Low Metallicity Compact Star Forming Galaxies

Pilot program in MEGARA commissioning

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& Commissioning Team

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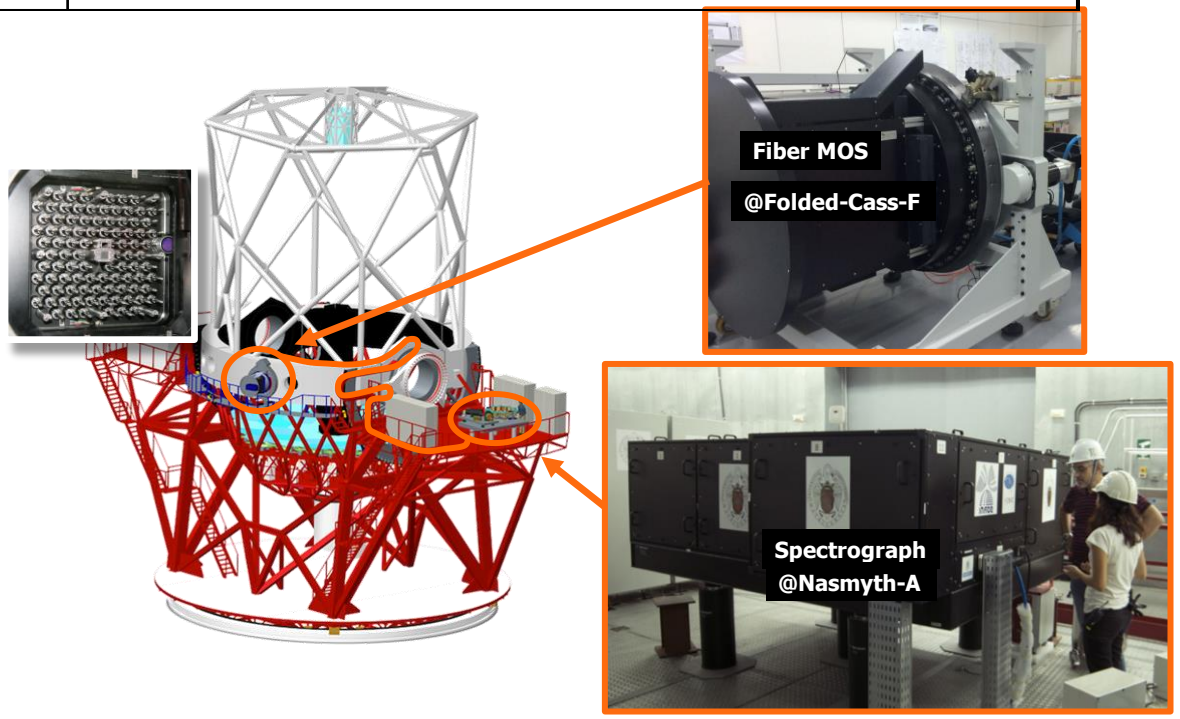
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- Projects on-going MEGARA-related
- Compact Star Forming Galaxies: Commissioning and Scientific goals
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- Conclusions

Multi
Espectrógrafo en
GTC de
Alta
Resolución para
Astronomía

Introducing MEGARA

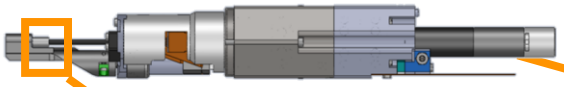
IFU bundle (LCB)	12.5 arcsec x 11.3 arcsec
MOS	92 × 7-fiber mini-IFUs in 3.5 arcmin x 3.5 arcmin
Spaxel (fiber) size	0.62 arcsec
Wavelength range	3650 - 10000 ÅÅ
Spectral resolution	R = 6000 (LR), 12000 (MR), 20000 (HR)
# of spectra	623 / 644 simultaneous fiber spectra (LCB / MOS)
GTC station	Folded-Cass F [spectrograph @ Nasmyth-A]



Multi Espectrógrafo en GTC de Alta Resolución para Astronomía

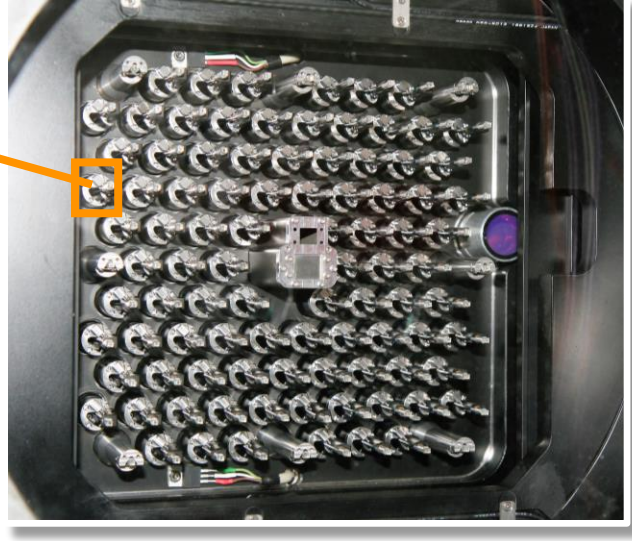
MEGARA Focal Plane

Robotic Positioner (RP)

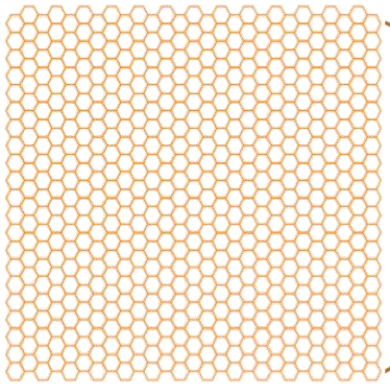


Fiber mini-bundle

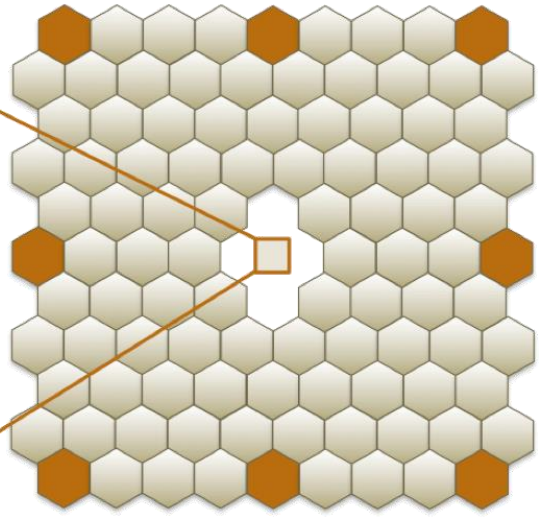




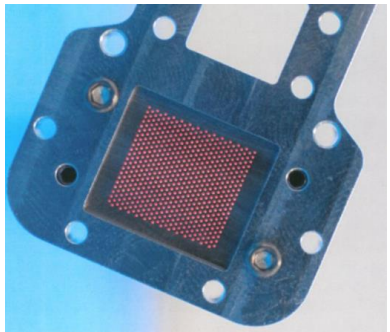
Spaxel size on sky	0.62 arcsec
LCB Central compact IFU + 8 sky mini-bundles	
Central IFU FoV	12.5x11.3 arcsec^2
Number of Fibers	
623	567 in IFU
	56 (8 x 7) fibers in sky mini-bundles
MOS	
Multi-Object	mini-IFUs in 3.5 x 3.5 arcmin^2
Number of Fibers	
	644 (92 x 7) fibers in 92 robots



12.5” x 11.3”



3.5’



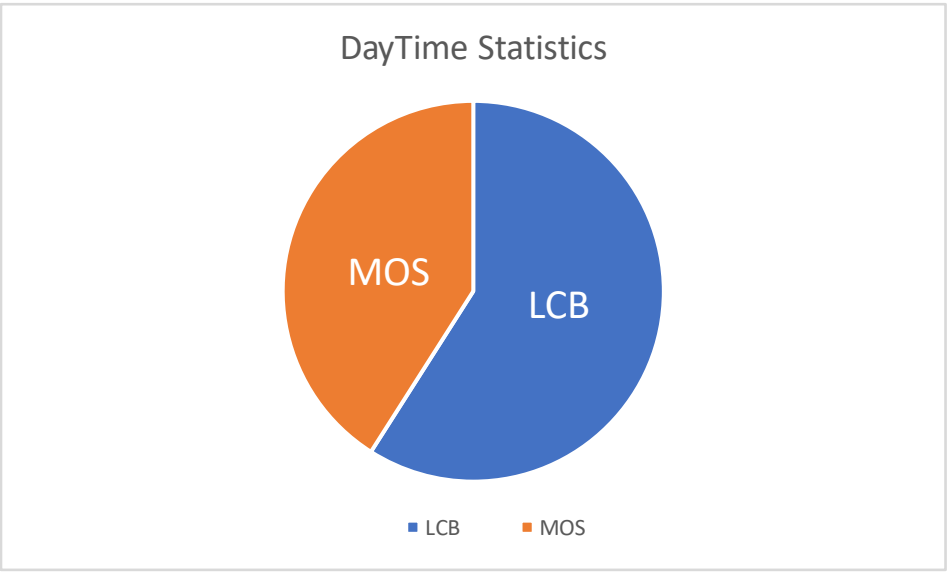
Spectroscopic set-ups

VPH	λmin_1 (Å)	λmin (Å)	λc (Å)	λmax (Å)	λmax_2 (Å)	Disp (Å/pix)
LR-U	3640,04	3654,32	4035,83	4391,88	4417,33	0,195
LR-B	4278,43	4332,05	4802,10	5199,96	5232,02	0,230
LR-V	5101,13	5143,74	5698,50	6168,19	6206,04	0,271
LR-R	6047,62	6096,54	6753,49	7303,21	7379,88	0,321
LR-I	7166,47	7224,11	8007,27	8640,37	8822,29	0,380
LR-Z	7978,45	8042,74	8903,41	9634,92	9692,58	0,421
MR-U	3911,99	3919,81	4107,57	4282,17	4289,11	0,092
MR-UB	4217,44	4226,38	4433,65	4625,79	4633,65	0,103
MR-B	4575,84	4585,66	4814,05	5025,07	5033,66	0,112
MR-G	4952,15	4963,22	5213,96	5445,00	5454,62	0,126
MR-V	5369,03	5413,11	5670,35	5923,90	5659,56	0,135
MR-VR	5850,19	5894,23	6171,69	6448,52	6468,52	0,148
MR-R	6228,15	6243,10	6567,26	6865,26	6878,27	0,163
MR-RI	6748,88	6764,58	7117,12	7440,85	7454,46	0,172
MR-I	7369,39	7386,53	7773,10	8127,95	8142,75	0,189
MR-Z	8787,88	8810,52	9274,83	9698,97	9740,20	0,220
HR-R	6397,62	6405,61	6606,49	6797,14	6804,87	0,098
HR-I	8358,64	8380,20	8632,98	8882,38	8984,87	0,130

