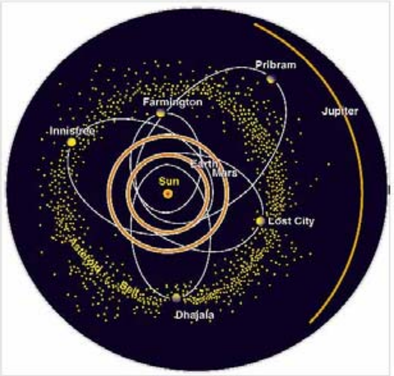

Meteor Tracking Networks: Past, Present, and Future

by
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PURPOSE

This paper details the evolution of meteor tracking networks from 1960 to the present. Meteor tracking depends on technology, interest, and mission philosophy. This paper will analyze the evolution of meteor tracking networks in terms of their era, mission, technology, and overall support for the future.

BACKGROUND

Since the L'Aigle fall, on April 26, 1803, it has been accepted that meteors are matter that can fall to the earth rather than venerable religious events. Therefore as time passed scientific interest in meteors and their associated meteorites has grown. Culminating in today's scientific philosophy that meteors/meteorites are the key to unlocking the configuration of the early Solar System and its evolution [Gaffey, 2002]. Consequently, scientists desire:

- to recover meteorites as soon as possible to minimize Earthly modification;
- to identify when and where meteors are entering the Earth's atmosphere to potentially become meteorites;
- to understanding meteorite origins and meteor orbital characteristics [Poltkin, 1996].

Therefore meteors, which will potentially become study-able meteorites, have been tracked formally for years by multiple techniques producing quantum leaps in observational technology and meteor/meteorite knowledge.

IN THE BEGINNING

(1960 - 1980s)

A successful observation of a meteor consists of two images (photographs) from stations separated by 20km or more [McCrosky, 1965]. This dual observation data set allows the scientist to determine the true path the meteor will take through the atmosphere, its probable impact location, as well as its previous heliocentric orbit. Two stations could supply such data sets, as attempted by Harvard in 1936 and Ondrejov in 1951, however success would be inhibited by the sky coverage limitations of only two stations. Therefore networks of photographic observations stations of greater than two stations were established (See Table 1) to formally observe the night sky in hopes of acquiring the aforementioned data sets reliably. The following are the original formal networks (> two stations) that began from 1963 – 1969:

1. European Fireball Network (1963 – Germany/Czechoslovakia)
2. Prairie Network (1964 – United States of America)
3. Meteorite Observation and Recovery Project (MORP) Network (1971 - Canada).

Parameter	European Fireball Network	Prairie Network	MORP Network
Number of Stations	46	16	12
Station Spacing, km	87	250	193
Number of Cameras per Station	1	4	5
Focal Length, mm	5.7	152	50
Dash Length, mm	0.034	0.236	0.330
Meteor Timing	Visual Observers	Photometer/Shutter Code	Photometer
Sky coverage, km^2	10.8×10^5	11.4×10^5	8.3×10^5
Effective Ground Search Area, km^2	4.4×10^5	13.6×10^5	7.1×10^5

Table 1: Original Photographic Observation Network Characteristics [Halliday, 1971]

European Fireball Network. The first systematic meteor tracking network, administered by the Ondrejov Observatory, was operational in 1963 with 5 stations, prompted by the 1959 photographed fall of the Pribram meteorite in Czechoslovakia. By 1968 it was expanded by the installation of new stations (~15) in Germany and was named the European Fireball Network [Oberst, 1998]. Its mission was to obtain meteor records from two or more stations for scientific use. Each station in this network used one all-sky camera (Figure 1), 36mm film, and a rotating shutter and performed one manual exposure per night (See rendering of an all-night exposure results in Figure 6B) [Ceplecha, 1965]. From 1963 to 1988 the European Fireball Network (Figure 2) successfully observed fifteen (plus Pribram in 1959) meteors [Oberst, 1998]. In 1988 this network began involving amateur astronomers to operate stations and thereby expanded to northern Germany, Belgium, Switzerland, and Austria. The success of this network continued and is therefore operational at present.

