Onsala Proposal

Lerner O2024b01

Search for and monitoring of molecular species in bright comets 2025

Semester: nov2024 **Science Cat.: Solar system**

Abstract

Comets hold important clues from the formation of the solar system, but are difficult to study since few comets are bright at mm-wavelengths and those which are strong often appear with short notice. We thus submit a trigger-activated proposal. If one or several bright comets appear during the observing period, we would like to:

* search for molecular species in the 3-mm and 4-mm band,
* monitor activity, follow outbursts and possibly determine rotation periods using HCN observations.

The 4-mm band contains a number of deuterated molecules including HDO and has hardly been used for cometary studies. Successful detection of HDO would enable us to measure the important HDO/H2O ratio.

Target comets will be selected later depending on availability and a test observation will typically be performed before committing to a more extended observing campaign.

Applicants

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Is this a long term proposal: No

Overall scheduling requirements

Observations suggested in this proposal will only be executed if appropriate comets appear during the observing period. We thus request flexible scheduling where we can specify a target of interest and ask for observing time with relatively short notice (weeks to months). When having selected a candidate comet, we may initially want to ask for a single 4-8 hour observing block to evaluate the brightness of the comet, before requesting a larger amount of observing time.

Observing runs

run	telescope	instrument	time request (minimal)	frequency (GHz)	weather (pwv)	LST range	comments/constraints
A	OSO20M	3mm Receiver (85-116 GHz)	250h (4h)	89.6			Setting to cover HCN (1-0) and HNC (1-0) simultaneously. Observing runs and scheduling will depend on the available comets.
B	OSO20M	3mm Receiver (85-116 GHz)	120h (5h)	96.7			Setting to include CH3OH (2-1) lines and CS (2-1) simultaneously. Observing runs and scheduling will depend on the available comets.
C	OSO20M	4mm Receiver (67-87 GHz)	80h (5h)	80.578283			Setting for HDO 1(1,0)-1(1,1) line. Observing runs and scheduling will depend on the available comets.

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
Unknown comet	00:00:00.00	+00:00:00.0	J2000	0.0	1	A B C	Desired target - JPL ephemeris to be used - moving target
C/2024 E1 Wierzchos	00:00:00.00	+00:00:00.0	J2000	0.0	1	A B C	Possible target - JPL ephemeris to be used - moving target
210P/Christensen	00:00:00.00	+00:00:00.0	J2000	0.0	1	A B C	Possible target - JPL ephemeris to be used - moving target
24P/Schaumasse	00:00:00.00	+00:00:00.0	J2000	0.0	1	A B C	Possible target - JPL ephemeris to be used - moving target

Scientific Rationale

Comets are left-over material from the era when the solar system formed, and comet studies thus provide us with important clues about the conditions present at the time of their formation which are fundamental for understanding how planetary systems form.

While water is the dominating cometary volatile, the production rate of HCN follows that of water more closely than any other cometary molecule. It typically show a mixing ratio close to 0.1%; therefore, this molecule is commonly used as a proxy for the water production rate [Mumma & Charnley (2011)]. By combining observations of HCN over a range of heliocentric distances, the production rate variability can be studied and possibly connected to outgassing mechanisms, rotation, and distribution of volatiles near the nucleus surface.

We have previously undertaken observations of several comets with the Onsala 20m telescope in 2013 and 2015 to 2024, focusing on monitoring the HCN $J = 1 - 0$ triplet but also searching for other molecular species. Results from the early HCN monitoring have been published in [Wirström et al. (2016)] (see also figure 1), and we have also published a paper with results covering observations of 12 comets during the period 2016-2019 [Bergman et al. (2022)]. The most important observations published so far have been the monitoring of comet 46P/Wirtanen, where HCN was measured on 21 different days between 9 December 2018 and 11 January 2019, see figure 2. We are currently planning two further papers; one covering comets observed after 2019 and one paper specialized on 12P/Pons-Brooks which we observed during 2023-2024.

With this proposal, we intend to continue this work by observing more bright comets. We would also search for molecules in the 4-mm band, utilizing the capabilities of this fairly unique receiver at Onsala, if any of the comets in 2025 becomes bright enough.

Several strategies could be employed depending on the brightness of the comet. For very bright comets, we would like to search for HDO and possibly other deuterated molecules in the 4-mm band. These observations would be intermixed with observations of HCN, since we would use HCN as a proxy for H_2O, which would allow us to derive the HDO/H_2O ratio. For less bright comets, repeated HCN observations would monitor activity, follow outbursts and could possibly be used to determine rotation periods.

