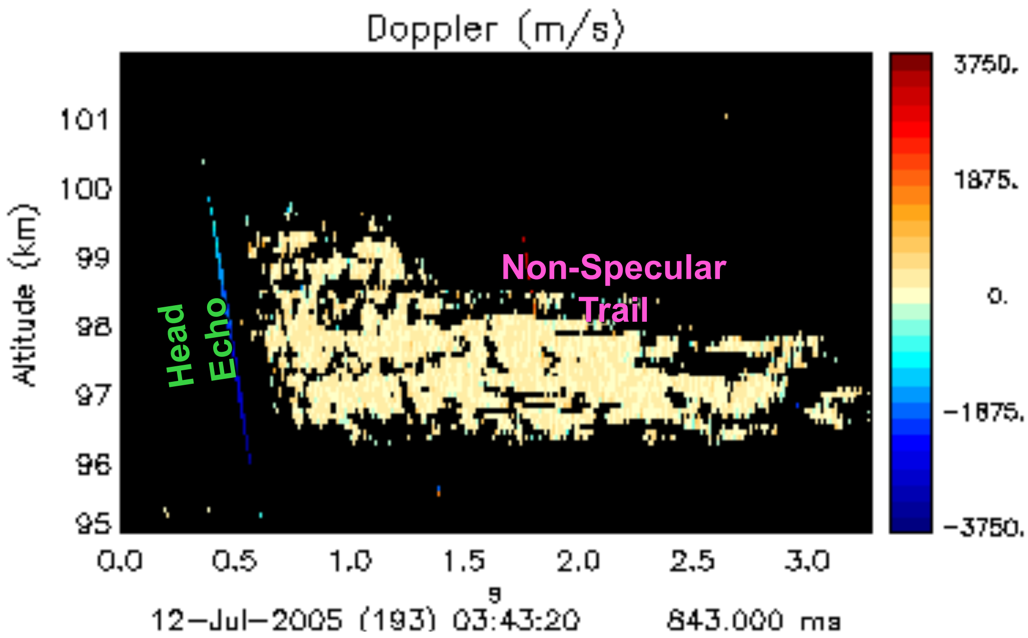
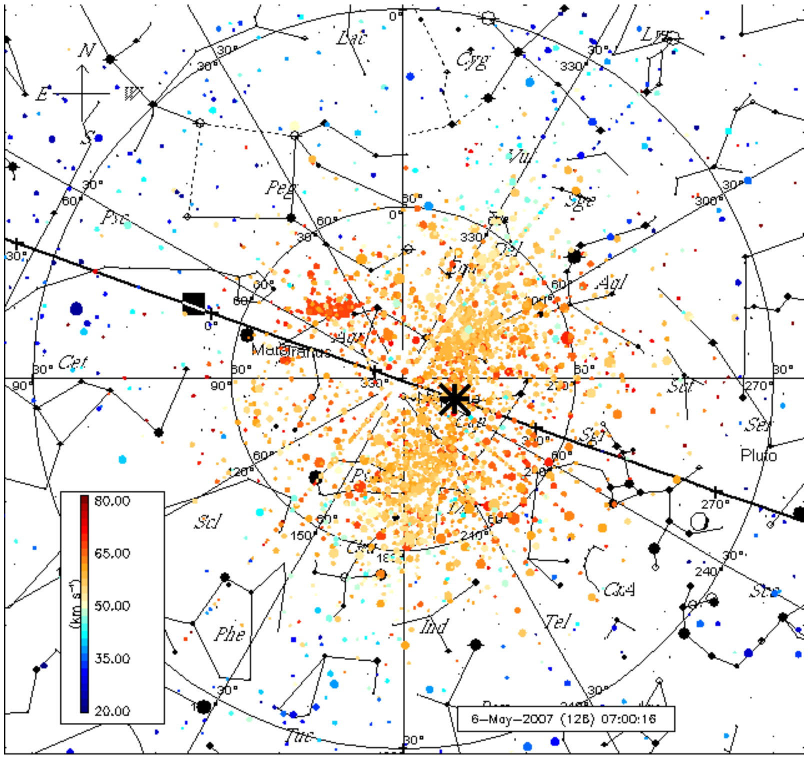
Radar meteor studies at the Jicamarca Radio Observatory: What has been done and what needs to be done





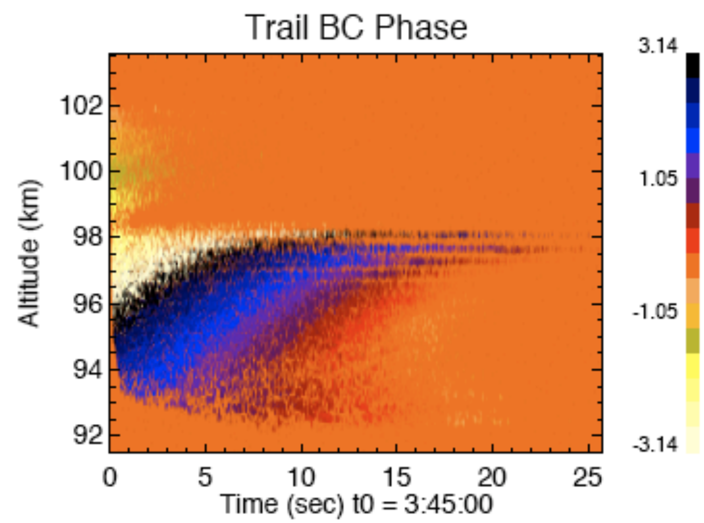
J. L. Chau[1] et al.

[1]Radio Observatorio de Jicamarca, Instituto Geofísico del Perú, Lima

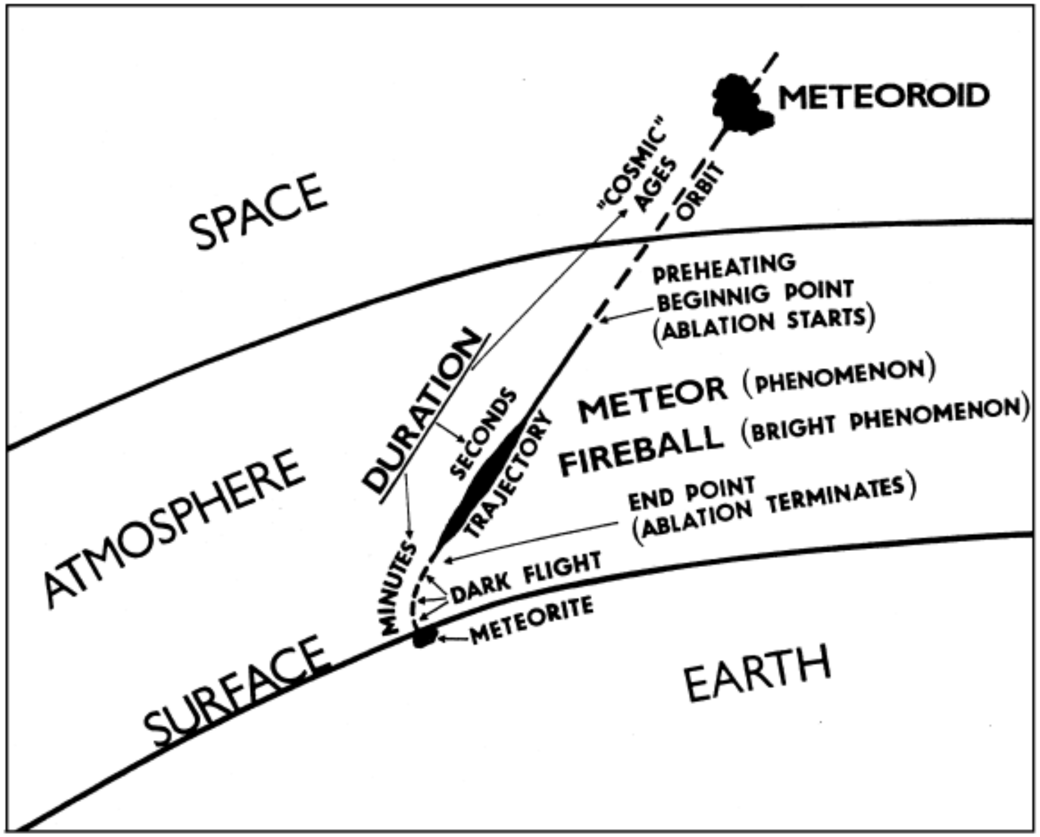
Stanford University – Jun 30, 2010

Outline

- Radar Meteor Echoes
- The Jicamarca Radio Observatory and its Upper Atmosphere
- JRO Meteor Observations
- Where do meteors come from?
  - Specular Meteor radar results
  - Jicamarca results
  - Conclusions
- What else has been done
- What needs to be done
- Trainee Program



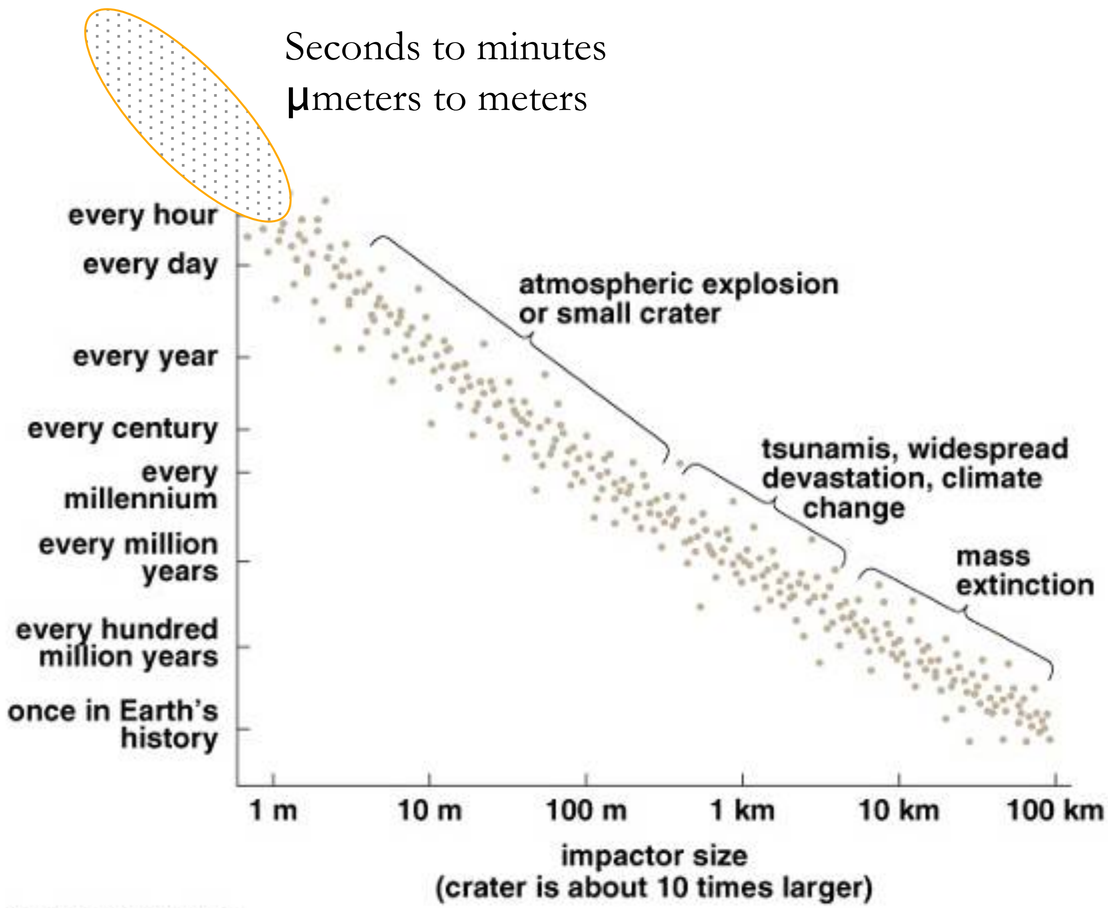
Meteoroid, Meteor, Meteorite



[de *Ceplecha et al.*,1998]

Meteoroids: Sizes and Frequency of Occurrence

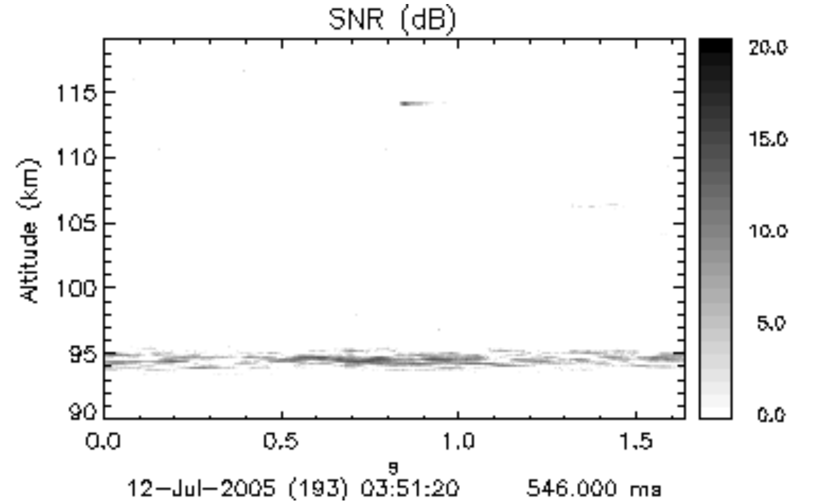
Radio Observatorio de JICAMARCA Radio Observatory

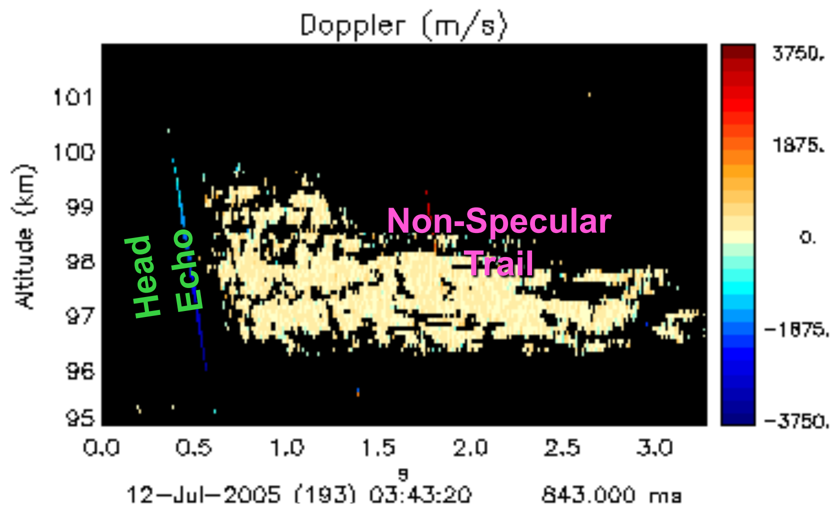


Radar Meteor Echoes

Radio Observatorio de JICAMARCA Radio Observatory

- Specular meteor trails
  - Bragg vector perpendicular to the meteor trajectory
- Meteor head echoes
  - From plasma irregularities surrounding the meteoroid
- Non-specular meteor trails
  - From field-aligned plasma irregularities behind the meteoroid.

