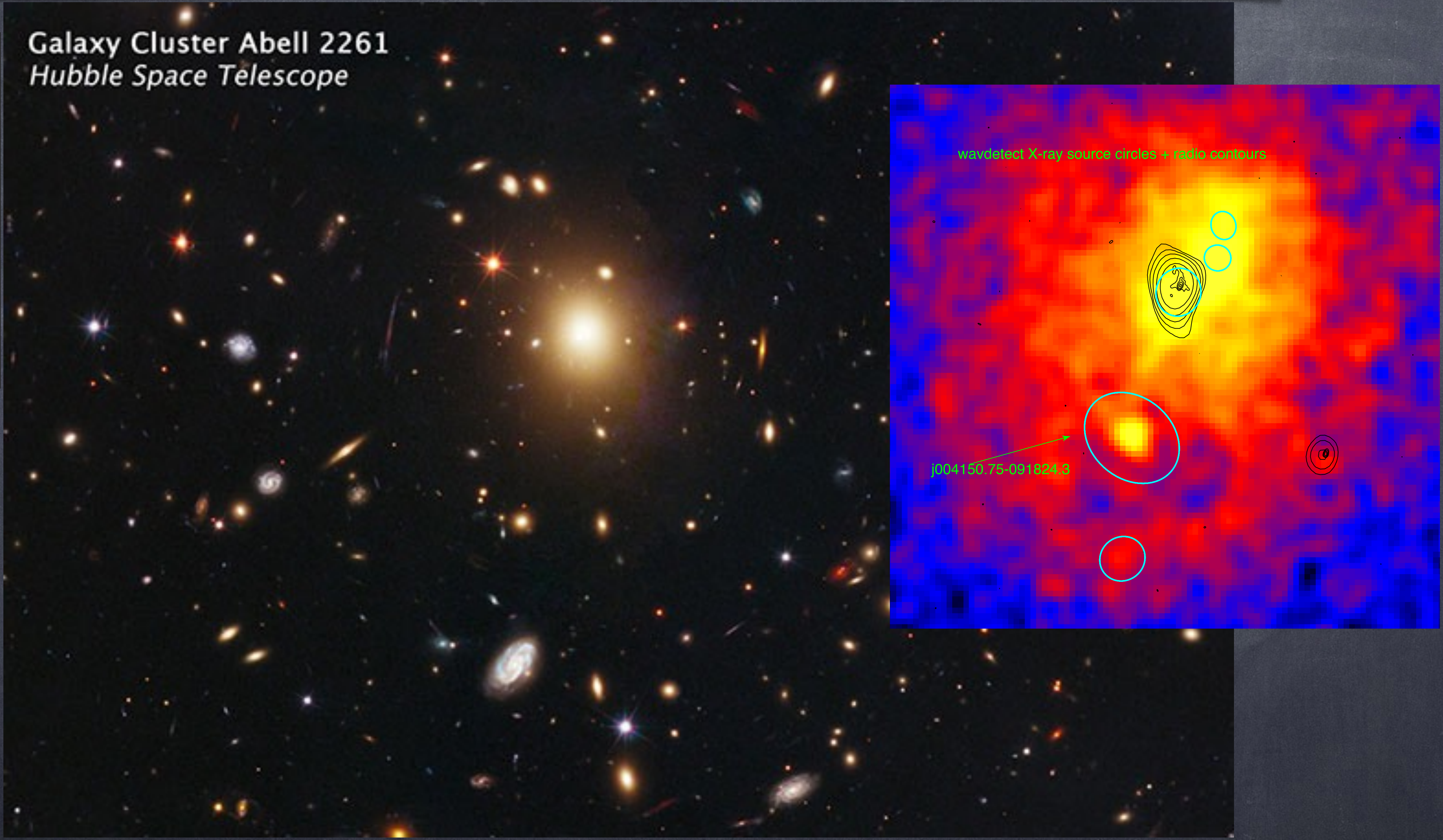
Is there a third Supermassive Black Hole associated with the cD galaxy Holm 15A?



Emmanuel Ríos López

Supervisors:
Dr. Omar López Cruz
Dr. Christopher Añorve

Collaboration:
Dr. Mark Birkinshaw
Dr. Divakara Mayya
Dr. Héctor Ibarra
Dr. Wayne Barkhouse

Guillermo Haro Workshop 2018

INAOE, September 6th 2018

Introduction

Brightest cluster galaxies (**BCGs**) are among the most massive galaxies in the present-day Universe.

- BCGs typically reside deep in the gravitational potentials of rich clusters and are classified as elliptical or **cD galaxies** (Lauer & Postman, 1992; Zhao et al., 2015).
- cD galaxies present an extended stellar halo of low surface brightness, which is absent in ellipticals.
- Presence of double or multiple nuclei detected by Morgan & Lesh (1965).
- BCGs and early-type galaxies brighter than $M_V \sim -21$ have *cores* (Faber et al., 1997; Lauer et al., 2007).
- An explanation regarding to their formation is the galactic *cannibalism* (White, 1976; Ostriker & Hausman, 1977; Garijo et al., 1997), in which BCGs are result of the interactions between smaller galaxies.
- They provide important information about the formation and evolution of the supermassive black hole (SMBH) with its host galaxy.

Introduction

The "*core*" can be defined as the central region of a galaxy where the surface brightness distribution shows a flattening.

- The SMBH "scouring" scenario for the creation of cores: *Dynamical interactions between galaxies* ➝ SMBH Binaries ➝ Formation of *cores*

-Begelman et al. 1980; Merritt 2013; Rantala et al. 2018 → The stars would be ejected from the centre of the newly created system, as the coalescence process of the binary reaches its final stage. This causes a "flattening" in the surface brightness distribution as r ➝ 0.

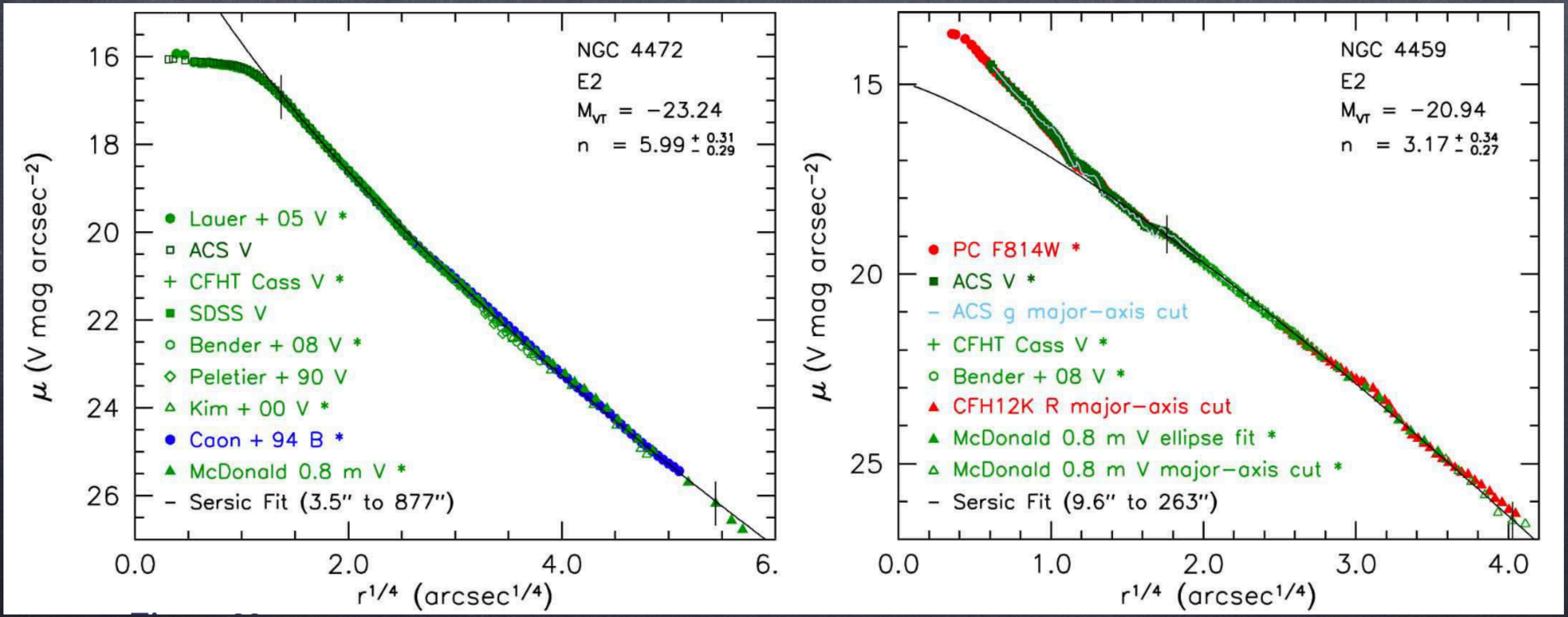


Fig. 1: Surface brightness profile in V banda of NGC 4472, a giant elliptical with core (left) and a galaxy with a cusp (right; Kormendy & Ho, 2013).

Introduction: The case of Holm 15A

López-Cruz et al., (2014) reported that the *core* of the cD galaxy Holm 15A, the BCG of Abell 85, is the largest known so far.

- Core radius: **r_γ=4.57 ± 0.06 kpc,**

- It could host a SMBH of mass $M_\bullet \sim (10^9 – 10^{11})\ M_\odot$.

The SMBH mass of Holm 15A was estimated using scaling laws.

