Universidad de Granada

Bars as laboratories to link SF and galaxy dynamics

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http://www.ugr.es/~astrofisica/index.html

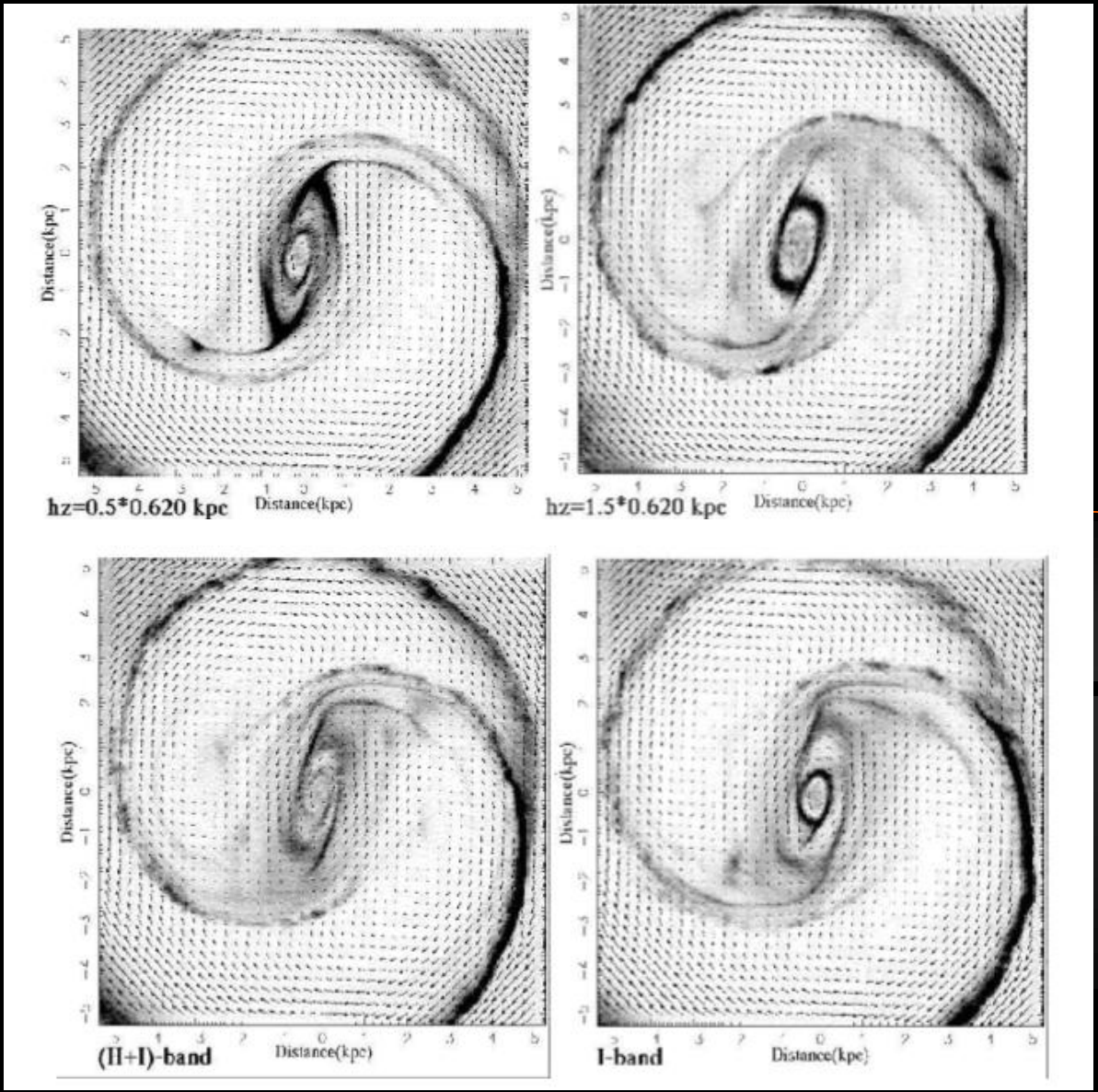
Bars: a brief introduction

About 30% of galaxies show strong bars, and about 60% show bars in the NIR (e.g. Jogee et al 2007, Menéndez-Delmestre et al 2007]

About 32% S0s, 55% early-type, 52% late types [Méndez-Abreu et al. 2008]

Scale relations with the disk

Bars: a brief introduction



The mass distribution determine the position of shock and the gas flow

Pérez et al. 2004

SF in bars: favoured or inhibited ?

- The relatively little amount of studies focused on SF in bar environments *(Phillips 1996; Martin & Friedli 1997, 1999; Sheth et al. 2000,2002; Verley et al. 2007, Rozas et al. 1999)*

- This has lead to ambiguous and/or contradictory statements:

"…These striking patterns [of SF knots] often lead to erroneous generalizations in the literature, for example that "star formation is triggered in bars" or just as often that "star formation is suppressed in bars"

Kennicutt 1994, 'Star Formation in barred galaxies'

