SUNGRAZING COMETS AS SOURCE OF PICKUP IONS AT EARTH ORBIT AND ULYSSES

Maciej Bzowski and Małgorzata Królikowska
Space Research Centre PAS, Bartycka 18A, 00-716 Warsaw, Poland

ABSTRACT

Most of the sungrazing comets observed by LASCO at SOHO belong to the Kreutz group of comets and follow trajectories that are tightly clumped in space. Statistical analysis of 9 years of SOHO observations suggests that the true apparition rate of these comets is as high as one every other day. Practically all these comets break up before perihelion passage. Their material is dissociated and ionized, and subsequently transported away from the Sun as pickup ions in the solar wind. Their mean mass flux is about $3.1 \times 10^4$ g·s$^{-1}$. Since the breakup occurs between 40 and 4 solar radii and the ionization is almost immediate, the expected location of these ions in the phase space is close to the location of the inner source of pickup ions. Assuming radial propagation, the cometary pickups should be observable at Earth between August and January, with peak probability at the end of September. At Ulysses, they should be observable approximately between −25 and 40 degrees ecliptic latitude during the fast latitude scans, the first of which occurred in 1995 and the second in 2001. The population of cometary pickup ions should be augmented by about 40% by solar wind protons as a result of charge exchange with the cometary neutral hydrogen and oxygen atoms and subsequent reionization of the newly-created Energetic Neutral Atoms, streaming with respect to the solar wind. In total, the average flux of the pickup ions related to the sungrazing comets at 1 AU should be about $1.6 \times 10^5$ g·s$^{-1}$·sr$^{-1}$ within the detection area (and null outside it). This value is comparable to the flux of the inner source-pickup ions.

Key words: interplanetary medium; solar wind; comets; pickup ions; inner source; heliosphere.

1. INTRODUCTION

Pickup ions (PUIs) in the solar wind are former neutral atoms of thermal energy, ionized and picked up by the magnetic field frozen in the solar wind (Fahr 1973). The main source of PUIs is neutral interstellar gas. PUIs from interstellar helium were discovered by Möbius et al. (1985) and from interstellar hydrogen by Gloeckler et al. (1993). The inner source of PUIs was discovered by Geiss et al. (1995). Observations of the PUI distribution function (Gloeckler & Geiss 1998) and modeling suggest that the peak source rates of these ions occur between 10 and 30 $R_S$ and its elemental composition is similar to the composition of solar wind (Gloeckler et al. 2000).

Several explanations of the PUI inner source were proposed, all of them involving some kind of interaction of interplanetary dust with the solar wind: recycling of the solar wind ions on dust grains (Gloeckler et al. 2000, Schwadron et al. 2000), neutralization of solar wind ions on nanometer-sized dust grains (Wimmer Schweingruber & Bochsler 2003), and ionization and pickup of products of collisions of dust grains close to the Sun (Mann & Czechowski 2005). None of these scenarios is able to fully explain the observations and one of the important problems is the lack of sufficient amount of dust so close to the Sun (Mann & Czechowski 2005). A more thorough discussion of these scenarios is offered by Allegrini et al. (2005).

It seems that there might be more than just one “inner source” of PUIs. In a recent paper Bzowski & Królikowska (2005) (further on: BK05) suggested that at least a part of the inner source of pickup ions might be the material released by sungrazing comets from the Kreutz group. In this short communications we recapitulate and expand these ideas and results.
2. KREUTZ SUNGRAZERS AS SOURCE OF PICKUP IONS

Shortly after beginning of operations, the LASCO coronograph onboard the SOHO spacecraft discovered a stream of comets approaching the Sun to a few solar radii \( [\text{Biesecker et al. 2002}] \). Observations show that 85% of these comets belong to a single group of comets, discovered by Kreutz \( [\text{Kreutz 1901}] \) and carrying its name. The Kreutz comets seem to have been present since their discovery until now, as evidenced by limited optical and space-borne observations listed by BK05; they were present at the discovery of the inner source by Ulysses and have been observed until now. Based on the yearly pattern of perihelion times rate observed during first 2 years of LASCO operations, which features peaks in June and December, \( [\text{Biesecker et al. 2002}] \) concluded that the true Kreutz rate is much higher than observed due a geometrical instrument selection effect and equal to about 1 every other day. This rate was confirmed by BK05 based on a 9 year’s statistics.

