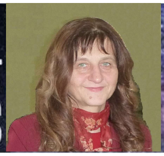


Kharkiv
Ukraine

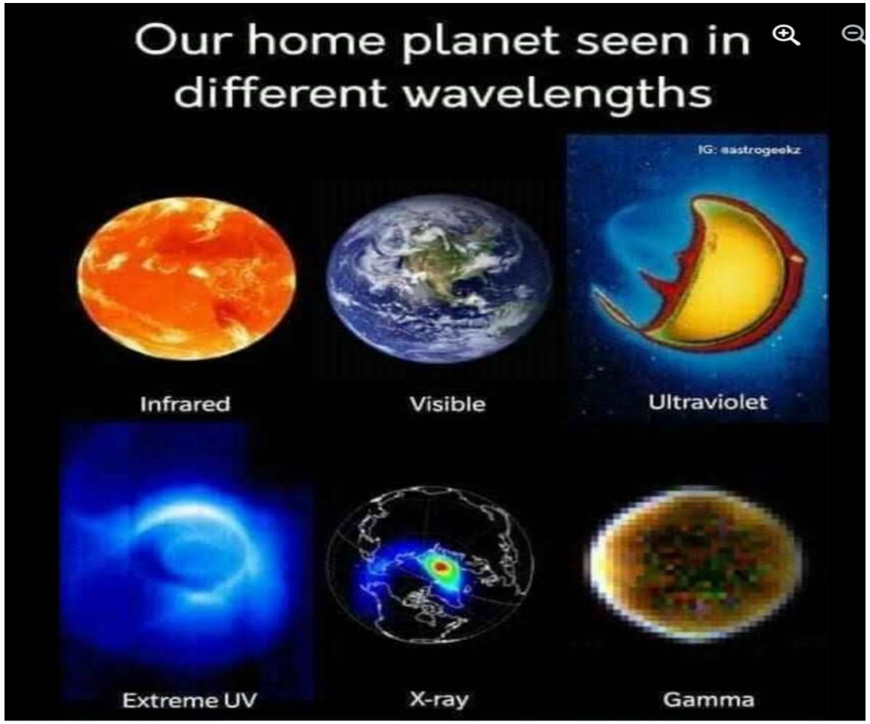
Meteor Radio Technology

Svitlana Kolomiyets

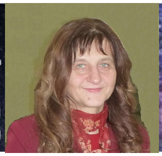
Kharkiv National University of Radio Electronics (NURE)

BL Kashcheyev Radio Astronomy Research Laboratory

How the Earth is visible at different wavelengths from Space.



The rotating Earth in the radio range looks like this: powerful radiation from Japan, then from China, then silence for a long time, and then all European countries glow in the radio beams. Then again a long time of silence, as the Atlantic Ocean goes, and again a powerful glow: the USA and Mexico.



Svitlana Kolomiyets

METEOR RADIO TECHNOLOGY

Objectives

- **The purpose** of the report is to present the features of meteor radio technologies in meteor science, astronomy, radio astronomy and some other areas. As well as discussion of the possible impact of meteor radio technologies on dark and quiet skies for science and society. The **object of research** of meteor radio technologies is the meteoroid, the meteor trail and radio waves. **Subject of research** - scattered or reflected signal and its characteristics

Fig.1

Jordan Ragsdale caught this bright fireball using an AllSky Camera System (https://www.allskycams.com/). This fireball occurred at 00:20 MDT (06:20 UT) on 12 August 2021, from Eagle, Idaho, USA ©Jordan Ragsdale

