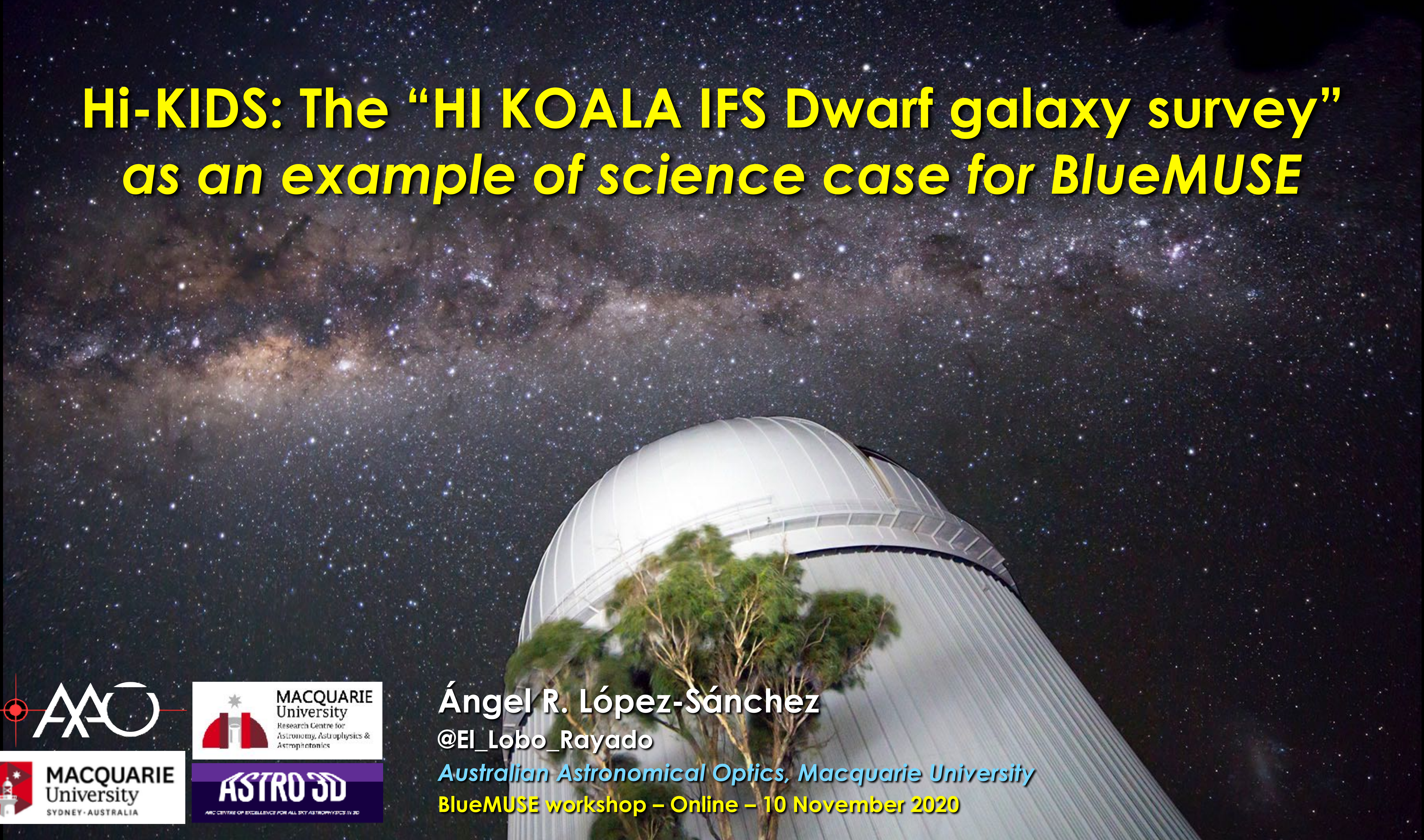


Hi-KIDS: The "HI KOALA IFS Dwarf galaxy survey" *as an example of science case for BlueMUSE*

Ángel R. López-Sánchez

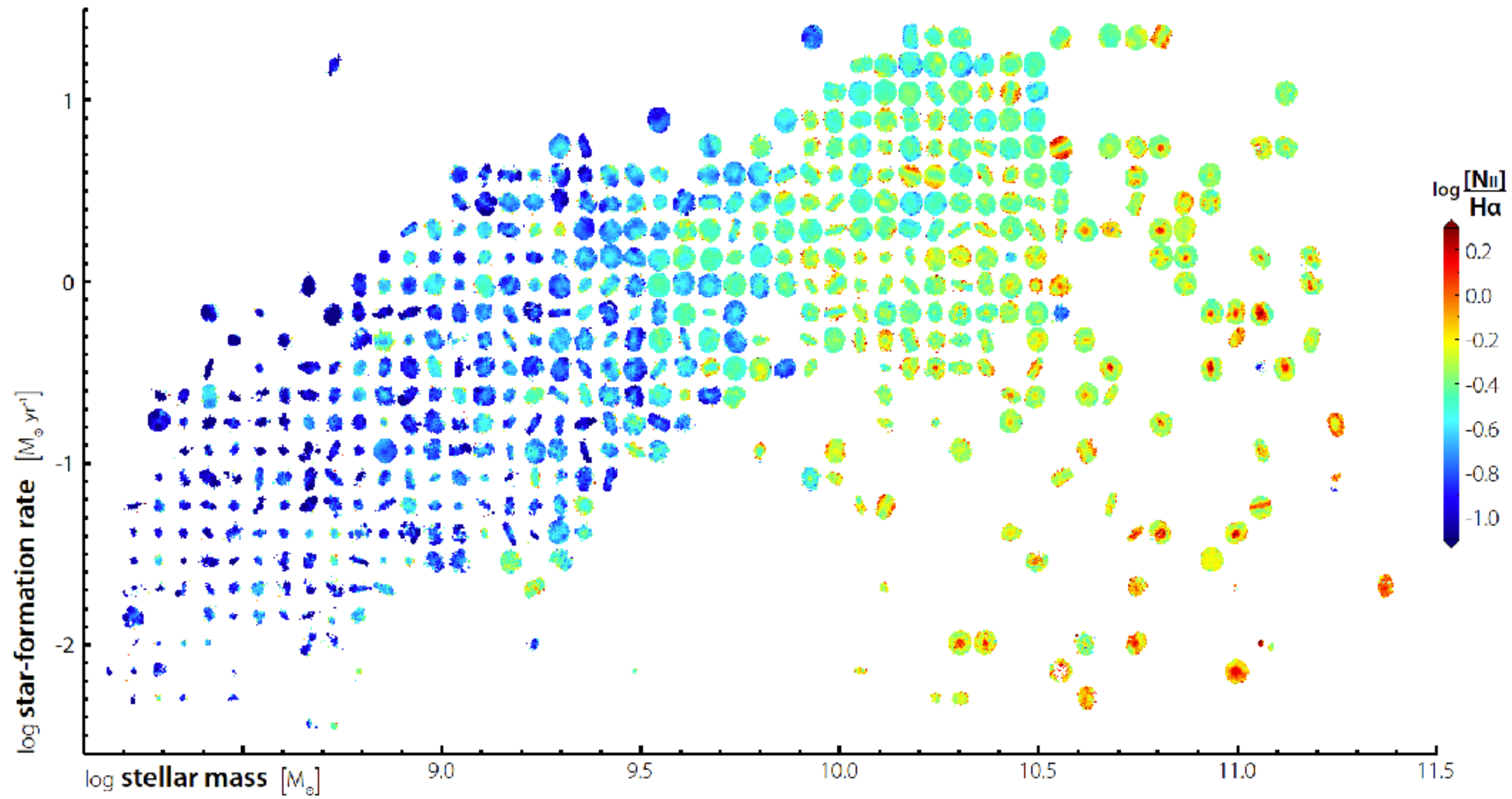
@El_Lobo_Rayado

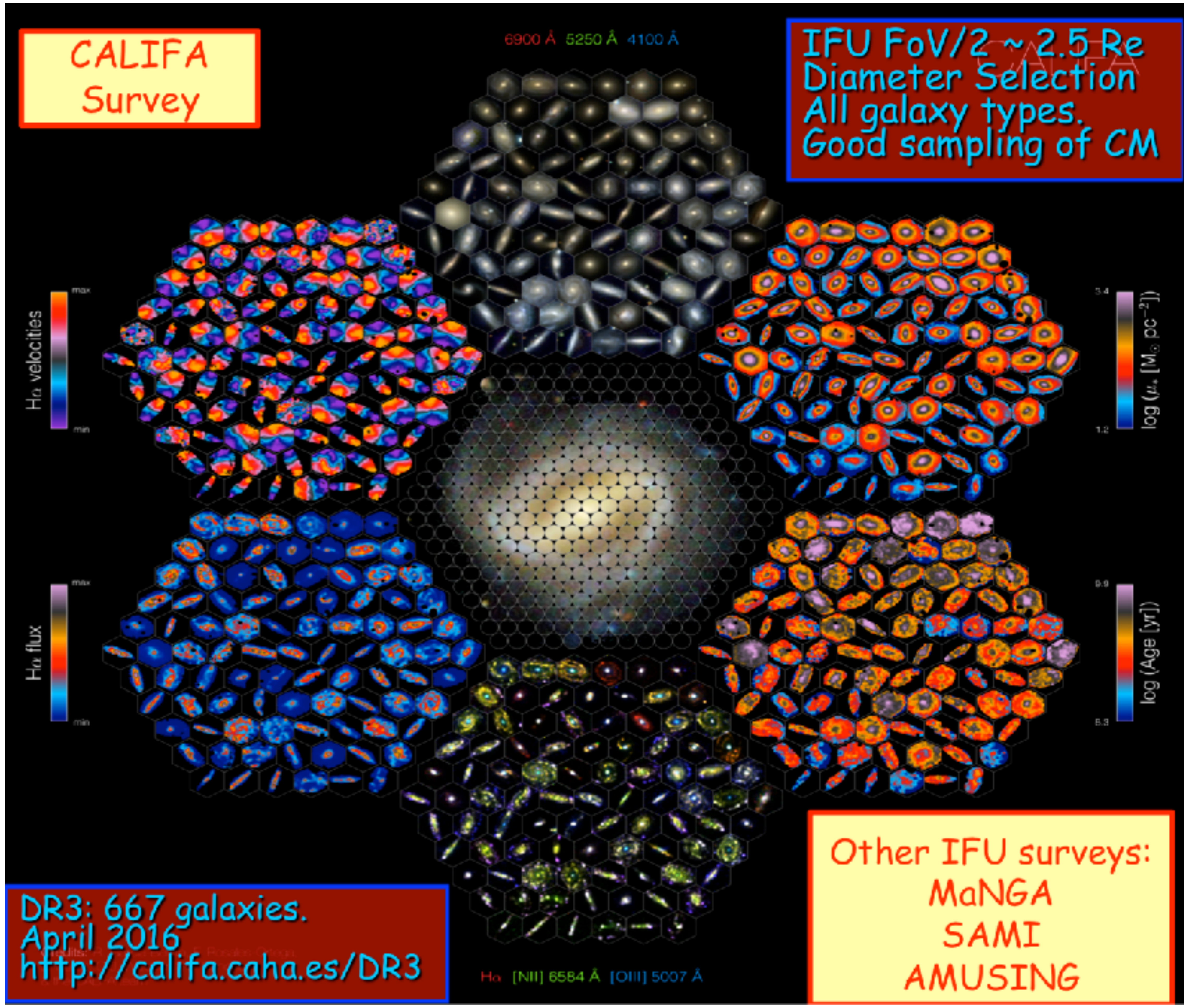
Australian Astronomical Optics, Macquarie University

BlueMUSE workshop – Online – 10 November 2020

IFS galaxy surveys: what do they observe?

- They all target the "**normal**" galaxy population.
  - ➡ **CALIFA**: Sánchez et al. (2012, 2013, 2015, 2016), Walcher et al. (2015)
  - ➡ **SAMI:** Croom et al. 2012, Bryant et al. 2015, Green et al. 2017
  - ➡ **MaNGA** (Bundy et al. 2015)
- **Dwarf galaxies** ($M_{star} \sim 10^6 - 10^9\ M_\odot$) tend to be **massively under-represented**, especially when compared with volume-limited surveys (e.g. Lee et al. 2009, 2011).





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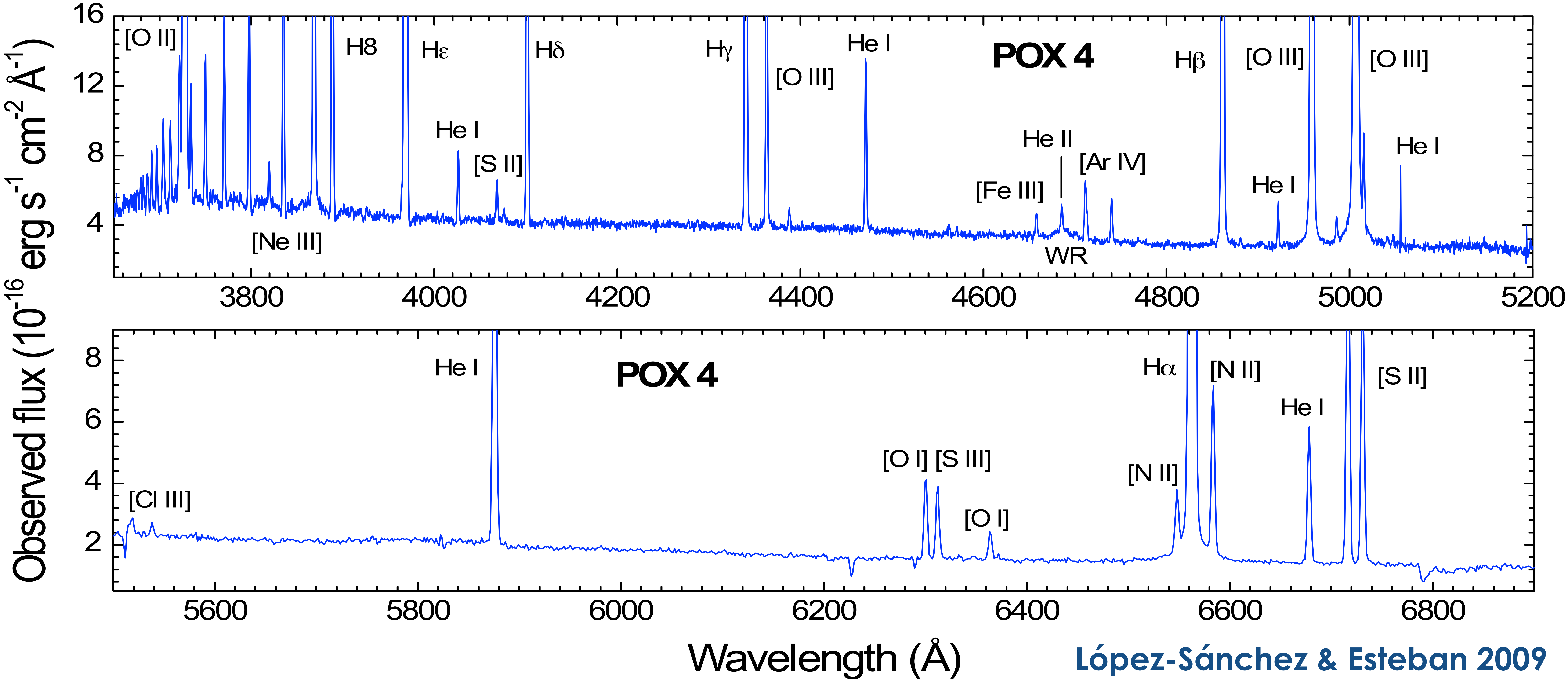

