Australian Government
Geoscience Australia

How to use geodetic VLBI to measure relativistic light deflection from extragalactic objects

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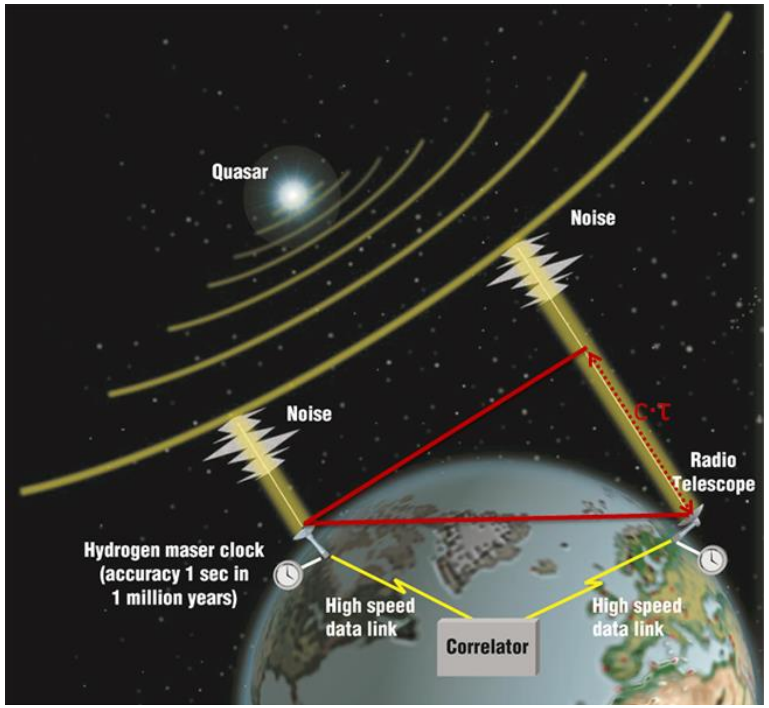
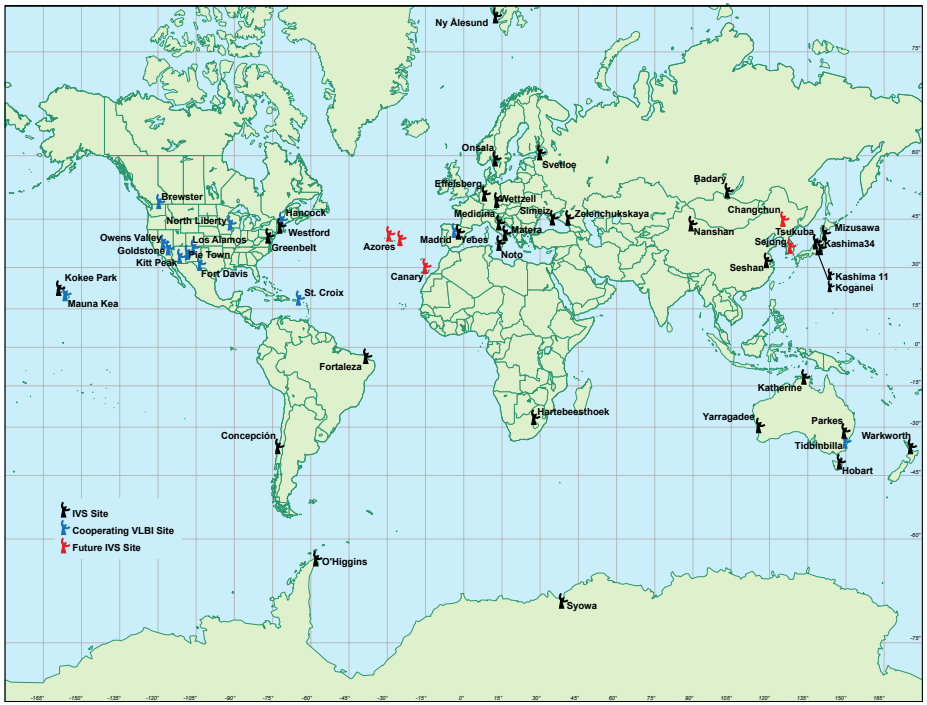
General relativity

