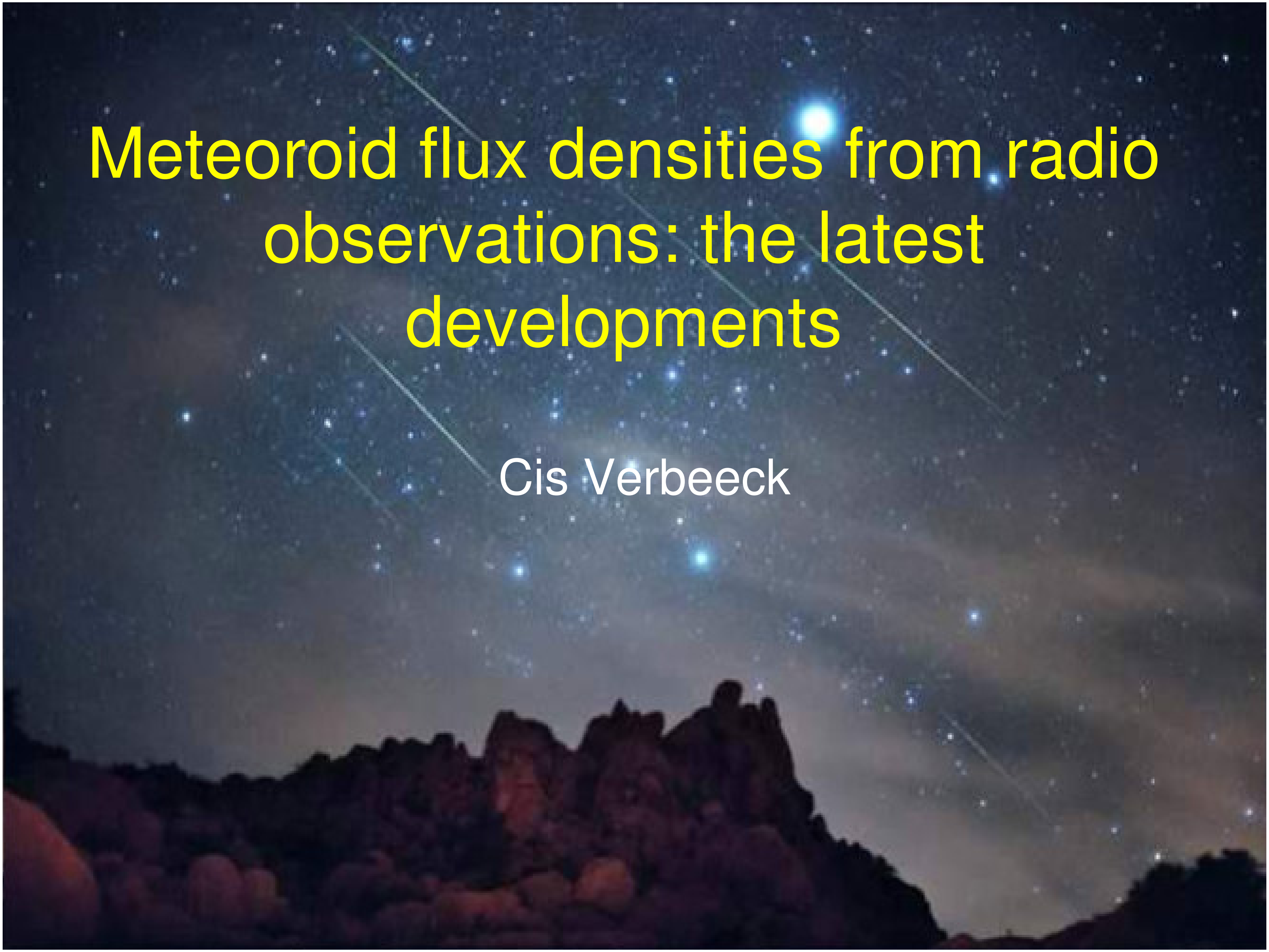


Meteoroid flux densities from radio observations: the latest developments

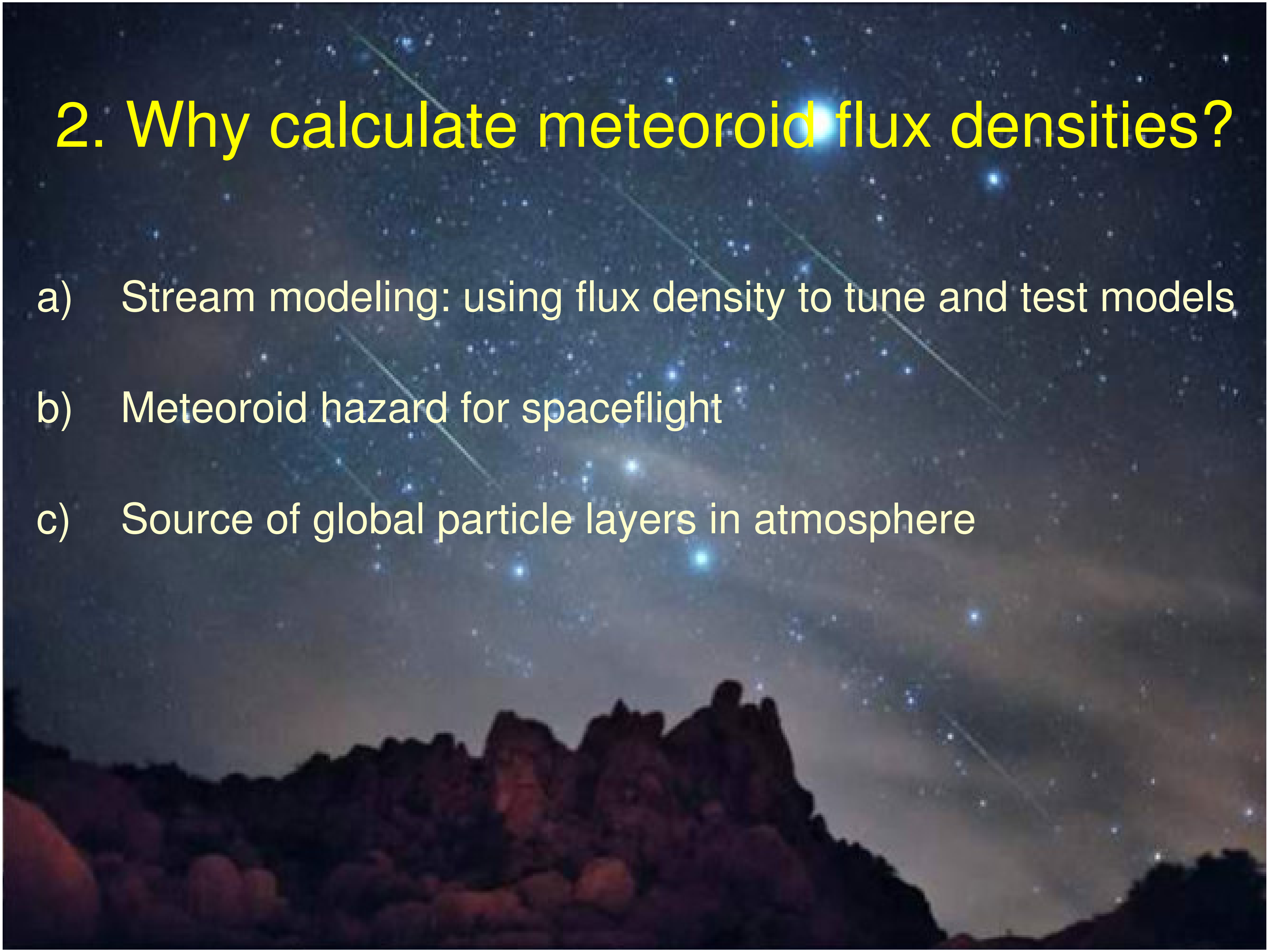
Cis Verbeeck

Outline

1. Introduction
2. Why calculate meteoroid flux densities?
3. Kaiser method
4. Belkovich method
5. Ryabova method
6. Verbeeck method
7. Summary

