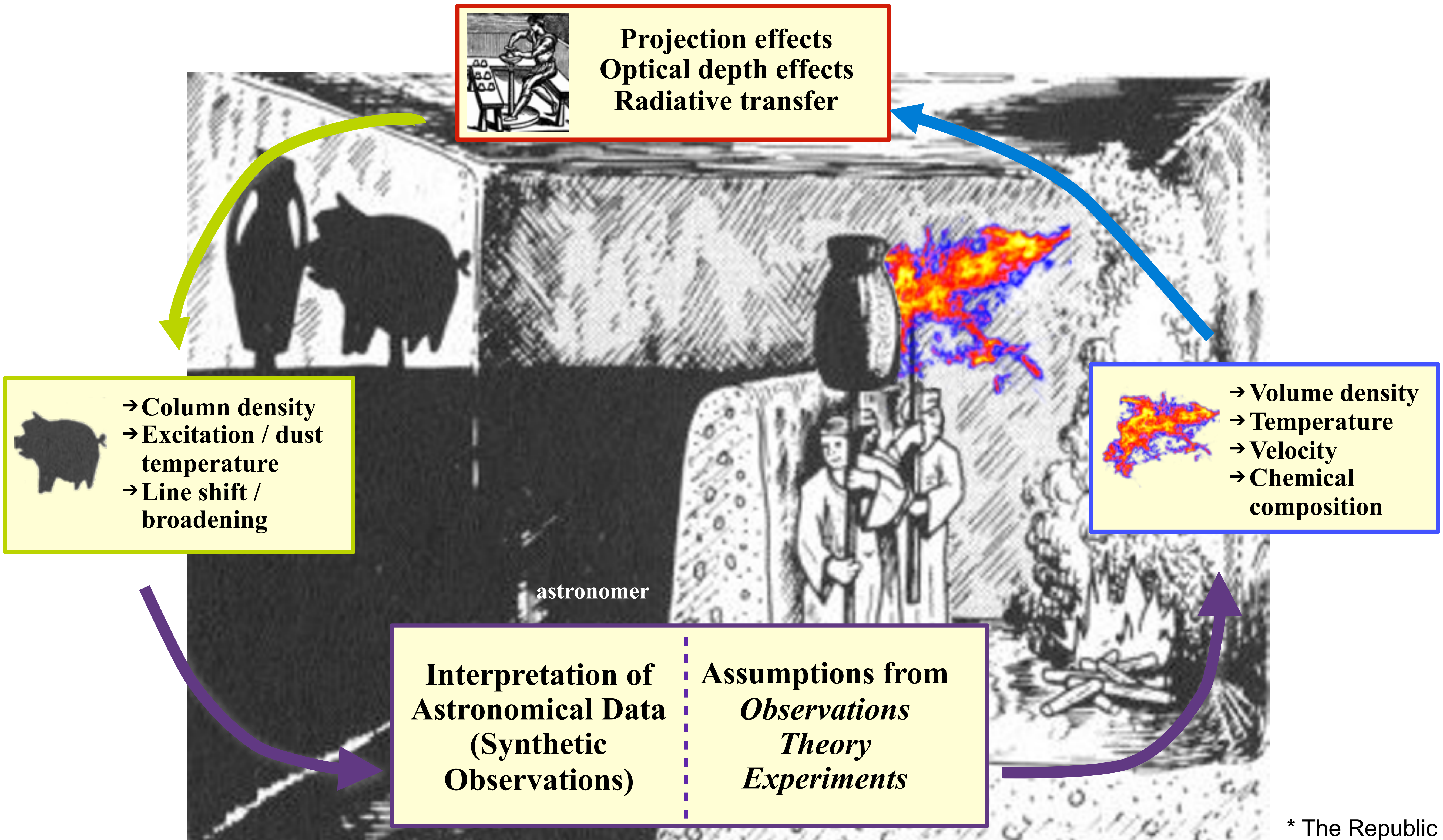


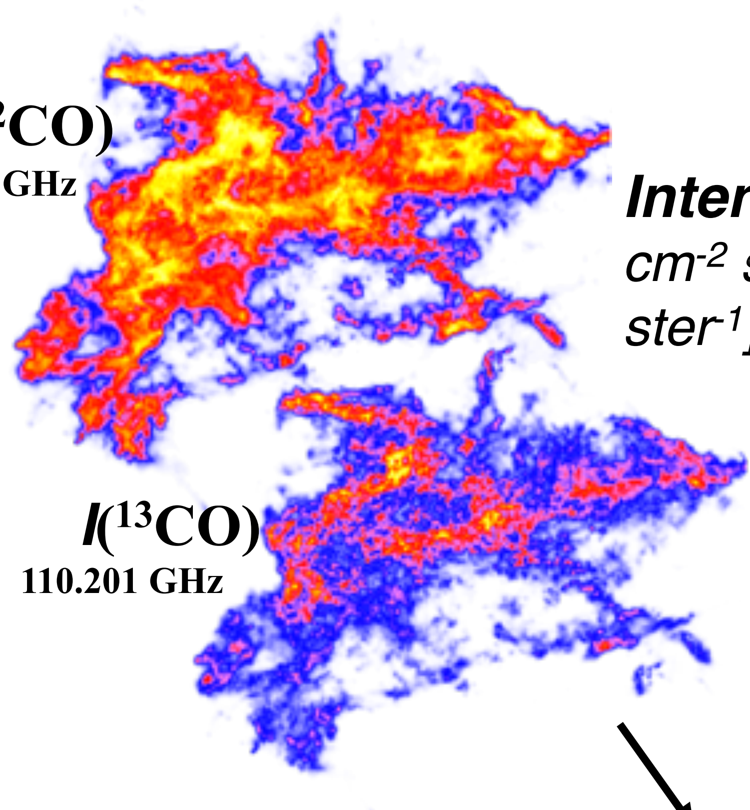
Laszlo Szücs, image from criticalthinking-mc205.wikispaces.com

* The Republic (514a-520a)

Example: from CO emission to total column density

J=1-0

$I(^{12}CO)$ 115.271 GHz



$I(^{13}CO)$ 110.201 GHz

Intensity [erg cm^{-2} s^{-1} Hz^{-1} ster^{-1}]

Brightness temperature [K]

T_B^{12}

T_B^{13}

Following Wilson et al. 2009

Assumptions I.

$I(^{12}CO)$ is optically thick

$I(^{13}CO)$ is optically thin

Along a line of sight uniform T_{ex} and same for ^{12}CO and ^{13}CO

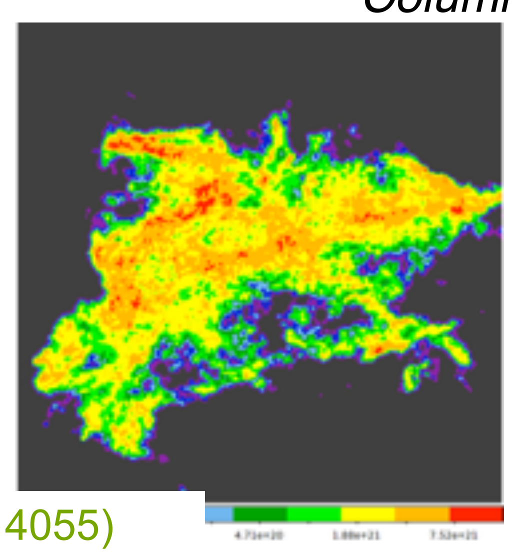
$$T_{\rm ex} = 5.5/\ln\left(1 + \frac{5.5}{T_B^{12} + 0.82}\right)$$

$$\tau_{13}(v) = -\ln\left[1 - \frac{T_{\rm B}^{13}}{5.3}\left\{\exp\left(\frac{5.3}{T_{\rm ex}} - 1\right)^{-1} - 0.16\right\}^{-1}\right],$$

LTE

$$N(^{13}{\rm CO}) = 3.0 \times 10^{14}\frac{T_{\rm ex}\int \tau_{13}(v)dv}{1 - \exp(-5.3/T_{\rm ex})}$$

Column density [cm^{-2}]



Assumptions II.

Uniform $N(^{12}CO)/N(^{13}CO)$ ~ 60 *

$N(H_2)/N(^{12}CO)$ ratio ~ 6.6×10^3 **

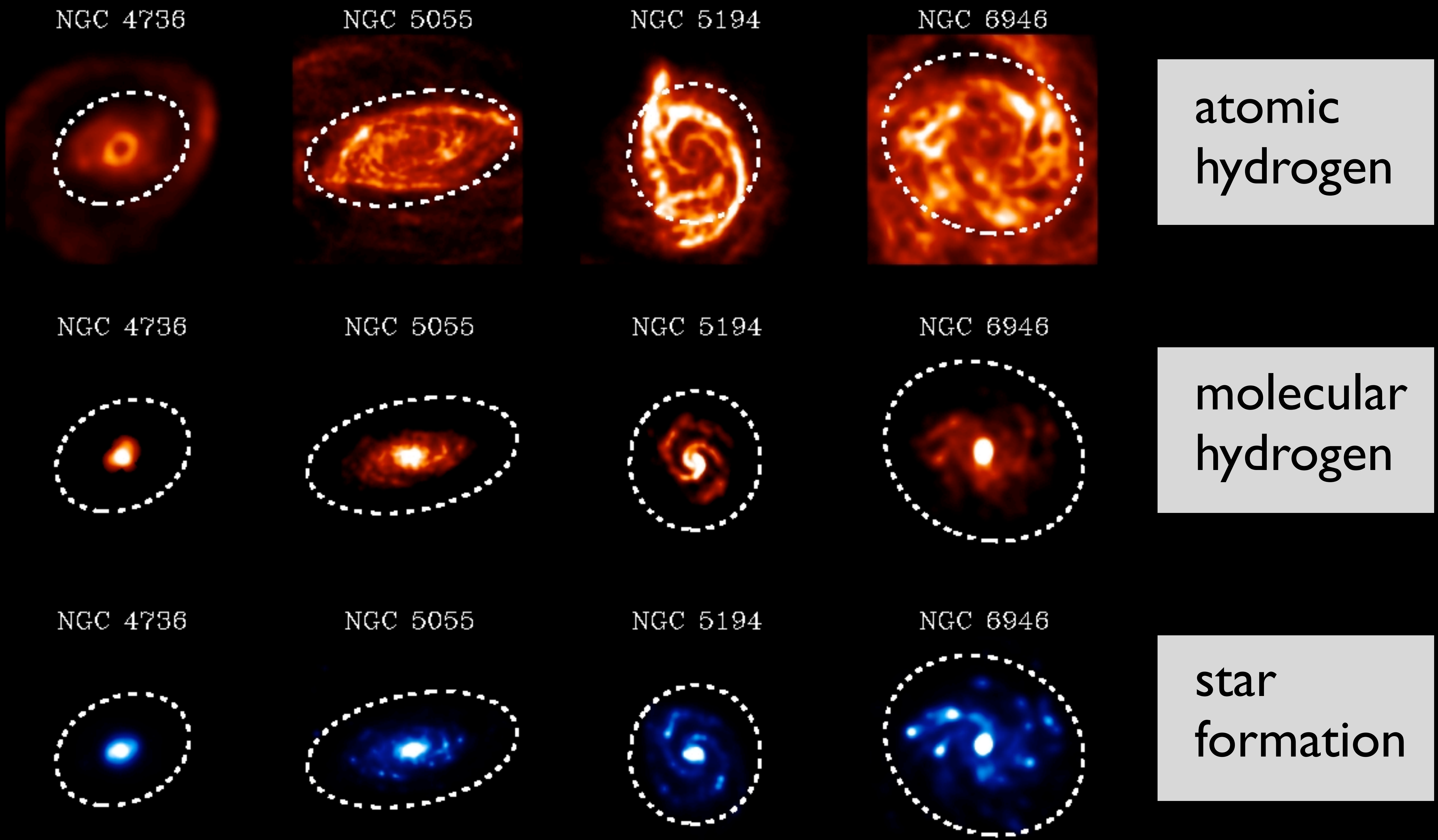
Astrophysical interpretation

Laszlo Szücs et al. (2014, MNRAS, 445, 4055)

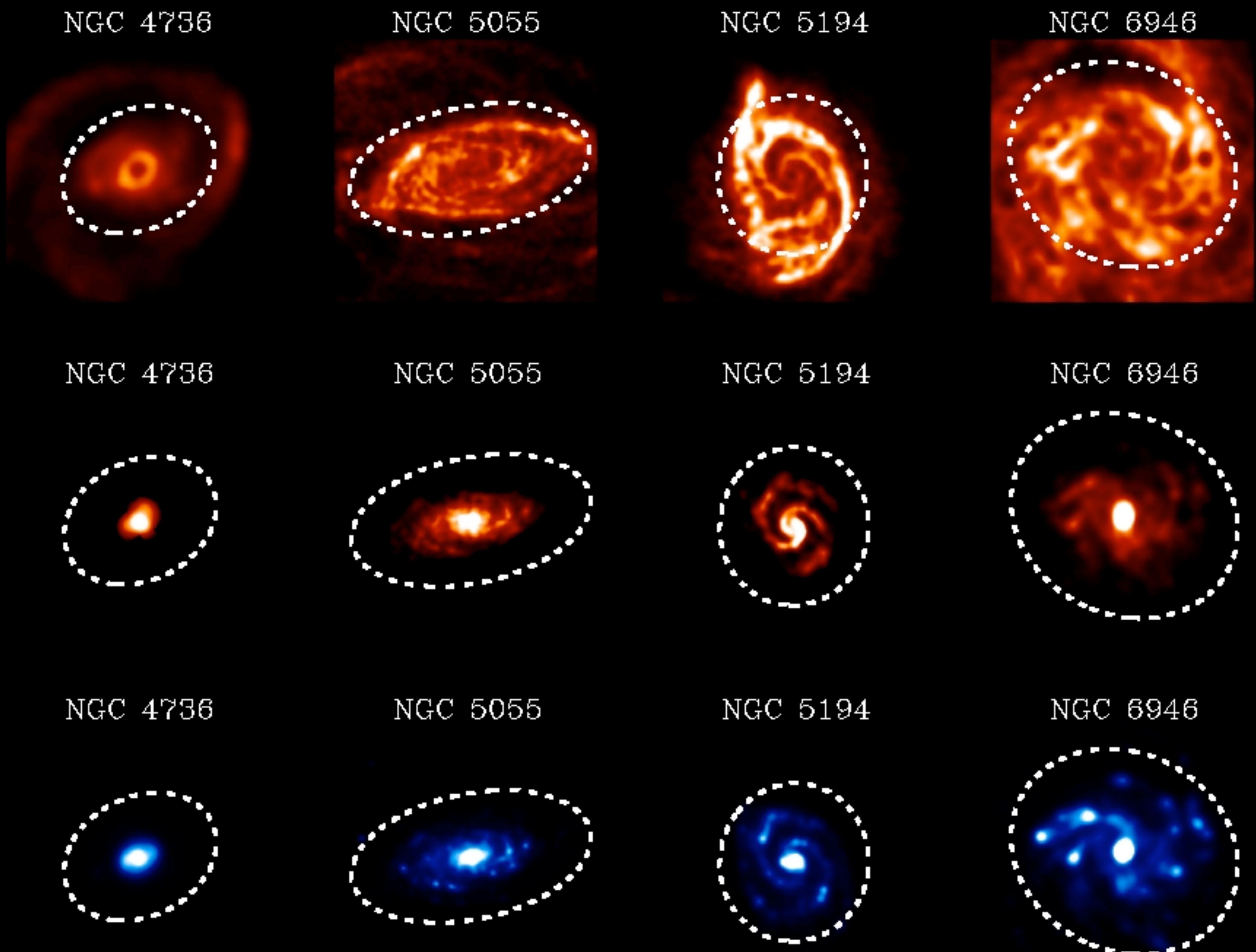
* Langer & Penzias (1990)

** Pineda et al. (2009)


global SF relations



galaxies from THINGS and HERACLES survey
(images from Frank Bigiel, ZAH/ITA)



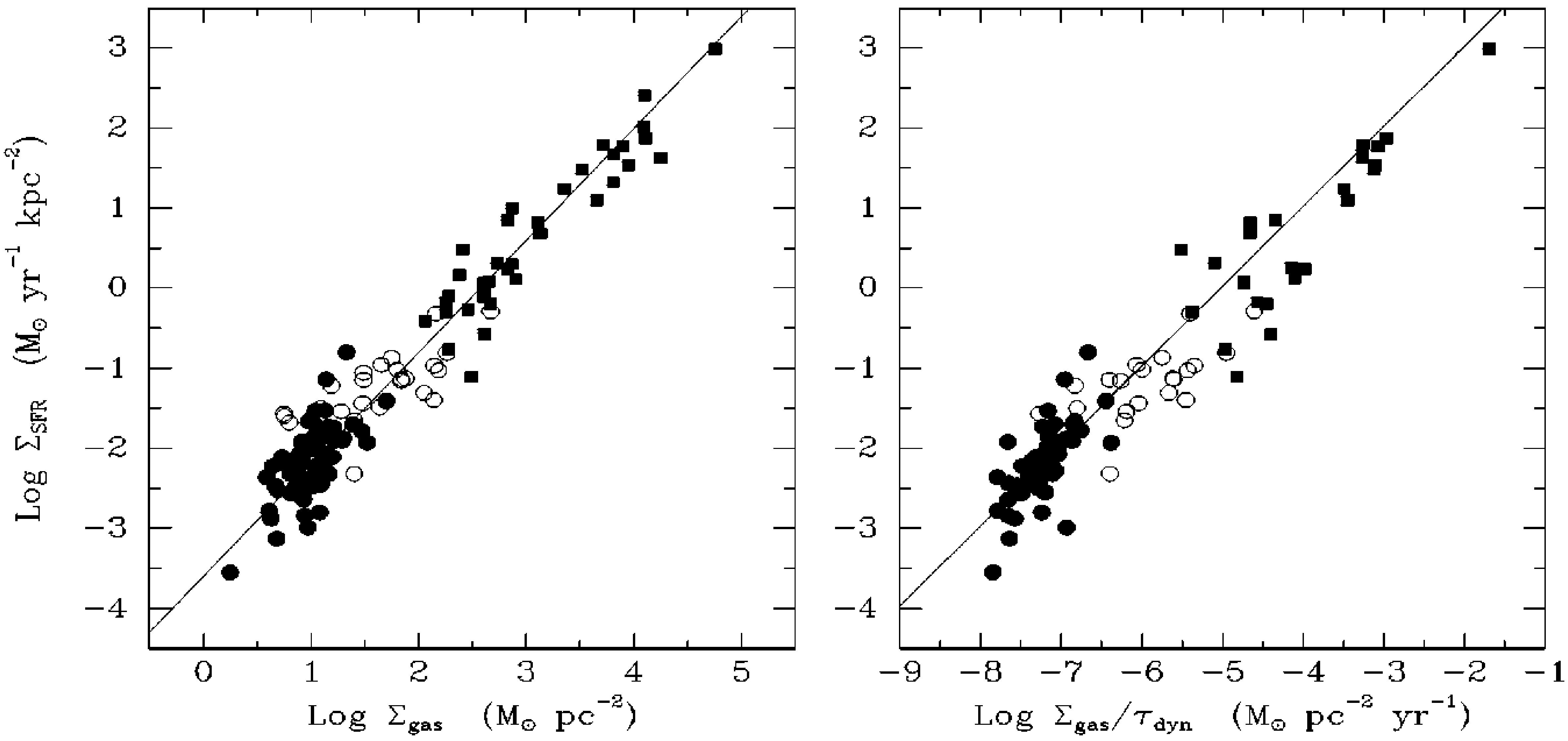
atomic hydrogen

molecular hydrogen

star formation

- HI gas more extended
- H2 and SF well correlated

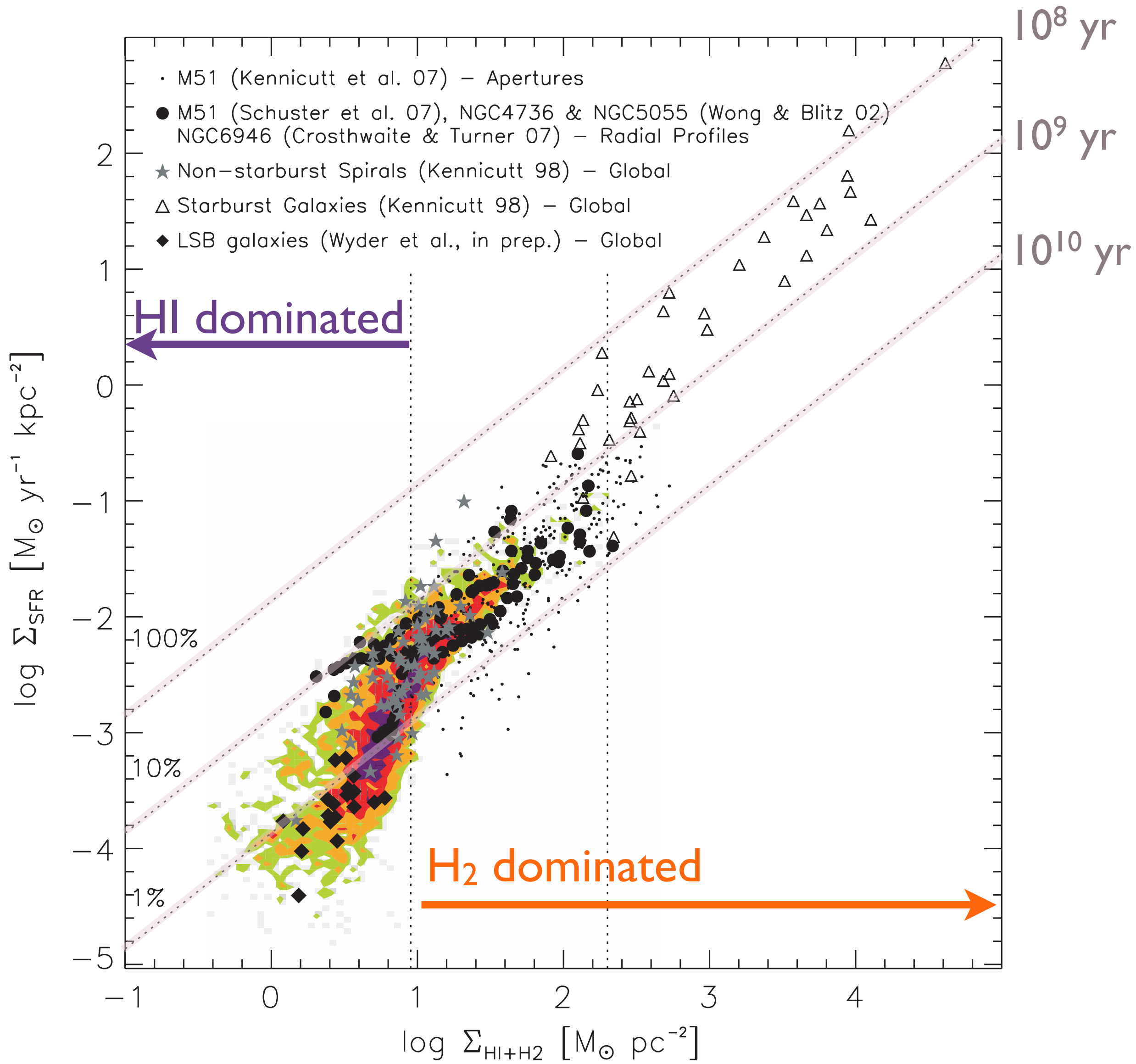
galaxies from THINGS and HERACLES survey
(images from Frank Bigiel, ZAH/ITA)



Kennicutt (1998, ARAA, 36, 189)

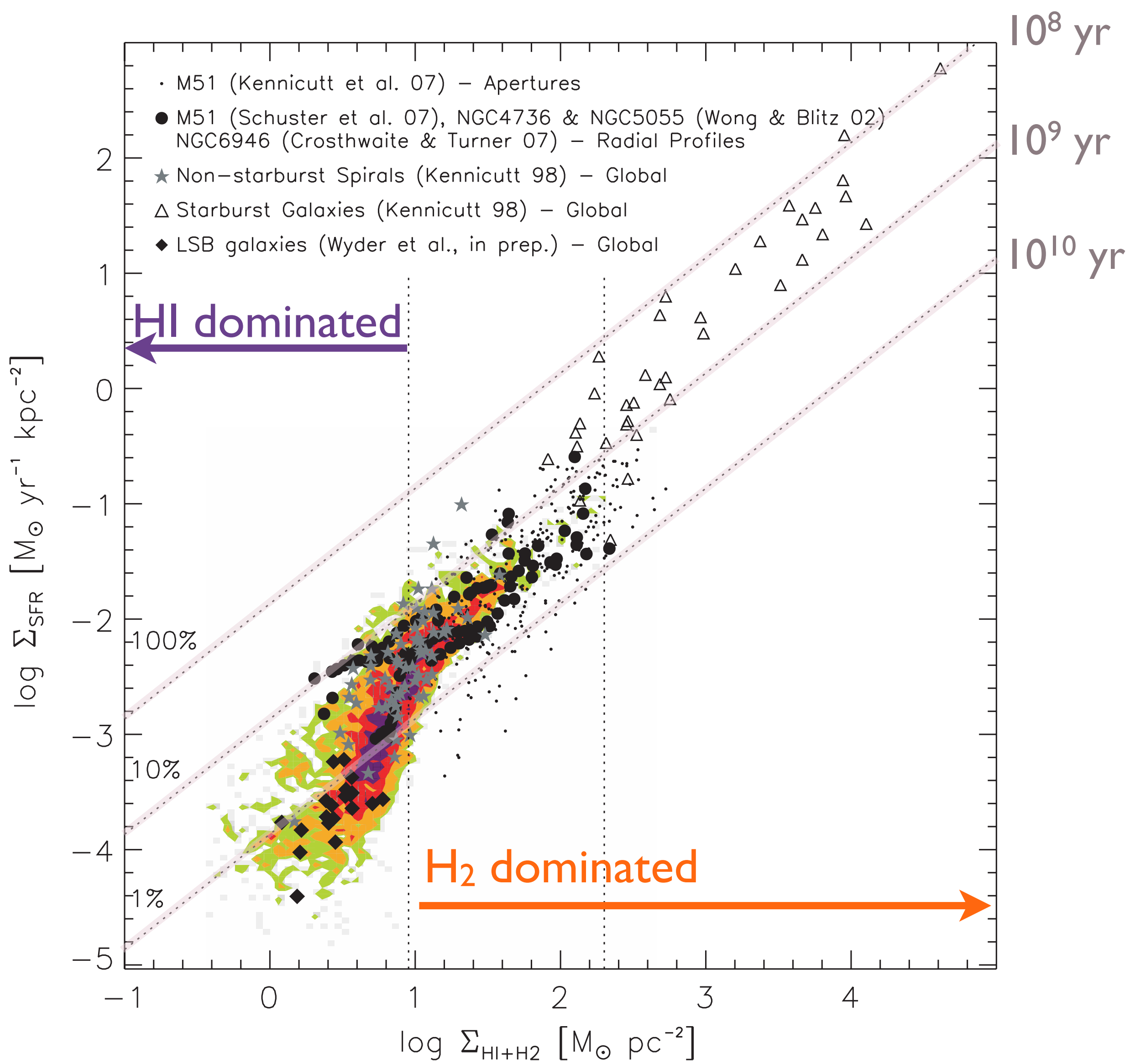
- when considering galaxies as a whole, there seems to be a ***super-linear relation*** between total gas *(H_2+H)* and the star formation rate *(SFR)* with slope ~1.4:

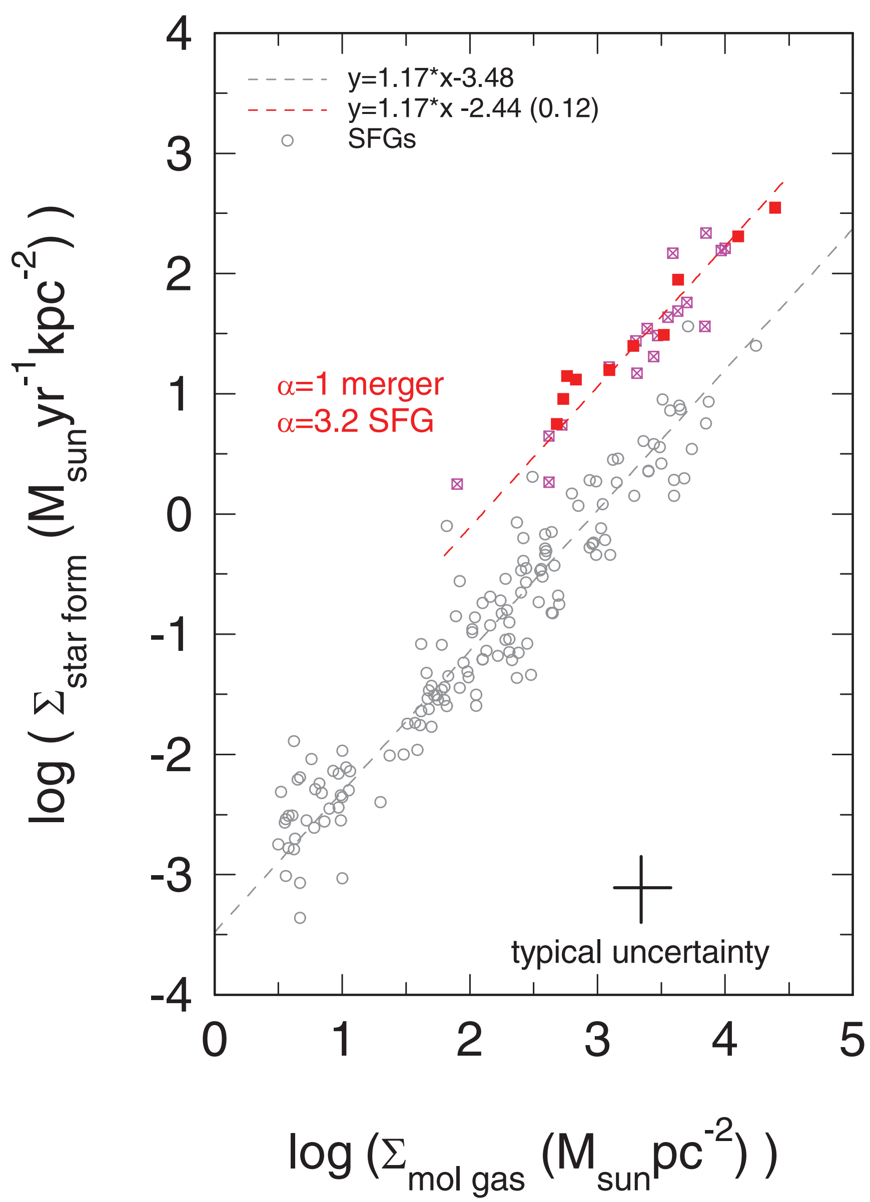
$$\Sigma_{SFR} = (2.5 \pm 0.7) \times 10^{-4} \left(\frac{\Sigma_{gas}}{1\ M_\odot\ \mathrm{pc}^{-2}} \right)^{1.4 \pm 0.15} M_\odot\ \mathrm{year}^{-1}\,\mathrm{kpc}^{-2}$$



Bigiel et al. (2008, AJ, 136, 2846)

- for "resolved" galaxies on scales of 0.5-1 kpc, there seems to be a ***linear relation*** between ***H_2 and SFR***
- implying a roughly ***constant depletion time*** of a few x 10^9 yr

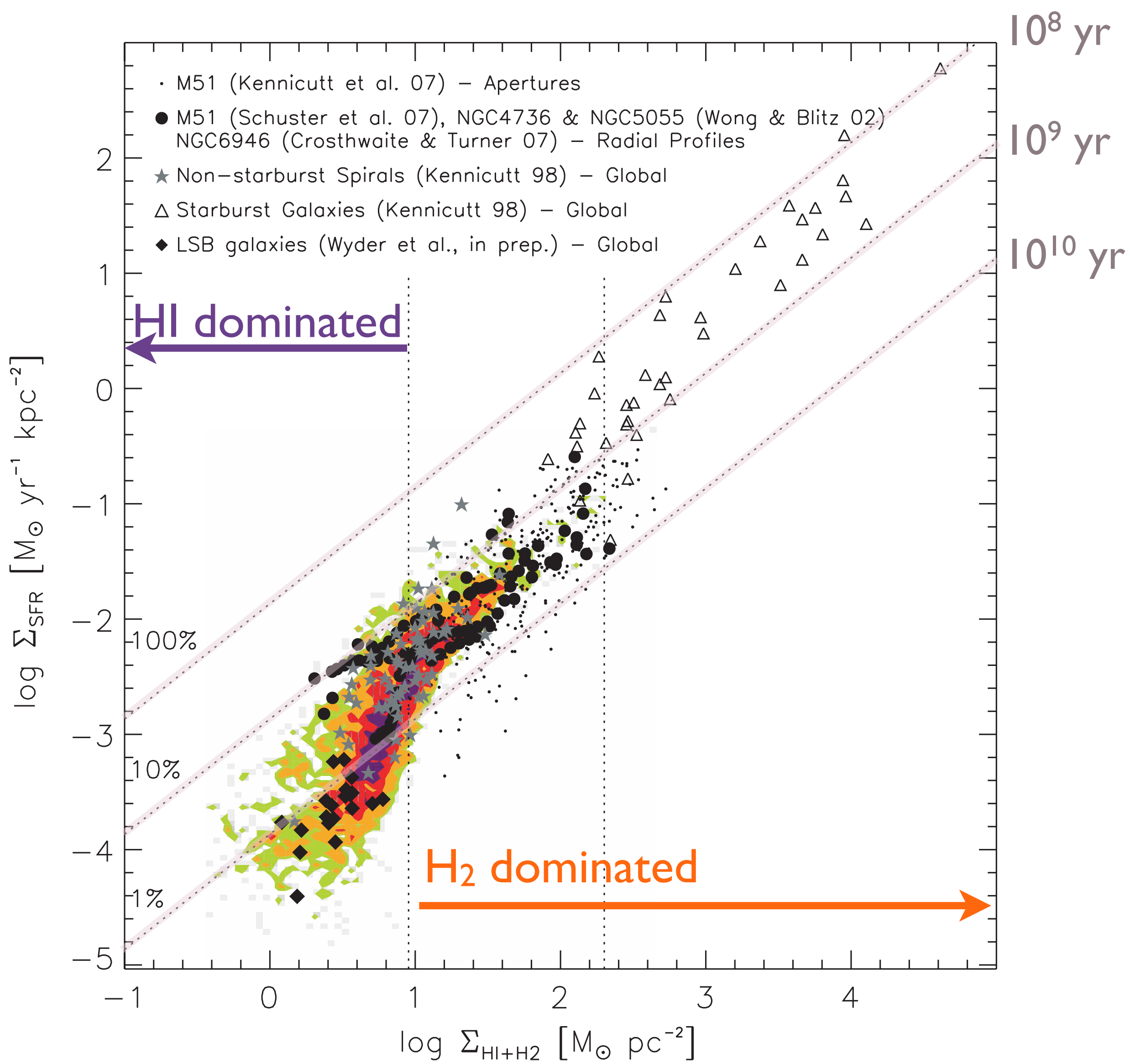




Bigiel et al. (2008, AJ, 136, 2846)

Genzel et al. (2010, MNRAS, AJ, 407, 2091)

- for “resolved” galaxies on scales of 0.5-1 kpc, there seems to be a ***linear relation*** between ***H_2 and SFR***
- implying a roughly ***constant depletion time*** of a few x 10^9 yr
- but with different normalization for starburst galaxies compared to normal ones



