High resolution – high frequency properties of relativistic jets in AGN.

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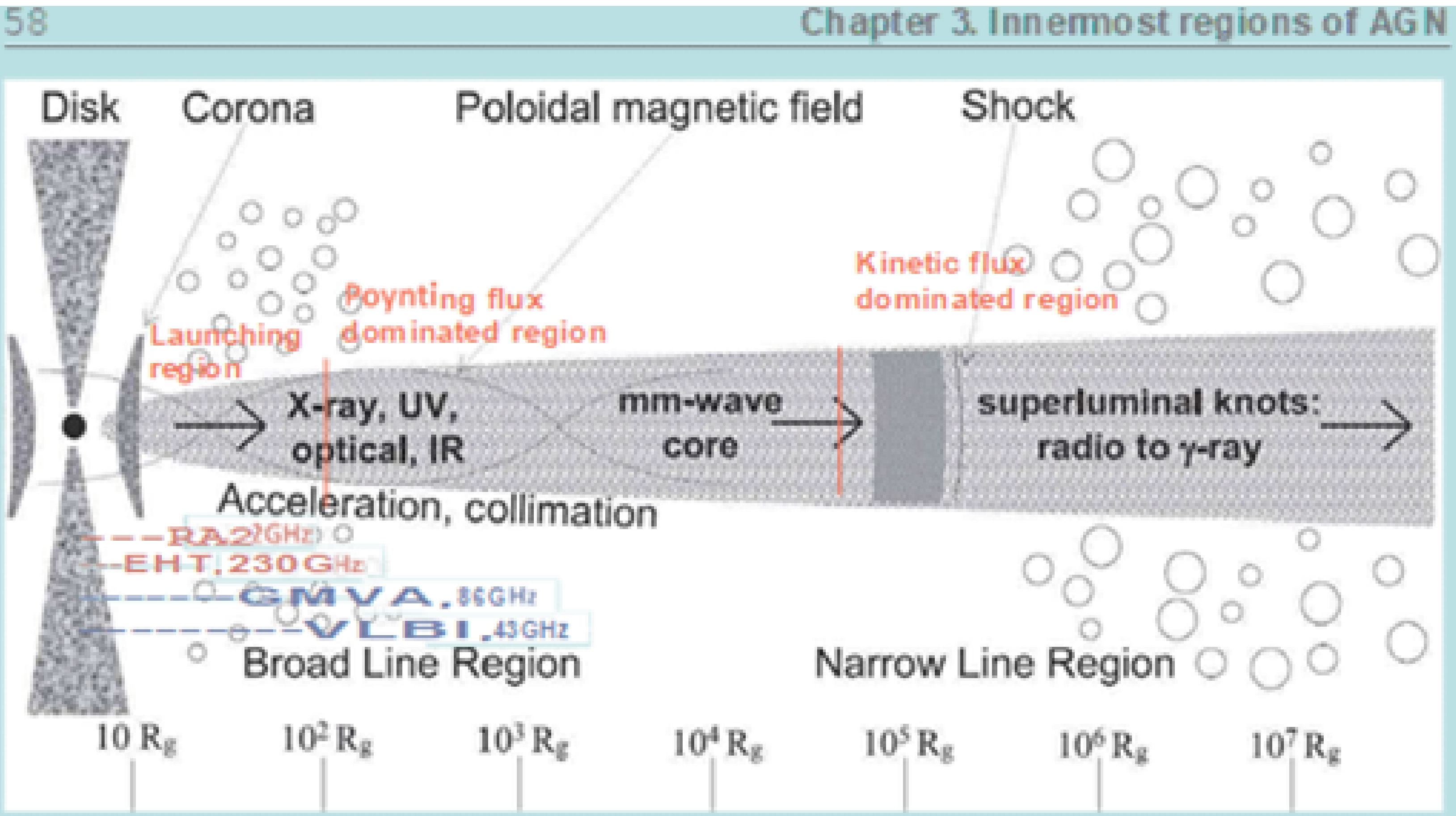
In recent years sensitivity VLBI imaging at high frequencies and high resolution has become possible.

Wide banding observing and more available telescopes provide important results on jet starting regions and jet properties



In nearby objects such as M87 global VLBI at 43 GHz can probe jet collimation and acceleration region.

Space VLBI (RA at 22 GHz) could resolve the jet launching region, however these observations could have opacity problems ➔

higher frequency as GMVA and EHT

At higher distances we need high frequency space VLBI for a better angular resolution

Available antennas operating at ≥ 86 GHz:
Effelsberg, Onsala, Pico Veleta, Yebes, Metsähovi (Finland), GBT (Green Bank T), GLT (Greenland T), LMT (Large MM T Mexico), SMT (Arizona), LLAMA (in Argentina), SPT (South Pole), …………

Available interferometer operating at ≥ 86 GHz:
KVN (Korean V Network), NOEMA (expanded PdB F), VLBA (NRAO, 8), ALMA, SMA (Mauna Kea), NMA (NAOJ), ……….

New: A simultaneous microwave compact Triple-Band receiving system to be installed on the three Italian radio telescopes (SRT-64m, Medicina and Noto-32+32m). The three cryogenic microwave receivers will operate simultaneously in the K / Q / W Bands (18 – 26 GHz, 34 – 50 GHz, 80 – 116 GHz).

New telescopes, e.g. in Thailand.

…………

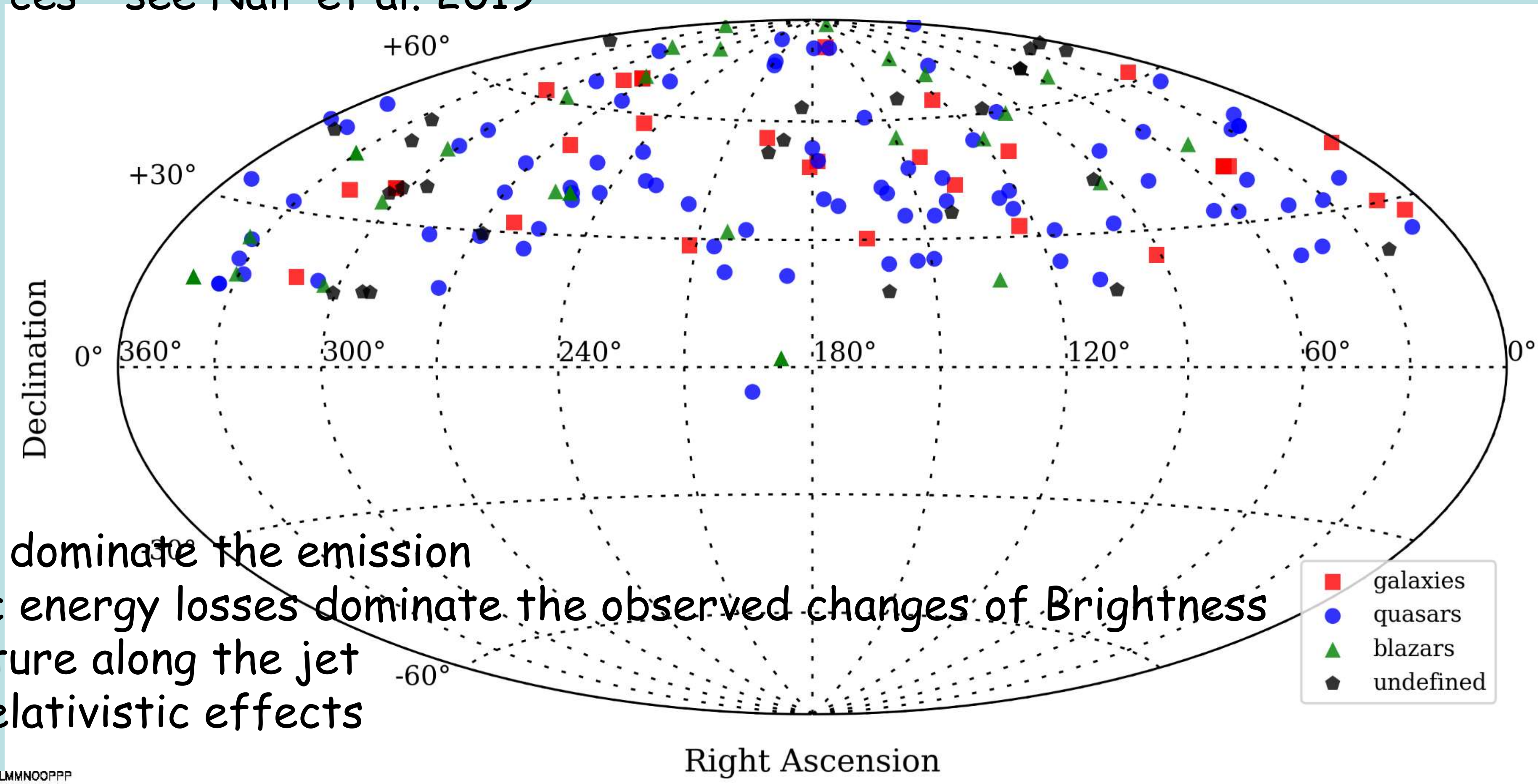
Observing **open sky** opportunities are present using the GMVA

