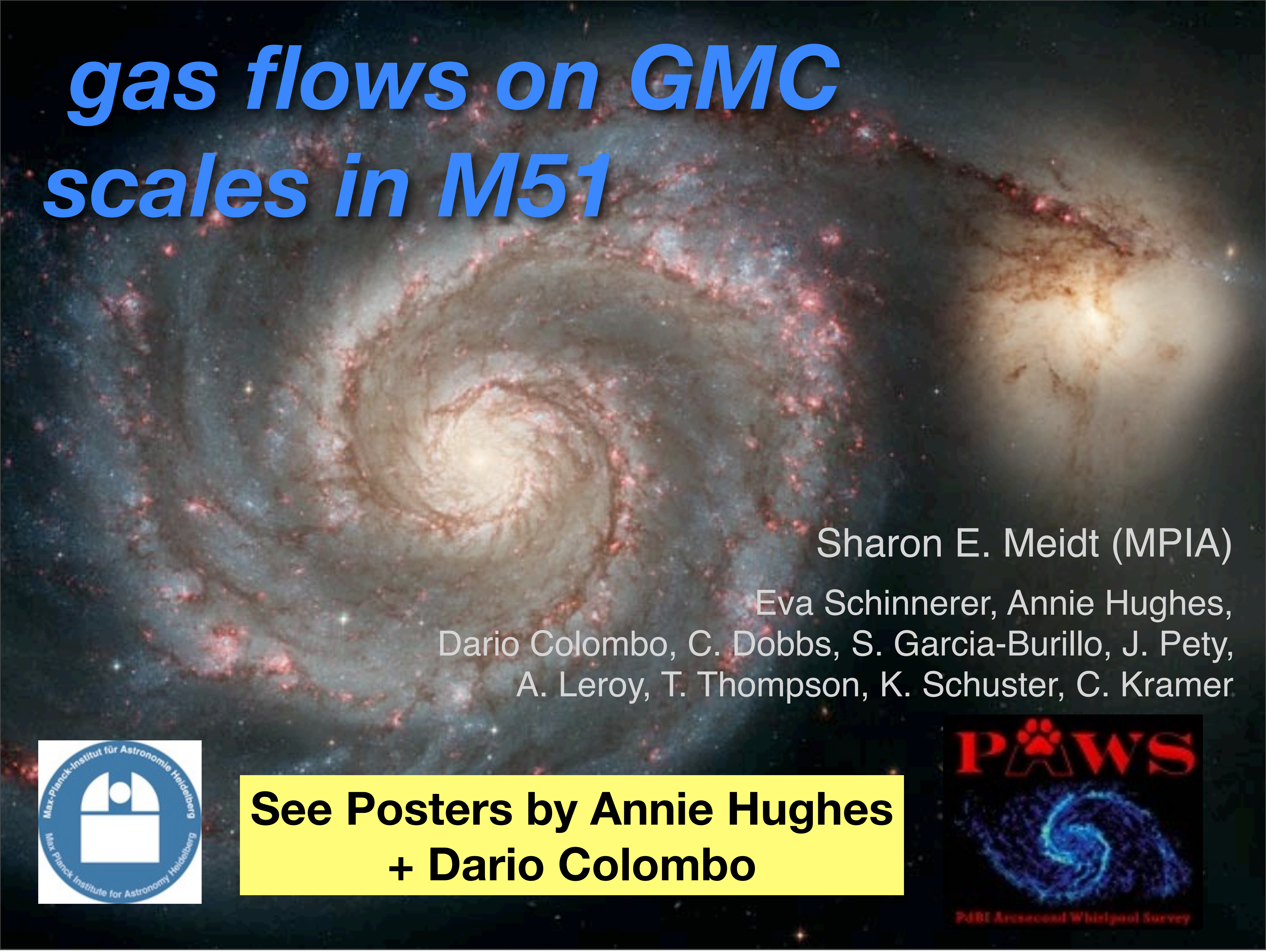
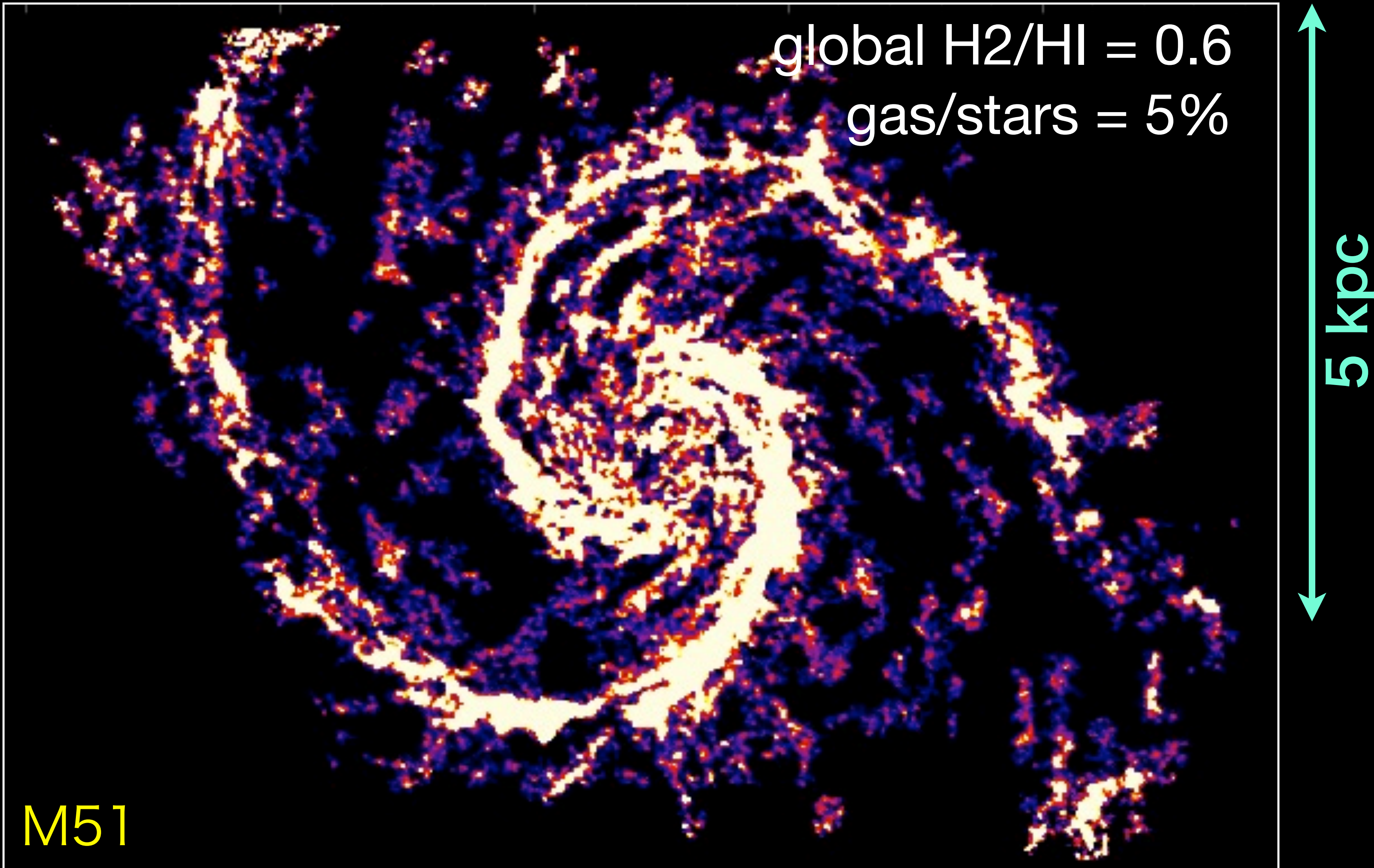


gas flows on GMC scales in M51

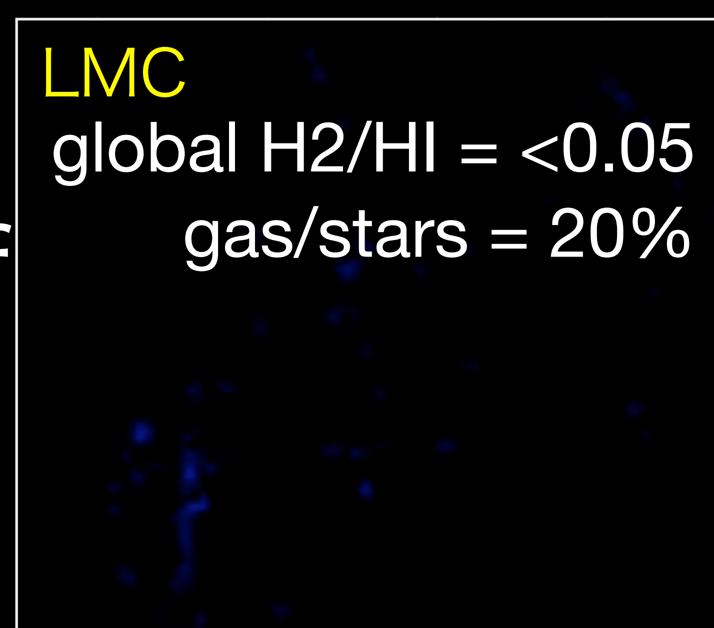
Sharon E. Meidt (MPIA)

Eva Schinnerer, Annie Hughes, Dario Colombo, C. Dobbs, S. Garcia-Burillo, J. Pety, A. Leroy, T. Thompson, K. Schuster, C. Kramer

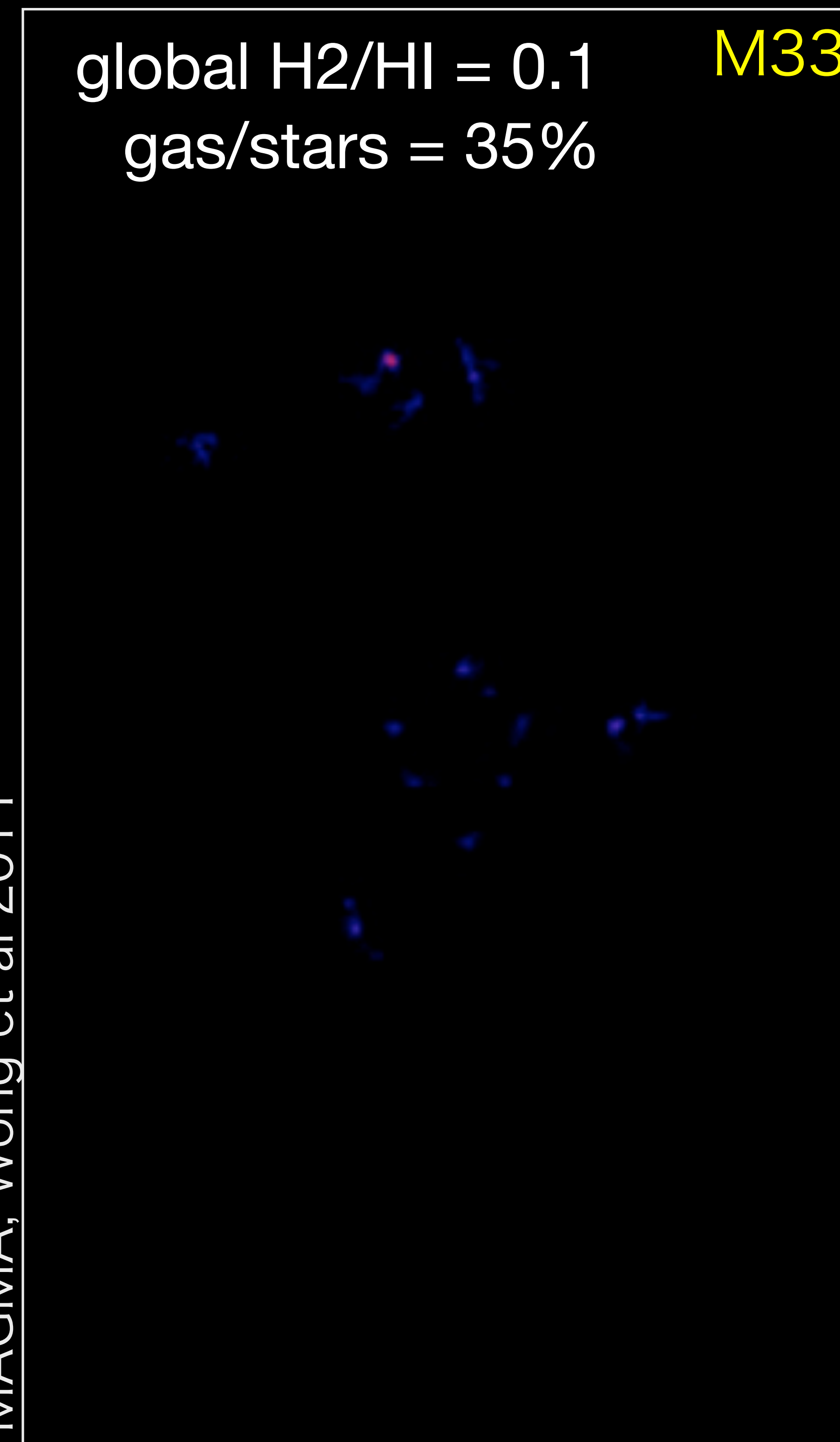
See Posters by Annie Hughes + Dario Colombo



Properties of GMCs in M51 vs two nearby dwarf galaxies (Hughes et al., in prep)



MAGMA, Wong et al 2011

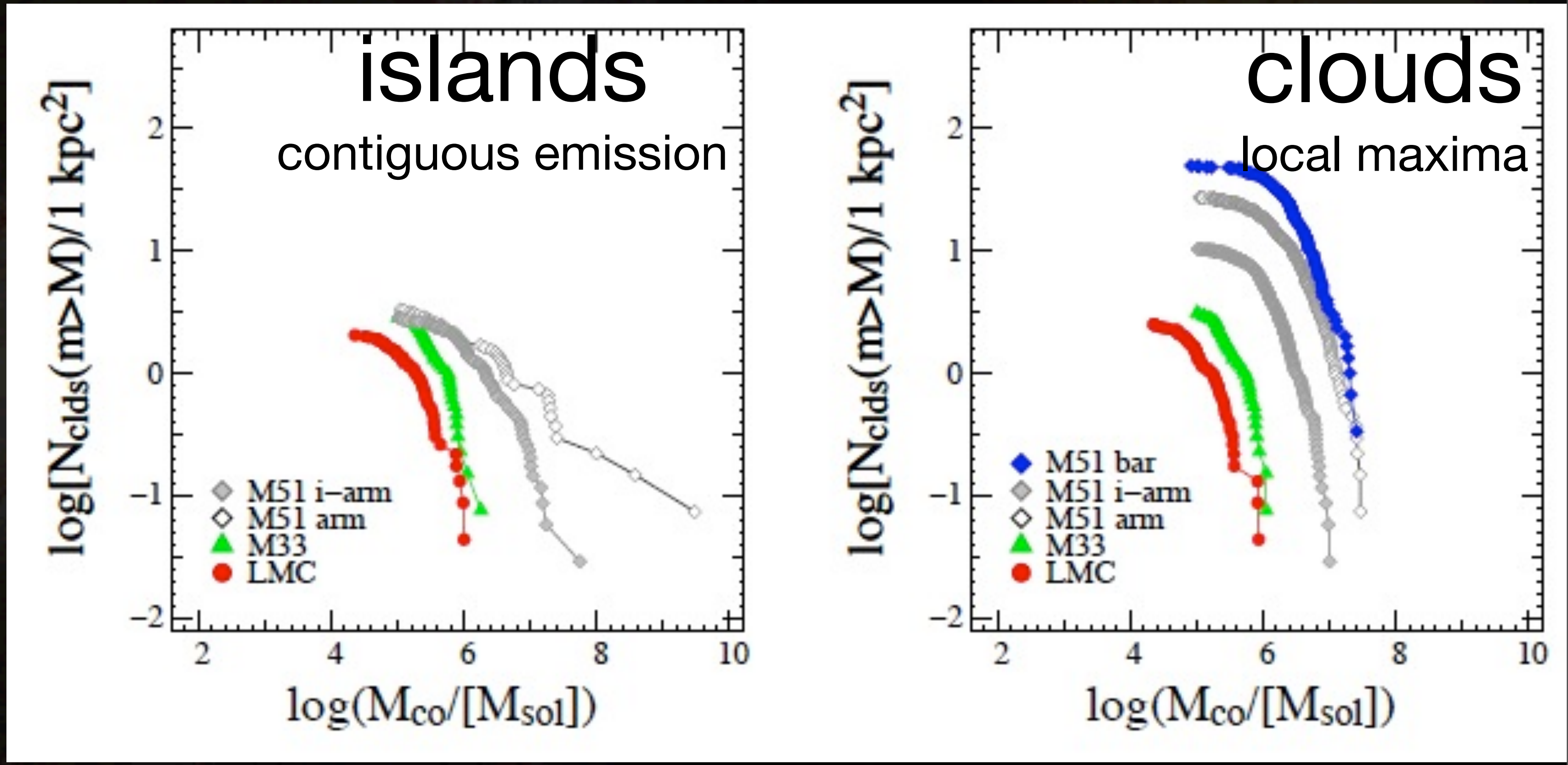


FCRAO+BIMA, Rosolowsky et al 2007

molecular gas properties

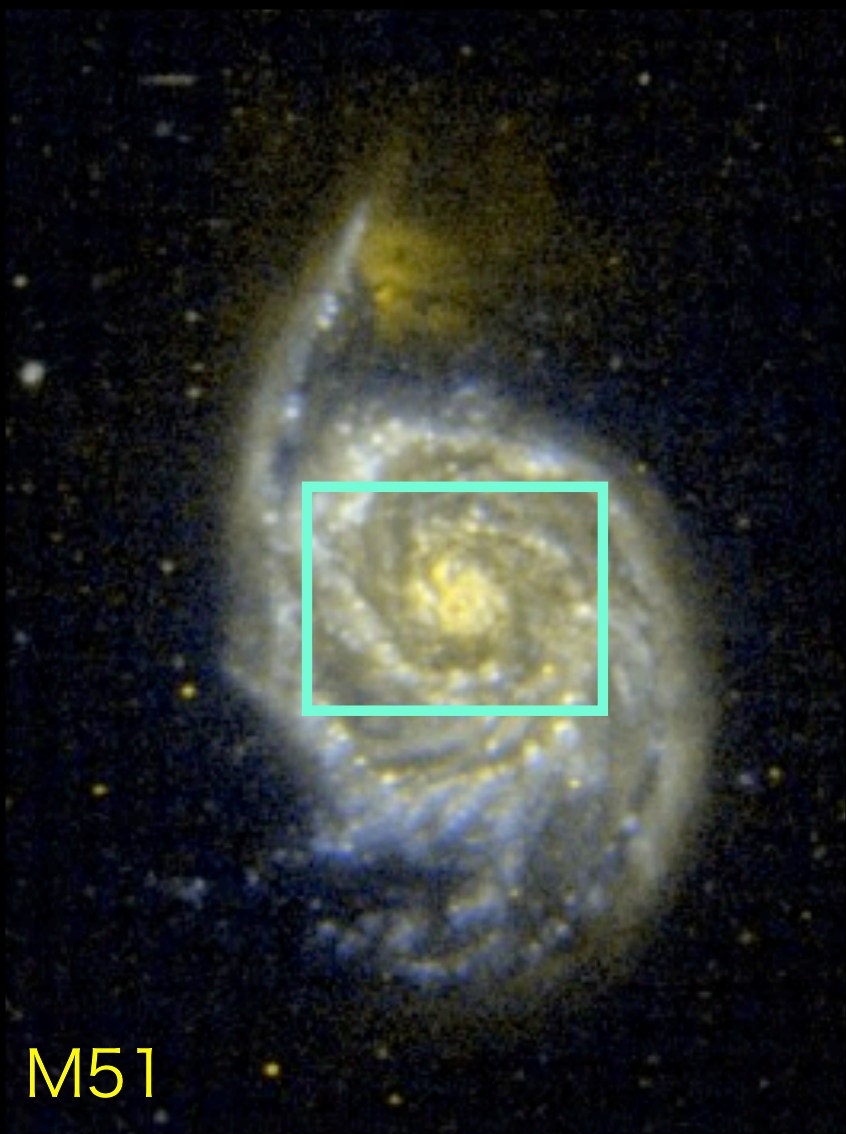
After homogenizing the datasets, M51 GMCs:

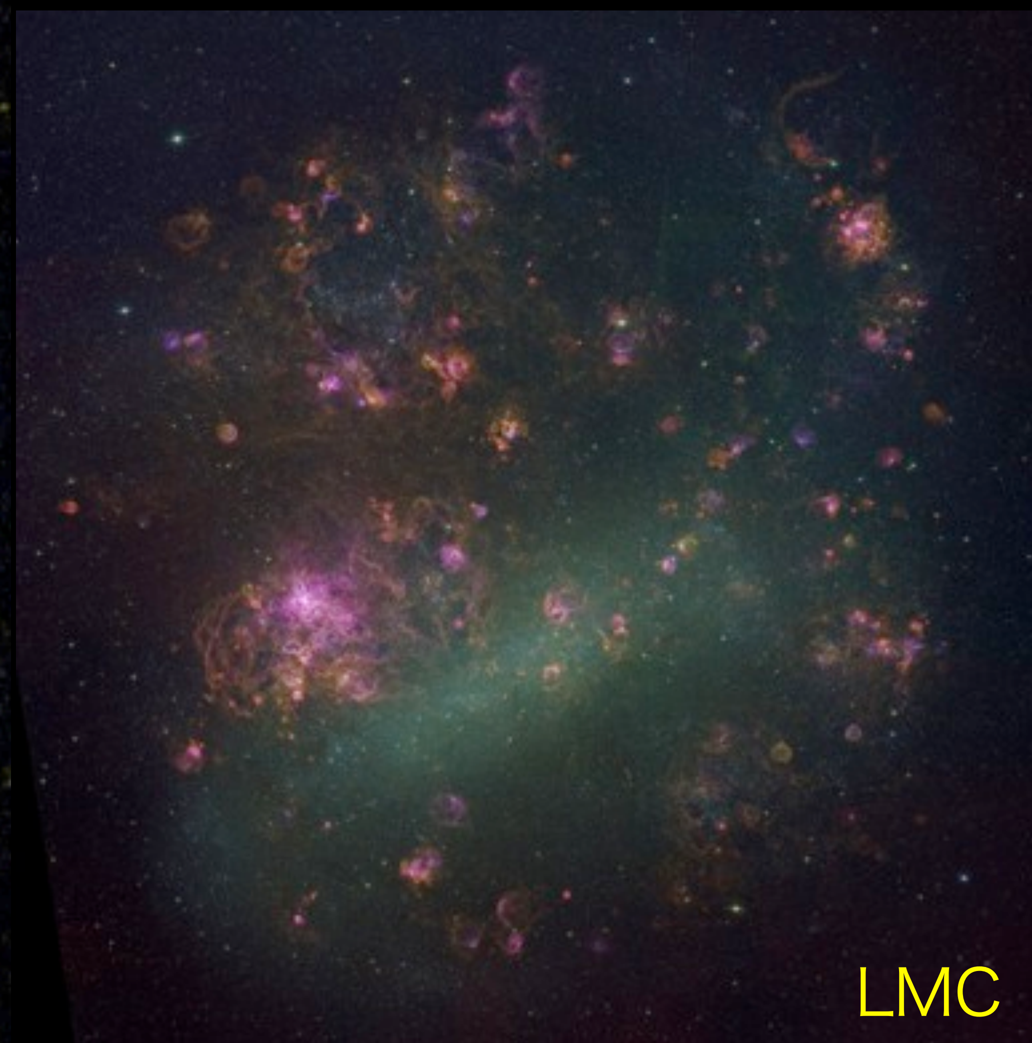
- are brighter (peak T and surface brightness)
- have larger linewidths (especially relative to size) than GMCs in M33 and the LMC
- M51 **interarm** clouds more like clouds in the low-mass galaxies



Hughes et al. 2012

GALEX, Gil de Paz et al 2006





MCELS, Smith et al 1999

GALEX, Gil de Paz et al 2006

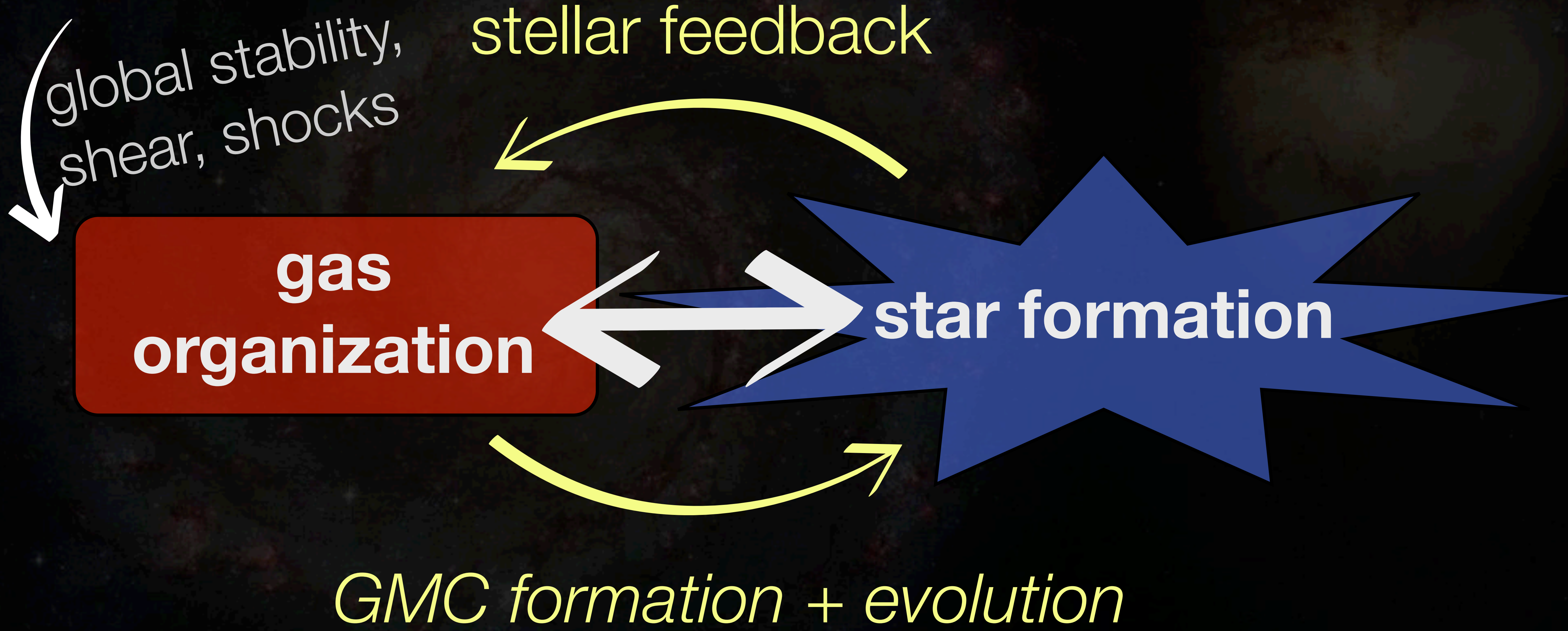
I. **molecular gas is organized differently from galaxy to galaxy**

II. overview of dynamical environments

III. GMC properties depend on environment

IV. organization + environment influences global patterns of star formation

gas kinematics in spiral potentials



does the static picture (e.g. Krumholz et al.) apply?

