PRIMJENA DUGOBAZIČNE INTERFEROMETRIJE (VLBI) NA PLANETARNE MISIJE

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Sadržaj seminara

Dugobazična interferometrija (Very Long Baseline Interferometry – VLBI) najpreciznija je radioastronomska tehnika na svijetu. Iznosimo kratak uvod u VLBI opažačku metodu.

PRIDE: Planetary Radio Interferometry and Doppler Experiment inicijativa je koja primjenjuje VLBI tehnike u svrhu ultrapreciznog lociranja svemirskih letjelica u Sunčevom sustavu.

Kreiramo PRIDE promatračku kampanju za dva aktivna orbitera oko Marsa.

1.

DUGOBAZIČNA INTERFEROMETRIJA

Pregled povijesti, sadašnjosti i budućnosti VLBI

Prvi radioteleskop: Karl Janskyjev „ringišpil”, 1933.

Prvi paraboličkі ‘tanjur’: Grote Reber, 1937.

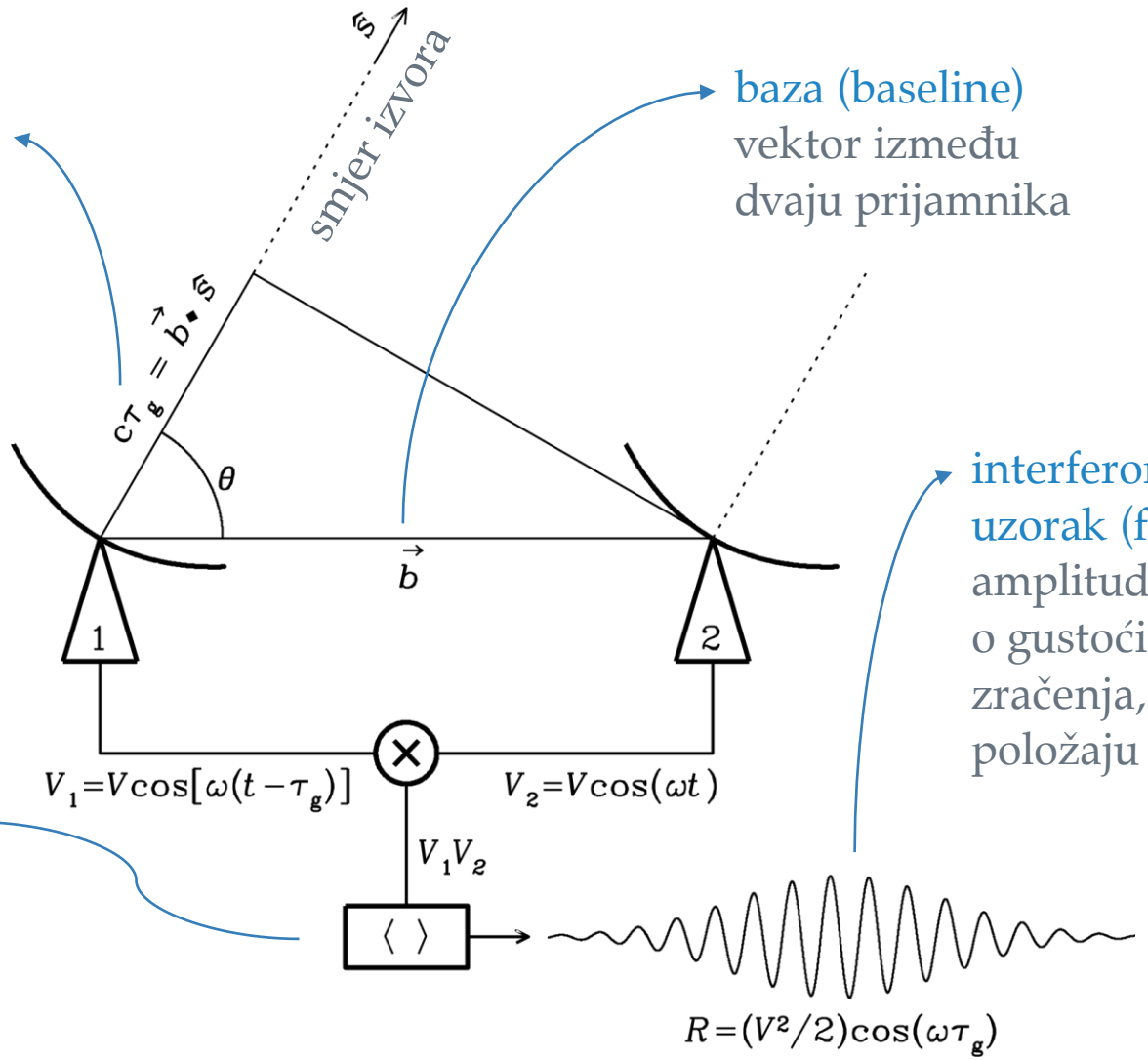
Radio interferometrija (1946.)

geometrijsko kašnjenje (delay)
retardacija između dvaju signala

baza (baseline)
vektor između dvaju prijamnika

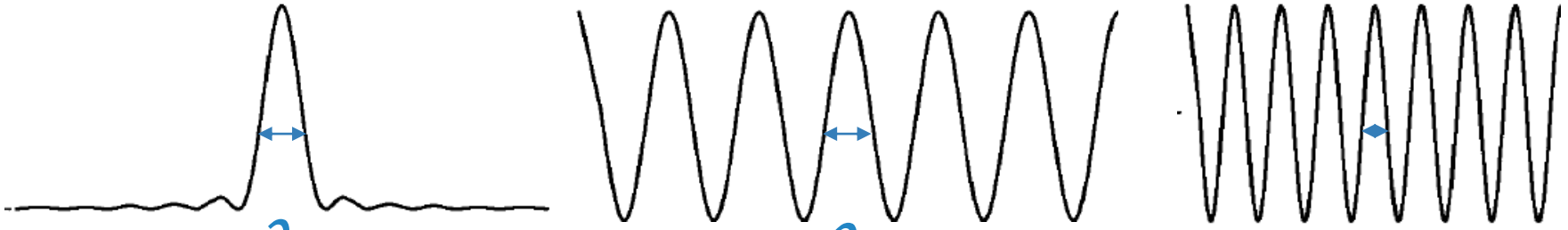
interferometrijski uzorak (fringe)
amplituda ovisna o gustoći toka zračenja, faza o položaju izvora

korelator
pojačava, množi i usrednjuje signal



Karakteristične kutne skale

Zamislimo da su teleskopi na pomičnim tračnicama između $Bmin$ i $Bmax$.



$$\frac{\lambda}{D}$$

razlučivost jedne antene promjera D

↓

vidno polje

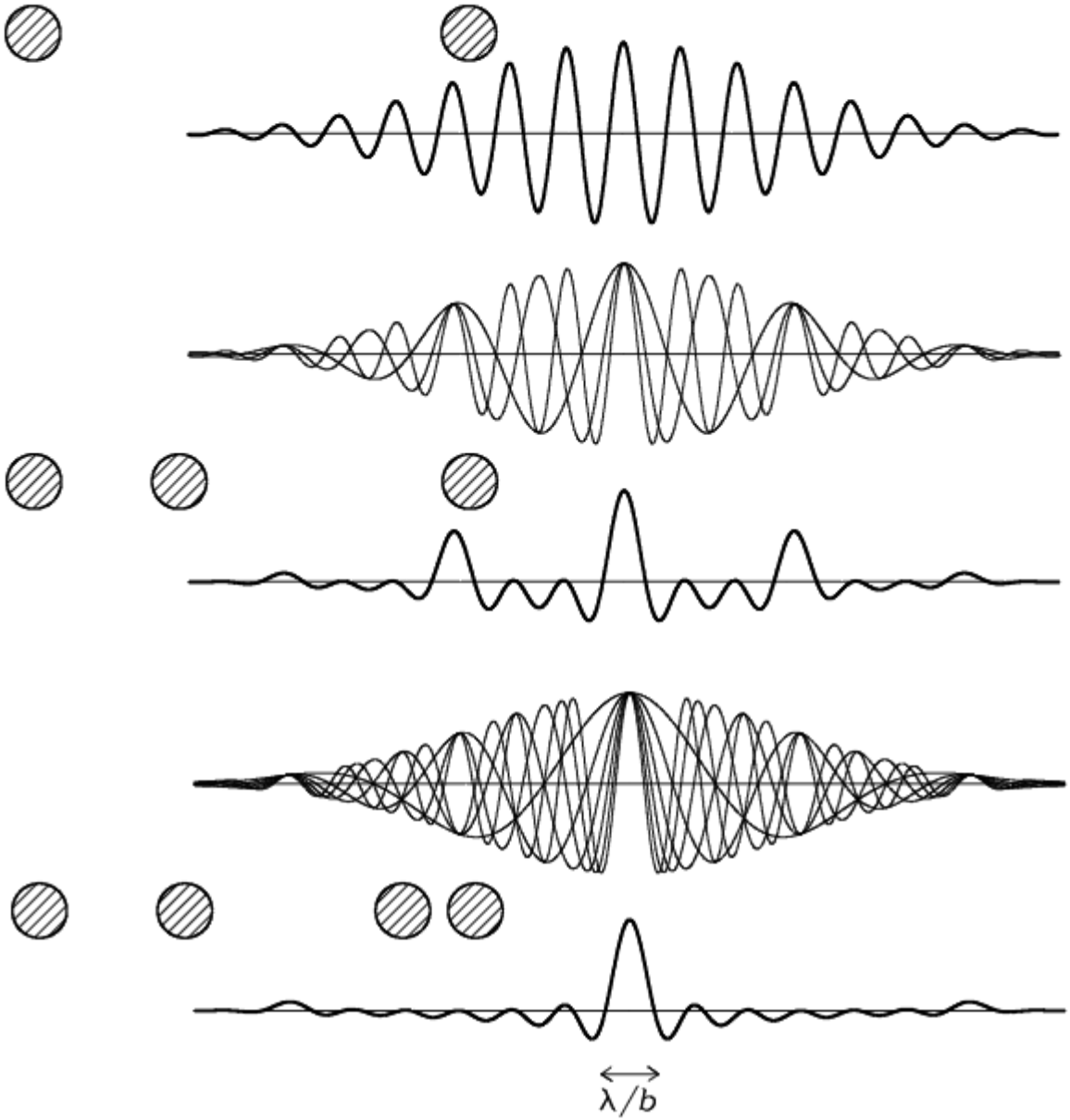
$$\frac{\lambda}{B_{min}}$$

razlučivost interferometra na kratkoj bazi

$$\frac{\lambda}{B_{max}}$$

razlučivost interferometra na dugoj bazi

kutni raspon koji možemo opažati



2 antene
1 baza

3 antene → N
3 baze → N(N-1)/2

4 antene
6 baza

Sintetizirani odziv (synthesized beam) teži k Gaussijanu! Interferometar se ponaša kao jedna velika antena promjera b!

Westerbork Synthesis Radio Telescope, 1970.

