Australian Government
Geoscience Australia

Application of the AOV network for radio source data production

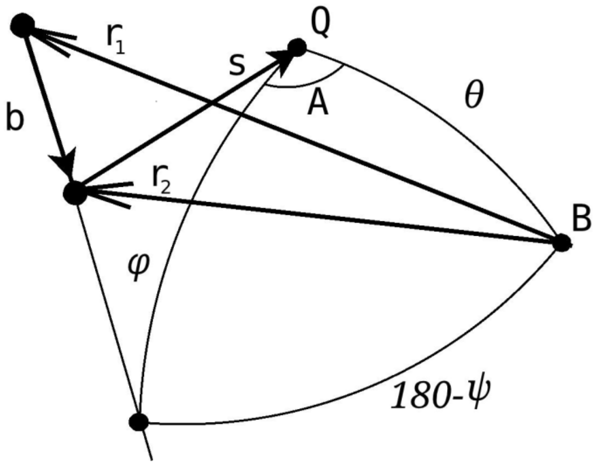
Oleg Titov (Geoscience Australia)

APPLYING GEOSCIENCE TO AUSTRALIA'S MOST IMPORTANT CHALLENGES

Outline

1. Structure delay
2. Modelling
3. Radio source astrometry
4. Technology impact
5. Asia Oceania VLBI opportunities
6. General relativity experiments

General Relativity (Titov, Girdiuk, 2015)



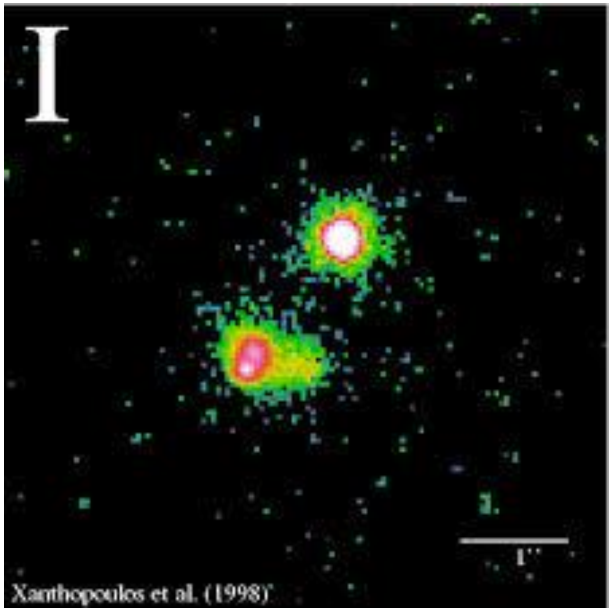
$$\tau_{GR} = \alpha \frac{b}{c} \sin\varphi \cos A$$

Any positional offset results in extra time delay

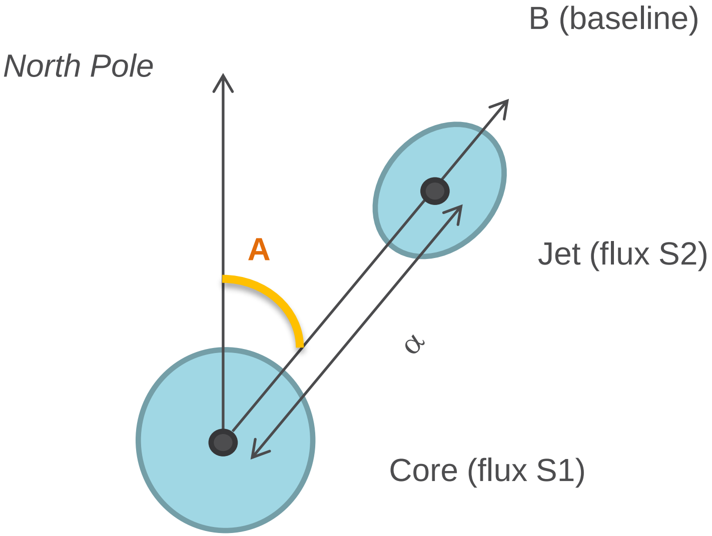
α - light deflection; τ – group delay

Structure delay

no difference with the GR effect



Xanthopoulos et al. (1998)



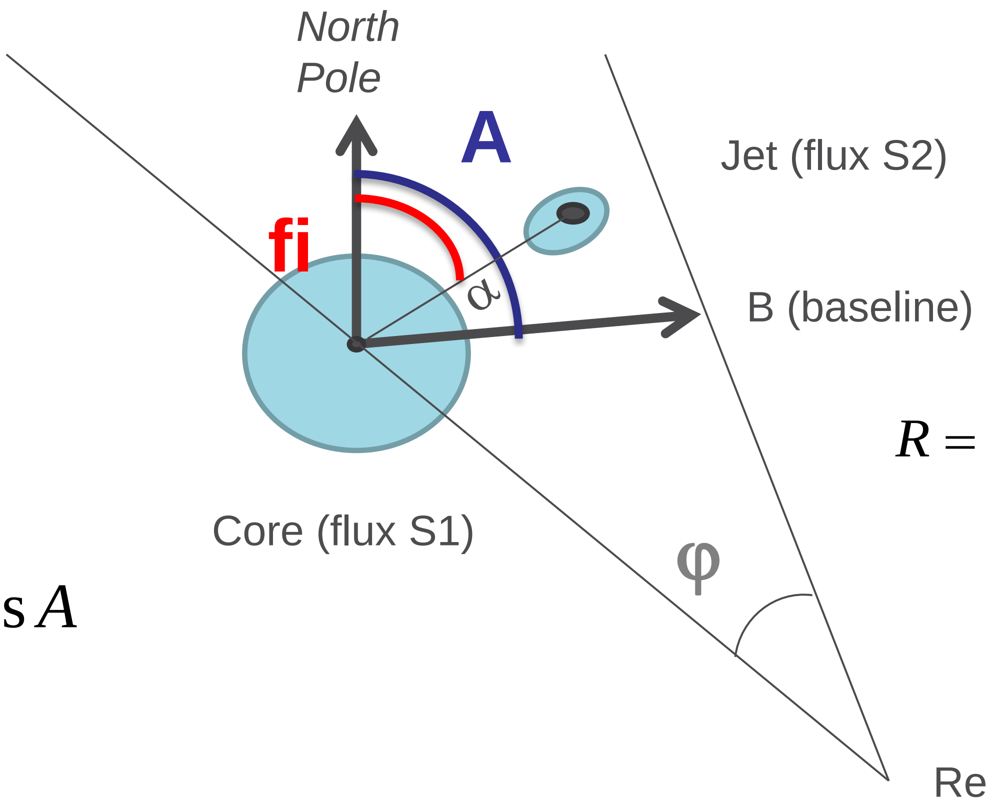
$$\tau = \alpha \frac{b}{c} \sin \varphi \cos A$$

Modeling (Charlot, AJ, 1990)

B – baseline length

λ – wavelength

ω – frequency



$$K = \frac{S_2}{S_1}$$

$$R = \frac{B\alpha}{\lambda}\cos(A + fi)$$

$$\tau = \alpha \frac{b}{c} \sin\varphi \cos A$$

$$\tau_{str} = \frac{2\pi K(1-K)}{\omega(1+K)} \frac{[1-\cos(2\pi R)]R}{K^2 + 2K\cos(2\pi R) + 1}$$

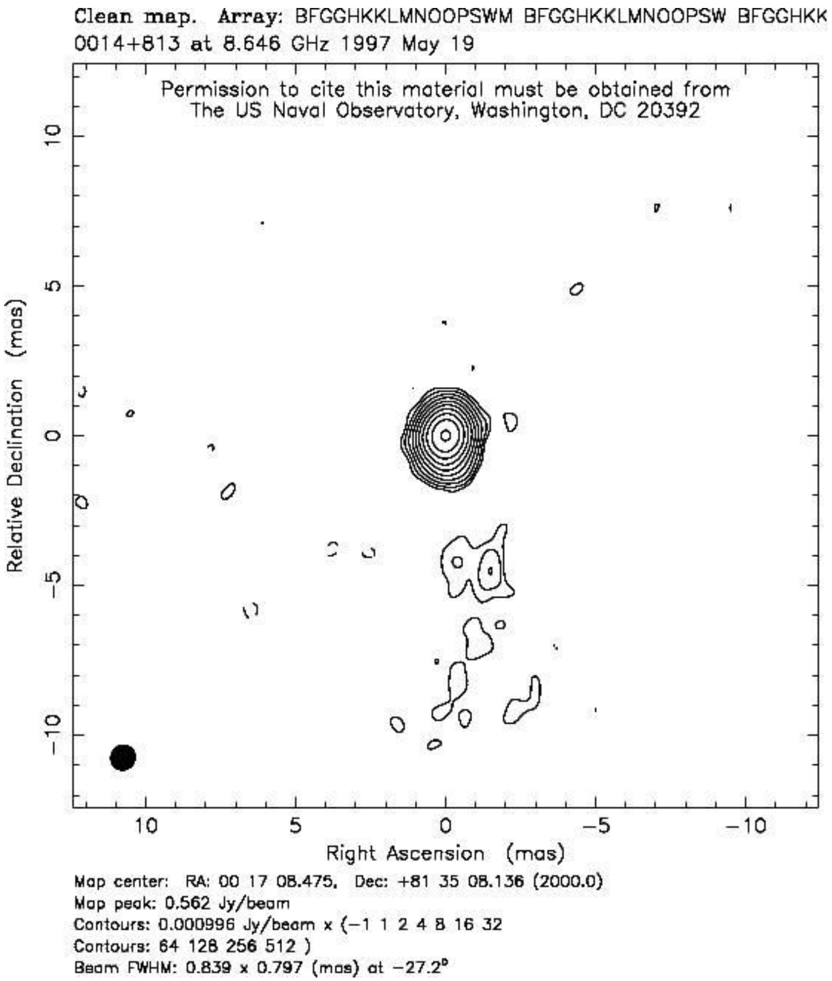
$$\tau_{str} = \frac{K(\alpha_1 - \alpha_2)}{\omega} \frac{\sin(2\pi R)}{K^2 + 2K\cos(2\pi R) + 1}$$

