

ミリ波サブミリ波VLBIの現状と将来

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Contents

- EHT and (sub)mm VLBI for imaging black hole shadow
- Our recent activity
- Future Prospect

1. EHT and mm VLBI for imaging black hole shadow

Resolving 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



Fukue et al 1989

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	$M_{\text{BH}}/M_{\text{sun}}$	Distance	Angular radius
Sgr A*	4×10^6	8 kpc	$10 \mu\text{as}$
M87	6×10^9	15 Mpc	$7 \mu\text{as}$
M104	1×10^9	10 Mpc	$2 \mu\text{as}$
Cen A	5×10^7	4 Mpc	$0.25 \mu\text{as}$

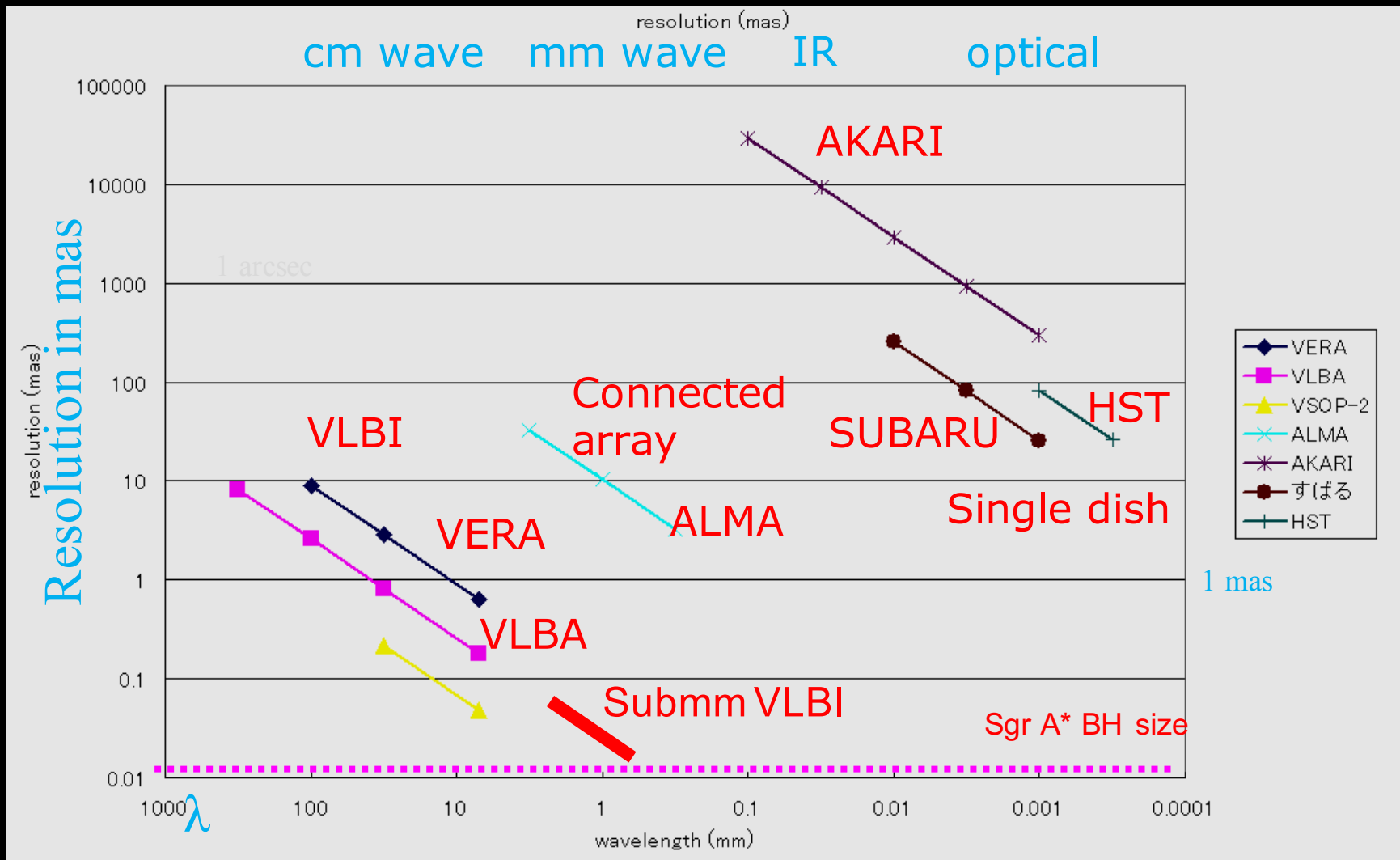


