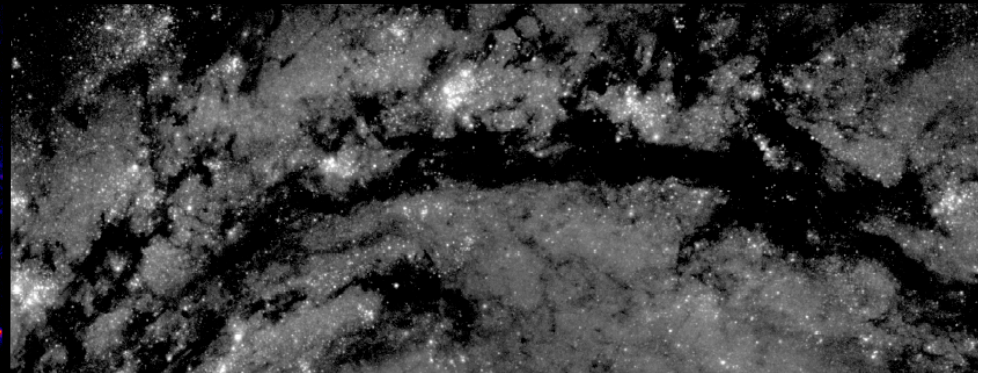
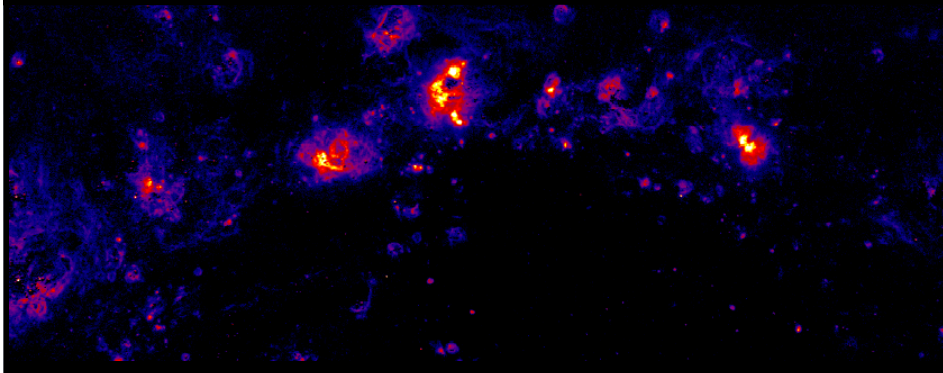
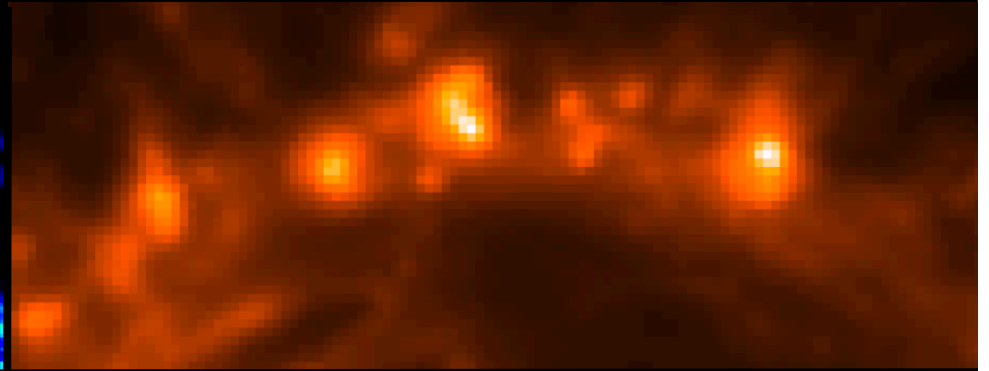
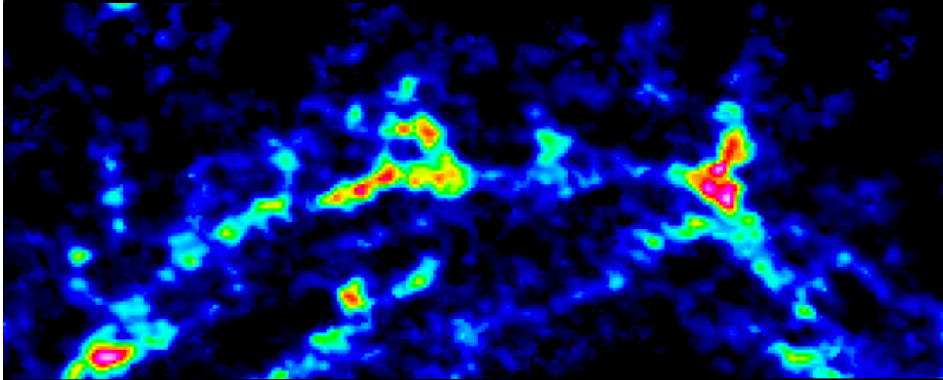


# Anatomy of a Spiral Arm



Eva Schinnerer

Max Planck Institute for Astronomy



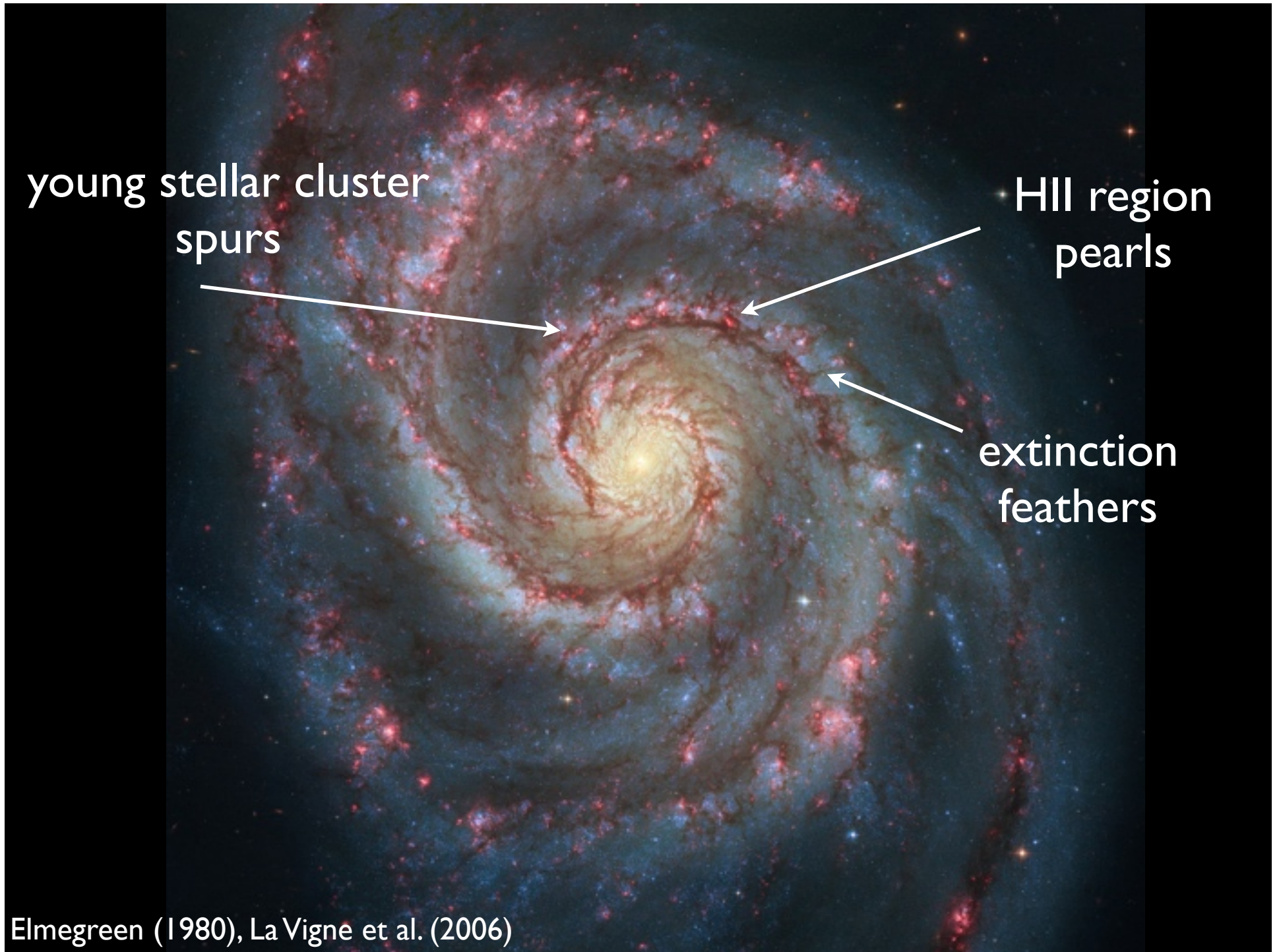


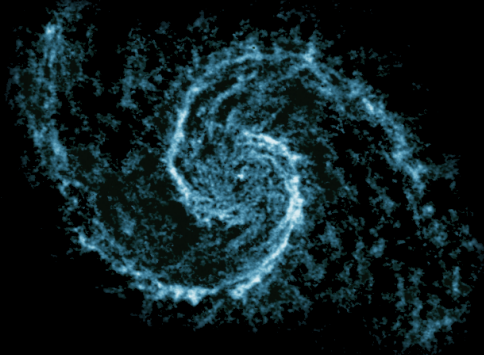
young stellar cluster  
spurs

HII region  
pearls

extinction  
feathers

Elmegreen (1980), La Vigne et al. (2006)





