

Summary of some references concerning  
the radio detection of meteors  
and related topics

There is an extensive scientific and engineering literature dealing with the subject of ionization trails produced by the passing of meteors through our atmosphere. The purpose of this summary is not to be as complete as possible, but to pinpoint several aspects that the writer thinks can be of use to the MARIACHI project.

A pertinent study of bibliographical references has been made in the presentation of the MARIACHI project. For this reason, this summary has to be complementary and will be guided by the questions put forward by Michael Marx and Helio Takai in an e-mail communication, dated November 7, 2005, addressed to professor Djuric.

The Japanese physicist Hantaro Nagaoka (1929) appears to have been the first to point out the meteor effects on radio propagation [Jernovics90, Mathews04]. As he noted that the meteoroid composition was metallic, he suggested that submicron dust would be distributed along the meteor path and it would result in ionization attachment leaving a hole in the atmosphere, provoking irregular and diffuse reflections from this ionized layer, and disrupting radio communications. The first possibly confirmed meteor effects were published by Skellett in 1931 [Mathews04], who established that the effects observed with a new ionosphere/propagation pulse-sounding technique were due to meteor-induced ionization patches that caused the virtual height to the ionosphere to suddenly decrease.

The Doppler whistles which can be heard under certain conditions on short wave radio signals during the passage of meteors were studied for the first time by Chamanlal and Venkatamaran in 1941 [Manning et al. 1946]. Their explanation was that the whistles were heterodyne notes caused by the interference of the direct radio wave from the sending station and the reflected wave from the rapidly moving ionized surface associated with the meteor.

The U. S. Federal Communications Commission acknowledged in 1945, by measuring signal bursts from FM stations in the 40-50 Mhz band at distances beyond the range of the ground wave, that reflections occurred from trails of ionization produced by meteors [Manning et al. 1946]. Many other authors confirmed and commented on the radio detection of meteor trails during the 40's [Appleton47].

Manning [Manning48] explains that there are two types of reflection which may be obtained from the ionization trails. The first are the signal bursts, that result when the transmitted signal is reflected from the cylinder of meteoric ionization such that the incident and reflected rays make supplementary angles with the meteor's path. The second are the meteor whistles, of a transient nature, which apparently results when a continuous wave signal impinges upon the head of the rapidly advancing column of ionization. Due to the motion of the reflecting point, the returned signal suffers a Doppler shift in frequency and may be combined with a portion of the original transmitted energy to produce a beat frequency which ordinarily lies within the audible range. The author shows that meteoric velocity and range can be determined by combined pulse and whistle observations. He also proposes a way to determine the direction and position of a meteor path by observations at three receiving locations.

Eshleman and Manning in 1954 [Eshleman et al. 1955] pointed out that was possible to transmit a continuous signal from point to point by taking advantage of these specular reflections from ionization trails formed in the E-region of the ionosphere by meteors of all sizes. The use of this

forward scattering type of propagation gave birth to the branch of communications known as meteor-burst communications (MBC). The physical effects that affect this type of propagation are the mass distribution of meteors, the electron line density of the trail, the path length and geometry, the frequency, the diffusion rate of meteor trails, and the height of meteor trail formation, along with the radiant density distribution of meteors and the galactic noise sources [Mawrey et al. 1993]. For example, a trail, produced by a meteoroid with a velocity of 30 km/s, has an initial diameter of 0.4m at 80 km, 2.0m at 104 km, and 4.0m at 116 km [Elford80]. The reflection from a trail that varies its diameter in the way prescribed directly affects MBC.