The abundance of deuterated molecules has been found to vary between different comets. Especially the ratio between deuterated water and normal water is of specific interest since comets have been suggested to be a main source for the water on Earth. Although there are comets with a HDO/H_2O ratio similar to that of water on Earth such as 103P/Hartley 2 and C/2014 Q2 (Lovejoy) most comets have a HDO/H_2O ratio between 1.3 and 4.0 that of Earth [Altwegg et al. (2015)], [Biver et al. (2016)]. The total number of comets studied is not large though. Studies of more comets are needed to get better statistics of the HDO/H_2O ratio in the comet population and to understand the differences we observe.

The most abundant large ($>$ 5 atoms), organic molecule measured in cometary ices is CH_3OH. According to a review by Mumma & Charnley (2011) it has a measured abundance range relative to H_2O between 0.3% and 4%. The CH_3OH observed in cometary comae is believed to be parent species directly sublimated off the icy core, and the structure of its rotational spectrum makes CH_3OH a favourable temperature probe for comets. In the case of an active comet, we therefore propose to monitor the CH_3OH line quartet at 96.7 GHz in parallel with HCN observations. To date, our best CH_3OH observations were made in late December 2018, when we observed comet 46P/Wirtanen and detected the 96.7 GHz quartet as well as three other CH_3OH lines between 95.1 and 97.6 GHz, see figure 3.

Comets can behave very unpredictably. This is often the case with long-periodic comets where it is not uncommon that the brightness differs by orders of magnitudes from predictions. Short-periodic comets which have been observed on multiple perihelion passages are generally more well-behaving but also less active although they can undergo dramatic outbursts, for example 17P/Holmes in 2007 [Ishiguro et al. (2013)] or 41P/Tuttle-Giacobini-Kresák in 1973

[Kresák (1974)]. Halley-class comet 12P/Pons-Brooks did undergo several outbursts during the latter half of 2023 and we did capture one of the big ones in mid-November, see figure 4.

After a couple of comet-rich years, the prospects for 2025 do look a bit bleaker. There are a couple of short-periodic comets which may become observable in November-December: 24P/Schaumasse and 210P/Christensen. The only brighter comet currently predicted for 2025 is C/2024 E1 Wierzchos, an Oort-cloud comet which could become fairly bright at the end of the year and in early 2026. Unfortunately, it heads towards the southern sky, so the best possibilities to observe it would occur in November. However, bright comets do sometimes appear with short notice, and we hope that some yet undiscovered comet(s) worth observing will appear during 2025.

Facilities Requested

Although the Onsala 20m telescope is not the most sensitive telescope, it can be used for bright comets, as our earlier observations have shown. Due to the combination of limited visibility windows and very dynamic and variable outgassing characteristics of comets, such observations can add important data points to often limited data sets. With the 4-mm receiver, we have a fairly unique instrument for a frequency band where not very much work has been done on comets. Also at the 3-mm band, we can search for and monitor a number of important molecular species.

We plan to use both the 3-mm and 4-mm receiver in combination with the Onsala FFT spectrometer (OSA). The 4 GHz mode will allow us to observe several important lines simultaneously; we can for example cover HCN, HNC and HCO^+ with the same frequency setting.

Observing Requirements

To be worth observing, the comet has to be strong enough that we get a clear HCN detection ($> 3\sigma$) in less than 8 hours, since we prefer not to stack data from different days due to possible changes in activity. To reach an r.m.s. of 5 mK with 76.3 kHz resolution (widest OSA spectrometer band) at 45° elevation for HCN, CH_3OH and HDO would take 5.2, 7.5 and 5.0 hours, respectively, in frequency-switching mode. Since we want to study variations in activity, we want to repeat measurements over as many days as possible and we thus request a total of up to 450 hours. The amount of time used will depend on availability of suitable targets.

Observing Plan

We plan to take advantage of the 4 GHz bandwidth to cover several important molecular transitions simultaneously and use frequency switching with 60 seconds integration time and a 5–25 MHz frequency throw employing fully automated BIFROST command files, which would allow us to observe at any time including weekends and public holidays.

We may initially ask for a single 4-8 hour observing block to evaluate the brightness of the comet through observations of HCN, before requesting a larger amount of observing time. If the HCN line is easily detected, we would continue by observing CH_3OH and, if very bright, also HDO and possibly other species. We would continue to reobserve HCN regularly to monitor changes in activity, possible outbursts and potentially detect variations related to the rotation period of the nucleus.

