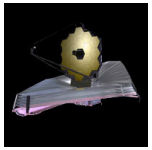

4339 - NIRSpec IFU spectroscopy of the first active binary intermediate-mass black hole and its host galaxy

Cycle: 2, Proposal Category: GO

INVESTIGATORS

Name	*Institution*
Dr. Igor Chilingarian (PI)	**Smithsonian Institution Astrophysical Observatory**
Mr. Kirill Grishin (CoI) (ESA Member)	Universite Paris Diderot (Paris 7)
Fedor Kolganov (CoI)	Moscow State University
Anton Mironov (CoI)	Moscow State University
Dmitrii Matveev (CoI)	Moscow State University
Evgenii Rubtsov (CoI)	Sternberg State Astronomical Institute
Victoria Toptun (CoI) (ESA Member)	European Southern Observatory - Germany
Ivan Kuzmin (CoI)	Moscow State University
Mariia Demianenko (CoI)	Moscow Institute of Physics and Technology
Vladimir Goradzhanov (CoI)	Moscow State University
Dr. Ivan Katkov (CoI)	New York University Abu Dhabi
Dr. Franz Bauer (CoI)	Space Science Institute
Mr. Ernesto Antonio Camacho (CoI)	Pontificia Universidad Catolica de Chile

OBSERVATIONS

Folder	*Observation*	*Label*	*Observing Template*	*Science Target*
Observation Folder				
	1	J163159.59+243740.2	NIRSpec IFU Spectroscopy	(1) J163159.59+243740.2
	2	sky	NIRSpec IFU Spectroscopy	(2) J163159.59+243740.2-sky

ABSTRACT

The origin and evolution of supermassive black holes (SMBHs) in galaxy centers remain critical open questions in modern astrophysics. SMBHs grow from yet unidentified BH seeds by accreting gas in active galactic nucleus (AGN) phases or via coalescences during galaxy mergers. Low-mass BH seeds (100s MSun) should leave behind a population of intermediate-mass BHs (IMBHs), which hence are the key to unlock SMBH origins. SMBH binaries form at the pre-coalescence stage and then become the sources of gravitational waves, which may ultimately be detected at cosmological distances by the LISA space mission.

We present the first 10:1 mass ratio (10^6/10^5 MSun) active sub-pc-separated IMBH binary, J1631+24 (z=0.0433; 190Mpc) detected via double-peaked broad optical hydrogen lines separated in velocity by 300 km/s in a compact low-mass elliptical galaxy with morphology suggestive of a past merger. The two-component shape and the velocity separation have persisted for 18+ years, as confirmed by ground-based optical spectra. This prototype system proves that hierarchical growth of SMBHs extends to the low-mass regime, although most of its characteristics remain poorly constrained.

We propose to collect deep R=2700 NIRSpec IFU spectra for J1631+24 to (i) measure the internal kinematics and stellar population of its host galaxy and search for signatures of a dry minor merger which led to the formation of a binary IMBH; (ii) decompose broad Paschen and Brackett hydrogen lines, where the components should be better separable vs Balmer lines; (iii) map the AGN-driven outflow detected from ground-based spectra; (iv) search for high-ionisation NIR coronal lines predicted by IMBH models.

OBSERVING DESCRIPTION

JWST justification. Our project requires spatially resolved maps of internal kinematics and stellar populations of a galaxy which is only about 2 arcsec across in the sky and a good separation of its active nucleus from the stellar body. It requires high spatial resolution and a large collecting area of a 6-10 m class telescope to reach the signal-to-noise ratio of 5 per spectral pixel in absorption lines. While in principle, spatially resolved kinematics can be obtained from ground-based adaptive optics-assisted integral-field unit observations with NIFS at Gemini-North, OSIRIS at Keck, or soon-to-be-commissioned ERIS at ESO VLT, the redshift value of z=0.043 pushes the K-band CO-series of absorption lines, which are the best features to derive internal kinematics in the near-infrared into the area of strong telluric absorption. The same applies to the emission-line spectrum of the active nucleus: all important emission lines with broad components are located in the spectral ranges having 30-50% telluric absorption. Another complication is the broad component of a spatial point-spread function of AO-assisted observations, which makes the spatially-resolved emission-line diagnostic hard if at all possible and will also spill the light from a very bright AGN onto stellar components, hampering the determination of stellar population parameters and velocity dispersion. This makes the JWST NIRspec IFU the only instrument which can be used to achieve our

science goals.

NIRSpec setup justification. The intrinsic stellar velocity dispersion of J1631+24 estimated from ground-based spectra is 64 km/s. This requires the high-resolution gratings of NIRSpec IFU. We request continuous wavelength coverage from 0.97--3.05 um, which is achievable with the two setups, G140H/F100LP + G235H/F170LP: this will cover all emission lines we propose to measure from Siii in the blue to Br beta in the red and also numerous stellar absorption features in the H and K bands, which we will use to estimate internal kinematics, ages, and metallicities of stellar populations. We notice that 2 or 3 of the 6 CO bands will fall into the NIRSpec detector gap (depending on the position of a given spaxel in the field of view), however, the remaining 3-4 hold sufficient amounts of spectral information for precise determination of internal kinematics.

