Star Formation in Extreme ISM

Cycle 0 ALMA results -- unfortunately not

spiral arm SF

Sgr A* and Arp 220

non-extreme : for MW , SFR $\sim$ 3 $M_\odot$ yr^{-1}

$M_{H2} \sim 3\times10^9$ $M_\odot$

➔ $\tau \sim 10^9$ yr

$SFR/M_{H2} \sim 10^{-9}$ $M_\odot$ yr^{-1} / $M_\odot$

provocative ??'s

lifetime of GMCs (actually H2 lifetime) – 10, 100 1000 Myr ??

how can u use opt. thick line to measure mass ??

which line is best : CO , 13CO , HCN ??

mid-plane pressure ➔ H2/HI ??

is gas consumption time (H2) constant ??

why ??

effects, of metalicity ?

can go both ways

less H2 and cooling ? but less feedback (heating and P_{rad})

Galactic H_2 from CO surveys :

~3000 GMCs (only ~200 HII region > M42)

MW GMCs :

$<M> \sim 2\text{-}4 \times 10^5\ M_\odot$

$< D> \sim 40$ pc

$< n_{H2}> = 180\ (D/40\text{pc})^{-0.9}\ \text{cm}^{-3}$

NB : $<n_{H2}>\ \sim 0.1\ n_{crit}$ but $\tau_{CO} \sim 10$ ➔ CO thermalized

large CO linewidths ~ 10 x thermal at 10-20K

➔ supersonic turbulent press. ~ 100 x P_{ISM}

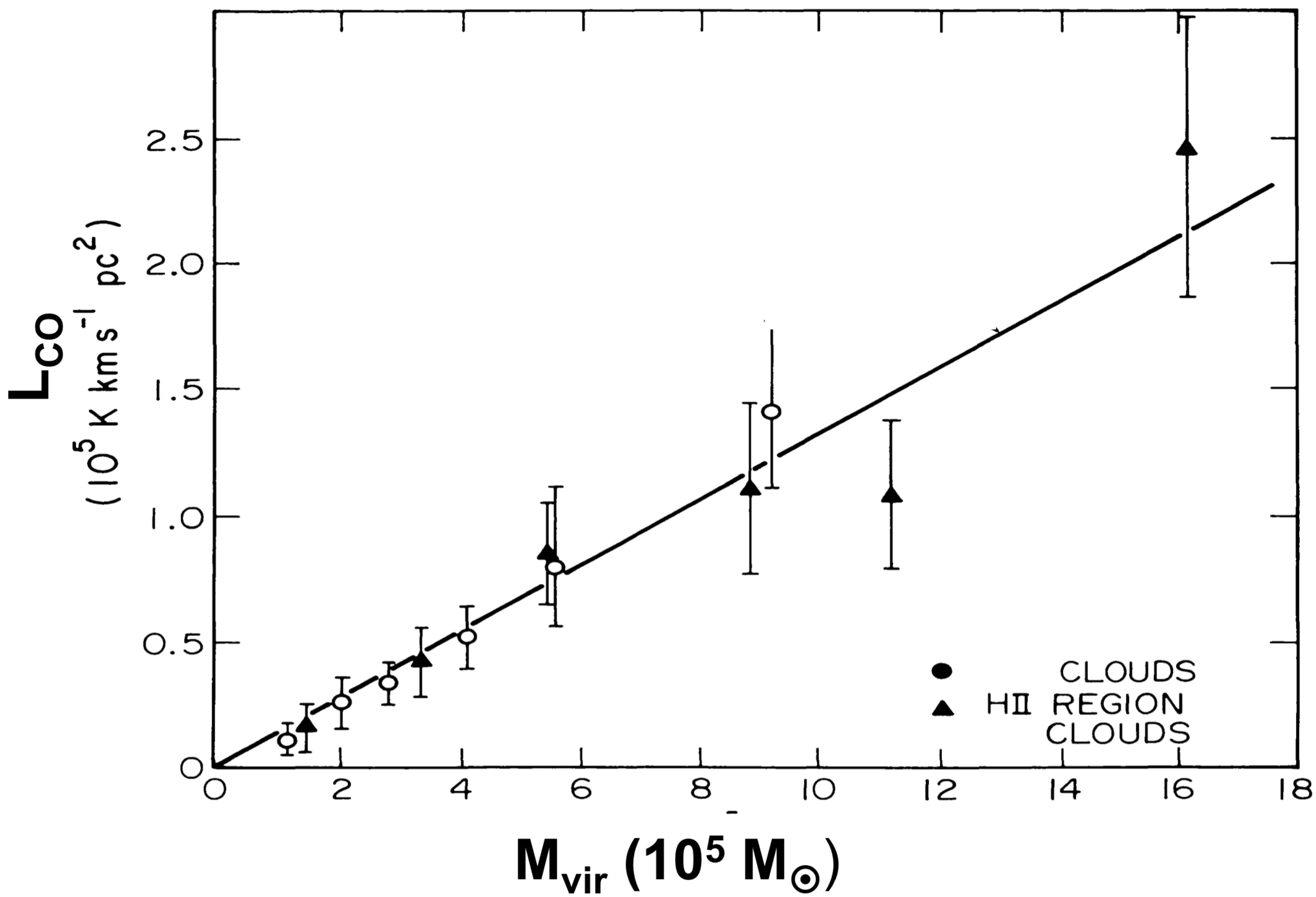
➔ disturbance in external medium can't affect clouds

