



GLT計画の進捗 と 今後の日本と台湾の協力への期待

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On behalf of Greenland Telescope Project Team
In collaboration with ASIAA, SAO/CfA, MIT Haystack Observatory and NRAO

Milestones of Greenland Telescope Project



2009: VLBI group was formed, and its primary target is mm/submm VLBI

2010: ASIAA and SAO/CfA, submitted Expression of Interest to NSF in US for the use of ALMA

2011: We were selected as the recipient and initial inspection of the telescope was done at VLA site. First trip to Greenland to deploy the radiometer.

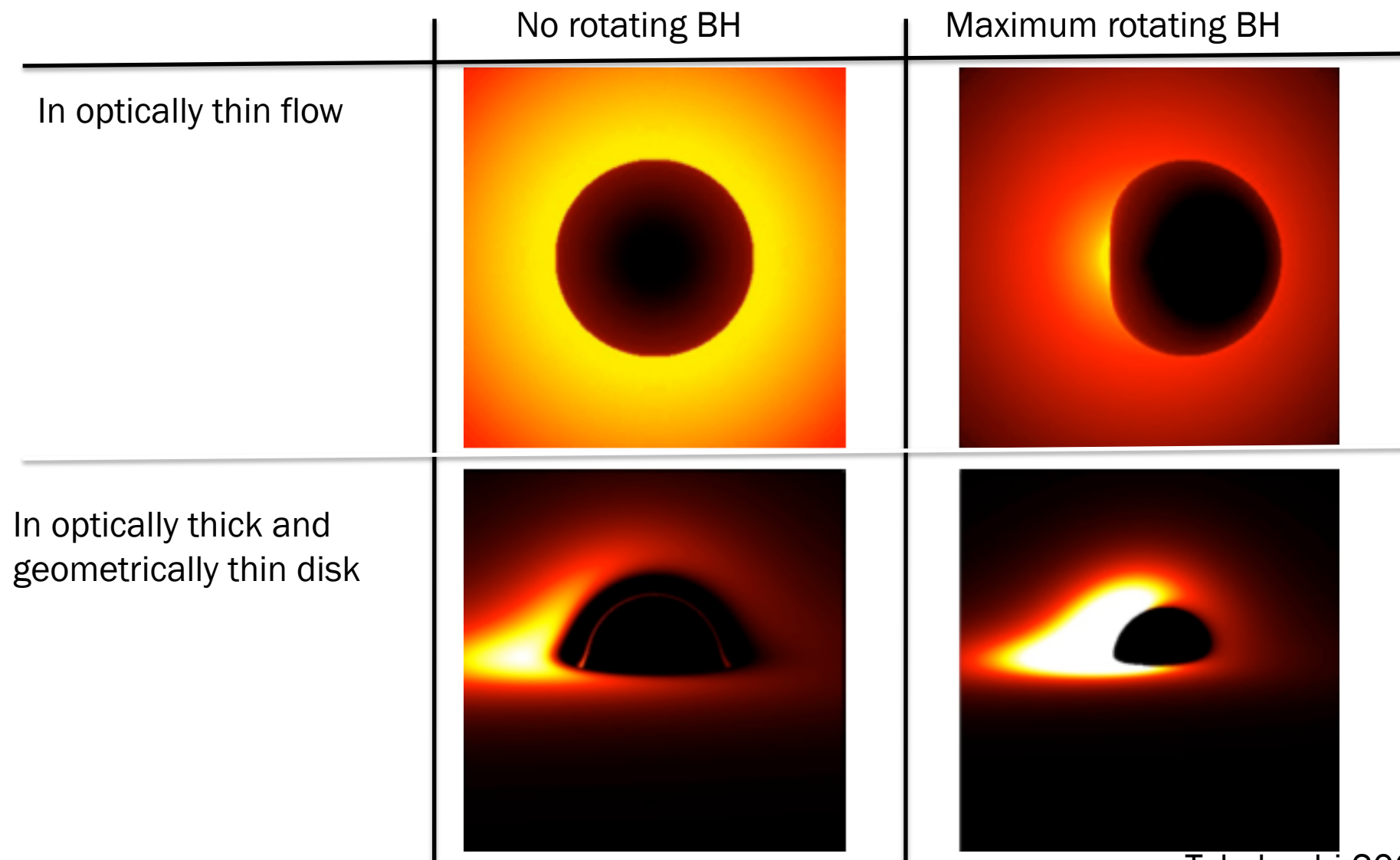
2012: Disassemble the antennas.

2013 - 2014: Retrofitting the telescope.

2015: Complete retrofitting the telescope.

2016: Targeting to ship the telescope to Thule, that is the gate port of Greenland, and reassemble the telescope and plan to have first light at there.

Our intension



Takahashi 2004

Apparent Size of BH

Source	Sgr A*	M 87	Cen A
BH Mass	$0.045 \times 10^8 M_{\odot}$	$66 (35) \times 10^8 M_{\odot}$	$0.45 \times 10^8 M_{\odot}$
Distance	0.008 Mpc	16.7 Mpc	3.4 Mpc
r_s	11 μas	8 (4) μas	0.3 μas
Size of Shadow	52 μas	40 (20) μas	1.5 μas

Resolution $\propto \lambda / D$

λ : wavelength

D: baseline



c.f. If λ is 1 mm (300 GHz) and D is 4000 km,
resolution is 50 μas .

Submm VLBI is the only way to achieve this angular resolution in near future !!