The ionization trail that is formed by the friction of the meteoroid particle and the atmosphere may be tens of kilometers long and it is usually produced at a height of between 80 and 120 km above the earth's surface, notwithstanding the relatively small size of the particle, thanks to its high kinetic energy. After a short period of time, the trail diffuses and its ability to sustain radio wave reflection ceases [Handley92]. The location and the times of occurrence of the trails are random, but it has been observed that the meteors strike the atmosphere more during the dawn hour, and their incidence is lower during the sunset. There is also a seasonal variation of meteor incidence, which happens because the intersections of meteor orbits with the Earth's orbit are not uniformly distributed, but are concentrated so as to produce a maximum of intersections in August and a minimum in February [Jernovics90]. This observation is valid for the so-called sporadic meteors. There exist also the shower meteors, which are group of particles moving at the same velocity in well-defined orbits around the sun; they produce well known passes that are awaited by the amateur and professional astronomers, either for enjoyment or for study (like the Leonids, Perseids, and Aquarids meteors).

Two major classes of meteor trails have been identified: underdense and overdense trails. There is a third group, called the transition group, that is mainly used for statistical studies of meteor events [Meisel99]. The density referred to is the ionization density, measured in number of electrons per meter. Underdense trails, more frequent, are generally of lower amplitude and shorter duration than overdense trails. In MBC communications, the overdense trails are primarily responsible for the bulk of the hourly data throughput (more than 60%). Trail durations for underdense trails are typically 100 to 300 ms, while for overdense trails, durations of several seconds are not uncommon. This brief trail existence can be used for burst-mode data communications between one point and another within a radius of 2000 km without the need for repeaters.

For a useful MBC or forward-scattering link to be formed, the meteor trails must be tangential to an ellipse whose focal points are the transmitter and the receiver ends of the link [Wislez95]. Since most trail reflections are specular rather than diffuse, the signal from the trail is reflected onto the earth as an oblong reception zone or *footprint*. The dimensions of this zone are dependent on the beam-pattern of the transmitting antenna and are typically 40 km long and 20 km wide for 100% signal interception using 4-5 element Yagi antennas [Yavuz90]. Any receiving radio device located outside this zone will be unable to listen to the transmitted signal.

The American Meteor Society (AMS) in 1977 established the AMS Radio Scatter Program (which later changed its name to the AMS Radiometeor Project) with the long term goal of setting up and maintaining a network of amateur operated radiometeor stations, each collecting data on the meteor flux on a continuous operating basis. The first full time prototype station became operational in 1993, using an Apple IIe platform for data collection. Other additional stations have been added since then. This project is not intended to substitute the visual counting of meteor rates that volunteers from the society have kept doing over the years. The first efforts to automatically count the meteor events using an amateur operated forward-scatter radio system was pioneered by the AMS Kansas Meteor group in

the late 1950's [Richardson and Meisel 1996].

The AMS (Bulletin No. 203) notices that the most convenient frequency band for use in meteor event detection is the low VHF television band (55-88 Mhz) which corresponds to broadcast channels 2 through 6. In addition to the primary picture signal, each TV channel also carries two subcarriers frequencies: one for sound set at 4.5 Mhz higher than the picture carrier frequency, and one for color located 3.58 Mhz higher than the picture carrier frequency. Nevertheless, since the picture carrier frequency contains most of the broadcast power, this is the one which is of utmost interest for radiometeor work.

In the choice of the VHF frequency band for meteor detection, it has to be considered other forms of propagation which can affect the VHF range: tropospheric scatter, D-layer scatter, high-powered ionospheric scatter, sporadic E activity, equatorial spread f, radio aurora, temperature inversion ducting, and polar cap absorption.

The most common antenna used for radiometeor work, once a station choice has been made, is the Yagi antenna, built for a gain of about 10 dB S/N, with a beam width of about 30 degrees, cut specifically for the chosen frequency. It may have 4 to 5 elements, even though 3- or 6-element Yagi antennas have been used successfully. Other technical features of importance related to antenna design can be found in the abovementioned bulletin from the AMS.

