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The established meteor showers as seen in video meteoroid orbit surveys

Peter Jenniskens, Peter S. Gural, and David Holman

SETI Institute, 189 Bernardo Ave., Mountain View, CA 94043, USA
Petrus.M.Jenniskens@nasa.gov

The International Astronomical Union has recognized 95 meteor showers as established. Some of those showers are incidental meteor outbursts, but many are annual meteor showers that show up nicely in the recent meteoroid orbit surveys using multi-station low-light video cameras. Here, we present first year results of our Cameras for Allsky Meteor Surveillance (CAMS) project in California, and combine those data with the 2007–2009 results from the SonotaCo network in Japan to create a set of radiant maps that shows many of the established showers. The video cameras detect meteors in the range of magnitudes +4 to −4, i.e., in much the same range as seen by visual observers. These maps serve to help guide visual observations of meteor showers.

1 Introduction

The Cameras for Allsky Meteor Surveillance (CAMS) project was established in October of 2010, and obtained 47 000 meteoroid orbits by the end of 2011. The network consists of 60 video cameras spread over three stations in California, located at Fremont Peak Observatory near Monterey, at Lick Observatory near San Jose, and in the city of Sunnyvale in Silicon Valley. The stations are operated by amateur astronomers Rick Morales (FPO) and Jim Albers (Sunnyvale), and by the Lick Observatory staff astronomer Bryant Grigsby. Other amateur astronomers have added single cameras operated from a PC, in an effort coordinated by Dave Samuels (Jenniskens et al., 2011).

Heart of the project is the CAMS software package, which processes the video records of the many cameras in a semi-automated (but also sufficient interactive) fashion. The software includes a new way to estimate the best trajectories from multiple video camera records (Gural, 2012), accurate photometry, quality control from an interactive step to judge each multi-station result, and rigorous Monte Carlo error analyses.

The purpose of CAMS is to help establish more meteor showers in the IAU Working List. After the 2009 IAU General Assembly, 64 meteor showers were established. In part thanks to CAMS, that number is now 95, following the IAU General Assembly in Beijing.

The first-year results of CAMS do not yet cover all nights in the year, but thanks to a similar ongoing project in Japan by the SonotaCo consortium, there are sufficient orbits measured to give a nice overview of the annual meteor showers. SonotaCo published 64 000 meteoroid orbits in the period 2007 to 2009. More recently, results from 2010 and 2011 were also published, but those were not available yet when the maps in this paper were created. The maps, and much of this text, were published earlier as an online contribution to an August 2012 article in *Sky & Telescope*. Some notes are added with respect to other showers since established.

2 The showers in January

The first map (Figure 1) shows the showers in the first week of January. The concentric color[1] pattern reflects the motion of the Earth: meteors that collide head-on have a higher speed (red), those that approach Earth sideways are yellow, those that catch up on the Earth from behind are blue. In blue are the slow meteors from what is called the "anti-helion" source, as in "opposite to the Sun" (Jenniskens, 2006). These are meteors on short-period Jupiter Family Comet (JFC) orbits, taking typically 5–7 years to round the Sun. These meteors are seen mostly in the evening and around midnight. The comets originate in the Kuiper Belt. When the meteoroids round the Sun, they approach the Earth from the daytime side. These are called the "helion" source, and the showers have the predicate "Daytime" if they approach from less than 32° of the Sun. These are sometimes visible in the hour before dawn.

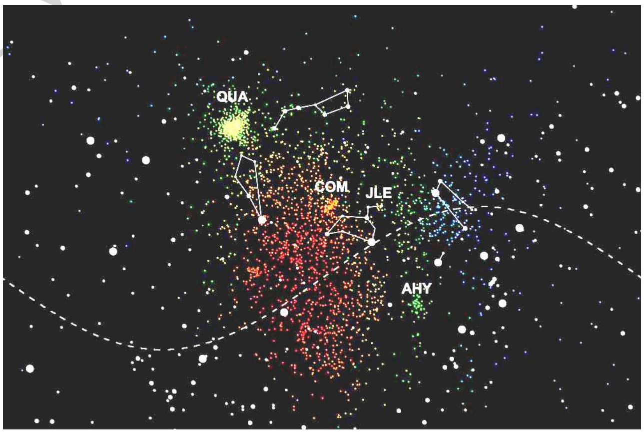

Figure 1 – January 1–7 (2831 SonotaCo and 381 CAMS).