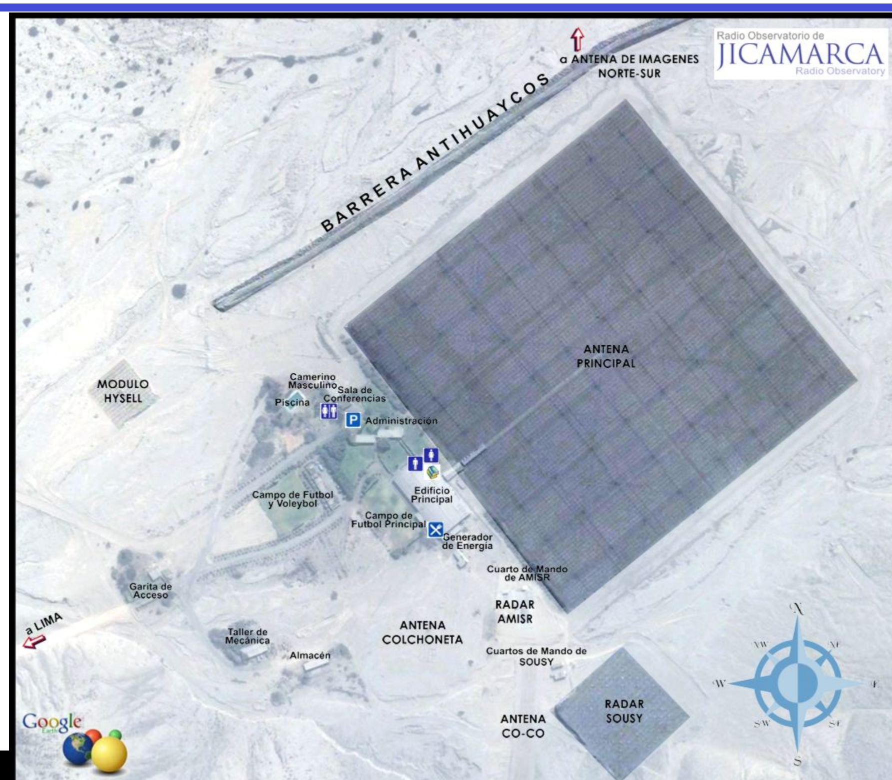


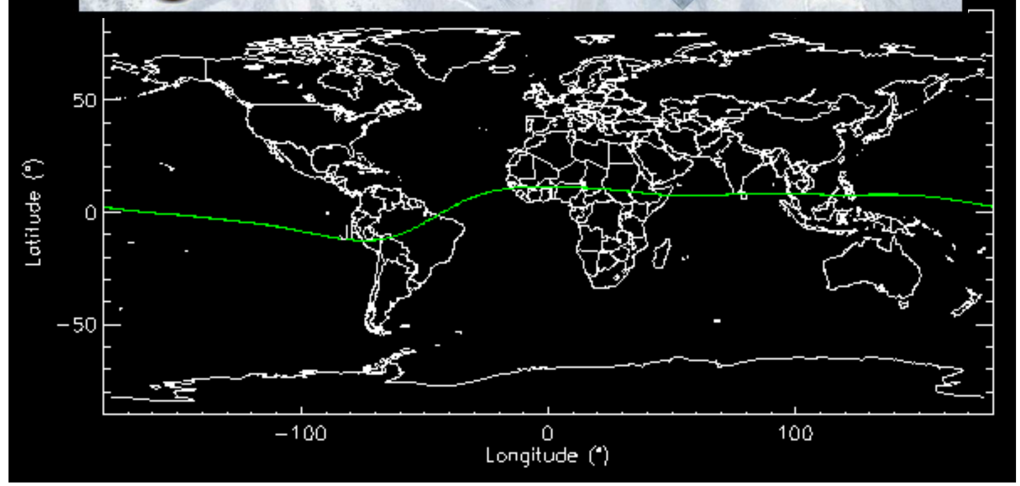


The Jicamarca Radio Observatory

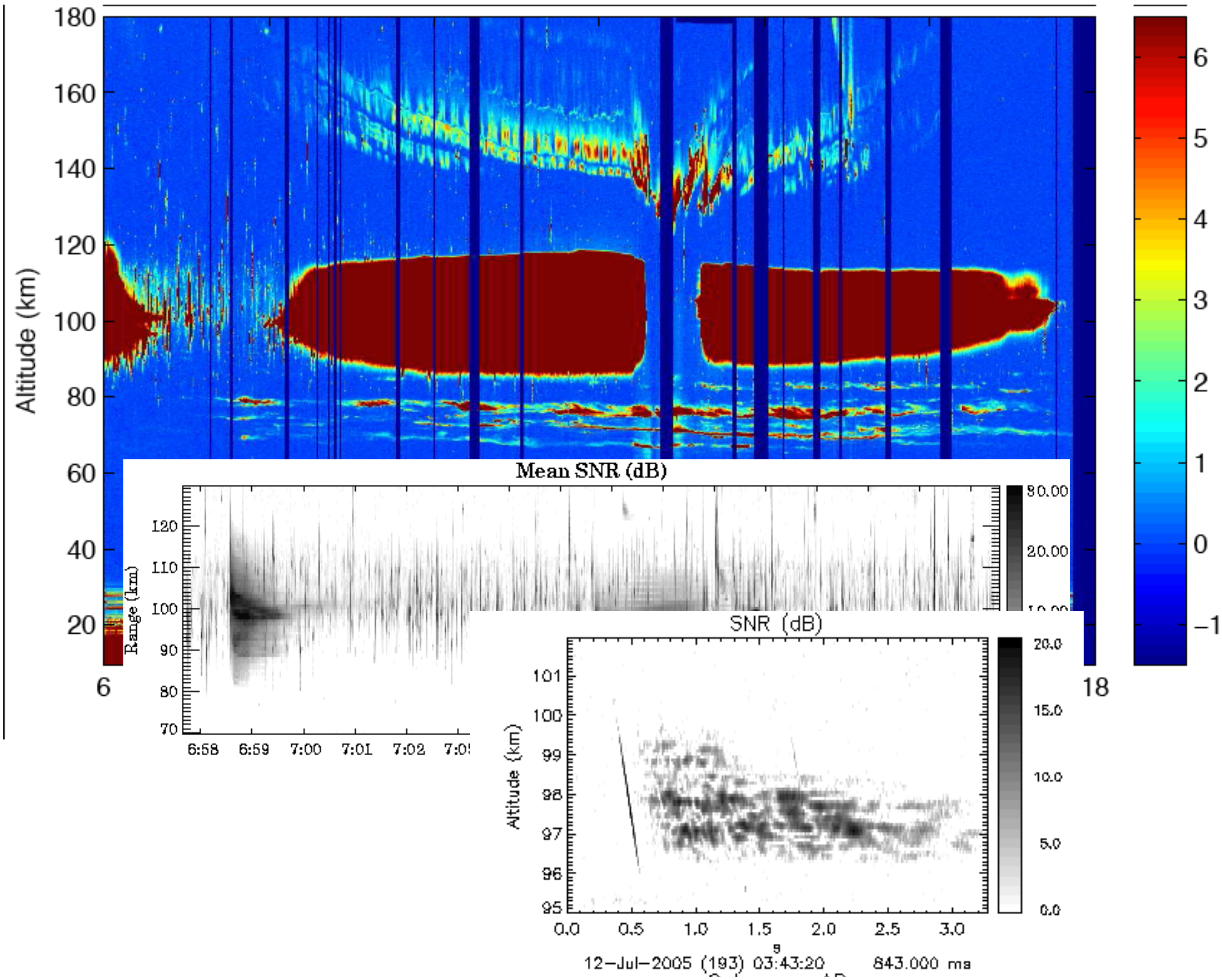
Radio Observatorio de JICAMARCA Radio Observatory

- Built in 1961 by the US NBS and then donated to IGP in 1969.
- Operating frequency: 50 MHz
- Antenna type: array of 18,432 dipoles, organized in 8x8 cross-polarized modules.
- Pointing directions: within 3 degrees from on-axis. Phase changes are currently done manually.
- Transmitters: 3 x 1.5 MW peak-power with 5% duty cycle.
- Located "under" the magnetic equator (dip 1º).





Radio Echoes Over Jicamarca



150-km echoes
Daytime

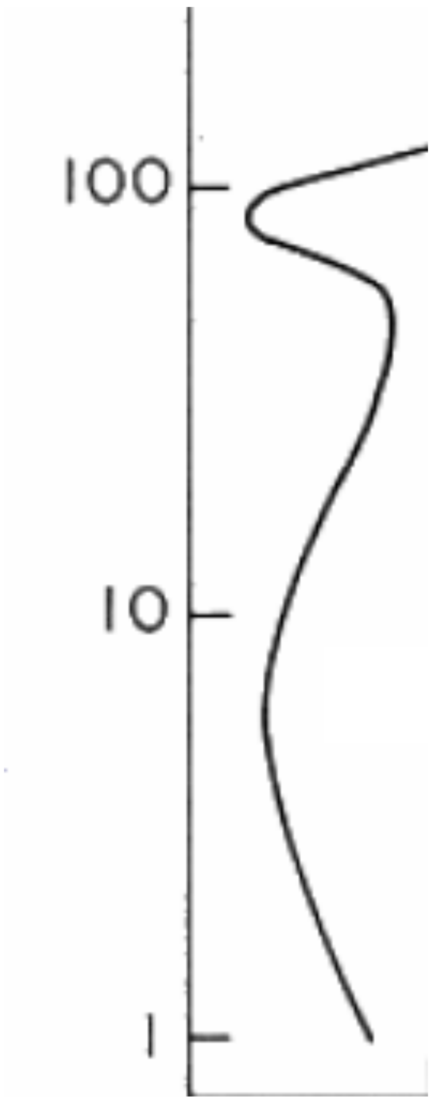
EEJ echoes
All Day
(Daytime stronger)

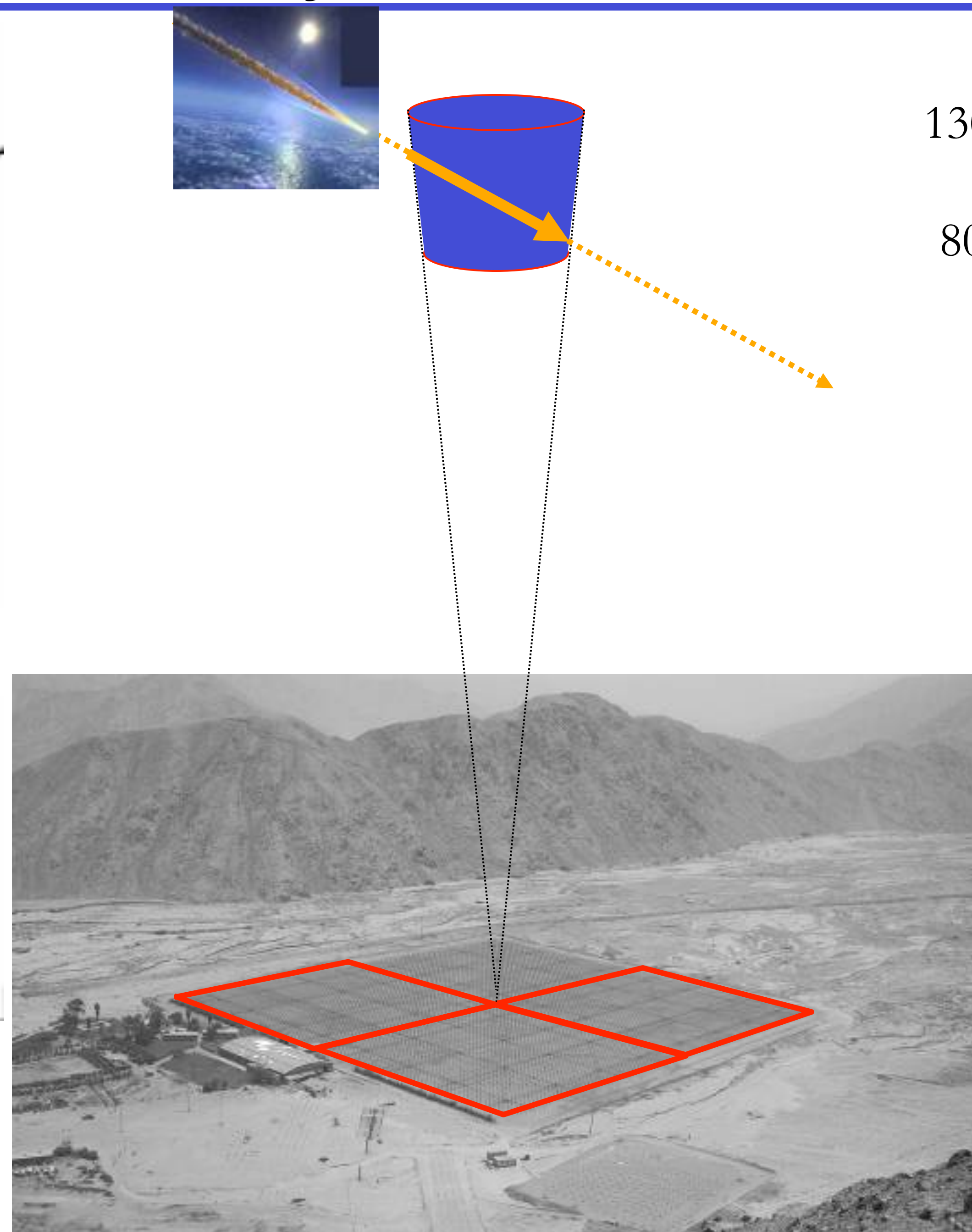
Meteor echoes
All Day
(head, non-specular and specular trails)

