

Galaxies and Clusters of Galaxies

Task Leader: Andrew J. Humphrey

Mission Statement

We aim at providing world-class contributions to the understanding of the assembly history of galaxies. Our strategic focus is on the observational aspects of extragalactic astronomy (ranging from the radio to the X-ray).

The Team members are involved in several international collaborations: Euclid Consortium; CALIFA Survey; Sloan Digital Sky Survey (SDSS); XMM-Newton Cluster Survey (XCS).

Researchers

Mercedes E. Filho
Jean Michel Gomes
Andrew J. Humphrey
Patricio Lagos
Catarina Lobo
Breezy Ocaña Flaquer
Polychronis Papaderos
Pedro T.P. Viana

PhD & MSc Students

Leandro S. M. Cardoso
Rui A. A. Fernandes
Bruno R. L. Ribeiro

Collaborators

Sónia Antón
Jarle Brinchmann
Paula A. M. Brochado

Main research fields

- Assembly history of massive galaxies & their co-evolution with Active Galactic Nuclei (AGN) since $z \approx 4$
- Galaxy clusters and their impact on galaxy evolution
- Dwarf galaxies as building blocks of normal galaxies

Expertise

- Structural investigations of galaxies via (optical & near-infrared) surface photometry
- Radioastronomical studies of galaxies (21 cm HI, molecular gas, radio continuum): single-dish & interferometry
- X-ray imaging & spectroscopy (ROSAT, XMM-Newton, Chandra)
- Single-fiber & longslit spectroscopy: determination of chemical abundances and kinematics
- **Integral Field Unit (IFU) spectroscopy**
- Spectral (evolutionary & population) synthesis

We place special emphasis on

- a) the development and consolidation of expertise in the new technique of IFU spectroscopy
- b) the development of conceptually novel, self-consistent and CPU-time efficient spectral synthesis codes, permitting exploration of the star formation history of galaxies

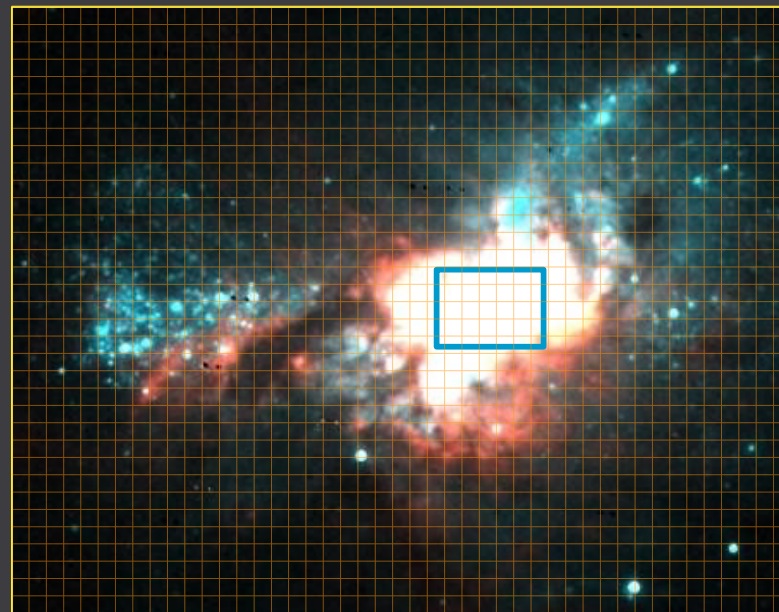
with the mid-term (~ 5 yr) goal of

becoming one of the leading European research centers in galaxy evolution studies

IFU spectroscopy



Longslit or single-aperture
spectrum within 1-5 arcsec



IFU array (1 arcsec/spaxel)

- by more than an order of magnitude more efficient than traditional longslit & single-fiber spectroscopic techniques
- permitting *spatially resolved* studies of the
 - chemical abundance patterns and kinematics of the warm ($\sim 10^4$ K)
 - the **star formation history (SFH)** and **chemical properties** of the stellar component

Limitations of existing IFU spectrographs: small field of view (≤ 50 arcsec) with ≤ 6000 spaxels (spectral pixels) + low spectral resolution ($R \sim 800$) and/or narrow spectral range (≤ 2000 Å)

Next-generation IFU spectrographs will overcome these limitations.

