Study of stellar wind energy flux: from the Sun to Beltegeuse

G. Le Chat, N. Meyer-Vernet and K. Issautier

LESIA, Observatoire de Paris, CNRS, UPMC, Université Paris Diderot ; 5 place Jules Janssen, 92190 Meudon, France

Abstract. This study examines the solar wind energy flux, from 17 years of Ulysses measurements at different heliolatitudes, completed by multi-instrument observations. The solar wind energy flux is almost constant, nearly independant on wind speed and solar activity. We then compare the energy flux of the Sun to the stellar wind fluxes, in addition to the luminosity fluxes, from young stars to supergiants. A share processus of origin and acceleration of the main-sequence stars and cool giants' winds is suggested. T-Tauri stars' winds show a possible result of an accretion powered wind.

Keywords: solar wind, stellar wind, energy flux, mass-loss rate
PACS: 96.60.Vg, 97.10.Me

INTRODUCTION

During the last two decades our knowledge of the solar wind had been increased by the Ulysses mission. Ulysses was the first and only spacecraft exploring the heliosphere outside the ecliptic plan, from 80° south to 80° north heliolatitudes. This allowed us to have a global view of the solar wind.

In this paper, we study the stellar wind energy flux, defined in the equation 1,

$$W = \frac{\dot{M}}{4\pi R^2}\left(\frac{V^2}{2} + \frac{MG}{R}\right) \quad (1)$$

where $\dot{M}$ is the mass-loss rates, R and M the star radius and mass, V the stellar wind bulk speed, and G the Gravitational constant. In other words, the wind energy flux is the sum (per unit surface on the star) of the kinetic energy of the wind and the energy needed to lift it out the star's gravitational potential.

We focuse on the solar case, before extending this study to other stars.

SOLAR WIND

In this work, we use the ULYSSES/SWOOPS observations (Bame 1992 [1]), namely the solar wind proton and alpha particle densities and the solar wind speed. We also use the solar wind ions density and speed of the WIND/SWE instrument (Gloeckler 1995 [6]) to have a reference point near the Earth's orbit. The SWOOPS data cover the period from 1992 to 2008 and the SWE's one from 1995 to 2008, without times period when WIND was inside the Earth magnetosphere.

CP1094, *Cool Stars, Stellar Systems and the Sun: 15th Cambridge Workshop,* edited by E. Stempels

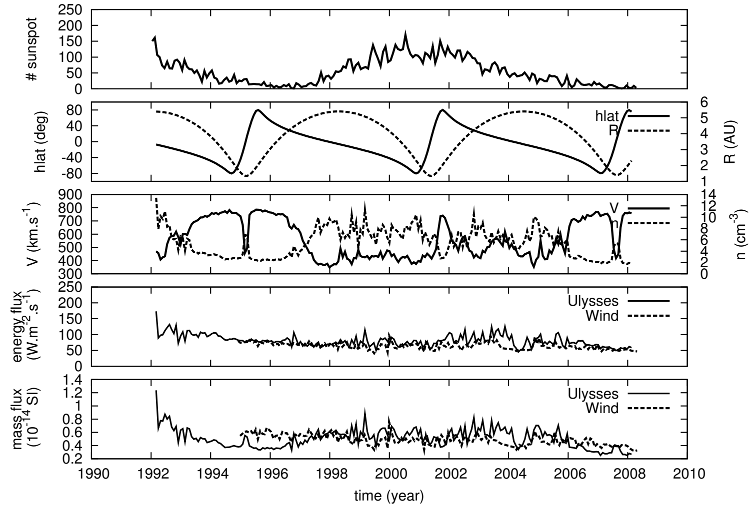

FIGURE 1. *From top to bottom :* the solar sunspot number; the Ulysses spacecraft heliocentric latitude (hlat) and distance (R); the solar wind speed and density (protons + alpha particles) measured by Ulysses; the solar wind energy flux at the solar surface computes from Ulysses (continuous) and Wind (dashed) data; and the solar wind mass flux scaled at 1 AU computes from Ulysses (continuous) and Wind (dashed) data. The energy flux and mass flux data are averages over a solar rotation (taken as 27.2 days).

Figure 1 shows that the solar wind energy fluxes from SWOOPS and SWE instruments match everytime both instruments are available. This is not the case for the mass flux, where the SWOOPS and SWE data only match when the Ulysses spacecraft was close enougth to the ecliptic plane (between 30°S and 30°N latitude). Furthermore, the energy flux measured on Ulysses remains constant as the spacecraft heliolatitude varies from $-80°$ to $+80°$, whereas the wind speed and the mass flux varie by a factor of two. Therefore, the solar wind energy flux is independant on heliocentric latitude and wind speed.

Figure 1 also shows that the solar wind energy flux is almost independent on solar activity. The mean value of the energy flux, over the 17 years of Ulysses data, is $79 W.m^{-2}$ at the solar surface, which is about 10^{-6} of the luminosity flux. Nevertheless, the last minimum of solar activity shows a significant decrease in nearly all the solar wind properties: magnetic field (Smith et al, 2008 [14]), electron temperature and density (Issautier et al, 2008 [9]) and proton and alpha particles density (McComas et al, 2008 [12]), producing a decrease in the solar wind energy flux of about 20% between the solar minima of activity near 1996 and 2008.

