The source structure effect in broadband observations

Sergei Bolotin[1], Karen Baver[1], Olga Bolotina, John M. Gipson[1], David Gordon[1], Karine le Bail[1] and Daniel S. MacMillan[1]

[1]NVI, Inc.
7257D Hanover Parkway
Greenbelt, MD 20770

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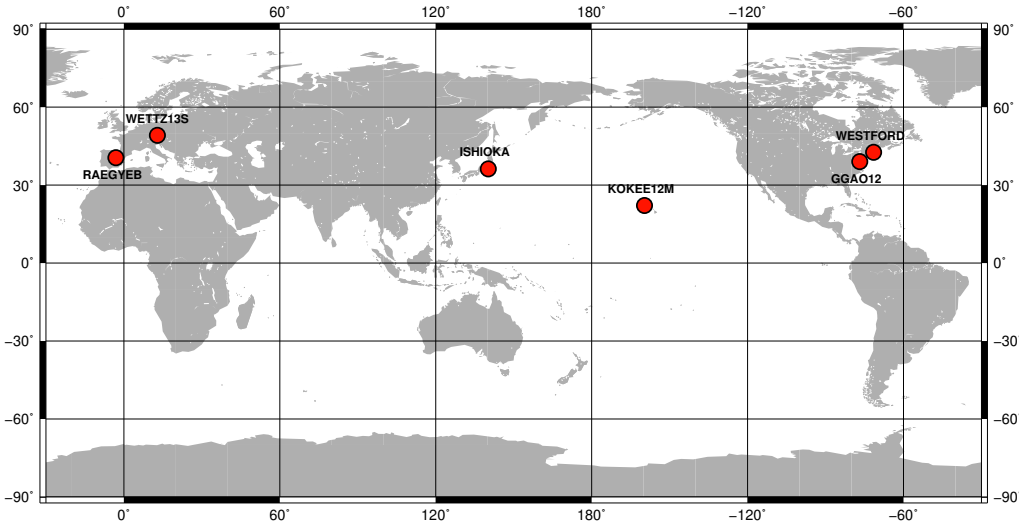
VGOS CONT17 observations

Broadband VLBI observations

- Three station networks participated in CONT17 VLBI campaign: the legacy S/X, VLBA and VGOS networks.
- the VGOS network consists of six station: GGAO12M, ISHIOKA, KOKEE12M, RAEGYEB, WESTFORD and WETTZ13S.
- The stations performed observations during five continuous days: December 3 – 7, 2017.
- The observations were done in the current broadband demonstration mode, recording only half of the possible channels to give a data rate of 8 Gbps instead of the possible 16 Gbps.
- The VGOS observations were correlated at the MIT Haystack Correlator.



- Preliminary data analysis has been performed at Goddard Space Flight Center, NASA and the observations now are available for public access.
- Unfortunately, one of the VGOS stations, Yebes, had a problem with hardware, so it was not included in the analysis.

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Data analysis of the broadband observations

Software

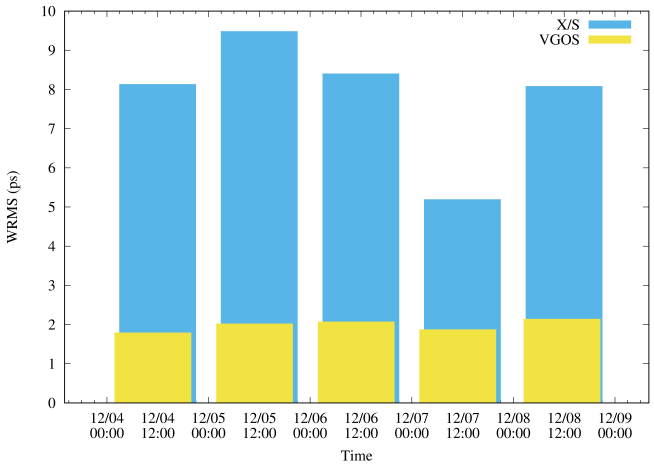
The observations were processed by νSolve software using the embedded software using the embedded ECMAScript to treat data uniformly.

