EPSC Abstracts
Vol. 13, EPSC-DPS2019-412-3, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Earth-based radar observations of the spin axis orientation, spin precession rate, and moment of inertia of Venus

Jean-Luc Margot (1,2) (1) UCLA Department of Earth, Planetary, and Space Sciences, Los Angeles, California, USA
(2) UCLA Department of Physics and Astronomy, Los Angeles, California, USA (jlm@epss.ucla.edu)

Abstract

Venus is Earth's nearest planetary neighbor and closest analog in the Solar System in terms of mass, radius, and density. However, Venus remains enigmatic on a variety of fundamental levels: the size of its core is unknown [e.g., 20]; whether the core is solid or liquid is uncertain [e.g., 22, 1, 4, 16]; and its atmospheric superrotation, 60 times faster than the solid body, is not well understood [e.g., 18, 17].

Since 2006, I have been obtaining Earth-based radar observations of Venus with the goal of advancing our understanding of Venus's interior and atmosphere with two key measurements. First, I am securing accurate measurements of the spin axis orientation of Venus, which are essential to enable a high-precision measurement of the spin precession rate. This precession measurement will in turn yield the polar moment of inertia of the planet, an unmeasured yet fundamental quantity that, absent seismology data, will provide the most reliable estimate of the size of the core. Second, I am quantifying the amplitudes of secular and daily variations in the length of day (LOD), which will provide new data constraints relating to variations in atmospheric angular momentum (AAM) and the dynamics of the atmosphere. These constraints, in conjunction with general circulation models (GCMs), will enable tests of hypotheses related to, e.g., the superrotation and the generation of distinctive planetary-scale atmospheric features that are stationary with respect to the solid body [5, 15]. In this presentation, I focus on the spin axis orientation, precession rate, and moment of inertia.

The current estimates of the spin axis orientation of Venus enabled by the Magellan mission [19] include a landmark-based estimate with 46″ uncertainties [3, $\alpha = (272.76 \pm 0.02)^\circ, \delta = (67.16 \pm 0.01)^\circ$] and a gravity-based estimate with 23″ uncertainties [10, $\alpha = (272.743 \pm 0.006)^\circ, \delta = (67.156 \pm 0.006)^\circ$]. Between the Magellan epoch of ∼J1990.0 and J2030.0, the predicted excursion in the orientation of the spin axis is approximately 82″ [2]. If we obtained a measurement of the spin axis orientation with infinite precision at epoch ∼J2030.0 and combined it with the best Magellan estimate, the measured precession rate would have residual uncertainties of 28% (23″/82″), which is not geophysically useful.

Between 2006 and 2019, I have obtained 20 Earth-based radar observations of the *instantaneous* spin state of Venus with the Goldstone Solar System Radar and the Green Bank Telescope [e.g., 11]. These observations are sufficient to measure the spin axis orientation with a precision of 8″. The observations also enable an unambiguous detection of Venus's spin precession and an estimate of the moment of inertia with 10–15% uncertainties. I will describe these results and the prospects associated with the 2020 and 2021 observations.

The Earth-based radar technique used in this work relies on observations of speckles [6, 7, 8, 9] and is sometimes referred to as "radar speckle tracking". It yielded a measurement of the spin axis orientation of Mercury with <5″ precision [13, 14], which is in good agreement (<1″) with an independent estimate obtained by analyzing four years of MESSENGER spacecraft data [21, 12].

Acknowledgments

This work was supported in part by the NASA Planetary Astronomy program under grants NNG05GG18G, NNX09AQ69G, NNX12AG34G, and 80NSSC19K0870. The Goldstone Solar System Radar is operated by NASA's Jet Propulsion Laboratory. The Green Bank Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc. Software and support from NASA's Navigation and Ancillary Information Facility (NAIF) is gratefully acknowledged.

References

[1] J. Arkani-Hamed and M. N. Toksoz. Thermal evolution of Venus. *Physics of the Earth and Planetary Interiors*, 34:232–250, 1984.

[2] L. Cottereau and J. Souchay. Rotation of rigid Venus: a complete precession-nutation model. A&A, 507:1635–1648, 2009.

[3] M. E. Davies, T. R. Colvin, P. G. Rogers, P. W. Chodas, W. L. Sjogren, E. L. Akim, V. A. Stepaniants, Z. P. Vlasova, and A. I. Zakharov. The rotation period, direction of the north pole, and geodetic control network of Venus. *J. Geophys. Res.*, 97:13141–, 1992.

