Structure and Kinematics of CO (2-1) in the Central Region of NGC 4258

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NGC 4258...

- Nearby AGN: Seyfert 2 or LINER (7.2 Mpc; Herrnstein et al. 1999)
- Bisymmetric anomalous arms (cm-wave, Hα, X-ray; van der Kruit 1972)
- CO(3-2), CO(2-1), CO(1-0) detected (Cox and Downes 1996)
- Sub-parsec edge-on disk traced traced by H_2O (Miyoshi et al. 1995)

+ In M51, the CO(1-0) line is associated with mainly galactic arms. However, CO(2-1) and (3-2) are concentrated at the center (Matsushita et al. 2004). Is this trend common in Seyfert galaxies ?
+ In NGC4258, dynamics of kilo-parsec-scale and parsec-scale are different. Until now, nobody see a link between the two dynamics.
+ CO traces the bars ? or the shock region by jets ?

=> SMA Observations toward the CO(2-1) of NGC4258

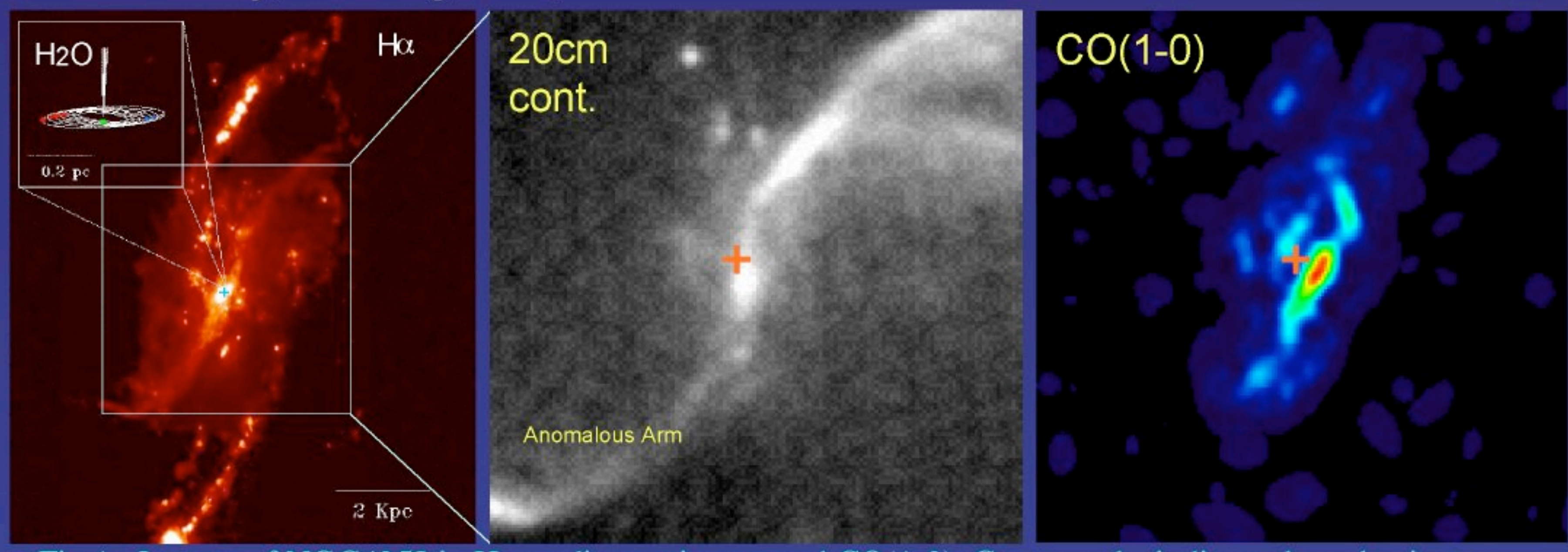


Fig.1: Images of NGC4258 in Hα, radio continuum and CO(1-0). Cross marks indicate the galactic center.

Integrated CO 2-1 emissions

Our CO(2-1) integrated intensity map reveal three areas of emission as past CO(1-0) observations detected (Plante et al. 1991, Helfer et al. 2003). We use hereafter same nomenclature for these components as Plante et al. (1991) identified as Fig.2. Distributions of CO(2-1) emissions are similar to CO(1-0) (Plante et al. 1991, Helfer et al. 2003). Unlike M51, no concentrated CO(2-1) is seen in center.