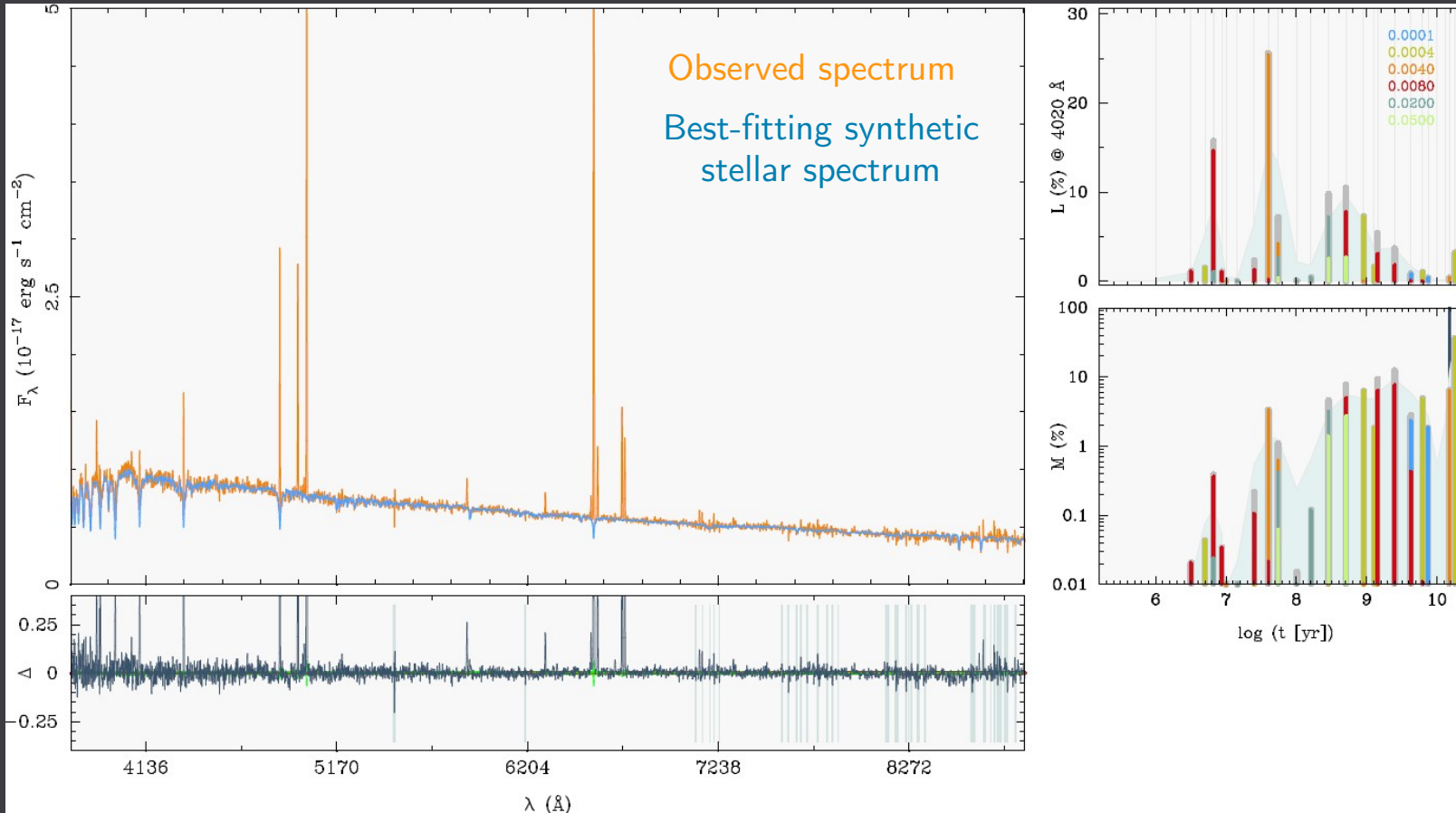
Example: **ESO VLT/MUSE** (2013/14): **90,000 spaxels** over a **field of view of 1 arcmin**