I. molecular gas is organized differently from galaxy to galaxy

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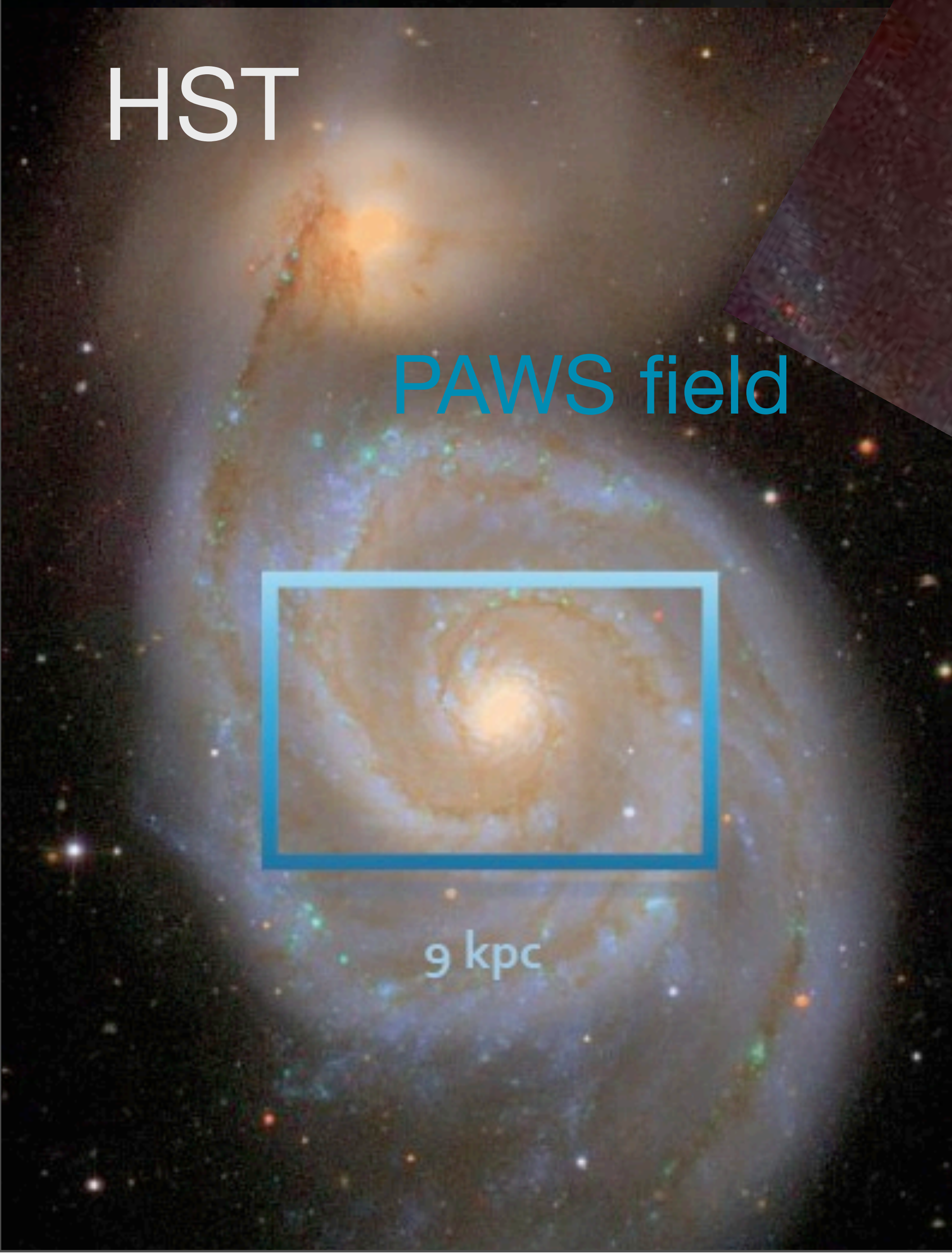
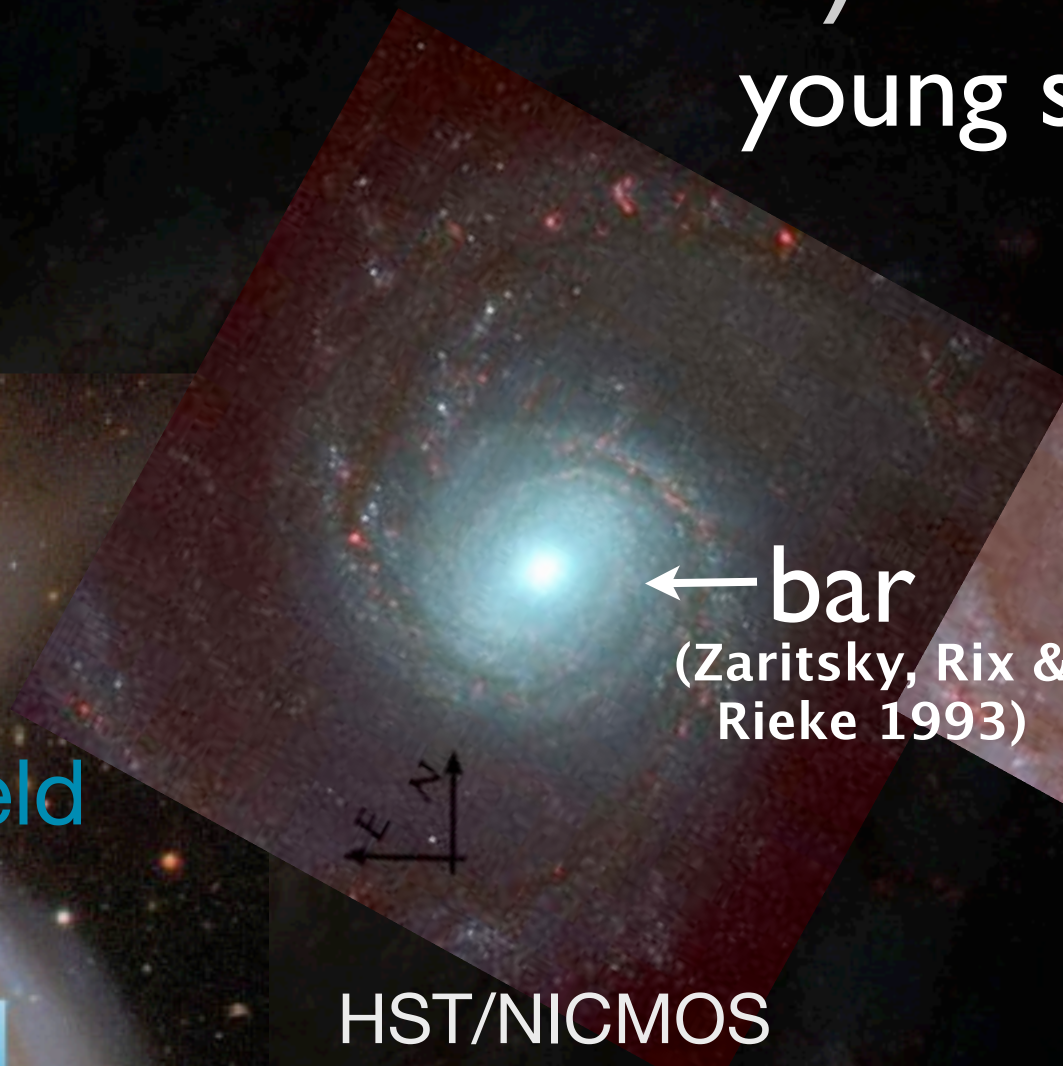
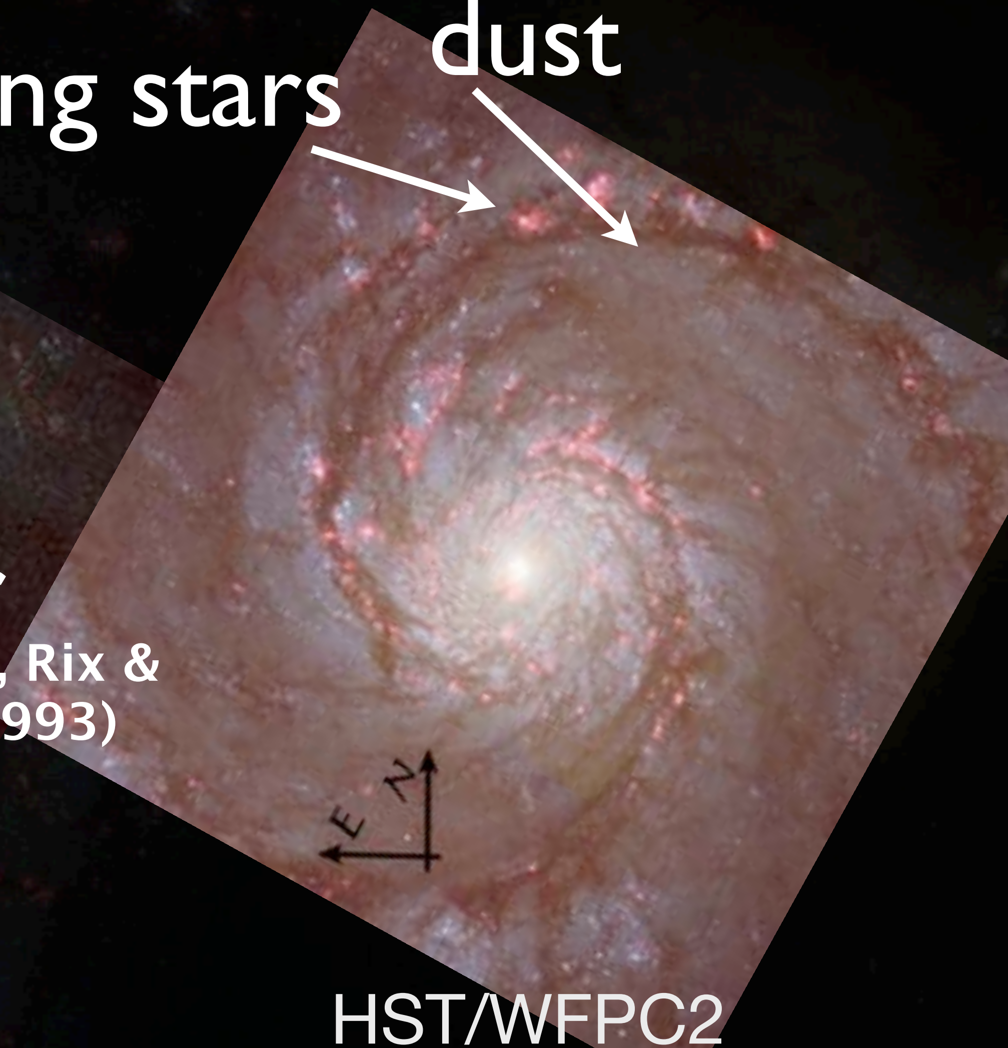
M51 (NGC 5194)





HST/NICMOS
Red: Paα, Green:J, Blue: K

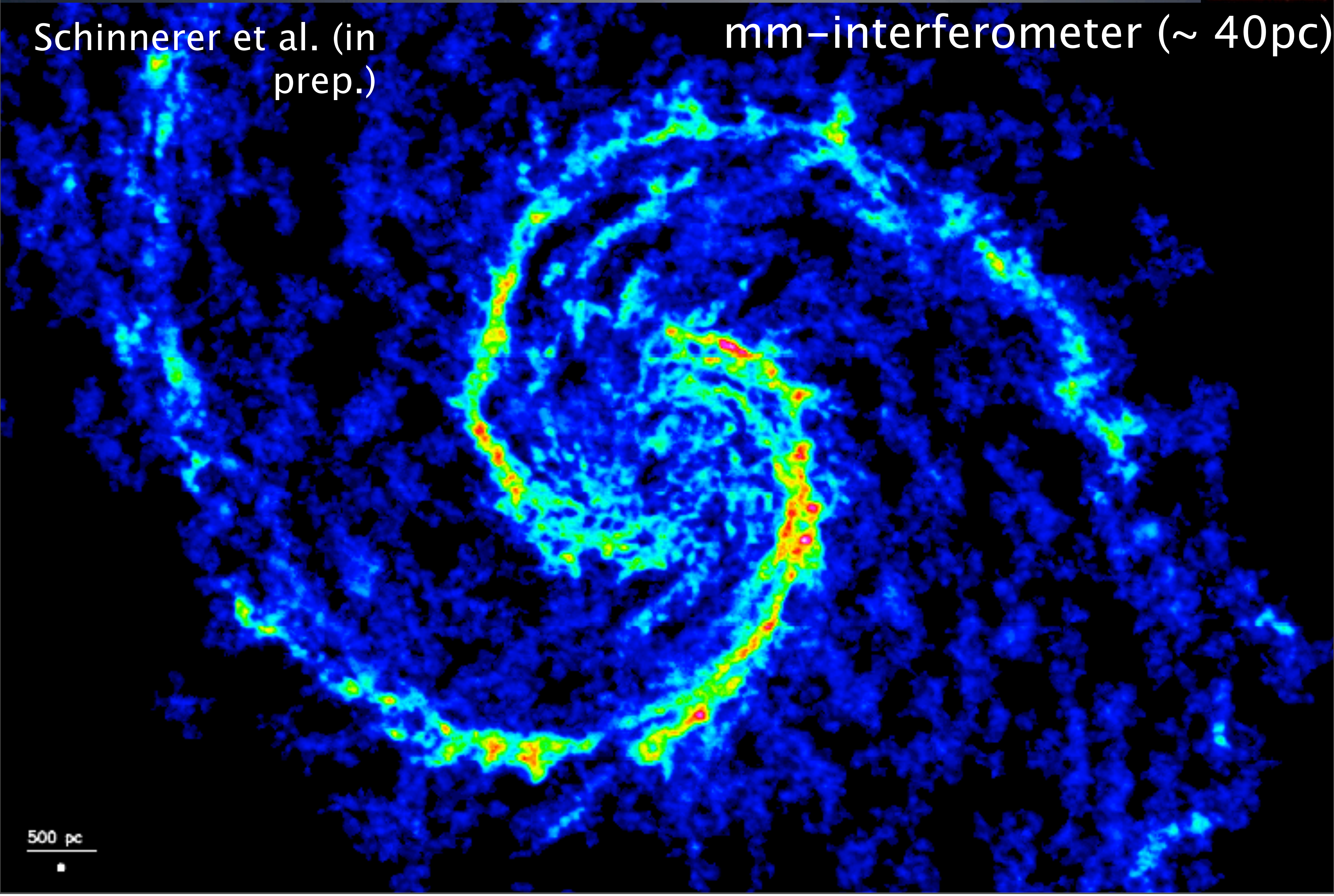


HST/WFPC2
Red: Hα, Green:V, Blue: B

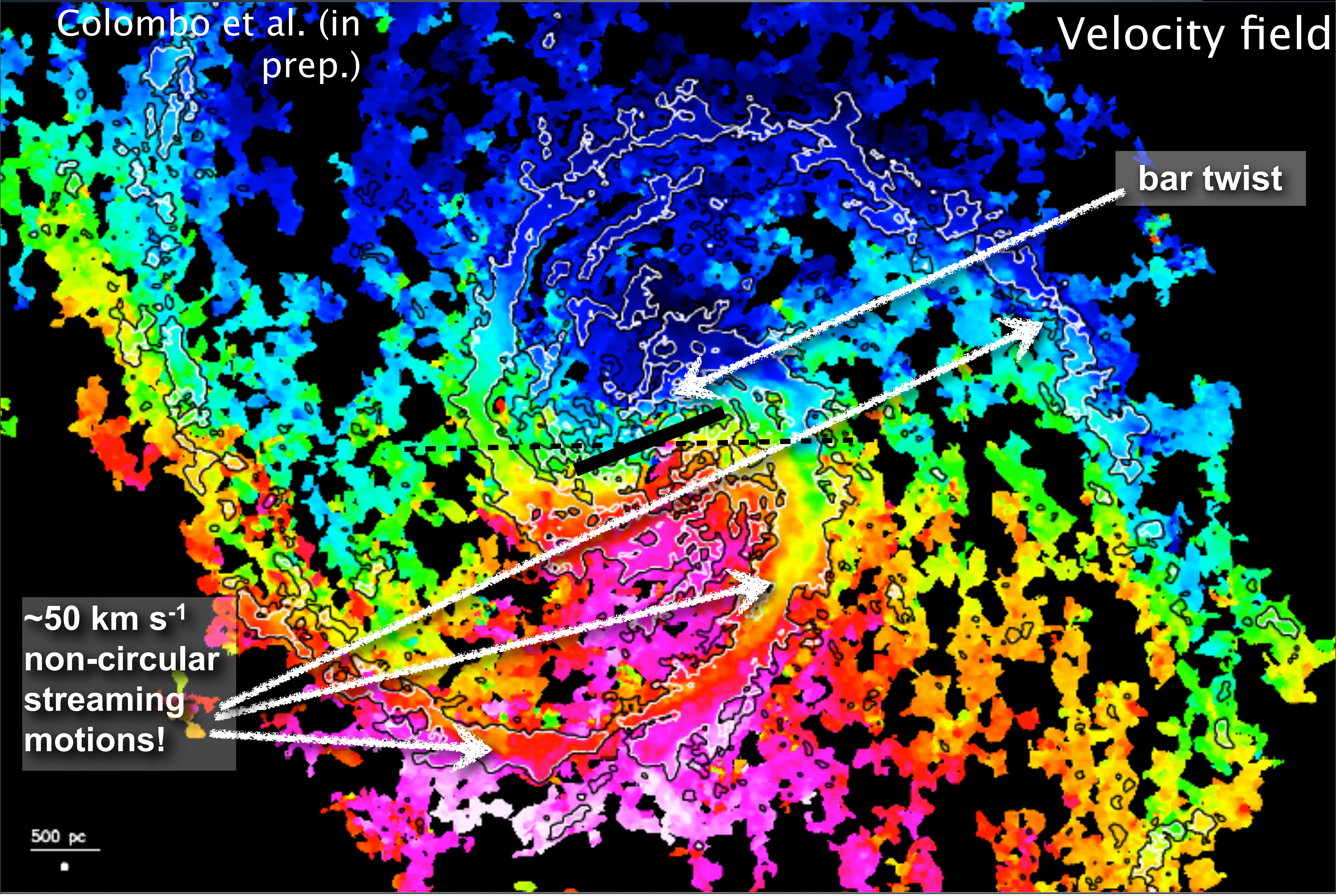
Molecular Gas disk of M51

Schinnerer et al. (in prep.)

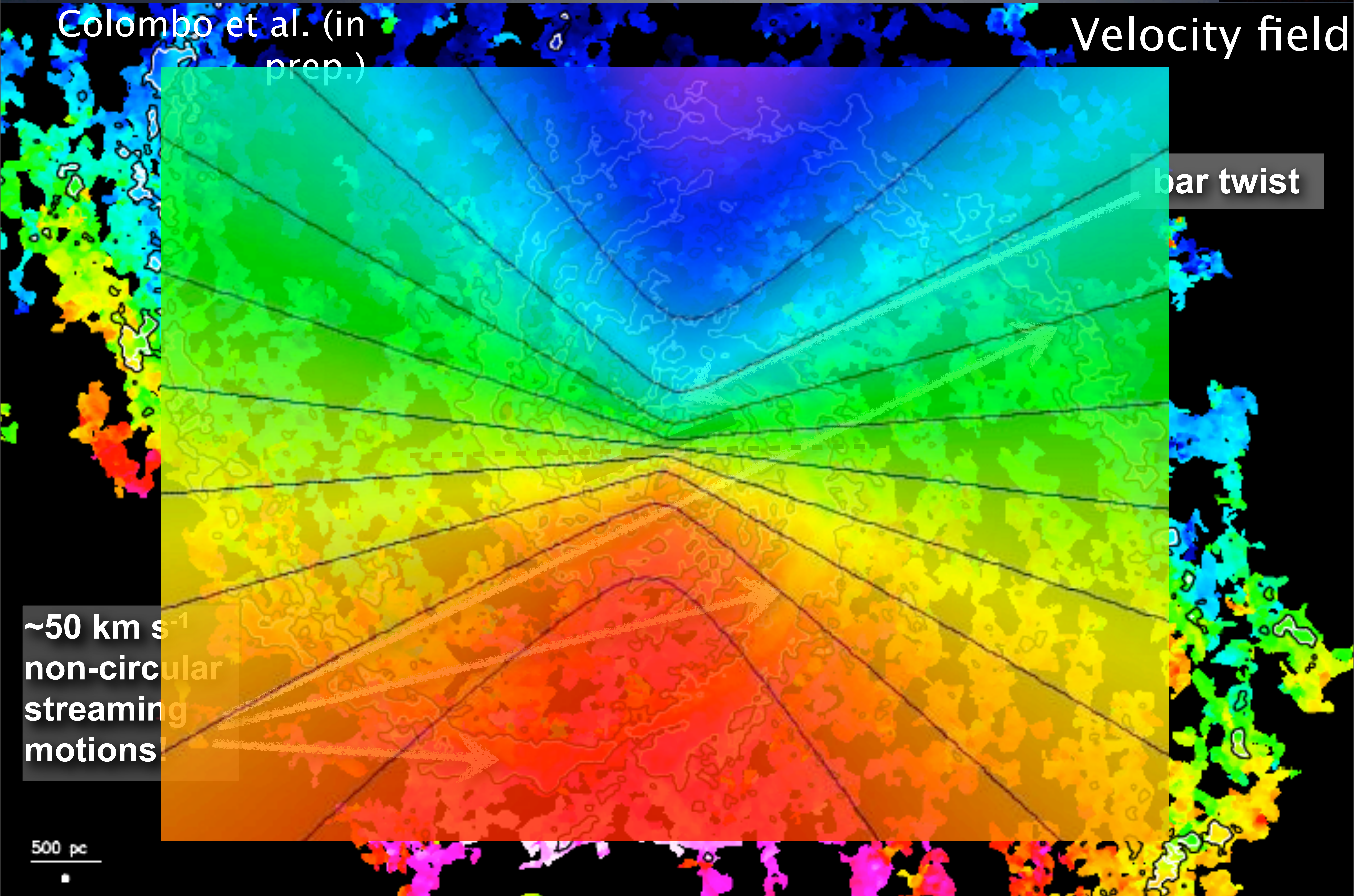
mm-interferometer (~ 40pc)



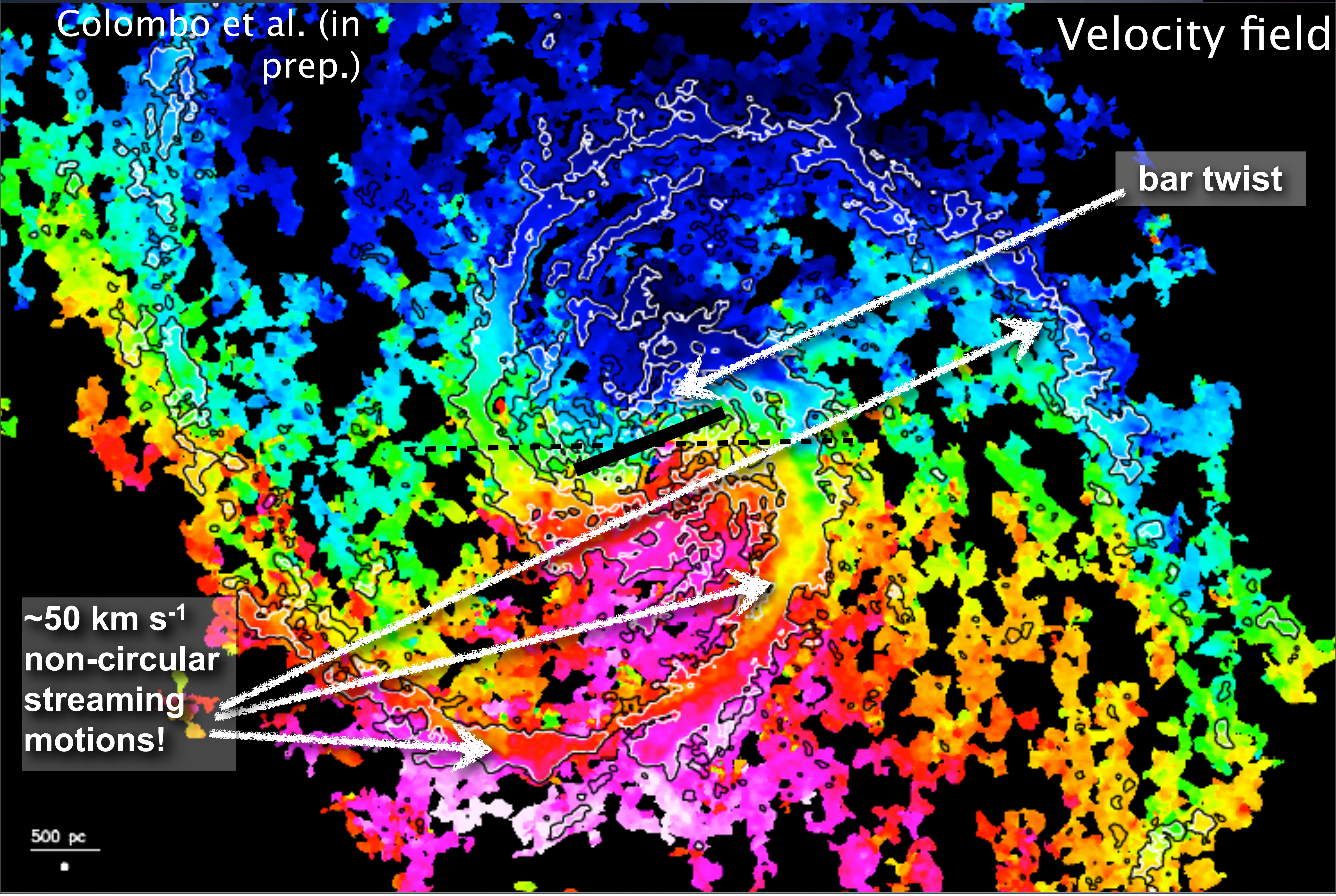
Molecular Gas disk of M51



Molecular Gas disk of M51



Molecular Gas disk of M51



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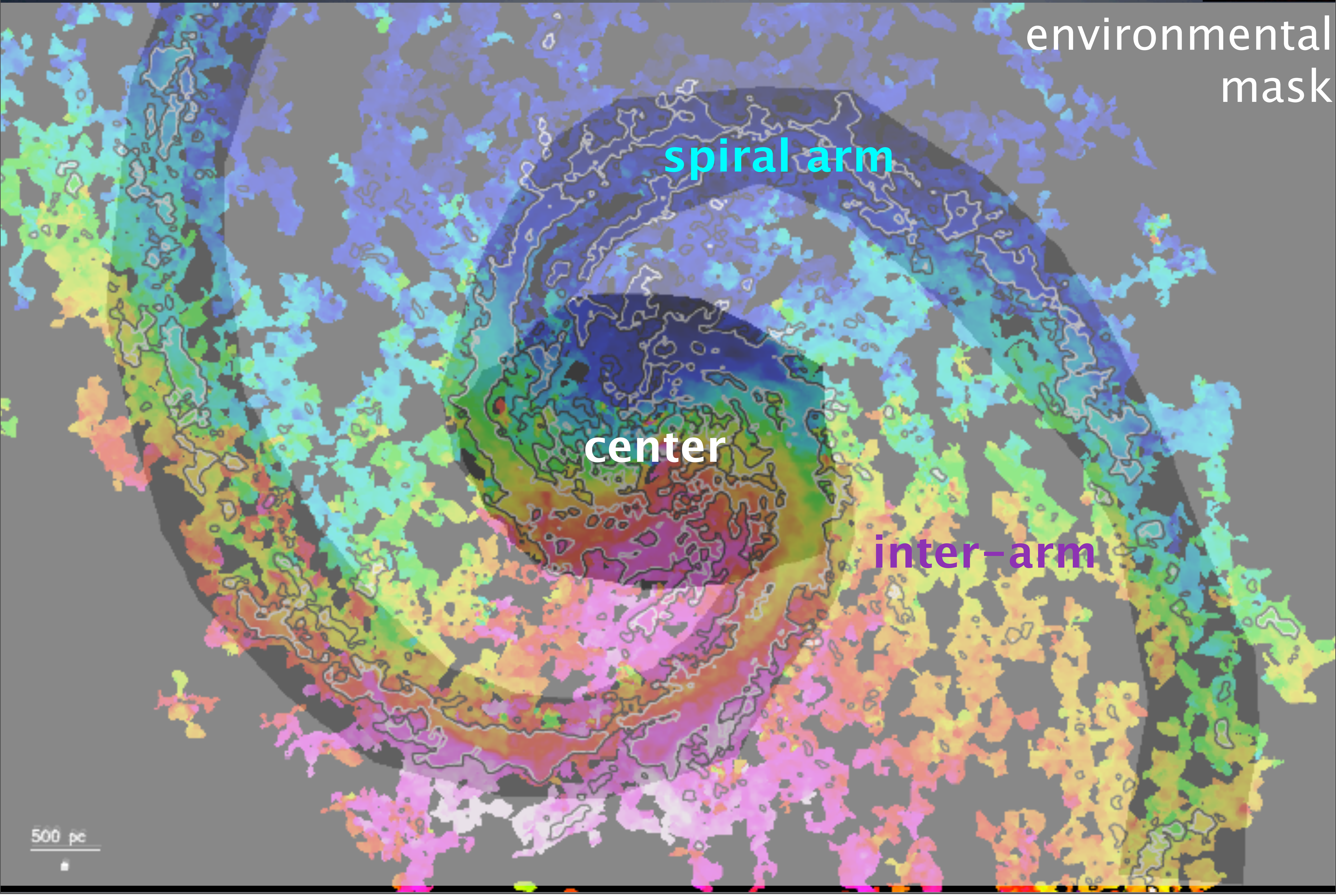

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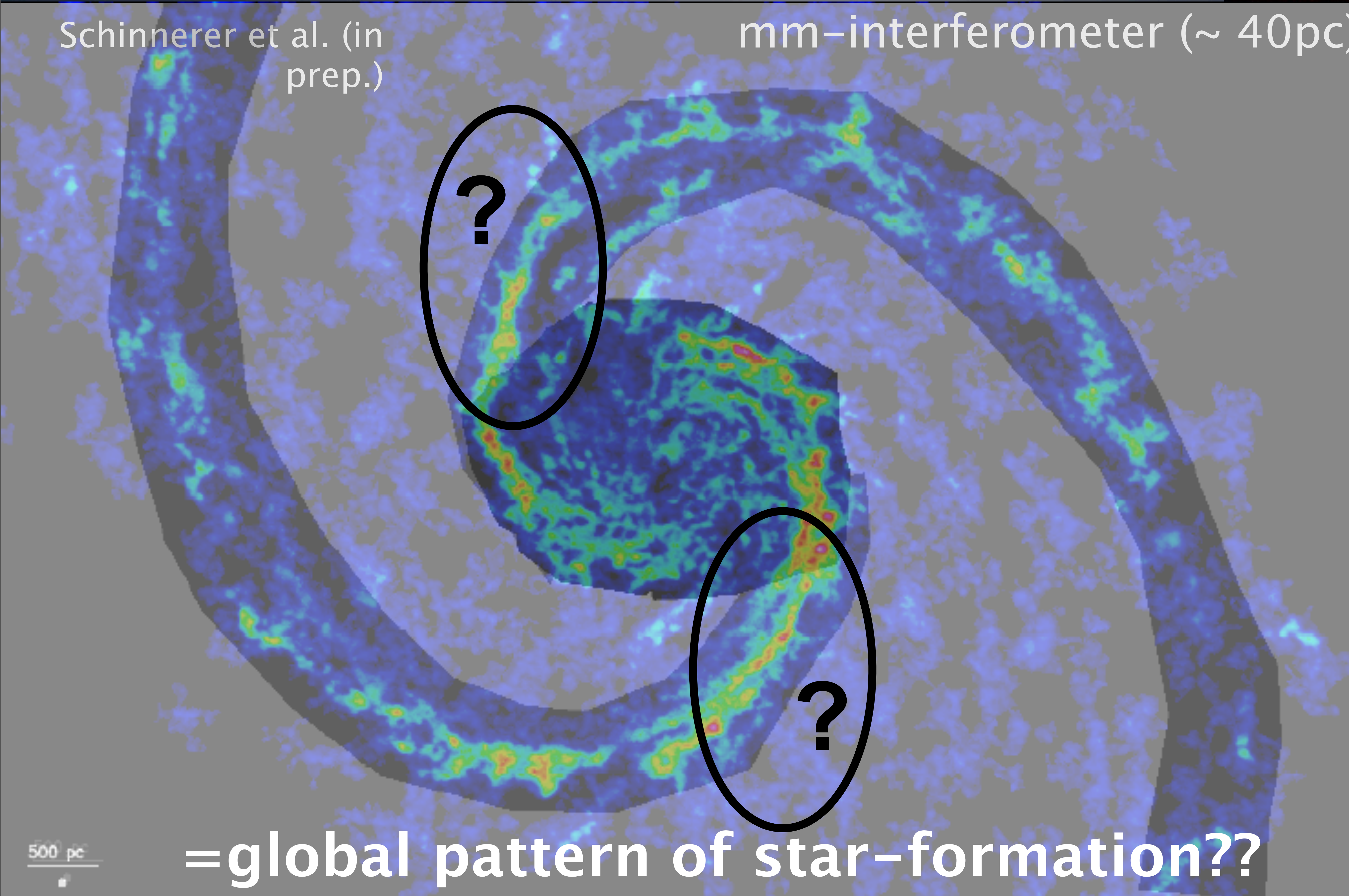

=global pattern of star-formation??