GMCs self-gravitating (not thermal press. support)

estimating H2 masses –

for resolved clouds M_{vir}

correlated with L_{CO} (= area $T_{CO}\,\Delta v$)



How can an optically thick CO line measure mass ??

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$L_{CO} = \pi R^2 T_k \Delta v$

$= (3\pi G/4\varrho)^{1/2} T_k M_{GMC}$ for self-gravit. GMCs

L_{CO} varies as $(T_k / \varrho^{1/2}) M_{GMC}$

➔ if T & ϱ ~ constant , M_{GMC} = constant x L_{CO}

CO levels thermalized due to photon trapping ➔ $T_x \sim T_k$

note : for $\tau > 1$ photon trapping
T_x varies as $(\text{abundance})^{0.4}$ => constant varies slowly with metalicity (z) & mass density

what about 13CO and HCN ??

intuition : internal state of GMC not affected by external disturbances in diffuse ISM ($P_{turb} \sim 100 \; P_{ISM}$)

once formed , very hard to disrupt GMC

i.e. GMCs have large 'inertia'

➔ internal SFE ~ constant

how long do the GMCs last ??

GMCs / H_2 can't be confined to arms

continuity (mass cons.) =>

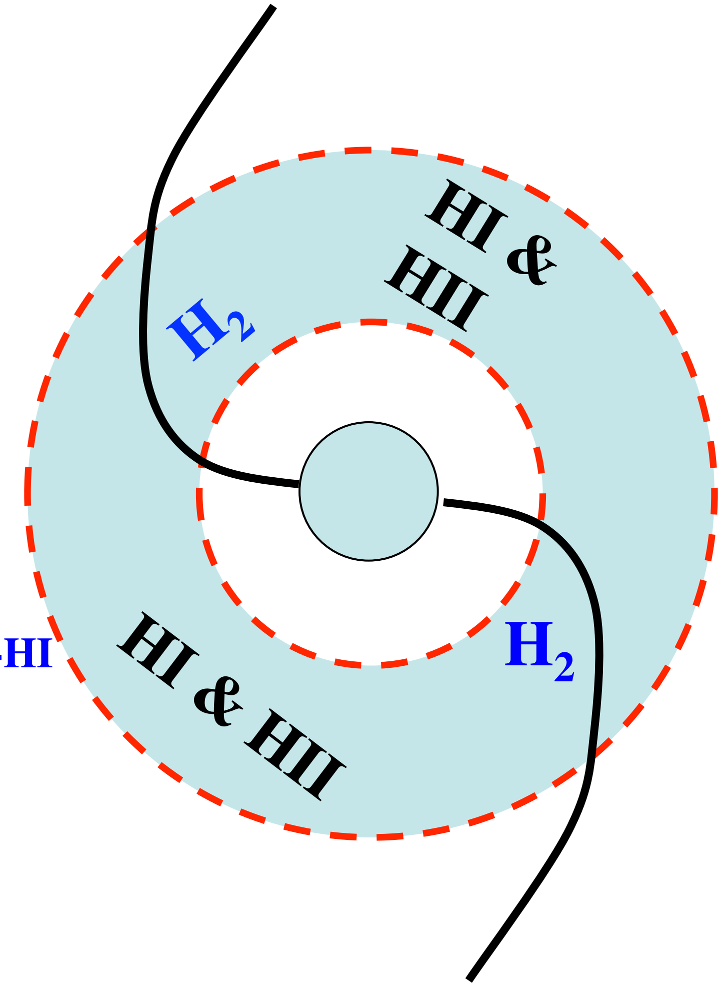
$M_{H2} / \tau_{H2} = (M_{HI} + M_{HII}) / \tau_{HI\text{-}HII}$

