Micro-arcsec scale imaging of Black Holes and Jets: Global millimeter-VLBI with ALMA

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(on behalf of the team)

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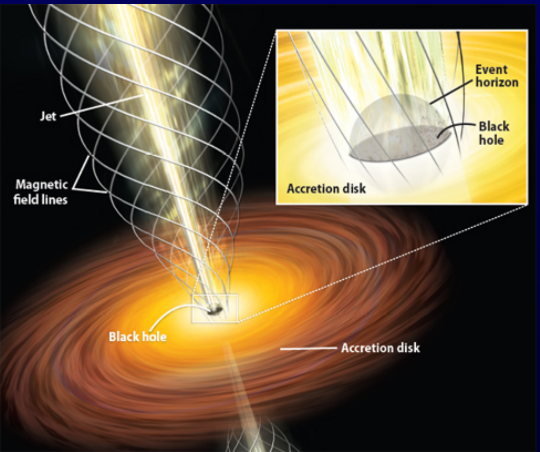


people involved:

MPIfR: W. Alef, U. Bach, A. Bertarini, T. Krichbaum,
H. Rottmann, A. Roy, J. Wagner, J.A. Zensus, et al.

APEX: R. Güsten, K. Menten, D. Muders, et al.

IRAM: M. Bremer, P. Cox, A. Grosz, K.-F. Schuster, S. Sanchez, et al.

OSO: M. Lindqvist, I. Marti-Vidal, H. Olofsson, M. Pantaleev, et al.

INAF: G. Tuccari, et al.

ESO: R. Laing, G. Wieching, et al.

1mm VLBI, collaboration with:

Haystack: R. Capallo, G. Crew, S. Doeleman, V. Fish, R. Lu, M. Titus, et al.

Carma: G. Bower, R. Plambeck, M. Wright, et al.

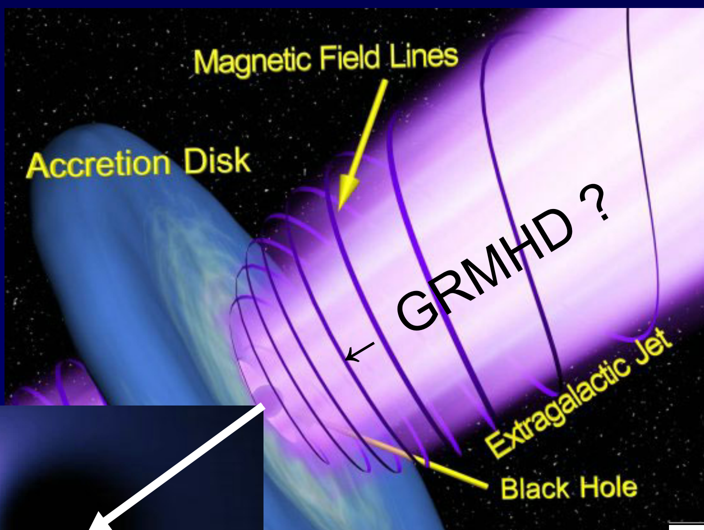
JCMT: P. Friberg, R. Tilanus, et al.

SMA: R. Blundell, J. Weintroub, K. Young, et al.

SMTO: R. Freund, D. Marrone, P. Strittmatter, L. Ziurys et al.

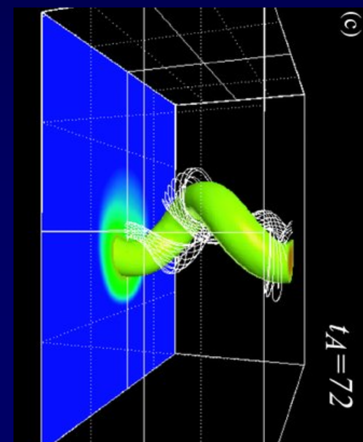
Scientific Motivation:

Detailed understanding of initial jet formation, acceleration and collimation. Image region around SMBHs, test GR near event horizon and test jet launching models.

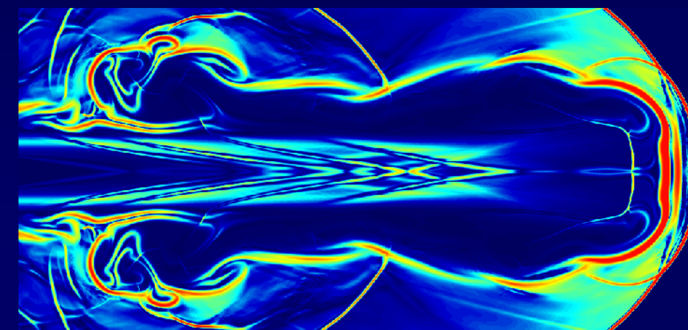


Relativistic aberration around rotating BH

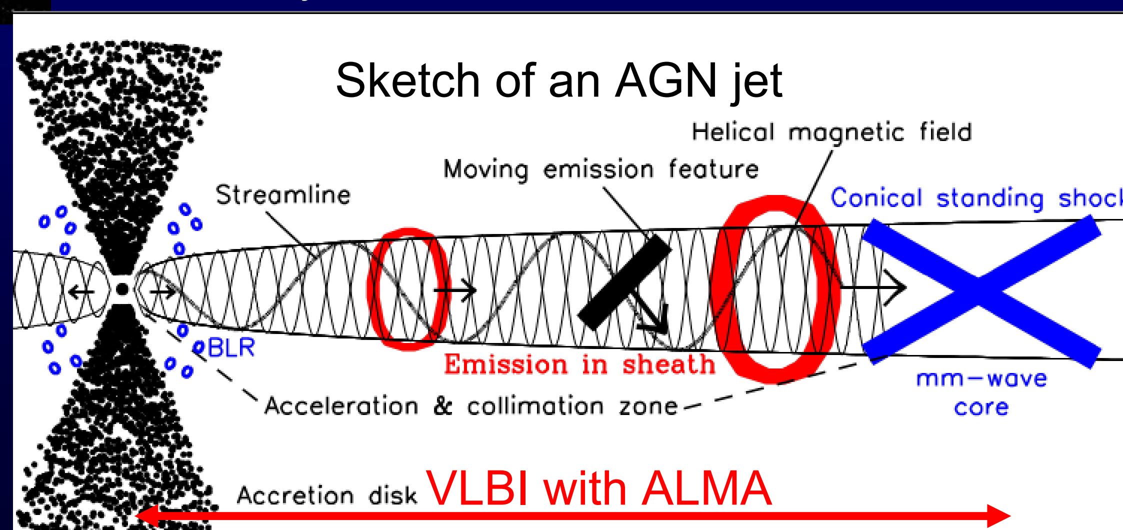
Jet energy extraction from accretion disk and/or spin of Black Hole, role of B-field?



Rotation & instabilities cause helical jets



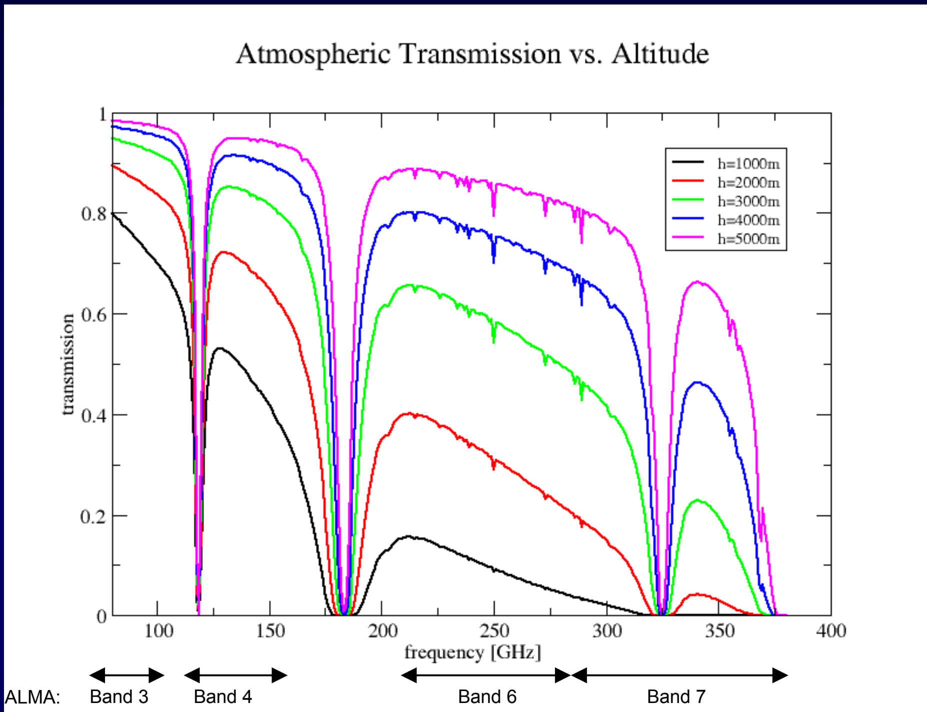
instabilities and shocks propagating through jet