Parameterization

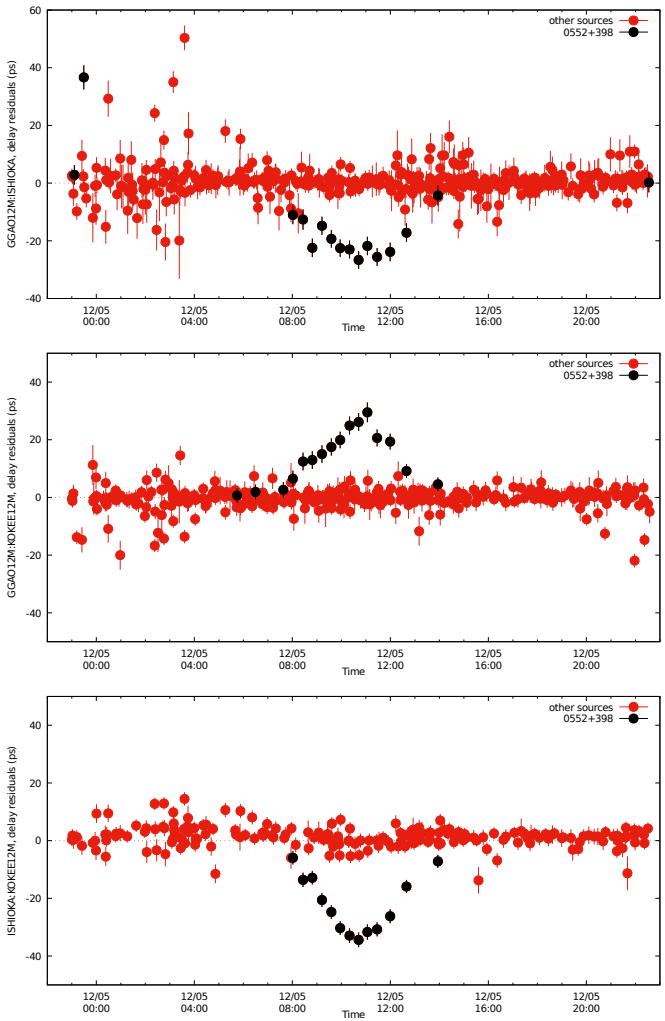
The baseline vectors, source positions and angles of nutation were estimated as local parameters. Station clock offsets, wet zenith delays, and atmospheric gradients were estimated as stochastic parameters (random walk model).

Residuals

Residuals of VGOS sessions much smaller than for the corresponding X/S legacy CONT17 sessions.



Anomalies in delay residuals, 17DEC04VG



Residuals for baselines of the stations GGAO12M, ISHIOKA and KOKEE12M.

- Anomalous residuals for 0552+398 are visible at all five VGOS session.
- The WRMS for the source, 12-13ps, are much bigger than the WRMS for a session, 2-3ps.
- The "standard" data edit procedure would consider these residuals as outliers and they will be removed from the data analysis.

Two points source structure model

Thomas (1980) and Charlot (1990): the source structure affects the group delay as

$$\tau_s = \frac{Z_s \frac{\partial Z_c}{\partial \omega} - Z_c \frac{\partial Z_s}{\partial \omega}}{{Z_s}^2 + {Z_c}^2}$$

where

$$Z_c = \iint I(\vec{P}, \omega, t) \cos(\omega \frac{\vec{b}\vec{P}}{c}) d\Omega$$

$$Z_s = \iint I(\vec{P}, \omega, t) \sin(\omega \frac{\vec{b}\vec{P}}{c}) d\Omega$$

Assume a source consist of two close points at $\vec{P_1}$ and $\vec{P_2}$:

$$I(\vec{P}) = g_1 \delta(\vec{P} - \vec{P_1}) + g_2 \delta(\vec{P} - \vec{P_2})$$

then the source structure effect in the group delay will be

$$\tau_s = -\frac{R}{f} \frac{K(K + \cos(2\pi R))}{1 + K^2 + 2K \cos(2\pi R)}$$

where

$$K = g_2/g_1, g_2 < g_1$$

$$R = (\vec{b}/\lambda)\vec{P_1}\vec{P_2}$$

and the center of the local system is chosen in the brightest component.