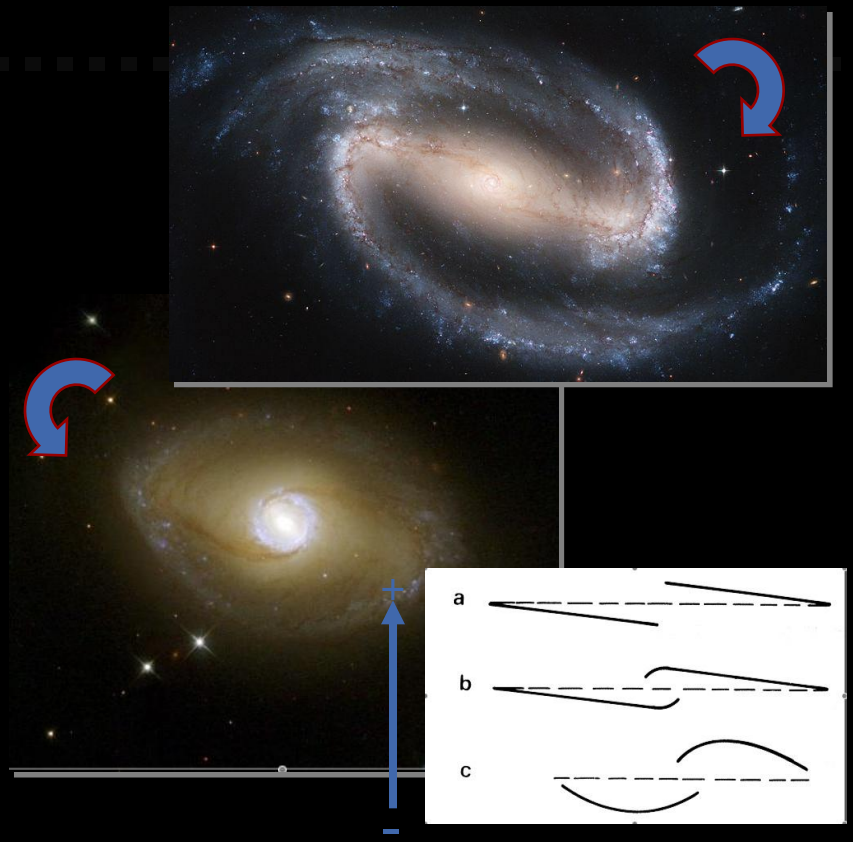
Observational studies generally focused on global morphological and physical properties of HII regions in bars ***without a direct relation with dynamical bar parameters***.

Where are stars expected to form ? (I)

Presence of SF in bars ⟷ ? Bar strength

- Fluid dynamic simulations predictions:

  - Bar dust lanes form in the leading side of the bar (assuming trailing arms)
  - Shape of bar dust lanes is correlated with bar strength *(Athanassoula 1992)*
  - Highest density loci (bar dust lanes) are also the loci of *high shear and shocks in strong bars*



From Athanassoula 1992

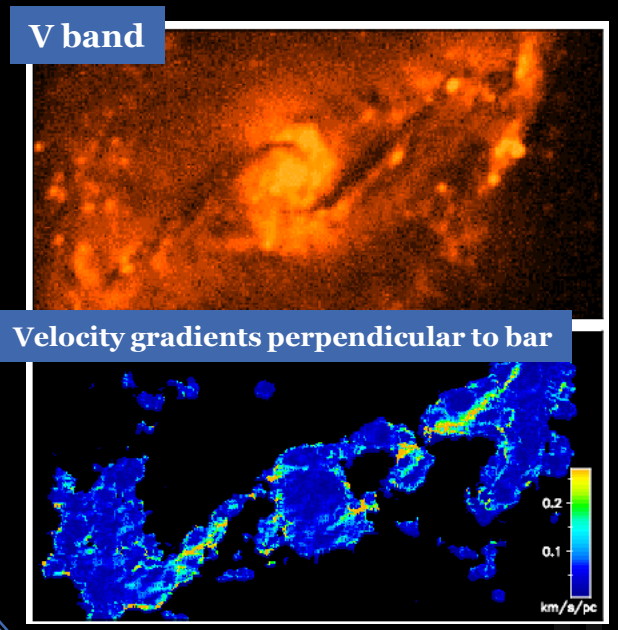
"SF is not expected to happen along the bar in strong bars"

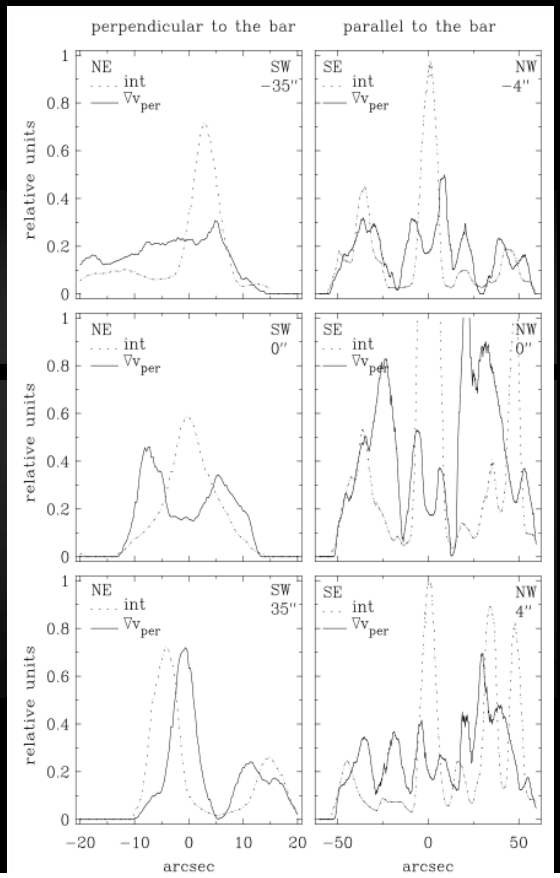
Where are stars expected to form ? (II)

Observational and numerical evidence that strong shear inhibit star formation. *(e.g. Reynaud & Downes 1998; Zurita et al. 2004; Tubbs 1982)*

..but ...

Even if avoiding dust lanes, there is **evidence for the presence of SF along (certain) strong bars** (not just in centres and bar ends).



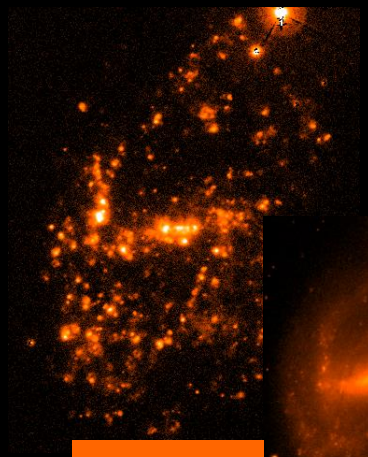


Anti-correlation between loci of maximum velocity gradients perpendicular to the bar and the HII regions

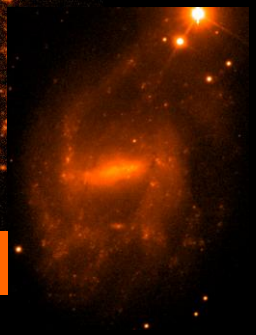
What determines the presence of SF in certain bars and their absence in others?

