Mem. S.A.It. Suppl. Vol. 10, 192

Memorie della
Supplementi

Observations of comets with the Sardinia Radio Telescope (SRT)

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Abstract. The study of comets can give precious information on the conditions present in the solar nebula at the time of the formation of the solar system and on the first step of the formation of life on Earth. The goal of comet observations is to derive the original chemical composition of the cometary nucleus. Particularly important are the organic complex molecules present in comets that may have triggered the life on Earth. However all the complex molecules are destroyed by the solar UV radiation, producing less complex molecules, radicals and ions. These are concentrated close to the nucleus, where the scattering of solar radiation by dust makes it very difficult to detect their signatures in most spectral regions. The radio spectral domain is very suitable to detect them because here most of them have rotational transitions, while the emission of the dust is very low. In this paper we will discuss a possible use of the Sardinia Radio Telescope for studies of cometary physics.

1. Introduction

The comets are the most primordial bodies of the solar system and their study can give precious information on the conditions present at the time of the solar system formation. Comets contain a large amount of organic matter and they are supposed to have deposited on Earth the first complex organic matter from which life was formed. Cometary nuclei are composed of volatile components, mainly water ice plus other molecules trapped in it or under ice form as well, and solid state components, made by silicate and carbon particles and a large amount of organic solids (e.g. CHON particles).

Whenever a comet approaches the Sun, the ices sublimate and escape from the nuclei dragging along the solid particles. This process produces the coma of a comet, which is continuously dispersed in the interplanetary medium and reformed by sublimation. The original molecules escaping from the nucleus are more or less promptly dissociated and/or ionized by the solar UV radiation. It should be noted that the nuclei are generally undetectable, because they are hidden in the emission of the coma. Moreover the density of the coma is very low and apart from a small region of some tens of km in the inner part there are virtually no collisions between the molecules. Emission of the coma is usually due to scattered solar radiation: resonant scattering for the gaseous component and Mie-scattering for the solid component. At wavelengths longer than about 3 μm we have also thermal emission from the solid components.

The scattering by the gaseous component can produce a) electronic transitions, detectable in the UV and visible spectral regions, b) ro-vibrational transitions, detectable in the near-IR, and c) rotational transitions, observable in the radio region. Of course electronic excitations can produce also vibrational and rotational transitions by cascade decays.

The radio spectral region, especially in the mm and sub-mm, is particularly important for astrobiological studies, because most complex organic molecules have rotational transitions in these regions (see for example Crovisier et al. 2004).

In this paper we will discuss a possible use of the Sardinia Radio Telescope for cometary studies.

2. SRT

The goal of any comet observation is to obtain the original comet composition and physical structure of the nucleus. The best measurement of this can be done only *in situ* with space missions. And even in this case we can study only the external part of the nucleus, that may have already undergone some modifications because of the heating by solar radiation. Remote observations can give only an approximate knowledge, because the composition can be derived only through models of the cometary coma. As already said, the original molecules (the so-called parent species) escaping from the nucleus are dissociated and/or ionized by the solar UV radiation, producing more simple molecules, radicals (daughter species) and ions. Figure 1 gives some examples of coma column density for various species. For a species with no destruction, like refractory dust grains, escaping with constant velocity, the number density decreases as the square of ρ, with ρ the nucleocentric distance. Hence the column density is going as ρ^{-1}, i.e. linear with slope -1 in a log-log plot. In the case of parent species that are destroyed by the solar radiation, their column density decreases as ρ^{-1} multiplied by an exponential factor that depends on the lifetime of the molecule. In the figure examples of parent species with different lifetimes are given. Daughter species, that are produced by the dissociation of the parent ones, have profiles that are much flatter in the inner part and similar to the parent ones in the outer part, where also they are destroyed by the solar radiation.

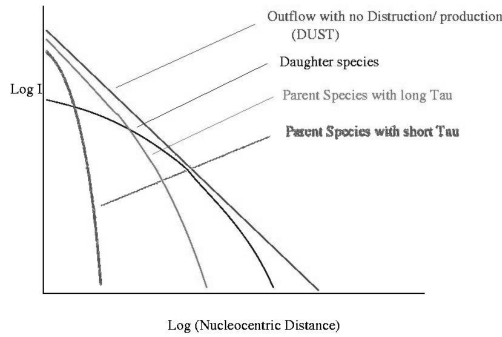

Fig. 1. Example of log-log plot of column densities of various species in function of the nucleocentric distance (see text). Parent species are always concentrated close to the nucleus with profiles depending on their lifetime (Tau).

From the figure we can already learn something. If we want to observe a parent species, especially in the radio domain where the antenna beams are large, it is better to observe comets at close geocentric distances than far away, even if they might be brighter.

An example of parent and daughter species is H_2O. Its main destroying channel, in the case of quiet Sun, is dissociation to OH+H with a probability of 85% and a lifetime of 97×10^3 s. The remaining dissociation channels produce H, H_2, O and ions. Since water is the main constituent of a cometary nucleus and OH is its main dissociation product, the measurement of OH production rates, via the electronic resonant scattering in the UV or by the Λ-splitting transition pumped by the decay of the UV transition in the radio (1666-1667 MHz), have been the only methods to measure the cometary water production rates for a long time.

Also the OH, a daughter species, is eventually destroyed by the solar radiation producing the "grand-daughter" species O and H with a probability of 98% and a lifetime of $83{\times}10^3$ s. The remaining 2% is ionized.

It is important to point out that the cometary abundances, measured with respect to that of water, depend on the heliocentric distance (Biver et al. 2002). This is because very volatile elements will start to sublimate at low temperatures, i. e. at large heliocentric distance as for example CO, while others will start much closer, like water ice that becomes the main source of activity at about 3 AU from the Sun. For that reason the abundances are usually given at 1 AU.

The Sardinia Radio Telescope can play an important role in cometary physics. Besides the measurement of OH to derive water production rates it can be used to detect ammonia in bright and nearby comets. Ammonia has been detected only in a few bright comets and it would be interesting to measure its abundance in many other comets.

The SRT can be used to measure the HCN, the possible parent of CN, a radical that has long been known to give its most prominent line in the visible spectral region. So far there are disagreements between production rates computed with HCN transitions and those with CN. For that reason it would be very interesting to measure simultaneously and at different heliocentric distances HCN with SRT and CN in the visible with an optical telescope.

The SRT can be also used to search for undetected species as, for example, water dimer (transition $2_0E^- - 1_0E^+$ at 24.284 GHz), deuterated water (transition $1_{10} - 1_{11}$ at 80.578 GHz) and cyanodiacetylene (HC_5N, transition 34−33 at 90.526 GHz) (Bocklée-Morvan & Crovisier 2002).

Another open and interesting problem is the ratio HCN/HNC. This ratio, regarded as an indicator for the origin of the ices, has been measured for few comets. It seems to be very similar to that measured in warm quiescent molecular clouds (Bocklée-Morvan & Crovisier 2002): this is suggesting that cometary nuclei can be composed of relatively unprocessed interstellar ices. Anyway, the strong variations of this ratio along the orbit, measured in C/1995 Hale-Bopp, cast some doubts on the true significance of this ratio. More data are needed.

It must be noted that observations of comets need some requirements that usually are not necessary: first of all the comets move with respect to the stars, so differential tracking of the telescope is necessary. Secondly, especially for comets at their closest approach to the Earth, the geocentric velocity can change significantly during the same observing run. This must be taken into account in the acquisition.

3. Conclusion

It has been shown that the SRT can become an important instrument for the study of some important problems in cometary physics.

References

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