Toward determining a more stringent constraint on the variability of the gravitational constant G via VLBI astrometry on PSR J0437–4715

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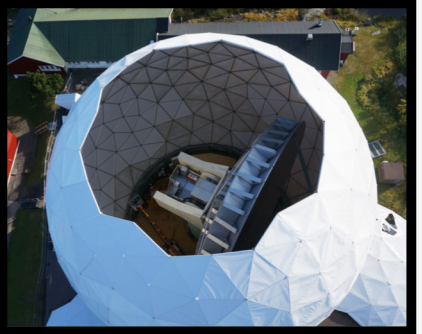
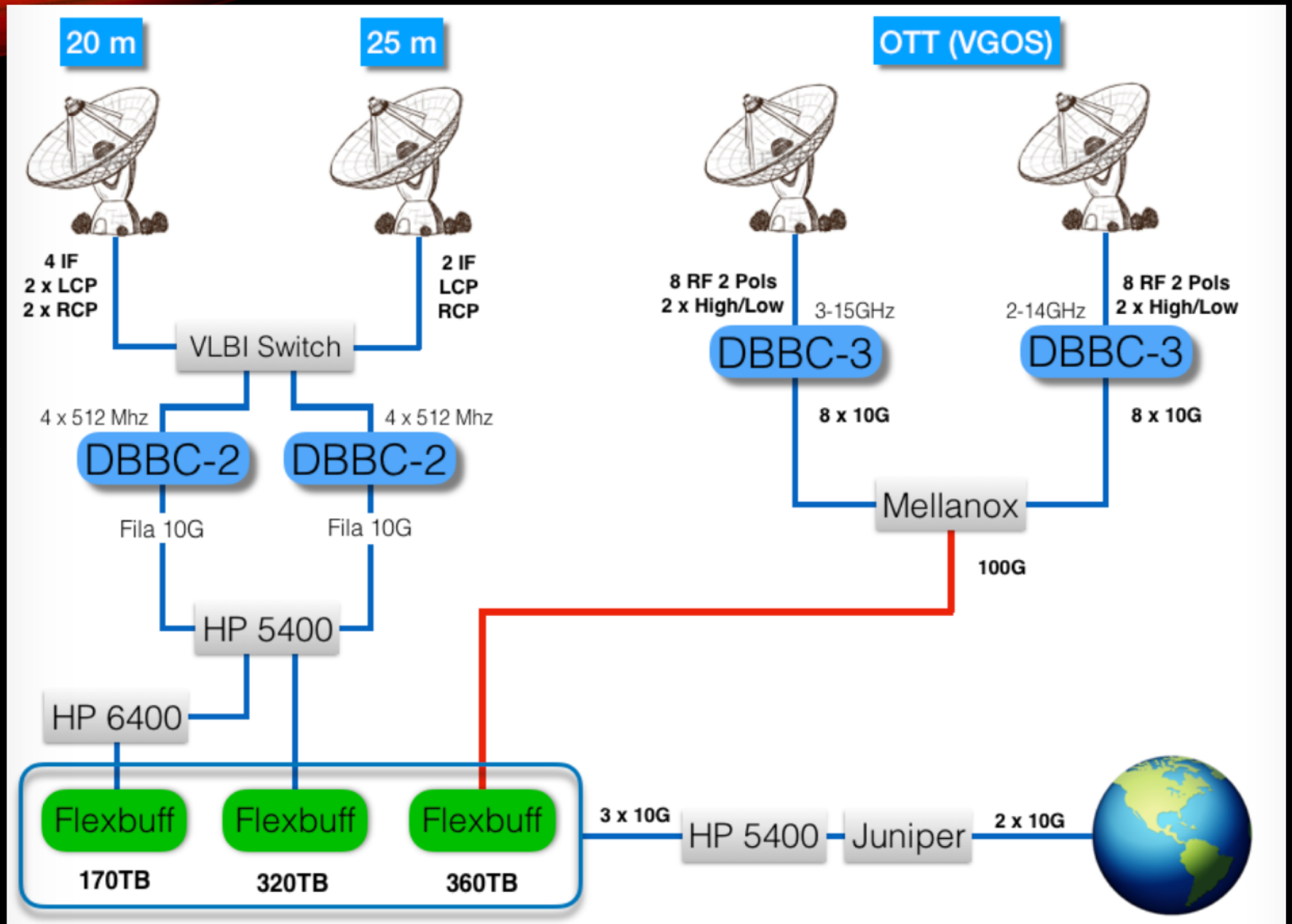
VLBI facilities at Onsala Space Observatory



Onsala 20 m
Bands: S,X, K, Q, W

Onsala 20 m
Bands: L, C



OTT, 13.2 m

Collaborators

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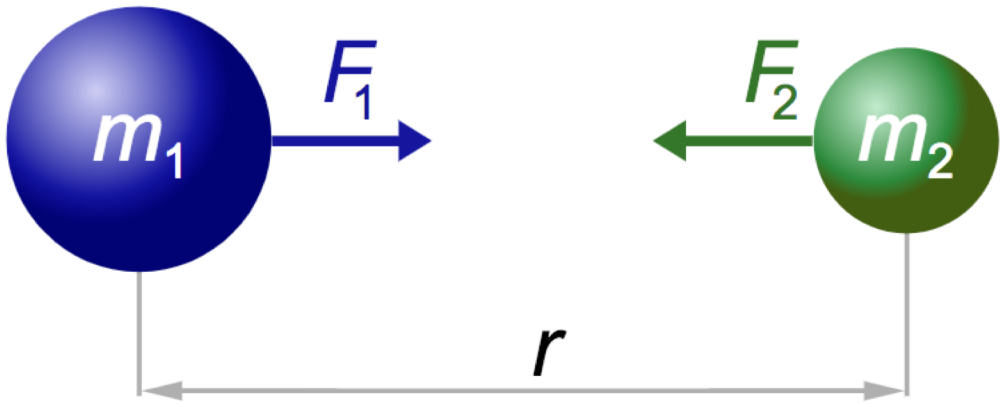
Newton gravitational constant G

