Australian Government

Geoscience Australia

Proper motions of reference radio sources

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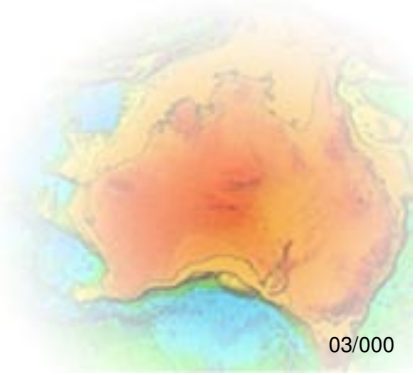


Systematic proper motions

1*st harmonic* $(P_{10}; P_{11})$

$$P_{10} = \sin\delta$$

$$P_{11}^{c} = \cos\delta\cos\alpha$$

$$P_{11}^{s} = \cos\delta\sin\alpha$$

Secular aberration drift

Acceleration of the Solar system barycentre?

2*nd harmonic* $(P_{20}; P_{21}; P_{22})$

$$P_{20} = \frac{1}{2}(3\sin^2\delta - 1)$$

$$P_{21}^{c} = 3\sin\delta\cos\delta\sin\alpha$$

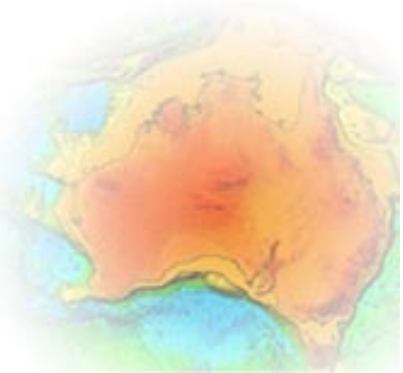
$$P_{21}^{s} = 3\sin\delta\cos\delta\cos\alpha$$

$$P_{22}^{c} = 3\cos^2\delta\sin 2\alpha$$

$$P_{22}^{s} = 3\cos^2\delta\cos 2\alpha$$

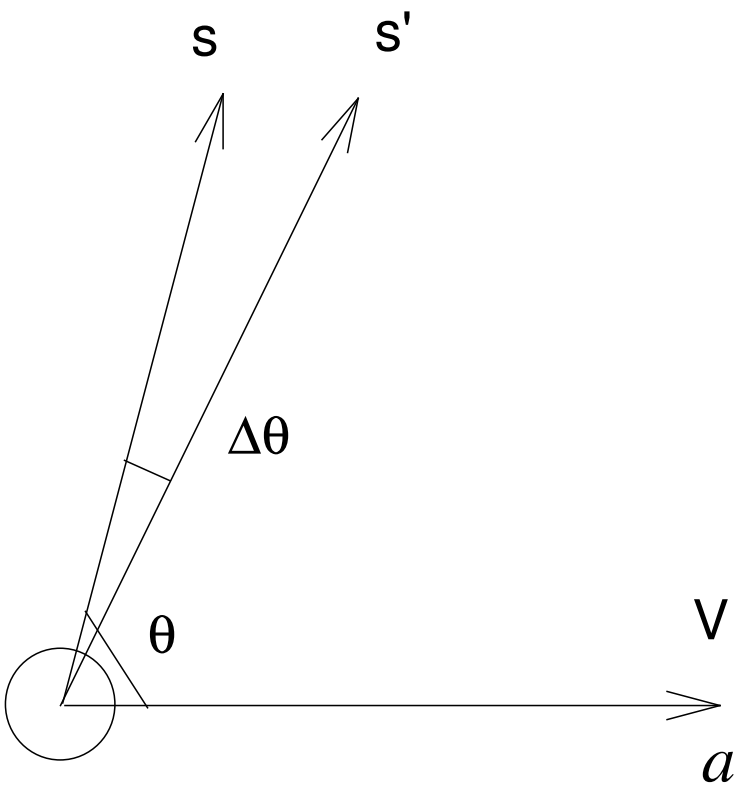
Gravitational waves in the Universe??

