An Inner Molecular Bar or Disk in NGC 5195

S. Aalto

G. Rydbeck

Onsala Rymdobservatorium, Chalmers Tekniska Högskola, S-439 92
Onsala, Sweden

Abstract. High resolution OVRO CO 1-0 observations of the inner kpc of the M51-companion NGC 5195 reveal the presence of a kpc-sized bar, or possibly an inclined disk with a two armed spiral, at the center of the optical bar. The molecular mass of the feature is $2.7 \times 10^8 \, M_\odot$, half of which is within a radius of 250 pc. The resulting gas surface density of $10^3 \, M_\odot \, pc^{-2}$ is typical for starbursts. However, the lack of evidence for current star formation suggests that either some mechanism is preventing stars from forming, or the standard CO to H$_2$ conversion factor substantially overestimates the available amounts of molecular gas.

1. Introduction

NGC 5195, the intriguing SBa/0 companion of M51, shows exceptionally bright 15 $\mu$m emission from a central point source suggesting intense nuclear activity (Boulade et al. 1996). Warm IR colours and a respectable FIR luminosity points towards a starburst scenario, while the lack of bright H$\alpha$ emission seems to contradict this notion. Boulade et al. suggest that the activity is powered by an evolved starburst, but the possibility of LINER activity or ongoing star formation is also considered. High resolution CO observations help us address both the nature of the central activity as well as the mechanisms responsible for feeding the nucleus with molecular gas. Secondary features, such as bars within bars, have been proposed as a possible mechanism of gas fueling nuclear activity (e.g. Shlosman et al. 1990). The proximity of NGC 5195 allows detailed studies of gas transport processes that are likely to feed the activity also within more distant, luminous systems. Below we present a preliminary analysis of our high resolution OVRO CO 1-0 observations.

2. Molecular gas distribution and kinematics

In Figure 1 we see the CO distribution in the eastern and central part of NGC 5195 overlayed on a DSS optical image. Even though we have not mapped the whole of NGC 5195 it is clear that the gas is very concentrated towards the center. The eastern CO emission is well correlated with the foreground dust absorption in the M51 northern arm which covers part of the galaxy. The inner 500 pc of NGC 5195 is in rough solid body rotation with a position angle of
Approx. 95°. The projected maximum velocity is 80 \text{ km s}^{-1}, and the dynamical mass inside a radius of 250 pc is $7 \times 10^8 \text{ M}_\odot$ (for $i = 45^\circ$). Figure 2 shows higher resolution images of the central region of NGC 5195. The CO emission is double peaked and appears to be part of a ring-like structure. The kinematic center is however not at the center of this ring, but rather on the brighter of the two peaks, which also coincides with the NIR peak emission. The peak brightness temperature is 5 K (for a linear resolution of $\approx 100$ pc). This suggests that the brightness temperature of each cloud is rather moderate, or that there is an ensemble of warm clouds of low filling factor. The morphology of the CO emission suggest that the gas clouds could be travelling along the x2 orbits of the bar. The possibility of an inclined disk with spiral arms cannot, however, be excluded at this stage. Disturbances in the velocity field indicate the presence of gas streaming in the inner kpc.

2.1. Molecular gas mass

The total recovered flux in NGC 5195 is 320 Jy km s$^{-1}$, corresponding to $2.7 \times 10^8 \text{ M}_\odot$ for $D=9.6 \text{ Mpc}$ (for a conversion factor of $X = N(\text{H}_2)/I(^{12}\text{CO}) = 2.3 \times 10^{20}$
Figure 2. The left panel shows the high resolution (2\arcsec) CO 1-0 integrated intensity image. The grayscale ranges from 0 to the peak flux (41.4 Jy beam\(^{-1}\) km s\(^{-1}\)) and the contours go from (1,5...29,40,...,90)\times 0.83 Jy beam\(^{-1}\) km s\(^{-1}\). The right panel shows the velocity field where the contours range from 550 km s\(^{-1}\) to 740 km s\(^{-1}\) with 27 km s\(^{-1}\) increment. The grayscale range from 530 to 730 km s\(^{-1}\). The white cross marks the position of the peak 2.2 \(\mu\)m emission (Smith et al. 1990). The dotted lines in the right figure mark the suggested position of the inner spiral arms.

cm\(^{-2}\) (K km s\(^{-1}\))\(^{-1}\)). Half of this gas mass is found within a radius of 250 pc. This results in an average gas surface density close to \(10^3\) M\(_\odot\) pc\(^{-2}\) in the inner 500 pc, and 20% of the dynamical mass is molecular. For the M51 arm we find 81 Jy km s\(^{-1}\) corresponding to a mass of \(6.8 \times 10^7\) M\(_\odot\). We recover 60\% \(\pm\) 20\% of the OSO 20m single dish flux in the same area.