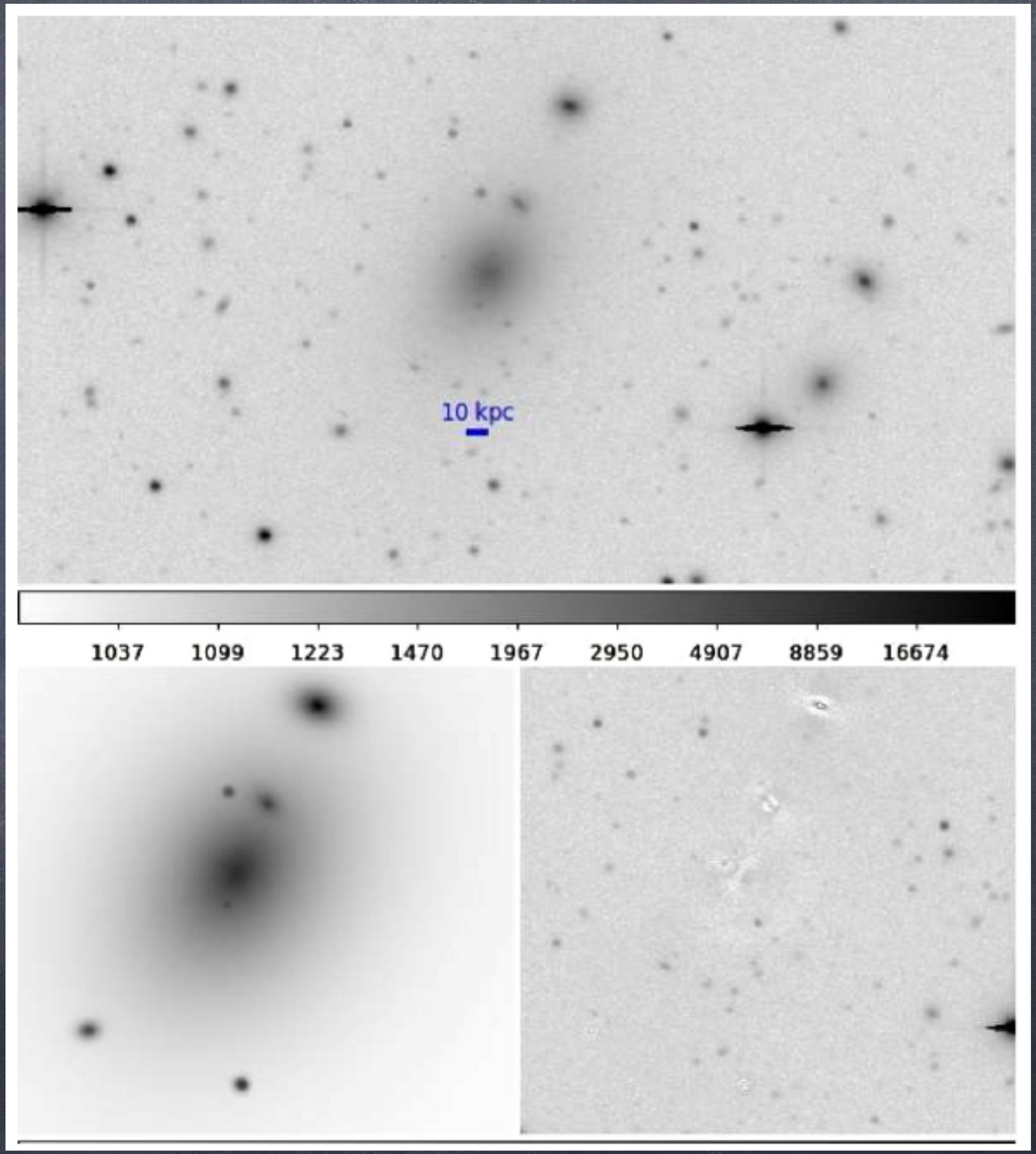
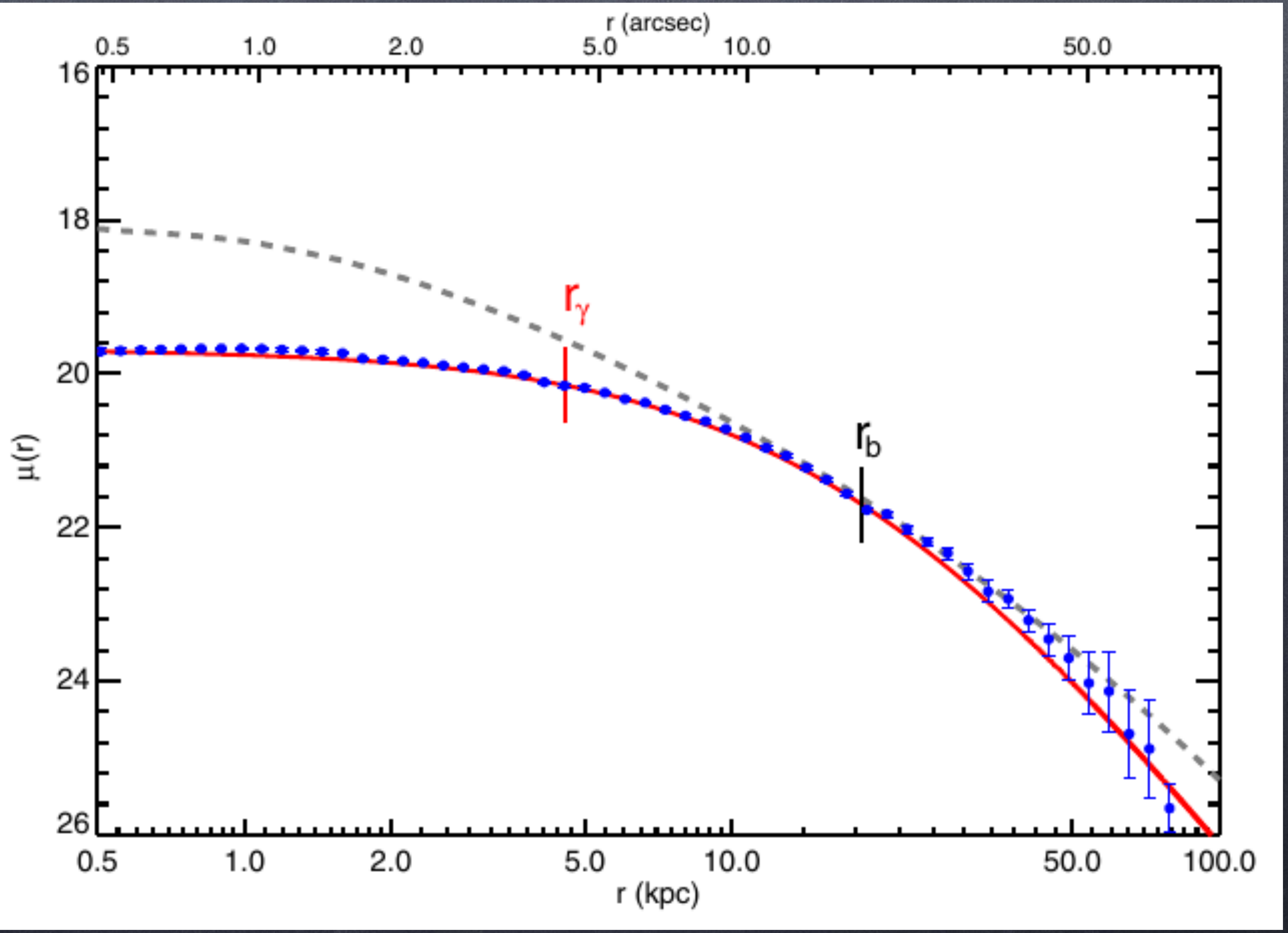


Fig. 2: LOCOS image in R band of Holm 15A. Top panel shows a part of the original image. Bottom left panel shows the model generated with GALFIT using Nuker profile. In the bottom right panel is the residual image. Horizontal bar displays the intensity scale in arbitrary units (López-Cruz et al., 2014).

Holm 15A: Black Hole Mass Estimates

Relation	$M_\bullet$ $[M_\odot]$	Reference
$M_\bullet - \sigma$	$\sim 2.1 \times 10^9$	Kormendy & Ho (2013, Equation (6))
$M_\bullet - L_{K,\mathrm{bulge}}$[a]	$\sim 9.2 \times 10^9$	Kormendy & Ho (2013, Equation (7))
$M_\bullet - L_{V,\mathrm{def}}$	$\sim 2.6 \times 10^{11}$	Kormendy & Bender (2009, Equation (3))
$M_\bullet - r_b$	$\sim 1.7 \times 10^{11}$	Rusli et al. (2013, Equation (13))
$M_\bullet - r_\gamma$	$\sim 3.1 \times 10^{11}$	Lauer et al. (2007, Equation (26))

From **López-Cruz et al., (2014)**



Introduction: The case of Holm 15A

- It seems that large cores (r >1 kpc, Holm 15A and A2261-BCG) are not very common, hence it could be a brief evolutive phase in the evolution of BCGs.

- It is expected that galaxies with large *cores* could host extremely massive BHs ($M_\bullet \sim 10^{10} M_\odot$; McConnell et al., 2012) and that Ultramassive Black Holes ($M_\bullet \geq 10^{10} M_\odot$) in BCGs follow special scaling laws (Hlavacek-Larrondo et al., 2012).

- Hence the detection of SMBHs in the highest mass ranges becomes very important in order to set limitations for scaling laws.