Gwinn et al (1997); MacMillan (2003)



No convincing evidence of systematic were presented so far

Secular aberration and drift



$$\Delta\theta = -\frac{V}{c}\sin\theta$$

$$\Delta\theta + \mu\Delta t = -\frac{V + a\Delta t}{c}\sin\theta$$

$$\mu\Delta t = -\frac{a\Delta t}{c}\sin\theta$$

$$\mu = -\frac{a}{c}\sin\theta$$

Correction in VLBI model

$$\Delta\tau_{geom} = -\frac{1}{c}(\bar{b}, \bar{\mu})\Delta t$$

$$\bar{\mu} = \frac{1}{c}(\bar{a} - \bar{s}(\bar{s}, \bar{a}))$$

We can't separate the degree-1 systematic and acceleration. Both approaches are equivalent

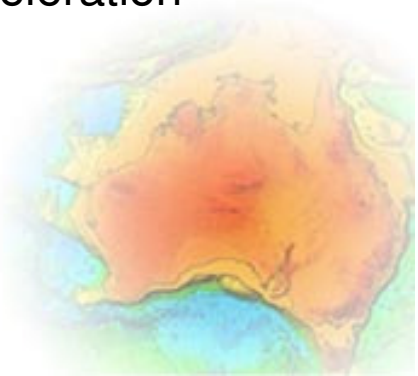
Either the radio source position to be corrected for proper motions

$s' = s + \mu t$

or

the Earth barycentre velocity should be corrected for the constant acceleration vector

$V = V_{\oplus} + at$



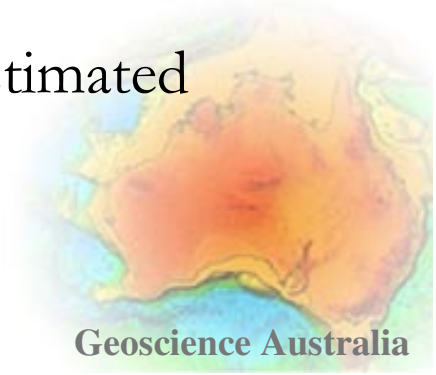
Global VLBI solutions

The effect of secular aberration drift can be estimated from analysis of a global set of VLBI data

3554 daily VLBI sessions since 1980
~ 27 years
~3.9 million of observations in total
~ 1500 radio sources

Direct adjustment (one-step) to reduce the source structure effect; OCCAM

the amplitudes of spherical function harmonics are estimated directly from time delays $\tau \rightarrow$ A(1), A(2), A(3);
MacMillan (2003)

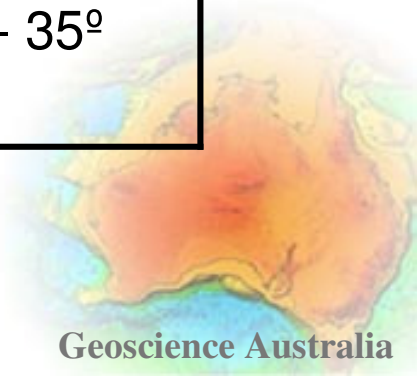


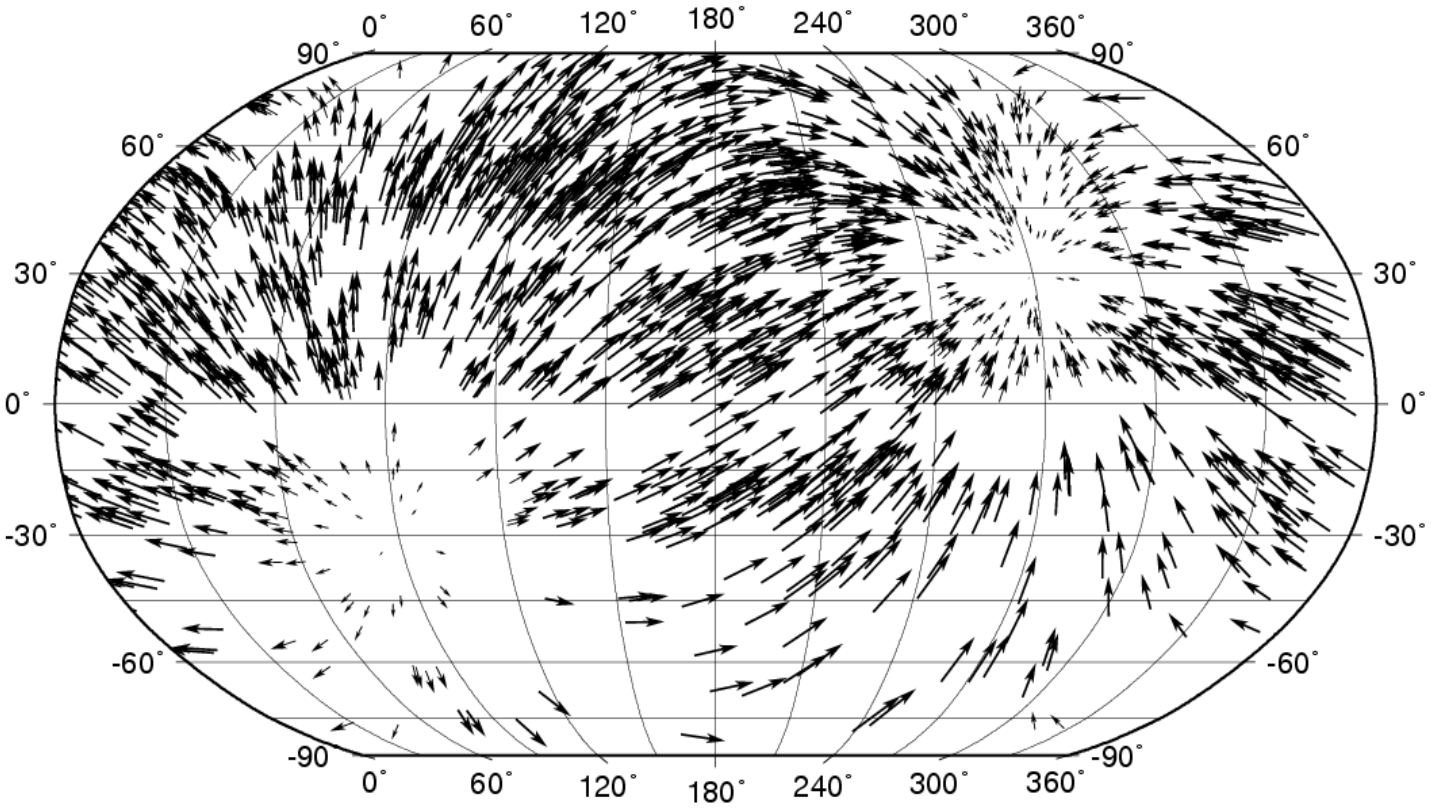
Global VLBI solutions (acceleration)