López-Sánchez & Esteban 2009

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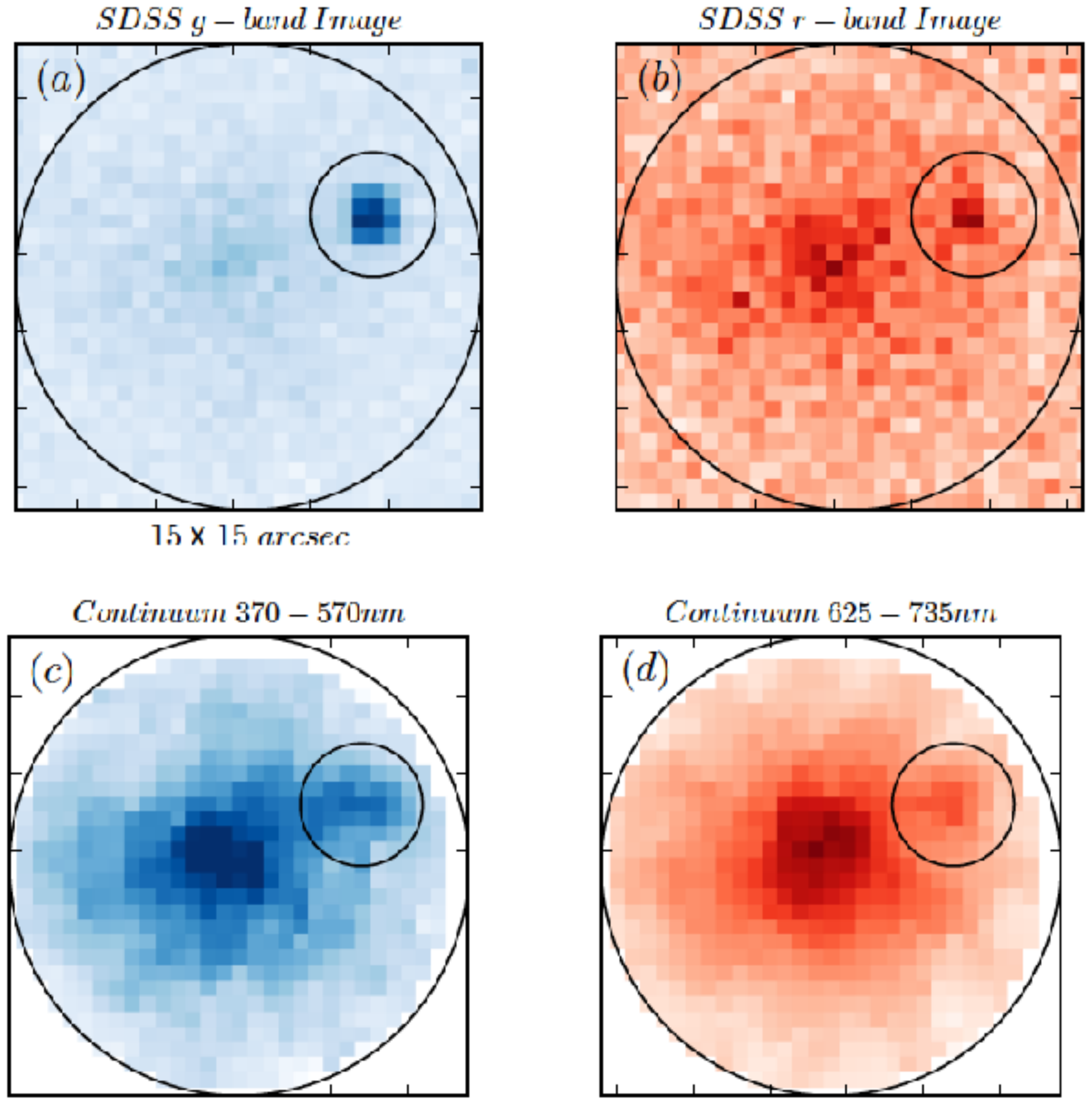
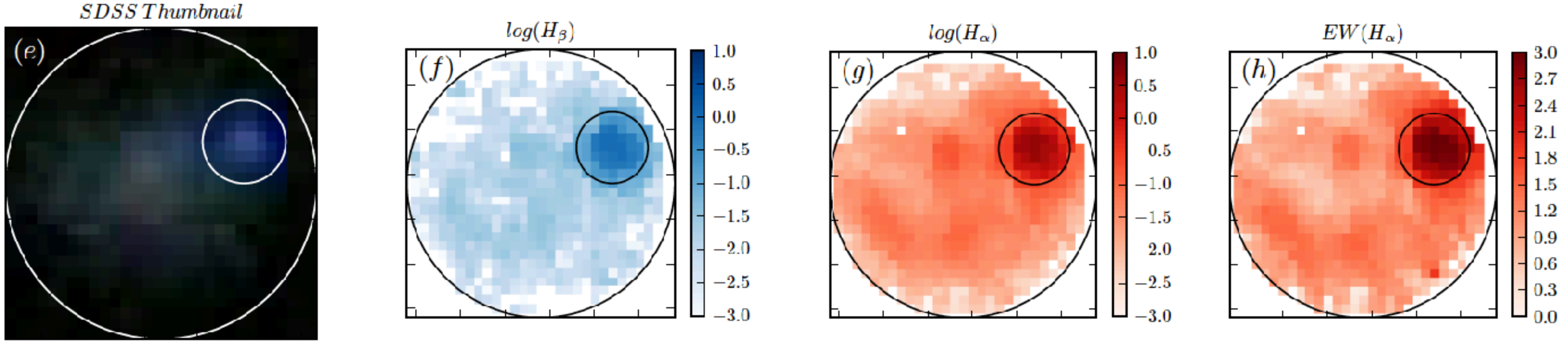


Richards et at. (2014)



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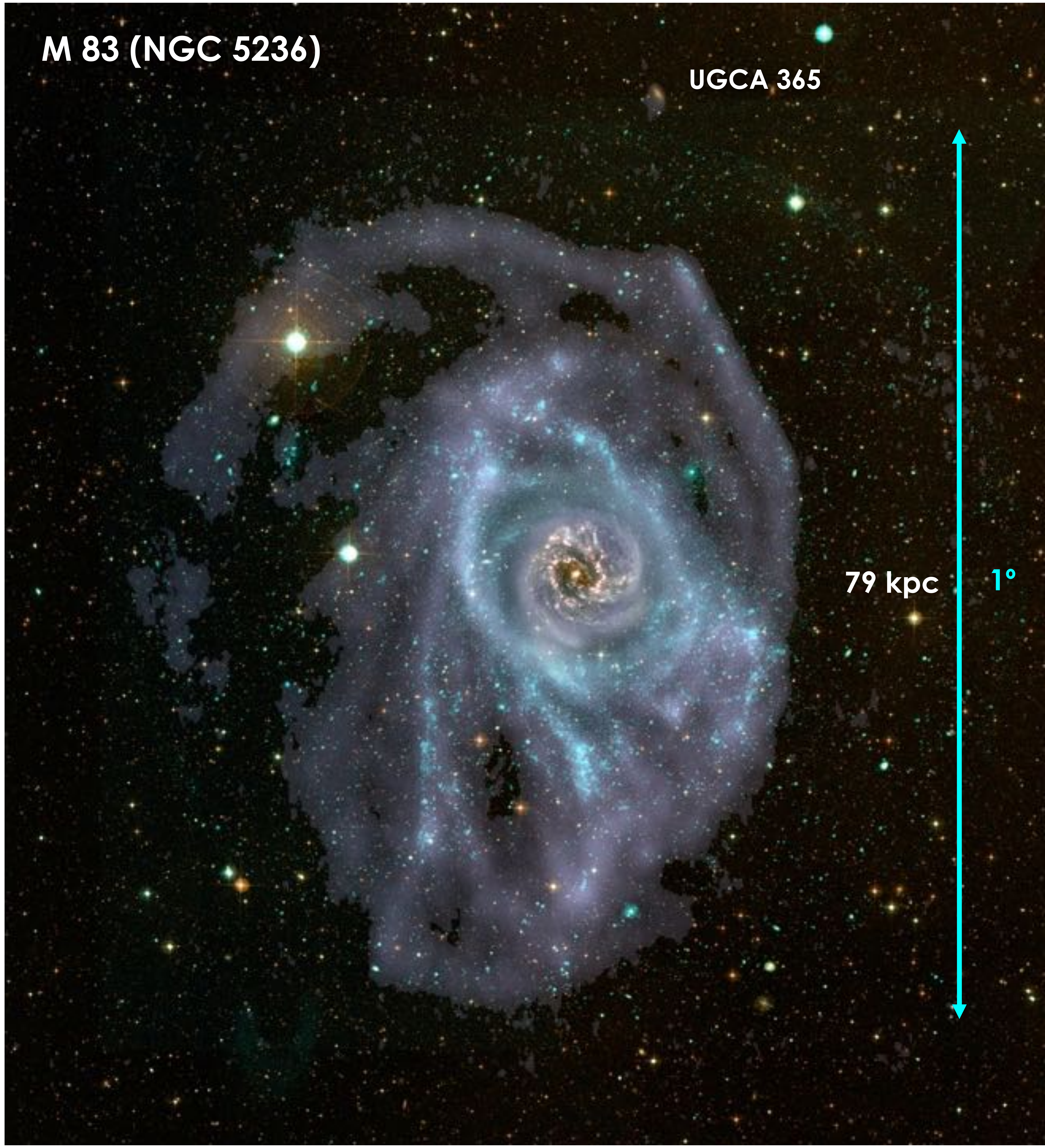
- Many of the galaxies observed are relatively **too far away to be well resolved** (see the discussion in Richards et al. 2014 about H II regions within SAMI galaxies).
- The (scarce) **H I data** available from single-dish observations, thus lacking any spatial information.

Need of **a *DEEP* IFS *DWARF* galaxy survey including *INTERFEROMETRIC HI* data !!**

Koribalski et al. 2018,
The Local Volume HI Survey (LVHIS)

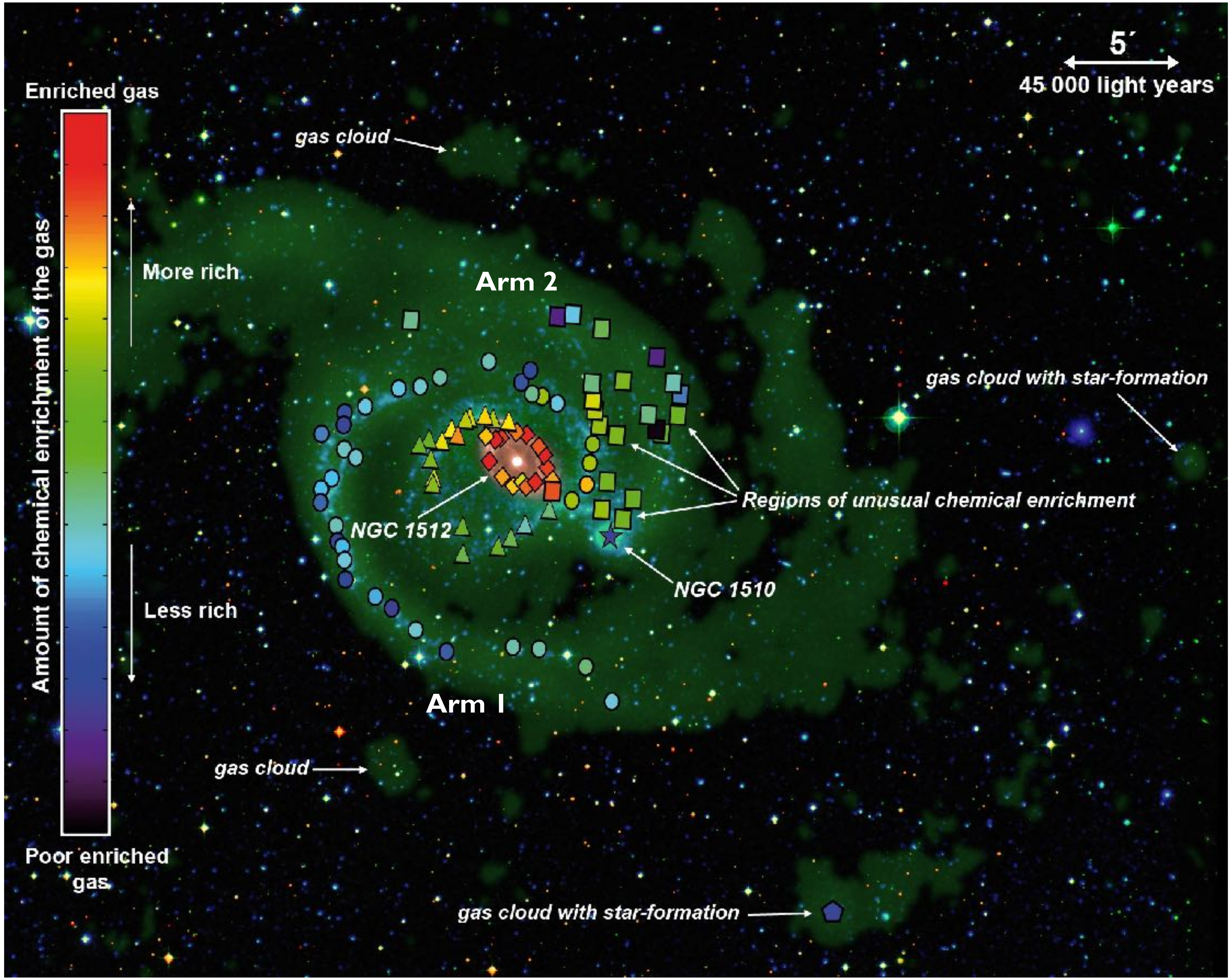


Low-resolution H I map (pale blue) + UV (dark blue) + R (green) + J (red), Ángel López-Sánchez

Metals: Connecting stars and gas to understand galaxy evolution

- Metals is a way of measuring **HOW MUCH THE GAS HAS BEEN PROCESSED INTO STARS**
- Informs about the **star formation history** of galaxies
- Traces **infalling** of pristine gas... or **outflows** of processed gas
- Helps to disentangle the **nature** of diffuse objects around galaxies
- Example:
  gas, stars and metals in NGC 1512 / 1510

  - Arm 2 has experienced a larger chemical enrichment that Arm 1.
  - The gas already had **a lot of metals** before the star-formation started!
  - Metals are coming from the **circumgalactic medium**, perhaps from dwarf, low-luminosity, gas-rich galaxies which have been slowly accreted and destroyed into the system.



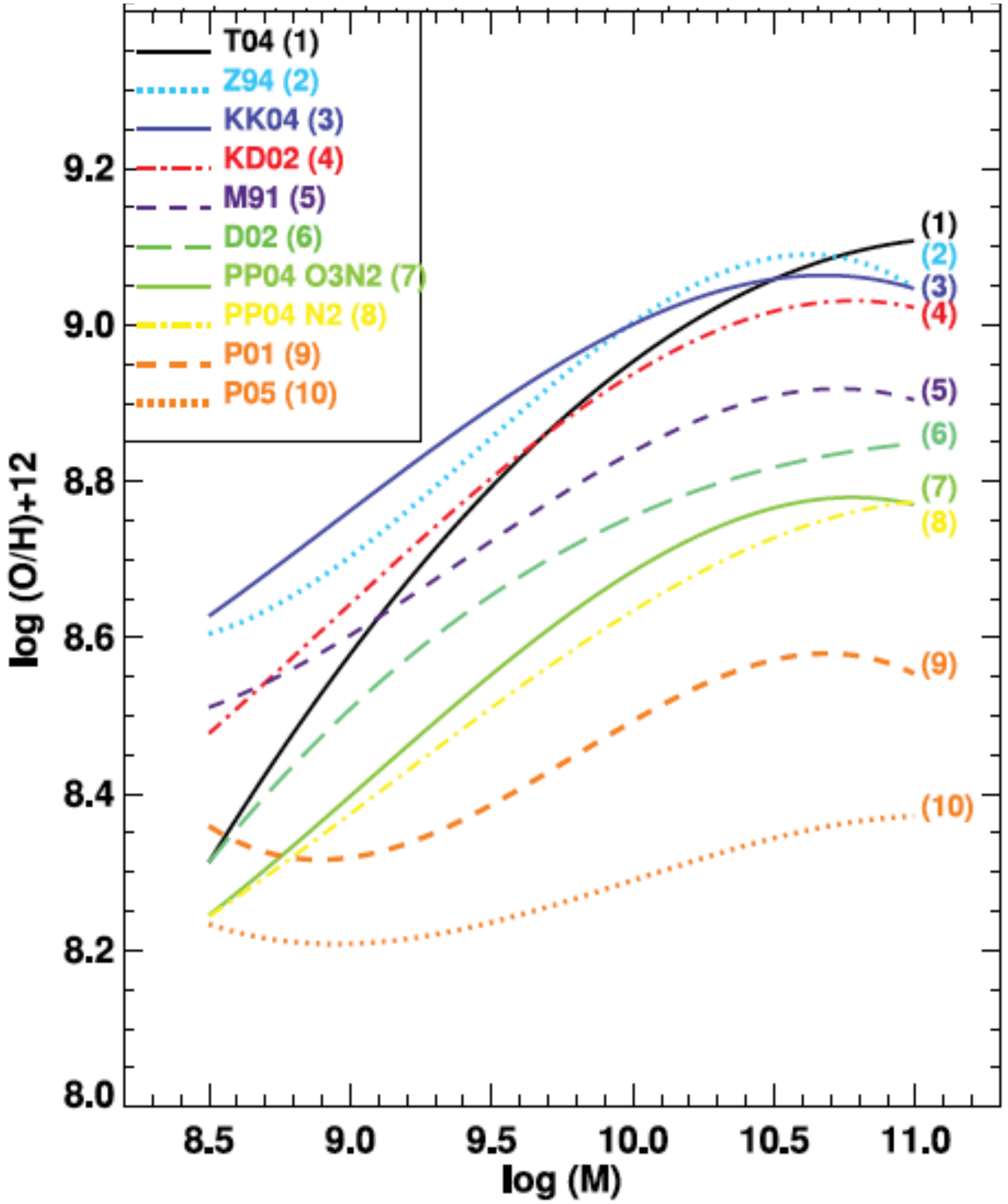
Koribalski & López-Sánchez 2009, MNRAS
López-Sánchez et al. 2015, MNRAS, 450, 3381