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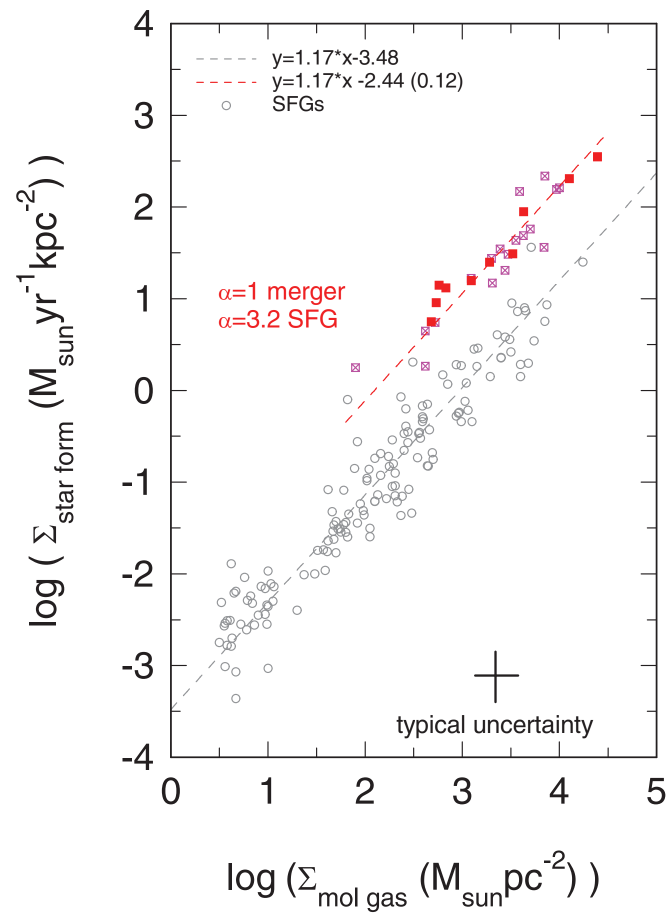

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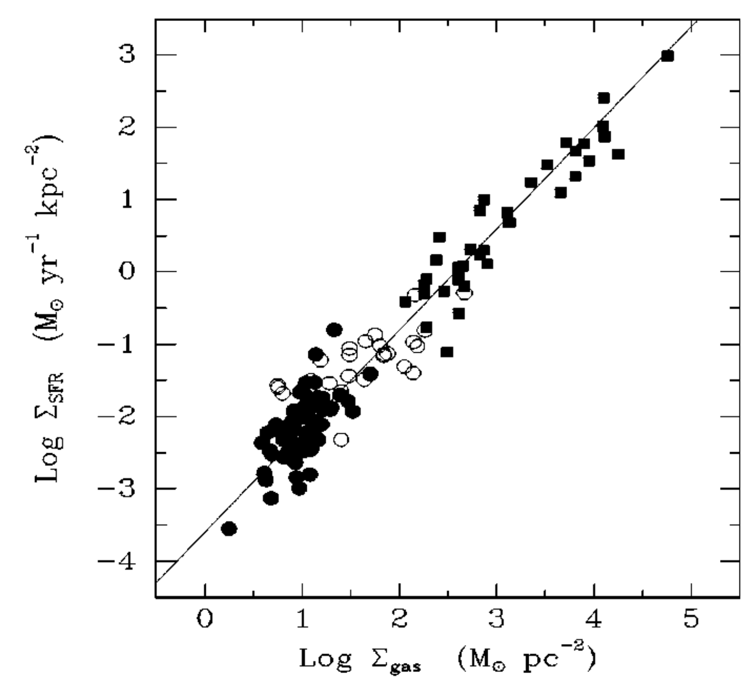
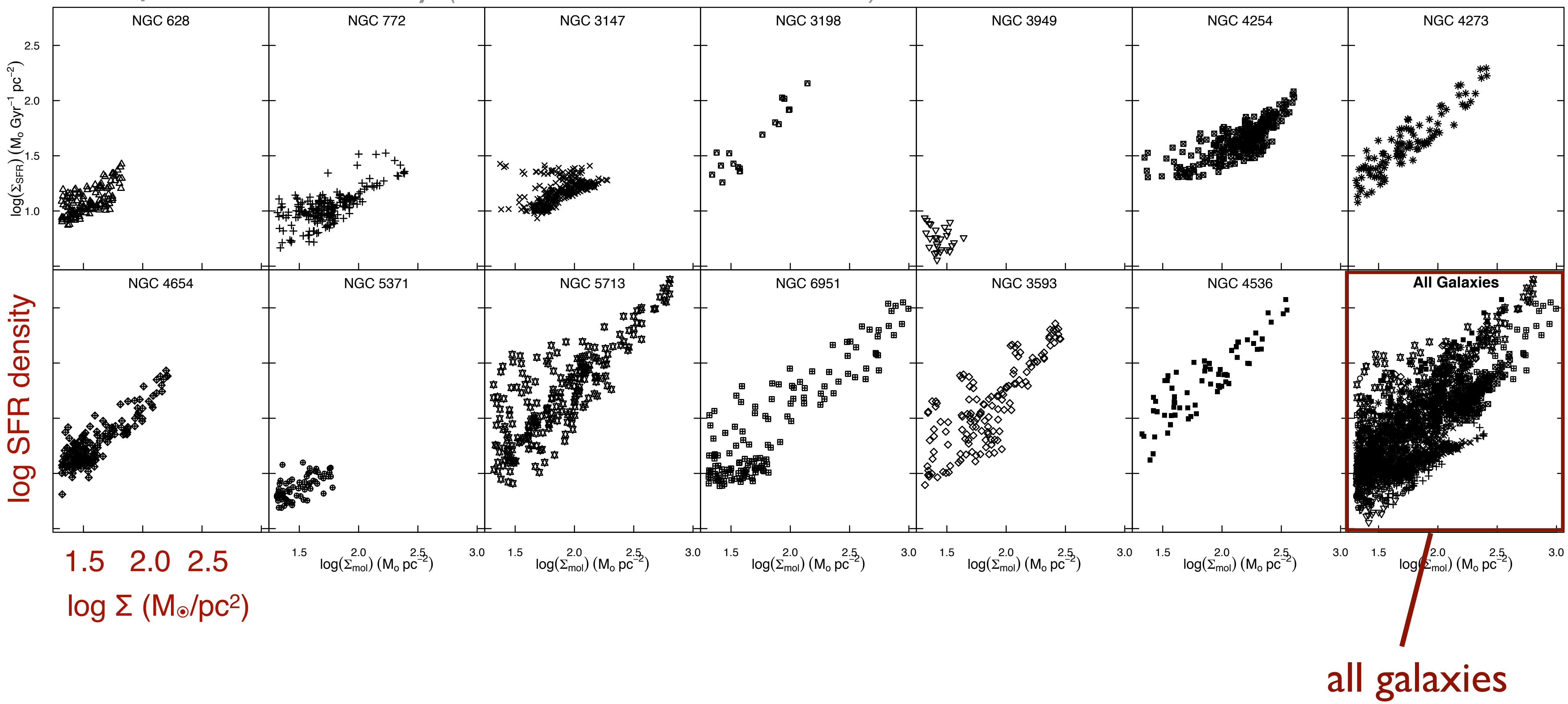


Kennicutt (1998, ARAA, 36, 189)

true physical behavior may be (much) ***more complicated*** than simple models assume!

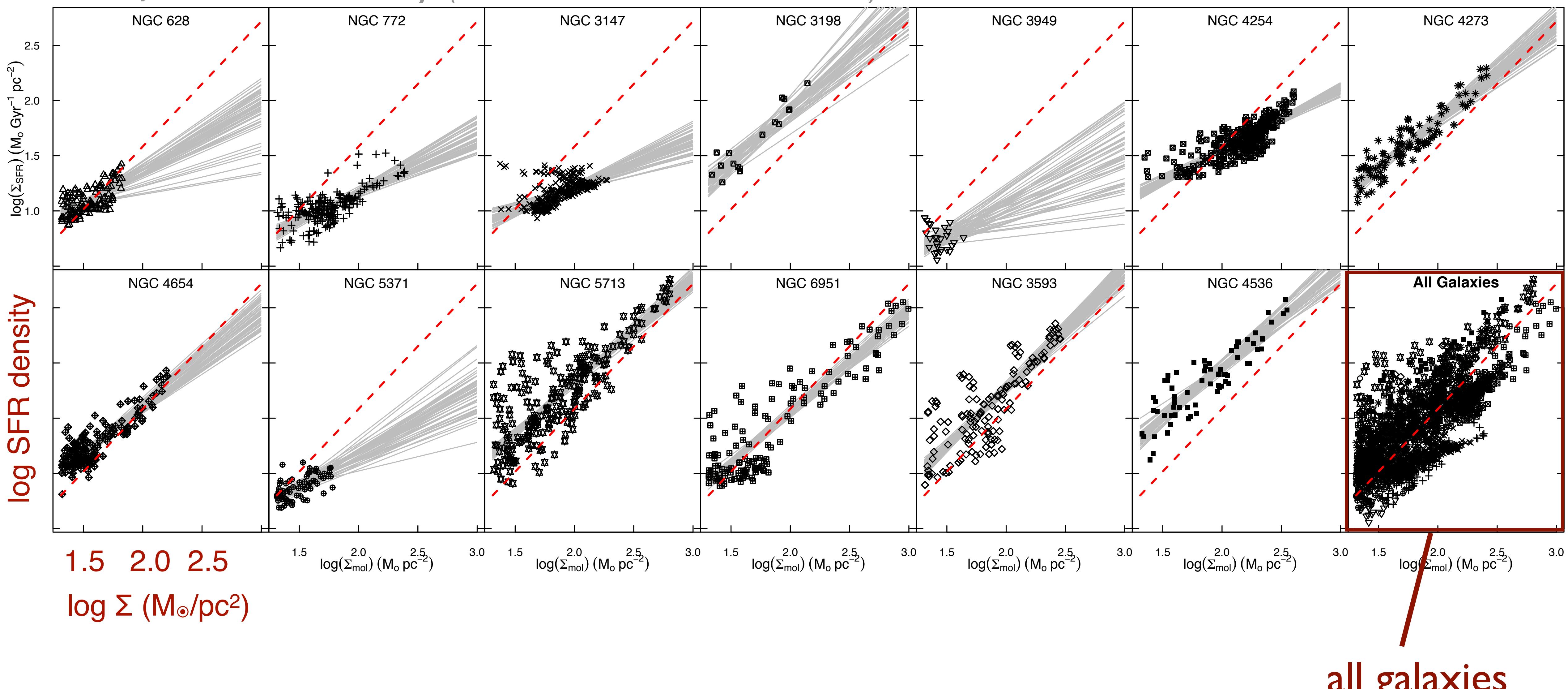
data from STING survey (Rahman et al. 2011, 2012)



- QUIZ: do you see a universal Σ_{H2} - Σ_{SFR} relation?

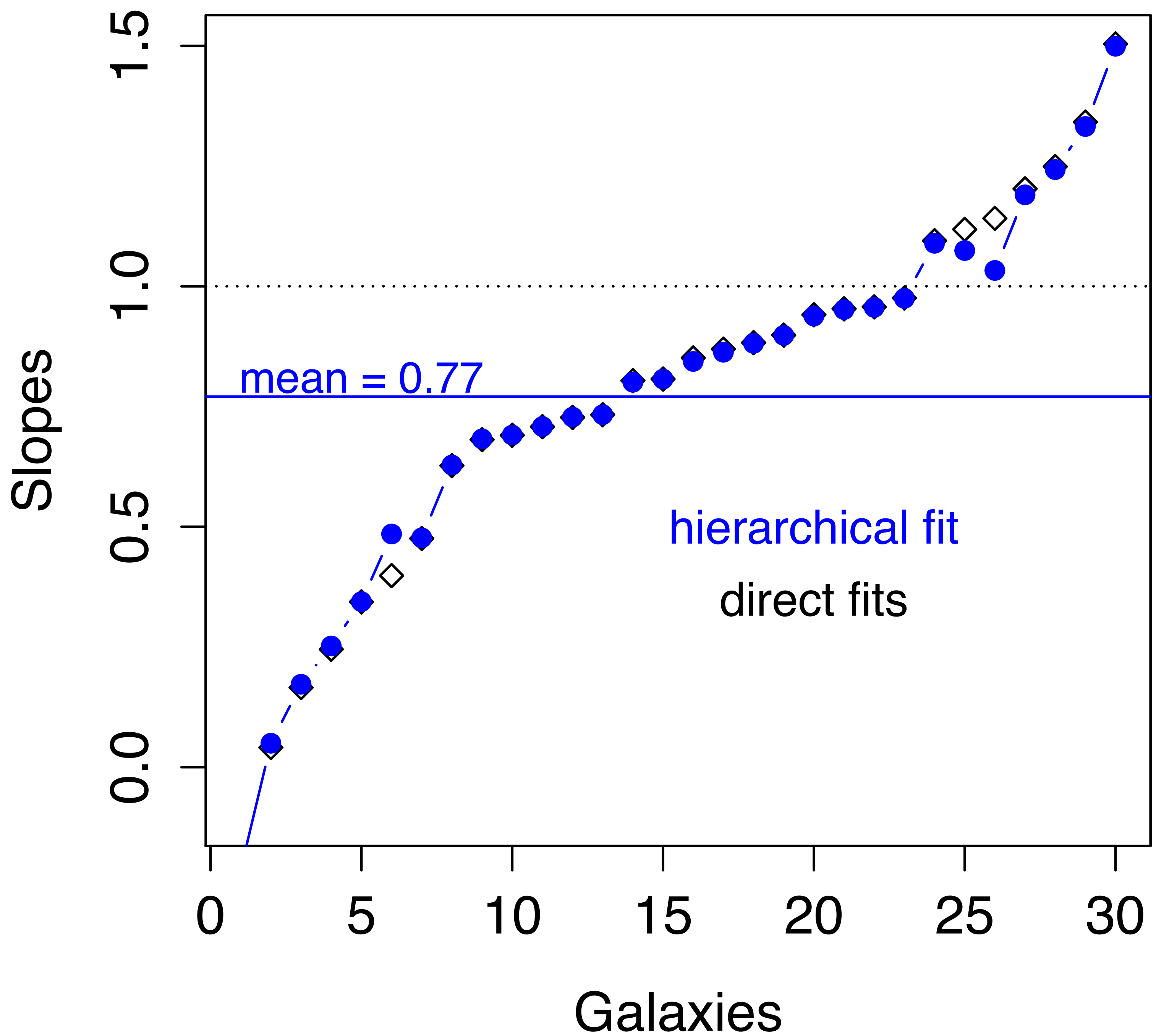
Shetty et al. (2014, MNRAS, 437, L61, see also Shetty, Kelly, Bigiel, 2013, MNRAS, 430, 288)

data from STING survey (Rahman et al. 2011, 2012)



- QUIZ: do we really see a universal Σ_{H2} - Σ_{SFR} relation?
- ANSWER: - large galaxy-to-galaxy variations
  - relation is often sublinear

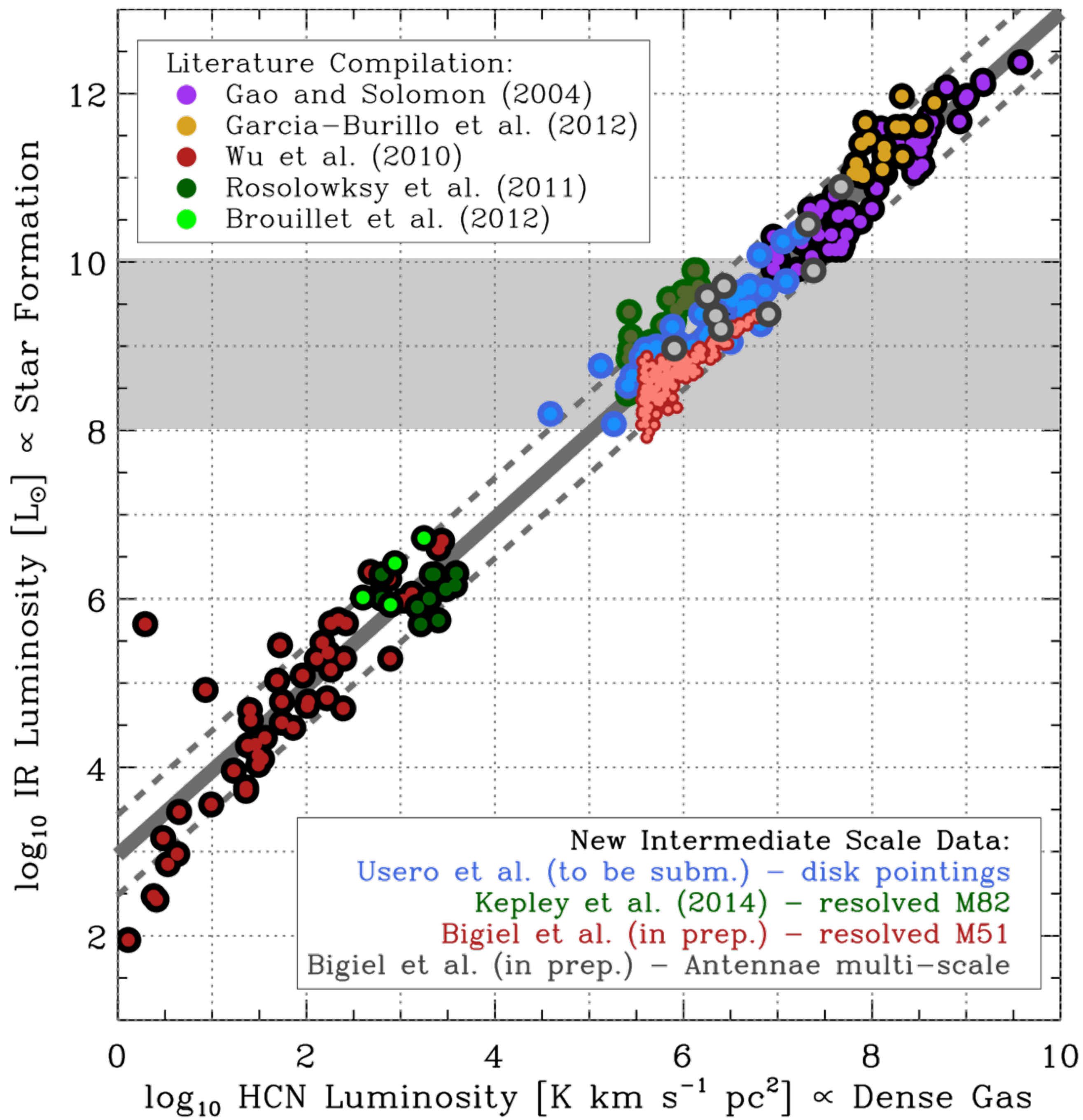
Shetty et al. (2014, MNRAS, 437, L61, see also Shetty, Kelly, Bigiel, 2013, MNRAS, 430, 288)



- analysis of THINGS/ HERACLES data
- many galaxies show sublinear KS-type relation

Image from R. Shetty / thanks to Adam Leroy for providing the THINGS/HERACLES data.

- *HOWEVER:* there seems to be a relation between SFR tracers and dense gas tracers that extends over many orders of magnitude *!!*
- this includes many different objects



New data:
Disk pointings (Usero et al.)
EMPIRE pilot: M51 pixels
Antenna pointings

figure from Frank Bigiel (ZAH/ITA)

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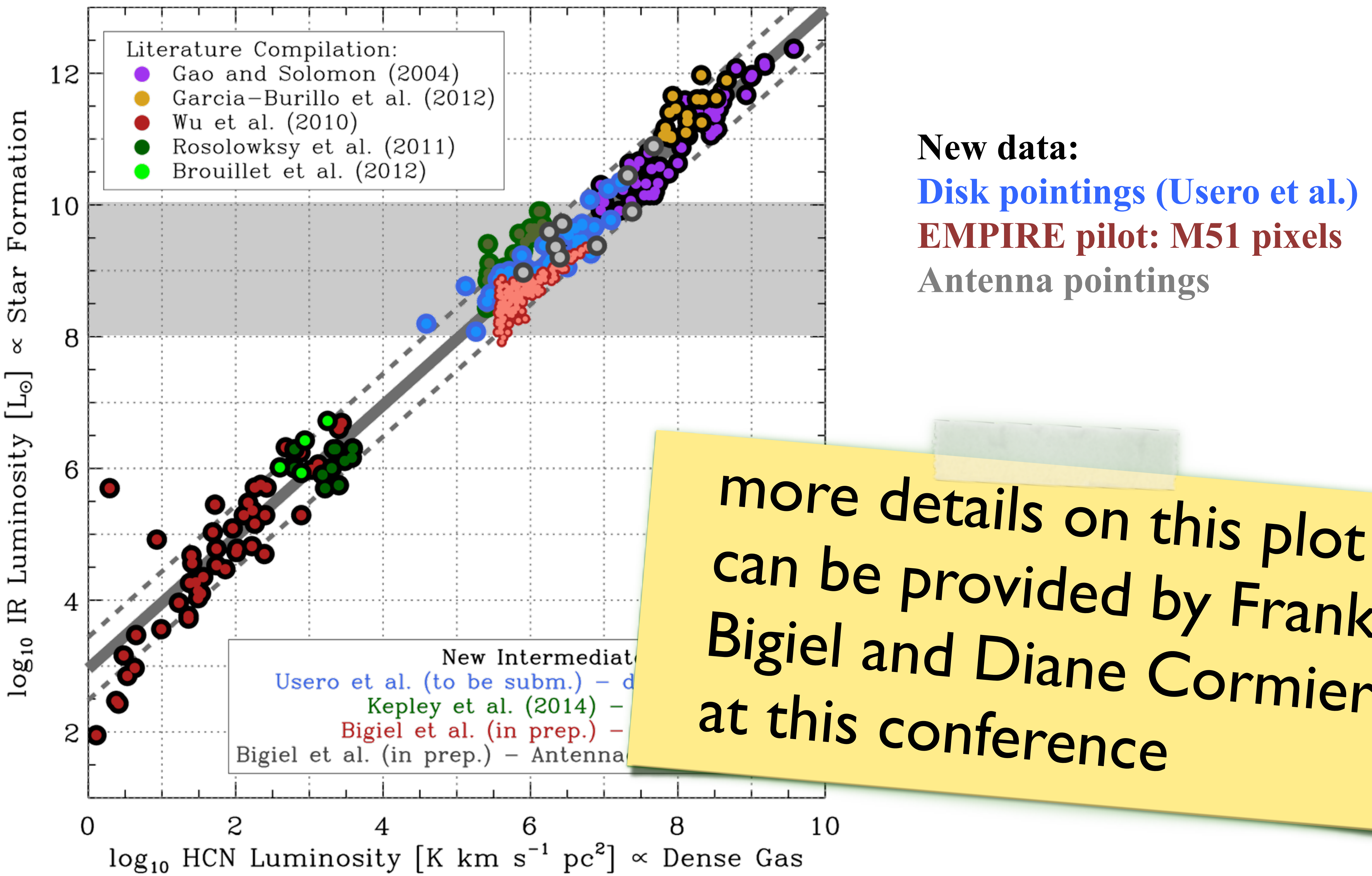
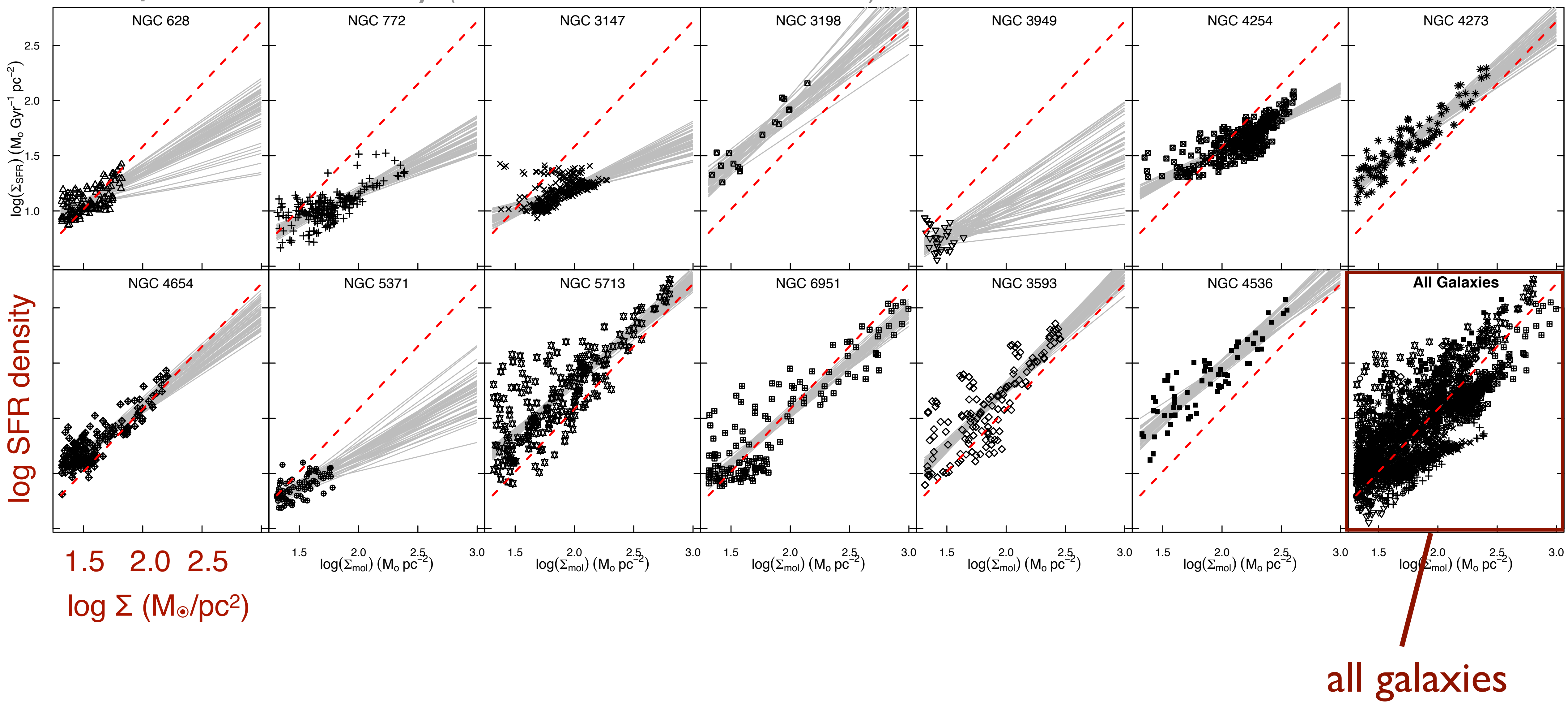


more details on this plot can be provided by Frank Bigiel and Diane Cormier at this conference

figure from Frank Bigiel (ZAH/ITA)

data from STING survey (Rahman et al. 2011, 2012)



Shetty et al. (2014, MNRAS, 437, L61, see also Shetty, Kelly, Bigiel, 2013, MNRAS, 430, 288)

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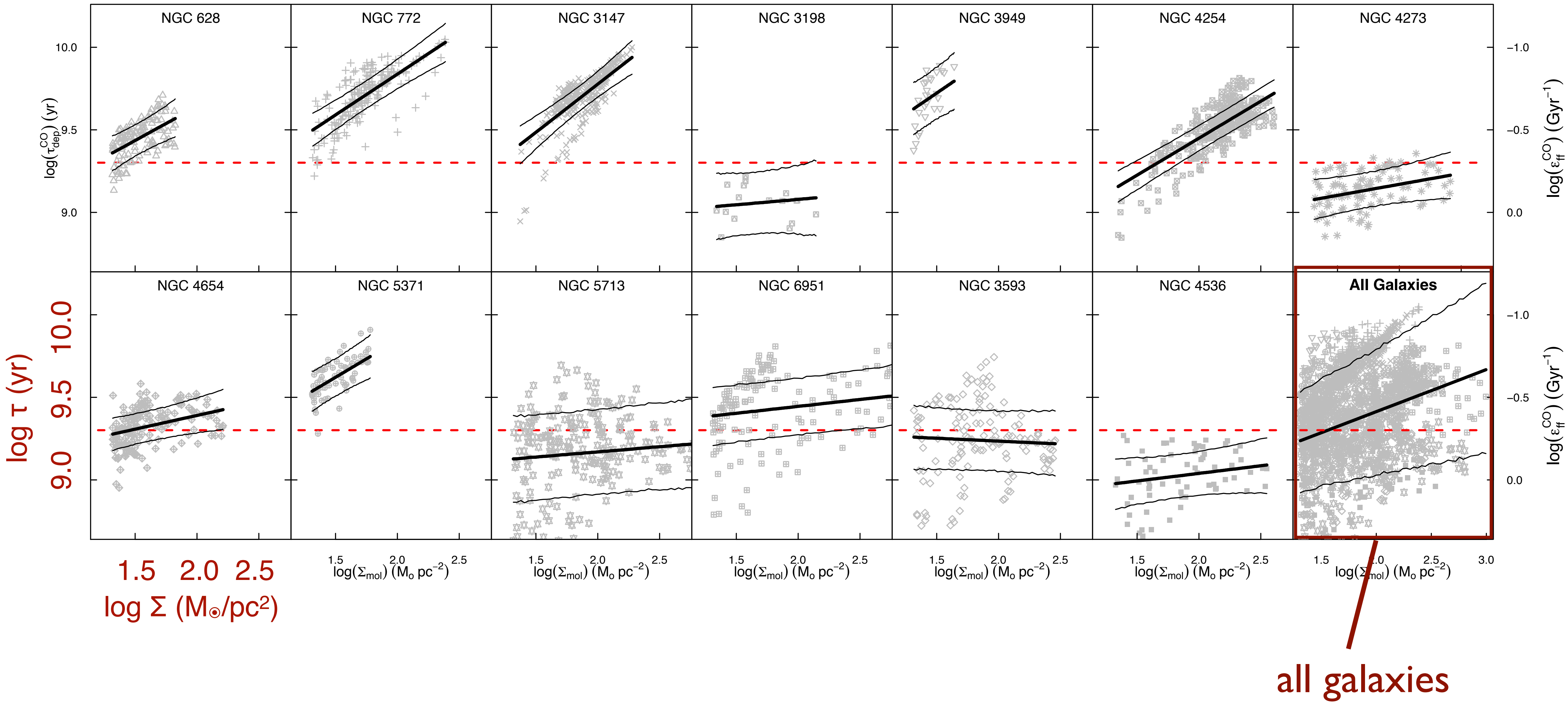
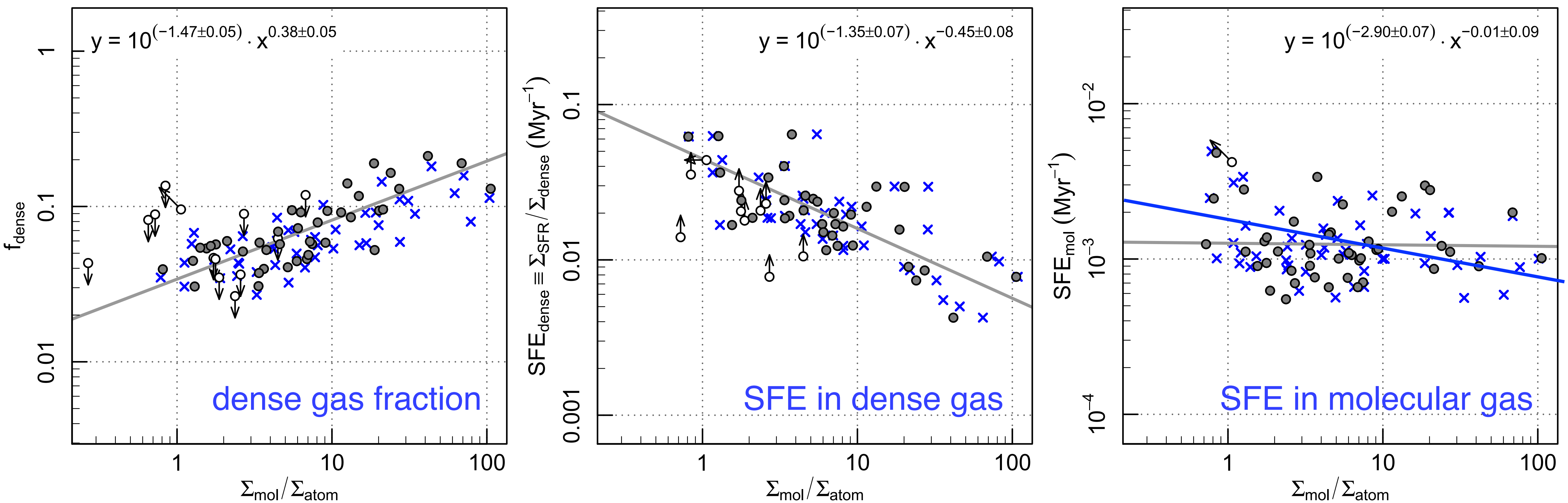


Hierarchical Bayesian model for STING galaxies indicate *varying depleting times*. Depletion time *increases* with increasing density. *Why ??*

Shetty et al. (2014, MNRAS, 437, L61)

- ***EMPIRE Survey (PI Frank Bigiel):***
- IR-to-HCN ratio varies systematically as function of local disk structure (here stellar surface density)
- dense gas is less good in forming stars in overall dense regions (longer depletion time)



- ***different galaxies in survey***

Usero (2015, ApJ, 150, 115)

