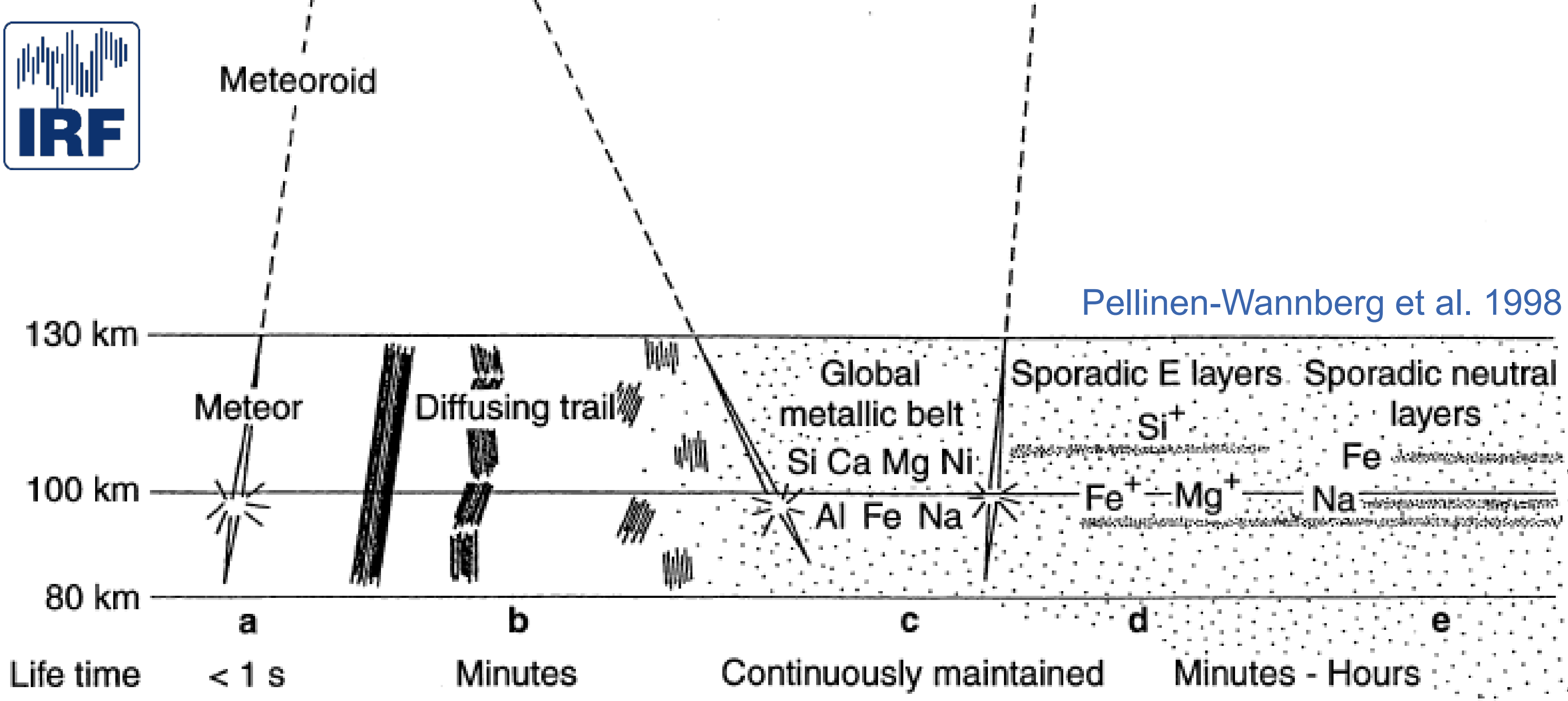


Pellinen-Wannberg et al. 1998

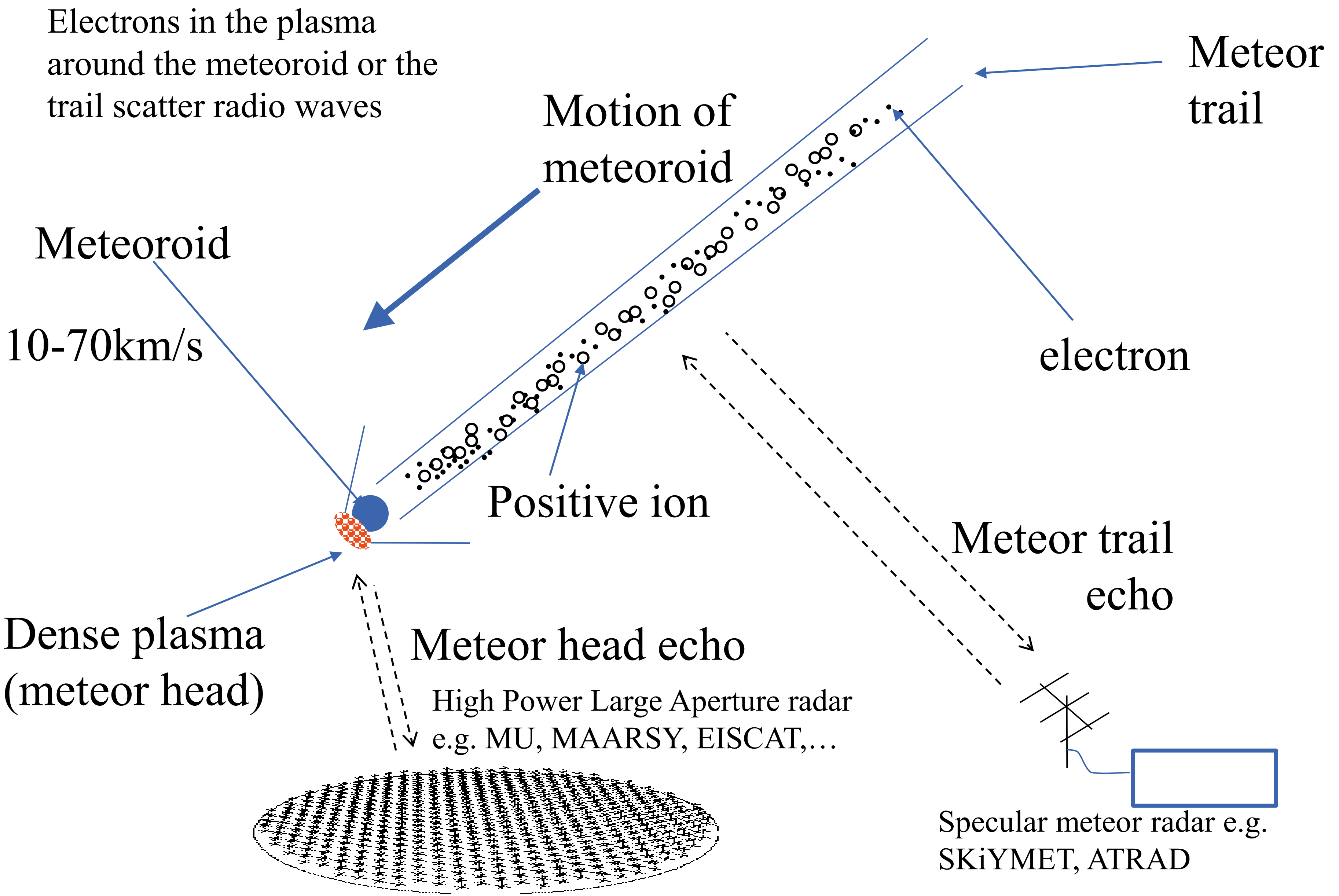
# HIGH-POWER LARGE-APERTURE (HPLA) VS SPECULAR METEOR RADAR OBSERVATIONS

Johan Kero and Daniel Kastinen

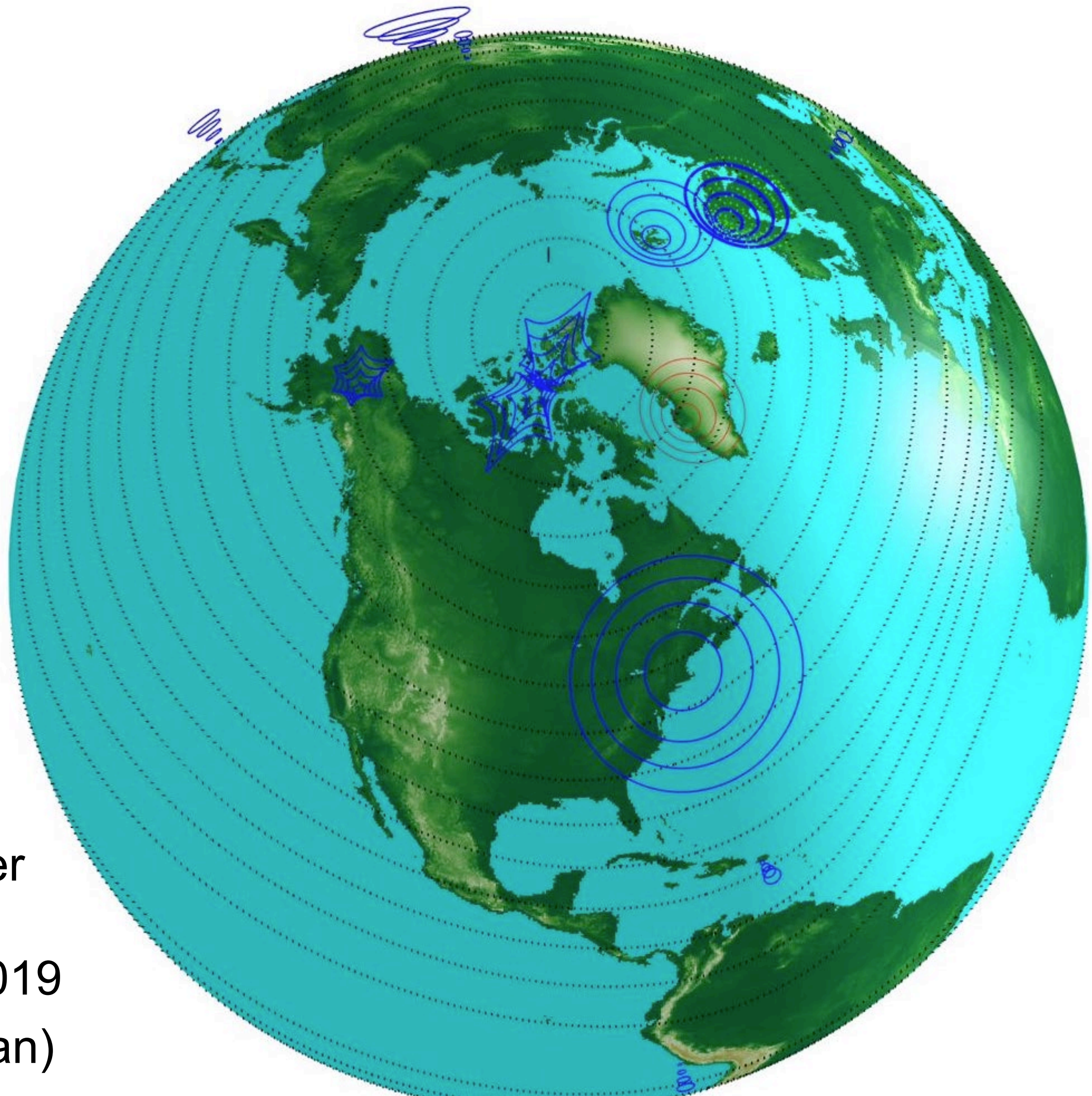
Swedish Institute of Space Physics (IRF), Kiruna, Sweden

with credits to EISCAT and Kyoto University MU radar staff

# METEOR HEAD AND TRAIL ECHOES



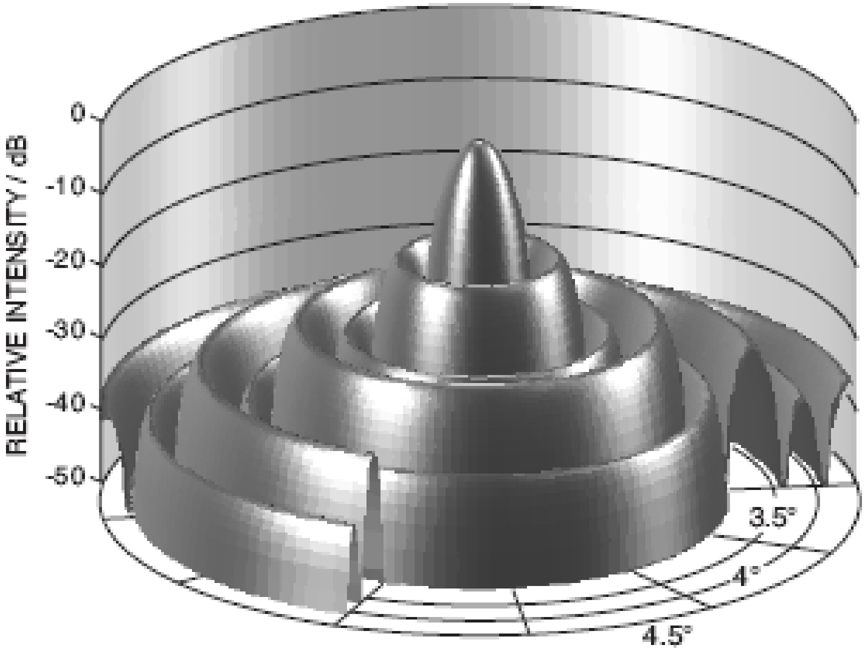
# HIGH-POWER LARGE-APERTURE RADARS



Depicted here:
Incoherent scatter
radar systems
in operation in 2019
(Craig Heinselman)

| Radar | Geographical location | Frequency [MHz] | Antenna and aperture | Peak power and max duty cycle |
|---|---|---|---|---|
| ALTAIR | Kwajalein Atoll Marshall Islands | 160 422 | Parabolic dish: 1,660m$^2$ | 6MW, 5% |
| AMISR | Alaska, USA Resolute Bay, Canada | 440 | Phased array: 715m$^2$ | 2MW, 10% |
| Arecibo | Puerto Rico | 430 | Spherical dish: 73,000m$^2$ | 2MW, 6% |
| EISCAT UHF | Northern Scandinavia | 930 | Parabolic dish: 800m$^2$ | 2MW, 12% |
| EISCAT VHF | Northern Scandinavia | 224 | Parabolic cylinder dish: 4,800m$^2$ | 1.6MW, 12% |
| EISCAT Svalbard Radar: ESR | Spitsbergen | 500 | Parabolic dishes: 800m$^2$ , 1,400m$^2$ | 1MW, 12% |
| EISCAT 3D | Northern Scandinavia | 233 | 3-5 phased arrays: 3-5 x 3,850m$^2$ | 5-10MW, 25% |
| Jicamarca | Peru | 49.9 | Phased array: 85,000m$^2$ | 1.5MW, 6% |
| MAARSY | Norway | 53.5 | Phased array: 6,300m$^2$ | 0.8MW, 5% |
| Millstone Hill | Massachusetts USA | 440 | Parabolic dishes: 1,660 , 3,525m$^2$ | 2.5MW, 6% |
| MU | Shikaragi Japan | 46.5 | Phased array: 8,300m$^2$ | 1MW, 5% |
| PANSY | Showa Station Antarctica | 47 | Phased array: 18,000 | 0.5MW, 5% |
| Sondrestrøm | Greenland | 1,290 | Parabolic dish: 800 | 3MW, 3% |

