Astrophysical Phenomena Revealed by Space VLBI
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The Proposed ARISE Space-VLBI Mission

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Abstract

ARISE is an antenna dedicated to space-VLBI that has been proposed to NASA as a mission for the future. The basic design is for a sensitive antenna that can observe at frequencies as high as 86 GHz. The apogee of the orbit is envisioned to be about 40,000 km in order to provide angular resolution as fine as 6 μarcsec (FWHM of longest baseline at 86 GHz). The main objective is to observe the jets of blazars as close to the central engine as possible and to measure the properties of water masers for $\sim$ 20 active galactic nuclei in order to extract information about the central massive black holes. Other possible observations include studies of intraday variability, gravitational lenses, and the regions of X-ray and γ-ray emission in blazars.

1 Introduction

HALCA has shown that VLBI with space-based antennas is possible. Indeed, the similarity of the 5 GHz *VSOP* images with 15 and 22 GHz VBLA images is a measure of the high fidelity of the former. Now that it is clear that space-VLBI can work, it is time to design new missions that extend to higher frequencies and higher orbits, leading to a quantum jump in resolution.

The *ARISE* space-VLBI mission has been proposed to NASA. The principal investigator is James Ulvestad of the National Radio Astronomy Observatory, while Arthur Chmielewski of the Jet Propulsion Laboratory is the project engineer. The author is the chair of a large international *ad hoc* scientific advisory group.

In this short contribution, the author will describe briefly the characteristics of *ARISE* and the scientific studies that it will enable, if the mission is mounted. More details of the ARISE mission are available from http://arise.jpl.nasa.gov/ .

2 Characteristics of *ARISE*

The original design calls for an inflatable antenna with a diameter of 25 m. Since inflatable space antennas represent new, perhaps risky technology, and since it is not clear whether such an antenna could be made smooth enough to observe with high efficiency at 86 GHz, an alternate plan is to use a smaller (12–15 m) rigid antenna. In order to maintain high sensitivity, the data rate would need to be 1 to 8 Gbits s^{-1} and the system temperatures would need to be very low, 10–40 K. The receivers would be polarization-capable. The mission could be launched as early as 2008, with a nominal lifetime of 3 years.

The orbit of *ARISE* would likely be highly elliptical in order to cause precession driven by close encounters with the slightly non-spherical Earth. Such precession would allow various regions of the sky to be observed at maximum angular resolution from one several-month period to the next. The proposed apogee is about 40,000 km, which would give maximum baselines of about 50,000 km with Earth-based antennas. This would provide angular resolutions corresponding to the FWHM of the uniformly-weighted beam of 15 and 30 μarcsec at 86 and 43 GHz, respectively — about 5 times finer than with ground-based arrays. The FWHM resolution of the longest baseline would be $\sim$ 2.5 times finer still, or about 6 μarcsec at 86 GHz. The lower frequencies that would be made available on *ARISE* are the subject of debate at the present time.

There are many technical aspects that need to be worked out, such as how to get the high data rates and how to secure a sufficient number of ground stations for data transmission.

3 Scientific Studies with *ARISE*

The cores of blazar jets remain essentially unresolved even at 22 and 43 GHz with the VLBA (see Figure 1 and Marscher et al., these proceedings). Yet, above 30–80 GHz, the cores of most blazars become optically thin. With significantly finer resolution — as would be provided by *ARISE* — we could image the cores at 43 and 86 GHz in order to resolve the cores in both total and polarized intensity. Furthermore, the X-ray and γ-ray emitting regions of the jet are directly associated with radio flares and ejections of superluminal components (Marscher et al. and Marchenko-Jorstad et al., these proceedings). The angular resolution of arrays including *ARISE* will probably be sufficient to ex-