Very soon (2014-2016): **MEGARA** @ 10.4m GTC, **VIRUS** @ 9.2m HET

Spectral Synthesis

permits derivation of the star formation- and metal enrichment history of galaxies.

Two (complementary) approaches: **evolutionary** and **population** (or semi-empirical) spectral synthesis models



Luminosity
contribution
 x_i of
Simple Stellar
Populations

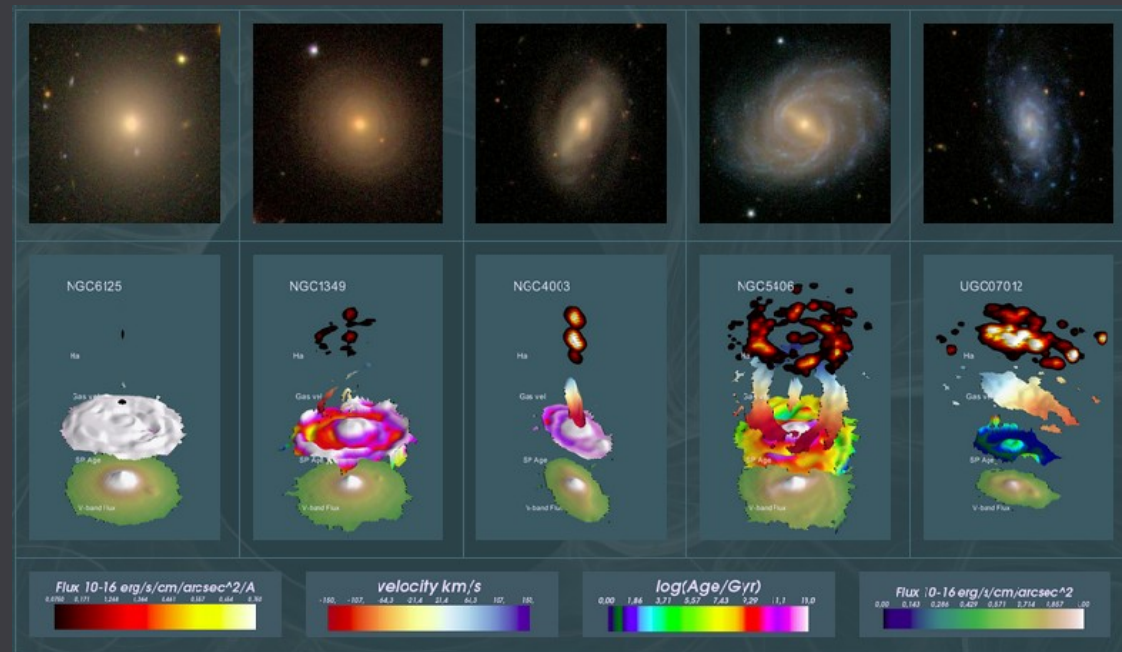
Mass
contribution
 μ_i of
Simple Stellar
Populations

Limitations

- related to the spectral resolution, missing physical ingredients in fits (multiple extinction components, nebular emission, AGN power-law), degeneracies in the fits, high CPU time consumption (i.e. 5 min/fit on an i7@2.93 GHz CPU → 300 CPU days for a VLT/MUSE IFU data cube)
- a new generation of spectral synthesis codes is needed to cope with the challenges posed by (and take advantage of) future IFU spectrographs + a pipeline for automated processing & post-processing of IFU data

Galaxies and Clusters of Galaxies

- **Porto3D** pipeline (automated spectral synthesis and post-processing of IFU data cubes
→ first science paper from the CALIFA IFU Galaxy Survey)