- ***EMPIRE Survey (PI Frank Bigiel):***
- IR-to-HCN ratio varies systematically as function of local disk structure (here stellar surface density)
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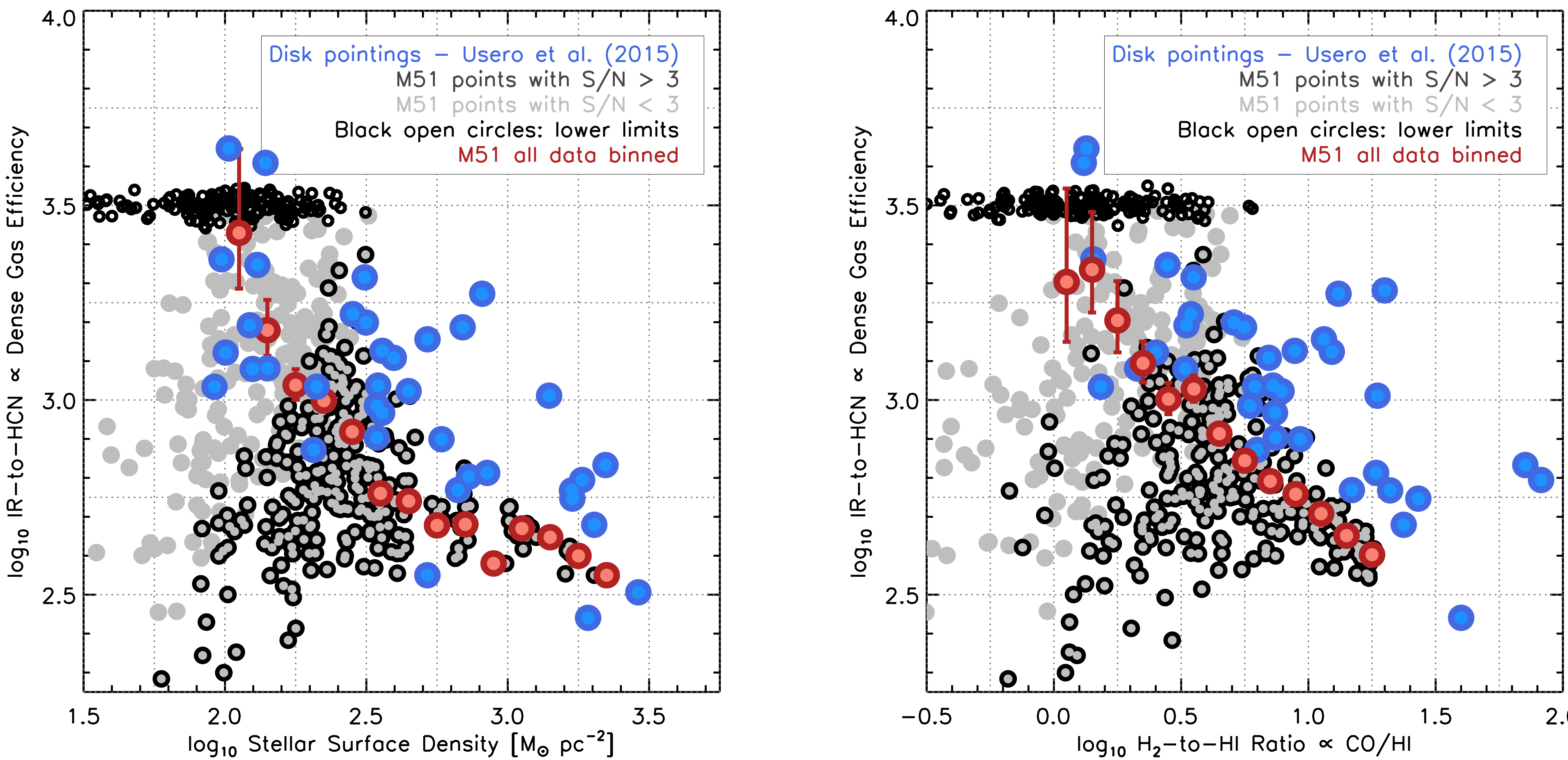
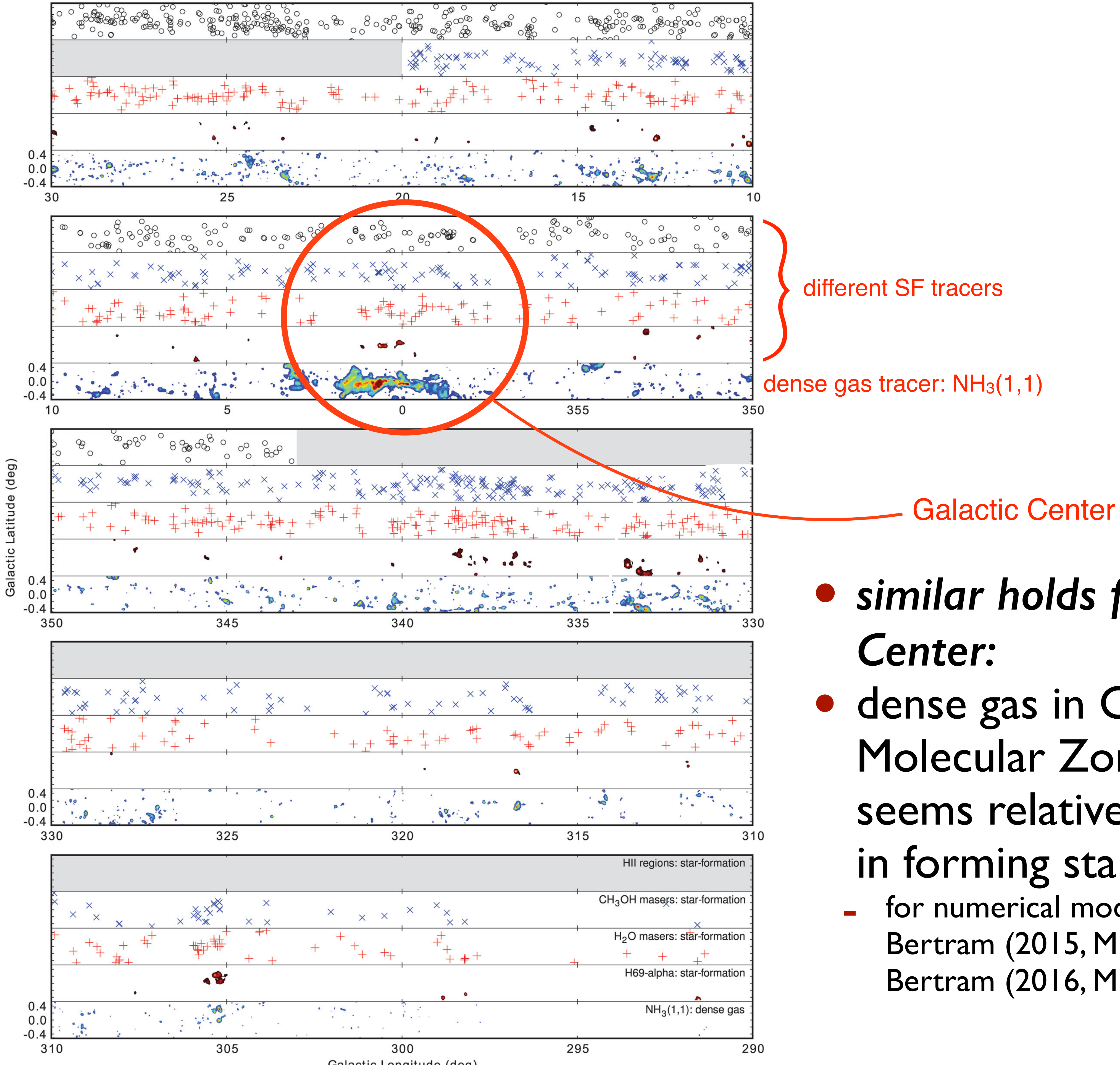


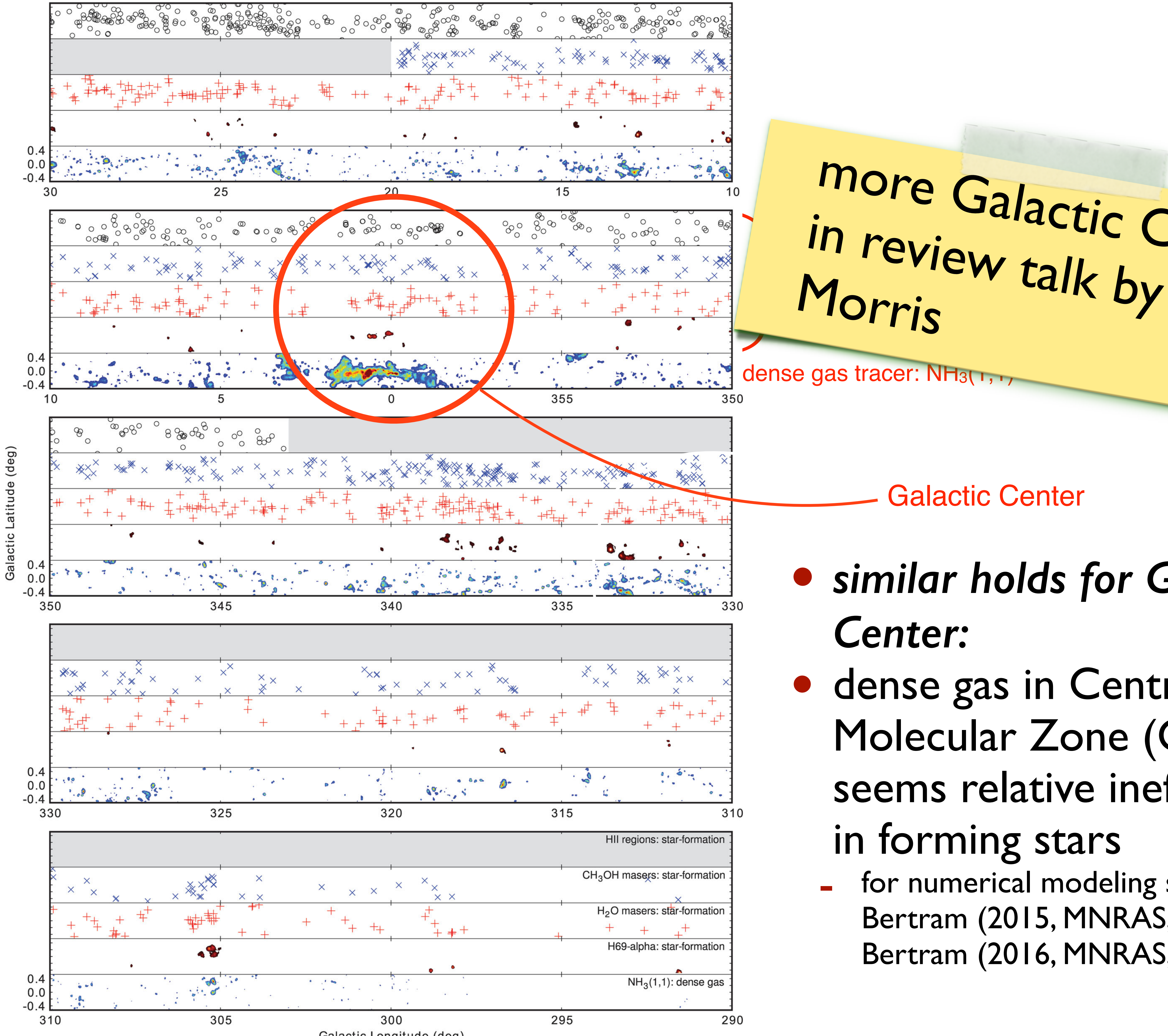
- ***resolved data in M51***

Bigiel et al. (2016, ApJ, 822, L26)



- ***similar holds for Galactic Center:***
- dense gas in Central Molecular Zone (CMZ) seems relative inefficient in forming stars
  - for numerical modeling see Bertram (2015, MNRAS, 451, 3679), Bertram (2016, MNRAS, 455, 3763)

Longmore et al. (2013, MNRAS 429, 987)



more Galactic Center in review talk by Mark Morris

- ***similar holds for Galactic Center:***
- dense gas in Central Molecular Zone (CMZ) seems relative inefficient in forming stars
  - for numerical modeling see Bertram (2015, MNRAS, 451, 3679), Bertram (2016, MNRAS, 455, 3763)

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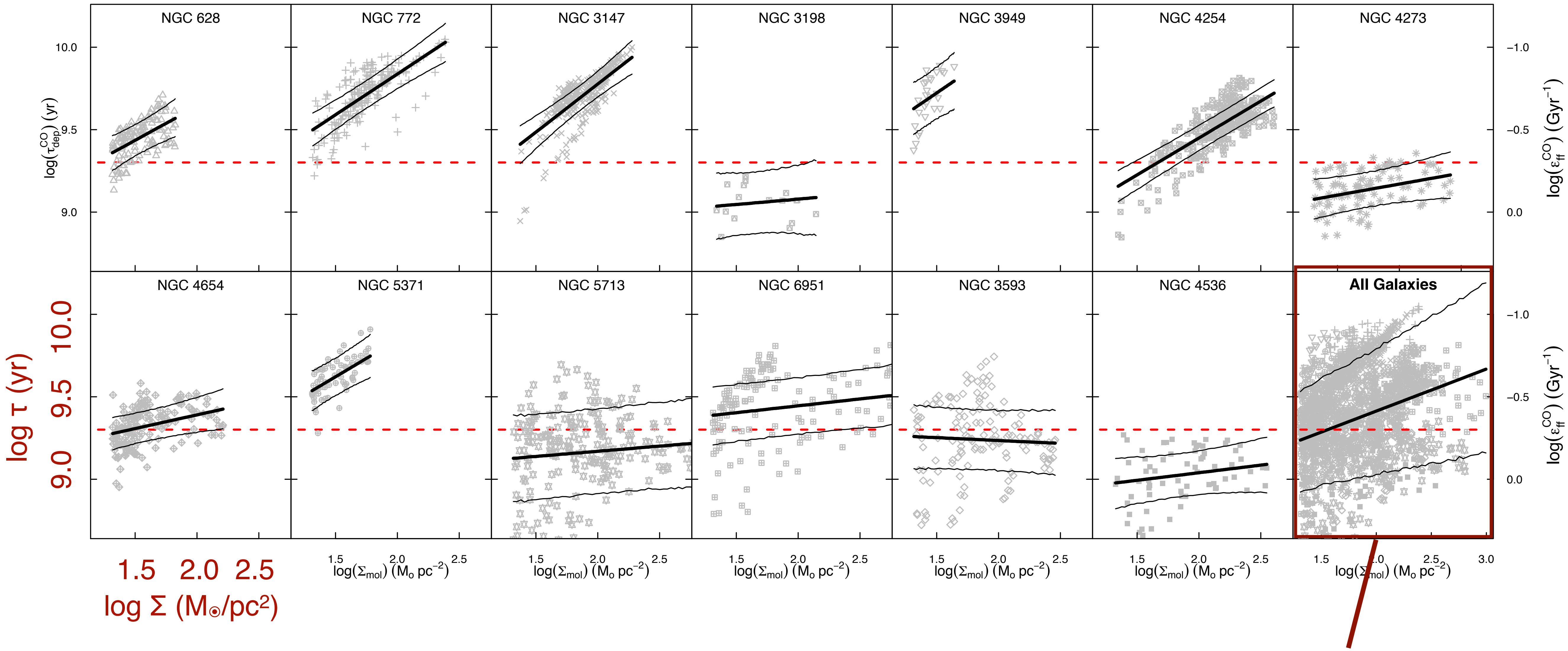
data from STING survey (Rahman et al. 2011, 2012)

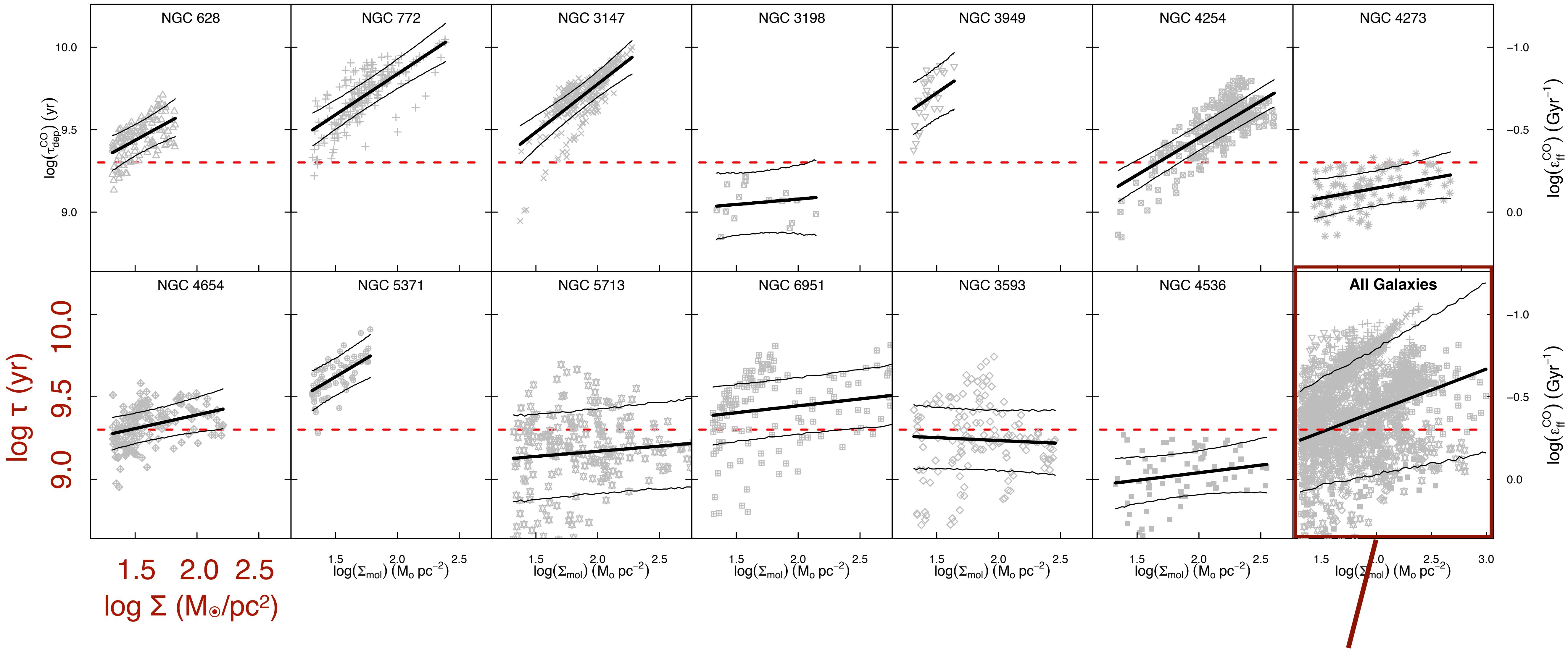


physical origin of this behavior?

- maybe strong shear in dense arms (example M51, Meidt et al. 2013)...
- maybe non-star forming H_2 gas becomes traced by CO at high column densities (recall H_2 needs A_V~1, CO needs A_V~2,)…

Shetty et al. (2013, MNRAS, 437, L61, see also Shetty, Kelly, Bigiel, 2013, MNRAS, 430, 288)

data from STING survey (Rahman et al. 2011, 2012)



physical origin of this behavior?

SEARCH FOR CO-dark H_2 GAS
here SOFIA can provide major input

Shetty et al. (2013, MNRAS, 437, L61, see also Shetty, Kelly, Bigiel, 2013, MNRAS, 430, 288)

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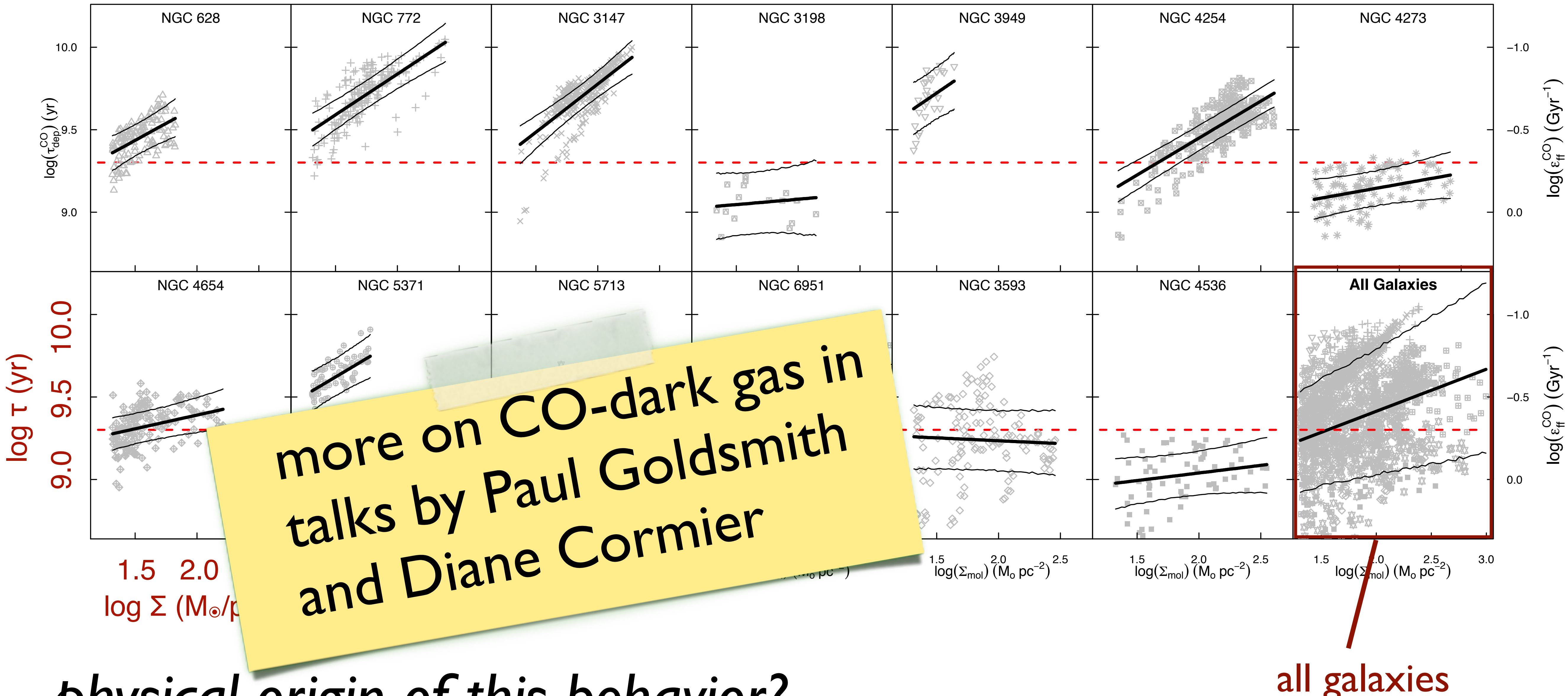


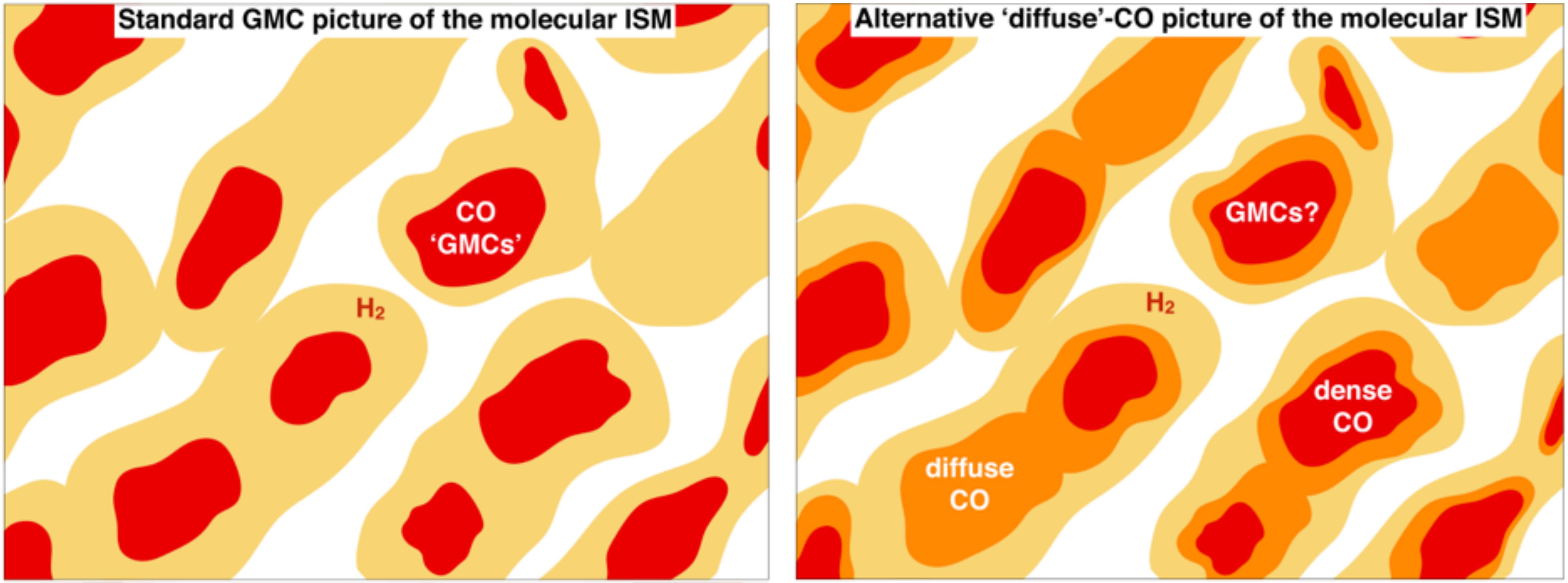
physical origin of this behavior?

SEARCH FOR CO-dark H_2 GAS

here SOFIA can provide major input

Shetty et al. (2013, MNRAS, 437, L61, see also Shetty, Kelly, Bigiel, 2013, MNRAS, 430, 288)

dense vs. diffuse CO-traced H_2 gas



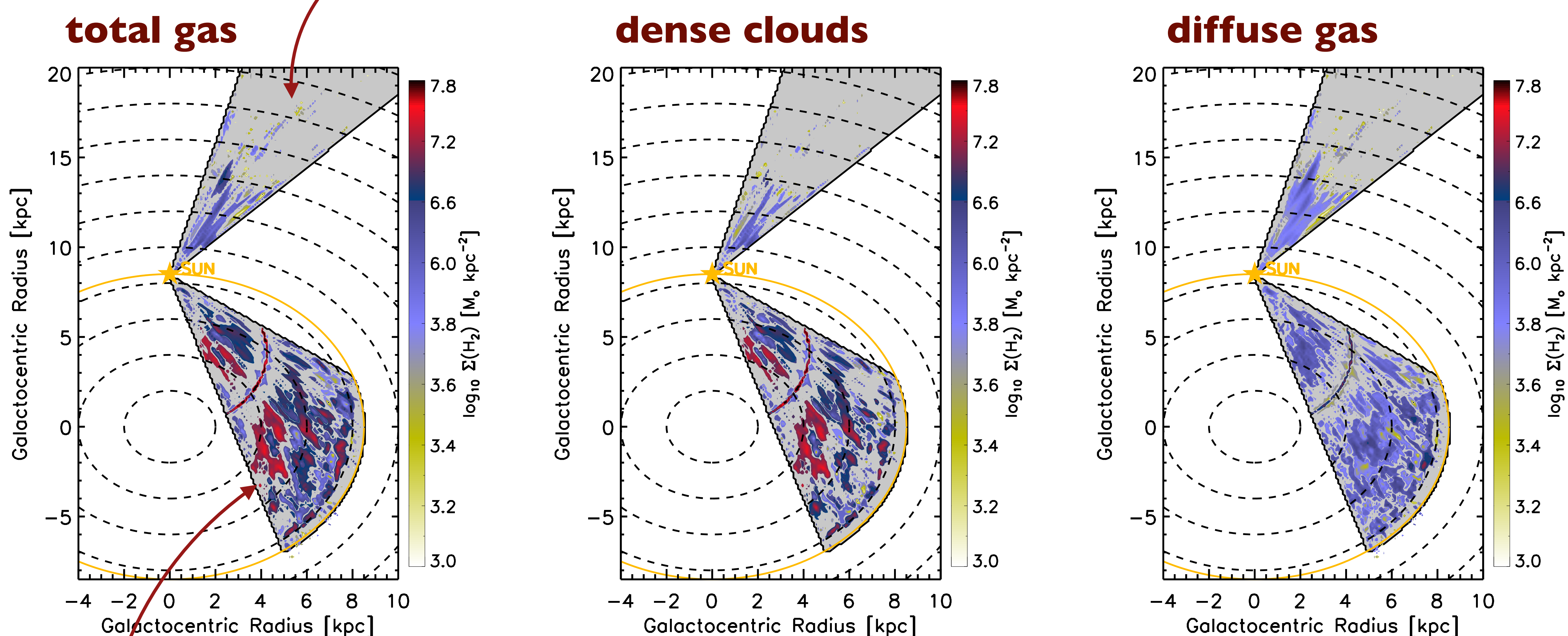
in addition:

- maybe a large fraction of H_2 (even if traced by CO) may not be in dense clouds, but in a diffuse state!

Shetty et al. (2014, MNRAS, 422, 2208)

observational approach

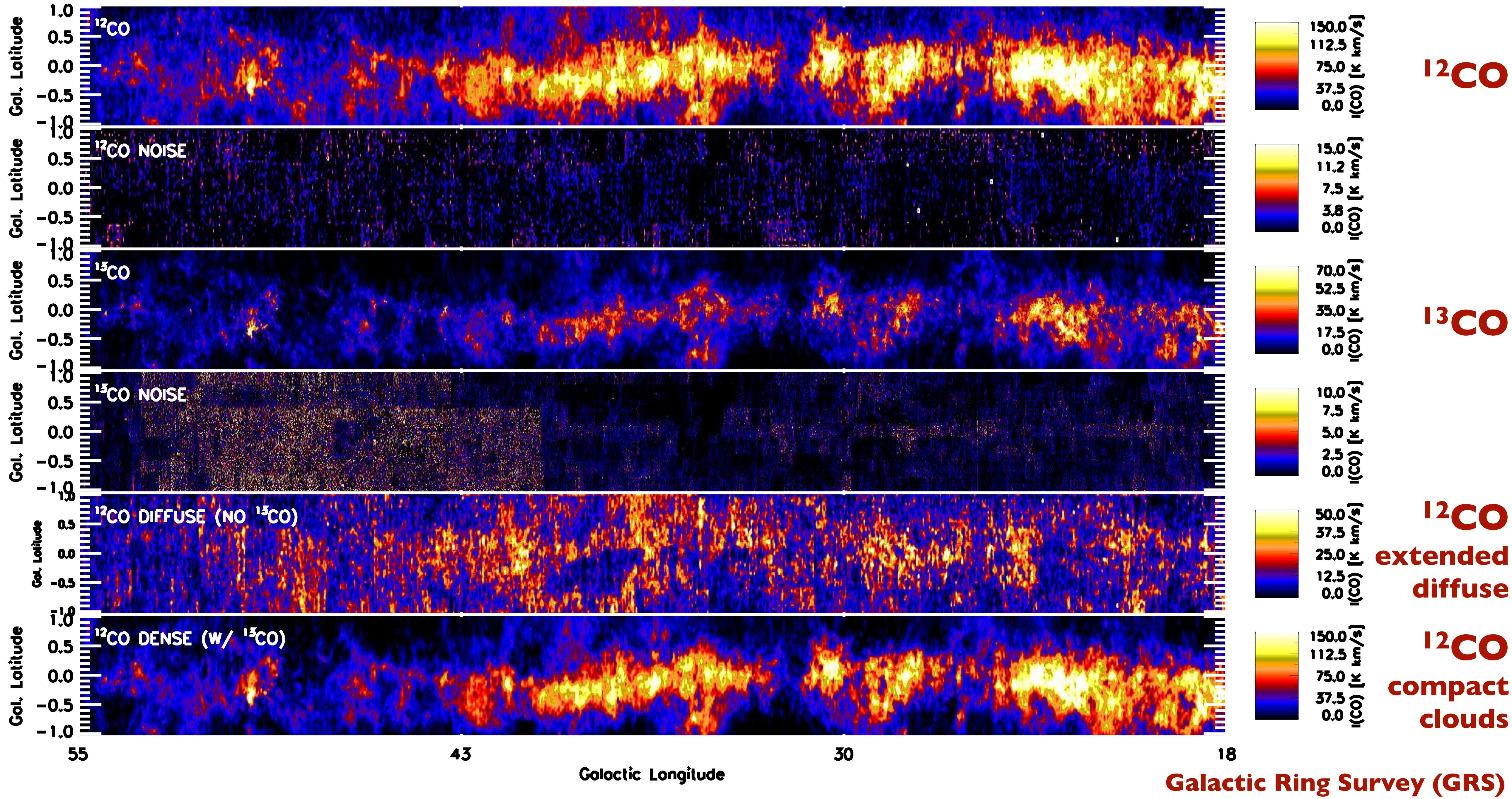
OUTER GALAXY:
EXEF survey



Exeter-Five College Radio Astronomy Observatory (EXFC)
Galactic Ring Survey (GRS)

INNER GALAXY:
Galactic Ring Survey (GRS)

Roman-Duval et al. (2016, ApJ, 818, 144)



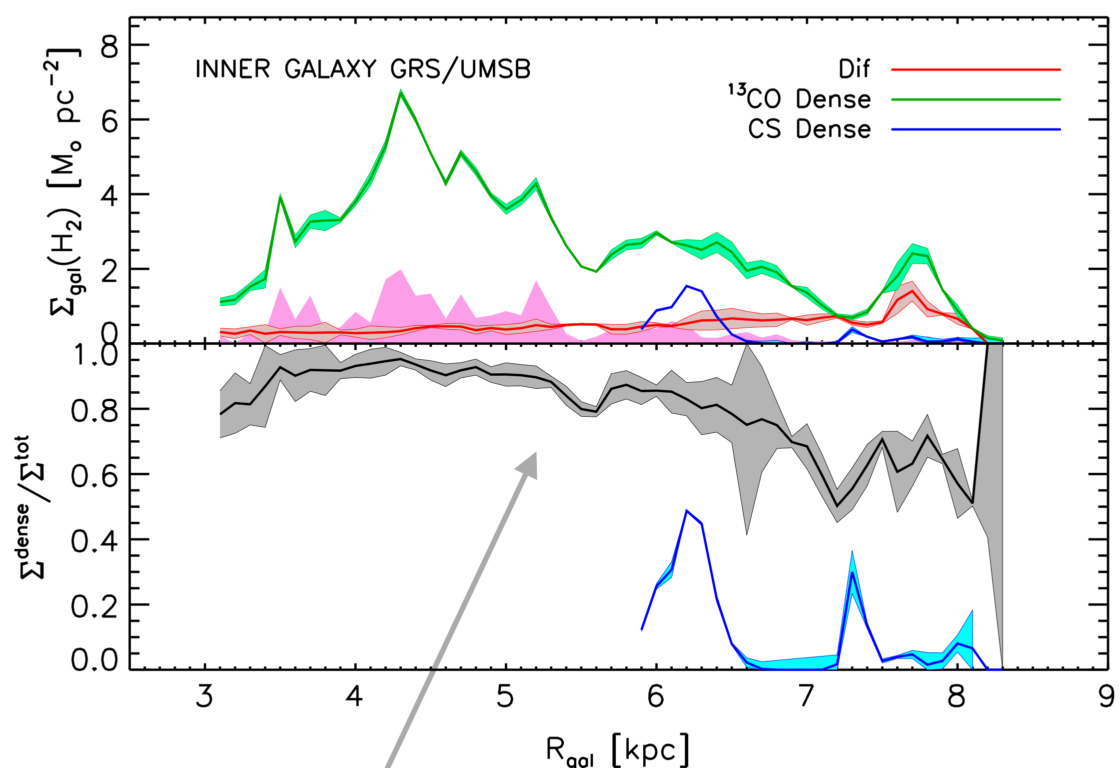
observational approach:

- comparison of ^{13}CO (tracing mostly dense clouds) and ^{12}CO tracing all the gas (including the more diffuse component)

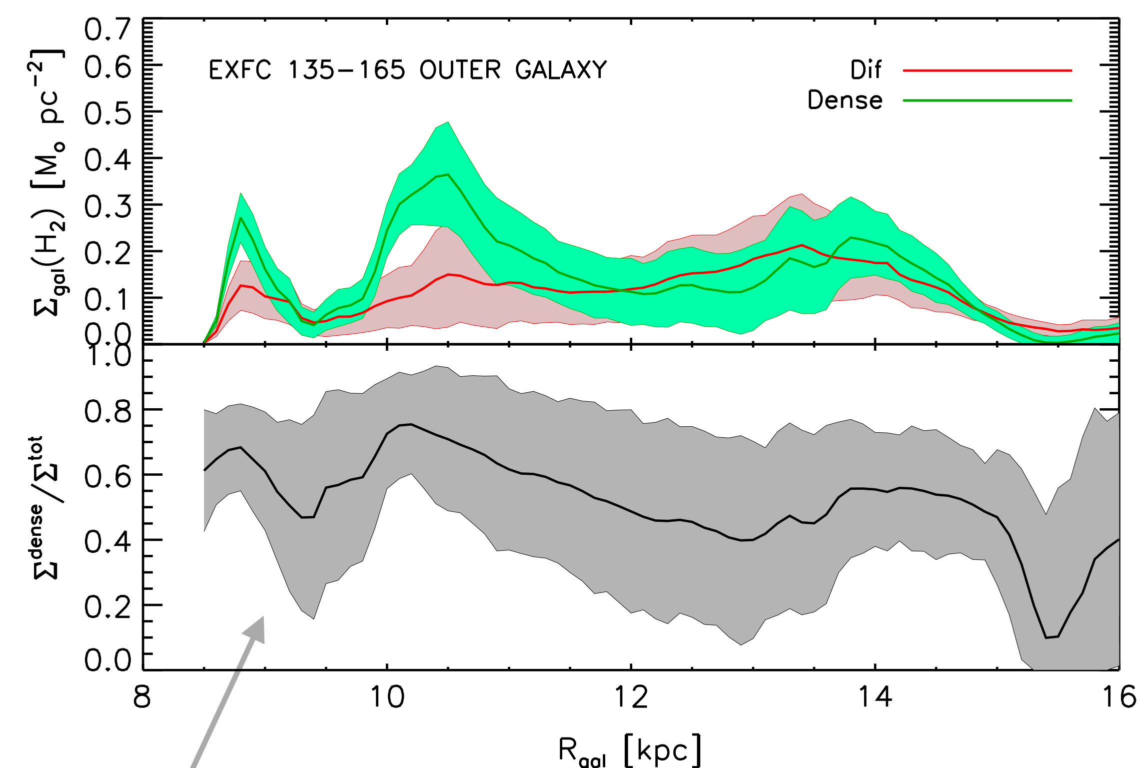
Roman-Duval et al. (2016, ApJ, 818, 144)

dense gas fraction as function of radius

INNER GALAXY: Galactic Ring Survey (GRS)