The Global 3mm VLBI Array (GMVA) consists of 8 VLBA antennas equipped with 3mm receivers, the 100m GBT, the IRAM 30m telescope on Pico Veleta (Spain), the phased NOEMA interferometer on Plateau de Bure (France), the MPIfR 100m radio telescope in Effelsberg (Germany), the OSO 20m radio telescope at Onsala (Sweden), the 14m telescope in Metsähovi (Finland), and the OAN 40m telescope in Yebes (Spain).

In addition, telescopes of the Korean VLBI Network (KVN) and the Greenland Telescope (GLT) can be requested as part of the GMVA. Proposals which ask for ALMA as part of a GMVA observation must be submitted to the GMVA and in parallel to ALMA at their appropriate proposal deadline.

GMVA survey of ultracompact sources at 86 GHz

162 sources – see Nair et al. 2019

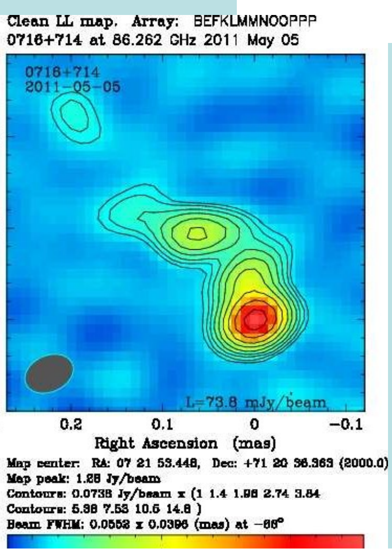


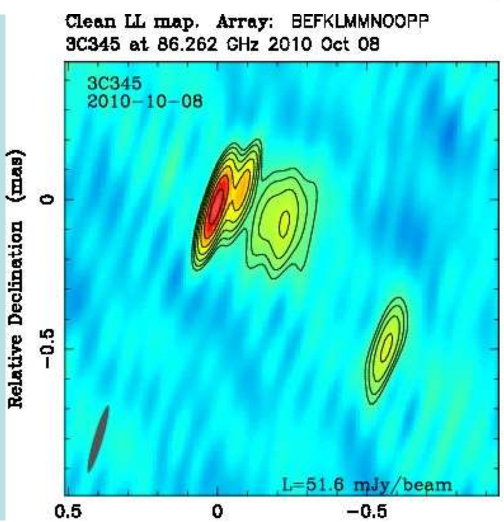
IC losses dominate the emission

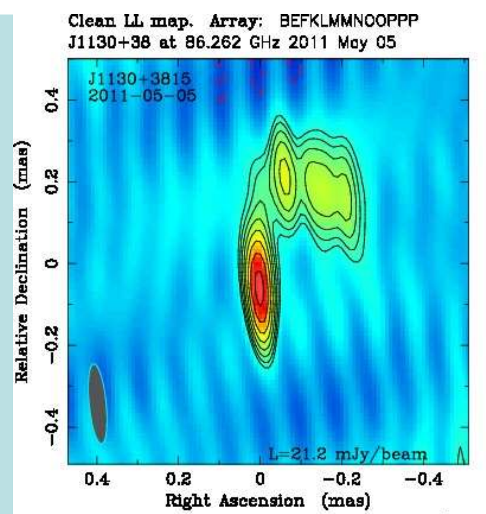
Adiabatic energy losses dominate the observed changes of Brightness

Temperature along the jet

Strong relativistic effects





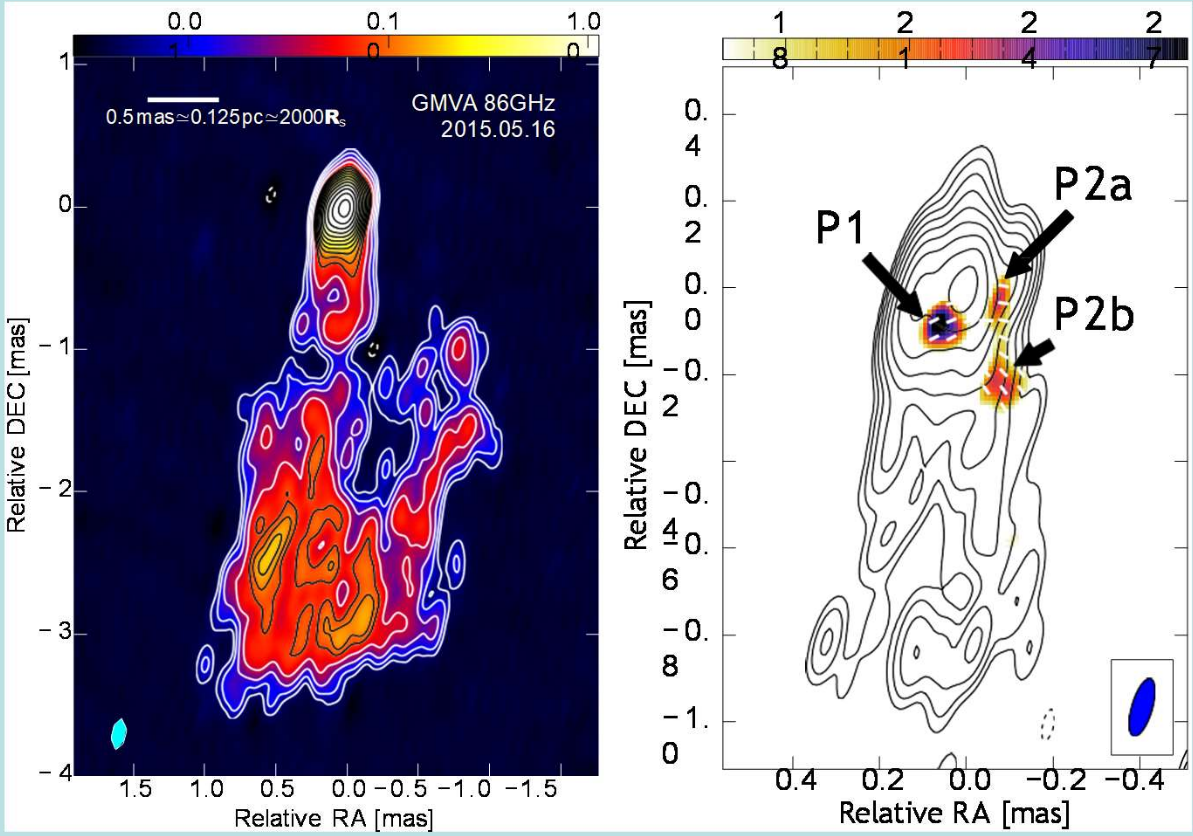


GMVA and Space VLBI

3C84 imaged with GMVA at 86 GHz, polarization mode.

