EHTおよびVERA+KVNによる
銀河中心巨大ブラックホールの観測

Mareki Honma

Mizusawa VLBI observatory, NAOJ

ALMA phasing team

Touching the event horizons of BHs

- AGN core is most-likely a super-massive black hole.

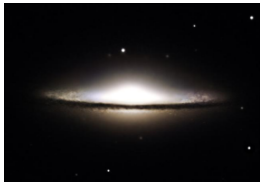
- Yet, there is no confirmation of existence of event horizon

Direct detection of BH shadow is an ultimate confirmation of existence of BH. (or negative results may indicate an existence of naked singularity !?)

- New breakthrough for experimental BH physics!?

BH size

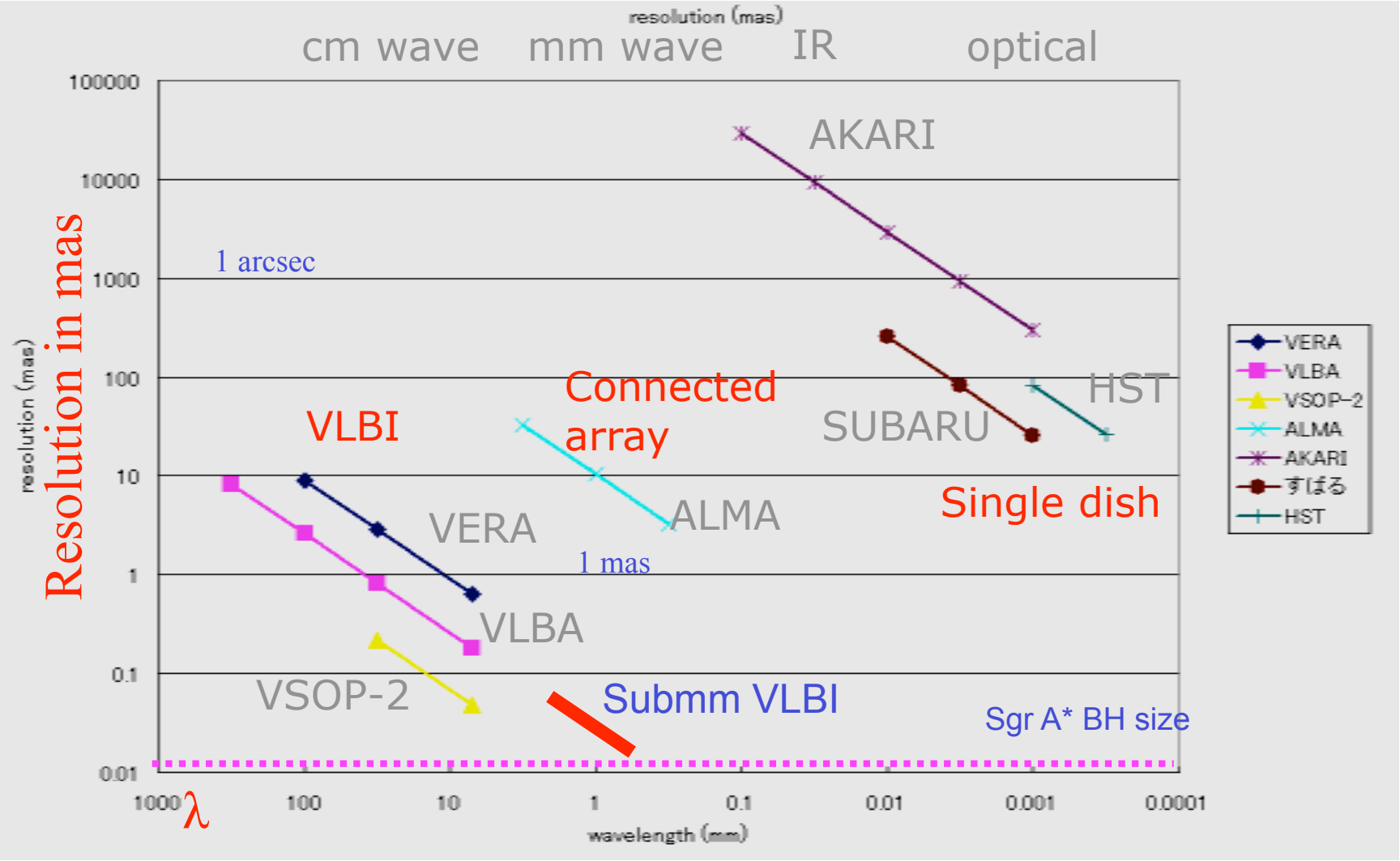
source	M_{BH}/M_{sun}	Distance	Angular radius
Sgr A*	4 x 10^6	8 kpc	10μas
M87	6 x 10^9	15 Mpc	7μas
M104	1 x 10^9	10 Mpc	2μas
Cen A	5 x 10^7	4 Mpc	0.25μas



Shadow diameter : 1~5 times Schwartshild radius
For imaging shadow, ~ 10μas resolution is required

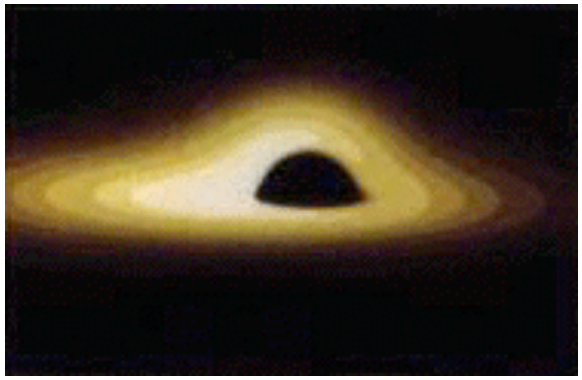
Angular resolution of telescopes

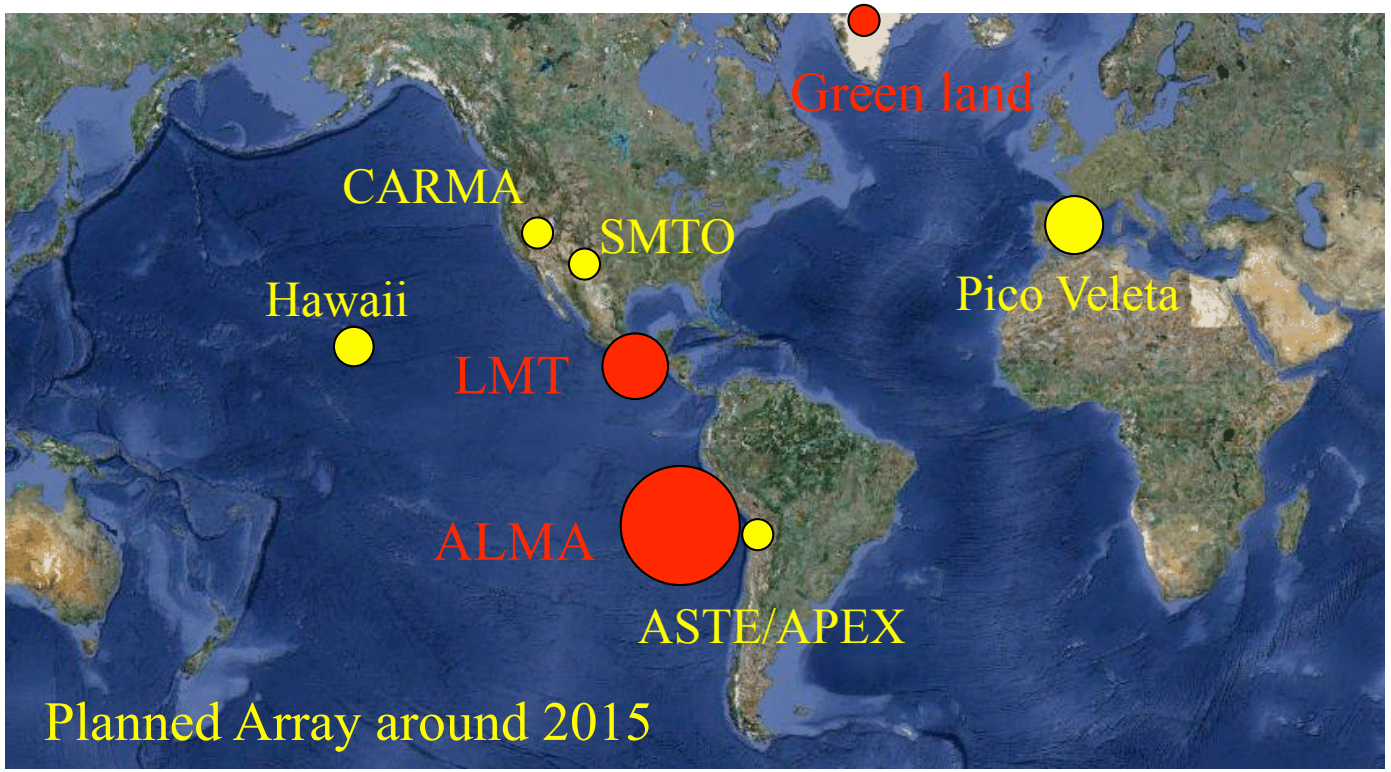
- Wavelength – angular resolution diagram



Event Horizon Telescope

- Global network of mm/sub-mm VLBI to Image BH shadow, jet-root etc.
- Target source : Sgr A*, M87, Blazars, etc.
- Target resolution : ~20 uas or higher

