Investigating AGN/starburst activities through ALMA multi-line observations in the mid-stage IR-bright merger VV114

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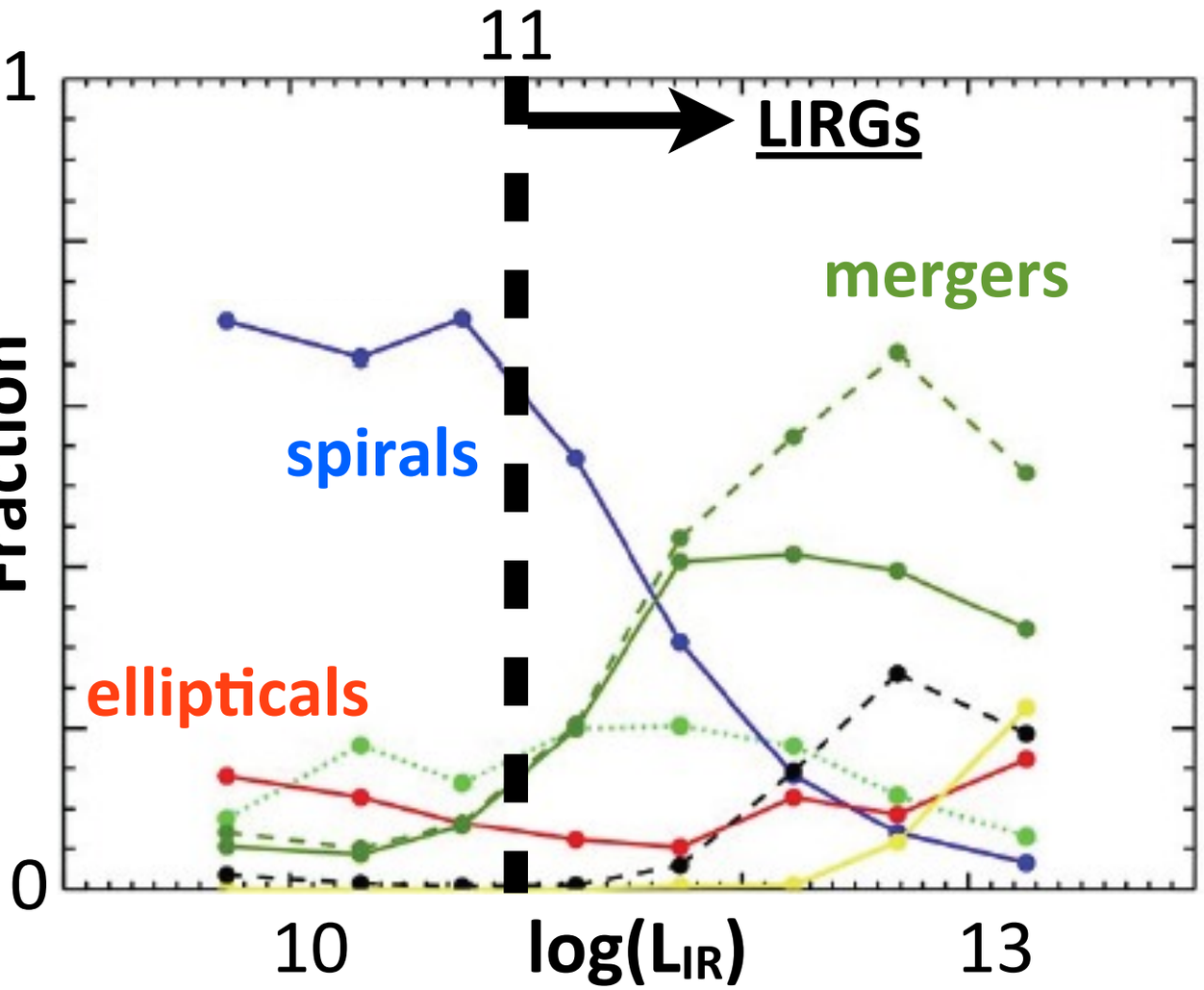
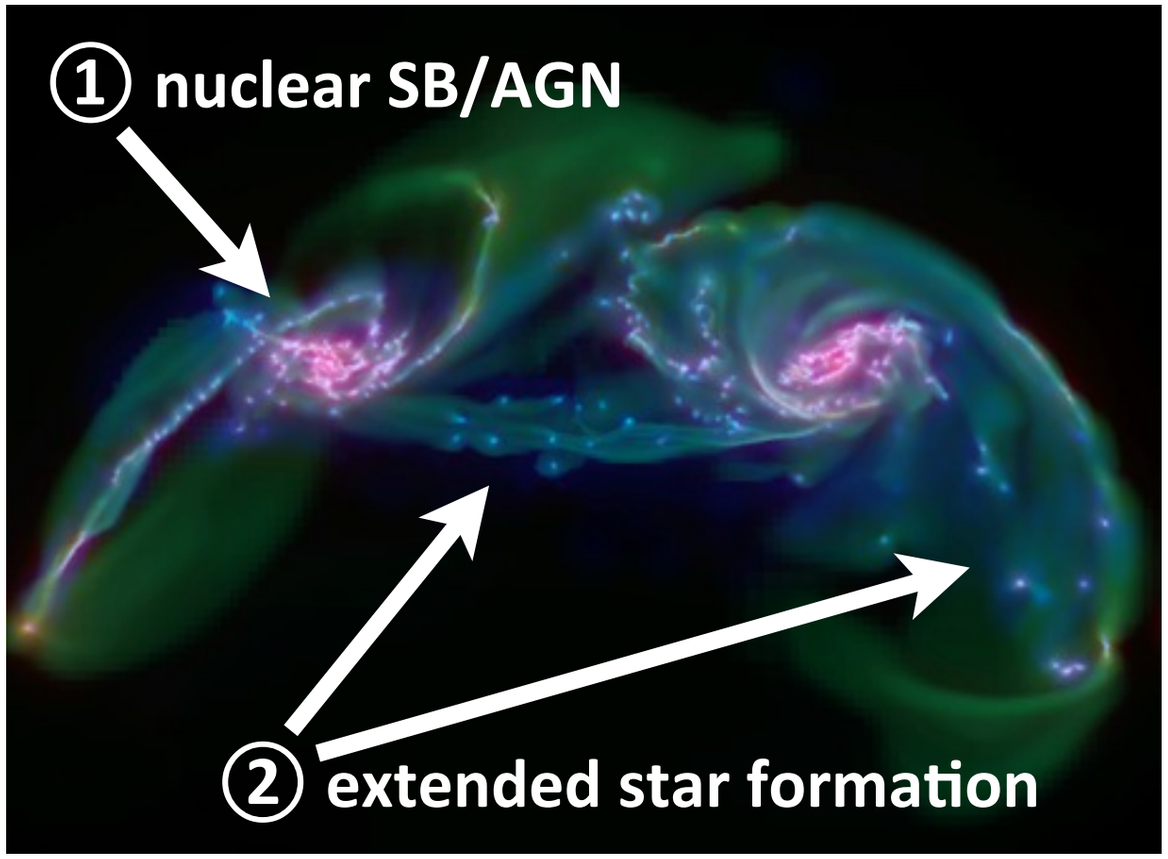
INTRODUCTION

U/LIRGs in the Universe





Most of luminous galaxies (U/LIRGs) are merging galaxies.

