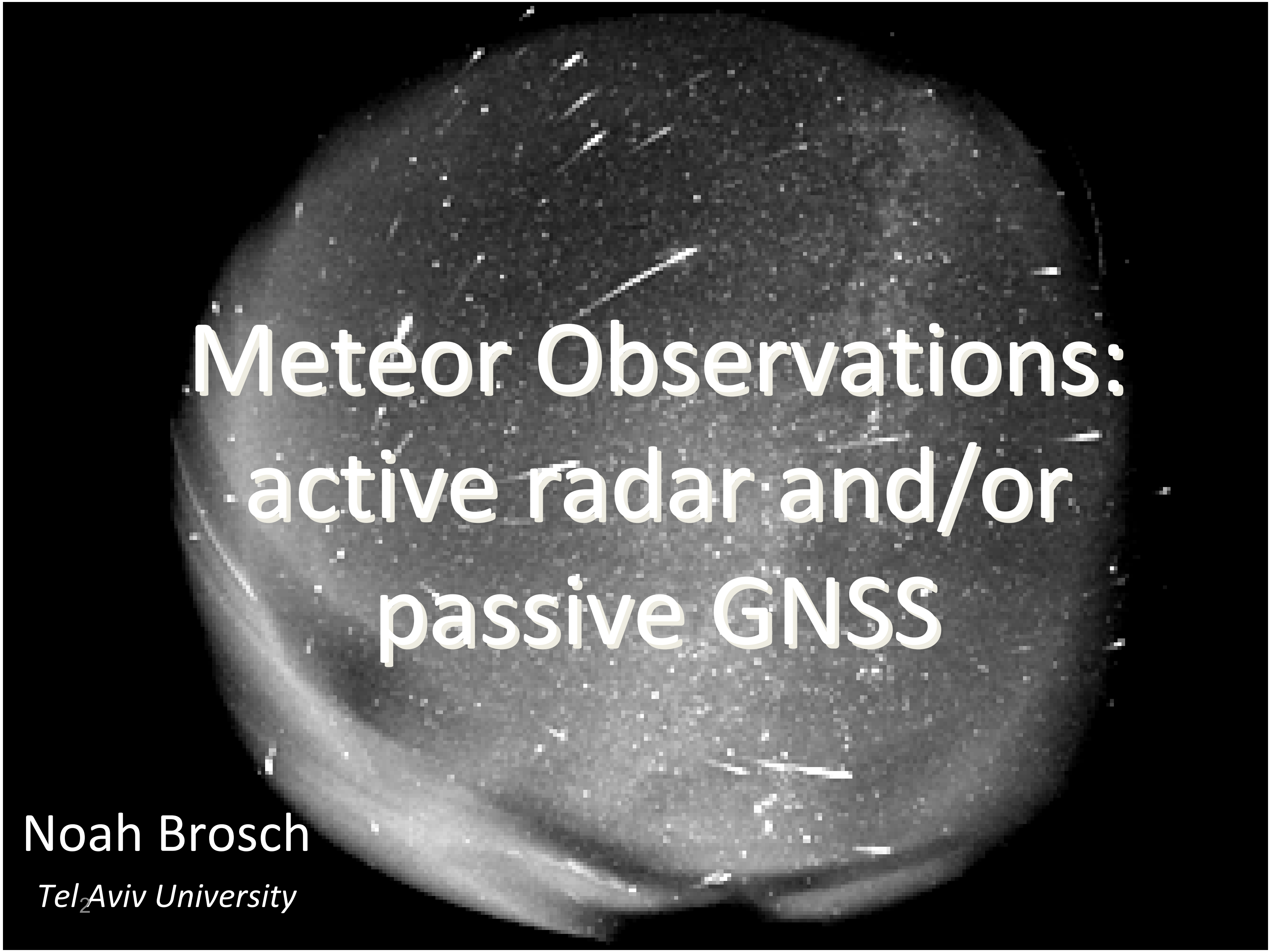
# GeoSpace: what is missing?



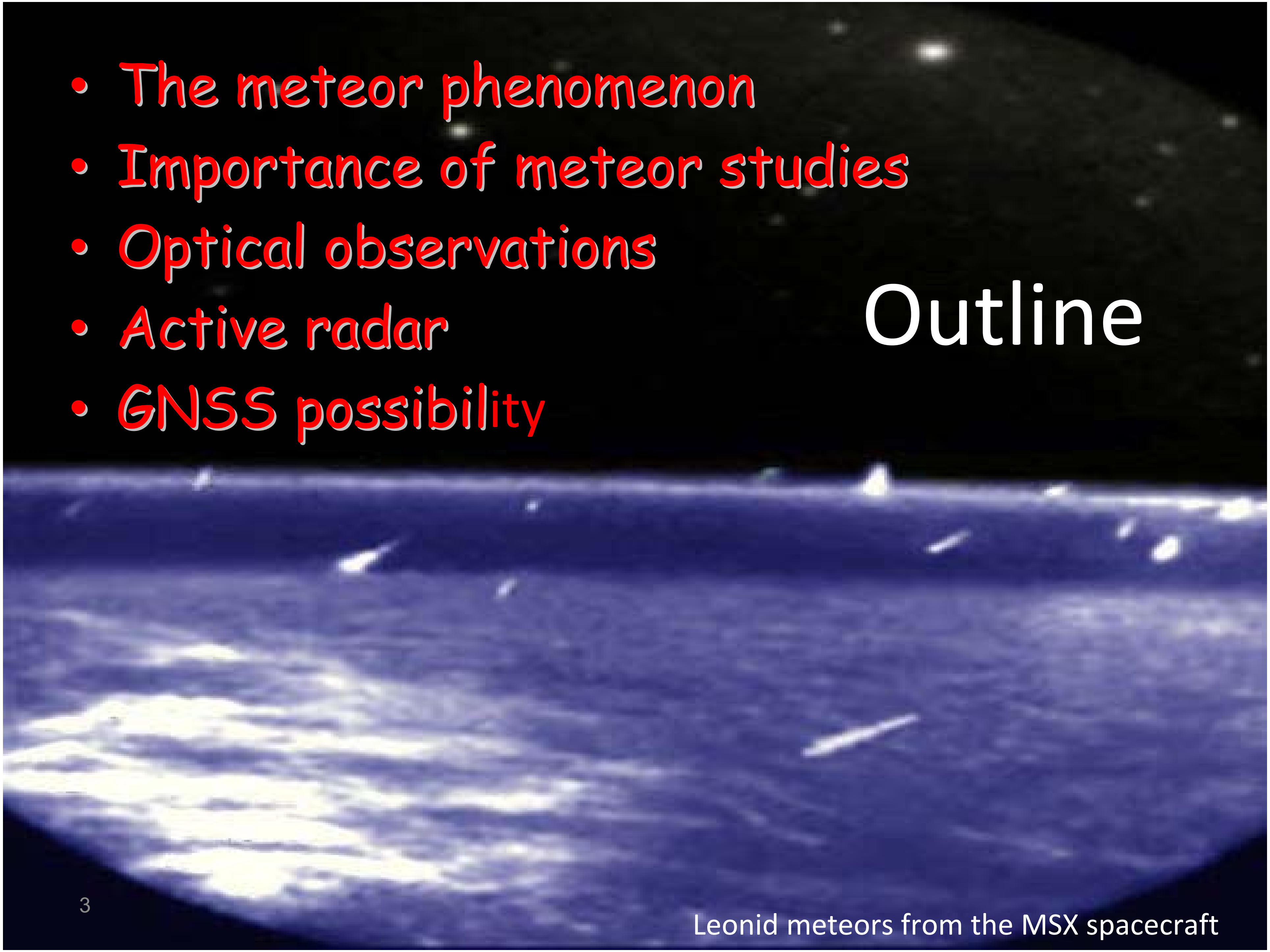
# Meteor Observations: active radar and/or passive GNSS

Noah Brosch

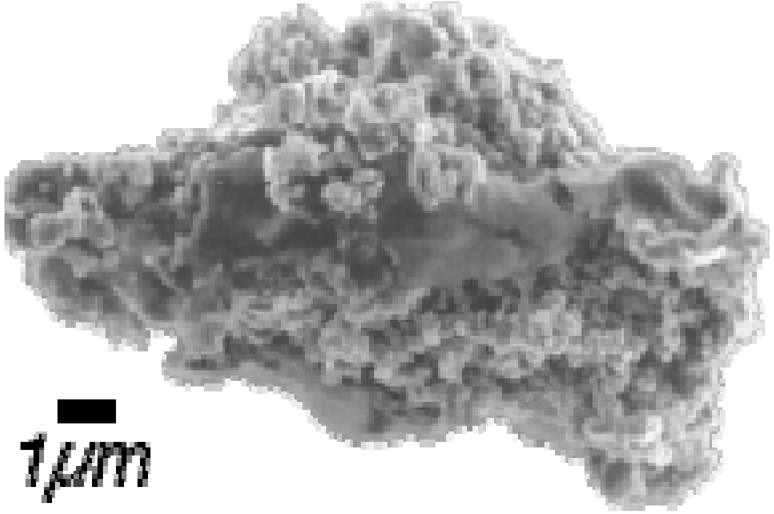
*Tel Aviv University*

# Outline

- The meteor phenomenon
- Importance of meteor studies
- Optical observations
- Active radar
- GNSS possibility