1. Introduction

- Meteoroid flux density $Q(m_*)$: number of stream meteoroids having masses $\geq m_*$ intersecting unit area in unit time ($\perp$ velocity vector)
- Typical values: $Q(m_* = 10^{-3}\ \mathrm{g}) = 10^{-11}$-$10^{-12}\ \mathrm{m^{-2}\ s^{-1}}$
- Mass index s: exponent such that number dN_m of meteoroids having masses in $[m, m + dm]$ is proportional to m^{-s}
- Note that $\frac{Q(m)}{Q(m_*)} = \left(\frac{m}{m_*}\right)^{1-s}$


2. Why calculate meteoroid flux densities?
a) Stream modeling: using flux density to tune and test models
b) Meteoroid hazard for spaceflight
c) Source of global particle layers in atmosphere

Why calculate meteoroid flux densities?

a) Stream modeling: using flux to tune and test models

- Solar System origin, dynamics, composotion
- Smallest population only observable by radar and forward scatter

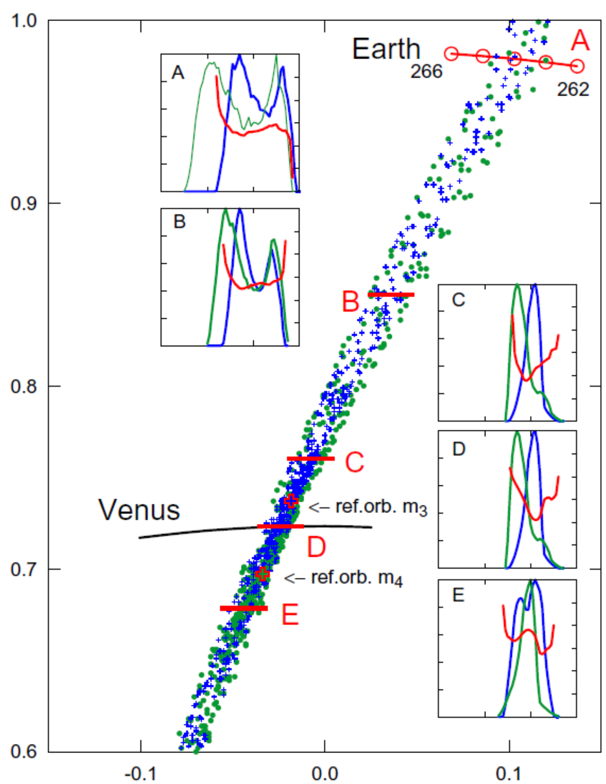


Figure 7 – The Geminid model cross-section in the ecliptic plane (Cartesian coordinates), for orbits of particles with masses m_3 (+) and m_4 (•). The Earth's orbit ($\lambda_\odot = 262° - 266°$) is designated by A, and other sections are designated by B, C, D and E. The inserts show the corresponding activity profiles, i.e., the flux density Q variations for particles masses m_3 (blue) and m_4 (green), and a profile for the mass index s (red).

G.O. Ryabova and A. Martínez (2006)
Proc. Radio Meteor School 2005, 68-77.

Why calculate meteoroid flux densities?

b) Meteoroid hazard for spaceflight

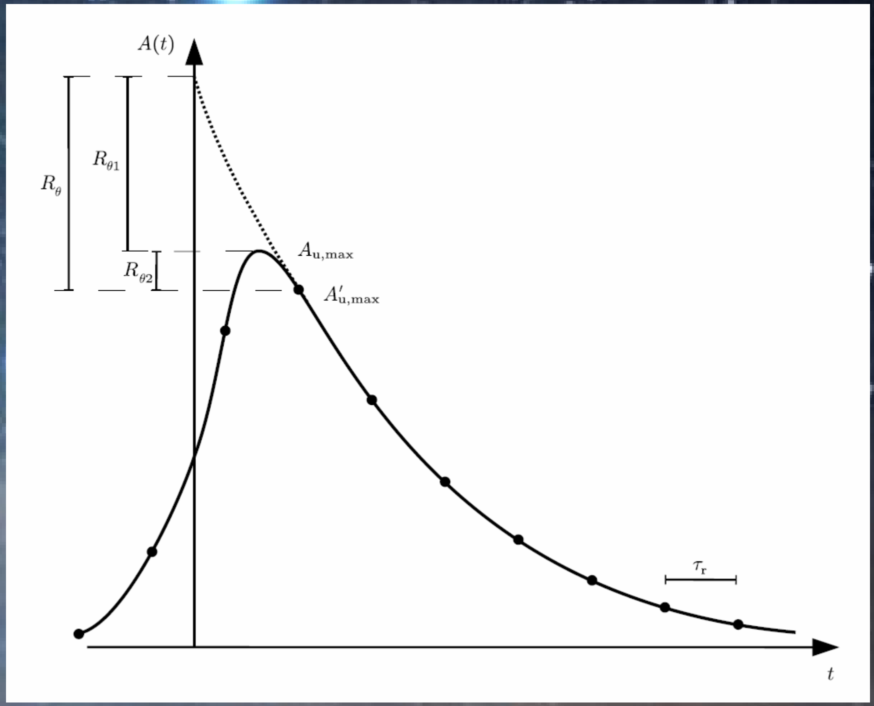
- 1999 Leonids: no Shuttle launches in November

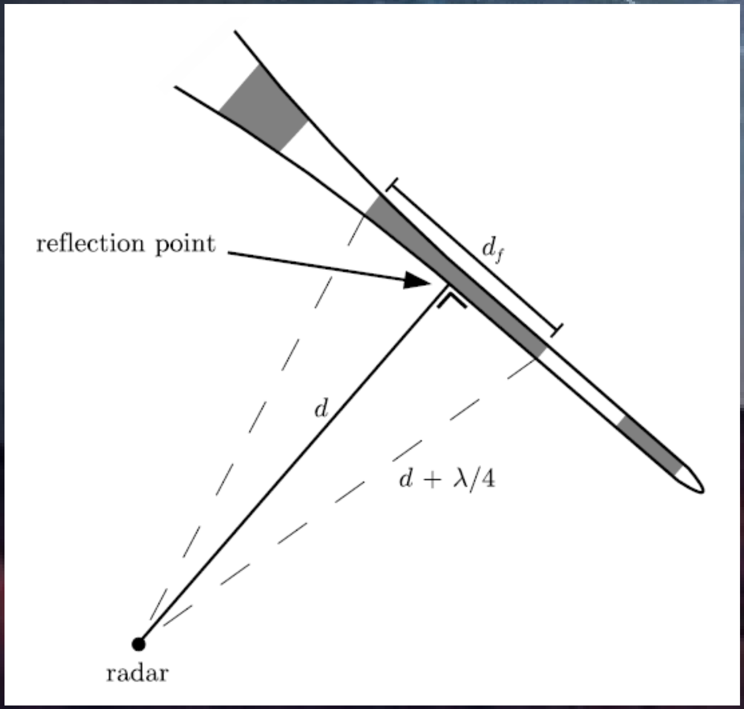
c) Source of global particle layers in atmosphere

- Neutral metal atoms
- Metal ions (Sporadic E)
- Meteoric smoke particles (PMSE, NLC)

Selection effects

- Initial trail radius effect
  - ⇒ less high meteors observed
  - ⇒ flux density underestimated
- Finite velocity effect
  - ⇒ less slow meteors observed
  - ⇒ flux density underestimated

