H II Regions in NGC 5128

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Among the many mysteries which nature has graciously presented to us in the southern hemisphere, the giant galaxy NGC 5128 is one of the greatest. It is a prodigious emitter of X-rays and radio waves and the origin of all this energy appears to be the nuclear region. In order to better understand this galaxy and the reason(s) for its peculiarity, many studies have recently been undertaken. One of these deals with the regions of ionized hydrogen, and the investigator, Dr. Claus Möllenhoff from Landessternwarte Heidelberg-Königstuhl, Fed. Rep. of Germany, here presents some of the most recent results.

The Galaxy NGC 5128

The peculiar galaxy NGC 5128 is one of the most remarkable astronomical objects in the southern sky. It is a very bright elliptical galaxy superimposed by a conspicuous equatorial dust lane (fig. 1). NGC 5128 is the optical centre of a strong and very extended radio source ("Cen A", with an apparent diameter of more than 8 degrees in the southern sky). NGC 5128 is the nearest giant radio galaxy (distance approximately 5 million parsecs = 16 million light-years), so it offers the opportunity of detailed optical observations. Our knowledge about this galaxy has strongly increased since the erection of serveral large telescopes in the southern hemisphere.

The most conspicuous feature in NGC 5128 is the big dust lane. It consists of a chaotic mixture of absorbing dust, light-emitting filaments of excited gas, and young blue stars. It is not yet clear if this dust lane is in reality a giant ring or a disk-like region penetrating the whole galaxy. Radial velocity measurements have shown that the dust lane rotates much faster than the galaxy itself.

This mixture of hot blue stars, dust, and gas is characteristic for regions where star formation takes place. The young blue stars excite and ionize the gas in their neighbourhood, so the gas radiates at characteristic wavelengths. Such radiating gas clouds are called emission nebulae or H II regions. A lot of such H II regions can be detected in the dust lane of NGC 5128. Spectroscopic observations of H II regions allow conclusions about their physical parameters and chemical composition. For this reason, during spring 1978 and during spring 1979, two observational programmes were carried out on La Silla with the 1 m, the 1.5 m and the 3.6 m telescopes.

Identification of the H II Regions

The most characteristic optical radiation of H II regions is the emission of the hydrogen Balmer lines (Hα 6563 Å, Hβ 4861 Å, Hγ 4340 Å, etc.) and the so-called "forbidden" lines (e.g. [OII] 3727 Å, [OIII] 4959, 5007 Å, [NII] 6548, 6584 Å), which are excited by collisions of the atoms in the nebula. The easiest way to locate H II regions in extra-galactic objects is therefore to photograph them through appropriate optical filters which just let pass the emission lines of the nebulae and suppress everything else. This can be done by using a set of interference filters which are adjusted to the wavelengths of the emission lines.

During five nights in March 1978 a number of such exposures were obtained with the ESO 1 m telescope. As these interference filters let pass only a very small portion of the spectrum, it was necessary to use an image intensifier. The exposure times were typically one to two hours (without filter only a couple of minutes were needed, see e.g. figure 1).

Figure 2 shows an exposure through an interference filter centred around 4775 Å (~50 Å bandwidth). There are no bright nebular emission lines within the transmission range of this filter. What can be seen in the picture is mainly the continuous light of the stars. Therefore, the gas filaments in the dust lane appear rather weak.

Another filter was centred around 6600 Å with a bandwidth of 170 Å. This filter included especially the Hα and [NII] lines (see fig. 3). Therefore, all bright spots on this picture having no counterpart on the continuum picture (fig. 2) are regions in the galaxy which are especially bright in Hα and [NII]. Thus these bright spots must be H II regions, they are marked by small arrows in figure 3. Note also the bright Hα-radiating gas filaments in the dust lane visible in this picture.