PdBI Arcsecond Whirlpool Survey

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



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

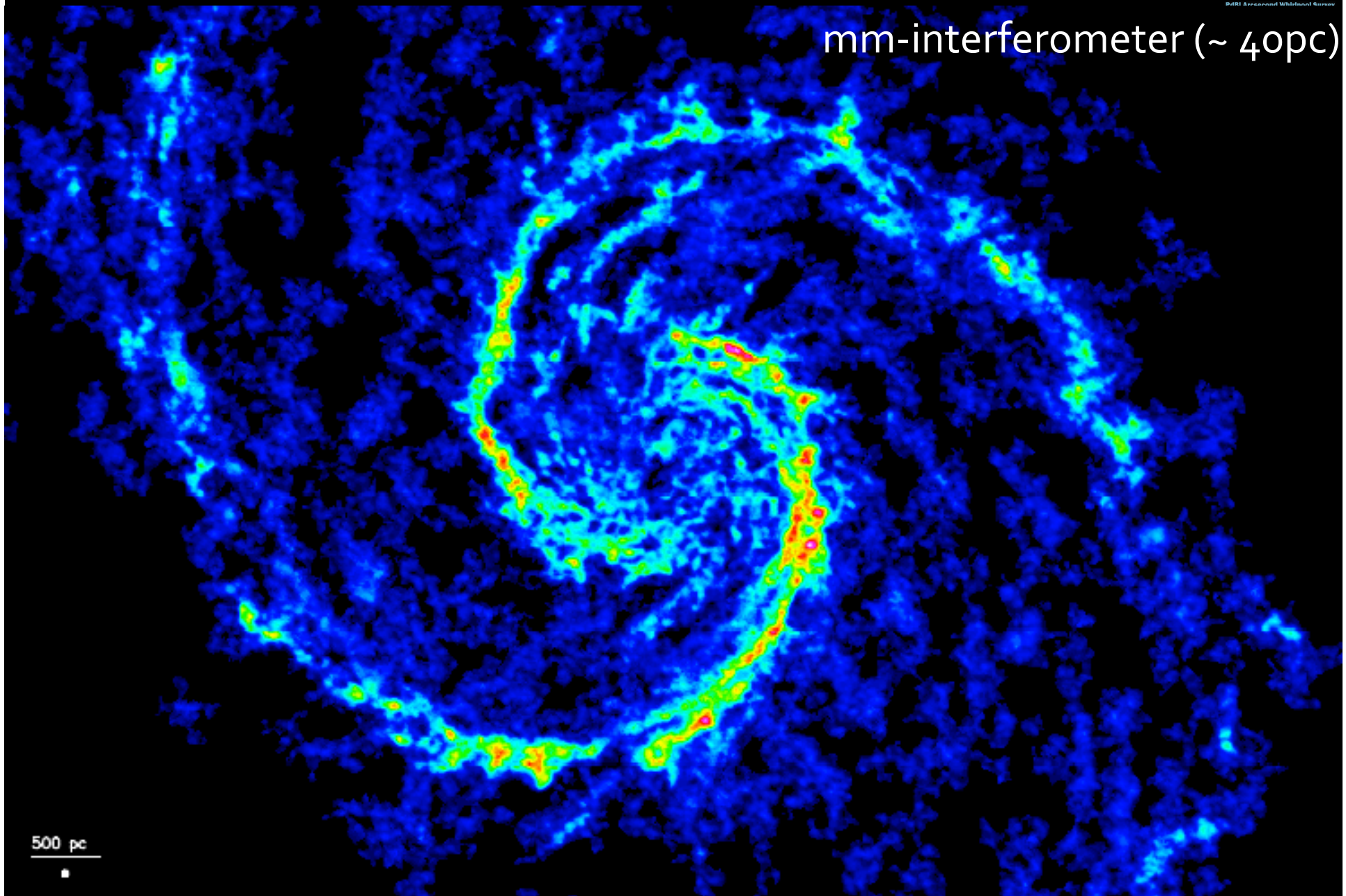




# Molecular Gas Disk of M51

Schinnerer et al. (2013)

mm-interferometer (~ 40pc)

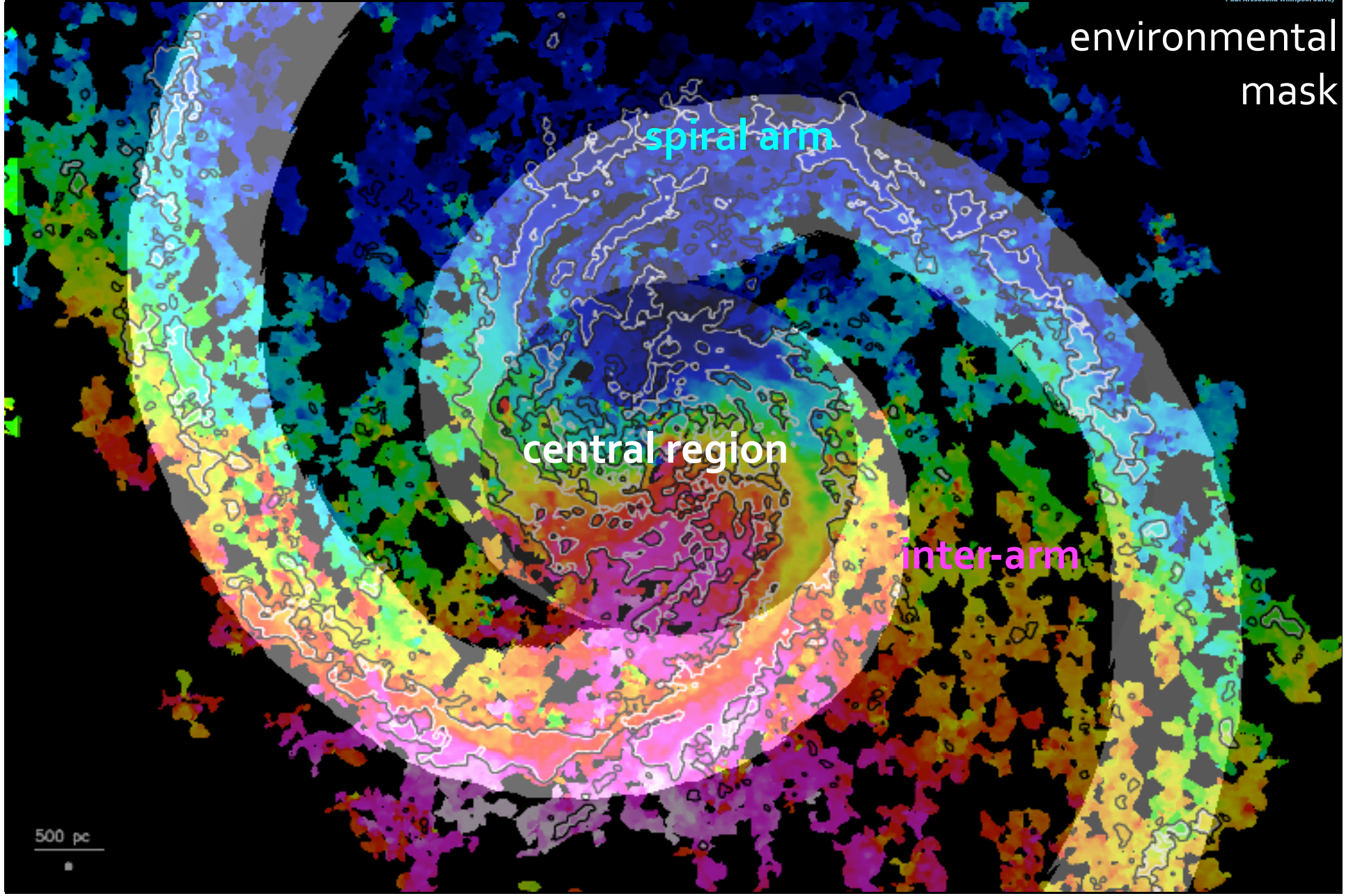


500 pc

# Molecular Gas disk of M51

Colombo et al. (subm.)

environmental  
mask



spiral arm

central region

inter-arm

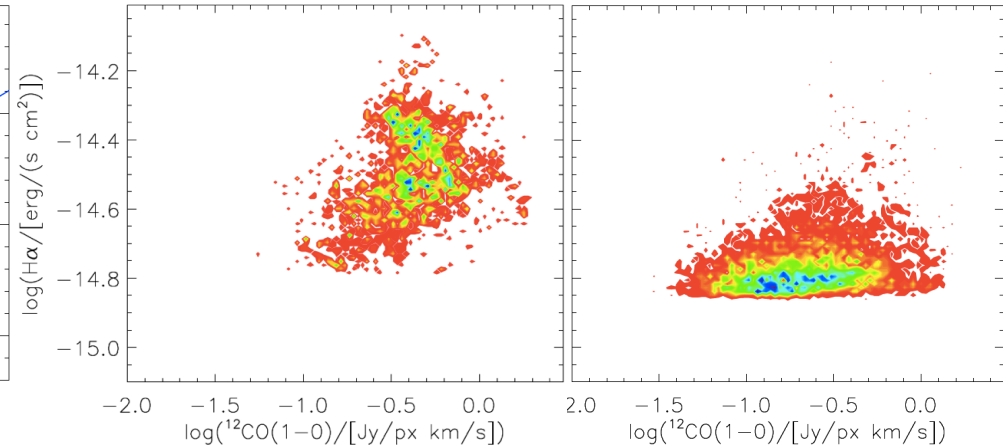
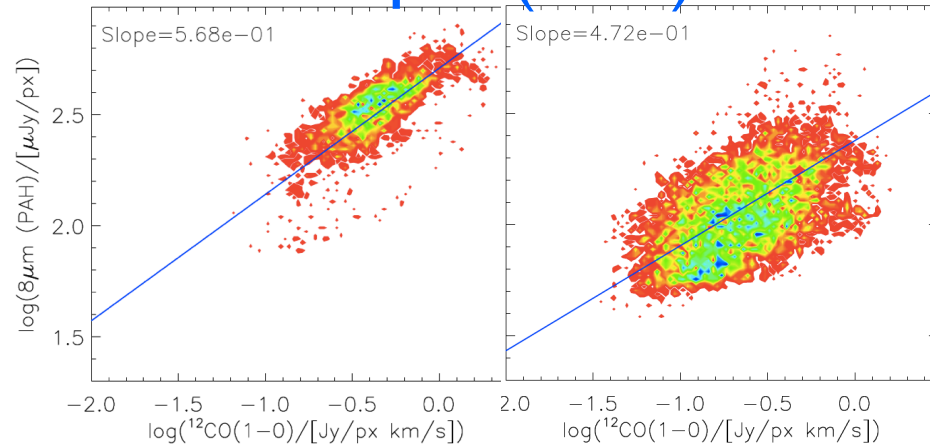
500 pc