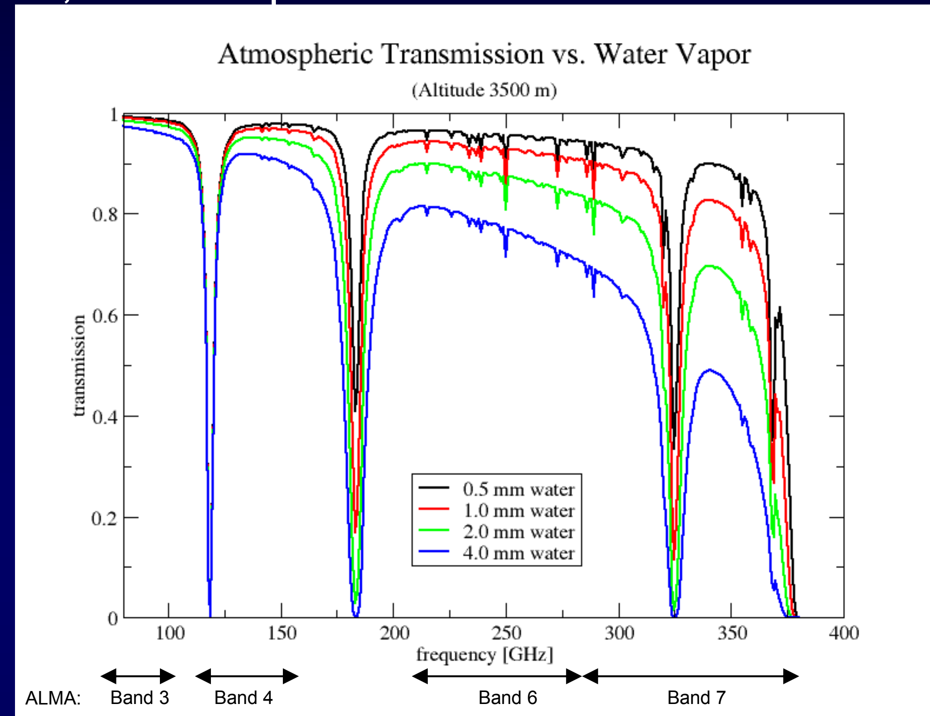


fundamental tests of BH physics possible with mm-VLBI

Atmospheric windows for mm-/sub-mm VLBI

for 1mm VLBI: H > 3000m, water vapor < 2mm





atmospheric windows allow mm-VLBI in the following bands:

- 43 GHz (SiO) AB1 31 - 45 GHz VLBA, VERA, HSA, EVN, regular
- 86 GHz (SiO) AB3 84 - 116 GHz GMVA, VLBA, regular
- 129/150 GHz AB4 125 - 163 GHz pilot studies, transatlantic fringes established
- 215/230 GHz AB6 211 - 275 GHz US+IRAM+APEX, regular
- 345 GHz AB7 275 - 373 GHz planned

The Global Millimeter VLBI Array (GMVA)

Imaging with ~40 μas resolution at 86 GHz

Baseline Sensitivity

in Europe:

10 – 75 mJy

in US:

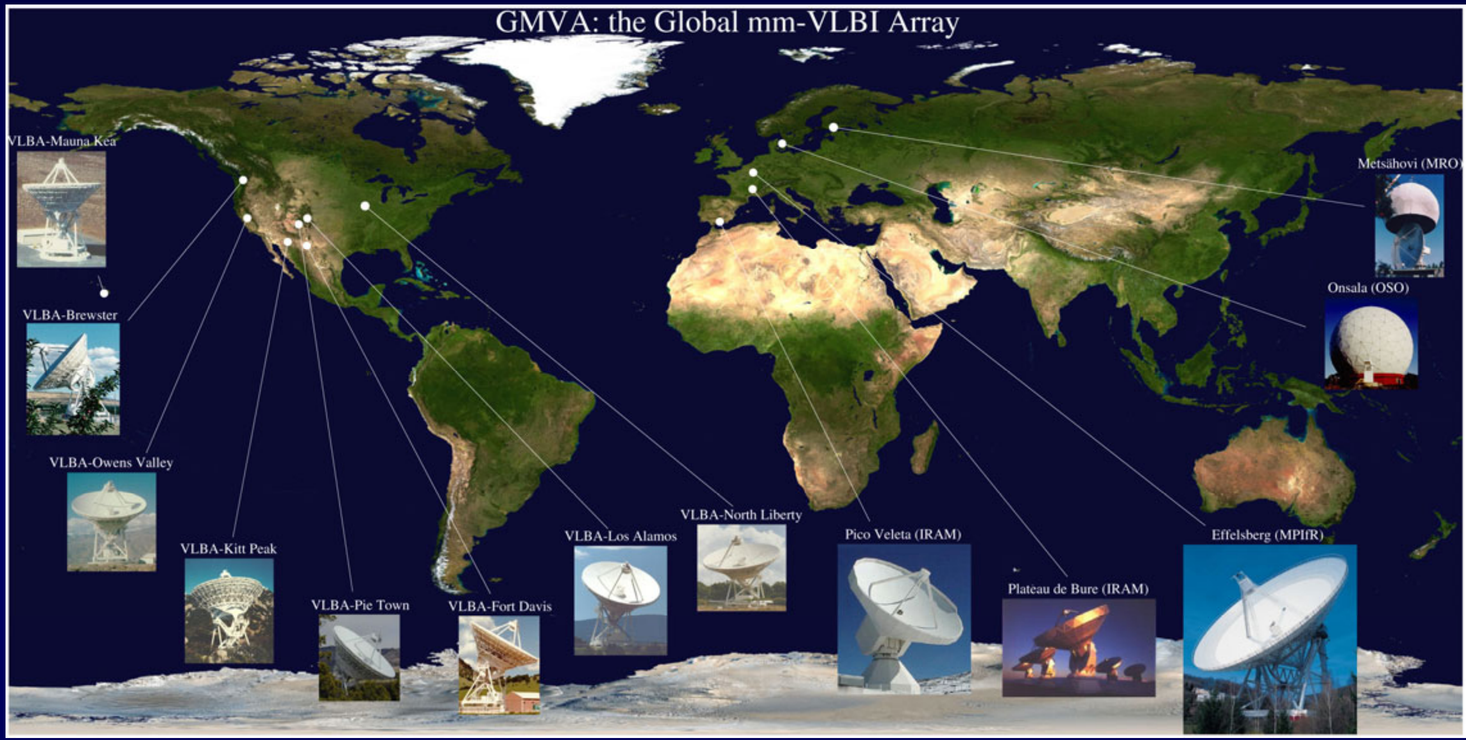
25 – 75 mJy

transatlantic:

10 – 75 mJy

Array:

0.3 – 1 mJy / hr



(assume 7σ, 100sec, 2 Gbps)

http://www.mpifr-bonn.mpg.de/div/vlbi/globalmm

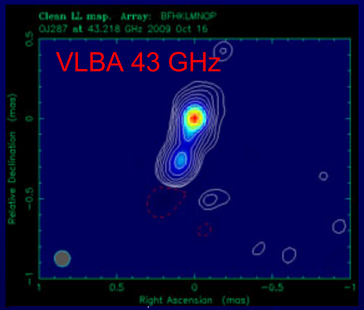
- Europe: Effelsberg (100m), Pico Veleta (30m), Plateau de Bure (35m), Onsala (20m), Metsähovi (14m), Yebes (40m), planned: KVN, SRT, ALMA, ...
- USA: 8 x VLBA (25m), GBT (100m), planned: LMT (50m)

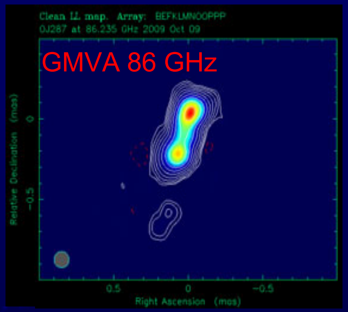
Existing VLBI arrays observing at mm-wavelength

• 9mm (32 GHz): DSN+EB+Geo-VLBI telescopes	planned
• 7mm (43 GHz): HSA, VLBA, EVN, Vera + KVN	regular
• 3mm (86 GHz): GMVA, VLBA	regular
• 2mm (129/150 GHz): IRAM+SMTO+Metsahovi	fringes in early 2000
• 1mm (230 GHz): IRAM+APEX+SMTO+CARMA+SMA/JCMT	once per year

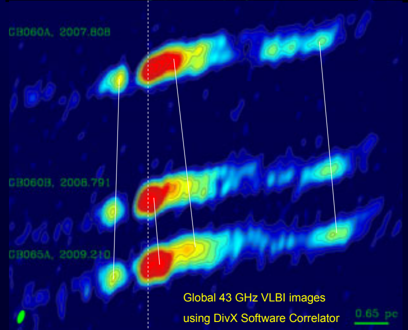
new results from global 3mm VLBI with the GMVA:

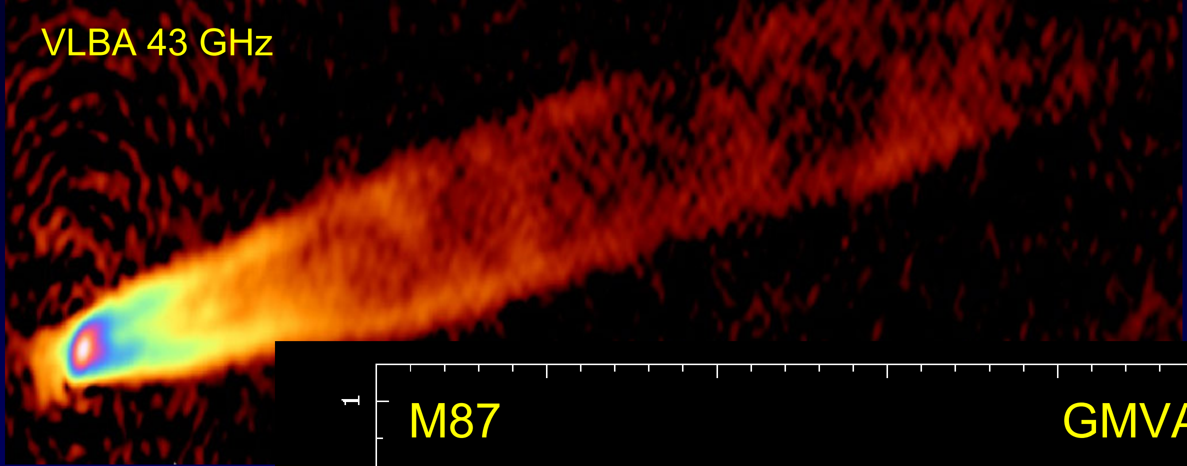
see posters: J. Hodgson et al. (OJ287)





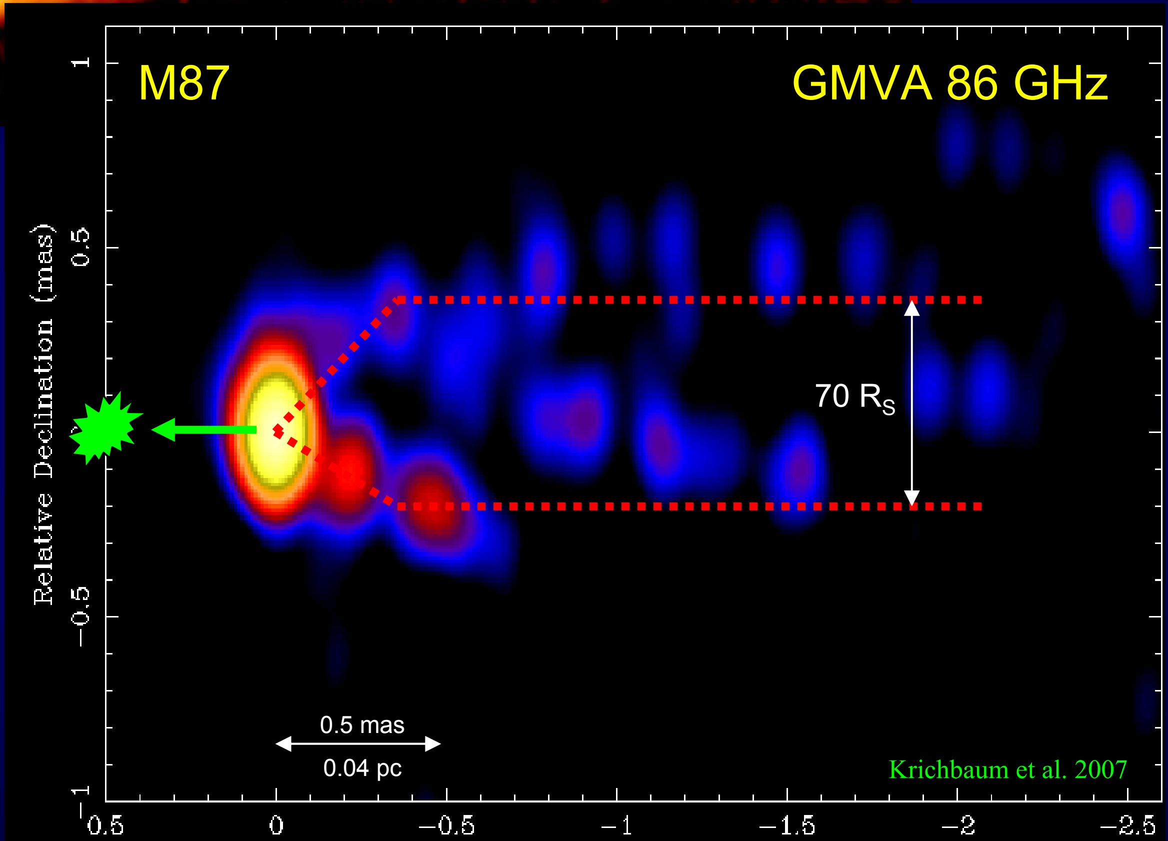
B. Boccardi et al. (Cygnus A)





Walker et al. 2008

Size of jet base may be too small for magnetic sling-shot acceleration. Evidence for direct coupling to BH spin ? → a GR-MHD Dynamo ?



Krichbaum et al. 2007

unknown separation from BH

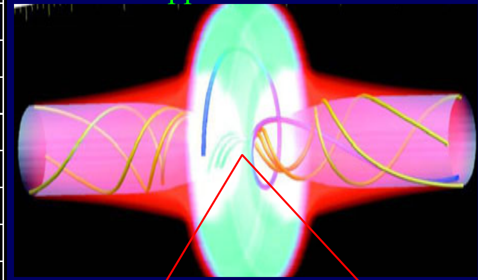
Phaseref.:

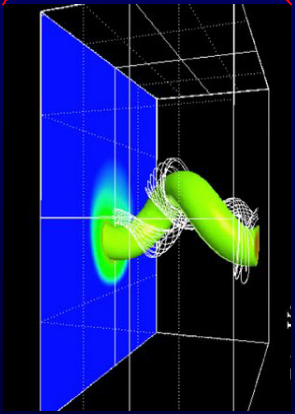
D=14-23 R_s

Hada et al. 2011

MHD Jet Simmulation:

Casse & Keppens 2004





Mizuno et al. 2009

Limit to the size of the jet base (uniform weighting):

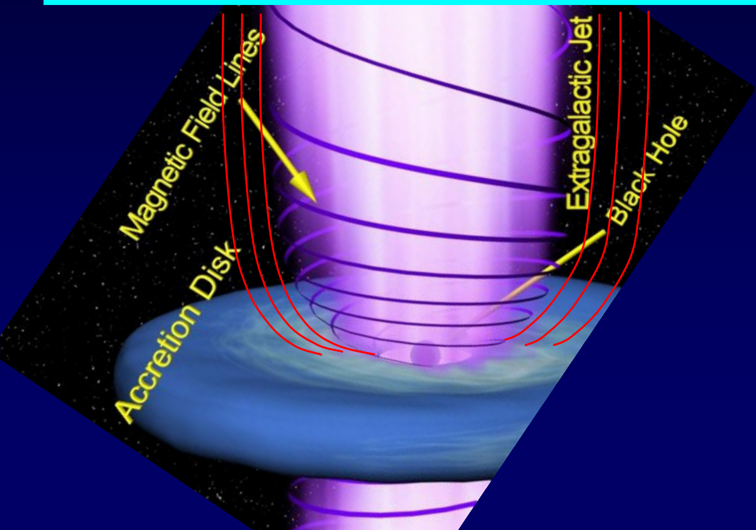
197 x 54 μas = 21 x 6 light days = 27 x 8 R_s^9

transverse width of jet at 0.5 mas: ~70 R_s^9

BP versus BZ mechanism

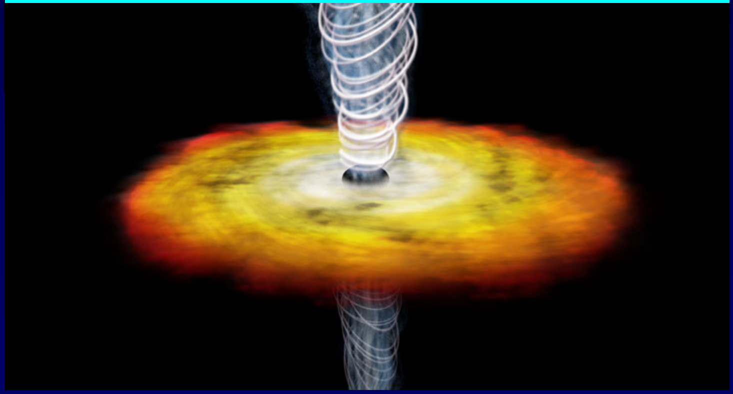
Blandford – Payne mechanism:

centrifugal acceleration in magnetized accretion disk wind



Blandford – Znajek mechanism:

electromagnetic extraction of rotational energy from Kerr BH



measure

Jet speed f(r,z)

Jet width f(z)

T_B f(z)