MEGARA @ GTC





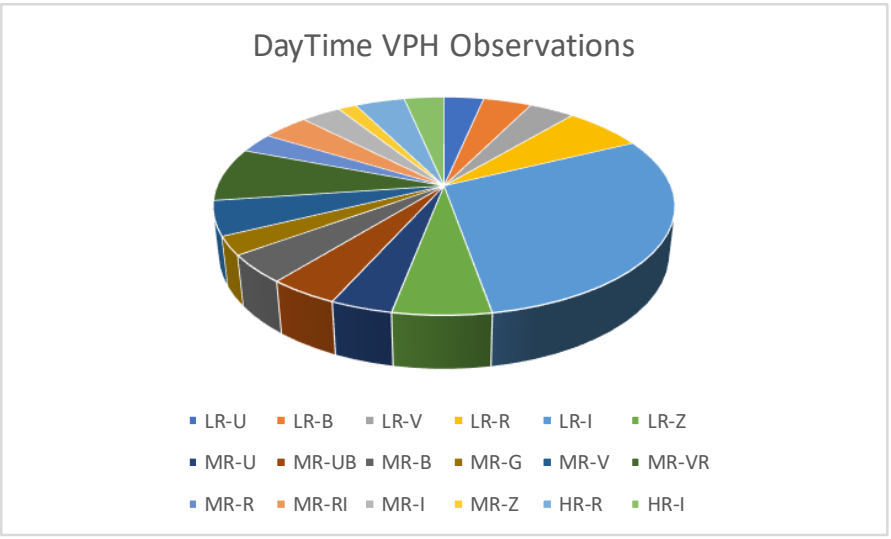


DayTime commissioning

851 Images

- 497 LCB
- 345 MOS

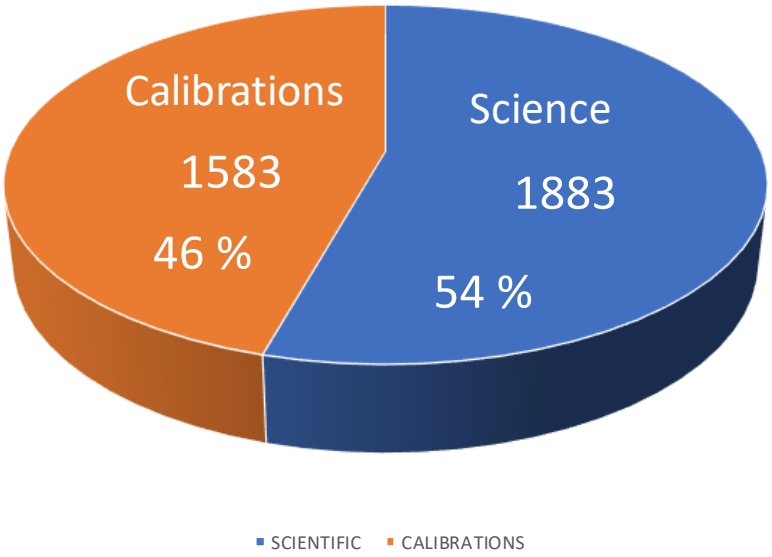
530,431 spectra!



~ 1000 spectrograph mechanisms movements

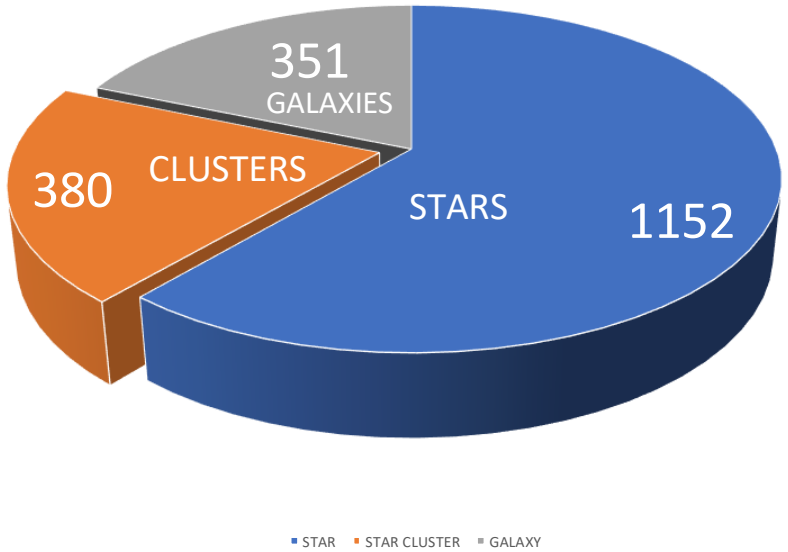
~ 50,000 MOS robotic positioners movements

Scientific vs Calibration during Nighttime runs

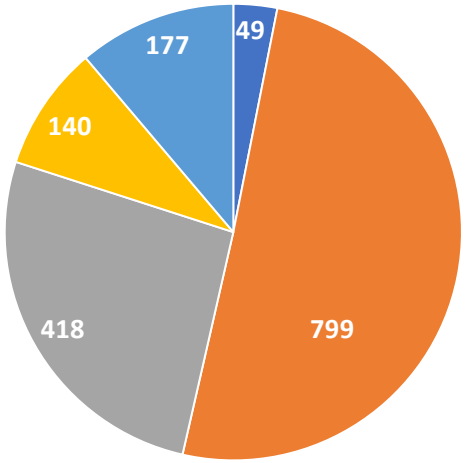


NightTime commissioning

SCIENTIFIC TARGETS



Calibrations during Nighttime



1583 Images 46 % of the nighttime observations, mostly in DayTime or Twilight

Projects on progress

- **Empirical Stellar Library MEGARA-GTC**
- PopStar upgrade to MEGARA resolution with both models and observed spectra
- **Kinematics and Stellar Populations in Low Metallicity Compact Star Forming Galaxies (pilot program: J1608+3528 and J0159+0751)**
- Kinematics and Stellar populations in NGC7714 at R=20000 in HR-R (Hα) and HR-I (CaT and Paschen lines)

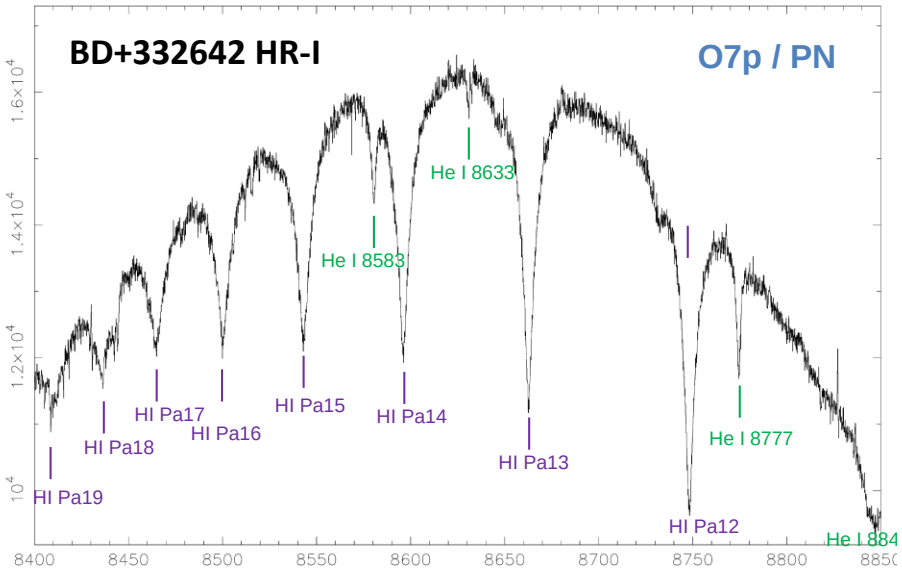
Proposals submitted to Spanish CAT

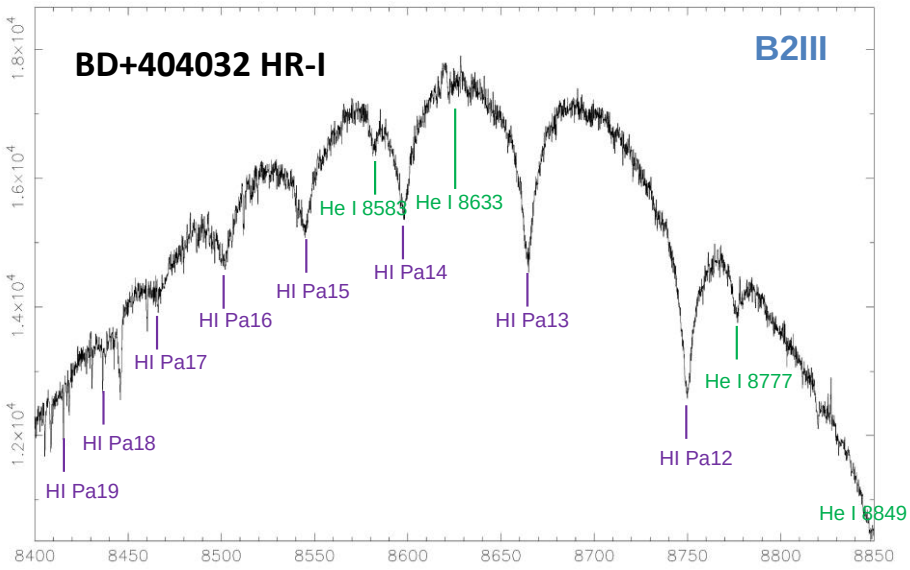
- Filler Program for MEGARA-GTC Stellar Library
- Study on J1154+2443 (46% leakage of continuum photons, Yzotov etal. 2018)

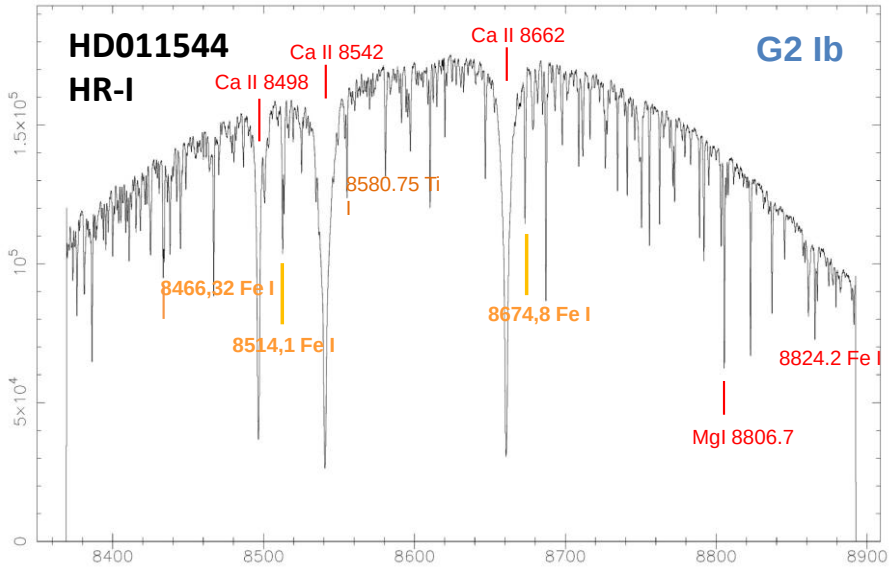
MEGARA-GTC Stellar Library

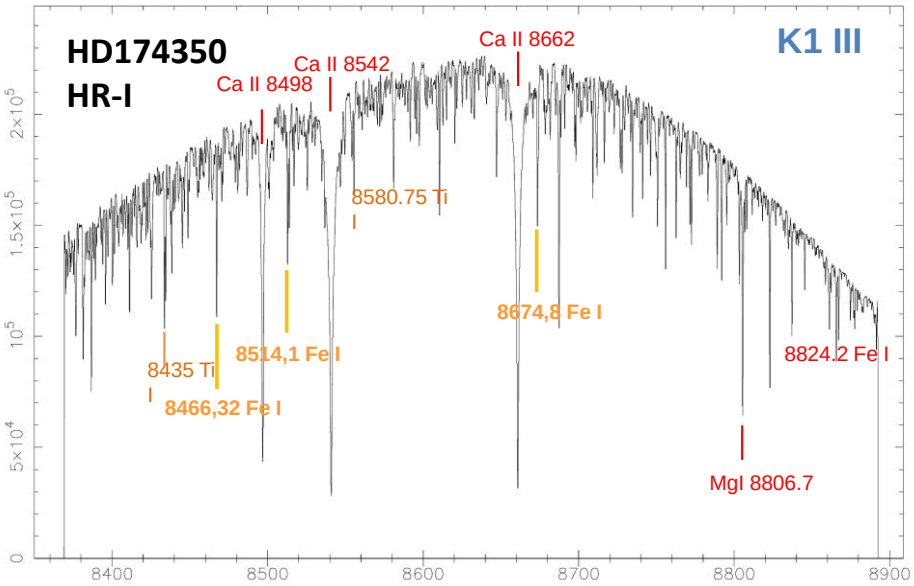
- An empirical spectral library is crucial for having the necessary stellar population templates to interpret the observations taken with the same instrumental set-up.
- There is not a complete library, either empirical or theoretical able to fulfill the MEGARA parameters. MEGARA needs its own spectral library
- During the commissioning we observed, in twilight or resulted from other tests
  - 40 stars in different spectral set-ups with the LCB (23 in HR-I)
  - 88 stars in M15 in all set-ups
- We are writing a paper presenting the library and the commissioning results for HR-I (observations fully reduced including flux calibration)
- We have submitted a filler proposal to GTC to observe the star library with priority on HR-R and HR-I (for HR-I we have already 111 stars)
- We are finishing the database webtool to support the observations, to be co-funded by INAOE, FRACTAL and CIEMAT (a prototype is being tested)

