The 8th East Asia VLBI Workshop 2015, Sapporo, Japan, 8-10 July 2015

Developments in Expanding the Event Horizon Telescope: Phased ALMA and South Pole Telescope

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on behalf of European and Korean (sub)mm-VLBI

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What is the South Pole Telescope?

The South Pole Telescope

A 10m dish for CMB mapping

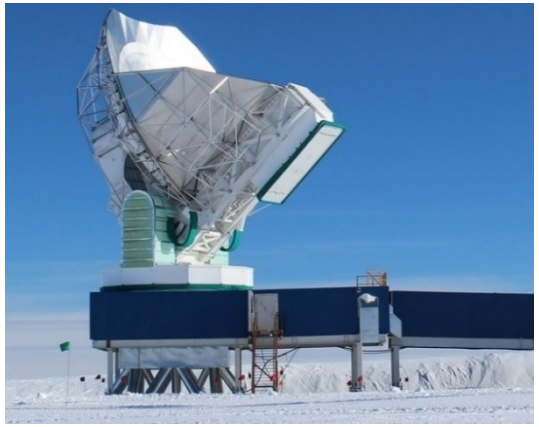
- Operated by University of Chicago

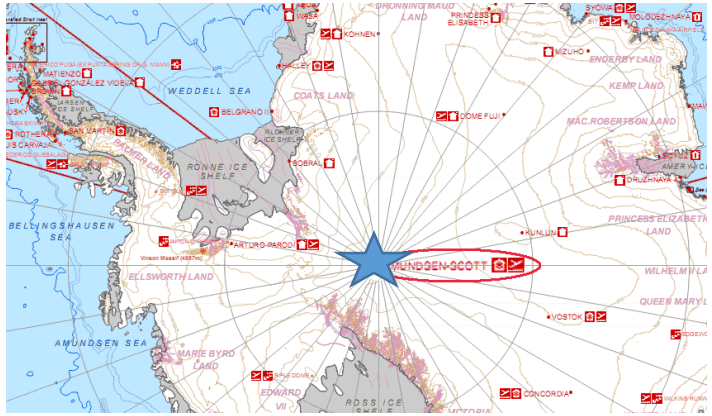
Recent VLBI capability

- PI is Dan Marrone at University of Arizona
- $700k NSF grant 2012-2015 for upgrade
- VLBI system with R2DBE, Mark6, maser, …
- Dual-band EHT receiver by UArizona
  - ALMA mixers, 230 GHz + 345 GHz
  - fixed 1st LO (221.10 GHz, LSB)
  - diagnostic spectrometers
- Position, by SPT VLBI Team

  Lat -89.9899996°
  Lon -44.8727509°
  Alt 2843.5m
  (position of GPS antenna, within ~15m of VLBI)

Image credit: C.H. Greer





(sub)mm-VLBI?

Science Drivers of (sub)mm-VLBI

Fine scale structure related to black hole/disk/jet systems
M 87, BL Lac, NGC 1052, …