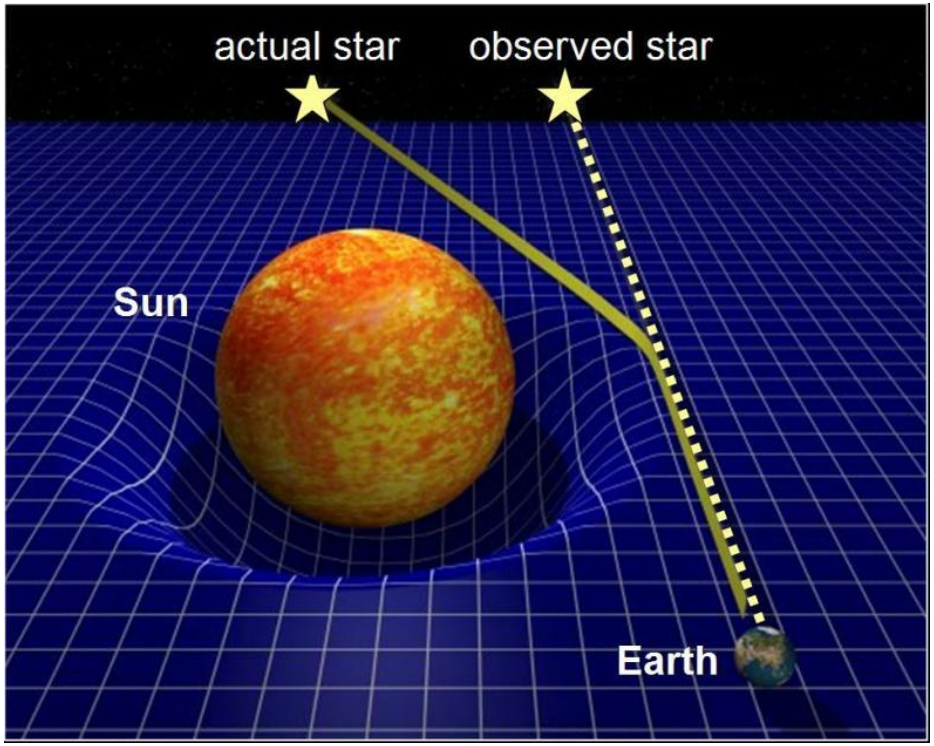




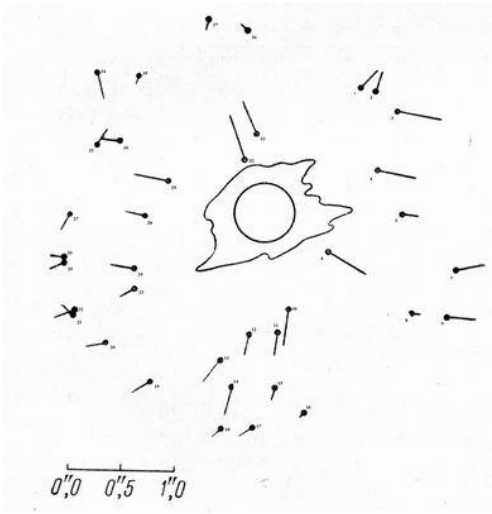
$$\tau_{GR} = \tau_{grav} + \tau_{coord} = \frac{2GM}{c^3} \ln \frac{|\boldsymbol{r}_1| + (\boldsymbol{r}_1 \cdot \boldsymbol{s})}{|\boldsymbol{r}_2| + (\boldsymbol{r}_2 \cdot \boldsymbol{s})} + \frac{(\boldsymbol{b} \cdot \boldsymbol{s})}{c} \frac{2GM}{c^2 r} = \alpha \frac{b}{c} \sin\varphi \cos A$$

Gravitational delay (difference of two Shapiro delays) is linked to deflection angle