Sinteza slike

Izmjereni interferentni uzorak direktno je povezan s distribucijom intenziteta na nebu (van Cittert-Zernike teorem):

$$V(u,v) \Longleftrightarrow T(x,y)$$

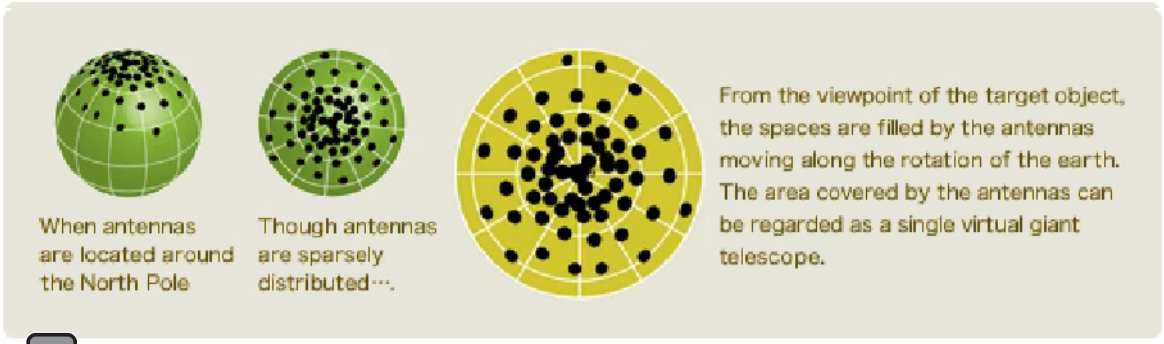
2D Fourier

kompleksna vidljivost (ono što mjerimo)

distribucija intenziteta (ono što nas zanima)

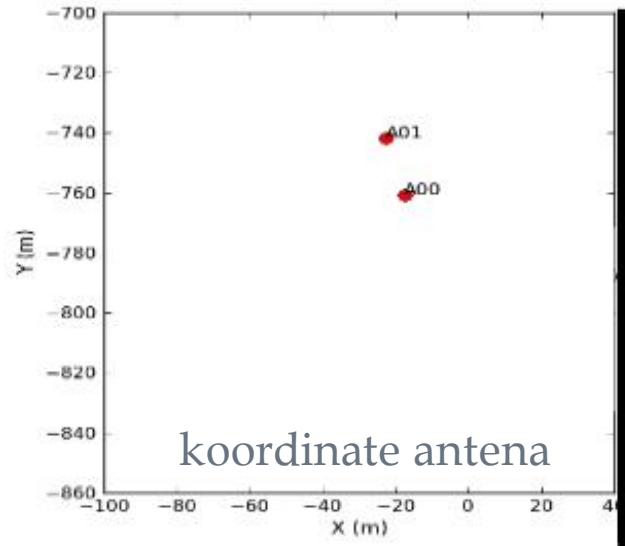
Što bolji sampling u prostoru baza, $\Longrightarrow$ To bolja kvaliteta slike!

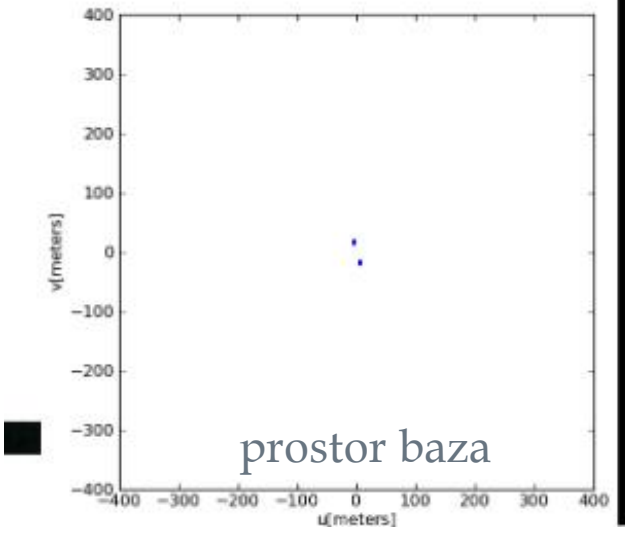
Earth Rotation Aperture Synthesis (Ryle 1961.)

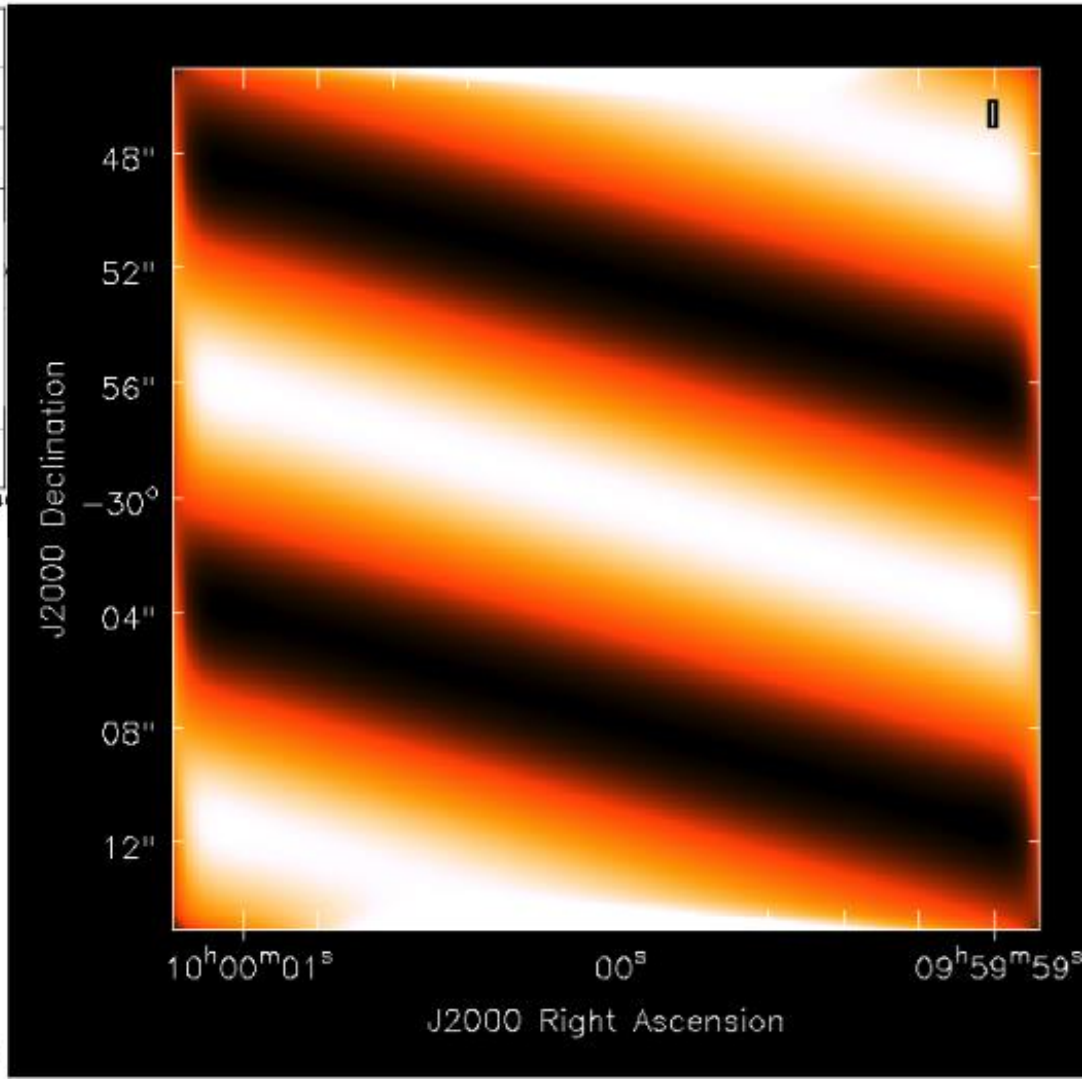


* The actual ALMA antenna location differs from the figure above. The figure is a conceptual illustration to explain the principle of the "aperture synthesis" technique (interferometric imaging method) in a very simple way.