Accretion and structure at event horizon scales
Sgr A*, M 87

… objects scatter-broadened or self-absorbed at longer wavelengths

Galactic center pulsars

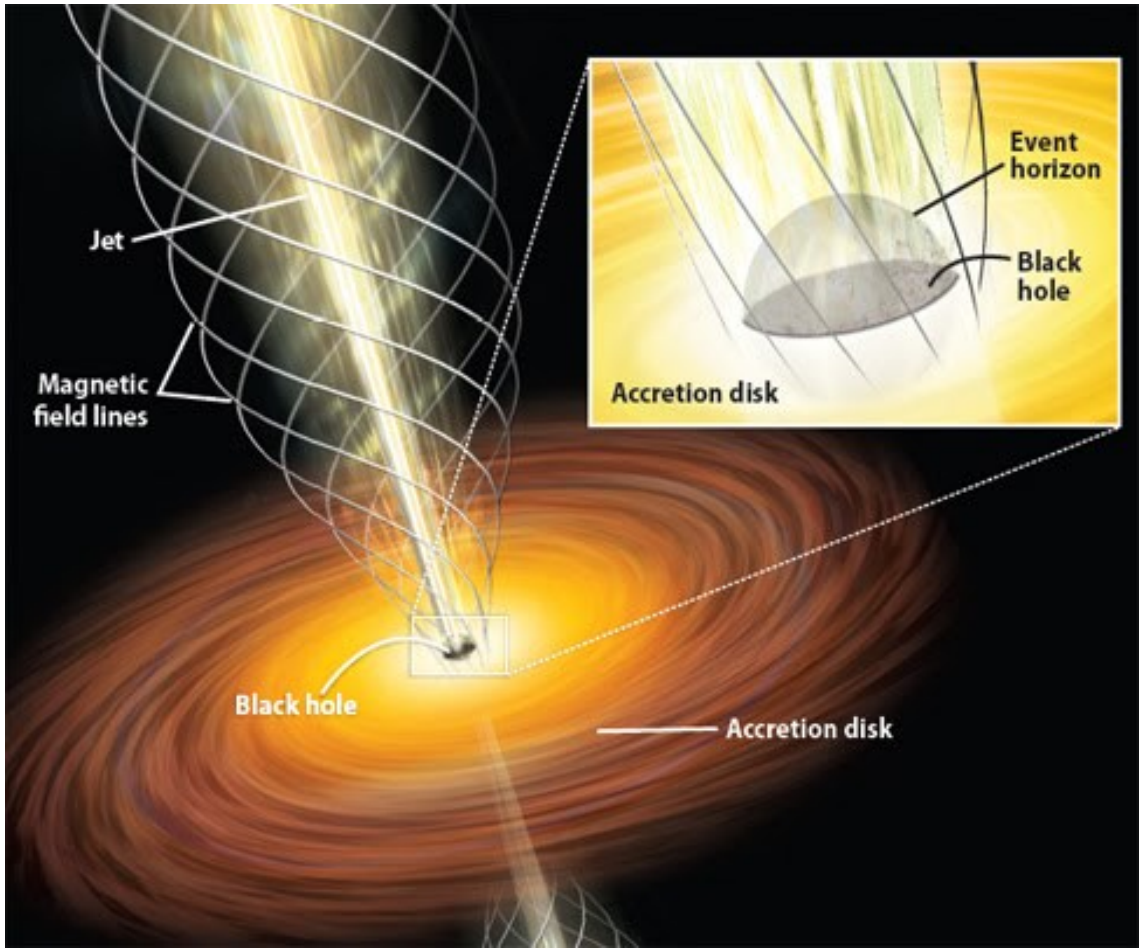


Image credit Astronomy/Roen Kelly

Requirements

High resolution to resolve expected structure

past progress

2003 IRAM 30m–ARO SMT 230 GHz : ~30 µas

2007 EHT ARO SMT–CARMA–SMA/JCMT : ~60 µas

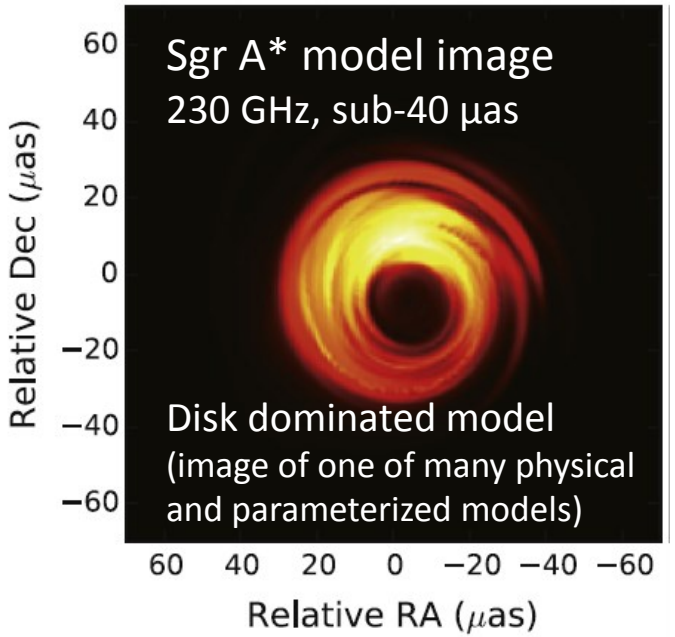
2012 APEX–SMA–ARO SMT, 2013/2015 EHT : ~28 µas

Sensitivity of some mJy (Δt≈1h, BW≈2 GHz)

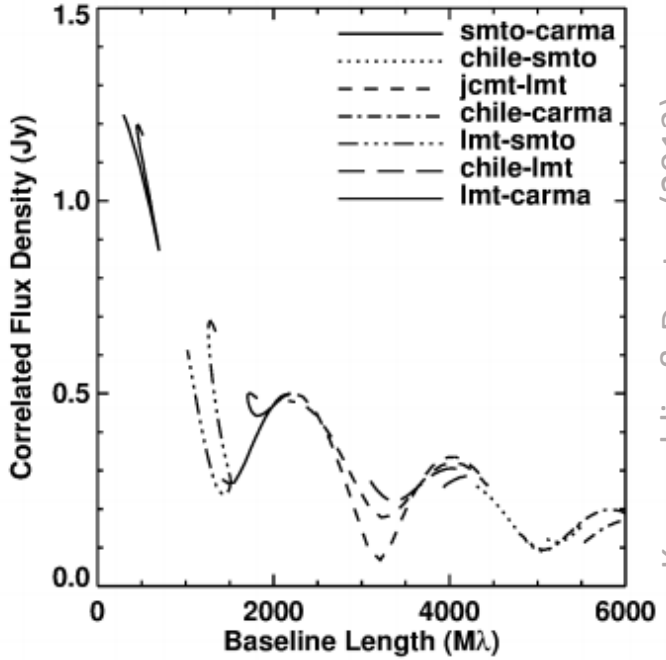
need SMA/JCMT, ~~CARMA~~, ALMA

Sufficient uv coverage for imaging, modelfit

requires many stations: ARO SMT, SMA, JCMT, APEX, LMT, PdBi/NOEMA, IRAM 30m, CARMA, …



Dexter et. al (2012)



Kamruddin & Dexter (2013)

230 GHz VLBI Stations

March 2015 EHT

rk

230 GHz VLBI Stations

Future EHT

Others:

- upgrading (PdBi/NOEMA)
- in progress (GLT, SPART)
- planned (CSO, Effelsberg)

Image credit: New York Times, 9 June 2015

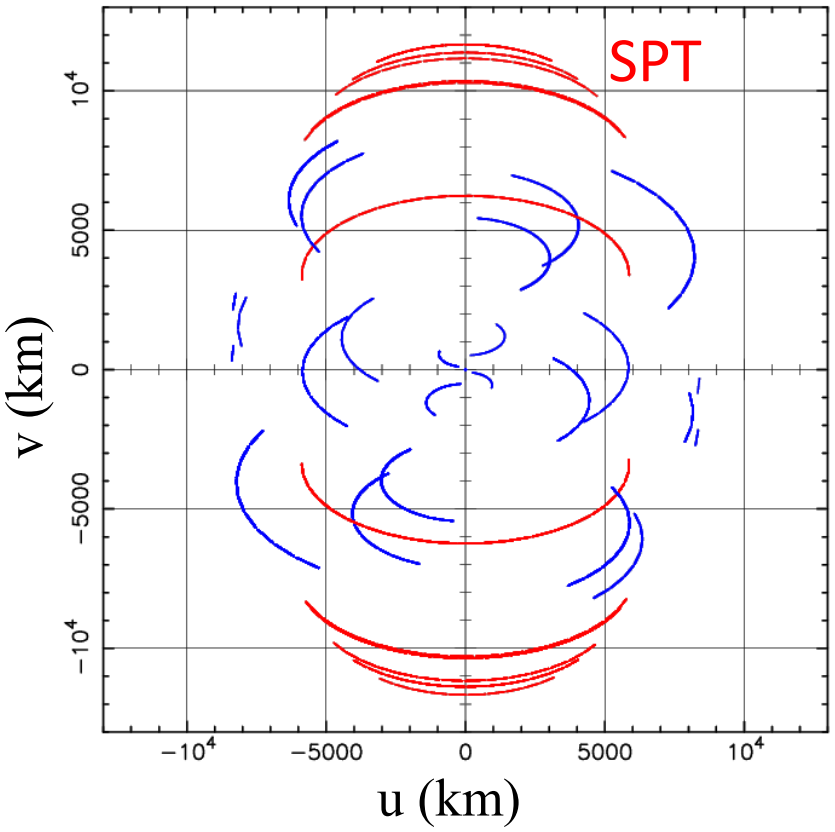
Why add South Pole Telescope and ALMA?

Coverage on Sgr A* and M 87 (out of many other AGN science targets!)

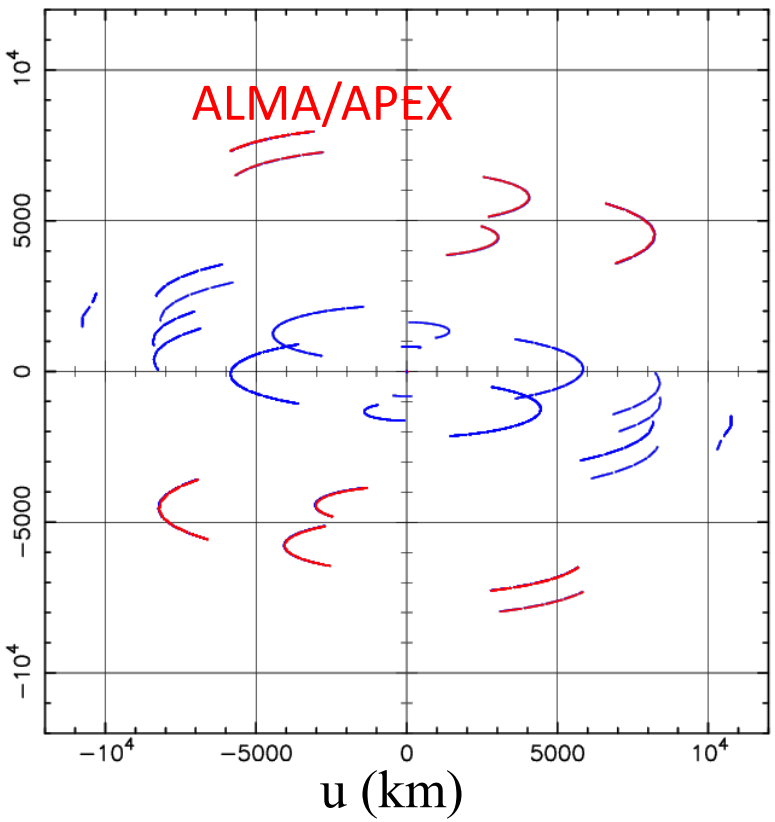
If SPT and ALMA/APEX added to the mm-VLBI network

