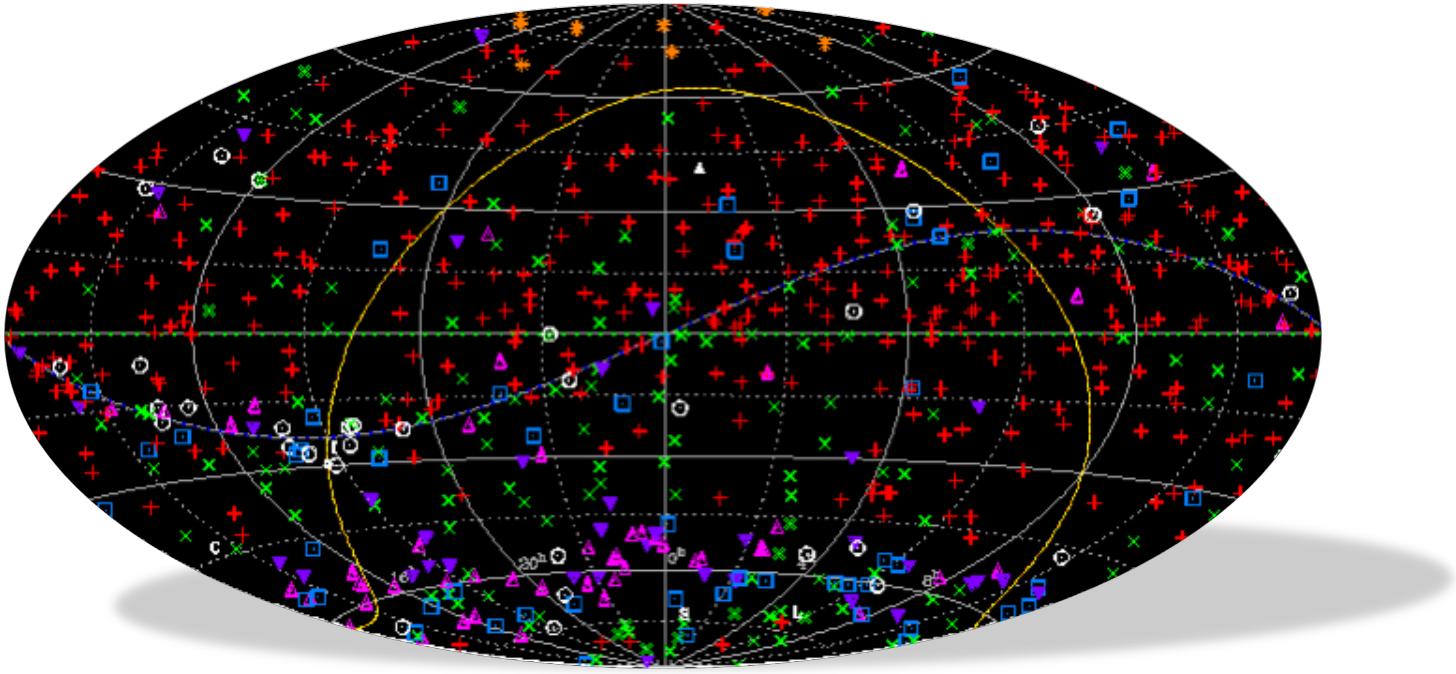
Journees, Paris, France, 2019 Oct 7-9

X/Ka (8.4/32 GHz) Celestial Frame: Roadmap to the future



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Outline

- Why Build a Celestial Frame at X/Ka-band. (8.4/32 GHz) ?
  Structure advantage over S/X perhaps even over K-band
  Dual-band ionosphere calibrations like S/X no need for GNSS cals as for K-band

- X/Ka Frame now a part of ICRF-3: current status.

- Limitations of Current X/Ka ground station network geometry

- Improving the network:
  Malargüe, Argentina 34-meter: Improve SNR, add dual band

  Misasa, Japan 54-meter: Add new baselines with high sensitivity

- Longer term:
  Explore adding X/Ka to VLBA: multi-baseline yields more delays per session
  JPL will assemble an 8-35 GHz broadband prototype by end of year

Why build a Celestial Reference Frame at X/Ka?

- Spacecraft are allocated three frequencies: S (2.3 GHz), X (8,4 GHz), Ka (32 GHz)

