European Organisation for Astronomical Research in the Southern Hemisphere

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APPLICATION FOR OBSERVING TIME

PERIOD: **102Z**

DDT

Important Notice:

1. Title

Category: **D–5**

Testing long GRB SNe as a source of r-process material in the Universe - the case of GRB 171205A/SN 2017iuk.

2. Abstract / Total Time Requested

Total Amount of Time:

The first kilonova ever discovered, the remnant of a binary neutron star merger, has finally provided direct evidence for r-process heavy elements production. Recent theoretical work has identified a second channel for this process, the core-collapse supernovae accompanying long GRBs. Given the much larger predicted yield, such channel could be in fact dominant. Moreover, the rapid timescale of GRB production ($\sim$ Myr) explains better than NS mergers the early r-process enrichment of some ultra-faint dwarf galaxies, like Reticulum II.
While the early phases of GRB-SNe are powered by “regular” Ni decay, the presence of r-process elements becomes visible in the NIR, at late epochs ($\gtrsim$ 300 days after explosion), when the outer layers have become transparent. Fortunately, one of the closest GRB/SNe every discovered, the once-in-a-decade event SN 2017iuk, is observable right now, and provides a unique chance to test r-process production in these objects.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Type
A	102	HAWKI	1h	any	n	0.8	CLR	s	
B	102	XSHOOTER	5h	any	n	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:

SN 2017iuk is the third closest GRB-associated SN ever detected – a once-per-decade event – and the first detected since X-shooter started operations. This SN is currently fading, and as the theoretical work motivating these observations was published after the P103 submission deadline, a DDT proposal is the only avenue to secure these observations. Given the scarcity of GRB-SNe at this proximity, this is a unique opportunity to test the suggested origin of a significant fraction of the Galactic r-process material.

6. Principal Investigator: jselsing

6a. Investigators:

All CoIs moved to the end of the document.

7. Description of the proposed programme

A – Scientific Rationale:

The origin of the metals, up to the iron peak group, is well explained by thermonuclear burning, inside stars. Heavier elements, however, are thought to originate via neutron capture, and subsequent β-decay. The site where such process occurs, however, is still debated.

The fading UV/optical/IR counterpart, AT2017gfo (Abbott et al. 2017 ApJl 848, L12), to the gravitational waves from the binary neutron star (BNS) merger GW170817 (Abbott et al. 2017, Phys. Rev. Lett. 119, 161101) matched theoretical predictions for the signature of the radioactive decay of freshly synthesised r-process nuclei. In particular, the late-time IR emission from the event was interpreted as evidence for the production of heavy lanthanide nuclei. Based on the inferred yield of r-process elements in this single event, and the BNS rate now measured by LIGO, BNS mergers are likely a major source of r-process nuclei in the Galaxy (e.g. Kasen, Metzger, Barnes et al., Nature, 551, 80). However, given a single event the uncertainties on this estimate remain large and there is still room for other sources to contribute, or even dominate, the Galactic r-process budget. Indeed, the requirement for prompt r-process enrichment in ultra-faint dwarf galaxies (Ji et al. 2016 Nature, 531, 610) and in carbon-enhanced metal-poor stars (e.g. Safarzadeh et al., arXiv:1812.02779) poses a challenge for a BNS scenario, as there may not be sufficient BNS mergers occurring in the required short time scales. In early stages of galaxy evolution, there thus appears to be a need for an additional source of r-process material, which has been suggested to be a rare subtype of supernovae (e.g. Côté et al. 2018 arXiv:1809.03525).

Similar physical conditions as those present during BNS mergers occur in other astrophysical environments, particularly the collapse of massive rotating stars ("collapsars"), the central engines of long-duration gamma-ray bursts. Recently, Siegel et al. 2018 (arXiv:1810.00098) proposed that black hole accretion disk outflows formed in collapsars may give rise to r-process nucleosynthesis in a similar manner to BNS mergers. The key, novel ingredient in this model is the self-consistent treatment of proton/electron nuclear interactions, leading to formation of free neutrons, which enables a significantly enhancement of r-process production. Despite the lower rate of collapsars, compared to BNS mergers, the mass in the accretion disk is much higher, thus likely making them an important r-process site. However, unlike in BNS mergers, in collapsars the r-process material would be deeply embedded behind the bulk of the supernova ejecta, revealing its presence only at late times once the (normal composition) outer material becomes transparent. By observing a GRB supernova at late times, several months after the explosion, we propose to search for the hallmark NIR signatures of r-process nucleosynthesis in collapsars. Note that collapsars still produce large amounts of ^{56}Ni, which powers the early epochs of the light curve. r-process elements are likely confined to the inner regions, closer to the accretion disk, deeply embedded inside the ejecta. Their signatures can therefore only appear once the surrounding material has become transparent, $\sim$ 100s of days after the explosion.

