European Organisation for Astronomical Research in the Southern Hemisphere

OBSERVING PROGRAMMES OFFICE • Karl-Schwarzschild-Straße 2 • D-85748 Garching bei München • e-mail: opo@eso.org • Tel.: +49 89 320 06473

APPLICATION FOR OBSERVING TIME PERIOD: **104A**

Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of CoIs and the agreement to act according to the ESO policy and regulations, should observing time be granted.

1. Title Category: **B–6**

Merging and AGN feedback in action: the ENLR of Mrk 783.

2. Abstract / Total Time Requested

Total Amount of Time:

The extended narrow-line region (ENLR) is a puzzling structure of highly ionized gas, with a typical conical or bi-conical shape, typical of active galactic nuclei (AGN). It is often aligned with the extended radio emission of AGN, which is typically produced by the relativistic jets and this, together with the presence of a complex kinematics, is usually interpreted as a proof of the interaction between the jets and the ISM of the AGN host galaxy. We propose here observation of Mrk 783, one of the most interesting and peculiar narrow-line Seyfert 1 galaxies classified so far. Mrk 783 shows one of the largest extended radio emission discovered in a NLS1 coupled with a very large ENLR. Several features, including a possible double nucleus, indicate that the object underwent a merging with a companion in relatively recent times. Studying this object with MUSE will shed new light on the relation between the AGN and its host galaxy and the role of merging in the formation of

3. Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Type
A	104	MUSE	3h	feb	g	0.8	CLR	s	

4. Number of nights/hours	Telescope(s)	Amount of time
a) already awarded to this project:		
b) still required to complete this project:		

5. Special remarks:

6. Principal Investigator: marcoberton

6a. Investigators:

All CoIs moved to the end of the document.

7. Description of the proposed programme

A – Scientific Rationale: The extended narrow-line region (ENLR) is a structure of ionized gas typical of active galactic nuclei (AGN) predicted by the unified model of AGN (Antonucci 1993, ARA&A, 31, 473). It has a characteristic conical or bi-conical shape with the apexes pointing the AGN, due to the collimation of the radiation caused by the AGN torus, and sizes comparable with those of the whole host galaxy (Mulchaey+ 1996, ApJ, 467, 197; Schmitt+ 2003, ApJ, 597, 768). It is often aligned to the radio emission produced by the AGN (e.g. Schmitt+ 2003, Morganti+ 2007, A&A, 476, 735) and sometimes it shows complex line profiles (Ozaki 2009, PASJ, 61, 259, Congiu+ 2017a, MNRAS, 471, 562) produced by outflows observed both in the cold and warm phase of the interstellar medium (ISM; Morganti+ 1998, AJ, 115, 915; Morganti+ 2015, A&A, 580, A1). This is usually considered a hint of interaction between the radio jets and the ISM in the ENLR (Unger+ 1987, MNRAS, 228, 671; Wilson+ 1994, AJ, 107, 1227; Nagar+ 1999, ApJS, 120, 209; Schmitt+ 2003, Berton+ 2016, A&A, 591, 88), making it a natural laboratory to study the influence of the AGN in the life of the host galaxy, the so called AGN feedback (Fabian 2012, ARA&A, 50, 455).
The ENLR has been detailedly studied only in an handful of objects ($\sim$ 50 so far, Netzer H., 2015, ARA&A, 53, 365), and observed probably in twice the number of objects. The small number of discovered structures is probably caused by a combination of biases of the observations (the development of new integral field spectrograph is bringing to the discovery and analysis of new structures, e.g. He+ 2018, MNRAS, 478, 3614) and of intrinsic properties such as: the shape of the ionizing continuum, the gas distribution and the inclination of the AGN (Mulchaey+ 1996). These last properties are also the reason why ENLRs are usually hosted in type 2 sources (60-70% He+ 2018).
Mrk 783 is a narrow-line Seyfert 1 (NLS1) galaxy, a peculiar subclass of the traditional Seyfert 1 galaxies characterized by broad permitted lines (Hβ in particular) with a full width at half maximum smaller than 2000 km s^{-1}, that are often considered young and evolving AGN (Mathur, 2000, MNRAS, 314, 17). Among NLS1s Mrk 783 is particularly interesting because it is one of the few objects of this class showing kpc-scale radio emission (Congiu+ 2017b, A&A, 603, 32; Fig. 1-A). The emission shows some peculiar properties (e.g. very steep spectral indexes), and it has been classified as a relic (Congiu+ 2017b).
An optical follow-up of the source revealed that the interesting properties of this object are not limited to the radio band. Long-slit spectra of the source (fig 1-b) revealed the presence of an ENLR, with an extraordinary size for an object of the nearby universe (38 kpc), aligned with the axis of the extended radio emission (Fig. 1-a,b). On the other hand, archival SDSS images show extended structures similar to tidal tails at least on one side of the AGN, while close to the nucleus there seems to be a second, point-like, structure which might be a secondary nucleus of the galaxy with unknown origin (Fig. 1-c).
All these properties make Mrk 783 an extremely interesting object to study. The presence of both an ENLR and an extended radio emission makes Mrk 783 perfect to investigate the interaction between these two structures, namely the AGN feedback. The object is even more interesting because of the presence of the tidal tail and of the putative secondary nucleus observed closed to the AGN, possible hints of a recent merging. Merging are believed to be able to trigger the activity of active galaxies (e.g. Chiaberge+ 2015, ApJ, 806, 147, Järvelä+ 2018, A&A, 619, 69; Berton+ 2019, AJ, 157, 48), and to bring gas to the ENLR (e.g. Cracco+ 2011, MNRAS, 418, 2630).
A deep, detailed study of Mrk 783 and its ENLR will allow us to improve our knowledge of these still far from understood mechanisms (feedback and mergings) in the life of AGN.

