Kinematics and abundances of circumnuclear star-forming regions

Guillermo F. Hägele
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...and a lot of collaborators that will appear in the corresponding part of the talk...

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These perturbations of the gas flow trigger nuclear star formation in the bulges of some barred spiral galaxies.
The bulges of some nearby spiral galaxies show *intense star-forming regions* located in a *roughly annular pattern* around their nuclei.
CNSFRs, with sizes going from a few tens to a few hundreds of pc (e.g., Díaz & Pérez-Montero, 2000) seem to be made of several HII regions ionized by luminous compact stellar clusters whose sizes, as measured from high spatial resolution HST images, are seen to be of only a few pc.
In general, CNSFRs and giant HII regions in the discs of galaxies are very much alike, although the former look more compact and show higher peak surface brightness (Kennicutt et al., 1989) than the latter.
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Their large \( H\alpha \) luminosities, typically higher than \( 10^{39} \text{ erg s}^{-1} \), point to relatively massive star clusters as their ionization source, which minimizes the uncertainties due to small number statistics when applying population synthesis techniques (see e.g. Cerviño et al., 2002).
In general, CNSFRs and giant HII regions in the discs of galaxies are much alike, although the former look more compact and show higher peak surface brightness than the latter. Their large $\text{H} \alpha$ luminosities, typically higher than $10^{39}$ erg s$^{-1}$, point to relatively massive star clusters as their ionization source, which minimizes the uncertainties due to small number statistics when applying population synthesis techniques (see e.g. Cerviño et al., 2002). Added interest in the study of CNSFRs comes from the fact that they are in general of high metal abundance (Díaz et al., 2006, 2007).
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Added interest in the study of CNSFRs comes from the fact that they are in general of high metal abundance (Díaz et al., 2006, 2007), therefore they provide clues for the understanding of star formation phenomena at large metallicities, and, being close to the nuclear regions, for the determination of metallicity gradients in spiral galaxies.
The velocity field of CNSF rings of early type spirals:

This project is part of a **study of the physics** of CNSFRs in spiral galaxies.
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As part of a program designed to measure the dynamical masses of CNSFRs, we have analysed long slit high spectral resolution data obtained with the WHT and the ISIS spectrograph in the blue (Hβ and [OIII]) and the red (CaII triplet lines; CaT) which have allowed to measure star and gas velocity dispersions in several CNSFRs of spiral galaxies.

Notice the absence of conspicuous emission lines in the red spectral range for this region.

The dashed line shows the obtained spectrum; the solid line represents the spectrum after subtracting the emission lines.

NGC3351
Hägele et al. (2007)
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The velocity field of CNSF rings of early type spirals:

Stellar velocity dispersions are between 31 and 73 km/s.
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Stellar velocity dispersions are between 31 and 73 km/s. For NGC3310 these values and those derived for the gas from the Hβ emission line using a single Gaussian fit are in relatively good agreement.
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Stellar velocity dispersions are between 31 and 73 km/s. The [OIII]5007Å presents velocity dispersions almost coincident with the stellar ones, or slightly, for NGC2903 and NGC3351, while in the case of NGC3310 its behaviour is very similar to that shown by the Hβ line.

Hägele et al. (2009b)
The velocity field of CNSF rings of early type spirals:

However, the best Gaussian fits involved two different components for the gas:

The optimal fit was found for two different components for all the regions.

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However, the best Gaussian fits involved two different components for the gas: a “broad component” with a velocity dispersion similar to that measured for the stars for NGC2903 and NGC3351, and larger by about 20 km/s for NGC3310.
The velocity field of CNSF rings of early type spirals:

However, the best Gaussian fits involved two different components for the gas: and a “narrow component” with velocity dispersions lower than the stellar one by about 30 km/s.
All these facts point to a complex gas velocity field in the circumnuclear regions of these galaxies.
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The measurements are compatible with the existence of **two kinematically distinct components** in the gas.
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When plotted in a $[\text{OIII}]/H\beta$ vs. $[\text{NII}]/H\alpha$ diagram (BPT, Baldwin, Phillips & Terlevich, 1981), the two systems are clearly segregated for the high-metallicity regions of NGC2903 and NGC3351.

with the narrow component having the lowest excitation and being among the lowest excitation line ratios detected within the SDSS dataset of starburst systems.

In the regions of the low-metallicity galaxy, NGC3310, these two components and those values derived using the single Gaussian fit are very similar.