OUTER GALAXY: Exeter Fife College survey



dense gas fraction as function of Galactic radius

Roman-Duval et al. (2016, ApJ, 818, 144)

dense gas fraction as function of radius

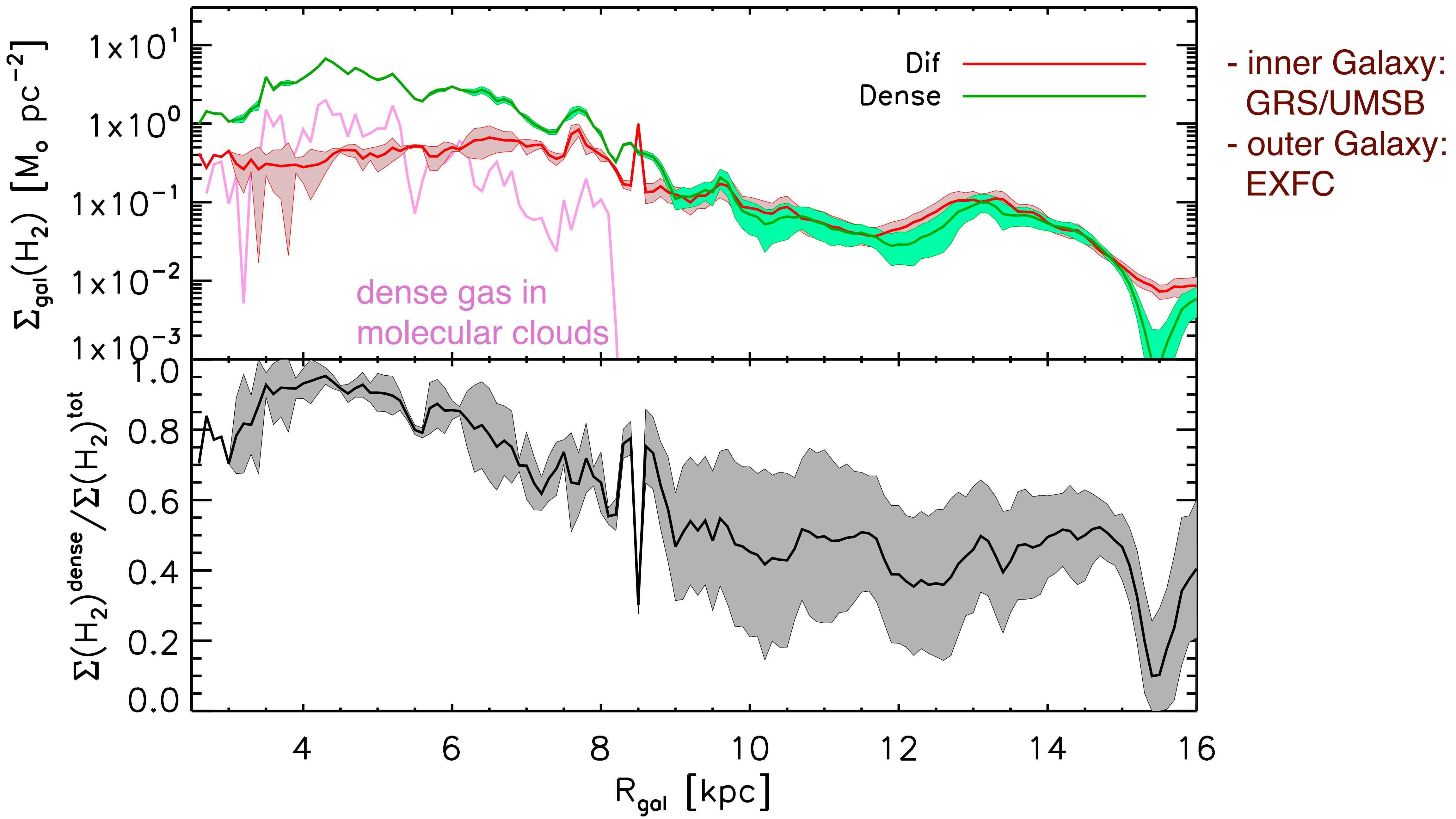
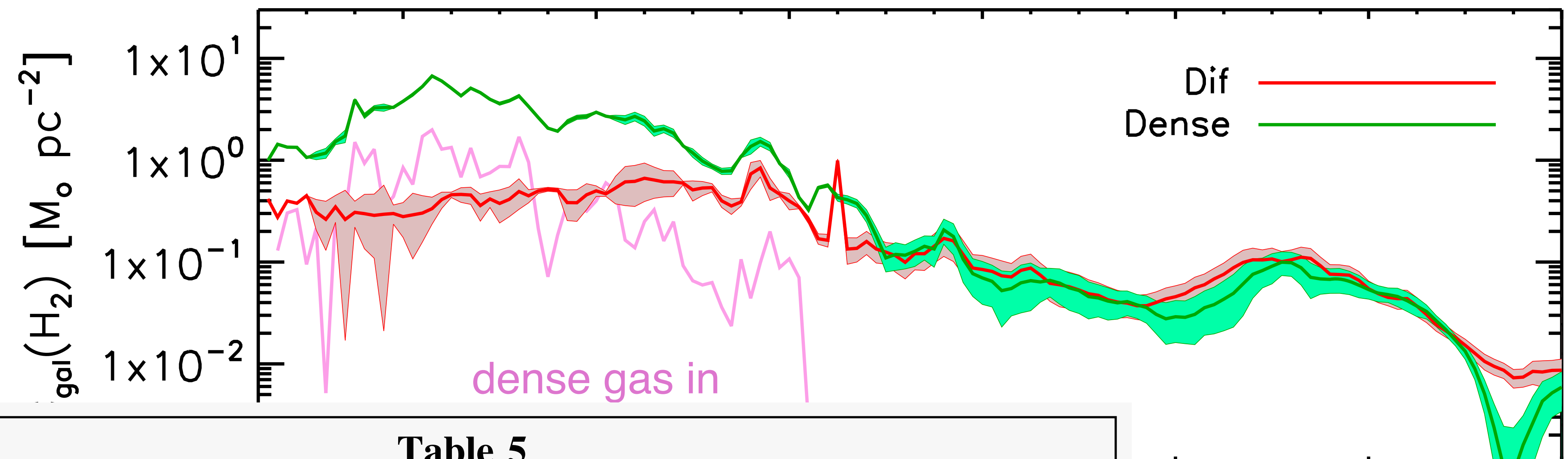


Figure 13. Average Galactic H_2 surface densities of the diffuse (red, detected in ^{12}CO, undetected in ^{13}CO) and dense (green, detected in ^{12}CO and ^{13}CO) components as a function of Galactocentric radius (in bins of width 0.1 kpc), in logarithmic scale, combining all data sets. In the inner Galaxy, the pink line indicates the surface density of H_2 in molecular clouds identified in Roman-Duval et al. (2010).

Roman-Duval et al. (2016, ApJ, 818, 144)

dense gas fraction as function of radius



- inner Galaxy: GRS/UMSB
- outer Galaxy: EXFC

Table 5
Total Luminosity and Molecular Mass in the Milky Way in the Diffuse and Dense Components Traced by ^{12}CO

		Inner	Outer	Total
L(^{12}CO)	Diffuse	2.0×10^1	4.0	2.4×10^1
	Dense	1.1×10^2	3.8	1.1×10^2
	Very dense	4.8	…	4.8
	Total	1.3×10^2	7.7	1.4×10^2
$M(H_2)$	Diffuse	9.3×10^7	6.0×10^7	1.5×10^8
	Dense	4.6×10^8	3.9×10^7	4.9×10^8
	Very dense	2.9×10^7	…	2.9×10^7
	Total	5.5×10^8	9.9×10^7	6.5×10^8

fraction CO-traced H2 gas in Milky Way:
~1/4 diffuse
~3/4 dense
~1/20 in known molecular clouds only !!!

Roman-Duval et al. (2016, ApJ, 818, 144)

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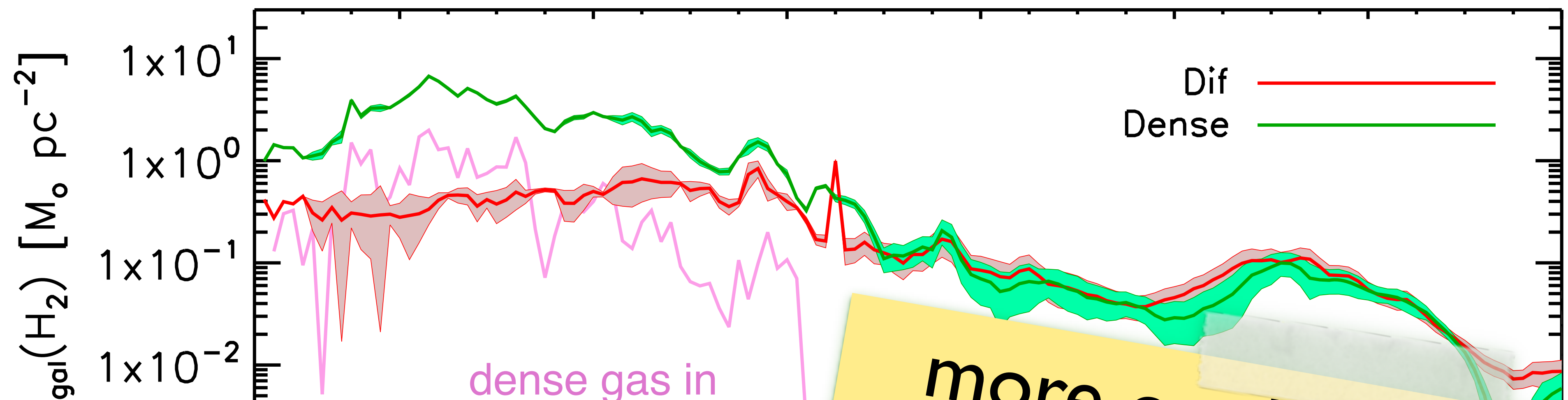

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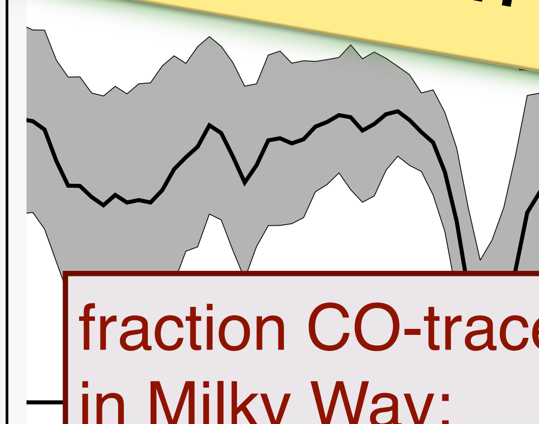
more on diffuse gas in talk by Julia Roman-Duval



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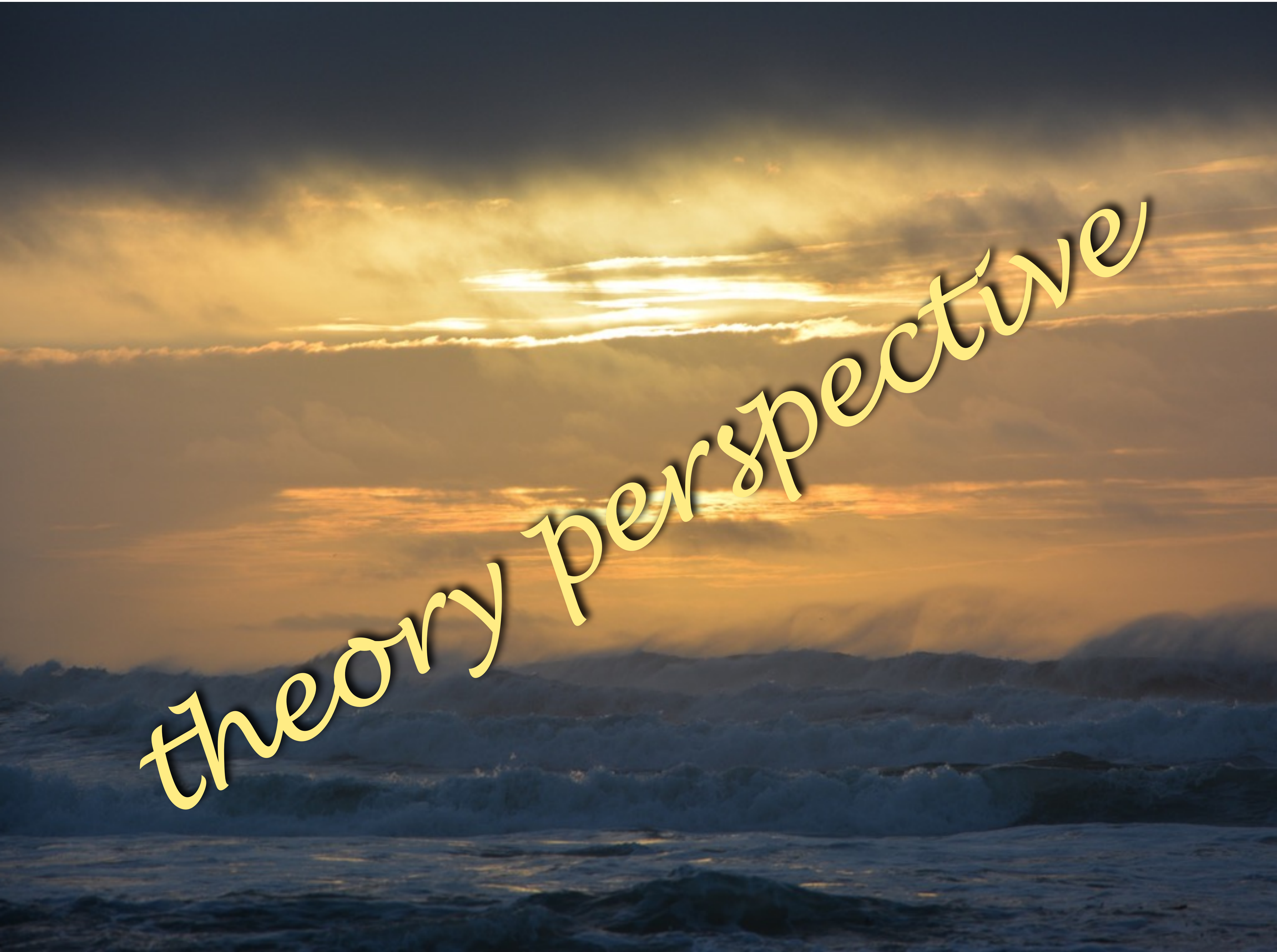
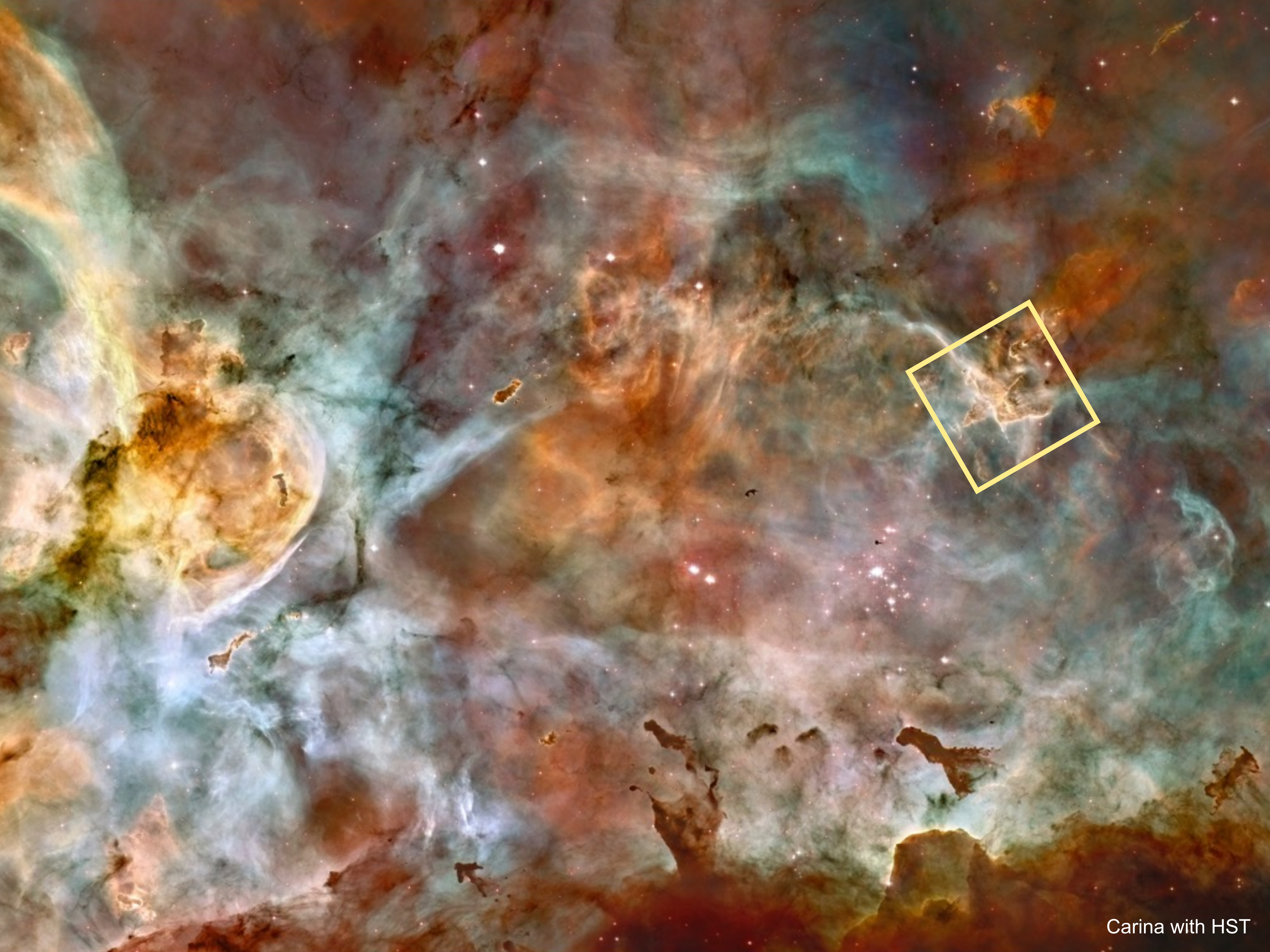
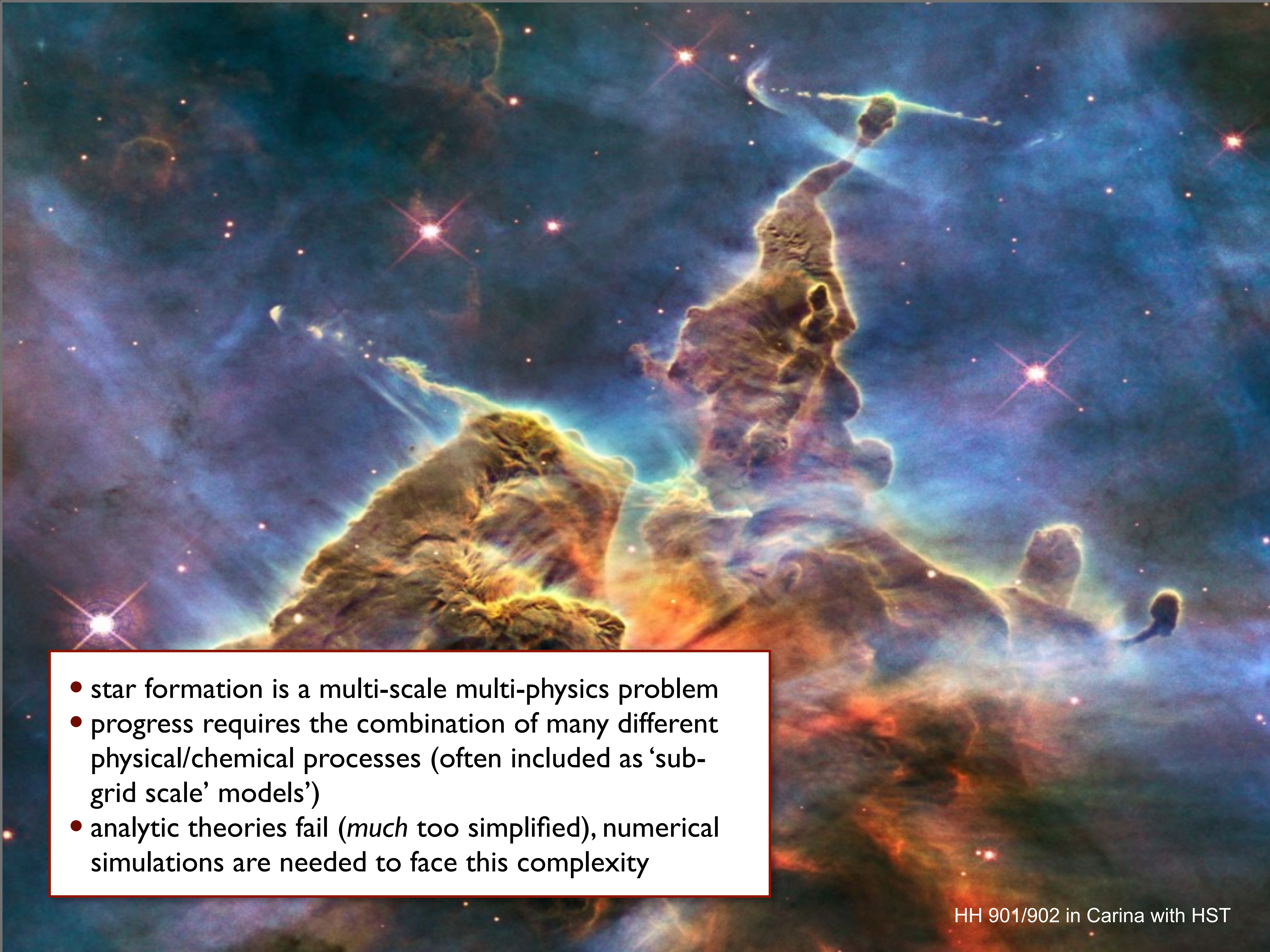

theory perspective


Carina with HST



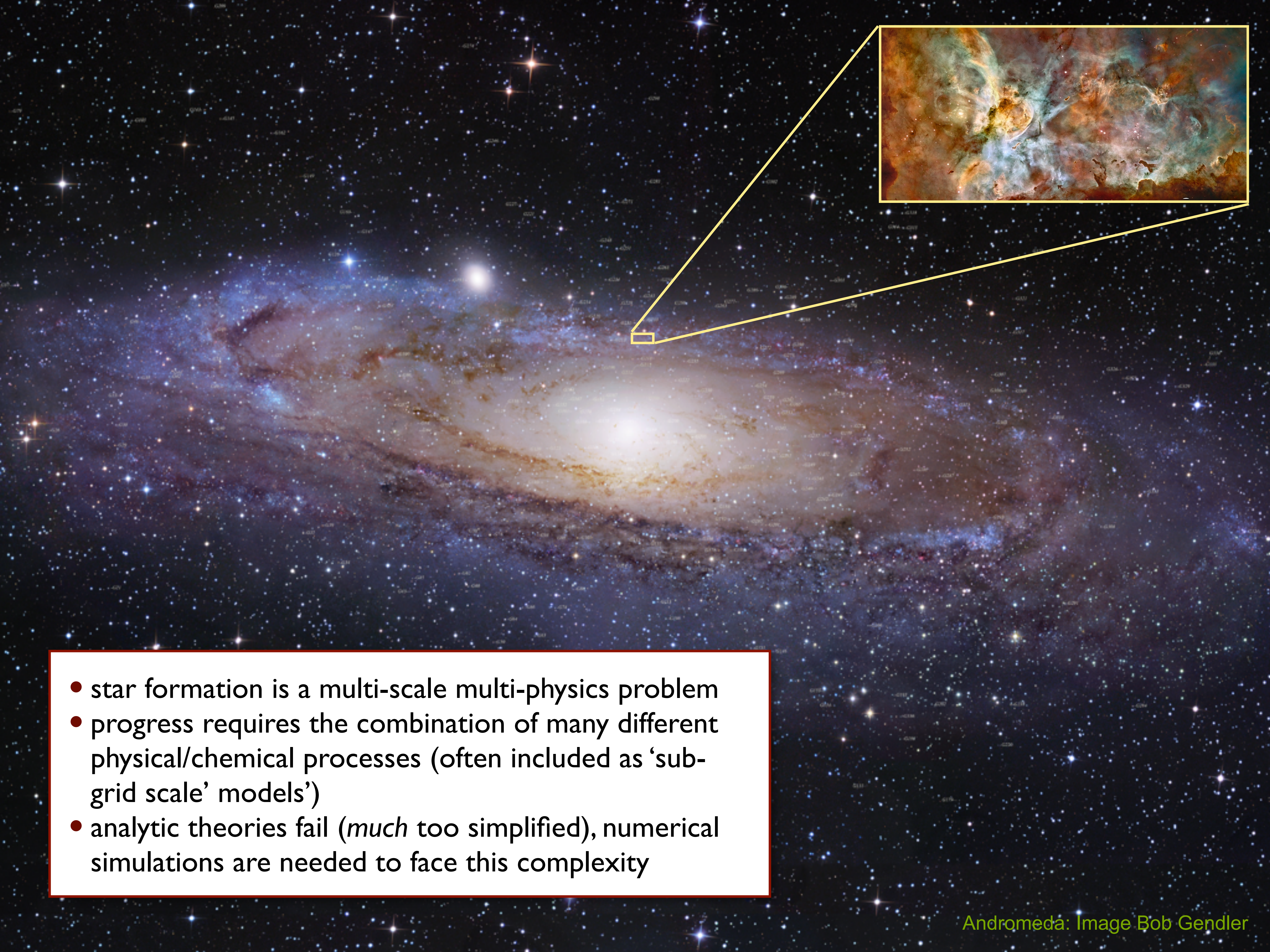
Carina with HST

HH 901/902 in Carina with HST



- star formation is a multi-scale multi-physics problem
- progress requires the combination of many different physical/chemical processes (often included as 'sub-grid scale' models')
- analytic theories fail (*much* too simplified), numerical simulations are needed to face this complexity

HH 901/902 in Carina with HST



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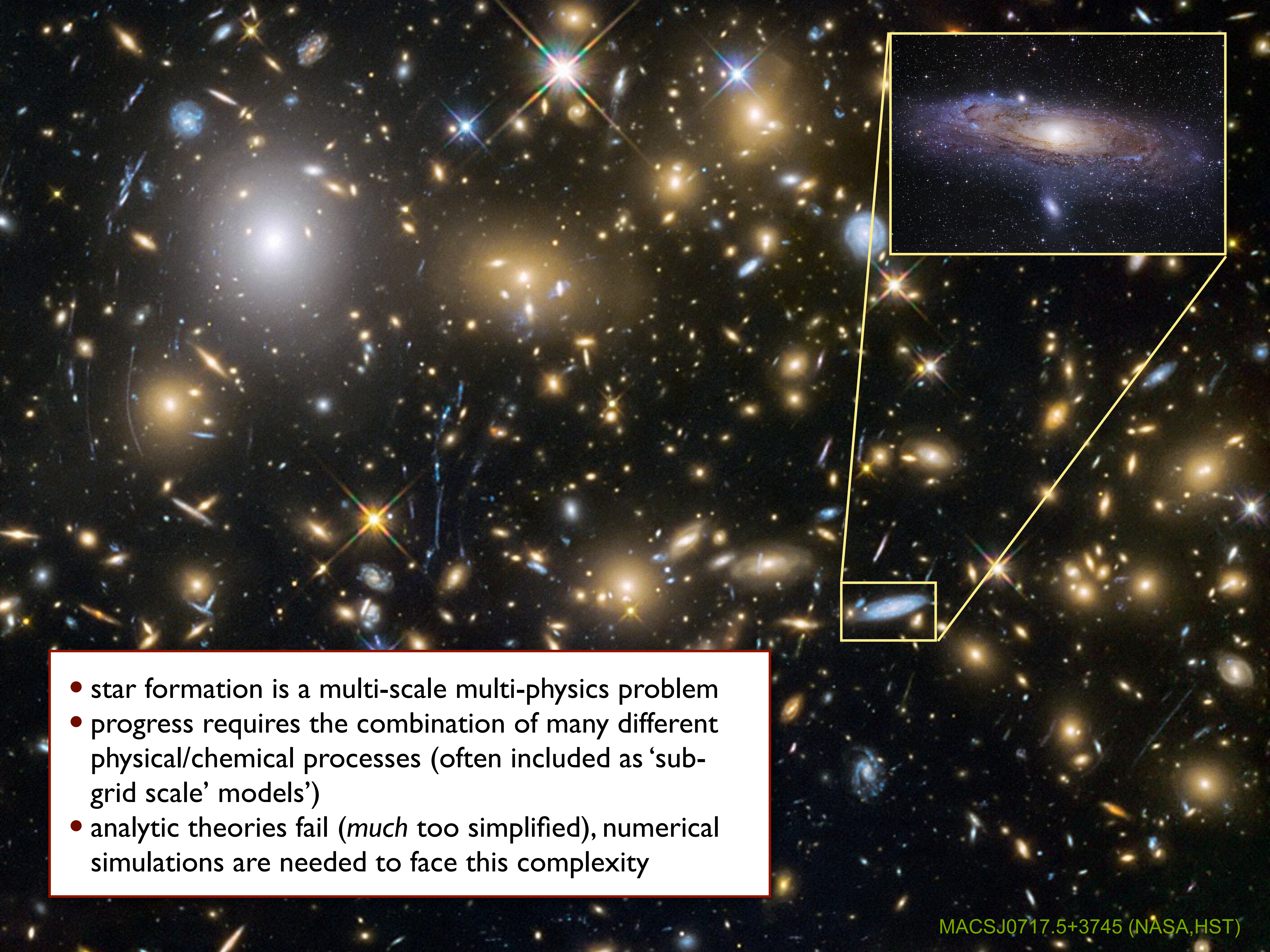
Andromeda: Image Bob Gendler



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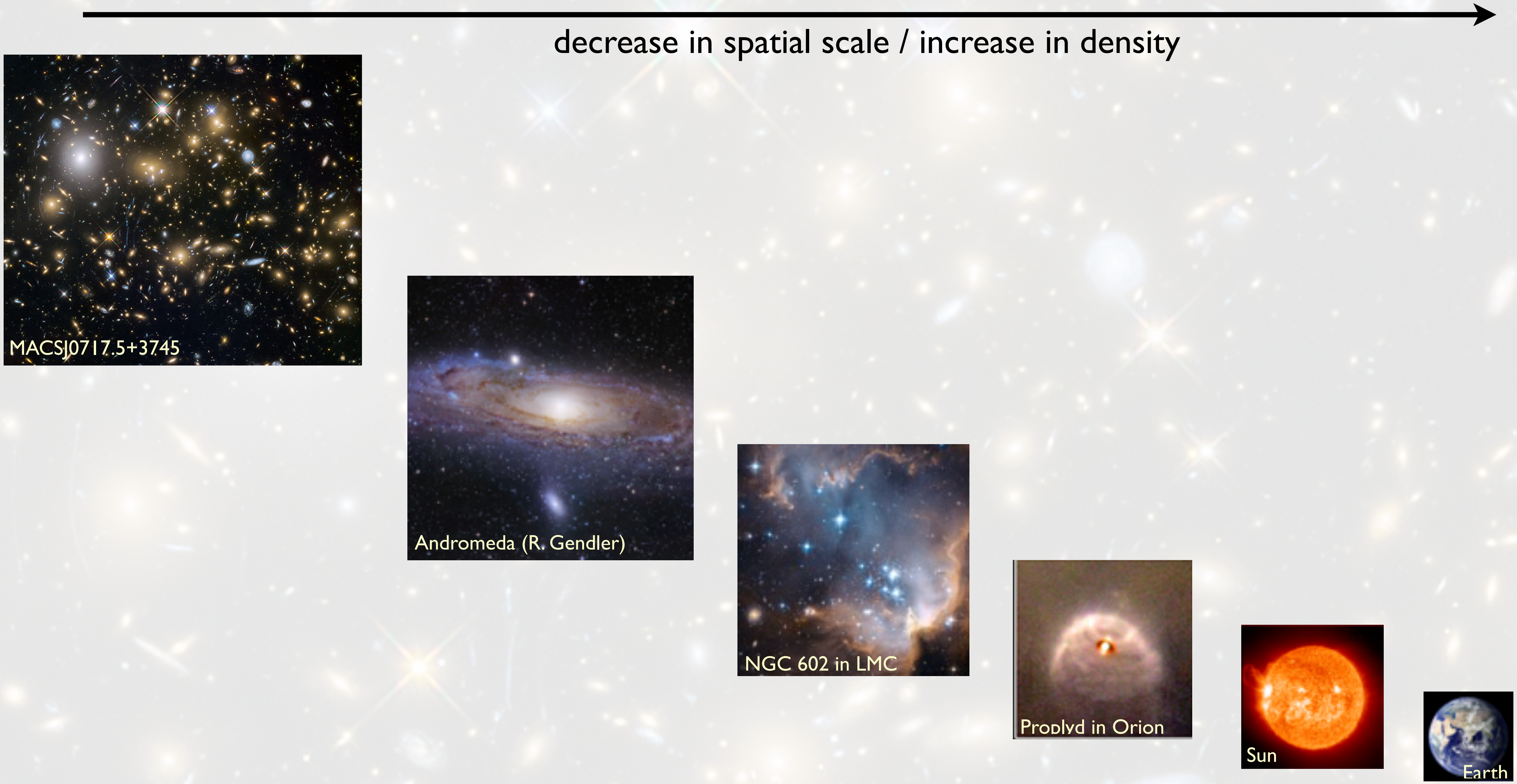

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MACSJ0717.5+3745 (NASA,HST)

early theoretical models

- *Jeans (1902):* Interplay between self-gravity and thermal pressure
  - stability of homogeneous spherical density enhancements against gravitational collapse
  - dispersion relation:

$$\omega^2 = c_s^2 k^2 - 4\pi G \rho_0$$

  - instability when $\omega^2 < 0$
  - minimal mass: $M_J = \frac{1}{6}\pi^{-5/2} G^{-3/2} \rho_0^{-1/2} c_s^3 \propto \rho_0^{-1/2} T^{+3/2}$

Sir James Jeans, 1877 - 1946

first approach to turbulence

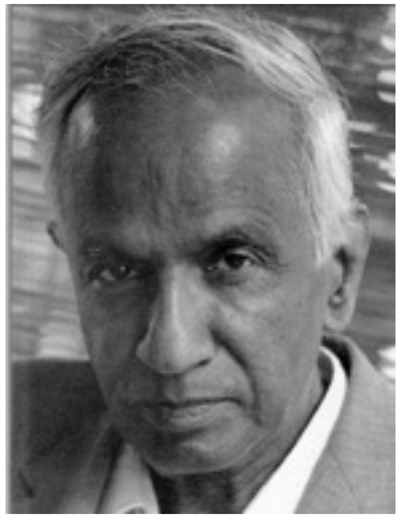
- *von Weizsäcker (1943, 1951)* and *Chandrasekhar (1951):* concept of ***MICROTURBULENCE***
  - BASIC ASSUMPTION: separation of scales between dynamics and turbulence

    $\ell_{turb} \ll \ell_{dyn}$
  - then turbulent velocity dispersion contributes to effective soundspeed:

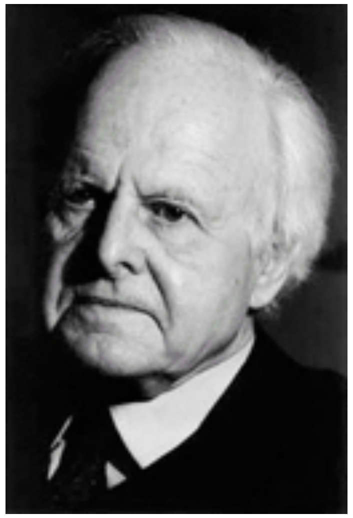
$$c_c^2 \mapsto c_c^2 + \sigma_{rms}^2$$

  - → Larger effective Jeans masses → more stability
  - BUT: *(1) turbulence depends on k:* $\sigma_{rms}^2(k)$