Mesospheric echoes
Daytime

Stratospheric and Tropospheric echoes
All Day

Interferometric Observations of Meteor-head echoes at JRO



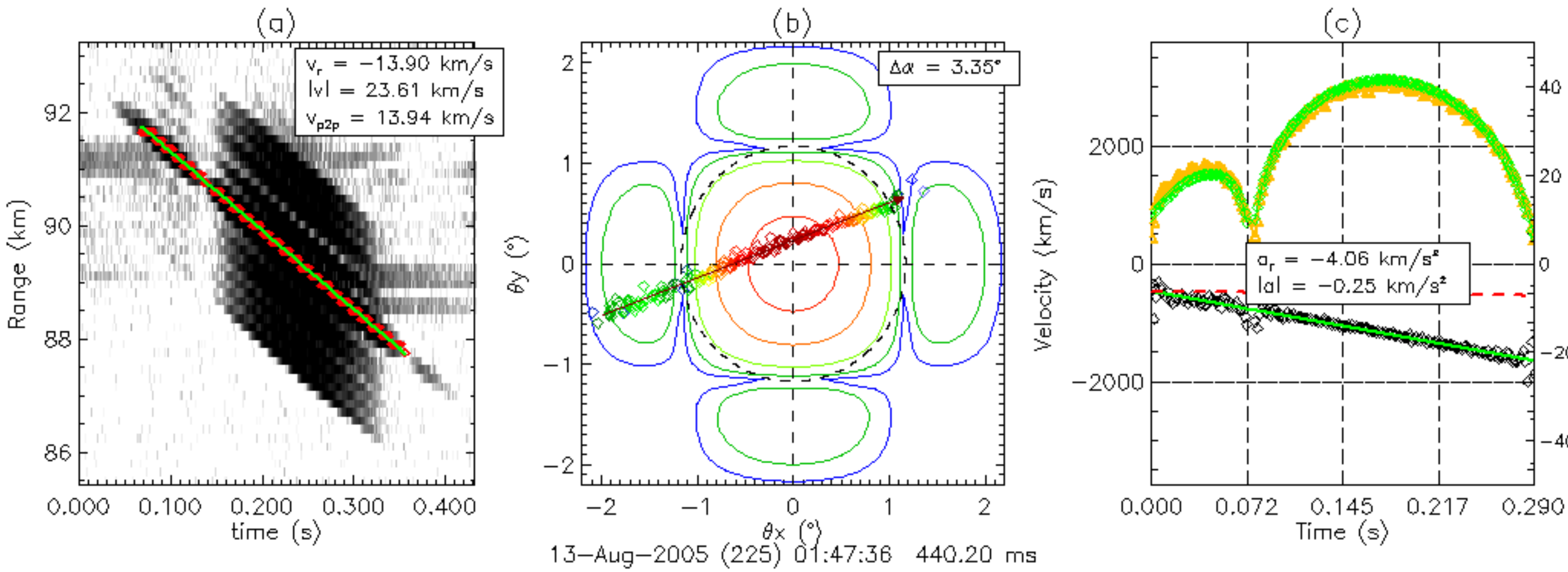


Antenna: 300m x 300m
Peak power: 2 MW
Frequency: 50 MHz
HPBW: ~1°

Not a scale

Measured and Derived Parameters

Radio Observatorio de JICAMARCA Radio Observatory



Measured Parameters

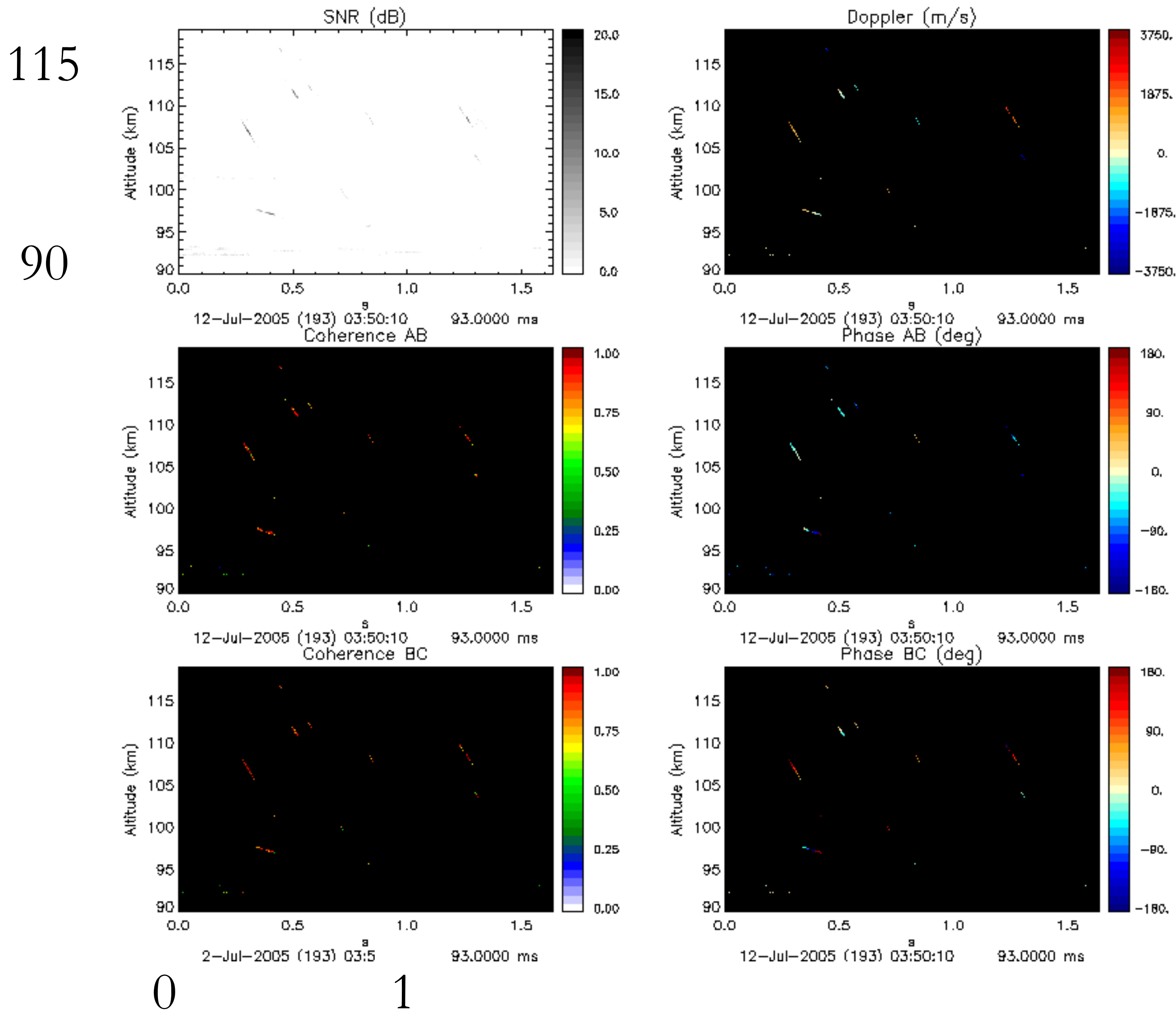
- Initial range
- Range and time coverage
- Radial velocity (coarse and fine)
- Radial deceleration
- Azimuth (from direction cosines)

Derived Parameters

- Zenith angle
- Absolute geocentric velocity
- Absolute deceleration
- Orbital parameters (inclination, eccentricity, axis length, origin)
- Other (e.g., mass)

Example: Many "weak" head echoes

Radio Observatorio de
JICAMARCA
Radio Observatory

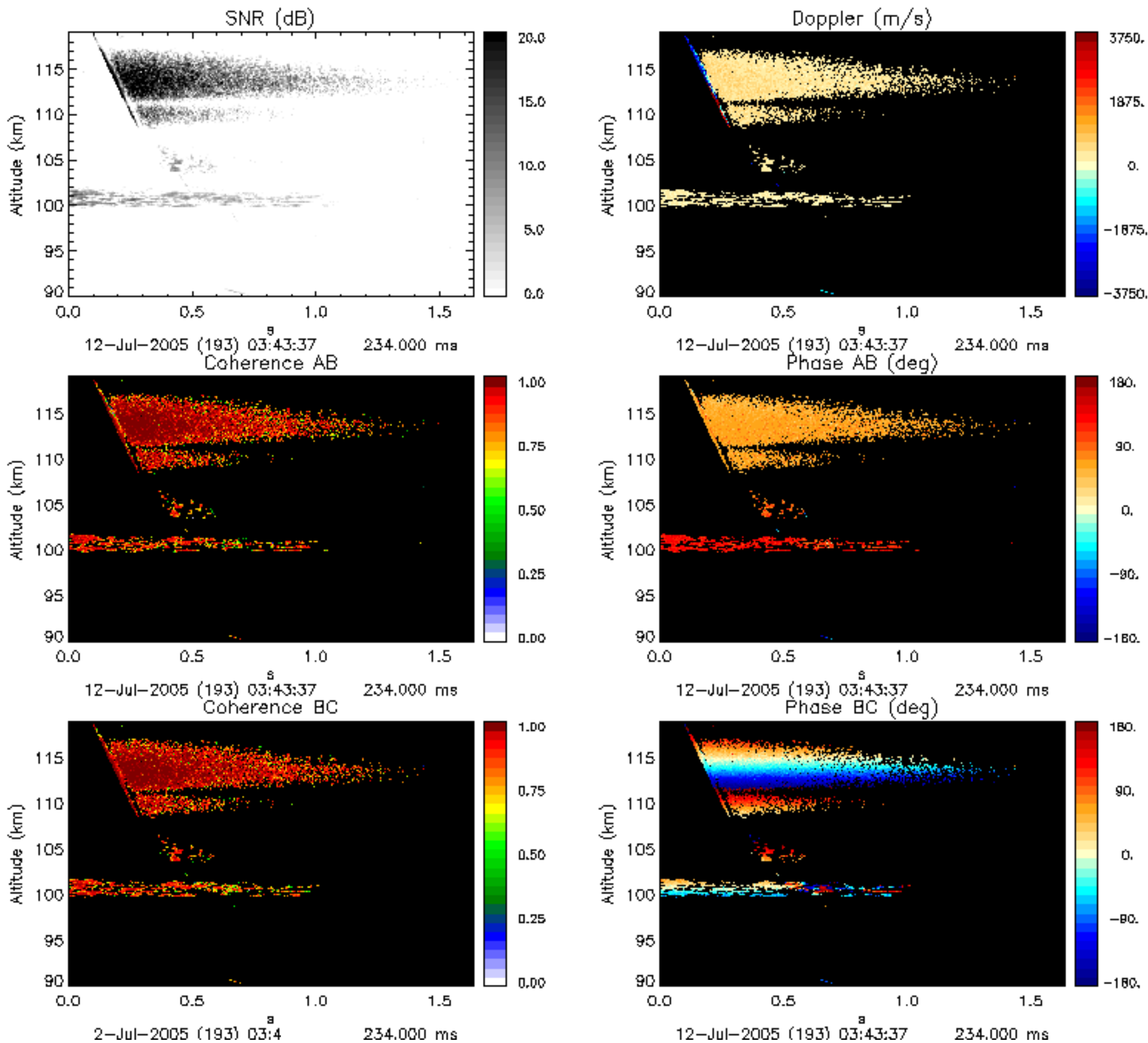


Examples: High Altitude Heads & Trails

Radio Observatorio de JICAMARCA Radio Observatory

115

90



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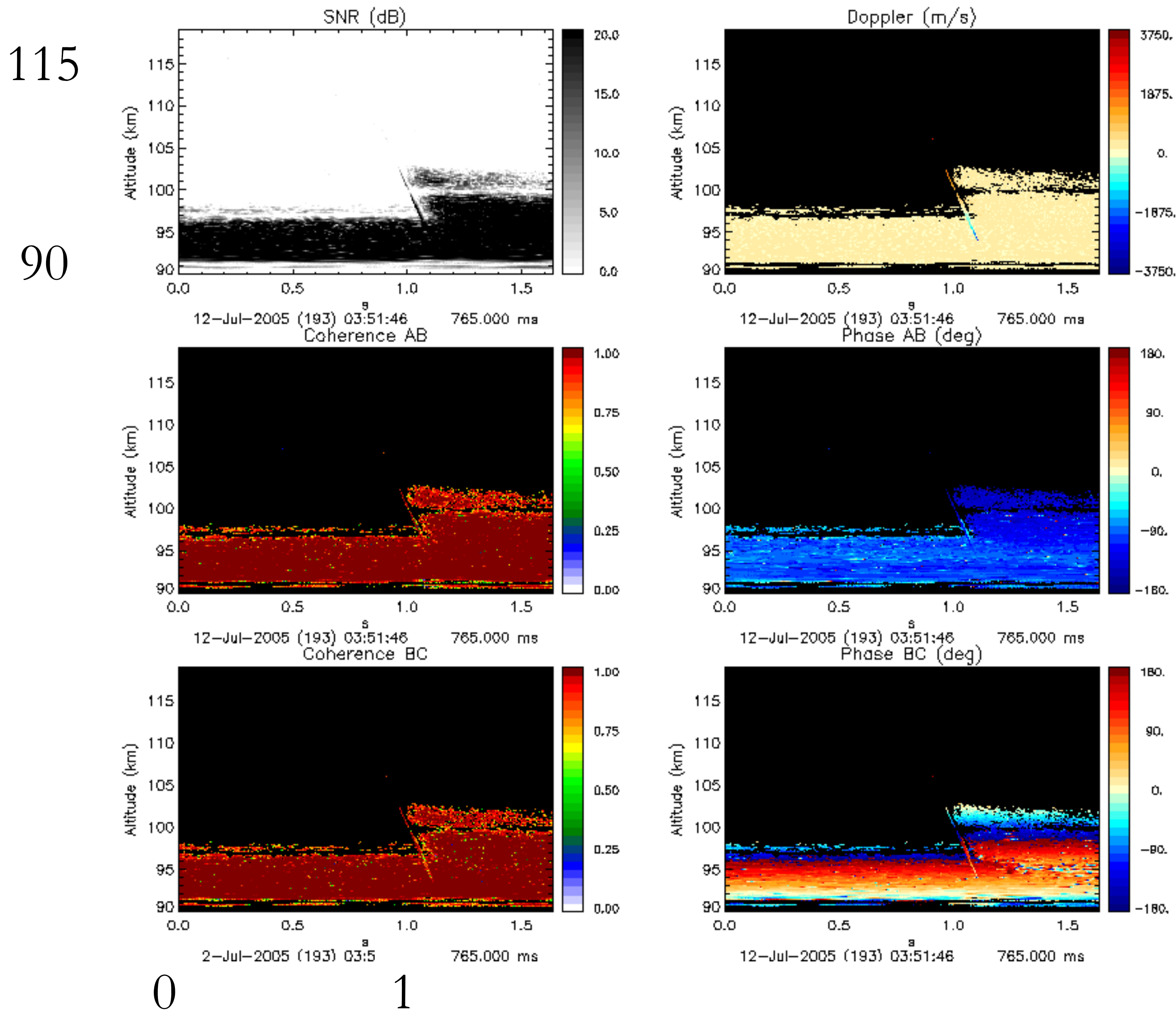
Example: Coexistence with other Field-aligned Irregularities