Shadow diameter : 1~5 times Schwarzschild radius

For imaging shadow, $\sim 10 \mu\text{as}$ resolution is required

Angular resolution of telescopes

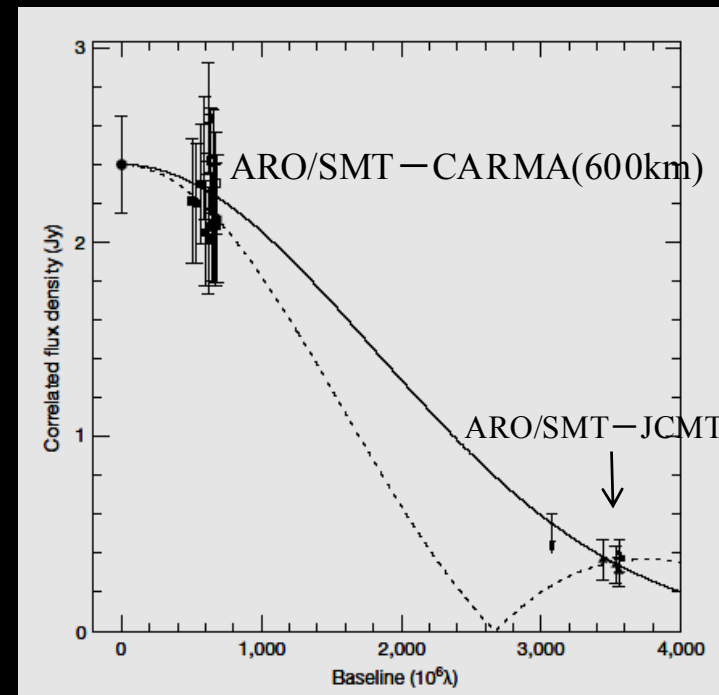
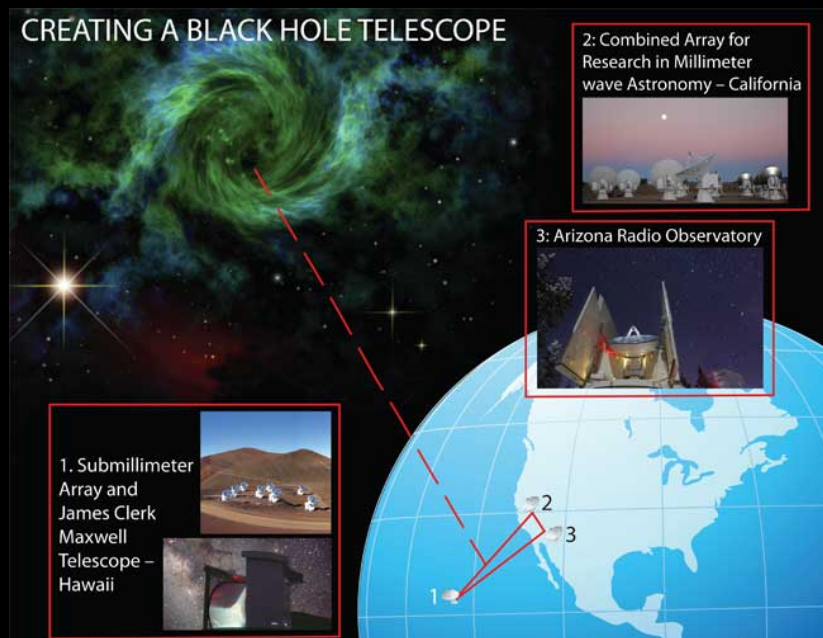
- angular resolution: $\Theta \sim \lambda / D$



Sgr A* case

Doeleman+(2008)

- 230GHz VLBI with JCMT – SMT – CARMA



Non-imaging analysis (traditional UV distance plot)

- $37 \pm (16, 10)$ Intrinsic diameter of Sgr A*
- As compact as $\sim 4 R_s$

M87 jet-base detection

VLBA @ 7mm

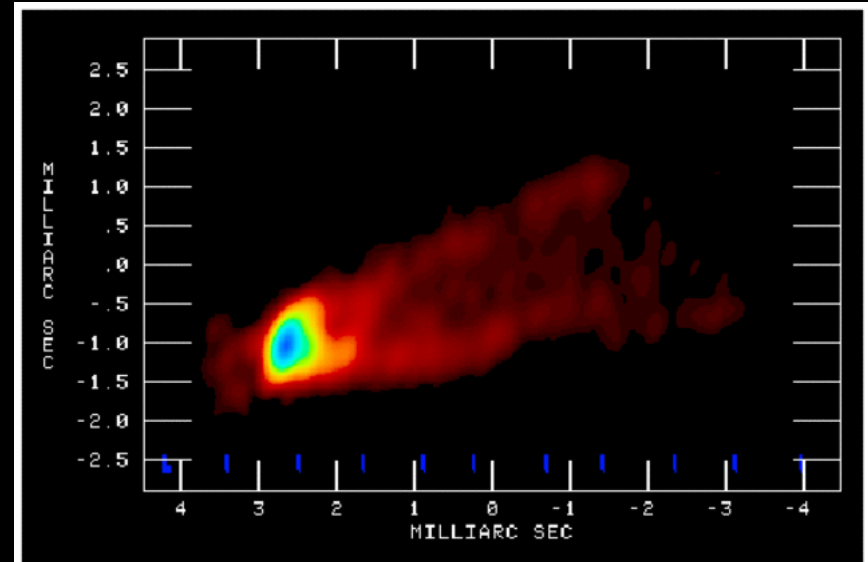


M 87 (NGC 4486)

