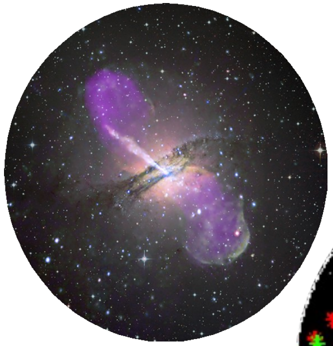
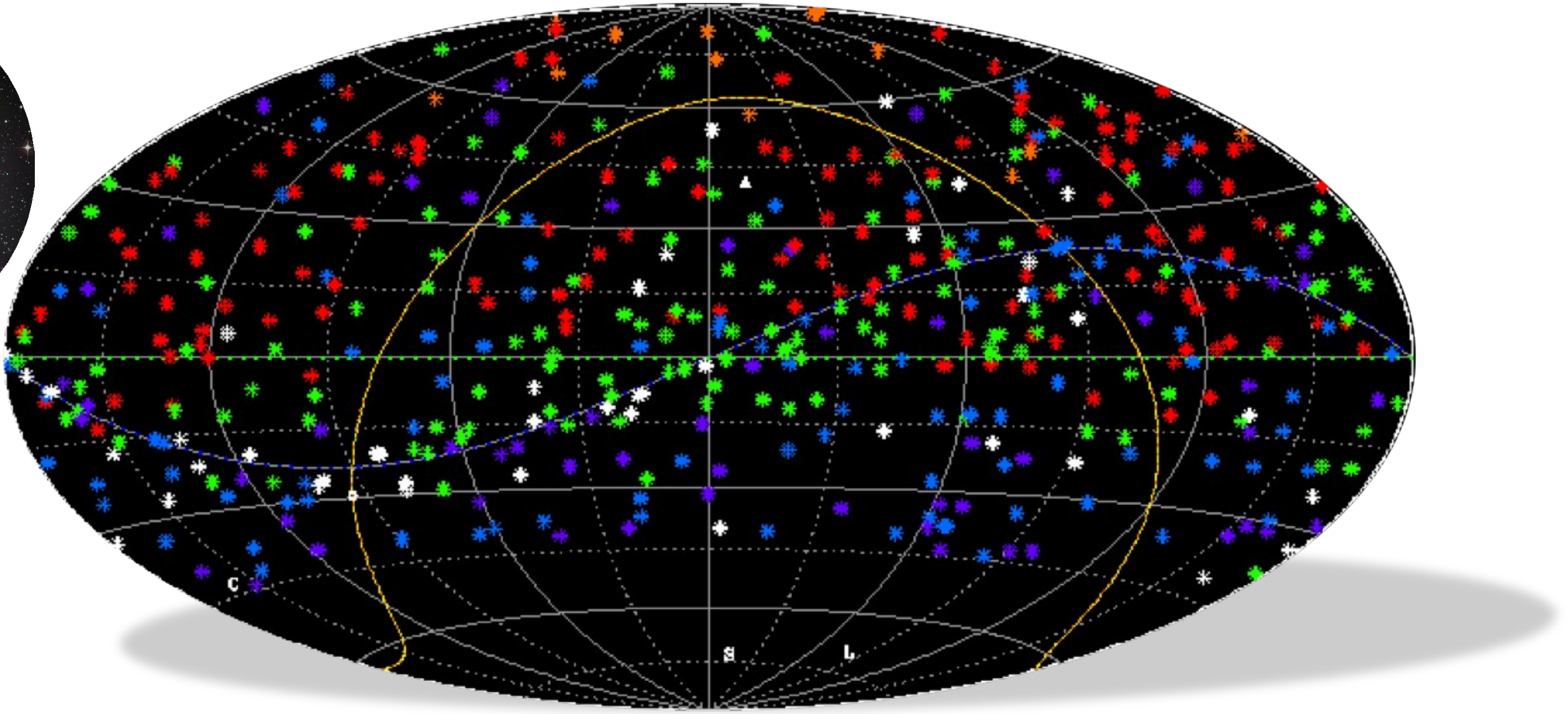
The X/Ka-band Extragalactic Reference Frame





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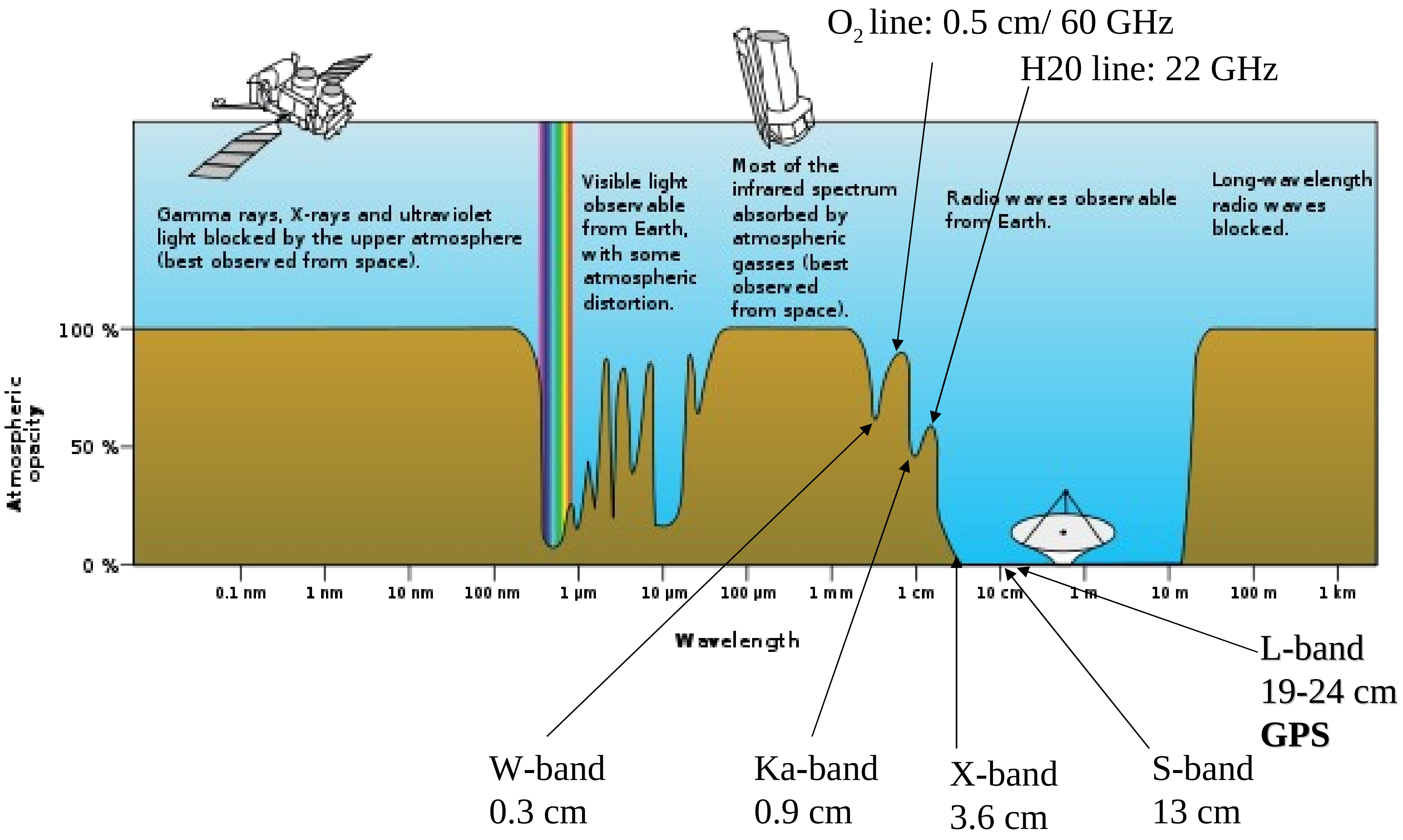
Overview

