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A white paper response to call for community input for alternate science investigations for the Kepler spacecraft

Simultaneous Rosetta in situ and Kepler remote observations of the tail and coma of comet 67P/Churyumov-Gerasimenko

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Abstract

We propose to use the Kepler telescope as a comet tail monitor during a 5-months interval in 2014-2015 while at the same time the Rosetta spacecraft will be performing *in situ* measurements in the near comet environment.
The ESA corner stone mission Rosetta will arrive at comet 67P/Churyumov-Gerasimenko after a 10-year cruise phase in the solar system. While in orbit around the comet the extensive instrument package onboard will monitor the comet nucleus, coma and tail, and study their evolution as the comet approaches the Sun. We can at the same time make us of Kepler remote observations to gain a global view of the entire coma and tail. The science topics we anticipate to do within this kind of campaign include:

- Monitor the evolution of the cometary coma and tail as the comet approaches the Sun
- Study the structure and dynamics of the tail and coma caused by solar wind variability
- Remotely observe comet tail disconnection events
- The total dust brightness from Kepler will be useful to monitor the overall production from the comet.
- Combine Kepler observations with earth-based remote measurements to get a stereo view of the tail structure of the comet
- The 0.5 AU Kepler–Earth distance implies that Kepler can observe the comet when Earth-based observations are obscured by the Sun

Background

The ESA spacecraft Rosetta, launched in 2004, will arrive at the comet in May 2014, at a distance of about 3.2 AU from the Sun, after which measurements of the comet and its coma will commence [*Glassmeier et al.,* 2007]. Aside from remote observations, much of the current understanding of the structure of cometary comae come from limited 'snapshot' studies during spacecraft flybys. A comet like 67P is composed of icy material, formed during the dawn of the solar system. In the outer solar system it has remained unchanged with no geological activity or atmospheric erosion, hence being one of the most pristine objects in the solar system. In the 1950's the gravitational field of Jupiter disturbed its orbit and set it into a new one much closer to the Sun (aphelion at 5.7 AU, perihelion at 1.3 AU and an orbital period of 6.4 years).

Figure 1. Comet 67P observed on 27 March 2003 when the comet was at a distance of 2.6 AU from the Sun. The picture spans 0.19 x 0.19 deg and was taken from a distance of 1.7 AU. Exposure time was 36 minutes with a red filter. The tail is at this time about 10^6 km long. Image credit: DLR

When within ~3 AU the solar heating of the comet increases the activity and the outgassing rapidly intensifies [*e.g., Davidsson et al.,* 2010]. The gas and dust exhausted from the nucleus is partly ionised by solar EUV photoionisation and charge exchange processes with the solar wind. Sunlight will scatter on the exhausted dust and make it visible for remote observations. For an active comet close to the Sun with a fully developed coma many different plasma regions and boundaries develop due to the interaction with the solar wind. [*Neubauer et al.*, 1986, *Cravens et al.,* 1987].

The coma around the comet acts as an obstacle to the solar wind flow [e.g., *Thomsen et al.,* 1986]. This leads to the creation of an induced cometary magnetosphere, in some ways similar to the induced magnetospheres of Titan, Mars and Venus. Simulations have shown that for Rosetta, the bow shock ahead of the induced magnetosphere forms first when within 2 AU from the Sun while the magnetic pileup boundary forms already beyond 3.2 AU [*Hansen et al.,* 2007]. From 67P's previous perihelion pass it was estimated that the outgassing was about 10^{27} mol/s, which implies that the sub-solar standoff distance of the bow shock would be a few times 10^4 km [*Mendis and Horányi.,* 2013].

The bow shock of comet Halley was observed at a distance of about 10^6 km from the nucleus [*Coates et al.,* 1997b, and references therein] and cometary ions have been observed up to $2.8 \cdot 10^6$ km away from the nucleus of comet Grigg-Skjellerup [*Goldstein et al.,* 1994]. The size of the interaction region between the cometary coma and the solar wind strongly depends on the activity of the comet, and therefore also on the distance to the Sun, as can be seen in Figure 2.

One thing that is of major importance for this paper is the gradual transition from the low activity case to the high activity case outlined in Figure 2. There is a tremendous development of the plasma environment around a comet as it approaches the Sun. Furthermore, the outgassing of material from the nucleus is not necessarily uniform, making the situation in the coma even more interesting.

