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LUNES : LUNar tErahertz teleScope

Expanding the electromagnetic window

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THz astronomy

The terahertz (THz) or far infrared (FIR) part of the electromagnetic spectrum (0.1-10 THz or 30-3000 µm) was discovered more than 100 years ago by Heinrich Rubens. It appeared rapidly that strong interaction exists between these waves and the matter, particularly polar matter. He discovered for example that the strongest absorption lines of water vapor (H_2O) are in this range. But progress in the THz range were very slow due to the lack of powerful sources and of sensitive detectors. A particular feature is that the photon energies are close to the thermal energy at the earth's mean temperature ($h\nu \approx kT$). Nevertheless astronomical observations and discoveries were done in the millimeter wave and mid-infrared ranges, filling progressively the gap between optical astronomy and radioastronomy. But since more than 20 years unprecedented THz observations are possible thanks to new sensitive devices like microbolometer arrays and hot electron bolometers. These technologies were used in the STO balloon, Planck and Herschel satellites, the SOFIA stratospheric observatory, etc… [1].

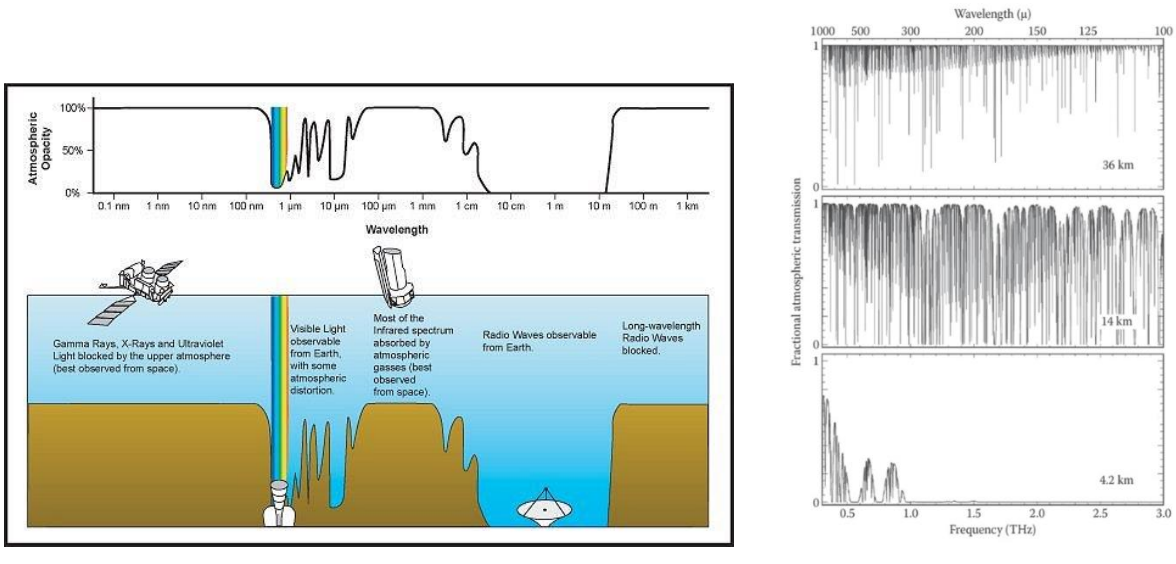

Figure 1 : Left : Electromagnetic wave transmission of the atmosphere. Right : THz atmospheric transmission for typical weather conditions from mountaintop site (4.2 km), airborne altitudes (14 km), and balloon-borne altitudes (36 km) [1].

High performance heterodyne receivers are also used in ground based observatory like ALMA (Atacama Large Millimeter/submillimeter Array). In the millimeter wave range (30-300 GHz) the atmosphere transparency is generally sufficient particularly at high altitude but large portions of the spectrum are not accessible from ground mainly due to O_2 and H_2O absorption and above 1 THz (300 µm) up to 30 THz (10 µm), astronomy is almost impossible from the earth's ground (see figure 1). Our atmosphere blocks all these radiations coming from space. As already mentioned balloons, aircraft and satellites can provide interesting platforms but several problems persists : the aperture of the telescope is limited (generally to few meters maximum), the available DC power is limited (less limited in an aircraft), and the observation time is also limited (less on a satellite).

New opportunities

We have recently celebrated the 50^{th} anniversary of the first steps on the moon. Several public agencies and private companies have plans to come-back to the moon for a more permanent stay. In 2015 ESA has proposed the moon village project, an international cooperation to build a permanent base on the moon. Several astronomers have supported the idea that science should be a part of the future exploitation of the moon and particularly astronomy. It was proposed for example to construct a radiotelescope on the hidden side of the moon in order to detect low frequency radio waves (<30 MHz) that are normally blocked by the earth's ionosphere (figure 1). It would provide crucial information about the « dark ages » after the big bang [2].