Ultra-high-sensitivity HDTV I.I. color camera (NHK)
Exp. 40 sec. (10 frames coadded) January 16, 1999

Subaru Telescope, National Astronomical Observatory of Japan

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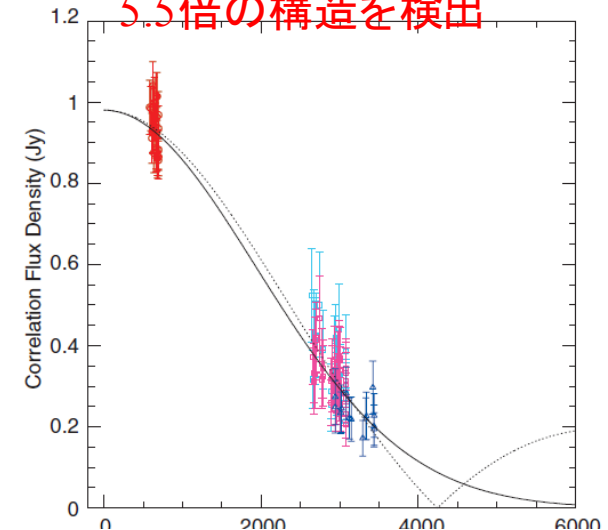
Science 338, 355 (2012)

REPORTS

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

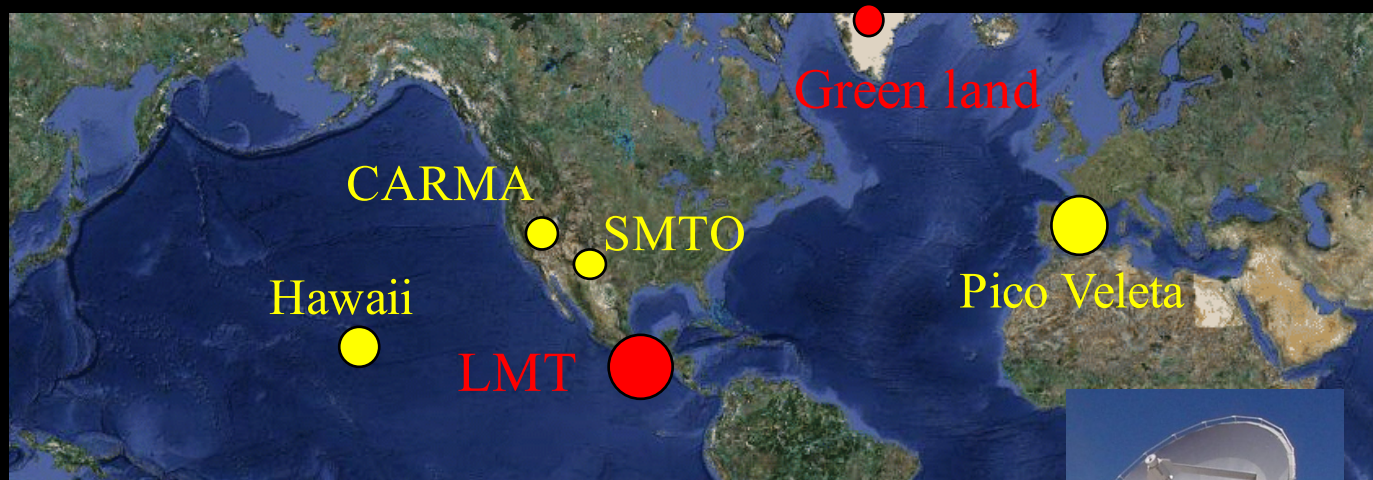
Sheperd S. Doeleman,^{1,2*} Vincent L. Fish,¹ David E. Schenck,^{1,3†} Christopher Beaudoin,¹ Ray Blundell,² Geoffrey C. Bower,⁴ Avery E. Broderick,^{5,6} Richard Chamberlin,⁷ Robert Freund,³ Per Friberg,⁸ Mark A. Gurwell,² Paul T. P. Ho,⁹ Mareki Honma,^{10,11} Makoto Inoue,⁹ Thomas P. Krichbaum,¹² James 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

シュバルツシルト半径の
5.5倍の構造を検出



EHT (Event Horizon Telescope)

(sub)mm VLBI array to resolve BH images



ALMA (NRAO/ESO/NAOJ)



APP (ALMA Phase-up Project)

International collaboration
for ALMA up-grade



- ALMA board acceptance in 2012
- APP CDR (Critical Design Review) held in 2013
- APP test observations in 2014/15
- Open use in 2016 ? (Cycle-4 ?)