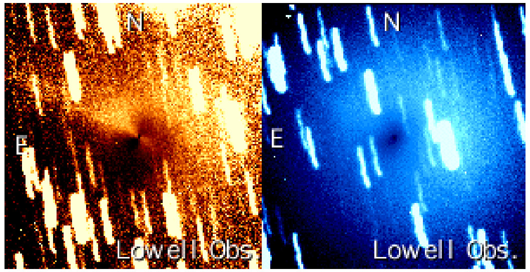
Leonid meteors from the MSX spacecraft

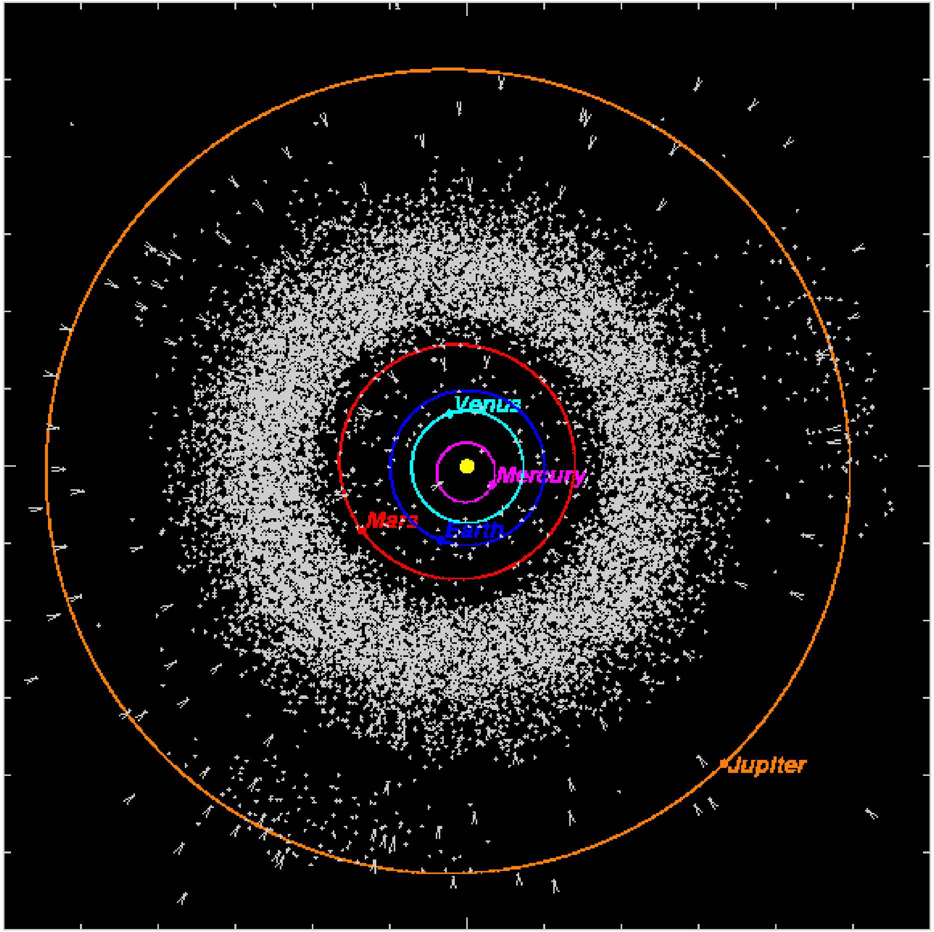



# Meteors, meteoroids & meteorites

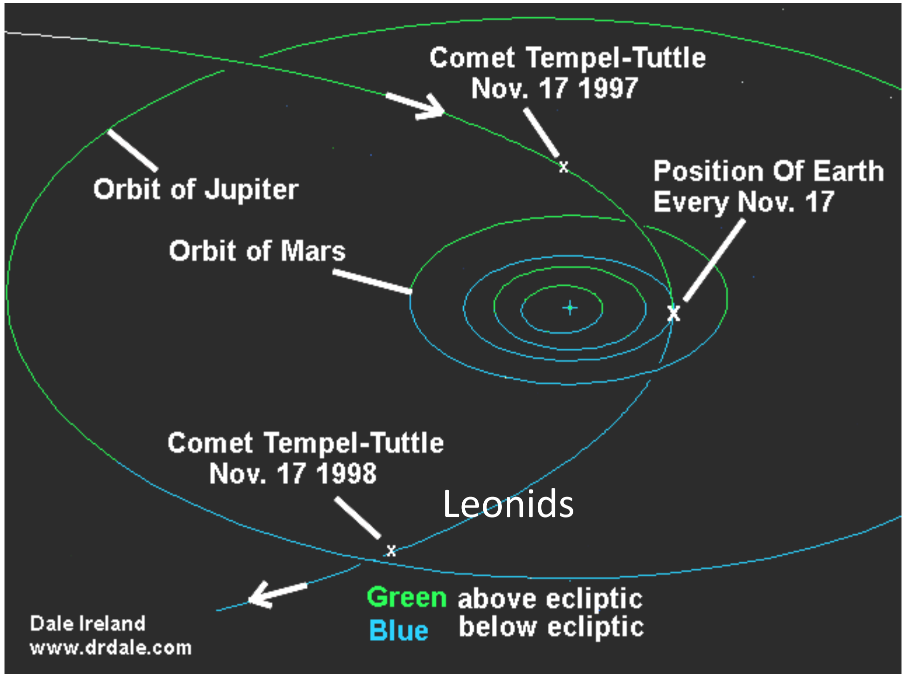
# Meteor sources: interplanetary space

(remnants of Solar System formation)

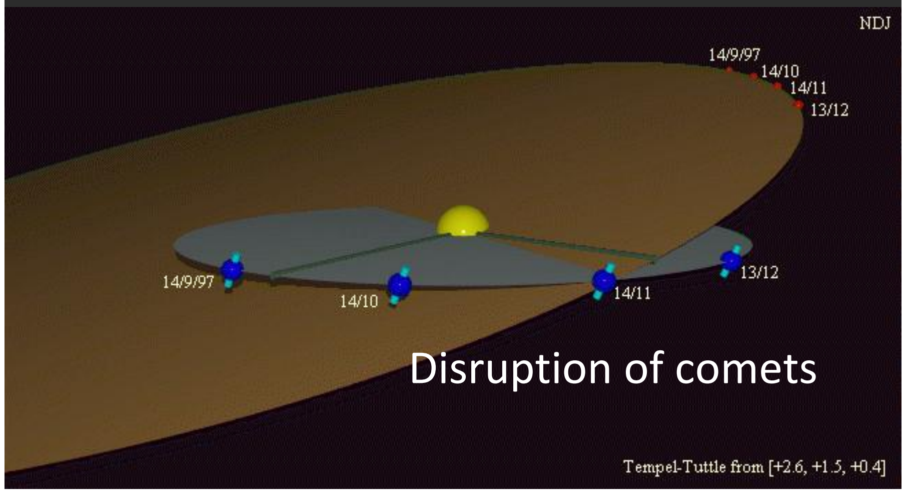



Grinding of asteroids




Leonids




Disruption of comets

# Meteor sources: Interstellar?

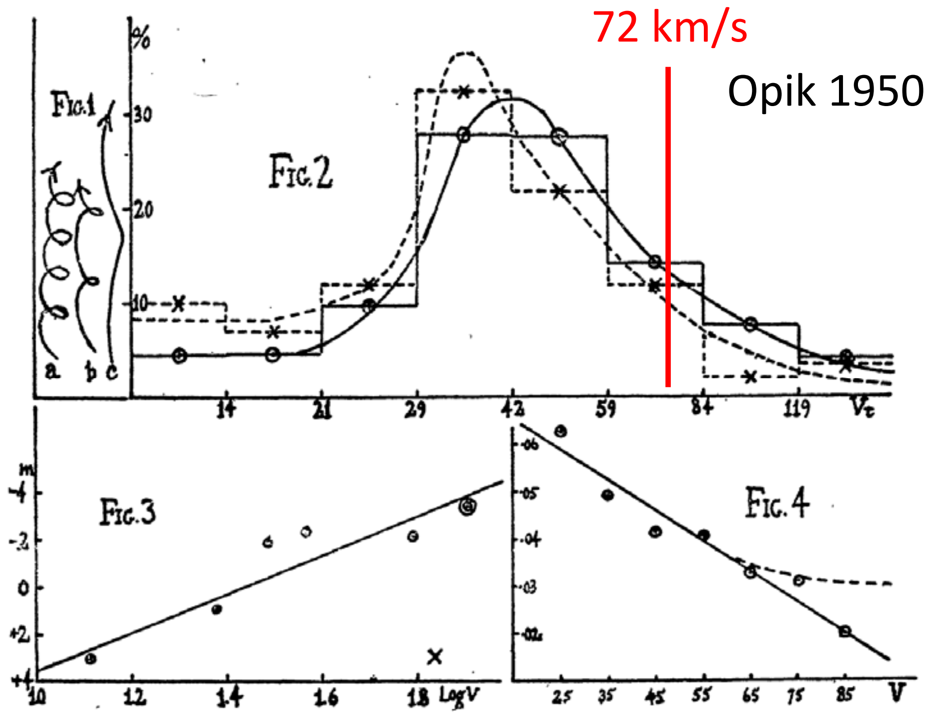



Fig. 1. Cycloid meteor trails at the Rocking Mirror.