→

Shape of Nozzle

Magnetic Field

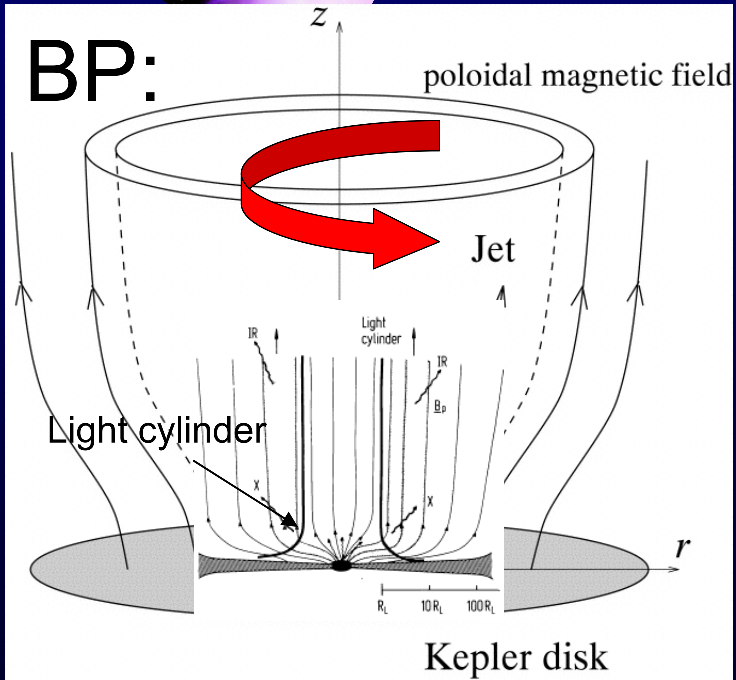
BH Spin

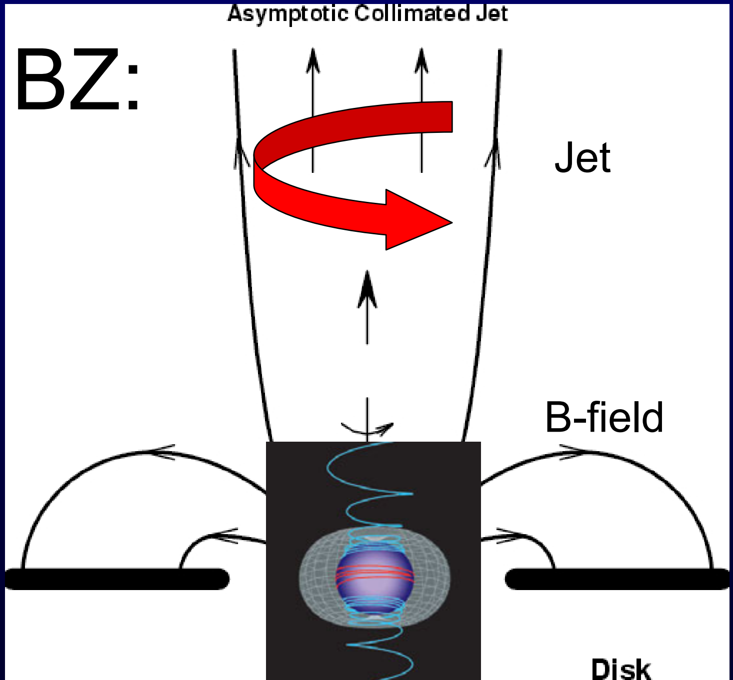
etc.

need to reach

scale of

a few R_G





Brightness temperature:

$$T_{\mathrm{b,s}} = \frac{2\ln 2}{\pi k_{\mathrm{B}}} \frac{S_{\mathrm{tot}}\lambda^2}{d^2}(1+z)$$

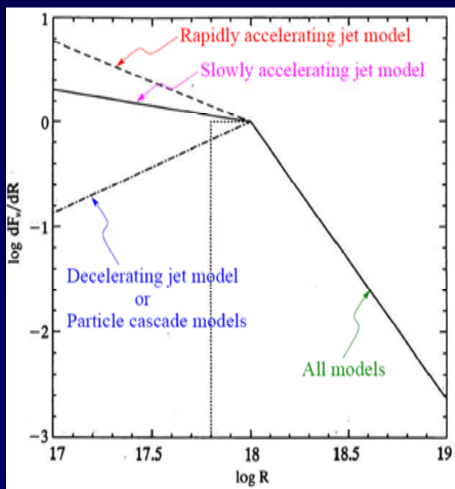
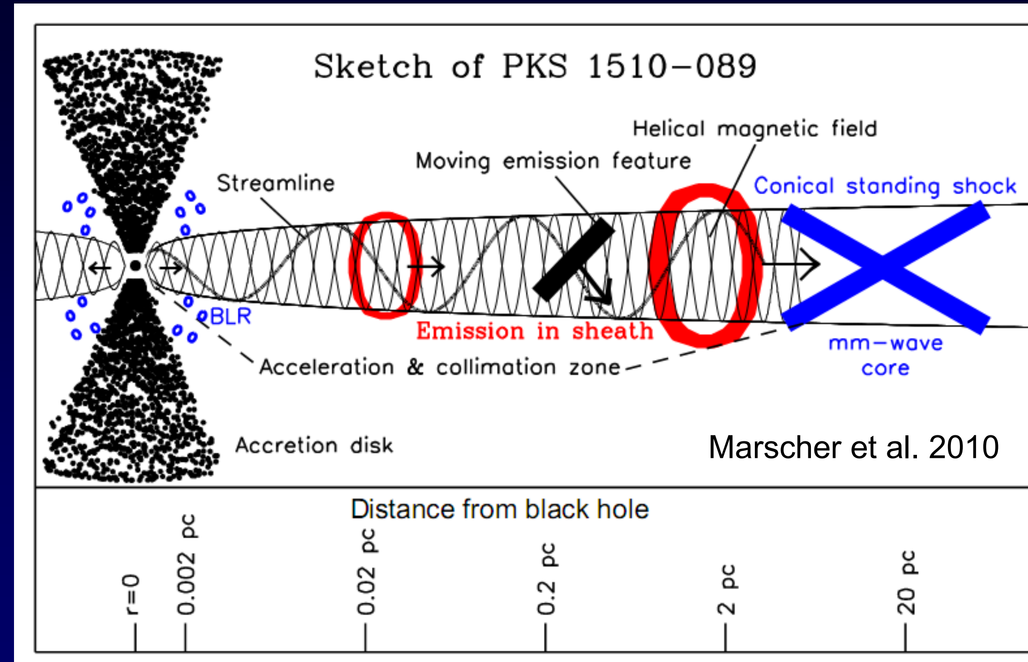
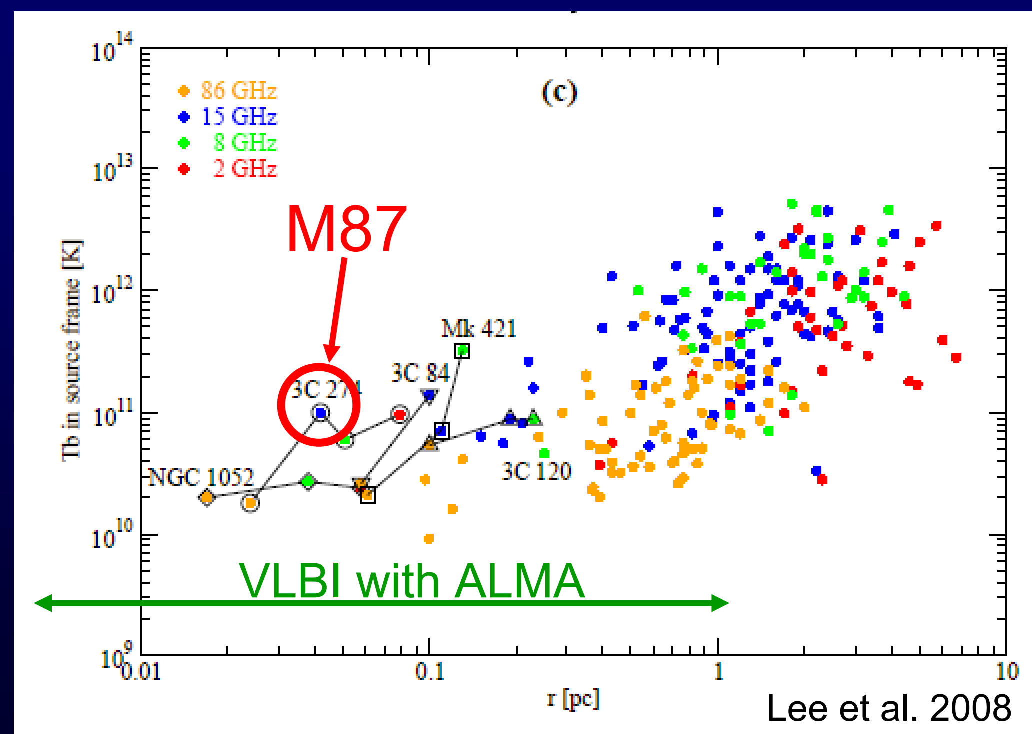


