



The Greenland Telescope

Ming-Tang Chen

Academia Sinica, Institute of Astronomy & Astrophysics

on behave of
The GLT Project



Science Target

- Science Target:
 - Black hole shadow imaging, M87.
 - Submm /THz single dish observation
- Key Enabling Factors:
 - Maturity of several key technologies: submm wavelengths detection, wide-band detection,
 - High-speed digitizers and processor (Moore's law in play)
 - Demonstration of VLBI observation at submm wavelengths
 - **ALMA phase-up ready by 2015.**
- Strong Competition: EHT is ready to link up with ALMA. New European initiative
- Unique Opportunity: 230 GHz observation with phased-up ALMA in **2016-17.**

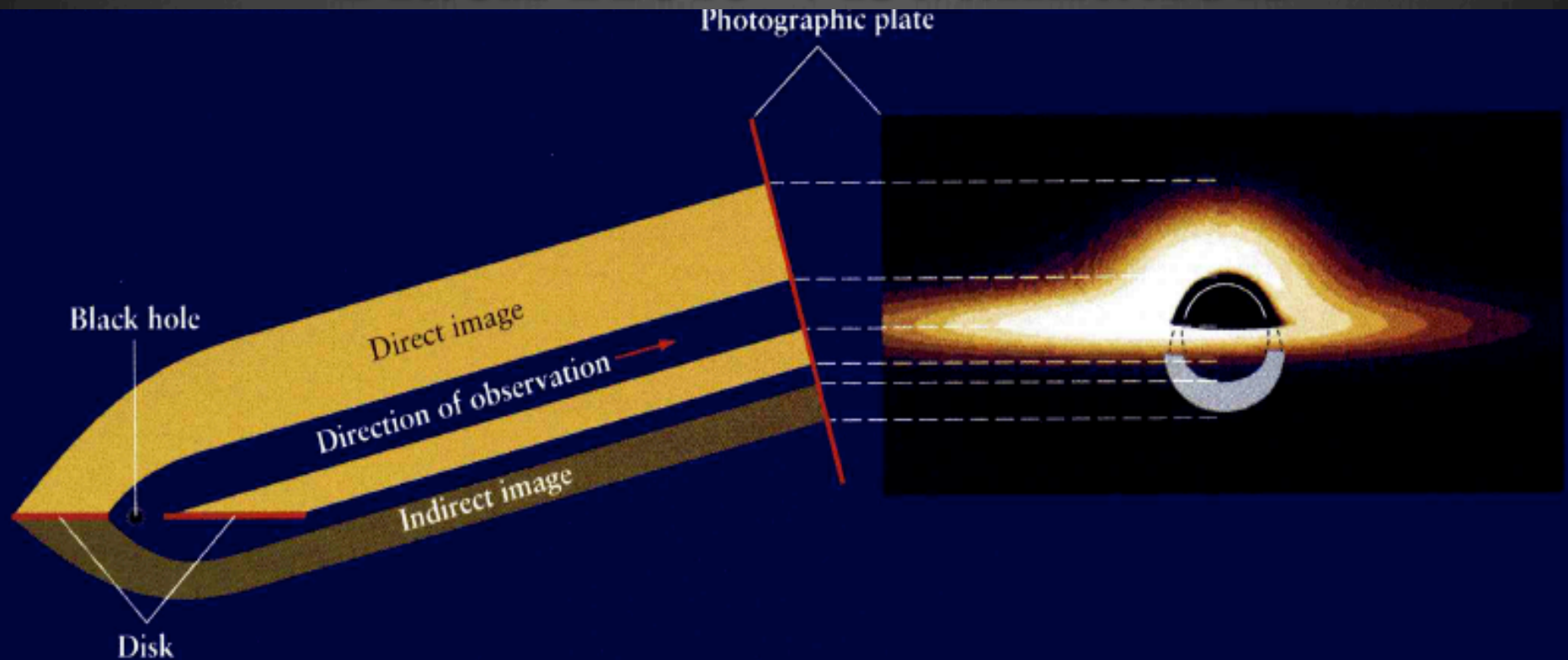


Project Collaborators

- Academia Sinica Institute of Astronomy & Astrophysics (ASIAA) (PI: Paul Ho, Co-I Inoue Makoto, PM: MT Chen)
 - Instrument development, retrofitting, deployment, testing and operations, etc.
- Smithsonian Astrophysical Observatory (SAO)
 - Major collaborator with all above tasks, site development
- MIT Haystack
 - VLBI technology
- National Radio Astronomy Observatory
 - Telescope dis/assembly, testing logistics at VLA site
- Denmark Astronomy Community: Potential collaborator



Black Hole Visualization



- Accretion disk is bright.
- Disk behind BH is seen by bending of light. The asymmetry of the disk is due to Doppler effect of its rotation.





