Understanding interacting and merging galaxies with Gemini/GMOS

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Why does interacting galaxies are important?

Galaxy transformation and evolution

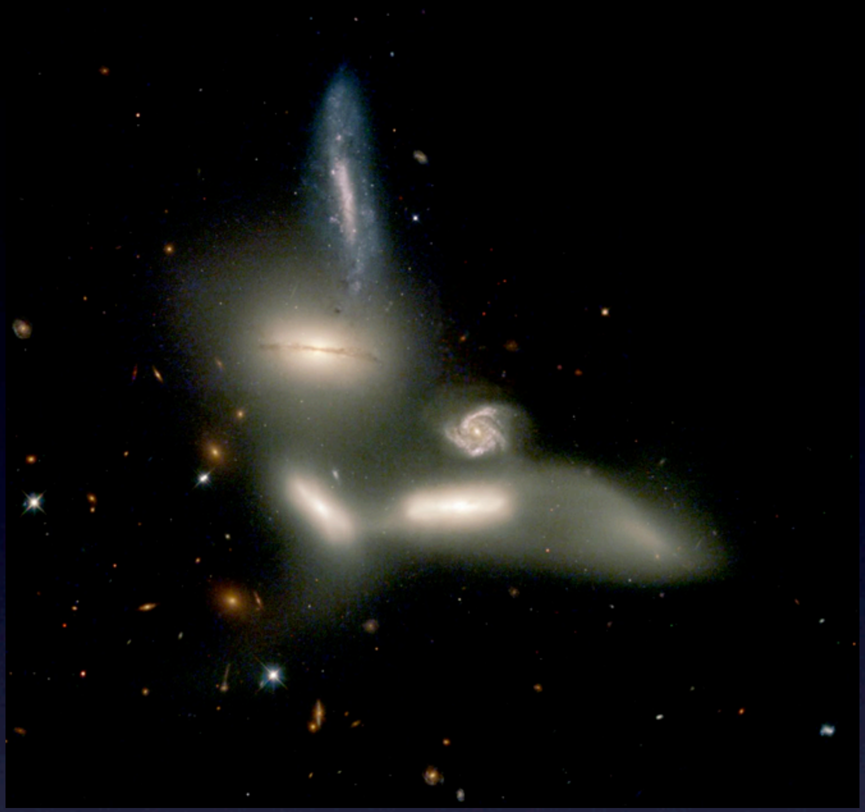
What kind of phenomena can we study in interacting systems?

Formation of new stellar systems	SF process	Chemical evolution	Nuclear activity

What kind of environment favour galaxy-galaxy interactions?

Dense environments	Galaxy pairs/ triplets	*Compact groups*

Compact groups of galaxies: Small groups of galaxies, where the projected separation of the galaxies is of the order of the size of the galaxies

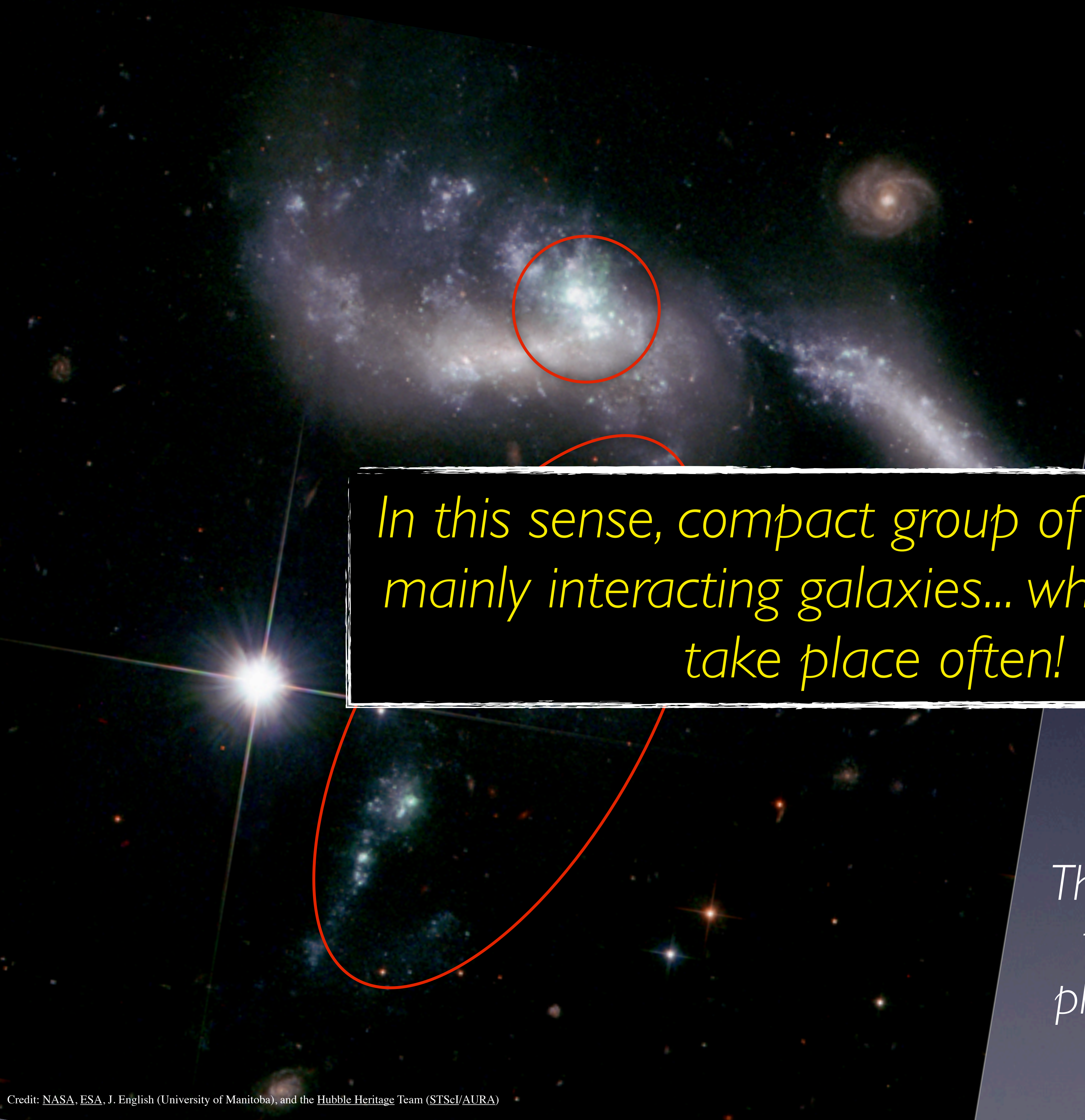


These systems display low dispersion velocities, of the order of ~250 km/s

These systems have been catalogued by different authors, by using different criteria:

- Hickson Compact Group Catalogue (HCG, Hickson 1982, 100 groups)
  Visual identification on the POSS I photographic plates
  $4 \leq N \leq 10$ within a 3-mag range from the brightest galaxy
  $\mu_R \leq 26$ mag/arcsec^2 (compactness) $\theta_N > 3\ \theta_G$ (isolation)

- Garcia et al. 1993, 1995 (Lyon-Meudon Extragalactic database)
- Díaz-Gimenez et al. 2012 (2MASS)
- Hernandez-Fernandez et al. 2015 (GALEX)
- Sohn et al. 2016 (SDSS DR12)



Credit: NASA, ESA, J. English (University of Manitoba), and the Hubble Heritage Team (STScI/AURA)

An interesting example of galaxy-galaxy interaction... HCG 31

In this sense, compact group of galaxies are mainly interacting galaxies... where mergers take place often!

systems...

The presence of tidal tails is a common phenomena in these systems

Some effects of galaxy-galaxy interactions in the intergalactic medium

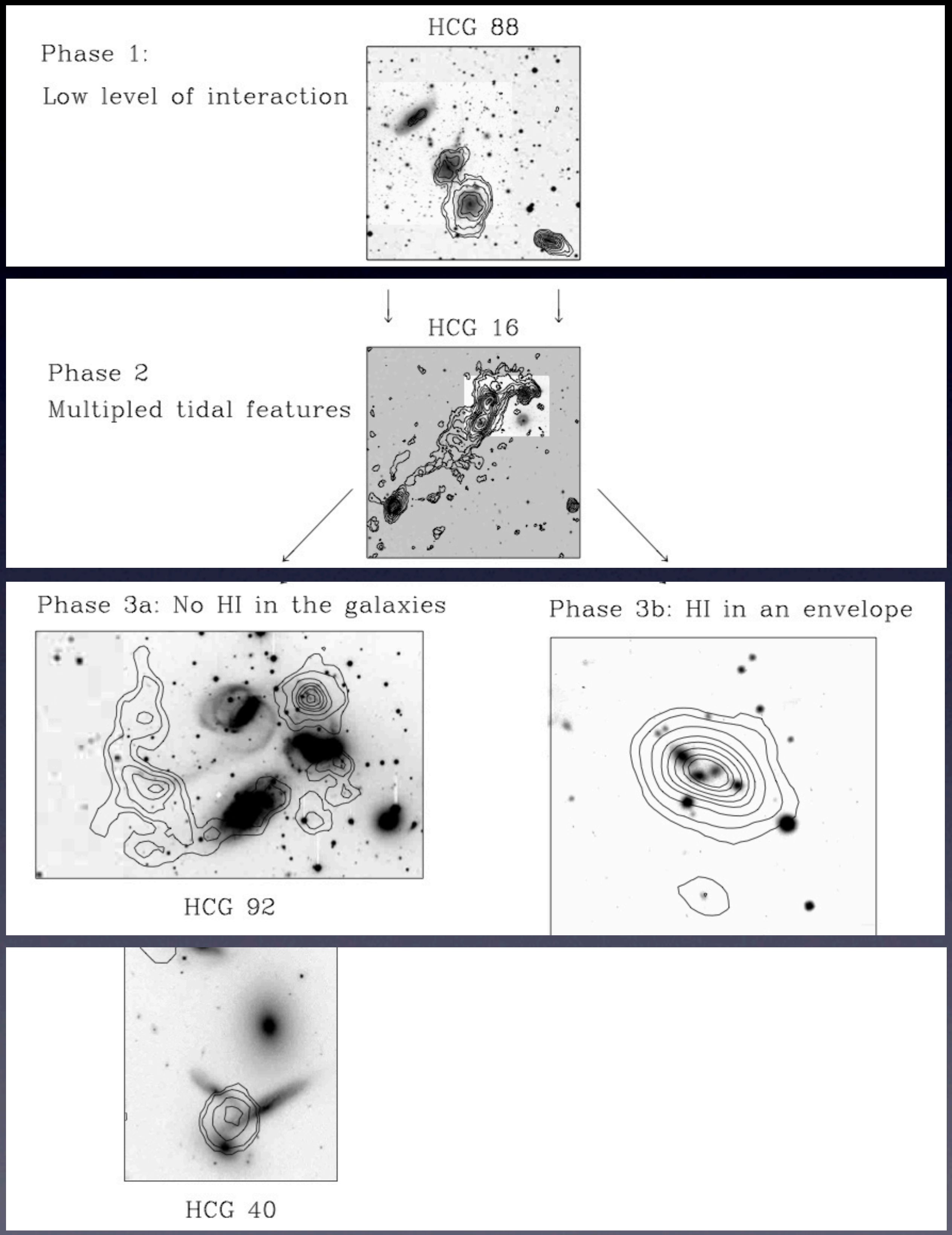
Given the galaxy-galaxy interactions, some neutral gas can be ejected into the intergalactic medium

HCG galaxies are deficient in their HI content, compared with its predicted HI mass

HCG displays gaseous tidal tails

In some cases, the neutral hydrogen covers all members of HCG

Verdes-Montenegro et al. (2001) classified the interaction level in HCG depending on its HI content



Verdes-Montenegro et al. (2001)

Some effects of galaxy-galaxy interactions in the intergalactic medium

Tidal tails... a typical signature of galaxy-galaxy interactions

Some effects of galaxy-galaxy interactions in the intergalactic medium

Interacting galaxies in compact groups → Gas in the intragroup medium due to galaxy interactions

↓

Spectroscopic observations of interacting galaxies can help us to understand the star formation process in the intergalactic medium and in the tidal tails of interacting systems... Also, this information can help us to understand the chemical evolution of these systems

..but, are these star-forming regions formed "in situ" or they were ejected from the parent galaxies during interaction process? → how does the metal mixing work in interacting galaxies and tidal tails?

What kind of objects are those new stellar systems?

Tidal Dwarf Galaxies (TDG)

- Duc & Mirabel (1998)
- Weilbacher et al. (2000)
- Mendes de Oliveira et al. (2001)
- Boquien et al. (2010)
- Sweet et al. (2016)
- Lee-Waddell et al. (2016)
- Sengupta et al. (2017)

Intergalactic HII regions (IHII)

-Oosteloo et al. (2004)

-Mendes de Oliveira et al. (2004)

-Ryan-Weber et al. (2004)

- Werk et al. (2010)
- Kellar et al. (2012)

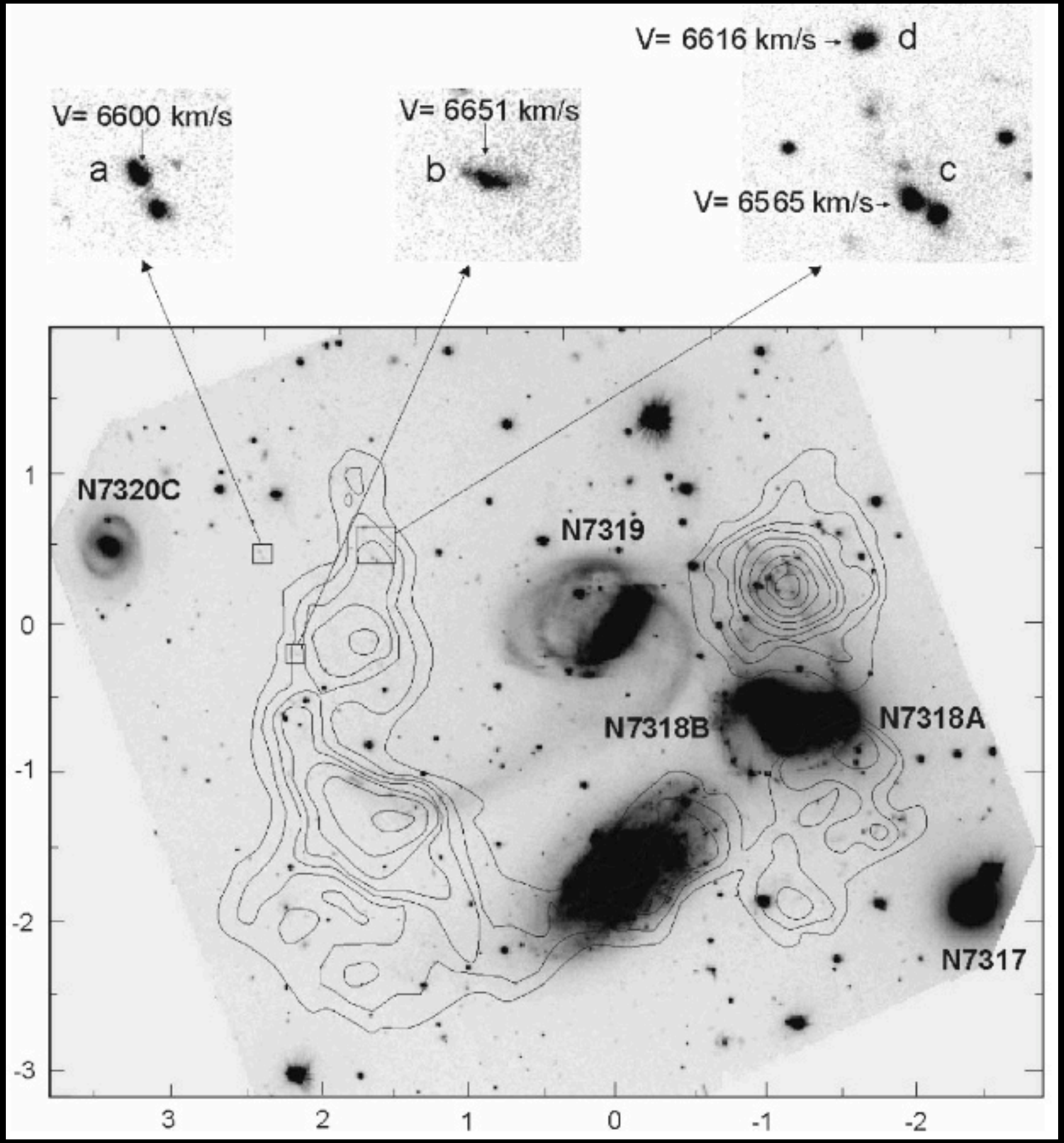
The most important difference between TDG and IHII is the MASS.