Kero et al. 2019



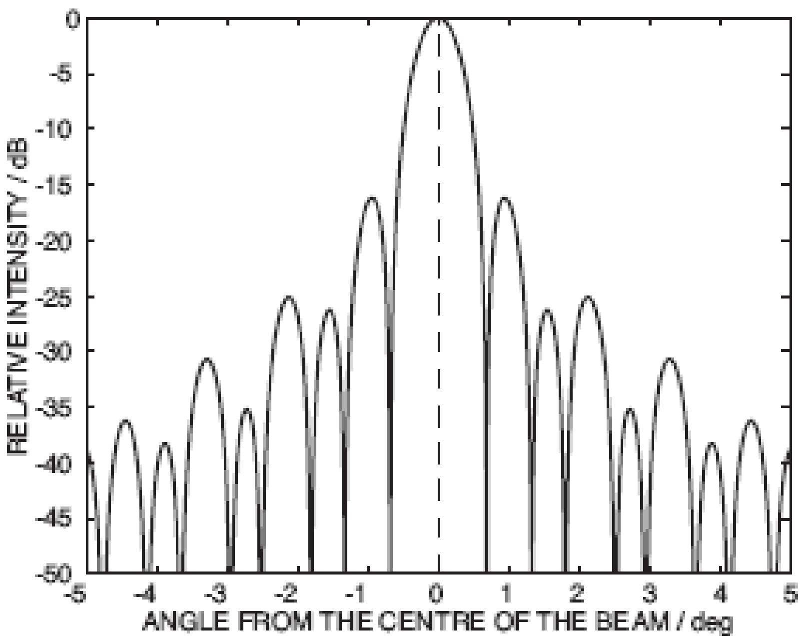
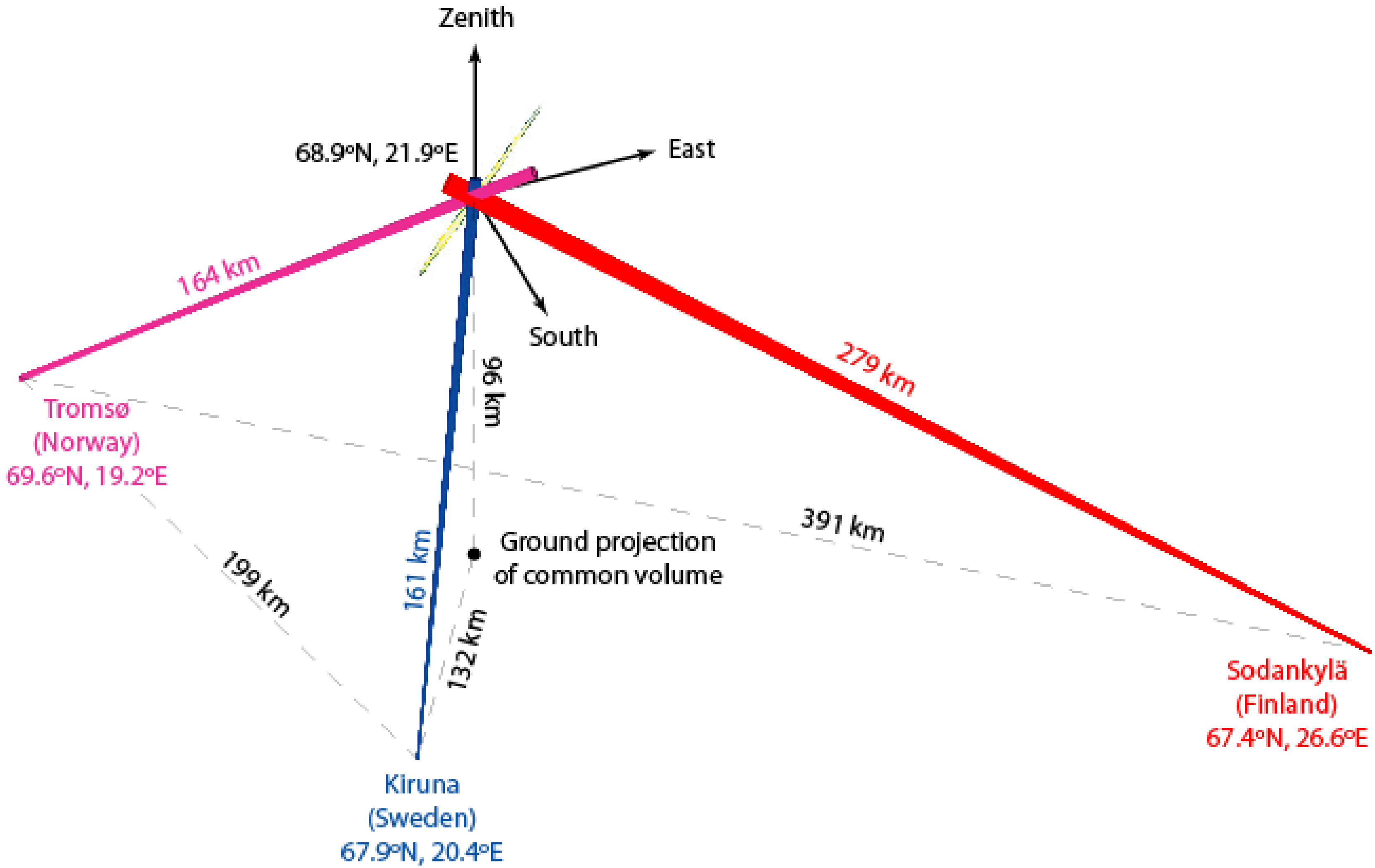



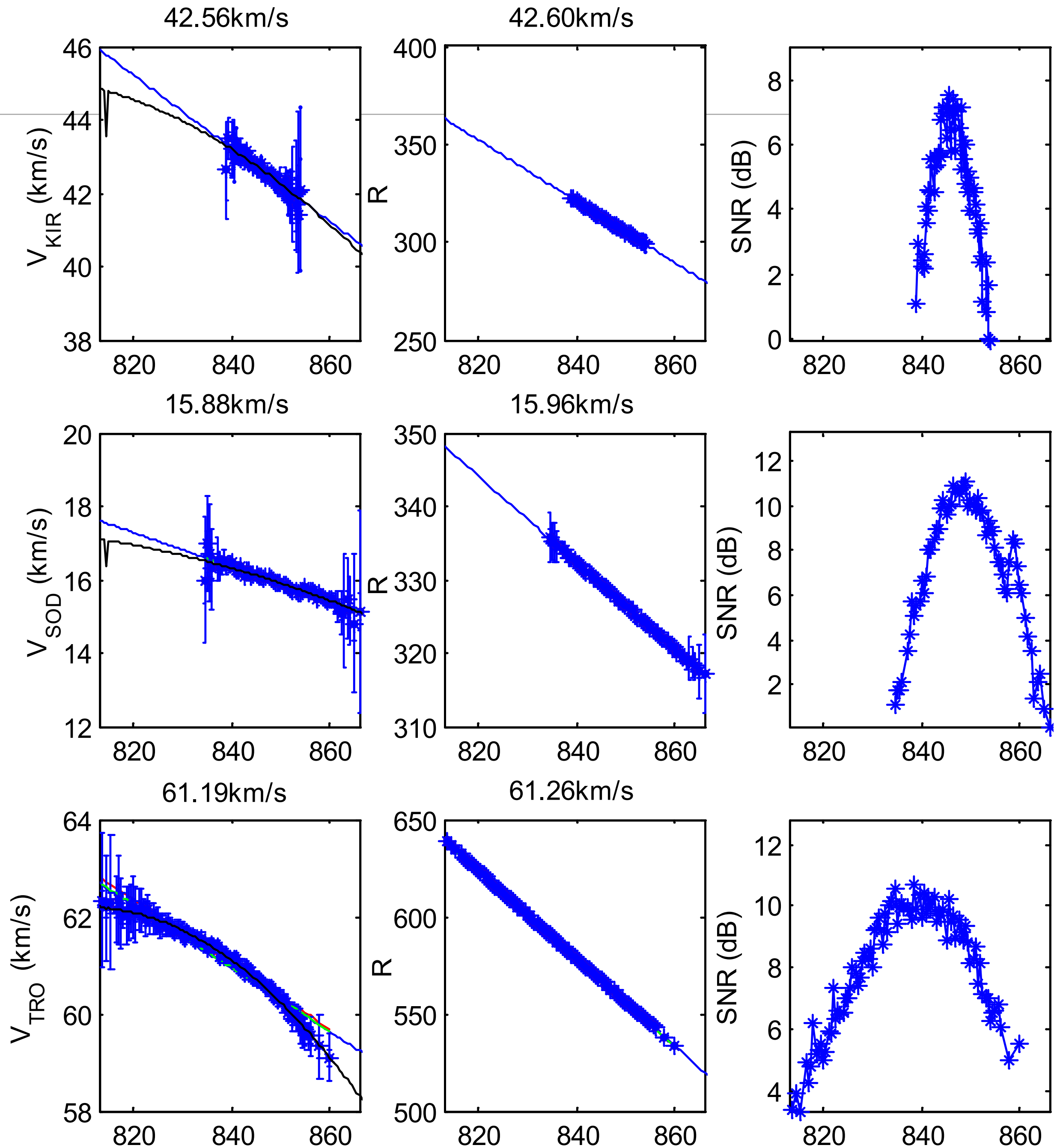

Figure 2.6 from Nygrén, T. (1996), Introduction to incoherent scatter measurements, 1st ed., Invers, Sodankylä, Finland


Zenith
68.9°N, 21.9°E
East
South
164 km
279 km
96 km
Tromsø
(Norway)
69.6°N, 19.2°E
391 km
Ground projection
of common volume
199 km
161 km
132 km
Sodankylä
(Finland)
67.4°N, 26.6°E
Kiruna
(Sweden)
67.9°N, 20.4°E

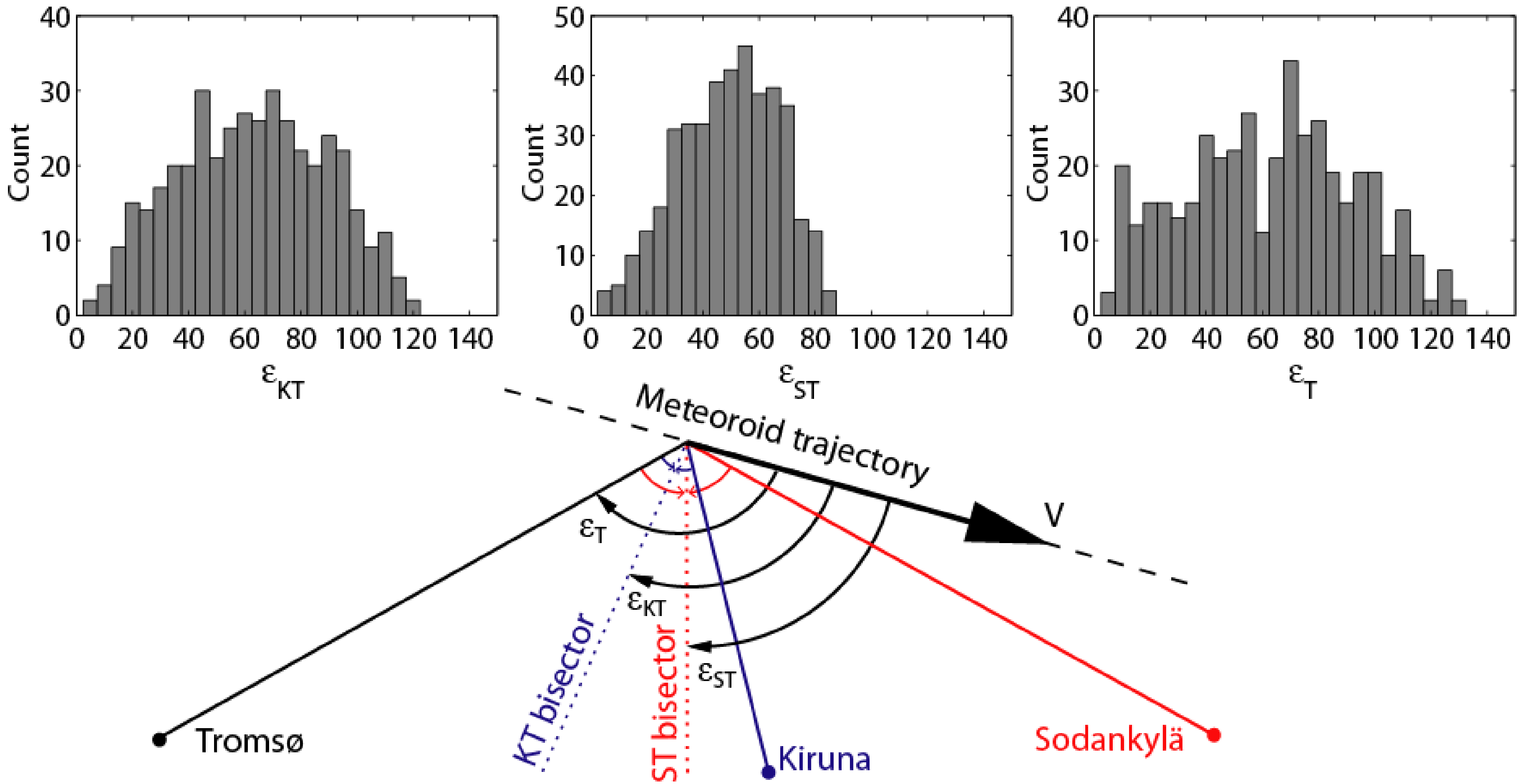
KIRUNA:

SODANKYLÄ:

TROMSØ:

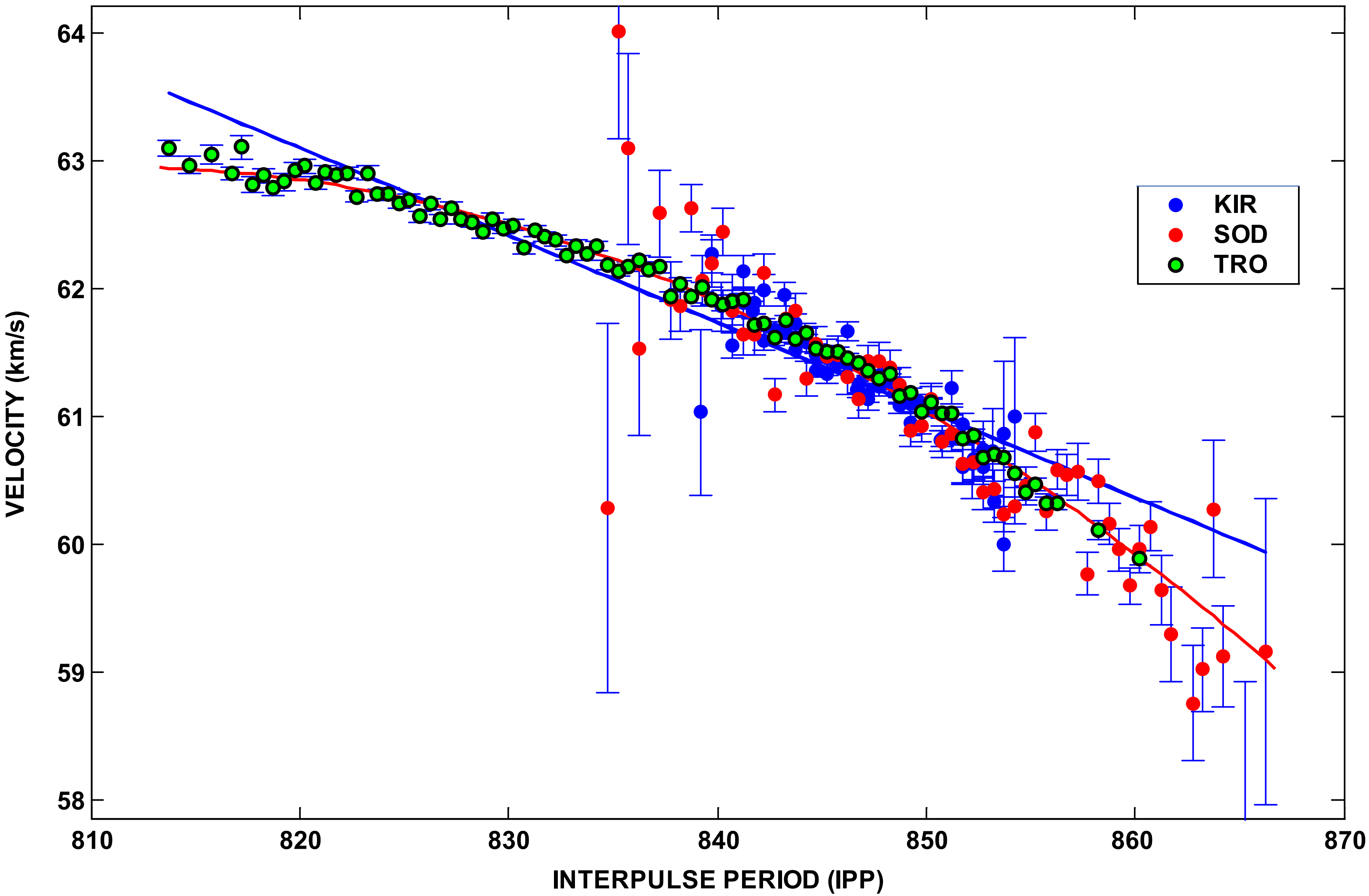


# HEAD ECHO ASPECT INDEPENDENCE

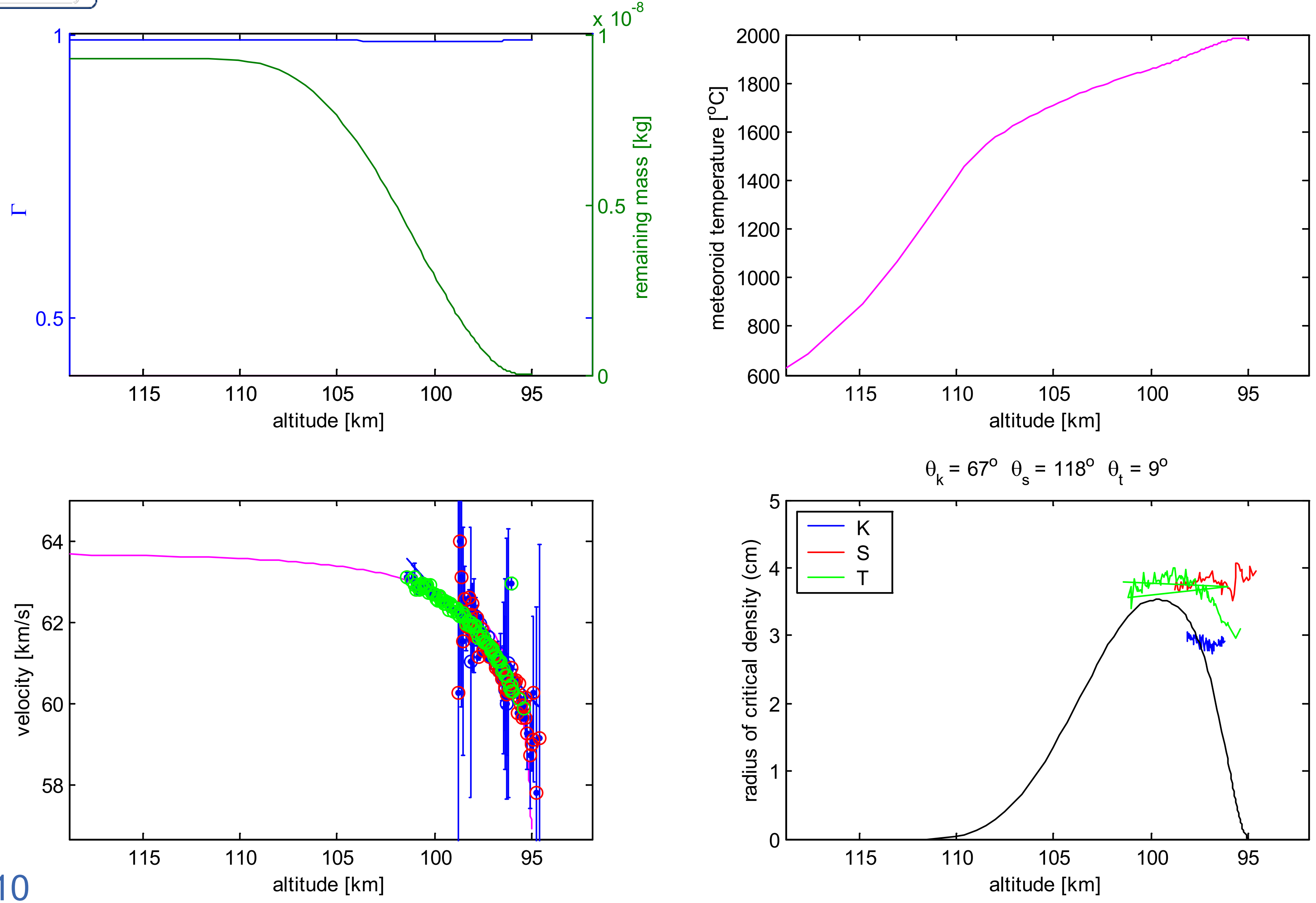



Kero et al., 2008

# METEOROID VELOCITY



velocity = 63.7 km/s; zenith angle = 49.9°
mass = $9\cdot10^{-9}$ kg; radius = 90 μm; (if spherical and density = 3.3 g/cm³)



# METEOROID MASS DETERMINATION

## Photometric mass (optical):

light energy

luminous efficiency

$$I = \tau \frac{1}{2} \frac{dm}{dt} v^2 \quad \Rightarrow \quad M_p = \frac{2}{\tau V^2} \int I dt$$

meteoroid speed

## Ionization mass (radar):

electrons per unit trail length

$$q v \mu = \beta \frac{dm}{dt} \quad \Rightarrow \quad M_q = \int \frac{q \mu V}{\beta} dt$$

atomic mass

ionization probability

## Dynamic mass (conservation of momentum):

drag coefficient

cross-sectional area

$$M_d = \frac{\Gamma A}{\left(\frac{dV}{dt}\right)} \rho_a V^2$$

deceleration

atmospheric density

# METEOROID MASS DETERMINATION

## Photometric mass (optical):

light energy — luminous efficiency — meteoroid speed

$$I = \tau \frac{1}{2} \frac{dm}{dt} v^2 \quad \Rightarrow \quad M_p = \frac{2}{\tau V^2} \int I dt$$

- role of fragmentation
- luminous efficiency (spectral lines, bandpass specific etc.)

## Ionization mass (radar):

electrons per unit trail length — atomic mass — ionization probability

$$q v \mu = \beta \frac{dm}{dt} \quad \Rightarrow \quad M_q = \int \frac{q \mu V}{\beta} dt$$

+ ionization probability
- role of fragmentation
- electron distribution near meteoroid

## Dynamic mass (conservation of momentum):

drag coefficient — cross-sectional area — deceleration — atmospheric density

$$M_d = \frac{\Gamma A}{(\frac{dV}{dt})} \rho_a V^2$$

# MU radar (Middle and Upper atmosphere)


Monostatic coherent pulse Doppler radar
Antenna aperture: 8330 m2
Pulse length: 1 – 500 µs

VHF 46.5MHz, 1MW output
Beam width: 3.6 deg
475 antennas

# METEOR HEAD ECHO DATA @ MU

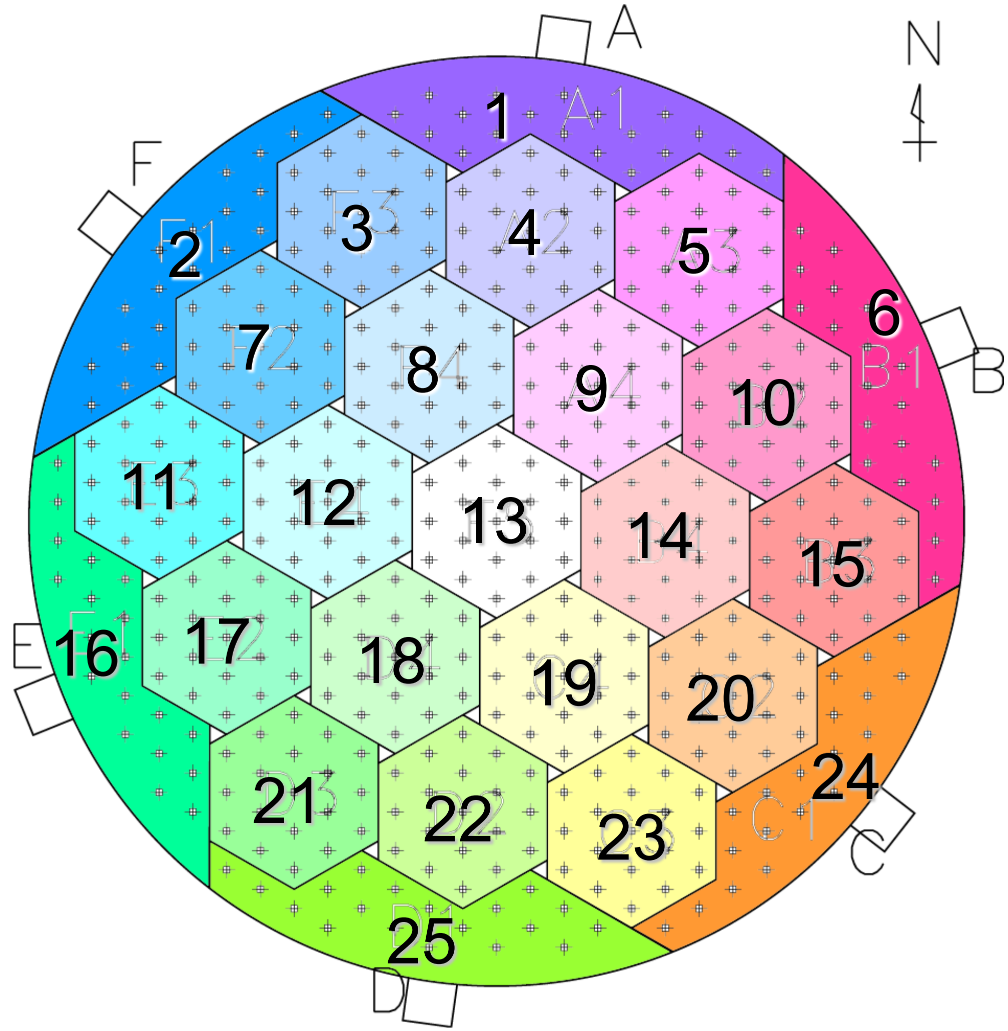
Time series of 32 bit
complex voltages:

25 channels

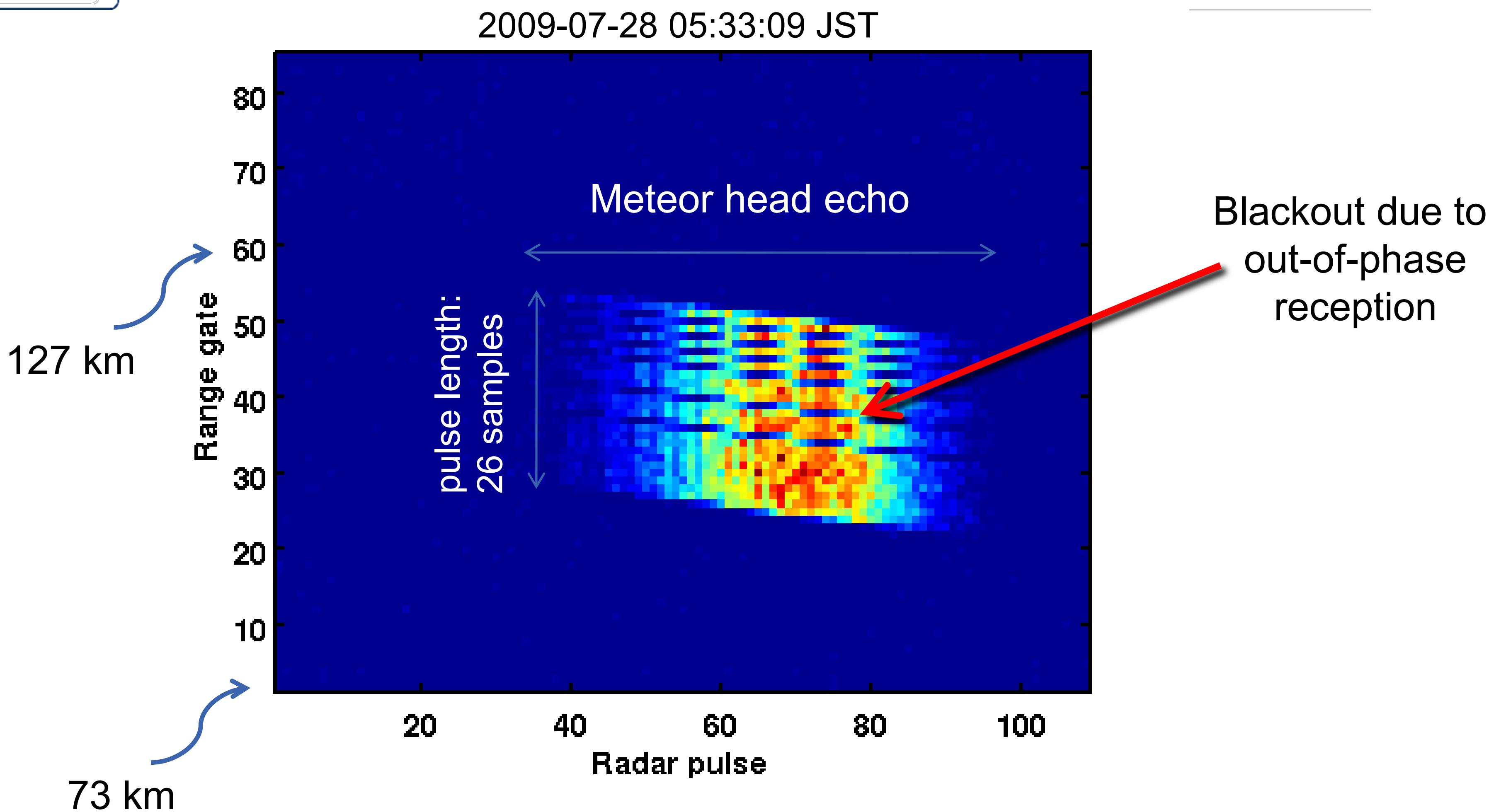
85 ranges

332 times per second

About 20 GB/hour



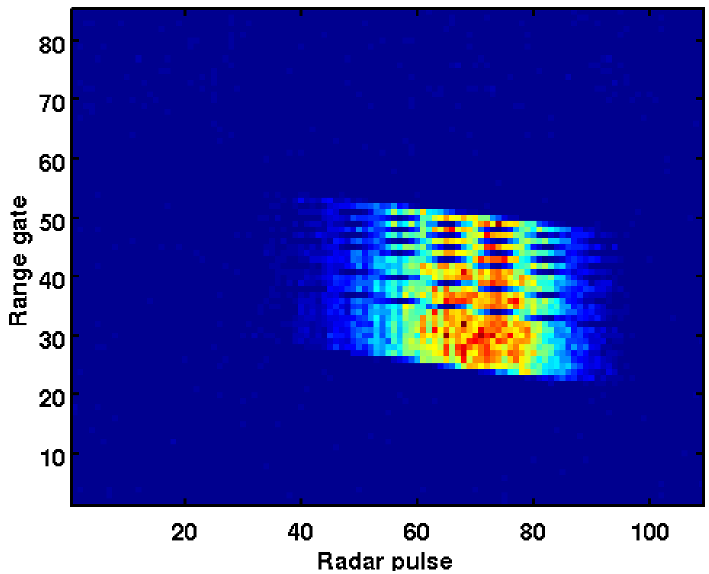
# METEOR HEAD ECHO DATA @ MU

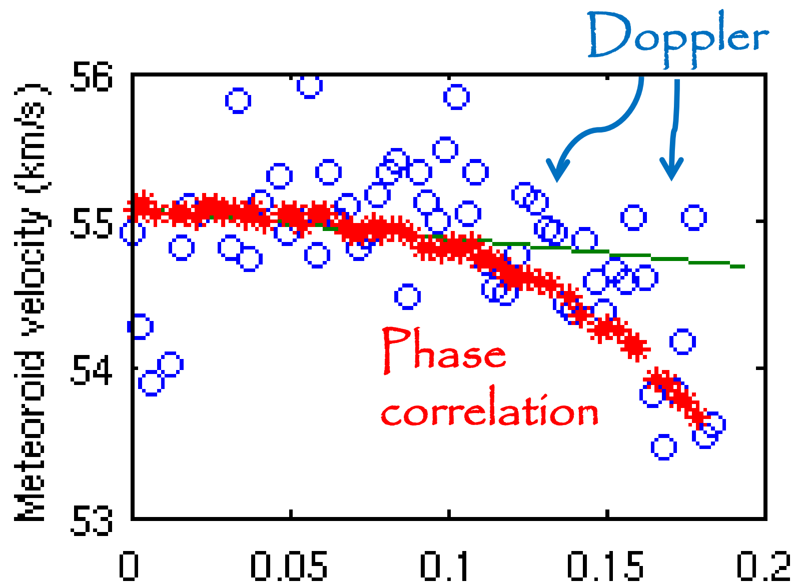



Transmission of 26x6μs: 156 μs pulse

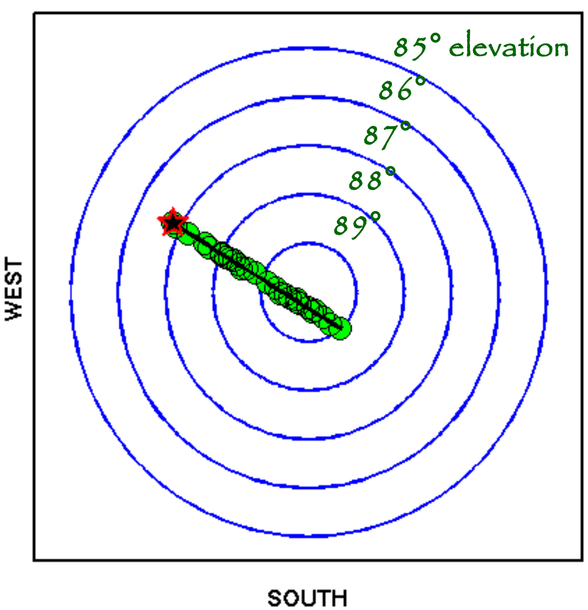
Interpulse period: 3.12 ms

Range gate: 6 μs ≈ 900 m

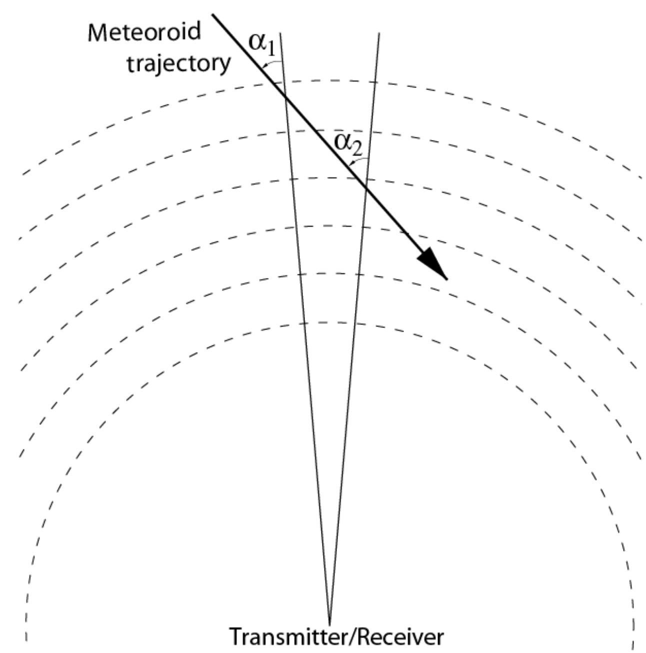



2009-07-28 05:33:09 JST

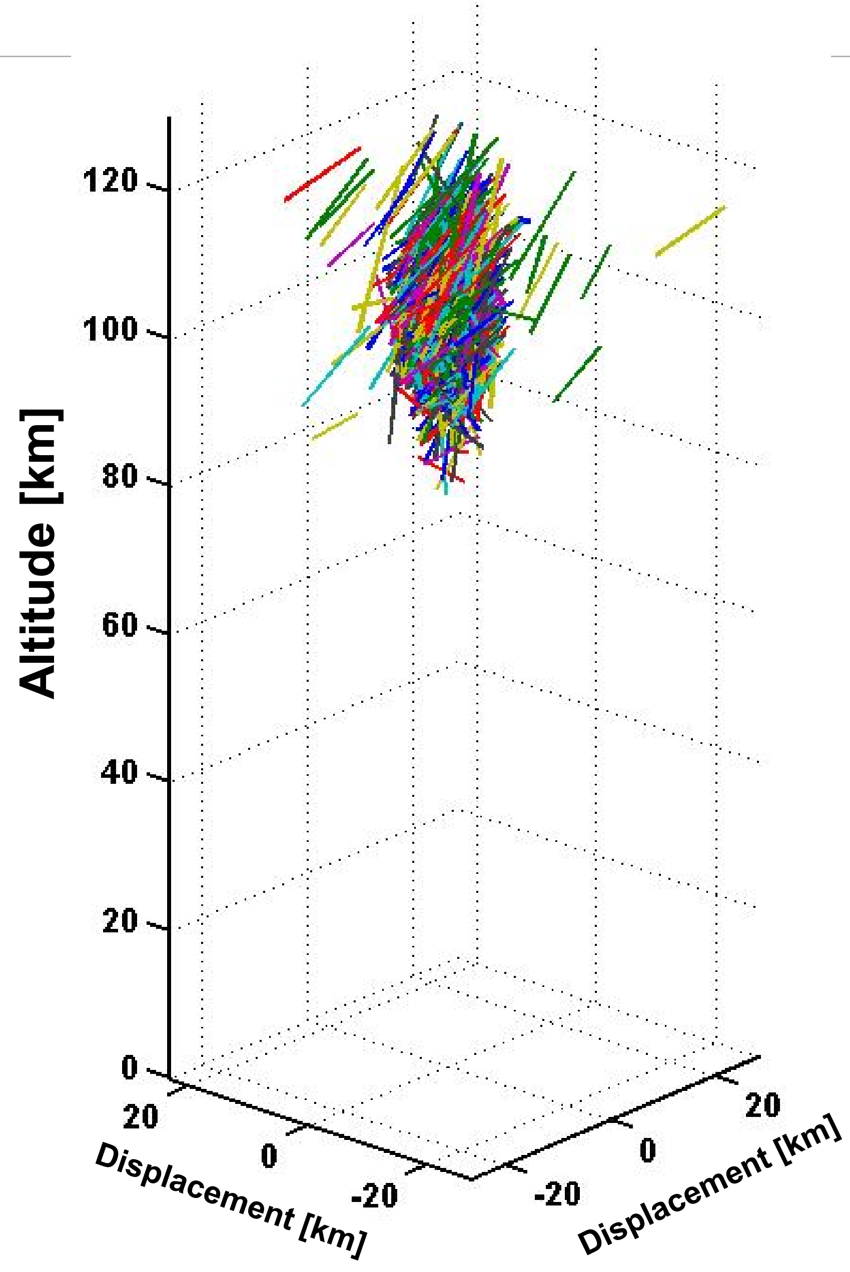



# Meteor head echo at the MU radar

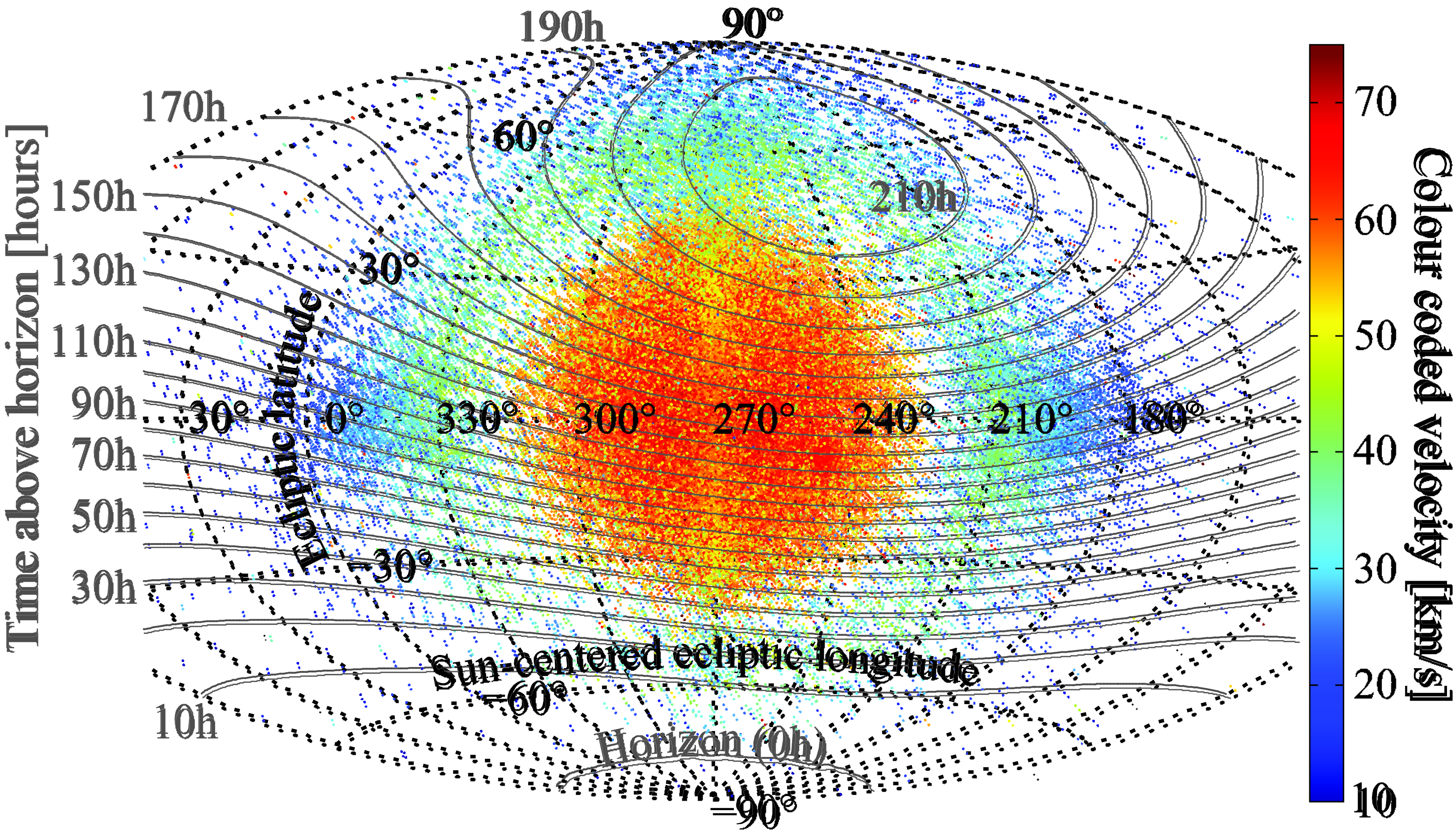



Kero et al., 2012

# 1000 METEORS IN THE MU BEAM



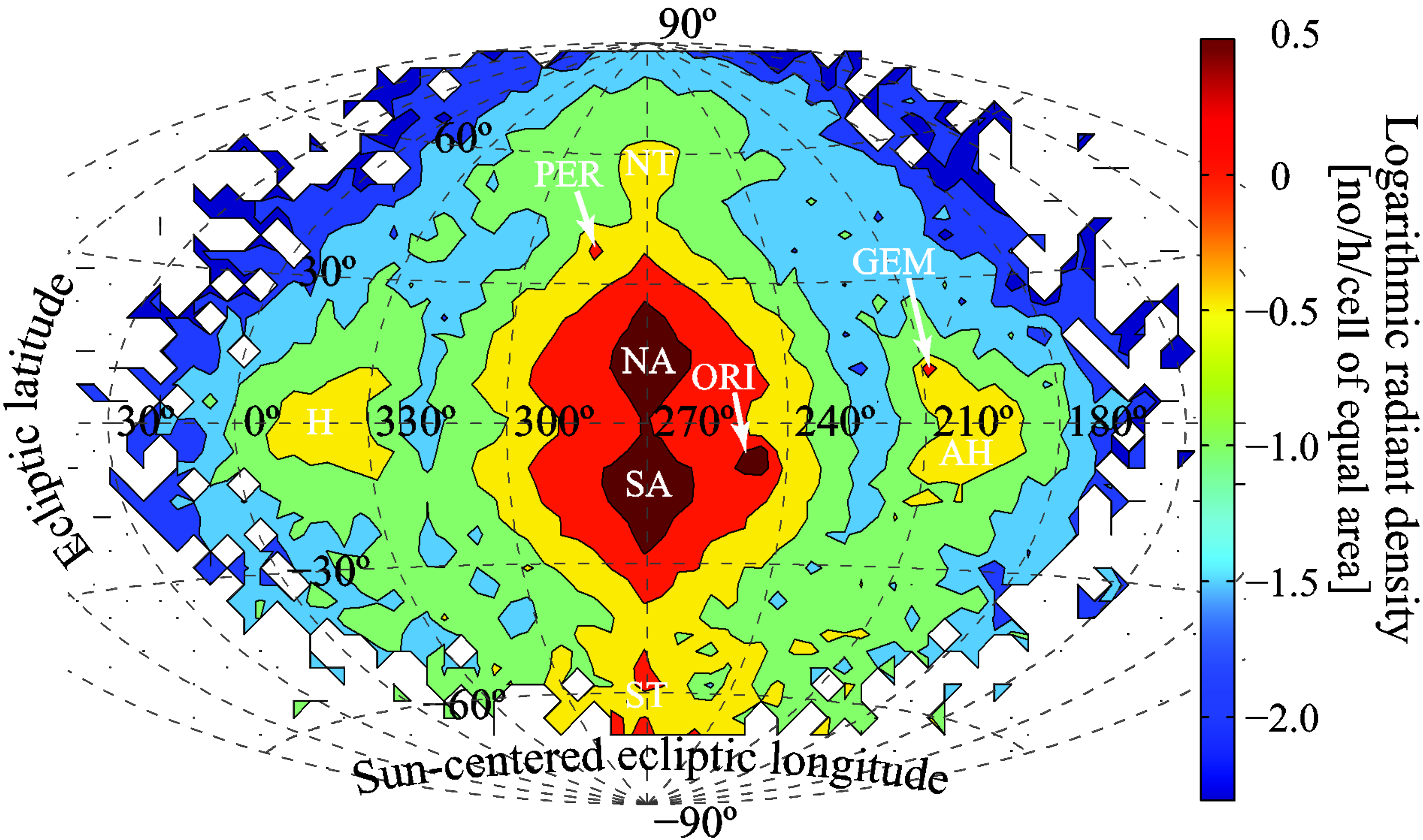
# MU METEOR RADIANTS




106139 meteors

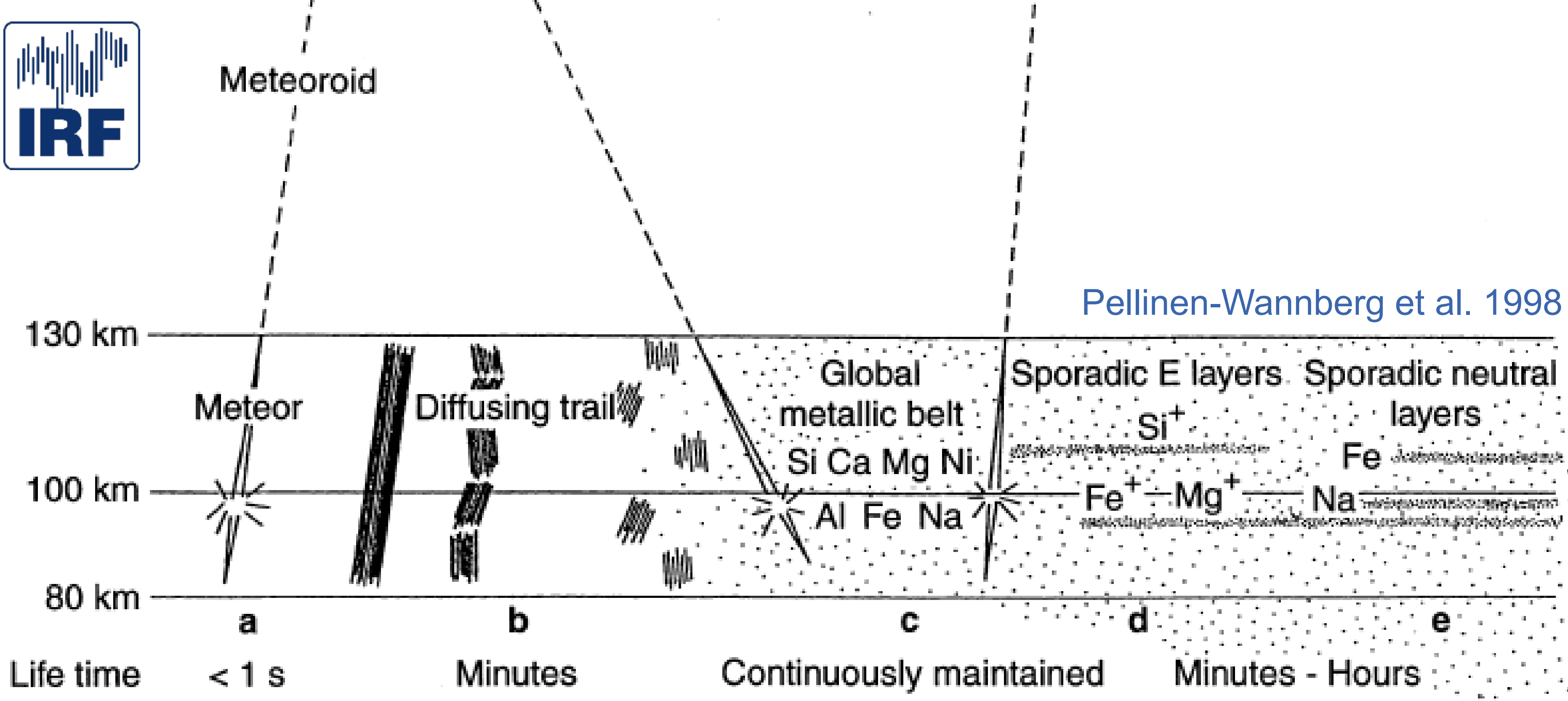
Kero et al., 2012

# MU METEOR RADIANT DENSITY



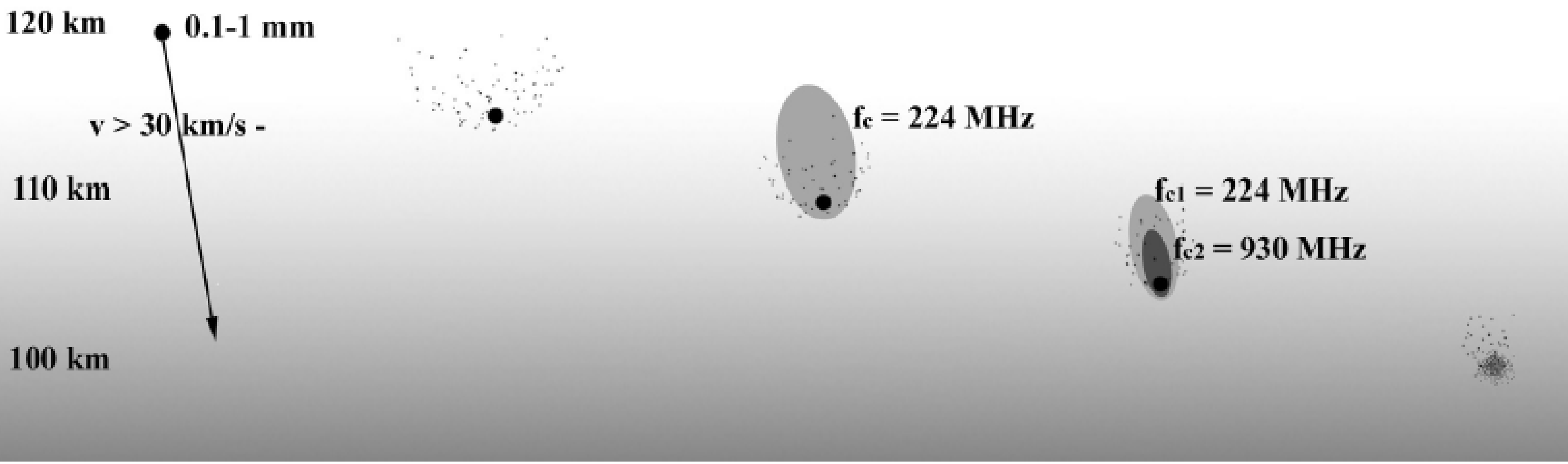

106139 meteors

Kero et al., 2012




Pellinen-Wannberg et al. 1998

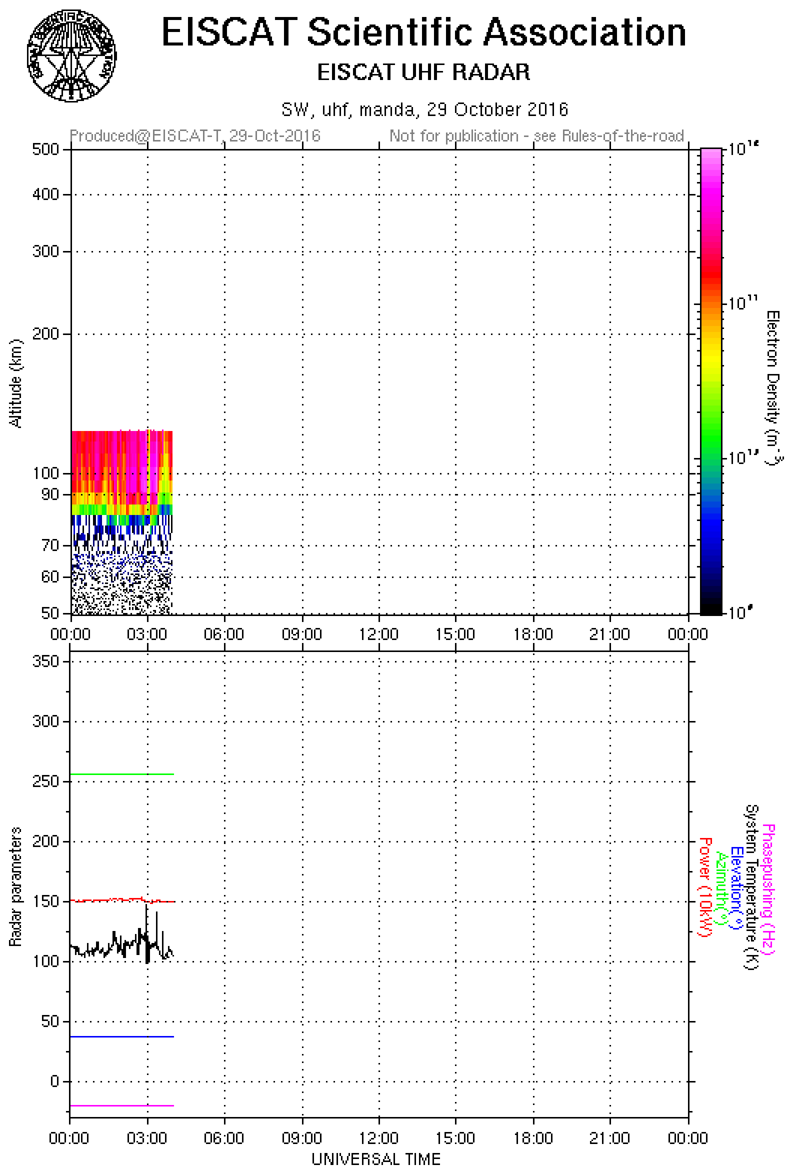
The appearance of overdense head echo condition for EISCAT observation

