Unlocking the meteor toolbox for aeronomy and planetary science

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Advancing Technology

Meteor Introduction

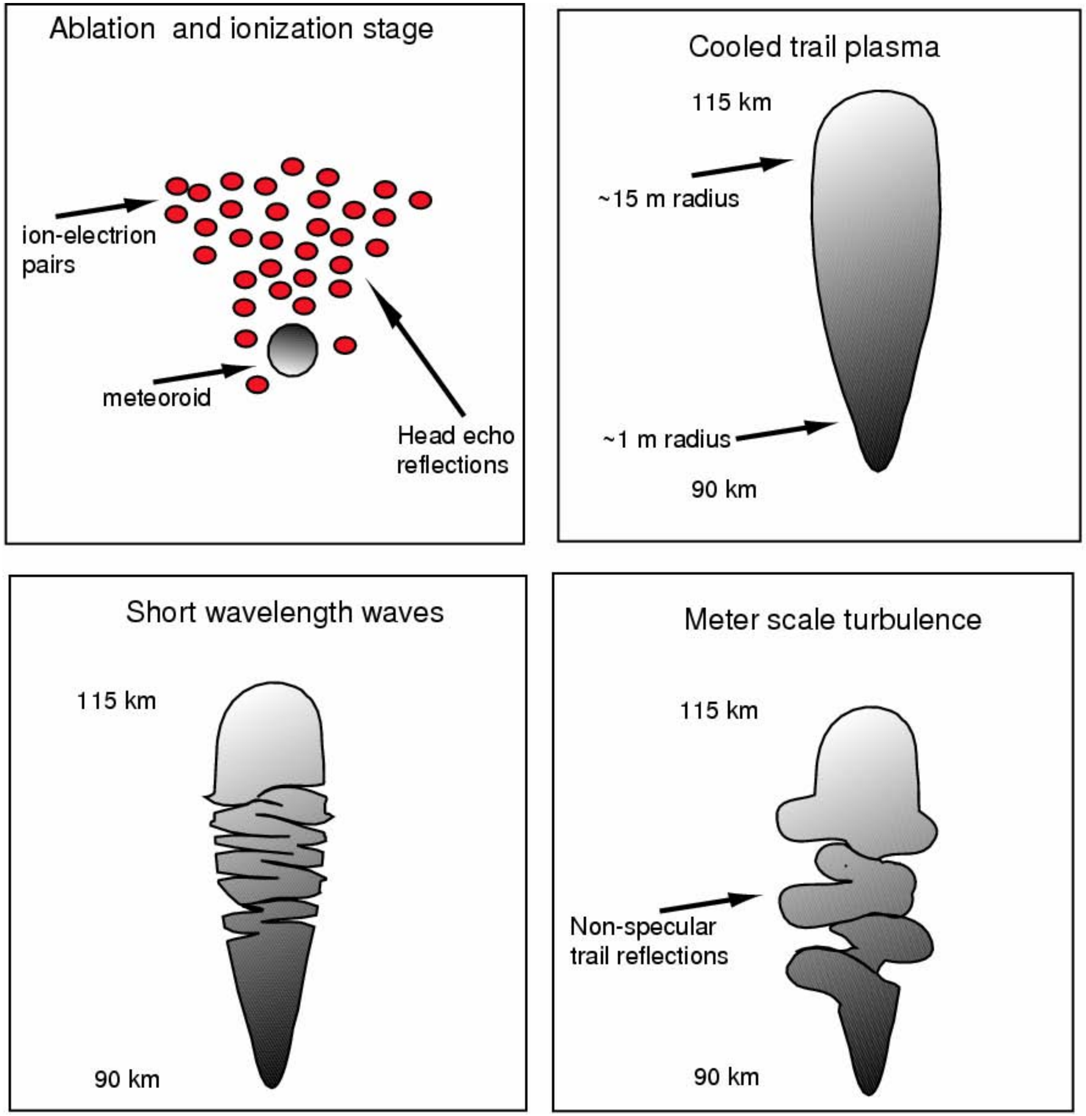
- ~2000-200 000 tons of yearly meteor flux
- Meteoroids enter the atmosphere at 11-80 km/s mostly evaporating near 100 km altitude
- Football field area is struck as frequently as every second
- Many of these trails have more ionization in 1 meter then the entire column density above them
- Trail motion and diffusion is used to track neutral winds and temperature

Why CEDAR should care

- Meteors provide ALL the metals (ions and neutrals) responsible for PMSE/NLC and sporadic-E.
- Meteors and their by-products already provide crucial information on the physics of the mesopause (meteor radars, metal lidars, imagers)
- Radar and optical observations of meteors can potentially tell you just about anything you want to know about the mesopause region (collision cross-sections, thermalization rates, temperature, neutral and ion densities, winds, E fields

Background Science

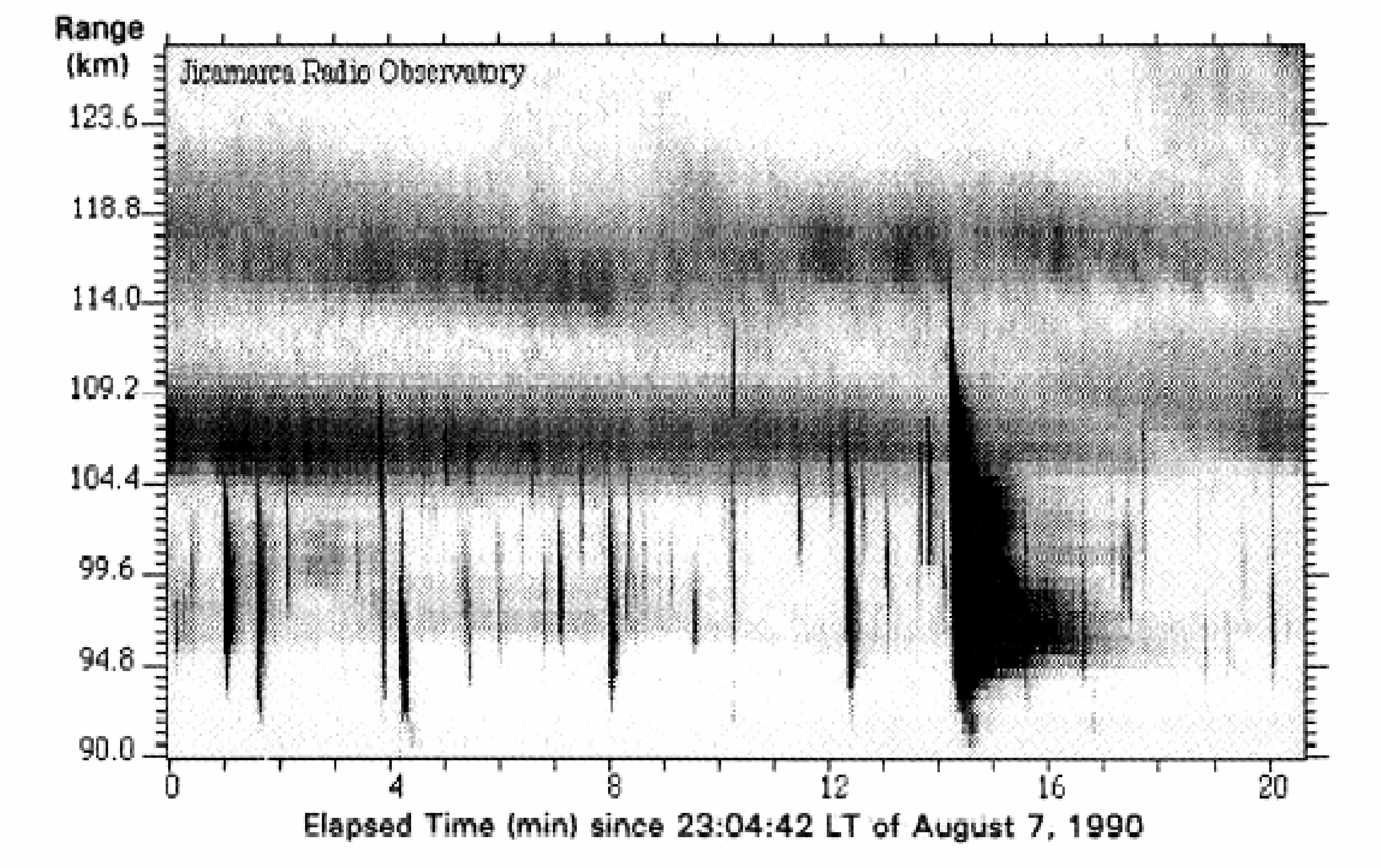
- Instabilities immediately arise in a portion of the trail plasma
- Waves produce turbulence in the form of Field Aligned Irregularities (FAI)
- Radar reflects from FAI



So what’s being/needs to be done

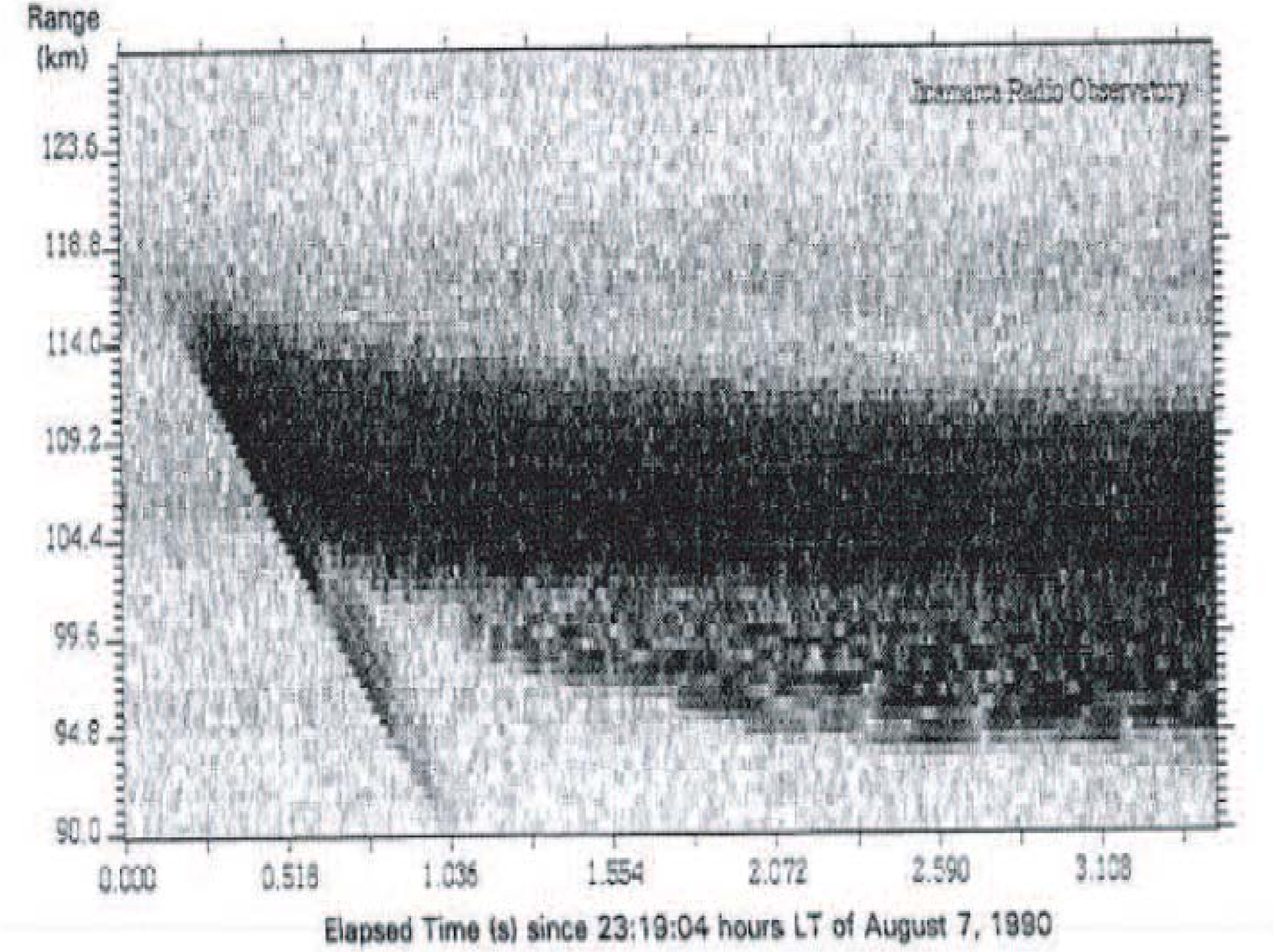
- Accurately characterize radar response to meteor plasma
- Constrain the open questions on the physics of meteor evolution so we can model and extract the parameters of interest

Long Duration Trails



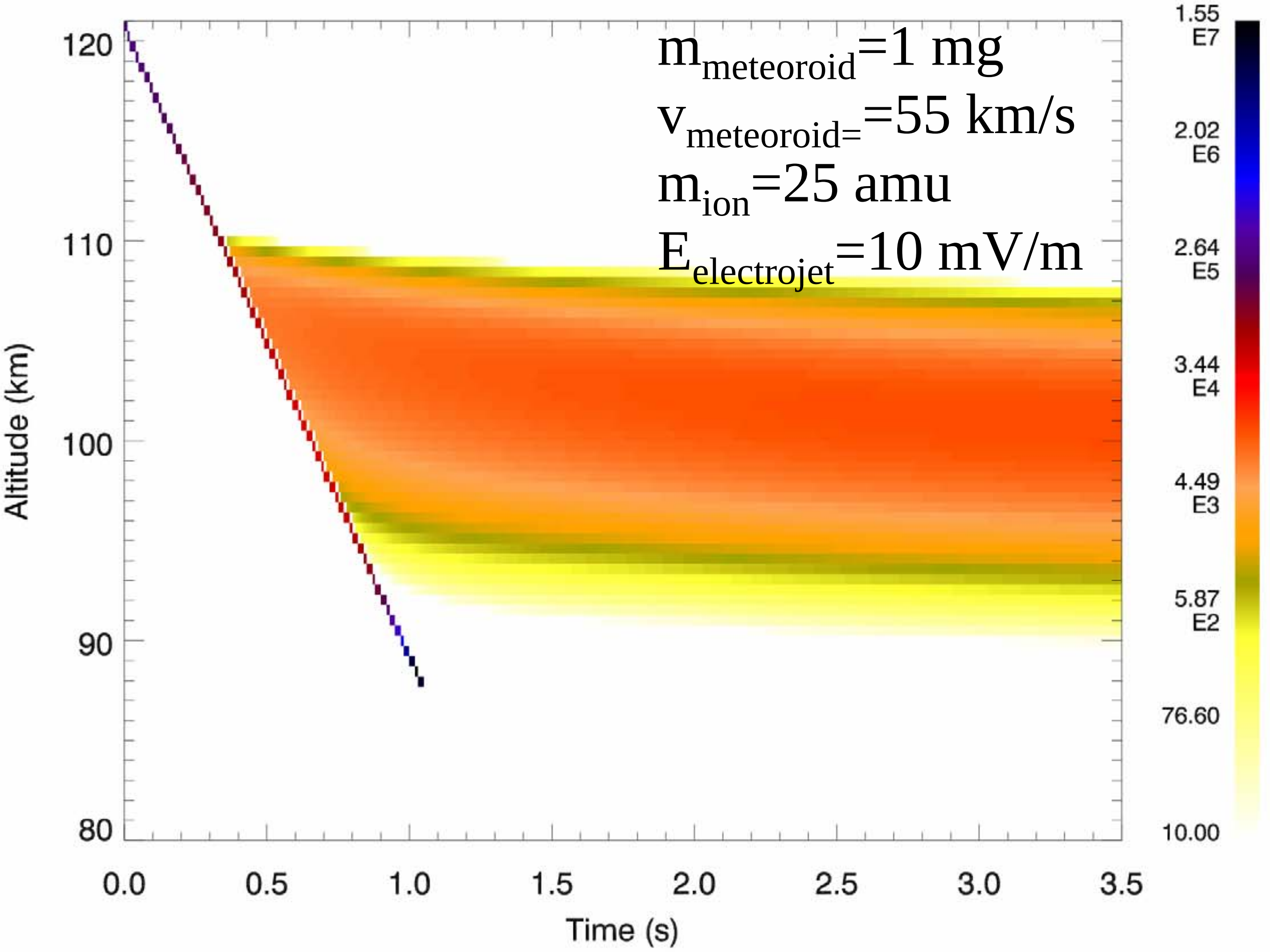
Reproduced from Chapin and Kudeki, JGR 1994