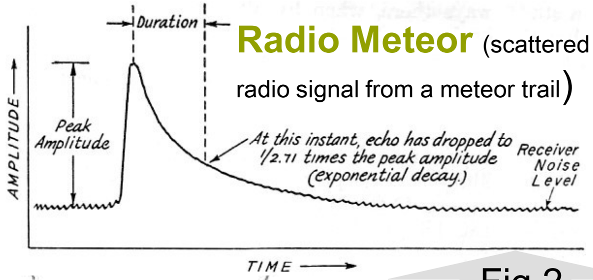


Fig.2

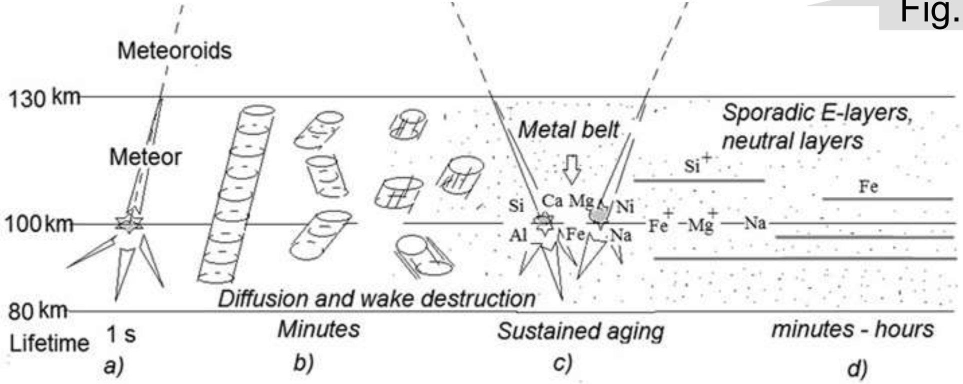
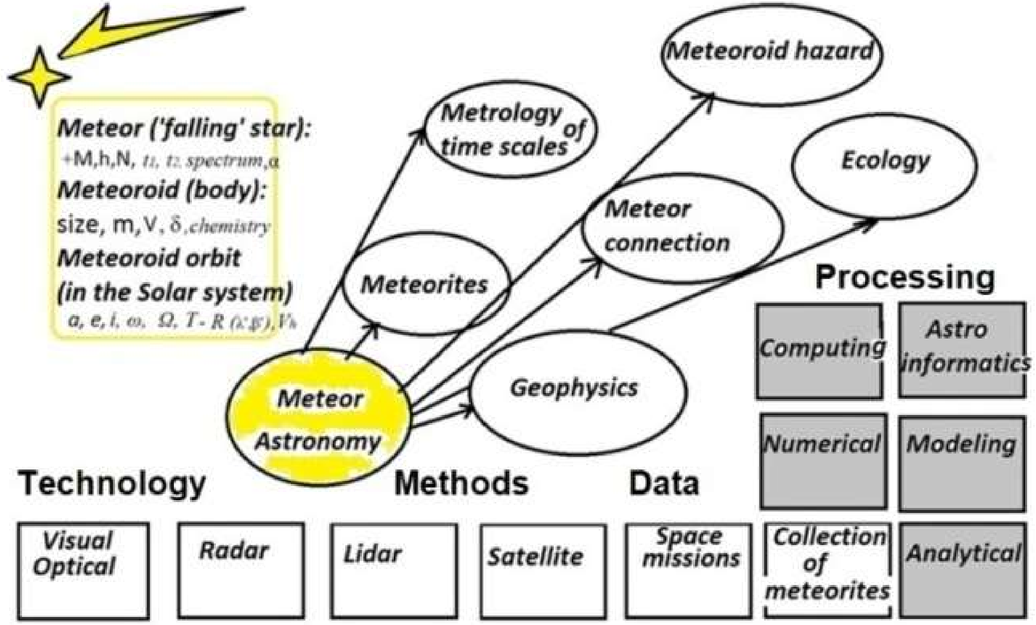


Fig.3

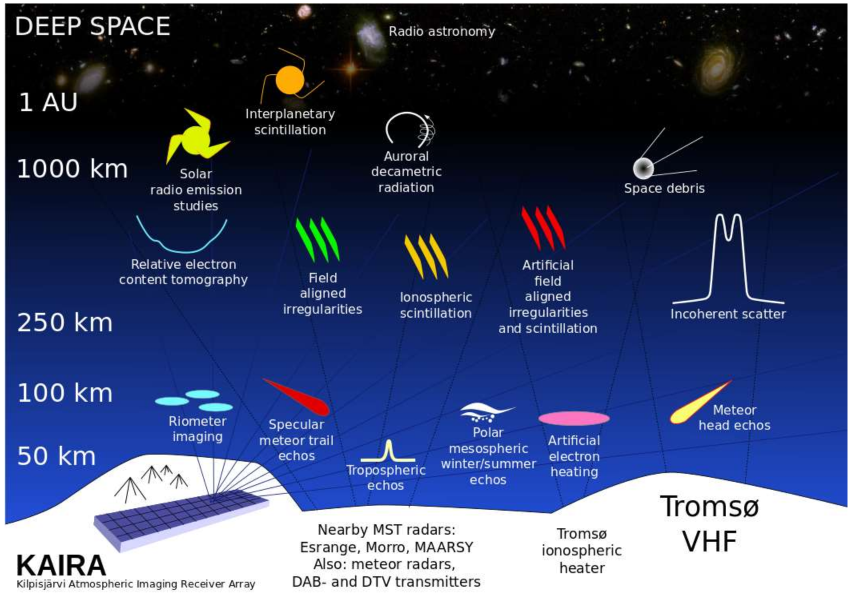
CREDIT: Fig.1,2,3

Meteor Radar Data

- **Primary**
  Signals, time series;
- **Secondary**
  2) Number of meteors, time series; 3) Velocities, coordinates of an radiant, elements of an orbit, time series;
- **Data processing**
  4)Distributions parameters (histograms and more);
- **Models**;
- **Forecast**



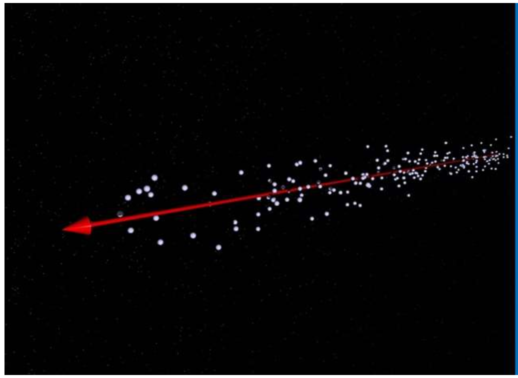
Radio Astronomy & Meteor Radio Astronomy