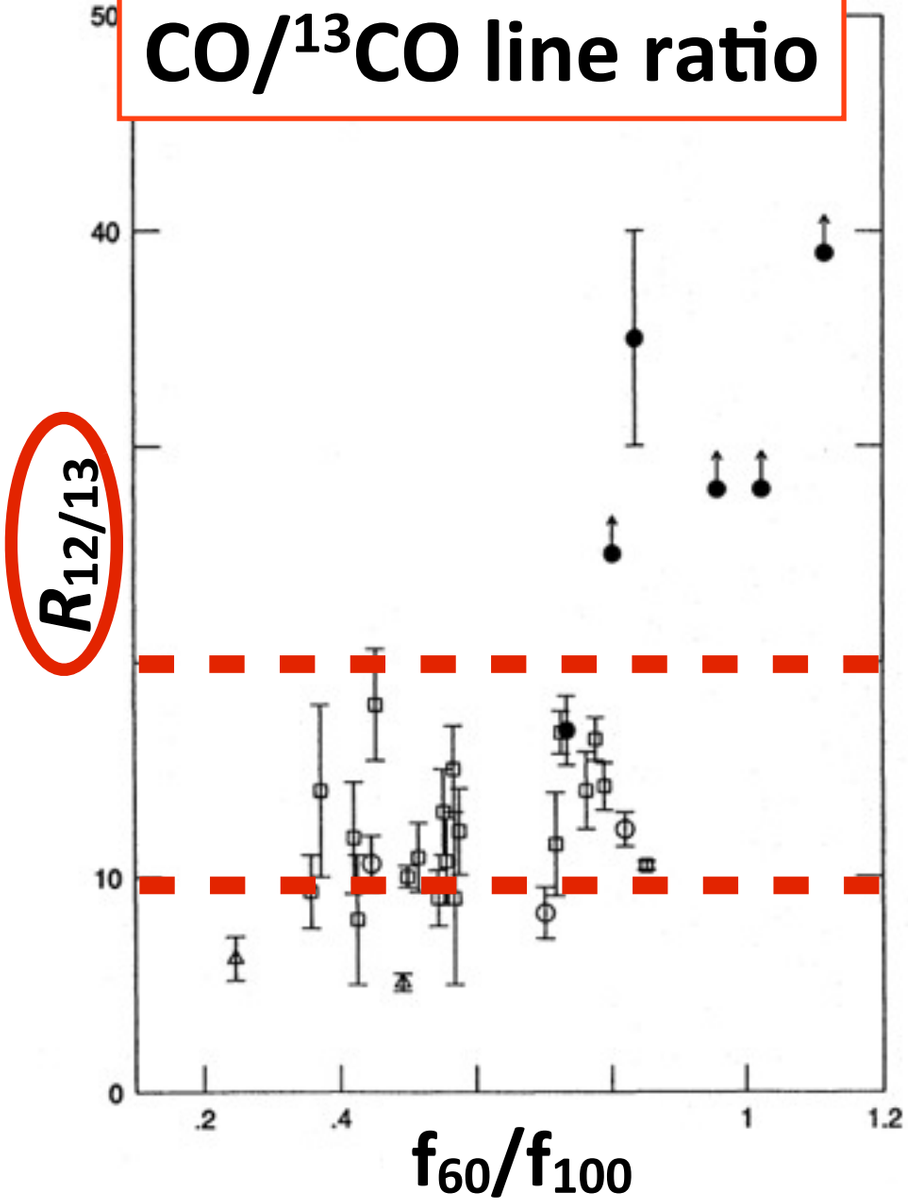
AGN/starburst activities are triggered by galaxy collisions.

High sensitivity and resolution observations of molecular gas are required!