gas fraction ~80% molecular

➔ $M_{H2} \sim 4 \times M_{HI}+M_{HII}$

$\tau_{H2} = \tau_{HI\text{-}HII} \, M_{H2} / (M_{HI} + M_{HII}) \sim 4 \times \tau_{HI\text{-}HI}$

$\Rightarrow \tau_{H2} >> \tau_{HI\text{-}HII} \geq 3 \times 10^7$ yrs

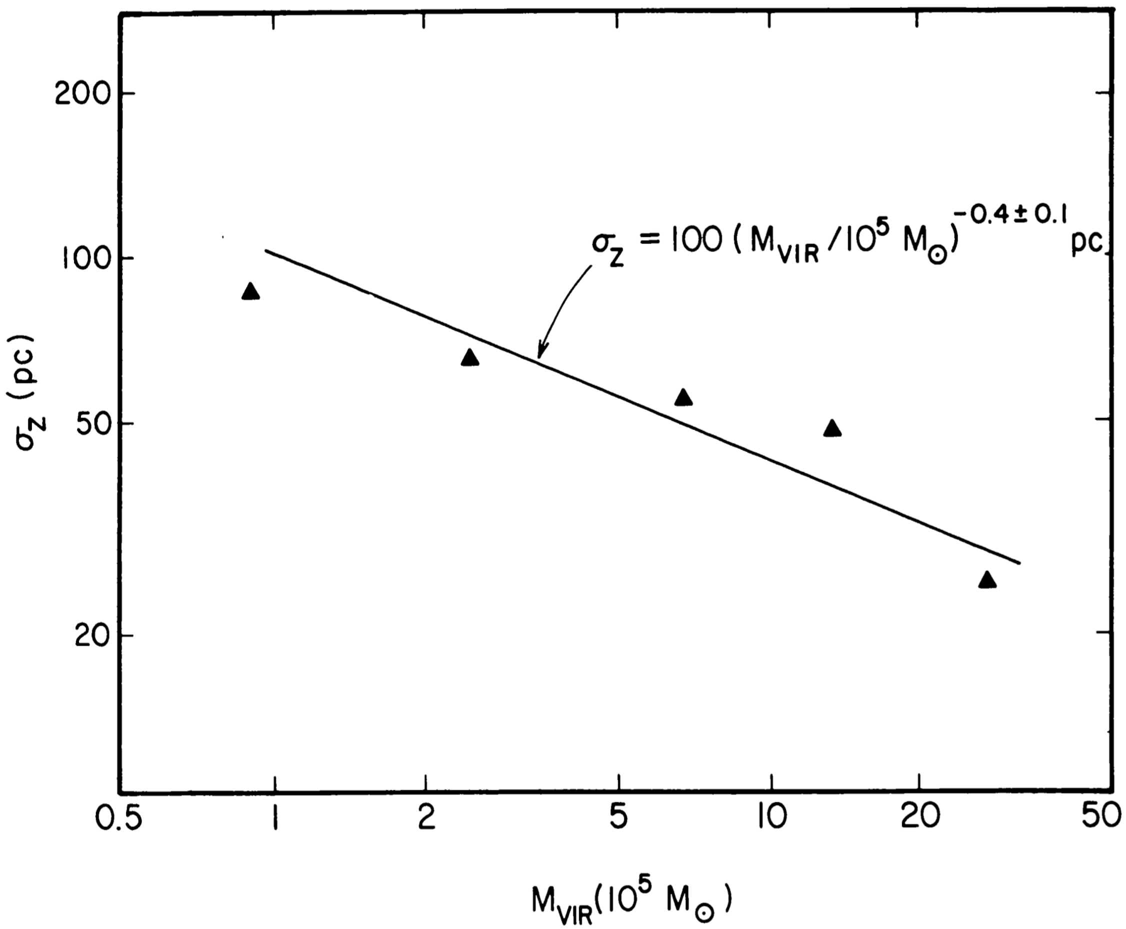


⇒typical H_2 lifetime >> 10^8 yrs !!
(lifetime of H_2, not necessarily GMC)

cloud assoc. w/i arms shear apart upon leaving arms

equipartition of cloud KE

➔ **massive clouds w/ lowest σ_v**