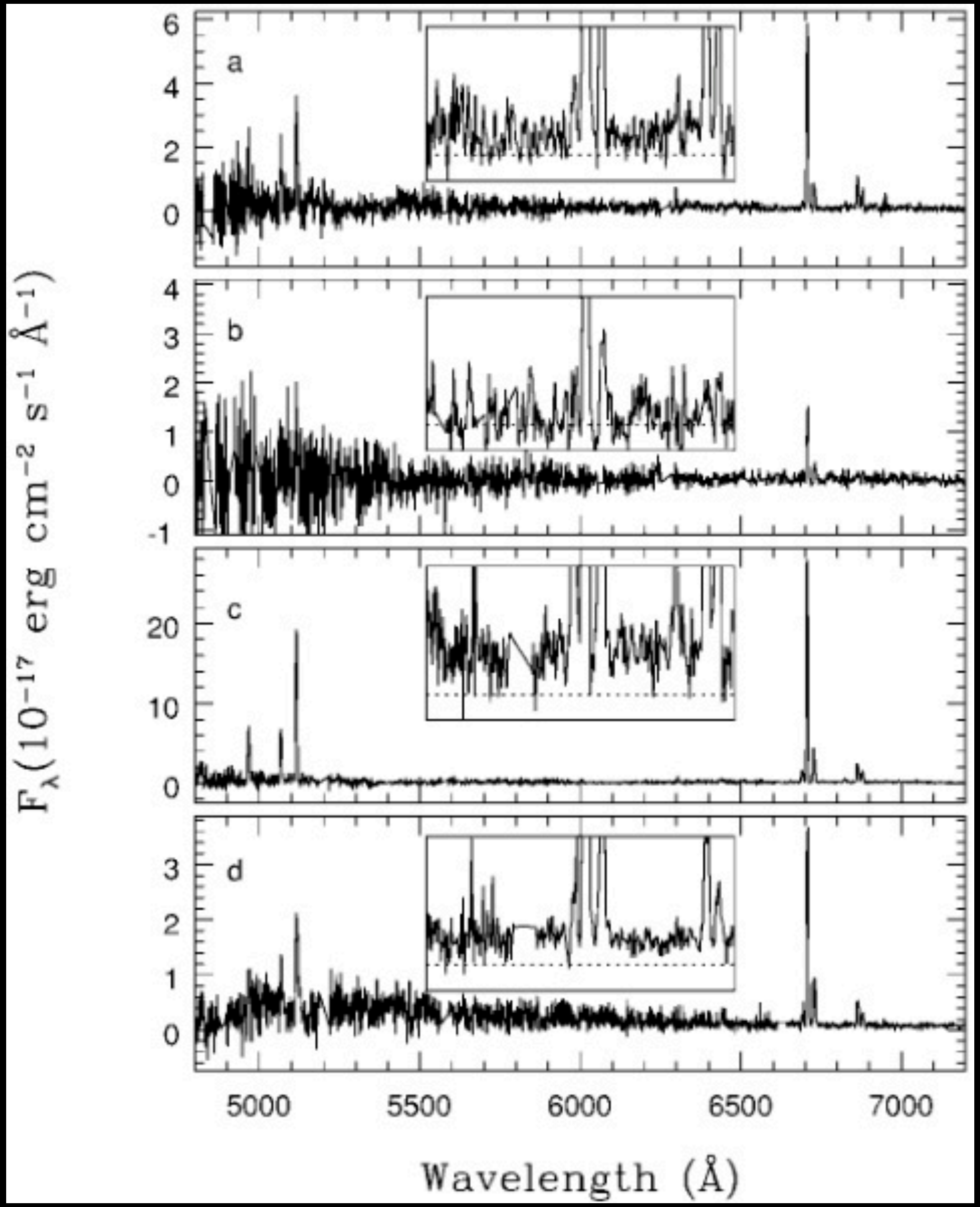
TDG~10^{8}-10^{9} M_{SUN}

IHII~10^{4} M_{SUN}

Some examples of star formation in tidal tails

A nursery of young objects: Intergalactic HII regions in the Stephan's Quintet (Mendes de Oliveira et al. 2004, de Mello et al. 2012)

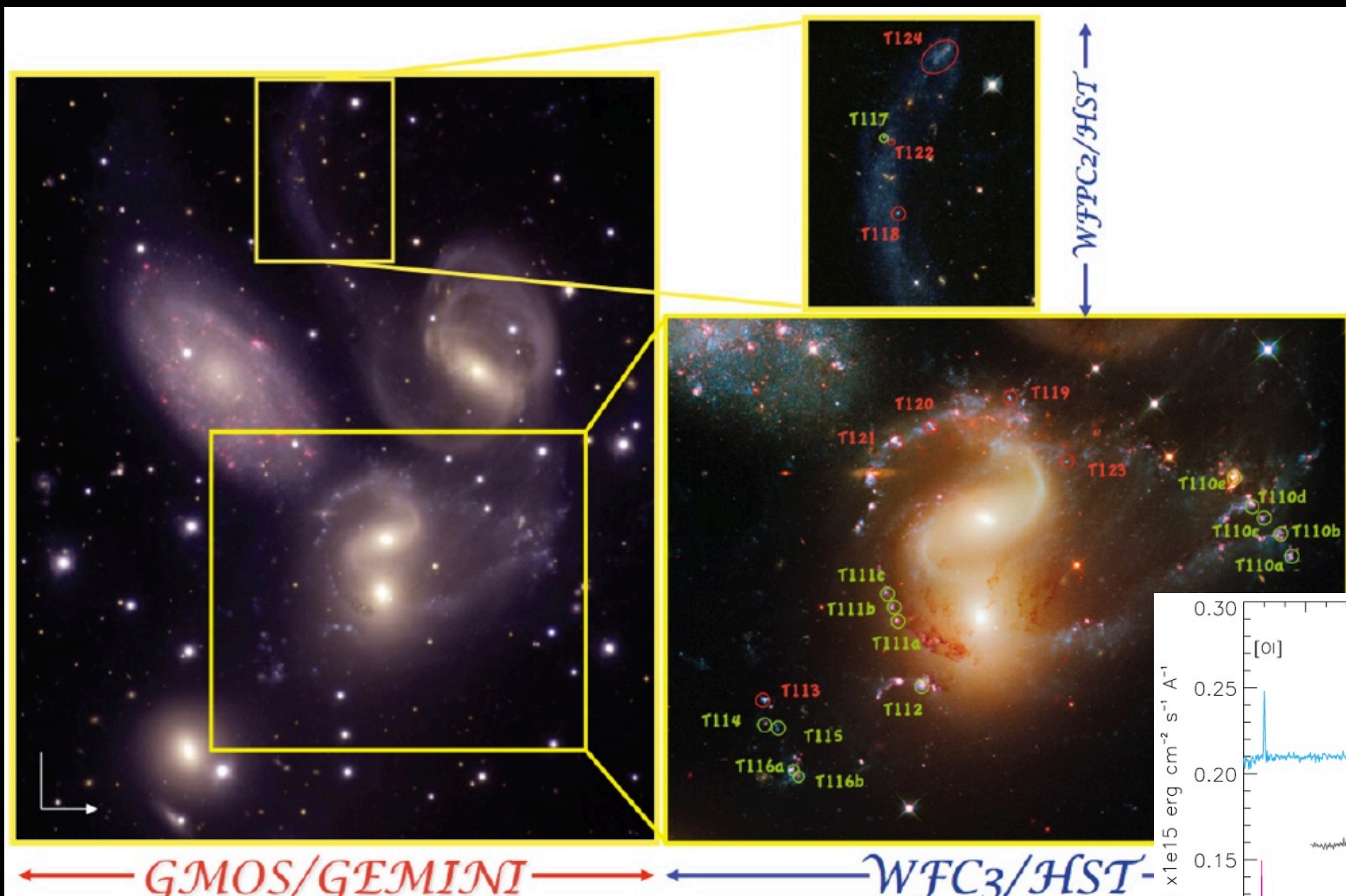




Gemini/GMOS observations were used to report the discovery of a couple of young star-forming regions outside the main body of the galaxies. These regions have masses of the order of 10^4 solar masses.

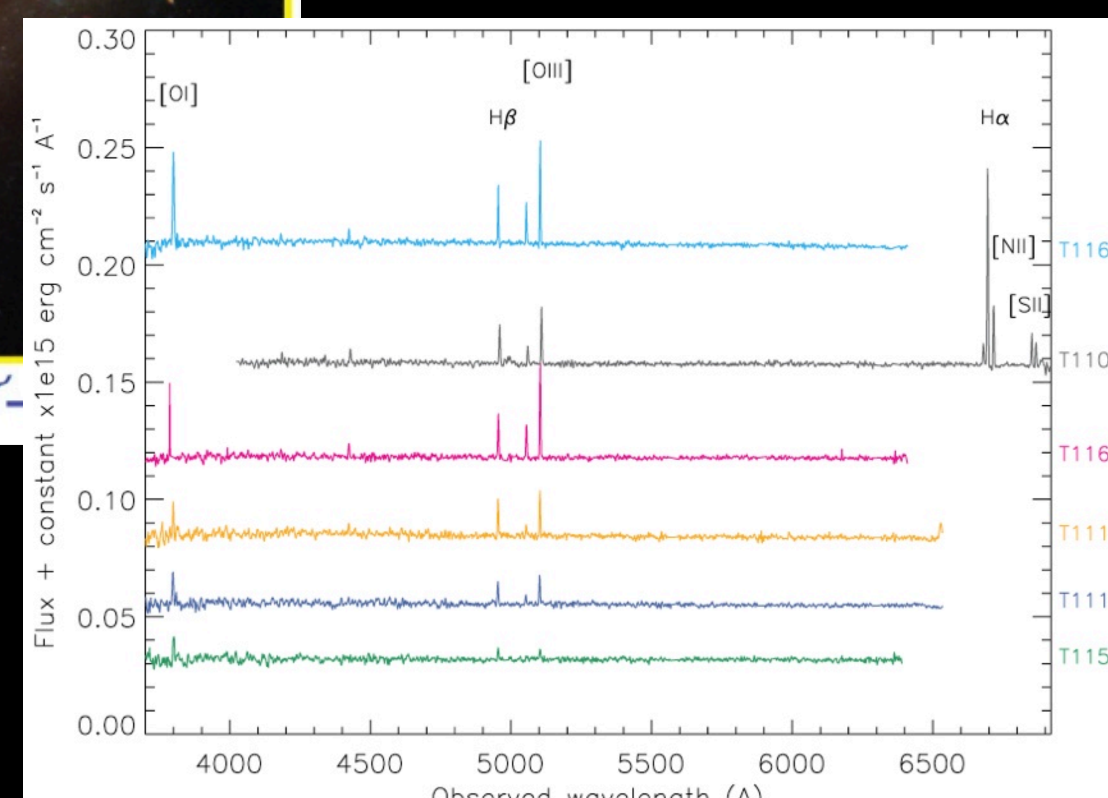
Some examples of star formation in tidal tails

Gemini Spectroscopic Survey of Young Star Clusters in Merging/Interacting Galaxies (Trancho et al. 2007a, 2007b, Bastian et al. 2009, Trancho et al. 2012)



"Many of the clusters are found to be relatively long-lived, given their spectrosopically derived ages, while their high masses suggest that they will likely evolve to eventually become intergalactic clusters."

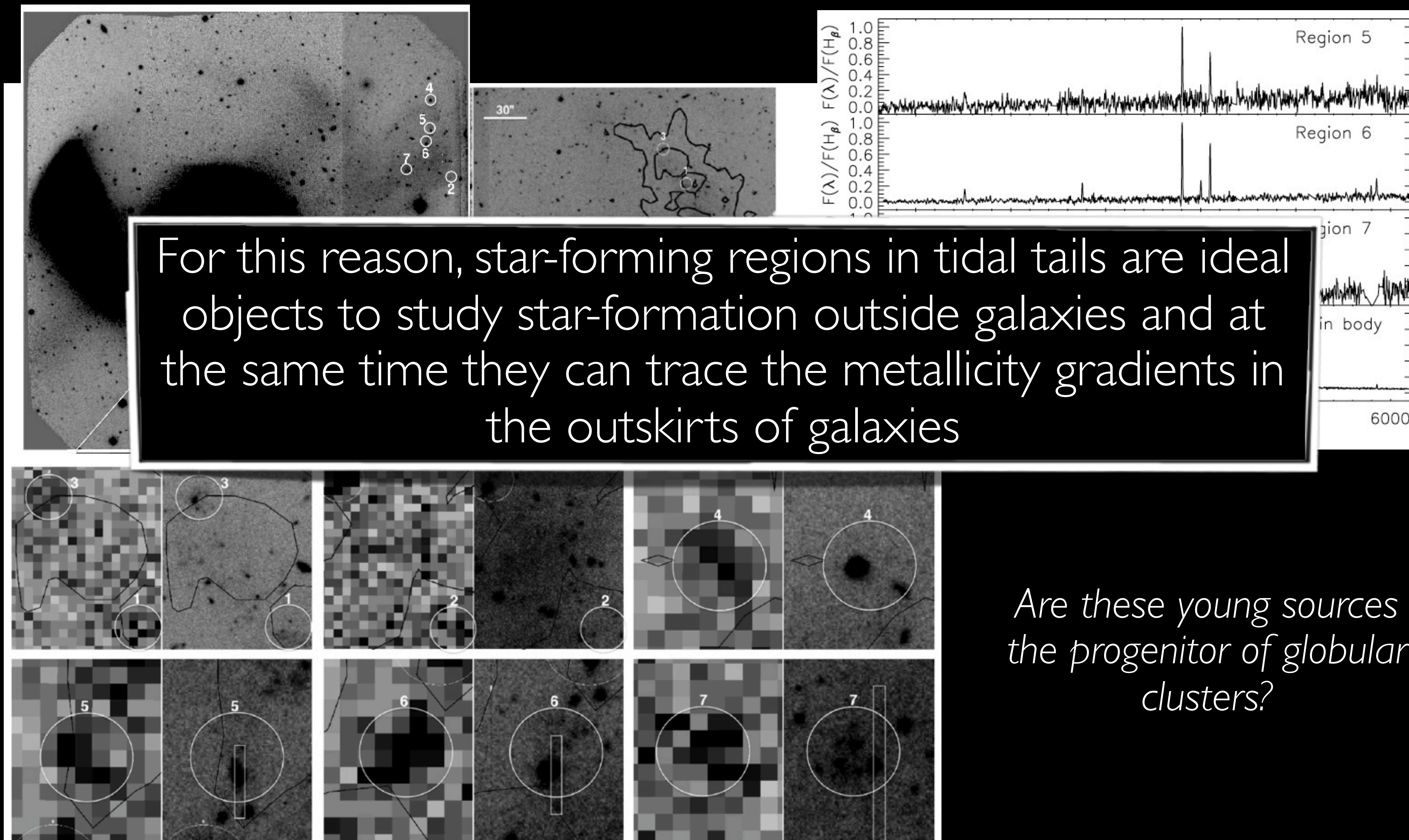
Trancho et al. 2012



Most of these objects are emission line regions, with no continuum emission

Some examples of star formation in tidal tails

In the case of NGC 2782, Gemini/GMOS data detected young regions in a extended gaseous tidal tail (30 kpc)



For this reason, star-forming regions in tidal tails are ideal objects to study star-formation outside galaxies and at the same time they can trace the metallicity gradients in the outskirts of galaxies

Are these young sources the progenitor of globular clusters?

