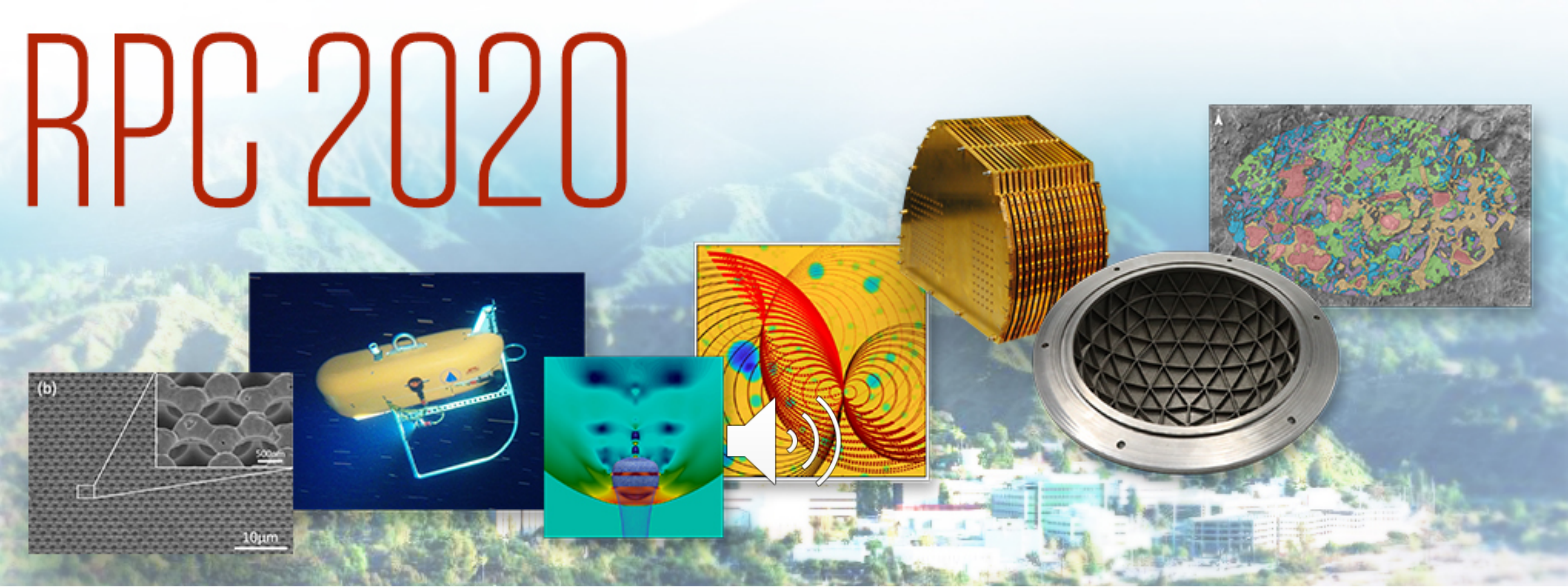

Virtual Research Presentation Conference

Advancing Celestial Frames at Multiple Wavelengths

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Program: Strategic Initiative

Assigned Presentation # RPC-002

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Tutorial Introduction

Abstract

JPL requires accurate reference frames in order to navigate its missions throughout the solar system. These frames are built using naturally occurring radio sources ("quasars") because their extreme distance (billions of lights years) means that they stay in the same angular location at the part-per-billion level.

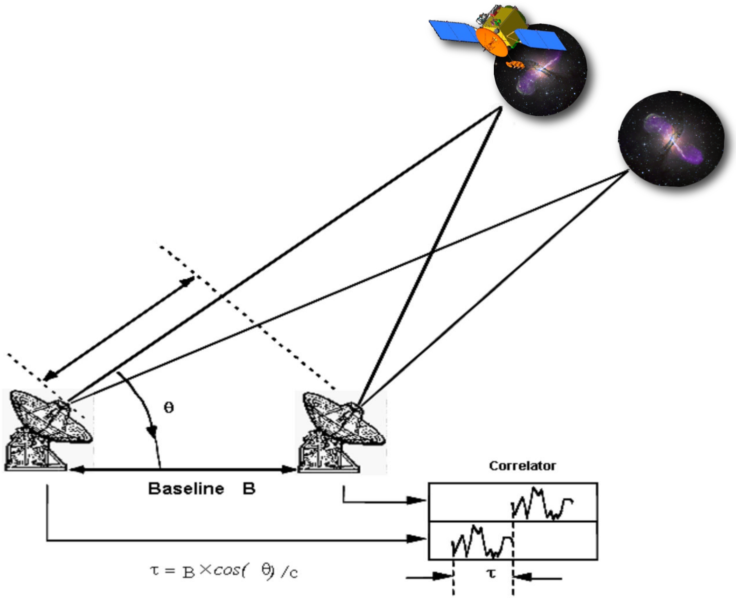
In order to ensure JPL's continued leadership in next generation celestial reference frames (CRF), we are working

(1) to improve the X/Ka (32 GHz) celestial frame, especially in declination where the need for enhancement is greatest.