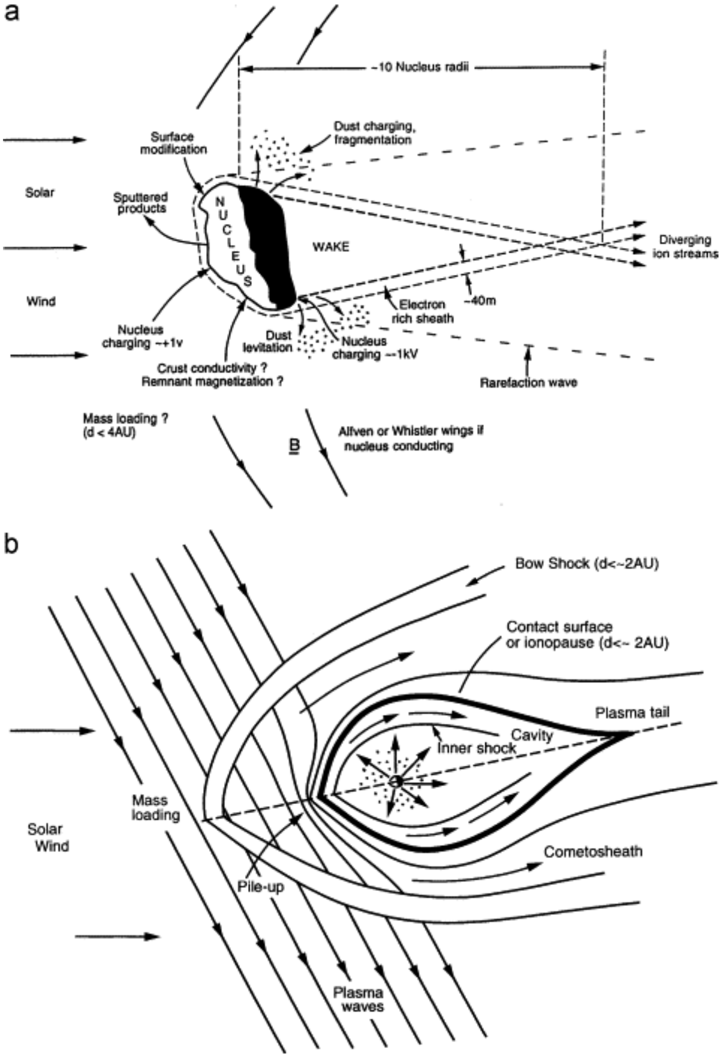

Figure 2. The solar wind interaction with a comet during (a) low and (b) high activity [from Coates, 1997a]. With Rosetta in situ measurement and with remote Kepler and groundbased observations we can now follow the transition from one state to the other.

The uneven surface on the comet causes varying illumination intensity and gasses may escape more easily through cracks and fissures in the nucleus. Comet 67P is rotating with a period of about 12 hours and the more active regions will exhaust material in different directions as the comet rotates. Remote observations have indicated that effective outgassing occurs from only about 3-4% of the surface area [*Schleicher,* 2006]. This implies that at least the inner coma will be very asymmetrical, possibly leading to a very asymmetric outer coma as well, with bumps and kinks on all the described plasma boundaries and regions [*Rubin et al.,* 2012; *Wiehle et al.*, 2011]. With Rosetta we can study the development of the coma and the structure and variability of the various plasma boundaries and regions as it approaches the Sun. Using Kepler as a remote observer at a distance of around 0.5 AU away from Earth will give an additional view of the structure and evolution of the cometary coma and tail. There are already extensive Earth-based observation campaigns involving several meter-sized telescopes as well as amateur astronomers, see https://sites.google.com/site/67prosetta/ for more info.

Science objectives

During its approach toward the Sun, the comet 67P will go from being an essentially quiet 2-kilometre sized icy body, to become increasingly more active and develop a huge coma, while Rosetta will be in orbit around the comet. The coma build-up has never been studied *in situ* before and we now have the unique opportunity to also follow this process remotely with the Kepler telescope as well as with Earth-based telescopes situated at different heliospheric longitudes.