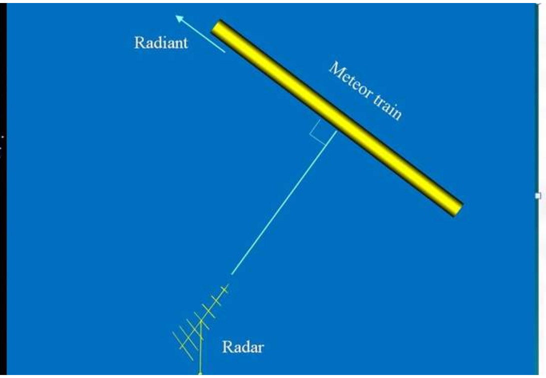


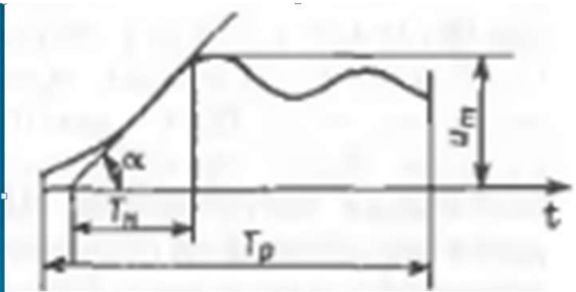
Meteors are usually observed in the optical range, with a range of visual vision (380 ÷750 nm). Meteors occur as a result of the invasion of the Earth's atmosphere by meteoroids from space. A meteoroid is a rock or particle with a limiting size of 30 mn to one meter in diameter. The meteoroid's own radio emission is very small and will not be considered in this report. When the meteors appears, the density of electrons in atmosphere increase and the radio wave of high frequency reflects. The total range of radio waves have frequencies *f* as high as 300 GHz to as low as 30 Hz (λ :10 mm÷10,000 km, $f=c/\lambda$). Radio meteor technologies use a small fraction of the frequencies of this common range. At the same time, **an active source of radio emission is required to carry out meteor measurements.**

Fig. 6 Example of the Radio Sky at the junction of possibilities KAIRA (Kilpisjärvi Atmospheric Imaging Receiver Array / LBA system operates from approximately 20 to 80 MHz, since 2012) & others. CREDIT [13

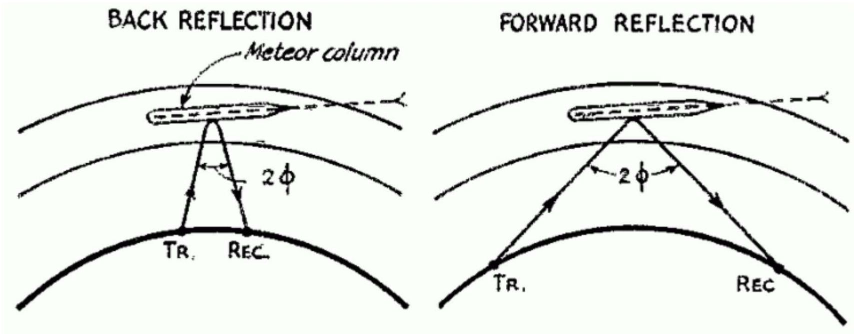
In the radar method of observing meteors, information messages are formed as a result of the interaction of a meteor body with the Earth's atmosphere and the reflection of radio waves from the resulting meteor trail (**Figs. below**).



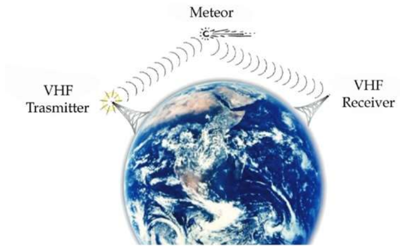




Meteor echo - reflected signal,
Amplitude-Time Characteristic



Radio meteor ground-based sounding (Fig.) of the atmosphere at frequencies of 20-75 MHz is associated with the state and dynamics of the Earth's atmosphere at altitudes of 70 - 130 km, the influx of meteor substance into the Earth's atmosphere and its distribution in the interplanetary space of the Solar System. Information is obtained using electromagnetic waves emitted by the transmitter and recorded by the receiver by reflecting radio echoes from meteor trails.



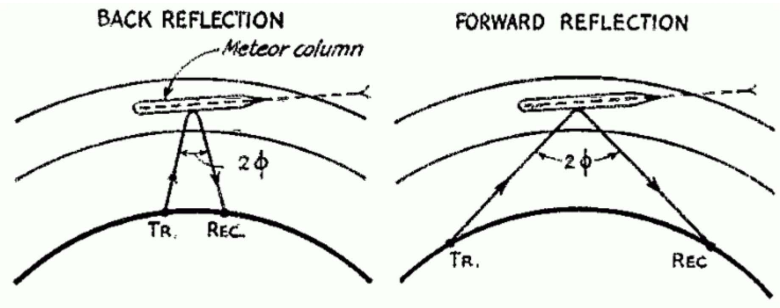


Fig. Illustrating backward and forward reflection (or "scattering") from a meteor trail [14], which may be **underdense**, over-dense, intermediate

Forward scattering of VHF radio waves by the meteor ionized trails incorporates unique characteristics for usage in various applications. The oblique incidence of radio signals off the meteor trails enables the detection of faint meteors using low power transmitters. Currently, it is widely used in amateur observations, including for the organization of observation radio networks [http://www.rmob.org/index.php]. It is professionally used in meteor communications and in metrology of time and frequency scales. There are forecasts for a great future in professional astronomical research too. VHF (65-73MHz); FM (88-108 MHZ)

backward reflection
(activity and radio echo ATC, speed, radiant, orbit)

- own transmitter of signals
- main receiver and transmitter are combined, additional remote points are separated by ~ 3-5 km
- satisfactory theory of radio echo (classic theory)
- specular reflections
- the limiting heights of meteor occurrence are ~ 105 km
- the sensitivity is up to +13^ M)
- classical implementation and reliable interpretation
- frequency ~30 MHz (λ: 4-10 m)

forward scattering
(activity and radio echo ATC, speed?)