# Center vs. Arms in M51

pixel-by-pixel correlation of CO (x-axis) @ 110pc with:

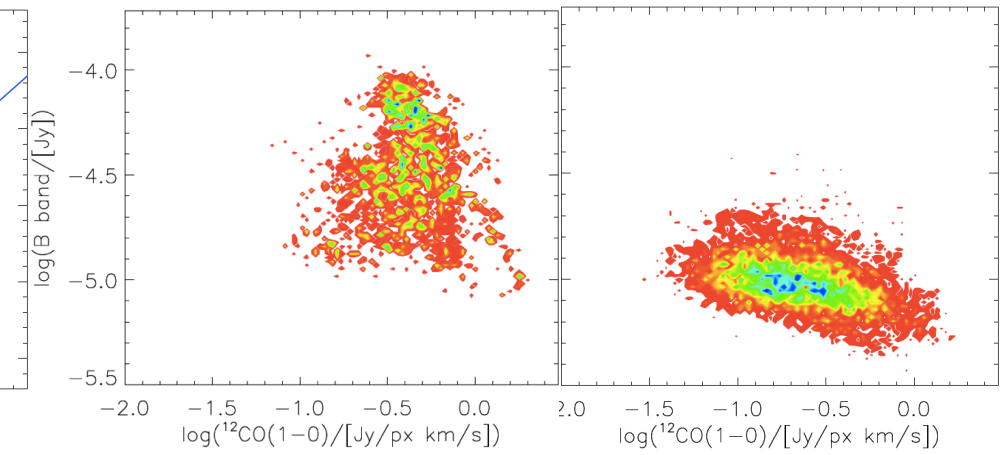
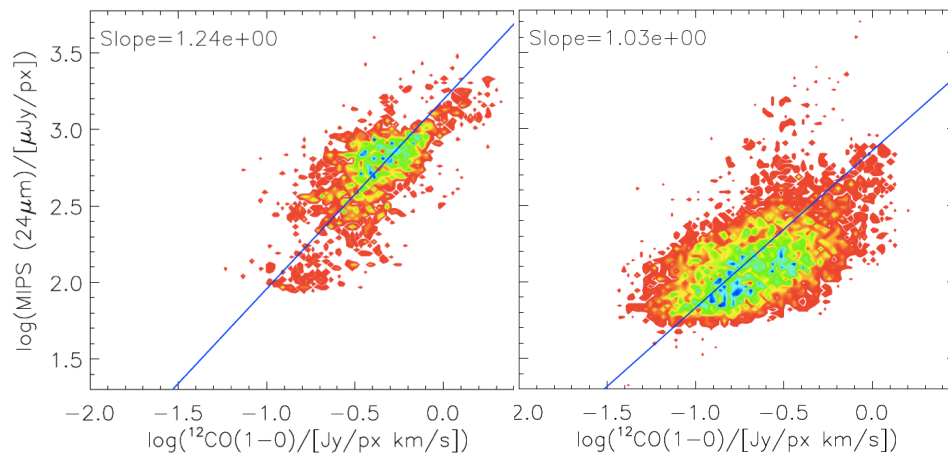
8 $\mu$ m (PAH)

H $\alpha$



24 $\mu$ m

B band



center

arms

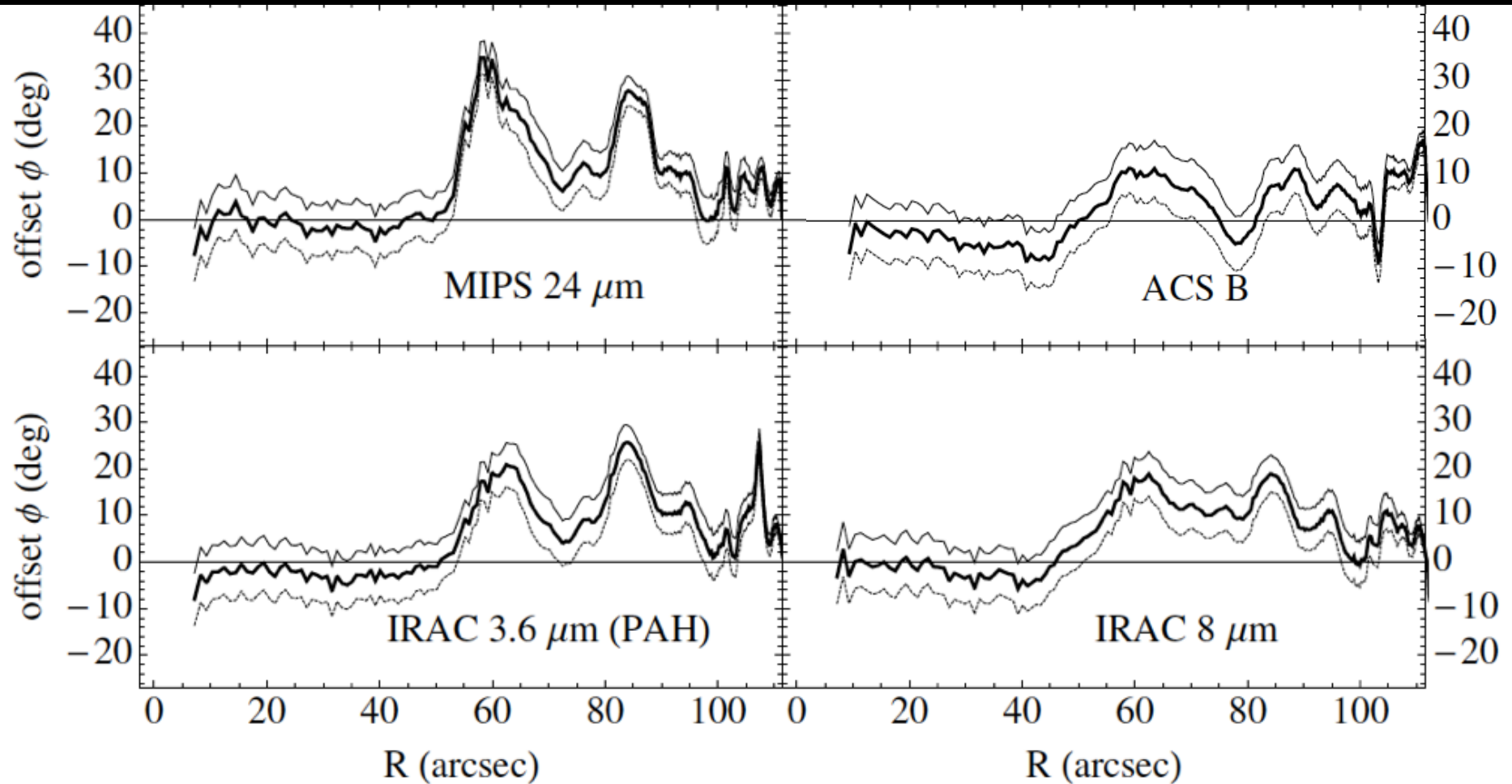
center

arms

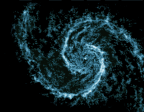


# Spiral arms in M51 disk

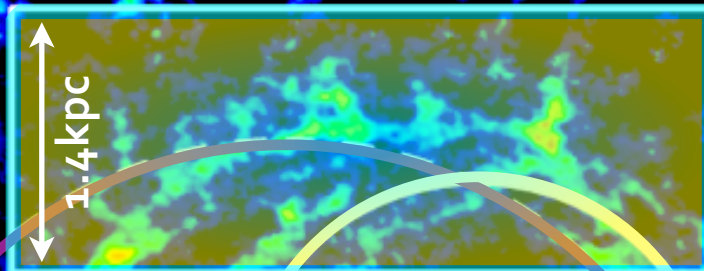
polar cross correlation of CO emission with:



# Spiral Segment in M51



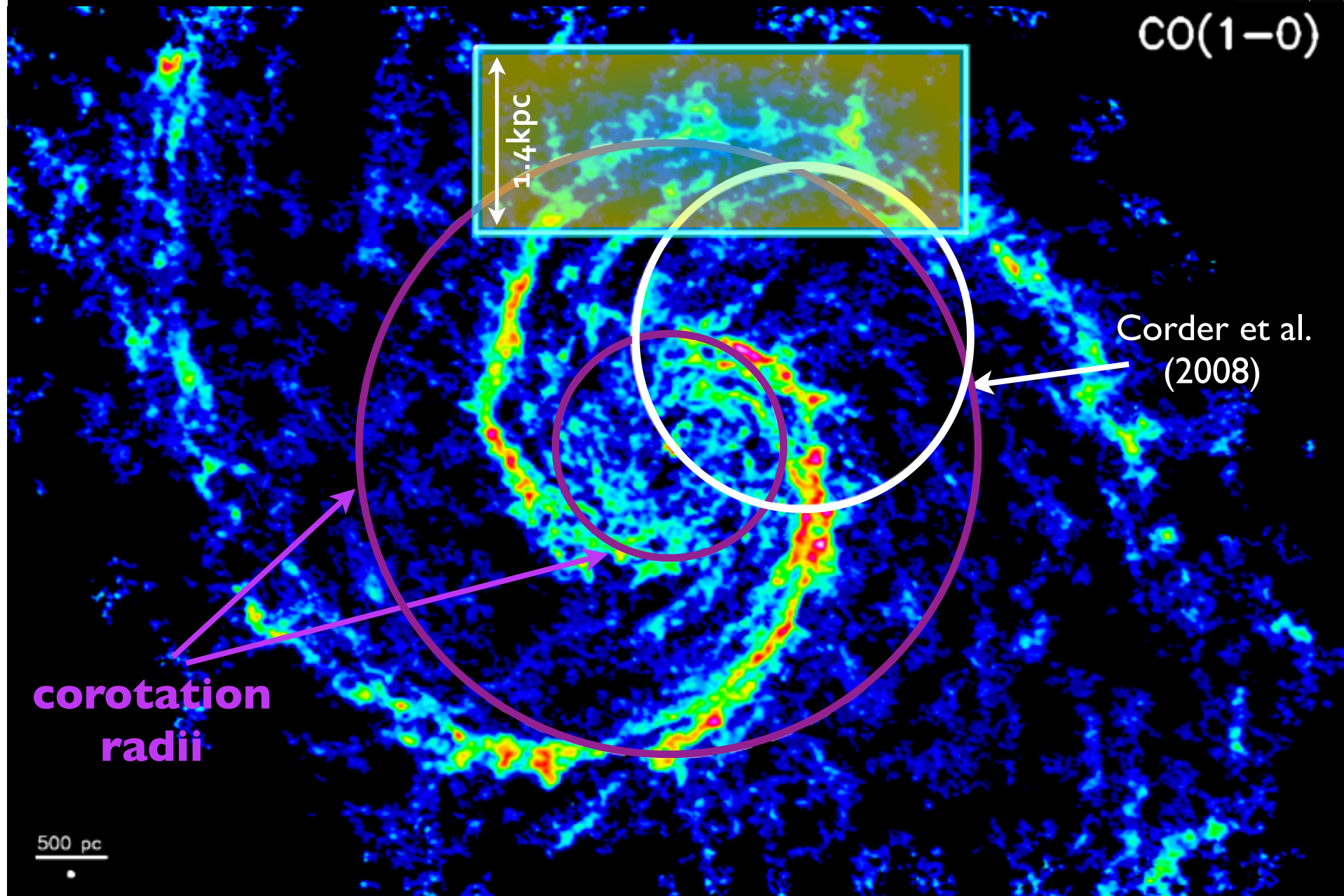
CO(1-0)



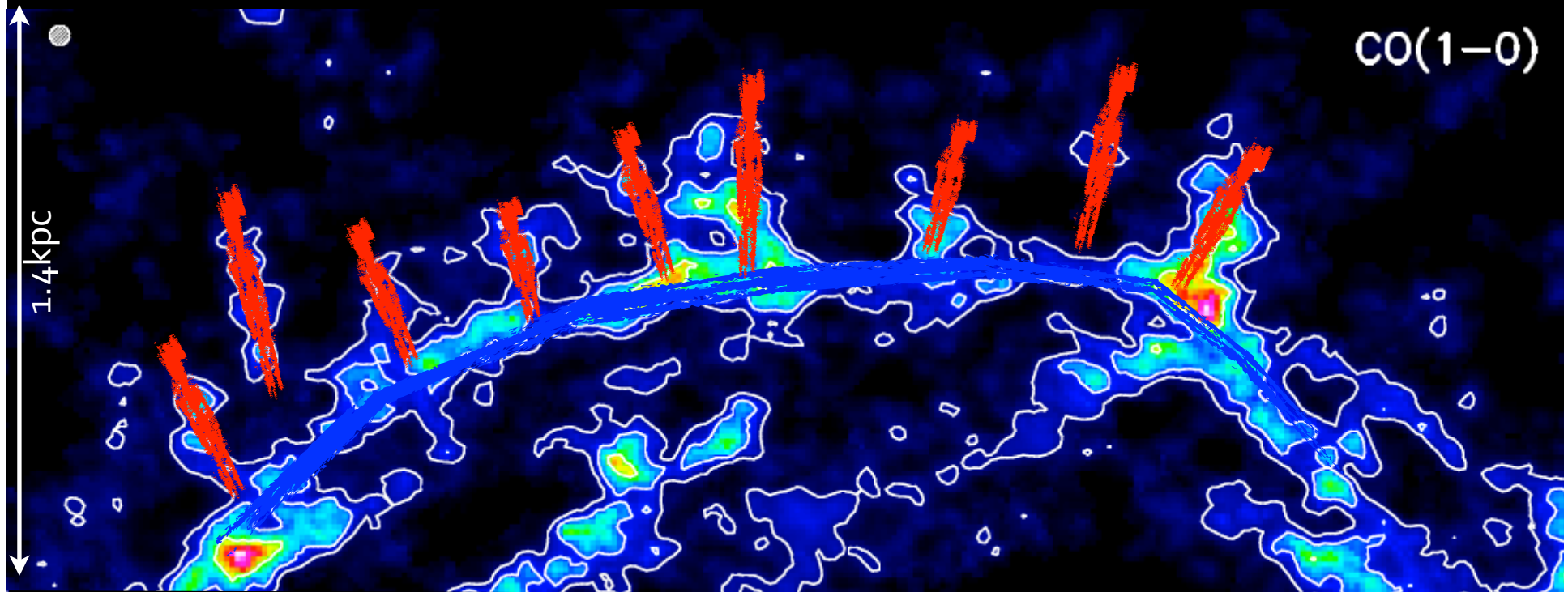
Corder et al.  
(2008)

corotation  
radii

500 pc

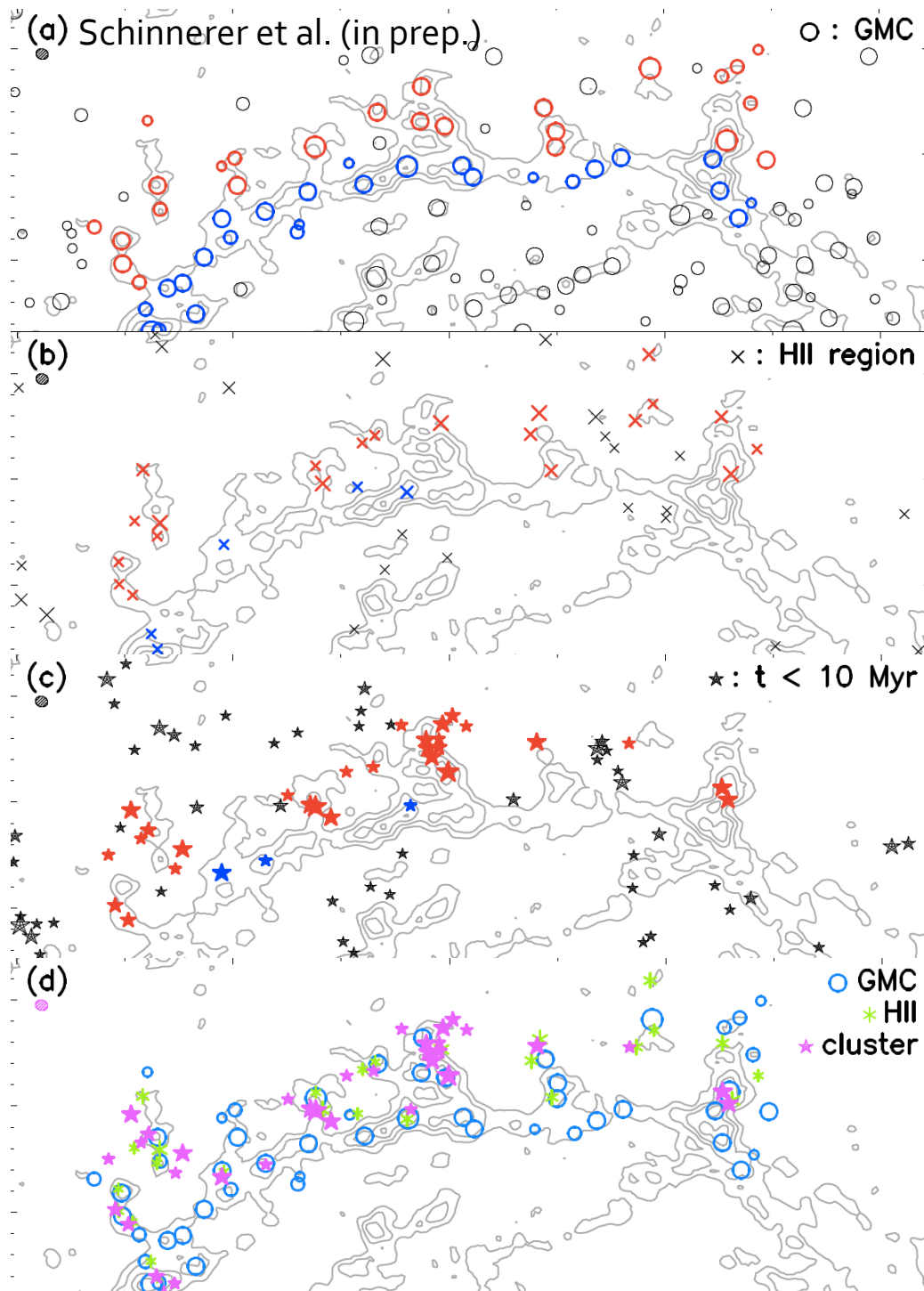


# Spiral Segment in M51



arm

spurs/feathers



GMCs in arm & spurs  
i.e. distinct locations  
(Colombo et al. subm.)

