On the perplexing kinematic properties of starforming regions in “hot spot” galaxies

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What's CIRCUMNUCLEAR?

Wofford, Leitherer & Chandar, 2011, ApJ, 727, 100

"In the context of disk galaxies, a nuclear or circumnuclear ring is a region of large gas surface density and enhanced star formation, located within 2 kpc of the galactic nucleus"

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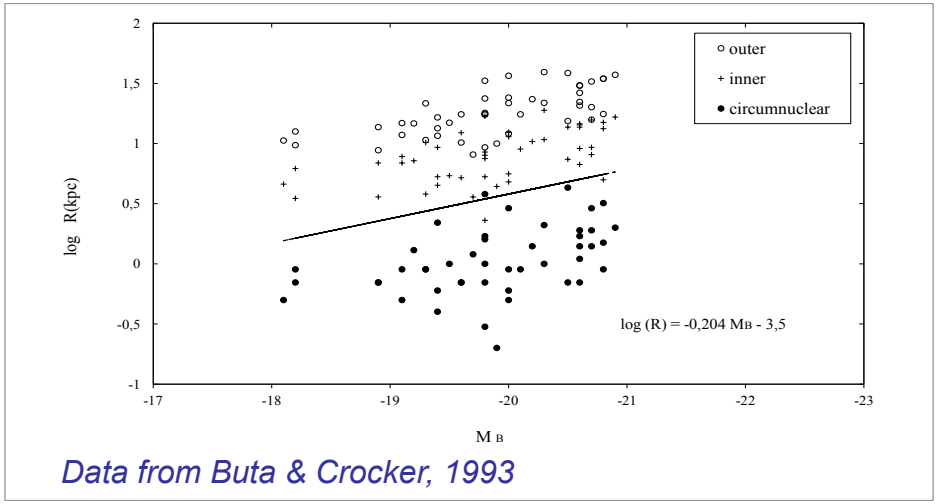
"Note that the term "starburst" does not have a general definition"

"We define a star-forming nuclear ring as a ring of intense star formation in the proximity of the nucleus of a galaxy".

Comeron et al. 2010, MNRAS, 402, 2462

How to define a circumnuclear ring

Mar Álvarez-Álvarez, 2015, MNRAS, 451, 3173



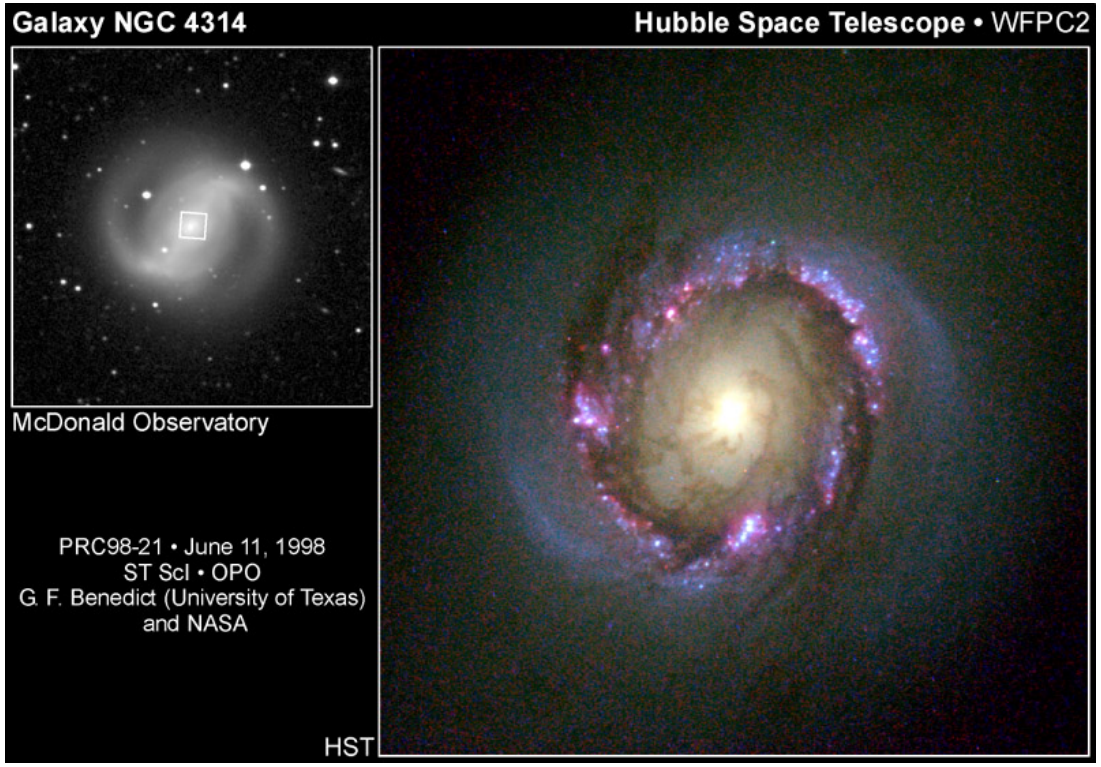
Data from Buta & Crocker, 1993

- The galactocentric distance of rings depend on the integrated luminosity of a given galaxy.
- It is possible to identify: nuclear, inner and outer rings.
- We have defined a “limiting radius” for each galaxy, which depends on its absolute magnitude, below which a ring is said to be nuclear.
- A star-forming region inside this galactocentric distance is classified as **CNSFR**.

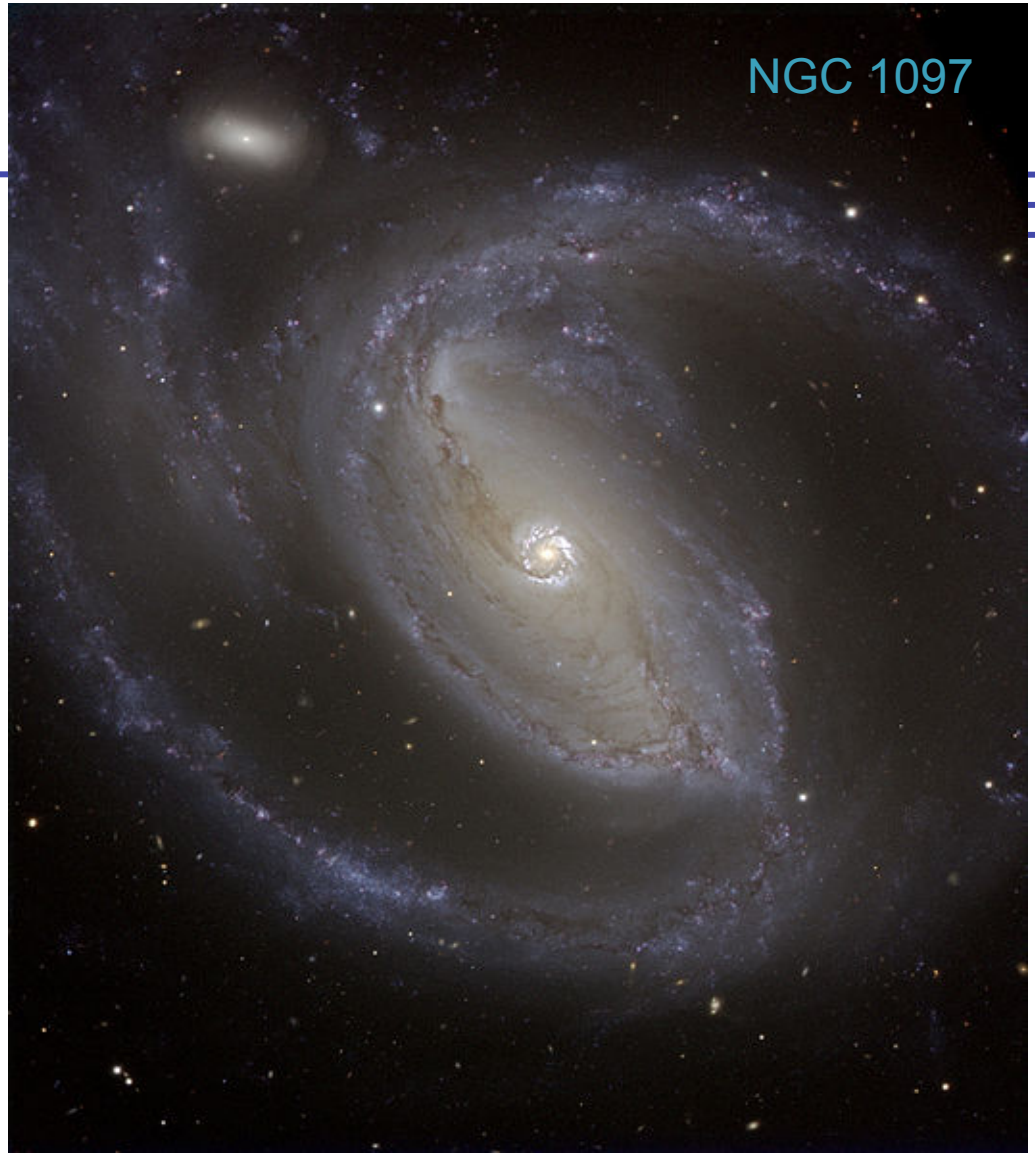
*'A **"circumnuclear starburst"** is a region composed of star condensations with individual masses ranging from a few ×10^4 to greater than 10^6 $M_\odot$, bright in the ultraviolet (UV) because they have recently emerged from their birth clouds (the nuclear galactic ring), and contain hot and massive O and/or B stars.'*

