GLACE: GaLAxy Cluster Evolution Survey

Overview and status

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and

the GLACE team

Outline of this Presentation

1. GLACE in a nutshell
2. Scientific motivation
3. Objectives
4. Survey requirements
5. Technical implementation
6. Observations
7. Data reduction
8. First results: Cl0024+1654
9. Conclusions

GLACE in a nutshell

- GLACE is a large OSIRIS/GTC survey aimed to study the evolution of ELGs within galaxy clusters across the cosmic time.
- Targeting several clusters in three different redshift windows (~0.40, ~0.63, ~0.86) chosen to avoid strong atmospheric OH lines.
- The observation technique is Tunable Filter (TF) scan mode.
- Several emission lines to be observed (depending on z): [OII] 3727, Hβ, [OIII]5007, Hα/[NII].
- GLACE@0.86 was presented and approved as an ESO/GTC programme in period 86B. Observations have been just started (semester 11A).
- GLACE@0.40/0.65 are being implemented as standard CAT (Spanish Time allocation) proposals plus OSIRIS guaranteed time.

The GLACE Team

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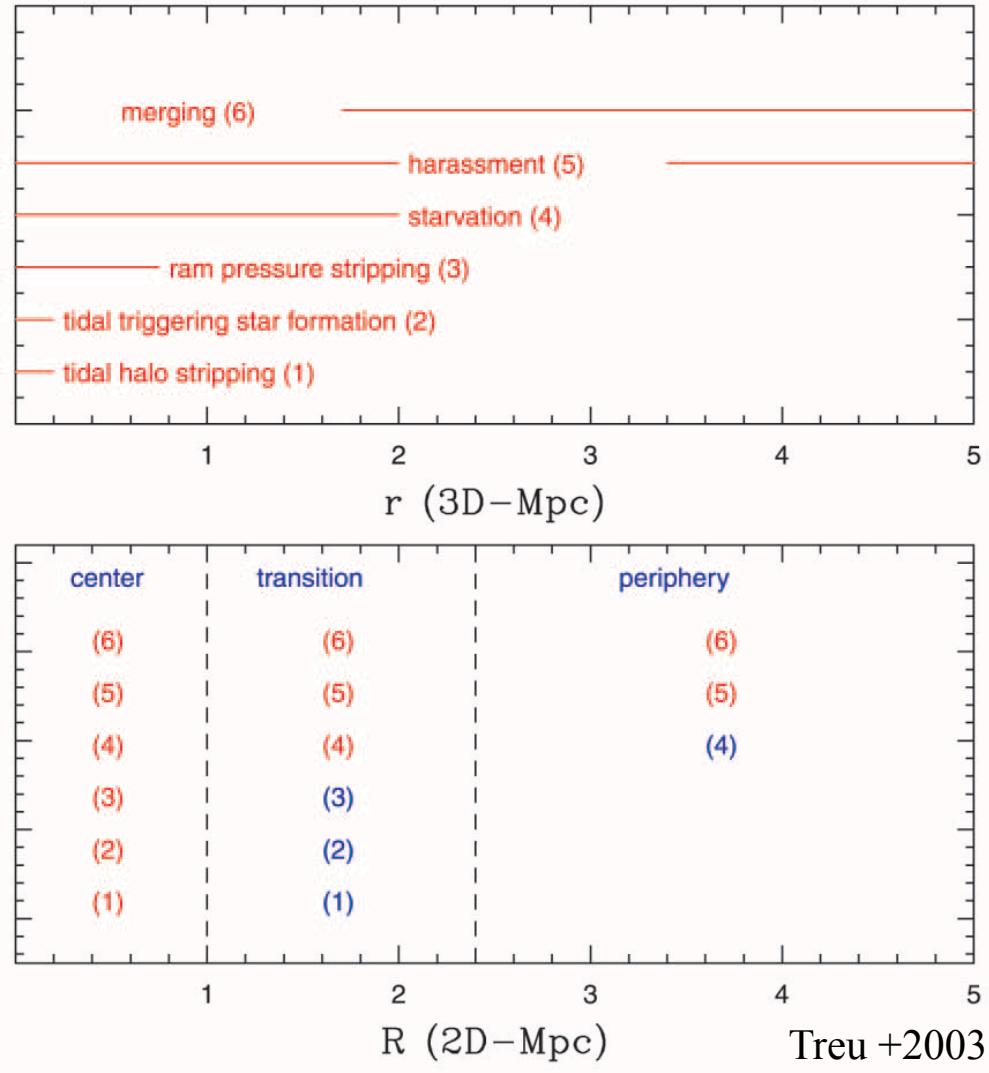
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Scientific motivation I

- The cores of nearby clusters are dominated by red, passively evolving early-type galaxies. At higher redshift, significant evolution of the properties is observed (BO effect)
- Increase of (obscured) SF and AGN activity with cosmic time.
- Even in a single epoch, aspects of these evolutionary trends are seen with cluster-centric distance (e.g. colour gradients).
- It is very likely that the build-up of clusters through accretion modifies the properties of galaxies as a function of redshift and environment (e.g. quenching star formation, transforming spirals into S0s).
- Several mechanisms (sometimes with opposite effects) can be in place, including:
  - Galaxy-ICM interactions:ram-pressure stripping, thermal evaporation of ISM, turbulent and viscous stripping, pressure-triggered SF. When a slow decrease of the SF is produced, these mechanisms are collectively labelled as *starvation*
  - Galaxy-cluster gravitational potential interactions: tidal compression, tidal truncation
  - Galaxy-galaxy interactions: mergers (low-speed interactions), harassment (high-speed interactions)

Scientific motivation II

- Each mechanism is most effective in a different environment, leaving a footprint on data.
- TF narrow-band imaging is specially well suited for such a study



GLACE objectives

GLACE is an innovative survey of ELGs aimed to study the evolution of galaxies in clusters and clusters of galaxies, addressing a number of issues, including:

- Star formation in clusters:
  - ✓ Variation of star formation properties with position within the large-scale structure, testing different models of environmental influence in galaxy evolution (galaxy-galaxy, galaxy-ICM interactions).
  - ✓ Star formation history of galaxies in clusters
- The role of AGNs (fraction vs. density) → We will be able to discriminate SF/AGN using standard diagnostics (BPT)
- Distribution of galaxy metallicities: effect of environment in metallicity (metallicity-environment relation), metallicity gradient across the cluster. R23, N2, N2O3 methods.
- Cluster accretion history: evolution of the galaxy accretion rate (infall).

In addition, we will get:

- Wealth of accurate galaxy redshifts
- Comparison of field vs. cluster galaxies at similar redshift (at the z=0.4 OTELO window)
- Optical counterparts of HERSCHEL clusters (PEP)
- Optical cooling flows in cluster central galaxies (by-product)
- Field LAEs and other outliers including lensed images (by-product)