The Kreutz comets follow very similar, highly-elliptical (almost parabolic) orbits and disintegrate between 40 and 4 \( R_S \) in a well-constrained region of space. Based on analysis by Sekanina \( [\text{2003}] \), BK05 estimated the mass influx from the Keutz comets at \( 3.1 \cdot 10^4 \text{ g s}^{-1} \). As close to the Sun as the Kreutz comets disintegrate, the whole material is very quickly (minutes to hours) dissolved into atoms and simple molecules, ionized and picked up by the solar wind. The ionization processes are charge exchange between the cometary neutral atoms and solar wind protons, impact of solar wind electrons and ionization by solar EUV photons. The charge exchange effectively contributes an extra source of the comets-related PUIs: one of the reaction products is an Energetic Neutral H-atom (H-ENA) which, being relatively slow close to the Sun, eventually gets ionized. Since before ionization it had a non-zero velocity with respect to the accelerating solar wind in the location of its reionization, it becomes and extra PUI proton. A more thorough discussion of this reaction channel and related physics is provided by BK05. They estimate that the H ENA reionization channel increases the number of the comet-related PUI’s by about 40% and that the cometary PUI composition (by number) will be 43% of H, 27% of O, 25% of C, and 5% of other elements, as Mg, Si, Fe etc. It is worth noticing as well that the cometary dust, especially the grains released before breakup, are subject to the same interaction with solar wind as in all proposed “dusty” scenarios of the inner source origin, and as such are able to produce, e.g., neon PUI, also observed in the inner source, and makes extra targets for the dust-related mechanisms of inner-source PUI production. Since, however, details of the interaction of dust grains with solar wind during such a short time as it remains between grain release at the breakup of nucleus and evaporation of these grains...
in the heat from the Sun, it is difficult to assess qualitatively the extra intensity of inner source from this channel.

Assuming radial propagation of PUIs from the pickup location away from the Sun, as schematically illustrated in Fig. 1, BK05 predicted that an Earth-bound spacecraft should be in a favorable position to observe the cometary PUIs since the end of July until beginning of November each year, with the peak probability of detection at the end of September, and Ulysses on its polar orbit around the Sun should be inside the detection region between Feb.10, 1995 and May 14, 1995, and again during the next revolution, between April 23 and July 23, 2001, while in the ecliptic latitude band between $-26^\circ$ and $41^\circ$.

In this paper we refine this prediction, as illustrated in Fig. 2 for Earth-bound spacecraft and in Fig. 3 for Ulysses. BK05 assessed the average count rate at 1 AU at 12.5 s$^{-1}$ cm$^{-2}$. Fig. 2 shows that the probability of detection is highly peaked within the indicated time interval of DOY 215 – DOY 310 and that the core of the probability distribution function is contained between DOY 260 and DOY 290, which corresponds to September 17 and October 17. The mean count rate during this interval should be $\sim 3$-fold higher than originally estimated, reaching an easily-detectable value of $\sim 40$ s$^{-1}$ cm$^{-2}$. Ulysses should see the core of the probability distribution function when between $5^\circ$ and $25^\circ$ north ecliptic latitude in Spring of 1995 and 2001.

3. DISCUSSION

BK05 considered a hypothesis that the Kreutz sungrazers could be in fact the sole inner source of PUIs. If this should be the case (and if the hypothesis of radial propagation of the cometary PUIs from their birth place holds), then the inner source should be observable only during the intervals indicated by BK05. Allegrini et al. (2003) checked this hypothesis, searching for the inner source PUIs in Ulysses data during three selected intervals outside the intervals suggested by BK05, and found that the inner source is there, correlated with the solar wind flux and stable over the solar cycle. Hence the sungrazing comets cannot be the sole inner source of PUI. Nevertheless, analysis of inner source observations during the intervals suggested by BK05 and in this paper still needs to be done. Allegrini et al. (2003) report lower production of C and O (5 and 7 x $10^8$ g s$^{-1}$, respectively) than inferred by Geiss et al. (1996) (2 · $10^6$ g s$^{-1}$ each), who refer to Ulysses observations performed in the latitude band including the band suggested by BK05 as prone for detection of cometary PUIs.

