

ALMA/miniTAO Observations of the IR-bright Merger VV114



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Introduction

Cycle 0 observations

Results

Discussion

Summary & future works

INTRODUCTION

U/LIRGs

FIR luminosity: $> 10^{11} L_{\text{sun}}$

Morphology: Merging/Interacting

Large population at $z = 1 - 3$

Observations < Simulations

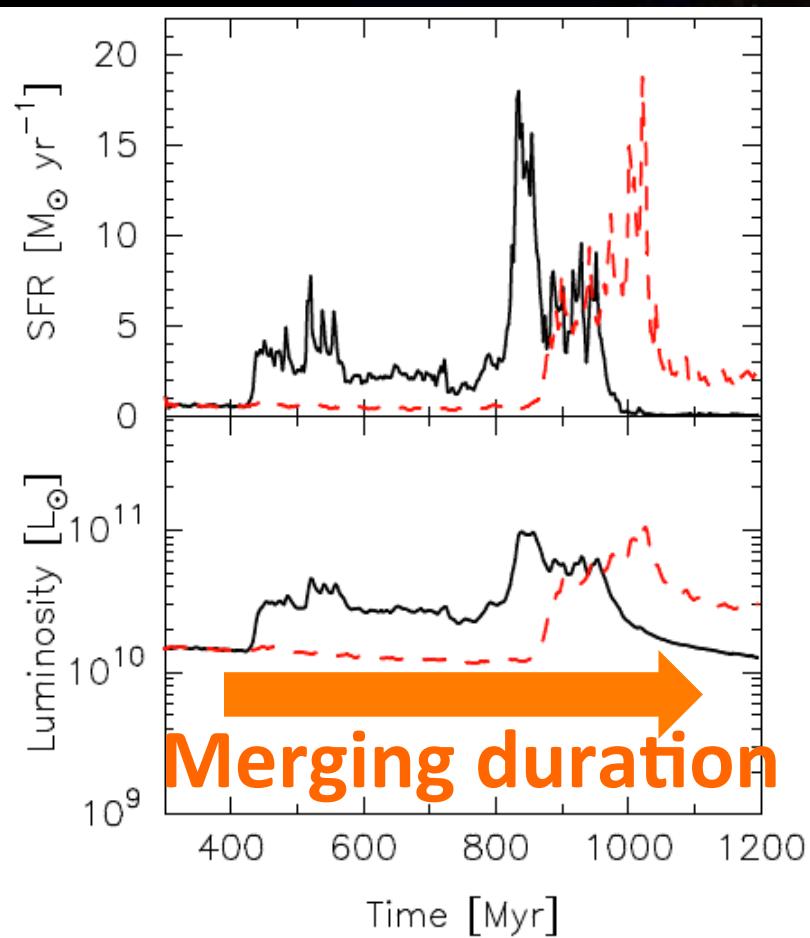
Numerical Simulations

Key to galaxy formation and evolution and their associate SF environment!



Numerical Simulations

Key to galaxy formation and evolution and their associate SF environment!



VV114

$z = 0.02$

$L_{\text{FIR}} = 4.1 \times 10^{11} L_{\text{sun}}$ (Soifer+87)

$M_{\text{H}_2} = 5.1 \times 10^{10} M_{\text{sun}}$ (Yun+94)