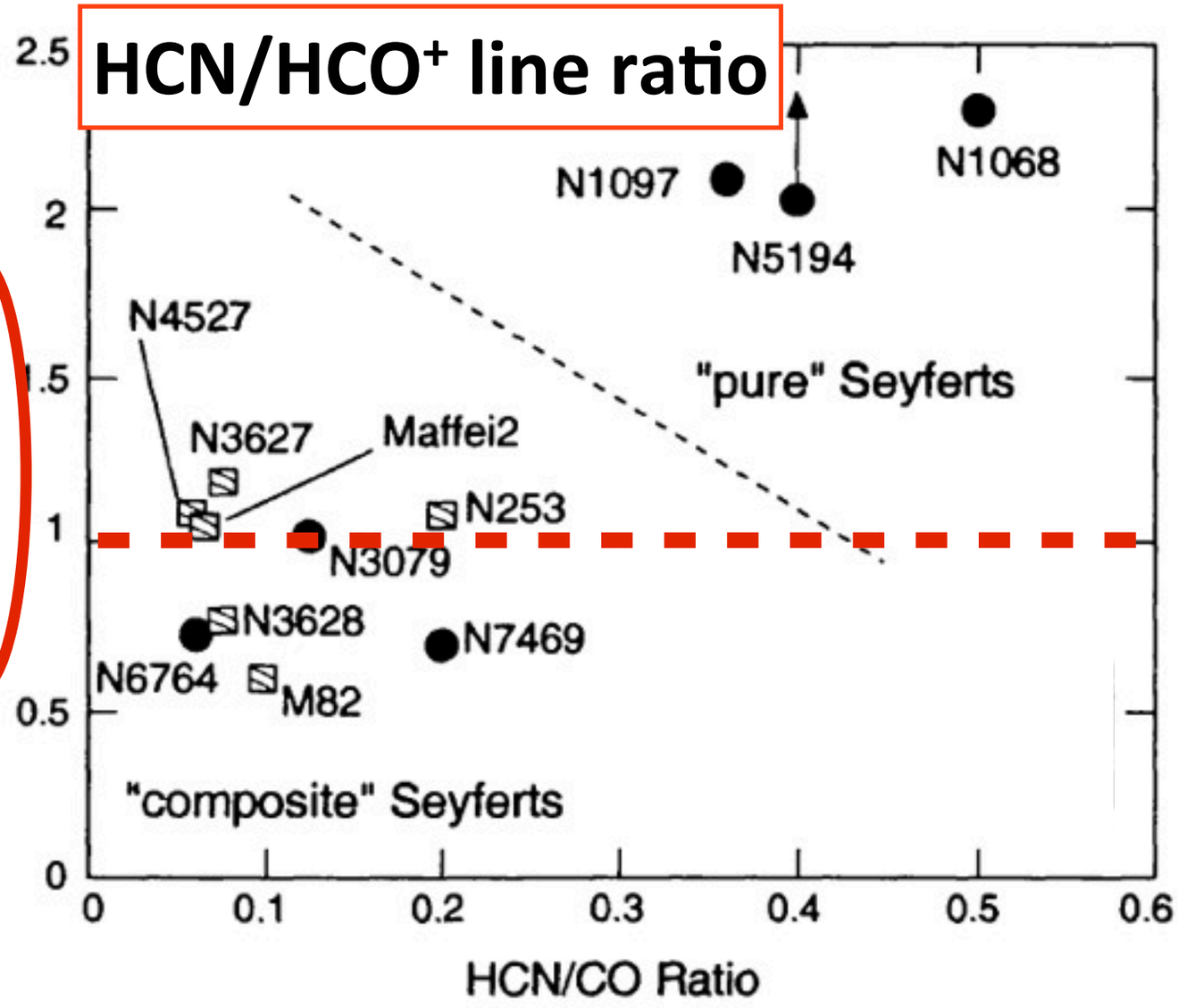
Teyssier+10; Kartaltepe+10

Molecular line ratios using single-dishes

CO/^{13}CO line ratio



HCN/HCO$^+$ line ratio



~ 5: Galactic GMCs

10 - 15: normal starburst galaxies

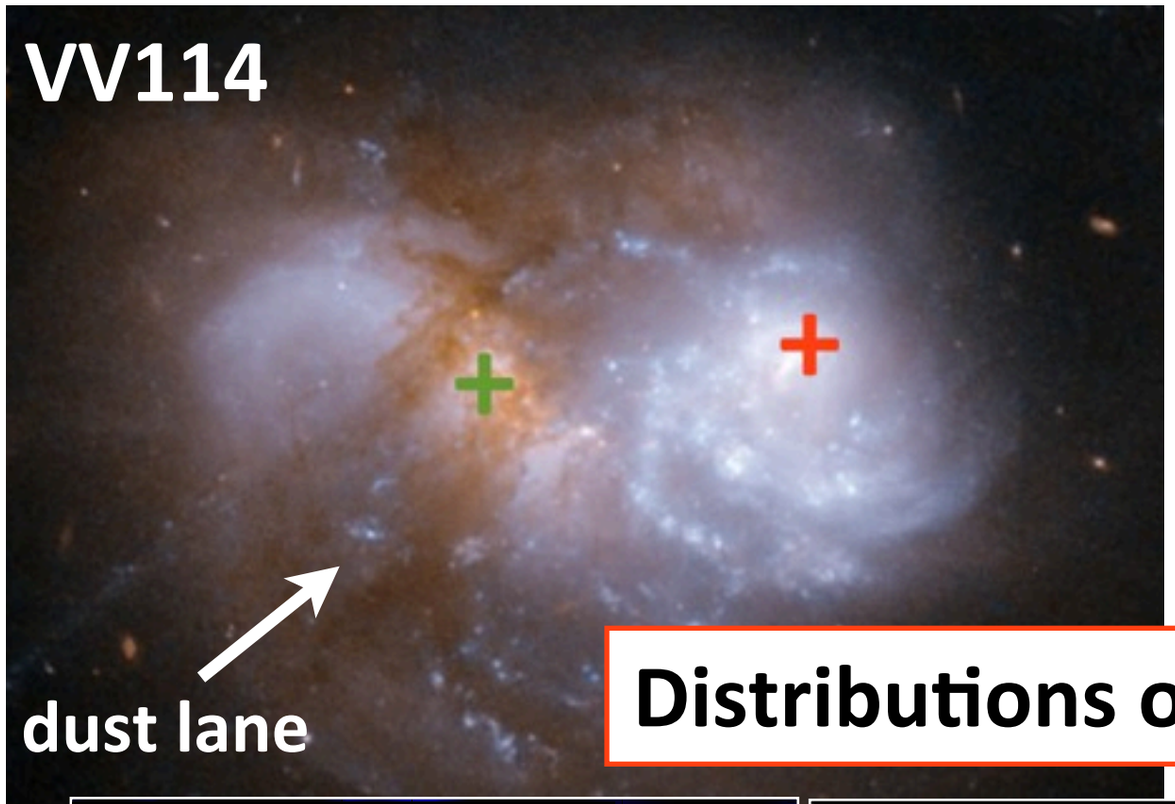
> 20: luminous mergers

> 1: AGN-dominated

< 1: Starburst-dominated

Kohno+01; Imanishi+07; Aalto+95; 00; 02; 07

AGN/SB activities in the mid-stage merger VV114



D_L = 86 Mpc (z = 0.02)

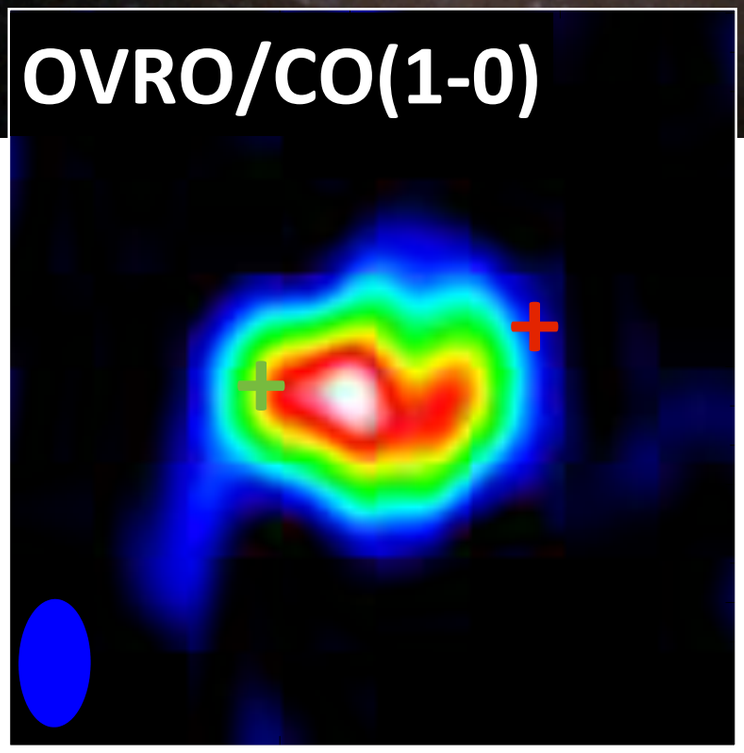
L_{FIR} = 4.1 x 10^{11} L_{sun} (LIRG)

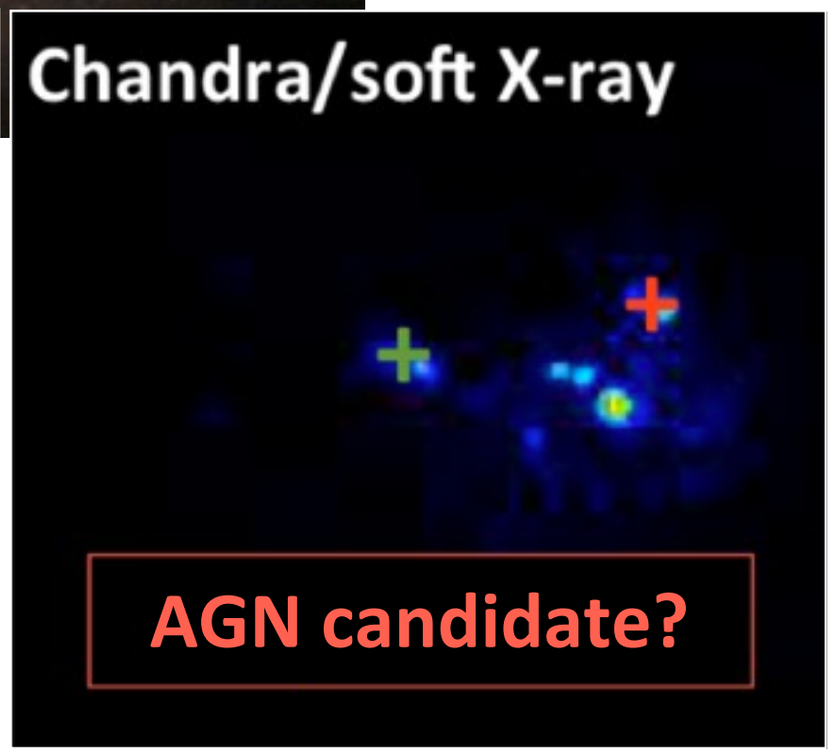
M_{gas} = 5.1 x 10^{10} M_{sun}

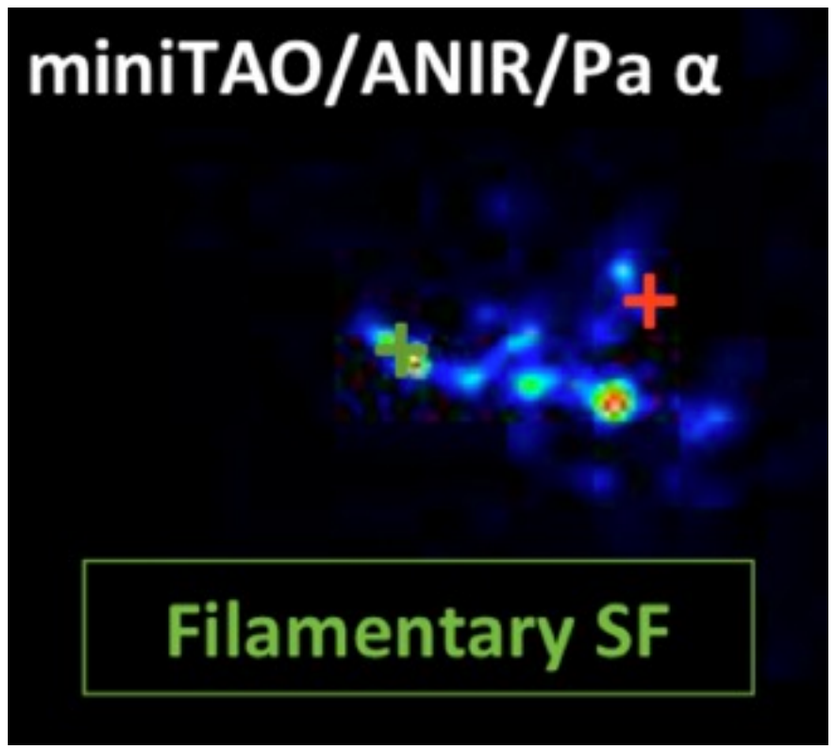
nuclear separation = 6 kpc

SFR ~ 45 M_{sun}/yr

Distributions of moelcular line ratios in VV114?