ALMA VLBI era is coming soon

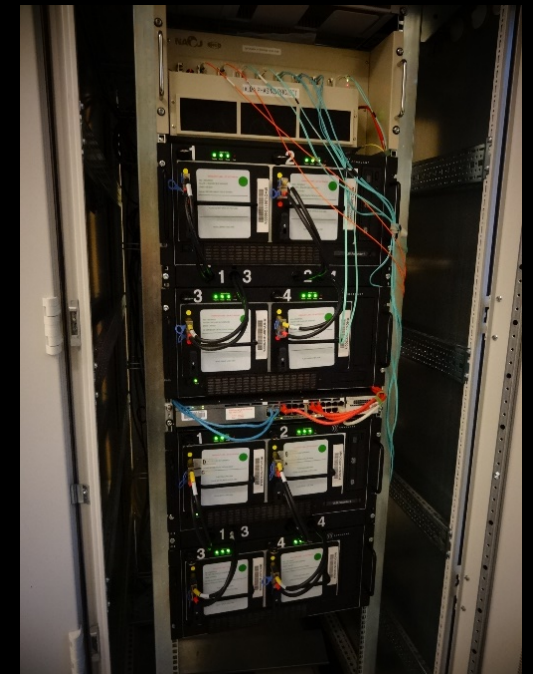
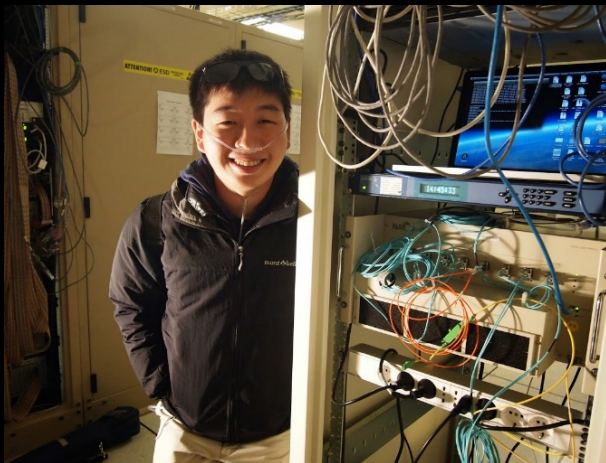
We need to get prepared for the era for sub-mm VLBI with ALMA



APP contribution from Japan

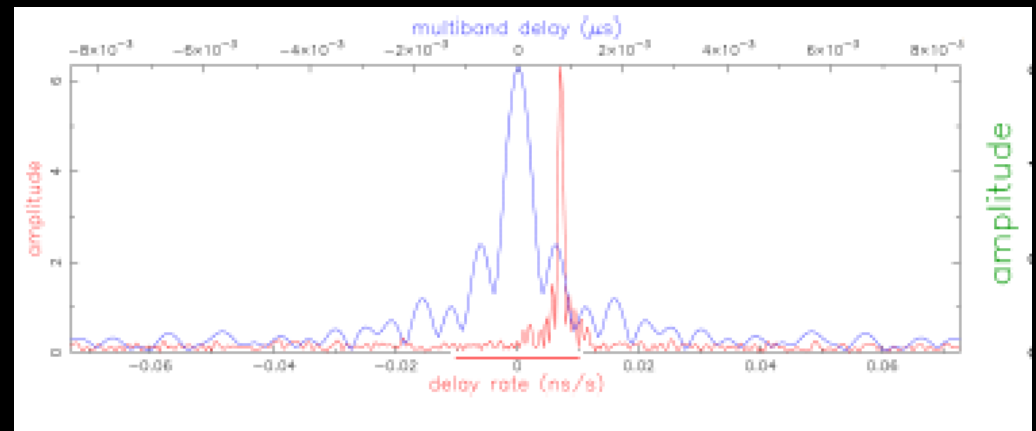
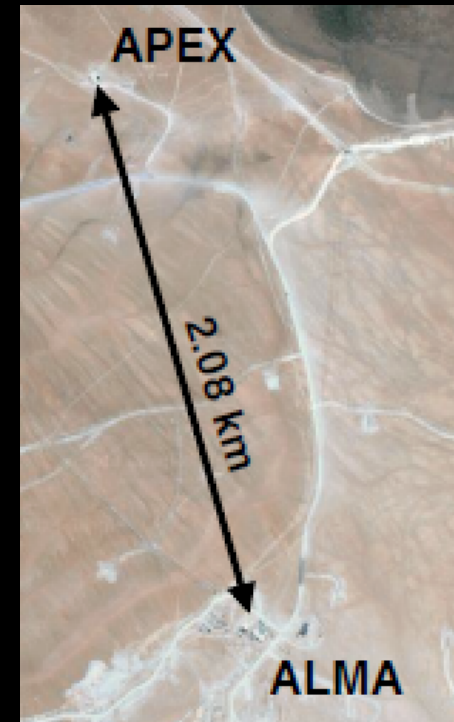
- contribution to APP: optical fiber link (AOS-OSF)
 - data transmission between ALMA site (5000m) and OSF (2900m) through one fiber
 - 8 x 8 Gbps DWDM modules