CONT'14 – many "unstable" sources were observed

CONT'14, post-fit residuals of radio source 0014+813 (strong astrometrically unstable, many scans during the 15-day campaign)

Post-fit residuals after global adjustment may reveal a signal as a function of angle A

Radio source 0014+813 (VLBA image)


Clean map. **Array:** BFGGHKKLMNOOPSWM BFGGHKKLMNOOPSW BFGGHKK
0014+813 at 8.646 GHz 1997 May 19

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The US Naval Observatory, Washington, DC 20392

Map center: RA: 00 17 08.475, Dec: +81 35 08.136 (2000.0)
Map peak: 0.562 Jy/beam
Contours: 0.000996 Jy/beam x (−1 1 2 4 8 16 32
Contours: 64 128 256 512)
Beam FWHM: 0.839 x 0.797 (mas) at −27.2°

This research has made use of the United States Naval Observatory (USNO) Radio Reference Frame Image Database (RRFID).

Radio source 0014+813 (Titov, 2007)

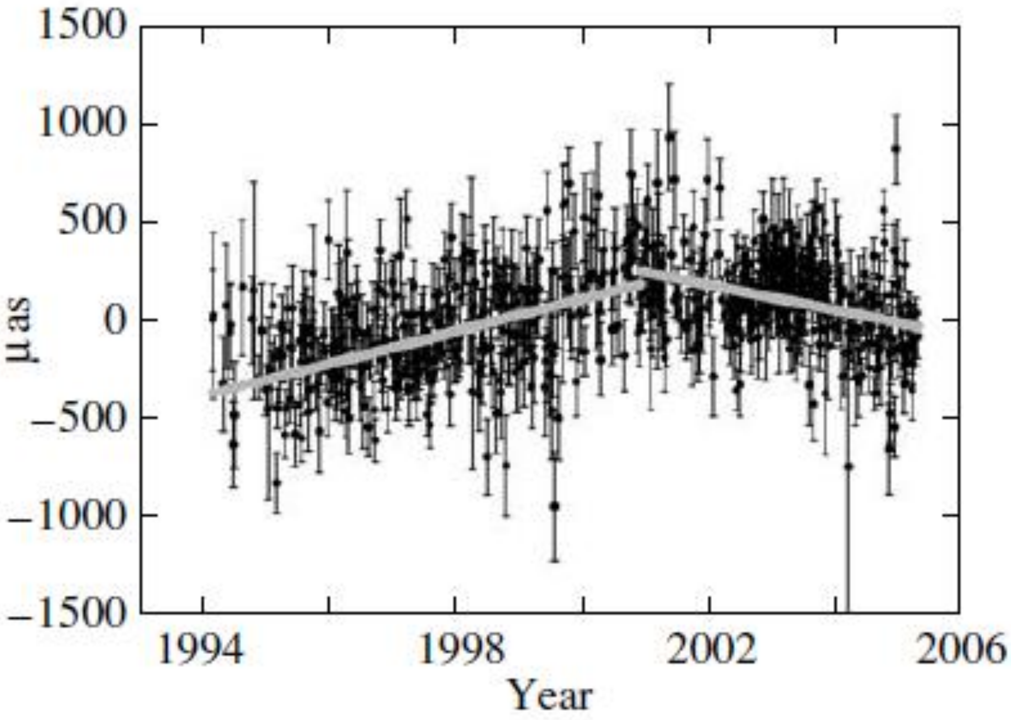
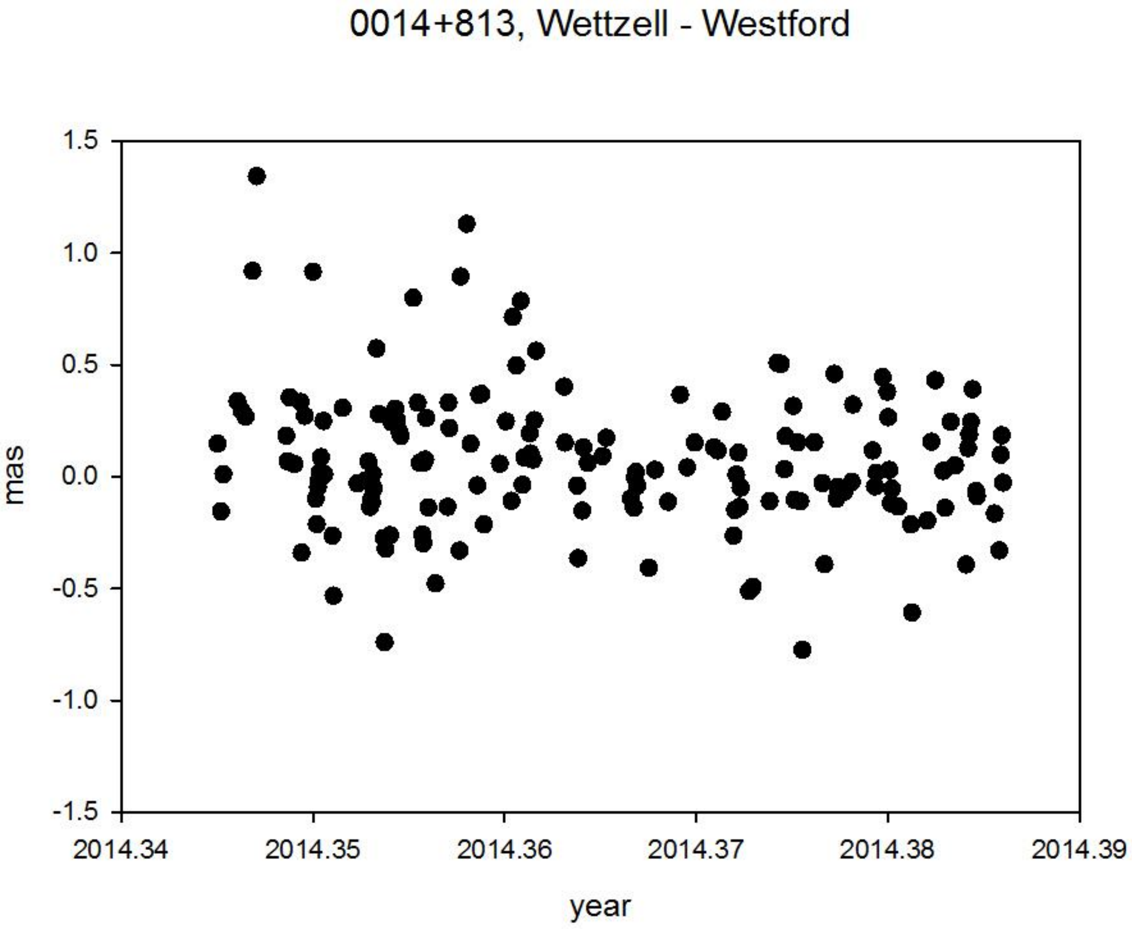


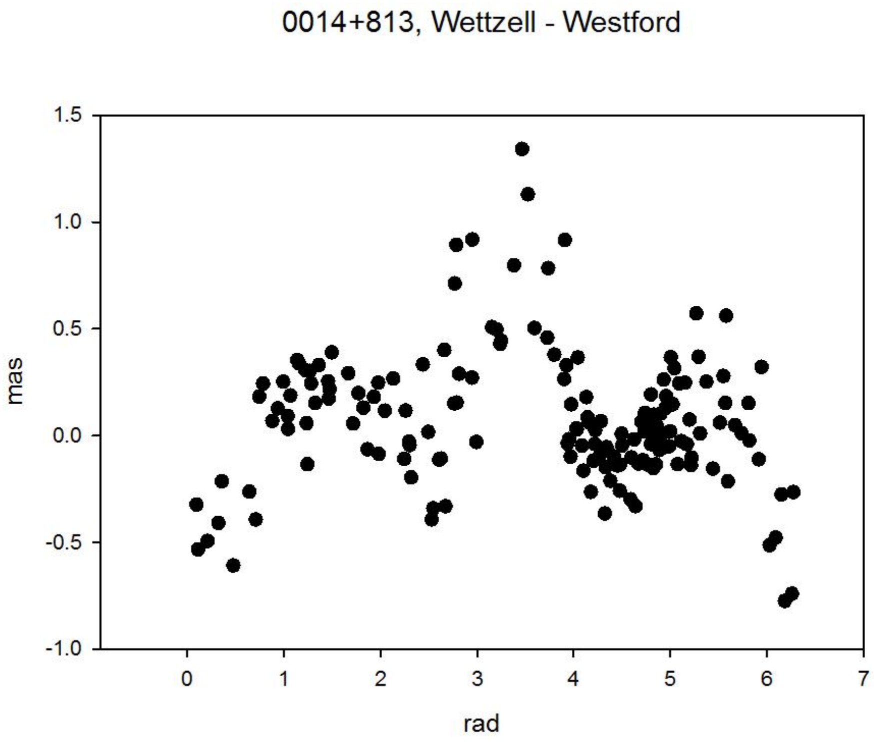
Fig. 3. Daily estimates of the coordinates for the quasar 0014+813 in declination and approximation by linear splines.

