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The X/Ka-band (8.4/32 GHz) Celestial Reference Frame

Can it be more accurate than the ICRF-2?

Executive Summary: Celestial angular coordinates (α,δ) are derived from VLBI measurements at 8.4/ 32 GHz (36/ 9 mm) of Active Galactic Nuclei. Agreement with S/X is at the part per billion level. X/Ka has reduced astrophysical systematics vs. S/X.

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Abstract: Observations at X/Ka-band are motivated by their ability to access more compact source morphology and reduced core shift relative to observations at the historically standard S/X-band. In addition, the factor of four increase in interferometer resolution at Ka-band should resolve out some wide binary black holes which are a topic of concern for AGN centroid stability. Given these motivations, an X/Ka-band (8.4/32 GHz) celestial reference frame has been constructed using a combined NASA and ESA Deep Space Network. In 110 observing sessions we detected 660 sources covering the full 24 hours of right ascension and the full range of declinations. The resulting XKa median precision is now better than the ICRF-2 precision (for common sources) thereby raising the question of which frame is more accurate.

Comparison of 532 X/Ka sources in common with the S/X-band (2.3/8.4 GHz) ICRF2 produced wRMS agreement of better than 200 μas. There is evidence for systematic errors at the 100 μas level. Known errors include limited SNR, lack of phase calibration, troposphere mismodelling, and terrestrial frame distortions. Actions are underway to reduce all of these errors. In particular, a collaboration between NASA and the ESA deep space antenna in Malargüe, Argentina is quickly reducing weaknesses in the southern hemisphere. By comparing coordinate estimates, we probe the accuracy limits of current celestial frames in an effort to understand the advantages of each frame.