Scheduling Requirements

The exact observing windows are difficult to specify in advance, since they depend on the behaviour of the comets. We will follow reports from professional as well as amateur astronomers to judge when it may be worth trying to observe these comets, and we thus need flexibility in the scheduling, especially if some comet happen to undergo a sudden outburst.

References

[Altwegg et al. (2015)] Altwegg K., Balsiger H., Bar-Nun H., et al.: "67P/Churyumov-Gerasimenko, a Jupiter family comet with a high D/H ratio", Science, 347, 1, 2015.

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[Mumma & Charnley (2011)] Mumma M.J. & Charnley S.B.: "The Chemical Composition of Comets — Emerging Taxonomies and Natal Heritage", ARA&A, 49, 471, 2011.

[Wirström et al. (2016)] Wirström E.S., Lerner M.S., Källström P., et al.: "HCN observations of comets C/2013 R1 (Lovejoy) and C/2014 Q2 (Lovejoy)", A&A, 588, A72, 2016.

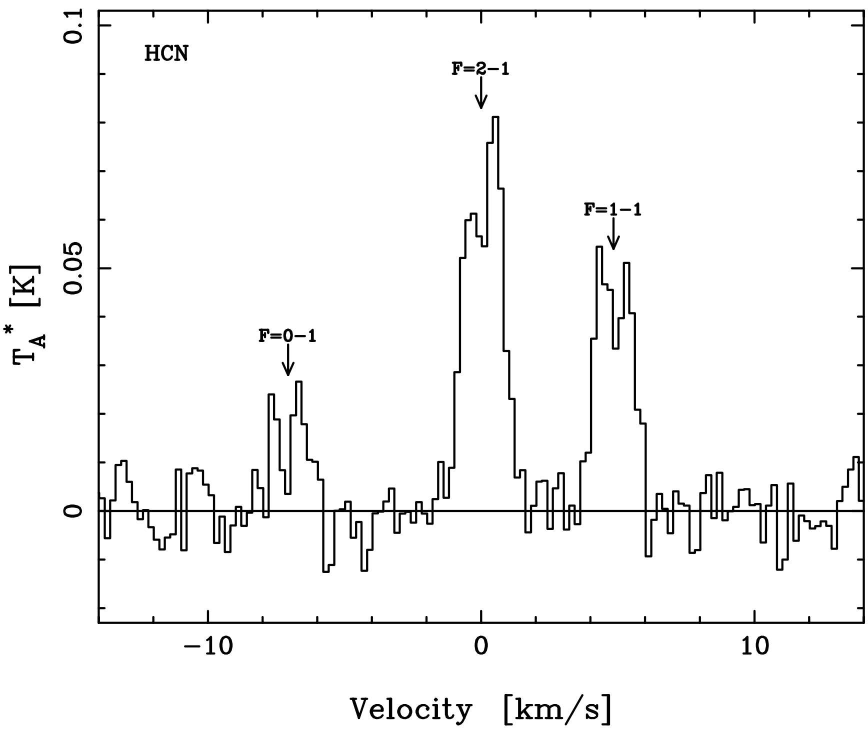

Figure 1: The HCN $J = 1 - 0$ triplet observed in comet C/2014 Q2 (Lovejoy) with the Onsala 20m telescope on January 14, 2015. From this data, we derived an estimate for the HCN production rate of $4.5 \pm 0.1 \times 10^{26}$ molecules/s, and a HCN abundance relative to water of 0.09%.