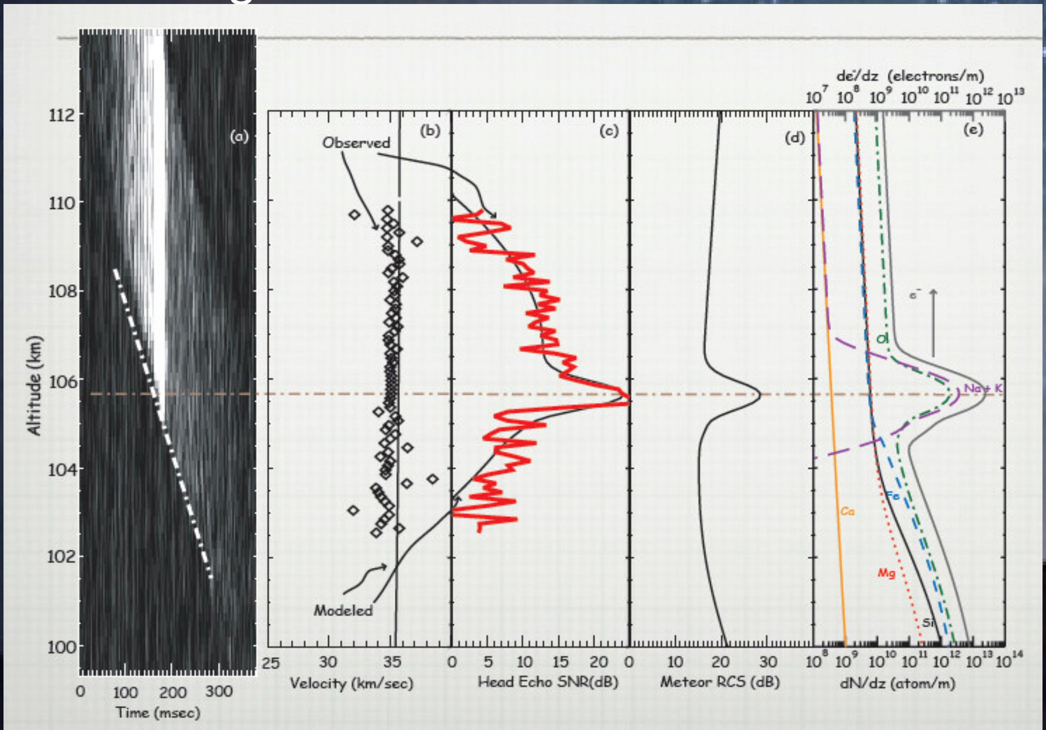




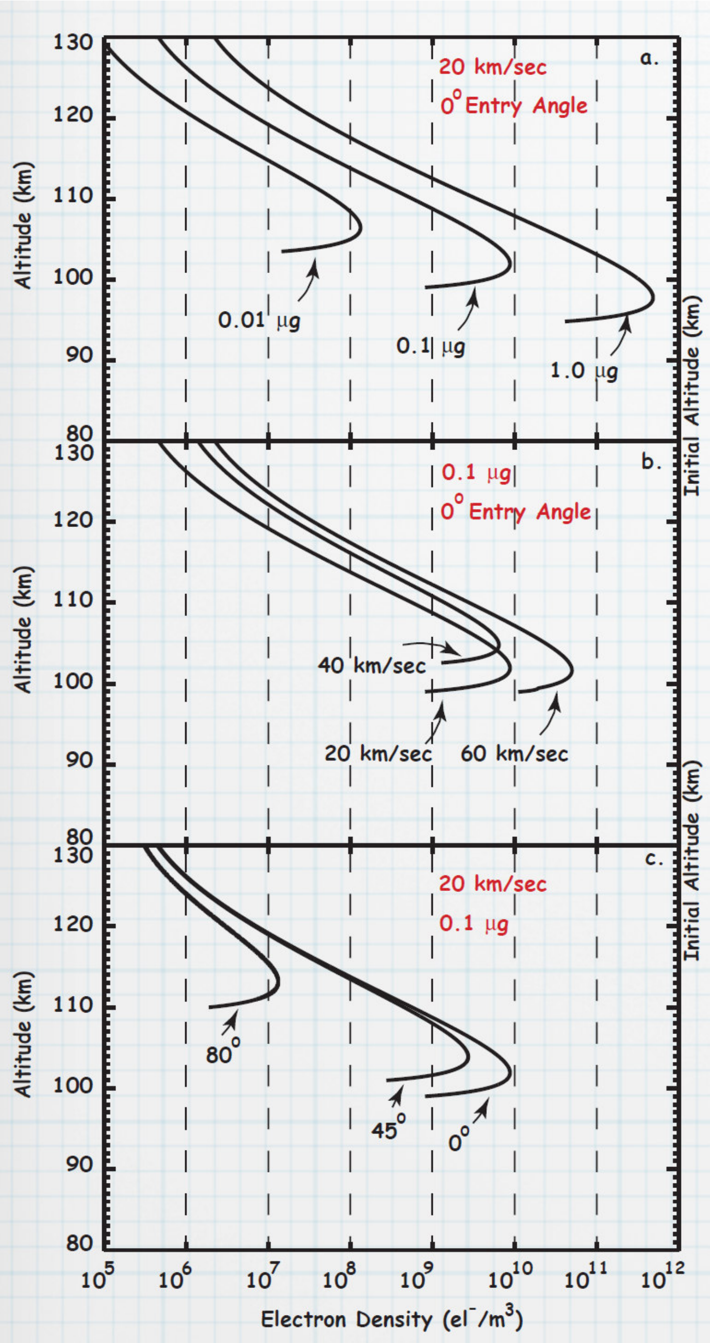
- PRF effect
  - ⇒ less short-lived meteors observed
  - ⇒ flux density underestimated
- Lower mass limit mismatch

Ionization profiles

Mass (, velocity, zenith angle, composition)
$\Rightarrow$ electron line density $\alpha = \alpha(h)$,
including start and end height



D. Janches, L.P. Dyrud, S.L. Broadley, and J.M.C. Plane (2009) *Geophys. Res. Lett.* 36, L06101.



J.T. Fentzke and D. Janches (2008) *JGR* 113, A03304.