ICRF	List by Feissell-Vernier	z<1, not 'unstable'	z>1, not 'unstable'
212 ICRF (NNR) as global 102 as local	199 'stable' (NNR) as global 163 as local	172 'close' and not 'unstable' (NNR) 1895 as local	150 'distant' and not 'unstable' (NNR) 1917 as local
27.4 +/- 2.0 µas/year	22.6 +/- 2.9	23.5 +/- 3.6	27.6 +/- 2.8
RA = 271º +/- 3º DE = 8 º +/- 10º	RA = 269º +/- 4º DE = 30 º +/- 11º	RA = 285º +/- 6º DE = 35º +/- 12º	RA = 266º +/- 4º DE = 13 º +/- 11º

Acceleration of the Solar system due to the Galaxy rotation

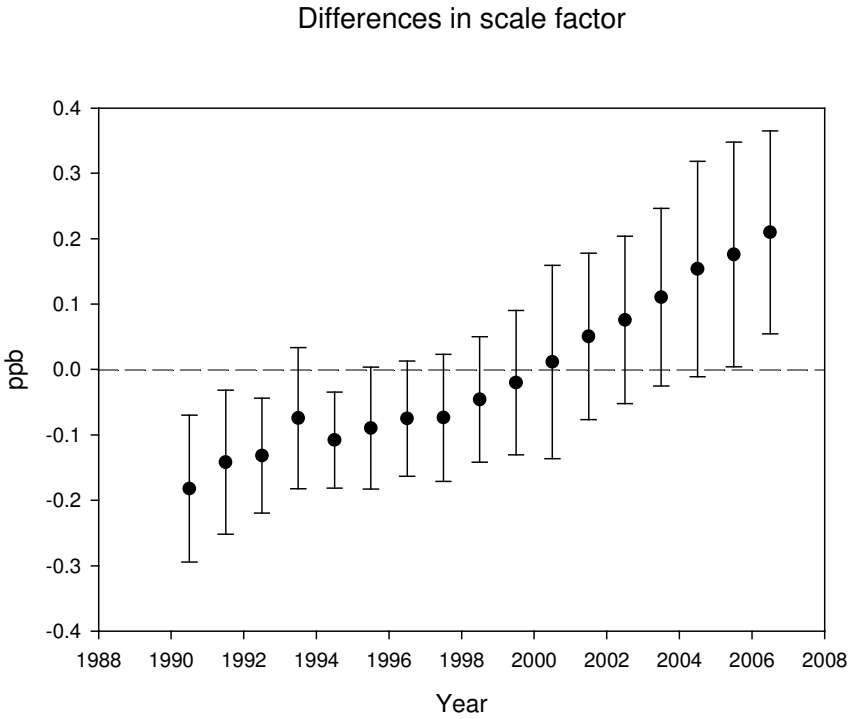
	Expected acceleration	Observed estimates
The magnitude of the effect	4 μas/year	23-28 μas/year
Direction on the sky	RA = 270º, DE = -30º	RA = 265º - 285º DE = 8º - 35º