STELLAR WIND

We use stellar wind data for a spread of stars: red dwarfs in binary systems (Debes 2006 [5]); solar-like stars (Wood et al., 2005 [15]); cool giants (Lobel & Dupree, 2000 [10], Robinson et al., 1998 [13], Carpenter et al., 1999 [2], Harper et al., 1995 [7]); and T Tauri Stars (Hartigan et al., 1995 [8]).

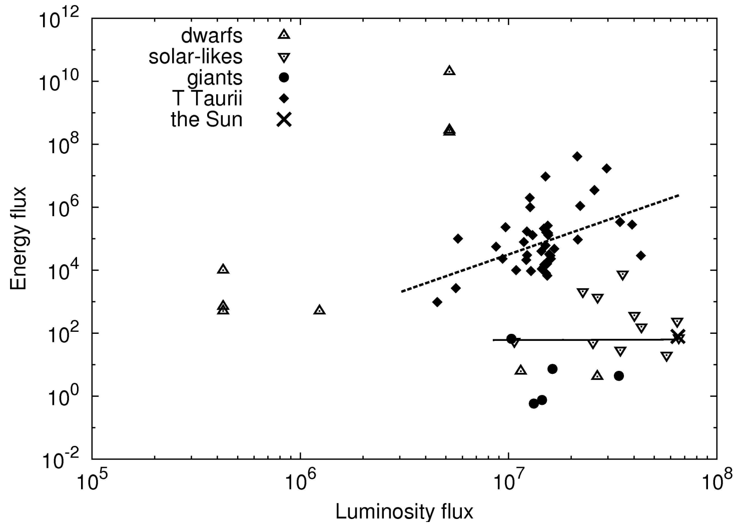

FIGURE 2. Stellar wind energy flux versus luminosity flux, for differents kind of stars mentioned in the figure. Lines are linear fits (see text).

This data set contains stars with mass ranging from $0.1\,M_{\odot}$ to $630\,M_{\odot}$, with effective temperature from $3\,000°K$ to $27\,000°K$ and mass-loss rate from $10^{-16}\,M_{\odot}.yr^{-1}$ to $8.10^{-8}\,M_{\odot}.yr^{-1}$.

Figure 2 compares the stellar wind energy flux (equation 1) with the star luminosity flux (from SIMBAD and references therein). Four groups of data can be seen in fig. 2: one with the T Tauri stars (diamonds); an other with the Sun (cross), the solar-like stars (head down triangles) and the cool giants (circles); and the last two ones by the red dwarfs (head up triangles).

Fits, using nonlinear least-squares Marquardt-Levenberg algorithm, show that the energy flux of the T tauri stars varies as luminosity flux at the power 2.3 ± 0.7. For the Sun, solar-like and cool giants group, the energy fluxes are roughtly independant of the luminosity flux ($W \propto L^{0.02\pm0.5}$), being equal to $10^2\,W.m^{-2}$ to a factor of 10^2. The latter result should be taken with caution considering the observational limits to measure mass-loss rate for main sequence stars (Cranmer 2008 [4]). The red dwarfs have an energy flux in the same range except the three higher ones which correspond to the stars with the bigger accretion mass or for one case (RD464) to a possibly triple system (Debes 2006 [5]).

DISCUSSION

The energy flux of the solar wind is similar in the whole heliosphere, and doesn't change between fast and slow wind. Therefore the energy flux should be a good observable for stellar winds.

The study of a spread of stellar winds shows that the energy flux is almost constant for Solar-like and cool giant stars. This suggests a shared processus at the origin and the acceleration of stellar winds. The higher energy flux of the T-Tauri stars and binary dwarfs can be a result of accretion powered stellar winds (Matt & Pudritz 2005 [11] and Cranmer 2008 [3]).

ACKNOWLEDGMENTS

We thank ESA and the SWOOPS instrument team (D. McComas, PI) for making Ulysses plasma data available on the ESA web site, and .W. Ogilvie, A.J. Lazarus and M.R. Aellig for the SWE data. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.

REFERENCES

1. Bame, S. J., et al. 1992, *A&AS*, **92**, 237-265.
2. Carpenter, K. G., et al. 1999, *ApJ*, **521**, 382-406
3. Cranmer, S. R. 2008, *ApJ*, **689**, in press
4. Cranmer, S. R. 2008, in *14th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun*, ed. G. van Belle, ASP Conf. Series **384**, 317.
5. Debes, J. H. 2006, *ApJ*, **652**, 636-642
6. Gloeckler, G., et al. 1995, *Space Science Reviews*, **71**, 79-124.
7. Harper, G. M., et al. 1995, *ApJ*, **452**, 407
8. Hartigan, P., Edwards, S. & Ghandour, L. 1995, *ApJ*, **452**, 736
9. Issautier, K., G., et al. 2008, *Geophys. Res. Lett.*, doi:10.1029/2008GL034912, in press. (accepted 7 August 2008)
10. Lobel, A. & Dupree, A. K. 2000, *ApJ*, **545**, 454-474
11. Matt, S. & Pudritz, R. E. 2005, *ApJ*, **632**, L135-L138
12. McComas, D. J., et al. 2008, *Geophys. Res. Lett.*, doi:10.1029/2008GL034896, in press. (accepted 14 August 2008)
13. Robinson, R. D.; Carpenter, K. G. & Brown, A. 1998, *ApJ*, **502**, 396
14. Smith, E. J., & A. Balogh 2008, *Geophys. Res. Lett.*, doi:10.1029/2008GL035345, in press. (accepted 13 August 2008)
15. Wood, B. E., et al. 2005, *ApJ*, **628**, L143-L146