A differential study of inner and outer disk HII regions of nearby spiral galaxies

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Abstract: HII regions are all studied following the same general prescription and models, but the influence of their environments may produce differences in their star formation processes. We analyse two samples of 725 inner and 671 outer disk HII regions from 263 nearby spiral galaxies, observed by the CALIFA survey with integral field spectroscopy. Observations are compared with predictions of 540 Cloudy photoionisation models using diagnostic and evolutionary diagrams. Systematic physical differences are confirmed between ionising clusters of inner and outer HII regions. These differences condition the validity and range of reliability of oxygen abundance and ionisation parameter calibrations commonly applied to the study of HII regions.

Context

Despite the observationally inferred different physical properties of HII regions located in **inner and outer zones** of galaxy disks, the general methods applied to the study of star-forming processes and the estimation of abundances have been derived from observations of intermediate disk regions, brighter and with more prominent emission lines, and assumed to be valid for regions over the whole galactic disks.

The advent of **Integral Field Spectroscopy (IFS)** has changed this situation, providing access to large samples of spatially resolved, high-quality and homogeneous data from HII regions across the whole surface of galaxy disks. This allows for the first time the characterisation and comparison of these extreme regions physical properties, generating key information for galaxy formation theories and chemical evolution models.

Within this context, the **main goal** of this work is the differential study of two large samples of inner and outer HII regions observed with IFS, in order to explore the existence of intrinsic differences in the star-forming processes as a function of the region location and the environment.

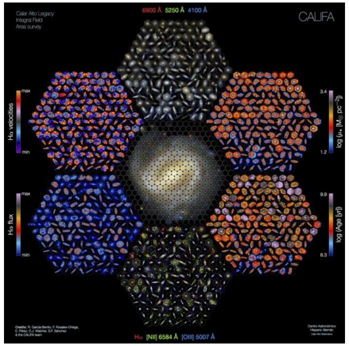
Observations, work sample and photoionisation models

Observations:

Calar Alto Legacy Integral Field Area survey (CALIFA). Sánchez et al. (2012)

3,5m telescope, CAHA. PMAS spectrograph, PPAK mode.

Wavelength range: 3745-7500 Å. FoV: 74 x 65 $arcsec^2$ (hexagonal)



Work sample:

Galaxies: 263 isolated spirals observed by the CALIFA survey until September 2014

HII regions spectra extraction and line fitting: HIIExplorer (Sánchez et al. 2012b) and FIT3D (Sánchez et al. 2011b)

Inner regions: Located closer to the centre than $\log R(kpc) = -0.204\ M_B - 3.5$ (Álvarez-Álvarez et al. 2015)
Total sample of 725 regions.

Outer regions: Located at a distance larger than 2 R_{eff} from the centre. Total sample of 671 regions.

Photoionisation models:

Cloudy photoionisation code (Ferland et al. 2013).

SEDs: PopStar evolutionary synthesis models (Mollá et al. 2009). Salpeter IMF.

Ages: 1 to 5,2 Myr. Metallicities: 0,006 to 0,018. Ionisation parameter: -3,75 to -2,5 (log). Total of 540 models.

Diagnostic diagrams

The **N2 index** may not be valid as abundance tracer for inner regions, due to the [NII] saturation at high *Z*.

The double-valued behaviour of the [SII]/Hα ratio with oxygen abundance conditions the **reliability ranges** of *Z* and *u* calibrations based on this ratio.

