Onsala Proposal

Ramakrishnan 0108.F-9325

Constraining the accretion physics from the sub-millimetre upturn in low-luminosity AGN

Semester: may2021 **Science Cat.: External galaxies**

Abstract

We can leverage the transformational EHT results on Sgr A* and M87 to explore a larger sample of nearby
galaxies (thus larger parameter space of SMBH mass, spin, accretion rate, jet power, morphology, and orientation). In order to improve our understanding of the physics of, and around, BHs we have constructed
the 'EHT+Sample' as follows (Sgr A* and M 87 are excluded as they are already EHT key targets). This sample also offers the potential of resolving additional black hole shadows/rings, orbiting hot-spots in the
accretion inflow, and jet launching regions.

We thus request multi-frequency flux density measurements of a sample of 10 LLAGNs in order to constrain their accretion physics based on the disk+jet modelling. A dedicated modelling of the radio to X-ray spectra can help to better understand the relation between extended and compact emission and its relation to the accretion properties. In addition to seeking VLBI observations of the potential sources obtained from this study, we will also try to obtain the optical and X-ray fluxes using other facilities.

Applicants

Name	Affiliation	Email	Country		Potential observer
Venkatessh Ramakrishnan	Universidad de Concepcion (Astronomy)	vramakrishnan@udec.cl	Chile	Pi	Yes
Violette Impellizzeri	Leiden University	violette@strw.leidenuniv.nl	Netherlands		
Chi Kwan Chan	University of Arizona	chanc@arizona.edu	United States		

Contact Author

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Phone(second)		***City***	
Fax		***State***	
		Country	Chile

Is this a long term proposal: No

No overall scheduling requirements

Observing runs

run	telescope	instrument	time request (minimal)	frequency (GHz)	weather (pwv)	LST range	comments/constraints
A	APEX	SEPIA180 (159-211 GHz)	30h (30h)	177	any		Due to 183 GHz H2O maser line studies, the frequency will be tailored such that the USB corresponds to 183 GHz in the source frame.
B	APEX	SEPIA345 (277-371 GHz)	3h (3h)	351	0.5-1 mm		
C	APEX	SEPIA660 (581-727 GHz)	10h (10h)	697	< 0.5mm		

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
Mrk1419	09:40:36.38	+03:34:37.0	J2000	4923.0	14	B	
M87	12:30:49.42	+12:23:28.0	J2000	1288.0	180	A	
NGC4552	12:35:39.81	+12:33:22.8	J2000	345.0	14	B	
NGC4278	12:20:06.83	+29:16:50.7	J2000	626.0	55	C	
NGC4945	13:05:27.28	-49:28:04.4	J2000	558.0	55	C	
Circinus	14:13:09.90	-65:20:21.0	J2000	429.0	55	C	
CenA	13:25:27.62	-43:01:08.8	J2000	545.0	180	A	
NGC4945	13:05:27.28	-49:28:04.4	J2000	558.0	180	A	
M87	12:30:49.42	+12:23:28.0	J2000	1288.0	55	C	
NGC5077	13:19:31.67	-12:39:25.1	J2000	2809.0	180	A	
Circinus	14:13:09.90	-65:20:21.0	J2000	429.0	180	A	
NGC1068	02:42:40.77	-00:00:47.8	J2000	1126.0	14	B	
CenA	13:25:27.62	-43:01:08.8	J2000	545.0	55	C	
Circinus	14:13:09.90	-65:20:21.0	J2000	429.0	14	B	
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NGC1068	02:42:40.77	-00:00:47.8	J2000	1126.0	55	C	
NGC1052	02:41:04.80	-08:15:20.8	J2000	1498.0	55	C	
NGC5077	13:19:31.67	-12:39:25.1	J2000	2809.0	14	B	
NGC1052	02:41:04.80	-08:15:20.8	J2000	1498.0	180	A	
Mrk1419	09:40:36.38	+03:34:37.0	J2000	4923.0	55	C	