Ángel R. López-Sánchez @El_Lobo_Rayado

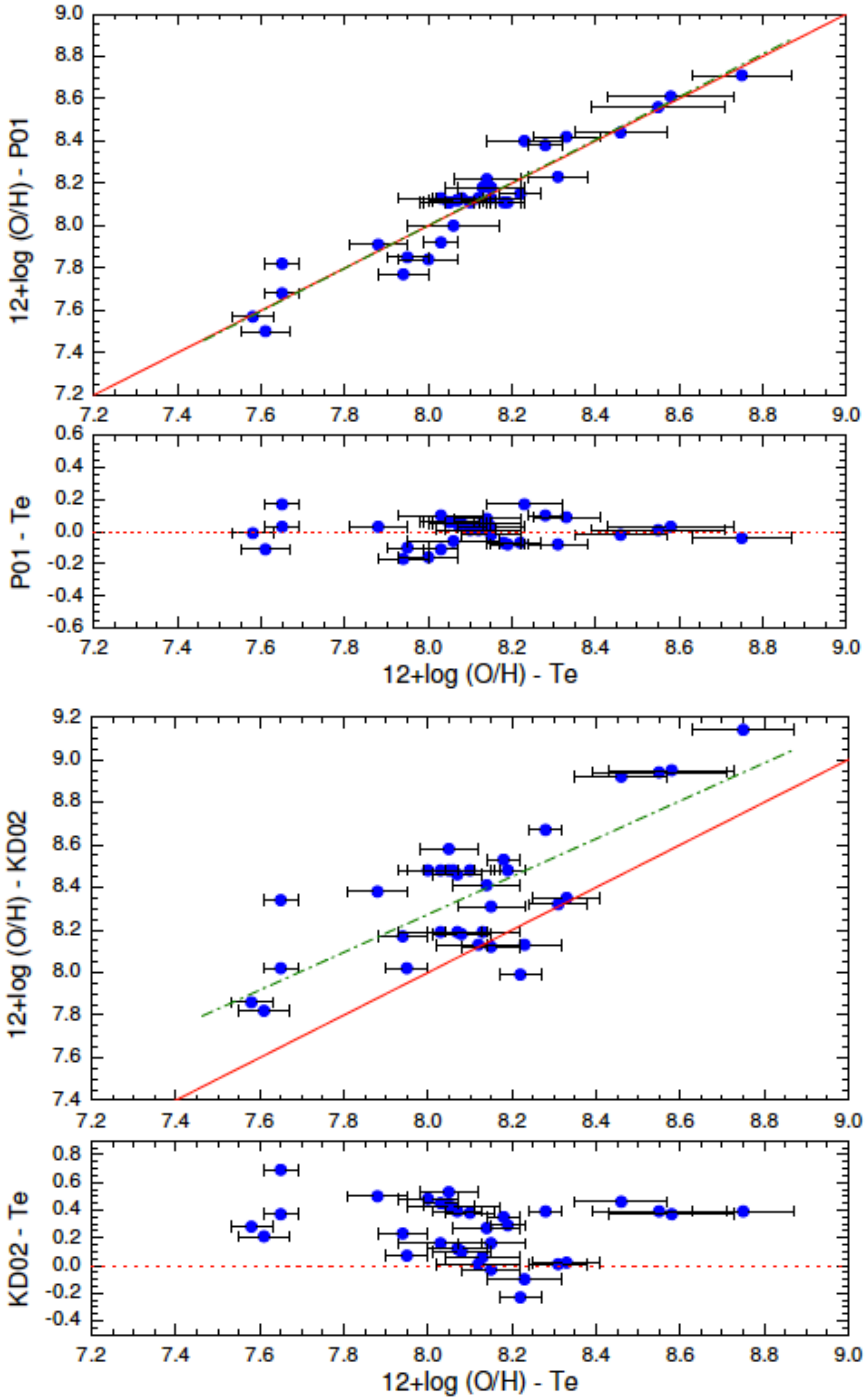
A warning about gas-phase metallicities

- **OXYGEN ABUNDANCE**: 12 + log (O / H)

1. The problem of the **ABSOLUTE** scale



Kewley & Ellison 2008



López-Sánchez, PhD (2006)
López-Sánchez & Esteban, 2010b, A&A, 517, 85
López-Sánchez, Dopita, Kewley et al. 2012, MNRAS, 426, 2630

A warning about gas-phase metallicities

- **OXYGEN ABUNDANCE**: 12 + log (O / H)

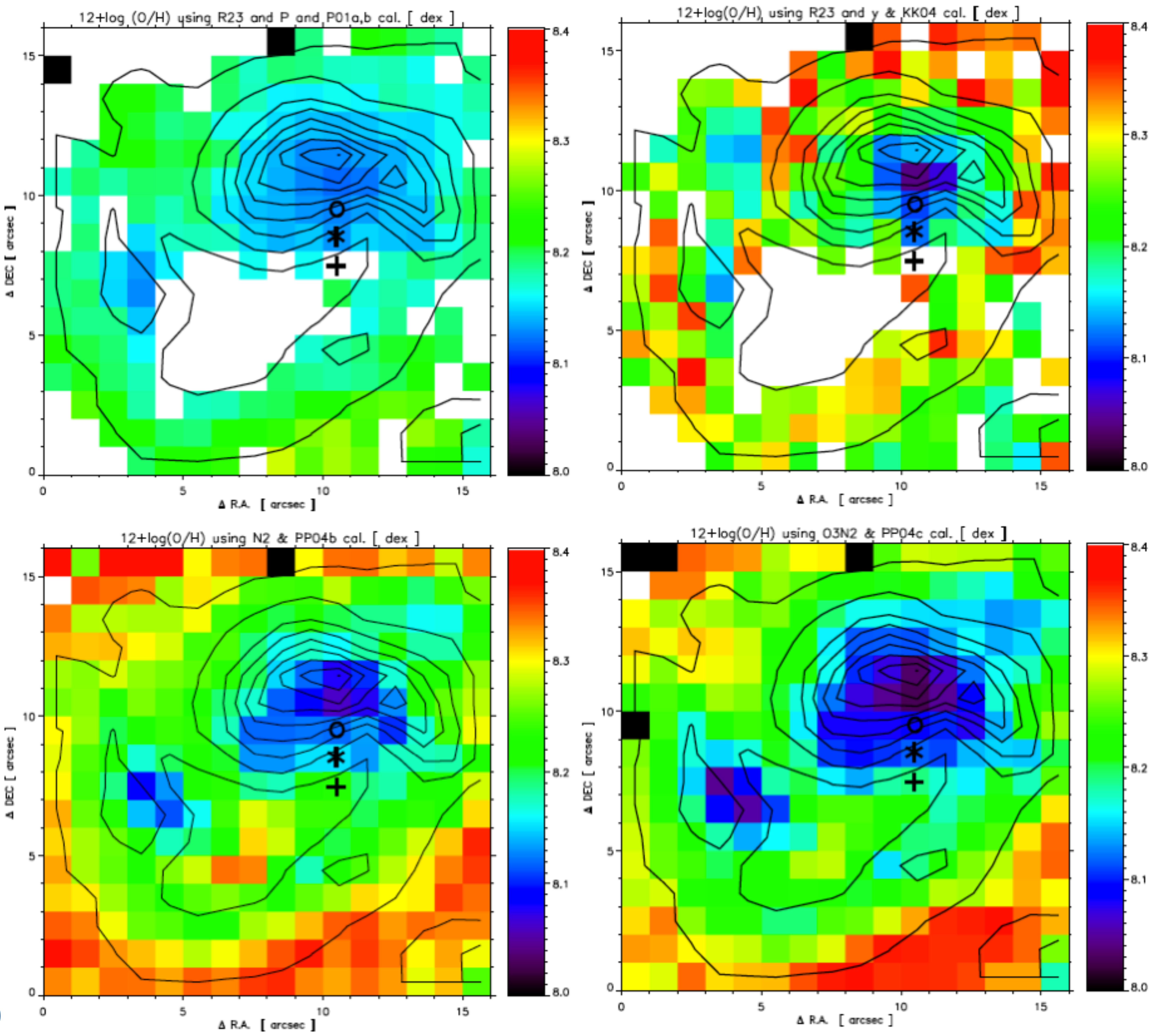
1. The problem of the **ABSOLUTE** scale
2. **Resolving HII regions** when using IFS data

★ The **ionization structure** plays an important role !

  – Evident when using N2 and O_3N_2

★ IFS analyses of star-forming galaxies needs **observations deep enough to detect the faint auroral lines** (see also James et al. 2009, 2010).

★ **IMPORTANT:** Oxygen abundance maps obtained using empirical calibrations **may show features that are not related with the actual metallicity** distribution of a star-forming galaxy but with the **IONIZATION STRUCTURE** within its giant H II regions.



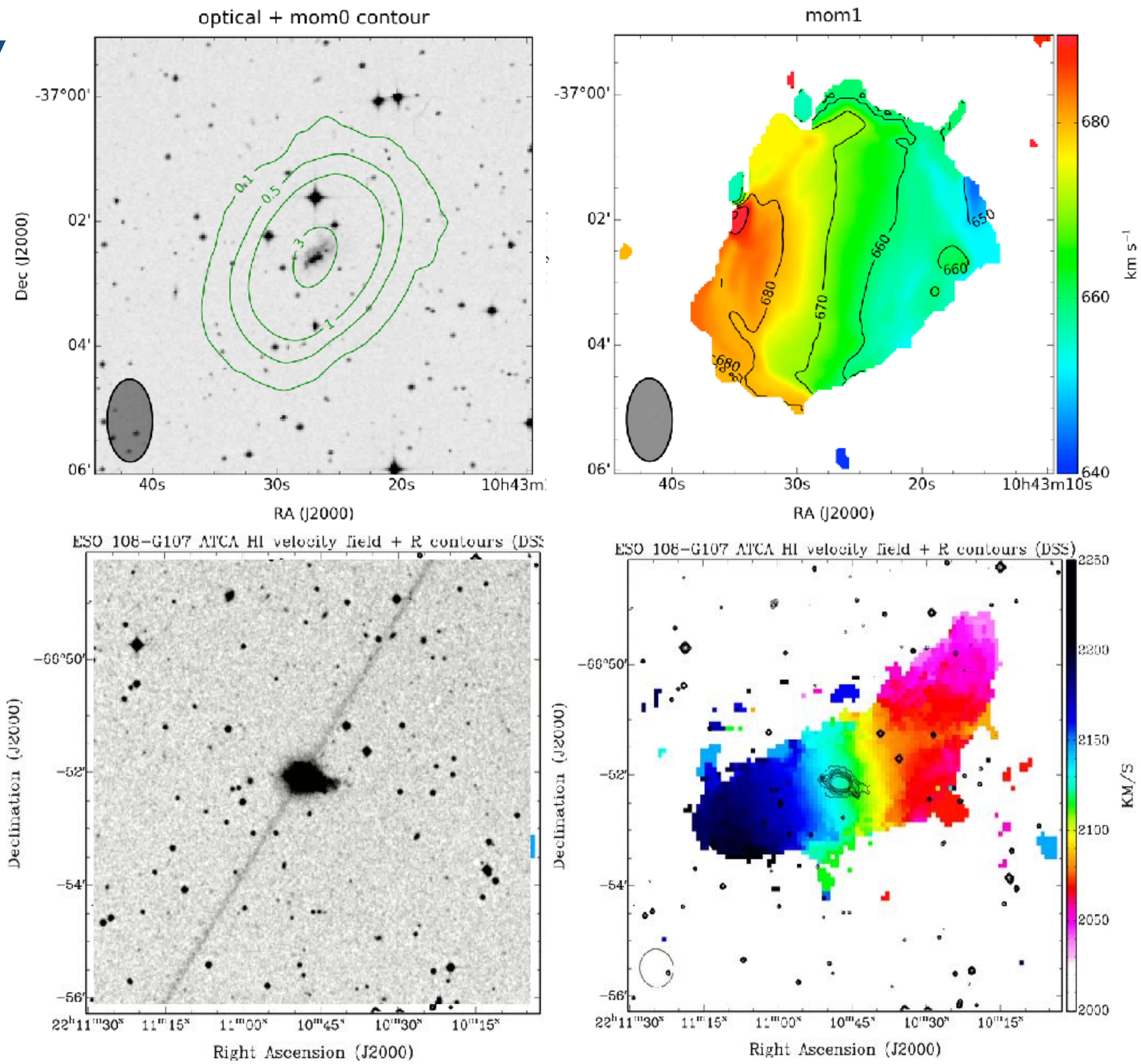
López-Sánchez et al. 2011, MNRAS, 411, 2076 (PMAS data)

HI KOALA IFS Dwarf galaxies Survey

Hi-KIDS

PI: Ángel López-Sánchez

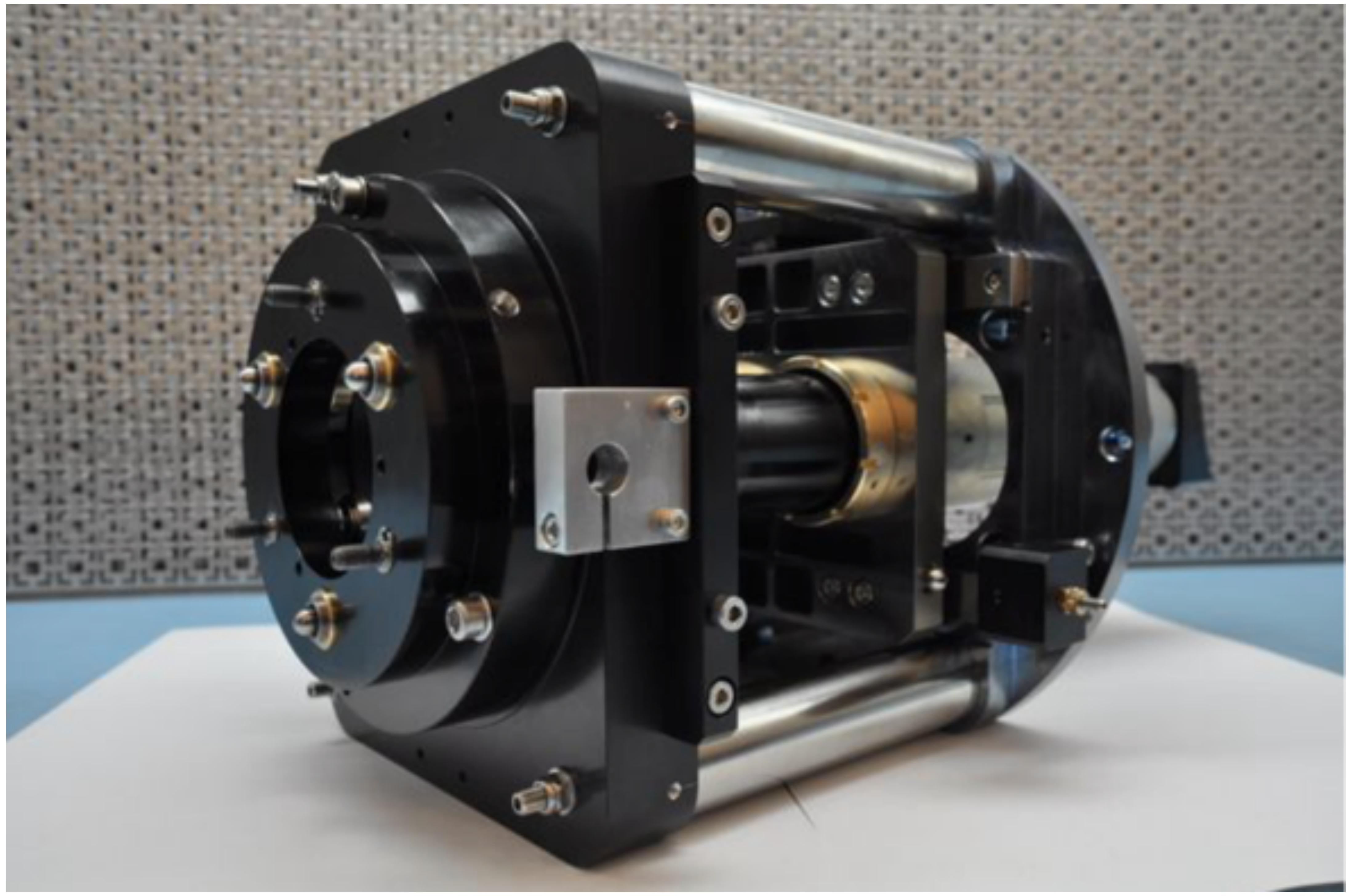
- Exploring a parameter space not studied by current IFS surveys we are obtaining **high-quality IFS data** of **nearby dwarf galaxies** with available **21-cm HI interferometric radio** data.
- We are using **KOALA+AAOmega at the 3.9m AAT** to assemble deep, good-quality IFS data:
  - ✓ 7 x 30 min exposures / pointing
  - ✓ **3650 – 9100 λλ** range:
  - ✓ **[O II] 3727 -> [S III] 9065**.
- Sample selection:
  - ✓ **Local Volume HI Survey**, Koribalski et al. (2018).
  - ✓ **Faint Irregular Galaxy GMRT Survey,** Begum et al. (2008).
  - ✓ **BCDGs observed at the ATCA**, López-Sánchez et al. 2008.