- **FADO** & **REBETIKO** (population & evolutionary synthesis codes, under development at CAUP)*

*: Project supported by the FCT grant “An exploration of the assembly history of galaxies with the novel concept of self-consistent spectral synthesis”



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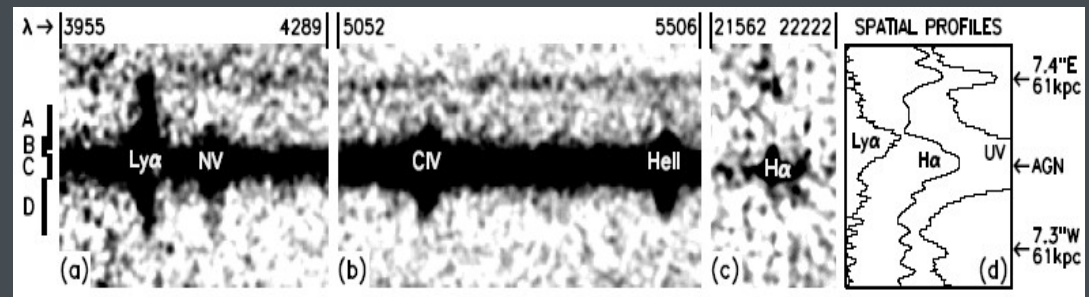
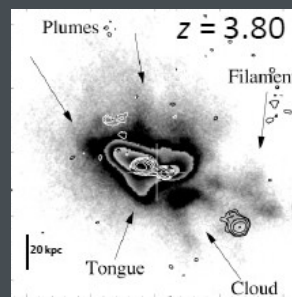
Collaborators

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Paula A. M. Brochado

- Assembly history of massive galaxies & galaxy-AGN co-evolution
 - gas inflow, starburst activity & Active Galactic Nuclei (AGN) in massive galaxies at $2 \leq z \leq 4$: extended nebular and Lyman- α halos and starburst/AGN-driven feedback



An extended Lyman- α halo around a high- z QSO (Humphrey et al. 2012)

- IFU spectroscopy of the stellar and ionized gas component in Ultraluminous Infrared Galaxies
- role of dry mergers on the buildup of massive galaxies



P. Brochado (2013, PhD Thesis, University of Porto) & Brochado et al. 2013, in prep.)

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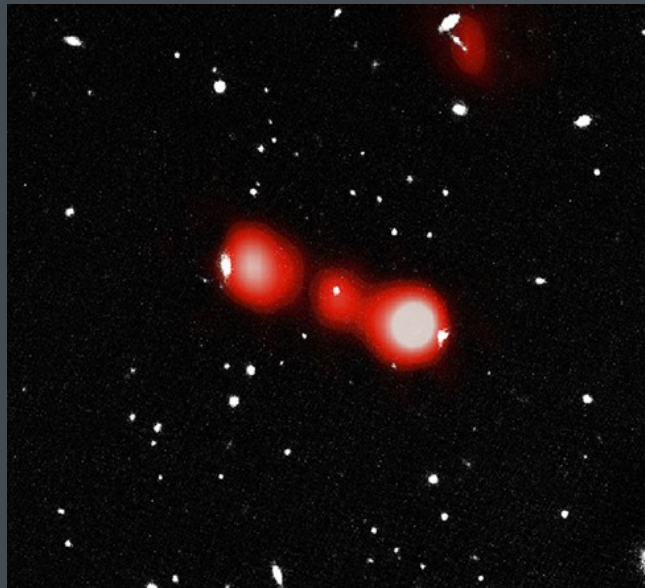
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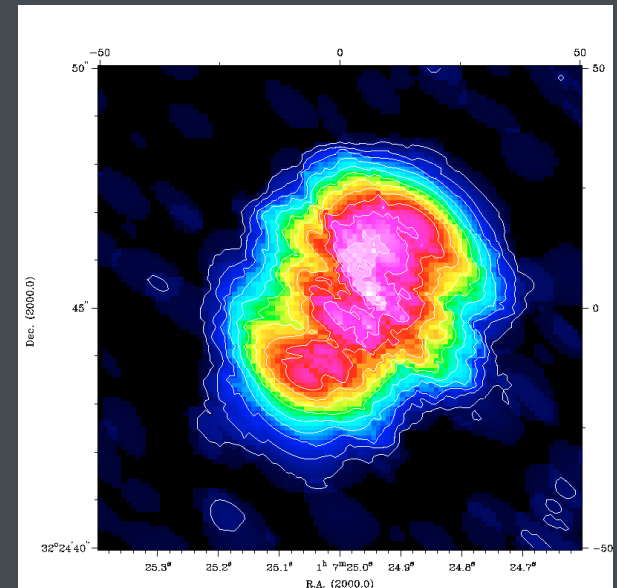
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■ Assembly history of massive galaxies & galaxy-AGN co-evolution