Sizes of Black Holes



	Shadow Size (μ asec)	Mass (10^6 Mo)	Distance (Mpc)
Sgr A*	50	4.1 +- 0.6	0.008
M87	39	6600 +- 400	17.0
M31	18	180 +- 80	0.80
M60	12	2100 +- 600	16.5
NGC 5128 (Cen A)	7	310 +- 30	4.5

Note: Here we assume $R_{\text{shadow}} \sim 5 \times R_{\text{sch}}$ Gebhardt et al. (2011)



Feasibility of Submm VLBI



Doeleman et al. (2008)

Doeleman et al. (2012)

nature

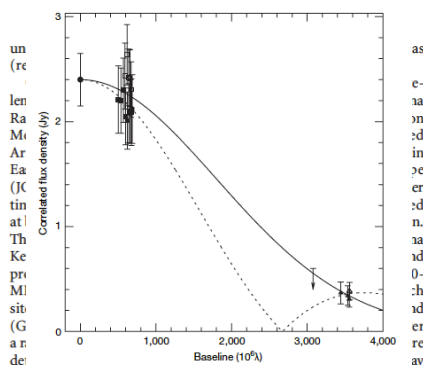
Vol 455 | 4 September 2008 | doi:10.1038/nature07245

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.



Sgr A*

Size $\approx 40 \mu\text{as}$ ($\approx 4 r_{\text{sch}}$)

Scienceexpress

Reports

Jet Launching Structure Resolved Near the Supermassive Black Hole in M87

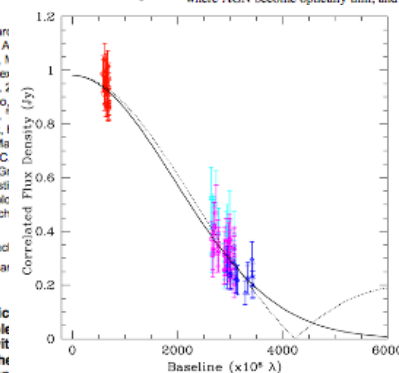
Sheperd S. Doeleman^{1,*}, Vincent L. Fish¹, David E. Schenck^{1,2,†}, Christopher Beaudoin¹, Ray Blundell³, Geoffrey C. Bower⁴, Avery E. Broderick⁵, Richard Chamberlin⁶, Robert Freund⁷, Per Friberg⁸, Mark A. Gurwell⁹, Paul T. P. Ho¹⁰, Mareki Honma¹¹, Makoto Inoue¹², Thomas P. Krichbaum¹³, James Lamb¹⁴, Abraham Loeb¹⁵, Colin Longsdale¹⁶, Daniel P. Marrone¹⁷, James M. Moran¹⁸, Tomoaki Oyama¹⁹, Richard Plambeck²⁰, Rurik A. Primiani²¹, Alan E. Rogers²², Daniel L. Smythe²³, Jason Sothoo²⁴, Peter Strittmatter²⁵, Remo P. J. Tilanus²⁶, Michael Titus²⁷, Jonathan Weintraub²⁸, Melvyn Wright²⁹, Ken H. Young³⁰, Lucy Ziurys³¹

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Approximately 10% of active galactic nuclei exhibit relativistic jets powered by accretion of matter onto super massive black holes. Measured width profiles of such jets on large scales agree with collimation, predicted structure on accretion disk scales at the innermost scales. We report radio interferometry observation

scales for extragalactic jet sources. High-resolution radio interferometry of these sources at cm 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 anti-parallel (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 become optically thin, and



Vir A* (M 87)

