C. R. Physique 17 (2016) 985–994

Contents lists available at ScienceDirect

Comptes Rendus Physique

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Comets at radio wavelengths

L'étude des comètes en ondes radio

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A R T I C L E   I N F O

Article history:
Available online 10 August 2016

Keywords:
Comets
Chemical composition
Radio astronomy
Solar System formation

Mots-clés :
Comètes
Composition chimique
Formation du système solaire
Radioastronomie

A B S T R A C T

Comets are considered as the most primitive objects in the Solar System. Their composition provides information on the composition of the primitive solar nebula, 4.6 Gyr ago. The radio domain is a privileged tool to study the composition of cometary ices. Observations of the OH radical at 18 cm wavelength allow us to measure the water production rate. A wealth of molecules (and some of their isotopologues) coming from the sublimation of ices in the nucleus have been identified by observations in the millimetre and submillimetre domains. We present an historical review on radio observations of comets, focusing on the results from our group, and including recent observations with the Nançay radio telescope, the IRAM antennas, the *Odin* satellite, the *Herschel* space observatory, ALMA, and the MIRO instrument aboard the *Rosetta* space probe.

R É S U M É

Les comètes sont considérées comme les vestiges les mieux préservés du système solaire primitif. Leur composition nous renseigne sur la composition de la nébuleuse primitive il y a 4,6 milliards d'années, fournissant des contraintes sur la formation du système solaire. La radioastronomie est un outil privilégié pour l'étude des glaces cométaires. Le domaine décimétrique permet de mesurer la production en eau, par l'observation du radical OH à 18 cm de longueur d'onde. Le domaine millimétrique et submillimétrique permet d'observer de nombreuses molécules provenant de la sublimation des glaces du noyau, ainsi que leurs isotopologues. Nous présentons un panorama historique des découvertes sur les comètes faites en radioastronomie, mettant l'accent sur les résultats de notre groupe, et incluant des observations récentes faites avec le radiotélescope de Nançay, les antennes de l'IRAM, le satellite *Odin*, l'observatoire spatial *Herschel*, ALMA et l'instrument MIRO de la sonde spatiale *Rosetta*.

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http://dx.doi.org/10.1016/j.crhy.2016.07.020

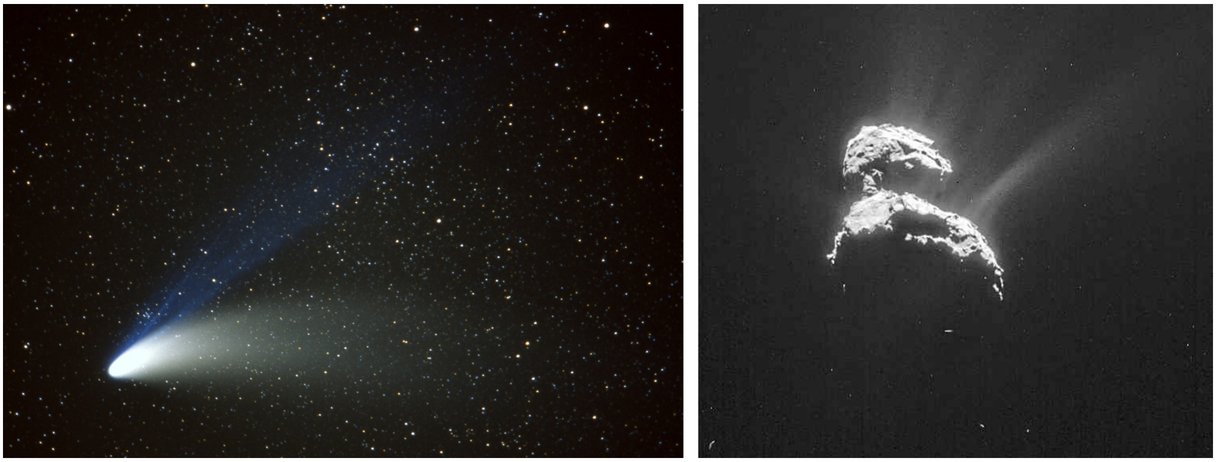

Fig. 1. Cometary images. Left: Comet C/1995 O1 (Hale–Bopp) observed from the Earth on 6 April 1997 (photo: N. Biver). The ion and dust tails are spread here over several 10^7 km (to compare with the Sun–Earth distance 1 AU = 1.5×10^8 km). Right: The nucleus of comet 67P/Churyumov–Gerasimenko observed at a distance of 198 km by the *Rosetta* space probe on 18 February 2015 (©ESA/*Rosetta*/NAVCAM). The size of the nucleus is about 4 km. This image was processed to enhance the dust jets that escape the nucleus.

1. Introduction

With a size of a few kilometres, cometary nuclei are practically unobservable at a distance. Their direct study requires exploration by spacecraft. However, they are icy bodies. When they approach the Sun, ices sublimate, releasing gas and dust, which form an atmosphere and tails that may become very spectacular (Fig. 1). As they contain matter which remained practically intact since the beginning of the formation of the Solar System, these bodies are precious testimonies from the past that justify dedicated studies.

Early in the history of radio astronomy, the first attempts to observe *great comets* C/1956 R1 (Arend–Roland), C/1965 S1 (Ikeya–Seki), C/1969 Y1 (Bennett) and a few others did not yield probing results. Indeed, it is not easy to observe a comet at radio wavelengths. The signal is weak so that large radio telescopes, equipped with sensitive receivers, are needed. The observations should only be attempted on bright comets, which are rare. For these moving objects, one must blindly rely on ephemerides and the telescope tracking system. Last but not least, comets are variable, unpredictable objects, so that an observation can difficultly be repeated for confirmation. It is thus not a surprise that the beginnings of the radio investigation of comets were a succession of failures, missed opportunities, contradictory results and doubtful detections that could not be confirmed.

2. 1973: comet Kohoutek

At the end of 1973, the NASA organized a worldwide campaign to observe comet C/1973 E1 (Kohoutek), in support to its observation aboard the Skylab orbital station. Following this opportunity, the observation of the OH radical lines at 18-cm wavelength was attempted at Nançay. Their detection was the first detection of a comet at radio wavelengths (Fig. 2, [1,2]).

The OH radical is a photodissociation product of water, the major constituent of cometary ices. Its observation allows one to determine the production rate of water, and thus to quantify the activity of the comet. This observation of comet Kohoutek was the beginning of a programme of systematic observations, which is still ongoing at the Nançay radio telescope. More than 130 comets were thus observed. The evolution of their activity was followed, in some cases over many months, to prepare or to complement their observations with other instruments.

3. 1986: Halley's comet

The historic and mythical Halley's comet (1P/Halley) was in 1986 the target of a space exploration by no less than five spacecraft. Its observation from the Earth was also the topic of an international supporting campaign advocated by the *International Halley Watch*. The radio aspects of this campaign [4] were coordinated by Éric Gérard (France), William Irvine, and F. Peter Schloerb (United States).

The OH 18-cm lines in Halley's comet have been monitored with the Nançay radio telescope for a year and a half in 1985–1986 and with several other telescopes [3,4]. The same lines were also mapped with the Very Large Array (VLA) interferometer [5]. Hydrogen cyanide (HCN) was detected by the newly commissioned 30-m radio telescope of IRAM ("Institut de radio astronomie millimétrique") at Pico Veleta (Spain) (Fig. 3, [6]).

This marked the entry of cometary radio astronomy in the world of molecular radio spectroscopy, already so successful in the study of interstellar molecules. A short time after came the identification, still at IRAM, of methanol (CH_3OH) and hydrogen sulphide (H_2S) in comets C/1989 X1 (Austin) and C/1990 K1 (Levy) [7].