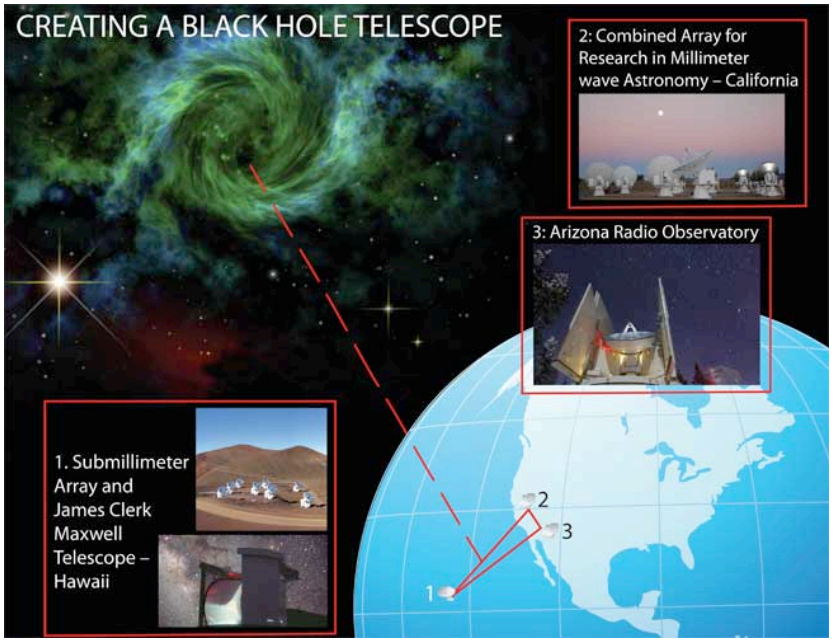


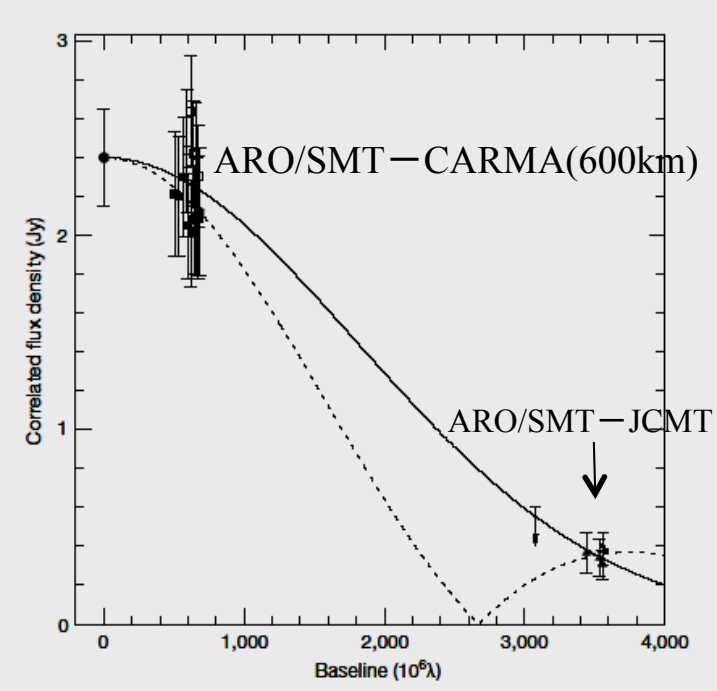


Phase-up ALMA joining in ~2015

Doeleman+(2008)

- 230GHz VLBI with JCMT – SMTO – CARMA



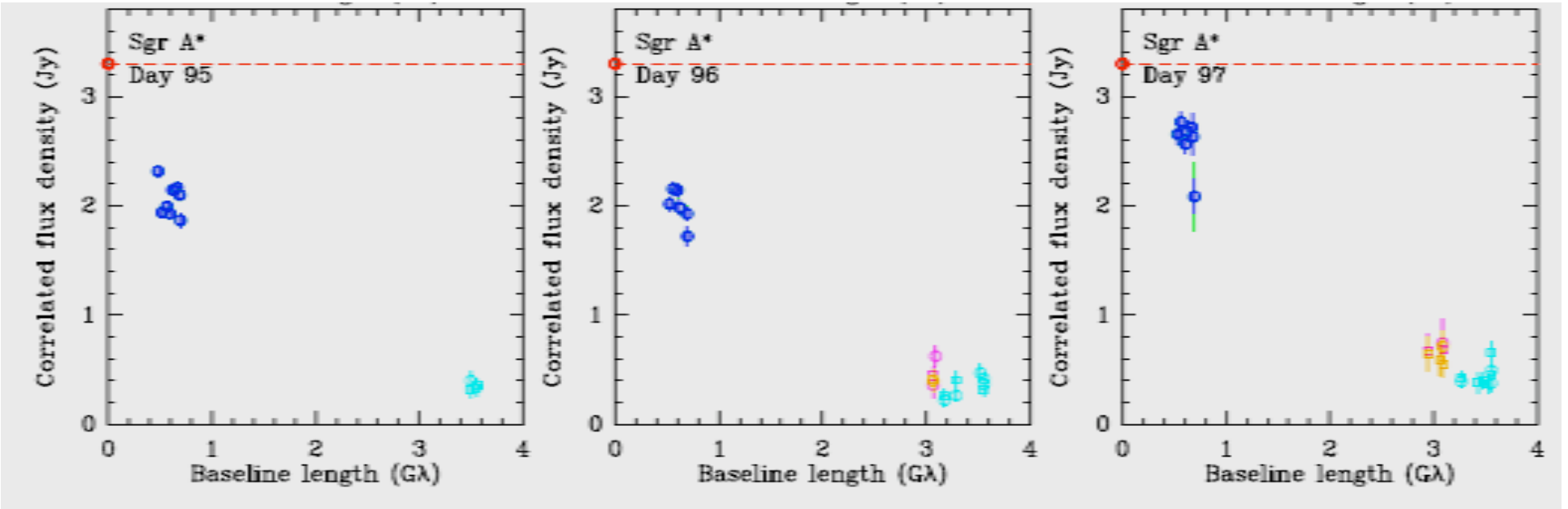


Non-imaging analysis (traditional UV distance plot)

- 37±(16,10) uas as intrinsic diameter of Sgr A*
- As compact as ~ 4 R_s

Sgr A* in 2009 April

- 3-day obs. with Hawaii-SMTO-CARMA
- Detection with all baselines
- Variation with SMTO-CARMA baseline

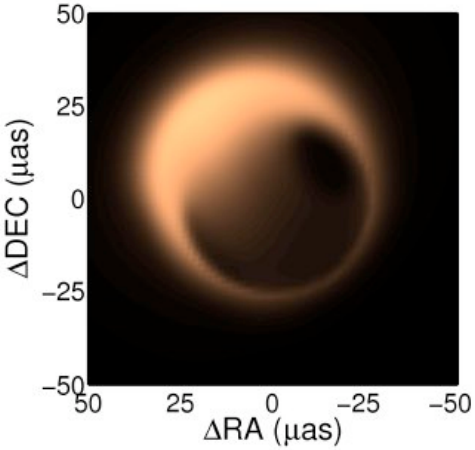


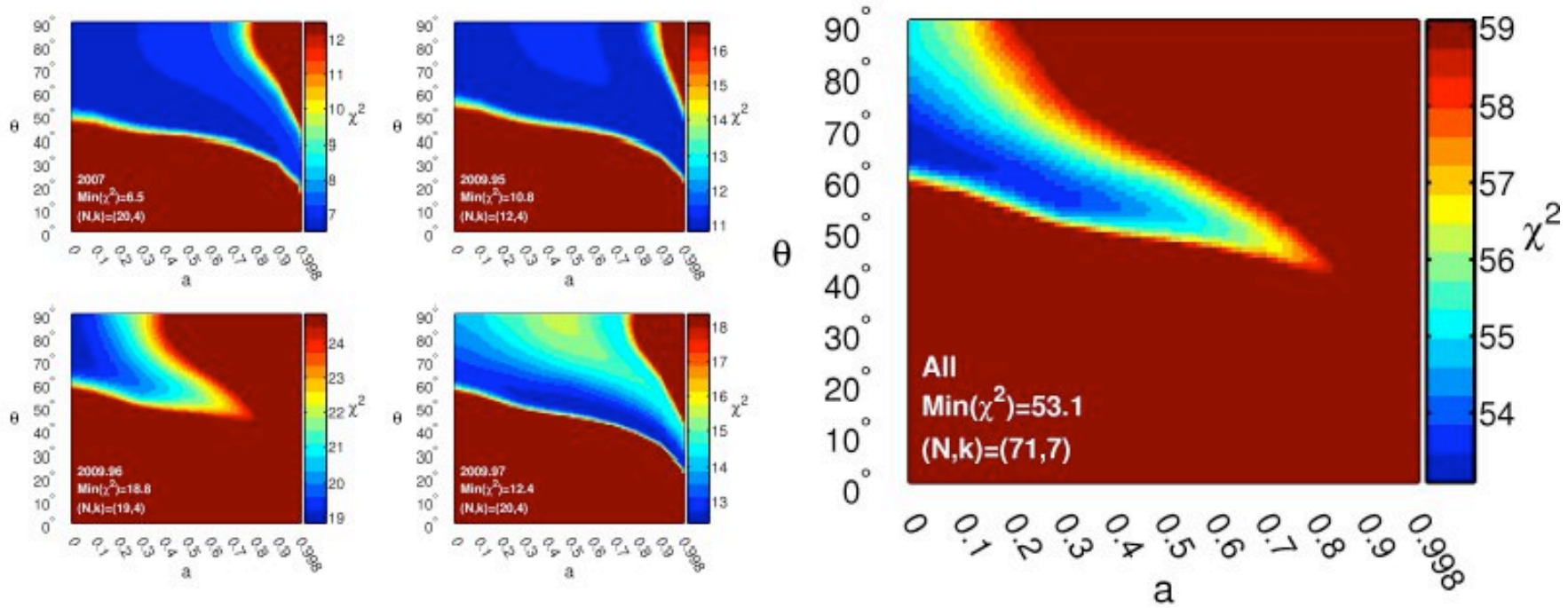
Structure variation at 0.4 mas scale (~ 4 AU, ~ 40 R_g)