Long Duration Trails



Reproduced from Chapin and Kudeki, JGR 1994

Modeled Long Duration Trail



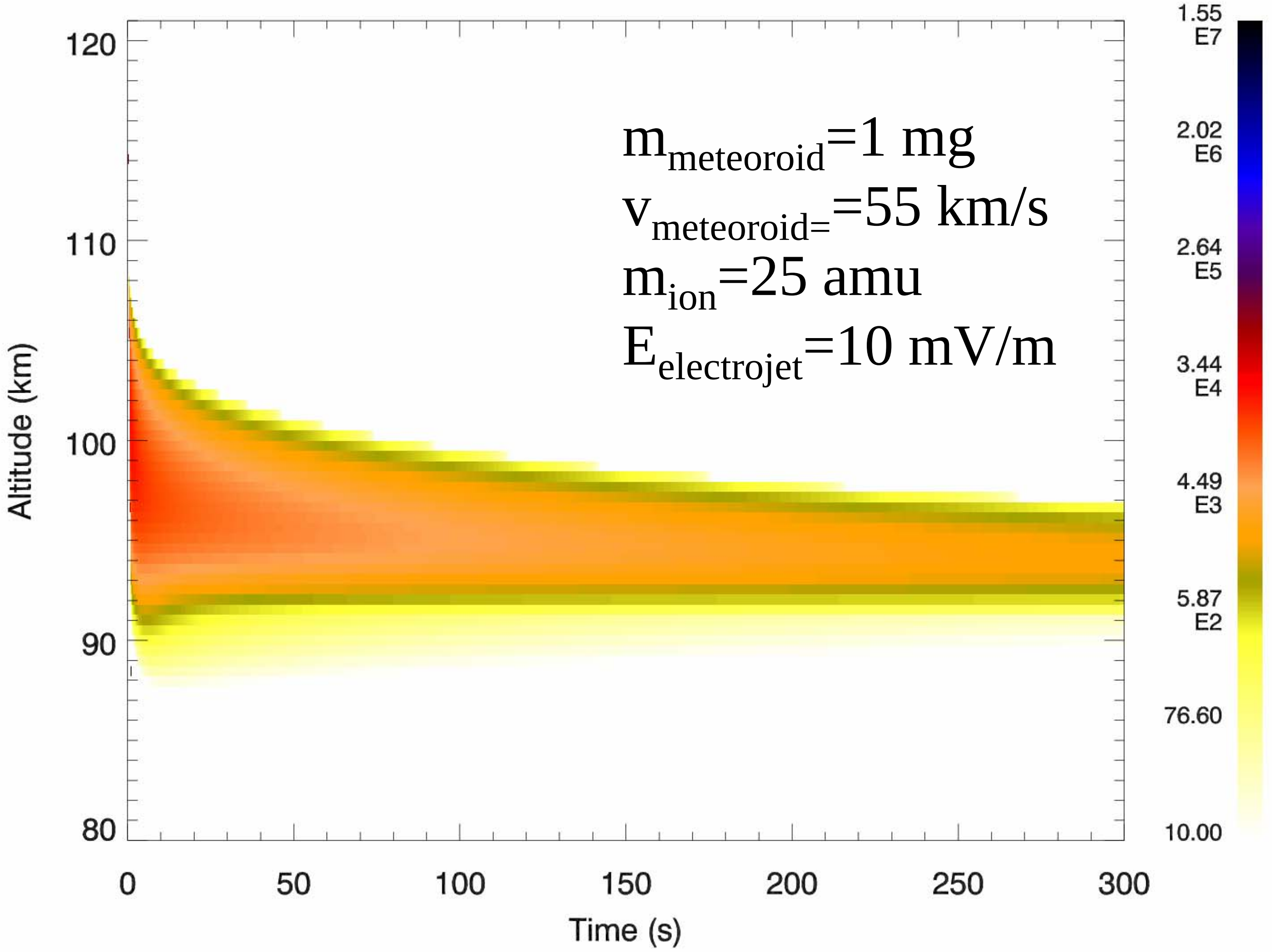
$m_{meteoroid}$=1 mg

$v_{meteoroid=}$=55 km/s

m_{ion}=25 amu

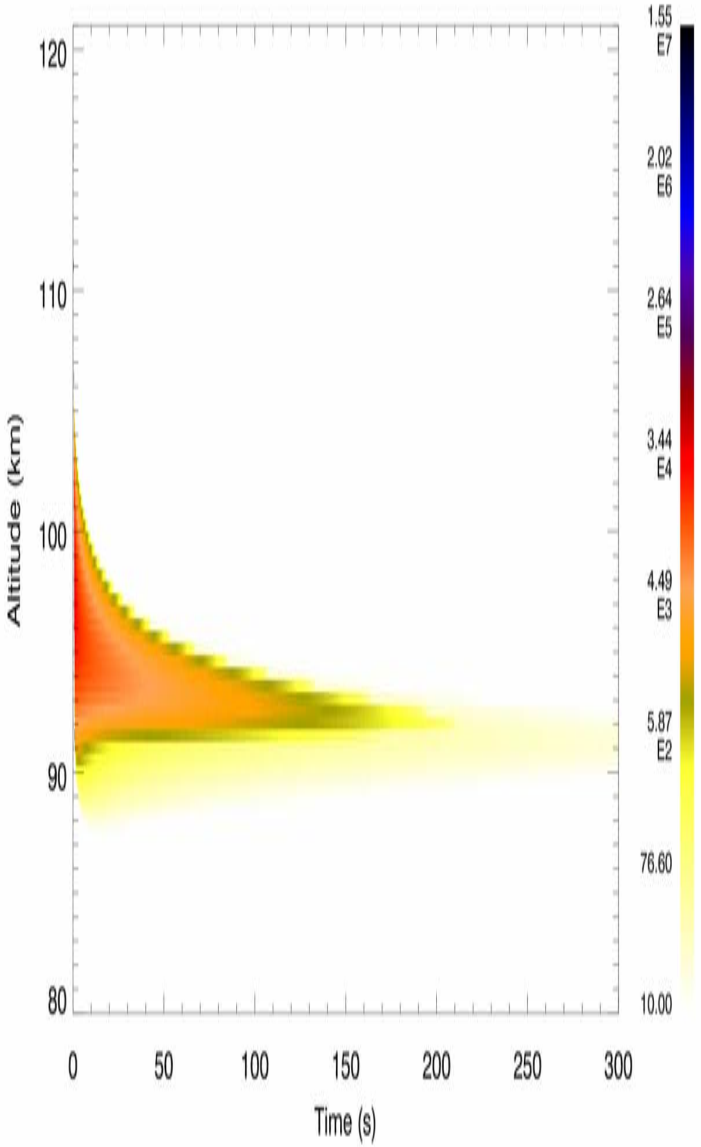
$E_{electrojet}$=10 mV/m

Modeled Long Duration Trail



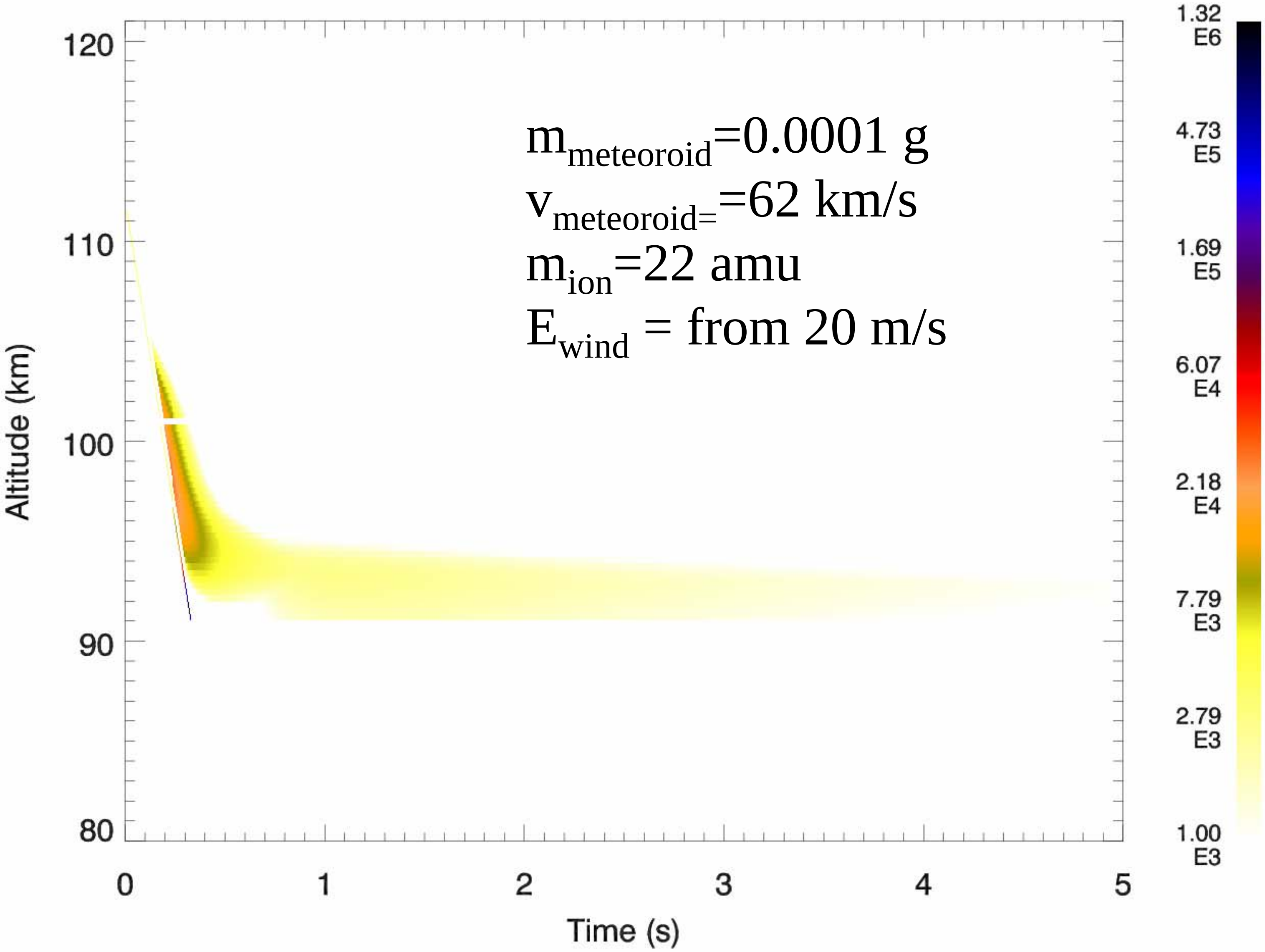
$m_{meteoroid}$=1 mg
$v_{meteoroid=}$=55 km/s
m_{ion}=25 amu
$E_{electrojet}$=10 mV/m

100 fold increase in density



$m_{meteoroid}$=1 mg
$v_{meteoroid=}$=55 km/s
m_{ion}=25 amu
$E_{electrojet}$=10 mV/m

