APOPHIS AND THE WAVES: THE NEED FOR FREQUENCY COORDINATION AND RADIO AMATEUR AND UNIVERSITY COMMUNITY SUPPORT BEFORE, DURING, AFTER CLOSE APPROACH. J. T. Grundmann[1#], S. Fexer[1]*, M. Laabs[2]*, D. Plettemeier[2], [1]DLR German Aerospace Center, Institute of Space Systems, Robert-Hooke-Strasse 7, 28359 Bremen, Germany, [#]jan.grundmann@dlr.de, [2]Dresden University of Technology, Chair for RF Engineering, Helmholtzstr. 10, 01069 Dresden, Germany, *licensed radio amateur.

Introduction: On Earth most definitely and likely also around the Moon, in the few days centred on Friday, April 13th, 2029, 21:45 UT, every informed and curious naked eye, lens, mirror and dish within the horizon will be aimed at (99942) Apophis for an once-in-a-1000 years opportunity of scientific observations. Most will watch or listen. Many will transmit. Some will get in the way of others. And a few will blast it with all they can – for the best of science.

No Risk,… It is difficult to make predictions, especially about the future. But by 2029, the world will have changed. Again.

The Good… More satellites than have ever been launched since the beginning of the space age to this day will reach low Earth orbit (LEO) within the coming decade – and almost all of them will be in active use and transmit 24/7/365 providing broadband services equally to the farthest and most disadvantaged corners of the globe. Whatever way the Internet of Things (IoT) will choose to proceed on, along it will produce billions and billions of microwave transceivers, most if not all Software-Defined Radios (SDR), flocking the more prosperous real estate of this planet. Most pieces of this most delicate and sophisticated hardware, some of which have not yet been invented, capable of providing performance and sensitivity levels several times more than have ever been experienced, fitted together with a precision better than today's finest silicon, will be as common as pennies and used with the same benign indifference as an Apollo-era pencil. But a few will fall into the lap of curious scientific creativity.

…the Bad… In the rush towards a world of calm convenience at our fingertips, not only the noise floor will quite likely rise and spread until the few reserved bands and radio-quiet zones will appear like holes punched out of a somewhat neglected lawn. There will also be pressure and occasional pre-emptive compliance to encroach upon and ultimately fill these holes with more profitable use, whether by rule or exemption. [a] Even without such trends, increasing intensity and occurrence of adjacent-band interference from sources moving in orbit or in the back pockets of passers-by can be expected as more and more devices of everyday life become 'connected' and tens of direct-to-mobile transmitting low-flying satellites are in the sky at any time and place.

…and the Ugly. Although predictable by its orbit, the observational situation around Apophis' fly-by is highly dynamic in terms of viewing angles, apparent motion, signal-to-noise ratio, roundtrip delays, resolution, pulse rates, link budget, and just about every other parameter including the asteroid's chaotic rotation – and all their uncertainties. This hard to define precisely and highly time-variable once-in-a-lifetime scenario calls for global coordination, not least because Earth rotates underneath the sub-asteroid point. While astronomical observations have been coordinated successfully many times before, Apophis will quite likely be the first target to be observed simultaneously by many active parties which may include planetary radars, radars for which it will be the only asteroid ever within range, methods using laser illumination, in-situ spacecraft transmitting their telemetry and communicating with landers sounding the interior. The regulatory world of radio transmissions however is organized for long-term stability in allocation and standards, with correspondingly slow and thorough processes. This is not to say that such institutions can not handle sudden exceptions or act consistently in fluid crises. But unique as it may be to any scientific mind, the Apophis encounter is not the next banking crisis nor pandemic. And it is a predictably brief transient one-off event.

… No Fun: The authors hold that the best way to stay ahead of this challenging situation is to take matters into the hands of the interested communities. Consequently, the intention here is not to present a solution but to initiate the beginnings of the first discussions towards one that will be timely with respect to a deadline set firmly by celestial mechanics and sufficient for all those looking ahead towards it.

Connections to make in this context are not limited to the following:

- with satellite operators, e.g. for transmitter blanking times while in the beam (mutually?) or use of these global networks to link involved ground stations
- with amateur radio operators, e.g. for off-loading spacecraft tracking efforts by

support from multiple redundant amateor-operated sites, to free up the space operations ground stations' 'big dishes' for science tasks

- with amateur radio developers, e.g. for mobile ground stations to collect multi-static data (see below)
- between (planetary) radar facilities, e.g. for illumination scheduling at pulse level, possibly including bi- or multi-lateral bi- or multistatic modes
- with space- and radio-related and other public awareness and educational outreach institutions, to encourage own observations and raise awareness for 'light pollution' in the telescopic as well as radio bands

Some Examples for Supporting Solutions, Capabilities, and the Potential for Science:

Fixed and Mobile Ground Stations: On the premises of the DLR Institute of Space Systems in Bremen, there is the ham radio club station DK0DLR, which also acts as a satellite ground station on the respective bands. It offers a broad variety of frequency ranges and antenna types, including two sets of redundant UHF yagi arrays with TLE-tracking rotator.

Affilated with the fixed station, the mobile ground station L.A.R.S. is used for radio communication at remote sites. This station is installed in a standard 20 ft shipping container and can operate on the three main amateur radio satellite frequencies (VHF, UHF, S band) and also offers different other experimental receiving capabilities.

As part of a cooperation with the Hochschule Bremen, these stations have been equipped with an experimental SDR WSPR (weak signal propagation report) receiver.

Both stations are operated and maintained by the Electronics Laboratory of the Institute.

A huge multi-static radio observation system could be realized by combining a large number of receive stations. These stations should be distributed around the globe to maximize the virtual aperture size.

Utilizing one powerful transmitting antenna to send a radio signal to the target and receiving it coherently by 50-200 ground stations could increase the resolution dramatically, in terms an accurate trajectory and possibly a medium resolution radar imaging of Apophis.

The ambiguity of the signal can be resolved by the a-priory knowledge of the approximate position of the asteroid.

Similar, a passive radio system could be realized utilizing interfering and/or intentionally generated signals of near-by spacecrafts. The key challenge is coherency of the receiver and motivation of the voluntary radio amateurs. Worldwide coherence could be achieved by GPS disciplined clock sources in conjunction with a calibration to a common, known signal (e.g. from a geostationary satellite with known position)

Motivation of radio amateurs could be increased by a very low cost or even gratis hardware for the experiment they could utilize for other experiments afterwards. In return they would obligate in participating in the mission.

Conclusion: The long-standing support of the STEREO mission by radio amateurs monitoring the live space weather beacons has proven this community to be of utmost quality and reliability. We strive to explore and include the capabilities of the public and interested citizen scientists to achieve the best observation campaign possible by the end of the decade.

Acknowledgments: Considerations of other uses of radars at asteroids in the distance or wireless networks of nanospacecraft and their connection to radio/radar astronomy and the radio amateur community grew from our work on the DLR projects MASCOT, MASCOT2 and GOSSAMER-1 as well as through the E-Lab at DLR Bremen run by Lars Hauer.

References: [a] A. Lopatka, Physics Today, Aug.2020, vol.73, №8, 22-24.