Properties of the ISM in and around NGC 2146

N. Neininger[1], A. Tarchi[1], A. Greve[2]

[1]Radioastronomisches Institut der Universität Bonn, Auf dem Hügel 71, D-53121 Bonn, Germany
[2]IRAM, 300, rue de la piscine, F-38406 St. Martin d'Hères, France

Abstract

We present recent work on the status of the ISM in the starburst galaxy NGC 2146 from optical and high angular resolution radio studies at mm and cm wavelengths. We derived the properties of the outflow and found indications that the burst is just in its starting phase. A trigger for this activity has however not yet been identified.

1 The galaxy

NGC 2146 is classified as a SB(s)ab pec (NED) and has been remarked as a peculiar object already 80 years ago; F.G. Pease noted on its shape: "A most remarkable nebula... An irregular mass of nebulosity... Superimposed on this bright mass is a dark marking in the form of a hand, with four talon-like fingers stretching Sp and with three stars standing out upon it." (cf. Fig. 1). Later it was recognized that this galaxy shows also remarkable spectroscopic properties, both in the optical and in the radio regime. In fact, it turned out to be unusually bright at cm wavelengths, showing a typical non-thermal spectrum while the optical line intensities are consistent with HII regions (Benvenuti et al. 1975, see also the sketch of the arm pattern there).

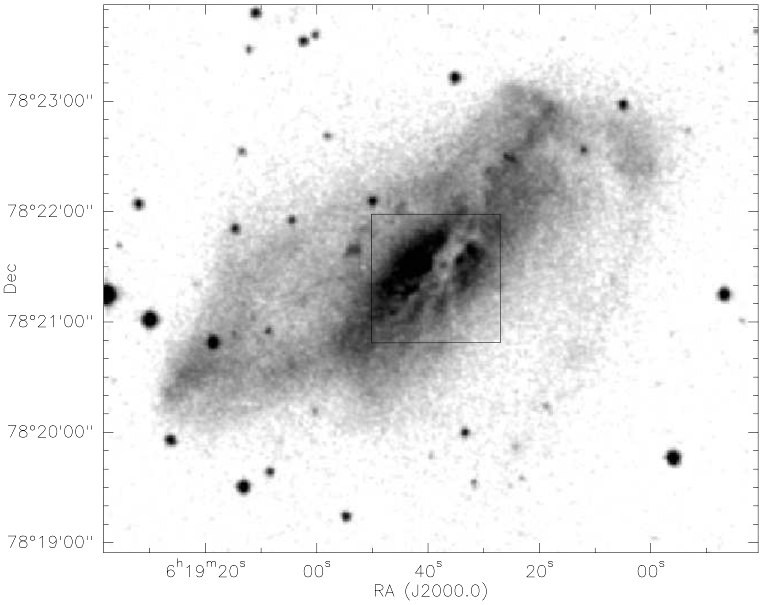

Figure 1: Grey-scale representation of the galaxy NGC 2146 from a blue POSS plate. Note the irregular shape that may be described as three-armed and the strong, asymmetric dust lane. Its shape has been described as a hand, whose fingers are stretching towards the south-east. This is why this galaxy is sometimes referred to as "Dusty Hand galaxy". The box marks the field size used in Fig. 2. Coordinates are J 2000.0

With the advent of new observations in wave bands not accessible earlier (in particular from IRAS) it became clear that NGC 2146 is in fact an active starburst galaxy: the FIR luminosity is high (7×10^{10} $L_\odot$) and the FIR spectral distribution classifies it as a superluminous galaxy, but

"Dwarf Galaxies and their Environment"; Bad Honnef, Germany, 23-27 January 2001; Eds. K.S. de Boer, R.-J.Dettmar, U. Klein; Shaker Verlag