requires cloud last several GMC-GMC collision times

$\tau_{GMC\text{-}GMC} \gtrsim 10^8$ **yrs**

M51 spiral arms

??? why are HII regions concentrated in arms / spurs
if H2 clouds also are in interarm regions

high surface density of H2 in arms ➔ cloud-cloud collisions

Σ_{H2}**(arms) ~ 500 – 1000 $M_\odot pc^{-2}$**

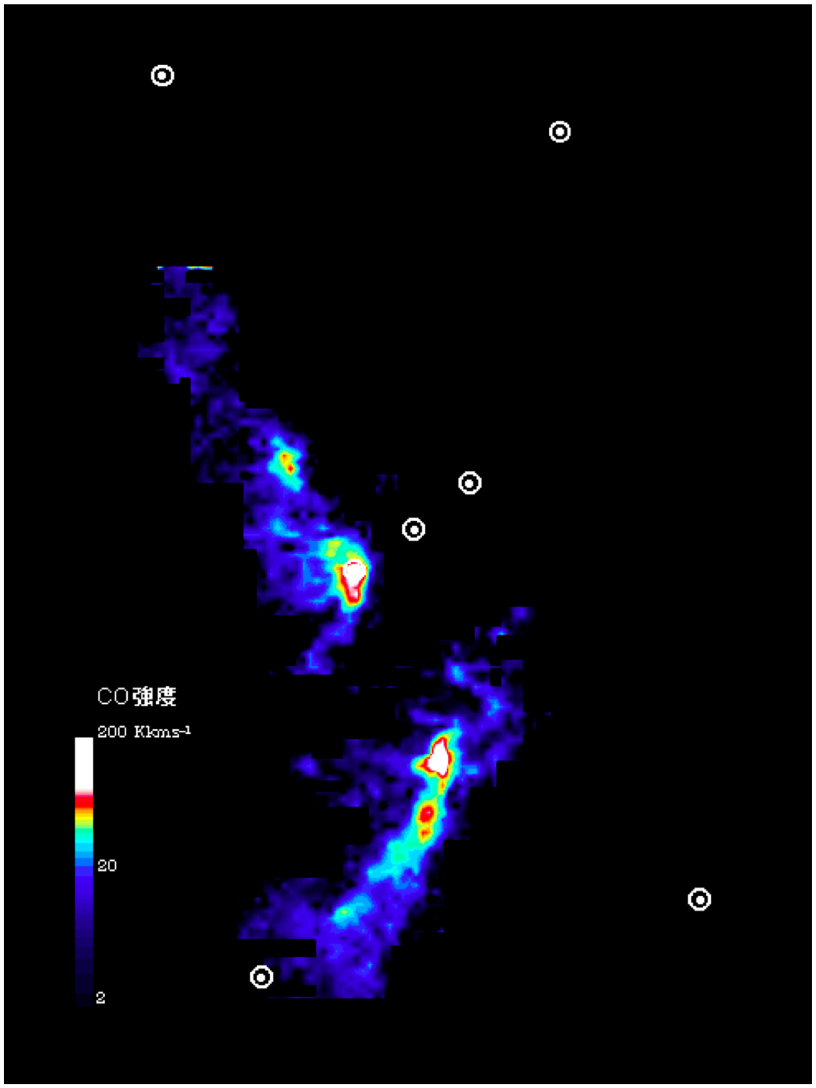
for $4x10^5 M_\odot$ 40 pc diam. GMC, $\Sigma_{H2} = 300\ M_\odot pc^{-2}$
➔area filling ~0.5 in spiral arms