Figure adopted from A. Marscher (1995)

Measure brightness temperature to discriminate between jet models and to determine jet acceleration

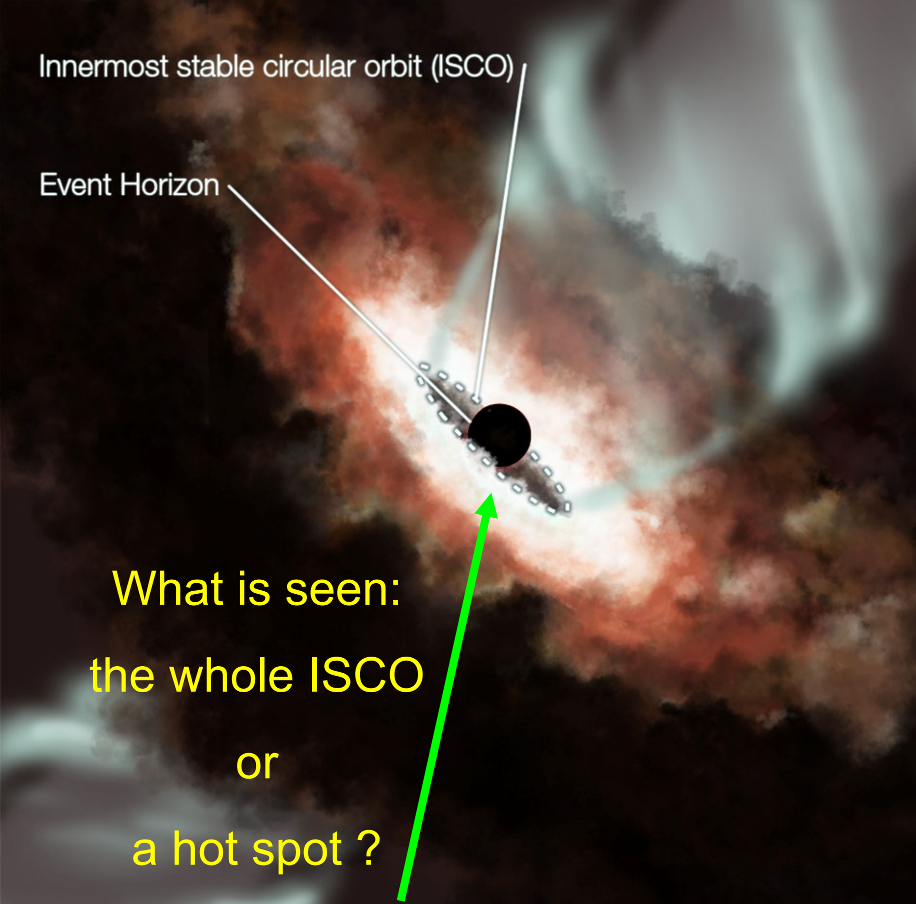
study jet formation and acceleration using mm-VLBI with ALMA

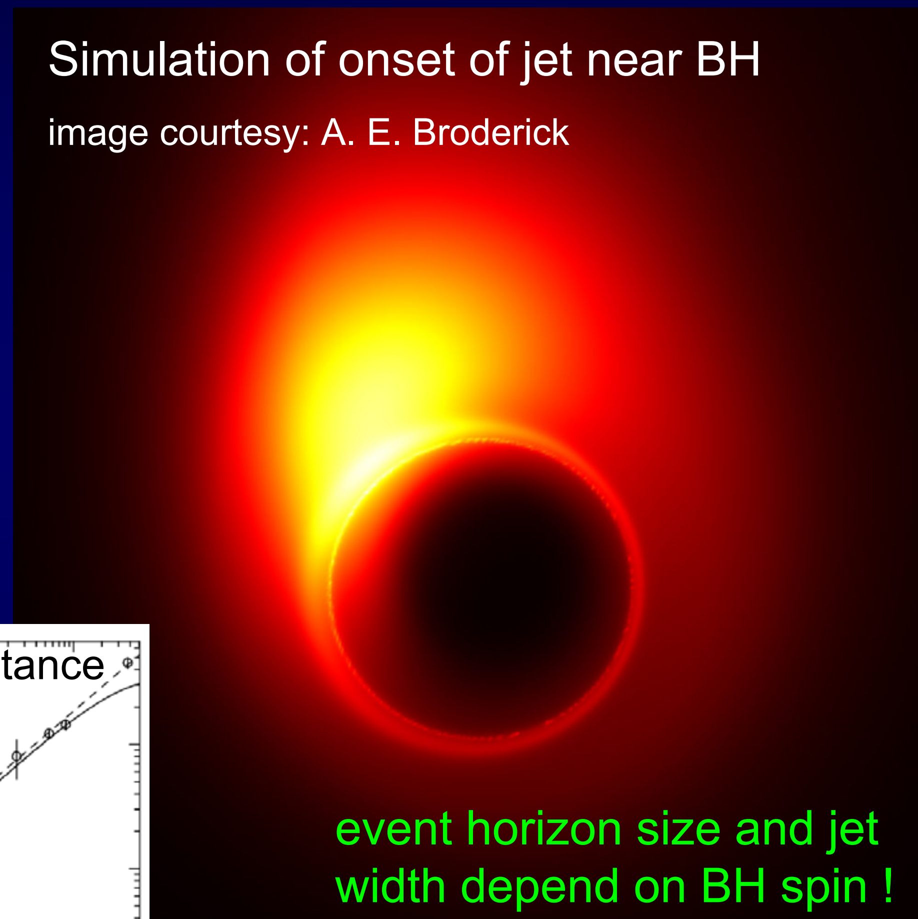


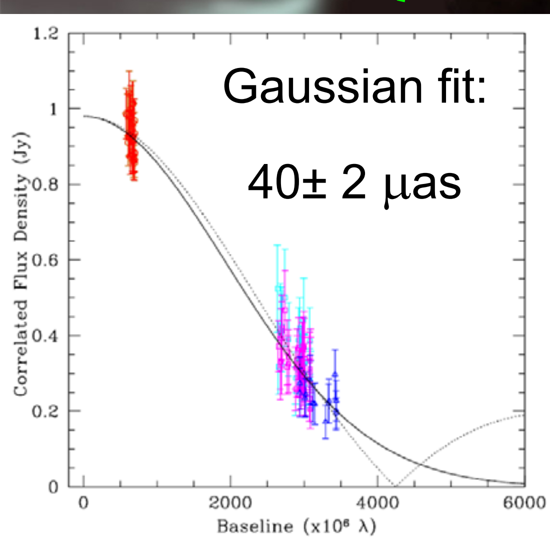


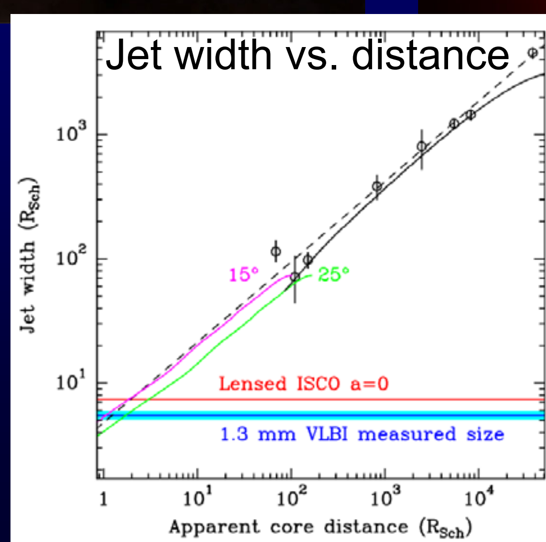
New size estimate of M87's jet nozzle from 3 station VLBI at 230 GHz

(4000 km baseline length)









component size < $(5.5 \pm 0.4)\ R_S$

Doeleman et al. 2012, Science

Competing Jet Models

synchrotron self-absorbed conical jet (Blandford-Königl jet)