- TV or FM station signals
- receiver and transmitter are separated by ~ 1500-2000 km
- corrected radio echo theory based on backward reflection
- scattering geometry-ellipsoidal
- the limiting heights of meteor occurrence are about 7 km higher
- the sensitivity is higher (theoretically up to +15^ M)
- technically difficult to implement and interpretation
- broadcast station frequencies > 30 MHz e.g. 88.2, 94.8 MHz

Radioecho theory / underdense meteors

During radar observations, the electromagnetic energy of the transmitter of the radar station, reflected or scattered by the electrons of the trail, is recorded. The maximum signal power back reflected from an underdense meteor trail is described by the expression Pmax.

$$P_{\max} = \frac{P_t G_t G_r \lambda^3 \alpha^2}{32\pi^2 R^3}\left(\frac{e^2}{mc^2}\right)\left(e^{-\frac{4\pi^2 r_0^2}{\lambda^2}}\right)^2 (\varphi(\Delta))^2$$

where P_t - is the transmitter power (Watts), G_r, G_t are the directivity of the receiving and transmitting antennas, λ is the radar wavelength (m), α is the linear electron density, e, m are the charge and mass electron, c is the velocity of light, R is the slant distance to the trail (km), Δ is the shape factor of the amplitude-time characteristic (ATC) of the meteor trail (Kashcheyev&Lebedinets 1961).

$$P_r = \frac{P_t G_t G_r \lambda^3 \alpha^2}{32\pi^2 R^3}\left(\frac{e^2}{mc^2}\right)^2\Bigg|_{x_0=\infty,\ r_0=0,\ \Delta=0}$$

$$I = \frac{1}{\sqrt{2}}\int_{-\infty}^{x_0} e^{i\frac{\pi}{2}x^2} e^{-\Delta(x_0-x)}dx = 1$$

$$R \approx R_0 + s^2/2R_0$$

r_0 - starting radius of the trail;
x_0 - normalized coordinate of the head of the trail from the point of specular reflection
(Lovell &Clegg 1953)

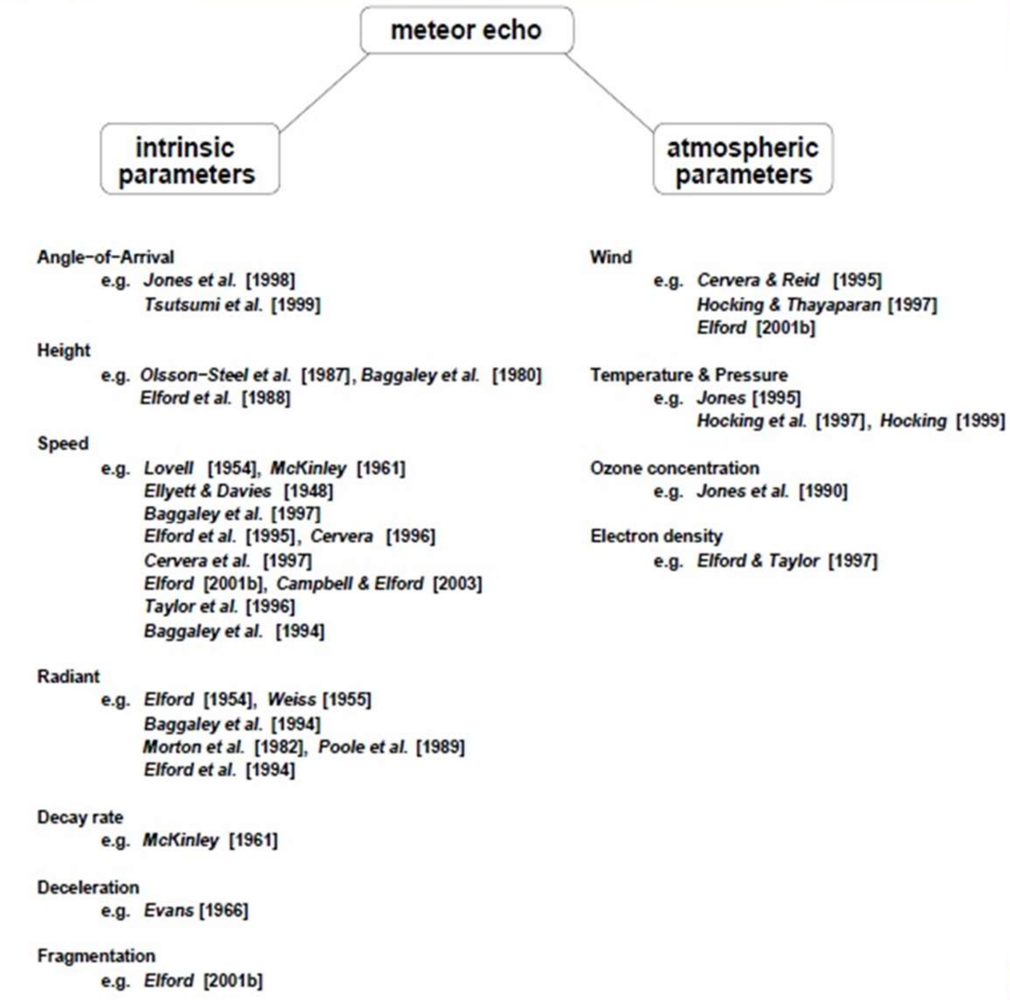
$$\Delta = \frac{8\pi^2 D\sqrt{R}}{v\lambda^{2/3}}$$

$$\varphi(\Delta) = \left(\frac{1-e^{-\sqrt{2}\Delta}}{\Delta\sqrt{2}}\right) = I_{max}$$

D - ambipolar diffusion coefficient
(Peregudov 1959)

The incident wave penetrates the meteor trail and is scattered by individual free electrons, which vibrate in the applied field without colliding with other particles. Each electron behaves as if there are no other electrons nearby. An **underdense meteor trail:**