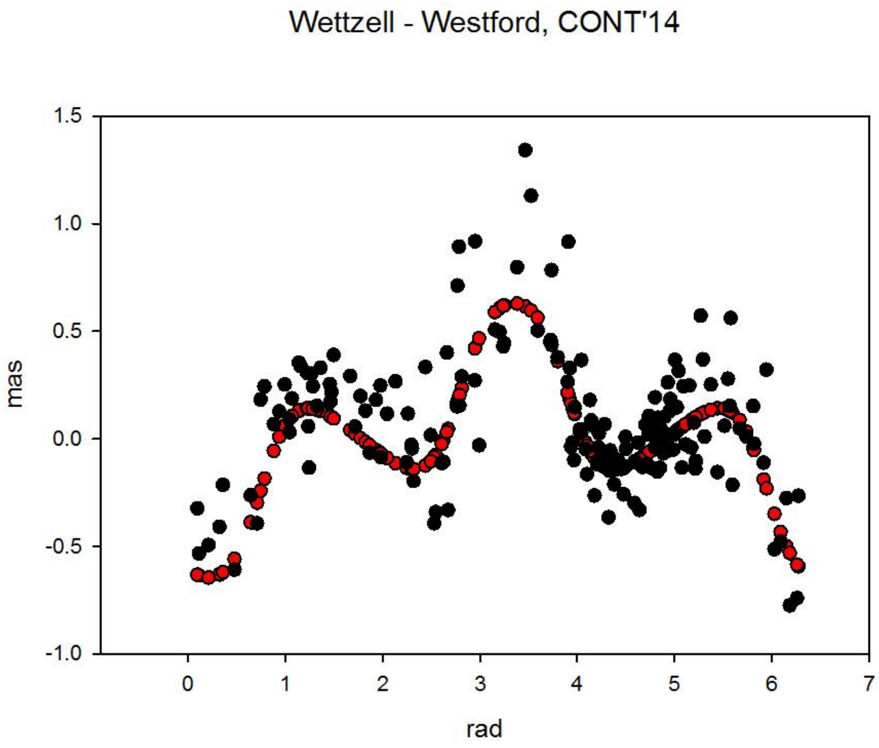
Post-fit residuals (0014+813) vs time



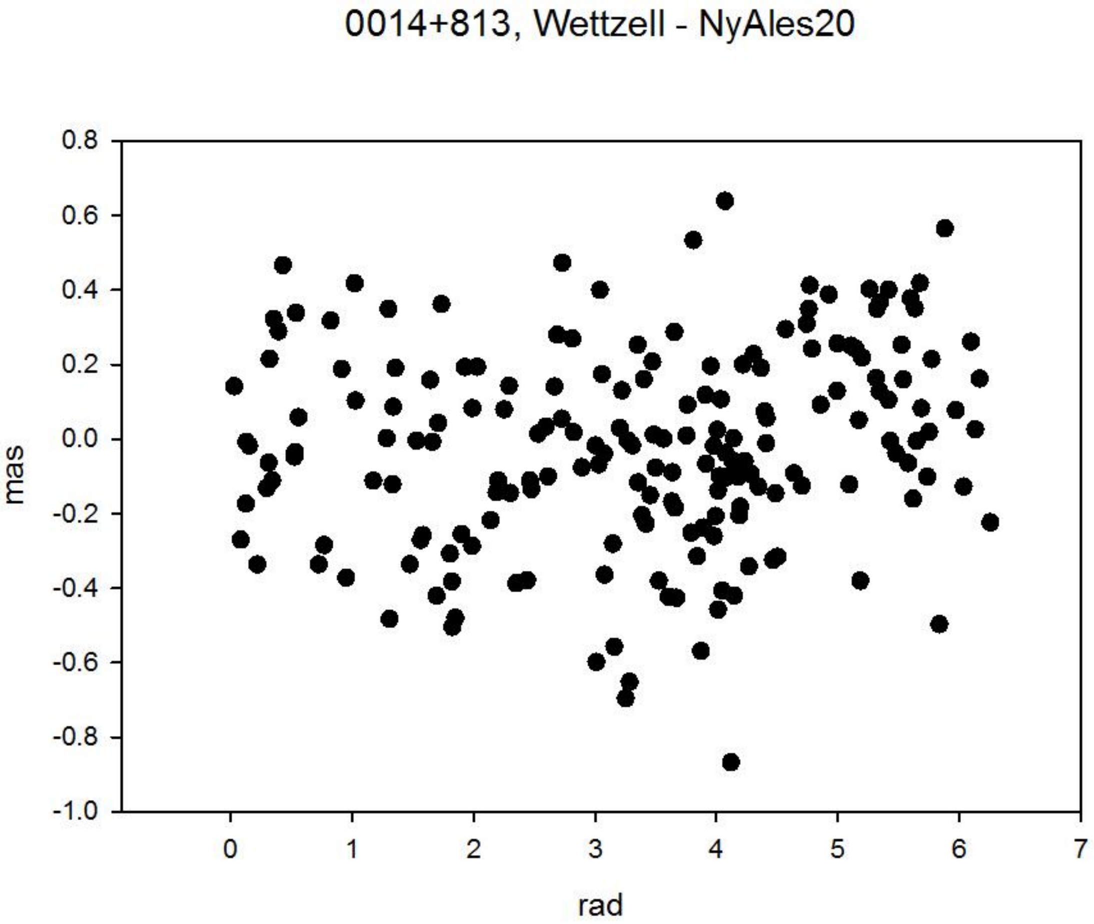
Short baselines do not reveal a signal!