with ARO-SMT, SMA/JCMT, LMT, IRAM 30m, PdBi

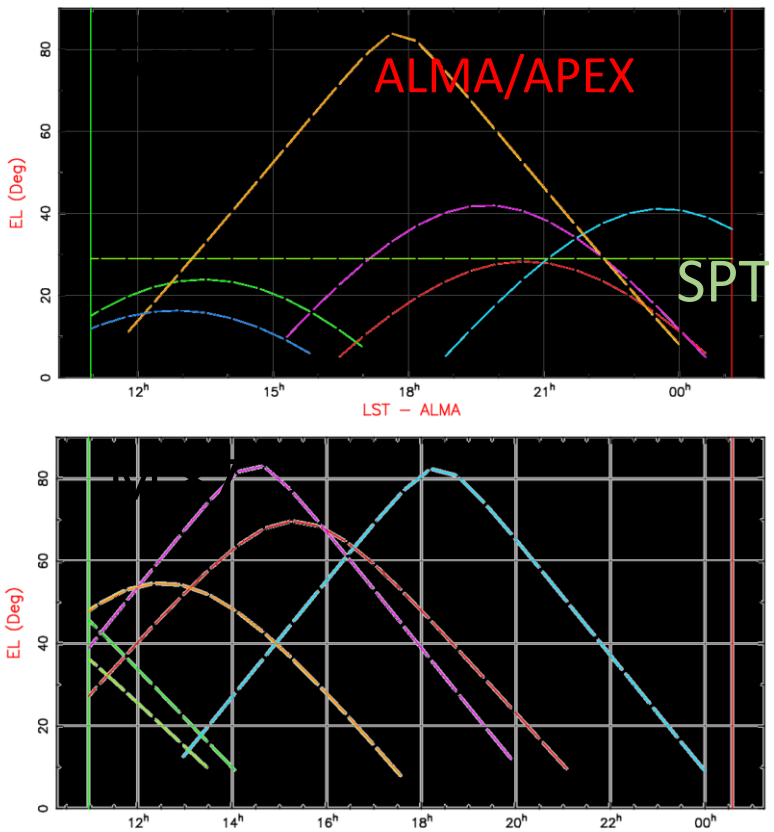
Sgr A* uv coverage



M 87 uv coverage



Source elevation 24h



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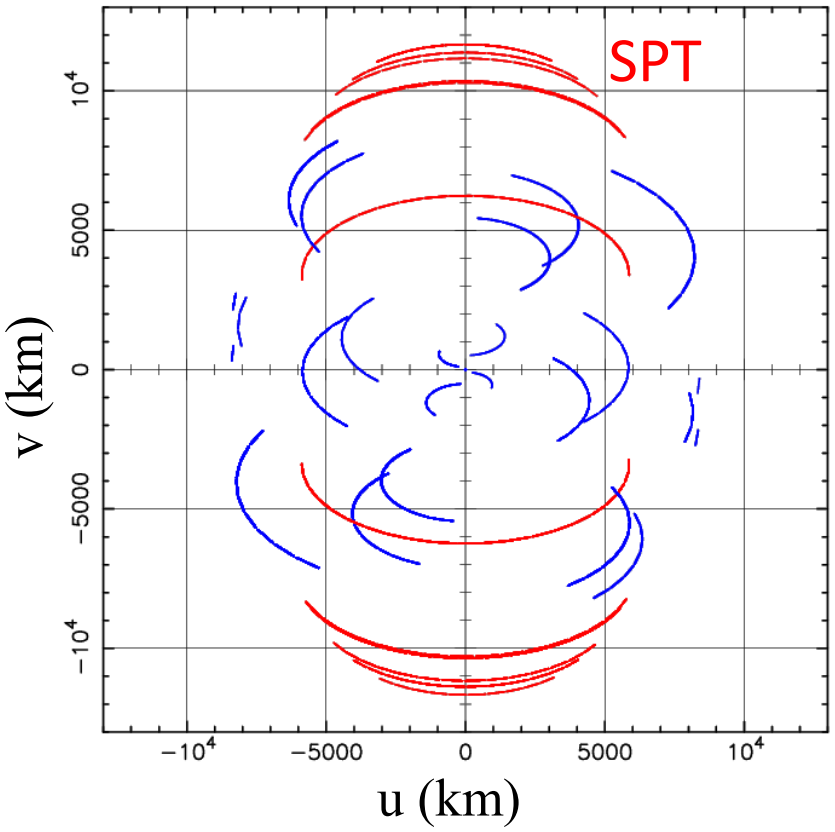
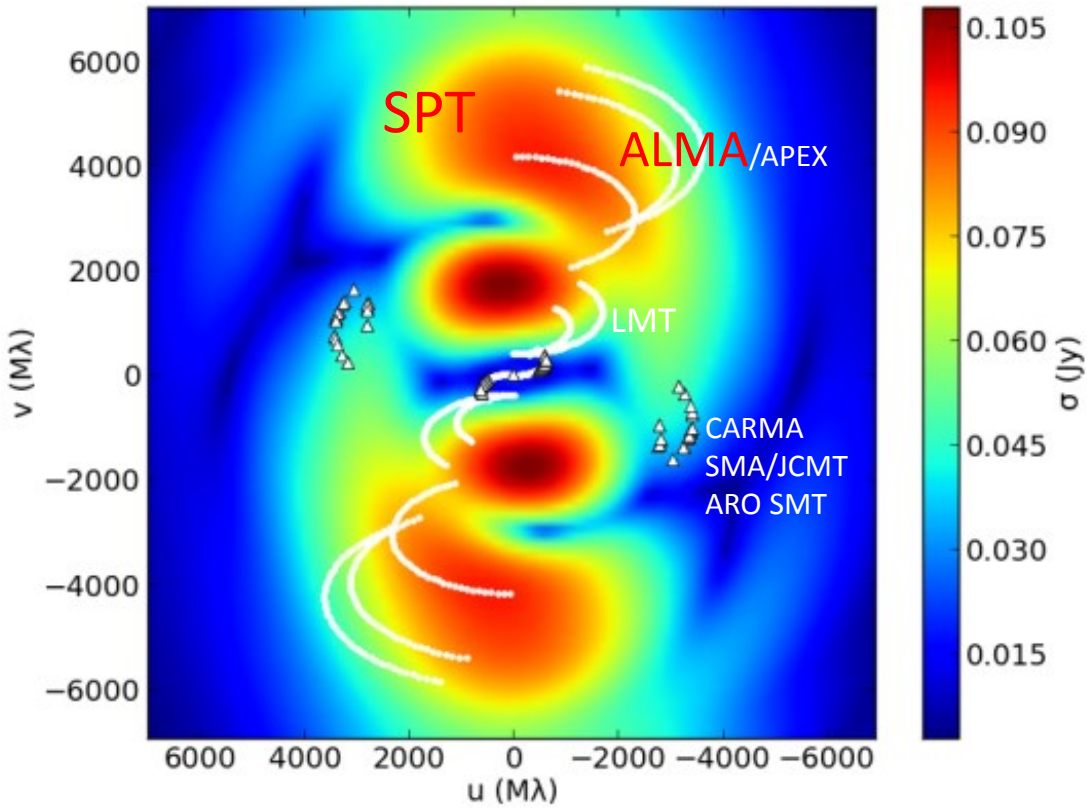