- AGN: Synchrotron emission and spectral energy distribution
- Molecular gas reservoir and fueling of AGN activity



Radio continuum map of a reborn AGN (Filho et al. 2011)



CO (1→0) map of the radio galaxy 3CR 31 (Ocaña-Flaquer et al. 2010)

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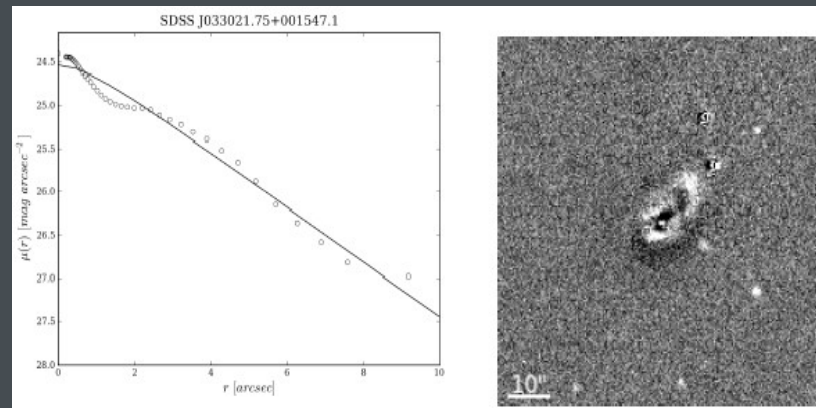
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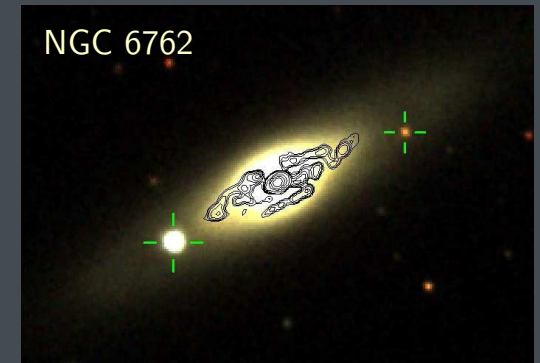
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& CAAUL team

- Assembly history of massive galaxies & galaxy-AGN co-evolution
- Bulges vs pseudo-bulges: photometric properties and morphological substructure, chemical properties, star formation history (SDSS & CALIFA data)

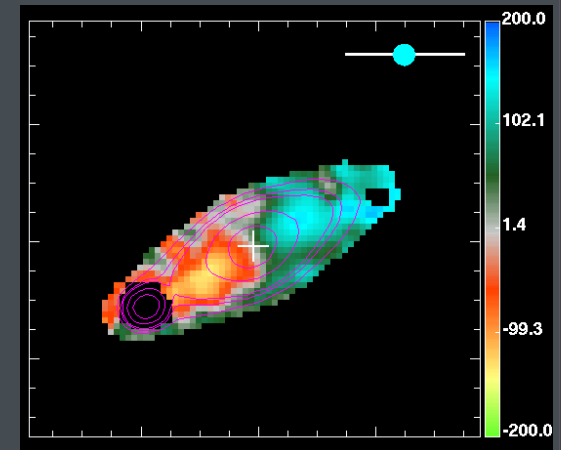


Example from the photometric analysis of a pseudo-bulge galaxy from SDSS (B. Ribeiro, MSc thesis, University of Porto 2012; Ribeiro et al. 2013, in prep.)