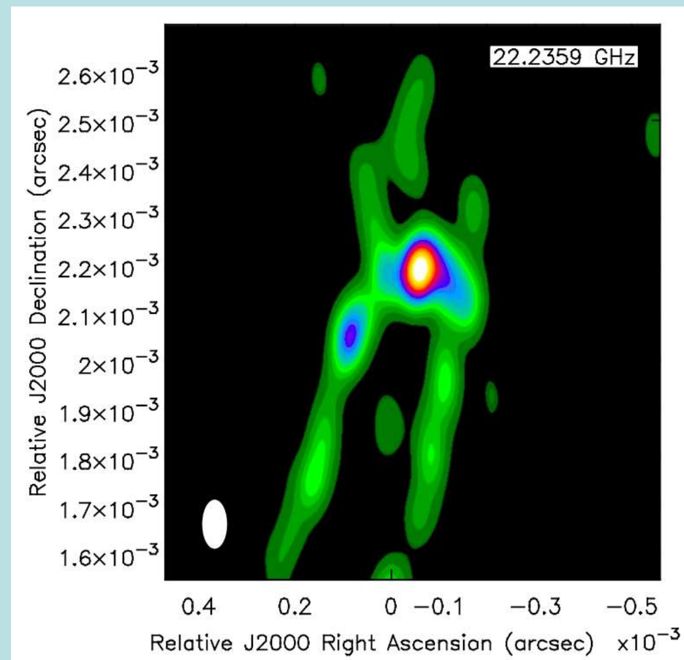
Angular resolution 140 x 50 μas

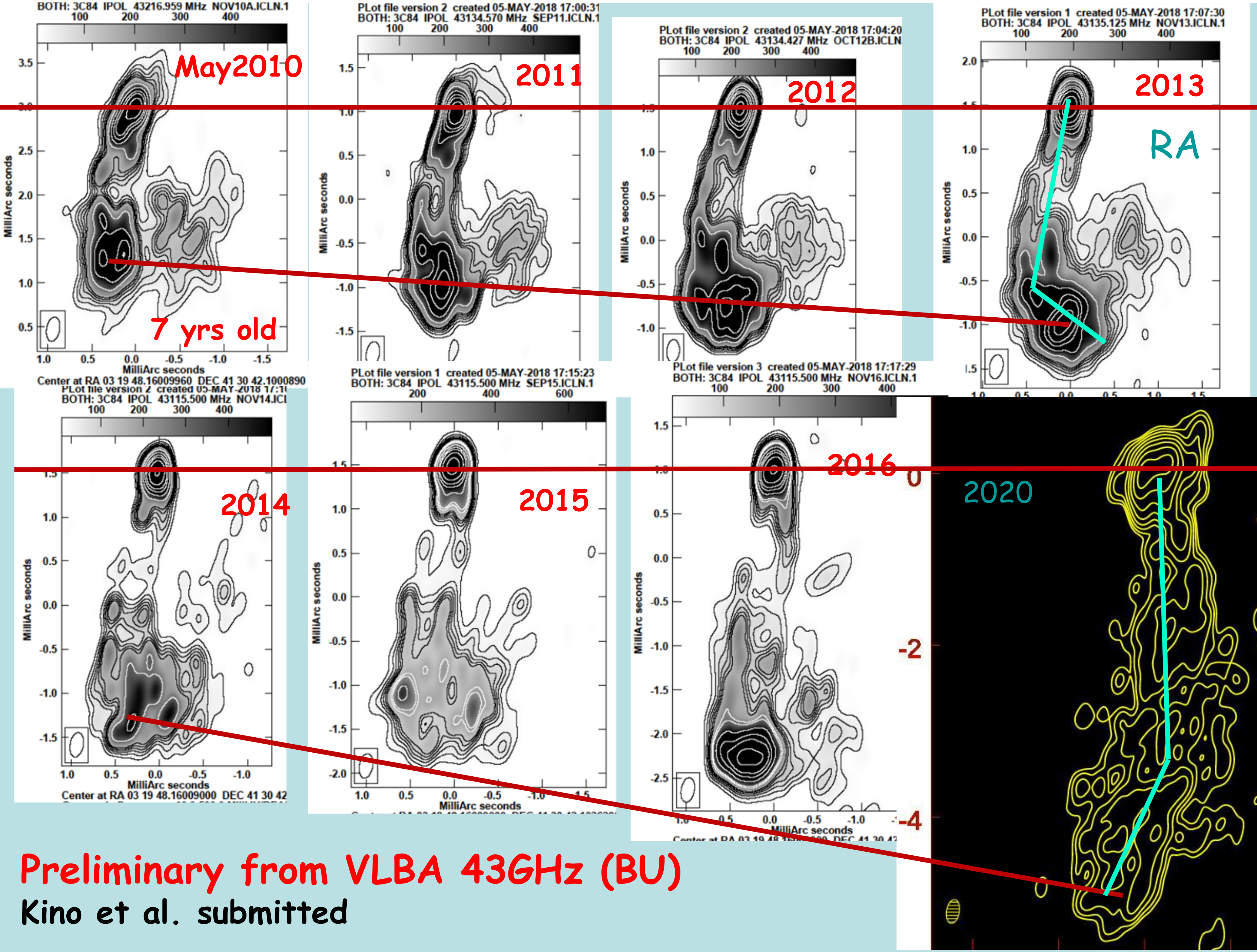
High RM caused by a boundary layer in a transversely stratified jey



RadioAstron image: 0.10 x 0.05 mas
Almost cylindrical jet profile
Transverse radius of about 250 rg at only 350rg from the core (deprojected)

➔ Very rapid espansion on scales < 100 rg
or it is launched from the accretion disk





Preliminary from VLBA 43GHz (BU)