$\alpha \ll \alpha$critical ~ 10^12 el/ cm

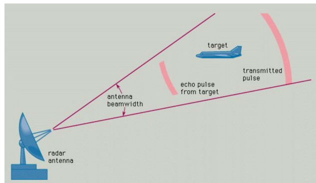


Possible characteristics obtained from meteor radio echoes, divided into intrinsic (angle of arrival, altitude, velocity, radiant coordinates, destruction rate, deceleration) and atmospheric (wind, temperature and pressure, ozone concentration, electron density) with using (Galligan 2000):

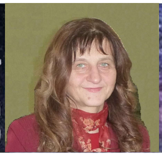
- Radio echo - a radio signal that is a reflection of the sent (or reached the target) radio signal.
- The transmission of information is carried out with the help of a signal.
- A signal is a physical process that displays a message.
- The message is the form of presentation of information (text, speech, images, digital data).
- The signal can be transmitted over a distance in the form of some disturbance of the medium (electrical, light, acoustic, etc.)

Conflict of interests: careful terms ‘radar’&’radio telescope’

- Today radar astronomy is a technique of observing nearby astronomical objects by reflecting microwaves off target objects and analyzing the reflections.
- **Radar** (Radio Detection and Ranging) is a detection system that uses radio waves to determine the distance (range), angle, or velocity of objects.
- Radio telescope is a specialized antenna and radio receiver used to detect radio waves from astronomical radio sources in the sky. Radar astronomy differs from radio astronomy in that the latter is a passive observation and the former an active one.
- With the use of radio technology in meteor research (we mean radar technology), we operate with meteor radio information. We will talk about a radar method based on the property of a meteor trail to scatter radio waves. **The next slide (13) demonstrates the features of radio meteor information.**



Extensive flow of information e.g. 3-4 thousand reflected signals per hour (Fedynsky et al. 1976)	The random nature of the phenomena and the inability to reproduce (reobserve) the same event	Distortion due to high selectivity
Result of the interaction of meteor substance ionosphere and electromagnetic waves	Indirect observation The need to solve an indirect problem	The need for standardization of measuring systems and measurement methods
Statistical parameters (abudance/activity) and individual mesuarements of velocities, radiants, orbits	Stochasticity of the investigated processes	Complex special processing and interpretation methods
Availability of measurements at any time of the day, any time of the year, in any weather	Information arises only in the presence of a meteor ionization trail/the degree of ionization requires different approaches	The result of reflectiom or scattering of the original radio signal from an external source
Radio meteor information is a part of all information collected by various methods	It needs for geophysics, astronomy, radio connection, time and frequency metrology etc.	Its development connected with global international projects IGY -1957 etc. + GLOBMETS-80s



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METEOR RADIO TECHNOLOGY

Background (the first)

In XX age radio technologies have made the same revolution in science as Galileo's telescope in 1609

- Oct 4, 1957: Open space era
- IGY1957: Global International Geophysical Year1957 project
- 1954: B. Lovell* proposed the meteor radar research program for the IGY1957
- 1954: B.Kashcheyev**&team registered the first radio meteors in Ukraine (USSR)
- 1947: E.Appleton obtained a Nobel Prize (for his confirmation of existence of ionosphere in 1927)
- 1945: the first radio meteor observations in UK

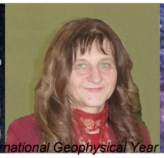
Proposed to research meteors using radar method in IGY1957

*B.Lovell (1913-2012), UK

Became the best in meteor research using radar method in IGY1957 and…

**B.Kashcheyev (1920-2004), Ukraine

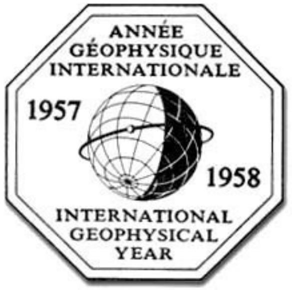
MARS: Meteor Automated Radar System

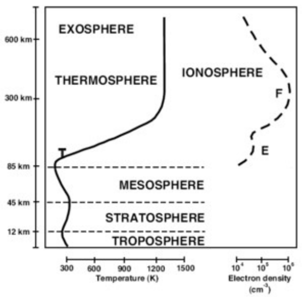


International Geophysical Year *International Heliophysical Year*

IGY: V section "Ionosphere and Meteor"

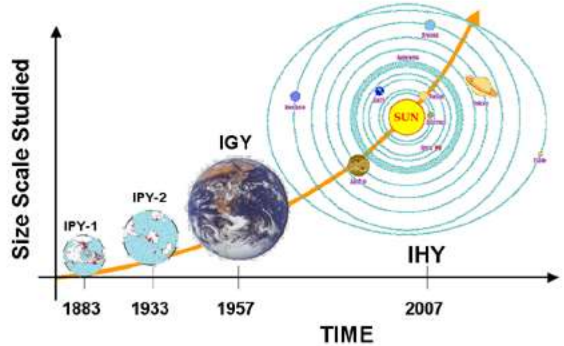
- International Geophysical Year (IGY) 1957 - worldwide program of geophysical research that was conducted from July **1957** to December 1958
- **An IGY incubator.** IGY was directed toward a systematic study of the Earth and its planetary environment. The IGY encompassed research in 11 fields of geophysics.
- ~ 70 countries-participants





IHY: Discipline " Meteors, Meteoroids, Dust"

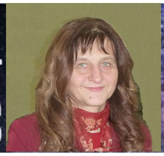
- International Heliophysical Year (IHY) 2007



An important part of the IHY2007 activities will be preserving the history and memory of IGY 1957.