Radio Observatorio de
JICAMARCA
Radio Observatory

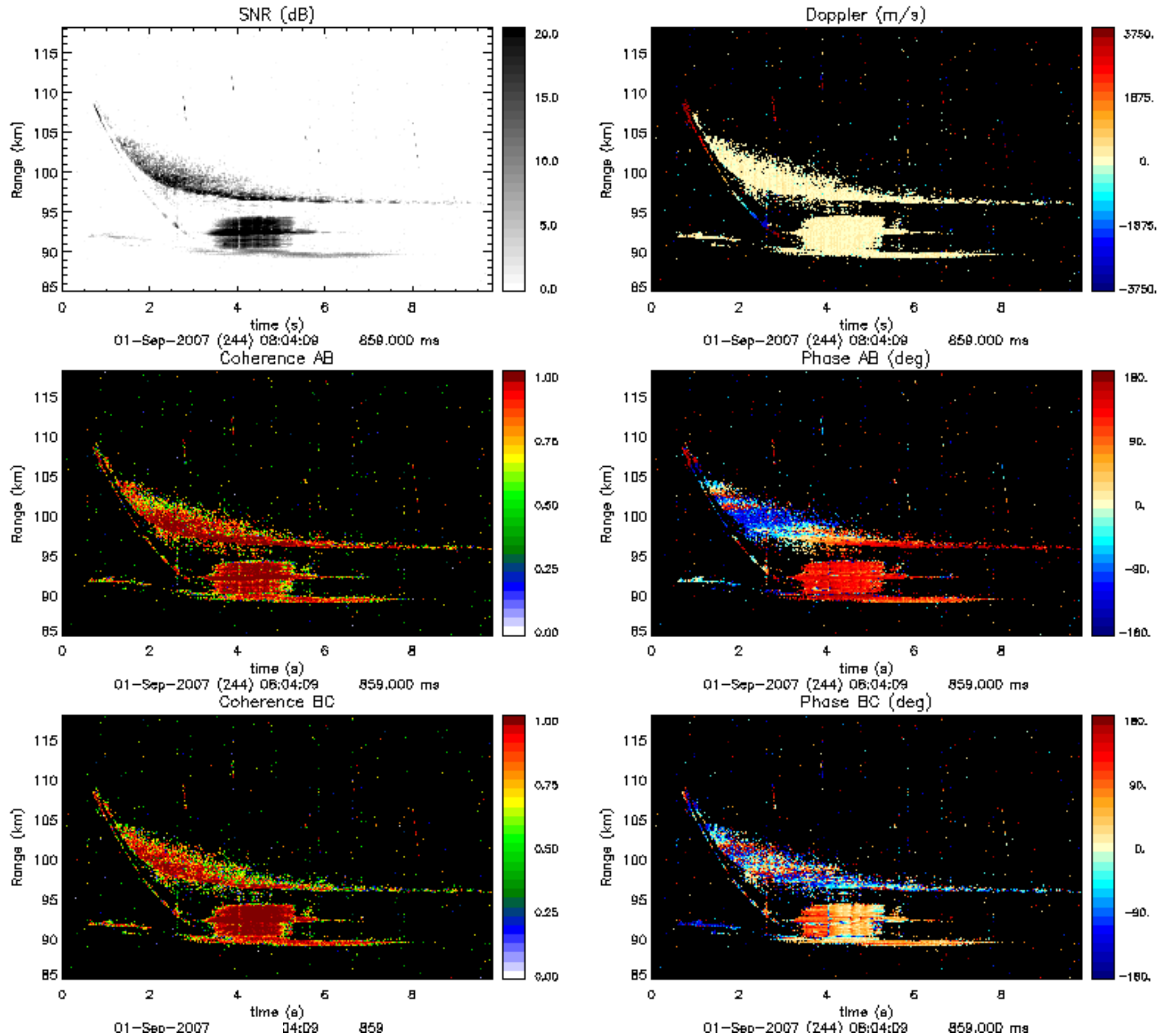


Example: Long Lasting meteors

Radio Observatorio de JICAMARCA Radio Observatory

115

85



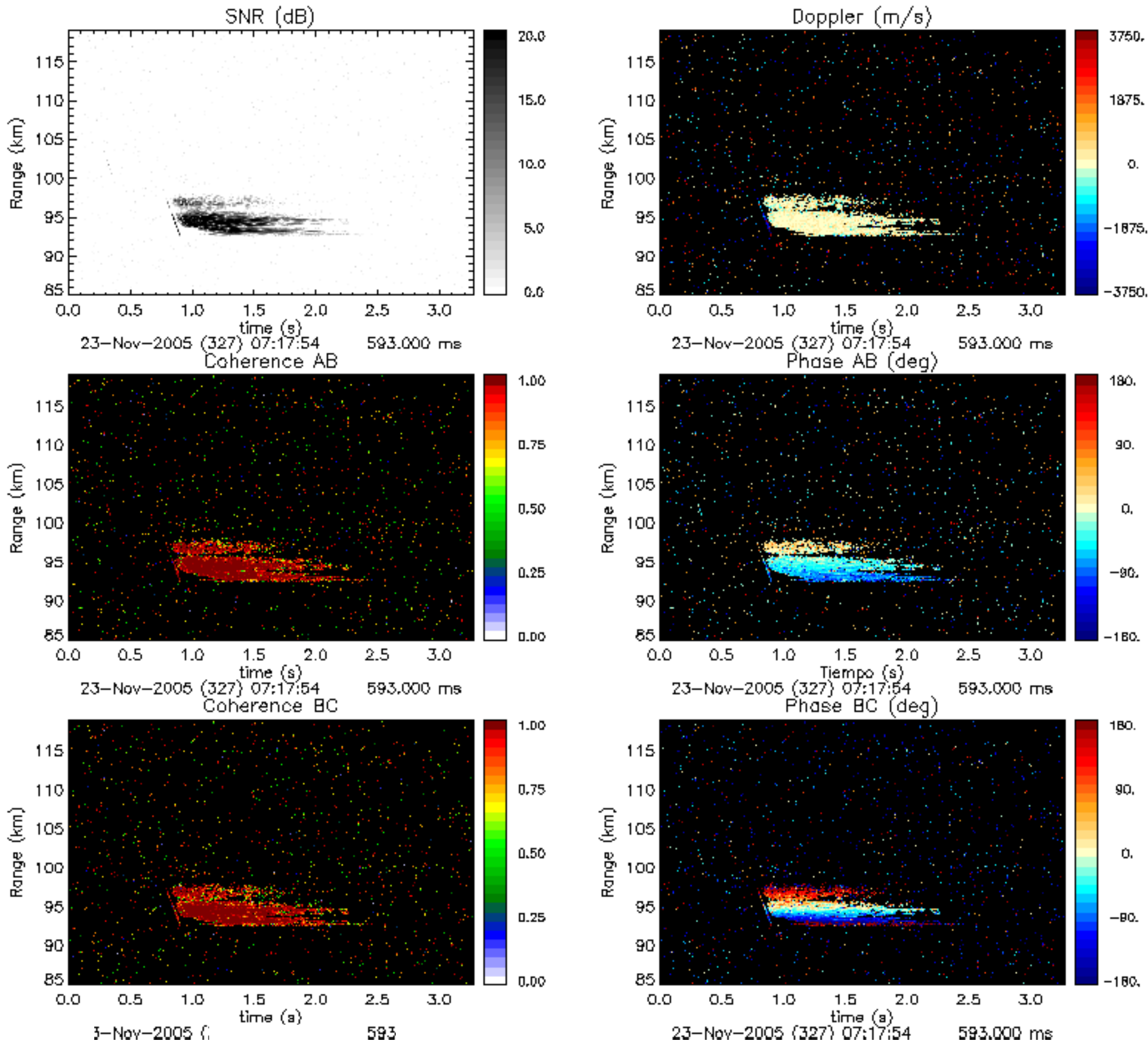
0 4 8

Short-Pulse vs. Coded Observations

Radio Observatorio de JICAMARCA Radio Observatory

115

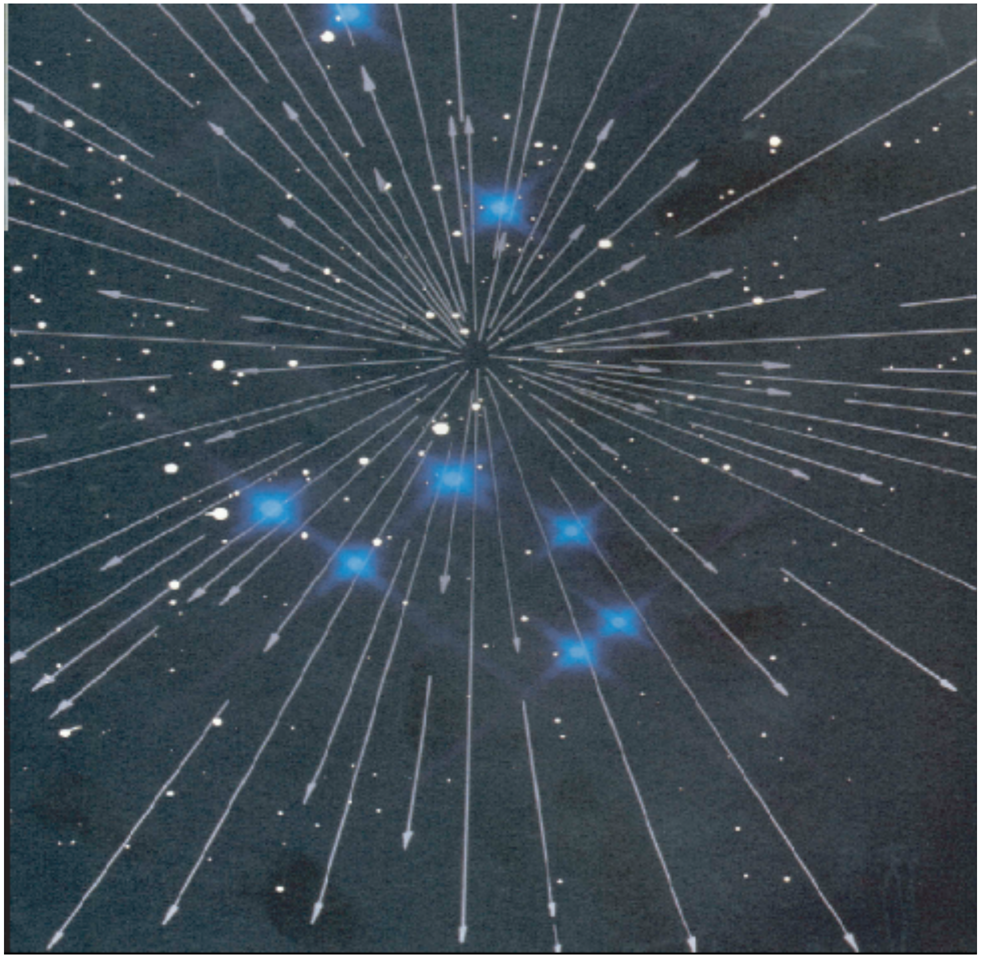
85



0 1.5 3.0

Where do meteors come from?

Radio Observatorio de
JICAMARCA
Radio Observatory



What do we know from SMRs?

Meteor sources as Observed by Specular Meteor Radars (SMRs) (1)

Radio Observatorio de JICAMARCA Radio Observatory

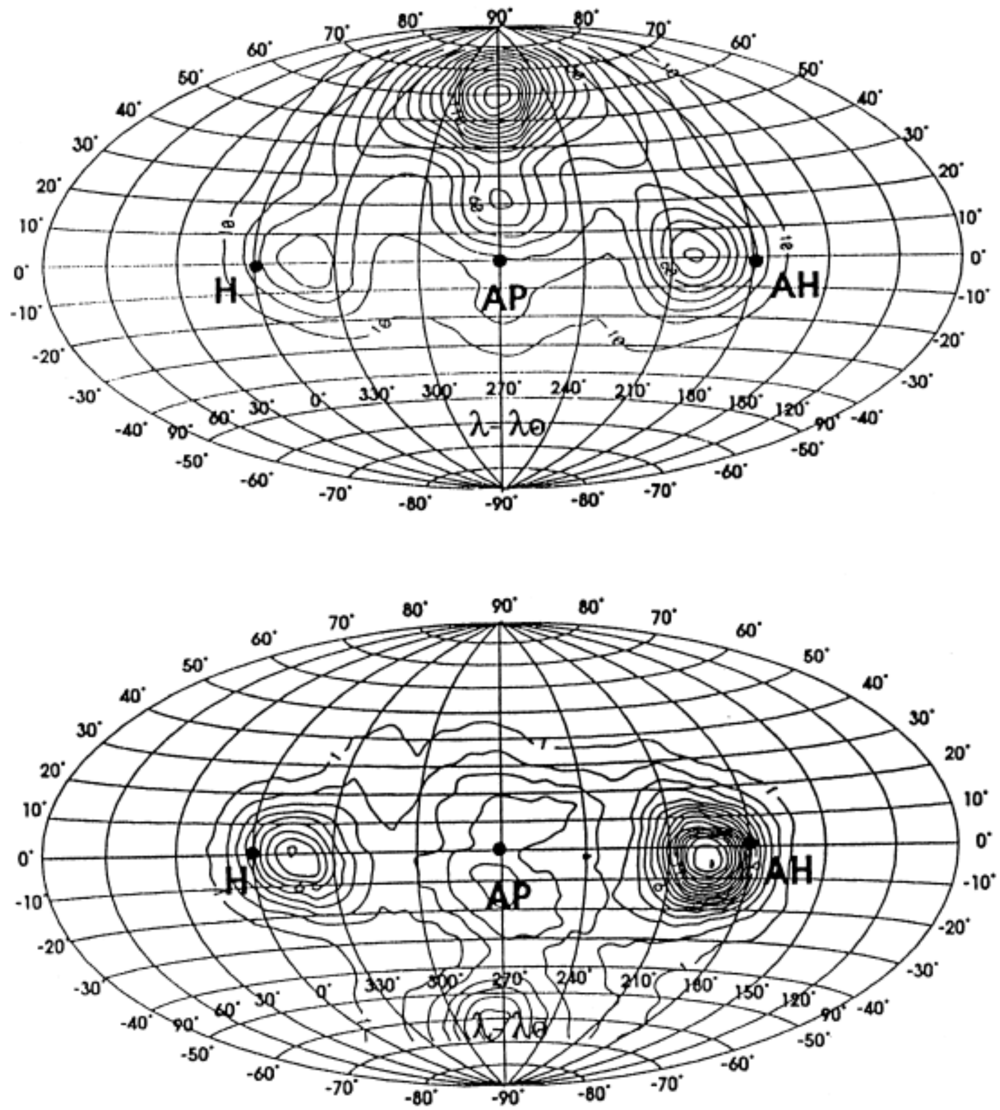


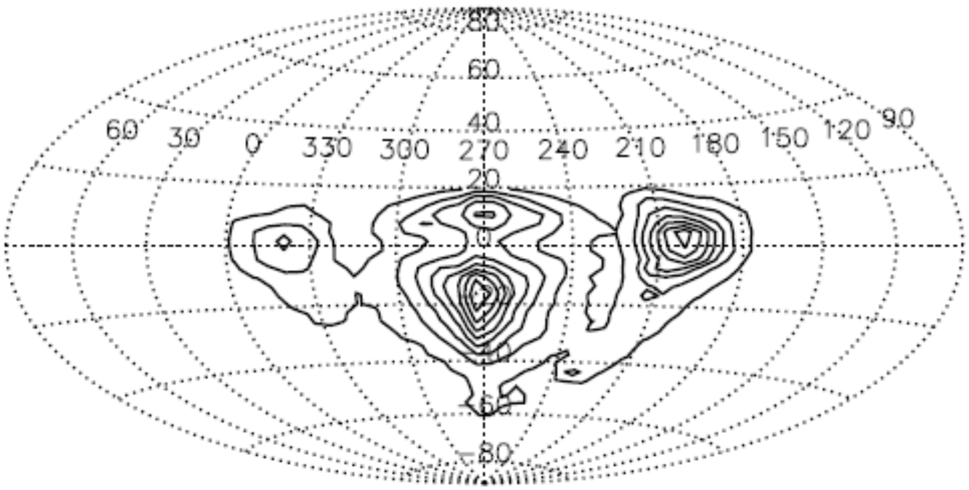
Figure 23. Contours of apparent density of meteor radiants from the combined Harvard (upper plot) and Adelaide (lower plot) radio surveys (Jones and Brown, 1994). **H** denotes the position of the Sun, **AP** the Earth's apex and **AH** the antihelion point.