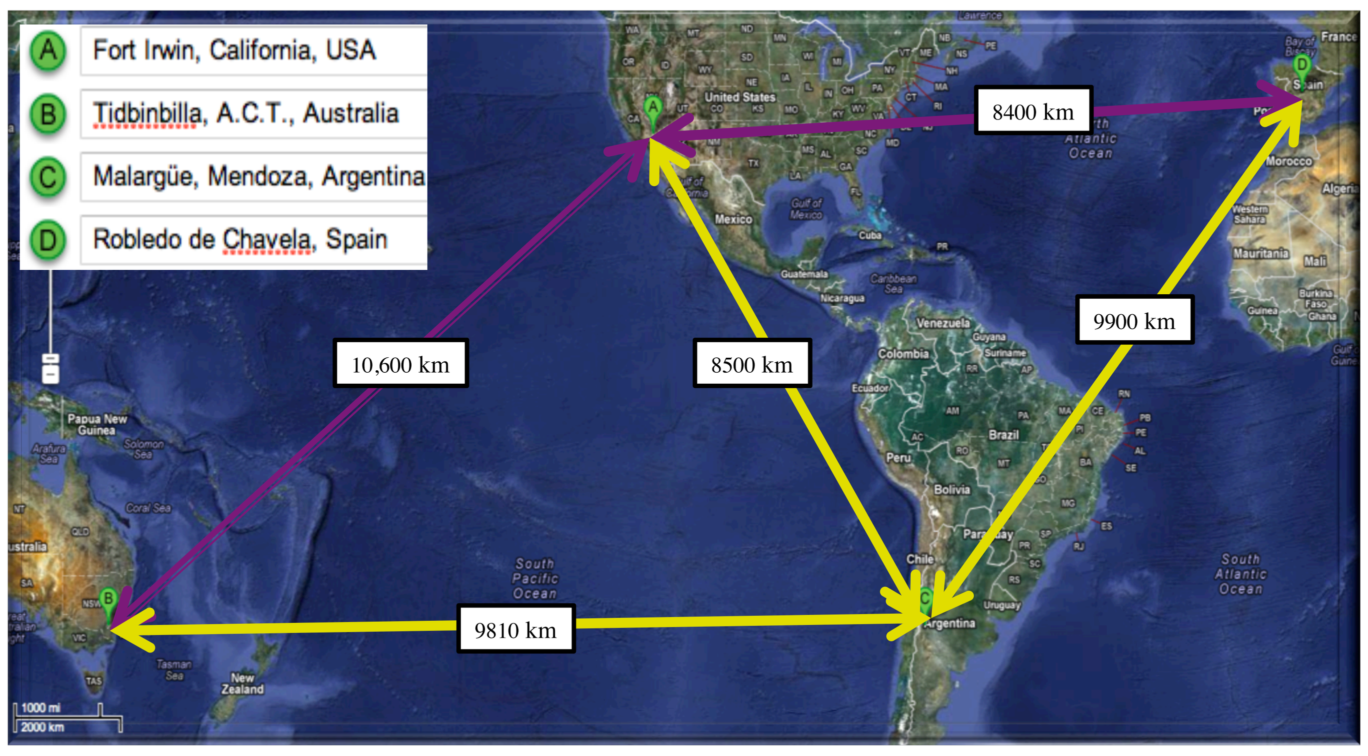


Fig. 1 NASA-ESA Ka-band network. The addition of ESA's Argentina station adds 3 baselines & Full Sky coverage .

I. High Frequency Radio Frames: As radio frequencies increase, sources tend to be more core dominated as the extended structure in the jets tends to fade away with increasing frequency (fig. 3,4). The spatial offset of the emissions from the AGN engine due to opacity effects ("core shift") is reduced as frequency increases.

Advantages of Ka-band compared to S/X-band:

- More compact, stable sources (Fig. 3,4)
- Reduced opacity effects: "core shift"
- Ionosphere & solar plasma effects reduced by 15X.

Disadvantages of Ka-band:

- More weather sensitive (fig. 5)
- Shorter coherence times
- Weaker sources, many resolved
- Antenna pointing is more difficult,.
- Combined effect is lower sensitivity,

But increasing data rates are rapidly compensating. We have increased JPL operations from 0.5 to 2.0 Gbps.

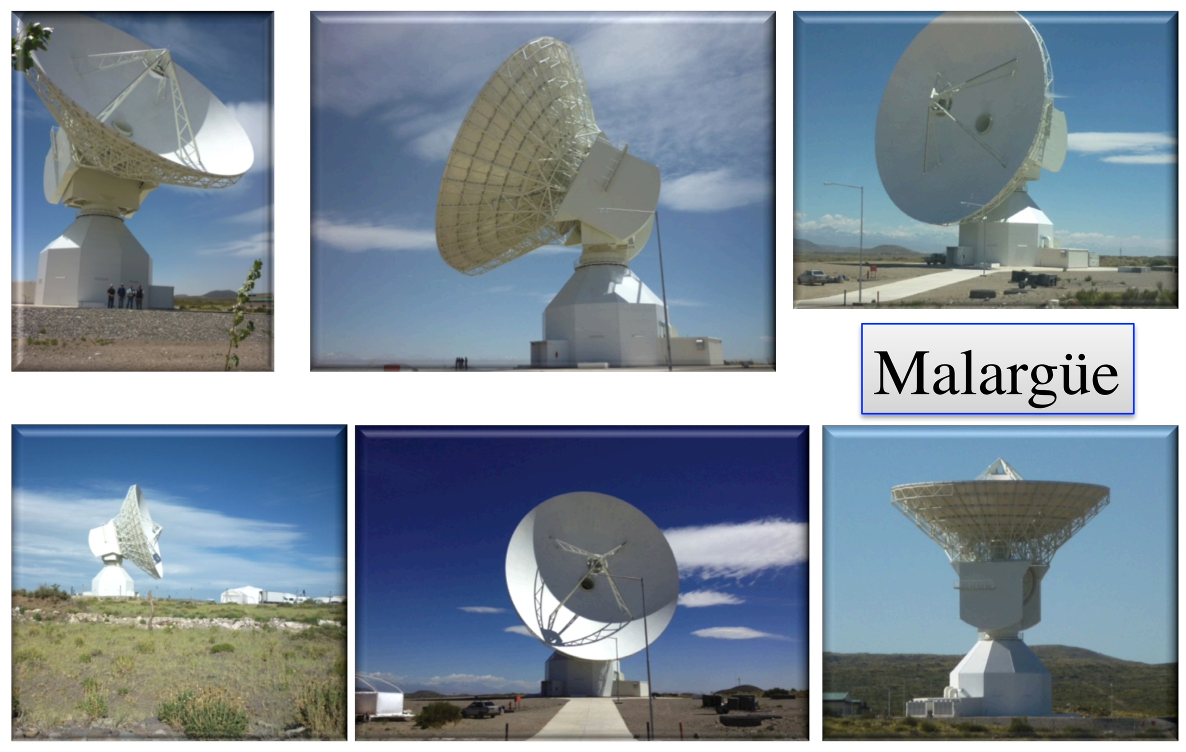


Fig. 2 ESA's 35-meter beam waveguide antenna, DSA03, Malargüe, Argentina. This dry site is at about 1500 meters altitude in desert behind the Andes mountain range (*photo: L.A. White, 2012 Dec*).