Torres-Flores et al. (2012)

Some examples of star formation in tidal tails

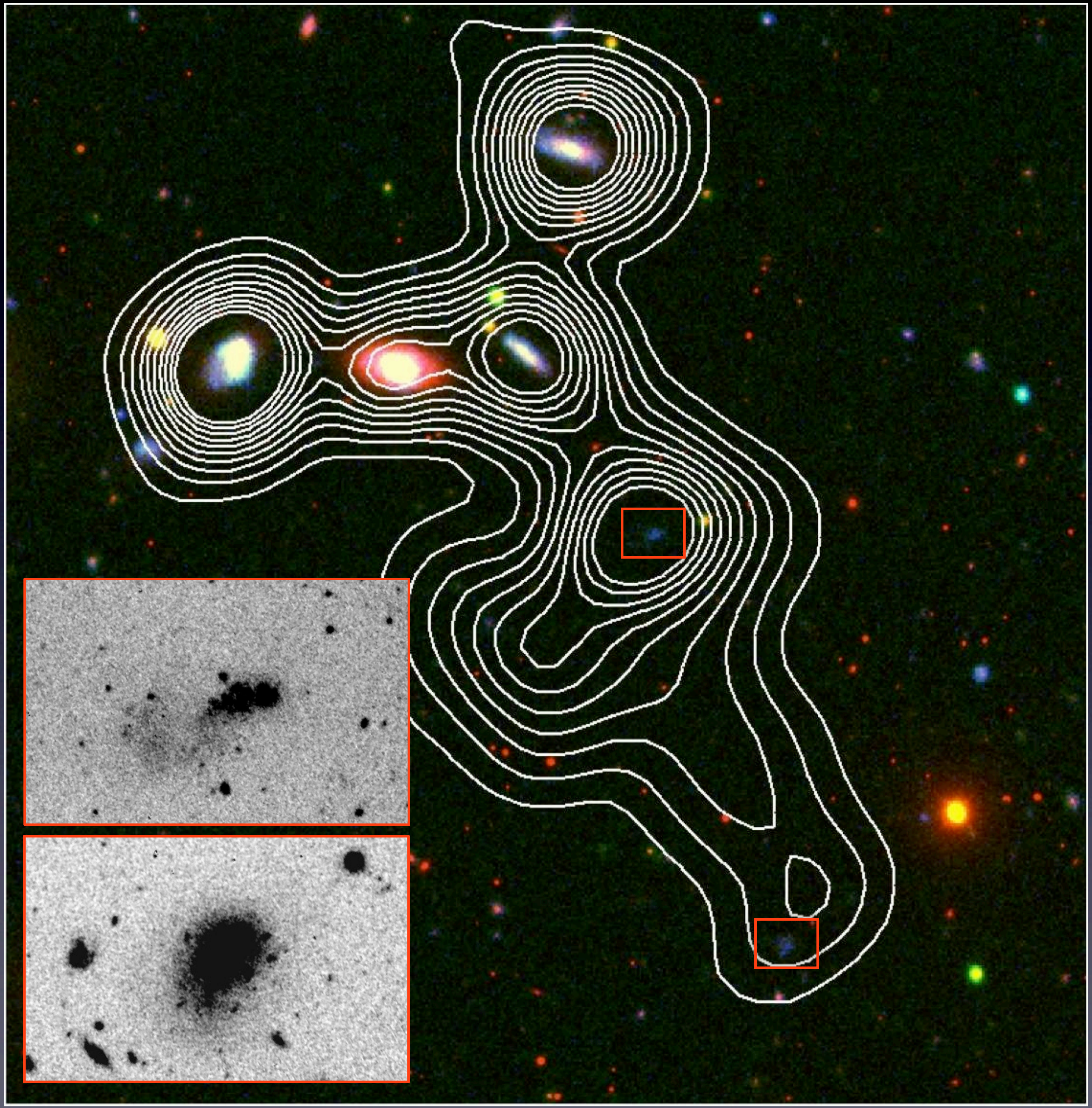
HCG 100: Four late-type galaxies

Tidal features: *We should expect more than an optical counterpart!*

Where is the HI gas in this system?

Gemini/GMOS spectra shows that these regions belong to HCG100, having solar metallicities

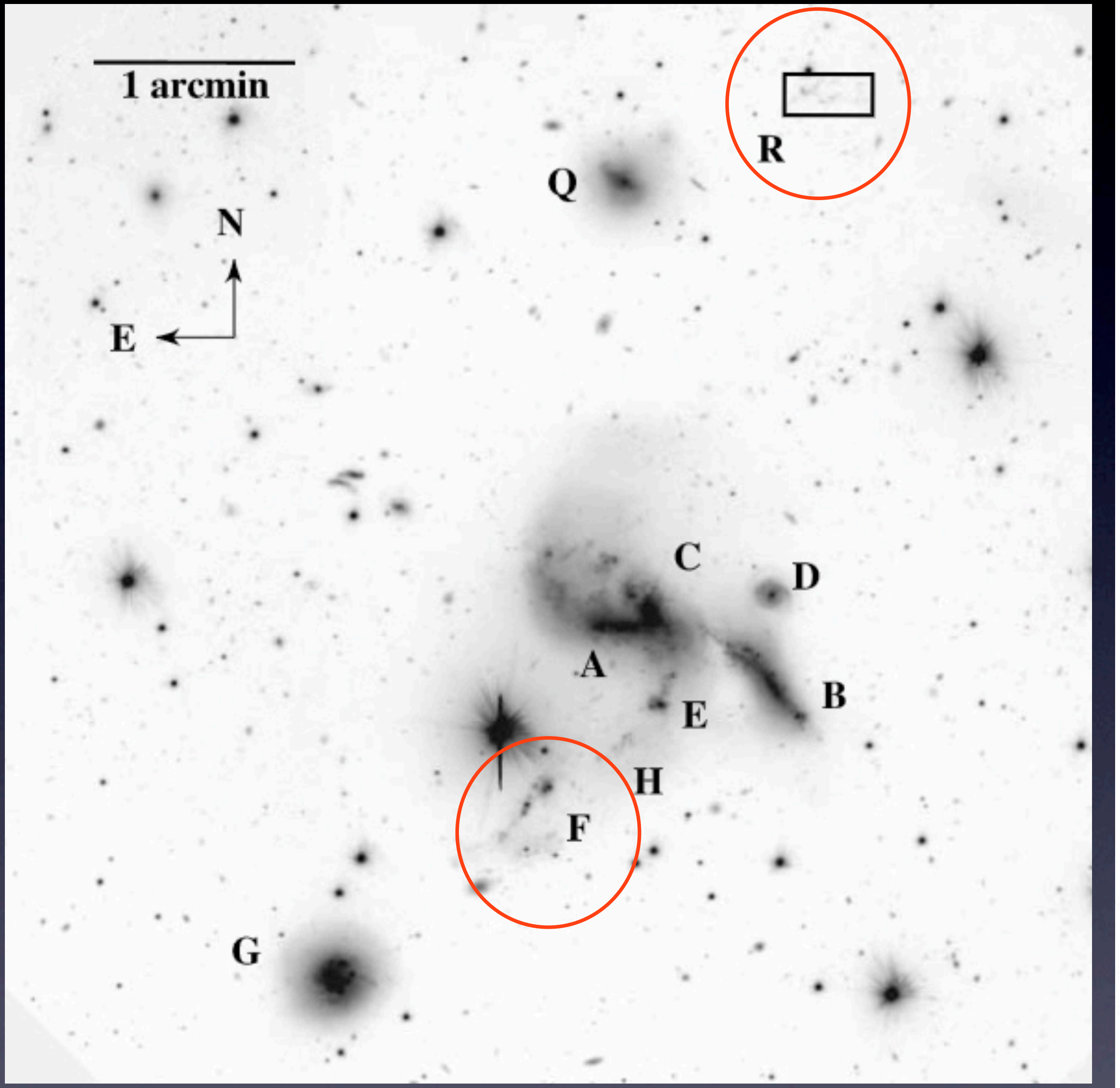
TDG candidates

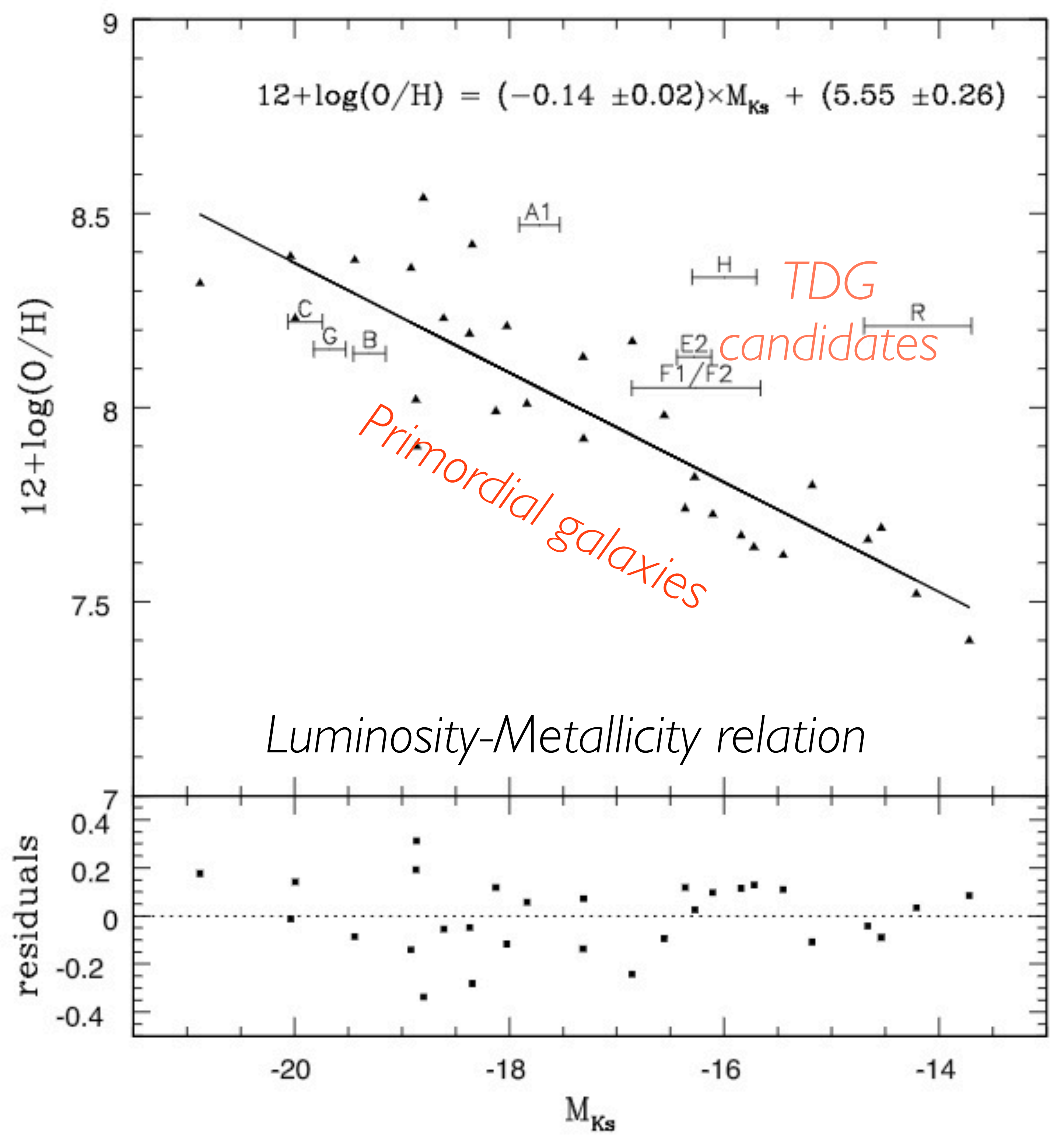


de Mello, Torres-Flores & Mendes de Oliveira (2008), de Mello et al. (2012)

Some examples of star formation in tidal tails

The case of the merging system HCG 31





Gemini/ GMOS reveals the presence of new TDG candidates in the system HCG 31

Mendes de Oliveira et al. (2006)

These TDG candidates are formed from pre-enriched material... Kinematic studies are necessary to determine the gravitational support of these sources!

What is the importance of these extragalactic star-forming regions?

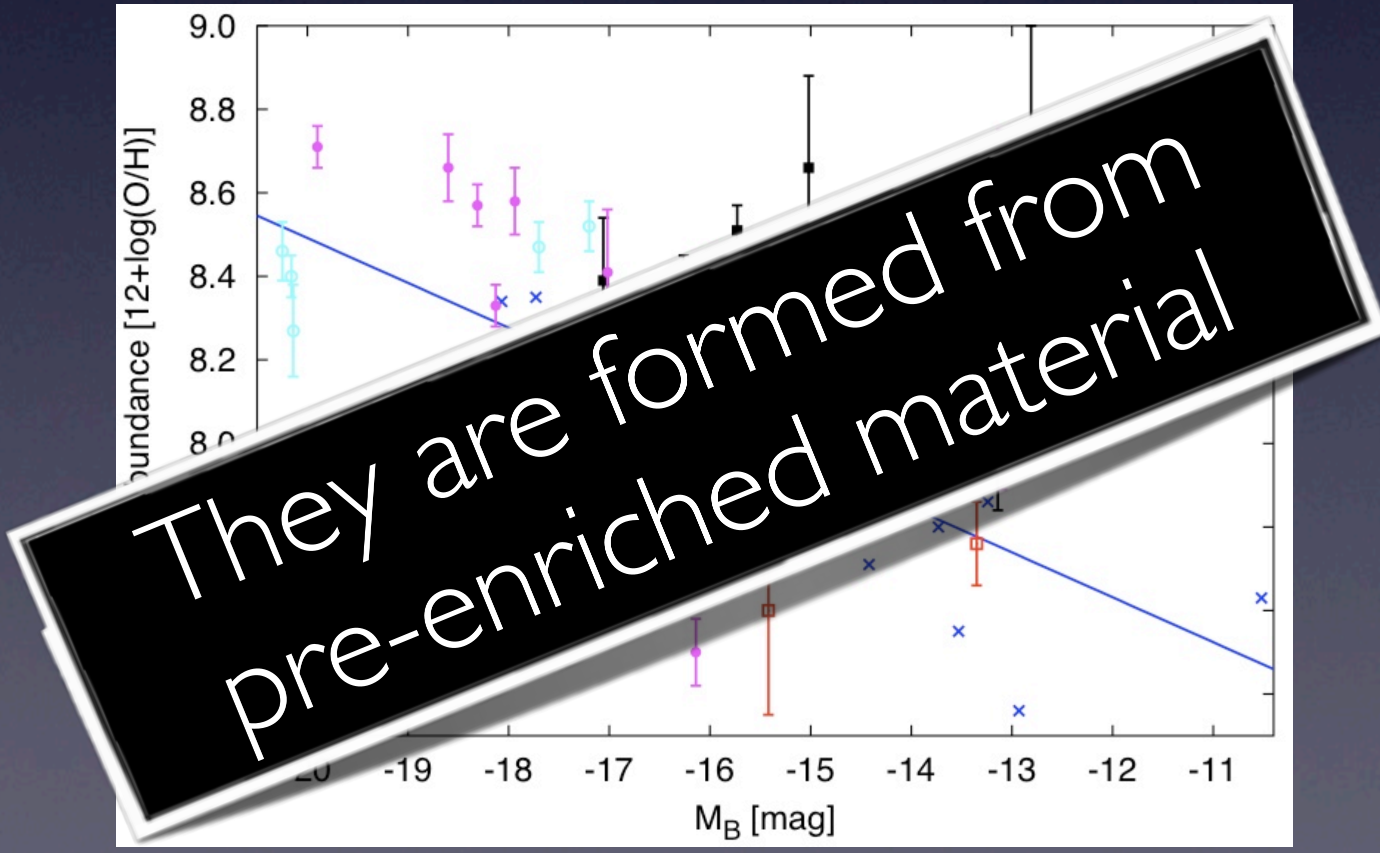
TDGs should be free of dark matter

But... what about their rotation curves?