3. Kaiser method

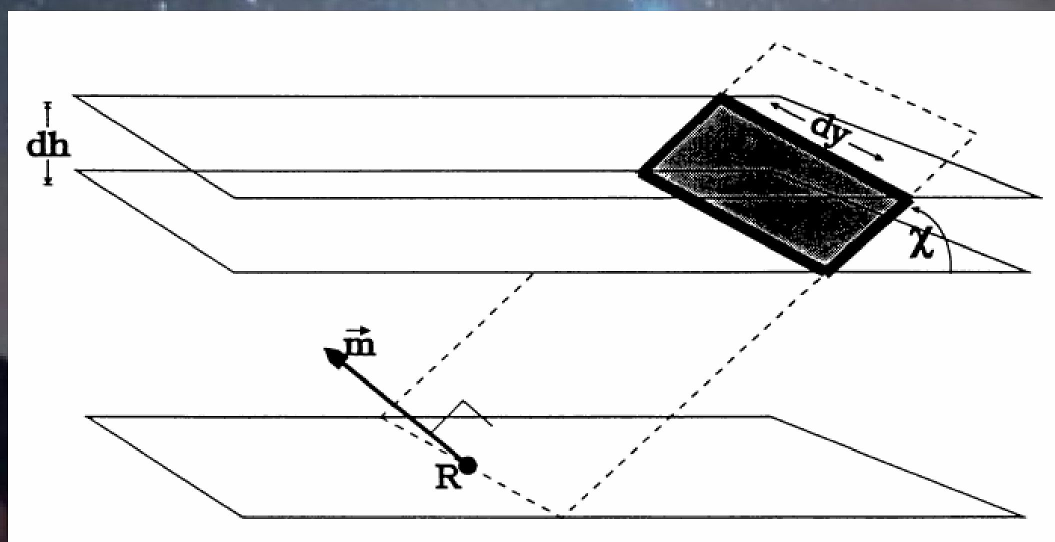
a) Basic ideas

b) Selection effects

T. Kaiser (1960) *MNRAS* 121, 284-298.

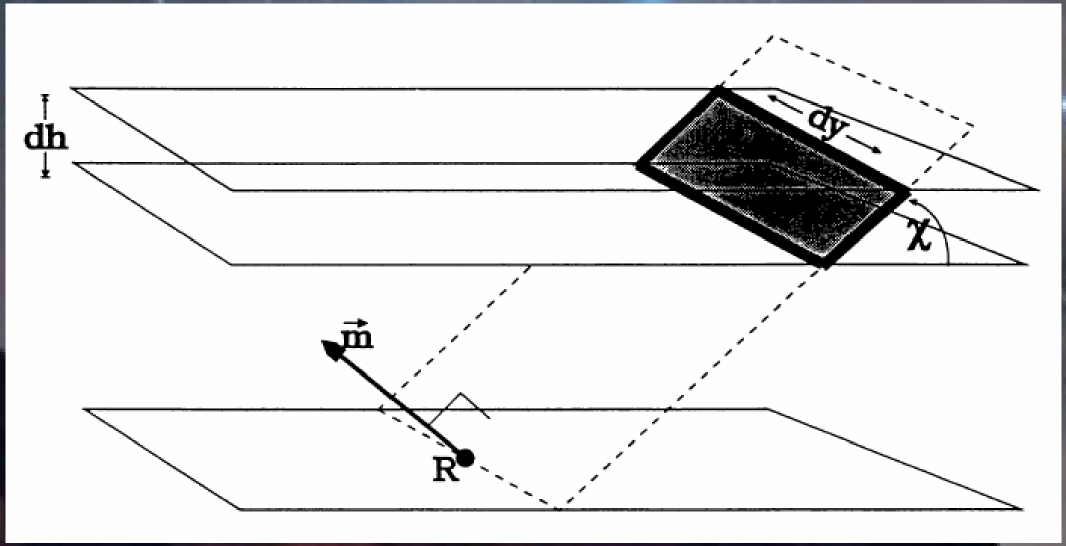
Kaiser method: basic ideas (1)

- Count number *N* of meteoroids from particular radiant in particular period of time
- Fixed meteor height
- Fixed vertical meteor zone extent depending on stream velocity, entry angle and mass index
- Effective collecting area *S* = vertical width • horizontal « length »



Kaiser method: basic ideas (2)

- Define m_0 as minimal detectable mass in direction of max gain
- Horizontal « length » w.r.t. m_0: ~ $(\cos \chi)^{s-1} \cdot \int (G_T G_R/R^3)^{(s-1)/2}\, dy$
- Flux density w.r.t. m_0: $Q(m_0) = N/S$
- Wanted flux density: $Q(m_*) = Q(m_0) \cdot (m_*/m_0)^{1-s}$



Kaiser method: selection effects

- Initial trail radius effect
  - meteor height zone not dependent on signal strength
- Finite velocity effect
- PRF effect
- Lower mass limit mismatch

4. Belkovich method

a) Basic ideas

b) Extra features

c) Results

d) Selection effects

O.I. Belkovich (1971) *Statistical theory of meteor radar observations*. Kazan University, Russia (in Russian).

O.I. Belkovich and V.S. Tokhtasev (1974) *Bull. Astron. Inst. Czech.* 25:2, 112-115; 25:6, 370-374.

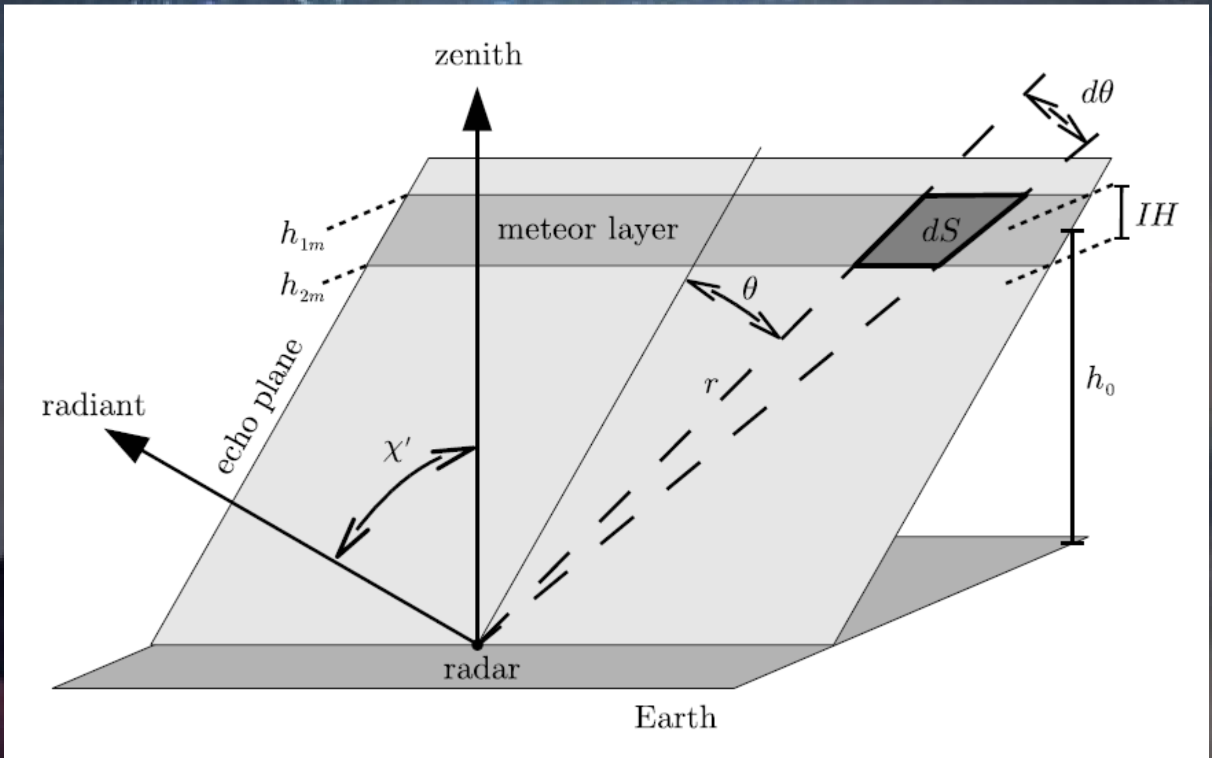
O.I. Belkovich and C. Verbeeck (2006) *Proc. Radio Meteor School 2005*, 38-47.

O.I. Belkovich and S. Suleymanova (1999). *Meteoroids 1998*, 103–106.

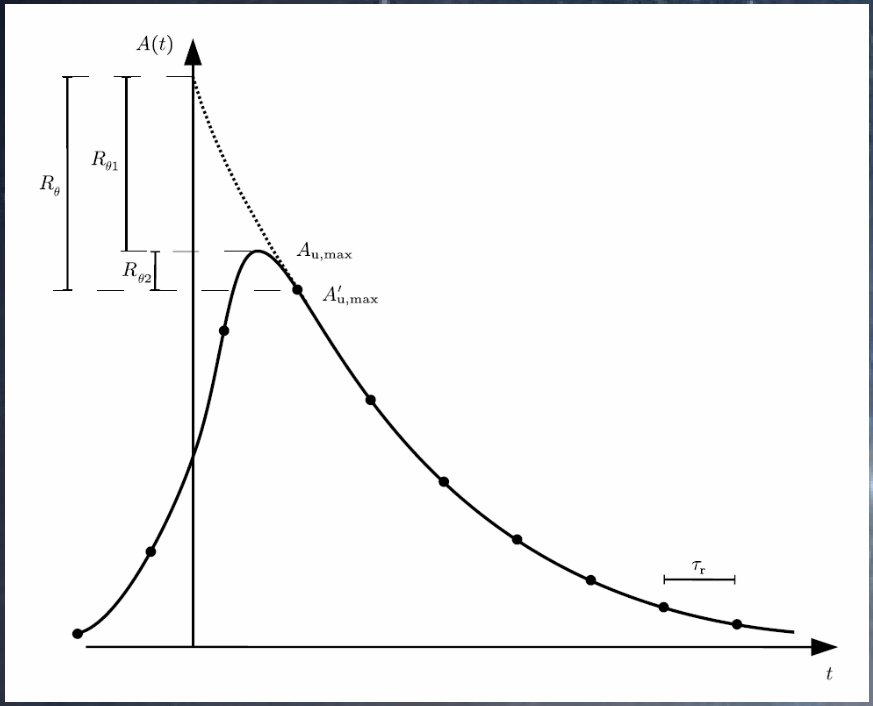
S. Suleymanova, C. Verbeeck, and J.-M. Wislez (2007) *Proc. IMC 2006*, 162-174.