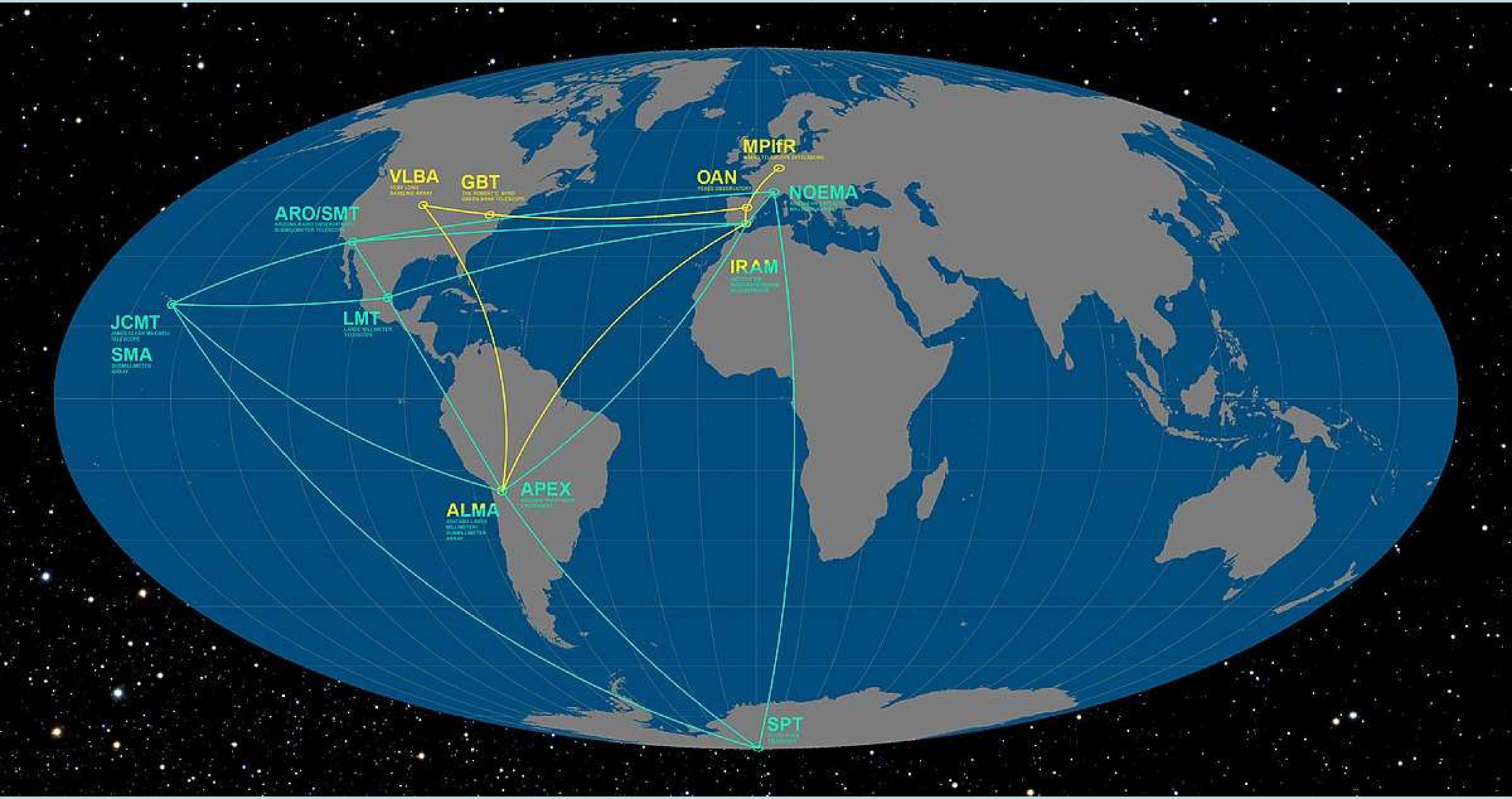
Kino et al. submitted

The **Event Horizon Telescope** is a 1.3 mm (230 GHz) VLBI array whose primary goal is to observe and image nearby supermassive black holes with sufficient angular resolution to resolve the hot material just outside the black hole event horizon.

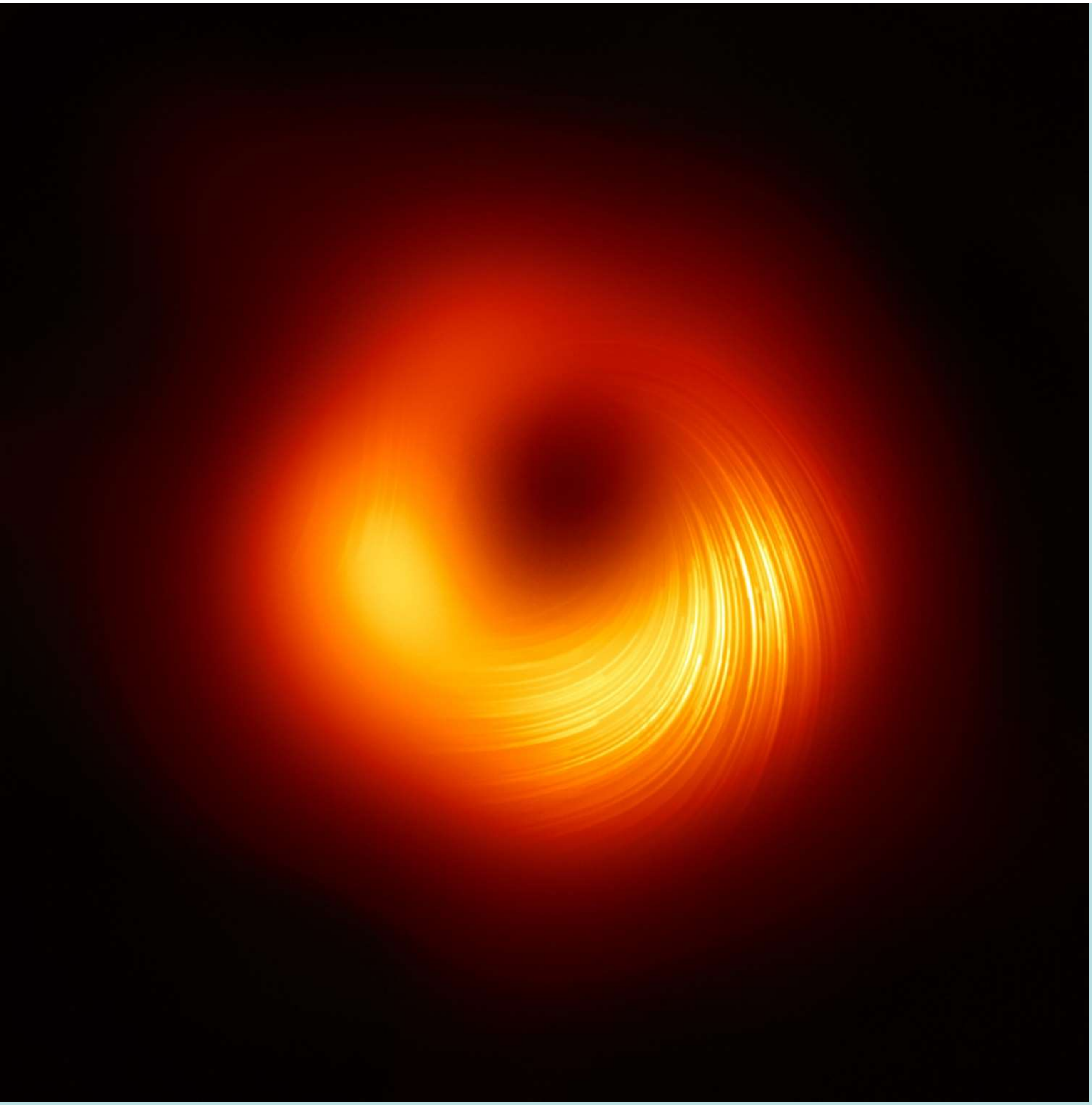
The EHT network currently consists of telescopes in Chile, France, Greenland, Mexico, the South Pole, and the USA (Arizona and Hawaii) that together provide a resolution of better than 30 microarcsec.

To provide the sensitivity required to observe sources at such fine detail, EHT partners have developed ultrawide-bandwidth instrumentation and correlation facilities capable of handling very high data rates.

Using ALMA as a phased array offers unprecedented sensitivity at very high angular resolution, making one order of magnitude weaker sources accessible to µas-resolution studies and greatly improving image fidelity for the brighter objects .



A map of the EHT. Stations active in 2017 and 2018 are shown with connecting lines and labeled in yellow, sites in commission are labeled in green.