- Combining many years of observations and stations at different latitudes, 6 main sources have been identified with SMRs:
  - North Apex
  - South Apex
  - Helion
  - Anti Helion
  - North Toroidal
  - South Toroidal

[from *Ceplecha et al.*, 1998]

Meteor sources as Observed by Specular Meteor Radars (SMRs) (2)

Radio Observatorio de JICAMARCA Radio Observatory



Direct observations

Figure 1. The radiant distribution of $\sim 4 \times 10^5$ meteors detected by AMOR between 1995 May and 1999 October. Ecliptic longitude (λ) is referenced to the solar longitude ($\lambda_\odot$) to avoid longitudinal motion of the source regions throughout the year. On this diagram the Sun is at 0° and the apex of the Earth's way is at 270°.

After in-atmosphere corrections

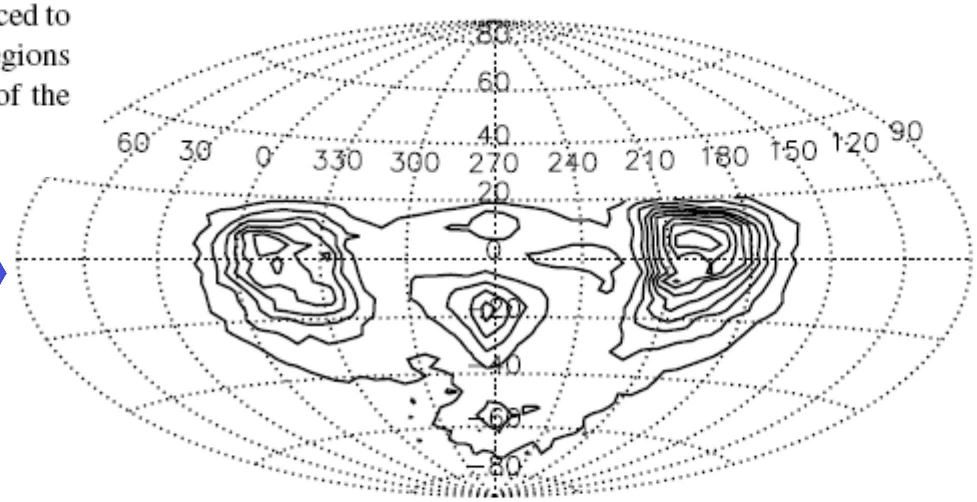
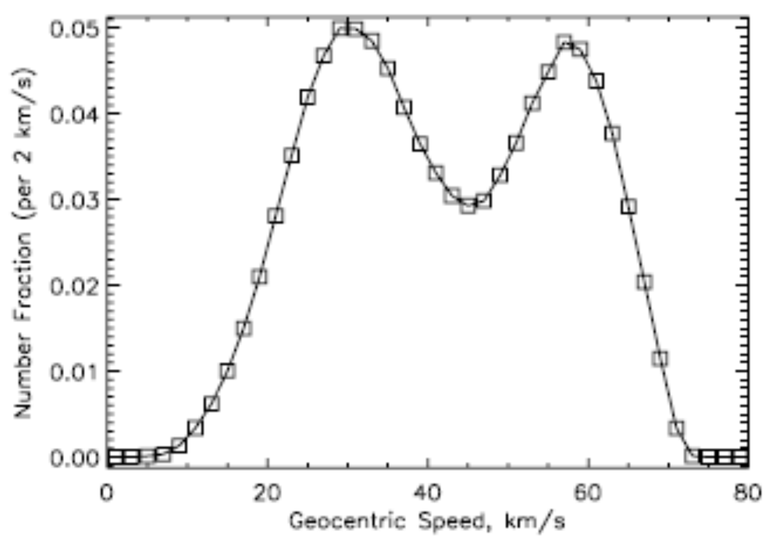
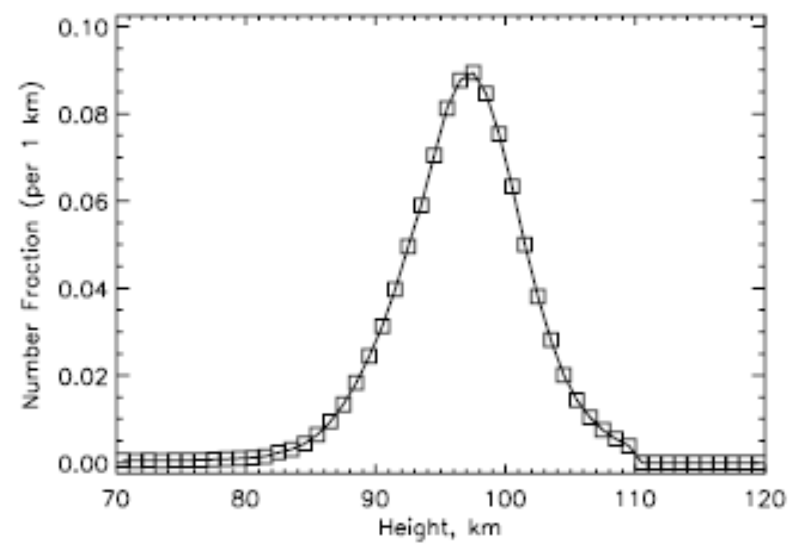


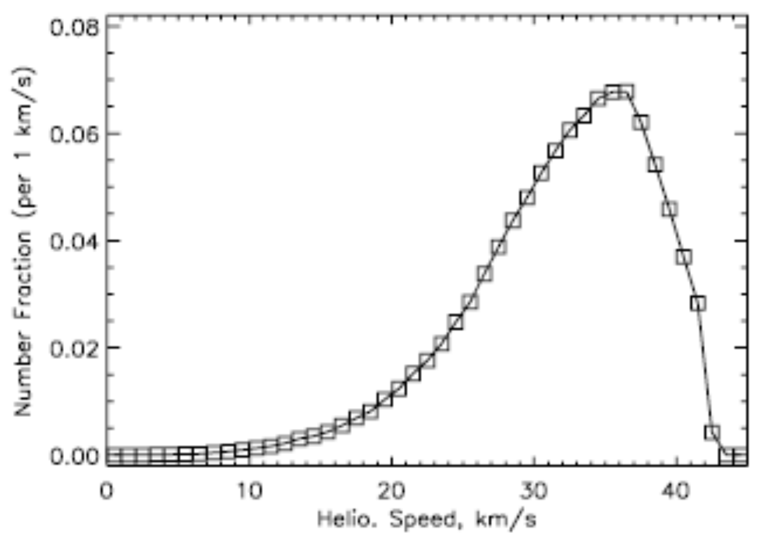
Figure 3. As for Fig. 1, but with the in-atmosphere observational biases removed as described in Section 3.

[from *Galligan and Baggaley,* 2005]

Typical Results from Specular Meteor Radars (SMRs) (3)







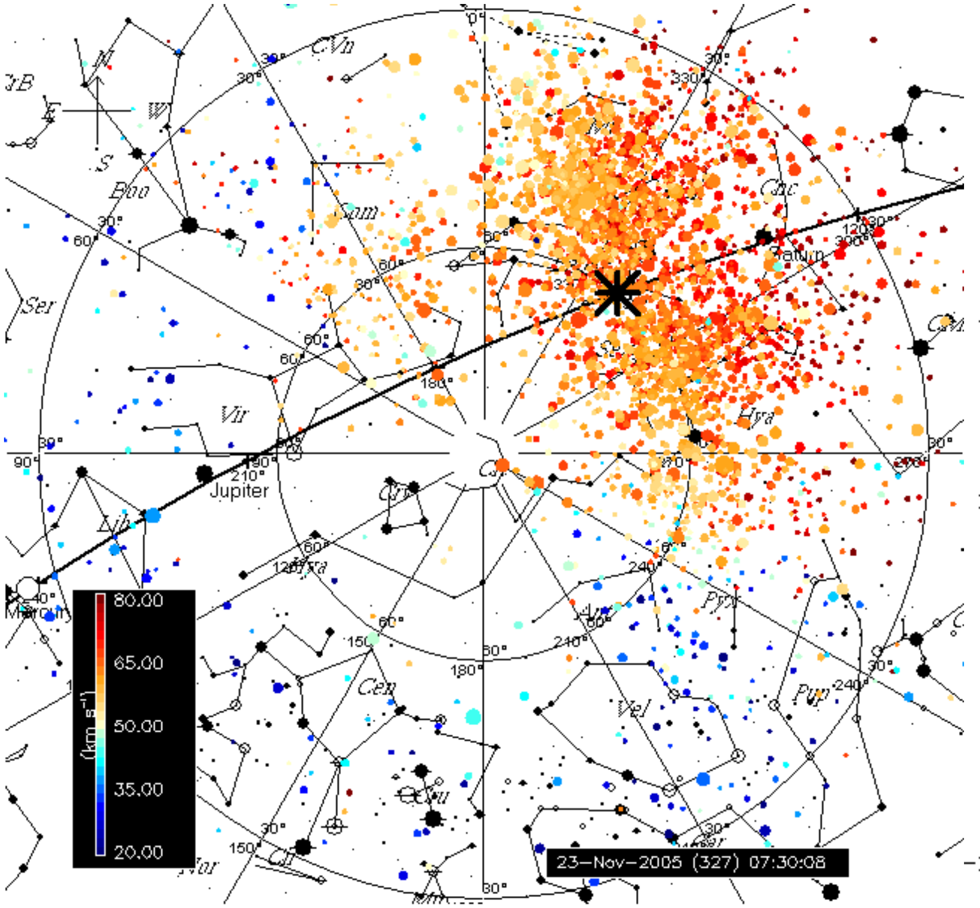
Speed and Altitude Distributions

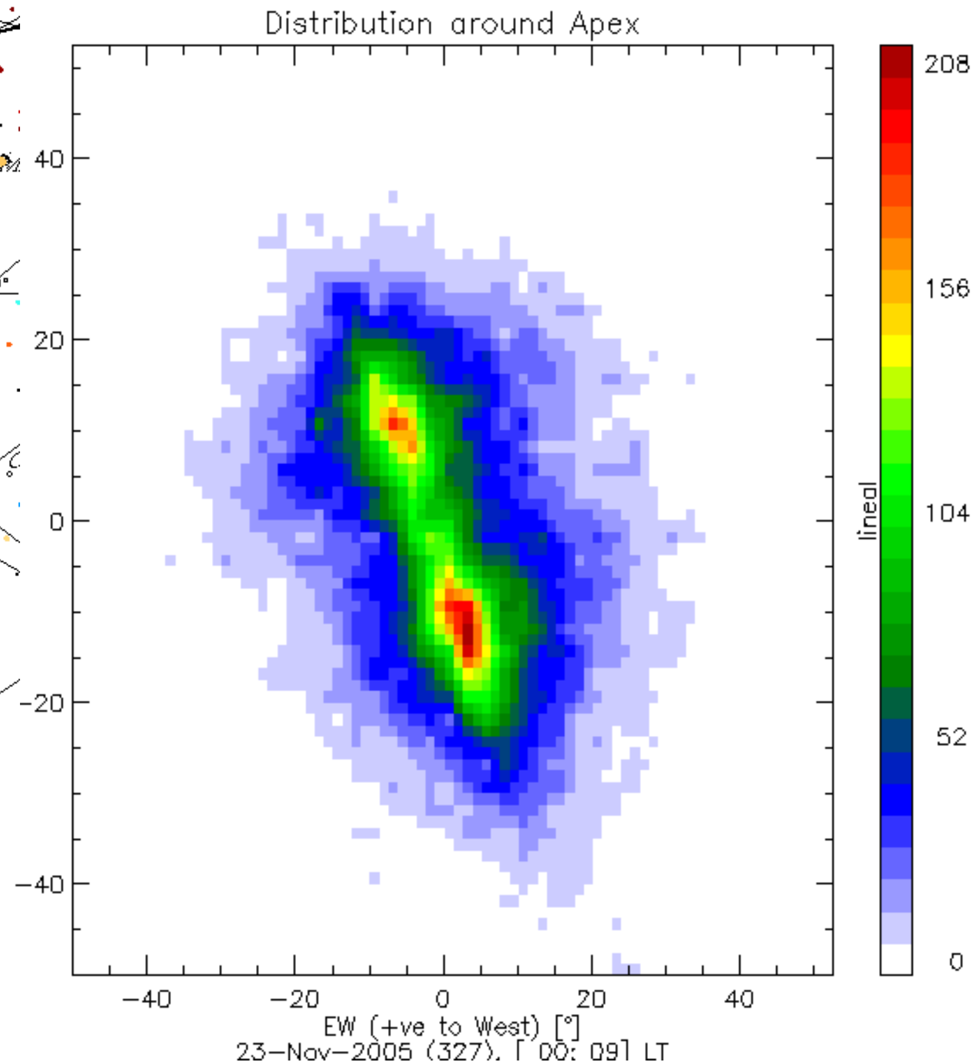
[from *Galligan and Baggaley,* 2004]

What do we know from Jicamarca?

