Dynamically regulated star formation:

the role of gas flows on ISM structure

Sharon E. Meidt (MPIA)

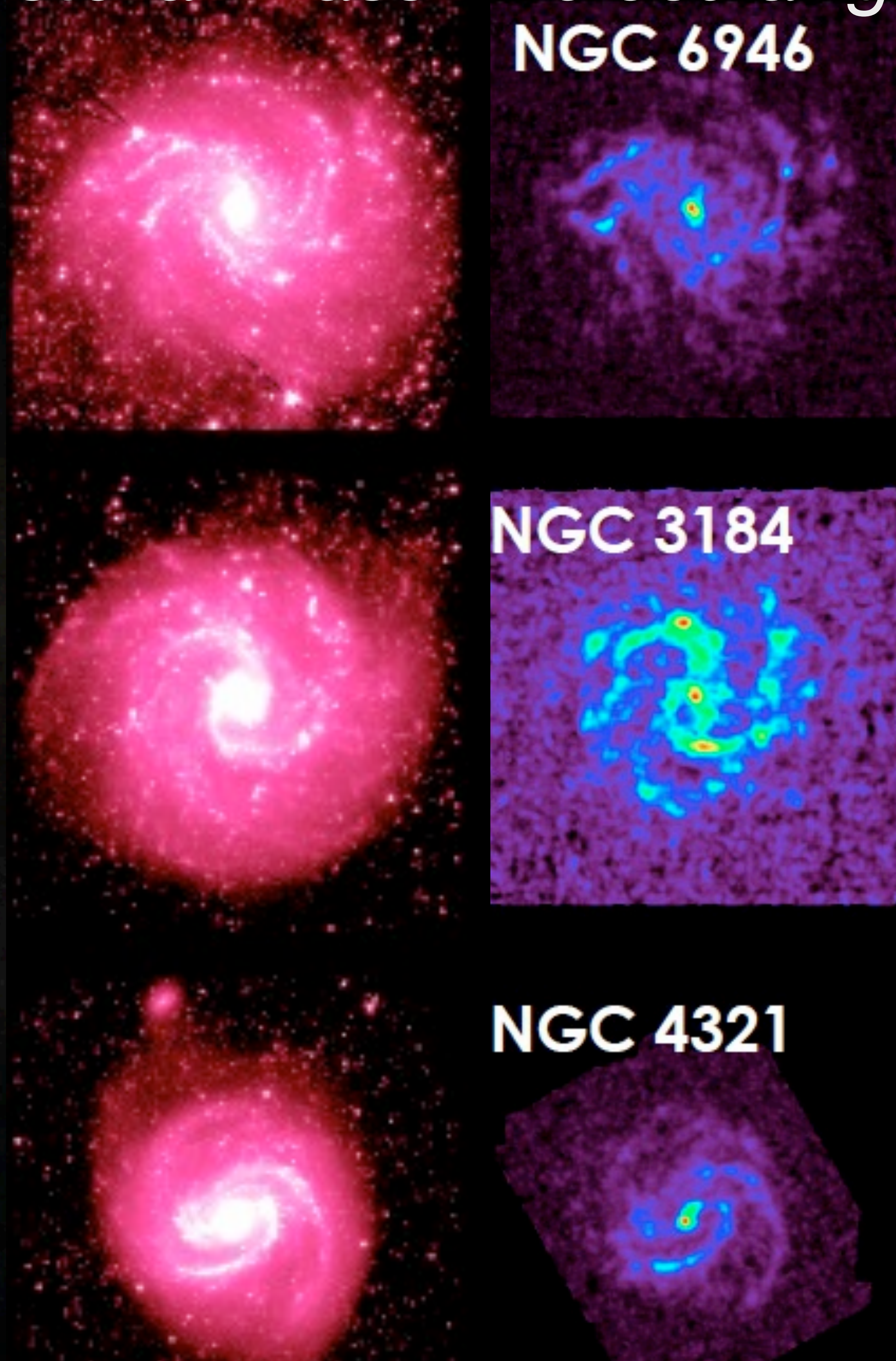
with

A. Hughes, E. Schinnerer, S. Garcia-Burillo, D. Colombo, C. Dobbs, A. Leroy, C. Kramer, K. Schuster, G. Dumas, T. Thompson

Max-Planck-Institut für Astronomie Heidelberg
Max Planck Institute for Astronomy Heidelberg

PAWS
PdBI Arcsecond Whirlpool Survey

stellar mass *molecular gas*



SINGS

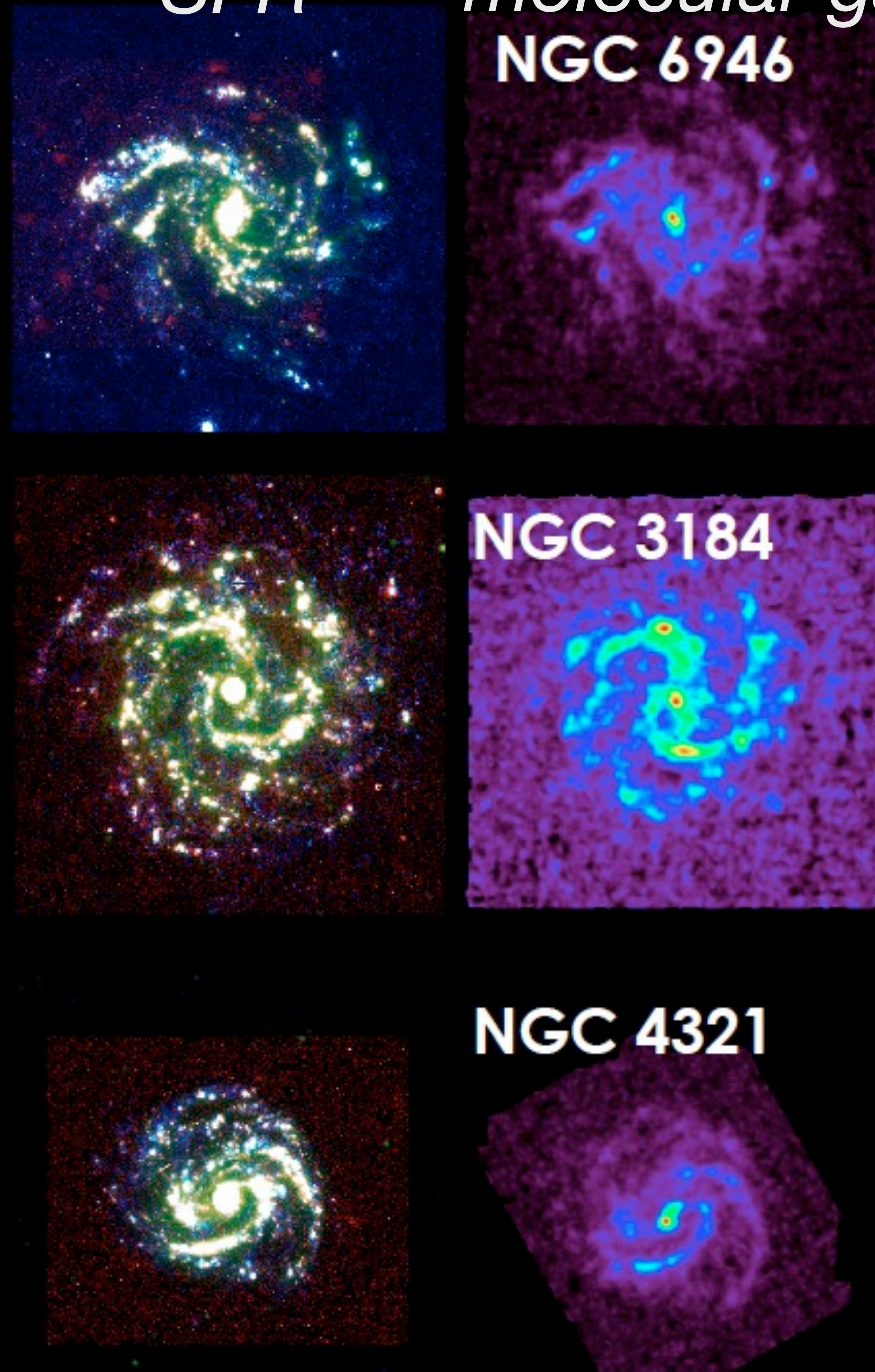
Kennicutt et al. (2003)

HERACLES

Leroy et al. (2008)

slide following A. Leroy

SFR *molecular gas*



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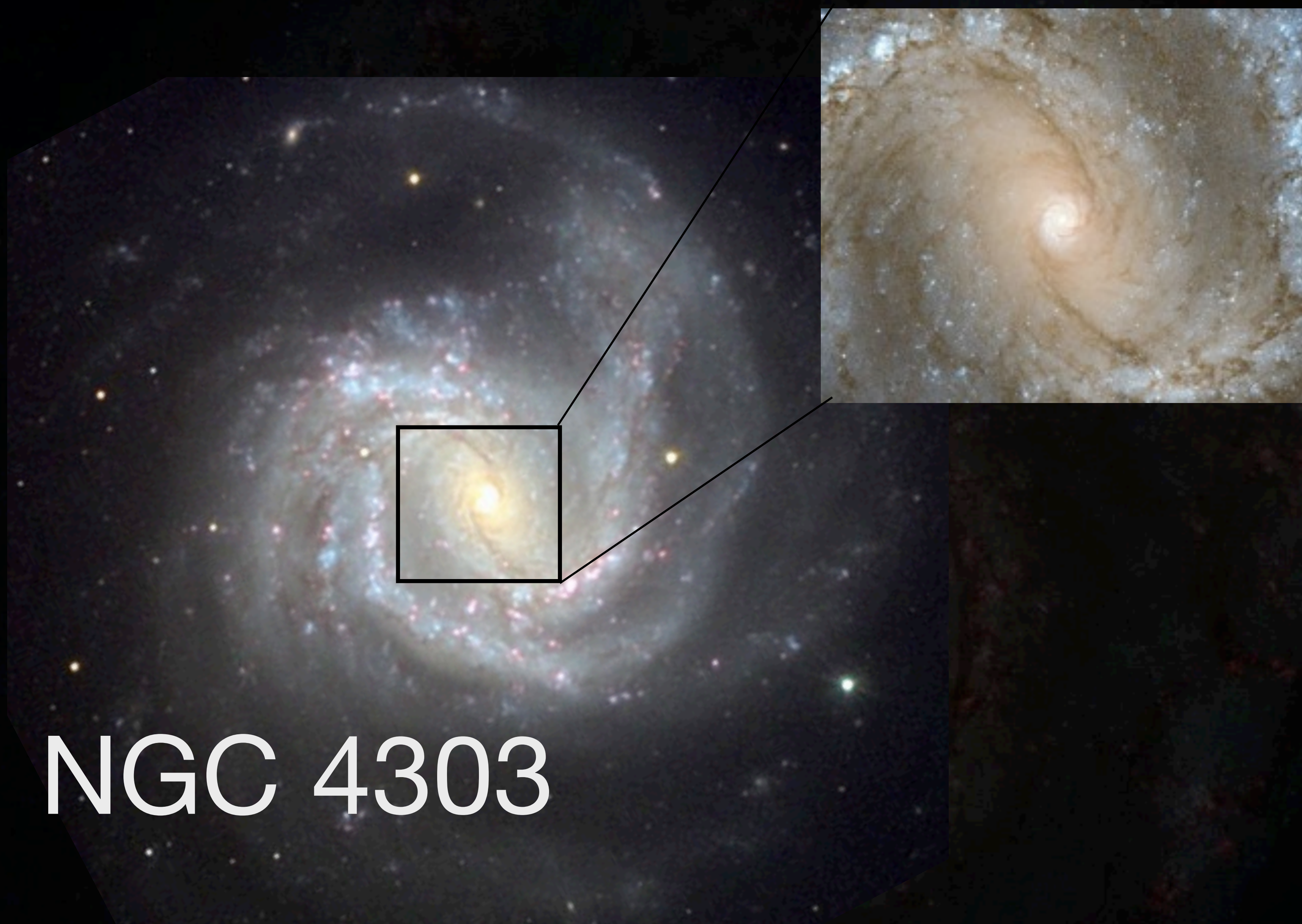
high gas surface density, little star formation



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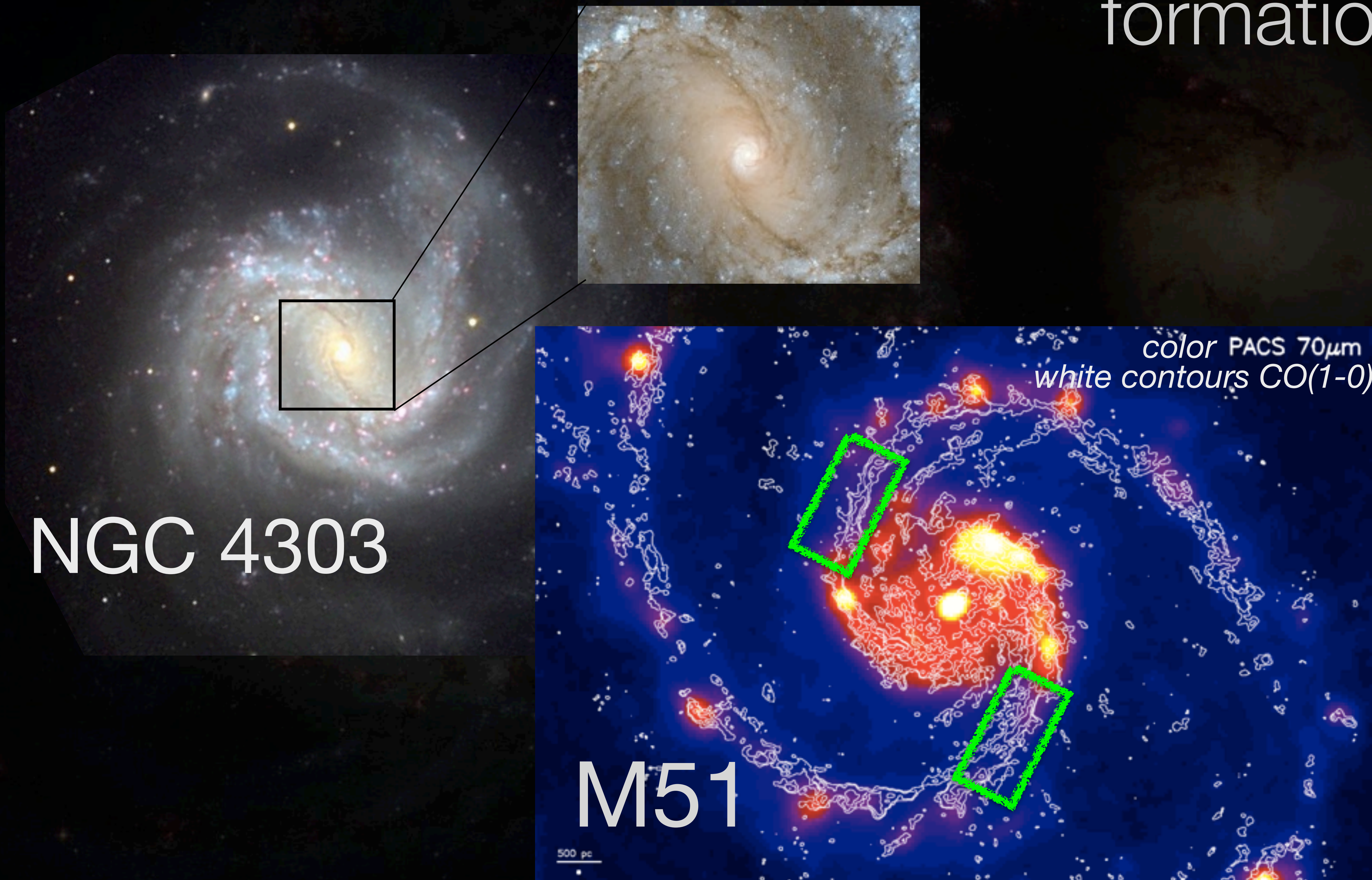
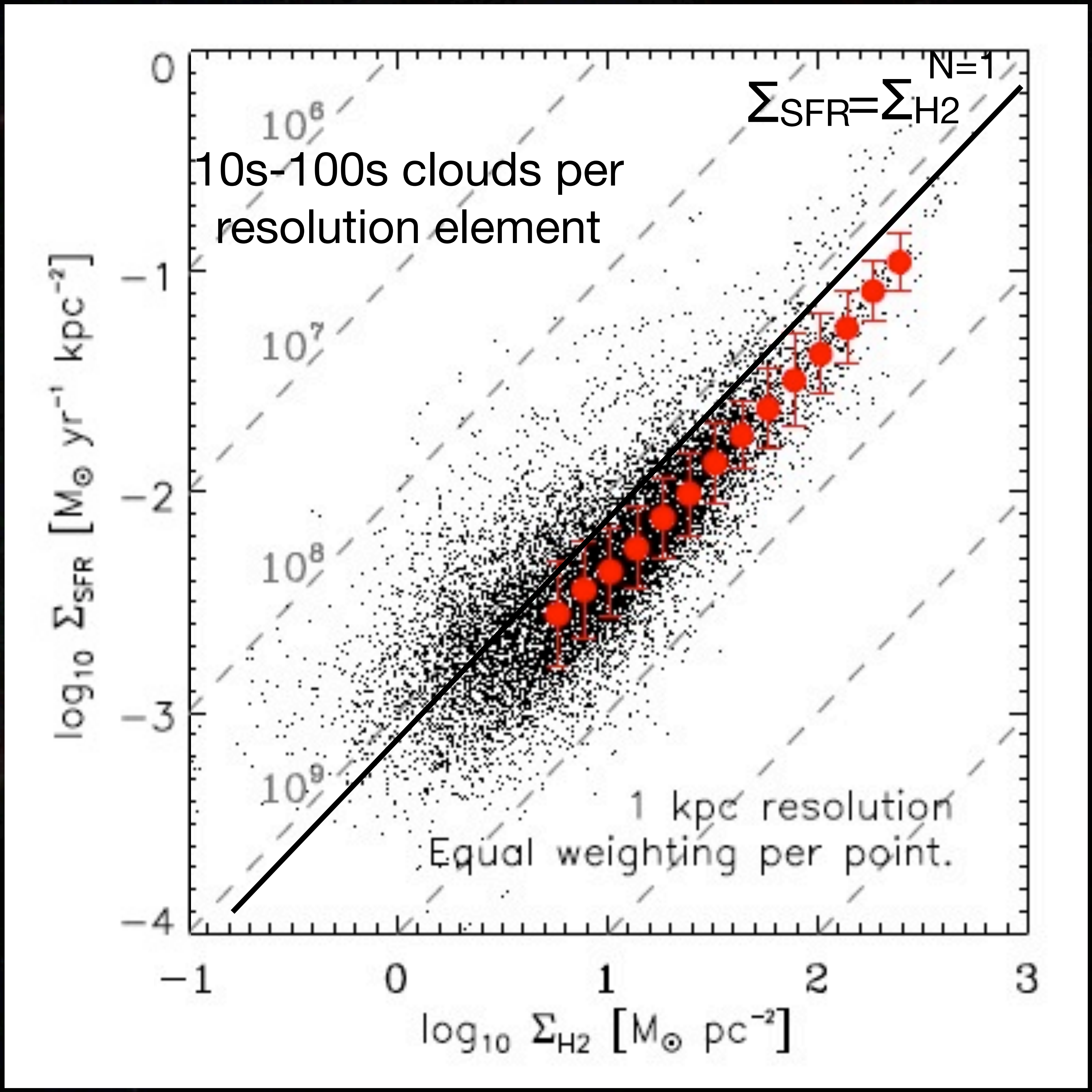


spatially-resolved star formation relation

Bigiel et al. (2008;2011)



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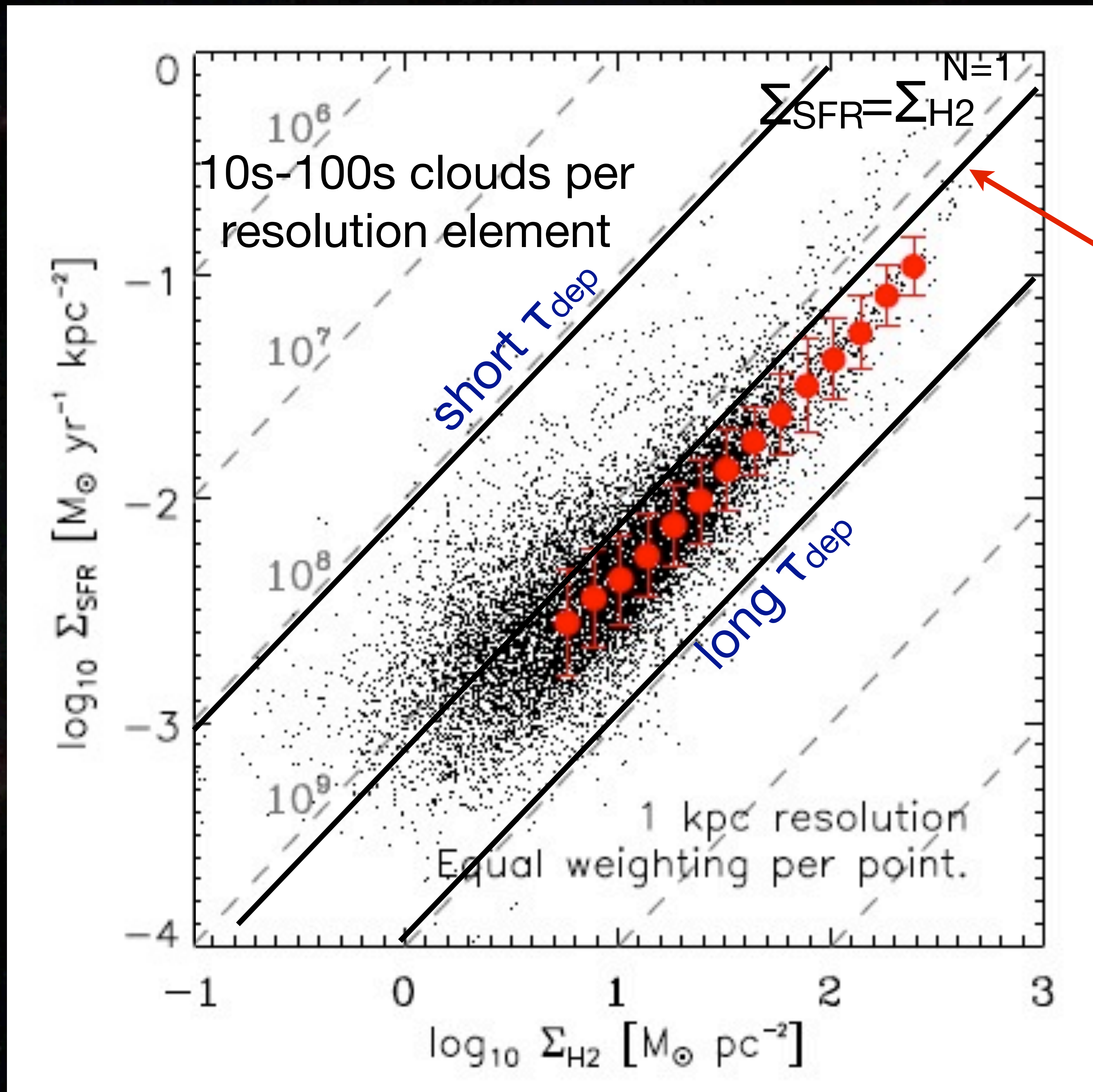

constant
molecular gas depletion time
$\tau_{dep} = \Sigma_{H2} / \Sigma_{SFR}$

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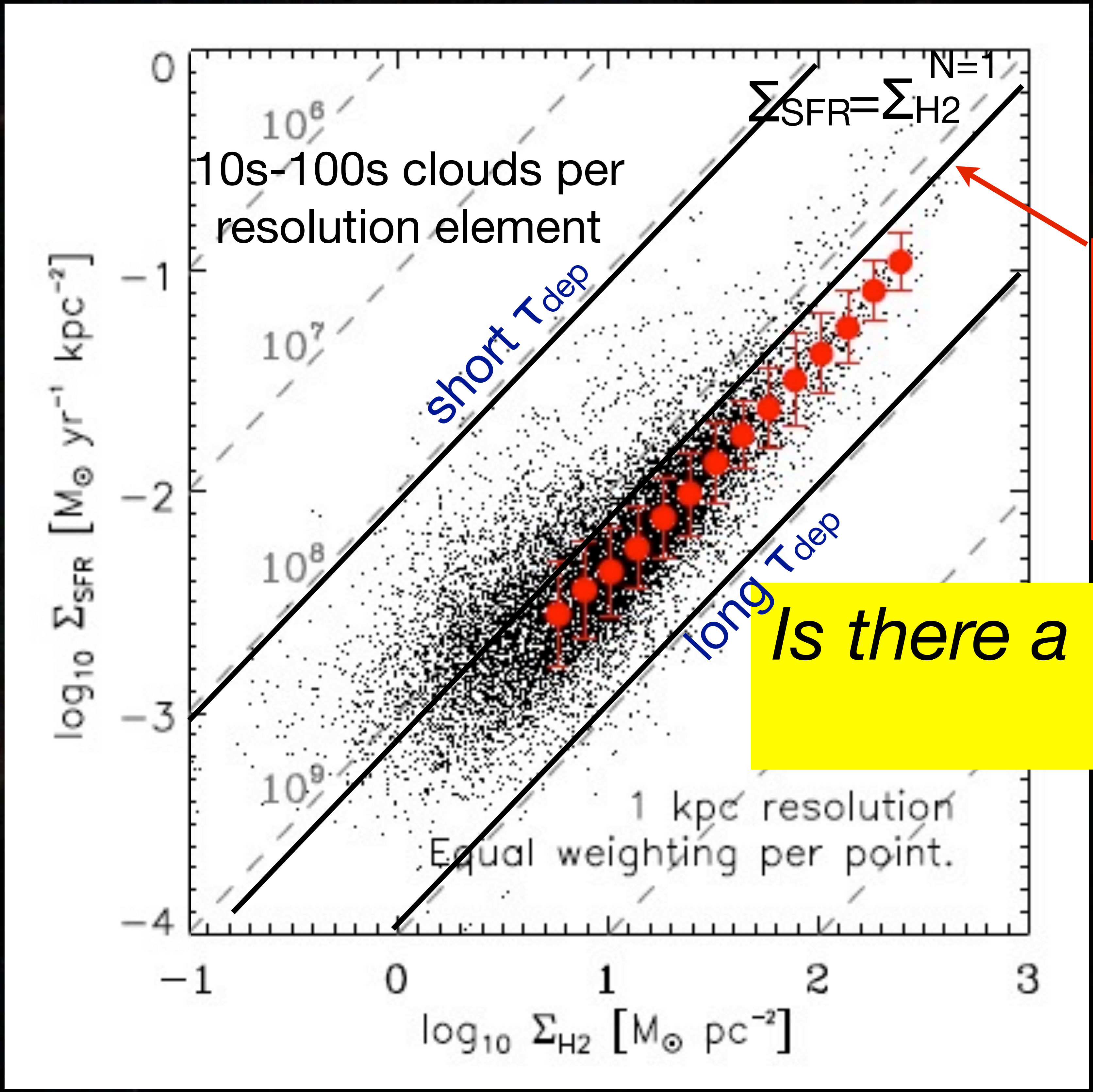

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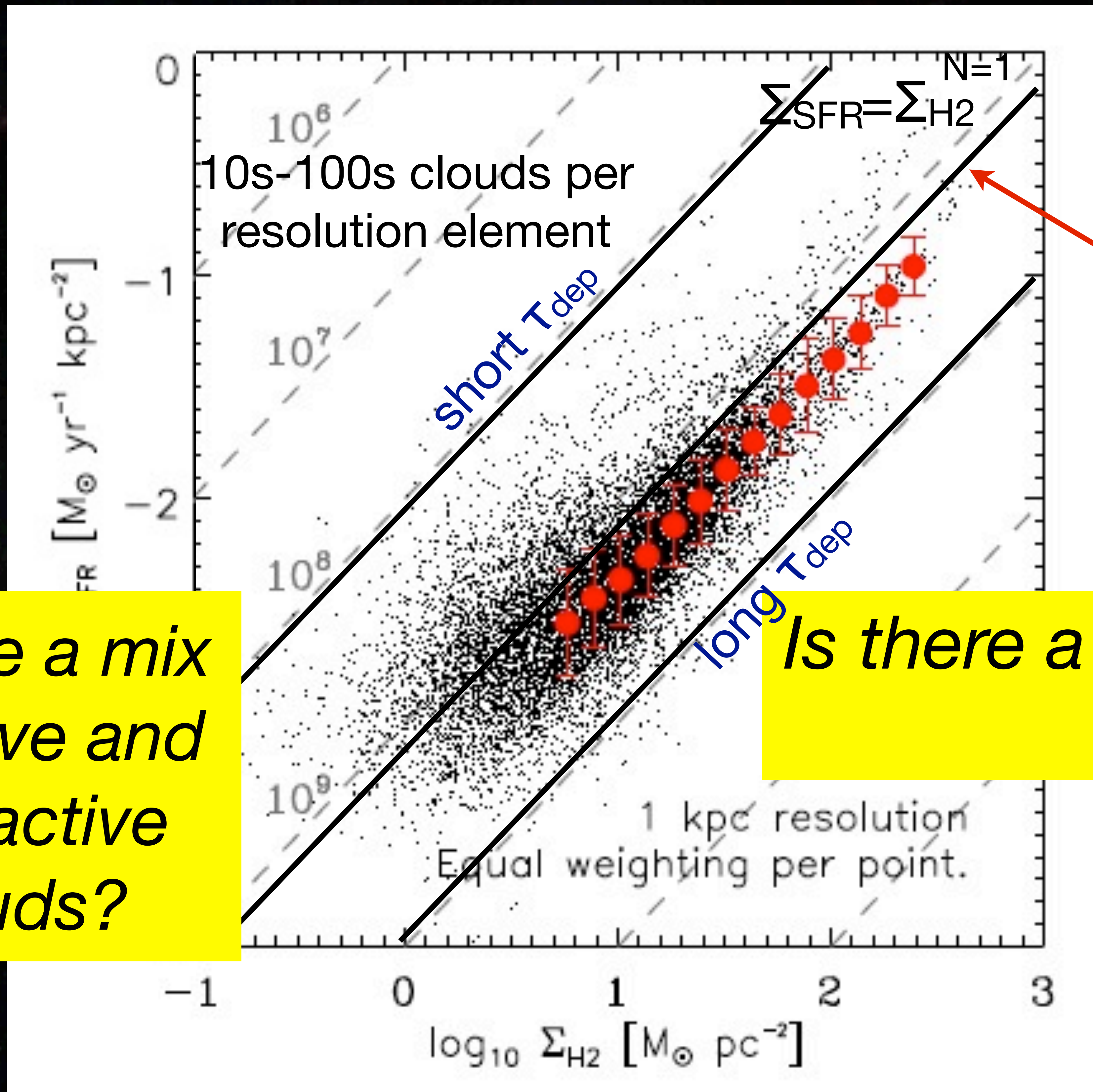
Is there a 'universal cloud'?

cloud scaling relations

spatially-resolved star formation relation

Bigiel et al. (2008;2011)



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is there a mix of active and non-active clouds?

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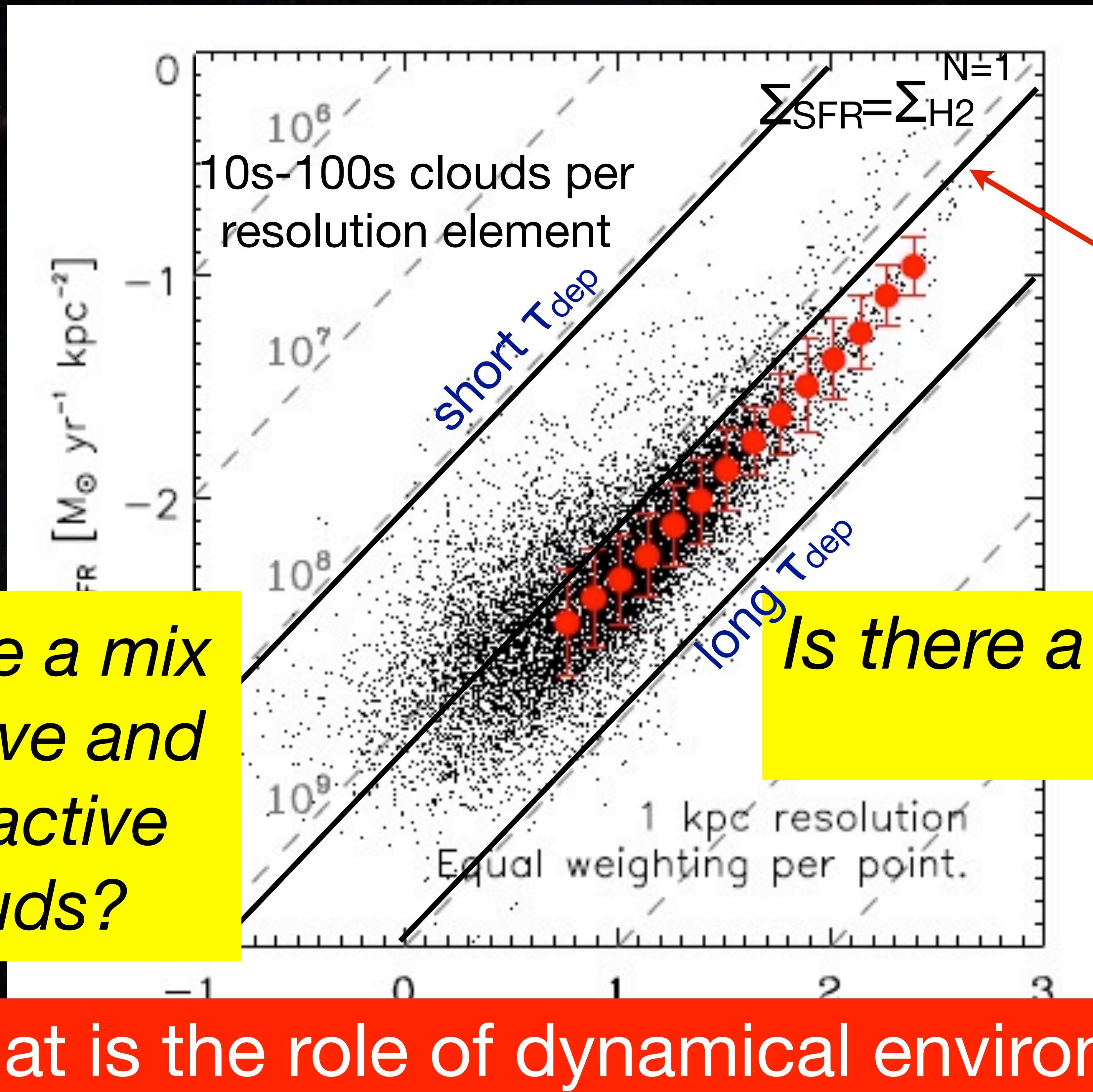

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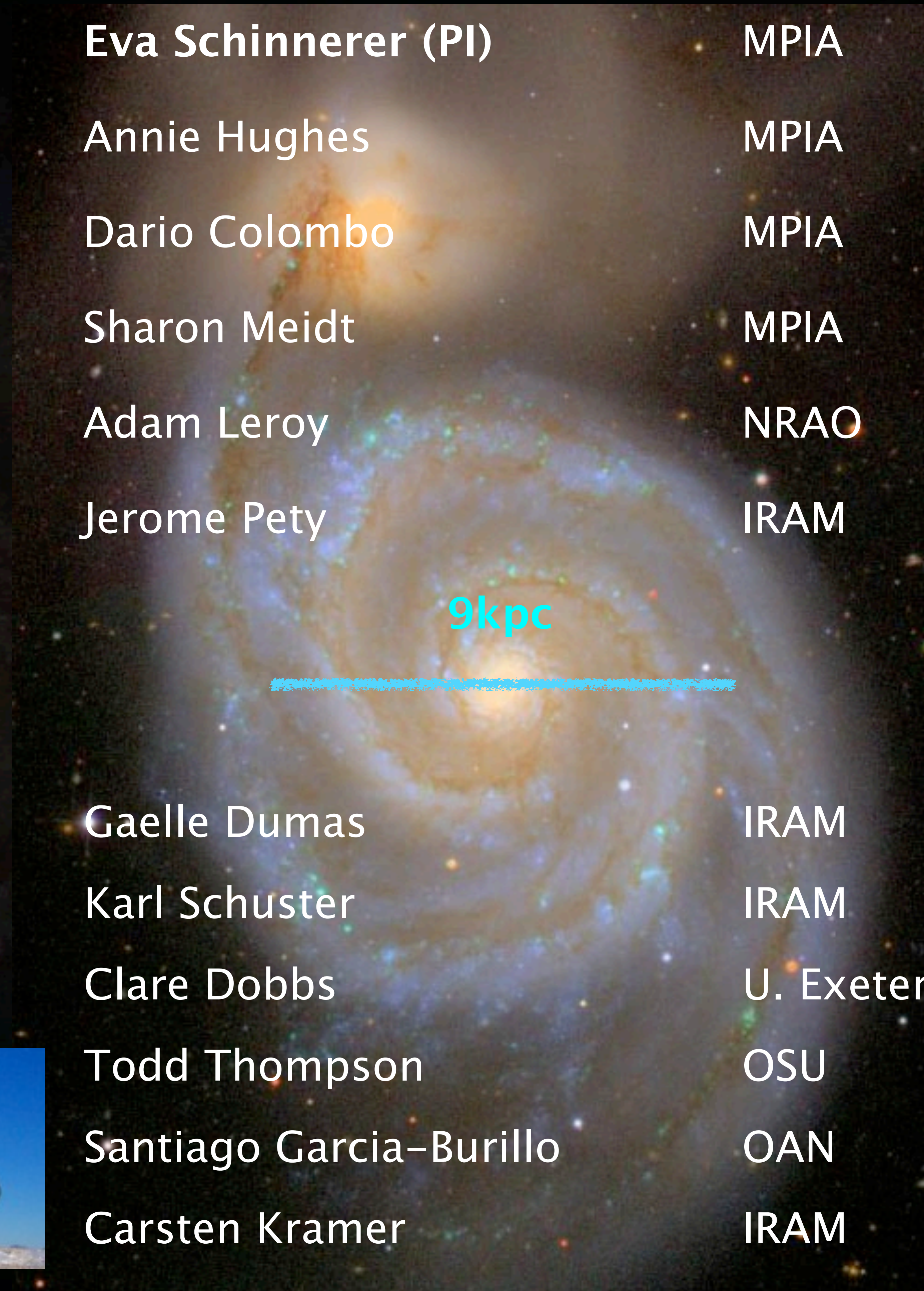
cloud scaling relations

what is the role of dynamical environment?