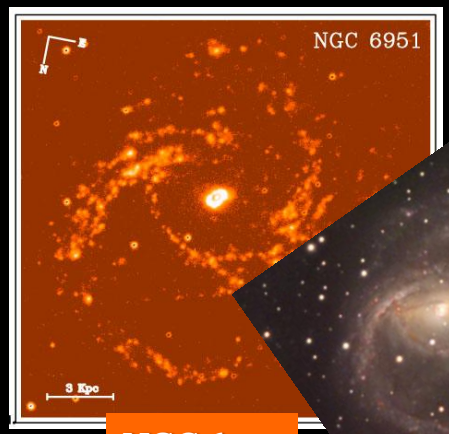
Where do stars form?

Which parameters determine SF in bars?

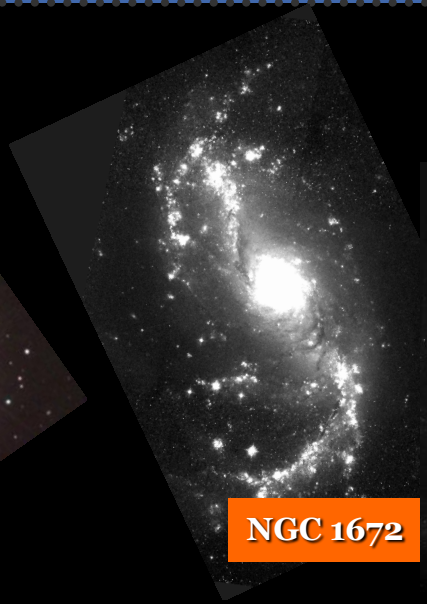


NGC 7741





NGC 6951



NGC 1672

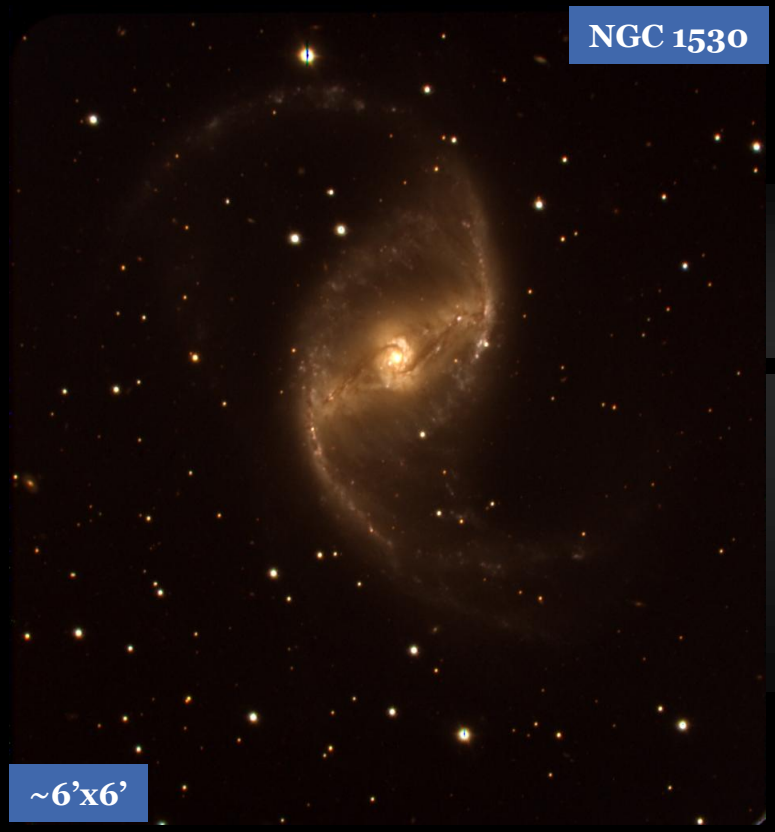
The project: understanding SF in bars

Aim: Study properties of the bar and its regions of recent massive star formation

Elucidate conditions under which HII region form and their spatial relation to the principal dynamical features of the bar