General relativity – light bending



Special expeditions to observe total Solar eclipses since 1919

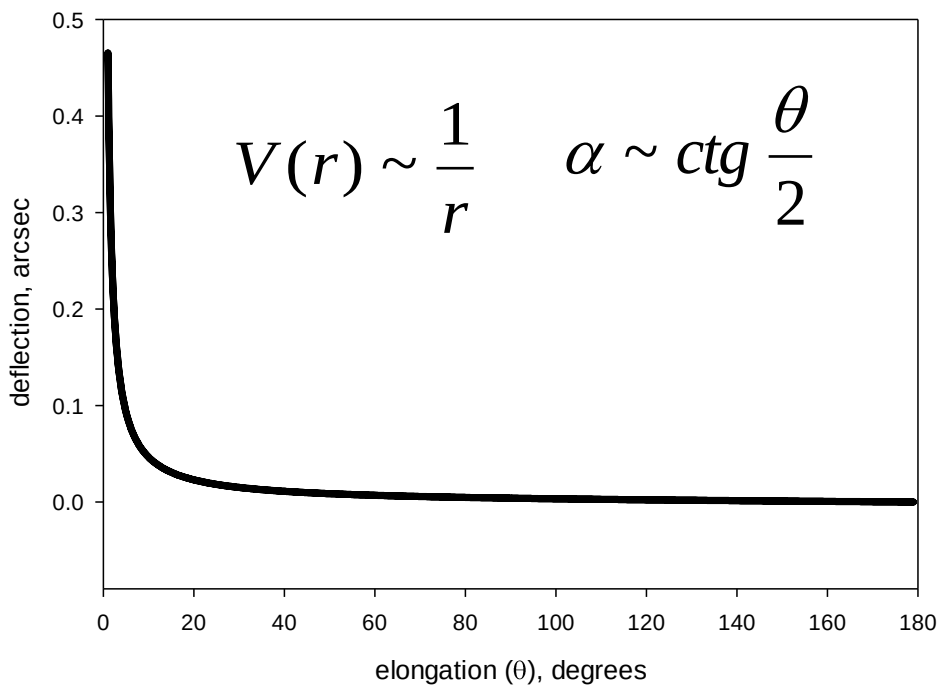


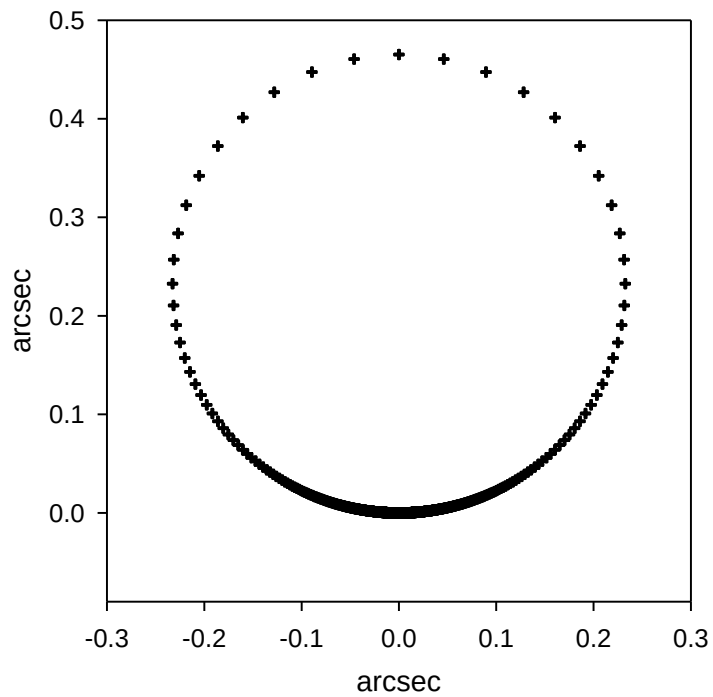
Now VLBI is doing it every session!

Light deflection in VLBI

$$\alpha = \frac{4GM}{c^2 R}$$ at the small angle approximation, Einstein (1915)

$$\alpha = \frac{2GM}{c^2 R}\frac{\sin\theta}{1-\cos\theta}$$ Shapiro, Science, (1967); Ward, ApJ, (1970)