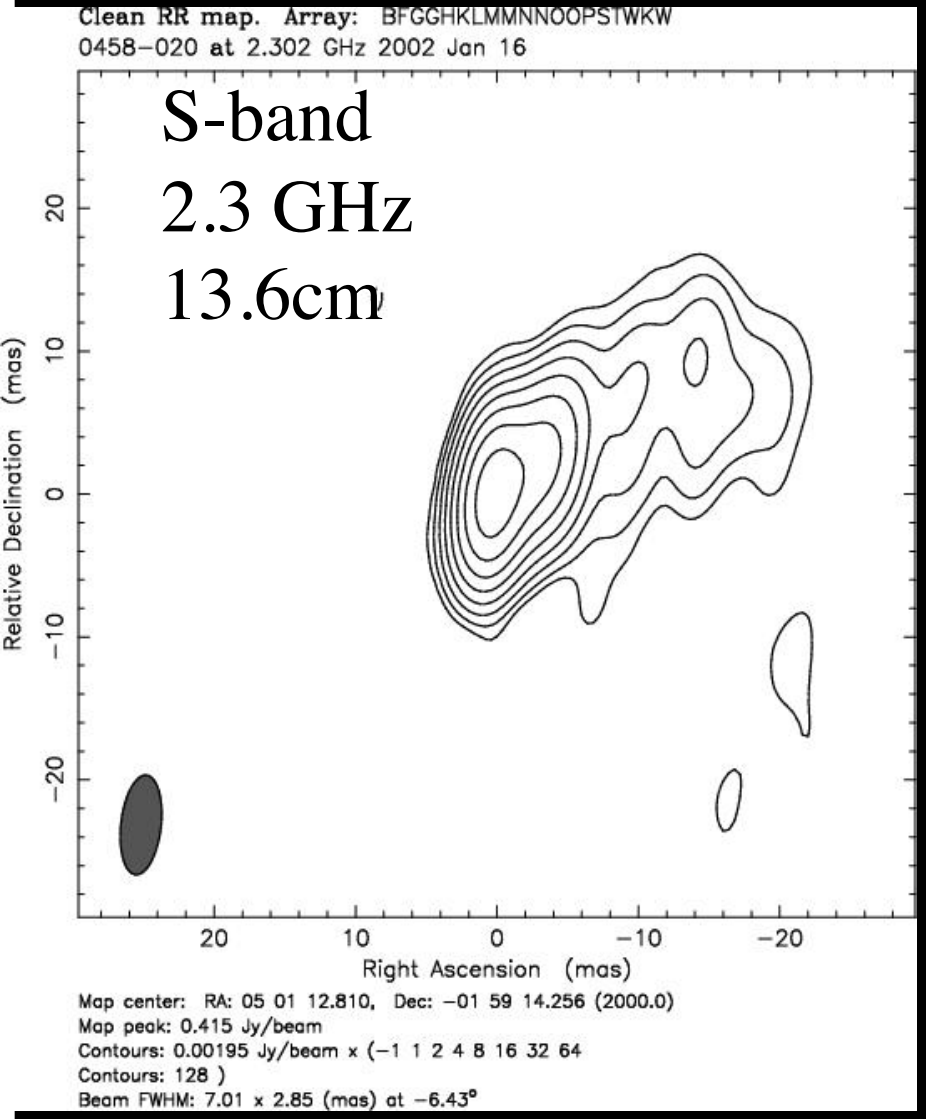
- S-band usefulness is decreasing rapidly
  Very few new missions at S-band
  RFI at S-band is degrading the band (Wif-Fi etc.)
  Source structure worse at low frequencies

- X-band is now the "workhorse" frequency, but nearing structure floor at ~30 μas

- Ka-band advantages:
  More bandwidth: 500 MHz allocation, DDOR tones can spread up to 200 MHz
  Higher telemetry rates
  Solar plasmas effect reduced as 1/ frequency squared
    This allows tracking much closer to the Sun e.g. Parker Solar Probe

  X/Ka dual-band calibrates ionosphere (solves K-band ion calibration issue)
  More compact structure than S/X

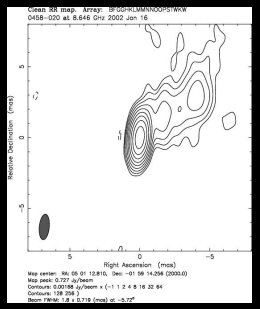
Why X/Ka? Source Structure vs. Frequency

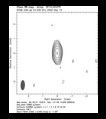


X-band
8.6 GHz
3.6cm

K-band
24 GHz
1.2cm

Q-band
43 GHz
0.7cm





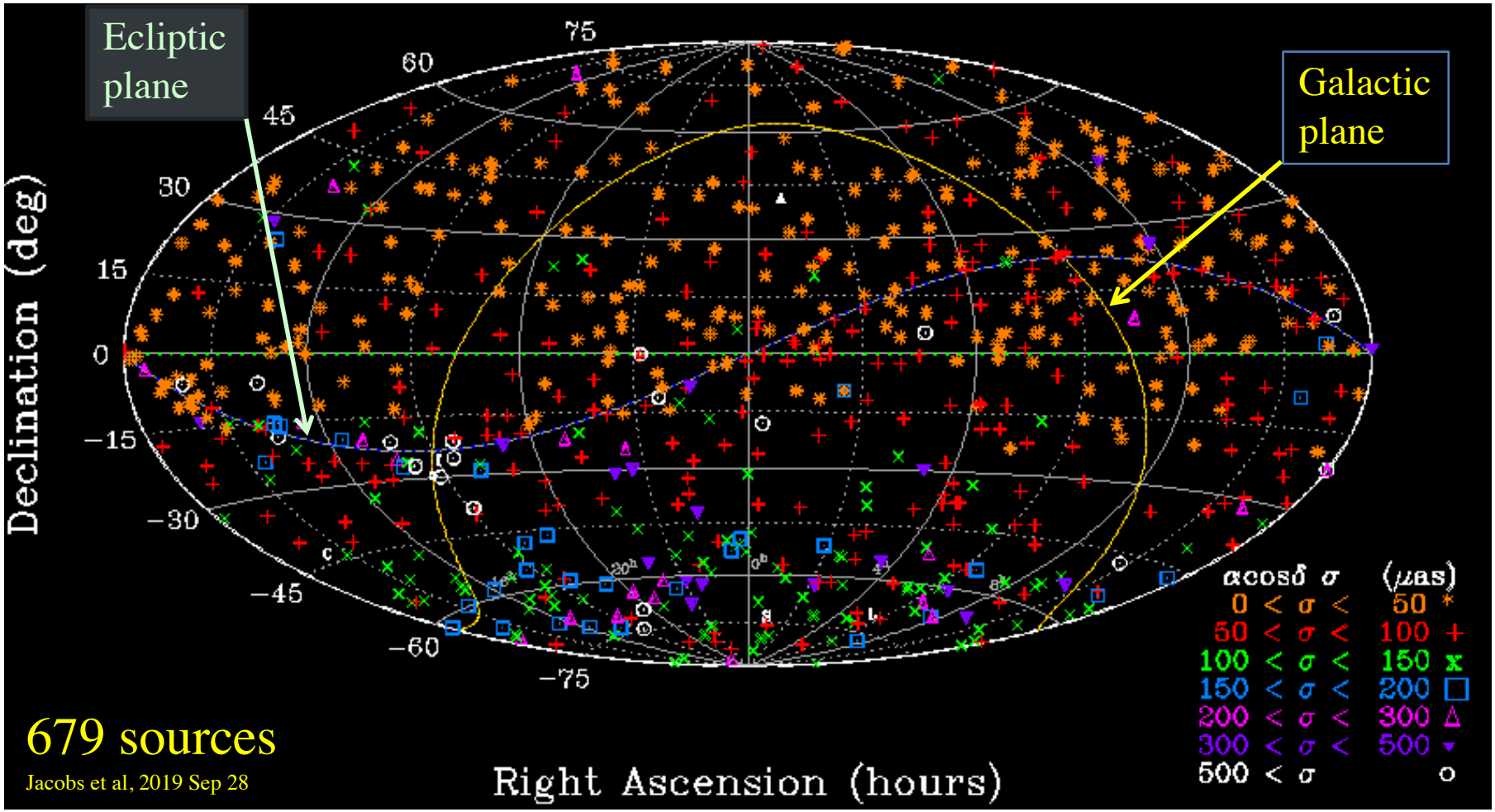
The sources become better →
Less structure