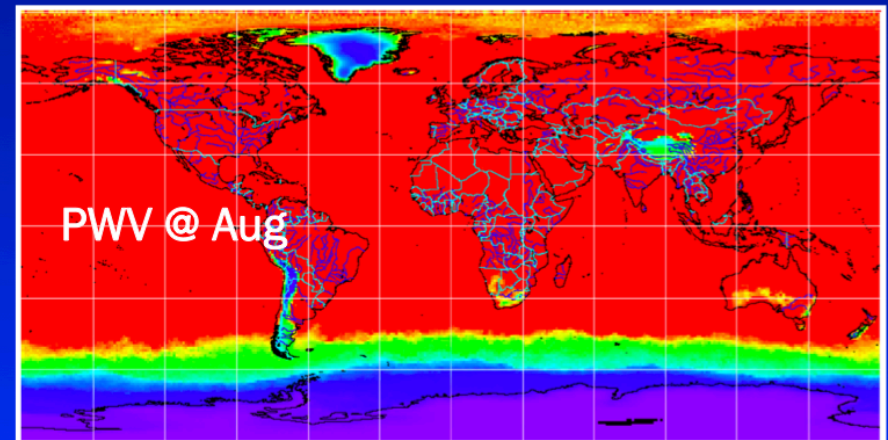
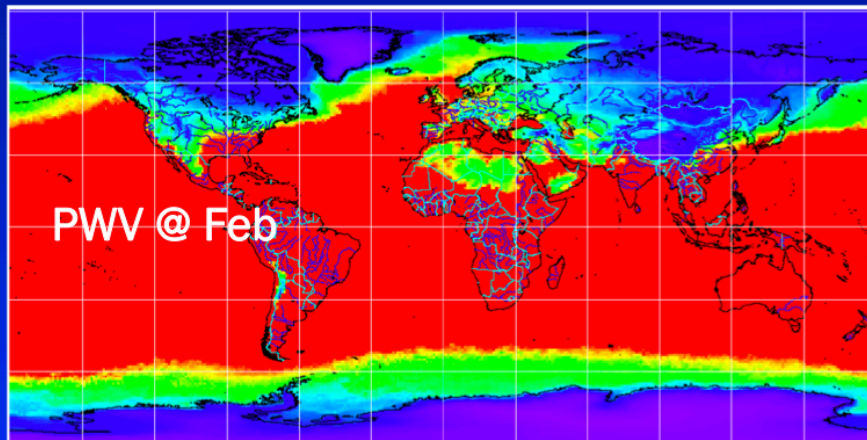
Size $\approx 40 \mu\text{as}$ ($\approx 5 r_{\text{sch}}$)



Site selection

For the submm VLBI site

1. Low Precipitable Water Vapor (PWV)
Low temperature/High mountain/Desert
2. Outstanding contribution to submm VLBI
3. Mutual visibility with ALMA and SMA
4. Easy to access (including infrastructures)



PWV > 10 mm in red color

Distribution of PWV by Terra and Aqua (NASA)



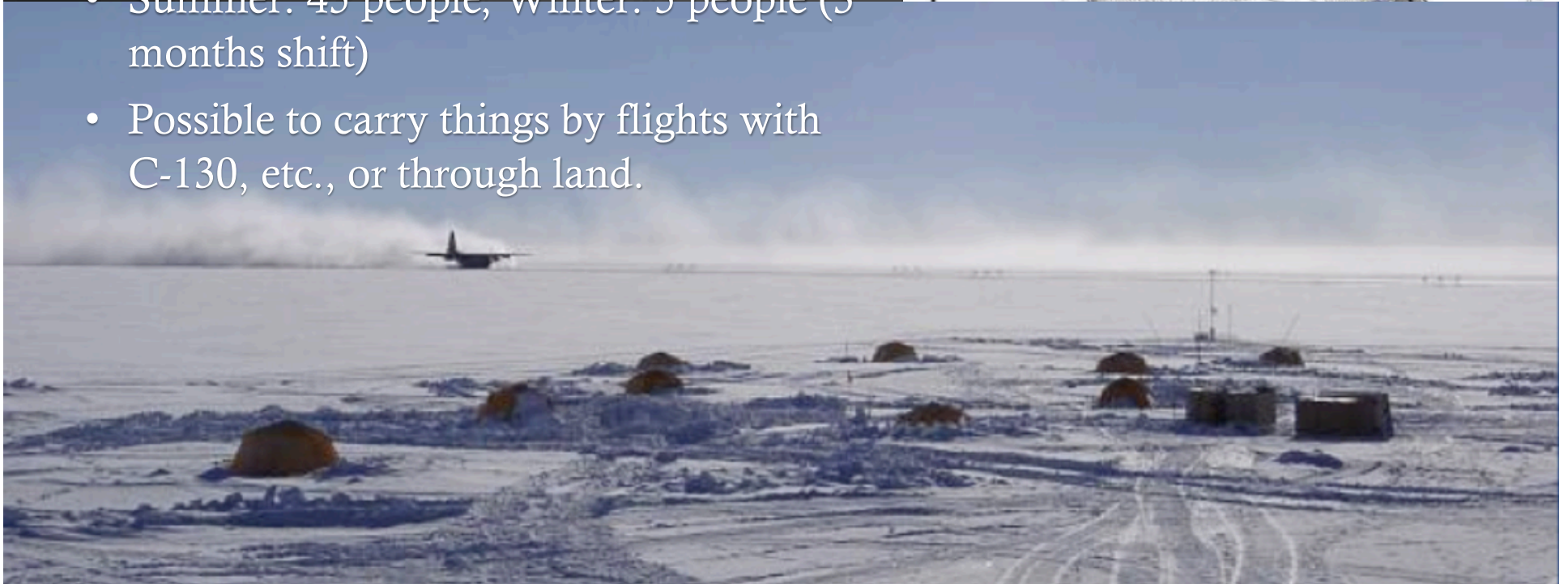
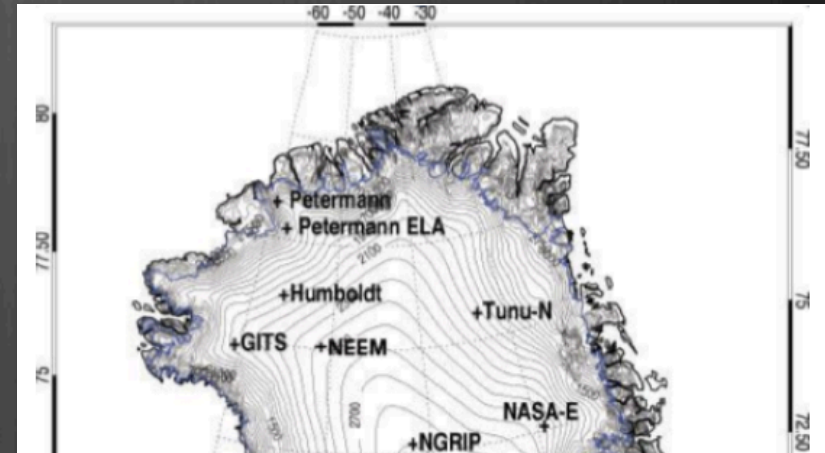
Site Selection