Post-fit residuals (0014+813) vs A





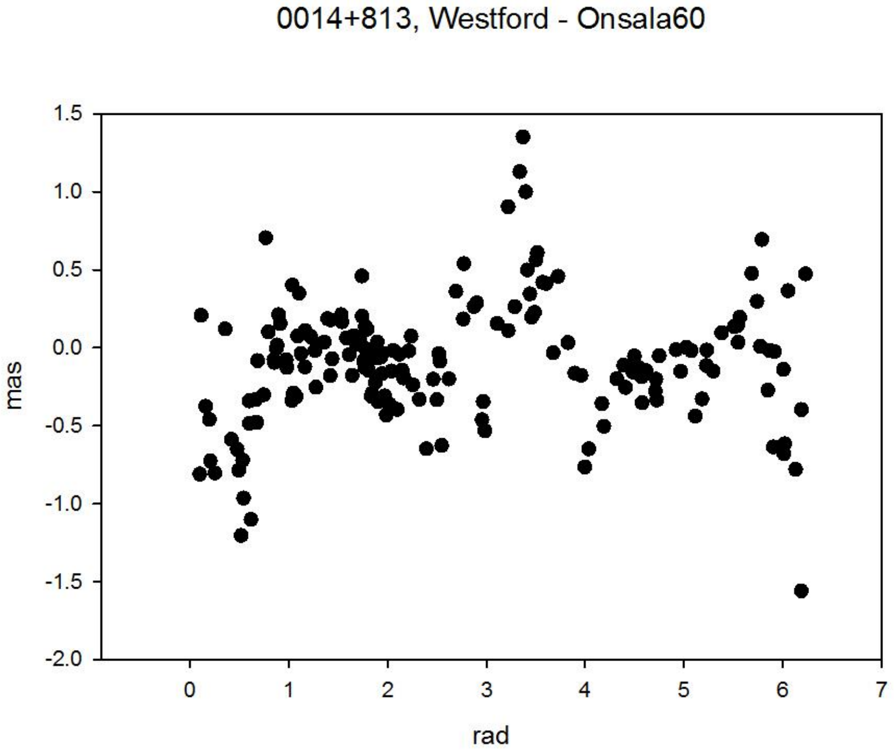
Post-fit residuals (0014+813) vs A

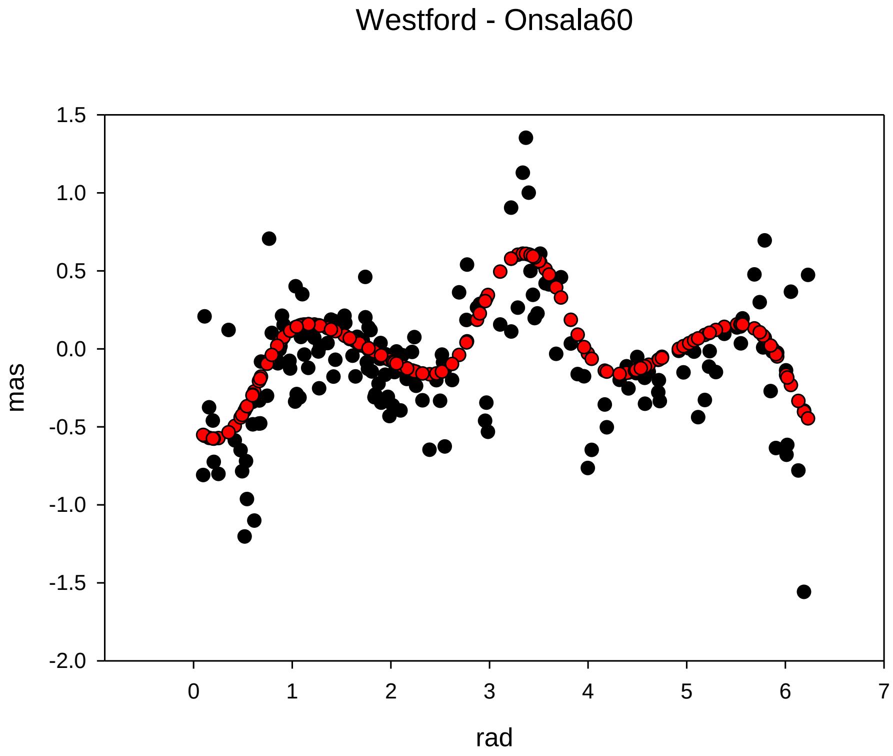


1 mas = 3 cm

Short baselines do not reveal a signal!

Post-fit residuals (0014+813) vs A





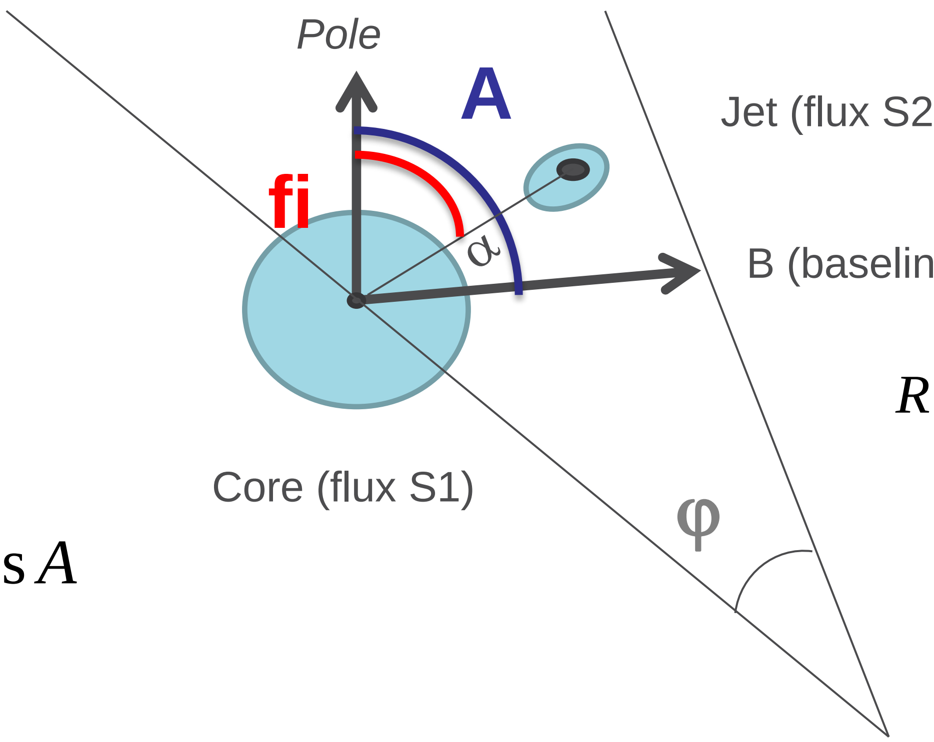
1 mas = 3 cm

Modeling (Charlot, AJ, 1990)

B – baseline length

λ – wavelength

ω – frequency



North Pole

Jet (flux S2)

B (baseline)

Core (flux S1)

Reference origin

$$K = \frac{S_2}{S_1}$$

$$R = \frac{B\alpha}{\lambda}\cos(A + fi)$$

$$\tau = \alpha\frac{b}{c}\sin\varphi\cos A$$

$$\tau_{str} = \frac{2\pi K(1-K)}{\omega(1+K)}\,\frac{[1-\cos(2\pi R)]R}{K^2 + 2K\cos(2\pi R) + 1}$$

$$\tau_{str} = \frac{K(\alpha_1 - \alpha_2)}{\omega}\,\frac{\sin(2\pi R)}{K^2 + 2K\cos(2\pi R) + 1}$$

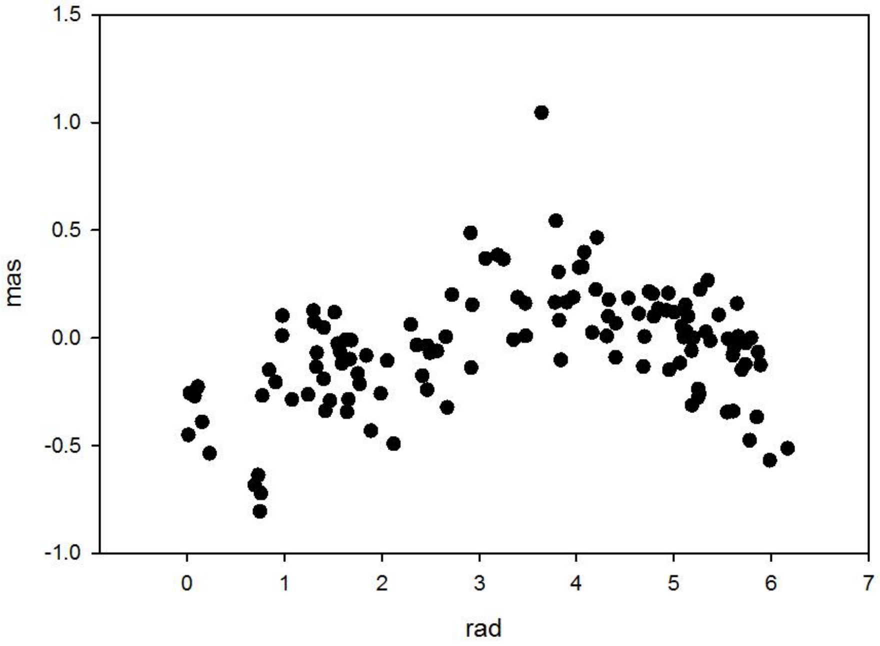
Modeling (two-component model)

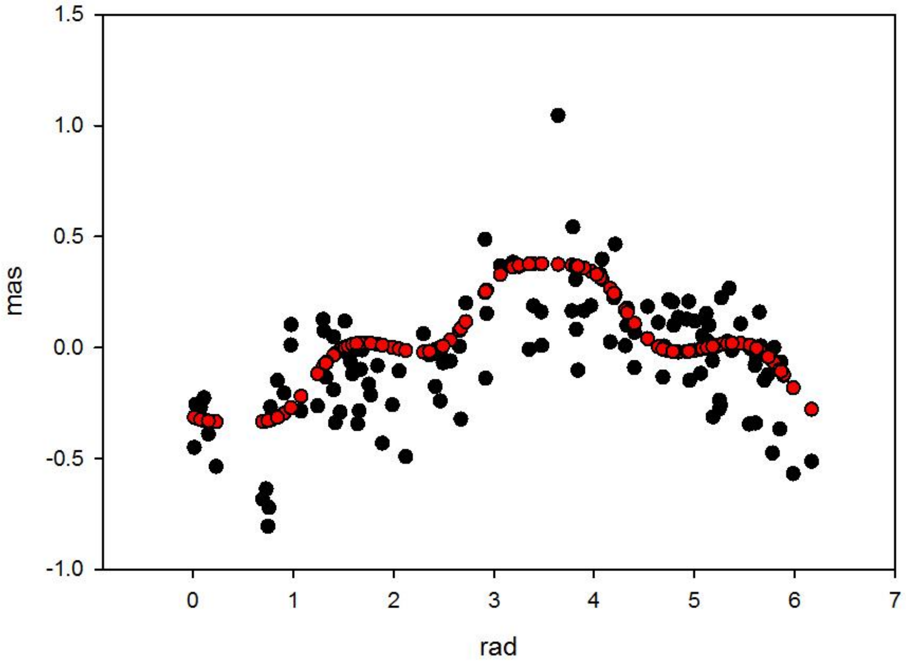
Baseline	R (mas)	K	Phase (degrees)	Stucture index, $\Delta\alpha$	Length (thousands km)
WESTFORD YEBES40M	0.60	0.40	164	-4.0	5377
WESTFORD ONSALA60	0.60	0.47	165	-2.6	5601
WETTZELL BADARY	0.55	0.33	175	-1.0	5726
WESTFORD WETTZELL	0.60	0.40	170	-2.8	5998
NYALES20 TSUKUB32	0.60	0.25	160	-1.0	6498
YEBES40M BADARY	0.60	0.30	170	-3.8	7079
ZELENCHK TSUKUB32	0.60	0.25	180	-5.0	7441
WESTFORD ZELENCHK	0.60	0.70	175	-2.1	7770
TSUKUB32 ONSALA60	0.55	0.85	175	-1.0	7940
WETTZELL TSUKUB32	0.40	0.47	175	-5.0	8445
WESTFORD BADARY	0.60	0.85	175	-4.2	8672
TSUKUB32 YEBES40M	0.40	0.55	185	-5.0	9510
WESTFORD TSUKUB32	0.40	0.62	170	-5.0	9506