CO(1-0) in central 9kpc at
GMC resolution (40pc, $10^5 M_{sun}$)

IRAM
30m: 40 hr
PdBI: 170 hr



Eva Schinnerer (PI)	MPIA
Annie Hughes	MPIA
Dario Colombo	MPIA
Sharon Meidt	MPIA
Adam Leroy	NRAO
Jerome Pety	IRAM
Gaelle Dumas	IRAM
Karl Schuster	IRAM
Clare Dobbs	U. Exeter
Todd Thompson	OSU
Santiago Garcia-Burillo	OAN
Carsten Kramer	IRAM

PAWS: Highest resolution map of M51

PAWS (PI:Schinnerer)

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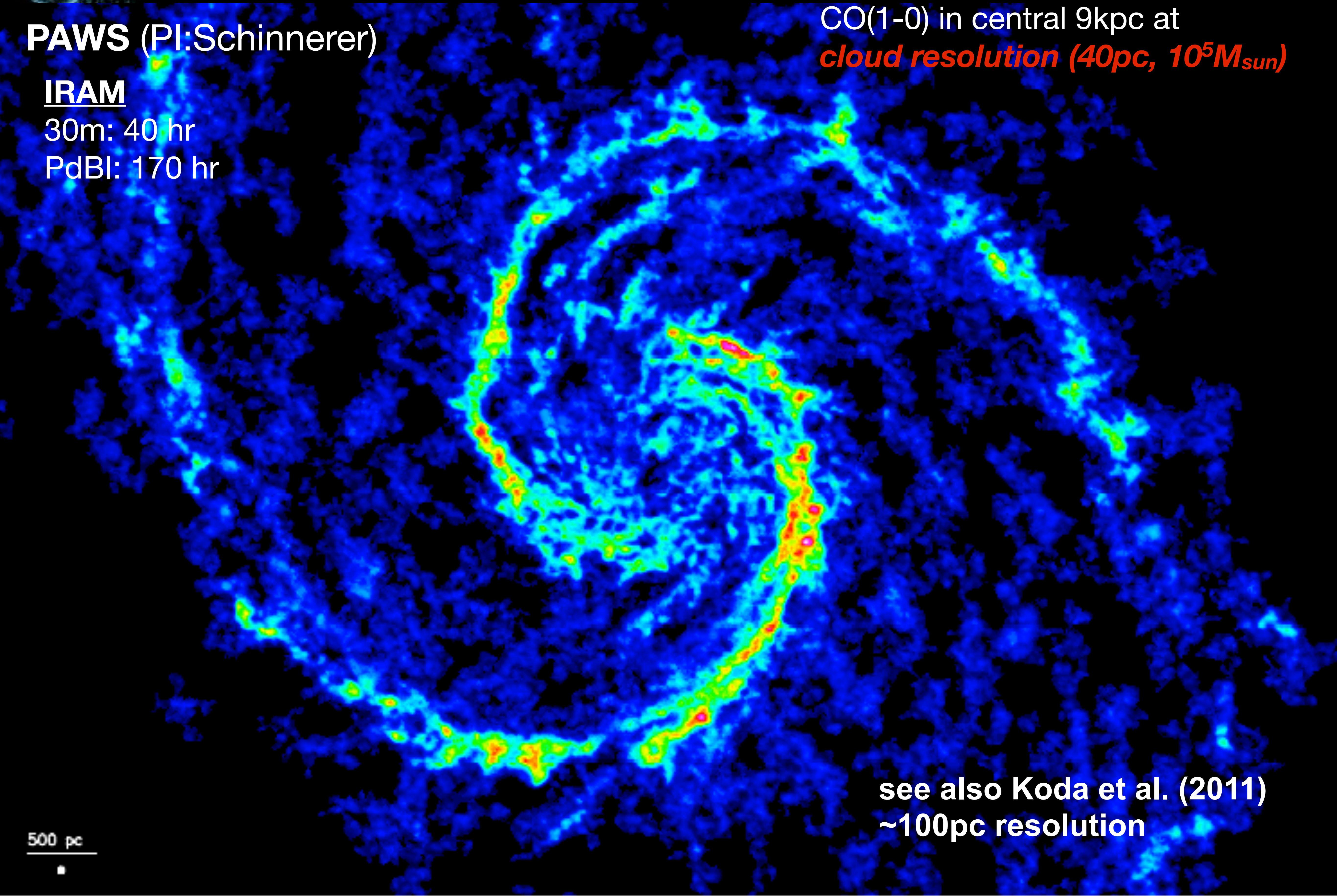
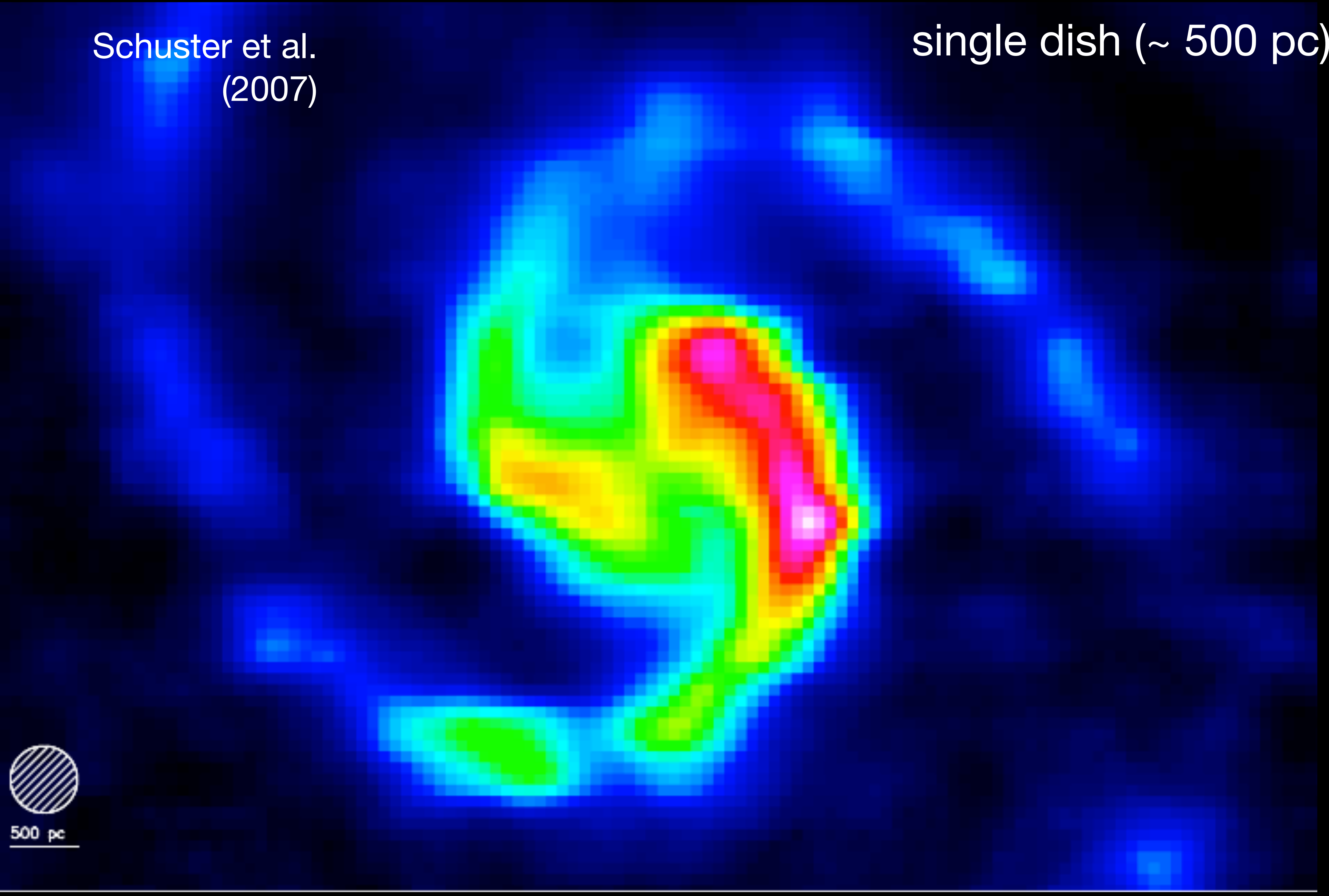


see also Koda et al. (2011)

~100pc resolution

Molecular Gas disk of M51



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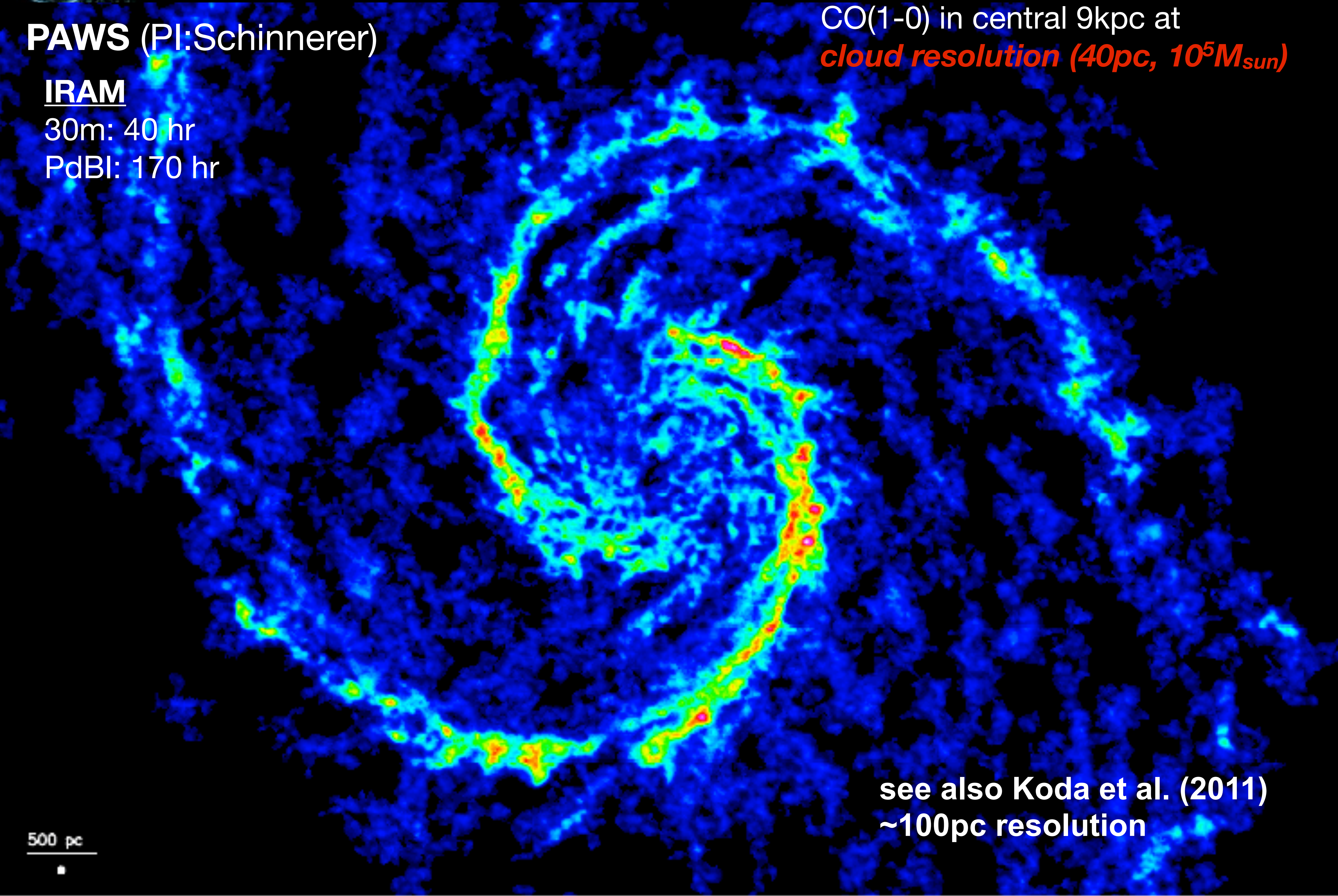

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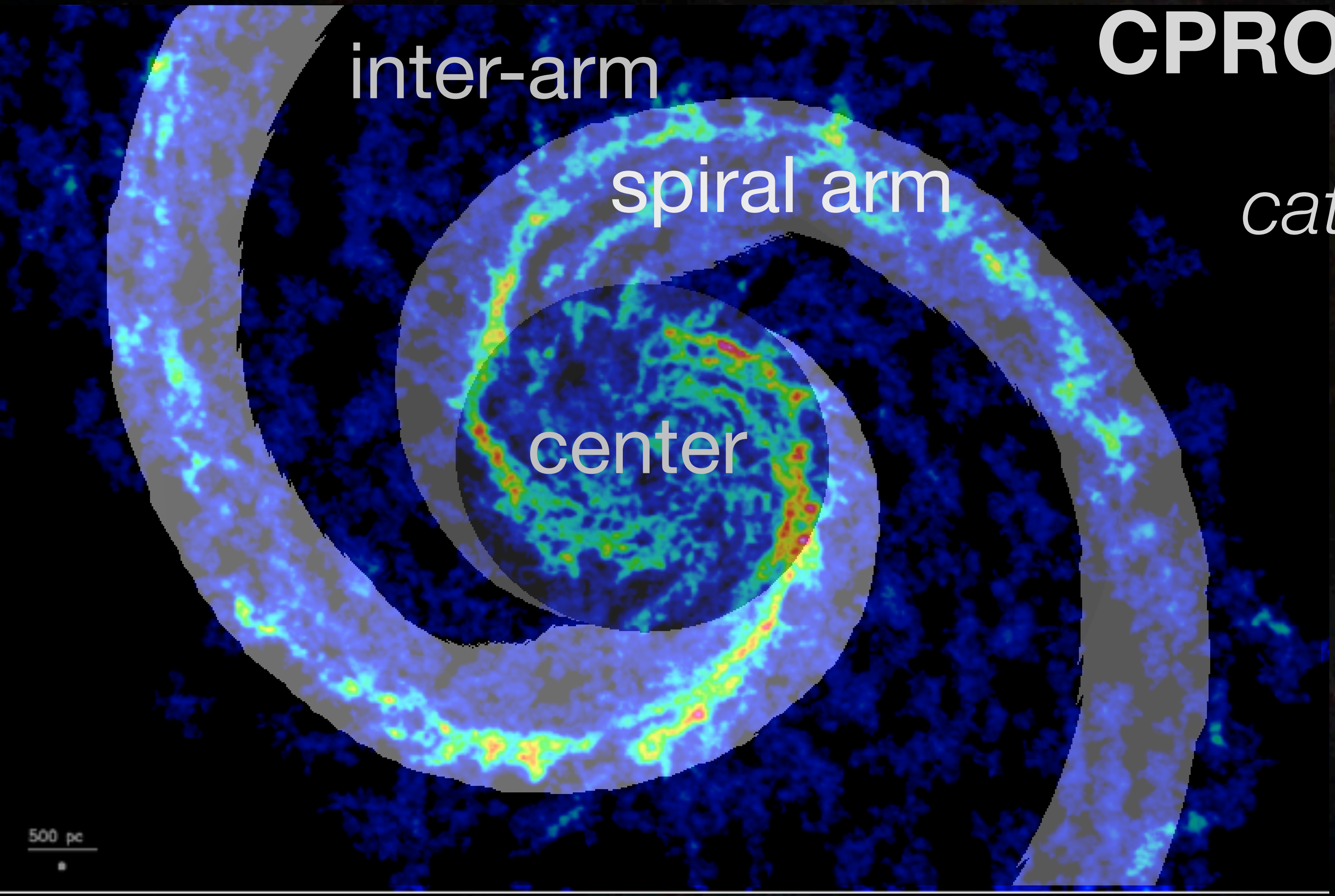
cloud properties depend on environment!

PAWS

Hughes, Meidt et al. (2013a)
Colombo et al. (2014a)



CPROPS decomposition

Rosolowsky & Leroy (2006)

catalog of >1000 clouds!

PdBI Arcsecond Whirlpool Survey

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PAWS

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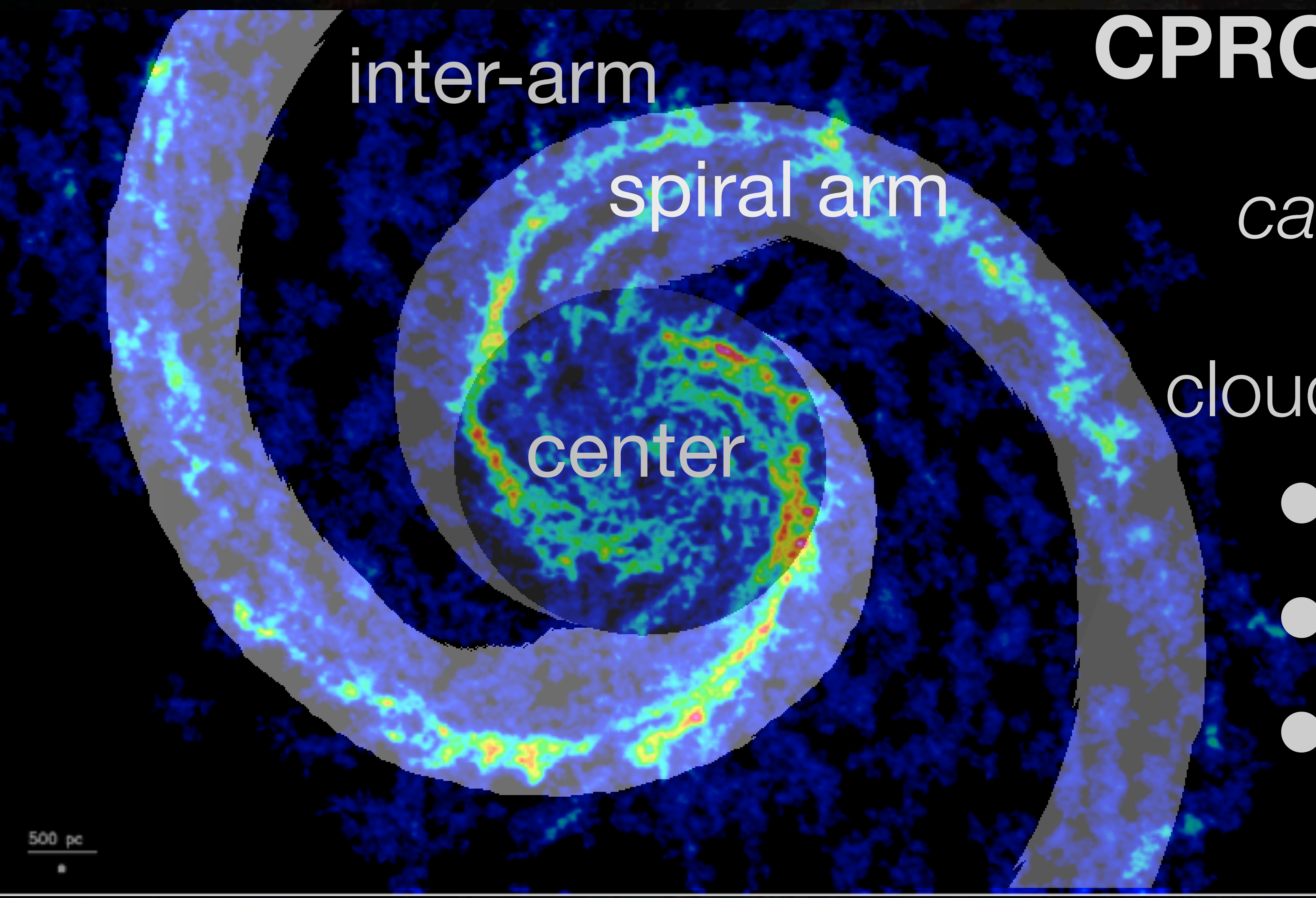


CPROPS decomposition

Rosolowsky & Leroy (2006)

catalog of >1000 clouds!

clouds in **ARM** are

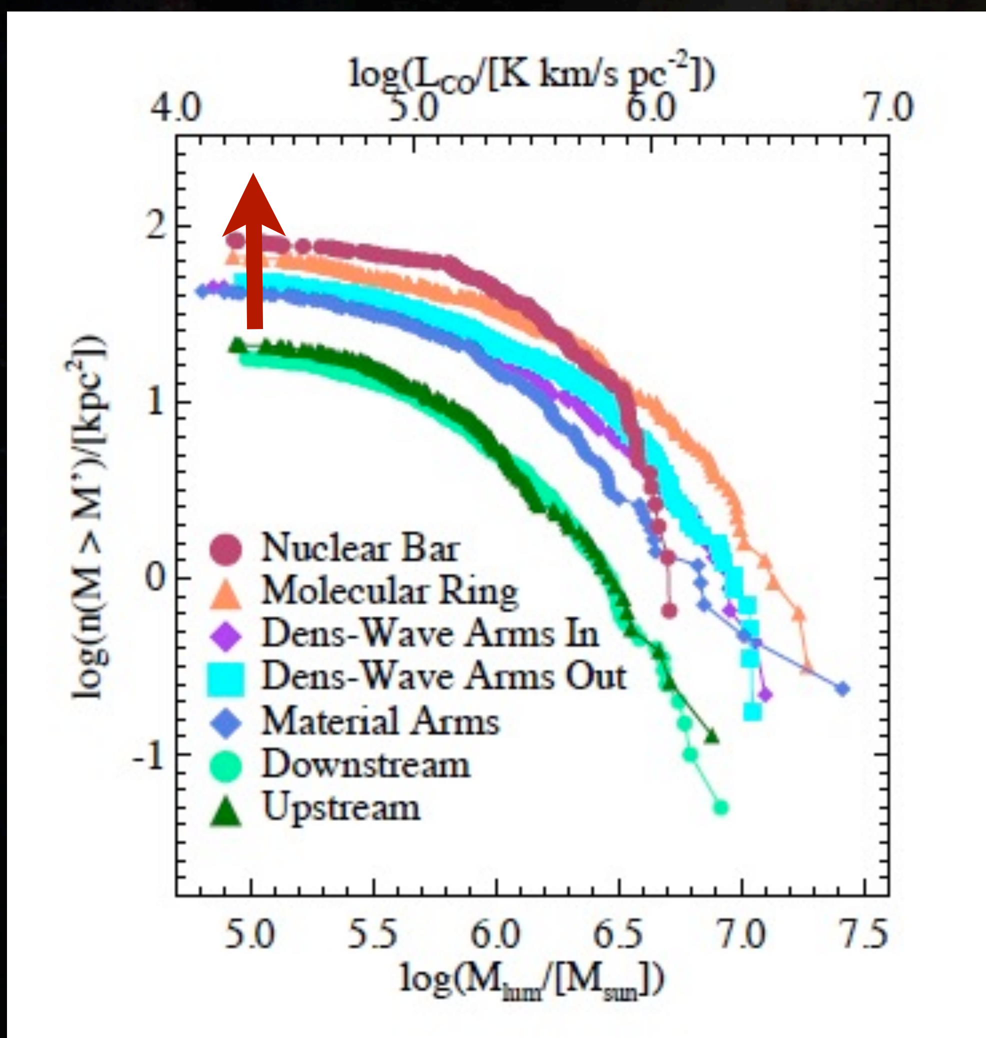
- **brighter,**
- **more massive,**
- **higher gas surface density**

compared to **inter-ARM**

PAWS
PdBI Arcsecond Whirlpool Survey

cloud properties depend on environment! *the role of spiral arms*

Colombo et al. (2014a)



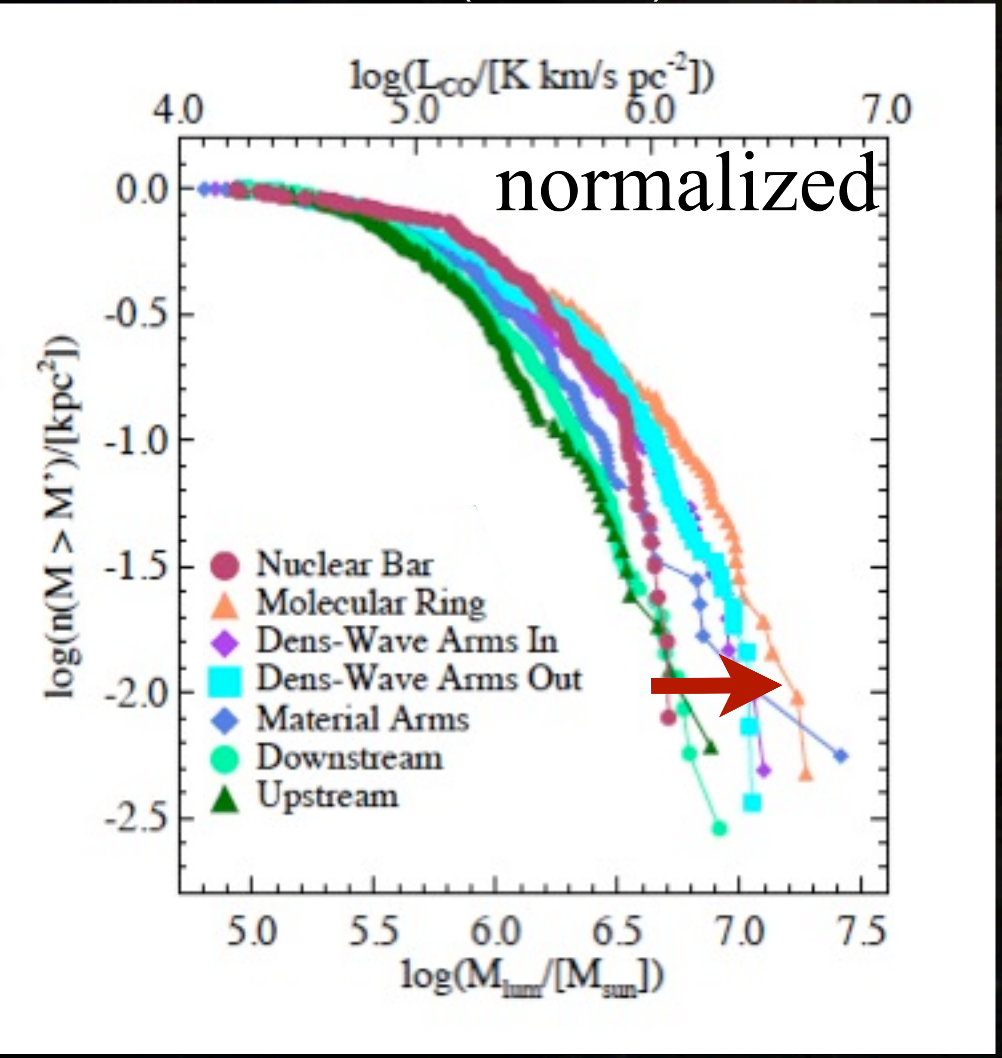
mass spectrum: formation/destruction

spiral arms sweep up material, aid in

-formation via instability ***number***

cloud properties depend on environment! *the role of spiral arms*

Colombo et al. (2014a)



mass spectrum: formation/destruction

spiral arms sweep up material, aid in

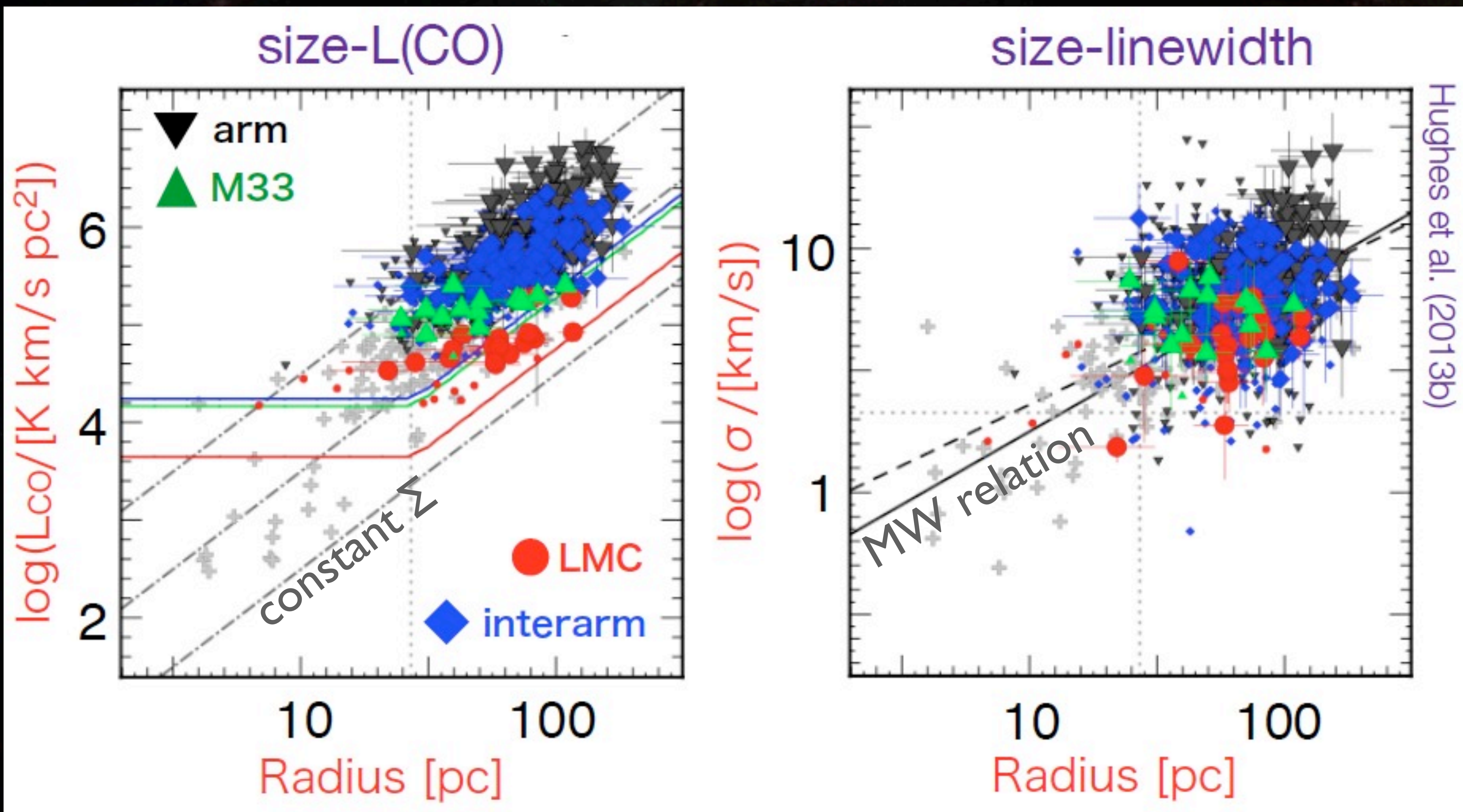
-formation via instability ***number***

-cloud mass growth via collision/ agglomeration ***high mass end***

clouds destroyed via shear and feedback in interarm

PdBI Arcsecond Whirlpool Survey

cloud properties depend on environment! *cloud 'scaling relations'*



Hughes, Meidt et al. (2013a)

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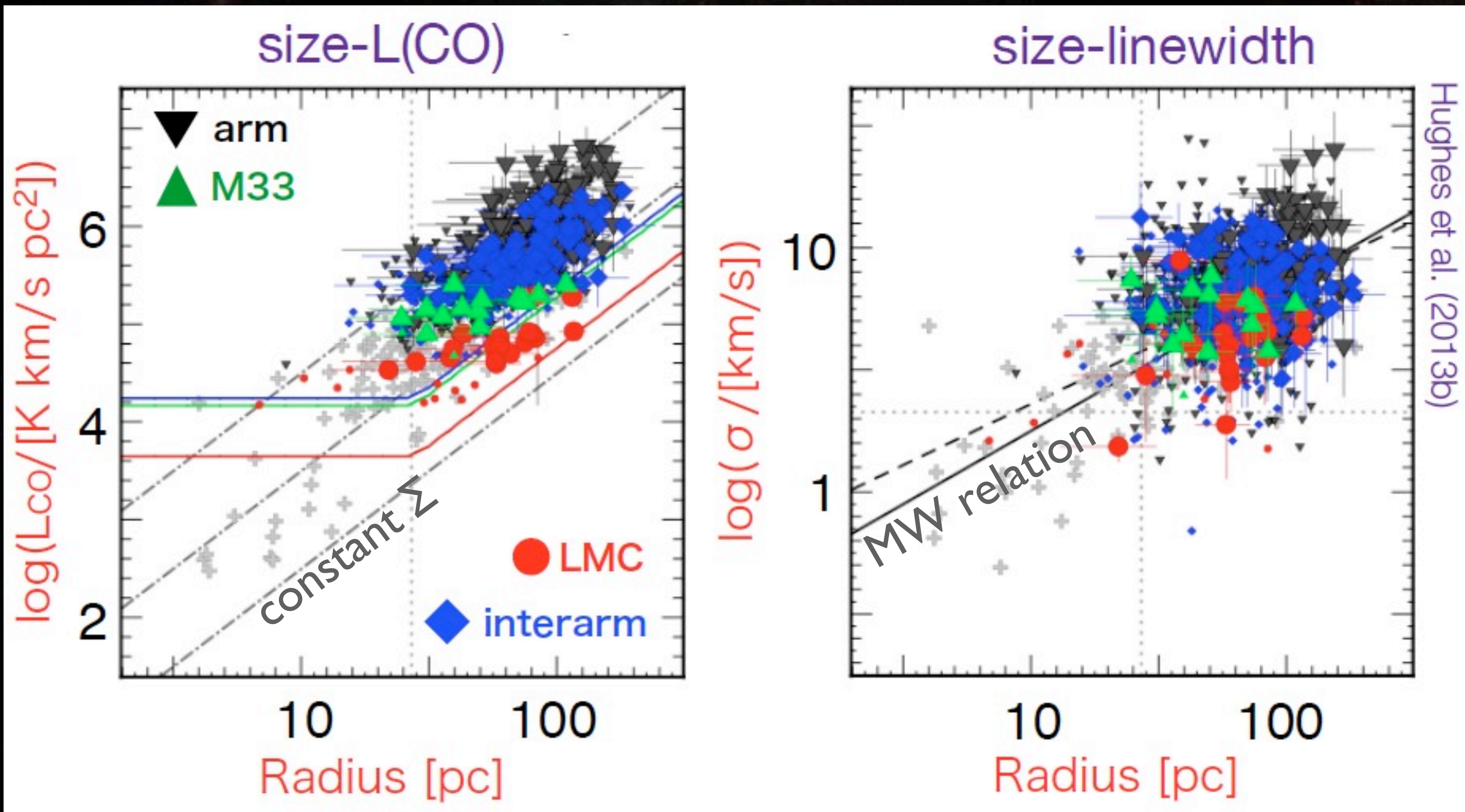
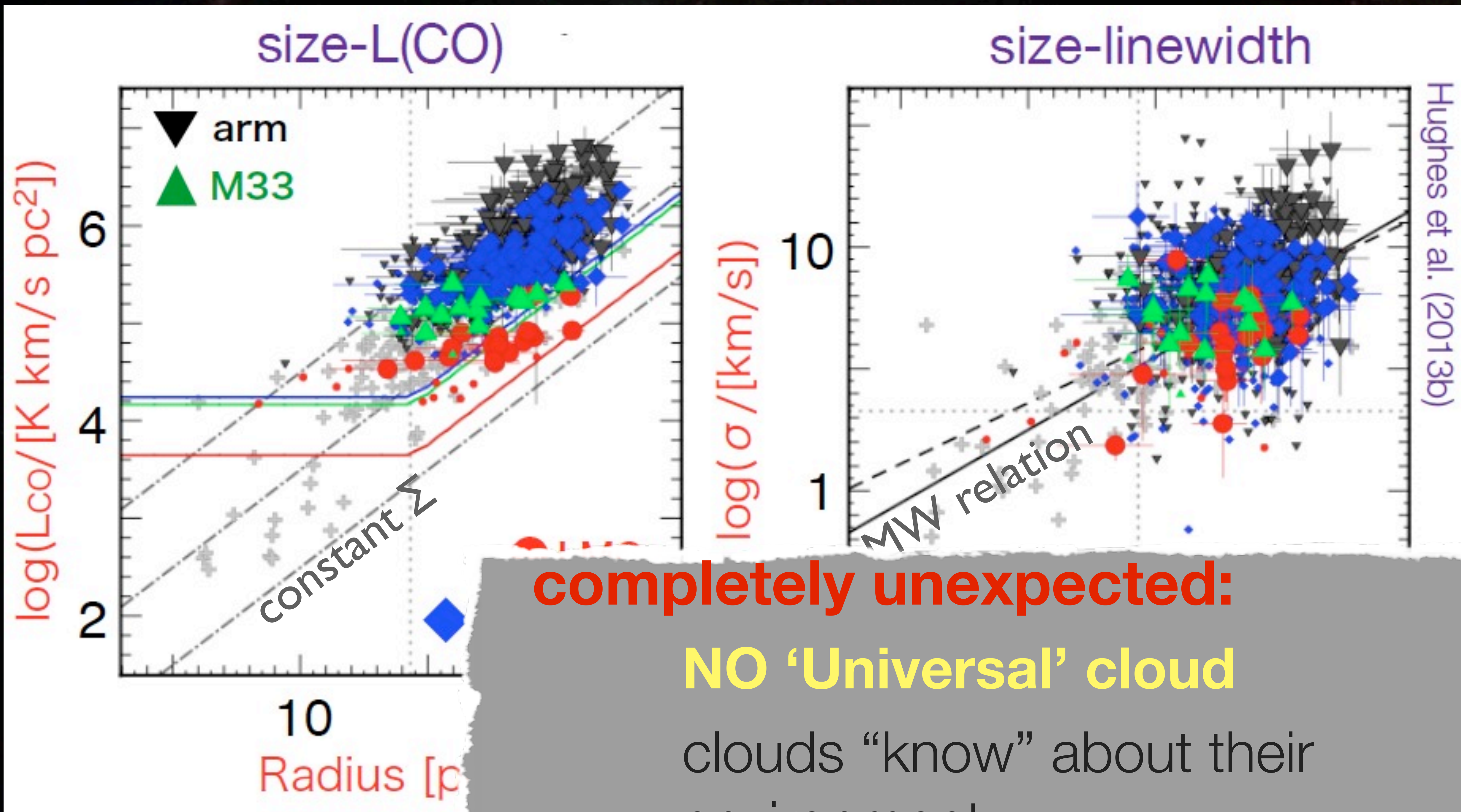