- Ka-band pros and cons

- Status of current radio-based celestial frames
  - ICRF2: wavelength 3.6cm, 3.4K objects, 40-100 µas
  - K-band: wavelength 1.2cm, 0.3K objects, 100-250 µas
  - X/Ka: wavelength 9mm, 0.5K objects, 200-300 µas

- Need southern stations: complementary geometry

Ka-band on Edge of Radio Window

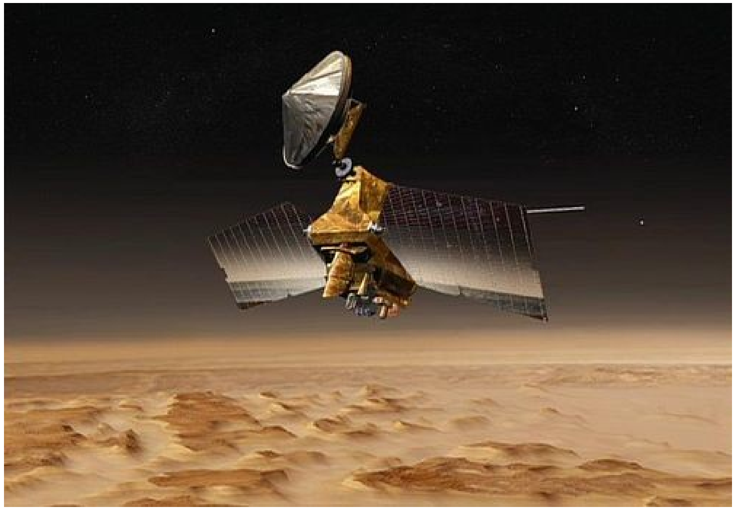


Motivation for Ka-band: 9mm/32 GHz

• Astrometry, Geodesy and Deep Space navigation,
have been at 3.6cm/8.4 GHz (X-band) with 2.3 GHz (S-band) plasma cals

Ka-band (9mm/32 GHz) Advantages

- More *compact* sources which should lead to more *stable* positions!
- Higher Telemetry Rates: +5 to +8 dB
- Smaller, lighter RF spacecraft systems
- Avoid S-band *RFI* issues
- Ionosphere & solar plasma down 15X !! at 32 GHz (Ka-band) compared to 8 GHz thus observe closer to Sun & Galactic center



http://mars.jpl.nasa.gov/mro/multimedia/images/?ImageID=3373

Mars Reconnaissance Orbiter 2005 demonstrated Ka-band Communications and Navigation.

Disadvantages of Higher radio frequencies:

- More weather sensitive, higher system temp.
- Shorter coherence times
- Weaker sources, Many sources resolved
- Antenna Pointing more difficult