CO(2-1) emission is detected with velocity range from 200 km/s to 650 km/s in V_{LSR}, which is consistent with past single-dish observations with the IRAM 30-m telescope (Cox and Downes 1996). Convolving with the same beam size as the single dish (12.5"), we estimate that the interferometer recovered ~60 % of the single dish flux. The missing flux is due to the lack of short (<10 m) baselines.

The integrated intensity in the center is 3σ level (6.3 Jy/beam km/s). Assuming the ratio of integrated intensity CO(2-1)/CO(1-0) =1, we can estimate the column density of molecular hydrogen $N_{H2}=7.5\times10^{21}$ cm^{-2} in the center using a Galactic CO-H2 conversion factor of 3.0×10^{20} cm^{-2} (K km s^{-1})$^{-1}$ (Solomon et al. 1987). The value is not far from the values of column density of atomic hydrogen N_H=5.9-13.6x10^{22} cm^{-2} revealed by X-ray observations (Fruscione et al. 2005). Mass of the molecular gas at the center within the beamsize is estimated to be 4.5x10^6 M_{solar}.

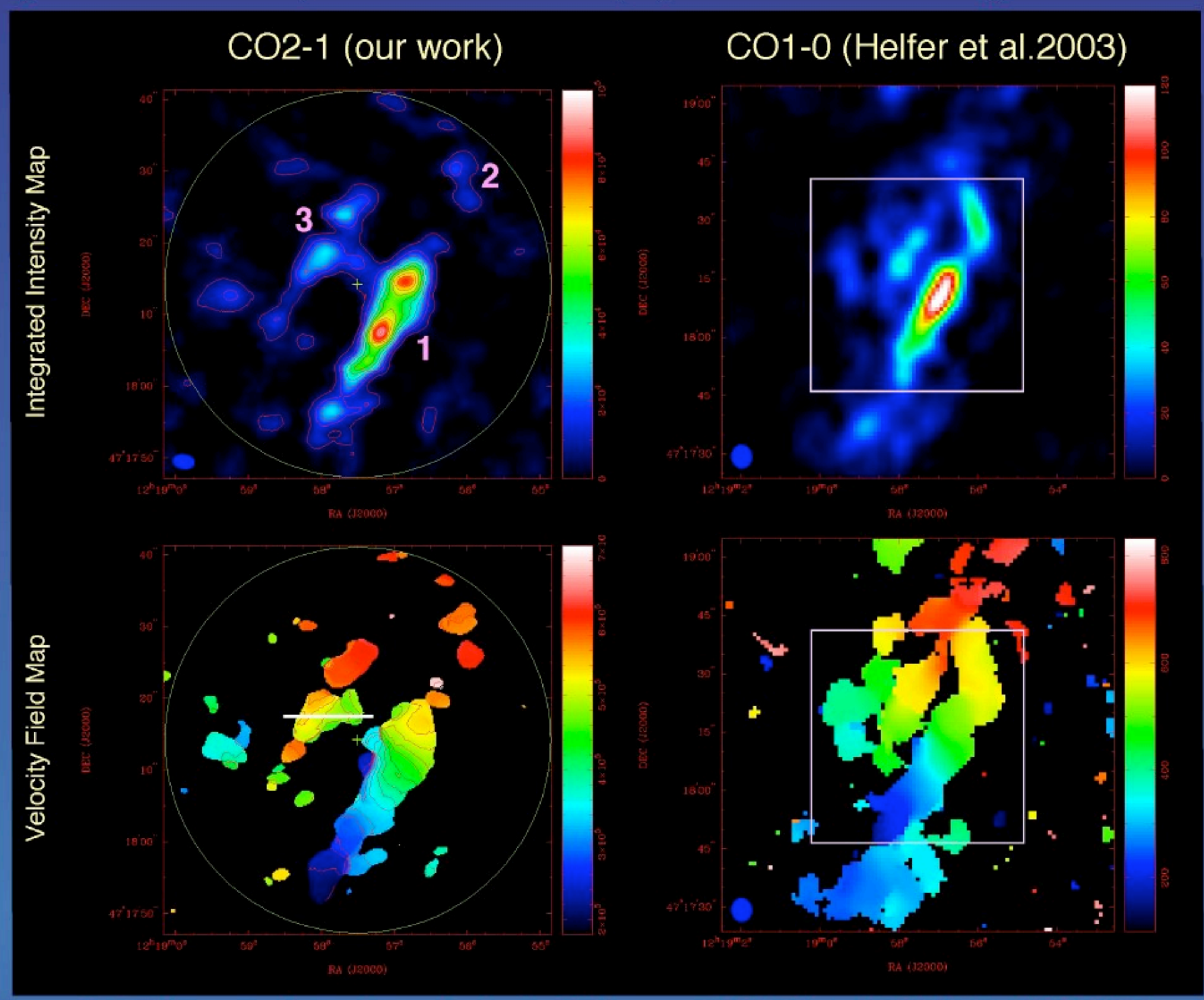


Fig.2: Integrated intensity and velocity field maps of CO(2-1) and CO(1-0) in NGC4258