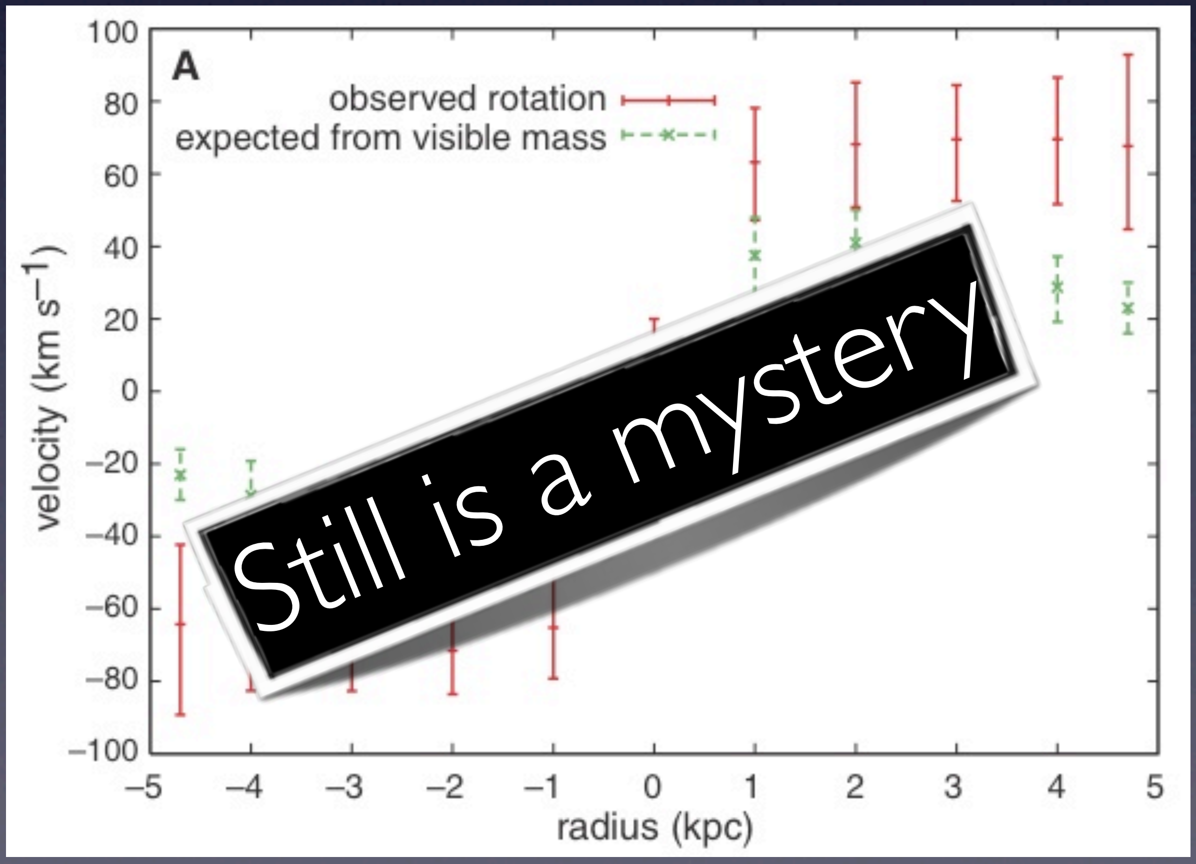
Flat rotation curves?

Cold molecular gas?

Why do these objects have high metallicities?



Weilbacher et al. (2003)

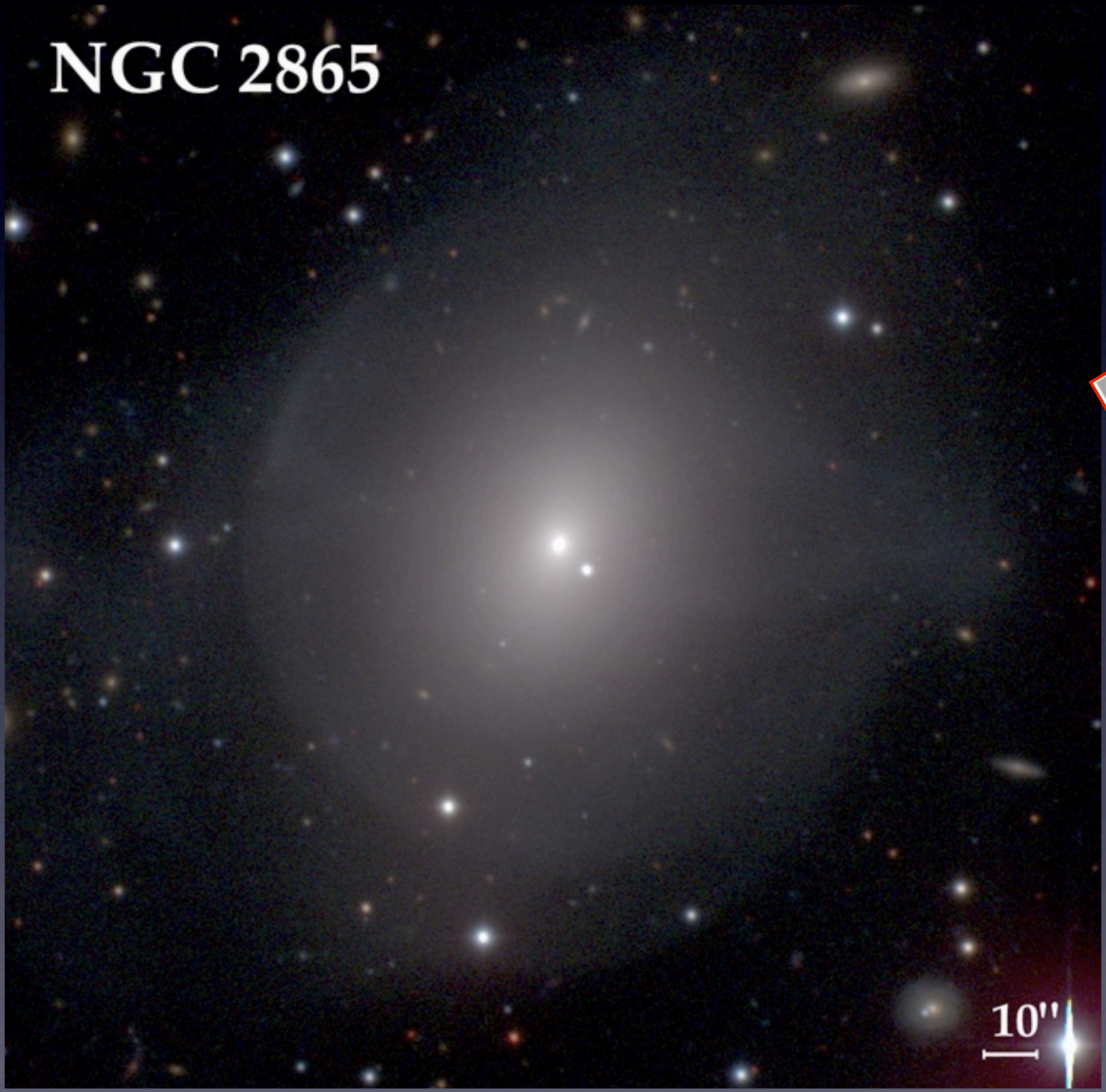


Bournaud et al. (2007)

But star forming regions can be found even in merger remnants (with no obvious tidal tails)

A census of Halpha emitters objects around NGC 2865
Urrutia-Viscarra et al. (2014)

Observations: MSIS technique on Gemini/GMOS



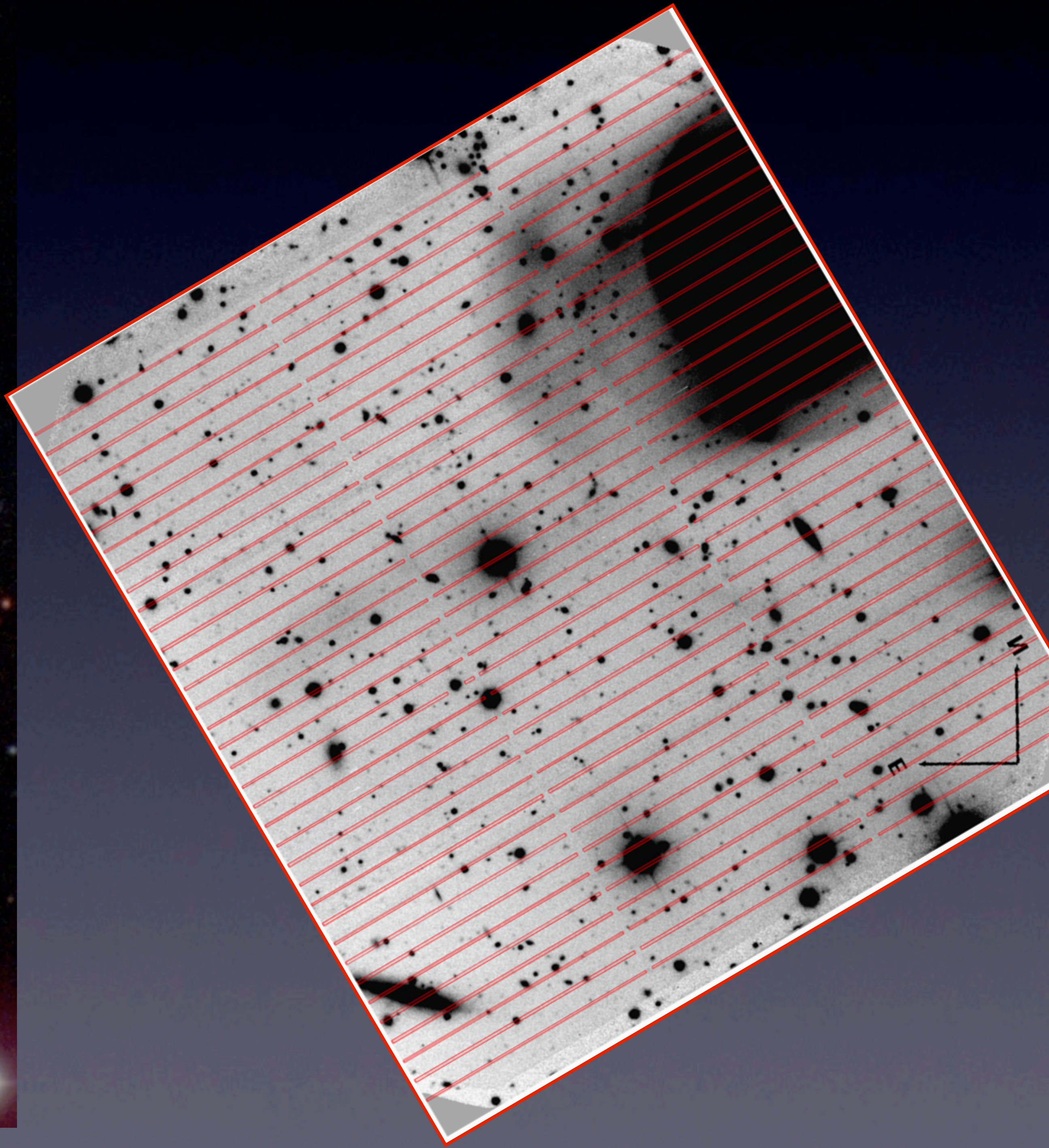
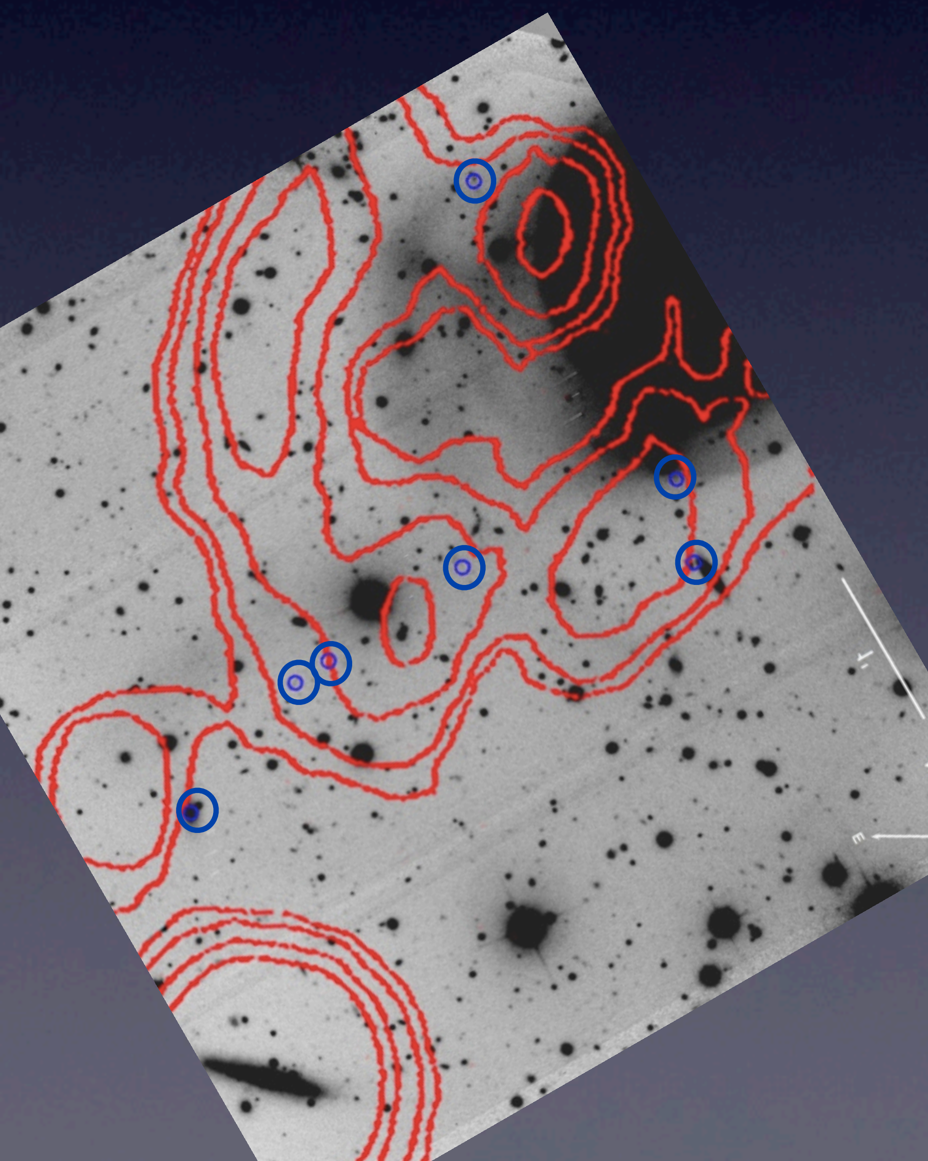


Image taken form "The Carnegie-Irvine Galaxy Survey (CGS)"