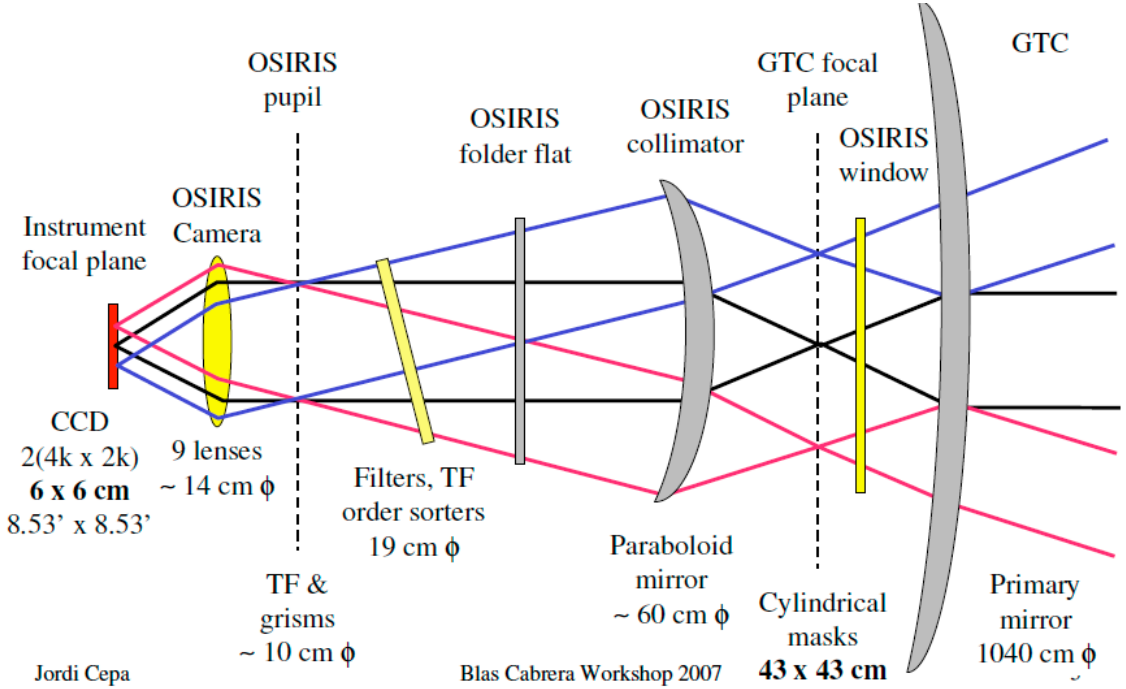
GTC in a nutshell

- Fully steerable alt-az telescope
- Segmented f/17 primary of 10.4m effective diameter
- With 36 segments
- Pupil at secondary mirror
- Secondary made of Be with fast tip-tilt capabilities
- 7 Focal stations:
  - 2 Nasmyth→ currently equipped with de-rotators
  - 1 Cassegrain
  - 4 Folded Cassegrain
- Day one instruments: OSIRIS & CanariCam



OSIRIS in a nutshell

- Selected as optical Day One instrument in 1999 after an international Announcement of Opportunity
- Multiple purpose instrument (multiplexing modes): broad- and narrow-band imaging, long- slit and MOS spectroscopy and fast modes
- Wide FOV
- High red efficiency and good UV-blue transmission
- Excellent image quality
- Very small overheads (1/5-1/10 that of similar instruments)
- Maximum spectral resolution 5.000 (higher R under study)
- First common user instrument using TF in 8-10m telescopes
- Build by IAC with IA-UNAM collaboration



TF basics

A TF is an etalon with micron cavity spacing

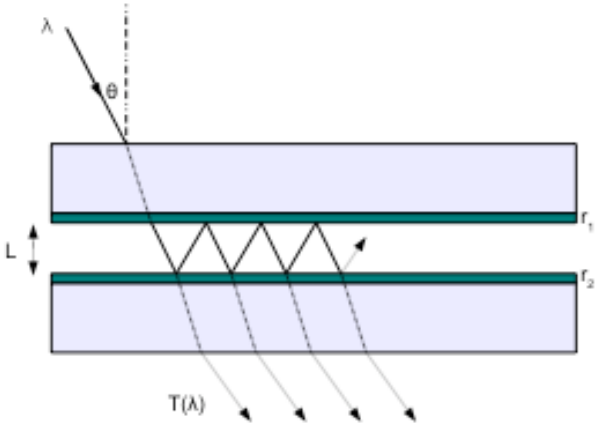
I.e.: sees the Jaquinot spot (nearly monochromatic FOV)

Is equivalent to very low R 3D spectroscopy

However there is a λ drift to the blue from centre to edge

Tuning cavity spacing allows selecting wavelength and FWHM

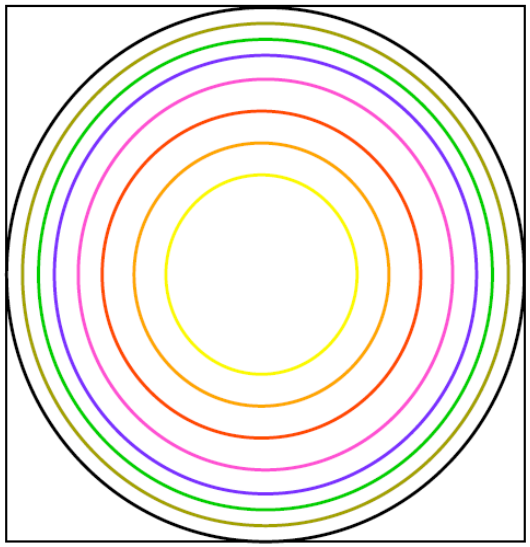
$$m\lambda = 2\mu L \cos\theta$$



•To cover the full wavelength range (365-1000 nm) OSIRIS have two TF that overlap at the zero redshift Hα line:

- **Blue: 365-670 nm**
- **Red: 650-1000 nm**

$$\lambda(r) = \lambda_0 \left[1 - 7{,}9520 \times 10^{-4} \left(\frac{r}{arcmin}\right)^2\right]$$



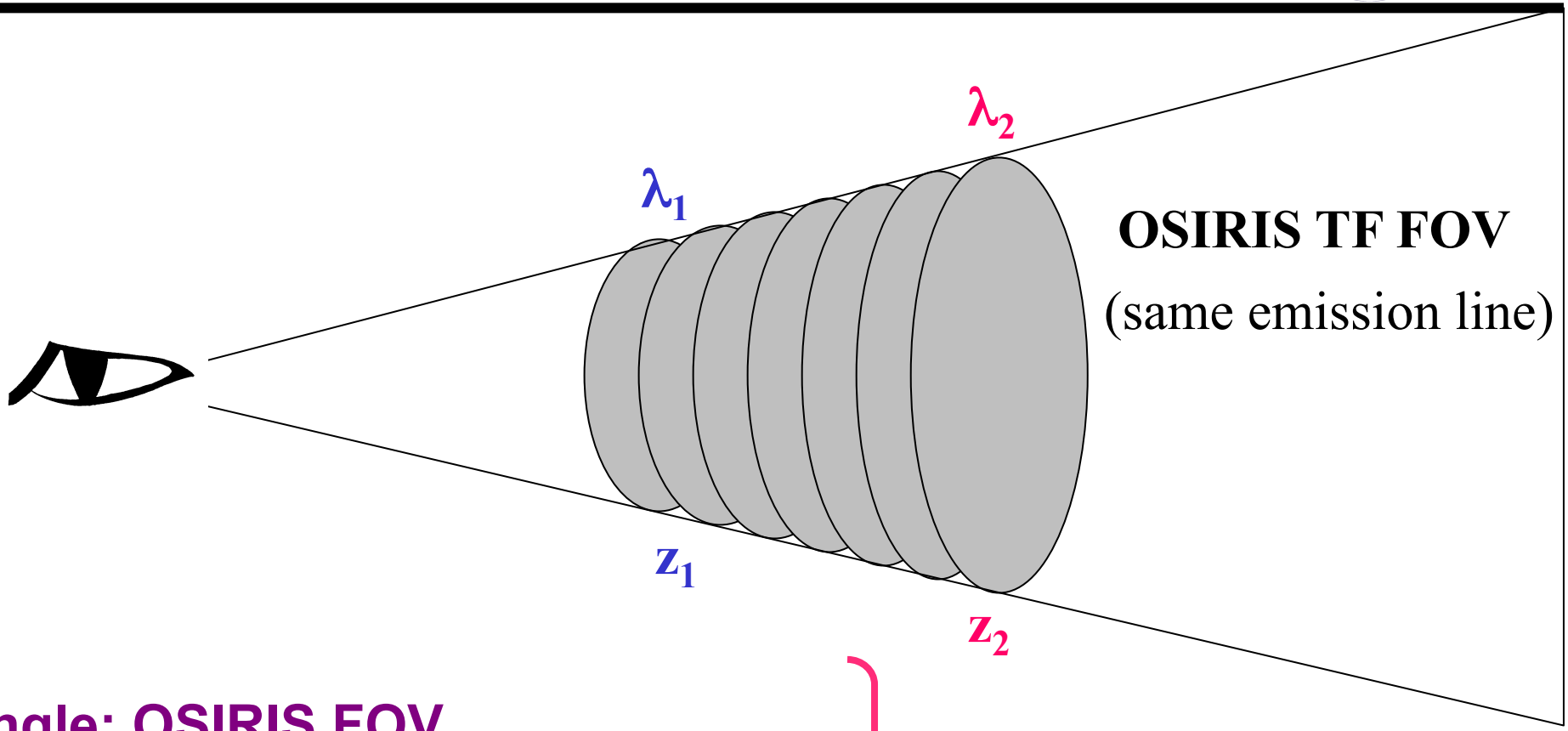
For OSIRIS TF the shift from centre to edge (at 4') is 1.27% (i.e.: –83 Å @ 6563 Å).