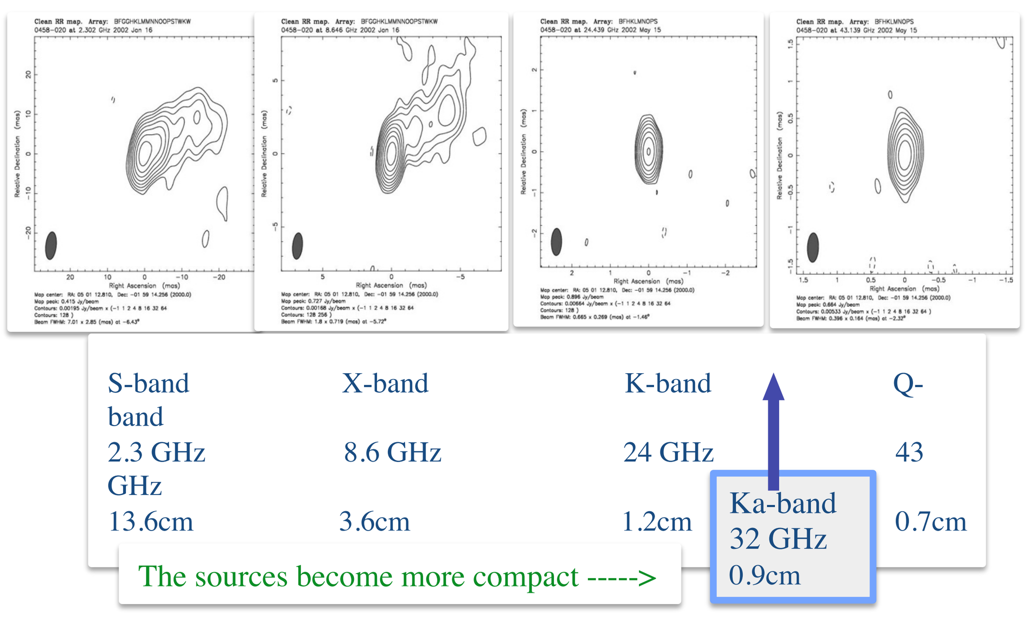


Fig. 3: Source structure & compactness vs. wavelength (Charlot+, 2010; Pushkarev+, 2012)

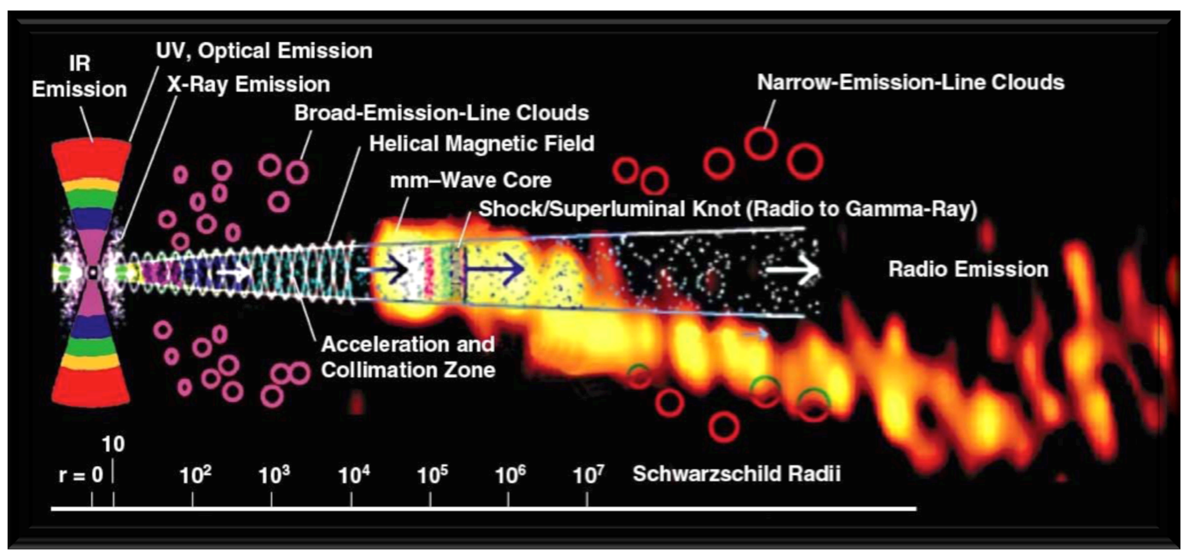


Fig. 4: Schematic of Active Galactic Nuclei (Marscher, 2006, Krichbaum, 1999, Wehrle, 2010)