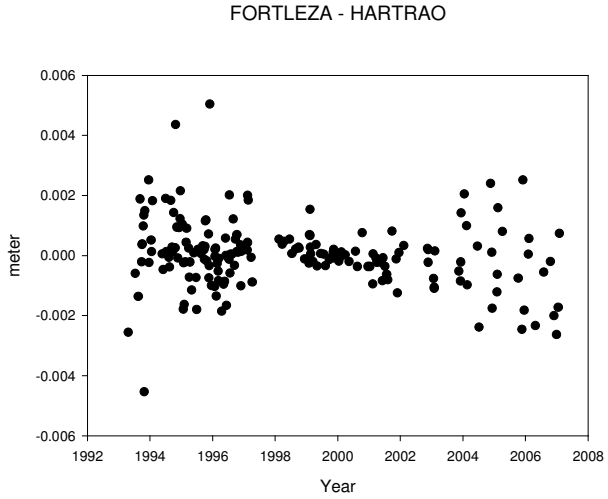


Calculated systematic for 2004 sources in (α,δ)

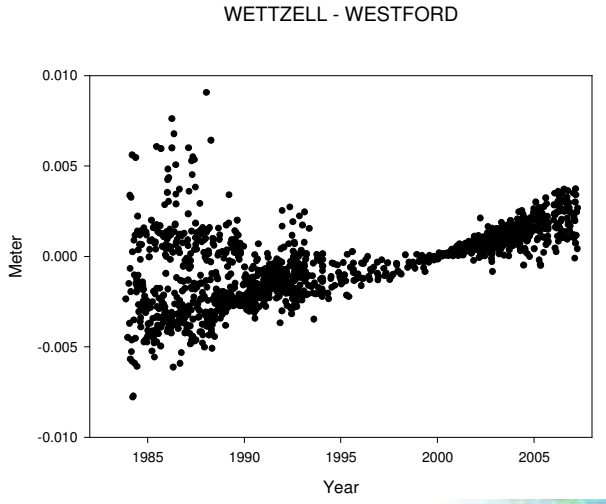
Effect on geodetic results

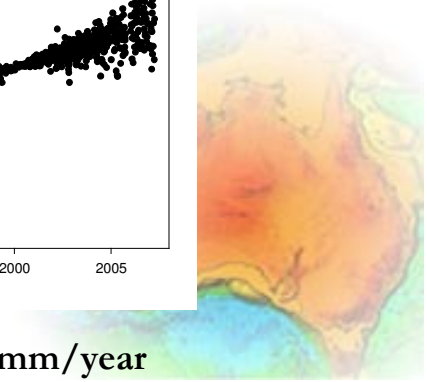


Solution 2 – Solution 1:
0.025 ppb/year 0.15 mm/year



ΔV = 0.23 ± 0.04 mm/year

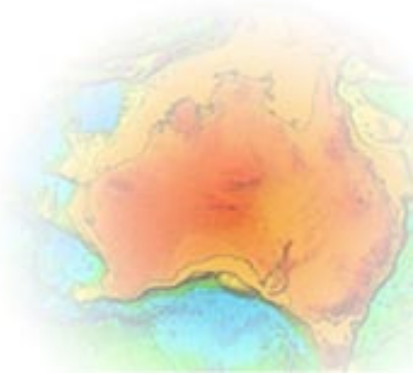




ΔV = -0.10 ± 0.01 mm/year

Acceleration ??

- The Planet X (Jupiter mass at the distance 70 au);
- The low luminosity ‘brown dwarf’ in our neighborhood (0.1 Solar Mass at the distance 700 au) ;
- The Galaxy structure (spiral arms, hidden mass);
- The Local Group of galaxies (hidden mass);
- The Universe rotation. (i.e. the Gödel metric instead of the Minkowski metric comes down to the effect of global rotation);



Second harmonic (interpretation)

$$2nd\ harmonic\ (P_{20}; P_{21}; P_{22})$$

$$P_{20} = \frac{1}{2}(3\sin^2\delta - 1)$$

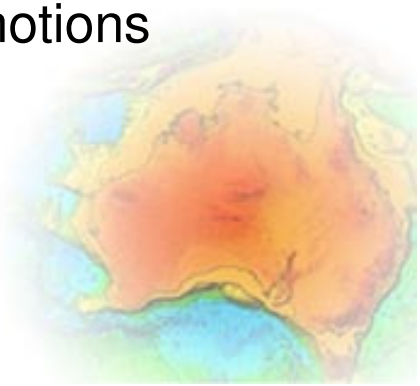
$$P_{21}^c = 3\sin\delta\cos\delta\sin\alpha$$

$$P_{21}^s = 3\sin\delta\cos\delta\cos\alpha$$

$$P_{22}^c = 3\cos^2\delta\sin 2\alpha$$

$$P_{22}^s = 3\cos^2\delta\cos 2\alpha$$

- Pyne et al (1996), Gwinn et al. (1997) argued that gravitational waves would cause the systematic in the radio source proper motions
- Kinematic interpretation