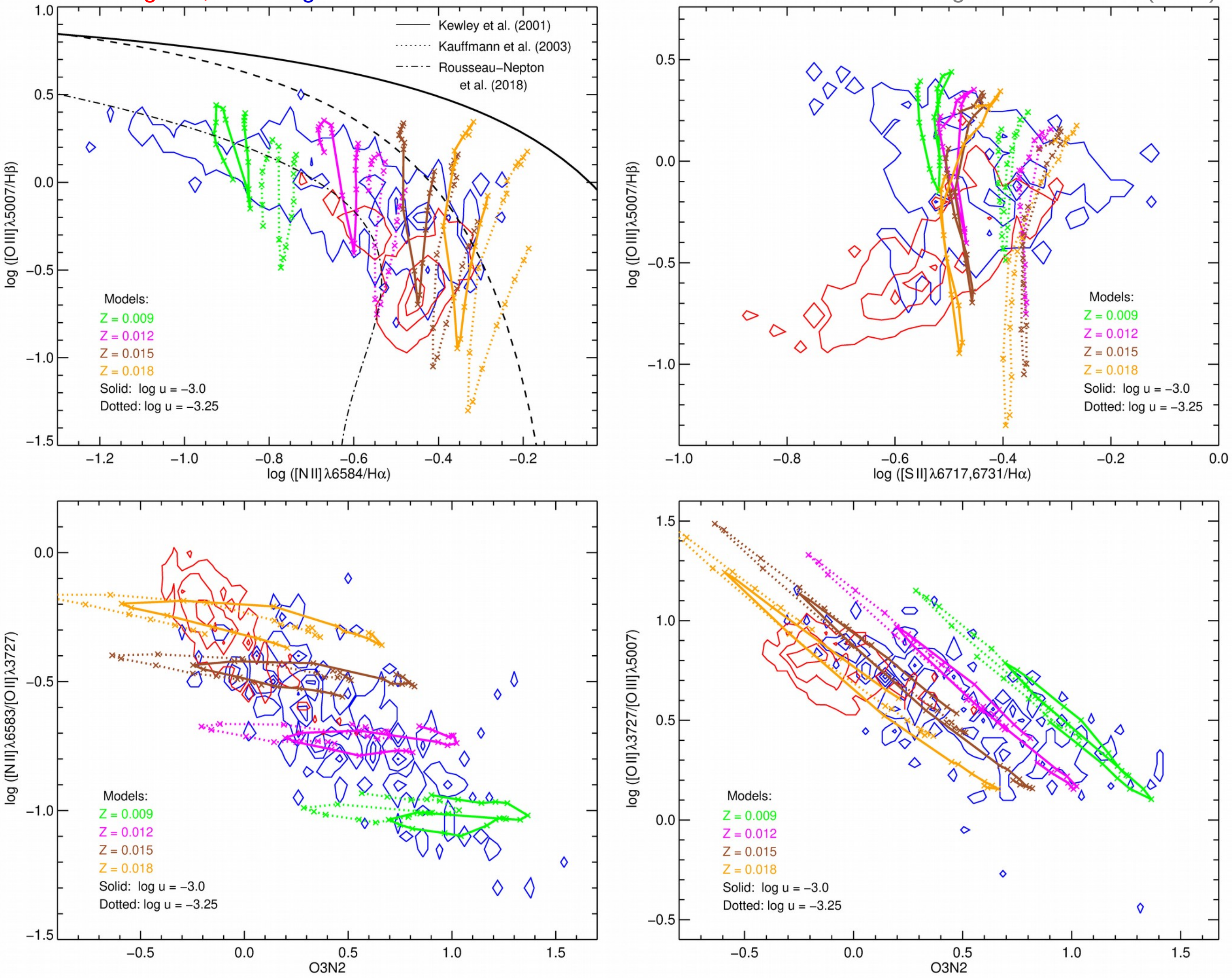
The strong degeneracy between age and ionisation parameter conditions the derivation of **abundance calibrations** based on the O3N2 index.

Inner regions:

- **Higher [NII]/[OII] values** than expected. This may indicate a change in the slope of the relation between N/O and O/H.
- **Lower [OII]/[OIII]** values than expected. This may indicate a change in the way this ratio traces *u*, or a non-linear relation between *u* and *Z*.