Soifer+87; Yun+94; Grimes+06; Evans+08; Tateuchi+12

OBSERVATIONS & RESULTS

Cycle 0 ALMA observations (P.I. D. Iono)

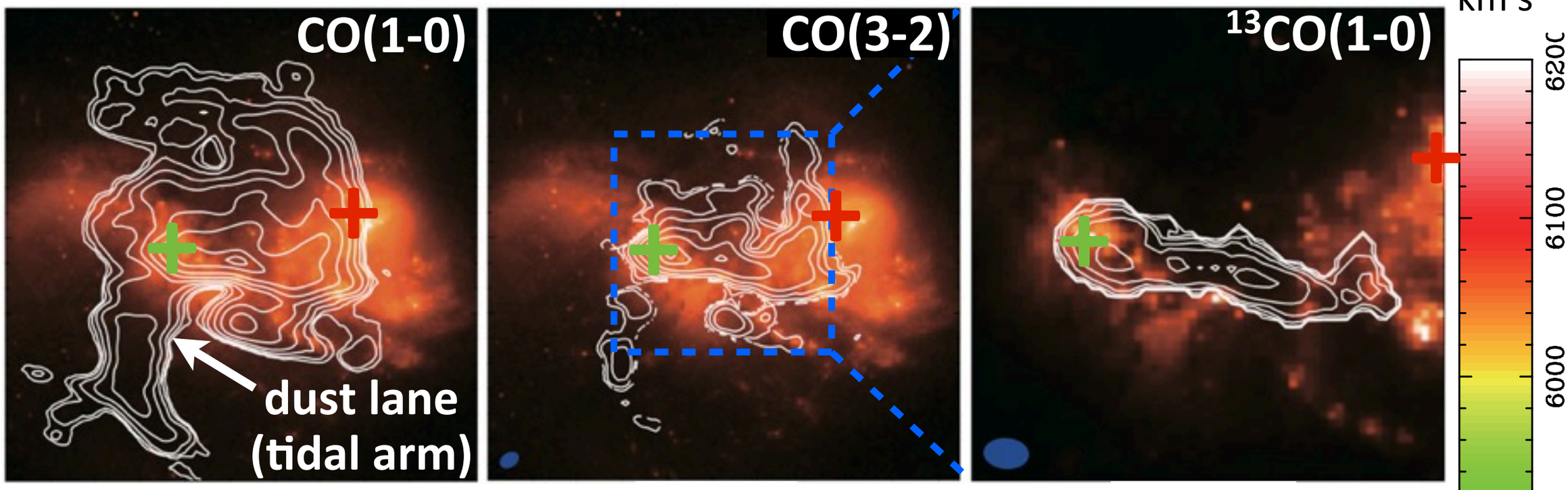
	rest freq. [GHz]	obs. time [min.]	angular res. [arcsec.]	n_{crit} [cm^{-3}]
CO(1-0)	115.27	81	2.0 × 1.3	4.1×10^2
^{13}CO(1-0)	110.20	61	1.8 × 1.2	1.5×10^3
CO(3-2)	345.80	200	1.3 × 1.0	8.4×10^3
HCN(4-3)	354.51	203	0.44 × 0.36	8.5×10^6
HCO^+(4-3)	356.73	203	0.45 × 0.39	1.8×10^6

Band 3 & Band 7
fourteen - twenty 12m antennas
compact & extended configurations

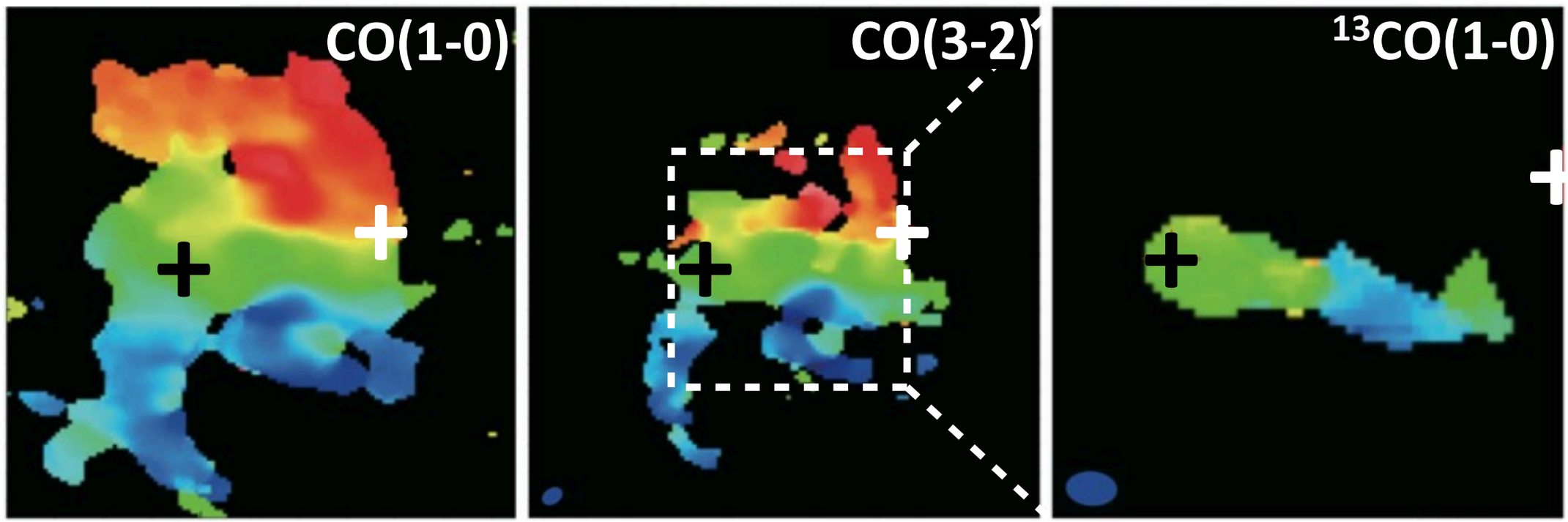
10 molecular lines, 110 GHz, and 340 GHz continuum!!

Diffuse gas in VV114 (T. Saito et al. 2013)

