Advancing Celestial Frames at Multiple Wavelengths

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Program: Strategic Initiative

Project Objective:

To advance JPL's leadership in Celestial Reference Frames at multiple wavelengths with emphasis on K-band (24 GHz) and X/Ka-bands (8/32 GHz). These frames are required for navigating deep space missions to their targets.

Specific near term objectives:
(1) Establish K and X/Ka frames are part of the IAU's International Celestial Frame (ICRF-3)

(2) Reduce systematic differences amongst frames at various wavelengths

(3) Image sources at K-band.

(4) Improve observing network geometry at Ka-band by adding JAXA's Misasa 54-m antenna.

FY18/19 Results:

We use the Very Long Baseline Interferometry (VLBI) technique to measure the angular positions of Active Galactic Nuclei. VLBI achieves world class resolution from using a synthesized beam of a few 100 μ arc-seconds (μas).

•. Helped establish 3rd Generation IAU standard frame, ICRf-3, effective 2019 Jan 01.

• Acquired about 1.5 Petabytes radio interferometric (VLBI) data to build and enhance the radio frames

• Improved sensitivity of observing systems:
Demonstrated doubling of K-band network to 4 Gbps
Tripled data rate to ESA's Malargüe Argentina station for X/Ka-band work.

• Imaged 200+ sources at K-band. Acquired data on another 700+ sources

• First K-band images using 4 Gbps and first images with dual polarization.

• Improved temporal resolution by a factor of 8 for GPS-based ionosphere calibrations for K-band data.

Benefits to NASA and JPL (or significance of results):

This work benefits all deep space missions by developing celestial reference frames which seamlessly transition amongst X, K, Ka, and optical bands to create a unified multi-wavelength navigation system. We are improving the current state of the art by improving sensitivity and geometry of he VLBI network of stations.

• We have been part of the IAU's effort to adopt a next generation standard celestial frame, the ICRF-3 which for the first time is multi-wavelength.
• Imaging work at K-band (24 GHz) guide source selection for Ka-band deltaDOR making angular navigation more reliable and accurate.
• Our inter-agency VLBI collaborations with ESA and JAXA have increased accuracy while reducing costs by sharing resources.
• Linking the radio frame and the optical frame of ESA's Gaia mission leverages the $1Billion investment by ESA to NASA's benefit.