λ_C = 656 nm
655 nm
654 nm
653 nm
652 nm
651 nm
650 nm
649 nm
648 nm

The key issue is the differential line transmission along target

Jordi Cepa Blas Cabrera Workshop 2007 27

TF tomography with OSIRIS

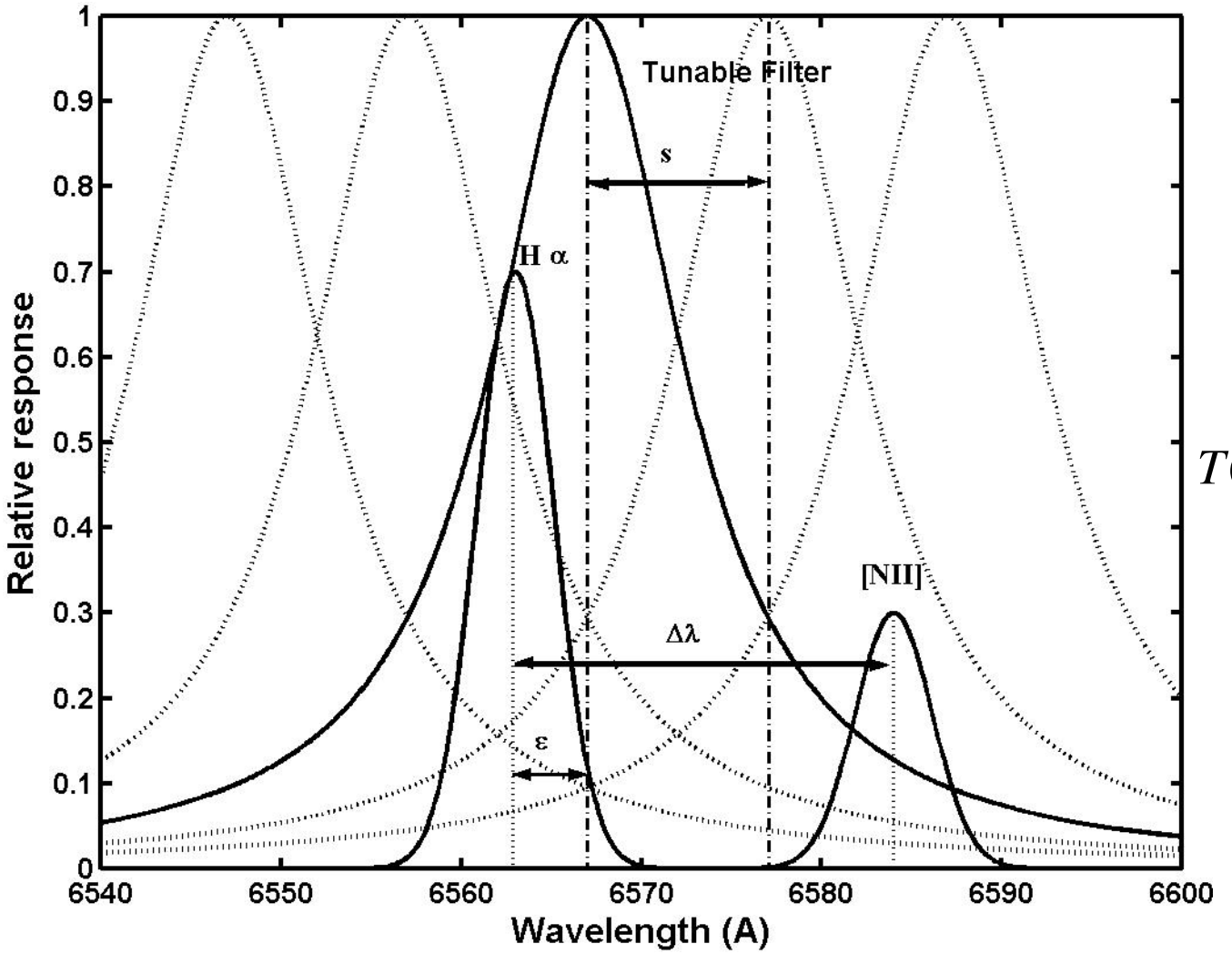


Angle: OSIRIS FOV

Heigh: Δλ scanned = λ_2-λ_1

Limiting magnitude: exposure time

Limited flux survey of a perfectly defined velocity range

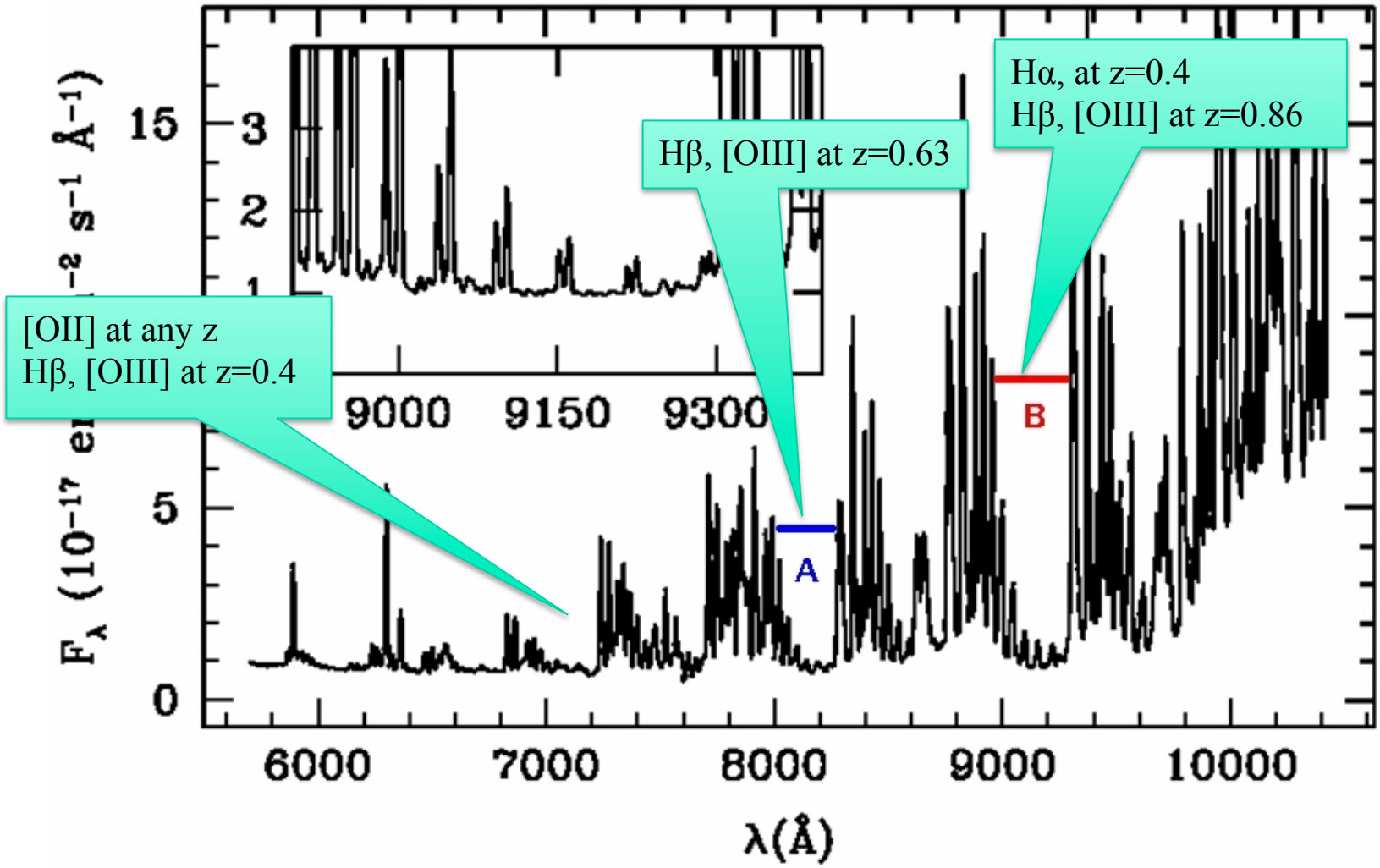


$$T(\lambda) \approx \left[1 + \left(\frac{2(\lambda - \lambda_0)}{\Delta_{FWHM}}\right)^2\right]^{-1}$$