Targets are continued on the last page

Scientific Rationale

There is strong evidence that Supermassive black holes (SMBHs; $\sim 10^5 - 10^{10}\ M_{\odot}$) are present in most galaxies, and their mass is typically 0.5% of the host galaxy bulge (e.g., Saglia et al., 2016), i.e., the evolution of a galaxy and its SMBH is coeval, and an AGN phase(s) is an integral part of galaxy evolution. Nevertheless, it is important to note that the 'massive compact dark objects' traced in kinematic studies (which probe scales much larger than the Schwarzschild radius ($R_{Sch} = 2GM_{SMBH}/c^2$) or Gravitational radius ($R_g = 0.5{*}R_{Sch}$) are presumed to be SMBHs only due to the lack of other viable explanations within known physics (e.g., Narayan & McClintock, 2013; Broderick et al., 2015). The Event Horizon Telescope (EHT) results on M87 (Event Horizon Telescope Collaboration et al., 2019) now directly and almost unequivocally provide evidence for the existence of at least one SMBH.

In an AGN toy-model, the SMBH is surrounded by an optically-thick geometrically-thin accretion disk (few tens to few thousands R_g) and/or a quasi-spherical accretion inflow in the innermost tens of R_g (e.g., Narayan, 1996). SMBHs appear to care more about their accretion rate relative to the Eddington limit rather than their mass; like X-ray binaries, they have 'hard' or 'soft' states (Yuan & Narayan, 2014). The former state has high accretion rates relative to Eddington and the emission is primarily dominated by the accretion disk and BLR/NLR (e.g. Seyfert galaxies). The latter (low-luminosity AGNs or LLAGNs) has low Eddington accretion rates, puffed up inner accretion disks and radio jets. LLAGN accretion flows have been modelled with radiatively inefficient accretion flows (RIAFs), jets, or both (e.g., Narayan, 1996; Markoff et al., 2007; Event Horizon Telescope Collaboration et al., 2019).

Some of the most potential emission-related processes connected to the radiation at sub-millimetre wavelengths are:

Synchrotron self-absorption: In the case of a synchrotron jet, its self-absorbed radio emission potentially contributes to the millimetre excess if the jet is still very compact due to being embedded in a very dense environment at the nuclear region of the galaxy. Synchrotron self-absorption makes a power-law spectrum convex by absorption at lower frequencies.

Synchrotron from accretion flow: Both X-ray emission with a cut-off at ~ 100 keV and an inverted radio spectrum can be produced by hot accretion flow, such as the RIAFs. The model advection-dominated accretion flow (ADAF; Narayan & Yi, 1994), takes into account the thermal synchrotron process in radio, which can explain SEDs of low-luminosity AGNs with low accretion rates. On the other hand, many observations of nearby AGNs indicate that radio luminosities are roughly an order of magnitude greater than those predicted by the ADAF model; more efficient (thermal) synchrotron emission from a jet base, which may correspond to a steady jet in X-ray binaries in the low/hard state, may additionally contribute to the observed radio luminosities.

Synchrotron from disk corona: Inoue & Doi (2014) presented that the synchrotron from non-thermal electrons in coronae above the accretion disks of nearby Seyfert galaxies is potentially detectable at the sub-millimetre regime using the APEX sensitivities. A strong correlation is known to exist between the quiescent radio and X-ray emission in coronally active cool stars. AGNs might also mimic the property, if the same mechanism magnetically heats coronae above accretion disks.

Objectives: We can leverage the transformational EHT results on Sgr A* and M87 to explore a larger sample of nearby galaxies (thus larger parameter space of SMBH mass, spin, accretion rate, jet power, morphology, and orientation). In order to improve our understanding of the physics of, and around, BHs we have constructed the 'EHT+Sample' as follows (Sgr A* and M 87 are excluded as they are already EHT key targets). This sample also offers the potential of resolving additional black hole shadows/rings, orbiting hot-spots in the accretion inflow, and jet launching regions.