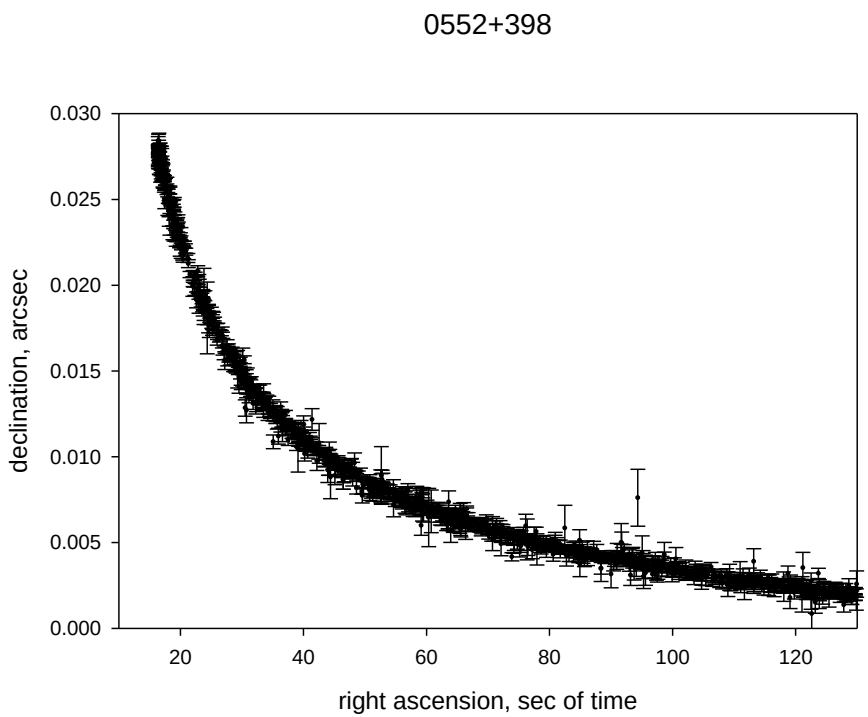


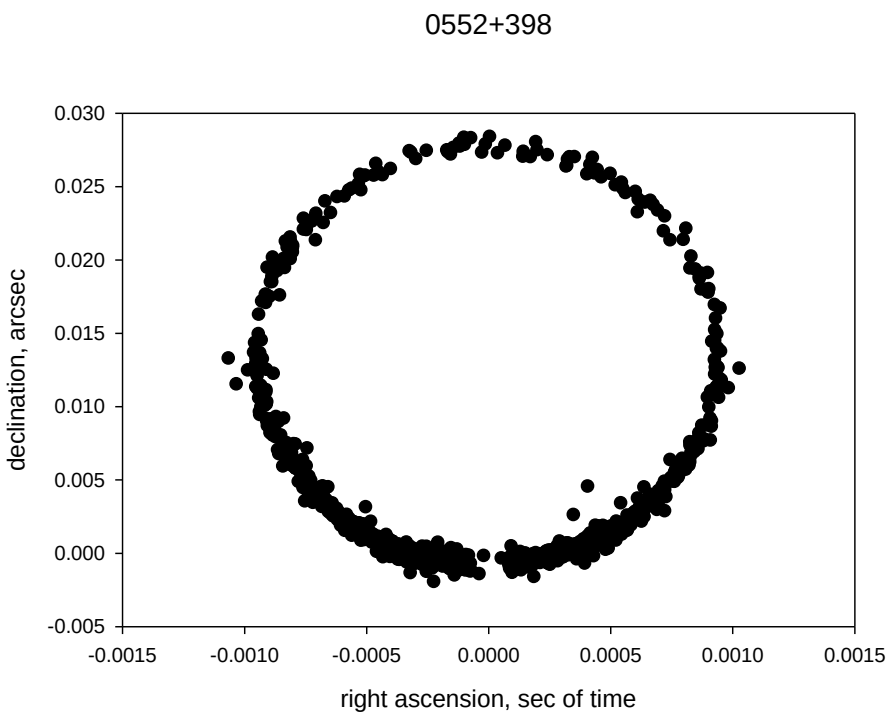


For a radio source within 1° from Sun

Light deflection angle 0552+398

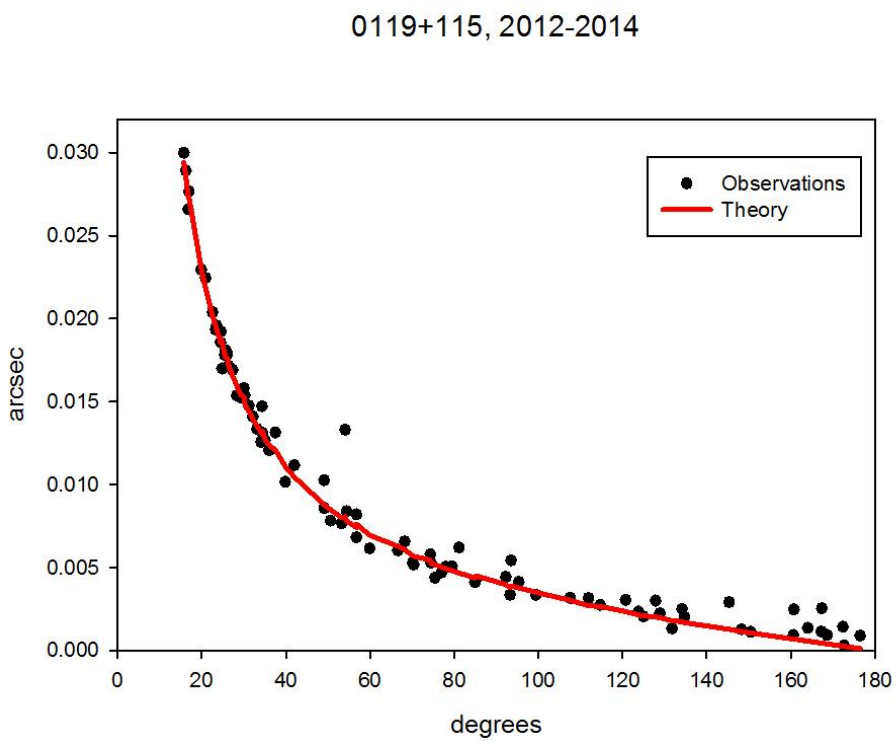
$$\alpha = \frac{2GM}{c^2 R} \frac{\sin\theta}{1-\cos\theta}$$