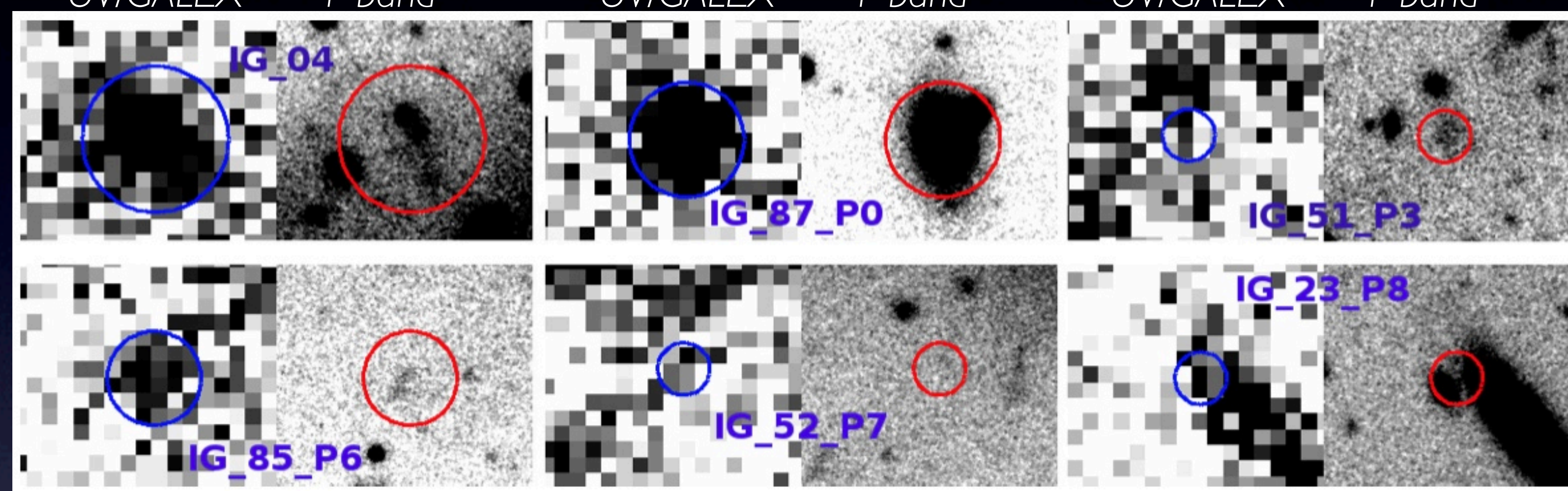
But star forming regions can be found even in merger remnants (with no obvious tidal tails)

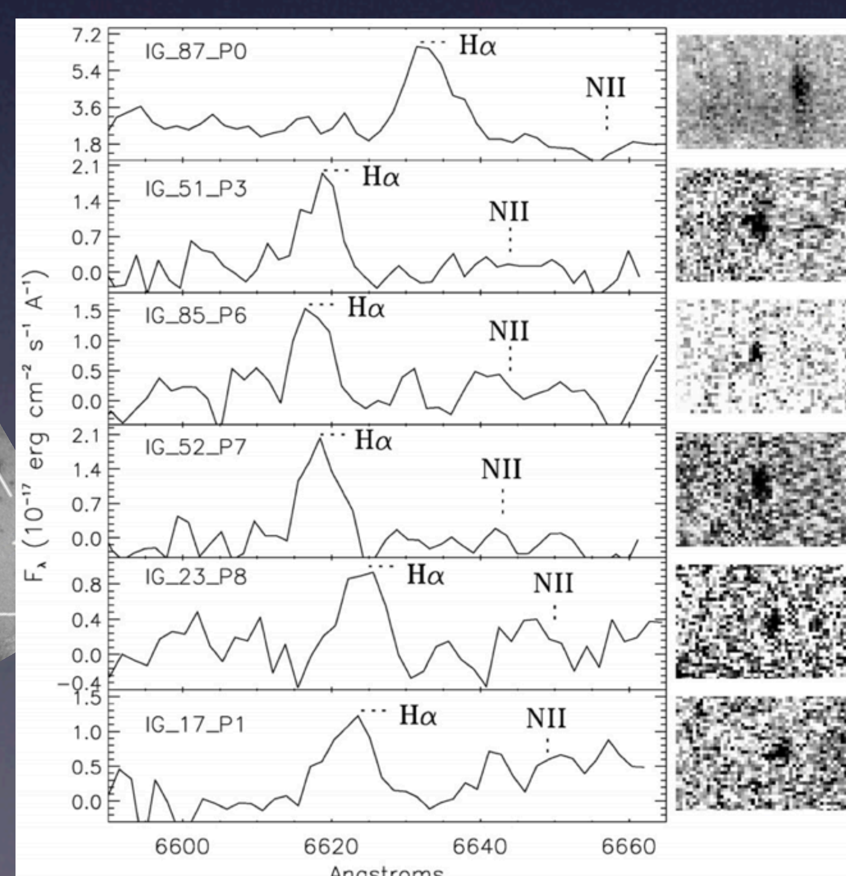
A census of Halpha emitters objects around NGC 2865
Urrutia-Viscarra et al. (2014)

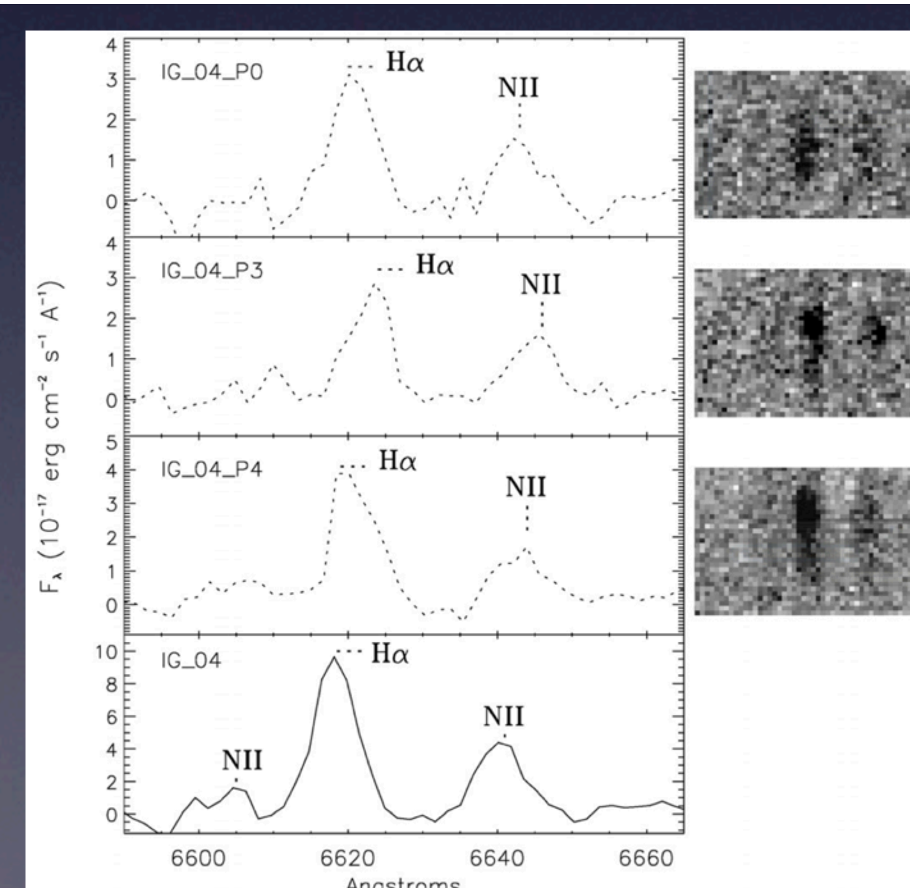
This technique allows the detection of seven faint star-forming regions in the outskirts of NGC 2865



UV/GALEX r'-band UV/GALEX r'-band UV/GALEX r'-band



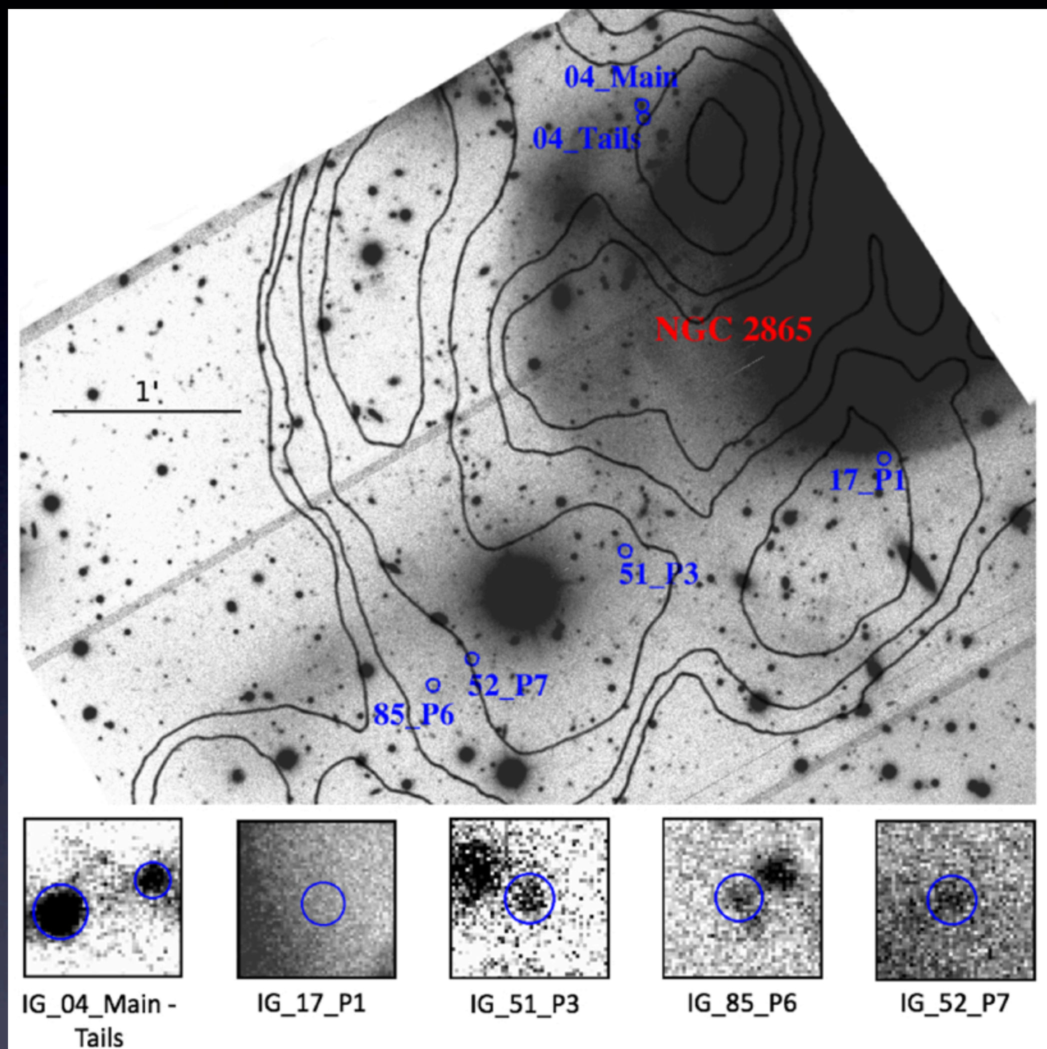


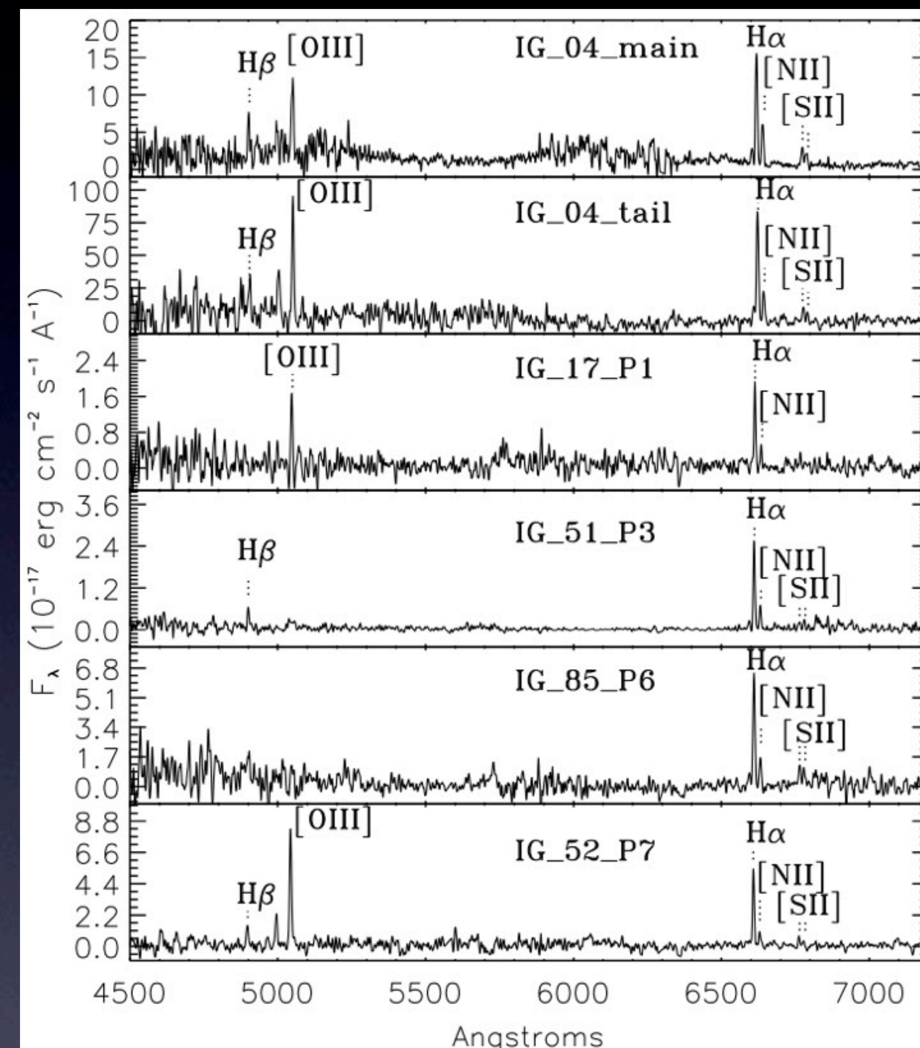


But star forming regions can be found even in merger remnants (with no obvious tidal tails)

Six of the MSIS detections have been recently confirmed by Gemini/GMOS multislit spectroscopy

Urrutia-Viscarra, Torres-Flores, Mendes de Oliveira et al. (2017)





Main properties:

- *Young regions (Halpha emitters) ~ 10 Myrs*
- *High oxygen abundances, 12+log(O/H)~8.5-8.7*
- *Projected distance from NGC 2865: 16-40 kpc*
- *Regions are located on HI projected densities of ~ 10^{19} cm^{-2} , which is below the typical threshold for star formation (Maybhate et al. 2007)*
- *Are these sources the progenitor of a new generation of globular clusters?*

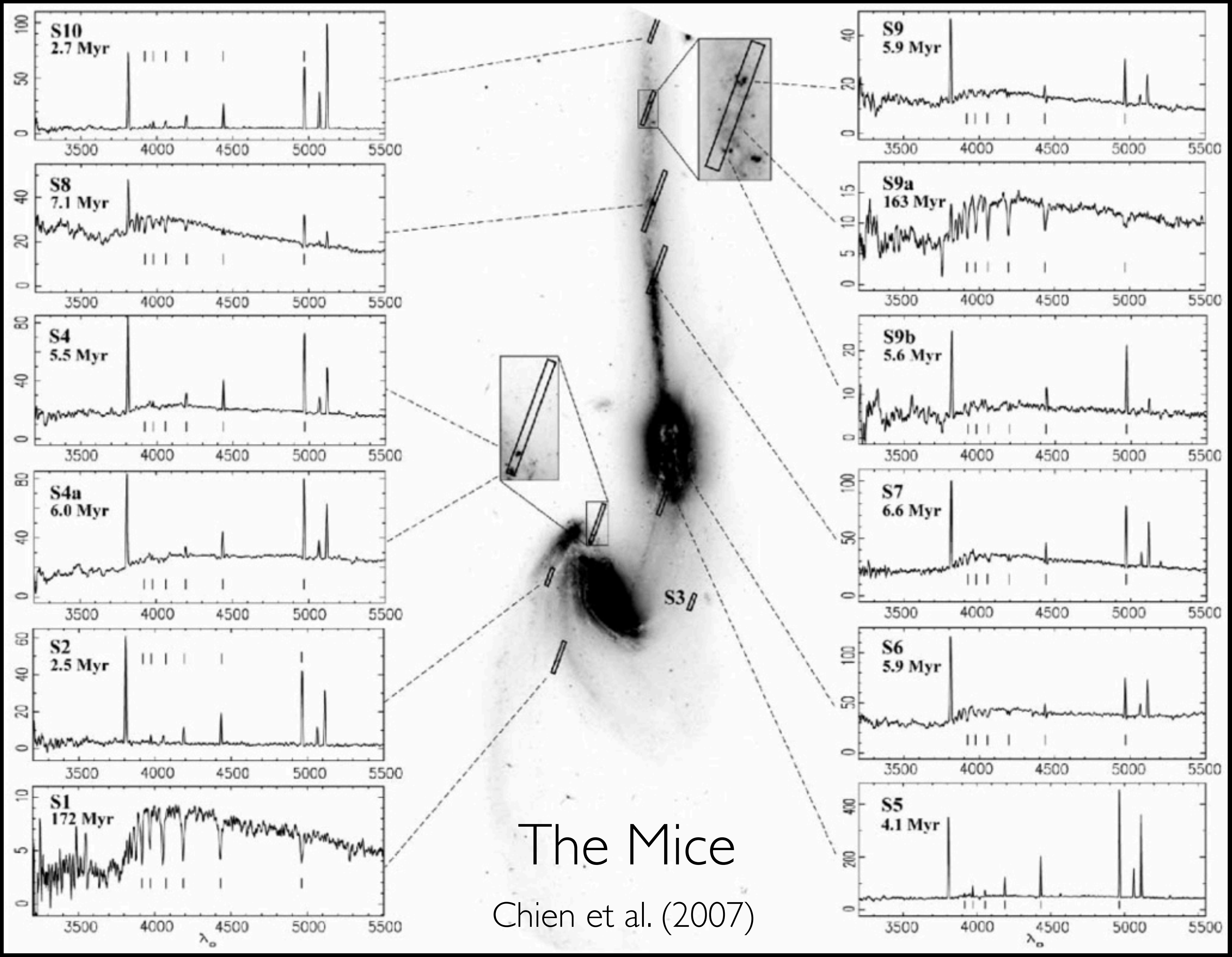
So far, what have we learn by studying interacting galaxies with Gemini/GMOS?