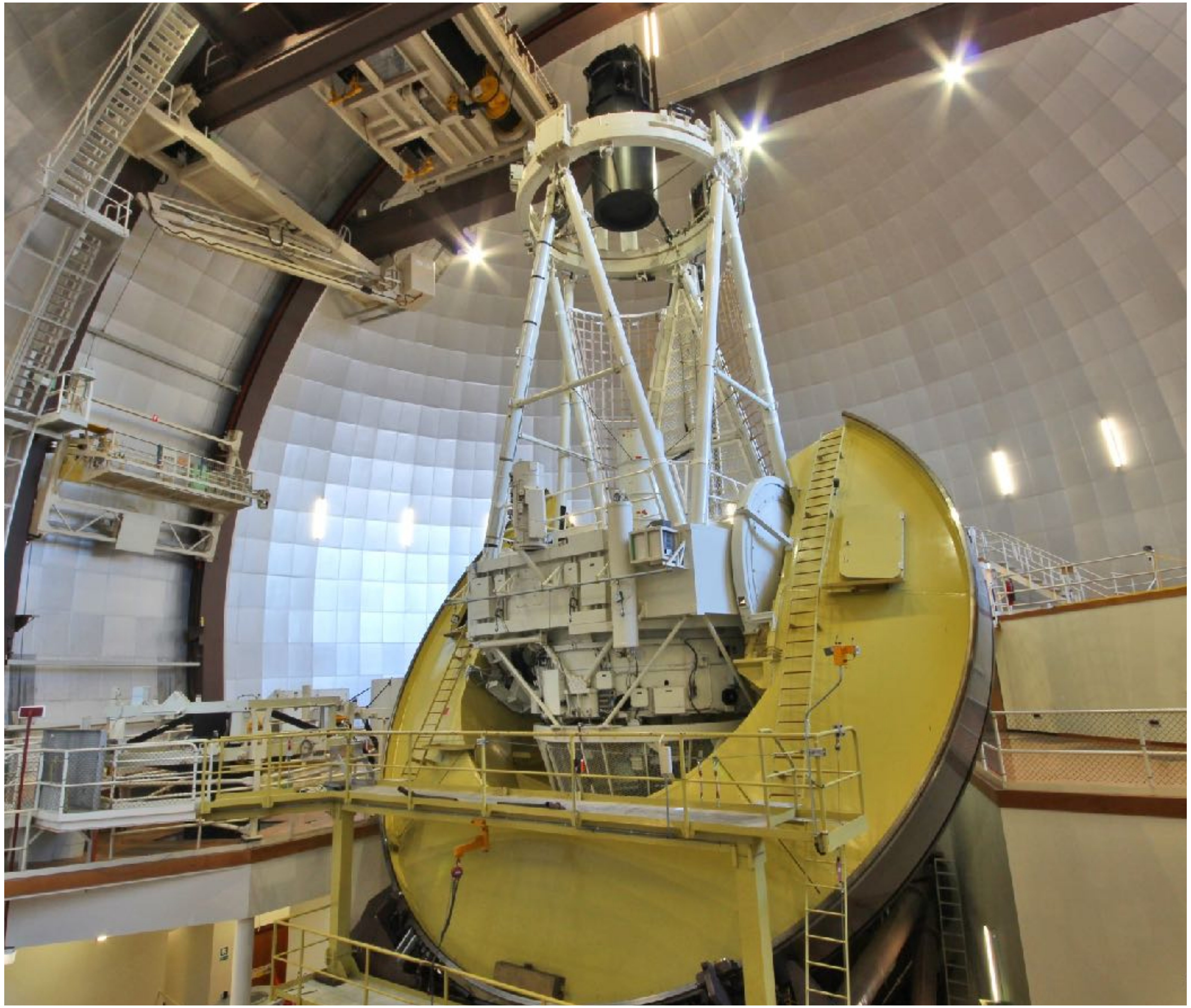


KOALA IFU at the Anglo-Australian Telescope

Instrument Scientist: **Ángel R. López-Sánchez**

- **KOALA (Kilofibre Optical AAT Lenslet Array)** is a wide-field, high efficiency, integral field unit (IFU)
- It is mounted at the **f/8 Cassegrain focus** and feeds the **AAOmega spectrograph** via a 31m fibre run.





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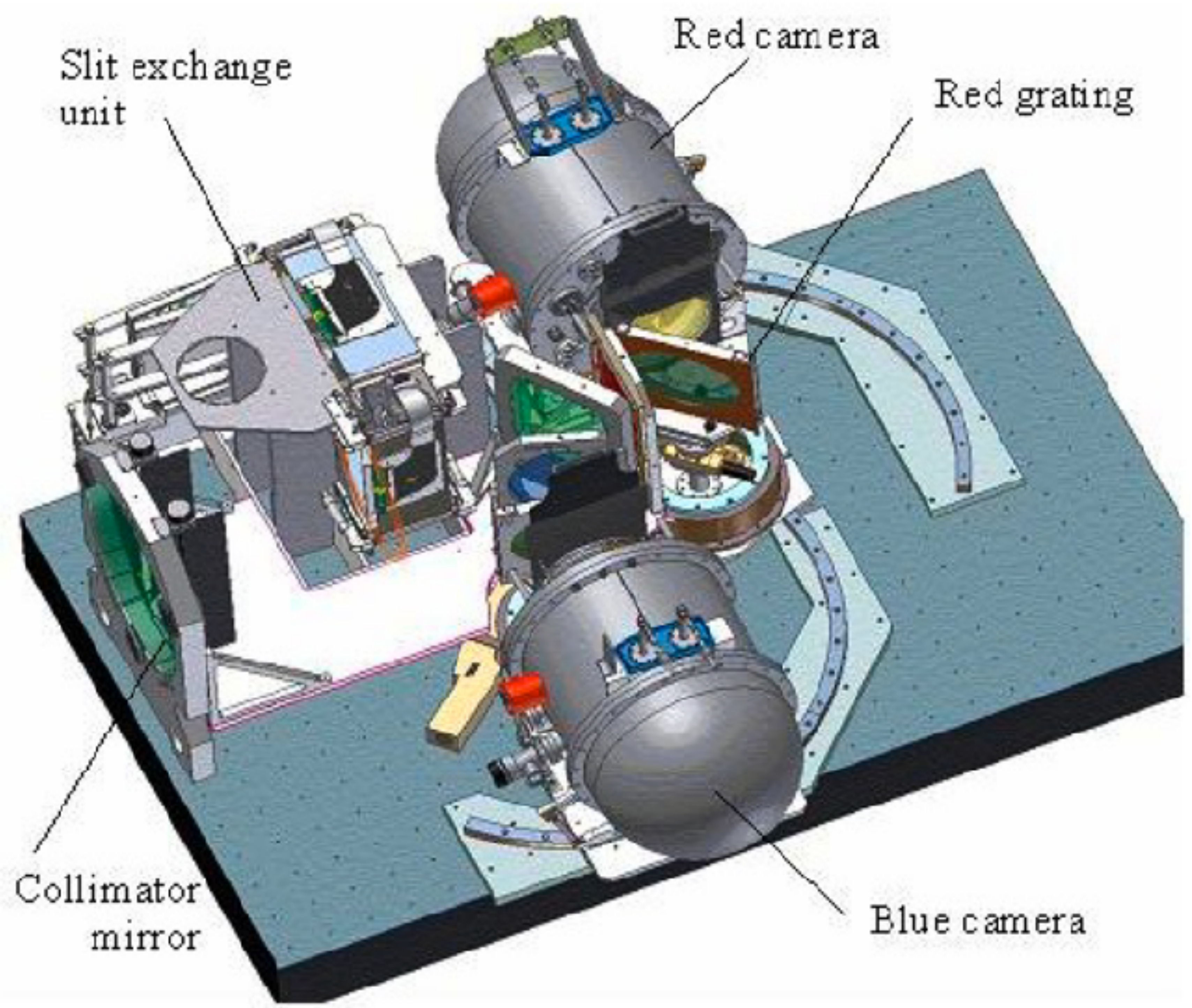
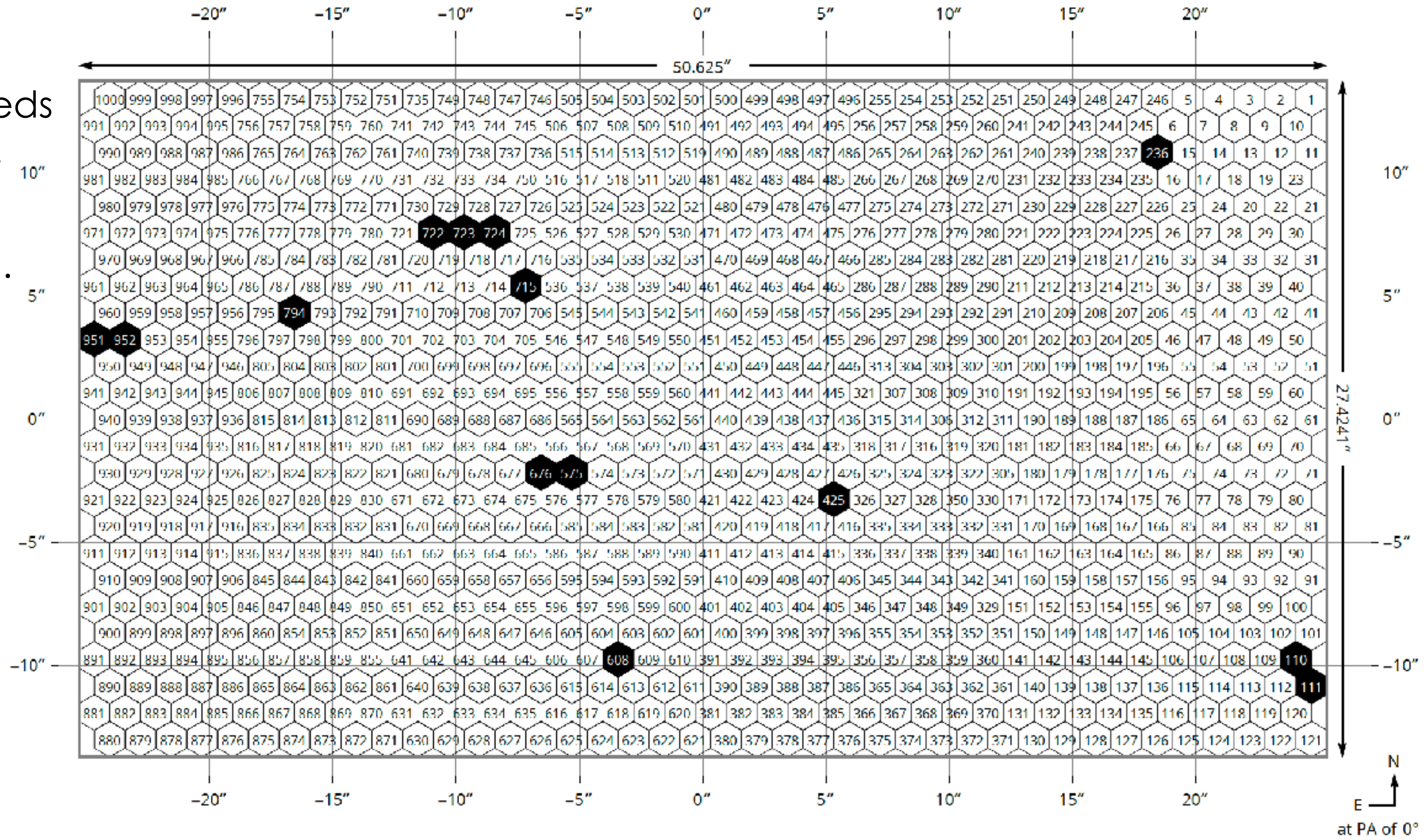
- **AAOmega** is a double beam spectrograph with selectable wavelength coverage and resolution.
  - ✓Same spectrograph used for **SAMI**





- It has **1000 hexagonal lenslets**
- The field of view is selectable:
  - ✓**15.3” x 28.3”**, with **0.7”** spatial sampling
  - ✓**27.4” x 50.6”**, with **1.25”** spatial sampling

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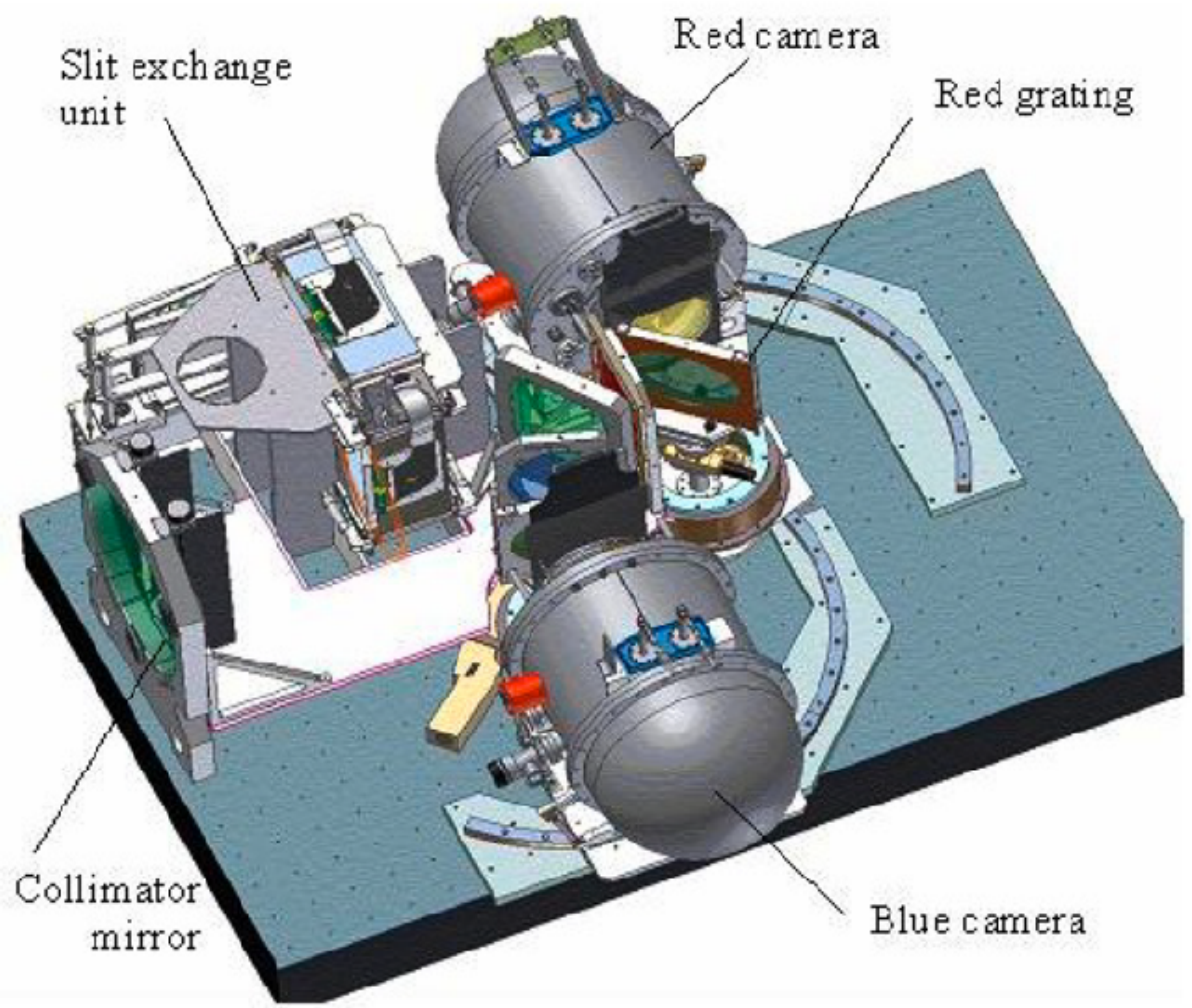

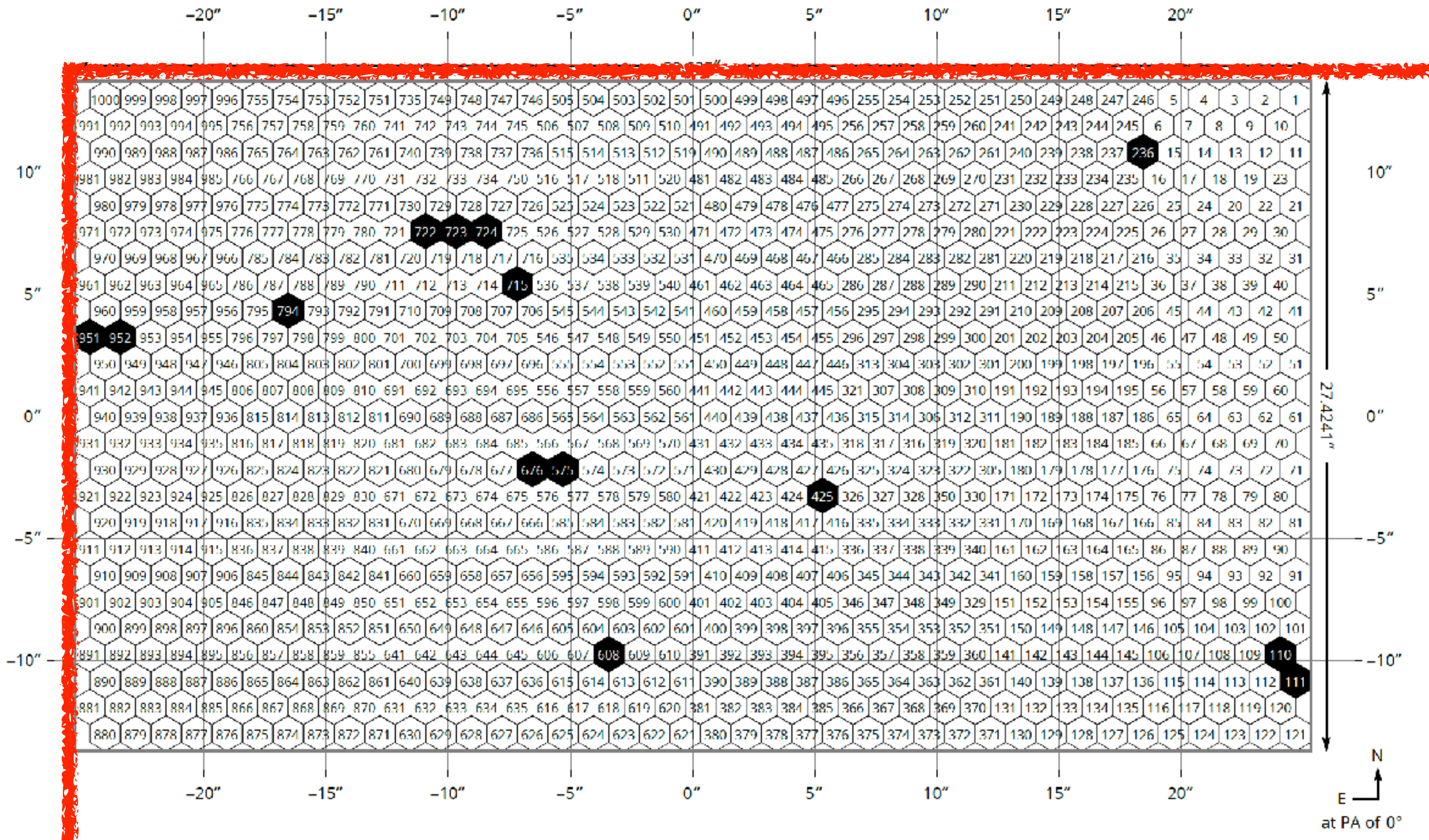

KOALA FoV = 39% MUSE FoV

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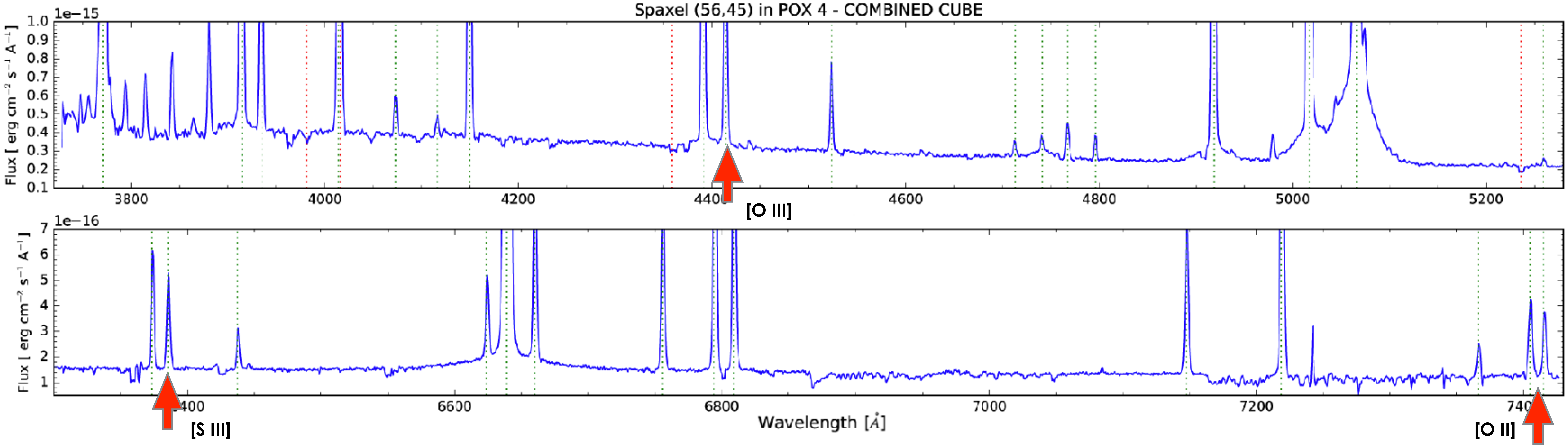
Hi-KIDS: Specific Science Objectives #1

