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Molecular Gas and Star Formation in the Centers of Virgo Spirals

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MOTIVATION

The CO and Hα flux distributions for a sample of Virgo spirals ~~have been~~ were mapped out in an attempt to understand the coupling between gas dynamics and star formation in spiral galaxies. A broad range of morphological types were observed (types Sab through Scd) under the hypothesis that the gas dynamics is most influential in determining the overall appearance of a spiral galaxy. Only non-barred spirals were considered so that the well-studied but complicated properties of bars and their role in inducing star formation would not be a factor. All galaxies were chosen from the Virgo cluster to eliminate uncertainties due to distance errors. Since the dynamical seat of a spiral is at its center, it was expected that the dynamics of the central region would influence global properties of the rest of the disk. This could happen through the existence or absence of an inner Lindblad resonance (according to the degree of central concentration of mass) to modulate swing amplification of spiral waves, or the persistence of an oval distortion to initiate an instability which leads to spiral structure.

OBSERVATIONS

Observations at the Owens Valley mm-wave interferometer mapped out the CO $J = 1 \rightarrow 0$ emission at the centers of the eight spirals NGC 4254, 4303, 4321, 4501, 4535, 4536, 4569, and 4654. The resolution of the images is about $5'' \times 7''$, or $350\,\mathrm{pc} \times 500\,\mathrm{pc}$, assuming a distance of 14.6 Mpc. The $65''$ field of view encompasses the central 4.6 kpc of these galaxies. Velocity field information was obtained at $13\,\mathrm{km\,sec^{-1}}$ resolution over a $415\,\mathrm{km\,sec^{-1}}$ range. Observations took place over a period of three years, so the image quality improved with increasing system sensitivity over that time. These images are shown in Figure 1. Each contour level is a factor of 1.5 times the one outside it, and all images are produced from a subset of the same levels to permit easy comparison. All maps are at the same scale and have boundaries at the primary beam size. Units are $\mathrm{Jy\,km\,sec^{-1}\,beam^{-1}}$.