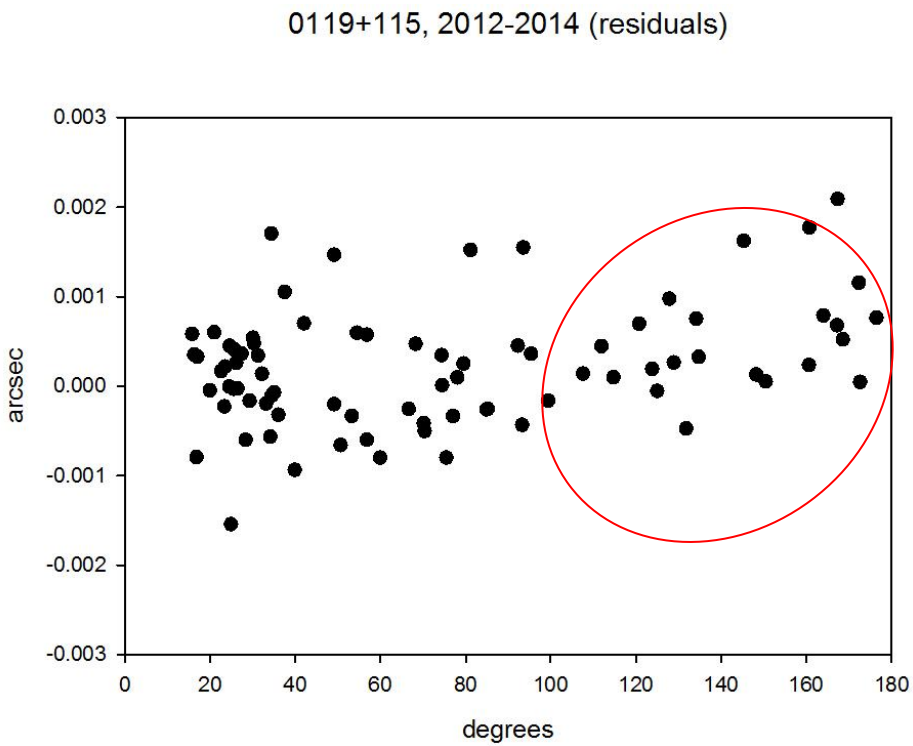




Real data, 1991-2001, each session, each radio source

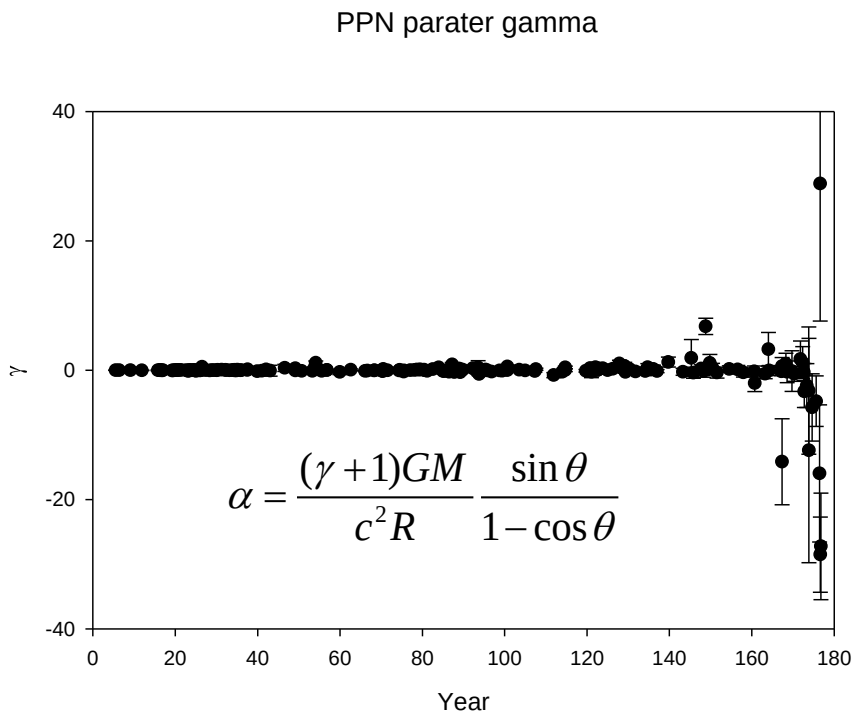
Deflection residuals *0119+115* 2012-2014

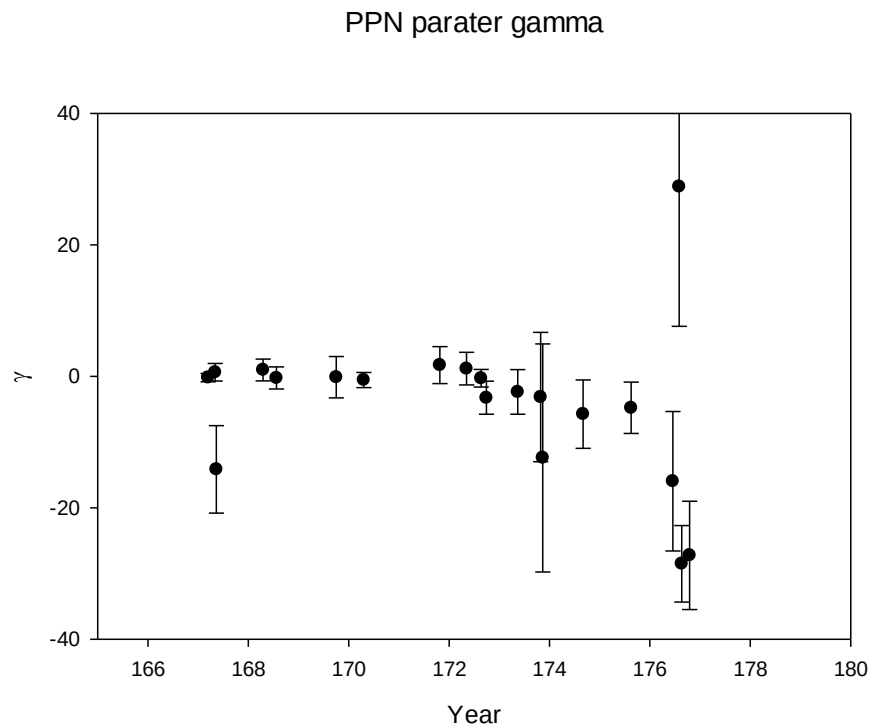




Residuals are positive at large elongation angles!