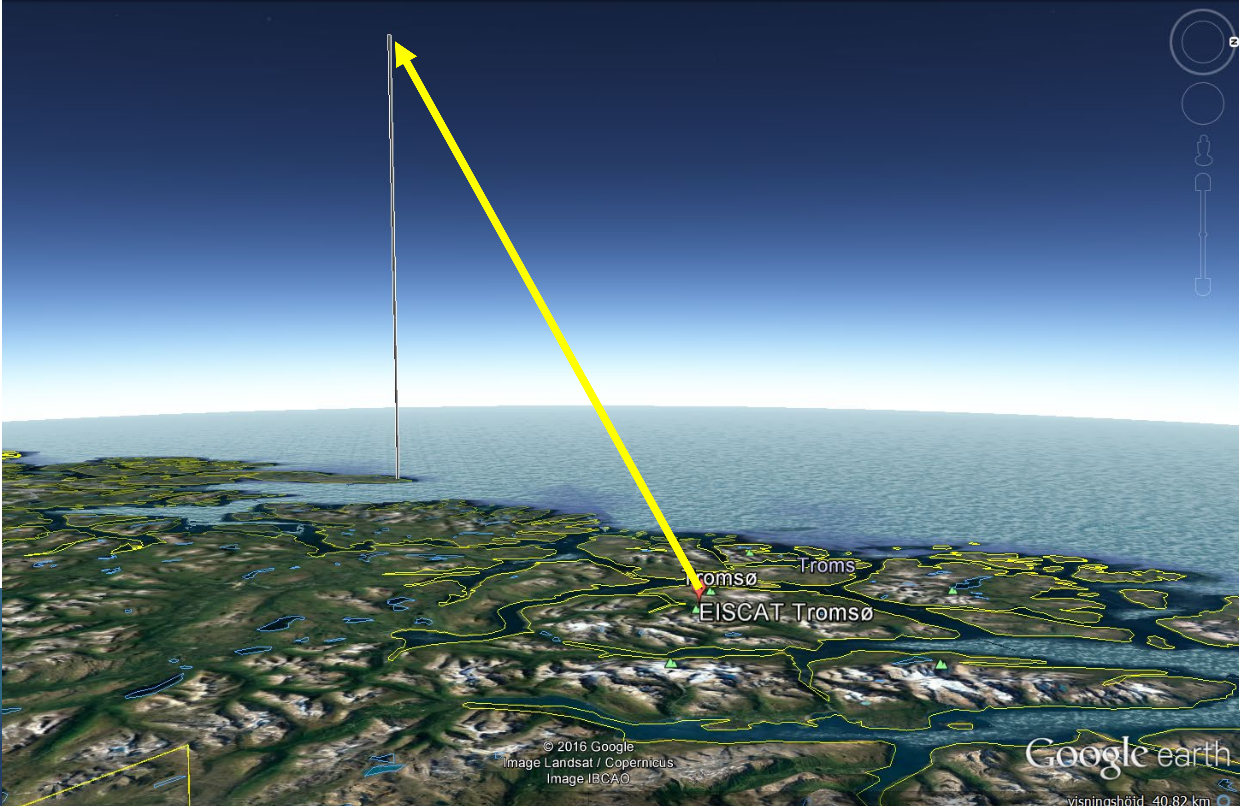



Pellinen-Wannberg (2005)

| Location | Tromsø | |
|---|---|---|
| Band | VHF | UHF |
| Transmitter frequencies | 222.8 - 225.4 MHz | 926.6 - 930.5 MHz |
| Transmitter | 1 klystron | 2 klystrons |
| Peak power | 1.6 MW | 2 MW |
| Average power | 200 kW | 250 kW |
| Pulse duration | 1 µs - 2.0 ms | 1 µs - 2.0 ms |
| Minimum interpulse | 1.0 ms | 1.0 ms |
| Phase coding | Binary | Binary |
| Receiver frequencies | 214.3-234.7 MHz | 921.0-933.5 MHz |
| Receiver | Analog | Analog |
| System temperature | 250-350 K | 90-110 K |
| Antenna | Four 30×40 m steerable parabolic cylinders | 32 m steerable parabolic dish |
| Feed system | Line feed, 128 crossed dipoles | Cassegrain |
| Gain | 46 dBi | 48.1 dBi |
| Polarisation | Circular | Circular |

| Name | Code length [bit] | Baud length [µs] | Sampling rate [µs] | Range span [km] | Time resolution [s] | Plasma line | Raw data |
|---|---|---|---|---|---|---|---|
| manda | 61 | 2.4 | 1.2 | 19–209 | 4.8 | - | Yes |