Many of the basic parameters of the comet are unknown, such as its gravity and the pressure from the outgassing, which will affect the plasma environment around it as well as the measurements themselves. During approximately the first 6 months, called Phase A, the spacecraft will orbit the comet gravitationally bound with a relative velocity on the order of 0.1 m/s or less. The spacecraft will then be carefully oriented such that the 60-meter long solar panels are directed toward the Sun and perpendicular to the outgassing material from the cometary nucleus, to prevent the drag from the outflowing gas blowing the spacecraft out of its orbit. During this mapping phase, our instruments will monitor the physical plasma processes occurring within the coma. The electric and magnetic fields together with the ion and electron populations will be measured and mapped. Phase B of the mission starts as the comet approaches perihelion, when the fluxes of escaping material from the comet increase such that the spacecraft will not be able to stay in a stable orbit any longer. Rosetta will then instead start to make regular flyby maneuvers of low speed, typically <1 m/s. The estimation is that there is enough fuel to complete 16 such flyby maneuvers. During this phase we will be able to study the plasma in the expanding cometary coma and the development of the inner boundaries of the electromagnetic interaction between the plasma in the coma and the impacting solar wind.

In addition, we will also be able to study the effect of the solar wind variability on the coma structure and dynamics, as we have previously done for the induced magnetospheres of Mars and Venus [Edberg et al, 2010, 2011]. We anticipate that the plasma environment and the various boundaries and regions will vary in response to upstream solar wind fluctuations, as the pressure balance between regions will change. Furthermore, previous optical observations of other comets have shown that the huge cometary tail can simply snap and disconnect from the comet, a process which has been linked to crossings of solar wind sector boundaries [*Niedner and Brandt,* 1978], and to CME/CIR impacts with associated magnetic field reversals [*Jones and Brandt,* 2004; *Kuchar et al.,* 2008]. A famous example of this process is the comet Encke's tail disconnection event, which can be viewed at http://www.youtube.com/watch?v=zGVLlRJLeWs. This is of course highly interesting to study when exploring the physics of the coma. By using Kepler observations together with long-term in situ Rosetta measurements we are more likely to observe such disconnection events. Due to its position mainly close to the nucleus, it is unlikely that Rosetta will be able to directly observe the reconnection processes. However, reconnection causes particle acceleration, and the energetic particles from the tail entering the coma will cause increased ionization and a variety of plasma processes yet to be explored. Therefore it would be even more beneficial to have remote observations from Kepler, which could give a sequence of images of the entire tail as it disconnects. This is virgin territory: no spacecraft has ever before conducted observations in the coma during a tail disruption event, and to our knowledge no theoretical or numerical investigations of coma response to a disruption event have ever been made. Kepler observations would increase the probability of seeing such events. If observing at the same time as the Earth-based campaigns it could give very interesting stereo-views that could untangle the details of disconnection process further.

Kepler observation campaign

We propose to perform remote observation campaigns from October 2014 until February 2015, see Figure 3 for observation geometry. In this interval the viewing direction is more than 45 deg off from the Sun direction, the comet will be gradually increasing its active due to the decreasing distance to the Sun. The heliocentric distance will decrease from about 3.3 AU to 2.5 AU and the Kepler-67P separation will go decrease from 4.2 AU to 2.0 AU.

Rosetta will go into orbit around 67P in August 2014 and perihelion of 67P is about one year later, in August 2015. In October 2014 the observational geometry is favorable for both Earth based remote observations as well as from Kepler.