Belkovich method: basic ideas

- Similar to Kaiser technique, but using polar coordinates: partition meteor layer into trapezia dS_θ defined by angles θ and $d\theta$
- h_{1m} and h_{2m} dependent on mass (ionization profile)
- dS_θ = weighted average of trapezia for all masses above m_*



Belkovich method: extra features



- Finite velocity effect
- PRF effect
- Combined fine-tuning of mass index and flux density
- Meteor height zone dependent on (empirical) ionization profile
- Forward scatter version exists

The correction factor R_θ statistically corrects for these two effects, and is given by:

$$R_\theta = \begin{cases} \exp\left(-0.79(kr_0)^{1.74} - 0.79\Theta_\theta^{0.88} + 0.14(kr_0)\Theta_\theta^{0.68}\right) & \text{if} \quad \Theta_\theta < 1, \\ \left(\dfrac{1}{2\Theta_\theta}\right) \cdot \exp\left(-0.79(kr_0)^{1.74} + 0.14(kr_0) - 0.1\right) & \text{if} \quad \Theta_\theta > 1, \end{cases} \tag{5}$$

where $k = 2\pi/\lambda$, r_0 is the initial radius, and Θ_θ a quantity quantifying the extent of the effect:

$$\Theta_\theta = \frac{\tau_f + \tau_{\mathrm{r}}}{2\tau_0}, \tag{6}$$

where τ_f is the time the meteoroid needs to travel half of the first Fresnel zone, τ_{r} is the time between pulses, and τ_0 is the decay time at the characteristic height h_0. Θ_θ compares the duration of the two disturbing processes with the diffusion time constant, and thus indicates whether they are significant.

Belkovich method: results

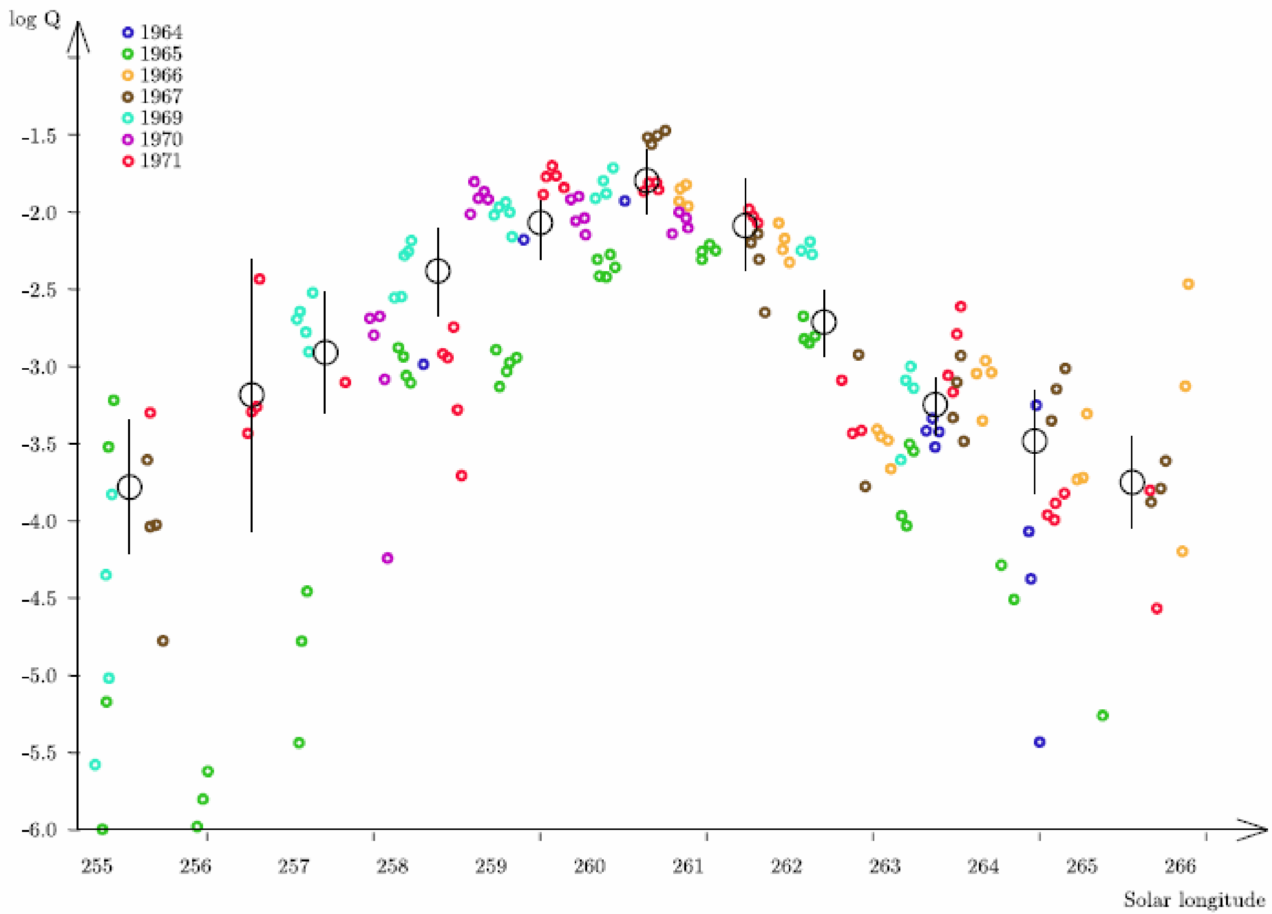


Figure 6 – The (logarithmically scaled) flux density profile of the Geminids in the 1964–1971 period, as a function of solar longitude $\lambda_\odot$ (J2000.0). Since the Geminids are a very stable shower, the activity is very similar year after year.

O.I. Belkovich, D. Pajović, and C. Verbeeck (2006) *Proc. Radio Meteor School 2005*, 48-54.

Belkovich method: selection effects

- Initial trail radius effect
  - meteor height zone for *m* not dependent on signal strength
- Finite velocity effect solved
- PRF effect solved
- Lower mass limit mismatch
  - lower mass limit varies throughout dS_θ

5. Ryabova method

a) Basic ideas

b) Sensitivity curves and ionization curves

c) Selection effects

G.V. Andreev and G.O. Ryabova (1984) *Astronomiya i geodeziya* 10, 131-136; 11, 22-30. (in Russian)