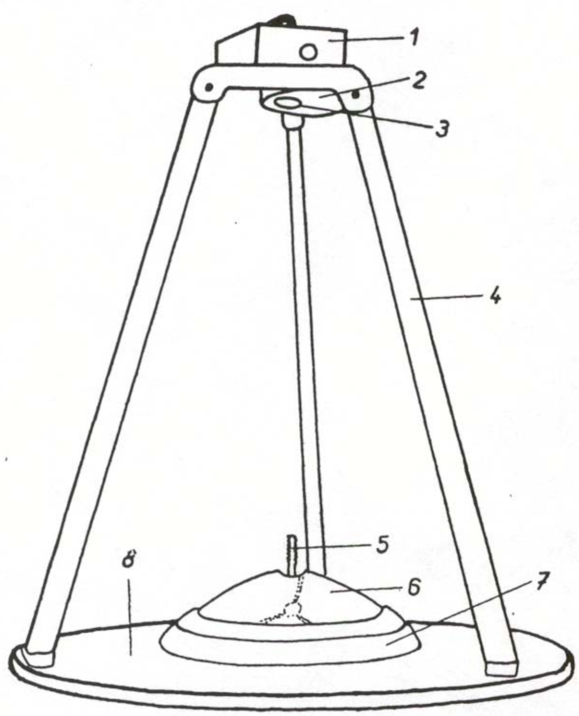

Fig. 1. Schematic picture of all-sky camera: *1* — cover of top-box used for location of film camera, *2* — rotating shutter part of top-box, *3* — aperture, *4* — supporting bar, *5* — screw for fixing mirror cover, *6* — mirror, *7* — mirror holder, *8* — basal slab.

Figure 1: All-sky Camera [Ceplecha, 1965]

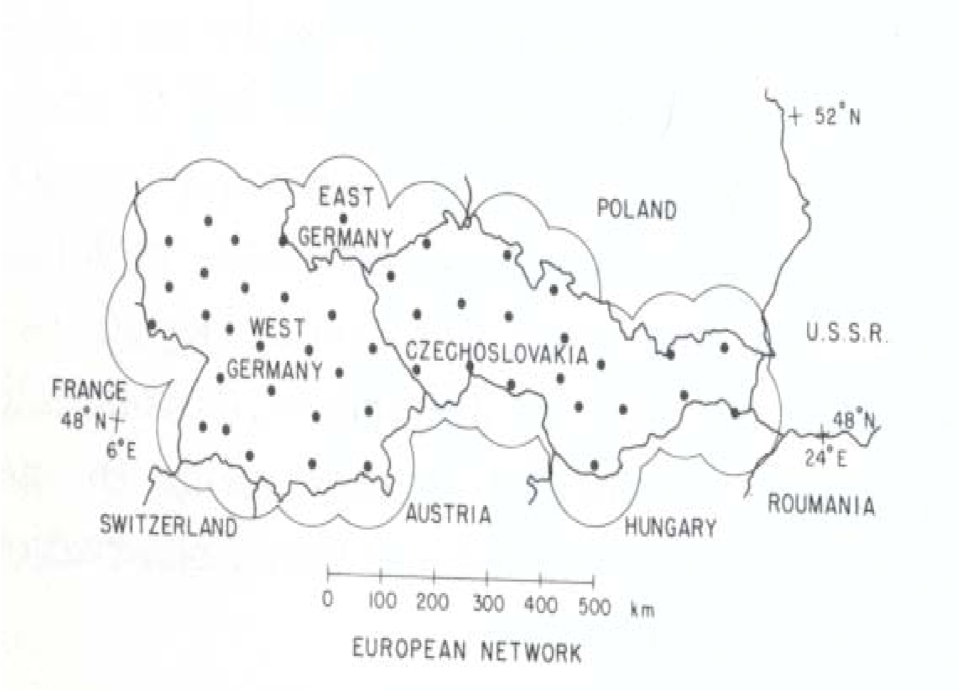

Figure 2: European Fireball Network Stations Pre-1988 [Halliday, 1971]

Prairie Network. The second systematic meteor tracking network, administered by the Smithsonian Institution, was operational in March of 1964 with 10 stations in the Midwest United States. This network evolved to its final configuration of 16 stations (Figure 3) extending from South Dakota to Oklahoma and from Illinois to Nebraska by May 1964 [McCrosky, 1965]. Its mission was to gather the most data on the brightest meteors to find meteorites. Each station in this network used four Super-Schmidt T-11 cameras (Figure 4), 390-ft of film, a switching shutter, a sky photometer, and a cloud detector since each station was to operate autonomously. During its operations from 1964 – 1975 this network recorded approximately 320 fireball observations, with one resulting in a meteorite find, the Lost City meteorite [Ceplecha, 1987]. However, as the 1970s began the public and the US congress were more interested in the war in Vietnam and civil riots than space/meteor science and this network along with the Apollo program were victims of federal budget cutting. Specifically, operations of the Prairie Network were terminated in 1975 due to lack of funding and very limited fulfillment of its mission to assist in finding meteorites.