Ka-band
32 GHz
0.9cm

Images credit: Pushkarev & Kovalev A&A, 544, 2012 (SX); *Charlot et al, AJ, 139, 2010 (KQ)*

Current Status of X/Ka Celestial Frame

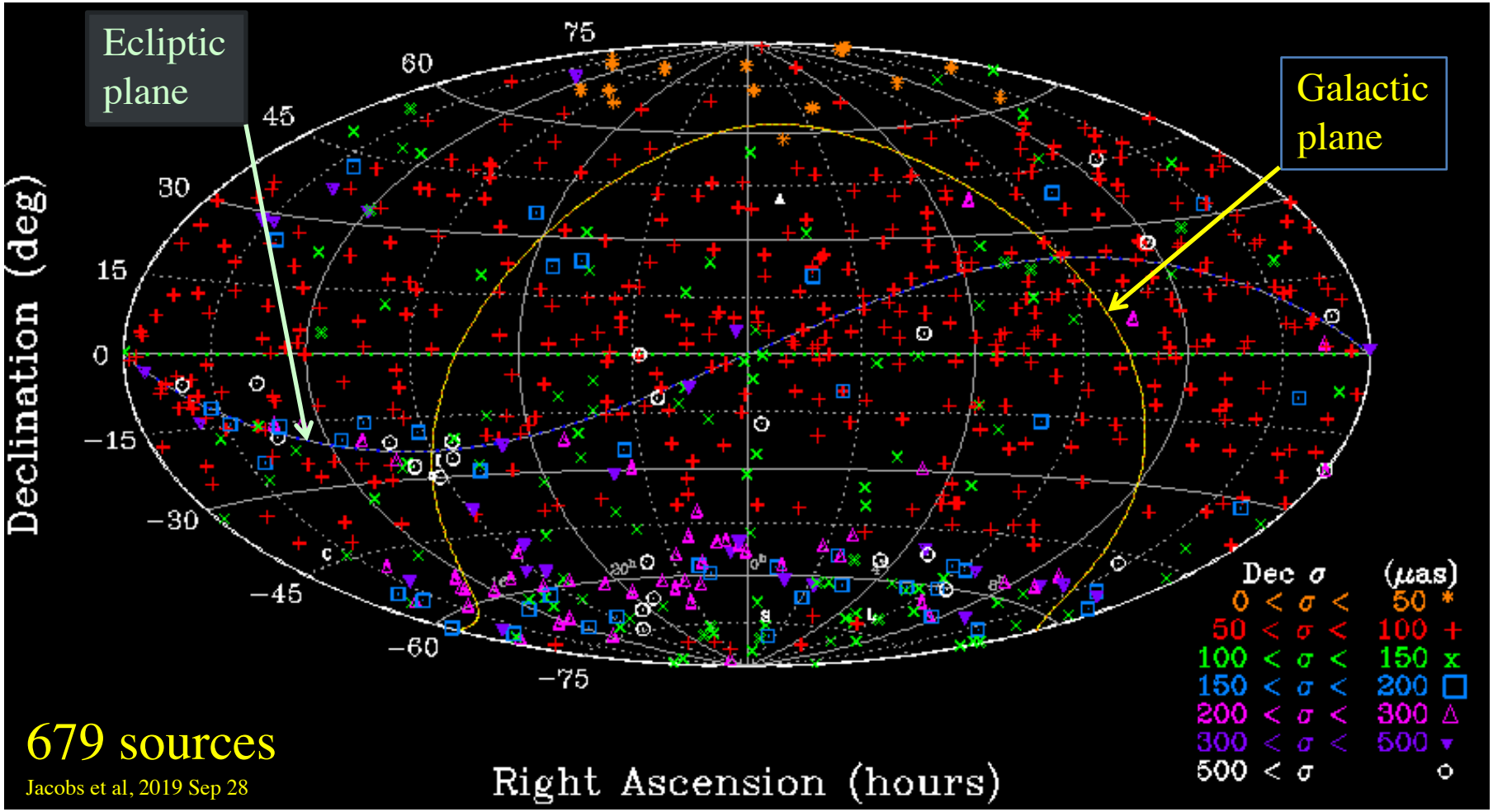
Ka (32 GHz, 9mm) Right Ascension sigmas (precision)



- Strengths:
  - Uniform spatial density
  - less structure than S/X (3.6cm)
  - needed only 80K observations vs. SX's 13 million!

