

## **Forthcoming mutual events of planets and astrometric radio sources**

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**Abstract.** Radio astronomy observations of close approaches of the Solar system planets to compact radio sources as well as radio source occultations by planets may be of large interest for planetary sciences, dynamical astronomy, and testing gravity theories. In this paper, we present extended lists of occultations of astrometric radio sources observed in the framework of various astrometric and geodetic VLBI programs by planets, and close approaches of planets to radio sources expected in the nearest years. Computations are made making use of the EPOS software package.

### **Introduction**

Very long baseline interferometry (VLBI) and single dish radio observations of close approaches of the Solar system bodies (planets, satellites, asteroids) to compact radio sources, as well as radio source occultations by planets may be of large interest for planetary sciences, dynamical astronomy, and testing gravity theories. In this paper we present a new extended version of the list of occultations of astrometric radio sources (i.e. having reliable coordinates at the milliarcsecond level of accuracy) by planets, and close approaches of planets to radio sources expected in the nearest 40 years compiled at the Pulkovo Observatory. Previous lists presented in [1, 2] were substantially revised in two respects. First, a new version of software to find occultation and approaches was used. Second, the list of astrometric radio sources was extended.

All computations of the mutual events circumstances have been made at the Pulkovo Observatory making use of the EPOS software package (<http://www.gao.spb.ru/personal/neo/ENG/ESUPP/main.htm>) and other programs. The list of astrometric radio sources has been taken from the OCARS catalog available at [http://www.gao.spb.ru/english/as/ac\\_vlbi/ocars.txt](http://www.gao.spb.ru/english/as/ac_vlbi/ocars.txt).

### **Occultations of astrometric radio sources by planets**

Observations of occultations of compact radio sources by Solar system planets may be interesting for several astronomical and physical applications, such as testing GR [1], improvement of planet orbits and their tie to the International Celestial Reference Frame (ICRF) [3], and planetary researches [4, 5]. List of nearest expected events is shown in Table 1 along with the elongation from the Sun. The latter is important for planning of radio astronomy observations. If the radio source is too close to the Sun, it may be impossible to observe it. Nevertheless, we include all the events found during our calculations for completeness.

Occultations of radio sources by planets, like solar eclipses, generally speaking can only be observed in a limited region. A map of the shadow path and detailed circumstances for each VLBI station situated on the shadow path for several selected occultations that will occur in regions with several stations and hence most interesting for radio astronomy experiments are given in [2].

One can see that occultations of astrometric radio sources by planets, especially by outer planets, suitable for radio observations are rare events. However, some physical applications do not require knowledge of accurate source coordinates. For such studies, any compact radio source can be observed, which makes experiment scheduling much easier.

### **Close angular approaches of planet to astrometric radio sources**

During close angular approaches of Solar system planets to astrometric radio sources, the apparent positions of these sources shift due to relativistic effects. Thus, these events may be used for testing gravity theories, see, e.g., [1] and paper cited therein. This fact was successfully demonstrated in the experiments on the measurements of radio source position shifts during the approaches of Jupiter carried out in 1988 and 2002 [6, 7]. Basic circumstances for the coming events (10 years in advance for Jupiter and 15 years for other planets) are shown in Table 2.

Table 1. Occultations of astrometric radio sources by planets

Planet	Date, UT Y M D	Source	Elongation, deg
Venus	2012 12 24.4	1631–208	23W
Mercury	2014 07 30.2	0750+218	11W
Venus	2015 08 06.8	0947+064	15E
Jupiter	2016 04 10.4	1101+077	144E
Venus	2020 01 16.7	2220–119	38E
Venus	2020 07 17.7	0446+178	42W
Mercury	2022 11 14.7	1529–195	4E
Jupiter	2025 09 18.6	0725+219	65W
Mercury	2027 03 21.7	2220–119	27W
Saturn	2028 10 24.8	0223+113	173W
Mercury	2029 01 14.3	1958–179	5E
Venus	2029 02 28.2	2221–116	6W
Mercury	2029 04 16.1	0243+181	19E
Mercury	2029 12 27.9	1858–212	8E
Mercury	2030 02 27.6	2208–137	9W
Jupiter	2033 02 04.2	2104–173	1W

## Summary

In this paper, we present new lists of found mutual events of astrometric extragalactic radio sources and Solar system planets. The circumstances of both occultations and close angular approaches have been calculated. For these computations, we considered only astrometric radio sources having reliable coordinates at the milliarcsecond level of accuracy. Observations of these sources are used when the tie to the ICRF is important. For other, mainly physical, studies any compact source may be suitable for observations, see, e.g., [3].