installed in June 2014



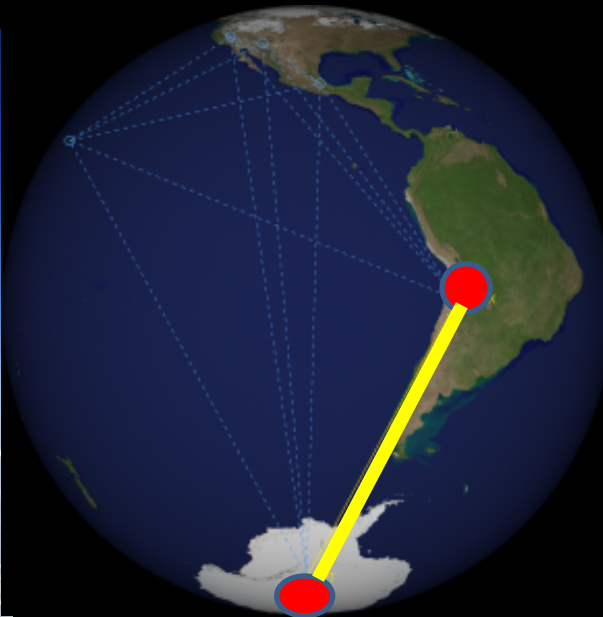
APP First Fringe detection

- 13 Jan 2015
- Short-baseline experiments with APEX
- Full VLBI mode (Independent maser, recorder)
- Fringe detected for 0522-0364 (bright calibrator)