➔ collision times , $\tau_{cl\text{-}cl}$ ~ 1/nσv ~ 40 Myr in arms

➔ ~ ¼ of clouds suffer collision
during 10 Myr arm transit time

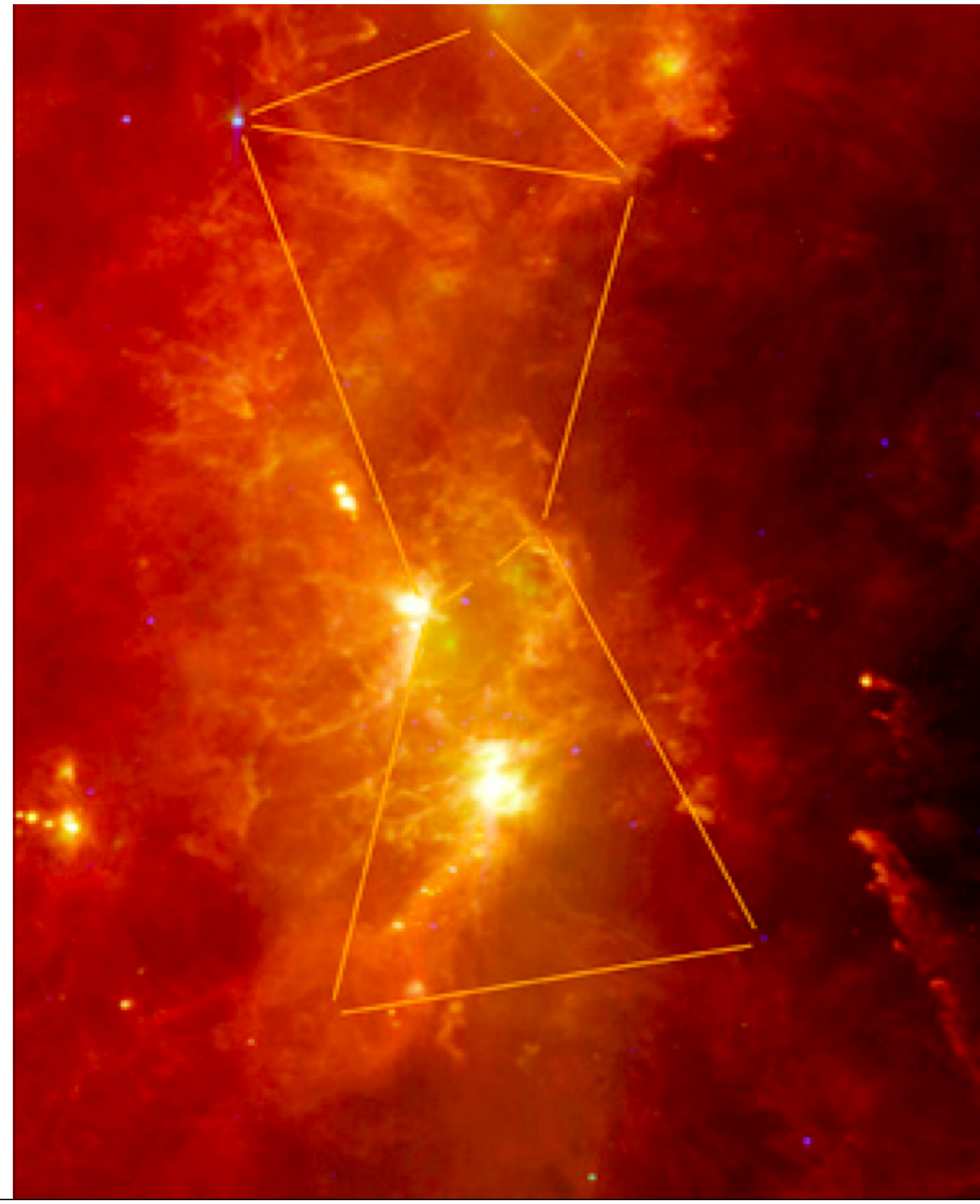
Orion GMCs – possible collision ?