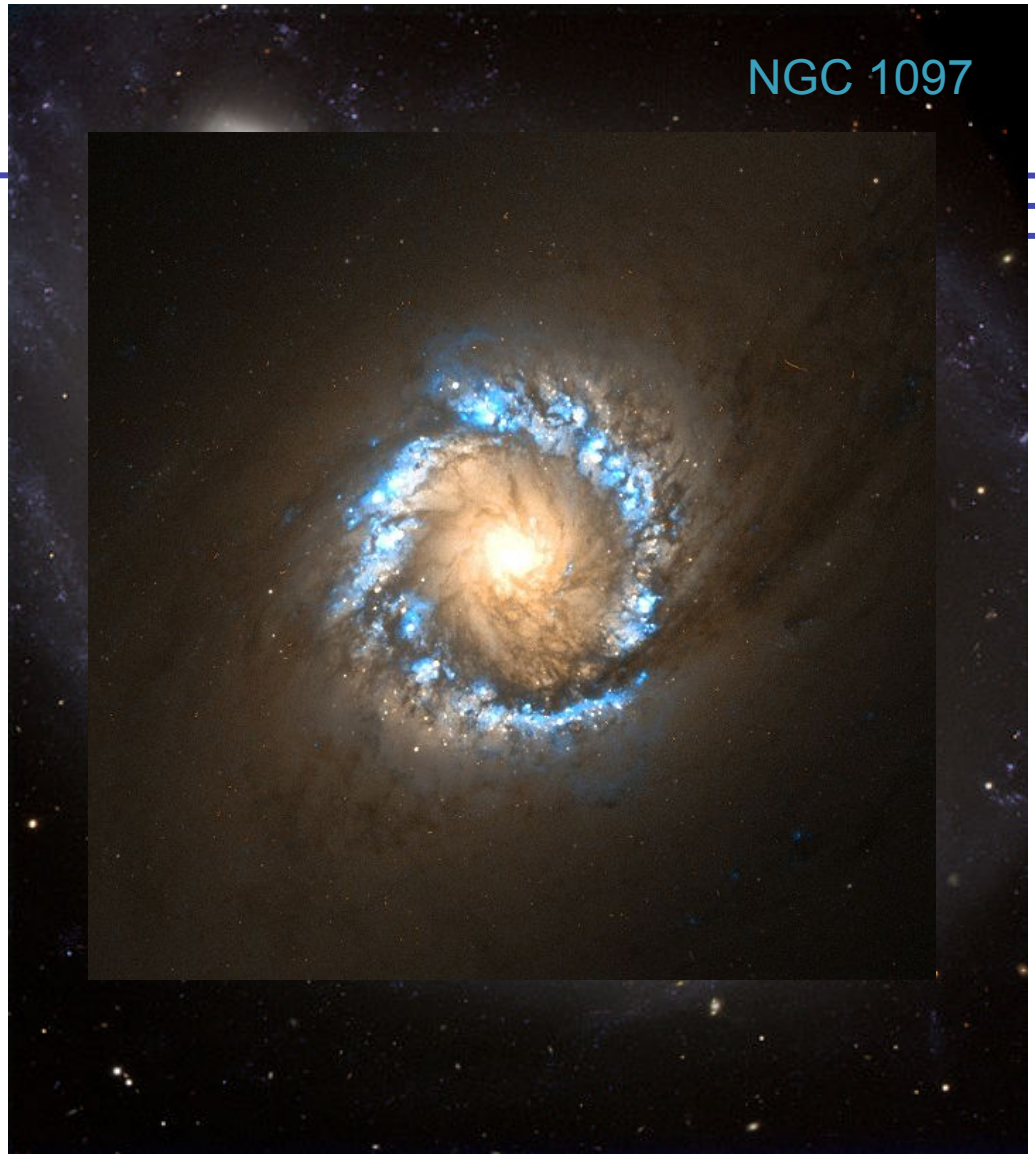
Wofford, Leitherer & Chandar, 2011, ApJ, 727, 100

Circumnuclear Star Forming Regions
"HOT SPOTS"



- Similar to luminous and large HII regions but more compact.
- They show higher peak surface brightness
- In many cases they contribute substantially to the emission of the entire nuclear region of the galaxy.


NGC 1097


NGC 1097

A "circumnuclear starburst" is a region composed of star condensations with individual masses ranging from a few ×10^4 to greater than 10^6 $M_\odot$, bright in the ultraviolet (UV) because they have recently emerged from their birth clouds (the nuclear galactic ring), and contain hot and massive O and/or B stars.

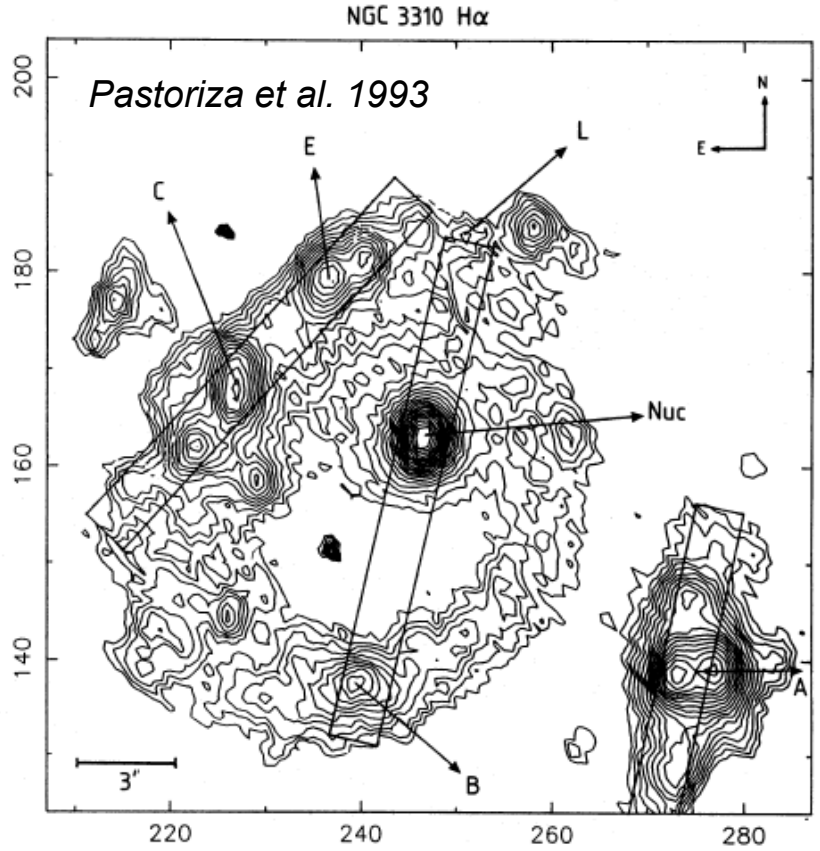
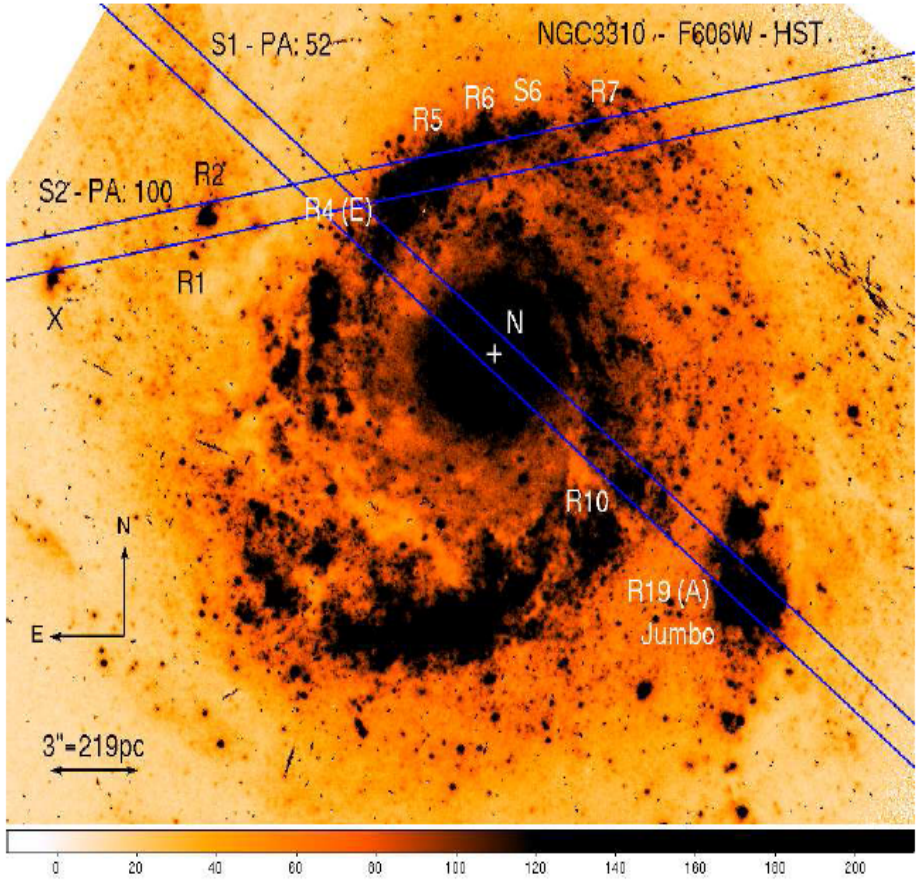


Figure 1. Hα image of NGC 3310 showing our selected slit positions. Nuc, A, B, C, E and L label the regions studied in the abundance analysis.