Sporadic Meteors as Observed from Jicamarca Coordinates

Radio Observatorio de JICAMARCA Radio Observatory





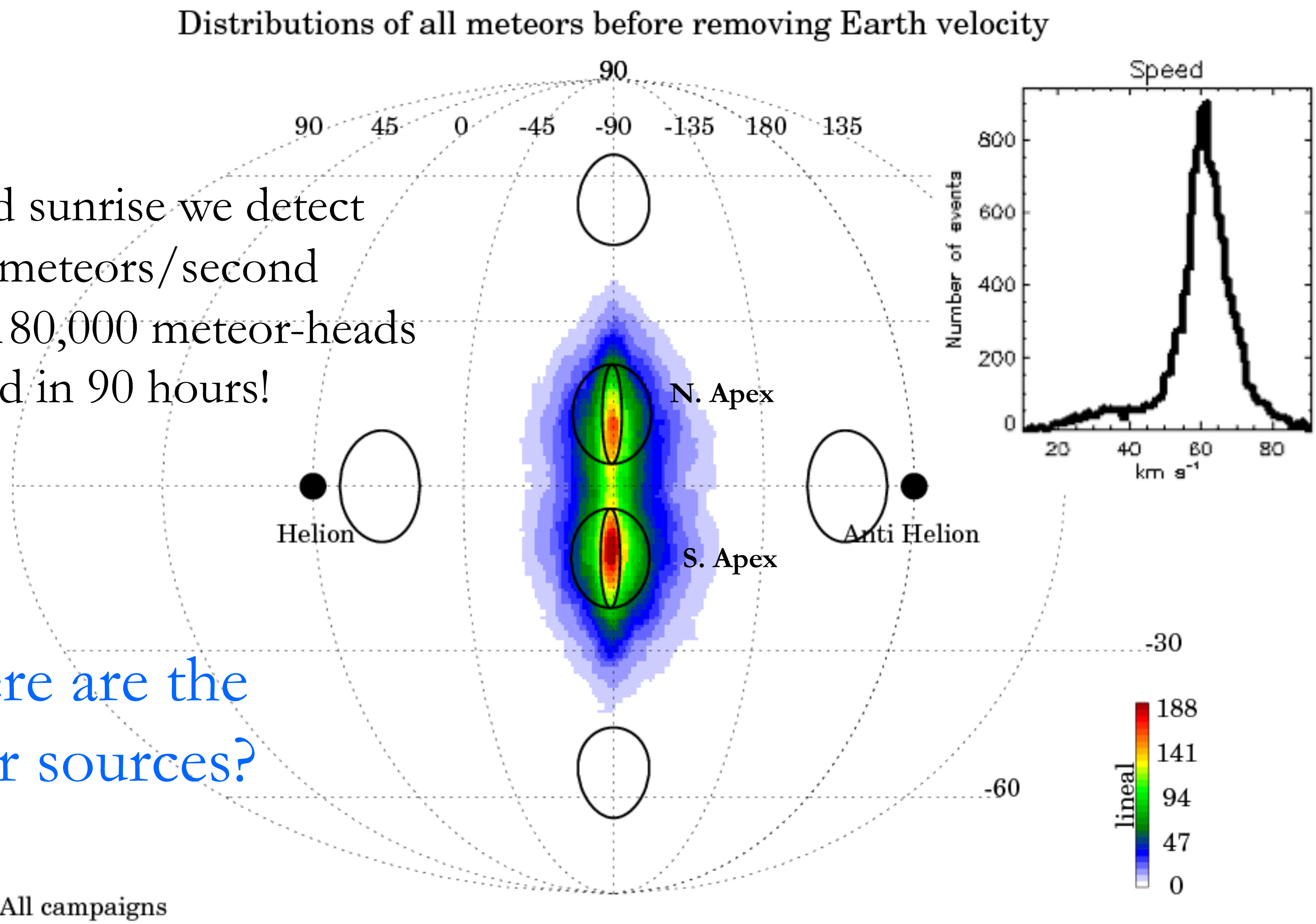
[from *Chau and Woodman*, 2004]

Raw meteor distributions from Jicamarca observations

Radio Observatorio de JICAMARCA Radio Observatory

•Around sunrise we detect up to 4 meteors/second

•From 180,000 meteor-heads observed in 90 hours!

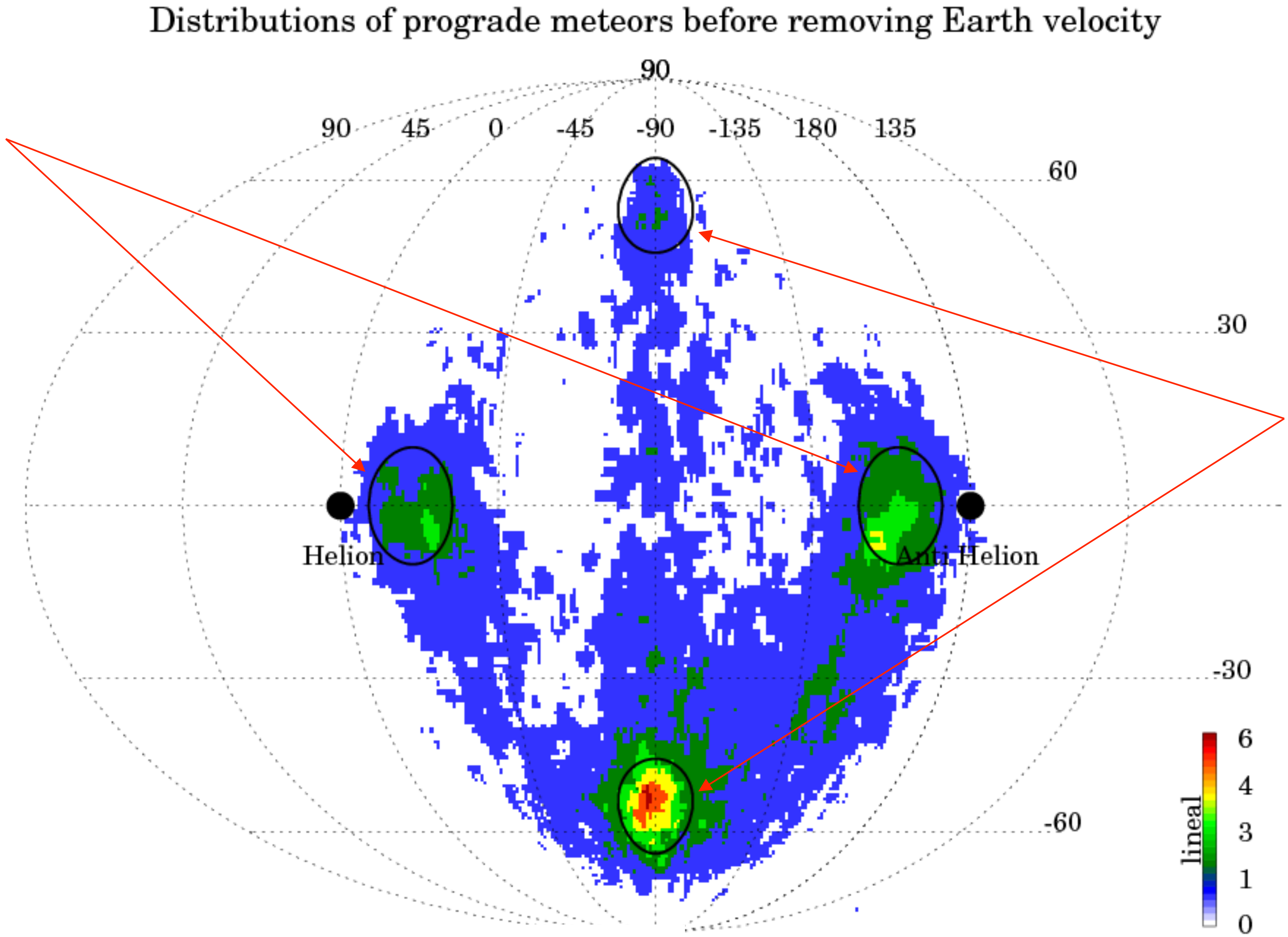


Where are the other sources?

[from *Chau et al.*, 2007]

Meteor distributions: Prograde only

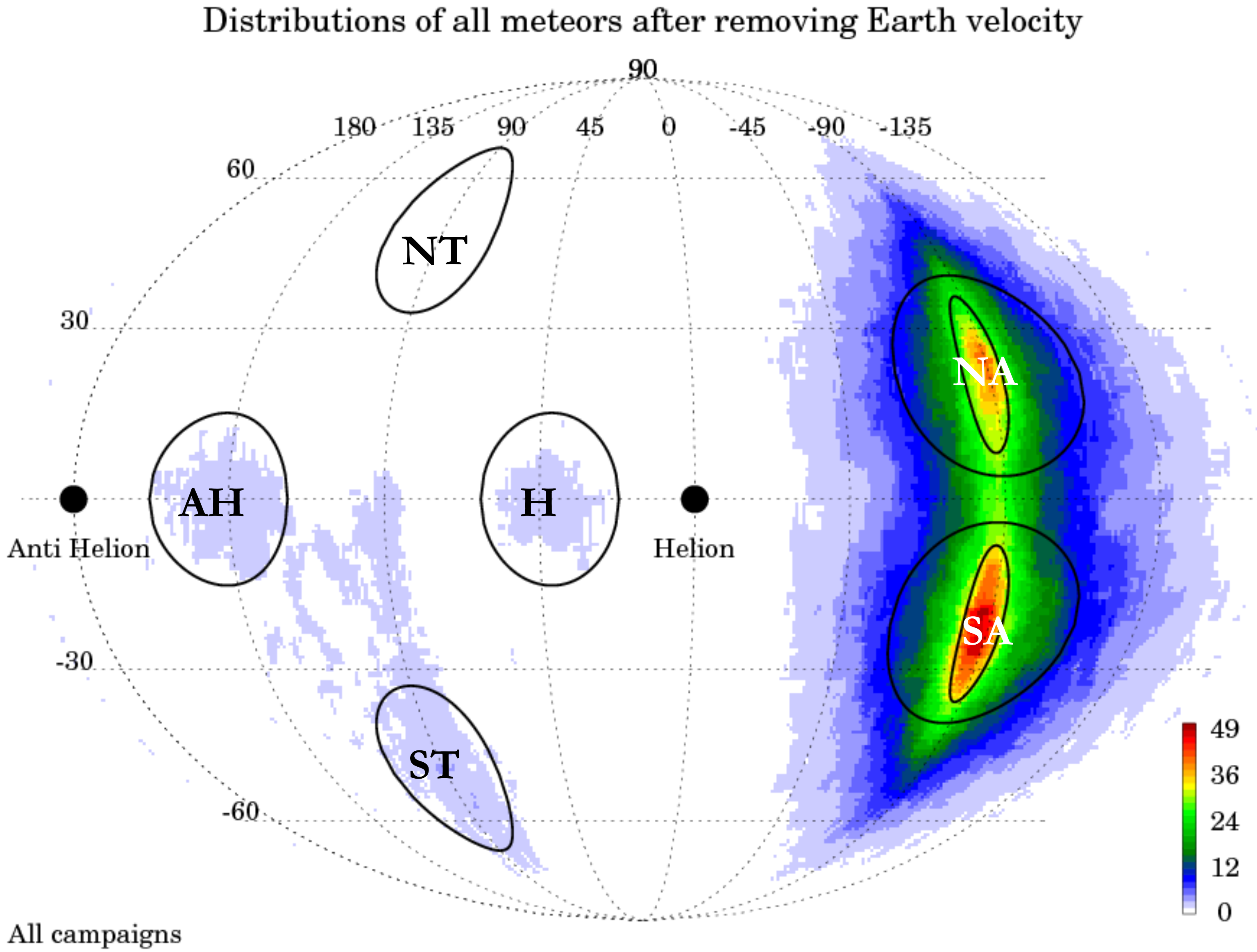
Radio Observatorio de JICAMARCA Radio Observatory



Note: Asymmetric distributions

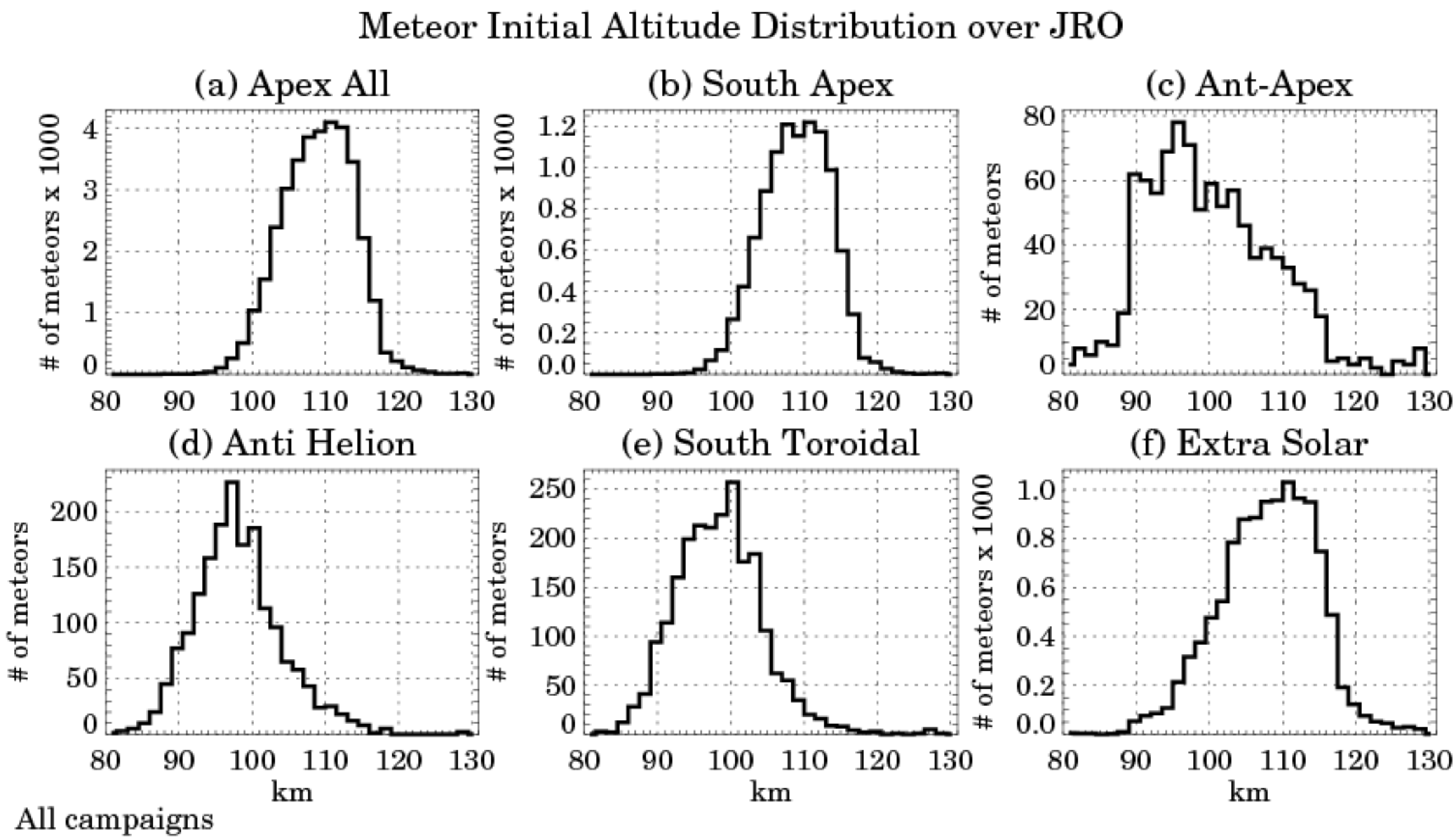
Meteor Distributions after removing Earth velocity: All