Integrated intensity ~ 800 resolution

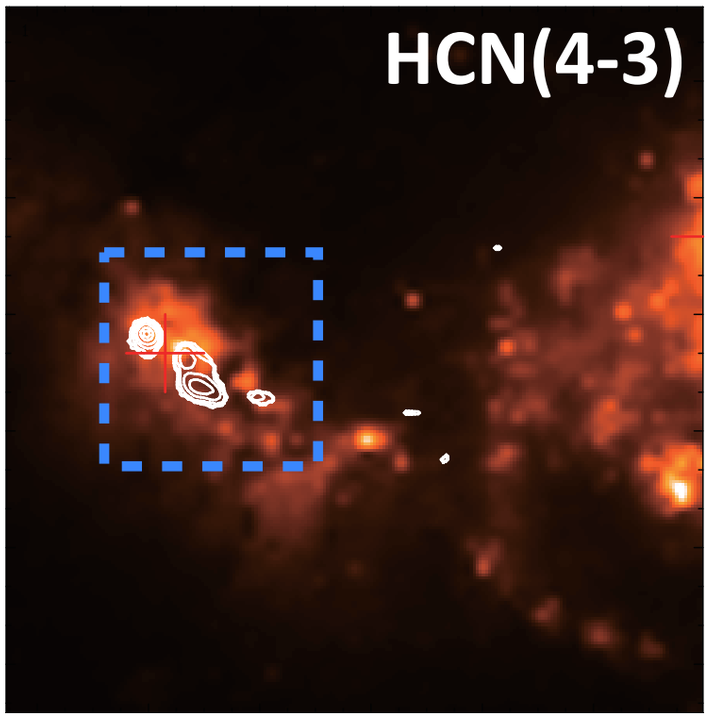


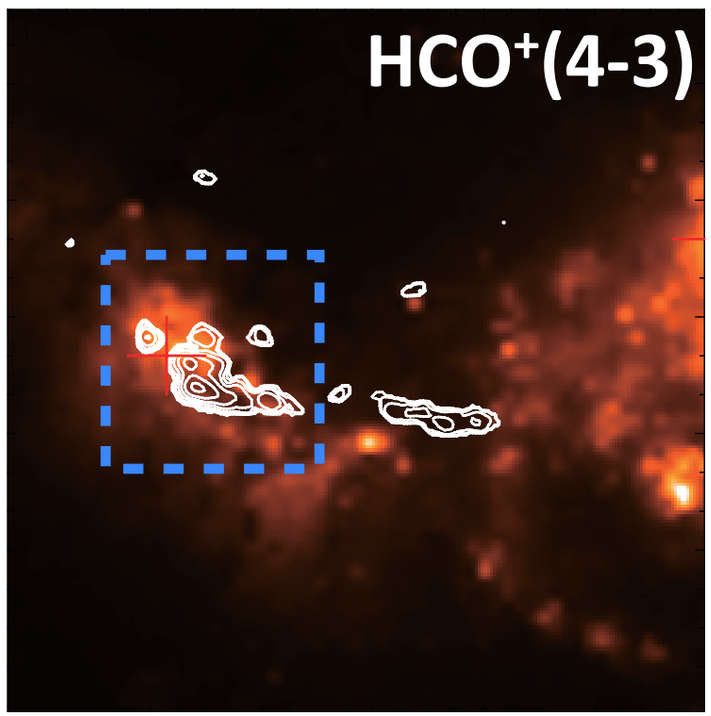
velocity field



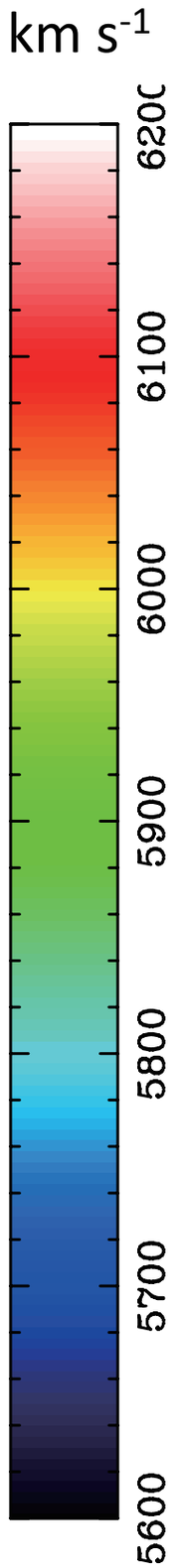
Dense gas in VV114 (D. Iono et al. 2013)