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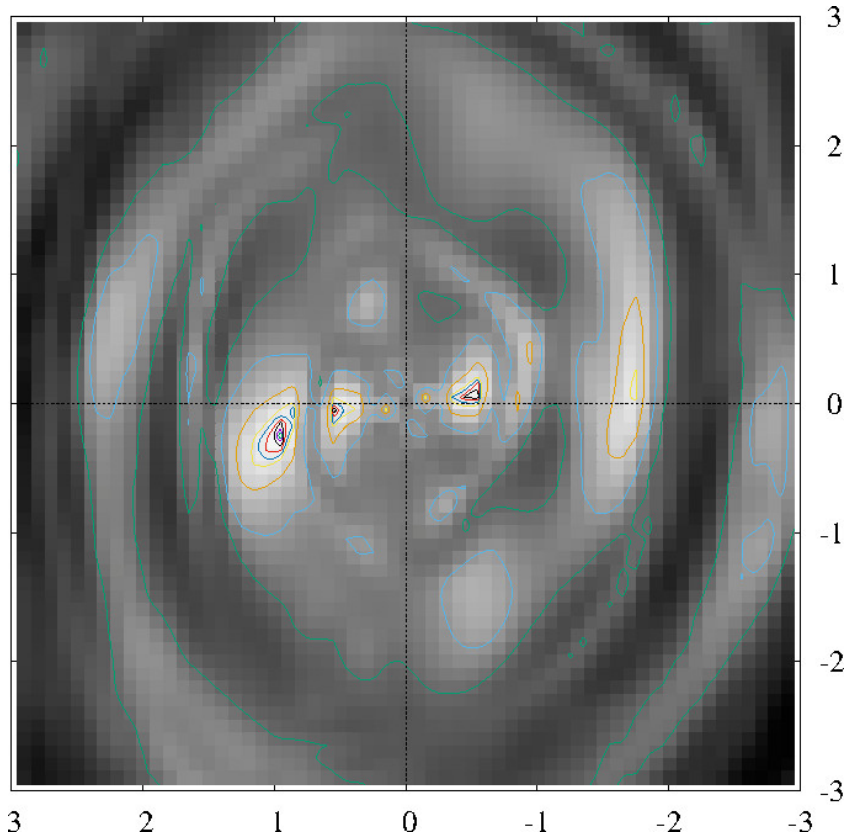
Searching for initial values of the model

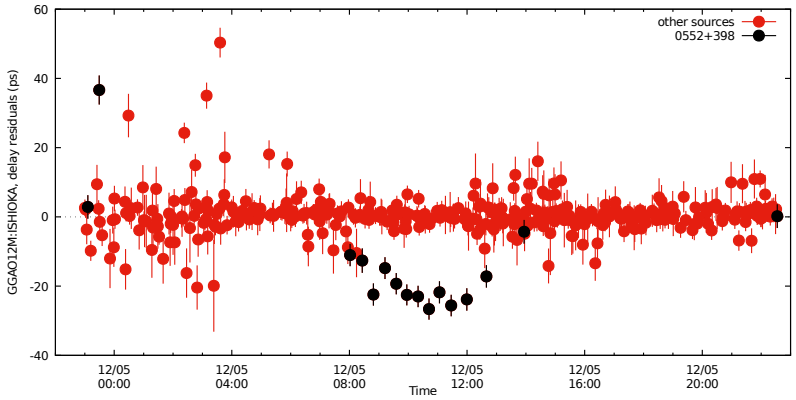
- The two point source structure model consists of the following parameters: an offset of the second component from the central point, (x, y), and a ratio of the amplitudes of the components, K.
- To use the least square estimation we first have to search for the initial values of the model.
- For a fixed position of the second component, (x, y), we estimated the ratio of the amplitudes.
- The image shows distribution of WRMS of the source referred to the minimal WRMS, $WRMS(x, y) - WRMS_{min}$.