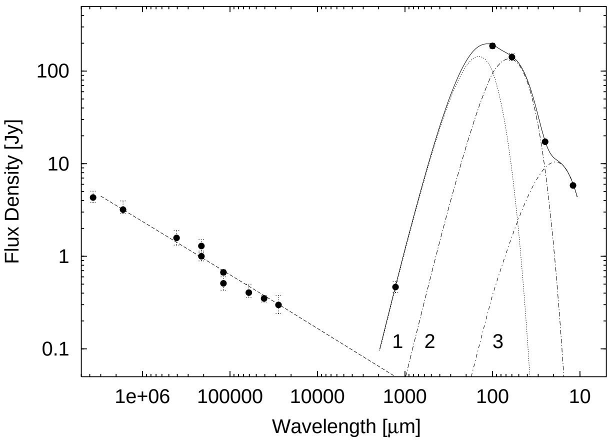

Figure 2: The global spectrum of NGC 2146 in the radio and sub-mm range. The dashed line represents a fit with $S \propto \nu^{-0.74}$, indicating a non-thermal origin. The dotted and dot-dashed lines mark a three-component grey-body fit to the thermal dust emission, with a coldest component of 21 K (Greve et al., in prep.). In the cm range, the spectrum is that of a typical spiral galaxy, but the bulk of the dust is warmer than usual and the dominance of the dust emission is clearly resembling that of M 82.

without an active nucleus (Hutchings et al. 1990). Young et al. (1988) had derived a star formation rate (SFR) of more than 6 $M_\odot$ per year; the values given today lie in the range of 5 to 15 $M_\odot$ a^{-1} and are typically two times larger than those for M 82 (Greve et al. 2000).

Starburst galaxies are quite common in the universe, but only few are close enough to study them in detail like M 82: the analysis of "Deep Fields" indicates that there was a maximum of star formation activity at $z \simeq 1 \ldots 2$ and a steep decline since (see e.g. Madau et al. 1998). Hence it is important to study the starburst phase when trying to understand the history of galaxy formation, but the choice is limited. NGC 2146 is four times further away than M 82 at a distance of 14.5 Mpc and it has puzzled astronomers ever since the starburst nature was recognized: usually the initial trigger of the activity is easily identified as being caused by a close interaction or a merger. Here, none of the two scenarios seems to have happened – no disturbances typical for a merger are found and no close companion or other signs of an encounter (Fisher & Tully 1976).

2 Overview of the studies

NGC 2146 has been studied by us in three principal wavelength ranges: a) obtaining optical spectra of various stellar and gaseous lines at the William Herschel Telescope (WHT), b) mapping the galaxy in three different transitions of CO with the Plateau de Bure interferometer (PdBI) and c) observing it at high angular resolution in cm radio wave bands using interferometers like MERLIN, VLA, VLBA, EVN and VLBI.

Optical observations

We obtained long-slit spectra in R and NIR at the 4.2-m WHT on La Palma. The aim of these observations was two-fold: first, the line profiles were used to derive the rotation of gas and stars in the galaxy and the outflow cone (see Greve et al. 2000) and second, the line ratios were analyzed to derive the excitation mechanisms and electron densities (Greve et al. 2000, and in prep.). It was found that the electron density in the starburst region of NGC 2146 is of the order of $200 \ldots 500\,\mathrm{cm}^{-3}$, much lower than the $1000\,\mathrm{cm}^{-3}$ found in M 82. Likewise, the data hint at higher ionized states in M 82, i.e. at hotter gas. It must be noted, however, that the extinction towards the starburst region of M 82 is much higher than in NGC 2146, so that we are likely to trace different volumes.

In the outflow of NGC 2146 we find indications of shock excited material, whereas the gas in the starburst region itself closely resembles that of HII regions. In principle, this is the expected behaviour but the regions dominated by one respective the other excitation mechanism are much more overlapping *spatially* in NGC 2146.

