The structure and propagation of the misaligned jet M87

Blazars through Sharp Multi-Wavelength Eyes, May 30 – June 3 2016, Malaga **Kazuhiro Hada (NAOJ)**

The structure and propagation of the misaligned jet M87

- 1. Brief overview of our M87 VLBI studies
 - Radio-gamma connection in 2012
 - Jet base imaging at 86GHz
 - HST-1 monitor with EVN/VLBA
- 2. M87 jet on parsec scales (more fresh)
 New VLBA+Y27 imaging at 15GHz
- 3. New VLBI facility KaVA

Blazars through Sharp Multi-Wavelength Eyes, May 30 – June 3 2016, Malaga **Kazuhiro Hada (NAOJ)**

M87 as a misaligned blazar

- Nearby jet, large BH
 BH shadow, jet launching
- FR-I (⇔ BL Lac objects)
 - Viewing angle ~15-30°
- Similarities to blazars
 - Variable γ-rays, X-rays
 - SED
 - Superluminal HST-1





01 Oct 200

¢_{radio}[Jy]

o.:



A closer look at the jet base (Hada+2016, ApJ)



- Limb-brightening continuing down to z<30Rs
- Apparent opening angle >~100°
- Near side of the sheath pointing toward us at ~5°

HST-1 monitor: quick update

- Significant transverse motions after emergence
- Turnarounds
- Various βapp between 4c and 6c
- Likely 3D helical motions



M87 jet on pc scales:



An improved view of the transverse structure?

M87 in the context of the spine-sheath paradigm

VLBA 15GHz (Kovalev+) VLBA 43GHz (Walker+)

Limb-brightening of M87 jet may be puzzling

- HST-1 kinematics suggest a small viewing angle (<19°) for this jet
- Favors "the faster flow is more δ -boosted to us": δ (spine) > δ (sheath)
- Why we don't see any spine emission?

An even deeper jet image would be necessary

We have made a very deep VLBA observation at 15GHz in concert with the phased-VLA, 2Gbps

New 15GHz image (Nov/2015, uniform weight)

0.4 pc (projected)



15

10

- Uniform weight: 0
- Natural weight: 1.

A persistent triple-ridge structure







We start to see the spine in M87 !?

Ultra-narrow width (or opening angle), more straight, harder spectra, and stronger collimation efficiency

Maybe not easy to interpret the central ridge to be on the same layer of the outer sheath

Possible idea?

- the fast spine itself
- the boundary between the spine and the inner surface of the sheath



KaVA: The KVN and VERA Array

- The first international VL
- Form a single better perf
- As the "core array" of fut
- 22GHz, 43GHz so far
- Data correlation at KASI
- Regular scientific operati



KaVA



Official Logo? (under debate)

Current array performance

	KVN	VERA	KaVA
Num. of antenna	3	4	7
Num. of baseline	3	6	21
Baseline length shortest/longest [km]	305 / 476	1019 / 2270	305 / 2270
Angular resolution at K / Q [mas]	5.6 / 3.0	1.2 / 0.6	1.2 / 0.6
Polarization	LHCP/RHCP	LHCP	LHCP
Recording rate	1Gbps	1Gbps	1Gbps
1σ Baseline sensitivity at K [mJy]	6 (KVN-KVN)	11 (VERA-VERA)	8 (KVN-VERA)
1σ Baseline sensitivity at Q [mJy]	9 (KVN-KVN)	22 (VERA-VERA)	14 (KVN-VERA)
1σ Image sensitivity at K [mJy]	0.3	0.4	0.2
1σ Image sensitivity at Q [mJy]	0.5	0.8	0.3

Baseline sensitivity: 120 sec integration time Image sensitivity: 4 hr integration time Bandwidth of 256MHz assumed

What's nice (so far)

KaVA

Imaging capability

- Good uv-coverage, <1mas resolution
- Homogeneous antenna spec over the array

Monitoring capability, agility

- KaVA operates quasi-full year (except mid June-July)
- Monitor cadence of 1-2weeks or less OK
- ToO available if requested