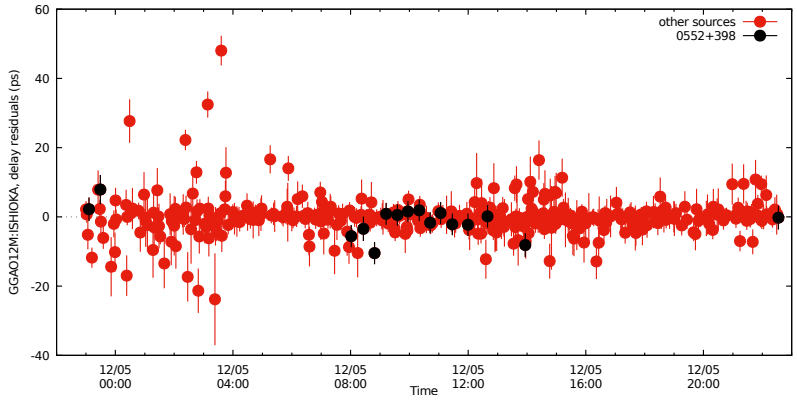


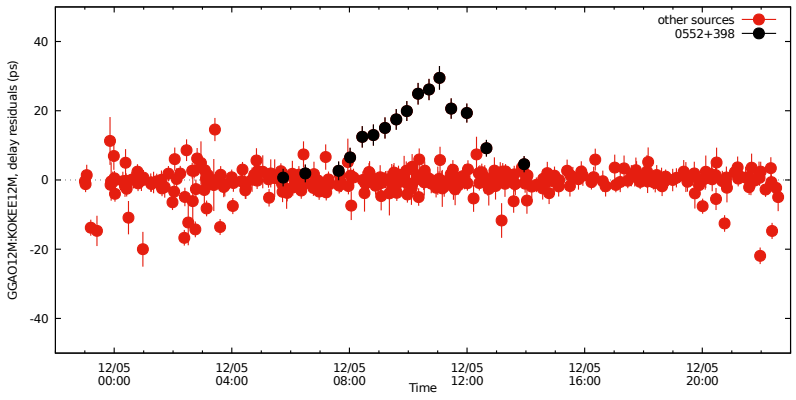
Results of the model parameters estimation

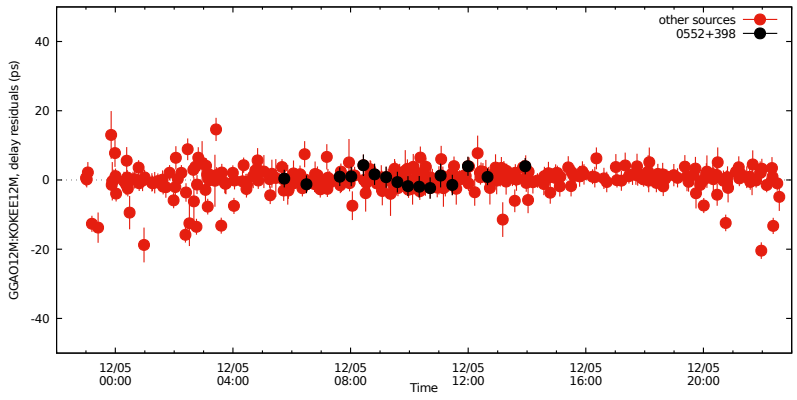
session	Number of obs. Usable	Used	WRMS for 0552+398 (ps) Model:off	Model:on	Model parameters K value	σ	x(μas) value	σ	y(μas) value	σ
17DEC03VG	134	132	13.6	2.8	0.385	0.006	900	5	-128	8
17DEC04VG	118	118	13.5	2.3	0.352	0.012	930	10	-223	20
17DEC05VG	138	137	13.8	2.6	0.390	0.007	900	5	-105	10
17DEC06VG	90	90	15.2	3.2	0.384	0.007	905	5	-98	10
17DEC07VG	149	149	13.3	2.8	0.378	0.007	911	5	-155	9

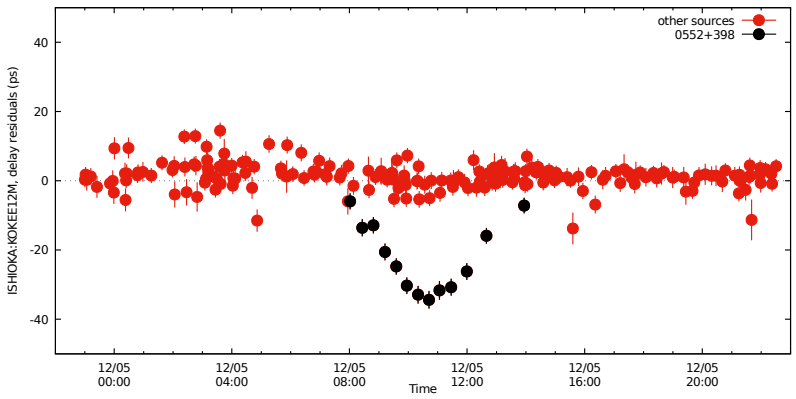
Residuals after the model has been applied