SDSS data from López (2005)
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SDSS data from López (2005) with the narrow component having the lowest excitation and being among the lowest excitation line ratios detected within the SDSS dataset of starburst systems.

**Several results derived from the observations of the different emission lines could be affected**, among others: the **classification of the activity** in the central regions of galaxies, the inferences about the **nature** of the **source of ionization**, the gas **abundance determinations**, the **number of ionizing photons** from a given region and any quantity derived from them, etc.

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Hägele (2008)
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We therefore propose to observe the circunnuclear region of NGC3351, NGC2903 and NGC3310 with PMAS in lens array configuration at the higher spectral resolution.
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We plan to observe their central circumnuclear regions with PMAS in the lens array configuration at the intermediate spatial resolution of 0.75″, since average seeing in CAHA is about 1 arcsec.
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We plan to observe their central circumnuclear regions with PMAS in the lens array configuration at the intermediate spatial resolution of 0.75”, since average seeing in CAHA is about 1 arcsec.

Due to the sizes of the regions to be observed, one position covers the circumnuclear region of NGC2903, a mosaic of two positions will be needed for NGC3351, and three for NGC3310.
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We will use the 1200 lpmm grating in first order (forward blaze) in three different angles.
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Díaz et al. (2007)

One centered at 6551 Å covering from 6212 to 6871 Å and including the lines of [OI] λ 6300 Å, Hα, [NII] λ λ 6548,6584 Å and [SII] λ λ 6717,6731 Å.

Díaz et al. (2007)

A second one centered at 8452 Å covering from 8162 to 8720 Å including the CaT stellar lines.

Hägele et al. (2007)

The third one will be centered at 9124 Å covering from 8854 to 9371 Å including the [SIII] λ 9069 Å and Paschen P9 and P10 lines.

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The velocity field of CNSF rings of early type spirals:

We will use the 1200 lpm grating in first order (forward blaze) in three different angles, covering the region between 6200 Å and 9600 Å at different grating angles to include collisionally excited gas of ions in different ionization stages and H recombination lines, and the CaT stellar feature.

The [SIII] lines are much stronger than the [OIII] λ 5007Å line in high metallicity regions (see Castellanos et al. 2002, Díaz et al. 2007) so their detection would allow a better measurement of the velocity dispersion of the highly ionized gas.

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This proposal, for NGC3351 only, was awarded 1 night in period F-2007 (F07-3.5-043) that was almost entirely lost by bad weather.
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Hα flux map where the main CNSFR can be seen.

Radial velocity map showing the inner galaxy rotation.
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- **Hα flux** map where the main CNSFR can be seen.
- **Radial velocity map** showing the inner galaxy rotation.

This observation showed that the project is feasible.
A second observation run was performed for NGC3351 on 28 April 2008 in service mode.

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A second observation run was performed for NGC3351 on 28 April 2008 in service mode, using PMAS in the lens array configuration at a spatial resolution of 1" (FOV 16”x16”) and the V600 grating!!!

Spectral resolution: 0.8-0.7 Å/px
2x2 binning
FWHM: 3.6-3.7 Å/px
Two spectral ranges:
6147-7718Å
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The data don’t have enough spectral resolution to separate the narrow and the broad components of the emission lines, and to derive the stellar velocity dispersion from the CaT with the required accuracy.
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Two spectral ranges:
- J-band (1.17-1.37 μm)
- H-band (1.47-1.8 μm)

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Two spectral ranges: J-band (1.17-1.37 μm) and H-band (1.47-1.8 μm). FOV: 3.2”x4.8”

There is a relatively small area observed in both spectral ranges.
The velocity field of the CNSF regions of NGC1068: Progress report (work slowly in progress)

Example of what we can see in the J-band.
The velocity field of the CNSF regions of NGC1068: Progress report (work slowly in progress)

Examples of the multi-components found in the Paβ emission line.
The velocity field of the CNSF regions of NGC1068: Progress report (work slowly in progress)

Velocity field made using the main Paβ component (obs. 28, a single field of view). Spaxel: 0.15”x0.15”

Rebinned using a 2x2 Gaussian filter
The velocity field of the CNSF regions of NGC1068: Progress report (work slowly in progress)

All the data were reduced (by Damián Mast) and analysed using the GEMINI routines for IRAF.