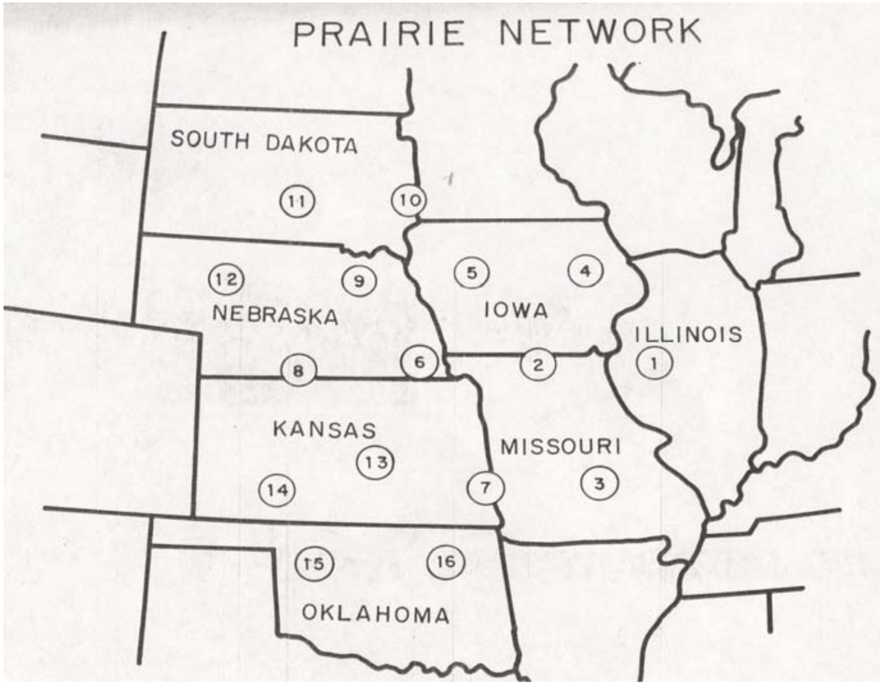

Figure 3: Prairie Network Stations [McCrosky, 1965]

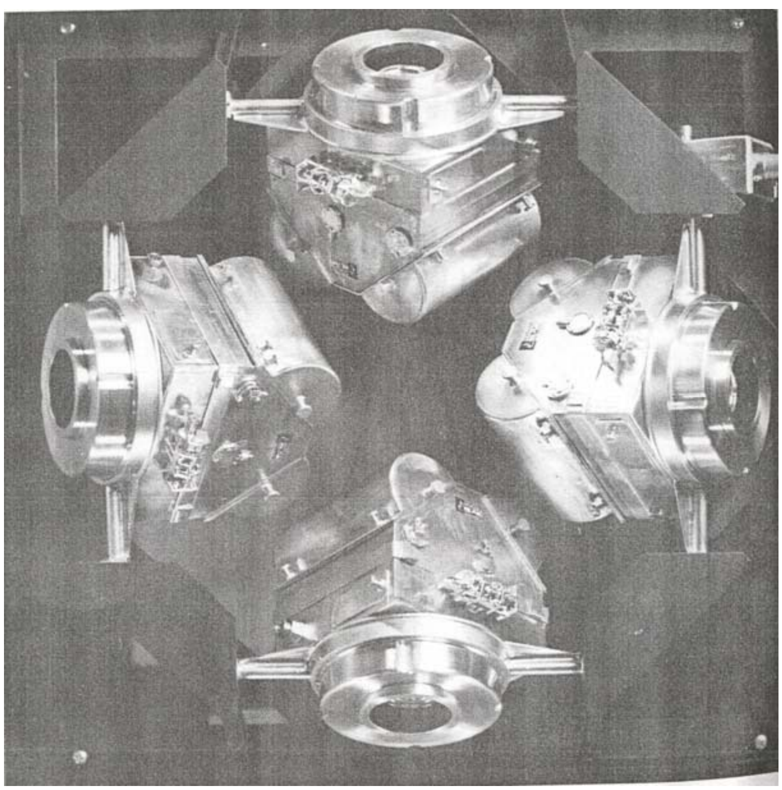

Figure 4: Super-Schmidt T-11 cameras [McCrosky, 1965]