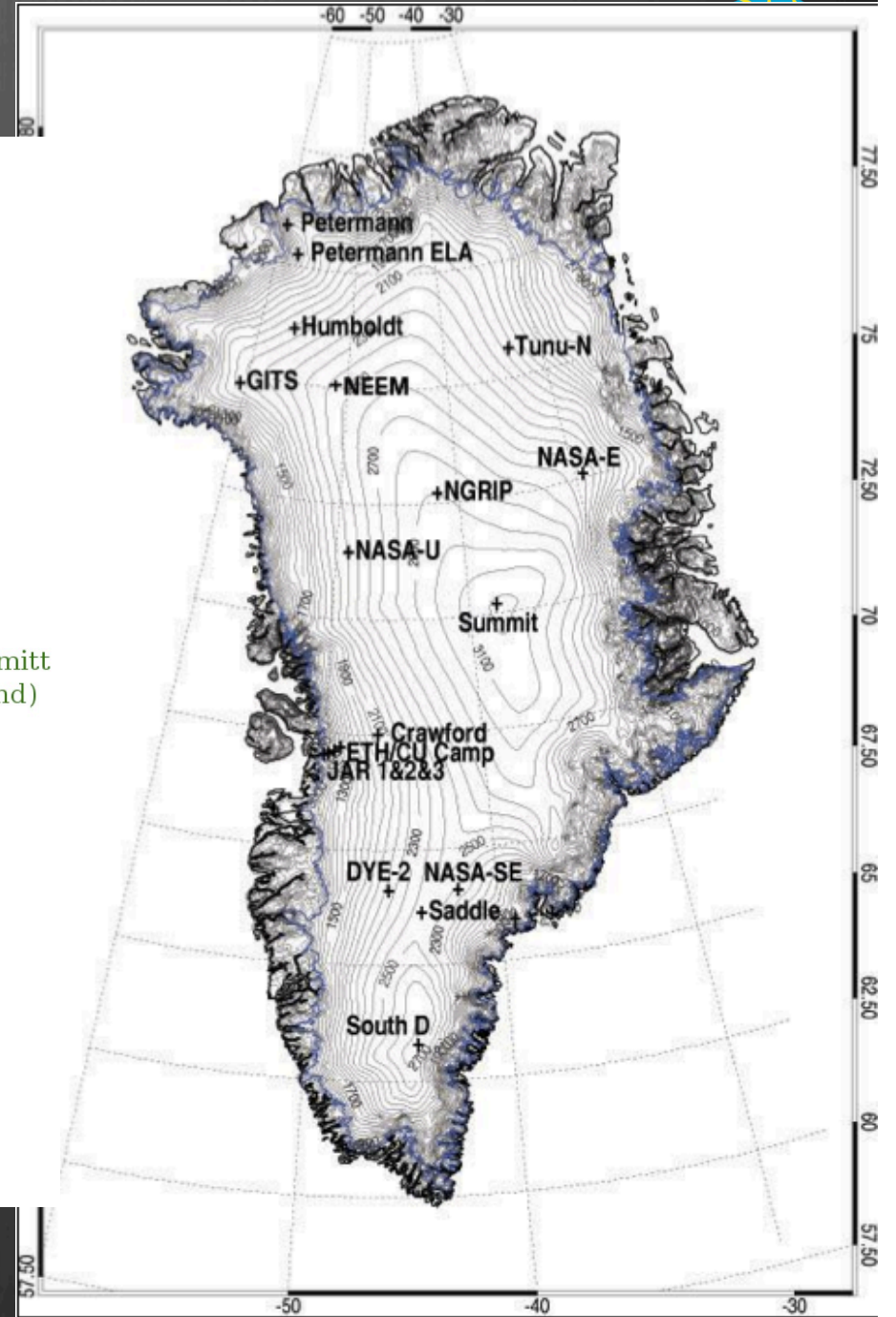
- No obvious site in the Southern Hemisphere, except Northern Chile and Antarctica.
- South Alaska (Mt. McKinley): Difficult to access.
- Tibet: opposite side of ALMA, so impossible to have baseline with it.
- **Greenland: Similar condition as South Pole. It is also possible to have baselines with ALMA/SMA.**



