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Radiant mapping with bistatic radars: a new method

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Abstract. We present a new method of radiant mapping developed for forward-scatter radars. This method is able to reconstruct the meteor radiant distribution from interferometric observations carried out by a single receiving station. The technique has been tested by numerical simulations and the preliminary results are presented here.

Key words. Meteoroids, meteors, radar, radiant mapping

1. Introduction

Every year our planet intercepts a huge amount of interplanetary particles, such as meteoroids and interplanetary dust. Small interplanetary bodies interact strongly with Earth's atmosphere and generate light and ionization phenomena known as meteors. A significant part of this activity is represented by meteor streams: swarms of meteoroids travelling on similar orbits. Meteoroids belonging to a specific stream have the same parent body and, for a perspective effect, appear to radiate from a small region in the sky, called meteor radiant.
Non-gravitational forces due to the solar radiation (Poynting-Robertson effect, radiation pressure, etc.) lead to a slow dispersion of the stream and cause the mass segregation of the meteoroids. The latter effect is reflected on the difference between the radiant positions determined by optical and radar observations (Watanabe et al. 1992). Therefore radar study of radiant is useful not only to know the evolutionary stage of meteor streams, but especially to improve our knowledge of the interplanetary forces acting on minor bodies of Solar System. The determination of meteor radiants is also the first step in the calculation of the meteoroid orbits in a stream, but its measure is difficult to obtain from observations carried out by a single radar station. Since 1948 several methods of radiant mapping have been developed for this purpose, but most of them are applicable only to backscatter radars because their more simple geometry with respect to a forward-scatter setup. In fact, only one method of radiant mapping is available so far for bistatic radar systems using a single receiving station.
In 1987, Morton and Jones showed that the radiant map could be calculated from the distribution of the directions normal to the different planes containing the meteor trails (Morton & Jones 1982). The method has been applied to a bistatic radar using a 5 antenna interferometer achieving an accuracy better

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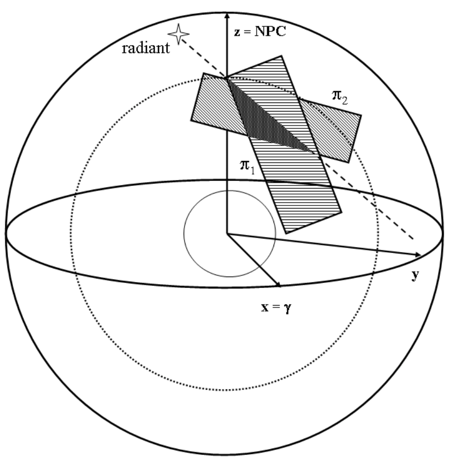

Fig. 1. Intersection of planes π_1 and π_2 containing two different trails. The reference is co-rotating with the celestial sphere, since x and z axes coincide with the equinox (γ) and the north celestial pole (NCP), respectively.

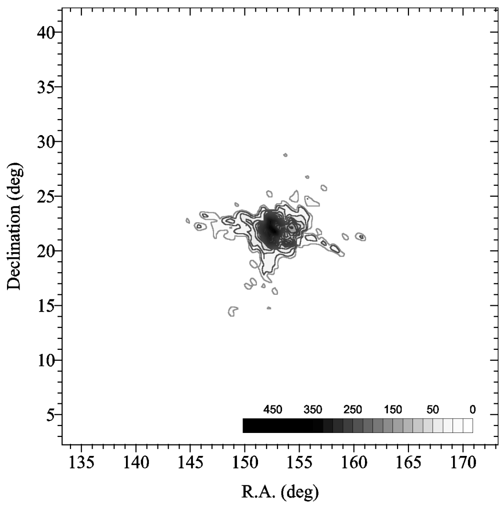

Fig. 2. Radiant mapping obtained for 75 Leonid meteors without sporadic background activity. Radiant: $\alpha = 153^{\circ}$; $\delta = +22^{\circ}$; FWHM = 1°. Radiant strength is expressed in terms of number density of map points in a grid with a resolution of 0.5°.

than 1° in the measure of the radiant position (Jones & Morton 1992). In this paper, we briefly describe a new method of radiant mapping. Although some modifications are necessary to improve the technique, preliminary results obtained from numerical simulations are presented.

2. Theory

The present method, likewise to that of Morton and Jones, is based on the geometric properties of the oblique scattering in a forward-scatter radar. Meteors can be observed only if trails are tangent to one member of the family of ellipsoids of revolution having transmitter and receiver as common foci. Unfortunately a single station observation provide us an incomplete information on the meteor trajectory. In fact it is possible to calculate only the plane on which the trail lies, but its orientation in this plane remains unknown. Therefore the radiant of individual meteors cannot be calculated. In any case, there is an additional information: trajectories of meteoroids belonging to the same radiant are parallel. The intersection between the plane containing a meteor trail with another plane including a second trail, gives the direction of the original trails.

The rotation of the Earth could prevent the application of the method for non-simultaneous trails, because in the local reference tangent planes rotate in time. However, this problem is solved by passing in a reference co-rotating with the celestial sphere (Fig. 1). The intersection of each pair of different planes gives a direction that projected on the celestial sphere gives a point in the map. So, if N radio echoes are observed and for each of them we are able to determine the equation of the plain where the related trail lies, the map will contain $\frac{N(N-1)}{2}$ points.