Figure 4 is a schematical map of the location of these objects. Most of the emission nebulae were found at the edges of the dust lane or just south of it. They have a typical diameter of 2–4 arcseconds corresponding to 50–100 parsecs in NGC 5128. A remarkable object is the emission region No. 13. In the 4775 Å exposure two distinct bright stellar knots are visible. They appear still brighter on exposures which were taken through filters of shorter wavelengths. However, they are hardly visible on extremely red exposures. Therefore, these two knots are probably very blue (i.e. hot) stars of a remarkable luminosity ($M_B \approx -9$ to -10). They are obviously the exciting stars for the H II region No. 13. In the 6600 Å exposure (fig. 3) the knots are not distinguishable, they are immersed in a much larger region of emitting gas.

The object No. 1 is not a "normal" H II region, it is the nucleus of NGC 5128. This nucleus was discovered in 1969 by S. van den Bergh and in 1971 independently by W. E. Kunkel and H. V. Bradt (*Astrophys. Journ.* **170,** L 7) on infrared plates. The nucleus is a huge cluster of stars, it is probably the "power station" for the giant radio sources outside the optical galaxy. The nucleus comprises a mass of approximately 1,000 million solar masses in a region of ~ 100 parsecs (~ 300 light-years) diameter (this is only a small fraction of the total mass of NGC 5128). Moreover the nucleus contains a lot of excited gas which makes it visible in our filter photographs (fig. 3).

Van den Bergh (1976, *Astrophys. Journ.* **208,** 673) showed by extensive photometric measurements that approximately 25 million years ago a burst of star formation took place in the nucleus. This burst was probably caused by giant explosions in the nucleus, those explosions which are also supposed to be responsible for the formation of the radio sources and jets of excited matter outside the galaxy.

Spectroscopic Observation with the 1.5 m Telescope

In order to get a better understanding of the H II regions in the dust belt a spectroscopic programme was run during

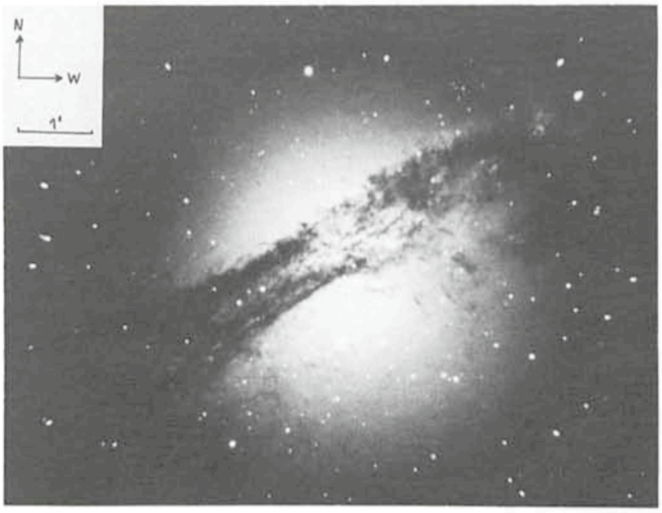

Fig. 1.

Fig. 2.

Fig. 3.

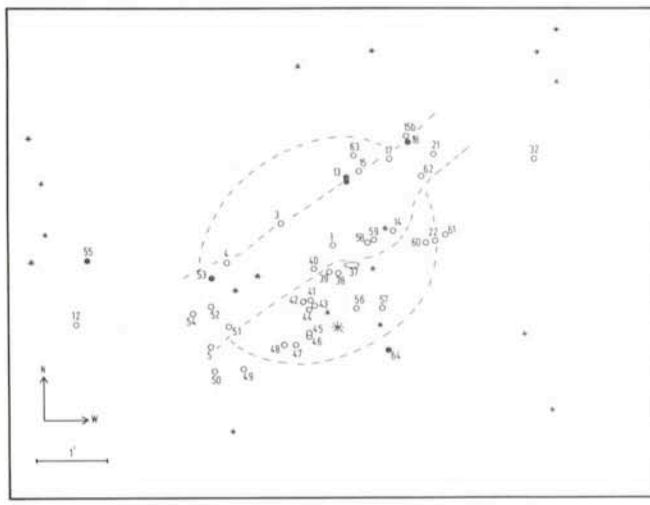

Fig. 4.