Deflection residuals *0119+115* 2011-2014





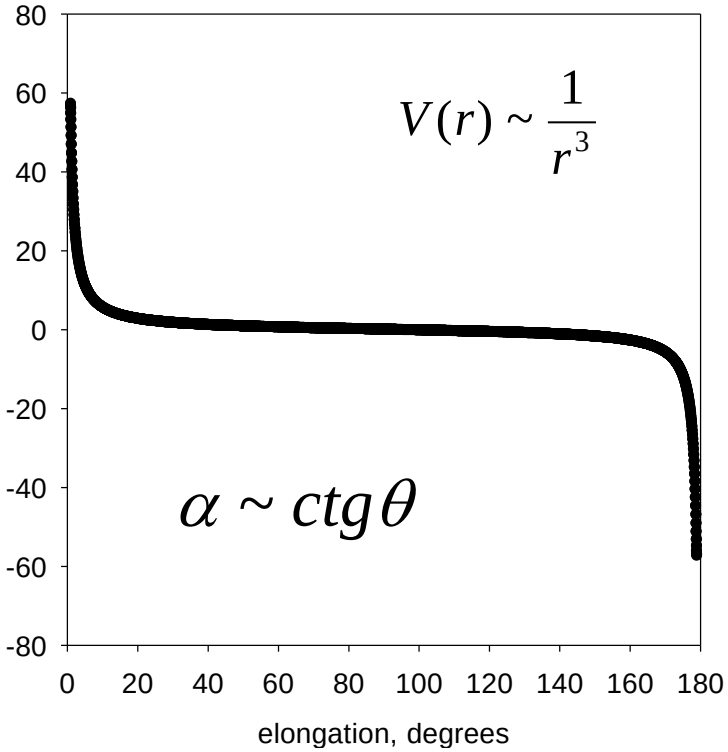
$$\Delta\gamma = \Delta\alpha \frac{c^2 r}{GM} \frac{1-\cos\theta}{\sin\theta}$$

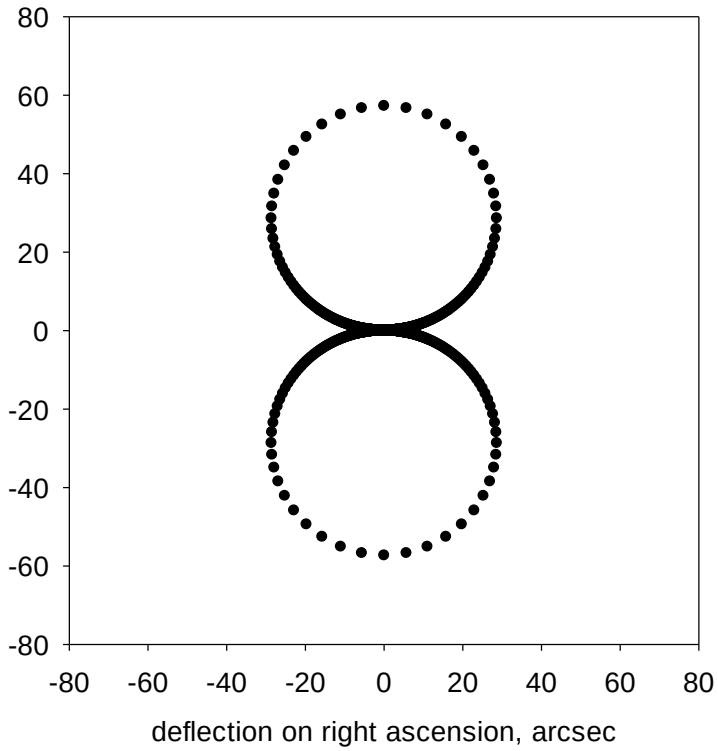
Two estimates $\Delta\gamma$ = -27 +/- 8 and -28 +/- 5 within 4 degrees from the anti Solar point

Brane world gravity

Randall and Sundrum (hep-th 9906064,1999); Rubakov, UFN, (2001)