Exposure time, signal-to-noise, and dithering strategy. We will apply Voronoi adaptive binning to the NIRSpec data cube and subsequently process it using full-spectrum fitting using intermediate-resolution stellar population models based on the X-Shooter Spectral Library, modified for our purposes using synthetic stellar atmospheres to fill the wavelength gaps originating from telluric absorption bands. We use the published recipe and code to estimate the required signal-to-noise ratio that we need for internal kinematics: we require S/N=10 per spectral element in each binned spaxel in both spectral setups to reach the precision of 7 km/s in radial velocity and stellar velocity dispersion required for successful dynamical modelling of J1624+31. This will be reachable in a 0.2 arcsec-diameter spaxel after binning at $1 r_e ~ 1 arcsec in 9,045 sec on-source, which corresponds to 4 exposures per setup using the NIRSpec exposure time calculator if we use the NRSIRS2 readout pattern in 6 groups and 5 integration per exposure. Closer to the galaxy center, the S/N ratio increases rapidly and reaches 30 in a single unbinned spaxel just outside the AGN point source. We use an ETC Scene with a galaxy represented by 2 S'ersic (stellar body) and 1 PSF component (AGN) with the parameters from the 2D light profile decomposition of the archival F814W HST WFPC2/PC image. We propose to use IFU Nod Off-Scene with a 4-point dither pattern and the sky exposure time of 25% of the on-source integration (1 exposure, 6 groups, 5 integrations; 2261 sec). We emphasize that this is not an available option in the exposure time calculator, which always sets the off-set exposure to 100% of the on-source exposure duration; so we model our strategy as 5 individual exposures without dithers. Then, for each setup we request 11306 sec of pure exposure time or 6.08 h for the entire program in two spectral setups without overheads and 9.19 h of charged time.
.

Fixed Targets

#	Name	Target Coordinates	Targ. Coord. Corrections	Miscellaneous
(1)	J163159.59+243740.2	RA: 16 31 59.5946 (247.9983108d) Dec: +24 37 40.26 (24.62785d) Equinox: J2000		
Comments: *Category=Galaxy* *Description=[Active galaxies]*				
(2)	J163159.59+243740.2-sky	RA: 16 31 58.6100 (247.9942083d) Dec: +24 37 55.00 (24.63194d) Equinox: J2000		
Comments: *Category=Unidentified* *Description=[Blank field]*				

Observation

Proposal 4339, Observation 1: J163159.59+243740.2

Fri Apr 05 21:00:40 GMT 2024

Diagnostic Status: Warning

Observing Template: NIRSpec IFU Spectroscopy

Diagnostics

(Visit 1:1) Warning (Form): Overheads are provisional until the Visit Planner has been run.

Fixed Targets

#	Name	Target Coordinates	Targ. Coord. Corrections	Miscellaneous
(1)	J163159.59+243740.2	RA: 16 31 59.5946 (247.9983108d) Dec: +24 37 40.26 (24.62785d) Equinox: J2000		

Comments:
Category=Galaxy
Description=[Active galaxies]

Template

TA Method
NONE

Dithers

#	Dither Type	Size	Starting Point	Number of Points	Points
1	CYCLING	MEDIUM	1	4	

Spectral Elements

#	Grating/Filter	Readout Pattern	Groups/Int	Integrations/Exp	Leakcal	Dither	Autocal	Total Dithers	Total Integrations	Total Exposure Time	ETC Wkbk.Calc ID
1	G140H/F100LP	NRSIRS2	18	2	false	true	NONE	4	8	10620.712	195624
2	G235H/F170LP	NRSIRS2	18	2	false	true	NONE	4	8	10620.712	195624

Special Requirements

Aperture PA Range 282.97164917 to 353.97164917 Degrees (V3 144.0 to 215.0)

Sequence Observations 1, 2, Non-interruptible

Observation

Proposal 4339, Observation 2: sky

Fri Apr 05 21:00:40 GMT 2024

Diagnostic Status: Warning

Observing Template: NIRSpec IFU Spectroscopy

Diagnostics

(Visit 2:1) Warning (Form): Overheads are provisional until the Visit Planner has been run.

Fixed Targets

#	Name	Target Coordinates	Targ. Coord. Corrections	Miscellaneous
(2)	J163159.59+243740.2-sky	RA: 16 31 58.6100 (247.9942083d) Dec: +24 37 55.00 (24.63194d) Equinox: J2000		

Comments:
Category=Unidentified
Description=[Blank field]

Template

TA Method
NONE

Dithers

#	Dither Type	Size	Starting Point	Number of Points	Points
1	NONE				

Spectral Elements

#	Grating/Filter	Readout Pattern	Groups/Int	Integrations/Exp	Leakcal	Dither	Autocal	Total Dithers	Total Integrations	Total Exposure Time	ETC Wkbk.Calc ID
1	G140H/F100LP	NRSIRS2	18	1	false	false	NONE	1	1	1327.589	
2	G235H/F170LP	NRSIRS2	18	1	false	false	NONE	1	1	1327.589	

Special Requirements

Sequence Observations 1, 2, Non-interruptible