In red are the fast meteors from the so-called "Apex" source: meteors that collide with the Earth nearly head-on. The cameras are particularly sensitive to these fast meteors and see many in the hours before dawn. These

[1] *The printed Proceedings are reproduced in black and white. For the full-color illustrations, we refer to* http://www.imo.net/imc2012/proceedings/jenniskens-1-2012.pdf. (Eds.)

are mostly from Long-Period Comets (LPC), orbiting the Sun once every 250 years or more, and Halley-type comets (HTC) which take 20–250 years to round the Sun. These originate in the Oort cloud.

Meteor showers are named after the nearest star, or constellation of stars, by substituting "id" for the ending of the genitive (possessive) Latin form. The Quadrantids (QUA) originate from the short-period asteroid-like object 2003 EH_1, which is now a dormant Jupiter Family Comet (JFC) that broke up about 500 years ago. The Quadrantids' orbit has an inclination of 72° relative to the plane of the ecliptic (dashed line in all figures). The α Hydrids (AHY) are from an unknown Halley-type comet with a 55° inclined orbit. The January Leonids (JLE) are from a rare retrograde (inclination 99°) LPC source, only recently recognized as a strong shower in radar observations with the Canadian Meteor Orbit Radar (CMOR) (Brown et al., 2010). The Comae Berenicids (COM) are active in all of December and January. The long activity period points to an unknown Halley-type comet source.

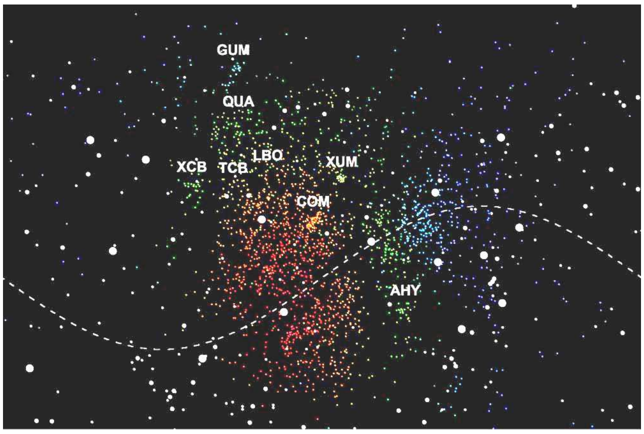

Figure 2 – January 10–19 (1498 SonotaCo and 450 CAMS).

For ten days centered on January 19 (Figure 2), CAMS detected an unusual shower (called a meteor outburst) of γ Ursae Minorids (GUM), known from an outburst of bright meteors the year before. The γ Ursae Minorids are a JFC shower at high ($i = 47°$) inclination. SonotaCo's discovery of the January ξ Ursae Majorids (XUM) was verified during January 17–20. The January ξ Ursae Majorids are an unusually short-period ($P = 1.8$ years) shower of high ($i = 67°$) inclination, possibly asteroidal in origin. Several meteor showers from the Bootid-Coronae Borealid cluster were identified in CMOR radar observations (Brown et al., 2010). CAMS detected the ξ Coronae Borealids (XCB), but not so clearly the λ Bootids (LBO) or the θ Coronae Borealids (TCB). These are highly inclined JFC showers.

3 The showers in February

On February 4, 2011, CAMS detected a compact cluster of 6 identical orbits of a new shower now called the February η Draconids (FED). This brief shower was