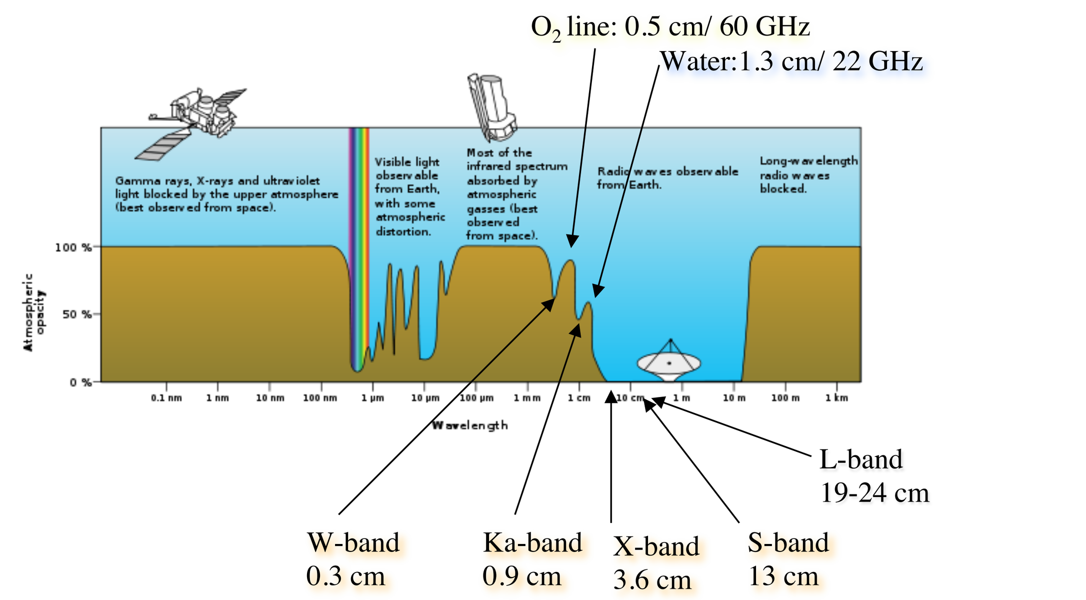


Fig. 5: The radio "window" is transparent compared to most of the spectrum (credit: NASA) Ka-band (32 GHz) is in the saddle point between H_20 (22 GHz) and O_2 (60 GHz) lines.