Fig. 1: *Unfiltered photograph of NGC 5128 with the ESO 1 m telescope. Since the whole spectrum of visual light could pass, it is not possible to decide from such an integrated picture if a certain bright region in the galaxy is a conglomerate of stars (continuous spectrum) or an emission nebula (discrete line spectrum). Due to the image intensifier the exposure time was only 5 minutes.*

Fig. 2: *Photograph through a narrow-band interference filter of 4775 Å central wavelength, 85 minutes exposure time. Only continuous (stellar) light contributes to this picture. The deformation of the stellar images in the outer regions is due to the image intensifier.*

Fig. 3: *In this case the interference filter was centred at 6600 Å, therefore especially the bright Hα and [N II] lines of excited gas material could pass. Note the bright filaments of excited gas in the dust lane. The arrows mark a large number of bright spots which are not visible in figure 2. They are H II regions which are bright in the Hα* and [N II] lines.

Fig. 4: *Schematical map of the H II regions identified in figure 3. They concentrate mainly at the borders of the dust lane and south of it.*

April 1979 on La Silla. The 1.5 m telescope, equipped with the Boller & Chivens spectrograph and the Carnegie image intensifier was used. The longest slit (3.8 arcmin projected on the sky) allowed the spectroscopy of several H II regions simultaneously, together with the underlying galaxy. The dispersion was 114 Å/mm (1st order) leading to spectrograms from ~ 3500 to 6000 Å.

Figure 5 shows one of these spectrograms. The slit was orientated along the NE border of the dust lane, crossing the H II regions No. 18, 17, 15, 13, 3, and 4 (from top to bottom in figure 5). The spectrogram shows the emission lines of these H II regions together with the absorption line spectrum of the stars in the galaxy. The H II regions threading along the slit appear like pearls on a string at the corresponding wavelengths of their emission lines in the spectrum.

The most prominent emission line (apart from the night sky lines O I 5577 Å and Na I 5893 Å, which of course cover the whole width of the spectrum) is [O II] 3727 Å. It is not only visible (as bright dots) at the location of the H II regions, but covers (however weaker) the whole dust lane. This means that collisionally excited gas is present all over the dust lane. Moreover [O III] 4959, 5007 Å and the hydrogen Balmer lines (Hδ 4102, Hγ 4340, Hβ 4861 Å) are easily visible. The uppermost H II region (No. 18) shows also Hε 3970 + [Ne III] 3968 Å, [Ne III] 3869 Å, and a weak blue continuum. The very bright blue continuum above the middle of the spectrogram is the H II region No. 13. This blue continuum belongs without doubt to the hot stars which excite the gas around them. The continuum is so bright that it outshines a part of the nebular emission lines. It does not show any absorption feature at this spectral