MORP Network. The third of the original systematic meteor tracking network, administered by the University of Saskatchewan, was operational in 1971 with 12 stations in western Canada (Figure 5). Its mission was to obtain meteor records from two or more stations for scientific use. Each station in this network used five Super-Komura cameras, 70-mm film, masking and chopping shutter, meteor detector (photomultiplier tube) and exposure control circuitry since as with the Prairie Network each station was to operate relatively autonomously. During its operations from 1971 – 1985 this network recorded many fireball observations, with only one resulting in a meteorite find, the Innesfree meteorite [Halliday, 1978]. Therefore the MORP Network was dismantled in 1985 due to a lack of funding support given that Canadian meteorite finds/discoveries were continuing during this period mostly without the use of MORP data.

Figure 5: MORP Stations [MIAC, 2002]
(Note: Innesfree is meteorite fall location not station)

AT PRESENT

(1980s - 2002)

The success of the original three meteor tracking networks shows that photographic data on meteors can be acquired and used for orbital characteristics, its origins, and/or its character but meteorite impact predictions have been problematic. The problem in predicting an impact location for a meteorite from photographic data is primarily due to a meteor's luminosity variations as it traverses the atmosphere. A meteor's luminosity terminates as it slows down (~ 3km/s) in the atmosphere and heating is too low create a visible fireball. Although with an observed terminal velocity and deceleration an impact location can be predicted to within 1 km [Ceplecha, 1987]. However the meteorite ground search itself can be the restricting factor as seen by the 50 searches done for all three of the original networks only yielding 3 meteorite finds. Therefore the original network that remains, the European Fireball Network, and those that have recently been established have the ultimate goal of identifying orbital and atmospheric characteristics, its origins, and its potential to become a meteorite rather than predicting its exact impact location.

European Fireball Network. This network was successful in its mission to record meteor events in the beginning of meteor tracking chronology, given that its success was not intimately tied to the recovery of meteorites, and therefore remains operational today. In 1990 the European Fireball Network expanded again due to the reunification of Germany and today the network has 34 stations across Germany, Czech and Slovak Republics, Belgium, Switzerland, and Austria (Figure 6A). Each station now uses either Leitz cameras or all-sky cameras with a Zeiss-Distagon fish-eye lenses, 9x12cm film, and 12.5Hz shutters [Oberst, 1998]. The operations of this network are no longer just coordinated by the Ondrejov Observatory. At present the German Aerospace Center's Institute of Planetary Exploration and the Ondrejov Observatory are co-coordinators of the network's efforts. Currently, the network detects over 50 fireballs per year with 50% of those being successful observation of a meteor consisting of two images [Oberst, 1998]. However this network's post-creation-data and spectacular images (Figure 6B) has produced no more meteorite finds to date.