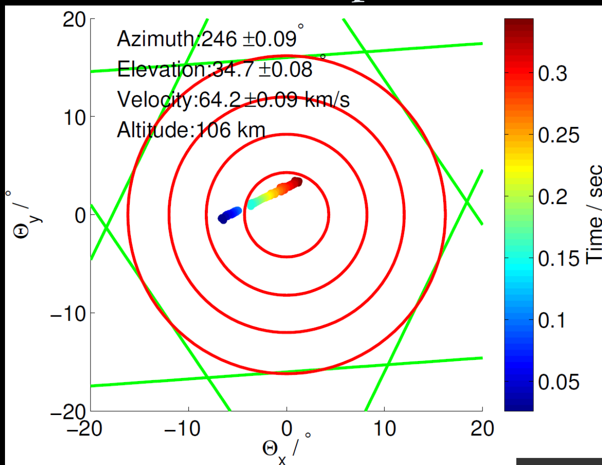


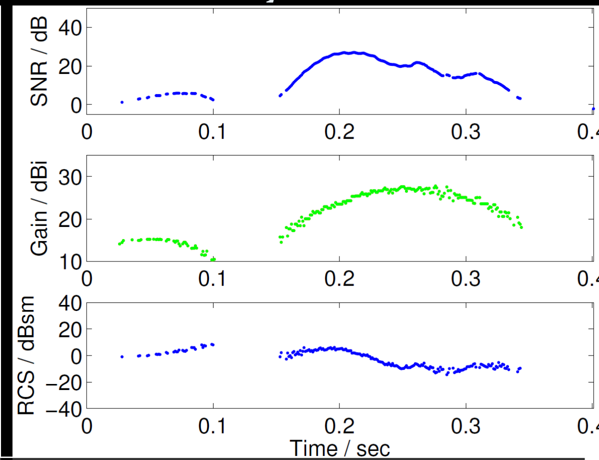



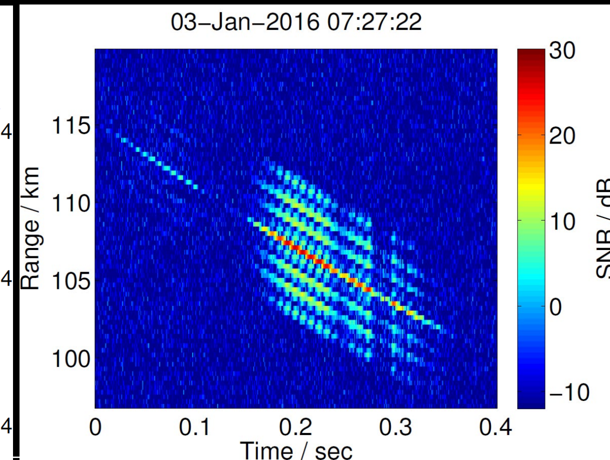



MAARSY on Andöya, IAP Kühlungsborn

# Middle Atmosphere Alomar Radar System-MAARSY

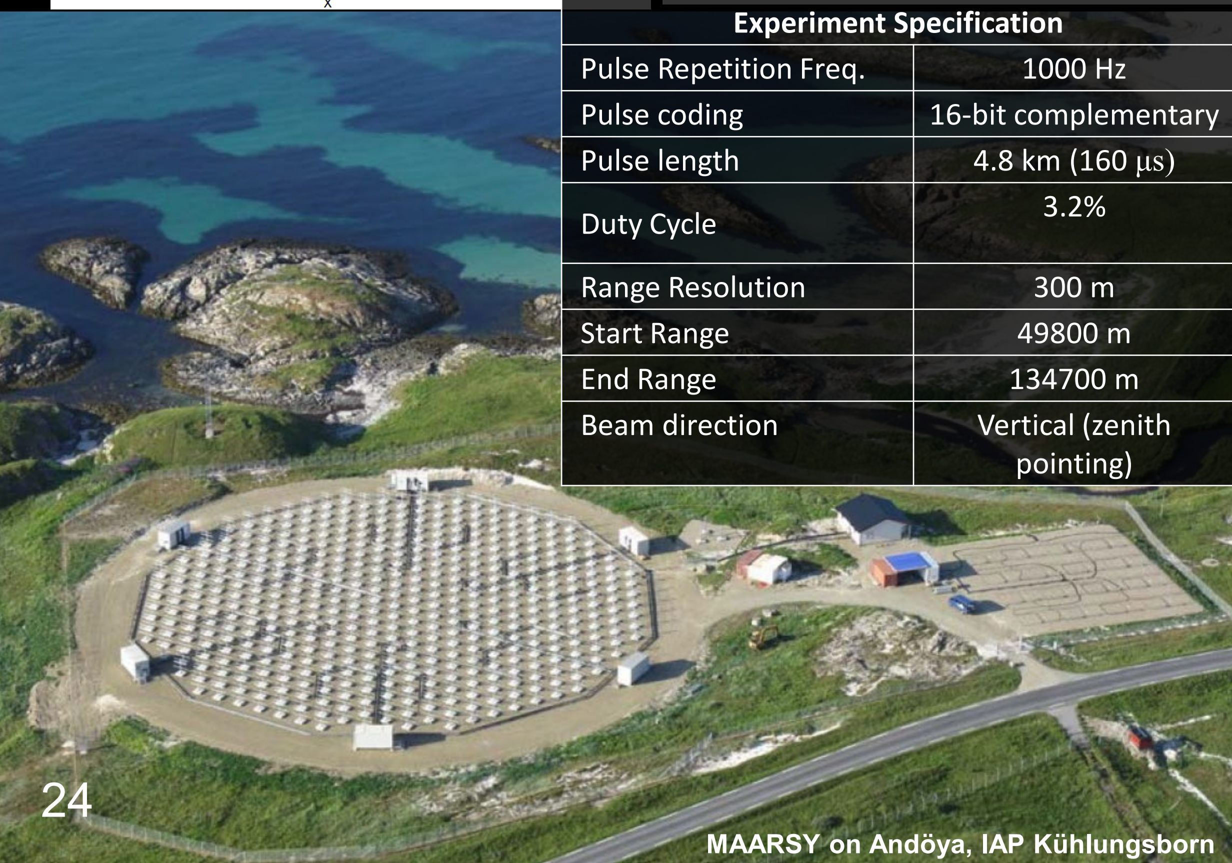


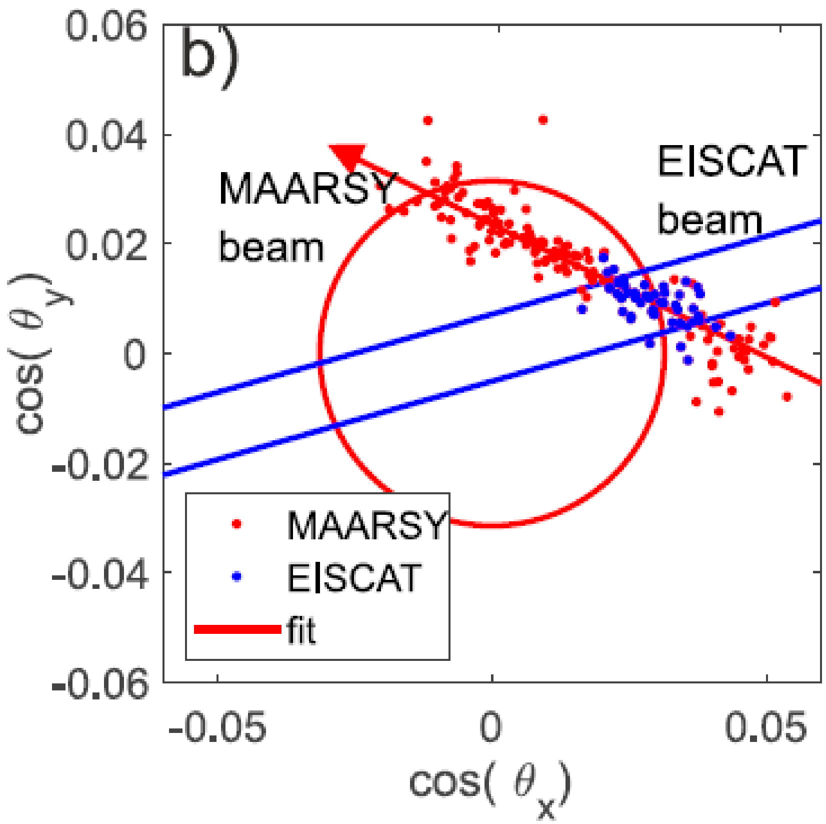

| Experiment Specification | |
|---|---|
| Pulse Repetition Freq. | 1000 Hz |
| Pulse coding | 16-bit complementary |
| Pulse length | 4.8 km (160 μs) |
| Duty Cycle | 3.2% |
| Range Resolution | 300 m |
| Start Range | 49800 m |
| End Range | 134700 m |
| Beam direction | Vertical (zenith pointing) |

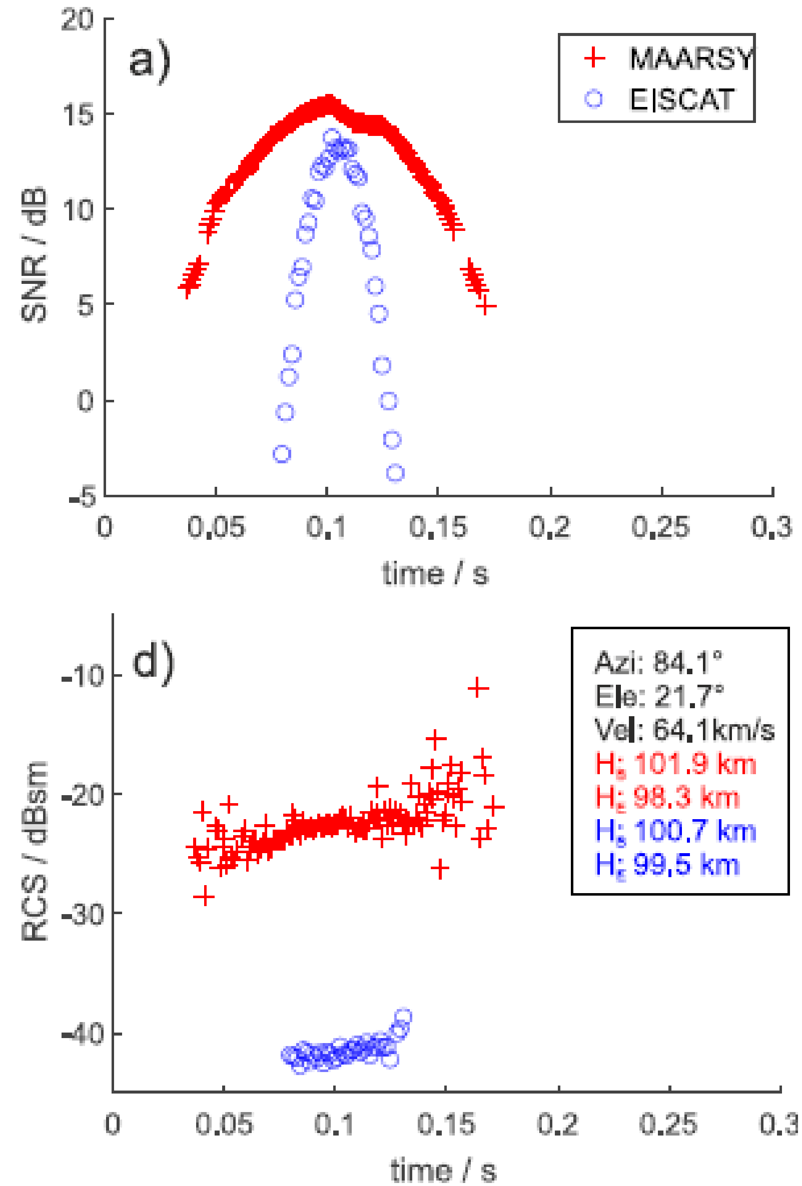
| Hardware Specification | |
|---|---|
| Frequency | 53.5 MHz |
| Transceiver-modules | 433 |
| Power | ~866 kW |
| Antennas | 433 3-element (crossed) Yagi Antennas |
| Gain | 33.7 dBi |
| Aperture | ~6300 m$^2$ |
| Beam width | 3.6° |
| Beam steering capabilities | freely steerable with 35° off-zenith |
| Receiver channels | 16 |