(2) to quantify source compactness using images at K-band (24 GHz)

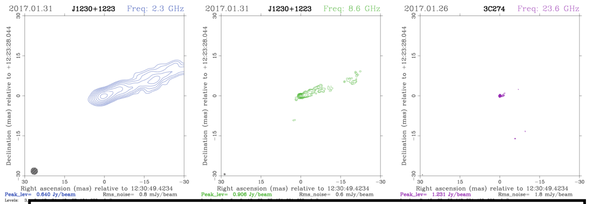
(3) to assess and reduce systematic errors by comparing the 24 and 32 GHz radio frames to the Gaia optical frame which provides a totally independent wavelength and technique for verification.

(4) to infuse the gains produced into JPL navigation infrastructure and international standards.



We use the Very Long Baseline Interferometry (VLBI) technique which is a phased array with separate clocks at each site due to the intercontinental separation of antennas. The angular resolution scales as wavelength over baseline length. At Ka-band (9mm) on ~9,000km baselines this gives us the nanoradian (ppb) resolution needed to meet navigation requirements

Problem Description



Source compactness improves with frequency from 2 -> 8-> 24 GHz
(de Witt et al, Jourees, 2019)

a) Context: Why this problem and why now

JPL is NASA's lead center for solar system exploration. Exploring Mars's surface and other similarly challenging destinations requires VLBI angular measurement accuracy on the order of one part per billion. This has been achieved using the distant (billions of light years) quasars as stable radio beacons as observed simultaneously at S/X-bands (2.3, 8.4 GHz). However, S-band is quickly becoming obsolete due to (1) increasing RFI, (2) the DSN and external partners gradually abandoning S-band, (3) noise floor from source structure (4) the need for higher telemetry bandwidth (5) the need to track near the sun.

b) State-of-the-art: The International Celestial Reference Frame-2 (ICRF2) based on S/X observations was adopted by the IAU in 2009 and has been the state-of-the-art. However, it suffers from the above issues with S-band as well as a systematic geometric dipole distortion approaching 0.5 nanoradian as a function of declination which consumes 100% of the required error budget going forward.

c) Relevance to NASA and JPL: Solar system work is moving towards Ka-band in order to get increased telemetry bandwidth. As S/X antennas (DSS 15,45, and soon 65) are retired, they are being replaced by X/Ka antennas. Already we are seeing three major space agencies with Ka-band missions: NASA (Parker Solar Probe), ESA (Bepi-Columbo), JAXA (Hayabusa-2). These are driven in part by the need to get close to the Sun where Ka-band is less corrupted than S or X-band.

The work described here will create next generation reference frames at K and Ka-bands which will overcome the problems described above and enable JPL to have more accurate angular navigation which is sustainable into the future.

Methodology

a) **Experiment and Analysis plan:**

Develop global Celestial Reference Frames (CRFs) at K (24 GHz) and Ka-bands (32 GHz)

Raise the K and Ka CRFs to the status of international standards as part of the 3rd International CRF (ICRF3)

Reduce systematic errors in K and Ka-bands by increasing the observations and improving observing geometry

-- Specifically collaborations of Japan-Australia & California-Argentina north-south baselines to improve declinations.

Compare radio results to Gaia optical results as an independent check of technique.

b) **Innovations and advancements:**

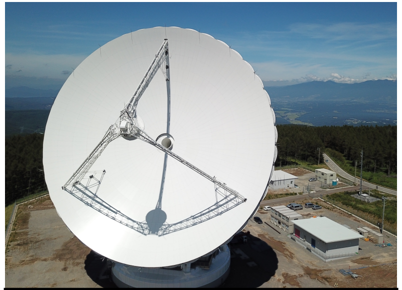
Move observations from X-band (8 GHz) to K-band (24 GHz) and Ka-band (32 GHz)

-- Improves stability by reducing extended structure

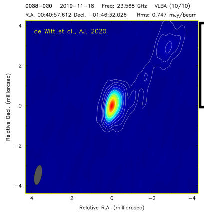
-- Increase data rates enabling quicker, more sustainable frames

-- Improve geometry by adding baselines to Japan and Argentina

-- Improve statistical analysis by modelling observation correlations due to tropospheric turbulence at Ka-band



Misasa, Japan 54-meter (JAXA)



K-band image

Results

a) Accomplishments:

International standard frame, ICRF3, now includes K and Ka-band for first time ever. Paper accepted for publication.

Sensitivity increased at K-band by a factor of 1.4, also increased sensitivity at Ka-band at Argentina by a factor of 2

700 sources imaged at K-band to quantify effects of extended structure

Dipole distortion at Ka-band reduced from >300 µas to 102±49 µas, quadrupole from 200 to 145±19 µas.

First ever Ka "fringes" Japan to Australia proving end to end experiments work on this critical north-south baseline.

b) Significance:

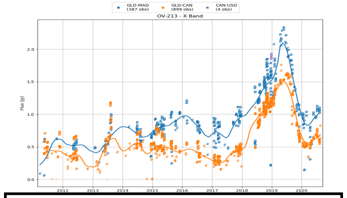
New K and Ka frames made international standards enabling seamless navigation amongst S/X, K, Ka and optical.

Sensitivity and geometry improvements speed progress towards goals as evidenced by the factor of 3 reduction in Ka-band dipole distortion.

c) Next steps:

Enhance analysis with correlated observation weighting at Ka-band

Infuse results into operations: deliver X/Ka frame, K-band images, X/Ka source strength database



Source strength 5-year history

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