GLACE Requirements

- **Sample** clusters in three redshift windows at ~0.40, ~0.63, ~0.86. These windows are relatively free from sky lines.
- **Up to $2R_{vir}$ ~ 3 Mpc**
- **Scanning a velocity field of ~6000 km/s (±3000 km/s)** (plus enough slices to compensate for wavelength shift)
- **Velocity resolution better than 200 km/s** (@Hα)
- **Flux limit:** allowing to reach 2 $M_{\odot}$/yr (below MW SFR) with 1 mag extinction in Hα and S/N≥3
- **Sample selection:** based on the availability of multi-wavelength data
- **Use TF for flux calibration**
- **In the z=0.4 bin, observe:**
  - Hα/[NII]6584, Hβ and [OIII]5007 with the RED TF
  - [OII]3727 with the BLUE TF
  - Deblending Hα from [NII]658.4 nm
  - To obtain extinction corrected SFR, Z, and BPT diagnostics
- **In the z=0.63 and 0.86 bins, observe:**
  - [OII]3727 with the BLUE TF (at 0.63) or RED TF (at 0.86)
  - Hβ and [OIII]5007 with the RED TF
  - To obtain [OII]-derived SFR, Z (R23).
  - Hα/[NII] from NIR spectroscopy (LIRIS and EMIR)

GLACE Requirements



GLACE instrumental setup

- **General**
  - − Binning 2×2
  - - 1-2 fields (8 arcmin ϕ) per cluster
  - - Dithering at least 3 images to get rid off spurious sources (e.g. ghosts)
- **For z = 0.40**
  - − Red TF tuning for Hα and [NII] to deblend both lines
    - · FWHM of 12 Å
    - · Scan step (sampling) of 6 Å
  - - TF tuning for [OII] (blue TF) Hβ and [OIII] (red TF)
    - · FWHM of 20 Å
    - · Scan step of 10 Å (1/2 FWHM)
- **For z = 0.63, 0.86**
  - −TF tuning for [OII] (blue TF at 0.63, red TF at 0.86), Hβ and [OIII] (red TF):
    - · FWHM of 20 Å
    - · Scan step (sampling) of 10 Å
- **Limiting flux:**
  - −Assuming SFR = 2 $M_{\odot}$/yr, 1 mag internal extinction at Hα, Kennicut (1994) relation SFR($M_{\odot}$/yr) = 7.9 × 10^{-42}L(Hα) (erg/s), we get f(Hα) = 7.55×10^{-17}erg/s/cm^2

The case for using TF in GLACE

TF are advantageous wrt MOS in cases of

- **Very faint emission line sources**
- **Requiring flux calibration**
- **Very high number of sources per field**
- **Observing few lines**

Which is the case for GLACE:

- **Flux calibration required for precise SFR determination**
- **> 1000 sources per field present** (> 10 masks vs. λ drift and # lines)
- **We observe only 3 to 5 lines.**

GLACE observations

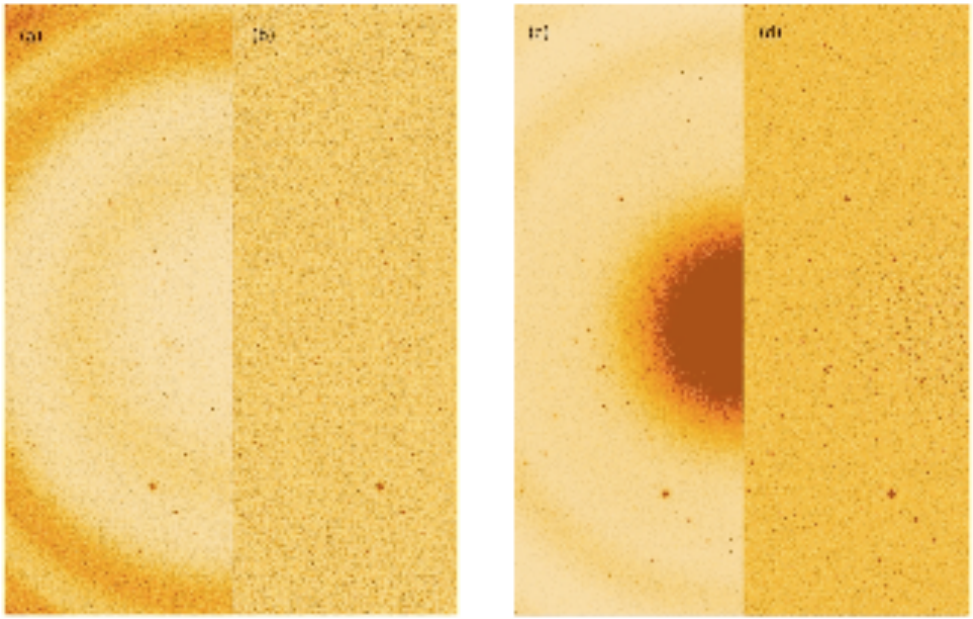
Target	z	Exp. Time (h)	Num. OSIRIS fields	Status of observations
Zw Cl0024+1654	0.395	24	2	On-going[1]
RX J1416.4+4446	0.40	24	2	To be proposed
XMMLSS-XLSSC 001	0.613	40	2	To be proposed
Cl J1227.9-1138	0.636	40	2	To be proposed
RX J1257.2+4738	0.86	72	1	On-going ESO/GTC[2]
RCSJ162009+2929.1	0.86	72	1	Approved ESO/GTC[3]

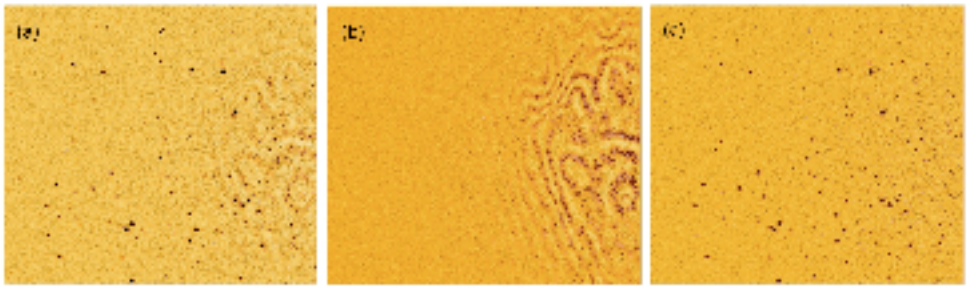
[1]GTC63-09B, GTC8-10AGOS, GTC47-10B done. Additional time (GTC47-11B) awarded in semester 11B to complete Hβ and [OIII] coverage.
[2]GTC2012-11ESO: 8 dark nights (72h) allocated in 11A (program 186.A-2012, P86)
[3]Implementation recommended by OPC (program 186.A-2012, P88). Approval by ESO/GTC liaison committee pending.

Data processing

- Data processing consists of three steps:
  - Image preparation: includes sky ring and fringing removal
  - Source detection: must consider wavelength shifts due to dithering.
  - Calibration: standard narrow band imaging procedure
  - TF-specific steps are implemented sing a version of the TFRED package (Jones et al 2002)