B – Immediate Objective: We propose to observe the NLS1 galaxy Mrk 783 with MUSE, in order to investigate the following topics:
1) Did Mrk 783 undergo a recent merging? The presence of structure similar to tidal tails (fig 1-C) seems to suggest that the galaxy recently merged with a companion. Merging episodes are very important for the life of AGN, since they can to feed gas to the AGN (Hopkins+ 2010, MNRAS, 407, 1529) and to trigger the launch of a relativistic jet (Chiaberge+ 2015). The analysis of spatially resolved velocity and velocity dispersion maps of the gas in Mrk 783, together with the study of the profile of the emission lines could reveal the presence of motions not related to the normal rotation of th gas in a galaxy, but that can be associated with accretion of matter from an external object as a consequence of an interaction, confirming or rejecting the merging scenario.
2) What is the origin of the ENLR? Mrk 783 shows an ENLR with a unique extension, not only for a Type 1 AGN but for AGN in general. Several works claim that the ENLR gas can be brought to the host galaxy via merging (Ciroi+ 2005, MNRAS, 360, 253; Cracco+ 2011). Is this the case also for Mrk 783? The morphology of the ENLR that will be recovered from MUSE observations could answer this question. Studying the morphology of the ENLR is basically studying its gas distribution. The presence of isolated clumps of gas or disturbed structures, combined with the kinematics already discussed in the previous point, will help understand the origin of the gas of the ENLR.
3) What is the ionization source of the gas? The large number of emission lines present in the MUSE wavelength range can be used to build diagnostic diagrams (Baldwin+ 1981, PASP, 93, 5) to investigate the ionization source of the gas. This is fundamental to characterize the gas emission in the whole galaxy. While AGN are usually responsible for photo-ionizing the gas in ENLRs, NLS1s are known to host a significant amount

7. Description of the proposed programme and attachments

Description of the proposed programme (continued)

of star formation (Sani+ 2010, MNRAS, 403, 1246) that can also provide ionizing photons. Star formation can also be responsible for part of the diffuse radio emission of this galaxy, therefore identifying the star forming regions and estimating the star formation rate using the Hα emission lines where it is not produced by the AGN is fundamental to better understand the emission of this object at all wavelengths.

4) Are the ENLR and the extended radio emission related? In AGN radio and optical extended emission are often observed together and with similar morphologies and orientations (e.g. Schmitt+03, Kharb+06). Usually this is explained as the results of the interaction between host galaxy ISM and the relativistic jets. The spectra that have been analyzed already suggest the alignment of these two structures in Mrk 783. Nevertheless, only a detailed comparison between the morphology of the radio emission and of the ENLR in the regions of the galaxy where they are both observed can confirm the relation between the two structures, revealing the exact position where the interaction took place, since (Congiu+ 17) classified the radio emission as a relic. This can be done thanks to the matching spatial resolution between the VLA data available for this object and the observations we are proposing with MUSE.