We thus request multi-frequency flux density measurements of a sample of 10 LLAGNs in order to constrain their accretion physics based on the disk+jet modelling. A dedicated modelling of the radio to X-ray spectra can help to better understand the relation between extended and compact emission and its relation to the accretion properties. In addition to seeking VLBI observations of the potential sources obtained from this study, we will also try to obtain the optical and X-ray fluxes using LCO and Chandra facilities.

We also intend to undertake a pilot survey of the 183 GHz H2O line in proposed galaxies. The potential discovery of the submillimetre H2O disk-maser will open up unique possibilities to probe the nature of the central region of galaxies to constrain the masses of the supermassive black holes. If the presence of the line is confirmed it will open new opportunities of conducting a survey of a larger sample of such submillimetre maser disks at different redshifts with the APEX and ALMA. This might have profound implications for our understanding of both cosmology (constraining cosmological models) and the physics of SMBHs in the near future.

Facilities Requested

We request APEX observations using the SEPIA receivers 180, 345 and 660 to constrain the accretion and jet physics in a sample of nearby active galaxies.

Observing Requirements

We have used the ON-OFF observing time calculator at APEX V7.3 to estimate the total time needed to achieve our goal. We request a tuning frequency of 183 GHz in the USB, 345 and 691 GHz in the LSB for the three SEPIA receivers. The sensitivity and resolution of APEX at respective frequencies is sufficient to constrain the continuum emission to be nuclear in these active galaxies. We require modest SNR observations that allows us to robustly constrain the accretion/jet physics using our models. Using SEPIA180 tuned to 183 GHz in the USB, selecting a spectral resolution of 20 km/s and assuming a typical source elevation of 60 deg and a typical PWV of 2.0 mm, we could get down to a noise of 450 mK[Ta*] in 2.9 hours (including telescope and calibration overheads). Using SEPIA345 tuned to 345 GHz in the LSB, selecting a spectral resolution of 20 km/s and assuming a typical source elevation of 45 deg and a typical PWV of 1.0 mm, we could get down to a noise of 5 mK[Ta*] in 13.5 minutes (including telescope and calibration overheads). Using SEPIA660 tuned to 691 GHz in the LSB, selecting a spectral resolution of 20 km/s and assuming a typical source elevation of 45 deg and a typical PWV of 0.5 mm, we could get down to a noise of 5 mK[Ta*] in 55.2 minutes (including telescope and calibration overheads). Thus, in total it amounts to 41.5 hours for the entire sample with 10 sources. We add another 30-minutes per frequency for technical setup extending the total time request to 43 hours.

Scheduling Requirements

Since switching frequencies takes up a bulk of the overheads, we request observations at a given frequency for all sources before switching to another band. The source can be scheduled during any day of the semester.

References: • Broderick, A. E., et al. 2015, ApJ **805**, 179. • Davelaar, J., et al. 2019, A&A **632**, A2. • Event Horizon Telescope Collaboration, et al. 2019, ApJ **875** (1), L1. • Humphreys, E. M. L., et al. 2016, A&A **592**, L13. • Inoue, Y., Doi, A. 2014, PASJ **66**, L8. • Markoff, S., et al. 2007, MNRAS **379**, 1519. • Narayan, R. 1996, ApJ **462**, 136. • Narayan, R., McClintock, J. E. 2013, *ArXiv e-prints* . • Narayan, R., Yi, I. 1994, ApJ **428**, L13. • Saglia, R. P., et al. 2016, ApJ **818** (1), 47. • van den Bosch, R. C. E. 2016, ApJ **831**, 134. • Yuan, F., Narayan, R. 2014, ARA&A **52**, 529.

