## Astrometry with VLBI

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# Happy 25<sup>th</sup> Anniversary, VLBA





# Outline

- Brief history, background
- Some selected results
  Comments on relation to GAIA
- The future

# VLBA Proposal (1982)

- What was the original astrometric "intent" 25 years ago?
- VLBA designed to measure "... parallax with a precision considerably better than 0.001 arcsec"
- "The ability of the VLBA to measure angular coordinates ... will open up an exciting range of astrometric problems ..."
- Geodesy is closely related to astrometry

## Selected results

- These are representative, and reflect a "selection bias"
- Omission of a result is not indicative of lack of importance
- See review by Reid & Honma (2014)
- Impact: direct distance measurements for galactic and extra-galactic objects

#### Pleiades distance controversy

#### Melis et al. (2014)





## Pleiades distance

- High sensitivity array: VLBA+Arecibo+GBT
- *Hipparcos* result in conflict with other distances to Pleiades
- Parallax error < 70 µarcsec including depth effects</li>
- GAIA expects < 30 μarcsec at end of mission, stars V < 15 mag.</li>
- HIPPARCOS error source is still unknown

#### Distance across the Milky Way

- Masers provide distances to star forming regions and spiral structure in the Galaxy BeSSeL VLBA project (Reid et al.)
- Spiral arm structure traced, mean parallax uncertainty =  $27\mu$ arcsec
- Distance across the Milky Way: parallax =  $49 \pm 6\mu$ arcsec => 20.4 Kpc to 13%

#### View across the Milky Way



Bill Saxton, NRAO/AUI/NSF; Robert Hurt, NASA

## Pulsar Parallaxes

- Pulsar Pi: A. Dellar and collaborators, results coming
- Pulsars offer observational probes of:
  - Gravitational physics
  - Nuclear physics
  - Stellar evolution

Pulsar distances used for luminosity calibration, transverse velocity, electron density (galactic models)

#### Pulsar parallax J2222-0137

- Binary pulsar; very low eccentricity implies white dwarf companion
- No optical counterpart;
  d<sub>DM</sub> = 312 pc too low?
- VLBA says no!
  - D =  $267.2 \pm 0.7$  pc 0.4% distance accuracy
  - Companion must be the coldest white dwarf
     3000 K or unusual NS (Deller et al. 2013,
     Kaplan et al. 2014)



# Supermassive Black Hole Binary Proper motion

- 0402+379: A Supermassive black hole binary resolved with a 7 pc separation (Rodriguez et al. 2006)
- Precursor of low frequency (eLISA or Pulsar Timing Array) Gravitational Waves
- 12 years of VLBA astrometry reveals orbital motion (Bansal et al. 2017)



#### Relative astrometry, core shift



#### Proper motion results

• 
$$\mu_{RA} = -0.887^{+0.056}_{-0.083}$$
 mas / yr

- $\mu_{\text{DEC}} = 1.286^{+0.115}_{-0.086} mas / yr$
- At z=0.055,  $v = 0.0054 \pm 0.0003c$ v = 1600 km / sec

## **Future Capabilities**

- S/X band dichroic sets the VLBA astrometric standard, but RFI is a significant impact in S band.
- X/Ka band promising for VLBI , but Ka is limited to spacecraft tracking sites
- Dual C/K band: simultaneous methanol (6.7 GHz) and water (22 GHz) maser astrophysics
- C, X and K band are common used receivers

#### Upgrade thoughts, future observations

- Consider C/K or X/K dichroic
- Test observations of X-K-X and C-K-C in nearsimultaneous modes for performance estimates
- Build on published 24 and 43 GHz work (e.g. Lanyi et al. AJ, 2010) that investigated the astrometric performance at high frequencies.
- Sensitivity gain with C band vs. X