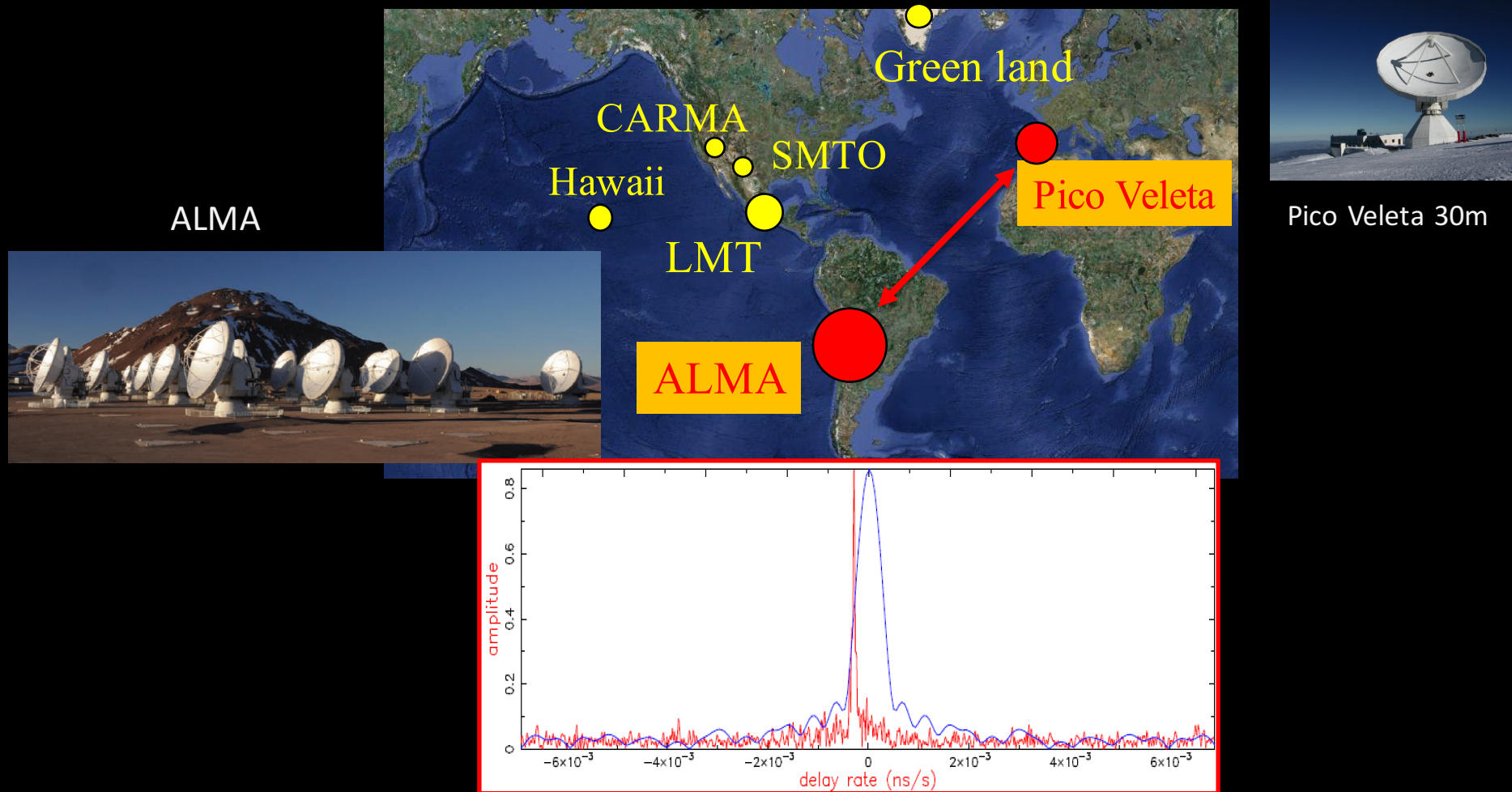
Fringe detection with SPT

- Test observations in Jan 2015
- Fringe detected at 1.3 mm between SPT and APEX !!



Inter-continental fringe detection

Fringe detection at 1.3mm between ALMA and IRAM 30m



ALMA—Pico Veleta fringe on 29 Mar 2015

2. Our recent activity

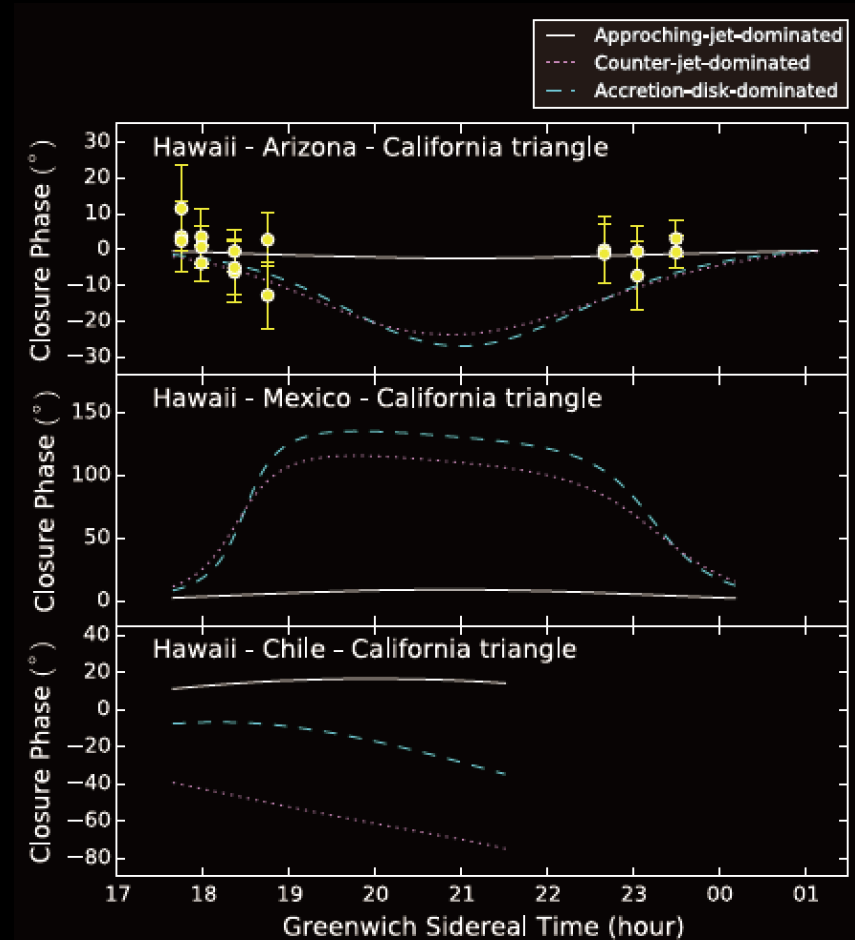
EHT activities in Japan

- Science activities

EHT data analysis

M87 at 230G (Akiyama+ 2015)

Closure phase detected at 1mm !