Figures

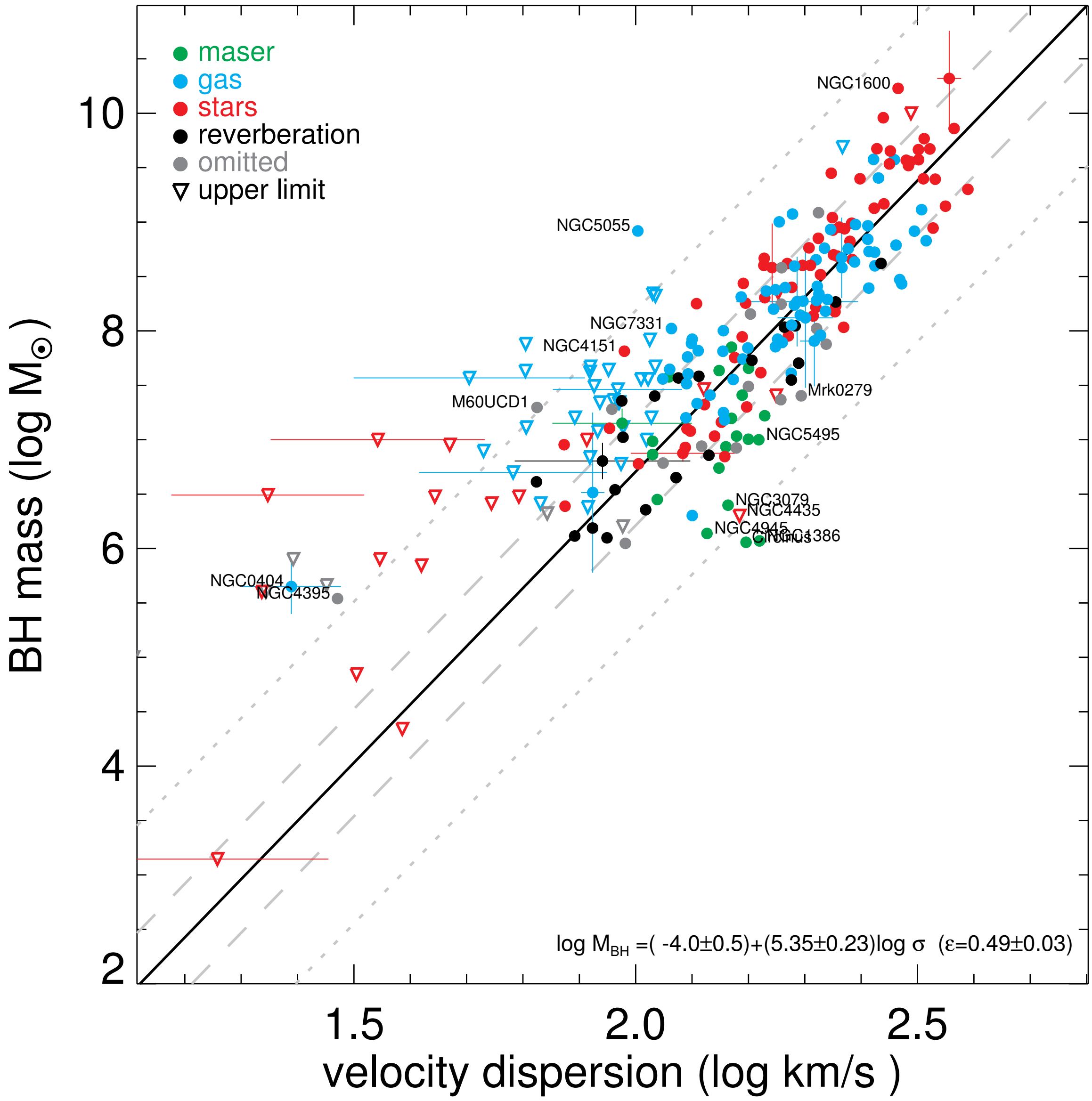

Figure 1: Black hole mass vs Velocity dispersion relation as reported in van den Bosch (2016). The sparsity of maser-detected galaxies can be noticed demanding for more high-sensitive surveys. Masers can provide a better estimate of the mass of the SMBH owing to their remarkable sensitivity and will help in improving the systematics of all sources in the plane shown here.