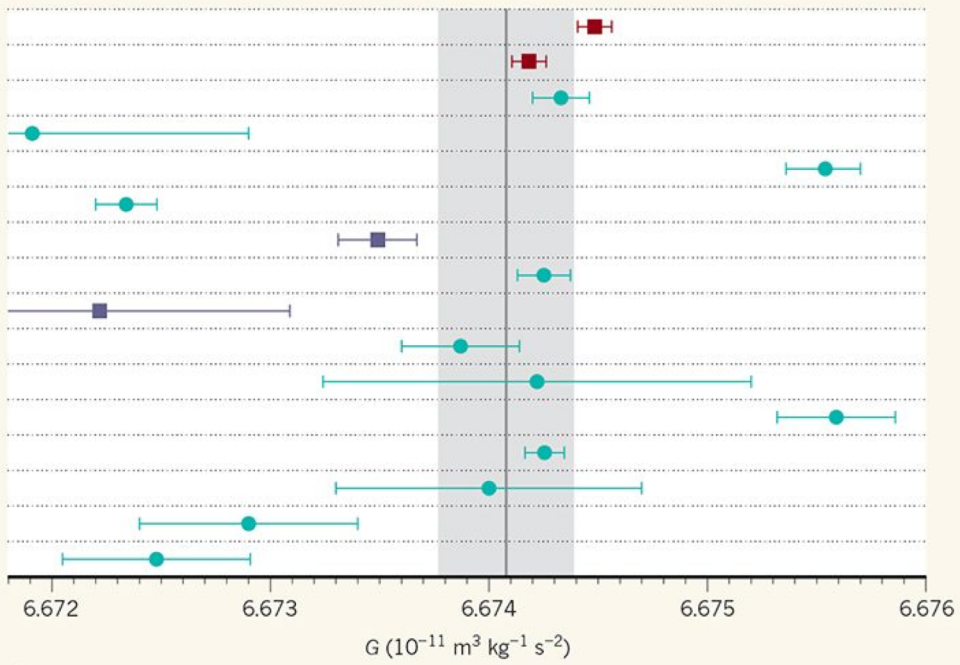
- $G = 6.674 \times 10^{-11}\ m^3 kg^{-1} s^{-2}$

- Best precision (red): 1×10^{-5}

(Li et al. 2018, Nature, 560, 582)



$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$



Constraining $\dot{G}$ with millisecond pulsars

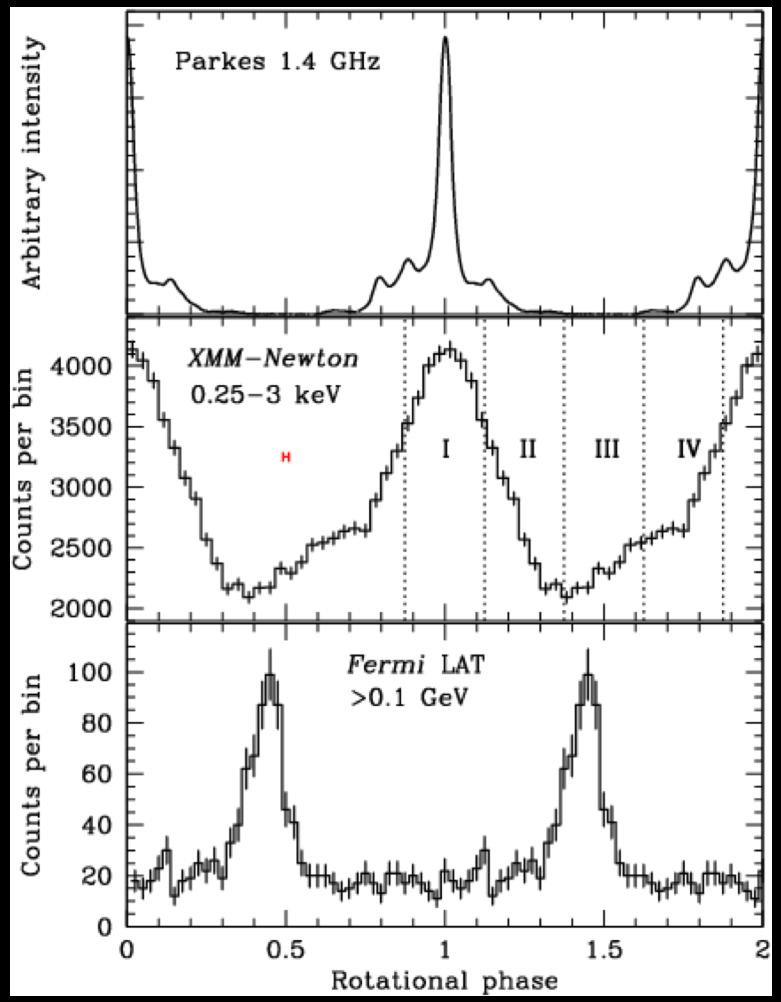
- The time variability of G (Damour et al. 1988)

$$\dot{G} = \frac{dG}{dt}$$

$$\frac{\dot{G}}{G} \approx -\frac{\mu}{2c}[D_k - D_\pi]$$

- c: light speed.
- μ: $total\ proper\ motion$ of the pulsar in a binary system.
- D_k: The kinematic distance measured with the timing parameters (P_b, $\dot{P}_b$, μ).
- D_π: the distance measured with the annual parallax π.