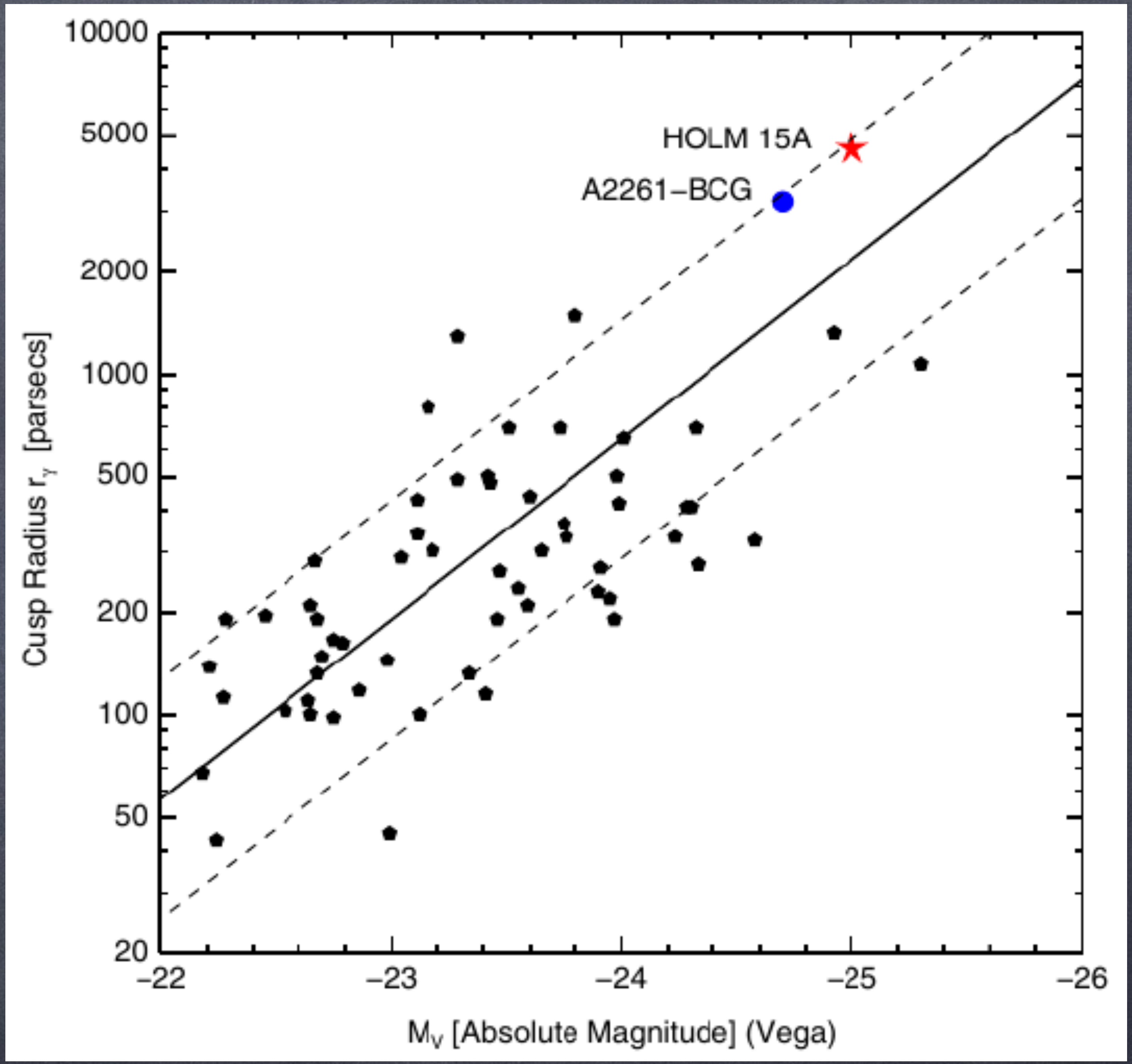
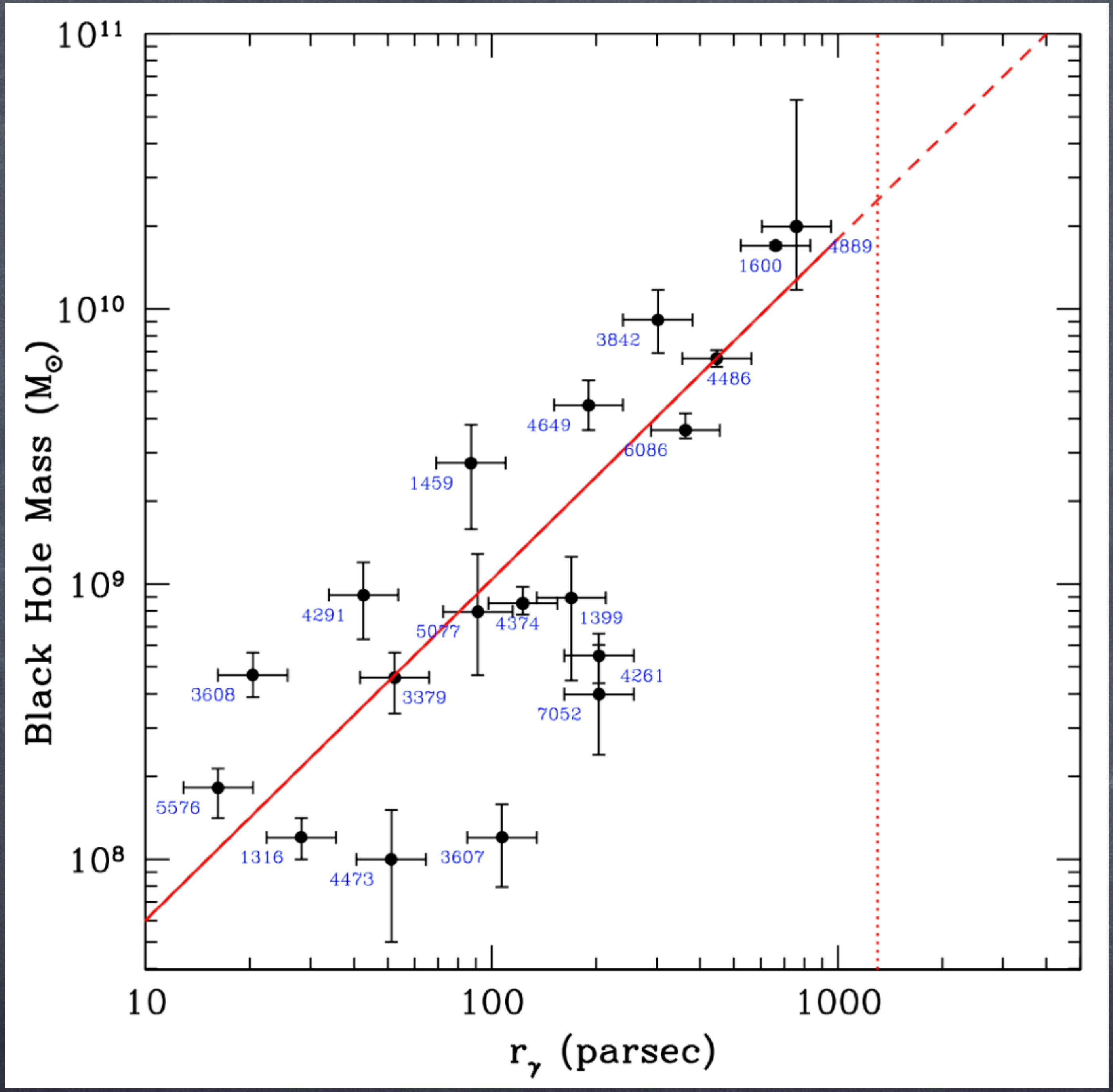


Fig. 4: Correlation between r_γ and luminosity in V band for galaxies with core (from López-Cruz et al. 2014).

MBH-rγ relation



Data for rγ values from literature, e.g., Lauer et al. (2007), Rusli et al. (2013).

No BH masses have been measured for any galaxy with rγ > 1 kpc.

GALFIT

Radial profile functions

Describe the radia fall-off in flux, such as: Sérsic, Exponential Disc, Nuker, among others.

Sérsic profile (Sérsic 1967):

$$\Sigma(r) = \Sigma_e exp\left[-\kappa\left(\left(\frac{r}{r_e}\right)^{1/n} - 1\right)\right]$$

where *re* is the effective radius, *Σe* is the surface brightness at *re*, *n* is the Sérsic Index.

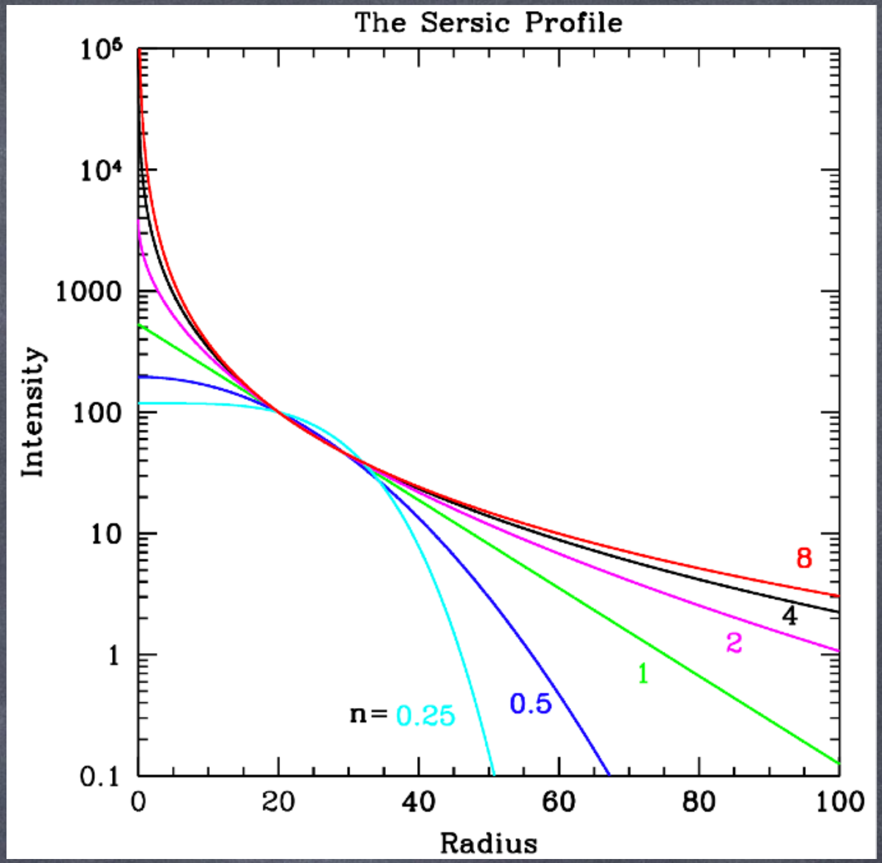


Fig 6: Sérsic profile with re and Σe fixed.

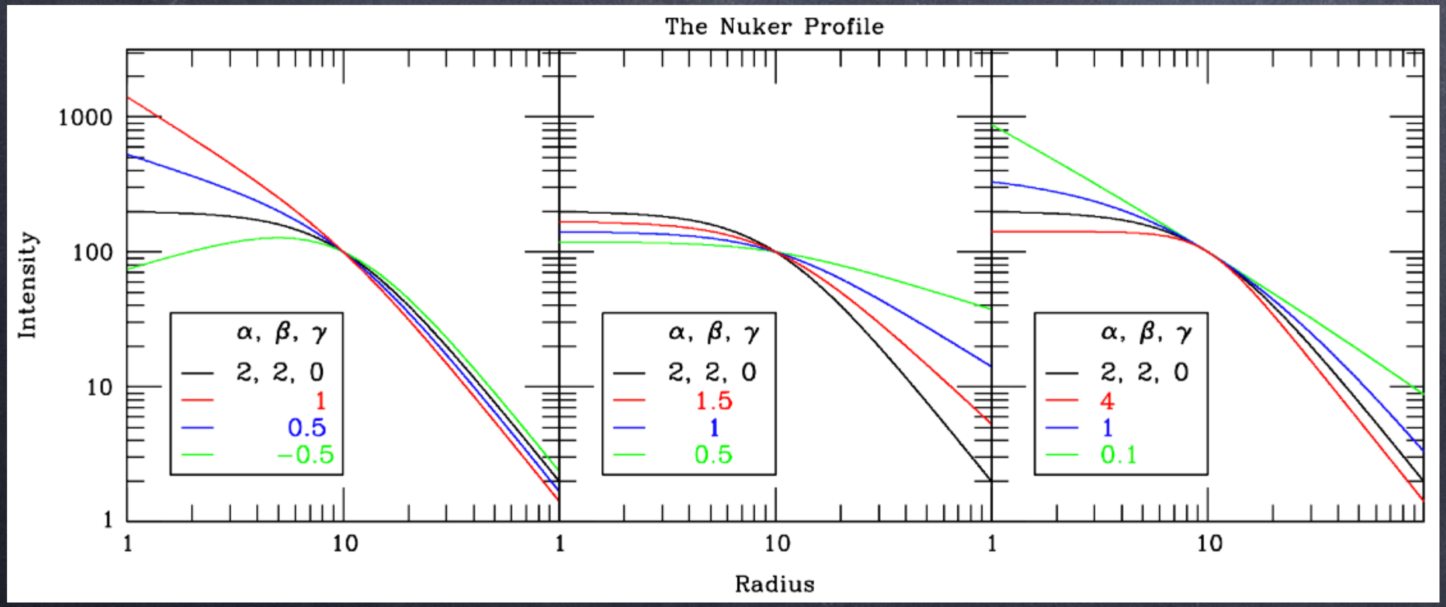


Fig 5: Nuker profile The black reference curve has parameters r_b = 10, α = 2, β = 2, γ = 0, and I_b = 100. For the other colored lines.

Nuker profile (Lauer et al. 1995):

$$r_\gamma \equiv r_b\left(\frac{\gamma' - \gamma}{\beta - \gamma'}\right)^{1/\alpha}$$

$$I(r) = I_b\, 2^{\frac{\beta-\gamma}{\alpha}} \left(\frac{r}{r_b}\right)^{-\gamma} \left[1 + \left(\frac{r}{r_b}\right)^{\alpha}\right]^{\frac{\gamma-\beta}{\alpha}}$$

where β is the outer power-law slope, γ is the inner slope, and α controls the sharpness of the transition.

J004150: A possible third SMBH associated with Holm 15A?

- López-Cruz et al. (2014) proposed that the compact X-ray source associated with SDSS J004150.75-091824 (hereafter **J004150**; RA=00:41:50.46, DEC= -09:18:11.34) could be a third SMBH associated with Holm 15A.

- This target, lying at 13.74” from the center of Holm 15A, is a quasar candidate with **z_phot ~ 0.9.**

- For this, Holm 15A represents an ideal opportunity for testing the SMBH “scouring” scenario for the creation of BCG cores.