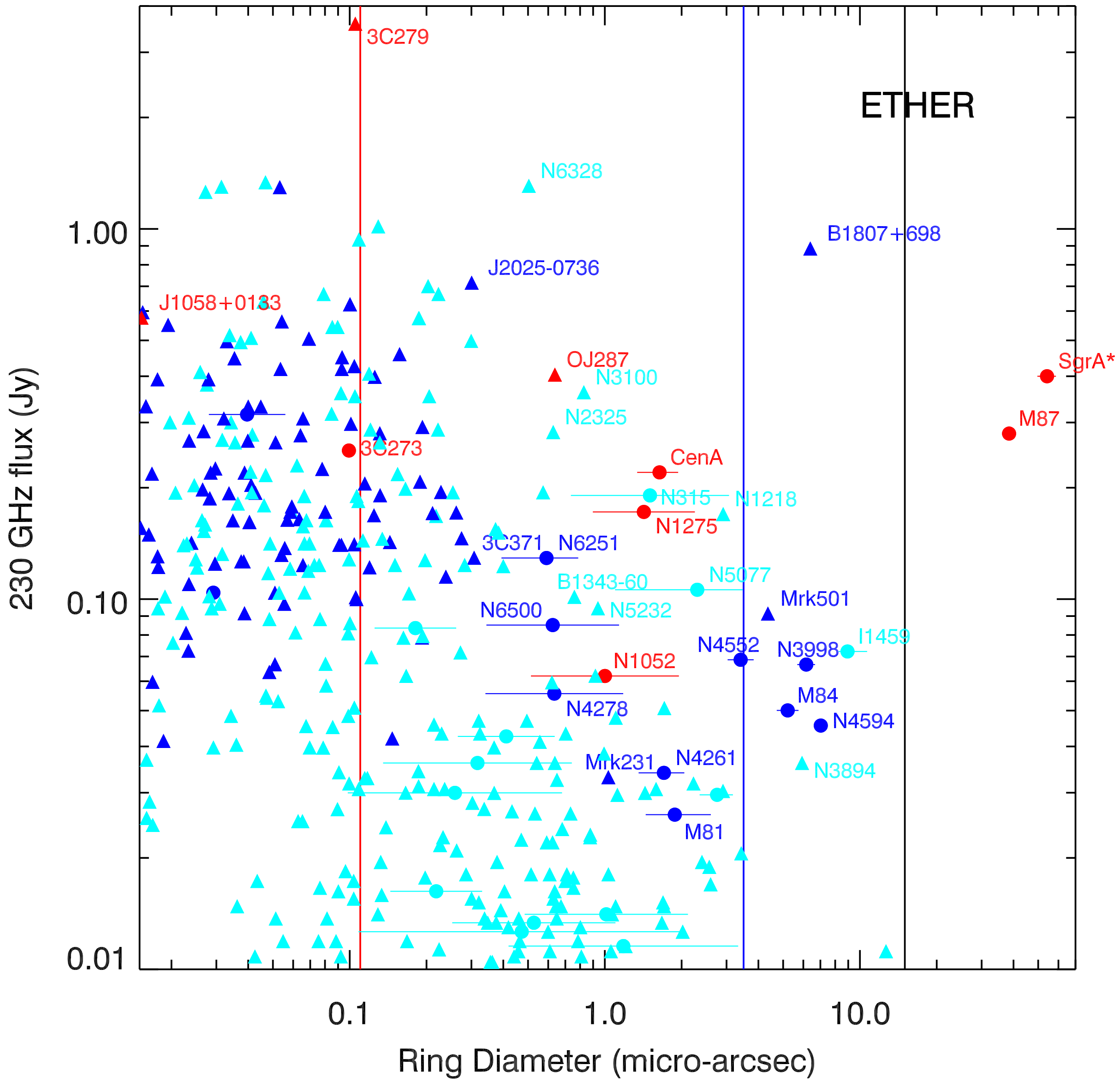

Figure 2: Expected mas-scale 230 GHz peak flux (Jansky) versus ring size (in units of the nominal 22μarcsec resolution of the EHT). The current EHT, 345 GHz EHT, and geostationary orbit to ground EHT, will resolve the rings in galaxies to the left of the red, blue, and green lines, respectively. Red symbols denote galaxies already observed with the EHT and filled symbols denote galaxies previously detected with 43GHz VLBA or GMVA. We propose for those 10 southern sources with a higher ring diameter from this image.