Modeled Short Duration Trail



$m_{meteoroid}$=0.0001 g

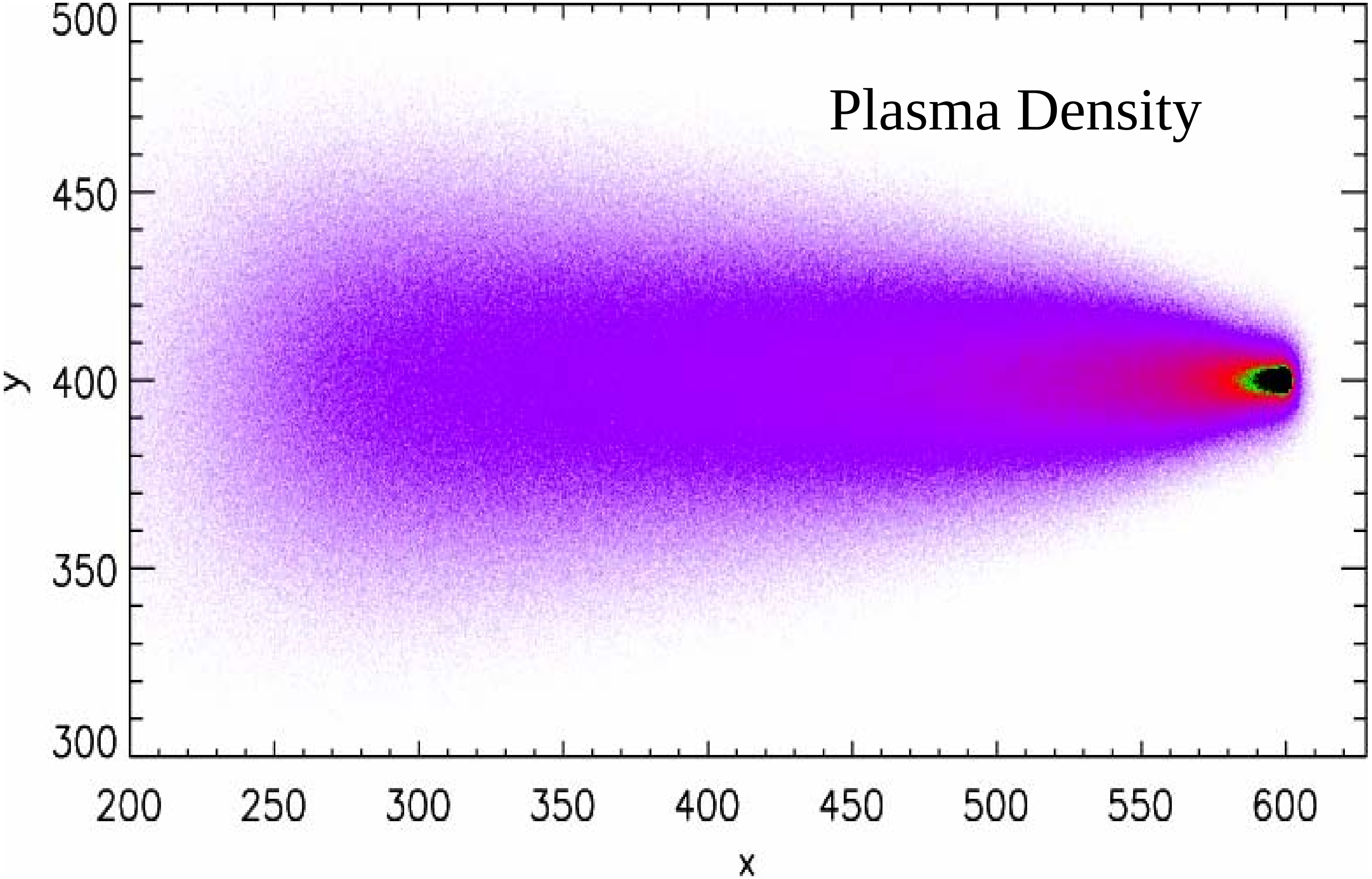
$v_{meteoroid=}$=62 km/s

m_{ion}=22 amu

E_{wind} = from 20 m/s

Meteor Head Simulation at 100km

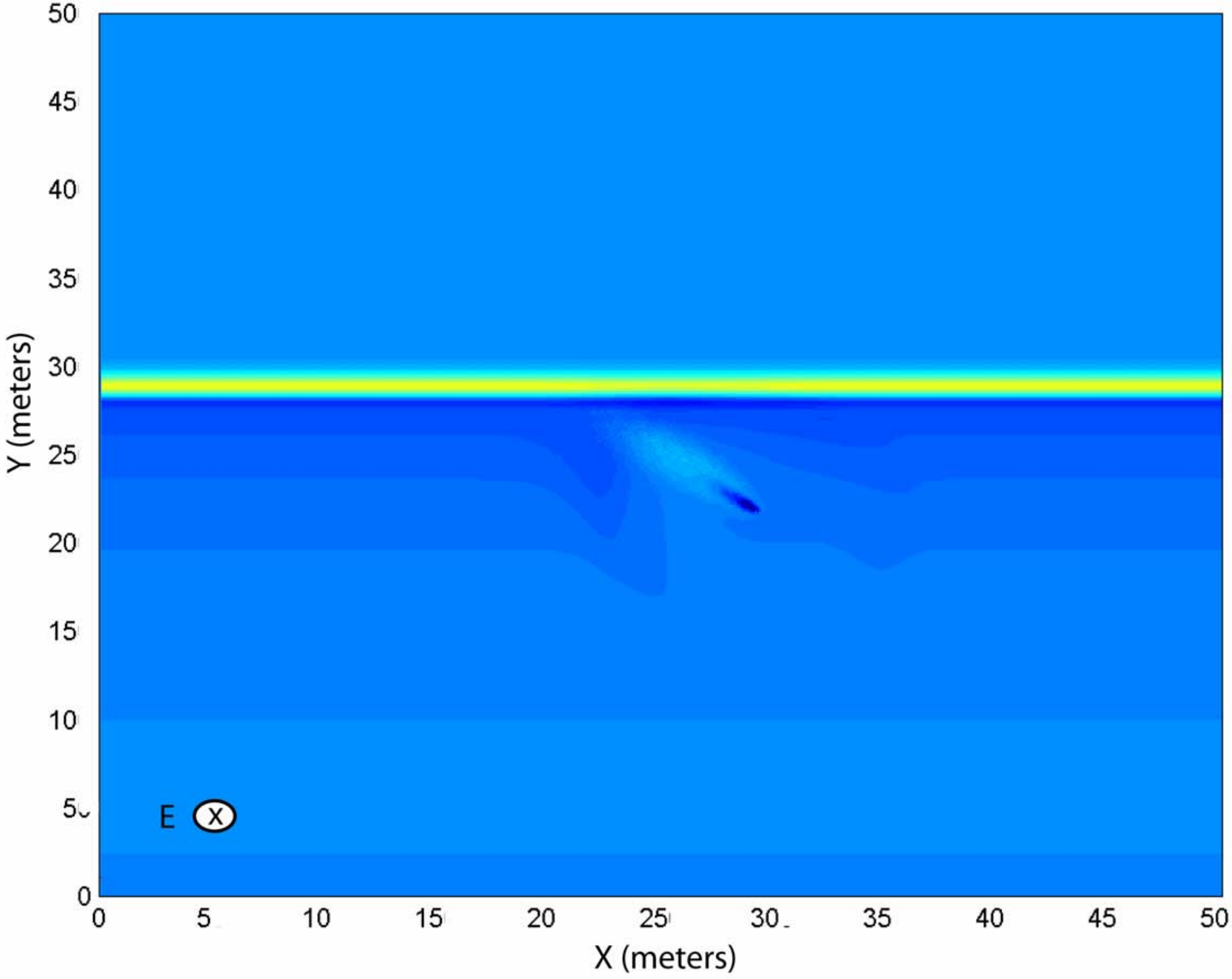
Conducted CAS Oslo, Norway



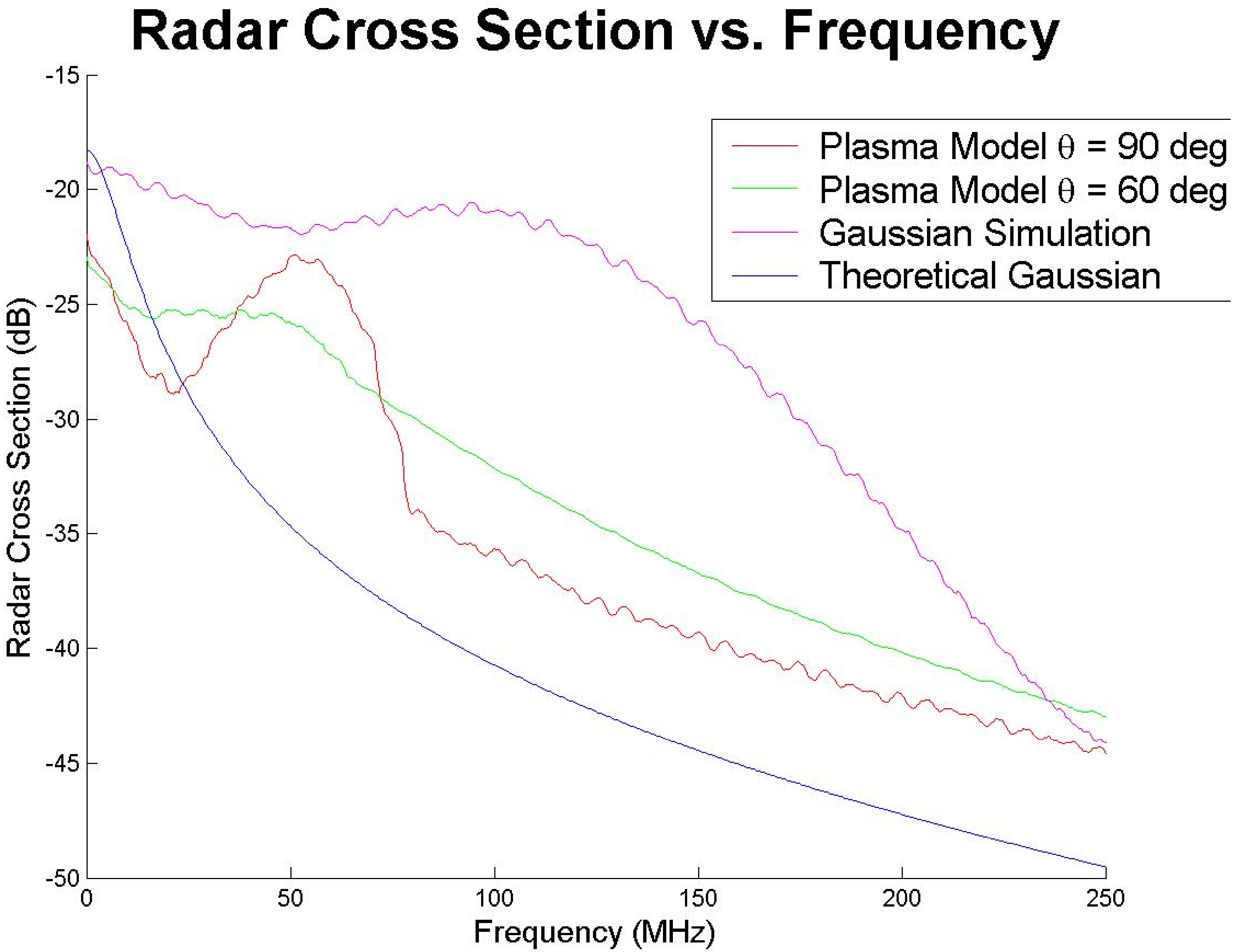
~30 meters

~60 meters

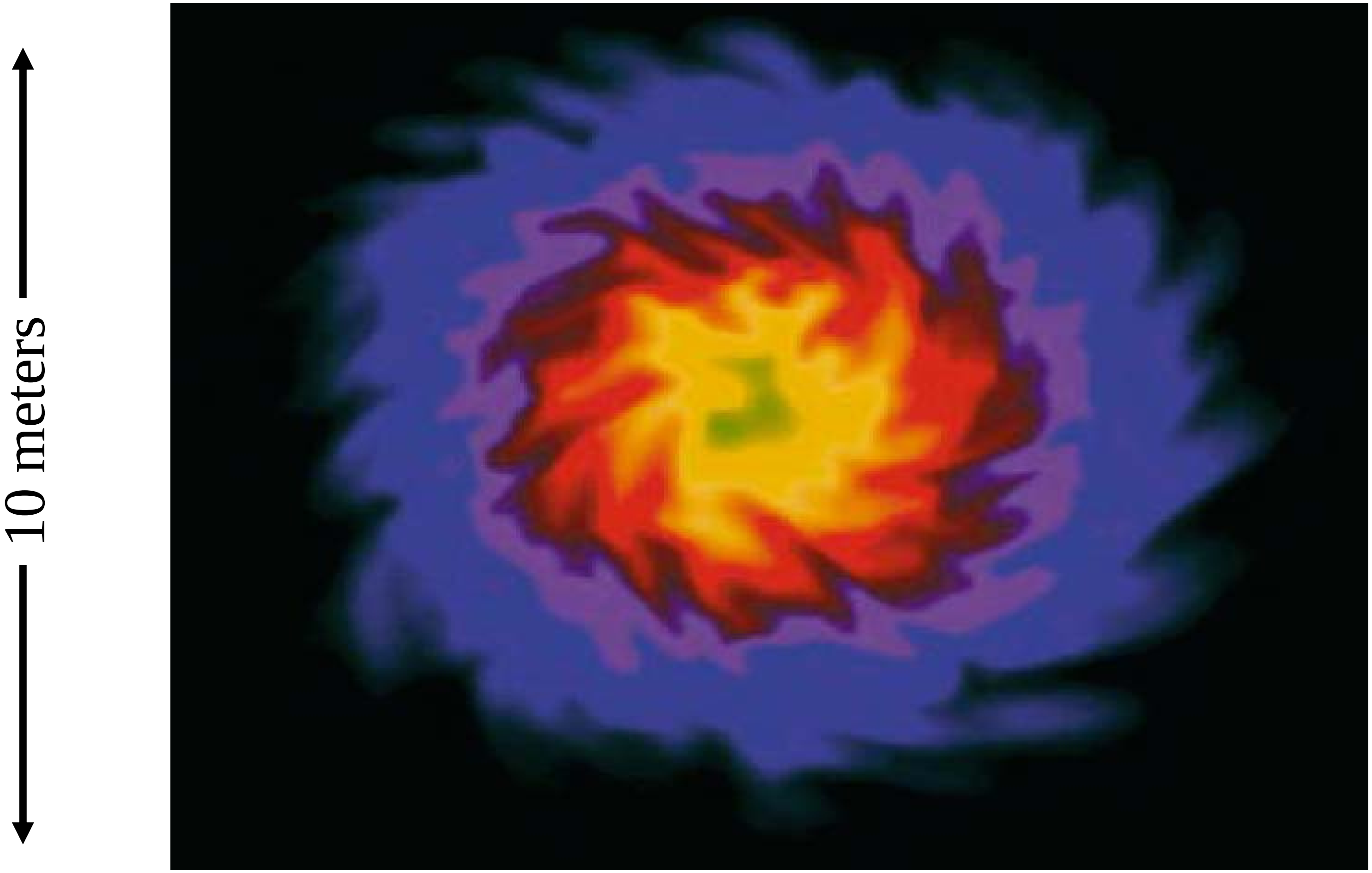
Early Stage Meteor FDTD



EM pulse
propagation


Radar Cross Section vs. Frequency
Radar Cross Section (dB)
-15
-20
-25
-30
-35
-40
-45
-50
Frequency (MHz)
0
50
100
150
200
250
Plasma Model θ = 90 deg
Plasma Model θ = 60 deg
Gaussian Simulation
Theoretical Gaussian

Next- Simulate reflection from this



Cross-section of a meteor trail plasma density

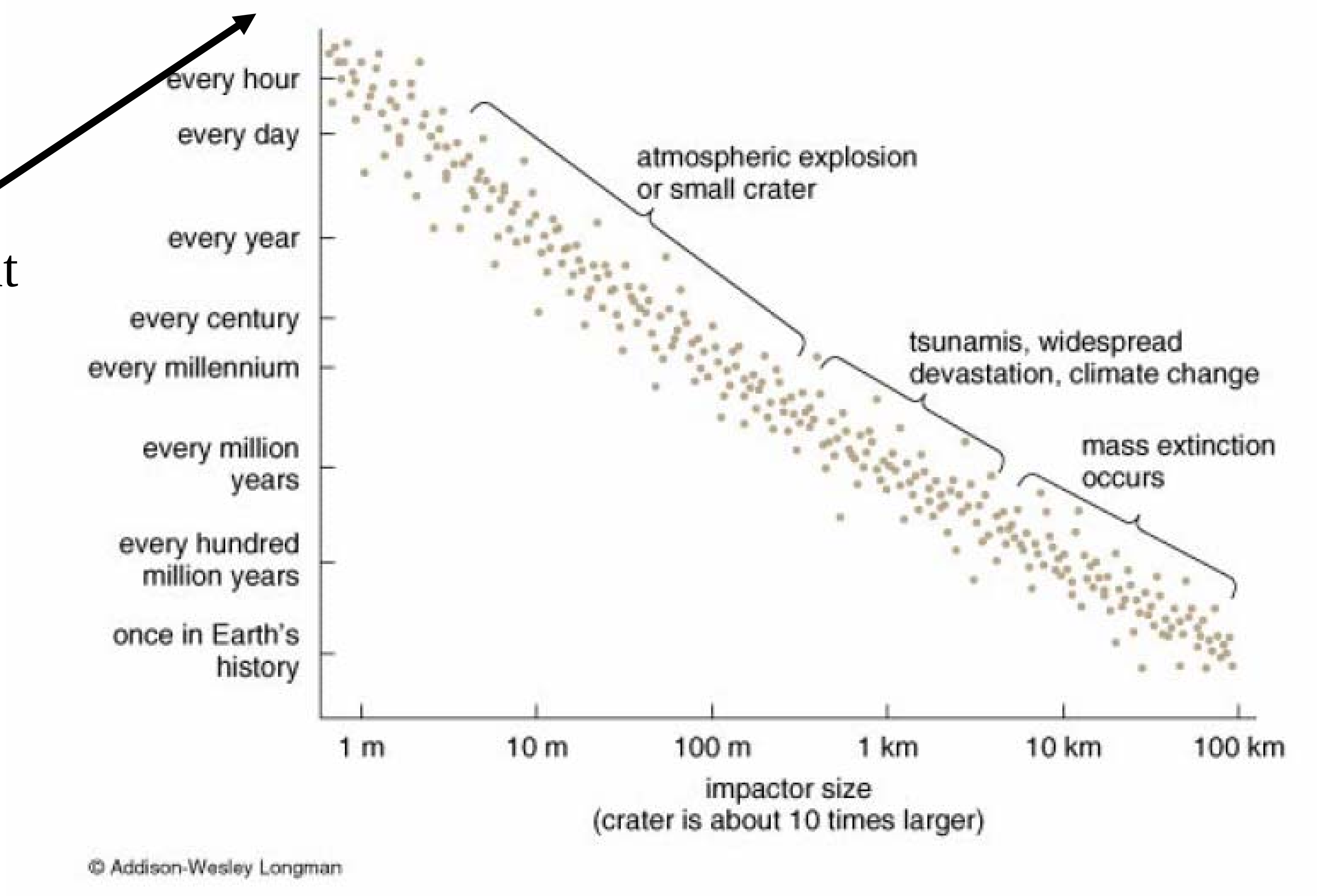
Meteor Summary

- Unlocking means generating a physical understanding of meteor evolution
- Head echo reflection seems to come from high density core (implications for the ionization/collisions)
- Long Duration trails perp to B come from plasma instability (sensitive tracer for electron density)
- In time, modern meteor radar observations will provide monitoring of many parameters from 90-120 km