- A follow-up study of the cD galaxy Holm 15A in order to prove whether J004150 is a background source or a bound black hole, which could be tested by optical spectroscopy of J004150.

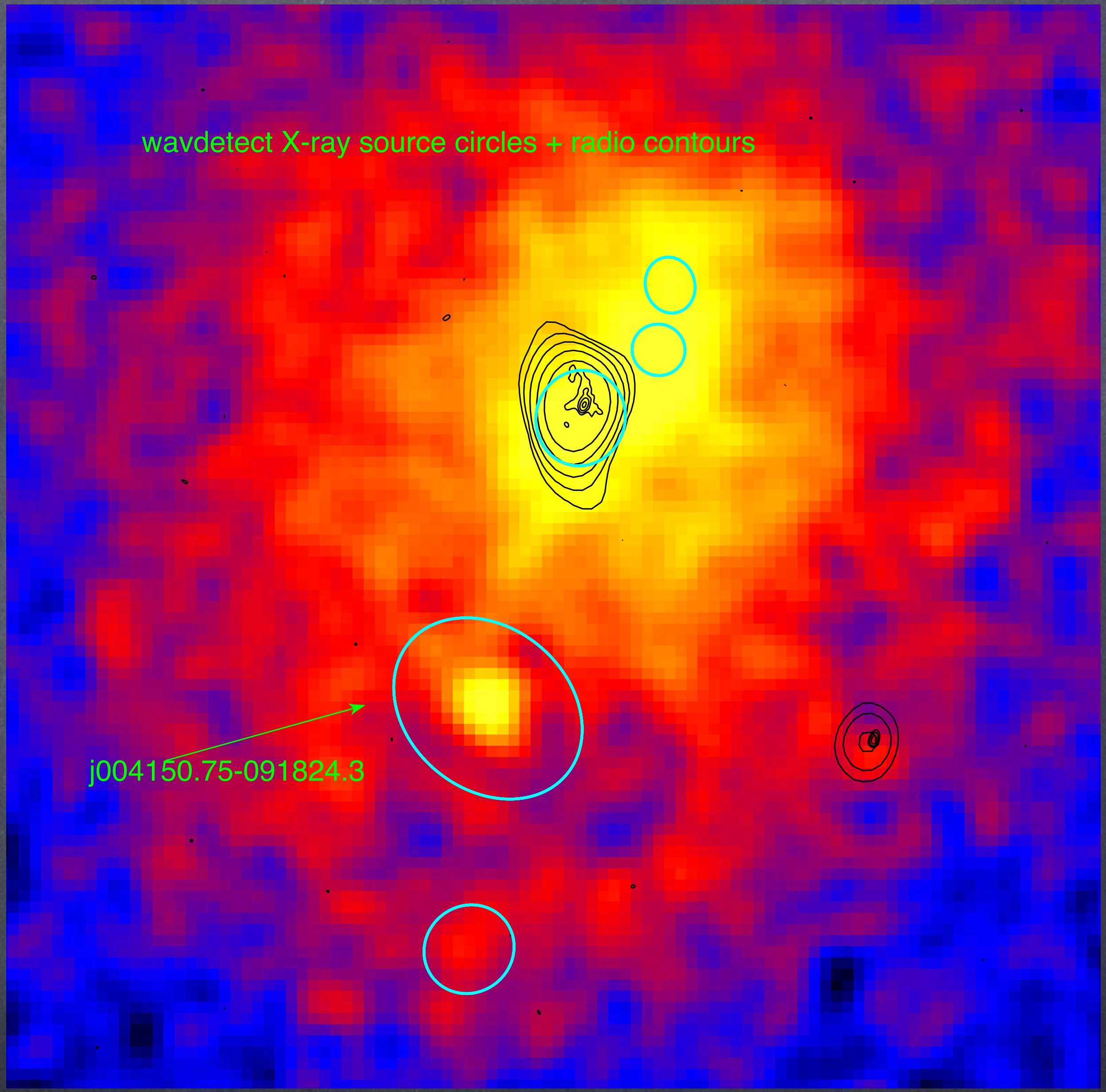


Fig. 7: Chandra X-ray image of Abell 85 with radio contours superimposed indicating the source J004150, lying at 13.74” from the center of Holm 15A.

J004150: A possible third SMBH associated with Holm 15A?

Hence, have acquired new spectroscopical data from GTC using OSIRIS-MOS mode for Holm 15A to study its nuclear region.

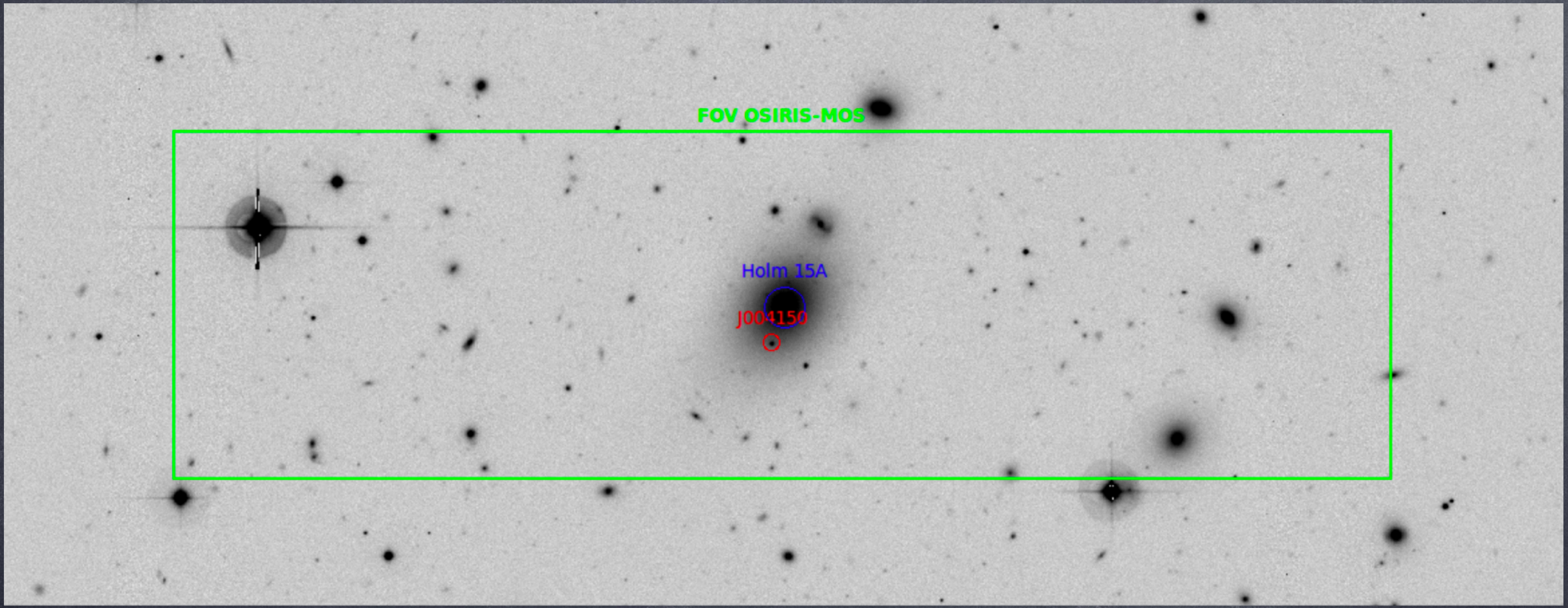
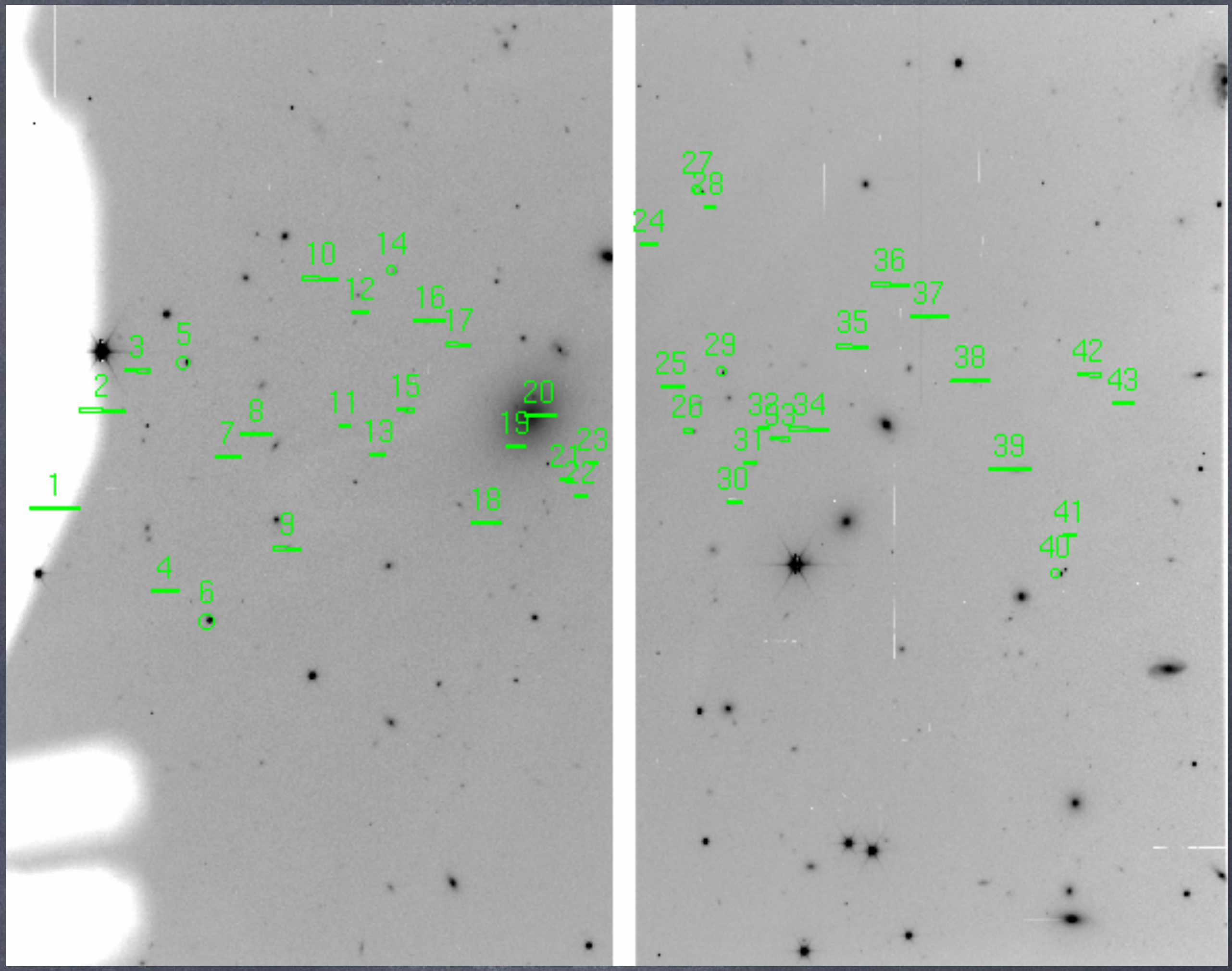


Fig. 8: Holm 15A (blue circle), J004150 (red circle) and OSIRIS-MOS field of view (green rectangle). North is at the top and East at the left in the image.