MEGARA-GTC Stellar Library









Compact Star Forming Galaxies

- We observed two low metallicity CSFG from the sample of 5 SDSS galaxies published by Izotov, Thuan, & Guseva (2017) with LBT 8.4m data.
- The commissioning objective (primary goal) was to observe an emission line target with reasonable magnitude for the available time to test the LRs continuity and to feed the Exposure Time Calculator. For that reason we selected a target observed with a large (8-10m) telescope. Finally we could observe a second target of the sample choosing 3 MRs although due to bad weather in the last run we could complete only 2 set-ups.
- The scientific goal (limited to what it was possible to do) was to test the strength of MEGARA to study CSFGs for improving the spatially resolved diagnostics on chemical composition, gas and stellar properties and kinematics, Lyα leakage problem, together with the improvement on gas diagnostics difficult due to the blending of the lines at lower spectral resolution.

Large Binocular Telescope (8.4m) observation

Izotov, Y. I.; Thuan, T. X.; Guseva, N. G. (2017)

Name	R.A.(J2000)	Dec.(J2000)	O32a	z	g
J0159+0751	01:59:52.75	+07:51:48.90	39	0.0611	19.47
J1608+3528	16:08:10.36	+35:28:09.30	43	0.0327	18.59





12 “ x 12 “ SDSS Images

Name	Date	Instrument	Exposure (s)	Long Slit (arcsec)	Airmass
J0159+0751	2016-01-02	MODS1	3200 (4 x 800)	60 × 1.2	1.10
J1608+3528	2013-06-08	MODS1	2400 (3 x 800)	60 × 1.2	1.24

3200 Å – 10000 Å with G400L 0.5 Å/pix (blue) and G700L 0.8 Å/pix (red) $R \sim$ 2000.

Reference:

Izotov, Y. I.; Thuan, T. X.; Guseva, N. G., 2017 M.N.R.A.S, Volume 471, Issue 1, p.548-561 (October 2017)

LBT observations of compact star-forming galaxies with extremely high [O III]/[O II] flux ratios: He I emission-line ratios as diagnostics of Lyman continuum leakage

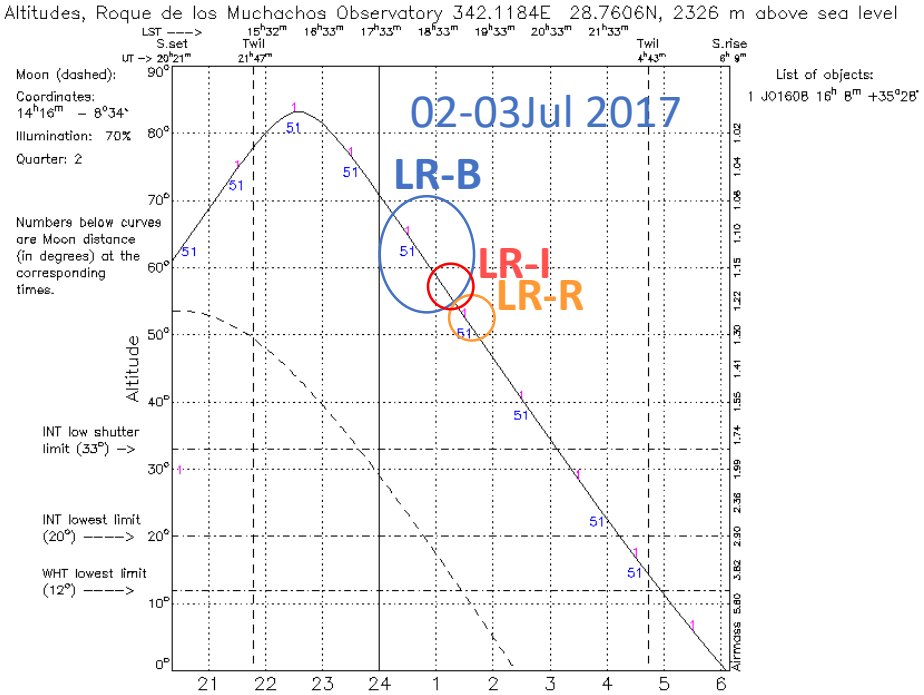
	12+logO/H	log L(Hβ) erg s^{-1}	F(Hβ) 10^{-16}erg s^{-1} cm^{-2}	EW(Hβ) Å	Mg	MFUV	log M⋆/M⊙	SFR
J0159+0751	7.54	40.93	26.74	387	−18.73	−17.56	6.69	1.9
J1608+3528	7.79	40.41	47.07	407	−18.43	−17.01	7.04	0.6

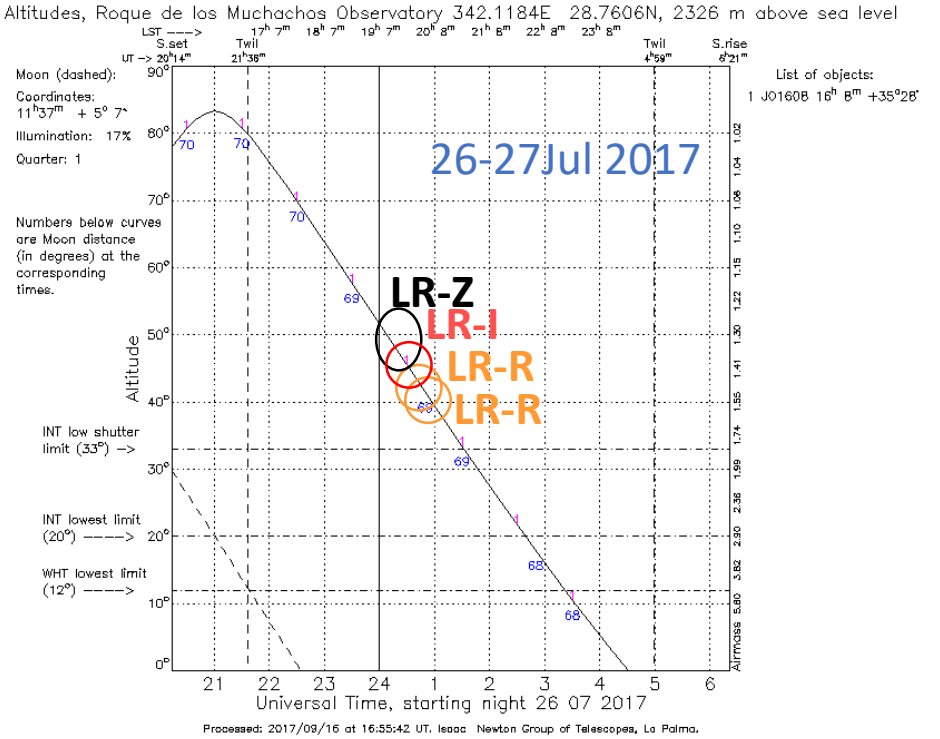
Izotov, Y. I.; Thuan, T. X.; Guseva, N. G. (2017)

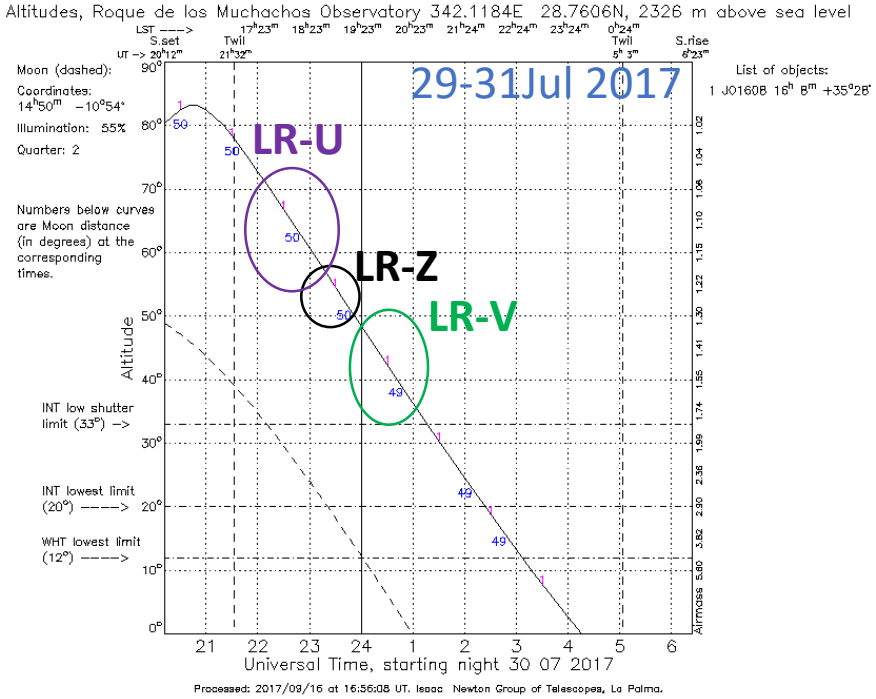
Public data with SDSS (VIS), GALEX (UV) and WISE (MIR)

Public data from HST and COS, Cosmic Origins Spectrograph, (http://www.stsci.edu/hst/cos). COS is the high-sensitivity, medium- and low-resolution spectroscopy of astronomical objects in the 1150-3200 Å range.

Observations are with COS + G130M centered at 1327 Å + PSA (2.5” diameter) with resolving power between 16000 and 21000 and images that can allow target detection < 0.1”.