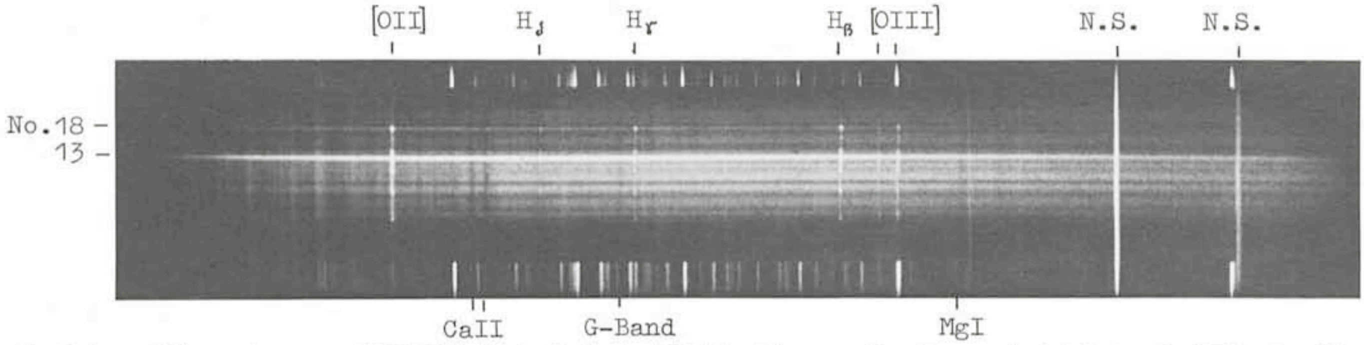

Fig. 5: *Image tube spectrogram of NGC 5128 obtained with the ESO 1.5 m telescope. The slit was orientated along the NE border of the dust lane and crosses a number of H II regions (from top to bottom in the spectrogram). Each H II region produces a bright spot in the spectrum at the wavelengths of the nebular emission lines (indicated on top). The location of two H II regions is indicated at the left margin. The stars of the underlying galaxy can be identified by their most prominent absorption lines (indicated at the bottom margin). The bright emission lines ("N. S.") in the long-wave region of the spectrum are due to the terrestrial night sky.*

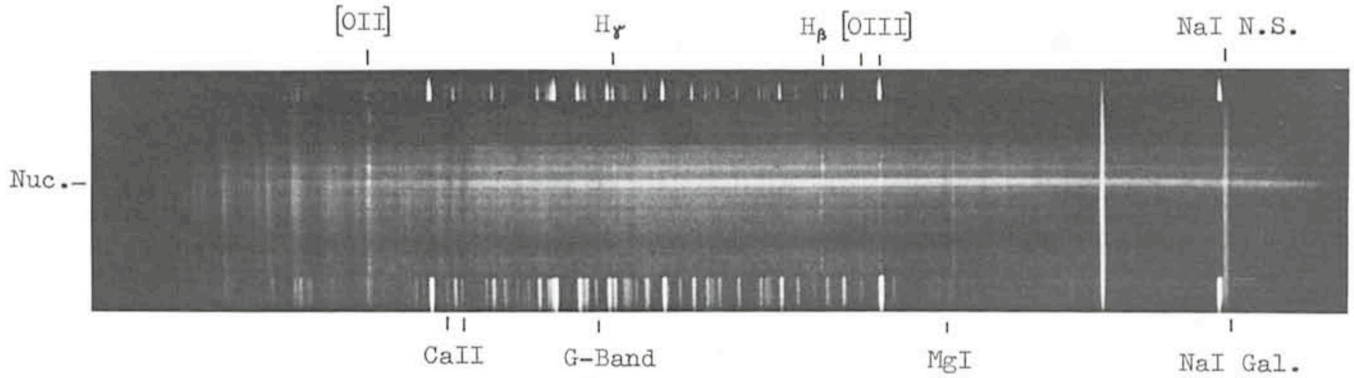

Fig. 6: *Similar spectrogram as figure 5; however, the slit crosses the nucleus of NGC 5128. The bright red continuum of the nucleus is very conspicuous. The broad absorption lines in this continuum (indicated at the bottom margin) show that the nucleus is a giant star cluster. This star cluster also contains excited gas detectable by the typical emission lines (marked at the top). Note the Na I emission line of the terrestrial night sky and the red shifted Na I absorption line of the nucleus of NGC 5128.*

resolution; the nature of the blue stars is therefore not easy to decide. Note the inclination of the nebular emission lines which reflects the rotation of the H II regions around the centre of the galaxy.

The main absorption lines in the spectrum of the underlying galaxy are marked in figure 5: Ca II 3934, 3968 Å, the G-Band (~ 4300 Å), Fe 4383 Å, and Mg I 5167–5184 Å. The structures visible near the short-wave end of the spectrum are the emission bands of the atmospheric airglow (O_2 molecules).

In figure 6 the slit of the spectrograph is again orientated parallel to the dust lane, however, it now crosses the nucleus of NGC 5128. The continuum (bifurcated at the blue end) of the nucleus is very conspicuous in the red. Again [O II], [O III], Hβ and Hγ are visible, but not as bright as in the H II regions at the NE border of the dust lane. It is easily visible that the nucleus contains a cluster of evolved stars: the absorption lines mentioned above are also visible in the continuum of the nucleus. Remarkable is also the very broad Na I 5893 Å absorption of the nucleus (red-shifted against the night sky emission line of Na I). The width of the Na I absorption line is more than 15 Å, which corresponds to a velocity dispersion of 750 km s^{-1}. Such velocities can of course not occur in single stars, what we see is the superposition of the Na I absorption of a whole cluster of stars.