+: each nucleus (miniTAO/Ks-band)
→ separation: 6kpc



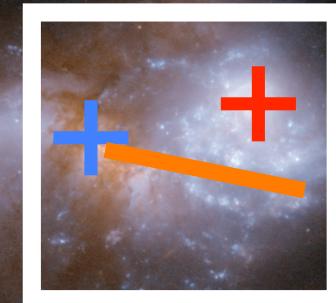
VV114W

VV114E

is a mid or late stage merger

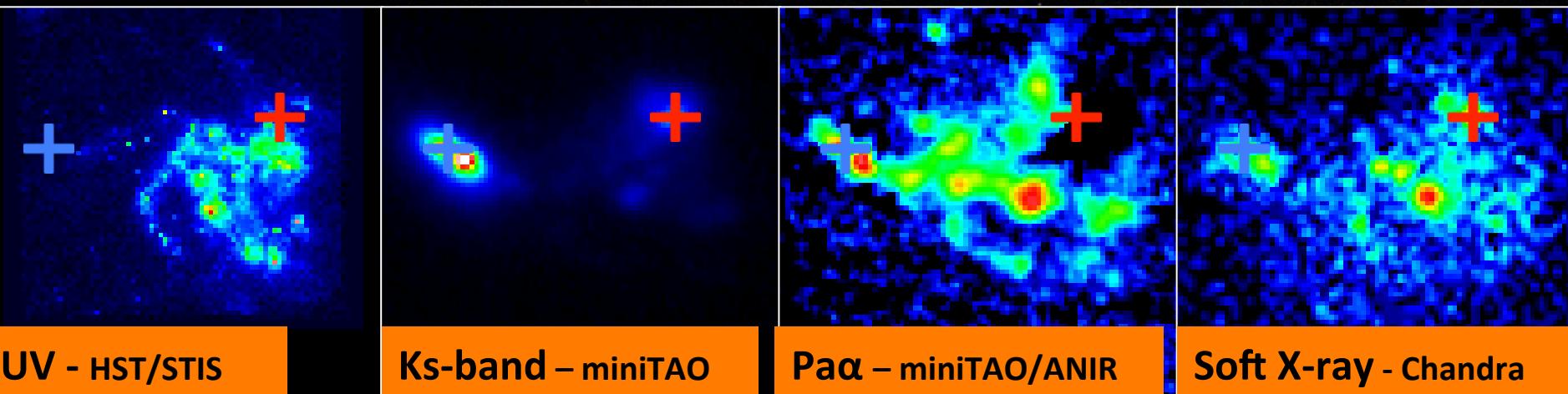
VV114

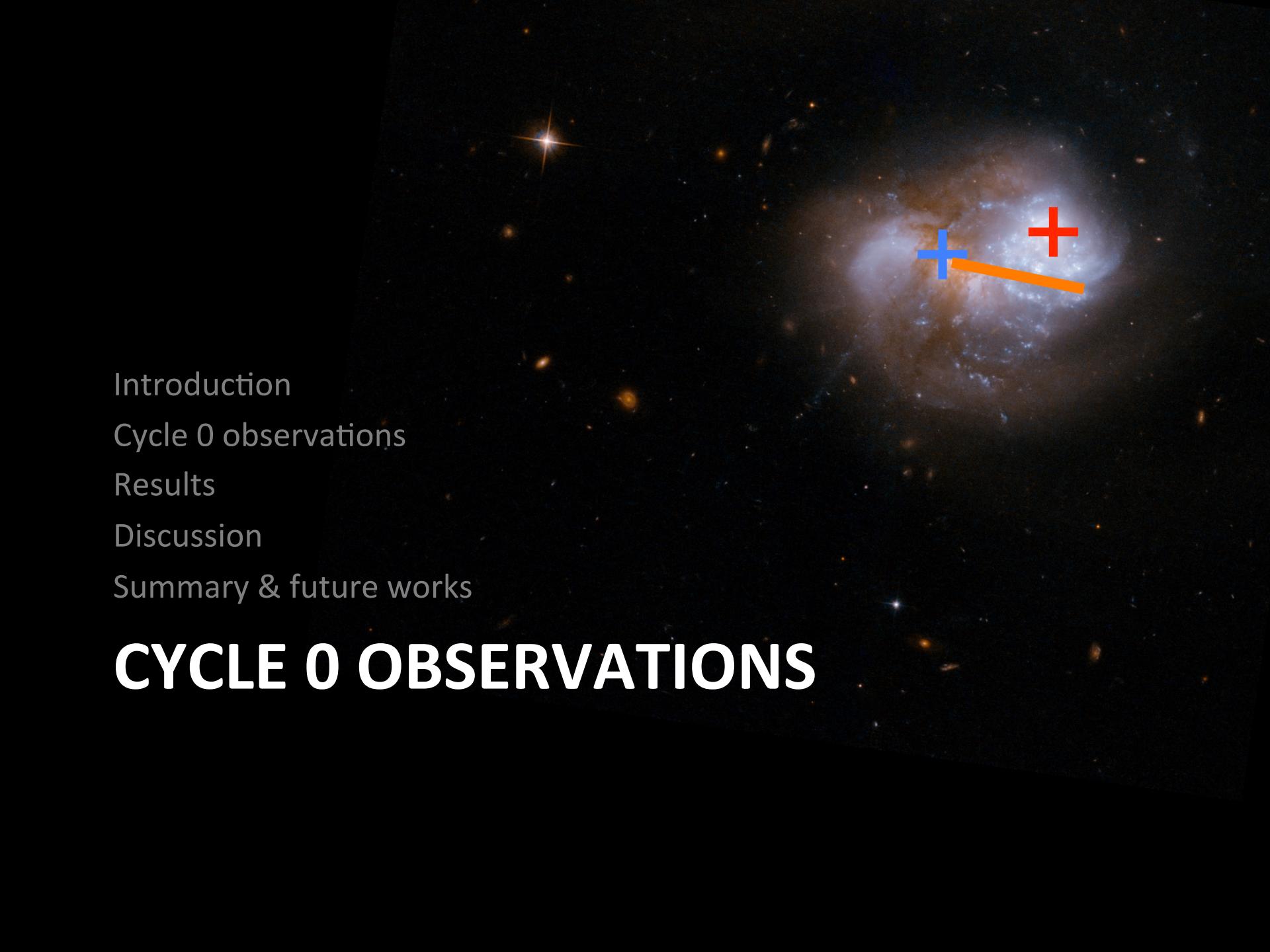
VV114E: Obscured SB and/or AGN
mid-IR and X-ray



VV114W: Diffuse SB
mid-IR

VV114: Extended SFs across galaxy disks
Global SFR_{Paα} $\sim 45.1 \text{ M}_{\text{sun}}/\text{yr}$