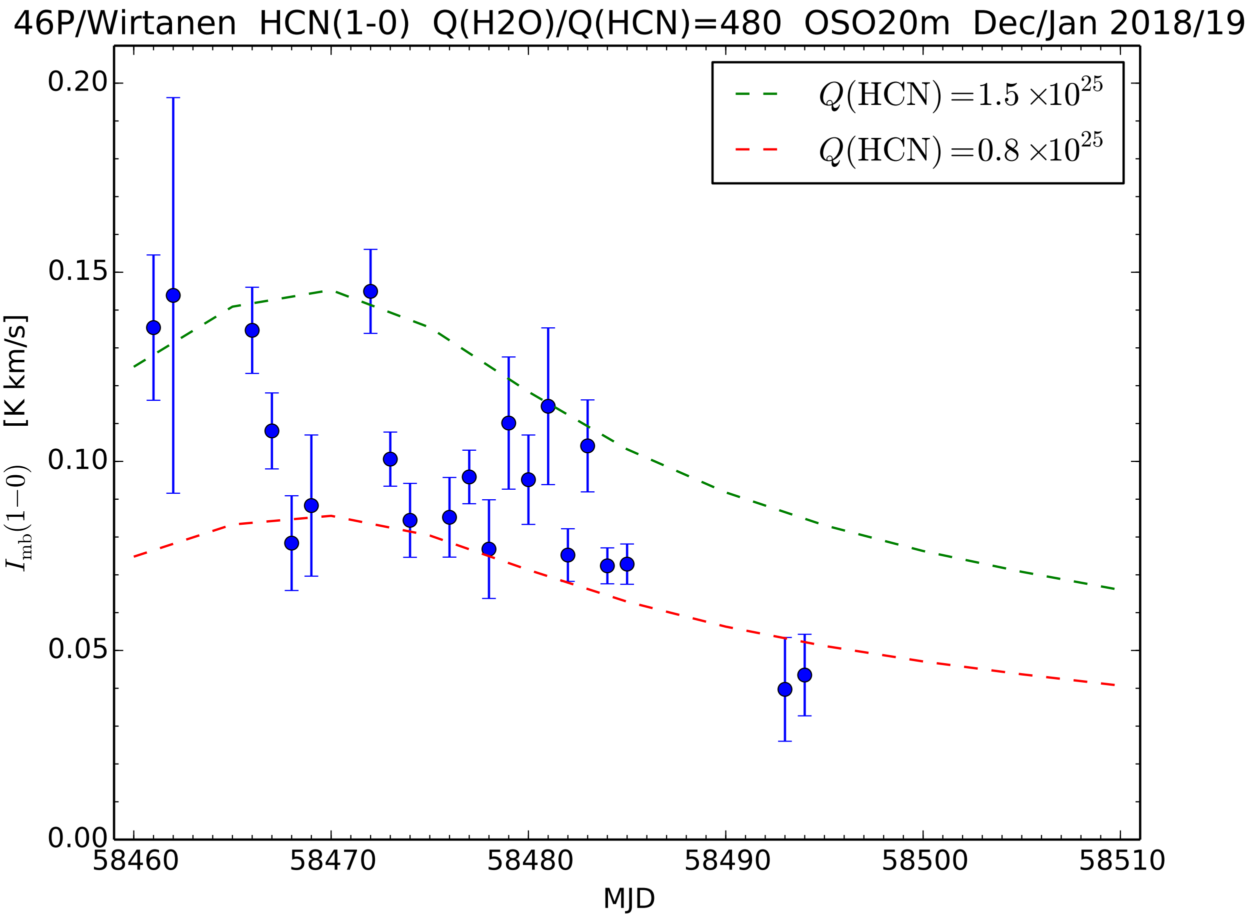

Figure 2: Variations in the intensity of the HCN $J = 1 - 0$ triplet observed in comet 46P/Wirtanen with the Onsala 20m telescope during December 2018 and January 2019. The early observations have larger error bars, since the comet was only observable at low elevations, while differences in error bars in later observations mostly are due to the weather conditions. The dashed lines represent expected variations in intensity based on model calculations using two different production rates.

Figure 3: The seven CH_3OH lines detected in comet 46P/Wirtanen in late December 2018 with the Onsala 20m telescope. Data from several days representing about 60 hours of observing time were added together. Using a bandwidth of 4 GHz allowed the detection of three additional lines apart from the line quartet at 96.7 GHz. The dashed red lines indicate the expected locations of the lines and the green areas indicate the parts of the spectra that were used for baseline subtractions.