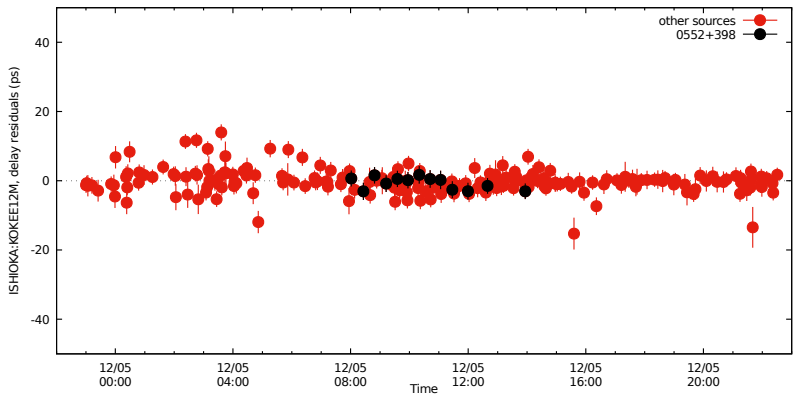








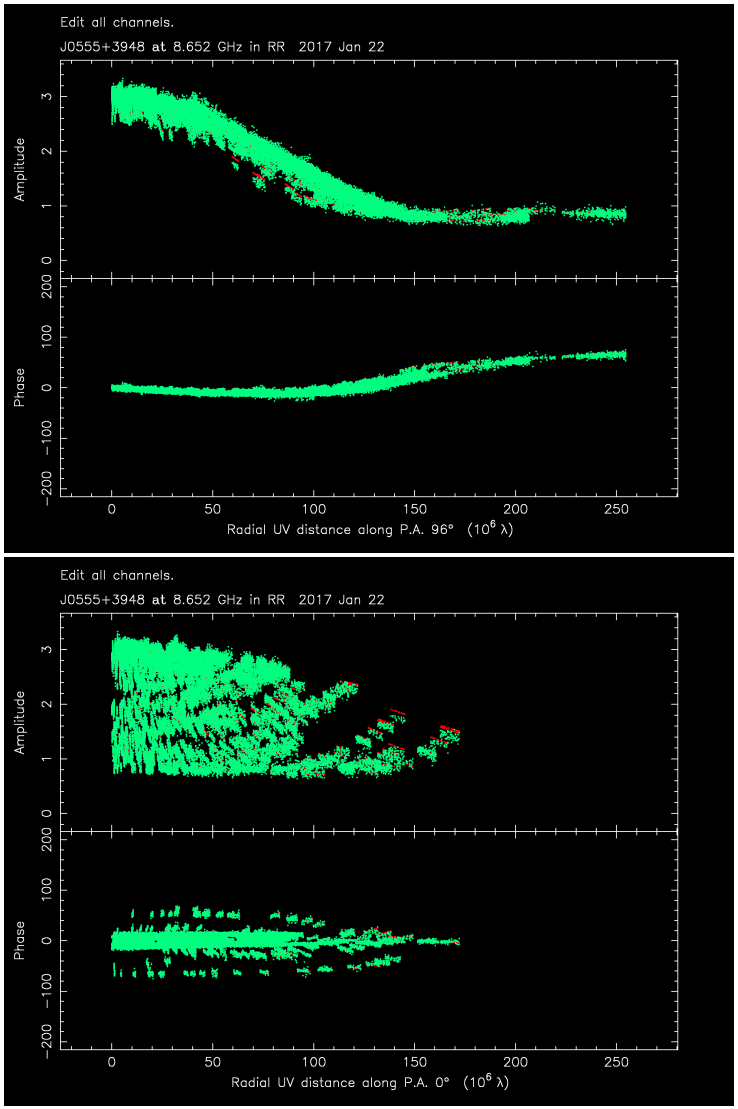




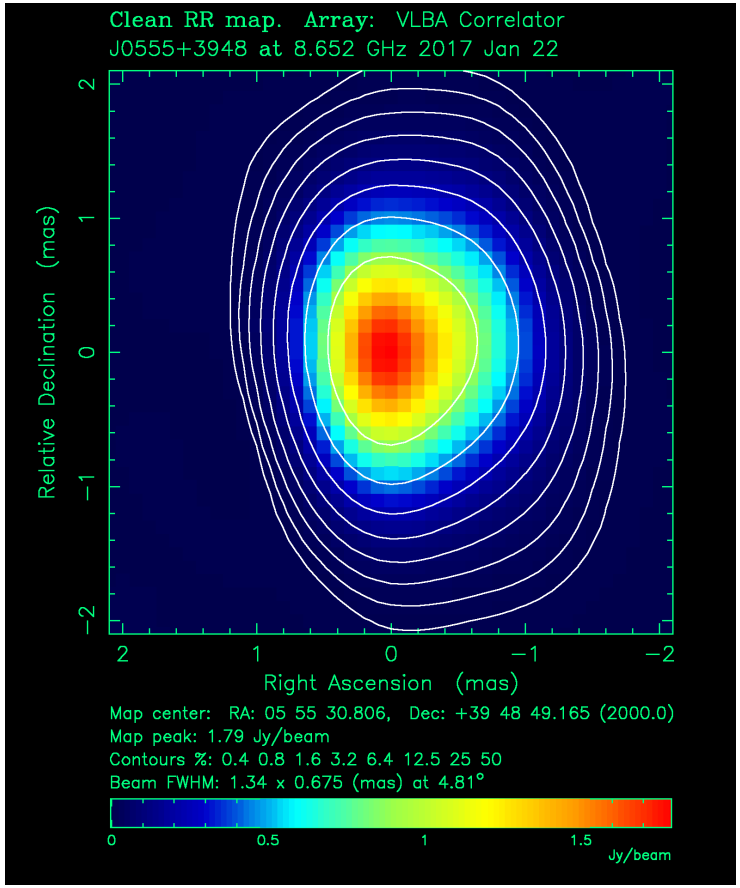
Residuals without the source structure model.

Residuals after the model was estimated.

Confirmation of the structure of 0552+398



Radial plots of the amplitudes and phases for 0552+398.



The map of 0552+398 from VLBA observations.

Leonid Petrov investigated VLBA observations of the source 0552+398 and found its axial symmetry along the angle 96°.

Multiple points source structure model

For multiple points source structure model the brightness distribution can be written as

$$I(\vec{P}) = g_0\delta(\vec{P} - \vec{P}_0) + \sum_{i=1}^{N} g_i\delta(\vec{P} - \vec{P}_i)$$

and the source structure effect in group delay

$$\tau_s = -\frac{1}{f}\frac{\sum_{i=1}^{N} k_i R_i \cos(2\pi R_i) + \sum_{i=1}^{N} {k_i}^2 R_i + \sum_{i=1}^{N-1}\sum_{j=i+1}^{N} k_i k_j (R_i + R_j)\cos(2\pi(R_i - R_j))}{1 + \sum_{i=1}^{N} {k_i}^2 + 2[\sum_{i=1}^{N} k_i \cos(2\pi R_i) + \sum_{i=1}^{N-1}\sum_{j=i+1}^{N} k_i k_j \cos(2\pi(R_i - R_j))]}$$