Kinematic interpretation

$$e_{11} = e_{22} = e_{33} = H$$

$$V = Hr$$

$$\mu_\alpha = 0$$

$$\mu_\delta = 0$$

The Hubble law

$$e_{11} \neq e_{22} \neq e_{33}$$

$$V = H(\alpha, \delta)r$$

$$\mu_\alpha \neq 0$$

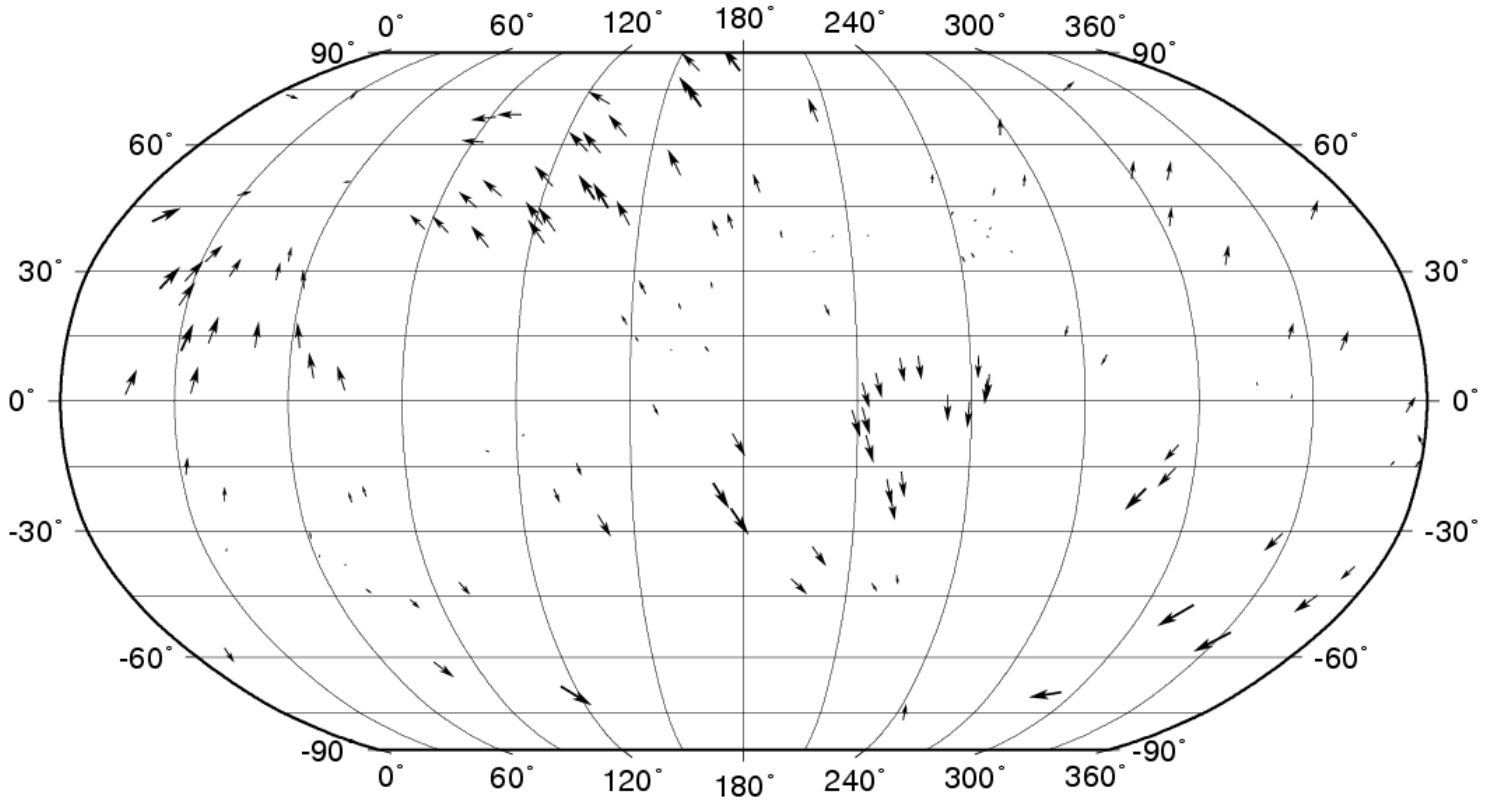
$$\mu_\delta \neq 0$$

Anisotropy and non-zero systematic

Global VLBI solutions (second term)