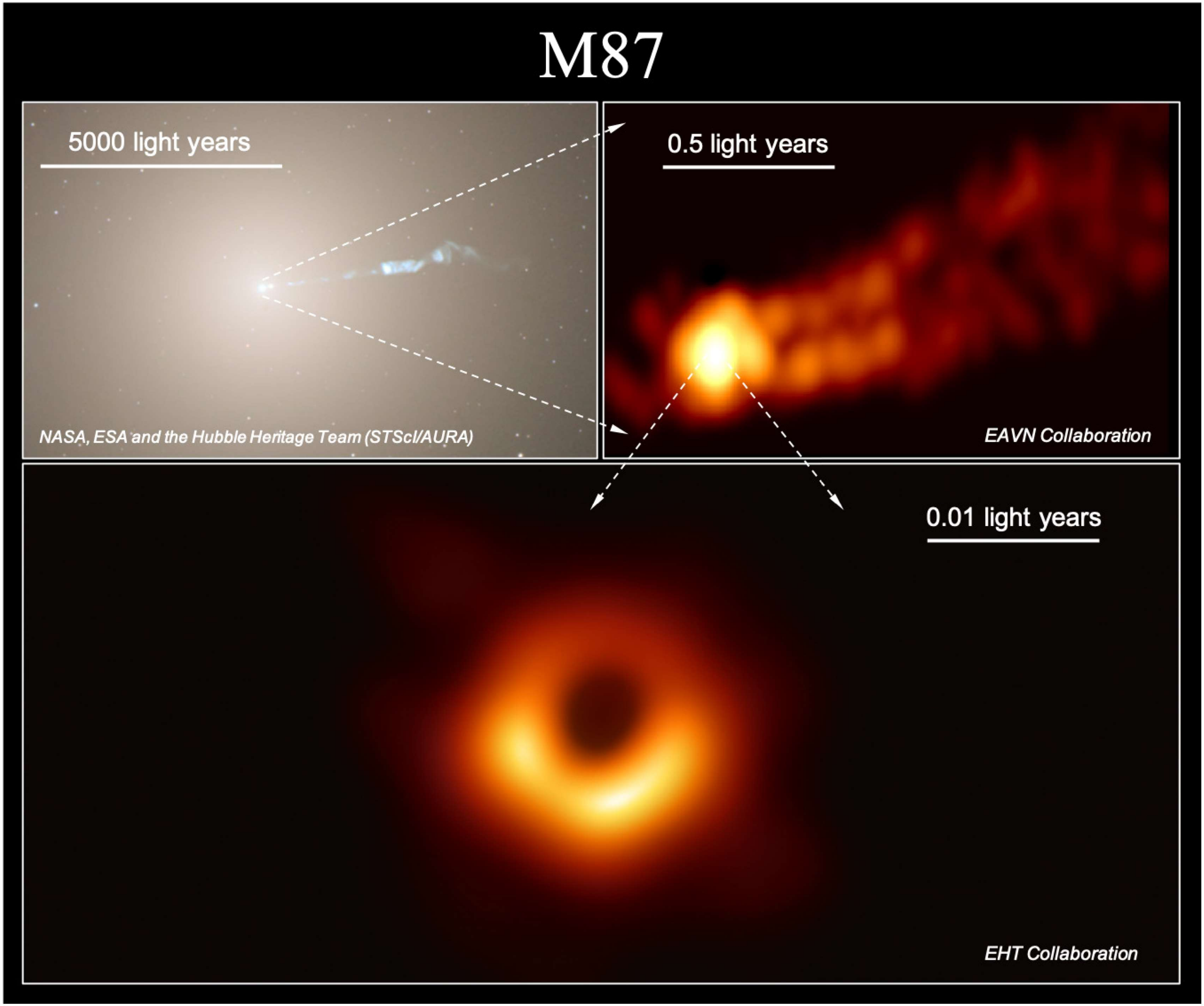
EHT produced resolved Polarized intensity maps in the near-horizon region around SMBH in M87.

Using this result with ALMA resuls at the same time, constrain accretion flow and jet models

From depolarization: n_e 10^{4-7} cm^{-3}; magnetic field B ~1-30 G

➔ Magnetic fields are dynamically important

EHT collaboration ApJ 910, L13 March 20, 2001


M87
5000 light years
NASA, ESA and the Hubble Heritage Team (STScI/AURA)
0.5 light years
EAVN Collaboration
0.01 light years
EHT Collaboration

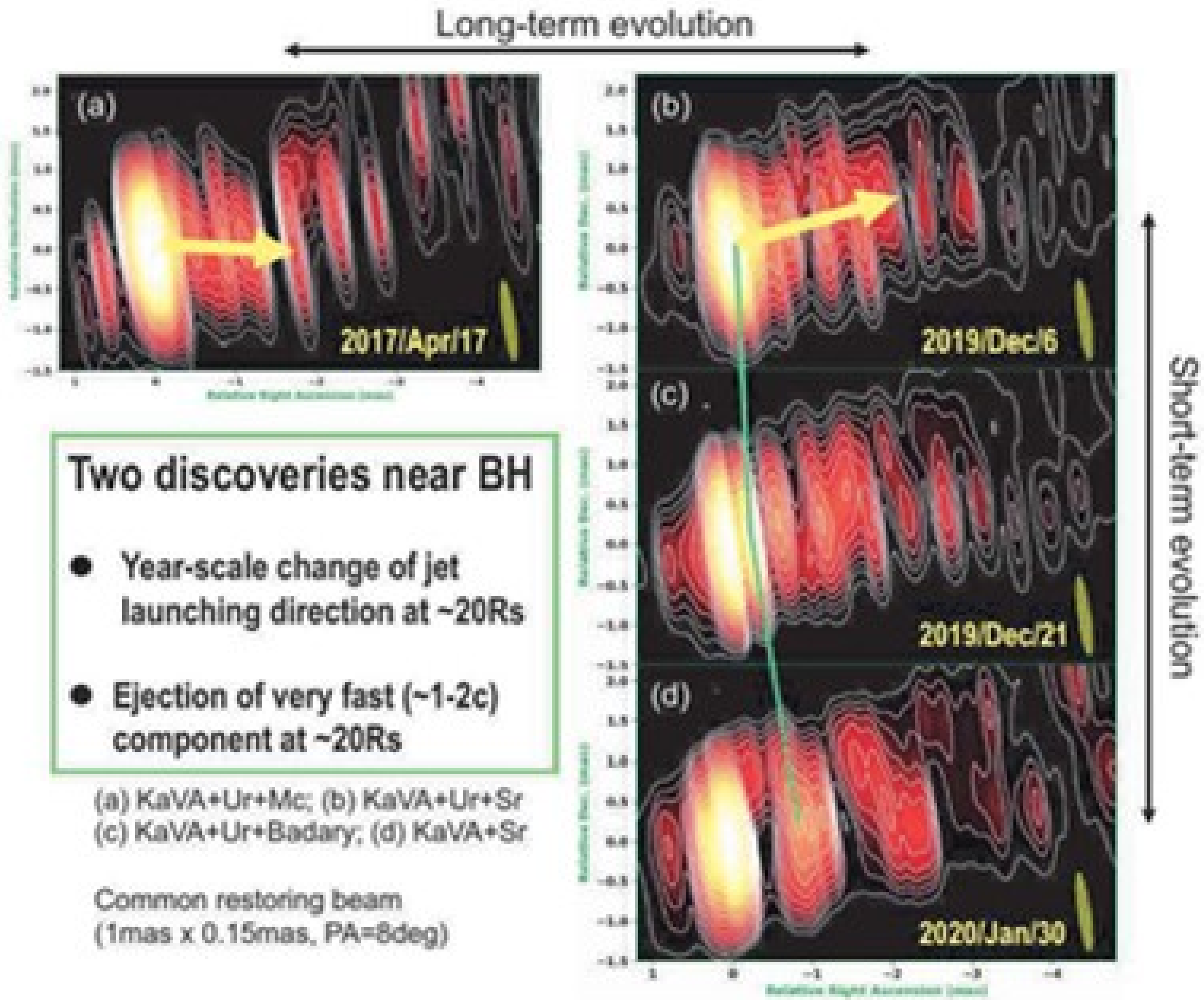


Figure 2: Short- and long-term structural evolution of the inner jet of M87 from Eating VLBI project.