Spectroscopic Observation with the 3.6 m Telescope

In order to get more detailed information about the individual H II regions in NGC 5128, three more nights of spectroscopic observation were spent at the ESO 3.6 m telescope (during March 1979). The spectra were not exposed on a photographic plate but onto the photocathode of the IDS ("Image Dissector Scanner") System. The results of the scanner observations are stored digitally on magnetic tape. The main advantage of the scanner is that the response is absolutely linear to the incident intensity. Therefore, quantitative comparisons between different emission lines or of the continuum are much more accurate than from a photographic plate.

A "normal" astronomer needs some time to get familiar with this really nice scanner system. However, with the helpful introduction of Dr. Schnur and Dr. Pedersen this was not a big problem. The scanner records two spectra simultaneously in two different slits A and B. The standard procedure is now that the object is put into slit A while slit B records the sky background. After approximately 10 minutes of integration the slits are interchanged (star in B, sky in A) in order to get rid of any inhomogeneities of the photocathode. This procedure is repeated several times, all integrations of the corresponding slits are added together, the corresponding sky background is subtracted. The observations end when the summarized spectrum has a sufficiently good signal-to-noise ratio (all results can be monitored on a cathode ray screen). It is extremely helpful that the spectrum can already be seen during the observation. These weak H II regions are sometimes difficult to find (even with the 3.6 m telescope), so the astronomer can see at once if something was wrong. A dispersion of 171 Å/mm was chosen, thus the whole visual region of 3850 to 6800 Å was obtained in the 2048 scanner channels. The total exposure times were typically 60 to 90 minutes.

Figure 7 shows the scanner spectrum of the H II region No. 18. The values from the computer are plotted as a curve. Because of the linearity of the system the diagram shows directly the intensities of the emitted lines. The most important lines are identified in the figure. From the intensity ratios of some emission lines one can directly compute some physical parameters in this H II region. We get a rough temperature estimate of $T \approx 10{,}000$ °K and an electron density of $n_e = 100$ to $200\ cm^{-3}$. These values are typical, also for H II regions in our own galaxy.

Figure 8 shows the scanner spectrum of the H II region No. 13. The emission line spectrum is very similar to that of No. 18, however, a strong blue continuum is superimposed. This continuum results from the blue stellar objects mentioned above. The absorption lines in that spectrum (Ca II 3934, 3968 Å, Mg I 5167–84 Å) do *not* belong to these blue stellar objects. This can easily be verified from figure 5. One has to consider that the slit of the scanner was 6 arcsecond long and therefore the spectrum is contaminated by the surrounding galaxy.

Figure 9 shows the scanner spectrum of the nucleus of NGC 5128. The most conspicuous detail is the strong continuum increasing towards the red end. This continuum shows a number of broad emission lines which are typical for evolved stars (G–K).

The distance of the two slits A and B of the scanner is 20 (or 40) arcseconds. This leads to some problems with the elimination of the night sky from our spectrograms. Since NGC 5128 is such an extended object, slit B will always see some point in the galaxy (and not the pure night sky) while slit A is pointed towards the nucleus. Then the standard procedure of subtraction will of course lead to wrong results. Therefore in the case of figure 9 the night sky was taken from an extra observation well outside the galaxy. However, since the night sky background changes with time and direction, there remain some remnants of the night sky lines (O I 5577, 6300, 6364 Å, marked by N. S.). Especially interesting is the Na I 5893 Å line: The spectrum shows the non-displaced Na I emission of our atmosphere (marked by N. S.) and—red-displaced according to the radial velocity of NGC 5128—the Na I absorption in the continuum of the nucleus (see also fig. 6).