Sky ring subtraction

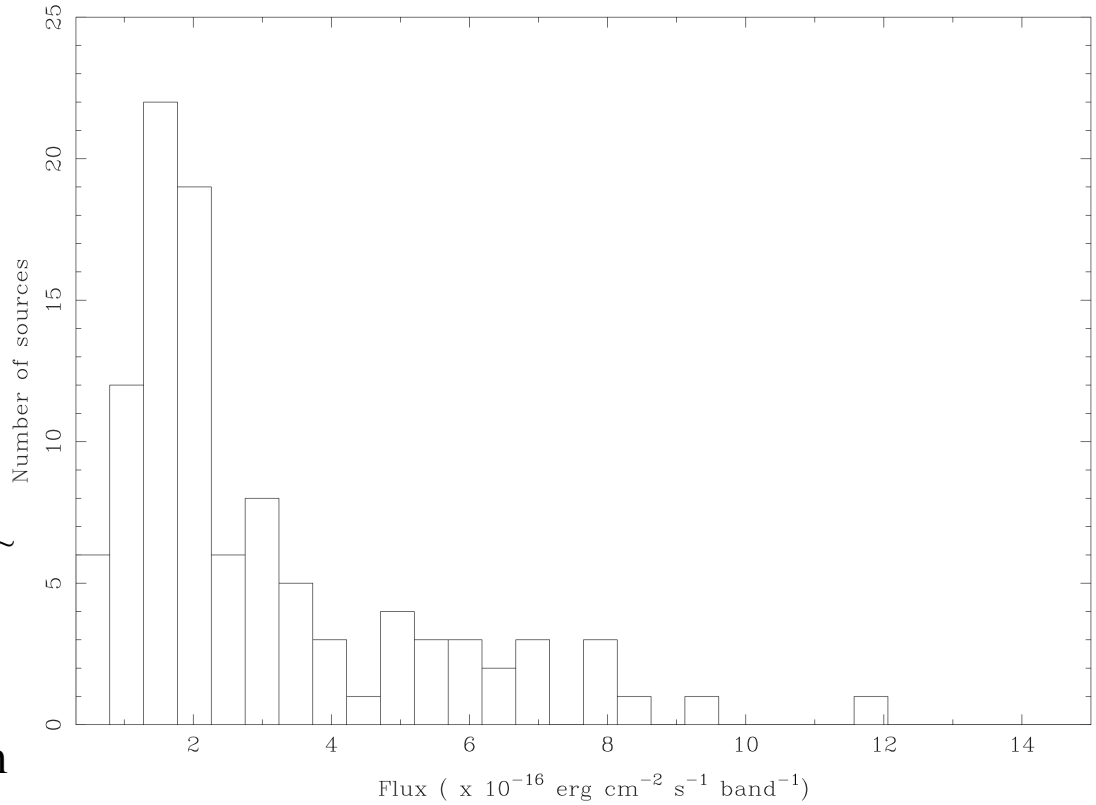




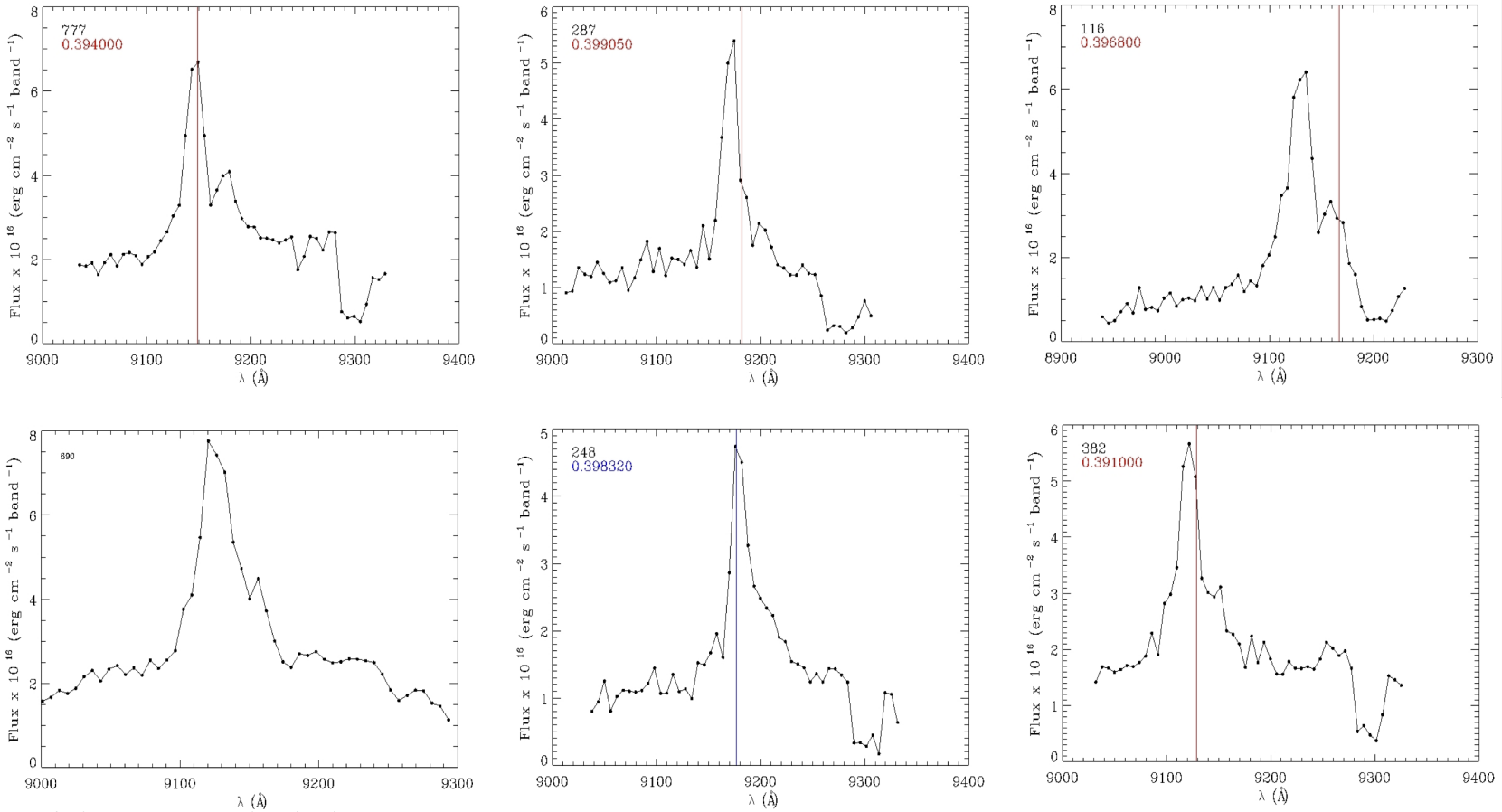
Removing fringing

First results: Cl0024+1654

- So far, we have processed the Hα data taken in semesters 09B and 10A of the rich cluster Cl0024+1654 (z=0.395, r_{vir}=1.7Mpc)
- 5.15hours on-source integration time, covering the range 9047-9341Å in 50 steps.
- From our Hα+[NII] maps we have obtained a raw catalog of 722 sources (> 3σ) in a region of 7.5 × 8.5 arcmin
  - From these, 89 very robust (high S/N) ELGs have been extracted.
  - The completeness limit of this sample is ~ 1.5 X 10^{-16}erg $s^{-1}cm^{-2}band^{-1}$ or f(Hα) ~6×10^{-17}erg $s^{-1}cm^{-2}$ i.e. even below the requirement.
- Our detection density, ~1.4 $arcmin^{-2}$ is comparable with the average density in Kodama+04 in Cl0024 or Koyama+11 in A851(narrow band imaging with Suprime-Cam at the Subaru telescope)



The Hα pseudo-spectra

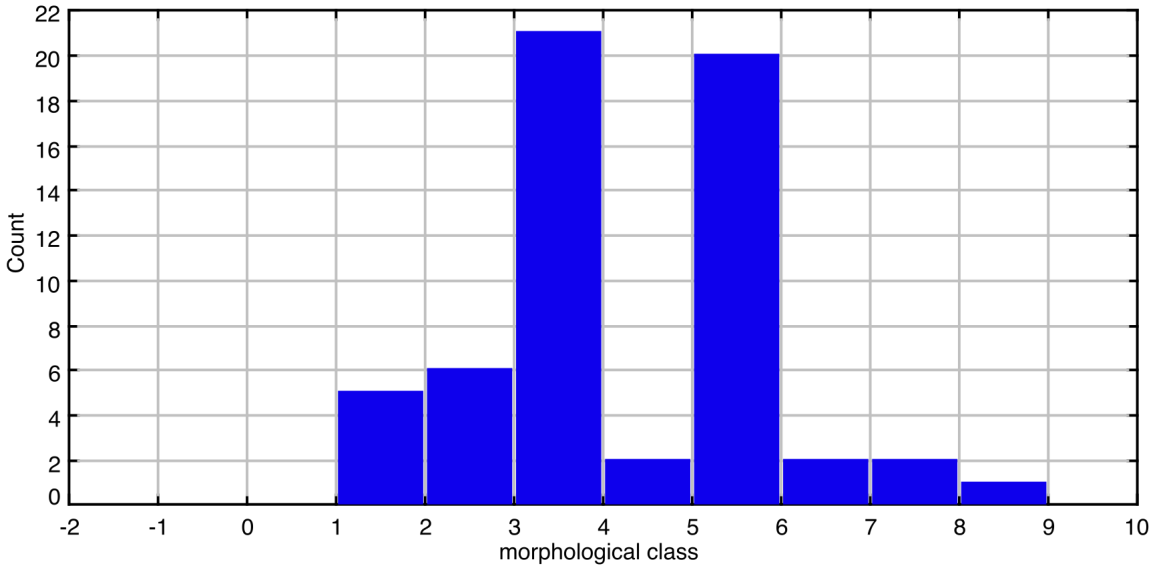


- Work in progress includes:
  - a precise deblending of Hα and [NII] lines
  - accurate determination of the line wavelengths.