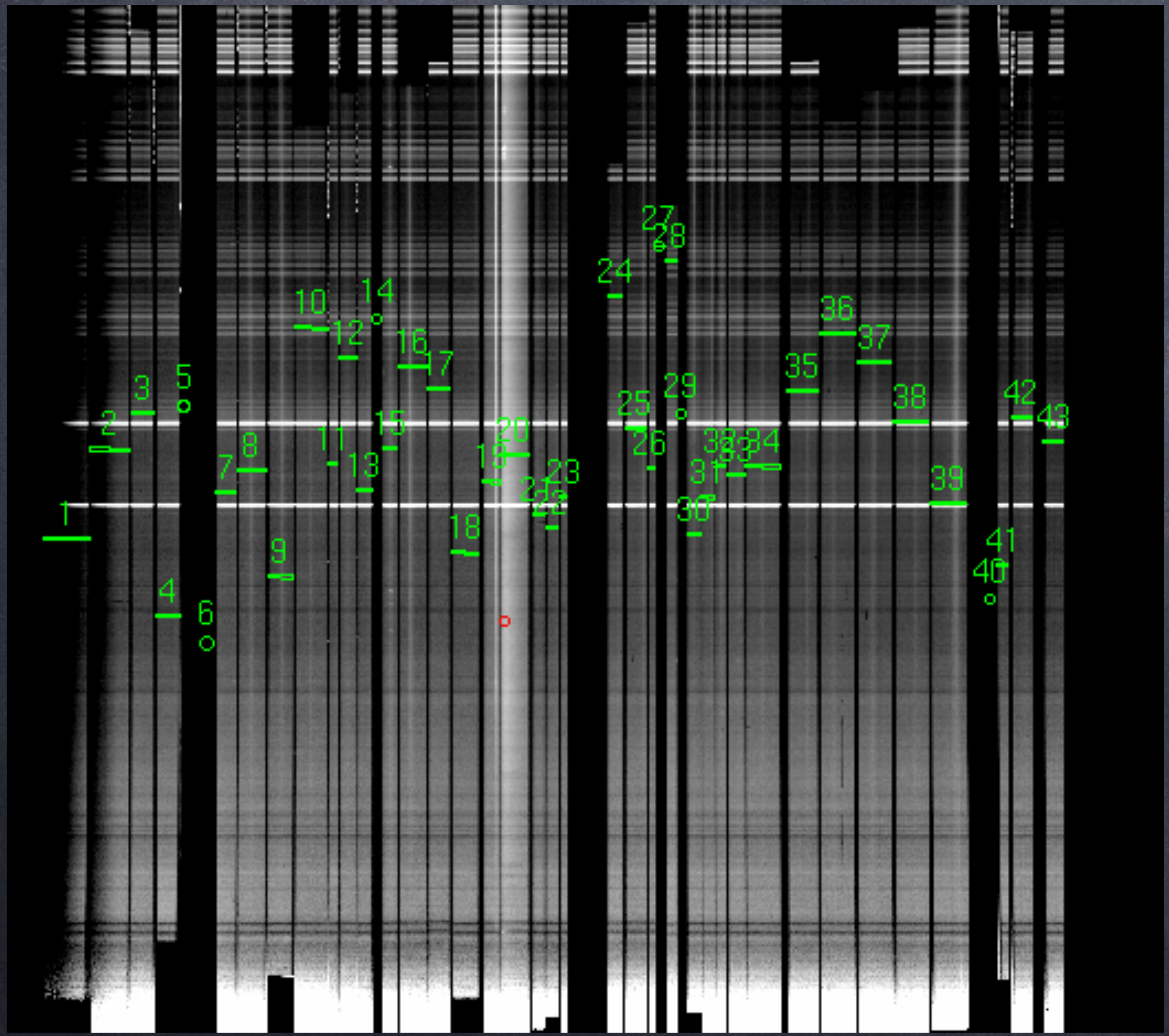
Gran Telescopio CANARIAS (GTC) Data

-Positions of the slit lets en el OSIRIS FoV on the Abell 85 image (top) and on the calibrated 2D spectra (bottom).

- Data reduction —> New MOS pipeline developed by D. Mayya (Gómez-González, Mayya & Rosa-González, 2016)



- Fig. 10: GTC/OSIRIS FoV centered on Holm 15A.



- —> Fig. 9: Calibrated 2D spectral image.

Preliminary results

Holm 15A Spectrum

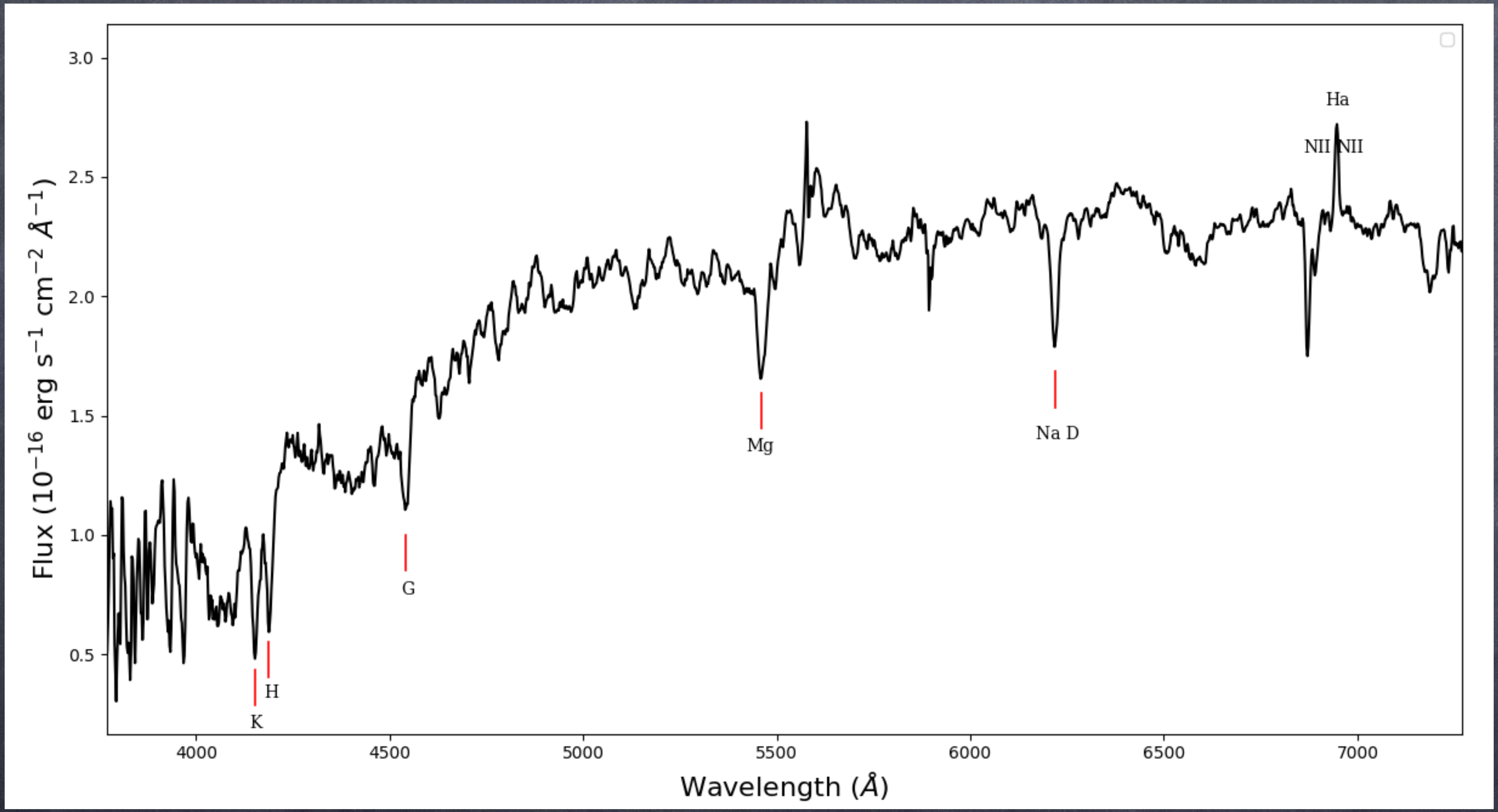
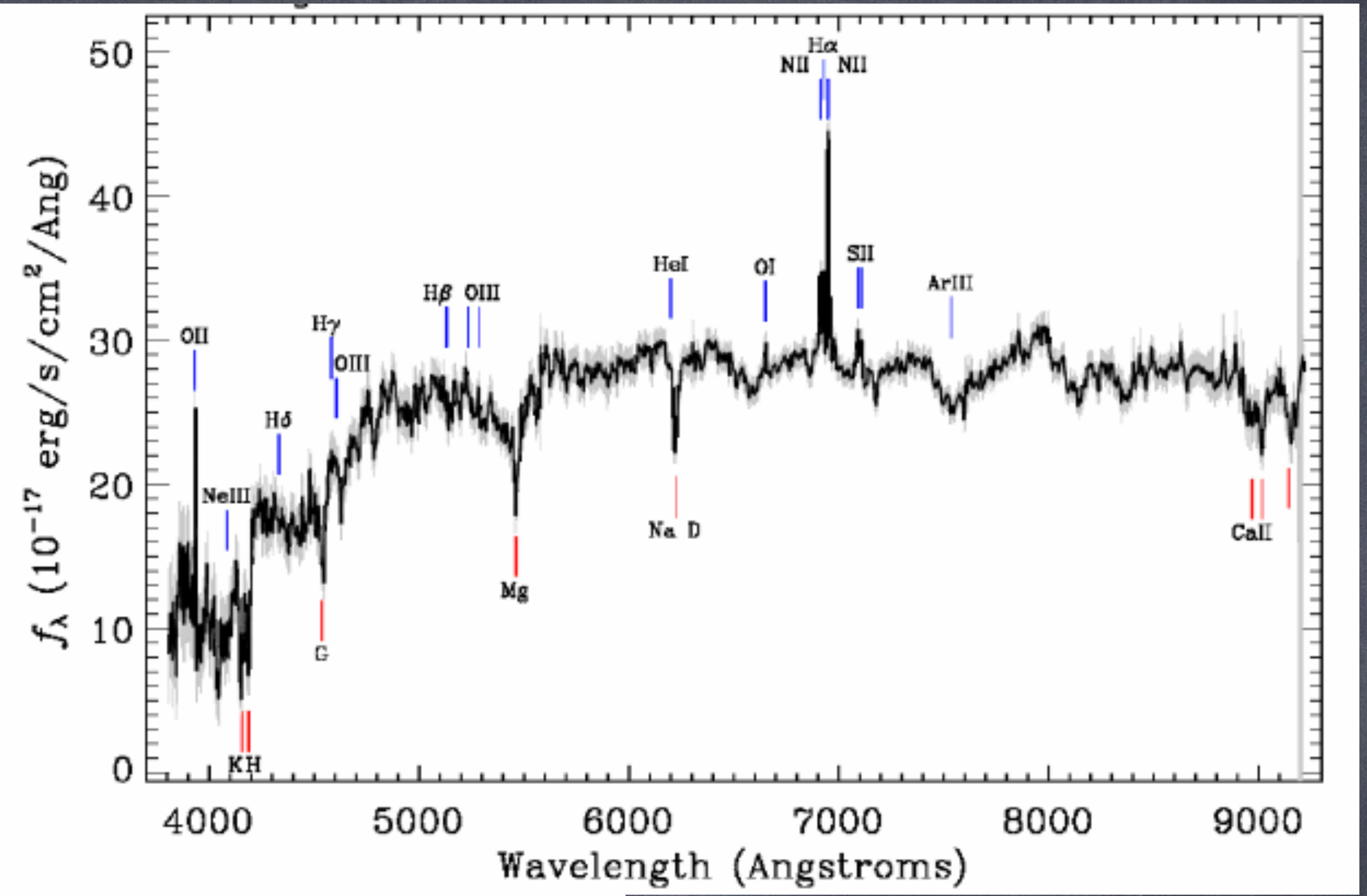
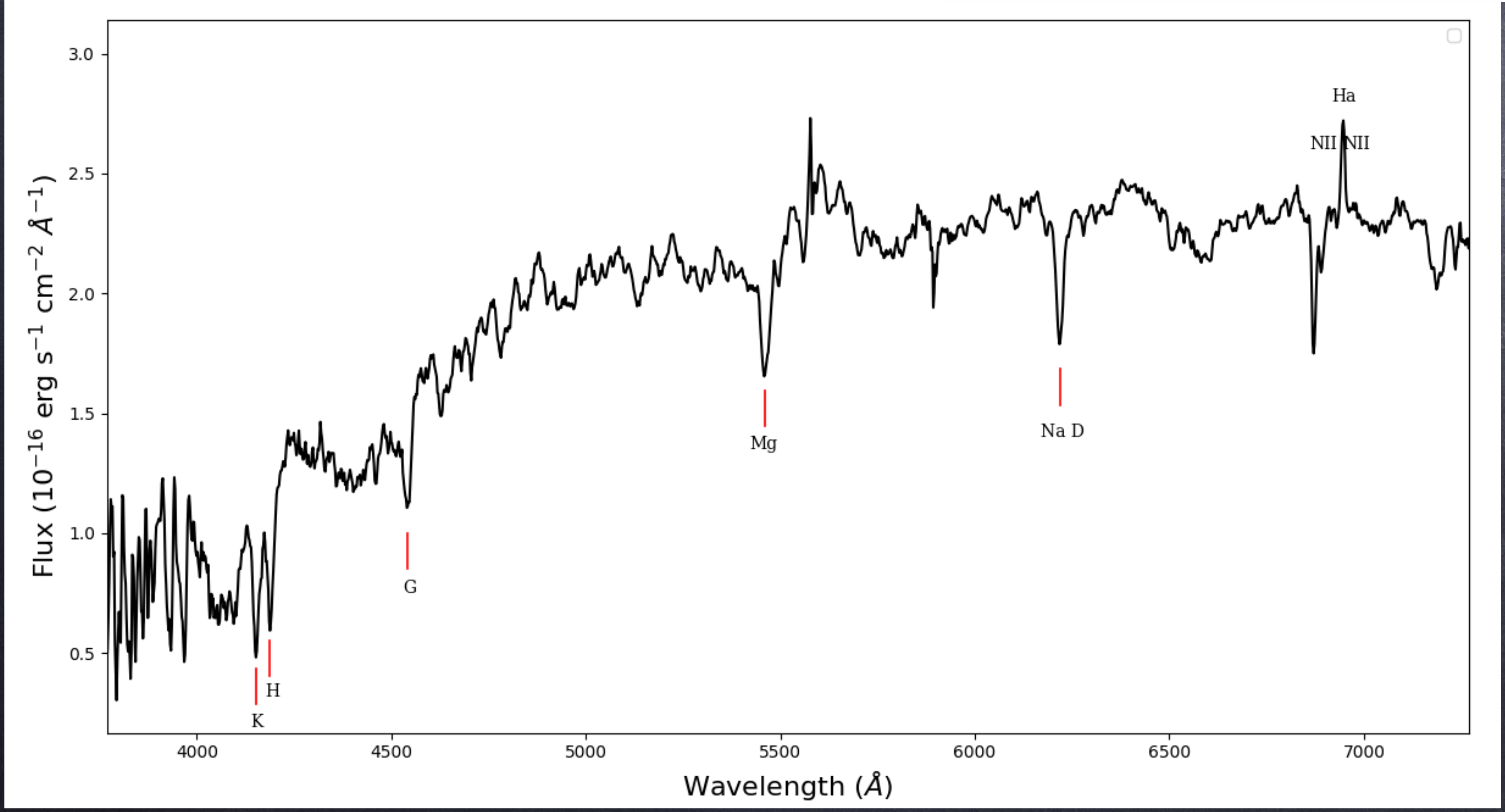