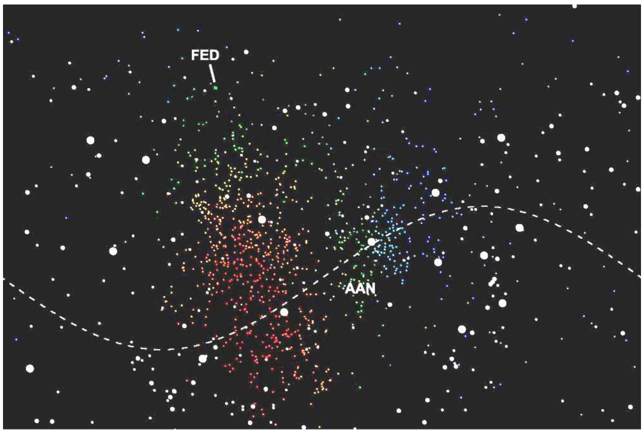

Figure 3 – February 1–6 (370 SonotaCo and 546 CAMS).

caused by the 1-revolution dust trail of a yet-to-be-discovered long period comet (Jenniskens and Gural, 2011). Such showers occur only on occasion, typically once or twice every 60 years for any given comet, when the comet's dust trail wanders briefly in the Earth's path. The detection of this dust trail was a big deal, because it pointed to the existence of a potentially hazardous comet that could impact the Earth.

The α Antliids (AAN) are from a low-perihelion ($q = 0.14$ AU), high-inclination ($i \approx 50°$) JFC source that has not yet been identified (Figure 3). The other established shower in February, the southern hemisphere α Centaurids (ACE), are not visible from California. That shower is known from annual activity and occasional meteor outbursts.

4 The showers in March

In March, there is now only one established shower, the η Virginids (EVI). This is the one month in the year when California weather is consistently cloudy. SonotaCo data (Figure 4) show activity from the short-period η Virginids in the middle of the month, a JFC shower added to the list of established showers in Beijing.

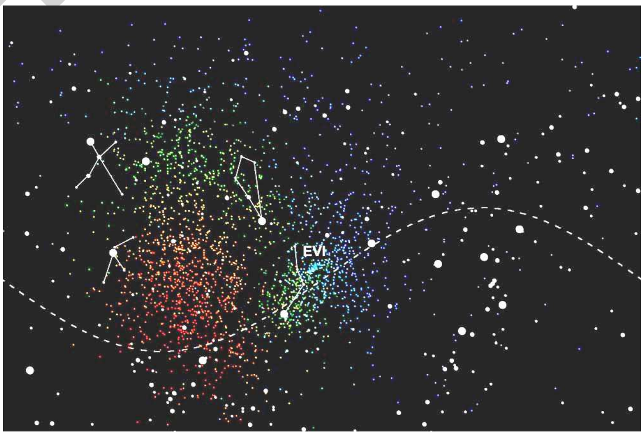

Figure 4 – March 1–31 (1863 SonotaCo and 294 CAMS).

5 The showers in April

Around April 22, the Lyrids (LYR) peak. They originate from an unusual long-period comet, C/1861 G1 Thatcher. This comet's orbit is sufficiently short (about

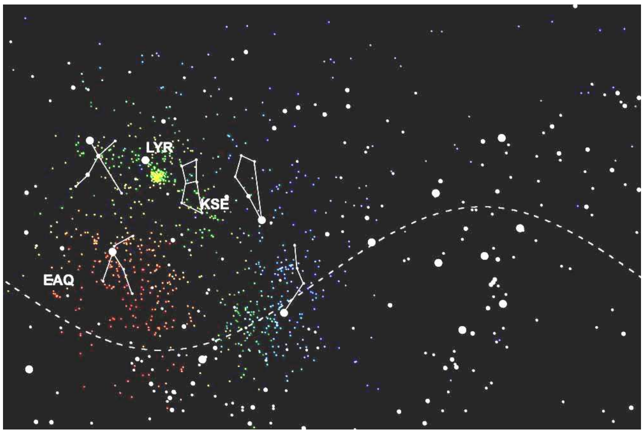

Figure 5 – April 8–25 (802 SonotaCo and 256 CAMS).