Big ones, luckily not so often

Arizona meteor crater

Meteor impact frequency



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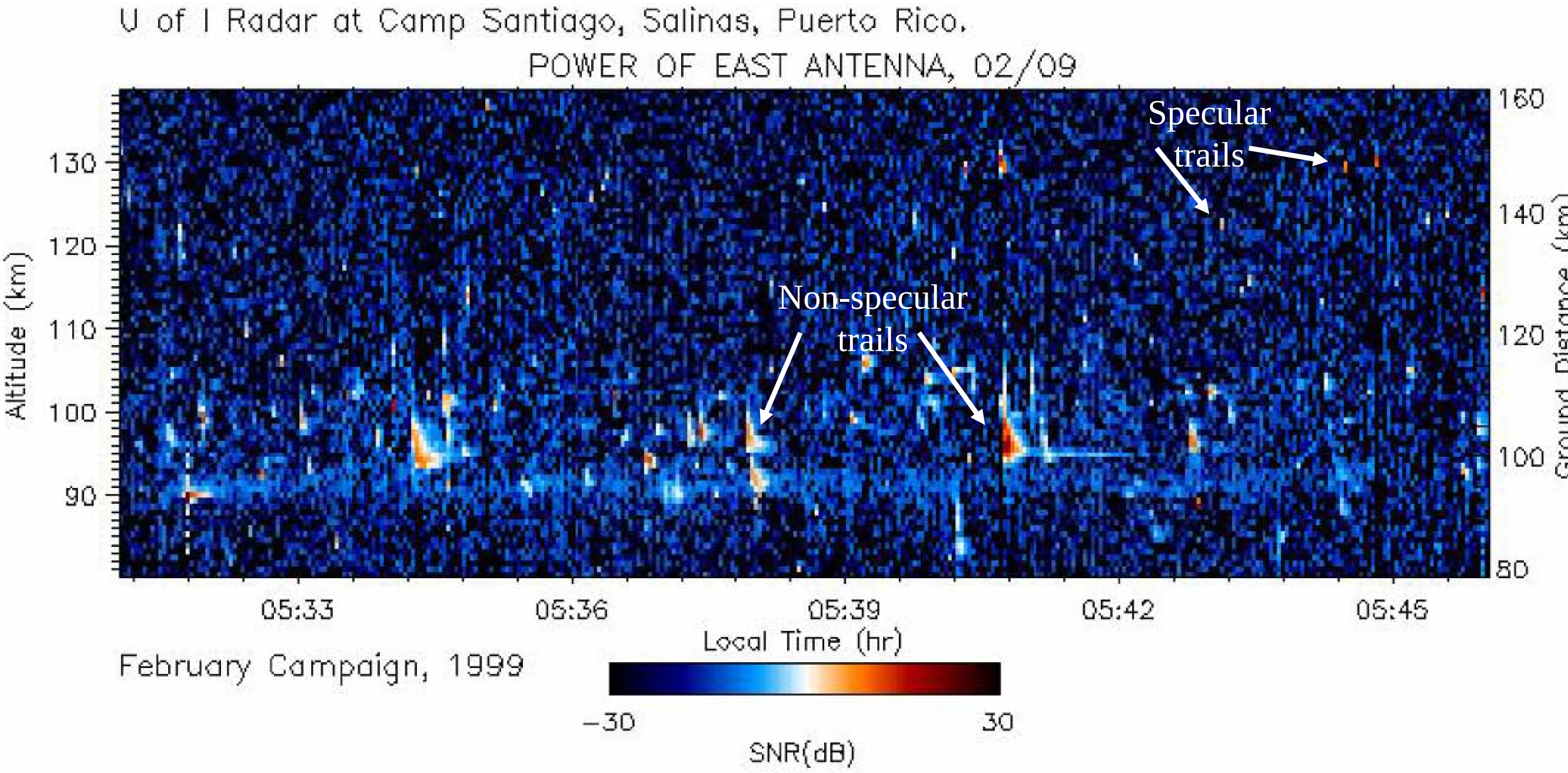
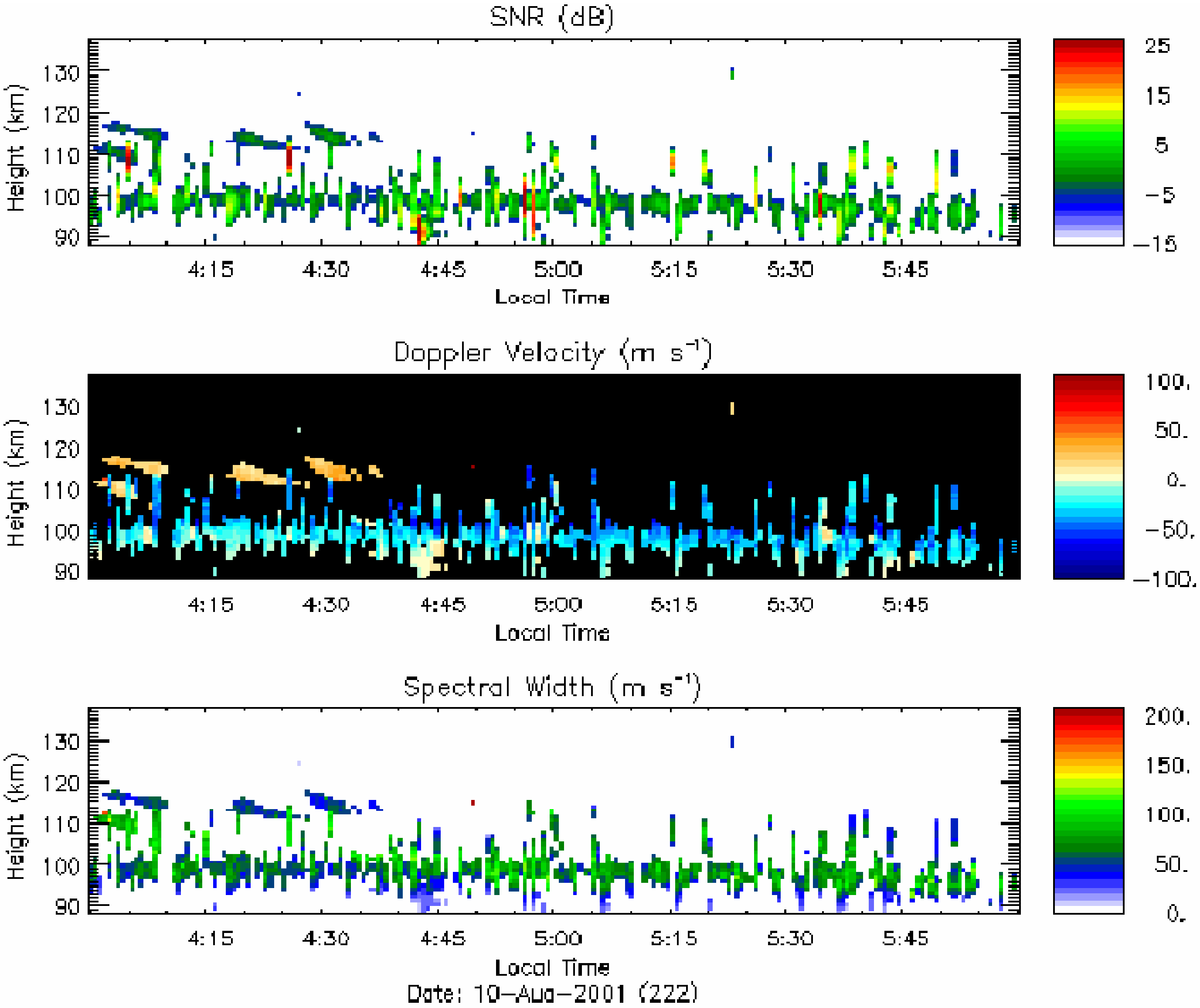
What about
up here?

15 Min. Coqui II Radar Data



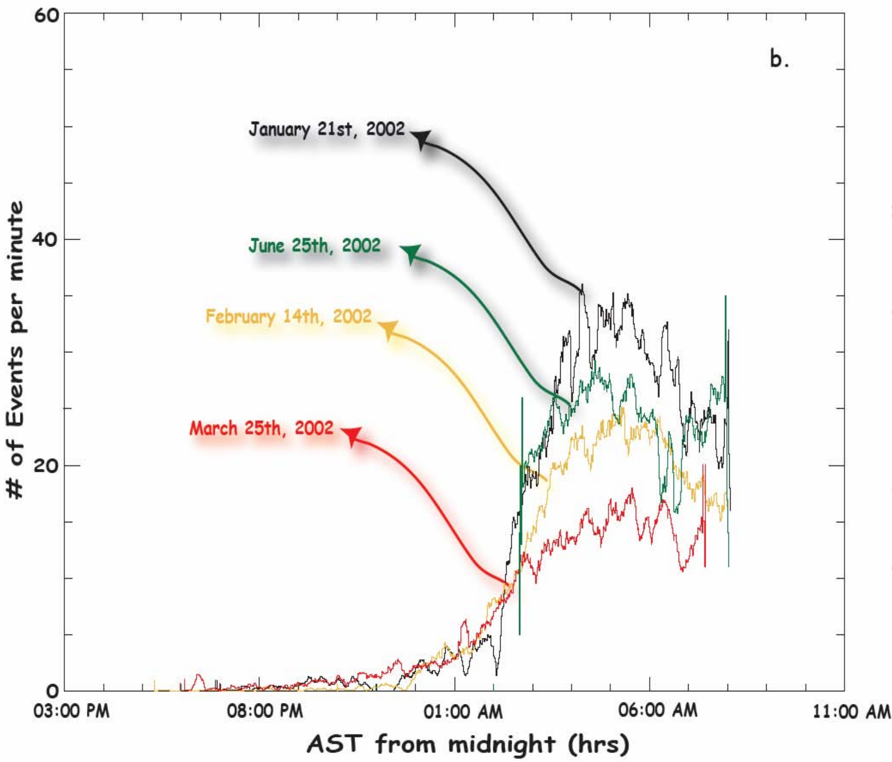
- 50 MHz coherent radar deployed to observe E-region irregularities also observes large numbers of both specular and non-specular meteor trails (C. Julio Urbina)

Piura Non-specular Trails



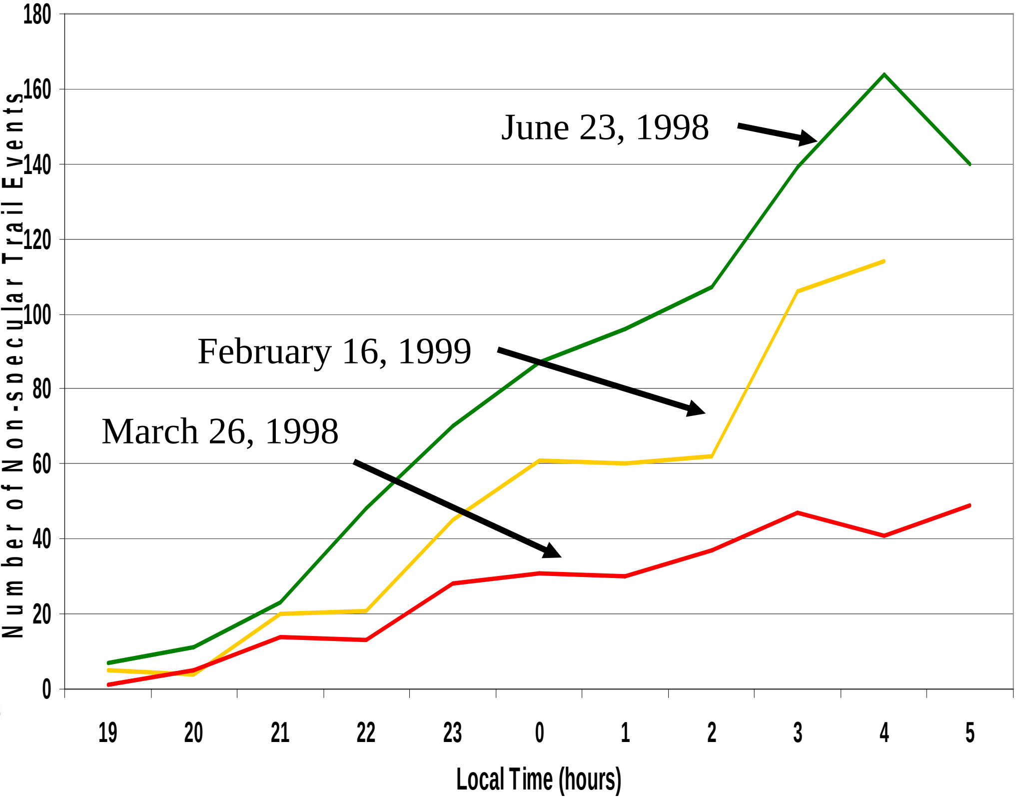
Courtesy of Jorge Chau, Jicamarca Observatory