Credit Hada and Kravchenko

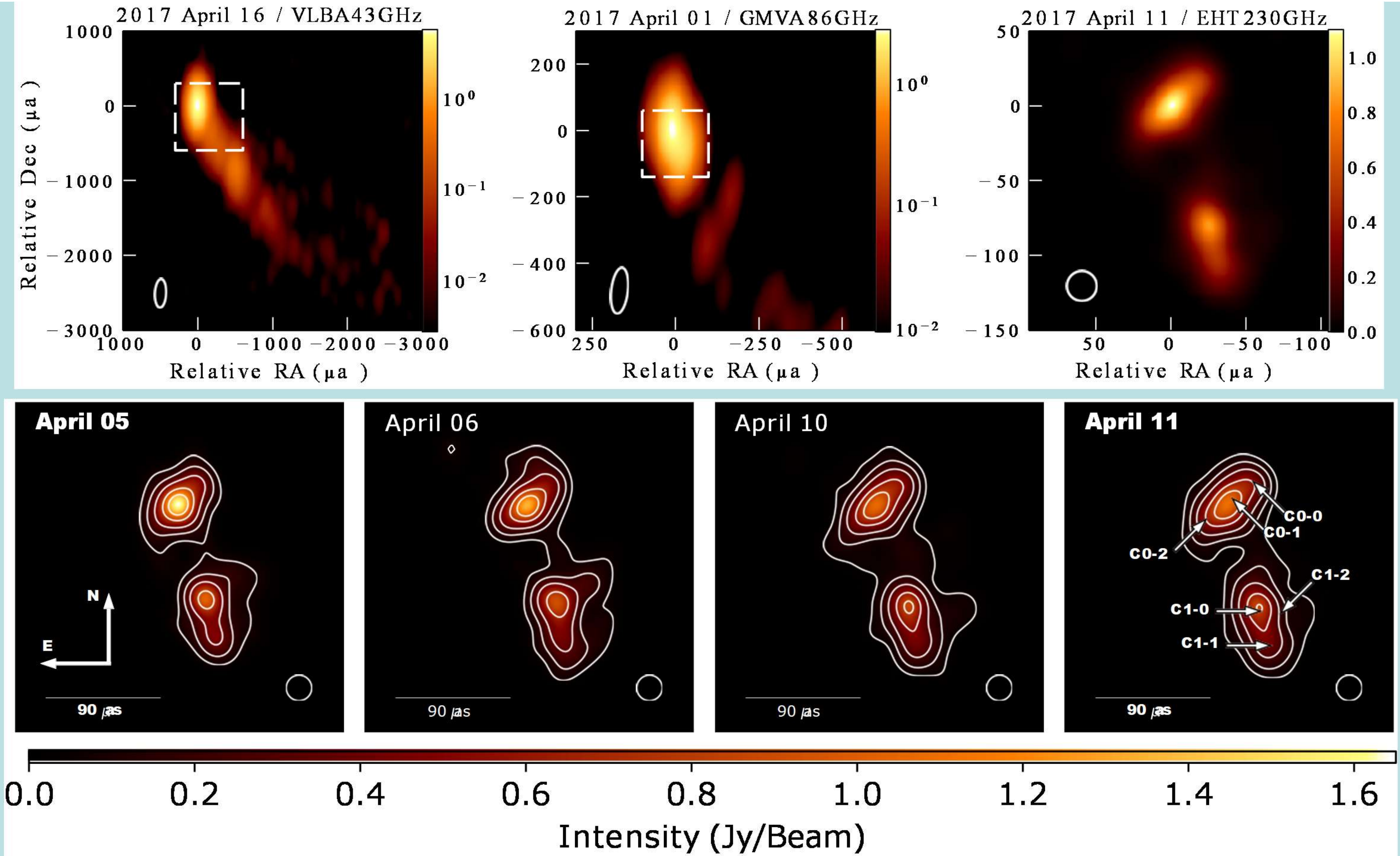
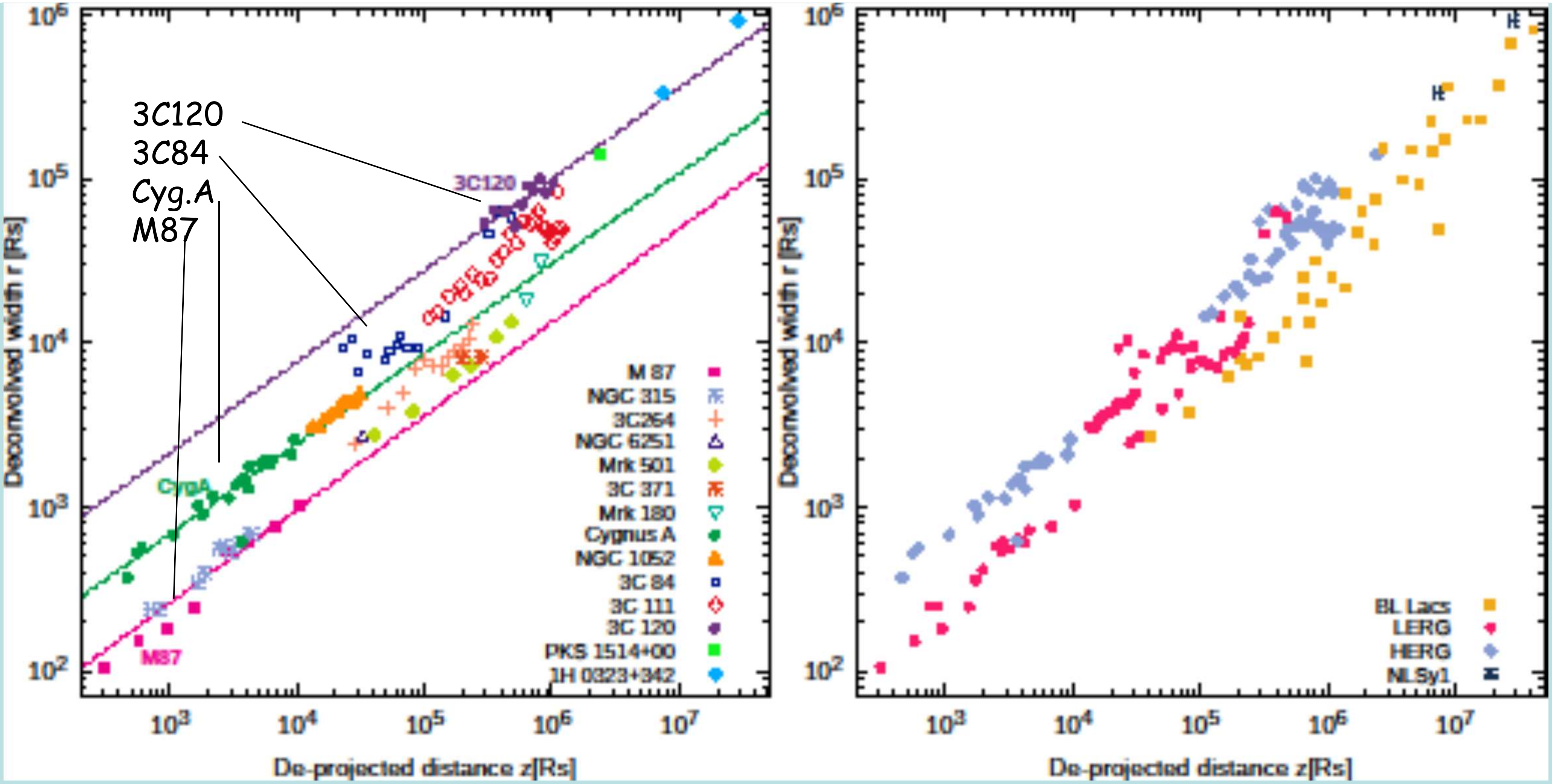


Illustration of multiwavelength 3C 279 jet structure in April 2017. The white rectangles shows the field of view of the next panels at the higher 86 and 230 GHz frequencies. We note that the centers of the images (0,0) correspond to the location of the peak of total intensity. (From left to right) the beam sizes are 150 × 380, 50 × 139, and 20 × 20 μas^2.

