Abstract:

IRAM, F.38106, St. Martin d'Hères, France

MICHEL CULLEN

AND

MPIfR, D-53121 Bonn, Germany

IRAM, F.38106, St. Martin d'Hères, France

NICKOLAS NININCHEN

Mapping the Cold Dust in Edge-on Galaxies at 1.2 mm Wavelength
Figure 1. a) The λ 1.2 mm continuum emission of NGC 4565 smoothed to a resolution of 20″; contour levels are 3, 6, ... 21 mJy/beam. b) The brightness distributions of the integrated line intensities of atomic and molecular gas along the major axis of NGC 4565 together with the λ 1.2 mm intensity and the 21-cm continuum.

the λ 1.2 mm continuum emission of two nearby spirals, NGC 891 and M 51. This emission there was found to correlate tightly with CO and poorly with HI. It was not even clearly detected beyond NGC 891’s molecular “ring”, in a region where HI emission is still strong. The mean dust temperatures derived from the λ 1.2 mm and FIR flux densities were found to be ≤ 20 K.

In order to further study the properties of the ISM, we observed two more edge-on galaxies of similar type, NGC 4565 (Neininger et al. 1996) and NGC 5907 (Dumke et al. 1996). In particular, NGC 4565 was chosen because of its weak CO emission: the dust emissivity per H atom is on the average 2 – 4 times larger for the molecular clouds than for the HI clouds. Thus, the dust associated with the atomic gas becomes predominant only when the H₂ column density becomes very small – which is the case in the outer parts of NGC 4565. The edge-on geometry (i ≥ 85°) ensures long lines of sight in the disk which helps to detect weak components of the ISM.

2. Observations

The observations of NGC 891 were carried out in February 1993 with a 7-channel bolometer array (Kreysa 1992), those of NGC 5907 and NGC 4565 with an instrument upgraded to 19 channels in March 1995. The beamwidths are 11″ (HPBW), and the spacing between two adjacent channels 20″.
The equivalent bandwidth $\Delta \nu$ and central frequency $\nu_c$ should be close to 70 GHz and 245 GHz (1.2 mm), respectively (see Guélin et al. 1995).

The maps are mosaics of up to 26 overlapping submaps, each of the size of a few arcmin$^2$. During the observations, the subreflector was wobbled at 2 Hz in azimuth with a beam throw between 30" and 50". For each channel, a second order baseline was fitted to every azimuth scan, the scans were combined and restored into single beam maps and regridded in equatorial coordinates; after correcting the intensities for atmospheric absorption, they were calibrated with respect to the planets. Finally, the different channel maps were combined to yield a single map which reached a maximum sensitivity of $1 \ldots 1.5$ mJy per 12" beam for the observations of NGC 4565.

3. Findings

In all three objects, the bulk of the molecular gas lies within a radius of 4–5 kpc from the center. The central component is relatively bright in NGC 891 and strongly dominating in NGC 5907. The central 3 kpc region of NGC 4565 hosts little interstellar matter, except for a compact 'ring' of molecular gas (of diameter $\simeq 1$ kpc). In NGC 891 and NGC 4565 a strong molecular ring is visible which contains most of the molecular gas. The bulk of the atomic gas is situated further out, forming a broad 'plateau' peaking at $R \approx 9 - 15$ kpc and extending up to $R \approx 15 - 20$ kpc. The outer plateau and molecular ring of NGC 4565 show narrow density structures, which are probably spiral arms.

The $\lambda$ 1.2 mm emission, which is the most reliable tracer of interstellar dust, follows closely the CO brightness distribution in the central region and in the molecular ring; this holds for all three galaxies. In NGC 891 there is no sign of $\lambda$ 1.2 mm emission further out (Guélin et al. 1993); in NGC 5907, this emission is a bit more extended than the CO disk and two bumps at a radius of about 10 kpc coincide with the HI at a place where no CO is left (Dumke et al. 1996). In NGC 4565, however, the $\lambda$ 1.2 mm emission follows HI in the outer regions of the disk as soon as the CO emission becomes weak. This way, it extends significantly further out than the emission of the molecular gas and it is possible to derive the properties of the cold dust that is associated with the atomic gas.

The outer HI disks of all three galaxies are warped. Because of the lack of detected emission, no trace of it can be seen in the $\lambda$ 1.2 mm maps of NGC 891 and NGC 5907. However, the onset of NGC 4565's warp is clearly visible in the 1.2 mm cold dust emission at the NW side. In the SE, the HI warp is by far less prominent, but a hint at it is seen just at the edge of our map.
4. Results

The most interesting result is the observation of $\lambda$ 1.2 mm cold dust emission at galactocentric distances $> 10$ kpc in the H\textsc{i} ring and in the warp of NGC 4565. In these outer regions, where the gas is mostly in the atomic form (this is indicated by the weakness of the CO emission), it is possible to measure the dust emissivity per H-atom. For the average dust temperature of 15 K (derived from a fit to 160 $\mu$m, 200 $\mu$m and 1.2 mm data) the comparison of the integrated H\textsc{i} line intensity with the observed $\lambda$ 1.2 mm flux intensity yields an absorption cross section per H-atom $\sigma_H^T = 5 \times 10^{-17}$ cm$^2$(H-atom)$^{-1}$ and a mean dust absorption coefficient $\kappa = 0.002$ cm$^2$g$^{-1}$ (Neininger et al. 1996). These cross sections and temperatures are similar to those predicted in local diffuse clouds (see Draine & Lee 1984).

The comparison of the three galaxies does not hint at a correspondence between the Hubble type of the galaxy and the relative extent of the cold dust emission; a trend is however visible for the distribution of the molecular gas: there is a stronger ring in the galaxy of earlier type and a stronger central component in the later type. NGC 4565 is possibly a barred galaxy (it has a peanut-shaped bulge and also the non-circular motions observed in CO hint at this – see Neininger et al. 1996); this could influence the distribution of its ISM. Observations at mm and FIR wavelengths are in progress to further study these aspects.

The mass of the molecular gas in NGC 4565 is low compared to the mass of atomic gas. The molecular gas mass, inside the strip along the major axis covered by our CO observations, is found to be $1.0 \times 10^9 M_\odot$, when using the Galactic CO-to-H$_2$ conversion factor ($X = 2.3 \times 10^{20}$ cm$^{-2}$K$^{-1}$km$^{-1}$s$^{-1}$ – Strong et al. 1988), and $\approx 0.4 \times 10^9 M_\odot$ when using the values derived from the $\lambda$ 1.2 mm emission. This corresponds respectively to $\approx 1/2$ and 1/5 of the H\textsc{i} mass in the same area ($2 \times 10^9 M_\odot$).

References

Cox, P. Mezger, P.G.M., 1989, A\&A Review 1, 49