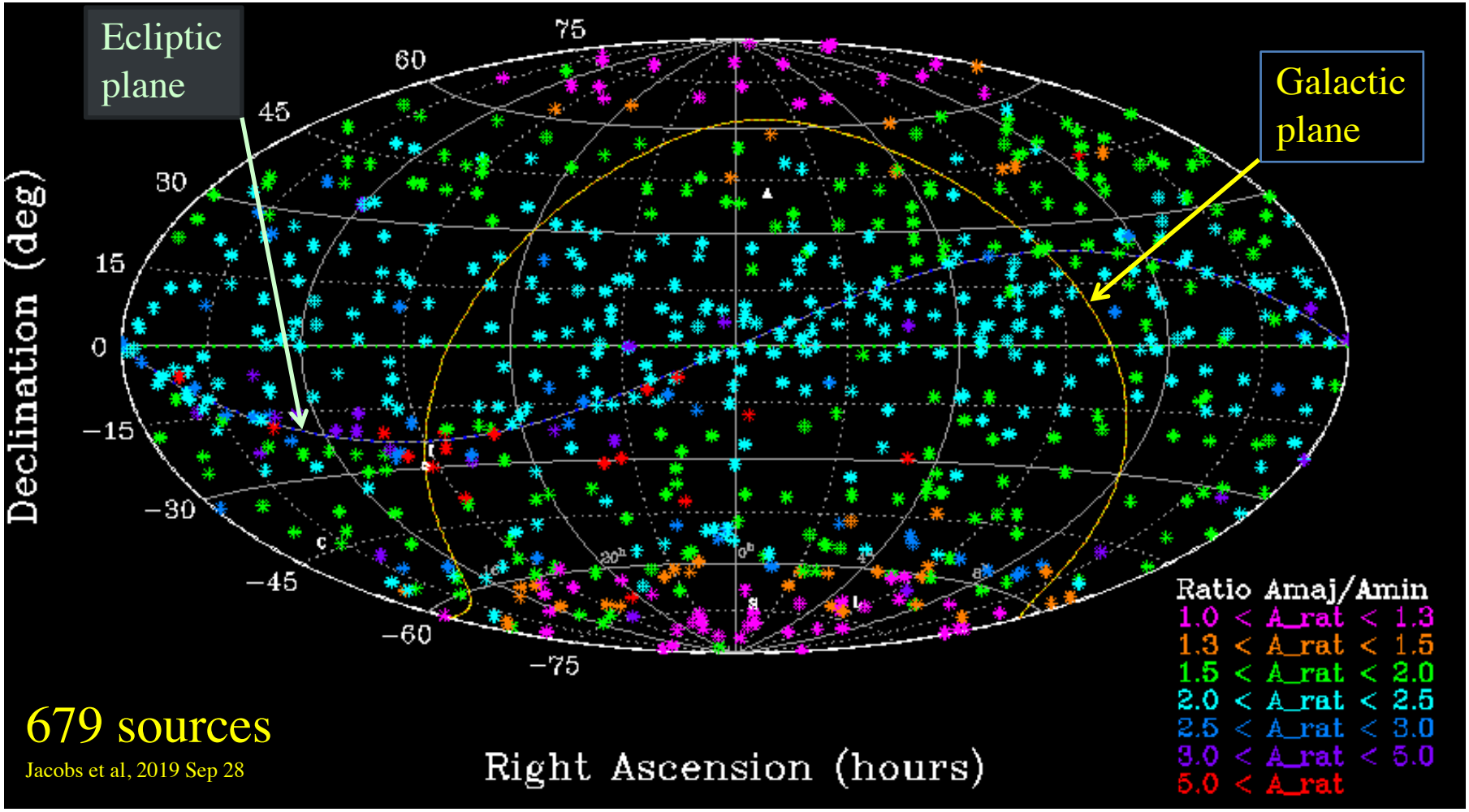
- Weaknesses:
  - Poor near Galactic center due to inter-stellar media scattering
  - South weak due to limited time on ESA's Argentina station
  - Limited Argentina-California data makes vulnerable to δ zonals
  - Limited Argentina-Australia weakens δ from -45 to -60 deg

Ka (32 GHz, 9mm) Declination sigma (precision)



- Declination precision ~2 times worse than RA precision
- Especially weak in southern ecliptic and far south

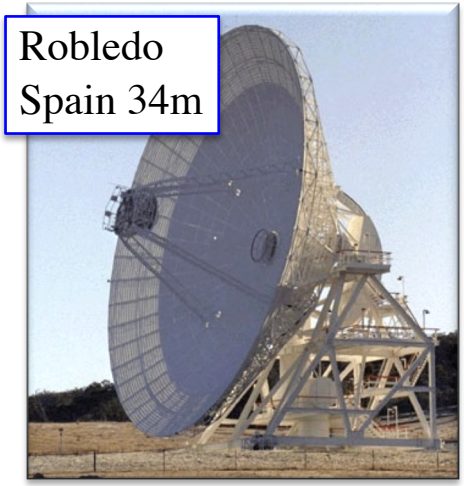
Ka (32 GHz, 9mm) Ellipse elongation: A_{maj}/A_{min}



- Ratio Amaj/Amin shows how elongated ellipse is.
- Error ellipses typically asymmetric by factor ~2
- Southern Ecliptic is worse by a factor of 3-5 or more