Fig. 11: GTC/OSIRIS spectra in B-band of Holm 15A showing the spectral features like H_alpha and [NII] 6548, 6583 (Ríos-López et al. in prep.).

Holm 15A SDSS Spectrum





Preliminary results

- J004150 spectrum

- The main goal is to know if there is a third SMBH gravitationally bound to Holm 15A, as López-Cruz et al. (2014) proposed.

We found that **J004150 is not gravitationally bound to Holm 15A** (located at z=0.055), instead it is a high-redshifted **background QSO at z= 1.56 !!**

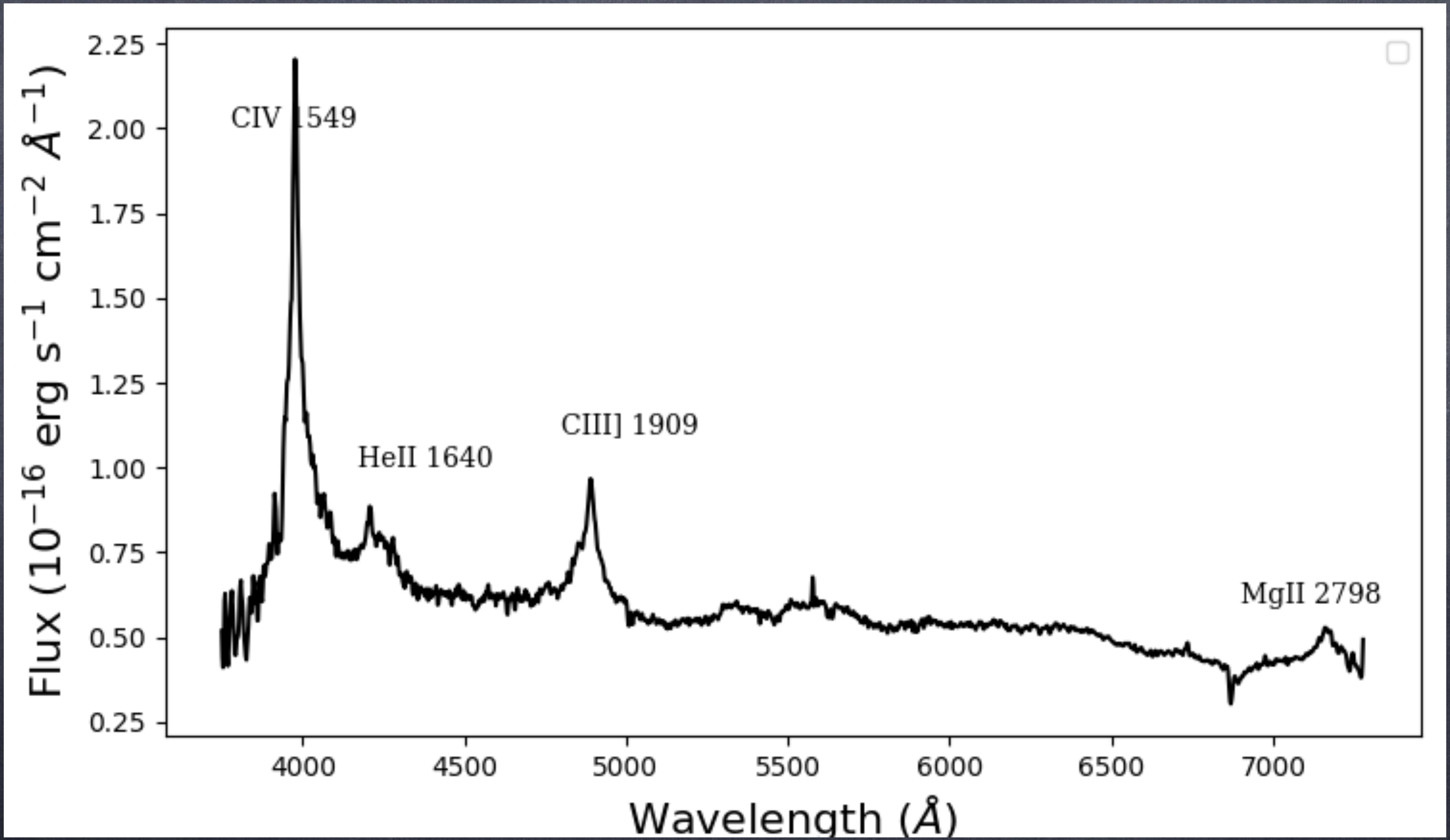
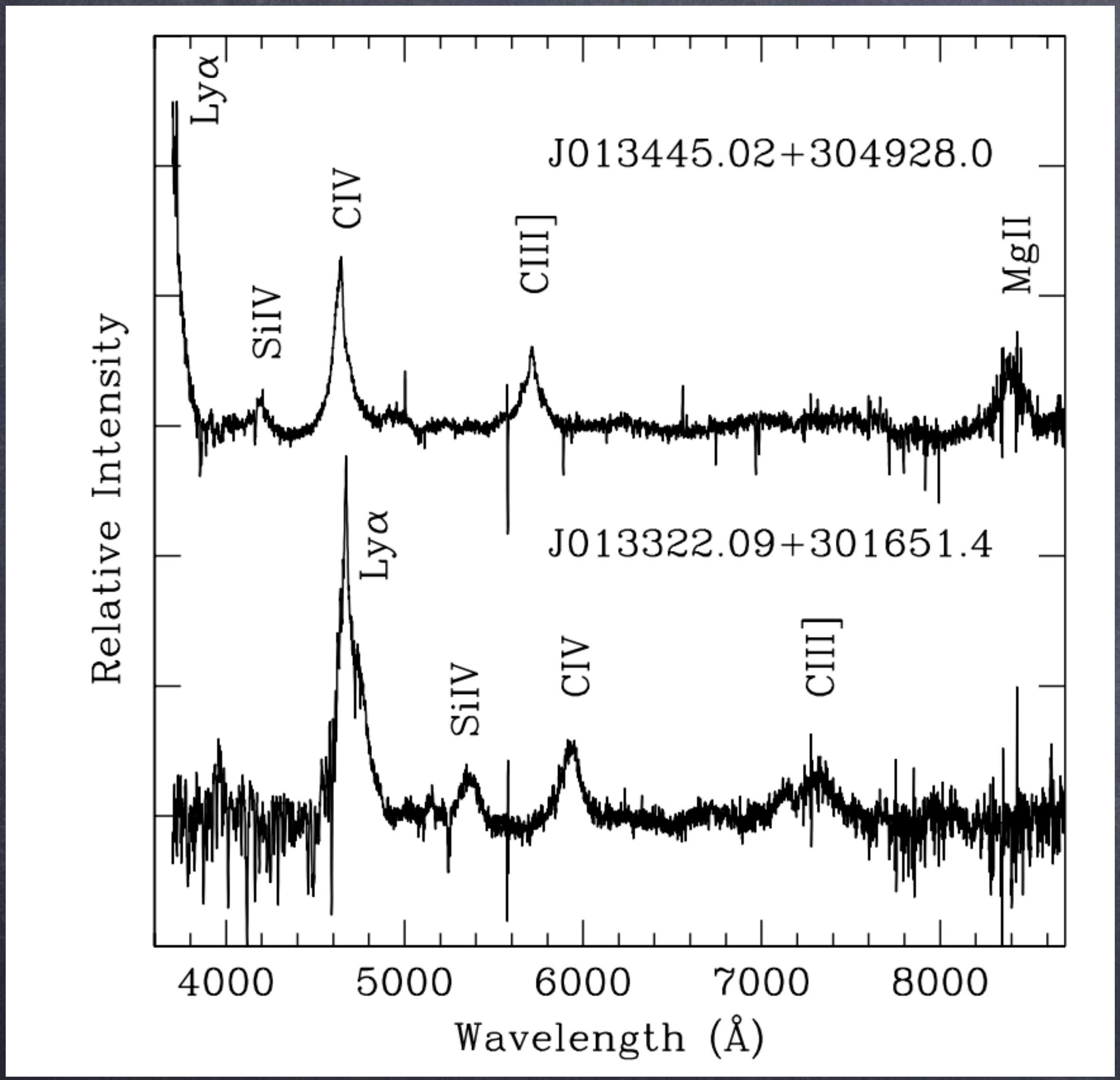