I. molecular gas is organized differently from galaxy to galaxy

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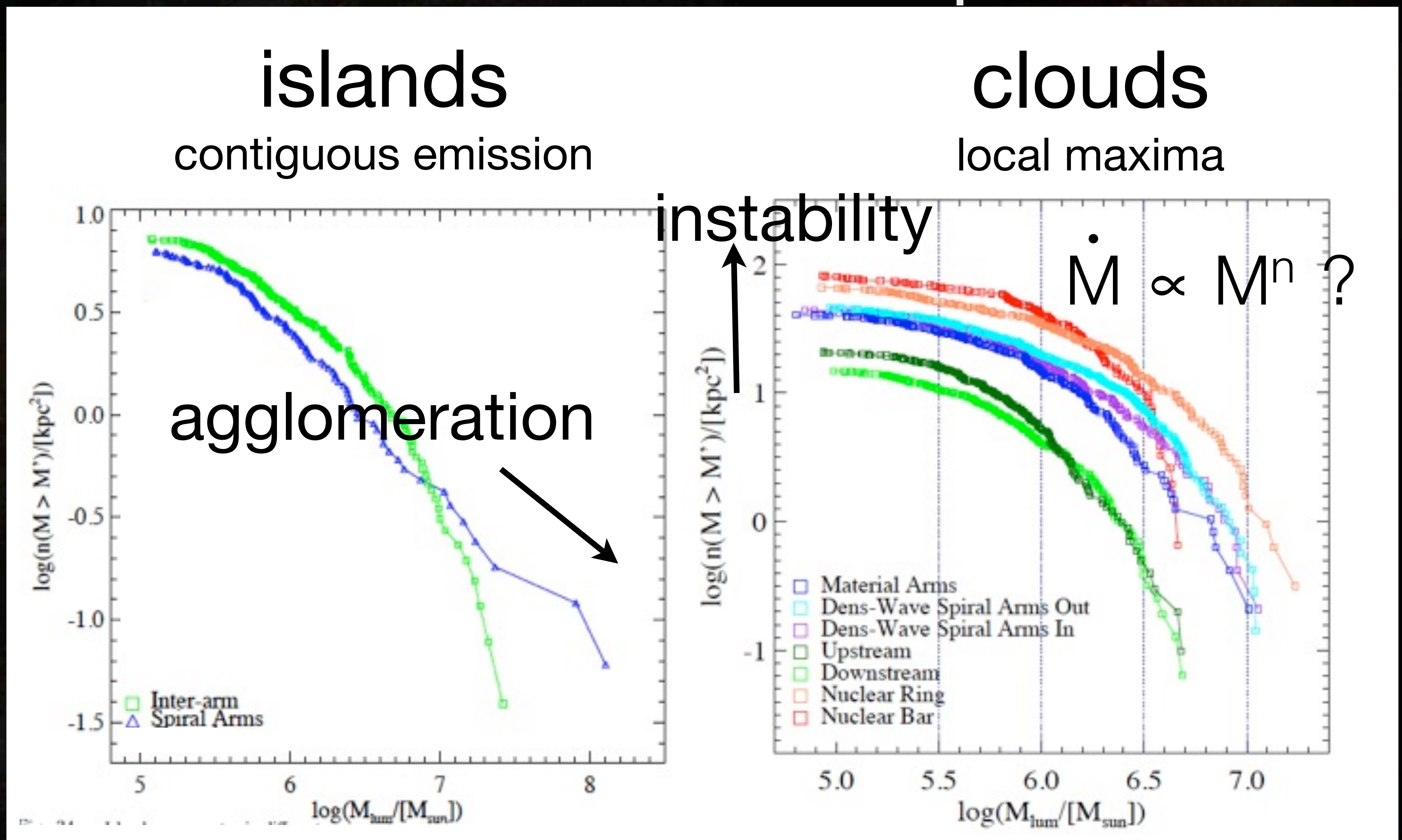
molecular cloud formation in M51

- 50% of CO emission in cloud structures
- GMC properties vary as a function of environment Colombo et al., 2012, in prep

shapes +normalization different!

cumulative mass spectra



mass fraction of collapse unstable clouds→SFE

I. overview of PAWS environments

II. molecular gas is organized differently from galaxy to galaxy

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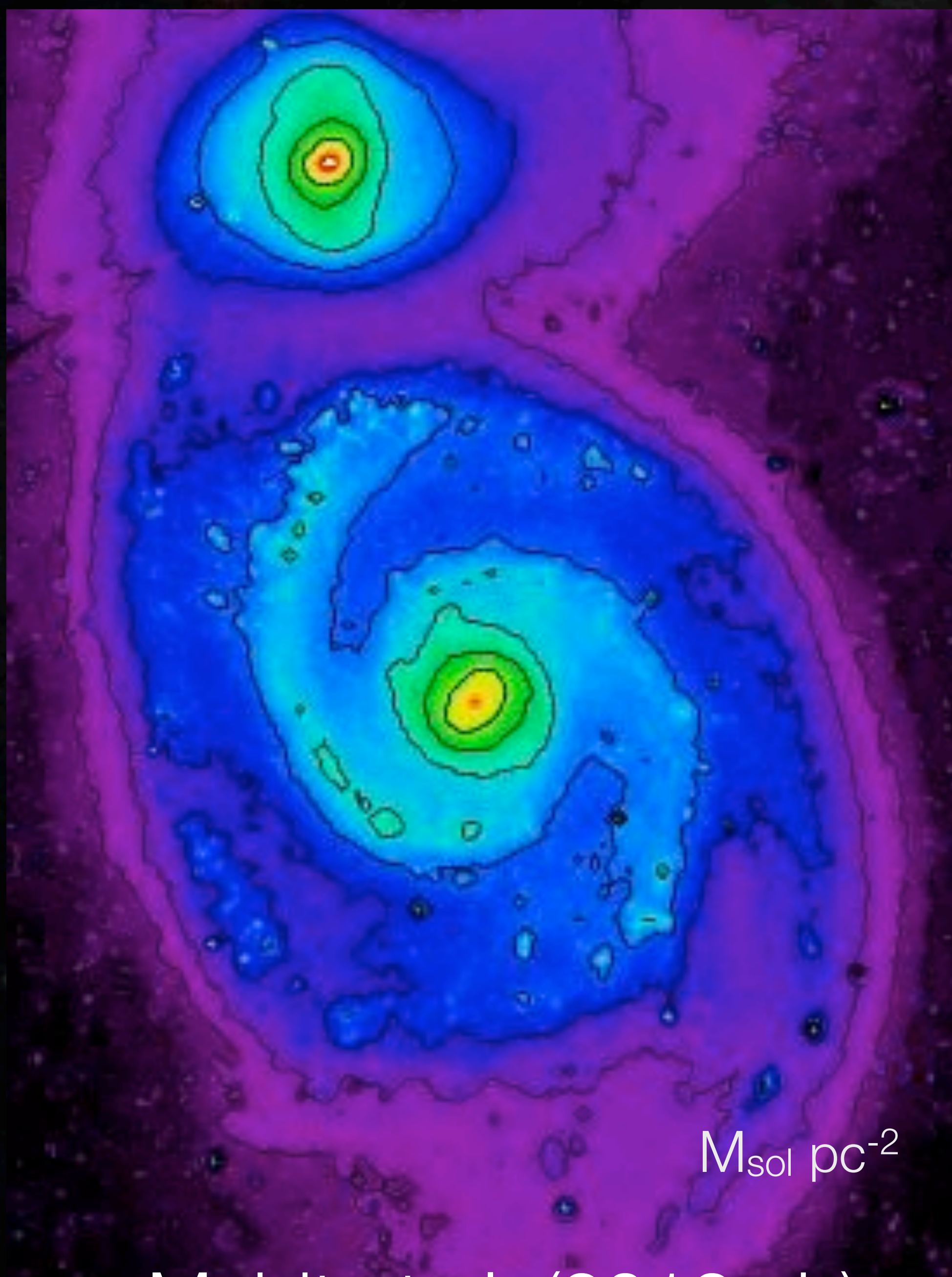
IV. **organization + environment influences global patterns of star formation**

Present-day Torques

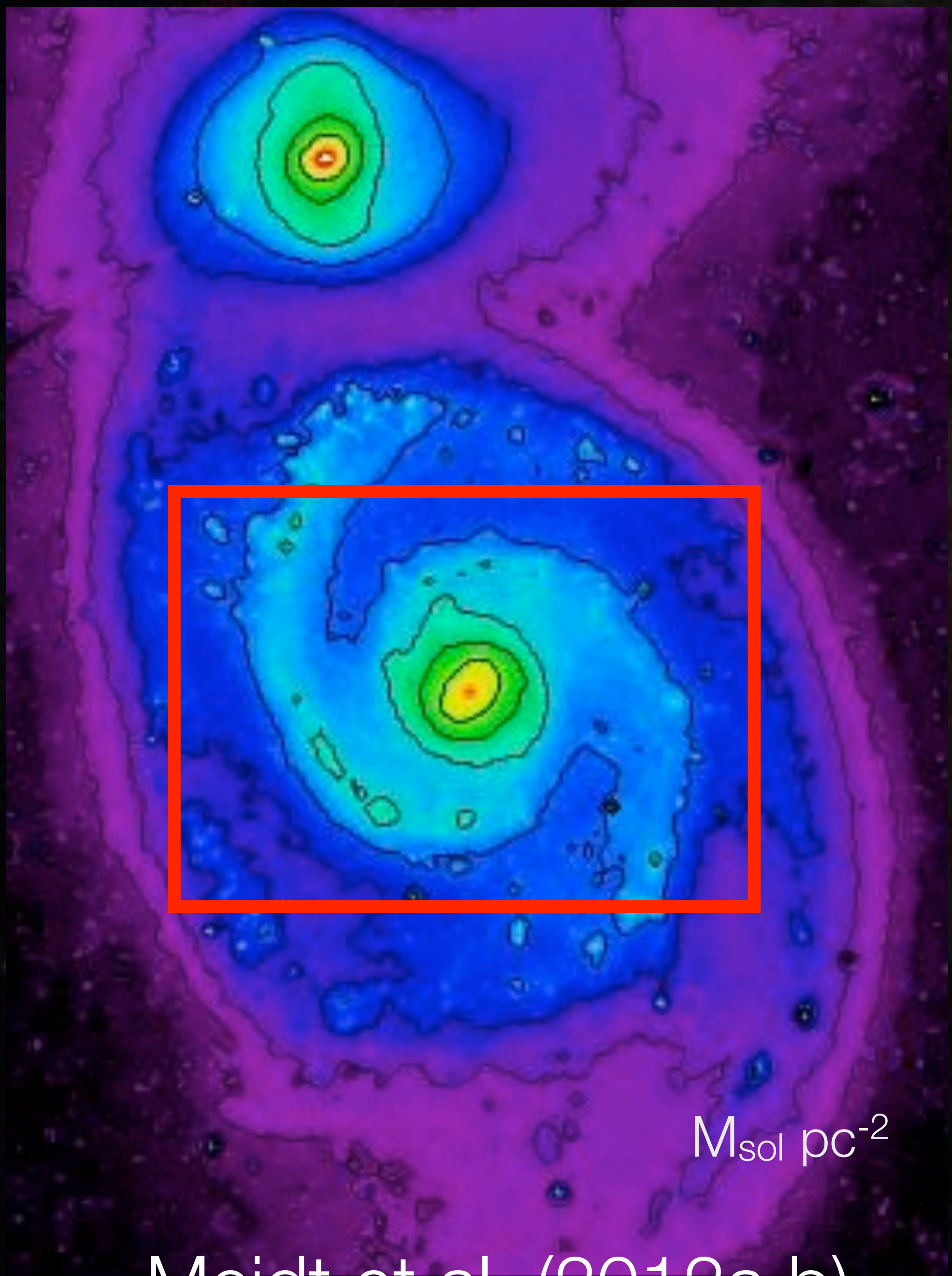
stellar mass surface density



Meidt et al. (2012a,b)
Eskew, Zaritsky & Meidt (2012)

Present-day Torques

stellar mass surface density



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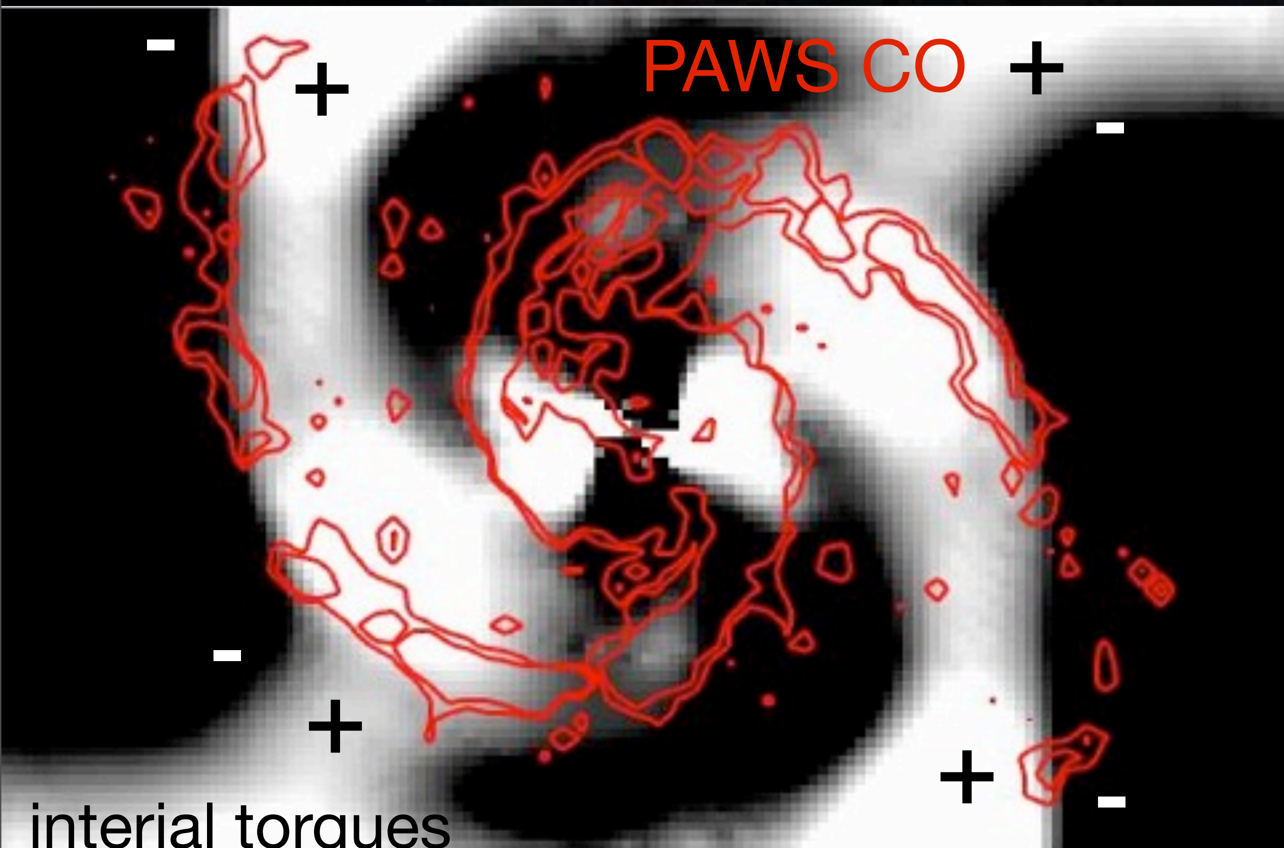
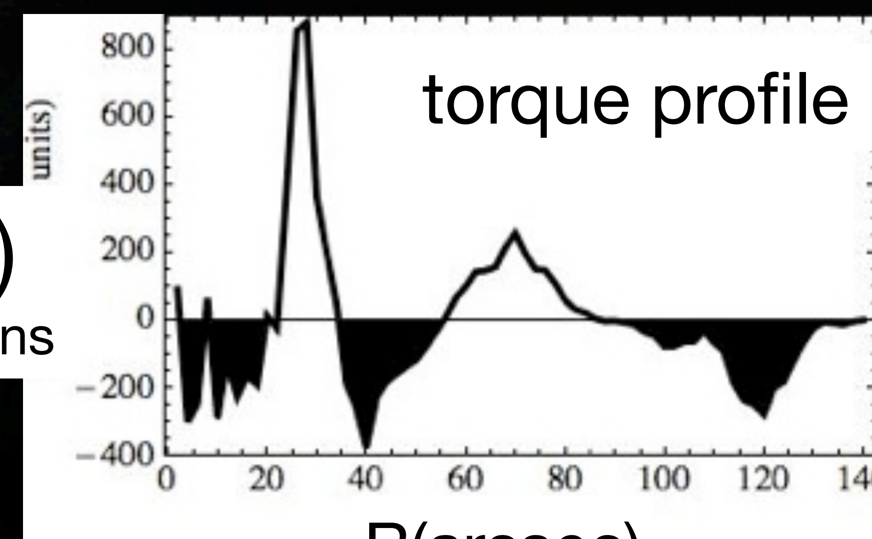
Present-day Torques



R×∇Φ

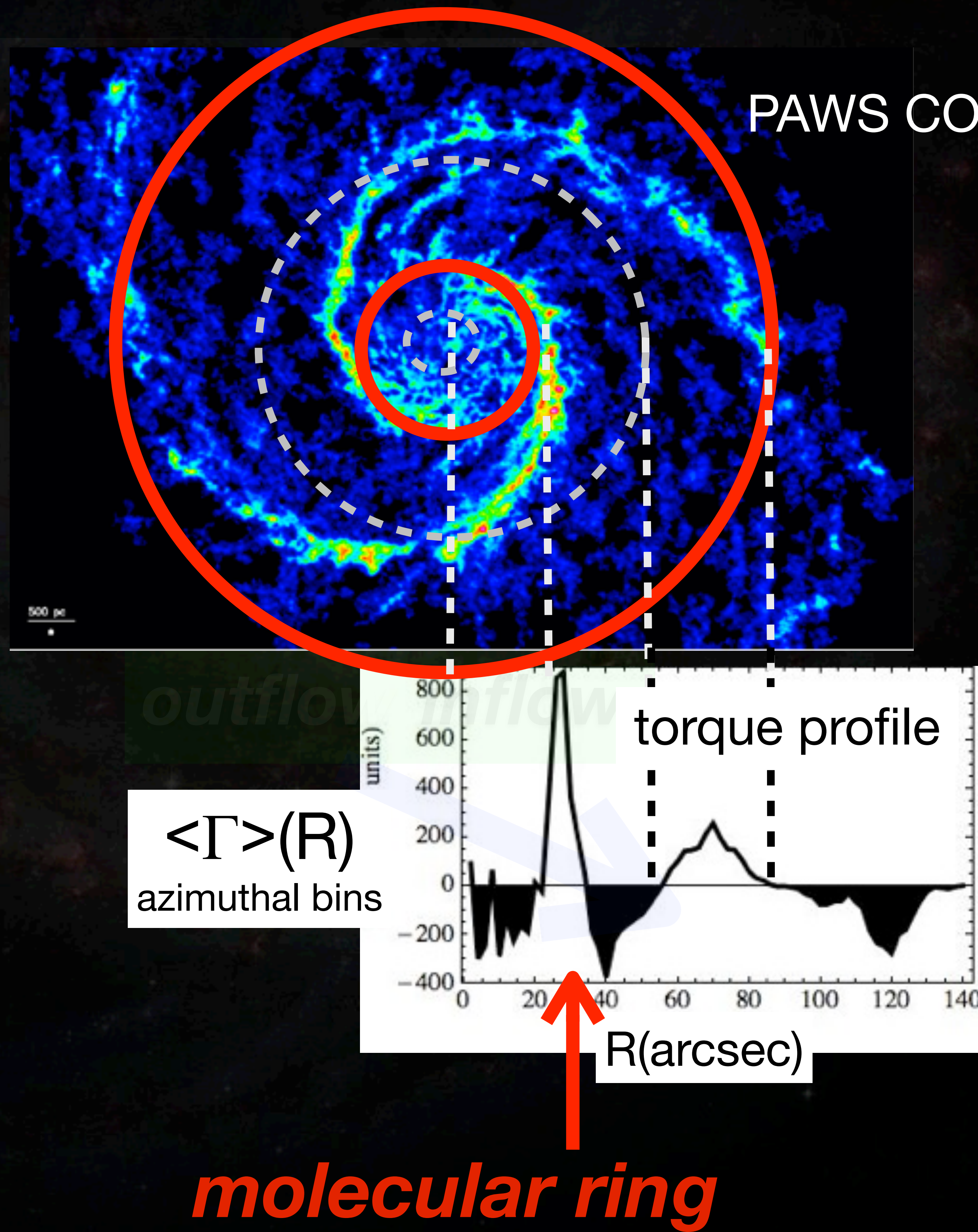
outflow inflow

<Γ>(R)
azimuthal bins



Radius = proxy for environment (bar, spiral)

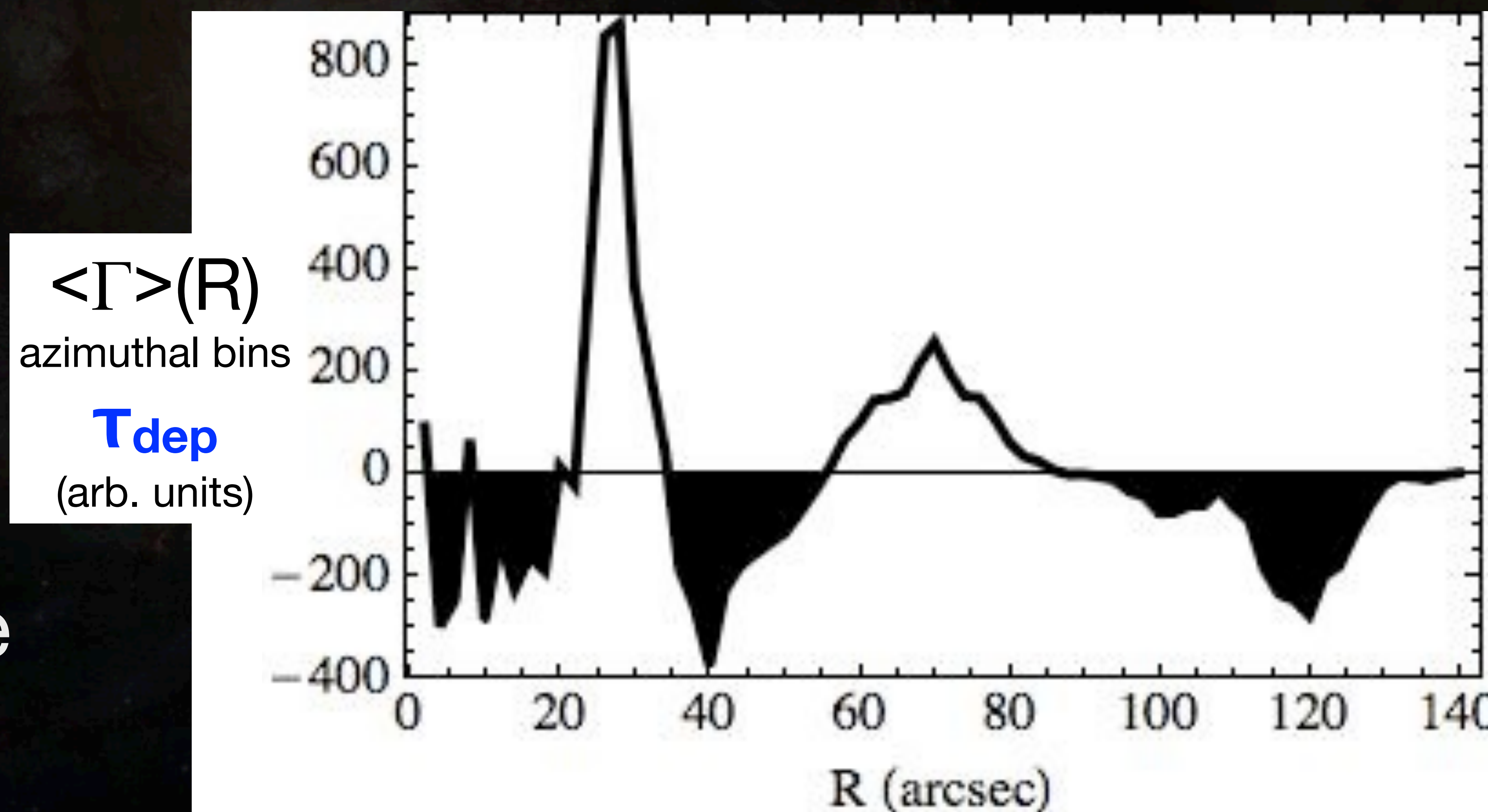
Present-day Torques



Spiral arm Torques

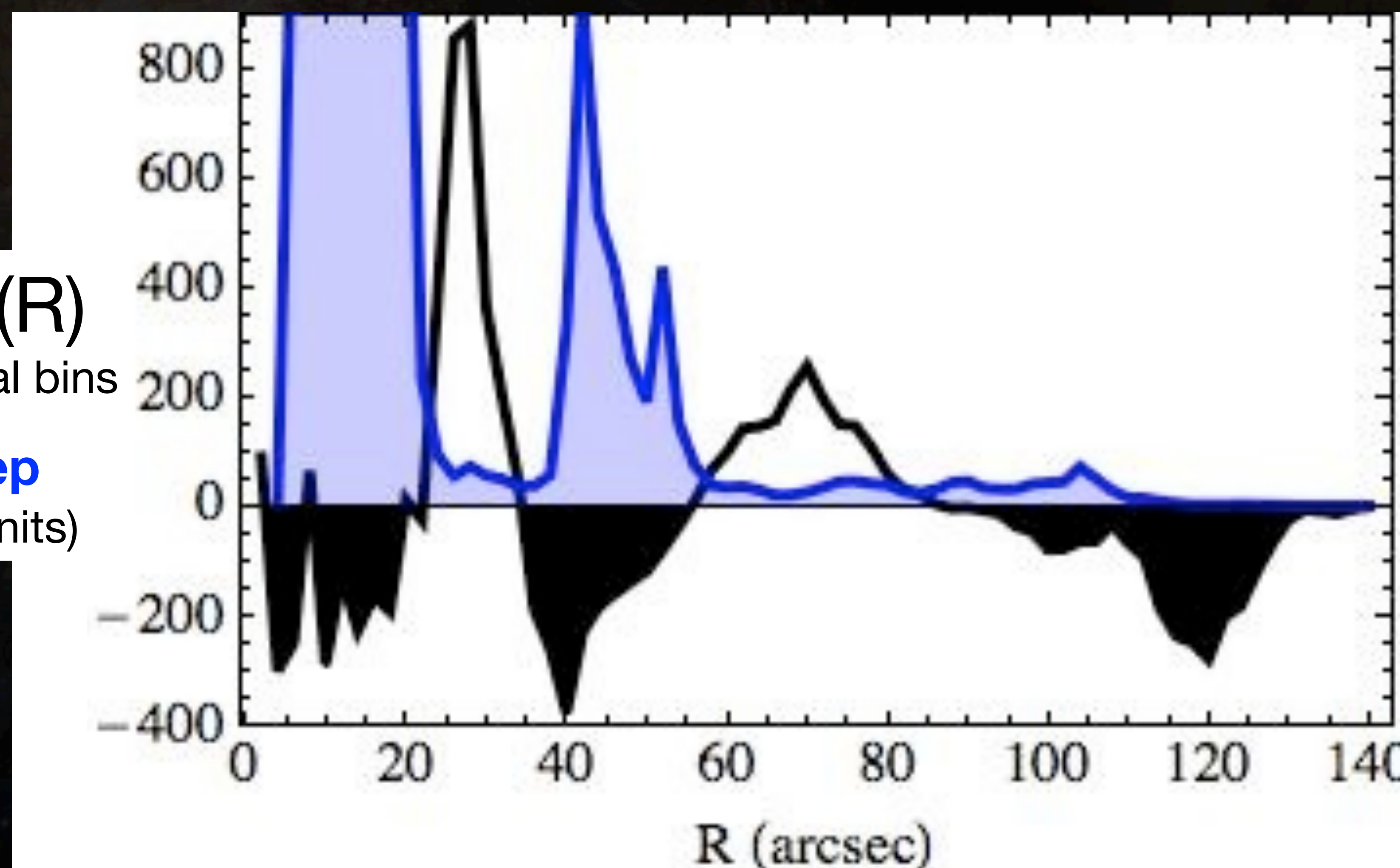
from PAWS kinematics

inflow=large $|V_{stream}|$



Spiral arm Torques

<Γ>(R)
azimuthal bins
τ_{dep}
(arb. units)