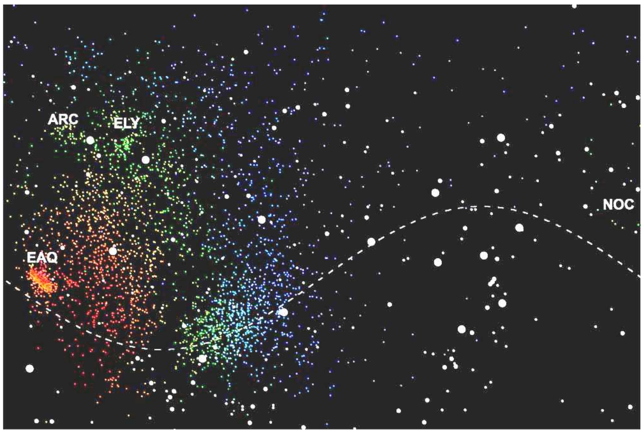

Figure 6 – April 26–May 14 (1804 SonotaCo and 1861 CAMS).

415 years) to build up a dense stream. The 1-revolution trail causes intense outbursts about every 60 years. After the Lyrids, Comet 1P/Halley's η Aquariids (EAQ) first show up in the early morning. The κ Serpentids (KSE) are active for a few days around April 10, a high ($i = 68°$) inclination JFC shower (Figure 5). Not shown are the π Puppids (PPU), a southern hemisphere shower known for periodic meteor outbursts that originate from the weakly active JFC comet 26P/Grigg-Skjellerup, and the Daytime April Piscids (APS).

6 The showers in May

Around May 10, the η Lyrids (ELY) peak, originating from the big, but weakly active, long-period comet C/1983 H1 IRAS-Araki-Alcock. In late April and early May, a JFC stream with a relatively high inclination creates the April ρ Cygnids (ARC), a shower discovered in the CMOR data and confirmed by CAMS. In this time of year, the blue anthelion showers are strong, but the streams are dispersed and only discriminated in the day-to-day plots. So far, SonotaCo and CAMS picked up just one meteor each of the Northern Daytime ω Cetids (NOC), a low-perihelion high inclination JFC shower (Figure 6). Radar also recognizes the Southern Daytime ω Cetids (OCE) and the Southern Daytime May Arietids (SMA).

On occasion, the Earth will encounter dust from Comet 73P/Schwassmann-Wachmann in late May and early June, creating a shower called the θ Herculids (THE). Around June 7, the Daytime Arietids (ARI) are detected in the CAMS data in the hour before dawn. We were able to demonstrate that the meteoroids had the same semi-major axis as the Marsden group of Sungrazers, and we suspect that both comet family and meteoroid stream were created at the same time from a comet disruption. Radar detects the Daytime ζ Perseids (ZPE) and Daytime β Taurids (BTA), which are the twin showers of the Northern and Southern Taurids in November. Radar also detects the Daytime λ Taurids (DLT).

7 The showers in June

Late June is best known for occasional outbursts of the June Bootid shower (JBO) from weakly active JFC comet 7P/Pons-Winnecke. No such outburst occurred in recent years. The Corvids (COR) were only seen by Cuno Hoffmeister, who noticed many slow meteors on several days around June 26, 1937, while observing from the southern hemisphere. The annual Northern June Aquilids (NZC) is a strong shower starting in June, but lasting until the end of July. It has a counterpart, the Southern June Aquilids (SZC), which is detected for a shorter period in early July. Both JFC showers have a short perihelion distance, but relatively high inclination. These are not part of the Machholz Complex of streams that include the Daytime Arietids. The ϵ Perseids (EPR) are mostly a daytime shower, but a few meteors were detected. CAMS now also confirms strong activity from apex showers φ Piscids (PPS), detected by CMOR, and c Andromedids (CAN), first detected by single-station video observations collected by the International Meteor Organization (Figure 7).

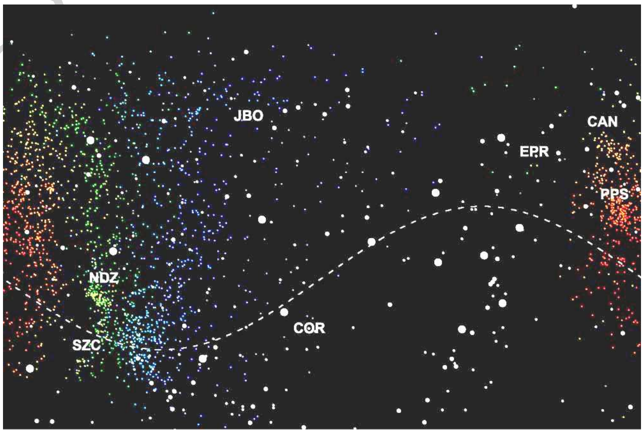

Figure 7 – June 22–July 6 (467 SonotaCo and 1683 CAMS).