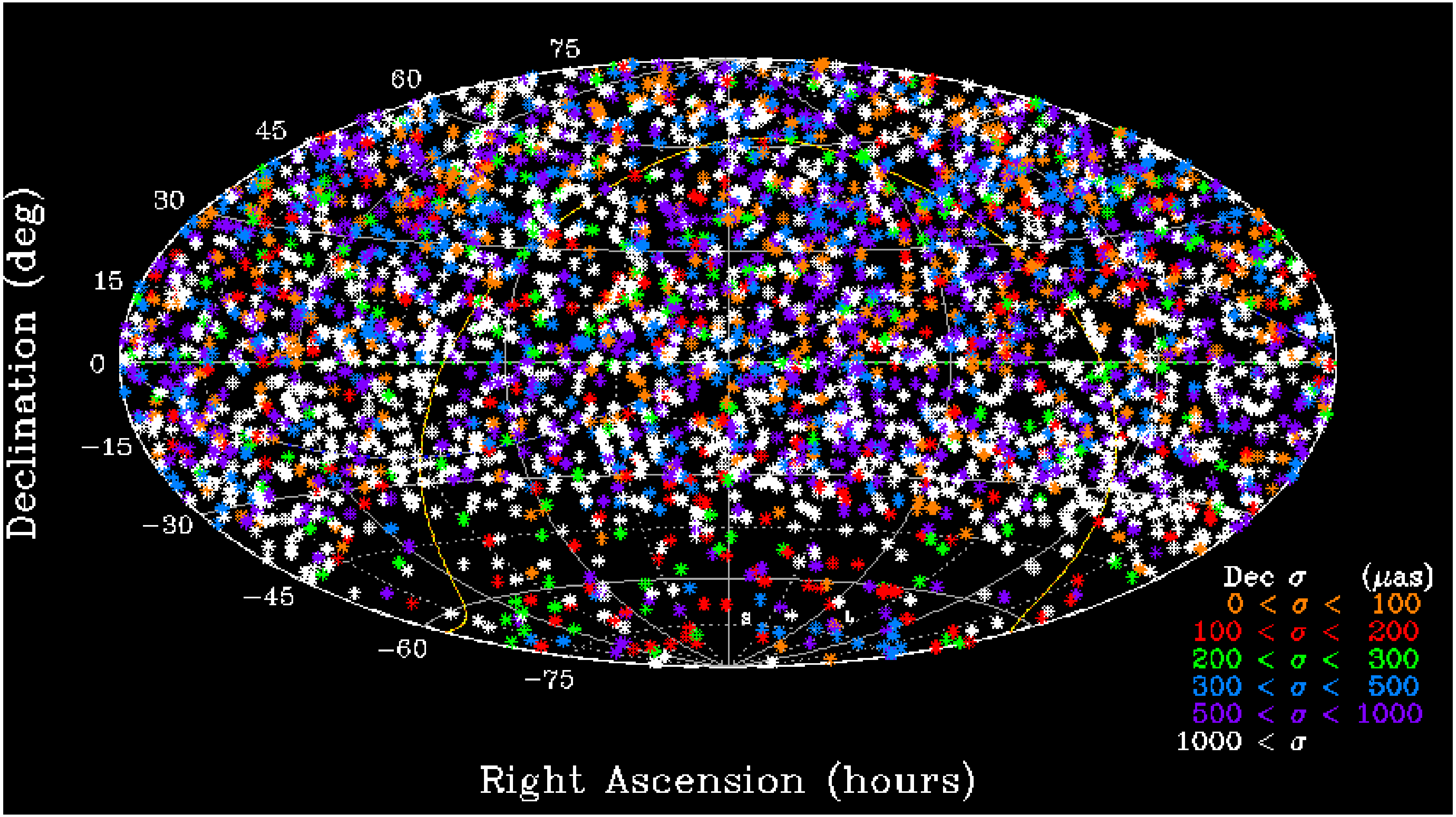
Current Status of Celestial Reference Frames at radio wavelengths:

S/X ICRF2: 3.6cm, 8 GHz

K-band: 1.2cm, 24 GHz

X/Ka-band: 9mm, 32 GHz

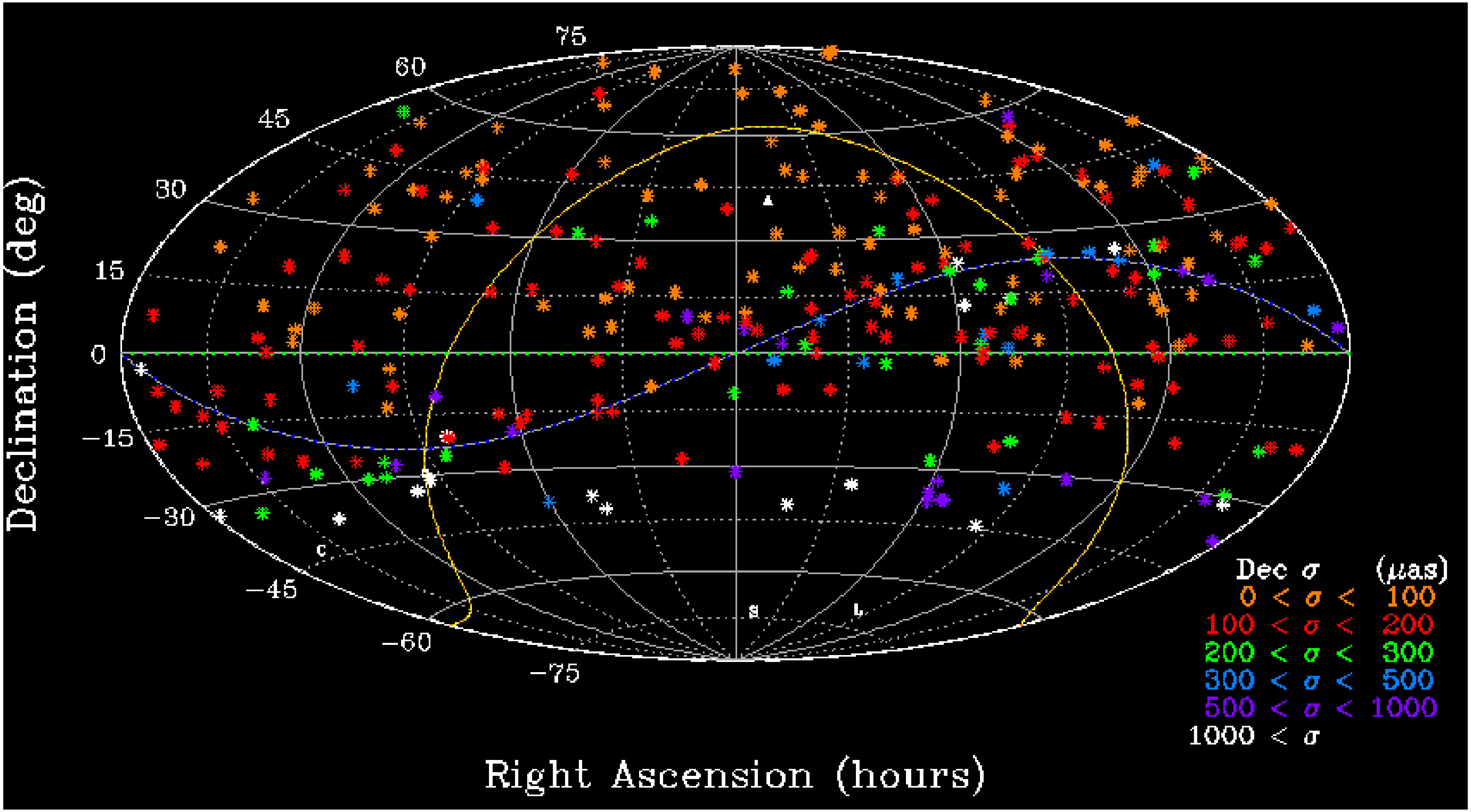
ICRF2 S/X 3.6cm: 3414 sources



40 μas floor. ~1200 obj. well observed, ~2000 survey session only

Credit: Ma et al, eds. Fey, Gordon, Jacobs, IERS Tech. Note 35, Germany, 2009

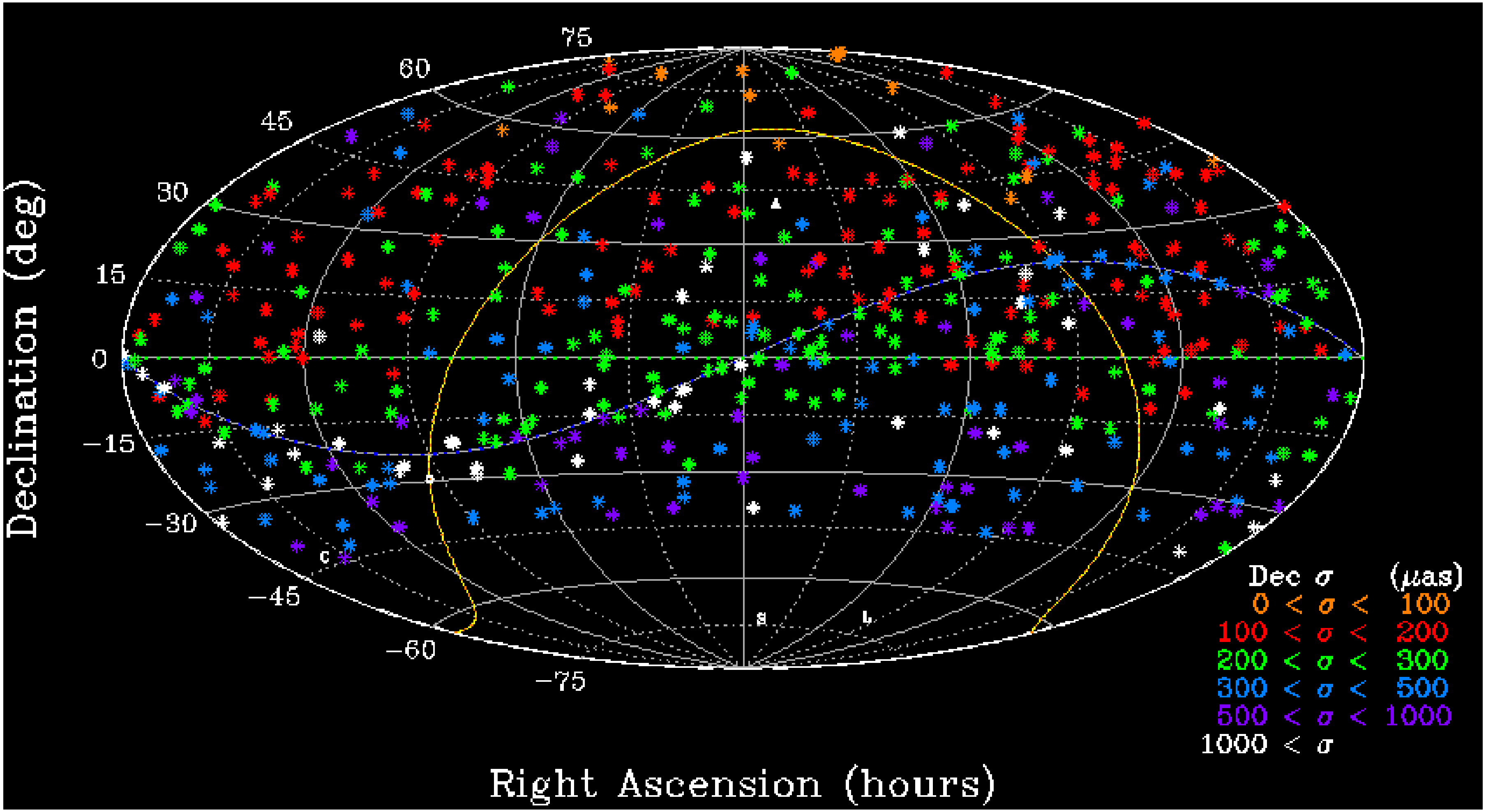
K-band 1.2cm: 278 Sources



VLBA all northern, poor below Dec. -30˚. ΔDec vs. Dec tilt= 500 μas

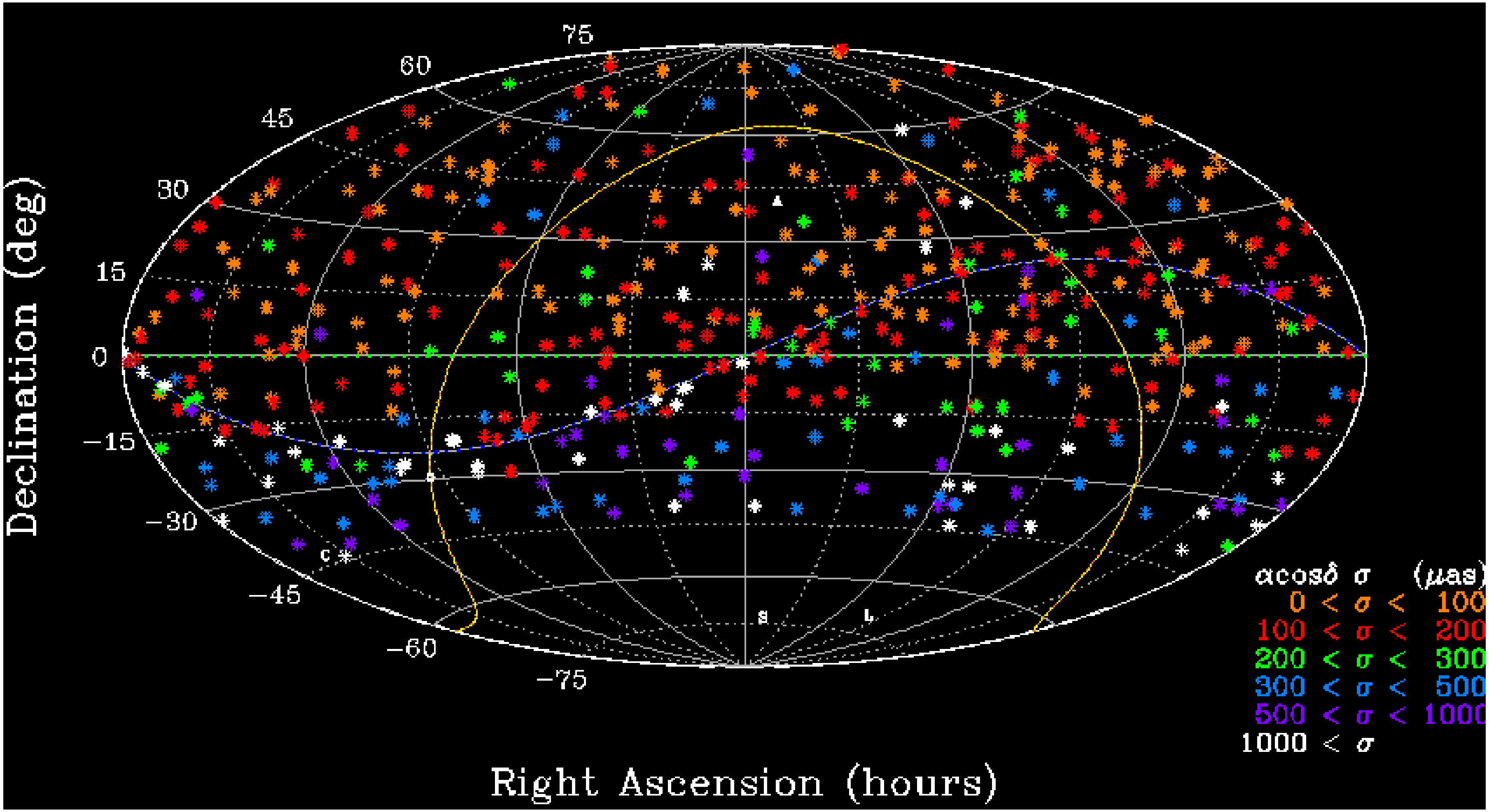
Credit: Lanyi et al, AJ, 139, 5, 2010; Charlot et al, AJ, 139, 5, 2010