$$V(r) = -\frac{G_{(4)}}{r}\left(1 + \frac{\text{const}}{k^2 r^2}\right).$$





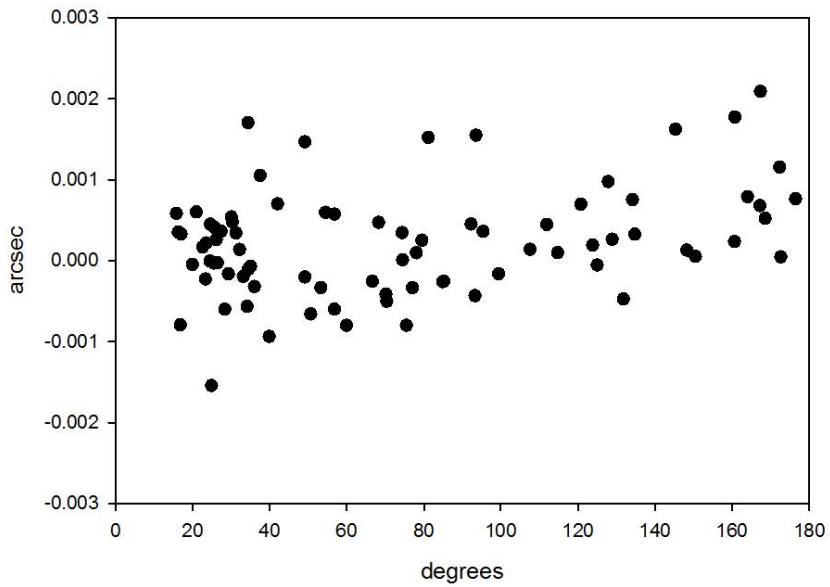
For a radio source within 1° from Sun, magnitude is conditional

Expected change in coordinates

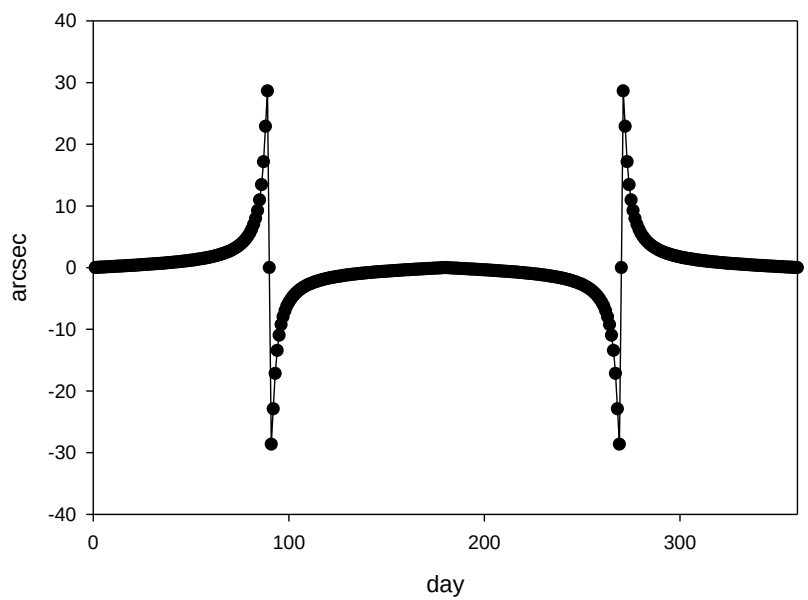
$$V(r) = -\frac{G_{(4)}}{r}\left(1 + \frac{\text{const}}{k^2 r^2}\right).$$

$$\alpha \sim ctg\,\theta$$

0119+115, 2012-2014 (residuals)



Correction to right ascension



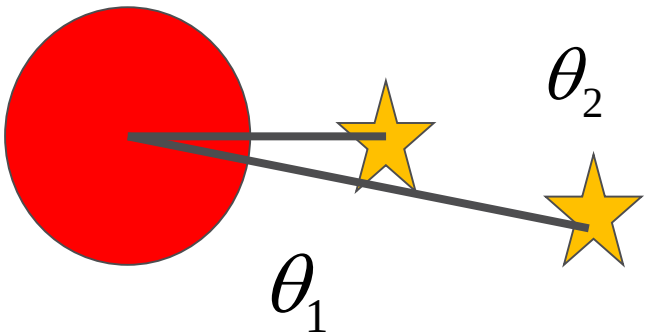
List of quasars within 0°.1 from ecliptic

0055+060	0°.075	
0547+234	0.025	
0558+234	-0.023	
0603+234	0.049	
0723+219	-0.070	
0725+219	-0.00187	**7”**
0741+214	0.075	
0749+211	0.076	
0956+124	-0.095	
1226-028	0.012	
1346-109	0.062	
1437-153	0.036	
1907-224	0.045	
2243-081	-0.065	
2322-040	0°.008	~25”

11 Jan 2016

Secondary deflection angle (two telescopes)

$$\Delta\theta = \theta_2 - \theta_1 \sim b / r \sim 8''$$



$$\alpha_1 = \frac{4GM}{c^2 R_1} \qquad \alpha_2 = \frac{4GM}{c^2 R_2}$$

$$\alpha'' = \alpha_2 - \alpha_1 \sim \frac{4GMb}{c^2 R^2}$$

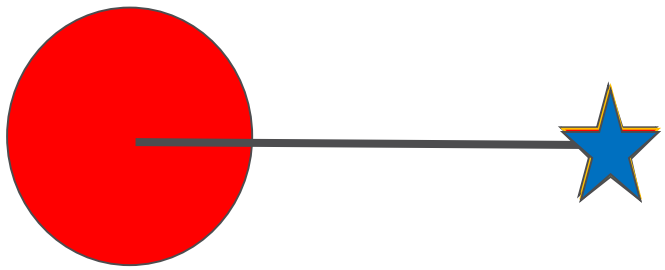
R (km)	α	α'',
		b=10000 km
700,000 (grazing light, 0°.25)	1".75	0".00125
$2.8 \cdot 10^6$ (1°)	0".45	0".00078
$5.6 \cdot 10^6$ (2°)	0".22	0".00019
$15 \cdot 10^6$ (5°)	0".09	0".00003

Depends on baseline length!