J1608 + 3528 Observations

J1608 + 3528: MEGARA Observations

7,25 hr on target, uniform values of pointing, weather conditions and elevation

VPH	Mode	Date	UT	Exp. Time (s)	AirMass	Seeing Average (TNG)	Dust Average (TNG)
LR-B	LCB	02/07/2017	00:48 - 02:15	4 x 1200	1.14 – 1.34	0.52	1.1
LR-R	LCB	02/07/2017	02:16 - 02:50	3 x 600	1.34 – 1.59	0.50	0.7
LR-I	LCB	03/07/2017	00:41 - 01:30	2x900 + 1x800	1.13 – 1.22	-----	0.3
LR-Z	LCB	26/07/2017	00:14 - 00:50	3 x 600	1.32 – 1.42	0.80	29.1
LR-R	LCB	26/07/2017	00:51 - 01:05	3 x 200	1.50 – 1.56	0.90	29.2
LR-I	LCB	27/07/2017	00:04 - 00:38	3 x 600	1.30 – 1.40	0.33	8.0
LR-R	LCB	27/07/2017	00:39 - 00:58	3 x 300	1.46 – 1.54	0.41	6.0
LR-Z	LCB	29/07/2017	22:58 - 00:01	3 x 1200	1.13 – 1.24	0.70	7.9
LR-V	LCB	29/07/2017	00:04 - 01:07	3 x 1200	1.33 – 1.55	0.61	7.5
LR-U	LCB	31/07/2017	22:02 - 23:27	4 x 1200	1.05 – 1.17	0.73	2.2

IPA: 196,744 º PA = 0,589º (*) at the moment of starting the observations we had not derived the right IAA

We cannot reach the same S/N than Yzotov with these exposure times

J1608 + 3528: Observations

7,25 hr on target, uniform values of pointing, weather conditions and elevation

VPH	Mode	Date	UT	Exp. Time (s)	AirMass	Seeing Average (TNG)	Dust Average (TNG)
LR-B	LCB	02/07/2017	00:48 - 02:15	4 x 1200	1.14 – 1.34	0.52	1.1
LR-R	LCB	02/07/2017	02:16 - 02:50	3 x 600	1.34 – 1.59	0.50	0.7
LR-I	LCB	03/07/2017	00:41 - 01:30	2x900 + 1x800	1.13 – 1.22	-----	0.3
LR-Z	LCB	26/07/2017	00:14 - 00:50	3 x 600	1.32 – 1.42	0.80	29.1
LR-R	LCB	26/07/2017	00:51 - 01:05	3 x 200	1.50 – 1.56	0.90	29.2
LR-I	LCB	27/07/2017	00:04 - 00:38	3 x 600	1.30 – 1.40	0.33	8.0
LR-R	LCB	27/07/2017	00:39 - 00:58	3 x 300	1.46 – 1.54	0.41	6.0
LR-Z	LCB	29/07/2017	22:58 - 00:01	3 x 1200	1.13 – 1.24	0.70	7.9
LR-V	LCB	29/07/2017	00:04 - 01:07	3 x 1200	1.33 – 1.55	0.61	7.5
LR-U	LCB	31/07/2017	22:02 - 23:27	4 x 1200	1.05 – 1.17	0.73	2.2

IPA: 196,744 º PA = 0,589º (*) at the moment of starting the observations we had not derived the right IAA

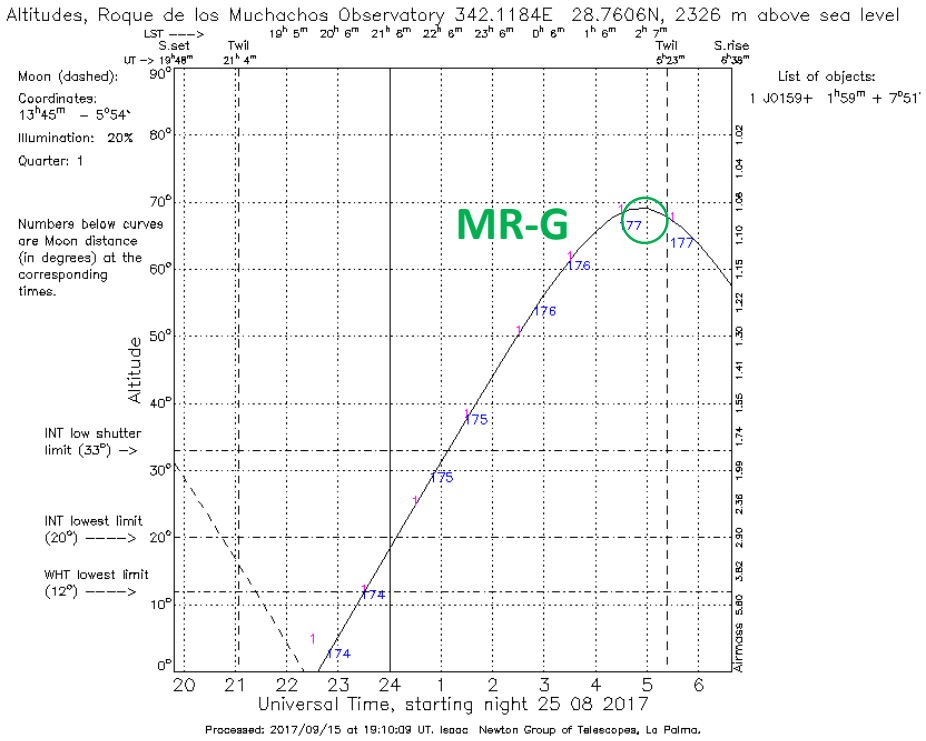
3539 Å – 9330 Å in all positions reaching 3525 Å – 9386 Å in the central fibers

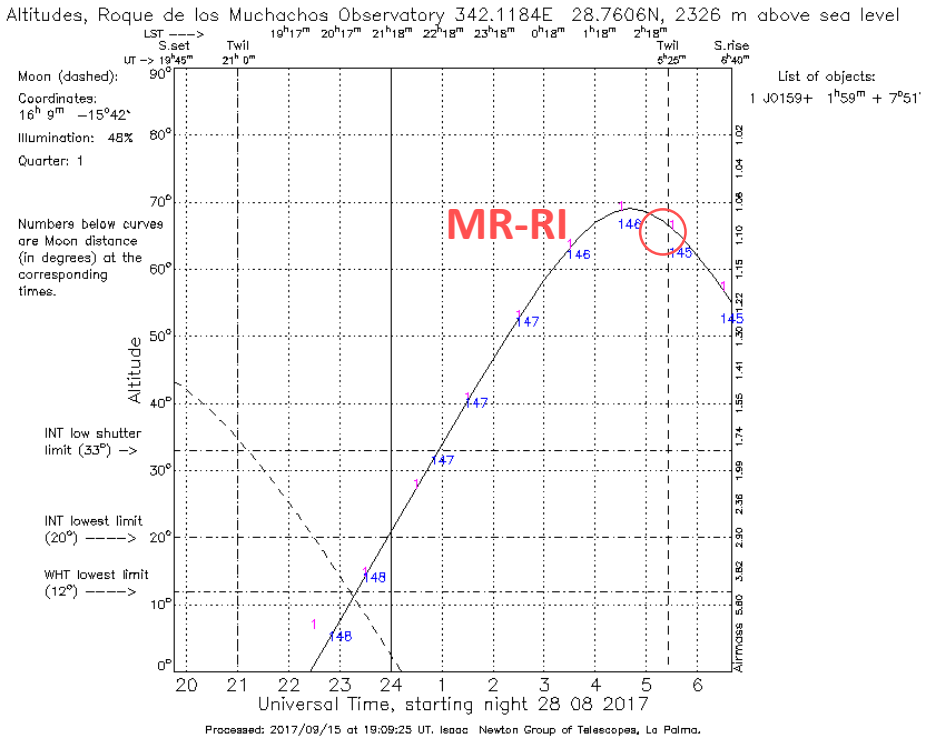
	Rest frame wavelength range at z = 0.0327					**J1608 + 3528**
VPH	λmin_1 (Å)	λmin (Å)	λc (Å)	λmax (Å)	λmax_2 (Å)	Disp (Å/pix)
LR-U	3524.78	3538.61	3908.04	4252.81	4277.46	0.195
LR-B	4142.96	4194.88	4650.04	5035.31	5066.35	0.230
LR-V	4939.60	4980.87	5518.06	5972.88	6009.53	0.271
LR-R	5856.12	5903.50	6539.64	7071.96	7146.20	0.321
LR-I	6939.55	6995.36	7753.72	8366.78	8542.94	0.380
LR-Z	7725.82	7788.07	8621.49	9329.83	9385.67	0.421

J0159 + 0751: Observations

VPH	Mode	Date	UT	Exp. Time (s)	AirMass	Seeing Average (TNG)	Dust Average (TNG)
MR-G	LCB	25/08/2017	04:23 - 05:30	3 x 1200	1,07	0,57 “	16,50 μgm^{-3}
MR-RI	LCB	28/08/2017	04:48 - 05:52	3 x 1200	1,07	0,71”	11,02 μgm^{-3}