Kim et al. 2020 A&A 640,69

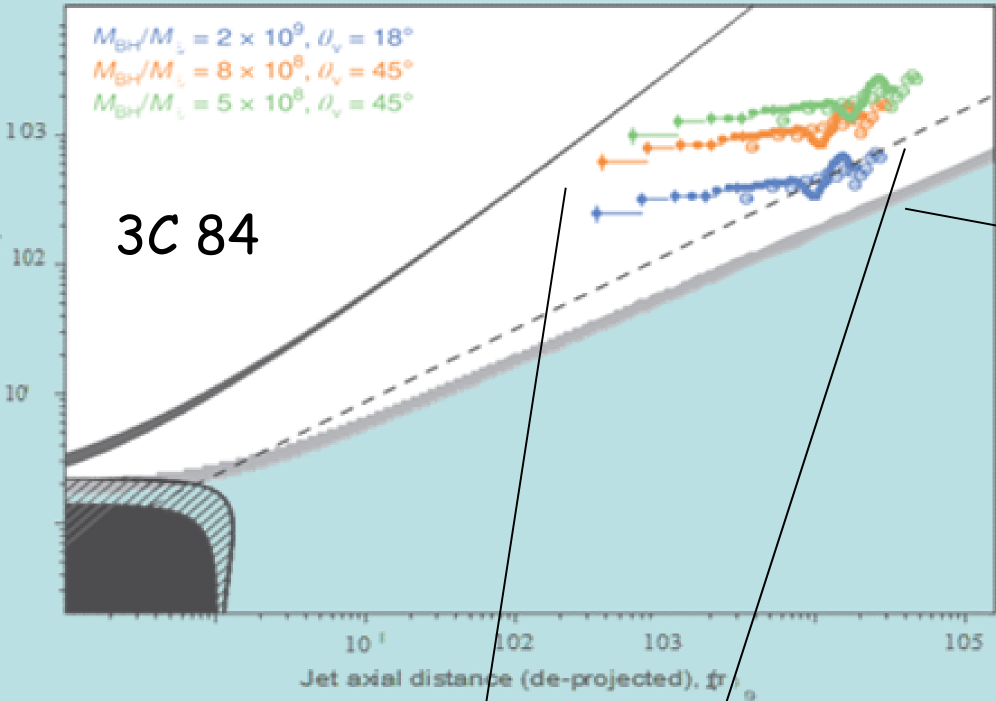


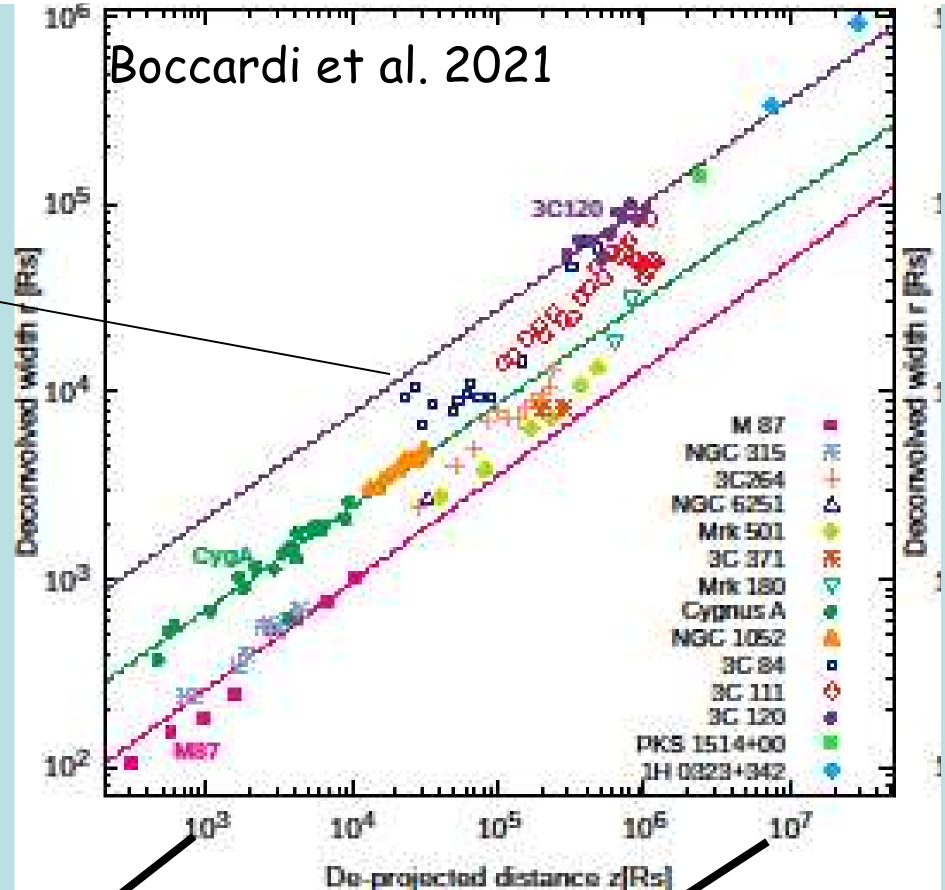
Boccardi et al. 2021 presented a detailed study of the jet collimation in NGC 315 and compared results with other HEG (cold efficient accretion disk) and LEG (hot inefficient a.d.) galaxies

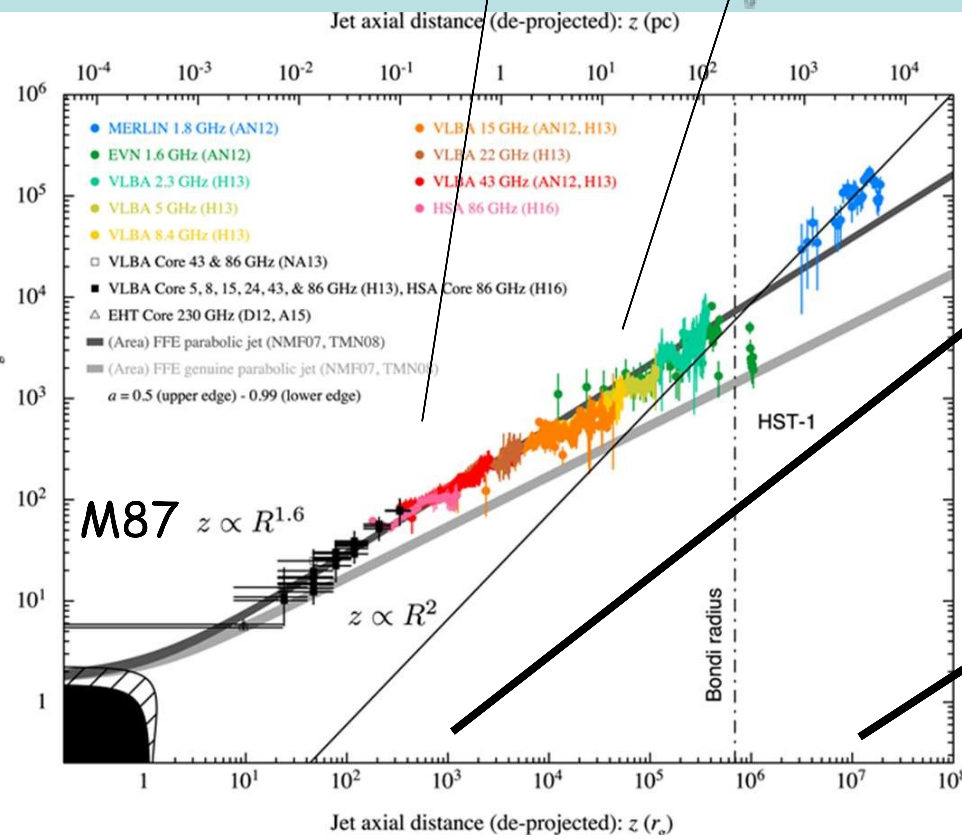
- In NGC 315 and other low luminosity g. **(LEG)** initial jet confinement from a thick disk extending out to 10^3 – 10^4 Rs is possible
- At the same de-projected distance **LEG** expanding profiles are well aligned with **BL-LACS**
- Hot disk **(LEG)** are anchored in the innermost disk regions as M 87
- Jet collimation in **HEG** proceed over larger scales than in **LEG**
- Cold disk can launch collimated winds; jets in **HEG** surrounded by more prominent outer sheaths, outer launch radius > 100 Rs
- More extended collimation zones are in jets surrounded by thicker sheaths (confined by a wind layer) in agreement with the detection in X-ray of ultra-fast outflows in most of the **HEG**
- Disk winds could be at the origin of **FRI/FRII dichotomy**. A powerful sheath stabilizes the inner jet spine by shielding it against entrainment from the ISM enabling the jet to reach the IGM with a high degree of collimation