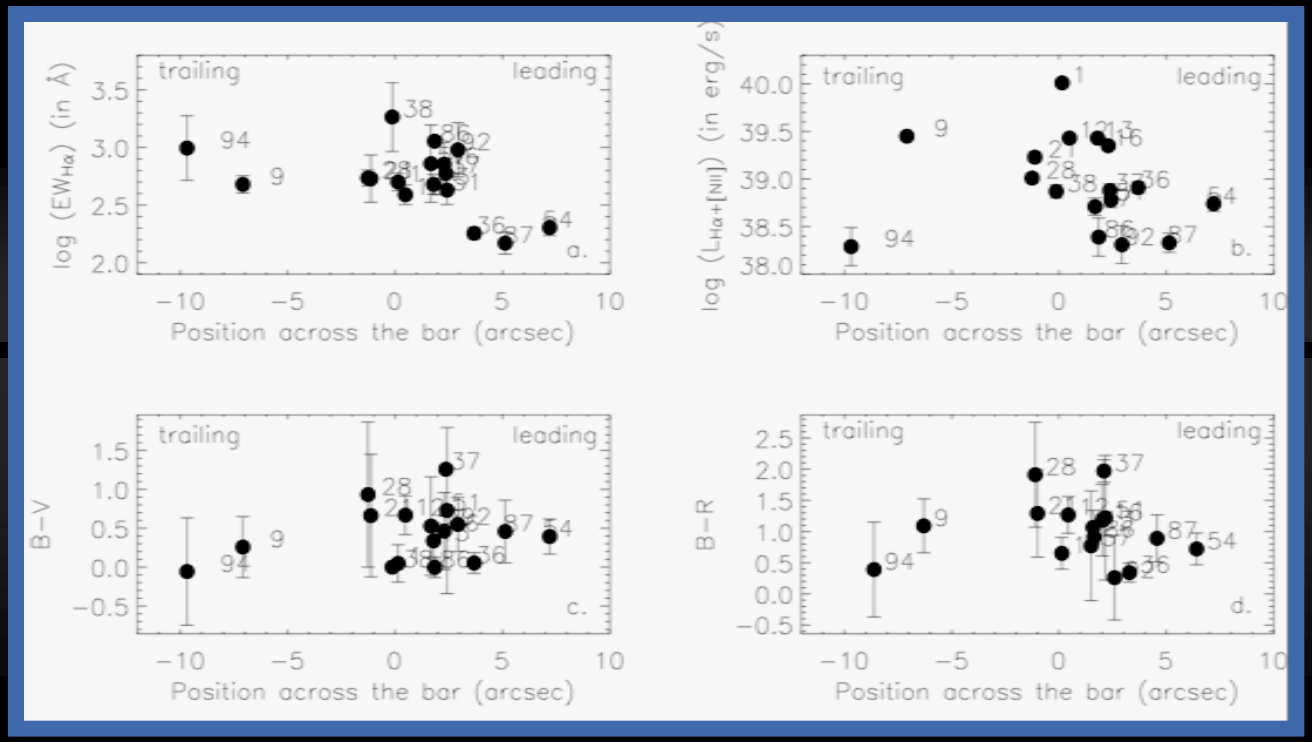
1. *NGC 1530*

- One of the strongest bars ever observed (bar strength 0.73, *Block et al. 2004*)
- Nearby (37 Mpc) and isolated *(Verley et al. 2007)*
- It presents current star formation along its bar
- 2D ionized gas kinematics information is available (from TAURUS II @ the 4.2m WHT)



Bar major axis length ~24 kpc

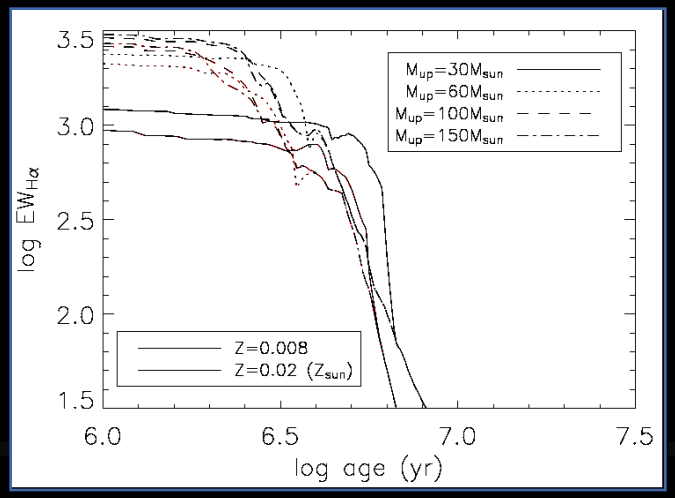
The NGC 1530 bar: HII region properties



The HII regions located further away from the bar dust lane, on its leading side, have lower $EW_{H\alpha}$ (by factor ~4-5)

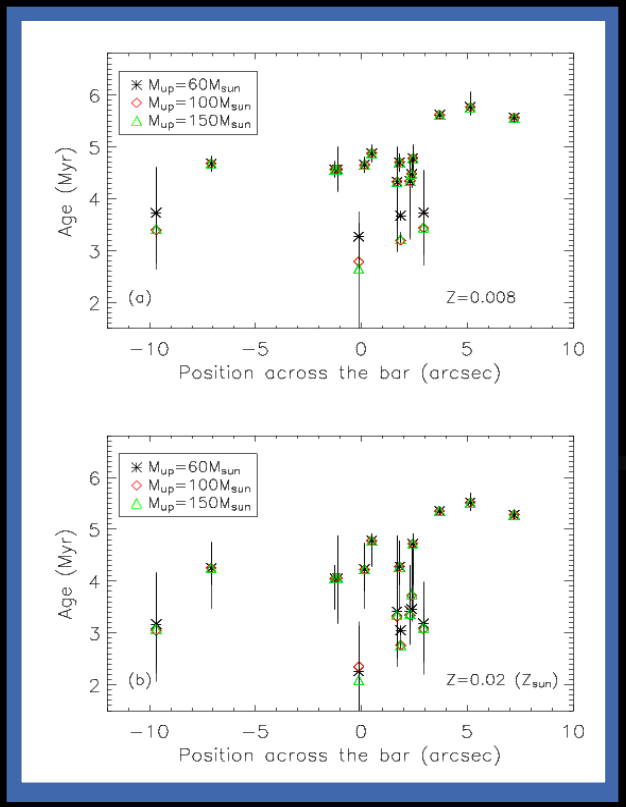
Age difference across the bar

$EW_{H\alpha}$ → ratio of ionizing to continuum photons emitted by the stellar cluster → depends on the **IMF**, **metallicity** and **evolutionary status**



(+ $EW_{H\alpha}$ vs. distance)