1 hr on target, uniform values of pointing, weather conditions and elevation

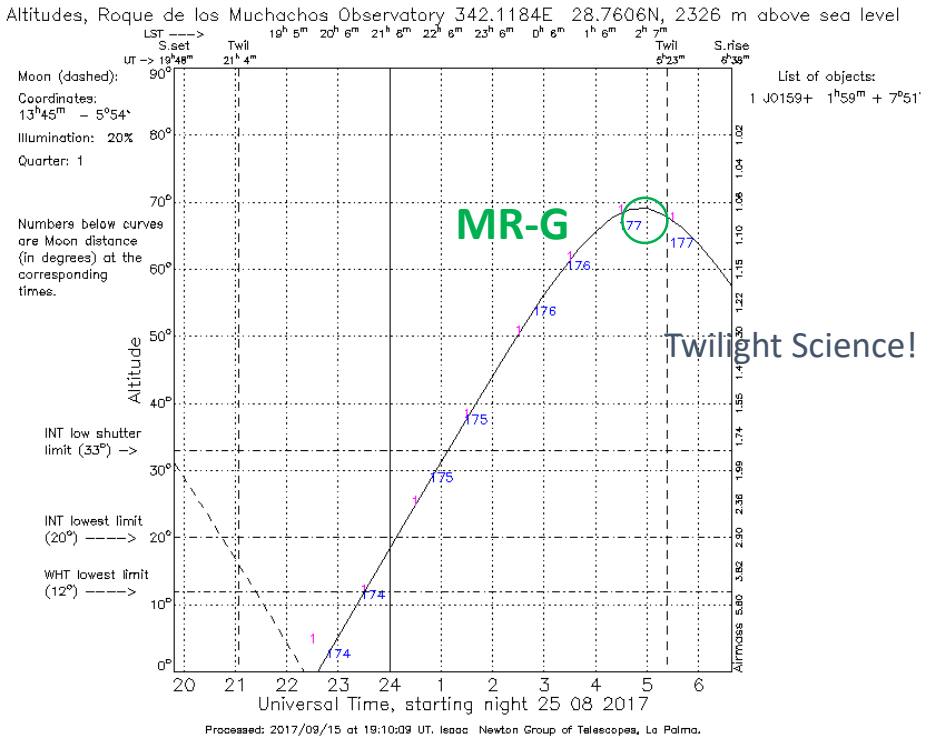


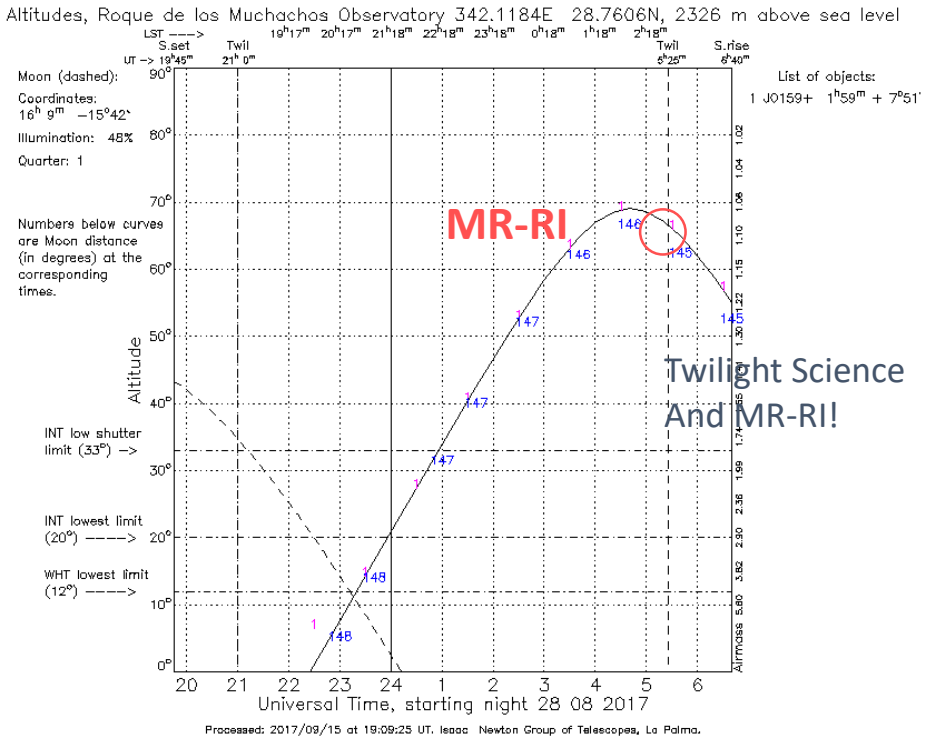


J0159 + 0751: Observations

VPH	Mode	Date	UT	Exp. Time (s)	AirMass	Seeing Average (TNG)	Dust Average (TNG)
MR-G	LCB	25/08/2017	04:23 - 05:30	3 x 1200	1,07	0,57 “	16,50 μgm^{-3}
MR-RI	LCB	28/08/2017	04:48 - 05:52	3 x 1200	1,07	0,71”	11,02 μgm^{-3}

1 hr on target, uniform values of pointing, weather conditions and elevation





4677 Å – 5131 Å in all positions reaching 4667 Å – 5141 Å in the central fibers

6375 Å – 7012 Å in all positions reaching 6360 Å – 7025 Å in the central fibers

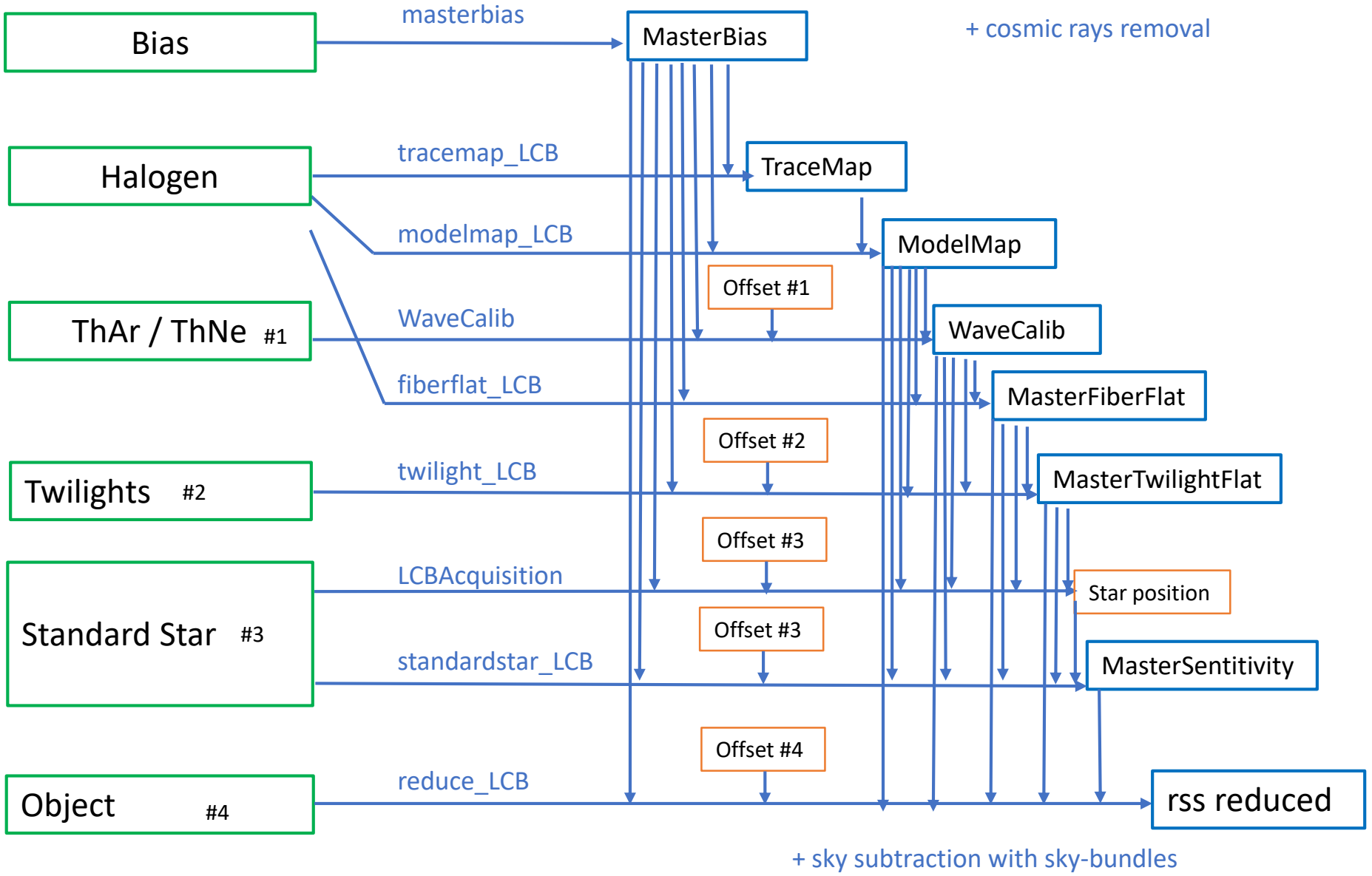
	Rest frame wavelength range at z = 0.0611					**J0159 + 0751**
MR-G	4667.00	4677.43	4913.73	5131.47	5140.53	0.126
MR-RI	6360.27	6375.06	6707.30	7012.39	7025.22	0.172

He II	4685.9	4972.3 Å
[Ar IV]+He I	4712.0	4999.9 Å
[Ar IV]	4740.2	5029.8 Å
Hβ	4861.3	5158.4 Å
He I	4921.9	5222.7 Å
[O III]	4958.9	5261.9 Å
[Fe III]	4988.0	5292.8 Å
[O III]	5006.8	5312.7 Å
He I	5015.7	5322.1 Å

[N II]	6548.1	6948.2
Hα	6562.8	6963.8
[N II]	6583.4	6985.6
He I	6678.1	7086.1
[S II]	6716.4	7126.8
[S II]	6730.8	7142.1

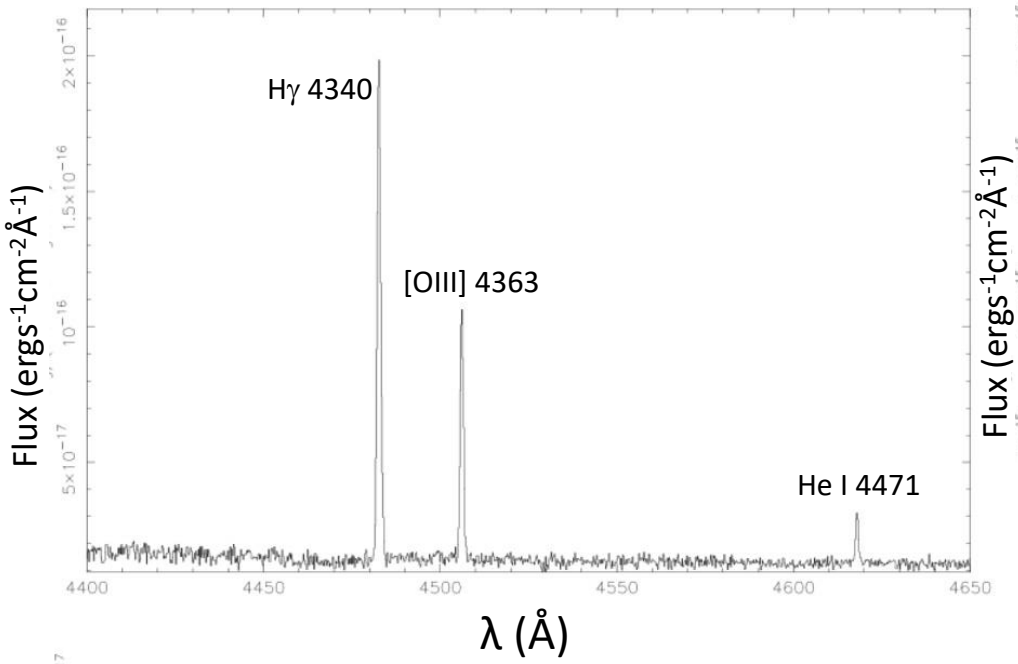
It was not possible to observe MR-B to complete the data with the 4363[OIII] for O abundance determination