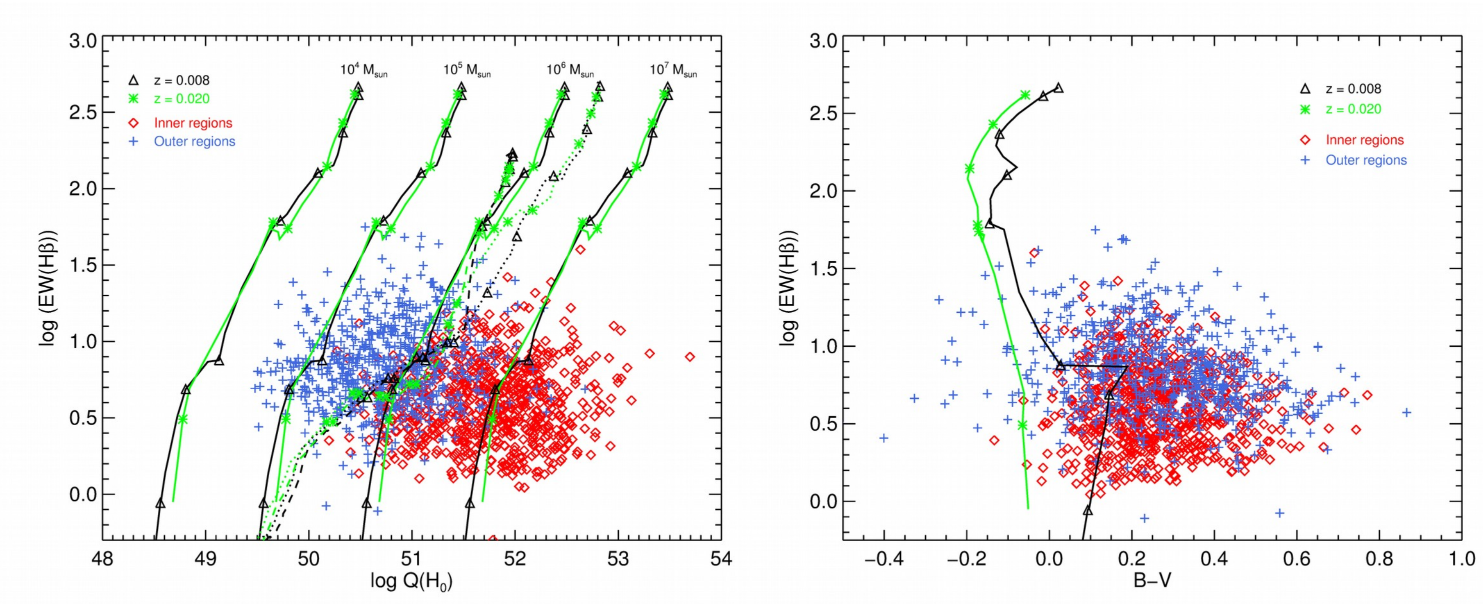
Inner regions, outer regions

Rodríguez-Baras et al. (2019)



Evolutionary diagrams

Degeneracies prevent the estimation of age using the diagnostic diagrams. We analyse the evolutionary state using the Hβ equivalent width, EW(Hβ) (decreasing function with age), number of ionising photons, $Q(H_0)$ (increasing function with mass and decreasing with age) and B-V colour (slowlier evolution with age than EW(Hβ)).



Solid lines: PopStar models
Dotted and dashed lines:
SB99 models

Rodríguez-Baras et al. (2019)

Ages: Inner regions show lower equivalent widths, denoting later evolutionary stages.

Masses: Inner regions may be star-forming complexes. Outer regions may suffer stochastic effects.

Both samples show **composite populations**, with contributions of non-ionising and/or underlying stellar populations.

Conclusions

[See: Rodríguez Baras et al. (2018), Rodríguez-Baras et al. (2019)]

1. Observational properties. Clear differences are found between inner and outer HII regions. Comparison with theoretical models reveals differences between ionising cluster physical properties: metallicity, mass and age.

2. Metallicity. Inner regions show higher metallicities. Some particularities:

- *The N2 index.* It is not valid for inner regions, due to the [NII] saturation at high *Z*.
- *The O3N2 index.* Valid for both inner and outer regions, although calibrations based on this index may be influenced by physical conditions of the employed HII region sample.
- *The N2O2 index.* Inner regions show higher N2O2 values than expected, indicating an increase in the slope of the relation between N/O and O/H.
- *Model predictions.* Degeneracies and discrepancies prevent a quantitative estimation of metallicites, recommending the use of several diagnostic diagrams.

3. Ionisation parameter.

- *The S2 index.* It does not trace *u* for the high-metallicity regime, thus it is not valid for inner regions.
- *The [OII]/[OIII] ratio.* Inner regions show higher [OII]/[OIII] values than expected. Either this ratio does not trace *u* for inner region physical conditions or the *Z-u* relation is non-linear.

4. Ionising masses. Inner regions show higher masses, pointing again to the observation of clumps. Outer regions may be affected by stochastic effects.

5. Ages. Outer regions show higher EW(Hβ), pointing to younger ages. However, both inner and outer regions show evidence of composite populations, confirmed by B-V colours. The ionising population has a contribution of ~1%, lower for the inner regions.

6. HII region properties. Inner regions show larger angular sizes, lower filling factors and larger ionised hydrogen masses, pointing to large star-forming complexes instead of individual regions. Outer regions show unresolved angular sizes.