Starburst 99 (v5.1)
Leitherer et al. 1999

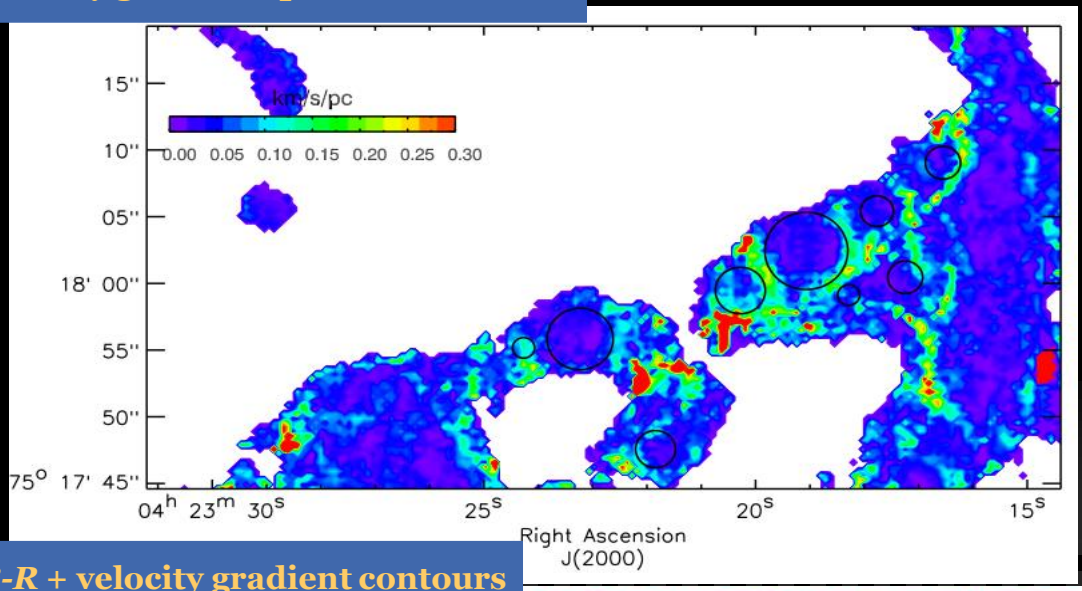


- *HII regions located further away from the bar dust lane on the leading side are (at least) on average **~1.4-1.7 Myr** older than the rest.*
- Allowing for a conservative average loss fraction of Lyc photons of 50%, this difference in age increases up to **~1.5 - 2.5 Myr**

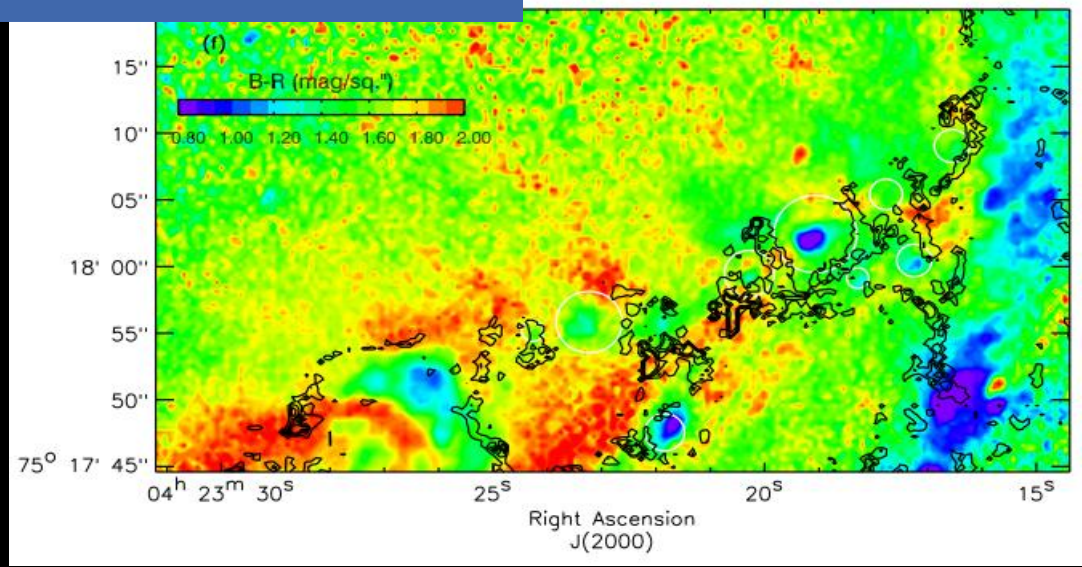
In addition to the **age difference** between regions of the trailing of leading side of the bar dust lane, we find

- presence of dust spurs in the trailing side of the bar dust lane
- good spatial agreement between location spurs and velocity gradients in the direction of the bar major axis

Velocity gradients parallel to the bar



***B-R* + velocity gradient contours**



Are these gradients tracing flow of gas along the spurs towards the main bar dust lane?

- Relative velocity gas-bar is lower in those 'spurs' (high velocity gradient loci) by ~25-50 km/s (which favours cloud survival).
- Contribution from outflows from individual HII regions can not be discarded (*Relaño et al. 2005*)