GRB171205A/SN2017iuk at $z = 0.0368$ is a $\sim$ 380 days old, very nearby long-duration GRB with an accompanying SN (D'Elia et al. 2018, arXiv: 1810.03339). The direct detection of jet cocoon signatures in the early spectra (Izzo et al. 2018, Nature, in press) makes this SN a perfect candidate to test the model by Siegel et al. In particualr, SN2017iuk is the third nearest GRB/SN discovered after SN1998bw and 2006aj (Cano et al. 2017, Advances in Astronomy, 8929054) and must thus be regarded as a "once-in-a-decade" chance to test the suggest model and to observe the late-time evolution of GRB/SNe.

B – Immediate Objective:

We here propose to observe the evolution of GRB171205A/SN2017iuk, $\sim$ 1 year after the explosion. Our primary science goal is to test the suggestion that GRB-SNe are an important source of r-process elements. This is possible due to the near-infrared excess emission in the late phases, predicted by the presence of r-process enriched ejecta. As a useful byproduct, we will also get the chance to secure observations of the late nebular phase of the most nearby GRB-SNe. The observations will, independently of the presence of r-process material in the ejecta, allow us to derive constraints on the composition, kinematics and geometry of this very rare sub-type of supernovae.

The observations will consist of J-band imaging in the near-infrared to put constraints on the light-curve brightness in the region where the r-process dominated spectrum of the kilonova, AT2017gfo, was the brightest. The accurate determination of the flux density will allow direct comparison with models. Spectroscopy is required to simultaneously search for the presence of optically thin lines, that have become transparent through the ^{56}Ni powered part of the emission. The appearance of the SN, at this time, allows us to constrain the possible amount of the r-process element powering, which is one of the key observable predictions of the theoretical models.

SN2017iuk has just become observable again, but is fading. Based on the extrapolated light curve from Siegel et al. (2018), it will be brightest in the near-infrared. The prospect of detecting nebular emission from r-process elements, provides a tantalising opportunity to find the first direct, spectroscopic evidence for the production site of the alternative channel for the production of the Galactic r-process material.

7. Description of the proposed programme and attachments

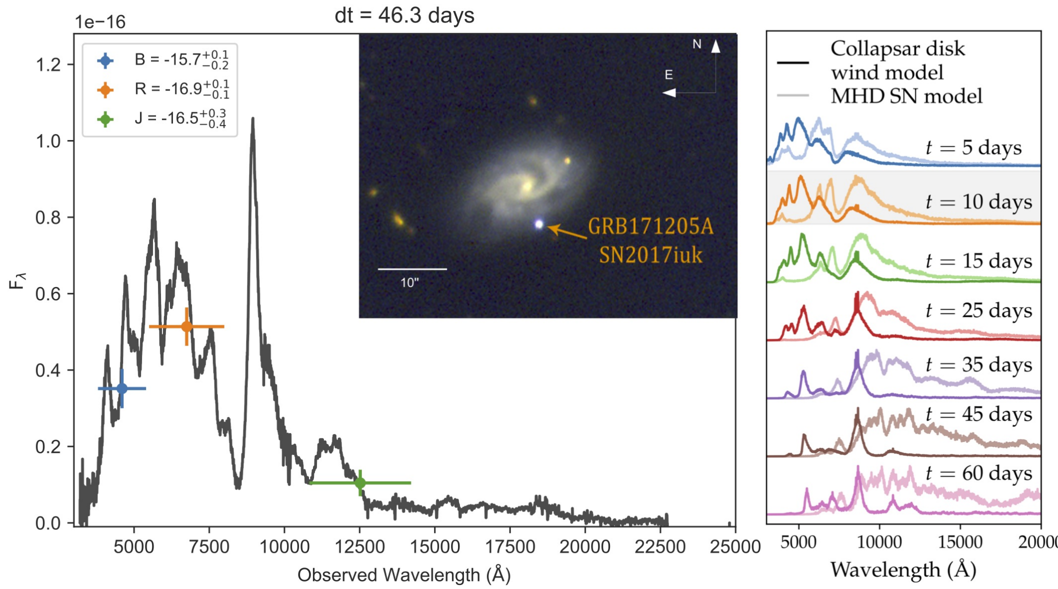

Fig. 1: Comparison between the observed spectrum of GRB171205A/SN2017iuk and the theoretically derived spectra. The left panel shows the spectrum of SN2017iuk 46 days after explosion where synthetic photometry has been overplotted. The right panel shows part of Fig. 3 from Siegel et al. (2018), where the synthetic spectra are shown for two cases (disk wind vs MHD SN) for the mixing of r-process elements among the ejecta. Already, the detection of a significant optical component in the observed spectra, indicates that any synthesised r-process material is not significantly mixed with the outer layers in SN2017iuk. Late-time spectroscopy will allow constraints on the presence of r-process lines. The inset shows the detection image of GRB171205A/SN2017iuk from Izzo et al. (2018).