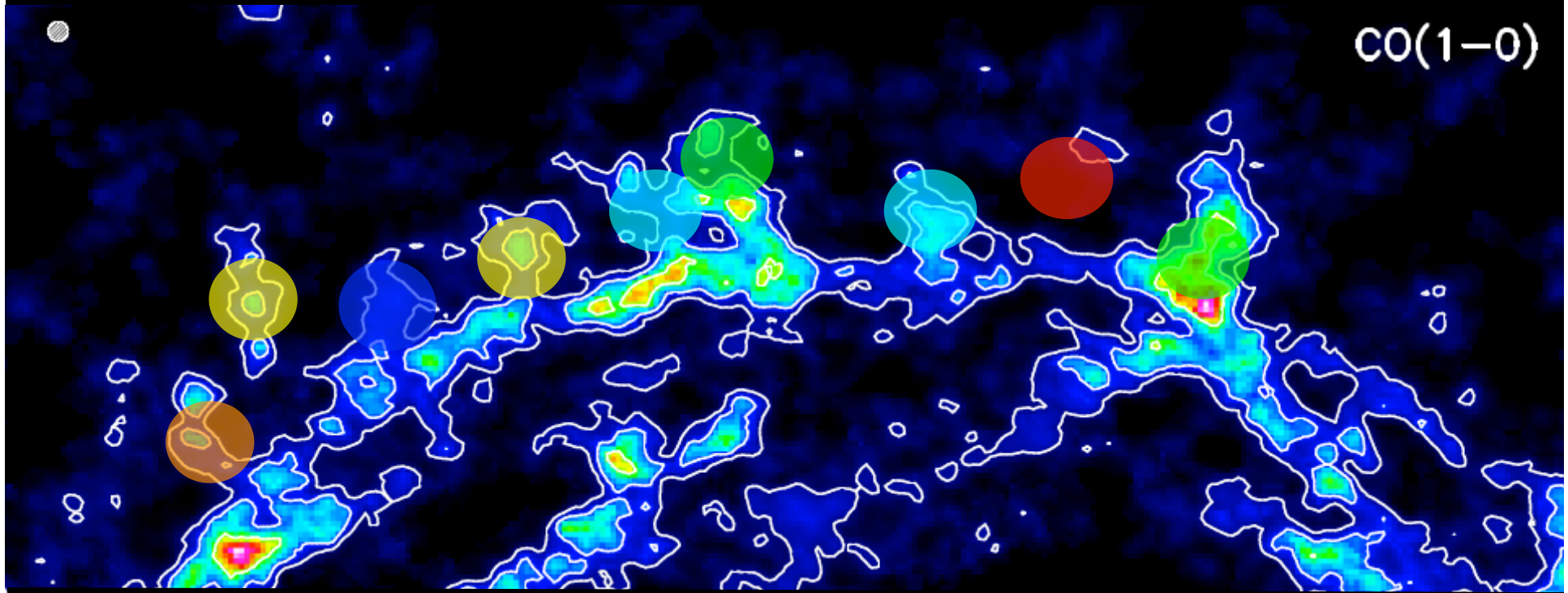
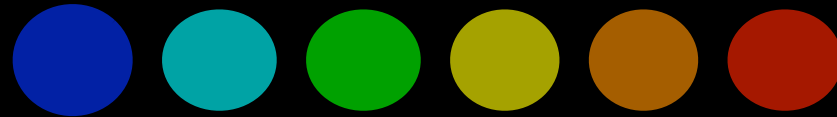
HII regions associated  
w/ spurs  
(Lee et al. 2011)

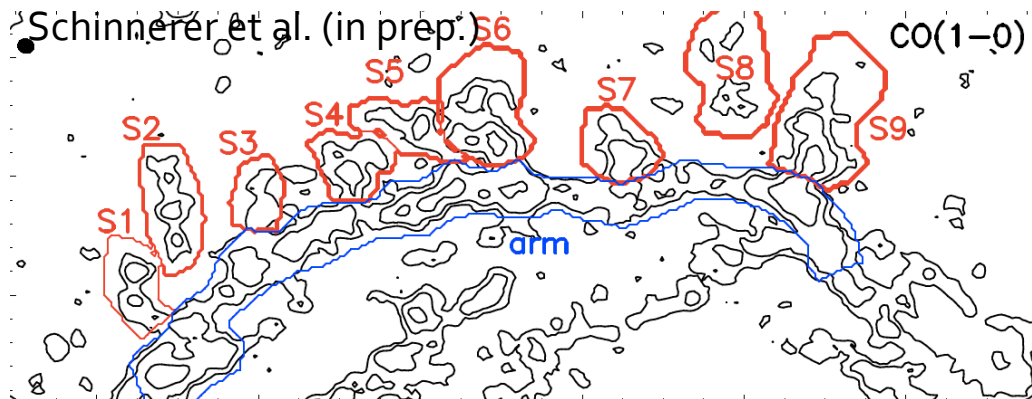
young ( $< 10$  Myr) stellar  
clusters associated w/ spurs  
(Chandar et al. 2011)

GMCs in arm/spurs  
star formation in spurs

# Star Formation History in Spurs

Star Formation age:





# # on GMCs, HII regions & stellar clusters

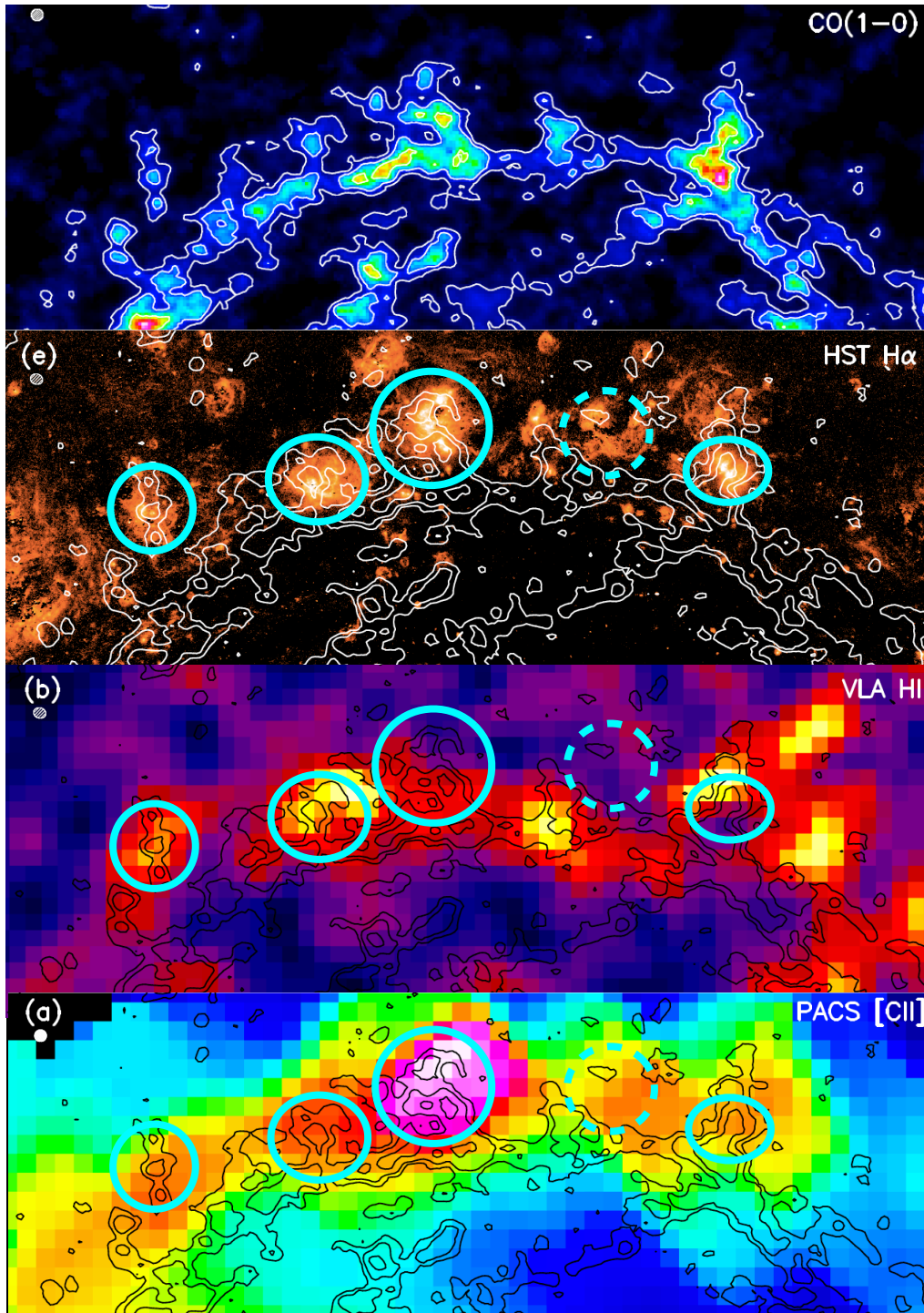
	arm	spurs
gas fraction in GMCs	75%	75 - 100%
$\langle M(\text{H}_2) \text{ in GMC} \rangle$	$2.4 \times 10^6 M_{\text{sun}}$	$3.0 \times 10^6 M_{\text{sun}}$
$\log \langle L(\text{H}\alpha) \rangle$	37.55	38.75
$\langle M_{\text{star}} \rangle$	$0.7 \times 10^4 M_{\text{sun}}$	$1.5 \times 10^5 M_{\text{sun}}$
$\epsilon = (M_{\text{star}}/M(\text{H}_2) \text{ in GMC})$	0.07%	$\sim 0.1 - 4 \%$