Meteor scatter studies can be done with relatively narrowband equipment (generally less than 10 Khz), but the best receiver (according to the AMS) is one of the high-quality multiband receivers available on the commercial market. Combined with a preamplifier, this receiver should have a sensitivity of between -130 dBm and -100 dBm, assuming an input impedance of 50 ohms. It should contain also a beat frequency oscillator, which can be used to monitor the carrier wave signal from the transmitter, in either continuous wave (CW) or single side-band (SSB) mode.

The automated meteor event detection by the AMS has considered the following points: (a) all detected events must rise greater than a preselected threshold value above the receiver background noise level; (b) long duration events (greater than two minutes) are discarded; (c) oscillating events with periods of less than three seconds are detected only once; (d) radio frequency interference, including lightning events, are ignored through the use of a second receiver to detect such events (when an event appears in both receivers, is ignored); (e) further statistical considerations help discriminate questionable events [Richardson and Meisel 1996]. Three parameters are collected for each meteor event: event occurrence time (*epoch*), signal amplitude, and event duration. Even though they are few, these parameters allow a great deal of information to be derived from them [Meisel and Richardson 1999].

Mallama and Espenak [Mallama and Espenak 1999] describe how their automated meteor counting apparatus combines signal intensity with audio tone analysis for meteor echo detection. The system is composed by three main components: a receiver (with both a signal meter and an audio outputs), an analog-to-digital board, and a personal computer. The automatic gain control output from the receiver is connected to the A/D board, which is polled by the computer. A sudden signal power increase by 3 dB or more alerts for a possible meteor echo in progress. A separate A/D channel is connected to the receiver's audio output. This interface helps distinguish true meteor forward-scattering from other types of signal enhancements like spurious electrical activity (lightning, circuit switching) that could otherwise be counted and invalidate the counting results. Samples from the audio signal are autocorrelated in order to find the frequency and power of the video carrier's tone. Due to the fact that

broadcast signals usually have spectral structure, peaks are produced in the autocorrelation spectrum. Every detected signal enhancement is tested by the analysis program to establish its origin. If the signal increase is due to a meteor, the faint video carrier tone rises above the noise background and the correlation coefficient will increase. A signal enhancement due to electrical noise will reduce the correlation because noise is devoid of spectral structure. In the case of lightning and other forms of interference (sparks, current interruption), their incoherent nature helps in their discrimination by the autocorrelation test. On the other hand, signals reflected by aircraft show varying intensity due to the changing reflection geometry and it could pass the autocorrelation test, but they can be distinguished from true meteor signals because they begin with a very small intensity echo, which gradually builds into a larger strength and greater variability. The device eliminates airplane echoes by requiring 1 s of quiet signal before allowing a trigger.

The end of the MARIACHI project is to detect extensive air showers (EAS) as evidence of the arrival of primary cosmic-ray particles of energies above 1 EeV. Because EAS produces ionization trails similar to that of meteors, the project tries to achieve another way of detection different from fluorescence detection or Cherenkov detection, as used in the Auger project, for instance. In order to discriminate between meteor trails and EAS trails, one has to look into the way both ionization columns forms, and in the resulting ionization density profile [Gorham00]. In the meteor case, the ionization column is produced by the ablation of material from its surface which produces the collision of atoms with kinetic energies in the range of 100-1000 eV with air molecules. The column will have a uniform distribution of radial density, and an initial radius of 2-10 m; its density will evolve with time due to diffusion, convective processes, bulk motions of the air, and the environment forces of electric and geomagnetic fields. Finally, electron attachment and recombination eventually complete the process of dissipating the ionization column. The EAS ionization column, on the other hand, is formed with a different initial distribution than that of a meteor, reflecting the evolution of the cross-sectional charged particle density; the column is not produced by a single body, but by the collective effects of the highly energetic particles that make up the body of the shower: the lateral distribution of these particles spreads out as the shower progresses, and because it propagates close to the speed of light, it appears almost instantaneously compared to even the fastest meteors.