Fish +(2011)

Sgr A* parameters up-dated

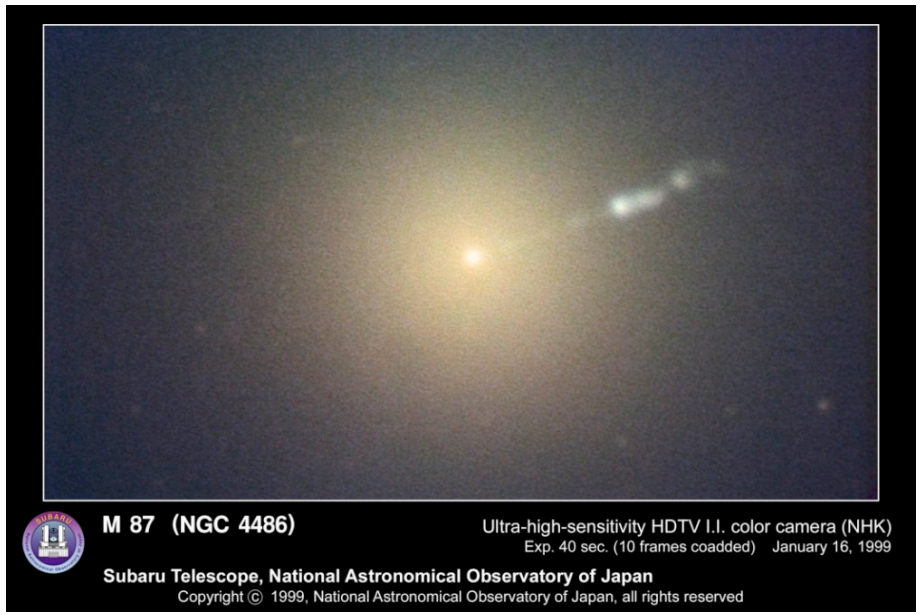
- Fish+(2011), Broderick+(2011) constraining parameters with 4-nights data (2007, + 3 days in 2009)

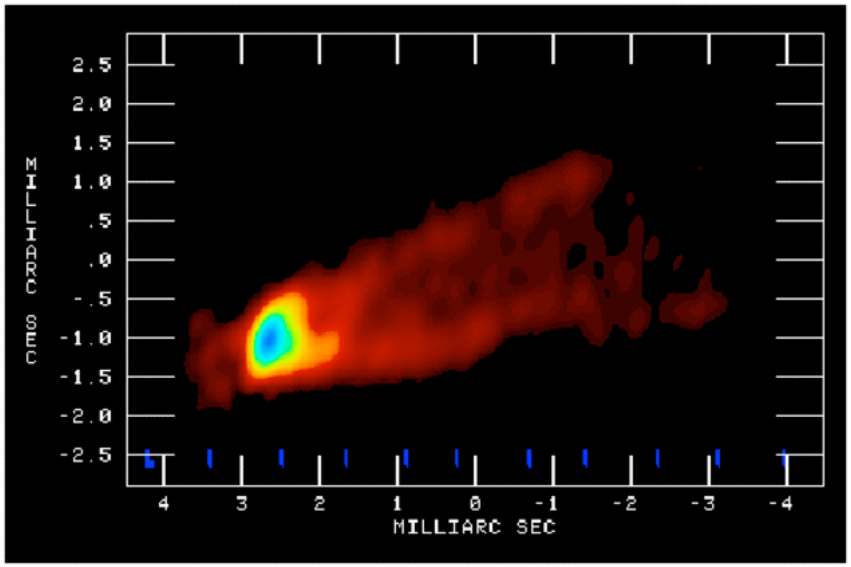




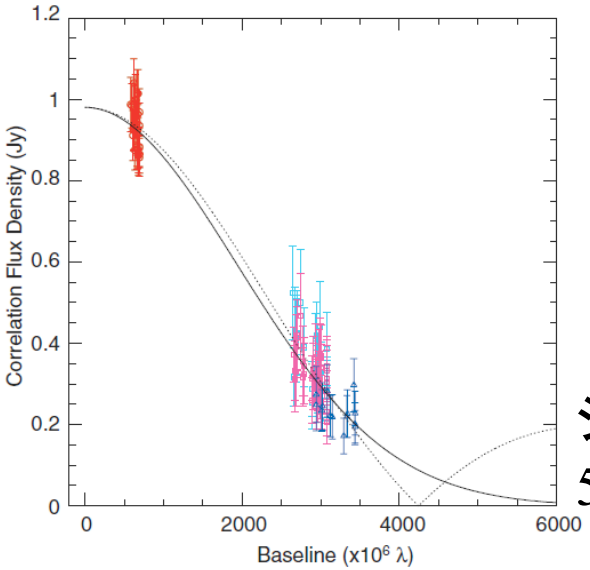
Low inclination/extreme Kerr case is ruled out (?)

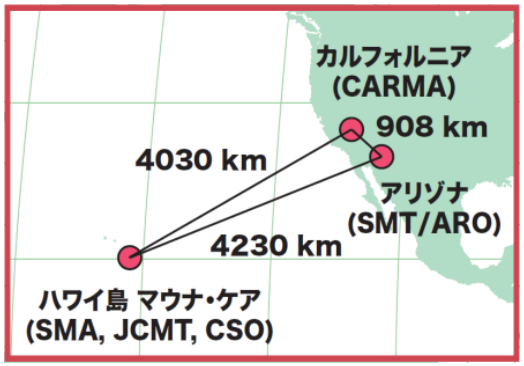
M87 jet-base detection





M87の光学写真（左）と中心部のジェット（右）





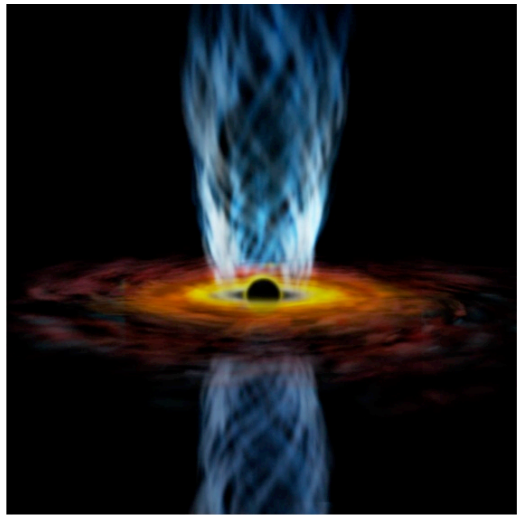
シュバルツシルト半径の
5.5倍の構造を検出

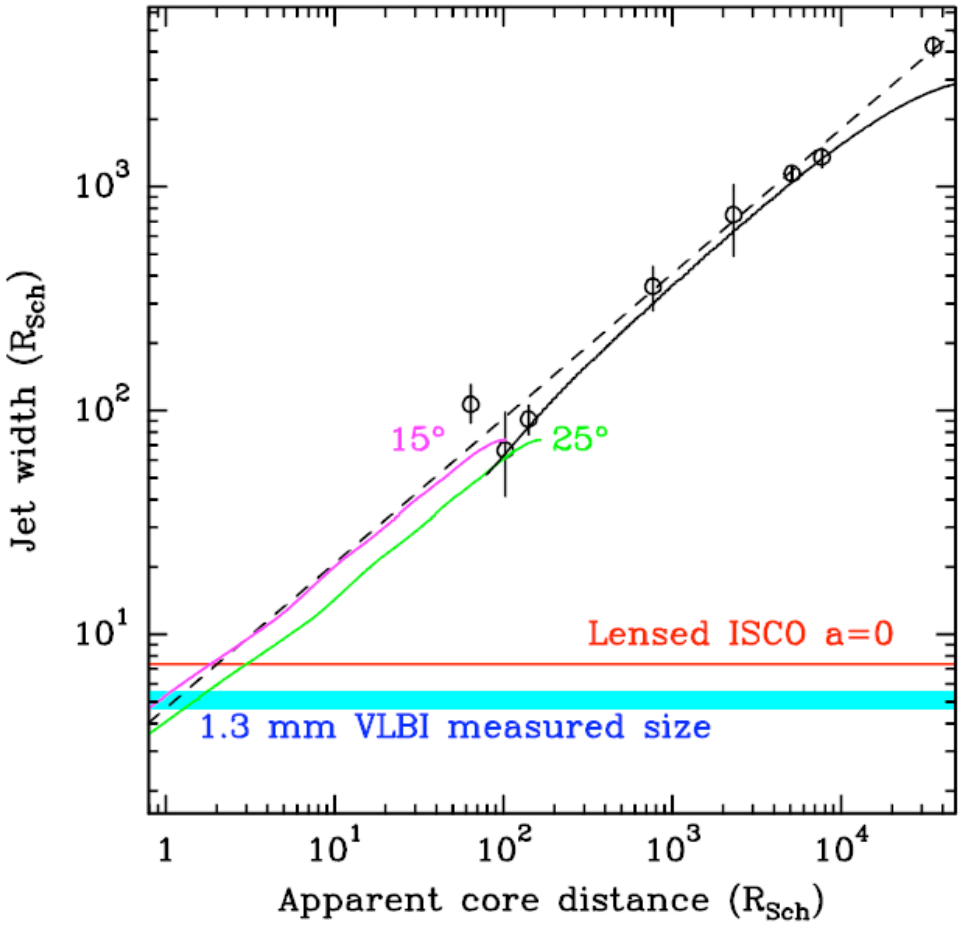
ブラックホール極く近傍の
ジェットの根元と考えられる
Doeleman+(2012), Science

M87 : spinning BH ?

- Observed size: smaller than ISCO of a=0 BH
- Position : within ~2 Rs (if Hada+11 applies to 230 GHz)
- Sheath launched from AD ?