Very preliminary results!!!
In a complementary project to the mapping of the entire velocity field of CNSF rings, we have asked high spatial resolution data in order to be able to resolve the contribution that every knot identified in the HST images makes to the overall profile as obtained from WHT ISIS spectra.
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The near-IR NIFS GEMINI-North slicer (IFU mode) will provide the spatial resolution needed when used in its active optics mode (AO) with a FOV of 3”x3” (time awarded in band-1).
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The velocity resolution obtained from [SIII] and H recombination lines (R~5000) in the Z band (0.94-1.15µm) will allow us to verify the presence of velocity fields within the star forming region.
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We propose to observe the detailed velocity structure of the numerous knots identified by the HST which have radius of 0.1″.
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We need to obtain high spatial resolution data, then we have selected a setup with the Adaptive Optics system, ALTAIR, for obtaining a 0.1”x0.12” resolution element in the IFU field of 3”x3”.
Díaz et al. (2000) have investigated the possible connection between nuclear activity and circumnuclear star formation by observing CNSFRs in galaxies with different degrees of nuclear activity in different broad and narrow band filters.
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More recently we have obtained slit spectrophotometric data on 12 circumnuclear HII regions in three early type spiral galaxies: NGC2903, NGC3351 and NGC3504 (Díaz et al. 2007).
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More recently we have obtained slit spectrophotometric data on 12 circumnuclear HII regions in three early type spiral galaxies: NGC2903, NGC3351 and NGC3504 (Díaz et al. 2007).

The metal content of the regions have been estimated using different empirical calibrators and turn out to be oversolar.
The CNSF rings of Seyfert galaxies:

The amount of available data on sulphur emission lines is increasingly growing, especially in the high metallicity regime. This makes possible for the first time to calibrate the $T_e([\text{SIII}])$ in terms of the $\log \text{SO}_{23}$ parameter.
The CNSF rings of Seyfert galaxies: The amount of available data on sulphur emission lines is increasingly growing, especially in the high metallicity regime. This makes possible to calibrate the $T_e([\text{SIII}])$ in terms of the $\log S_{O_{23}}$ parameter.

Only for high metallicity HII regions
Only for region $R1+R2$ in NGC2903 we could measure the $[\text{SIII}]\lambda 6312\text{Å}$ line and derive $T_e ([\text{SIII}])$, temperature slightly higher ($8400^{+4650}_{-1250}\text{K}$) than predicted by our proposed fit.

This temperature is higher than expected for a high metallicity HII region and inconsistent with what is indicated from different strong line diagnostics (Díaz et al. 2007).
The CNSF rings of Seyfert galaxies:

The abundances we derive using our $T_e([\text{SIII}])$ calibration are comparable to those found by Bresolin et al. (2005) for their sample of high metallicity HII regions.
Dors, Storchi-Bergmann, Riffel et al. (2008) combined optical IFU data from GEMINI South (GMOS-IFU) and a grid of photoionization models to determine gas abundances and star formation rates of the CNSFRs of two active galaxies: NGC1097 and NGC6951.

Spectral range: 5600-7000Å
R≈2300
FOV: 3 IFU fields of 15”x7” in each galaxy.
Spaxel: 0.1”x0.1”
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They found that the CNSFRs have oxygen abundances of $12 + \log(O/H) \approx 8.8$, similar to those of the most metal-rich nebulae located in the inner parts of the disks of spiral galaxies.

Spectral range: 5600-7000Å
$R \approx 2300$
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NGC1097
Dors et al. (2008)
The CNSF rings of Seyfert galaxies:

Riffel, Storchi-Bergmann, Dors et al. (2009) and Riffel, Storchi-Bergmann et al. (2008) using the near-IR slicers of GEMINI (GNIRS and NIFS in IFU mode) studied the AGN-starburst connection and the gas kinematics in the active galaxies NGC7582 and NGC4051, respectively.

**GNIRS**
- Spectral range: 2.1-2.4μm
- R≈5900
- FOV: 3.2”x4.8”
- Spaxel: 0.15”x0.15”

**NIFS**
- Spectral range: 2.0-2.4μm
- R≈5300
- FOV: 3.0”x3.0”
- Spaxel: 0.1”x0.12”

CO absorption lines, NGC4051
Riffel et al. (2008)
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They used the CO absorption feature to derived the stellar kinematics.

