ON THE FINE STRUCTURE IN THE FIREBALLS PEAK OF THE 1998 LEONIDS

COSTANTINO SIGISMONDI

Yale University, Dept. of Astronomy, 260 Whitney Ave. New Haven, CT 06511 USA; Astronomical Observatory of Rome and ICRA, International Center for Relativistic Astrophysics, Physics Dept., University of Rome "La Sapienza" P.le A.Moro 2 00185 Rome Italy e-mail: sigismondi@astro.yale.edu sigismondi@icra.it

The Leonids meteor shower of November 1998 has shown double activity. An unexpected shower of fireballs occurred about 16 hours before the expected maximum of the meteor activity [1]. The activity profile of the fireballs shower also revealed fine structure. The hypothesis for a tidal origin of such sub-structures is discussed. The close encounter of the meteoroid stream with the Earth in 1366 and the encounters with Saturn (in 1630) and Jupiter (in 1732), are identified as the cause of the main features of the structure. Such analysis can be applied to the incoming 2000 Leonids' display [2]. The meteoroids ejected during the 1333 perihelion passage of the parent comet 55P/Tempel-Tuttle (or even before) were trapped in the stable resonance zone 5/14 mean-motion with Jupiter [3]. In 1998 the Earth crossed this zone 16 hours before crossing the node of the parent comet's orbit. In contrast to the 1866 Leonids storm, when a filamentary structure was claimed, yet not confirmed by comparing data of different astronomers [4], the meteors in 1998 were all very much brighter than any local limiting magnitude, so they were easily visible in the city lights of Rome. The double peaked structure of the fireballs reflects the previous dynamical history of the cometary debris. Supppose that a bimodal debris cloud is initially separated by a distance δ, then, after the tides, the final separation becomes $D = v_{rel}\frac{\Delta t_{obs}}{cos\theta} = 650000$ Km, $v_{rel} = 71$ Km s^{-1} is the velocity of the meteoroids relative to Earth, and $\Delta t_{obs} = 2.6$ hours is the temporal separation between the two peaks. Let the separation be perpendicular, "$\perp$", to the comet's path (relative to the Earth) with its orbital plane inclined by $\theta \sim 18^o$

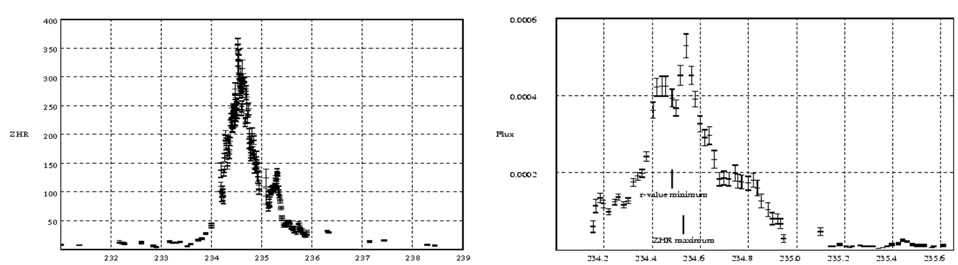

Figure 1. 1998 Leonids' activity, data from [1]. **Left:** The fireballs peaked at $\lambda_{\odot} \sim 234.5$. The 'storm' component occurred at $\lambda_{\odot} \sim 235.3$, with the population index $r \sim 2$ (if N_m is the number of meteors fainter than magnitude m, $N_{m+1} = N_m \cdot r$, lower values of r mean higher % of bright meteors). The fine structure appeared at $\lambda_{\odot} \sim 234.5$. **Right:** The double peak in the fireballs flux. The number of bright meteors per Km^2 versus solar longitude is plotted. Between $\lambda_{\odot} = 234^o4$ and 234^o55 we find that r was as low as $r \sim 1.3$.