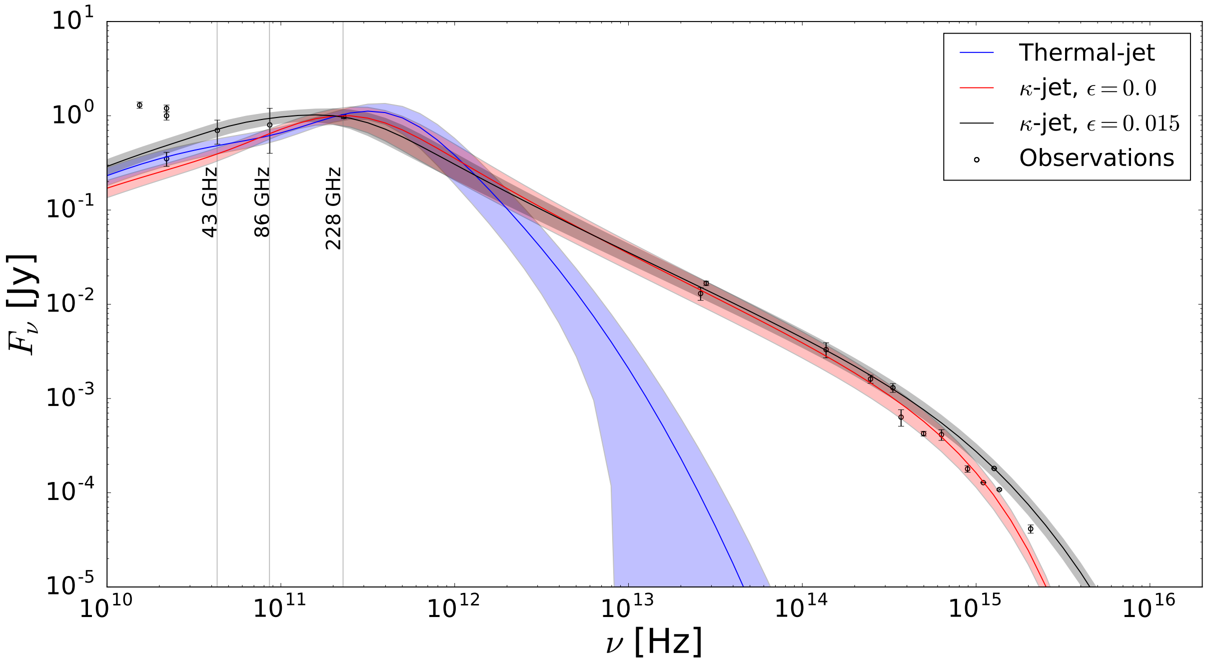

Figure 3: Broadband spectral energy distribution of M87 as reported in Davelaar et al. (2019). Different particle acceleration processes are denoted by lines of different colours. The lack of sub-millimetre fluxes for this source makes constraining the acceleration processes closer to the event horizon difficult. A similar modelling approach will be employed for all sources proposed here.