Hägele et al. 2010

Figure
analysi

the abundance

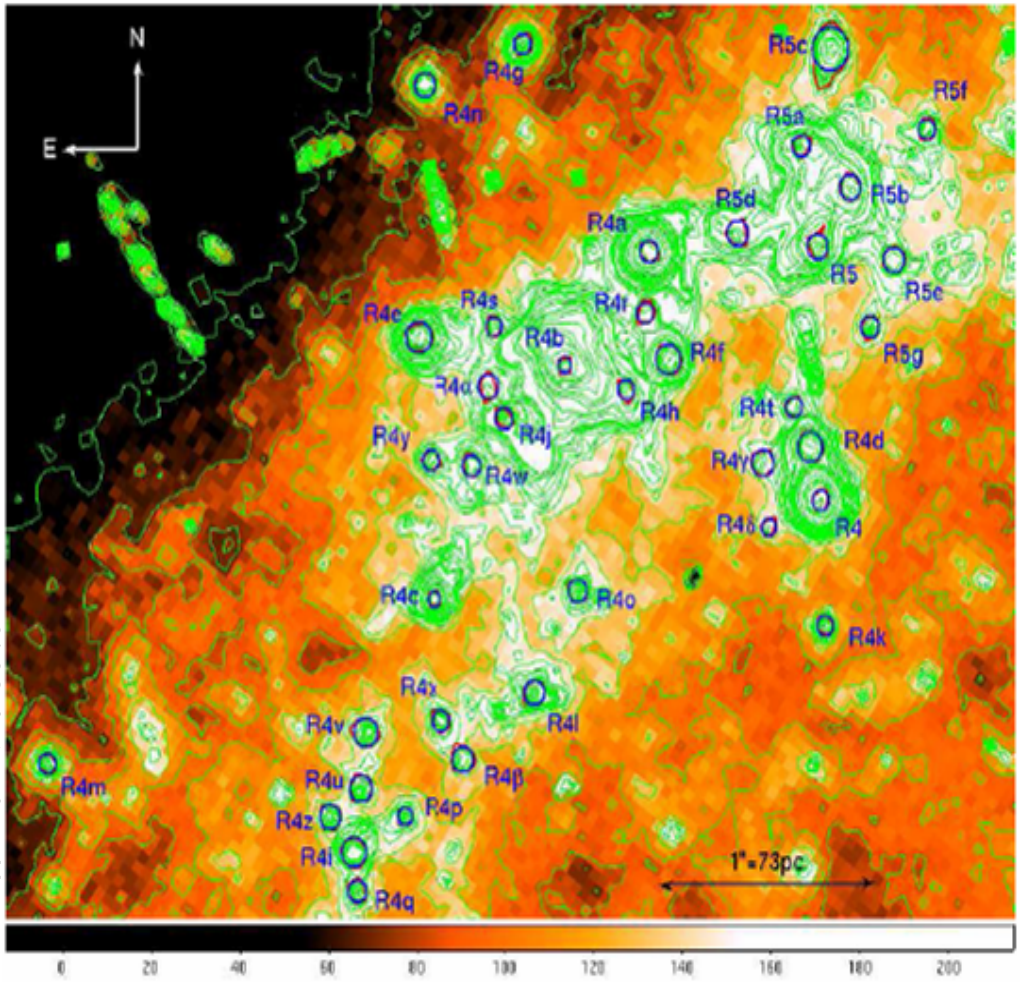


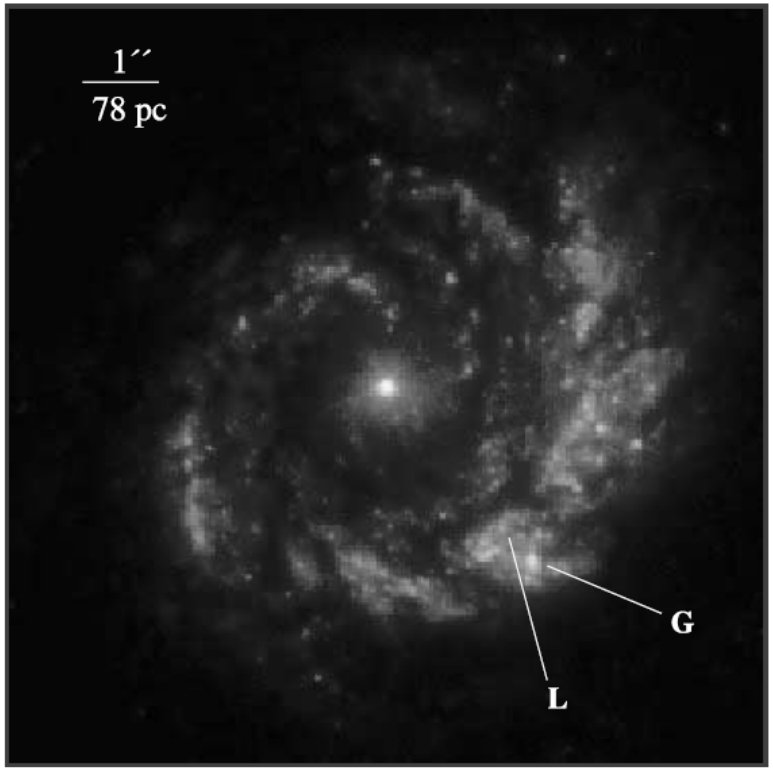
Figure
analysi

abundance

Why study CNSFR ? (some reasons …)

Wofford, Leitherer & Chandar, 2011, ApJ, 727, 100, and references therein

- Determining the ages, masses, and stellar IMFs of individual star clusters within circumnuclear starbursts is important for understanding the relations between:
  1. galaxy dynamics and interactions and the origin of circumnuclear star clusters
  2. massive star feedback and the fueling of AGN
  3. young massive star clusters and globular clusters



STIS UV image of the nuclear region of NGC 4303 (Colina el al. 2002, ApJ 579, 545)

- Rings or pseudo-rings of SFR are detected in the circumnuclear environments (inside ~ 300 pc) of 30 – 50 % of Seyfert 2 galaxies (*Cid-Fernandes et al. 2001, ApJ 558,81*)
- Even in the presence of an AGN, massive stars in CNSFR dominate the UV light (*Heckman et al. 1997, ApJ 482, 114*)

Why study CNSFR ? (some more reasons …)

Wofford, Leitherer & Chandar, 2011, ApJ, 727, 100, and references therein

- Circumnuclear starbursts in barred galaxies are perhaps the most numerous class of nearby starburst.
- Their detailed study can provide a steppingstone for studies of starbursts at higher redshifts.
- Local circumnuclear starbursts show star formation rate densities, UV colors, and spectral morphologies, similar to those of high-redshift Lyman break.

Grupo de Astrofísica
Universidad Autónoma de Madrid

NGC 3310

Smith et al. 1996 ApJ, 473L, 21

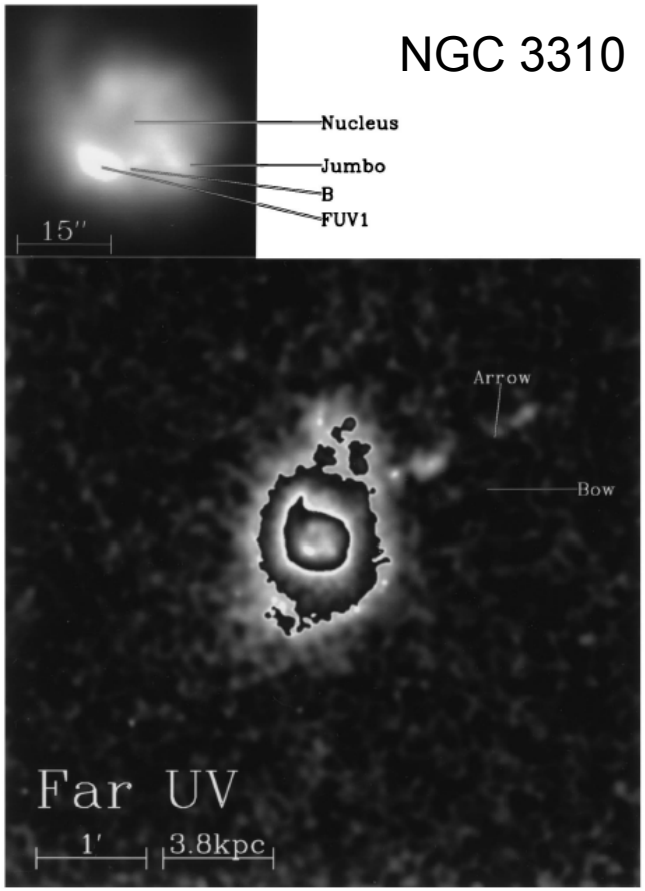


FIG. 2.—NGC 3310: far-ultraviolet (FUV). This image, obtained by the Ultraviolet Imaging Telescope, is the first ~arcsecond resolution FUV image of NGC 3310. The image is displayed as in Fig. 1. The circumnuclear starburst ring dominates the FUV morphology. The disk of NGC 3310 and the arrow are also sources of FUV emission. The semistellar nucleus and the bow are not detected in the FUV.