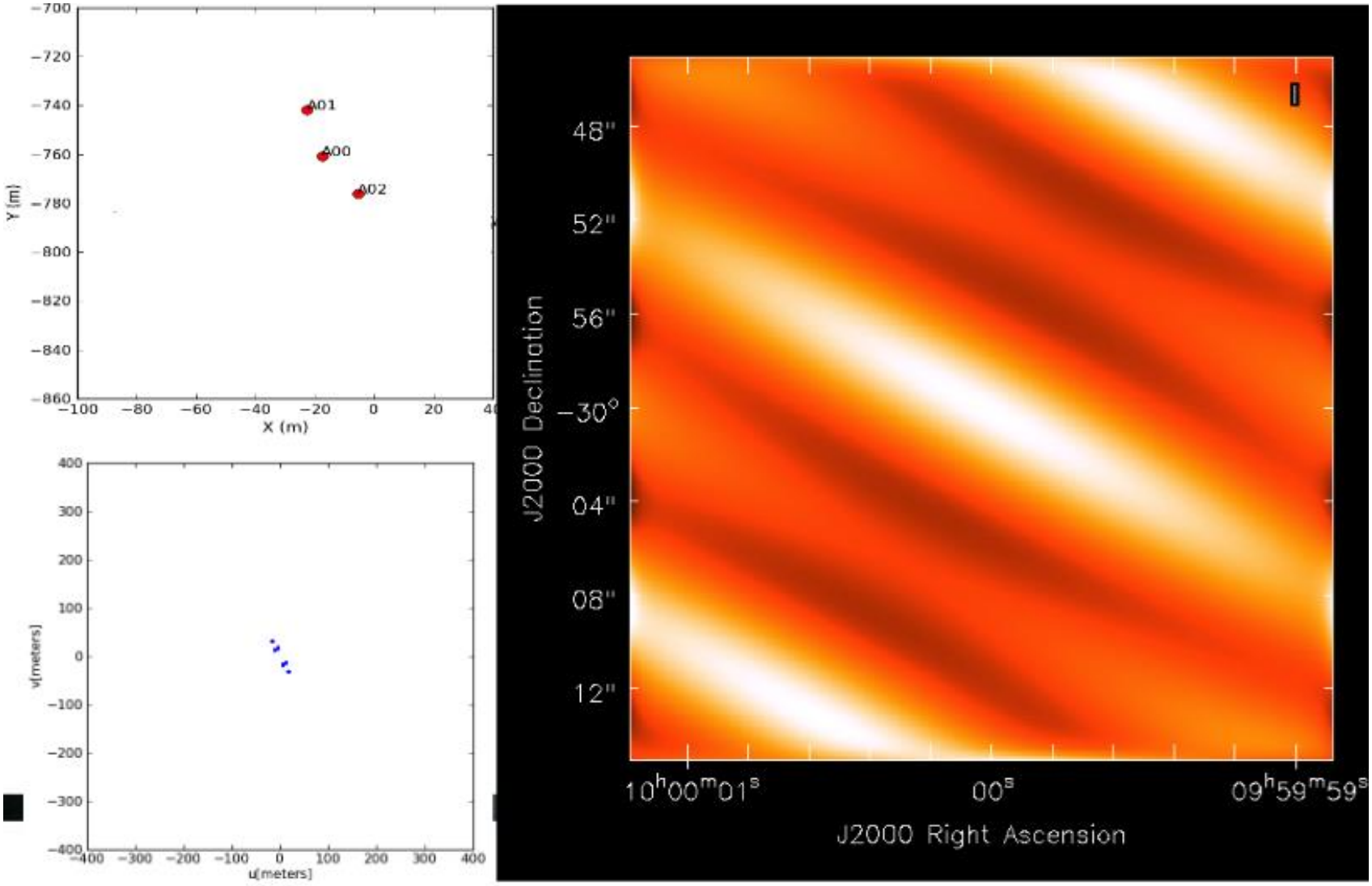
Dvije antene



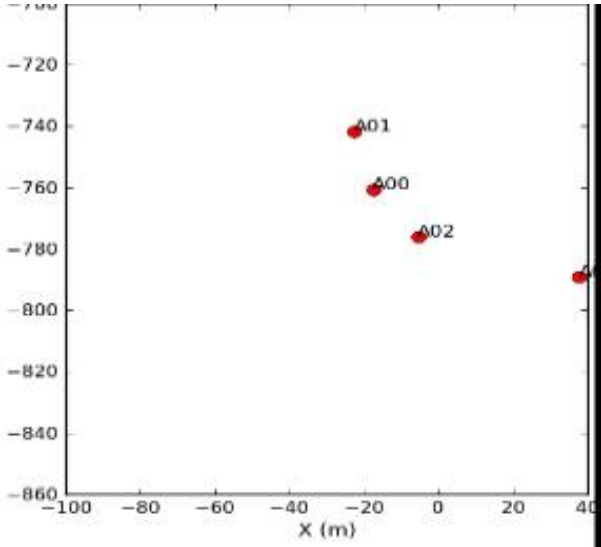


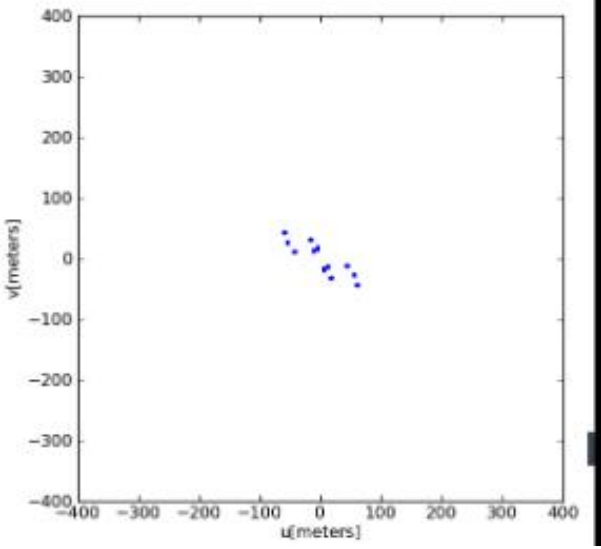


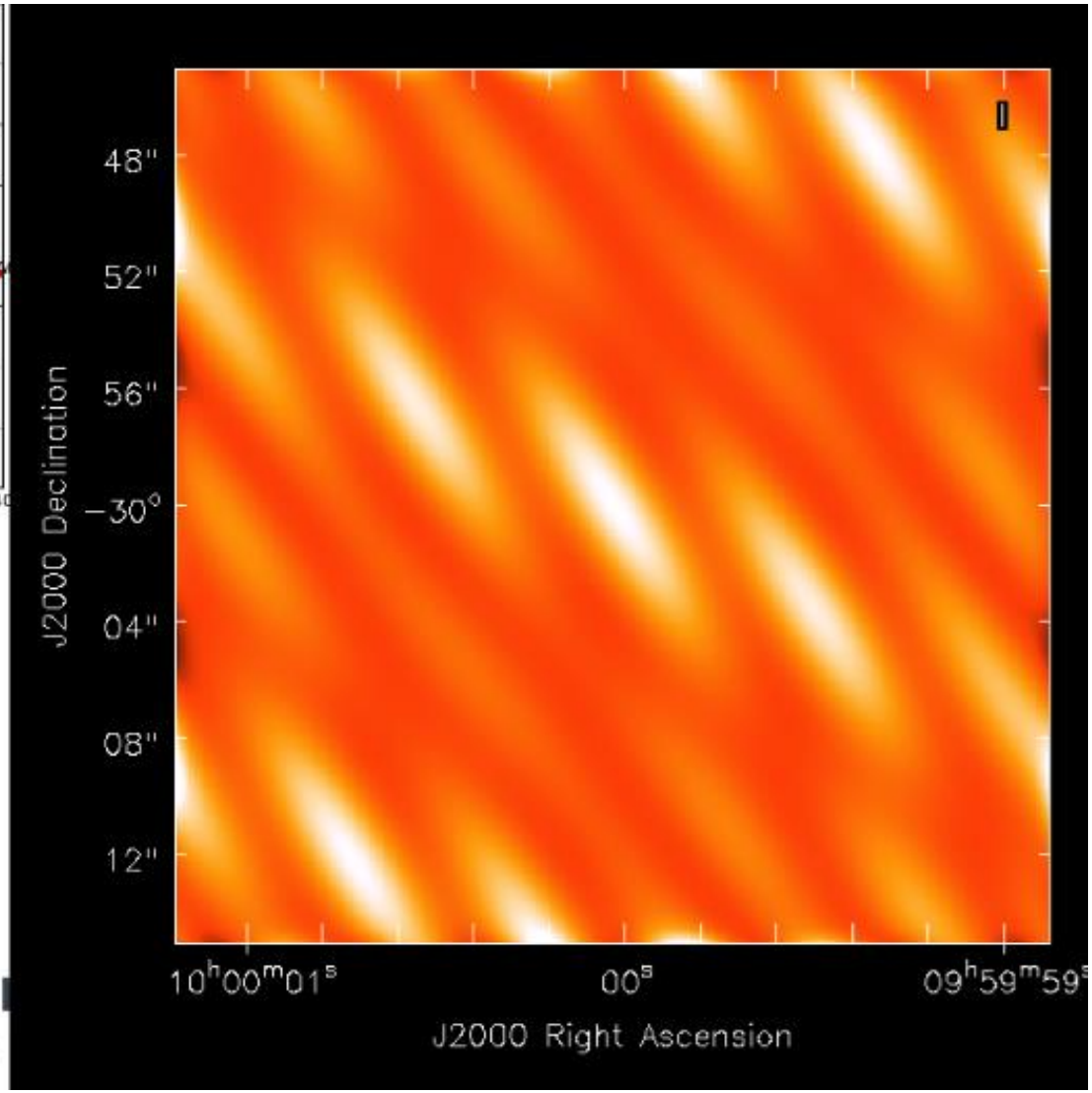
Tri antene


A01
A00
A02
Y (m)
X (m)
v[meters]
u[meters]
J2000 Declination
48"
52"
56"
−30°
04"
08"
12"
10h00m01s
00s
09h59m59s
J2000 Right Ascension