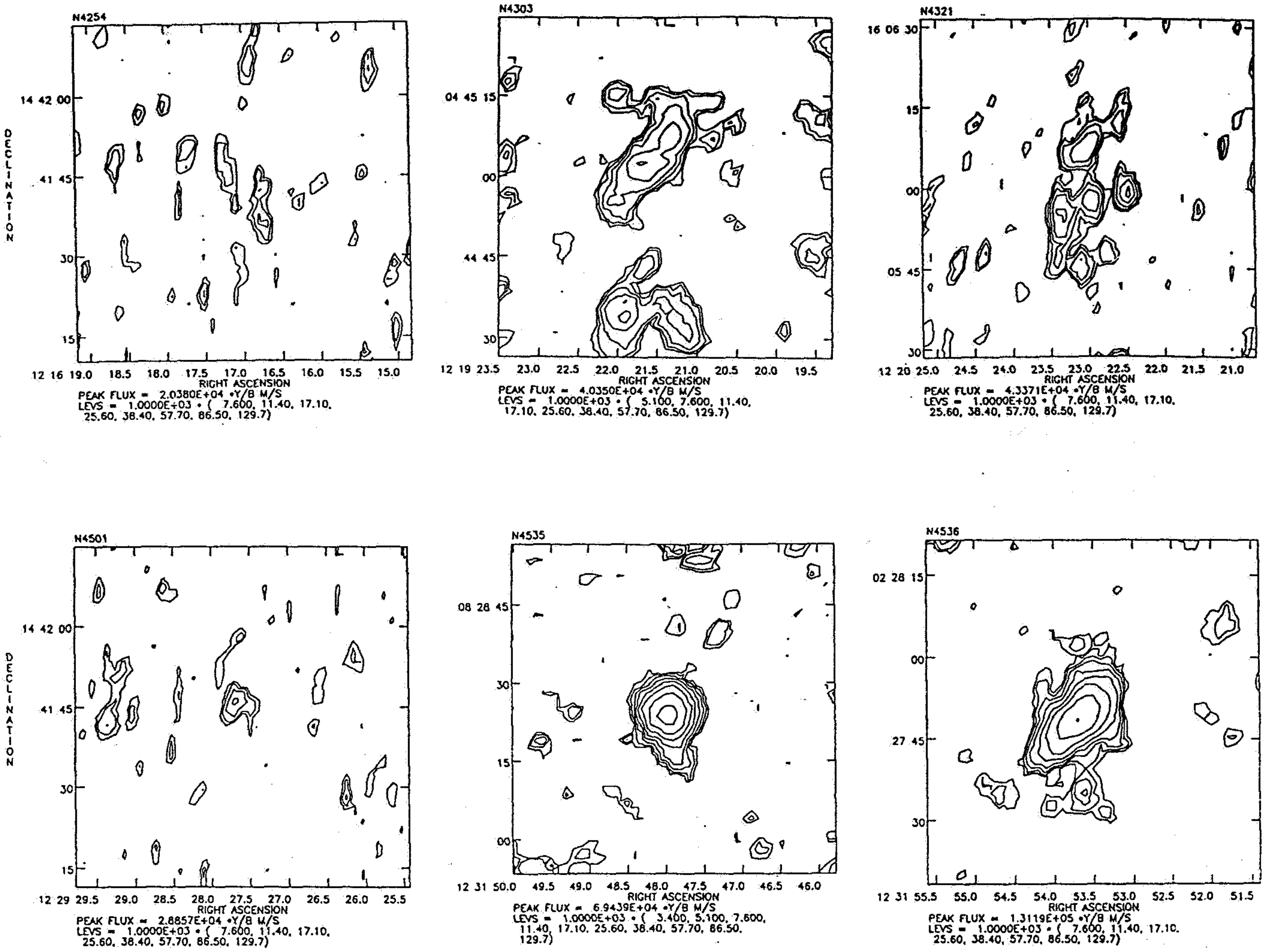
Maps of Hα emission were made from CCD photometry using the Palomar 60-inch telescope with re-imaging optics. The Hα maps were processed from two or three frames taken through narrowband (≈ 80 Å) filters encompassing Hα emission in the rest frame of the galaxy and the surrounding continuum. The frames were scaled and the continuum was subtracted. Absolute flux calibration was accomplished using images of G2V stars and assuming their spectral energy distribution is similar to that of the sun. Flux-calibrated maps of Hα emission are shown in Figure 2. The maps are at the same scale and show the same area as those in fig. 1, so the figures may be overlayed for comparison. As in fig. 1, each contour level is a factor of 1.5 greater than the one outside it. The units are $10^{-15}\,\mathrm{ergs\,sec^{-1}\,arcsec^{-2}}$ at the surface of the earth.