- To derive **precise chemical abundances** (O and N, but also Ne, Ar, S, Ne, and Fe)
  - using the **direct Te-method**, i.e. using T[O III], T[S III], T[Ar III], T[O II], or T[S II])
  - using both **SEL calibrations** based on photo-ionization models (Kewley & Dopita 2002, Morisset et al. 2016) and those based on direct estimations of the electron temperature.
- To analyse the physical conditions of the gas: **electron density, temperature**, **extinction, ionization structure** of the gas and constrain its **excitation mechanism.**
- To derive their local and global **star-formation rate**
  - We will combine this with GALEX FUV and MIPS 24μm data when available.



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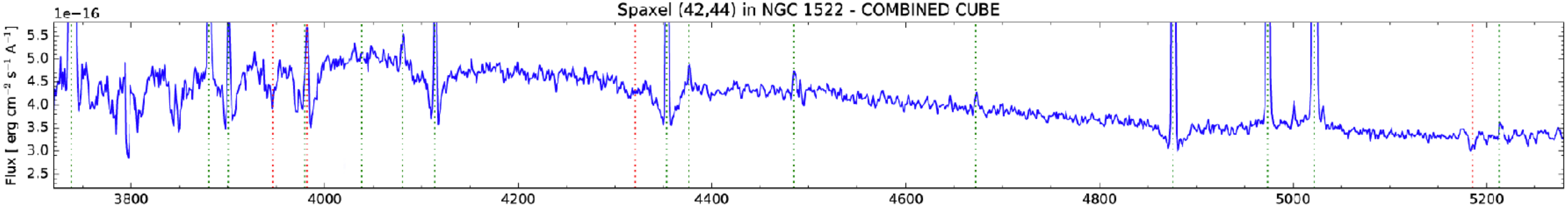
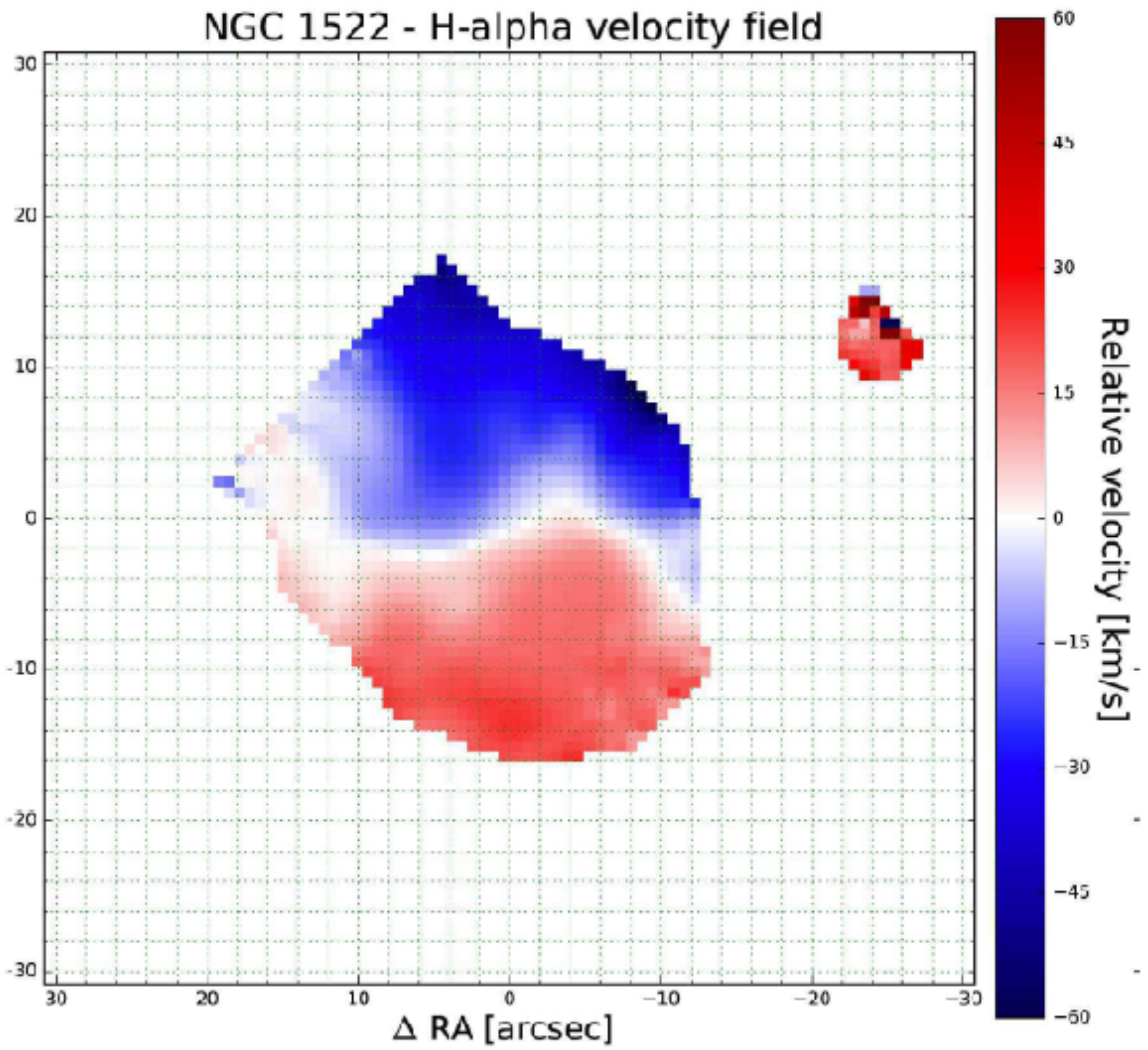
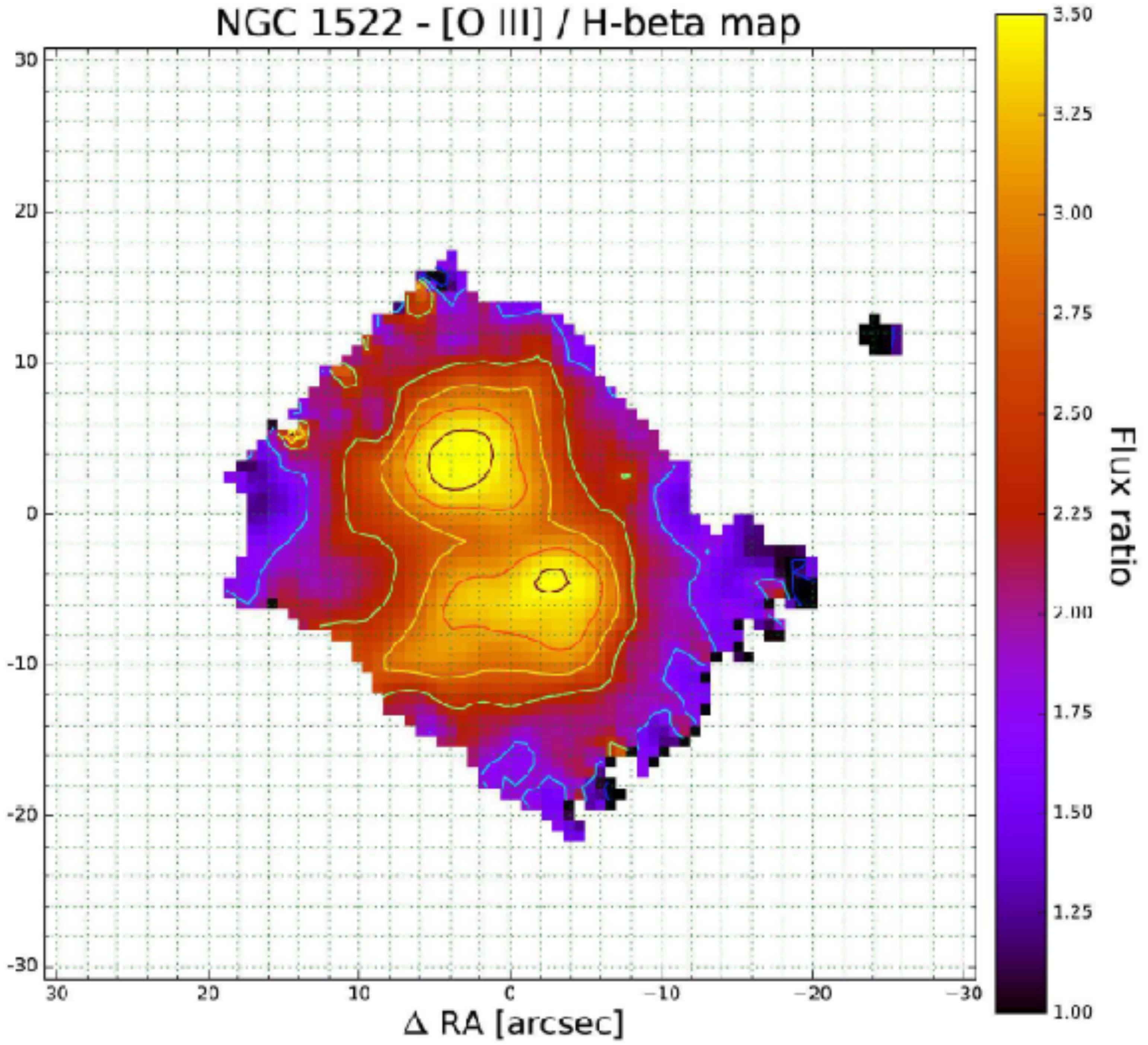
Hi-KIDS: Specific Science Objectives #2

- To estimate the properties of the **stellar populations:**
  - Using the **absorption lines** and the **stellar continuum** the age and metallicity of the stellar populations may be inferred via **stellar population synthesis models.**



- To analyse the **kinematics** of the **stars** and the **ionized gas:**
  - **Feedback** between the ISM and the massive stars
  - Get complement of the **galaxy dynamics** to that derived using the HI kinematics.
  - This analysis may also reveal **non-rotating gas** movements due to recent interactions, mergers, and **inflows** or **outflows** of gas.





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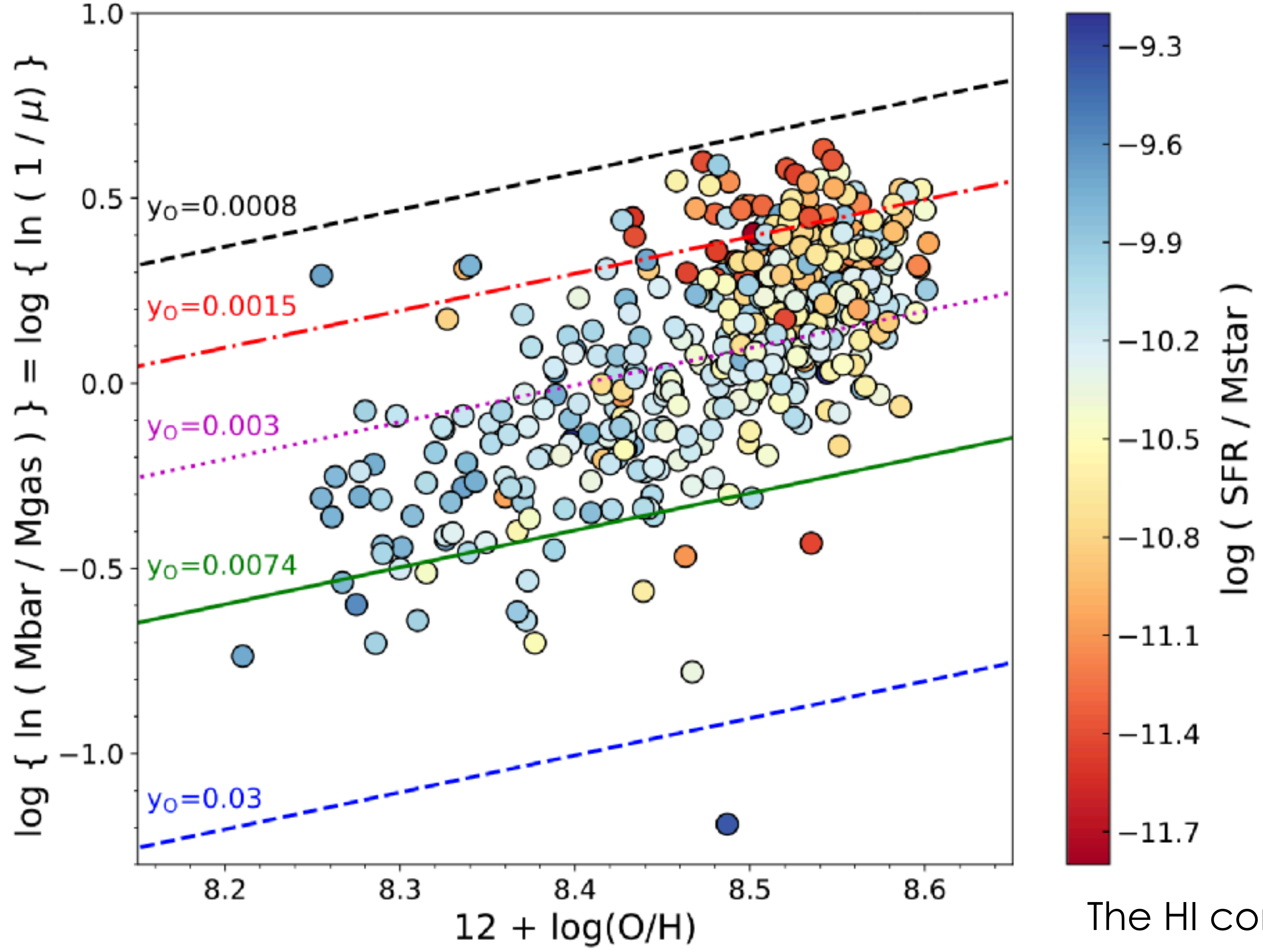
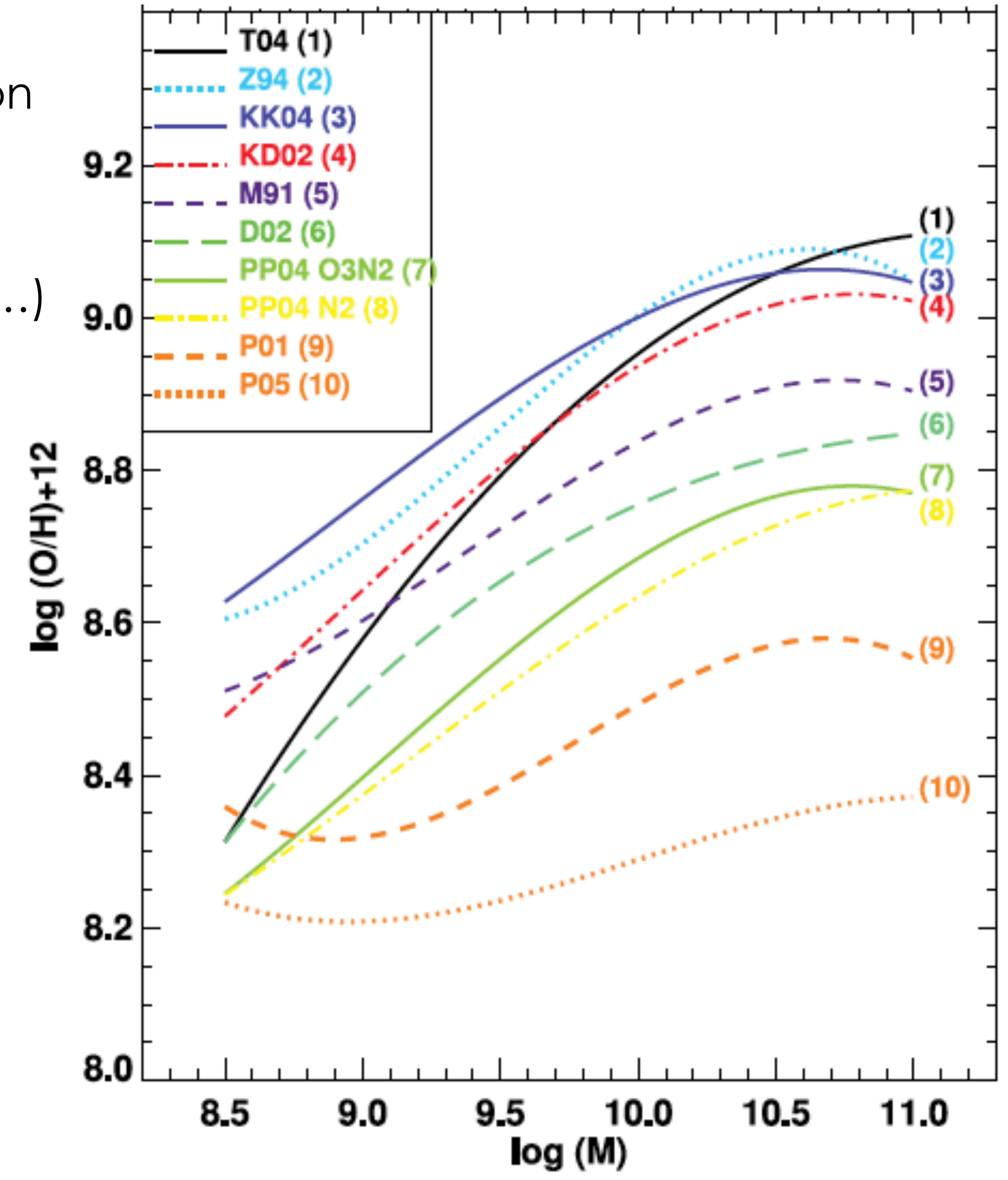
Hi-KIDS: Specific Science Objectives #3