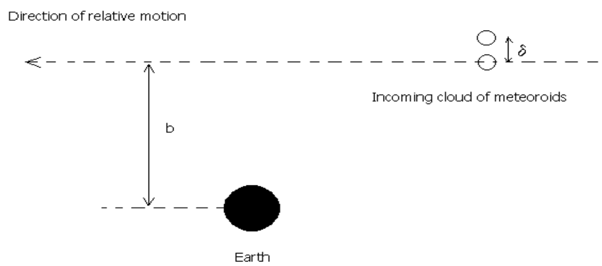

Figure 2. Geometry of the encounter in 1366 between the Earth and the cloud of meteoroids originating from the comet 55P/Tempel-Tuttle. The cloud is represented as a double body separated by δ upon which the tides operate. In 1366 the "impact parameter" b was $b_{\oplus} = 0.025AU$ [5].

with respect to the ecliptic. Several jets of gas and icy dust occur on the comet's surface. The largest meteoroids (≥ 1 cm, ≥ 10 g) orbit tightly around the comet's nucleus within $\delta = 25000$ Km (a typical *coma* dimension). The Earth's gravitational field gives them the escape velocity $v_{esc} \sim 2$ m s^{-1} to reach the resonant zone and the tidal impulse $\Delta v_{\perp,\oplus} \sim 2$ cm s^{-1} to reach 40% of the current separation D, after 632 years. Saturn and Jupiter power the initial impulse for the remaining 60% of D. Referring to the geometry described in figure 2 we obtain: $\Delta v_{\perp,\oplus} = \int_0^\infty \frac{F_{tidal}dt}{m} = 2\int_0^\infty \left(\frac{GM_\oplus}{x^2+b^2} - \frac{GM_\oplus}{x^2+(b+\delta)^2}\right) \frac{b}{\sqrt{x^2+b^2}} \frac{dx}{v_{rel}} \approx \frac{4GM_\oplus(\delta^2+2b\delta)}{3v_{rel}b^3}$ where m is the mass of an average meteroid, $M_\oplus$ the Earth's mass. The solution of the equation $\Delta v_{\perp,\oplus} n T_{orb} \approx 0.4 \cdot D$, with $T_{orb} = 33.25$ years, is a set of pairs (n, b). Varying the integer n, we can compare the corresponding value of b with the values of the geocentric distance of the comet during previous perihelion passages [5]. For $n = 19$ (i.e. 1366), the above equation yields b in agreement with the calculated geocentric distance at that time. This result agrees with the hypothesis that the fireball particles were ejected in 1333 [3], and it is obtained independently from temporal fine structure observations. The tidal actions of Saturn in 1630 (at 0.34 AU) and Jupiter in 1732 (at 0.83 AU) [5] give impulses $\Delta v_\perp \approx \Delta v_{\perp,\oplus}\sqrt{a}\,\frac{M_P}{M_\oplus}\left(\frac{b_P}{b_\oplus}\right)^{-2}$, where a is the heliocentric distance in AU of the encounter, "P" and "$\oplus$" refer to the planet and to the Earth. Saturn's tidal forces contribute 49% of the actual separation D, while Jupiter contributes 11%. Since they are in a resonant region, the tidal features survive for 632 years, without disappearing into the background. The size of the meteoroids prevente their depletion by radiation pressure.

Acknowledgments: Thanks are due to Dr. Irene Sigismondi, Dr. Renato Klippert and Prof. William van Altena for their valuable collaboration, and to Dr. Mark Gyssens and Dr. Rainer Arlt for their remarks.

References: [1] R. Arlt, P. Brown, WGN **27:6**, 267-285, (1999). [2] R. McNaught, D. Asher, WGN **27:6**, 85-102, (1999). [3] D.J. Asher, M.E. Bailey, V.V. Emel'yanenko, MNRAS **304**, L53, (1999). [4] P. Jenniskens, Astron. Astrophys., **295**, 206, (1995). [5] D.K. Yeomans, K.Yau, P.Weissman, Icarus, **124**, 407, (1996).