Dust at hyperbolic velocities observed by AMOR and by spacecraft dust detectors

**If IS, pieces of other stars!**

"On July 28, 2006 the 6-m telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences recorded the spectrum of a faint meteor. We confidently identify the lines of FeI and MgI, OI, NI and molecular-nitrogen ($N_2$) bands. The entry velocity of the meteor body into the Earth's atmosphere estimated from radial velocity is equal to 300 km/s." [Afanasiev et al. 2007 Astrophysical Bulletin, 62(4), pp.301-310 ]

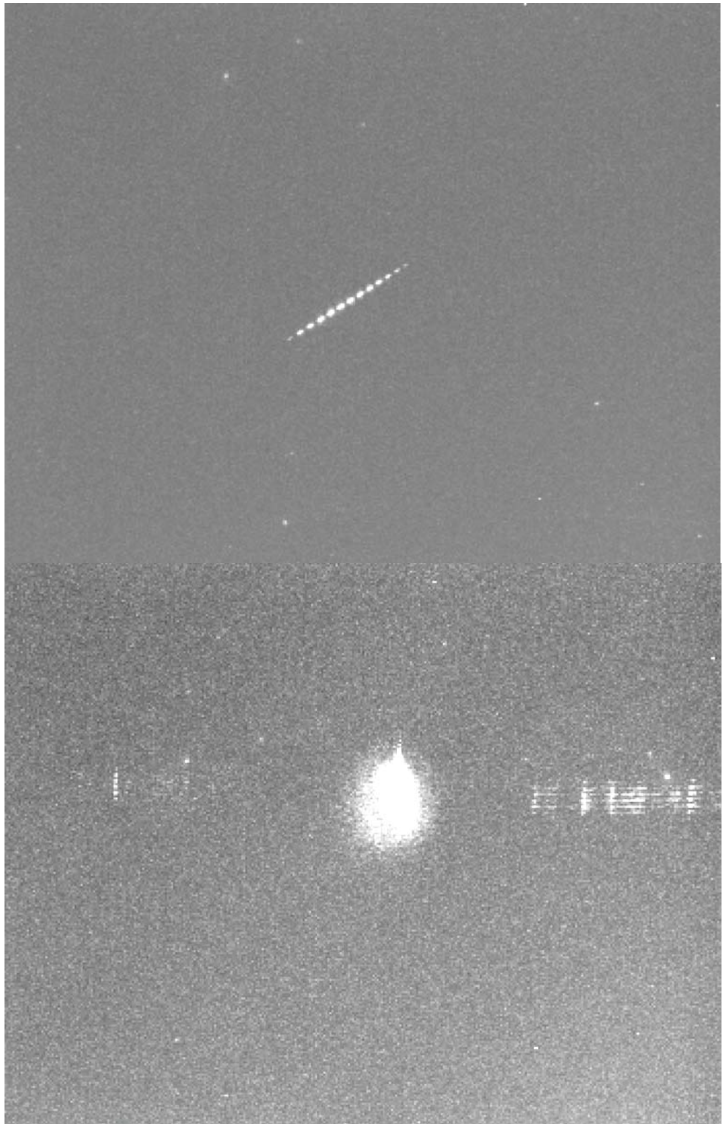
# Modes of investigation

Mainly optical (high-sensitivity video)
Projected position+angular velocity
Few spectra

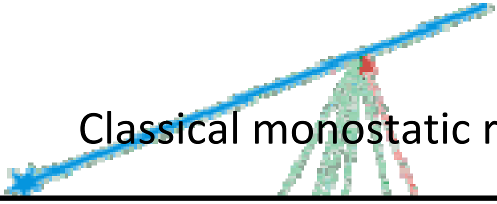
Some multi-site observations ➡ orbits

Done in Europe, USA, Canada, Japan,..

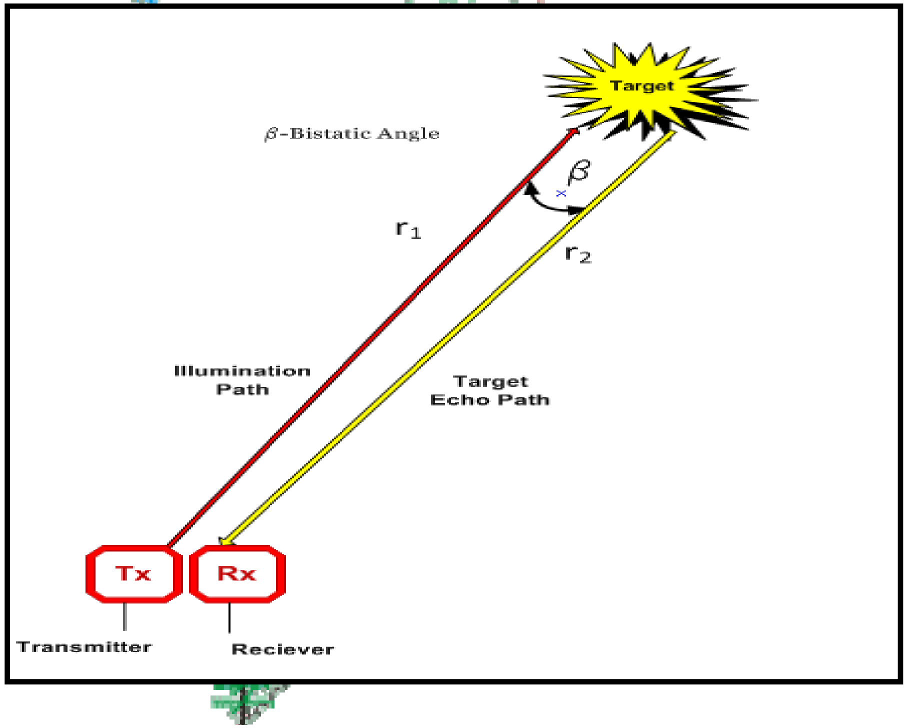
**Night-time only!**



# HF and HPLA radars

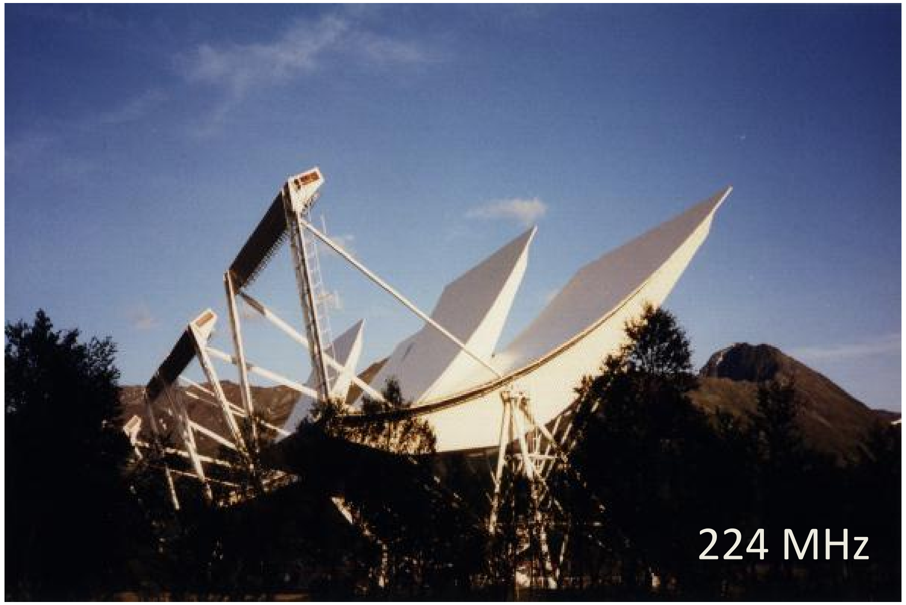


Classical monostatic radar




Classical meteor radar (HF)

Day and night!

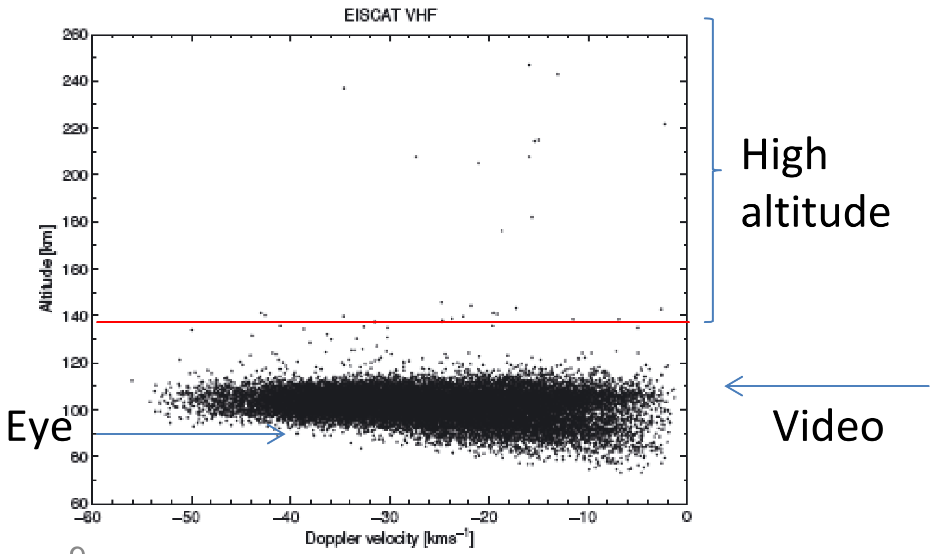
# EISCAT results

**"Unusual features in high statistics radar meteor studies at EISCAT",**
Mon. Not. R. Astron. Soc. **401, 1069–1079 (2010)**

3x8-h runs on consecutive nights in 2008 December.