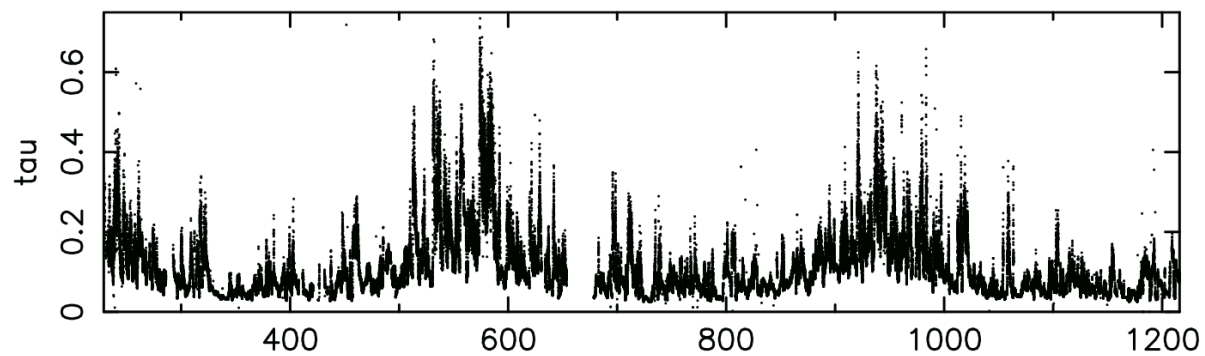
Greenland - Summit Station

- Established/operated by US NSF & Greenland Government.
 - Atmospheric and weather researches are mainly ongoing. Established on 1989.
 - N72.60°, W38.42°. Altitude: 3210m.
 - Summer: 45 people, Winter: 5 people (3 months shift)
 - Possible to carry things by flights with C-130, etc., or through land.