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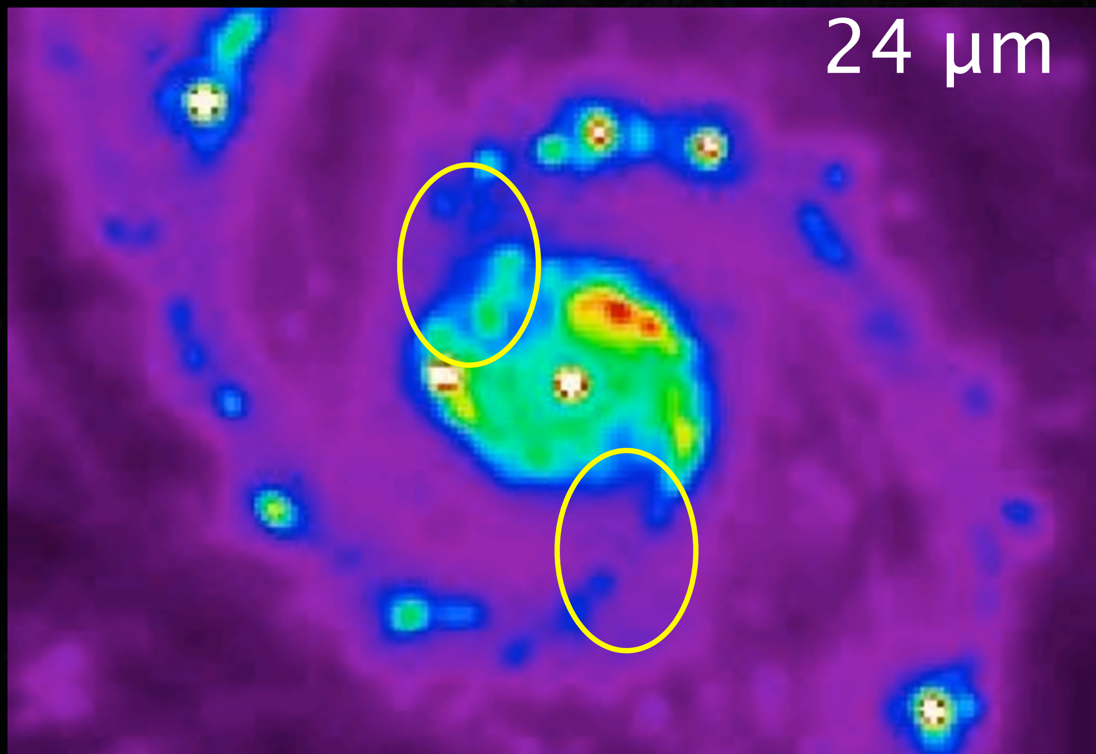
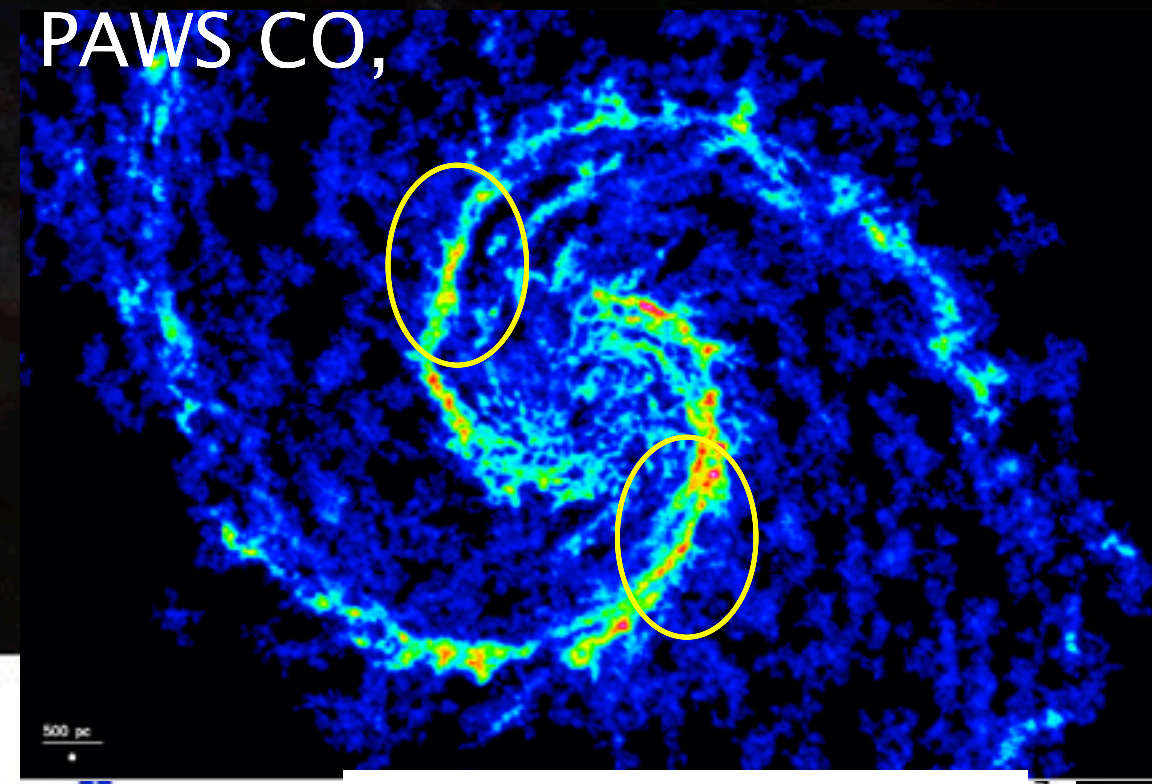
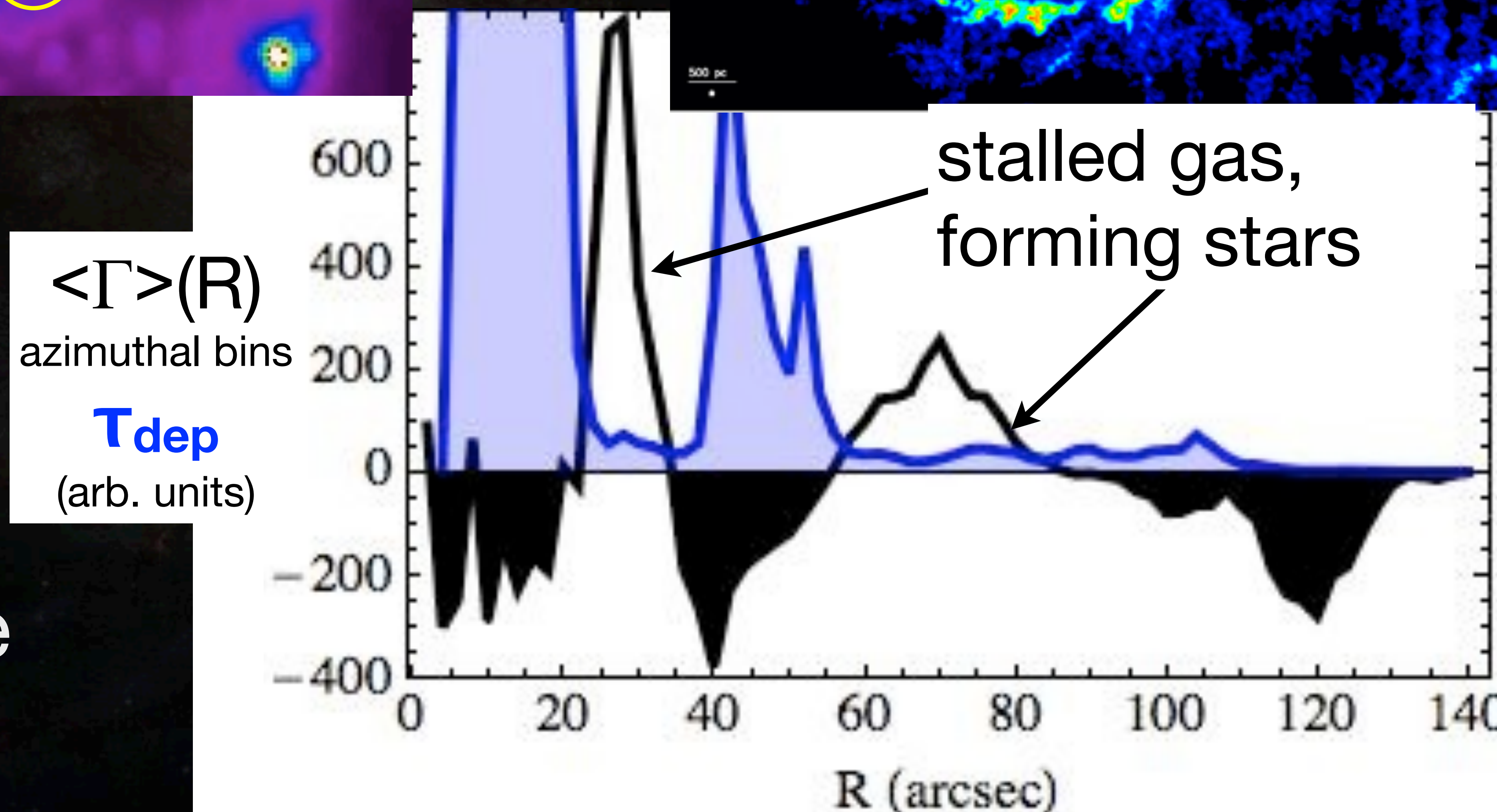
Spiral arm Torques







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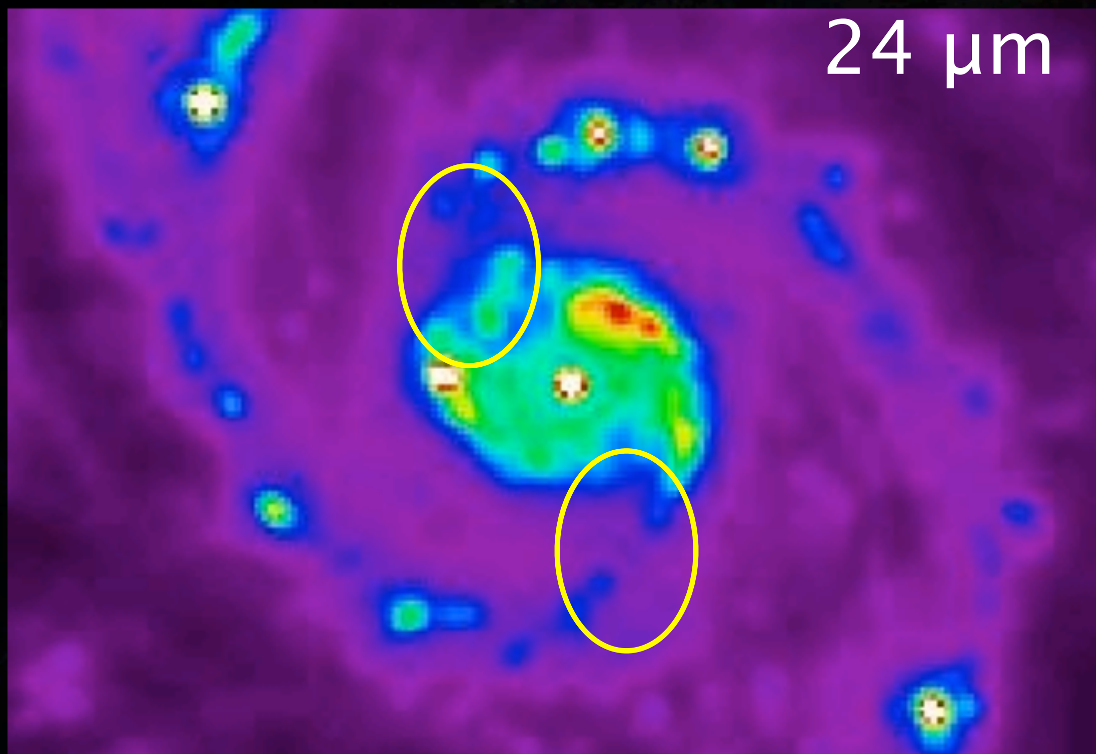

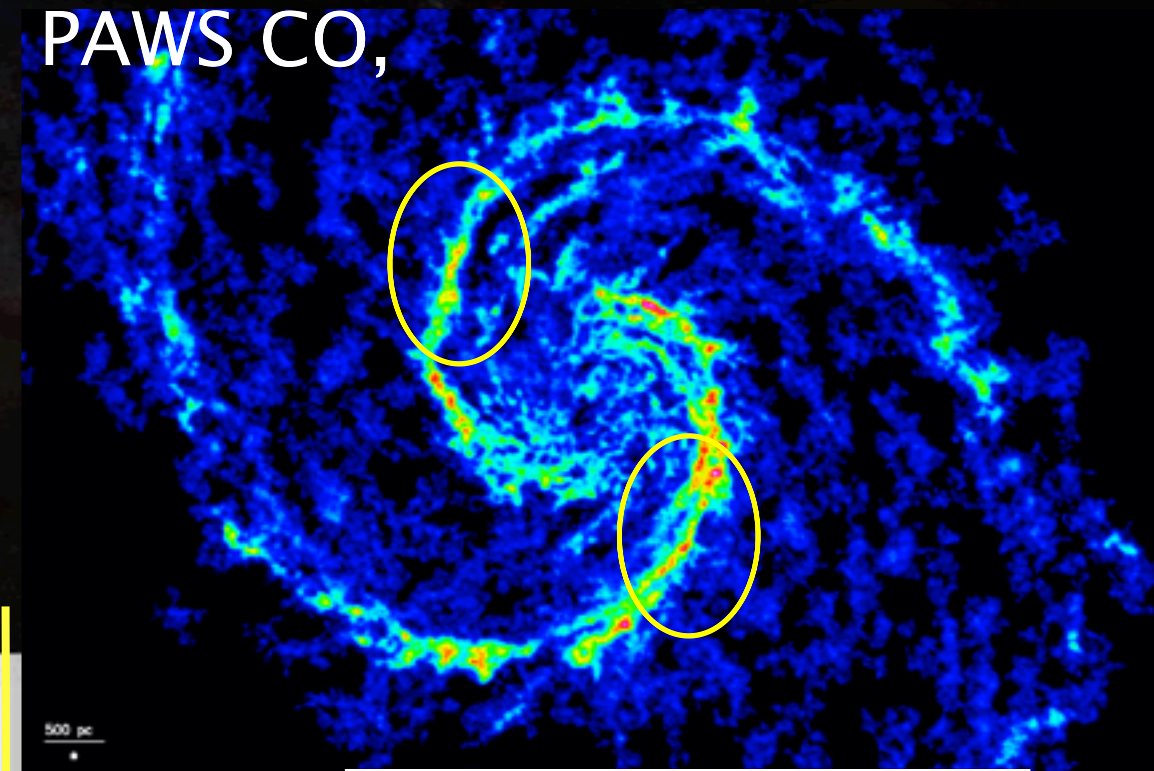

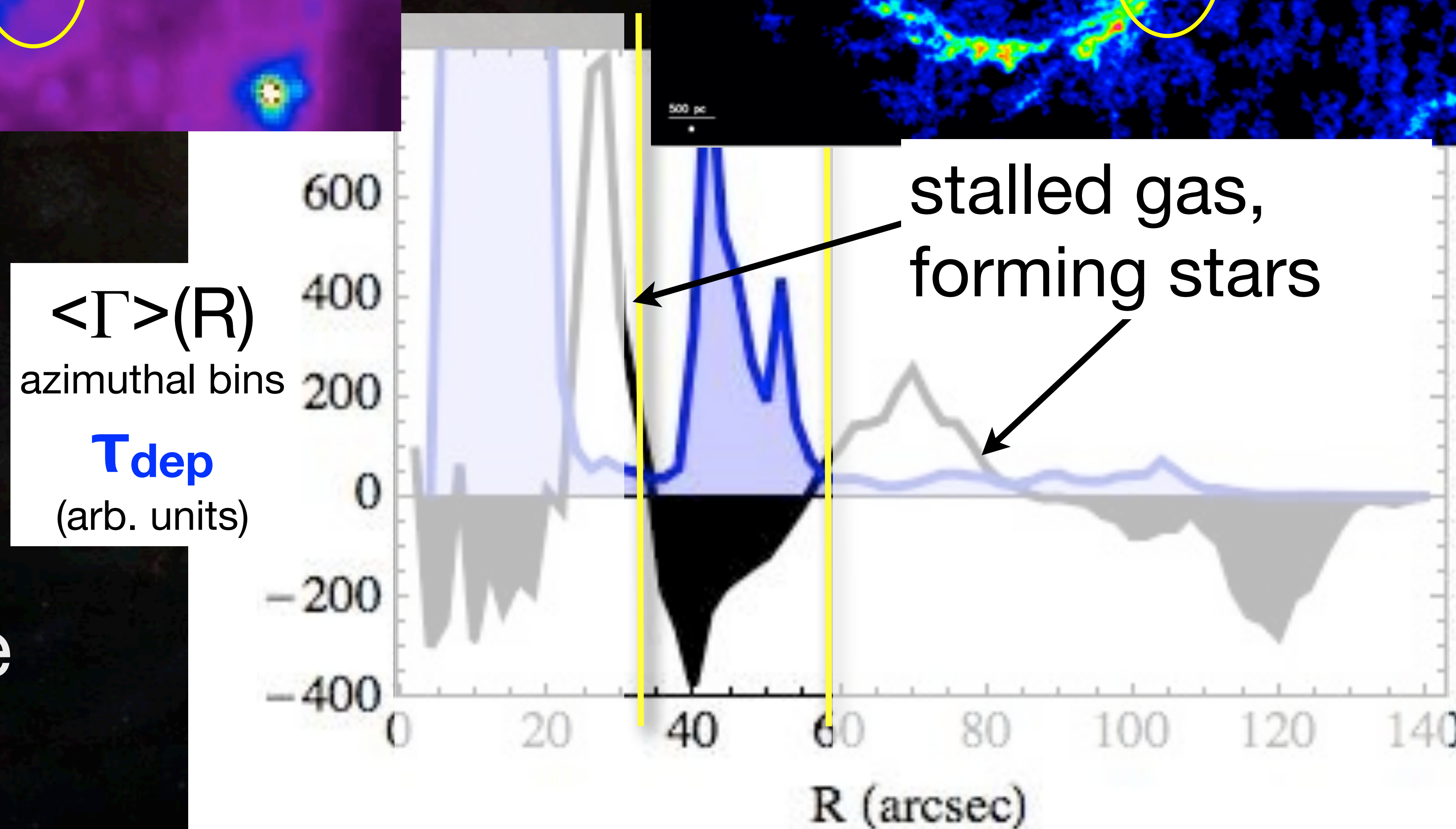

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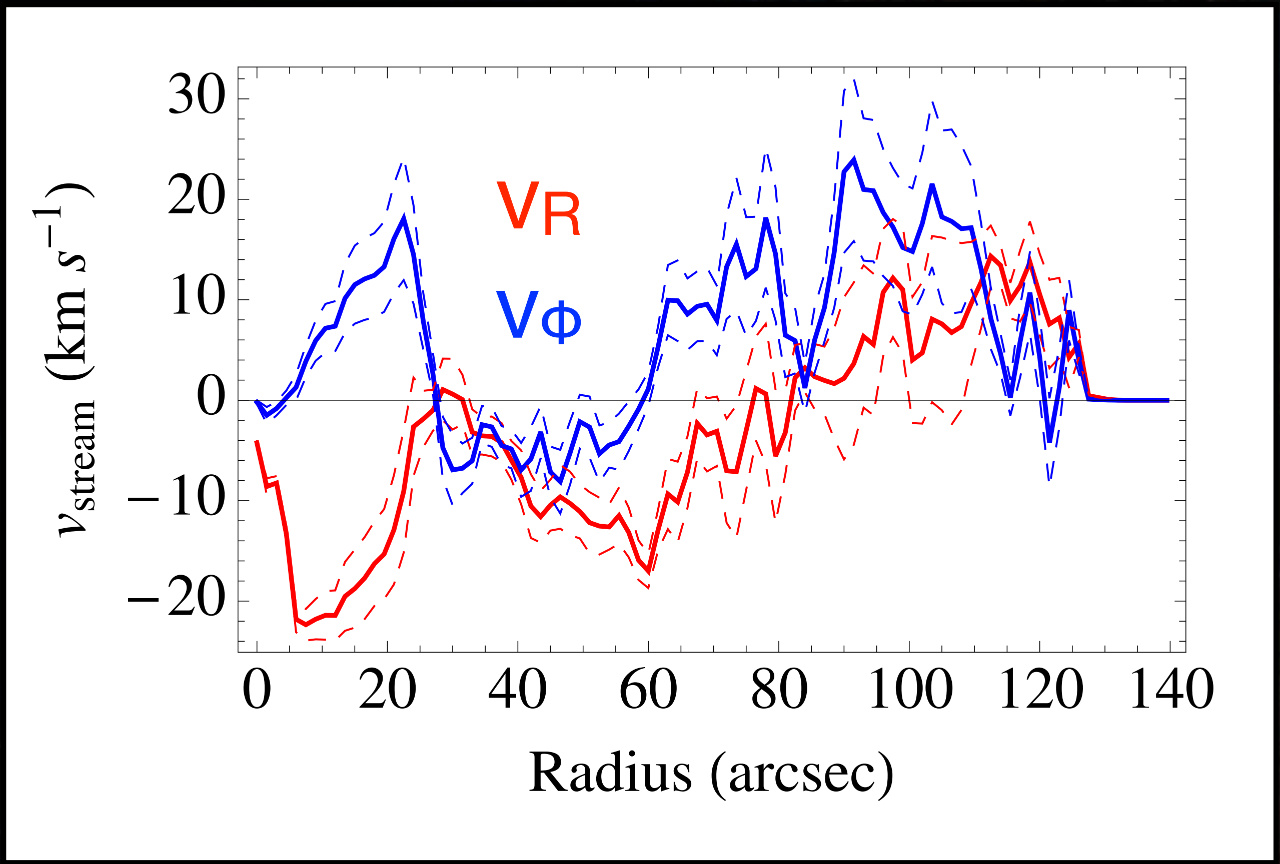
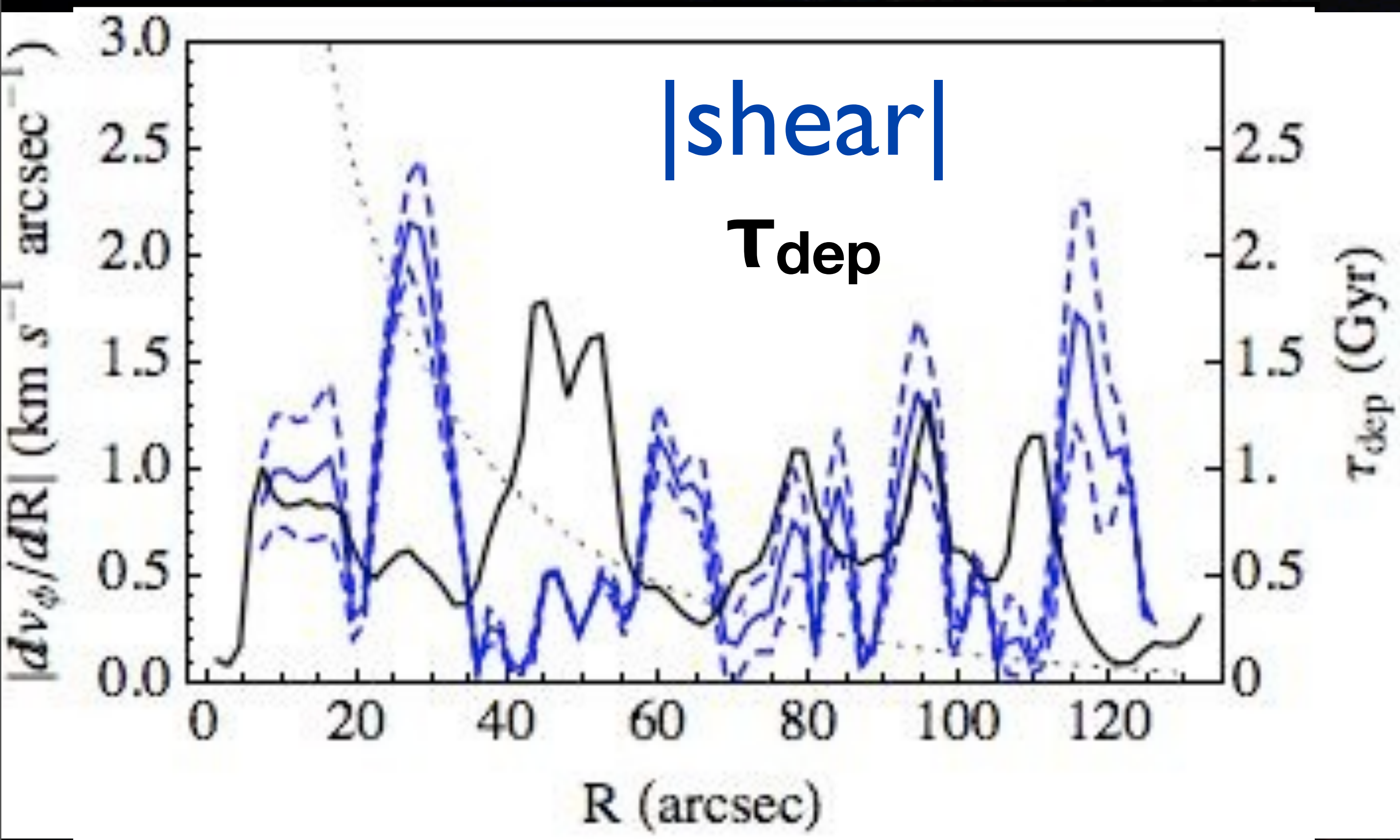


radial and azimuthal components of velocity reconstructed from within spiral arm frame (assuming v_r and v_Φ ~ constant along spiral segments)