Aiming to detect and study a high-altitude (h>150-km) meteor population, along with the meteors detected at classical ~100-km altitudes

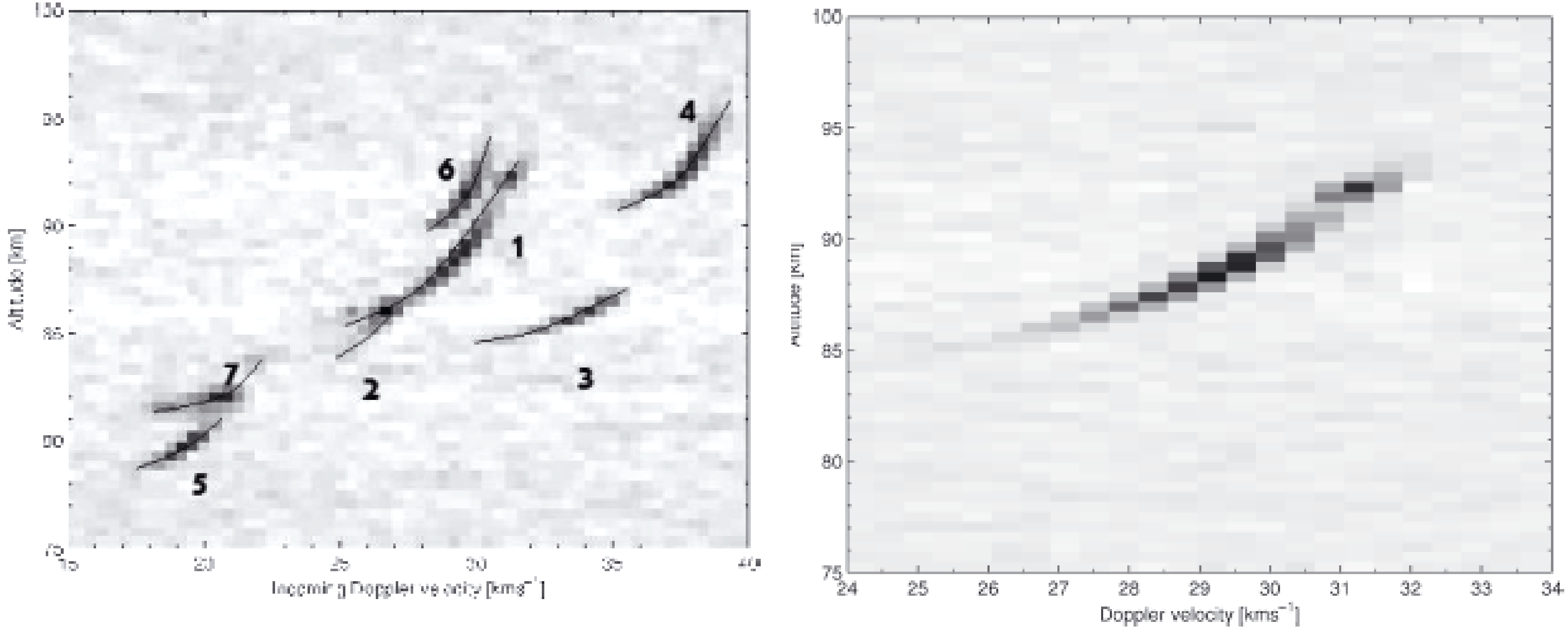
VHF detected during the 24-h period 22698 echoes identified as meteors. UHF echoes in the same period was 2138, most detected also at VHF.




Detected 11 VHF meteors above 150 km. with the record highest @**246.9 km**. No high-altitude UHF echoes and none with Doppler >60 km/s.

- High altitude meteors observed with video have a different appearance (fuzzy, jets,...)

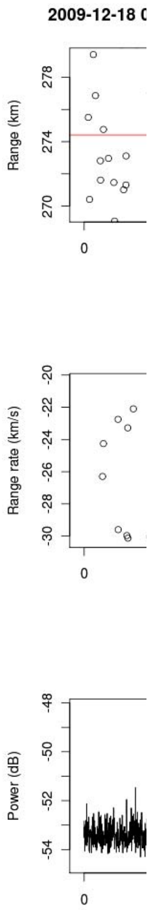
# EISCAT results: Decelerating meteors

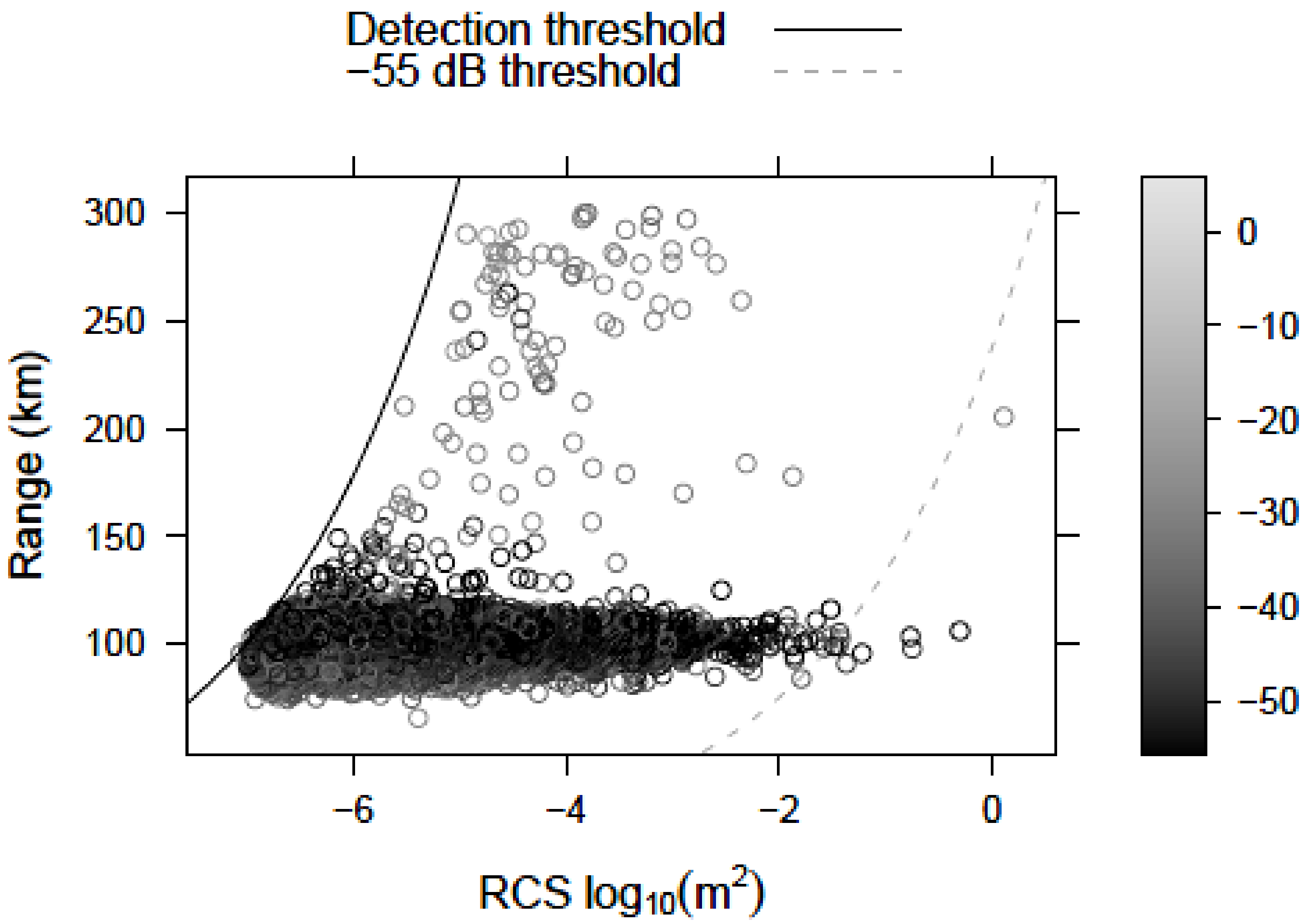


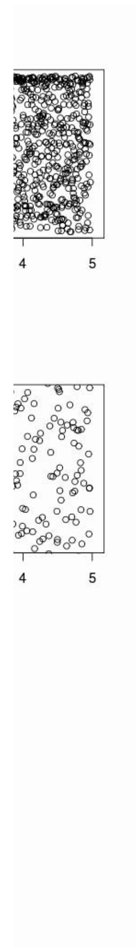

Altitude–Doppler-intensity plots

The detected meteoroid was a submm body that fragmented when the ram pressure reached about 0.5 pascal