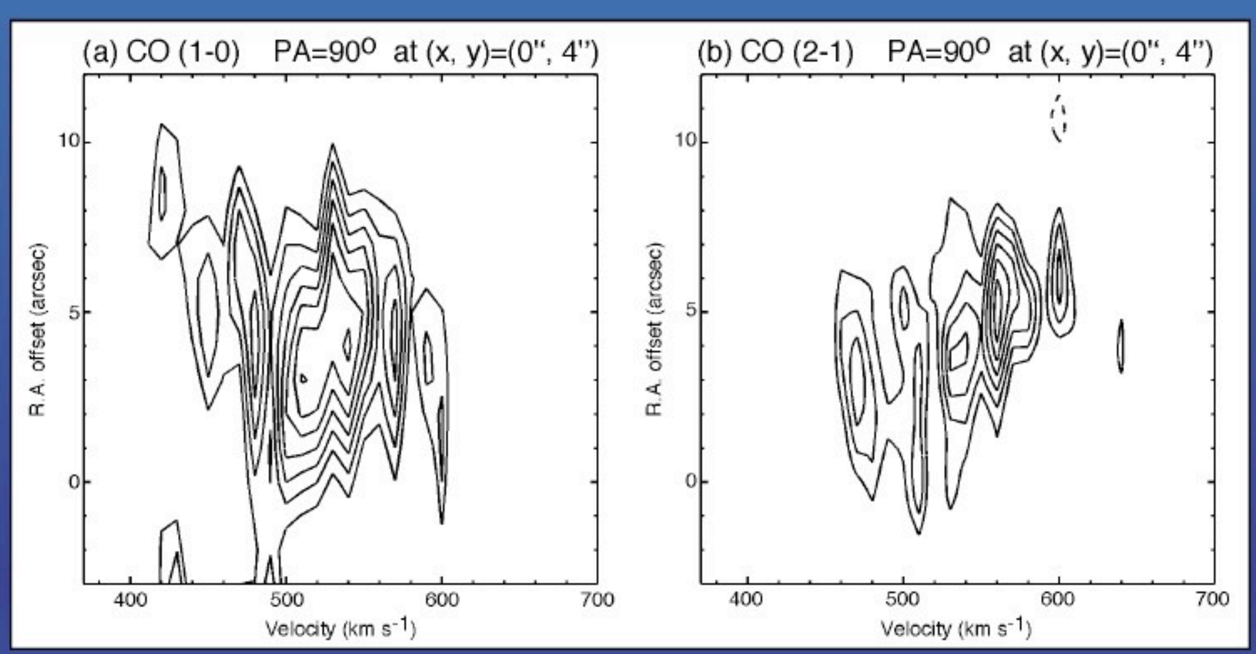


Fig.3: PV diagram at (0", 4") along PA=90°

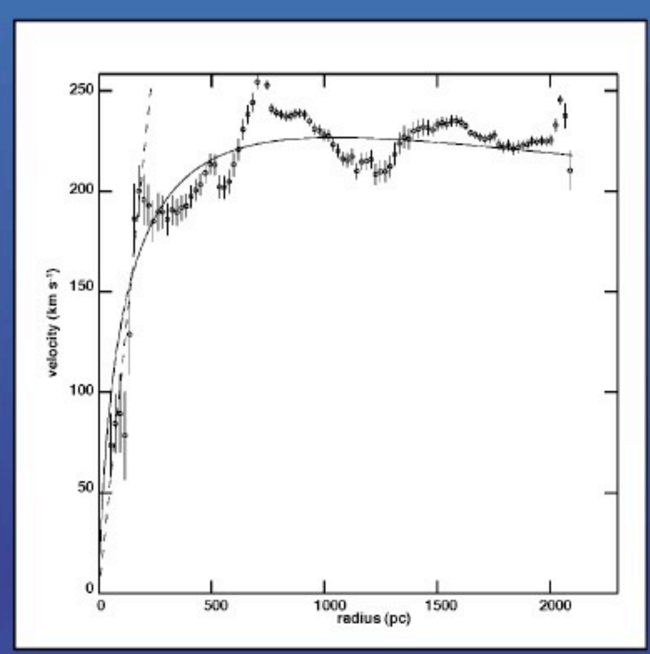