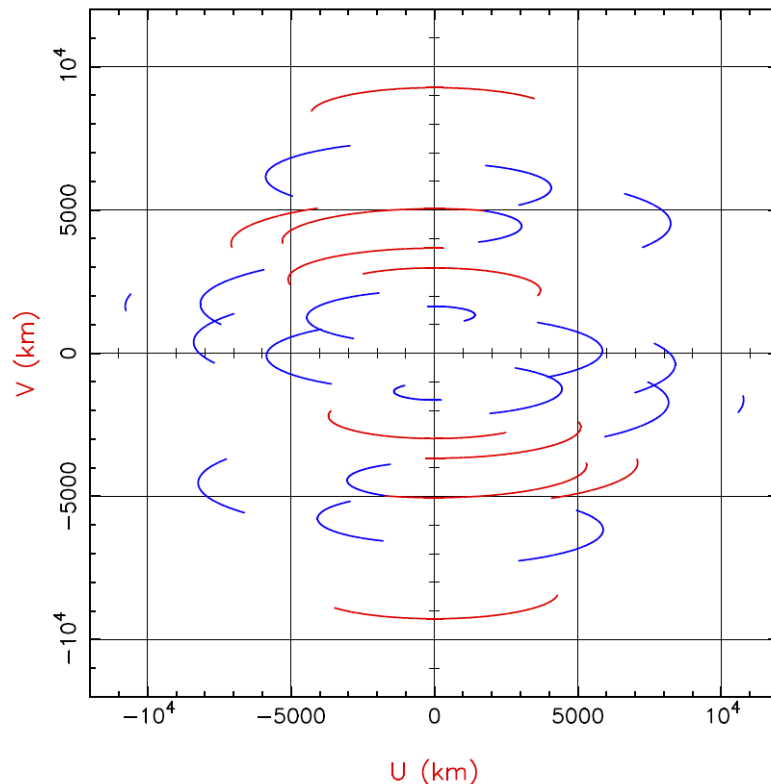
Logistics of Greenland



- Peak of the Greenland ice cap (3,200 m) at $72^{\circ}35'46.4''\text{N}$ $38^{\circ}25'19.1''\text{W}$
- Sponsored by the NSF, operated by CH2M Hill Polar Services (CPS)
- Camp population: 5 (winter) up to 50 (summer)
- Air National Guard provides LC-130 aircraft, twin otter aircraft or traverse.
- Network: Satellite link

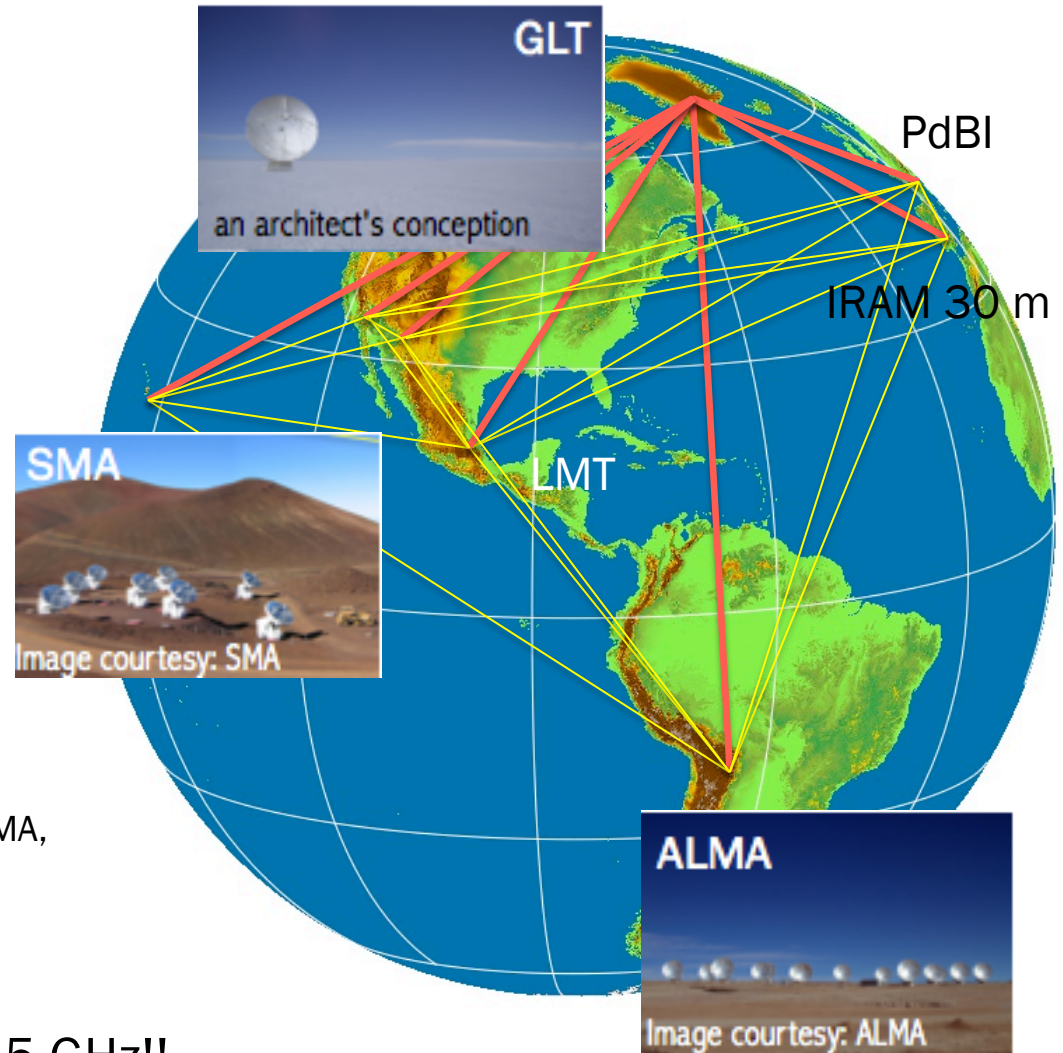
We will move 8 km north (downstream of the wind) from current Summit
to avoid contamination and pollution at current Summit.