PSR J0437–4715



- The brightest millisecond pulsar at radio
- The nearest millisecond pulsar
- One of a few extremely stable pulsars
- The most accurate distance measurements to a pulsar

Timing: $D_k = 157.0 \pm 2.4$ pc (100 μas, 1.5%)

--Verbiest et al. (2008) with Parkes64 at L band.

VLBI: $D_\pi = 156.3 \pm 1.3$ pc ($\pi = 6396 \pm 54$ μas)

$\frac{\dot{G}}{G} = (-5 \pm 26)\times10^{-13}\ \mathrm{yr}^{-1}$ (95% confidence)

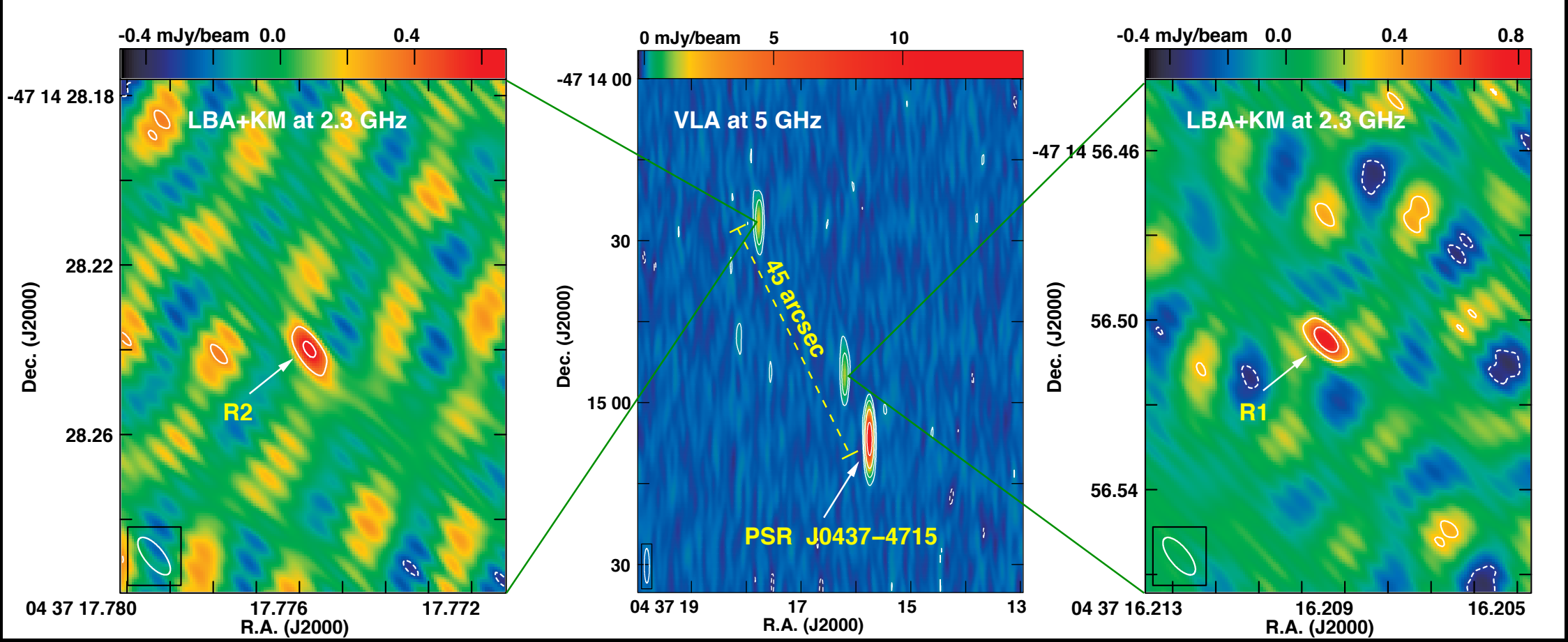
Lunar laser ranging: $(4 \pm 9)\times10^{-13}\mathrm{yr}^{-1}$ (Williams et al. 2004)

--Deller et al. (2008) with the LBA at 8.4 GHz.

Timing: $D_k = 156.79 \pm 0.25$ pc (10 μas, 0.16%)

--Reardon et al. (2016) with Parkes64 at L band.