Zurita & Pérez, 2008

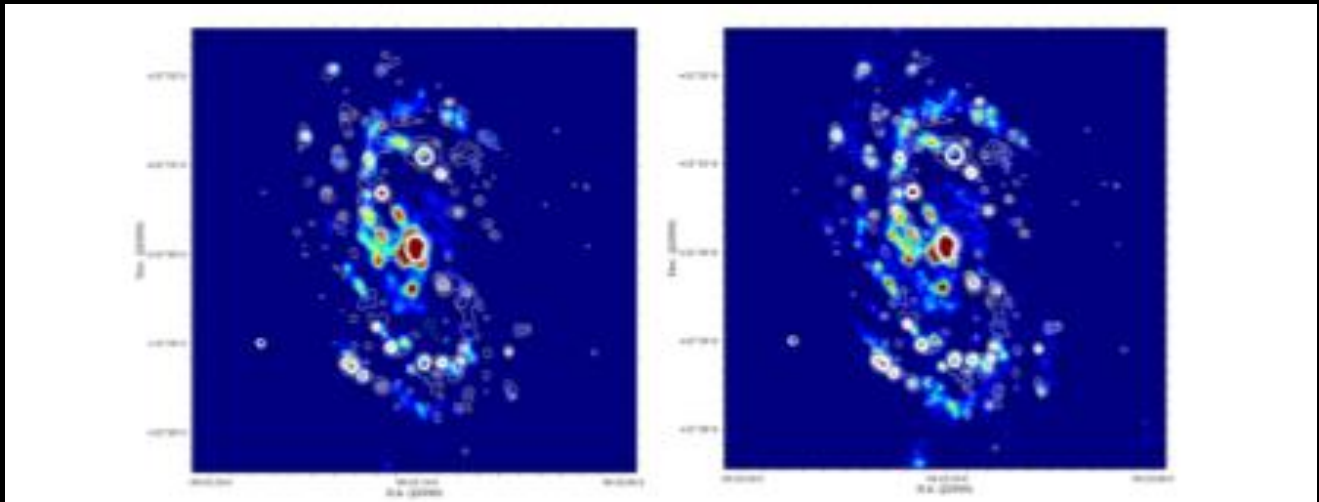
The project: understanding SF in bars

1. *NGC 2903*

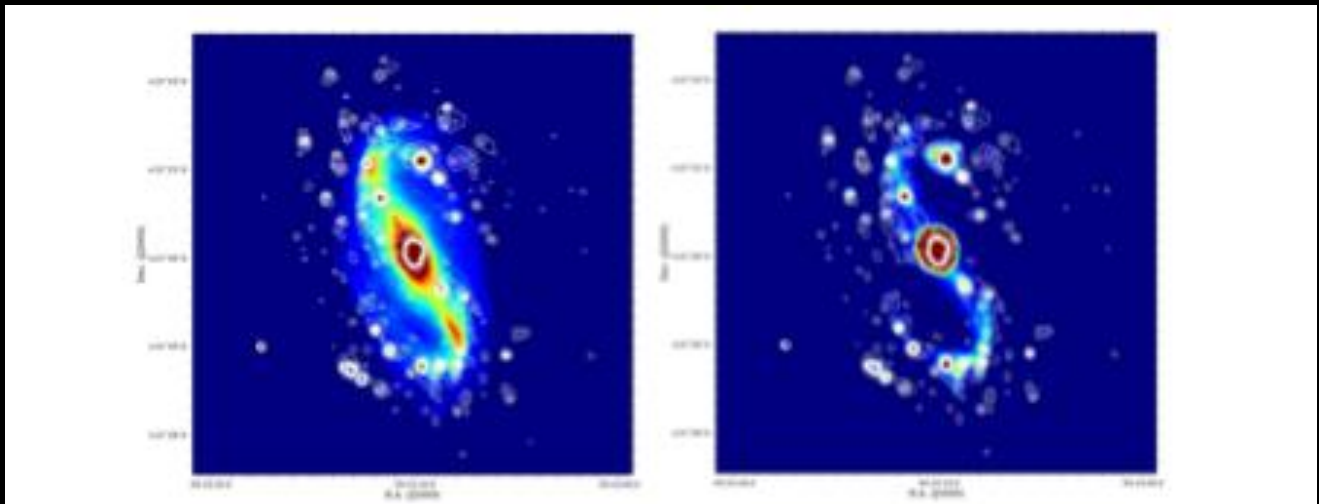
- Strong bar, nearby, good comparison with the results from NGC1530
- isolated
- It presents current star formation along its bar

- 2D ionized gas kinematics information is available (from GHAFAS) and HI data

The NGC 2903 bar: Star forming regions

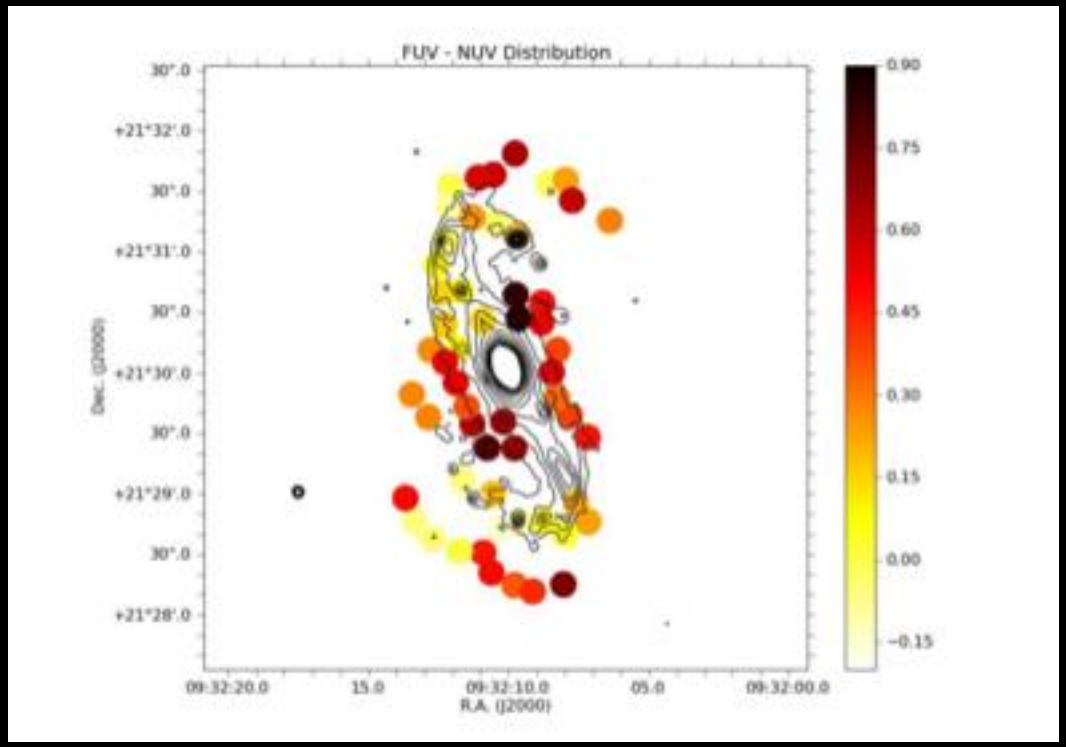


(a) NUV with overlaid Hα countours. (b) FUV with overlaid Hα contours.



(c) 3.6 μm with overlaid Hα contours. (d) 24 μm with overlaid Hα contours.

The NGC 2903 bar: Star forming regions



- *The bluer regions are compatible with ages between 3-10 Myr*
- The redder regions with UV colours raging between 0.4 and 0.85 are compatible with ages between 150 and 400 MYr

- *The SFRs of the bar region derived from Hα and from UV emission are 0.9 ± 0.2 $M_\odot yr^{-1}$ and 6.6 ± 1.0 $M_\odot yr^{-1}$ respectively.*

The project: understanding SF in bars

- Can our results be generalised to other bars?
- Can we set limits to the physical parameters that allow SF to occur ?

  relative gas - bar velocity -- shear (velocity gradient) -- gas density

  - Deep Hα imaging of strongly barred galaxies - *own data + archives*
  - Ionized gas kinematics (Fabry-Perot GHaFaS)
  - CO observations of strong bars with and without SF - 11 galaxies (June 2008, IRAM) + archived data
  - Influence of the magnetic field in the bar regions on the SF