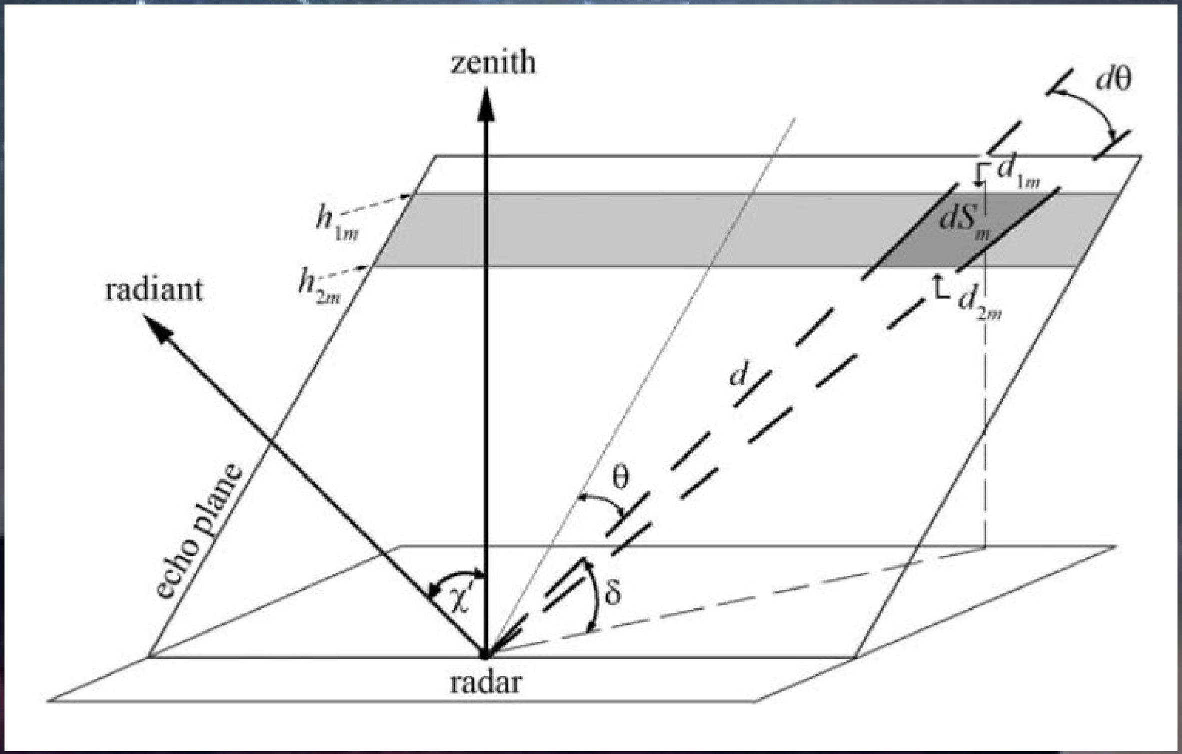
G.V. Andreev, A.E. Epishova, O.A. Mugruzina, and L.N. Rubtsov (1984) *Astronomiya i geodeziya* 13, 37-49. (in Russian)

G.O. Ryabova (2008) *WGN* 36:6, 120-123.

G.O. Ryabova (2009) *WGN* 37:2, 63-67.

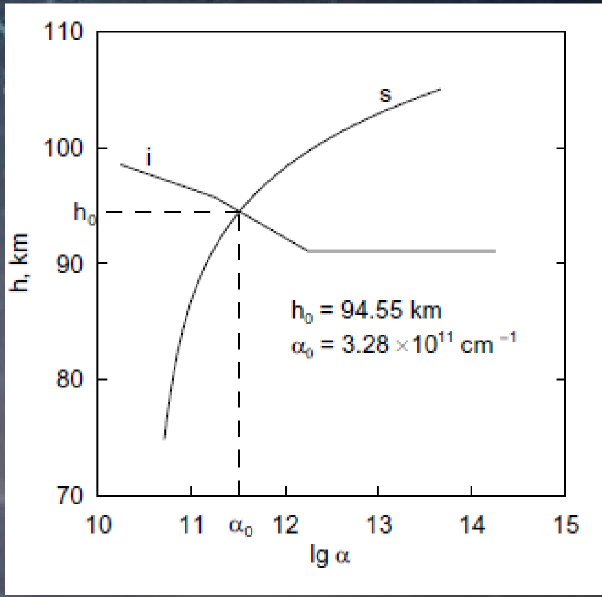
Ryabova method: basic ideas

- h_{1m} and h_{2m} correspond to detectable part of meteor trails (ionization profile and signal strength) ⇒ reliable ionization profiles needed
- dS_θ = weighted average of trapezia for all masses above m_θ
- To determine m_θ, consider ionization profile and signal strength



Ionization curves and sensitivity curves

- Ionization curve = physical model specifying for every line density α, height $h = h(\alpha)$ at which all meteors having α as max line density, reach this max value α.
- θ fixed. For every h, sensitivity curve specifies minimal detectable electron line density $\alpha = \alpha(h)$ (corresponding to radar threshold).
- Ionization curve $\cap$ sensitivity curve $\Rightarrow$ unique h_θ and α_θ such that meteor having max line density α_θ at h_θ corresponds to threshold.
- α_θ corresponds to m_θ.



Ryabova method: selection effects

- Initial trail radius effect solved
  - for every *m*, meteor height zone dependent on ionization profile and signal strength
- Finite velocity effect solved
- PRF effect solved
- Lower mass limit mismatch
  - lower mass limit varies throughout dS_θ

6. Verbeeck method

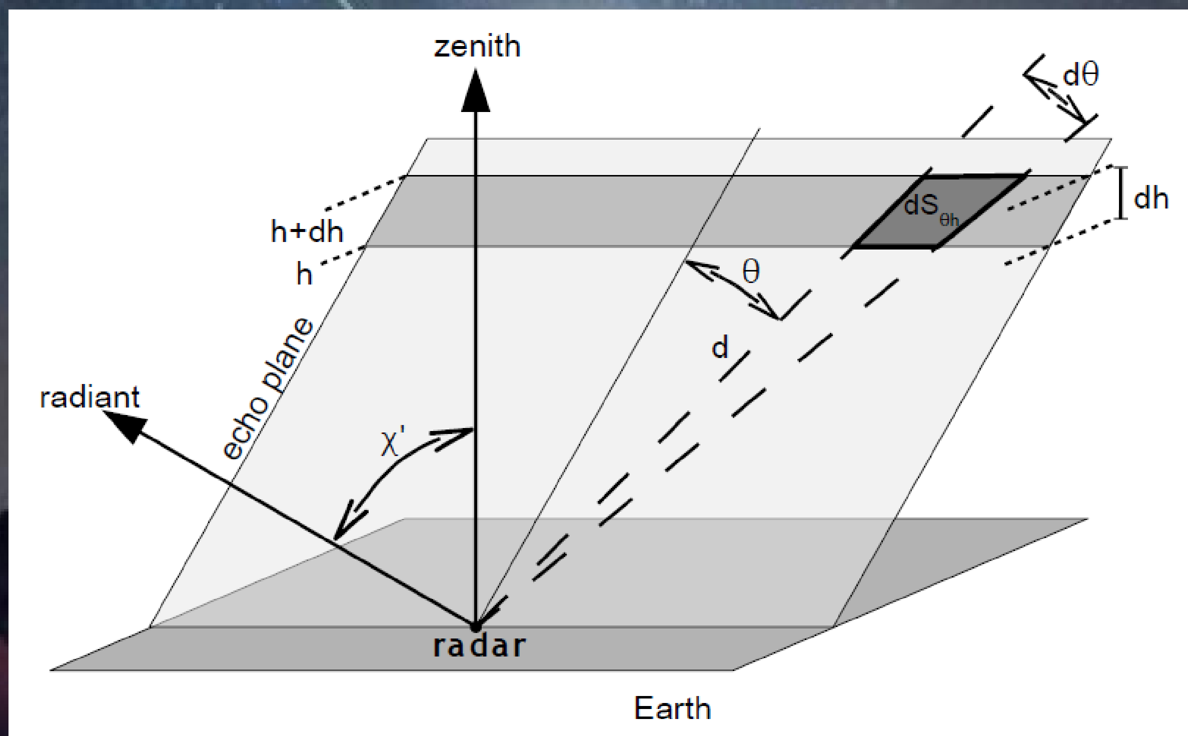
a) Basic ideas

b) Selection effects

Verbeeck method: basic ideas

- For every θ and h, determine min and max detectable masses $m_{\theta h}$ and $m'_{\theta h}$ (consider ionization profile and signal strength)
- Observed flux density in $dS_{\theta h}$ = for masses between $m_{\theta h}$ and $m'_{\theta h}$

$$N = \frac{Q(m_*) \cdot m_*^{s-1}}{\sin^2 \chi'} \cdot \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \frac{I''(\theta)}{\cos^2 \theta} d\theta, \qquad I''(\theta) = \int_{h_b}^{h_e} h \cdot (m_{\theta h}^{1-s} - m'^{1-s}_{\theta h}) dh.$$