Variance in Sgr A* crescent model images



Red: uv plane regions where crescent models differ the most.

Kamruddin & Dexter (2013)

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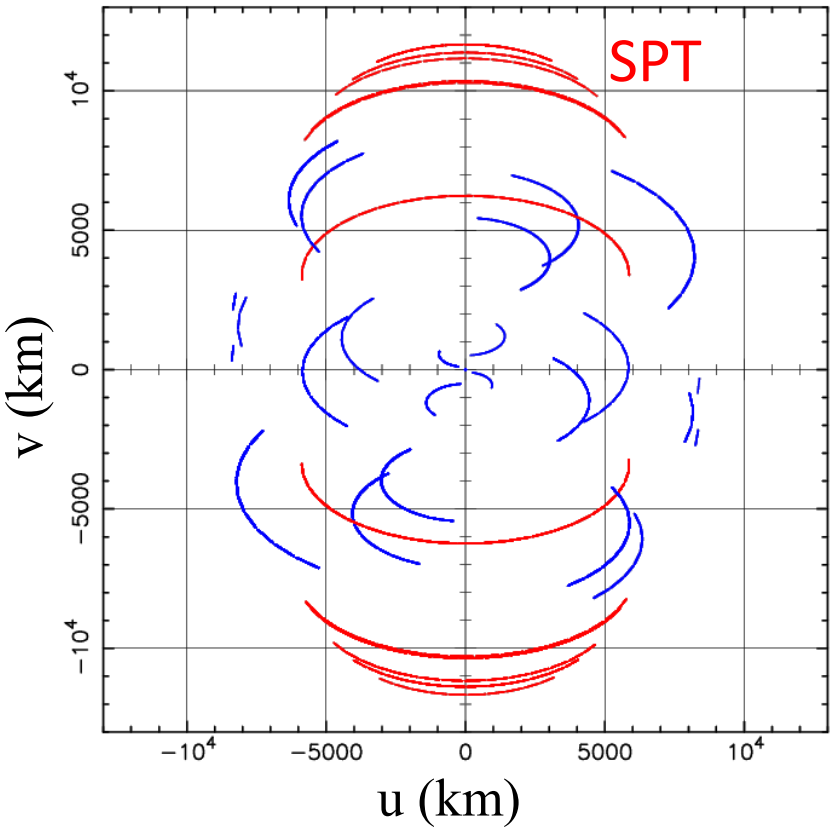
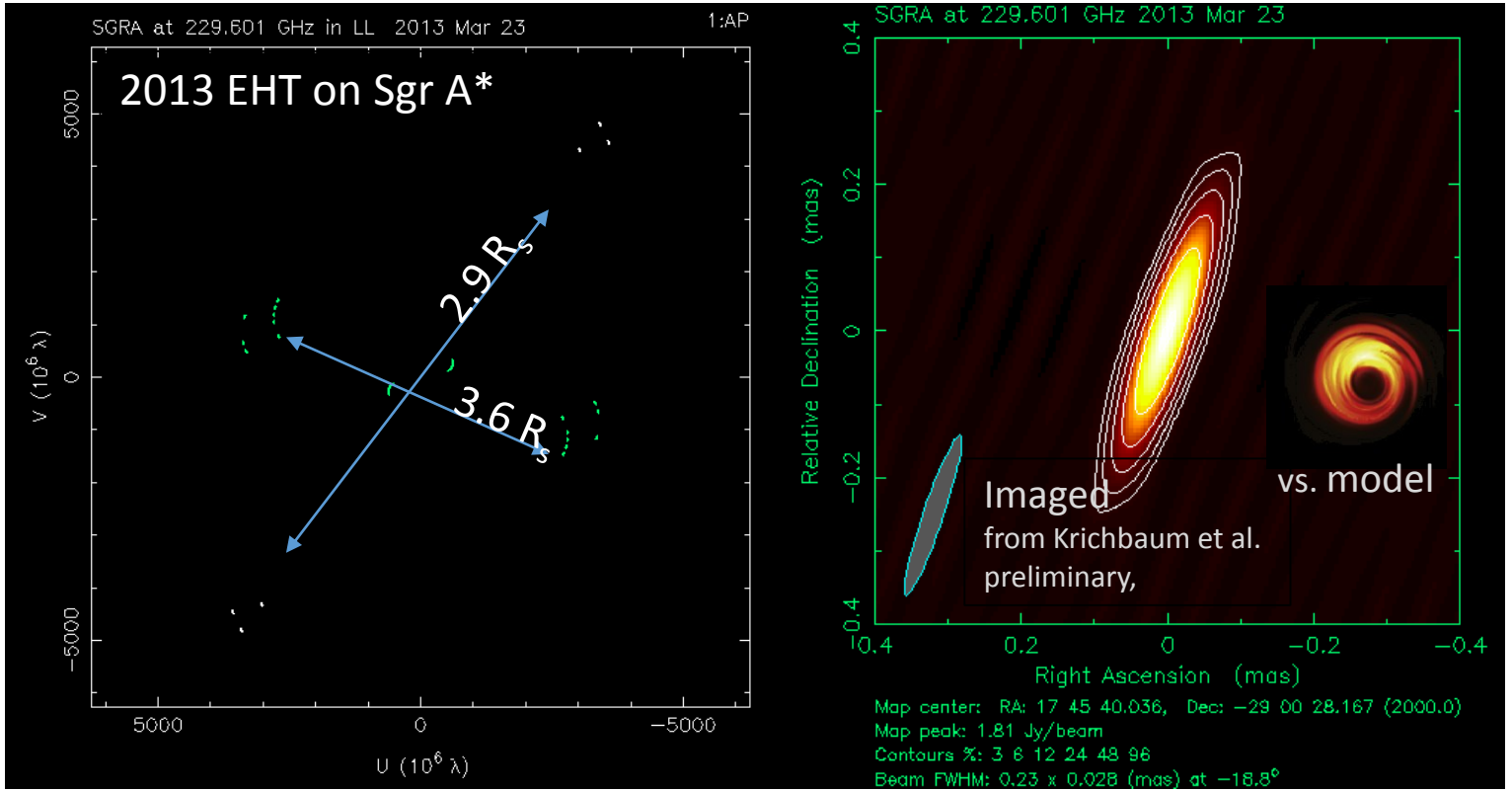
Sgr A* uv coverage