- To **computing modeling the chemical evolution of galaxies**.
  - Detailed **chemical evolution models** considering the effect of the star-formation history in the evolution of the O/H and N/O ratios and the gas-star fraction.
  - Efficiency of the **conversion of gas into stars** (optical+HI data needed)
  - Explore **scale relations** in dwarfs (including SK Law, SF main sequence, SFR-Z-M…)



The HI content of CALIFA galaxies **(López-Sánchez et al. in prep)**



Mass-Metallicity relation with different calibrations **(Kewley et al. 2008)**

Ángel R. López-Sánchez @El_Lobo_Rayado

Hi-KIDS: Observations at the 3.9m Anglo-Australia Telescope

N	Galaxy	Coordinates	Type	mB	Size	Vrad	DATE	Gratings	PA	EXP TIME	POS	RUN	OFFSETS
1	NGC1522	04 06 07.9 -52 40 06	BCDG	13.93	1.2 x 0.8	898	2016 01 16	580V + 1000R	-45	1200	A	47	0 0
								580V + 1000R			B	49	0.812N 0.951W
											C	50	1.646S 1.406W
											A	51	0.834N 2.357E
2	Tol 9	10 34 38.7 -28 35 00	BCDG	14.4	0.7 x 0.4	3190	2016 01 16	580V + 1000R	45?	1200	A	54	0 0
											B	55	0.812N 0.951 W
											C	56	1.646S 1.406W
							2018 02 22	580V + 1000R	135	1800		39-44	CHECK
							2018 02 24	580V + 1000R	135	1800		39-41	
							2018 03 09	580V + 385R	135	1200	a	61	0 0
											b	62	0.88N 0.88E
											d	63	1.53N 1.53W
3	POX 4	11 51 11.6 -20 36 02	BCDG	16.2	0.21 x 0.18	3589	2016 01 16	580V + 1000R	120	1800	A	58	0 0
											B	59	1.189N 0.386E
											D	60	0.669N 2.059W
							2018 03 10	580V + 385R	120	1200	a	91	0 0
											b	92	1.08N 0.62E
											d	93	1.08N 1.88W
4	Mkn 750	11 50 02.7 +15 01 23	BCDG	15.3	0.55 x 0.36	749	2016 01 16	580V + 1000R	135	1800	A	61	0 0
											B	62	1.066N 0.653E
											C	63	1.131N 1.846W
5	Tol 1924-416	19 27 58.2 -41 34 32	BCDG	13.3	0.8 x 0.4	2834	2016 06 29	580V + 385R	0	1800	a	58	0 0
											b	59	1.25W
											d	60	2.165S
							2017 10 13	580V + 385R	0	1200	A	32	0 0
											B	33	1.2N 0.8E
											C	34	0.4S 1.5W
								580V + 1000R	0	1200	C	36	0 0
											B	37	0.4N 1.5W
											A	38	1.2S 0.8W
6	IC 4870	19 37 37.6 -65 48 43	BCDG	13.9	1.6 x 0.9	875	2016 10 22	580V + 1000R	40	1800	a	37	0 0
											b	38	0.735N 1.091W
											d	39	1.752S 1.273W
							2018 04 27	580V + 385R	90	1800	c	38	0 0
											a	39	0.62S 1.06E
							2018 07 06	580V + 385R	40	1800	a	21	0 0
											b	22	0.735N 1.091W
											d	23	1.752S 1.273W
7	ESO 199-G007	02 58 04.2 -49 22 59	dS	16.4	1.0 x 0.4	631	2017 10 13	580V + 1000R	90	1500	A	50	0 0

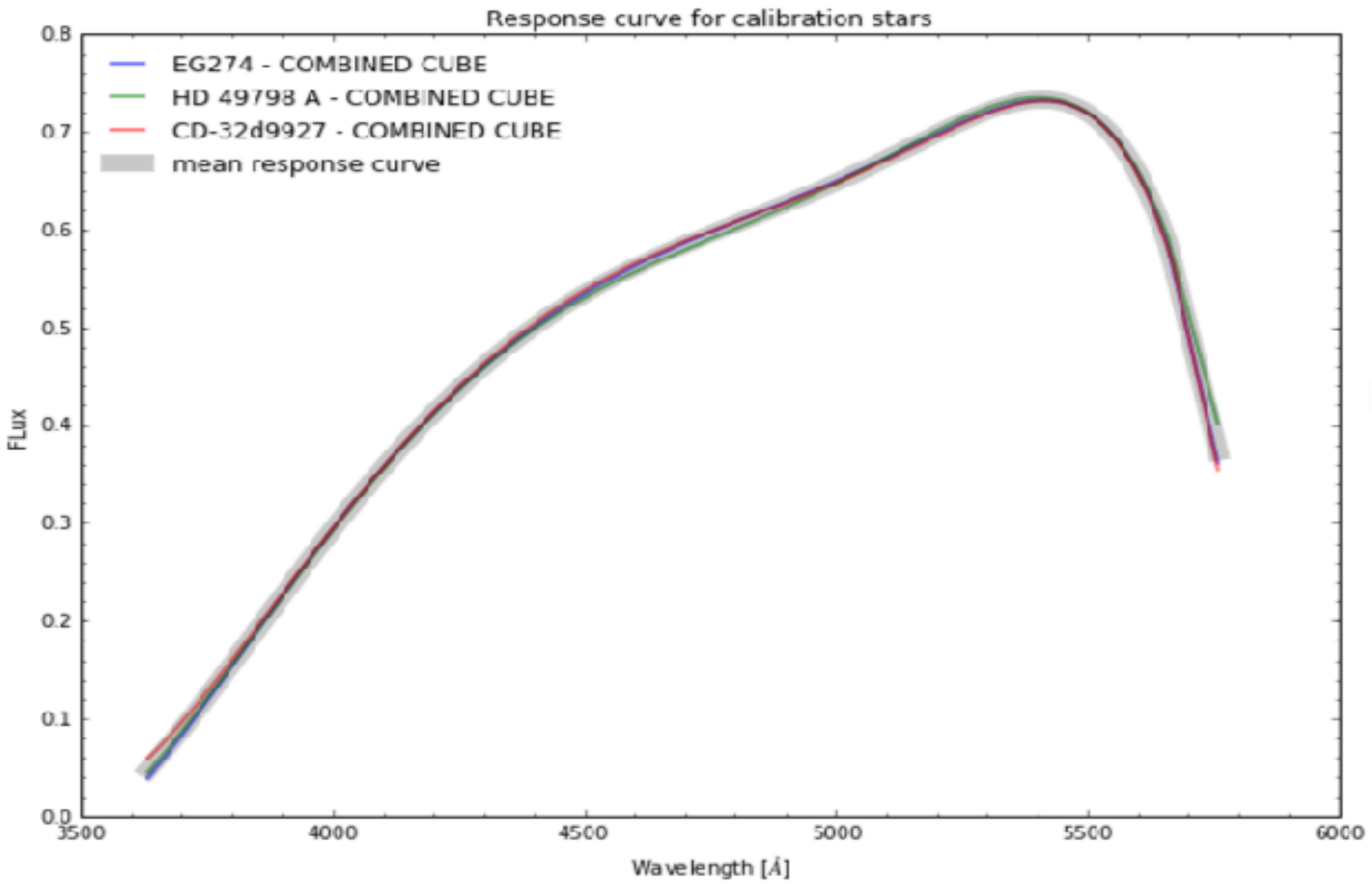
- Current status:
  - **72 galaxies observed ! (220 pointings)**
  - 50 nights so far!
  - **PyKOALA: new Python pipeline to reduce KOALA data!**

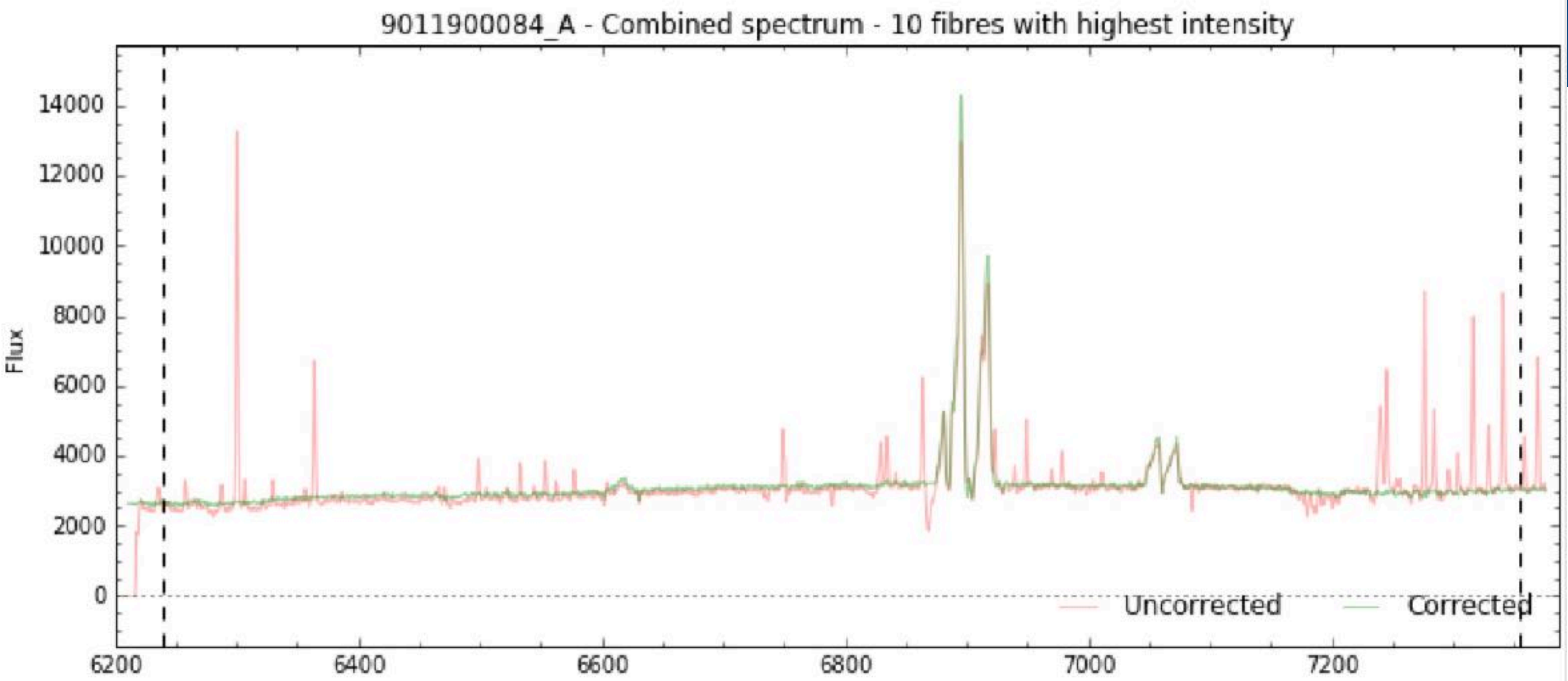
    (Still dealing with some details, but we are almost there…)
- Aim to get ~100 galaxies
- We are also getting **MUSE @ VLT** data of a subsample of the galaxies!
  - Observations conducted in P101 and P102.
- The data and derived products will be publicly available in **AAO Data Central**

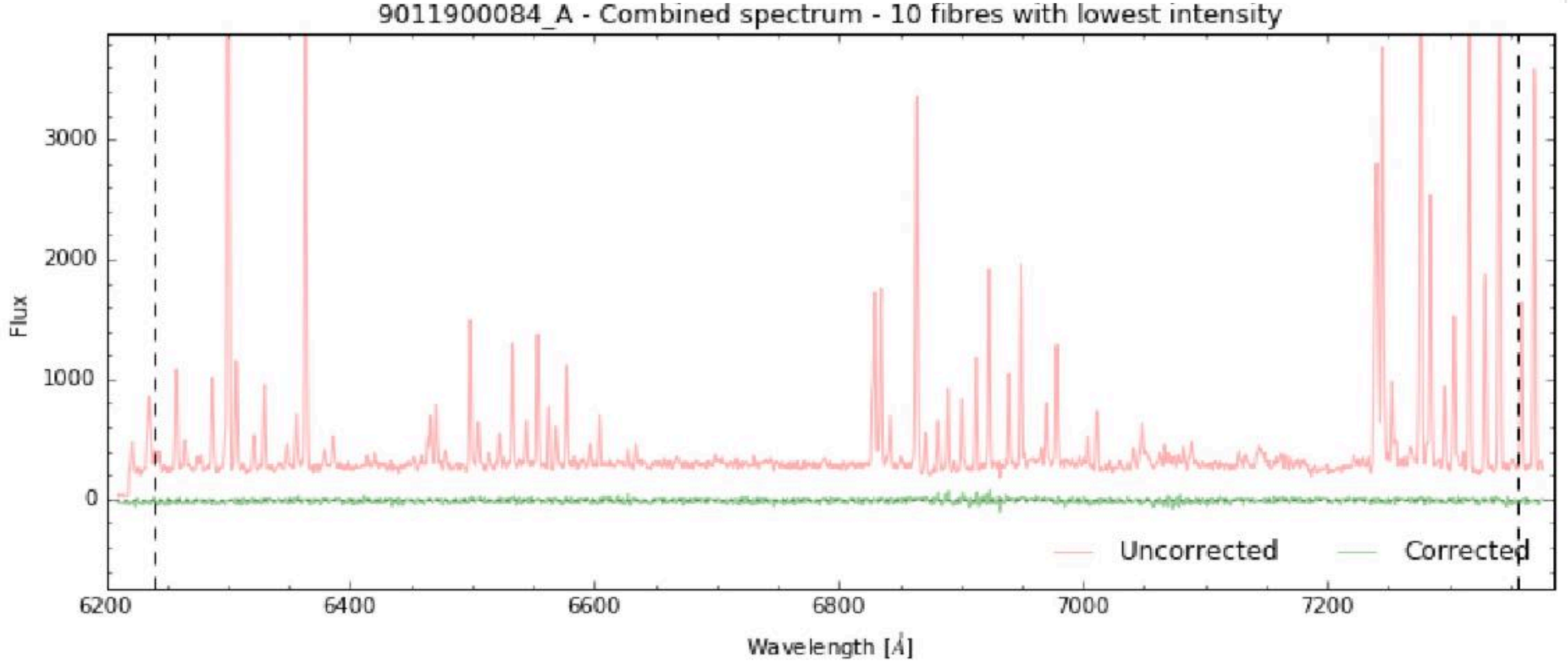
Processing KOALA data…

- New code **PyKOALA**:
  - Throughput correction
  - Correction for extinction
  - Absolute flux calibration (3-5 stars per night)
  - Sky subtraction and telluric correction
  - Correcting for atmospheric differential refraction
  - Cubing (from hexagonal lenslets) and mosaicing
  - Combine blue + red spectra
  - Tools for plotting, mapping & analyze the data