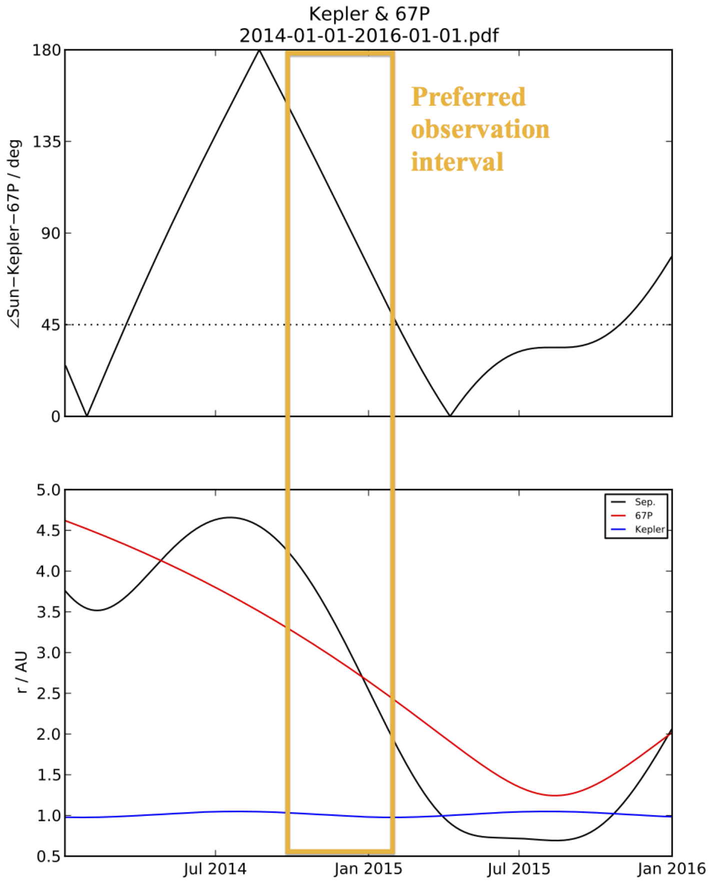

Figure 3. (top) Viewing angles from Kepler plotted as function of time. Kepler cannot observe targets within 45 deg from the Sun-direction. (bottom) Heliocentric distances of Kepler and 67P as well as the separation between Kepler and 67P.

If having to prioritize shorter intervals for observations we would choose to have observations later in the suggested interval rather than earlier due to several reasons. Firstly, towards the end of 2014 and the beginning of 2015 Earth will be behind the Sun such that the Kepler observations are extremely valuable in order to continue the remote monitoring when the Earth based observations are obstructed by the Sun. Secondly, toward the end of the interval the comet will be closer to the Sun and more active and at the same time scatter more sunlight such that the coma and tail are more visible, compared to early in the suggested interval.

It would of course be very beneficial to continue observations all the way to perihelion of 67P, but from Figure 3 it can be seen that the viewing direction is not possible due to the 45 deg limit.

We would of course prefer to have as long continuous monitoring as possible from Kepler, but depending on the telemetry rate available, the allocated observation time etc, we can think of a couple of scenarios for how to run Kepler observation campaigns. Details on the exact observations times will have to be resolved at a later stage, as the observation time and telemetry rate is presently unknown to us we can only state two scenarios for how we could run campaigns and what that yields in science return.

1) Continuous observations during the entire campaign

This will allow us detail studies of the coma and tail growth during the approach to the Sun, and to see how the dust brightness, which is a measure of the total dust production, varies. The probability of observing solar wind induced variability will be maximized in this scenario.

2) Multiple ~week-long intervals of observations

This will still allow us to study the growth of the coma and tail during the approach to the Sun, as well as the comet brightness. The probability of observing solar wind induced variability will be decreased in this scenario, but over a week's time it is quite likely to have at least one solar wind disturbance passing by, such as rotations of the interplanetary magnetic field, density enhancements, coronal mass ejections etc.

3) Hour-long observations spread out in time

This would give us snapshot views of the structure of the coma and tail that we could use for gaining understanding of how the coma outgassing is structured and how it interacts with the instantaneous ambient solar wind. If only a few such shorter observations are possible we would prioritize to have them towards of the end of the suggested observation campaign interval (i.e. Jan – Feb 2015).

The amount of structure and detail we will see of the cometary coma and tail will depend on the proximity to the Sun. The coma and tail will grow substantially as the comet approaches the Sun and the heating and subsequent outgassing starts to increase. The closer to the Sun the comet gets the more amount of scattered sunlight there will be. If the resolution of the Kepler observations is on the order of 5000 km (1 arcsec angular resolution at a distance of 2 AU), we should be able to see quite a lot of detail in a tail. The tail could well become on the order of

10^6 km long (see Figure 1). In the same way, we do not at this stage know how much of the full field of view of the instrument that is required to cover the entire comet tail. If the projected tail is 10^6 km at a distance of 2 AU we should only need to monitor a 0.5x0.5 deg area with Kepler. This is only about 0.25% of the full field of view. Reading a full frame image from Kepler takes about 20 min and we would only need a fraction of the image size, which would give us a perfectly fine cadence for studying solar wind induced variability.