R, phase stable

K, $\Delta\alpha$ - variable

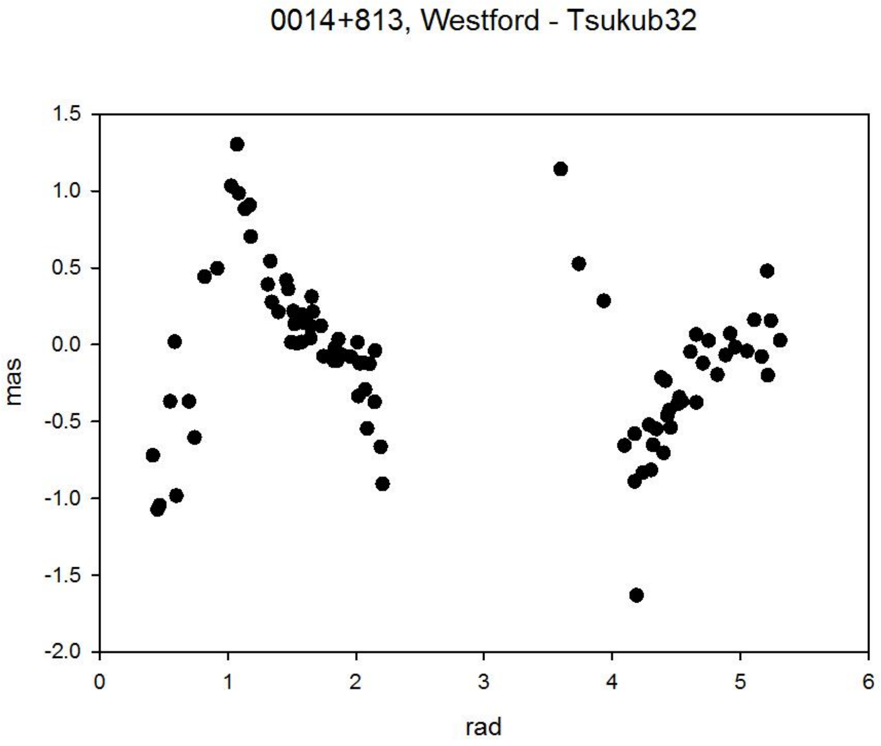
Post-fit residuals (0014+813) vs A

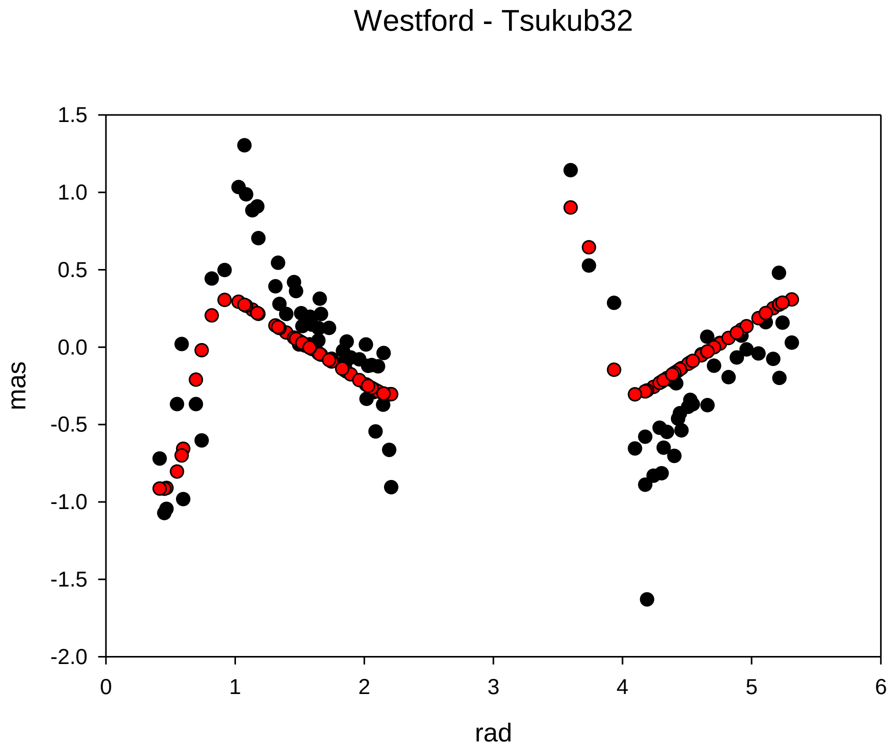

0014+813, Nyales20 - Tsukub32


Tsukub32 - Nyales20, CONT'14

1 mas = 3 cm

Post-fit residuals (0014+813) vs A

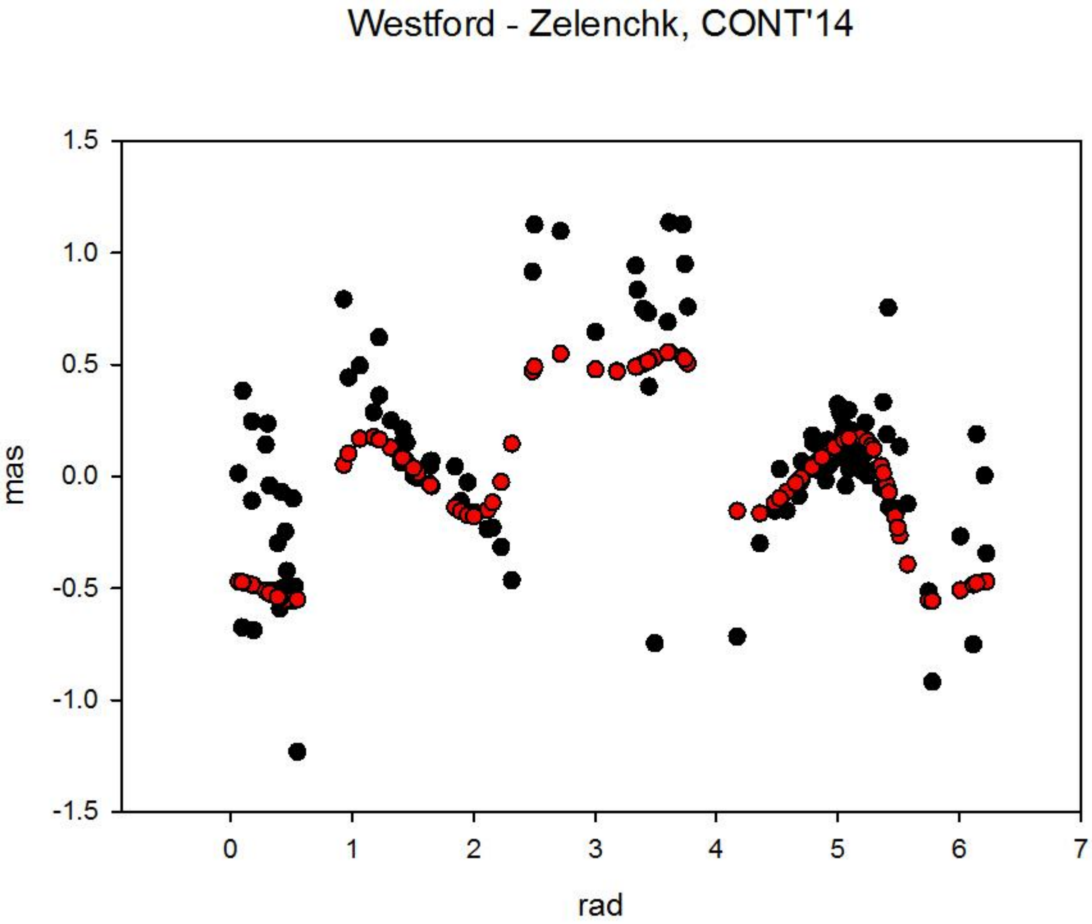




Spectral index difference is important!