Expected uv coverage



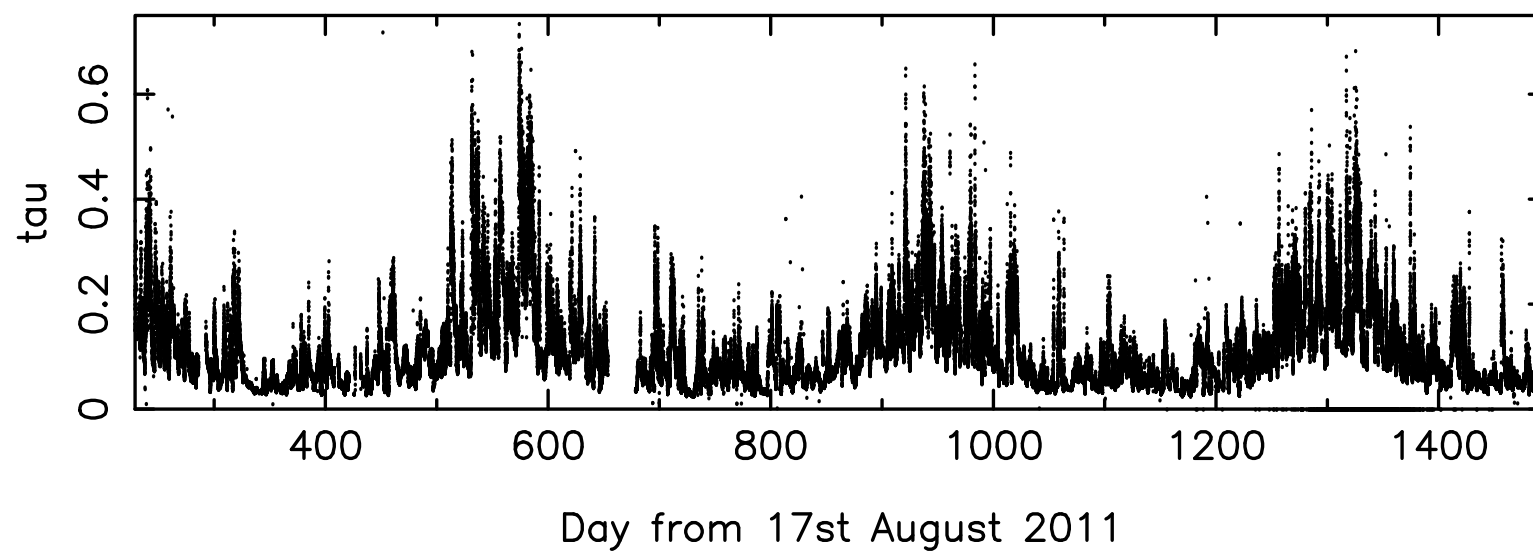
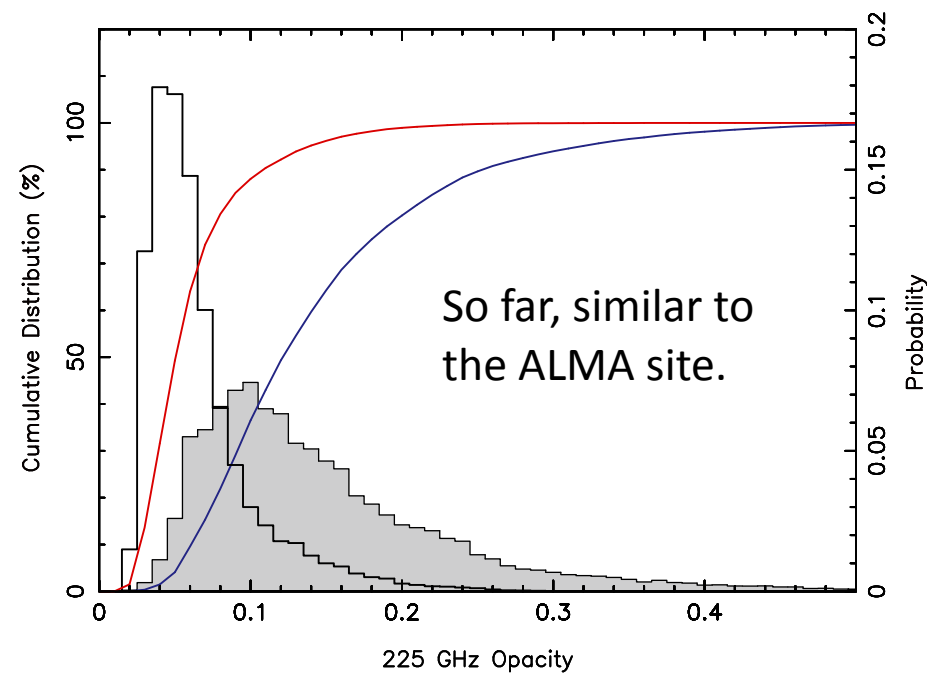
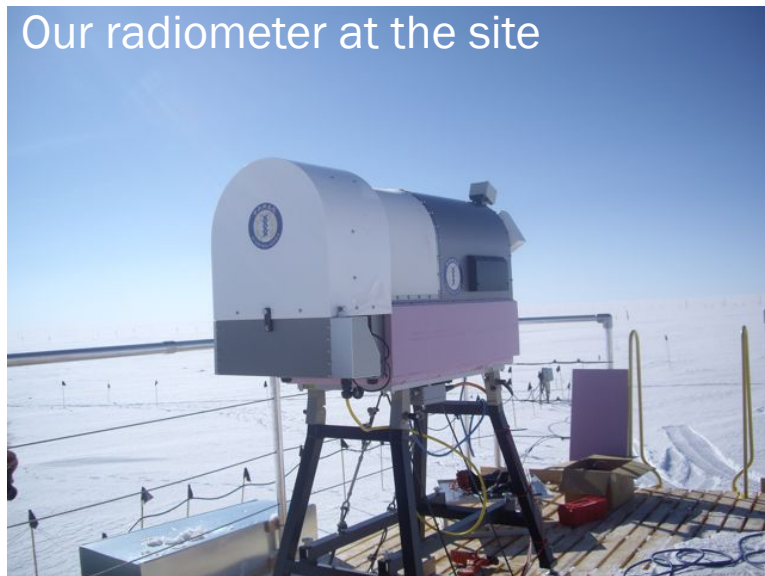
uv coverage for M 87 with Greenland station, SMA, ALMA, SMT, LMT and IRAM 30m. The Baseline with GL is red.