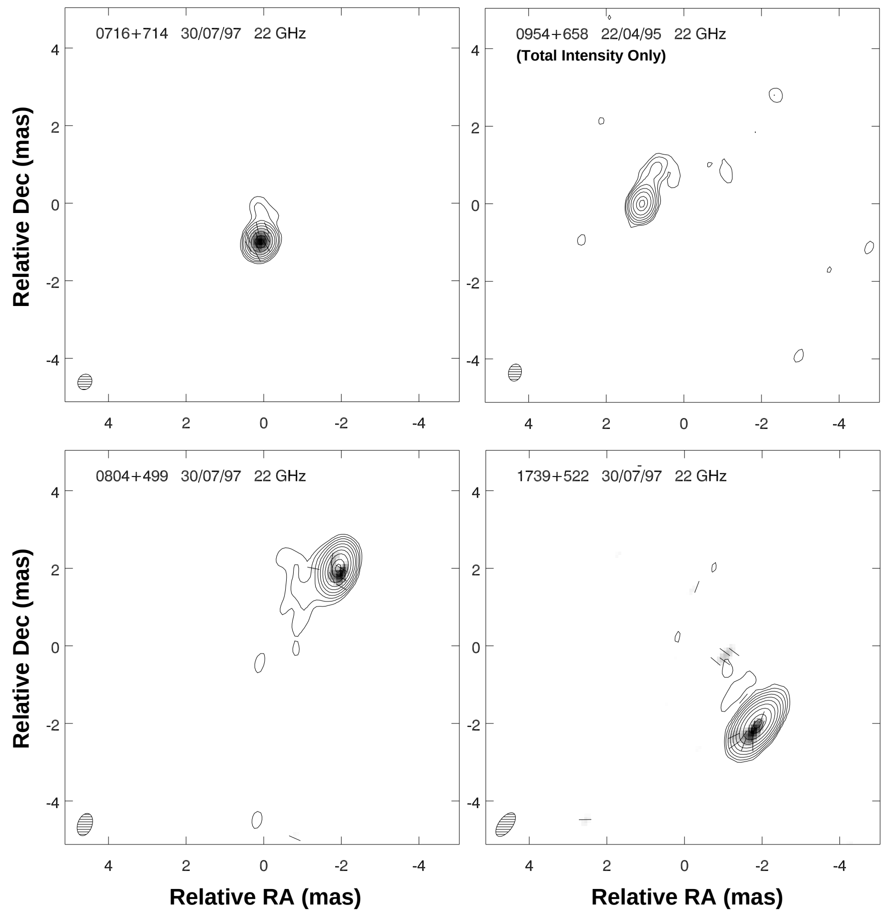

Figure 1: VLBA images of 4 γ-ray bright, intraday variable blazars at 22 GHz. Even at these high resolutions, the cores are essentially unresolved. The contours correspond to factors of 2 in total intensity, with the highest at 64%. The gray-scale shows polarized intensity, while the lines indicate the direction of the electric vectors. The maximum total intensities in Jy beam^{-1} (fractional polarizations of the cores) are: 0716+714: 1.01 (6.2%); 0804+499: 1.10 (0.5%); 0954+658: 0.57 (total intensity only); 1739+522: 1.58 (1.7%).

plore these high-energy emitting regions in blazar jets. This would be particularly valuable if simultaneous monitoring observations coulds be carried out with γ-ray and X-ray satellites.

The highest brightness temperature of a source that could be resolved by arrays that include *ARISE* $\sim 5 \times 10^{13}$ K. It must be stressed that this would be an *observed* brightness temperature, not simply inferred from variability timescales. Any sources with brightness temperatures this high would require Doppler beaming factors $\gtrsim 170(1+z)$ in order to be consistent with the inverse Compton limit of incoherent synchrotron radiation, where z is the redshift of the source. *ARISE* would therefore measure the range of brightness temperatures expected from intraday variables (IDVs), confirming whether they require extremely high Doppler factors or other emission models besides incoherent synchrotron radiation. Figure 1 presents high-frequency VLBA images of 4 IDVs, all of which are extremely core-dominated.

Studies of the motions of water megamasers in the outer accretion disks of relatively nearby active galactic nuclei (AGN) such as NGC 4258 can be used to determine the masses of the central black holes thought to power the nuclear activity. The higher resolution made possible by *ARISE* will allow ~ 20 of such systems to be studied at larger distances than is now possible.

Gravitational lenses provide effective resolution of background quasars that can be finer than 1 μarcsec, since the images are magnified by the lenses. Other studies include observations of high-redshift quasars and radio supernova remnants, which would be optimized if 5 and even 1.4 GHz receivers were to be included on *ARISE*.

4 Conclusion

If and when *ARISE* becomes operational, it will revolutionize our ability to image and understand the jets of blazars. Furthermore, it will open up about an order of magnitude of parameter space that will likely lead to unexpected discoveries. On the other hand, as our experience with *VSOP* has taught us, the image quality is not optimized when there is only one remote antenna. It is the author's wish that one or two other antennas — such as *VSOP-2* — could be in orbit at the same time and be included in the same arrays as *ARISE* so that truly magnificent ultra-fine resolution images could be made of cosmic compact radio sources.