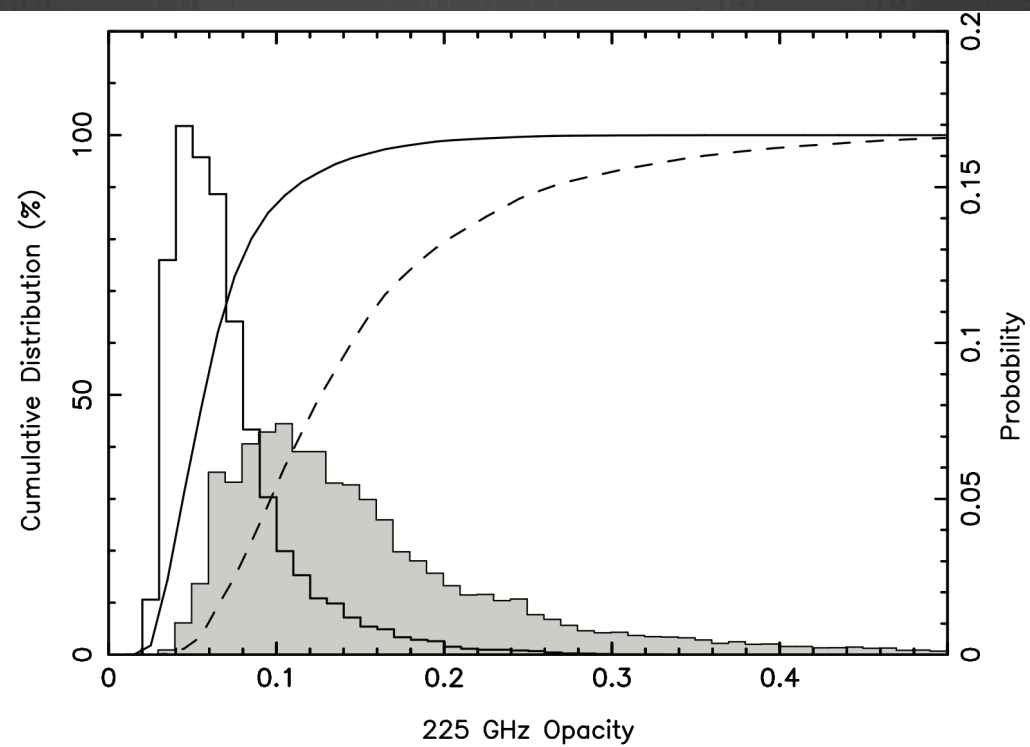
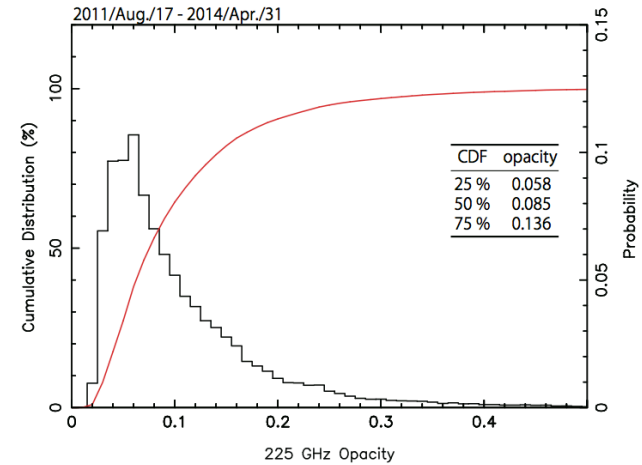








Day from 17th August 2011



2015 SCAR AAA



GLT Status Chronicle

- 12.2010: NSF Call for Proposal
- 04.2011: Antenna awarded to ASIAA/SAO
- 04.2011: Antenna inspection
- 07.2011: Antenna power-up, surface check
- 11.2011 – 03.2012: Antenna retrofit evaluation
- 06 – 08. 2012: Antenna pointing test in VLA (SAO & ASIAA)
- 09 – 12. 2012: Disassembly in Socorro (ARL & ASIAA)
- 09.2012 – 7.2015: Antenna retrofitting for cold (Vertex & ASIAA)
- 08.2015 – 04.2016: Transportation, pre-assembly in VLA.
- 06.2016: Components shipped to Thule
- 07.2016 – 2017: Thule development, antenna assembly & testing
- 2017 -2019: Low frequency operations in Thule

Visited Thule, cold weather training, several meetings with NSF, CRREL, contractors., several f2f meetings.



Baseline length & angular resolution

Table 1. Baseline length and spatial resolution

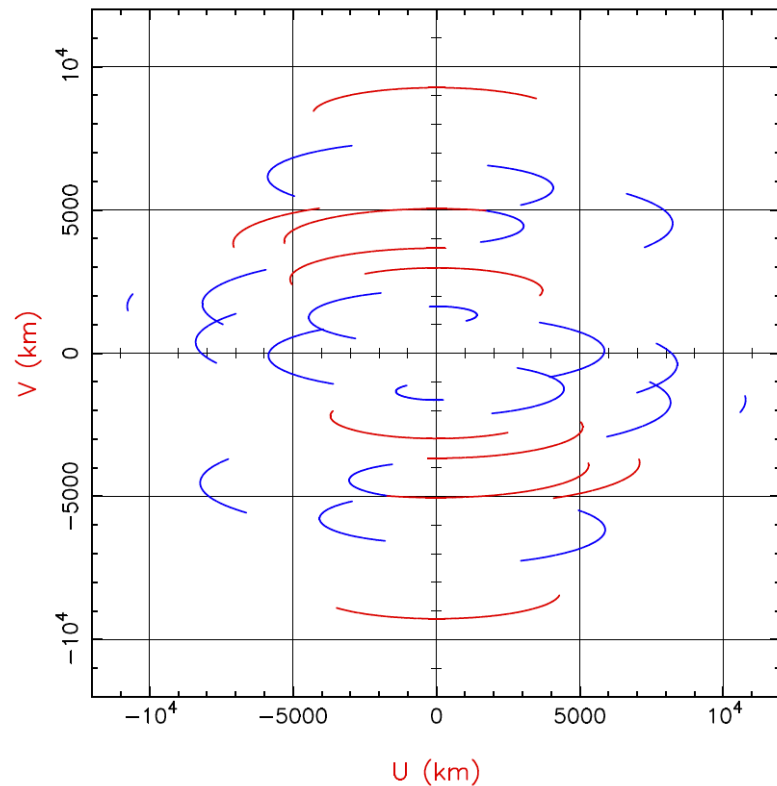
	PdBI	IRAM	ALMA	CARMA	SMT0	LMT	SMA	GLT
PdBI (B)	-	234	29	32	32	31	25.2	70.7
IRAM (V)	1,147	-	31.2	31.3	32.0	32.2	24.7	62.2
ALMA (A)	9,400	8,624	-	34.0	37.5	49.2	28.5	28.1
CARMA (C)	8,540	8,586	7,906	-	289.7	93.9	67.1	48.3
SMT0 (S)	8,481	8,402	7,176	928	-	136.9	58.1	46.8
LMT (L)	8,686	8,352	5,469	2,863	1,964	-	45.9	40.4
SMA (H)	10,671	10,907	9,448	4,009	4,627	5,858	-	33.2
GLT	3,805	4,323	9,572	5,570	5,742	6,647	8,096	-