Adding the South Pole Telescope and ALMA…

January 2015 Fringe Test at 230 GHz

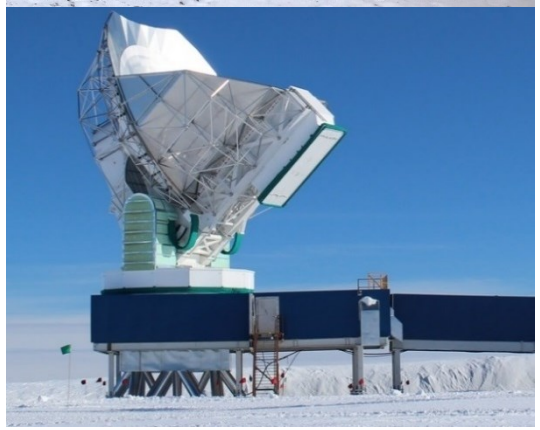
13 January : Chile : Phased ALMA + ALMA OSF dish + APEX

12m APEX by MPIfR-OSO-ESO (VLBI PI: Zensus et al.)
Station with VLBI since 2012, cf. Roy et al. EVN 2013, Wagner et al. 2015

Phased ALMA >70m thanks to APP (VLBI PI: S. Doeleman)
During technical time. Phased array occasionally worse than single dish.

17 January : Intercontinental : SPT + APEX

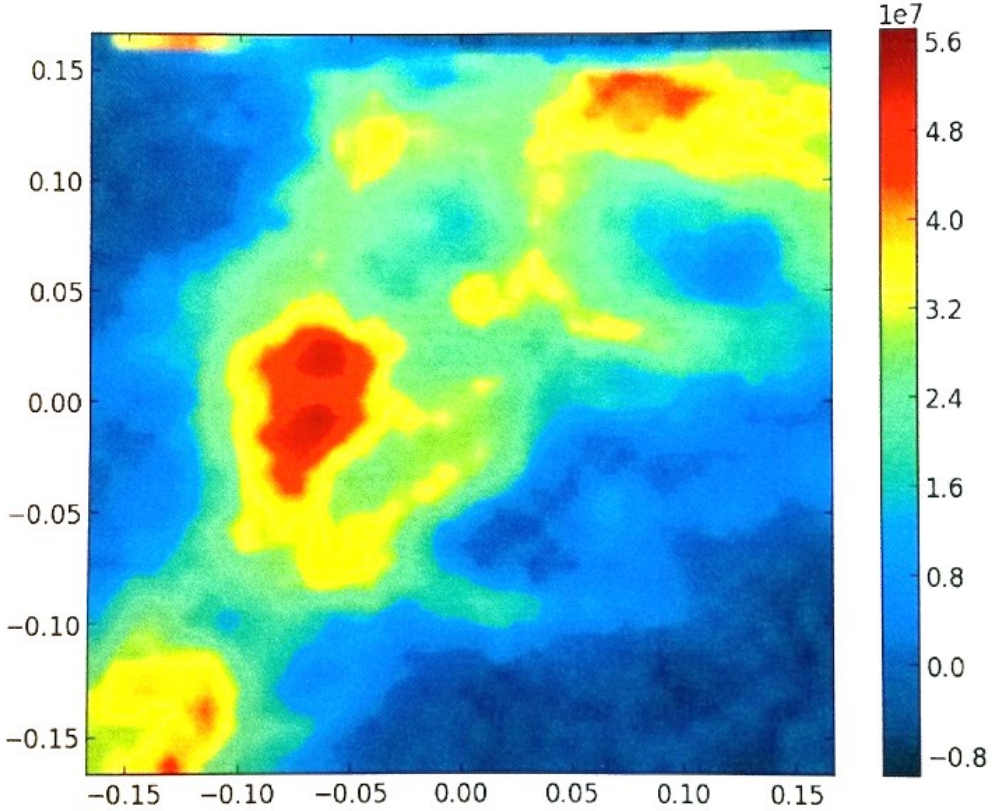
10m SPT by UChicago (VLBI PI: D. Marrone)
Access to South Pole challenging. Last-minute receiver installation, VLBI setup.

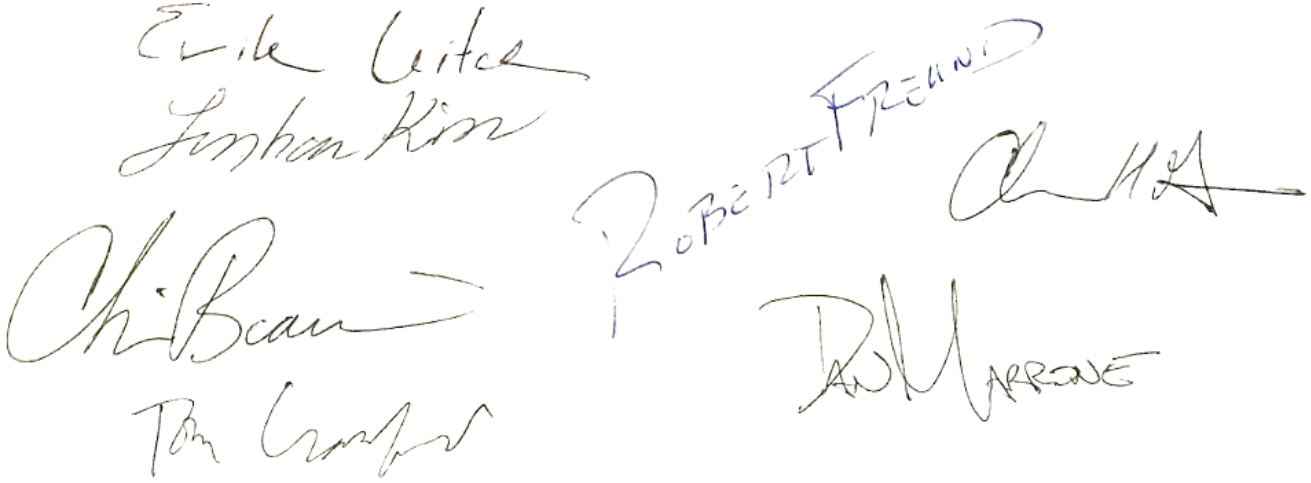


First Light of SPT VLBI Receiver

D. Marrone, 16 January 2015, sent by rare satellite link

Map of 215 GHz emission in 30’ region around Sgr B2





+ Chris Kendall, Jason Soohoo and John Carlstrom

“Frequency Calibrators”?