# 2009 EISCAT results



Genuine high-altitude meteor

Orbital debris and meteor

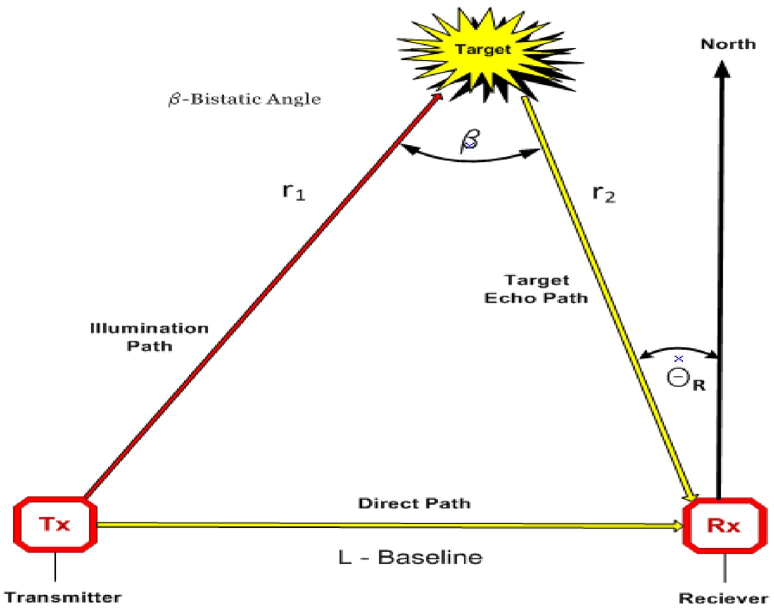
# Are HPLA radars the way to study meteors?

- HPLA radars produce good science but
  - (a) require large amounts of electricity,
  - (b) special frequency allocations, and
  - (c) have environmental influences
- Better find a passive means of studying meteors
- Use GNSS for passive radar on meteors?

***"When the transmitter is from a communications or broadcast system, i.e., not from a radar, entries are called a passive bistatic radar (PBR)."*** **N.J. Willis 2008,"Radar Handbook" ch. 23**

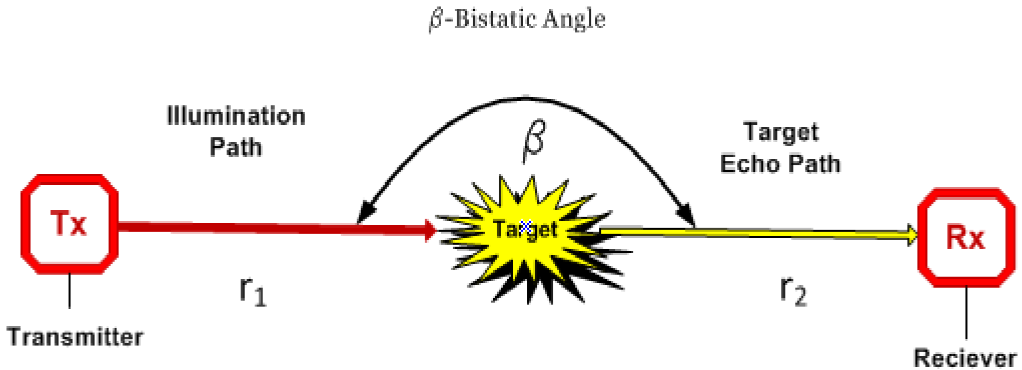
# PBR for meteors?

Bistatic Radar Geometry




$20<\beta<145$ degrees

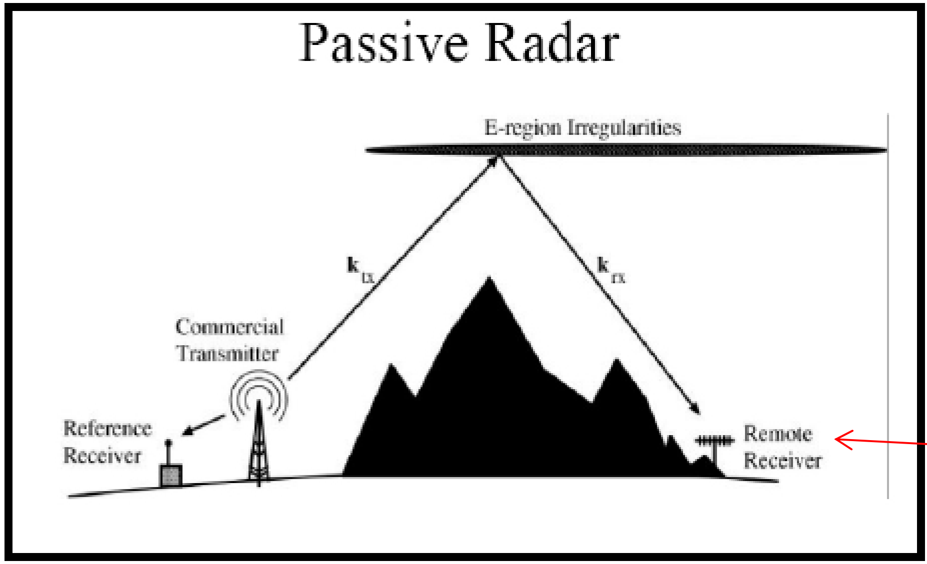

Forward/Fence Radar Geometry (limiting case)