X/Ka current Dec results: 469 Sources



Cal. to Madrid, Cal. to Australia. Weakens southward. No ΔDec tilt

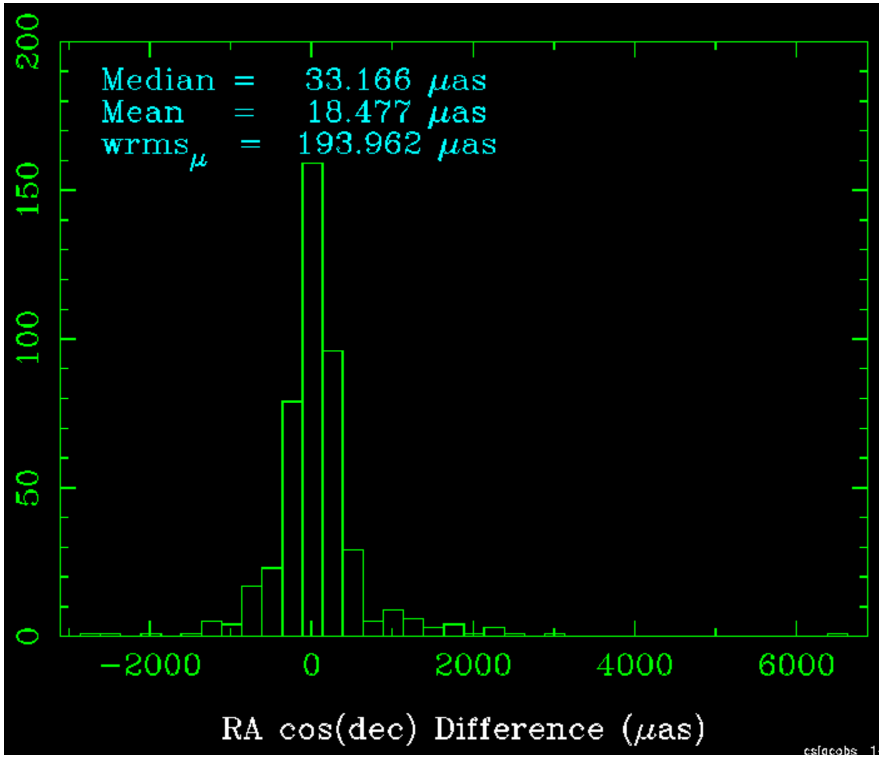
X/Ka current RA results: 469 Sources

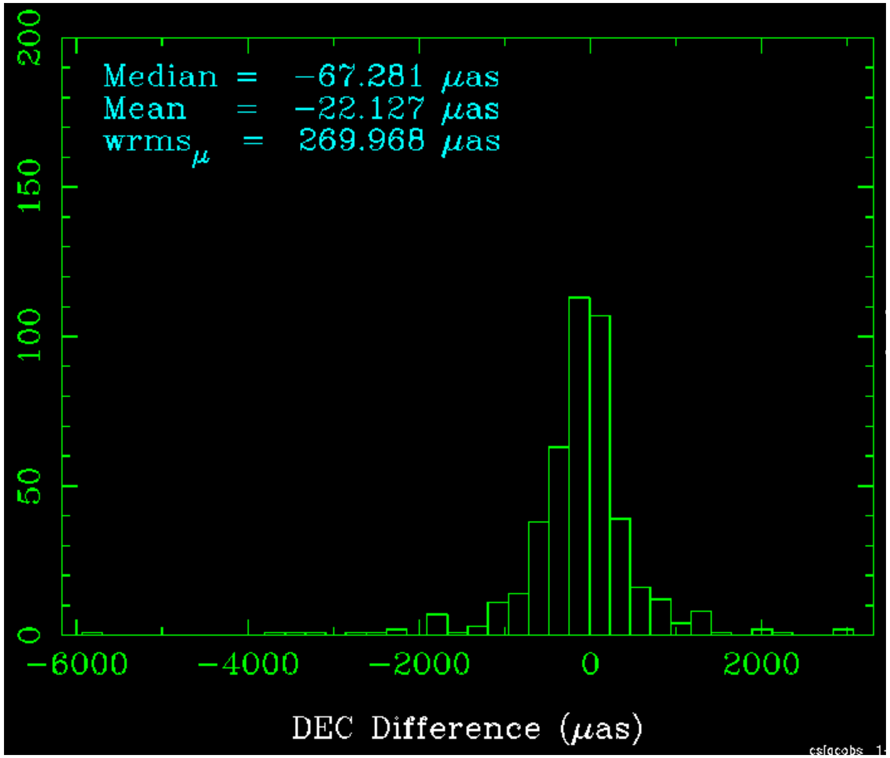


Cal. to Madrid, Cal. to Australia. Weakens south of Dec = -15deg

X/Ka (9mm) *vs.* ICRF2 at S/X (3.6cm)