CO



Courtesy of Seiichi Sakamoto (60cm telescope at U.Tokyo)

Infrared



destruction of GMCs

supernova :

1 per 50 yr w/i MW

10^7 yr ➔ $2x10^5$ SN w/i gal.

2000 GMCs ➔ max of 100 SN per cloud per 10^7 yrs

in reality most SN not near birthsites
➔ ~1 per 10^7 yrs since 1% of vol. filled by GMCs

most likely dominant effect is : shear breakup into smaller units after arms

SFR in MW gal. center

SUMMARY OF IR PROPERTIES FOR SELECTED REGIONS[a]

Region	Diameter (pc)	M_{H_2}[b] ($M_\odot$)	L_{IR}[b] ($L_\odot$)	L_{IR}/M_{H2} ($L_\odot/M_\odot$)	IRE[b]	T_d (K)
M17 (No. 8 Table 1)	18	9×10^4	3.4×10^6	37	3.0	48
	105	8×10^5	4×10^6	5	3.5	
W51 (No. 35 Table 1)	50	8.7×10^5	1.3×10^7	15	5	42
	98	3.2×10^6	1.8×10^7	5.6	7	
Galactic center[c]	740	2×10^8	6.8×10^8	3.5		31
Galactic disk[d]	...	2.2×10^9	6×10^9	2.8		29

Scoville & Good '89

SFR/M_{H2} varies but not low overall in Gal. Center

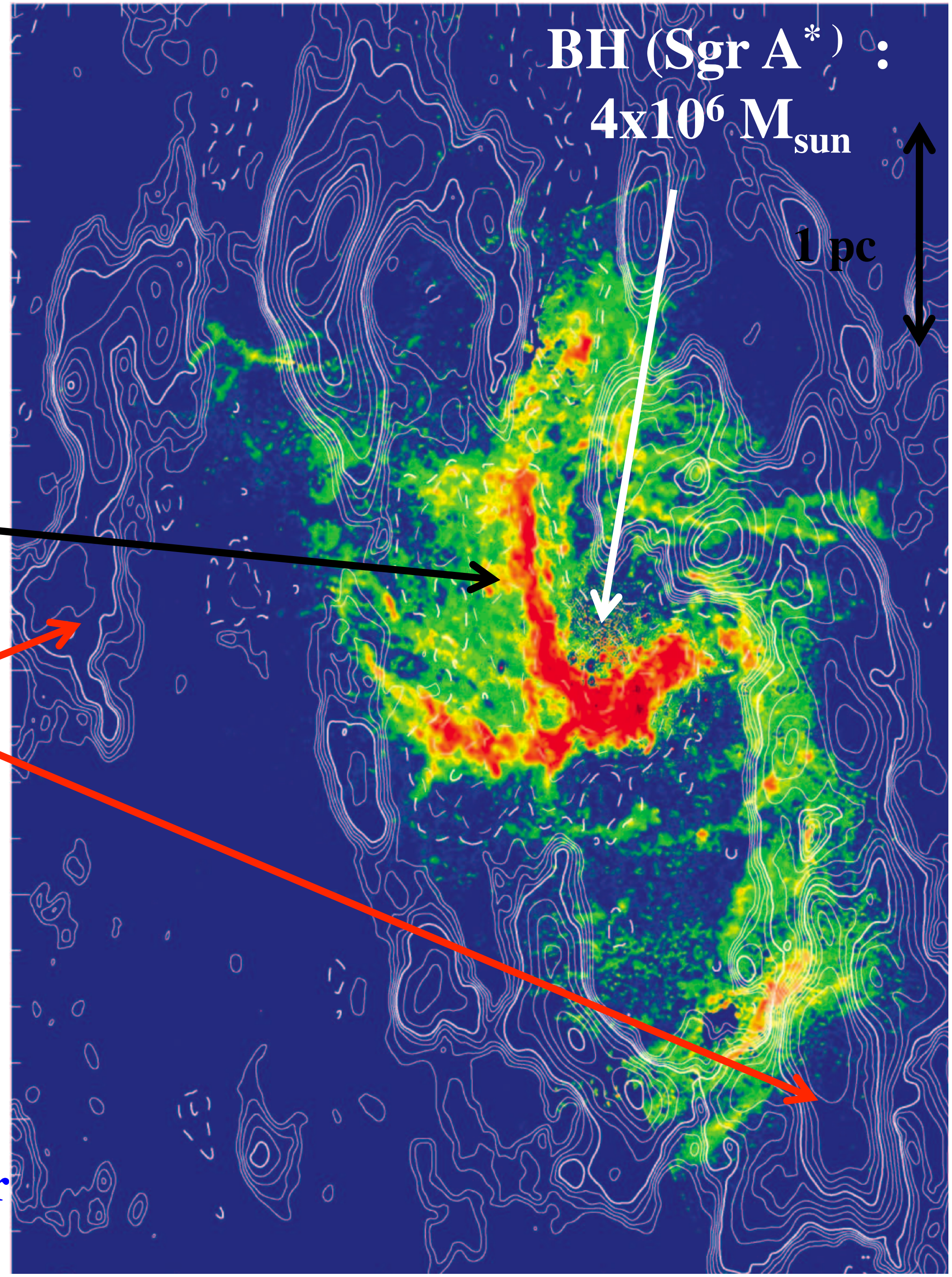
on the other hand ...