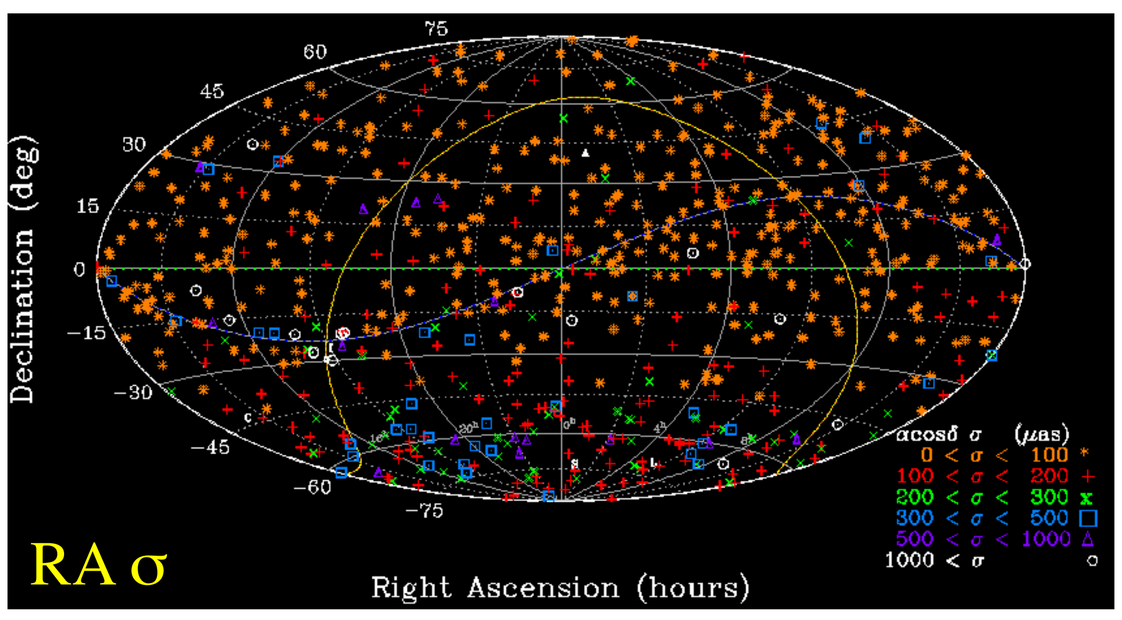


Fig. 6 RA* (arc) precision: Median s is 91 μas for 660 sources. Only 1 baseline for Dec < -45 deg