Radio Observatorio de JICAMARCA Radio Observatory



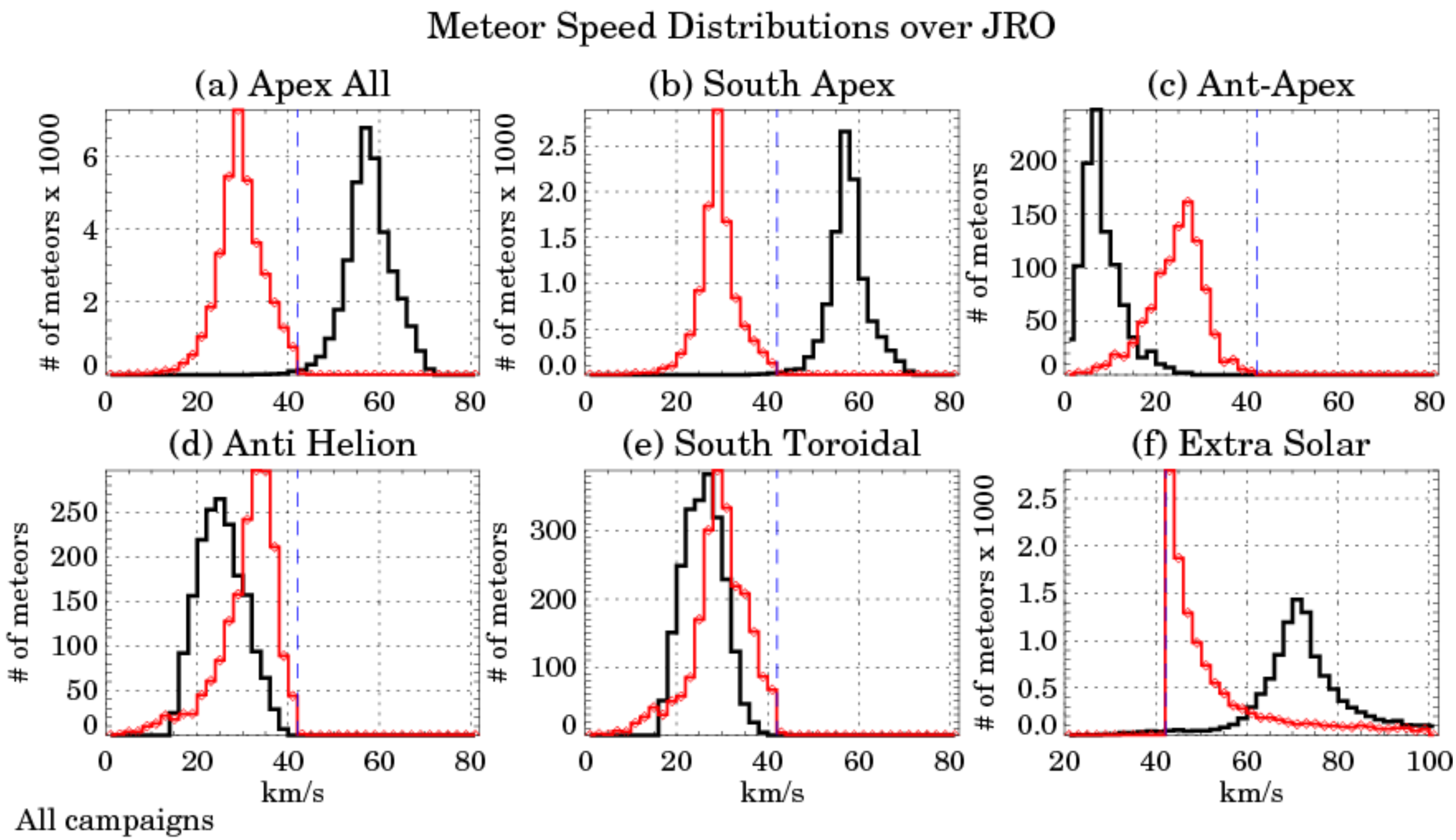
Altitude Distribution of selected Meteor Sources

Radio Observatorio de JICAMARCA Radio Observatory



Speed Distribution of selected Meteor Sources: Geocentric and Heliocentric

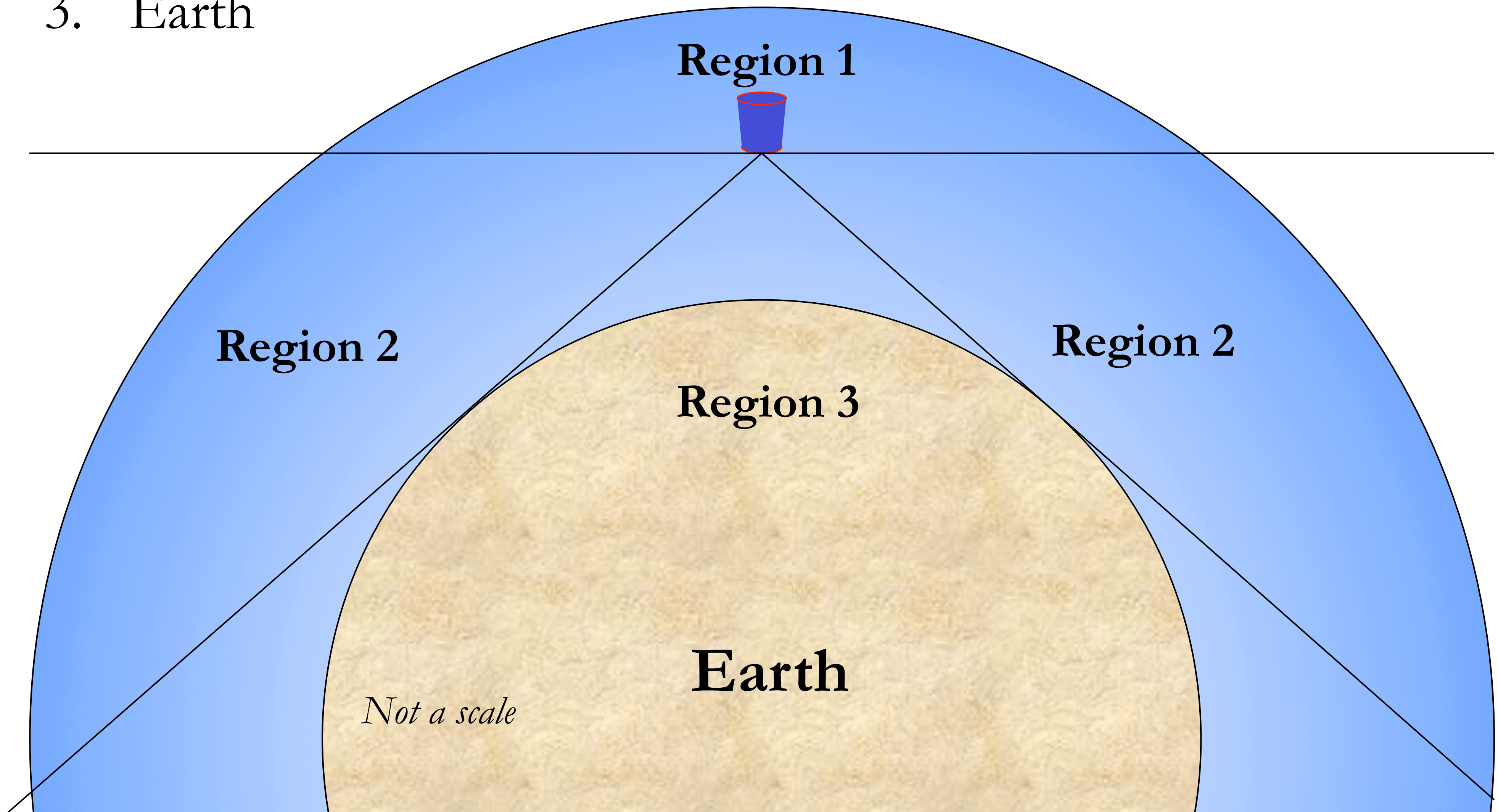
Radio Observatorio de JICAMARCA Radio Observatory



Angular Sensitivity Function or Atmospheric Filtering

1. Atmosphere/ionosphere
2. Longer atmospheric path
3. Earth

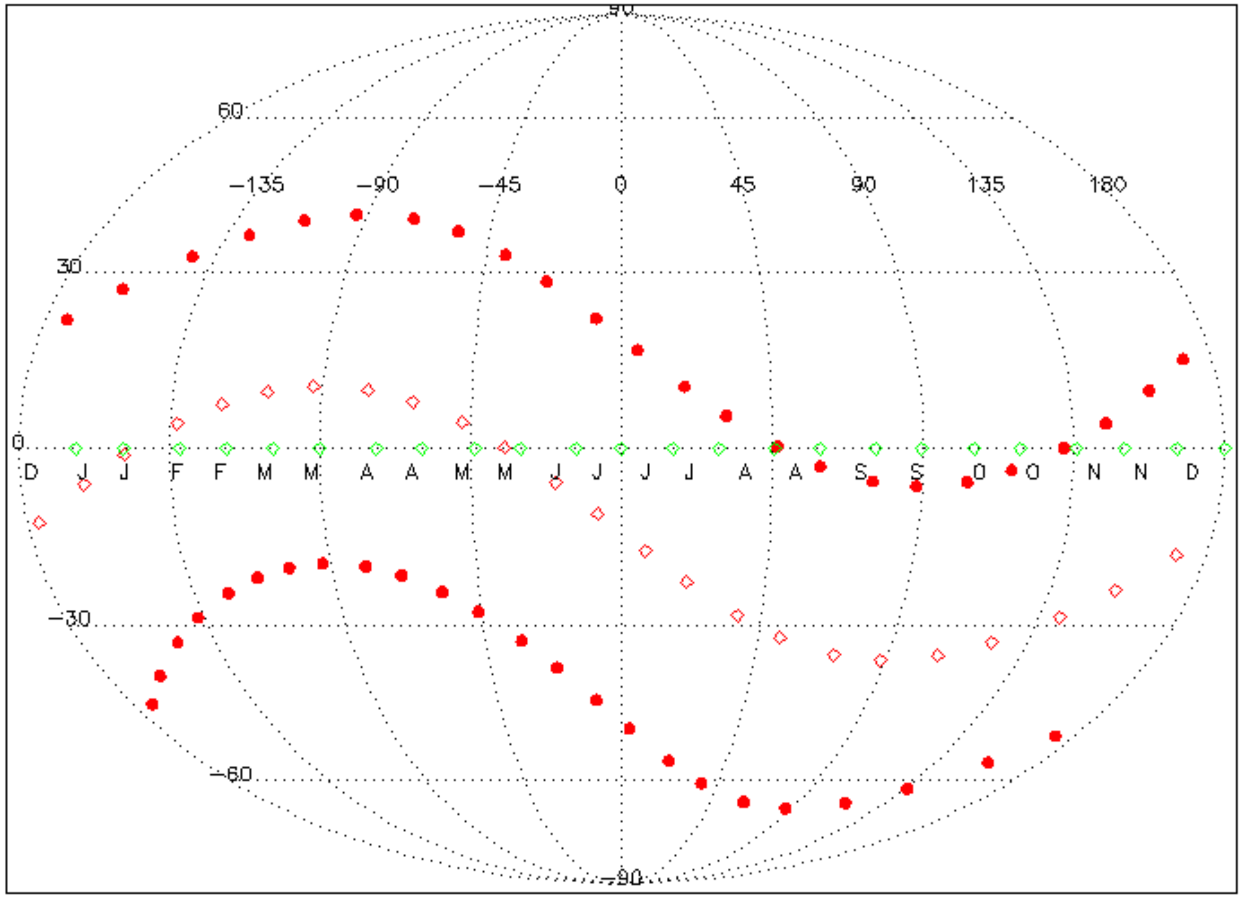
$$A(\theta) = \begin{cases} 1 - \dfrac{\cos f(\theta)}{2} & \text{for } 0^o < \theta < 180^o \\ 0 & \text{else} \end{cases}$$



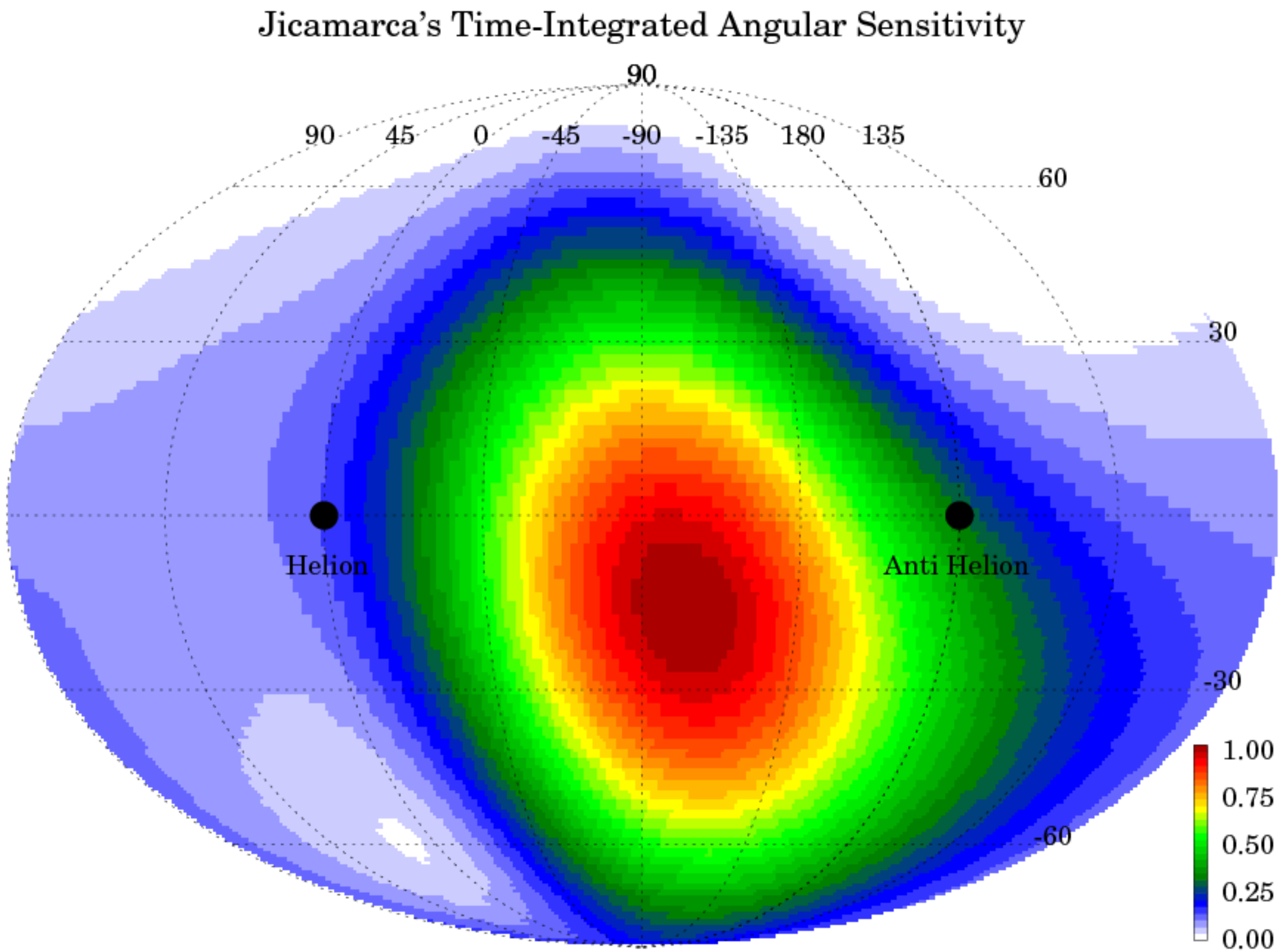
Angular Sensitivity Function for Different Times

Radio Observatorio de JICAMARCA Radio Observatory

- Geometry for 6 AM at different days of the year.
- On-axis beam position is denoted with red diamonds. Red circles represent zenith with respect to on-axis of 30º.
- The green diamonds represent the Apex location for the corresponding day of the year. At 6 AM both on-axis and Apex have equivalent heliocentric longitude.
- Note that most of our observations were centered around 6 AM, and 5 out 12 campaigns have been obtained around November, when northern hemisphere is at lower elevation angles.