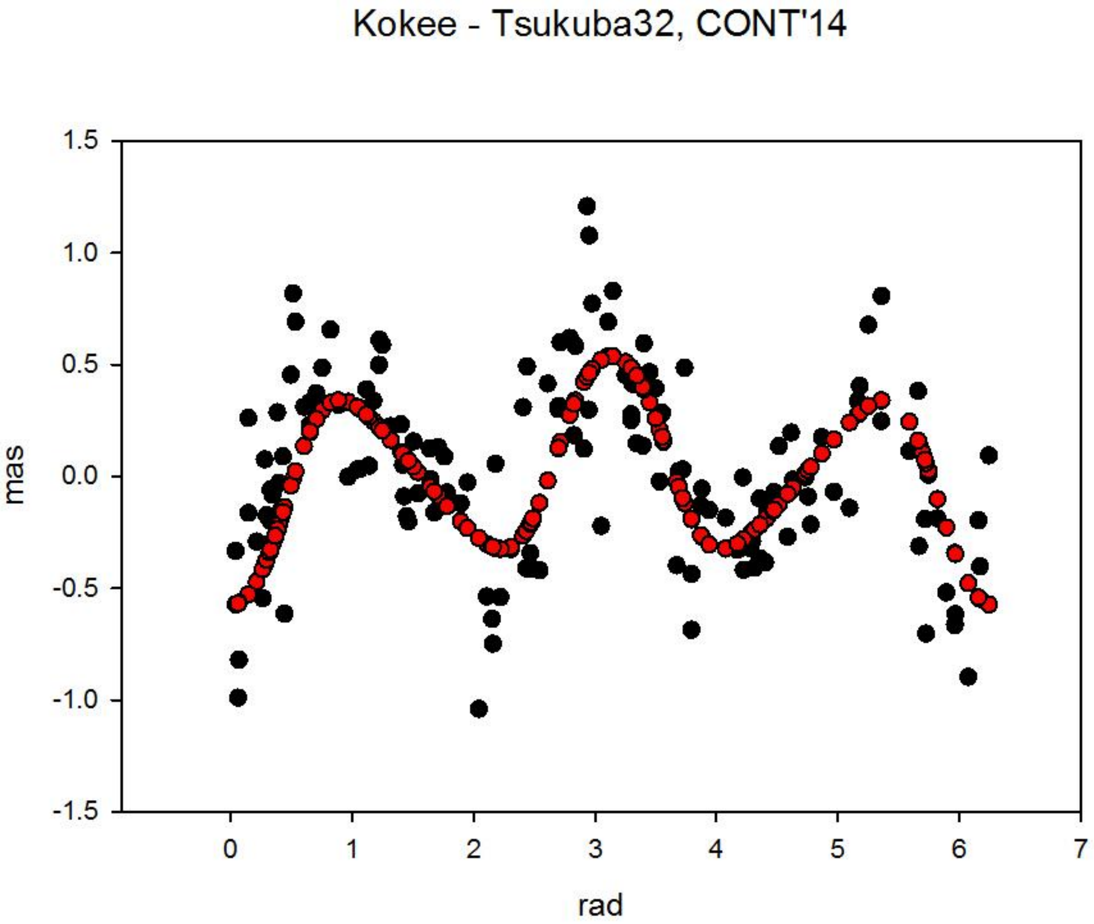
1 mas = 3 cm

Post-fit residuals (0014+813)



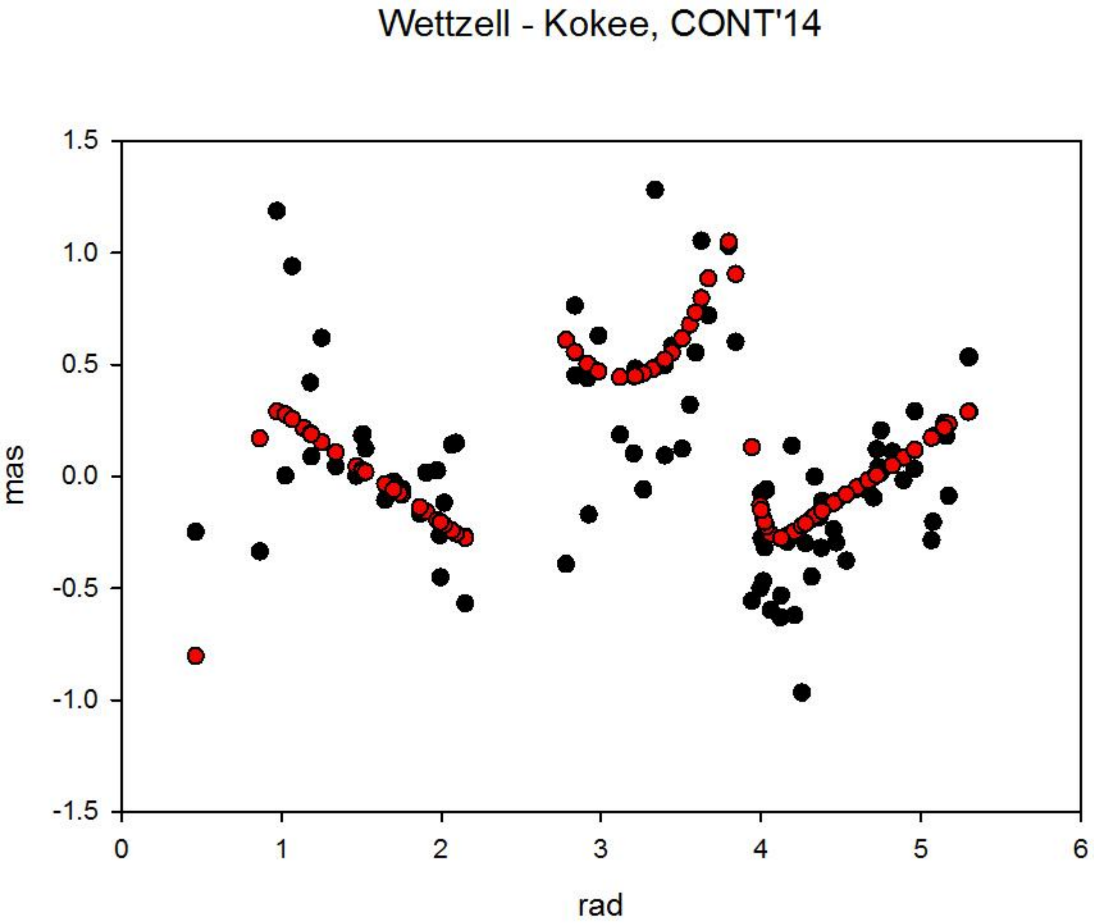
1 mas = 3 cm

Post-fit residuals (0014+813)



1 mas = 3 cm

Post-fit residuals (0014+813)



1 mas = 3 cm

Structure index

$$\alpha_1 - \alpha_2 = \Delta\alpha$$

$$\tau_{str} = \frac{K(\alpha_1 - \alpha_2)}{\omega} \frac{\sin(2\pi R)}{K^2 + 2K\cos(2\pi R) + 1}$$

1. Caused by the difference between core and jet. Core is optically thick, index is about +2.5, jet is optically thin with electron spectral density -2.5 (Charlot, 1990).
2. Additional contribution may come from hardware. The X-band is 1 GHz width (8.0 – 9.0), and all 8 channels are not calibrated.
3. Some hidden features? RFI? Source polarization? Ionosphere?