A few showers in the current list of established showers were not detected, all active around July 8–9: the α Lacertids (ALA), the ϵ Pegasids (EPG), the β Equuleids (BEQ), and the ψ Cassiopeiids. This could change when more meteors are observed. Radar observations (Brown et al., 2010) also recognize the Daytime ξ Orionids (XRI), which we cannot observe.

8 The showers in July

The Northern June Aquilids persist until the first day of August (Figure 8). In the last week of July, a new shower emerges at lower inclination (and declination), the Northern δ Aquariids (NDA), part of the Machholz Complex. The Southern δ Aquariids (SDA) are much stronger and have their maximum around July 29. Only recently, Machholz group sungrazer 2008 Y12 was recognized to be in an orbit similar to this stream. Further west, the slower α Capricornids (CAP) originate from mostly dormant JFC comet 169P/NEAT, which broke up about 5000 years ago. This shower is expected to increase in intensity in the future and peak as a major shower around 2375 AD. CAMS was able to verify the July γ Draconids (GDR), a long-period comet shower active around July 28 (Holman et al., 2011).

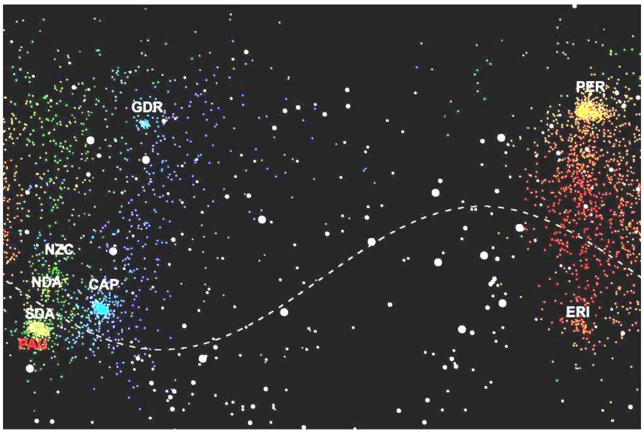

Figure 8 – July 22–August 2 (1461 SonotaCo and 2414 CAMS).

9 The showers in August

The Perseids from Halley-type comet 109P/Swift-Tuttle are first detected around July 12 and last through August 27. Another such long-duration shower, of possibly Halley-type origin, the η Eridanids (ERI), appear south of the ecliptic plane around July 19 and last until August 21. The proposed parent, Comet C/1852 K1 Charcornac, was not well observed and has a somewhat different perihelion distance.

The κ Cygnids (KCY) were not detected in the CAMS data from 2011, but do show up strongly in the Sonotaco data. This is a periodic shower from dormant JFC comet 2008 ED_{69} (Figure 9). The stream produces meteors mostly at Venus. The nearby August Draconids (AUD) are a brief JFC shower around August 14 with the same inclination ($i \approx 33°$) as the κ Cygnids, and may be related to the latter. The August Draconids are now confirmed. The Piscis Austrinids (PAU) are active in early August from a 56° inclined JFC source with an orbit that stretches well beyond Jupiter. Not so obvious in the data are the Northern ι Aquariids (NIA), nomally peaking around August 20, and the Southern ι Aquariids (SIA), nomally peaking on August 4. The anthelion source seems to be split in two. Finally, the southern

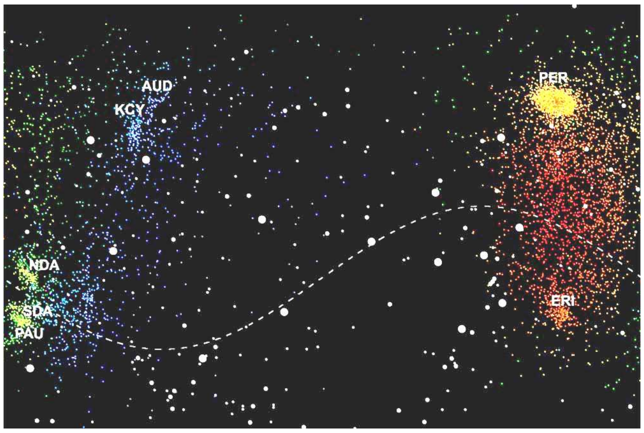

Figure 9 – August 6–16 (6135 SonotaCo and 3968 CAMS).

hemisphere β Hydrusids (BHY) are only known from a spectacular outburst on August 17, 1985.