An efficient and reliable meteor detection method has been proposed by Wen et al. [Wen et al. 2004] by using signal processing techniques on data obtained from the Arecibo Observatory 430-MHz UHF radar. The time and frequency domain characteristics of the transmit waveform are exploited. The meteor observations are made by using 45- $\mu$ s carrier pulses with an interpulse period (IPP) of 1 ms. The return signal is demodulated in in-phase and quadrature-phase channels and sampled at a 1- $\mu$ s<sup>-1</sup> rate. The radar used detects not the trail echo, but the meteor head echo. They proposed two different mathematical methods: in the first, a meteor is acknowledged by a periodic structure present in the frequency spectrum; in the second, they construct a matched filter bank to detect the energy of different Doppler frequency components, and when the energy surpasses certain threshold, a meteor detection is declared. The altitude of a meteor is calculated also by finding the peak of the matched filter output [Wen05]. Verbeeck also determined meteor heights by using forward scatter observations of the type that the MARIACHI project wants to use to achieve its goal [Verbeeck93].

## Bibliography

### Detection of UHECR

1. The Pierre Auger Observatory Design Report. Second edition (revised). The Auger Collaboration. March 1997.

2. P. W. Gorham. On the possibility of radar echo detection of ultra-high energy cosmic ray- and neutrino-induced extensive air showers. (Jet Propulsion Laboratory, California Institute of Technology). Cornell University, arXiv.org e-Print archive, [http://arxiv.org/PS\\_cache/hep-ex/pdf/0001/0001041.pdf](http://arxiv.org/PS_cache/hep-ex/pdf/0001/0001041.pdf).
3. N. G. Lehtinen, P. W. Gorham, A. R. Jacobson, and R. A. Roussel-Dupré. The FORTE VHF instrument as a high-energy cosmic ray detector. *Proceedings of SPIE*, vol. 4858, pp. 296-304, 2003.

#### Radio Detection of Meteors

1. L. A. Manning, R. A. Helliwell, O. G. Villard, Jr., and W. E. Evans, Jr. On the Detection of Meteors by Radio. *Phys. Rev.* 70, 767-768 (1946).
2. E. Appleton, and R. Naismith. The radio detection of meteor trails and allied phenomena. *Proc. Phys. Soc.* LIX, 3, 461-473 (1947).
3. L. A. Manning. The Theory of the Radio Detection of Meteors. *Journal of Applied Physics*, Vol. 19, No. 8, pp. 689-699, August 1948.
4. J.-M. Wislez. High Definition Radio Meteor Profile Interpretation. *Proceedings of the International Meteor Conference, Puimichel 1993*, edited by Paul Roggemans, International Meteor Organization, pp. 47-51, 1993.
5. C. Verbeeck. Determination of Meteor Heights by Forward Scatter Observations. *Proceedings of the International Meteor Conference, Puimichel 1993*, edited by Paul Roggemans, International Meteor Organization, pp. 52-56, 1993.
6. J.-M. Wislez. Letters to WGN: Radio reflection duration and visual magnitude. *WGN: the Journal of the International Meteor Organization*, Vol. 21, No. 6, pp. 244-245, pp. 1993.
7. S. Suzuki, T. Yoshida, K. Suzuki, and T. Akebo. Multi-Station TV Observations of the 1993 Perseids. *WGN: the Journal of the International Meteor Organization*, Vol. 22, No. 4, pp. 137-139, 1994.
8. J.-M. Wislez. Forward scattering of radio waves off meteor trails. *Proceedings of the International Meteor Conference, Brandenburg 1995*, edited by Paul Roggemans and André Knöfel, International Meteor Organization, pp. 99-117, 1995.
9. A. D. Taylor and W. G. Elford. Meteoroid orbital element distributions at 1 AU deduced from the Harvard Radio Meteor Project observations. *Earth Planets Space*, Vol. 50, pp. 569-575, 1998.
10. M. Tsutsumi, D. Holdsworth, T. Nakamura, and I. Reid. Meteor observations with an MF radar. *Earth Planets Space*, Vol. 51, pp. 691-699, 1999.
11. A. Mallama and F. Espenak. Automated Meteor Detection and the Leonid Shower. *Publications of the Astronomical Society of the Pacific*, Vol. 111, pp. 359-363, March 1999.
12. D. D. Meisel and J. E. Richardson. Statistical properties of meteors from a simple, passive forward scatter system. *Planetary and Space Science*, Vol. 47, pp. 107-124, 1999.
13. S. Close, S. M. Hunt, M. J. Minardi, and F. M. McKeen. Meteor Shower Characterization at Kwajalein Missile Range. *Lincoln Laboratory Journal*, Vol. 12, No. 1, pp. 33-44, 2000.
14. J. D. Mathews, J. Doherty, C.-H. Wen, S. J. Briczinski, D. Janches, and D. D. Meisel. An update on UHF radar meteor observations and associated signal processing techniques at Arecibo Observatory. *Journal of Atmospheric and Solar-Terrestrial Physics*, Vol. 65, pp. 1139-1149, 2003.
15. N. Murray, J. C. Weingartner, and C. Capobianco. On the flux of extrasolar dust in Earth's atmosphere. *The Astrophysical Journal*, vol 600, pp. 804-827, 10 January 2004.
16. N. Brosch, D. Polishook, R. Helled, S. Schijvarg, and M. Rosenkrantz. Radar and optical leonids. *Atmospheric Chemistry and Physics*, Vol. 4, pp. 1063-1069, 2004.
17. C.-H. Wen, J. F. Doherty, and J. D. Mathews. Time-Frequency Radar Processing for Meteor Detection. *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 42, No. 3, March 2004.
18. K. Tapping. Radio Observations of Meteors: the 2004 Perseid Meteor Shower Etc.