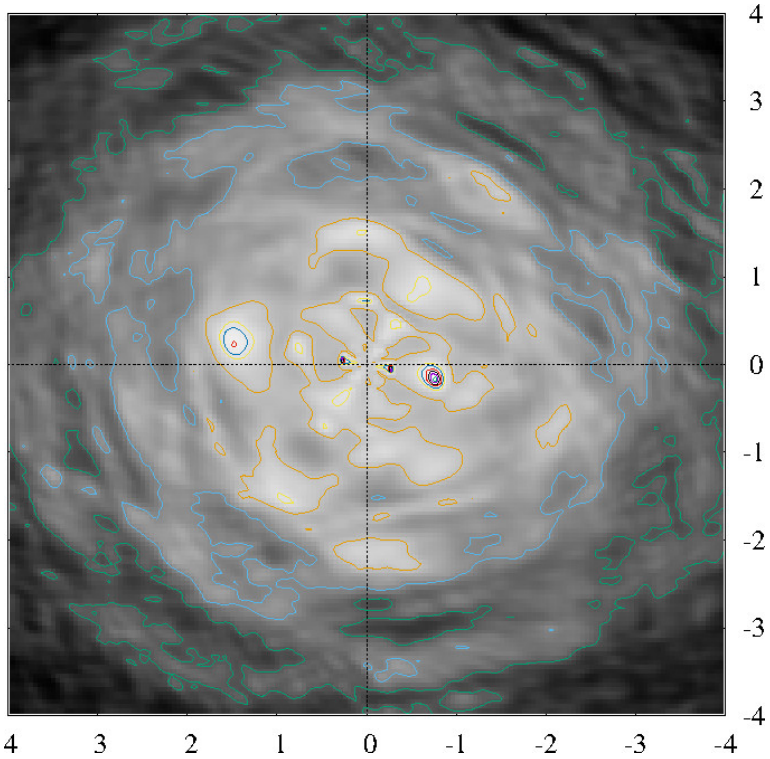
where

$$k_i = \frac{g_i}{g_0}, g_i < g_0$$

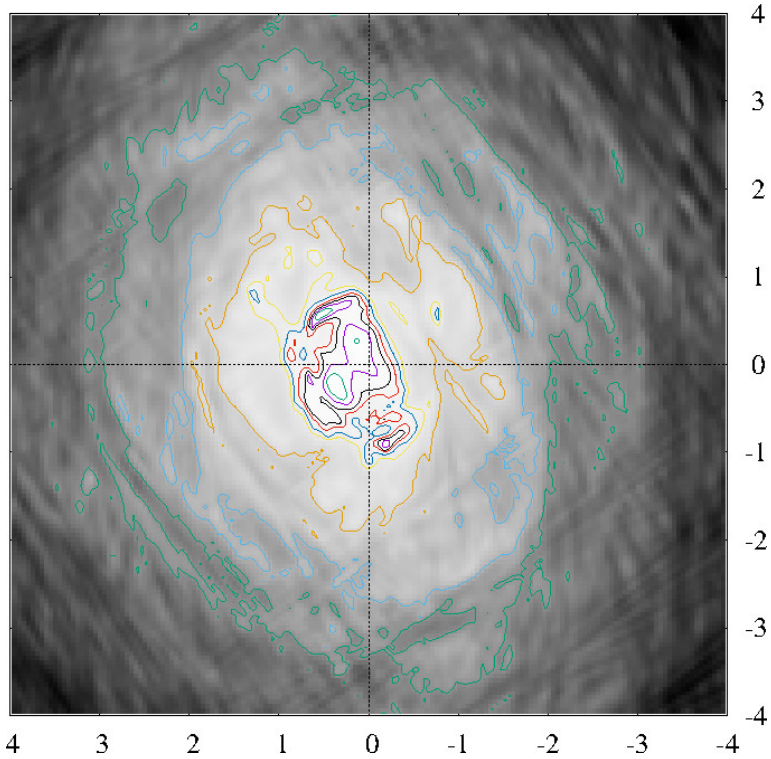
$$R_i = \frac{\vec{b}}{\lambda}\vec{P}_i$$

Searching initial values of the model

Searching for the second component.



Searching for the third component.



Estimating of the three component model for the source 2229+695 from 17DEC03VG.

Idx	Model parameters					
	K		x(μas)		y(μas)	
	value	σ	value	σ	value	σ
1	0.357	0.02	-750	20	-120	20
2	0.157	0.03	550	80	-160	60

Frequency dependent source structure model

The multiple points source structure model with components that have different spectral indexes:

$$I(\vec{P}) = g_0 \delta(\vec{P} - \vec{P_0}) + \sum_{i=1}^{N} g_i \delta(\vec{P} - \vec{P_i})$$

and

$$g_i = r_i (\frac{\omega}{\omega_0})^{\alpha_i}$$

The source structure effect in a group delay is

$$\tau_s = \frac{T_1}{Z^2} + \frac{T_2}{Z^2}$$

where

$$T_1 = -\frac{1}{2\pi f}[\sum_{i=1}^{N} \beta_i k_i \sin(2\pi R_i) + \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} k_i k_j (\beta_i - \beta_j) \sin(2\pi(R_i - R_j))]$$

$$T_2 = -\frac{1}{f}[\sum_{i=1}^{N} k_i R_i \cos(2\pi R_i) + \sum_{i=1}^{N} {k_i}^2 R_i + \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} k_i k_j (R_i + R_j) \cos(2\pi(R_i - R_j))]$$

$$Z^2 = 1 + \sum_{i=1}^{N} {k_i}^2 + 2[\sum_{i=1}^{N} k_i \cos(2\pi R_i) + \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} k_i k_j \cos(2\pi(R_i - R_j))]$$

$$\beta_i = \alpha_i - \alpha_0$$

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Estimation of the frequency dependent source structure model

Estimating of the model from 17DEC03VG.

Source	Idx	Model parameters							
		K		β		x(μas)		y(μas)	
		value	σ	value	σ	value	σ	value	σ
0016+731	1	0.6	0.2	0.6	2	380	8	0	50
	2	0.4	0.3	-1.5	3	-200	90	30	40
0552+398		0.31	0.02	-2.4	0.4	-770	20	-95	10
3C371		0.29	0.02	-0.1	0.3	-670	20	-140	10
3C418		0.34	0.02	0.4	0.3	-840	30	-230	20

Summary

The broadband observations conducted during CONT17 campaign showed potential of the new technique.