SMITH et al. (see 473, L22)

The starburst "ring" is the strongest organized source of FUV emission in NGC 3310; 30% of the total observed FUV emission is produced within a radius of 10". At redshifts of z ~ 2–3, this structure would be confined to a region 0.2" in diameter for Ω=1 and would appear pointlike in low-resolution observations. In the absence of diagnostic spectroscopy, a high-redshift NGC 3310–like object consequently could be mistaken for an active galactic nucleus (AGN).

Why study CNSFR ? (yet more reasons …)

- CNSFR in early type galaxies are expected to be of high metallicity, as corresponds to their position near the galactic bulge.

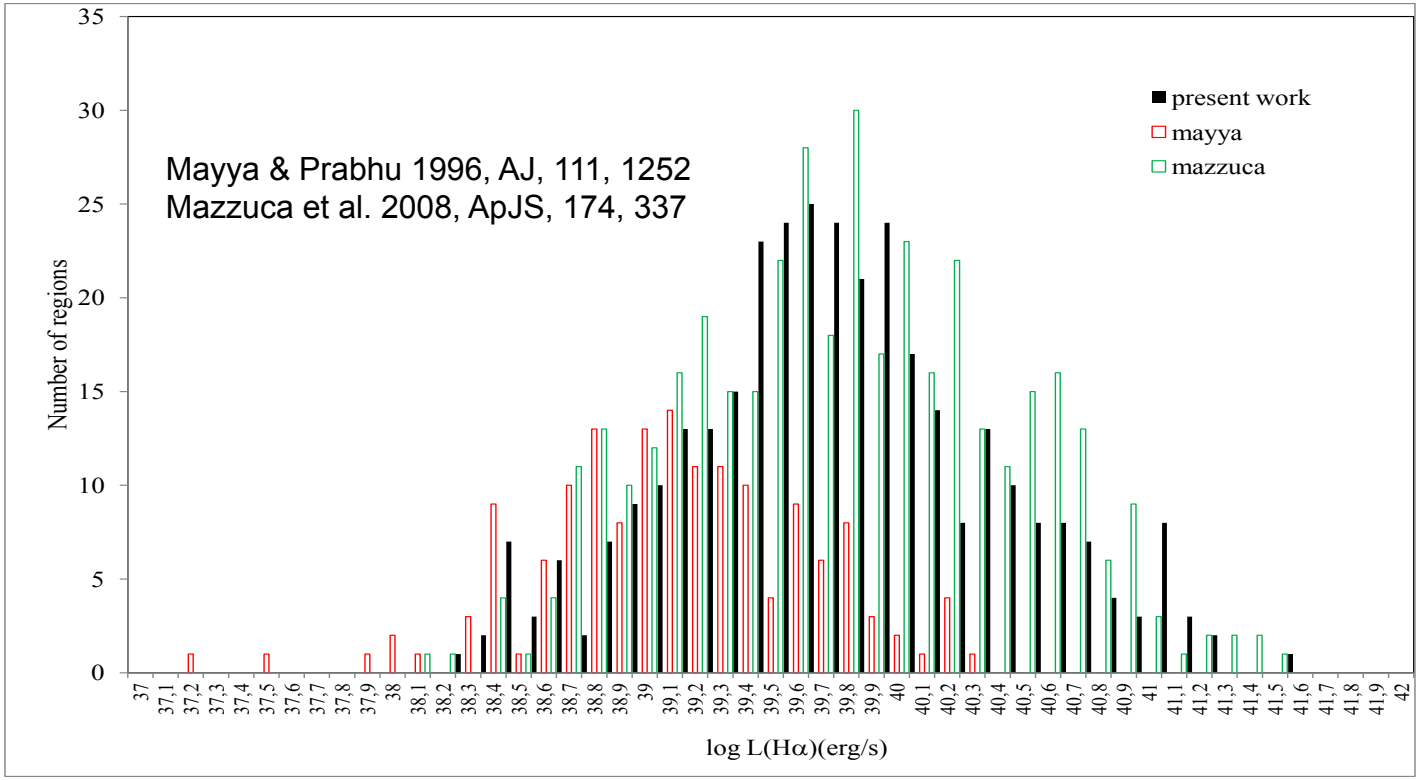
- They give us an opportunity to know the metal abundances of the central regions of galaxies (even those with an AGN) which have a high weight in the determination of metallicity gradients.

- They are natural laboratories to study how star formation proceeds in high metallicity environments.

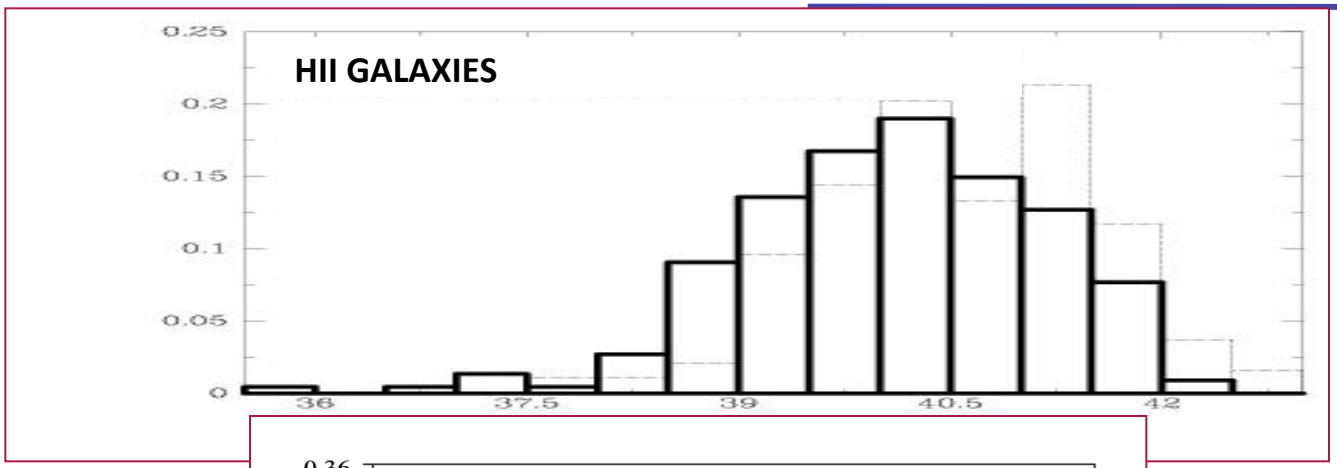
How Luminous are CNSFRs ?

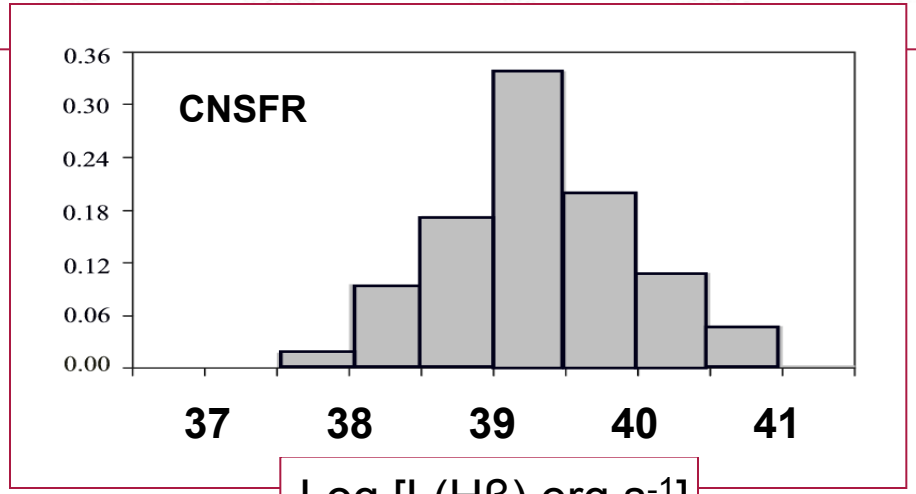
Mar Álvarez-Álvarez, 2015, MNRAS, 451, 3173

Hα luminosity compared to disk HII regions



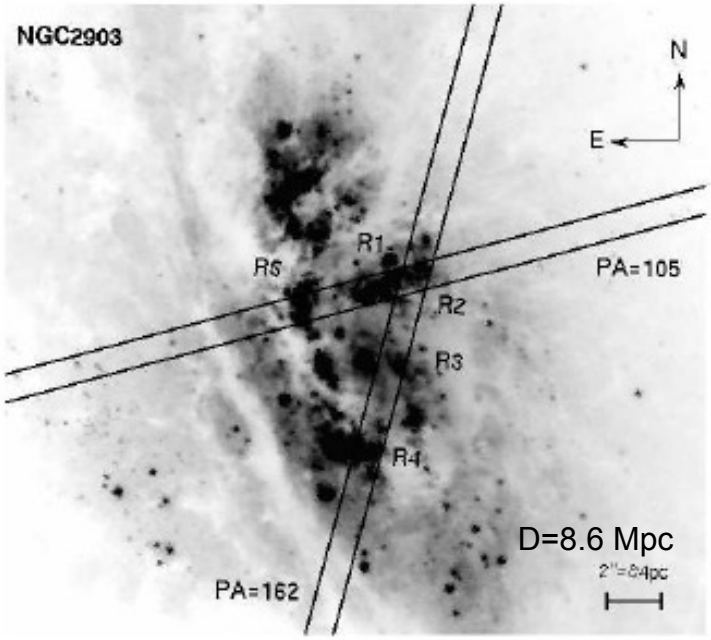
How luminous are CNSFRS ?