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CYCLE 0 OBSERVATIONS

Science goals



(1) Dense gas kinematics & distribution

→ Simultaneous HCN & HCO⁺ J = 4 - 3 with 0.4" resolution

(2) Dense gas mass fraction & global kinematics

→ ¹²CO & ¹³CO J = 3 - 2, 1 – 0 with 1.5" resolution

(3) A radiative transfer model analysis

→ quantify the dense gas density and T

Data information

17 - 19 × 12m antennas/Band3 and 7

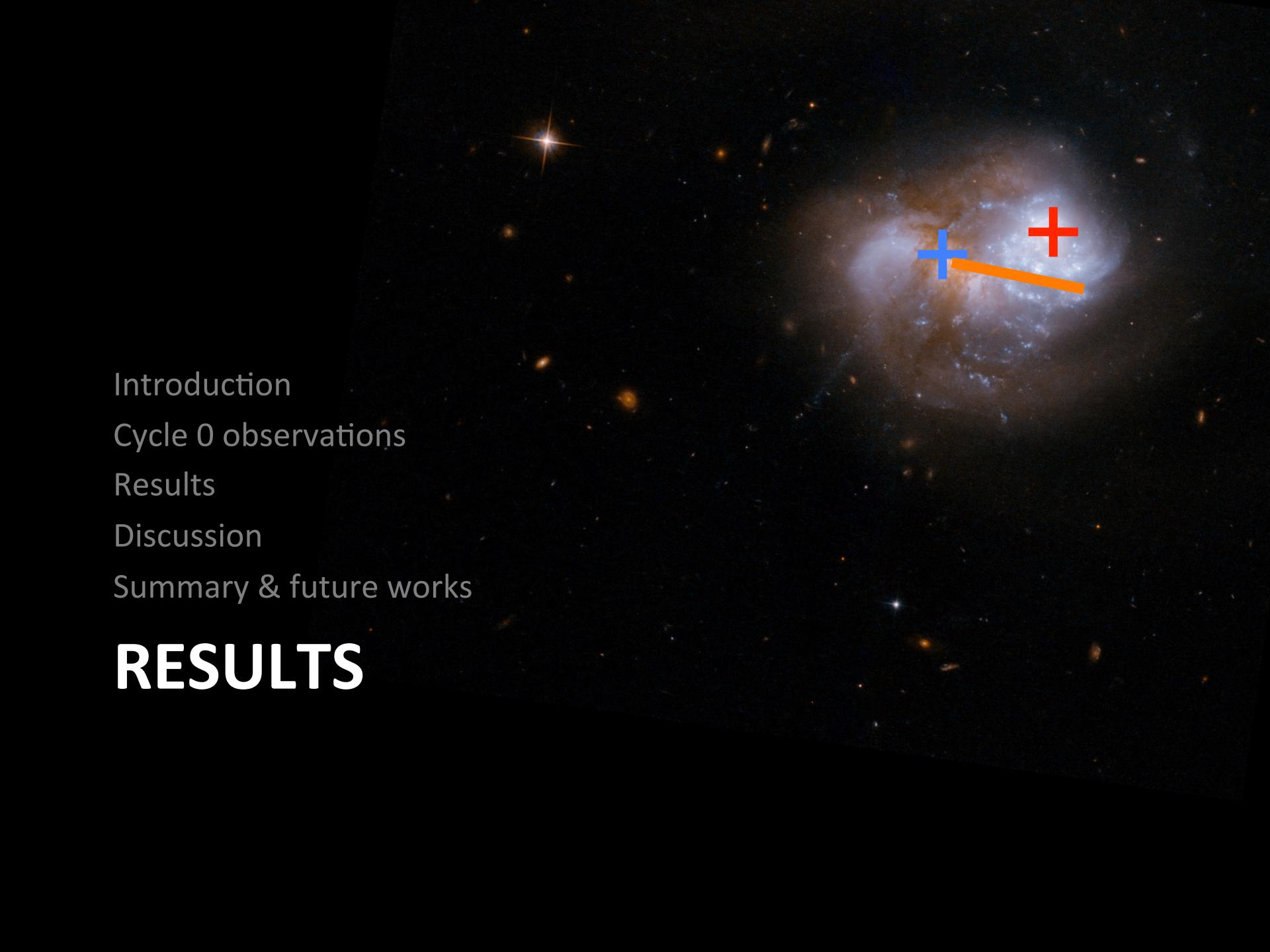


CMP and/or EXT configurations

Continuum emission in each observation

Using reduction package CASA

	Obs freq [GHz]	FOV [""]	On source time [min]	Beam size (1" = 370pc)	Critical density[cm ⁻³]
¹² CO(1-0)	112.96	53.7	38	2.0" × 1.3"	4.1×10^2
¹³ CO(1-0)	107.99	56.2	41	1.8" × 1.2"	1.5×10^3
¹² CO(3-2)	338.86	17.9	82	1.3" × 1.0"	8.4×10^3
HCO ⁺ (4-3)	349.58	17.4	86	0.44" × 0.36"	1.8×10^6
HCN(4-3)	347.50	17.6	86	0.45" × 0.39"	8.5×10^6



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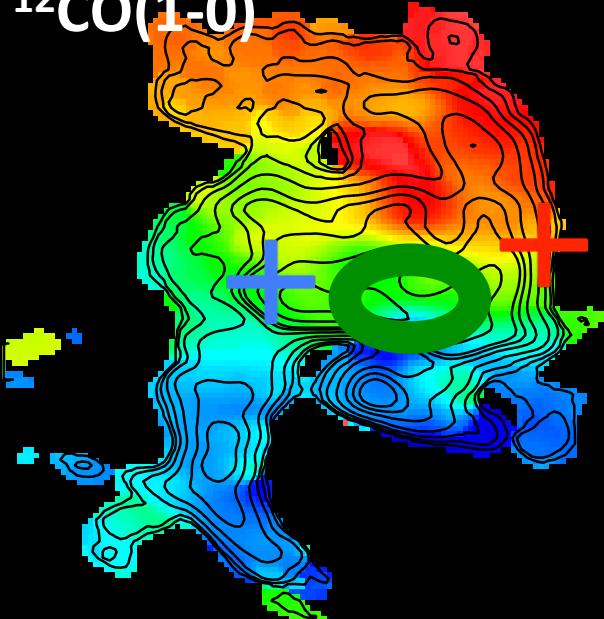
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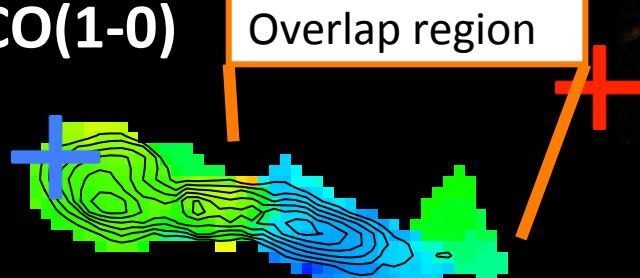
RESULTS