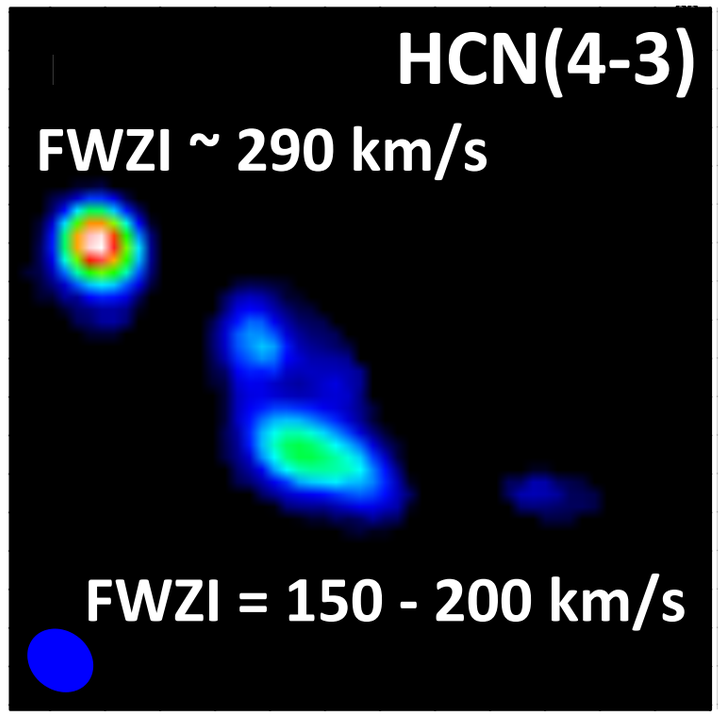
Integrated intensity ~ 200 resolution





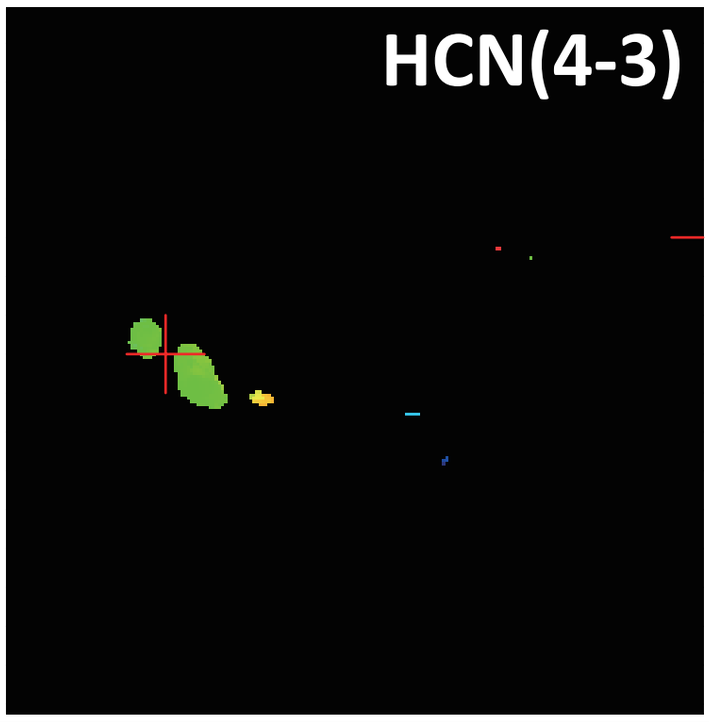
7.5 kpc

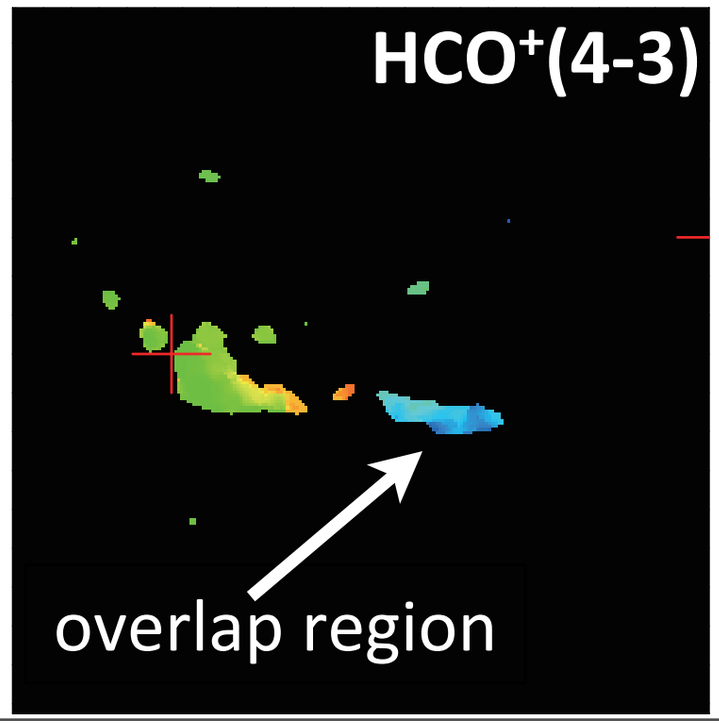


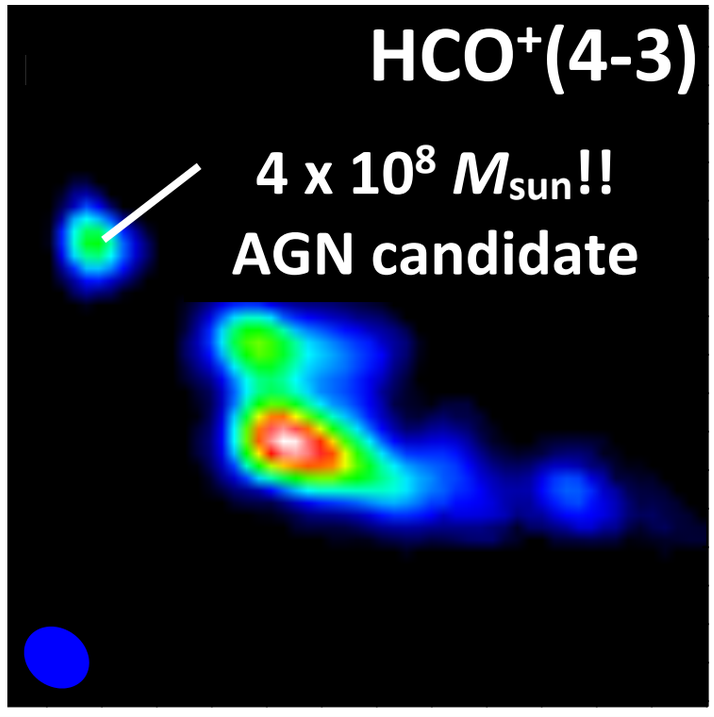


2 kpc

velocity field

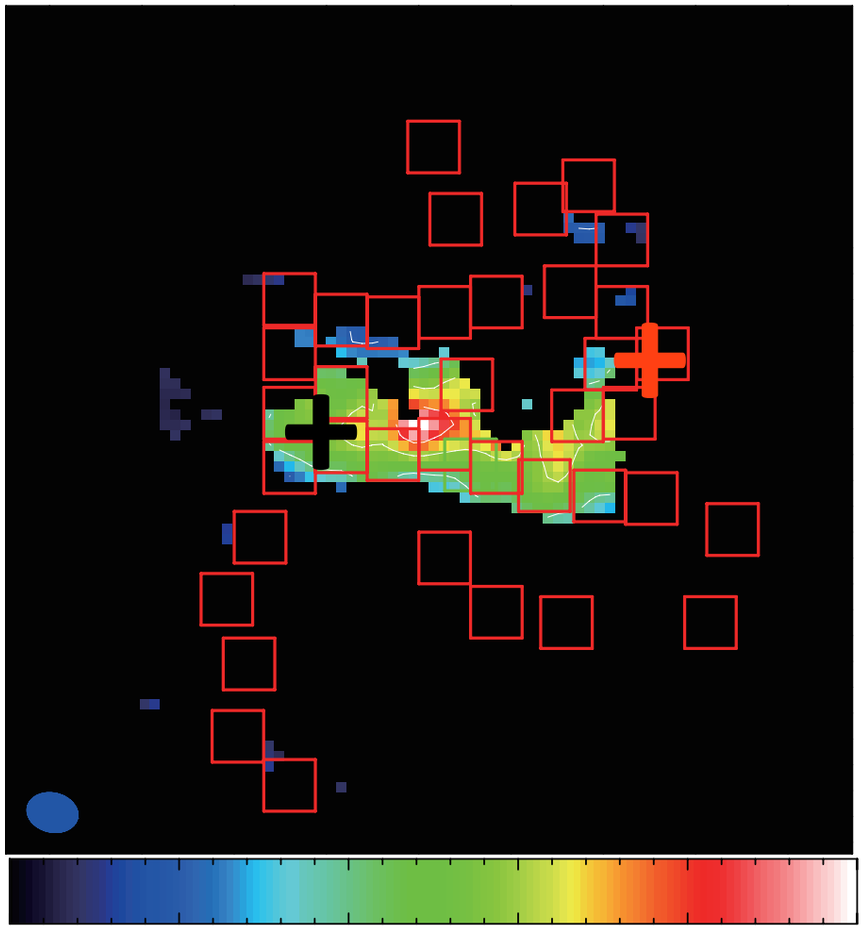




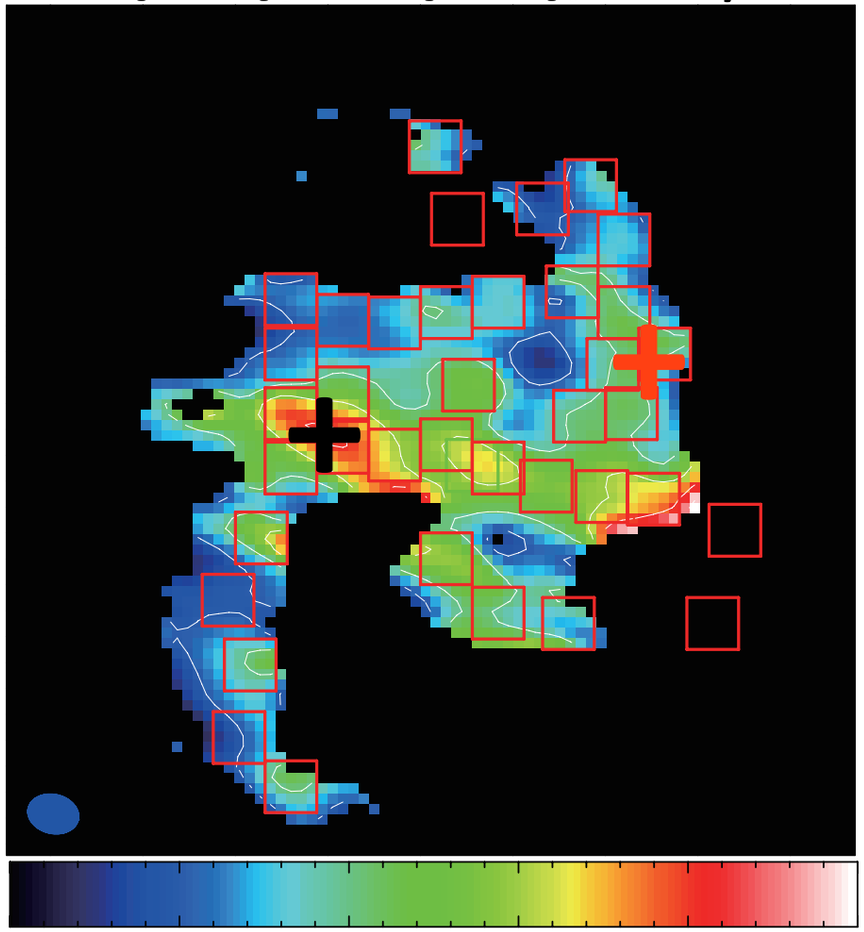


Distributions of the diagnostic line ratios

CO(1-0)/^{13}CO(1-0), $R_{12/13}$



CO(3-2)/CO(1-0), $R_{3\text{-}2/1\text{-}0}$



$R_{3\text{-}2/1\text{-}0}$ = 0.2 - 0.8: sub-thermalized (disk galaxies = 0.2 - 0.5)