Fig.4: Brandt rotation curve.

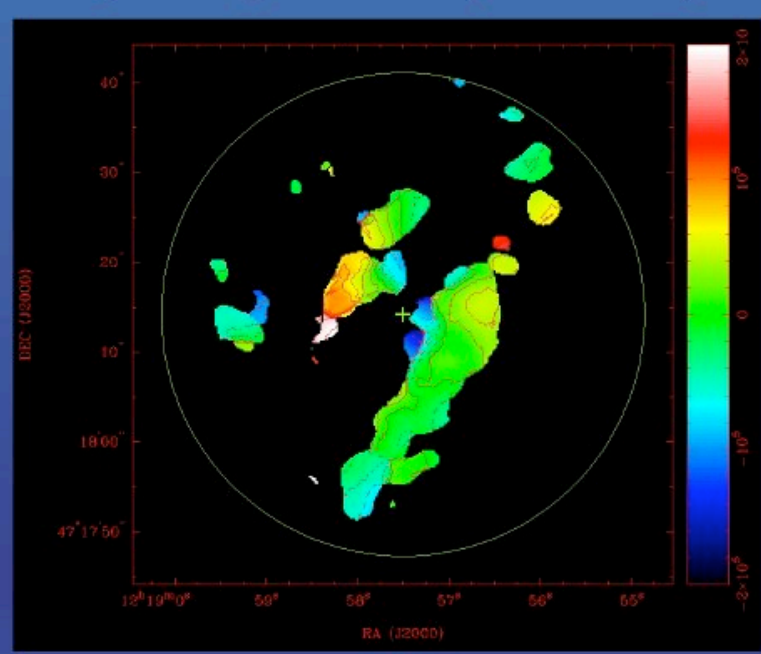


Fig.5: Residual velocity field of CO(2-1)