circumnuclear disk :

$r \sim 2$ pc

ionized spiral (Paschen α)

dense H_2 clumps (HCN)



CND : 1 – 3 pc radius

$M_{H2} \sim 5x10^5$ (~ GMC)

but ring w/ 10^{7-8} cm^{-3}

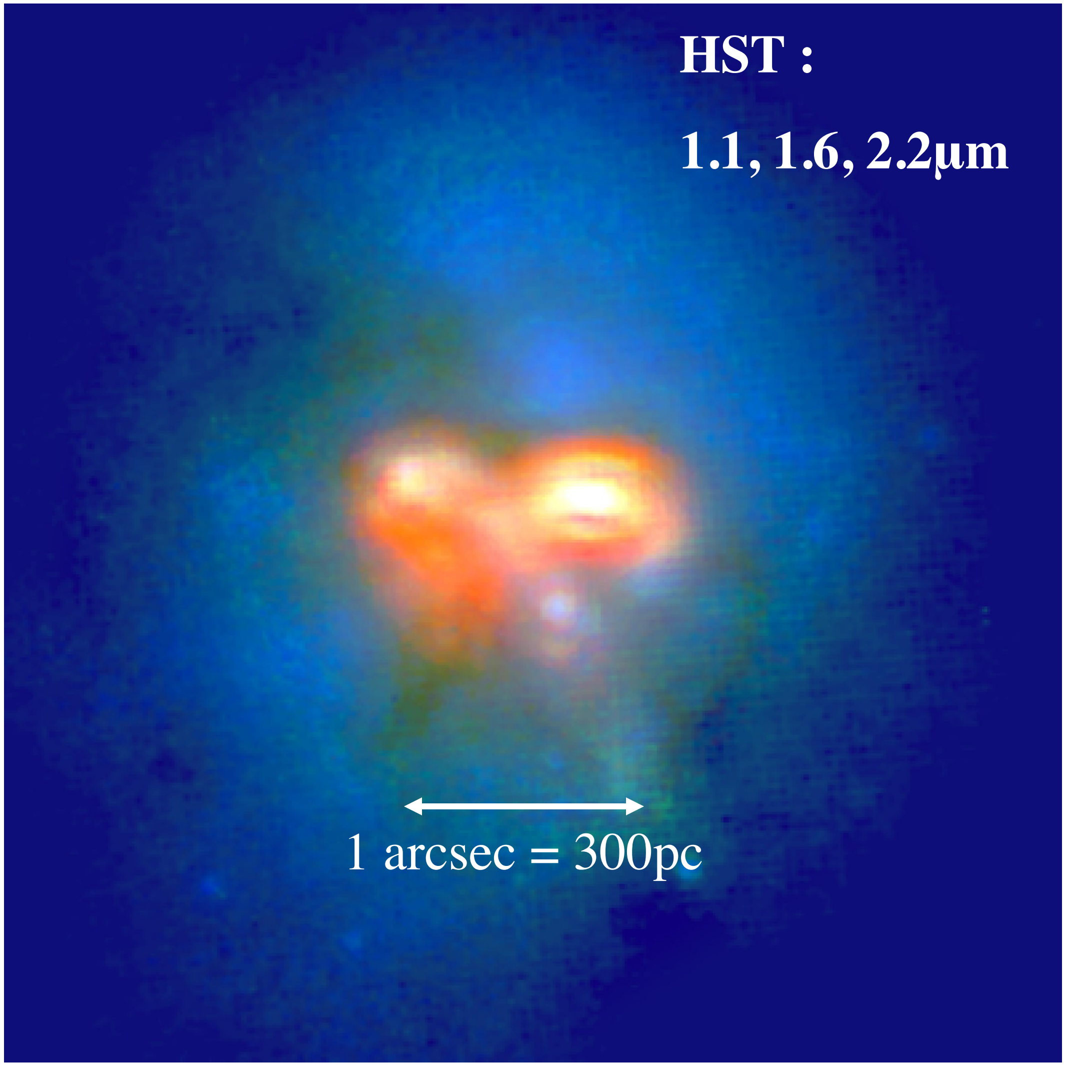
(tidally stable)