It will provide 9,000 km baseline,
and it corresponds to 20 μ as at 345 GHz!!



Site testing at Summit Camp @ 2011

Our radiometer at the site



Disassembly of antenna @ 2012



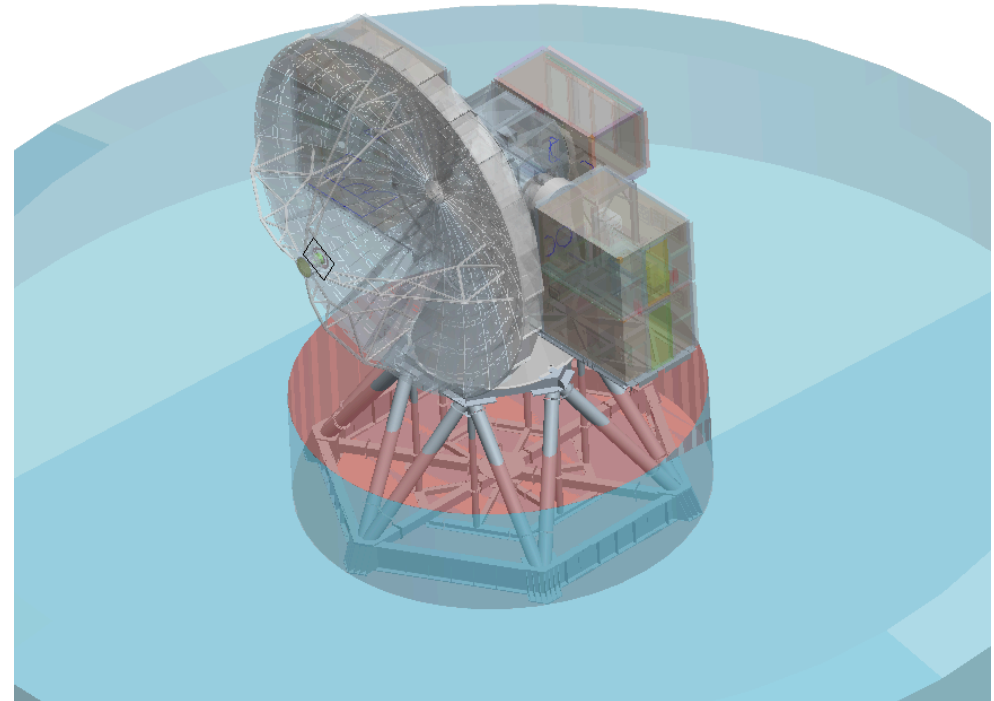
Retrofitting of telescope

Re-designed components:

- Quadrapod (subreflector support)
- Servo System
- AZ bearing
- HVAC System and Insulation
- Panel De-Ice System
- Hexapod (subreflector positioner and nutation)

Re-used components:

- Primary Mirror Panels
- Subreflector
- Invar Cone
- Elevation Counterweights
- Cabin
- AZ/EL encoders
- Yoke