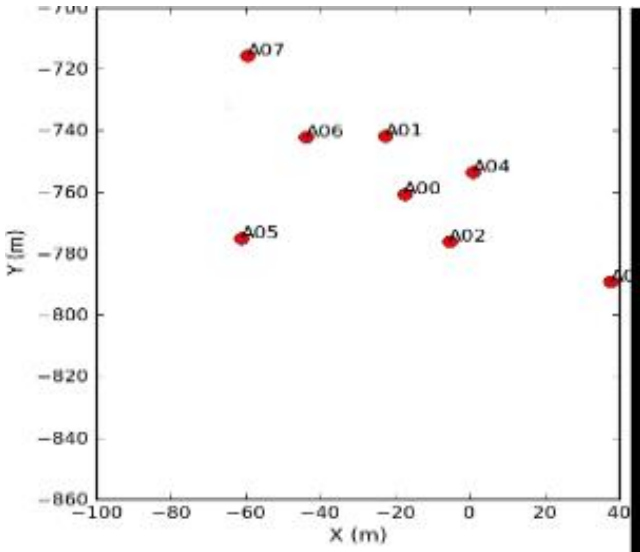
Četiri antene

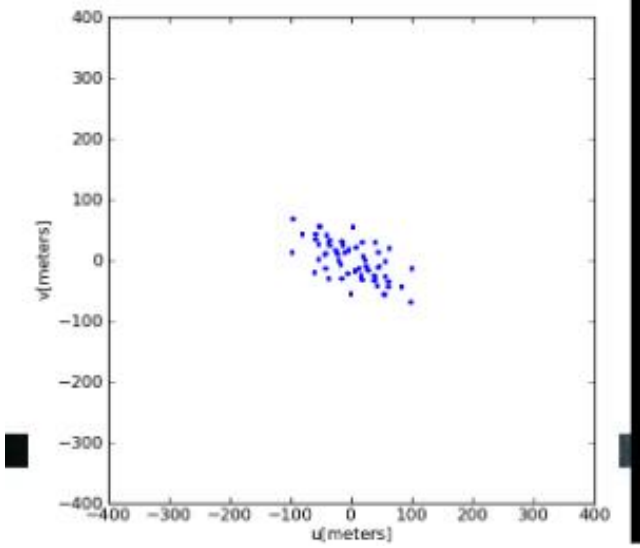


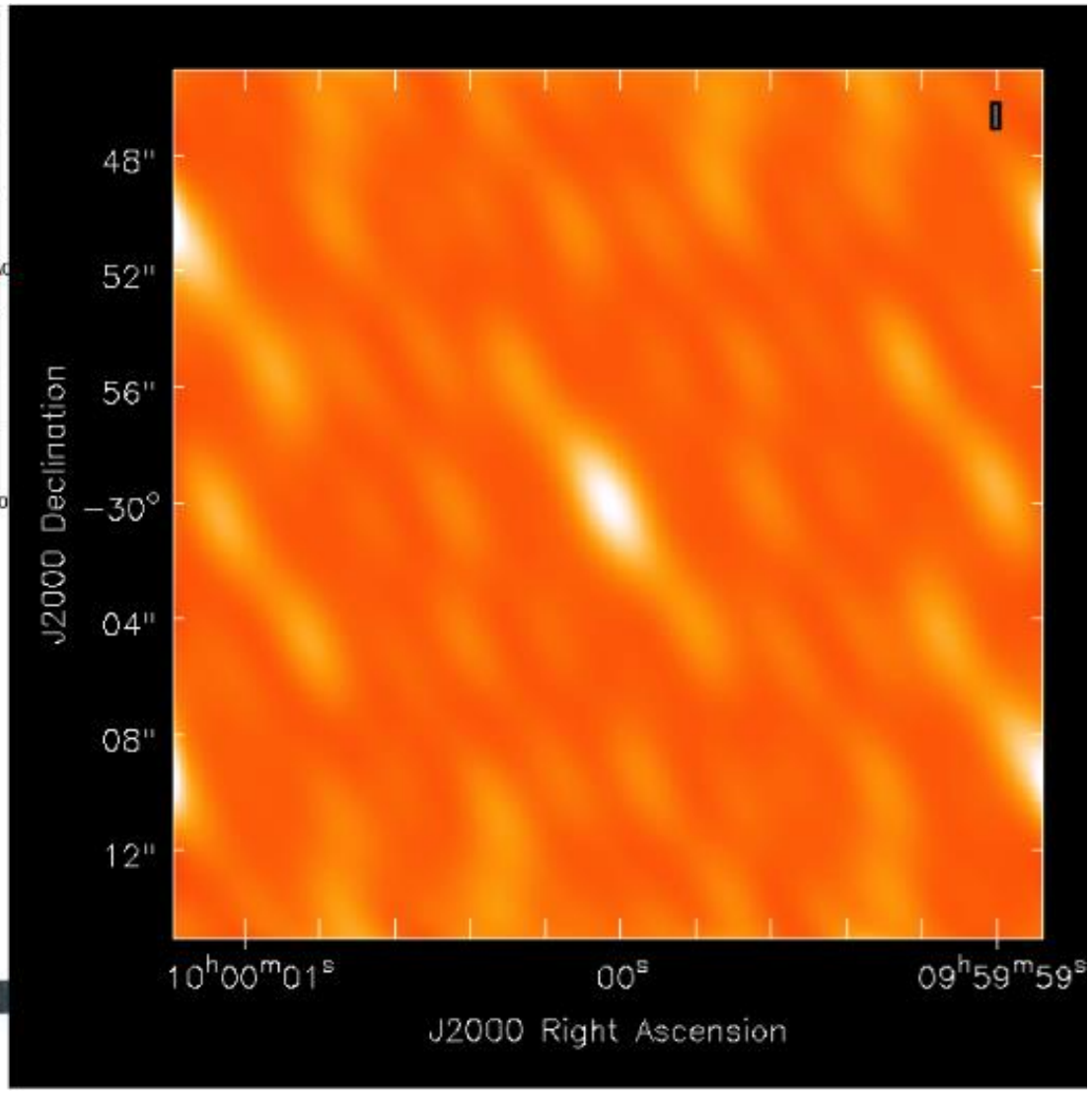




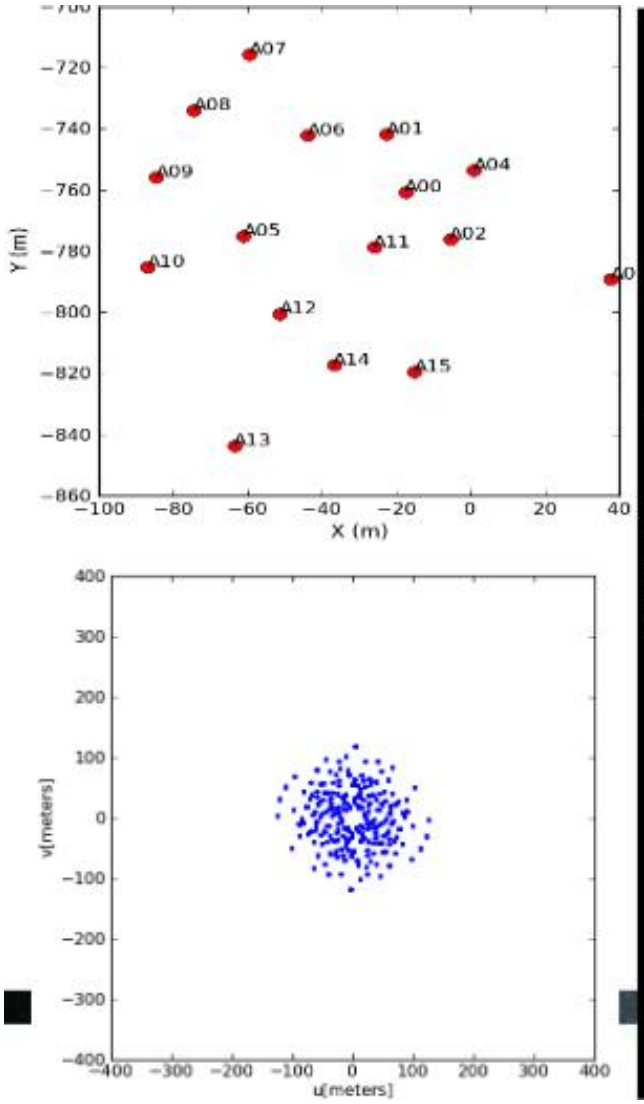
Osam antena

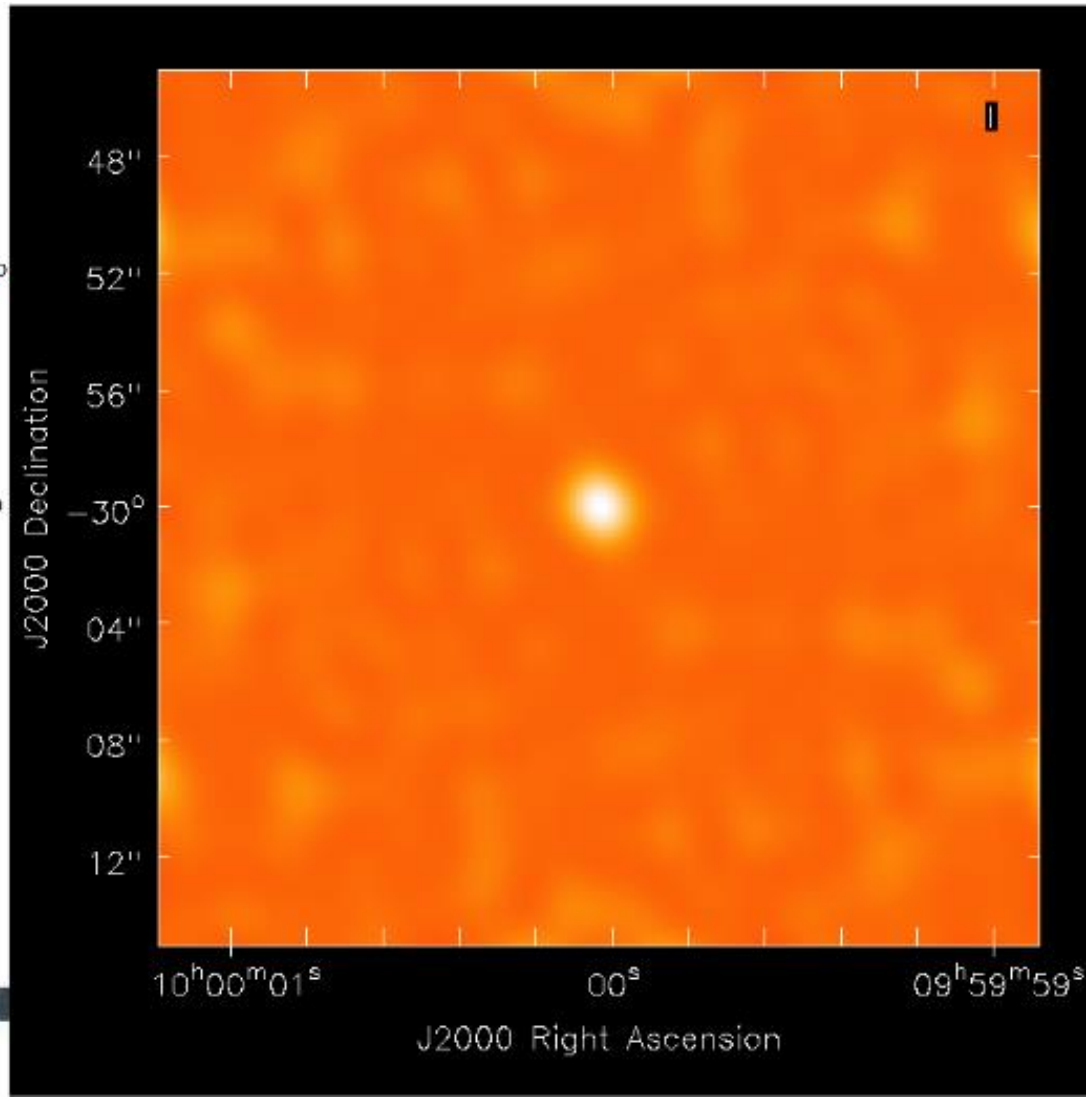

A07
A06
A01
A04
A00
A05
A02
Y (m)
X (m)


v[meters]
u[meters]

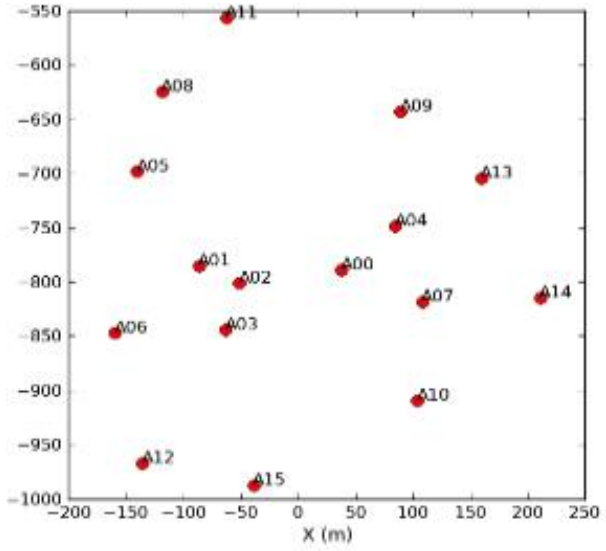

48''
52''
56''
−30°
04''
08''
12''
J2000 Declination
10h00m01s
00s
09h59m59s
J2000 Right Ascension

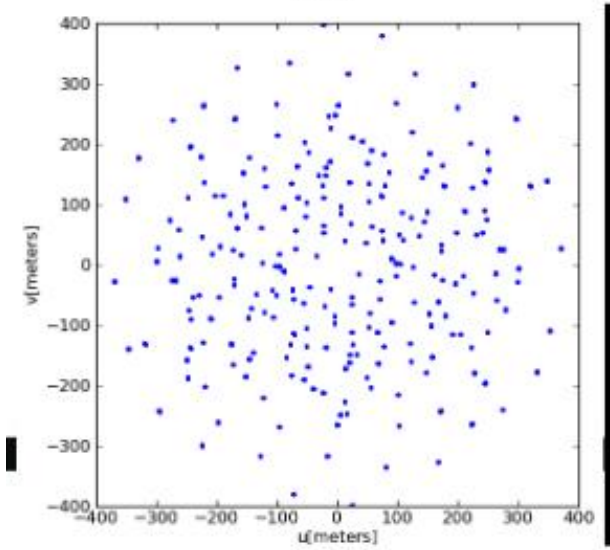
Šesnaest antena, kompaktna konf.