For various tasks, VLBI or single-dish radio observations can be performed. Different observing techniques and strategies may require pre-computation of different circumstances of the event of interest. These data can be calculated as well on request using the EPOS software and associated programs developed at the Pulkovo Observatory.

Tables presented above contain only basic circumstances for events expected in limited period of time. Full version of these Tables for all the events found for the period till 2050 with more details is available at the Pulkovo Observatory Web site [http://www.gao.spb.ru/english/as/ac\\_vlbi/#Approaches](http://www.gao.spb.ru/english/as/ac_vlbi/#Approaches). Besides, detailed computation of the circumstances for selected events of special interest, including also small Solar system bodies and extended lists of radio sources, can be performed on request.

## References

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Table 2. Close angular approaches of planets to astrometric radio sources. In this table,  $d$  is the angular distance between the planet and radio source,  $E$  is the elongation from the Sun

Planet	Date, UT Y M D	Source	$d$ , arcsec	$E$ , deg
Jupiter	2011 07 03.6	0210+119	341	66W
	2011 08 16.8	0229+131	488	104W
	2011 09 13.1	0229+131	149	130W
	2011 11 27.2	0156+105	285	147E
	2012 02 04.0	0201+113	490	78E
	2012 02 20.3	0210+119	342	64E
	2012 04 22.5	0300+162	115	16E
	2013 02 28.1	0420+210	216	88E
	2013 03 29.5	0435+217	563	63E
	2013 10 23.0	0723+219	123	100W
	2013 11 07.2	0725+219	388	114W
	2013 11 22.1	0723+219	351	130W
	2014 07 26.1	0814+201	488	1W
	2014 08 22.8	0839+187	360	21W
	2014 09 09.3	0854+178	310	35W
	2016 10 19.2	1229-021	506	18W
	2017 10 13.7	1352-104	69	10E
	2019 10 20.5	1717-229	222	55E
	2019 10 28.4	1723-229	184	48E
	2020 01 30.3	1853-226	542	27W
	2020 02 15.0	1907-224	91	39W
	2020 08 02.0	1922-224	78	160E
	2020 10 24.2	1922-224	355	79E
	2021 02 19.9	2104-173	149	17W
	2021 03 16.0	2126-158	528	36W
	2021 11 29.8	2147-144	79	77E
	Saturn	2013 12 05.8	1459-149	525
2014 08 26.3		1459-149	486	75E
2015 06 19.1		1548-177	156	152E
2015 11 19.1		1614-195	64	10E
2017 12 13.3		1752-225	73	8E
2019 11 16.6		1907-224	240	53E
2021 08 10.7		2044-188	20	171E
2021 08 19.0		2042-191	441	163E
2021 12 01.0		2042-191	382	60E
2021 12 08.1		2044-188	114	53E
2022 03 11.2		2126-158	521	31W
2022 05 29.1		2147-144	288	103W
2023 04 13.3		2221-116	33	49W
2023 04 18.2		2223-114	276	54W
2024 01 04.6		0220-119	370	50E
2024 03 18.5		2252-090	158	16W
2024 03 28.0		2256-084	388	25W
Uranus	2013 05 05.4	0036+030	558	35W
	2013 10 03.3	0036+030	362	179W
	2016 07 11.8	0127+084	313	86W
	2016 08 16.9	0127+084	259	120W
	2017 04 12.8	0127+084	499	2E
Neptune	2024 09 02.7	2354-021	498	162W