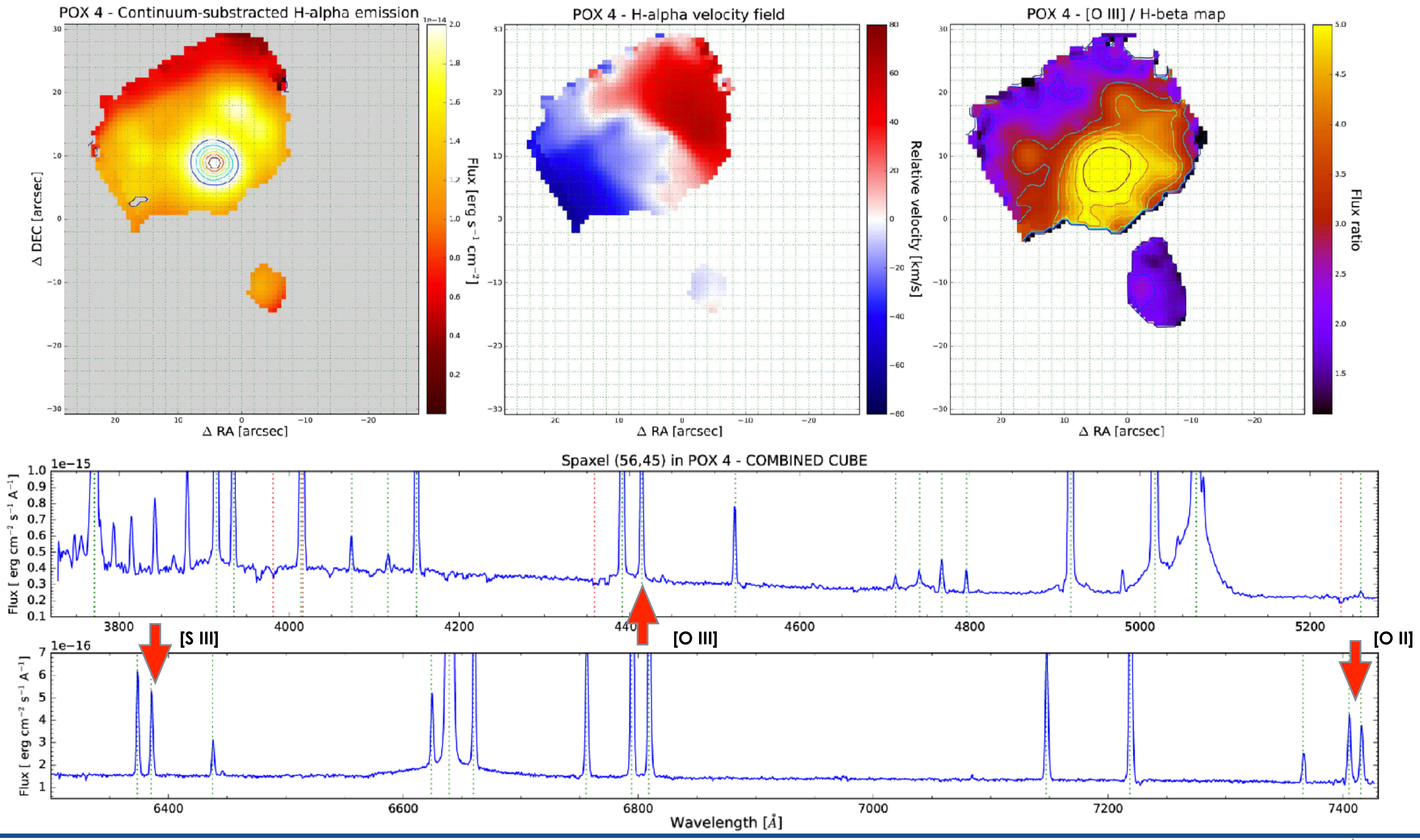
```
Mean value for  EG274  =  0.51433459943
Mean value for  HD 49798 A  =  0.513540083035
Mean value for  CD-32d9927  =  0.515940916424
Variation in flux calibrations =  0.49 %
```







Hi-KIDS: Preliminary results in BCDGs: POX 4



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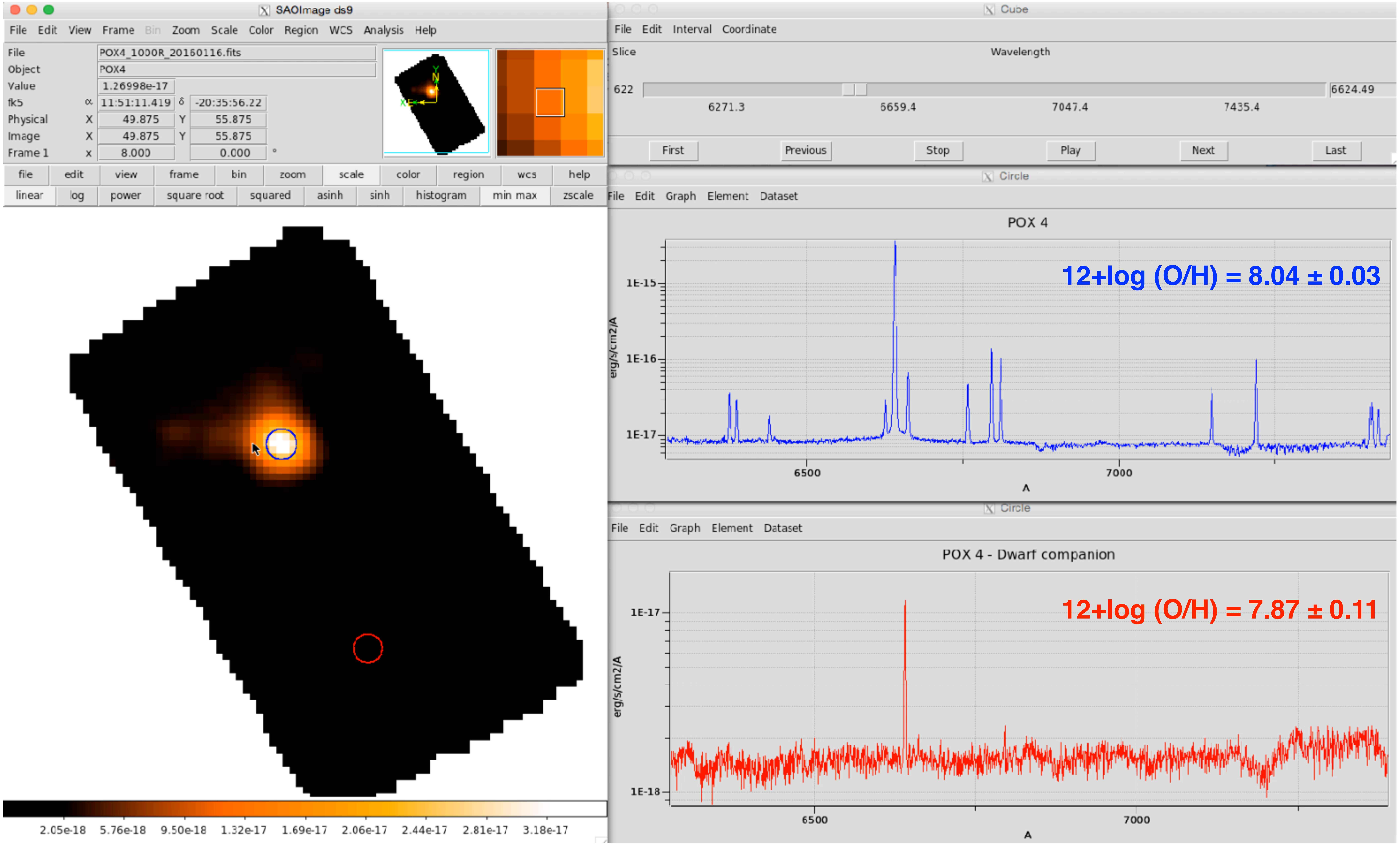

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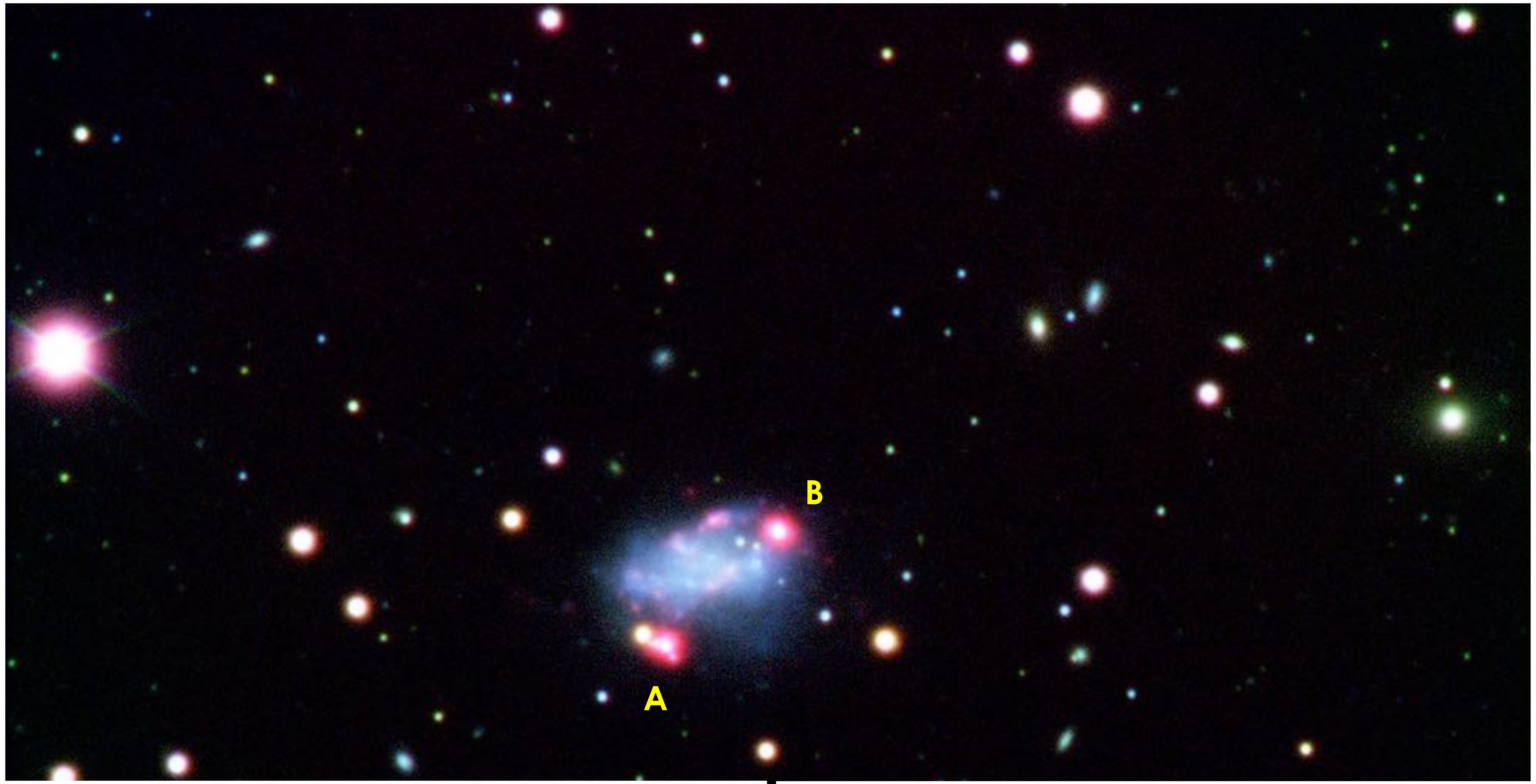
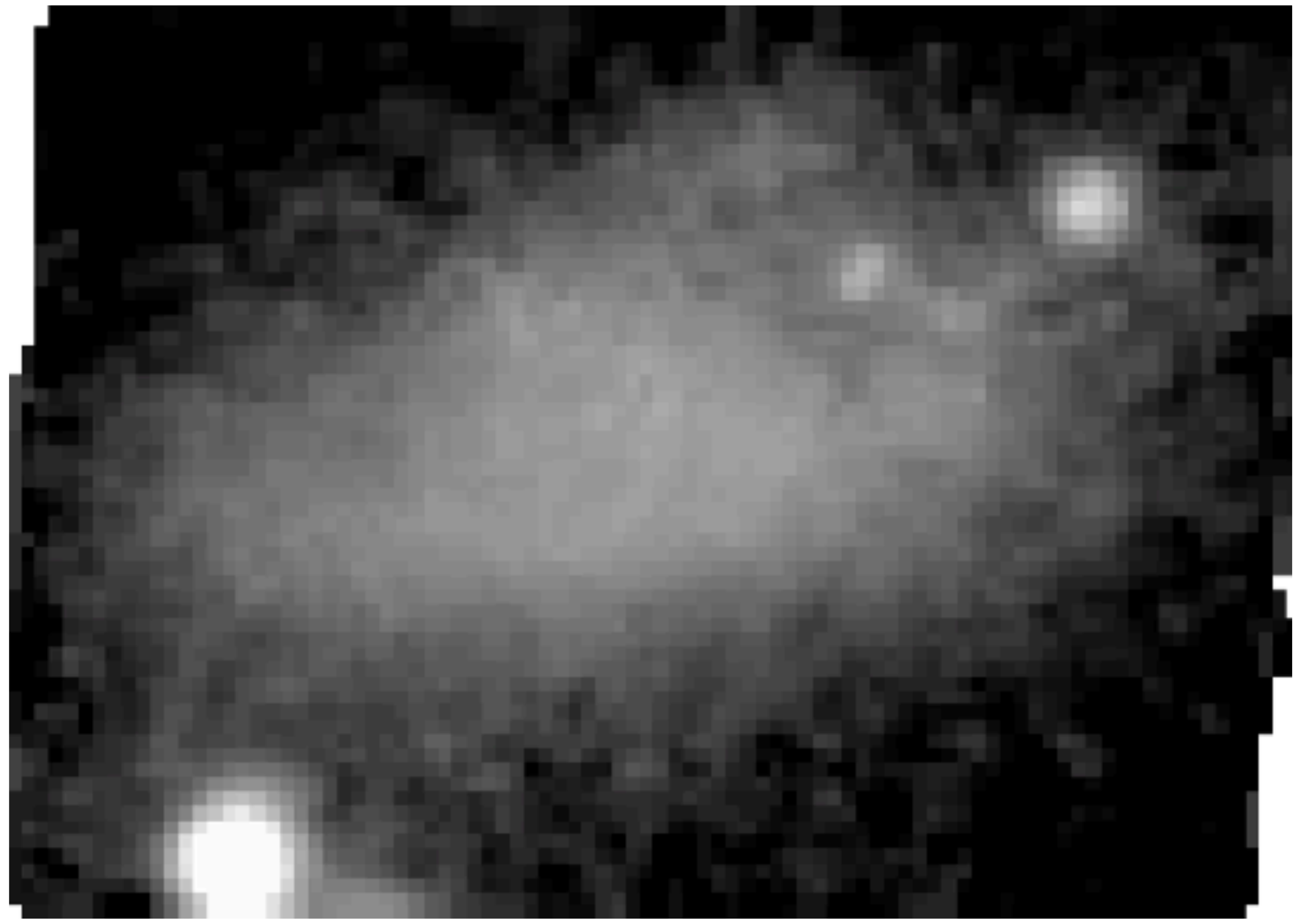
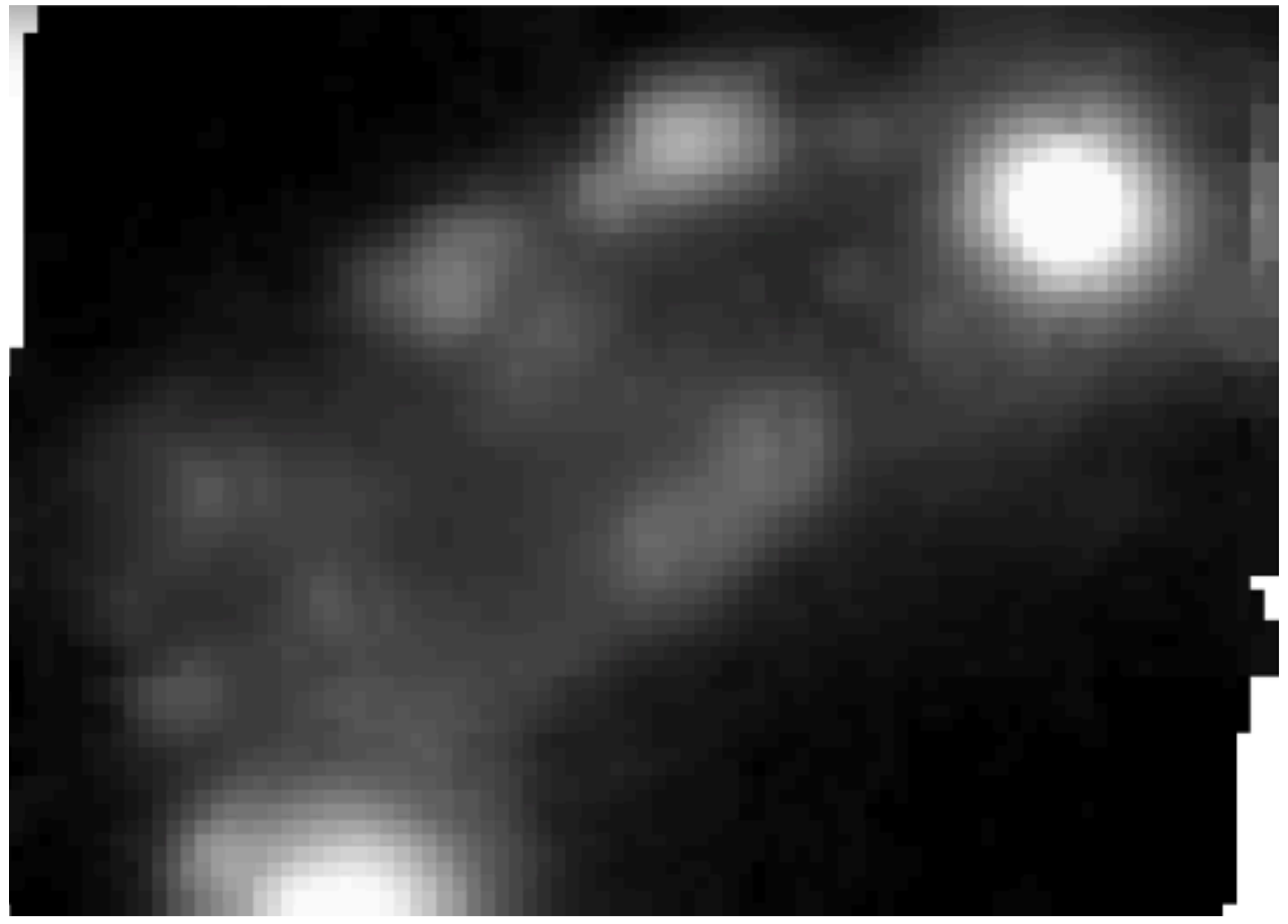
Hi-KIDS: Preliminary results in BCDGs: Tol 30