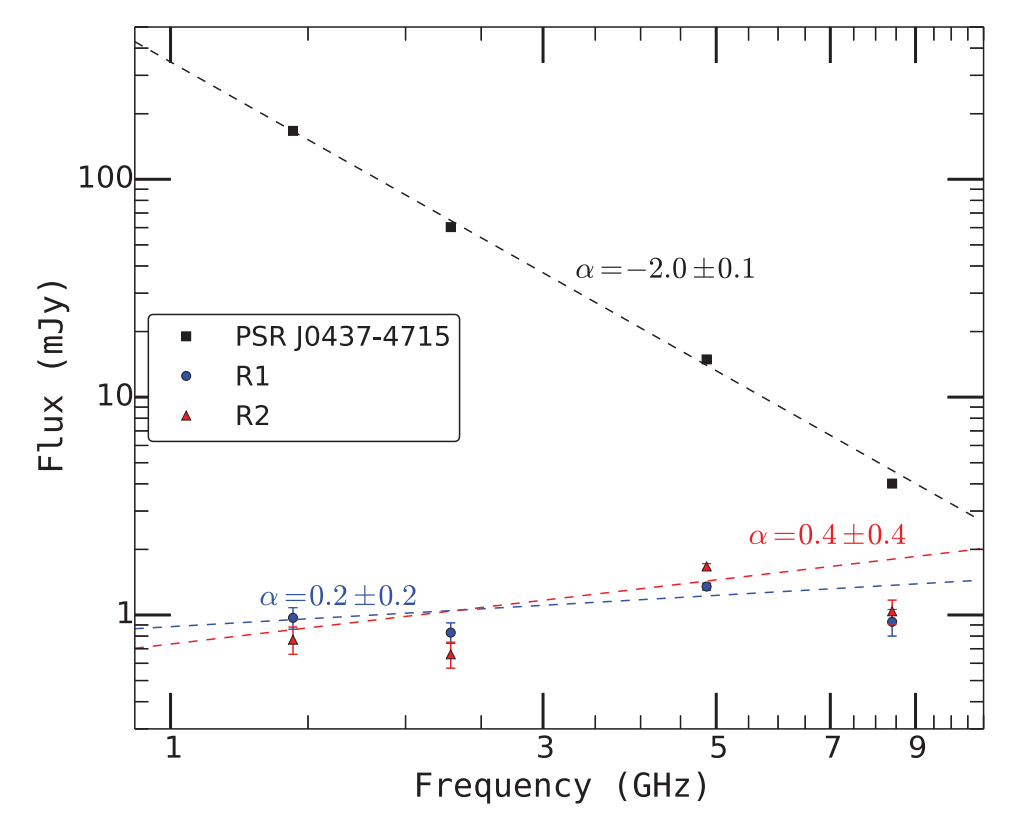
Discovery of two in-beam sources

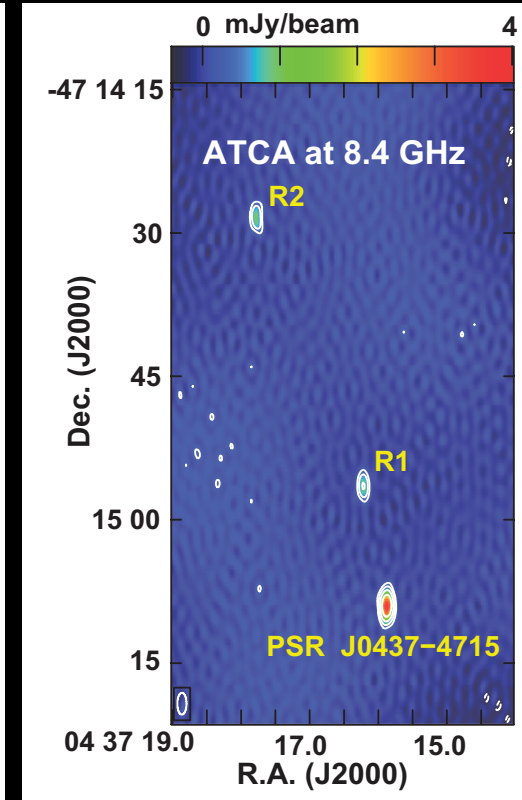


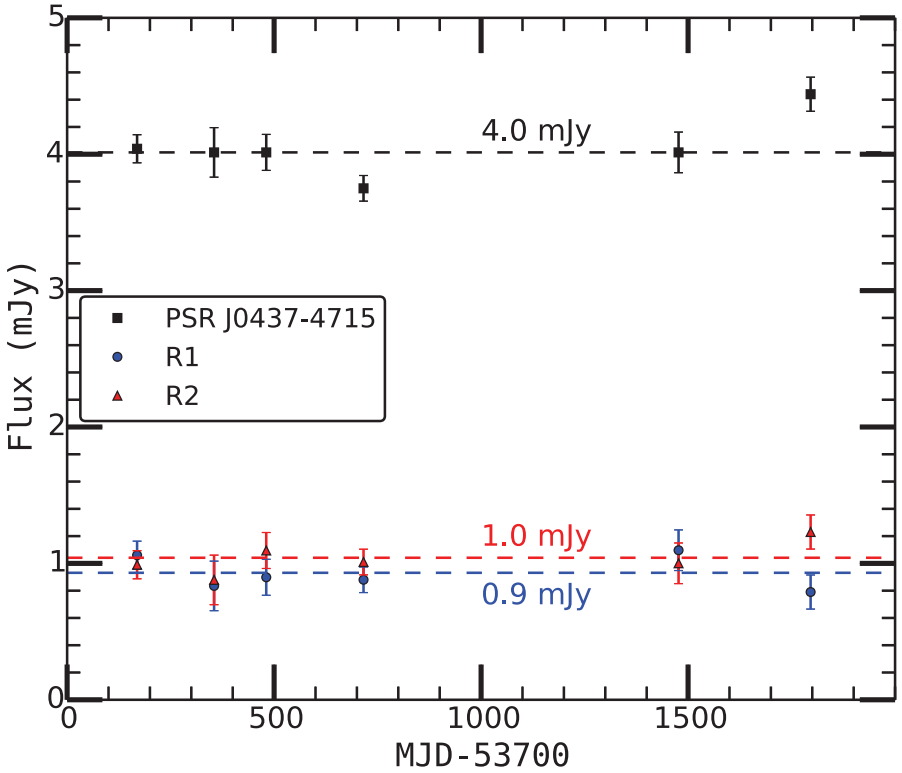
SNR~7 for R1 and R2.
Probability of the good luck: ~1/1000.

Setup: LBA+KM, 1 Gbps data rate & 6 hour on-source time.
Published by Li et al. (2018) in MNRAS.