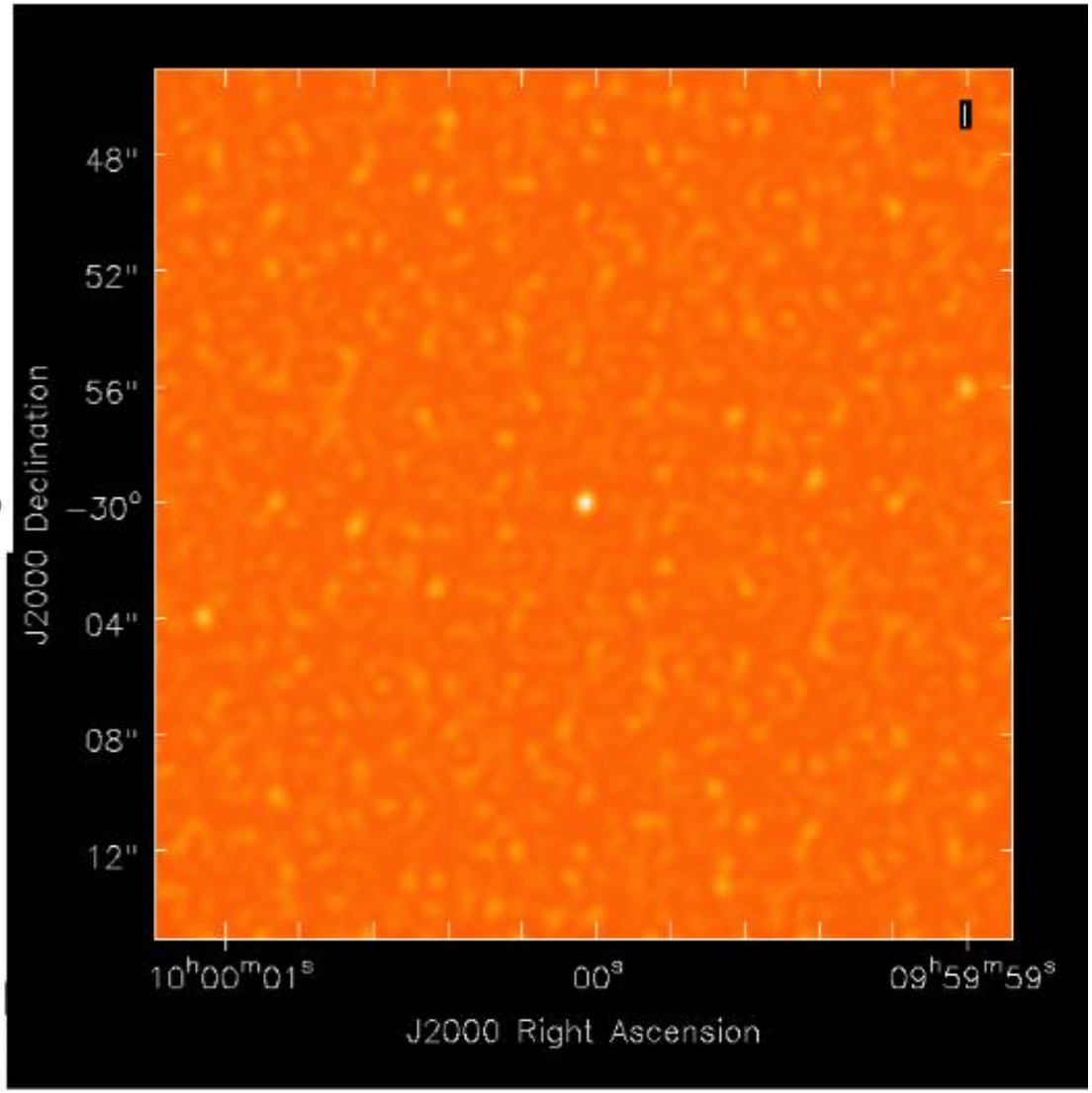




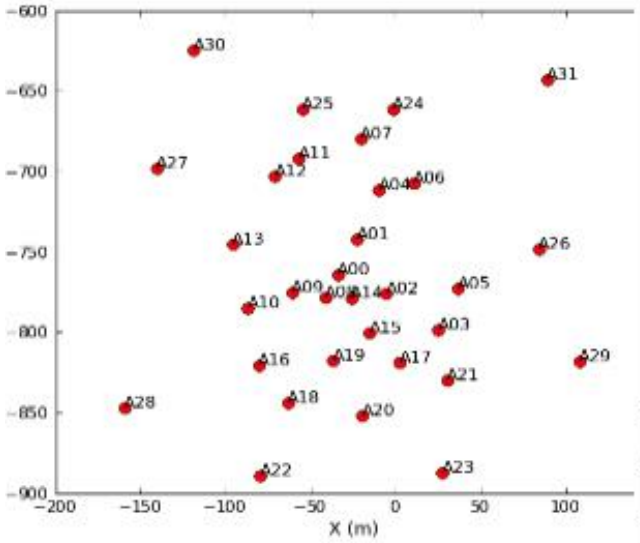
Šesnaest antena, ekstendirana konf.

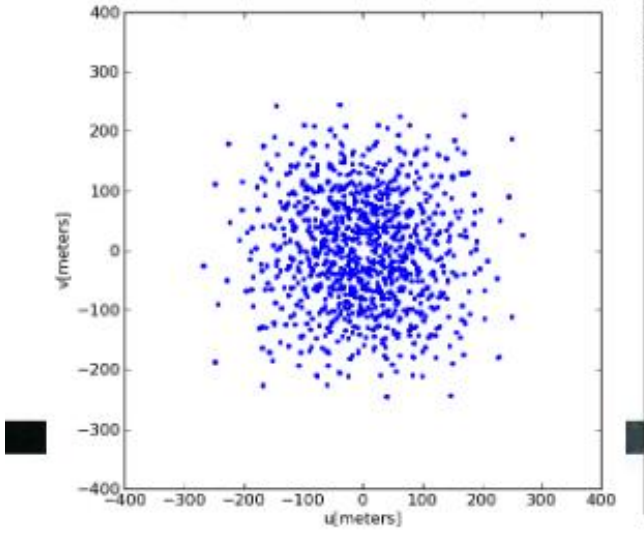


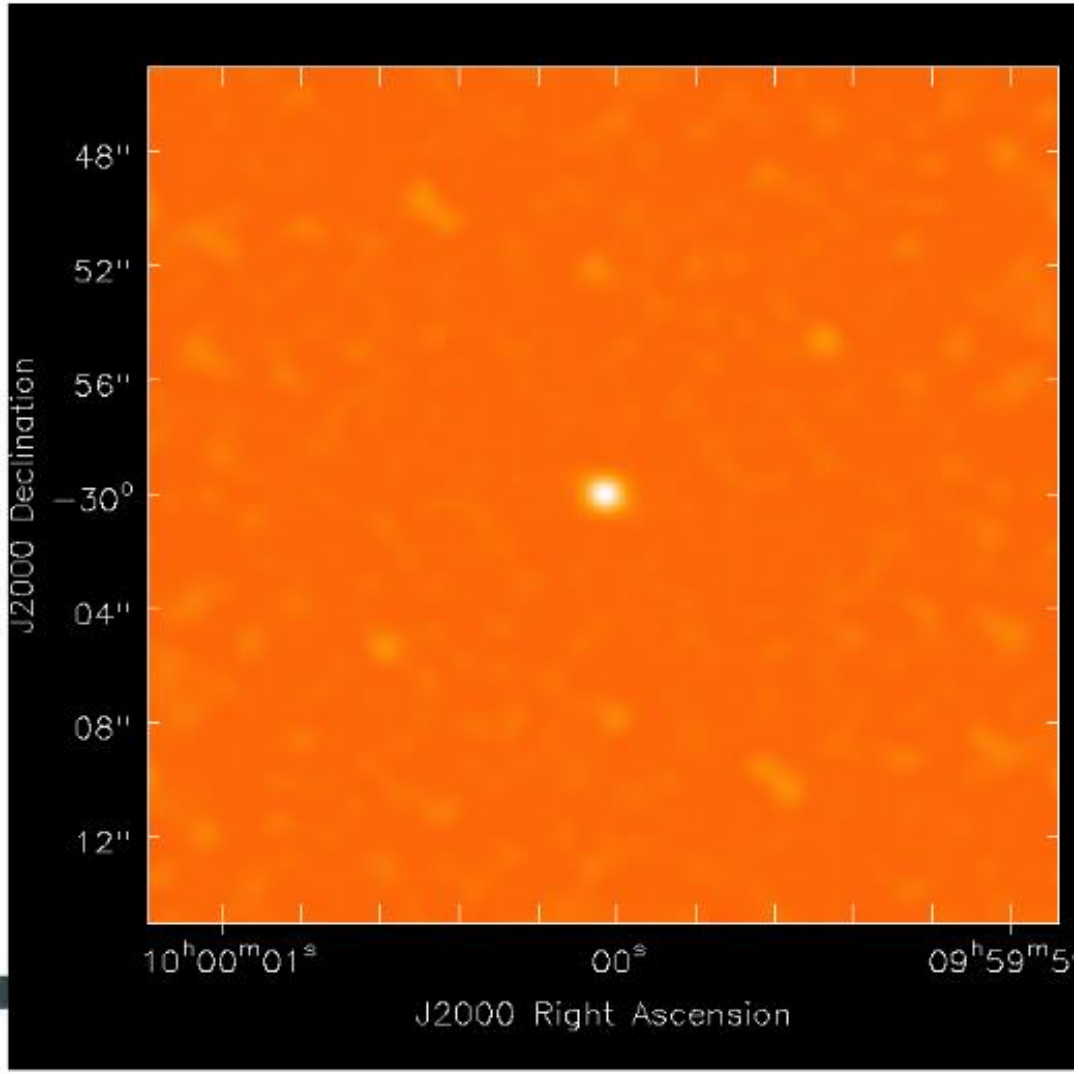




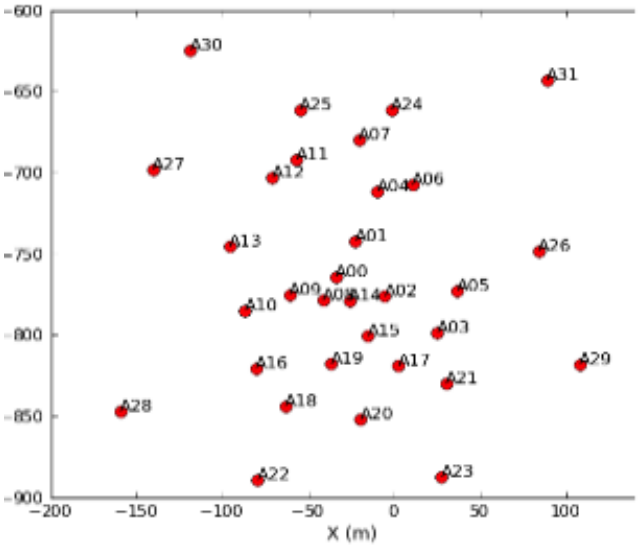
32 antene, „snapshot”

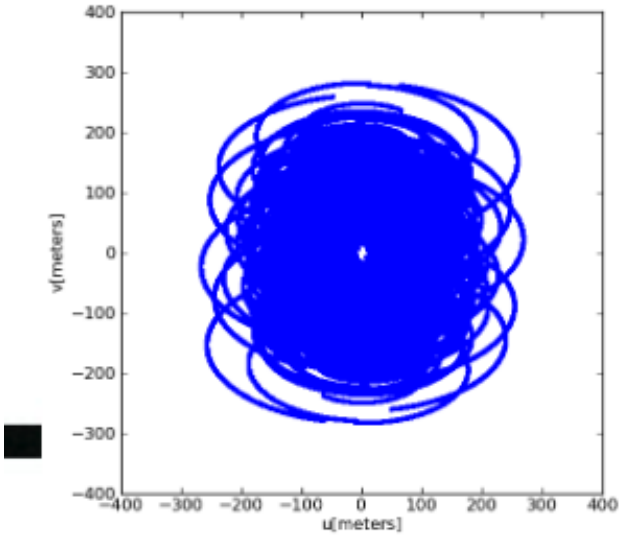


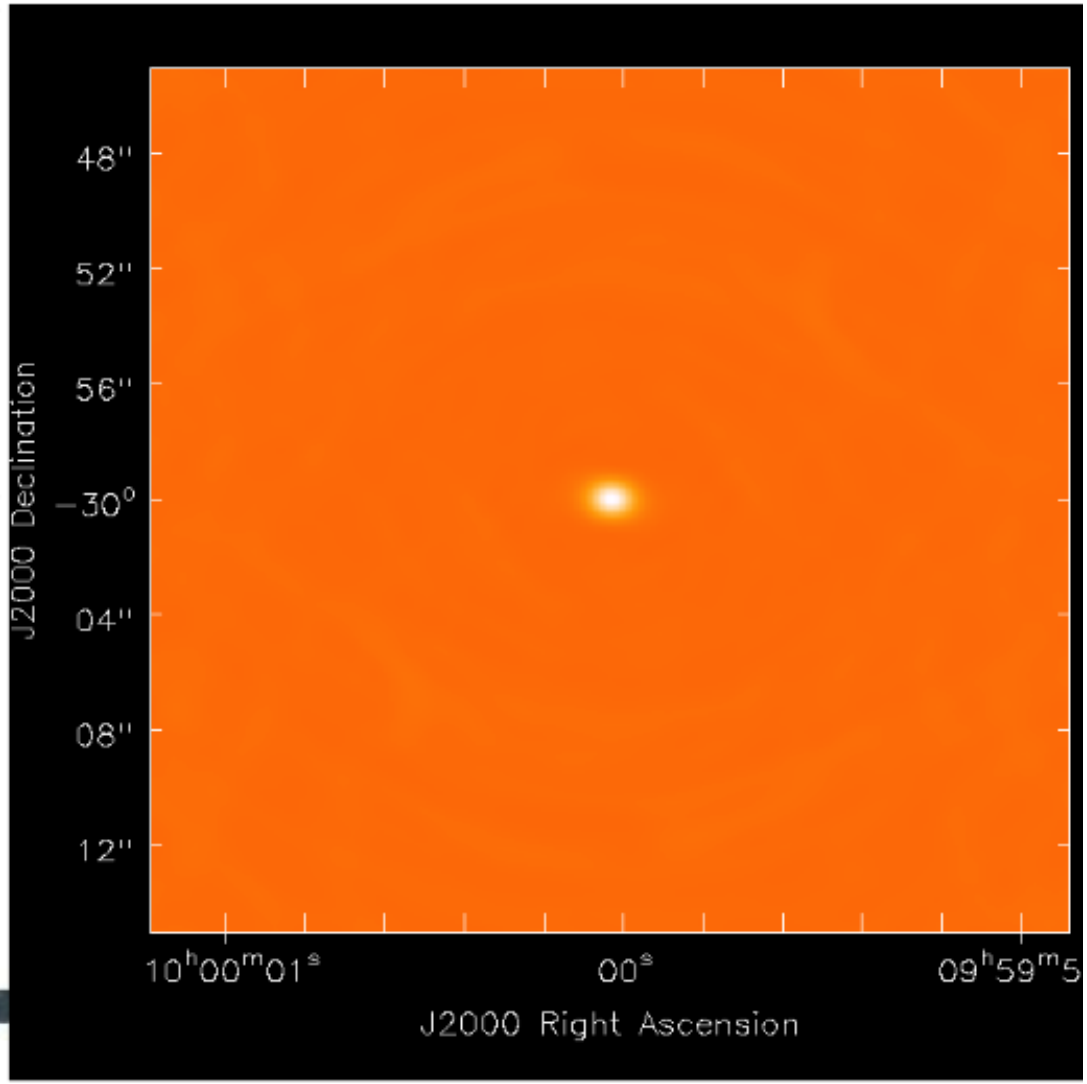




32 antene, 8 sati







OK, sada znamo raditi s interferometrima.