  > if so, suggests spinning BH





Science 338, 355 (2012) REPORTS

Jet-Launching Structure Resolved Near the Supermassive Black Hole in M87

Sheperd S. Doeleman,[1,2]* Vincent L. Fish,[1] David E. Schenck,[1,3]† Christopher Beaudoin,[1] Ray Blundell,[2] Geoffrey C. Bower,[4] Avery E. Broderick,[5,6] Richard Chamberlin,[7] Robert Freund,[3] Per Friberg,[8] Mark A. Gurwell,[2] Paul T. P. Ho,[9] Mareki Honma,[10,11] Makoto Inoue,[9] Thomas P. Krichbaum,[12] James Lamb,[13] Abraham Loeb,[2] Colin Lonsdale,[1] Daniel P. Marrone,[3] James M. Moran,[2] Tomoaki Oyama,[10] Richard Plambeck,[4] Rurik A. Primiani,[2] Alan E. E. Rogers,[1] Daniel L. Smythe,[1] Jason SooHoo,[1] Peter Strittmatter,[3] Remo P. J. Tilanus,[8,14] Michael Titus,[1] Jonathan Weintroub,[2] Melvyn Wright,[4] Ken H. Young,[2] Lucy M. Ziurys[3]

hole itself (*2*–*4*), but no observations to date have had the angular resolution required to detect and confirm structure on these scales for extragalactic jet sources. High-resolution radio interferometry of these sources at centimeter wavelengths is limited by optical depth effects that obscure the innermost accretion region. For these reasons, it remains unclear if jet formation requires a spinning black hole (*5*, *6*), and if so, whether jets are more likely to be formed when the orbital angular momentum of the accretion flow is parallel (prograde) or antiparallel (retrograde) to the black hole spin (*7*, *8*). To address these questions, we have assembled a very long baseline interferometry (VLBI) array operating at a wavelength of 1.3 mm, the Event Horizon Telescope (*9*), where AGN start to become optically thin and

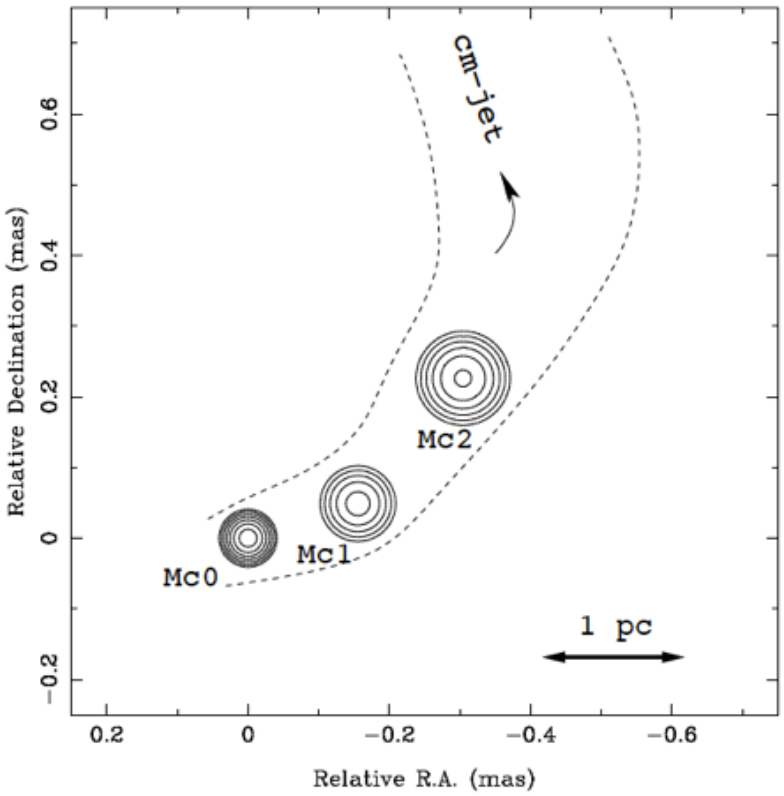
この論文のabstractを歌詞にした歌がYou tubeに投稿されている…

Approximately 10% of active galactic nuclei exhibit relativistic jets, which are powered by the accretion of matter onto supermassive black holes. Although the measured width profiles of such jets on large scales agree with theories of magnetic collimation, the predicted structure on accretion disk scales at the jet launch point has not been detected. We report radio interferometry observations, at a wavelength of 1.3 millimeters, of the elliptical galaxy M87 that spatially resolve the base of the jet in this source. The derived size of 5.5 ± 0.4 Schwarzschild radii is significantly smaller than the innermost edge of a retrograde accretion disk, suggesting that the M87 jet is powered by an accretion disk in a prograde orbit around a spinning black hole.

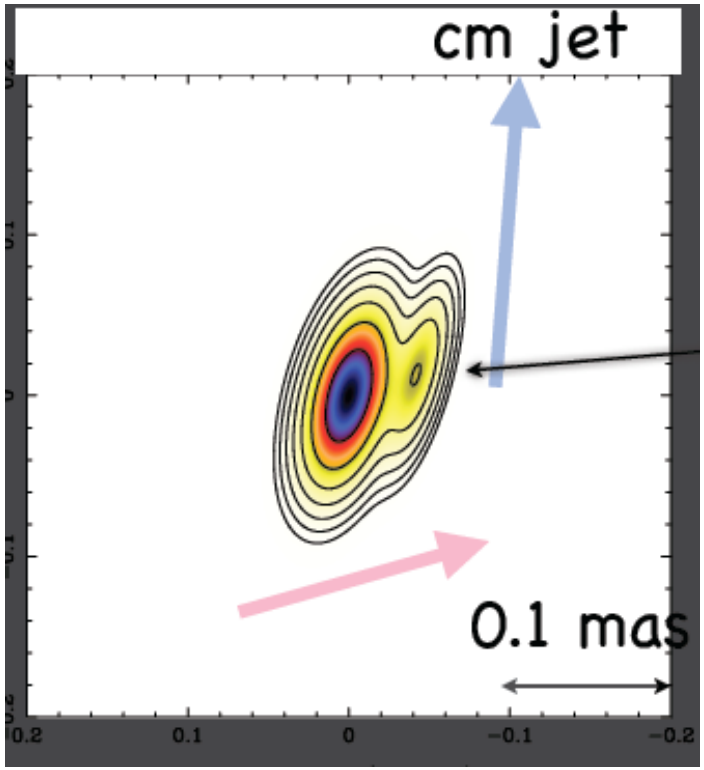
Blazar jets

- Jet root images at 230G !! ($\theta \sim 60$ μas)

J1924 by Lu+(2012)