Flat spectra & stable flux density => Most likely extragalactic radio cores



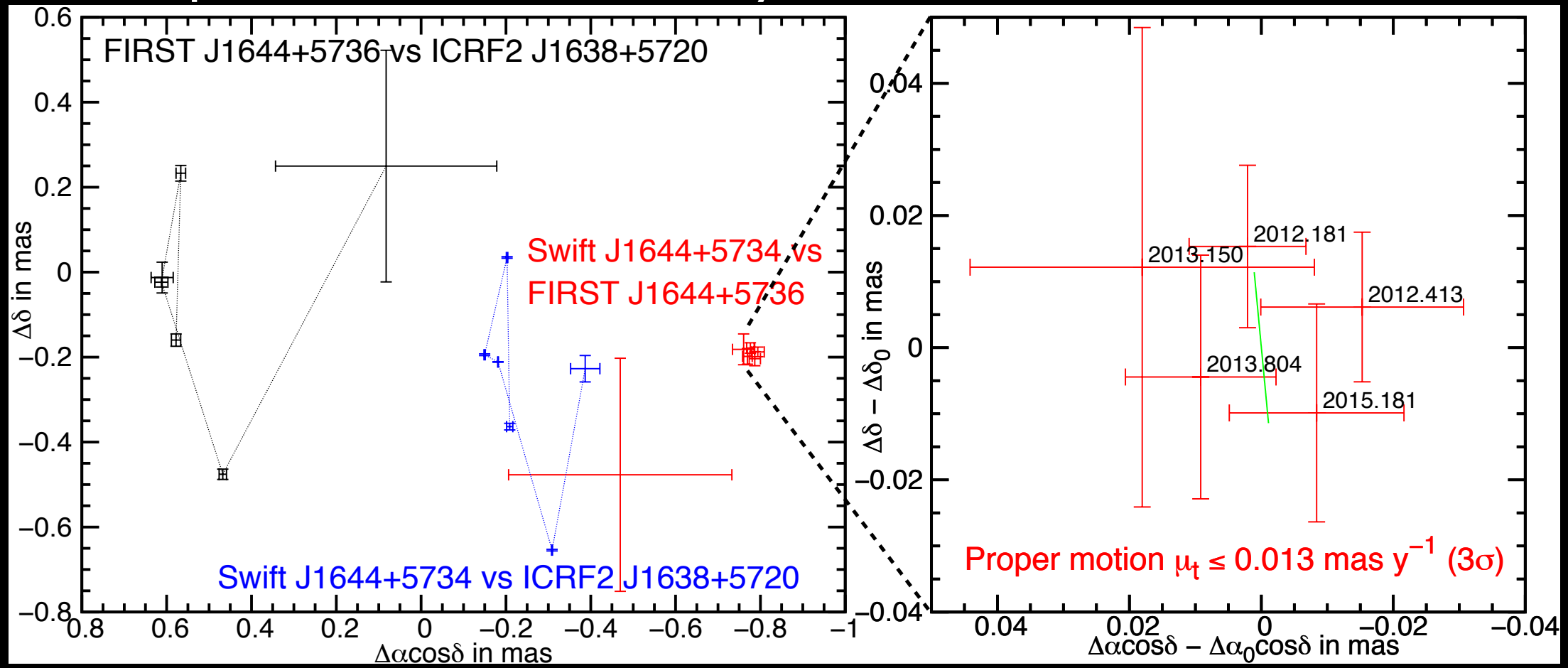




To reach an accuracy of <10 μas for the π

- The tiny separations allows the differential calibration to work extremely clean. The remaining systematic positional error: $\leq 4\ \mu$as (Deller et al. 2018).
- The stable radio luminosities indicate that they are likely stationary reference points.
- The relative astrometry between R1 and R2 also helps us to quantitively estimate the systematic positional errors caused by the radio core jitter.
- The flat spectra make broad-band VLBI observations become particular useful in improving the image SNRs.