Što želimo?
Duže baze!

Kad ih želimo?
Odmah!

Zašto ih želimo?
Za sintezu najpreciznijeg teleskopa na svijetu!

VLBI: Very Long Baseline Interferometry – baze 10,000-12,000 kilometara i više – rezolucija = Hubble x 1000

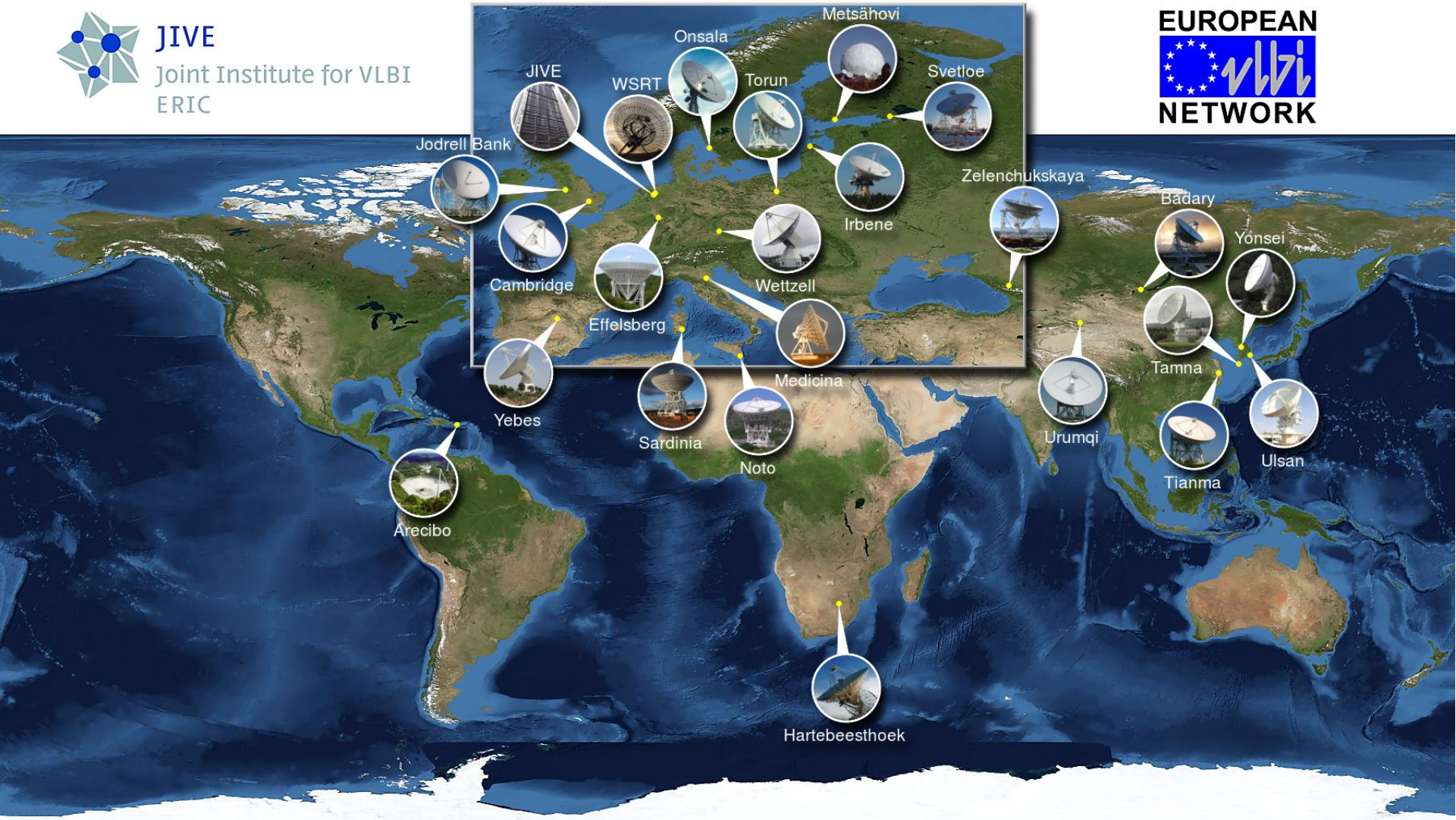
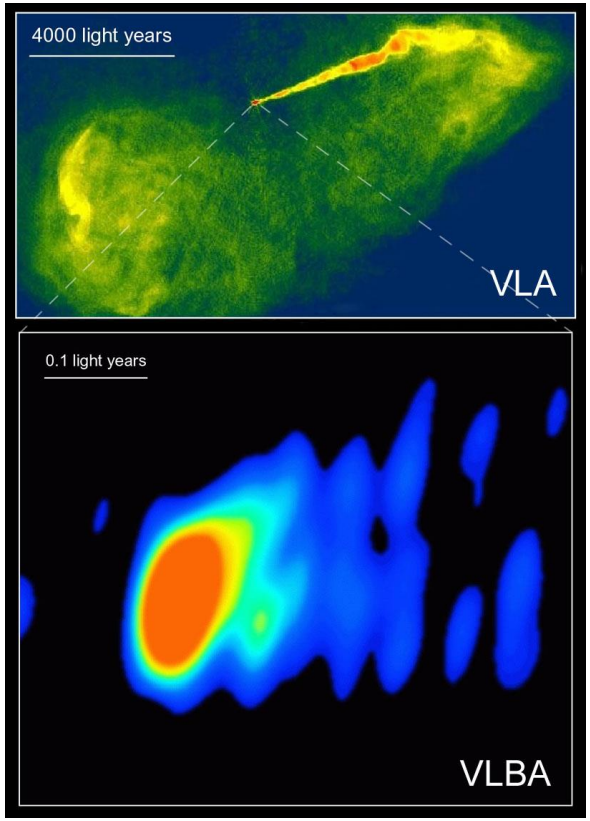


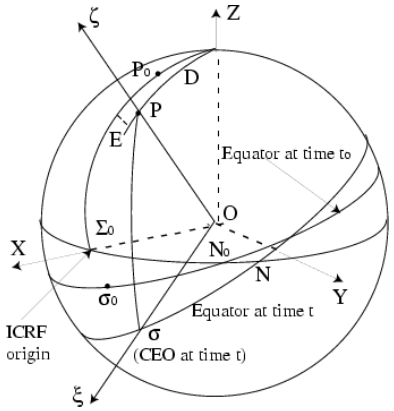
Image by Paul Boven (boven@jive.eu). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

elementi interferometra nisu međusobno povezani – podaci sa svakog teleskopa moraju se fizički transportirati do centra za obradu podataka gdje se nalazi superračunalo - korelator

Primjene VLBI

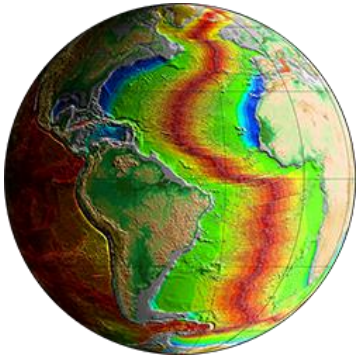


Visokorezolucijsko opažanje kozmičkih radio izvora



Definicija nebeskog koordinatnog sustava

Promatranje crne rupe u Mliječnom putu



Praćenje tektonskih ploča i duljine dana

Praćenje svemirskih letjelica

2.

PRIDE EKSPERIMENT

Primjena VLBI na praćenje svemirskih letjelica

Planetary Radio Interferometry and Doppler Experiment

JIVE inicijativa s ciljem ultra-preciznog određivanja vektora stanja svemirskih letjelica [Duev et al, 2012]

Bilo koja letjelica s radioodašiljačem

Bliski fazni kalibrator

VLBI opservable + radijalni Doppler

Povijest PRIDE tehnike

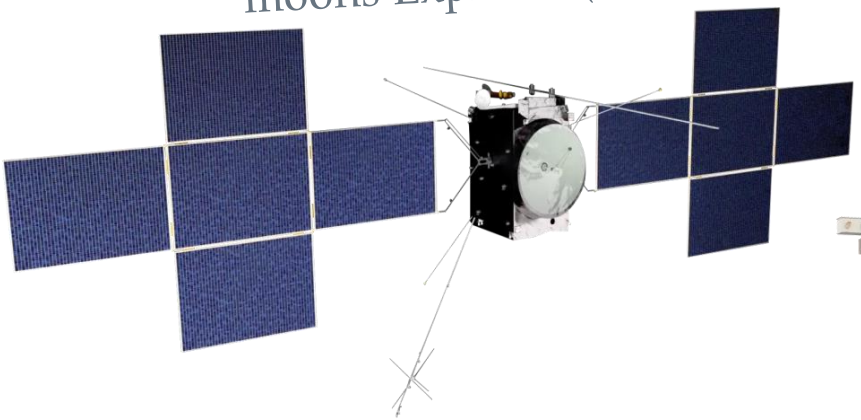
Cassini Huygens (2005.)
Praćenje slijetanja Huygens sonde na Saturnov mjesec Titan. VLBI mjerenja omogućila analizu vjetra u atmosferi.