Confusing mix in EHT telescope VLBI tuneability, sub-band configurations

Station	**Tuning**	**Backend sub-bands**
SPT	1st LO fixed, 2nd LO 1 GHz steps, LSB	2 x 2048 MHz with R2DBE
ALMA	Semi-flexible, overlapping quadrants, LSB/USB	4 x 16 x 62.5 MHz or variations of it
APEX	1st LO tunable (x12), 2nd LO 1 MHz steps, USB	1 x 2048 MHz with R2DBE, 2 x 16x64 MHz with 1st channel offset -32 MHz, or 2 x 16x62.5 MHz (“ALMA mode”) with 1st offset -31.25 MHz with DBBC2
ARO SMT	1st LO tunable (x3), USB/LSB	2 x 2048 MHz with R2DBE
IRAM 30m	1st LO semi-flexible, risky, e.g. 24 kHz offset, ..	2 x 16x32 MHz 1st channel offset -16.5 MHz
….	…	…

→ New untested VLBI observing modes that accommodate all stations : risky!
Station recordings at which on-sky frequency? Sideband? Sub-band? Nyquist zone?

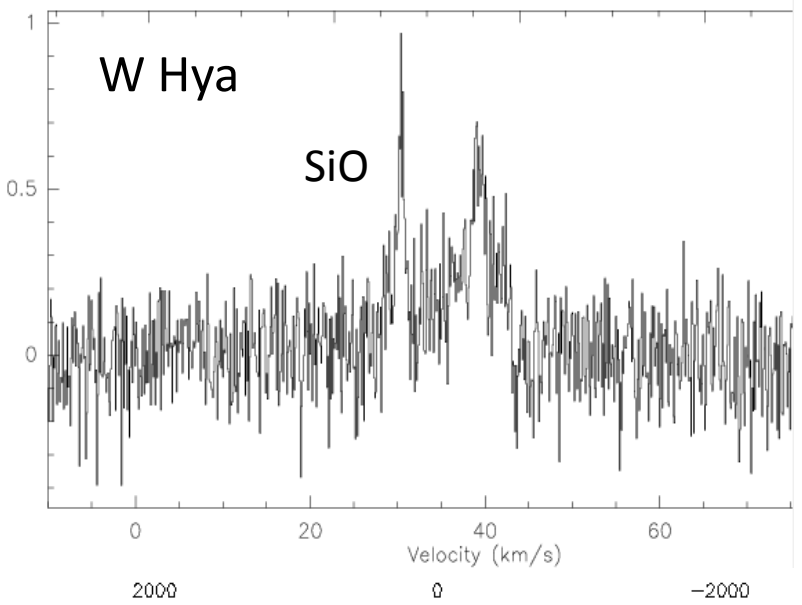
Mini-Survey for “Frequency Calibrators” at 215 GHz

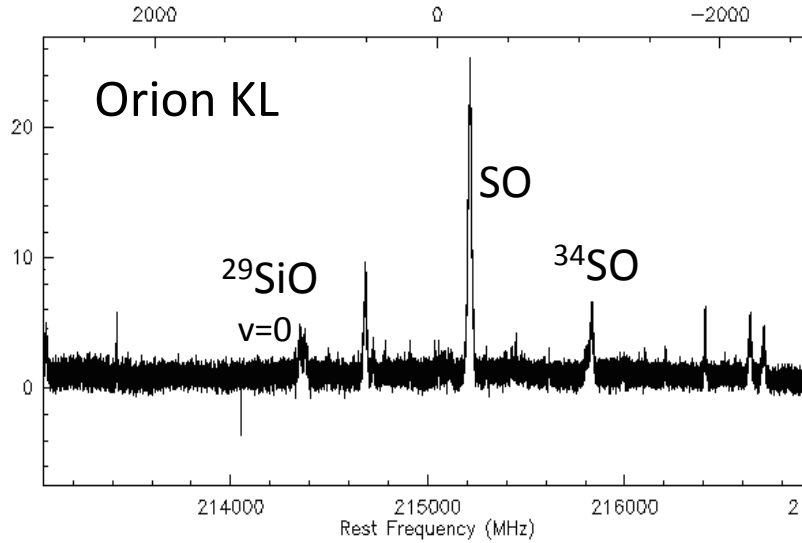
Selected known 86 GHz SiO masers visible to SPT
Two detected with APEX at 215 GHz:

Table 1: APEX Southern 215.6 GHz SiO (v=1 J=5-4) Mini-Survey

Source	RA	Dec (J200)	$T_a^\star$
R Dor	4:36:45.61	-62:04:37.9	< 1.0K
			2.0 K (217 GHz SiO)
W Hya	13:49:01.92	-28:22:03.36	0.9 K (215.6 GHz SiO)
Orion KL	5:35:14.50	-5:22:29.60	3.0 K (215.2 GHz SO)
L2 Pup	7:13:32.30	-44:38:22.92	< 0.8 K
VY CMa	7:22:58.33	-25:46:03.24	< 0.8 K
RW Vel	9:20:19.43	-49:31:30.72	< 1.5 K
LP Hya	9:25:51.20	-24:00:37.80	< 0.6 K
IW Hya	9:45:15.16	-22:01:44.76	< 1.0 K
V Ant	10:21:09.00	-34:47:18.60	< 1.0 K
X Cen	11:49:11.64	-41:45:27.36	< 1.0 K

Notes. APEX gain is 0.015 K Jy^{-1}. Spectrometer velocity coverage ± 2500 km s^{-1} and 20 s integration. $T_a^\star$ upper limits are 3σ. R Dor detection in 217 GHz SiO is out of SPT tuning range. The Orion KL line at 215.2 GHz is likely SO (cf. Sutton et al. 1985). PRELIMINARY.