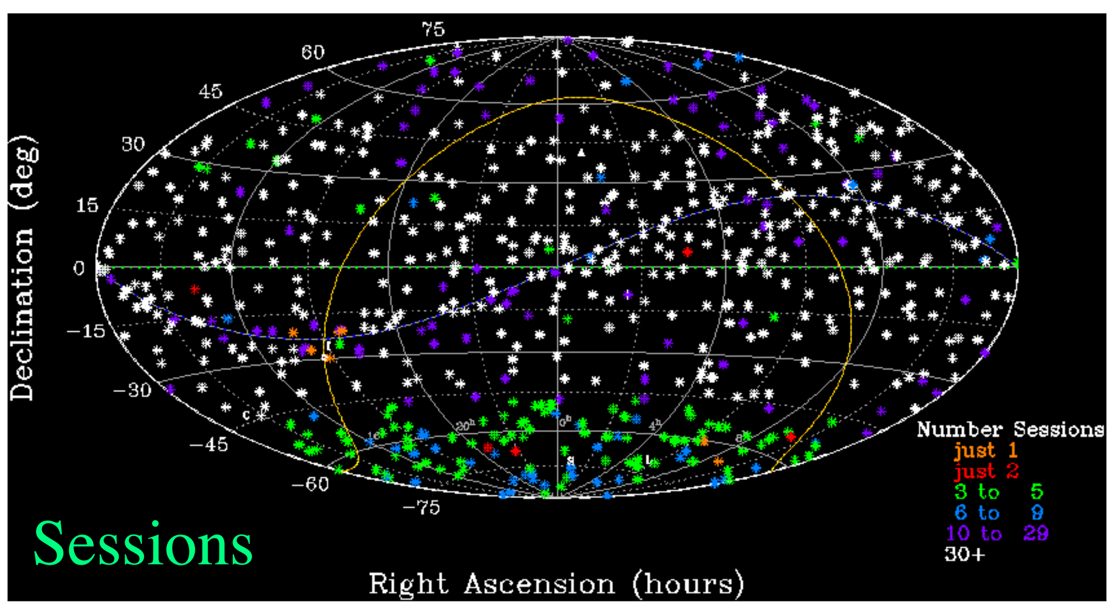


Fig. 8: Number of sessions: South cap (Dec< -45 deg) from 2 years, 1 baseline

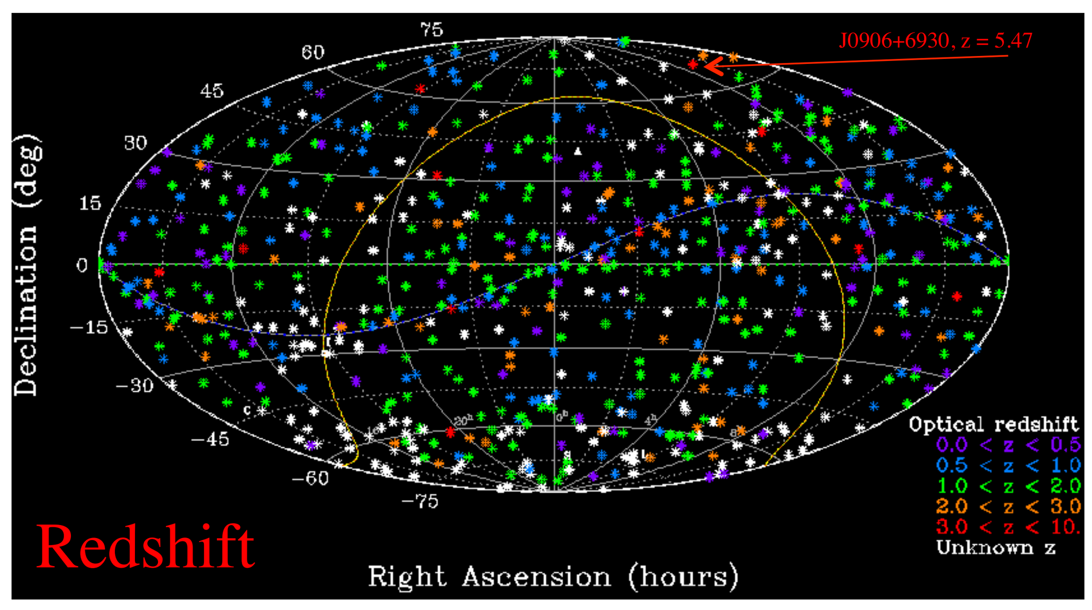


Fig. 10: Optical redshift: median redshift is about z=1.1. Largest redshift is z = 5.47

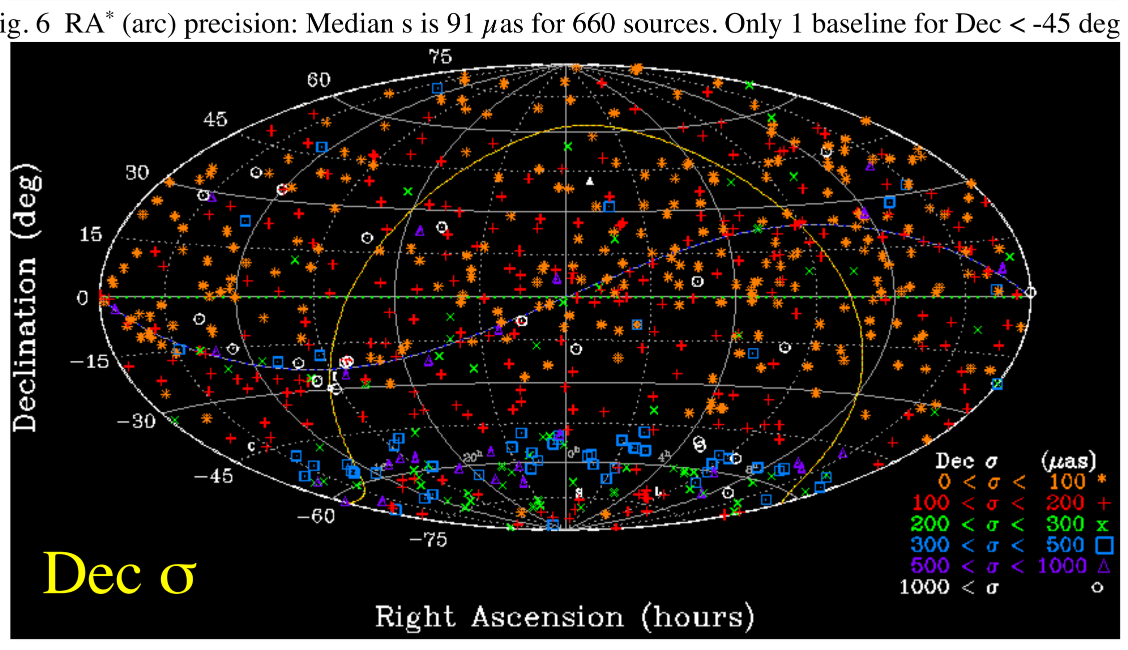


Fig. 7: Dec precision: Median σ is 119 μas for 660 sources. Note worse precision for Dec < -45 deg.