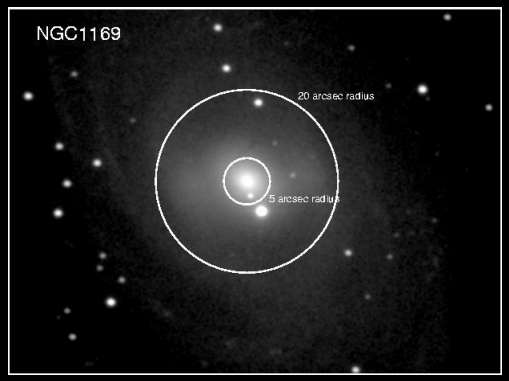
Bars as drivers of secular evolution

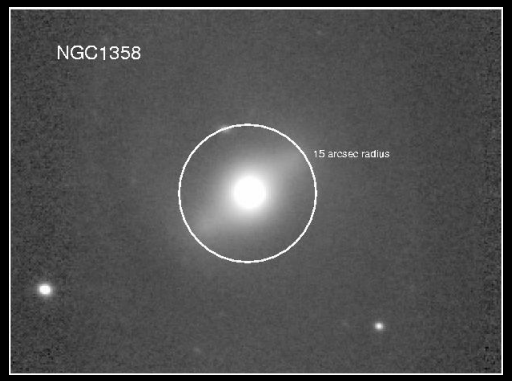
Bars are important mechanism for the transference of angular momentum. Bulge formation, AGN feeding.

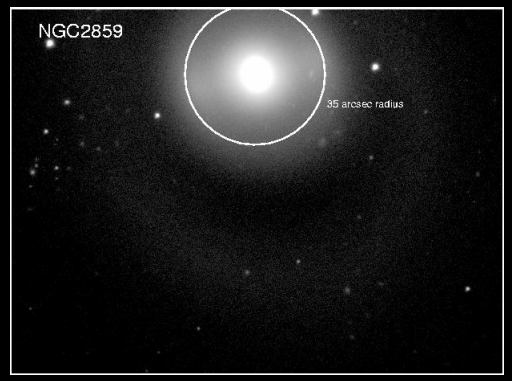
- Not even clear whether bar are long-lasting or get destroyed after a couple Gyrs.
  - The bar may disolve in the presence of a massive central component (e.g Friedli & Pfenniger 1991, Norman et al 1996)
  - Transfer of angular momentum from infalling gas to the bar can destroy the bar in 1-2 Gyr (Bournaud & Combes 2002)
  - Some computation show long-lasting bars (eg. Berentzen et al. 2007)

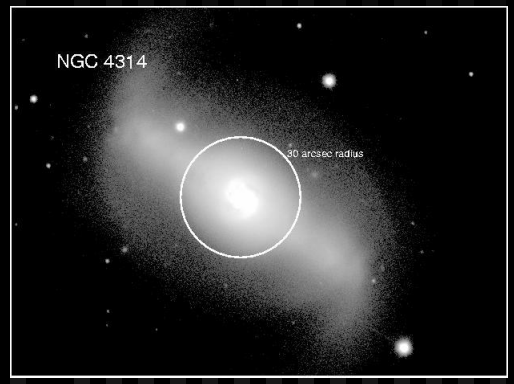
Do all bars go through these processes? Do some bars die while others are robust over many Hubble time?