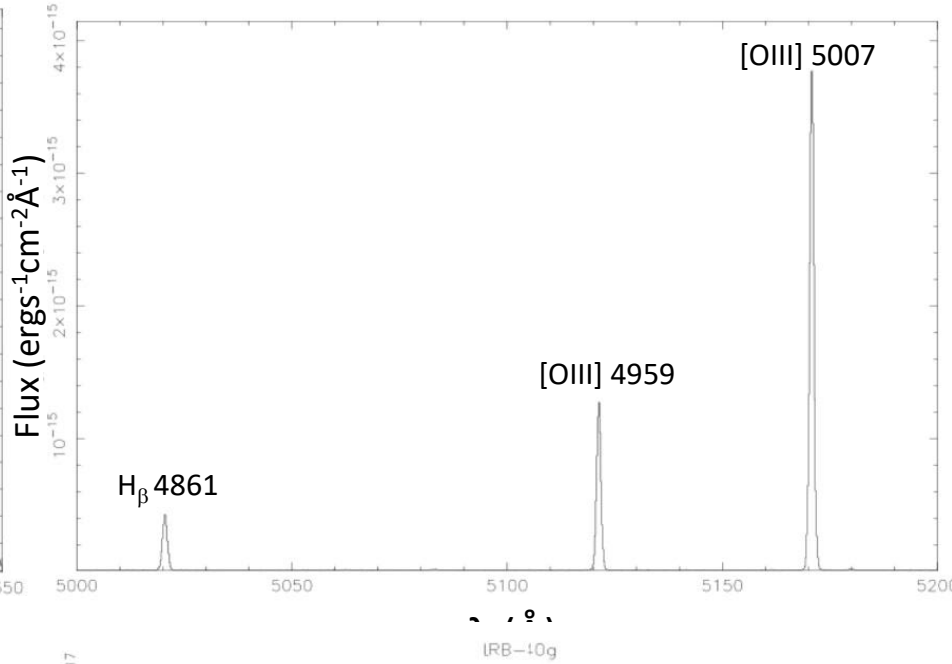
Data Reduction with MEGARA Pipeline

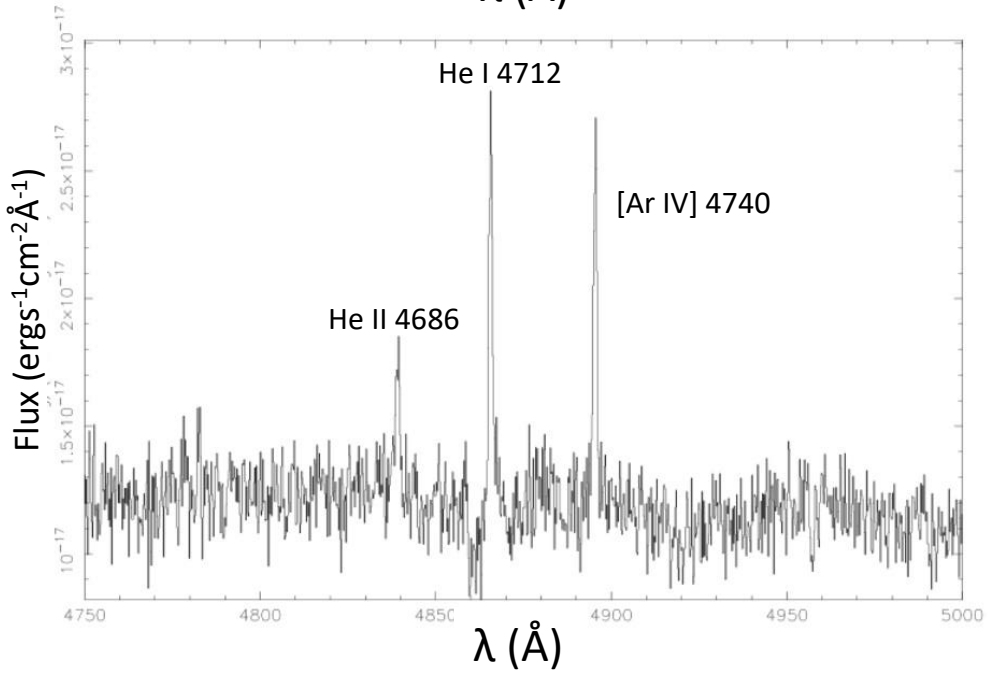


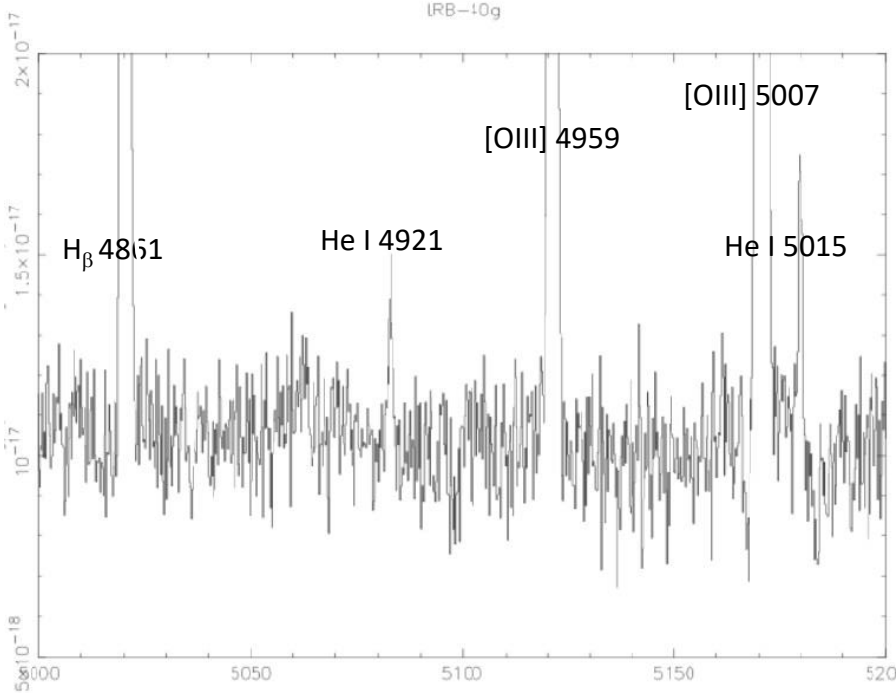
LR-B (spaxel central 40g), 0.62 arcsec

J1608 + 3528 LR-B



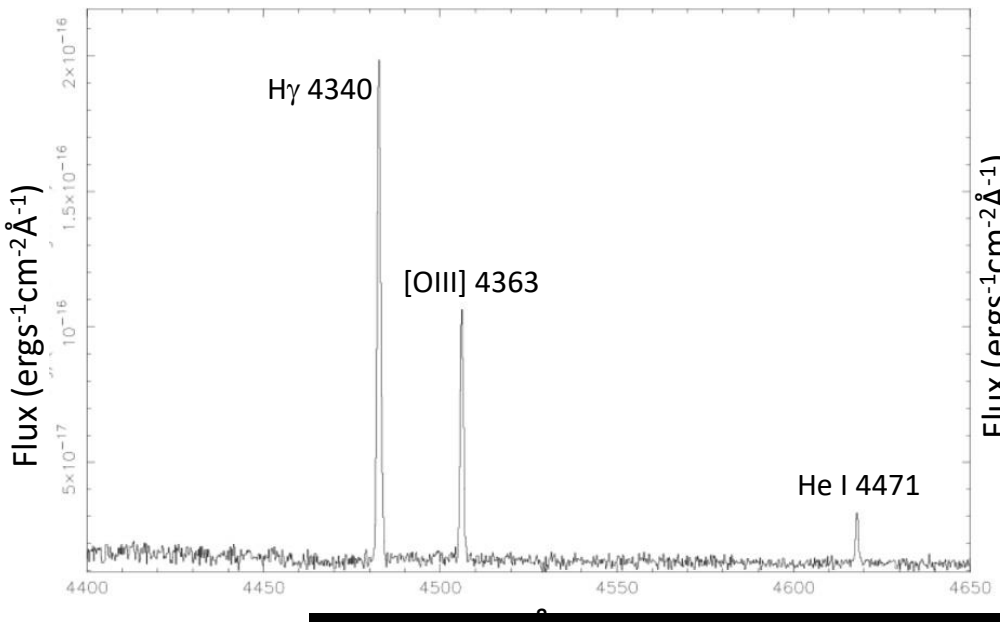


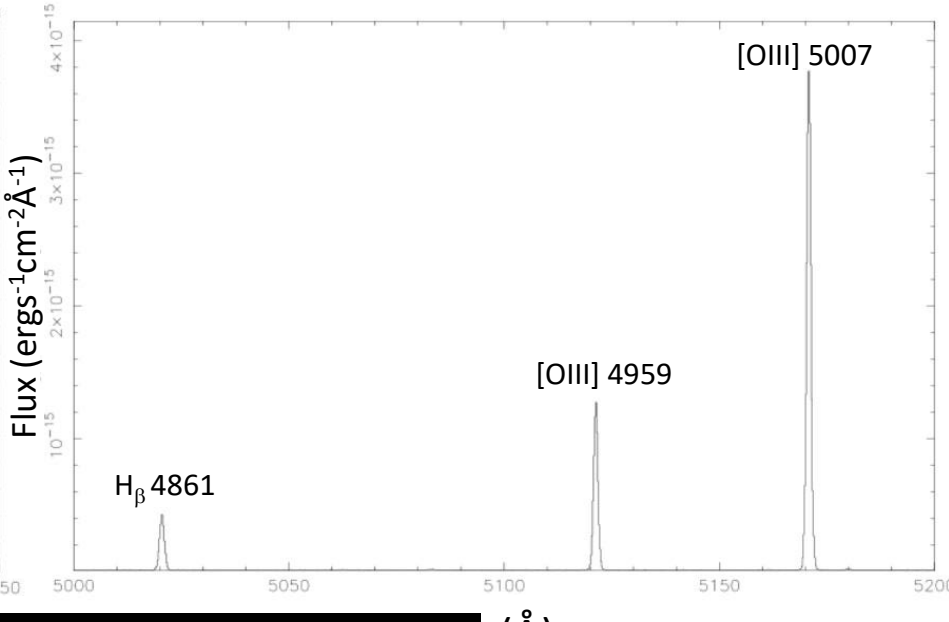


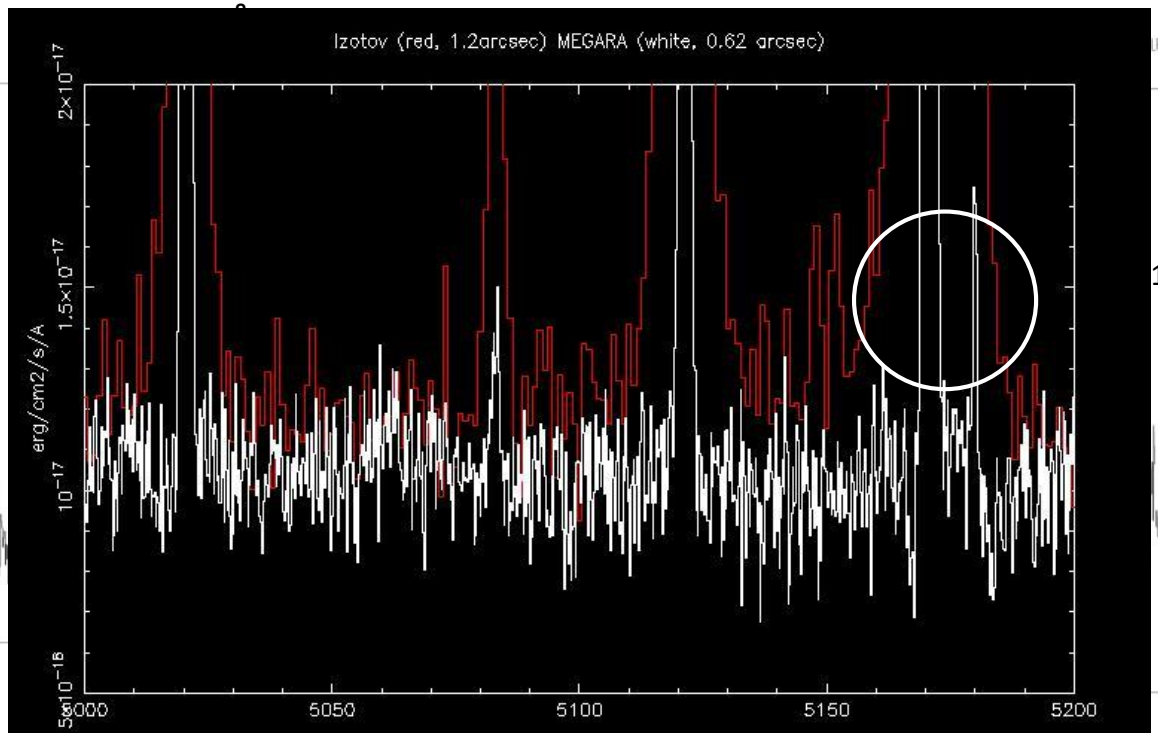


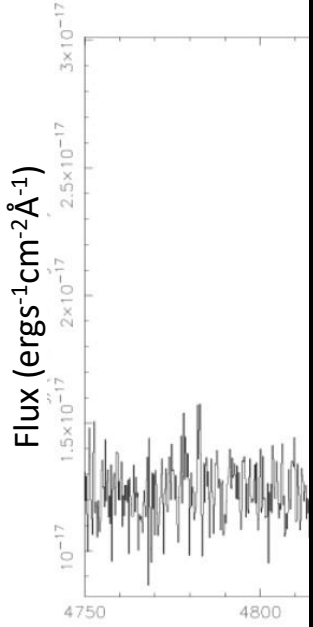
LR-B (spaxel central 40g), 0.62 arcsec

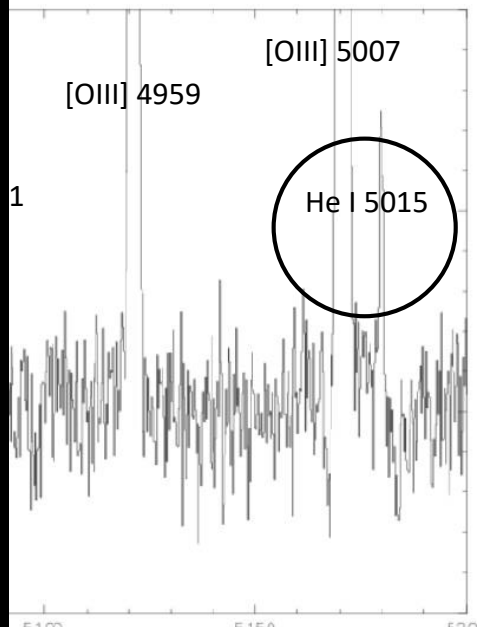
J1608 + 3528 LR-B

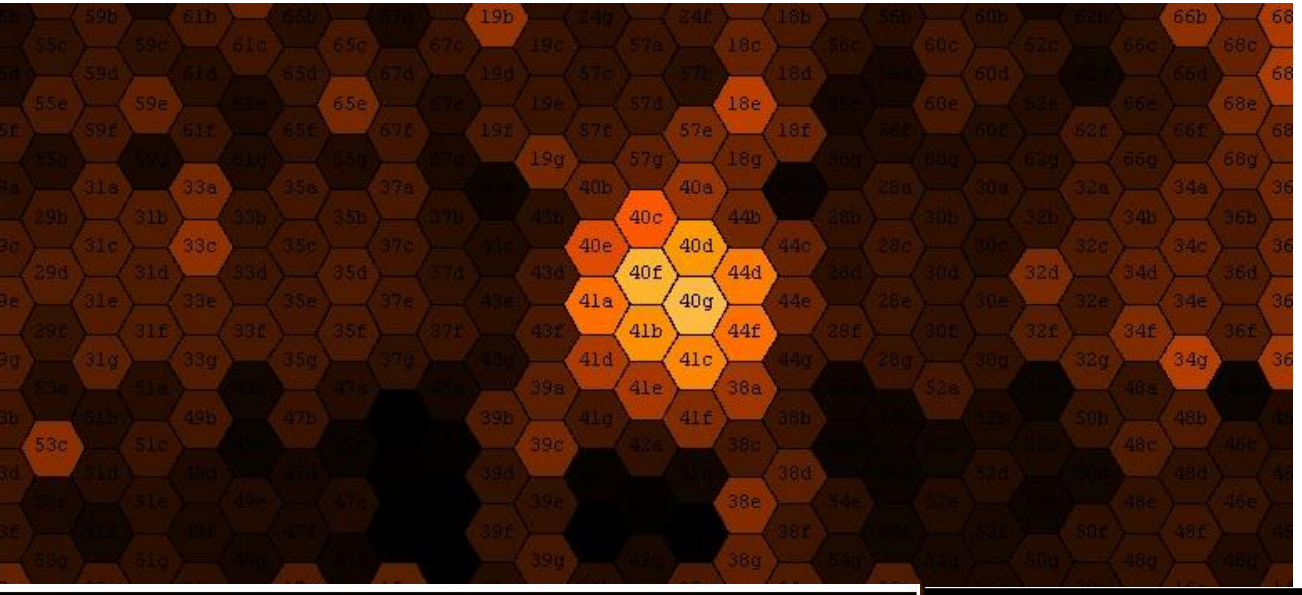






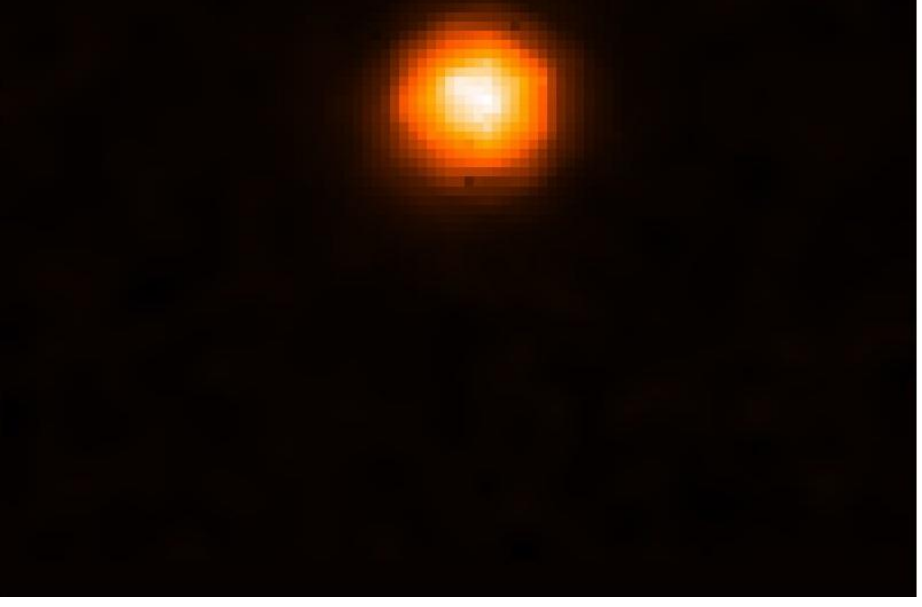






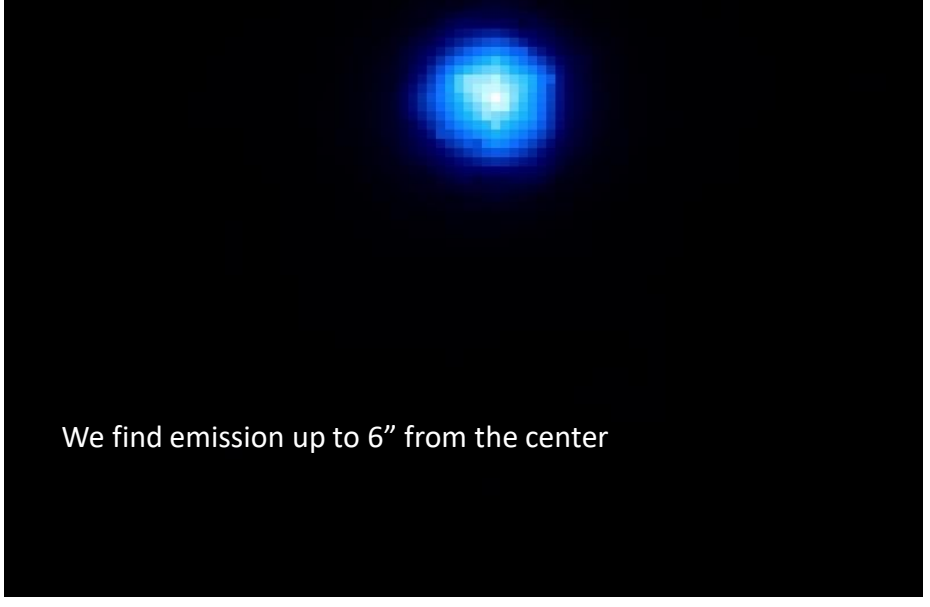
J1608 + 3528 LR-B

Hβ



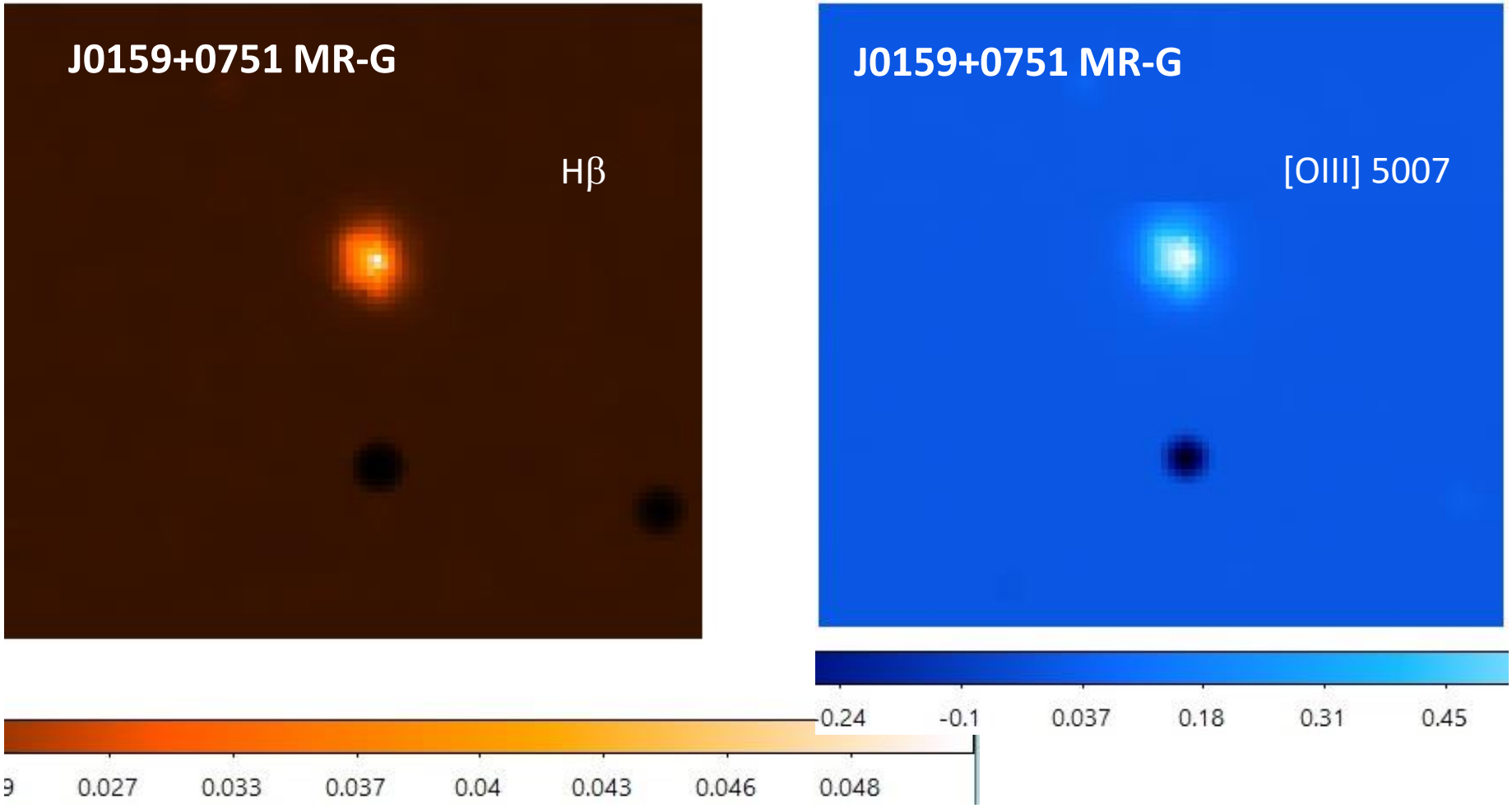
J1608 + 3528 LR-B

[OIII] 5007

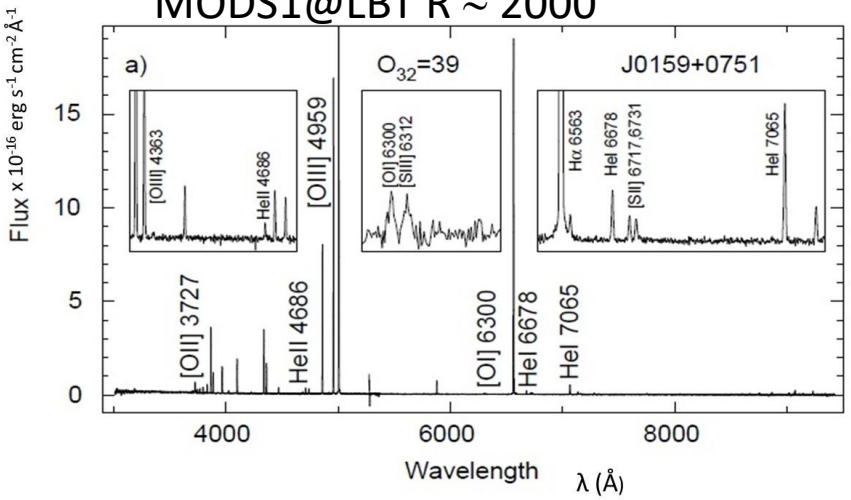


We find emission up to 6” from the center

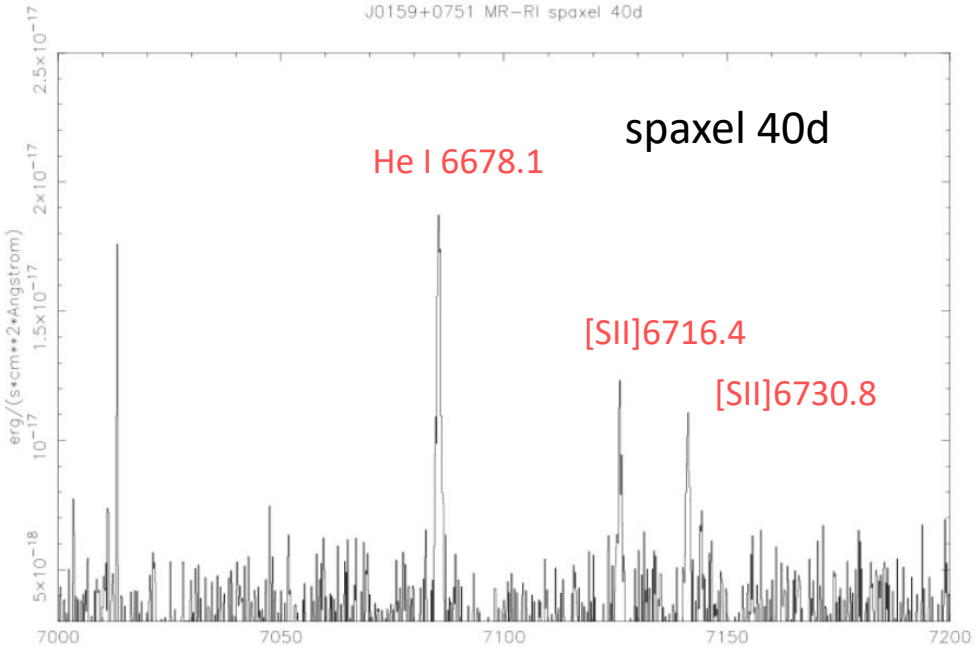
J0159 + 0751 @MR-G

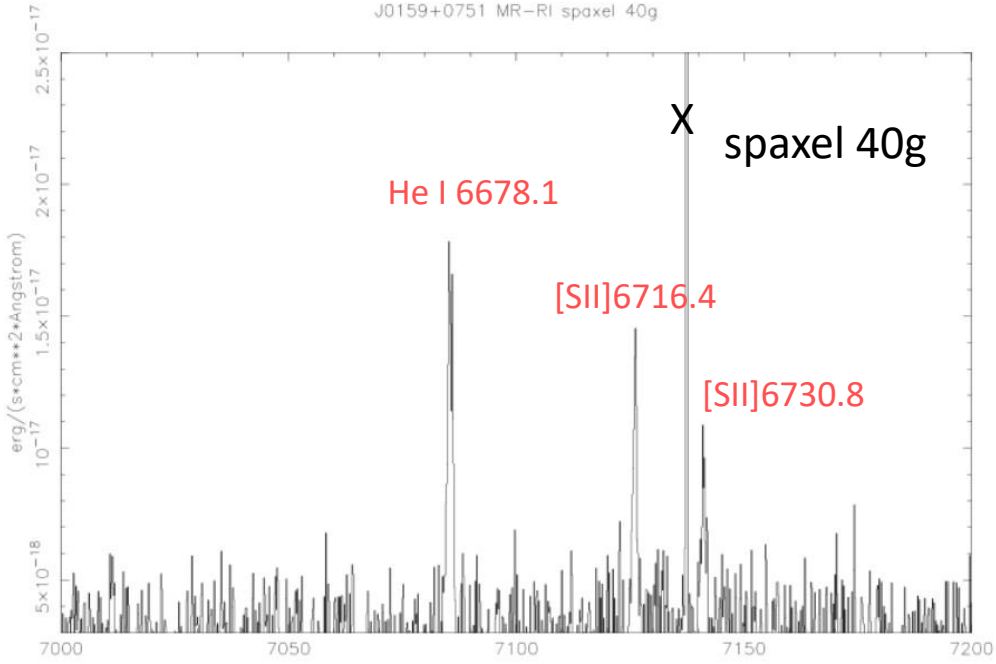


MODS1@LBT R ~ 2000