EHT activities in Japan

- Science activities

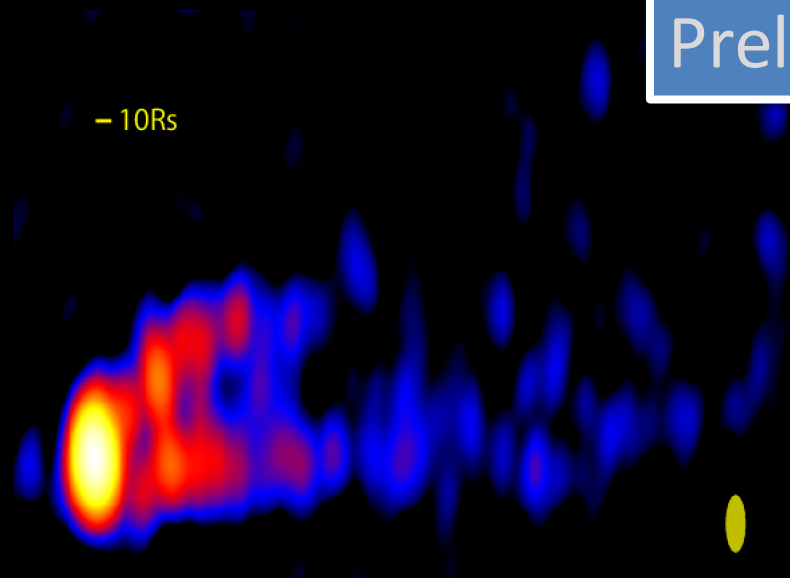
EHT data analysis

mm VLBI

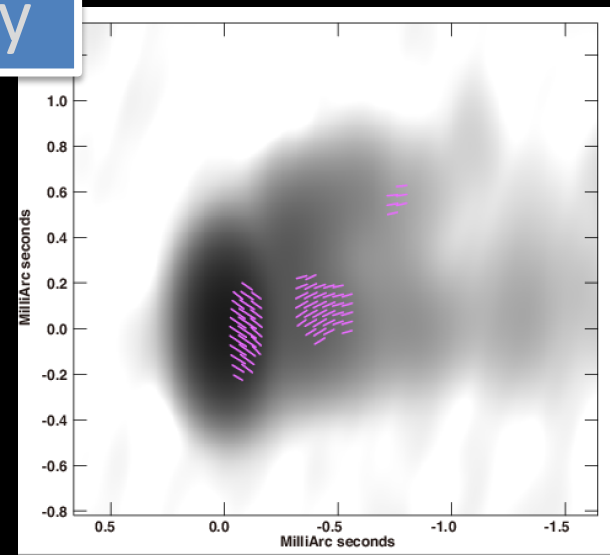
M87 at 230G (Akiyama+)

M87 86G imaging (Hada+)

Preliminary



M87 with HSA at 86G



Possible polarization at 86G

M87 86G image: Hada+ in prep.

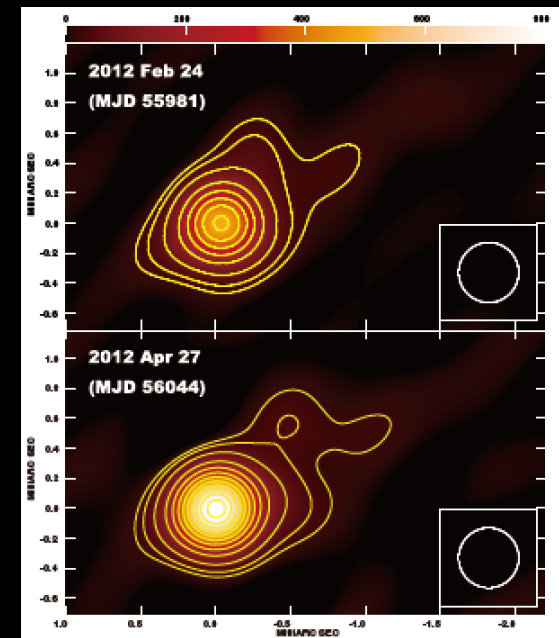
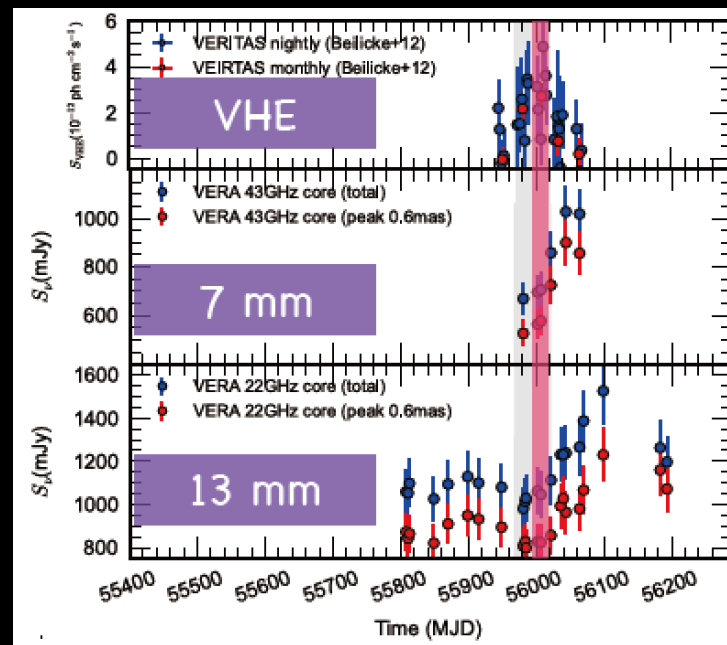
EHT activities in Japan