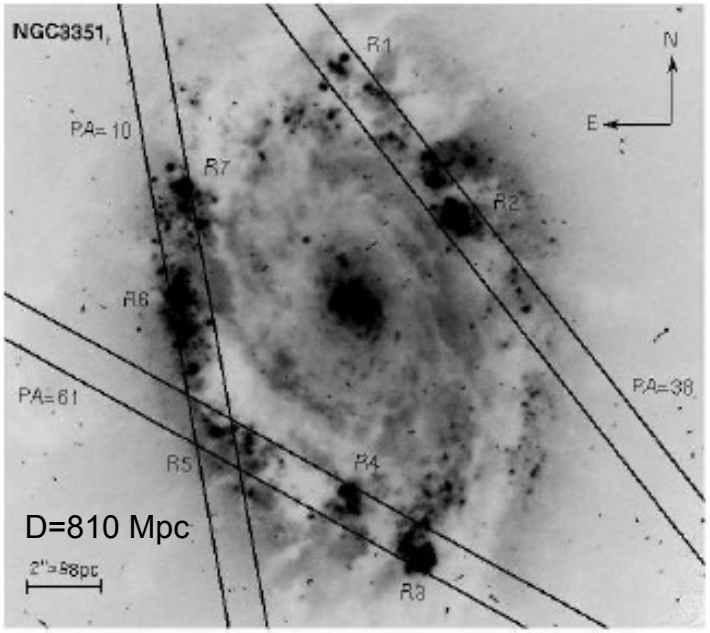


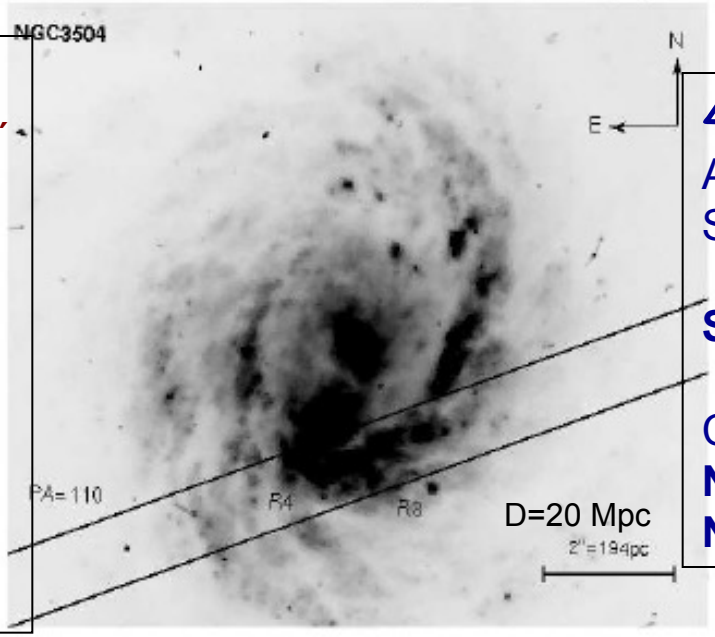


Hoyos & Díaz (2006)

Álvarez-Álvarez PhD Thesis (2002)







4.2 m WHT + ISIS

Average seeing ≈ 1.2 ´´
Slit width 1´´.5

Spectral resolutions:
0.4 Å/pix blue
0.8 Å/pix red

CNSFR in four galaxies:
NGC 2903, NGC 3351, NGC 3310, NGC 1068

4.2 m WHT + ISIS

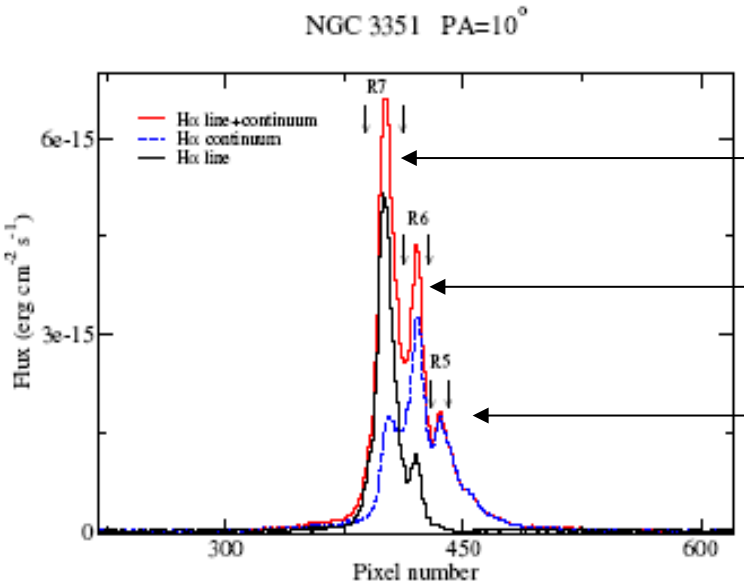
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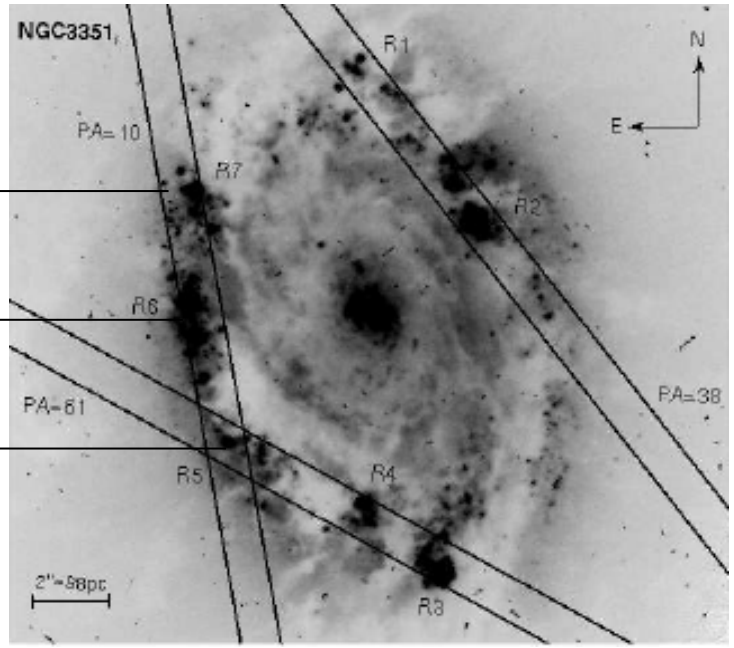
Spectral resolution ≈ 2 Å

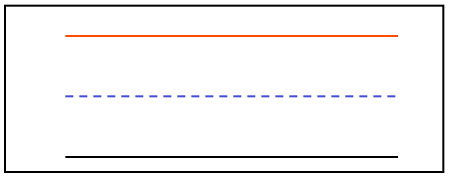
CNSFR in three galaxies:
NGC 2903, NGC 3351, NGC 3504

Figure 1. Observed CNSFR in each of the galaxies. The different slit positions are superimposed on images taken from the HST archive and obtained with the WFPC2 camera through the F606W filter. The position angles of every slit position are indicated.

