SPIN DYNAMICS AND DEEP INTERIOR OF MERCURY FROM EARTH-BASED HSDI. Igor V. Holin, Kravchenko str. 12-244, Moscow, Russia (holin@mail.cnt.ru).

Introduction: HSDI (Speckle Displacement Interferometry as proposed by Holin [1], [2]) is a new Earth-based radar technique to measure spin-vector variations (SVV) of planetary crusts to high precision. HSDI promises to be very effective in spin dynamics and deep interior studies of Mercury, Venus, Mars, and the Moon. To date, HSDI potentials in SVV are far of reach of other Earth-based techniques and possible space missions.

Historical Overview: In an attempt undertaken on my own initiative to define the limits to which rotation of an arbitrary object can be measured remotely by laser or radar, HSDI was developed in 1984-1987 mostly in libraries and at home, and also in an optical research laboratory at Moscow aviation institute (part time) with the thesis defended in March 1989.

As applied to radar astronomy, I presented HSDI in May 1989 at the Institute of radioengineering and electronics, USSR academy of sciences, where it was rejected by the group of academician V. A. Kotel'nikov because of complete misunderstanding. 20 years later, in March 2009, after HSDI had been checked positively (!) in USA, that outcome was conclusively confirmed by another academician, L. M. Zelenyi (Space research institute, Russian academy of sciences).

After having known about HSDI in May 2001 on the initiative of S. J. Peale and in accordance with the procedure [3] for determination of parameters related to the interior of Mercury, HSDI was tested in part, to ~ 10% and ~ 4% of its limiting accuracy in the absolute value and orientation of the spin-vector respectively, in USA with the Goldstone – Green Bank (GGB) radar interferometer since 2002 [4]. In 2004, some HSDI measurements were included into a nomination for the Urey Prize (outstanding achievements) and helped J.-L. Margot to receive it. Those experiments were proposed in 1988 [1], 1992 [2], patented in 1994 [5], and described in detail in 1998 [6], 1999 [7].

HSDI properties: HSDI is characterized by extremely fast operation, highest accuracy, and shaking economic efficiency.

Faster than light. The observation time for each HSDI experiment is within several tens of seconds, while the time taken by a radar signal or light to reach Mercury near its inferior conjunction with Earth and come back is about ten minutes. In this respect, HSDI operates faster than light. The total time for each experiment is within 11 minutes. Compare: a spacecraft needs ~ 7 years to become a Mercury orbiter plus a year of operation in the orbit, i.e. the total time is ~ 8 years.

Accuracy. HSDI limiting accuracy or Holin's limit (HL) [2] in an instantaneous spin-vector of Mercury's crust is $\sigma_{GGB} \sim 3 \wedge 10^{-6}$ for the current GGB configuration and up to $\sigma_{EAA} \sim 2 \wedge 10^{-7}$ with a new more powerful radar transmitter which can be constructed in the middle of Euro-Afro-Asia (EAA) [8], [9]. The analysis includes thermal noises in receivers, speckle decorrelation during their displacement, aperture averaging, atmospheric refraction, decorrelation from a finite speckle size along the line-of-sight [2], [6], [7], [9]. Many interferometers in use and repetition of the experiments lead to further improvements by ~ 2 orders of magnitude. These HSDI limits can not be approached by other projects in any observable future.

Economic efficiency. Each HSDI experiment gives two components of an instantaneous spin-vector and is of order ~ 10^4 USD. Two HSDI experiments cover more than a half of the four-parameter procedure [3] by measuring the 88-day libration amplitude φ of Mercury's crust, instantaneous obliquity, and deviation from a Cassini state. E.g., the current value for φ follows from a single HSDI experiment on June 02, 2002 as ~ 36" ± 5" (fig. 3A in [4]). Compare: an orbiter mission to Mercury is of order ~ 10^9 USD. From here, HSDI promises to save (tens) milliards in spin dynamics and deep interior studies of Mercury, Venus, Mars, and the Moon.

Full Group of States: One can imagine several states of Mercury's outer core, at the core-mantle boundary. State 1 is purely liquid when the core ignores the 88-day SVV of the mantle. When in State 2, the core partially follows the 88-day SVV. State 3 is a completely solidified core with the same SVV as the mantle.

With the absolute accuracy, Mercury is in State 2 for which States 1, 3 are the two ideal extreme cases.

Is Mercury's Core Liquid or Solid: To answer such a question (with State 2 missed!), the current projects promise to distinguish between States 1, 3 and deal with State 1 (State 3 is trivial). E.g., with $s = c_L/c$ near 0.5, Mercury is rather in State 1 than in State 3 and inversely with s near 1 [3], [10].

While the current projects can deal with States 1, 3, HSDI "allows" Mercury to be in State 2 covering the full range of Mercury states and possible values for s.

To Deal with Mercury: In accordance with the above definition, State 2 is specified through determination that the core partially follows the mantle. HSDI can deal with the problem via high precision monitor-

ing of the 88-day SVV which should be different for State 2 from those in States 1, 3. State 2, when specified through detection of the 88-day variation in the moment of inertia, can give valuable information about Mercury's interior properties. When the accuracy is not enough to specify State 2, approximations by States 1, 3 can be approved.