The indication that actually observed inner-source PUIs are partly due to the Kreutz comets would be a reduction of Ne content in the inner source PUI flux during the suggested intervals with an increase of the net inner source PUI flux. Apart from these, the cometary PUIs are hardly discernible from the “regular” inner source PUIs. As pointed out both by BK05 and Allegrini et al. (2003), they should occupy the same location in the phase space. Further, the composition should be similar, though the Ne content should be reduced since the only way to obtain Ne PUIs from the cometary material would be to neutralize the solar wind Ne ions on the cometary dust grains, which have short lifetimes at breakup. Since the main ionization channels for cometary material are charge exchange with solar wind protons and electron impact, the cometary PUI flux should be correlated with the solar wind flux similarly as observed in the case of regular inner source PUIs. Finally, contrary to the suggestion by Allegrini et al. (2003), counts from the cometary PUIs should show statistics relevant for a randomly-distributed source inside a well-constrained region of space. The apparition rate of the Kreutz comets (1 every two days) is well comparable with the travel time of PUIs from the breakup region to 1 AU and Ulysses and the apparition times of the Kreutz sungrazers follow Poisson distribution. Therefore also the PUI parcels from sungrazing comets should show a Poisson statistics,
though their source region will be constrained in space.

Summarizing: on one hand the intensity of inner source is still uncertain due to strong fluctuations and low count rate \(^{\text{Allegrini et al. 2005}}\). On the other hand, an independent estimate of mass inflow from sungrazing comets is available and this entire mass is converted into PUI with the inner source characteristics. Hence comparing observations of the inner source PUIs inside and outside the regions suggested by BK05 and in this paper could bring an important clue on the true rate of the inner source and consequently provide evidence on its nature.

ACKNOWLEDGMENTS

This research was supported by the Polish State Committee for Scientific Research Grant 1P03D 009 27.

REFERENCES

Allegrini, F., Schwadron, N. A., McComas, D. J., Gloeckler, G., & Geiss, J. 2005, J. Geophys. Res., 110, 5105
Biesecker, D. A., Lamy, P., Cyr, O. C. S., Llebaria, A., & Howard, R. A. 2002, Icarus, 157, 323
Bzowski, M. & Królikowska, M. 2005, Astron. Astrophys., 435, 723
Fahr, H. J. 1973, Solar Phys., 30, 193
Geiss, J., Gloeckler, G., Fisk, L. A., & von Steiger, R. 1995, J. Geophys. Res., 100, 23373
Geiss, J., Gloeckler, G., & von Steiger, R. 1996, Space Sci. Rev., 78, 43
Gloeckler, G., Fisk, L. A., Geiss, J., Schwadron, N. A., & Zurbuchen, T. H. 2000, J. Geophys. Res., 105, 7459
Gloeckler, G. & Geiss, J. 1998, Space Sci. Rev., 86, 127
Gloeckler, G., Geiss, J., Balsiger, H., et al. 1993, Science, 261, 70
Kreutz, H. 1901, Astron. Abhand., 1, 1
Mann, I. & Czechowski, A. 2005, Astrophys. J. Lett., 621, L73
Möbius, E., Hovestadt, D., Klecker, B., et al. 1985, nature, 318, 426
Schwadron, N. A., Geiss, J., Fisk, L. A., et al. 2000, J. Geophys. Res., 105, 7465
Sekanina, Z. 2003, Astrophys. J., 597, 1237
Wimmer Schweingruber, R. F. & Bochsler, P. 2003, Geophys. Res. Lett., 30, 49