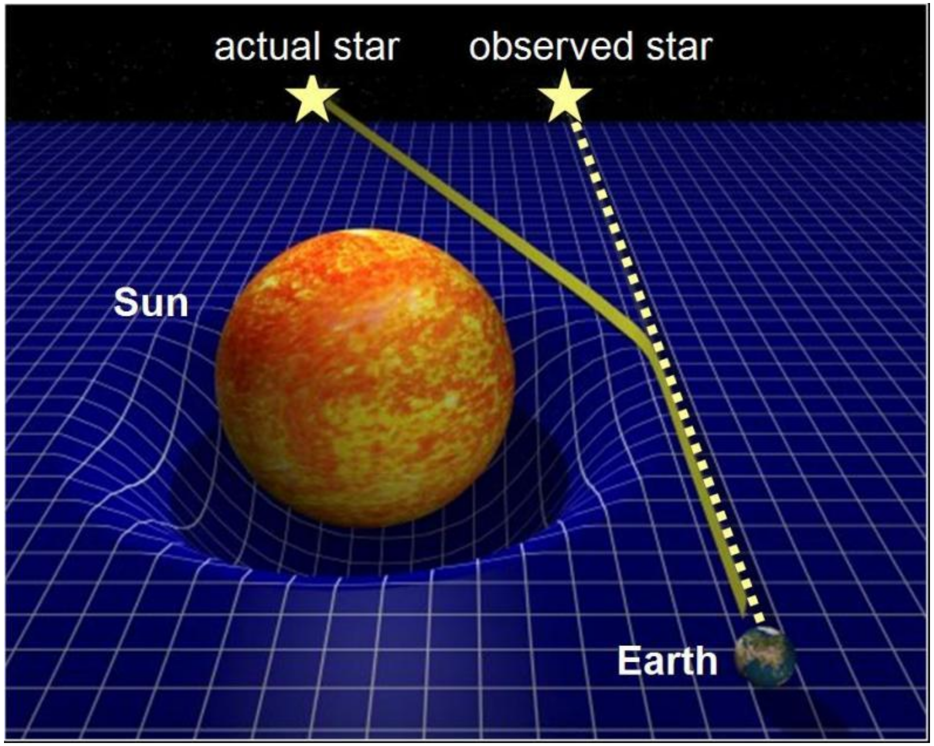
Application

1. Equatorial sources to be targeted by a network spread over both hemispheres. A range of baseline lengths is important.
2. AOV network looks good because it makes many baselines, although not too long.
3. A typical network should include a limited number of sources (<20) to produce more scans per sources for each baseline
4. Structure index is a critical parameter, could be caused by either the source nature or the receiver calibration (channels!)
5. Testing of the same source with the same network at different bandwidth (256, 512, 1024 Mbps in X band) may be interesting
6. The point whether <u>technology meets data analysis</u>. The residuals are directly hit by the hardware performance.

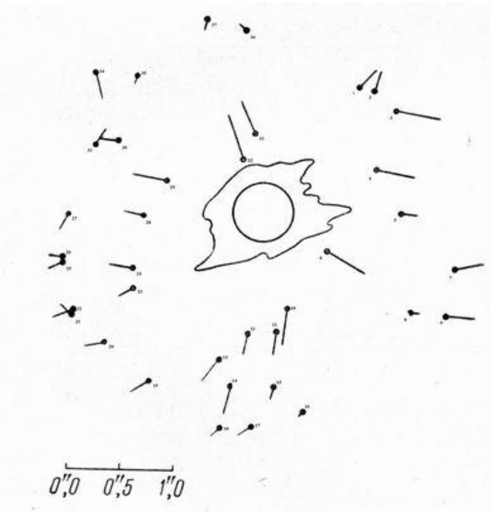
Conclusion

1. The equation linking group delay and light deflection could be used in other applications.
2. Systematic signal in post-fit residuals is found (“positional angle” A)
3. The systematic signal is likely to be caused by the source structure
4. Two-component model (core + jets in opposite directions) has been tried for 0014+813 during CONT’14; structure index is important!
5. Positional shift in declination of ~100 μas was found for 0014+813, but it may reach 1 mas.
6. No necessary make images to reduce VLBI data for the structure delay (resource saving!)

General relativity



Big expedition to observe Solar eclipse since 1919

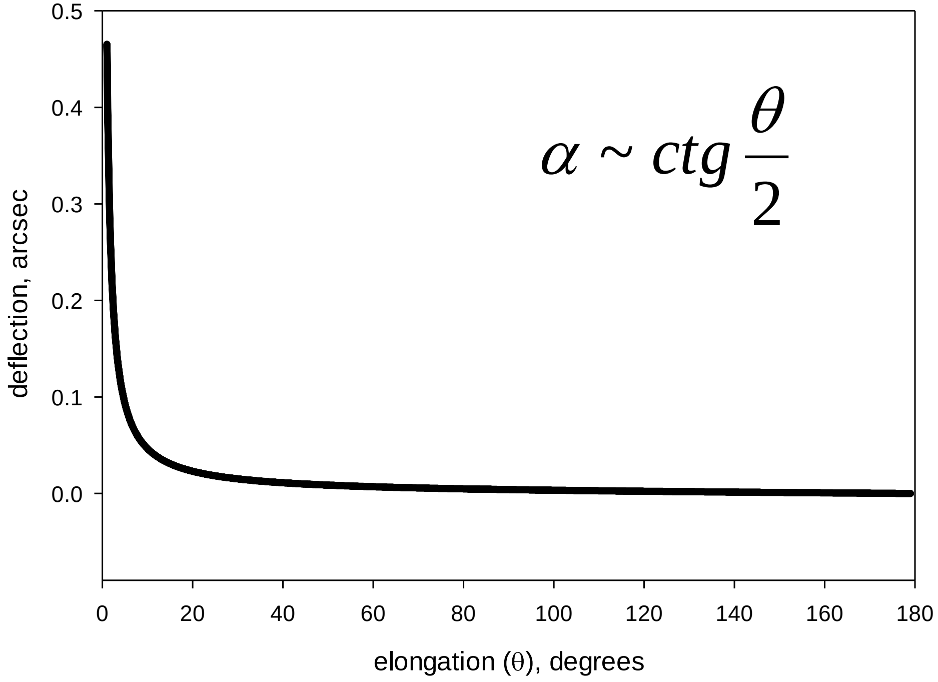


VLBI is doing that every session!