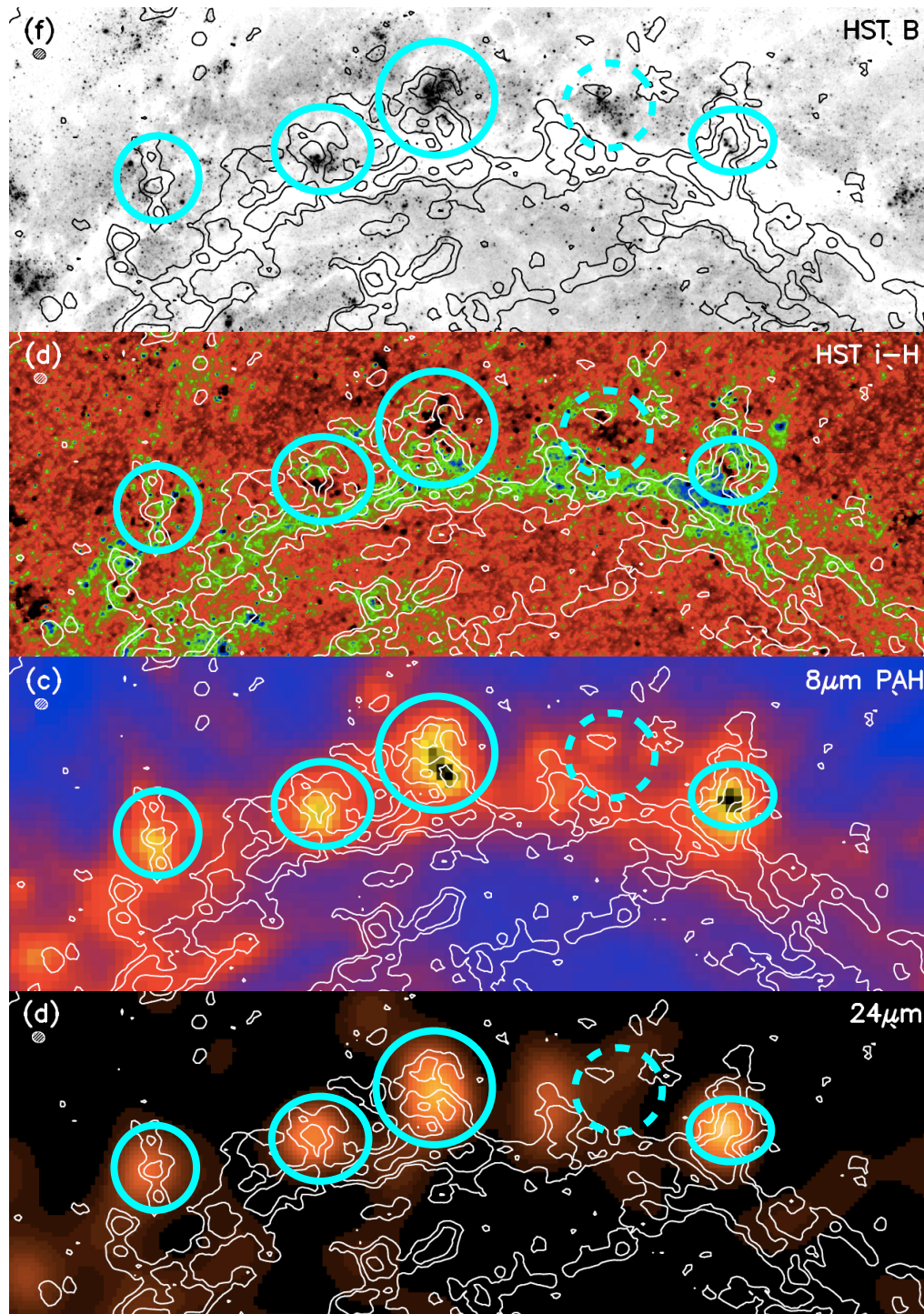
# Molecular Gas - dissociation products

HII regions are off gas arm  
along spurs, but varying

HI mostly off CO arm  
edges of bright HII region

CII off CO gas arm  
associated w/ HII regions





## Stars - dust heating

extinction vs. CO  
good spatial agreement  
fails in HII regions

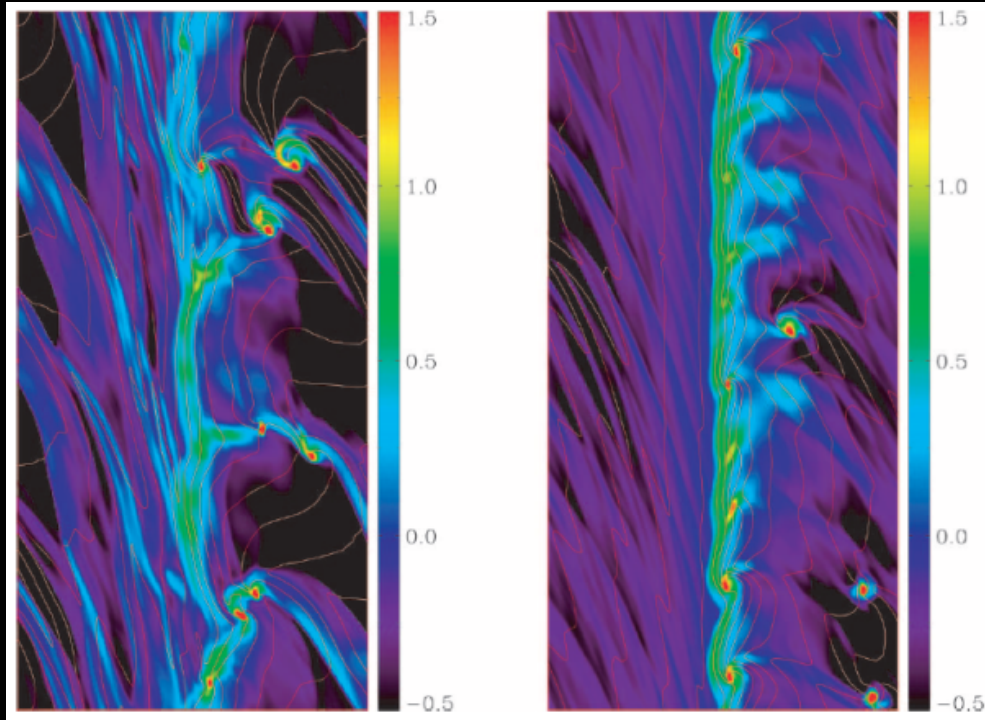
PAH 8  $\mu$ m correlated w/ CO  
& HII regions  
(hot dust contamination?)

hot dust (24  $\mu$ m)  
associated w/ HII regions



# How do spurs form?

Gravity (Jeans Instability)



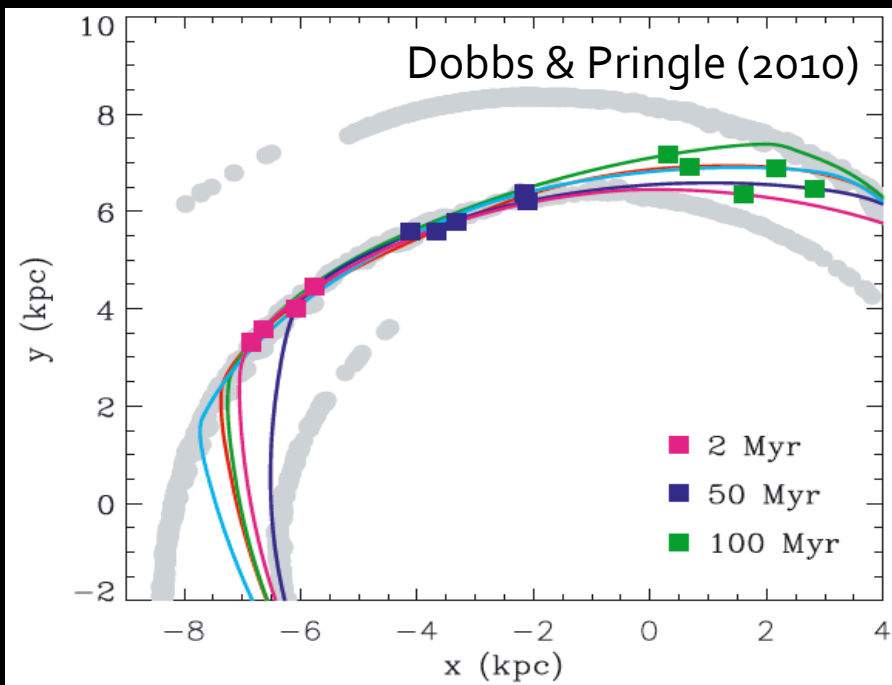
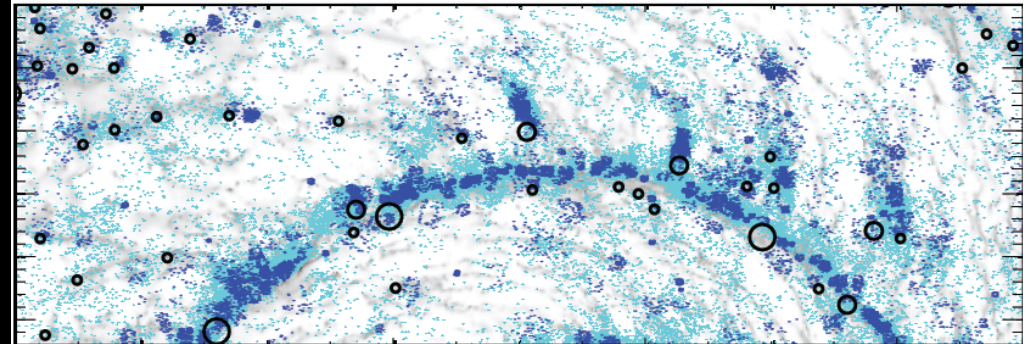
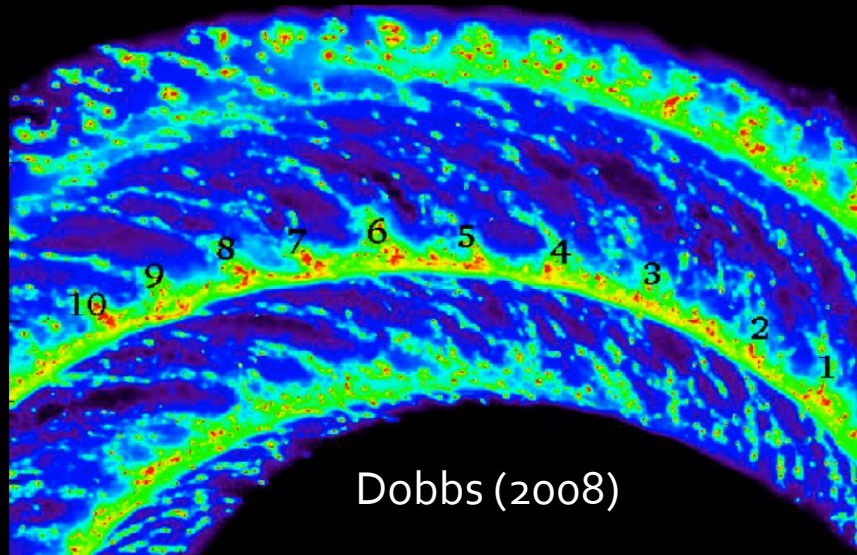
e.g. Kim & Ostriker (2001), Dobbs et al. (2006)