Accuracy of 450 X/Ka sources vs. S/X ICRF2 (current IAU standard)





RA: 194 μas = 0.9 nano-rad **Dec: 270 μas = 1.3 nano-rad**

S/X ICRF2: Ma et al, editors: Fey, Gordon & Jacobs, IERS, Germany, 2009

Improving VLBI

Systems Analysis shows dominant Errors are

- Limited SNR/sensitivity
  - already increased bit rates: 112 to 448 Mbps. Soon to 2048?
- Instrumentation: already building better hardware
  - Ka-band phase calibrators, Digital Back Ends (filters)
- Troposphere: better calibrations being explored

- **Weak geometry in Southern hemisphere**
  - Limits accuracy to about 1 nrad (200 µas) level
  - No observations below Declination of -45 Deg!
  - DSN at X/Ka has only Canberra, Australia (DSS 34)
  - Need 2nd site in the Southern hemisphere
    especially for upcoming southern ecliptic missions

How do we improve accuracy? Southern Coverage!

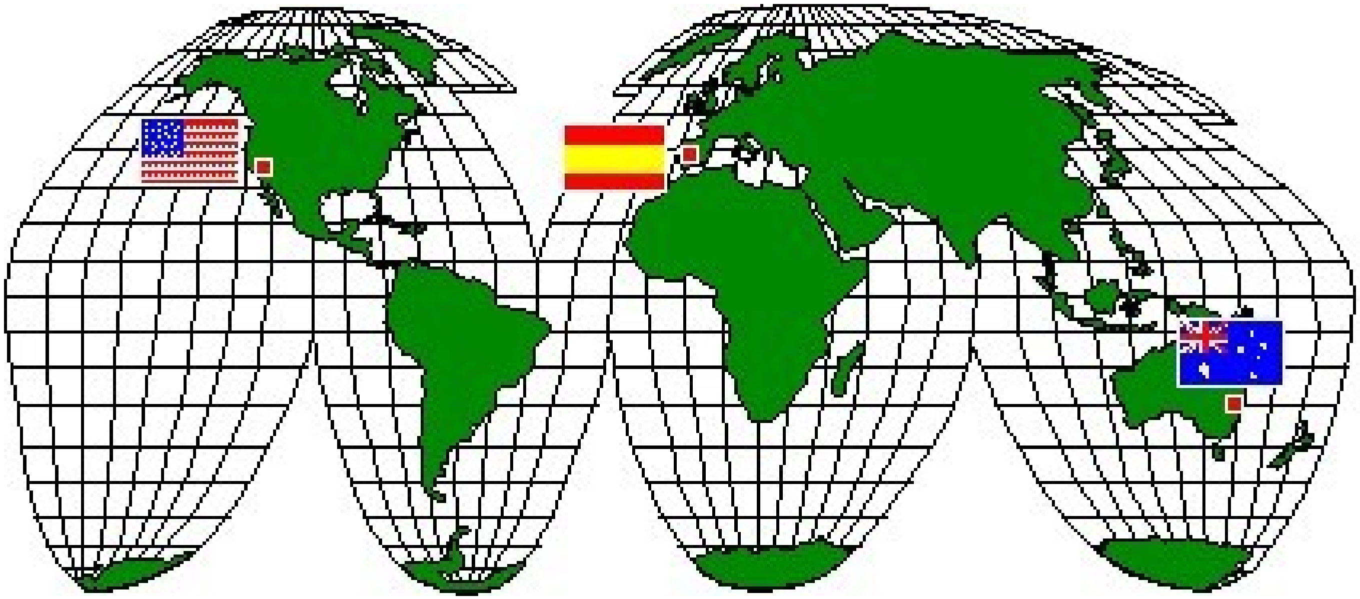
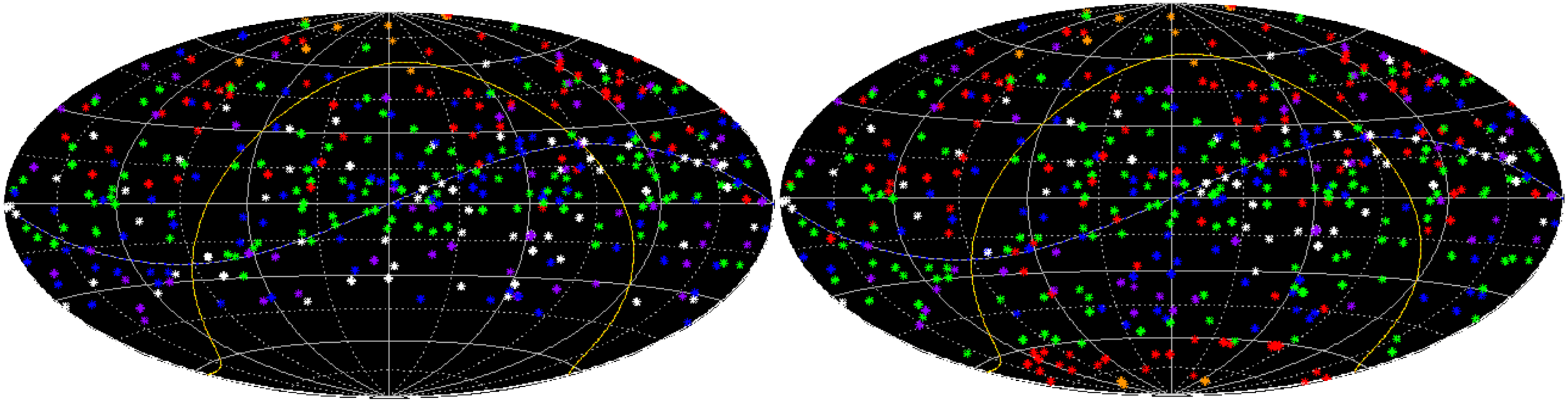


Figure credit: www.spacetoday.org/images/SolSys/DeepSpaceNetwork/NASA_DSN_WorldMap.gif

Simulation of Added Southern Station



50 sessions, No Sim. Southern Data *Adding Simulated data*

- 50 real X/Ka sessions augmented by simulated data
  simulate 1000 group delays, SNR = 50
  ~9000 km baseline: Australia to S. America or S. Africa

- Completes Declination coverage: cap region -45 to -90 deg
  200 μas (1 nrad) precision in south polar cap,
  mid south 200-1000 μas, all with just a few days observing.