NGC 6762



Unsharp-masked SDSS image
(Kehrig et al. 2012)



Gas velocity field (CALIFA data)
(Gomes et al. 2013, in prep.)

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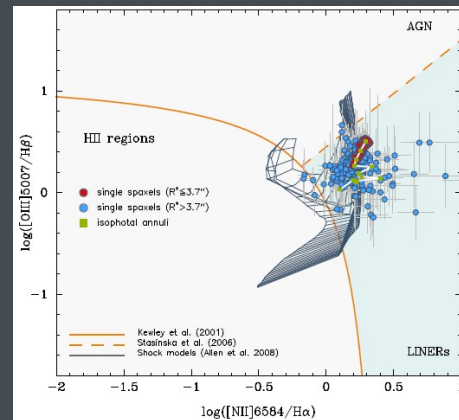
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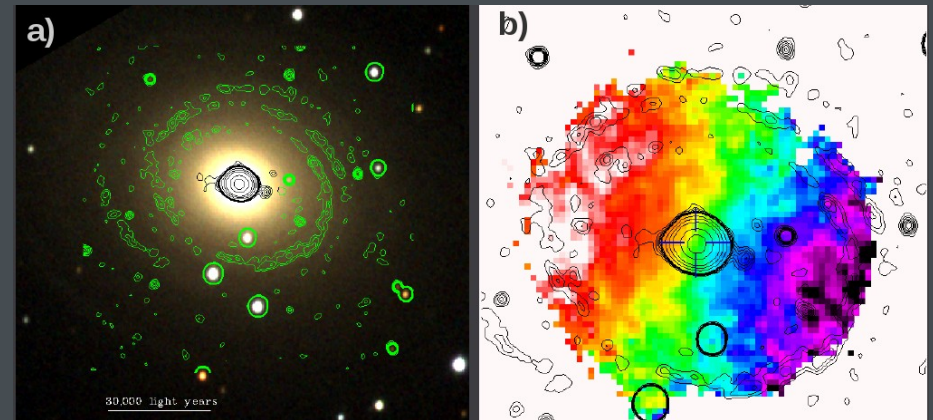
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■ Assembly history of massive galaxies & galaxy-AGN co-evolution

- Gas excitation mechanism(s) in elliptical galaxies (AGN, hot post-AGB stars, large-scale shocks?)
- Circum-nuclear star formation in AGN



Diagnostic emission-line ratio diagram for the elliptical AGN/LINER galaxy NGC 1167, based on CALIFA IFU data (Papaderos et al. 2013, in prep.)



(a) Unsharp-masked SDSS image of the elliptical galaxy NGC 1167 (contours) overlaid with a g band broad image.
(b) Stellar velocity field of NGC 1167, derived with Porto3D from CALIFA IFU data (from Gomes et al. 2013, in prep.).