Radio observations in the mm range

We observed NGC 2146 with the PdBI first in 1995 in the ^{12}CO(1-0) transition, later followed by another mosaicked map in the ^{13}CO(1-0) and ^{12}CO(2-1) lines (see Fig. 3). The emission of the CO is concentrated in a small volume around the centre, roughly coinciding with the starburst region as indicated by the radio sources (see below). Again, there are no anomalies that would indicate a hidden merger; a bit unusual, though, is the clear warp seen in the CO distribution, i.e. close to the centre and not far out as it is common for the HI structure of spiral galaxies.

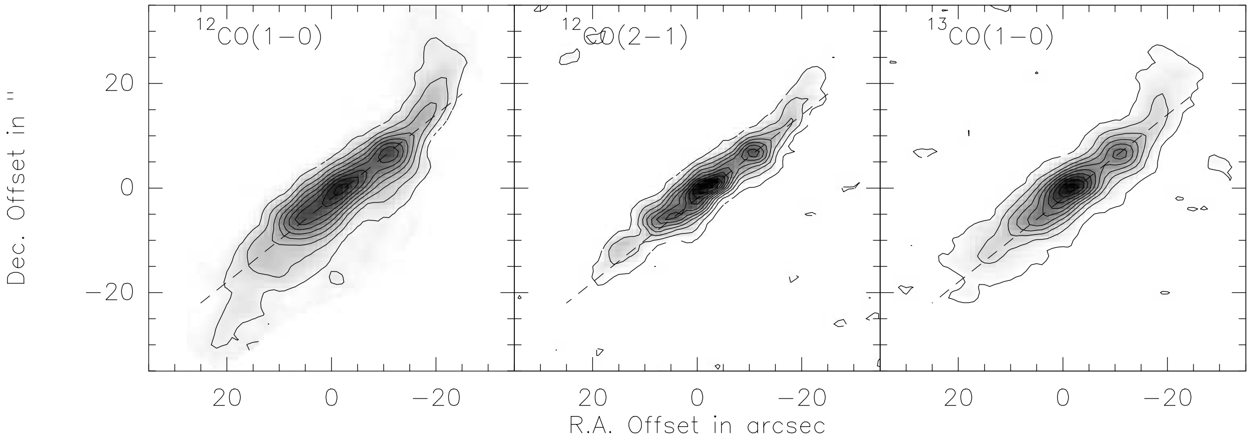

Figure 3: Velocity-integrated emission of three CO transitions: from left to right ^{12}CO(1-0), ^{12}CO(2-1) and ^{13}CO(1-0). The distribution is dominated by a clear central peak, but has a secondary maximum in all three transitions. A comparison with Fig. 1 shows that the molecular gas is concentrated around the centre.

We analyzed the morphology of the molecular gas together with the optical spectra and other data (8.4 GHz from Lisenfeld et al. 1996, CO from Young et al. 1988, X-rays from Armus et al. 1995) and derived the geometry of the outflow (Greve et al. 2000): the diameter of the base is about two times larger than in M 82 and the opening angle of the outflow cone is much wider (60° as compared to 25°).

The detailed state of the molecular gas is still under investigation. A first glance indicates a rise of the temperature towards the centre and a higher optical depth there. This is rather different from M 82, where the bulk of the molecular gas is situated at the border of the starburst region (Weiß et al. 2001) and the bright CO emission near the centre is just an effect of the higher temperatures there. In view of the postulated early phase of the burst (see below) a gas concentration towards the centre of NGC 2146 seems to be as plausible as the empty region for the "old" burst in M 82, but without a proper analysis no conclusion can be drawn yet.

Radio observations in the cm range

Shortly after the first PdBI observations we observed NGC 2146 with MERLIN at 5 GHz and combined the data with earlier VLA data. The aim was to investigate the radio continuum emission in detail. The angular resolution of the order of 10 mas allows to clearly separate 18 individual sources in the ridge of emission and to resolve about a third of them, but this number is much smaller than expected from a scaled model of M 82 (Tarchi et al. 2000). This discrepancy became even more pronounced when we observed NGC 2146 with MERLIN at 1.6 GHz: only half of the sources could be detected at the lower frequency and just three of them show the negative spectral index expected for a radio supernova (SN) or a supernova remnant (SNR).