IHY Supporting Organizations: SCOSTEP (Scientific Com. On Solar-Trrrestrial Physics), United Nations, IAU, AGU, NASA, ESA, IUGG, COSPAR, NCAR, AOGS, COST

N	City	φ	λ	*H* m	Scientific institutes / republics of the former USSR/Chair	Program, N igy
1	***Ashkhabad***	37 ° 56 '	58 ° 24 '	200	Astrophysical Laboratory of the Institute of Physics and Geophysics AS **Turkmen SSR** Sadykov.	**R, Ph, V** N696 (C126)
2	***Kazan***	55 ° 47 '	49° 07 '	80	Astronomical observatory named Engelgardt of Kazan University **Russian SFSR** /Kostylyov.	**R** N233
3	**Kiev**	**50 ° 27 '**	30° 30 '	185	Astronomical observatory named Shevchenko of Kiev University **Ukrainian SSR** /Bogorodskikh	**R, Ph, N320**
4	**Odessa**	**46 ° 29 '**	30° 46 '	50	Astronomical observatory named Shevchenko of Odessa University **Ukrainian SSR** /Tsesevich	**R, Ph, V N621**
5	Stalinabad ***Dushanbe***	38 ° 34 '	68° 46 '	820	Institute of Astrophysics AS **Tajik SSR** Babadzhanov.	**R, Ph, V** N680 (C115)
6	***Tomsk***	56 ° 29 '	84° 59 '	120	Tomsk Polytechnical Institute **Russian SFSR** Fialko.	**R** N224
7	**Kharkiv**	50 ° 00 '	36° 14 '	140	Kharkiv Polytechnical Institute (***faculty of Radioengineering)*** Ukrainian SSR(Ukraine) / **Kashcheyev**	**R, N358 (B141)**



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METEOR RADIO TECHNOLOGY

Commission 22 of the International Astronomical Union supervised the implementation of the IGY meteor program

- Meteors have appeared extremely important in numerous aspects for the IGY 1957/9 taking into account the incoming space era and revolutionary implementation of radar methods in scientific researches along with increased interest in the ionosphere
- For the successful implementation of the program for radar studies of meteors in Kharkiv in 1957, B.L. Kashcheev was nominated in 2007 by the organizers of the International Heliophysical Year 2007 project. It was a certificate and badge "Gold MGY1957".

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Kharkiv RadioMeteors (1954-…)

- Meteor automated system (MARS) with a powerful (1 MW) meteor transmitter. Operating frequency 31.1 MHz.
- **The number and characteristics of meteor radio reflections, radiants of meteor bodies, as well as to study the dynamic parameters of the Earth's atmosphere in the meteor region, the study of tides and gravitational waves etc.**
- Complex for passive location of meteor tracks, frequency 48 MHz (TV channel).
- WETA-complex / Wind Machine, 36.9 MHz

Multipurpose Geophysical Complex for Research of the Atmosphere and Inflow of Meteor Substance include meteor radar MARS (1957… has gained the status of the National Scientific Heritage of Ukraine since 2004.

Vilhuvatka village, Balakliya district, Kharkiv region
(~ 90 km from Kharkiv)

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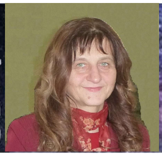
Kharkiv Radio Meteors

- BL Kashcheyev Radio Astronomy Research Laboratory (1958/2007-…)

Kharkiv Ukraine

Was held IV International Conference – Seminar, **Kashcheyev Seminar 2021**, 30 – 31 March, Kharkiv, Ukraine "METEORS AND CELESTIAL OBJECTS, WEATHER AND SPACE: FROM DATA AND TECHNOLOGY TO HERITAGE AND DEVELOPMENT"

Kharkiv



Svitlana Kolomiyets **METEOR RADIO TECHNOLOGY**

Historical and scientific significance&Why Kharkiv?

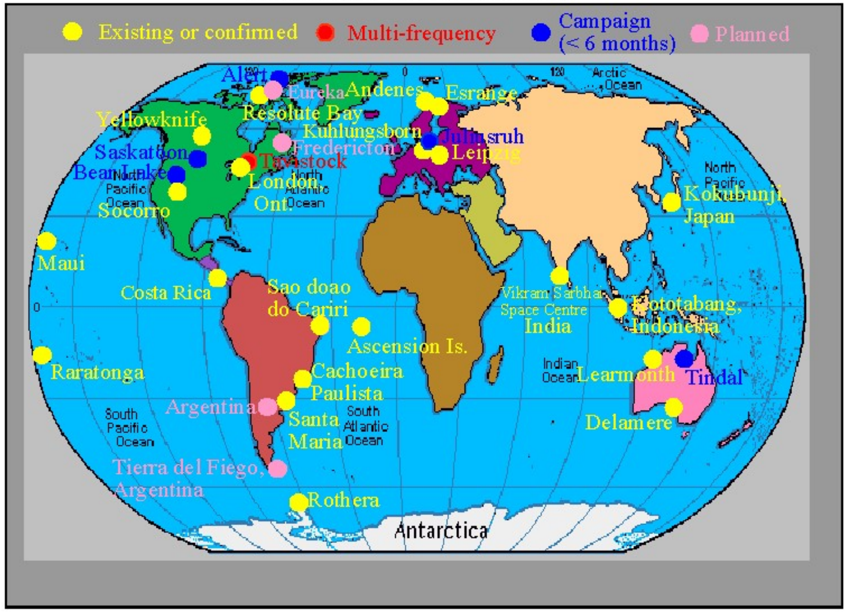
- Kharkiv meteor radar system (MARS, Ukraine) has acquired the status of the important historical astronomical instrument in world history.
- Meteor Centre for researching meteors in Kharkiv is a analogue of the observatory and performs the same functions of a generator and a battery of special knowledge and skills (the world-famous studio).
- Kharkiv and the location of the instrument were brand points on the globe, as the place where the world-class meteor radar studies were carried out.
- Kharkiv meteor radar research went down in the history of world meteor astronomy

