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# An orbital meteoroid stream survey using the Southern Argentina Agile MEteor Radar (SAAMER) based on a wavelet approach

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ABSTRACT

Over a million individually measured meteoroid orbits were collected with the Southern Argentina Agile MEteor Radar (SAAMER) between 2012–2015. This provides a robust statistical database to perform an initial orbital survey of meteor showers in the Southern Hemisphere via the application of a 3D wavelet transform. The method results in a composite year from all 4 years of data, enabling us to obtain an undisturbed year of meteor activity with more than one thousand meteors per day. Our automated meteor shower search methodology identified 58 showers. Of these showers, 24 were associated with previously reported showers from the IAU catalogue while 34 showers are new and not listed in the catalogue. Our searching method combined with our large data sample provides unprecedented accuracy in measuring meteor shower activity and description of shower characteristics in the Southern Hemisphere. Using simple modeling and clustering methods we also propose potential parent bodies for the newly discovered showers.

## 1. Introduction

The meteoroid background as measured at Earth can be broadly divided into two components: sporadic and shower meteors (Jenniskens, 2006). Sporadic meteoroids have no specific linkage to one another or to a particular parent body while shower meteoroids exhibit a common orbit suggestive of a physical linkage among stream members (variously defined by a host of possible similarity criteria, e.g. Valsecchi et al., 1999) which suggests a common parentage, though this parent body is often unknown. The fact that shower meteors may be linked to a parent makes them particularly valuable as proxy material for understanding comets and asteroids; shower meteors are small fragments of the parents and in effect, windows into the origin and evolution of these small solar system bodies. Identification of new showers may allow indirect sampling of parent bodies not previously studied and the particle distribution, shower duration, flux profile and radiant dispersion are diagnostic of the mode and timing of parent body decay. Such physical data on streams have been variously used to constrain meteoroid stream formation and evolution models (e.g. Jenniskens et al., 2010; Wiegert and Brown, 2005).

Besides the study of specific showers, some analyses require that dynamical models are compared against all known showers, in the forms of shower catalogs. Association between predicted showers and those observed form the basis for validation of such models. For example, Babadzhanov et al. (2008a) utilized a numerical integration method to investigate the orbital evolution of the near-Earth asteroid 2003 $EH_1$ and showed that its orbit intersects that of the Earth at eight different points with different values of argument of perihelion $\omega$. Since the resulting orbital parameters are different at each intersection the model explicitly predicted the existence of eight different meteor showers, presuming the complex was old enough. Using published catalogs, these theoretically predicted showers were tentatively identified with observed streams. However, better information about those streams was required to prove such association and set limits to the age of the stream complex. Clearly, establishing which showers exist and which are spurious becomes critical to validating such models. In this manner, meteor shower catalogs constrain the past orbital evolution and physical character of presently detected Near-Earth Objects (NEO; Babadzhanov et al., 2008c; 2008b).

Establishing the very existence of a shower is often a difficult task. Particularly for weaker streams, basic physical characteristics (radiant drift, duration, mass distribution) can be challenging to measure. While several dozen strong meteor showers have been known for many decades, the majority of showers are

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only weakly active and require large numbers of instrumentally recorded meteor radiants to separate the shower "signal" from the much stronger sporadic background "noise". Recently, optical surveys have overcome this barrier in part by using large numbers of small cameras and automated meteor detection software to obtain multi-station radiants for large datasets (SonotaCo, 2009; Molau and Rendtel, 2009; Jenniskens et al., 2011) and in so doing have identified several probable new minor showers. Optical instruments, however, are limited to nighttime hours and clear skies - the results of such surveys will tend to show large seasonal biases. Radar observations, in contrast, are able to record independent of weather and diurnal conditions. The major limitation of radar observations in shower characterization is the lower metric precision of each measured event; however this limitation is compensated through much larger datasets, with large number statistics providing higher sensitivity for detection of weak showers.

In the last two decades several long-term optical and radar orbit survey programs have been undertaken from northern hemisphere sites most notably The Cameras for Allsky Meteor Surveillance (CAMS, Jenniskens et al., 2011) based on optical observations and a complementary survey performed with the Canadian Meteor Orbit Radar (CMOR, Brown et al., 2010, hereafter B2010) utilizing backscatter transverse radio wave scattering. In contrast, the southern hemisphere has only two recent shower surveys performed using single-station radar observations (Younger et al., 2009; Janches et al., 2013). An effort to fill this gap utilizing optical and video observations has taken place in the past few years (Bland et al., 2012; Jopek et al., 2010; Molau and Kerr, 2014; Towner et al., 2015; Jenniskens et al., 2016a), focusing on larger fireballs but which are limited by weather and day/night cycles. We note that the Advanced Meteor Orbit Radar (AMOR) which operated in Christchurch, New Zealand during the 1990s, produced some 0.5 Megaorbits, but at such small particle sizes that only half a dozen of the strongest showers were visible in the resulting dataset (Galligan and Baggaley, 2004).