10 The showers in September

California was showered by Aurigids (AUR) from the 1-revolution dust trail of long-period comet C/1911 N1 Kiess on September 1, 2007. A weak annual shower is detected in CAMS data. The September ϵ Perseids (SPE), from an unknown long-period comet, peak from about September 9 to 12. The southern apex source has a diffuse shower, called the ν Eridanids (NUE), first detected in the SonotaCo data and verified by CAMS. This is a retrograde 140° inclined shower from a Halley-type comet. Early September sees emerging what is often called the Taurid Complex, with two branches: the Northern Taurids (NTA) and the Southern Taurids (STA). A complicated pattern of brief showers starts in the first week of September (Figure 10). CAMS data suggest that individual names are warranted.

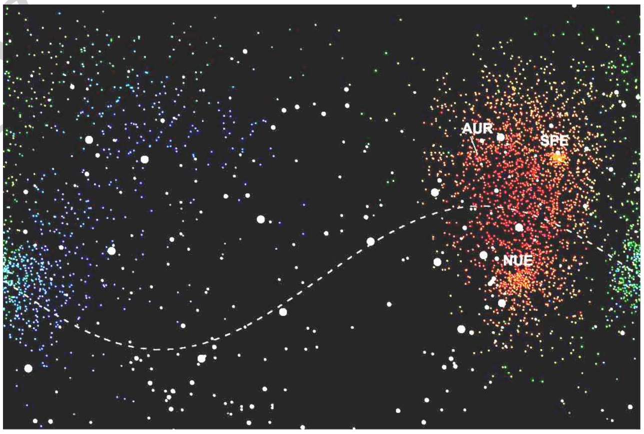

Figure 10 – August 30–September 12 (1774 SonotaCo and 1866 CAMS).

11 The showers in October

The Daytime Sextantids is associated with Asteroid 2005 UD, and with the Geminids/3200 Phaethon part of the Phaethon family, the only established association of meteor showers with asteroids. The weaker Daytime κ Leonids (KLE) were not detected. Early October is known for a number of irregular showers. The October

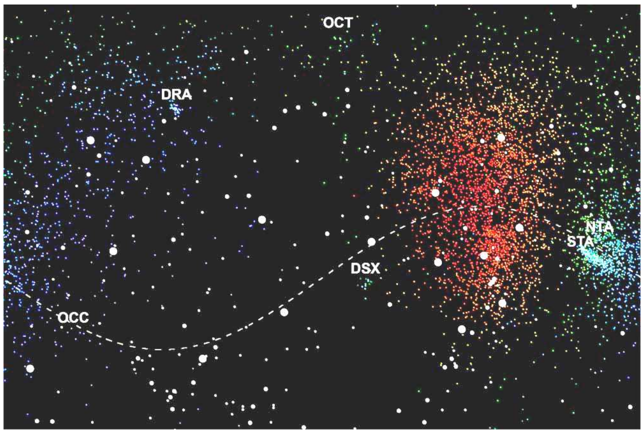

Figure 11 – September 20–October 10 (2341 SonotaCo and 3288 CAMS).

Capricornids (OCC) derive from the mostly dormant comet D/1978 R1 Haneda-Campos, which was recently trapped in the 2:1 mean-motion resonance that can trap dust as well. A meteor outburst from this shower was observed in 1978. On October 8, 2011, an intense outburst of the October Draconids (DRA) from Comet 21P/Giacobini-Zinner was observed from Europe. Two CAMS computers were operated from Kühlungsborn, Germany, providing the data shown. The radiant of the October Camelopardalids (OCT) was only recently determined by Finnish observer Jarmo Moilanen from video observations of an outburst of meteors on October 5, 2005 (Figure 11).