~10x better astrometry accuracy with respect to an 1mJy in-beam FIRST source



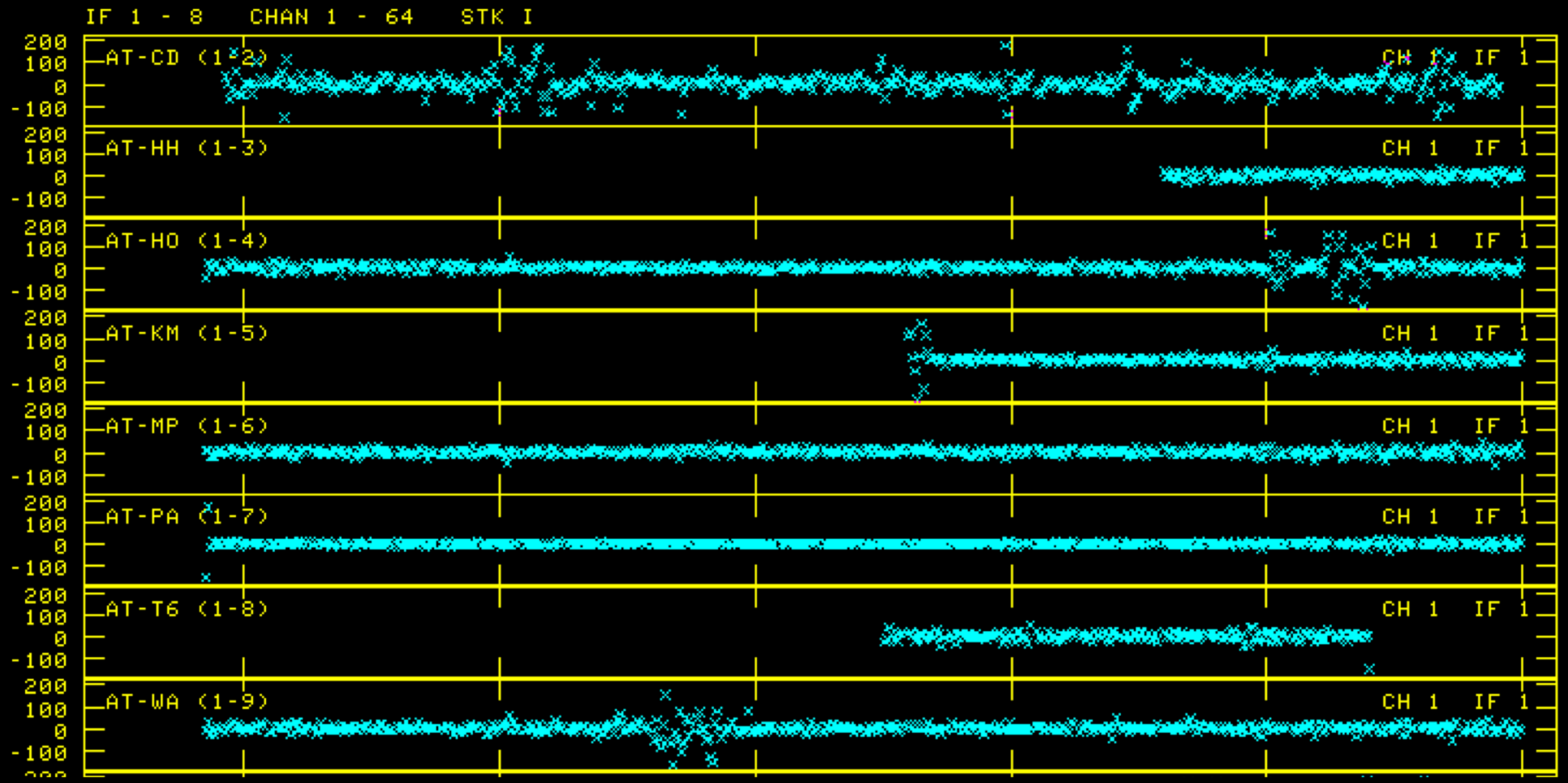
Yang et al. 2016, MNRAS

The ongoing astrometry observations with LBA+HhT6KmWa at 6.7 GHz

2 epochs observed

8/9 Stations
1 Gbps
Dual pol
