PMD Analysis Center Report

Vincenza Tornatore

Abstract We summarize the activities of the Politecnico di Milano (PMD) Analysis Center (AC) carried out during 2023 and 2024. Several initiatives have been undertaken to inform the geodetic VLBI community about the potential impacts of some private services regulated by the International Telecommunication Union (ITU) on both legacy S/X and VGOS observations. Frequency compatibility studies have been conducted to define the boundaries of safe zones where radio telescopes are shielded from strong signals emitted by ITU-regulated services, both terrestrial and satellite-based. Additionally, the AC has begun collaborating on a new mission concept called METRIC, which aims to study the upper atmosphere, gravitational physics, and geodesy from space.

1 General Information

The PMD IVS Analysis Center is located within the Department of Civil and Environmental Engineering (DICA) at Politecnico di Milano. This department includes a diverse community of faculty members, researchers, doctoral candidates, as well as technical and administrative personnel. DICA manages various laboratory facilities and is actively involved in teaching a range of subjects related to geodesy and geomatics.

VLBI session analyses have been routinely performed using the VieVS v3.2 software suite [1]. Vienna VLBI and Satellite Software (VieVS) encompasses a collection of tools developed by the Research Unit of Higher Geodesy within the GEO Department at TU Wien [2].

In addition, simulations and scheduling tasks have been explored using VieSched++. Both components operate within a MATLAB environment (version R2016b) and have been tested on Windows platforms.

2 Current Status and Activities

2.1 Compatibility Studies to Safeguard VLBI and VGOS Stations

Radio Astronomy is a passive service in telecommunications, meaning it only receives signals and does not transmit. It is protected under the Radio Regulations. Geodetic VLBI, classified under the Radio Astronomy Service (RAS) due to its observation of cosmic signals, does not typically use RAS-designated bands, as it requires broader bandwidths (32 MHz) than those allocated. Still, aligning VGOS channels with RAS bands could benefit spectrum management.

At the same time, International Mobile Telecommunications (IMT), including 5G, 6G, and UWB radar, are seeking additional spectrum between 2 GHz and 12 GHz. The 6.425–7.125 GHz range, proposed for 5G and Wi-Fi (RLAN), overlaps with VGOS bands B and C, risking interference that could reduce measurement sensitivity and accuracy. There is particular concern over the potential impact on the methanol line (6.650–6.6752 GHz), despite its protection under footnote 5.149 of the Radio Regulations.

Politecnico di Milano, Department of Civil and Environmental Engineering (DICA), Geodesy and Geomatic Area

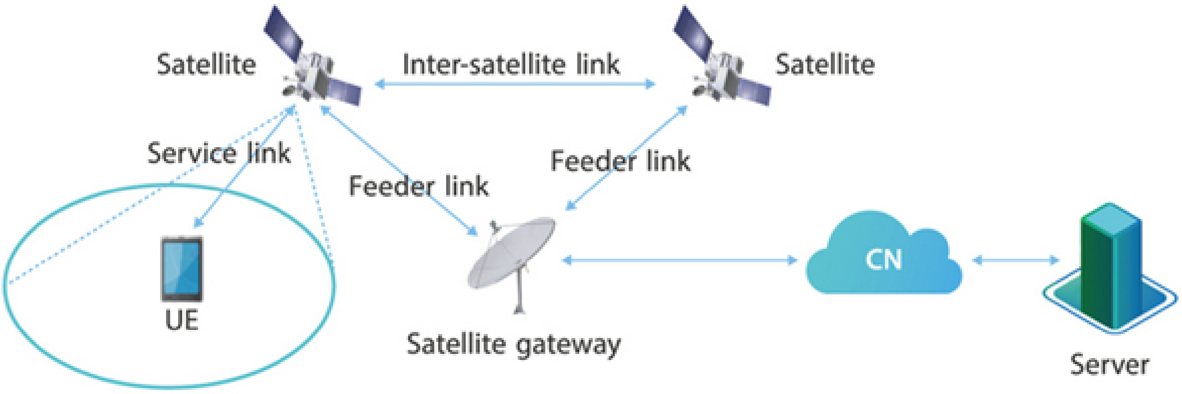

Fig. 1 5G NTN architecture. (Credits: Wang Y. and Hao R., ZTE, 2023.

The growing number of satellite constellations seeking radio spectrum for space-based internet threatens the preservation of the radio-quiet sky. Today the integration of satellite communication networks and terrestrial 5G networks can provide ubiquitous coverage capability. The 5G Non-terrestrial Network (NTN) consists of the user equipment (UE), satellite, satellite gateway, base station (gNB), core network (CN), and server (see Figure 1).

To address these issues, the PMD AC has conducted electromagnetic compatibility studies, in collaboration with members and observers of the Committee on Radio Astronomy Frequencies of the European Science Foundation (CRAF), to evaluate the impact of new commercial services on radio astronomy, geodetic VLBI, and VGOS, and to support mitigation strategies (e.g., [4, 5, 6, 7]).

All studies have utilized *pycraf* [3], a freely available Python package developed by CRAF for the studies of electromagnetic compatibility. Features relevant to RF analysis includes antenna models, elevation maps, and clutter identification.

International Mobile Telecommunications. International Mobile Telecommunications (IMT) covers not only emerging technologies like the Internet of Things (IoT) and machine-to-machine (M2M) communication but also includes commercial wireless infrastructure spanning multiple generations of mobile networks, including 2G through 5G.

The ITU is currently evaluating several frequency ranges for potential IMT allocation: 3300–3400 MHz, 3600–3800 MHz, 6425–7025 MHz, 7025–7125 MHz, and 10.0–10.5 GHz.

Among these, the 6425–7025 MHz band is particularly concerning for the Radio Astronomy Service (RAS), as it includes the critical methanol spectral line. For VGOS, any of these bands could pose interference issues, since they fall within its operational frequency range of 2–14 GHz.

The generic single-interferer case is the situation of a Base Station (BS) or User Equipment (UE) pointing directly at the RAS station, which is the worst-case scenario.

A compatibility study between IMT systems and radio astronomy has been conducted, covering both single-interference and aggregate scenarios. The analysis included sharing, adjacent-band, and spurious emissions cases.

As part of the study, individual assessments were performed for three Italian radio telescope sites. The evaluation used ITU-R propagation model P.452-16 and the P.2108 model for clutter loss—accounting for signal attenuation due to buildings and vegetation. Simulations assumed flat terrain in remote areas, typical of radio telescope locations, and focused on the 6.65 GHz frequency.

In the worst-case scenario, where a base station or user device transmits directly toward the radio observatory, results showed that interference distances for a generic flat site were similar to those of the Medicina telescope—exceeding 300 km for in-band interference.

This is attributed to the unobstructed landscape around the site.

While the SRT and Noto observatories are better shielded by surrounding mountains, coordination zones are still extensive for in-band scenarios. These zones become smaller for adjacent-band and spurious cases, with the shortest required separation distance being around 20 km.

Aggregated data requires treatment that is much more complex. First, random devices are deployed around the radio telescope. An area large enough to estimate the total power received by the radiotelescope had to be considered. A number of variables were taken into account, such as the antenna down-tilt for enhanced beam directivity, and beamforming efficiency, which reduces by 20% from in-band to spurious scenarios.

Compatibility Study between RLAN and RAS. WAS/RLAN (Wireless Access Systems / Radio Local Area Networks) are technologies that enable wireless connectivity between devices and local networks using radio signals. These systems are widely used to deliver high-speed internet access in various environments. RLANs typically support multiple devices within buildings or across campuses, while WAS offers internet access over smaller, localized areas.

Currently, there are approximately 19 billion active Wi-Fi devices worldwide, and this number is expected to increase significantly. To meet growing demand, RLANs are looking to expand their use of spectrum into the upper 6 GHz band—specifically from the existing 5.925–6.425 GHz range to a broader range of 5.925–7.125 GHz.

Given the potential for widespread deployment, a realistic aggregate interference scenario—where many devices operate near a radio astronomy station—has been assessed. As in earlier studies, detailed evaluations were carried out for the three major Italian radio astronomy facilities: SRT, Medicina, and Noto. These analyses incorporated actual population density data and land cover classifications to provide accurate, site-specific results. Such high-quality datasets are available for all European RAS observatories, offering reliable spatial detail for compatibility assessments. To check the complete study on this matter see [9].

The RLAN study shows that the required coordination distance to protect radio astronomy varies significantly depending on the telescope's location, primarily influenced by local population density. The presence of outdoor RLAN devices further increases the necessary coordination zone. Compared to IMT systems, RLAN generally requires a smaller coordination area in the 6.6 GHz band. Of the Italian sites studied, only the Medicina Observatory—due to its flat surroundings—requires a large coordination zone. In contrast, the mountainous terrain around SRT and Noto limits the required coordination zones to about 10–20 km.

In terms of compatibility at 6.6 GHz, IMT systems tend to require larger coordination zones than RLAN, largely because they use higher-powered outdoor transmitters. Another key difference is regulatory: IMT deployments are typically licensed, meaning device locations and numbers are known and manageable. RLAN use, however, is generally unlicensed, making it difficult to track or control the number and placement of active devices near observatories. This lack of information complicates coordination efforts.

The radio astronomy community does not oppose any specific service but stresses the need for effective protection from all potential sources of interference.

The findings from these compatibility studies have been submitted to the European Conference of Postal and Telecommunications Administrations (CEPT) and the Electronic Communications Committee (ECC), both of which oversee spectrum regulation across Europe. To check the complete study on this matter see [9].

NGSO Satellite Constellations. VLBI stations are facing increasing interference from artificial signal sources, both from terrestrial transmitters and, increasingly, from satellites. In particular, large non-geostationary orbit (non-GSO) satellite constellations are being deployed to deliver global, low-latency internet coverage. This has led to a rapid and continuous rise in the number of satellites in orbit.

For instance, the Starlink system operates with downlink frequencies between 10.7 and 12.7 GHz, and uplink transmissions between 14.0 and 14.5 GHz. These satellites transmit at power levels exceeding 40 dBm, vastly higher than the extremely weak cosmic signals VLBI aims to detect—often around -110 dBm. When a satellite's main beam aligns with that of a radio telescope, its downlink signal can overwhelm or even damage the sensitive low-noise amplifiers (LNAs) used in VGOS broadband receivers, (see also [10] ECC-Report 271, 2018, 2021).

2.2 METRIC: A Spacecraft Aimed at Upper Atmosphere Mapping, Gravitational Physics, and Geodesy

Measurement of EnvironmenTal and Relativistic In-orbit pre-Cessions (METRIC) is a space mission or a compact spacecraft to be placed in a low Earth orbit.

The platform will carry specialized equipment designed to support scientific research in atmospheric studies, fundamental physics, and geodesy. Its primary goals include: charting atmospheric density at key orbital altitudes—important for satellite reentry—using onboard acceleration sensors and tracking data; testing principles of fundamental physics by observing the behavior of a well-defined test mass; and acting as a space-based reference point to strengthen the connection between different space geodesy techniques. These three scientific aims are depicted in the Figure 2.

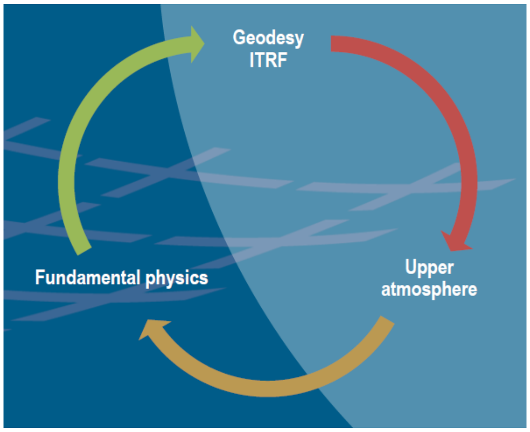

Fig. 2 A diagram of METRIC scientific objectives. (Credits Peron et al, Sofia 2022)

Although atmospheric science, fundamental physics, and geodesy are distinct disciplines, they are closely linked within the context of Earth system science and all require highly accurate orbit determination along with a well-calibrated space-based platform.

To support this, the METRIC spacecraft will be equipped with GNSS receivers, Satellite Laser Ranging (SLR) instrumentation, and a VLBI beacon, all carefully aligned and referenced to each other with high metrological precision. METRIC's key contribution to geodesy is enabling the co-location of multiple geodetic measurement techniques directly in space, helping to enhance the accuracy and long-term stability of the International Terrestrial Reference Frame (ITRF).

While GNSS and SLR are already established as space-geodetic methods involving satellite tracking from ground stations, VLBI observations of satellites are not yet routinely carried out. Current efforts are focused on defining the necessary conditions for observing the METRIC satellite with VLBI, including evaluating the characteristics of the VLBI Transmitter (VT), assessing observation feasibility and methodology, and determining visibility from the existing VLBI and VGOS station networks.

Ongoing research under the GENESIS mission is exploring the in-space co-location of all four space-geodetic techniques. This initiative, funded in 2023 (Delva et al. 2023), investigates the integration of a VLBI transmitter on a dedicated satellite or potentially on next-generation Galileo satellites. These studies also examine how the quality and number of satellite observations influence the accuracy of geodetic parameters (see Klopotek et al. 2020; Jaradat et al. 2021; Sert et al. 2022). Simulations involving VLBI tracking of Earth-orbiting satellites equipped with co-located geodetic instruments have also been carried out under various observational scenarios (e.g., Anderson et al. 2018). Together, these efforts provide a strong foundation for developing VLBI observations tailored to the METRIC mission.

As part of this initiative, we aim to design a VLBI beacon capable of transmitting in multiple sub-bands between 2 GHz and 14 GHz. This would ensure compatibility with both legacy and VGOS radio telescope networks using standard geodetic receiver configurations. Additionally, the option of extending the transmission into the Ka-band is being explored to further expand the signal bandwidth. METRIC could also serve as a precisely calibrated multi-frequency target to help link the International Celestial Reference Frame (ICRF) across different frequency ranges.

All transmissions must comply with International Telecommunication Union (ITU) power density regulations to avoid interference and ensure regulatory compliance. The METRIC mission is being developed in alignment with ongoing efforts by other international groups pursuing similar goals, promoting synergy and collaboration.

A feasibility study is underway to assess the practical implementation of a VLBI beacon on the METRIC satellite, ensuring it can be effectively observed by VLBI radio telescopes. Co-locating at least three geodetic instruments—GNSS, SLR, and VLBI—on a fully calibrated satellite platform will create a “core co-location site in space.” This approach is expected to reduce or eliminate technique-specific systematic errors, enhancing the accuracy of the International Terrestrial Reference Frame (ITRF). Moreover, VLBI tracking of satellites will offer a way to directly connect VLBI observations to Earth’s center of mass.

Finally, coordinated observation and data processing agreements between missions like METRIC (in low Earth orbit) and GENESIS (at 6000 km altitude) could lead to new geodetic products and improved global reference frame solutions. [8].

3 Future Plans

The PMD Analysis Center (PMD AC) will continue focusing on protecting VGOS frequency bands from harmful interference, which remains a key priority. Efforts will also include collaboration on spectrum management initiatives to raise awareness within the scientific community and the broader public about the importance of safeguarding geodetic VLBI and VGOS.

Additionally, comparisons between geodetic products derived from different space techniques are planned.

In the upcoming period, new investigations and experiments essential for the success of the METRIC mission will be conducted.

Acknowledgements

We acknowledge the Department of Civil and Environmental Engineering (DICA) of Politecnico di Milano University, in particular the Geodesy and Geomatics Area for hosting and supporting the IVS PMD AC activities.

We also thank CRAF and IVS for their activities and support, and for provision of data and products. We thank AC IRA INAF for research collaborations.

References

1. Böhm J., Sigrid Böhm, Janina Boisits, Anastasiia Girdiuk, Jakob Gruber, Andreas Hellerschmied, Hana Krásná, Daniel Landskron, Matthias Madzak, David Mayer, Jamie McCallum, Lucia McCallum, Matthias Schartner, Kamil Teke, Vienna VLBI and Satellite Software (VieVS) for Geodesy and Astrometry, Publications of the Astronomical Society of the Pacific,Vol.130(986),044503,2018. https://iopscience.iop.org/article/10.1088/1538-3873/aaa22b
2. URL 1: https://vievswiki.geo.tuwien.ac.at/VLBI-Analysis Date of Access: May 2025
3. Winkel, B.: pycraf https://github.com/bwinkel/pycraf Date of Access: May 2025
4. Giovanardi, F., Tornatore, V., Winkel, B., Bolli P. (2023) Compatibility studies between Radio Astronomy and three upcoming technologies, INAF Technical Reports, N. 282, https://doi.org/10.20371/INAF/TechRep/282
5. Di Vruno F. and Tornatore V. (2023) Large satellite constellations and their potential impact on VGOS operations, in IVS GM Proceedings, hosted by the Finnish Geospatial Research Institute (FGI), NLS, Helsinki, Finland March 28 - April 1, 2022 edited by Kyla L. Armstrong, Dirk Behrend and Karen D. Baver, NASA/CP-2022-0018789, pp. 19–28, 2019. https://ivscc.gsfc.nasa.gov/publications/gm2022/
6. Tornatore, V. (Published August 24, 2023). Major threats and challenges for present and future radio astronomical observations and VLBI technique. Zenodo. https://doi.org/10.5281/zenodo.8279521
7. Tornatore V., Bautista-Duran M., Ferreira J. S., García S., Hase H., Kallunki J., Lindqvist M., López-Pérez J.A., Madkour W., McKay D., Probst W., Tangen L. M., Winkel B.(2023) How to deal with expanding spectrum of telecommunication networks threatening VLBI?, in Proceedings of the 26th European VLBI Group for Geodesy and Astrometry Working Meeting — E-book, eds. Rudiger Haas, Eva Schroth, Alexander Neidhardt, pp. 160–165, DOI: 10.14459/2023md1730292
8. Peron R.,, Negusini M., Tornatore V., METRIC: A Mission Concept for a Spacecraft Aimed at Upper Atmosphere Mapping, Gravitational Physics, and Geodesy (2025), In: IVS 2024 General Meeting Proceedings, edited by Dirk Behrend, Karen D. Baver, and Kyla L. Armstrong, NASA/CP-20250002586, pp. 305–309, 2025. https://ivscc.gsfc.nasa.gov/publications/gm2024/
9. ECC Report 316 (03-2020) Sharing studies assessing short-term interference from Wireless Access Systems including Radio Local Area Networks (WAS/RLAN) into Fixed Service in the frequency band 5925–6425 MHz
10. ECC Report 271: Compatibility and sharing studies related to NGSO satellite systems operating in the FSS bands 10.7-12.75 GHz (space-to-Earth) and 14-14.5 GHz (Earth-to-space) (2018, 2021) https://docdb.cept.org/download/3422