Hughe

Σ and <σ>/R vary with galactic environment

cloud properties depend on environment! *cloud ‘scaling relations’*



completely unexpected:

NO ‘Universal’ cloud

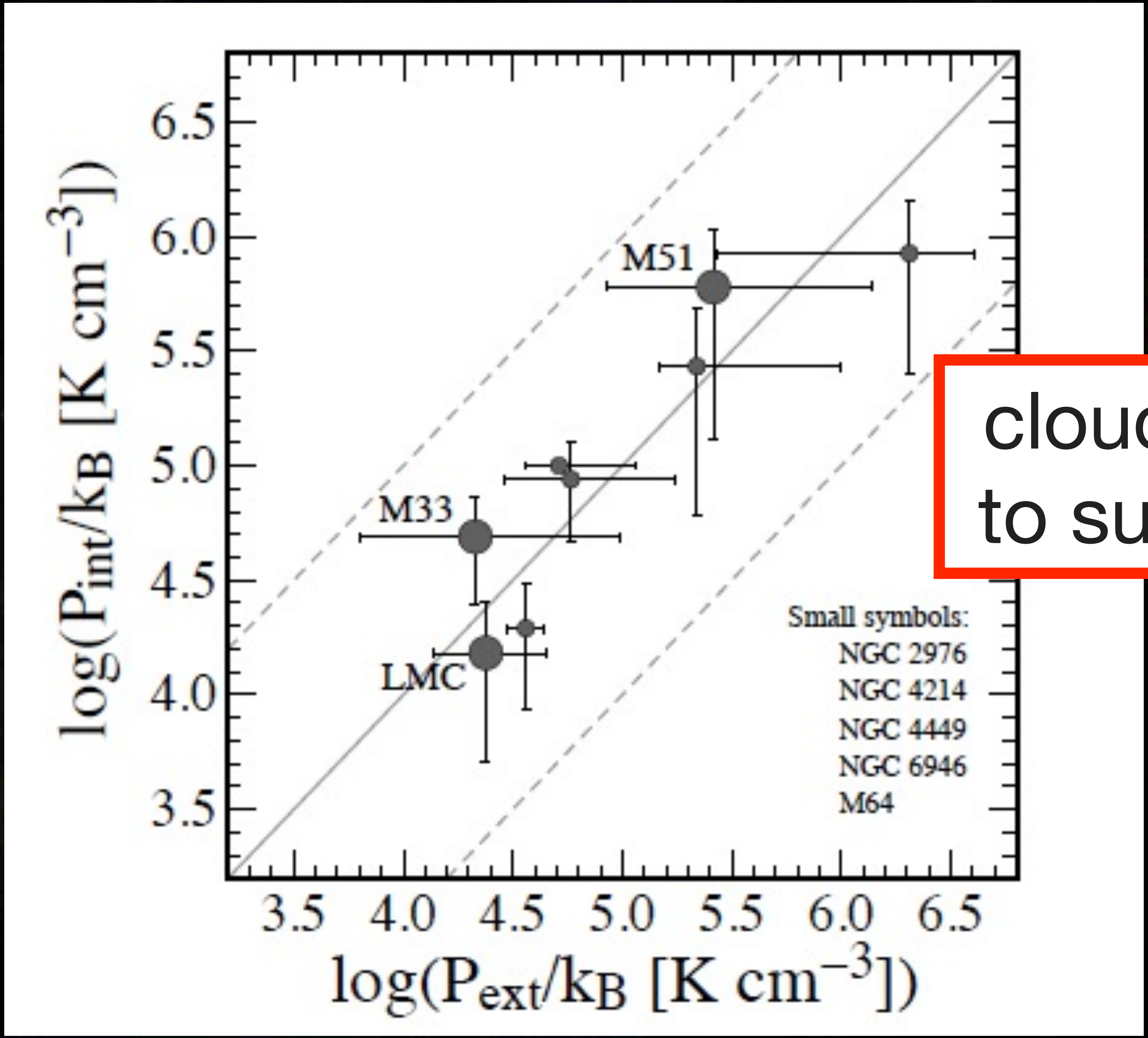
clouds “know” about their environment

Hughe

Σ and <σ>/R vary with galactic environment

Role of External Pressure

Hughes, Meidt et al. (2013a)



clouds coupled to surroundings

***KEY:** surface pressure important!*

Impact of (dynamical) environment

Impact of (dynamical) environment

- **dynamical suppression/regulation of star formation** *via pressure changes in flows*
  - test: M51 cloud stability, pressure + gas motions
  - implications for universal SF relation

Role of gas flows:

not all gas forms stars equally:
disk structures drive gas **flows**

gas flows REDUCE external pressure,
increase cloud stability

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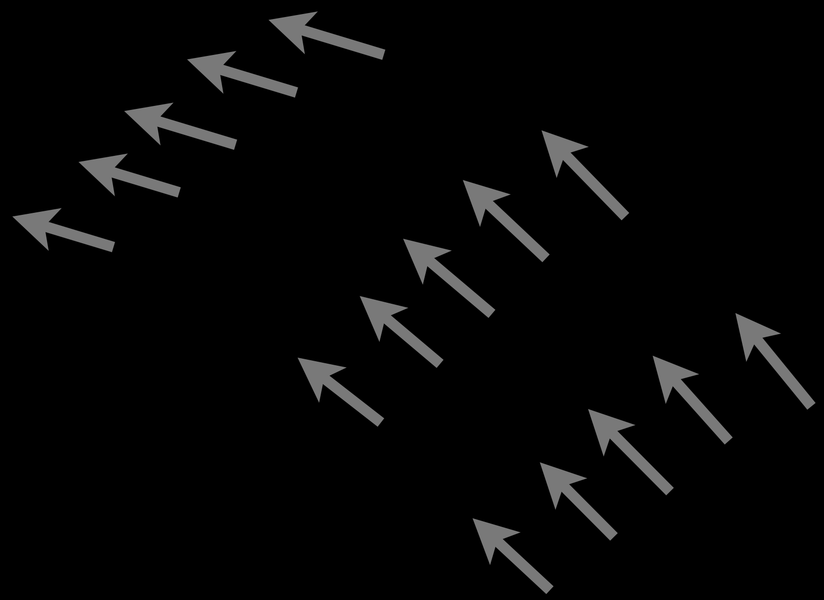
RESULT:

lower star formation rate, increase in gas depletion time

dynamical pressure

Meidt et al. (2013)



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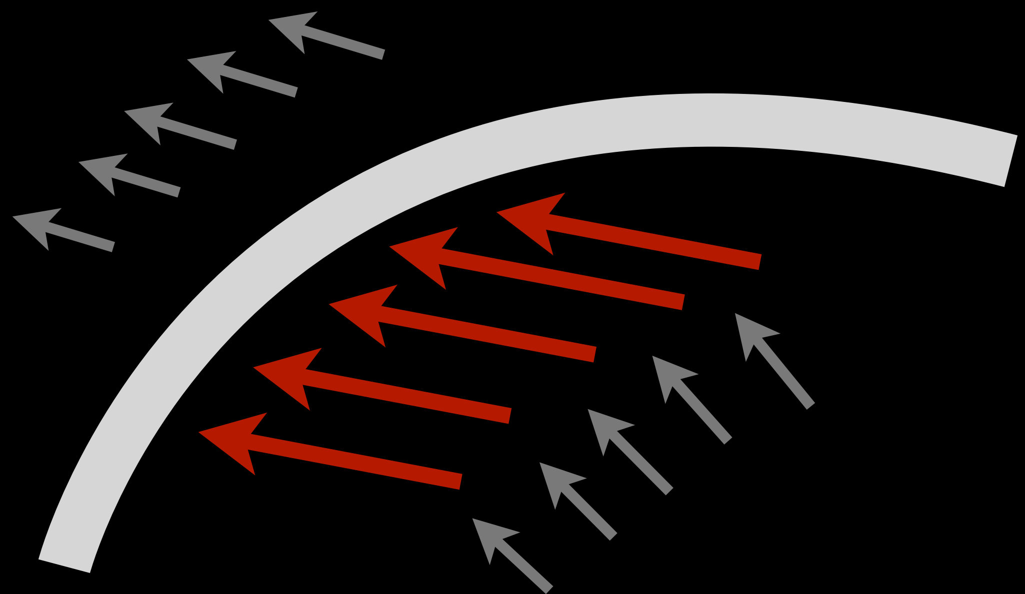

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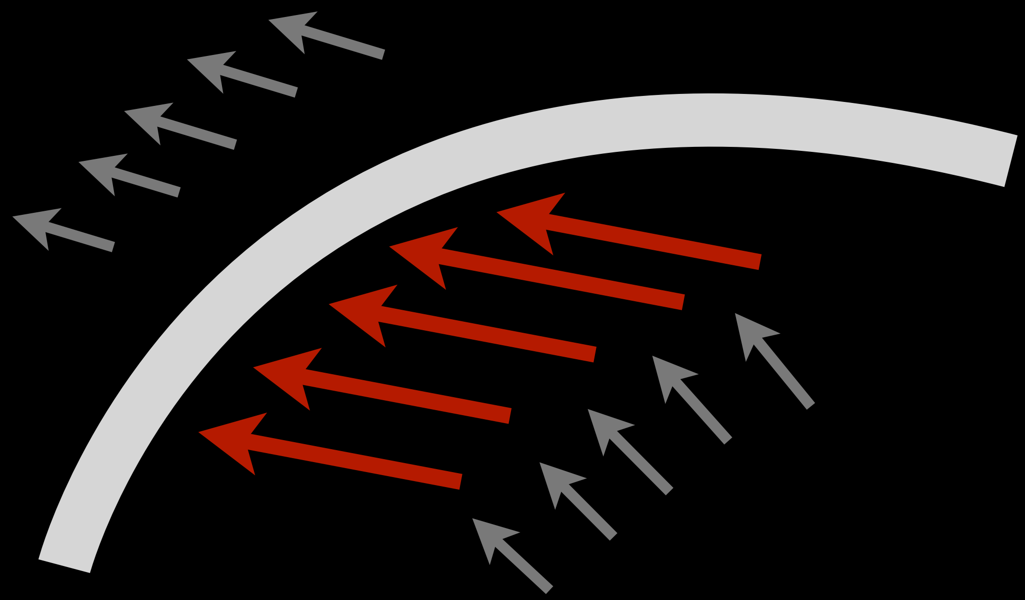
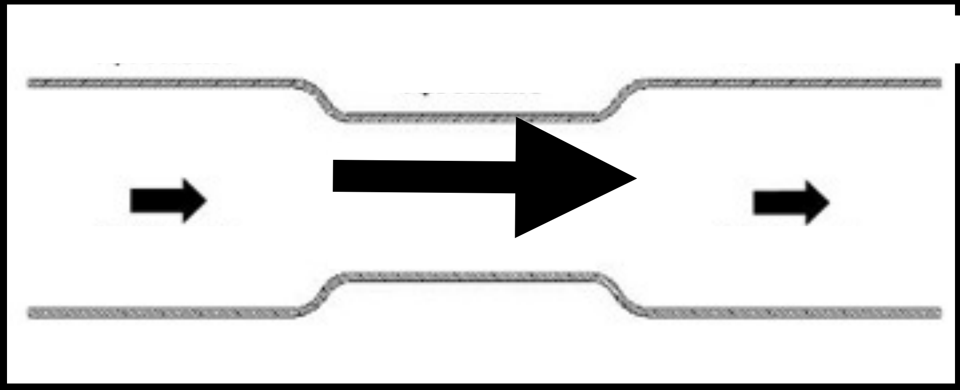


- *Bernoulli*: **gas in motion, reduced pressure**



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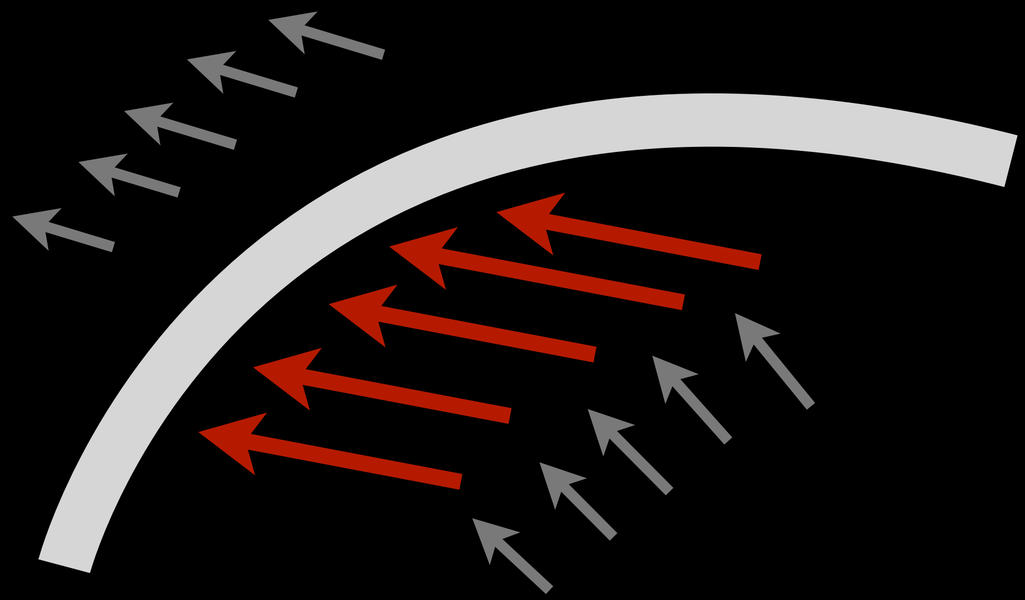
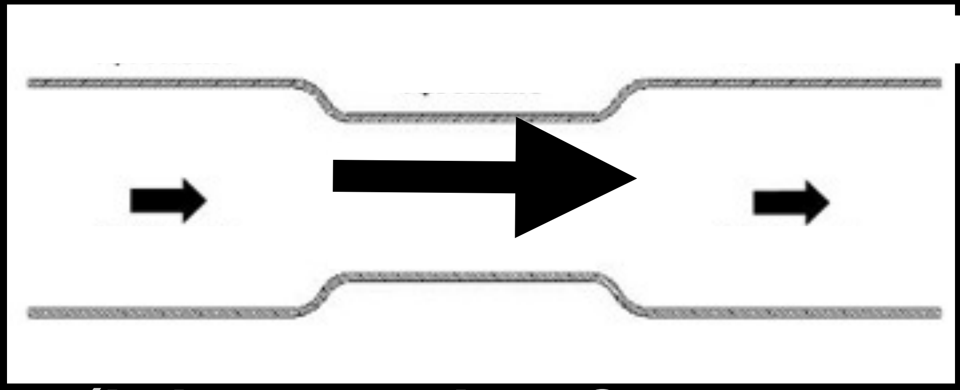
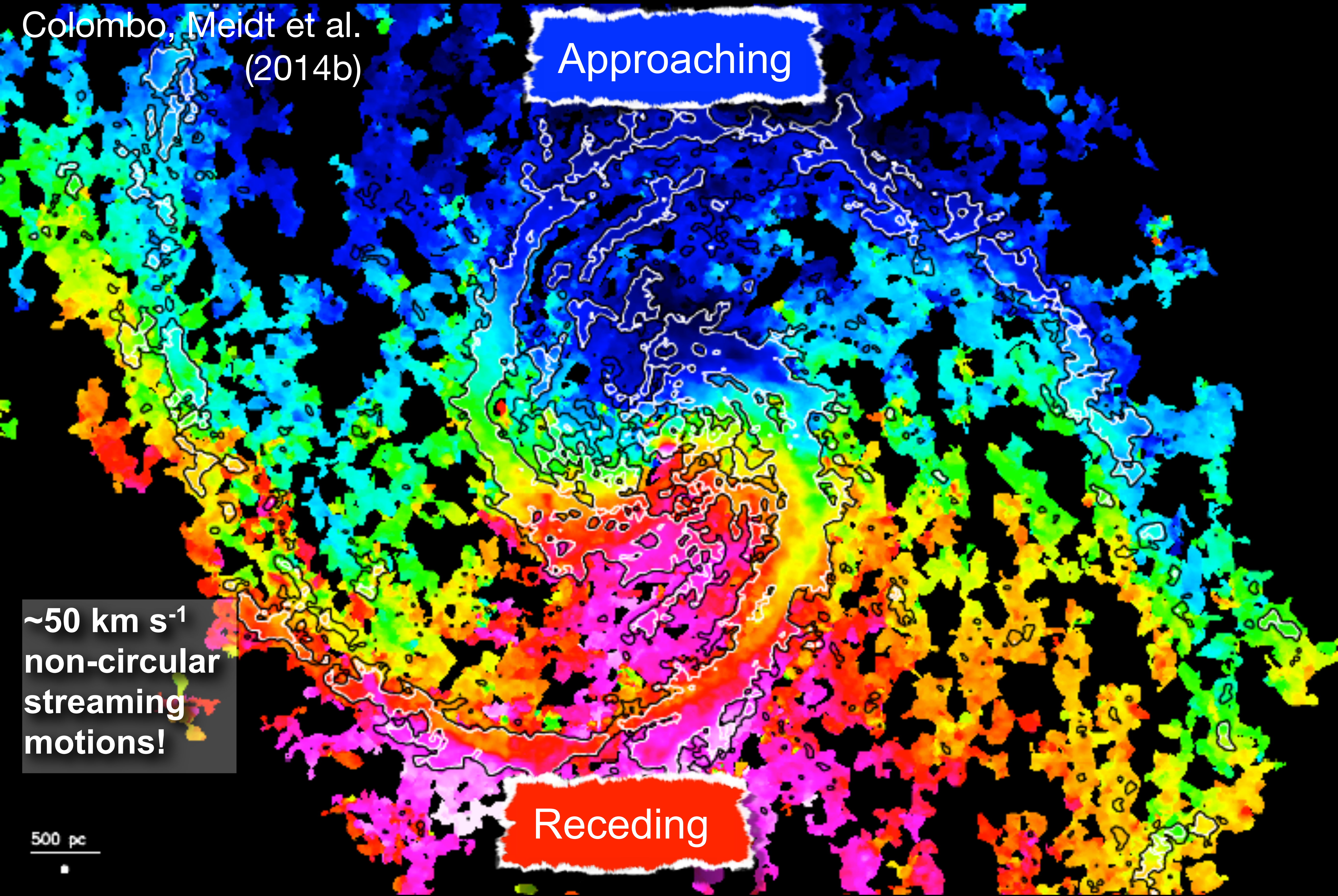




- *Bernoulli*: **gas in motion,**
  reduced pressure
- **increased cloud stable mass** (bigger before collapse)
- fewer collapse-unstable clouds
- **lower star formation, longer τ_{dep}**

Projected velocity field of M51



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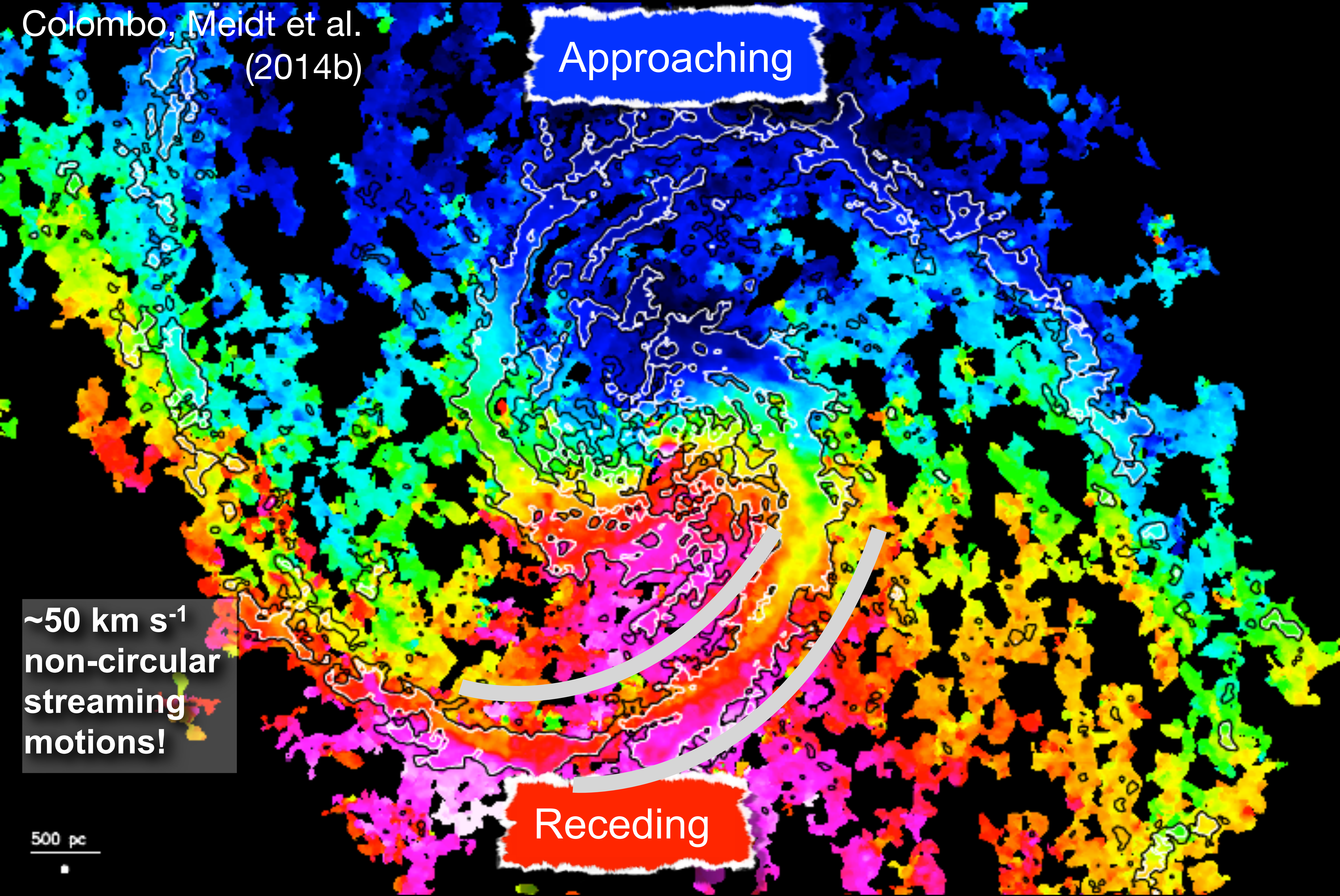

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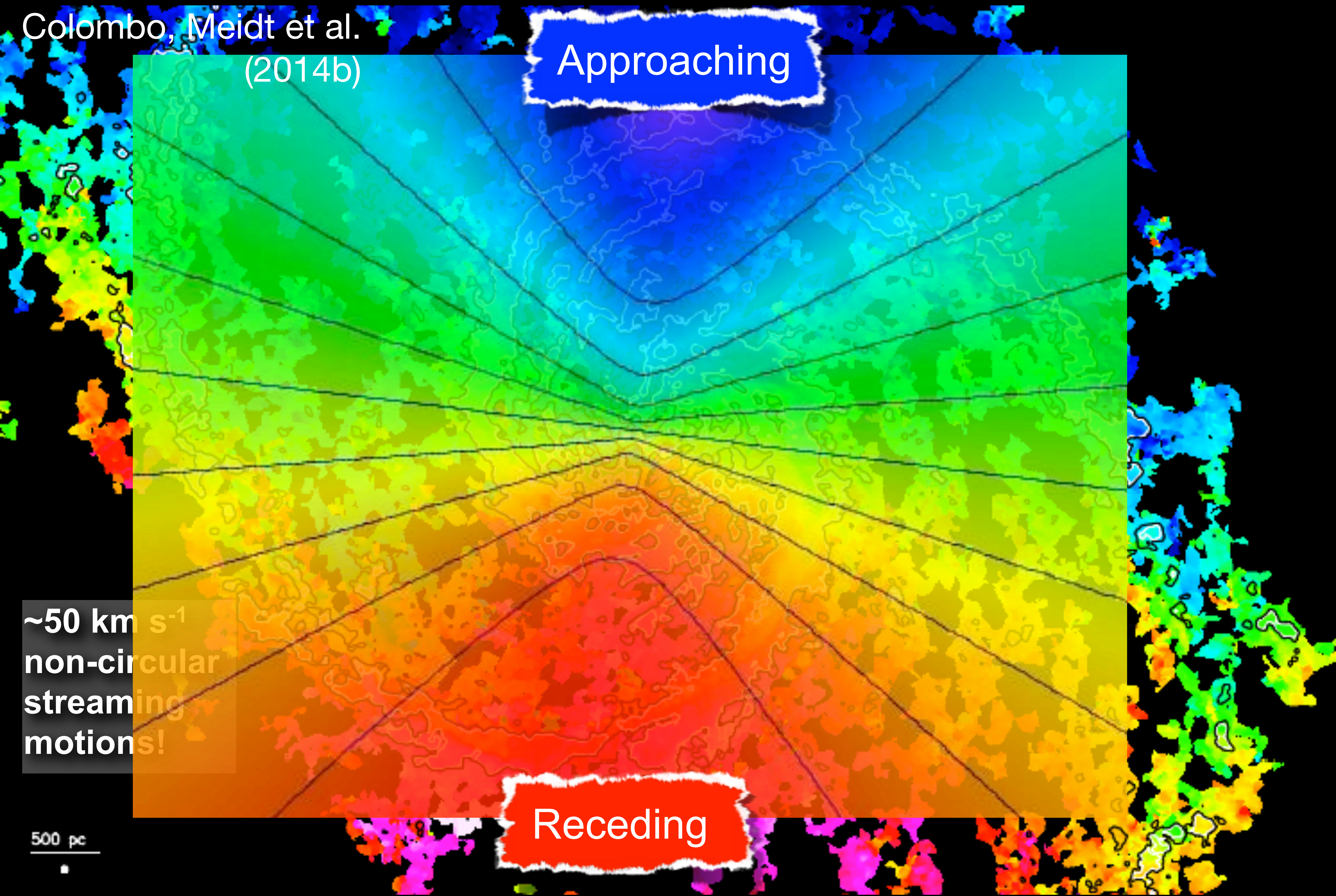

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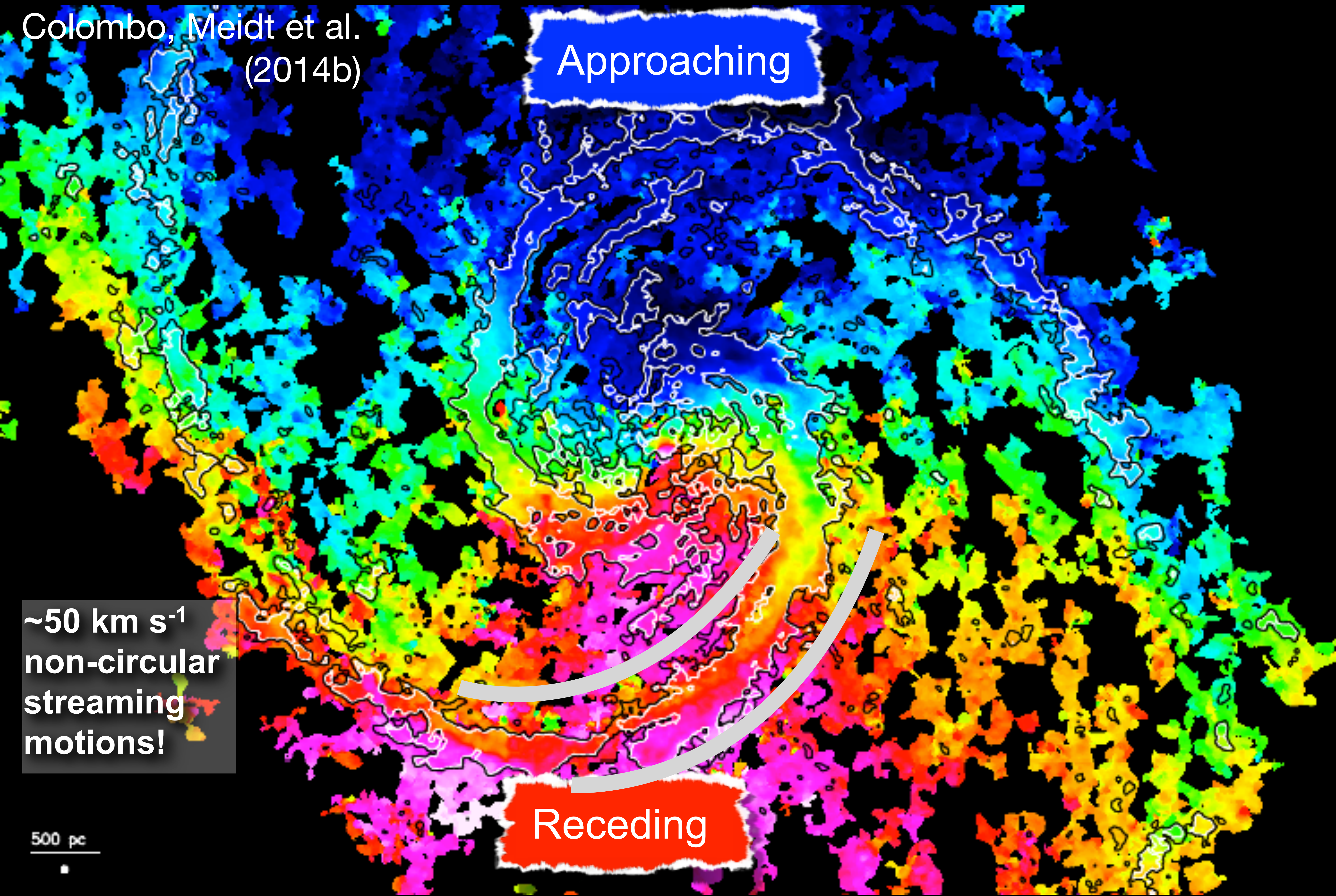
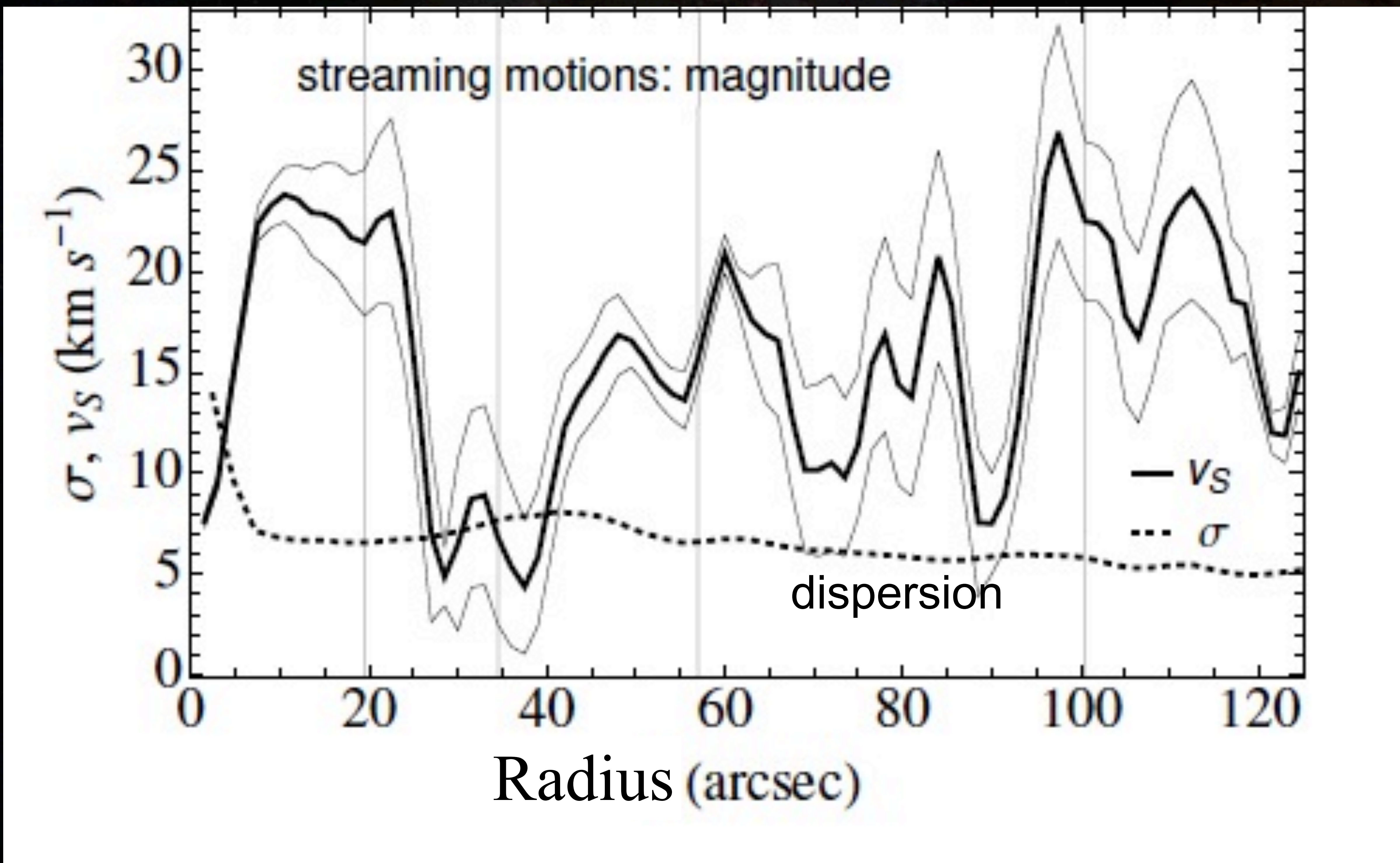