256 MHz per pol

Gating correlation

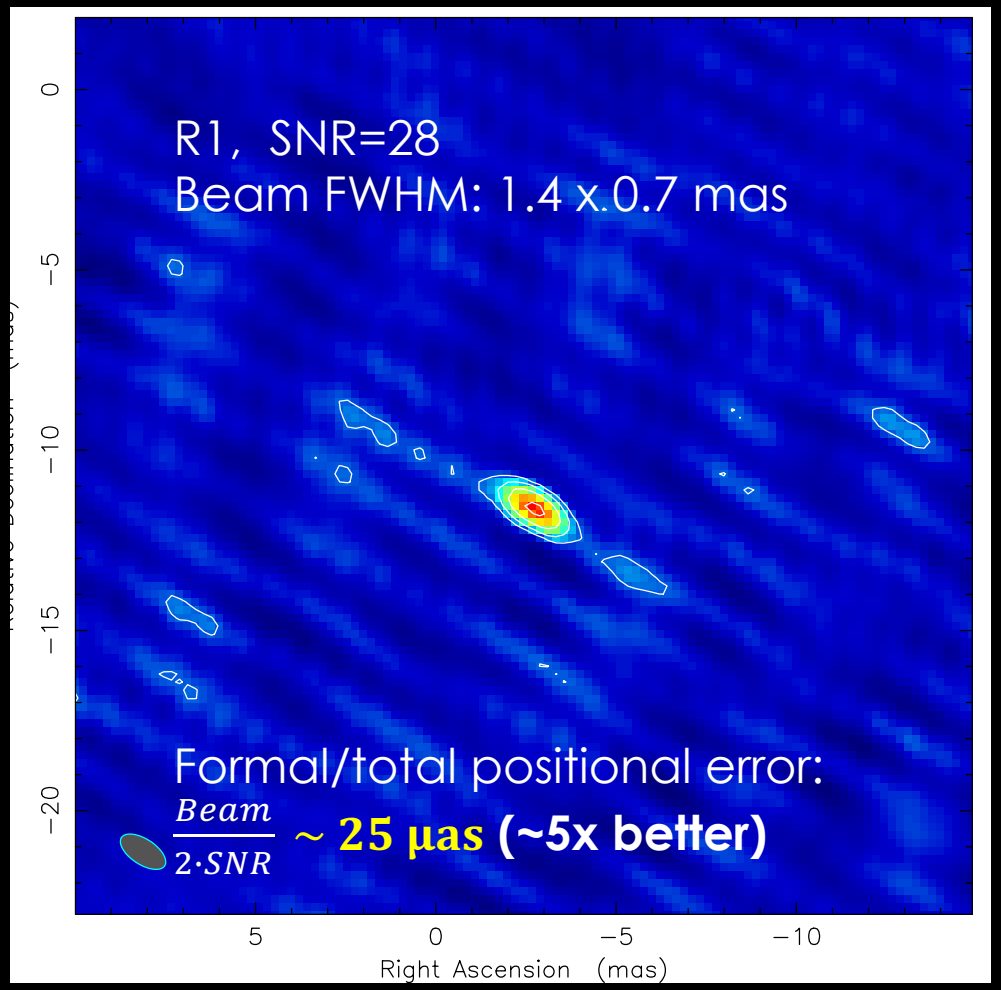


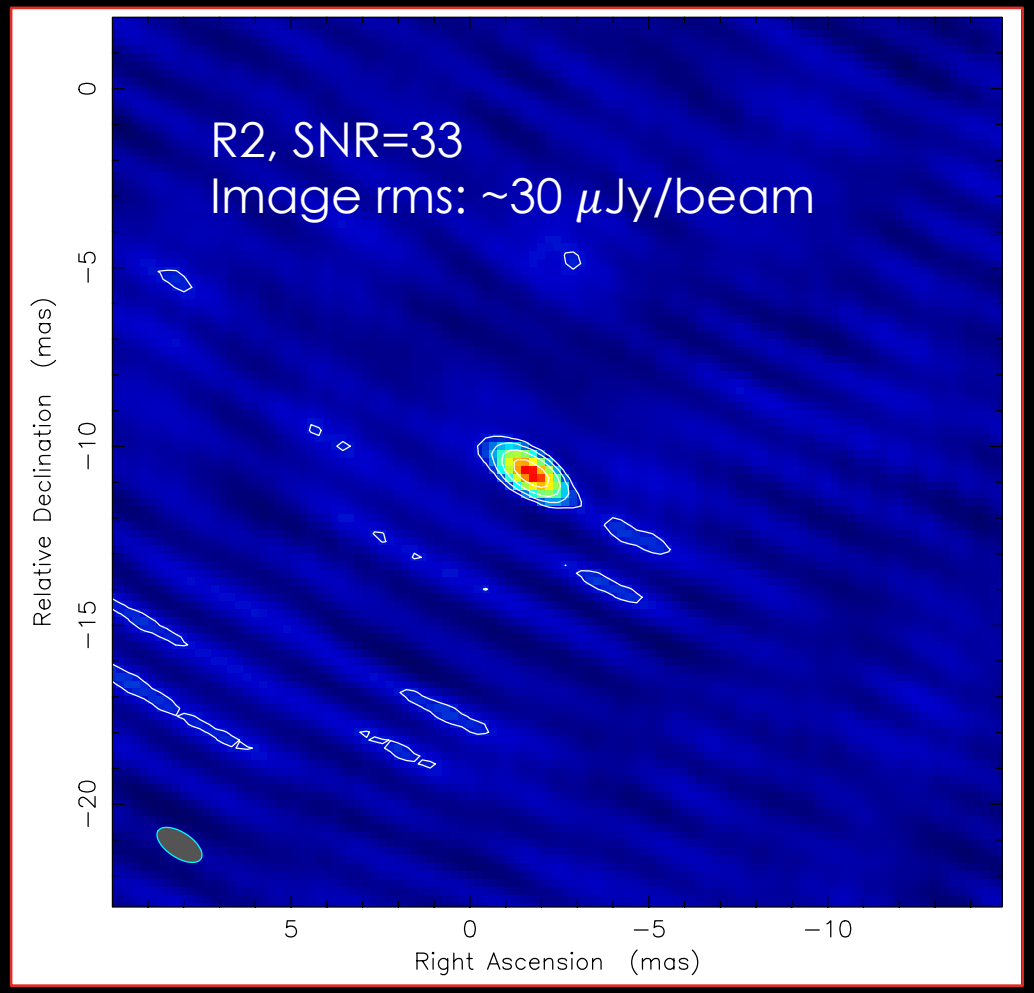
Phase vs time of 6mJy PSR J0437–4715 data in V558B.

Fringes are clearly seen on all the baselines to the ATCA in the two epochs.