    (2) supersonic turbulence → $\sigma_{rms}^2(k) >> c_s^2$ *usually*



S. Chandrasekhar, 1910 - 1995



C.F. von Weiszäcker, 1912 - 2007

problems of early dynamical theory

- molecular clouds are *highly Jeans-unstable,*
  yet, they do *NOT* form stars at high rate
  and with high efficiency (Zuckerman & Evans 1974 conundrum)
  (the observed global SFE in molecular clouds is *~5%*)
  → *something prevents large-scale collapse.*
- all throughout the early 1990's, molecular clouds had been thought to be long-lived quasi-equilibrium entities.
- molecular clouds are *magnetized*

magnetic star formation

- *Mestel & Spitzer (1956):* Magnetic fields can prevent collapse*!!!*
  - Critical mass for gravitational collapse in presence of B-field

$$M_{cr} = \frac{5^{3/2}}{48\pi^2} \frac{B^3}{G^{3/2}\rho^2}$$

  - Critical mass-to-flux ratio (Mouschovias & Spitzer 1976)

$$\left[\frac{M}{\Phi}\right]_{cr} = \frac{\zeta}{3\pi}\left[\frac{5}{G}\right]^{1/2}$$

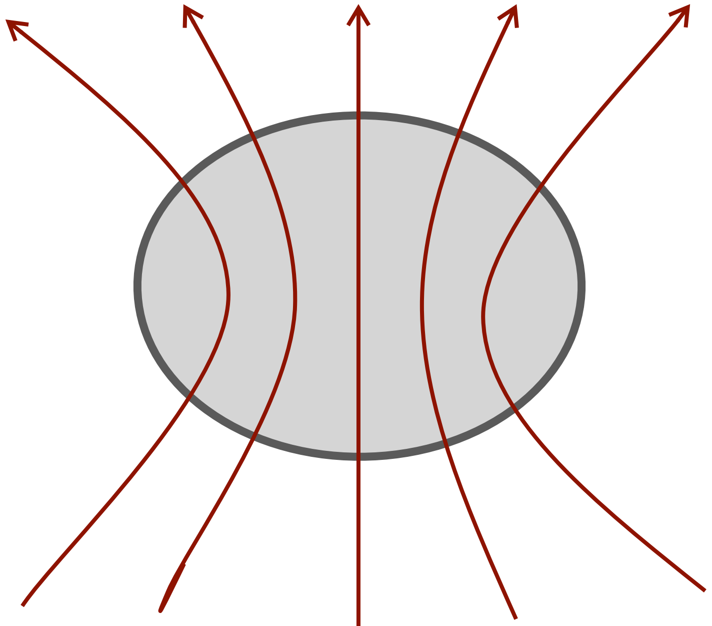
  - Ambipolar diffusion can initiate collapse

Lyman Spitzer, Jr., 1914 - 1997

"standard theory" of star formation

- BASIC ASSUMPTION: Stars form from magnetically highly subcritical cores
- Ambipolar diffusion slowly increases (M/Φ): $\tau_{AD} \approx 10\tau_{ff}$
- Once $(M/\Phi) > (M/\Phi)_{crit}$: dynamical collapse of SIS
  - Shu (1977) collapse solution
  - $dM/dt = 0.975\ c_s^3/G = \text{const.}$
- Was (in principle) only intended for isolated, low-mass stars

Frank Shu, 1943 -



problems of “standard theory”

- Observed B-fields are weak, at most marginally critical (Crutcher 1999, Bourke et al. 2001)
- Magnetic fields cannot prevent decay of turbulence
  (Mac Low et al. 1998, Stone et al. 1998, Padoan & Nordlund 1999)
- Structure of prestellar cores
  (e.g. Bacman et al. 2000, Alves et al. 2001)
- Strongly time varying dM/dt
  (e.g. Hendriksen et al. 1997, André et al. 2000)
- More extended infall motions than predicted by the standard model
  (Williams & Myers 2000, Myers et al. 2000)
- Most stars form as binaries
  (e.g. Lada 2006)
- As many prestellar cores as protostellar cores in SF regions (e.g. André et al 2002)
- Molecular cloud clumps are chemically young
  (Bergin & Langer 1997, Pratap et al 1997, Aikawa et al 2001)
- Stellar age distribution small ($\tau_{ff} << \tau_{AD}$)
  (Ballesteros-Paredes et al. 1999, Elmegreen 2000, Hartmann 2001)
- Strong theoretical criticism of the SIS as starting condition for gravitational collapse
  (e.g. Whitworth et al 1996, Nakano 1998, as summarized in Klessen & Mac Low 2004)
- Standard AD-dominated theory is incompatible with observations
  (Crutcher et al. 2009, 2010ab, Bertram et al. 2011)

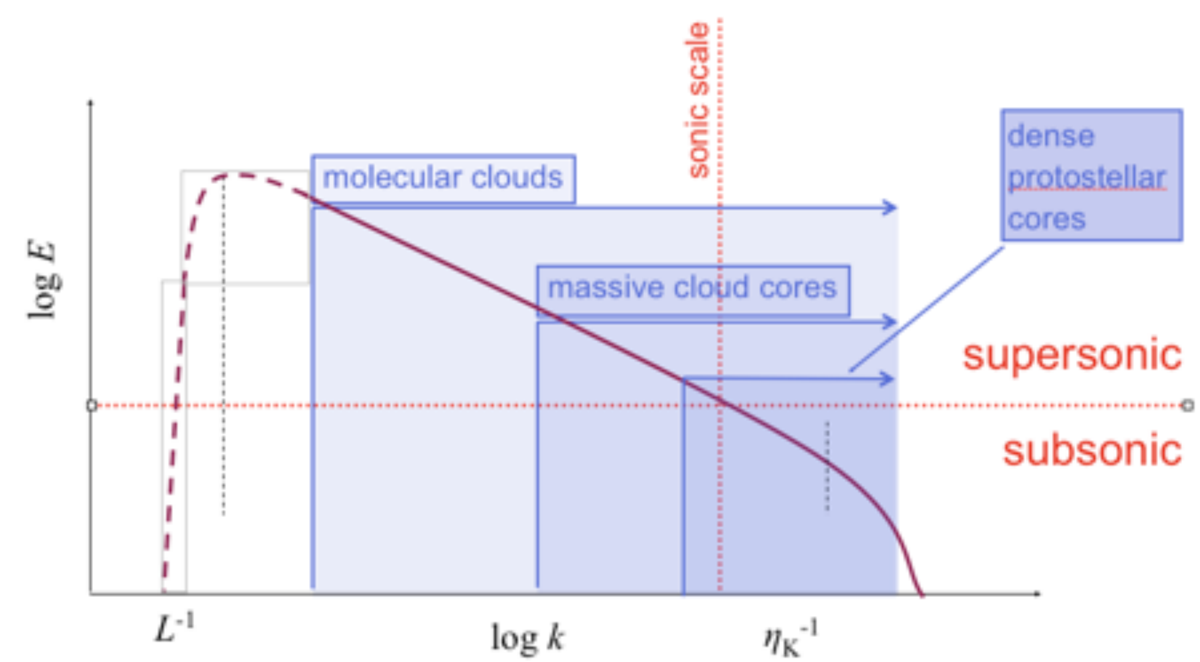
(see e.g. Mac Low & Klessen, 2004, Rev. Mod. Phys., 76, 125-194
Klessen & Glover, 2014, Saas Fee Lecture, arXiv:1412.5182)

gravoturbulent star formation

- BASIC ASSUMPTION:

  star formation is controlled by interplay between supersonic turbulence and self-gravity

- turbulence plays a *dual role*:
  - on *large scales* it *provides support*
  - on *small scales* it can *trigger collapse*
- some predictions:
  - dynamical star formation timescale τ_{ff}
  - high binary fraction
  - complex spatial structure of embedded star clusters
  - and many more . . .



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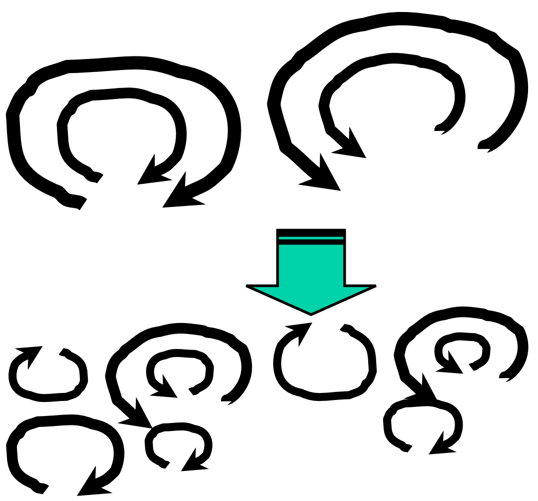
McKee & Ostriker, 2007, ARAA, 45, 565
Klessen & Glover, 2016, Saas Fee Lecture, 43, 86, arXiv:1412.5182)

properties of turbulence

- laminar flows turn *turbulent* at *high* *Reynolds* numbers

$$Re = \frac{\text{advection}}{\text{dissipation}} = \frac{VL}{\nu}$$



V= typical velocity on scale L, ν = *η*/*ρ* = kinematic viscosity,
turbulence for Re > 1000 → typical values in ISM 10^8-10^{10}

- Navier-Stokes equation (transport of momentum)

$$\rho\frac{d\vec{v}}{dt} = \rho\left(\frac{\partial\vec{v}}{\partial t} + (\vec{v}\cdot\vec{\nabla})\vec{v}\right) = -\vec{\nabla}P + \eta\,\vec{\nabla}^2\vec{v} + \left(\frac{\eta}{3} + \zeta\right)\vec{\nabla}(\vec{\nabla}\cdot\vec{v})$$

shear viscosity

bulk viscosity

$$\sigma_{ij} \equiv \eta\left(\frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i} - \frac{2}{3}\,\delta_{ij}\frac{\partial v_k}{\partial x_k}\right) + \zeta\delta_{ij}\frac{\partial v_k}{\partial x_k}$$

viscous stress tensor

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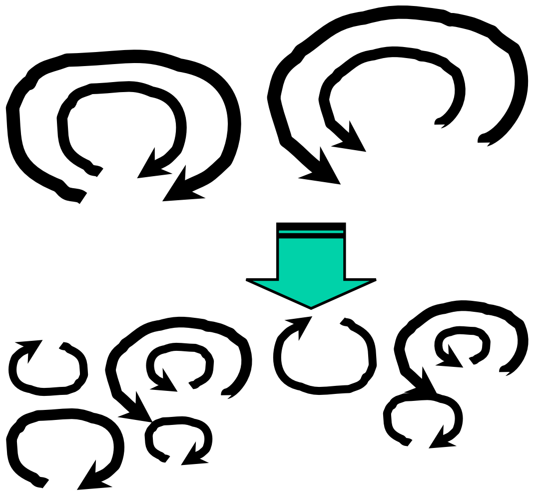

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- vortex streching --> turbulence is intrinsically anisotropic
(only on large scales you may get
homogeneity & isotropy in a statistical sense;
see Landau & Lifschitz, Chandrasekhar, Taylor, etc.)

(BUT: ISM turbulence: shocks & B-field
cause additional inhomogeneity)

Tornado over Portofino

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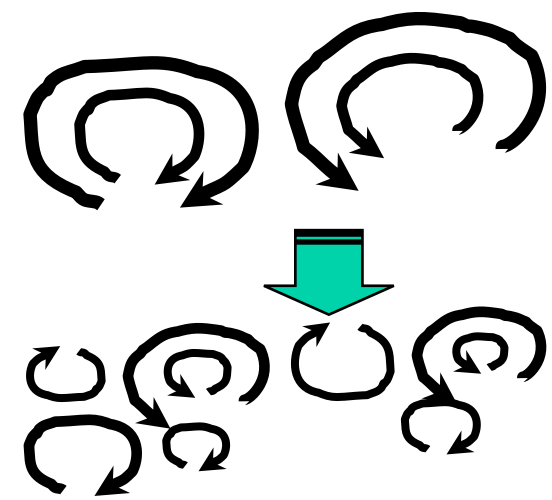

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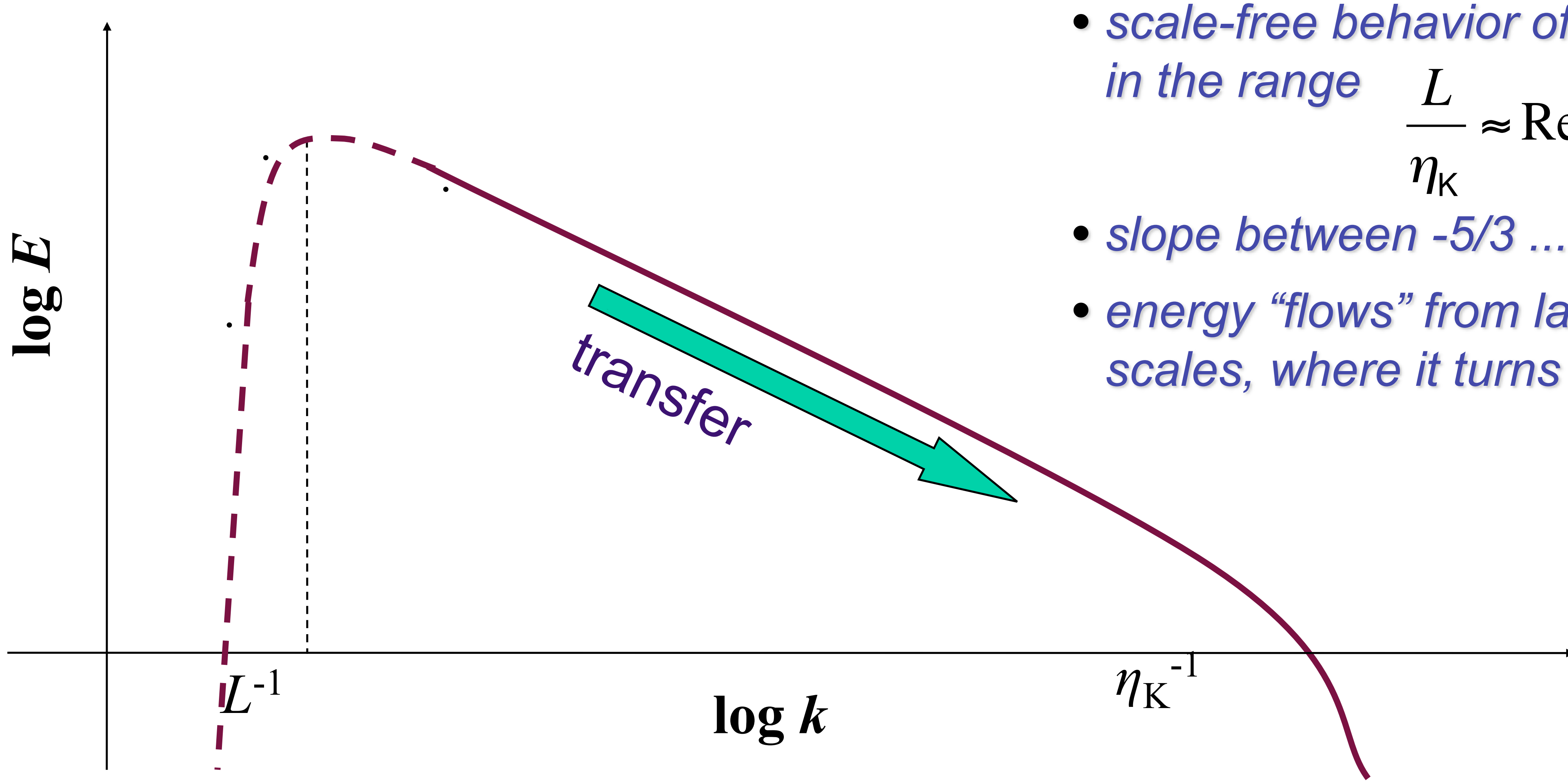
turbulent cascade in the ISM

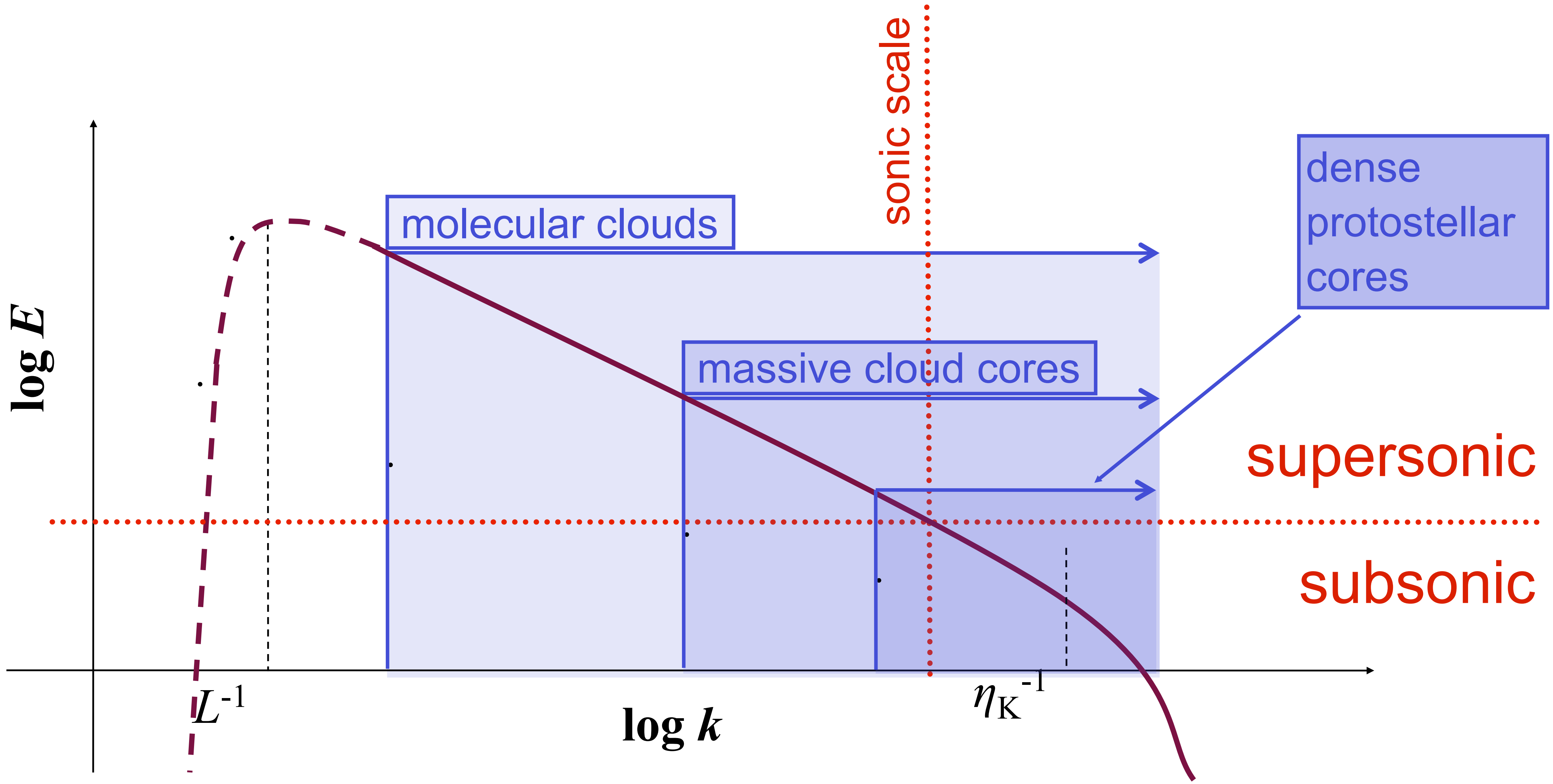


- *scale-free behavior of turbulence in the range* $\frac{L}{\eta_K} \approx \mathrm{Re}^{3/4}$
- *slope between -5/3 ... -2*
- *energy "flows" from large to small scales, where it turns into heat*

energy source & scale
NOT known
(supernovae, winds,
spiral density waves?)

dissipation scale not known
(ambipolar diffusion,
molecular diffusion?)

turbulent cascade in the ISM



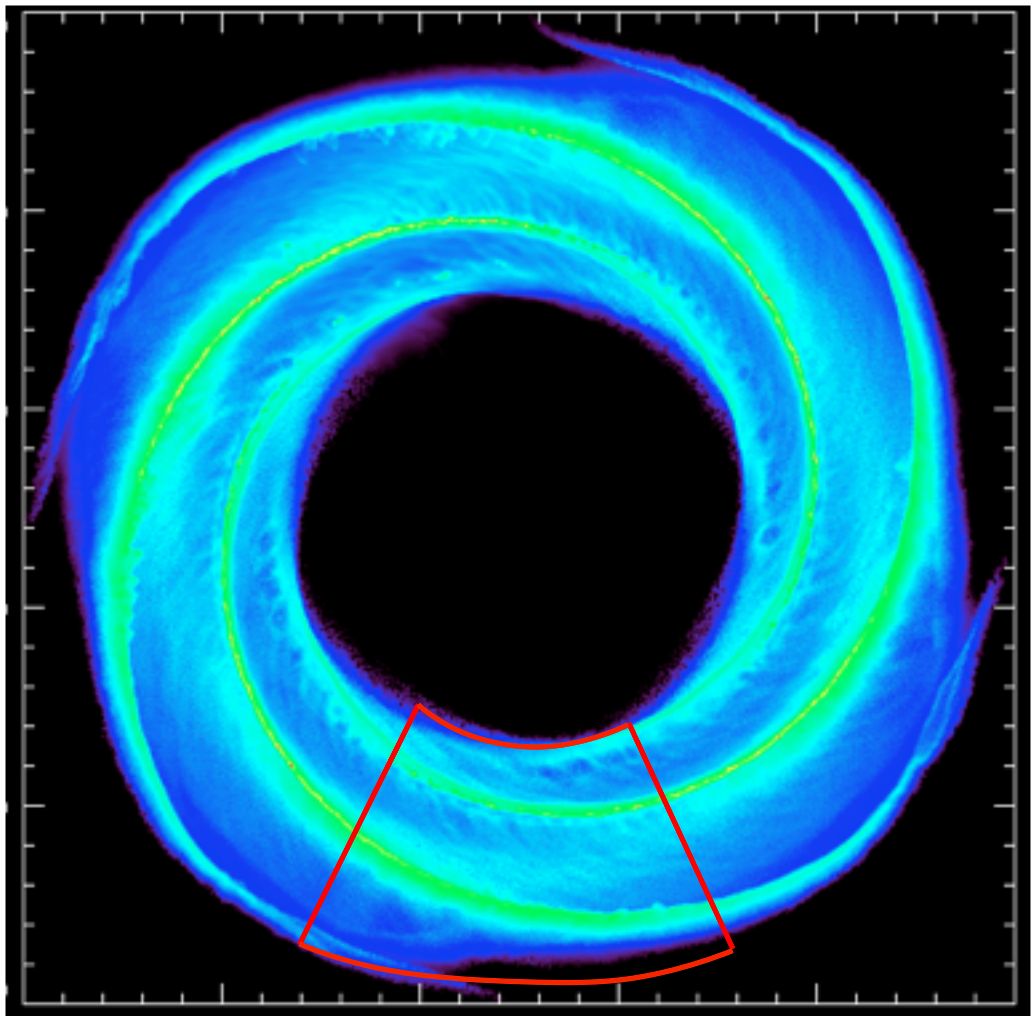
energy source & scale *NOT known* (supernovae, winds, spiral density waves?)

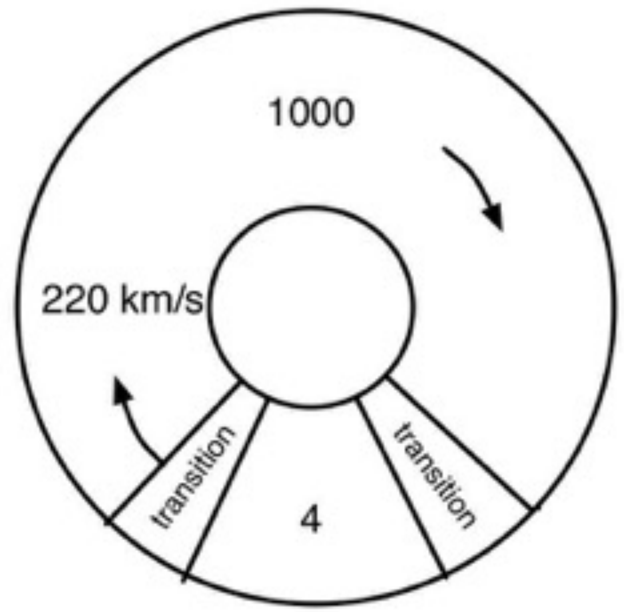
$\sigma_{rms} << 1$ km/s
$M_{rms} \leq 1$
$L \approx 0.1$ pc

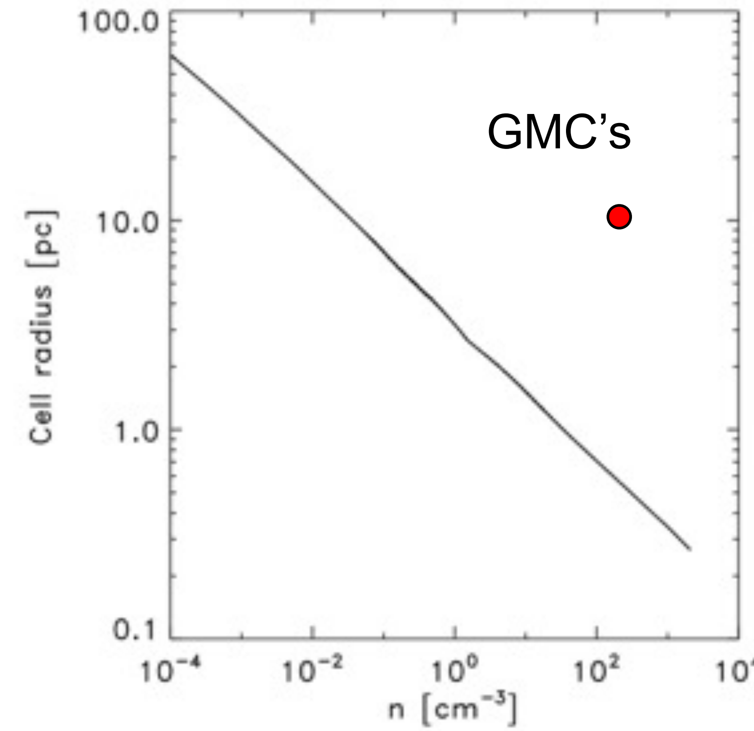
dissipation scale not known (ambipolar diffusion, molecular diffusion?)


CO-dark H_2 gas

modeling molecular cloud formation





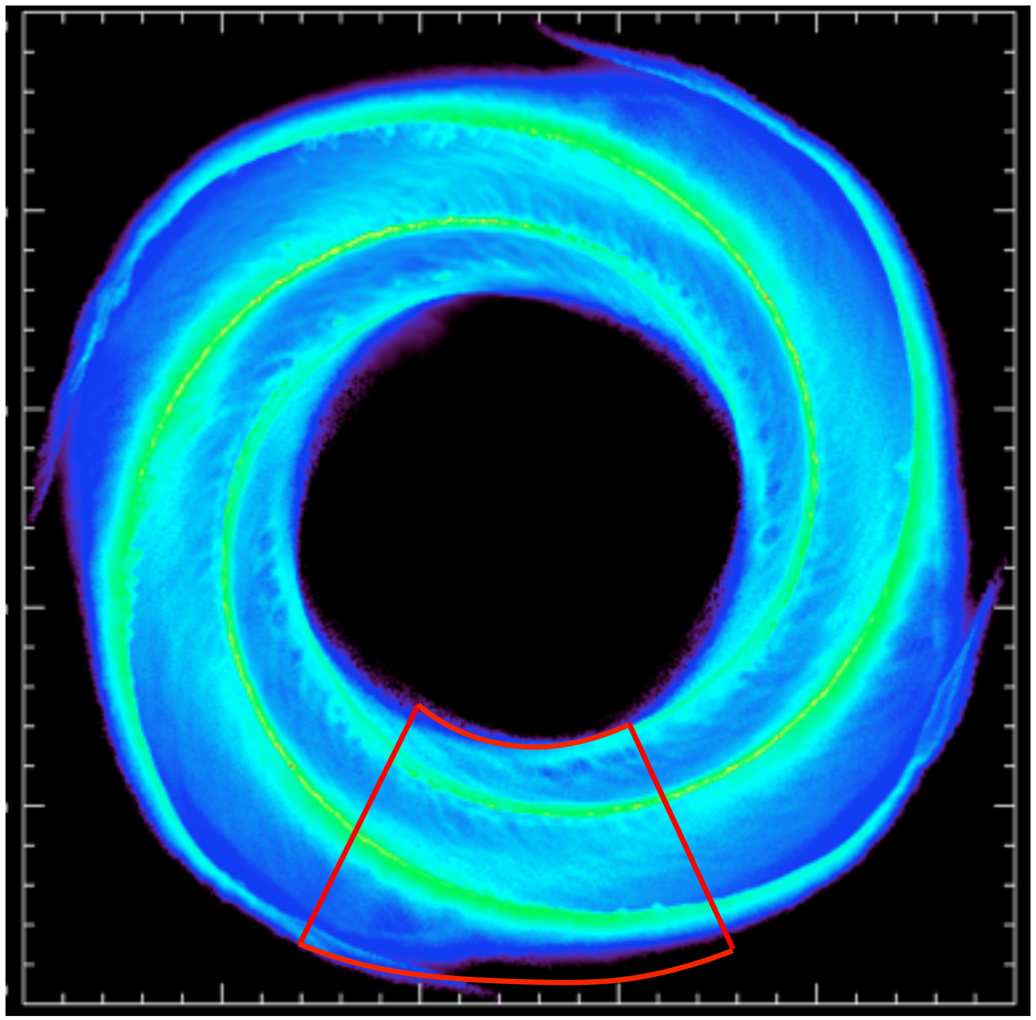


Simulation	Surface Density $M_\odot$ pc^{-2}	Radiation Field G_0
Milky Way	10	1
Low Density	4	1
Strong Field	10	10
Low & Weak	4	0.1

(Smith et al., 2014, MNRAS, 441, 1628)

- Arepo moving mesh code *(Springel 2010)*
- ***time dependent chemistry*** *(Glover et al. 2007)* gives heating & cooling in a 2 phase medium
- two layers of refinement with mass resolution down to 4 $M_\odot$ in full Galaxy simulation
- UV field and cosmic rays
- TreeCol *(Clark et al. 2012)*
- external spiral potential *(Dobbs & Bonnell 2006)*

modeling molecular cloud formation



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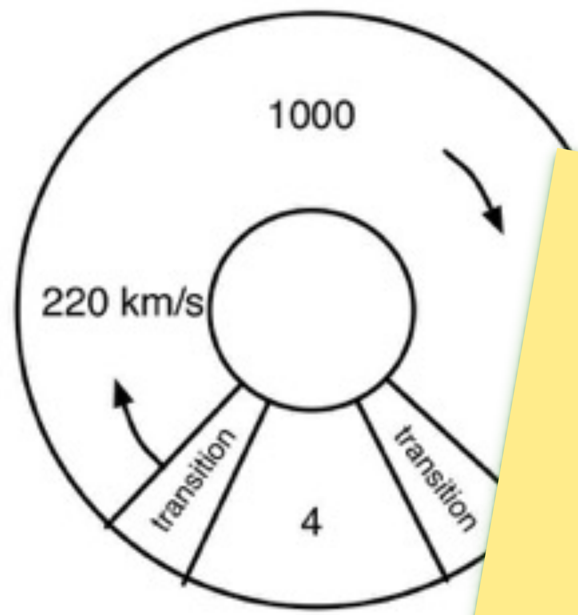

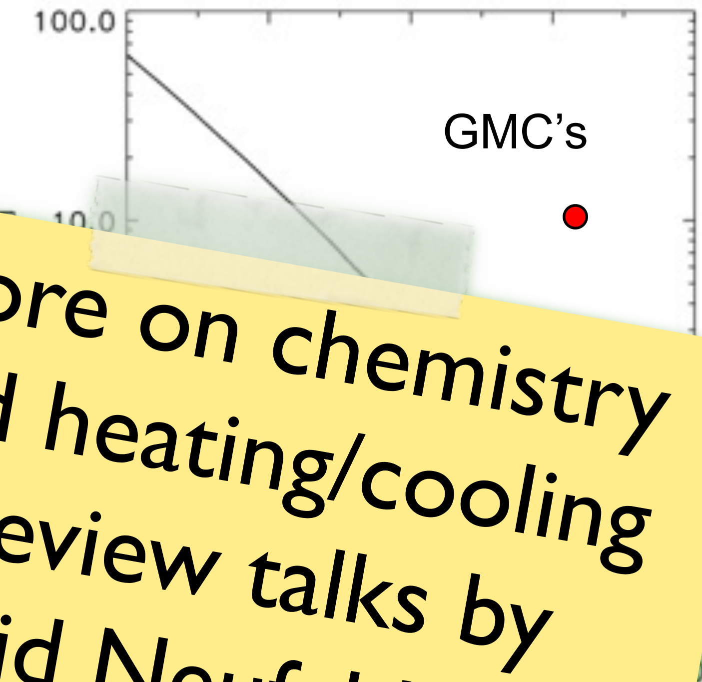

more on chemistry and heating/cooling in review talks by David Neufeld and Xander Tielens

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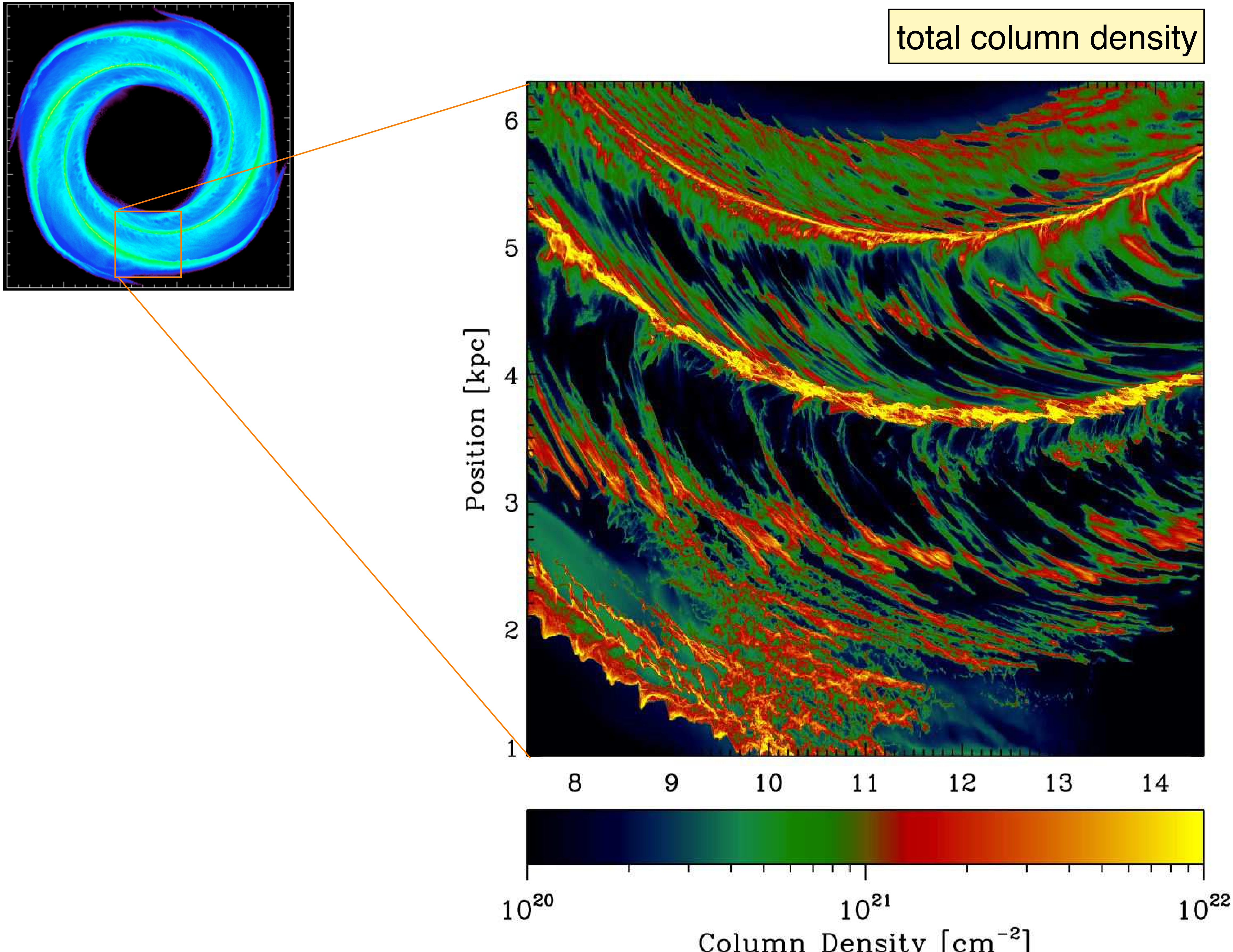