- This information allows to determine:
  - cluster membership
  - AGN contrbution
  - Star formation rate

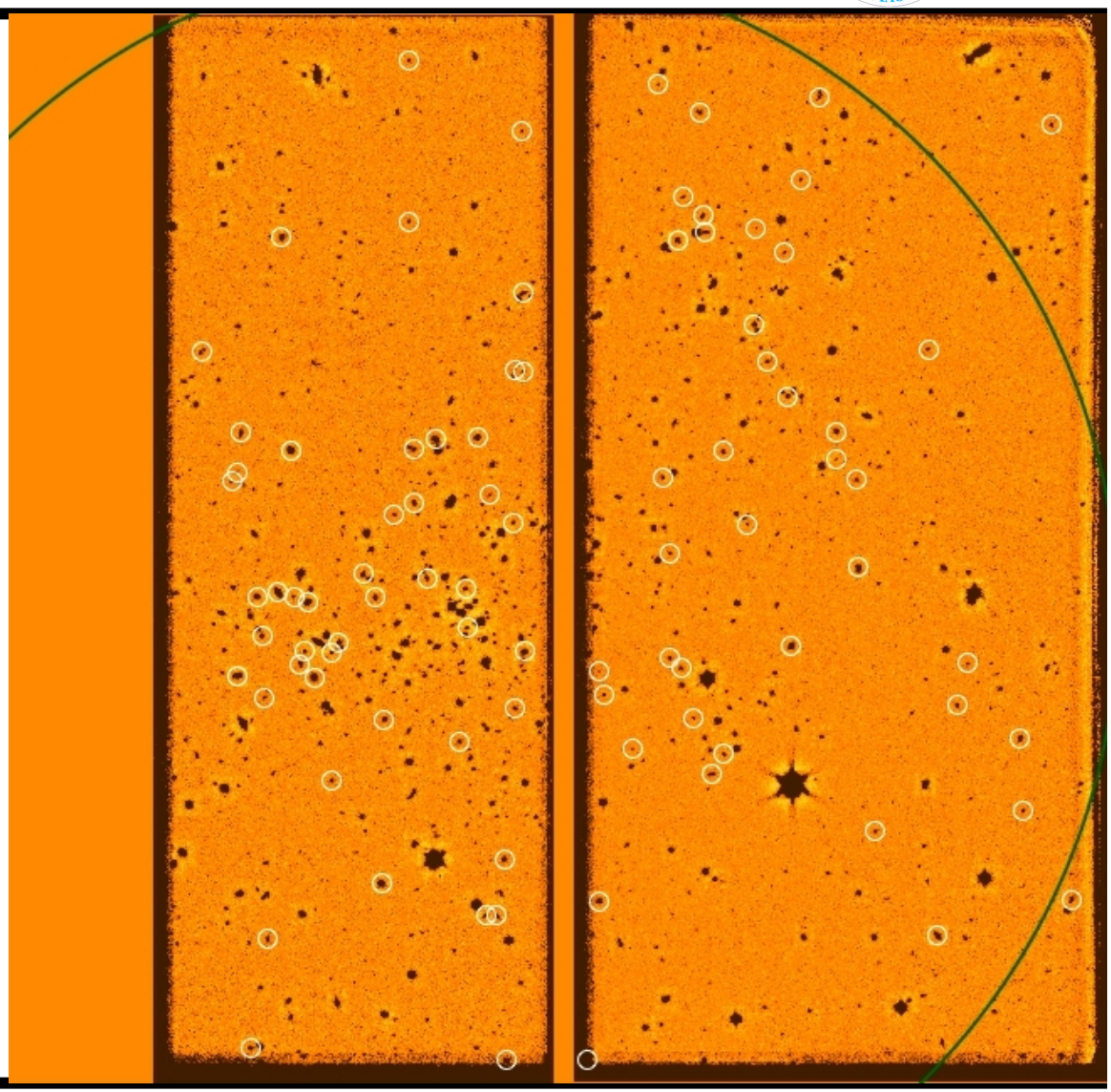
Morphology

- We have cross-matched our ELG catalogue with public photometric and spectroscopic catalogues at http://www.astro.caltech.edu/ ~smm/clusters/
- Using the Starlink TOPCAT tool using a search radius of 1.5 arcsec
- We found 100% match.
- From these, a morphological type was available for 59 objects:
- As expected, most of the ELGs are spiral galaxies (43), with a minor fraction of irregular, peculiar or mergers (5 objects).
- However, a significant fraction of the ELGs (11 sources) are early-type galaxies.



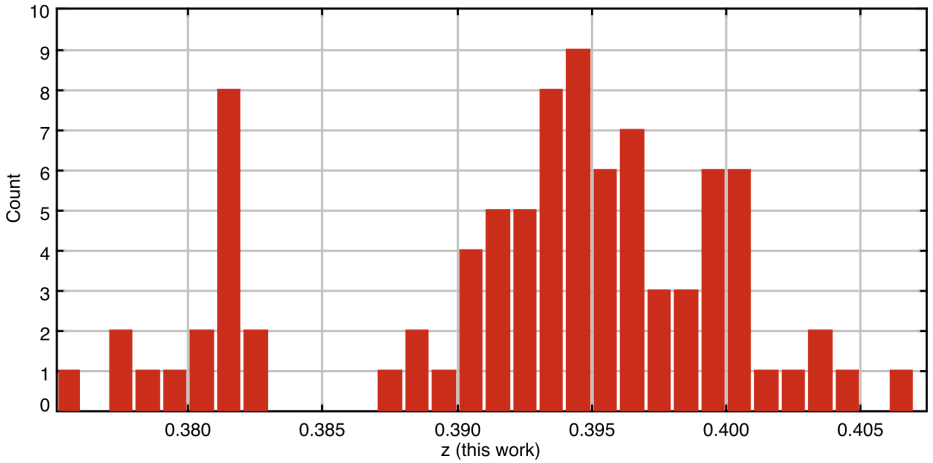
Morphology

- The spatial distribution of the ELG sample maps the presence of two components:
  - a structure assembling onto the cluster core from the NW with an orientation almost in the plane of the sky. This structure has been already reported by other authors (Moran+07; Zhang +05; Kneib+03).
  - A structure along the line of sight to the cluster centre, interpreted as an infalling group at high velocity (Czoske+01; Moran+07).
  - The second structure is also observed in the redshift distribution

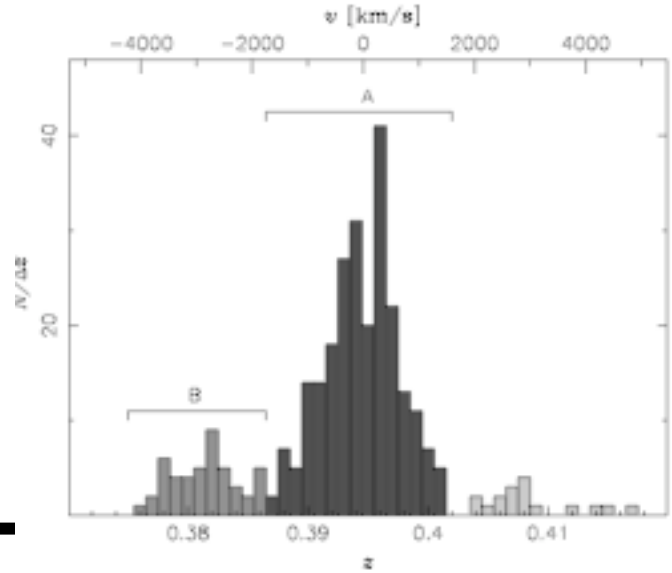


Redshift distribution

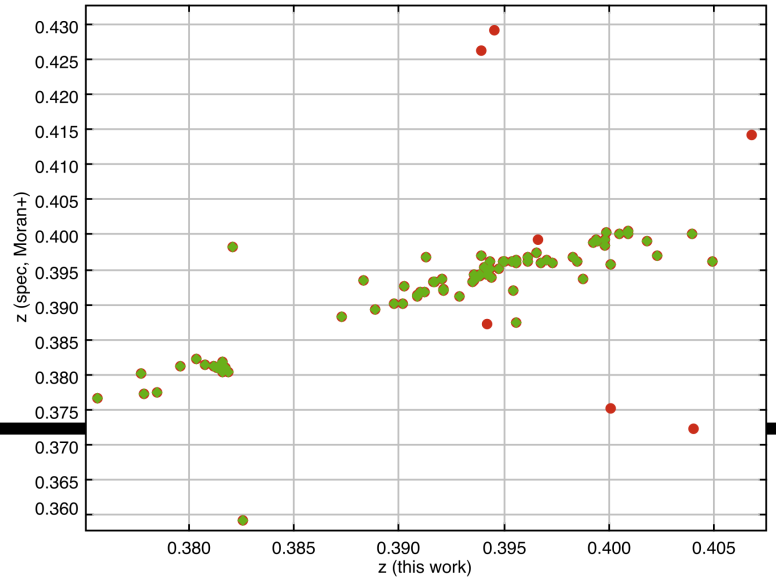
- Redshift estimates were available for 87 of our ELGs.
- From these, a vast majority (82) have a redshift close to that of the cluster.
- There was a remarkably good agreement between the redshift estimates derived from the position of the Hα line within our pseudo-spectra and those derived from spectroscopic measurements.