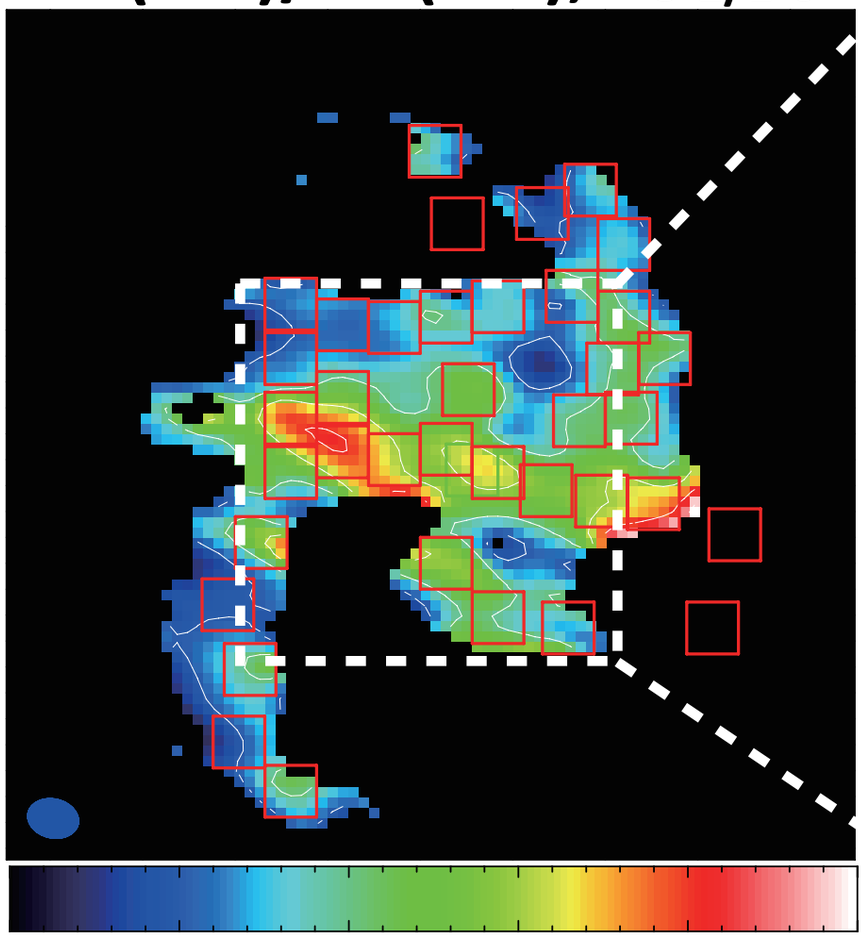
$R_{12/13}$ ~ 5 (arms), 20 (nuclei), **20 - 50 (overlap region)**

Unusually high $R_{12/13}$ at the filament!!

Aalto+97; Kohno+05; Warren+12; Imanishi&Nakanishi13; Iono+13

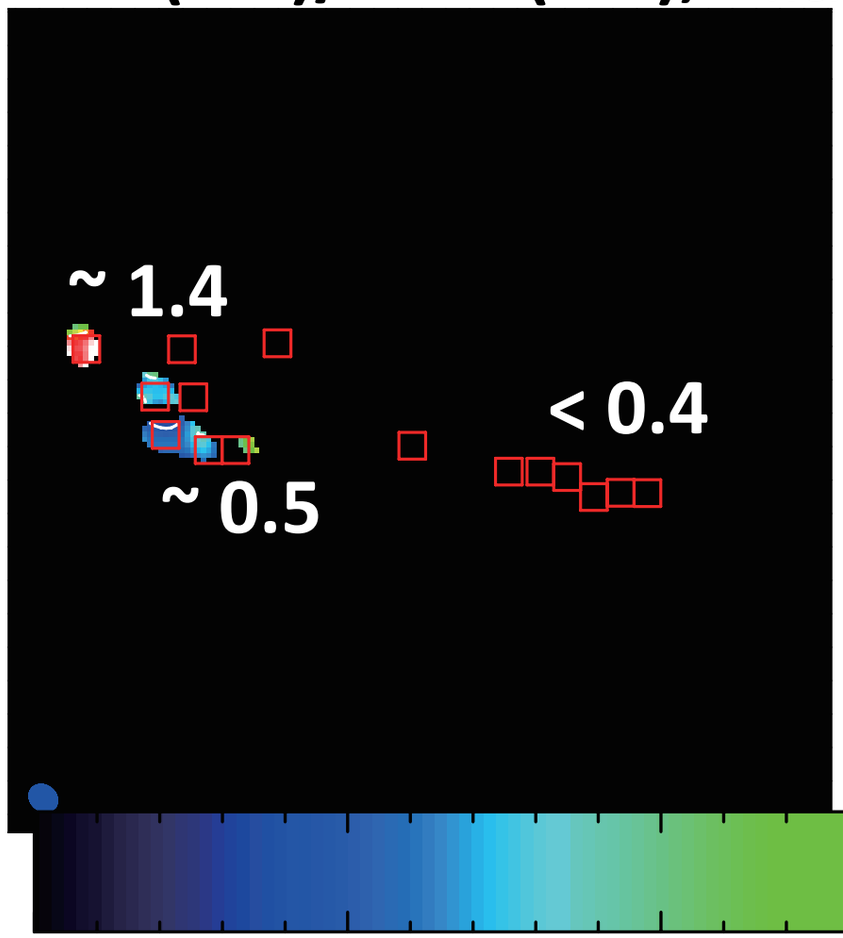
Distributions of the diagnostic line ratios

CO(3-2)/CO(1-0), $R_{3\text{-}2/1\text{-}0}$



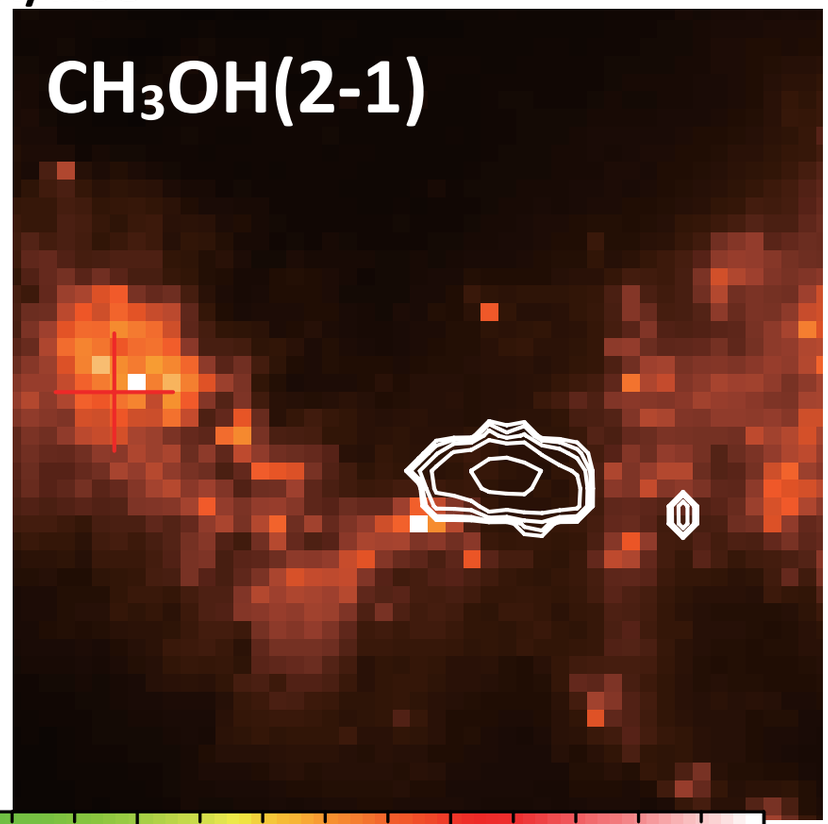
0 1

HCN(4-3)/HCO$^+$(4-3), $R_{HCN/HCO+}$



0 2

CH_3OH(2-1)