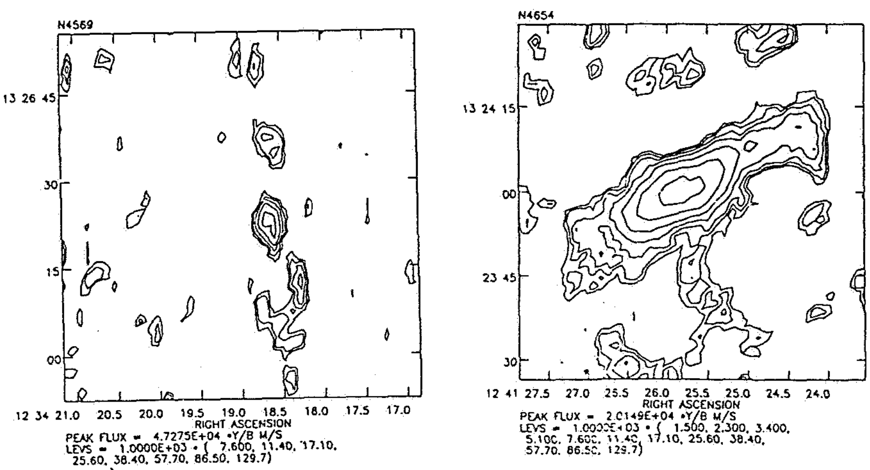
Discussion

One striking aspect of the CO distributions is the gratifying variety of forms displayed. Obvious molecular gas bars are present in NGC 4303 and NGC 4654, though neither galaxy shows an optical bar. The molecular gas distribution of NGC 4536 is elongated and is possibly a bar seen in projection in this rather inclined galaxy. The center of NGC 4254 has patchy CO emission with no obvious center. In contrast is NGC 4321, with the suggestion of spiral structure in the molecular gas to the very center and what possibly may be the start of two spiral arms. Other galaxies show rather featureless central gas concentrations with outlying wisps (NGC 4535 and NGC 4569) and without any other emission (NGC 4501).

Comparison with the Hα emission maps reveals the tendency of the Hα to follow the CO morphology. This tendency is perhaps most notable in the cases of NGC 4535 and NGC 4536. The center of NGC 4254 also has patchy Hα emission, though the correlation with CO peaks is not entirely evident. Both maps of NGC 4501 are similarly stark and featureless. The three concentrations of CO emission along a diagonal line across the center of NGC 4321 match with those in the Hα map, while the CO concentrations above and below are perhaps the elbows of interior spiral arms which begin to poke from the Hα map. The Hα emission distribution actually resembles a fan with four blades. This peculiar morphology may be evidence for an interesting dynamical state involving resonances at the center of NGC 4321. One notable exception to the tendency toward common morphology is NGC 4303, whose CO bar is completely absent from the featureless Hα concentration. It is, of course, expected at this resolution that young stars be seen where there is molecular gas, but the similarity in form and scale of the two components is still remarkable.

Half of the galaxies show evidence for a bar or oval distortion in their central CO distributions despite the selection against bars. It is possible that many spirals house small bars which are not optically evident. Gas could be collected and sequesterd by the resulting flow pattern (examples could be NGC 4321 and NGC 4536) or lose angular momentum and sink to the center (as in NGC 4303, perhaps), fueling much star formation in either case. Such distortions could be the source of a dynamical instability which drives spiral arm formation. Galaxies of earlier morphological type seem to have the more concentrated, featureless CO and Hα distributions (NGC 4501, NGC 4569). Coherent spiral arm formation may be hindered in these galaxies by the lack of a central dynamical instability, so the mechanism for collecting so much gas at the centers of these galaxies could be dynamical relaxation.





CO Maps

NGC	Beam arcsec^2	Flux %
4254	32.9	12
4303	48.9	31
4321	34.2	36
4501	30.0	8
4535	59.4	46
4536	57.7	54
4569	31.6	27
4654	53.5	63

Figure 1. CO $J = 1 \rightarrow 0$ integrated emission from Virgo spirals (left to right, top to bottom) NGC 4254, 4303, 4321, 4501, 4535, 4536, 4569, and 4654. Contours are a subset of 1.5, 2.3, 3.4, 5.1, 7.6, 11.4, 17.1, 25.6, 38.4, 57.7, 86.5, and 129.7 Jy km sec^{-1} beam^{-1}. Beam areas in arcsec^2 are shown in the small table. The estimated fraction of the total CO emission recovered in these interferometric images, also shown in the table, is based on single-dish observations at FCRAO by Jeff Kenney.