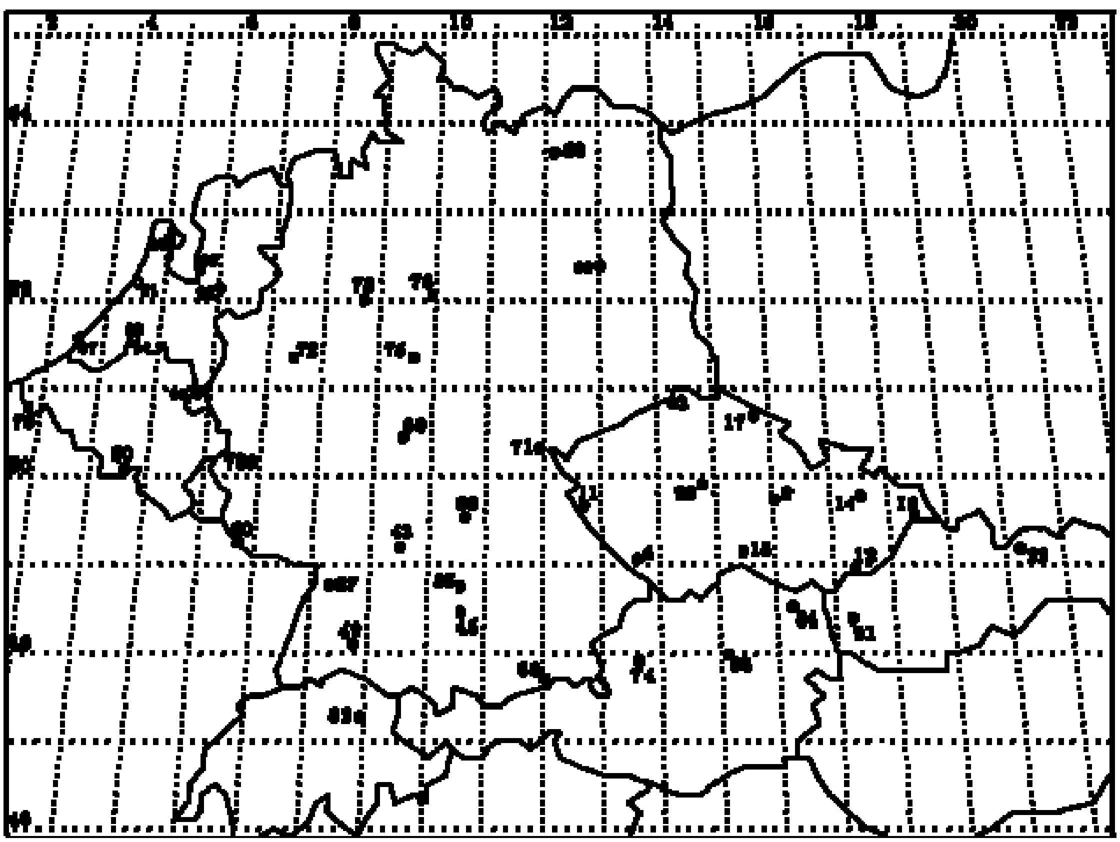

Figure 6A: European Fireball Network Stations [Oberst, 1998]

Figure 6B: European Fireball Network Station All-Night Exposure Fireball Image

"This exceptionally bright fireball meteor trail was photographed with a fish-eye camera at a Czech Republic station of the European Fireball Network on January 21, 1999. Of the star trails visible in this night-long exposure, the bright short arc in the upper left is due to Polaris, the north star. The breaks seen near the beginning of the fireball trail itself were produced by a shutter rotating 15 times a second. In all, three stations recorded the dazzling streak and their combined tracking information has revealed details of the meteor's brief atmospheric flight and previous interplanetary voyage. For example, the luminous trail is measured to begin at an altitude of 81.9 kilometers and covered 71.1 kilometers in 6.7 seconds." [GSFC, 1999]

Dutch Meteor Society. Hans Betlem founded the Dutch Meteor Society (DMS) in 1979 as an informal society of observers. Since then the DMS's members have been involved in meteor astronomy and meteorite searches/analyses. The DMS began informal visual/photographic meteor observations circa 1980. Since then the DMS has added video observation (1987) and radio meteor scatter observations (1993) to its capabilities via its member's research initiatives. The majority of DMS members currently use Cannon T-70 cameras equipped with high quality FD f/1.8-50 mm for photographic observations. Between 1980 and 1995, 998 successful photographic meteor observations (multi-station) have been made while video and radio data has been recorded for many periodic storms [Betlem, 2001]. In addition, the DMS currently runs 7 permanent automatic all-sky stations (Dutch All-Sky Network w/Cannon fish-eye lenses), as part of the European Fireball Network. However, like many other meteor networks the DMS's observations have not led to a meteorite find as of yet.

Dutch All-Sky Stations			
Code	**Station**	**Longitude**	**Latitude**
EN91	Leiden	52-11-02	04-30-01
EN92	Elsloo	50-56-45	05-46-02
EN95	Benningbroek	52-42-08.1	05-01-30.9
EN96	Loenen	52-07-17.6	06-01-27.4
EN97	Oostkapelle	51-34-21.7	03-32-15.9
EN98	Harderwijk	52-20-01.1	05-39-30.1
EN99	Bosschenhoofd	51-34-14.2	04-32-32.6

Table 2: Dutch All-Sky Stations [Betlem, 2001].