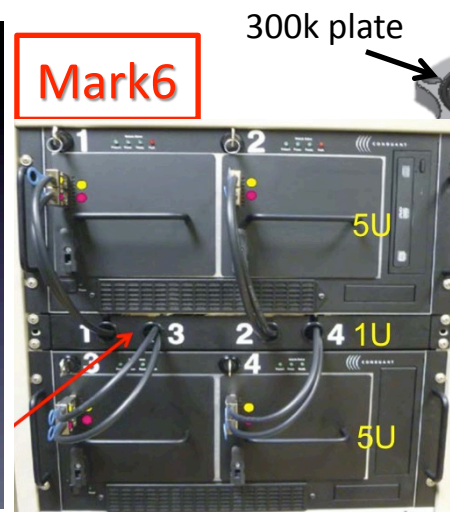
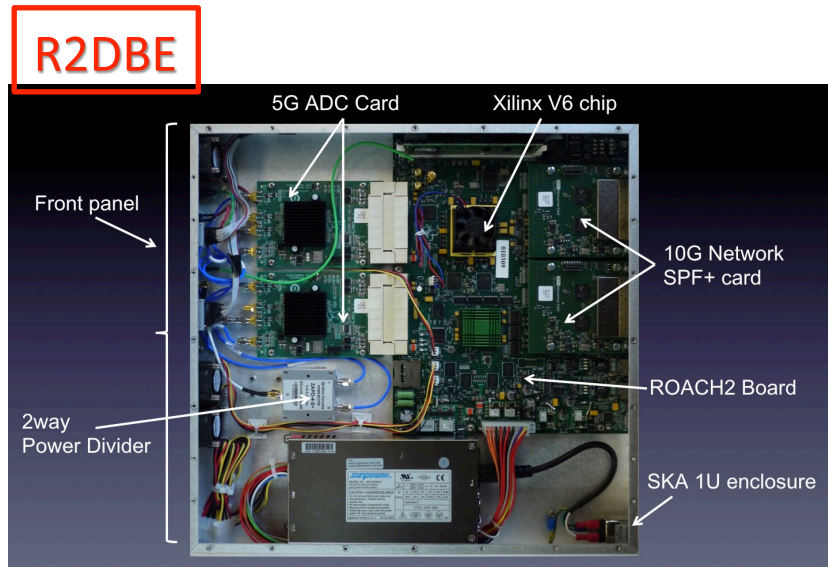
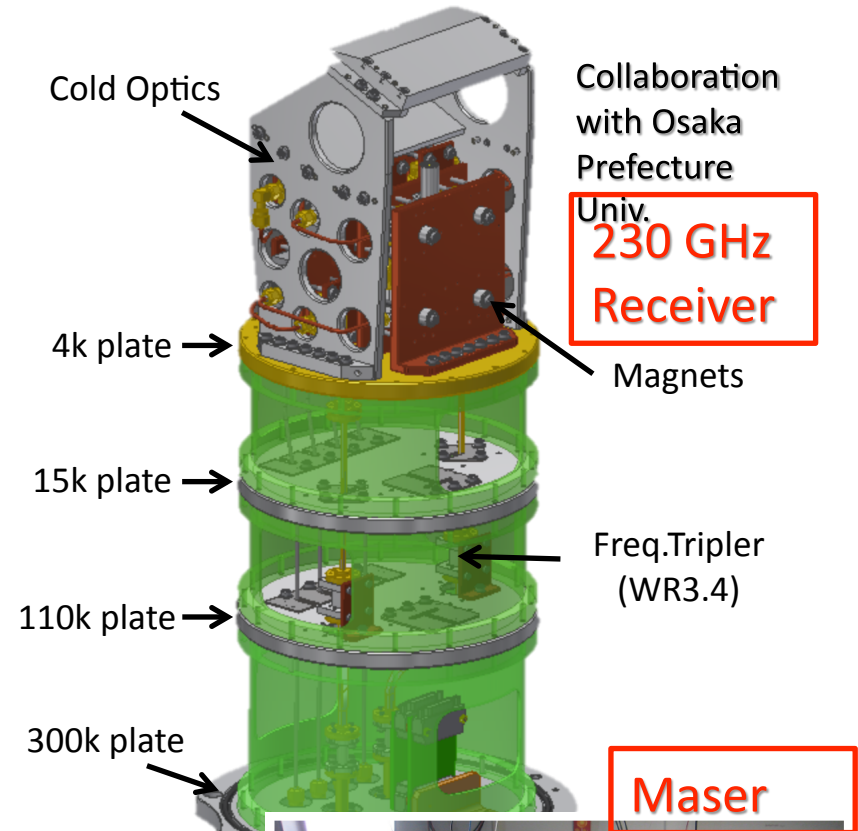
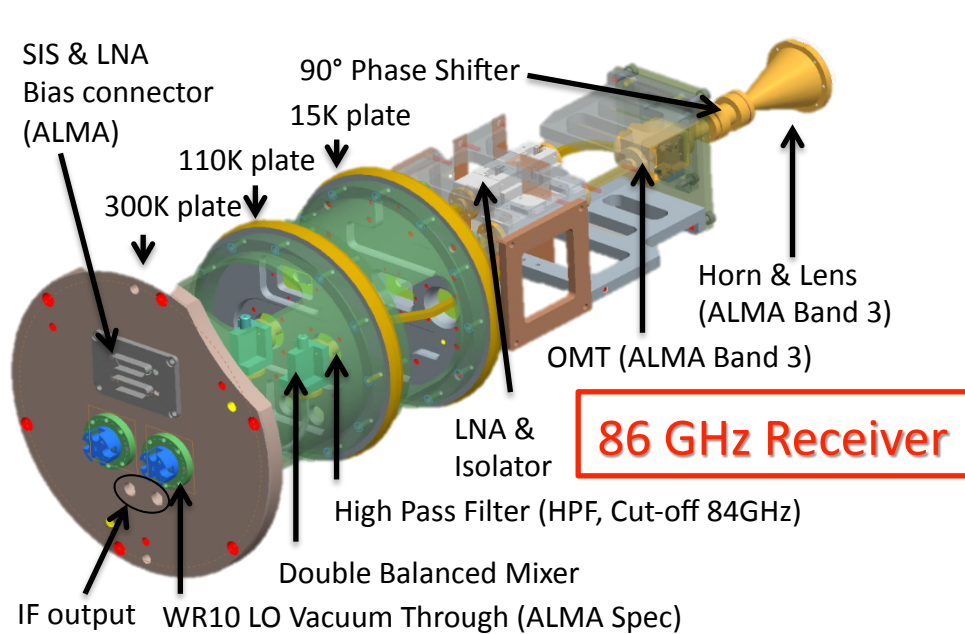


Plan for 2016 and beyond

- Antenna shipping to Thule (2016).
- Antenna re-assemble and test at Thule, including VLBI test (2016-2019).
- Single-dish & VLBI first light at Thule (2017-2018).
- Transport antenna across ice sheet (2019).
- First light at the Summit Station (2019/20).



Readiness for VLBI equipments



JCMT for mm/submm VLBI

JCMT legacy Proposal:

JEHT: The JCMT Event Horizon Telescope VLBI Survey Project

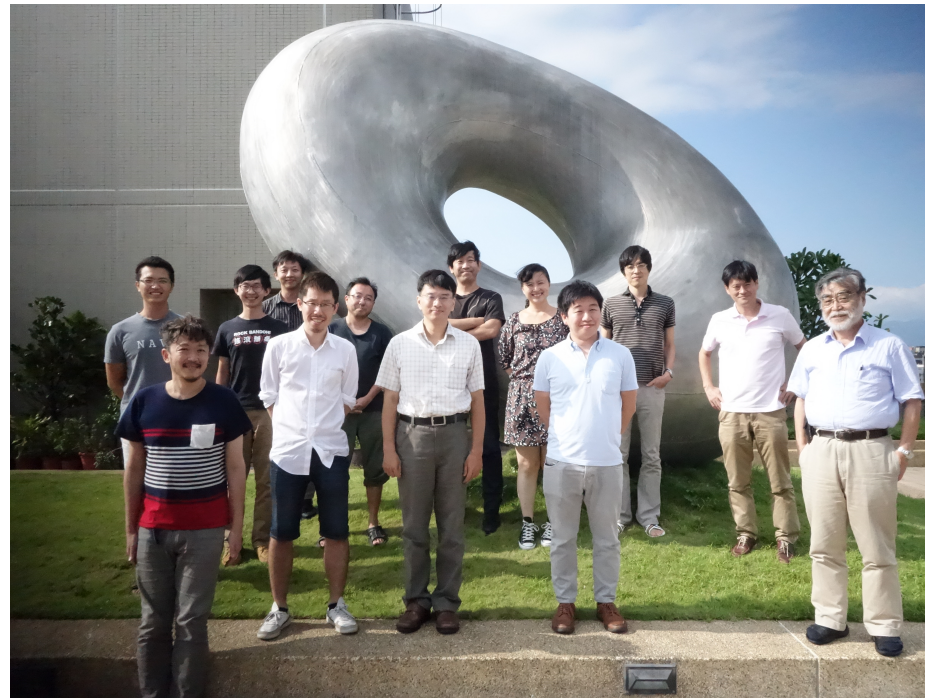
TABLE 1
PROJECT MEMBERSHIP

Region	PI	Co-Is
Canada	Avery Broderick (Waterloo) abroderick@perimeterinstitute.ca	
China	Zhiqiang Shen (ShAO) zshen@shao.ac.cn	Yongjun Chen, Wu Jiang (ShAO)
Japan	Mareki Honma (NAOJ) mareki.honma@nao.ac.jp	Kenta Fujisawa (Yamaguchi), Hideo Ogawa (Osaka), Kazunori Akiyama, Kazuhiro Hada (NAOJ)
Korea	Taehyun Jung (KASI) thjung@kasi.re.kr	Bong Won Sohn, Jan Wagner, Do-Young Byun, Jung-Won Lee, Gunagyao Zhao, Juan-Carlos Algaba-Marcos, Motoki Kino (KASI)
Taiwan	Makoto Inoue (ASIAA) inoue@asiaa.sinica.edu.tw	Yong-Sun Park, Sascha Trippe (SNU) Keiichi Asada, Lupin Lin, Satoki Matsushita, Masa Nakamura, Hiroaki Nishioka, Hung-Yi Pu (ASIAA)
Hawaii/Taiwan	Geoffrey Bower (ASIAA) gbower@asiaa.sinica.edu.tw	Paul Ho, Ming-Tang Chen (ASIAA)
UK	Simon Garrington (Manchester) simon.garrington@manchester.ac.uk	

Strong interests on mm/submm VLBI from the community in Japan, Korea, China, Taiwan.

NAOJ-ASIAA submm VLBI data workshop

- Under the framework of EHT, we had a workshop to transfer the skill to reduce submm VLBI data in this Aug at ASIAA.
- ASIAA provided minimum but necessary resources (cluster and working env.) to reduce submm VLBI data
- We are happy to provide this function to community in the collaboration with NAOJ/VLBI group for ALMA CY4.



M 87 symposium



Keynote Presentations



Luis Ho

Director, Kavli Institute for Astronomy and Astrophysics
University Chair Professor, Peking University

Super/ultra-massive Black Holes



Ramesh Narayan

Thomas Dudley Cabot Professor of the Natural Sciences, Harvard University
Senior Astronomer, Harvard-Smithsonian Center for Astrophysics

Black Hole Accretions



Roger Blandford

Luke Blossom Professor, School of Humanities and Sciences, Stanford University
Professor of Physics, Stanford University and SLAC National Accelerator Laboratory

Black Hole Jets



Andrew Fabian

Director, Institute of Astronomy, University of Cambridge
Royal Society Research Professor, Institute of Astronomy, University of Cambridge

Co-evolution of Galaxies and Black Holes

<http://events.asiaa.sinica.edu.tw/workshop/20160523/index.php>

Job opportunities



- EACOA Fellowships: Due Nov. 15th
- ASIAA postdoctoral Positions: Probably Due Dec. 15th

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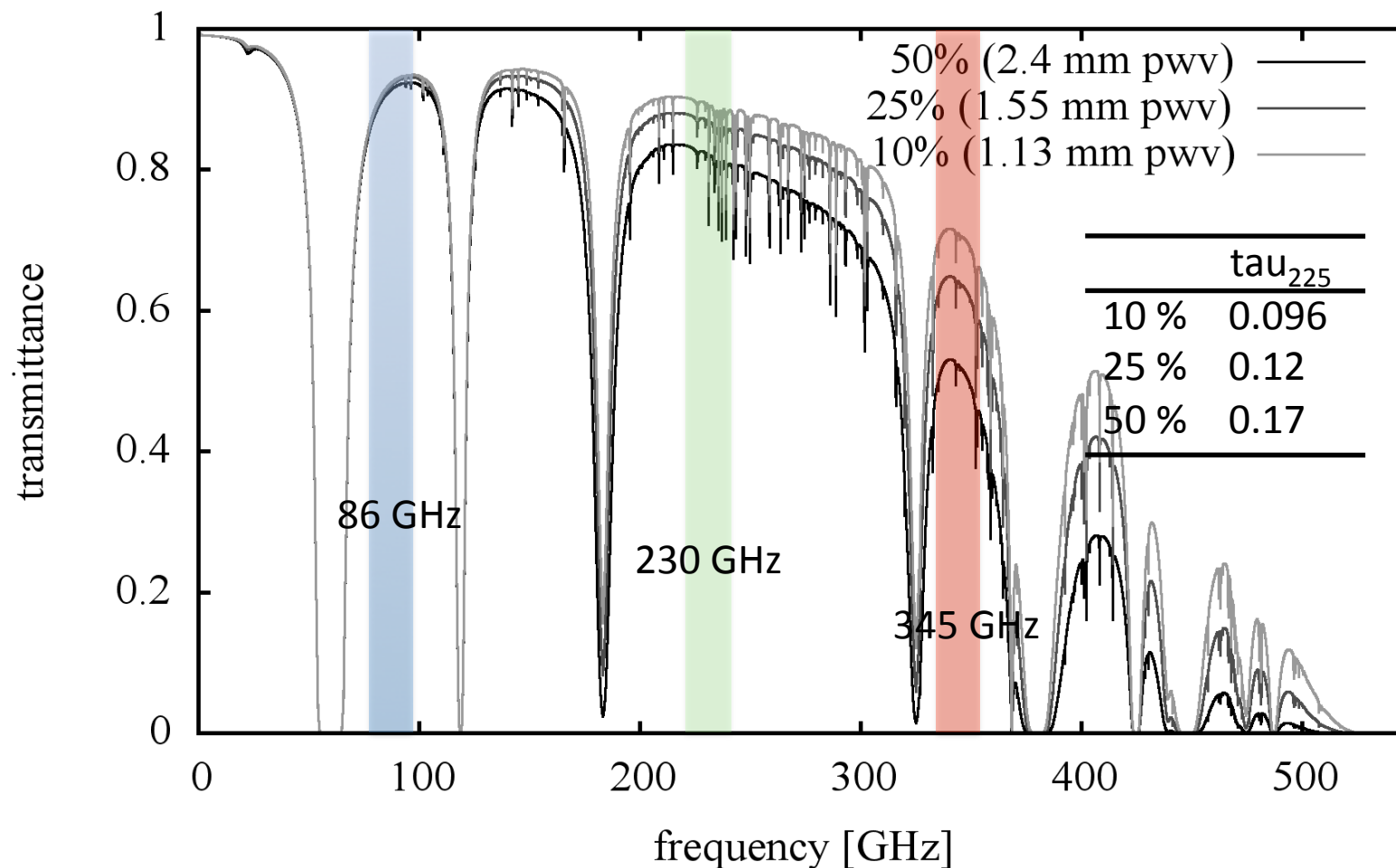
Summary