Band 3

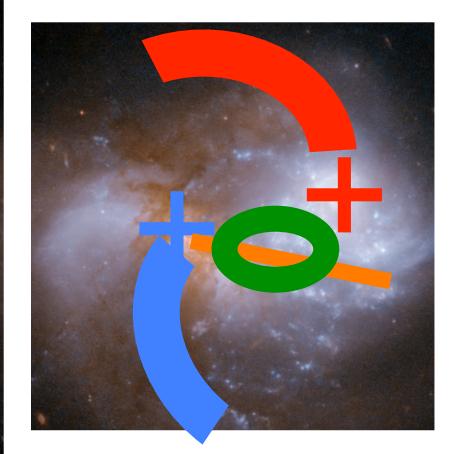
$^{12}\text{CO}(1-0)$



$^{13}\text{CO}(1-0)$



5600km/s 6200km/s



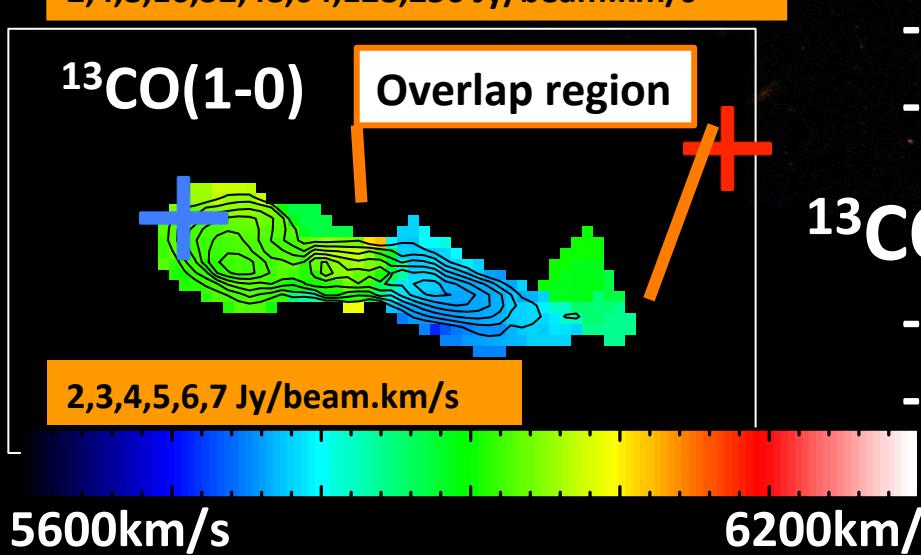
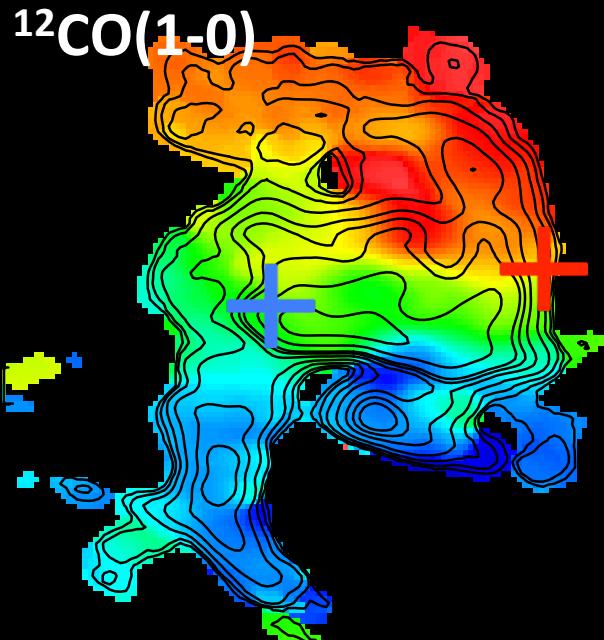
$^{12}\text{CO}(1-0) \sim 10^2 \text{cm}^{-3}$

- clearly dust lane
- $\sigma > 100 \text{km/s}$ between the nuclei
- derived H₂ mass = $4.7 \times 10^{10} M_{\text{sun}}$

$^{13}\text{CO}(1-0) \sim 10^3 \text{cm}^{-3}$

- Filamentary structure
- consistent with Pa alpha filament

Band 3



$^{12}\text{CO}(1-0) \sim 10^2 \text{cm}^{-3}$

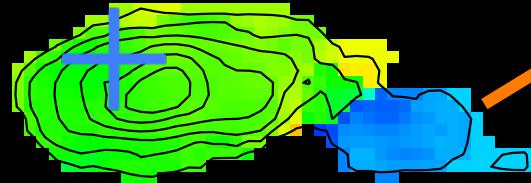
- clearly dust lane
- $\sigma > 100 \text{km/s}$ between the nuclei
- derived H₂ mass = $4.7 \times 10^{10} M_{\text{sun}}$

$^{13}\text{CO}(1-0) \sim 10^3 \text{cm}^{-3}$

- Filamentary structure
- consistent with Pa alpha filament

Band 3 -extra

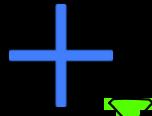
CN N = 1-0, J = 3/2-1/2



Overlap region

1, 3, 5, 7, 9, 11, 13, 15 Jy/beam.km/s

CS(2-1)



Overlap region



0.5, 1.5, 2.5 Jy/beam.km/s



5600km/s

6200km/s

CN N = 1-0, J = 1/2-1/2



1, 2, 3, 4, 5, 6 Jy/beam.km/s

CH₃OH(2-1)