There are two basic interpretations for such a behaviour: either there is foreground ionized gas with high emission measures causing free-free absorption or the sources with positive spectral index are optically thick ultra-dense HII regions (a mixed scenario is of course possible). The general explanation is a very young age of the burst phase: in NGC 2146, the massive stars have just formed and form dense groups surrounded by highly ionized gas, whereas in M 82 many of them have already blown off as SNe. The number of massive stars needed to push the gas into this state is quite high – up to the equivalent of 1000 OB stars, but similar numbers have been derived for other objects as well (Turner et al. 1998).

3 The present general picture in brief

We could accumulate a data base for NGC 2146 which allows a detailed comparison with the closer starburst galaxies. It spans the range from cm wavelengths to X-rays, with a significant amount of high-resolution data. From the analysis performed so far, we can sketch the following picture:

NGC 2146 is undoubtedly experiencing a phase of strongly enhanced star formation which manifests itself most clearly in the high FIR flux and the outflow of hot gas from the disk. The active region has about three times the diameter of the burst zone in M 82 and the star formation rate is about two times higher. Thermally excited gas dominates in this region whereas the outflow shows indications for shocks. The outflow cone is much wider than observed for M 82. This might hint at a lower external gas density.

The molecular gas is partly dragged out by the outflow activity, but seems to be much more concentrated towards the centre than in M 82. It shows no anomalies that would indicate a recent merger, except perhaps the warp of the emission distribution.

In the cm radio regime, most sources show spectral indices different from those expected for SNe or SNR. The most likely explanation is the presence of a large number of young, massive stars creating ultra-compact/ultra-dense HII regions with high electron densities. The large number of O- and B-stars plus the small number of clear SN(R) candidates imply a very recent onset of the starburst.

The question of what the trigger for this new activity is still remains unanswered. On the basis of the present data the most probable cause for the burst of star formation seems to be an encounter, although this explanation has severe difficulties: the interacting object should be close by, but could not yet be identified. The nearest neighbour, NGC 2146 A, has too large a velocity difference (Fisher & Tully 1976). Recently, Taramopoulos et al. (2001) presented a high-resolution VLA HI map showing "tidal tail" structures and have proposed a low-surface-brightness galaxy as the missing companion, but this object remains to be found.

References

Armus, L., Heckman, T.M., Weaver, K.A., Lehnert, M.D. 1995, ApJ 445, 666
Benvenuti, P., Capaccioli, M., D'Odorico, S. 1975, A&A 41, 91
Fisher, J.R., Tully, R.B. 1976, A&A 53, 397
Greve, A., Neininger, N., Tarchi, A., Sievers, A. 2000, A&A, 364, 409
Hutchings, J.B., Lo, E., Neff, S.G., Stanford, S.A., Unger, S.W. 1990, AJ 100, 60
Lisenfeld, U., Alexander, P., Pooley, G.G., Wilding, T. 1996, MNRAS 281, 301
Madau, P., Pozzetti, L., Dickinson, M. 1998, ApJ 498, 106
Pease, F.G. 1920, ApJ 51, 276
Taramopoulos, A., Payne, H., Briggs, F.H. 2001, A&A 365, 360
Tarchi, A., Neininger, N., Greve, A., Klein, U., Garrington, S. T., Muxlow, T. W. B., Pedlar, A., Glendenning, B. 2000, A&A 358, 95
Turner, J.L., Ho, P.T.P., Beck, S.C. 1998, AJ 116, 1212
Weiß, A., Neininger, N., Hüttemeister, S., Klein, U. 2001, A&A 365, 571
Young, J.S., Claussen, M.J., Kleinmann, S.G., Rubin, V.C., Scoville, N. 1988, ApJ 331, L81