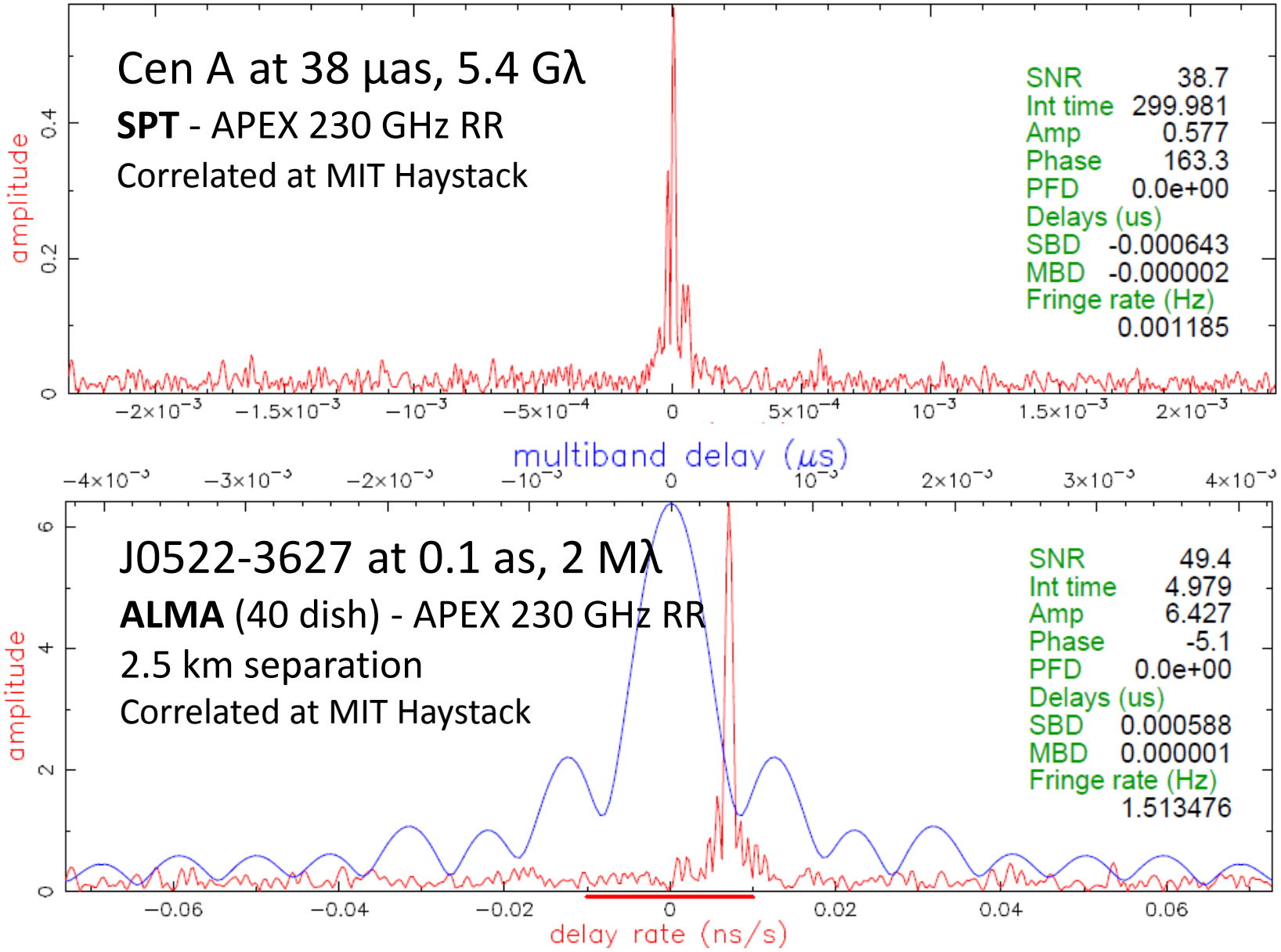




First VLBI Fringes!

Memos in progress for ALMA (G. Crew) and SPT (D. Marrone) …

ALMA phasing efficiency of >99%, see V. Fish [1]



[1] Workshop on mm-VLBI with ALMA, January 2015, Bologna, Italy

Progress Towards 345 GHz VLBI

- First test : 1 Apr 2015 with 3C 279

APEX + Pico Veleta + ARO-SMT	9.9 Gλ, ~21 μas E-W

In progress at MPIfR Bonn, no fringes, yet…

- Soon : 28 Jul - 3 Aug 2015 “ALMA EHT Evaluation” likely 3C 454.3

345 GHz ALMA + APEX + SMA	10.9 Gλ, ~19 μas N-S
in addition to main	
230 GHz ALMA + APEX + SMA + JCMT	7.2 Gλ, ~28 μas N-S
86 GHz ALMA + VLBA (+ Effelsberg)	2.5 Gλ, ~84 μas N-S

Summary

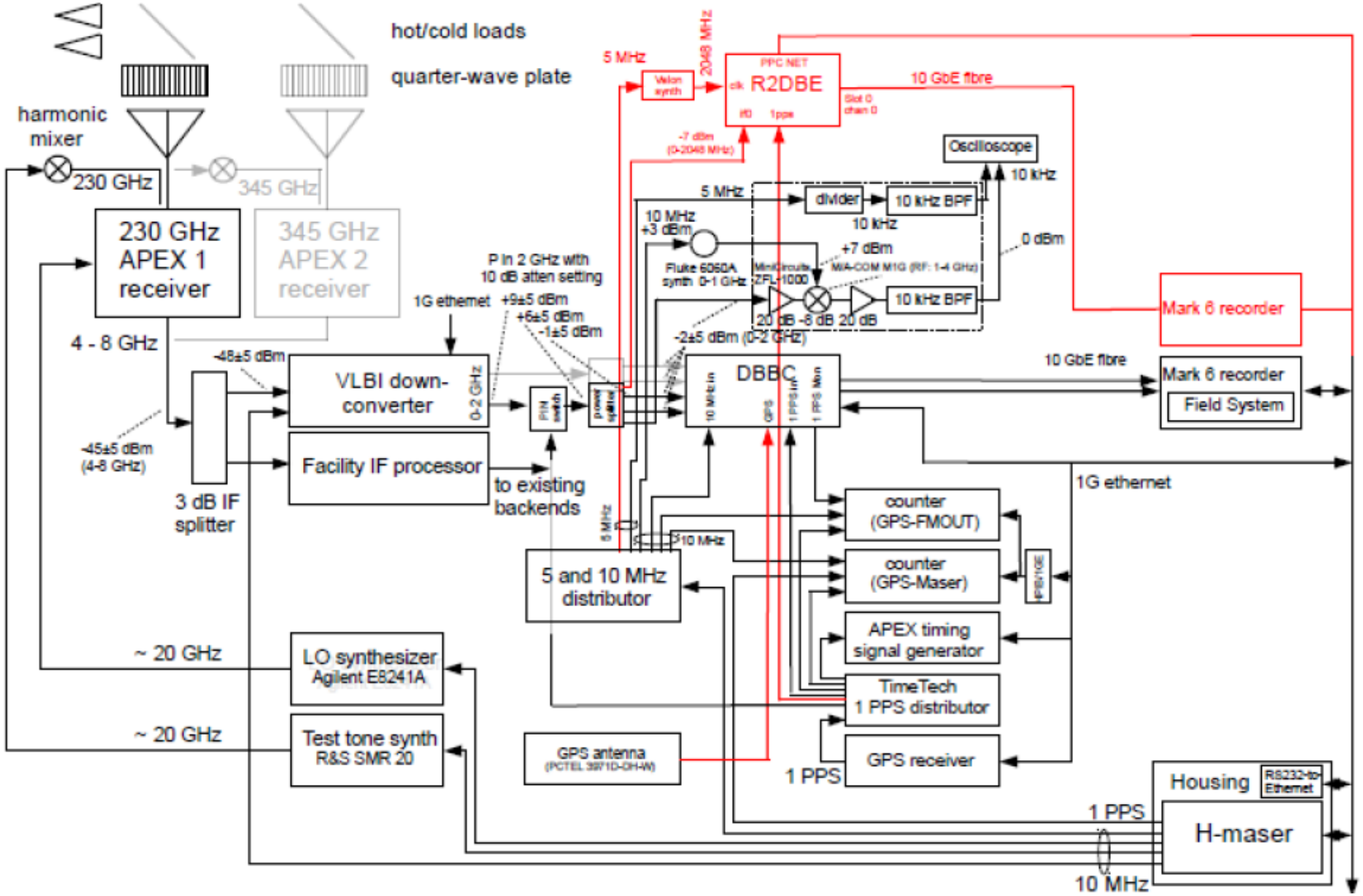
- Strong commissioning efforts by SPT and ALMA Phasing Project teams

  → Got Fringes

- Fingers crossed for 345 GHz VLBI fringe tests success this month

- In 2016 finally 230(/345) GHz science VLBI obs. including ALMA, SPT?