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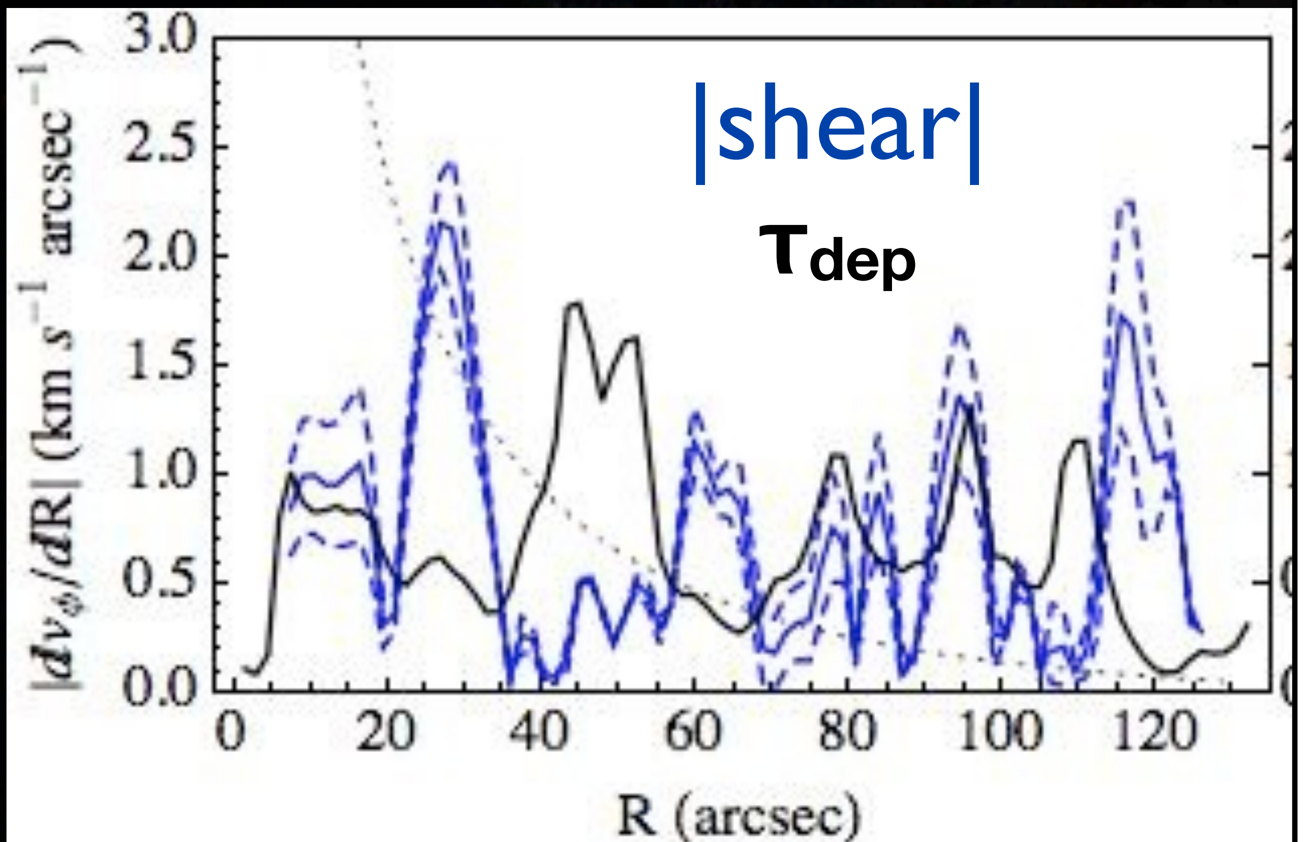
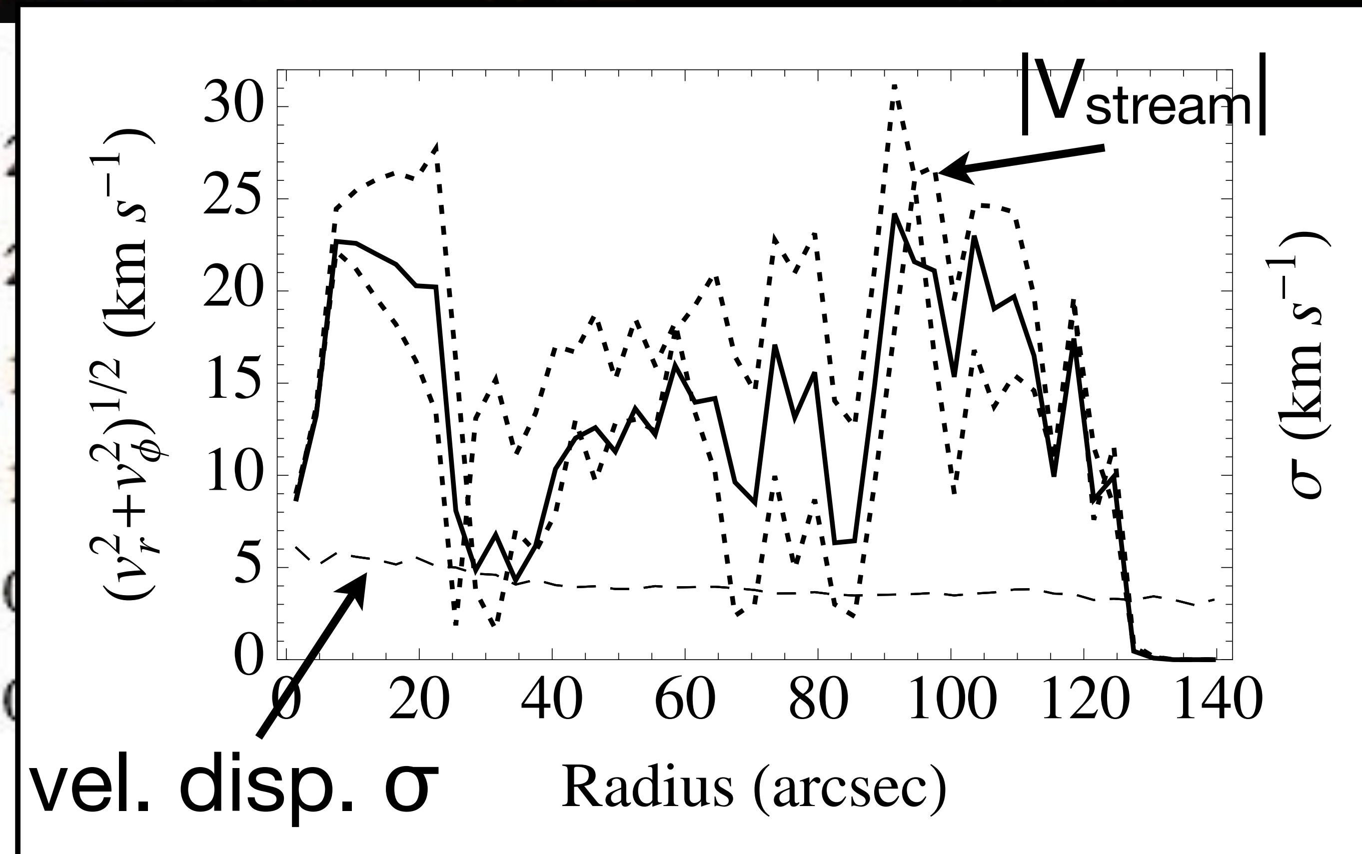
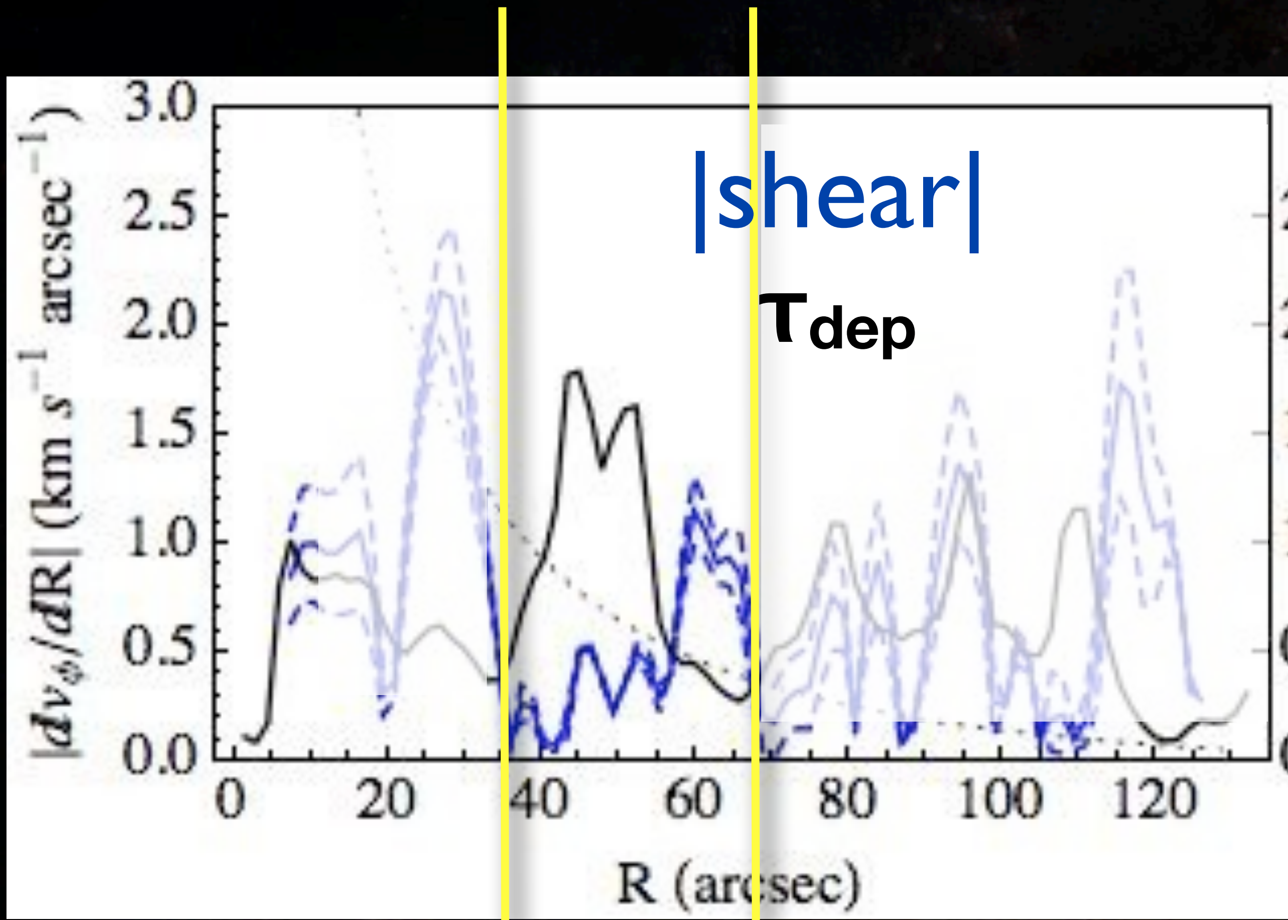
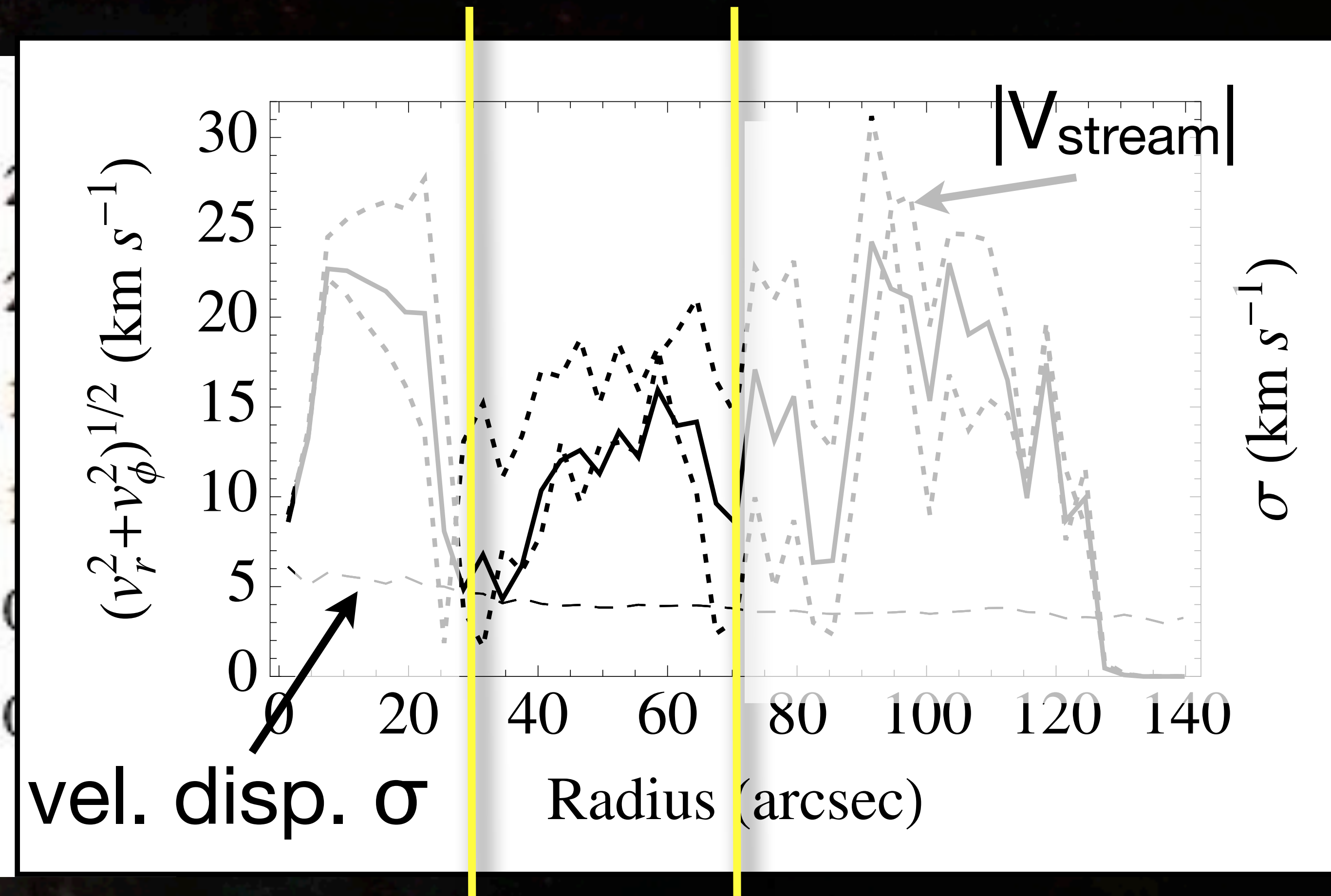




- support *not* from
  - shear (=*d*ln v_Φ/*d*lnR; cf. Dib & Helou 2012)
  - turbulent motions (regular σ along spiral)
  - stellar feedback

\+ arm shocks regular (Shetty et al. 2008)





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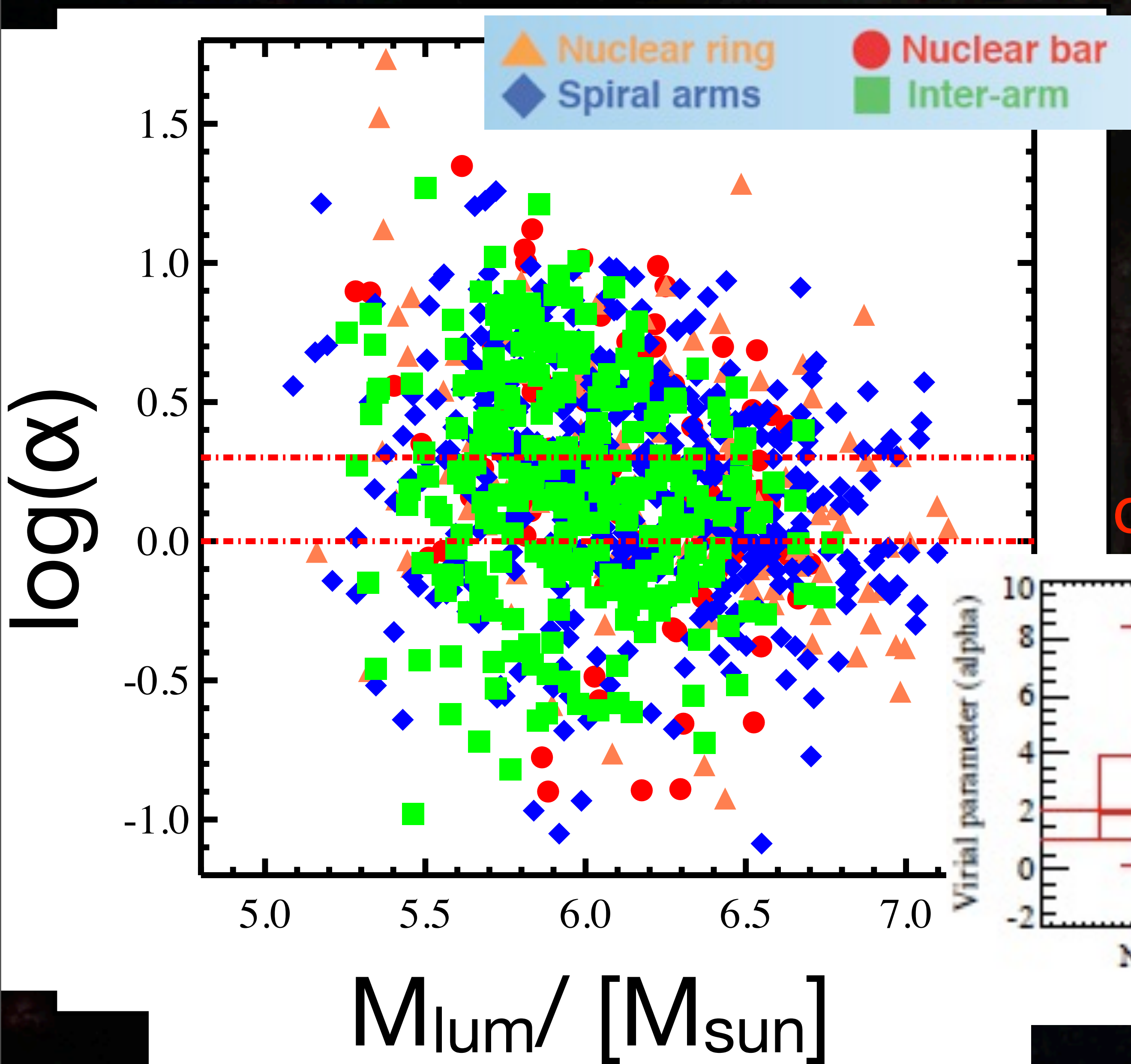
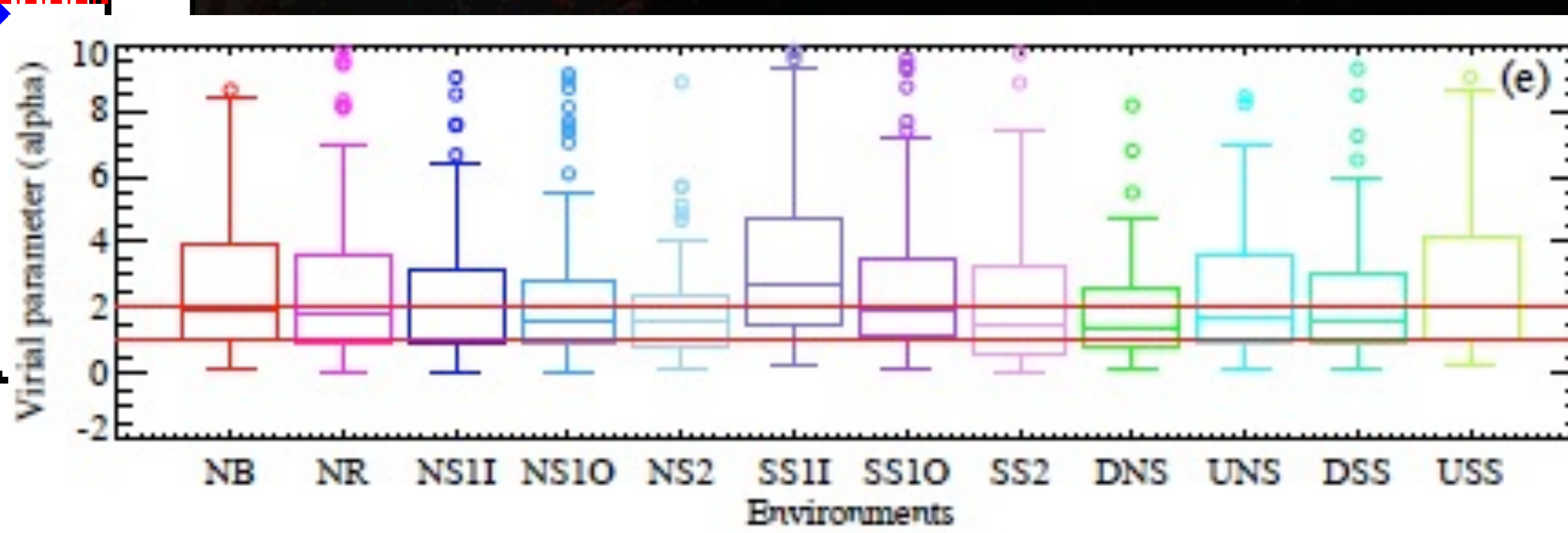
Pressure?



clouds unbound
or
pressure confined?

center arm1 arm2 interarm



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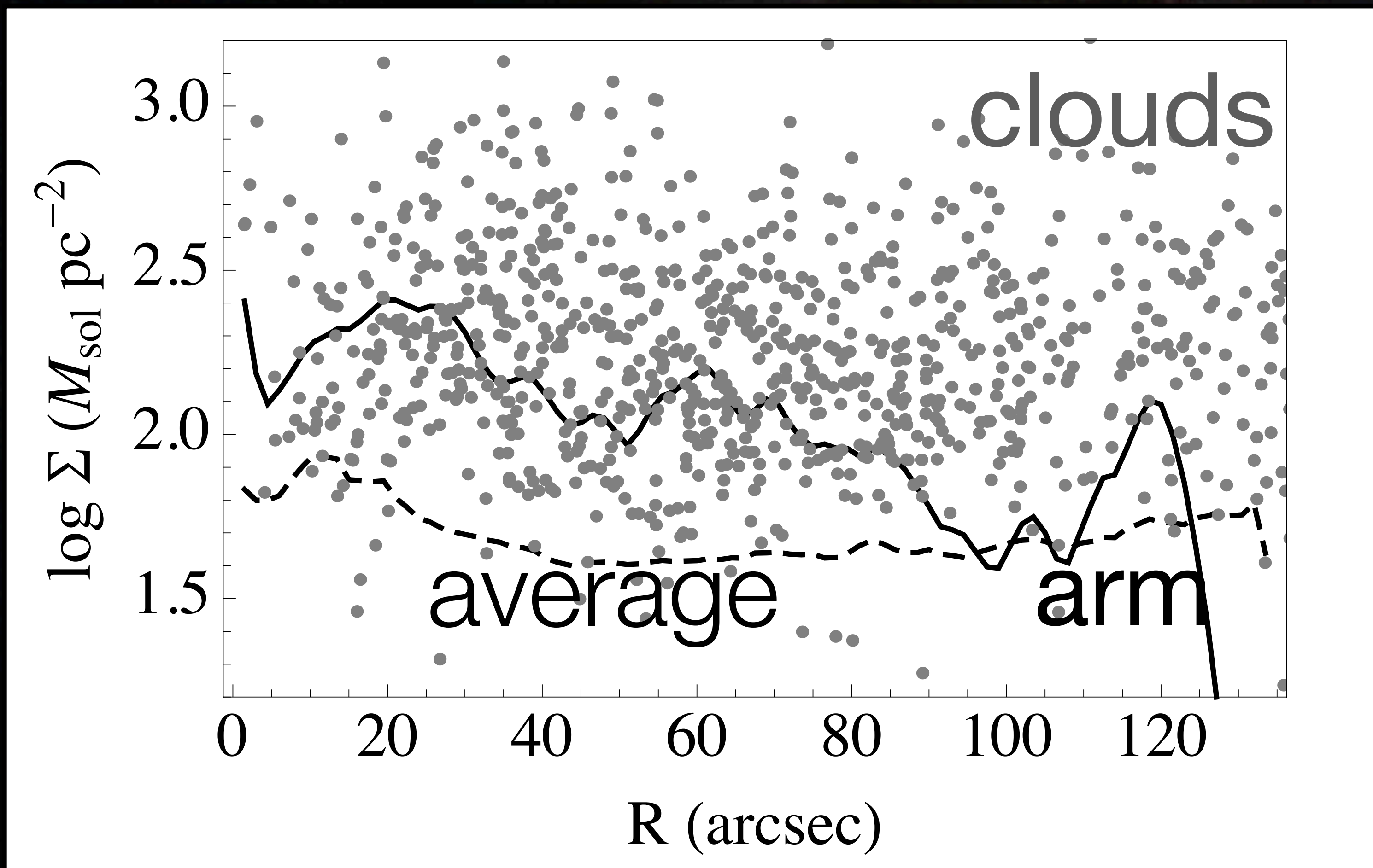
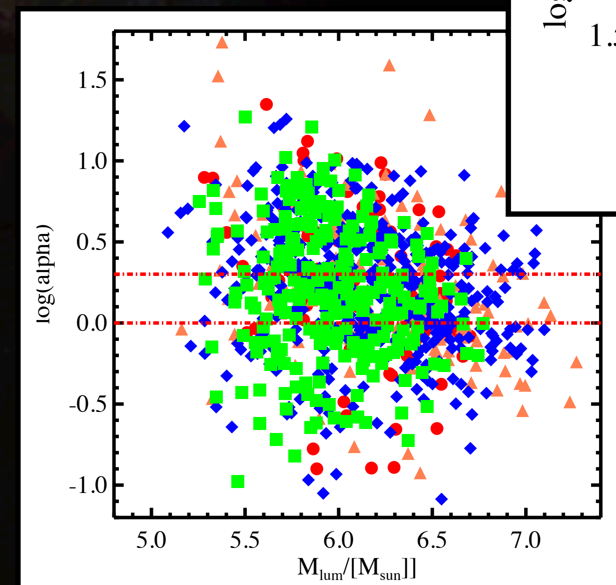
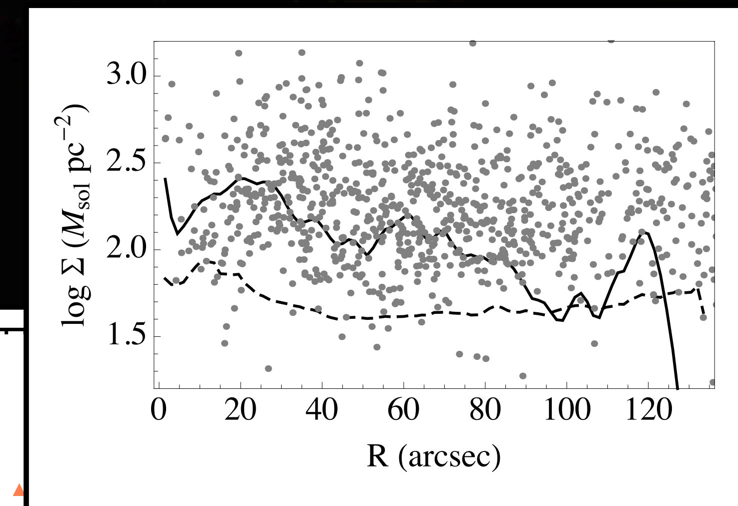


ambient P
comparable to
cloud P

surface pressure
important

change in stable mass threshold





change in stable mass threshold

clouds in motion:

1). **reduced surface pressure** (Bernoulli)

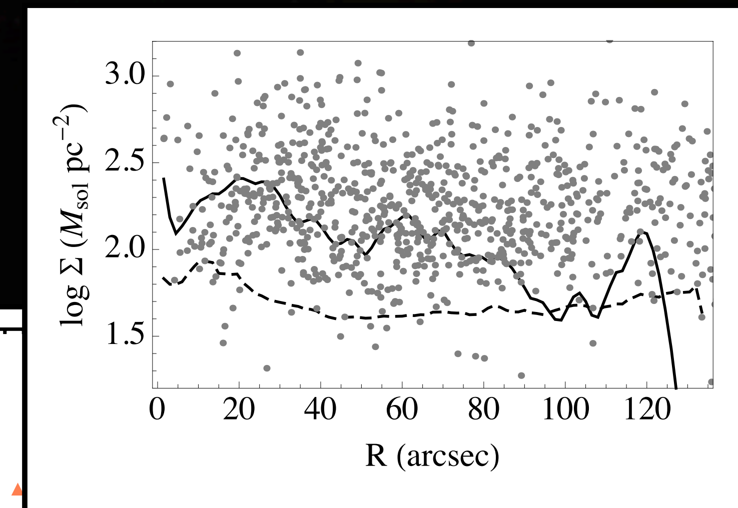
2). **increased** (Bonnor-Ebert) **stable mass**