At the time of the peak of the Orionid (ORI) shower from Comet 1P/Halley, on October 22, the Leonids Minorids (LMI) from Comet C/1739 K1 Zanotti are active, as well as a diffuse ϵ Geminids (EGE) from an unknown source. This shower was previously known from sparse photographic data and is now confirmed. At this time of the year, the Southern Taurids are more active than the Northern Taurids (Figure 12).

12 The showers in November

In the first week of November, part of the Northern Taurids (NTA) are associated with the dormant comet 2004 TG_{10}. Other parent bodies are suspected for other parts of the Taurid Complex. The Andromedids (AND) are much slower meteors that originate from the now defunct JFC comet 3D/Biela. The χ Taurids (CTA) and the θ Aurigids (THA) showers, confirmed by CAMS, have radiants close together, but different entry speeds. These are very different streams. The θ Aurigids are a JFC shower which is highly eccentric and has a low perihelion distance. The χ-Taurids, on the other hand, are a prograde Halley-type stream, with an inclination of only 17°. Further south are the o Eridanids (OER), from a relatively high inclination JFC comet with an 8-year period. The Orionids (ORI) are still active in early November, while the Leonids (LEO) from the Halley-type comet 55P/Tempel-Tuttle are just emerging. Finally, on November 5, 2009, SonotaCo detected an outburst of a new long-period comet shower north of the Leonids, now called the κ Ursae Majorids (KUM). Of this meteoroid stream, CAMS measured one orbit in 2011 (Figure 13).

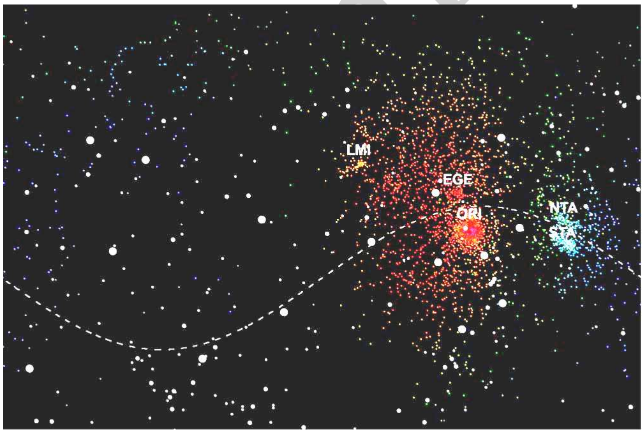

Figure 12 – October 18–29 (7683 SonotaCo).

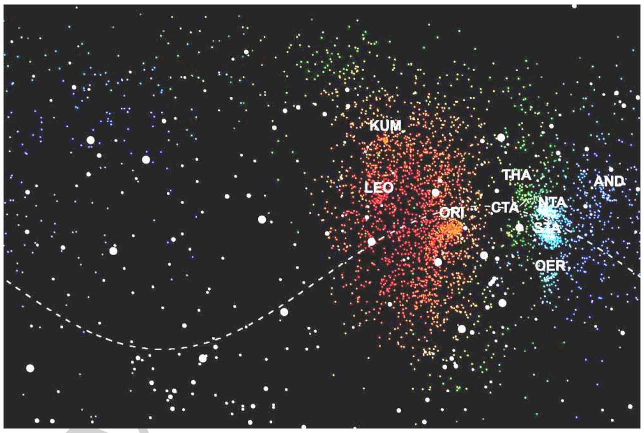

Figure 13 – November 1-10 (2474 SonotaCo and 2140 CAMS).

13 The showers in December

During December 3–6, CAMS detected yet another meteor outburst with a radiant in Cassiopeia, this time from a JFC comet, now called the December φ Cassiopeiids (DPC) (Figure 14).