Spanish Photographic Meteor Network. In 1997 the Spanish Photographic Meteor Network (SPMN) was established. This network uses both professional and amateur astronomers under the auspices of University Juam I, University of Barcelona, and Catalonian Institute Studies. The main mission of the SPMN is to study meteors, fireballs and meteorites in terms of there orbits from conventional photography, video and Charge-Coupled Device (CCD) techniques as well as each meteor streams' spatial densities, parent bodies, and spectroscopy. SPMN has 17 stations, with semi-automatic all-sky cameras with rotating shutters and CCD, as shown in Figure 7 [Pique, 2002]. All SPMN observation campaigns are open to amateur participation and the SPMN has been successfully meeting its objectives thus far.

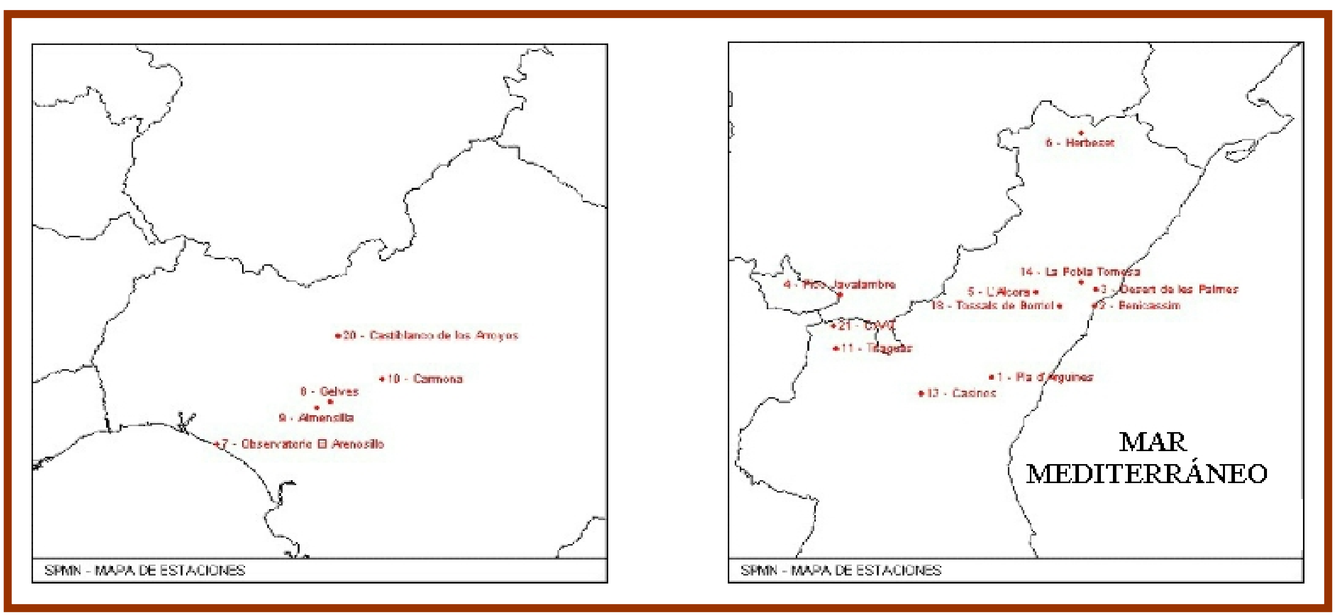

Figure 7: Spanish Photographic Meteor Network Stations [Pique, 2002]

NAMN Network. The North American Meteor Network was founded in June 1995. Its mission objectives are:

1. "Promote astronomy and related sciences
2. Recruit and train new observers in the methods of meteor observation
3. Coordinate North American observations" [Davis, 2001]

NAMN is an informal group of over 200 observers who collect large numbers of meteor and fireball observations. Observations consist of visual accounts, 35mm camera images, telescopic accounts, and radio detections. Routinely meteor images are collected via this amateur network and therefore the network is continuing to thrive.