Line and continuum emission

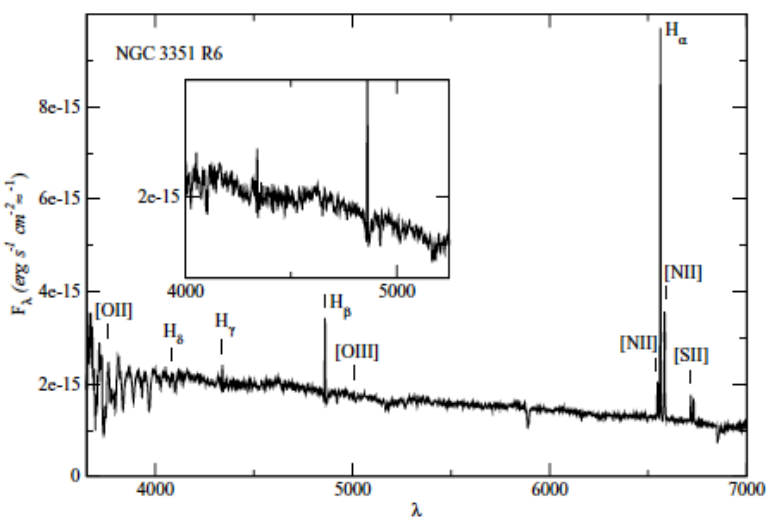


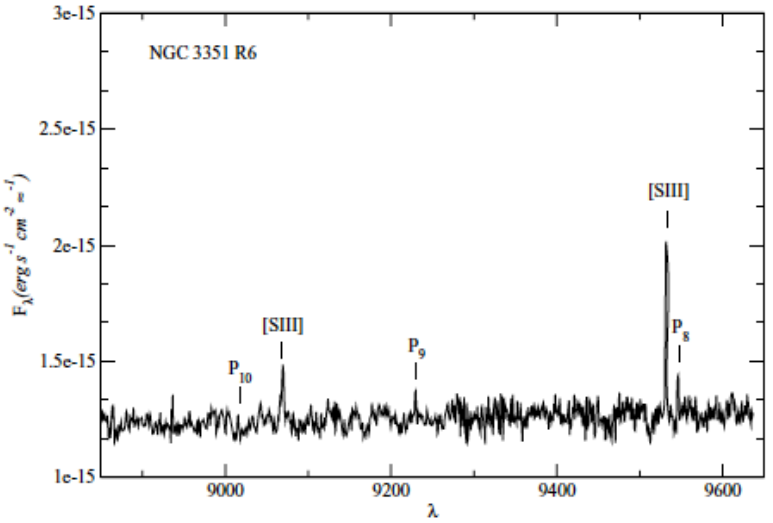




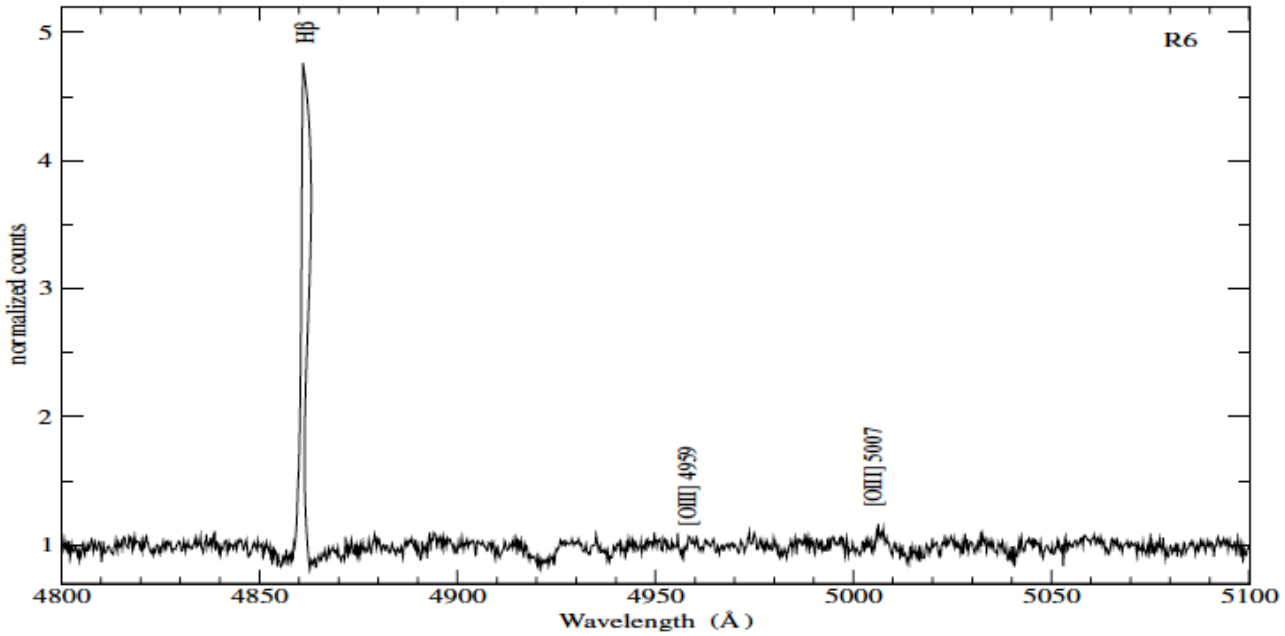
Hα line + continuum emission
Continuum emission adjacent to Hα
Continuum subtracted Hα emission

The effects of metallicity in gaseous emission lines : LRS

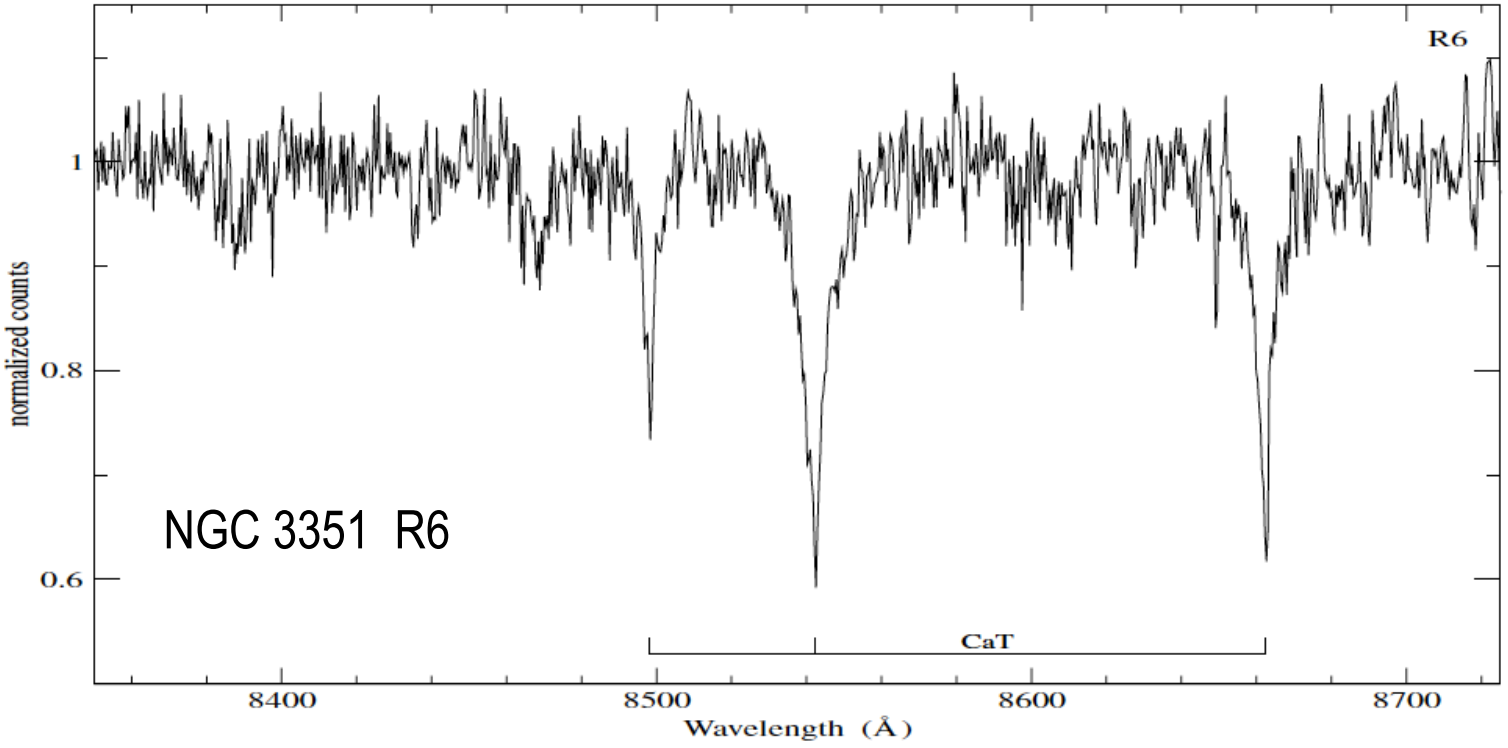




The effects of metallicity in gaseous emission lines: HRS



Stellar velocity dispersion measurements



Dynamical Masses

- Masses of CNSFR: $4.9 \times 10^6 - 4.3 \times 10^7\ M_\odot$
- Masses of individual clusters: $1.8 \times 10^6 - 8.7 \times 10^6\ M_\odot$
- Masses of ionizing clusters from Hα emission: $4.1 \times 10^5 - 2.4 \times 10^6\ M_\odot$

- Composite stellar populations. The **youngest** one dominates the UV and is responsible for the ionization, but contains only **10 % of the total mass**. ⟹ Low equivalent widths of emission lines

The emission line profiles

NGC 3351

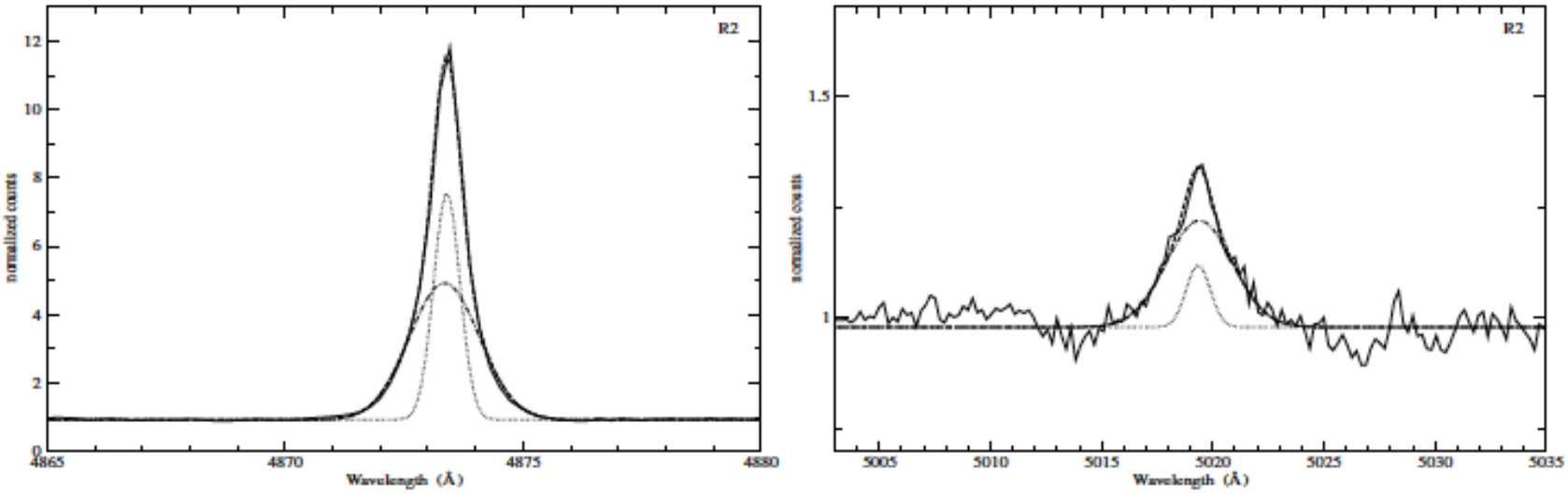
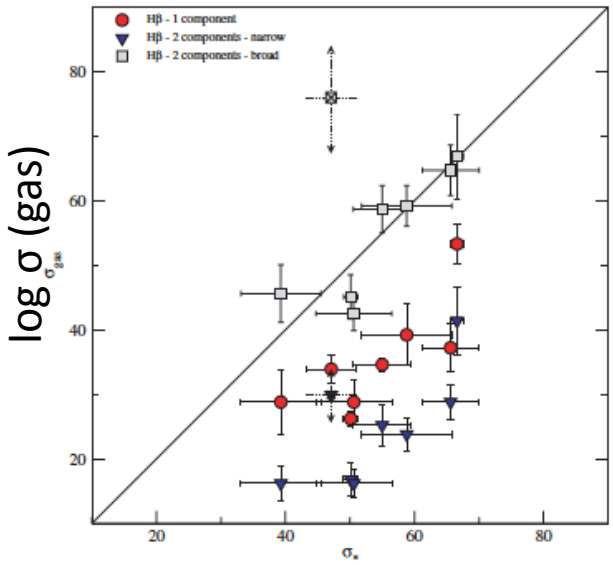