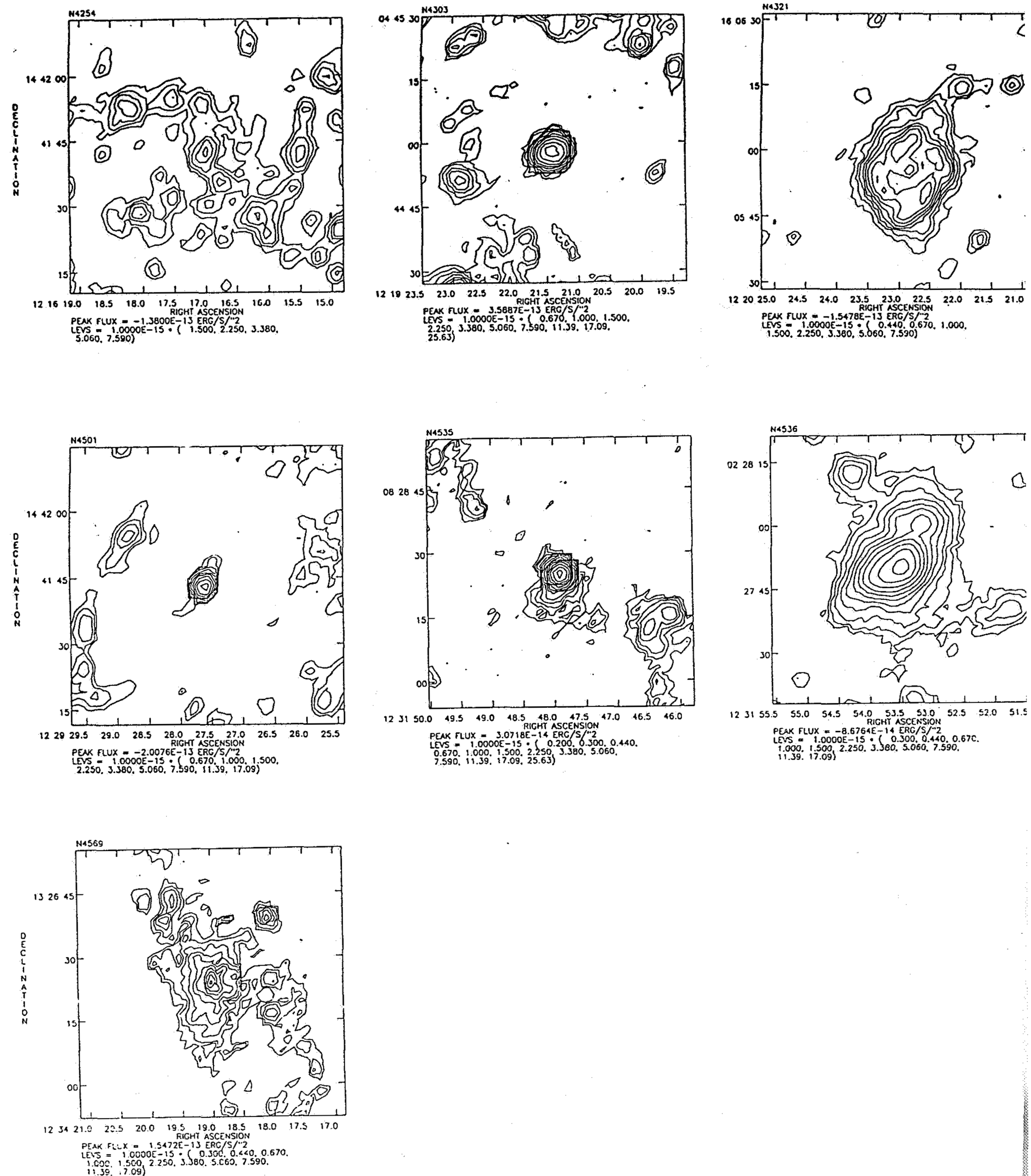


Figure 2. Hα emission from the same Virgo spirals as in fig. 1 (except NGC 4654, the last, is omitted). Contours are a subset of 0.2, 0.3, 0.44, 0.67, 1, 1.5, 2.25, 3.38, 5.06, 7.59, 11.39, 17.09, and 25.63×10^{-15} ergs sec^{-1} arcsec^{-2} at earth. The scale is the same as in fig. 1.