MAARSY on Andöya, IAP Kühlungsborn

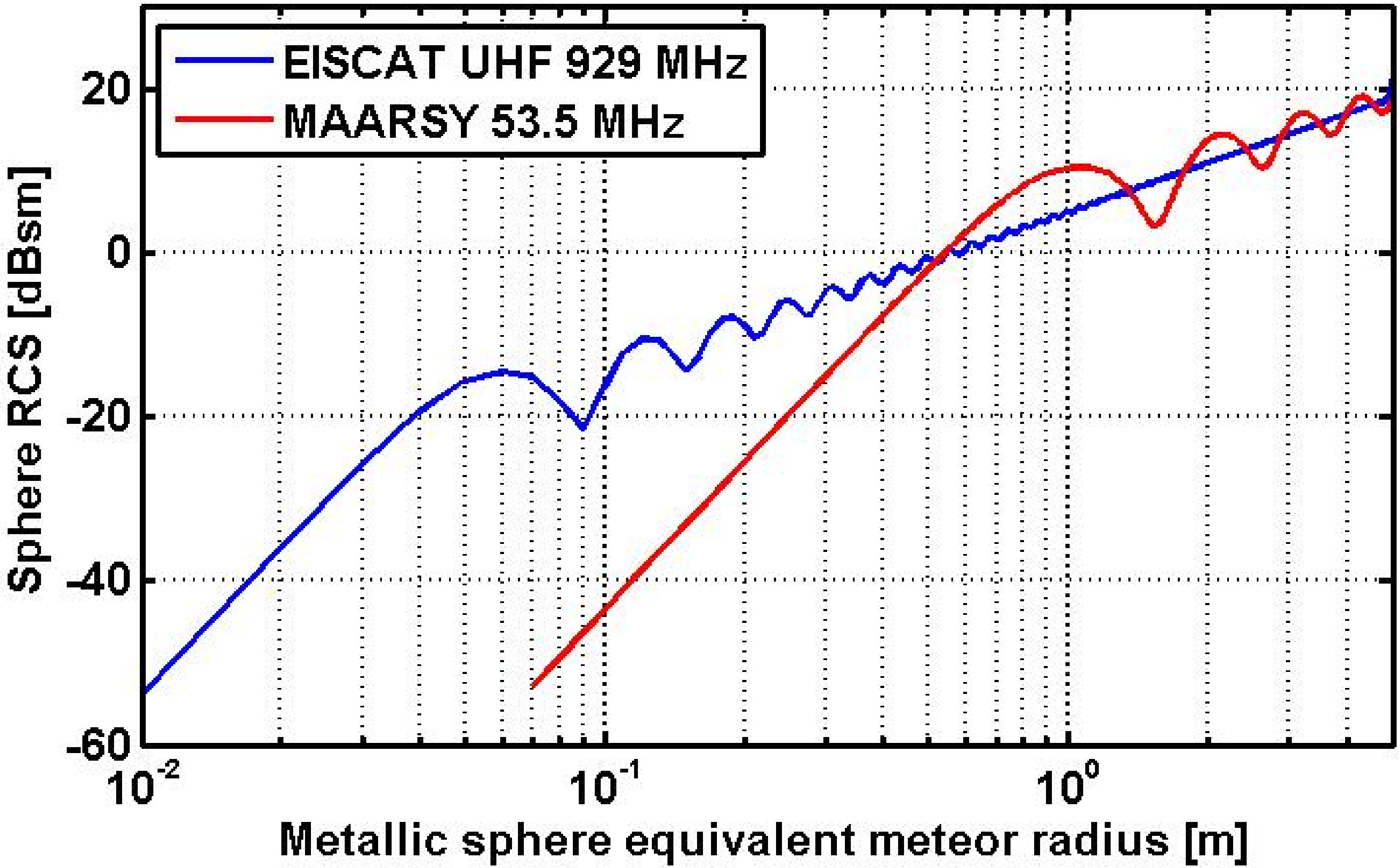
# DUAL FREQUENCY RADAR OBSERVATIONS



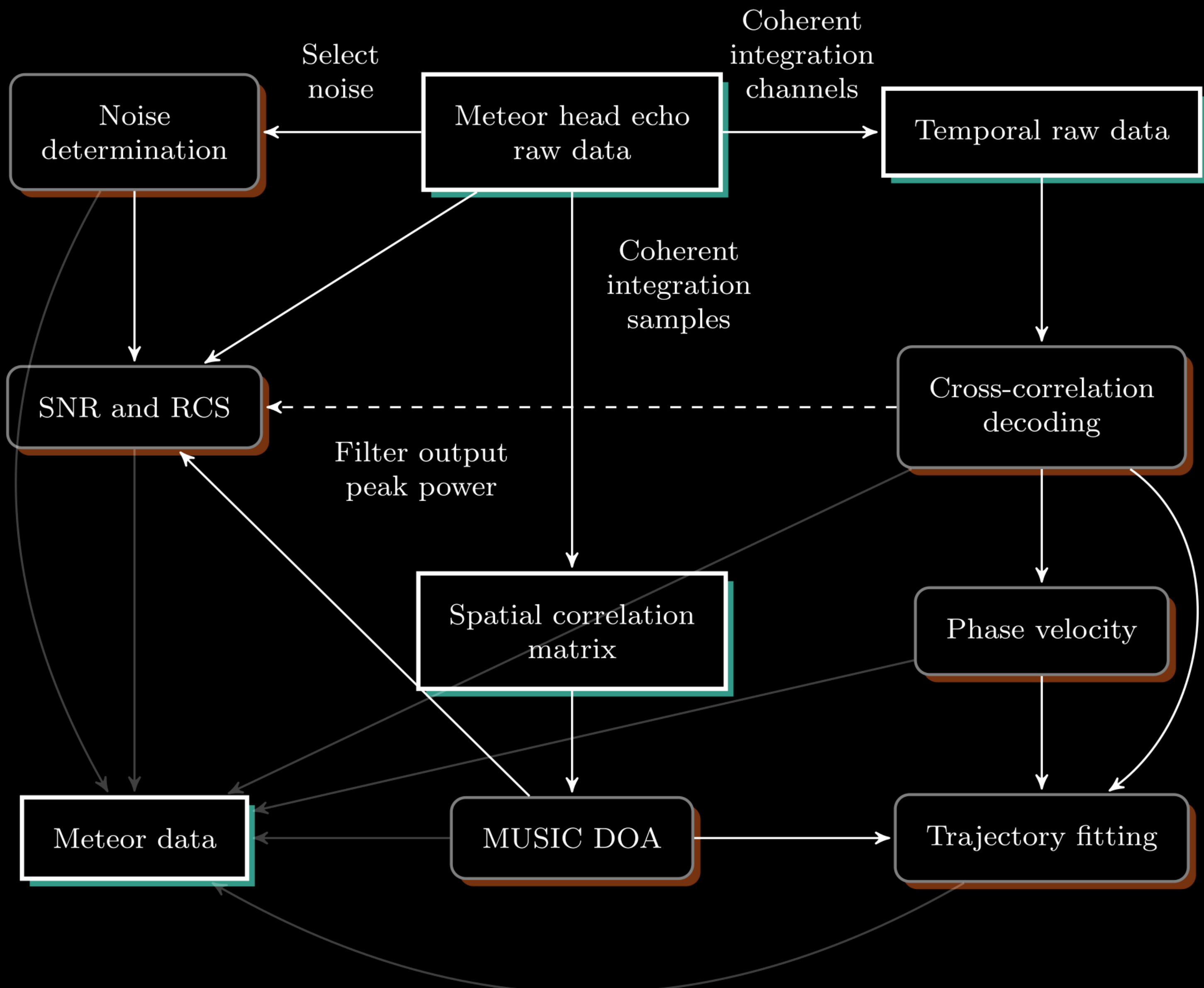




Schult et al. (2021)