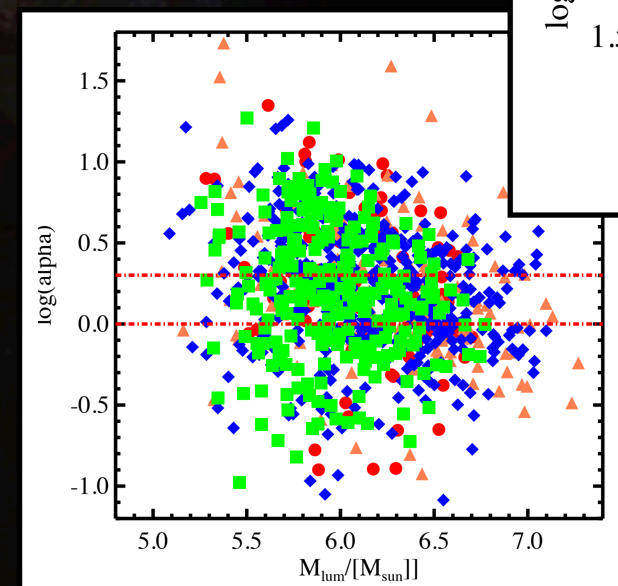
2b). reduced collapse-unstable fraction

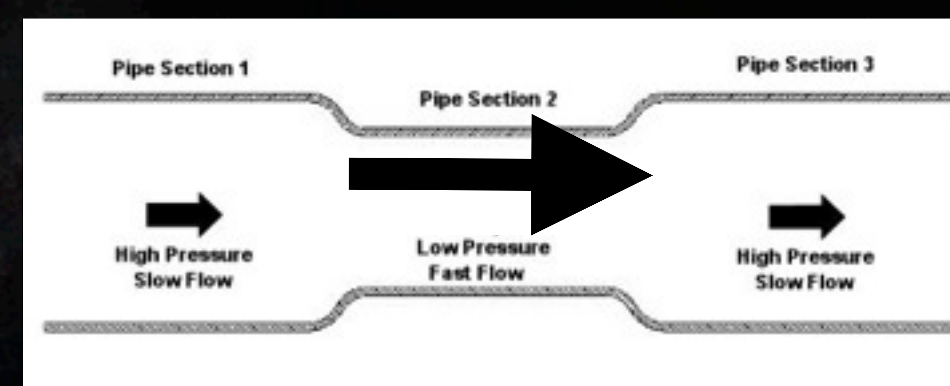
3). **lower SFE**

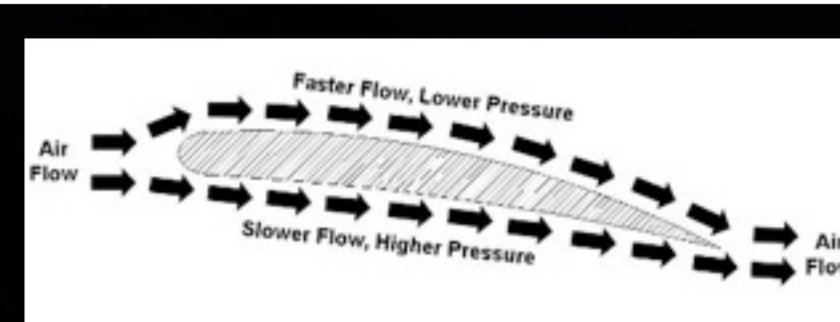
$$\ln \tau_{dep} \approx -(\Upsilon+1)\, \frac{v_{stream}^2}{4\sigma^2}$$

for $dN/dM \propto M^{\Upsilon}$



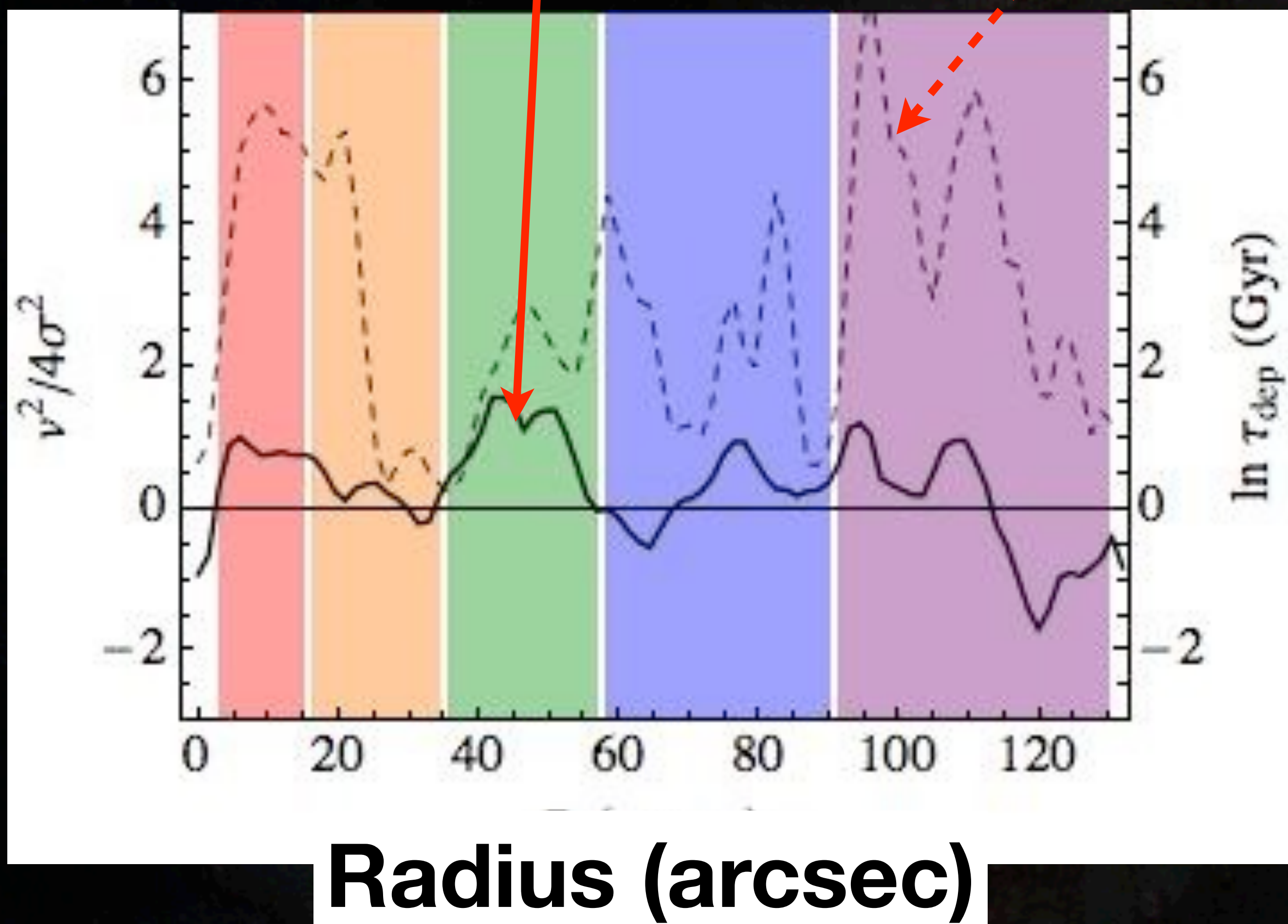






$$\ln \tau_{dep} \approx -(\gamma+1)\frac{v_{stream}^2}{4\sigma^2} + \ln \tau_{dep,0}$$

for $dN/dM \propto M^{\gamma}$



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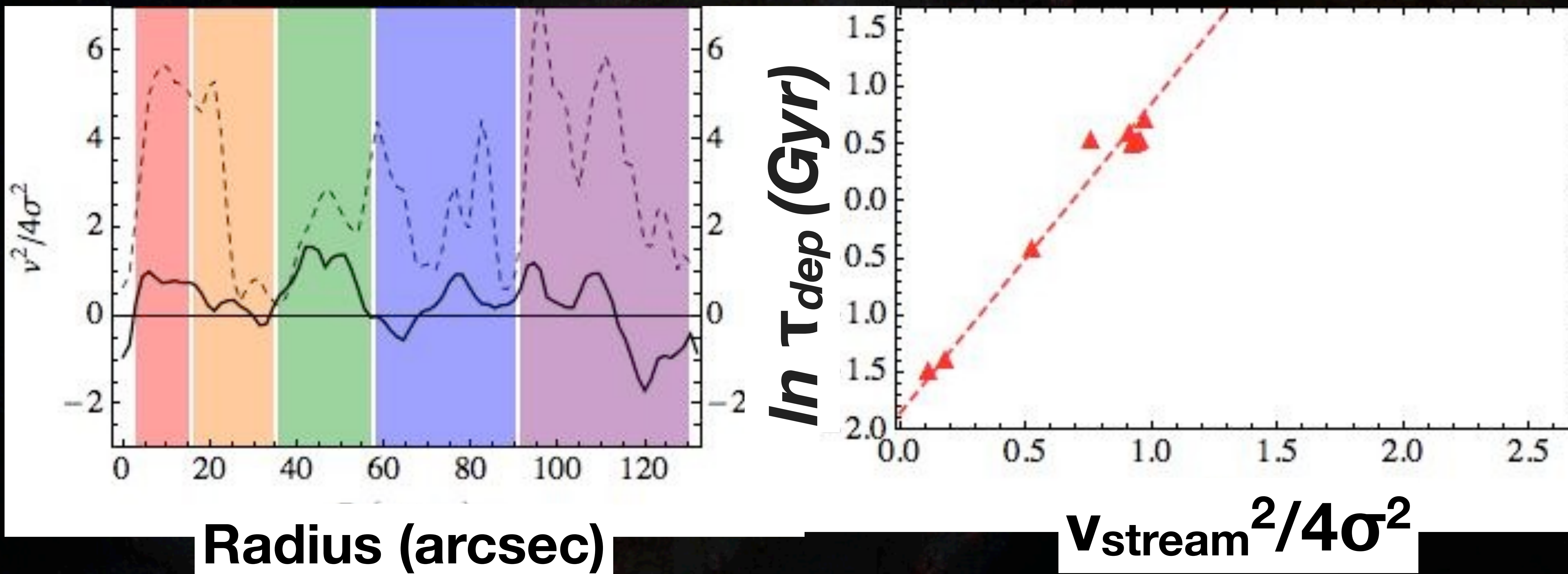

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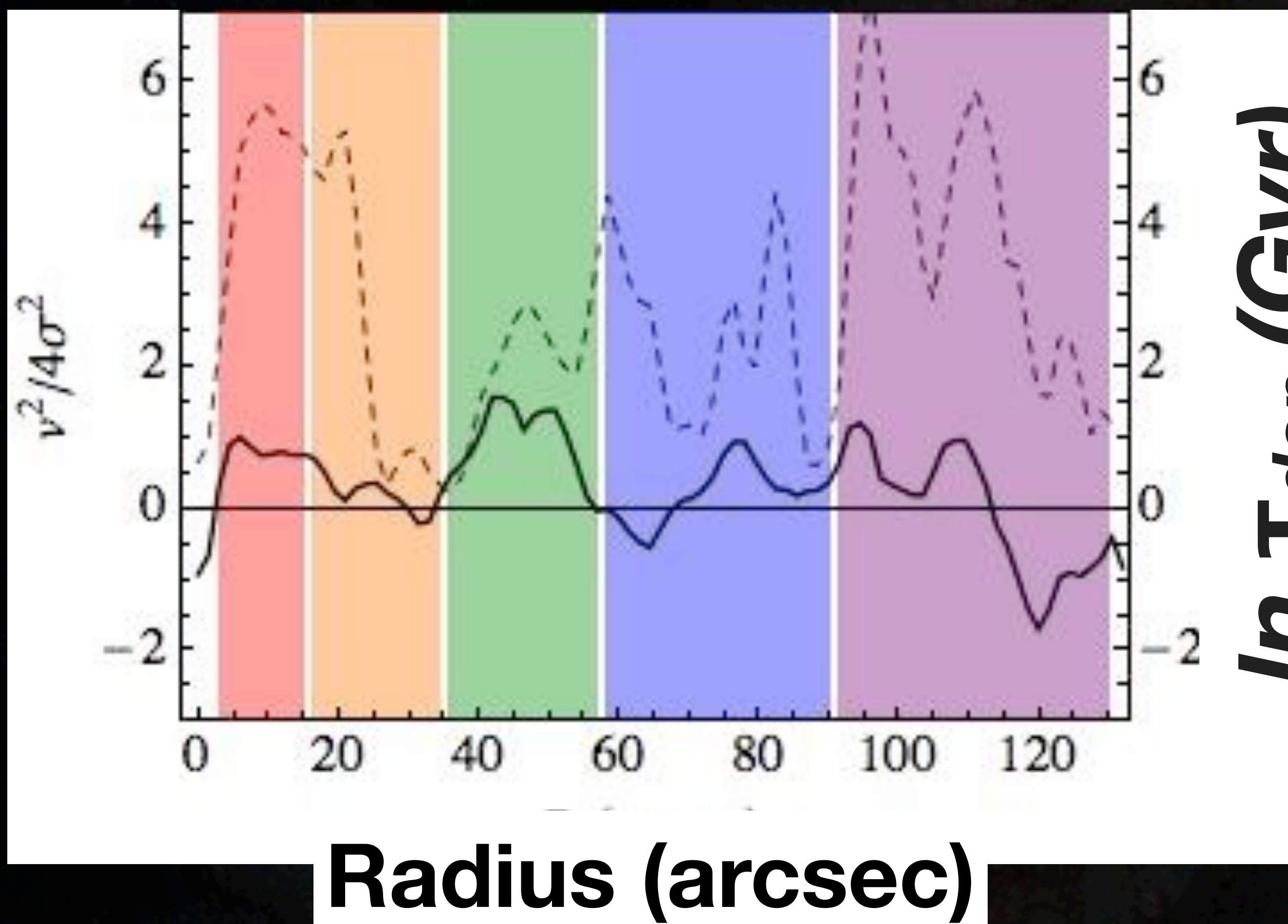

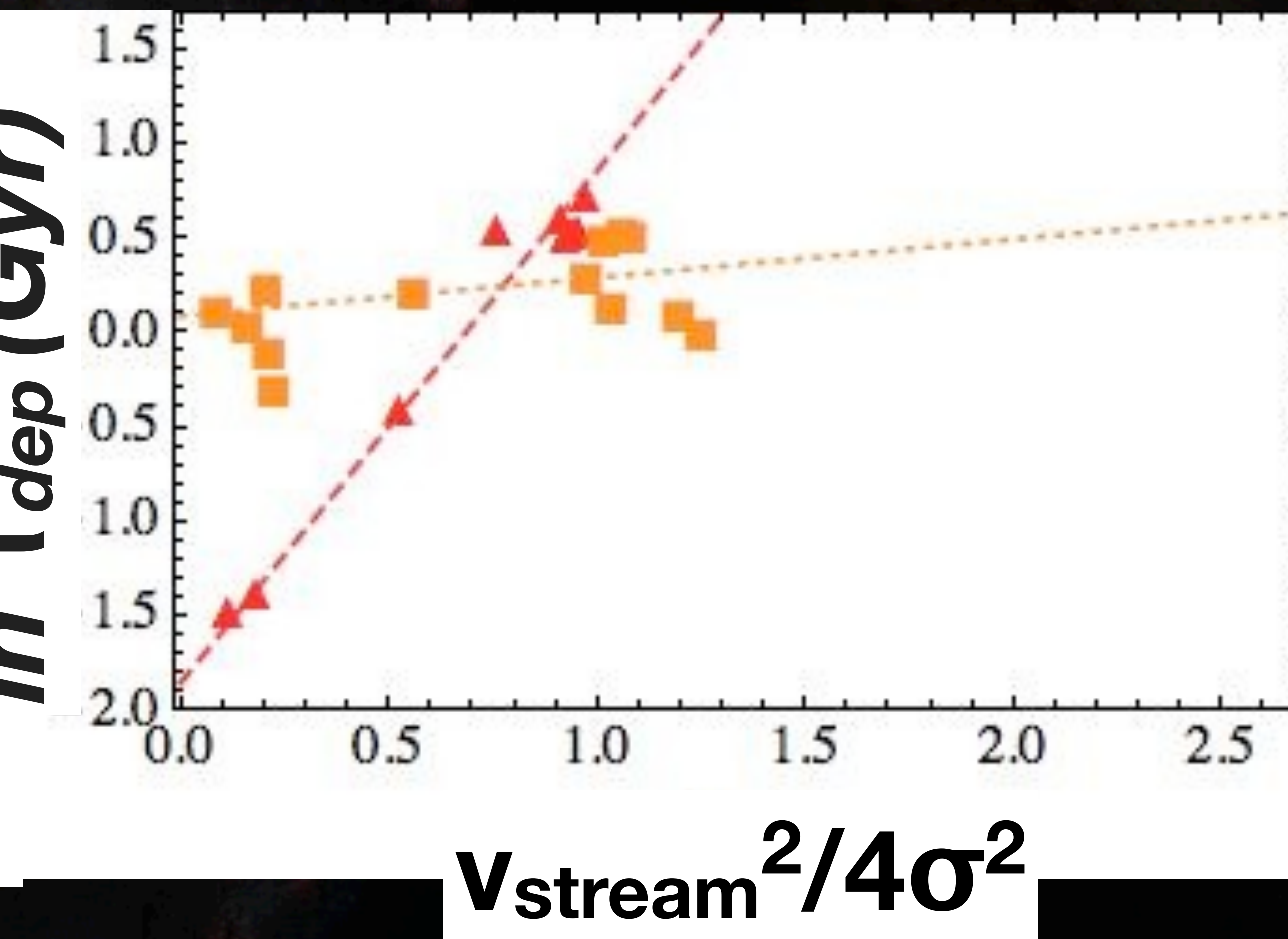

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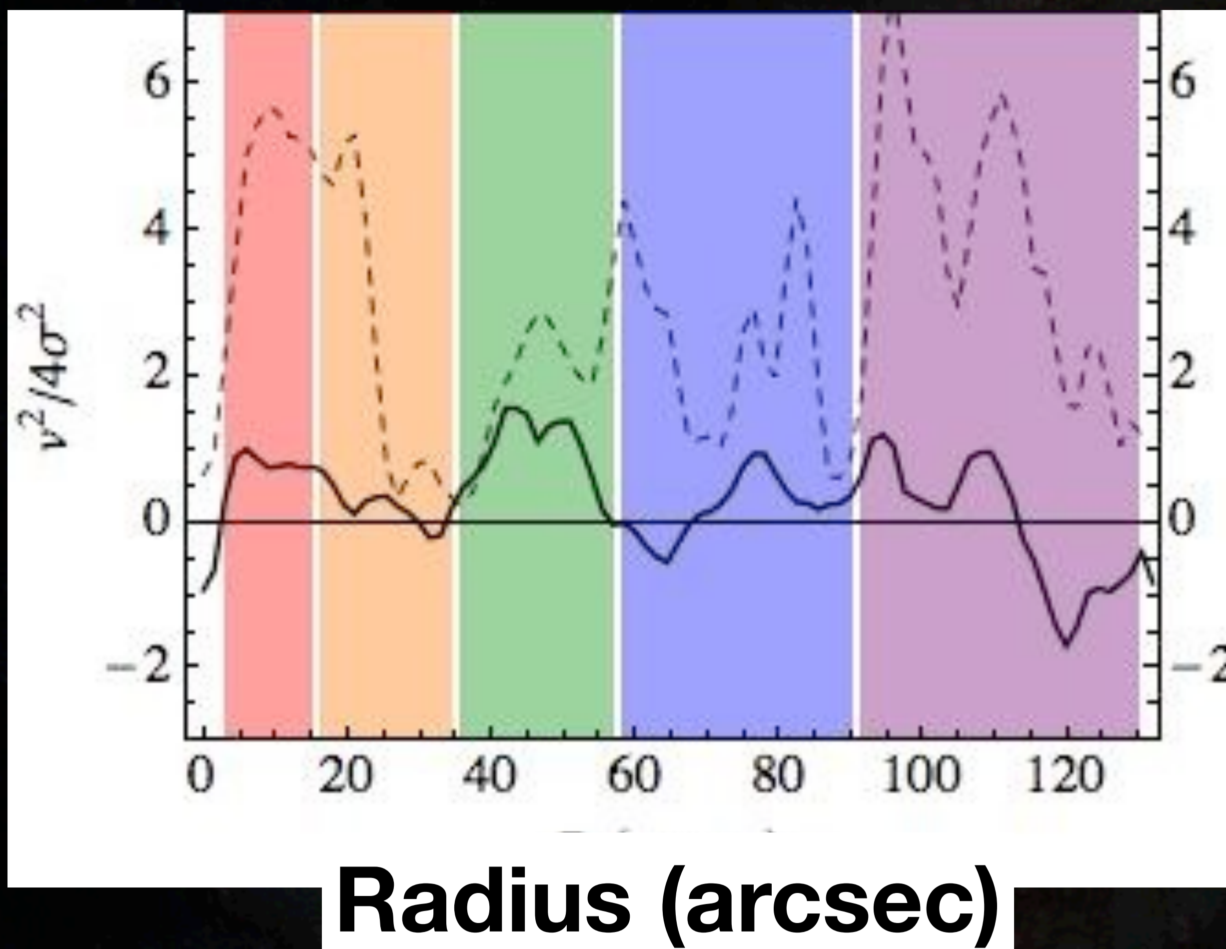

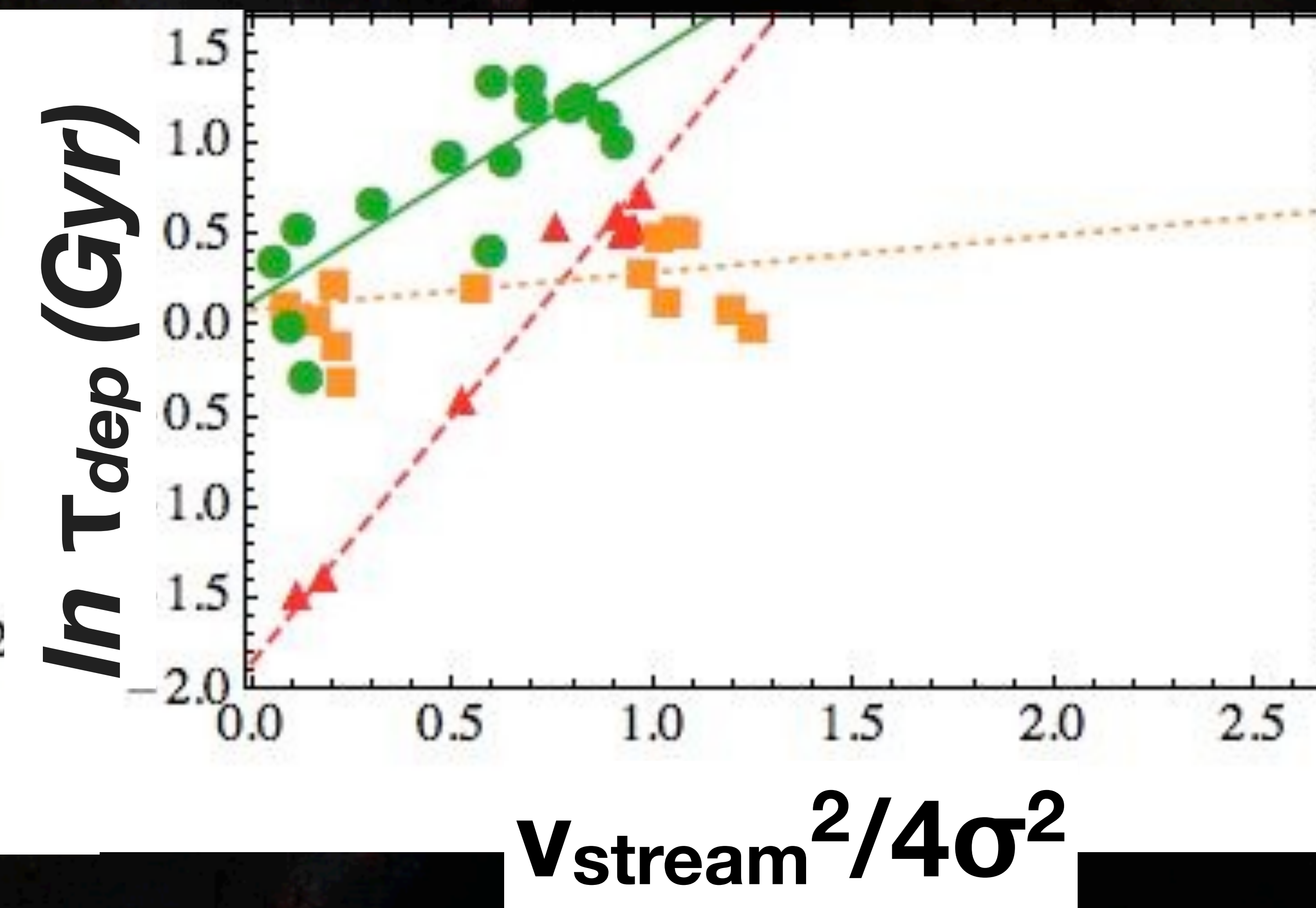

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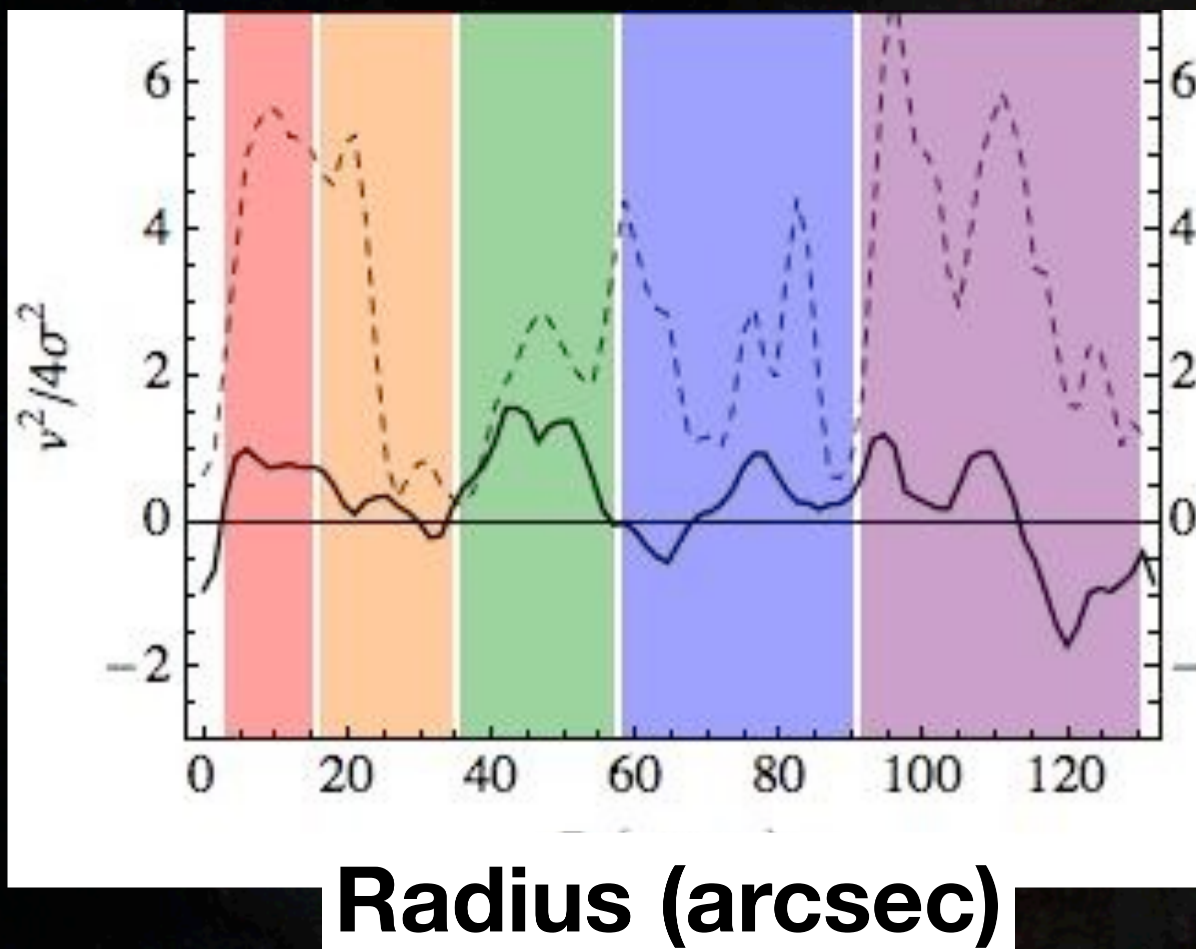