Verbeeck method: selection effects

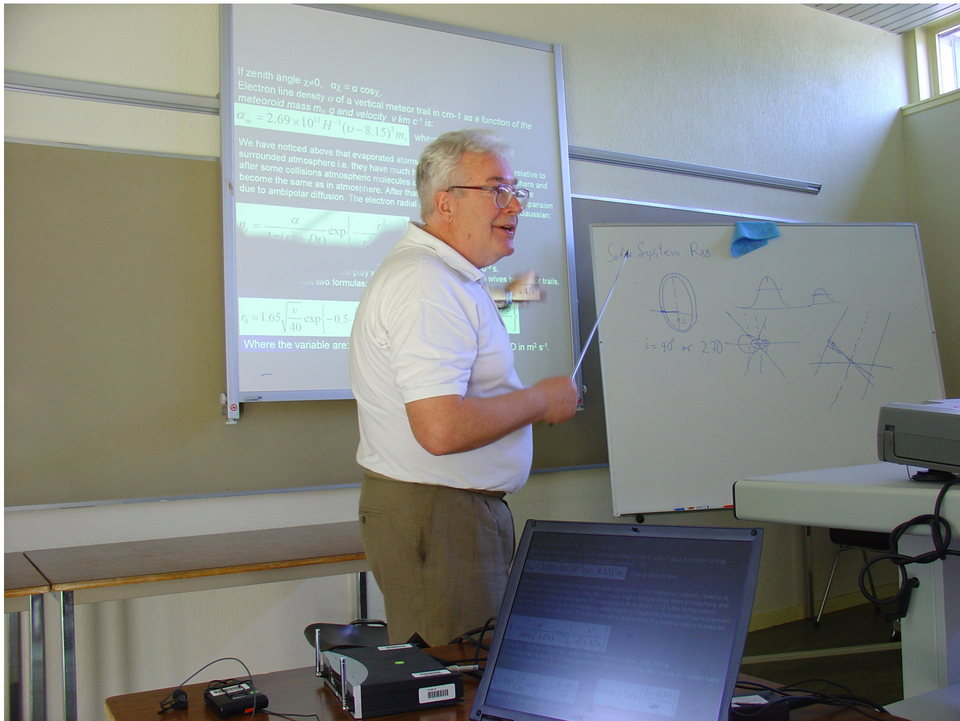
- Initial trail radius effect solved
  - for every θ and h, meteor mass range dependent on ionization profile and signal strength
- Finite velocity effect solved
- PRF effect solved
- Lower mass limit mismatch solved
  - lower mass limit constant throughout $dS_{\theta h}$

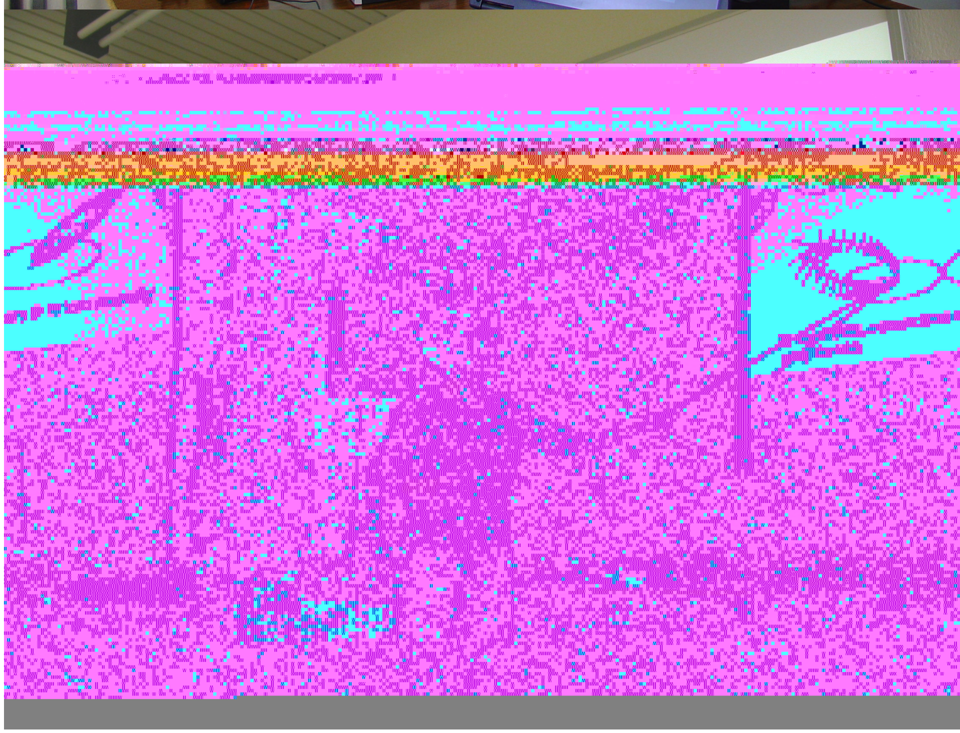
7. Summary

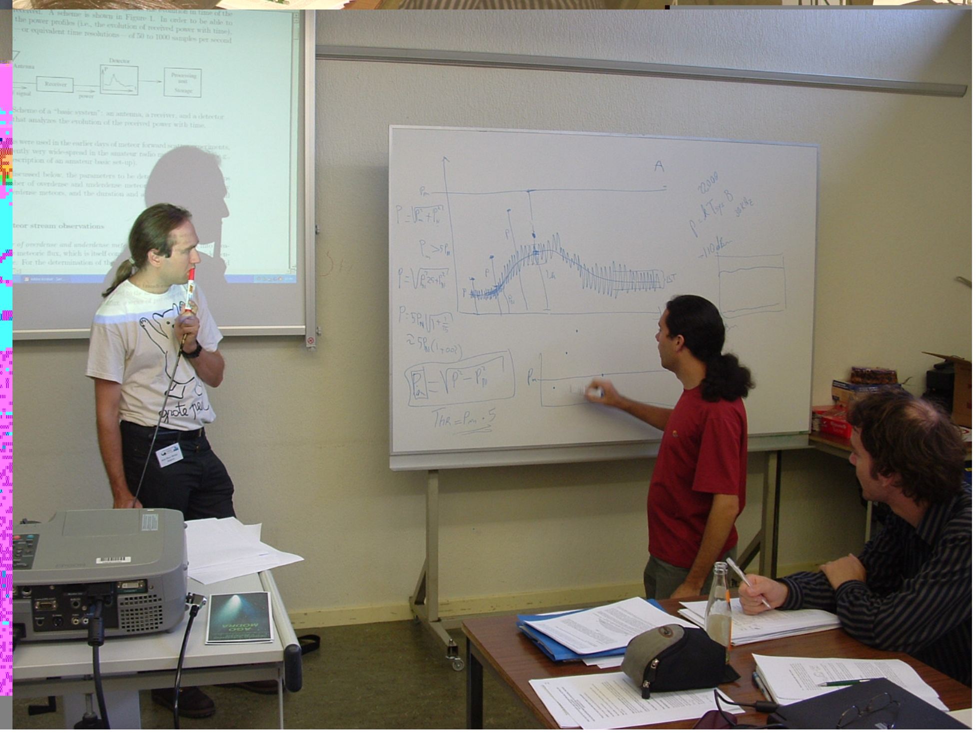
- Kaiser method suffers of several selection effects
- Belkovich method: finite velocity effect and PRF effect solved
- Ryabova method: + initial trail radius effect solved
- Verbeeck method: + lower mass limit mismatch solved
- Needed: accurate ionization profiles