- GLT is progressing
- Proposal to prepare for ALMA CY4.
- Please consider to come to ASIAA as the visitor and/or employee, especially young, middle age, and senior persons.

Estimated Opacity at Thule by Scott

Thule, Oct-May zenith transmittance



c.f. current submm VLBI observations have been conducted at around $\tau \sim 0.2-0.4$ for some sites.

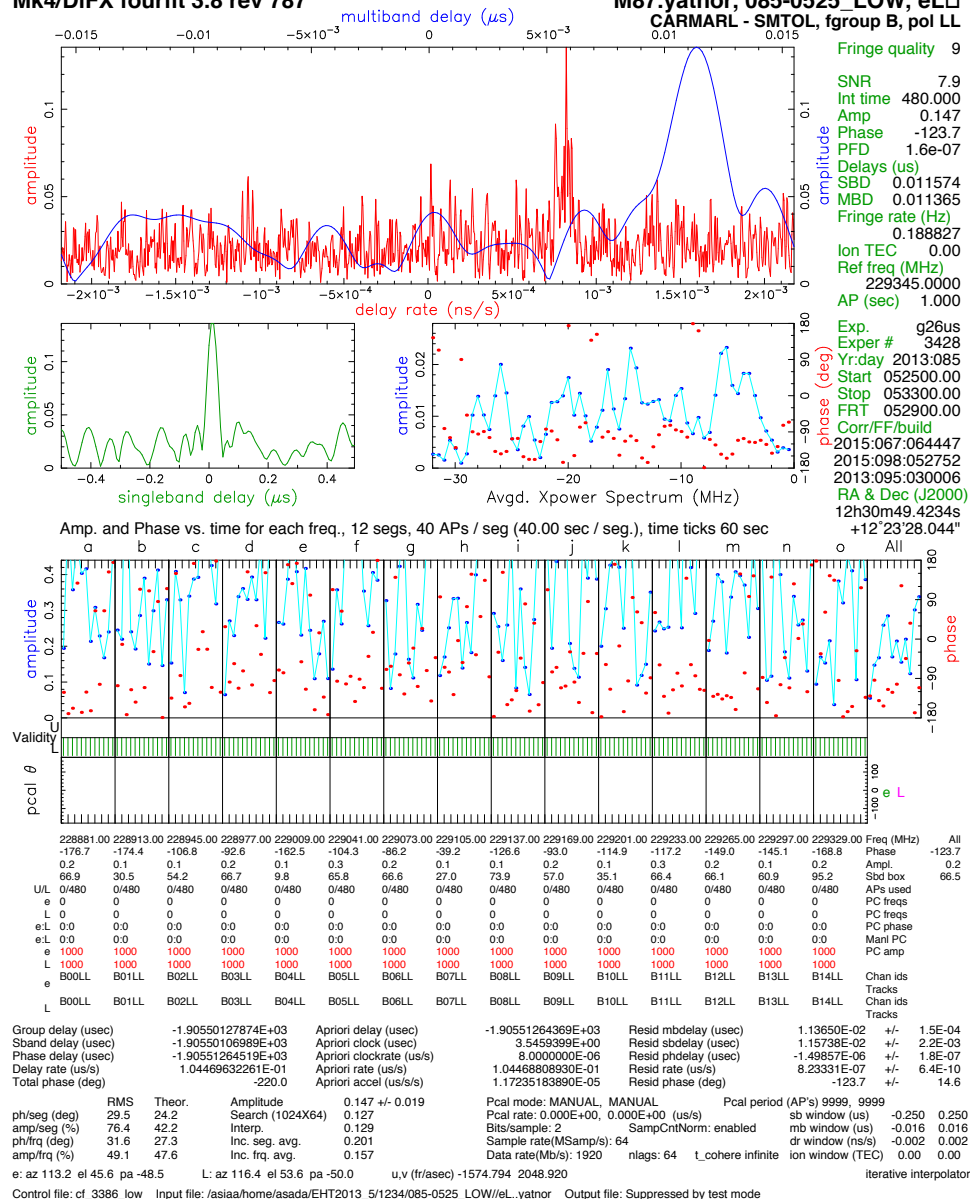


Risk: Low

ASIAA DiFX correlator

Mk4/DiFX fourfit 3.8 rev 787

M87.yatnor, 085-0525_LOW, eL
CARMARL - SMTOL, fgroup B, pol LL



Correlated with ASIAA DiFX correlator

Baseline: CRAMA – SMTOL

Frequency: 230 GHz

Source: M 87

Date: 2013/3/26

Duration: 480 sec

BW: 480 MHz



Submm VLBI as a tool to study BH

Doeleman et al. 2008

Doeleman et al. 2012

nature

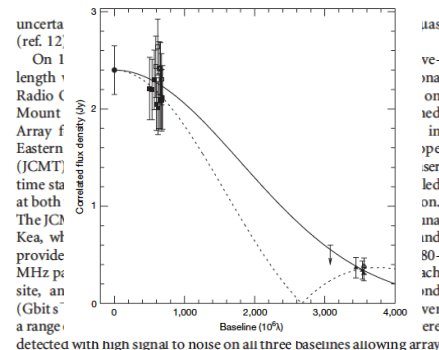
Vol 455 | 4 September 2008 | doi:10.1038/nature07245