Several THz astronomers claim that previous missions have « barely scratched the surface of what can be learned in this wavelength region » [3]. As it was proposed for low frequencies, for THz astronomy the « Holy Grail » would be to dispose of a large telescope on the moon. The first advantage would be that the aperture could be quite large (10 m or more) thanks to the fact that there is no atmosphere, the gravity is 1/6 compared to earth, and that the telescope can be assembled progressively by several missions and can use « folded » technology. Compared to a satellite the moon's ground can contribute to the thermal stability of the telescope even if every 14 days the thermal equilibrium will change, long period of stability can be expected for long observations.

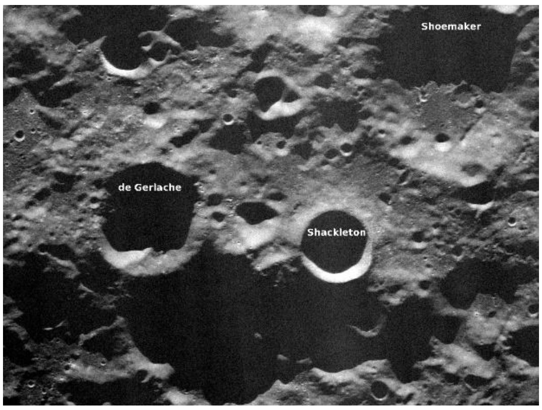

Figure 2 : Shackleton crater as imaged by earth-based radar [4].

Another important fact is that water ice presence have been confirmed in 2009 near the moon's poles. It has attracted a lot of attention because it can contribute a lot to a permanent base. This place is also interesting for a future THz telescope, thanks to cold craters that the sun never shines and also to permanently illuminated peaks that can provide permanent electrical power. The Schackleton crater (see figure 2), a 21 km diameter crater in the south pole, under continuous shadow where the temperature never exceeds 100 K has been proposed for an infrared telescope [5]. It would be also an ideal place for a THz telescope with very high stability and ultimate performance.

What to bring THz astronomy

A continuum of THz radiation is emitted by cool objects in the Universe, cloud of dust and gas. But in addition to this continuum radiation, THz spectroscopy is a powerful tool to study the interstallar medium (ISM) because it includes spectral lines from many important atoms, ions, radicals and molecules that are dispersed at very low density in the ISM. We can cite CI, CII, OI, OIII, NII, SiI and HD, CO, OH, CH, LiH, SiH, MgH, … Radiation of these lines may be quite strong, it has been estimated that the CII line at 1.9 THz may radiate 1% of the luminosity in its parent galaxy in that single line. Detection of these radiation is very important to understand the ISM and the evolution of stars. A lot of more complicated molecules have also been discovered in molecular clouds mainly below 1 THz due to the lack of instruments : HCN, HC_3N, CH_3OH, CH_3CN, HCOOH, alcools and amino-acids... but intense lines of important molecules may be present in the blind windows due to water vapor (for example around 557 and 752 GHz) and above 1 THz.

If a telescope of large aperture is available on the moon, detection of molecules in the atmosphere of exoplanets will be feasible. The molecules, radicals and atoms that are particularly interesting to be detected are : H_2O, HDO, OH, OI, O_2… Thanks to the strong transitions and the particular photon energy, THz is suited to the detection of these molecules in cool atmospheres like the one of earth-like planets. These observations will be complementary to the near- and mid-infrared spectrometry done by the JWST. It can bring essential information about exoplanets and the possibility that they can support life. It can be used also to observe the atmosphere of planets and satellite of our solar system (for example Venus, Titan, Encelade…).

Proposed characteristics and technology

The wavelength coverage would be ideally from 30 to 300 µm (1-10 THz), complementary to the JWST (0.6-28 µm) and the ALMA array (300-6000 µm). Possibly it could extend above 300 µm in order to complete blind windows of ALMA due to water vapor and oxygen : around 60, 120, 380, 500-600, 720-780 GHz. The aperture size should be at least 10 m, ideally 30 m.

The telescope should ideally be equiped with heterodyne receivers in order to allow high resolution THz spectroscopy and also arrays of direct detectors for imaging THz sources. New generation of local oscillators, mixers and detectors should be used. The use of low-temperature devices should be more easy if a place like the Shackleton crater is chosen. A very important point will be the power consumption of such a telescope inlcuding the data treatment and the transmission to the earth.

The telescope can be used also to observe the earth. Thanks to the many water lines in the THz range it will be useful to calibrate the telescope in various ranges and to check its resolution.

The first part of such a project could concern a single dish telescope but by successive missions one can imagine to construct several telescopes and to progressively form an interferometer comparable to ALMA.

Conclusion and outlook

The come-back on the moon should have science-driven projects. The possibility to build a THz observatory on the moon would make an essential contribution to astronomy. Despite a recognized scientific interest, the THz range of electromagnetic waves has been underused. For the first time we can imagine big parabolic mirrors with a perfect sky for many years of exploitation. It is a long term project and the collaboration of many scientists for many years will be needed but it will open the access to essential informations about our universe like the formation of stars and the distribution of water.

Bibliography

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