Baseline length D (km) is shown in lower left half, and spatial resolution in upper right half in λ/D (μas) at 230 GHz. A character in parentheses is a symbol of station in Figure 5.

Inoue et al. 2014, Radio Science

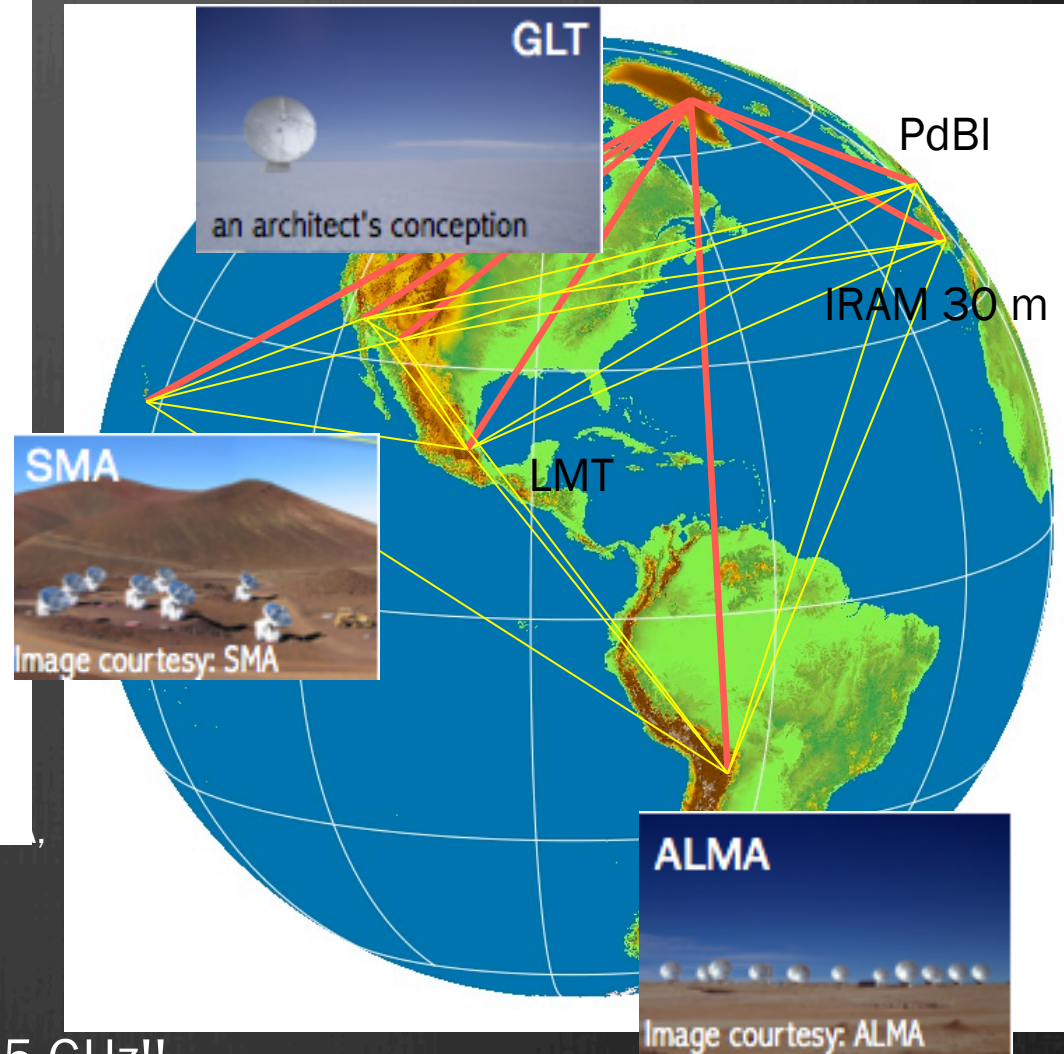


Expected uv coverage



ALMA, SMT, LMT and IRAM 30m. The Baseline with GL is red.

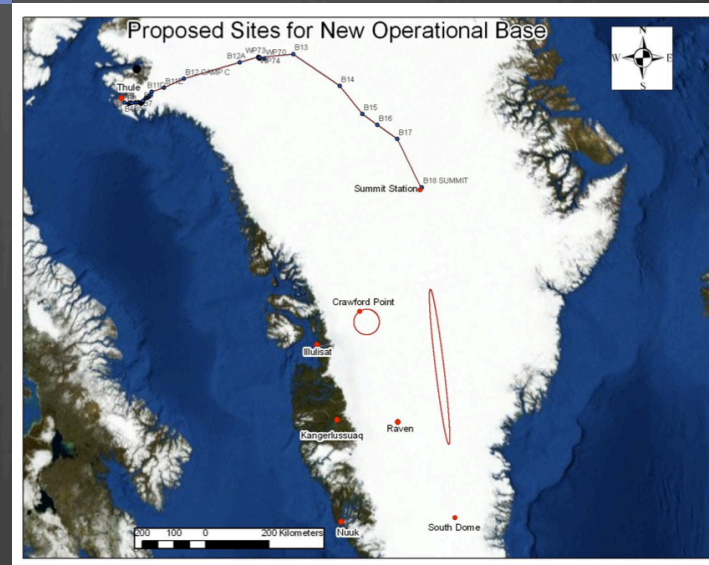
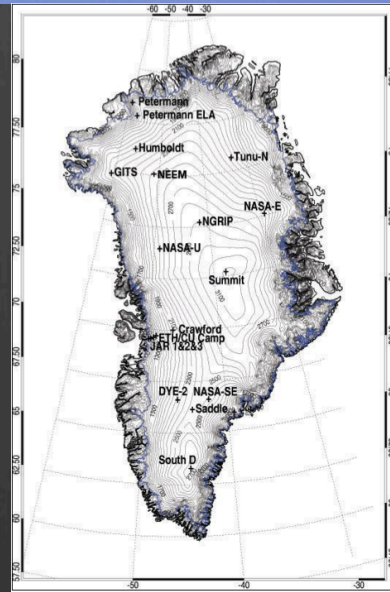
It will provide 9,000 km baseline,
and it corresponds to 20 μ as at 345 GHz!!







Receiver	Band (GHz)	Beams	Requirements	Source/Status
Holography Receiver	93	1 + ref	Secondary defocus, reference receiver, transmitter	SAO - Main receiver built Reference in build Optics under design
VLBI – W-Band	86	1	VLBI backend, tone injection	ASIAA
VLBI – Band 6 similar	211-275	1	VLBI backend, tone injection	Osaka Pref. Univ. Cryostat and optics: OPU/NAOJ
VLBI – Band 7	275-373	1	VLBI backend, tone injection	IRAM / ALMA type Cryostat and optics: OPU/NAOJ
350 GHz Multibeam	325-375	48	Flat focal plane	SAO - Prototype development underway
Bolometric Spectrometer	W-band - 350 GHz	Few?	Flat focal plane, pulse tube cooler	SAO/Cambridge – starting to plan technology development
THz Receivers	1.3 THz, 1.5 THz	1-7	Stable optics, good dish surface	SAO/ASIAA? – concept development



2015 SCAR AAA



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Thule Air Force Base in Greenland





GLT Status Summary

- 2015 - 2016:
 - Thule preparation; test pad, infrastructure, connections.
 - Antenna cold retrofit. To completed soon.
 - Build antenna support frame, servo containers, de-ice system.
 - Build VLBI receivers.
 - Build support camp and power station.
- 06.2016: All components at Norfolk
- 07.2016: Antenna to Greenland (Thule)
- 10.2016 – 02.2017: Antenna assembly in Thule
- 2017: GLT First light in Thule
- 2018: Antenna to Greenland Summit ?
- 2019: GLT Operational on Summit ?