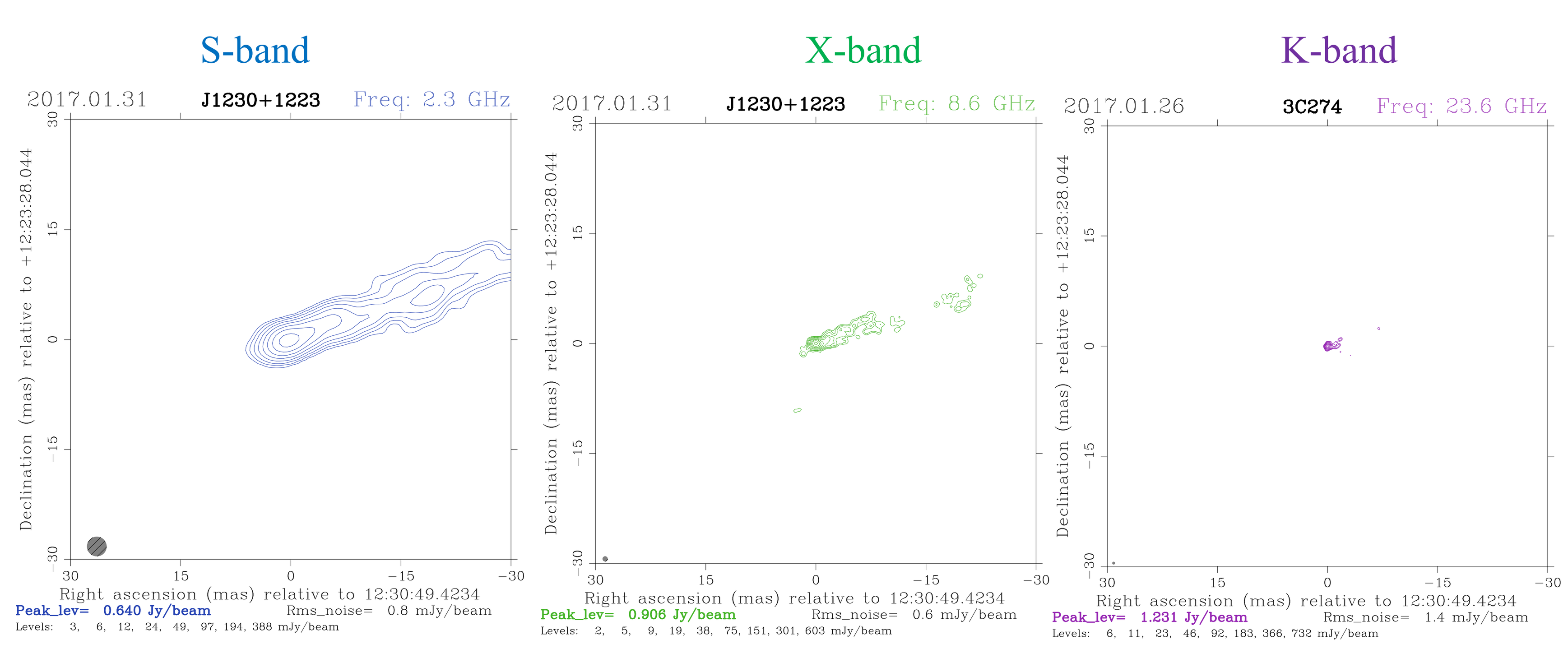

Fig. 1: **Sources get more point-like with increasing frequency:**
Radio source 3C 274 (J1230+1223) at three frequencies: 2.3 GHz (L. Petrov), 8.6 GHz (L. Petrov) and 23.6 GHz (de Witt+, 2019). 30 x 30 milliarsec scale. Note the trend towards more compact emissions vs. frequency. The extended jet structure to the East-North-East fades with increasing frequency as expected. Total flux (TF) diminishes with increasing frequency, the peak flux (PF) within a beam increases thus the fraction of total flux within a beam, the compactness ratio (CR), increases with frequency. This is a highly desired feature for sources acting as reference beacons for navigation.

Fig. 2 **Ka-band combined NASA/ESA/JAXA Deep Space Network**. Adding Japan's 54-meter (top left) improves geometry along weak direction (indicated by error ellipse)

Publications:

1. **C. S. Jacobs**, de Witt, Garcia-Miro, Gordon, Horiuchi, McCallum, Mercolino, Quick, Snedeker, `*Tying multiple Radio Wavelength Celestial Frames to the Gaia Optical Frame*,' 14th EVN Symposium, Granada Spain, 8- 11 October 2018.
2. **C.S. Jacobs**, de Witt, Gordon, Quick, McCallum, Krasna, Soja, `*K-band Celestial Frame Roadmap*,' USNO VLBI Workshop, 01 Nov 2018.
3. **C.S. Jacobs**, Belov, García-Miró, Horiuchi, Snedeker, Clark, Mercolino, Sotuela, White, `*The X/Ka-band 2019a Celestial Frame*', 24th EVGA, Las Palmas, Gran Canaria, Spain, 17-19 March 2019.
4. P. Charlot, **C.S. Jacobs**, and the ICRF3 working group, `*ICRF3: the new realization of the ICRF*,' 24th EVGA, Las Palmas, Gran Canaria, Spain, 17-19 March 2019.
5. A de Witt, Gordon, **Jacobs**, Krasna, McCallum, Quick, Soja, *The K-band 2019a (24 GHz) Celestial Reference Frame*, 24th EVGA, Las Palmas, Gran Canaria, Spain, 17-19 March 2019.
6. A.de Witt, Le Bail, **Jacobs**, Gordon, Schartner, Gruber, Shu, Nickola, McCallum, Weston, Horiuchi, `*Southern VLBI Operations Center*,' 24th EVGA, Las Palmas, Gran Canaria, Spain, 17-19 March 2019.
7. A. de Witt, **Jacobs**, Nickola, Gordon, Krasna, Le Bail, McCallum, Quick, Soja, Horiuchi, `*The K-band Celestial Reference Frame: First Imaging Results*,' Journees 2019, Paris, France, Oct. 2019.
8. C. García-Míro, **Jacobs**, Horiuchi, Snedeker, Clark, Mercolino, Sotuela, White, García, Colazo,`*The X/Ka-band (8.4/32 GHz) 2018b Celestial Reference Frame*,' 14th EVN Symposium, Granada Spain, 8-11 October 2018.
9. K. LeBail, de Witt, **Jacobs**, Gordon,`*Time stability of the K-band catalog sources*,' 24th EVGA, Las Palmas, Gran Canaria, Spain, 17-19 March 2019.
10. D. MacMillian , Fey, Gipson, Gordon, **Jacobs**, Krasna, Lambert, Malkin, Titov, Wang, and Xu, *Galactocentric Acceleration in VLBI Analysis: Findings of IVS WG8.* A&A, 26 July 2019.
11. B. Soja, **Jacobs**, Runge, Naudet, Gross, de Witt, Gordon, Quick, McCallum, Krasna, `*Ionospheric calibration for K-band Celestial Reference Frames*,' 24th EVGA, Las Palmas, Gran Canaria, Spain, 17-19 March 2019.

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