- Horiuchi et al talk will show plan to attack this area.

Declination Sigma

Orange: < 100 μas
Red: < 200
Green: < 300
Blue: < 500
Purple: < 1000
White: > 1000

<u>Gaia-Optical *vs*. VLBI-radio</u>:

Celestial Frame tie
and
Accuracy Verification

Gaia: 10^9 stars

- 500,000 quasars V< 20
  20,000 quasars V< 18
- radio loud 30-300+ mJy
  and
  optically bright: V<18
  ~2000 quasars
- Accuracy
  70 µas @ V=18
  25 µas @ V=16

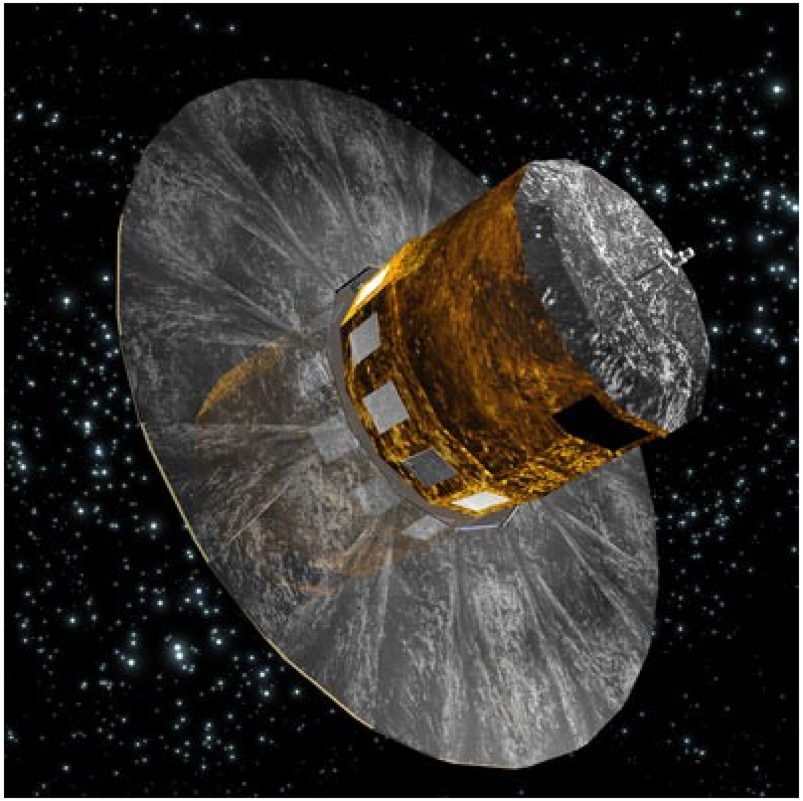
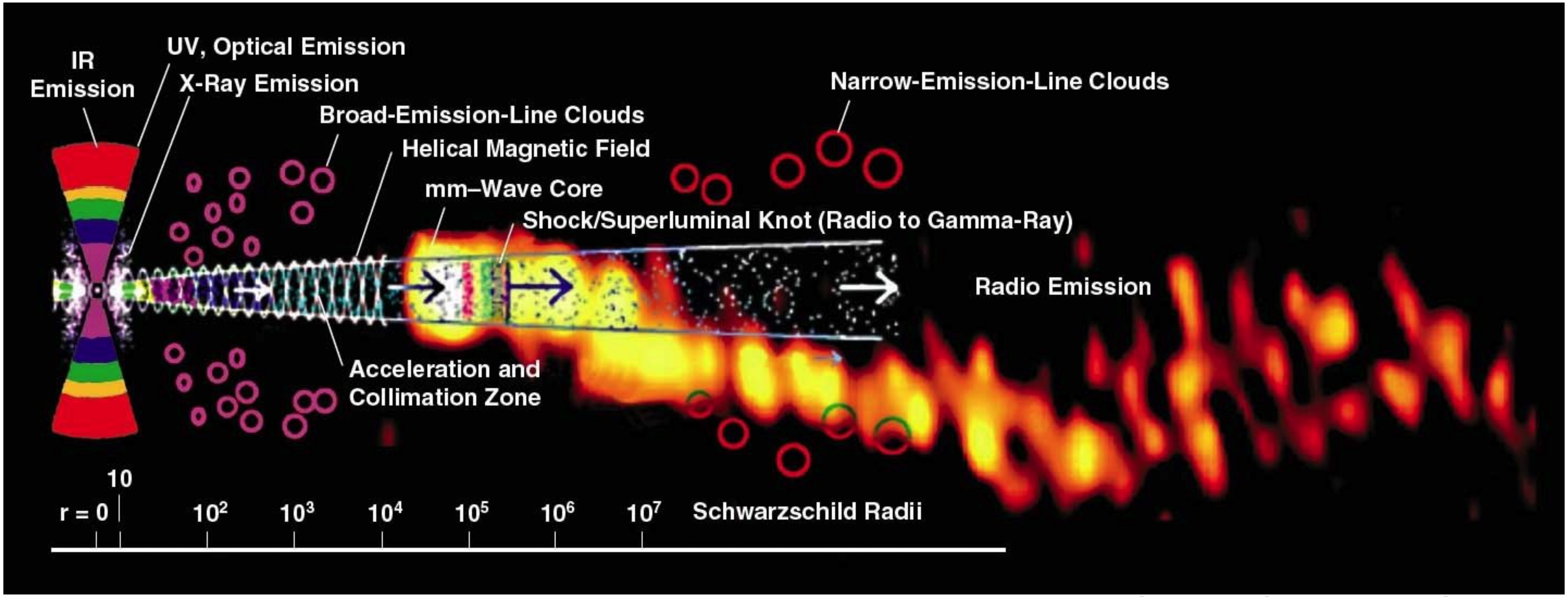