X/Ka Network

Goldstone Calif ornia 34m



Robledo Spain 34m

Tidbinbilla Australia 34m

Malargüe Argentina 35-m

Ka-band combined NASA/ESA Deep Space Net

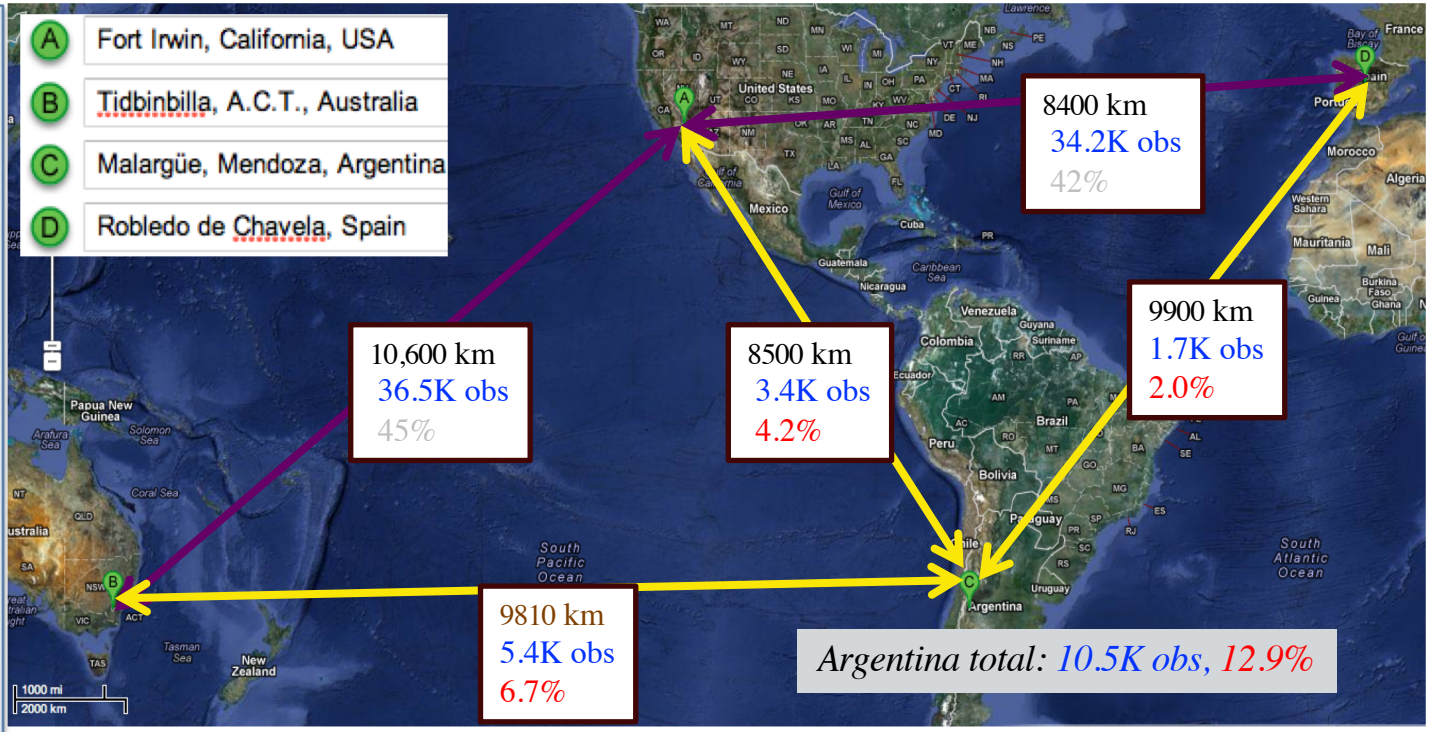
ESA Argentina to NASA-California under-observed by order of magnitude!

Baseline percentages

- Argentina is part of 3/5 baselines or 60% but only 13% of obs
- Aust- Argentina 6.7%
- Spain-Argentina 2.0%
- Calif- Argentina 4.2%

This baseline is under-observed by a factor of ~ 11.

More time on ESA's Argentina station would have a significant impact!