ICRF	List by Feissell-Vernier	z<1, not 'unstable'	z>1, not 'unstable'
212 ICRF (NNR) 102 as local	199 'stable' (NNR) 163 as local	172 'close' and not 'unstable' (NNR) 1895 as local	150 'distant' and not 'unstable' (NNR) 1917 as local
P(20) = 7.7 +/- 2.3 P(21) = 8.6 +/- 1.0 P'(21)= -2.1 +/- 1.0 P(22) = 1.1 +/- 0.6 P'(22) = -3.0 +/- 0.5	P(20) = 1.3 +/- 2.1 P(21) = 3.9 +/- 0.9 P'(21)= -1.7 +/- 0.9 P(22) = -0.1 +/- 0.5 P'(22) = -0.2 +/- 0.5	P(20) = 1.4 +/- 2.5 P(21) = 2.9 +/- 1.2 P'(21)= -2.8 +/- 1.2 P(22) = -1.4 +/- 0.8 P'(22) = 1.6 +/- 0.7	P(20) = 6.4 +/- 2.8 P(21) = 8.2 +/- 1.5 P'(21)= -8.2 +/- 1.6 P(22) = 4.4 +/- 0.9 P'(22) = -1.2 +/- 0.9

All units - μas/year



Calculated systematic for 150 ‘distant’ radio sources in (α,δ)

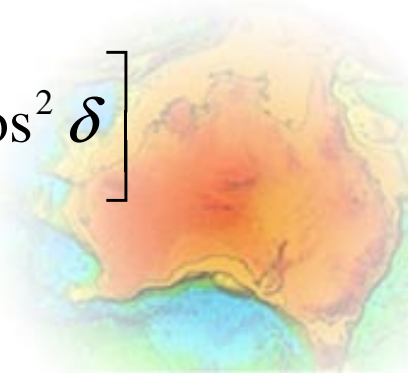
Anisotropy from VLBI and HST

Some evidence of the Hubble parameter anisotropy was found by SNI measurements (McClure and Dyer, 2007).

$$(e_{11}-e_{22}) \quad e_{33}-0.5(e_{11}+e_{22})$$

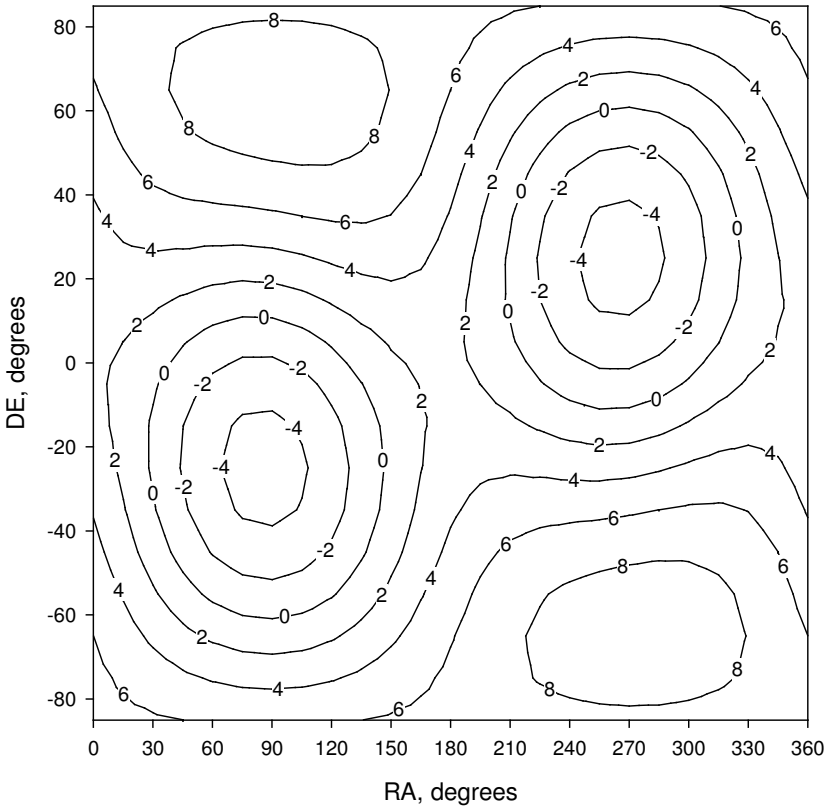
$$\tau \rightarrow (\mu) \rightarrow \left\{ \begin{matrix} e_{11}-e_{22} \\ e_{33}-0.5(e_{11}+e_{22}) \end{matrix} \right\} \rightarrow \Delta H(\alpha,\delta)$$

$$\Delta H = \left[(e_{33} - \frac{1}{2}(e_{11}+e_{22}))\sin^2\delta + \frac{1}{2}(e_{11}-e_{22})\cos 2\alpha \cos^2\delta \right]$$