Thank You


hot/cold loads
quarter-wave plate
harmonic mixer
230 GHz
345 GHz
230 GHz APEX 1 receiver
345 GHz APEX 2 receiver
4 - 8 GHz
-48±5 dBm
-45±5 dBm (4-8 GHz)
3 dB IF splitter
VLBI down-converter
0-2 GHz
Facility IF processor
to existing backends
1G ethernet
P in 2 GHz with 10 dB atten setting
+9±5 dBm
+6±5 dBm
-1±5 dBm
5 MHz
2048 MHz
Valon synth
PPC NET
R2DBE
clk
if0
1pps
Slot 0 chan 0
10 GbE fibre
-7 dBm (0-2048 MHz)
Oscilloscope
10 kHz
5 MHz
divider
10 kHz BPF
10 kHz
10 MHz +3 dBm
Fluke 6060A synth 0-1 GHz
Mini-Circuits ZFL-1000
MA-COM M1G (RF: 1-4 GHz)
+7 dBm
0 dBm
20 dB -6 dB 20 dB
10 kHz BPF
-2±5 dBm (0-2 GHz)
DBBC
10 MHz in
GPS
1 PPS in
1 PPS Mon
10 GbE fibre
Mark 6 recorder
Mark 6 recorder
Field System
1G ethernet
counter (GPS-FMOUT)
counter (GPS-Maser)
APEX timing signal generator
TimeTech 1 PPS distributor
GPS receiver
1 PPS
5 and 10 MHz distributor
10 MHz
~ 20 GHz
LO synthesizer Agilent E8241A
~ 20 GHz
Test tone synth R&S SMR 20
GPS antenna (PCTEL 39710-OH-W)
Housing
RS232-to-Ethernet
H-maser
1 PPS
10 MHz

Coverage on Sgr A* and M 87

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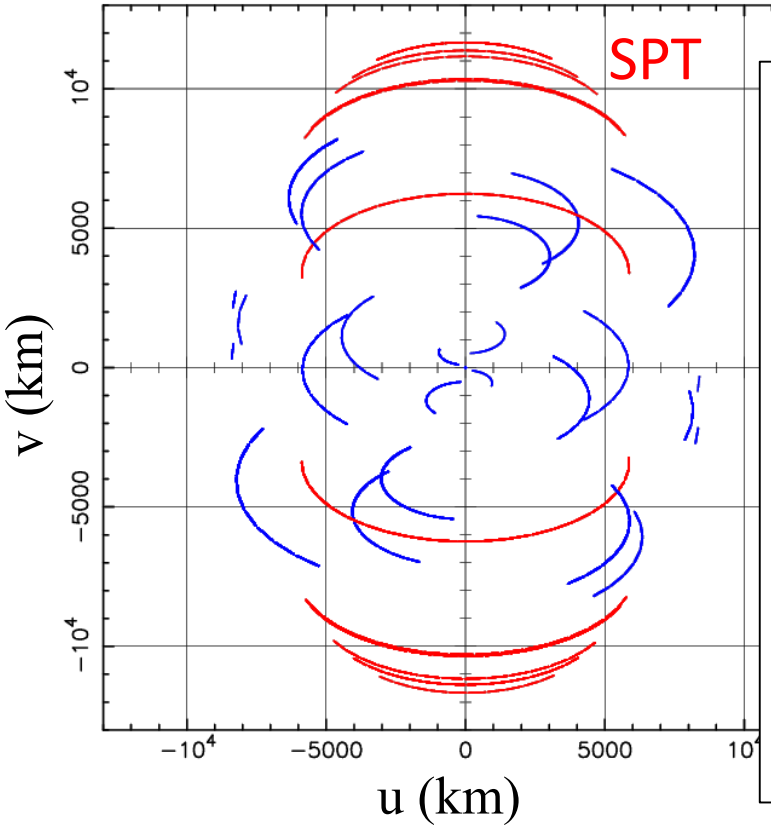
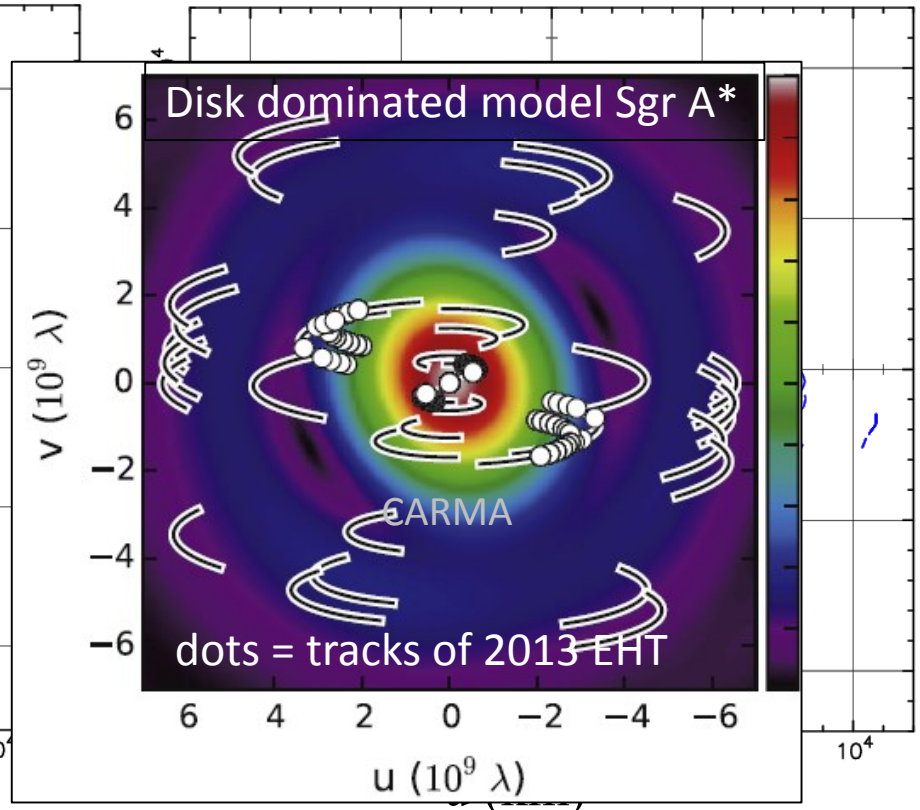
Sgr A* uv coverage



M 87 uv coverage



Akiyama et al. (ApJ in press)

Source elevation 24h