In this work we report on an extension of our earlier initial single-station radar study of meteor showers using the Southern Argentina Agile MEteor Radar (SAAMER, Janches et al., 2013, hereafter J2013). In J2013 we provisionally identified showers using radar measurements of individual meteor echoes and a statistical radiant approach which exploited the specular geometry of meteor backscatter detection along the lines first proposed by Jones (1977) and developed in detail by Jones and Jones (2006).

In this study we expand on J2013 by making use of individually measured radiants/orbits (totaling $\sim$ 1 Megaorbit) collected by the Orbital System; an upgrade of SAAMER into a system capable of recording meteor orbits by adding two remote receiving stations (Janches et al., 2015, hereafter referred as SAAMER-OS). Specifically, the orbits used in this study were collected in the time period January 2012-January 2016. As first proposed by Galligan and Baggaley (2002), we make use of the wavelet transform to extract shower signals from SAAMER-OS. For this study, we apply a 3D wavelet transform to identify showers, using the same general thresholds, background definition and shower linkage approach used by B2010 for the CMOR Northern Hemisphere radar survey. However, we have developed a revised method of computing background levels which includes both statistical fluctuations and the physical background averaged throughout the year. This approach has allowed us to improve sensitivity in both localizing 3D wavelet maxima and linking them together as probable showers as compared to the original B2010 CMOR survey. We also compare common showers observed by CMOR and SAAMER-OS in an effort to cross-validate results.

Finally, we have also explicitly applied our new shower linkage algorithm in an attempt to confirm all showers listed in the International Astronomical Union working list of meteor showers both on a year-to-year basis and in our composite single "virtual" year. Finally, we examine the probable origin and parent bodies of our newly detected showers.

## 2. Overview of SAAMER-OS hardware and detection software

The SAAMER-Orbital System (OS), described in detail in Janches et al. (2015) is hosted by the Estacion Astronomica Rio Grande (EARG), located in Rio Grande, Tierra del Fuego, Argentina. It consists of three distinct radar stations: the central station (SAAMER-C; 53.79S, 67.75W) that hosts the transmitting and interferometry-enabled receiving antenna arrays, the northern remote station (SAAMER-N; 53.68S, 67.87W) located approximately 13 km northwest of the central station, and the western remote station (SAAMER-W; 53.83S, 67.84W) located approximately 8 km southwest of the central station. SAAMER-C has been in operation since May 2008 and utilizes high peak transmitter power (60 kW) at a frequency of 32.55 MHz. Together with a relatively narrow beam pattern provided by an eight-antenna transmitter array comprised of 3-element crossed yagi antennas (Fritts et al., 2010, J2013) this allows detection of smaller meteoroids relative to most specular all-sky meteor radars (which have peak transmit powers of 6–20 kW; W. Hocking Personal Communication, 2015 and Fritts et al., 2012). The transmitting array is organized in a circular pattern of diameter 27.6 m (i.e., 3 times the radar wavelength) and the phase differences among transmitting antennas can be changed electronically, adding flexibility to the system to perform a number of transmitting and receiving modes (Janches et al., 2014). In normal operation mode each transmitting antenna transmits at a phase difference of 180° from the adjoining two antennas (i.e. every other antenna has the same phase), providing a gain pattern in which the majority of the power is focused into eight beams at 45° azimuth increments with peak power at approximately 35° zenith. The resulting transmit gain pattern results in the majority of meteor echo detections to occur between zenith angles of 15° and 50°. Details of the system parameters utilized for the different modes of operation can be found in Janches et al. (2013); 2014); 2015).

The limiting magnitude of SAAMER-OS appears to be close to radio magnitude +11 for single station observations, while the median magnitude for orbital system requiring data from at least two remote stations is likely closer to +9.5. Equivalent mass for orbital echoes from Verniani (1973) at 30 km $s^{-1}$ is $10^{-8}$ kg (or 300 microns in diameter). This is an order of magnitude in mass smaller than CMOR orbital masses (B2010).

A receiving antenna array with interferometry capability is also located at SAAMER-C. The array is a typical configuration for meteor radar systems consisting of 5 antennas, each of which is a 3-element vertically directed crossed yagi (Hocking et al., 1997). The two remote stations, SAAMER-N and SAAMER-W, were deployed in August 2010 to enable meteoroid orbit determination through the time of flight method (Baggaley et al., 1994) and are each equipped with a single 3-element vertically-directed crossed yagi receiving antenna. The remote stations were placed in such a way that they are in nearly orthogonal directions relative to SAAMER-C at a distance on the order of 10 km. For common meteor echoes detected by all three of the SAAMER-OS stations, the meteoroid trajectory and speed can be determined using the measured time delays between the detections combined with information from the interferometry from SAAMER-C (Baggaley et al., 1994; Webster and Jones, 2004; Brown et al., 2008). The details of how meteoroid orbits are measured are described in detail by Janches et al. (2015).

### 2.1. Data and results

Fig. 1 shows the daily count of determined meteoroid orbits observed throughout the survey period (January 2012–December