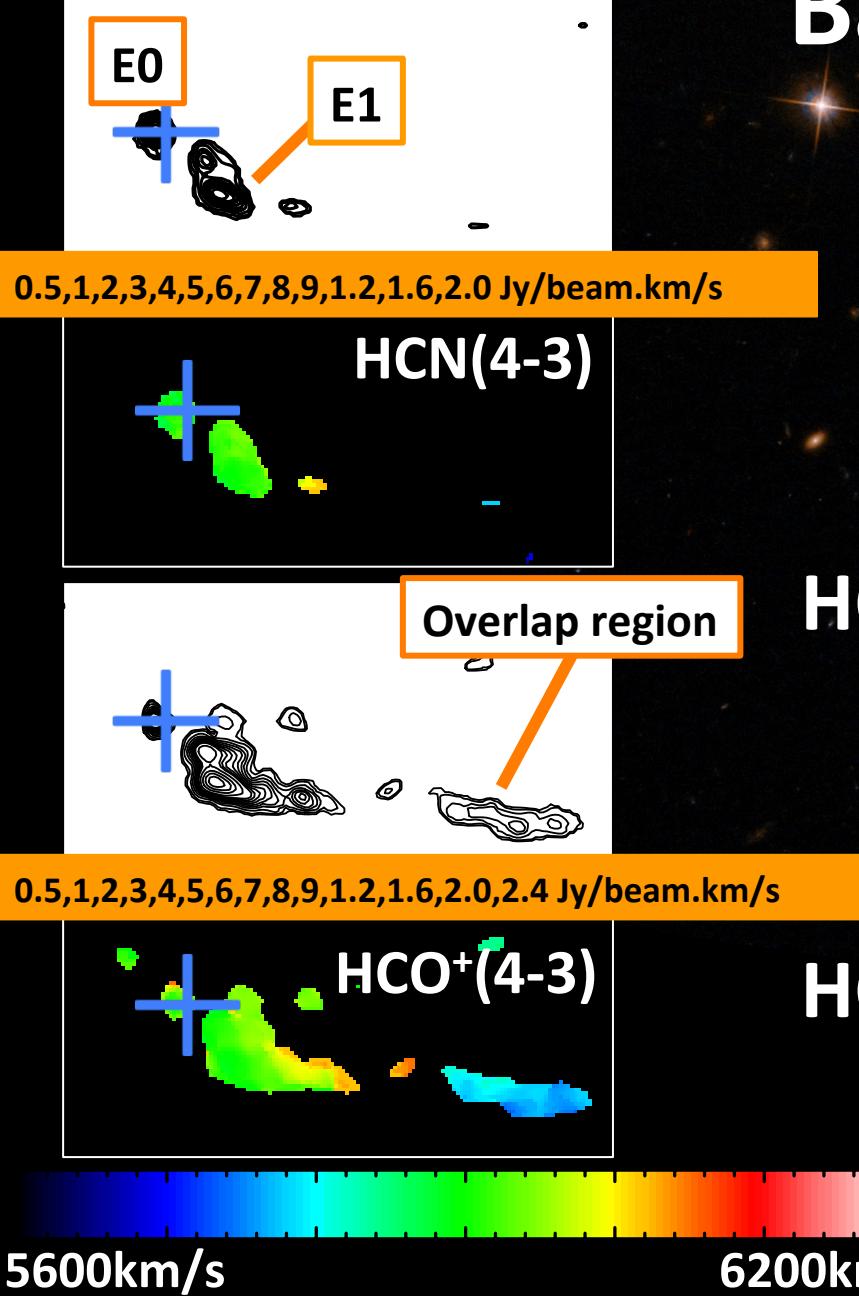


Overlap region



0.5, 1.5, 2.5, 3.5, 4.5 Jy/beam.km/s

Band 7



$\text{HCN}(4-3) \sim 10^7 \text{cm}^{-3}$

- Clumps at the nucleus
- Specific features: E0 and E1

$\text{HCN}(4-3) \sim 10^6 \text{cm}^{-3}$

- Clumps at the filament



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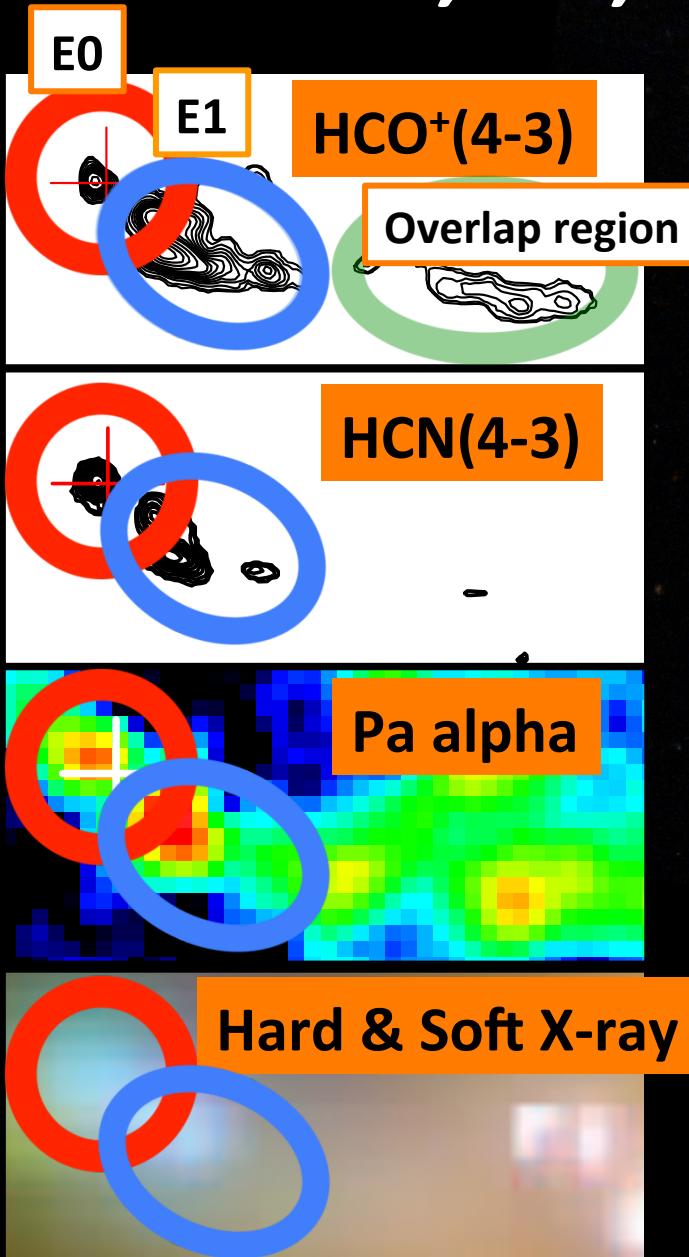
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DISCUSSION