Fig. 12: GTC spectrum of a z=1.56 background QSO in the nuclear region of Holm 15A.

J004150 is an "Interesting loser"

Neugent & Massey 2011; Neugent et al. 2012 —> Interesting losers!!



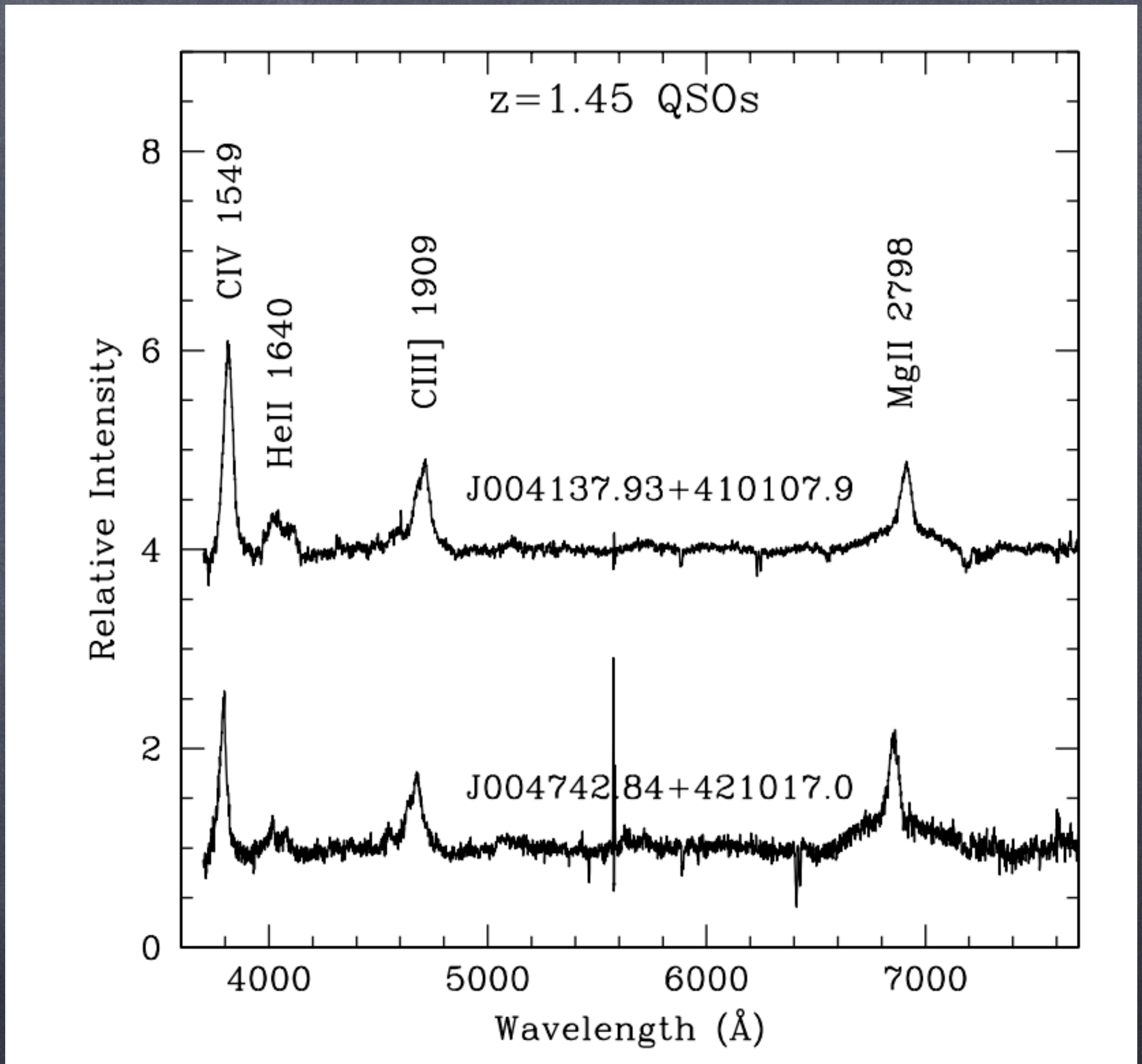
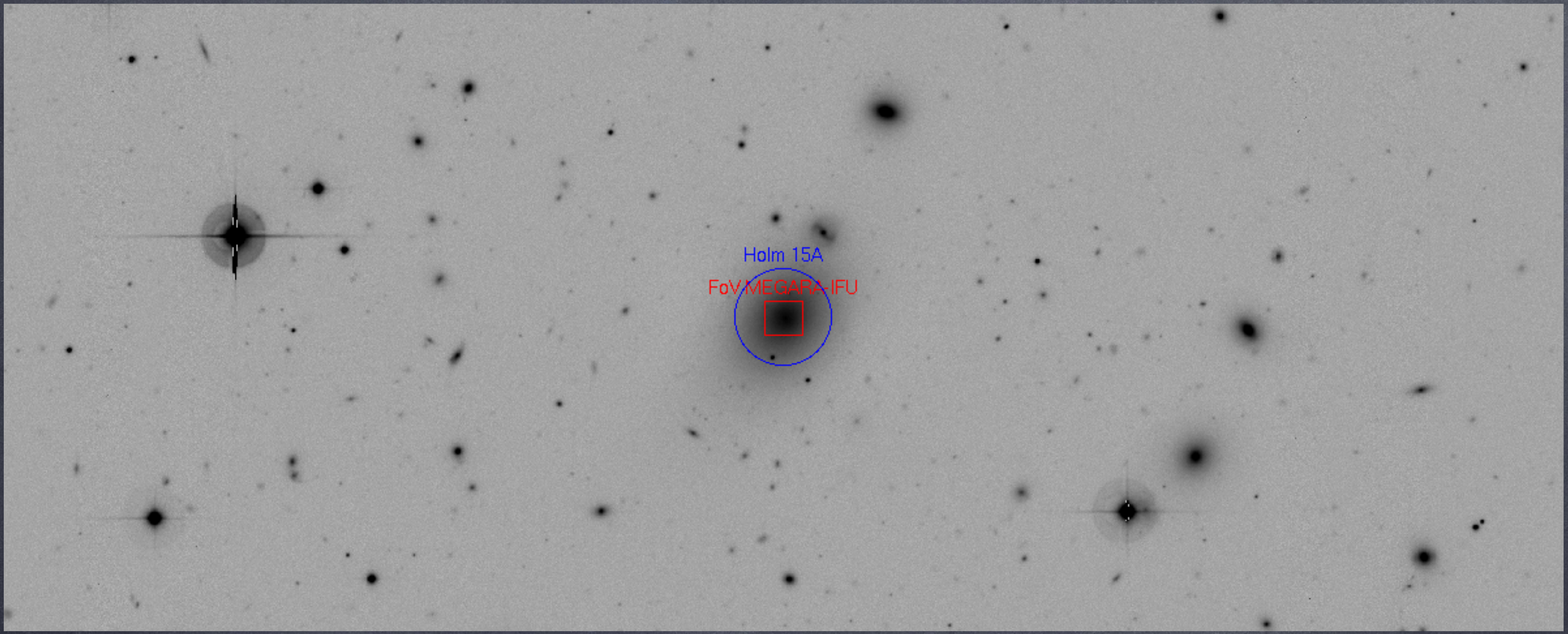


Fig. 13: Spectra of 'interesting losers' at z=1.99 and z=2.84 (left image, top and bottom respectively) background QSOs; while QSOs spectra at z=1.45 (right image, both).

MEGARA proposal

- We plan to map the central region of the galaxy with MEGARA/IFU at the lowest resolution mode around H_alpha in order to measure the Holm 15A's M_{BH} mass using gas and stars (Na D) as tracers.



- We have been awarded with 5 hrs (Mexican CAT) with the IFU Mode in Semester 2018B (GTC21-18BMEX).
- MEGARA LCB IFU: 12.5 X 11.3 arcsec^2
- Setup: VPH675-LR, LR-R (6094-7300 AA), R ~ 6000.
- Dither observations around the center of Holm 15A.
- SNR ~ 25 per voxel according to MEGARA ETC.
- Seeing limited*