Current State of Mercury's Core: Initial HSDI data were reduced to $\varphi \sim 60''$ [11] which specified a perfectly liquid core at $\sim 80\% - 85\%$ confidence and was the extreme value for the expected range $20'' - 60''$ [3]. The current value $\varphi \sim 36''$ [4] is centered at $s \sim 0.5$ with respect to the gravitational data from Mariner 10 and imply that at $\sim 95\%$ confidence the core is not in State 3 where at $\sim 50\%$ and $\sim 45\%$ confidence the core is in States 1 and 2 respectively [10]. From Messenger [12], volcanic activity on Mercury is dying away showing that the outer core at present is not so liquid as it was a billion or two years ago when the planet was volcanically active. With this argument added, State 2 becomes most probable. A weak, mostly of core origin magnetic field from Messenger [13] is consistent with State 2 as well. State 2 is much more difficult to deal with. As a compensation, it promises to be much more informative about Mercury's deep interior as compared to States 1, 3.

HSDI Projects on Mercury's Deep Inside:

GGB. Dedicated mainly to the needs of spacecraft exploration, the radar transmitter at Goldstone (~ 0.45 MW, ~ 70 m) allows $\sim 3 - 4$ HSDI experiments per year which cover only several per cent of the current needs. After ~ 20 years, HL will be $\sim \sigma_{GGB}/8 \sim 4 \wedge 10^{-7}$.

EAA. With a new dedicated mainly to the needs of radar astronomy fully steerable more powerful radar transmitter (~ 10 MW, ~ 100 m) in EAA, $n \sim 10$ radiotelescopes in Europe, $m \sim 5$ radiotelescopes in Asia which in together form $n{\cdot}m$ long-baseline transcontinental interferometers, and ~ 50 HSDI experiments per year with each interferometer, after ~ 20 years, HL will be $\sim \sigma_{EAA}/(10{\cdot}5{\cdot}50{\cdot}20)^{0.5} \sim 10^{-9}$. It is worth noting that within a year EAA's HL in φ will be $\sim 5 \wedge 10^{-9} \sim 1$ mas (milliarcsecond).

Interpretation of HSDI Data: Direct high precision HSDI measurements of SVV allow investigation of Mercury's deep inside in general case without *a priori* information or assumptions. To interpret data from future advanced radar facilities, both analytical models and computer simulations should be developed to $\sim 10^{-9} - 10^{-10}$.

Testing General Relativity: When substantial to so high accuracy as $\sim 10^{-9} \sim 0.2$ mas, relativistic effects in Mercury's rotation may lead to another test of general relativity in Solar system.

Radar Astronomy – "to be or not to be": The only in the world fully steerable and powerful radio transmitter at Goldstone (South California) was dedicated to the needs of spacecraft exploration at first and can serve radar astronomy very partially.

In turn, radar astronomy needs a much more powerful radar facility dedicated at first to its needs. In any observable future, HSDI prospects in EAA can be very attractive and may lead to an international initiative on organizing, e.g., CRRA (Center for Radio and Radar Astronomy) to coordinate work in radar and radio astronomy. It seems to be the case when international efforts may turn out to be especially effective.

Conclusion: The current projects were developed for the two extreme cases of a purely liquid or completely solidified outer core with an intermediate state excluded and do not cover the full range of Mercury states. Recent data reveal that Mercury may well be in an intermediate state which promises to be more informative about the deep interior properties and can be specified and studied to high precision by advanced Earth-based radar.

With the limiting accuracy of order $\sim 10^{-9} \sim 0.2$ mas, testing of general relativity from Mercury's rotation can not be excluded.

References: [1] Kholin (Holin) I. V. (1988) *Radiophys. Quant.Elec., 31,* 371. [2] Kholin (Holin) I. V. (1992) *Radiophys. Quant. Elec., 35,* 284. [3] Peale S. J. et. al. (2002) *Meteoritics & Planet. Sci., 37,* 1269. [4] Margot J.-L. et al. (2007) *Science, 316,* 710. [5] Holin I. V. (1994) *Patent of Russia #* 2091712. [6] Holin I. V. (1998) *Uspeckhi Sovremennoi Radioelectroniki, No. 4,* 3-15, in Russian. [7] Holin I. V. (1999) *Uspeckhi Sovremennoi Radioelectroniki, No. 7,* 16-28, in Russian. [8] Van Hoolst T. et al. (2007) *Space Sci. Rev., 132,* 203. [9] Holin I. V. "Mercury Radar Speckle Dynamics", submitted to *Icarus* on July 22, 2009. [10] Holin I. V. (2009) *LPS XXXX,* Abstract #1016. [11] Margot et al. (2004) *AGU FM,* Abstract #G33A-02. [12] Head J. W. et al. (2009) *Earth & Planet. Sci. Lett.,285,* 227. [13] Purucker M. E. et al. (2009)) *LPS XXXX,* Abstract #1277.