E0, E1, the overlap region



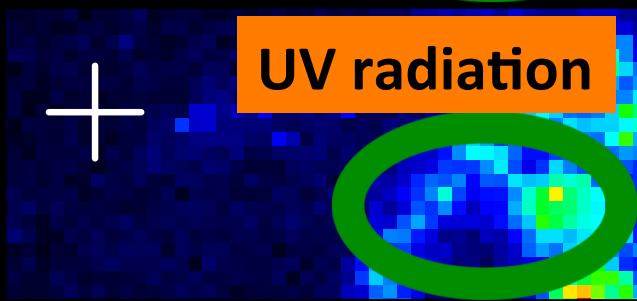
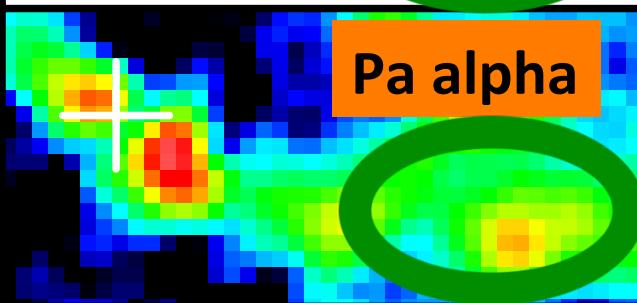
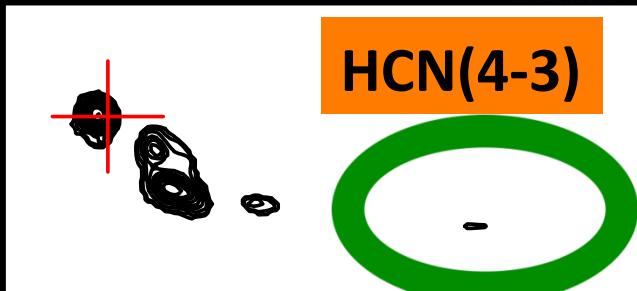
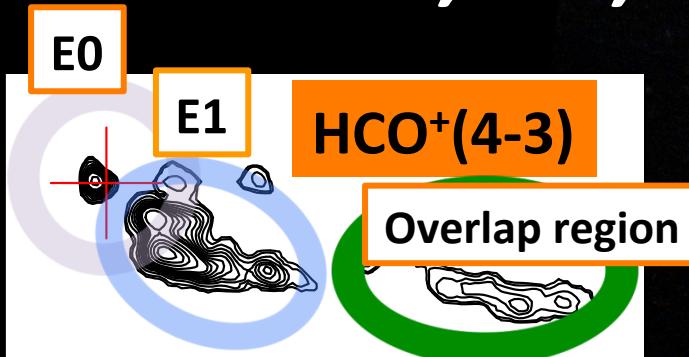
E0 = Obscured AGN

- point source ($r < 100\text{pc}$)
- broad line width ($\text{FWZI} \sim 300 \text{ km/s}$)
- $\text{HCN}/\text{HCO}^+ \sim 1.6$ (Kohno+01, Imanishi+07)
- $\text{HCN}/\text{CO} > 0.6 - 1.2$ (Aalto+97, 07)

E1 = Compact starburst

- extended source ($r > 200\text{pc}$)
- line width ($\text{FWZI} \sim 200 \text{ km/s}$)
- $\text{HCN}/\text{HCO}^+ \sim 0.5$
- $\text{HCN}/\text{CO} > 0.2 - 0.6$