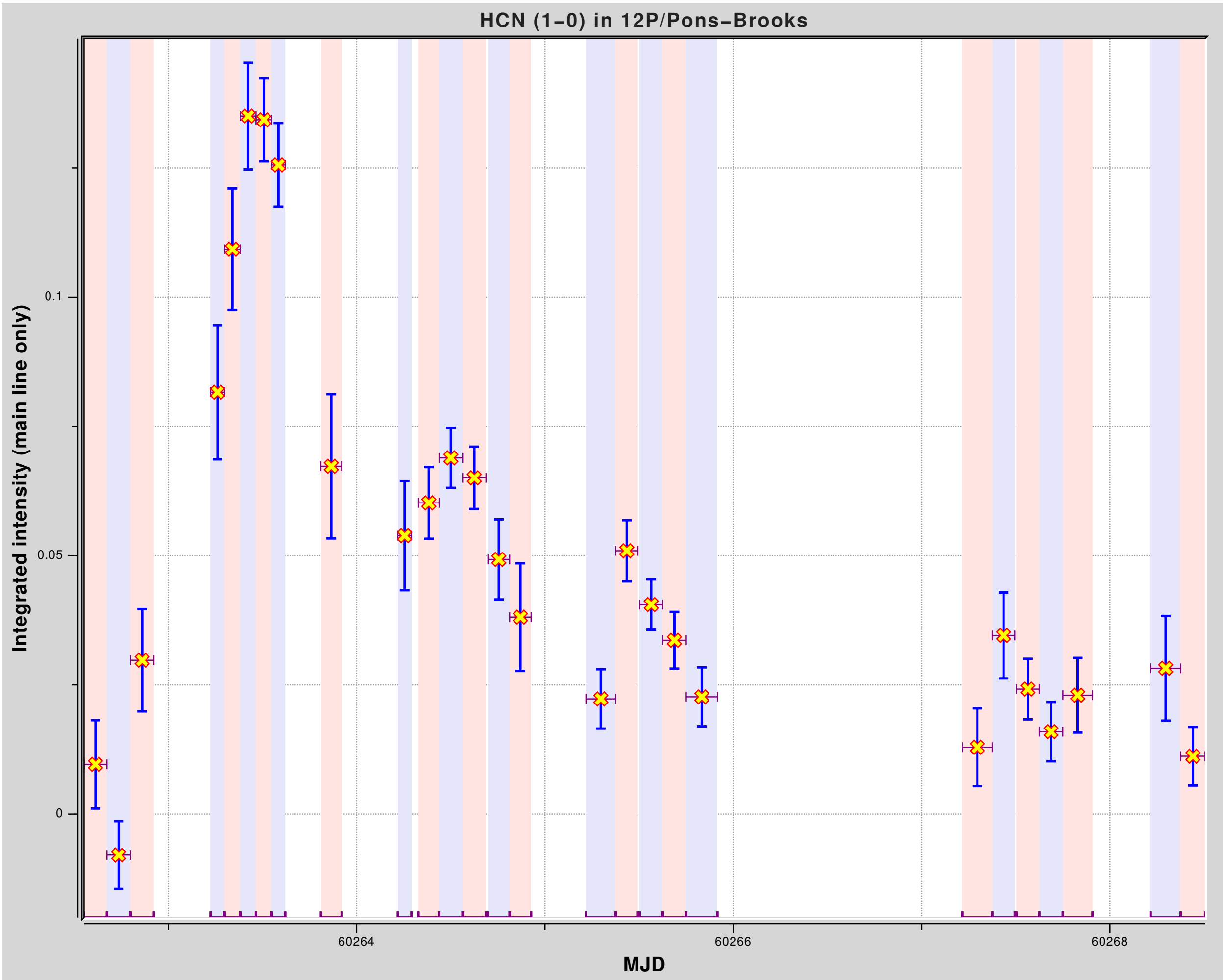

Figure 4: Variations in the integrated intensity of the main line in the HCN $J = 1 - 0$ triplet observed in mid-November 2023 during an outburst in comet 12P/Pons-Brooks. The red and blue stripes indicate the time periods when the data was taken for each data point presented. (This is a preliminary result which has not yet been published.)

No PhD Students involved

Linked proposal submitted to this TAC: No

Linked proposal submitted to other TACs: No

Relevant previous Allocations: Yes

A DDT proposal to monitor HCN(1-0) in comet C/2013 R1 (Lovejoy) November/December 2013 was submitted and awarded time (project O2013a-006). HCN was detected on 7 days with varying intensity. Results have been published in Wirström et al. 2016 (A&A 588, A72).
Thirteen regular proposals and five additional DDTs (O2016a-05, O2016b-01, O2017a-01, O2017b-03, O2018a-03, O2018b-01, O2019a-03, O2019b-01, O2020b-01, O2021b-01, O2022b-01, O2023b-01, O2023b-02, DDT-O2021b-05, DDT_OSO20M_06, DDT_OSO20M_08, DDT_OSO20M_02(2023) and DDT_OSO20M_03(2023)) similar to the present one were submitted for the previous observing periods and have been granted time. Unfortunately, there were no really bright comets appearing during these periods and the results obtained so far are HCN measurements for a number of comets as well as methanol detections in a few cases.
Results from observations of 12 comets during the period 2016-2019 were published in Bergman et al. 2022 (A&A 660, A118)

Additional remarks

This proposal requests flexible scheduling depending on availability of suitable targets.
If no suitable comet appear, none or only part of the requested observing time will be used.

Observations under proposal O2018a-03 have been used to commission automatic observing with the new BIFROST telescope control system. We intend to perform all future observations with fully automatic command files and can thus easily make use of telescope time on weekends/public holidays even with short notice.

Observing run info :