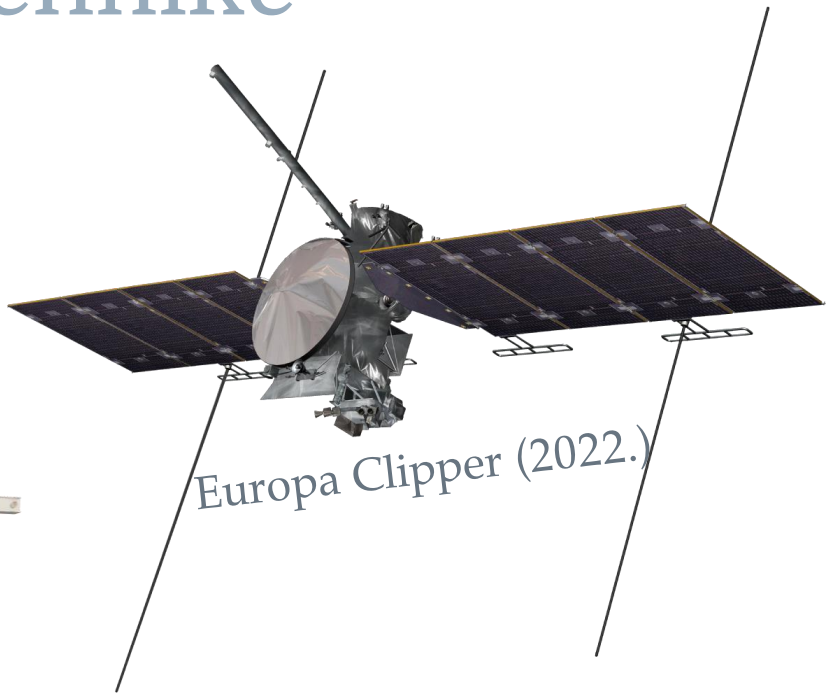
Venus Express (2012.)
Određivanje položaja do na 500-600 m duž putanje i 200-300 m okomito na putanju sa sigurnošću 3 sigma. Okultacija signala dala uvid u atmosferu.

Mars Express (2016.)
Položaj i brzina određeni s preciznošću **50 m i 30 μm/s.** Omogućilo analizu izbačaja mase Sunčeve korone i ispitivanje gravitacijskog polja Phobosa.

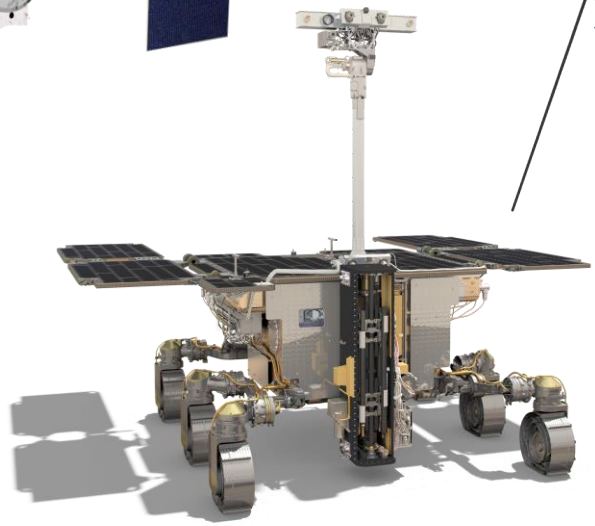
Budućnost PRIDE tehnike

JUICE: Jupiter ICy moons Explorer (2022.)





Europa Clipper (2022.)



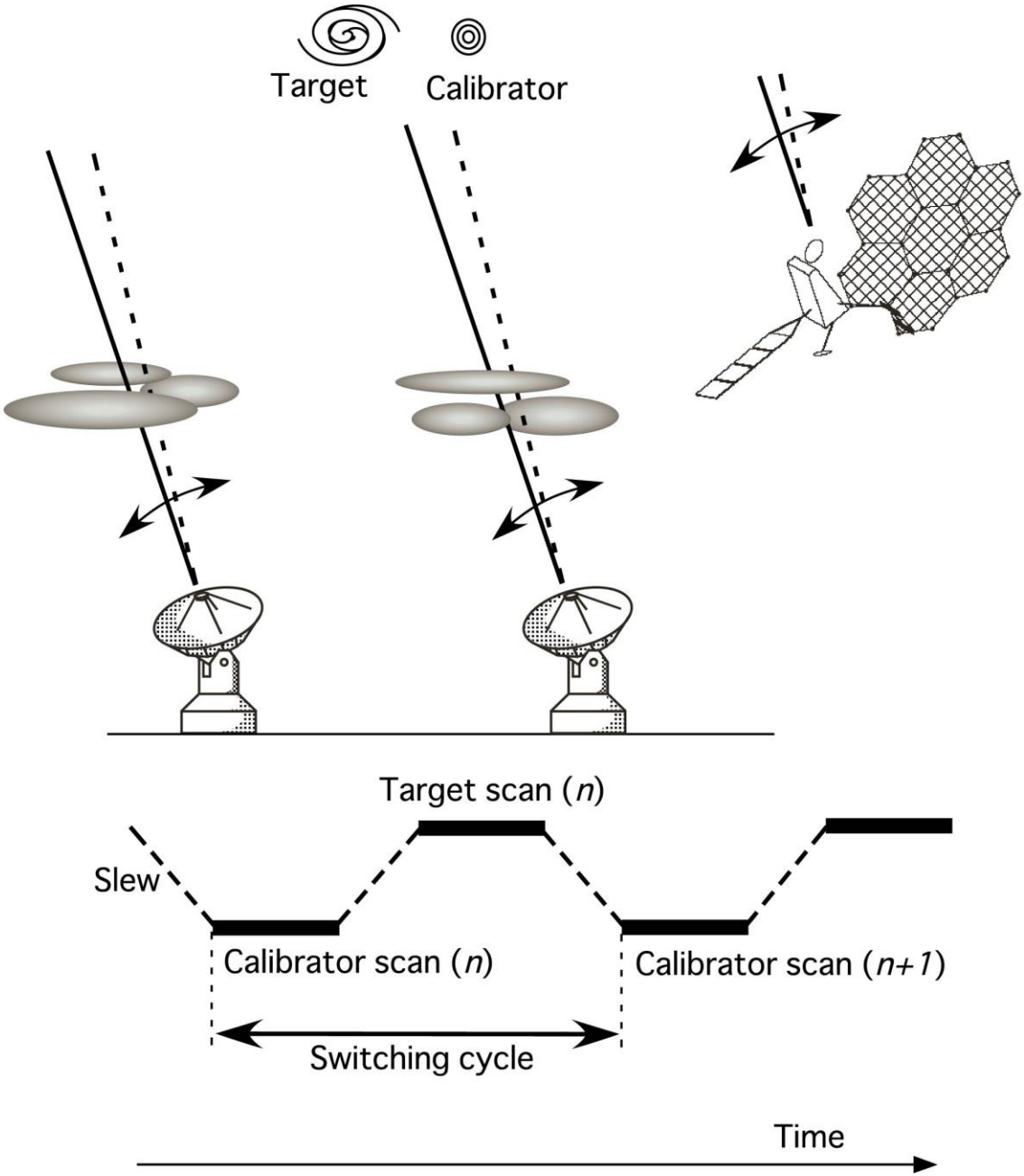
ExoMars 2020 sletač

Fazna kalibracija

Uz metu promatramo i bliski referentni kalibrator brzim pomicanjem antena (‘*nodding*’) kako bismo kompenzirali za fazne fluktuacije u atmosferi.

Dodatno, mogu se ukloniti i geometrijske pogreške, kao i nestabilnost lokalnog frekventnog standarda (maserskog sata).

Fazna kalibracija jedini je način za miliarksekundnu preciznost kod slabih izvora.



3.

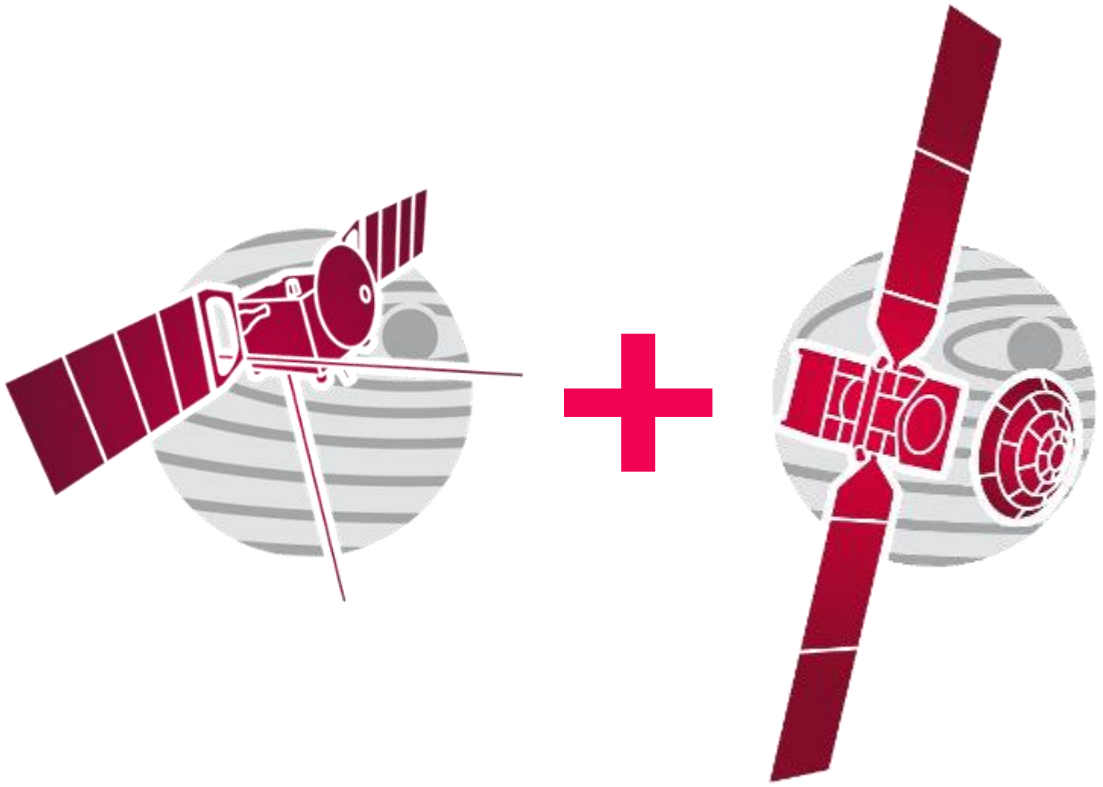
PLANIRANJE OPSERVACIJE

Koordinacija novog PRIDE eksperimenta

Dvostruki PRIDE eksperiment

Za cijenu jednog opažanja, mogli bismo rekonstruirati putanje za dva aktivna orbitera.

Mars Express (2001.)



ExoMars Trace Gas Orbiter (2016.)

Uspjeh eksperimenta ovisi o dostupnosti bliskog faznog kalibratora.