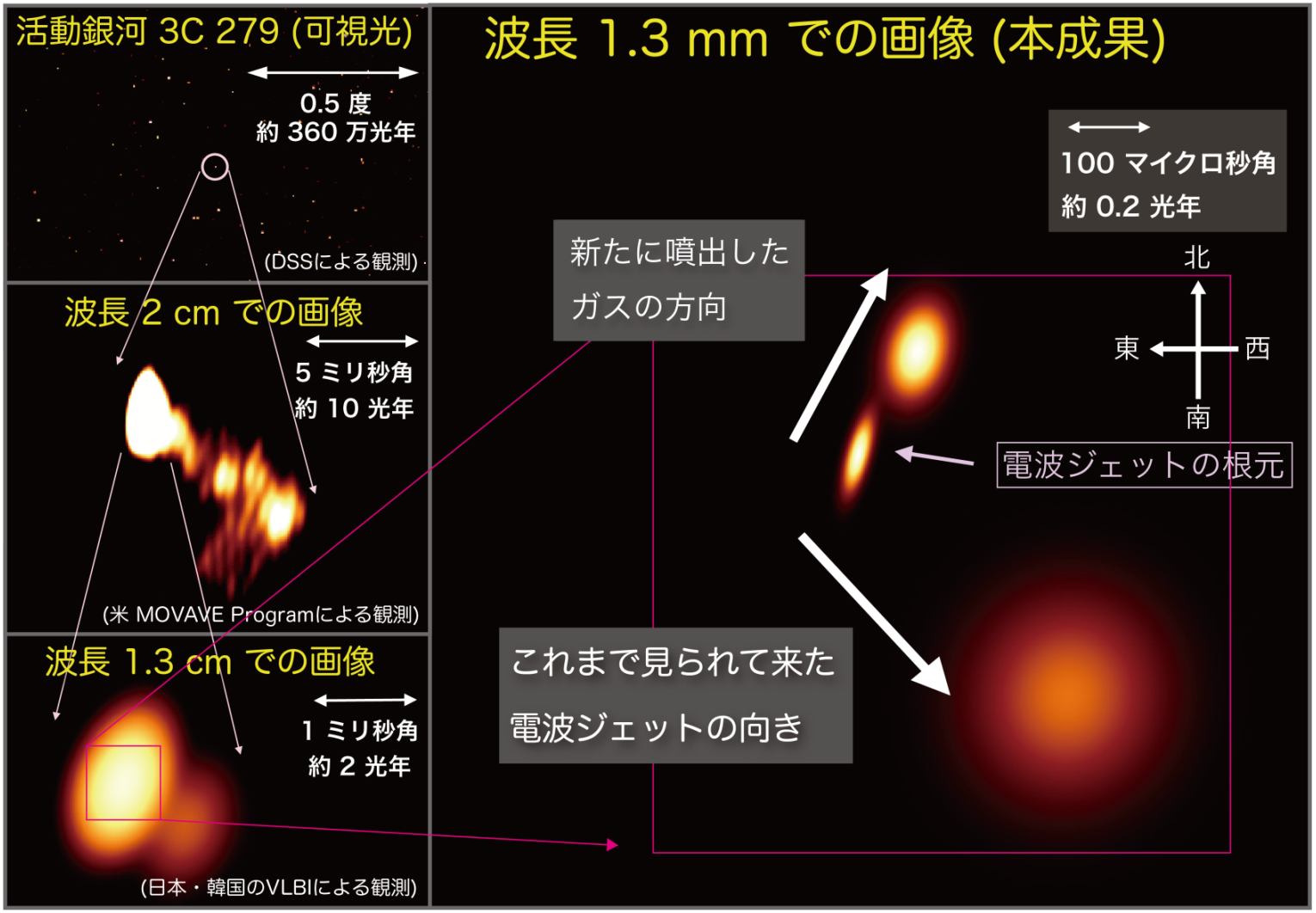


NRAO530 by Akiyama+



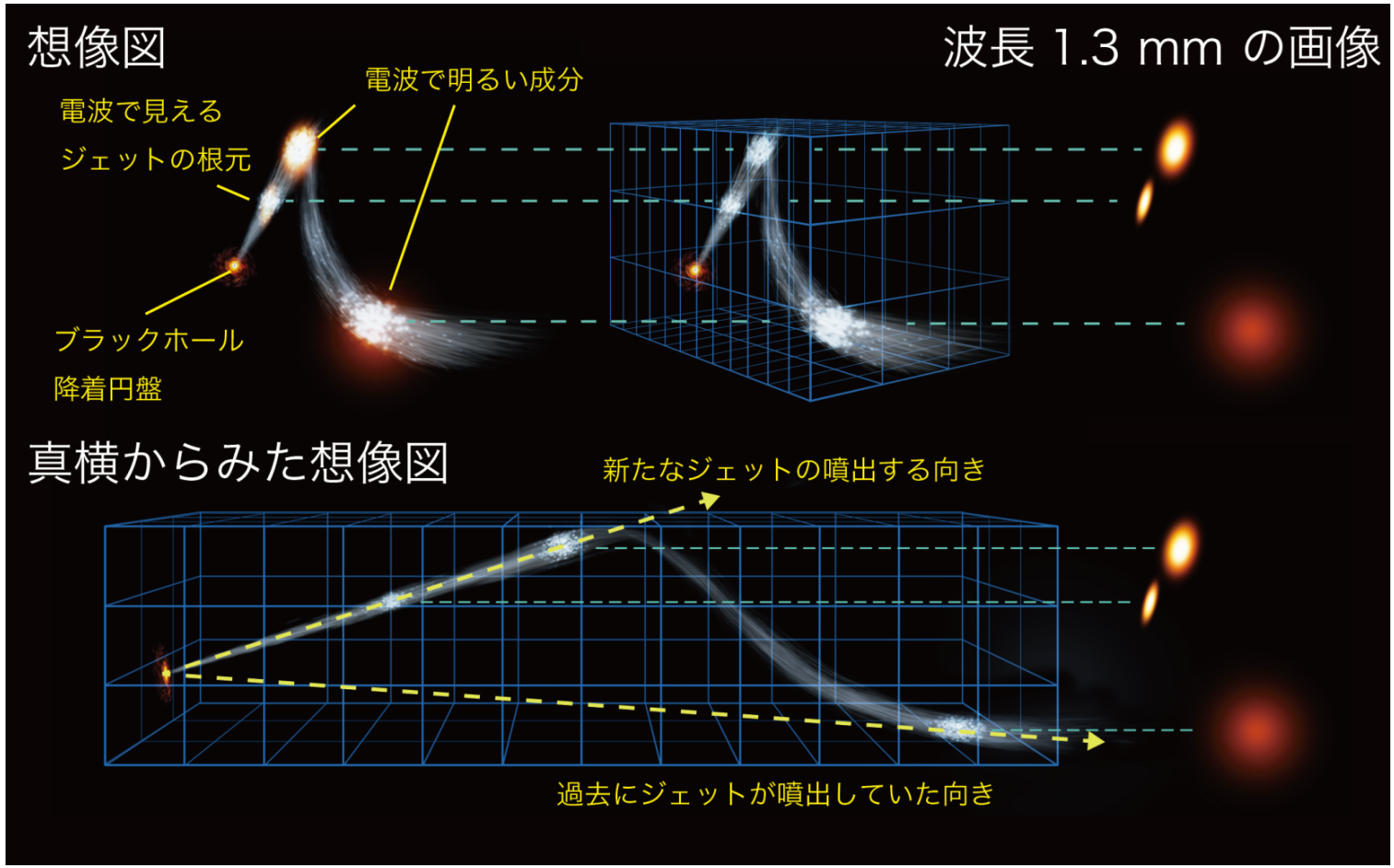
3C279 case

- Jet bending w.r.t. large scale jet



Interpretation of bending jet

- Small jet-angle variation



Status of APP (ALMA phase-up project)

- Phasing-up 64 of ALMA antenna for sub-mm VLBI
- MRI proposal already approved (2011)

- PDR meeting held in Nov 1~2.

- Now waiting for formal approval from ALMA project

New imaging technique with compressive sensing

- UV coverage of VLBI is sparse
- FFT from UV plane to image is usually done with 0 padding (otherwise ill-posed problem)

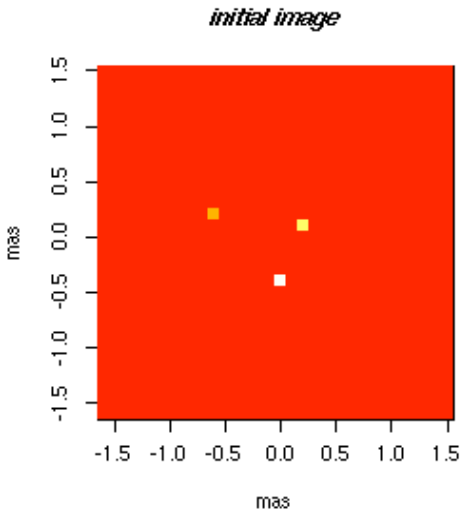
$$I_\nu(x,y) = \int\int S_\nu(u,v) e^{-2\pi i(ux+vy)} du dv$$

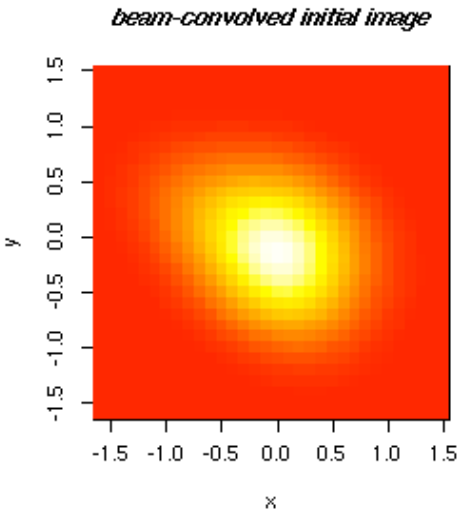
- Compressive sensing is a way to directly solve ill-posed linear equation under the condition that the solution is sparse enough
- No 0-padding allows us to get super resolution !

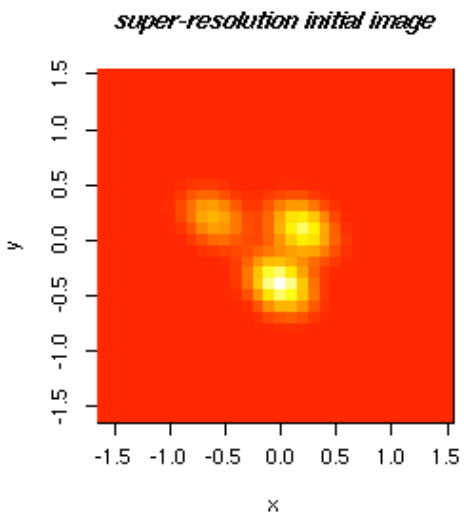
例：複数点源

- ビームサイズの1/2程度離れた複数点源
- 通常のイメージングでは判別不能（広がった像になる）
- 圧縮センシングによる超分解イメージなら点源が判別可能

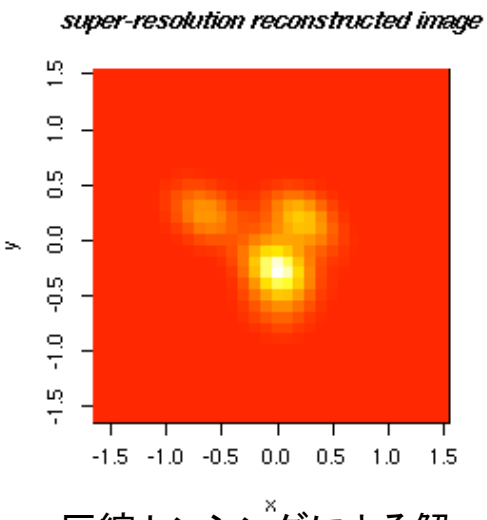
初期像 × 通常ビーム







初期像 × 超解像ビーム



圧縮センシングによる解 × 超解像ビーム

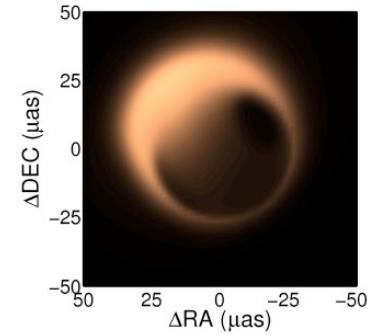
BH Shadow

- 通常のイメージングでは
  リング、三日月が分解不能

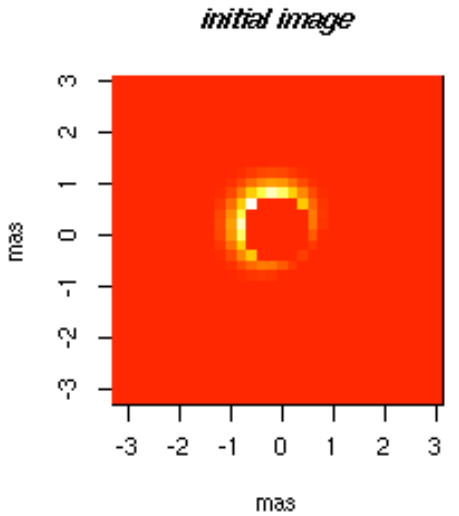
- 圧縮センシングによる
  超解像イメージなら形が
  判別可能

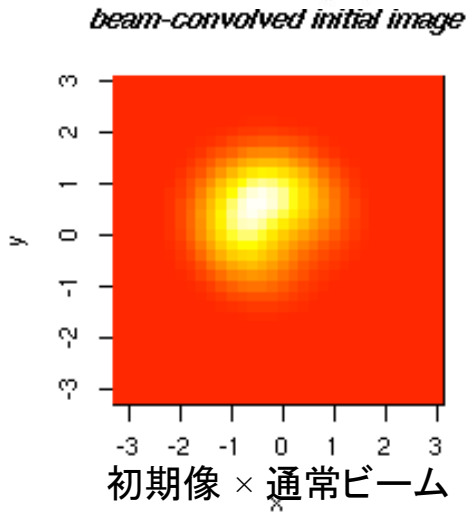
→

EHT観測によるBH観測に
大きなインパクト !?