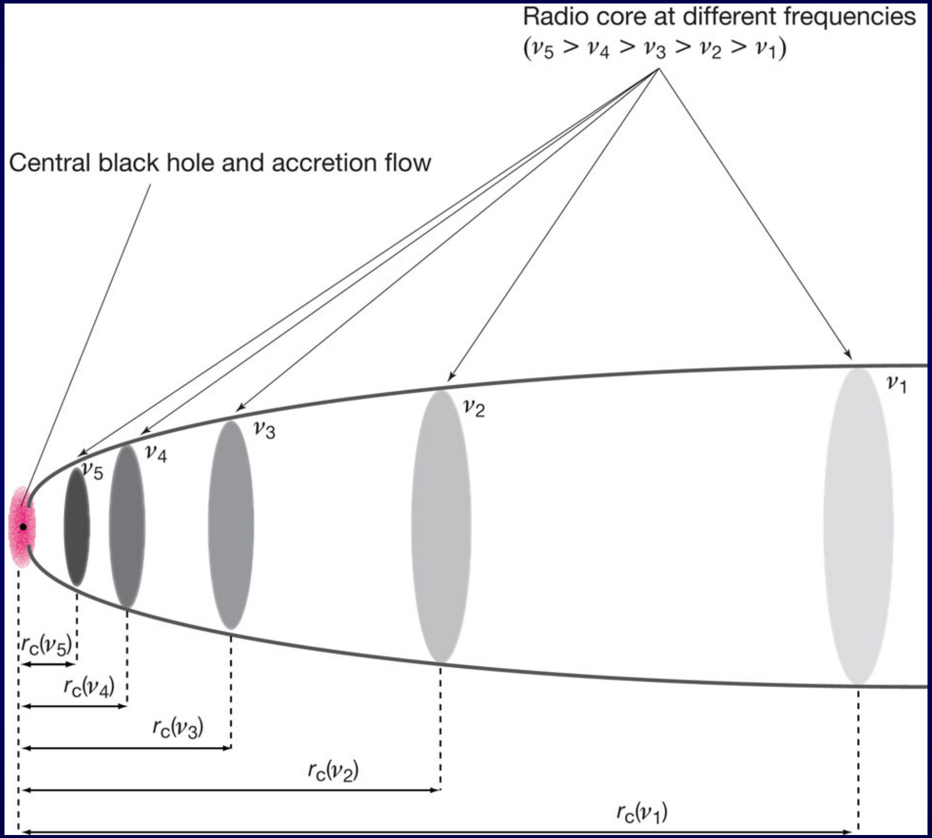
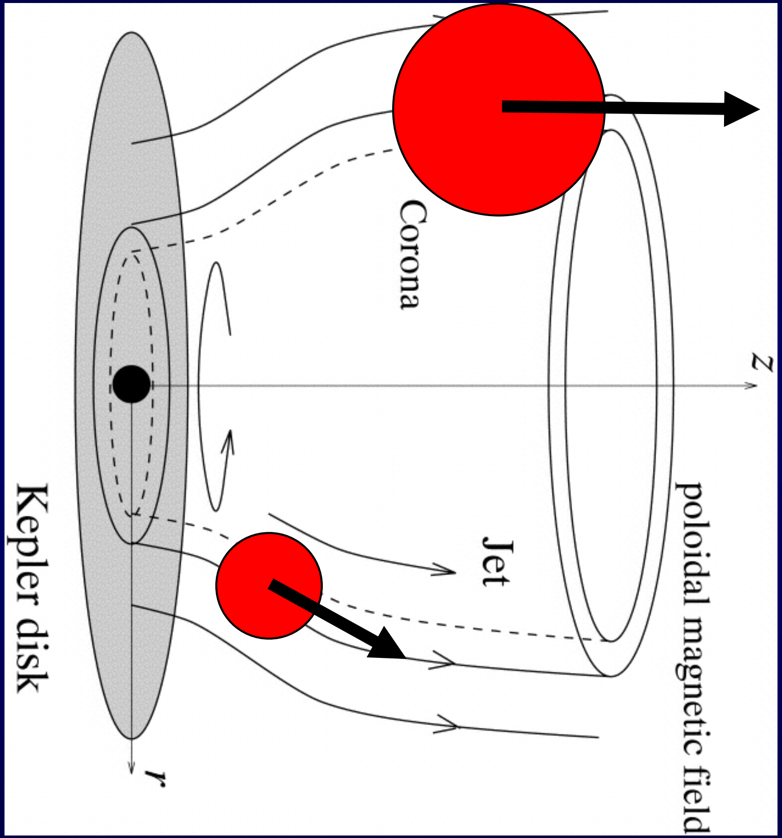


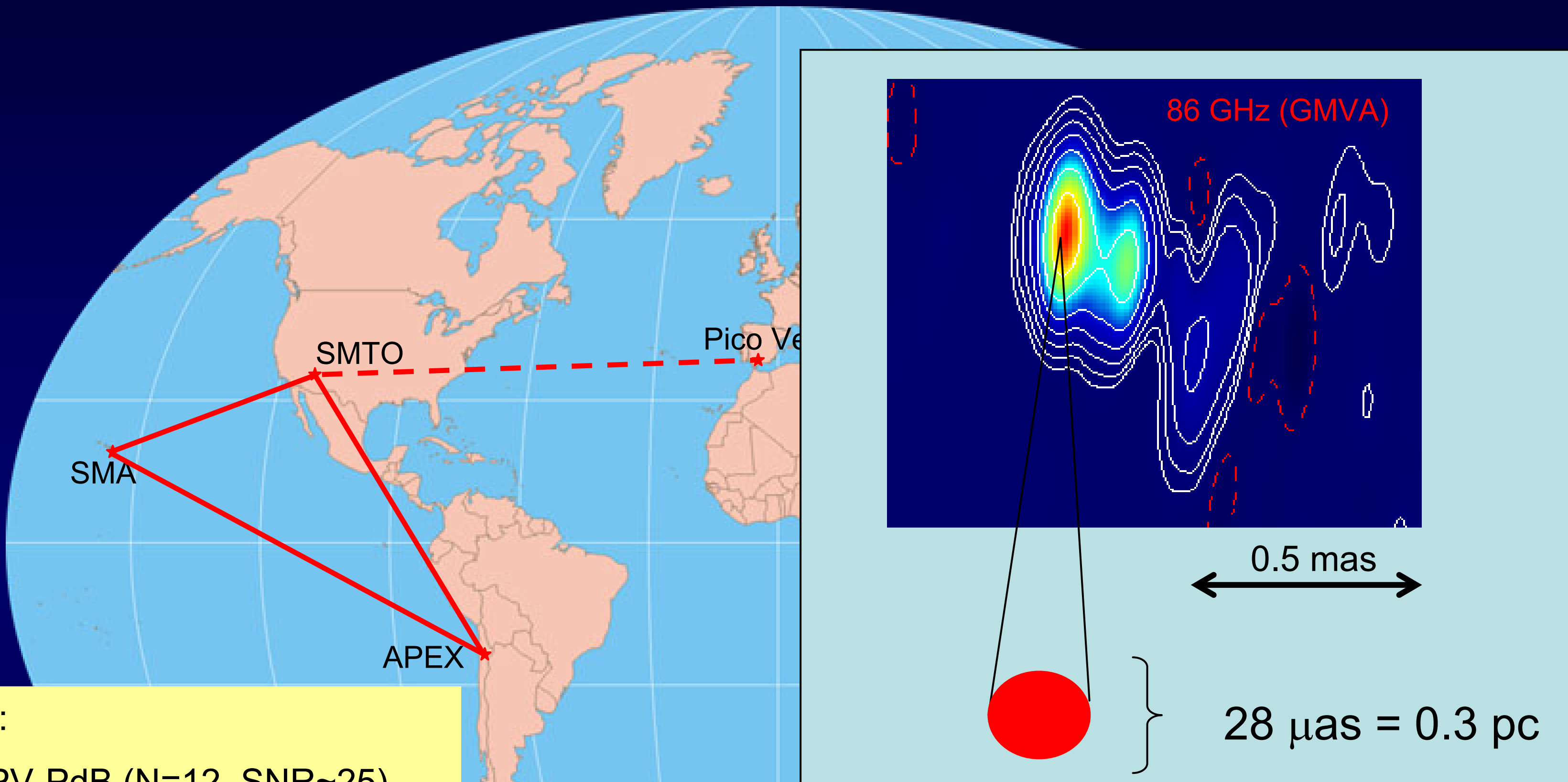
Figure from Hada et al. 2011, Nature

stratified (MHD) jet with moving hot spots or shocks



still unclear of what is seen at 1mm, need better map

Fringe detection with APEX at 230 GHz (May 7, 2012)



History:

1995: PV-PdB (N=12, SNR~25)

2002: PV-SMTO (N=2, SNR~7)