Arecibo 430 MHz radar head echo data



Courtesy of Diego Janches

Coqui II non-specular trail data



June 23, 1998

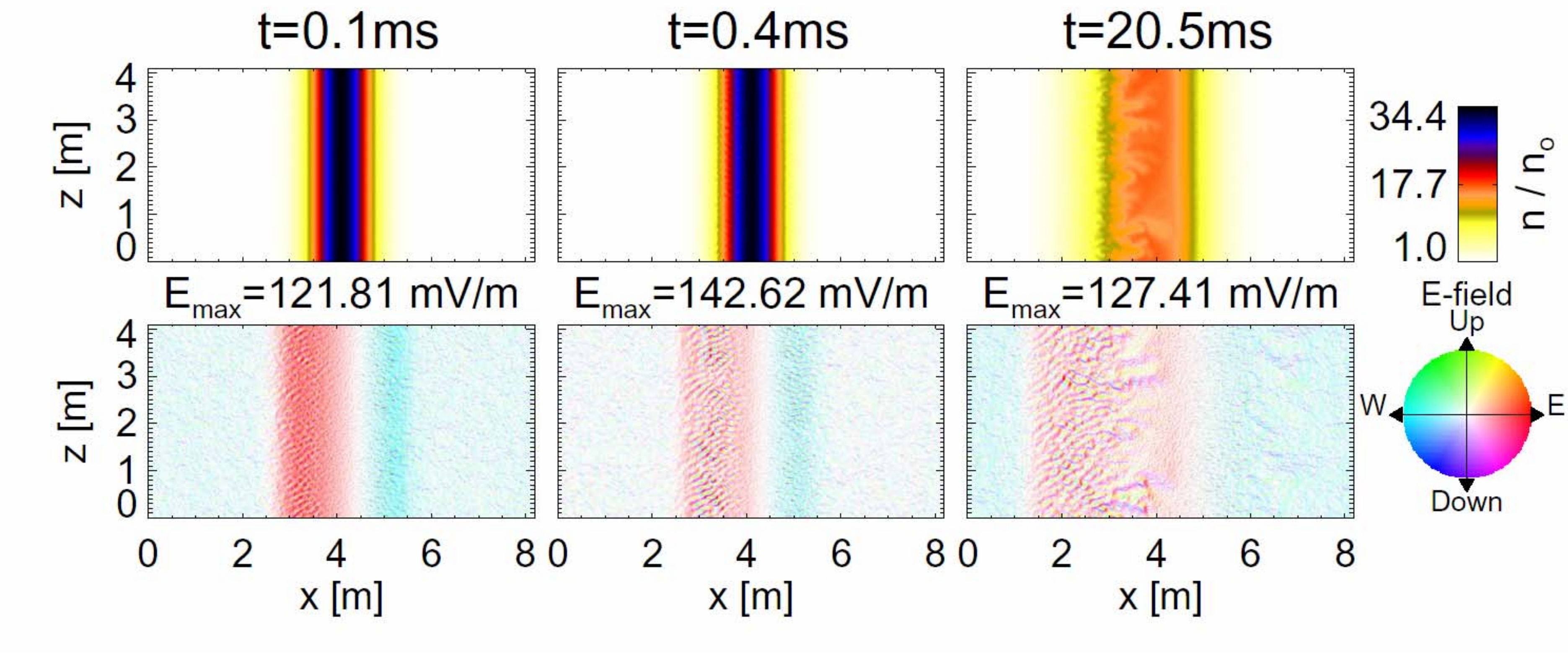
February 16, 1999

March 26, 1998

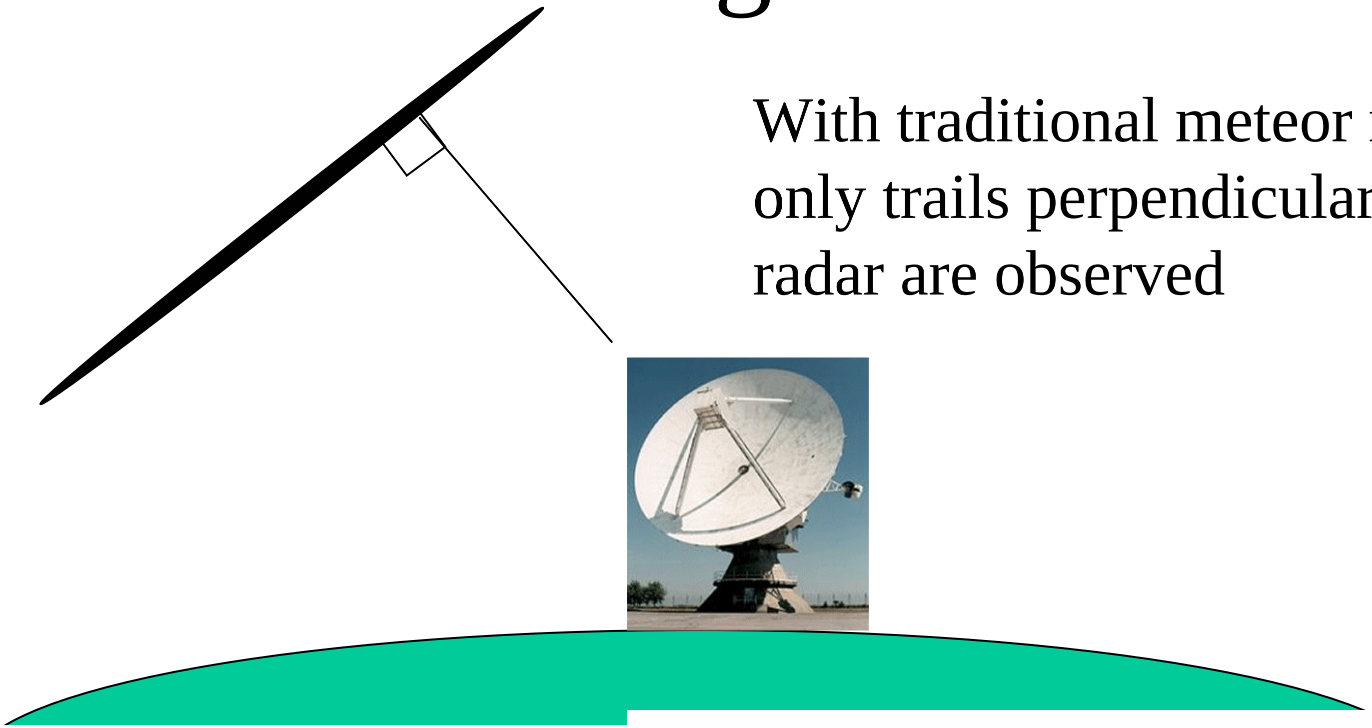
Noctilucent Clouds forming from meteor dust

Picture from NASA GSFC

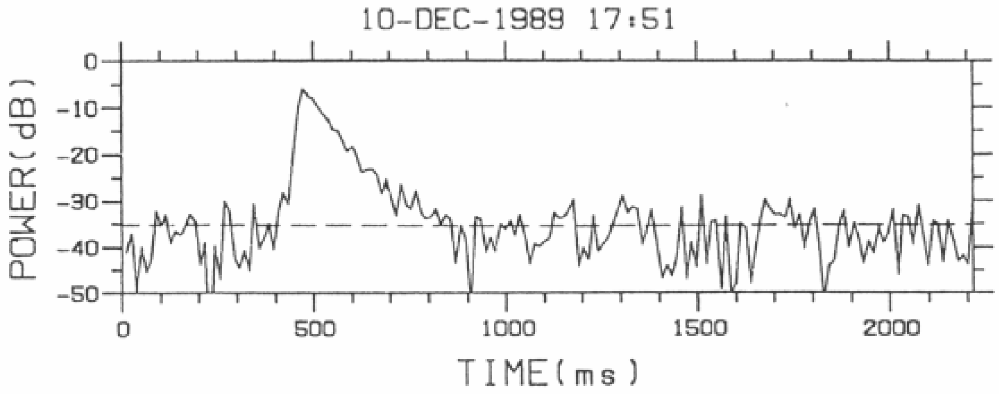
Simulation Trail ⊥ **B** to



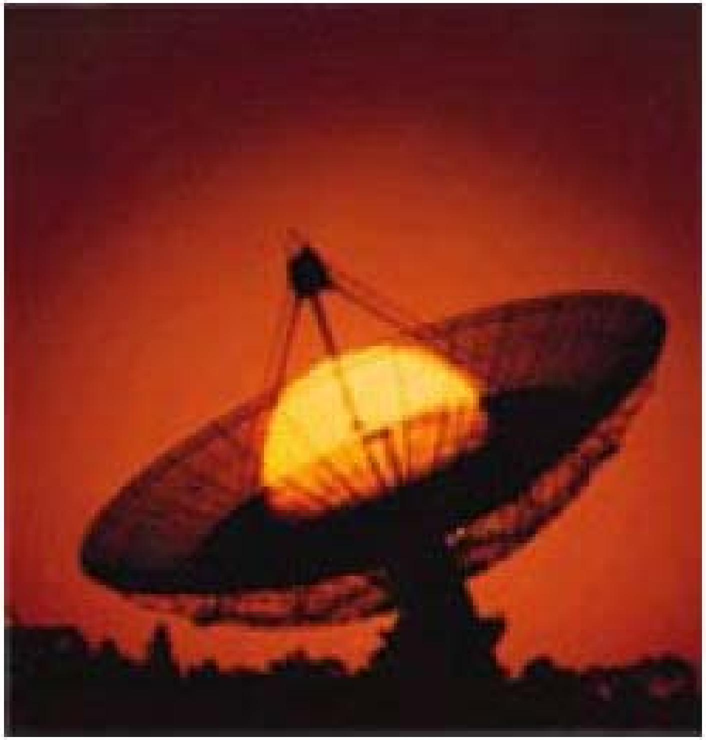
Observing a trail with radar



With traditional meteor radar observations:
only trails perpendicular to the
radar are observed



Large radars can do more

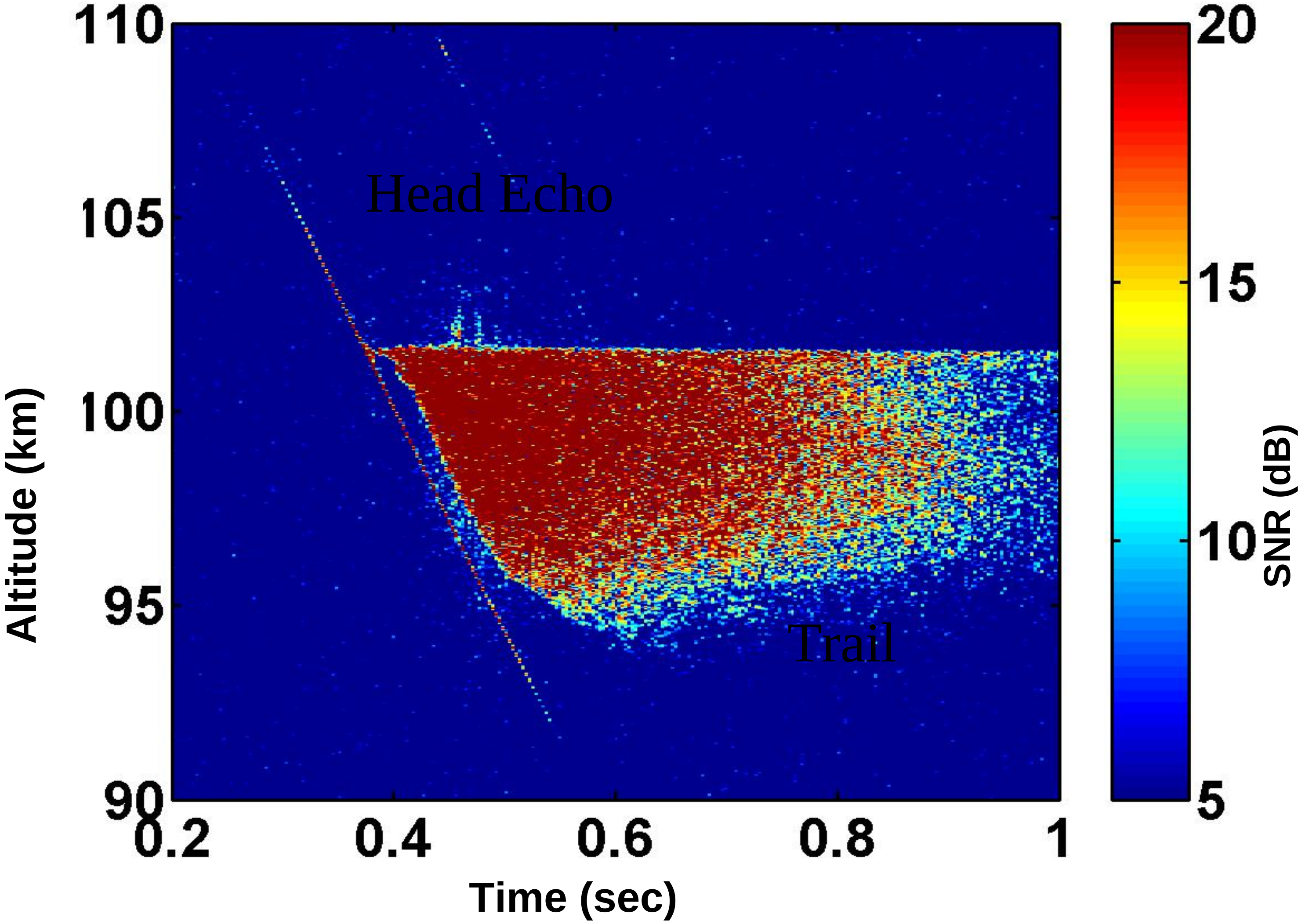


ALTAIR Radar -
Kwajelin Atoll

European Eiscat Radar- Svalbard

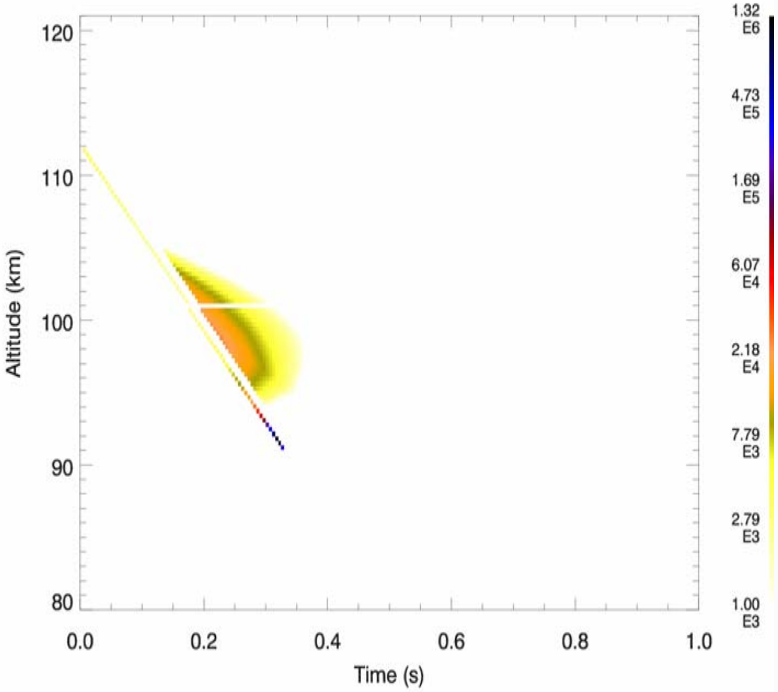
Arecibo Radar - Puerto Rico

Large Radar observations

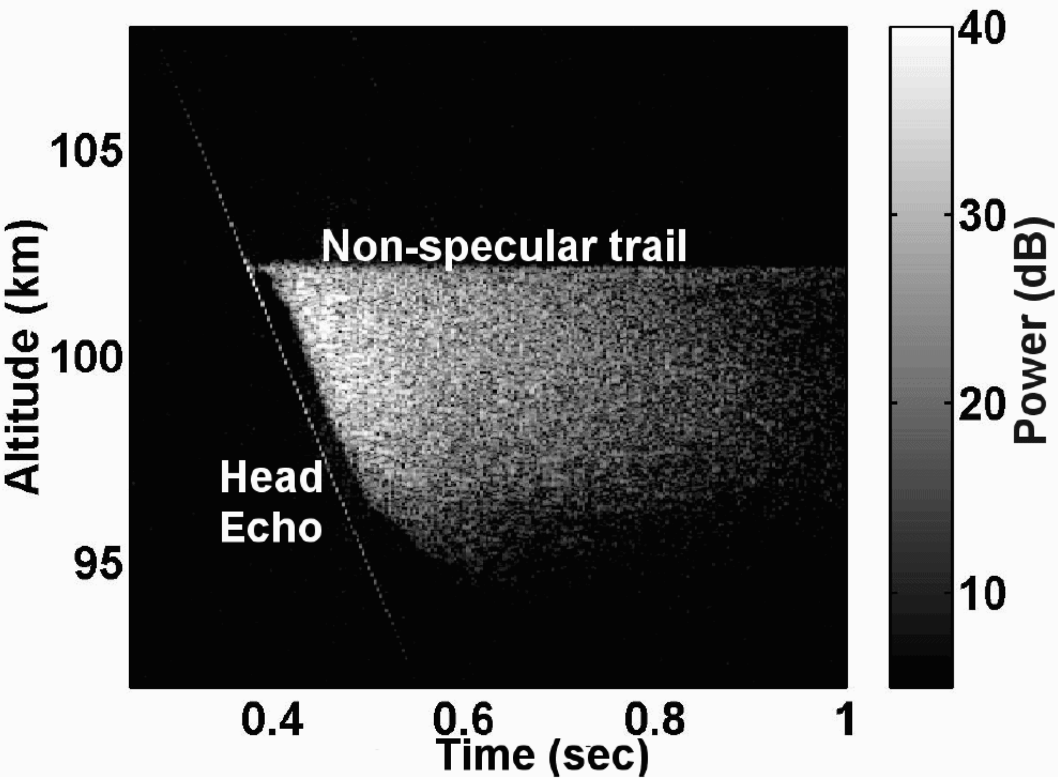


ALTAIR VHF Radar Observations (Sigrid Close JGR 2002)