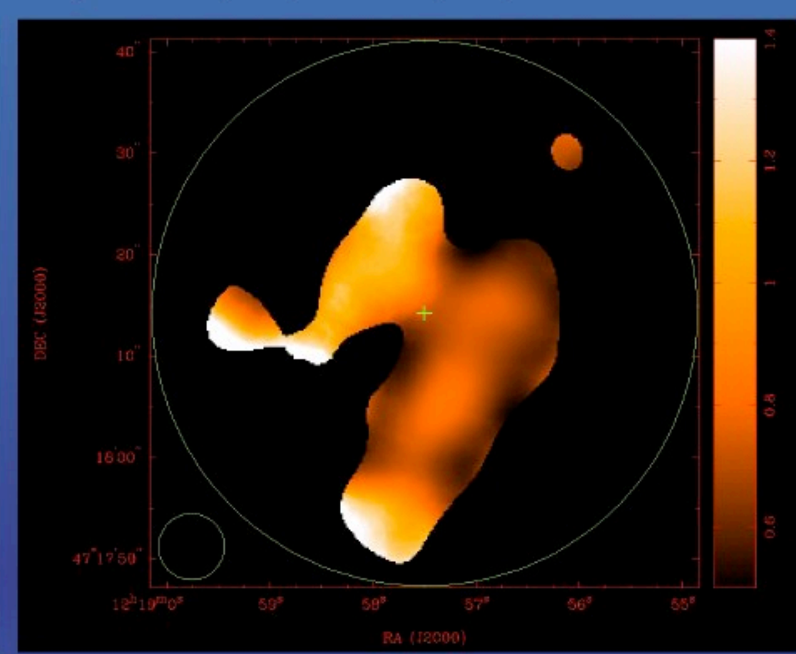


Fig.6: CO(2-1)/CO(1-0) line ratio map.

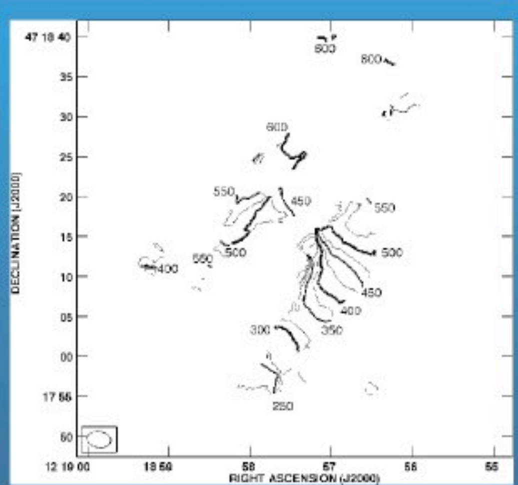
Isovelocity field

Contours of velocity field in Component 1 is almost perpendicular to the optical major axis of the galaxy. Contours near the center, however, is shifted ~30 deg. which agrees with velocity field of CO(1-0) Plante et al. (1991) showed. On component 3, we see another velocity gradient, which is not explained by simple galactic rotation. Figure 3 implies the velocity gradient along the east-west direction clearly. We attempted to the model the velocity field of BIMA-SONG CO(1-0) using the GAL task in AIPS. Parameters of the model is shown in table 1 (Brandt curve). Using the rotation model, dynamical mass within 200 pc radius is obtained as 1.3x10^9 M_{solar}, which is consistent with the dynamical mass within 200 pc radius of the Virgo spiral galaxies (0.1-3x10^9 M_{solar}; Sofue et al. 2003). Subtracting rotation of the model from the isovelocity map, the residual velocity field shows that the large velocity offset (150 km/s) on Component 3.

Table 1

Parameter	Our results	Previous results		
		Radio[a]	HI[b]	Hα[c]
RA (J2000)	12:18:57.52	12:18:57.50		
DEC (J2000)	47:18:15.88	47:18:14.20		
P.A. (deg)	160		150	146
Inclination (deg)	65.6		72	64
Vsys (km/s)	456		450	467

a: Brightest position at 6 cm radio continuum (Turner and Ho 1994)
b: Based on HI emission (van Albada 1980)
c: Based on Hα (van der Kruit 1974)