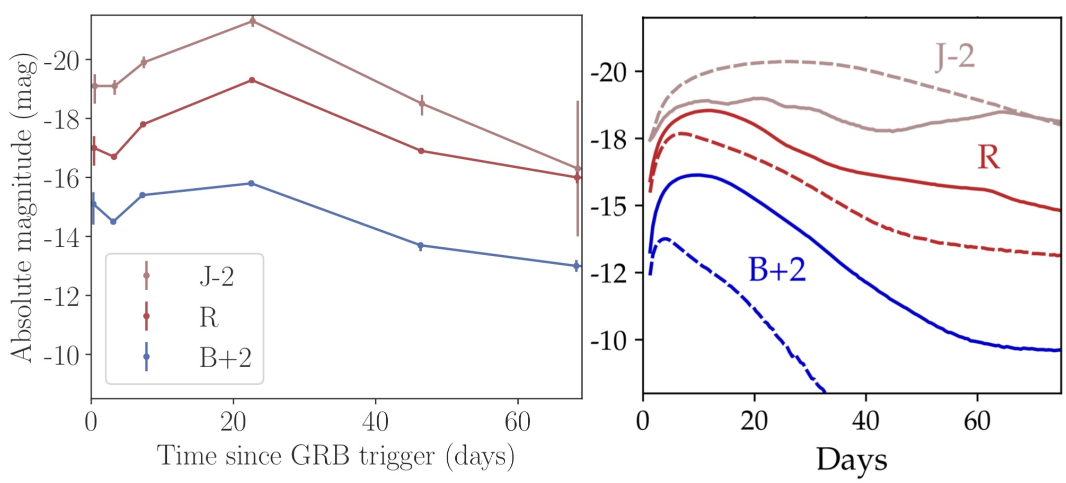

Fig. 2: Comparison between the light curve of SN2017iuk and the model from Siegel et al. (2018). On the left panel is the light curve based on the synthetic photometry of the spectra, derived by integrating the spectra over the passbands used in the theoretical models. The right panel shows the theoretical light curve from Fig. 3 in Siegel et al. (2018). Generally, the observed light curve of SN2017iuk is bluer than what is predicted by the model in which any freshly synthesised r-process material is mixed with the ^{56}Ni (dashed lines), as also suggested by the spectra (Fig. 1). The solid lines show models with more deeply embedded r-process material and are in better agreement with the currently available data.

8. Justification of requested observing time and observing conditions

Lunar Phase Justification: These are ToO observations primarily targeting the near-infrared, and thus the lunar phase is not important.

Time Justification: (including seeing overhead)

HAWK-I imaging: To calculate the required exposure time we use the HAWK-I Exposure Time Calculator Infrared Imaging Mode Version P103.3. Based on the extrapolated light-curve, the transient is expected to be around $J \sim 24$ AB mag. In order for us to confidently reject or confirm the model, a $\sim 10\sigma$ detection is required and for that we need 2000 s exposure, which including overhead totals 1 hr.

X-shooter spectroscopy: Similarly, we use the X-SHOOTER Exposure Time Calculator Version P103.3. As predicted by Siegel et al. (2018), the features we are looking for likely have a velocity comparable to the features in AT2017gfo. As the input spectrum, we therefore use the kilonova spectrum of AT2017gfo after 10.5 days, to get a spectrum dominated by near-infrared features. In 9600 s, we can get a S/N of 1 per spectral bin across the emission features. Because of the expected width of the features, we can bin the spectrum by close to 100 pixel elements, thus ensuring a S/N $\sim$ 10 over any potential line. This will allow us to identify them, if they are there, but otherwise exclude their presence at high significance. Including the overhead for the X-shooter observations result in 4 hr required to reach our science benchmark goal. These observations, will be spread over 4 OBs, each lasting $\sim$ 1 hour.

Because we are interested in near-infrared spectral features, we additionally require the best possible telluric correction. The target itself will be too faint to use for direct telluric correction, and we therefore specifically ask for a telluric standard star observation, taken immediately after each of the target OBs. We need 4 telluric OBs to match the science OBs, which accounting for overhead and 10 s telluric nodding observations amounts to $\sim$ 15 minutes per OB. We therefore ask for 1 additional hr to ensure the best possible telluric correction.

The total required time on X-shooter is thus 5 hours, including overhead.

8a. Telescope Justification:

At the magnitudes we are probing, an 8-m class telescope is needed and X-shooter is by far the best instrument to carry out near-infrared spectroscopy to look for emission lines. As the lines we are looking for are potentially of unknown origin and wavelength position, we need the coverage provided by X-shooter to adequately cover the region of interest. At these magnitudes, only the VLT has the necessary sensitivity to provide good signal-to-noise observations that are necessary to reach our science goals. In fact, SN2017iuk is the first GRB/SN close enough that these observations can be performed, since when X-shooter has become operational on the VLT.