- Interacting galaxies are excellent laboratories to study star-forming objects in extended tidal features.

- The fate of these newly formed objects is unclear and new observations. High resolution spectroscopy could be useful to disentangle their gravitational support.

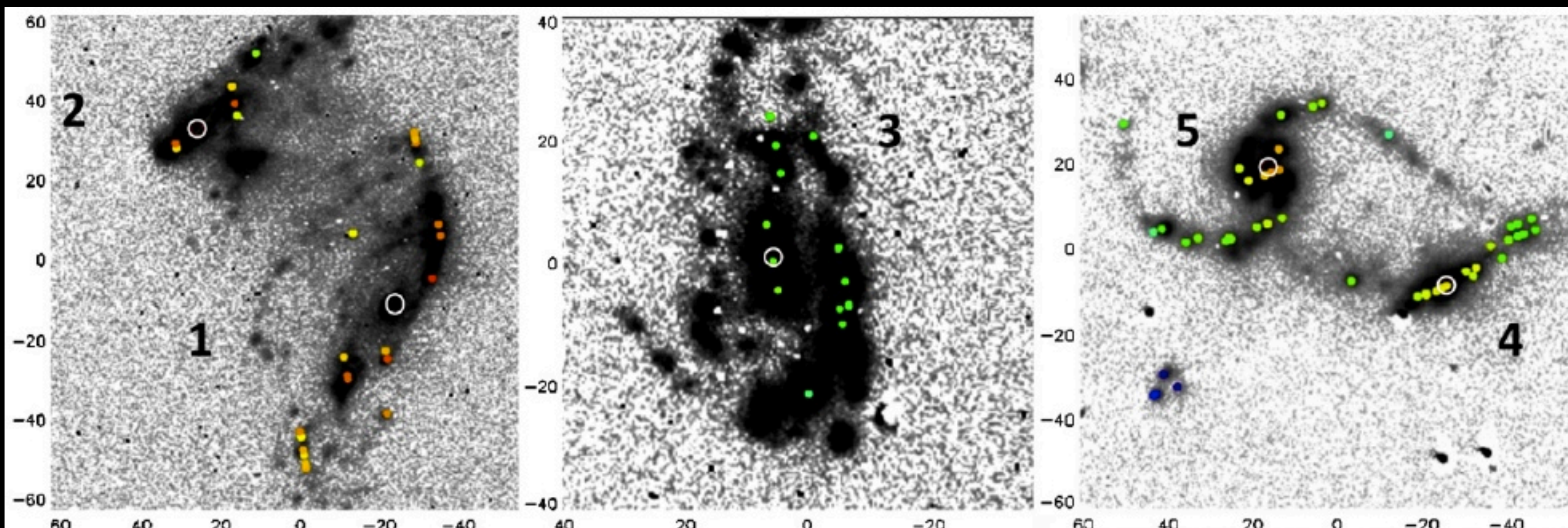
- These newly formed systems can be extremely useful to trace the physical properties of galaxies at large radii... specially the metal distribution of interacting galaxies.

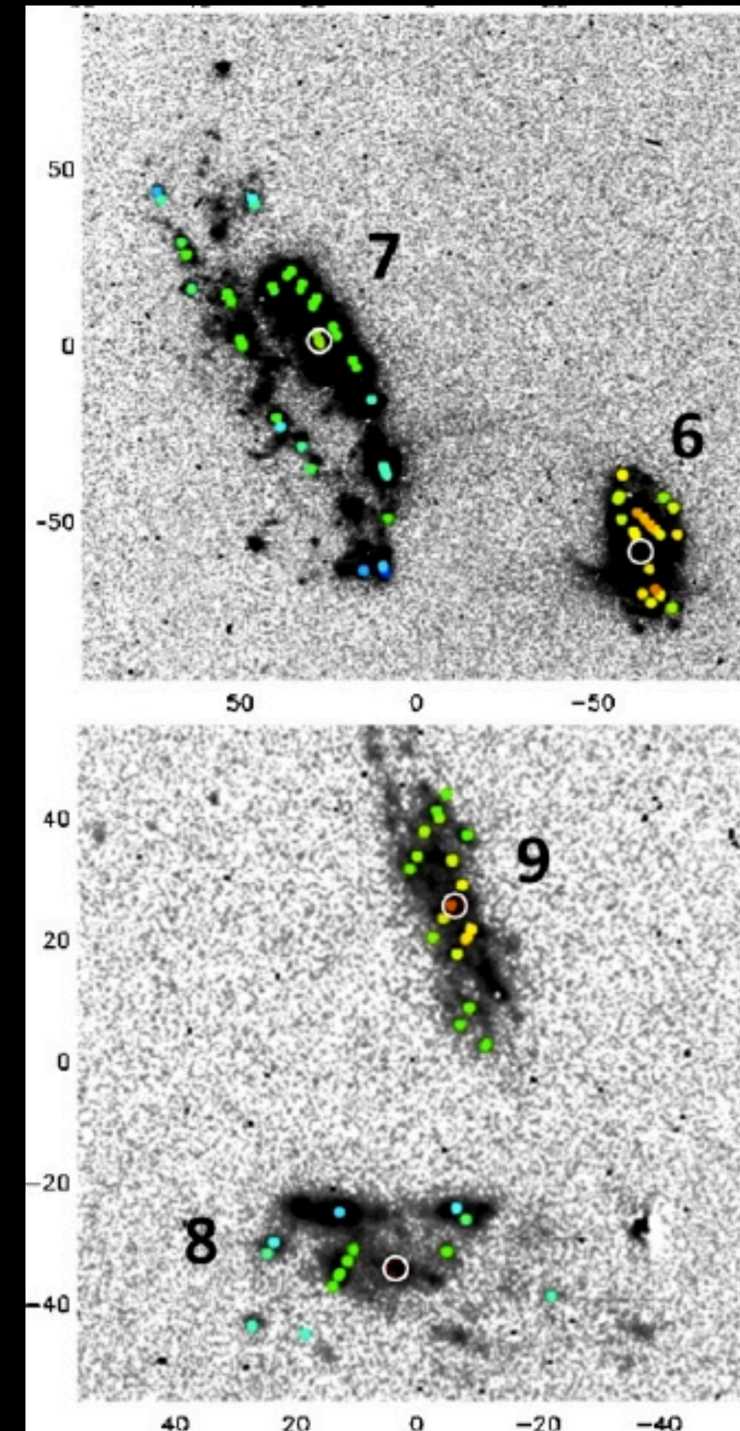
In this sense, what is the metallicity gradient in tidal tails?

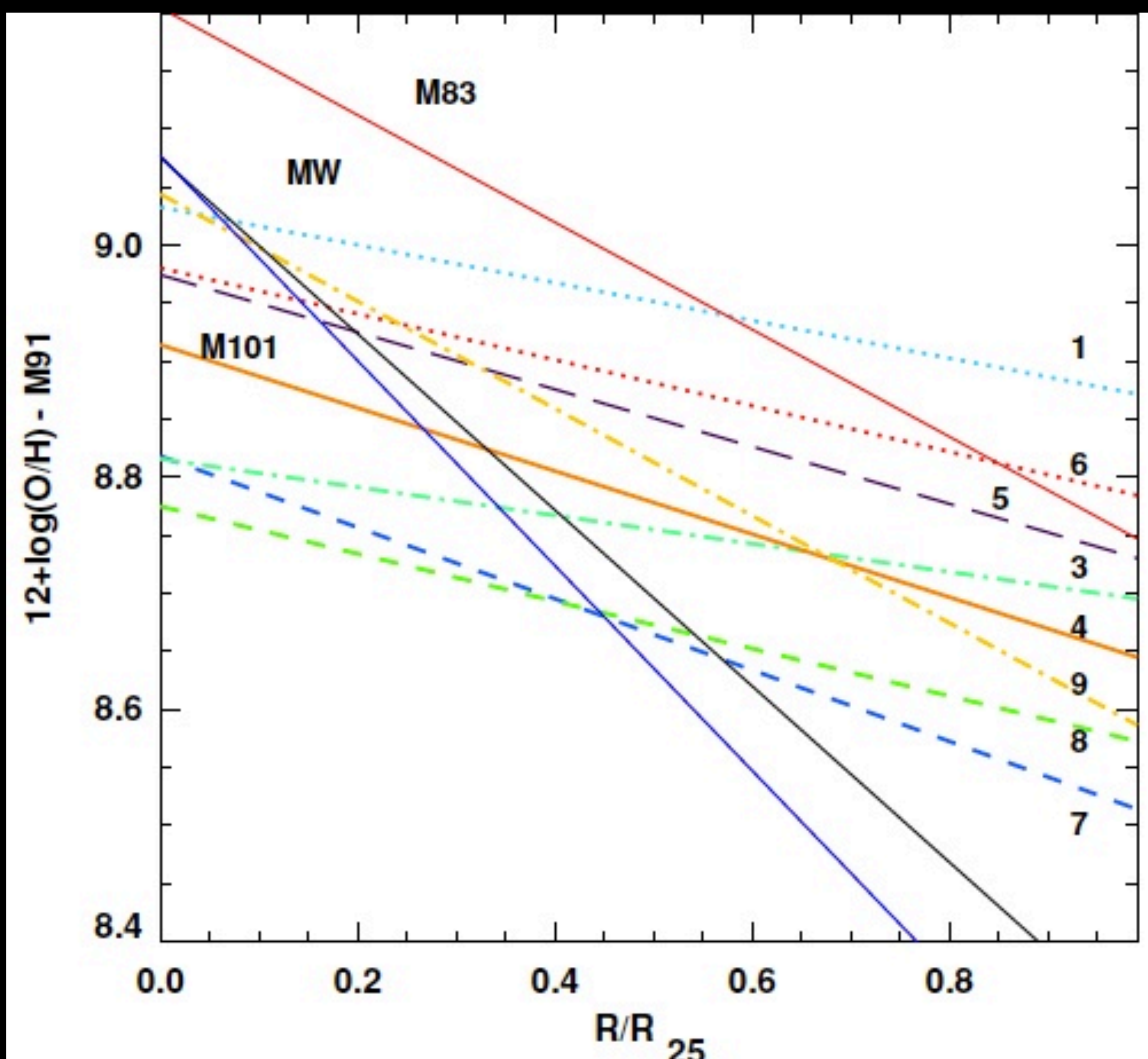


Using a few points, Chien et al. (2007) found a flat metallicity gradient for the tidal tails of this system

In the same context, Kewley et al. (2010) studied the metallicity gradients in a sample of galaxy pairs



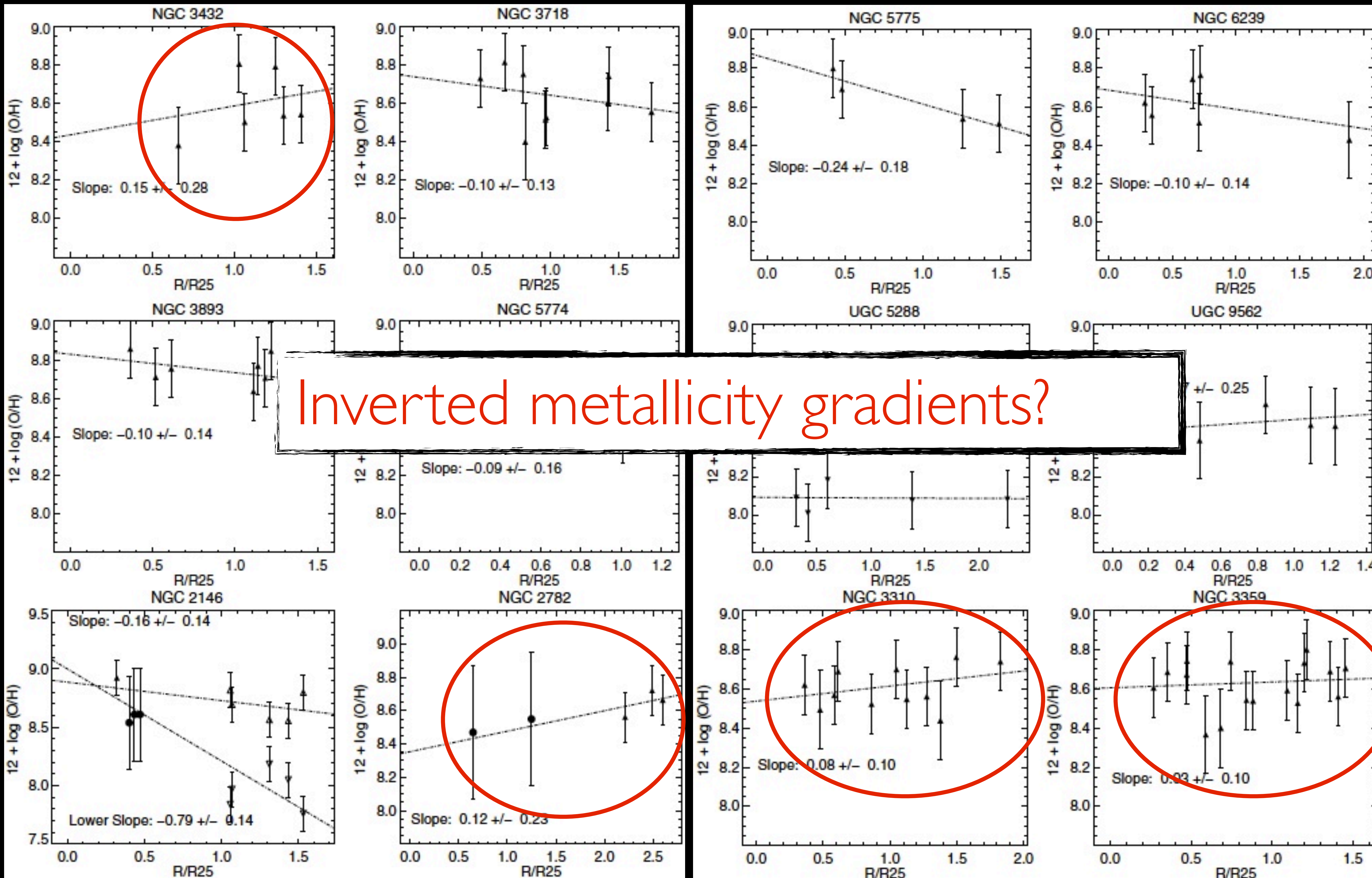




These authors found that galaxy pairs display flatter metallicity gradients than non-interacting objects