Light deflection at two-telescope observations

$$\Delta\theta = \theta_2 - \theta_1 \sim b / r \sim 8''$$

$$\alpha_1 = \frac{4GM}{c^2 R_1} \qquad \alpha_2 = \frac{4GM}{c^2 R_2}$$



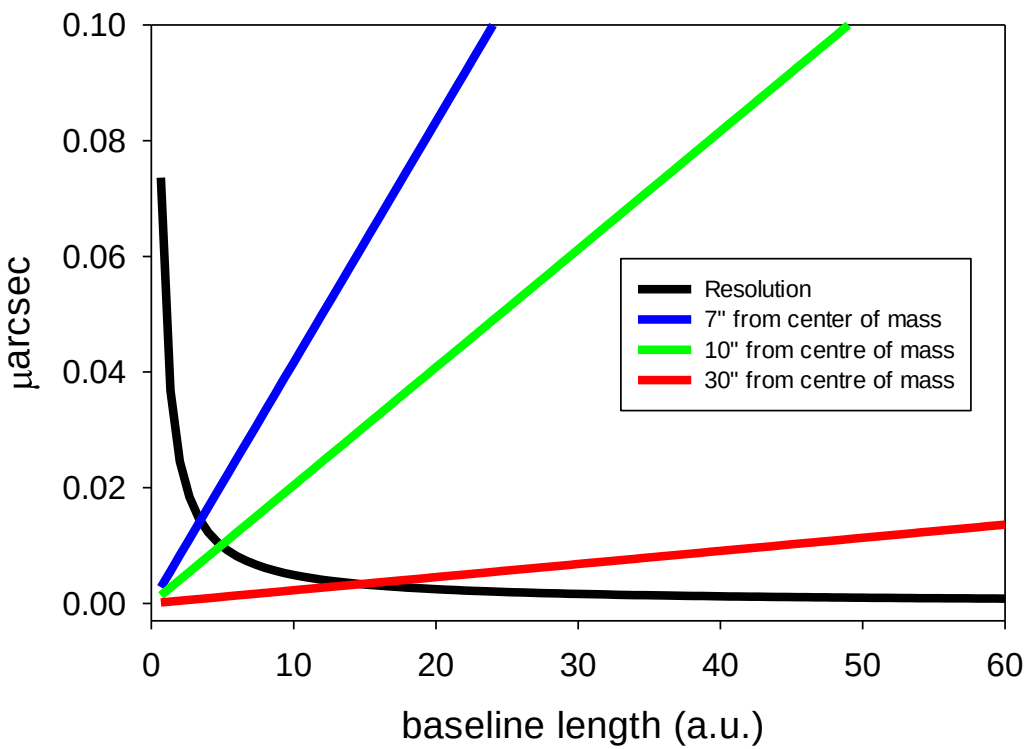
$$\alpha'' = \alpha_2 - \alpha_1 \sim \frac{2GMb}{c^2 R^2}$$

$$\alpha'' = \frac{2GMb}{c^2 R^2} \frac{\sin\varphi \cos 2A}{\cos A}$$

Each baseline produces own deflected image

Secondary deflection angle with space VLBI

M = 10^12 Solar Mass, b ~10+ au, r ~ 1 Gpc



$$\alpha \sim \frac{\lambda}{b}$$

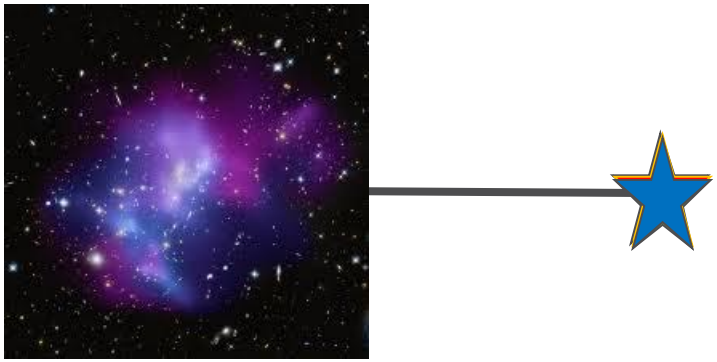
$$\alpha = \frac{4GM}{c^2 R}$$

$$\alpha'' = \frac{2GMb}{c^2 R^2} \frac{\sin\varphi \cos 2A}{\cos A}$$

b, A, φ - variable

Light deflection at two-telescope observations

Distant galaxy with unknown mass is observed with several very long baselines



Remote mass could be estimated instantly

$$\alpha'' = \frac{2GMb}{c^2R^2}\frac{\sin\varphi\cos 2A}{\cos A}$$

Any Questions?

Thank you for your attention!

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