[4] C. Dumoulin, G. Tobie, O. Verhoeven, P. Rosenblatt, and N. Rambaux. Tidal constraints on the interior of Venus. *Journal of Geophysical Research (Planets)*, 122:1338–1352, 2017.

[5] Tetsuya Fukuhara, Masahiko Futaguchi, George Hashimoto, Takeshi Horinouchi, Takeshi Imamura, Naomoto Iwagaimi, Toru Kouyama, Shin-ya Murakami, Masato Nakamura, Kazunori Ogohara, Mitsuteru Sato, Takao M Sato, Makoto Suzuki, Makoto Taguchi, Seiko Takagi, Munetaka Ueno, Shigeto Watanabe, Manabu Yamada, and Atsushi Yamazaki. Large stationary gravity wave in the atmosphere of venus. *Nature Geoscience*, 10:85–88, 2017.

[6] P. E. Green. Radar Astronomy Measurement Techniques. Technical Report 282, MIT Lincoln Laboratory, 1962.

[7] P. E. Green. Radar measurements. In J. V. Evans and T. Hagfors, editors, *Radar Astronomy*. McGraw-Hill, 1968.

[8] I. V. Holin. *Izvestiya Vysshikh Uchebnykh Zavedenii, Radiofizika*, 31(5):515–518, 1988.

[9] I. V. Holin. *Izvestiya Vysshikh Uchebnykh Zavedenii, Radiofizika*, 35(5):433–439, 1992.

[10] A. S. Konopliv, W. B. Banerdt, and W. L. Sjogren. Venus Gravity: 180^{th} Degree & Order Model. *Icarus*, 139:3–18, 1999.

[11] J. L. Margot. High-precision measurements of planetary spin states: Mercury, Venus, Galilean Satellites. In *EPSC-DPS Joint Meeting*, 2011.

[12] J. L. Margot, S. A. Hauck, E. Mazarico, S. Padovan, and S. J. Peale. Mercury's Internal Structure. In S. C. Solomon, L. R. Nittler, and B. J. Anderson, editors, *Mercury: The View after MESSENGER*, pages 85–113. Cambridge University Press, 2018.

[13] J. L. Margot, S. J. Peale, R. F. Jurgens, M. A. Slade, and I. V. Holin. Large Longitude Libration of Mercury Reveals a Molten Core. *Science*, 316:710–714, 2007.

[14] J. L. Margot, S. J. Peale, S. C. Solomon, S. A. Hauck, II, F. D. Ghigo, R. F. Jurgens, M. Yseboodt, J. D. Giorgini, S. Padovan, and D. B. Campbell. Mercury's moment of inertia from spin and gravity data. *Journal of Geophysical Research (Planets)*, 117(E16), 2012.

[15] T. Navarro, G. Schubert, and S. Lebonnois. Atmospheric mountain wave generation on Venus and its influence on the solid planet's rotation rate. *Nature Geoscience*, 11(7):487–491, 2018.

[16] J. G. O'Rourke, C. Gillmann, and P. Tackley. Prospects for an ancient dynamo and modern crustal remanent magnetism on Venus. *Earth and Planetary Science Letters*, 502:46–56, 2018.

[17] Peter L. Read and Sebastien Lebonnois. Superrotation on venus, on titan, and elsewhere. *Annual Review of Earth and Planetary Sciences*, 46(1):175–202, 2018.

[18] Agustín Sánchez-Lavega, Sebastien Lebonnois, Takeshi Imamura, Peter Read, and David Luz. The Atmospheric Dynamics of Venus. *Space Science Reviews*, 212(3):1541–1616, 2017.

[19] R. S. Saunders, G. H. Pettengill, R. E. Arvidson, W. L. Sjogren, W. T. K. Johnson, and L. Pieri. The Magellan Venus radar mapping mission. *Journal of Geophysical Research*, 95:8339–8355, 1990.

[20] Suzanne E. Smrekar, Anne Davaille, and Christophe Sotin. Venus Interior Structure and Dynamics. *Space Science Reviews*, 214(5):88, 2018.

[21] A. Stark, J. Oberst, F. Preusker, S. J. Peale, J. L. Margot, R. J. Phillips, G. A. Neumann, D. E. Smith, M. T. Zuber, and S. C. Solomon. First MESSENGER orbital observations of Mercury's librations. *Geophys. Res. Lett.*, 42:7881–7889, 2015.

[22] D. J. Stevenson. Planetary magnetic fields. *Reports of Progress in Physics*, 46:555–620, May 1983.