Periods (KhPI/ NURE)[1]	Meteor radar systems	Some Global International Projects etc.	Some dissertations, catalogs etc.	Registered meteor orbits (N)
1954	Registration of the first radiometeors in Ukraine			
1954-1957	Creations of the Kharkiv meteor observed base: the Balakleya scientific and research polygon (BSRP)			
1957-1959	MRS[2]	IGY[3] 1957/9	(Kashcheyev et al., 1961)	
1967-1971	MARS I[4]		(Kashcheyev et al.,1967)	90,000*
1968-1970		Equatorial expedition	Catalog I[5,6]	5330
1971-1978	MARS II[6]		(Catalog II[8], 1980)	250,000* (5317)
1981-1991	MARS III[7]		(Voloshchuk, 1984)	
1985-		GLOBMET[8]		
1985-87		IHW[9]		
1996-2000			(Voloshchuk et al., 1996)	
2000-2007			(Voloshchuk& Gorelov,2011	5160 (showers)
2004	Kharkiv meteor observed base (KhNURE BSCP)[9] was assigned the status of the National property of Ukraine			
2007/9		IHY[10] 2007/9	(Kolomiyets, 2011)	
2007	KhNURE Kashcheyev SRL RA SRD[11] was created			
2007-2021			(Kolomiyets,Voloshchuk et.al 2015-2020)	

An approximate map of the location of meteor radars around the globe

- Currently, there are numerous specialized meteor radars operating in the world (using specular reflections and frequencies of 15-40 MHz). The SKYiMET system (astronomical and geophysical modules jointly produced by Australia-Canada) has become widely used. Operating radars with orbit detection (the most advanced in astronomy) today are CMOR (17.45, 29.85, and 38.15 MHz, The Canadian Meteor Orbit Radar, Canada) (Table right , next page) and SAAMER (32.55 MHz, The Southern Argentina Agile Meteor Radar Orbital System, Argentina, Table 1 – below, next page)

SKiYMET Meteor Radars.



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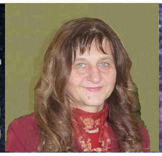
The enhanced design of the Southern Argentina Agile Meteor Radar (SAAMER) deployed at the Estacion Astronomica Rio Grande (EARG) in Tierra del Fuego, Argentina has the ability to apply different technologies on a single instrument, which adds value to scientific results.

Table 1. SAAMER System Parameters

Parameter	Value
Peak transmitted power	60 kW
Transmitting frequency	32.55 MHz
Pulse repetition frequency (PRF)	1765 Hz
Bandwidth	0.3 MHz
Pulse width	4 km
Range resolution	2 km
Pulse code	2 bit Barker

Country	Ukraine	Ukraine	Canada	New Zealand	PuertoRico
Radar name	MARS	MARS	CMOR	AMOR	Arecibo m.radar
Radar type	VHF	VHF	HF/VHF, SKiYMET	HF/VHF,	UHF, HPLA
Method	Impulse-diffraction, mirror reflect	Impulse-diffraction, mirror reflect	Impulse-diffraction, mirror reflect	Impulse-diffraction, mirror reflect	not mirror reflection
Frequency	**22. 38** MHz	**31. 1** MHz	**29. 85** MHz	**26. 2** MHz	**430** MHz
Site/city name	Kharkiv	Kharkiv	Tavistock, Ontario	Banks Peninsula	Arecibo
LAT (Site coordinate)	49˚ 24 ' 50 " N	49˚ 24 ' 50 " N	43^0.3 N	43^0.6 S	18˚ 20' 39" N
LON (Site coordinate)	36˚ 52 ΄ E	36˚ 52 ΄ E	-80˚ .8 E	172˚ .6 E	66˚ 45' 09" W
Observation period	1967-1971	1972-1978	May, 2002-till now	1995-1999	1997-1999, 2002
Registration	Amplitude/T/C	Amplitude/T/C	Amplitude/T/C	Amplitude/T/C	Head echo C
Holding	film	Paper final tape, computer	computer	computer	computer
Orbits (N)	~90 , 000	~250 , 000	>3 000 , 000	~500, 000	~120, 000
Magnitude	+8^m /+12^m	+12^m	+8^m	+8^m /+13^m	<20-100 microns



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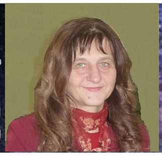
Conclusion

● 1.The informational content of the radar method is certainly maximum in comparison with other methods, including optical ones, and does not depend on light pollution or weather condition.

● 2.There are many advanced modern meteor radar instruments, e.g. SAAMER (32.5 MHZ) in Argentina , CMOR (29.85 MHz) in Canada, MAARSY (53.5 MHZ) in Norway. Also used special ones such as MU radar (46.5 MHz) in Japan, EISCAT (930 MHz) in Sweden.

● 3.There are historically and technologically significant meteor radar systems, among which there are both those that have ceased to exist, such as AMOR in New Zealand and the Harvard Meteor Project in USA, and dormant ones, such as MARS in Ukraine.