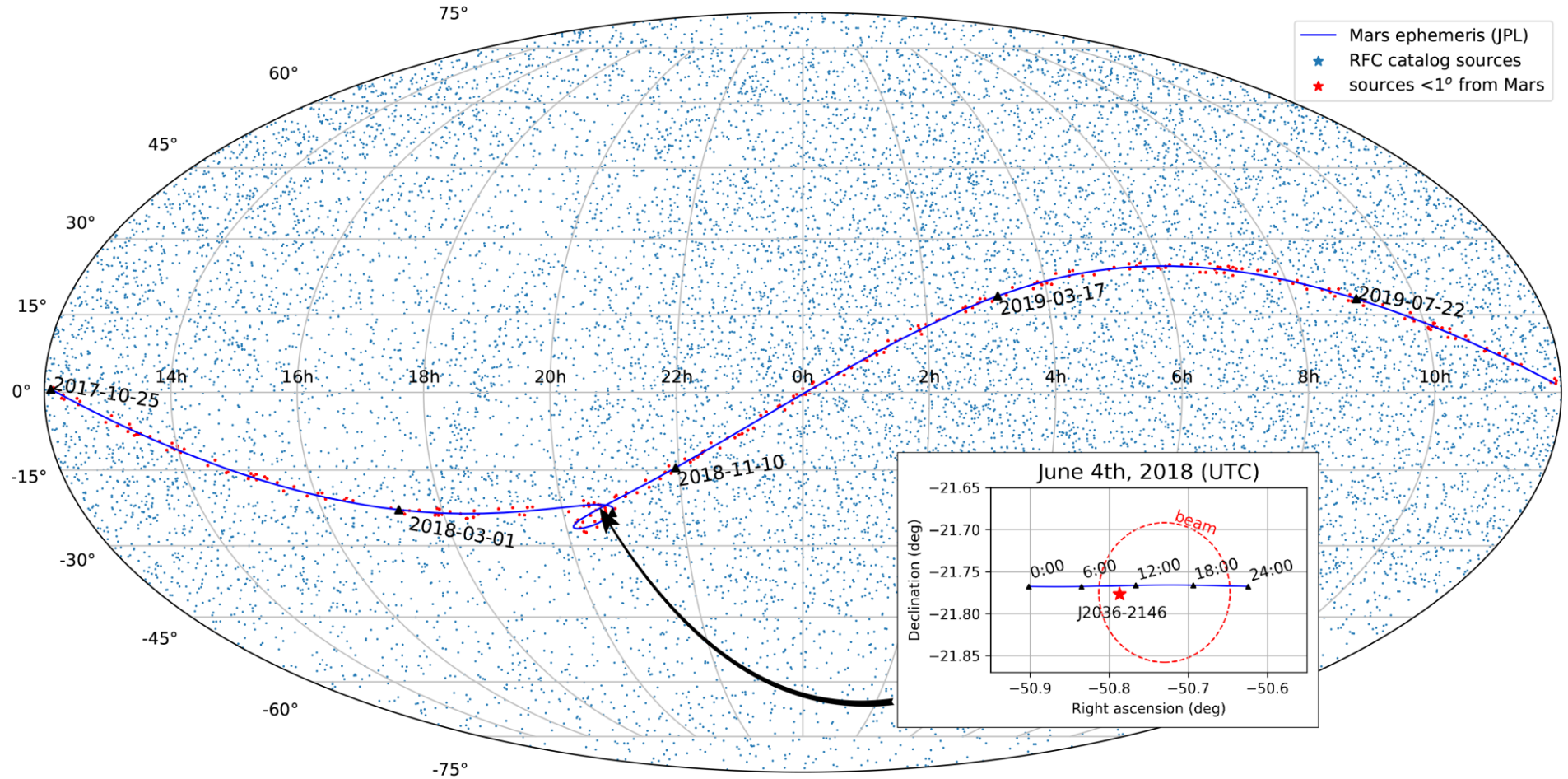
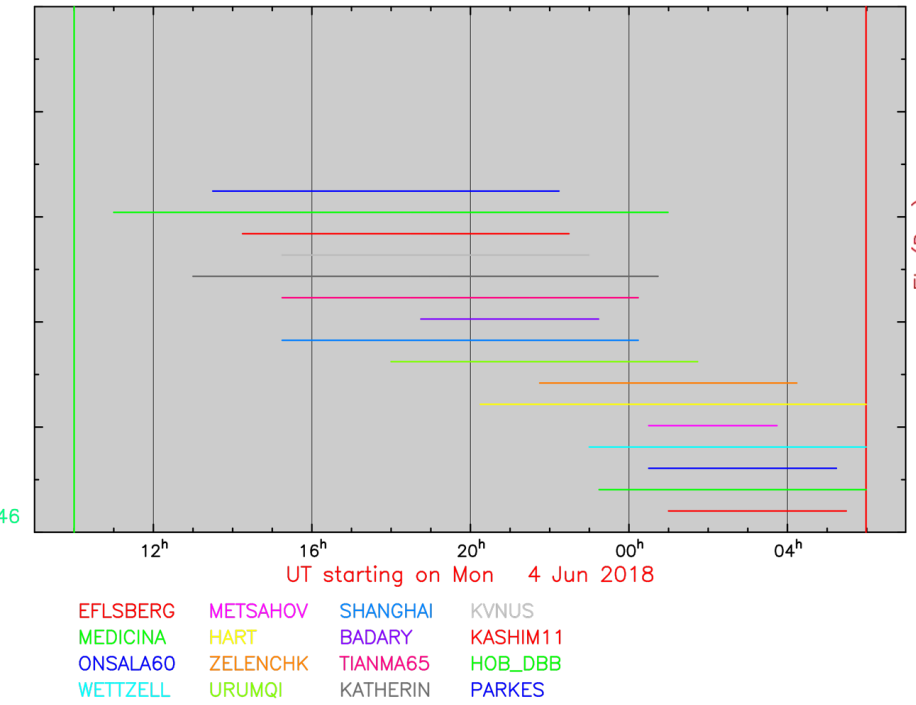


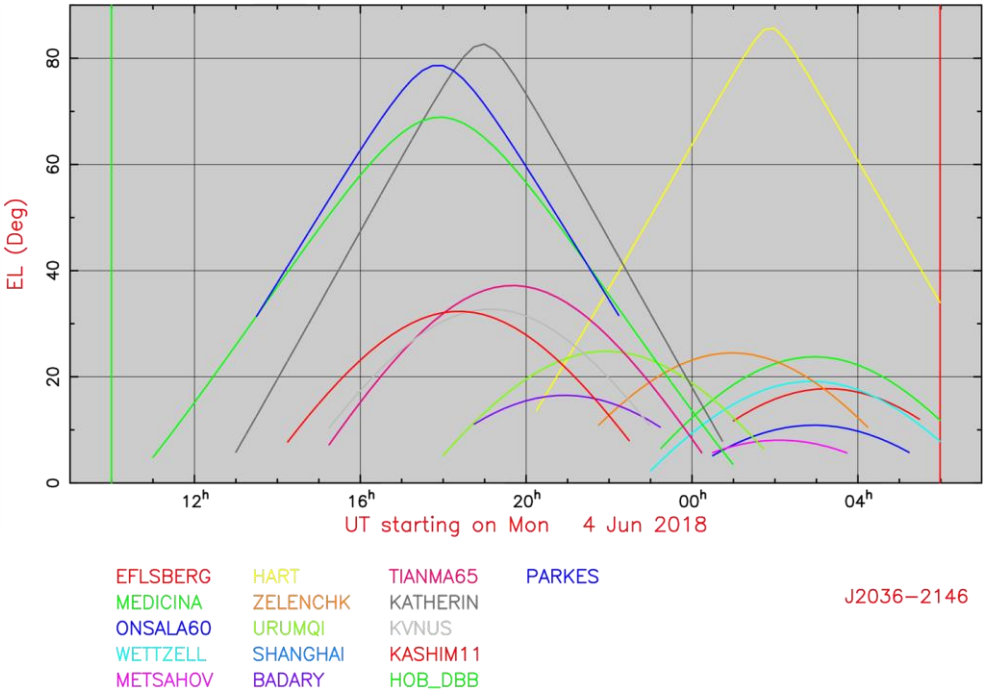
Table 1 Potential in-beam phase reference sources

RFC name	RA (h:m:s)	dec (d:m:s)	NED name	near pass date	Type
J2036-2146	20:36:51.172722	-21:46:36.74937	LQAC 309-021 001	2018-06-04	QSO
J2033-2253	20:33:16.629404	-22:53:17.00751	PKS 2030-23	2018-09-29	G
J2247-0850	22:47:52.193173	-08:50:22.07846	WISE J224752.19-085022.0	2018-12-02	*
J0033+0335	00:33:12.887751	+03:35:50.16565	GALEXASC J003312.82+033549.7	2019-01-14	UvS
J0103+0659	01:03:31.757397	+06:59:21.22107	PMN J0103+0659	2019-01-27	RadioS

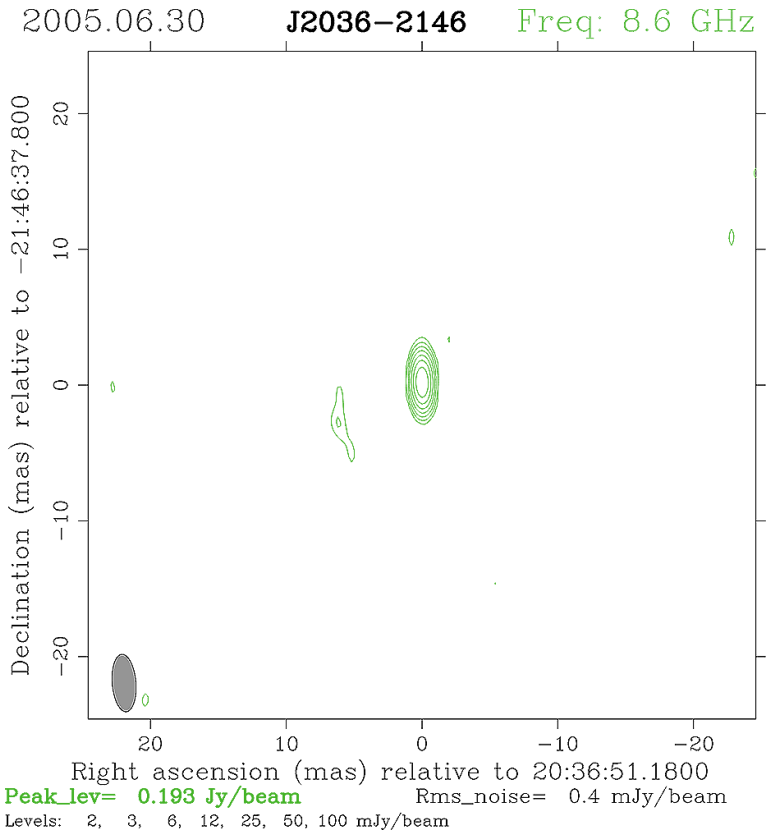
Promatračka prilika 4. lipnja 2018.

SCHED – program za planiranje i distribuciju VLBI promatračkih rasporeda





Nedovoljna elevacija za europske teleskope – promatrati od 16:00 do 22:00 UT koristeći teleskope Hobart (AU), Parkes (AU), Kashima (JP), Ulsan (KR), Katherine (AU), Tianma (CN), Shanghai (CN)



- kvazar na z=2.3
- radioizvor ravnog spektra
- kompaktan, nerazlučen (točkast)
- dobar kalibrator

Table 2 Angular separation between Mars and calibrator

Time (ISO, UTC)	Separation (d:m:s)
16:00:00.000	0:04:12.1915
17:00:00.000	0:04:52.4167
18:00:00.000	0:05:32.5103
19:00:00.000	0:06:12.2883
20:00:00.000	0:06:51.6035
21:00:00.000	0:07:30.3479
22:00:00.000	0:08:08.4561

- radijus vidnog polja barem 5′
- Rayleigh: $\theta[rad] = 1.22\lambda/D$
- letjelica emitira 8.4 GHz (3.6 cm)
- otpisujemo antene D>30m

4.
ZAKLJUČAK

Osvrnimo se na ključne pojmove

Ključni pojmovi

Dugobazična interferometrija

U 50 godina od svog začetka, VLBI je omogućila najoštriji pogled u Svemir. VLBI mreže danas se prostiru po svim kontinentima i čak izvan planeta, a njihova sinteza formira ekvivalentan teleskop s miliarksekundnom rezolucijom.

Planetary Radio Interferometry and Doppler Experiment

PRIDE tehnika služi se VLBI mrežama za ultraprecizno praćenje svemirskih letjelica u Sunčevom sustavu. Primjena ove metode na svemirske misije dala je uvid u unutarnje planete Sustava, a u budućnosti će se primjenjivati i na misije na vanjske planete.

Dvostruki PRIDE eksperiment

Rijetka prilika za poboljšavanje PRIDE tehnike kroz simultano promatranje dvaju letjelica i kalibratora bit će moguća 4. lipnja 2018. Osmišljena je promatračka kampanja EVN teleskopom kojom bismo mogli analizirati orbitalnu dinamiku Marsa.

Prilike za buduće istraživanje

Hvala!

Ima li pitanja?

: klindzic@jive.eu