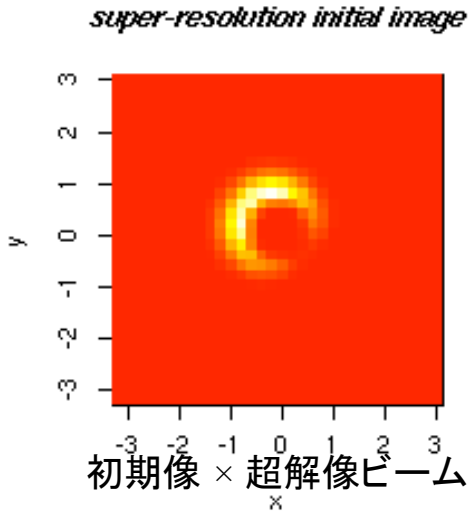


初期像

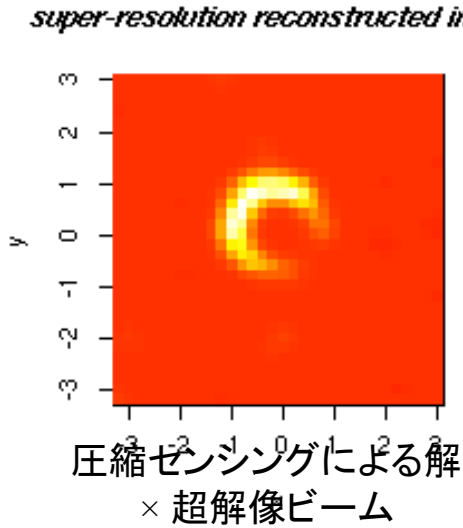




初期像 × 通常ビーム



初期像 × 超解像ビーム



圧縮センシングによる解
× 超解像ビーム

Something on KVN + VERA

Key features

•KVN+VERA provides much denser UV coverage

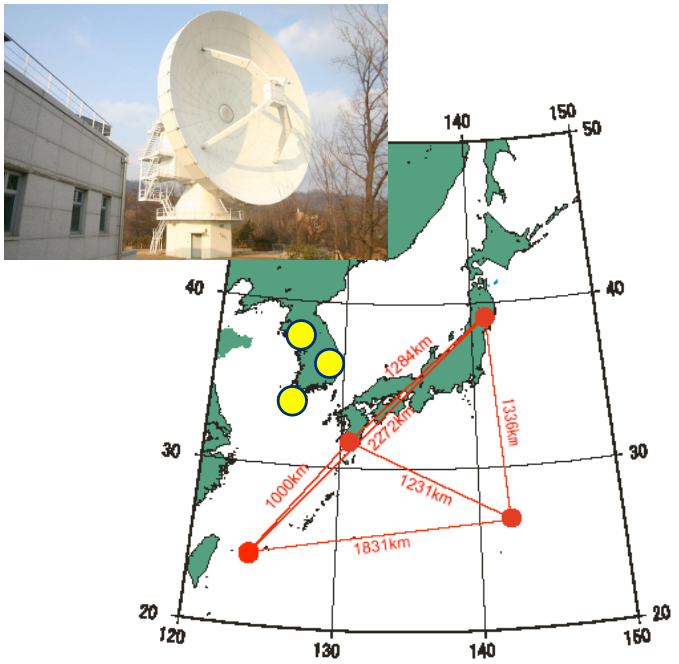
•7 stations, 21 Baselines with 300 – 2000 km

•Frequency 22 or 43 GHz (+86, 129 for KVN)