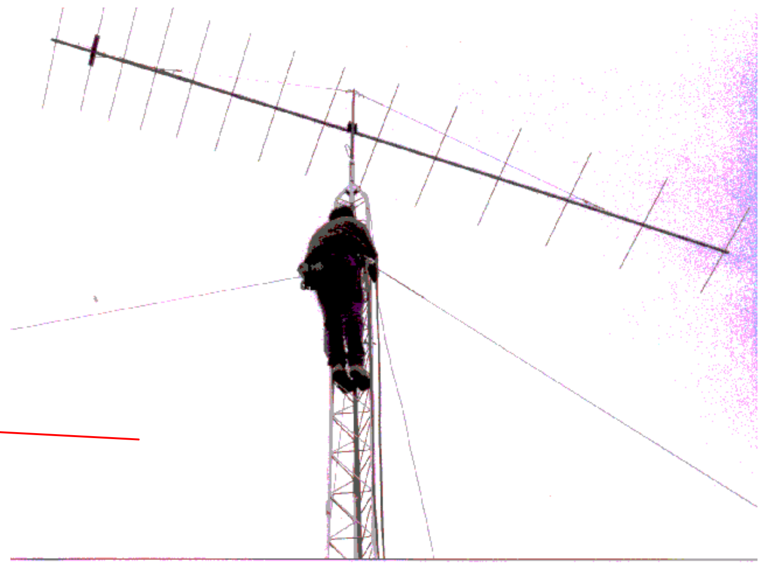



$145<\boldsymbol{\beta}<180$ degrees

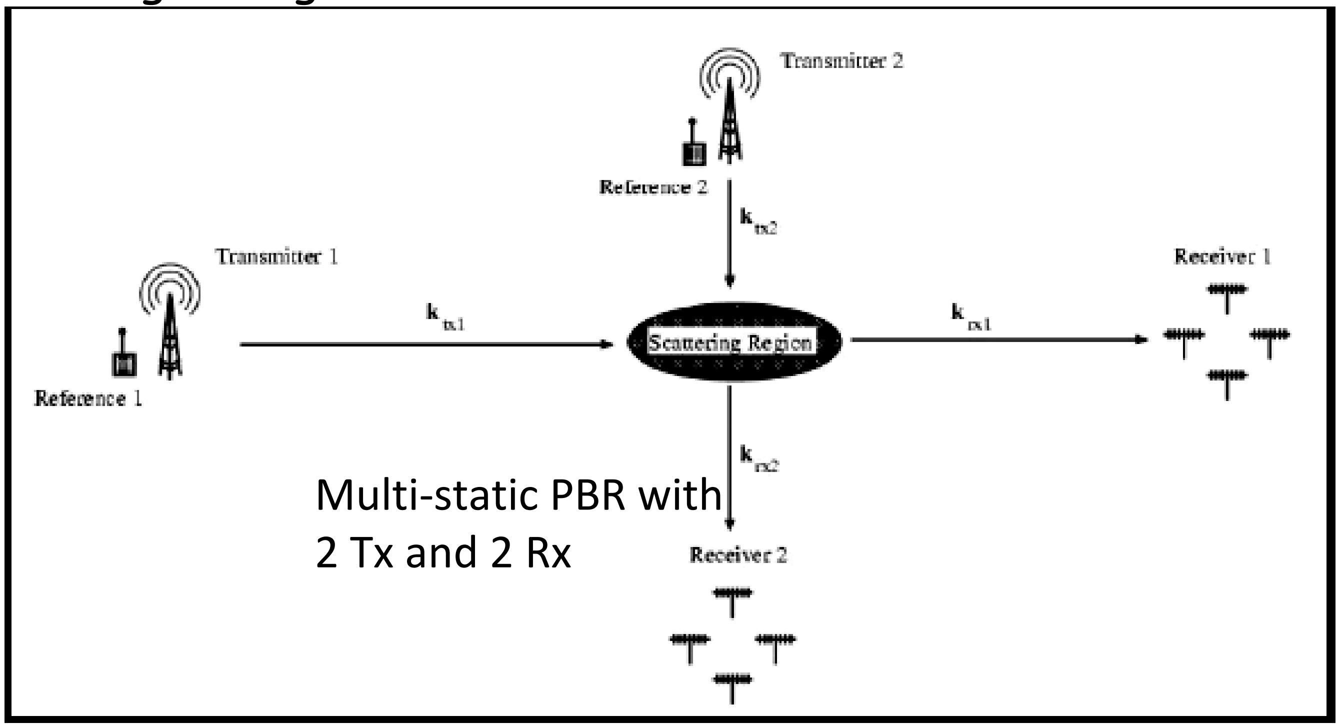


*John W. Franklin .ppt presentation on PBRs at U. N. Texas (web)*

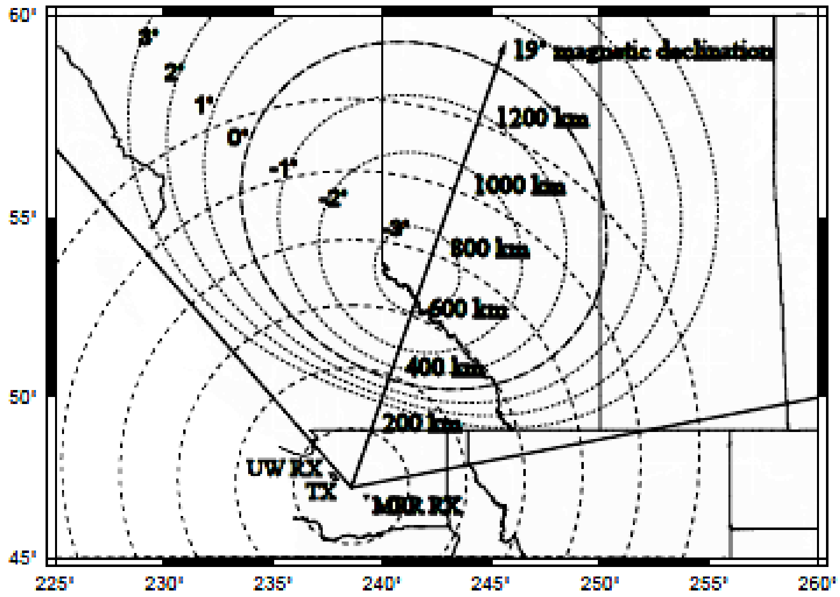


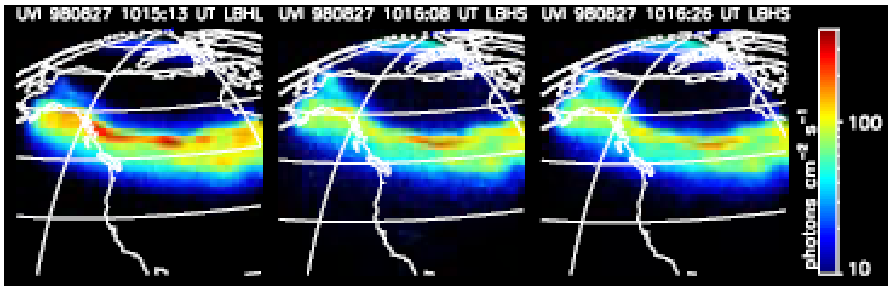
PBR for ionospheric disturbances: Reference receiver registers original signal

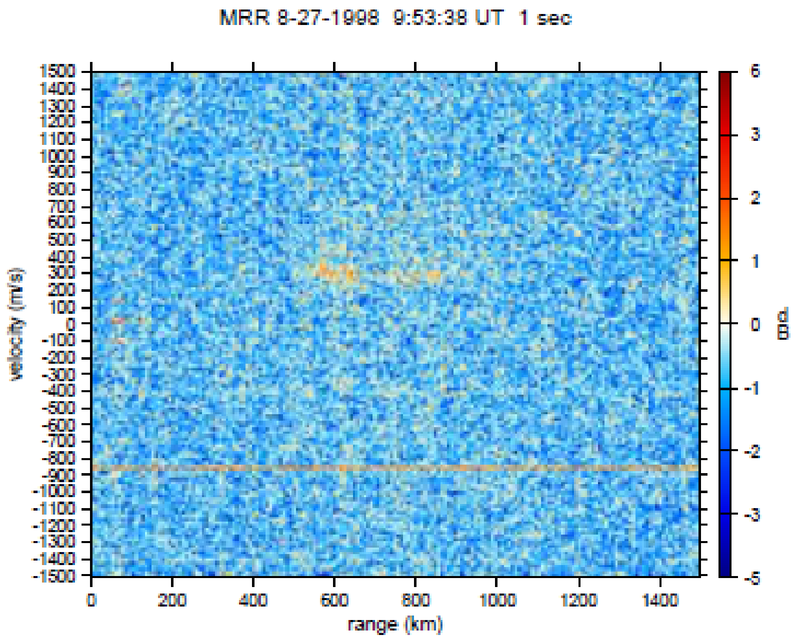



Multi-static PBR with 2 Tx and 2 Rx




Manastash Ridge PBR (NW USA, view over Canada)
88-108 MHz (FM radio)




**PBRs already detect ionospheric disturbances!**

Ionospheric E-region irregularities observed by MRR with simultaneous UV images of the aurora from the POLAR s/c (NASA)



Lind et al. 1999 GRL 26, 2155-2158

# Bistatic Radar Range Equation

Fraction of transmitted power that is reflected to receiver

$$P_r = P_t * \frac{\sigma_B}{4\pi r_1^2} G_t * \frac{A_e}{4\pi r_2^2}$$

Transmitted Power

Fraction of reflected power that is intercepted by receiving antenna

**where**

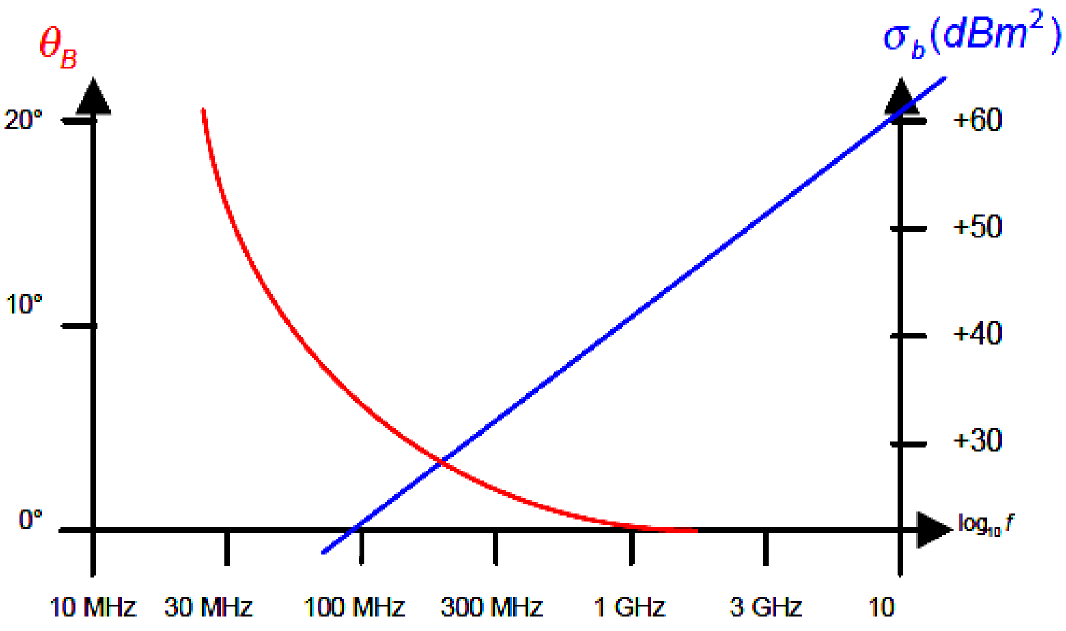
- $P_r$ **is the received signal power**
- $P_t$ **is the transmit power**
- $G_t$ **is the transmit antenna gain**
- $r_1$ **is the transmitter-to-target range**
- $\sigma_b$ **is the target bistatic RCS**
- $r_2$ **is the target-to-receiver range**
- $G_r$ **is the receive antenna gain**
- $\lambda$ **is the radar wavelength**

(Bistatic Radar Equation)

Using: $$A_e = \frac{G_r \lambda^2}{4\pi}$$

then: $$P_r = \frac{P_t G_t G_r \lambda^2 \sigma_B}{(4\pi)^3 r_1^2 r_2^2}$$

*John W. Franklin .ppt presentation on PBRs at U. N. Texas (web)*




Variation of forward scatter RCS and angular width of response ($d$ = 10m, $A$ = 10m$^2$).