Head Echos and non-specular Trails

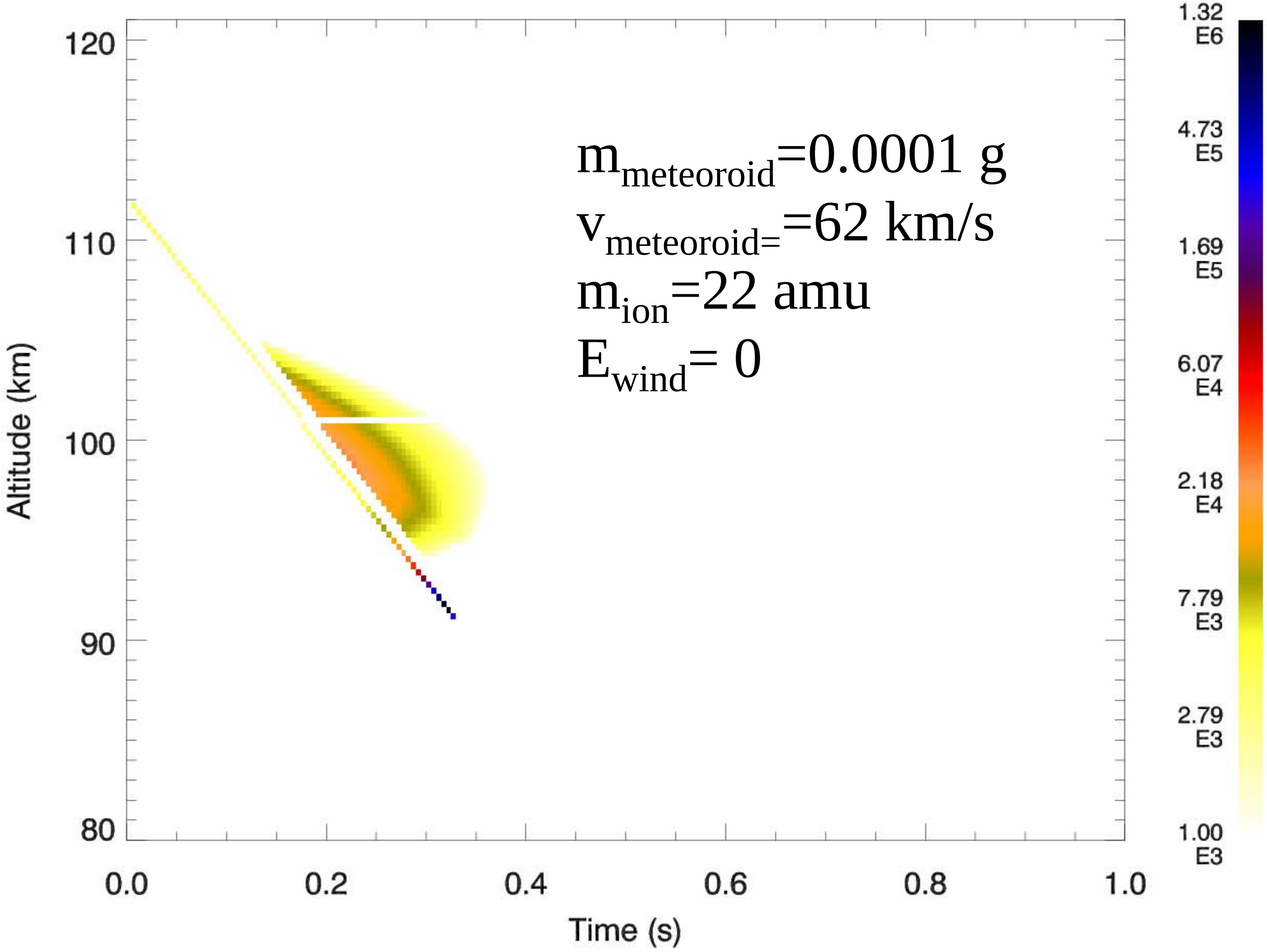


Modeled observation
V=62 km/s, m_m= 22 amu



ALTAIR VHF Radar Observations
Sigrid Close JGR 2002

Modeled Short Duration Trail



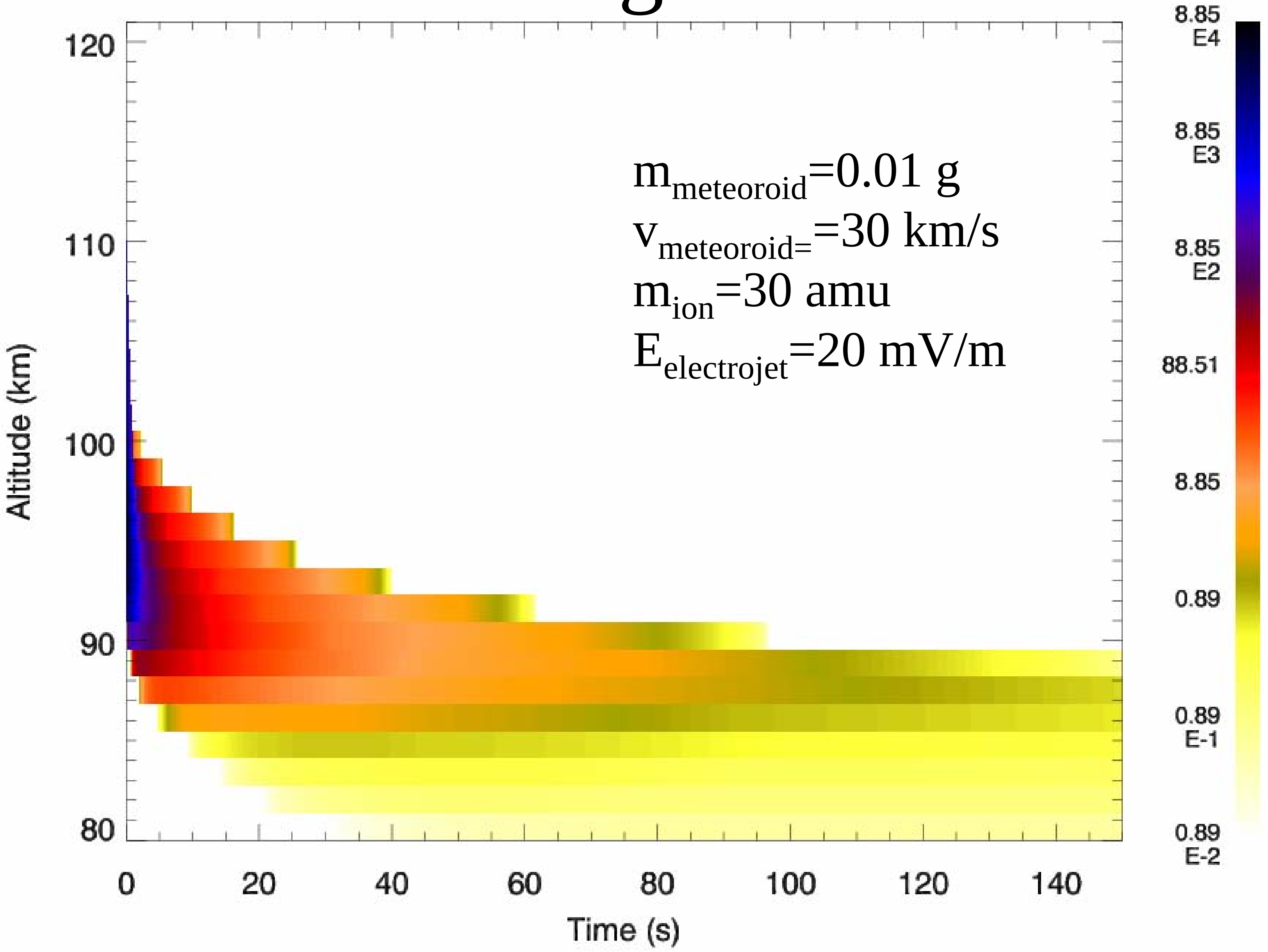
$m_{meteoroid}$=0.0001 g

$v_{meteoroid=}$=62 km/s

m_{ion}=22 amu

E_{wind}= 0

Modeled Long Duration Trail

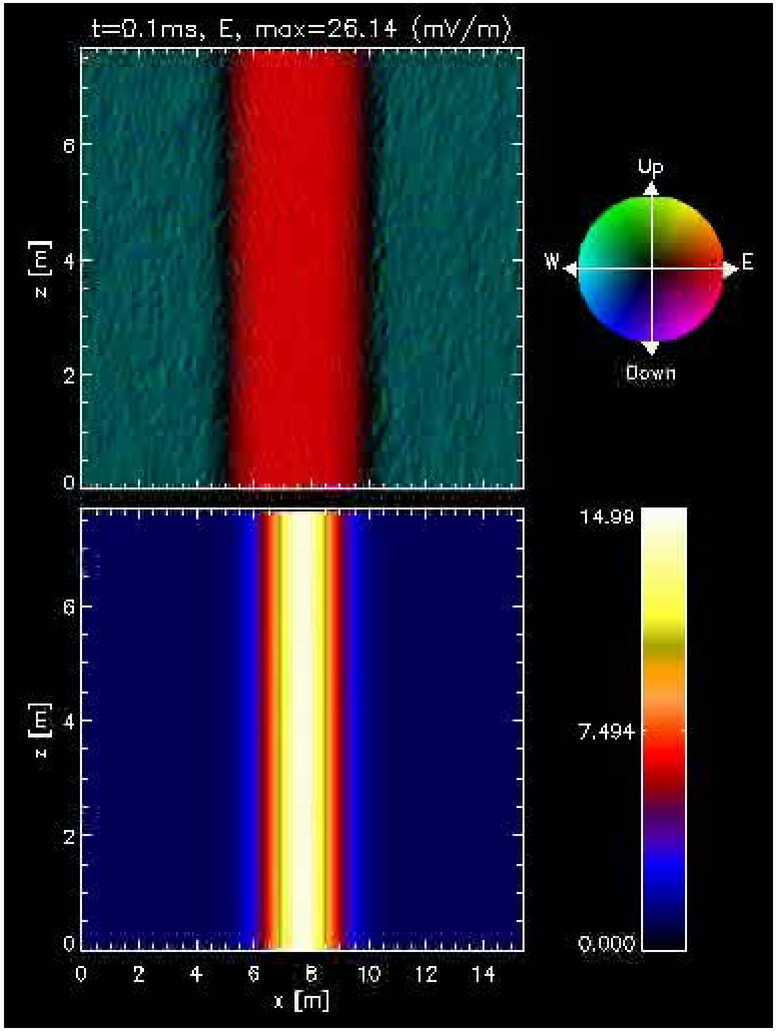


$m_{meteoroid}$=0.01 g

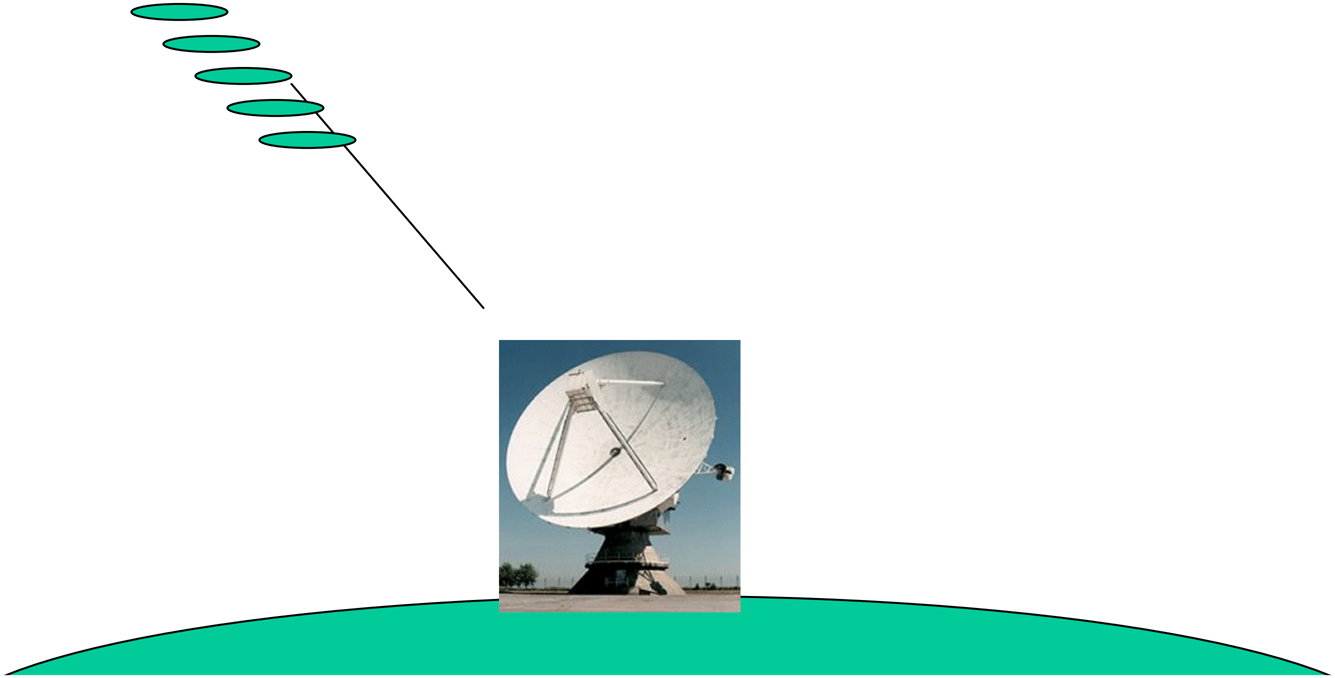
$v_{meteoroid=}$=30 km/s

m_{ion}=30 amu

$E_{electrojet}$=20 mV/m

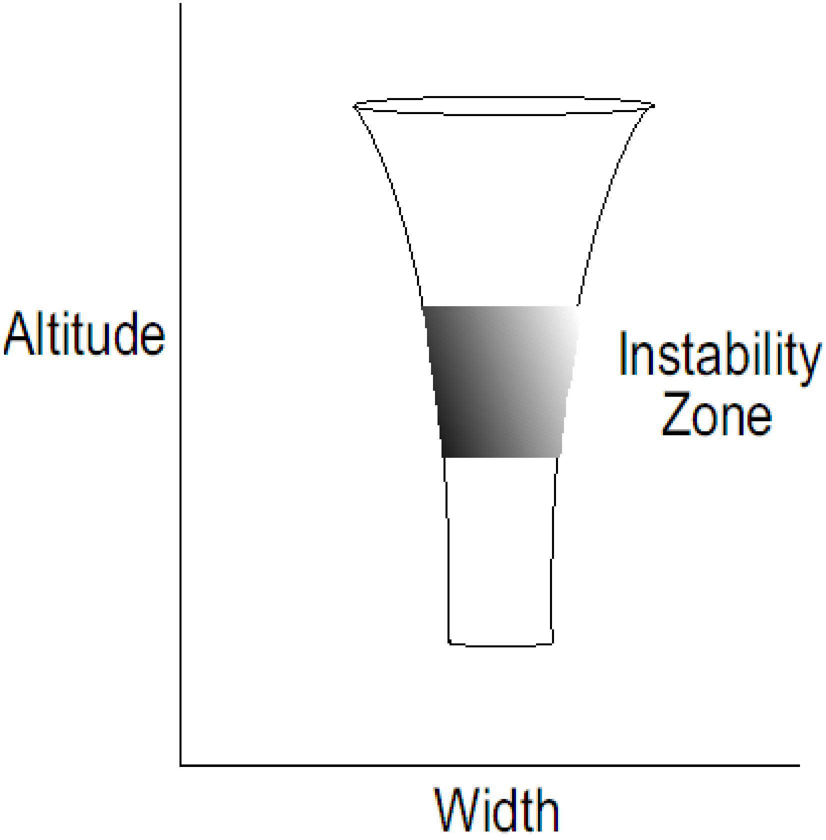

t=0.1ms, E, max=26.14 (mV/m)
z [m]
0
2
4
6
Up
W
E
Down
z [m]
0
2
4
6
0
2
4
6
8
10
12
14
x [m]
14.99
7.494
0.000