2007: SMTO-CARMA-JCMT/SMA

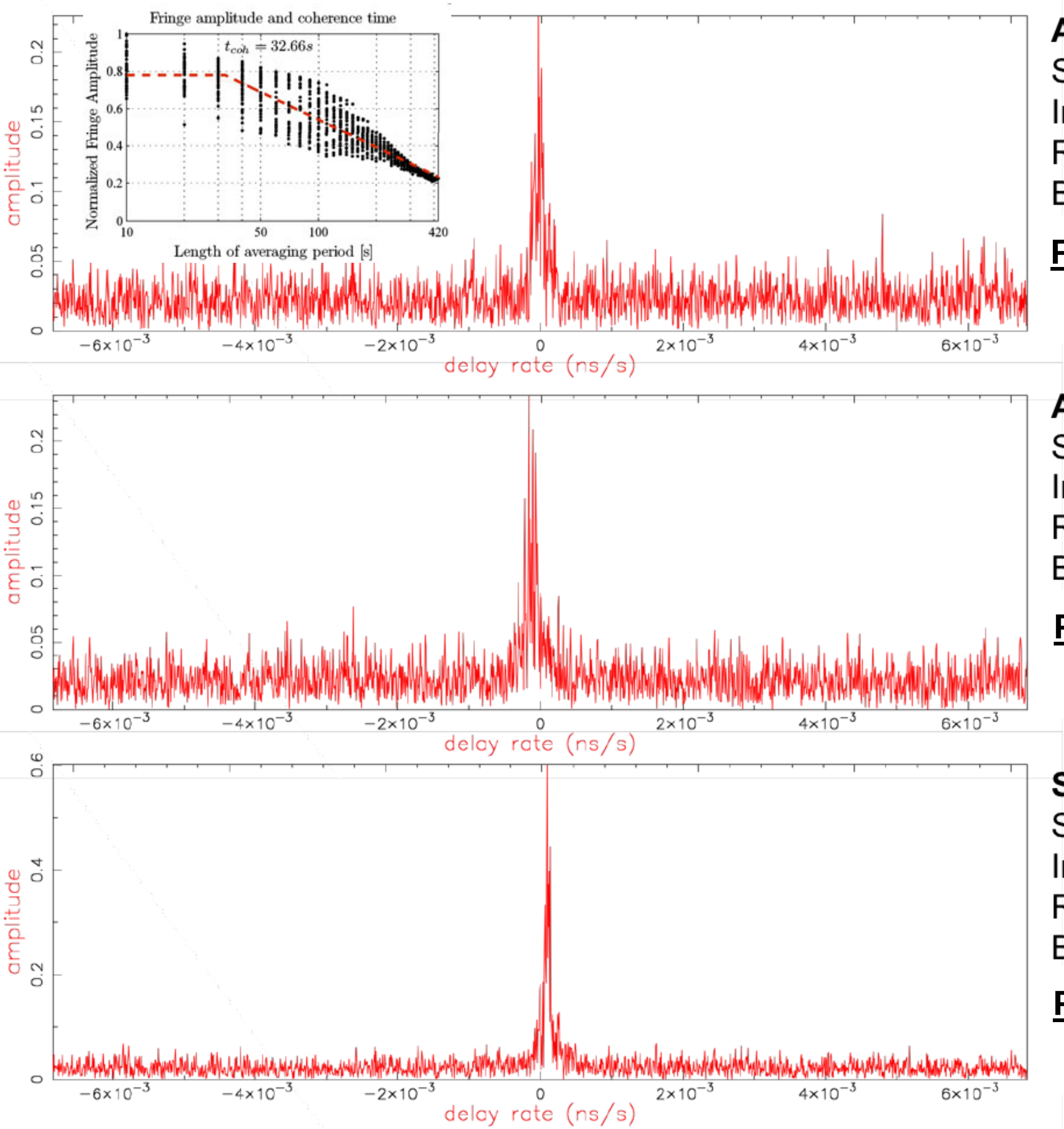
2011: failed to find APEX fringes

2012: AP-SMA-SMTO

Station	Station	Length (km)	Resolution (μas)
APEX	**SMA**	**9447**	**28,4**
APEX	**SMTO**	**7174**	**37,4**
SMTO	**SMA**	**4627**	**58,0**

★ existing station —— 1mm fringes established

First VLBI Fringes with the Apex telescope at 230 GHz (3C279, May 2012)



APEX – SMA
SNR = 12.3
Integration time = 7 min
Residual rate = 7.7 mHz
Baseline = 9447 km

Fringe spacing 28 µas

APEX – SMTO
SNR = 12.7
Integration time = 7 min
Residual rate = -37.9 mHz
Baseline = 7174 km

Fringe spacing 37 µas

SMA – SMTO
SNR = 32.6
Integration time = 7 min
Residual rate = 21.4 mHz
Baseline = 4627 km

Fringe spacing 58 µas

Roy et al. 2012, Krichbaum et al. 2012, Wagner et al. 2013

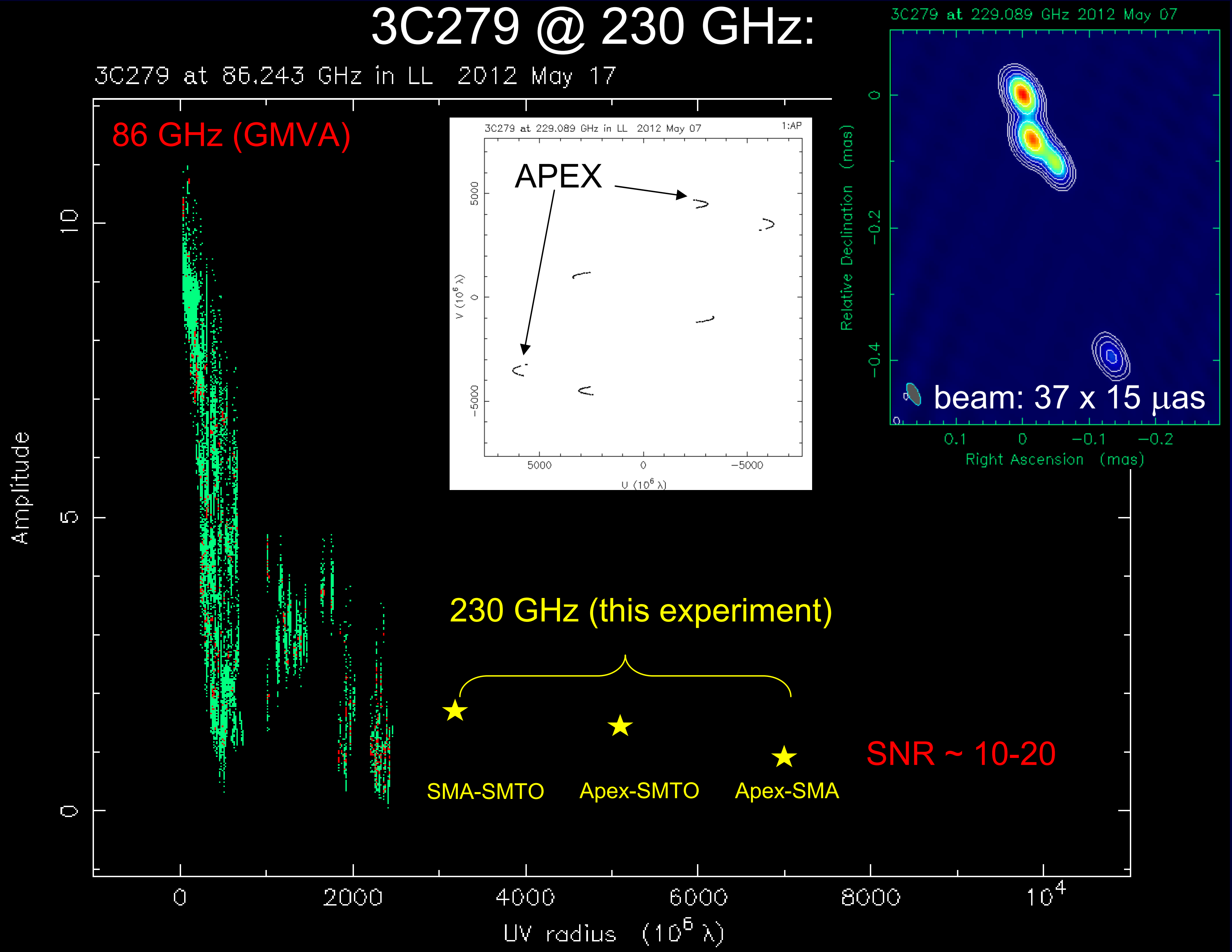
VLBI operation at APEX

Michael Lindqvist & Neil Nagar on Cerro Chajnantor.