The nucleus is not at all a normal H II region; this can already be seen by a first glance on the emission-line spectrum: Hα is (in contrast to figs. 7 and 8) weaker than [N II] 6584 Å, Hβ and the higher Balmer lines are hardly visible. One simple reason for that may be that the hydrogen emission lines are partly compensated by the absorption lines of the star cluster. However, the physical reasons for the excitation of the lines are probably not those of normal H II regions, the shocks of the explosions are also important here. A more detailed analysis is necessary before a reliable interpretation can be given.

All these spectrograms contain a lot of information about the physical parameters and the chemical abundances in these H II regions. The reduction of these data has just started and will still require much work. And there are also the measurements of the radial velocities which have not been mentioned in this article. All this will hopefully lead to an improved understanding of what is going on in the nucleus and in the dust lane of this spectacular galaxy.

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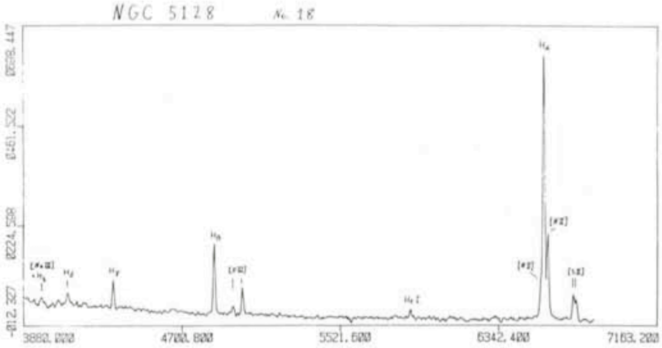

Fig. 7: *Scanner spectrogram of the H II region No. 18, obtained with the ESO 3.6 m telescope. It is a typical spectrum of an H II region, the most prominent emission lines are indicated. Such scanner spectrograms allow direct comparisons of line intensities.*

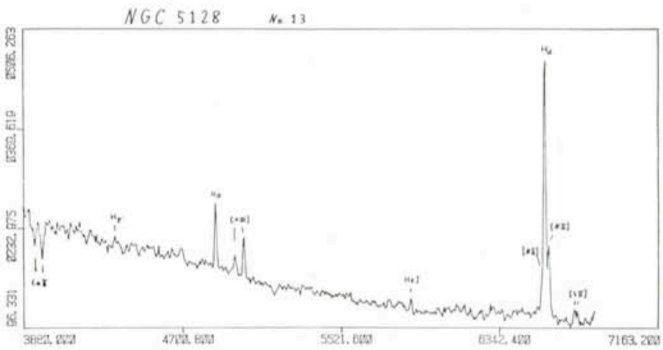

Fig. 8: *Scanner spectrogram of H II region No. 13. The exciting blue stars show themselves by a bright blue continuum. The absorption lines are not from this continuum but originate from the surrounding galaxy (see fig. 5).*

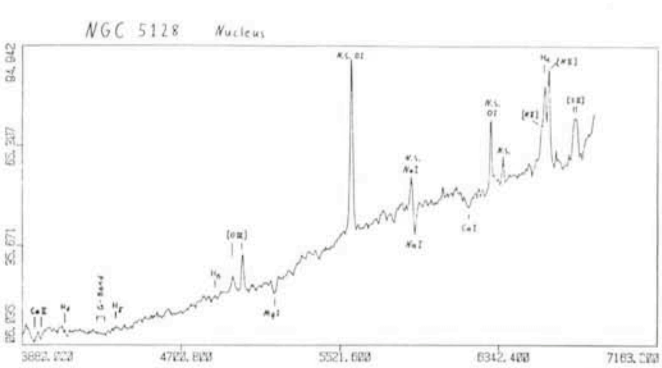

Fig. 9: *Scanner spectrogram of the nucleus of NGC 5128. The extremely red continuum and its absorption lines are very conspicuous. The Balmer lines of the excited gas are much weaker compared to H II region No. 18 (fig. 7). As the night sky was not completely eliminated there remain some remnant emission lines (marked by N. S.). Note especially the Na I night sky emission line and the red-shifted Na I absorption line of the nucleus (see also fig. 6).*