A number of low-perihelion showers show up in this compilation of CAMS and SonotaCo data. On November 11, the Halley-type November Orionids (NOO) first emerge and last until the peak of the Geminids in mid December, caused by an unknown Halley-type comet. The December Monocerotids (MON) show up on December 1 and last until the peak of the Ursids. These too originate from a Halley-type comet, probably Comet C/1917 F1 Mellish, although the orbital period of this comet is uncertain. The Geminids (GEM) are a highly eccentric high-inclination short-period shower. It originated from an asteroid, 3200 Phaethon. A number of other high-inclination near-Earth asteroids are known that have similar gray reflection spectra, forming a trail of breadcrumbs that lead to Asteroid 2 Pallas and its associated asteroid family.

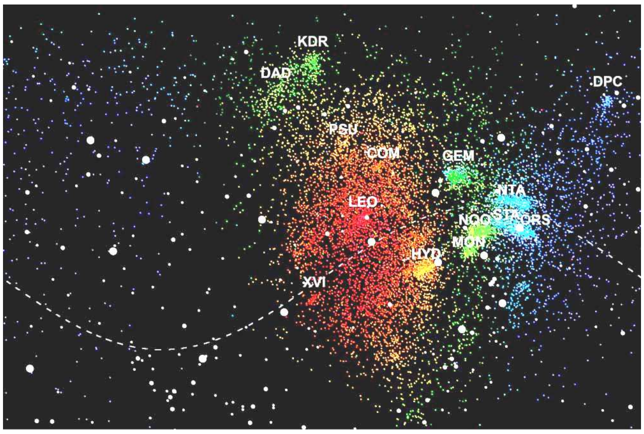

Figure 14 – December 1–8 (4250 SonotaCo and 3240 CAMS).

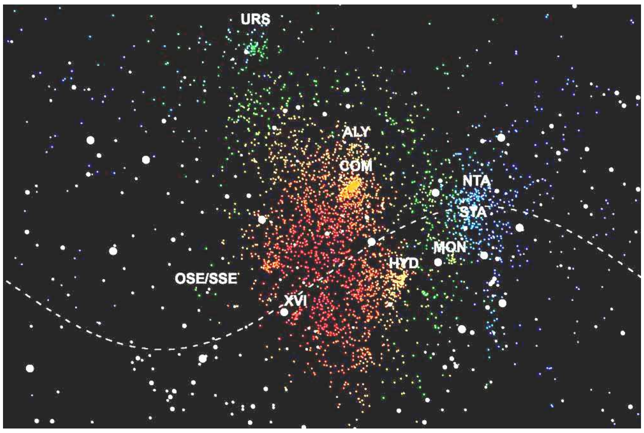

Figure 15 – December 18-25 (2805 SonotaCo).

The Leonids continue to be detected in early December. The December Comae Berenicids (COM) emerge on December 2, but continue until the end of January. CAMS detected a weak annual α Monocerotid (AMO) shower around November 22, from an unknown long-period comet, the 1-revolution dust trail of which caused the predicted 1995 outburst. At the same time, another shower emerges just north of it, called the σ Hydrids (HYD). This Halley-type shower swells to a major shower on December 6. No parent body is known.

The southern hemisphere Phoenicids (PHO) are periodic, and originate from Comet D/1819 W1 Blanpain. A remnant of this comet was discovered recently, and called 2003 WY_{25}. It was small, but still weakly active at perihelion. The Northern Taurids and Southern Taurids continue into December. Just west of the Southern Taurids are the Southern χ Orionids (ORS), a shower that is now confirmed.

The 74° inclined Halley-type December κ Draconids (KDR) were first recognized in SonotaCo data and later also detected in the CMOR radar observations. The December α Draconids (DAD) are a 72° inclined short-period JFC stream. The 170° inclined retrograde long-period December χ Virginids (XVI) are now also confirmed. The 119° inclined Halley-type ψ Ursae Majorids (PSU) were detected by CMOR and are now also confirmed.

The Ursids (URS) originate from Halley-type comet 8P/Tuttle. The shower has occasional outbursts. This time of year, in late December, the December Comae Berenicids (COM) peak, although they remain active throughout December and January. The 107° inclined long-period α Lyncids (ALY) are confirmed by CAMS. Finally, radar observations find two nearby daytime radiants with slightly different speed in Serpens: the ω Serpentids (OSE) and the σ Serpentids (SSE). A few meteors of these showers were detected by CAMS in early morning hours (Figure 15).

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