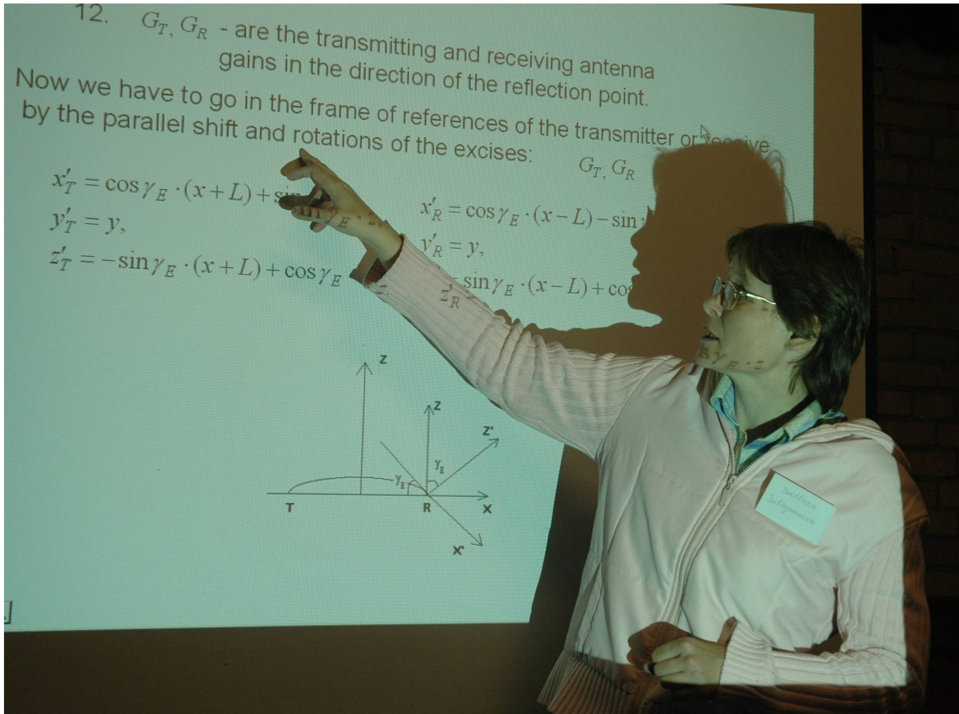
Acknowledgments

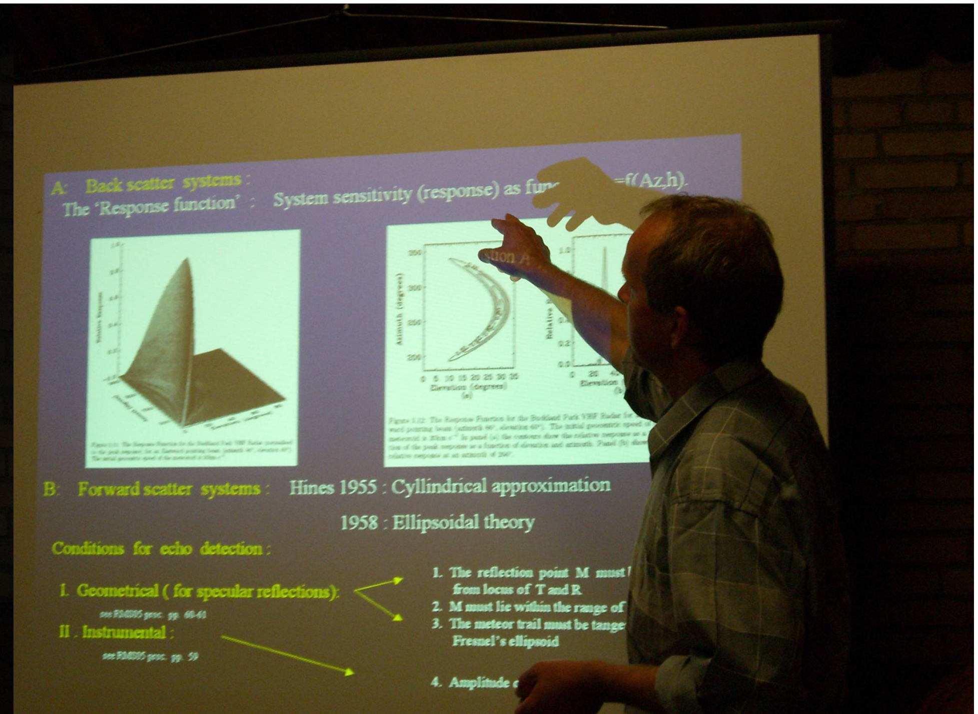
- Oleg Belkovich
- Galina Ryabova
- Svetlana Suleymanova
- Participants Radio Meteor Schools 2005-2006

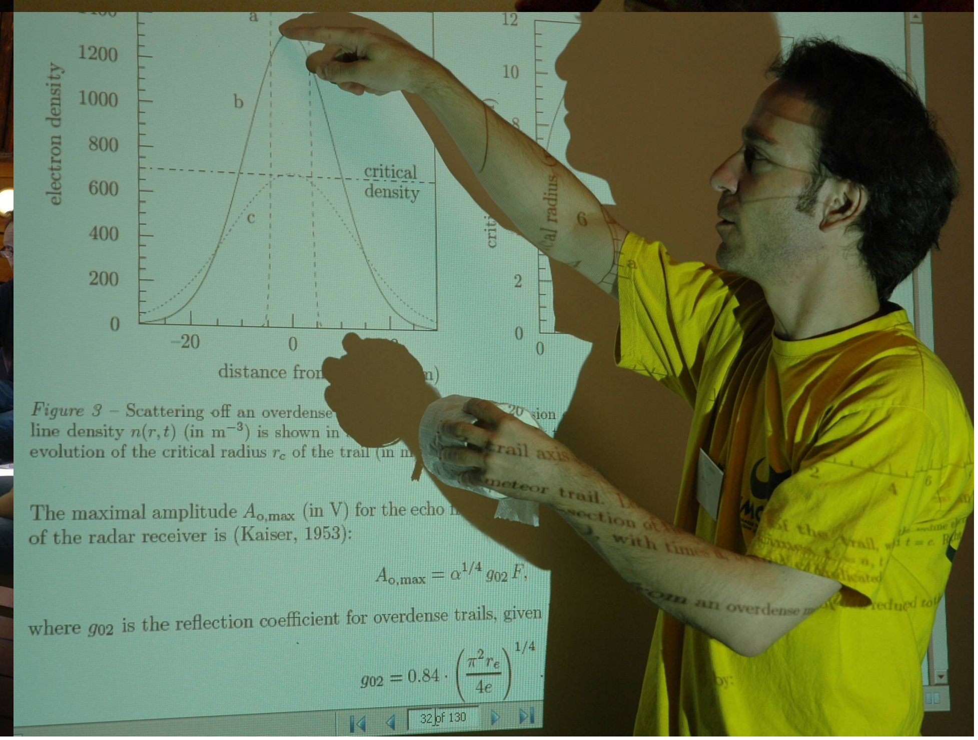







12.
- are the transmitting and receiving antenna gains in the direction of the reflection point.
Now we have to go in the frame of references of the transmitter or receive
by the parallel shift and rotations of the excises:


A: Back scatter systems :
The 'Response function' :
B: Forward scatter systems :
Hines 1955 : Cyllindrical approximation
1958 : Ellipsoidal theory
Conditions for echo detection :
I. Geometrical (for specular reflections):
II . Instrumental :
1. The reflection point M must
from locus of T and R
2. M must lie within the range of
3. The meteor trail must be tange
Fresnel's ellipsoid


electron density
critical
density
distance fro
The maximal amplitude $A_{o,max}$ (in V) for the echo
of the radar receiver is (Kaiser, 1953):
$A_{o,max} = \alpha^{1/4} g_{02} F$,
where g_{02} is the reflection coefficient for overdense trails, given
$g_{02} = 0.84 \cdot \left(\frac{\pi^2 r_e}{4e}\right)^{1/4}$