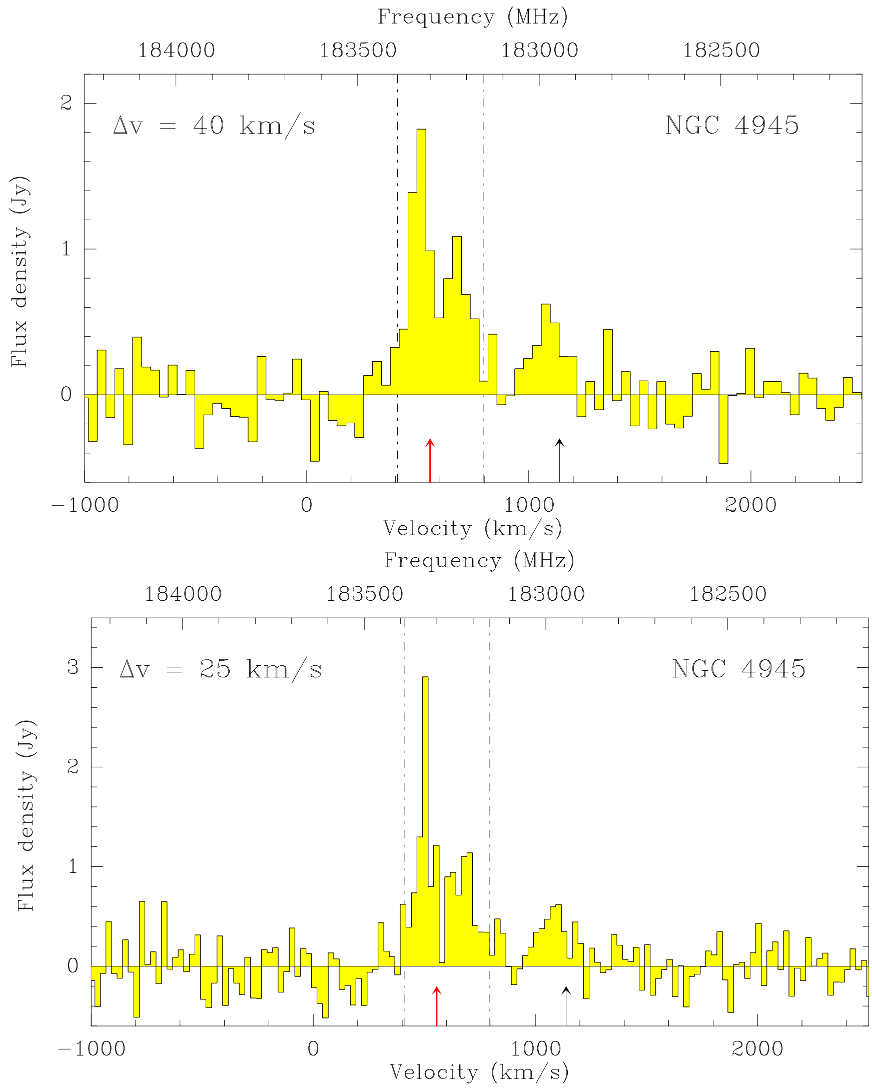

Figure 4: 183 GHz H2O line in NGC 4945 as reported in Humphreys et al. (2016). The prominence of this line allows one to use masers to constrain the black hole masses to a superior precision. We are interested to probe the variability of the line which can be attributed to the accretion process. Hence the interest to re-propose this target again in this proposal.

No PhD Students involved

Linked proposal submitted to this TAC: No

Linked proposal submitted to other TACs: No

Relevant previous Allocations: Yes

096.F-9312(A), 3hours, https://ui.adsabs.harvard.edu/abs/2016A%26A...592L..13H/abstract

Additional remarks

ESO=venkatessh

Observing run info :

Run: C backup strategy: Preference is given to weather <0.5mm but can also be executed during 0.5-1 mm conditions.

Targets

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