LETTERS

Event-horizon-scale structure in the supermassive black hole candidate at the Galactic Centre

Sheperd S. Doeleman¹, Jonathan Weintraub², Alan E. E. Rogers¹, Richard Plambeck³, Robert Freund⁴, Remo P. J. Tilanus^{5,6}, Per Friberg⁵, Lucy M. Ziurys⁴, James M. Moran², Brian Corey¹, Ken H. Young², Daniel L. Smythe¹, Michael Titus¹, Daniel P. Marrone^{7,8}, Roger J. Cappallo¹, Douglas C.-J. Bock⁹, Geoffrey C. Bower³, Richard Chamberlin¹⁰, Gary R. Davis⁵, Thomas P. Krichbaum¹¹, James Lamb¹², Holly Maness³, Arthur E. Niell¹, Alan Roy¹¹, Peter Strittmatter⁴, Daniel Werthimer¹³, Alan R. Whitney¹ & David Woody¹²

The cores of most galaxies are thought to harbour supermassive black holes, which power galactic nuclei by converting the gravitational energy of accreting matter into radiation¹. Sagittarius A* (Sgr A*), the compact source of radio, infrared and X-ray emission at the centre of the Milky Way, is the closest example of this phenomenon, with an estimated black hole mass that is 4,000,000 times that of the Sun^{2,3}. A long-standing astronomical goal is to resolve structures in the innermost accretion flow surrounding Sgr A*, where strong gravitational fields will distort the appearance of radiation emitted near the black hole. Radio observations at wavelengths of 3.5 mm and 7 mm have detected intrinsic structure in Sgr A*, but the spatial resolution of observations at these wavelengths is limited by interstellar scattering⁴⁻⁷. Here we report observations at a wavelength of 1.3 mm that set a size of 37^{+16}_{-10} microarcseconds on the intrinsic diameter of Sgr A*. This is less than the expected apparent size of the event horizon of the presumed black hole, suggesting that the bulk of Sgr A* emission may not be centred on the black hole, but arises in the surrounding accretion flow.



Size $\sim 40 \mu\text{as} \sim 4 r_s$!!

Sgr A*

Scienceexpress

Reports

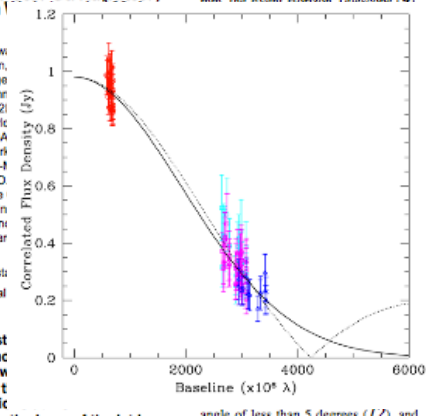
Jet Launching Structure Resolved Near the Supermassive Black Hole in M87

Sheperd S. Doeleman^{1,3*}, Vincent L. Fish¹, David E. Schenck^{1,2,†}, Christopher Beaudoin¹, Ray Blundell³, Geoffrey C. Bower⁴, Avery E. Broderick^{5,6}, Richard Chamberlin⁷, Robert Freund⁸, Per Friberg⁹, Mark A. Gurwell¹⁰, Paul T. P. Ho^{10,11}, Mareki Honma^{10,11}, Makoto Inoue⁹, Thomas P. Krichbaum¹², James Lamb¹³, Abraham Loeb¹⁴, Colin Lonsdale¹⁵, Daniel P. Marrone¹⁶, James M. Moran¹⁷, Tomoaki Oyama¹⁸, Richard Plambeck¹⁹, Rurik A. Primiani²⁰, Alan E. Rogers²¹, Daniel L. Smythe²², Jason SooHoo²³, Peter Strittmatter²⁴, Remo P. J. Tilanus^{25,26}, Michael Titus²⁷, Jonathan Wright²⁸, Ken H. Young²⁹, Lucy Ziurys³⁰

¹MIT Haystack Observatory, Off Route 40, Westford, MA 01886, USA. ²Steward Observatory, University of Arizona, 933 North Cherry Avenue, Tucson, Arizona 85724, USA. ³Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA. ⁴Department of Astronomy, University of California Berkeley, Hearsh Field Area, 3150 Chabot Avenue, Berkeley, CA 94720, USA. ⁵Perimeter Institute, 31 Caroline Street, North Waterloo, Ontario, Canada N2L 2A5. ⁶Department of Astronomy, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 2A5, Canada. ⁷Caltech Submillimeter Observatory, 111 Nowelo Street, Hilo, HI 96720, USA. ⁸Joint Astronomy Centre, 660 North A'ohoku Place, University Park, Hono, HI 96720, USA. ⁹Academia Sinica Institute for Astronomy and Astrophysics, 11F Astronomy Park, No. 1, Roosevelt Road, Sec. 4 Taipei 10617, Taiwan, R.O.C. ¹⁰Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan. ¹¹The Advanced Studies, Osawa, Mitaka, Tokyo 181-8588, Japan. ¹²Max-Planck-Institut für Radioastronomie, 53121 Bonn, Germany. ¹³OVRO, California Institute of Technology, 351-17, Pasadena, CA 91109, USA. ¹⁴Netherlands Organization for Scientific Research, 300, NL-2509 AC The Hague, Netherlands.

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†Present address: University of Colorado at Boulder, Dept. of Astrophysical Sciences, Boulder, CO, 80309 USA.

Approximately 10% of active galactic nuclei exhibit relativistic jets powered by accretion of matter onto super massive black holes. We report the first resolved structure on the innermost accretion flow of M87, showing a collimated, predicted structure on accretion disk scales at the event horizon. We report radio interferometry observations



Size $\sim 40 \mu\text{as} \sim 5 r_s$!!

Vir A* (M 87)

Submm VLBI is feasible and promising to image the shadow of BH !!