Sample and data coverage



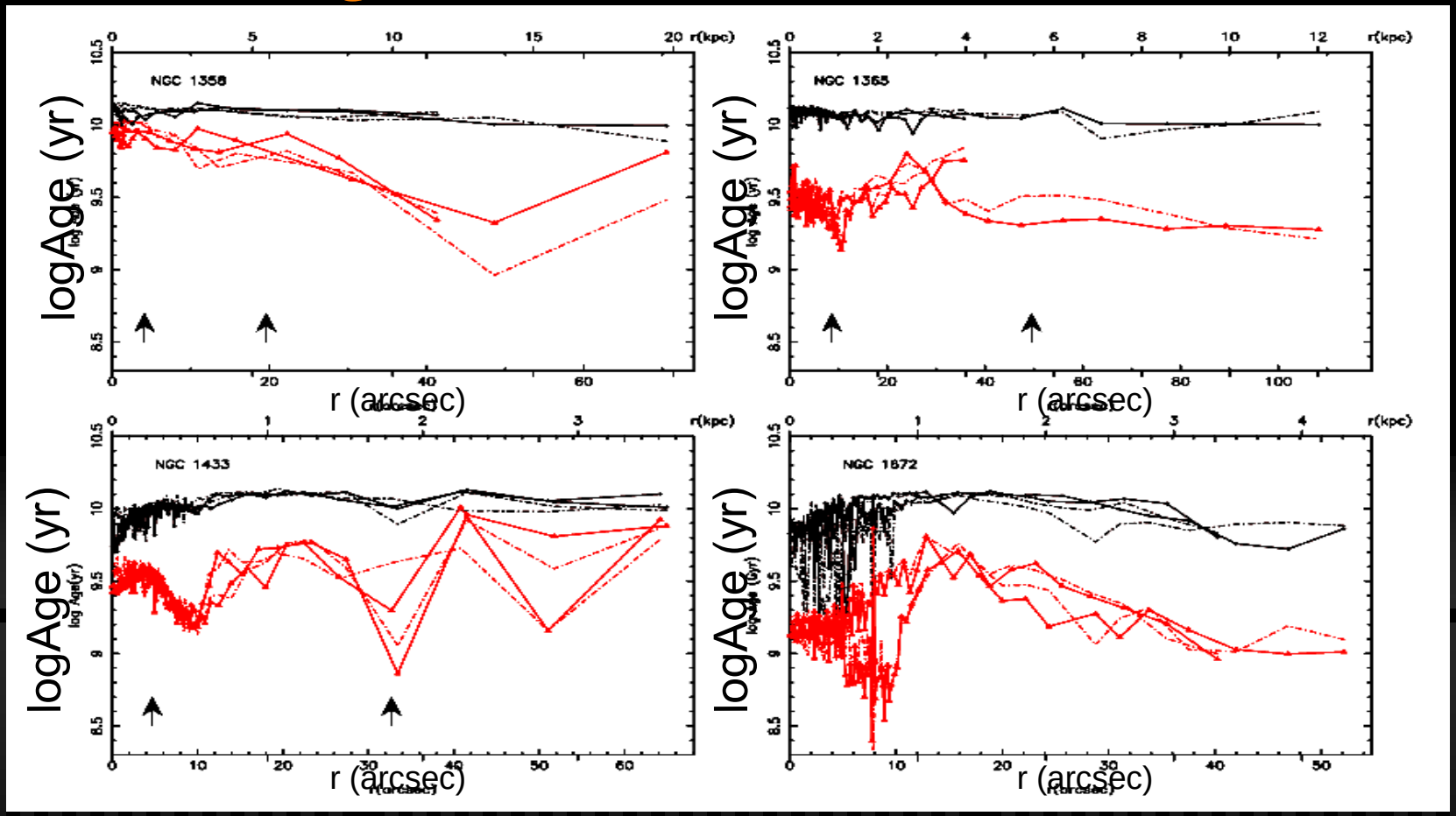






Two observation runs at La Palma (INT, IDS) and Siding Spring Observatory (DBS, 2.3m). Spectral range 5390-7314 Å, dispersion 1.1Å/pixel (*Pérez, Sánchez-Blázquez, Zurita 2007 Pérez, Sánchez-Blázquez, Zurita 2009*)

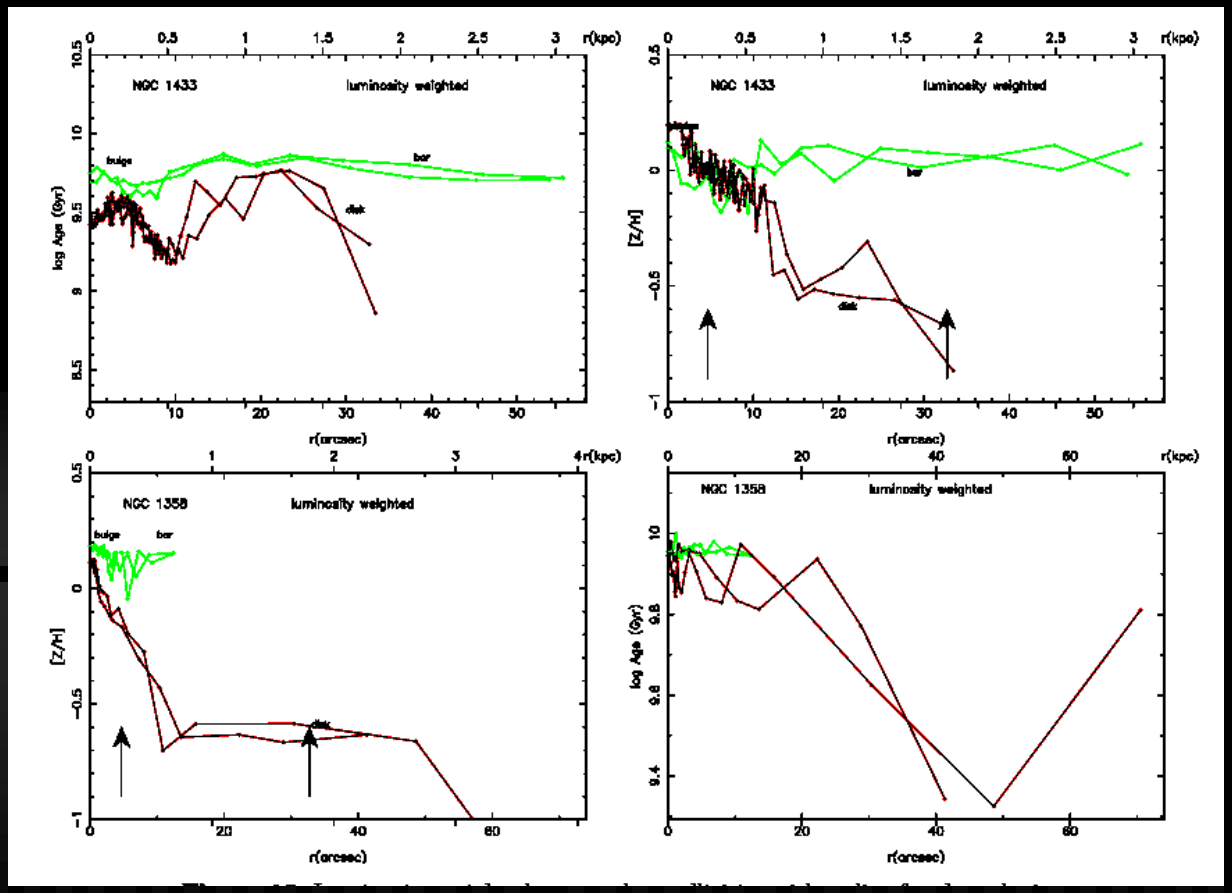
Star formation history of barred disk galaxies



Mass weighted gradiemts. Disks are dominated by an old population ~10Gyr. Radial migration or in placed already at z=1.5

Luminosity weigthed gradients -----> consistent with an inside-out formation

Star formation history of barred disk galaxies



In comparison with the stellar population of the disk, bars show older ages, higher metallicities and flatter gradients. Argues against a recent formation of the bar from disc material

Results: SFH of barred galaxies

- All the galaxies show a disk-like component in their centres
- We find a difference between the bulges of bar and unbarred galaxies
- We find that the majority of the stellar mass in the disks is composed of old stars. However, a larger fraction of young stars is present in the external parts compared to the inner disk.
- We find three types of bars according to their metallicity and age distribution along the bar.

1. Bars with a mean young/intermediate population (<2 Gyr) showing invariably negative metallicity gradients, among the lowest velocity disperion of the sample
2. Bars with no metallicity gradient. Their end of the bars are younger, this regions are linked to the bar morphology and therefore the burst has happened after bar formation (ages between 3-10 Gyr)
3. Bars with an older population and positive metallicity gradient.

Further on-going work

- **Study of the ionised gas metallicities (Florido et al.)**
- **Multiwavelength study of bars to characterise the SFH 1Gyr (Popping et al. submitted]**
- **Extension to later types (observing run at the WHT this weekend]**
- **Modelling of the formation of bars (Wozniak & Pérez]**
- **Characterization of the different gas phases & star formation in bars (Lisenfeld et al.]**