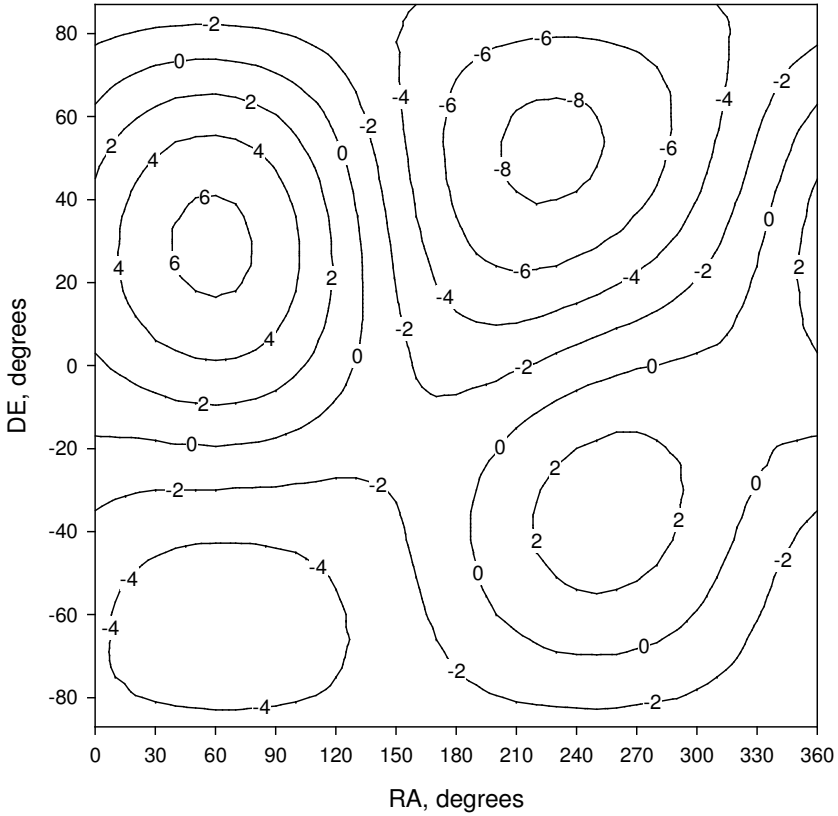


Anisotropy from VLBI and SNI data (HST)
km/sec·Mpc

Anisotropy from VLBI

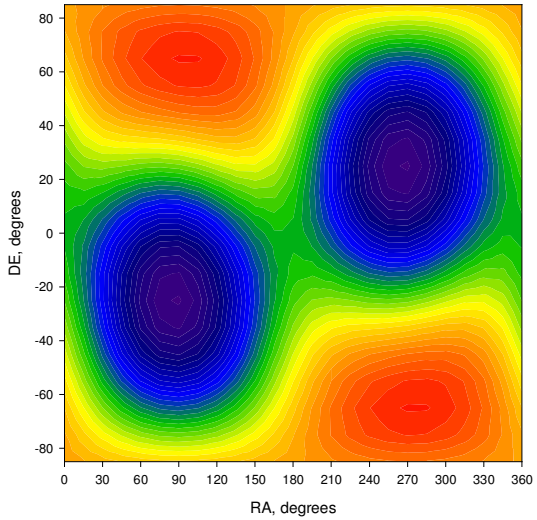


Anisotropy from HST data (76 points)

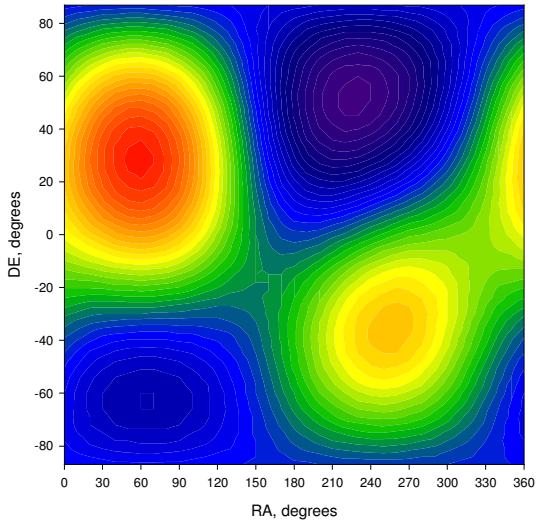


Anisotropy from VLBI and SNI data (km/sec·Mpc)