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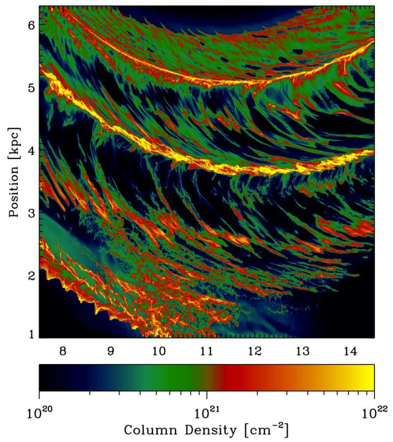
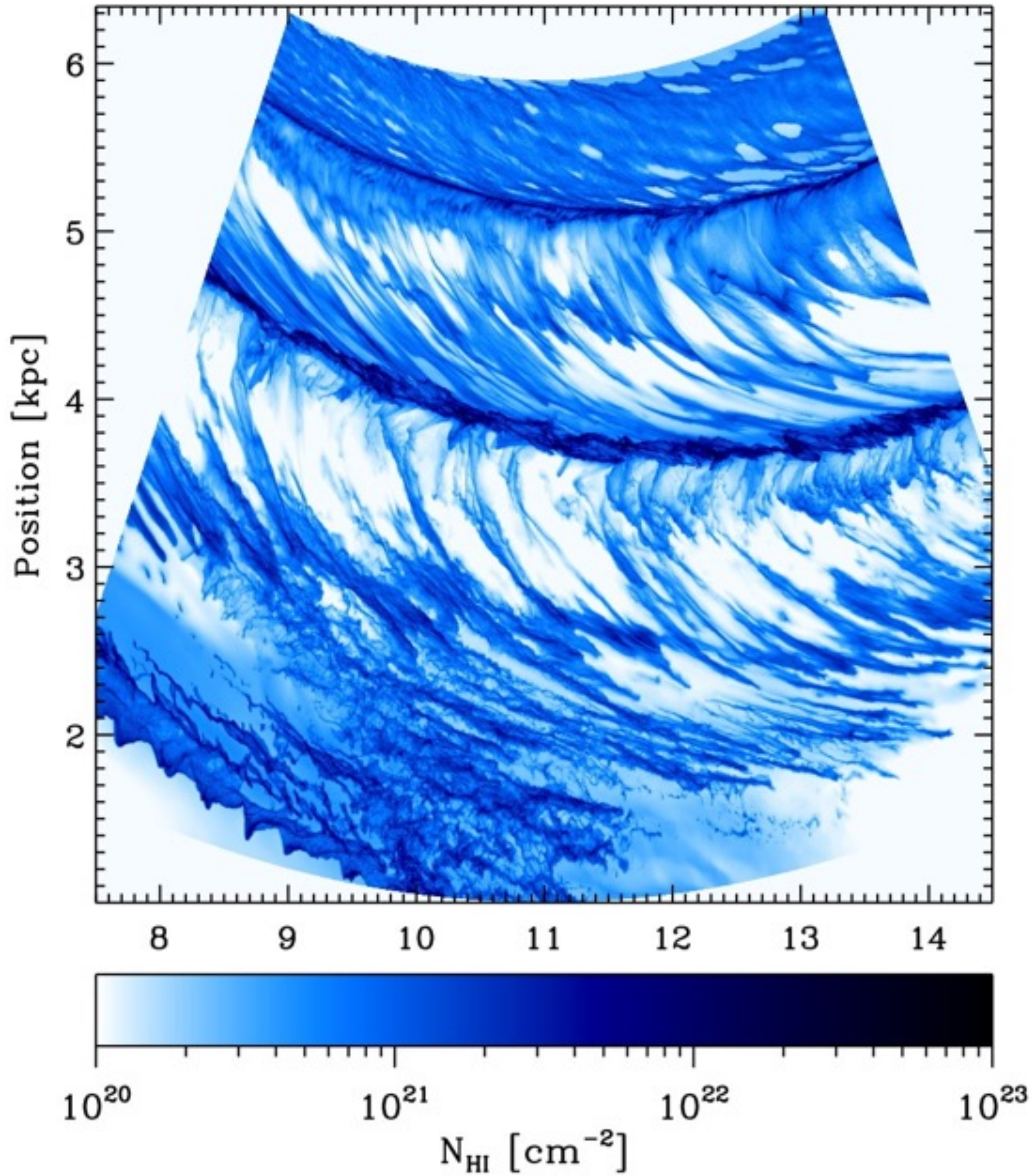
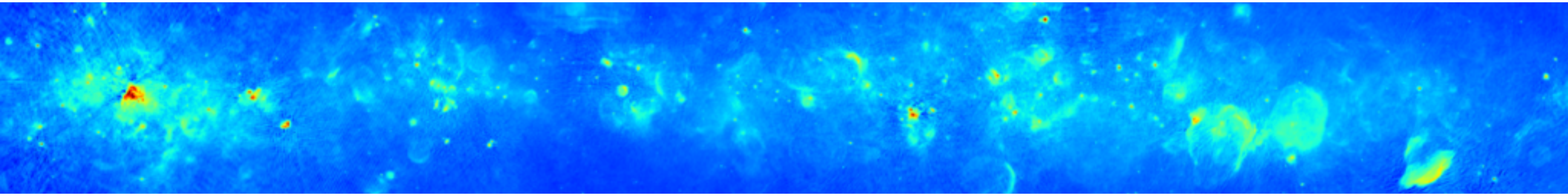


HI column density



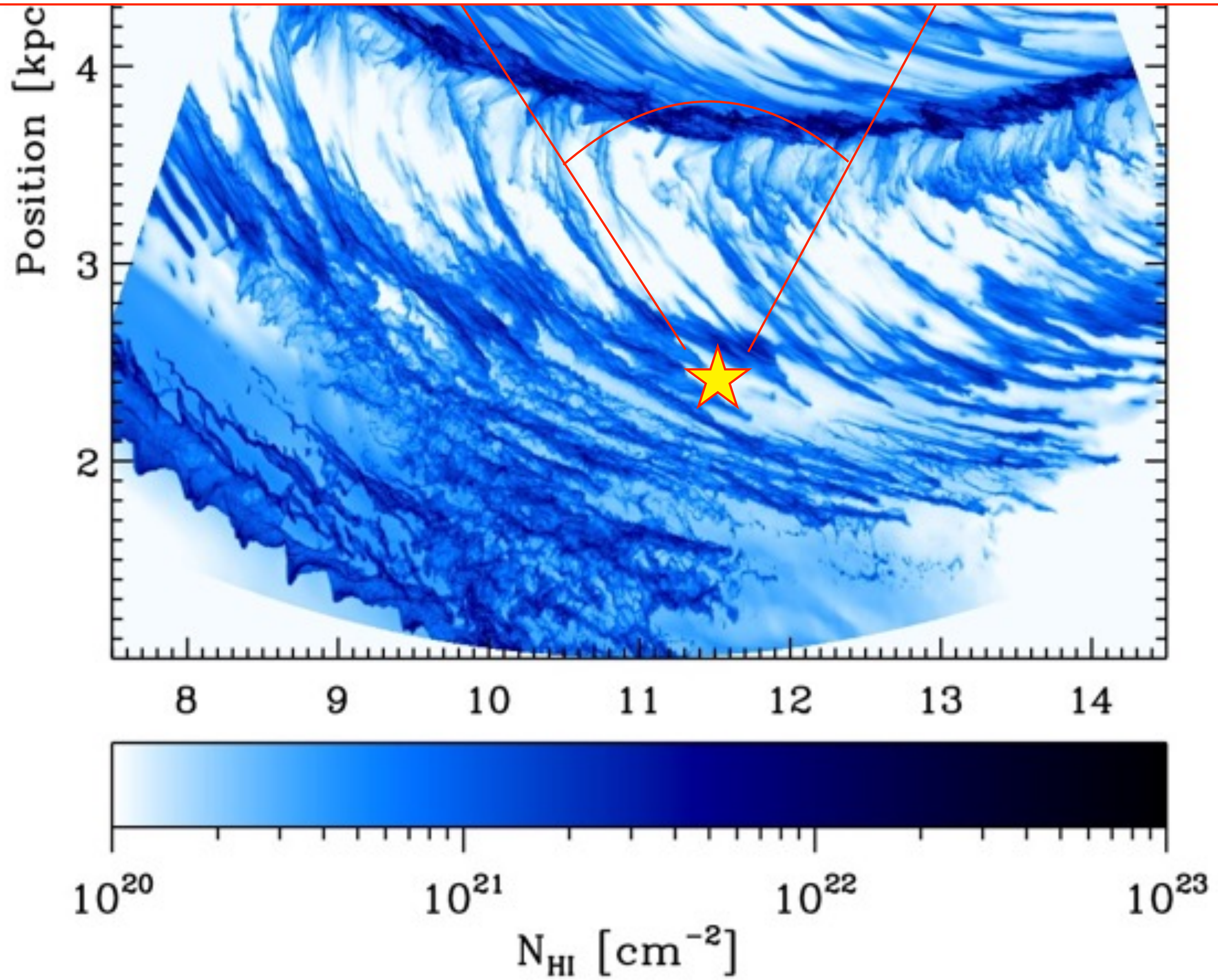
(Smith et al., 2014, MNRAS, 441, 1628)

image from THOR Galactic plane survey (PI H. Beuther): continuum emission around 21 cm



next step: produce all sky maps at various positions in the model galaxy (use RADMC-3D)

(Beuther et al., 2016, A&A, in press, arXiv:1609.03329, Bihr et al. 2016, A&A, 588, A97)



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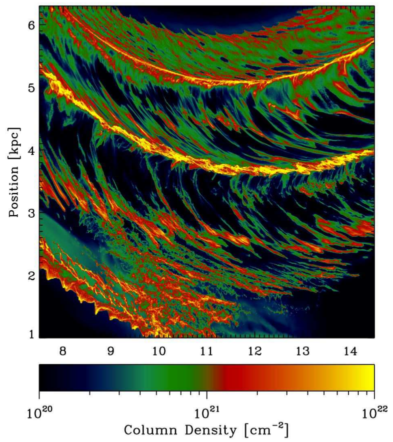

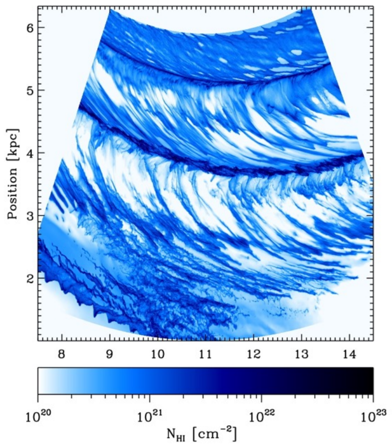

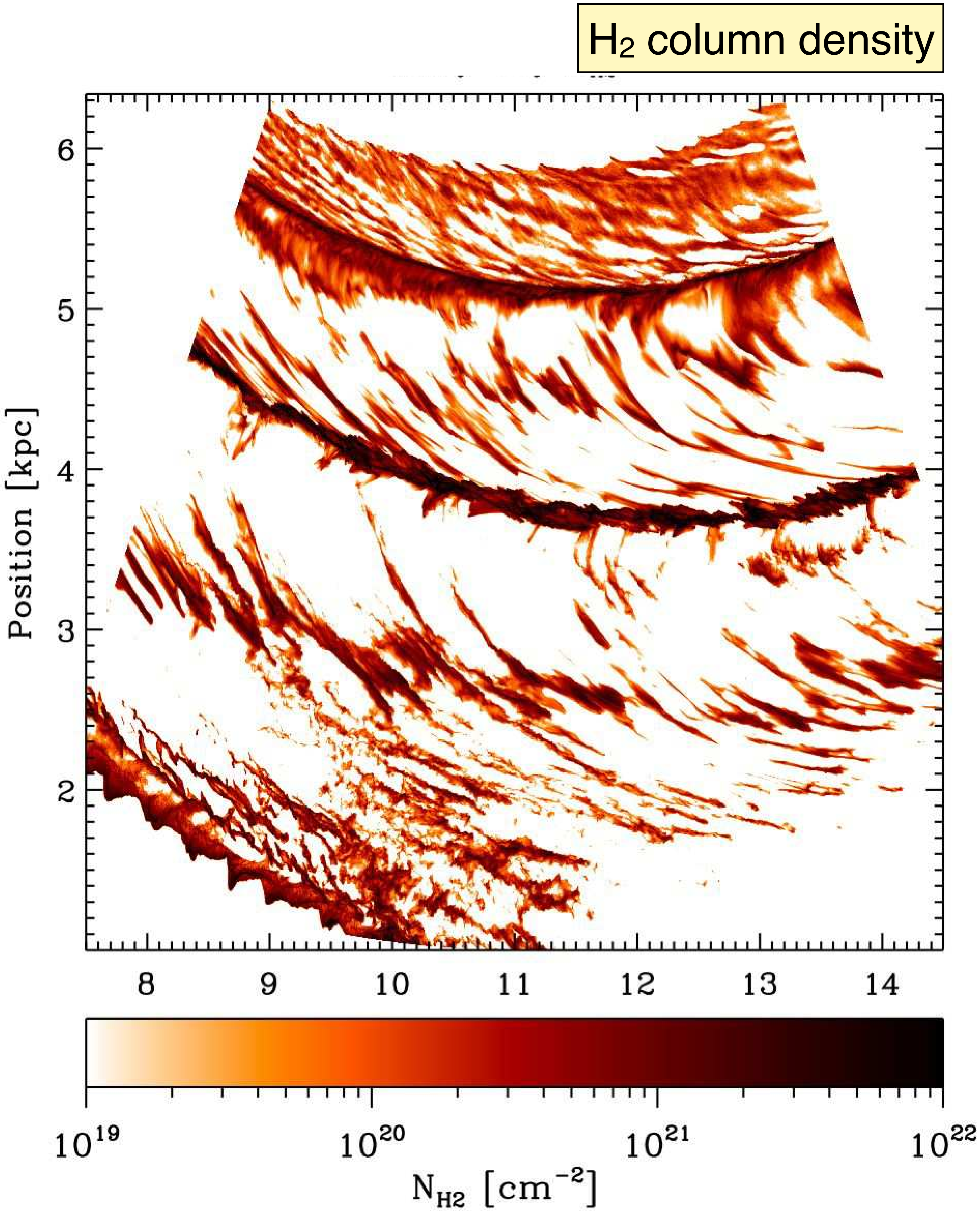

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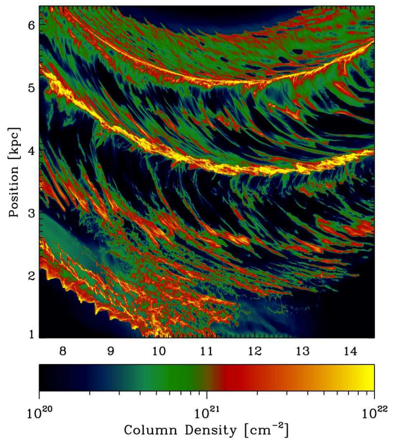
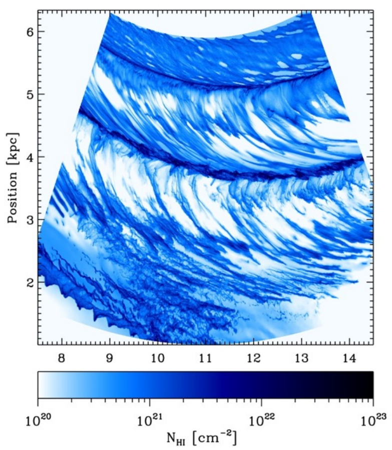
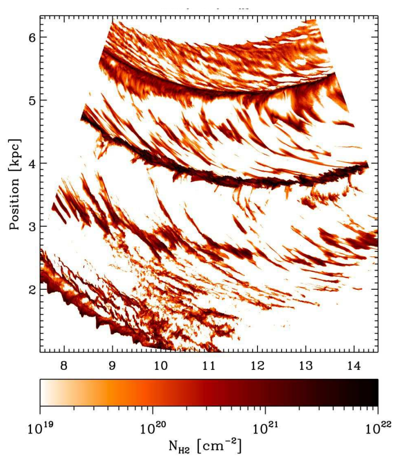
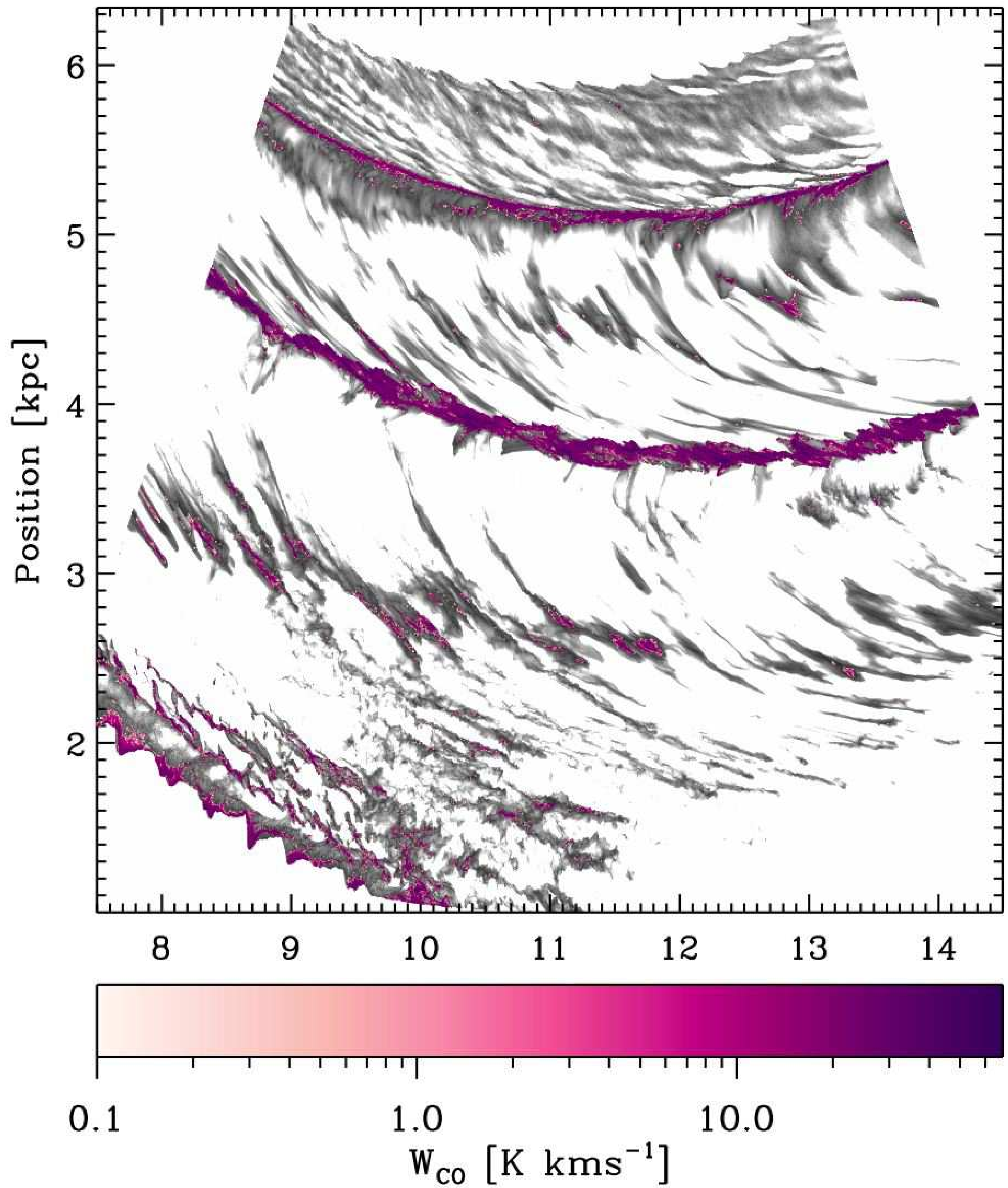
CO column density



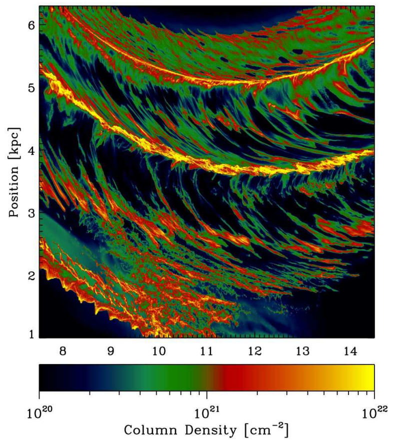


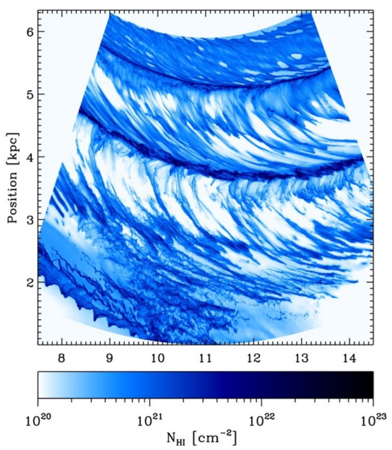


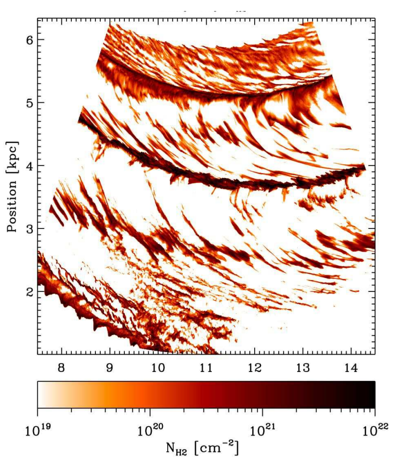


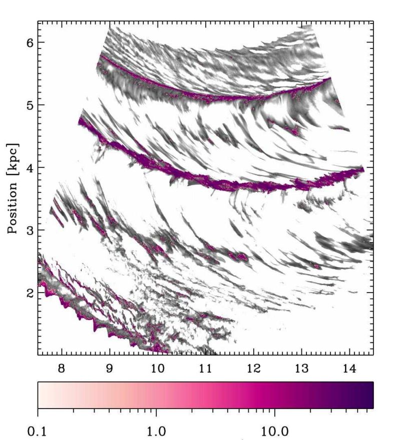
(Smith et al., 2014, MNRAS, 441, 1628)

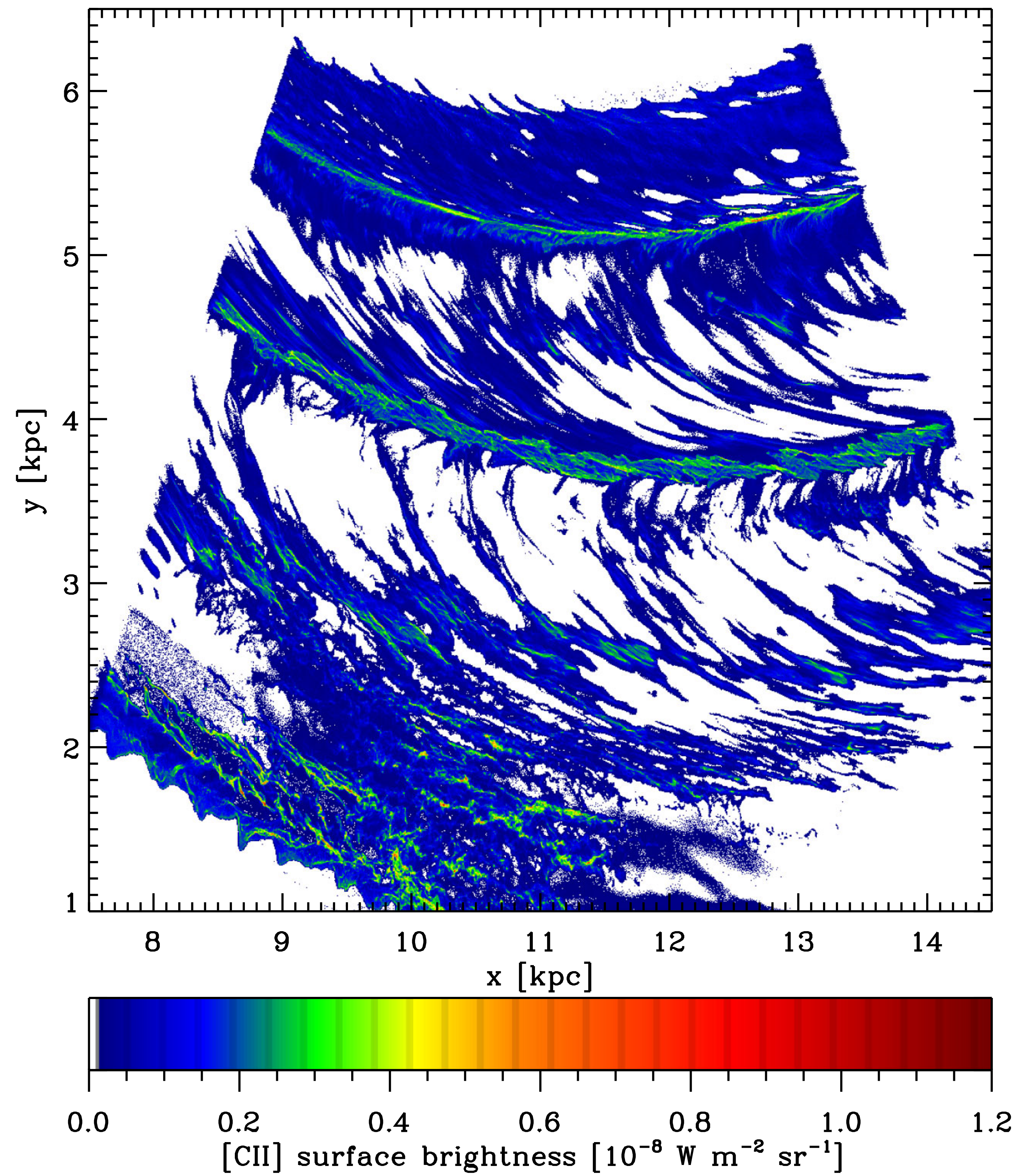
[CII] surface brightness







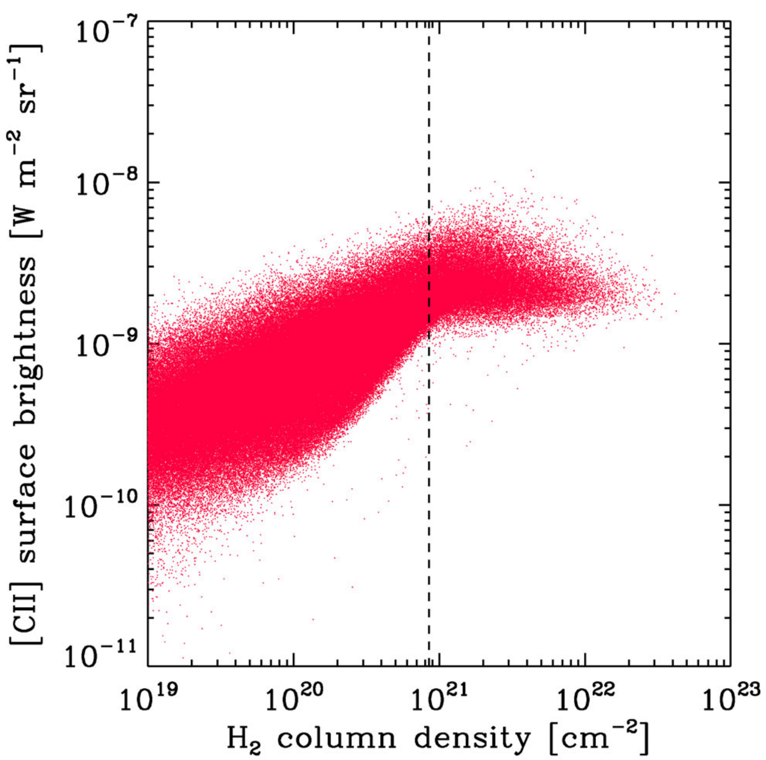


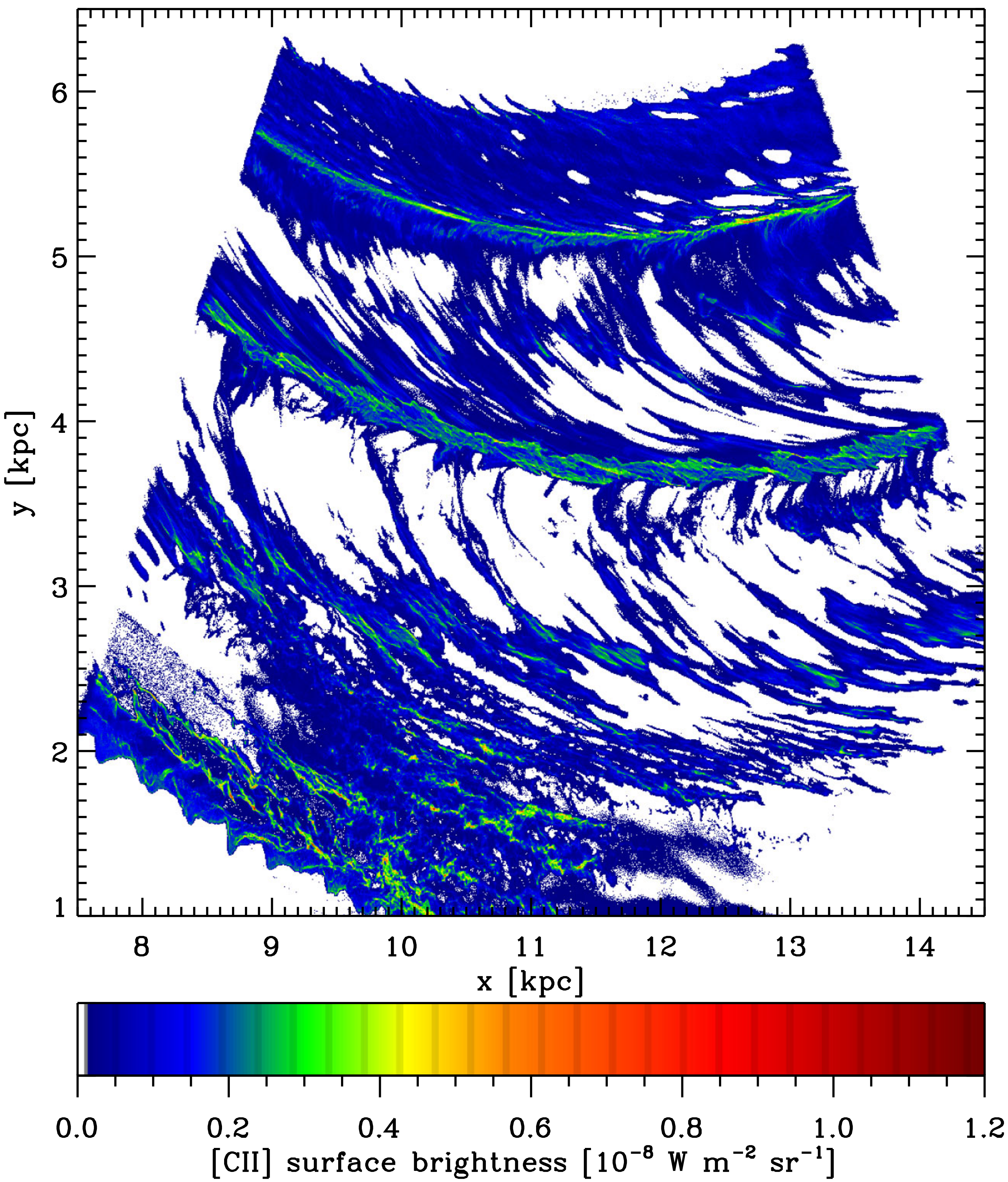


(Smith et al., 2014, MNRAS, 441, 1628, Glover & Smith, 2016, 462, 3011)

[CII] surface brightness

- weak correlation between [CII] emission and H_2 column density (saturation at large columns)
- CO-bright component is cold ($T \lesssim 30$ K) and gas is almost 100% molecular (clouds)
- CO-dark gas has range of temperatures ($30\text{ K} \lesssim T \lesssim 100$ K), H_2 fraction varies strongly





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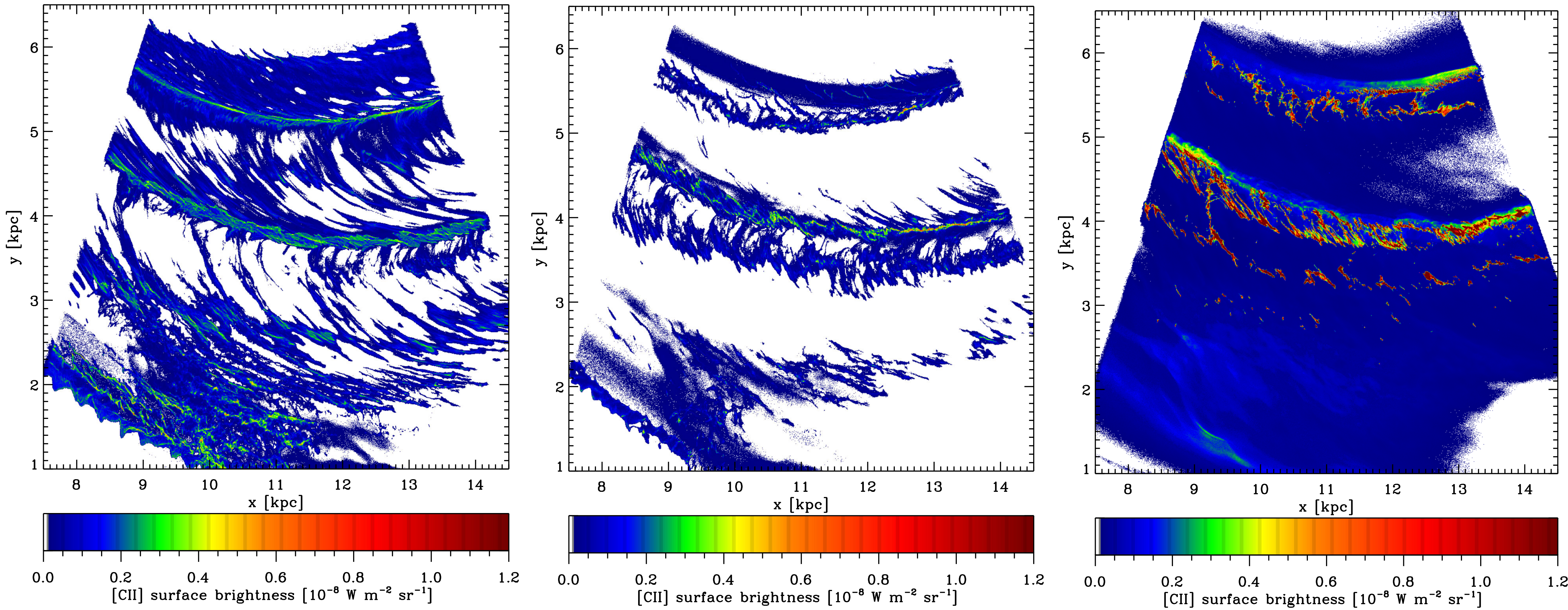