Metallicity gradients in other environments/galaxy types have been studied by other authors (e.g Bresolin et al. 2015, Ho et al. 2015, Sanchez et al. 2014)

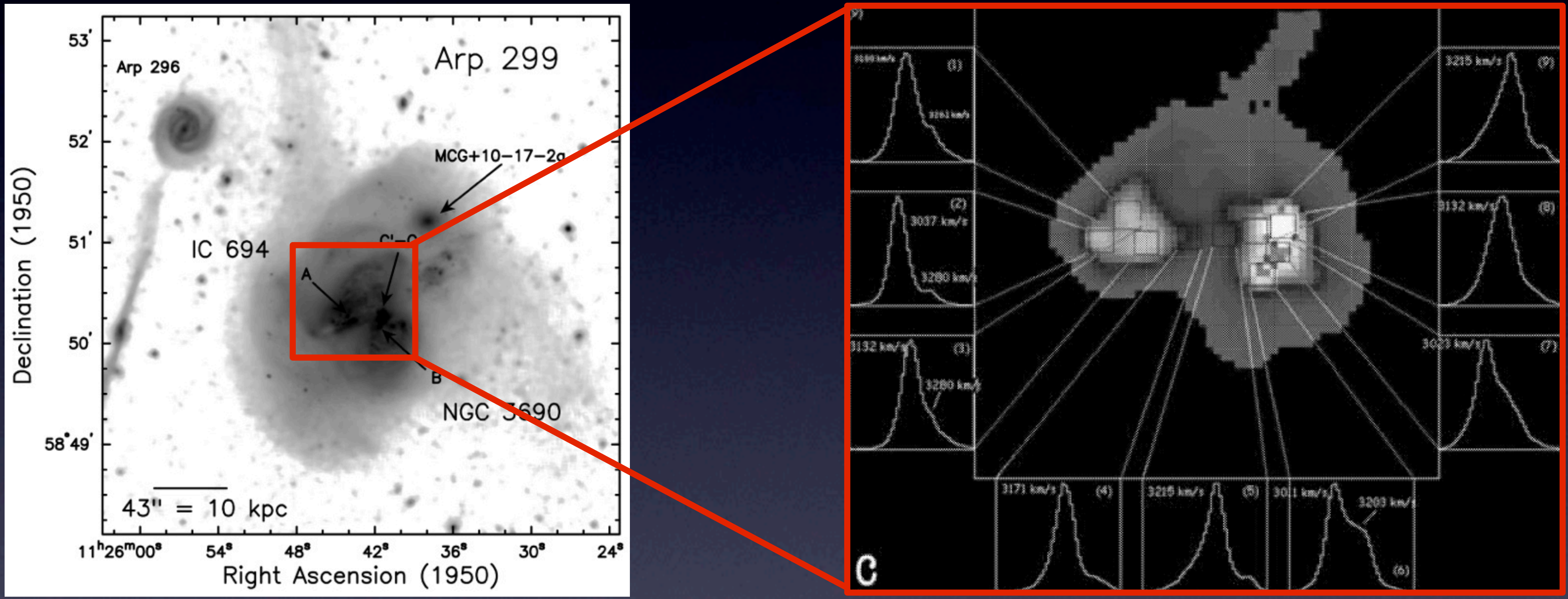
Werk et al. (2011) studied the metallicity gradients for a sample of interacting galaxies



Some effects of the galaxy-galaxy interaction process...

N-body simulations found flat or inverted metallicity gradients for interacting galaxies (Rupke et al. 2010) → This effect could be the result of a mixture of gases coming from the central and the external regions of the interacting galaxies

Also, gas flows along tidal structures can produce a flattening in the metallicity gradient along tidal tails



These facts motivated us to study oxygen abundance gradients in tidal tails and interacting galaxies, for which we have kinematic Fabry-Perot data

Oxygen abundances estimates: Gemini spectroscopic data and O3N2 and N2 methods.
Kinematic information: Fabry-Perot data observed at OHP, SOAR, and ESO 3.6m

This effort complement the work develop by other teams that have used GMOS to determine the effects of the interactions in the properties of galaxy pairs (Krabbe et al. 2014, 2017, Rosa et al. 2014)

Using Gemini/GMOS data we have analyzed some interacting systems...

Observations:

- Multislit technique to observe HII regions in interacting systems.

- Regions selected from u', g and r'-band images.

- We include IFU technique to map one merging system

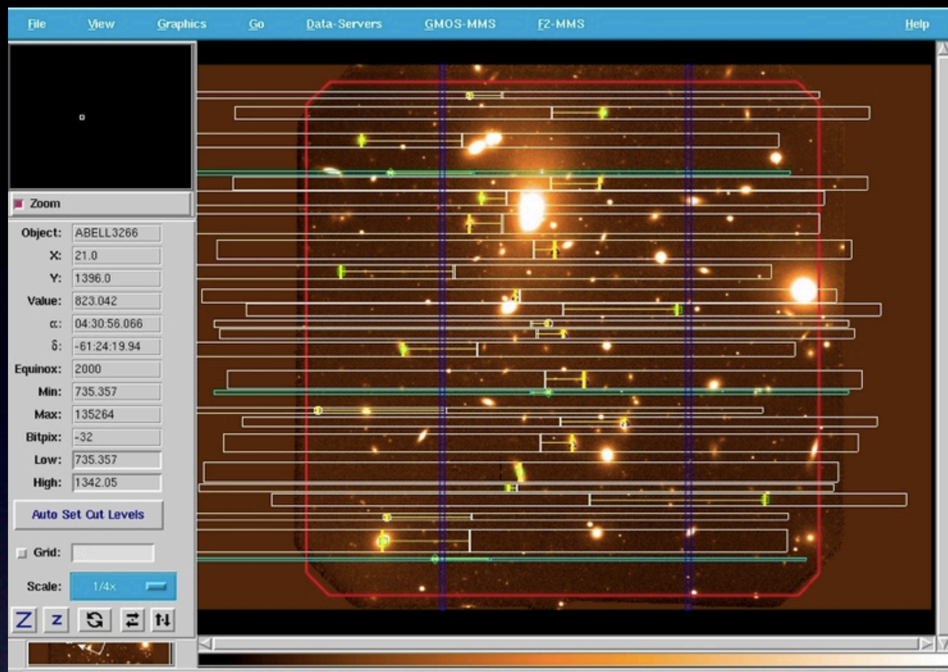
- Spectral coverage includes the main nebular emission lines ([OIII], Hbeta, [NII], Halpha, [SII]). Grating R400

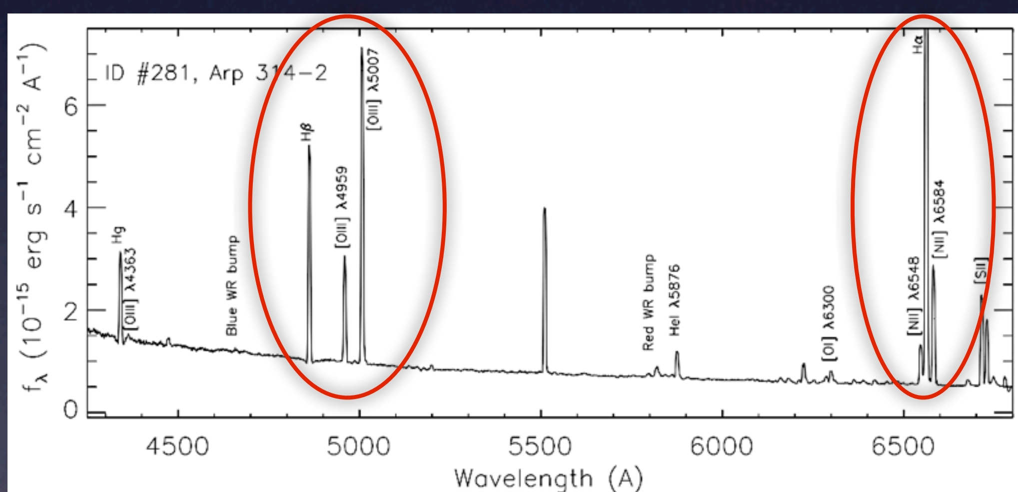
Sample: Southern interacting systems with signs of galaxy-galaxy encounters

- NGC 92
- HCG 31
- NGC 6845
- VV 304
- Arp 314
- NGC 1487

Using Gemini/GMOS data we have analyzed some interacting systems...

Procedure:





Then, oxygen abundances were derived as:

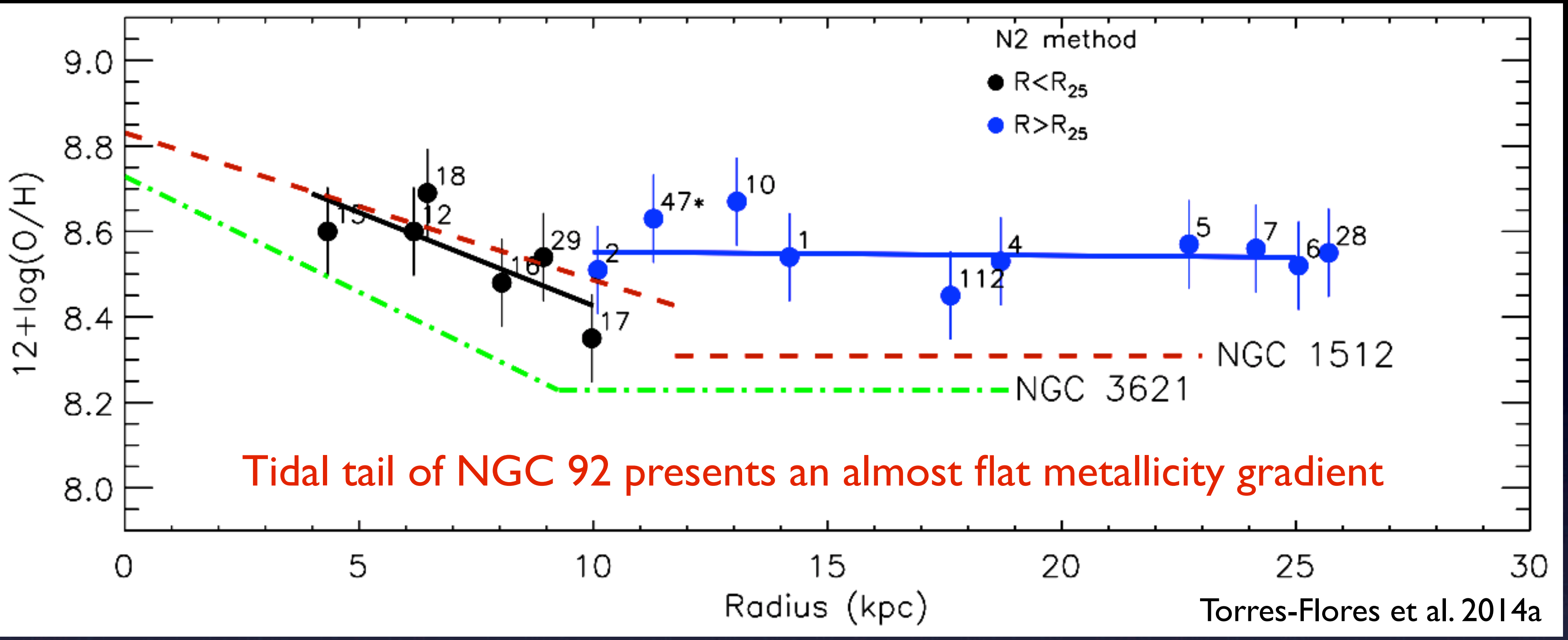
$$12 + \log(\mathrm{O/H}) = 8.533[\pm 0.012] - 0.214[\pm 0.012] \times \mathrm{O3N2}.$$

$$\mathrm{O3N2} = \log\left(\frac{[\mathrm{O\ III}]\lambda 5007}{\mathrm{H}\beta} \times \frac{\mathrm{H}\alpha}{[\mathrm{N\ II}]\lambda 6583}\right)$$

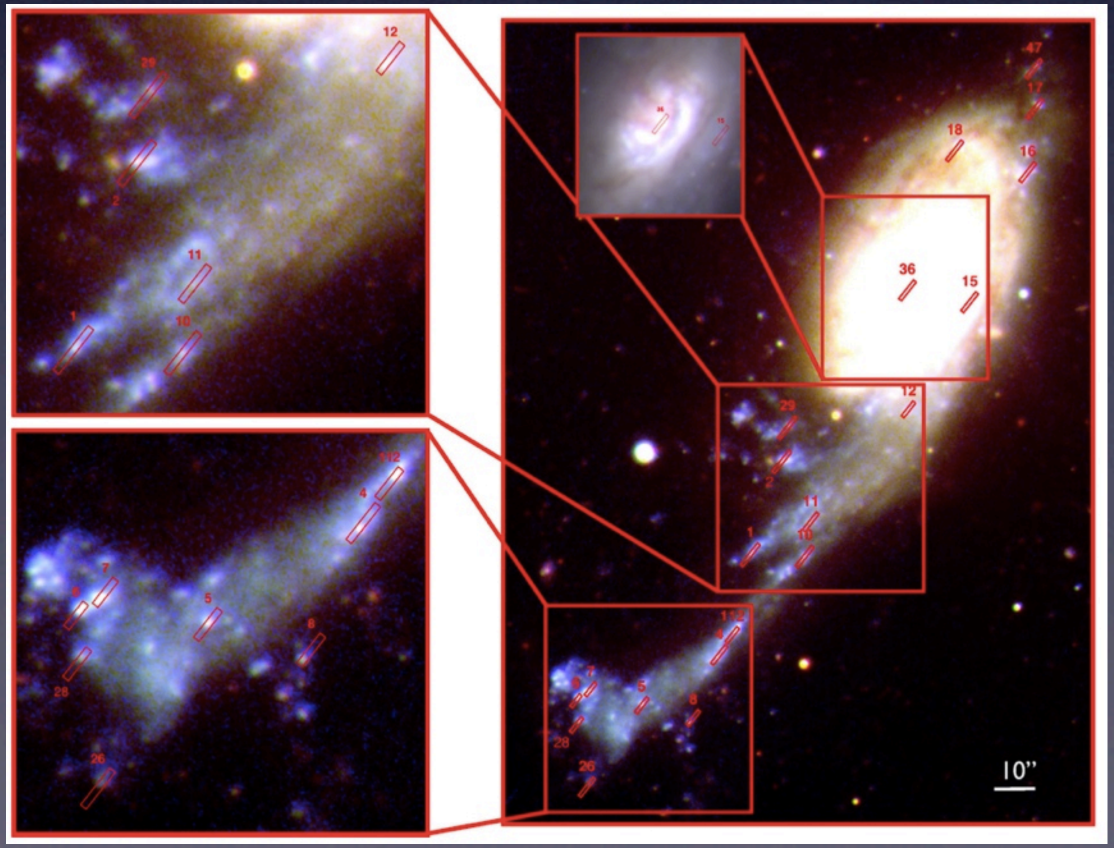
Marino et al. (2013)

Using Gemini/GMOS data we have analyzed some interacting systems...

NGC 92: Main galaxy of the Robert's Quartet CG



Oxygen abundances for different regions were estimated from the O3N2 and N2 methods (Marino et al. 2013)



Regions that are located at $R<R_{25}$ display a shallower slope than non interacting galaxies (e.g. Zaritsky et al. 1994)

Regions at radii larger than R_{25} display constant values for the oxygen abundances

Some comparisons...