Figure 9. Sections of the normalized spectrum of R2. The left-hand panel shows from 4865 to 4880 Å containing Hβ and the right-hand panel shows from 5003 to 5035 Å containing the [O III]λ5007 Å emission line. For both we have superposed the fits from the NGAUSSFIT task in IRAF; the dashed–dotted line is the broad component, the dotted line is the narrow component and the dashed line is the sum of both.

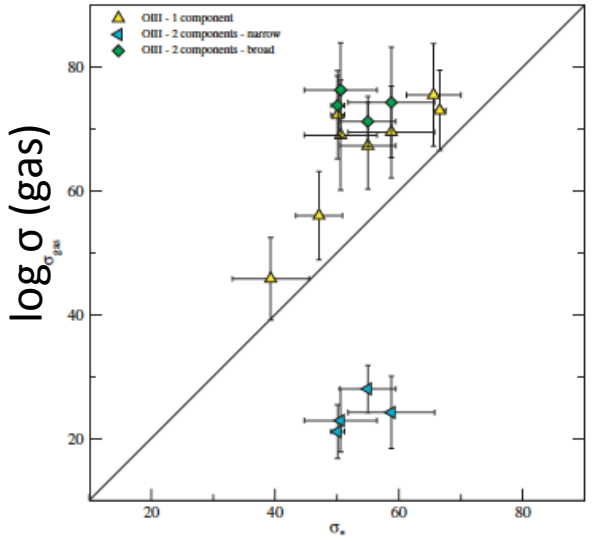
Stars and gas velocity dispersions

NGC 3351

Hβ



[OIII]



The emission line profiles

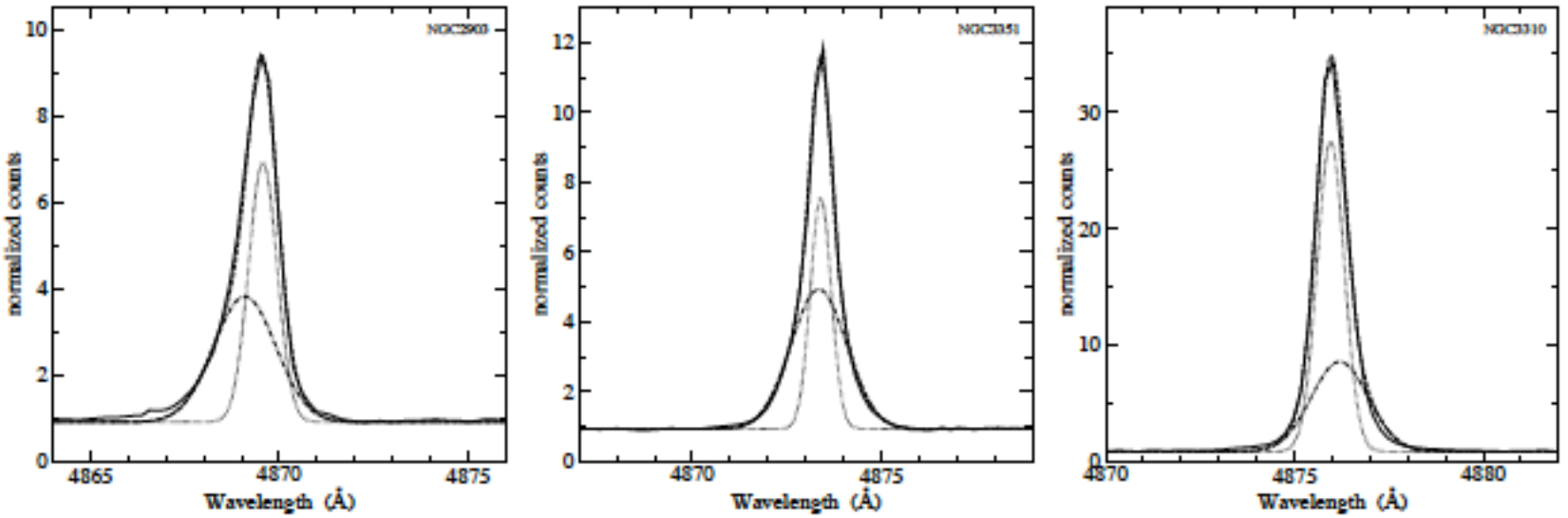


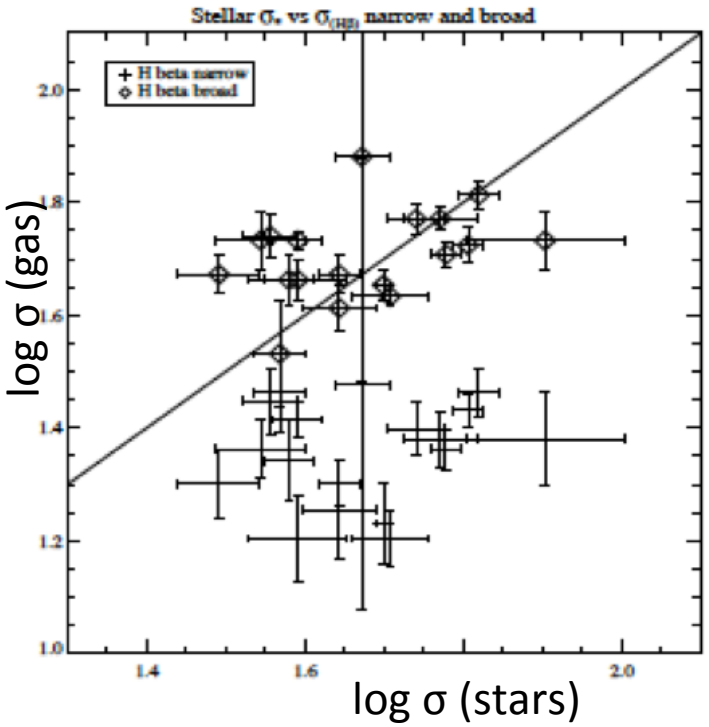
Figure 1. Optimal Gaussian fits to the Hβ line for observed regions in the galaxies: NGC 2903, NGC 3351 y NGC 3310. The two different components labelled "wide" and "narrow" are shown.

Region	σ_*	σ_g	Hβ σ_n	Hβ σ_b	[OIII] σ_g	[OIII] σ_n	[OIII] σ_b	M_*
				NGC 2903				
R1+R2	60±3	34±2	23±2	51±3	73 ± 8	26 ± 8	93 ± 9	1816±48
R1+R2	64±3	35±2	27±2	53±4	71 ± 9	27 ± 7	95 ± 10	2054±45
R4	44±3	32±2	20±2	47±4	76 ± 10	35 ± 9	89 ± 8	853±28
R7	37±3	32±4	29±5	34±8	59 ± 10	17 ± 5	67 ± 8	642±26
				NGC 3310				
R1+R2	80:	33±4	24±5	54±7	31 ± 4	22 ± 5	50 ± 4	911:
R4	36±3	34±3	28±4	55±5	32 ± 3	26 ± 3	52 ± 4	886 ±30
R4+R5	38±3	27±4	22±4	46±5	22 ± 3	18 ± 3	40 ± 2	1317 ±41
R6	35±5	30±3	23±3	54±7	28 ± 3	21 ± 3	56 ± 3	397 ±33
S6	31±4	27±3	20±3	47±4	26 ± 3	19 ± 3	47 ± 3	210 ±17
R7	44±5	21±5	18±4	41±4	17 ± 4	14 ± 3	36 ± 3	1413±60
R10	39±3	38±3	26±2	54±2	40 ± 3	26 ± 3	59 ± 4	588 ±28
J	—	34±2	25±2	61±3	30 ± 2	22 ± 2	57 ± 3	—
				NGC 3351				
R2	50±1	26±1	17±3	45±3	72 ± 7	21 ± 4	74 ± 5	129±6
R2	51±6	29±3	16±2	43±2	69 ± 9	23 ± 5	76 ± 8	131±23
R3	55±5	35±1	25±3	59±4	67 ± 7	28 ± 4	71 ± 4	417±31
R3	59±7	39±5	24±3	59±3	70 ± 7	24 ± 6	74 ± 9	477±47
R4	66±4	37±4	29±3	65±4	76 ± 8	—	—	87±12
R5	47±4	34±2	30:	76:	56 ± 7	—	—	49±8
R6	39±6	29±6	16±3	46±4	46 ± 7	—	—	434±39