3. Simulations

In order to test our method, we have developed a code which simulates the output of a single station radar interferometer having the capability to measure the distance, too. Hence, for each simulated meteor the direction of the reflection point respect to the receiver and the total distance from transmitter to re-

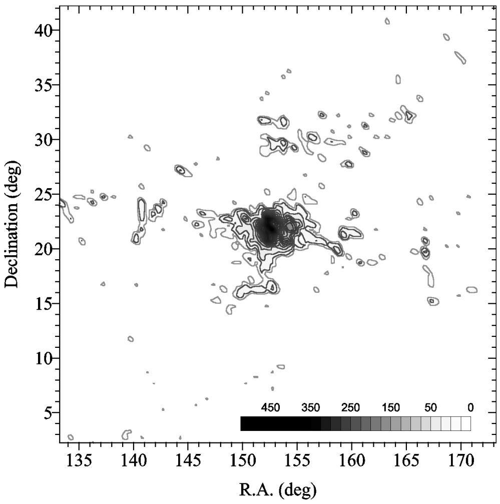

Fig. 3. Radiant mapping obtained for 75 Leonid and 40 sporadic meteors. Radiant: α = 153^o ; δ = +22^o ; FWHM = 1^o. Radiant strength is expressed in terms of number density of map points in a grid with a resolution of 0.5^o.

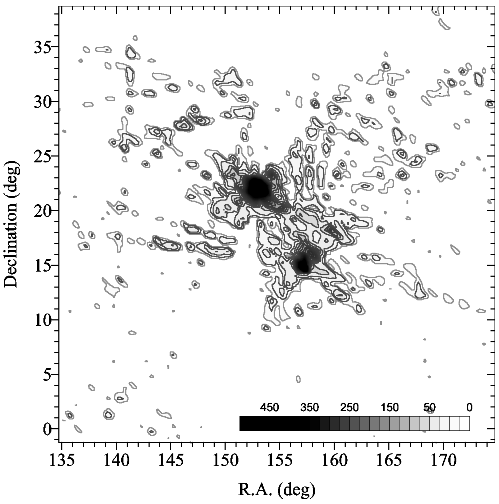

Fig. 4. Radiant mapping of two simultaneous streams superimposed to background. Radiant 1: number of meteors = 90; α = 153^o ; δ = +22^o ; FWHM = 1^o. Radiant 2: number of meteors = 41; α = 157^o ; δ = +15^o ; FWHM = 0.5^o. Radiant strength is expressed in terms of number density of map points in a grid with a resolution of 0.5^o.

ceiver through the reflection point are known. Radiants are assumed to have a gaussian profile, in the sense that both equatorial coordinates of simulated meteors are normally dispersed around the center of the radiant, within a specific celestial area. Although a radiant has actually a more complicated structure, the adopted simplification is useful.
In the first set of simulations we have considered the presence of only one radiant with a defined dispersion on right ascension and declination. Fig 2 shows the map obtained choosing the Leonid radiant (α = 153^o and δ = +22^o) with a FWHM of 1^o in both directions. The simulation cover 24 hrs of radar observations during the period of maximum Leonid stream activity: November 16, 1999 00-24 UT.

Even though the output data are generated for a symmetrical case, the corresponding maps show a form of elongation in the radiant shape. At the moment the reason of this distortion is not still clear. However from the maps it is possible to calculate the precise position of the radiant center and a linear relation between the actual size of the radiant and its dimension on the map, as a function of the radiant declination.

In the second set of simulations, the sporadic background activity has been superimposed to the shower. We have assumed a uniform distribution of the sporadic background on the whole sky. This is a simplification because the actual meteoroid influx to the Earth from sporadic activity is strongly anisotropic, being dominated by Helion and Antihelion sources (Taylor 1997). Several simulations have been performed with different background levels in order to determine the conditions at which the radiant was still recognizable. A map of the Leonid radiant with the presence of a strong sporadic background activity is illustrated in Fig. 3.

In the last set of simulations, we have considered two radiants different in strength and size, close in space, which activity is superimposed to the sporadic background. Fig. 4 shows a map resulting from one of these simulations.

It is worthwhile to notice that both radiants are totally resolved on the map. This could be very important when two or more radiants are active at the same time or if some substructures are present within a meteor stream.

4. Conclusions

Results of simulations indicate that the method of radiant mapping here presented allows us to achieve a very precise identification of meteor radiant, even when a strong background activity is superimposed. However reconstructed radiants show a slight elongation in shape with respect to the original ones. Furthermore, some artifacts, similar to tails, appear in the maps especially in presence of background. In principle, the elongation could be corrected by using the linear relations that exist between the actual and calculated size of the radiant, but artifacts are an additional shortcoming in the solution of the problem. Anyway, simulations show that the present method is not only reliable in identifying new faint meteor streams, but also in investigating their inner structures in terms of radiant distribution. Obviously, our method needs some improvements, so that new simulations are requested to understand other aspects of the radiant mapping.

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