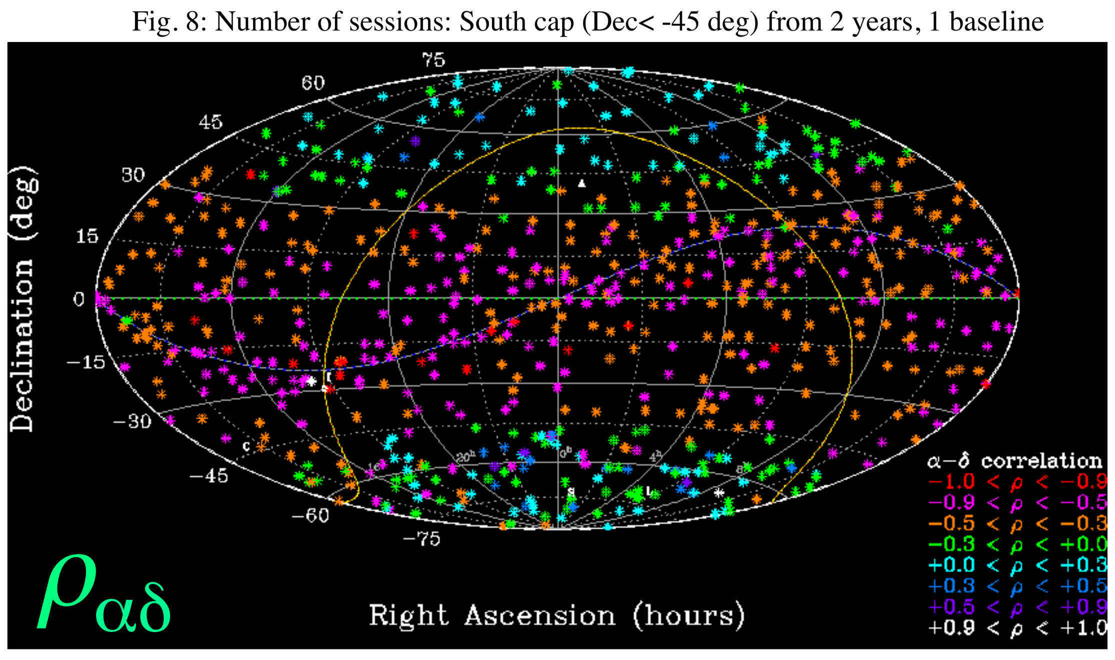


Fig. 9: RA-Dec correlations: Mid-Dec has large negative correlations. CA-Argentina will help.

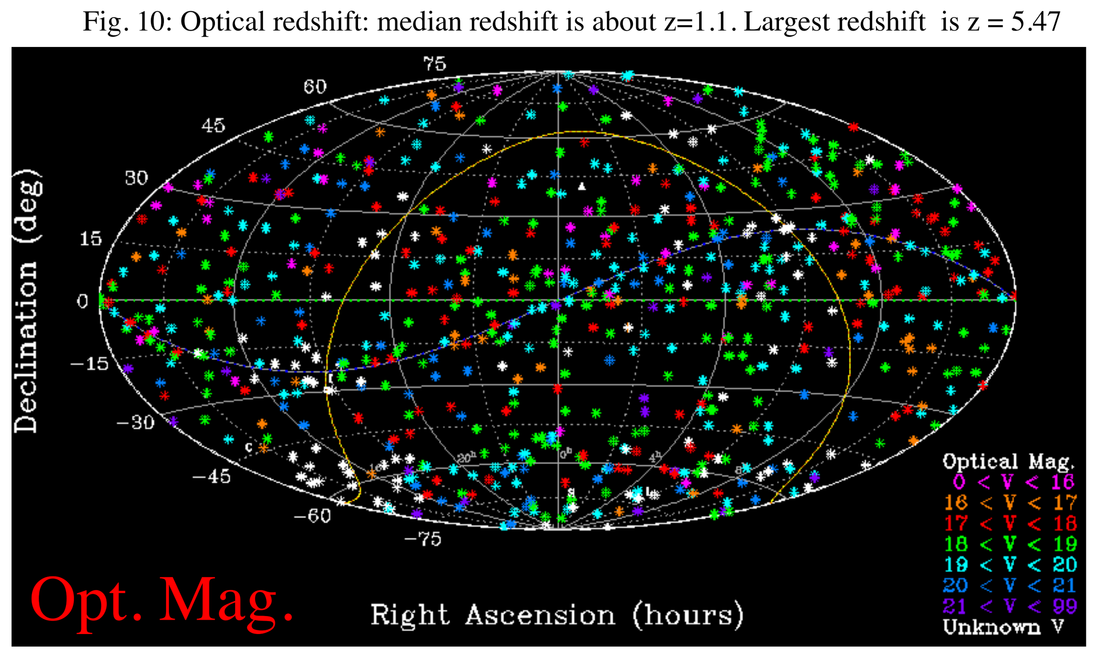
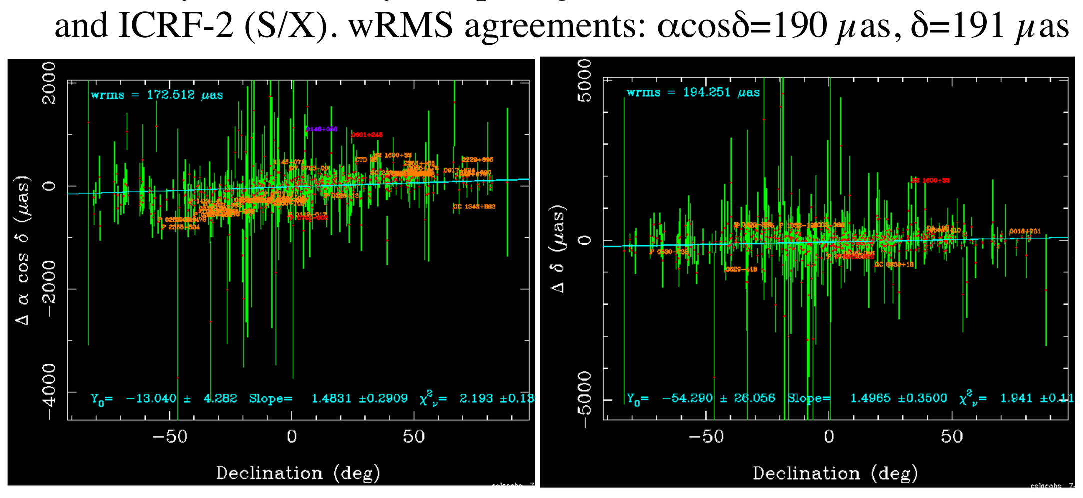