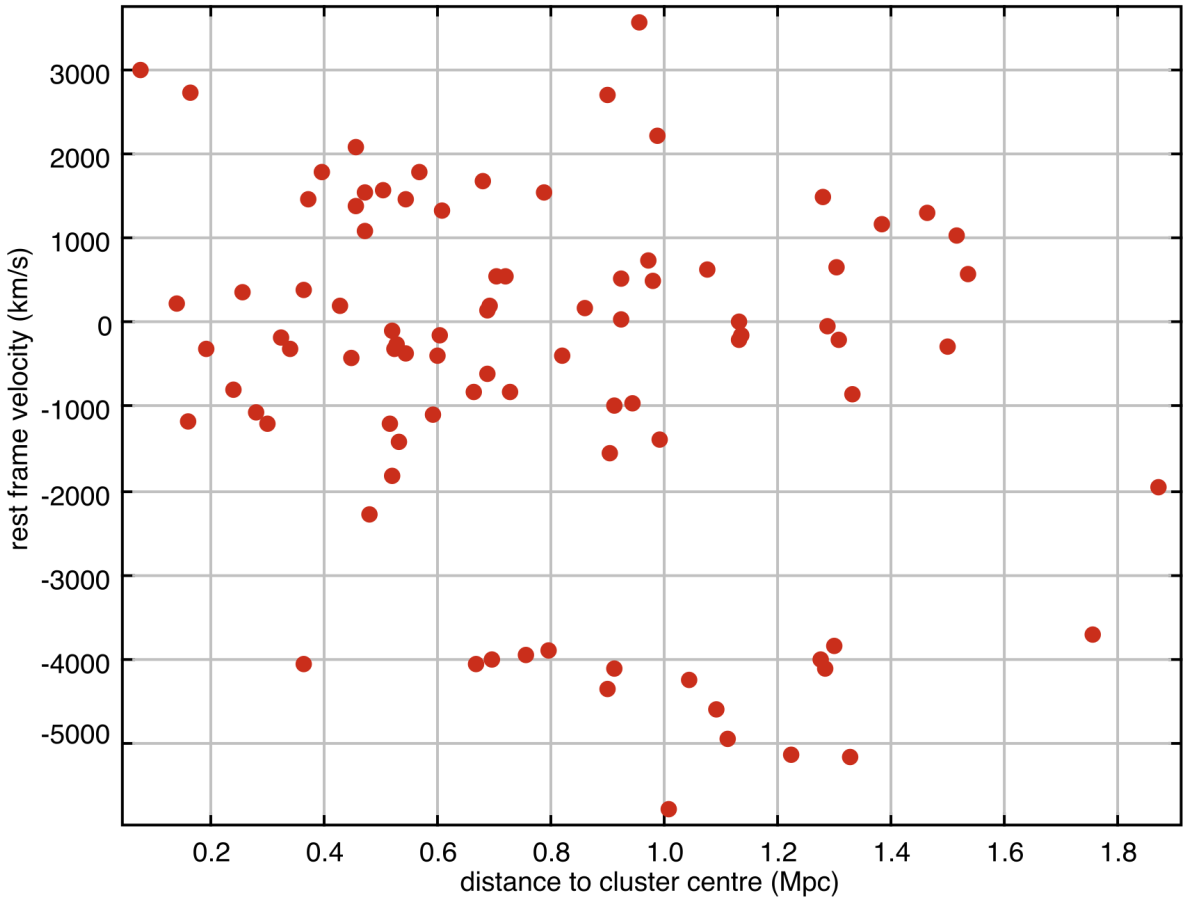
- We reproduce the double-peaked distribution observed by Czoske+01