- D = 29.3 Mpc, 1' = 8.5 kpc
- Optical size: **1.2' × 1'**
- Optical imagery and ionized gas analysis using 2.56m NOT & 3.9m AAT
- **Two intense star-forming** regions in opposite places within the galaxy
- Knot A:
  - **WR features**
  - **12+log O/H = 8.08 ± 0.05**
  - **log N/O = – 1.44 ± 0.06**
- Knot B:
  - **12+log O/H = 8.09 ± 0.05**
  - **log N/O = – 1.46 ± 0.06**
- Preliminary mosaic of 2 KOALA pointings using PyKOALA (work on progress…)
  - Stellar continuum + H-alpha map

Tol 30 – B (blue) + R (green) + Hα (red) ALFOSC @ 2.6m NOT

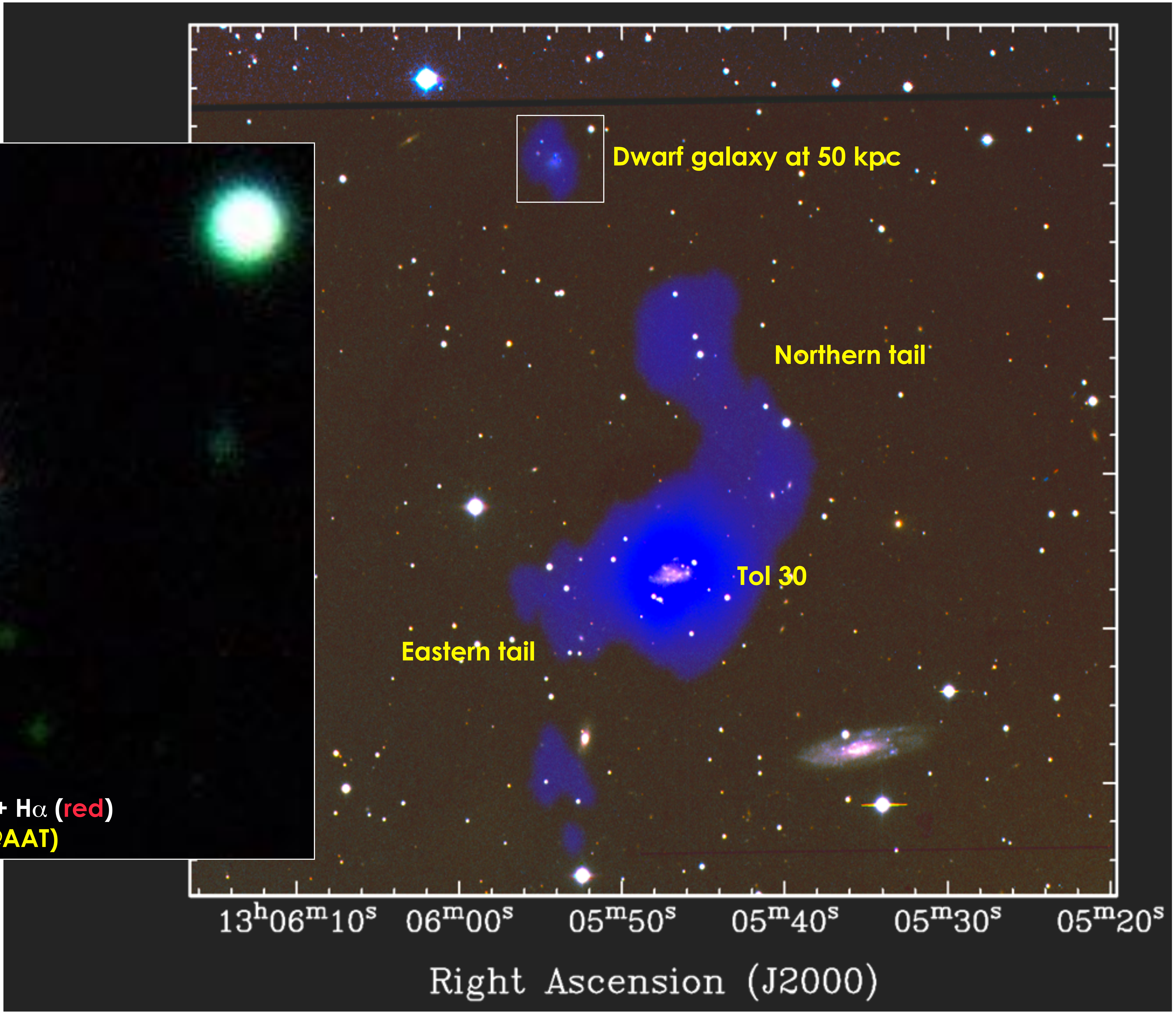
Ángel R. López-Sánchez @El_Lobo_Rayado

Hi-KIDS: Preliminary results in BCDGs: Tol 30 - HI distribution

- Deep optical imagery using WFC @ 2.5m INT
  - **Detection of nearby & diffuse non-stellar objects**

- **ATCA observations:**
  - **Total HI mass:**
    - M_{HI}: 1.4 × 10^9 $M_\odot$
  - **Tol 30:**
    - M_{HI}: 1.1 × 10^9 $M_\odot$
    - M_{HI}/L_B = 1.2
  - **Northern tail:**
    - M_{HI}: 2.1 × 10^8 $M_\odot$
    - 15% total HI mass
  - **Eastern tail:**
    - M_{HI}: 9.1 × 10^7 $M_\odot$
    - 7% total HI mass

- **TDG or dwarf obj?:**
  - M_{HI}: 2.3 × 10^7 $M_\odot$
  - M_{HI}/L_B = 0.12
  - It shows rotation!

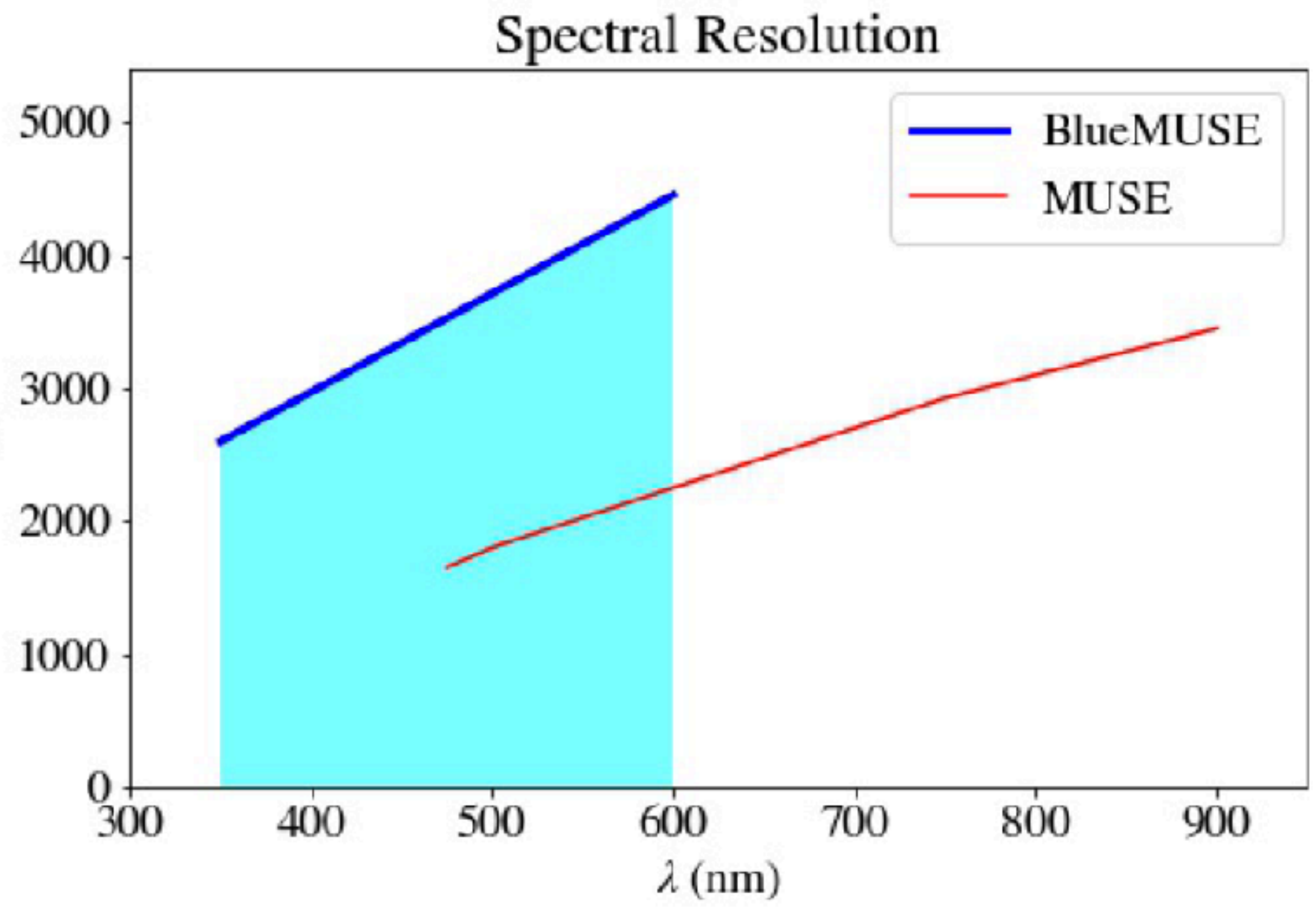


Tol 30 – HI map (blue) + V (green) + R (red) + ATCA + WFC @ 2.5m INT

Hi-KIDS as a science case for BlueMUSE

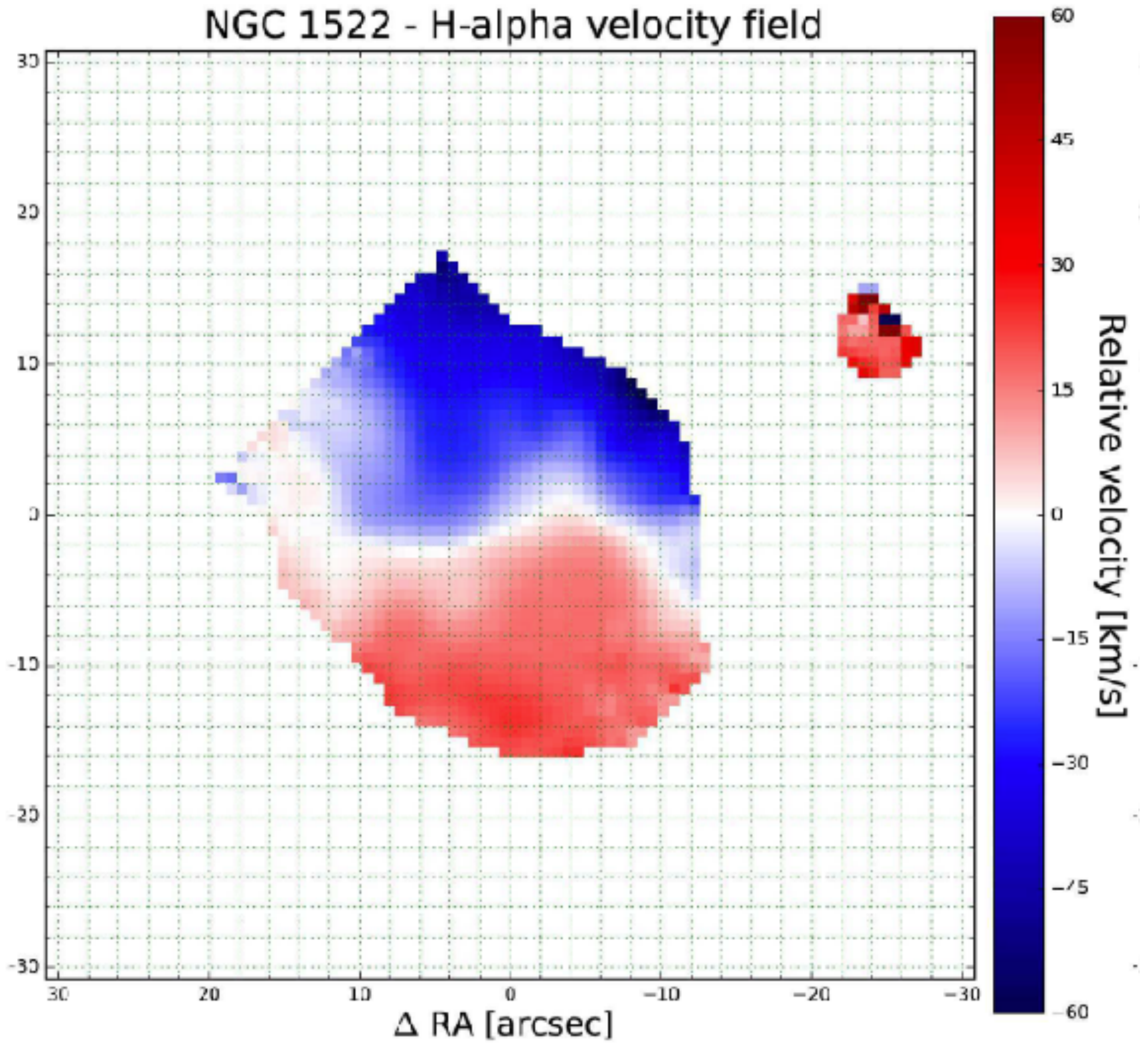
Resolving HII regions, ISM structure, stellar structure & stellar populations in nearby galaxies

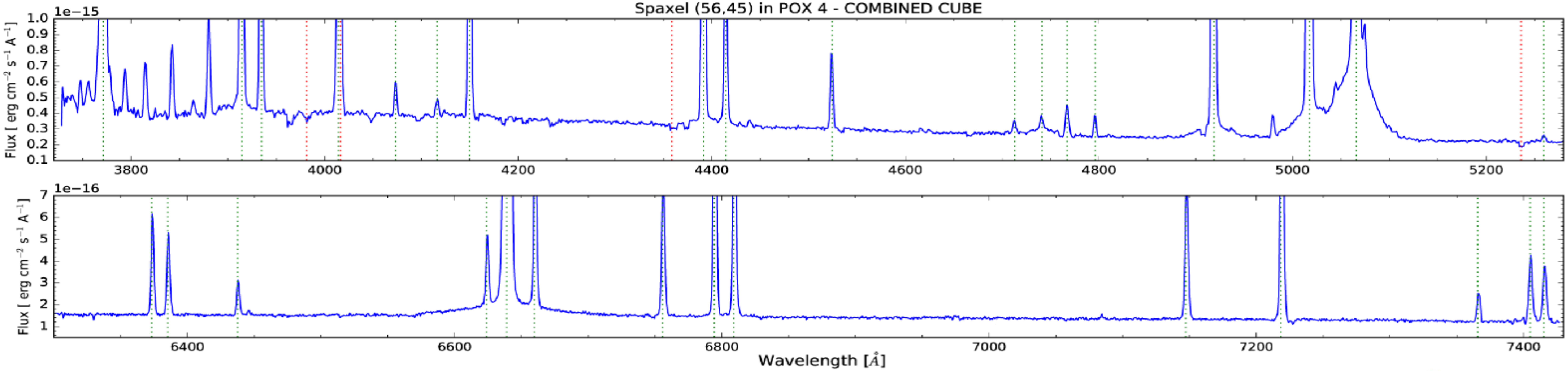
- **Massive stellar content** (fundamental to understand stochastic sampling of the **IMF**, needed for **SFR** & **SFH**).
- Studying **Wolf-Rayet** populations (ionizing sources).
- **Resolved stellar populations** (HI and He absorption lines).
- **HII regions** & **DIG** properties (temperature, densities, ionisation metallicities)using critical **[O II] λ3727 & [O III] λ4363 (Te-method)**
  - > Trace **gas inflows and outflows** !!
  - > **Time scales** for gas inflows and gas mixing.
  - > Exploring the **absolute O/H scale** (+ N, Ne, S, Ar …)
- Understanding **BCDGs**: feeding, processing, feedback.
- The power of having **HI gas** (e.g. WALLABY) + **radio continuum** (e.g. EMU) [ideally, also + **CO** (ALMA)].



Hi-KIDS: “HI KOALA IFS Dwarf galaxy Survey”

- Connecting **gas + stars + metals:** Key clues to understand galaxy evolution
- Using **KOALA+AAOmega at the 3.9m AAT** to assemble good-quality IFS data in the range [O II] λ3727 → [S III] λ9065.
  - **Exploring an exciting science case for BlueMUSE @VLT !**
- Targeting **dwarf** and **irregular** nearby galaxies for which **interferometric HI data** are already available.
  - **72** galaxies **ALREADY OBSERVED!**
  - **Complementary MUSE @ VLT data for ~10 galaxies!**
  - Development of the **PyKOALA pipeline to process & analyse KOALA data!**
  - Data will be publicly available in **AAO Data Central**
- Connections with large galaxy surveys **HECTOR** (IFS), **WALLABY** (HI), **EMU** (RC).





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