Multi-frequency monitor with

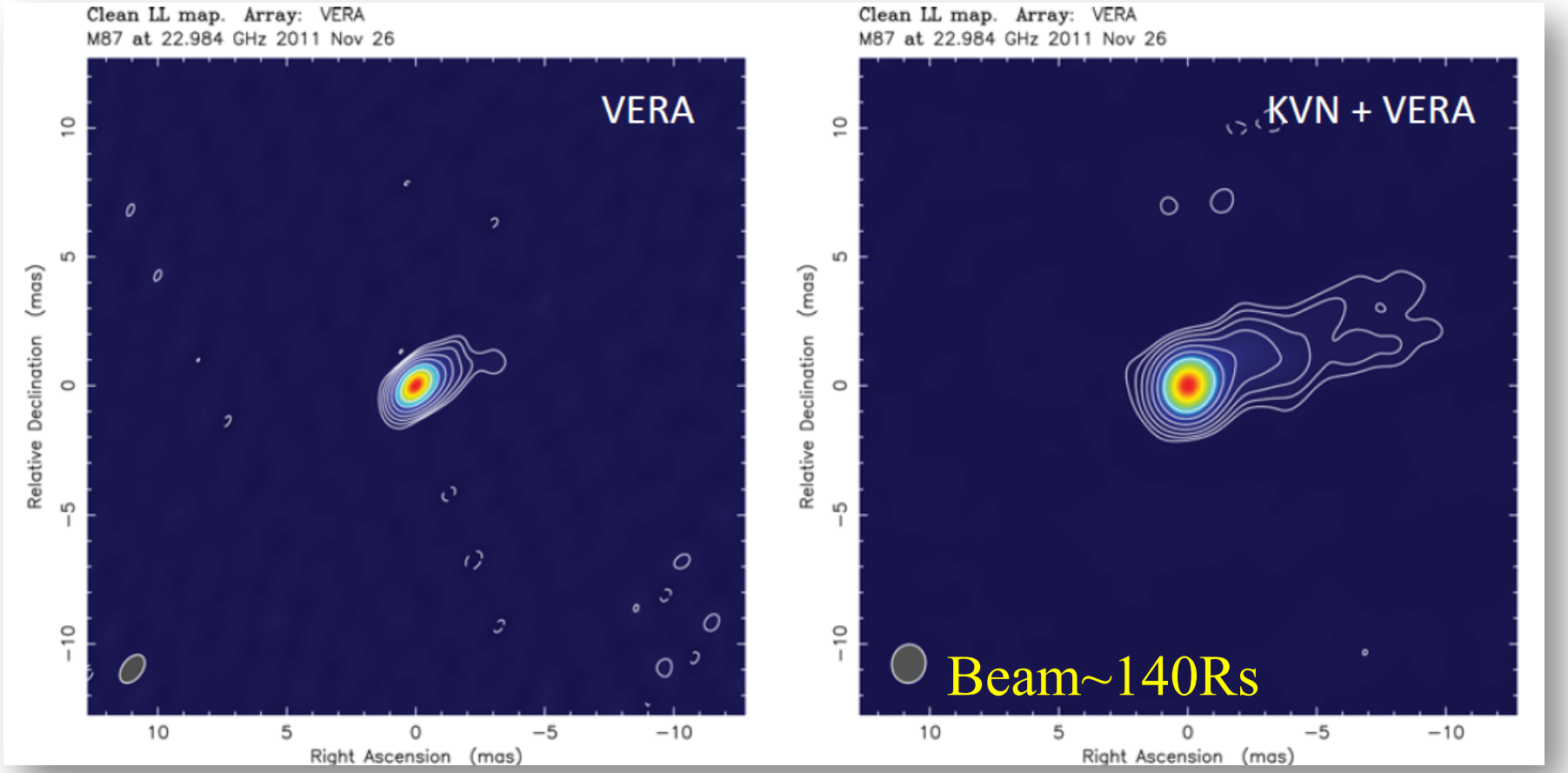
KVN +VERA of Sgr A*, M87,

and gamma-ray blazars



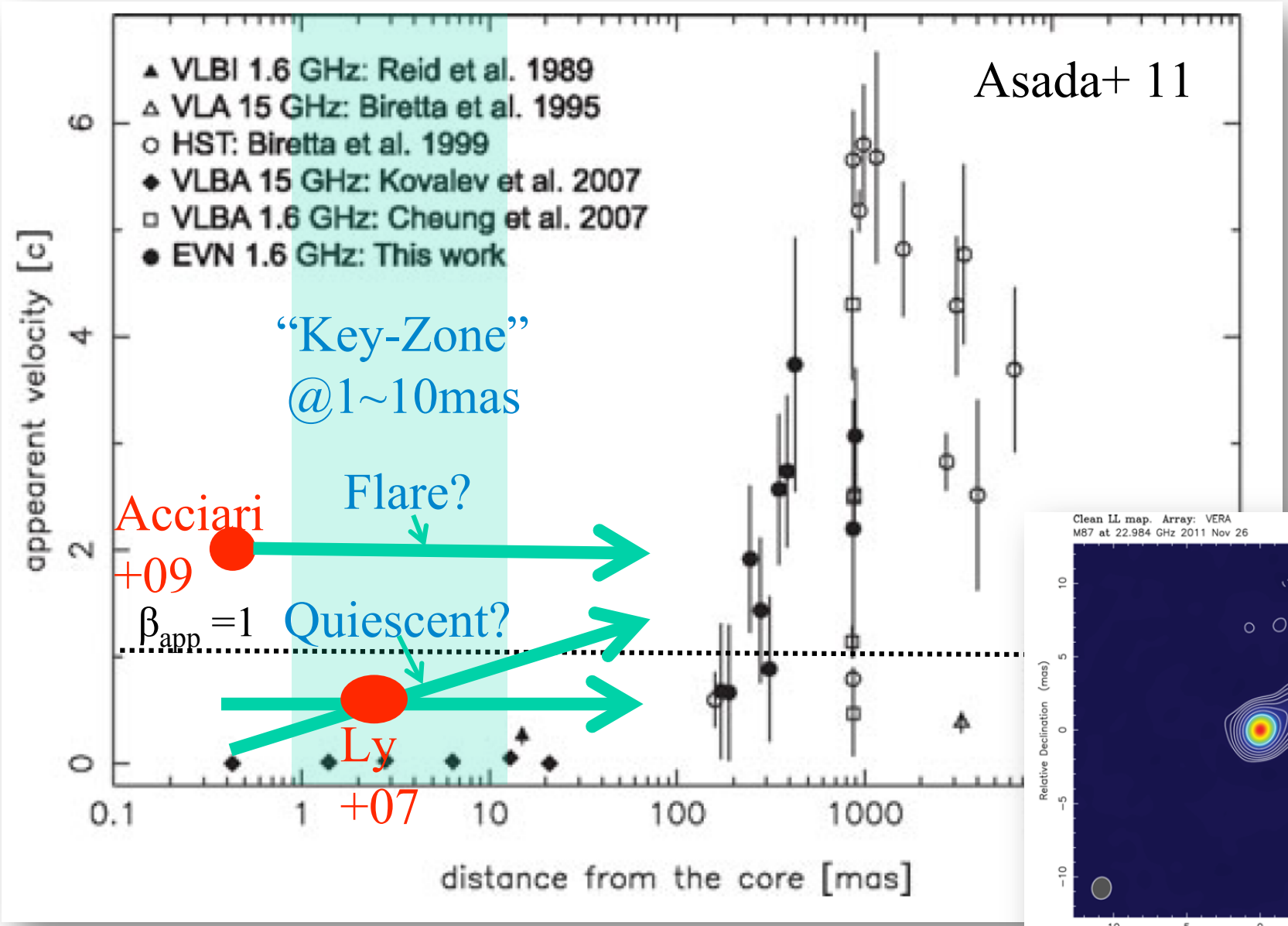
Improved M87 image @22GHz

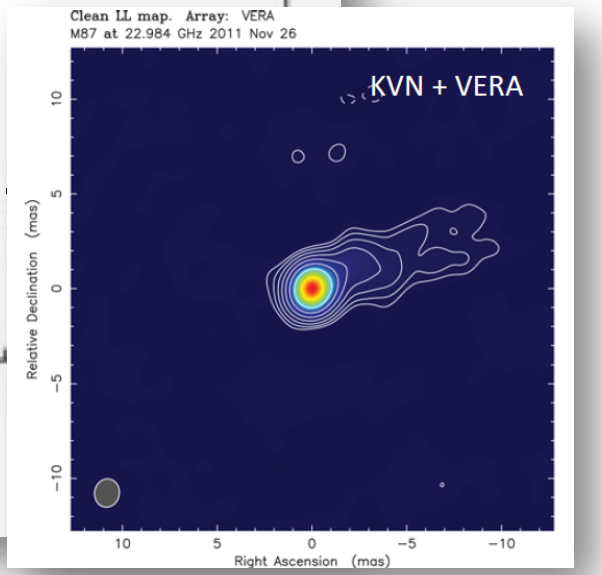
Data analysis: K. Niinuma



With KVN+VERA, we can clearly chase β_{app}@1~10mas.

M87 Jet launch/acceleration

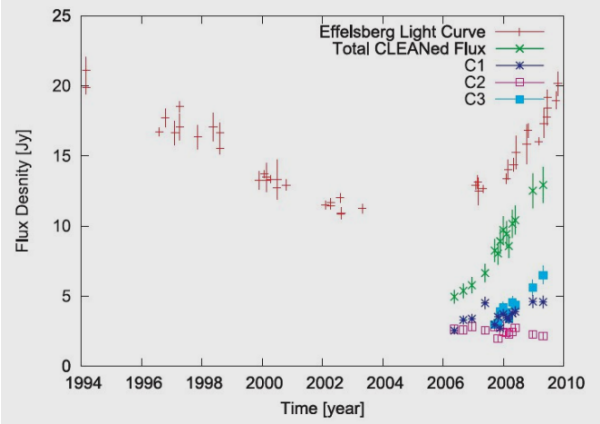




GENJI : Blazar monitor

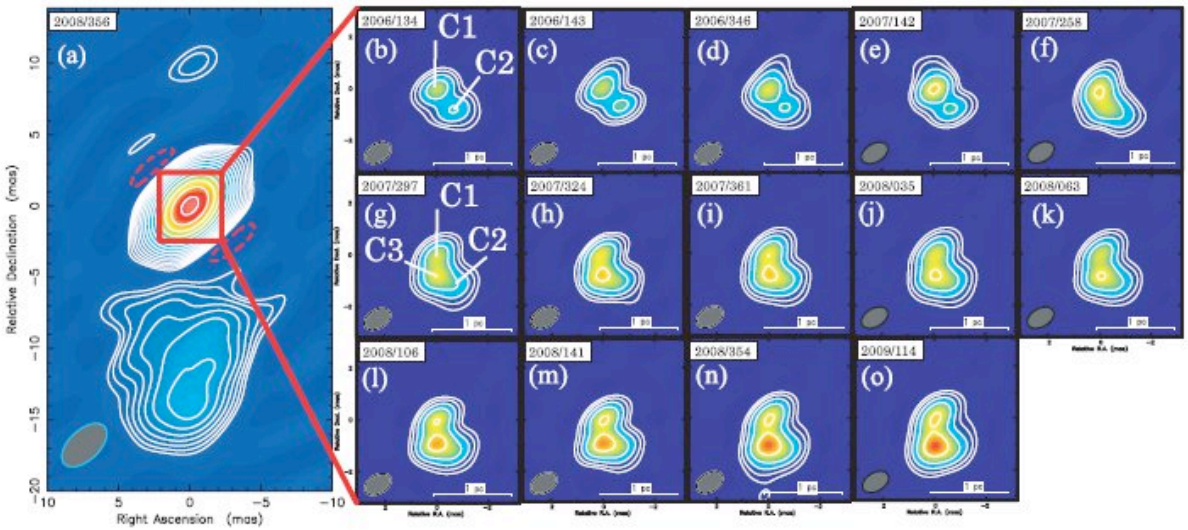
- Example : 3C84, radio jet detection (VERA) after γ-ray flare (Fermi)

Nagai+(2010)

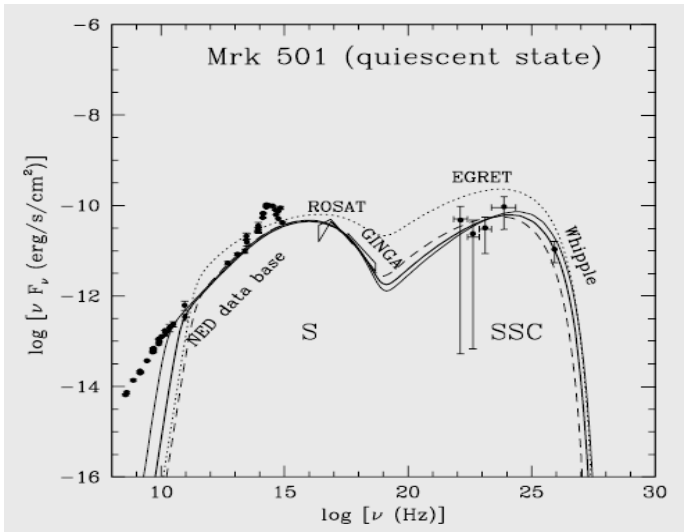


Radio light curve

VLBI map (2 x 2 pc), at 22 GHz



cm + (sub-)mm VLBI will lead comprehensive understanding (higher resolution & lower optical depth …)