The outer region of NGC 92 seems to be more metal rich than NGC 1512 and NGC 3621 (Bresolin et al. 2012)

Radial inflow of low-metallicity gas from the outskirts of the interacting galaxies + ejection of gas from the central regions of these galaxies (Rupke et al. 2010)

and/or

star formation in the tidal tail

and/or

Radial flow of gas along the tail...

Can we check these scenarios?

Star formation in the tidal tail... could it enhance the oxygen abundance during the life of the tidal tail?

Using GALEX data and HI information, we can have an estimation of the time necessary to increase the oxygen abundance from 12+log(O/H)~8.5 to 8.6 (just as an exercise)

$$\frac{O}{H} = \frac{(y_O\, t\, \Sigma_{SFR})}{\mu\, \Sigma_{HI}} \propto \mathrm{SFE}$$

Bresolin et al. (2012)

We found a time of 10 Gyr, using a yield (y_0) of 0.01... and the tail has an age of 190 Myrs!!!

Inverting the exercise, we can obtain the y_0 necessary to increase the oxygen abundances from 12+log(O/H)~8.5 to 8.6 in 190 Myrs...

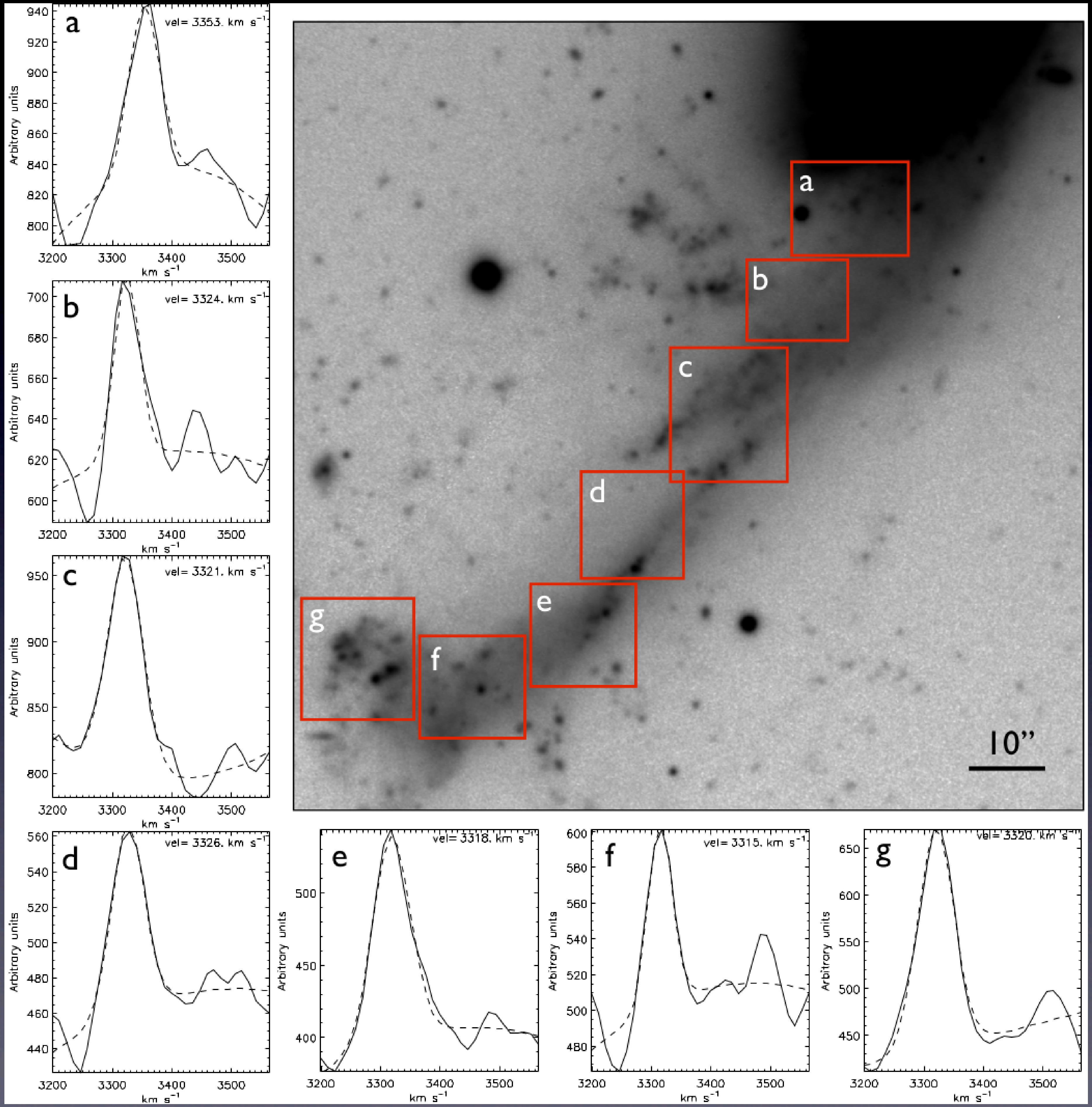
In this case, we derived a yield y_0~0.3, which is too high (typical value of 0.01, Maeder 1992)... however, the tail is gas rich!

Halpha Fabry-Perot observations of NGC 92

There is no flow of ionized gas along the tidal tail!

However, the tail could be in the plane of the galaxy disk and this structure coincides with the PA of the galaxy... in this case could not be possible to measure radial motions

Numerical simulations are needed!



what about the neutral gas...

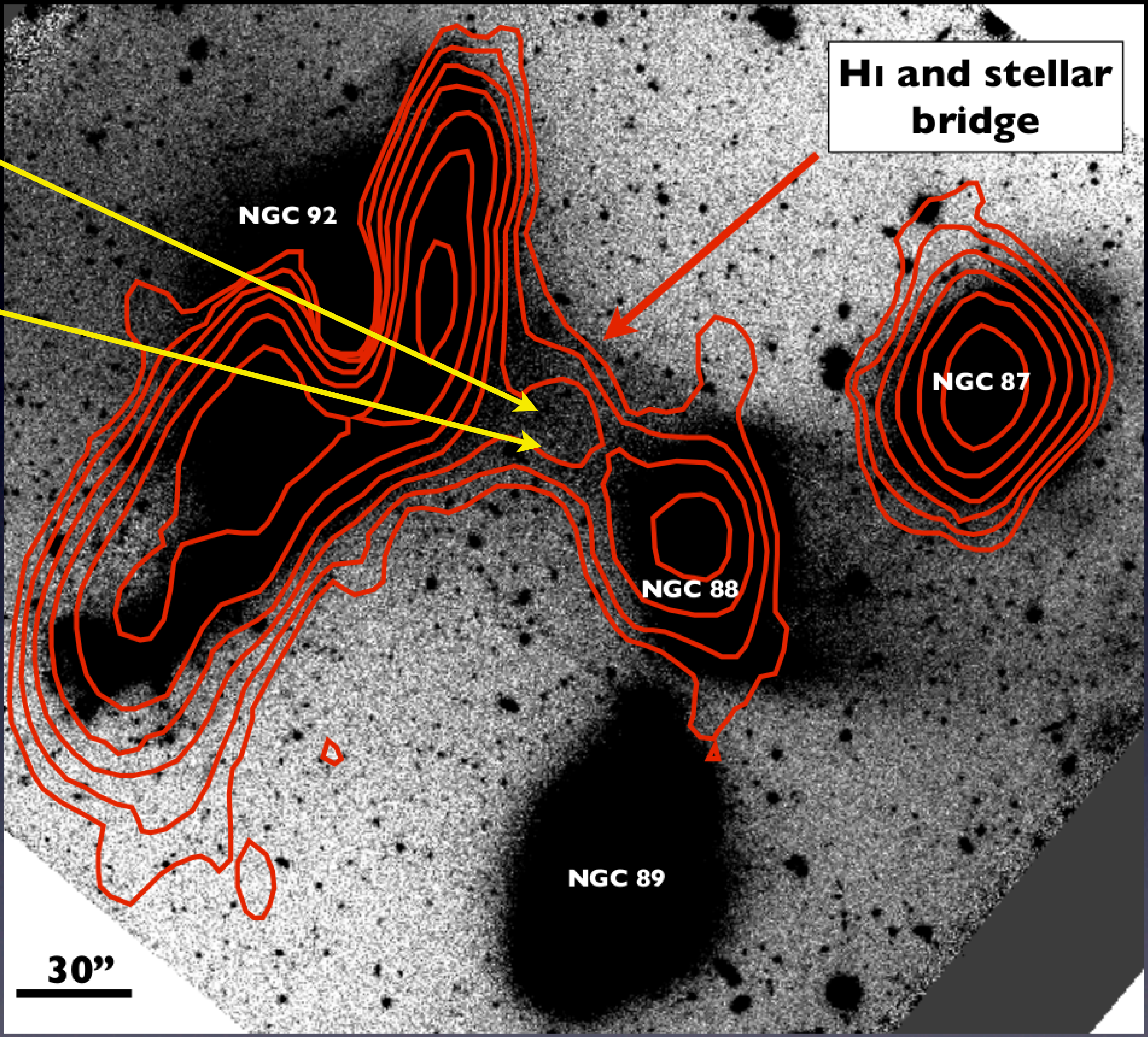
Gemini/GMOS r-band image reveals a stellar bridge between these galaxies

Pompei et al. (2007) found an HI bridge between NGC 92 and NGC 88... gas flows?

In fact, nuclear region of NGC 92 has a SFR~15 Msun/yr (Pompei et al. 2007)
and
NGC 88 has a oxygen abundance of 12+log(O/H)=8.54

Gas from NGC 88 can produce a dilution on the central original abundances of NGC 92 (consistent with Kewley et al. 2006)

Is the mixture of that neutral gas the main driver of a flat metallicity distribution?



The results listed above suggest that the mixing of "metal rich" and "metal poor" gases took place when NGC 92 was interacting with other object. The process of gas flow along the tidal tail is not the main driver in the flattening of the metallicity gradient.

Why does interacting galaxies are important?

Galaxy transformation and evolution

What kind of phenomena can we study in interacting systems?

Formation of new stellar systems

SF process

Chemical evolution

Nuclear activity

What kind of environment favors galaxy-galaxy interactions?

Dense environments

Galaxy pairs/ triplets

Compact groups

Summary

- Galaxies in compact groups appears as excellent laboratories to study galaxy-galaxy interactions.

- These systems are ideal laboratories to study newly formed star-forming regions.

- Interacting galaxies in compact groups display flatter oxygen abundances than the values displayed by non-interacting systems.

- Most of these galaxies display perturbed kinematics. Non-cirular motions can be identified in the residual velocity fields. These motions can be associated with gas flows, which should be responsible in producing the flattening in the abundances.

- Gemini/GMOS appears as a very useful instrument to study interacting galaxies, in its IFU, multislit and longslit mode!!!

Some advertisement...

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APLICATION PROCESS | ACADEMIC STAFF | CONTACT

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PROGRAM INFORMATION

The PhD in Astronomy program aims to train high-level scientists, capable of developing original and independent astronomy research based on a solid conceptual background. Both the astronomical infrastructure available in the north of Chile as well as international facilities will be used to strengthen the country´s scientific development.

The graduates of this PhD in Astronomy program will have a solid background in physical and astronomical concepts, and this will allow them to understand the processes related to the formation and evolution of the different kinds of objects and structures in the Universe, ranging from the formation of stars to the formation of clusters and superclusters of galaxies. Also, the PhD graduates will be autonomous and creative scientists, trained to carry out original research, which will be a real contribution to the national and international knowledge of astronomy. The graduates will be able to work both independently and collaboratively in working groups, with a high self-critical awareness.

http://astro.userena.cl/doctorado/index.html

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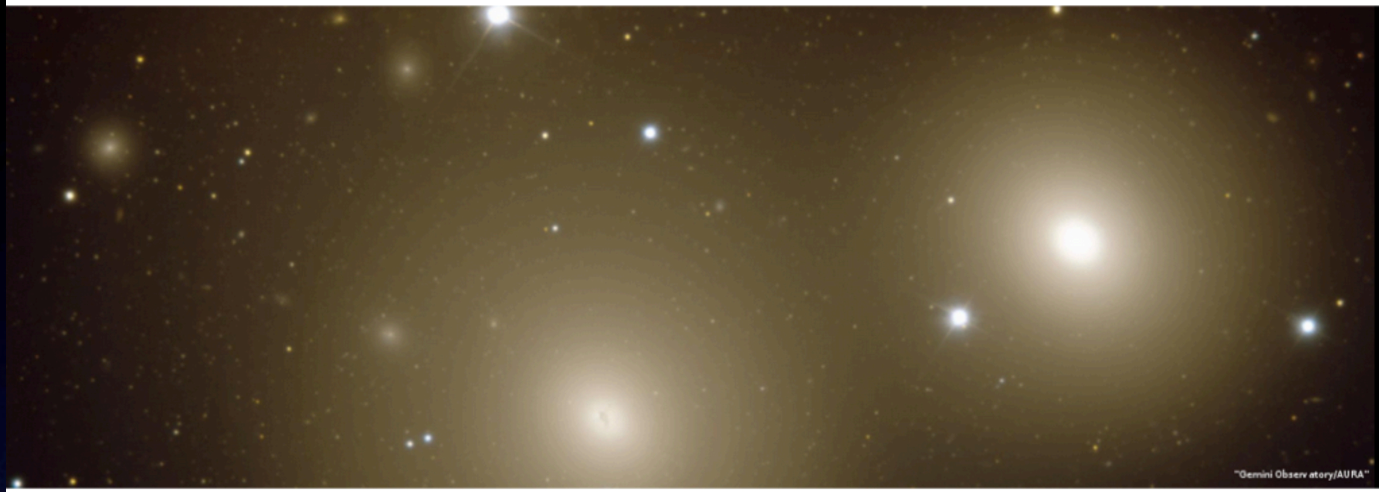
GGC2017

OCTOBER 23 TO 26, 2017 - LA SERENA, CHILE.

HOME PROGRAM PARTICIPANTS REGISTRATION THE VENUE



Galaxy Groups and Clusters II: Laboratories to study galaxy evolution

October 23-26, 2017 - La Serena, Chile.

A meeting organized by the
Physics and Astronomy Department of the University of La Serena.

Scientific Rationale:

Groups and clusters of galaxies are ideal laboratories to study galaxy transformation and evolution. The environment clearly plays an important role in the evolution of galaxies, however, there are several questions that remain open. For instance, how and when does the star formation quenching in galaxies occur? Does the group environment play any significant role in this context? What is the dominant quenching mechanism in dense environments?. The use of multiwavelength and IFU surveys such as SAMI, MaNGA, CALIFA, as well as new facilities like ALMA, MUSE, KMOS, have been used to find answers to these important questions. In addition, the inclusion of state-of-the-art simulations has been extremely useful to explain current observations and understand the underlying physics. However, these efforts should be increased and improved to understand in detail the processes in groups and clusters that transform galaxies. This fact and the need to review the current state of this field have motivated us to organize the second version of a successful meeting that took place a couple of years ago.

Motivation:

The main motivation of this meeting is to discuss recent results related to the evolution of galaxies in different environments, such as groups and clusters of galaxies, from an observational and theoretical point of view. In this second edition, participants are encouraged to highlight the potential of mutliwavelenght surveys, 3D spectroscopy, and advanced simulations in the study of galaxy evolution in dense structures.

Confirmed Speakers

Dennis Zaritsky, University of Arizona, USA

Alberto Molino, Universidade de Sao Paulo. Brazil

Matthieu Schaller. Inst. for Computational Cosmology. England

Julie Nantais, Universidad Andres Bello. Chile

Facundo Gomez. Universidad de La Serena. Chile

Antonela Monachesi, Universidad de La Serena. Chile

Yara Jaffe, ESO, Chile.

Marcus Vinicius Duarte, Universidade de Sao Paulo, Brazil.

Timeline

July 12, 2017: First announcement.

September 7, 2017. Contribution deadline (posters and talks)

September 15, 2017. Registration deadline

October 23-26, 2017: Meeting.

GEMINI OBSERVATORY

http://astro.userena.cl/GGC2017/

Thank you!