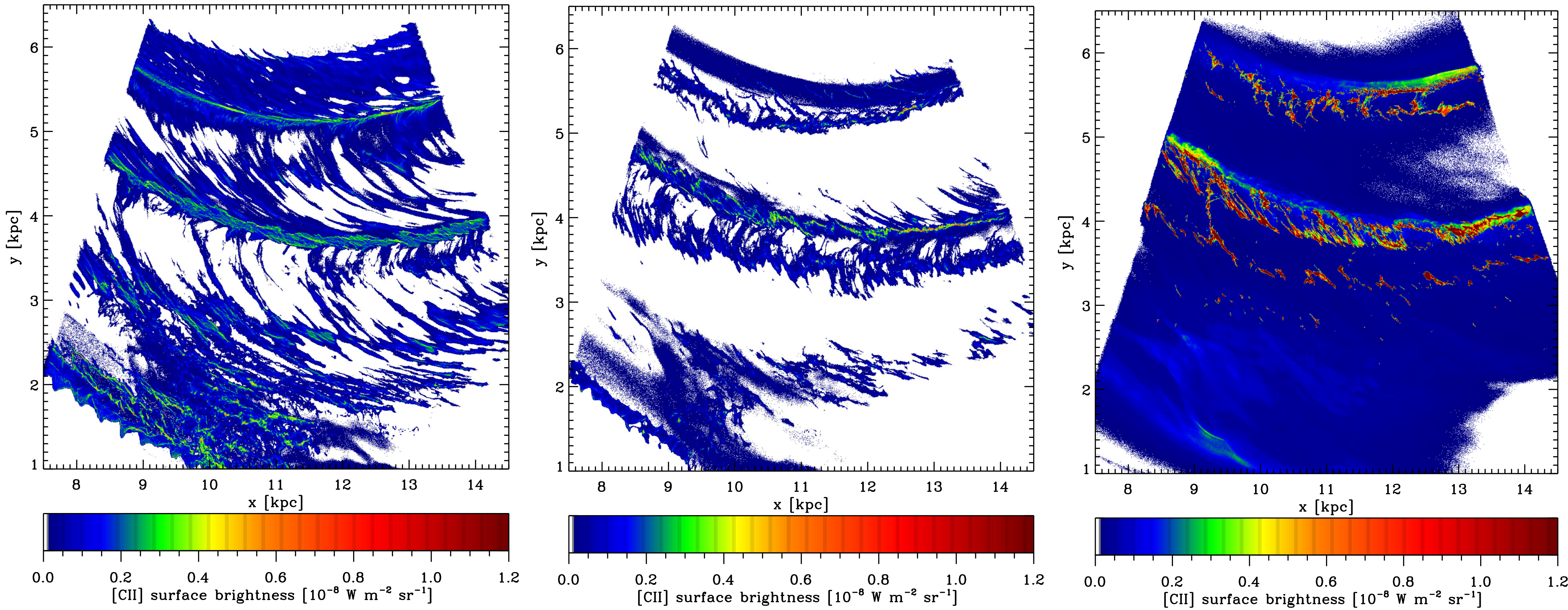
standard MW case

low surface density

standard surface density with high radiation field (G_0 = 17)

(Glover & Smith, 2016, 462, 3011)

[CII] surface brightness



st

surface density

radiation field

comparison with data from SOFIA large program on M51

(Glover & Smith, 2016, 462, 3011)

new models (full disk)

same as in Smith et al. (2014), but improved:

- more realistic potential (better disk scale height)
- larger disk area
- with *self-gravity* and supernovae feedback!
- two types now:
  - high resolution (4 M⊙) wedge as previously
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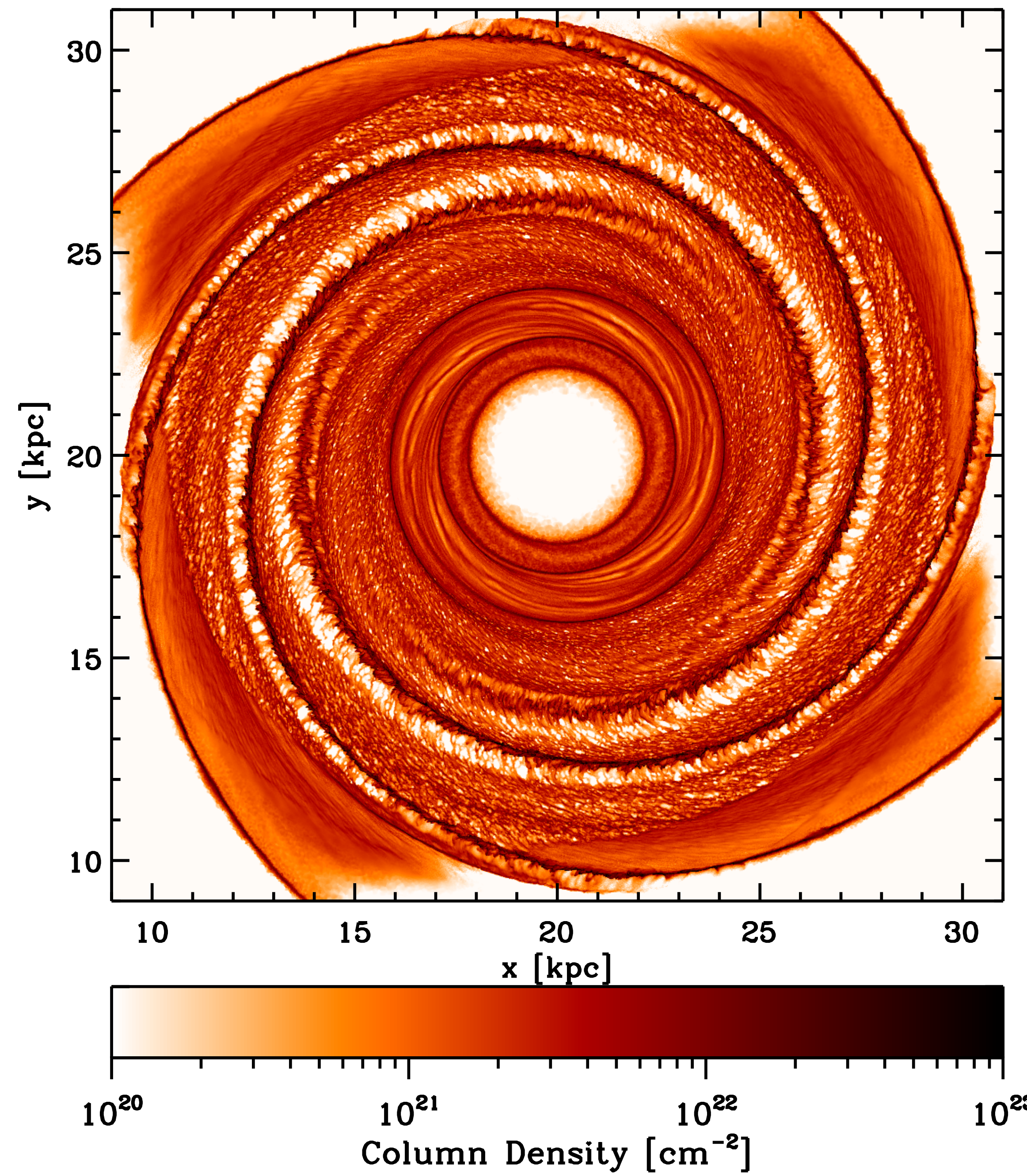

comparison with data from SOFIA large program on M51

current developments

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Ralf Klessen
17.10.2016

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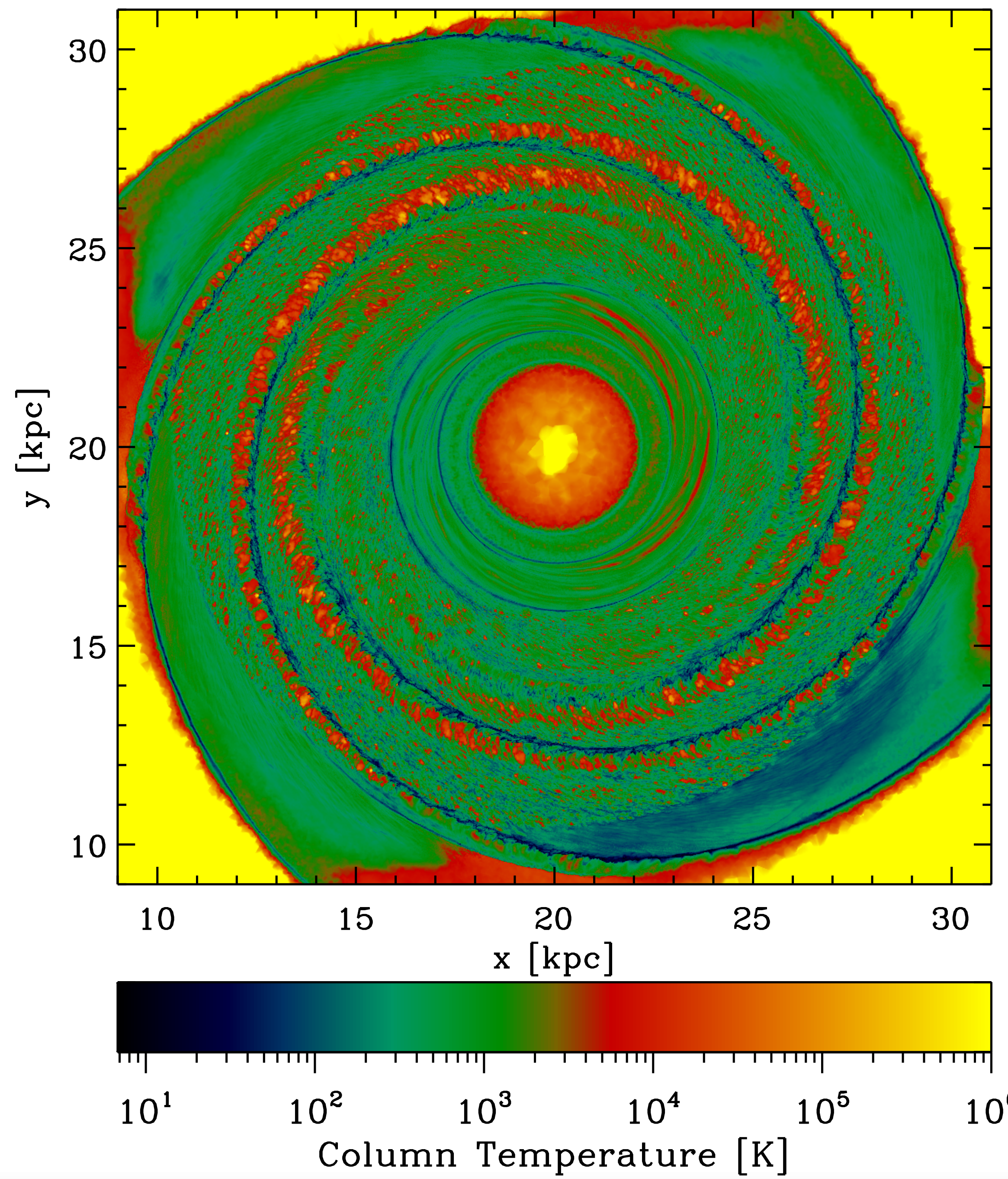

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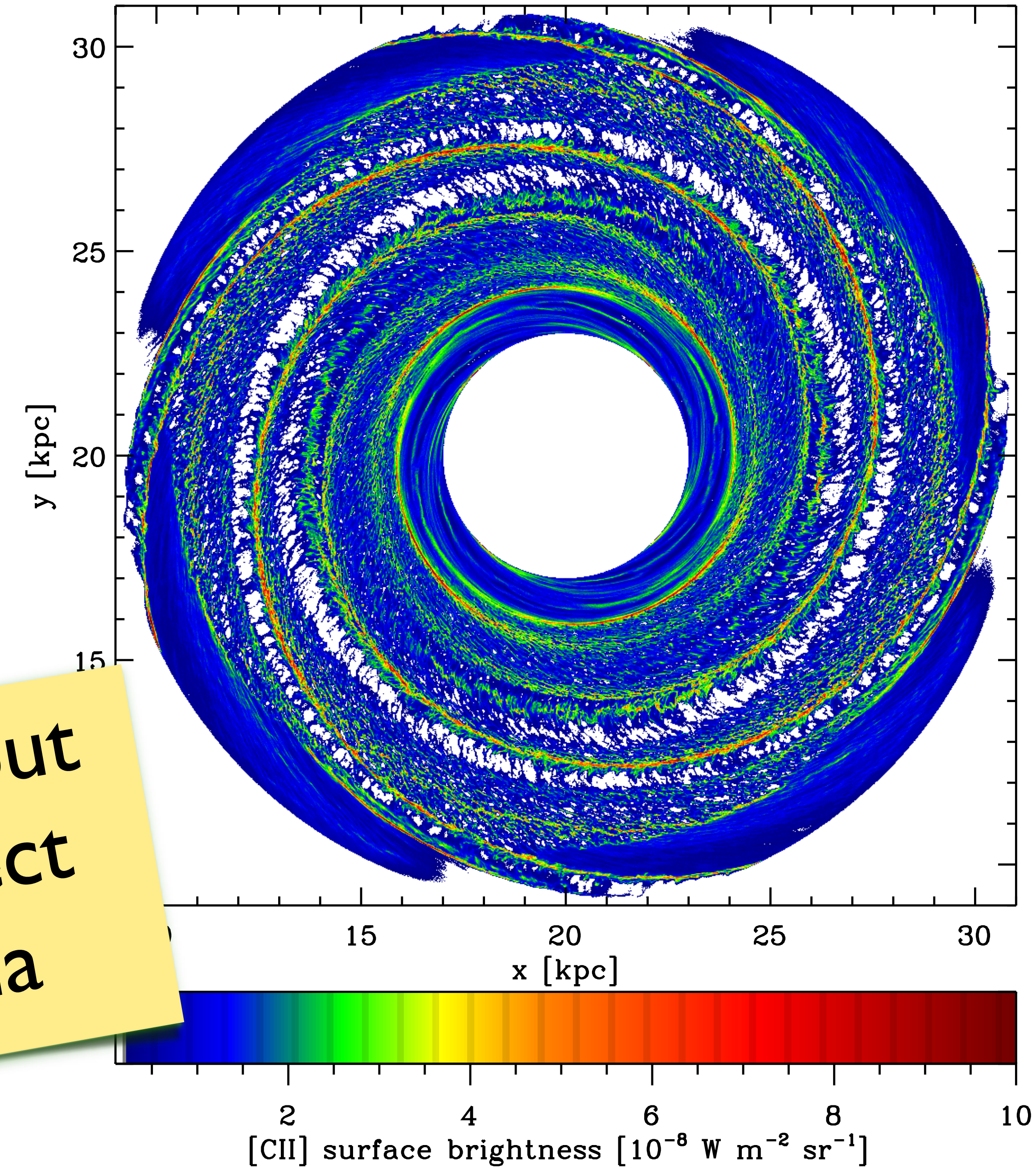
more information about the M51 SOFIA project in talk by Jorge Pineda



comparison with data from SOFIA large program on M51

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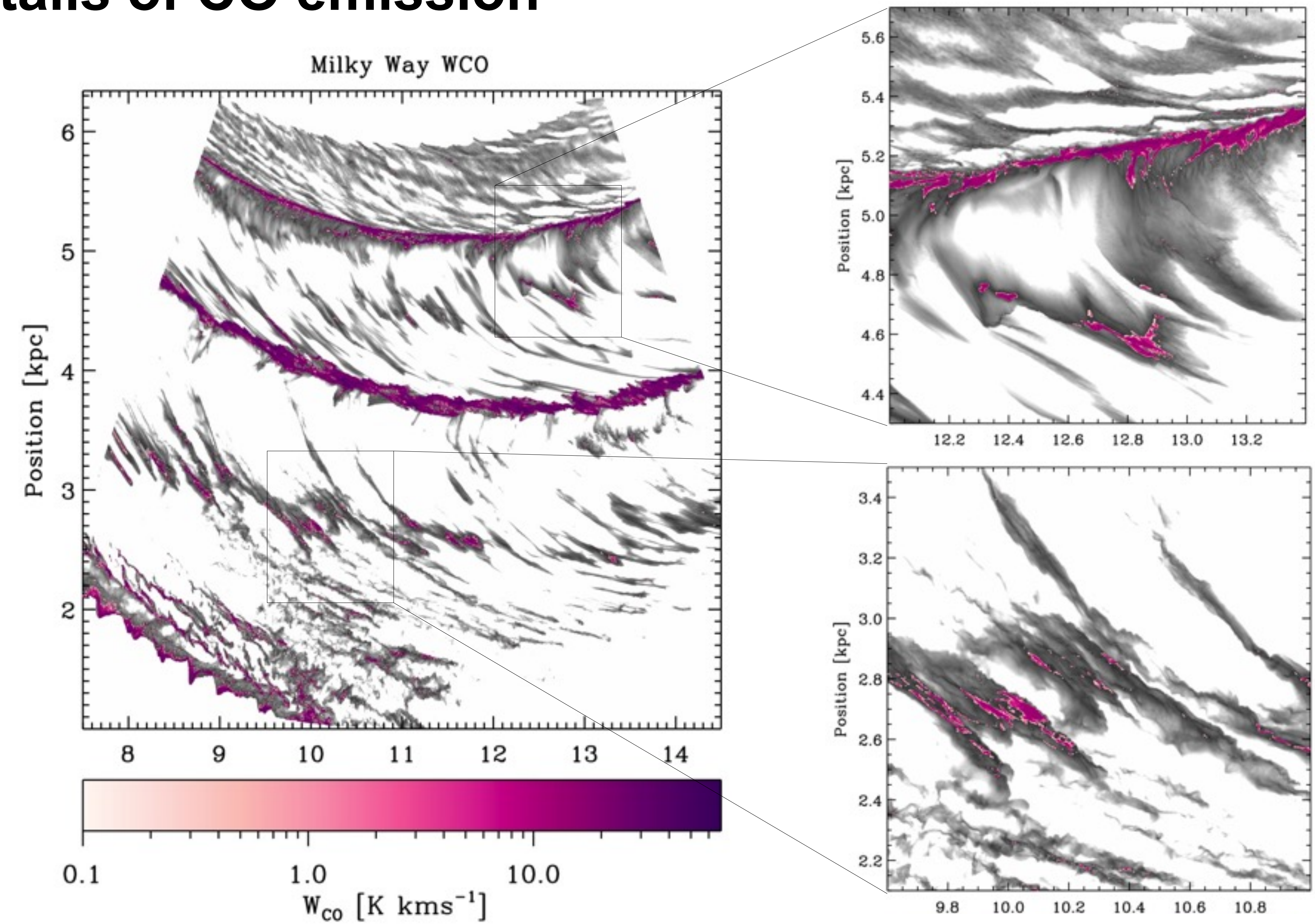
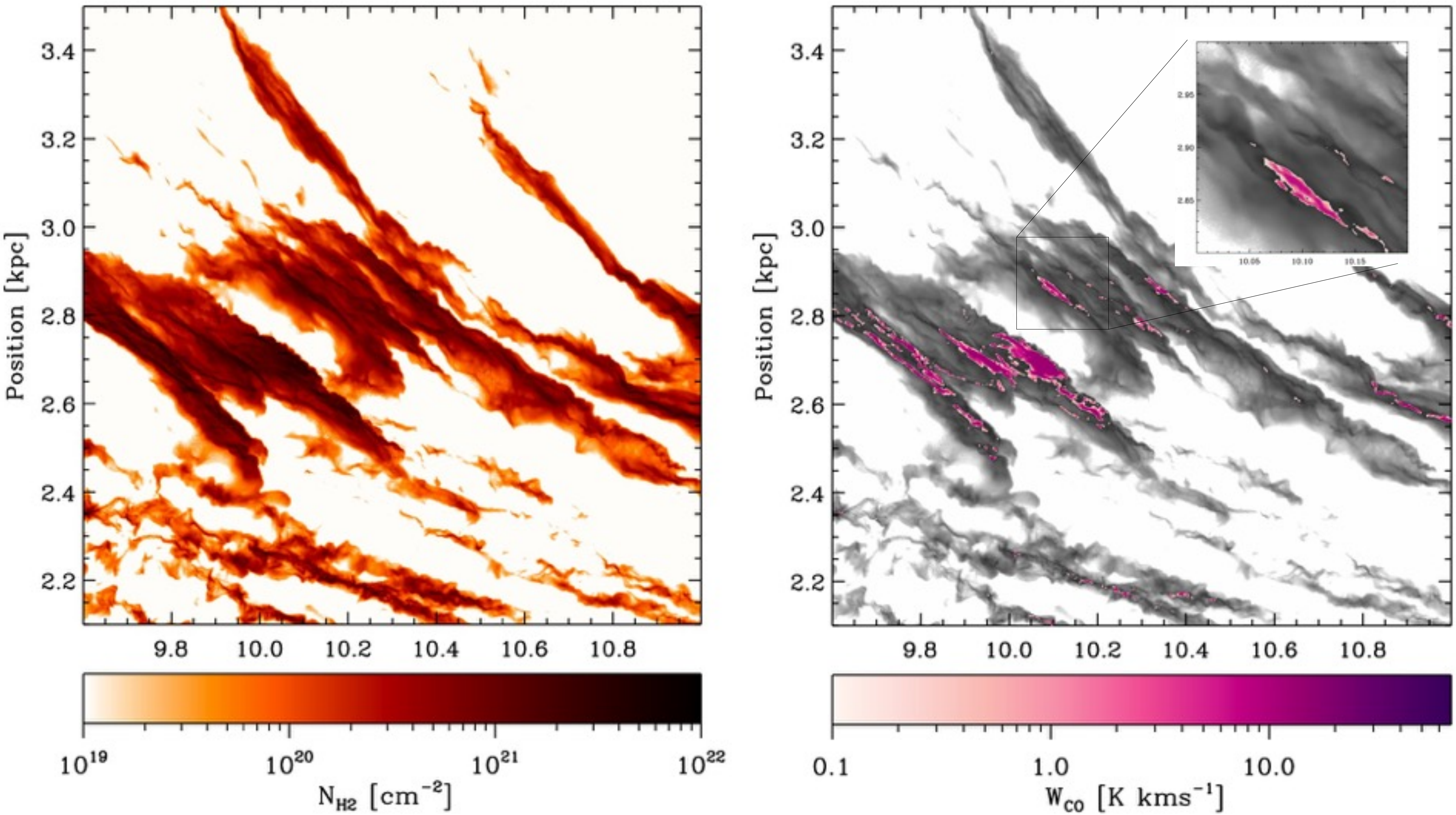
details of CO emission

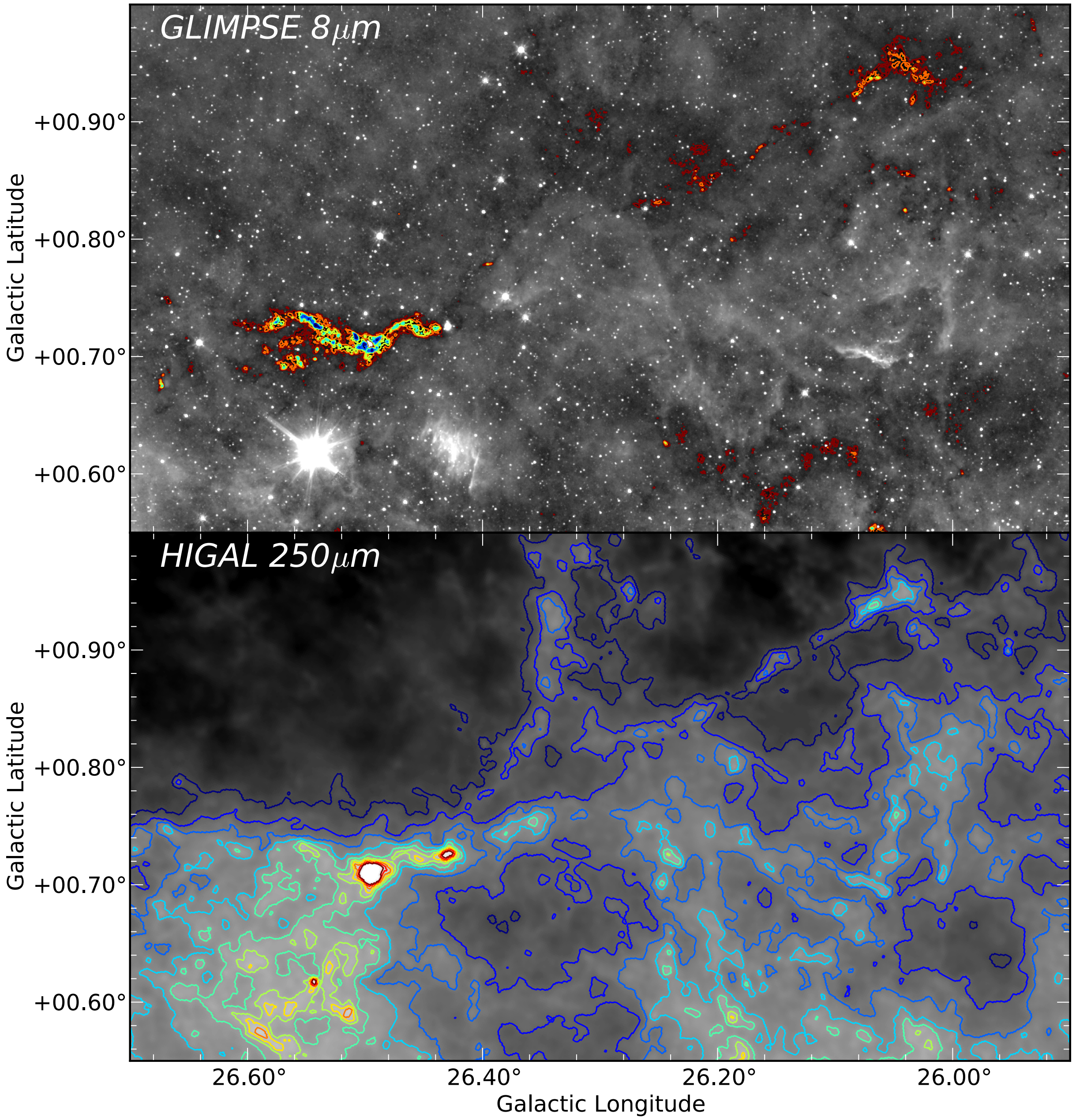


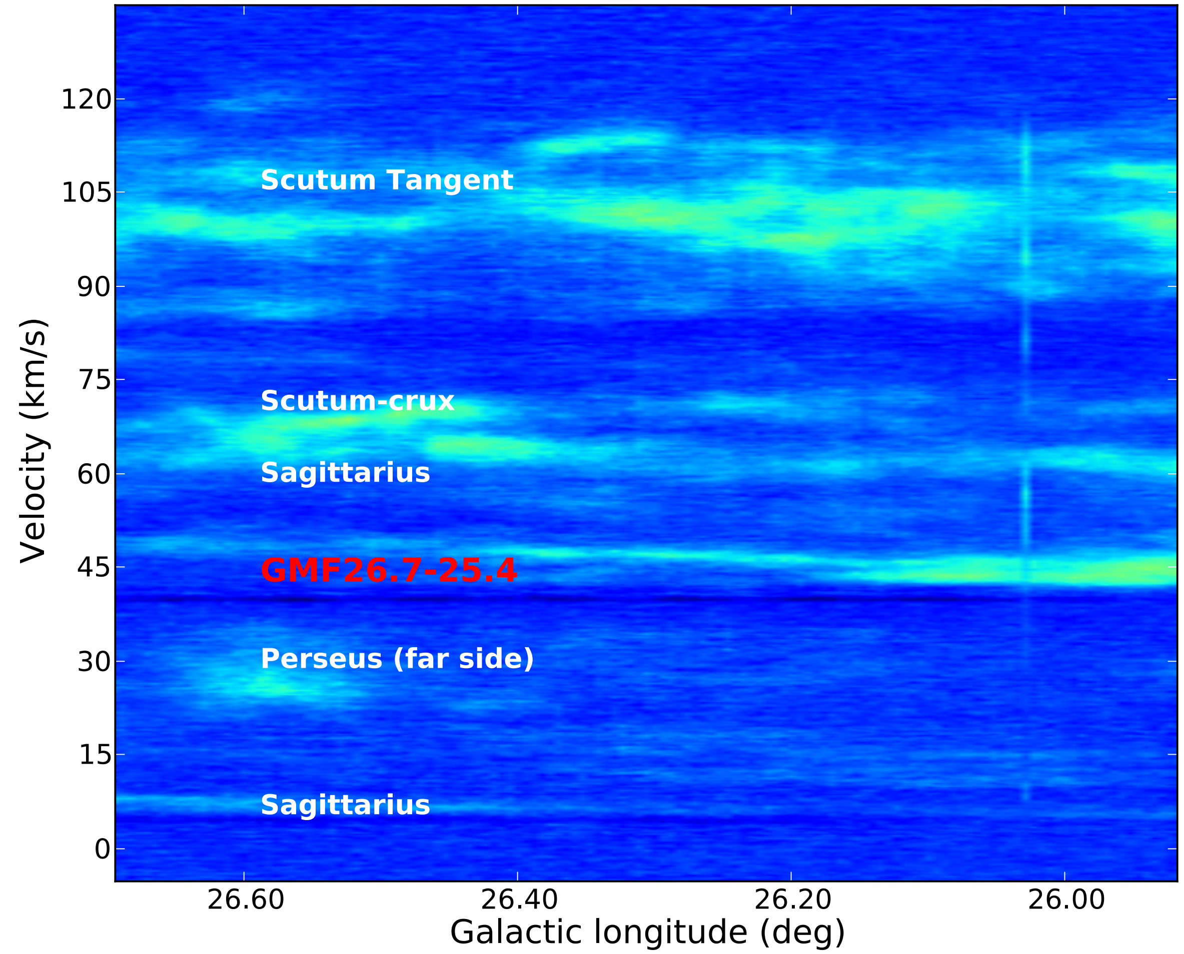
(Smith et al., 2014, MNRAS, 441, 1628)

relation between H_2 and CO



Filamentary molecular clouds in inter-arm regions are likely only the observable parts of much larger structures.





Filamentary molecular clouds in inter-arm regions are likely only the observable parts of much larger structures.

more on filaments in talks by Sarah Ragan and Edith Falgarone

Name	Cloud mass [$M_\odot$						
GMF 18.0-16.8	1.5e+5						
GMF 20.0-17.9	4.0e+5	4.8e+4					rm
GMF 26.7-25.4	2.0e+5	1.3e+4	6.5				
GMF 38.1-32.4a	7.0e+5	3.7e+4[a]	5.3	5.9			
GMF 38.1-32.4b	7.7e+4	5.0e+3[a]	6.5	6.2	11.5		
GMF 41.0-41.3	4.9e+4	7.7e+2	1.6	6.5	12.5	19	
GMF 54.0-52.0	6.8e+4	2.4e+3	3.5	7.3	11.2	25	W 52
Nessie	–	3.9e+5	–	5.6	–7.8	–	SC-arm
G32.02+0.06	2.0e+5	3.0e+4	15.0	4.7	19.7	48	

Ragan et al. (2014 A&A 568, A73)

dark gas fraction

Observational estimates:

Grenier et al. (2005) f_{DG} = 0.33-0.5

Planck coll. (2011)* f_{DG} = 0.54

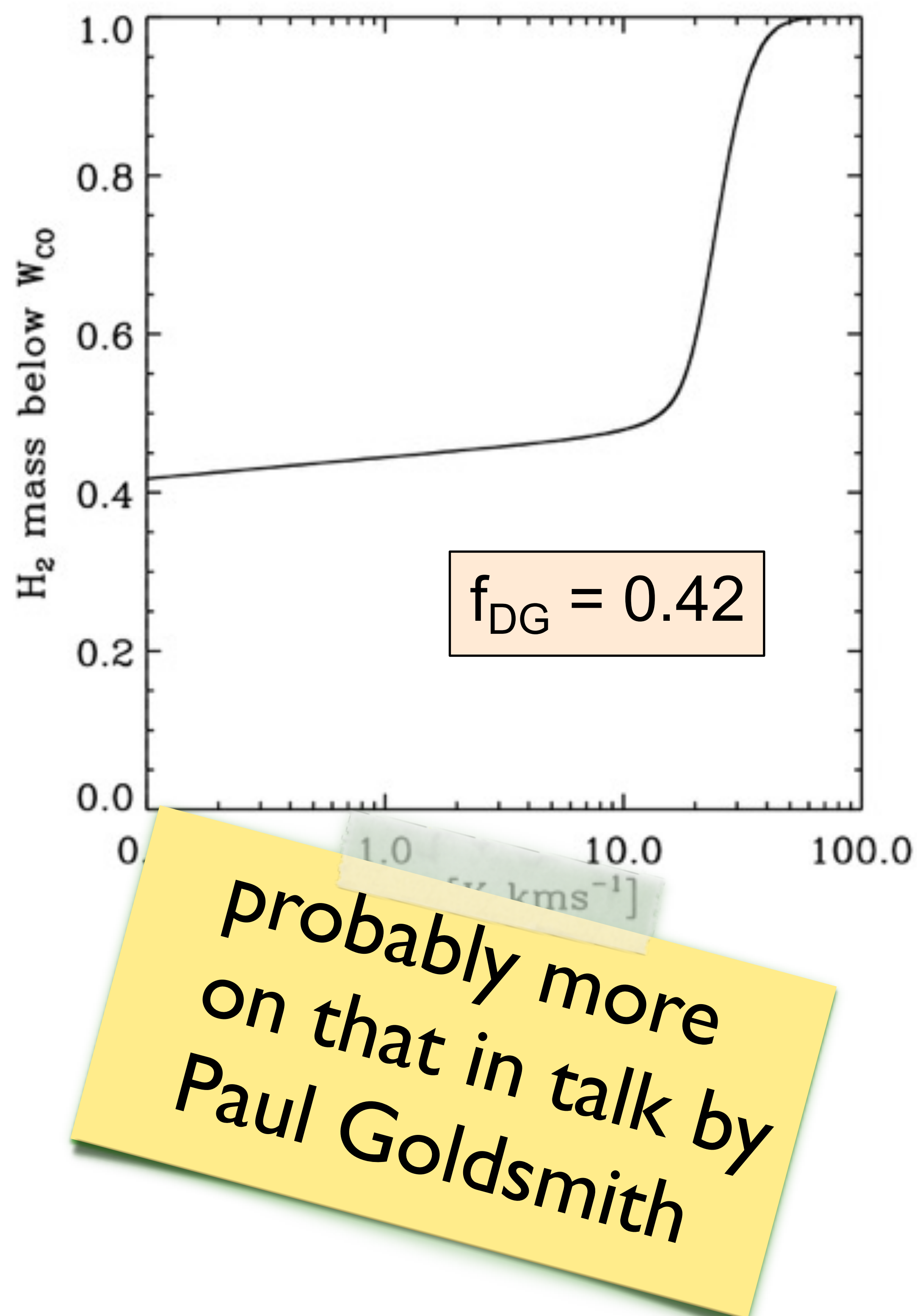
Paradis et al. (2012)* f_{DG} = 0.62

(inner f_{DG} = 0.71, outer f_{DG} = 0.43)

Pineda et al. (2013) f_{DG}= 0.3

Roman-Duval et al. (in prep.) f_{DG} ~ 0.5

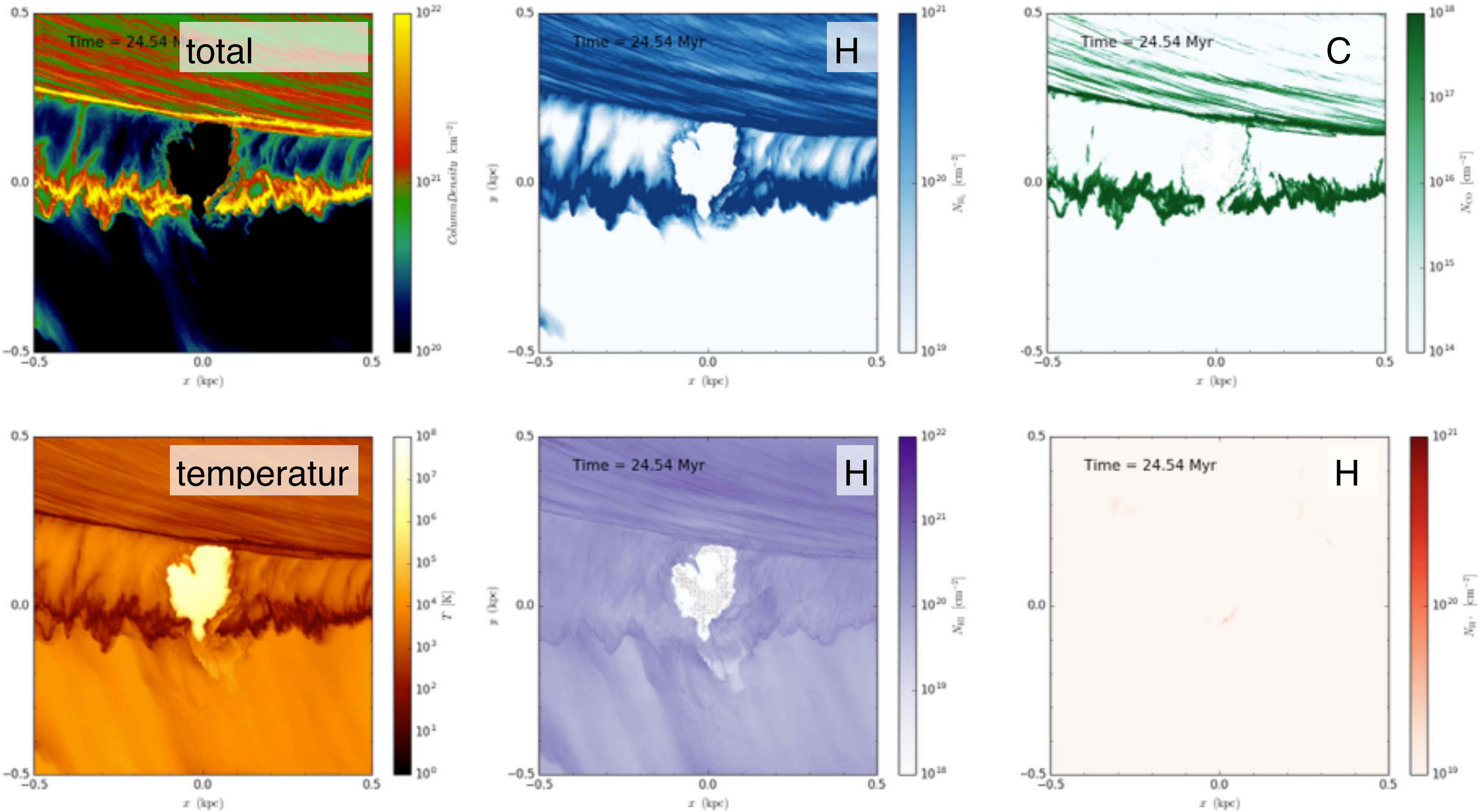
* dust methods have large uncertainties.