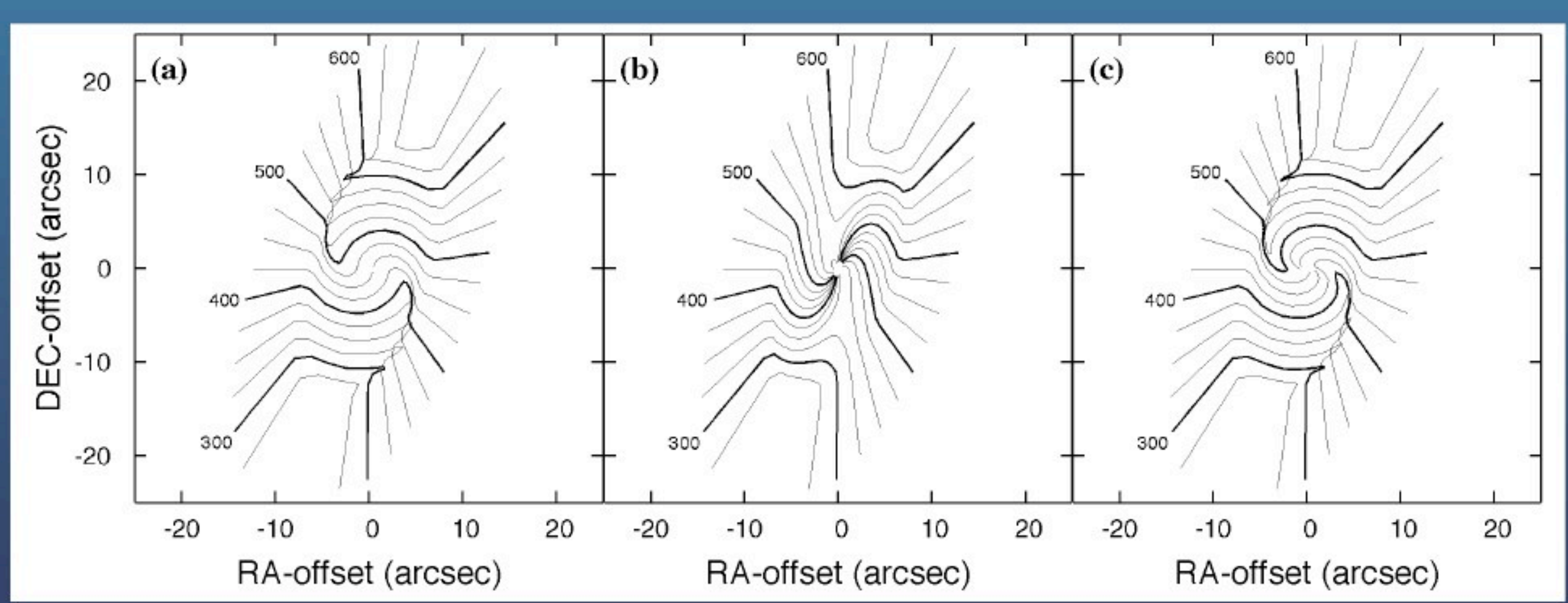


Fig.7: (a) Warped disk, (b) Expanding disk, and (c) Expanding warped disk.

CO(2-1)/CO(1-0) line ratio

The CO(2-1)/CO(1-0) line ratio allows us to get knowledge of physcal status of the CO molecular gas. We re-imaged the CO(1-0) map as if it was observed with same uv sampling as SMA from the BIMA CO(1-0) map, and smoothed with the same beam size. The line ratio map after the primary beam correction reveals that average of the line ratio on pixels in Component 3 is significantly higher (1.1+-0.2) compared to the ratio in Component 1 (0.7+-0.1). The value of line ratio in Component 2 has a relatively large error (0.7+-0.3), as the component lies near the edge of the primary beam. The line ratio value in Component 3 is close to the mean values of the CO(2-1)/CO(1-0) line ratio in nearby spiral galaxies (0.89+-0.06; Braine et al. 1993) and starburst galaxies 0.93+-0.22; Aalto et al. 1995). Our LVG analysis indicates that the N_{H2} on Component 1 is of the order of 100 /cm^3 for Tk of 30K. On the other hand, the density of the gas on Component 3 could be higher compared with those of the gas on Component 1.

Modeling of the central region in NGC4258

To account for the velocity field with these characters; [1]the velocity gradient along the major axis, [2] the tight and tilted velocity contours close to the center on Component 1, and [3] the velocity gradients on Component 3 along the east-west direction, we propose the combined model of expansion and warped disk. The major axis of the disk is tilted from P.A. of 90° to -20° , resulting in a warp, and it has a uniform expansion from the center.

The significant differences of CO(2-1)/CO(1-0) ratio and the residual velocity offset on Component 1 and 3 may imply that physical conditions of the gas on Component 1 and 3 are totally different each other. One possible hypothesis is that the gas on Component 3 is located closer to the center compared with the gas on Component 1. The gas on Component 1 would be heated by the central engine. Or, the gas on Component 3 could be perturbed by expansion or jets. Component 2 could be perturbed by the jet because it is located in front of the jet, but our result of CO(2-1)/CO(1-0) of Component 2 do not clearly support because the value has the large error.