Figure credit: http://www.esa.int/esaSC/120377_index_1_m.html#subhead7

9mm vs. 3.6cm? Core shift & structure

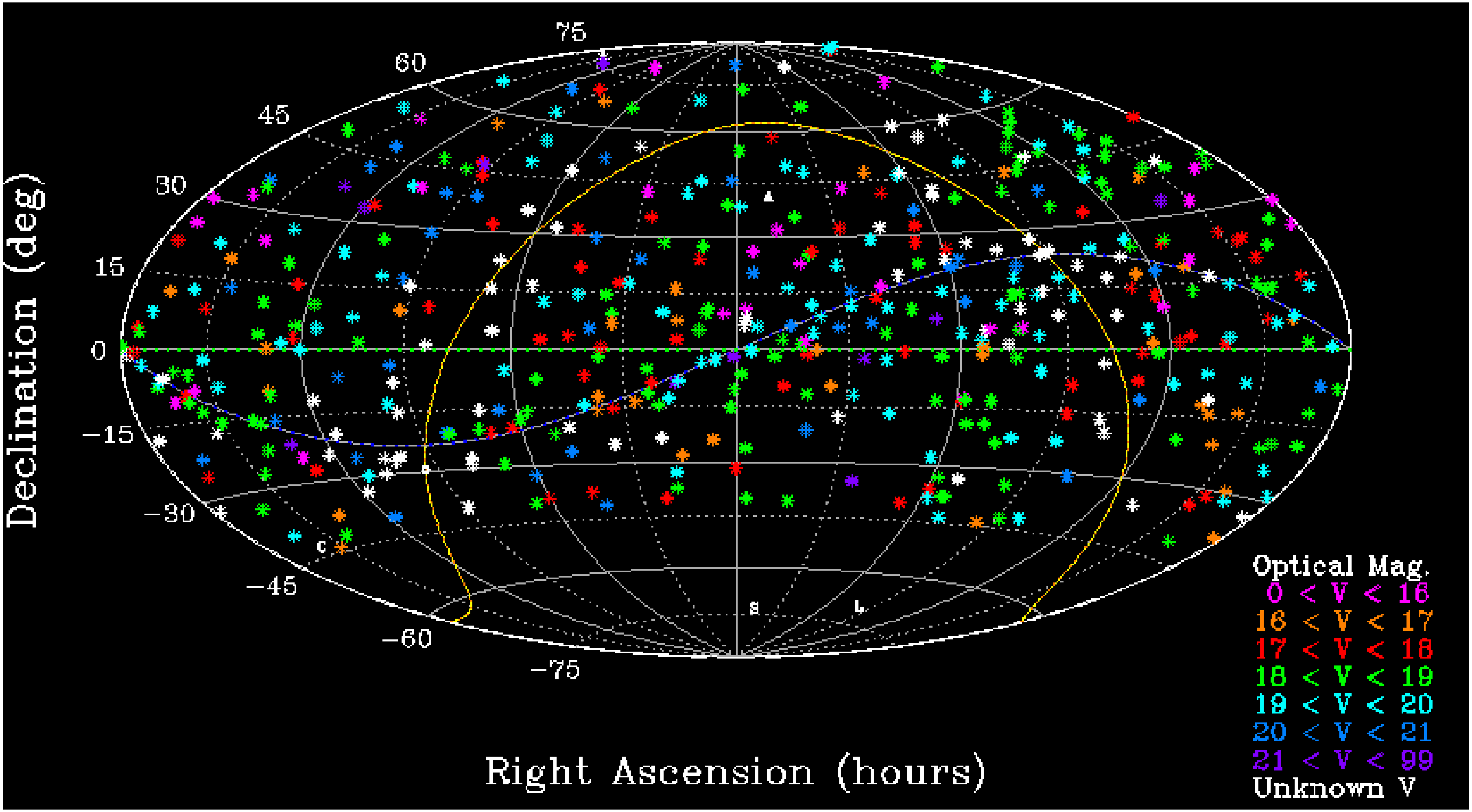


Credit: A. Marscher, Proc. Sci., Italy, 2006.
Overlay image: Krichbaum, et al, IRAM, 1999.
Montage: Wehrle et al, ASTRO-2010, no. 310.

Positions differences from 'core shift'

- wavelength dependent shift in radio centroid.
- *3.6cm to 9mm core shift:* 100 μas in phase delay centroid? <<100 μas in group delay centroid? (*Porcas, AA, 505, 1, 2009*)
- shorter wavelength closer to Black hole and Optical: 9mm X/Ka better
- Majid et al talk will give complementary info on source physics

Optical brightness of X/Ka 9mm sources



Median optical magnitude V_{med} = 18.6 magnitude *(71 obj. no data)*

> 130 objects optically bright by Gaia standard (V<18)

Gaia Optical vs. X/Ka 9mm frame tie

- 398 of 469 X/Ka 9mm objects with known optical V magnitudes

  132 objects optically bright (V< 18)

  213 objects optically weak (18 < V< 20)

  53 objects optically undetectable (V > 20)

  71 objects *no optical info yet* (*V = ??)*
- Simulated Gaia measurement errors (sigma RA, Dec) for 345 objects: median sigmas ~ 100 µas per component
- VLBI 9mm radio sigmas ~200 µas per component and improving
- Covariance calculation of 3-D rotational tie using current 9mm radio sigmas and simulated Gaia sigmas

  Rx +- 14 µas <- Weak. Needs south polar VLBI (Dec < -45)

  Ry +- 11 µas

  Rz +- 10 µas
- Now limited by radio sigmas for which 2-3X improvement possible. Potential for rotation sigmas ~5 µas per frame tie component

Conclusions

- Future tracking is moving to Ka-band: +5 to 8dB telemetry
- Quasar astrophysics: Ka position closer to optical position than S/X-based ICRF2, less extended structure expected
- Ka-band Celestial Frame: 469 Active Galactic Nuclei
- However, DSN lacks 2nd southern station
- Simulated Southern Geometry shows great promise
- Gaia tie:

  >130 objects radio loud @9mm *and* optically bright V<18

  Ties Gaia optical to VLBI radio frame

  Study astrophysics: core shift, jet vs. accretion disk

  Independent check on Gaia accuracy at 70-100 μas level

  5-15 μas potential precision for 3-D frame tie