1. Circumnuclear Star Forming Regions

Circumnuclear Star Forming Regions (CNSFR), also called hotspots, can be found in the inner parts of disc galaxies \((r < 1 \text{ kpc})\) where intense processes of star formation are taking place, associated to rings or pseudo-rings. They appear to be more compact and with a more pronounced peak in the surface brightness distribution than other types of HII regions. Regarding the properties of their stellar ionising populations, Álvarez-Álvarez, Díaz & Castellanos (2003) needed a composite population with both a just-formed burst and an older one in the WR-phase in order to explain some emission-line ratios, Wolf-Rayet features and blue colors. There is a coincidence in this point with some recent results for HII galaxies (Pérez-Montero & Díaz, 2004). Some of the properties of CNSFRs have been studied, analyzing a sample of them through spectrophotometrical observations, using diagnostic emission-line ratios involving oxygen and sulphur. The deduced properties have been compared with those of other families of objects and results from photo-ionisation models.
2. The sample of studied objects

We have selected a sample of emission line-objects from the literature with [OII], [OIII], [SII] and [SIII] emission lines, thus obtaining different empirical calibrators of the functional parameters, for different families of HII regions, including Giant extragalactic HII regions and HII galaxies. With the aim of comparing these properties with those of CNSFRs, we have compiled data from Pérez-Olea (1996) with observations of CNSFRs in NGC2903, NGC3351 and NGC3504, that include these lines as well. Data for other CNSFRs (M51; Díaz et al. 1991, NGC 3310; Pastoriza et al. 1993 and NGC 7714; González-Delgado et al. 1995) have been added too.

3. Functional parameters

Photoionisation equilibrium in HII regions is governed by three main parameters so-called functional: the metallicity, the ionisation parameter (i.e. the quotient of ionising photons to the density of particles) and the hardness of the incident continuum. In previous works it has been shown that the estimation of these parameters through the sulphur emission lines provide values of them with a high level of confidence.

![Figure 1](image.png)

*Figure 1.* Relation between the metallicity, in terms of 12+log(O/H), and the S23/O23 parameter for different families of HII regions, including CNSFRS.
Metallicity

Many CNSFRs are objects with very large metallicities ($Z \geq Z_\odot$), and it is no possible to ascertain their oxygen abundances through the direct method and, therefore, it is compulsory to use empirical parameters. For this sample we have used the parameter S23/O23 (Díaz & Pérez-Montero, 2000), that leads to values of oxygen abundance at high metallicities with little uncertainty. For the sample of CNSFRS from Pérez-Olea, , upper right corner in figure 1, we obtain values between 1.09 and 2.88 $Z_\odot$. On the other hand, the CNSFRS with low metallicities, for which it is possible to apply the direct method, present abundances between 0.22 and 0.55 $Z_\odot$.

![Figure 2. Relation between [SII]/[SIII] and the metallicity. For CNSFRS, this last obtained from the S23/O23 parameter.](image_url)

Ionisation parameter

It gives an idea of the excitation degree inside the nebula. Although, the [OII]/[OIII] ratio has been used frequently to parametrise it, we have used [SII]/[SIII] (Díaz et al., 1991), because this ratio has no dependence on effective temperature. This parameter, as we can see in figure 2, does not present any correlation with metallicity. CNSFRs, contrary to HII galaxies, tend to present large values of [SII]/[SIII], what implies low degrees of excitation.
Effective temperature

The temperature of the field of radiation can be deduced from the parameter $\eta'$ (Vilchez & Pagel, 1988), that is defined as a function of the bright emission lines of oxygen and sulphur:

$$\log \eta' = \frac{\log([\text{OII}])}{\log([\text{OIII}])} - \frac{\log([\text{SII}])}{\log([\text{SIII}])}$$

As we can see in figure 3, there seems to be a sequence defined by this temperature and the metallicity, represented by $S_{23}/O_{23}$ in this diagram, in such a way that, for instance, low metallicities correspond to higher effective equivalent temperatures. This is to be expected from stellar atmospheres theory. Nevertheless, CNSFRs are an exception because, independently of their oxygen abundance they present always very high effective temperatures.

Figure 3. Relation between $S_{23}/O_{23}$ and the $\eta'$ parameter. CNSFRs break the expected relation between metallicity and effective equivalent temperature.

4. Photo-ionisation models

There are two main problems that we have tried to address through the use of photo-ionisation models. Firstly, the searching for an explanation for the unexpected large effective temperatures found in CNSFRs independently of their metallicites. Secondly, the fact that the ionising spectra corresponding to
Figure 4. The $\eta'$ diagram. The scale of equivalent effective temperatures, in solid lines, is compared with observations and cluster model atmospheres in photo-ionisation models, represented by squares (see text for explanation).

The temperatures in these objects and in HII galaxies is harder than the hardest available cluster theoretically predicted spectra. For this purpose we have used CLOUDY 96 (Ferland, 2002), with Starburst 99 spectral energy distributions (atmospheres from Pauldrach et al. (2001) for O and B stars and Hillier & Miller (1998) for WR).

In the $\eta'$ diagram it is possible to scale Teff. with CoStar model stellar atmospheres. These are represented as solid lines in figure 4. Both CNSFRs and HII galaxies show equivalent temperatures higher than 50 kK, even for different excitation degrees and metallicities. Other types of objects lie between 30 and 40 kK. Open squares represent clusters models with SB99 atmospheres at 1.0 Myr. The ionisation structure of the nebula is dominated by these very young bursts in objects showing high Teff.

For each ionisation parameter, different metallicites have been chosen in order to simulate the gas conditions. These models have plane-parallel geometry and a constant density of $100 \text{ cm}^{-3}$. They are summarized in table 1.

As SB99 models cannot reach the high effective temperatures deduced in CNSFRs and, to a lesser degree, in HII galaxies, we have tested to what extent
the presence of all dust grain physics affects the equivalent temperature in the nebula. The models including dust grains are represented by dotted squares in figure 4. Although it is expected an increment of $T_{\text{eff}}$ at least at high metallicities, due to depletion factors and internal heating of the gas, there are only variations in the excitation degree, and in non-significant quantities.

Finally, the geometry of the gas can also affect the inner ionisation equilibrium and the functional parameters may vary their physical meaning. In the models represented by filled squares in figure 4 we have put the gas near to the ionising source, resulting in a spherical geometry. At low values of the ionisation parameter and high metallicities, that is the range of CNSFRs, the effective equivalent temperature is increased. Nevertheless, at high excitation degrees and low metallicities, that is the range of HII galaxies, there are not significant variations.

Therefore, although the mechanism of heating and ionisation of the gas in massive HII regions with very young and efficient processes of star formation in all ranges of metallicity is far from being well understood, the properties of the stellar ionising populations through direct observations in different bands and future more realistic assumptions about the geometry of the gas will shed some light on this issue.

Table 1. Chosen metallicities for each ionisation parameters in the described models.

| $\log U$ | $Z$ |
|---------|-----|
| -2.0    | 0.001, 0.004 |
| -2.5    | 0.004, 0.008 |
| -3.0    | 0.008, 0.020 |
| -3.5    | 0.020, 0.040 |

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