Kelvin-Helmholtz Instability

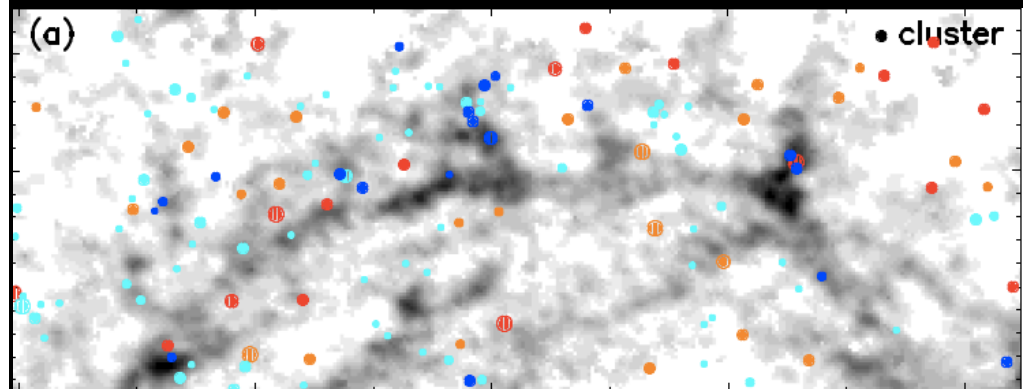


e.g. Wada & Koda (2004), Renaud et al. (2013)

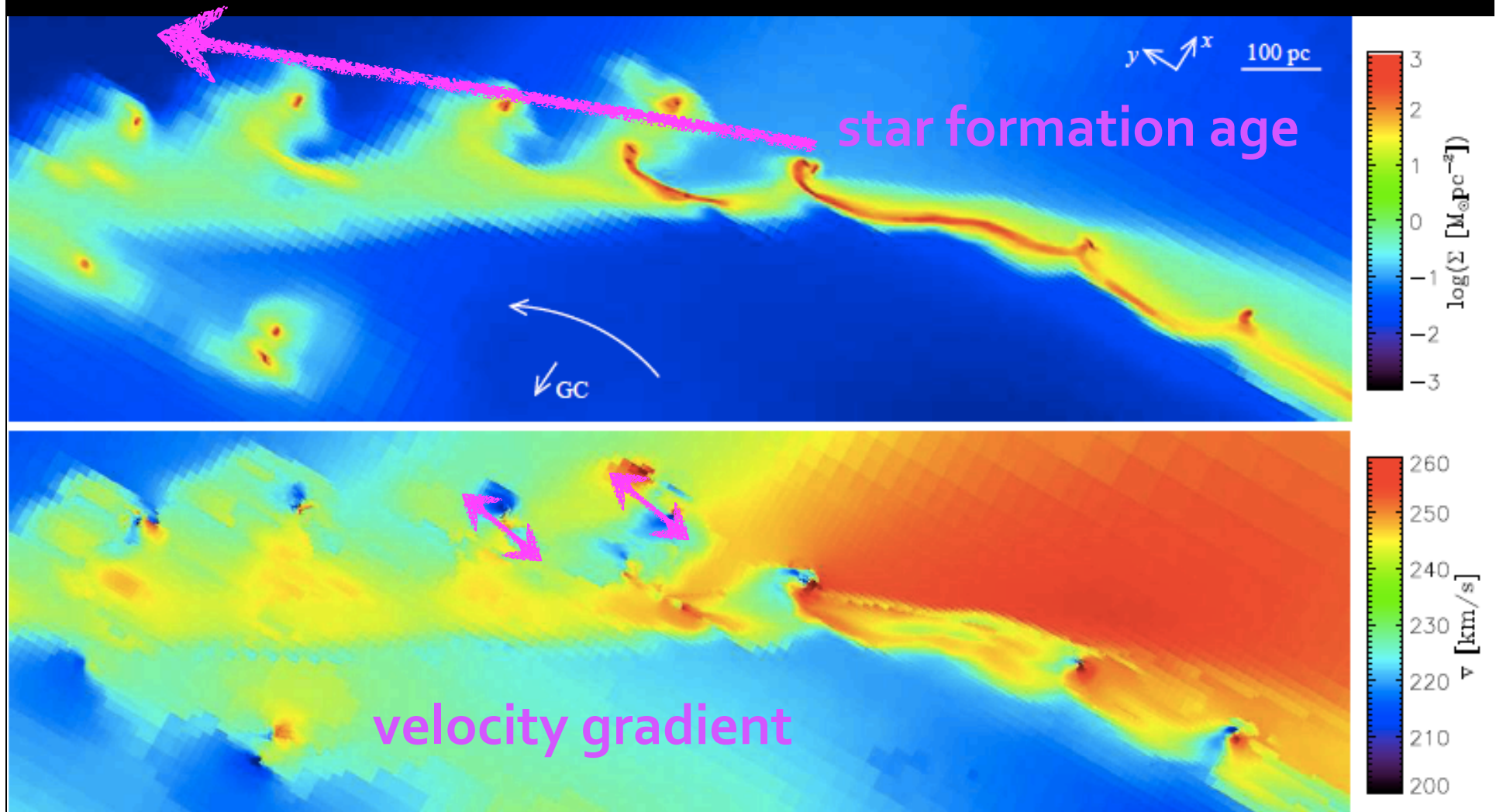
# Jeans Instability - Gravity



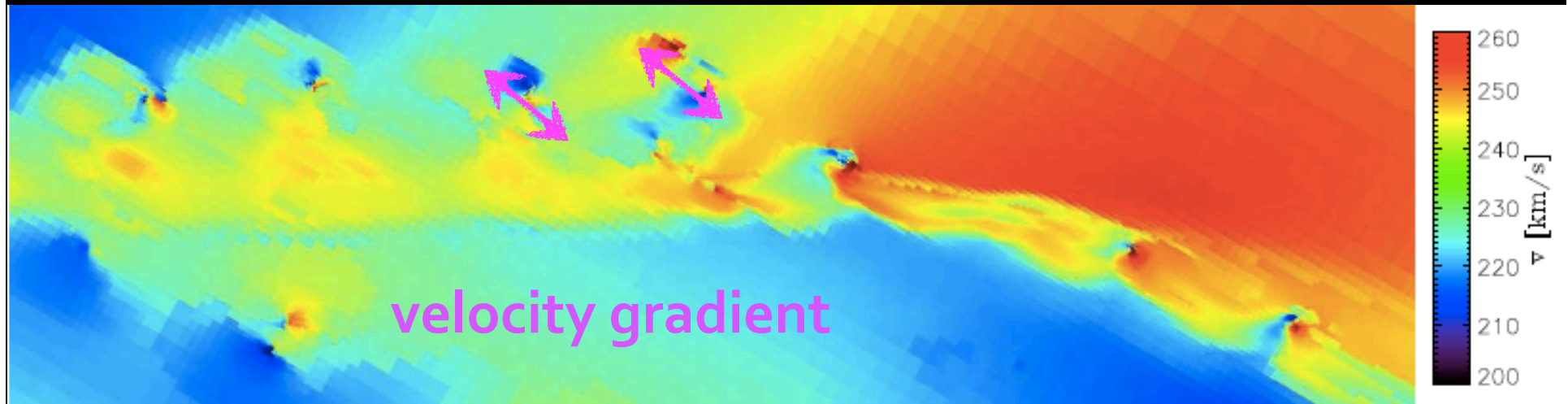
abundant star formation in arm  
but not observed:



# Kelvin-Helmholtz Instability

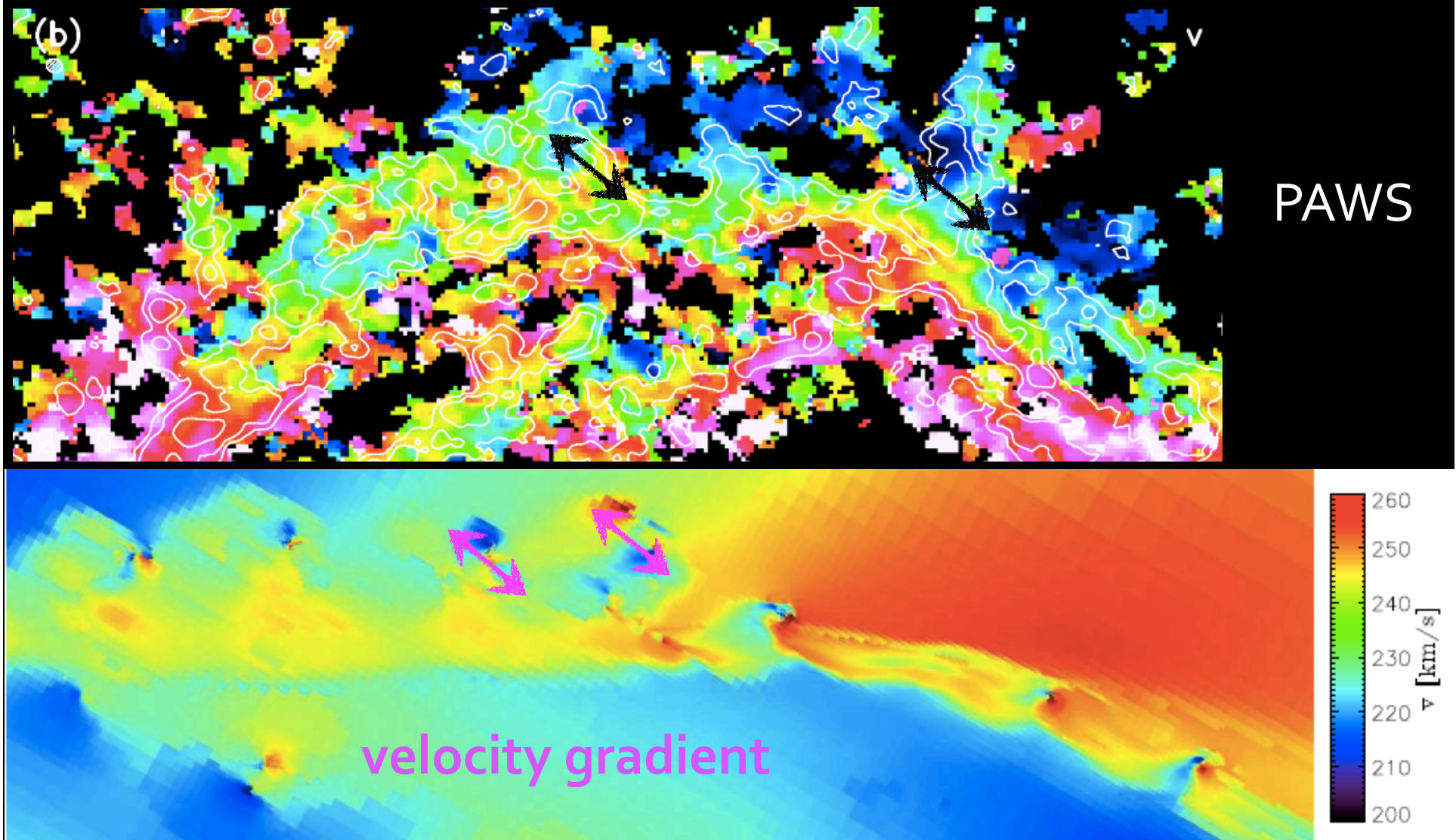


# Kelvin-Helmholtz Instability

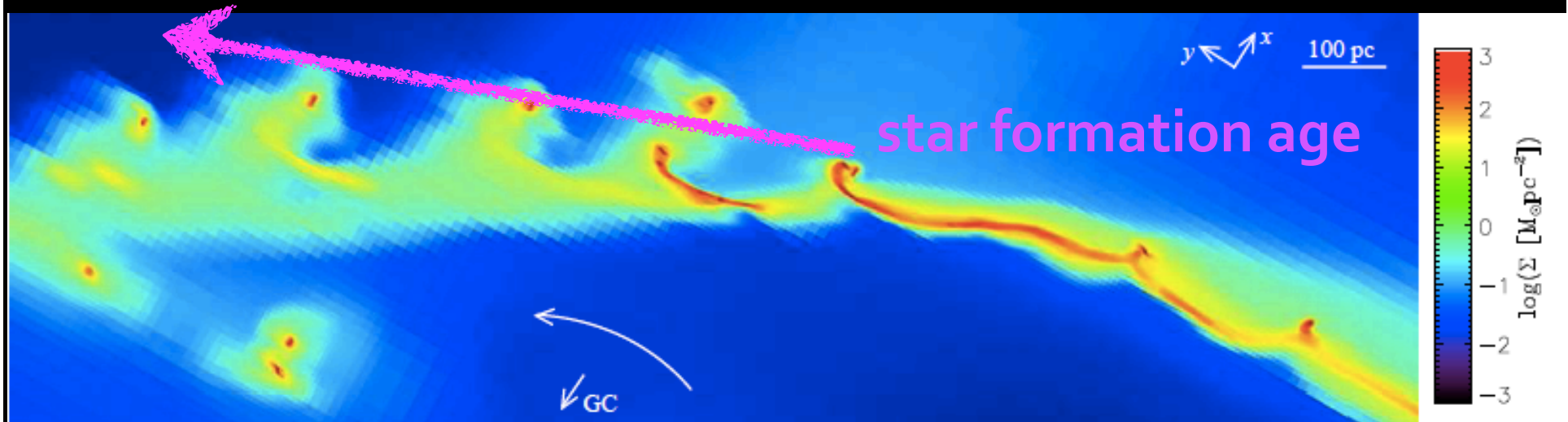


Renaud et al. (2013)

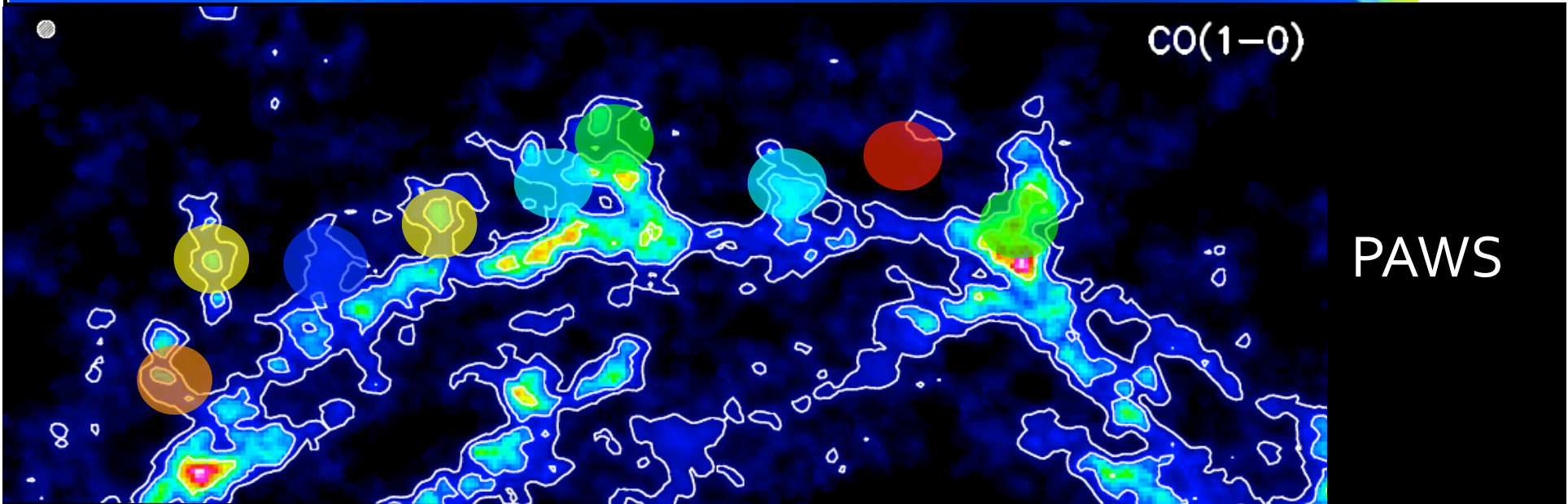
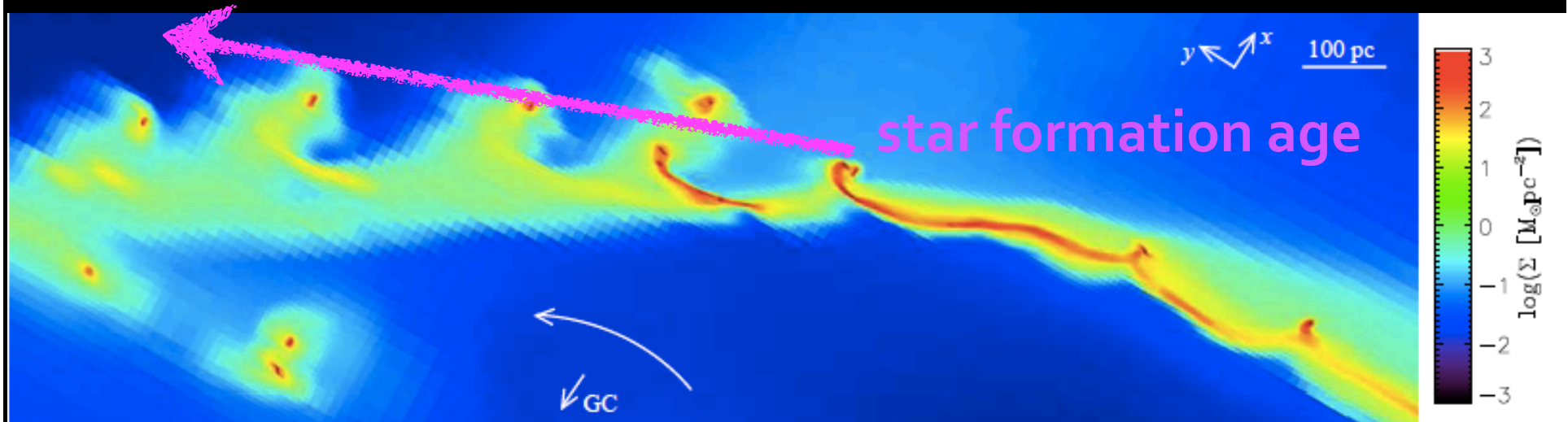
# Kelvin-Helmholtz Instability



# Kelvin-Helmholtz Instability



# Kelvin-Helmholtz Instability



# Summary & Conclusions

2 distinct environments in spiral segment (arm/spur)  
molecular gas (GMC) properties similar  
star formation basically restricted to spurs

star formation in spurs

strongly alters spur ISM (heating, dissociation)

no clear age trend

formation mechanism for spurs

unclear

modification by star formation feed-back