large variations in gas streaming motions



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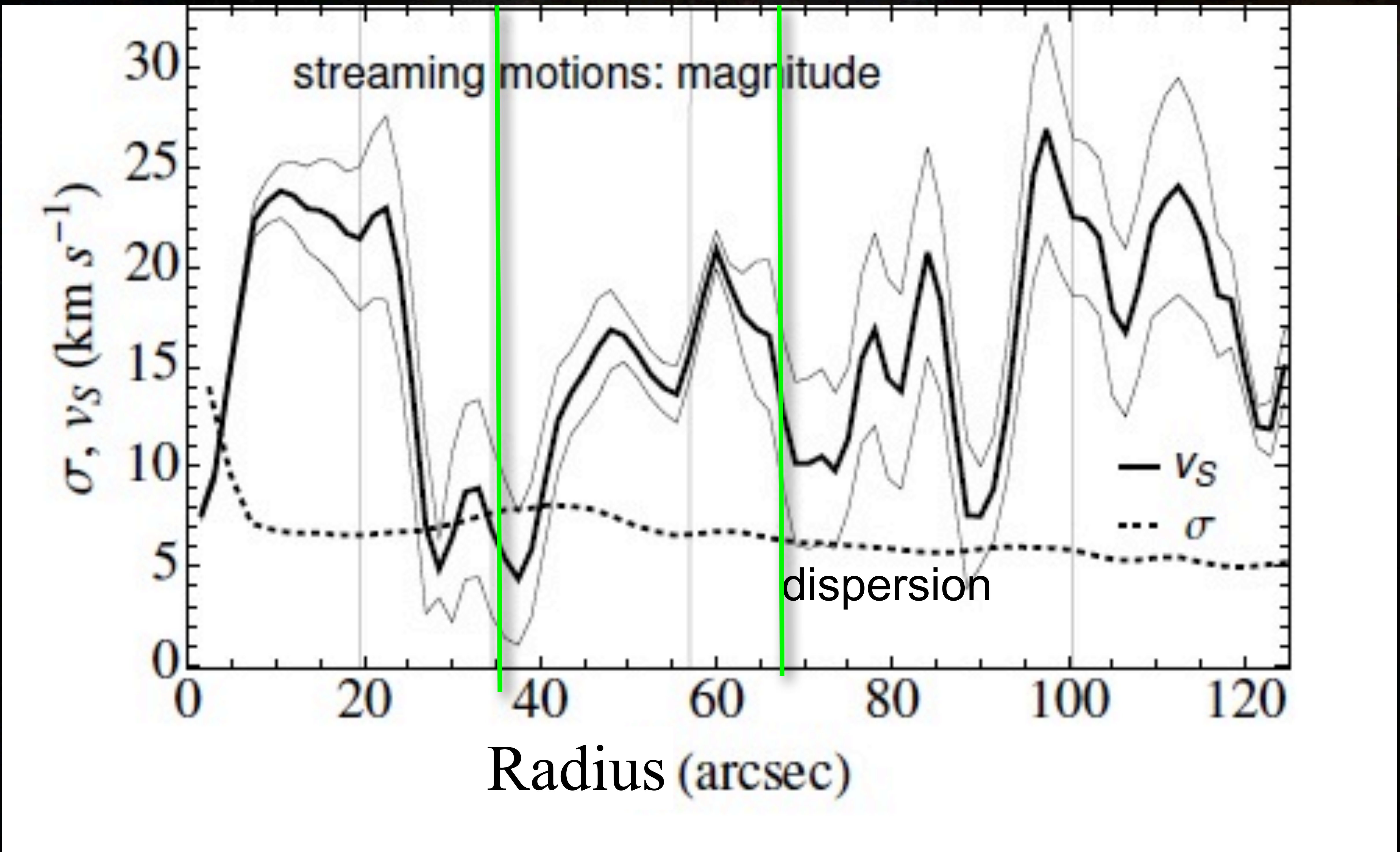
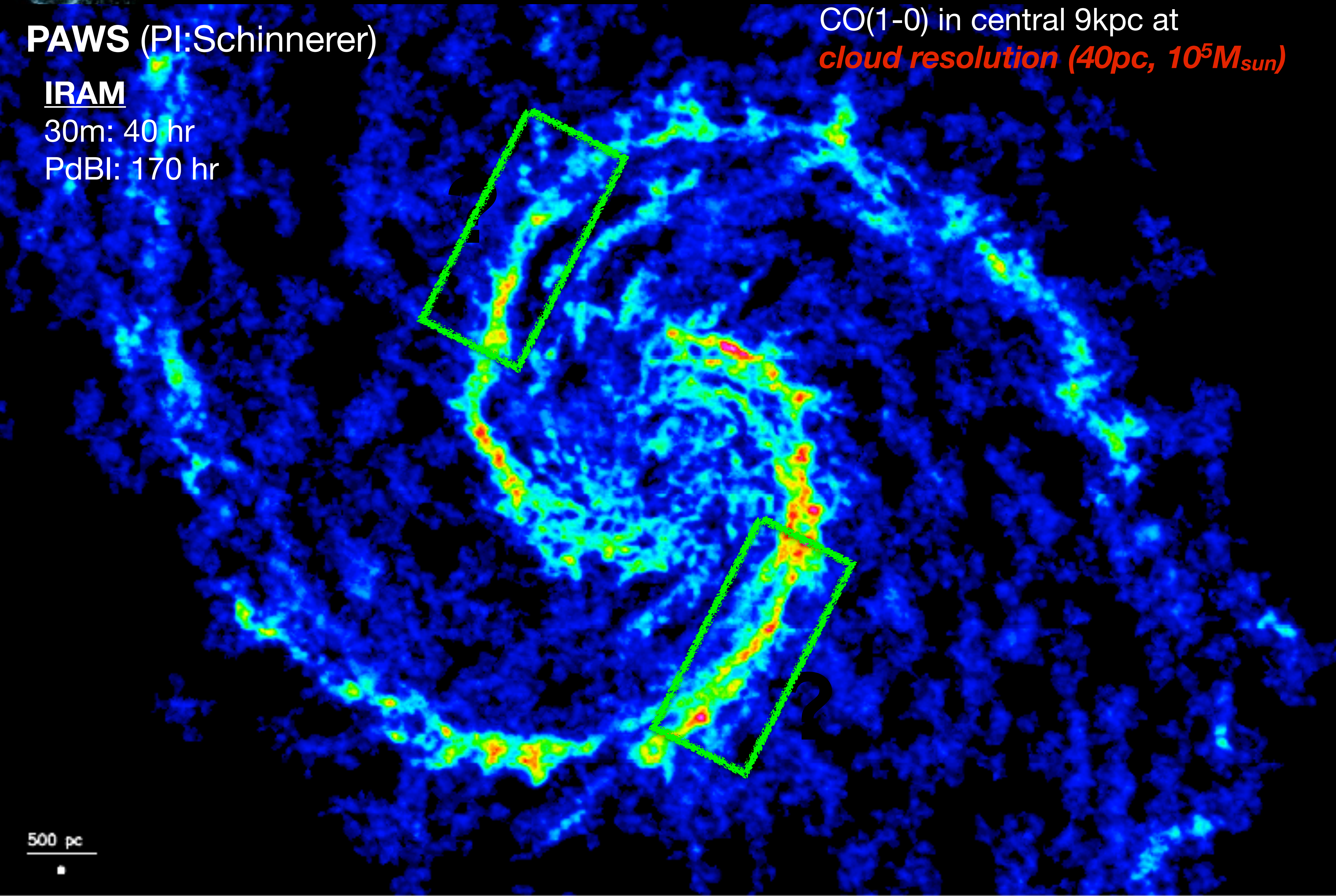
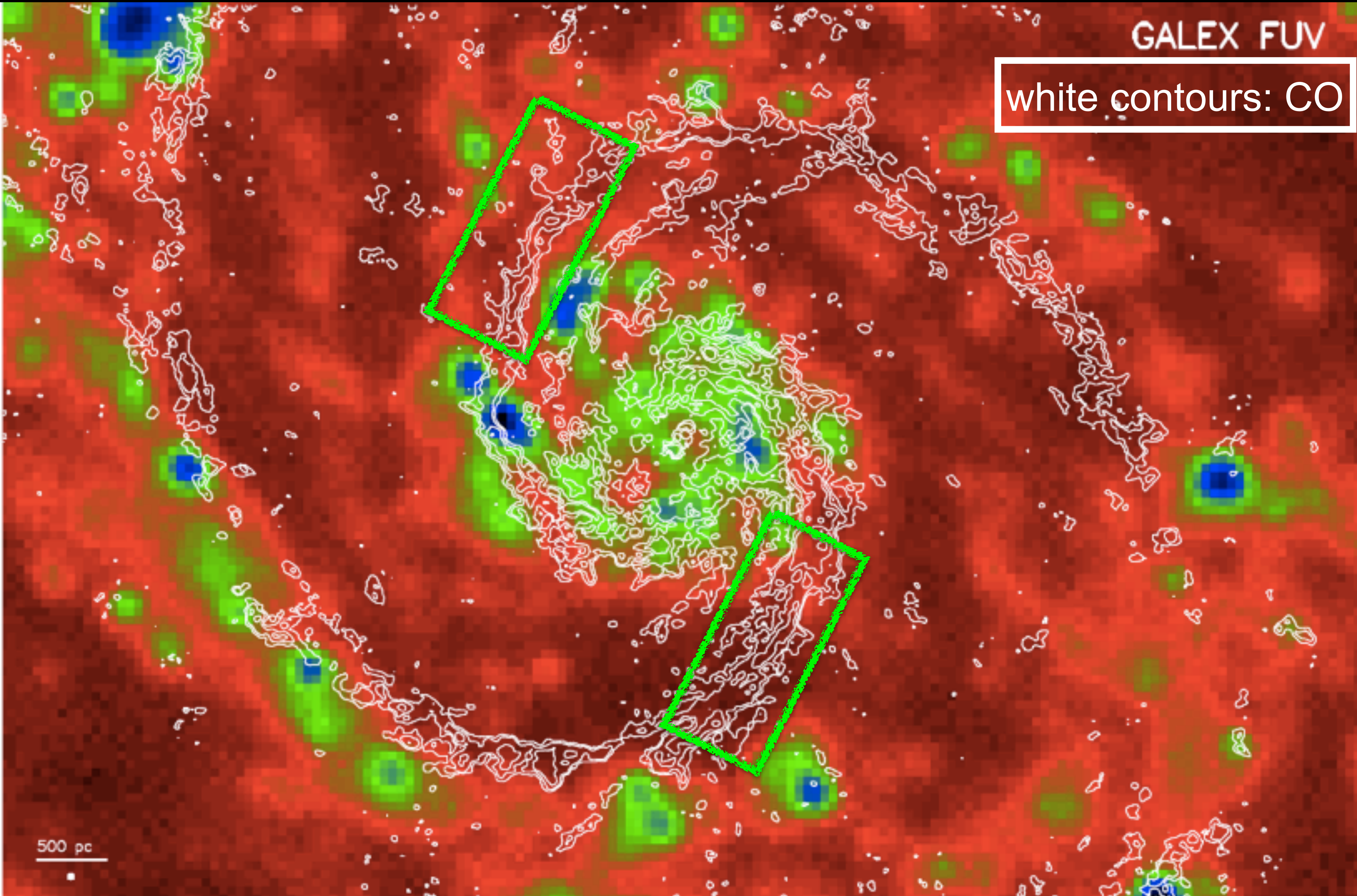


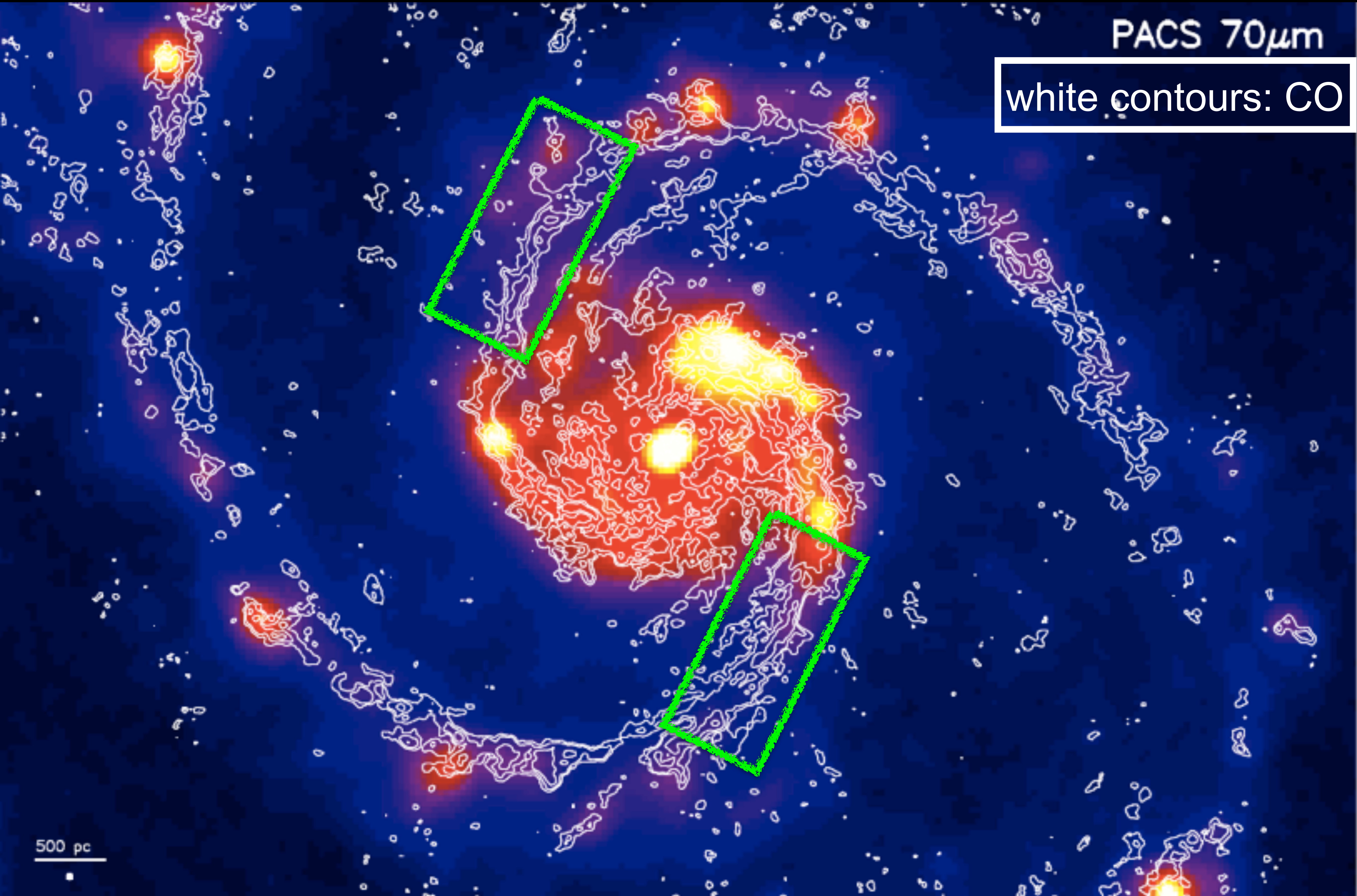
Molecular Gas disk of M51



Molecular Gas vs. UV



Molecular Gas vs. obscured SF



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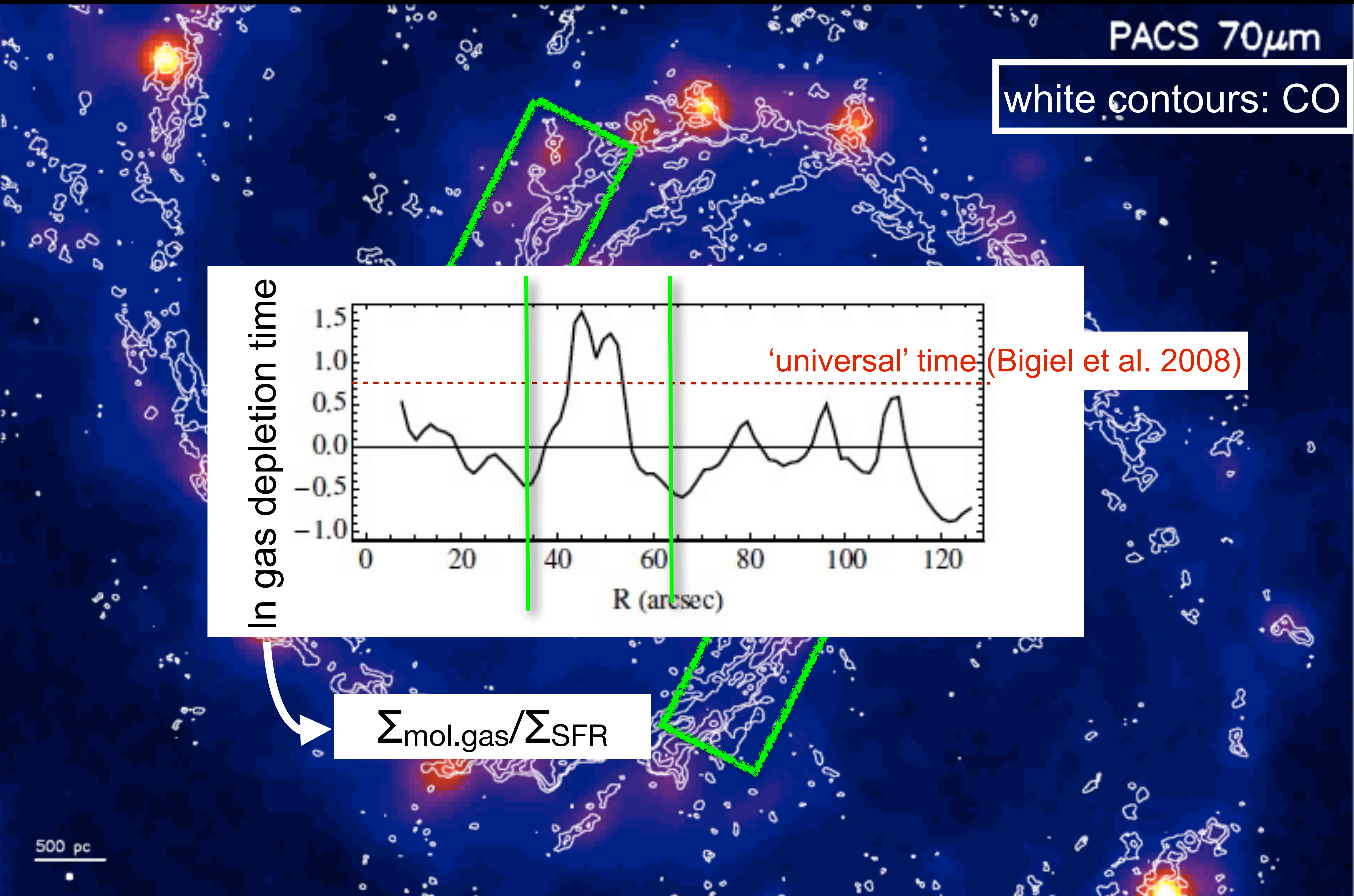

GMC Stabilization in M51

what shuts off star formation?

support *not* from the usual suspects:

Meidt et al. (2013)

GMC Stabilization in M51

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support *not* from the usual suspects:

- spiral arm shear

Meidt et al. (2013)

GMC Stabilization in M51

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- enhanced turbulent motions

Meidt et al. (2013)

GMC Stabilization in M51

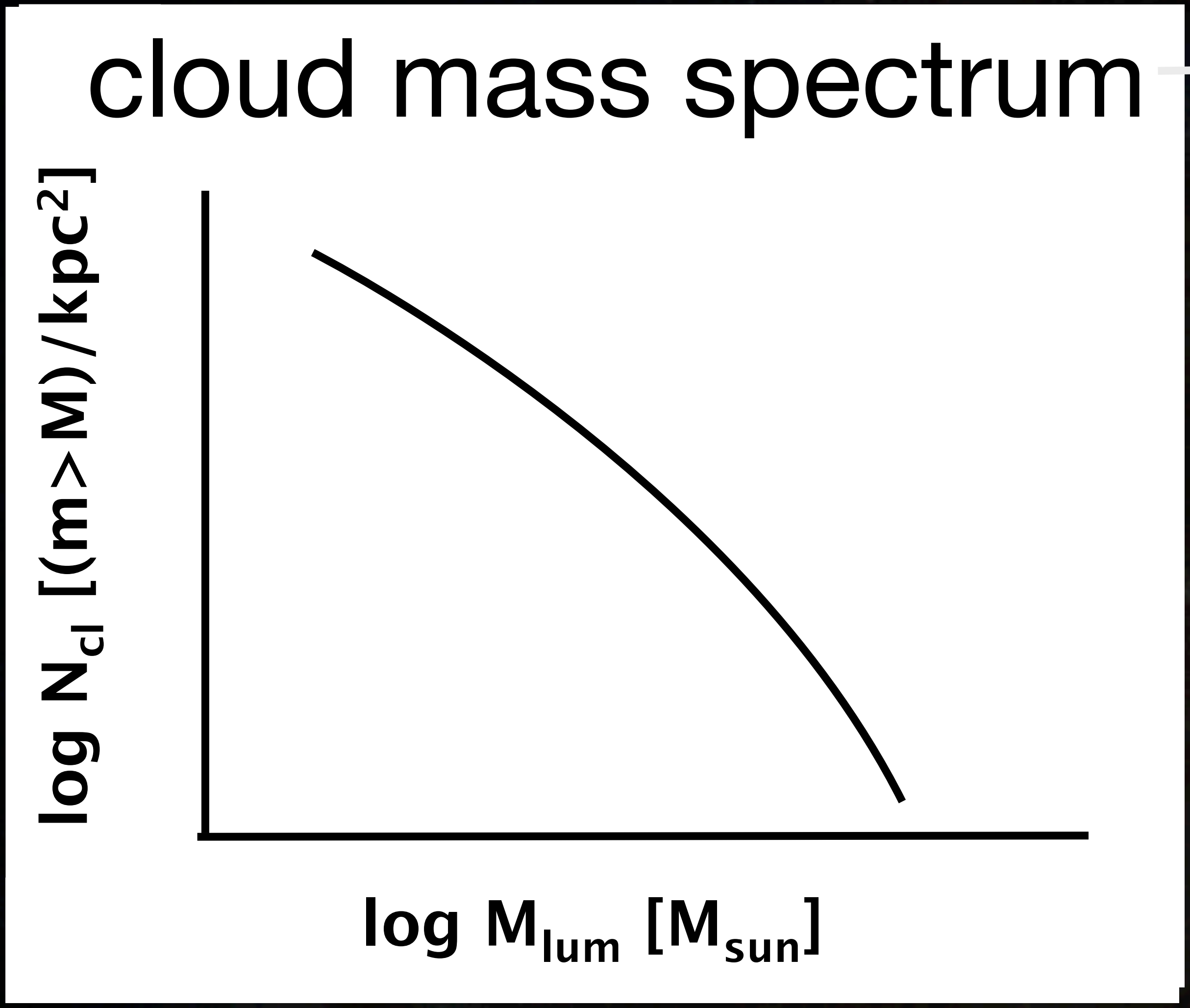
what shuts off star formation?

support *not* from the usual suspects:

- spiral arm shear
- enhanced turbulent motions
- stellar feedback (little Hα, UV, clusters <70Myr)

Meidt et al. (2013)

dynamical pressure *A Quantitative approach*



→ power-law with
$dN/dM \propto M^{\gamma}$

Meidt et al. (2013)

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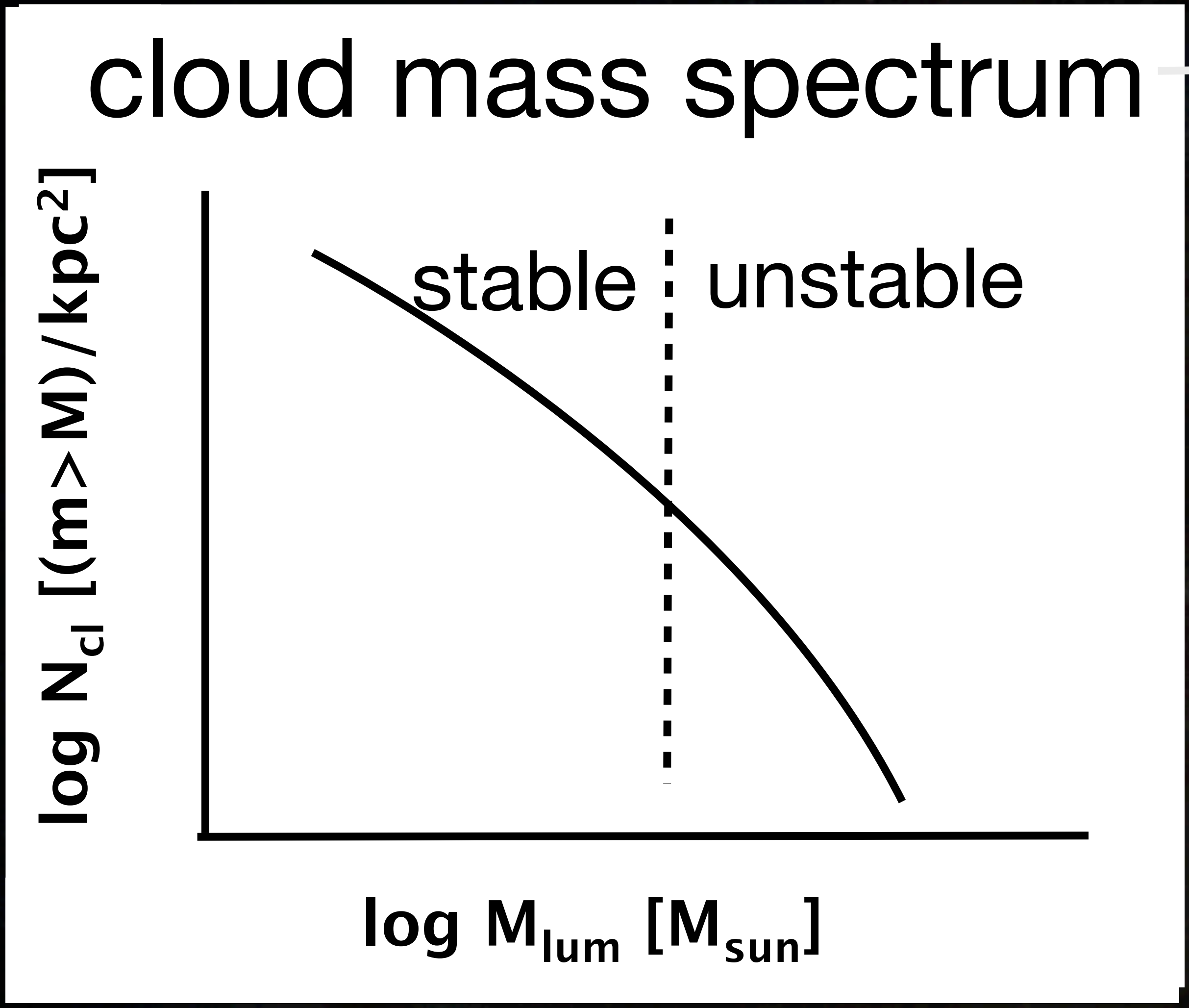

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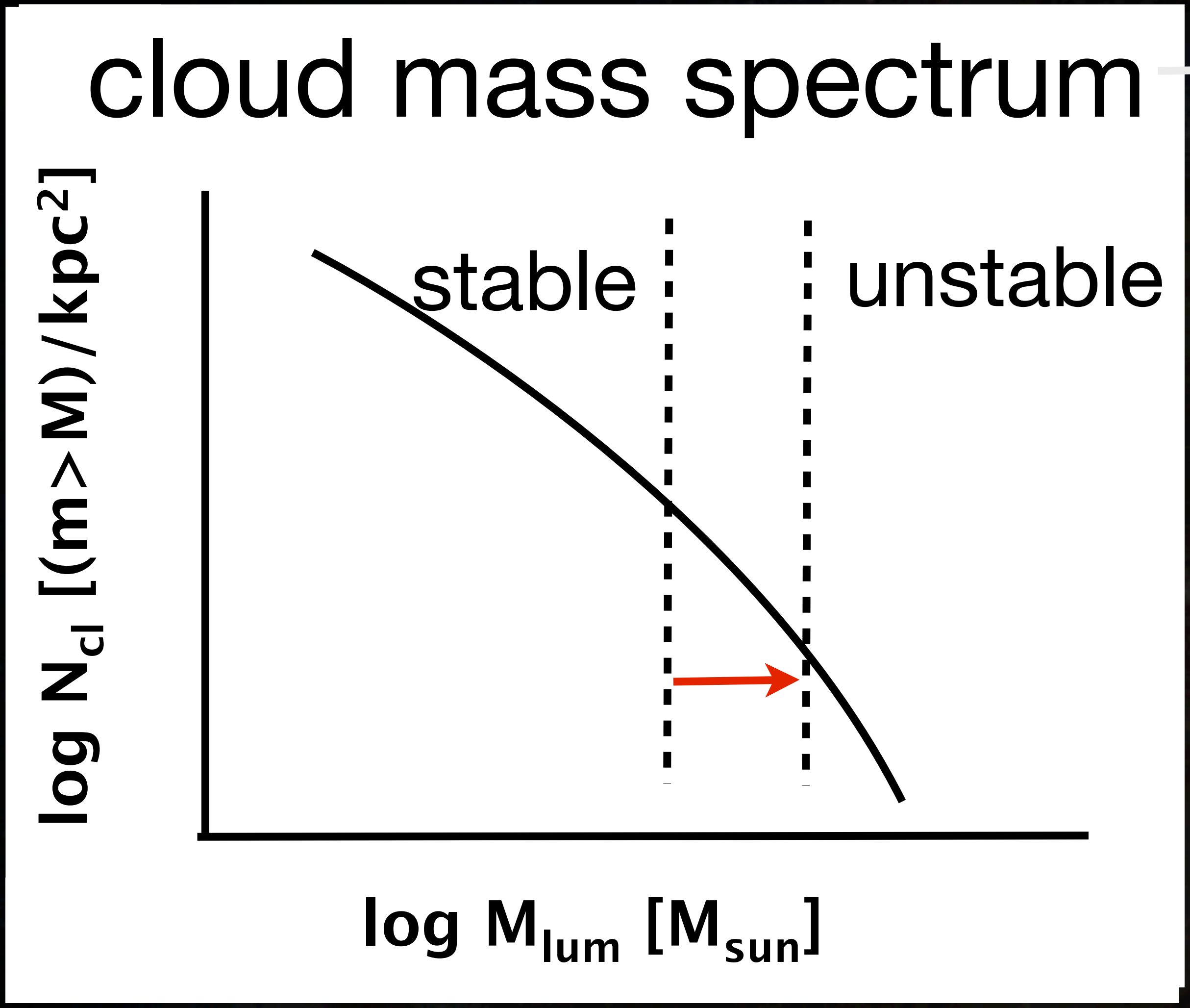

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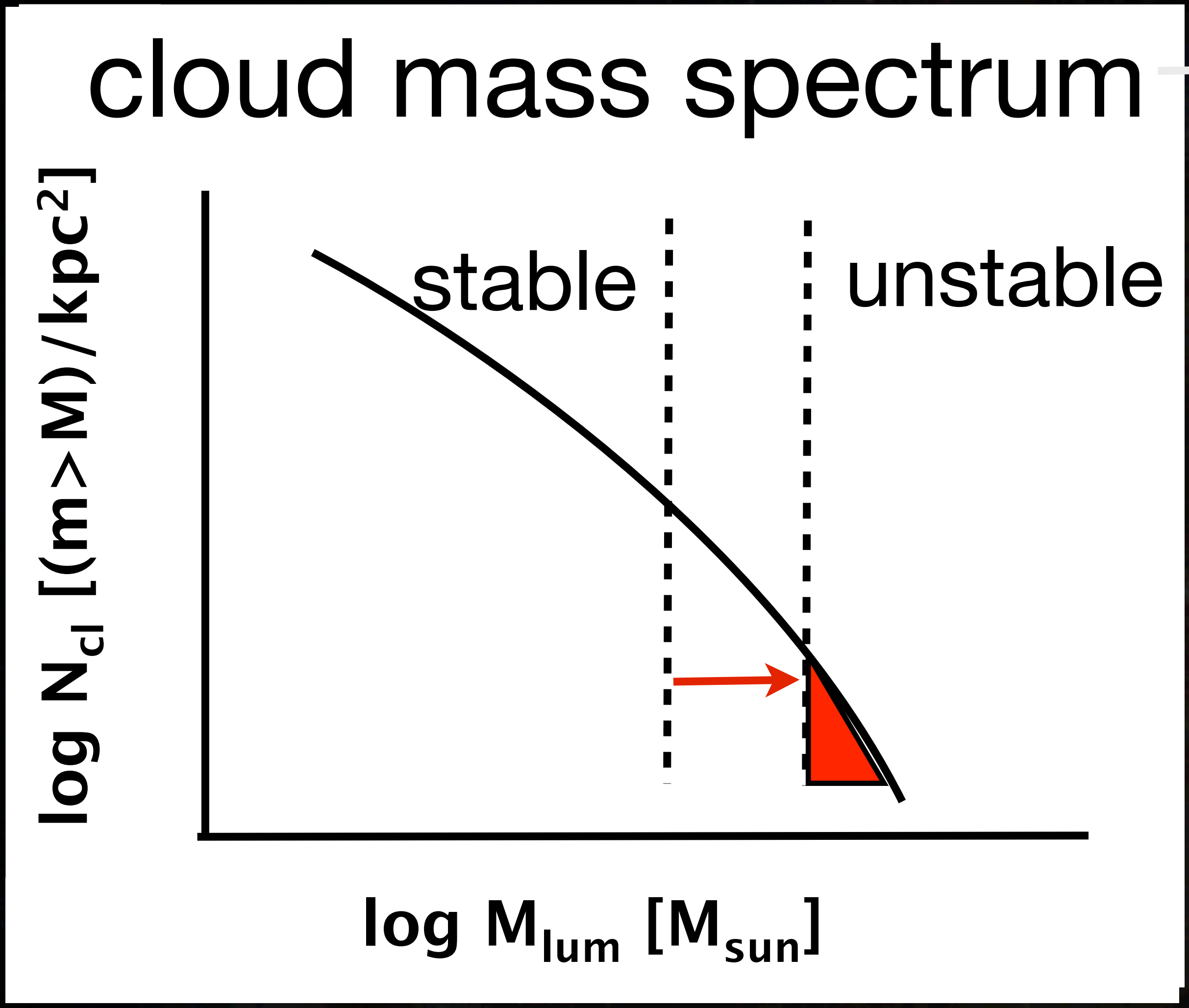
with v_{stream}
pressure decreased,
stable mass raised

Meidt et al. (2013)

dynamical pressure *A Quantitative approach*



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Meidt et al. (2013)

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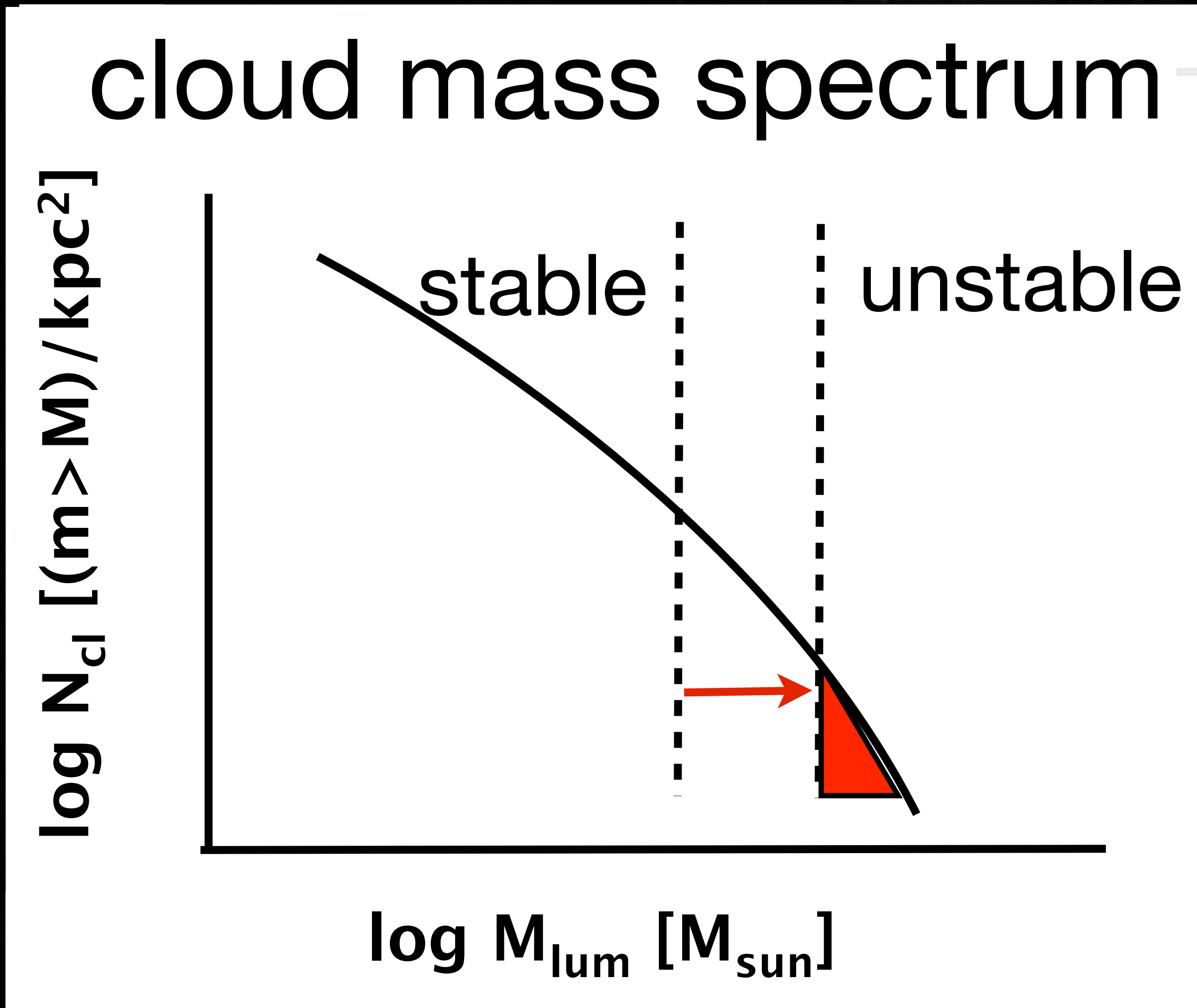

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depletion time
$\tau_{dep} = \Sigma_{H2} / \Sigma_{SFR}$

S. E. Meidt, 3D2014, March 10

Meidt et al. (2013)