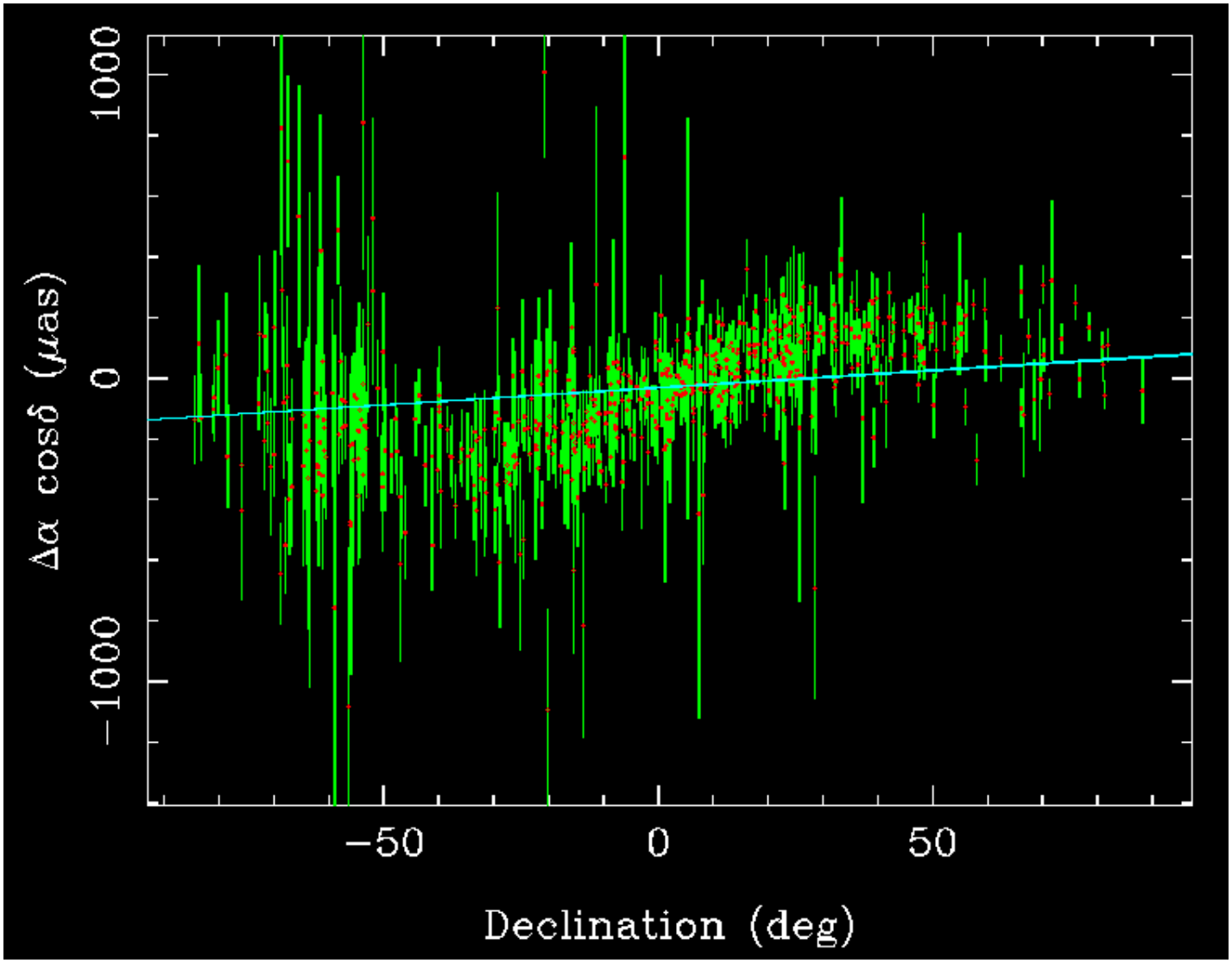


Maps credit: Google maps

ESA's Argentina 35-meter antenna **adds 3 baselines** to DSN's 2 baselines

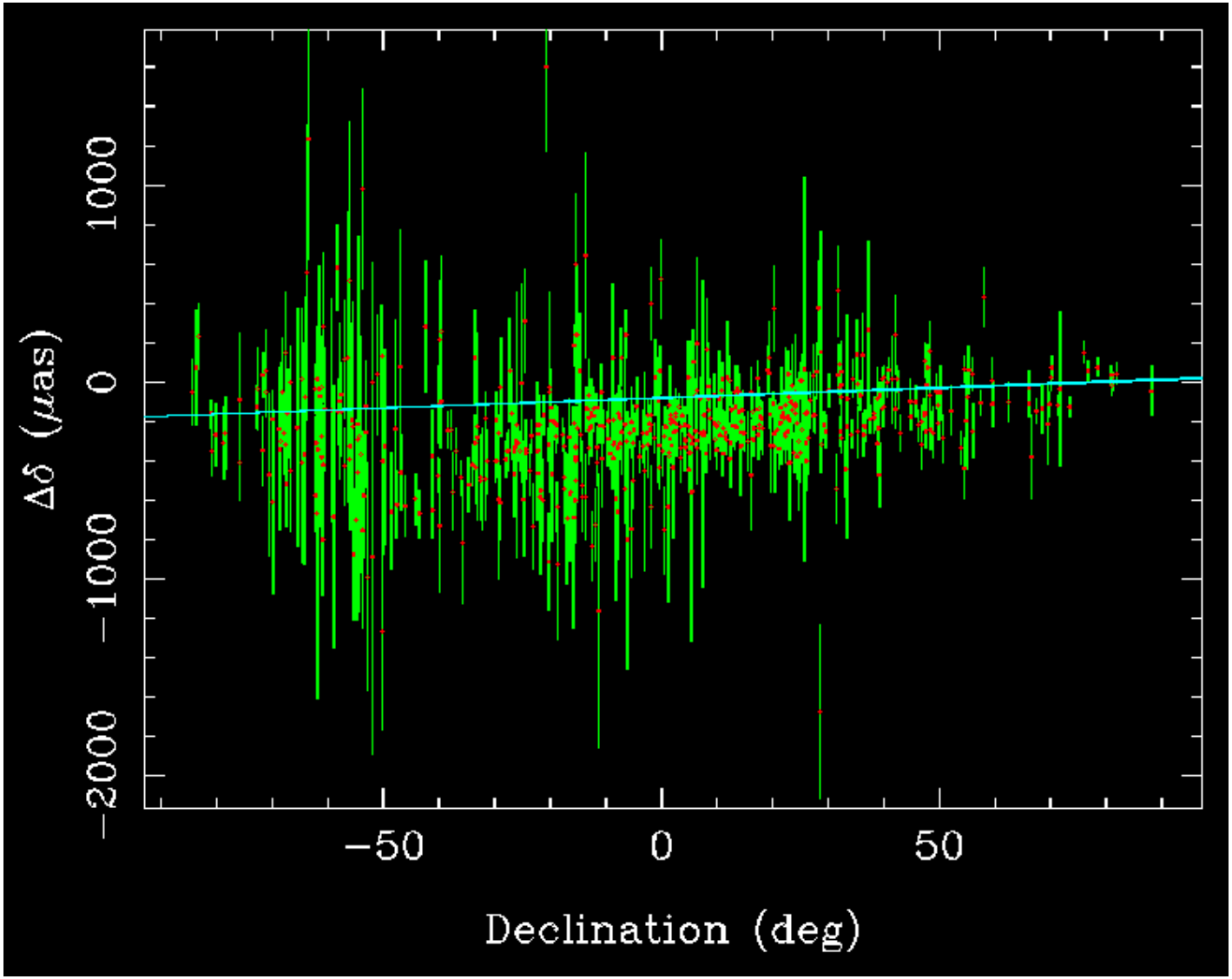
- Full sky coverage by accessing south polar cap
- near perpendicular mid-latitude baselines: CA to Aust./Argentina

XKa vs. SX-ICRF3: RA Zonal errors



Zonal Errors $\Delta\alpha\cos\delta \sim \sin(2\delta)$: Quad 2,0 = 210 +- 19 μas
Suspect North-South tradeoffs of troposphere and Celestial Frame