<u>Quasi-simultaneous use of K/Q available</u>

Can switch frequency every < 1hr

Phase-referencing

Can go to low-power sources

Imaging perfo





Monitoring performance (Hada, Park+ in prep)



KaVA Large Program (2016 Feb~)

Exploring the vicinity of super-massive black hole with KaVA: Intensive monitoring of M87 and Sgr A*

M. Kino (KASI), B.W. Sohn (KASI) and KaVA AGN Sub Working Group* (* The member list is attached in the last page.)

Abstract

Exploring the vicinity of super-massive black holes (SMBHs) is one of the frontiers in astrophysics. Because of the largeness of angular-sizes of the central SMBHs, Sagittarius A* (Sgr A*) is the excellent laboratory for studying gas accretion process onto SMBH and M87 is well known as the best case for investigating plasma outflow ultimately driven by SMBH. To get better understanding of plasma inflow/outflow physics near SMBHs, here we propose the monitoring programs of Sgr A* and M87. This program is composed of following three sub-programs, i.e., (i) mapping the jet velocity field in M87 and constraining magnetically-driven-jet paradigm, and (ii) probing the nature accreting plasma onto SMBH by monitoring Sgr A*, and (iii) conducting quasi-simultaneous coherent observations of M87 and Sgr A* with the Event Horizon Telescope (EHT) during its campaign observation periods.

Quasi-full-year monitor of M87 at a cadence of (1-2) weeks (both at 22 & 43GHz)

- Map velocity field, test MHD acceleration
- Catch high-energy events
- Complement EHT observations

See also poster by Sohn Bong-Won

Ongoing improvement

• Wider bandwidth recording

- 2Gbps under commissioning
- Up to 4-8 Gbps planned

Polarimetry

- 22GHz: under commissioning with 3KVN + 2VERA stations
- 43GHz: system also installing now
- Array expansion (towards "EAVN")
 - Tianma 65m etc.

Website http://kava.kasi.re.kr/kava_main.php



Welcome to KaVA



KaVA(KVN and VERA Array) is a combined VLBI array with KVN (Korean VLBI Network) and VERA (VLBI Exploration of Radio Astrometry) operated by Korea Astronomy and Space Science Institute (KASI) and National Astronomical Observatory of Japan (NAOJ), respectively... More

Proposal 2016B

Dear Colleagues,

We invite proposals for the open use observations of the KaVA, a joint array of the KVN (Korean VLBI Network) and the VERA (VLBI exploration of Radio Astrometry). The joint array ...More

Large Programs

- ESTEMA (Expanded Study on Stellar Masers)
- Exploring the vicinity of super-massive black hole with KaVA: Intensive monitoring of M87 and Sgr A*
- Understanding high-mass star formation through KaVA observations of water and methanol masers

Latest array details, call for proposal, data analysis, observation&correlation status, user support, what's new etc.



Call for Proposal

Please submit both coversheet (CS) and scientific justification (SJ) files according to the following naming rules below.

Naming Example: CS_your-full-name.pdf, SJ_your-full-name.pdf

Sample download TEX format

Contact e-mail address : <u>kavaobs@kasi.re.kr</u>

You can input from UT 15:00 (KST 00:00) on Apr 18, 2016 to UT 08:00 (KST 17:00) on Jun 01, 2016 (Deadline)

User ID (Name)	You are not login!	
PDF file CS PDF file SJ	ファイルを選択 選択されていません ファイルを選択 選択されていません	
Comment		

- Twice/yr call for proposal
 - May & November. Now open to all astronomers in the world
- 22 & 43GHz, 1Gbps/256MHz BW, single pol.
- Phase-referencing with fast-nodding mode now available

Summary

- Recent progress on M87 VLBI studies
 - Radio-gamma connection 2012
 - Imaging the jet base at 10Rs resolution
 - A decade-long HST-1 monitor
 - Spine-sheath structure on parsec scales
- KaVA: new regularly-operating VLBI facility
 - Suitable for studying AGN jets (imaging, kinematics, light curves etc..)
 - Waiting for your proposals!
 - More collaboration with other wavelengths!







KASI/KJJVC





























Yama





6.7 GHz

8 GHz 22 GHz 43 GHz

The East-Asian VLBI Network