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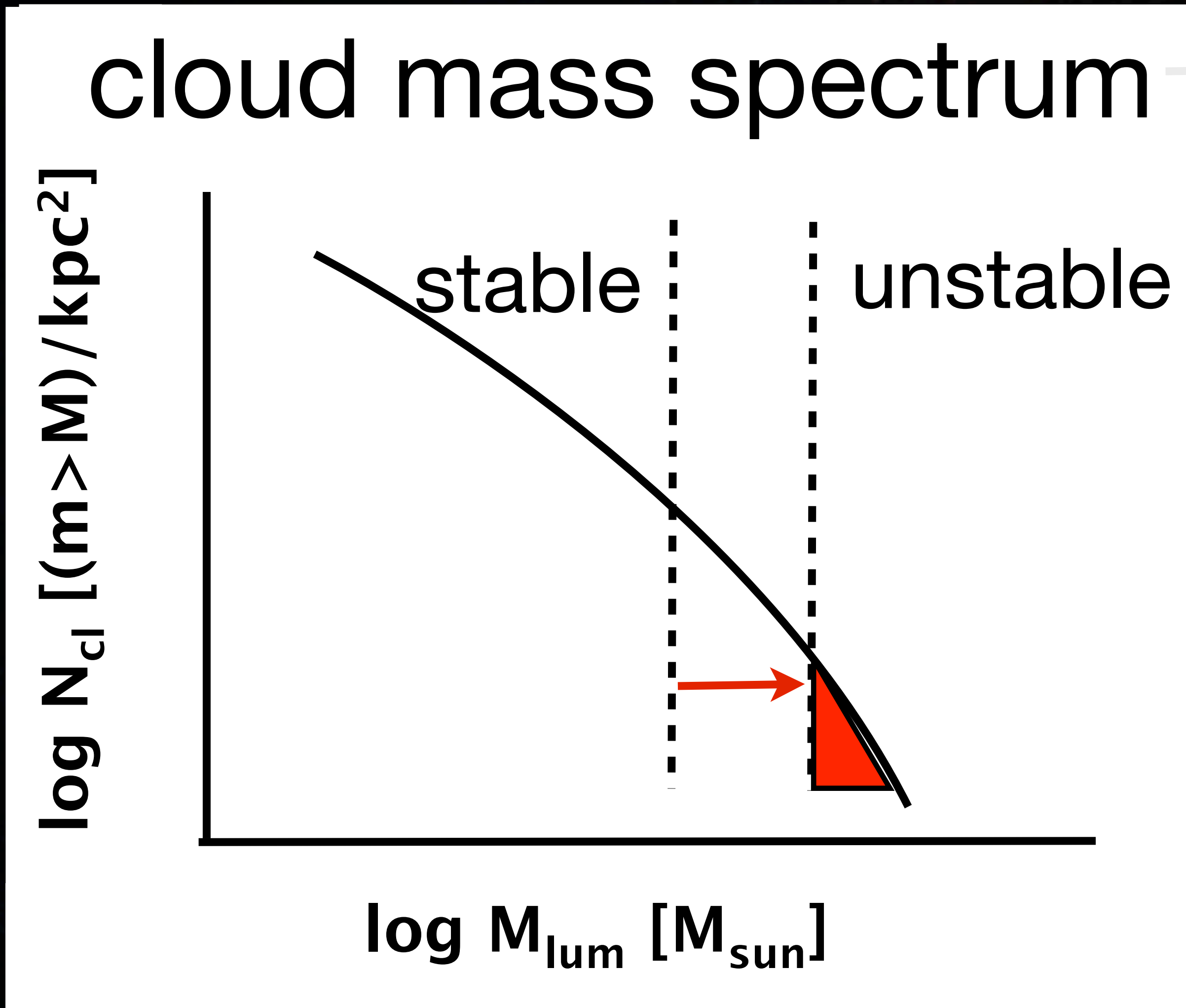

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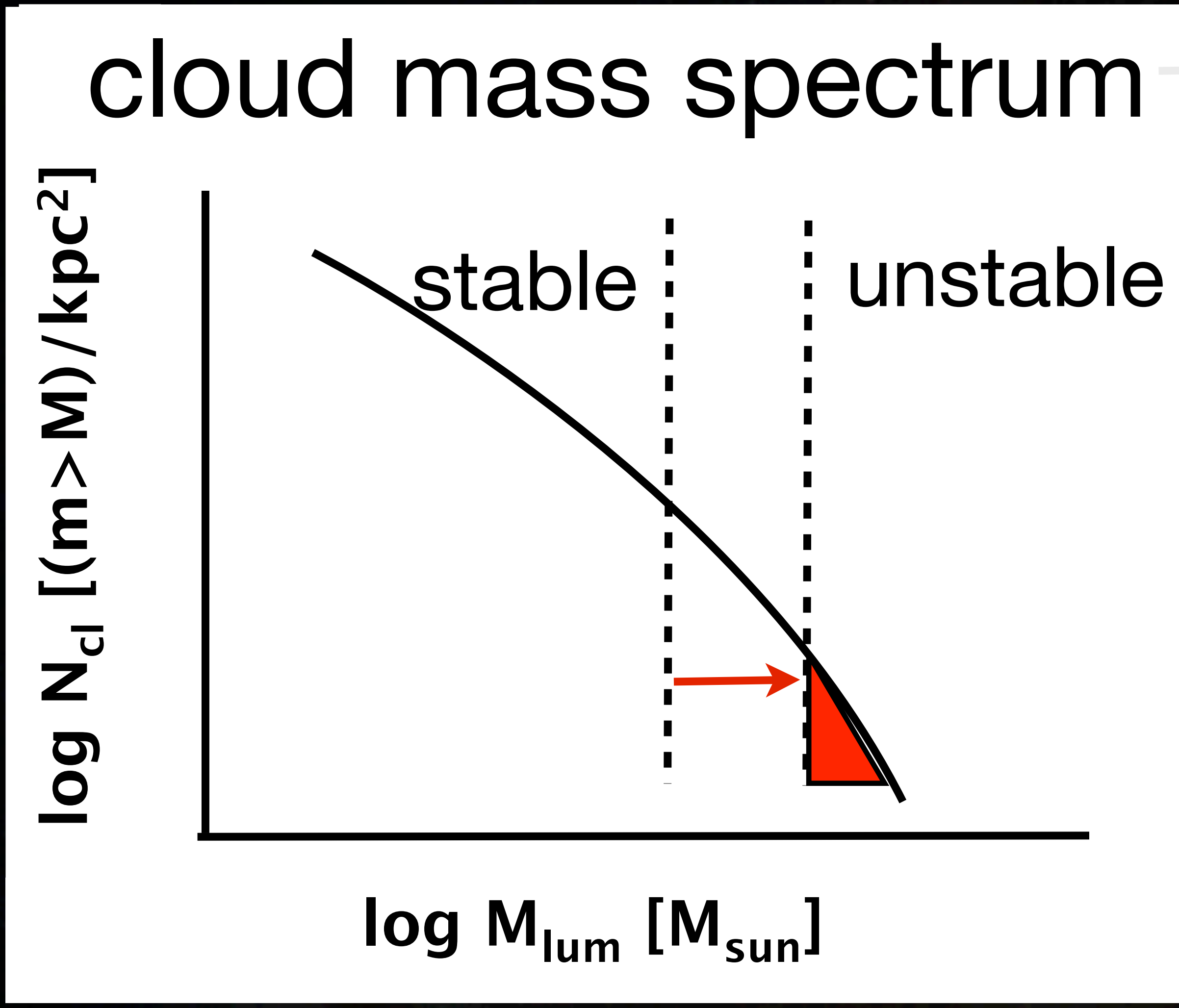
slope of cloud mass spectrum
$-1.3 < \gamma < -1.7$

Meidt et al. (2013)

dynamical pressure *A Quantitative approach*



→ power-law with
$dN/dM \propto M^{\Upsilon}$

with v_{stream}
pressure decreased,
stable mass raised

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

depletion time
$\tau_{dep} = \Sigma_{H2} / \Sigma_{SFR}$

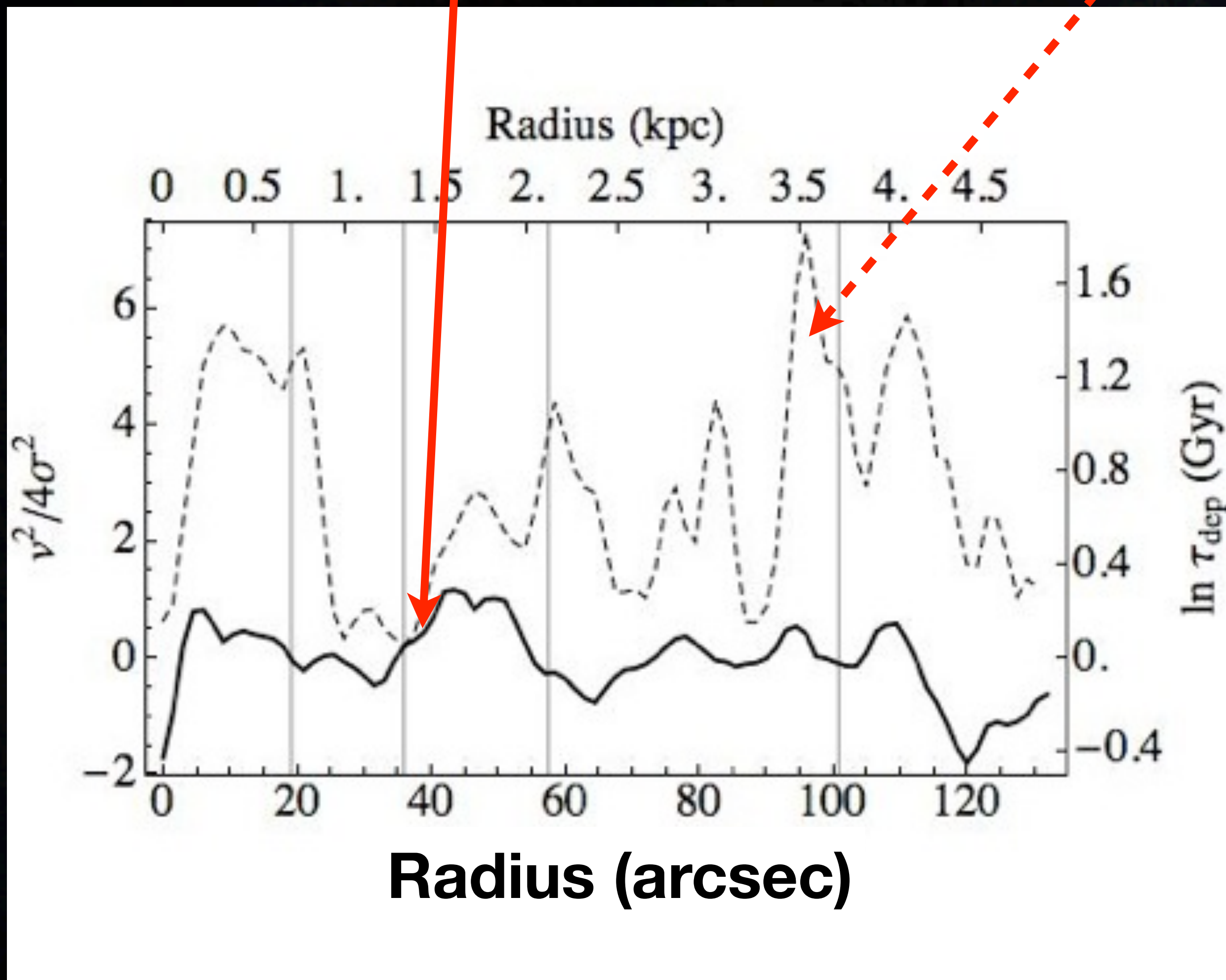
measure from
observed kinematics

slope of cloud mass
spectrum
$-1.3 < \Upsilon < -1.7$

Meidt et al. (2013)

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

only where $|\Upsilon|>1$



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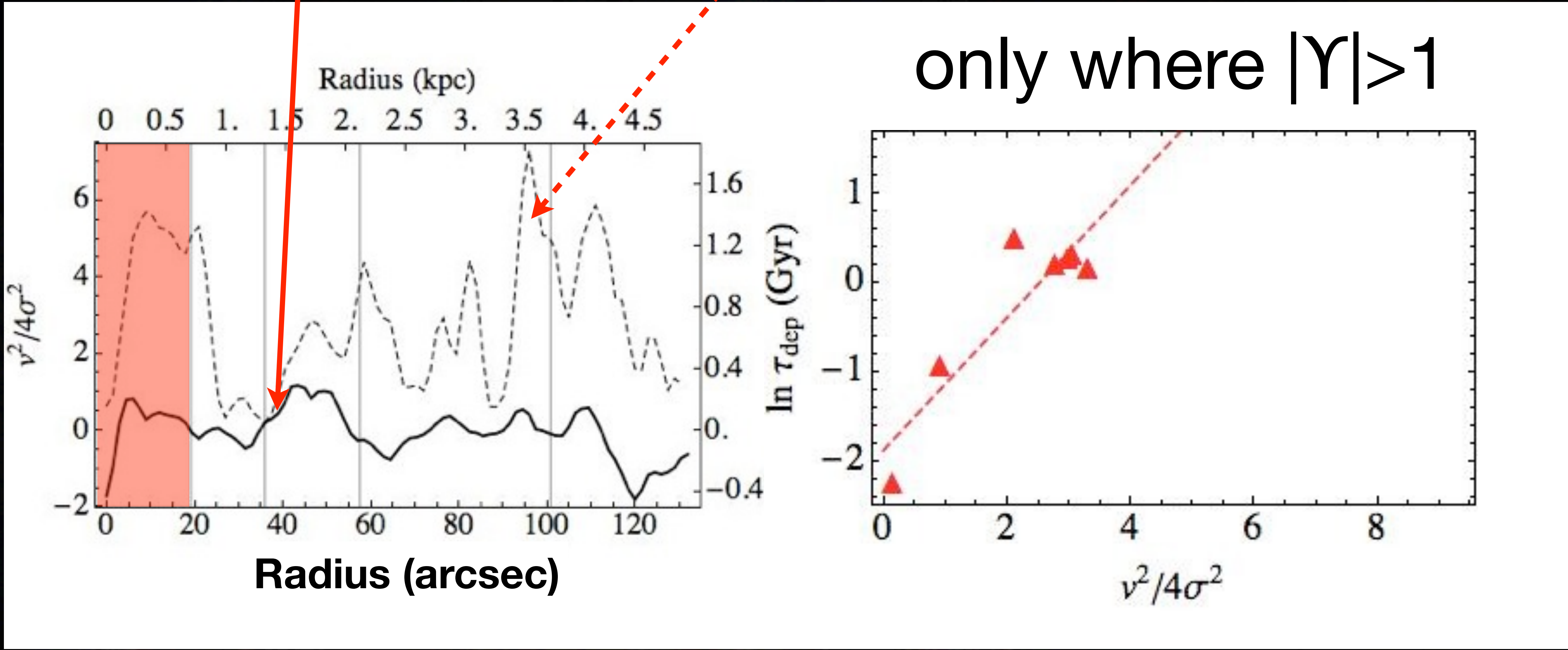

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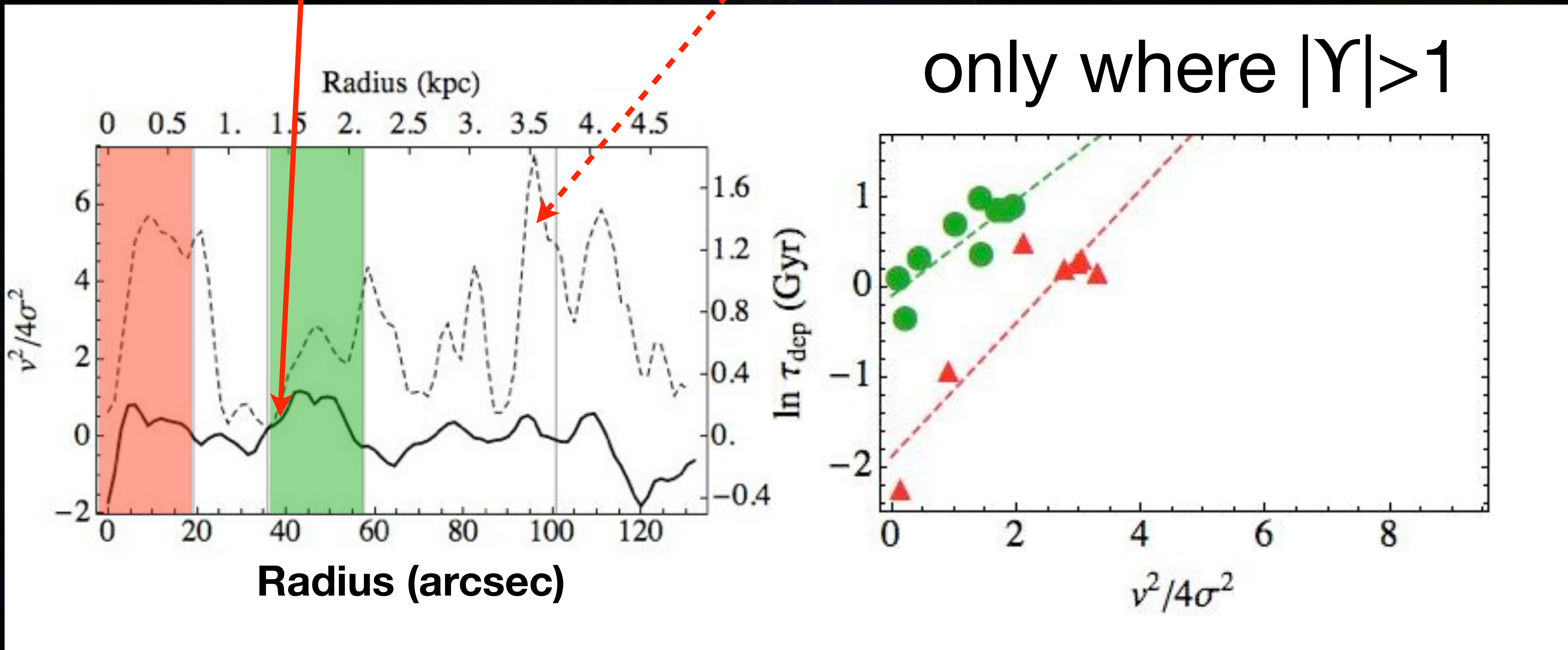

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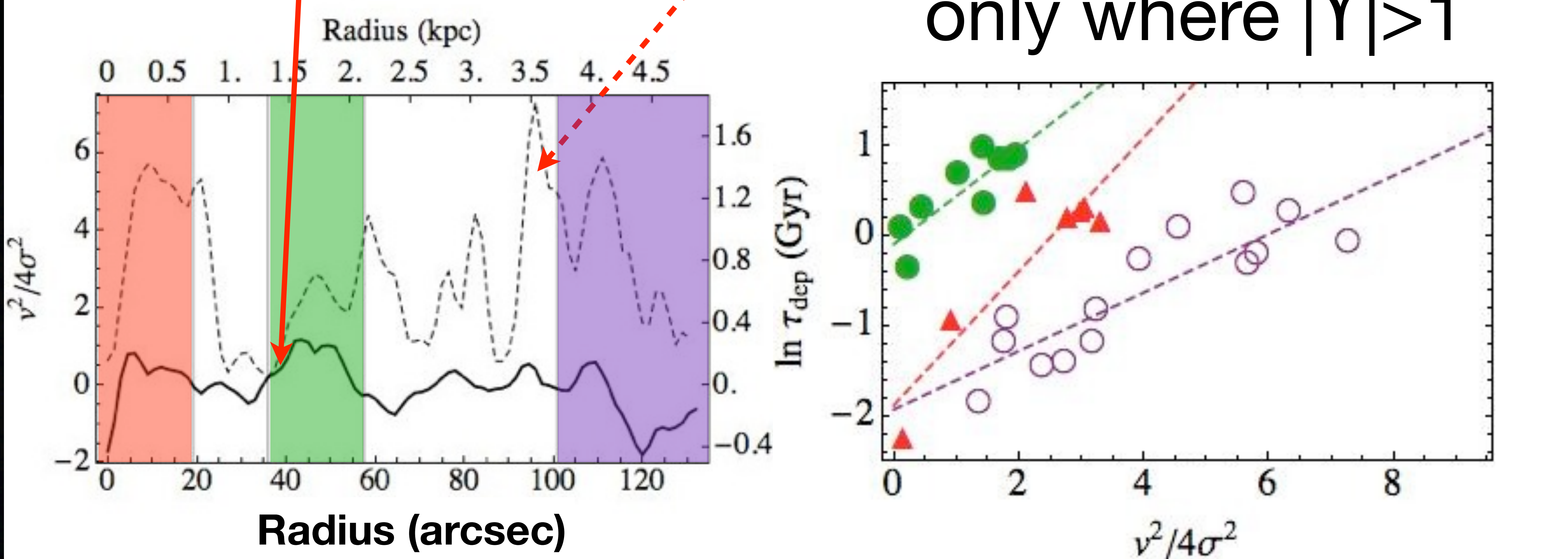

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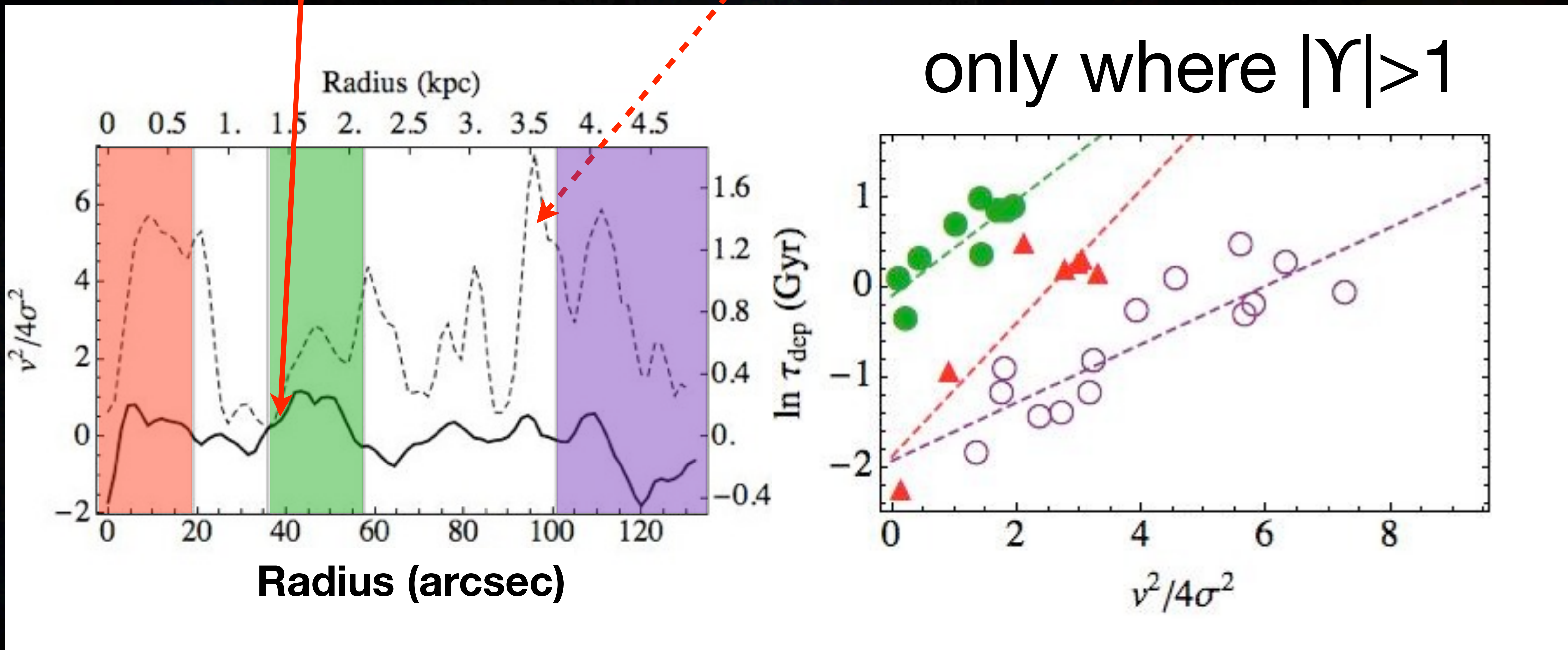
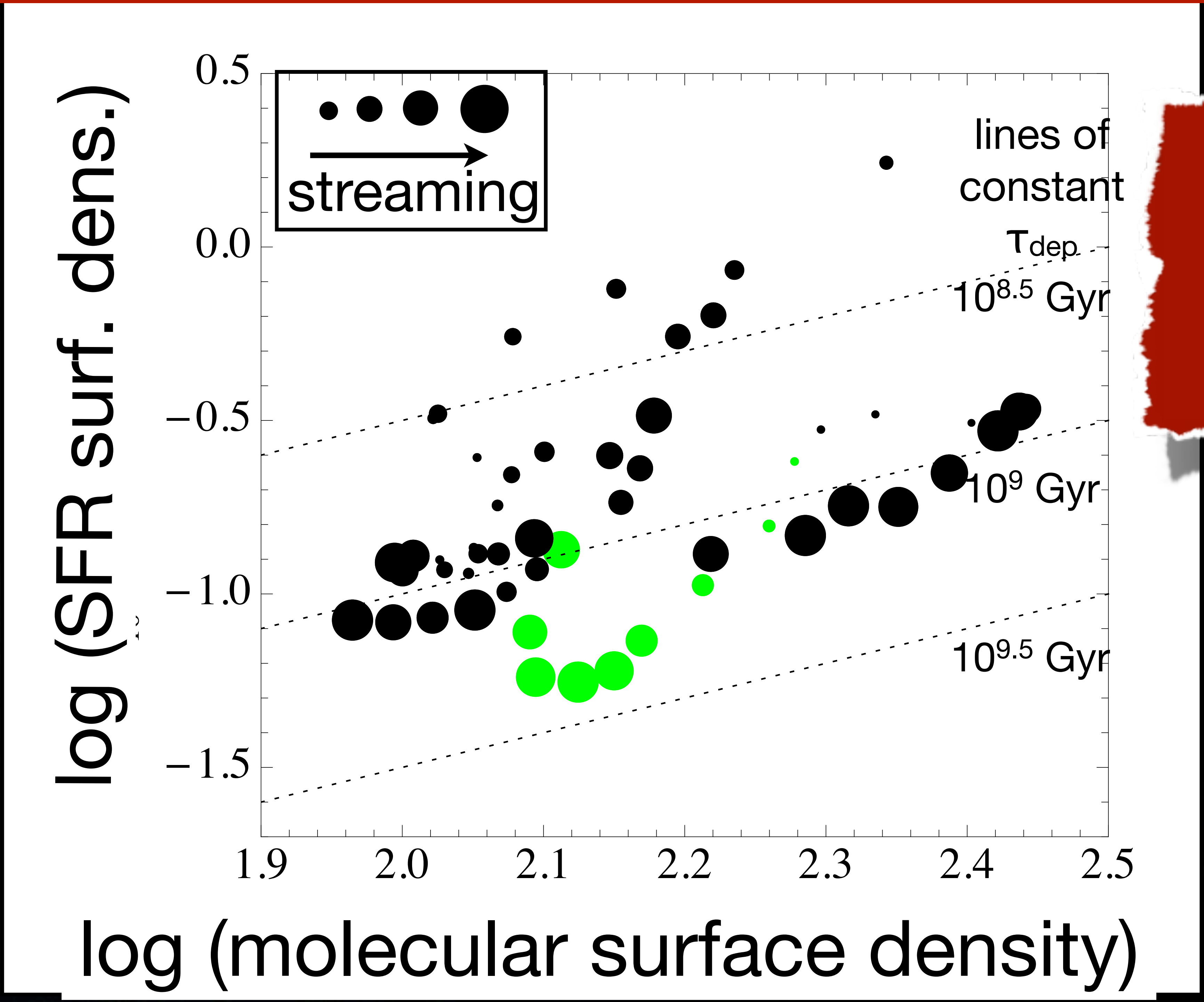


streaming motions lengthen gas depletion time

Meidt et al. (2013)

Scatter in star formation relation: ***gas motions***



streaming lengthens τ_{dep} to 2 Gyr

Meidt et al. (2013)

Clouds in their ***dynamical*** environment

- clouds **coupled** to environment: external + internal pressures similar!

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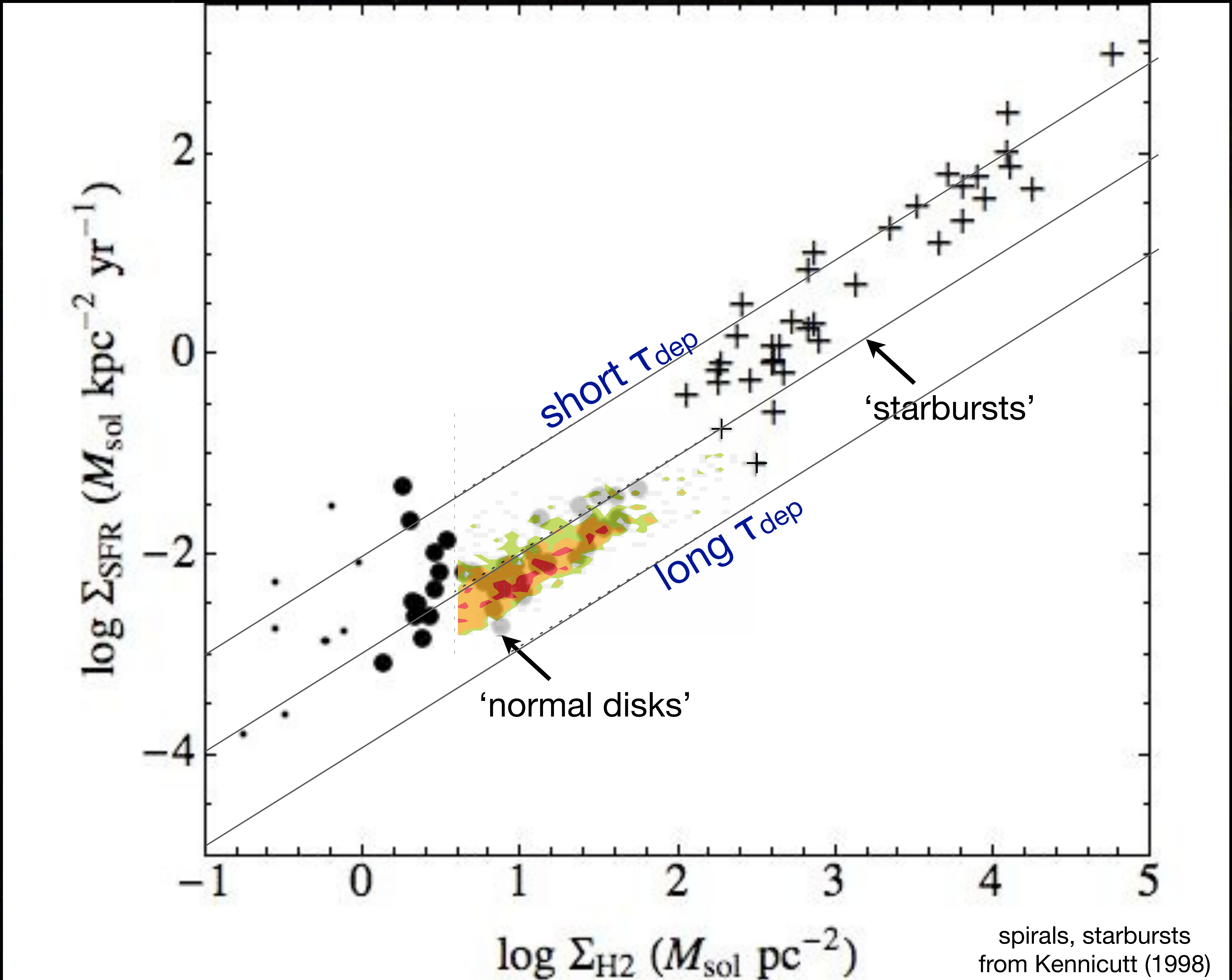
explains:

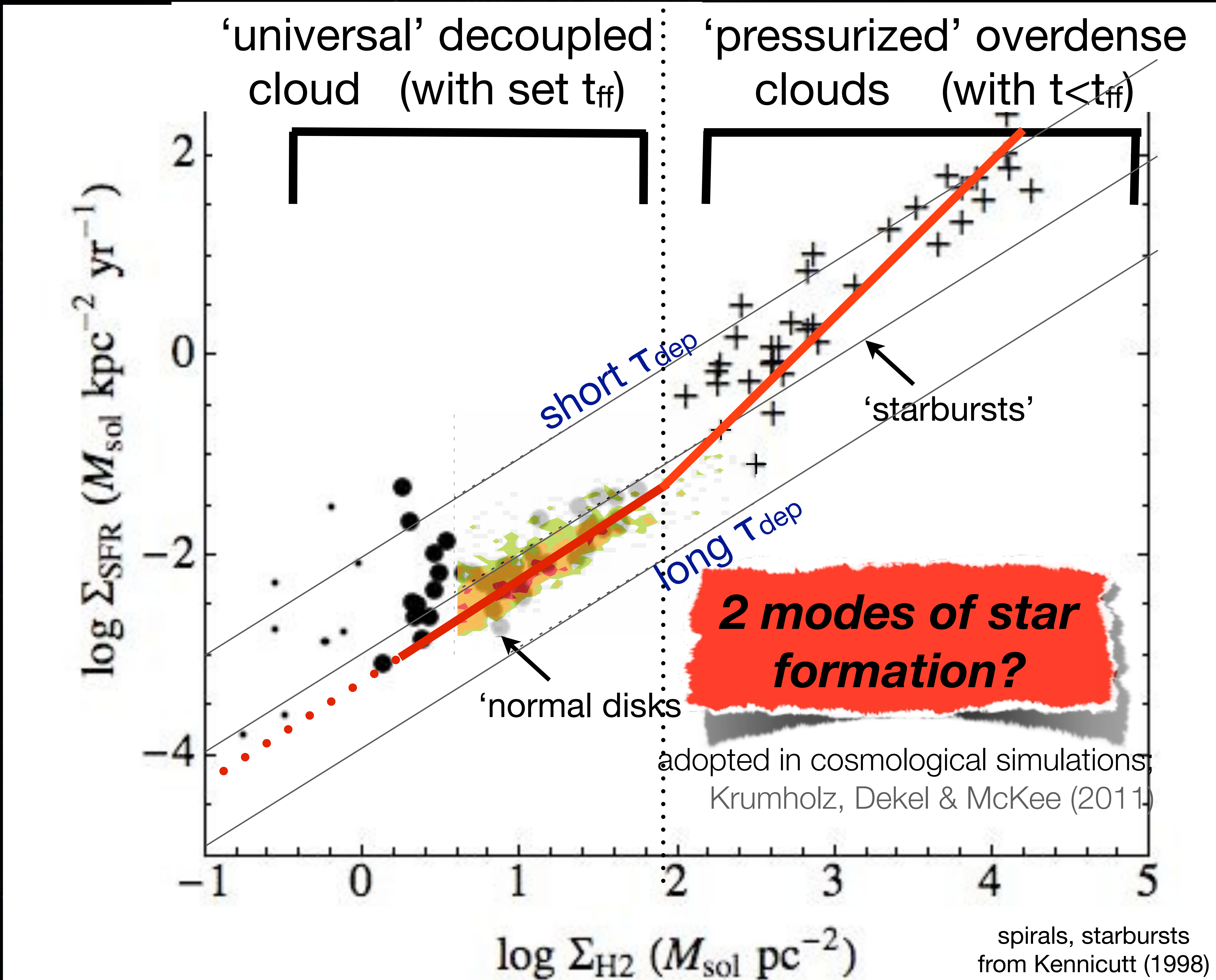
- *scatter in `1kpc' star formation relation*
- *range in depletion times* between *galaxies, from present-day to starbursts and disks at high-z*

Star Formation Relation



spirals, starbursts
from Kennicutt (1998)

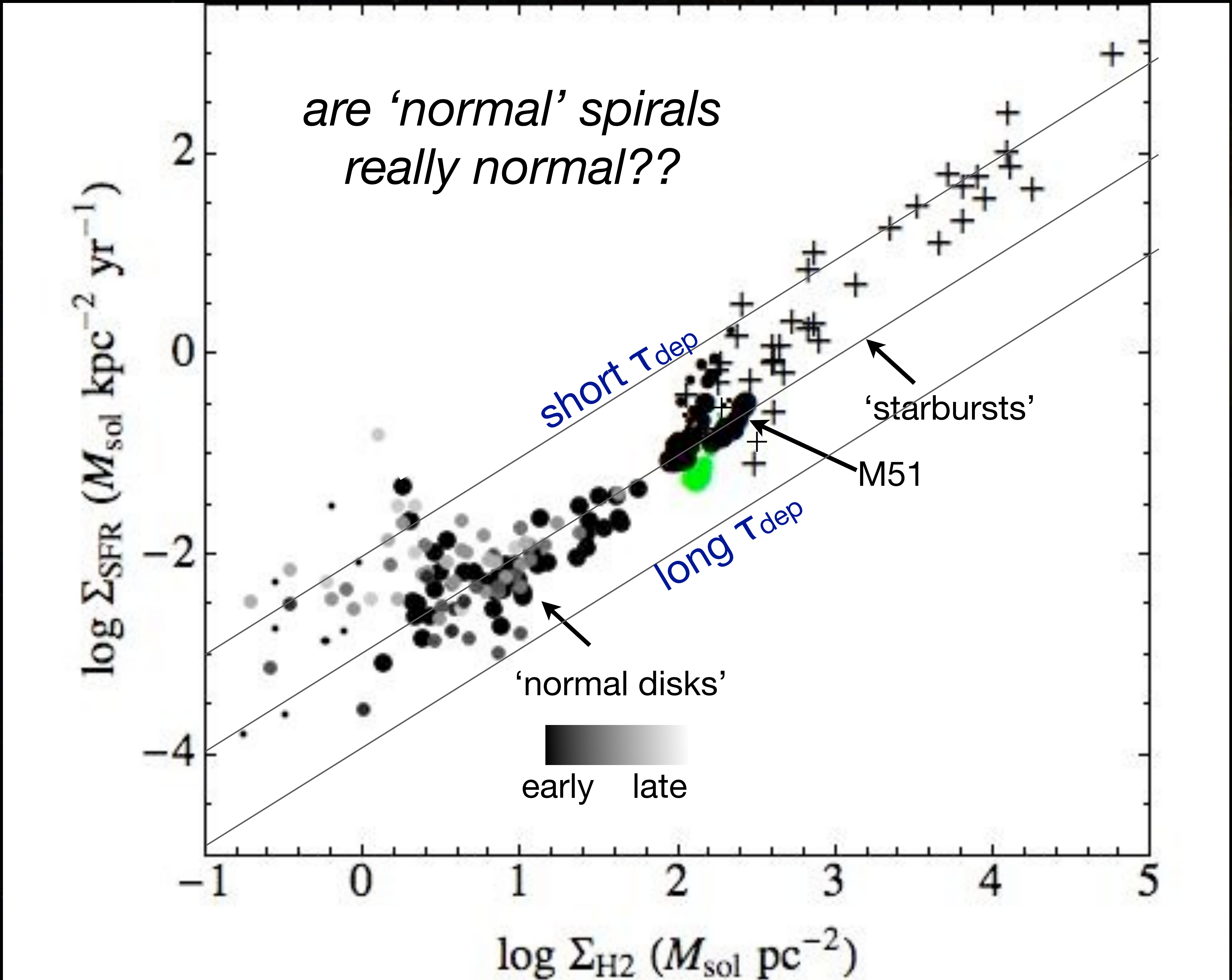
Star Formation Relation



- gas forms stars in a **single** fundamental mode

- departures from this mode due to presence of gas motions
  - **clouds prevented from forming stars**