Holm 15A Spectrum

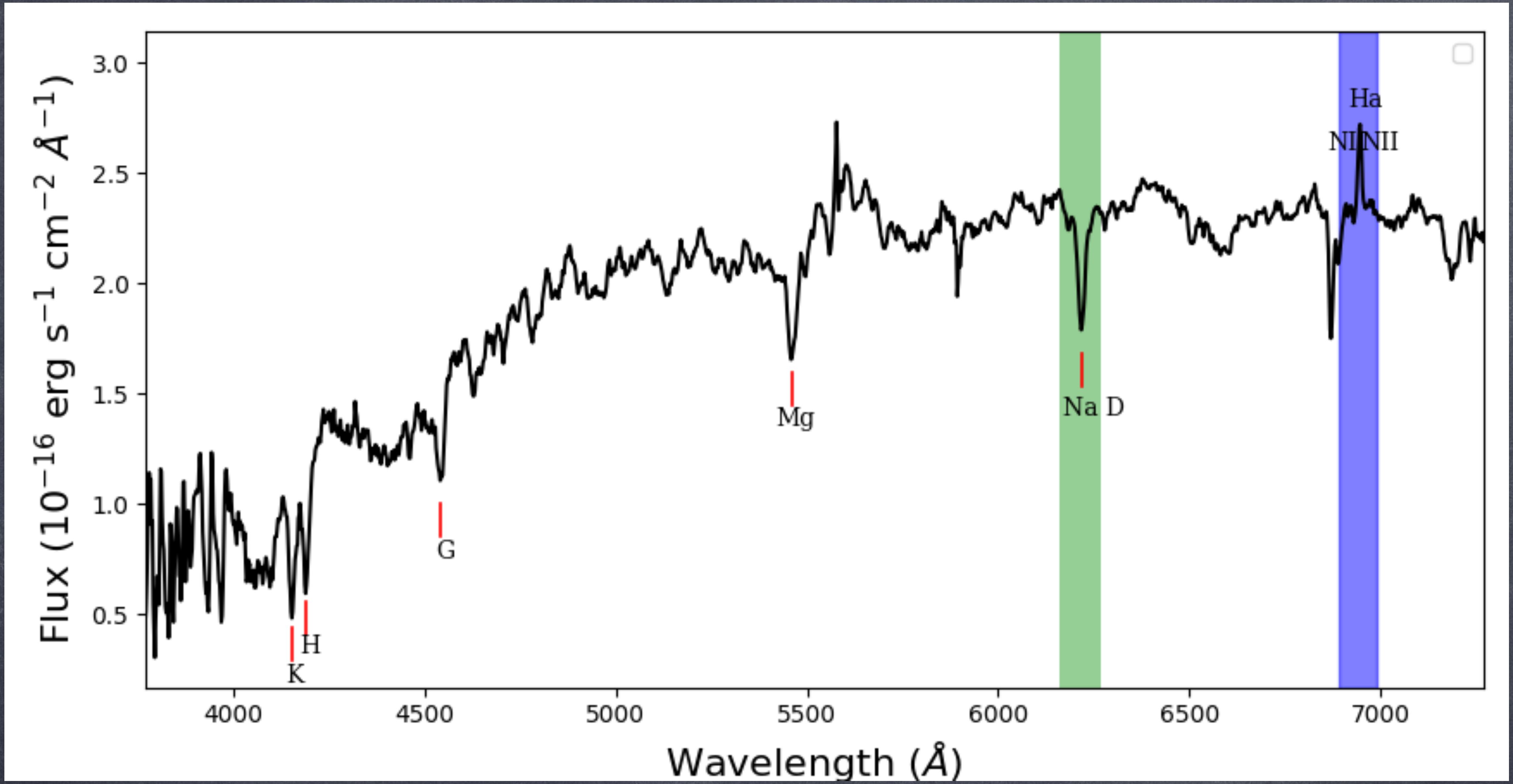
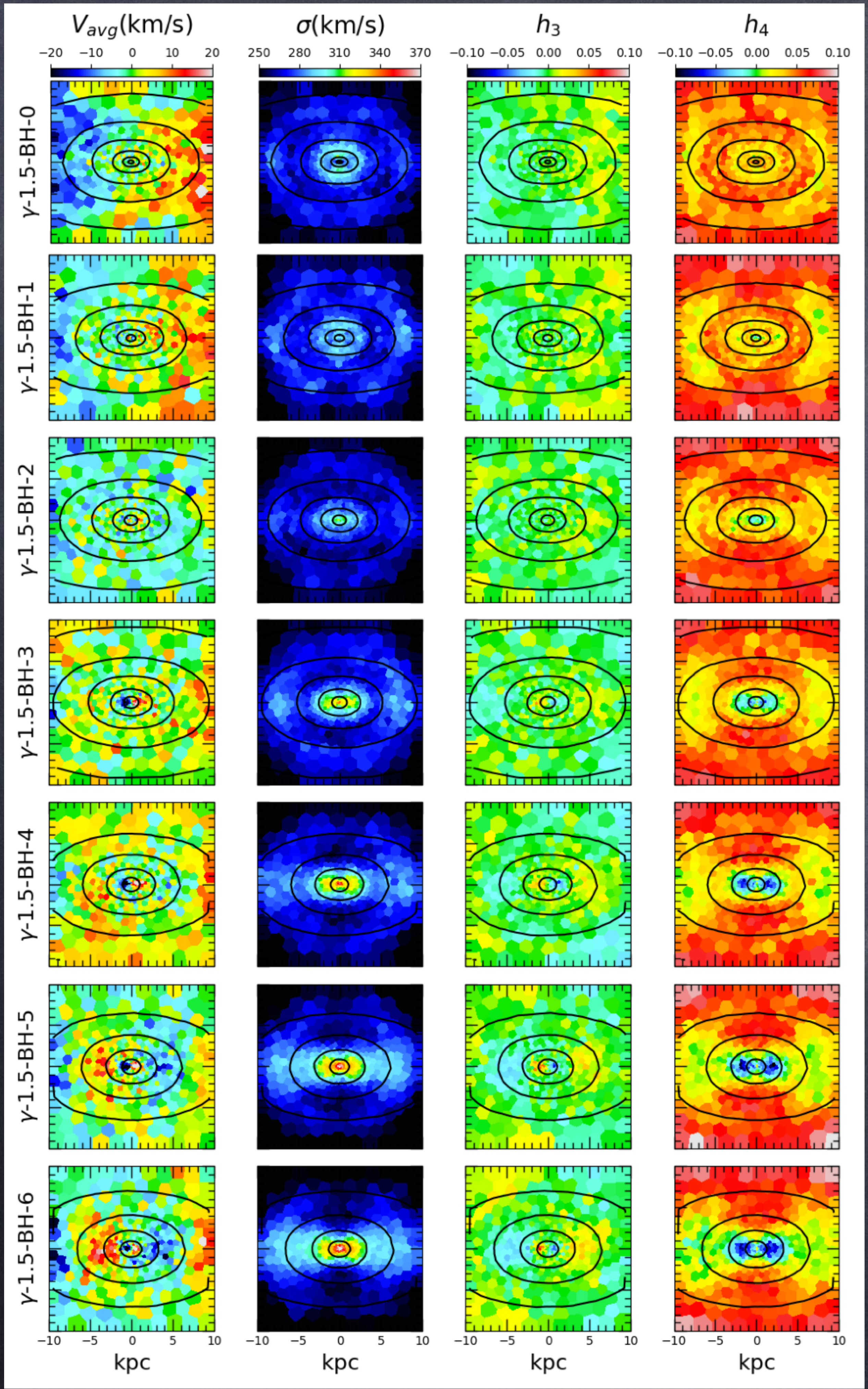


Fig. 15: GTC/OSIRIS spectra in B-band of Holm 15A showing the spectral features shaded in color like H_alpha and [NII] 6548, 6583 (blue) and NaD (green) (Ríos-López et al. in prep.).

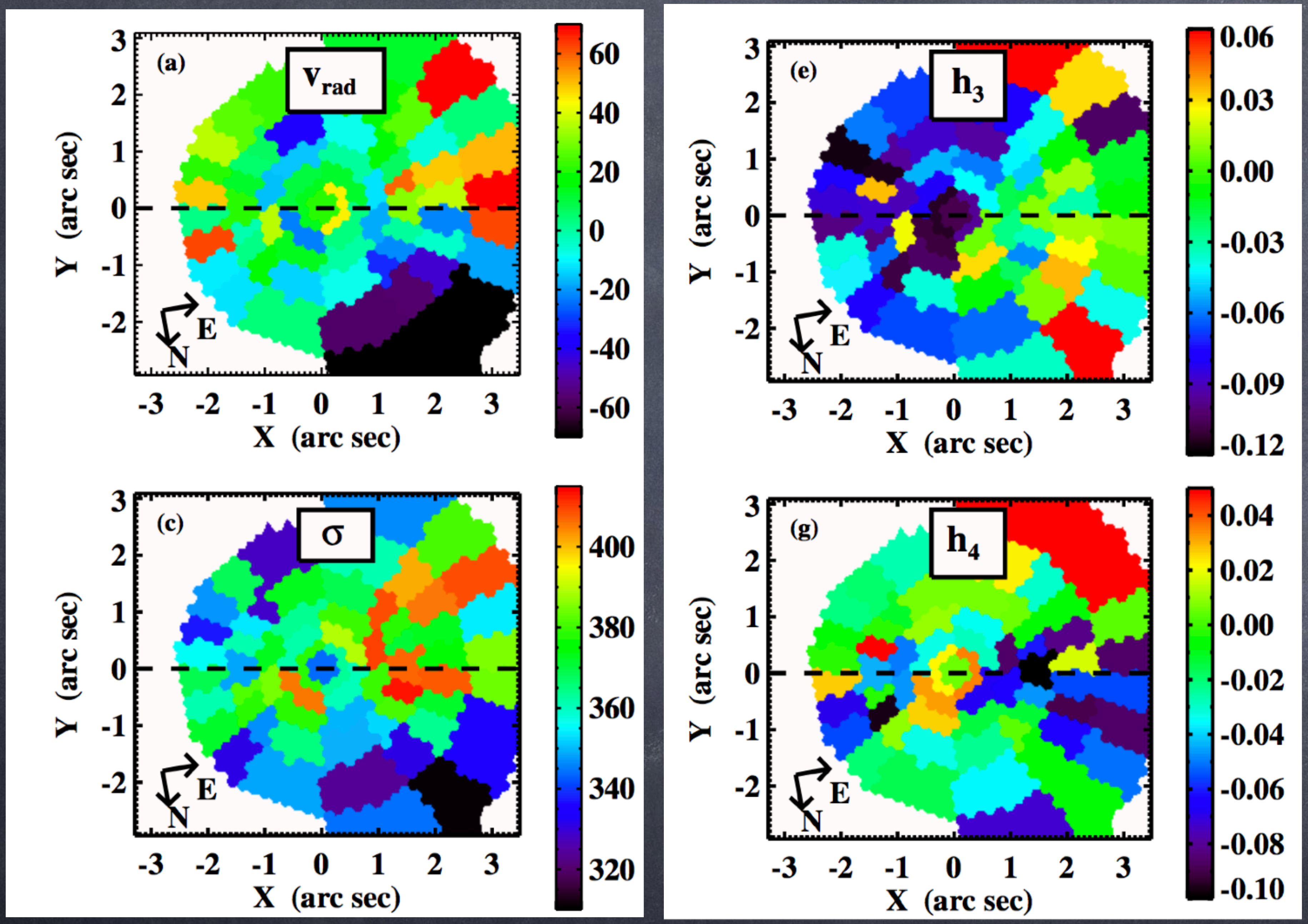


MEGARA capability is ideal to carry out this task

From **Rantala et al. 2018:** Simulated two-dimensional stellar kinematic maps.

From left to right: the line-of-sight velocity Vavg, the stellar velocity dispersion, h3 and h4

Some previous studies in BCGs



From **McConnell et al. 2012:** Two-dimensional stellar kinematic maps .

Line-of-sight velocity Vrad (top left), the stellar velocity dispersion (bottom left), h3 (top right) and h4 (bottom right).

VLA and OAGH observations

GTC (OSIRIS and MEGARA) observations are part of a complementary on-going program that we are performing for Holm 15A:

-VLA observations: (Project:18A-263), which are currently underway where we are looking for SMBH signatures at a resolution of 0.24” and a flux density sensitivity of the 2 µJy.

-GHAO 2.1m telescope: Semester 2018B. Measure wide-field stellar kinematics from absorption features in order to map velocity field of Holm 15A from the smallest to largest scales accesible.

Thank you!