E0, E1, the overlap region



E0 = AGN

E1= SB



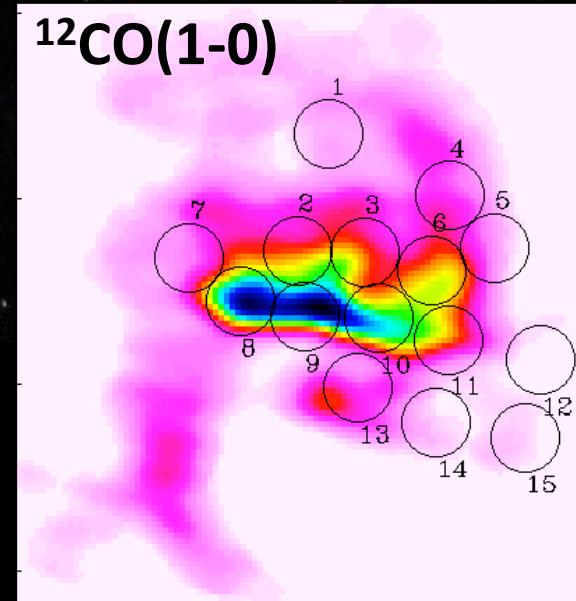
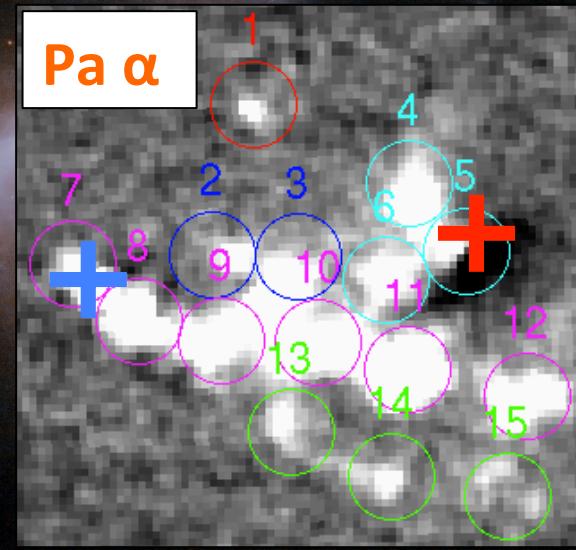
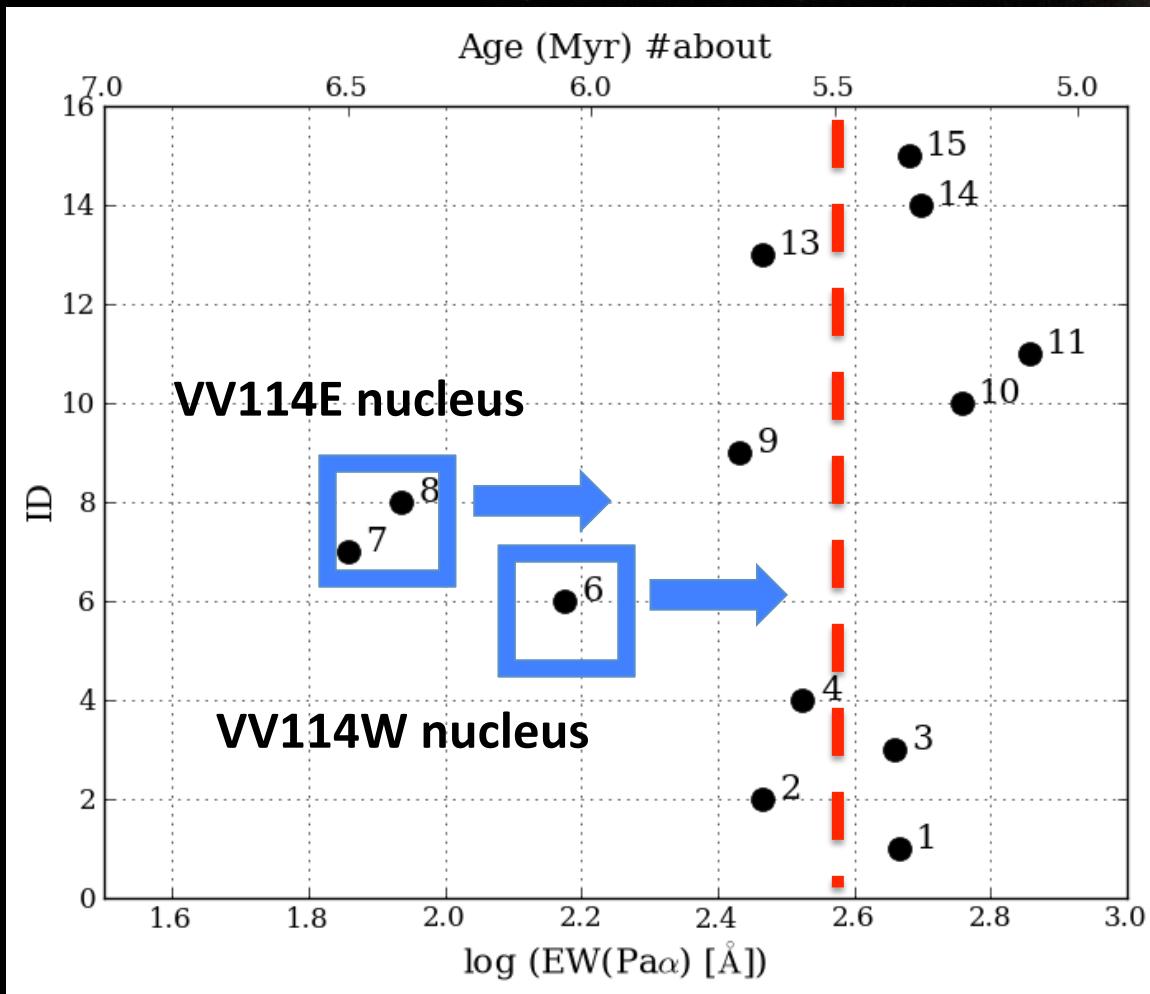
Overlap = Shock-induced SF

- a part of the filament
- diffuser (HCN , $\text{CS}(7-6)$ non-detection)
- turbulent ($\text{CO}(1-0)$: $\sigma > 100 \text{ km/s}$)
- $\text{CS}(2-1)$, methanol(2-1) (shock tracer?)

Matched- age KS-law (Tateuchi-san's work)

Aperture = 3.7'' (~ 1.4 kpc)