<http://www.ukaranet.org.uk/projects>.

19. J. D. Mathews. Radio science issues surrounding HF/VHF/UHF radar meteor studies. *Journal of Atmospheric and Solar-Terrestrial Physics*, Vol. 66, pp. 285-299, 2004.
20. C.-H. Wen, J. F. Doherty, J. D. Mathews, D. Janches. Meteor detection and non-periodic bursty interference removal for Arecibo data. *Journal of Atmospheric and Solar-Terrestrial Physics*, Vol. 67, pp. 275-281, 2005.
21. C.-H. Wen. Time-Frequency Signal Processing Techniques for Radar Remote Sensing. Ph.D. thesis, Department of Electrical Engineering, The Graduate School, Pennsylvania State University, May 2005.

#### Meteors in Communications

1. V. R. Eshleman, L. A. Manning, A. M. Peterson, and O. G. Villard, Jr. The role of meteors in extended-range VHF propagation. *IRE International Convention Record*, Vol. 3, pp. 61-62, March 1955.
2. G. R. Sugar. Radio propagation by reflection from meteor trails. *Proceedings of the IEEE*, Vol. 52, No. 2, pp. 116-136, February 1964.
3. J. Oetting. An analysis of meteor burst communications for military applications. *IEEE Transactions on Communications*, Vol. 28, No. 9, part 1, pp. 1591-1601, September 1980.
4. J. Weitzen; W. Birkemeier; M. Grossi. An estimate of the capacity of the meteor burst channel. *IEEE Transactions on Communications*, Vol. 32, No. 8, pp. 972-974, August 1984.
5. K. Kokjer; T. Roberts. Networked meteor-burst data communications. *IEEE Communications Magazine*, Vol. 24, No. 11, pp. 23-29, November 1986.
6. J. Weitzen. Communicating via meteor burst at short ranges. *IEEE Transactions on Communications*, Vol. 35, No. 11, pp. 1217-1221, November 1987.
7. J. Weitzen; W. T. Ralston. Meteor Scatter: an overview. *IEEE Transactions on Antennas and Propagation*, Vol. 36, No. 12, pp. 1813-1819, December 1988.
8. J. Weitzen. A comparison of the performance of several antenna configurations for short and long range meteor scatter communication. Conference record. *IEEE International Conference on Communications*, 11-14 June 1989, Vol. 2, pp. 1110-1114.
9. J. P. Jernovics Sr. Meteor Burst Communications: An Additional Means of Long-Haul Communications. <http://www.globalsecurity.org/space/library/report/1990/JJP.htm>.
10. D. Yavuz. Meteor Burst Communications. *IEEE Communications Magazine*, pp. 40-48, September 1990.
11. J. Weitzen; S. Bourque; M. Horton; P. M. Bench; A. D. Baily; J. C. Ostergaard. Distributions of underdense meteor trail amplitudes and application to meteor scatter communication system design. Conference Proceedings of the Ninth Annual International Phoenix Conference on Computers and Communications, pp. 237-240, 21-23 March 1990.