Star Formation Relation



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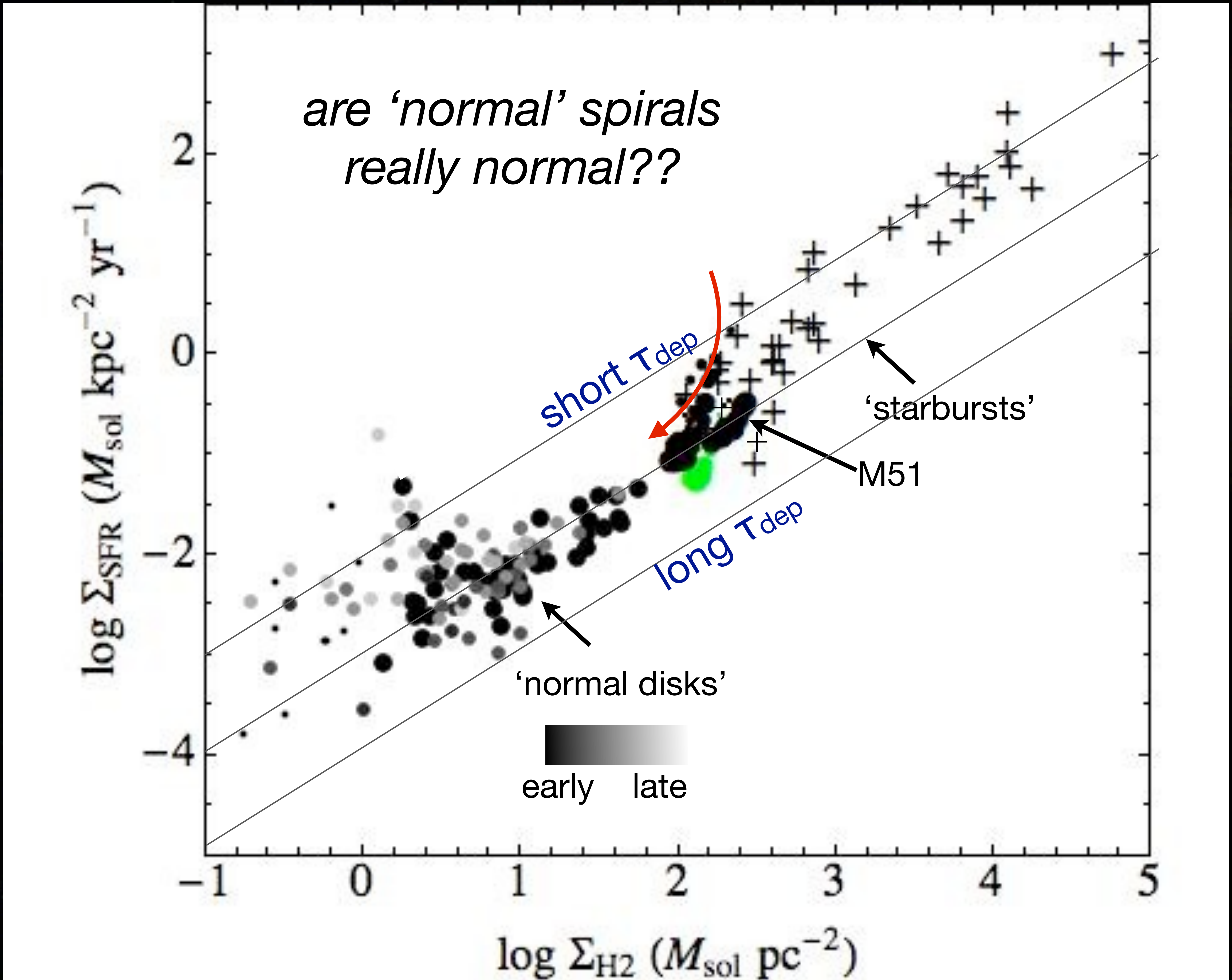
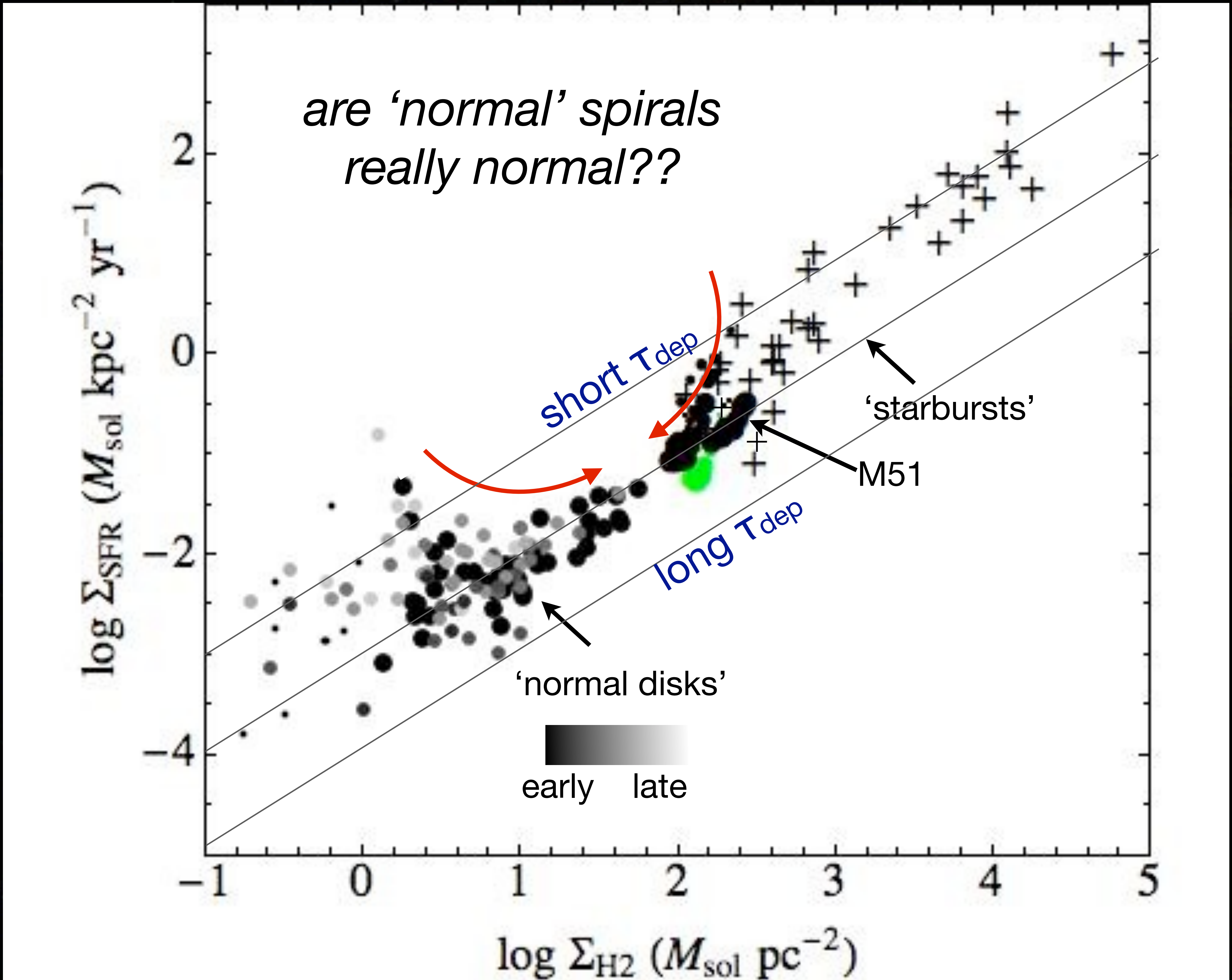
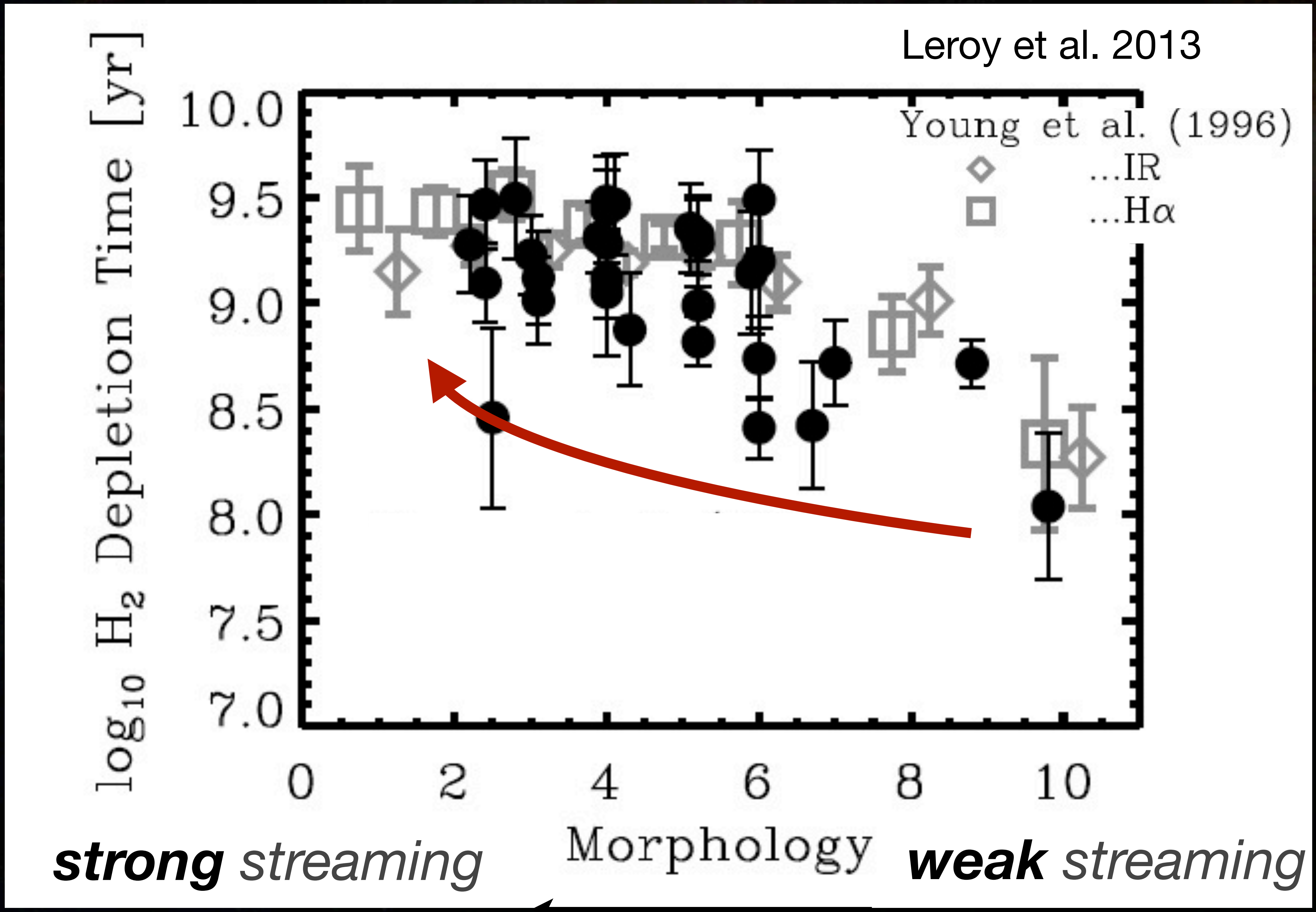


Star Formation Relation



Trends with disk morphology

since gas motions are larger in more massive disks,
τ_{dep} larger in more massive disks



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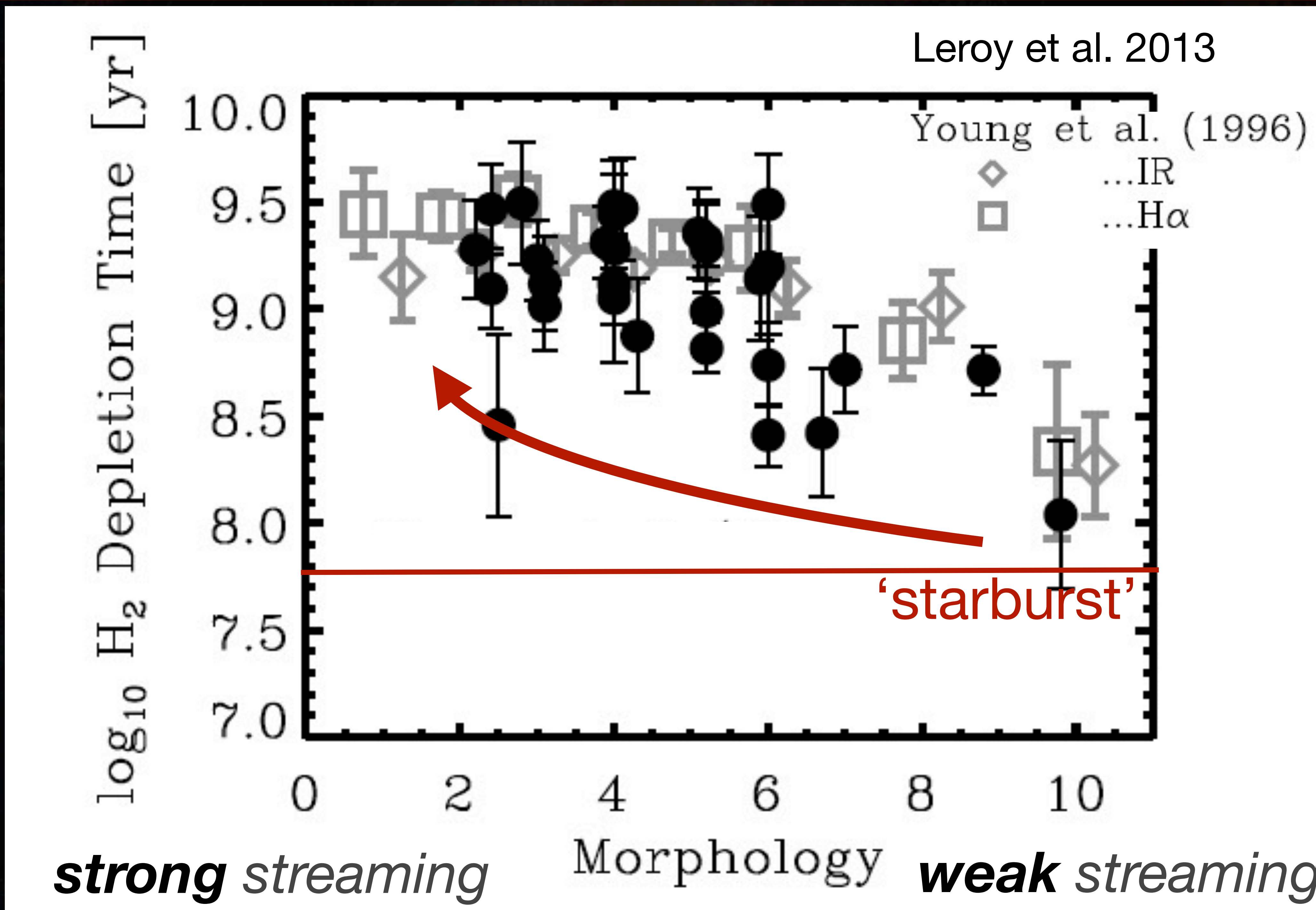
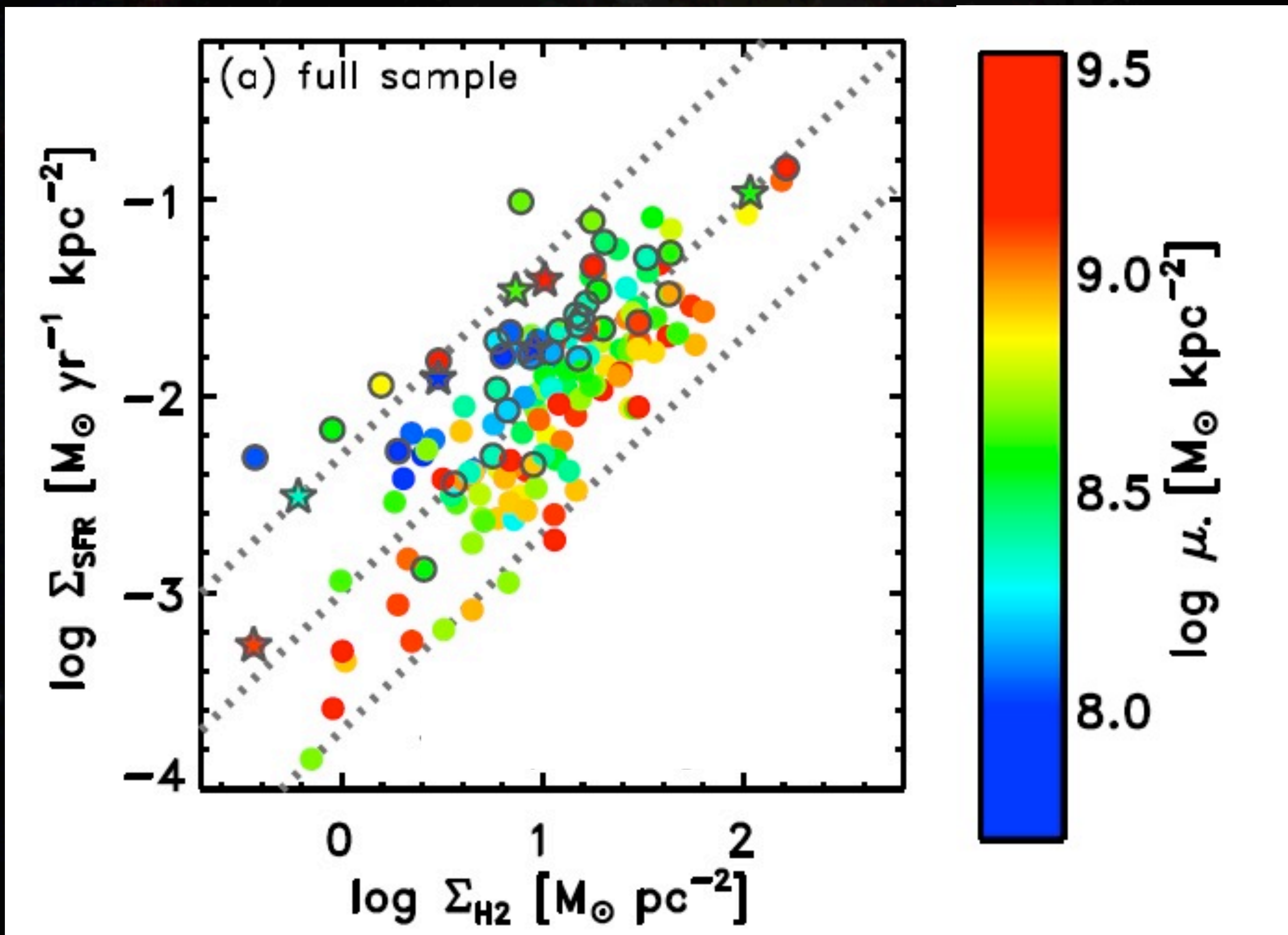


COLD GASS:
Saintonge et al. (2013)



Take Away

is there a universal
cloud?

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No

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is there a mix of active + non-active clouds?

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- conversion of gas to stars impacted by galactic dynamics

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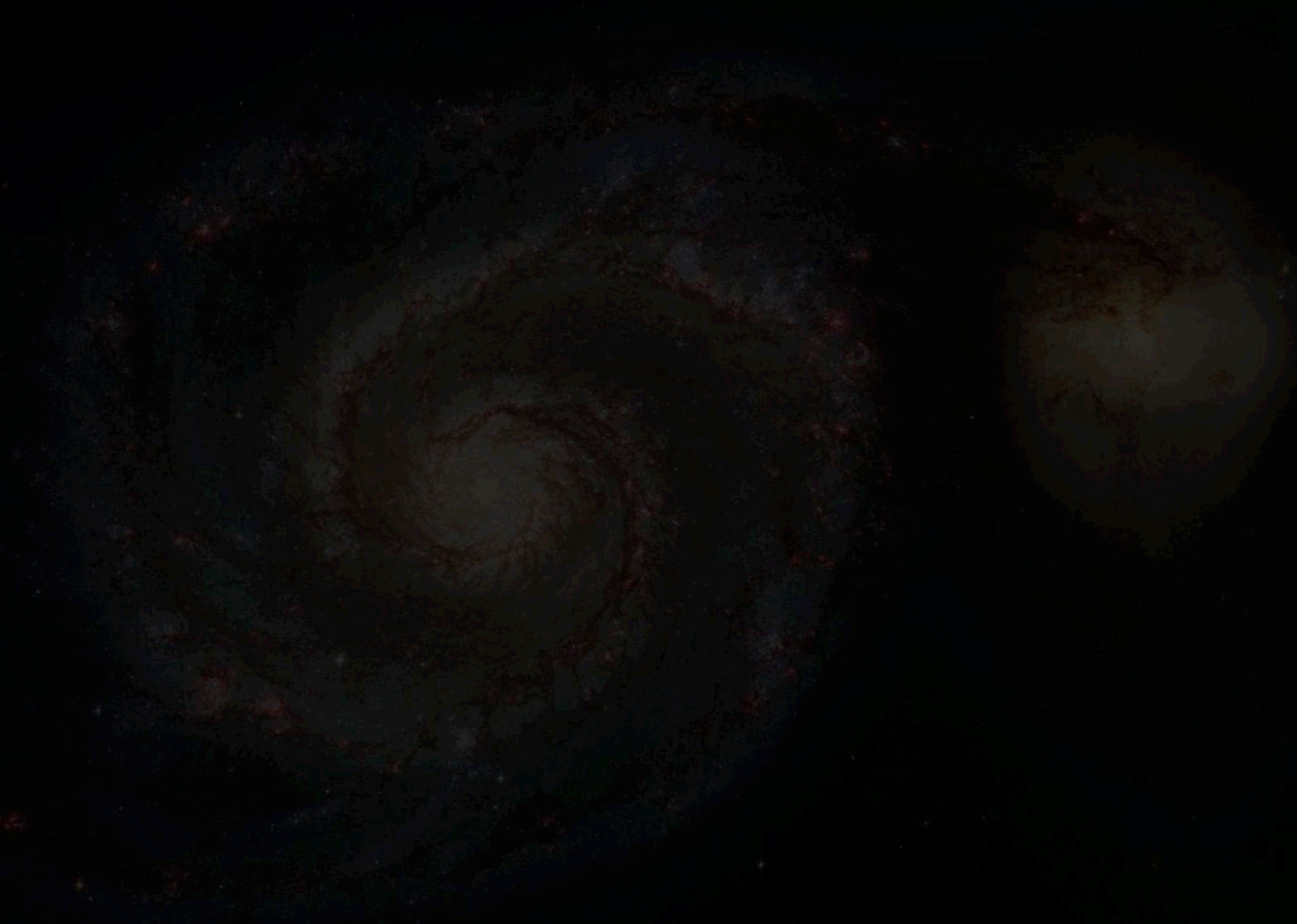
- conversion of gas to stars impacted by galactic dynamics
- non-circular streaming motions ***suppress*** *star formation* and ***lengthen*** *depletion time*
- physical interpretation for scatter in ‘Kennicutt-Schmidt’ star formation relation + a smooth link to high-z star formation



Impact of environment

- **dynamical suppression/regulation of star formation**
  - test: M51 cloud stability, pressure + gas motions
  - implications for universal SF relation
- **cloud lifetimes**
- **internal cloud structure**

Cloud lifetimes

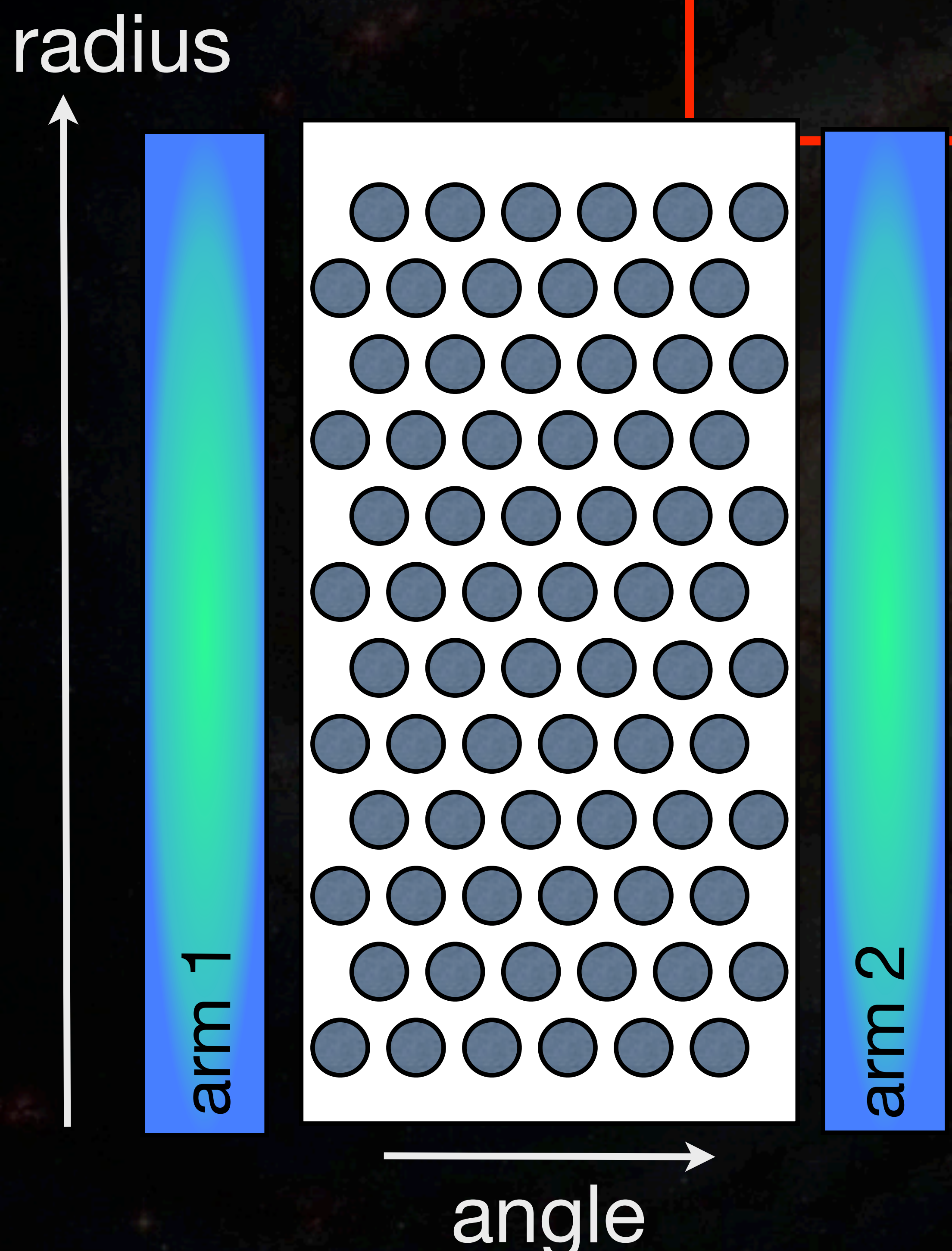
natural limit to timescale to convert gas in to stars

- clouds destroyed by shear, star formation feedback

- processes can be isolated in M51
  - in one radial zone: only shear (no feedback)

Cloud lifetimes

natural limit to timescale to convert gas in to stars



Meidt et al. (2014, in prep.)

Cloud lifetimes

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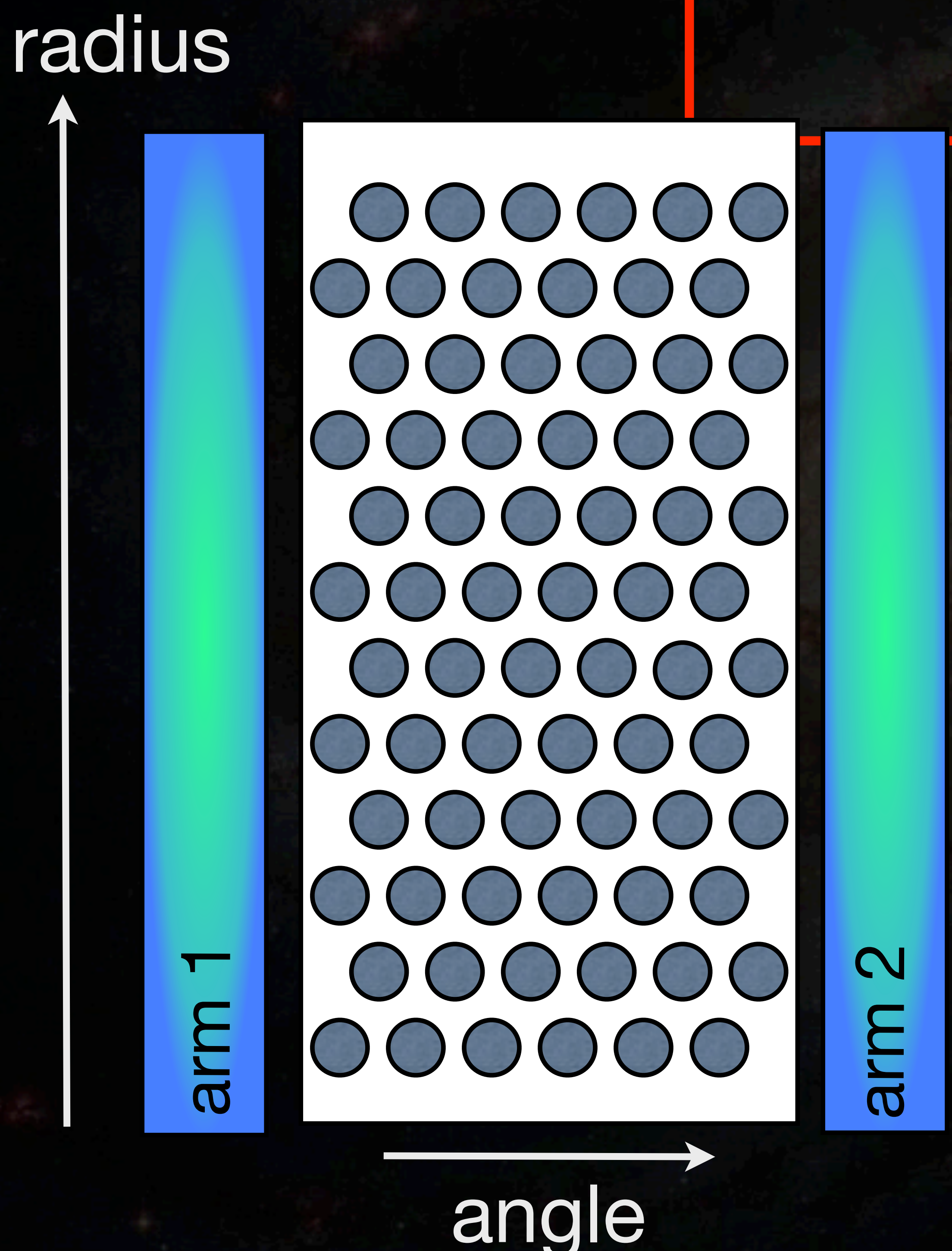

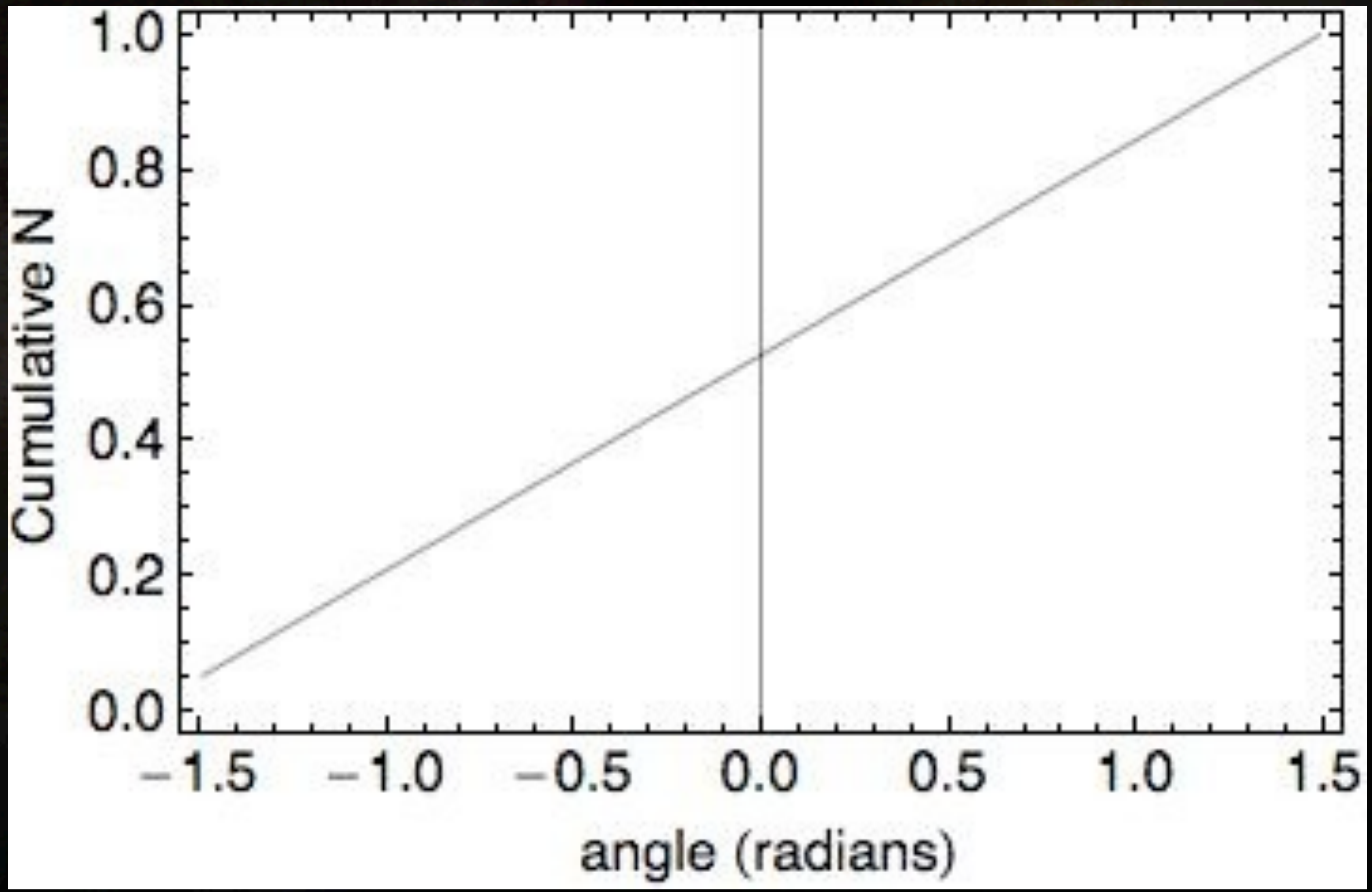

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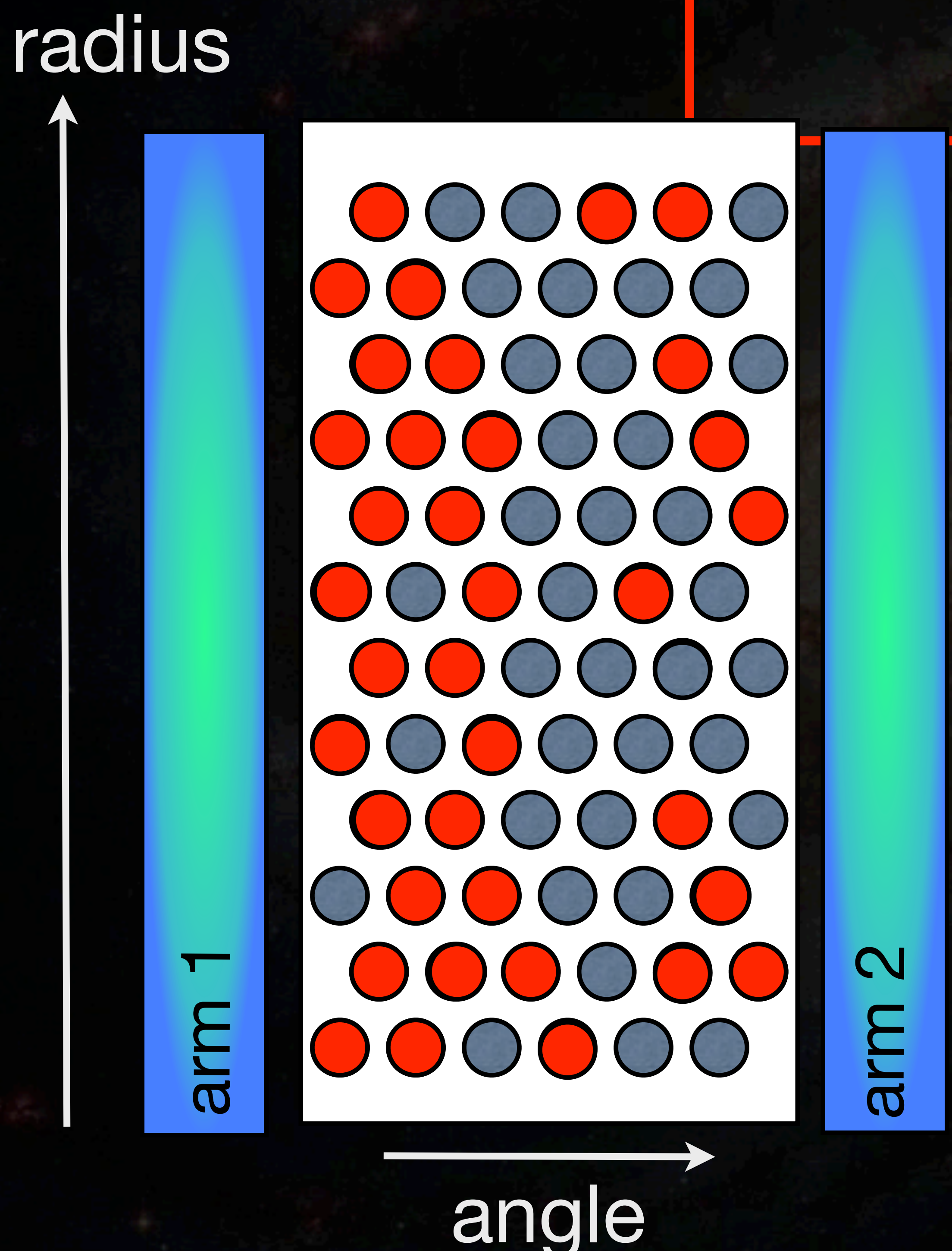

finite lifetime,
number decreases

Meidt et al. (2014, in prep.)

