Morphology and Kinematics of Molecular Gas in the Double-barred Galaxy NGC 3504
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Abstract
About one-third of barred galaxies have an inner secondary bar embedded within an outer primary bar (Laine et al. 2002; Erwin & Sparke 2002). They are so called double-barred galaxies. The investigation of inner bars is especially important as they can drive gas inflow to the nucleus of galaxies (Kormendy 1982; Shlosman, Frank & Begelman 1989). Here we present the results of ALMA CO (2-1) observation of the double-barred galaxy NGC 3504. With three times higher angular resolution (~0.8") than previous works, our observations reveal an inner molecular gas bar, a nuclear ring, and four inner spiral arm-like structures in the central 1 kpc region. The total molecular gas mass in the observed region (50"x57") is estimated to be 3.1x10^9 M_☉. We used the Kinemetry package (Krajnović et al. 2006) to fit our velocity field and quantify the contribution of circular rotation as well as non-circular perturbations. Our results give a new example of an inner gas bar within a gas-rich double-barred galaxy and suggest that the formation of double-barred galaxies could be associated with the existence of such gas structures. Based on this study, we are looking for an opportunity to observe double-barred galaxies at high redshifts using new-generation radio telescopes, such as SKA.

NGC 3504

(a) The SDSS g-band image. The white arrows indicate the dust lanes.
(b) The HST/WFPC2 F606W image, showing the central 2.4 kpc region.
(c) The HST/WFC3 F160W image. The contour levels are 10, 20, 30, 40, 60, 100, 200, and 600 electrons/s. The blue line represents the major axis of the inner bar with a length of 5".2 and position angle of 172°.

ALMA Observations
• CO (2-1) observations were carried out with the 12-m (C43-1 and C43-4) and 7-m arrays (Project code: 2016.1.00650.S, PI: Yu-Ting Wu).
• With a robust weighting of 0.5, the achieved beam size is about 0''.79 x 0''.64 and the rms noise is ~ 1 mJy/beam for the velocity resolution of 6.5 km/s.
• Moment 0 and 1 maps

Results
• Both axisymmetric and non-axisymmetric structures, including the inner molecular gas bar, the nuclear ring, and the nuclear spirals, are found in the central 1 kpc region. These inner structures were not recognized in previous publications due to the lack of sufficient angular resolution.
• The estimated total molecular mass is about 3.1x10^9 M_☉, corresponding to 17 per cent of the stellar mass.
• Circular motion strongly dominates at R = 3" - 8" (0.3 - 0.8 kpc), but radial motion becomes important in the regions where the bars are present, corresponding to R < 3" (0.3 kpc) and R = 10" - 25" (1.0 - 2.5 kpc).
• The existence of the inner gas bar and the large amount of gas in NGC 3504 support the scenario for the formation of double-barred galaxies associated with the existence of molecular gas.
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What are double-barred galaxies?
An example of a double-barred galaxy: NGC 3504

Why we care about double-barred galaxies?

- ~30% of local barred galaxies are double-barred galaxies (Erwin & Sparke 2002; Laine et al. 2002).
- One of mechanisms to drive gas inflow to the nucleus of galaxies (Kormendy 1982; Shlosman, Frank & Begelman 1989).
NGC 3504

- 45m telescope at Nobeyama Radio Observatory
- CO (1-0)
- HPBW=16''

- ALMA 12m + 7m
- CO (2-1)
- synthesized beam: 0''.79 x 0''.64 (PA=26 deg)

Kuno et al. (2000)

Wu et al. (2021, in revision)
Kinematic modelling

- We used *Kinemetry* (Krajnović et al. 2006) to fit the ALMA CO (2-1) velocity (moment 1) field.

Results

- Both axisymmetric and non-axisymmetric structures, including the inner molecular gas bar, the nuclear ring, and the nuclear spirals, are found in the central 1 kpc region.

- The estimated total molecular mass is about $3.1 \times 10^9 \, M_{\text{sun}}$, corresponding to 17 per cent of the stellar mass.

- The existence of the inner gas bar and the large amount of gas in NGC 3504 support the scenario for the formation of double-barred galaxies associated with the existence of molecular gas.