The bistatic RCS is a function of target size, shape, material, angle and carrier frequency

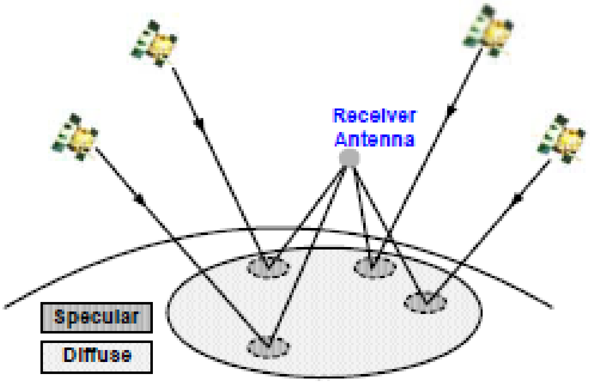
Usually, a bistatic RCS is smaller than the monostatic RCS

At some target angles a high bistatic RCS is achieved (**forward scatter**)

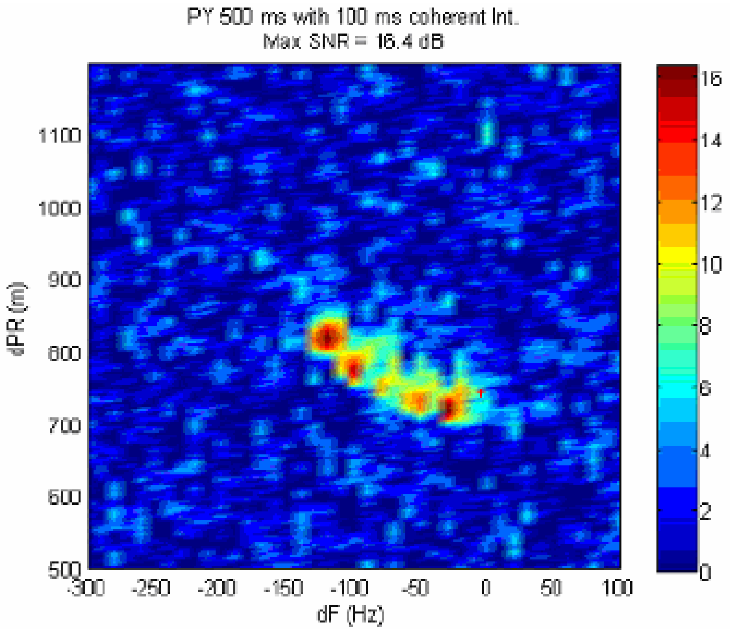
When scattering GNSS signals off meteor plasma, and receiving on the ground → ~forward scattering → higher $\sigma_B$

*John W. Franklin .ppt presentation on PBRs at U. N. Texas (web)*

# Actual GPS Bistatic Radar – ground echoes




GPS bistatic configuration
(specular reflection points)

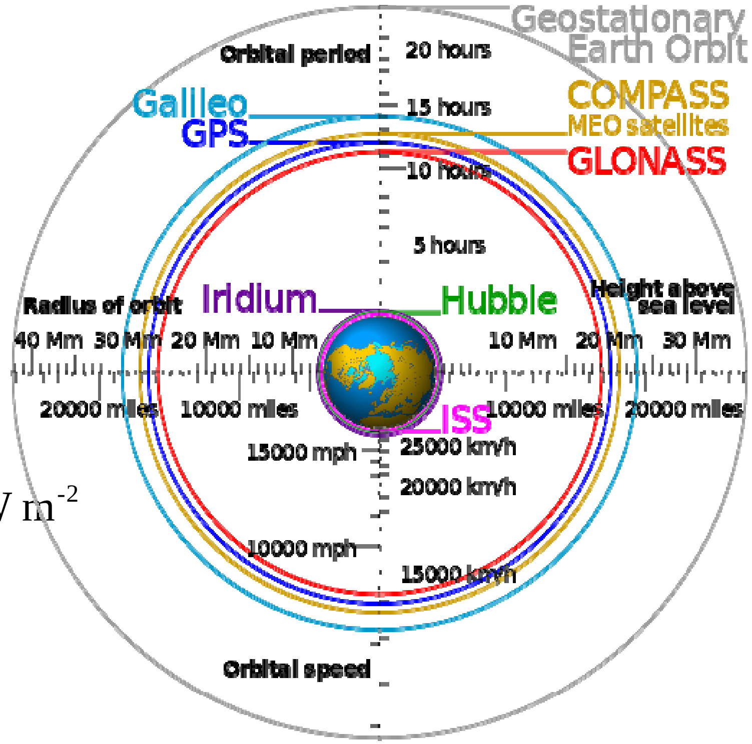




Actual bistatic radar returns


Airborne 96-element phased-array GPS antenna

Brown & Matthews 2007, Proc. ION NTM (San Diego)

# GPS for meteor measurements?




<u>GPS characteristics:</u>
Altitude=20200 km
PWR emitted=35W
Beam width=13°.8
ν~1.5 GHz

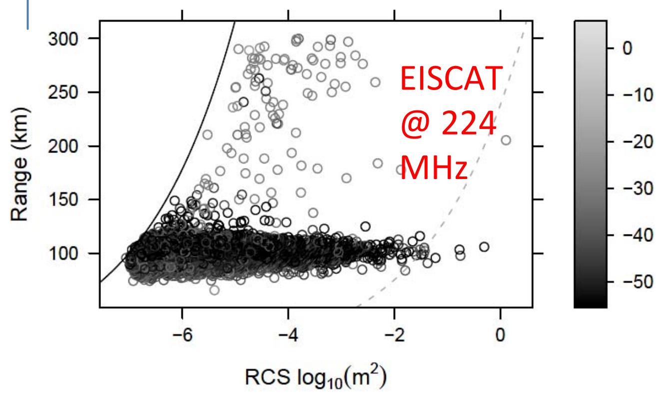
Similar data for GALILEO & GLONASS

<u>GPS exospheric detection</u>

Irradiation power density from GPS at 200-km altitude

$$\rho_i = \frac{P_i}{\pi\left(2\times10^7 \times \tan 6.9\right)^2} = -117 \text{ dB W m}^{-2}$$

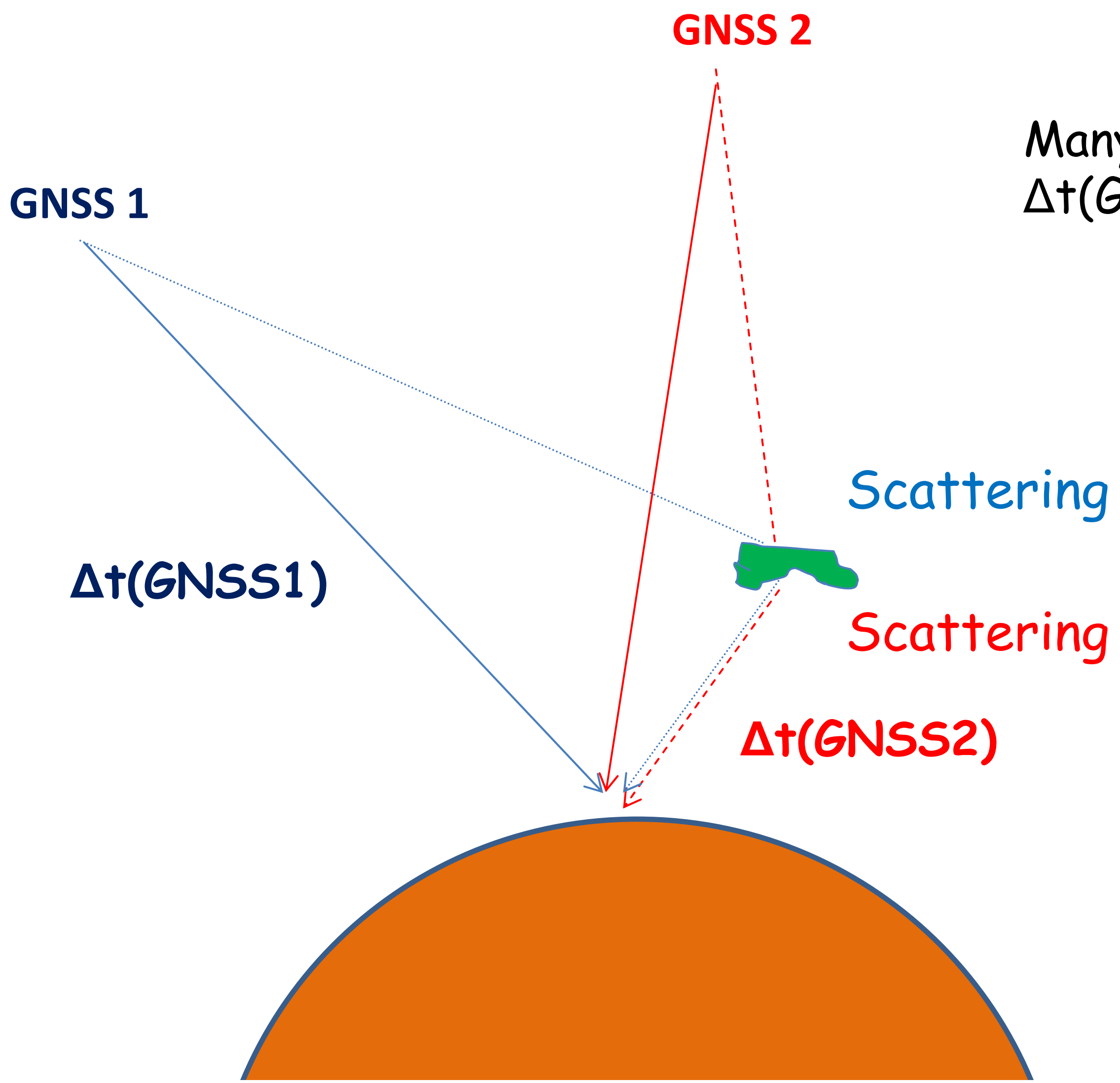
(assumes uniform distribution in the beam)