NIFS
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Taking into account all these results we are planning to ask time (joint proposal Argentina-Brasil) for the optical IFU instruments (GMOS-South and GMOS-North, in the IFU mode) and the near-IR slicers (GNIRS and NIFS, in the IFU mode) from GEMINI South and North.
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Then we will divide the project in three parts depending on the kind of study (abundances or kinematics), and the angular scale of the CNSFRs and the angular size of the ring.
The CNSF rings of Seyfert galaxies:

We mainly use the Atlas of Circumnuclear Regions of Seyfert galaxies by Muñoz-Marín et al. (2007) to select our sample.
The CNSF rings of Seyfert galaxies:

Parts of the project

1- If the CNSF ring is relatively extended in the sky and the galaxy do not have a very bright nucleus (normal, liners, Seyfert 2 galaxies) we will use GMOS-IFU with a FOV of 5”x7” (1 or 2 fields by object) and a spaxel of 0.2” (the spatial resolution depend on the seeing).

Mrk1210 – Sy2
Ring size ≈ 7”x7”

NGC4303 – Sy2
Ring size ≈ 8”x8”
The CNSF rings of Seyfert galaxies: Parts of the project

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HST-ACS F330W Muñoz-Marín et al. (2007)

We will devide this part of the project in two: abundances and kinematics.

Ring size ≈ 7”x7”

Ring size ≈ 8”x8”
1a- **Abundances:**

We will use an instrumental configuration with

- **wide spectral range** (4000-11000Å)
- **moderate spectral resolution** \(R=4300 \sim \Delta \lambda \approx 1.74\text{Å/px}\)
The CNSF rings of Seyfert galaxies: Parts of the project

1a- Abundances:
We will use an instrumental configuration with
- wide spectral range (4000-11000Å)
- moderate spectral resolution (R=4300 ~ Δλ≈1.74Å/px)

We will measure several emission lines (from [OII]λ3727Å to [SIII]λ9532Å) that will allow us to use empirical and semi-empirical methods (Díaz et al. 2007) and photoionization models (Dors et al. 2008) to derive abundances of the CNSFRs and the AGNs.
1b- Kinematics:

We will use an instrumental configuration with
- narrow spectral ranges
- high spectral resolution \((R=20000 \sim \Delta \lambda \approx 0.23\text{Å/px})\)
The CNSF rings of Seyfert galaxies: Parts of the project

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- narrow spectral ranges
- high spectral resolution \((R=20000 \sim \Delta \lambda \approx 0.23\text{Å/px})\)

We will measure some particular features: \(\text{H}_\alpha\), \([\text{NII}]\lambda\lambda 6548,6584\text{Å}\), \([\text{SII}]\lambda\lambda 6717,6731\text{Å}\), \([\text{SIII}]\lambda 9532\text{Å}\) and \(\text{Pa}_8\) emission lines and the CaT absorption lines to study the gas and stellar kinematics, respectively, and mapping the gas flows probably related with the AGNs.
The CNSF rings of Seyfert galaxies: Parts of the project

2- If the CNSF ring is relatively compact in the sky we will use NIFS and GNIRS (the near-IR slicers) with the active optics system and a FOV of 3”x3” and 3.2”x4.8”, respectively (1 or 2 fields by object), and a spaxel of 0.1”x0.04” and 0.15”x0.15”, respectively (the spatial resolution are given by the diffraction limit of the instrument + telescope).

Mrk42 – Sy1
Ring size ≈ 2”x2”

NGC7469 – Sy1
Ring size ≈ 4”x4”
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We need the AO to resolve the CNSFRs and to separate the Seyfert active nuclei from the ring.

Mrk42 – Sy1
Ring size ≈ 2”x2”

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## The CNSF rings of Seyfert galaxies: Parts of the project

### 2- Kinematics:

We will use an instrumental configuration with:

- **relatively narrow spectral ranges**
  - $Z \approx 0.94 - 1.15$; $J \approx 1.15 - 1.33$;
  - $H \approx 1.49 - 1.80$; $K \approx 1.49 - 1.80$

- **high spectral resolution** ($R = 5000 - 6000$)
The CNSF rings of Seyfert galaxies: Parts of the project

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We will measure some particular features: \([\text{SIII}]\lambda9532\text{Å}, \text{Pa}, \text{Br}, \text{H}_2\) emission lines and the CO absorption lines to study the gas and stellar kinematics, respectively, and mapping the gas flows probably related with the AGNs.
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That's all folks.

Thanks.