Preliminary imaging results

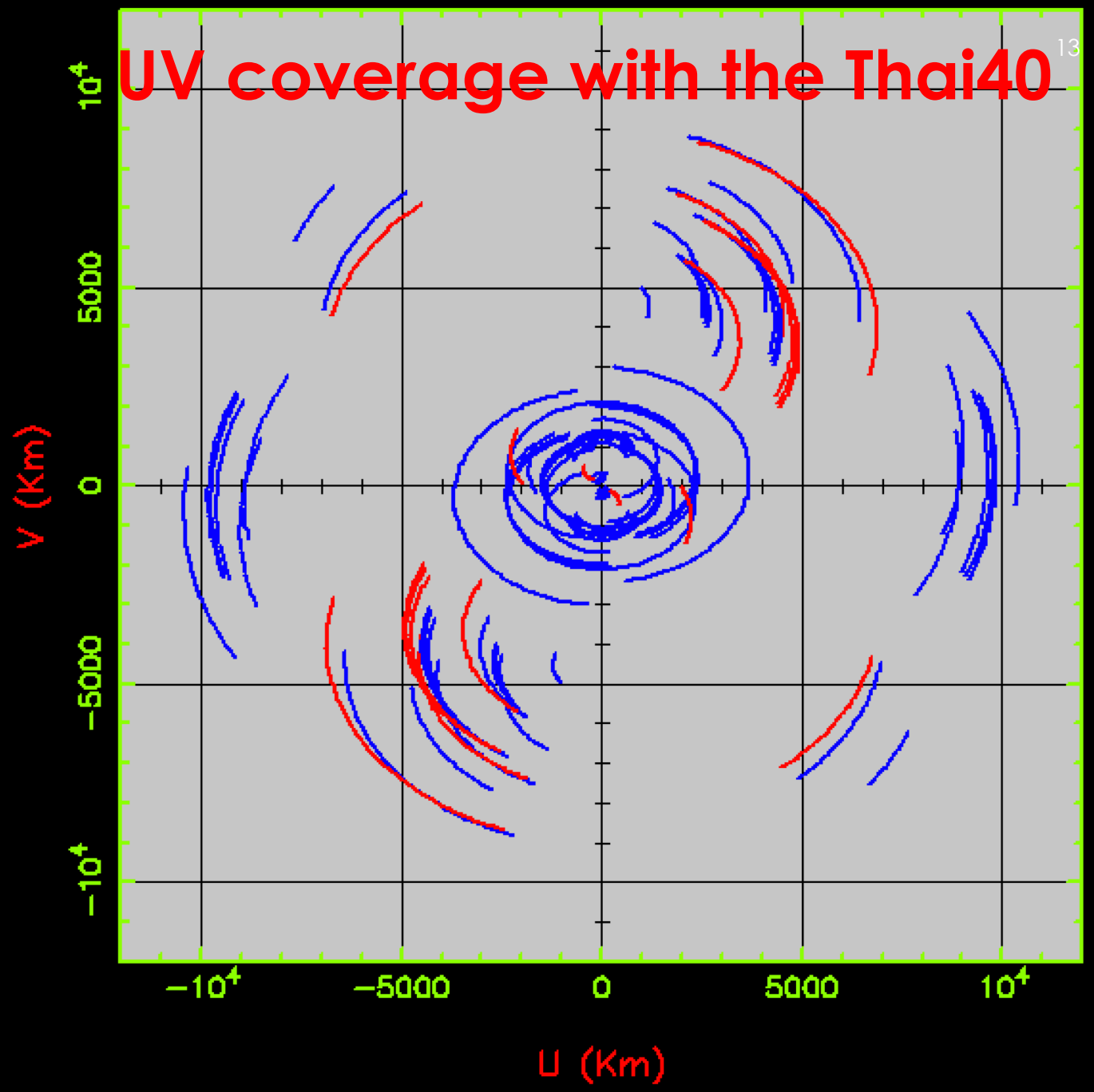
---- Zhixuan LI





The average total error of Deller et al. (2008): 132 μas per epoch

UV coverage with the Thai40



Upcoming upgrade

Thai40
C-band receiver is also an option in Phase 2.

WARK30M
A cooled 6.7 GHz receiver.

LBA
Plan to build new digital backends.

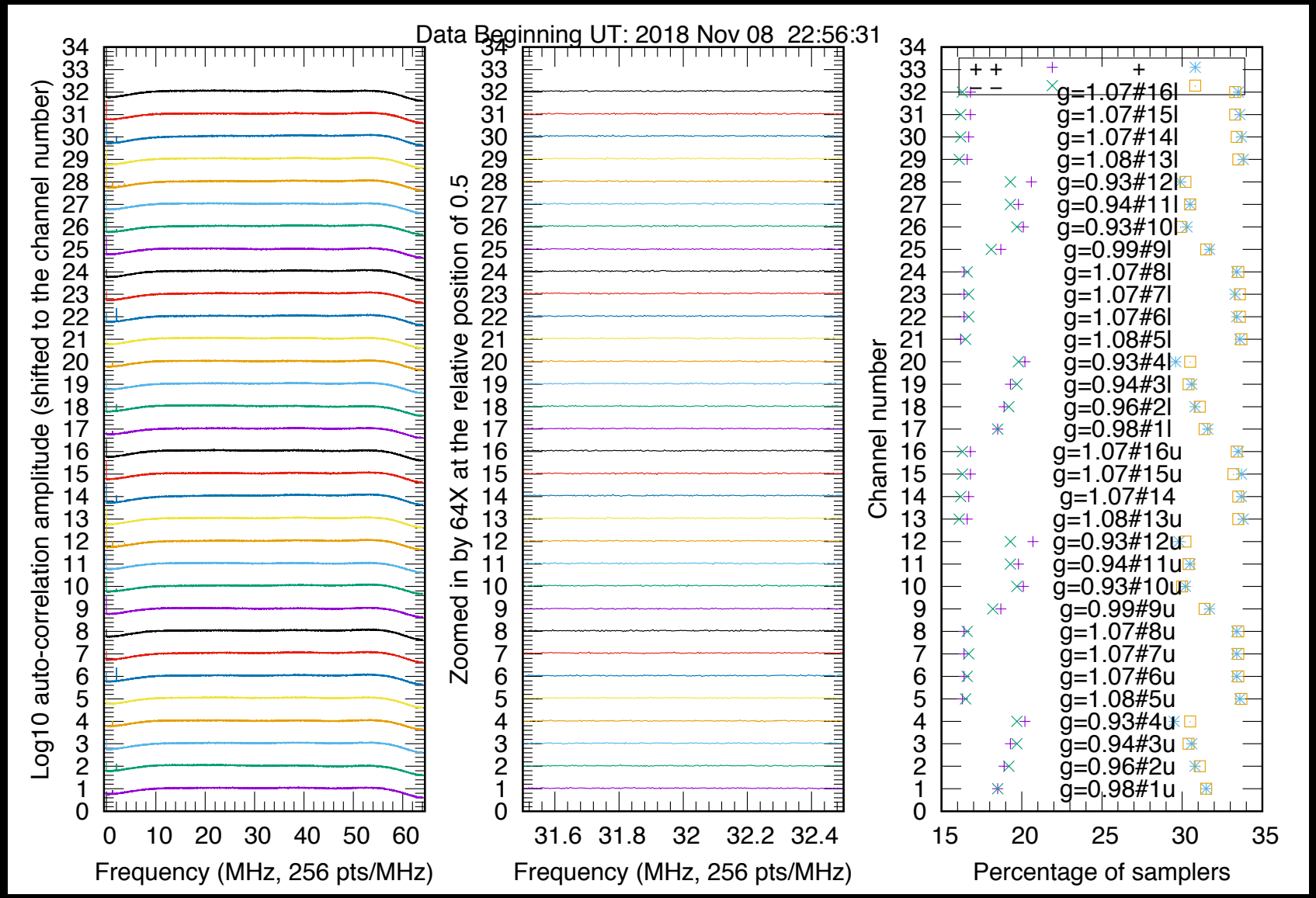
Upcoming booster: 8Gbps data rate with DBBC2

DBBC2 Stations
T6, Km, Hh, Wa, Cd, Ho

DDC V107beta
(G. Tuccari & S. Dornbusch)

-- 32 x 64 MHz x 2bit
-- 128 MHz VSI clock rate
-- 4 BBC per IF/board
-- Dual sideband
-- 1 GHz BW per pol

Plots of BBC bandpass shapes and sampler statistical distribution



SUMMARY

- Two in-beam sources extremely close to PSR J0437–4715 were found.
- It is quite promising for the ongoing VLBI astrometry observations at 6.7 GHz to gain an accuracy of <=25 μas for the π.
- No known bottlenecks on achieving extremely high parallax accuracy of <10 μas in the near future.
- Final goal: A factor of ~10 improvement on the constraint of $\frac{\dot{G}}{G}$.