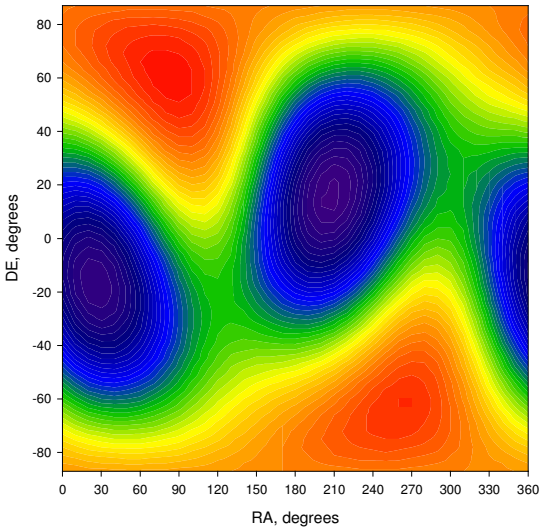
Anisotropy from VLBI



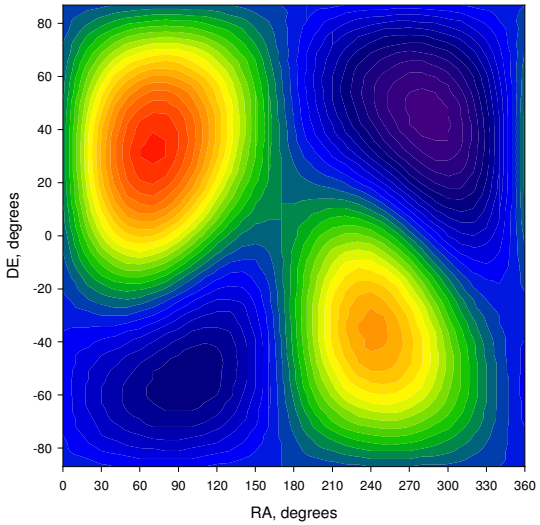
Anisotropy from HST data (76 points)

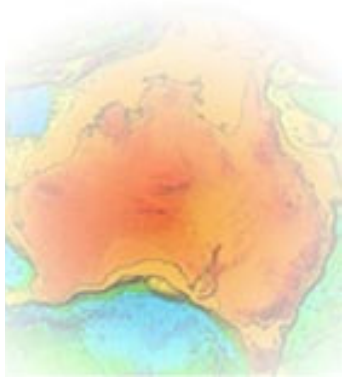


Comparison data (57 points)



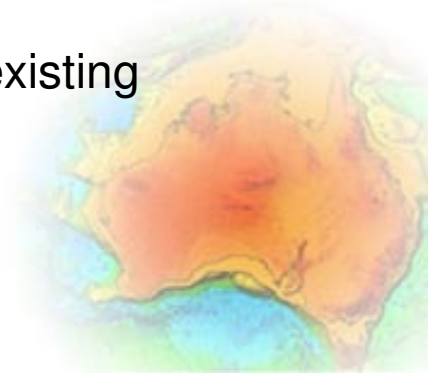
Anisotropy from all SNI data (133 points)





Conclusion

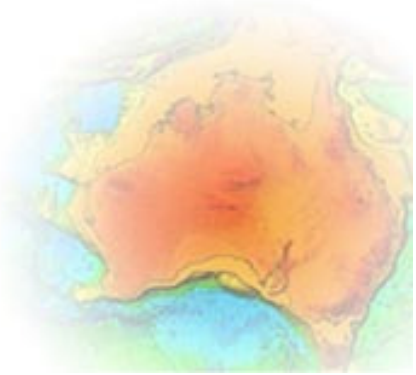
- Secular aberration drift ~25 μas/year has been indicated. Expected systematic (due to the Galaxy rotation) < 5 μas/year;
- Presumably, due to anomalous acceleration of the Solar system barycentre ~ 10^{-12} km/sec². Origin is unknown;
- The anisotropy of the Universe expansion induces the systematic proper motion and the Hubble constant anisotropy (12 km/sec*Mpc or 2.5 μas/year)
- Independent verification is very important (another software)
- More data wanted – new radio sources and new redshifts of existing sources



Conclusion

- Geodetic VLBI has a strong scientific potential even on the existing level of technology, and not limited by the traditional applications (geodesy and astrometry), but also cosmology

- Measure the Big Bang parameters



Thank you!