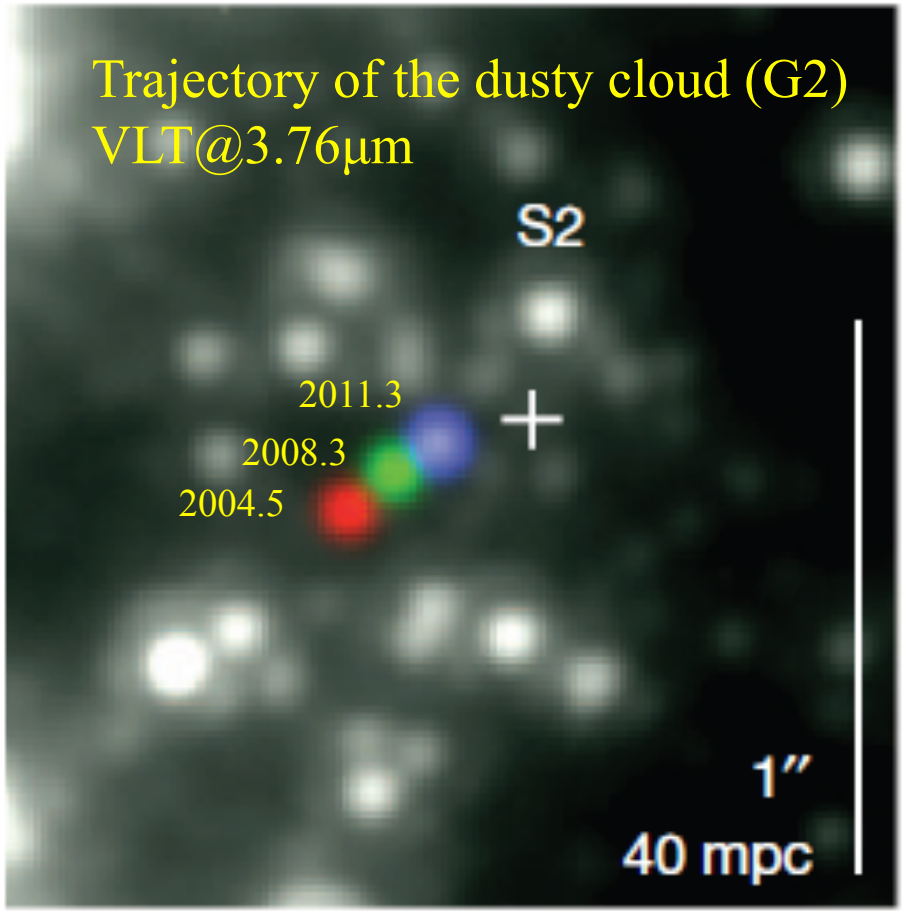


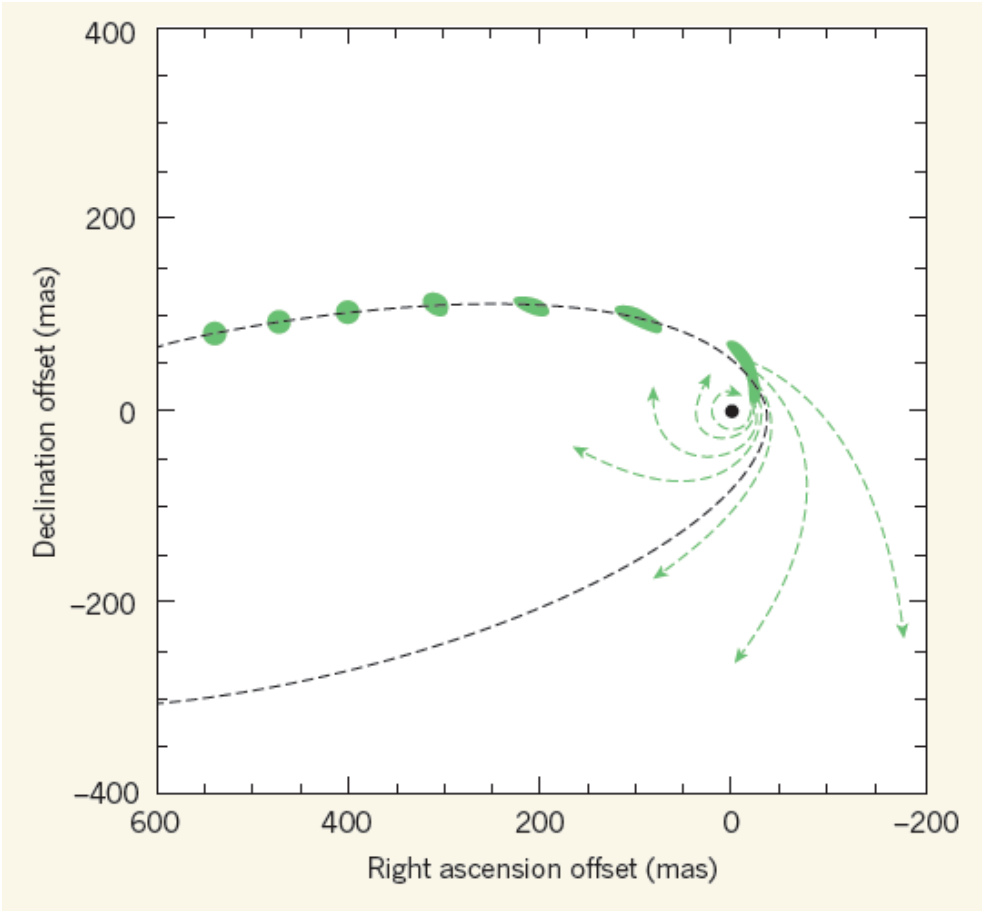
SSC model for Mrk 501 (Kino+2001)

γ-ray mitting region:<1000 AU

Sgr A* 2013 event

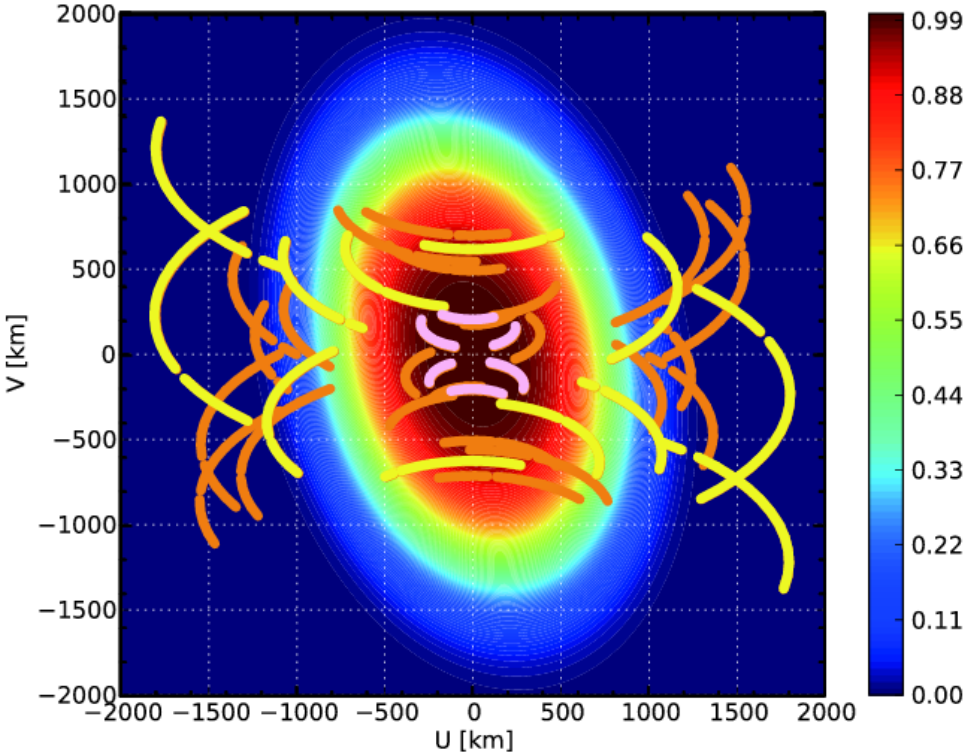
A gas cloud has been spotted approaching the Milky Way's central black hole. Observations of its closest approach, expected to occur in mid-2013, may offer insight into the black hole's immediate surroundings.





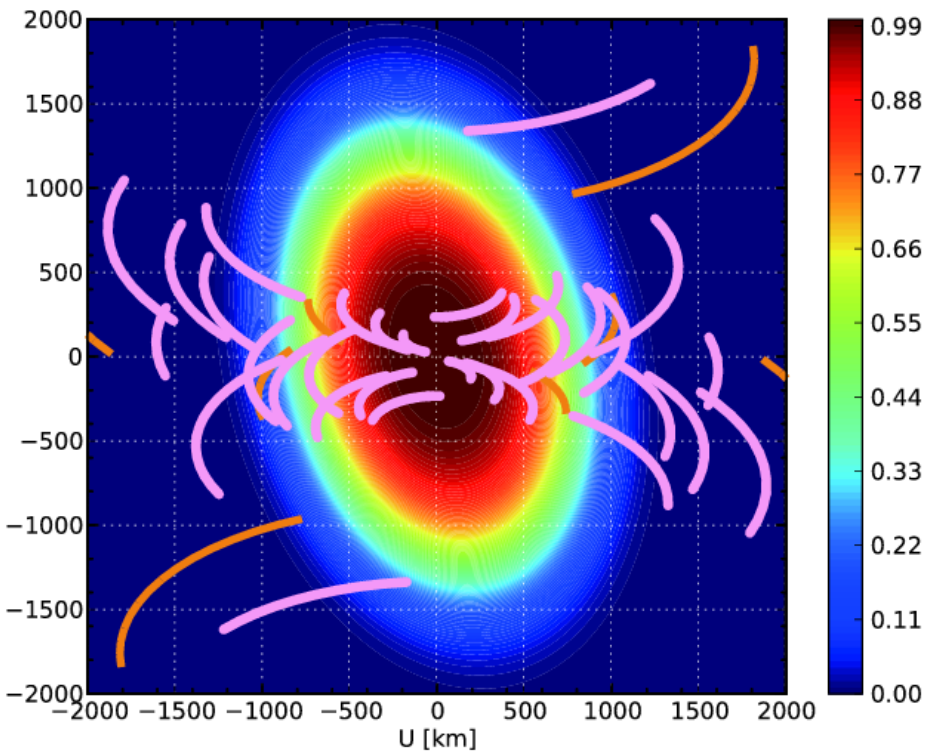
KVN+VERA has better (*u*,*v*) coverage than VLBA+GBT @ 43GHz!!!

KVN+VERA



Pink: KVN
Orange: KVN+VERA
Yellow: VERA only

VLBA+GBT



Pink: VLBA+GBT
Orange: VLBA only

Plan for 2013 Sgr A* event

- VERA monitoring every 3 weeks (proposed by Akiyama)

- Additional VERA+KVN imaging (TOO-type ?, but still commissioning phase)

- Collaboration with KVN team

  Single dish monitoring (22/43/86/129 GHz)

  + 3 station imaging up on flaring status