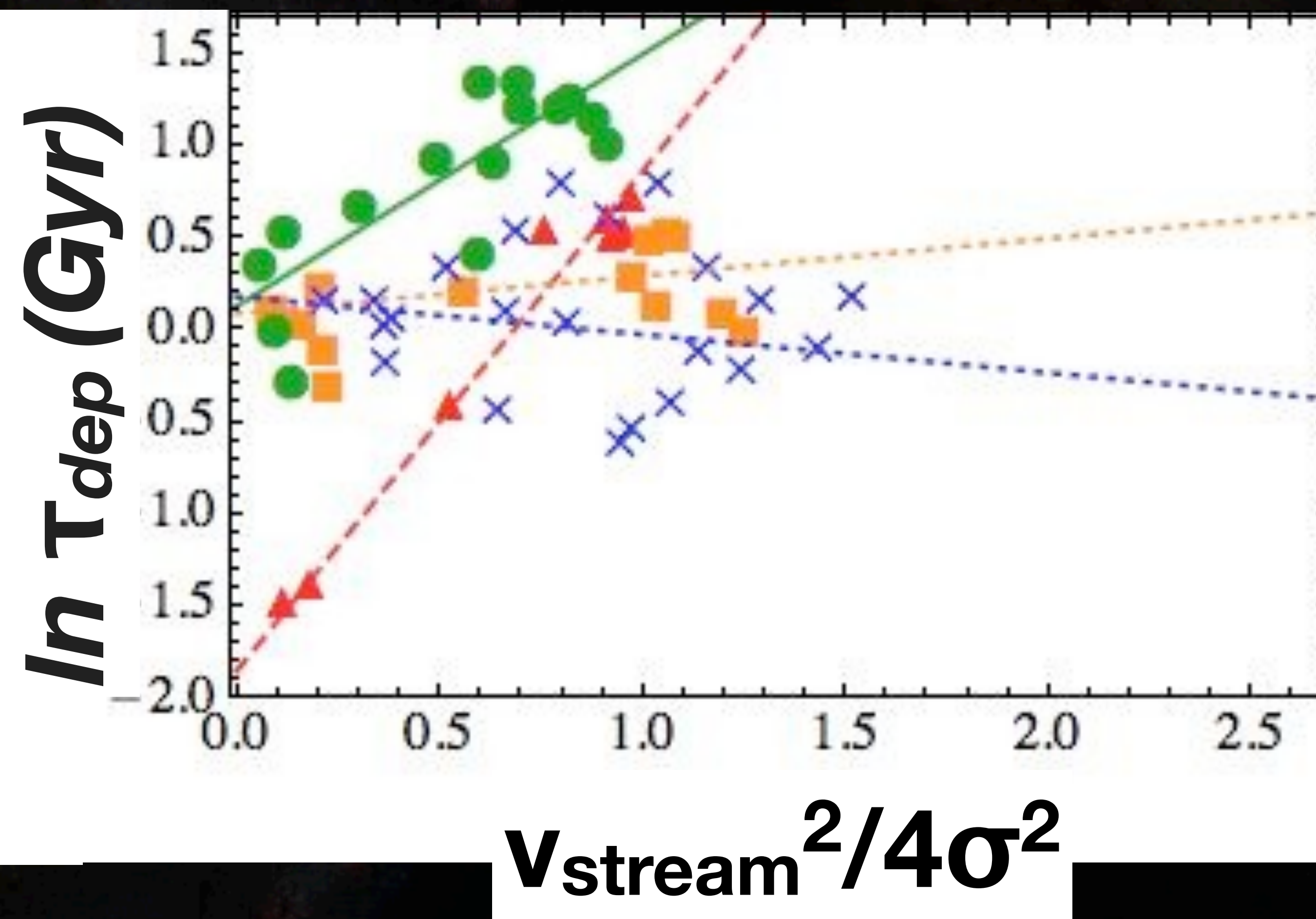

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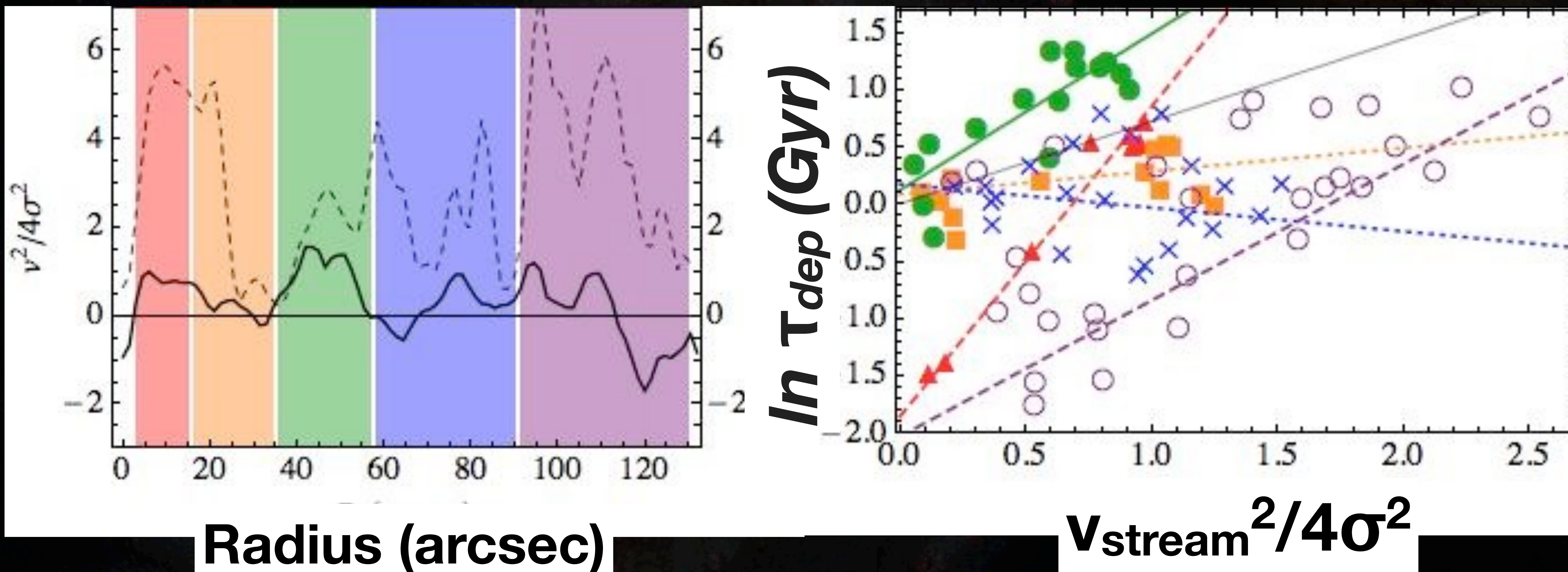


from slope

cloud mass spectrum index γ

$\langle\gamma\rangle = -1.6 \pm 0.5$

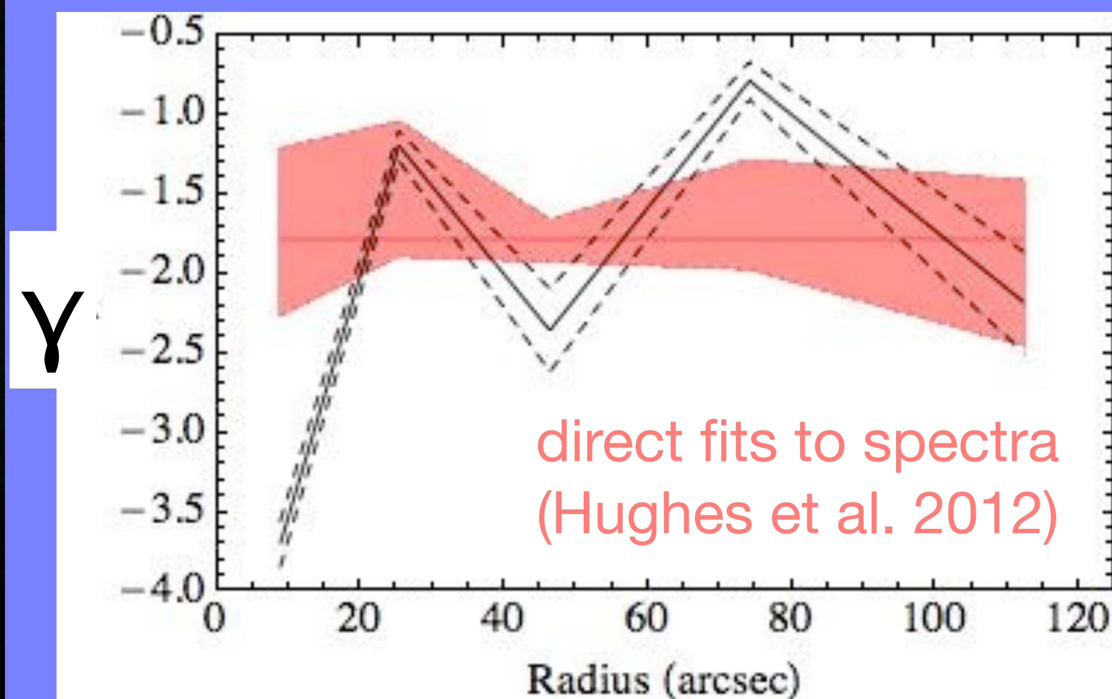
$\langle\gamma\rangle = -1.7 \pm 0.25$

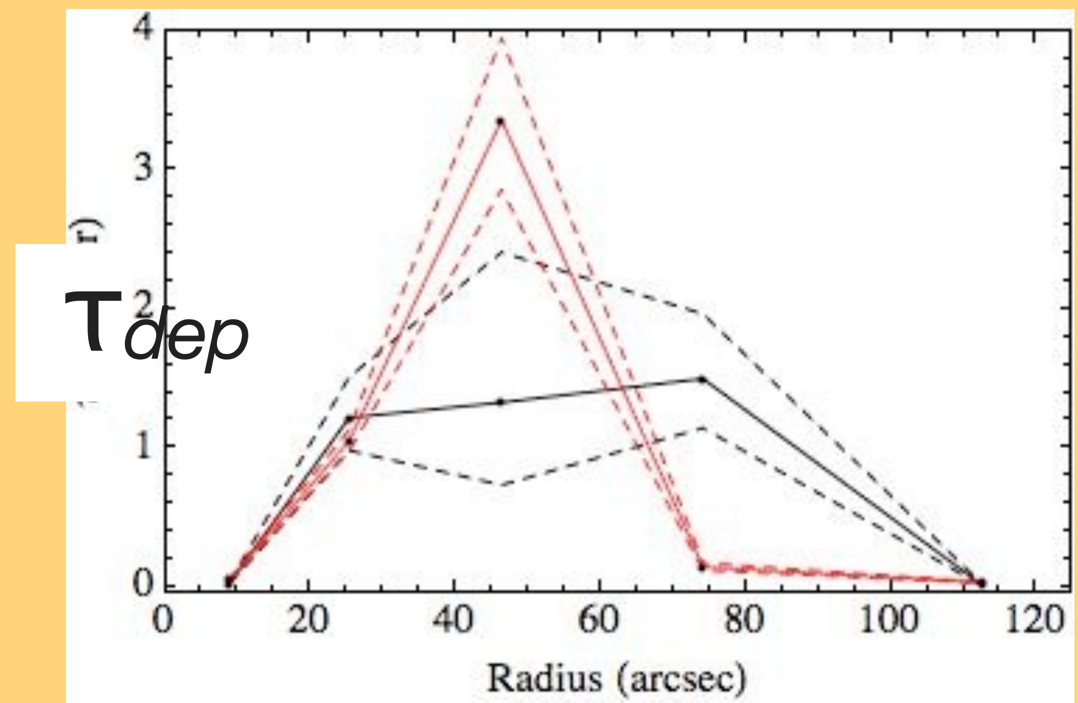
direct fits to spectra
(Hughes et al. 2012)

fiducial gas depletion time τ_{dep}

from y-intercept

cloud mass spectrum index γ

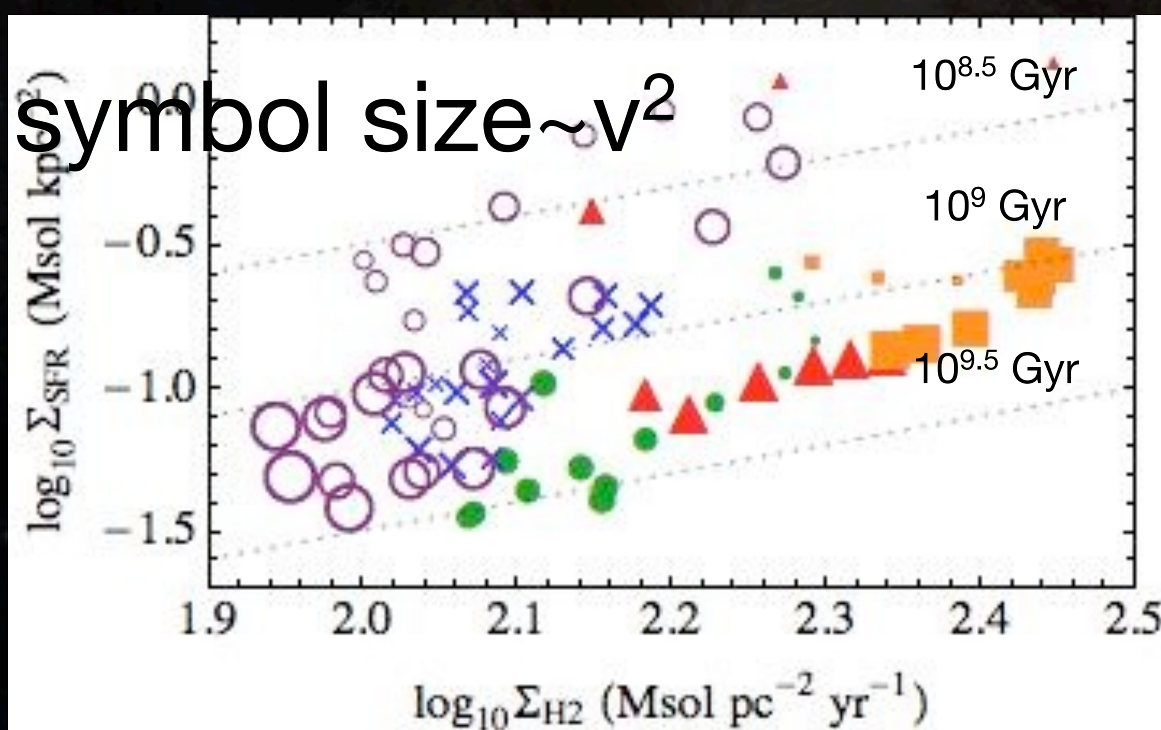


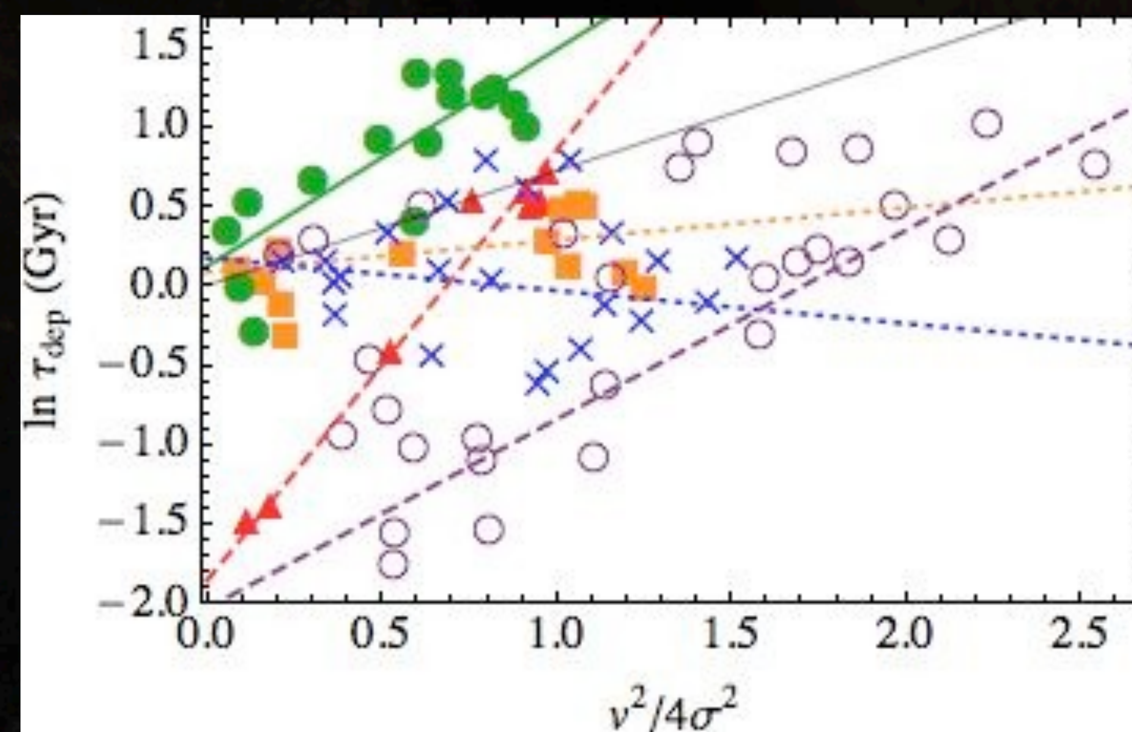


fiducial gas depletion time τ_{dep}

from y-intercept

- gas depletion time 1 Gyr?
- comparable to dwarfs with Galactic X_{CO}, starbursts
- are the 'normal' spiral galaxies not normal?





KS diagram

predictions, implications...

- streaming motions higher in looser spirals →early type spirals show greater scatter in KS relation?
- but global SFR independent of spiral strength (higher gas densities in stronger spirals offset by stronger streaming)
- variation in IMF?
  - low mass clouds disfavored by dynamical pressure
  - early SF in starbursts: no spiral-driven streaming

Summary

1. Do extragalactic GMCs have uniform physical properties? **No.**

2. Does dynamical environment matter? **Yes.**

3. Do gas flows impact cloud equilibrium ? **Yes.**

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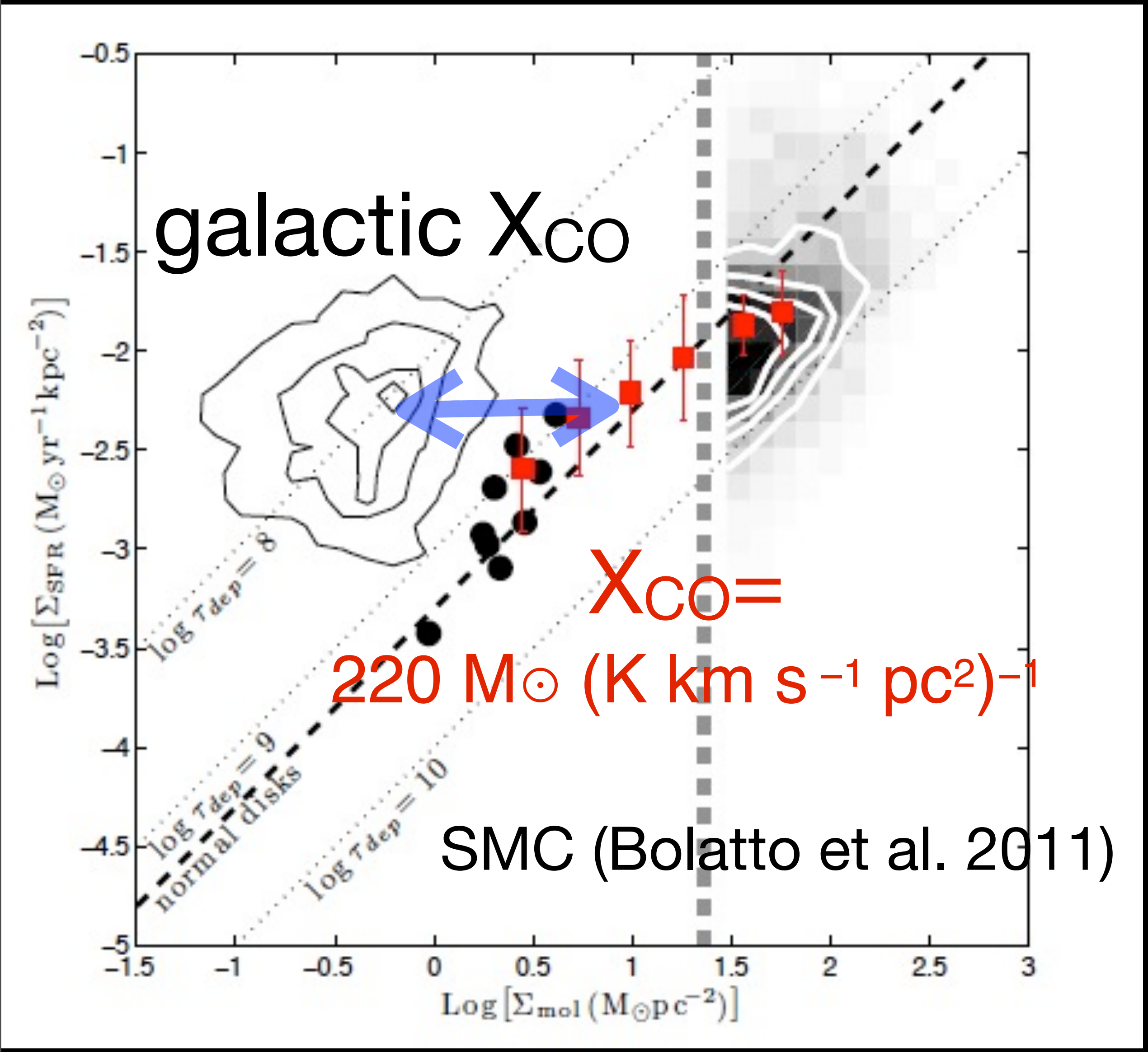
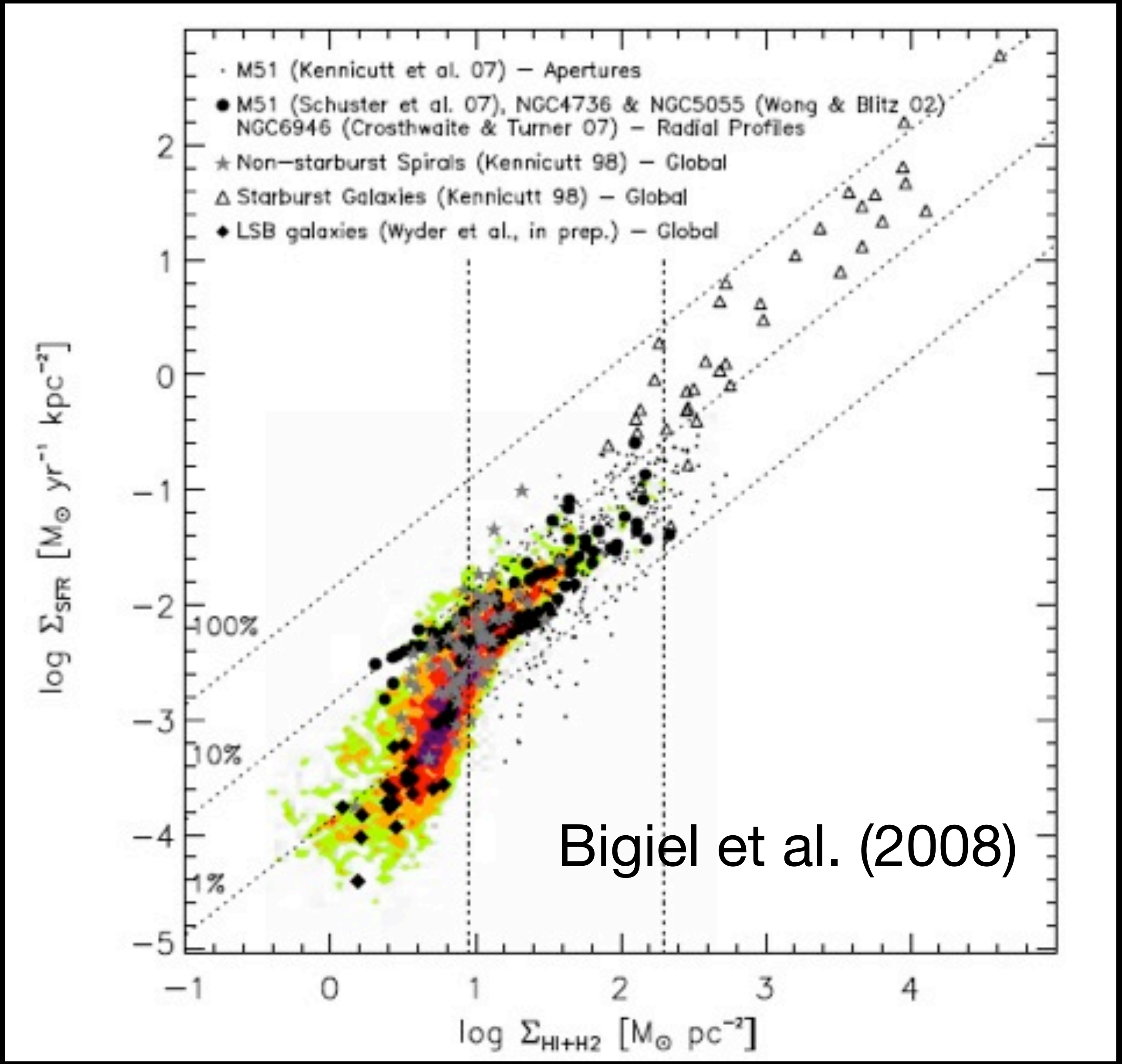
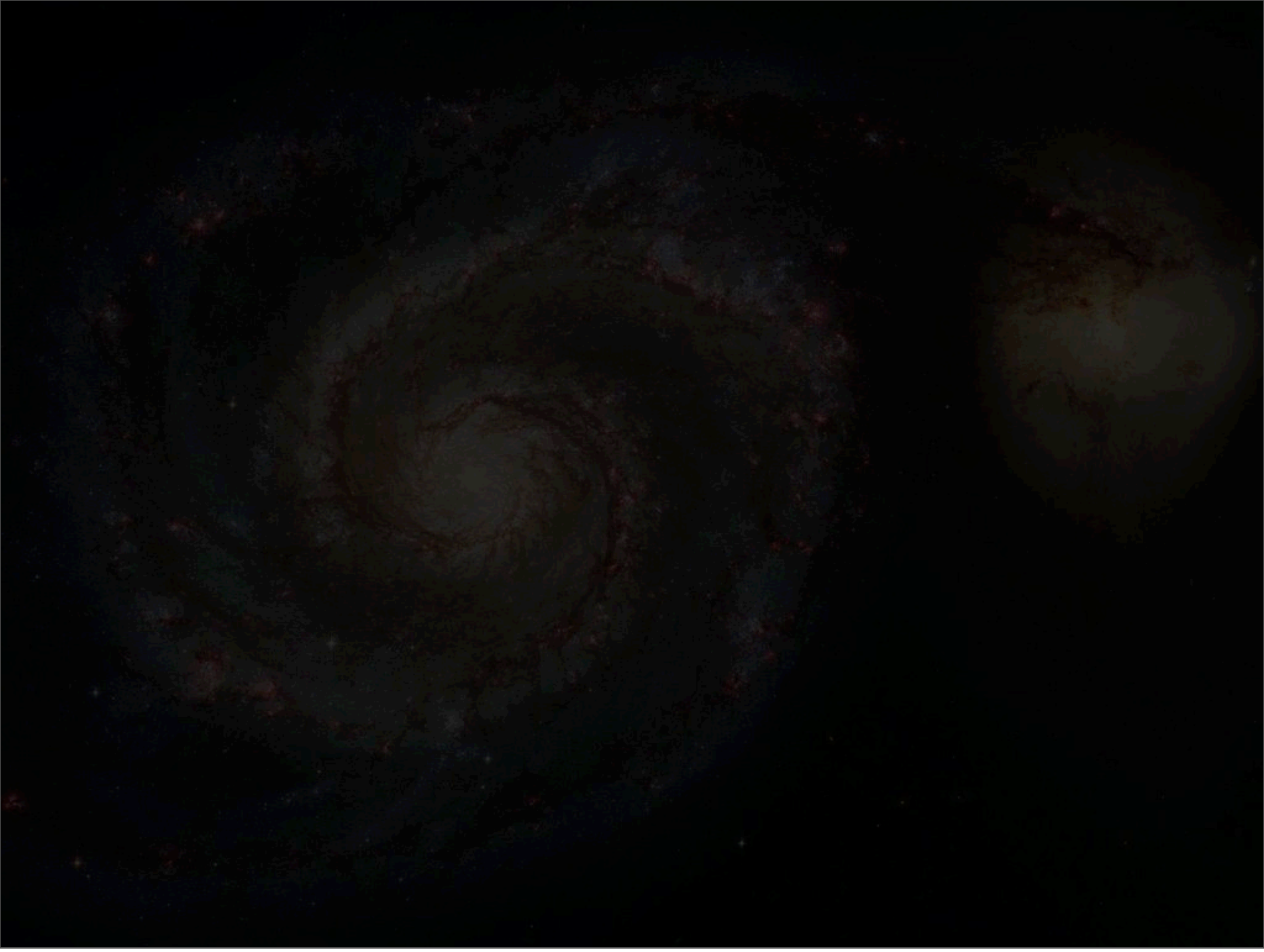
See Posters by Annie Hughes + Dario Colombo

3. Do gas flows impact cloud equilibrium ? **Yes.**


galactic XCO
XCO=
220 M⊙ (K km s-1 pc2)-1
SMC (Bolatto et al. 2011)
Log [ΣSFR (M⊙ yr−1 kpc−2)]
Log [Σmol (M⊙ pc−2)]
log τdep = 8
log τdep = 9
log τdep = 10
normal disks


M51 (Kennicutt et al. 07) – Apertures
M51 (Schuster et al. 07), NGC4736 & NGC5055 (Wong & Blitz 02)
NGC6946 (Crosthwaite & Turner 07) – Radial Profiles
Non–starburst Spirals (Kennicutt 98) – Global
Starburst Galaxies (Kennicutt 98) – Global
LSB galaxies (Wyder et al., in prep.) – Global
100%
10%
1%
log ΣSFR [M⊙ yr−1 kpc−2]
log ΣHI+H2 [M⊙ pc−2]
Bigiel et al. (2008)

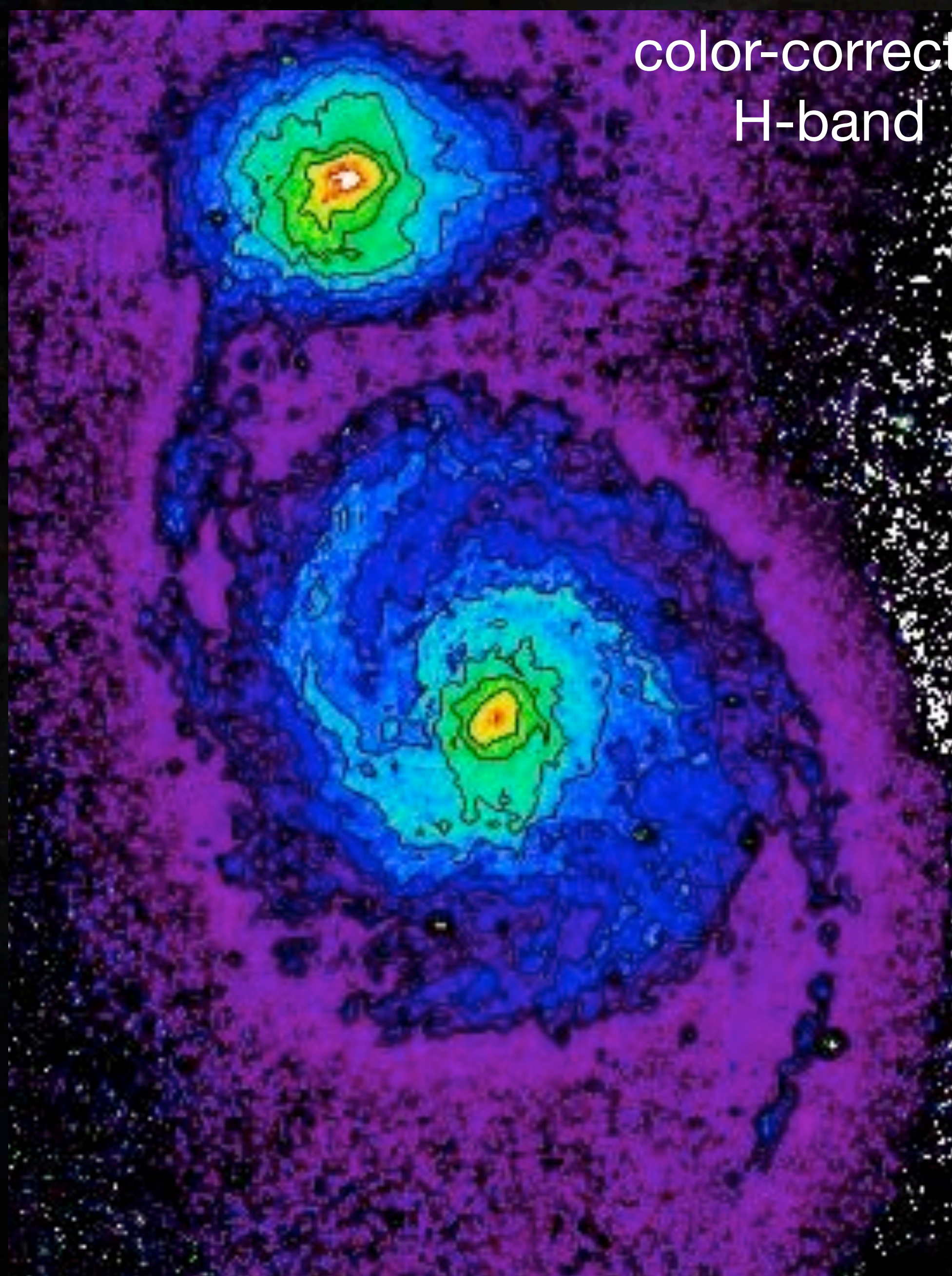


Stellar Mass+potential

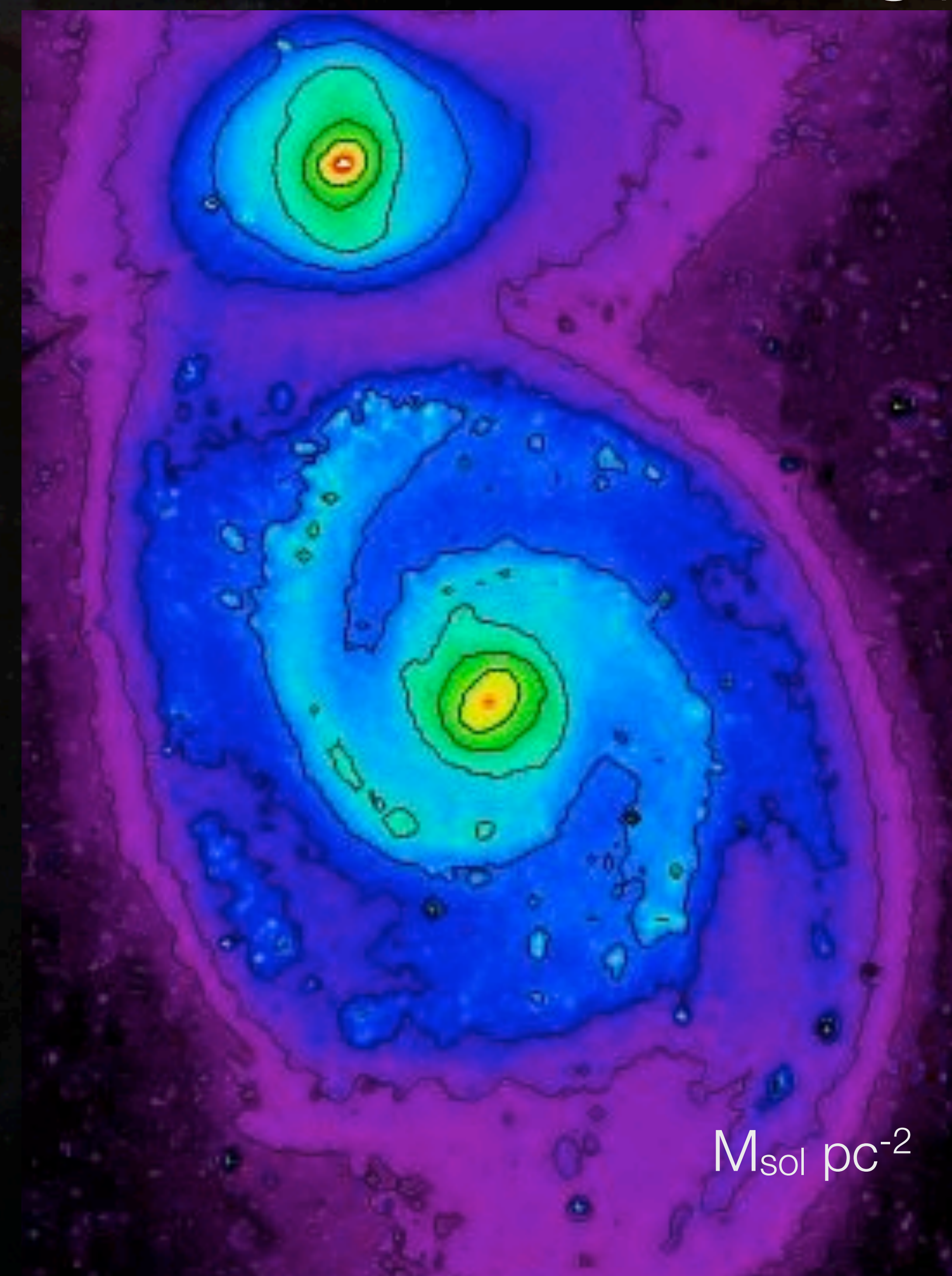
so is it a density wave, or not?