(Smith et al., 2014, MNRAS, 441, 1628)


what is coming …

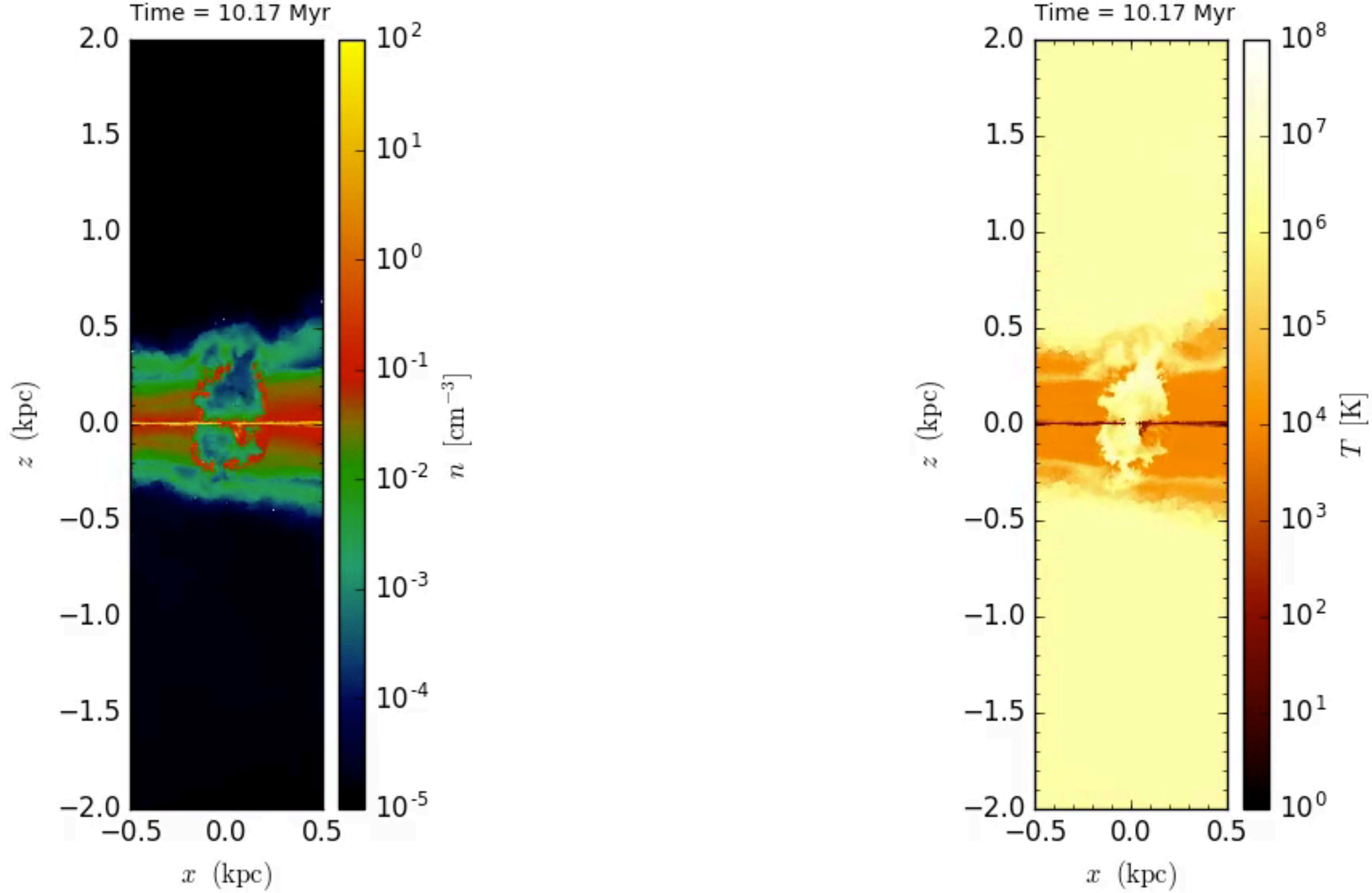
current developments



new models that include self-consistent star formation

Treß et al. (in preparation)

current developments



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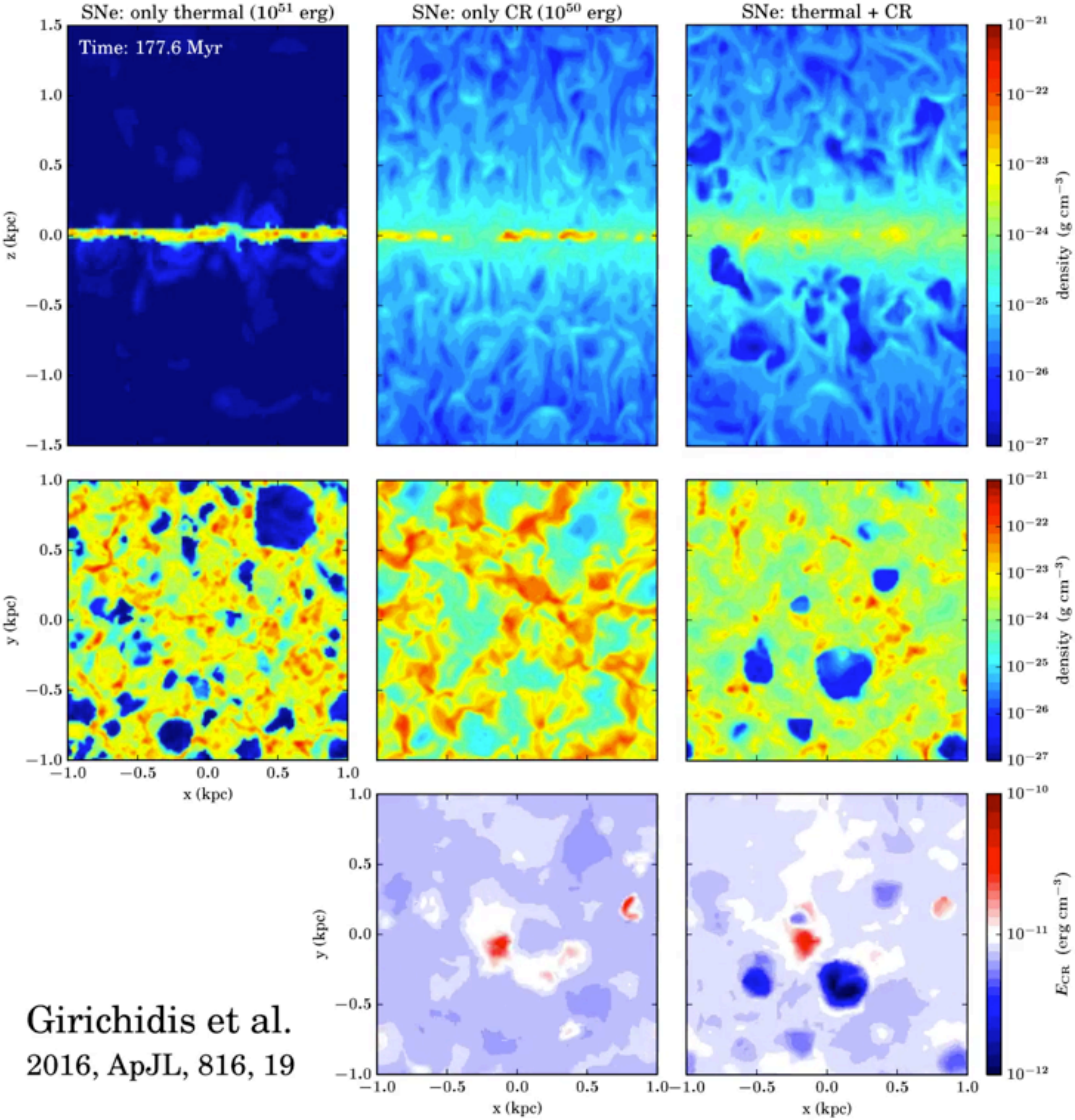
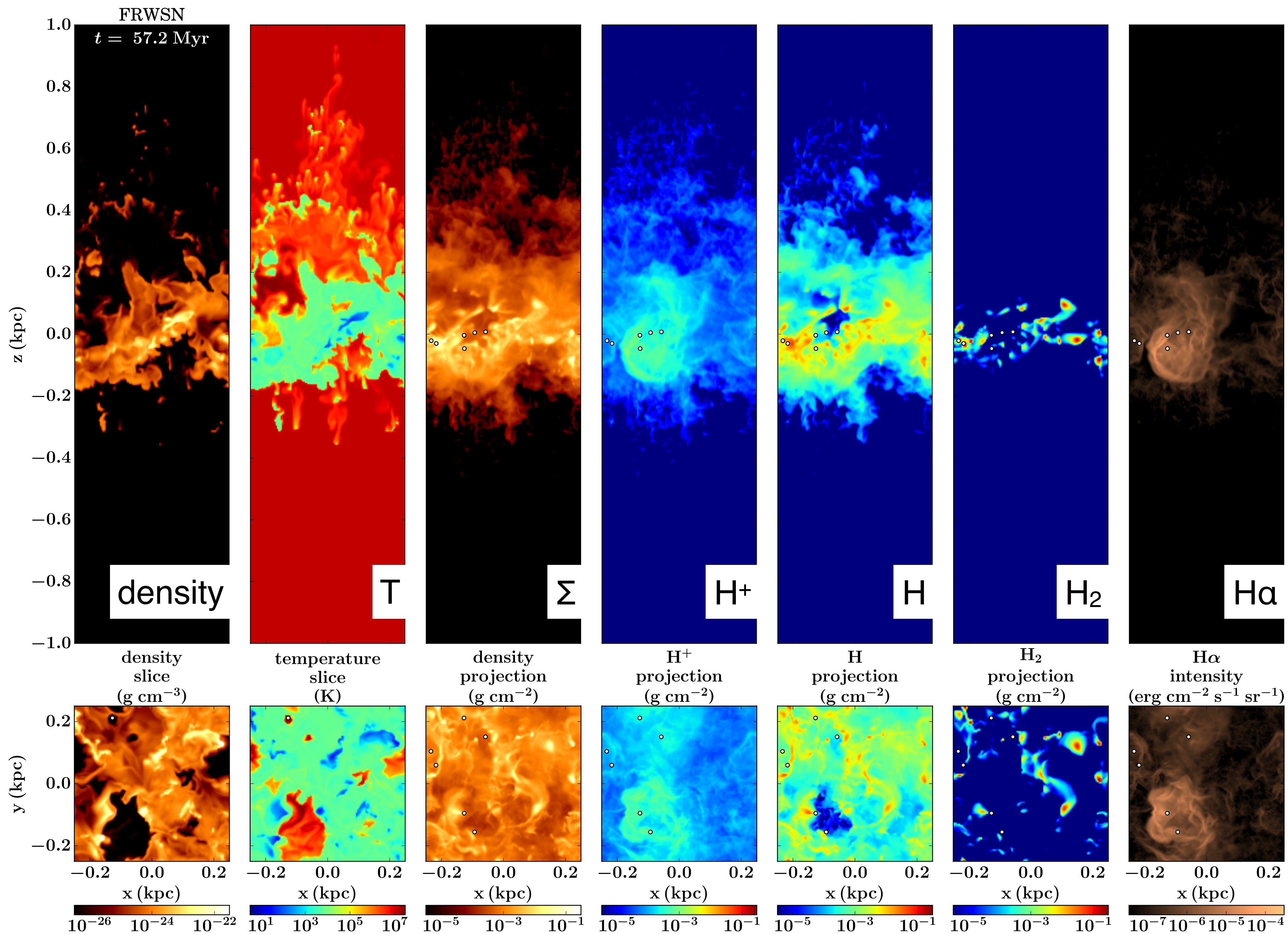


Girichidis et al.
2016, ApJL, 816, 19

see also:
Walch et al. 2015, MNRAS, 454, 238, Gatto et al. 2015, MNRAS, 449, 1057, Girichidis et al. 2016, MNRAS, 456, 3432

current developments

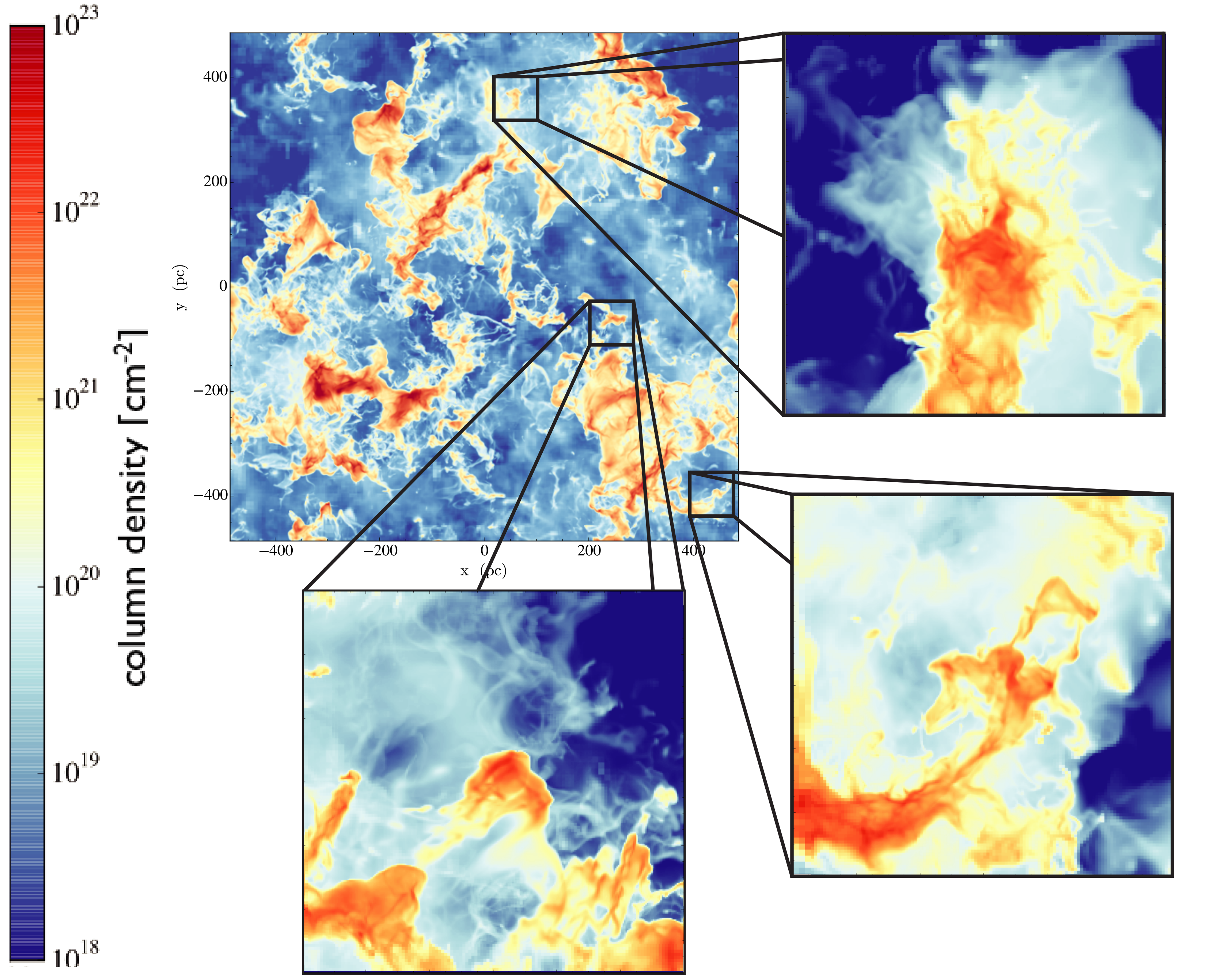


Peters et al. (2016, in prep)

synthetic maps in further observables: HI, Halpha, other radio recombination lines

SILCC collaboration: http://hera.ph1.uni-koeln.de/~silcc/

current developments

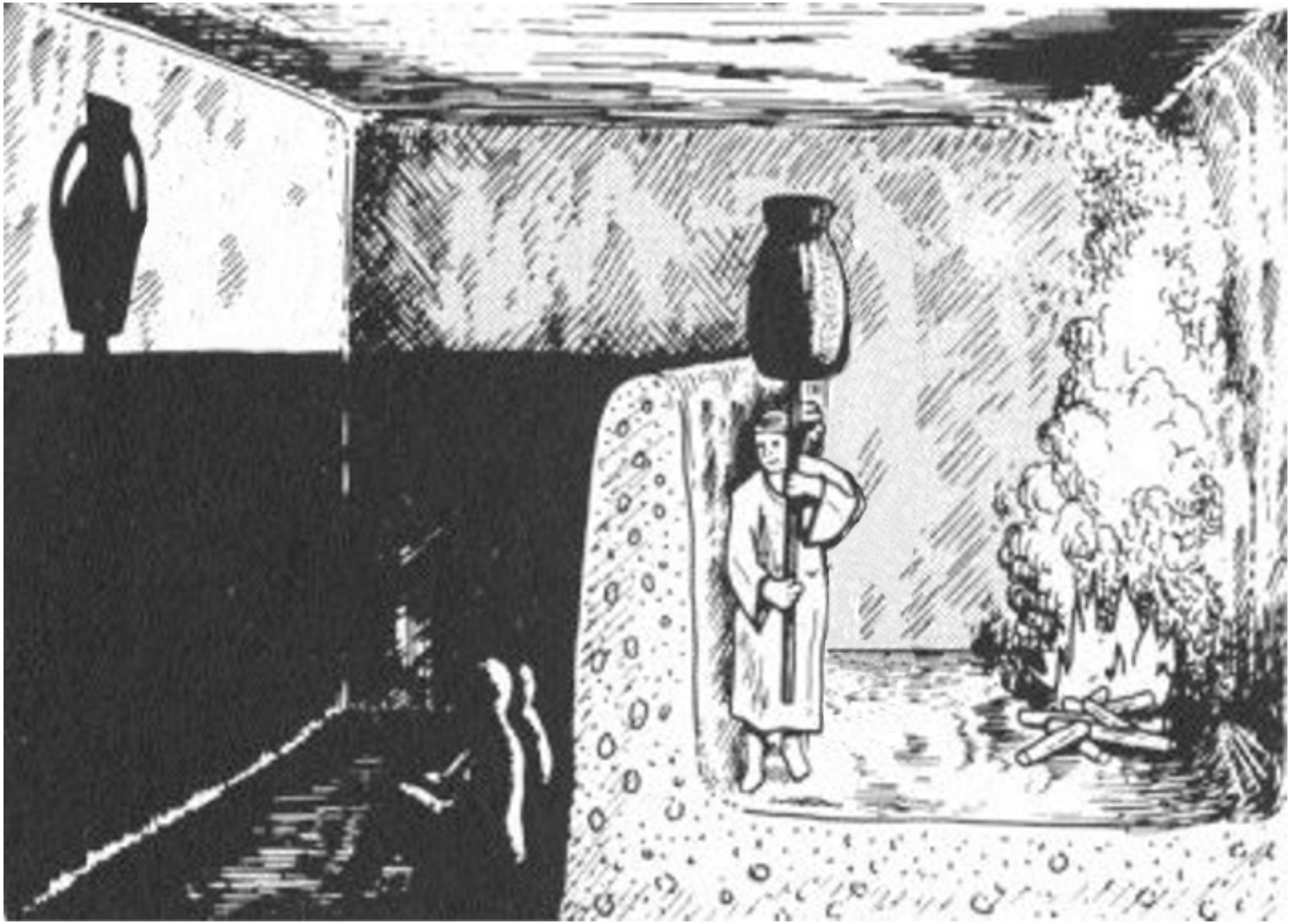


zoom-in calculations to provide better boundary conditions for star cluster formation simulations

Ibanez Mejia et al. (2016, ApJ, 824, 41), Ibanez Mejia et al. (2016, in prep.), Seifried et al. (2016, in prep.)


summary

ISM dynamics is intrinsically a multi-scale and multi-physics problem. Many different processes need to be considered simultaneously.



* The Republic (514a-520a)

Laszlo Szücs, image from criticalthinking-mc205.wikispaces.com

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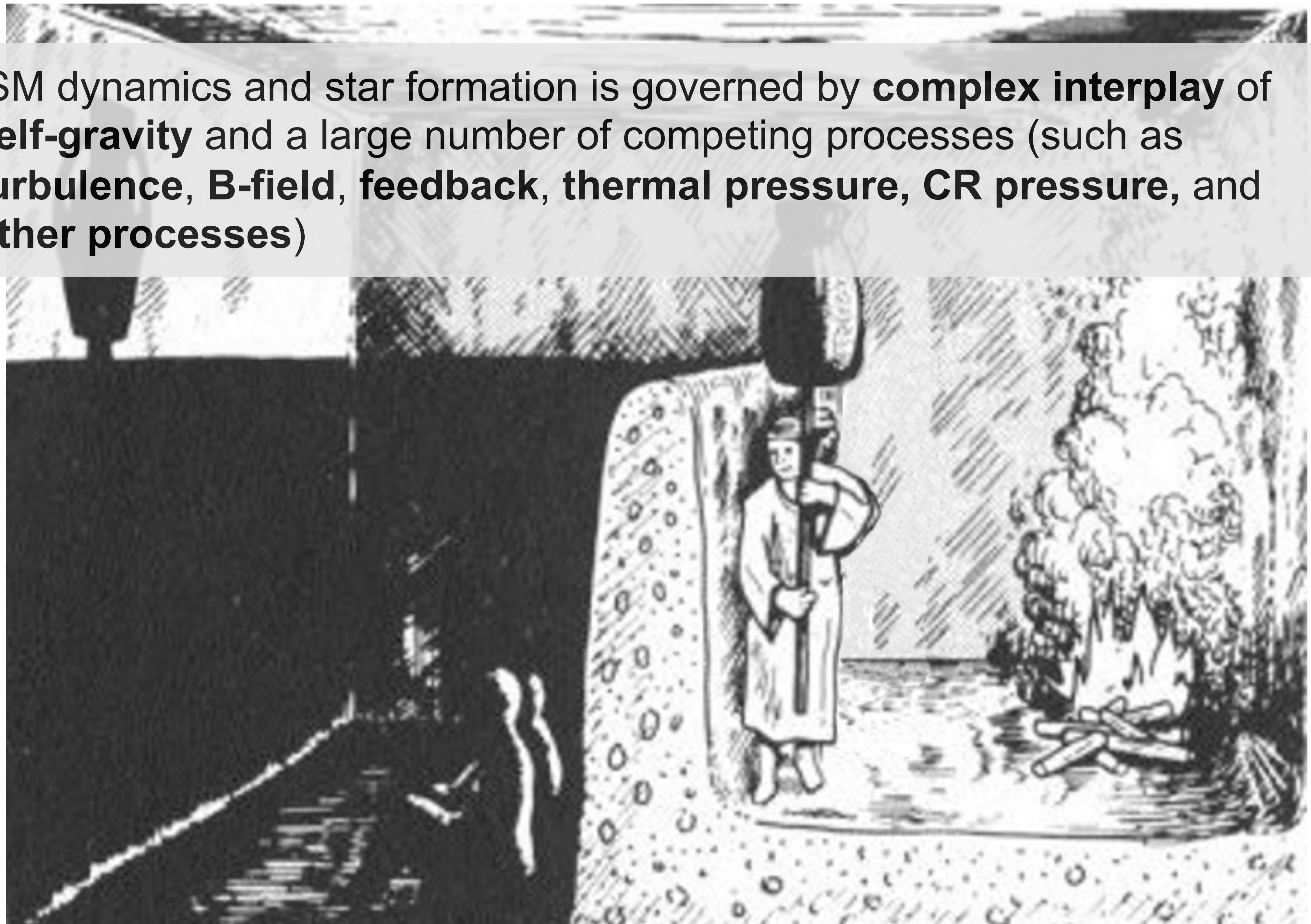

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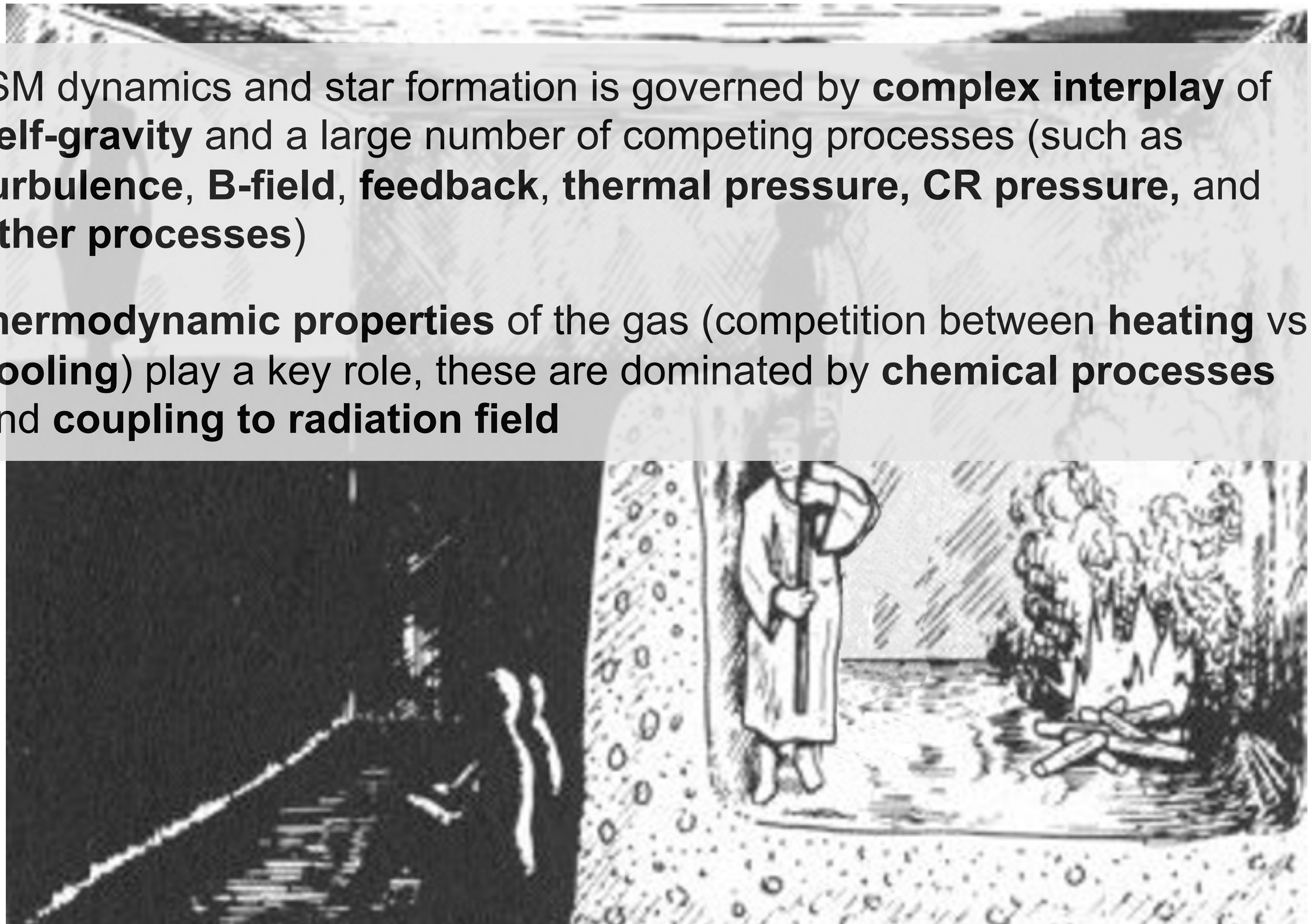

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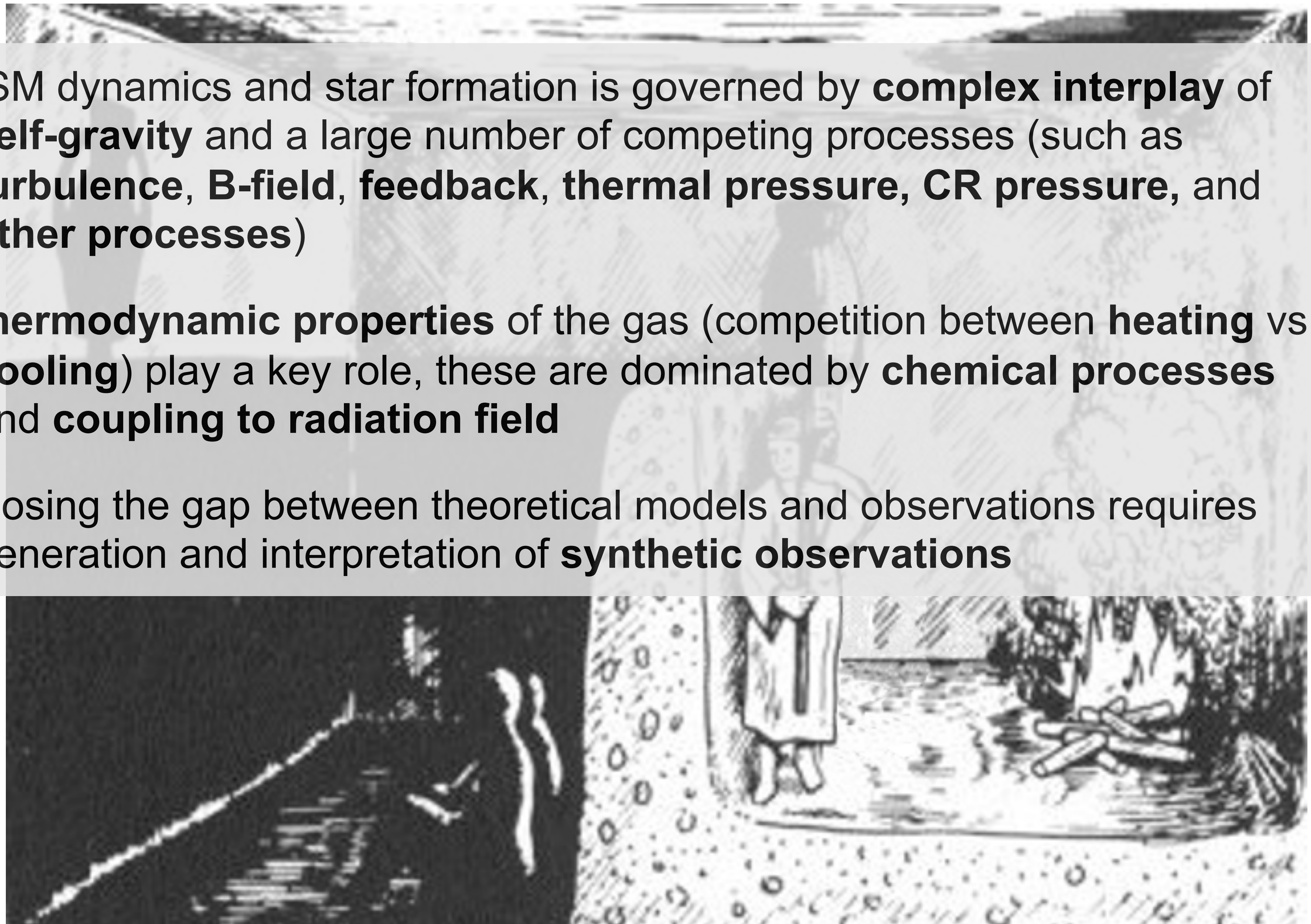

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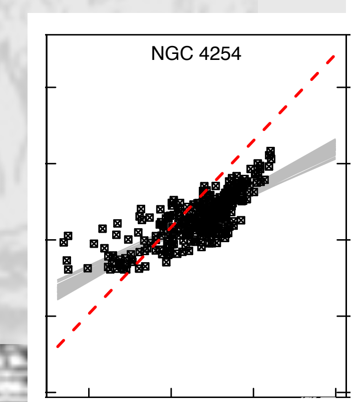

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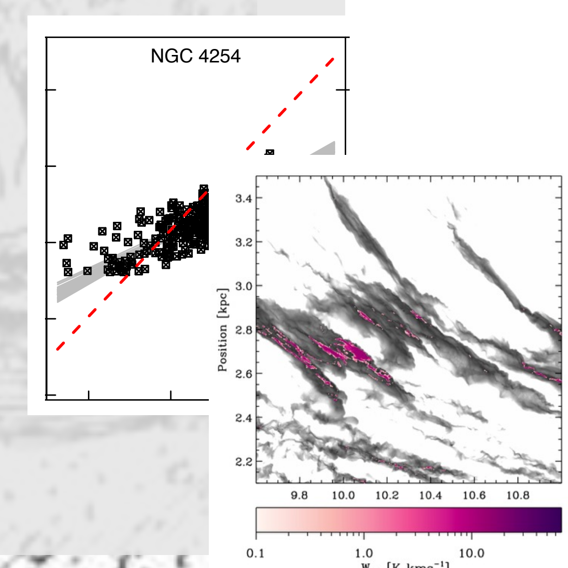

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- ISI... sel... turb... othe...
- therr... cooli... and c...
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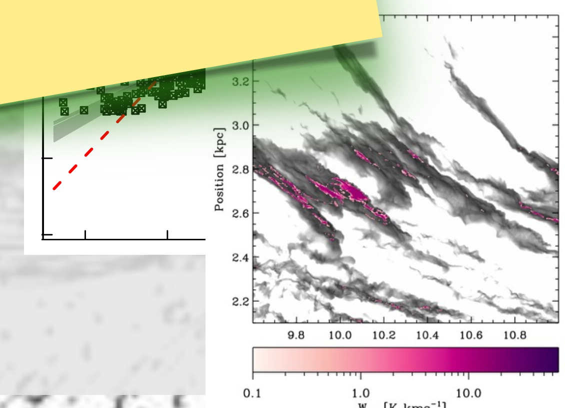
- *example*... relation l... on galact...
- *example 2*... ulations with time-dependent chemistry ... us to study the properties of CO-dark H2 gas

(personal) WISH LIST for SOFIA:

- help quantifying amount of CO-dark H_2 in the Milky Way and in other galaxies
- identify and characterize convergent flows in turbulent ISM that form molecular clouds —> help determining initial conditions for star (cluster) formation



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thanks