XKa vs. SX-ICRF3: Dec Zonal



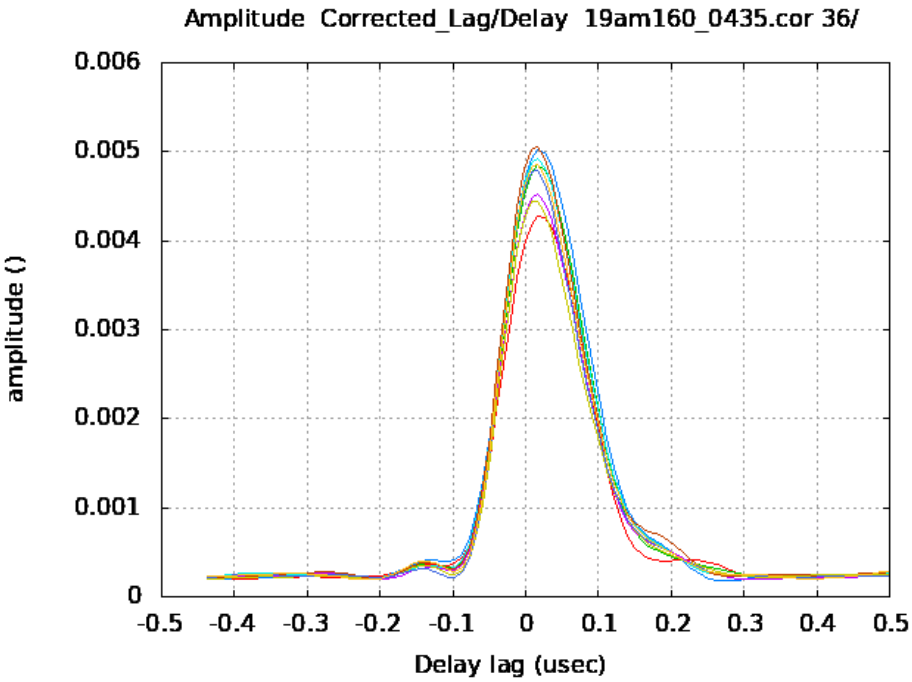
Zonal Errors $\Delta\delta \sim \cos\delta$: Dipole Z = -144 +- 54 μas
Dipole Z is 3 times weaker than X or Y dipole terms
Need stronger geometry

How to Improve the Network?

Strengthen SNR to baselines with Malargüe, Argentina 35-m

- Back end at Argentina station has been 256 Mbps limiting sensitivity

- Upgraded back end to 896 Mbps
  1st fringes 2019 June 09
  P 2255-282, T_int = 66 sec
  SNR = 713



- Working to increase to 1024 Mbps
- Internet connection speed tripled allowing e-transfer at higher rates
- Added dual-band backend X/Ka calibrates ionosphere directly

- Current spanned bandwidth is 300 MHz, limit delay precision
- Plans to upgrade to 500 MHz in next few years.

- Combined, these updates will increase source detection rate and improve delay precision by a factor of about 2.5 to 3.

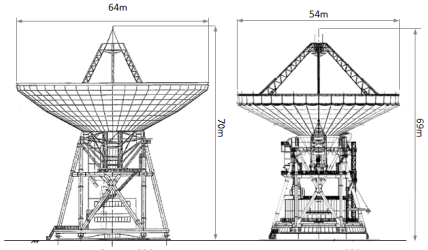
Malargüe, 35-m

New 54-m X/Ka antenna in Japan

- Japanese Space Agency, JAXA, completing 54-m X/Ka antenna Misasa, Japan (1.5 km from Ususda). No S-band, No S/X.

- X-band fringe test October 2019
- Ka-band fringe test March 2020

- X-band short baseline Misasa 54-m to Usuda 64m to tie new 54-m into ITRF



現行局の外観　GREAT局の外観

現行局	GREAT
主鏡：直径64m	主鏡：直径54m
重量：約1980t	重量：約2200t
周波数：S帯（2GHz）、X帯（8GHz）	周波数：X帯（8GHz）、Ka帯（32GHz）

credit: JAXA

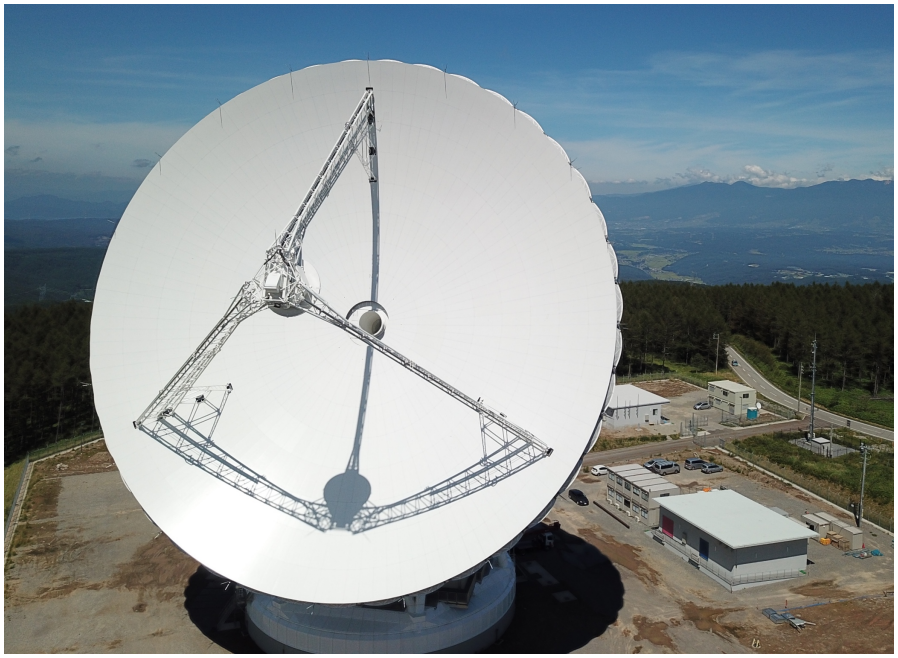
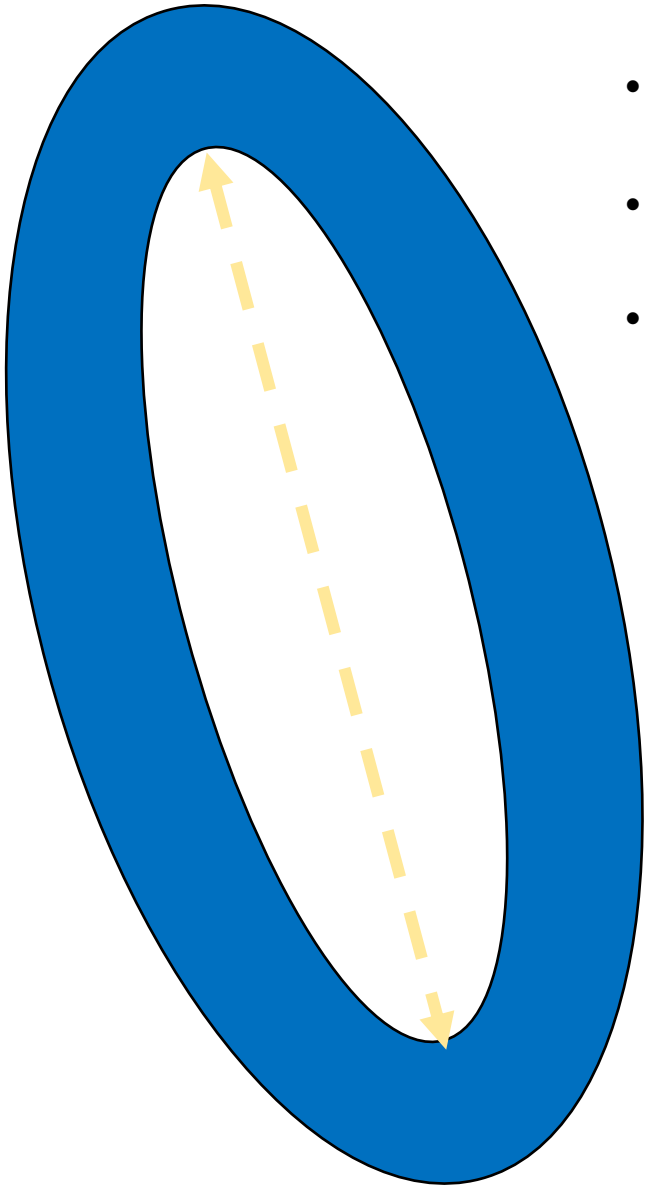