12. J. Weitzen. A study of the ground illumination footprint of meteor scatter communication. *IEEE Transactions on Communications*, Vol. 38, No. 4, pp. 426-430, April 1990.
13. J. Z. Schanker. Meteor Burst Communications. Boston: Artech House, Inc., 1990.
14. P. A. Handley and D. D. Fraser. Meteor-Burst Communications for Rural Environments. *AFRICON'92 Proceedings*, pp. 378-381, Institute of Electrical and Electronics Engineers, 1992.
15. J. Weitzen. Performance of short- and long-range meteor burst communication systems with different antennas. *IEEE Journal on Selected Areas in Communications*, Vol. 10, No. 3, pp. 491-496, April 1992.
16. R. S. Mawrey; J. D. Larsen; J. Weitzen. Meteor burst system design using an advanced computer-based prediction model. Conference record. *Military Communications Conference, MILCOM'93*, 11-14 October 1993, Vol. 2, pp. 397-401.

17.R. S. Mawrey; J. Weitzen. Measured performance of meteor burst systems using antenna beam steering. IEEE Transactions on Communications, Vol. 43, No. 2/3/4, pp. 1467-1476, February/March/April 1995.

#### Physics of Meteor Detection, and its Flight in the Atmosphere

1. V. R. Eshleman. The Effect of Radar Wavelength on Meteor Echo Rate. IRE Transactions on Antennas and Propagation, pp. 37-42, October 1953.
2. E. J. Öpik, Physics of Meteor Flight in the Atmosphere. Interscience Publishers, Inc., New York, 1958.
3. A. C. B. Lovell. 1962 Guthrie Lecture: The Physical Basis of the Research Programmes at Jodrell Bank. Proc. Phys. Soc., Vol. 81, pp. 385-411, 1963.
4. W. G. Elford. The Influence of the Atmosphere on Radar Meteor Rates. In: Solid Particles in the Solar System, I. Halliday and B. A. McIntosh (editors), International Astronomical Union, pp. 101-104, 1980.
5. K. A. Hill, L. A. Rogers, and R. L. Hawkes. High geocentric velocity meteor ablation. A&A preprint doi <http://dx.doi.org/10.1051/20053053>.

#### Construction of Radio Detectors

1. R. Roy and K. Tapping. A Brief History of the Indian River Observatory Radio Interferometer. Journal of the Royal Astronomical Society of Canada, Vol. 84, No. 4, pp. 260-274, August 1990.
2. T. Roelandts and W. Depoorter. Presentation of the RAMSES Automated Forward Scatter System. Proceedings of the International Meteor Conference, Puimichel 1993, edited by Paul Roggemans, International Meteor Organization, pp. 44-46, 1993.
3. J. Richardson and D. D. Meisel (compilers and reviewers). The American Meteor Society Radiometeor Project. AMS Bulletin No. 203. December 1996.

Jorge A. Romero  
December 9, 2005.