8b. DDT Justification:

The theoretical model that implicates GRB-SNe in the production of the r-process elements did not appear in the literature until after the P102 ESO proposal deadline and therefore it was not possible for us to apply for time to test this model in regular time. SN2017iuk is a once-in-a-decade chance to test this model as the close GRB-SNe are very rare. However our target is fading, therefore this will be the only chance in the foreseeable future to look for the formation of r-process elements in GRB-SNe.

Some of us are members of the "Stargate" gamma-ray burst program (PI N. Tanvir). We remark that these observations are completely outside the scope of that program, both in terms of science case and of allocated time.

8c. Calibration Request:

Standard Calibration

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

099.D-0382(A) (PI Pian), 099.D-0622(C) (PI D'Avanzo): X-shooter programme that obtained the first spectra of the kilonova, AT2017gfo. These observation defines the spectroscopic appearance of this completely new type of transient and is published in Nature (Pian et al. 2017).

099.A-0801(A) (PI Selsing): This programme covered the follow-up of gravitationally lensed SNe discovered in the RELICS survey. Only one suitable candidate was identified (RLC16Nim), for which this programme provided a redshift (Rodney et al. in prep).

1102.D-0353, 102.D-0353, 0102.D-0348: The ENGRAVE programme (the first ToO large program awarded in over a decade), devoted to study counterparts of gravitational wave sources. Several of us are key members of the collaboration. The PI (Selsing) is the ENGRAVE X-shooter instrument specialist, Co-I Izzo is FORS2 specialist, Co-I Malesani is part of the executive committee.

0100.D-0649, 0101.D-0648, 0102.D-0662 (PI Tanvir): Currently active programme and its predecessors to observe optical counterparts of GRBs. Has resulted in numerous publications, including the sample presentation paper by Selsing et al. 2018 (arXiv:1802.07727), as well as Selsing et al. (2018, A&A, 616, A48).

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.

This is a proposal for a fading transient. The data requested are not in the archive. We already have 7 epochs of X-shooter spectra, covering the first months, however the very late-time evolution is the most constraining for the amount of deeply embedded r-process material.

9b. GTO/Public Survey Duplications:

There is no duplication of targets/regions covered by ongoing GTO and/or Public Survey programmes.

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

J. Selsing et al., 2018 accepted for publication in A&A(arXiv:1802.07727): *"The X-shooter GRB afterglow legacy sample (XS-GRB)"*

J. Selsing et al., 2018 A&A, 616, A48: *"The host galaxy of the short GRB111117A at z=2.211: impact on the short GRB redshift distribution and progenitor channels"*

L. Izzo et al., 2018 accepted for publication in Nature: *"Jet cocoon signatures in the early spectra of a gamma-ray burst/supernova"*

Watson et al., 2018 submitted for publication in Nature: *"Discovery of neutron-capture elements in a neutron star merger'*

B.P. Abbott et al., 2017 ApJL, 848, 12: *"Multi-messenger Observations of a Binary Neutron Star Merger"*

E. Pian et al., 2017 Nature, 551, 67: *"Spectroscopic identification of r-process nucleosynthesis in a double neutron-star merger"*

J. Anderson et al., 2018 A&A, 620, A67: *"A nearby superluminous supernova with a long pre-maximum 'plateau' and strong C ii features"*

B. D. Metzger, 2017, Living Rev Relativ 20, 3. *"Kilonovae"*

Siegel et al., 2018, arXiv:1810.00098. *"The neutron star merger GW170817 points to collapsars as the main r-process source"*

J. Barnes et al., 2018, ApJ, 860, 38. *"A GRB and Broad-lined Type Ic Supernova from a Single Central Engine"*

11. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	SN2017iuk	11 09 39.55	-12 35 17.9	1	J=24		Superposed on a spiral galaxy	
B	SN2017iuk	11 09 39.55	-12 35 17.9	5	J=24		Superposed on a spiral galaxy	

Target Notes: All the time will be used to observe the fading SN2017iuk.

12. Scheduling requirements

13. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
102	XSHOOTER	B	300-2500nm	SLT
102	XSHOOTER	B	SLT	1.0,0.9,0.9JH
102	XSHOOTER	B	SLT	100k-1x2,100k-1x2 VIS,NDR
102	HAWKI	A	IMG	J

6b. Investigators:

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D. J.	Watson	14042
M.	Killi	14042
D.	Malesani	14042
J. P. U.	Fynbo	14042
J.	Bolmer	1261
P.	Schady	1496
D. A.	Kann	1392
L.	Izzo	1392
D. M.	Siegel	1215
J.	Barnes	1213
B.	Metzger	1214