Photo credits: JAXA

XKa: Typical Error Ellipse



- Major axis is ~ 2 times larger than Minor axis
- Major axis direction is close to Declination direction
- **Misasa-Tidbinbilla baseline direction is a near perfect match to improve the weakest direction!!**

Observing Plan between JAXA's 54-m and NASA's DSN

- Misasa 54-m Celestial Frame observations 6-12 times per year
  Full 24 hour sweep of the sky for each session.
  - Misasa to Canberra ~ 3-6 times per year
  - Misasa to Madrid ~ 1-2 times per year
  - Misasa to Goldstone ~1-2 times per year
  - Misasa to Malargüe ~1-2 times per year?

- VEX 1.5 schedule
  VDIF format data
  2048 Mbps

- Correlated at JPL
  Analysis at JPL

X/Ka for the VLBA?

- JPL is designing an X/Ka proto-type front end for possible use in VLBA

- Broadband 8-35 GHz, single Quadridge feed, broadband LNA
- Dual polarization (RCP/LCP) Full Stokes images of intensity & Polarization
- At least 2 bands simultaneously

- Potential for 4 simultaneous bands (X, Ku, K, Ka) !!
  at cost of extra downconverters and back-end recorder/sampler
  4 images simultaneously would enable:
  - -imaging of spectral index
  - -Faraday rotation between bands: magnetic fields
  - -core shifts
  - -simultaneous X/K and X/Ka celestial frames

- Target is VLBA unused spot on feed ring

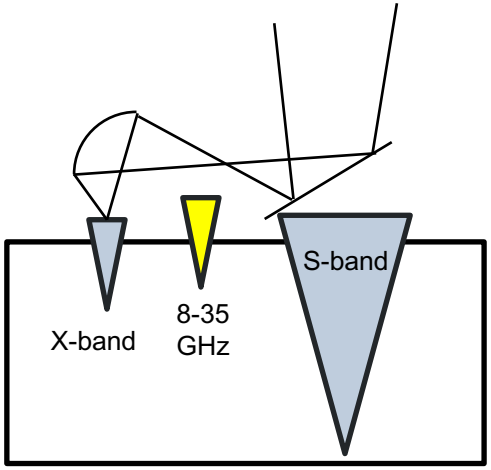
- 1st prototype assembled by end of year.

Credit: NRAO

X/Ka for the VLBA?

Approximate nominal phase center

- Target is VLBA unused spot between S and X feeds
- 1st prototype by end of year
- 3 prototypes by Sep 2021 allowing closure tests



Credit: Samoska et al, 2019.

Photo credit: NRAO

Wavelength	Frequency
90 cm*	327 MHz
50 cm*	610 MHz
20 cm	1.5 GHz
13 cm	2.3 GHz
6 cm	4.8 GHz
4 cm	8.4 GHz
2 cm	14 GHz
1.3 cm	23 GHz
7 mm	43 GHz
3 mm	86 GHz

Summary:

- **X/Ka now part of ICRF-3**

  Accuracy limited by systematic zonal errors vs. Declination

- **Roadmap:**
  - SNR improvements to Argentina:
  - Backend upgraded 256 to 896 Mbps, next step 1024 Mbps.
  - New Argentina backend is dual band X/Ka (was Ka only)

  - Adding JAXA's new 54-meter at Misasa, Japan.
  - Misasa 54-m can strengthen Declinations, constrain systematic zonal errors
  - **Misasa, Japan to Tidbinbilla, Australia baseline is in ideal direction!**

- **Long term: Potential for X/Ka on VLBA**

  Proto-typing possible X to Ka (8-35 GHz) broadband system for the VLBA

  Multi-baseline increases number of delays per session by order of magnitude

  Simultaneous 2 to 4 bands with dual polarization. Simultaneous X/K and X/Ka frames?