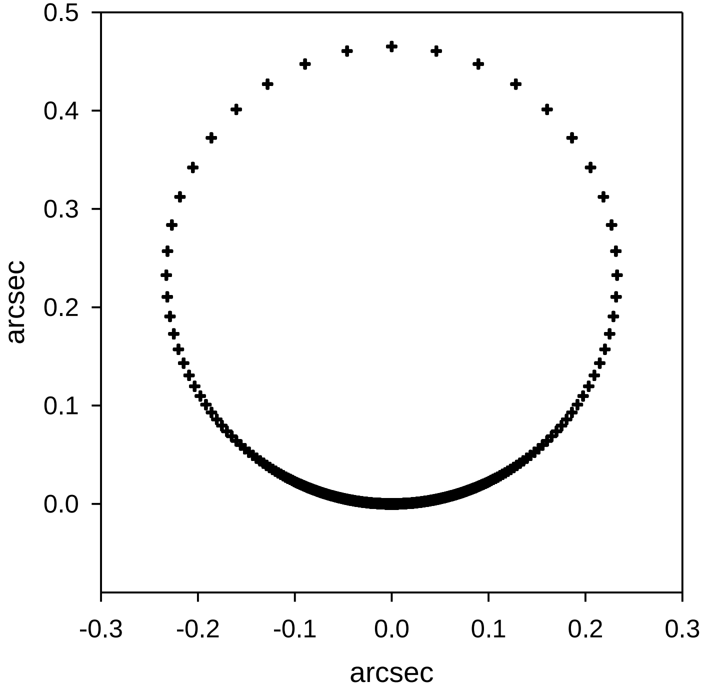
Light deflection in VLBI

$$V(r) \sim \frac{1}{r}$$

$$\alpha = \frac{2GM}{c^2 r_2} \frac{\sin\theta}{1-\cos\theta}$$



$$\alpha \sim ctg\frac{\theta}{2}$$

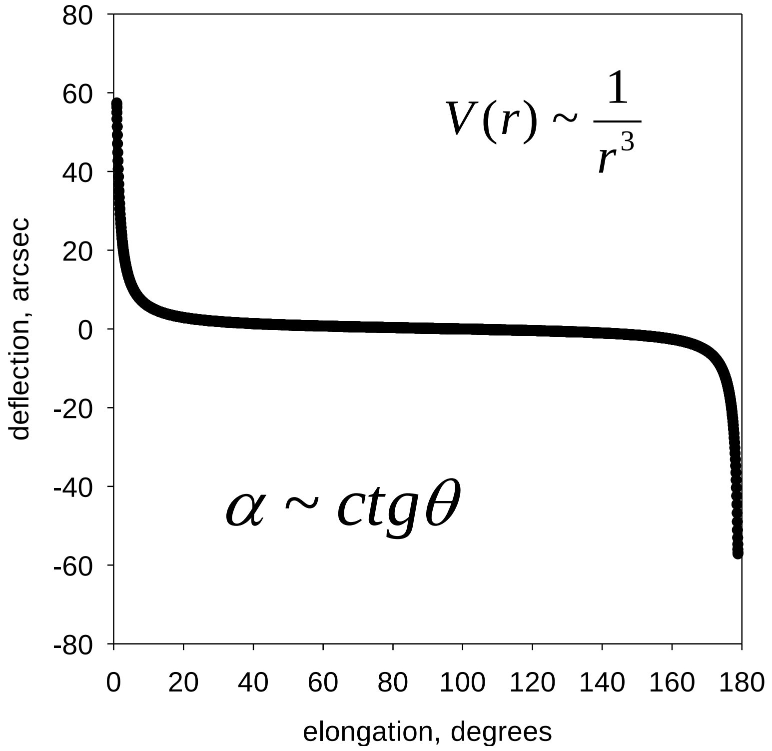


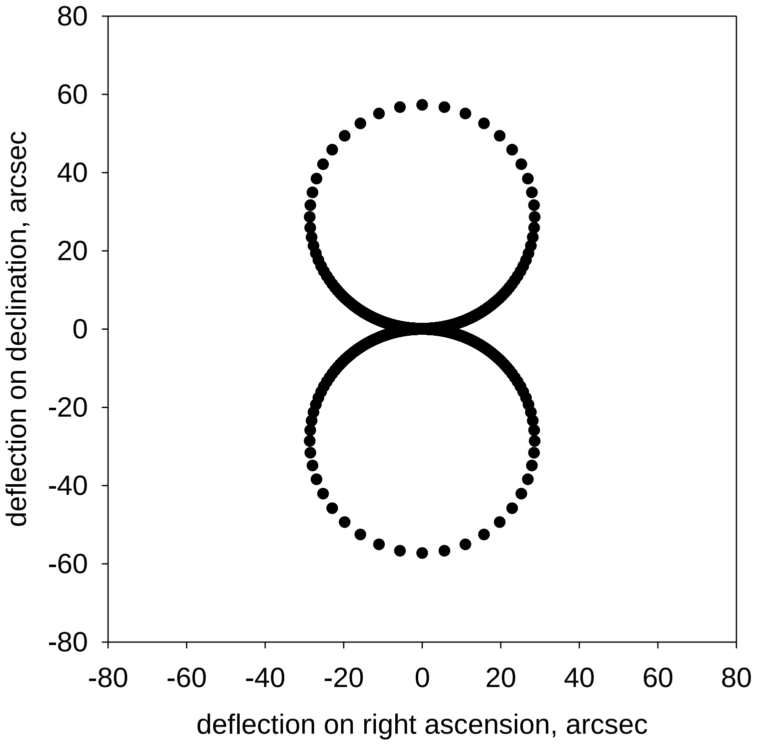
For a radio source within 1° from Sun

Brane world gravity

Randall and Sundrum (1999); Rubakov (2001)

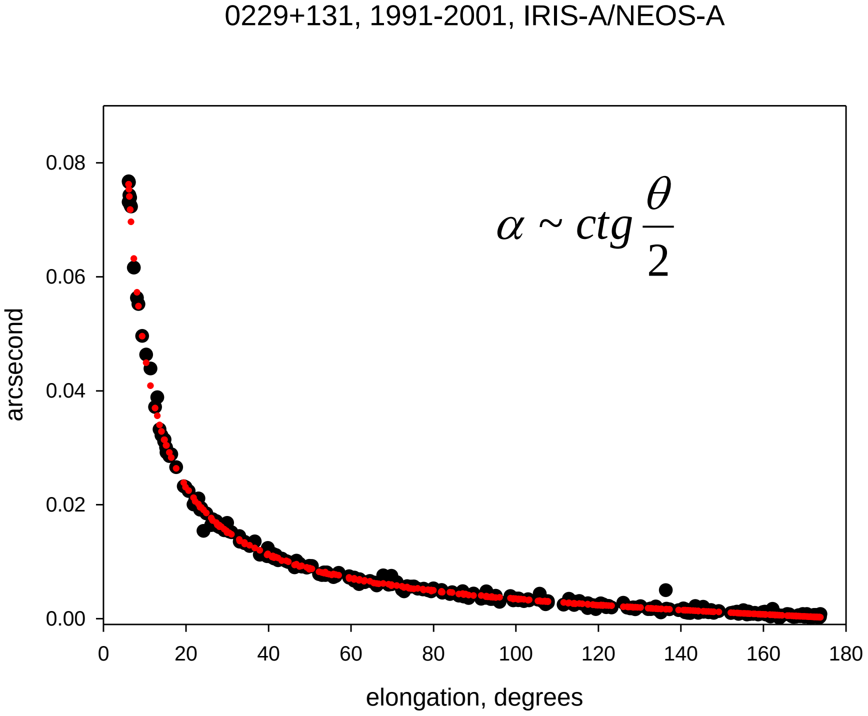
$$V(r) = G_N \frac{m_1 m_2}{r}\left(1 + \frac{1}{r^2 k^2}\right)$$

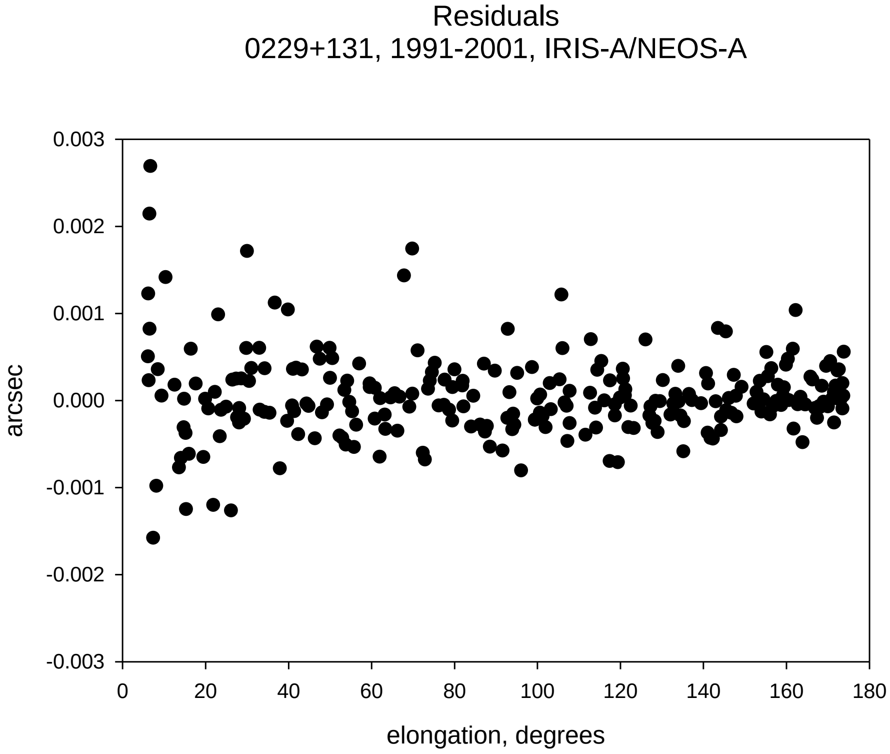




For a radio source within 1° from Sun, magnitude is conditional

Light deflection angle and residuals





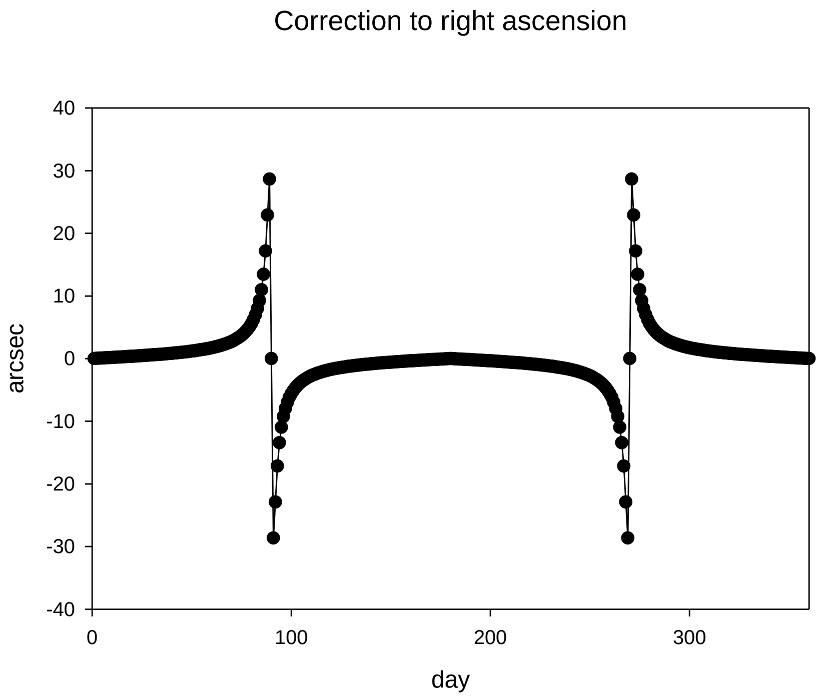
Precision is worse near the Sun, and better near to the anti-Sun point

Brane world gravity

Randall and Sundrum (1999); Rubakov (2001)

$$V(r) = G_N \frac{m_1 m_2}{r}\left(1 + \frac{1}{r^2 k^2}\right)$$

$$\alpha \sim ctg\theta$$



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

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”

10/11 Jan 2016

Two close sources.
0°.6;
Phase-reference observations are possible

Special session 10/11 Jan 2016

(David Mayer calculations)

```
 4 chars/hour
 STATN    | 0      3      6      9      12      15      18      21                          | #SCANS #OBS %OBS
HARTRAO |                                                   XXXXXXXXXXXXX                     |    37    101  61.2
HOBART26|                                                   XX                                |     4     24  14.5
KATH12M  |                                      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX          |    90    154  93.3
YARRA12M|                                      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX        |   101    165 100.0
```

10 Jan 2016 18 UT

11 Jan 2016 18 UT

7” approach

Big radio telescopes from Asia are required!
Next chance in 4 years.

Any Questions?

Thank you for your attention

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