Cloud lifetimes

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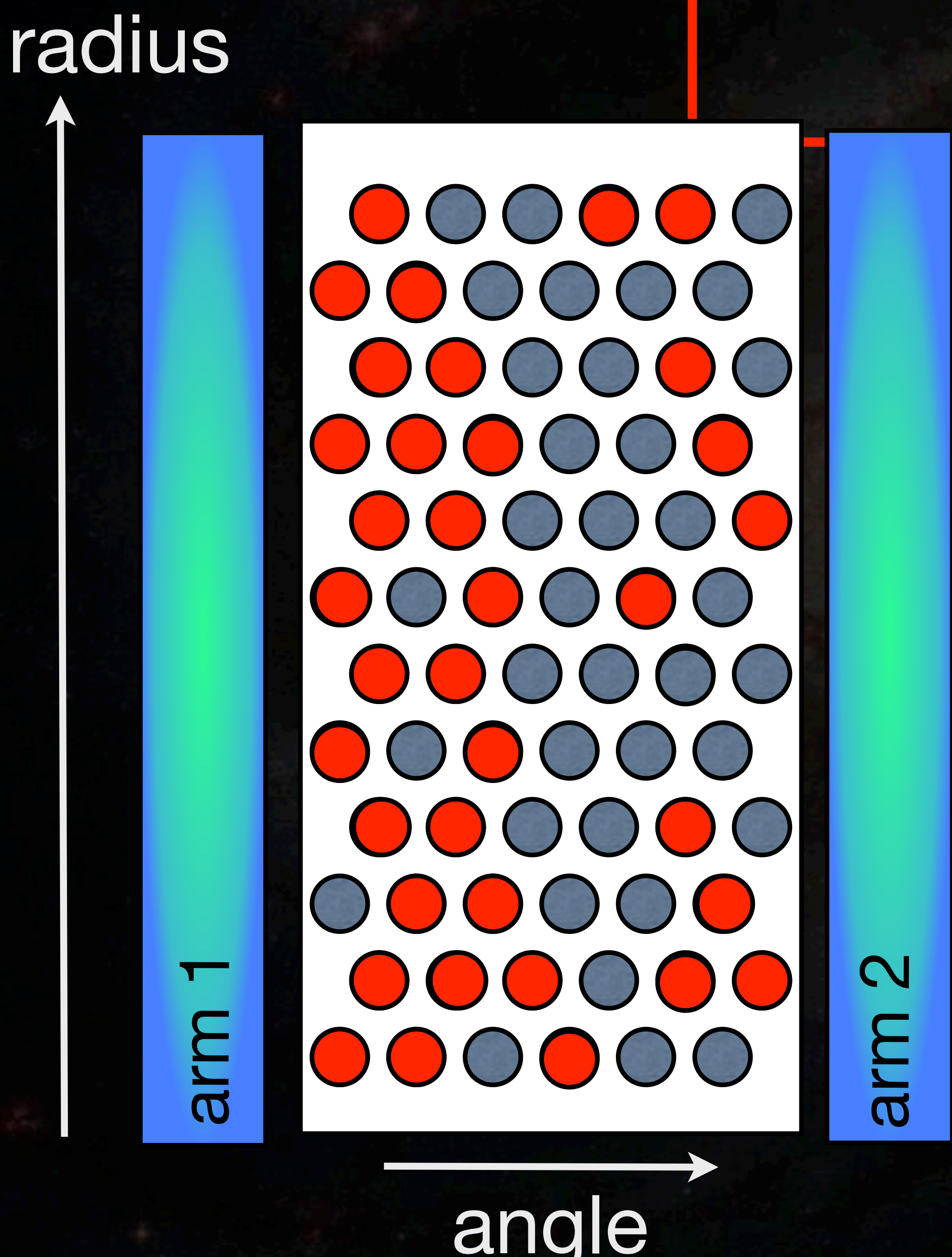

finite lifetime,
number decreases

$$\frac{N_{up}}{N_{down}} = \frac{\tau_{GMC}}{T_{travel}}$$

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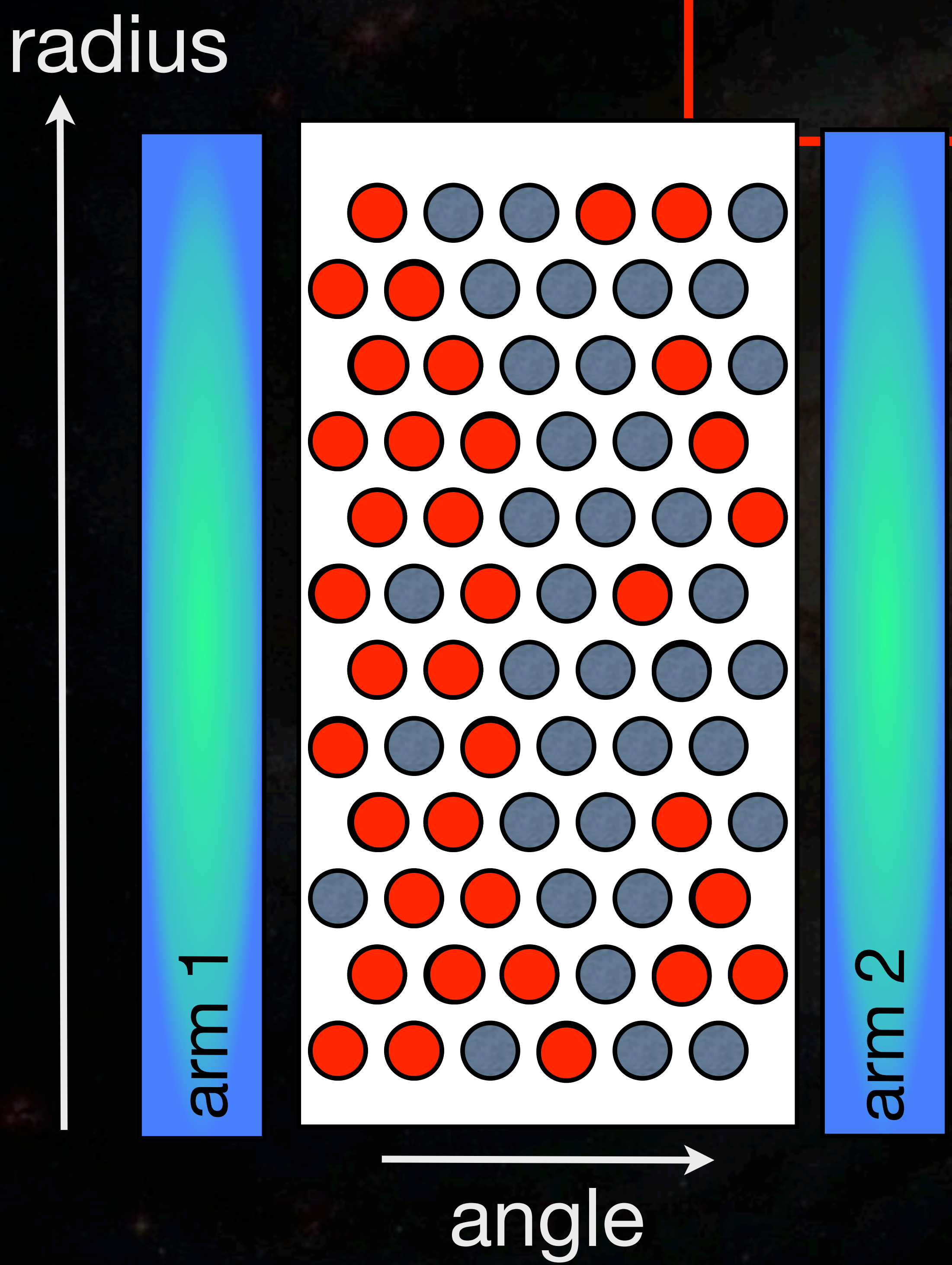
Cloud lifetimes

natural limit to timescale to convert gas in to stars

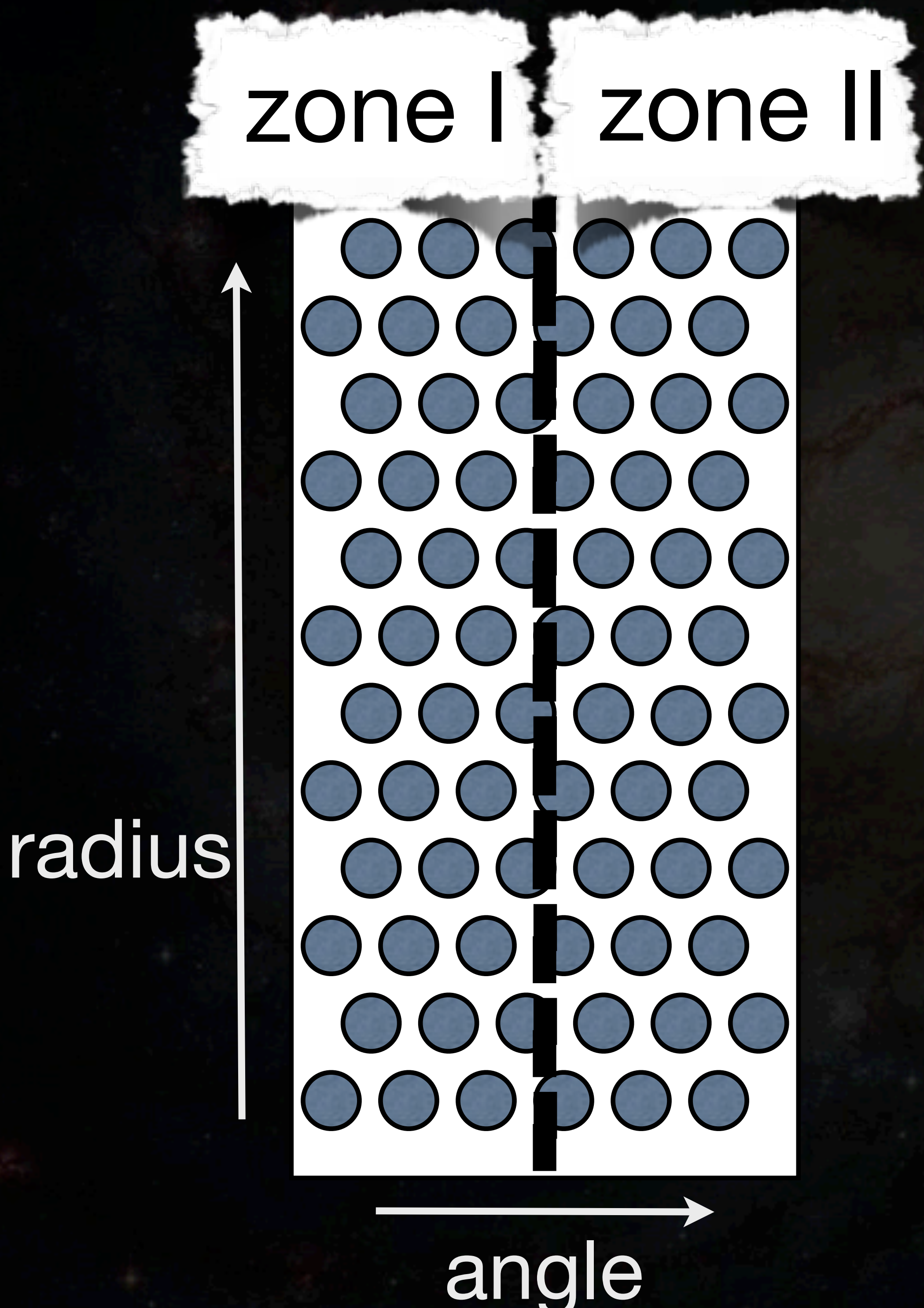


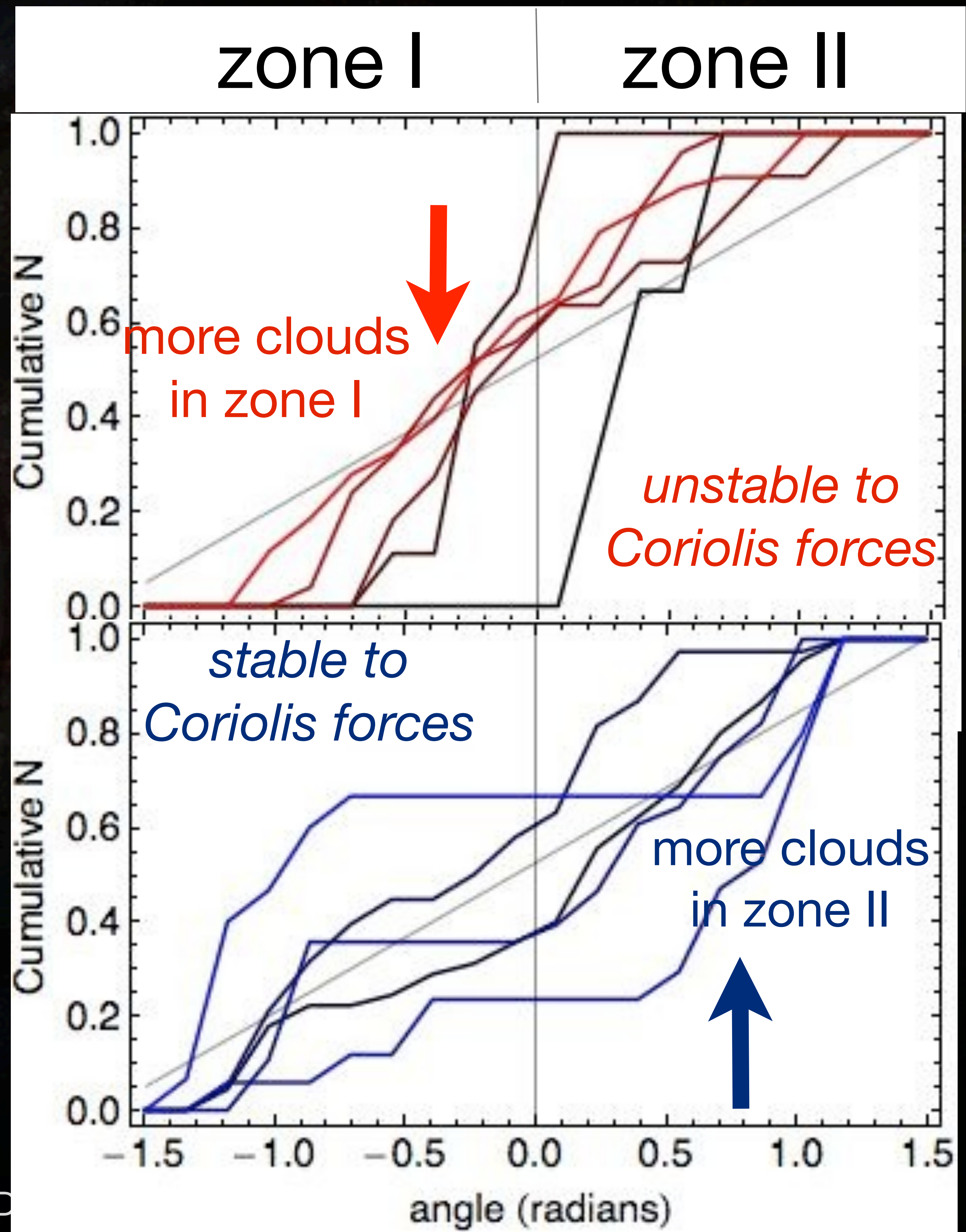
"unstable"
susceptible to Coriolis forces

"stable"
against Coriolis forces

Meidt et al. (2014, in prep.)

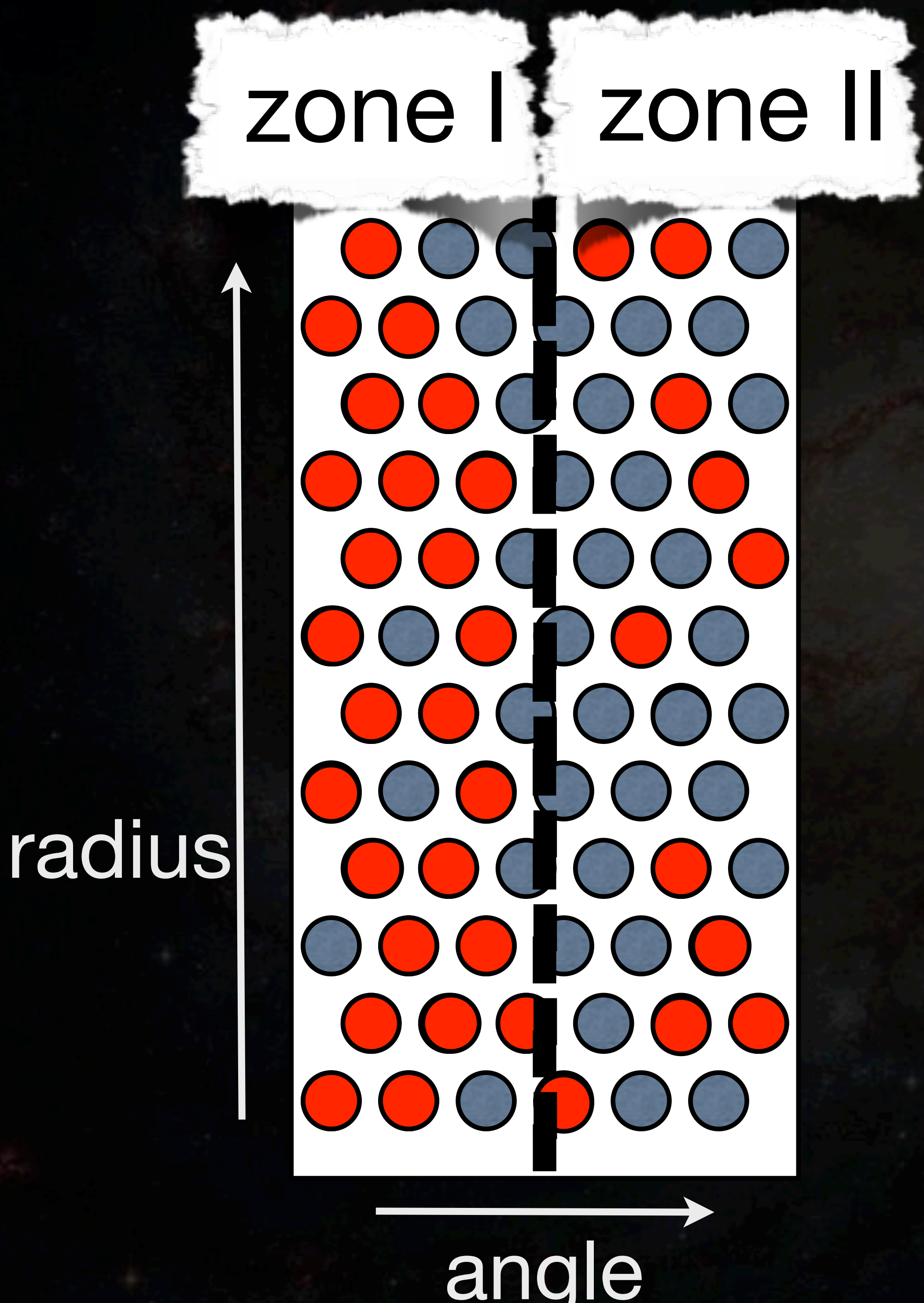
Cloud lifetimes

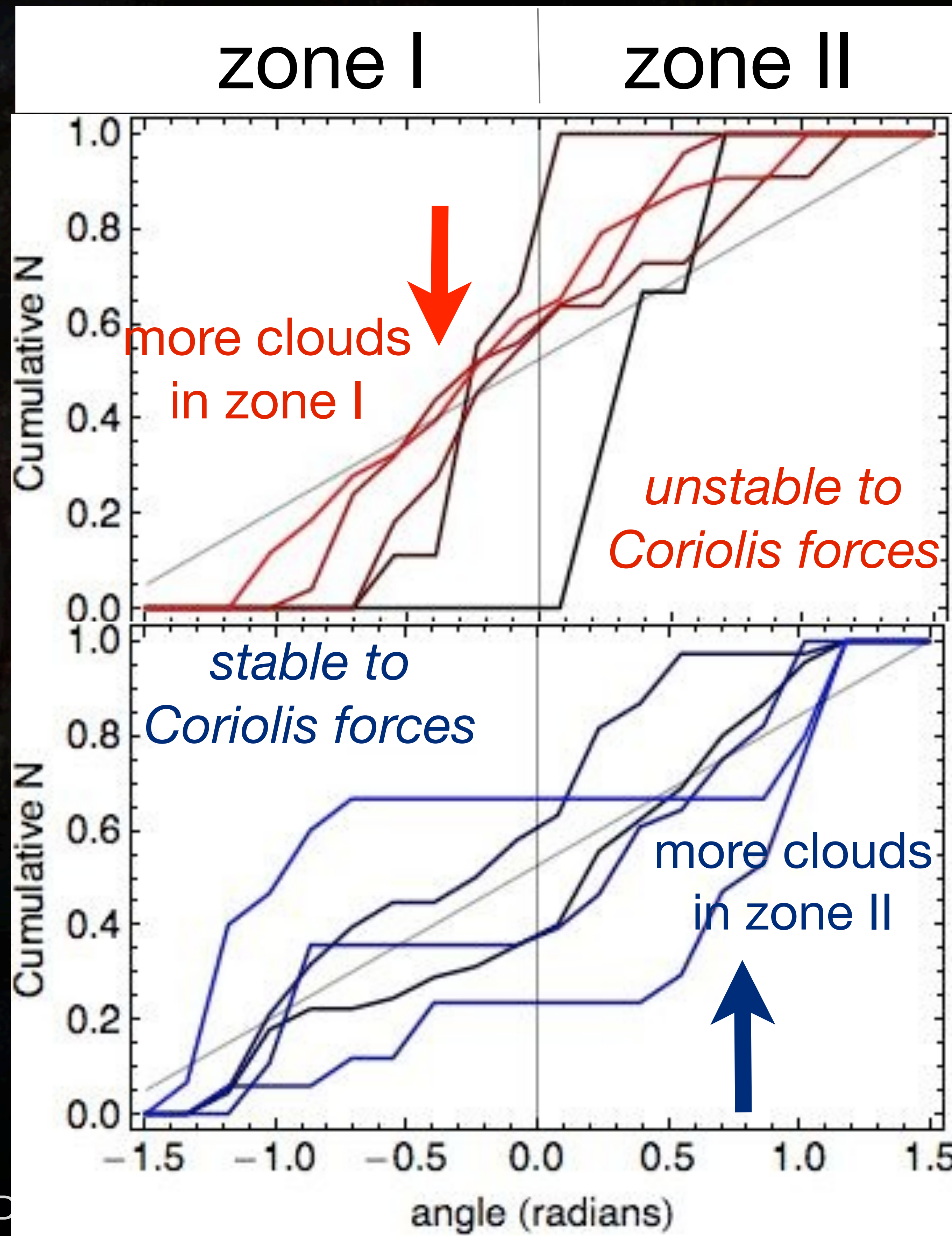




S. E. Meidt, 3D

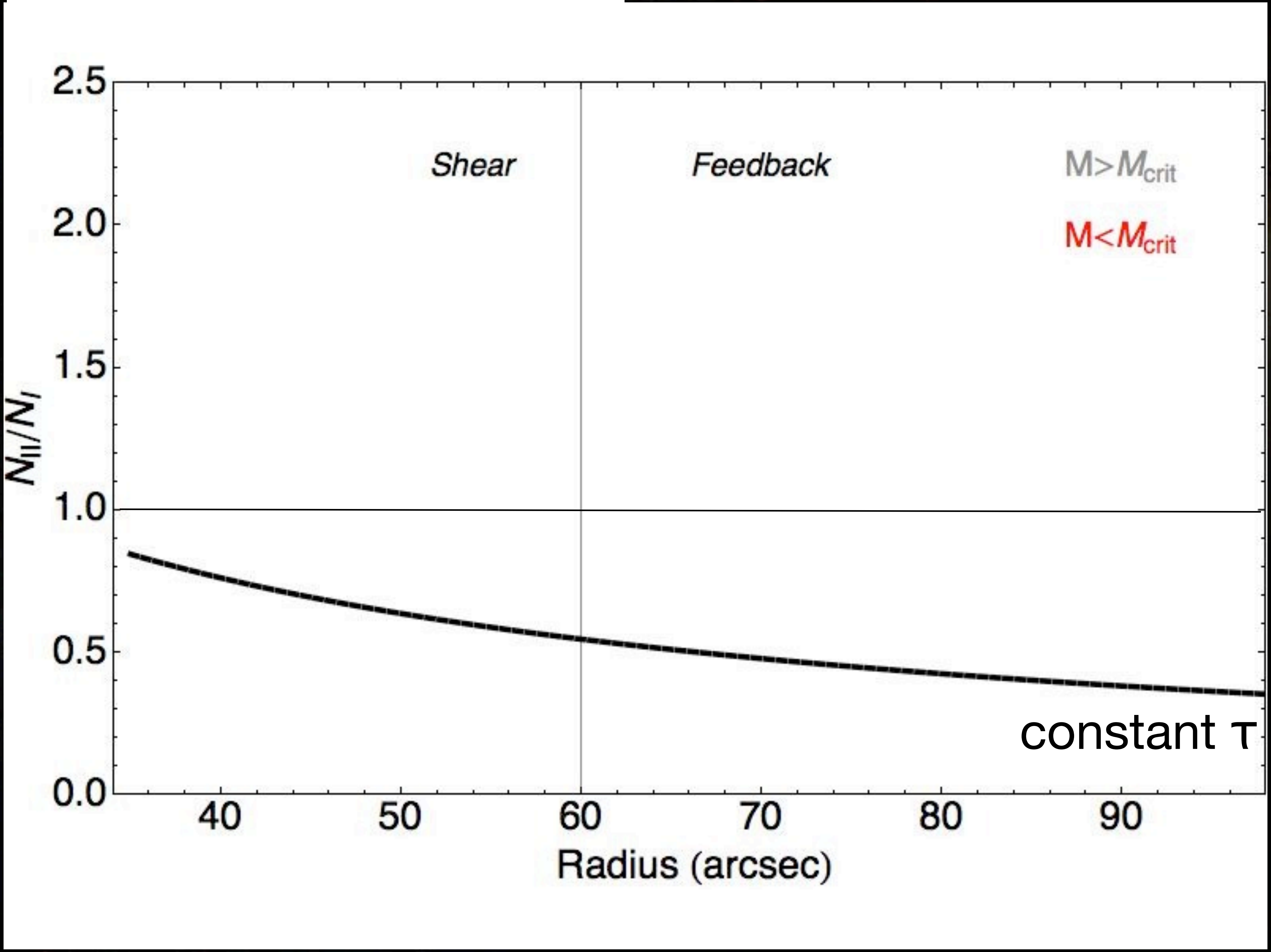
Cloud lifetimes





S. E. Meidt, 3D

split inter-arm in half



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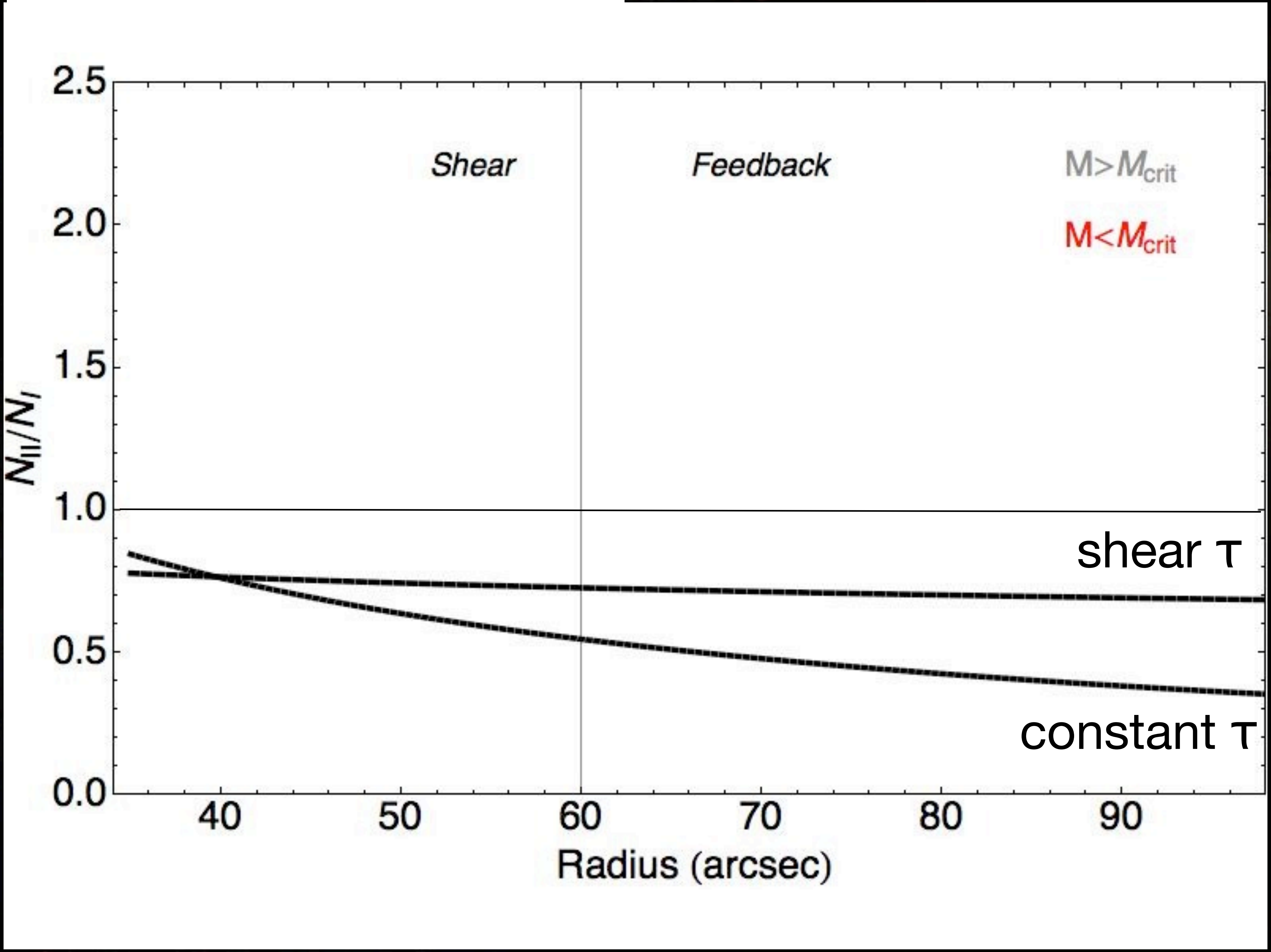

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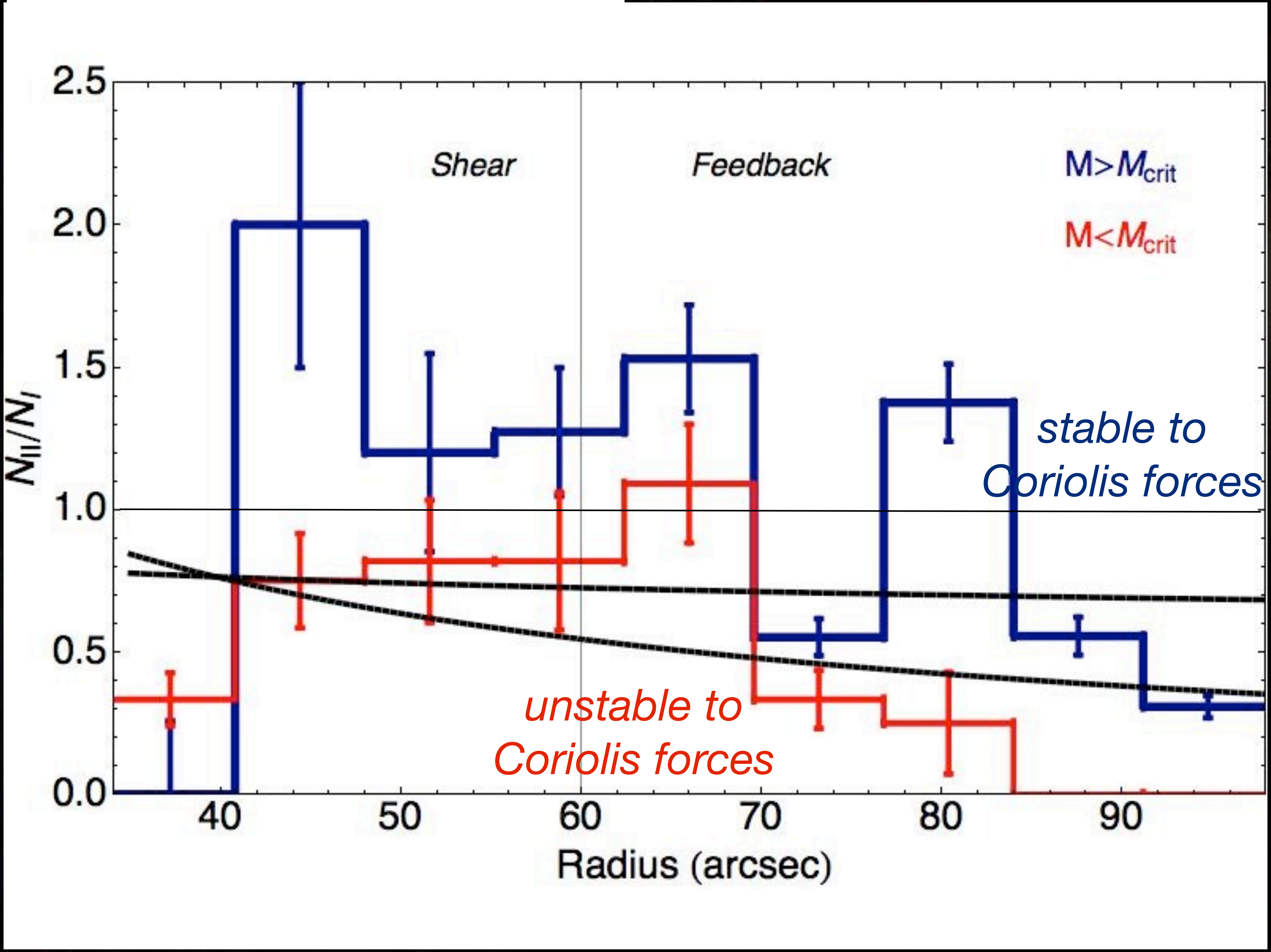