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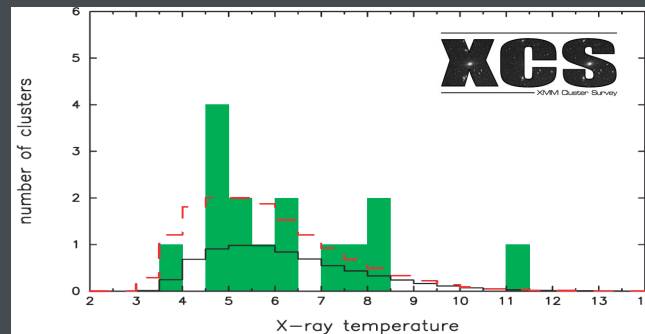
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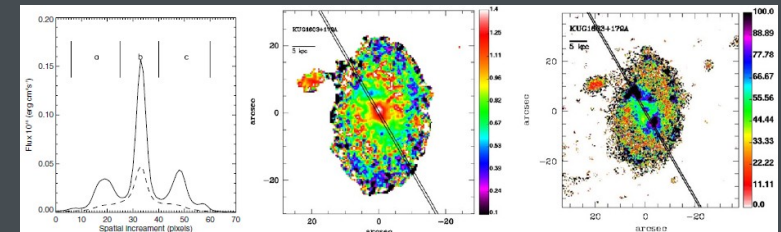
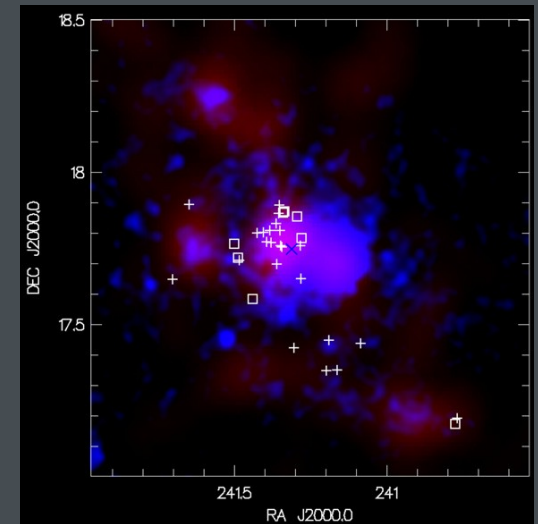
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Galaxy clusters and their impact on galaxy evolution

- Role of baryonic gas physics on the formation and evolution of groups and clusters of galaxies. The gas properties provide clues to the environmental influence on the galaxy population and are a proxy for the total mass of galaxy clusters, allowing for their use as cosmological probes.
- Star formation history and morphological galaxy transformations in clusters



Viana et al. (2012): XCS Survey



Petropoulou ... Papaderos et al. (2011)

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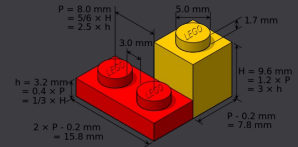
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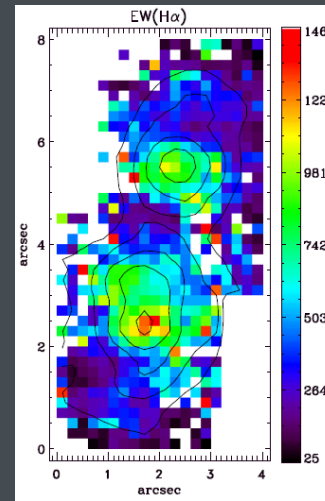
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■ Dwarf galaxies as building blocks of normal galaxies

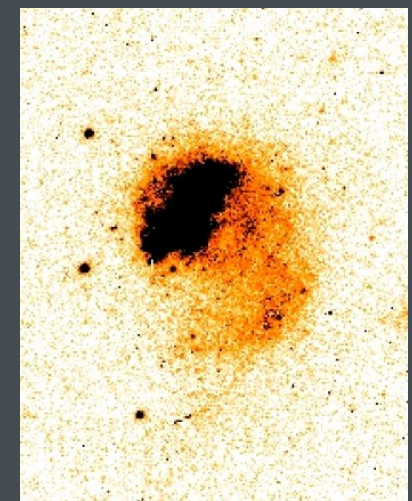
- A complete, volume-limited survey of dwarf galaxies in the nearby Universe (AVOCADO)
- Compact, low-mass starburst galaxies (*green peas*) at intermediate z
- HST & IFU studies of extremely metal-poor star-forming dwarf galaxies
- Nature of cometary dwarf galaxies



I Zw 18 (Papaderos et al. 2012)



HS 2236+1344 (Lagos et al. 2013a)



Tol 65 (Lagos et al. 2013b)