Tokyo Meteor Network**.** The Tokyo Meteor Network began photographic observation of meteors in 1989 with following mission objectives:

1. "Obtaining more accurate meteor orbital data by photographic observation using middle focus lenses of 85 - 100mm
2. Associating meteors with comets or minor planets by studying evolutions of the orbits
3. Studying meteor spectra." [Hidaka, 2002]

This network's efforts consist of amateur astronomers manually capturing meteor images on 35mm cameras with rotating shutters at 5 stations (Daisawa, Hadano, Okizu, Tsukuba, & Fujisawa). Results of these efforts have been very successful in meeting the objectives of the network.

Japan Fireball Network. The Japan Fireball Network is an observation network to collect meteor photographic footage. Footage is acquired via automatic camera every night in various parts of Japan [Shimoda, 1998]. This network's efforts consist of amateur astronomers capturing meteor images on 35mm cameras with rotating shutters, and/or on video tape using curved mirrors, and/or on Charge-Coupled Device (CCD) cameras at the stations shown in Figure 8. This network routinely acquires consistent and usable images and is therefore operational at present.

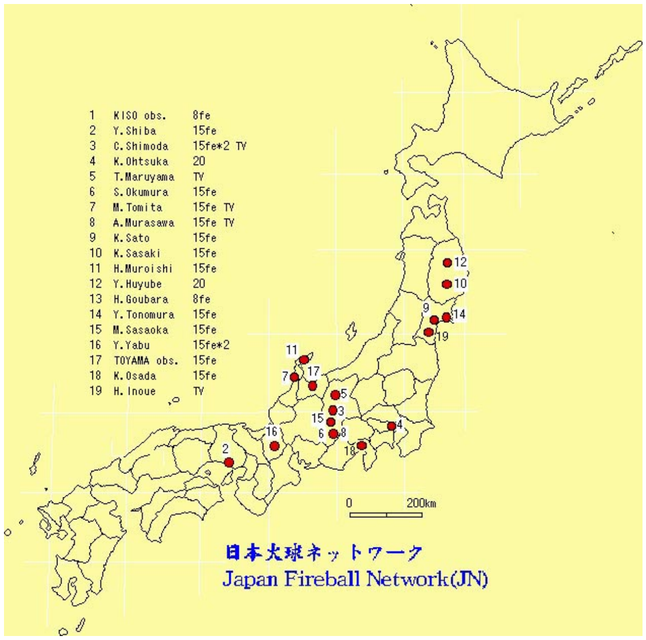

Figure 8: Japan Fireball Network Stations [Shimoda, 1998]

IN THE FUTURE

(2002 - *)***

As shown by the demise of the Prairie and MORP networks and the success of the current networks involvement of amateurs is a must [Oberst, 1998]. Not only does it provide ease of network expansion as shown in the European Fireball Network history but also provides free efforts and increased public support. There are currently a few organizations like The American Meteor Society, The International Meteor Organization, and NAMN as well as select Universities that promote meteor interest but the birth of the Internet, and its associated technology may mean the re-birth of more global interest. In addition, space-based observation platforms (i.e.; DOD/NOAA/GOES/ARGOS Satellites), airborne observatories, infrasound listening devices (i.e.; LANL – Figure 9), and global positioning systems may also increase the frequency of observations and increase the possibility of meteorite recovery. To date many meteor observation reports are available from these types of sources, which include sufficient data to assist researchers in meteor calculations and possible meteorite recovery. To illustrate the value of information from these types of sources a sample DOD report follows:

> "On 9 December 1997, sensors aboard DOD satellites detected the impact of a meteoroid at 08:15:55 UTC roughly midway between Nuuk and Qaqortoq, Greenland. The object broke into at least 4 pieces. One piece detonated at an altitude of about 46km at 62.9 degrees North Latitude, 50.9 degrees West Longitude. The remaining 3 pieces detonated in close proximity to one another at altitudes between 28 km, at 62.9 degrees North Latitude, 50.1 degrees West Longitude and 25 km at 62.9 degrees North Latitude, 50.0 degrees West Longitude." [GSFC, 1998]

However these types of assets are orbital and/or operational for other purposes and their operation and/or data releases can be discontinued at anytime.