$\tau_{orbit} = 10^5$ yr , $\tau_{dyn} = 10^4$ yr

Arp 220 (@77 Mpc) -- L = 2×10^{12} L_{sun}

double nuclei – 300 pc apart

3×10^9 M_{sun} H_2 on each, counter-rot.



Arp 220 --- inner dust source : 10^9 M_{sun} w/i r = 35 pc

10^{25} cm^{-2} ==> $A_V = 10^4$ mag, $\tau_{1mm} \sim 1$

10^5 cm^{-3}, not cloudy

$\tau_{orbit} = 10^5$ yr , $\tau_{dyn} = 3x10^5$ yr

why is SFR so low ??

Krumholz etal advocate SFR law ,

$$SFR = \frac{\varepsilon_{free-fall} M_{H2}}{\tau_{free-fall}}$$

$$\tau_{free-fall} = \sqrt{\frac{3\pi}{32G\rho}} = 2.3\ \mathrm{Myr}\left(\frac{300}{n_{H2}}\right)^{1/2}$$

	n_{H2}	$\tau_{free-fall}$
SgrA CND	$3\mathrm{x}10^7$	7,500 yr
Arp 220	$3\mathrm{x}10^5$	75,000 yr

for $\varepsilon = 0.02$,

$SFR = 1.3\ M_\Theta yr^{-1}$ in SgrA CND

$8000\ M_\Theta yr^{-1}$ in Arp 220

gas is dusty , therefore not standard accret.

rad. press. much greater

F_{rad} / g > 1 for Σ_L / Σ_M > 500 L_{sun} / M_{sun}

Arp 220 --

$\Sigma_L / \Sigma_M = 10^{12} / 10^9 = 10^3 L_{sun} / M_{sun}$

Sgr A CND –

tidal shear ??

high vel. disp.

lifetime of GMCs <u>(actually H2 lifetime)</u> – ~100 Myr ??

how can u use opt. thick line to measure mass ??

which line is best : CO , 13CO , HCN ??

mid-plane pressure ➔ H2/HI ?? X

gas consumption time (H2) varies 10-20x

mostly due to dynamical driving

effects, of metalicity ?

can go both ways

less H2 and cooling ? but less feedback (heating and P_{rad})