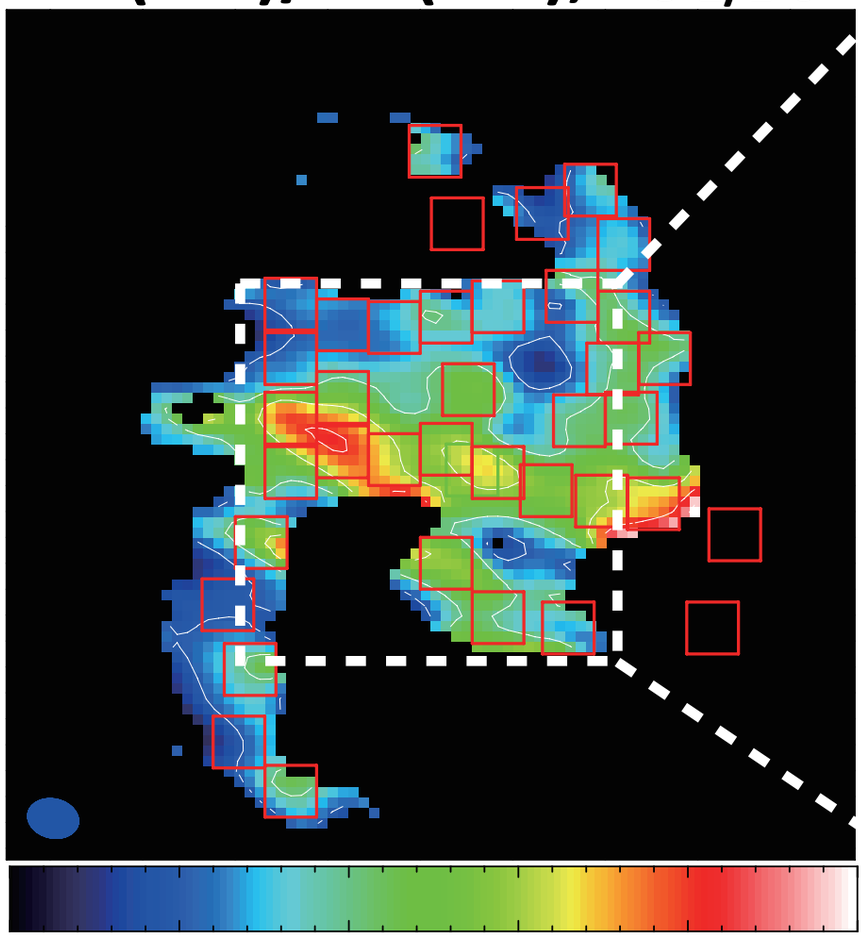


Overlap: $R_{HCN/HCO+} < 0.4$, $CH_3OH \sim 9 \times 10^{-9}$ cm^{-3} ⇒ shock-induced

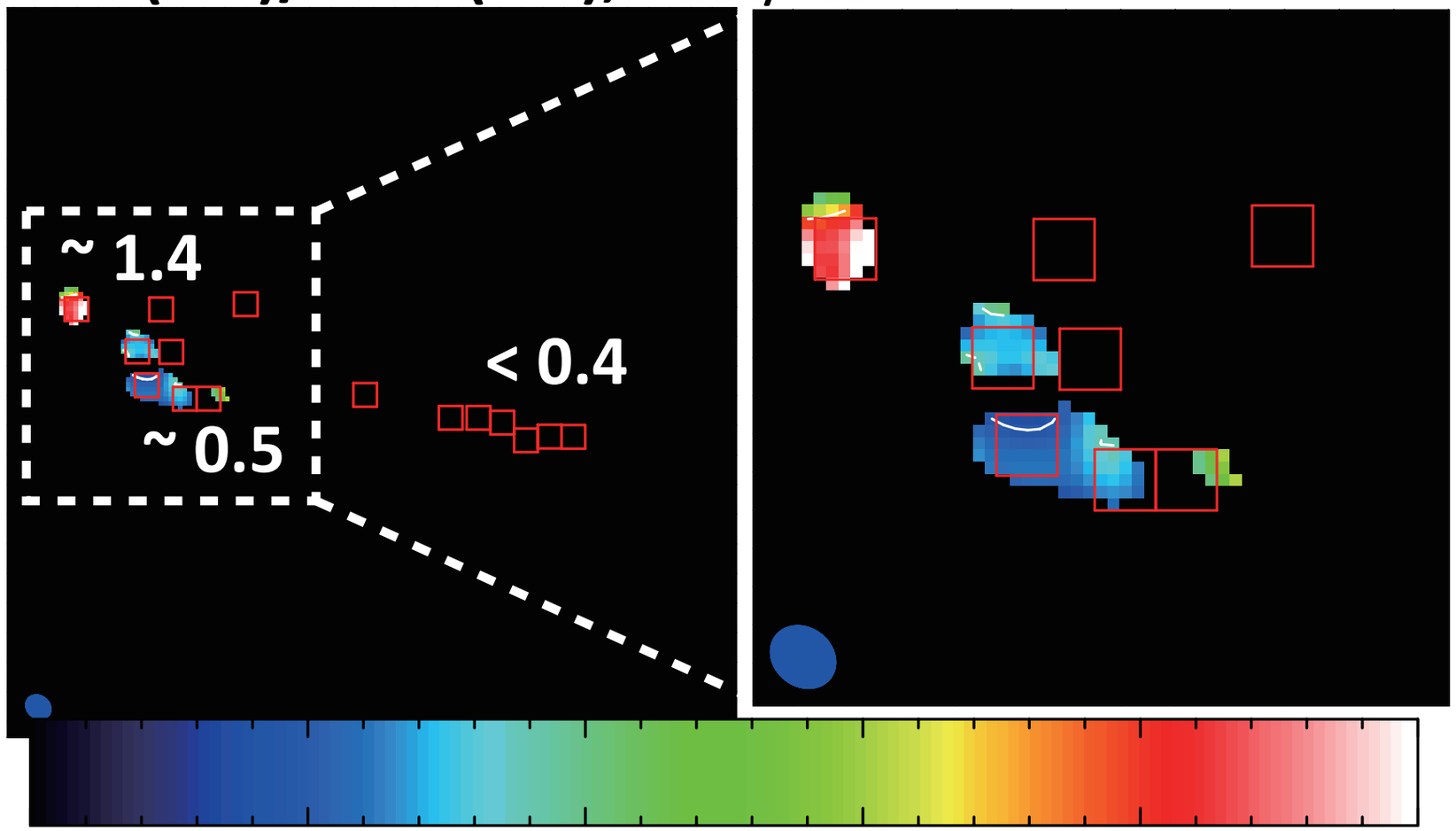
Aalto+97; Kohno+05; Warren+12; Imanishi&Nakanishi13; Iono+13

Distributions of the diagnostic line ratios

CO(3-2)/CO(1-0), $R_{3\text{-}2/1\text{-}0}$



HCN(4-3)/HCO+(4-3), $R_{HCN/HCO+}$



Overlap: $R_{HCN/HCO+} < 0.4$, $CH_3OH \sim 9 \times 10^{-9}$ cm^{-3} ⇒ shock-induced

Point source: ~ 4 x 10^8 M_{sun}, $R_{HCN/HCO+} \sim 1.4$ ⇒ AGN candidate

Clumps: strong Paα peak, $R_{HCN/HCO+} \sim 0.5$ ⇒ nuclear SB

Aalto+97; Kohno+05; Warren+12; Imanishi&Nakanishi13; Iono+13

Conclusion

Distributions of moelcular line ratios in VV114?

1. **<u>high sensitivity/resolution observations using ALMA</u>**
   - ~ 2” resolution CO(1-0), ^{13}CO(1-0), CO(3-2) maps
     ⇒ detect a dense gas filament for the first time
   - ~ 0”.5 resolution HCN(4-3), HCO^+(4-3) maps ⇒ AGN/SB
   - CH_3OH(2-1) line is only detected at the overlap region.

2. **<u>spatially-resolved $R_{3\text{-}2/1\text{-}0}$, $R_{12/13}$, $R_{HCN/HCO+}$</u>**
   - The central filament shows extremely high $R_{12/13}$. (than spirals)
   - AGN candidate only shows $R_{HCN/HCO+} > 1$.

Identify AGN, SB, and shock-induced overlap!!