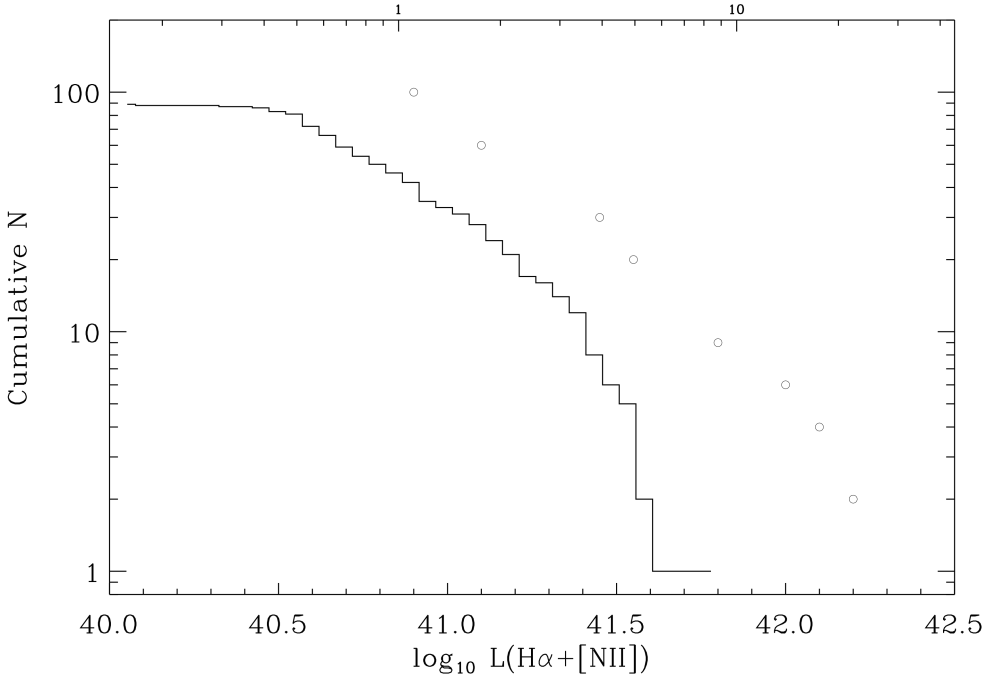
Czoske+2001

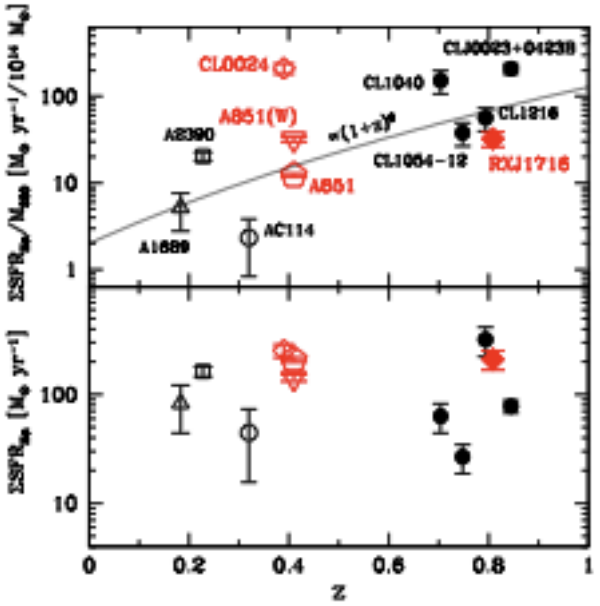


Angular distance vs. redshift

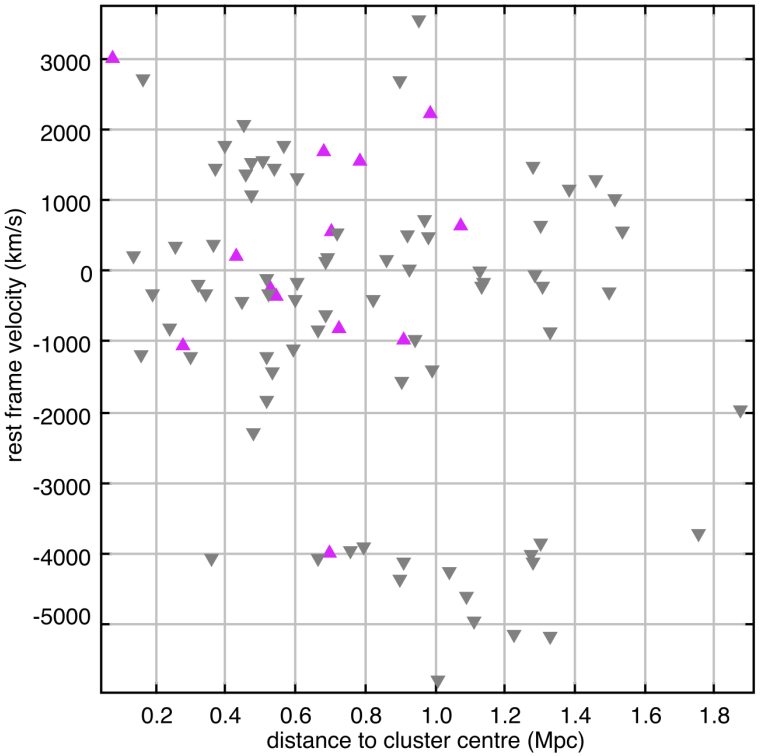


Hα luminosity function

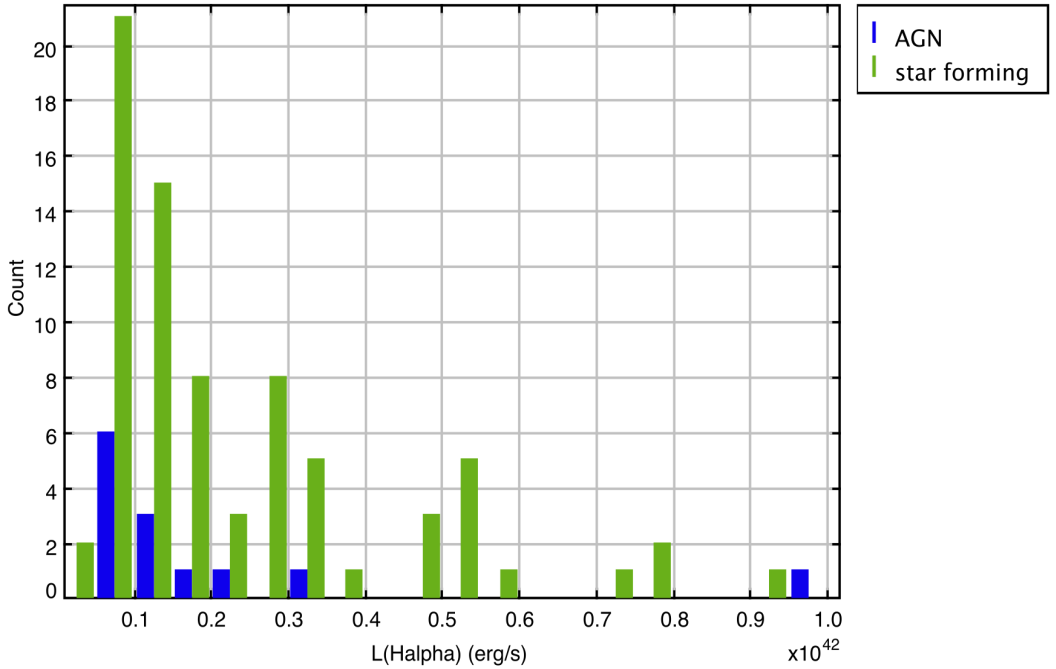




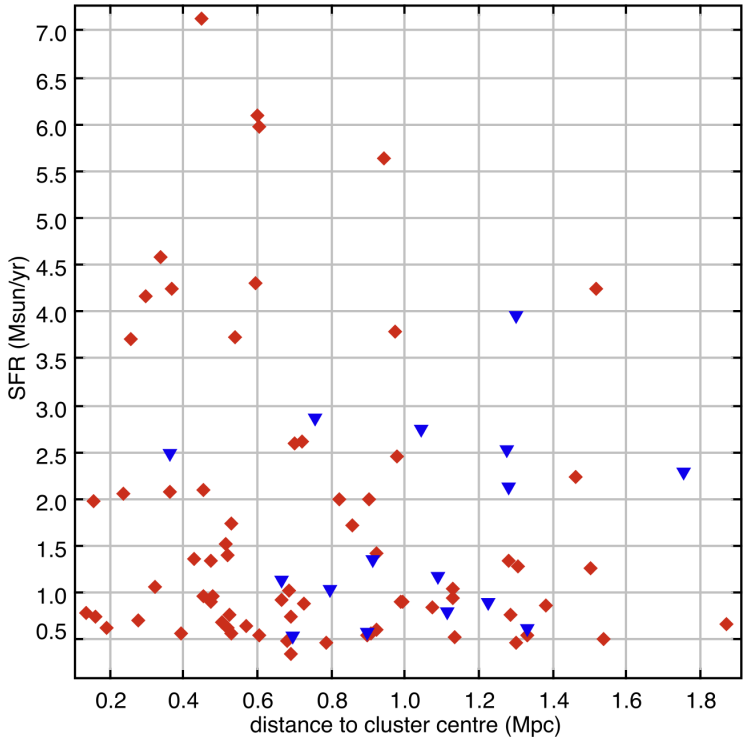
AGN fraction



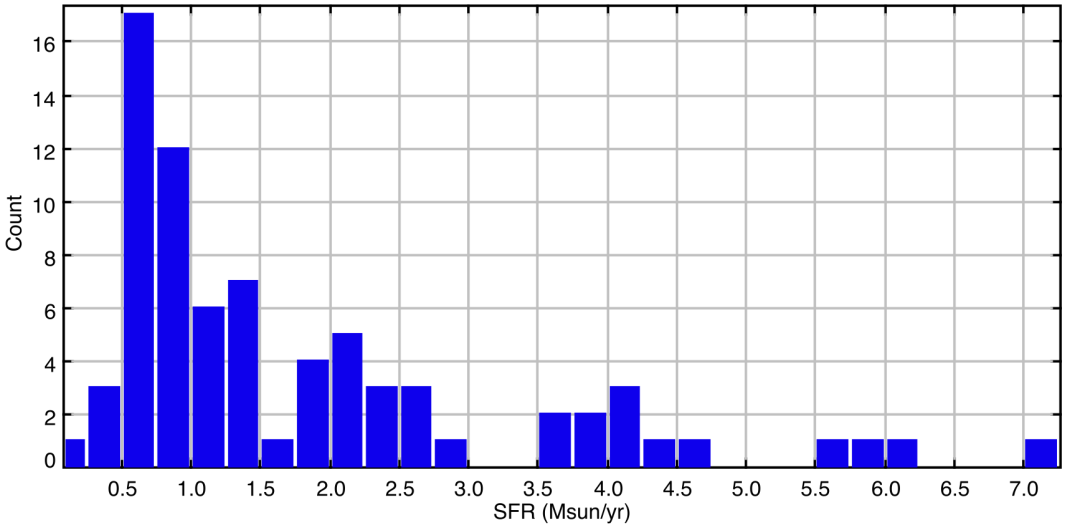
- Discriminated using standard separation diagnostics [NII]/Hα < 0.6 for SF galaxies
- According to this criterion, 85% (76) are SF galaxies and 15% (13) are AGN (either Seyferts or LINERs)



SFR ([NII]-deblended)



- Computed assuming 1 mag extinction at Hα



Summary and "conclusions"

1. GLACE is a large OSIRIS/GTC survey aimed to study the evolution ELGs in clusters and of clusters of galaxies across the cosmic time
2. Well suited for tunable filters, targeting a reduced set of emission lines ([OII], Hβ, [OIII], Hα/[NII]) in three redshift bins chosen to avoid strong atmospheric OH lines
3. Our first results confirm the technical feasibility and (as we believe) the scientific interest of the GLACE project