5) What is the nature of the putative secondary nucleus observed in SDSS images? Among the peculiarities of Mrk 783, the putative secondary nucleus observed close to the AGN is one of the most puzzling and interesting. While ground-based observations with no adaptive optics cannot fully disentangle the AGN emission from that of the putative secondary nucleus, the distance between the two structure (1.5 arcsec) is large enough that it is possible to model the AGN contribution to the spectrum of the other structure. In such a way it will be possible to recover the pure emission of the putative secondary nucleus that, coupled with a detailed analysis of the kinematics (both of the gas and of the stellar component) in the central part of the galaxy, will be able to clarify the origin of this puzzling structure. Possible nature of the secondary nucleus could be: a star forming region, the nucleus of a companion galaxy that recently merged with Mrk 783, the actual nucleus of the galaxy from which the supermassive black hole has been kicked out during a merging and so on. The spectrum of the region combine with information on the kinematics should be enough, if not identifying with confidence the origin of the structure, to ,at least, rule out most of the scenarios.

Because of all its peculiarities, Mrk 783 is a perfect target for MUSE observations. Even though Mrk 783 is a single object, and it might not be representative of the full class of NLS1 or of the whole AGN population in general, it could help understand some of the still open topics about them, such as the importance of merging in triggering AGN activity and in bringing gas into the ENLR, the role of star formation in NLS1 galaxies and the relation between the AGN jets and the ISM of the host.

Attachments (Figures)

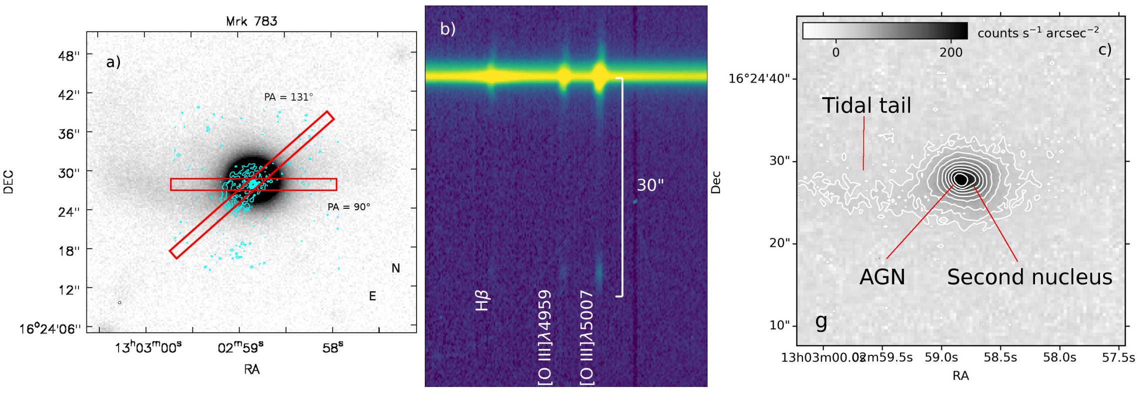

Fig. 1: **a)** g-band image of Mrk 783 acquired with AFOSC at the Asiago Astronomical Observatory, with contours of the VLA A array image in C-band of the source from (Congiu+ 2017b). The contours start from 3σ ($\sigma = 11\mu$Jy beam^{-1}) and they are separated by a factor $\sqrt{2}$. The beam size is $0.45'' \times 0.40''$ and the scale is 1.3kpc/$''$. The positions of the slit used for long slit observations are shown. **b)** Hβ + [O III]λ5007 spectral region from the long slit LDSS3 Magellan spectrum. Total exposure time 1 hour, seeing 0.8 arcsec, slit oriented along radio emission at PA = 131°. The spatial resolution is $0.189''$ px^{-1} and the dispersion is ~ 2 Å px^{-1}. The emission is traced in all lines up to 30 arcsec (38 kpc) from the nucleus. **c)** SDSS g-band image with surface brightness contours of Mrk 783. The position of the AGN, of the putative secondary nucleus and tidal tail are shown.

8. Justification of requested observing time and observing conditions

Lunar Phase Justification: We want to detect the extended line emission produced in the ENLR. Since the flux of the emission lines is fairly faint, we require at least grey time during the observations.