Pointing issues

As outlined in the call for white papers, the pointing direction will drift about 1.4 deg in 4 days, with a jitter of 0.5-1.0 arcsec. This should not be a problem for us since we will require much shorter integration times for each image – rough estimates are less than an hour. The apparent magnitude of the comet nucleus is ~13 mag at perihelion [*Snodgrass et al.*, 2013], see Figure 4. The magnitude in Figure 4 was calculated for Earth but should be similar from Kepler. An accuracy of 1 arcsec (about 5000km) is also fine for observing a coma and tail which is of the order of 10^6 km. We have chosen the observation campaign so that it the pointing of Kepler will not be within 45 deg of the Sun direction according to the requirements.

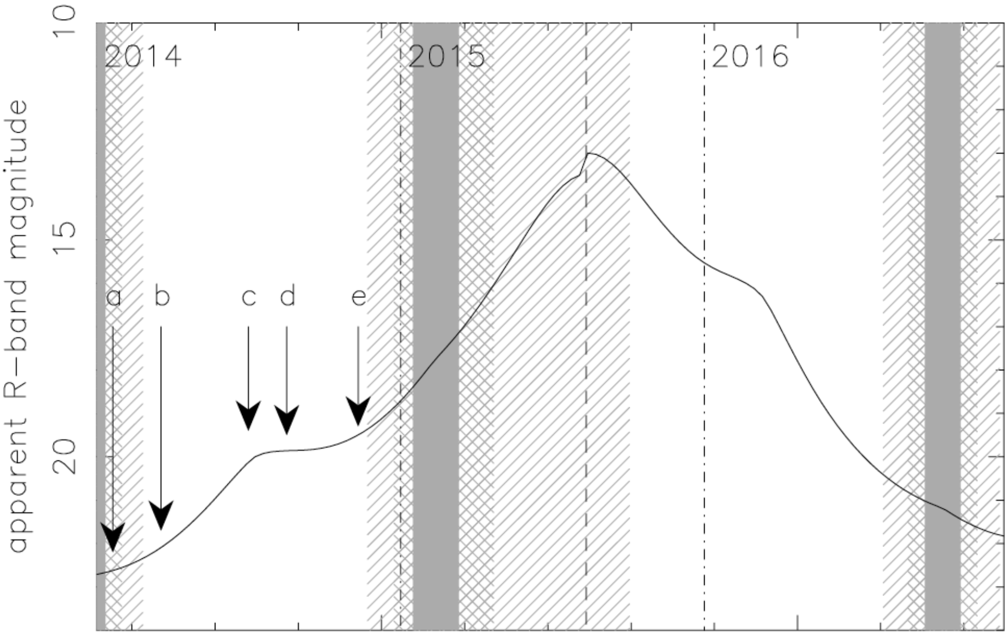

Figure 4. (Figure and caption text from Snodgrass et al., 2013) Predicted apparent R-band magnitude of the comet, as measured within an aperture with ρ = 10 000 km, for 2014–2016. This covers the active phase of the Rosetta mission, including any extended mission beyond the end of 2015. Mission milestones in 2014 are marked: (a) Switch on of the spacecraft (January 20th, 2014); (b) Expected beginning of detectable activity, at 4.3 AU (March 2014); (c) The nucleus begins to be resolved by the OSIRIS Narrow Angle Camera on Rosetta (July 2014); (d) Orbit insertion (August 2014, at 3.5 AU); (e) Lander released (November 2014, at 3 AU). Perihelion (in August 2015) is marked by a vertical dashed line.

Conclusions

We have proposed to use the Kepler telescope for observing the cometary coma and tail during a five-month interval in 2014-2015. This will significantly extend already planned Earth-based observation campaigns and give significant additional value to the *in situ* measurements to be conducted by the Rosetta spacecraft. The science return will include new knowledge of the cometary coma and tail growth as it approaches the Sun, how the dust production rate varies with solar distance, effects of solar wind variability on the coma including comet tail disconnection events, and stereo views of the coma and tail together with Earth-based observations.

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