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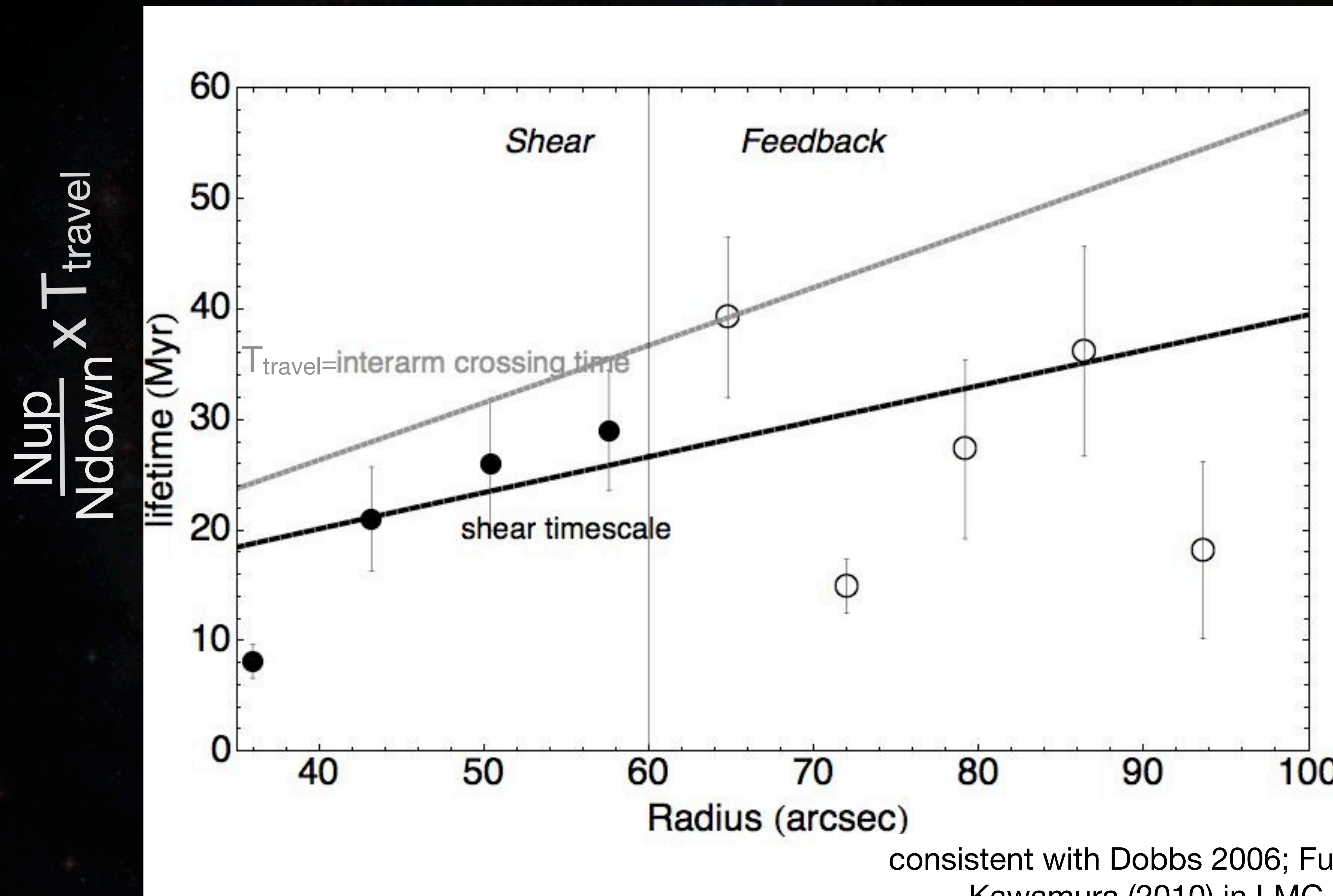
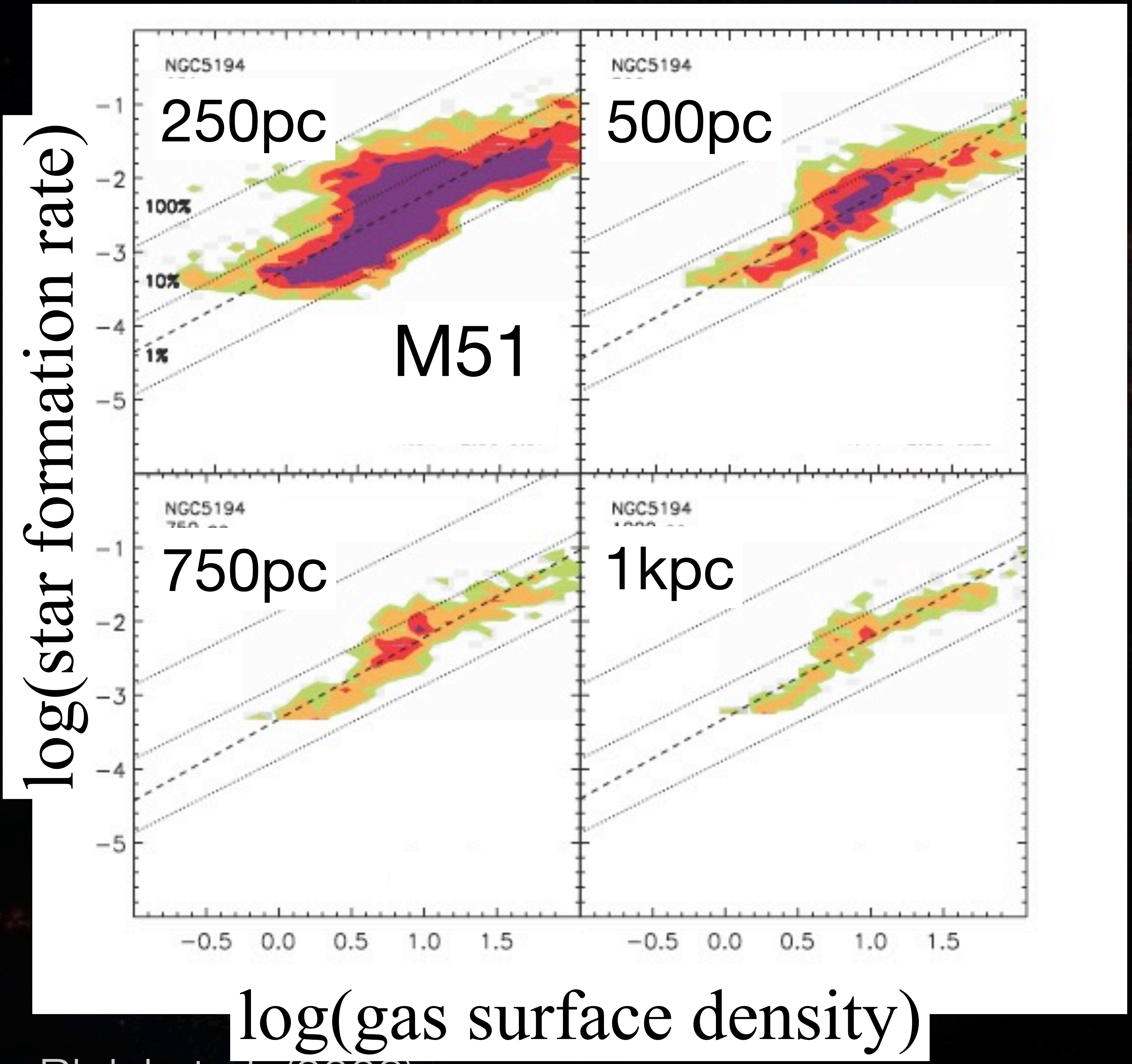


consistent with Dobbs 2006; Fukui & Kawamura (2010) in LMC

Scatter in the Star Formation relation



Bigiel et al. (2008)

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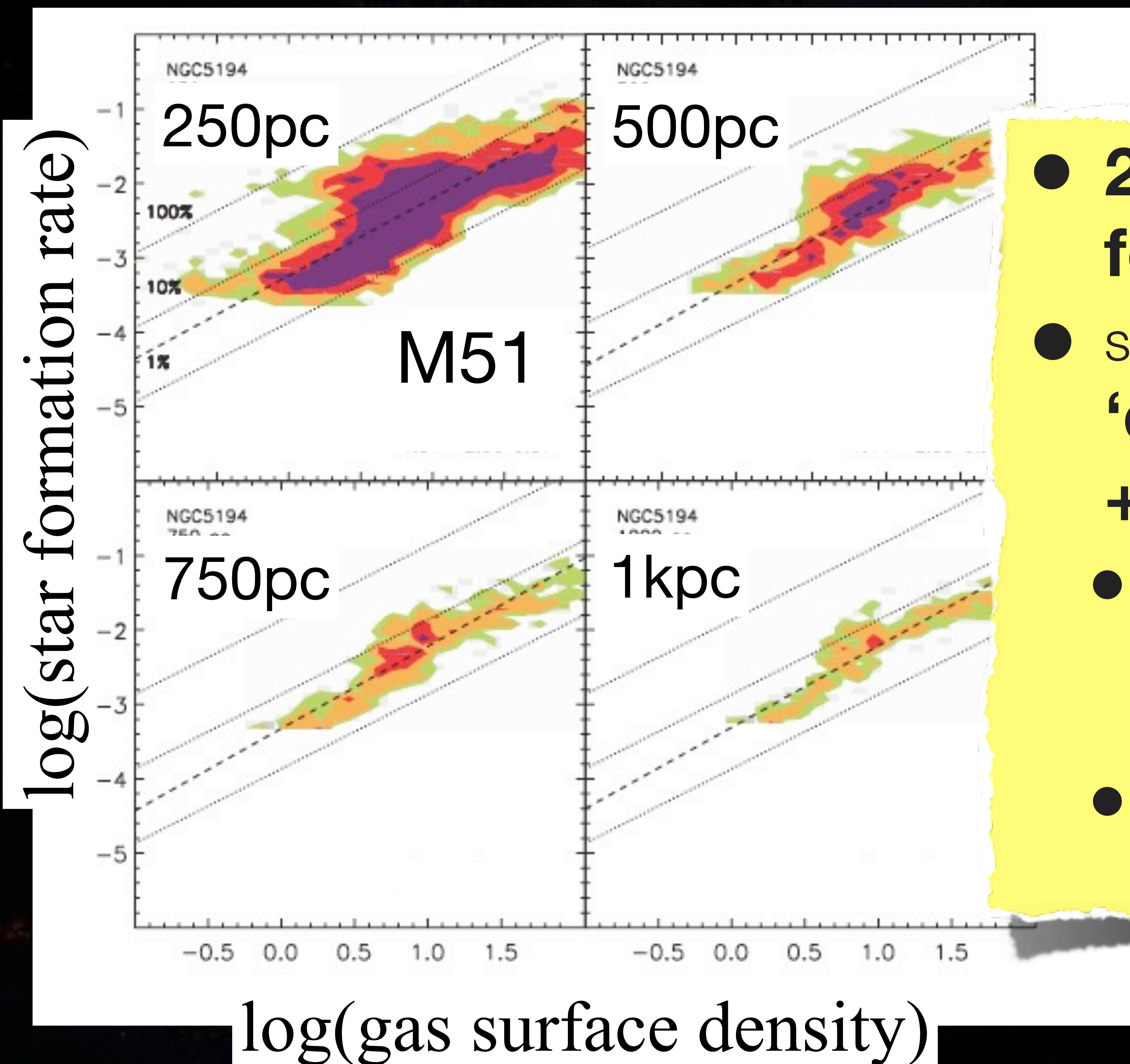

Bigiel et al. (2008)

- **2 modes of star formation**?
- scale-dependent scatter: **‘discreteness +stochasticity’**:
  - temporal & spatial decoupling of gas and stars
  - stellar feedback--cloud dispersal/destruction

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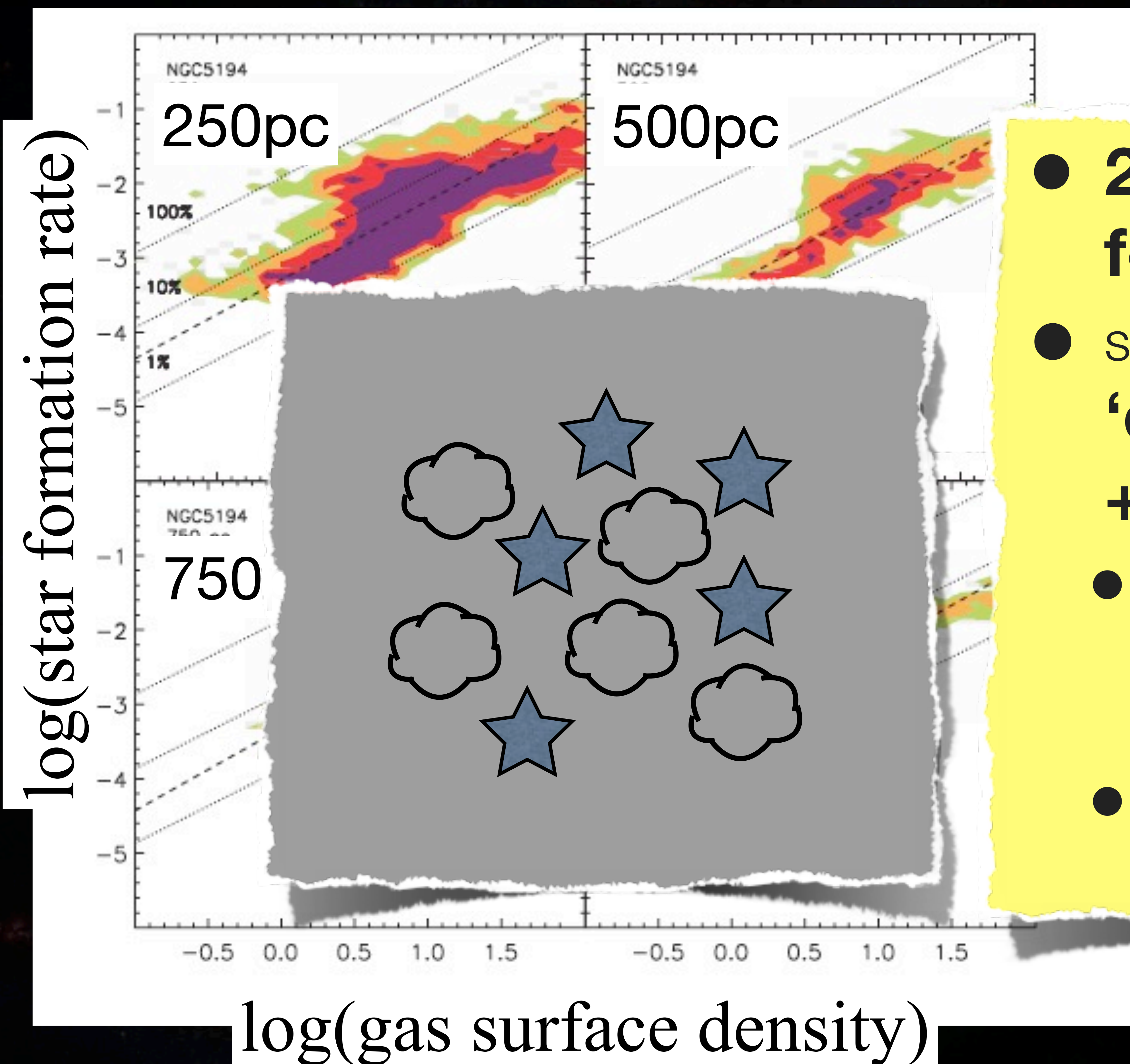

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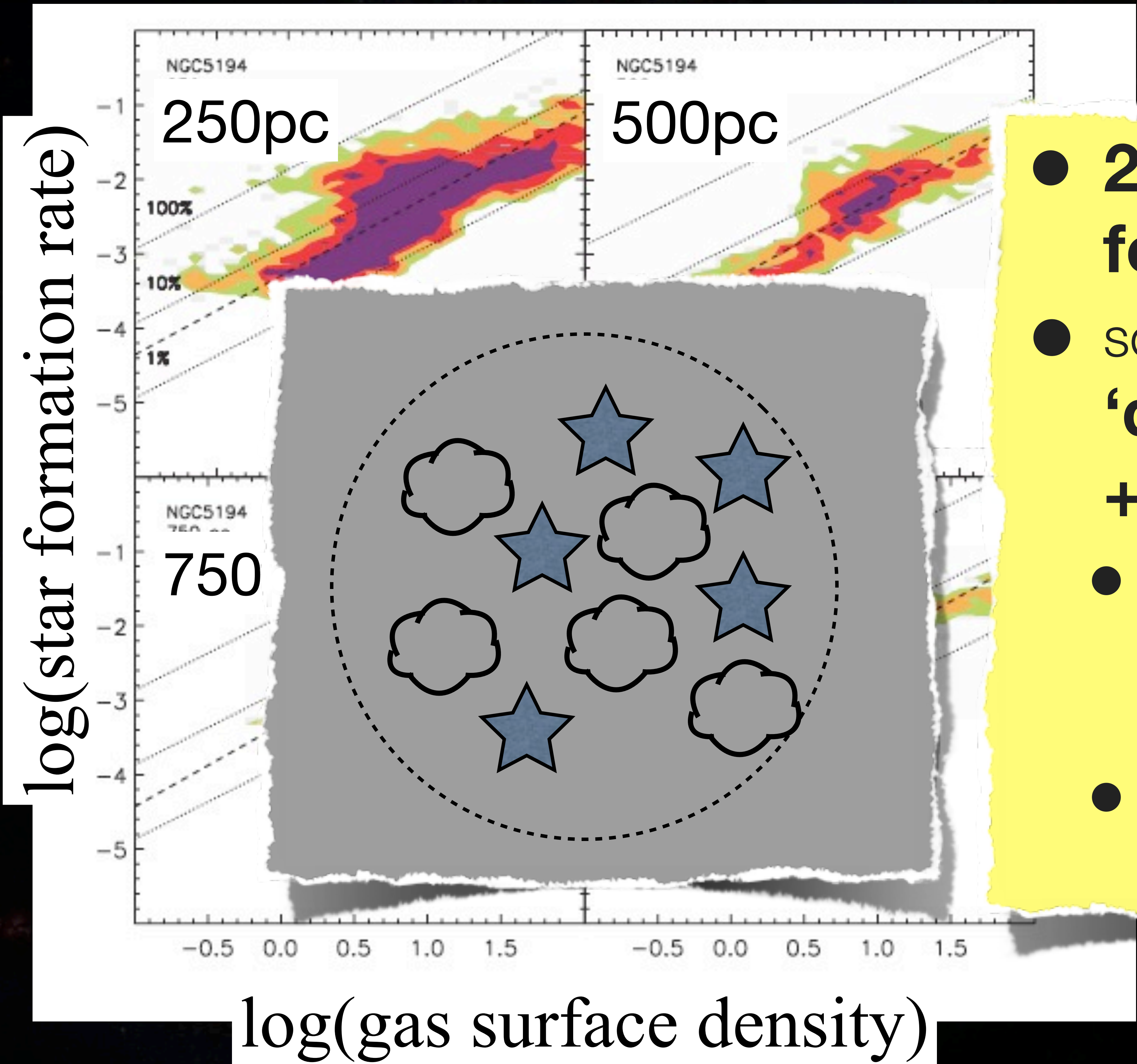

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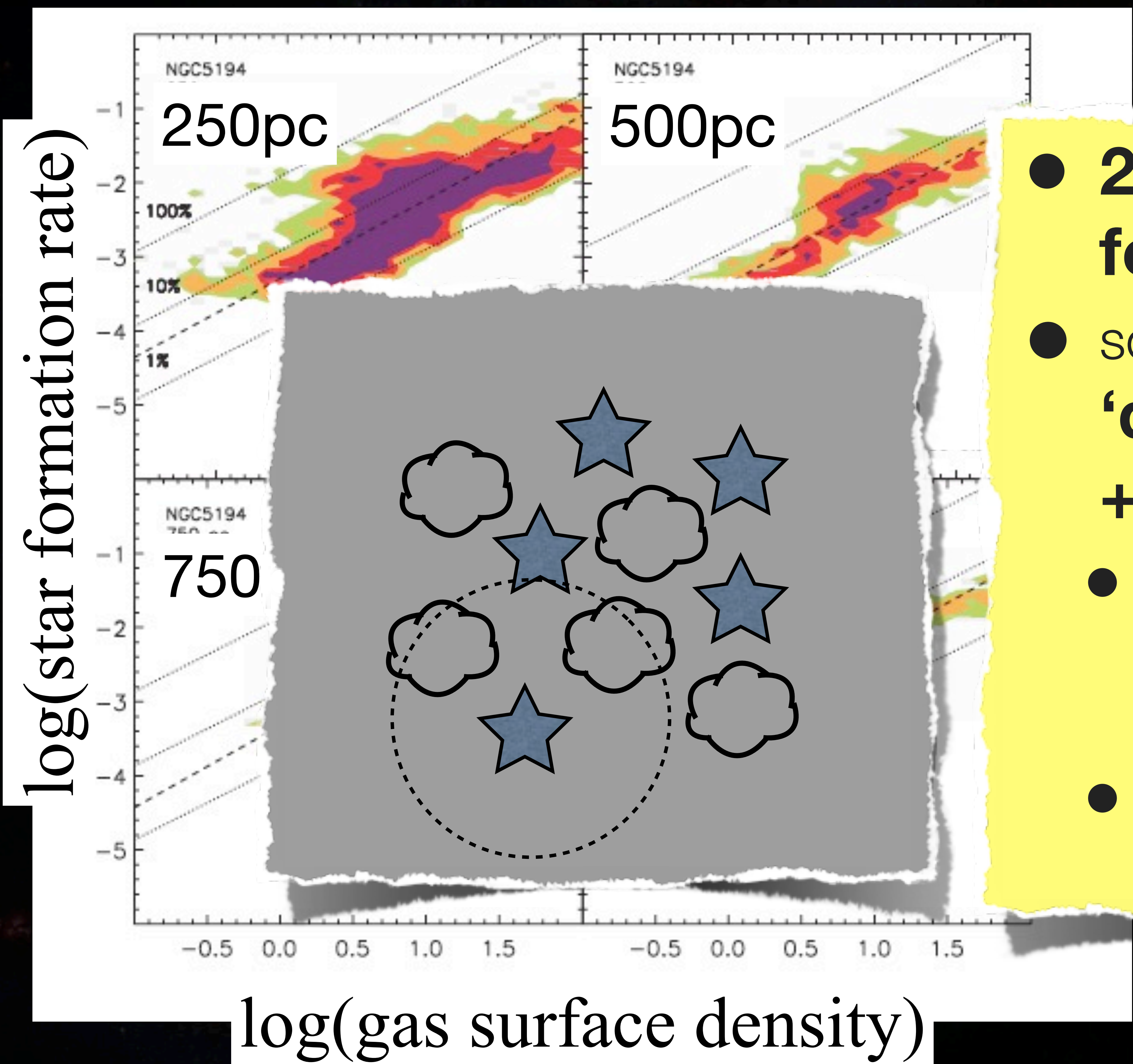

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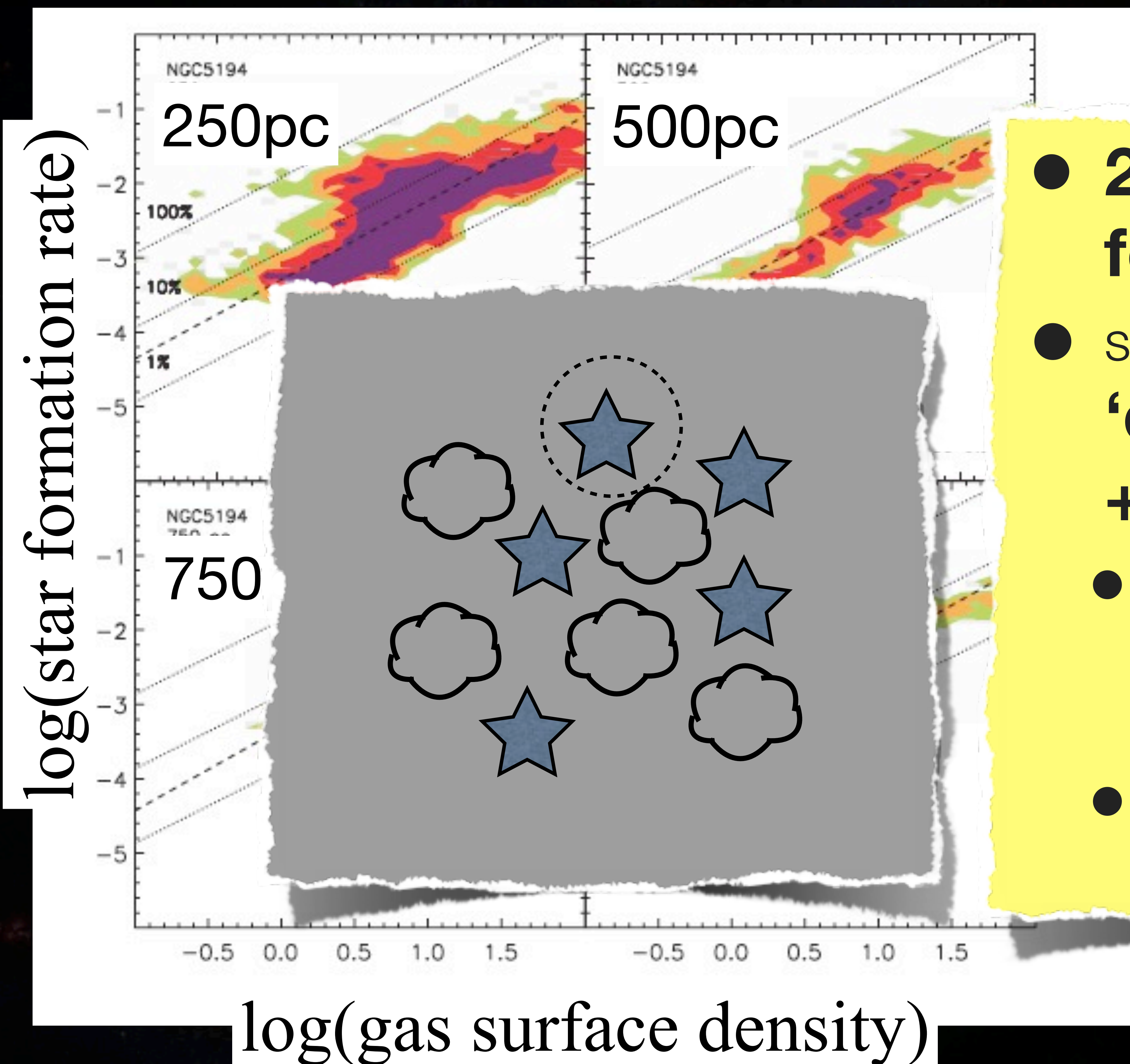

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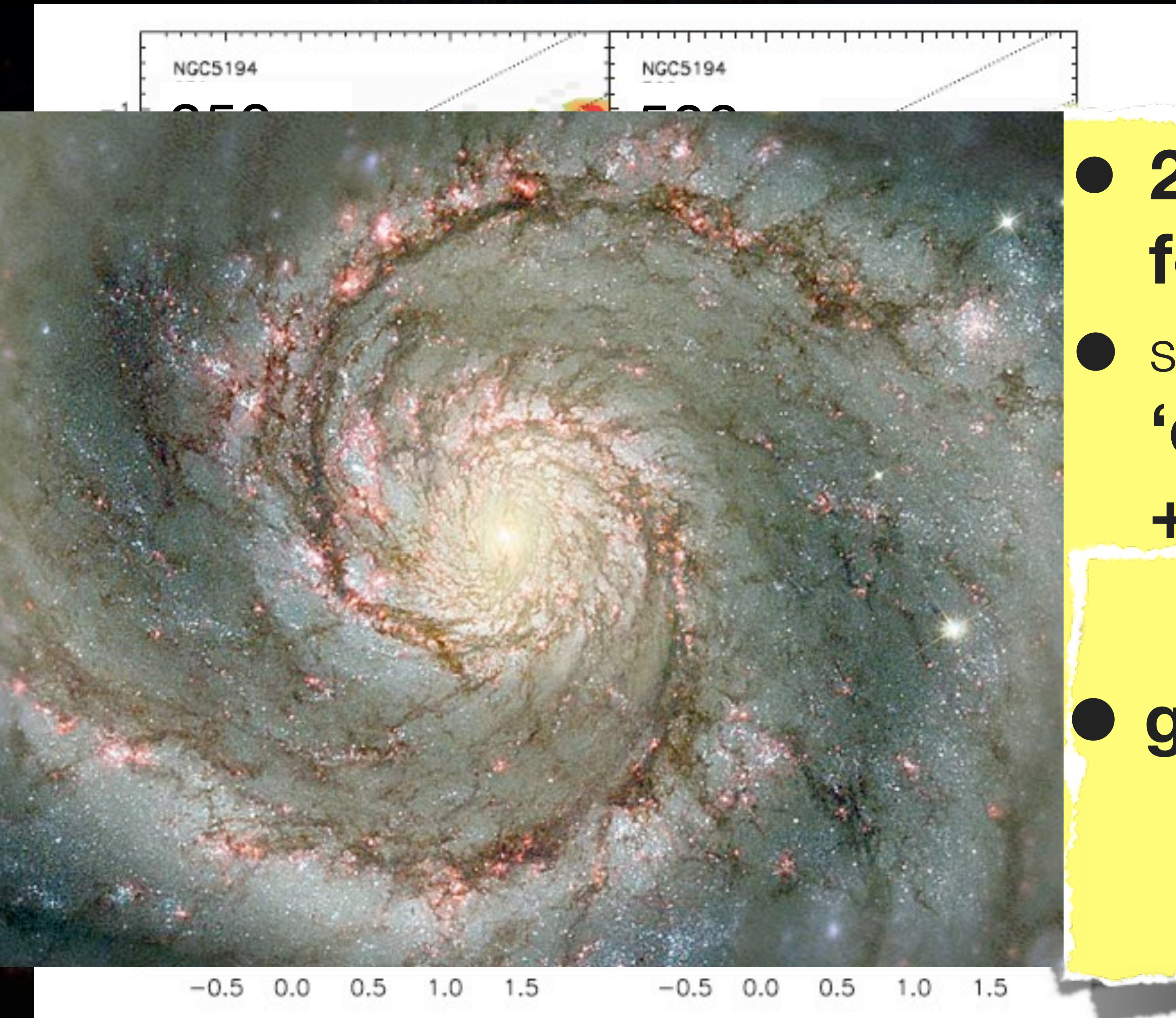
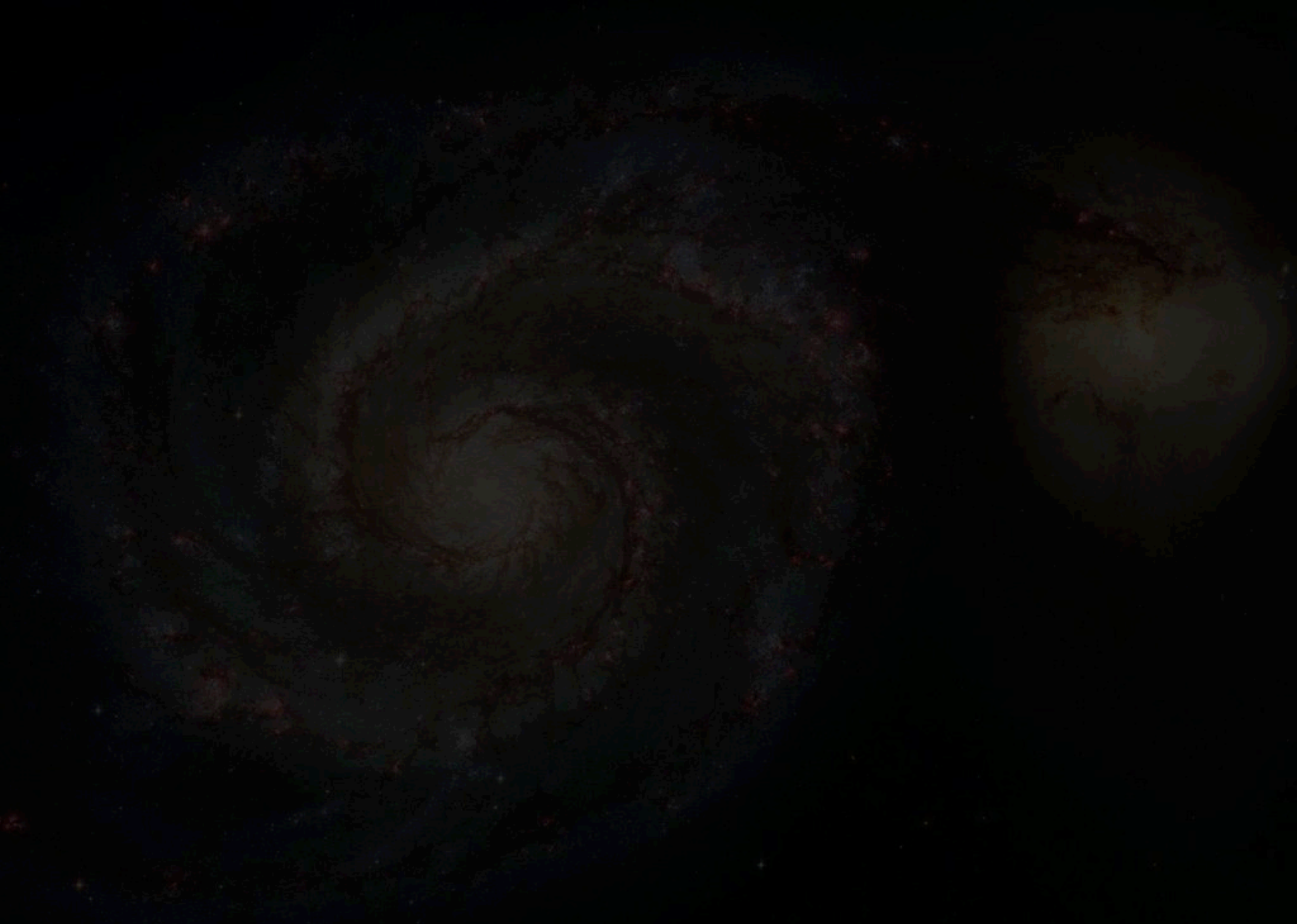
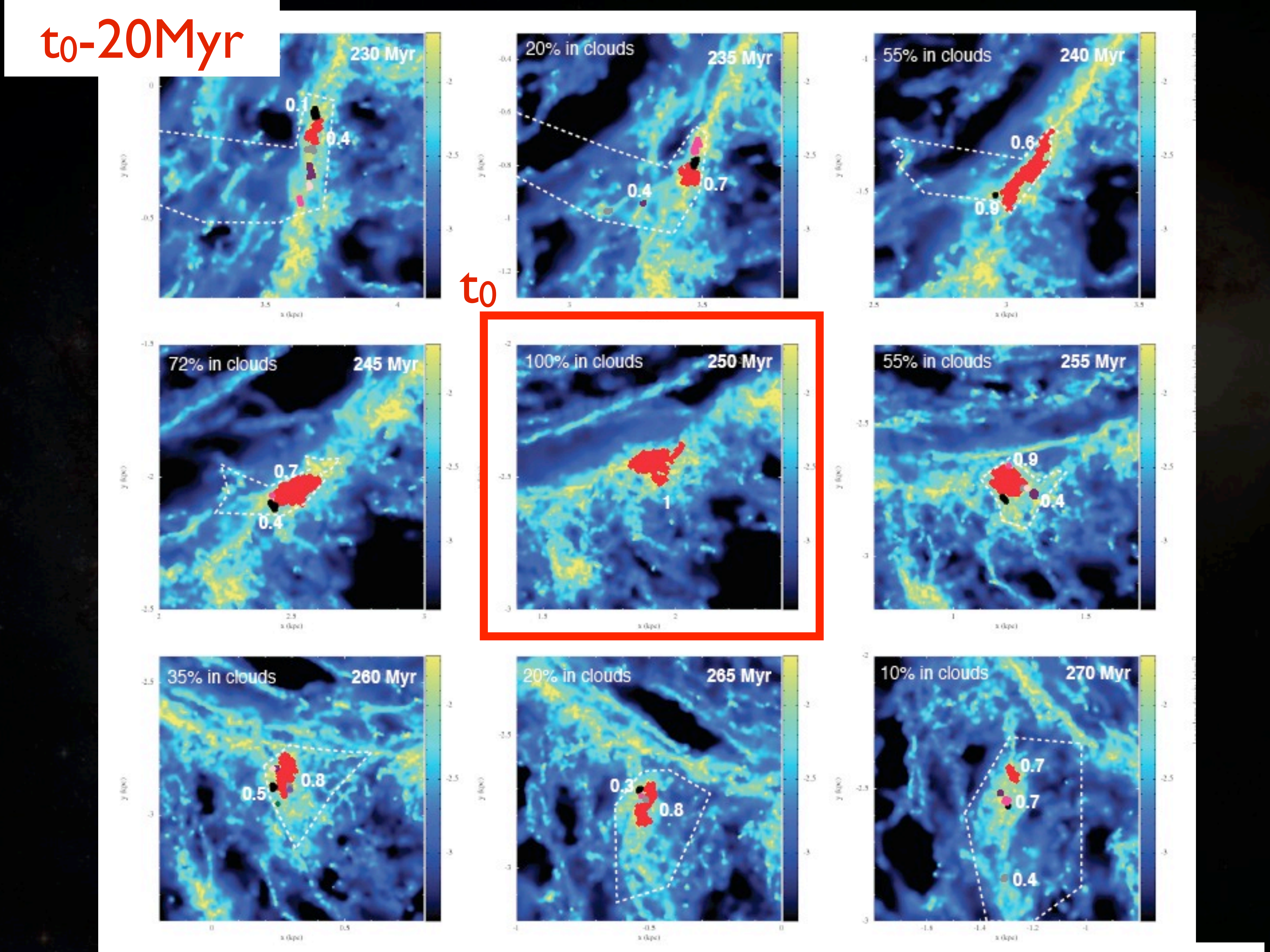


log(gas surface density)

Bigiel et al. (2008)

- **2 modes of star formation**?
- scale-dependent scatter: **‘discreteness +stochasticity’**:
- **galaxy dynamics**





Dobbs & Pringle (2013)