Scattered GPS power density of meteor with RCS=$10^{-6}$ $m^2$ seen from 200-km: 3.8 $10^{-27}$ $W/m^2$
(assumes isotropic distribution from meteor plasma)

Low intensity of scattered return ➡ special detection techniques

# Tomography of the ionosphere?




Many GNSS:
Δt(GNSS1), Δt(GNSS2),…

3D localization

Trajectory

Glennon 2006, J. GPS (1) 119-126

# Not a new idea…

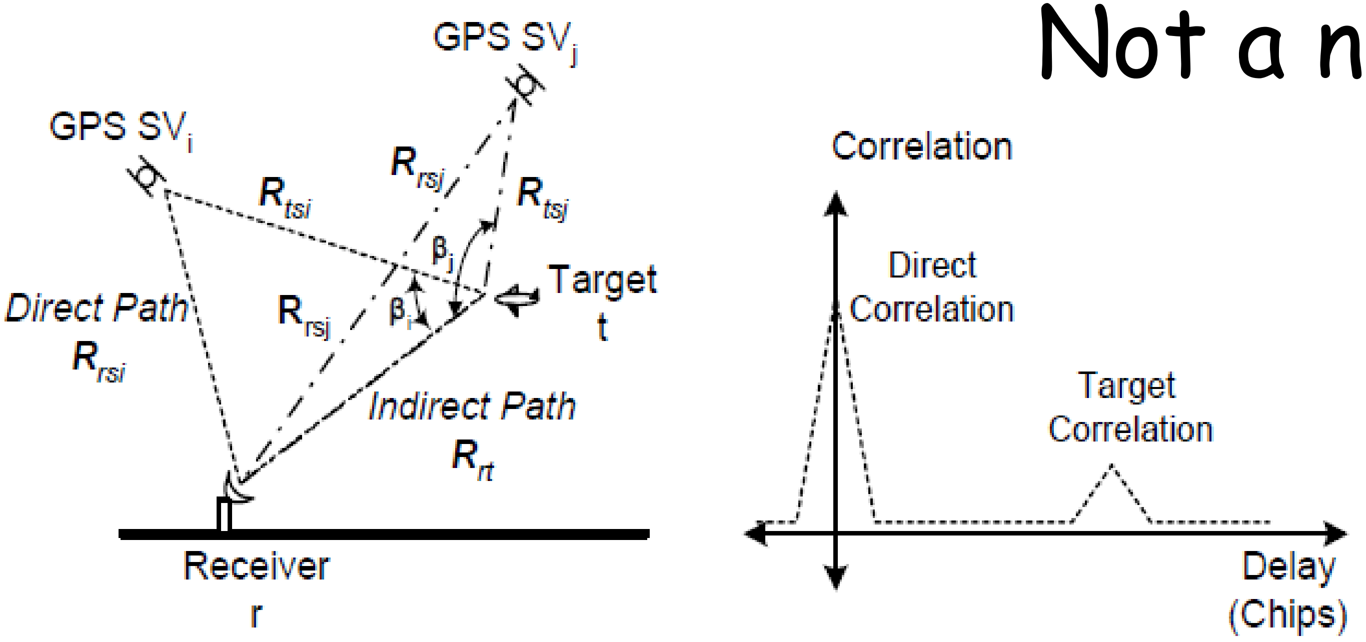



**Fig. 1**. System Geometry & Correlation Curves

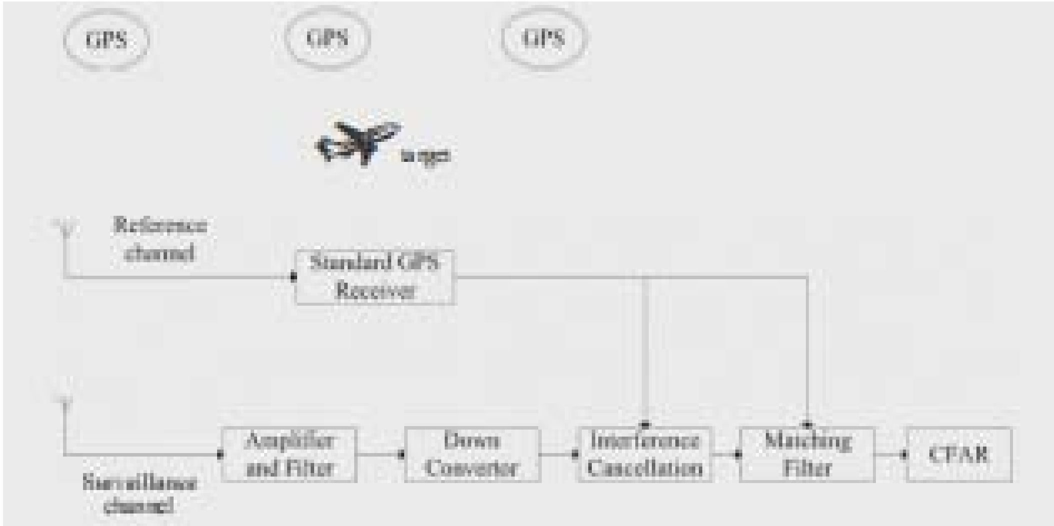


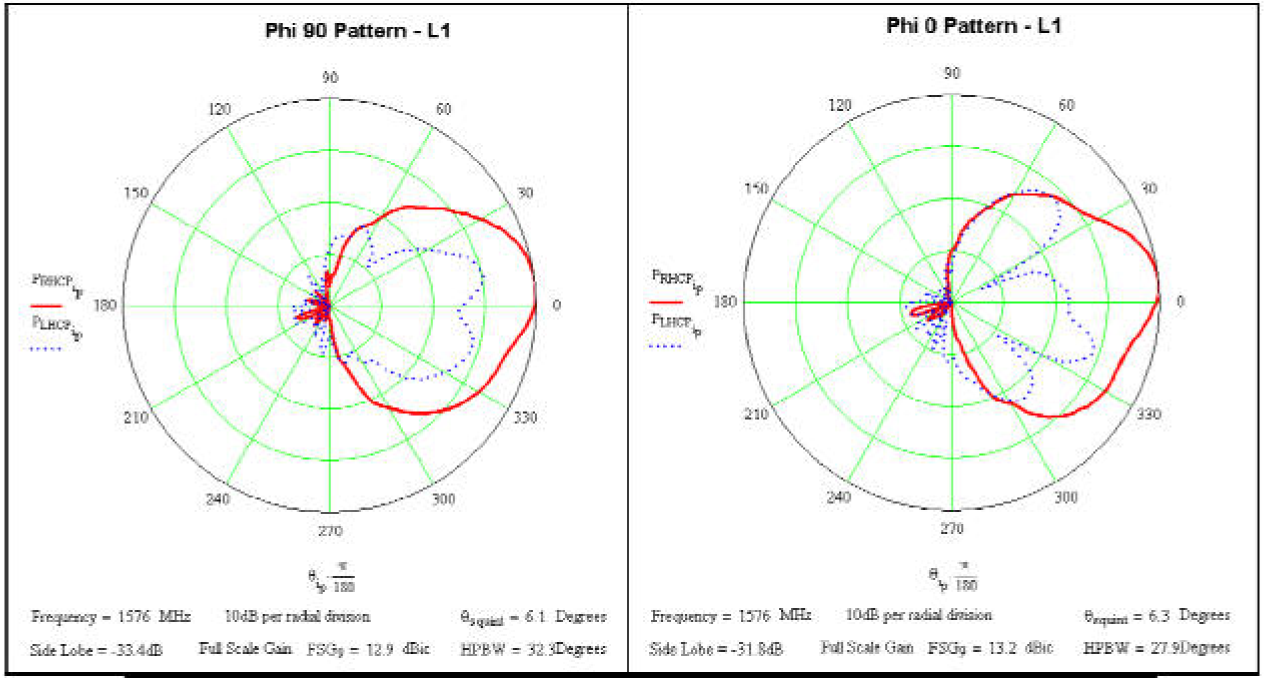

Figure 1. Receiver system of passive radar based on GPS.

Xu, Shen & Shan 2011 at the 3rd Int'l Conf. on Advanced Computer Control

# Commercial GPS antenna

**HC-238-13 Helicone Antenna**

**Gain (dB): 14.7 @ L2, 13.1 @ L1**



# Meteors