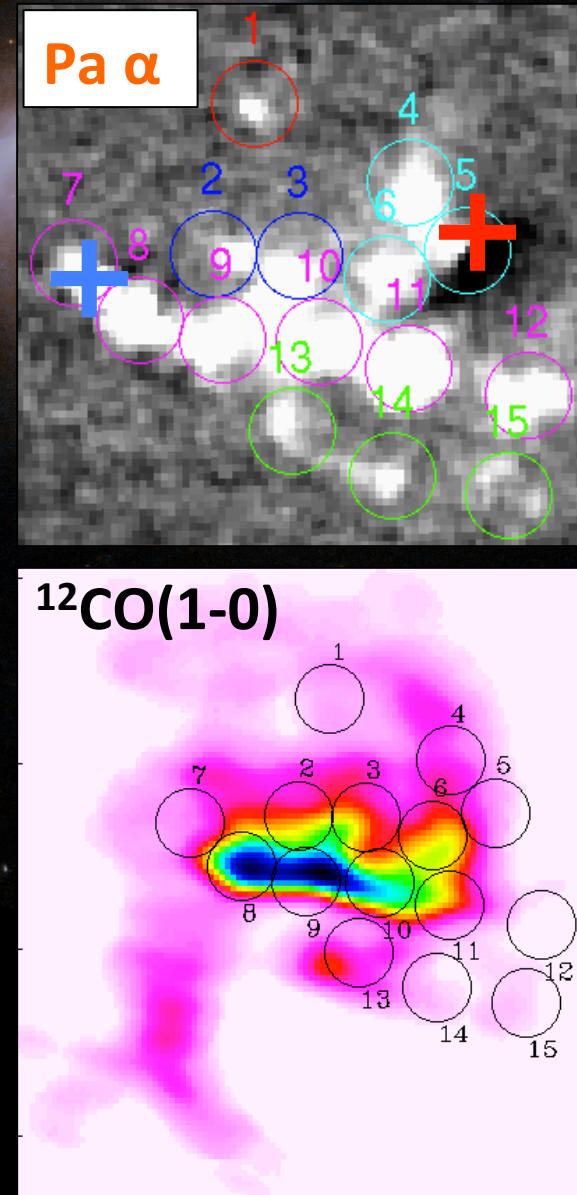
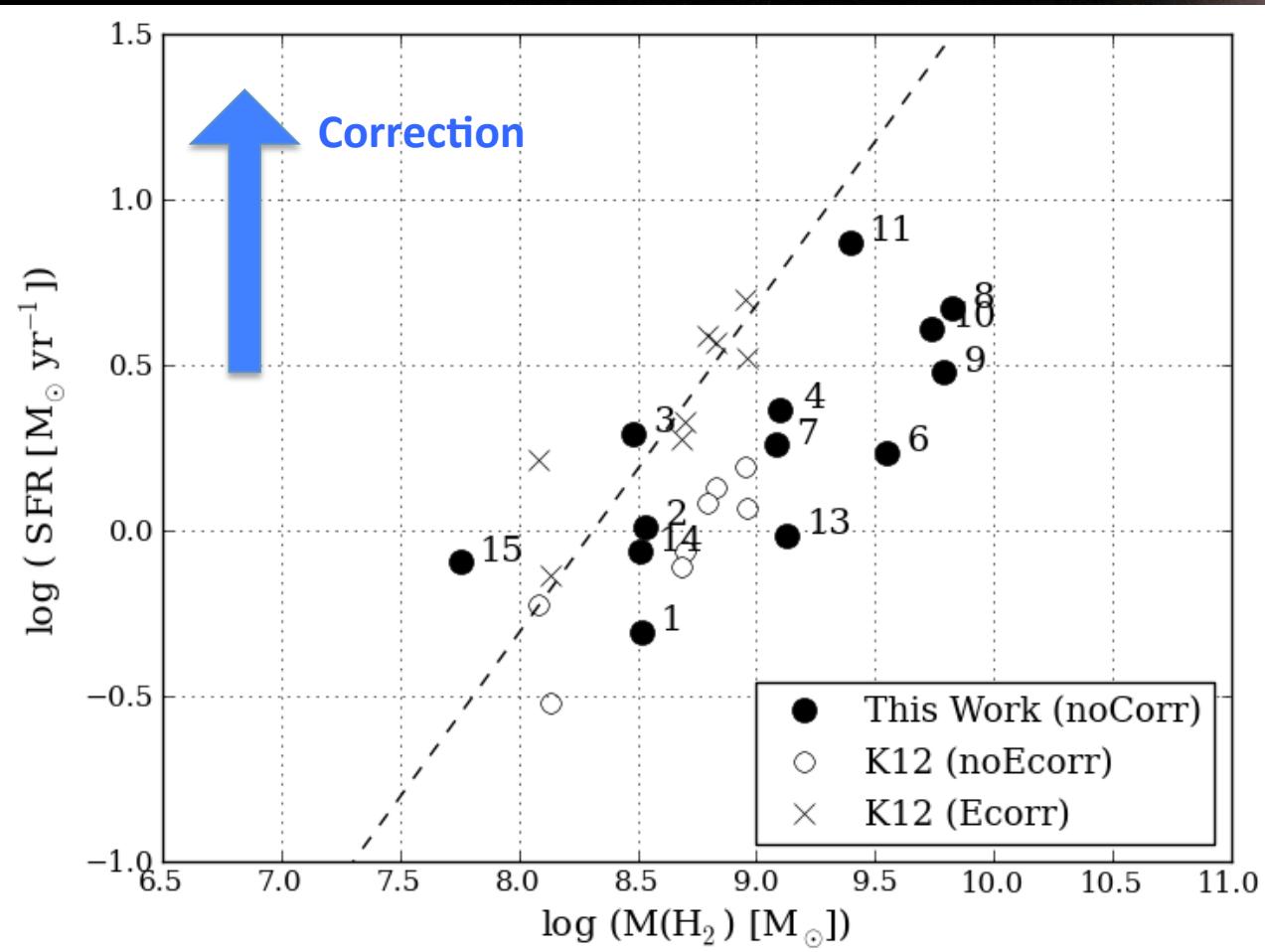
Age ~ 5.5 Myr



Matched- age KS-law (Tateuchi-san's work)

Comparison with Komugi+12

Age ~ 5.5 Myr





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SUMMARY & FUTURE WORKS

Summary

- CO(1-0), ^{13}CO (1-0), CO(3-2)
 - reveal **the global kinematics consistent with simulations.**
- High resolution HCN(4-3), HCO^+ (4-3), CS(7-6)
 - suggest **an obscured AGN and extended starburst in VV114E.**
- CN(1-0), CS(2-1), CH_3OH (2-1)
 - show **chemical differences between AGN, SB, Shock-induced SF.**
- Pa α
 - identify **the clumpy filament across the galaxy disks.**

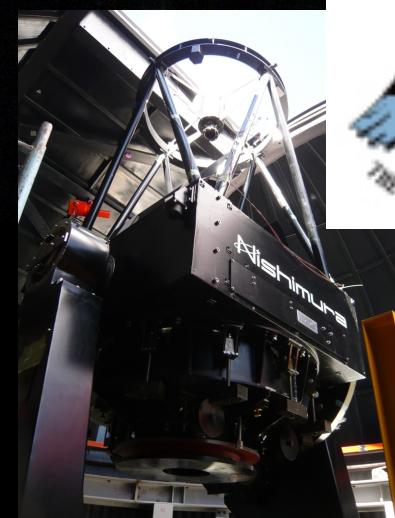
Future works

- LVG analysis

- NMA: HCN(1-0) and HCO⁺(1-0), SMA: CO(2-1)

- Corrected KS-law

- miniTAO/ANIR: Pa β , H α
 - CO(1-0), ^{13}CO (1-0), CO(3-2), CN(1-0), HCN(4-3), HCO⁺(4-3) ...
 - consistent with Komugi+12 ?





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THANK YOU!