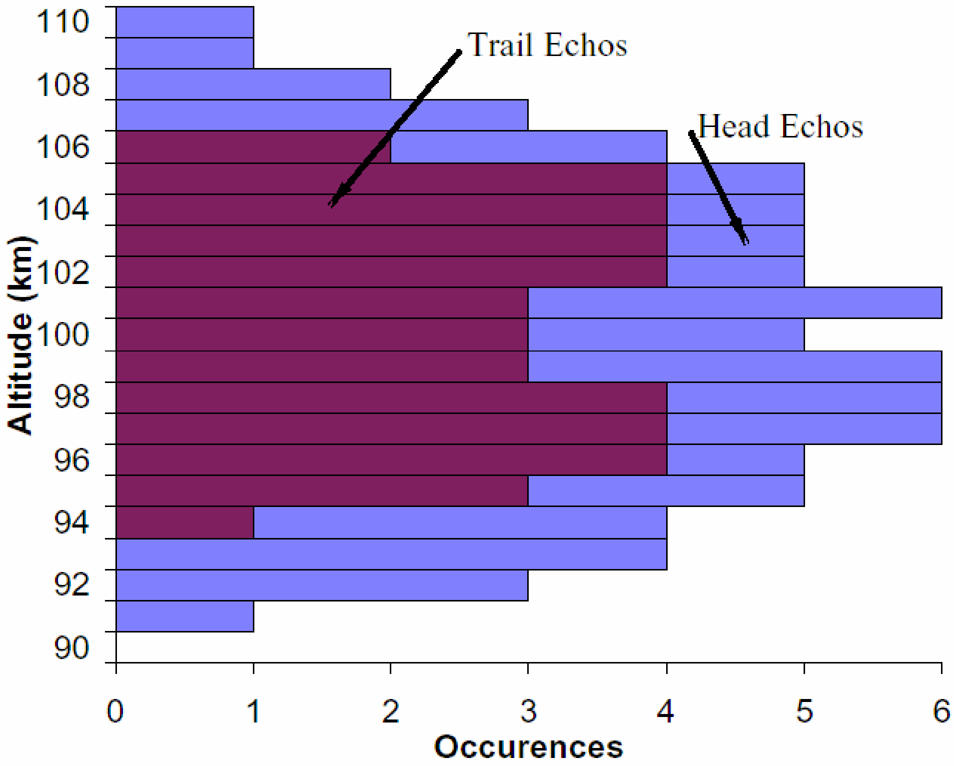
Observing a non-specular trail with radar



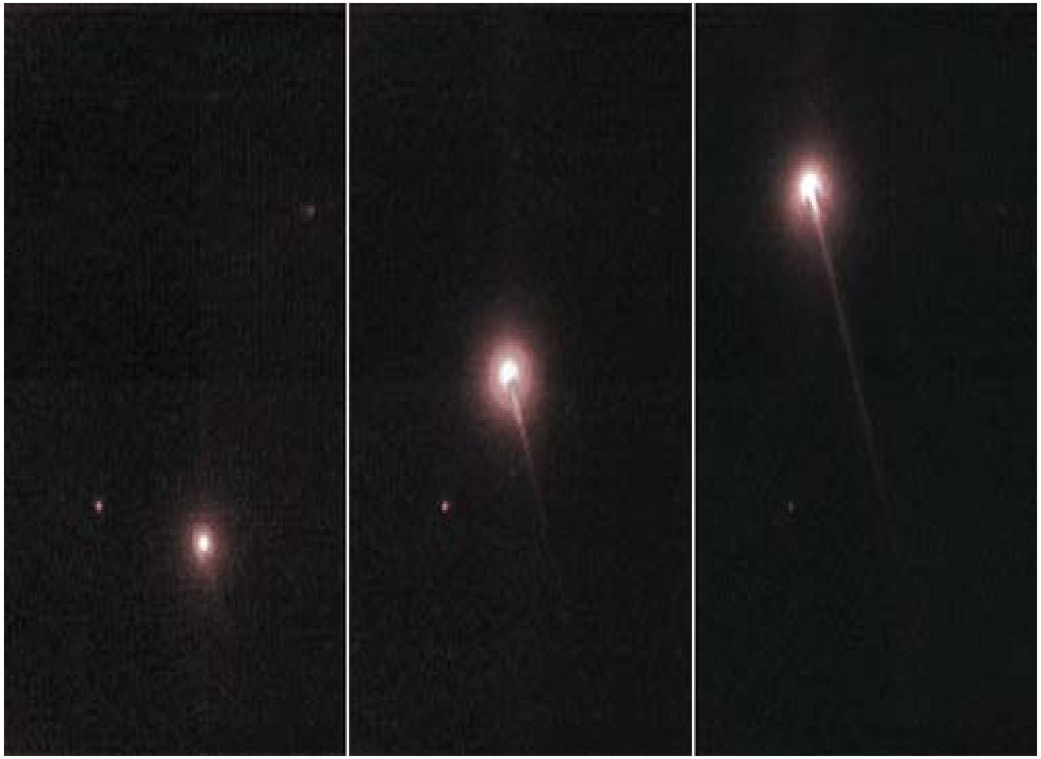
Irregularity Wavelength= ½ Radar Wavelength

Partially Unstable Plasma Columns



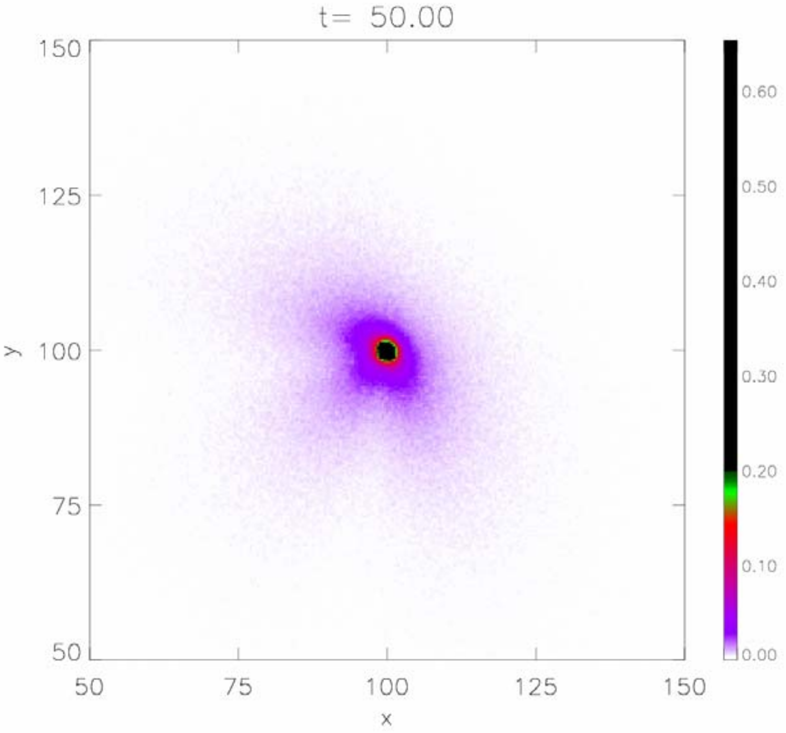


Head echo simulation



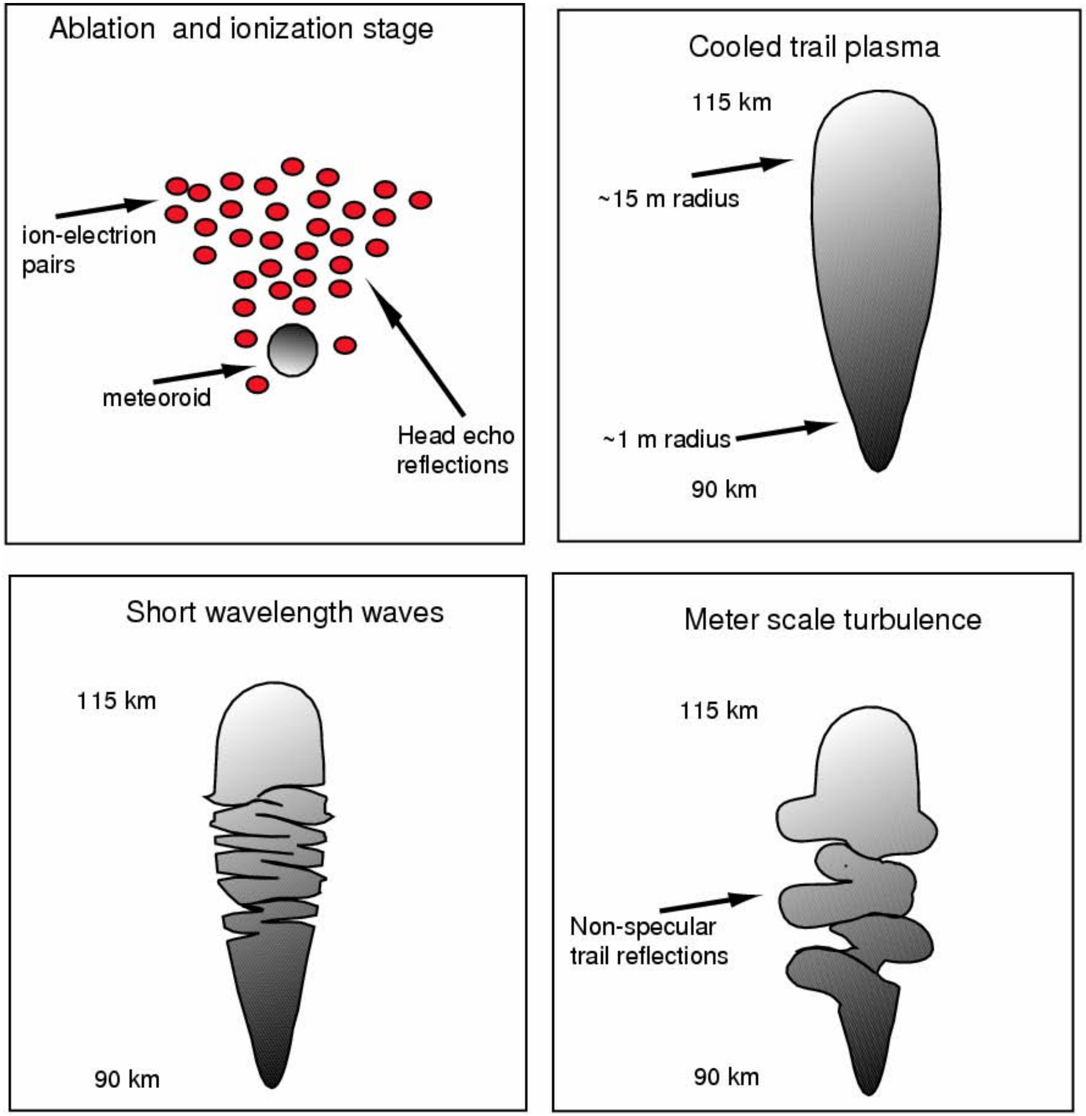
1000 frames per second of a Leonid micro-meteor over Alaska- Steinbeck-Nielson

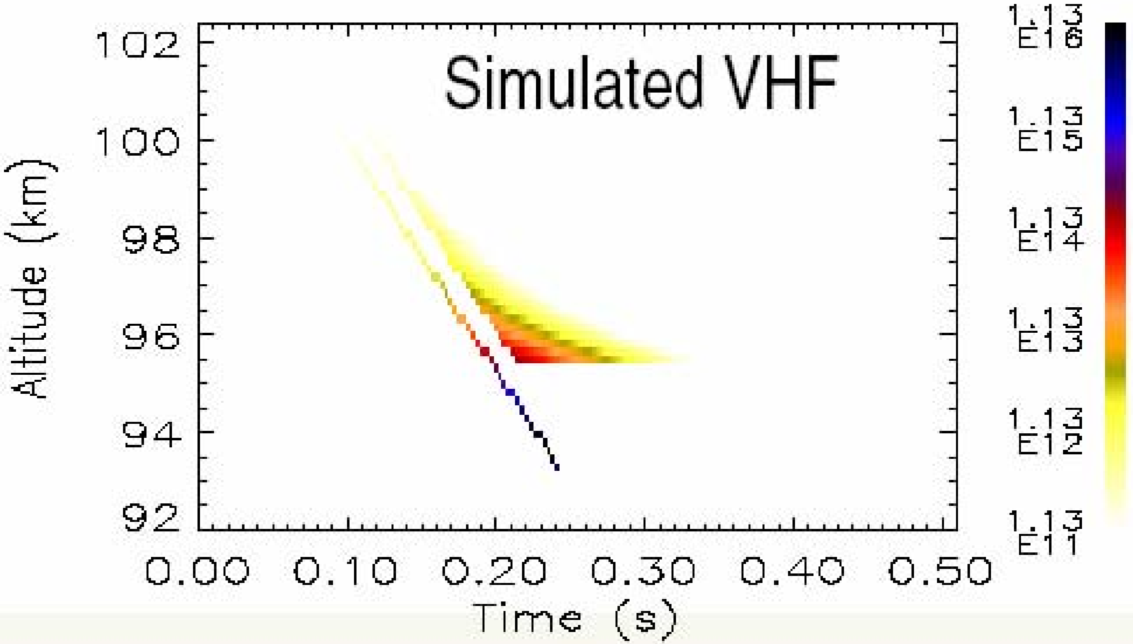
Simulation

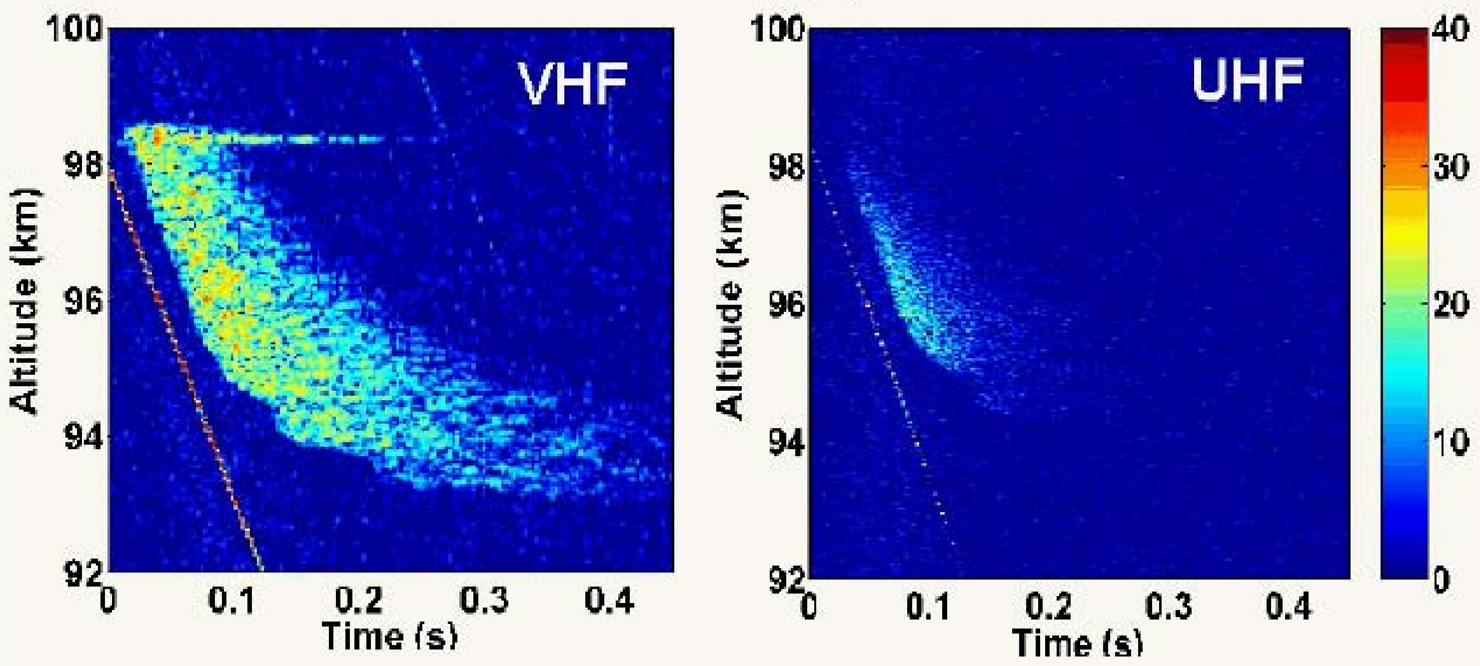


Meteor Trail Evolution

- Instabilities immediately arise in a portion of the trail plasma
- Waves produce turbulence in the form of plasma structure
- Radar reflects from structure