- Science activities

EHT data analysis M87 at 230G (Akiyama+)

mm VLBI M87 86G imaging (Hada+)

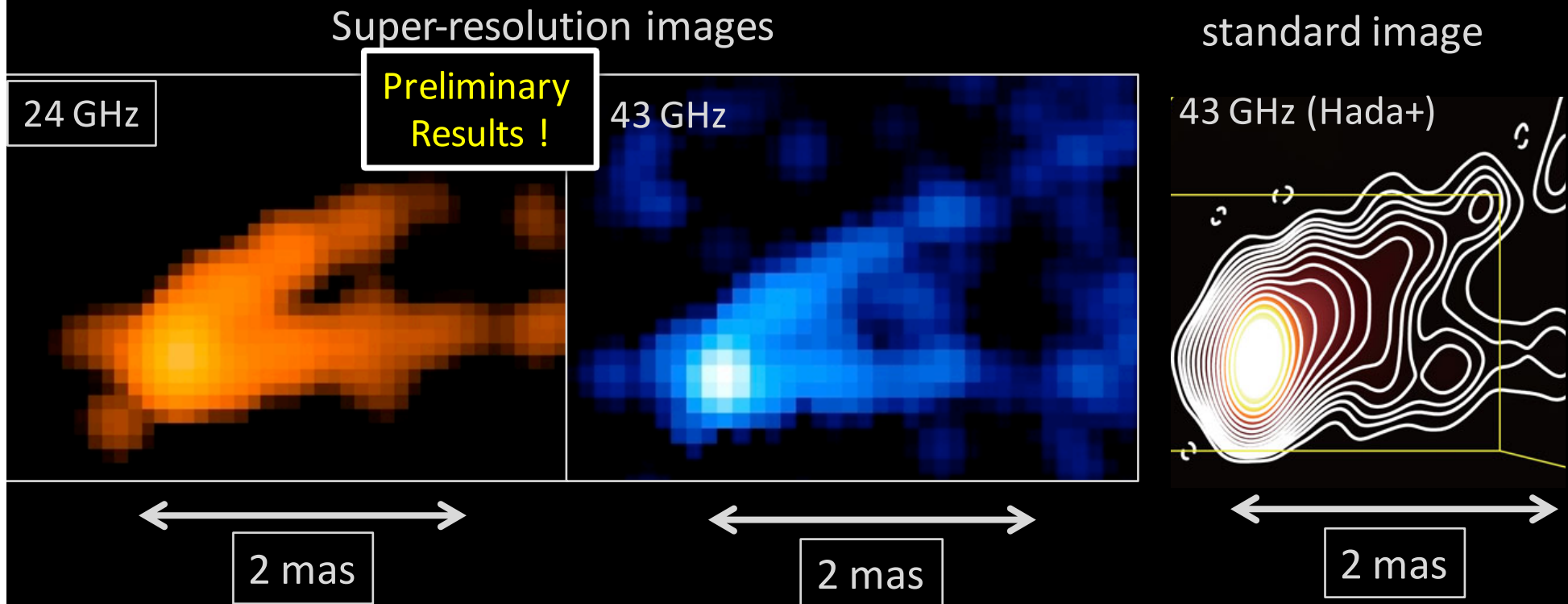
long-mm/cm monitoring with VERA and KaVA (Hada+)



M87 VHE and radio flare: Hada+(2014), ApJ, 785, 165

Super-resolution with sparse modeling

- M87 with VLBA at 22G/43G (Tazaki et al. in prep)



This kind of technique will be powerful for BH imaging

3. Future Prospect

Near future prospect

- Nearly everything ready for imaging black hole shadow !?
- mm-VLBI with ALMA will be coming in Cycle-4 (band 3 most certainly, and possibly band 6)
- EHT observations of Sgr A and M87 with ALMA in early 2017.

南極望遠鏡への期待

SPTの参加からもわかるように、(サブ)ミリ波 VLBIにとって重要な局

- 優れた観測条件
- 地理的要因(南北基線 etc.)
- もし30m鏡が出来たらインパクト大
- 10mクラスでも面白い
サブミリ波南極VLBI??
e.g., VLBI at 500 GHz -- 1 THz
ALMA, 南極(x2) + 気球