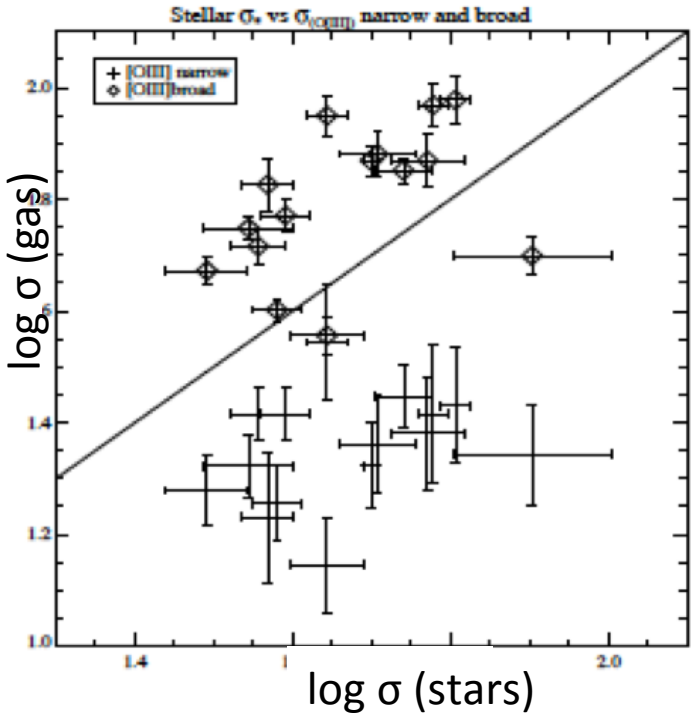
Note: velocity dispersions in km s^{-1}, masses in 10^5 $M_\odot$.

log σ (gas) vs σ (stars)

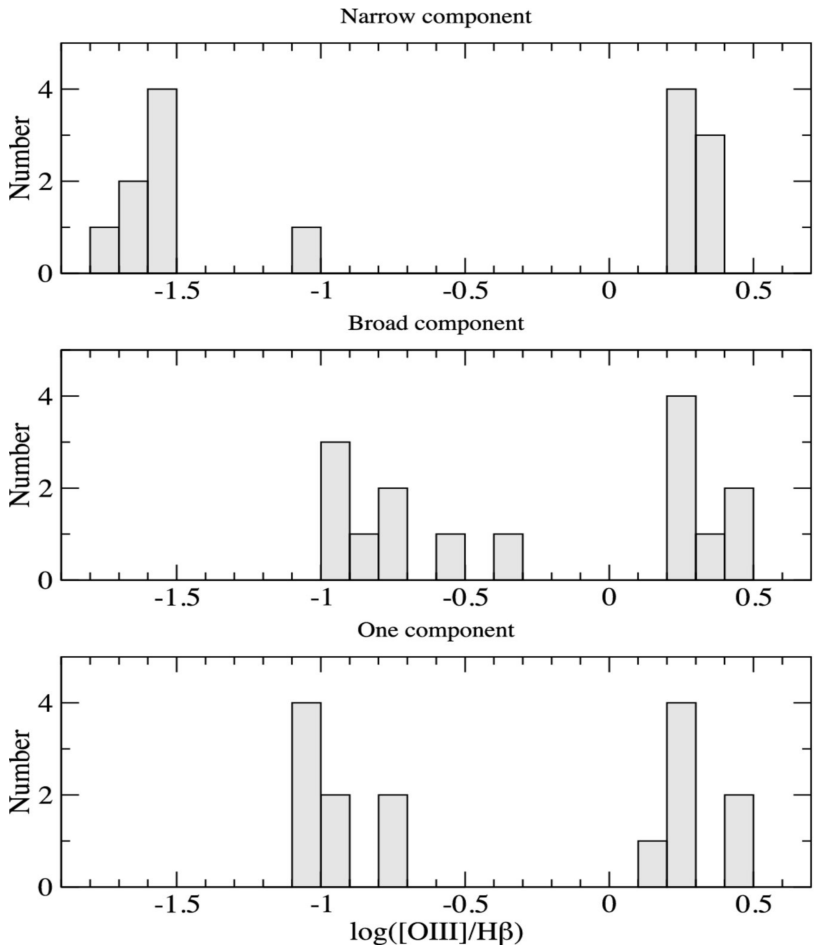
Hβ



[OIII]



The [OIII]/Hβ ratio



→ Maybe associated with a gaseous disk 😏

→ Most probably associated with the CNSFR 🙂

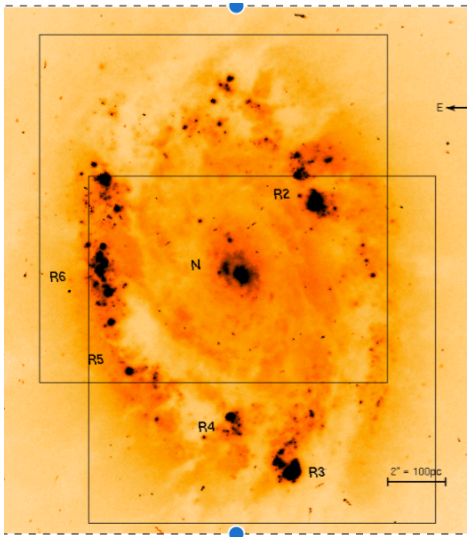
→ What we measure: probably none of the two 😟

Conclusions about kinematics

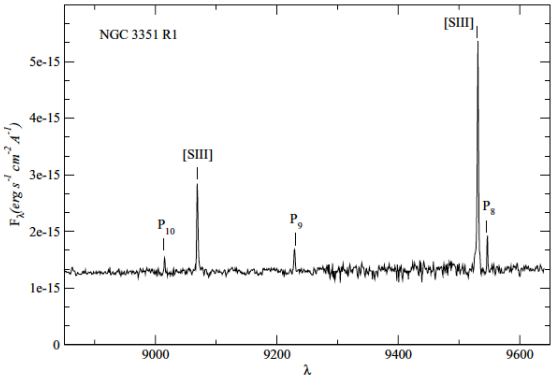
- Stellar velocity dispersions derived from CaT lines: 39 – 67 Km/s
- **Two kinematical components in the emission lines:**
  - **broad ~ 60 Km/s, that [OIII] and is similar to the $\sigma_{\star}$**
  - **Narrow ~ 25 Km/s, that dominates Hβ**
- We suggest a possible scenario involving an inner gaseous disc responsible for the narrow component of the emission lines.
- Properties of the ionized gas derived from global line ratios obtained with low-resolution spectroscopy in star-forming regions in the central regions of early-type galaxies might be in doubt.
- Given the ubiquity of these star-forming systems, **ionized gas analyses should be done preferably from high-dispersion spectra with high spatial resolution.**

A project for MEGARA (LCB)?

- Average size of the CNSFR in from Hα images is between 0.5 and 1 arcsec. The central circumnuclear region is about 12 × 16 arcsec^2. Maybe a mosaic of two positions will be needed.
- The resolution maybe at the limit ~25 km/sec.
- We would use the [SIII] lines which are stronger than those of [OIII]. With MR-Z we would get the [SIII] and Paschen lines (P10, P9).
- And twe need the CaT lines ... H-RI seems to be the only possibility.



PMAS 12x12 arcsec^2



ISIS low res

Test data from PMAS Lens Array

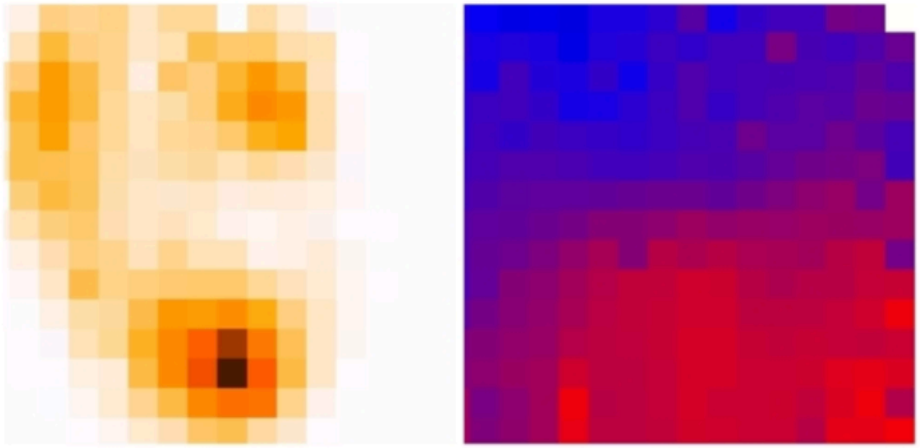


Figure 3: Left: Hα map of the CN region of NGC 3351 obtained in March 20 2007 (proposal F07-3.5-043) with the proposed PMAS configuration and a single 1200 s exposure centered at 6551 Å . The main CNSFR can be identified. Right: radial velocity map derived from the data showing the inner galaxy rotation. North is to the top and East is to the left.