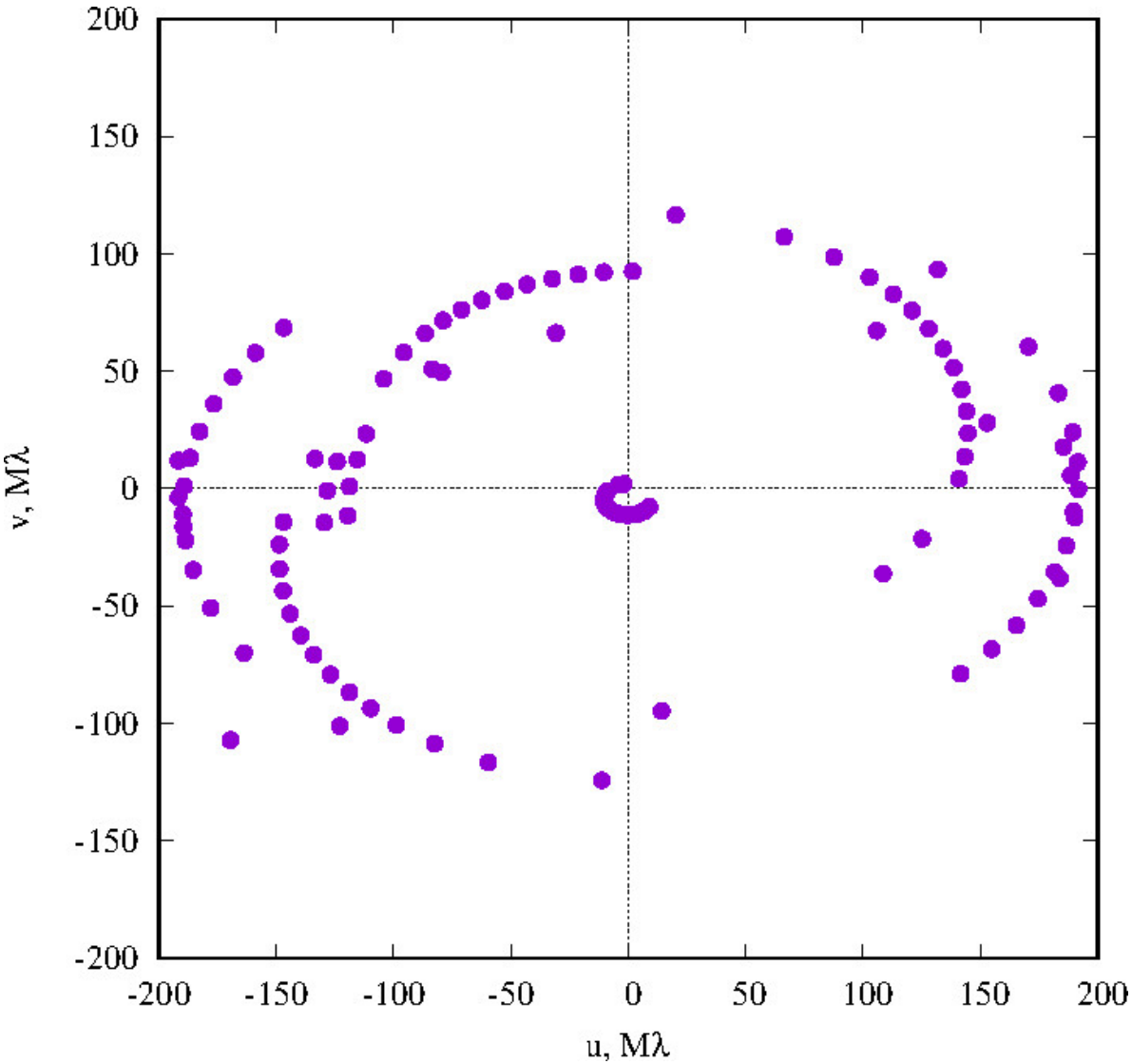
The effect of source structure is directly visible in the broadband observations.

Taking into account source structure effects may be necessary for routine analysis of VGOS observations.

The effect impacts ICRF.

Thank you for your attention!

Appendix


200
150
100
50
0
-50
-100
-150
-200
v, Mλ
-200
-150
-100
-50
0
50
100
150
200
u, Mλ

Searching for the fourth component.