3. Discussion

3.1. The starburst

The highly concentrated CO emission of NGC 5195 is fairly typical of interacting systems, where the central molecular gas fuels starburst activity and/or an AGN. NGC 5195 is, however, classified as an old starburst where star formation ceased some \(10^7\) years ago, and the absence of bright H\(\alpha\) emission supports this notion. Diffuse, shell-like H\(\alpha\) features may indicate a nuclear outflow similar to that of M 82 (Greenawalt 1998). It is interesting, therefore, to ponder why the previous starburst left a considerable amount of gas behind in the center. What mechanism made the star formation processes grind to a halt before the gas was consumed? The inner region of the galaxy is in an apparent solid body rotation, which should be favourable for star formation. The surface density of gas left behind is typical of that found in starburst galaxies, again offering no direct solutions to the cessation of star formation. It is of course possible that gas has been transported to the center after the previous burst of star formation, but that still leaves us with the question of what is preventing the gas from forming stars.
A possible clue may lie in the excitation of the molecular gas itself. From our single dish study of NGC 5195 we find that the emission from $^{13}$CO 1-0 is unusually faint with respect to the $^{12}$CO emission. The $^{12}$CO/$^{13}$CO 1–0 intensity ratio is $\gtrsim 20$, while the more typical value for galaxies is 10-15 (e.g. Aalto et al. 1995). The elevated ratio is caused by an overall reduction in the optical depth of the $^{12}$CO line which would likely be caused either by a) high temperatures in the gas or b) presence of diffuse unbound molecular gas. To distinguish between the two scenarios it is necessary to observe higher transitions of both $^{12}$CO and $^{13}$CO. Both scenarios may lead to an overestimate of the amount of molecular gas present by factors of 5-10. In this case, the starburst may simply have ceased because of the gas surface density being below threshold values. Smith (1982) find a high dust temperature ($T_d \approx 65$ K) for NGC 5195 which is comparable to the warmest of the luminous starburst galaxies. If indeed the activity in NGC 5195 is dominated by an evolved starburst, then the question is how it is capable of heating the dust to such high temperatures.

3.2. The inner bar or disk

The inner elongated structure is oriented roughly at right angles to the larger scale optical bar. This feature has not been seen before in NIR or optical, even if a $J$-band elongation at lower resolution (Smith et al. 1990) may well be associated with it. The discontinuities in the velocity field (see Figure 2) suggest the presence of gas streaming in the inner kpc of NGC 5195. Such regions are often associated with dust lanes and downstream H$\alpha$ emission, but only very faint and diffuse H$\alpha$ emission can be found in NGC 5195 and the shock may be too weak to produce sharp dust lanes. Kenney et al. 1992 discuss “twin peaks” features perpendicular to optical bars as resulting from orbit crowding near the ILR (Inner Lindblad Resonance). We speculate that the molecular feature in NGC 5195 shows that the gas has passed beyond the ILR to the nucleus of the galaxy. Further study, of both the overall kinematics of NGC 5195 as well as higher resolution observations of CO and NIR, is necessary to establish the true nature of the central molecular concentration.

References

Aalto, S., Booth, R.S., Black, J.H., Johansson, L.E.B. 1995, A&A, 300, 369
Boulade, O. et al., 1996, A&A, 315, L85
Greenawalt, B., Walterbos, R.A.M., Thilket, D., & Hoopes, C.G. 1998, ApJ, 506, 135
Kenney, J.D.P., Wilson, C.D., Scoville, N.Z., Devereux, N.A., Young, J.S. 1995, ApJ, 395, 79
Shlosman I., Begelmann, M.C., Frank, J. 1990 Nat 345, 679
Smith, J. 1982, ApJ, 261, 463
Smith, J., et al., 1990, ApJ, 362, 455