Fig. 11: Optical magnitude: Median V = 18.8. More than 184 sources bright for Gaia, (V < 18)

II. Accuracy: X/Ka vs. S/X

Accuracy estimated by comparing 532 sources common to X/Ka and ICRF-2 (S/X). wRMS agreements: $\alpha\cos\delta$=190 μas, δ=191 μas



III. Gaia Optical-Radio Frame Tie and Accuracy Verification:

Background: Launched in Dec. 2013, ESA's Gaia mission measures positions, proper motions and parallaxes of a billion objects as well as photometric and radial velocity measurements (Lindegren, 2008; Mignard, 2013). Gaia's observations will include approximately 500,000 AGN of which ~20,000 will be optically bright (V < 18 mag) thus enabling very high precisions: 70 μas @V=18 mag and 25 μas @V=16 mag.

Tie sources: Bourda *et al* (2012) estimate that 300+ AGNs should be both bright in the optical and bright and compact in the radio thus enabling both Gaia and VLBI to measure precisely a common set of sources in order rotationally align to better than 10 μas precision (1-σ, per 3-D component). X/Ka currently observes ~185 optically bright sources confirmed (fig. 11). Position offsets between VLBI & optical can be studied to characterize systematic errors. Having multiple radio frames (S/X, K, X/Ka) should be of great value in characterizing frequency dependent effects e.g. core shift.

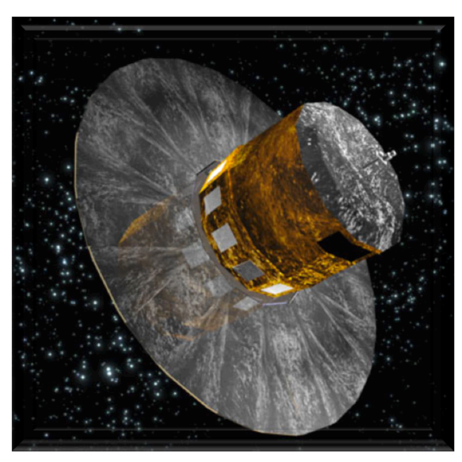


Fig. 12: Gaia launched in Dec 2013 toward L2 (www.esa.int/esaSC/120377_index_1_m.html#)

IV. Goals for the Future:

1. Number: 700 to 1000 sources. Greater density along ecliptic plane.
2. Precision: <= 70 μas (1-σ) to match/exceed Gaia
3. Uniformity: Improve south with baselines from Malargüe, Argentina to Australia, California, Spain.
4. Optical-radio frame tie: Add 30+ optically bright sources.

V. Conclusions: By leveraging improved geometry from ESA's southern station in Malargüe, Argentina and improved sensitivity on NASA baselines from 2 Gbps data rates, we are making rapid improvement in the precision of the X/Ka frame. We now have better median precision than the ICRF-2 for common sources. Whether we achieve superior accuracy will depend on controlling systematics.

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