Σ_{Z09}

color-corrected
H-band



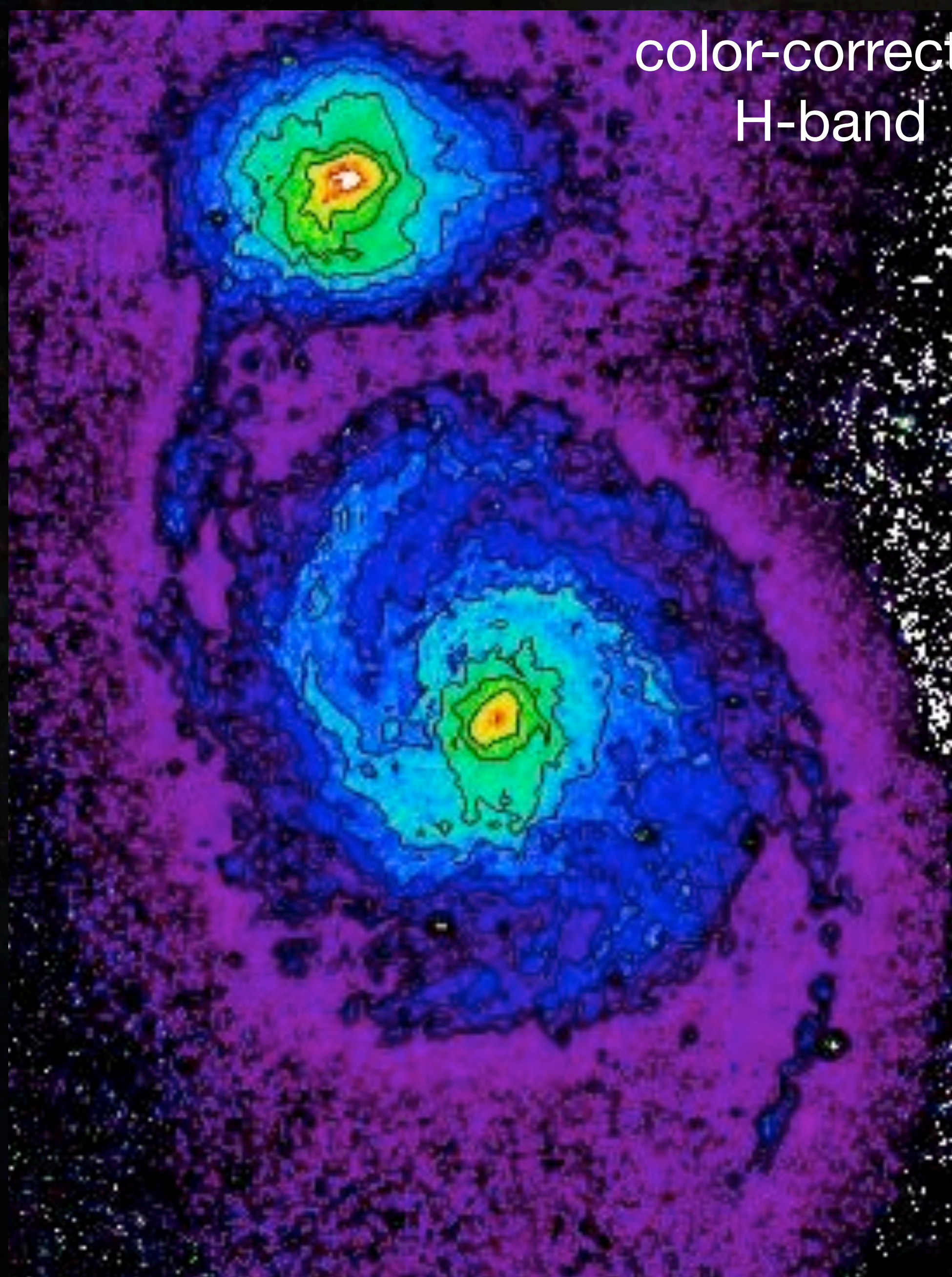
Σ_{S4G}



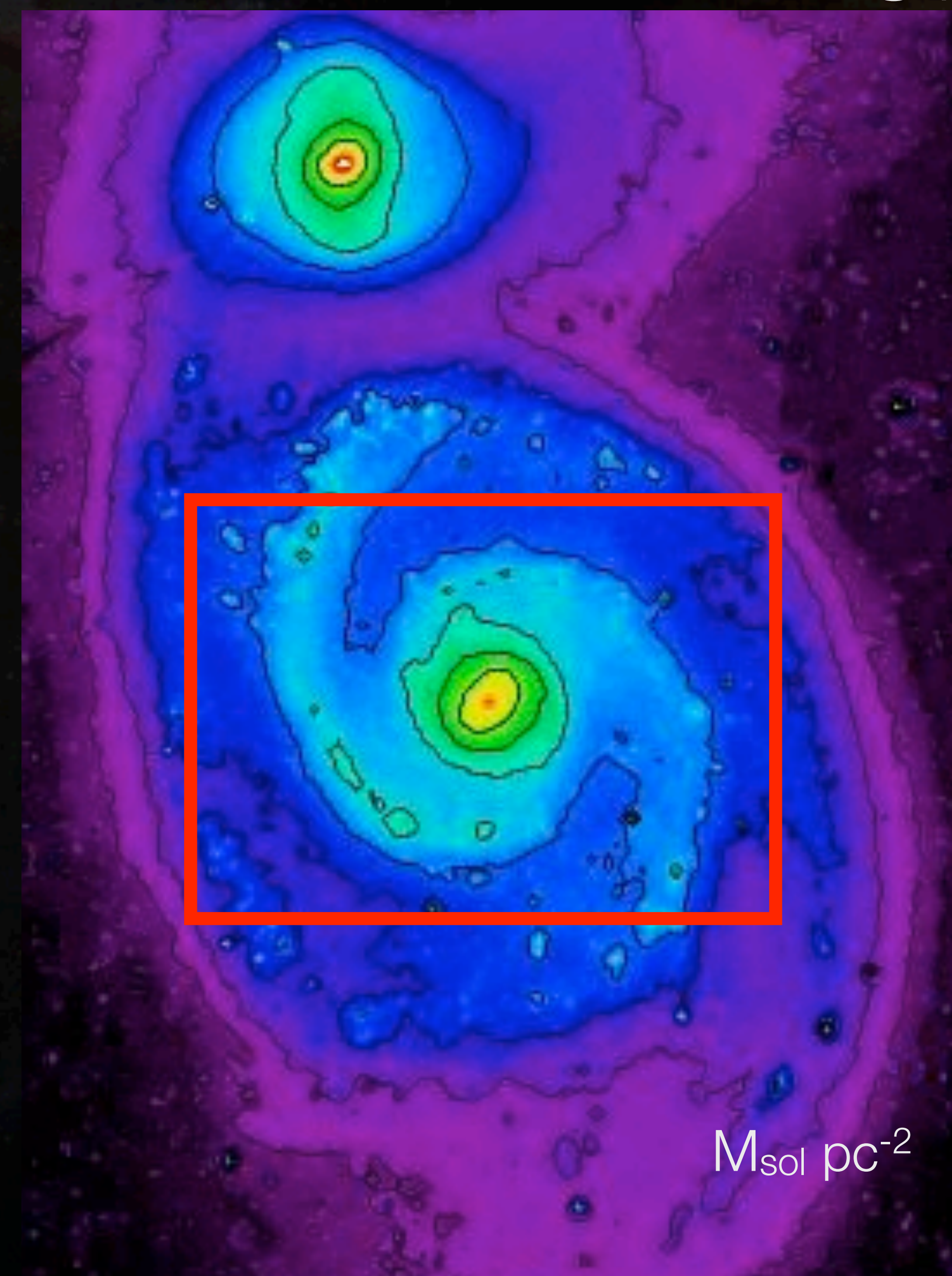
Stellar Mass+potential

so is it a density wave, or not?

Σ_{Z09}



Σ_{S4G}

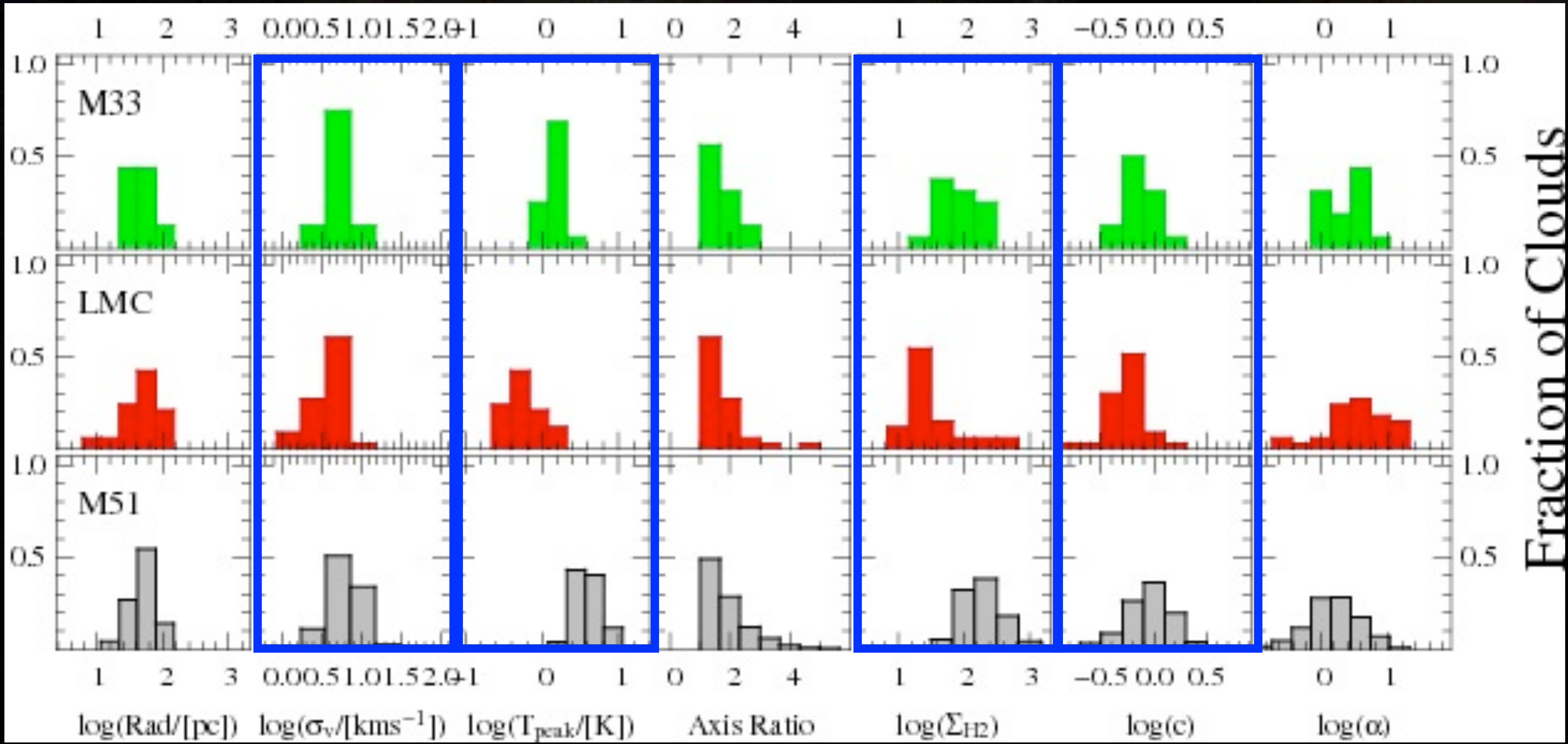


molecular gas properties

After homogenizing the datasets, M51 GMCs:

- are brighter (peak T and surface brightness)
- have larger linewidths (especially relative to size)

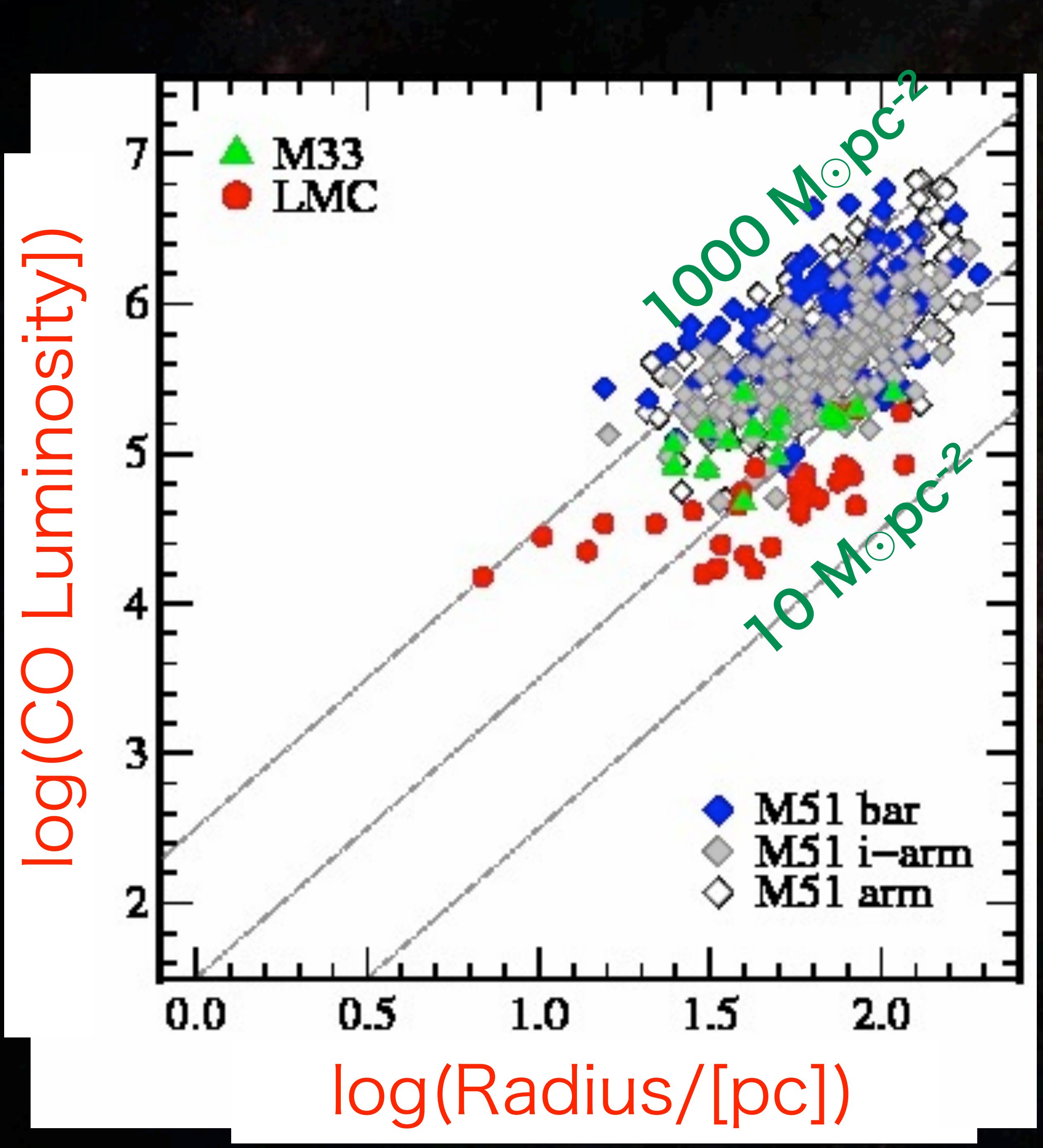
than GMCs in M33 and the LMC

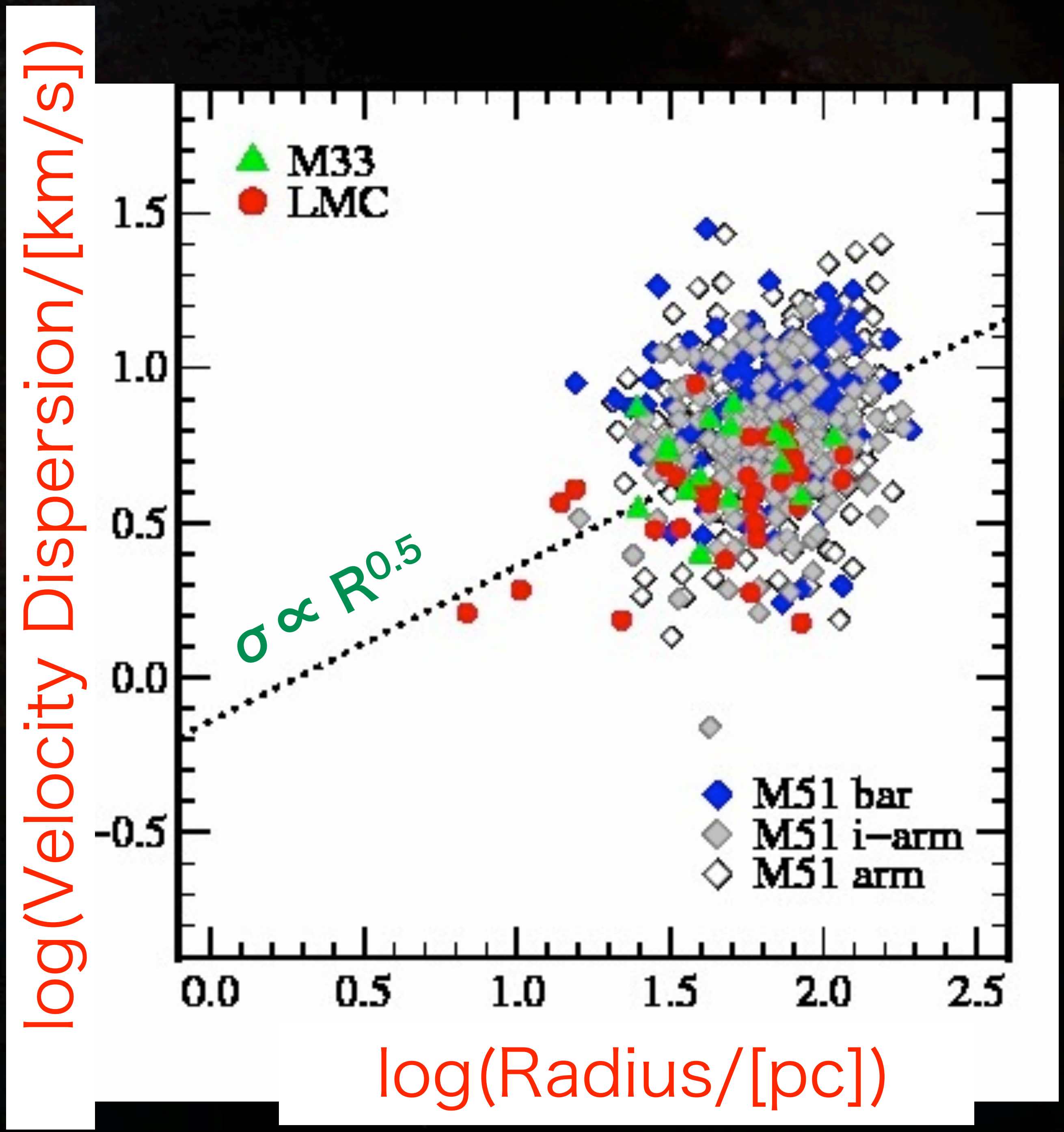




Property	M51	LMC	M33
Type	SA(s)bc pec	SB(s)m	SA(s)cd
Distance	7.6 Mpc	50.1kpc	0.84 Mpc
12 + log[O/H]	8.54	8.26	8.36
SFR [$M_\odot yr^{-1}$]	6	0.2	0.4
Global H_2/HI	0.6	<0.05	0.1
Global Gas/Stars	5%	20%	20 to 50%
Σ_{H2} [$M_\odot pc^{-2}$]	70	1	10
Σ_{HI} [$M_\odot pc^{-2}$]	10	15	10
Σ_* [$M_\odot pc^{-2}$]	500	50	100

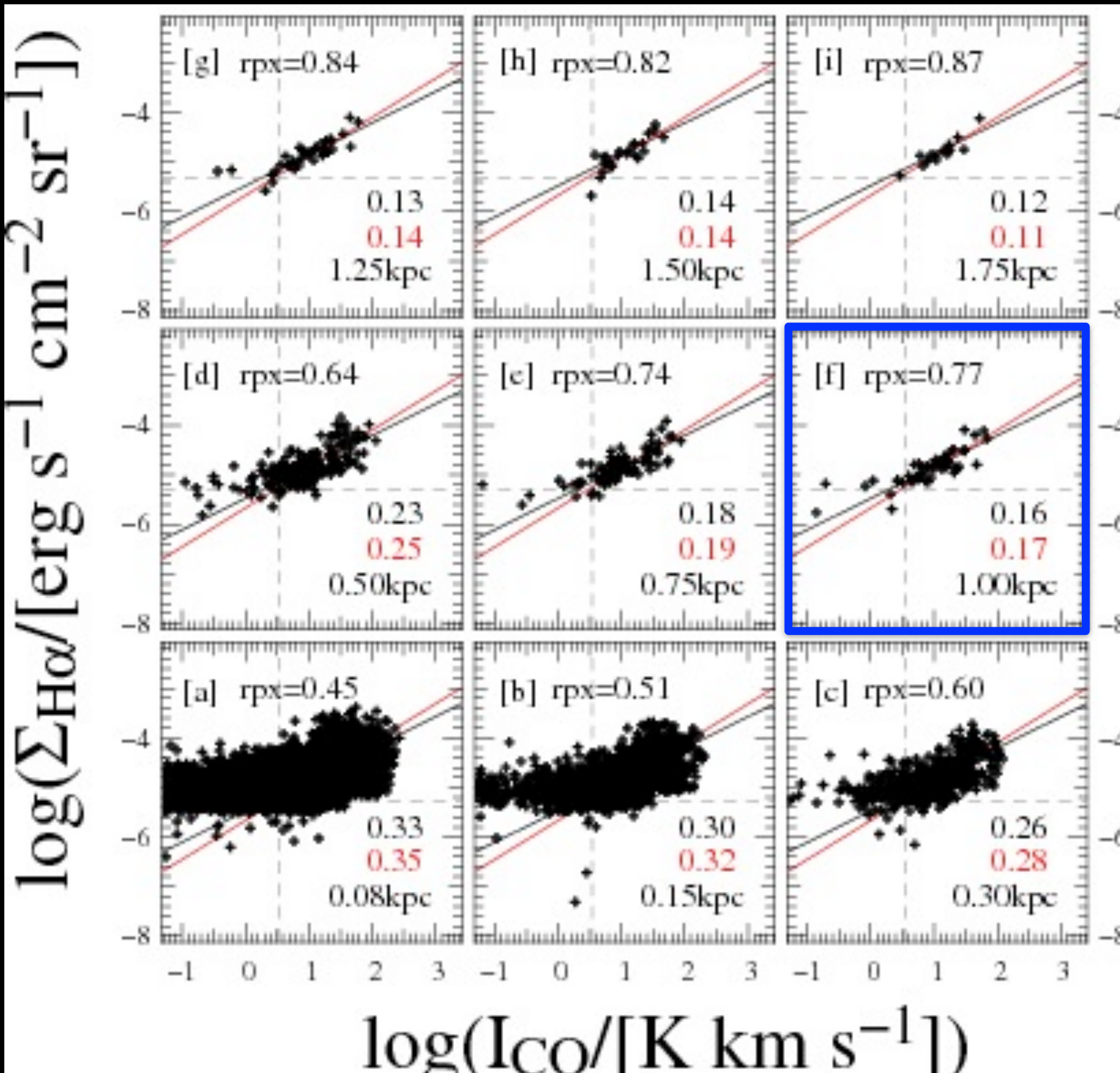
Larson's laws





Region	Total			GMC					
	(1) S	(2) L_{CO}	(3) Σ	(4) L_{CO}^{NX}	(5) L_{CO}^{EX}	(6) $\%^{NX}$	(7) $\%^{EX}$	(8) #	(9) N
	[kpc^2]	[10^7 K km/s pc^2]	$M_\odot$ pc^{-2}	[10^7 K km/s pc^2]					[kpc^{-2}]
Cube	47.00	90.83	84.19	17.81	48.65	19.6	53.6	1507	32.06
NB	1.53	7.48	213.11	1.35	4.01	18.0	53.6	126	82.33
NR	3.15	17.99	248.62	3.37	10.48	18.7	58.2	209	66.28
NS1I	2.36	5.50	101.52	1.09	3.32	19.8	60.2	86	36.40
NS1O	3.46	10.54	132.64	2.12	6.26	20.1	59.4	155	44.78
NS2	2.56	3.50	59.48	0.98	2.38	28.1	68.0	92	35.90
SS1I	2.42	8.21	148.01	1.26	3.98	15.3	48.5	126	52.15
SS1O	3.54	10.13	124.64	2.25	6.01	22.2	59.3	167	47.14
SS2	2.23	5.56	108.88	1.44	3.46	25.9	62.2	103	46.27
DNS	7.74	5.96	33.59	0.85	1.87	14.3	31.3	98	12.67
UNS	5.64	4.54	35.13	0.89	2.11	19.6	46.4	116	20.58
DSS	7.93	6.92	38.04	1.41	2.96	20.4	42.7	135	17.02
USS	4.44	4.45	43.70	0.80	1.83	18.1	41.1	94	21.17

CO & SF tracers in M51



Hughes, Leroy et al., in prep