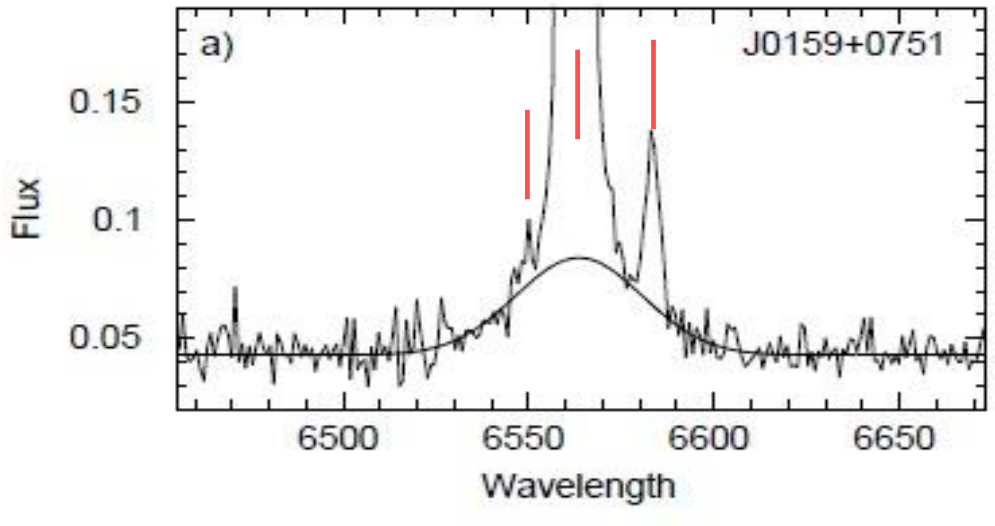
MEGARA@GTC R ~ 12000



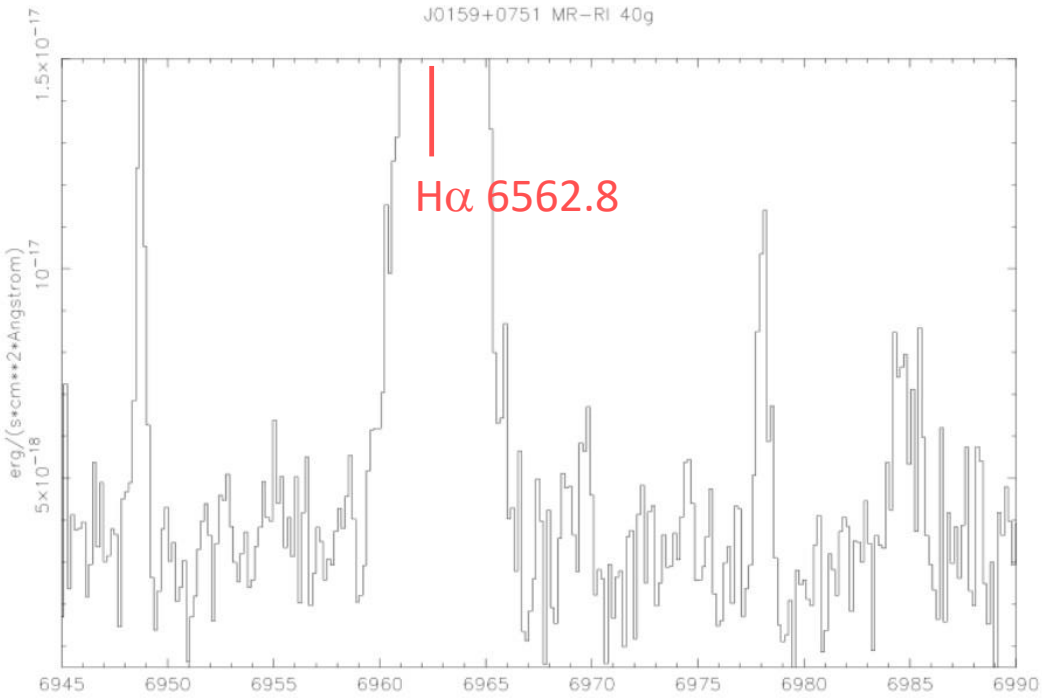


J0159 + 0751 @MR-RI

MODS1@LBT R ~ 2000



MEGARA@GTC R ~ 12000



Work in progress

- We have observed two low metallicity regions, originally detected by SDSS and with single observations with the LBT 8.4m telescope MODS1 long slit
- For the same exposure time (or similar) we detected (a fast data reduction was done in September 2017 to present the results at the RIA) with minimum work and standard basic pipeline (not optimized extraction) most of the emission lines than the LBT published observations. The flux calibration is fully consistent.
  - We have x 3 and x 6 higher resolution (with LR and MR observations). Our texp is not enough for the detection of the weakest lines with good S/N
  - We have 2D information at the LCB in very good seeing conditions
- We have done a high-quality data reduction of all 12 observations set-ups
- Better strategy for sky subtraction is needed in some gratings
- Improvement of S/N by combining exposures in different days
- We will analyze the lines and we will make the interpretation on the basis on PopStar Models

Conclusions

- **Work in progress for supporting MEGARA observations interpretation**
  - Empirical Stellar Library MEGARA-GTC
  - PopStar upgrade to MEGARA resolution with both models and observed spectra
- **MEGARA opens new opportunities for abundance determination (He e.g.) and a 2D detailed characterization of both gas and stellar populations in SFRs.**
- **Kinematics and Stellar Populations in Low Metallicity Compact Star Forming Galaxies (pilot program: J1608+3528 and J0159+0751)**
- Kinematics and Stellar populations in NGC7714 at R=20000 in HR-R (Hα) and HR-I (CaT and Paschen lines)

Proposals submitted to Spanish CAT

- Filler Program for MEGARA-GTC Stellar Library
- Study on J1154+2443 (46% leakage of continuum photons, Yzotov etal. 2018)