Conclusion (continuation 1)

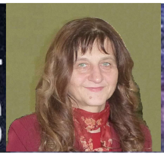
● 4. Dormant radar "MARS" was connected with frequencies 36.9; 22; 31.1 MHz. There was an experience of Equatorial expedition with using "Tropic" - 36.9 MHz

● 5. Despite the fact that in modern meteor radio technologies there is significant progress associated with new capabilities of the element base and other innovations, the MARS meteor radar has a number of undoubted advantages: first, it represents the stages of technology development based on its own experience; secondly, it still remains one of the most highly sensitive meteor radars, having the technology for registering meteors up to +12 magnitude. We can say that iron rusts, but technology continues to live.

Conclusion (continuation 3)

● 6. Meteor observation with the forward scatter method (2; 20-75; 40-50; 150; 500 MHz) provides an alternative inspiration for low-cost study of meteors (careful application). Work in this direction is welcome, although there are difficulties.

● 7. With a view to preserving the unique heritage and in the interests of the development of science it is important to recommend the creation in Ukraine in Kharkiv on the basis of the Kharkiv University of Radio Electronics with its existing structures: a laboratory, a suburban observational base and some other structures, a modern international center of meteor radio technologies for collective use with special targeted funding of the laboratory and the organization of installation on a suburban base of a modern SKYiMET radar.



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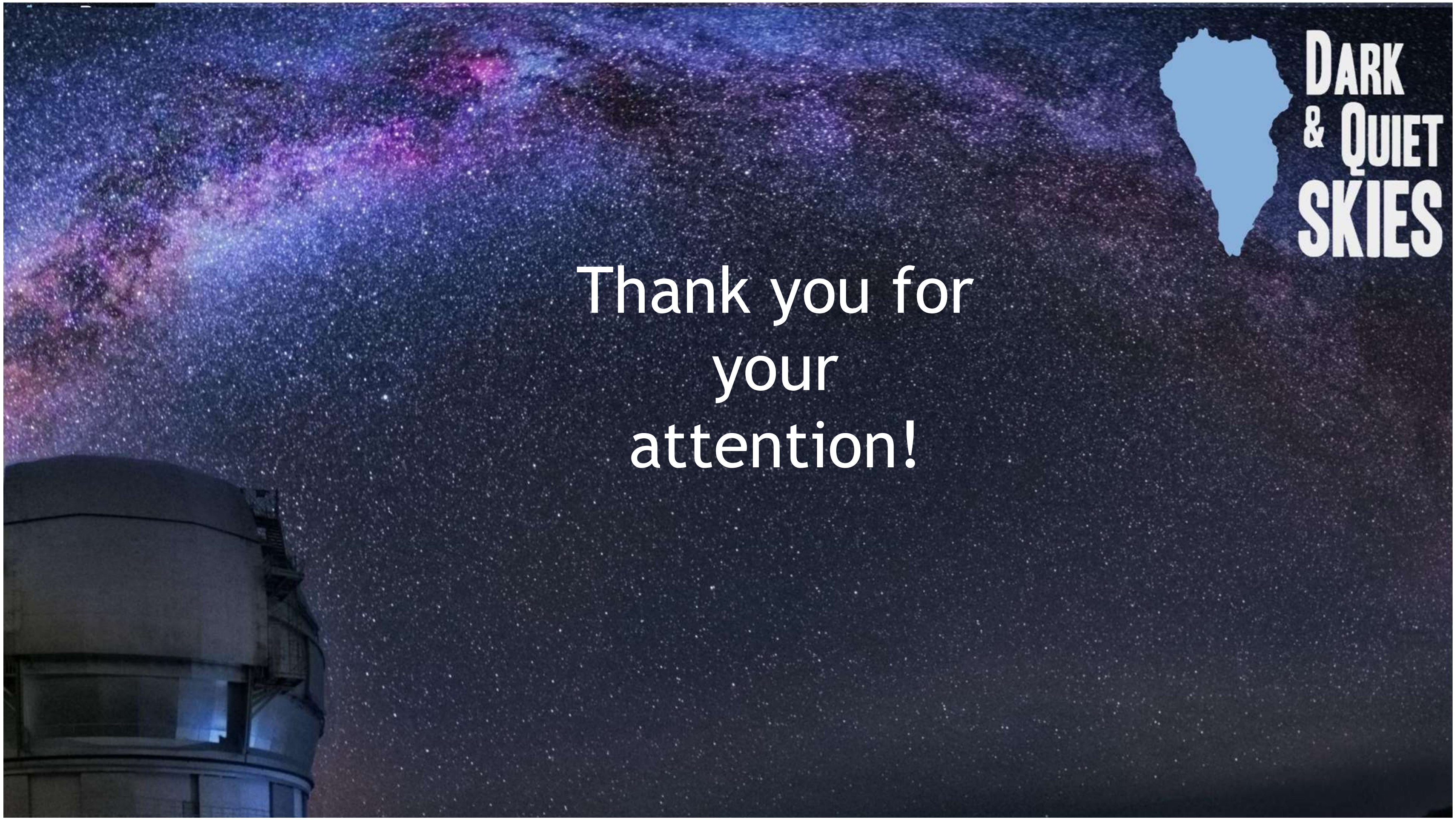
Conclusion (the ending)

● 8. From the point of view of frequency range pollution, professional meteor radar systems (for whose operating frequencies permission is always required) will not add much to the overall tangle of radio frequency interference for other reasons. The scientific benefits of the use of such radars give them the right to exist, as they are an irreplaceable research tool.

●9. Based on the foregoing, especially clause 8 of the Conclusion, accounting, monitoring and forecasting the real radio meteor situation remains a priority.

●10. Theoretical work and intellectual analysis is a necessary part of research.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& QUIET
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Thank you for your attention!