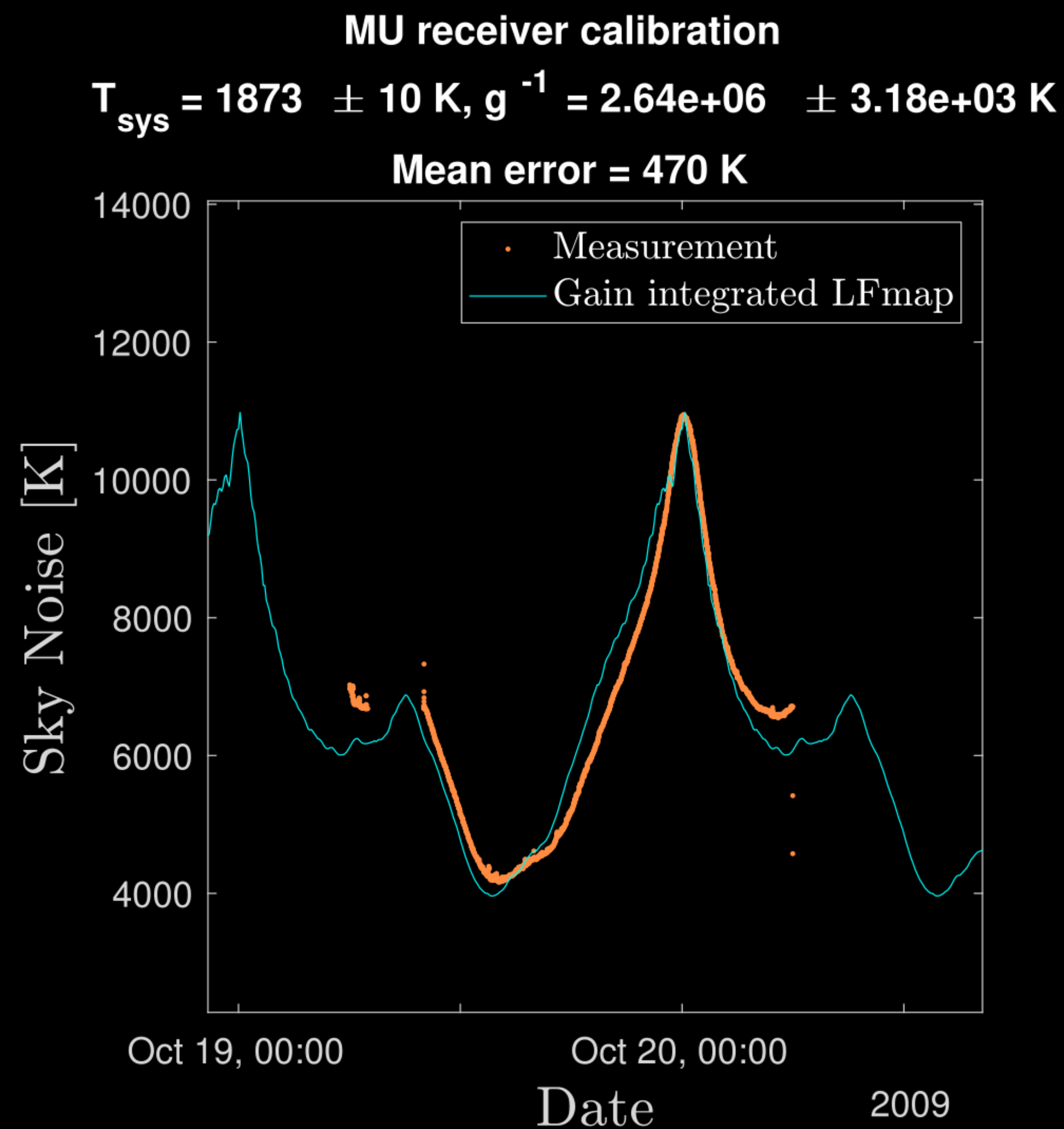
# RAYLEIGH SCATTERING



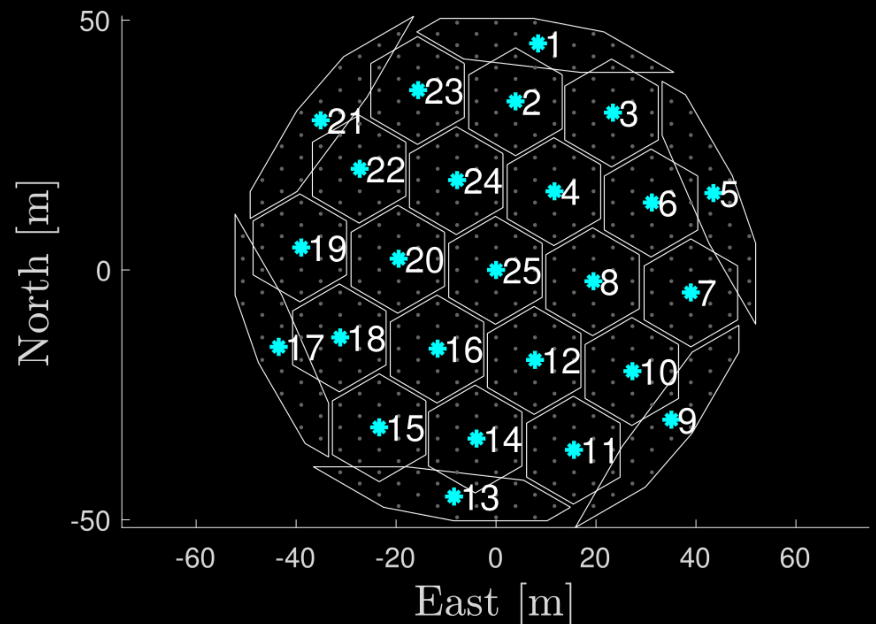
# SIGNAL ANALYSIS

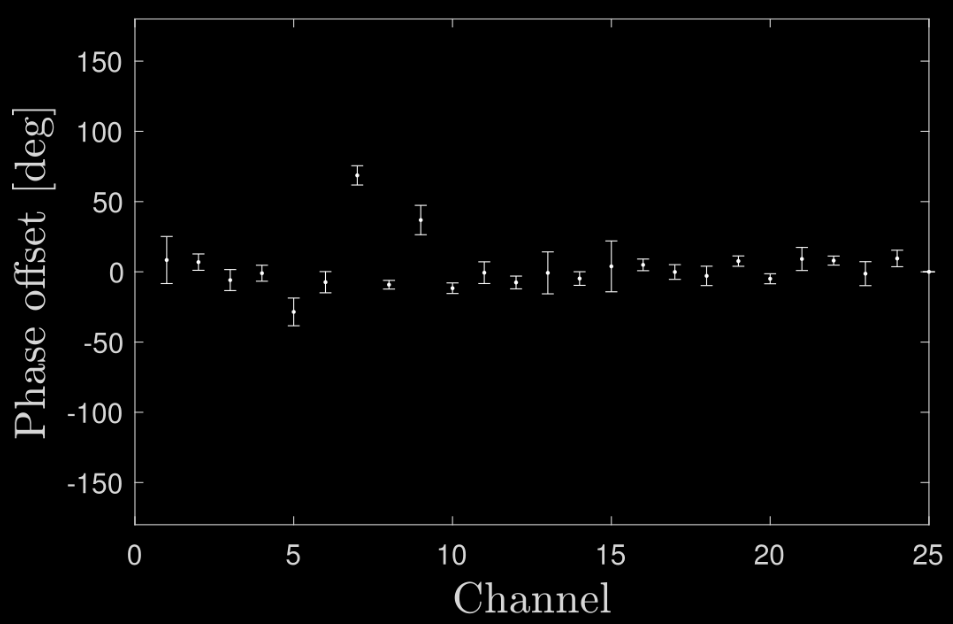


# SIGNAL ANALYSIS



# SIGNAL ANALYSIS



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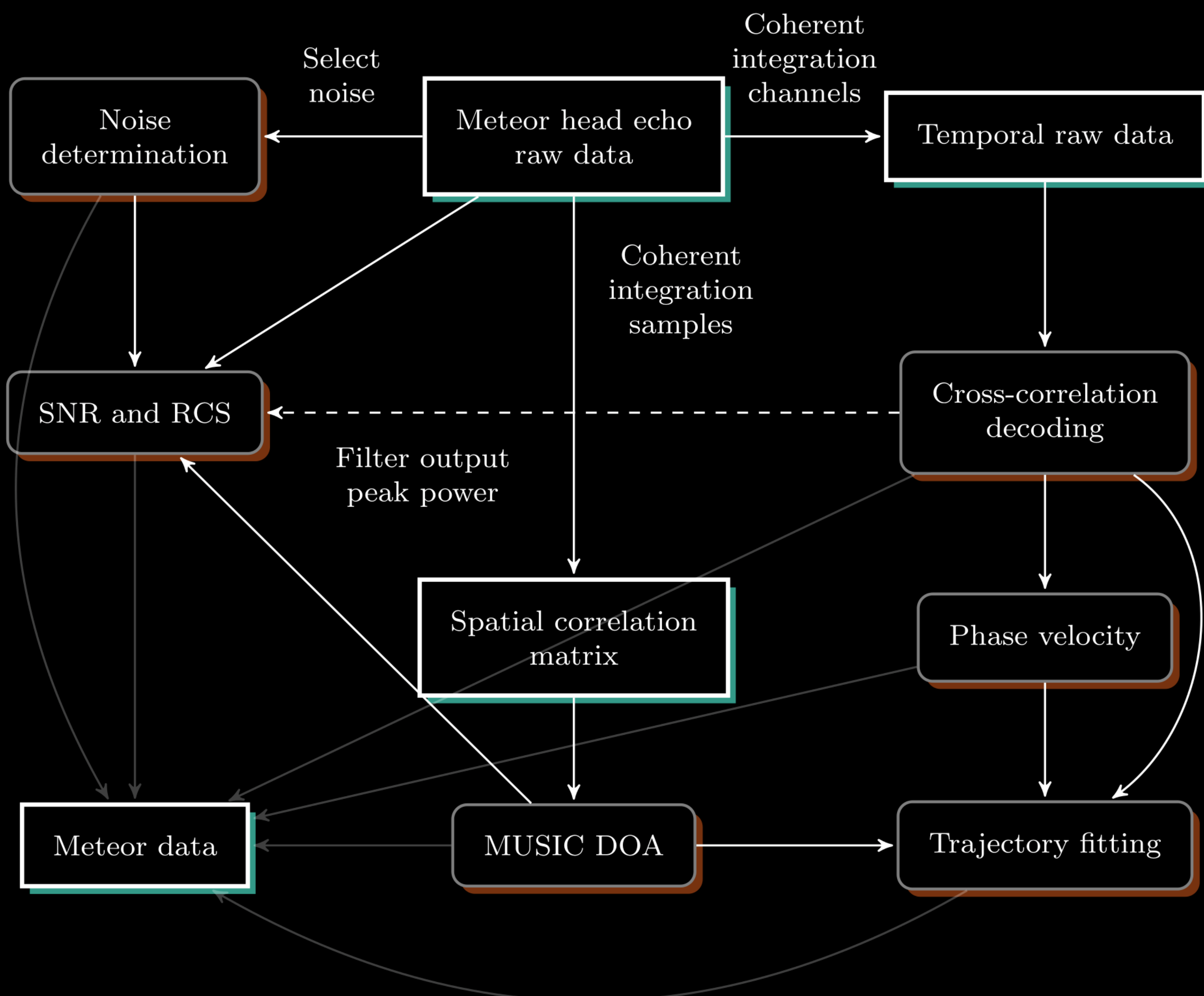
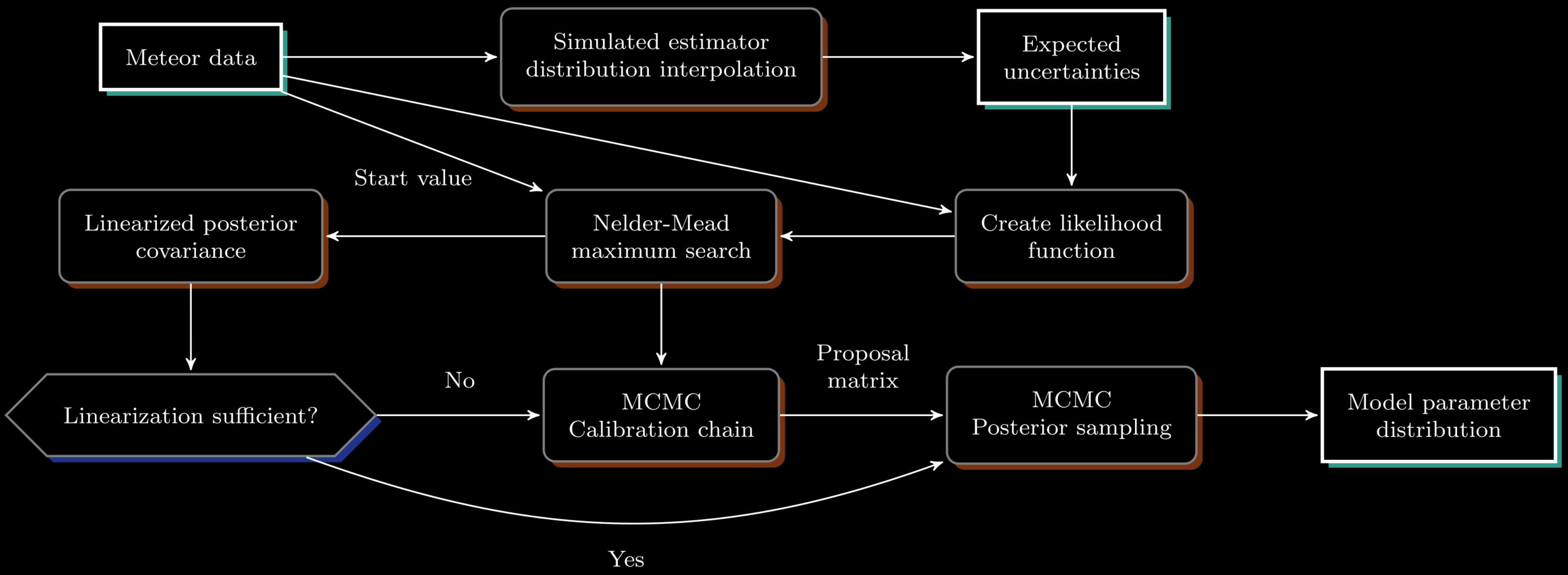


# SIGNAL ANALYSIS

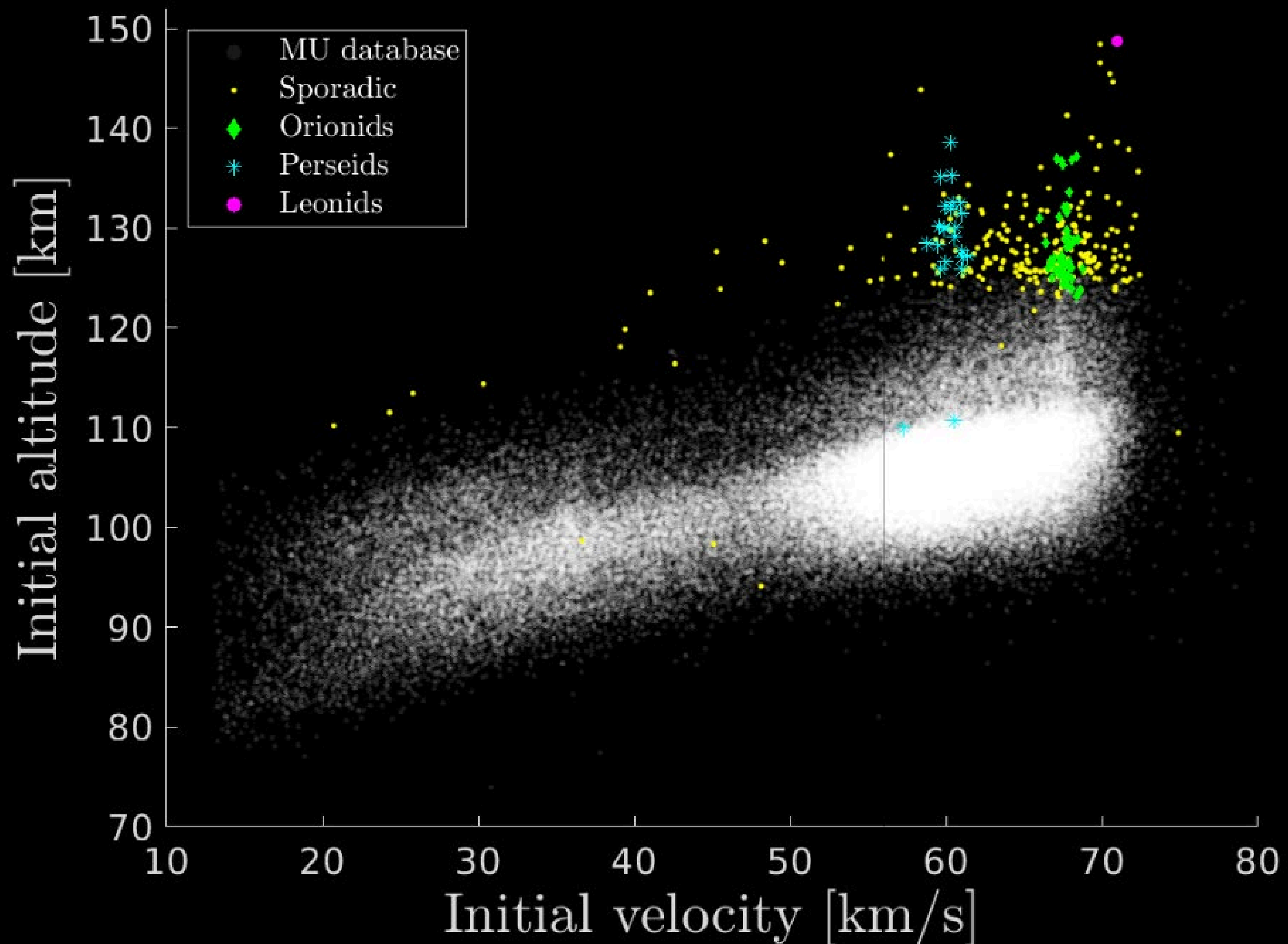


# Software

@ github.com/danielk333

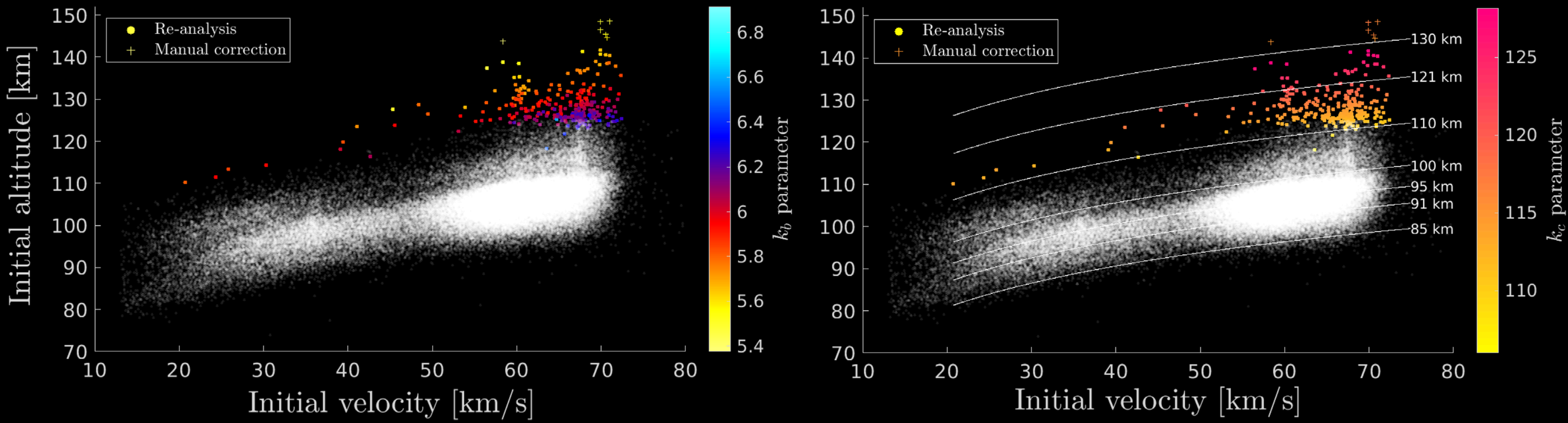
| | | |
|---|---|---|
| `metecho` | Meteor head echo analysis | [transferring] |
| `htpl` | Radar hard target processing lib | [refactoring] |
| `pyorb` | Kepler to cartesian elements | on PyPI |
| `pyant` | Radar antenna radiation patterns | on PyPI |
| `ablate` | Ablation model interfaces | [ongoing] |
| `pyod` | Orbit determination interfaces | [ongoing] |
| `dasst` | Meteoroid stream simulations | [Only prototype] |

# MU HIGH-ALTITUDE HEAD ECHOES



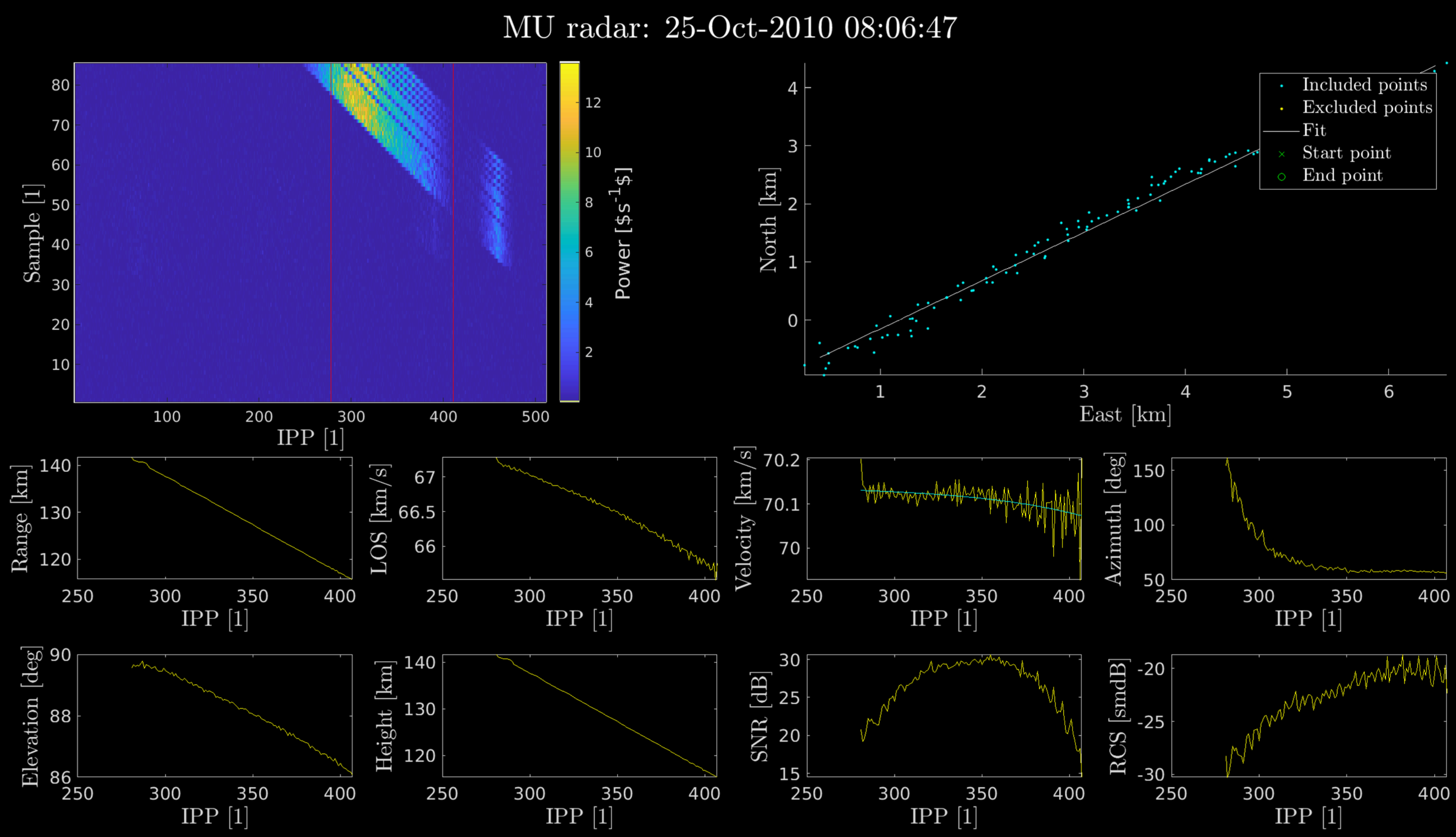

Kastinen & Kero (2022)

# MU HIGH-ALTITUDE HEAD ECHOES




Kastinen & Kero (2022)

# MU HIGH-ALTITUDE HEAD ECHOES




Kastinen & Kero (2022)