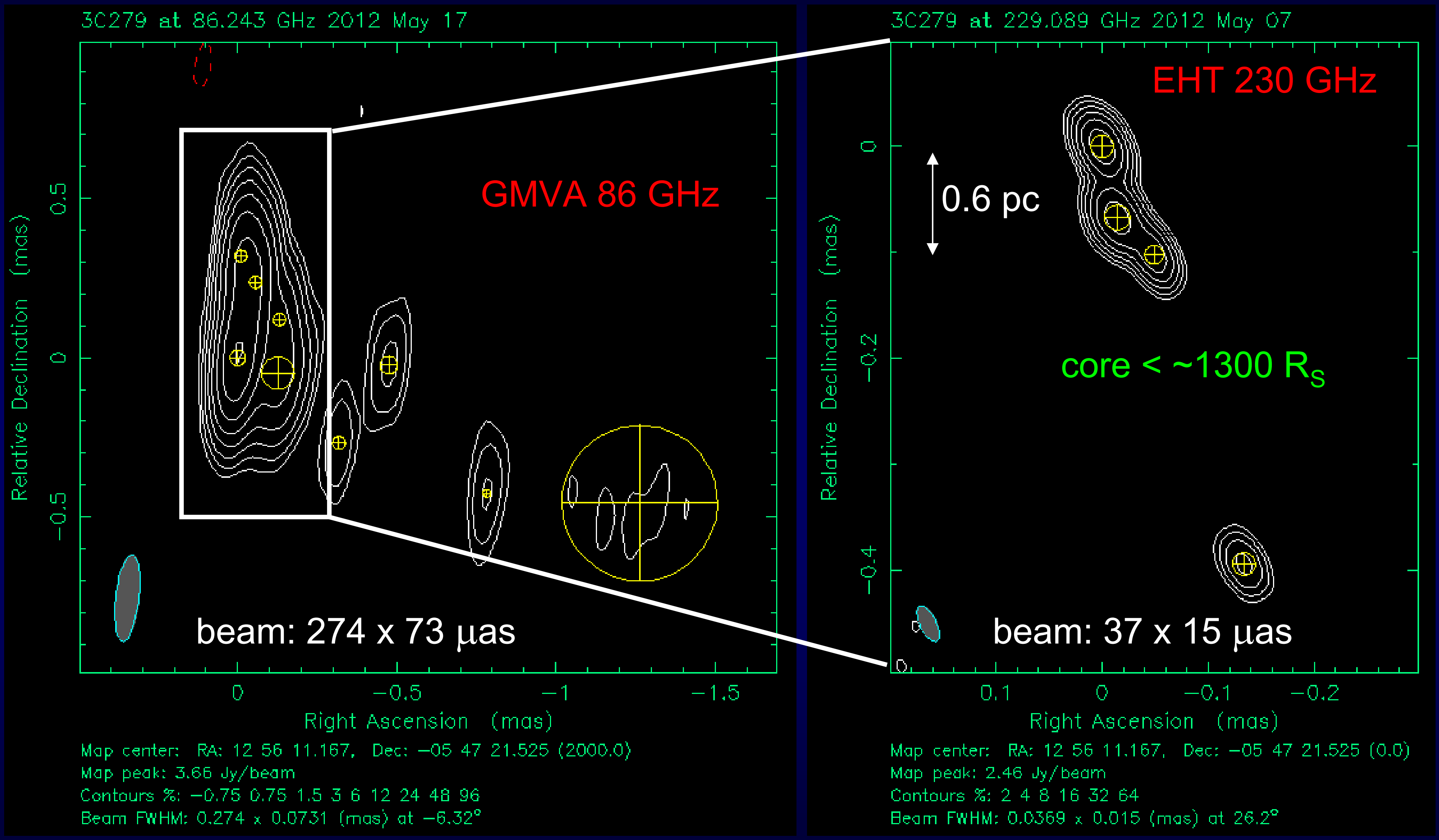
Fixing problem in pressure housing for the MK5 disks.(Jan Wagner)

Recorded modules ready for transport down at end of session. (Alan Roy & Michael Lindqvist)

3C279 @ 230 GHz:



North-South extension in 3C279 confirmed by 3mm VLBI



base of jet is transversely resolved and has a width of ~1 pc (~10^4 R_S)

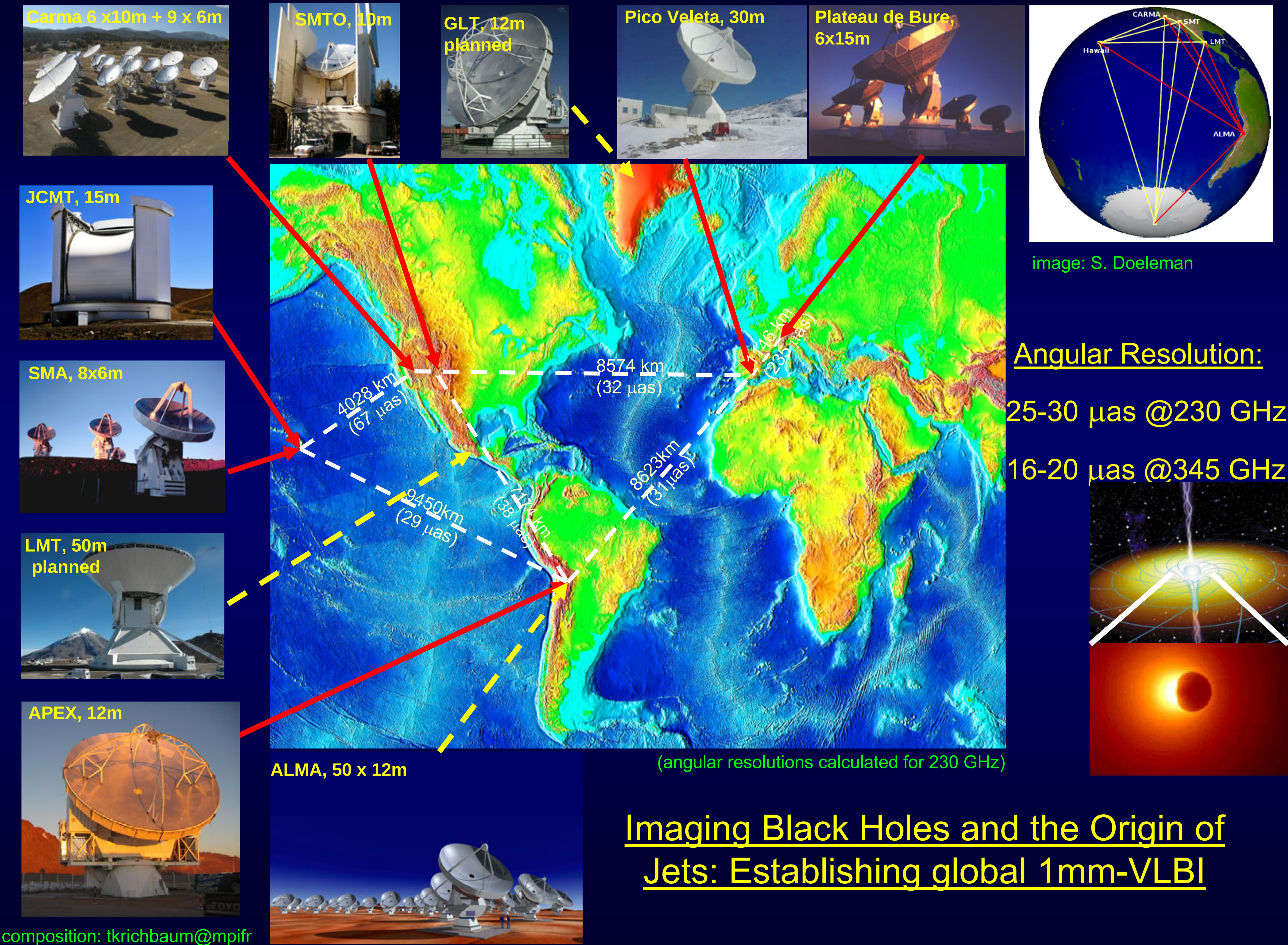
size of individual components (emission regions) < 0.1 pc (1000 R_S)

Imaging Black Holes and the Origin of Jets: Establishing global 1mm-VLBI

Angular Resolution:

25-30 µas @230 GHz

16-20 µas @345 GHz



Development of a ALMA Beam-former for Ultra High Resolution VLBI and Phased Array Science

The Alma Phasing Project (APP): An international collaboration

ALMA

NRAO

MIT HAYSTACK OBSERVATORY

Max-Planck-Institut für Radioastronomie

NAOJ

CfA

ESO

ACADEMIA SINICA

ONSALA RYMDOBSERVATORIUM
CHALMERS TEKNISKA HÖGSKOLA

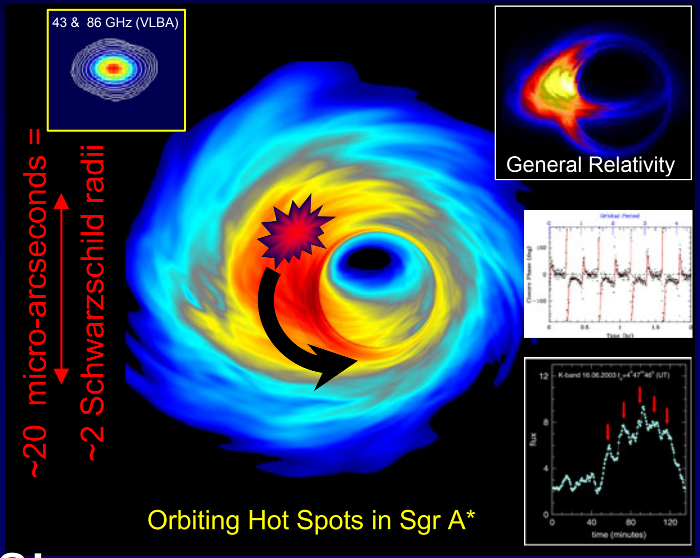
Université Joseph Fourier GRENOBLE

LAB

Image Black Holes and the origin of jets with sub-millimeter VLBI and ALMA

- achieve 10-25 micro-arcsecond resolution at sub-mm wavelengths
- image Sgr A* and M87 with a few R_G resolution (BH imaging and GR-effects)
- study jet formation and acceleration in nearby Radio-Galaxies (jet-disk connection, outburst ejection relations, etc.)
- study AGN and their SMBHs at high redshifts (cosmological evolution of SMBHs)
- establish a global sub-mm VLBI array: PV, PdBI, SMTO, Hawai, Carma, LMT, SPT, APEX/ ALMA (Event Horizon Telescope).
- the large collectiong area of ALMA is needed to reach milli-Jansky sensitivity

Sgr A*:



M87+Jets: