Comets in UV

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Abstract Comets are important “eyewitnesses” of Solar System formation and evolution. Important tests to determine the chemical composition and to study the physical processes in cometary nuclei and coma need data in the UV range of the electromagnetic spectrum. Comprehensive and complete studies require for additional ground-based observations and in-situ experiments. We briefly review observations of comets in the ultraviolet (UV) and discuss the prospects of UV observations of comets and exocomets with space-born instruments. A special refer is made to the World Space Observatory-Ultraviolet (WSO-UV) project.

Keywords comets: general, ultraviolet: general, ultraviolet: planetary systems

1 Introduction

Comets are common and very diverse minor bodies of the Solar System. They are common in extrasolar planetary systems too. Comets are very interesting objects in themselves. A wide variety of physical and chemical processes taking place in cometary coma make of them excellent space laboratories that help us understanding many phenomena not only in space but also on the Earth.

We can learn about the origin and early stages of the evolution of the Solar System analogues, by watching circumstellar protoplanetary disks and planets around other stars. As to the Solar System itself comets are considered to be the major “witnesses” of its formation and early evolution. The chemical composition of cometary cores is believed to basically represent the composition of the protoplanetary cloud from which the Solar System was formed approximately 4.5 billion years ago, i.e. over all this time the chemical composition of cores of comets (at least of the long period ones) has not undergone any significant changes.

At present, in the outer part of the Solar System two populations of small bodies are considered to be sources of the observed comets: the trans-Neptunian region, consisting of the Kuiper belt and the scattered disc (30 – 100 AU) and the Oort cloud (up to 100 000 AU ). In recent years, the Main asteroid belt is also considered as a source for main-belt comets. In many models the origin of these populations is associated with processes that accompany the formation of the planetary system (see e.g. Dones et al. 2015; Meierhenrich 2012).

We believe that careful analysis of the chemical composition of comets with adequate chemical model of early Solar System (protoplanetary disk) could help to restore information about area of the disk where these bodies have been formed. By linking this information with dynamic models of the evolution of Solar System, we can verify our understanding of the early Solar System.

At present, data on the comet composition of about twenty short-period and long-period comets can
be found in the literature (Bockelée-Morvan (2011); Mumma and Charnley (2011); Ootsubo et al. (2012); Paganini et al. (2014); Cochrane et al. (2015); Roth et al. (2017)). This data are presented in Fig. 1. Analysis of this data shows that there are no fundamental differences between the volatiles content in comets of different dynamic types. Of course, we should bear in mind that only the very deep interiors (> 50 m) of cometary nuclei would have information on the primary composition of comets.

Observations of cometary interiors are challenging. Since we are limited by the distant observations, a critical problem is distinguishing between the coma and the nucleus signatures. Chemical composition of the matter evaporated from the surface of the comet (i.e. coma) is typically far from primordial. The upper layers of the core of short period comets are intensively reprocessed during previous encounters with the Sun. This is confirmed by the data obtained for comet 67P/C-G in the Rosetta experiment (Le Roy et al. (2013); Rubin et al. (2013); Balsiger et al. (2016); Altweig et al. (2016); Mall et al. (2016)). This data are also represented in Fig. 1: asterisks (before perihelion) and by encircled asterisks (after perihelion). All the volatile components are stronger after perihelion passage, when the upper shielding layer is destroyed in the southern hemisphere of the comet. From the analysis of the data and considering the propagation velocity of heat within the nucleus, it can be concluded that observational data obtained 2 – 3 weeks after the perihelion comet is of particular value, since they will most adequately correspond to the composition of the cometary nucleus.

Many problems of determining the chemical composition of comets can only be solved by using observational data in the ultraviolet (UV) range of the electromagnetic spectrum. Cometary spectra in the UV and visible range include lines formed by scattering of the sunlight on solid dust particles and emission lines from the gas in coma. UV spectroscopy provides important information about the composition of a cometary coma. In general, cometary coma are dominated by emission features that originate from the dissociation products of water: OH, H and O, or correspond to secondary atomic, molecular, and ionic species, such as C, C+, CO, CO+, CO2+, S, and CS. Also, the spectra and images contain information on structure and dynamical features of coma. The spatial structure and time variations of the outflows inferred from the images and spectra help to reveal the structure and other properties of cores. There are ways to restore the thermal history of cores too. For instance, N2 and noble gases are both chemically inert and highly volatile (evaporate at very low temperatures), so they are particularly interesting clues on the comets thermal history. But they have not yet been detected by any UV instrument in cometary comas. Delsemme (1980) reminded that the atmospheric bands of ozone absorb strongly at wavelengths less than 300 nm and still absorb irregularly up to wavelengths longer than 320 nm. The 300 – 320 nm range (where the famous OH line at λ309 nm) lies is a very important “interface domain” typically covered by space-born UV instruments and still reachable by groud-based telescopes located in mountains. This makes possible various tests and calibrations.

In this paper we discuss findings from UV (far UV (FUV) and near UV (NUV)) observations of comets with space born instruments (Section 2). Special attention is paid to the prospects of the World Space Observatory – Ultraviolet (WSO-UV) project (Section 3). Concluding remarks are given in Section 4.

### 2 Half a century of UV-observations of comets from space

In an interesting review by Delsemme (1980) of early UV observations of comets, all spectral first-time identifications of comets are classified in three periods:

- **From the early times until 1911 (named by Delsemme (1980) as Dark Ages of Cometary Spectra),** when the two major features of the neutral coma spectrum, CN and C2, had been already identified as well as the two major ions of the ion tail (CO+ and N2+). Metallic lines had already been seen in a sun-grazing comet, and the first UV features below 340 nm had just been observed as a fuzzy unresolved band. Next thirty years was a period with no bright achievements in the field,

- **Period 1941 – 1970 started with the first definite detection by Swings et al. (1941) of OH(0-0) at 309 nm and NH(0-0) near 336 nm in the spectrum of comet Cunningham (1941)).** The discovery of the UV line of OH demonstrated that comets contain water. This was strongly confirmed by the first rocket and satellite experiments running UV observations of comets. The “space era” of UV studies of comets began about half a century ago.

- **Since then, we are in the “modern” epoch in UV studies.** A number of space-born instruments (few to 240 cm aperture, both spectroscopic and imaging ones) were (and are) used for numerous UV observations of comets. We think this period will continue up to the appearance of giant UV telescopes with aperture of 4 – 30 m. This future epoch will come not earlier than 20 years from now and currently, the
most powerful tools are telescopes of the 2 m class (HST, WSO-UV).

In the article by Delsemme (1980), the first two periods are described in some detail. Here we briefly discuss the most important scientific and technological achievements of the third epoch as well as some prospects for the coming decade. We think that the major directions for the UV observation of comets mentioned by Delsemme (1980) remain important in our days. These are: observations of the Lyman-α (Ly$\alpha$) halos of comets, OH observations and observations of C, O, S atoms, ions, and molecules. Both imaging and spectroscopic technologies are used.

2.1 Imagery and low resolution spectroscopy

Imagery and low resolution spectroscopy were historically the most popular technologies at the dawn of UV "space era".

2.1.1 Rocket and balloon UV experiments

First rocket and satellite experiments on UV observation of comets immediately brought the very impressive discovery of the immense (up to 1.5 million km across) Ly$\alpha$ halo of comets: Tago-Sato-Kosaka (1969g) (C/1969 T1) by the OAO-2 satellite (Code et al. (1970)) and an Aerobee sounding rocket (Jenkins and Winge (1972)); comet Bennett (1969i) (Bertaux and Blamont (1970)), comet Encke by the OAO-2 satellite and the OGO-5 satellite (Bertaux et al. (1973)). Comet West (1976 VI) was observed with an Aerobee rocket payload (instruments): spectra (Feldman and Brune (1976)) and imagery of the Ly$\alpha$ halo (Opal and Carruthers (1977)) were obtained. These are some of the first observations of comets in UV.

Rocket experiments remain important in our days. FUV imagery and objective grating spectroscopy of comet C/2012 S1 (ISON) were acquired from NASA sounding rocket 36.296 UG launched in 2013 (McCandliss et al. (2015)). The comet was 0.1° below ground horizon, 0.44 AU from the Sun. The payload reached an apogee of 279 km and the total time pointed at the comet was 353 s. A wide-field multi-object spectro-telescope called FORTIS (Far-UV Off Rowland-circle Telescope for Imaging and Spectroscopy) observed the Ly$\alpha$ emission making use of an objective grating mode through an open microshutter array over a 0.5 square degree field of view. Hydrogen production rate was estimated to be $\sim 5 \times 10^{29}$ atoms s$^{-1}$. They also acquired a broadband image of the comet in the 128 – 190 nm bandpass.

An obvious disadvantage of rocket experiments is the short exposure time. This is overcome by balloon missions. The UV window has been scarcely explored through balloons. An UV-VIS (Ultra-Violet/Visible) instrument was designed for the BOPPS mission (Balloon Observation Platform for Planetary Science) (Young et al. (2014)), BOPPS was launched in 2014 and
observed comets, using a 0.8 m aperture telescope, a pointing system that achieved better than 1’ pointing stability, and an imaging instrument suite covering from the near-ultraviolet to the mid-infrared. BOPPS observed two Oort cloud comets: C/2013 A1 (Siding Spring) and C/2014 E2 (Jacques). The major results were received with the IR instruments \cite{Cheng et al. (2017)}.

2.1.2 UV observations onboard interplanetary missions

Many planetary missions have been equipped with UV instruments that were capable to observe comets. We mention few of them.

The Ly$\alpha$ halo of comet Kohoutek was repeatedly observed by the UV spectrometer of the Mariner 10 spacecraft during its transit to planet Venus \cite{Kumar et al. (1973)} and by different instruments on board Skylab, namely, the electrographic Schmidt camera (110–150 nm) \cite{Carruthers et al. (1974)}, the high resolution spectrograph \cite{Keller et al. (1975)}. \cite{Crismani et al. (2013)} reported that NASA’s Imaging Ultraviolet Spectrograph (IUVS) (\lam\lambda\lambda\lambda 110 – 340 nm, resolution 0.5 nm) onboard the Mars Atmosphere and Volatile EvolutionN (MAVEN) orbiting spacecraft obtained images of the hydrogen coma of the planet-grazing comet C/2013 A1 (Siding Spring) 2 days before its close encounter with Mars. Observations by IUVS brought interesting results: the water production rate was \(1.1 \pm 0.5 \times 10^{28}\) molecules/s, the total impacting fluence of atoms and molecules corresponding to the photodissociation of water and its daughter species was \(2.4 \pm 1.2 \times 10^{24}\) kg. These observations were used to confirm predictions that the mass of delivered hydrogen is comparable to the existing reservoir above 150 km.

Spectral observations of Comets C/2012 S1 (ISON) and 2P/Encke were acquired by the MESSENGER spacecraft during the close passes of both comets by Mercury \cite{Vervack et al. (2014)}.

Several campaigns of cometary observations have been performed by the UV spectrometer SPICAV from 2012 to 2014. SPICAV is one of the Venera-Express instruments. The UV channel of SPICAV is a full UV imaging 40 mm aperture spectrometer for 118 – 320 nm, \(\Delta\lambda \sim 0.5\) nm. For the 6 observed comets water sublimation rates as a function of the Sun distance were estimated \cite{Chaufray and Bertaux (2013)}.

Comet 2P/Encke was observed with UVCS/SOHO near perihelion (2000 September 9 and 11) in the Lyman lines of hydrogen. \cite{Raymond et al. (2002)} reported that the narrow Ly$\alpha$ profile indicates that the observed photons are scattered from hydrogen atoms produced by dissociation of H$_2$O and OH, though a broader profile far from the coma suggests a contribution from hydrogen atoms produced by charge transfer with solar wind protons.

The relative paucity of solar UV photons has limited the observations from orbiting observatories. The highest spatial resolution has been obtained with the Space Telescope Imaging Spectrograph (STIS) on HST, but is typically limited to tens of kilometers for the comets passing the closest to the Earth. The ALICE FUV spectrograph onboard the Rosetta mission made possible observations on scales of tens to hundreds of meters near the nucleus of the comet. ALICE is an imaging spectrograph in the \(\lambda\lambda 70 – 205\) nm range, with resolution 0.8 – 1.2 nm. The slit is 5.5° long with a width of 0.05° – 0.10°. ALICE is an off-axis telescope feeding a 0.15-m normal incidence Rowland circle spectrograph with a concave holographic reflection grating. The MCP detector used solar-blind opaque photocathodes (KBr and CsI). \cite{Feldman et al. (2013)} reported the results of the observations beginning in August 2014, when the spacecraft entered an orbit about 100 km above the nucleus. These observations were an unique opportunity to probe the coma – nucleus interaction region that is not accessible to the in situ instruments on Rosetta or to observations from Earth orbit.

2.1.3 UV observations of comets onboard general purpose (astrophysical) missions

Observations of the Ly$\alpha$ halos of comets continued in forthcoming experiments. We briefly describe some examples.

The Copernicus satellite spectrometer scanned the Ly$\alpha$ halo of comets Kohoutek and Kobayashi-Berger-Milon \cite{Festou et al. (1979), Kaneda et al. (1986)} presented results of Ly$\alpha$ imaging of Ly$\alpha$ Halley comet performed with S/C Suisei. The strong “breathing” of comet Halley coma with a period of 2.2 days was monitored throughout all phases in the 1985 – 1986 perihelion passage. Concerning to the water production, postperihelion rates exceeded the preperihelion ones by factor of 2 or 3. This fact suggests a postperihelion heating of the cometary nucleus. Some fine structures in the Ly$\alpha$ photometry data taken at the encounter indicate spatial variations of the atomic hydrogen density in the coma. These may correspond to the shell structures in the images so far obtained and be ascribed to the presence of a hydrogen source other than H$_2$O in the cometary gas or dust particles. This second hydrogen source is expected to have a larger photo-dissociation rate than H$_2$O.

Molecules of OH were repeatedly observed in comets. For instance, the OH bands in spectra of on comets
Bennett, Kohoutek and periodic comet Encke were observed with the NASA Convair 990 aircraft especially equipped for this purpose. The OH bands are very strong in all UV spectrograms of comets that covered the proper range (Harvey (1974)).

Comet Halley was observed by the Soviet UV observatory “Astron” with the 80 cm telescope “Spika” onboard (the largest space telescope at that time). The telescope was equipped with a French scanning spectrometer (Boyarchuk (1986, 1994)). The very strong lines of OH at 309 nm and NH at 336 nm seen in the spectrograms are shown in Fig. 2.

Comet Seargent (1978 m), the first comet to be observed by the International Ultraviolet Explorer (IUE) satellite, resolved the OH (0-0) band into a rotational structure of at least ten different branches completely identified (Jackson (1980)). These first observations and the models developed to explain the structure and isophotes of the Lyα emission brought to the conclusion that the bulk of the production rate of hydrogen and OH comes from the photodissociation of H2O, which could be the major volatile constituent of comets.

The UV image of comet C/2009 P1 (Garradd) in the OH band was taken in April 1, 2012, when the comet was 229 million kilometers away (Bodewits et al. (2012)). The imagery was made by the Ultraviolet and Optical Telescope (UVOT). UVOT has a 30 cm aperture that provides a 17′ × 17′ field of view with a spatial resolution of 0.5′/pixel in the optical/UV band. Seven broadband filters allow color discrimination, and two grisms provide low-resolution spectroscopy at UV (170 – 520 nm) and optical (290 – 650 nm) wavelengths. These grisms provide a resolving power ~100 for point sources. UVOT and X-Ray Telescope were used to provide the first ever simultaneous X-ray and UV image of a comet Lulin (Carter et al. (2012)). The UV and X-ray emission are on opposite sides because comet Lulin has two oppositely directed tails. Lim et al. (2014) presented observation of both spectra and images of comet C/2001 Q4 (NEAT) created from the observations with Far-Ultraviolet Imaging Spectrograph (FIMS), onboard the Korean satellite STSAT-1, (launched in 2003). FIMS is a dual-channel FUV imaging spectrograph (S-channel 90 – 115 nm, L-channel 135 – 171 nm, and resolving power ~550 for both channels) with large imaged fields of view (S-channel 4°×4.6′, L-channel 7.5°×4.3′, and angular resolution 5’– 10’) optimized for the observation of the FUV radiation produced by hot gases in our Galaxy.

The Galaxy Evolution Explorer (GALEX) has observed 6 comets since 2005 (C/2004 Q2 (Machholz), 9P/Tempel1, 73P/Schwassmann-Wachmann3 Fragments B and C, 8P/Tuttle and C/2007 N3 (Lulin)). GALEX is a NASA Small Explorer (SMEX) mission designed to map the history of star formation in the Universe. GALEX’s telescopes aperture is 50 cm. Field cameras were equipped with grism providing the FUV (134 – 179 nm) channel and the NUV (175 – 310 nm) channels at resolution 1 – 2 nm.
well suited to cometary coma studies because of its high sensitivity and large field of view (1.2 degrees). \textit{Morgenthaler et al.} (2009) reported that OH and CS in the NUV were clearly detected in all of the comet data. The FUV channel recorded data during three of the comet observations and detected the bright CI 156.1 and 165.7 nm multiplets. There is an evidence of SI 147.5 nm emission in the FUV. The GALEX data were recorded with photon counting detectors, so it has been possible to reconstruct direct-mode and objective grism images in the reference frame of the comet.

2.2 Mid and high resolution spectroscopy

Higher resolution spectroscopy brings most detailed information on astronomical objects. But it requires rather large apertures and spectrographs with stable structures. We briefly describe some findings and technical details of the larger UV observatories.

*UV observations of comets with the International Ultraviolet Explorer (IUE).* The operation of the IUE satellite in 1978 – 1996 was a real breakthrough in UV observations, in general, and in comets, in particular. The IUE was able to observe objects no closer than 45° from the Sun, i.e., the comets that approached the Sun to about 0.7 AU were accessible. The stabilization system of the satellite allowed the observation of moving objects (comets) with an accuracy of several arcseconds for a 30-min exposure. UV spectrographs of the IUE satellite were practically the only option for systematic research and monitoring of the spatial distribution of some of the most common elements in cometary comas, which are the key to understanding the production mechanism of these elements. Practically all comets that reached the brightness of stellar magnitude 6 were observed with the IUE satellite. In total, 55 comets were systematically studied.

Very briefly, the results of 18.5 years of UV studies can be formulated as follows \cite{Feston1998}: comets are composed of dust, water, CO, and CO$_2$. The content of other molecules is a few per cent of the water content (from 0.5% to 1% in comet Hale-Bopp). Chemical composition of periodic and aperiodic comets differs by no more than a factor of two and also differs by the gas-to-dust mass ratio (see however more recent data presented in Fig.1). New species were discovered in the coma, and some of the most abundant nuclear species have been studied through the spatial distribution of their dissociation products. Time variations from few moths to hours were investigated in detail.

*UV studies of comets with the The Hubble Space Telescope (HST).* HST is currently the only option for obtaining UV cometary spectra in the 115 – 300 nm range. 44 comets were observed with the HST (till 2016).

The Space Telescope Imaging Spectrograph (STIS) which allows registration of spectra in a long-slit mode is a powerful tool for studying the gas in the inner parts of the coma with a high spatial resolution. This area is essential for cometary research, as the gas in these parts of comets might not be in the radiative equilibrium state; additionally, complex and little studied chemical reactions can take place there. Like the IUE the HST has a significant limitation for cometary research. This is the Sun avoidance angle which does not allow observations of objects closer than 50° from the Sun, i.e., approximately 0.8 AU. \textit{Feldman et al.} (2016) summarised the results obtained with HST for four comets observed in the FUV with the Cosmic Origins Spectrograph (COS): 103P/Hartley 2, C/2009 P1 (Garradd), C/2012 S1 (ISON) and C/2014 Q2 (Lovejoy). The principal objective was to determine the relative CO abundance from measurements of the CO Fourth Positive system in the spectral range of 140 – 170 nm. In the two brightest comets, nineteen bands of this system were clearly identified. The water production rate was derived from observations of the OH (0,0) band at 308.5 nm by the STIS. The derived CO/H$_2$O production rate ratio ranged from 0.3% for comet Hartley to 20% for comet Garradd.

Still most enigmatic cometary objects studied with the HST in last decade are the main belt comets (MBC). MBCs exhibit comet-like mass loss resulting from the sublimation of volatile ice even though they occupy orbits in the main asteroid belt. Till now there is no definite understanding on how these cometary bodies appeared in the main asteroid belt.

Of course field cameras of the HST were used for the observation of comets though the small field of view was a serious limitation.

*Comets with Far Ultraviolet Spectroscopic Explorer (FUSE).* The FUV region shortward of 200 nm, contains the resonance transitions of the cosmically abundant elements, as well as the electronic transitions of the most abundant simple molecules such as CO and H$_2$. The principal excitation mechanism in the ultraviolet is resonance fluorescence of solar radiation.

FUSE, launched in 1999 June, provided an orbiting capability for the temperature and density diagnostics of molecular species. FUSE spectral resolution was better than 0.04 nm in the wavelength range of 90 – 118.7 nm together with very high sensitivity to weak emissions, making possible both the search for minor
3 Future observations of comets with World Space Observatory – Ultraviolet (WSO-UV).

Observations of comets from space have several specific features. As per Sachkov (2016) these are:

- Comets are moving objects. Their velocities can reach tens of arcseconds per hour. For example, comet Halley moved at a velocity of 11′/hour, relative to the stars. For obtaining the UV spectra, it is necessary to support the spacecraft stabilization during long exposures, having a priori knowledge of this velocity.

- The presence of solar lines in the spectrum significantly complicates the observation for some cometary velocities since both solar and cometary spectra, are recorded together. The observed solar spectrum is shifted by the comet’s heliocentric velocity, the so-called Swings effect.

- Comets are variable objects. Cometary nuclei produce short-lived tails and comas. Monitoring of this temporal changes requires continuous or quasi-continuous observations.

- Comets are extended objects. Larger fields of view of cameras onboard space observatory are preferable. For (imaging) spectroscopy long-slit spectrographs are the most suitable.

- Comets are faint objects. Therefore, high resolution spectroscopic observations require for sufficiently large aperture telescopes.

- An important restriction in cometary studies from the near-Earth orbit is the significant sun avoidance angle which limits the observations during perihelion passage.

The World Space Observatory – Ultraviolet (WSO-UV) fits most of the requirements listed above. WSO-UV is a multi-purpose international space mission born as a response to the growing up demand for UV facilities by the astronomical community. WSO-UV was described in previous publications in great detail (see Shustov et al. 2011, 2014; Sachkov et al. 2014, 2016), for this reason only basic information on the project, relevant to the observation of comets, is briefly presented here.

The main scientific purpose of WSO-UV is the spectroscopic observation of faint UV sources and high resolution UV imaging. The parameters of the T-170M telescope (large 170 cm diameter primary mirror, UV optimized coating of the optical surfaces, high-accuracy guidance and stabilization system, etc.) were chosen to fit requirements of high angular resolution and maximum effective area in the 110 nm – 320 nm range. Construction of the telescope provides the solar avoidance angle about 40°. This is important for observations of comets at low angular distance from the Sun.

- high-resolution spectroscopic observations of point-like objects in the 110 – 320 nm spectral range. Resolving power of the two high resolution spectrographs designed for observations in the NUV (180 – 320 nm) and FUV (110 – 180 nm) is $R > 50000$;

- low-resolution (resolving power $R \sim 1000$) spectral observations. A long slit spectrograph will operate in the 110 – 320 nm range too. It is especially suitable for faint and extended objects such as comets;

- solar-blind FUV imaging with angular resolution ($0.08''$) for direct imaging with capabilities for low dispersion slit less spectroscopy;

- wide field NUV-visible imaging with field of view 10′×7.5′ and angular resolution 0.15′;

Broadly speaking, the spectroscopic capabilities of WSO-UV and HST are rather similar; in the NUV range, WSO-UV spectrographs will be more efficient than the HST/STIS spectrograph however, the sensitivity of HST/COS in the FUV range will not be matched by WSO-UV. To evaluate the impact of the design on the scientific objectives of the mission, a simulation software tool has been developed for the WUVS (Marcos-Arenal et al. 2017). This simulator builds on the development made for the PLATO space mission and it is designed to generate synthetic time-series of images by including models of all important noise sources.

Some characteristics of the Field Camera Unit (FCU) channels significantly differ from those of HST as shown in Table 1 (Hubble data are taken from HST Instrument Handbooks). In Fig. 3 we illustrate the difference between the field of view of the NUV imager and the high resolution camera PC1 WFPC-2 on board HST.

Similar to Weaver (2002) we consider that the main scientific objective is to obtain accurate abundance measurements for all known UV-emitting cometary species CO from the CO 4PG bands, C2 from the CO Cameron bands, S2 from the S2 B-X bands, CS2 from CS emissions, and water from OH emissions and to perform a deep search for any previously undetected species. The long slit capability of the WSO-UV will allow us to characterize the spatial distribution of the coma species, so that we can identify those derived from an extended source e.g. CO, study the decay of
Table 1 Comparative characteristics of the NUV and FUV channels of the FCU with those of HST/ACS/SBC and HST/WFC3/UVIS

| Parameters                  | FUV Channel       | NUV Channel       | HST/ACS/SBC       | HST/WFC3/UVIS     |
|-----------------------------|-------------------|-------------------|-------------------|-------------------|
| Detector                    | MCP               | CCD               | MCP, MAMA         | CCD               |
| Spectral range, nm          | 115–170           | 174–310 (ext. to 1000) | 115–170           | 200–1000          |
| D (primary mirror), m       | 1.7               | 1.7               | 2.4               | 2.4               |
| Field of view, arcsec       | 163 × 163         | 597 × 451         | 35 × 31           | 162 × 162         |
| Scale, arcsec/pixel         | 0.08[^a]          | 0.146             | 0.033 × 0.030     | 0.0395            |
| Detector size, mm           | 30                | 49 × 37           | 1k × 1k           | 61 × 61           |
| Detector format             | 2k × 2k           | 4k × 3k           | 1k × 1k           | 1k × 1k           |
| Number of filters           | up to 10+2 prims  | upto 15           | 6+2 prism         | 62                |

[^a] Angular resolution.

Fig. 3 Comparison between the field of view (FoV) of the WSO-UV NUV imager and the FoV of the planetary camera PC1 WFC-2 on HST. The Hubble image and field of comet 17P/Holmes has been taken from https://apod.nasa.gov/apod/ap071128.html. Each red rectangle in the lower left inset represents the FoV of the WSO-UV NUV imager. Notice that just 9 exposures are require to cover the inner coma at full.

short-lived species e.g. S2, and investigate the importance of electron impact on CO for the excitation of the Cameron bands. The latter issue can be definitively resolved with high spectral resolution observations of any comet having V<5. If an exceptionally bright (V<2) comet is discovered, we would then request Director’s time to measure the D/H ratio. The D/H ratio in cometary water is a key indicator of the role played by comets in the delivery of volatiles to the terrestrial planets. The deuterium abundance of water in comets preserves information about the formation conditions of our solar system, while also constraining the possible contribution of cometary water to Earth’s oceans. The D/H values in Jupiter Family (JF) comets and the ice ratios (CO/CO2/H2O) in both JF and Oort Cloud comets call into question the details of the dynamical processes for populating the modern reservoirs for these two dynamical classes. Bodewits (2015) noted that currently too few D/H ratios have been measured in comets to allow for a meaningful interpretation.

Contemporary interpretation of the term “comets” includes so called exocomets. We remind that exocomets (cometary activity in extrasolar systems) have been first detected in optical observations by the temporal variations of the CAII-K line (Ferlet et al. (1987)) and confirmed in UV observations spectra of
the well-studied β-Pictris debris disk with the HST (Vidal-Madjar et al. (1994)). In recent years many interesting results were obtained by intensive optical monitoring of high-resolution optical spectra of the Ca II lines in gaseous disks around selected stars. We think that UV monitoring can be also valuable for future studies of exocomets. Miles et al. (2016) presented the analysis of time-variable Doppler-shifted absorption features in FUV spectra of the unusual 49 Ceti debris disk. This nearly edge-on disk is one of the brightest known and is one of the very few containing detectable amounts of circumstellar (CS) gas as well as dust. Miles et al. (2016) calculated the velocity ranges and apparent column densities of the 49 Ceti variable gas, which appears to have been moving at velocities of tens to hundreds of km/s relative to the central star. The velocities in the redshifted variable event showed that the maximum distances of the infalling gas at the time of transit were about 0.05 – 0.2 AU from the central star. 

A preliminary composition analysis brought to conclusion that the C/O ratio in the infalling gas is super-solar, as it is in the bulk of the stable disk gas.

Measuring the evolution of gas and small bodies in the young planetary disks will help us understanding the formation of structures such as the Oort cloud and the Kuiper belt. However, this requires extensive monitoring programs that are very inefficient when carried out from low Earth orbit observatories like Hubble. WSO-UV should be able to run several monitoring programs simultaneously in a cost-efficient manner.

Comets aggregate from interplanetary dust and there are growing evidences that the large organic molecules found in the cometary samples come from the interstellar dust trapped in the pre-solar nebula (see e.g. Bertaux and Lallement (2017)). The UV spectrum is very sensitive to small particles and large molecules. WSO-UV imagers and filters sets are designed to measure variations of the extinction curve in the coma and together with the long slit spectrograph will allow characterizing variations between the comets populations in particle size distribution and molecular bands. WSO-UV FUV imager will be operated from high Earth orbit facilitating the monitoring and minimizing the contamination from the Earth geocorona.

4 Conclusions

Comets are important “eyewitnesses” of the processes involved in Solar System formation and evolution. Observations of the UV spectra of comets from rockets and satellites have brought to light some new clues on those primitive bodies that could be the link between interstellar molecules and the early planetary atmospheres, as well as the bridge between stellar and planetary astrophysics. Some ill known physical processes require to be addressed the acquisition of the data only attainable in the UV range of the electromagnetic spectrum. Thus, space-born facilities are required to study comets; complementary ground-based observations and in-situ experiments are also needed to get a comprehensive view of the problem.

We briefly reviewed half a century of UV observations of comets and argue that it was a very fruitful period for understanding the complex nature of comets and their role in the evolution of the Solar System. Both short- and long-term experiments made an invaluable contribution to the development of cometary science. Although research on comets in situ (such as the remarkable Rosetta project) yield direct and very important data, the remote study of comets will retain its significance for many decades.

The WSO-UV mission will guarantee the continuity of the UV observation of comets, as well as exocomets. The large FoV and high sensitivity of the NUV imager together with the high Earth orbit will made of WSO-UV the most efficient observatory ever flown to track comets evolution.

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