These results show the importance to study at the same time high frequency high resolution images of the 'engine', the SMBH shadows and accretion disk AND the starting jet region as well as the acceleration and collimation region

This can be obtained with
simultaneous multifrequency observations with Korean-like receivers (Taehyun talk)
and/or with a good ground uv-coverage to have high quality images at all scales: MSO will observe in multifrequency mode, on the ground different arrays could observe at different frequencies.


3C 84
$M_{BH}/M_\odot = 2 \times 10^9, \theta_v = 18°$
$M_{BH}/M_\odot = 8 \times 10^8, \theta_v = 45°$
$M_{BH}/M_\odot = 5 \times 10^8, \theta_v = 45°$
Jet axial distance (de-projected)


Boccardi et al. 2021
Deconvolved width r [Rs]
De-projected distance z[Rs]
3C120
CygA
M87
M 87
NGC 315
3C264
NGC 6251
Mrk 501
3C 371
Mrk 180
Cygnus A
NGC 1052
3C 84
3C 111
3C 120
PKS 1514+00
1H 0323+342


Jet axial distance (de-projected): z (pc)
MERLIN 1.8 GHz (AN12)
EVN 1.6 GHz (AN12)
VLBA 2.3 GHz (H13)
VLBA 5 GHz (H13)
VLBA 8.4 GHz (H13)
VLBA 15 GHz (AN12, H13)
VLBA 22 GHz (H13)
VLBA 43 GHz (AN12, H13)
HSA 86 GHz (H16)
VLBA Core 43 & 86 GHz (NA13)
VLBA Core 5, 8, 15, 24, 43, & 86 GHz (H13), HSA Core 86 GHz (H16)
EHT Core 230 GHz (D12, A15)
(Area) FFE parabolic jet (NMF07, TMN08)
(Area) FFE genuine parabolic jet (NMF07, TMN08)
a = 0.5 (upper edge) - 0.99 (lower edge)
M87 $z \propto R^{1.6}$
$z \propto R^2$
Bondi radius
HST-1
Jet axial distance (de-projected): z (r_s)

Space VLBI observations with MSO are unique to improve

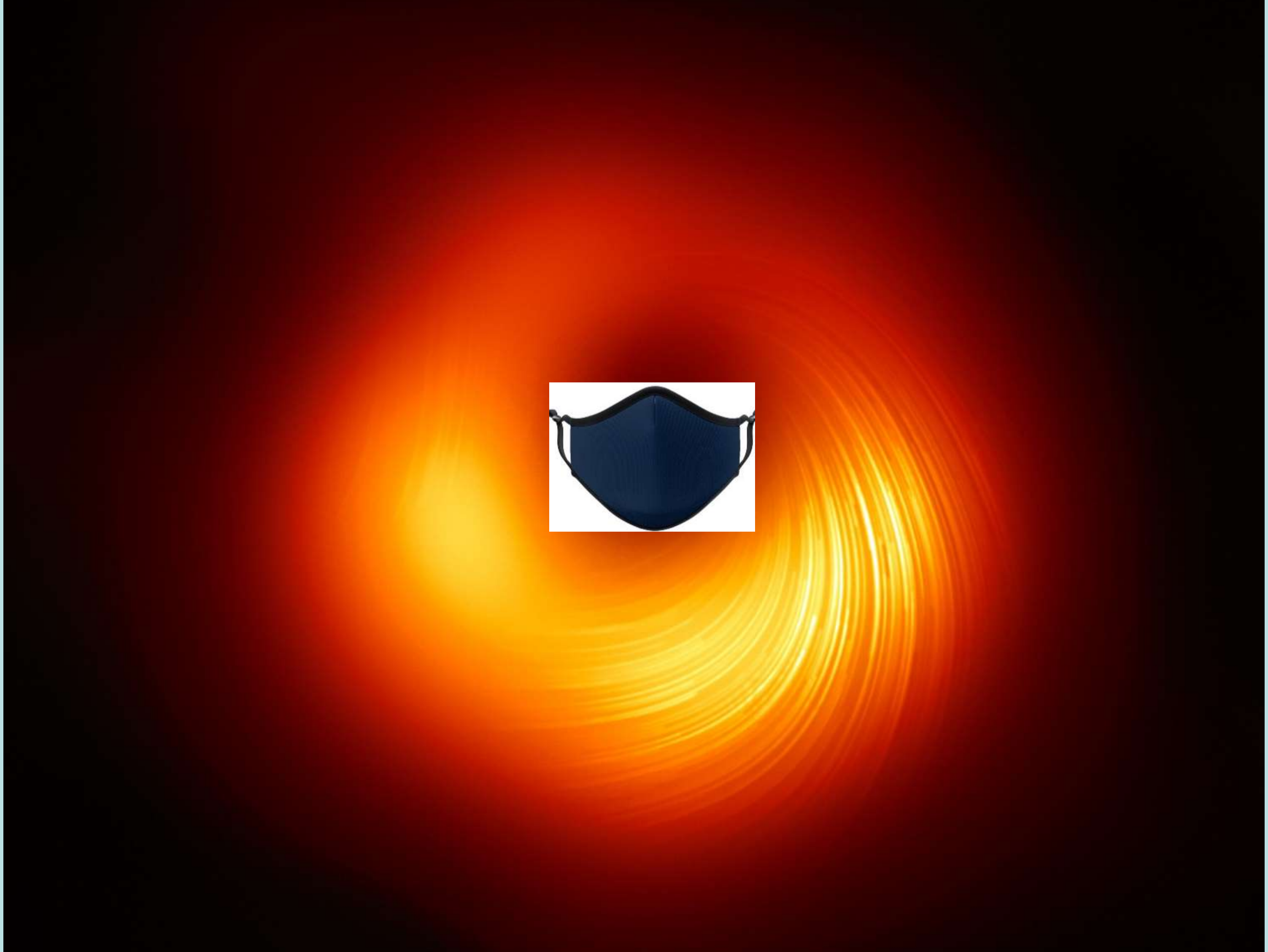
1) Our understanding of the jet starting region and its connection with the accretion disk and the SMBH
   Possible targets: a few sources with resolved limb-brightened jets. Jet collimation near the BH; jet structure related to the jet property and origin

2) Powerful AGN with VHE emission (and neutrino): origin of the VHE, particle emission, physical processes

3) NLS1 with radio jets in comparison with BLAZARS: same physic different power?

Key requirements will be
Imaging capabilities (space VLBI uv-coverage); multifrequency capability; good ground uv-coverage at all frequencies (different observing arrays?)

Thanks for the attention



I hope to meet you all in Moscow soon