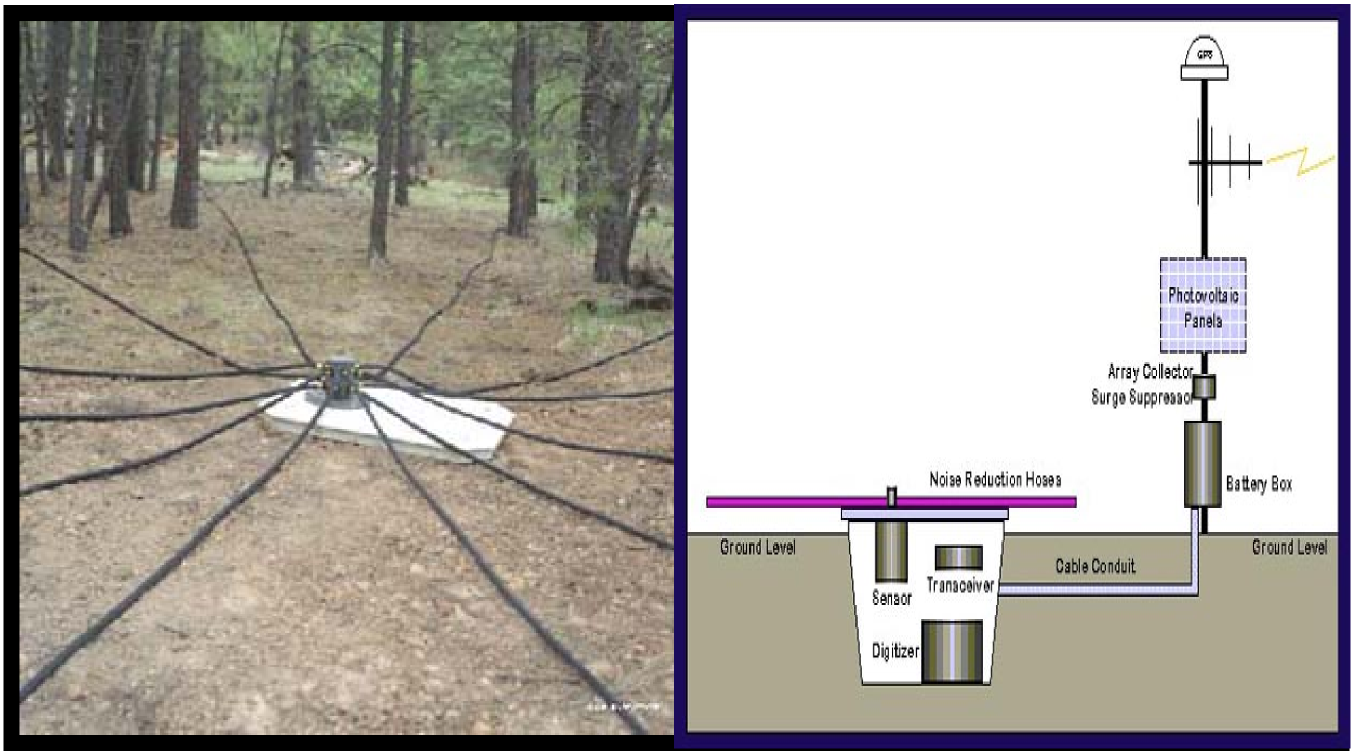

Figure 9: LANL Infrasound Listening Station [NNSA, 2001]

Note: "Using Los Alamos listening stations that can help alert international authorities to weapons tests by rogue groups or nations, researchers Rod Whitaker, Doug ReVelle and Peter Brown of Atmospheric and Climate Science (EES-8) detected two meteors entering the atmosphere on April 23 of this year *[2001]* and on Aug. 25 2000. Data from orbiting platforms confirmed the objects. … The meteors were very large, measuring about six and 10 feet in diameter." Entrances were equivalent to 2000 – 8000 tons of TNT. [Rickman, 2001]

CONCLUSION

Today's scientific philosophy that meteors/meteorites are the key to unlocking the configuration of the early Solar System and its evolution depends on meteorite recovery. Thus since meteor tracking/observation, both advanced and amateur, can aid researchers in finding meteorites, although with only limited success to-date, then efforts need to continue in this area. However, amateur involvement will most likely only keep the current level of capability thriving, therefore professional involvement will be needed to advance this field technologically (i.e., dedicated space-based efforts or advanced ground systems) and increase its meteorite locating success potential.

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