Time Justification: (including seeing overhead) We propose to observe the ENLR of Mrk 783 with MUSE in WFM and without adaptive optics. We used the Optical AO Integral-Field Spectroscopy Mode Version P104 ETC to estimate the exposure time. We also used as a reference the Hβ line, since it is fundamental to study the ionization of the gas via diagnostic diagrams and to measure the extinction of the gas. Moreover Hβ is one of the weakest lines we are interested in, so if we are able to detect it with a significant signal to noise ratio, we will be able to observe also the remaining, stronger emission lines ([O III]λ5007, Hα, etc.)
We considered a uniform distribution of gas, with a radius of 30 arcsec, which is a good approximation for Mrk 783 ENLR according to previously acquired data. Considering a width of the emission line of 5 Å, corresponding to a barely resolved line, with 2.2 hours of integration we would be able to detect the Hβ line with a signal-to-noise ratio (SNR) $\sim$ 5 up to a surface brightness of 7×10^{-17} erg s^{-1} cm^{-2} arcsec^{-2}. This sensitivity will allow us to detect and reliably measure Hβ flux in each single spaxels in most of the extension of the ENLR, maximizing the extension of the region for which diagnostic diagrams can be computed.
We simulated to observe the target during the night of February 1st, 2020, at 7 UT (gray time), at airmass 1.5 and with no spatial or spectral binning. We required a seeing better than 0.8 arcsec at zenith, which is fairly easy to obtain at Paranal, and will allow to sample the ENLR with a good amount of details.
Since the maximum limit for each OB is 1 hr, the 2.2 hrs of observing times will be divided in three OBs, each one including an acquisition loop, 4×660 s target offsets and 1×20 s sky offset. According to the MUSE User manual the best results are obtained changing the PA of 90° and performing a small dithering between each target offset. With this configuration, the total observed time we are going to ask including overheads is 3 hrs.

8a. Telescope Justification:

While narrow-band imaging could help solve some of these points, in particular those regarding the morphology of the ENLR, the redshift of the galaxy (z = 0.0672) is high enough that the [O III]λ5007 emission line, the best tracer of the ENLR, falls outside the range covered by sets of narrow-band filters available in almost all the largest observatory. Moreover the spectral information provided by a MUSE datacube are fundamental to fully characterize this interesting object. Because of the large FOV covered with a single pointing, the spatial and spectral resolution and the large diameter of the telescope, the combination of MUSE and VLT is the best one to study ENLRs. Emission lines map produced with MUSE have the same, if not better, quality with respect to those acquired with the best ground based imagers. Other available integral field spectrographs at other telescopes have unsuitable FOV to cover such an extended object (e.g. GMOS@Gemini) or they sacrifice spatial and spectral resolution (e.g. VIMOS@VLT)

8b. Observing Mode Justification (visitor or service):

N/A.

8c. Calibration Request:

Standard Calibration

9. Report on the use of ESO facilities during the last 2 years

This macro is optional and can be commented out.

9a. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If so, explain the need for new data.

No

9b. GTO/Public Survey Duplications:

10. Applicant's publications related to the subject of this application during the last 2 years

Berton M. et al., 2019, AJ, 157, 48; The Interacting Late-type Host Galaxy of the Radio-loud Narrow-line Seyfert 1 IRAS 20181-2244.

Järvelä E., Berton M., et al., A&A, 619, 69: Near-infrared morphologies of the host galaxies of narrow-line Seyfert 1 galaxies.

Congiu E. et al., 2017, A&A, 603, 32: Kiloparsec-scale emission in the narrow-line Seyfert 1 galaxy Mrk 783.

Congiu E. et al., 2017, MNRAS, 471, 562: High resolution spectroscopy of the extended narrow-line region of IC 5063 and NGC 7212.

Congiu E. et al., 2017, FrASS, 4, 27: Extended Narrow-Line Region in Seyfert Galaxies

11. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	Mrk 783	13 02 58.8	+16 24 27	3.0	17.4	$50''$	z = 0.067	

12. Scheduling requirements

This proposal involves time-critical observations, or observations to be performed at specific time intervals.

13. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
104	MUSE	A	WFM-NOAO-N	-

6b. Investigators:

	...moved from first page.	
E.	Congiu	1188
S.	Ciroi	1863