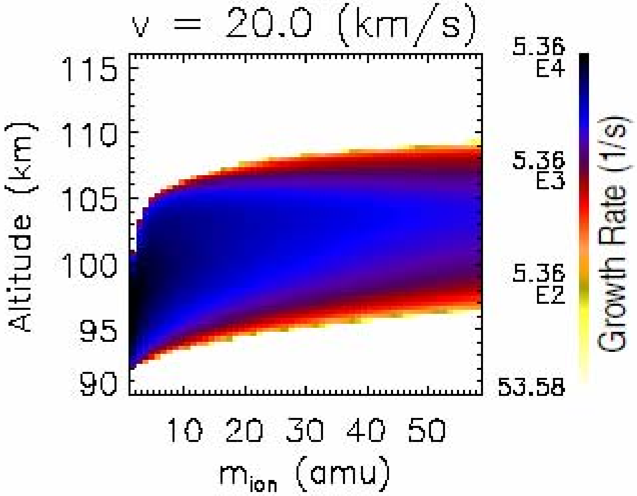


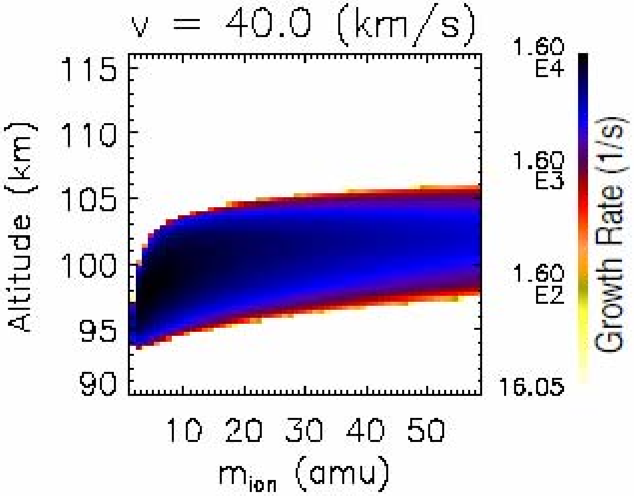

Simulated VHF
Altitude (km)
102
100
98
96
94
92
0.00
0.10
0.20
0.30
0.40
0.50
Time (s)
1.13 E16
1.13 E15
1.13 E14
1.13 E13
1.13 E12
1.13 E11


VHF
Altitude (km)
100
98
96
94
92
0
0.1
0.2
0.3
0.4
Time (s)
UHF
Altitude (km)
100
98
96
94
92
0
0.1
0.2
0.3
0.4
Time (s)
40
30
20
10
0

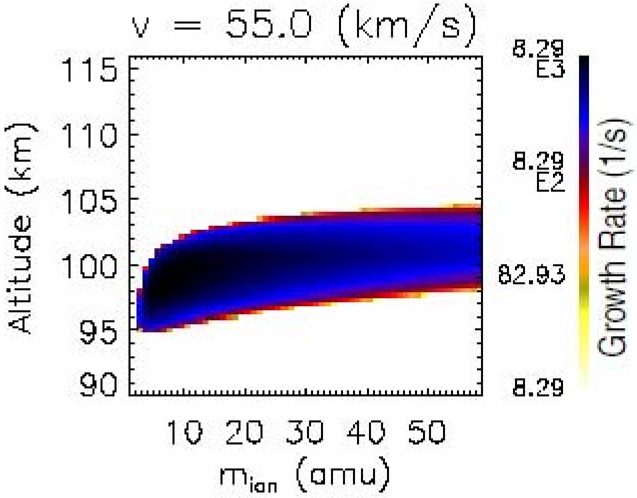
Instability Altitude Vs. Meteor Velocity and Composition

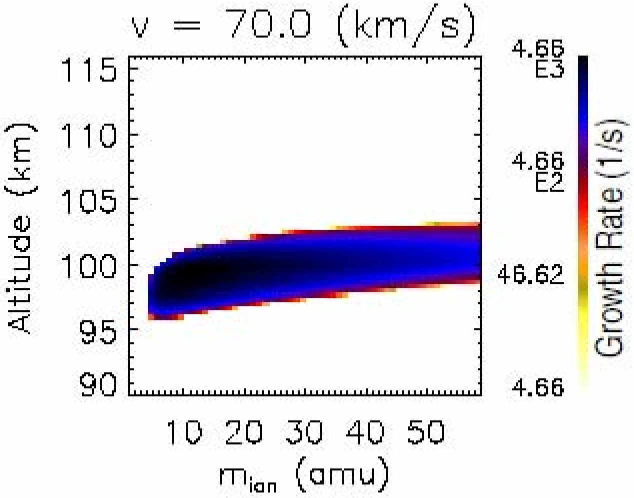
Velocity Dictates Altitude Span





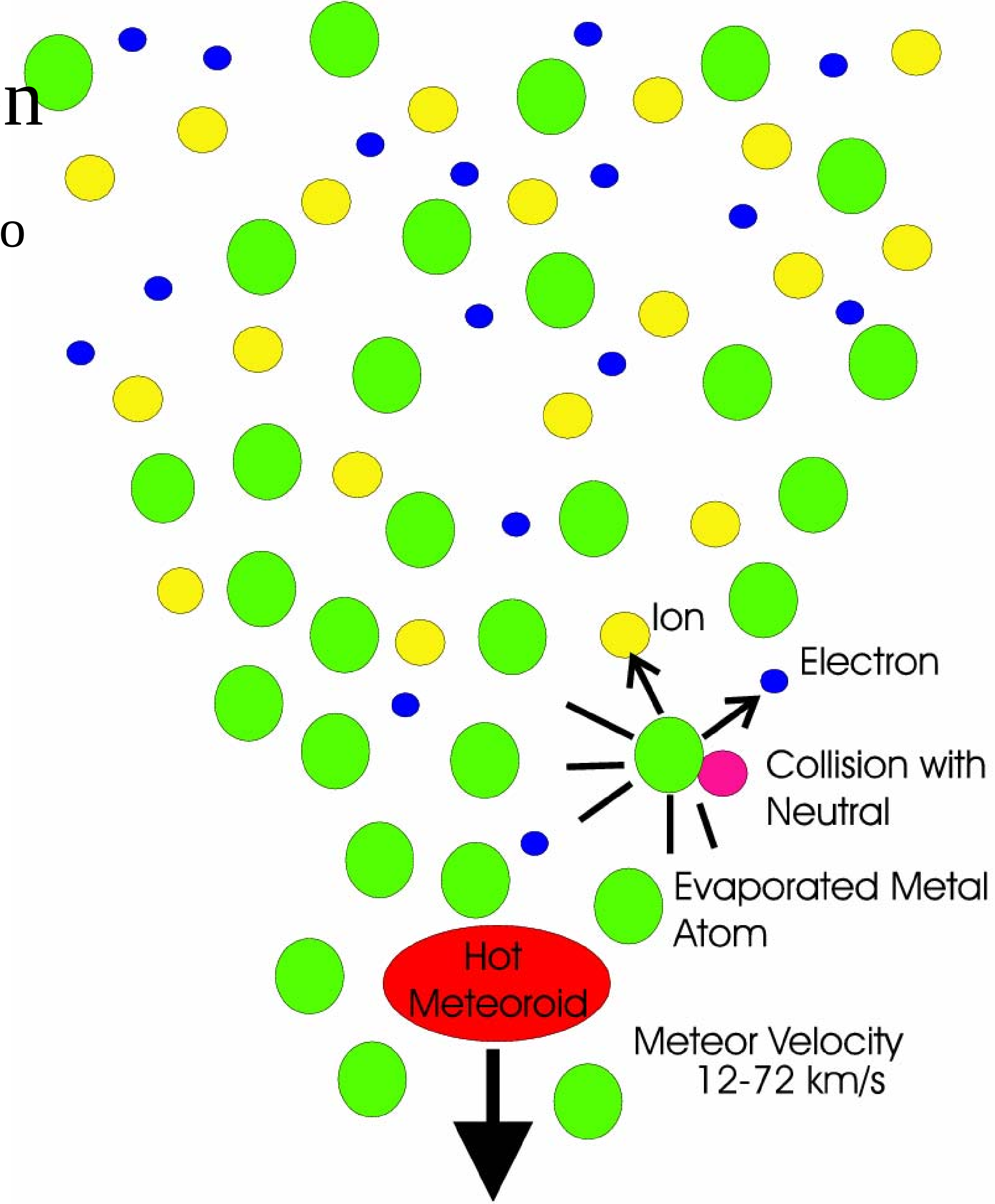
Composition Dictates Location

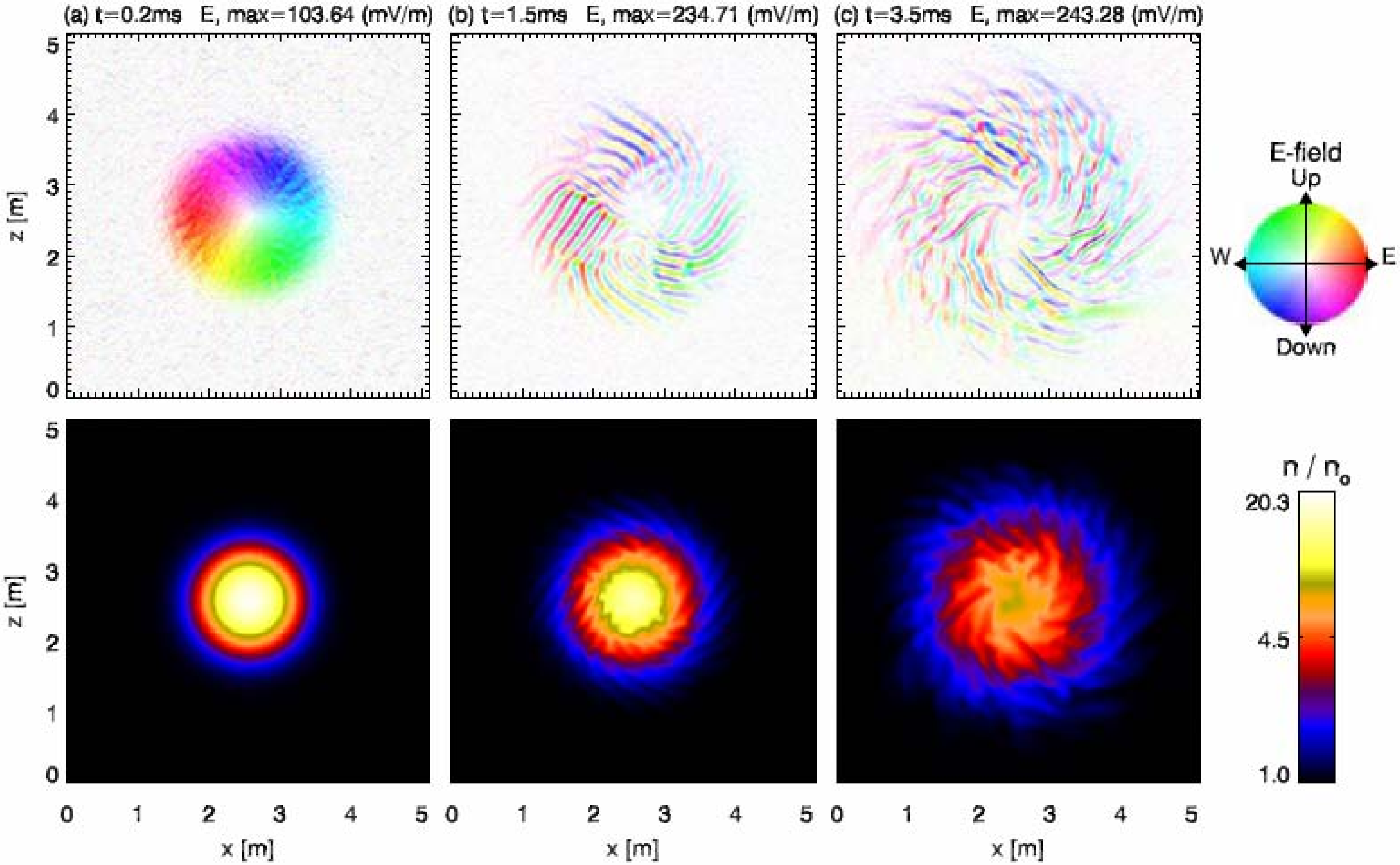




Trail Formation

1) Meteor heats up to 2000-3000 K
2) Atoms boil off surface
3) Collide with atmosphere
4) Form meteor ion and electron pair
5) Ions expand and cool to form trail



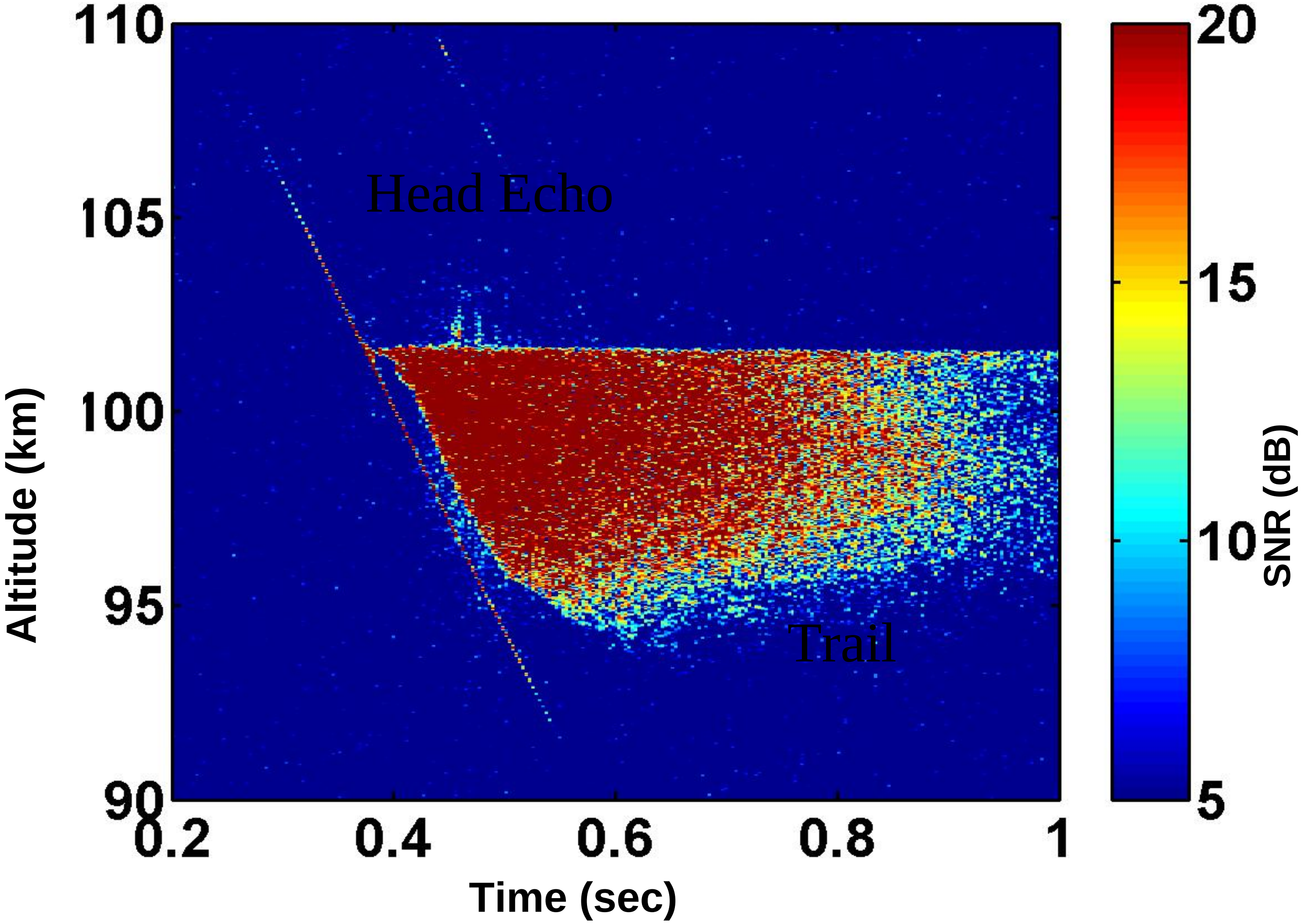


(a) t=0.2ms E, max=103.64 (mV/m)

(b) t=1.5ms E, max=234.71 (mV/m)

(c) t=3.5ms E, max=243.28 (mV/m)

Large Radar observations



ALTAIR VHF Radar Observations