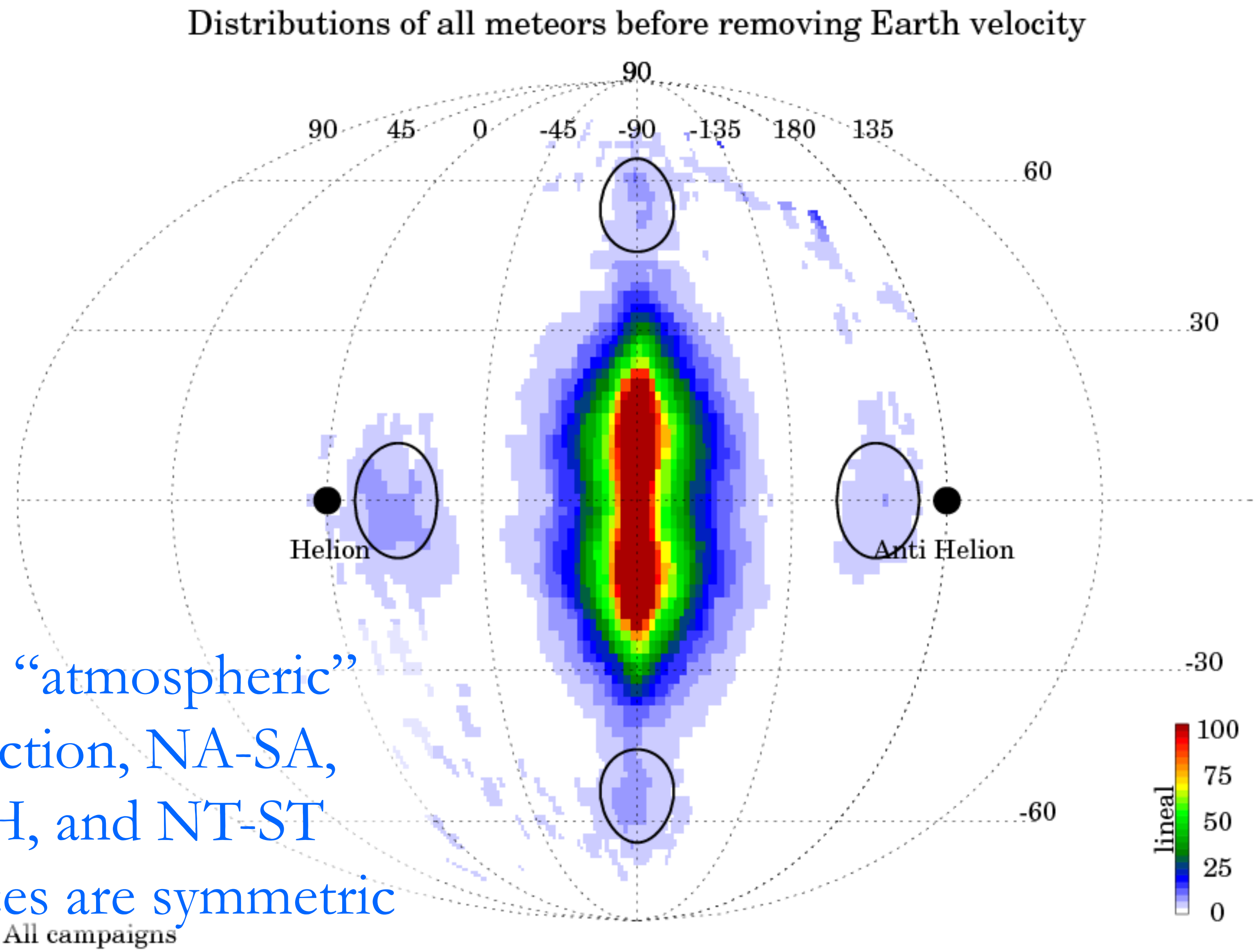
Time-integrated Angular Sensitivity Function



Based on days of the year and times of the day observed!

Meteor distributions: Corrected by angular function

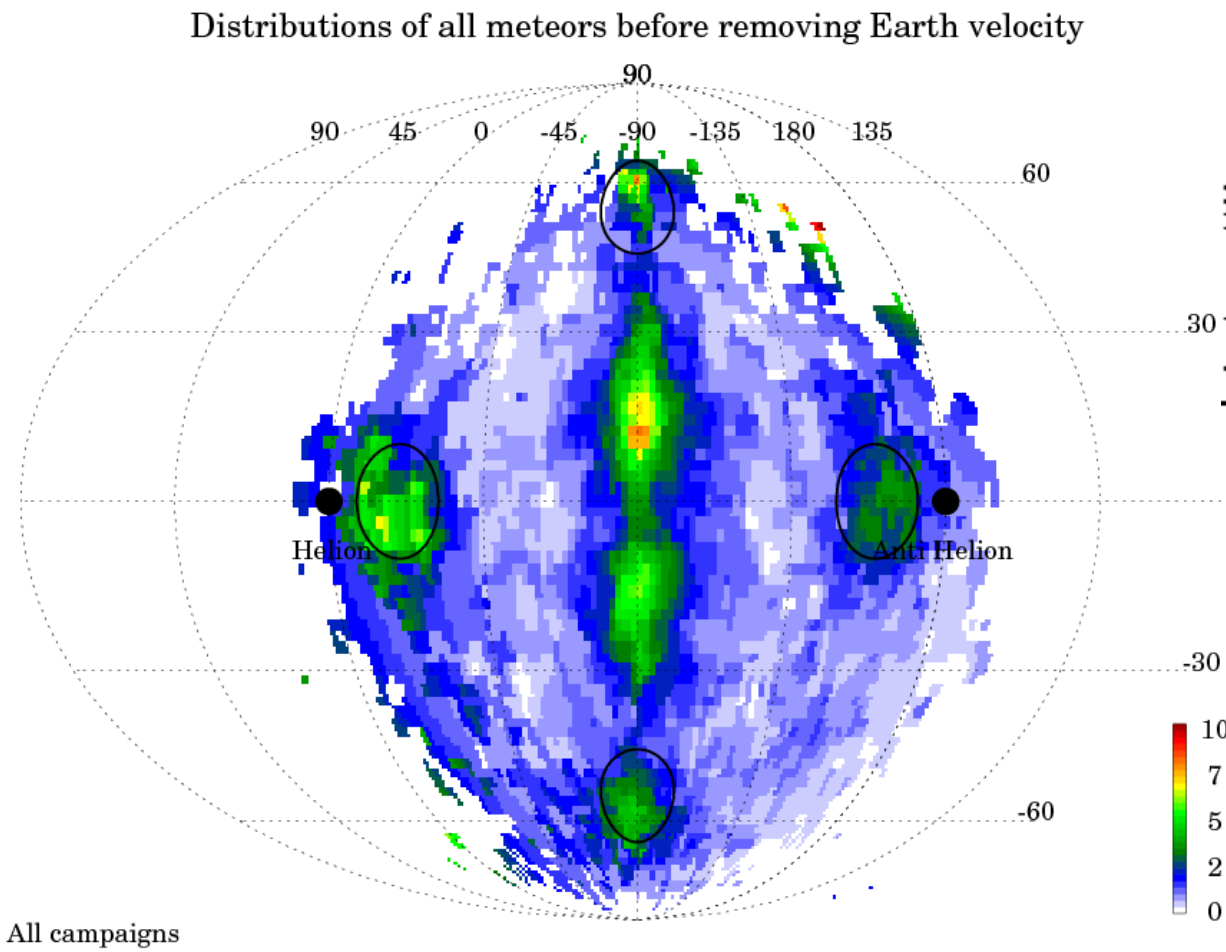
Radio Observatorio de JICAMARCA Radio Observatory

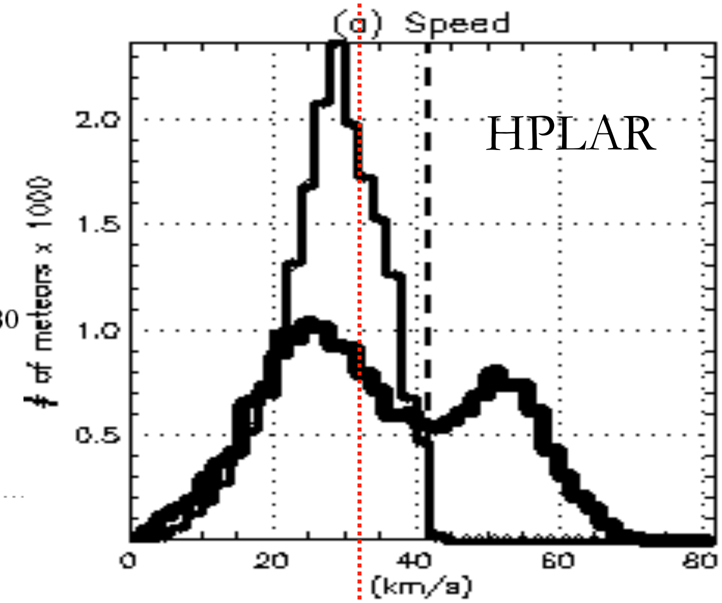


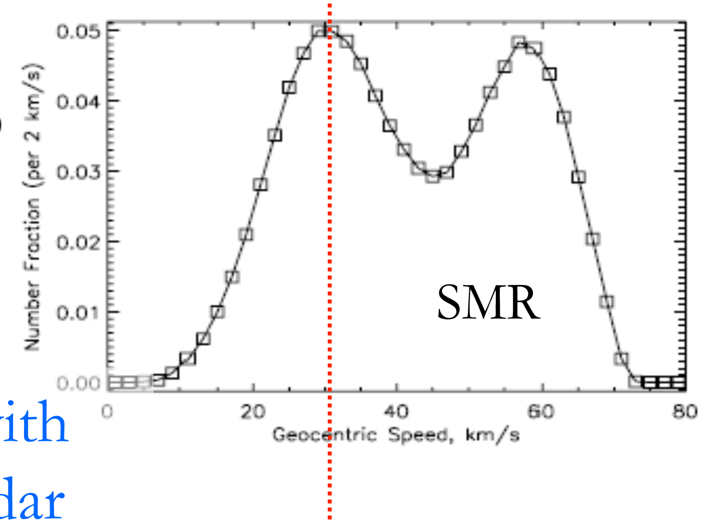
After "atmospheric" correction, NA-SA, AH-H, and NT-ST sources are symmetric

Meteor distributions below 100km

Radio Observatorio de JICAMARCA Radio Observatory







- Corrected by angular function (atmospheric filter) and using an altitude threshold of 100 km.

Close agreement with Specular Meteor radar (SMR) results

HPLAR vs SMR results

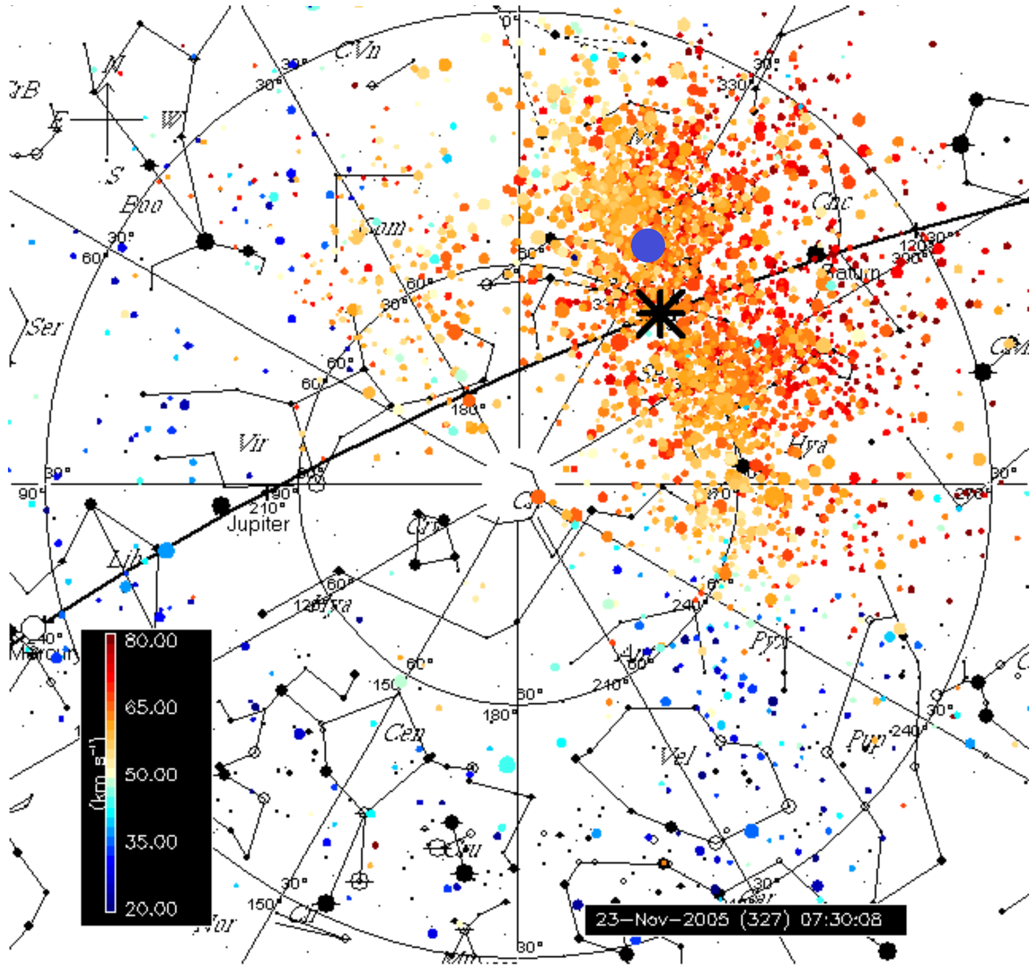
Radio Observatorio de JICAMARCA Radio Observatory

- HPLARs are able to detect meteors coming from all known sporadic sources (Helion, Anti-Helion, North and South Toroidal, North and South Apex) + highly elliptical North and South Apex sources that ionize at higher altitudes.
- Using a simple atmospheric filter and an upper altitude threshold
  - HPLAR populations are in closer agreement with SMR results
  - Velocity distributions are in very good agreement.
- But …

Can HPLARs detect meteor showers?

Radio Observatorio de
JICAMARCA
Radio Observatory

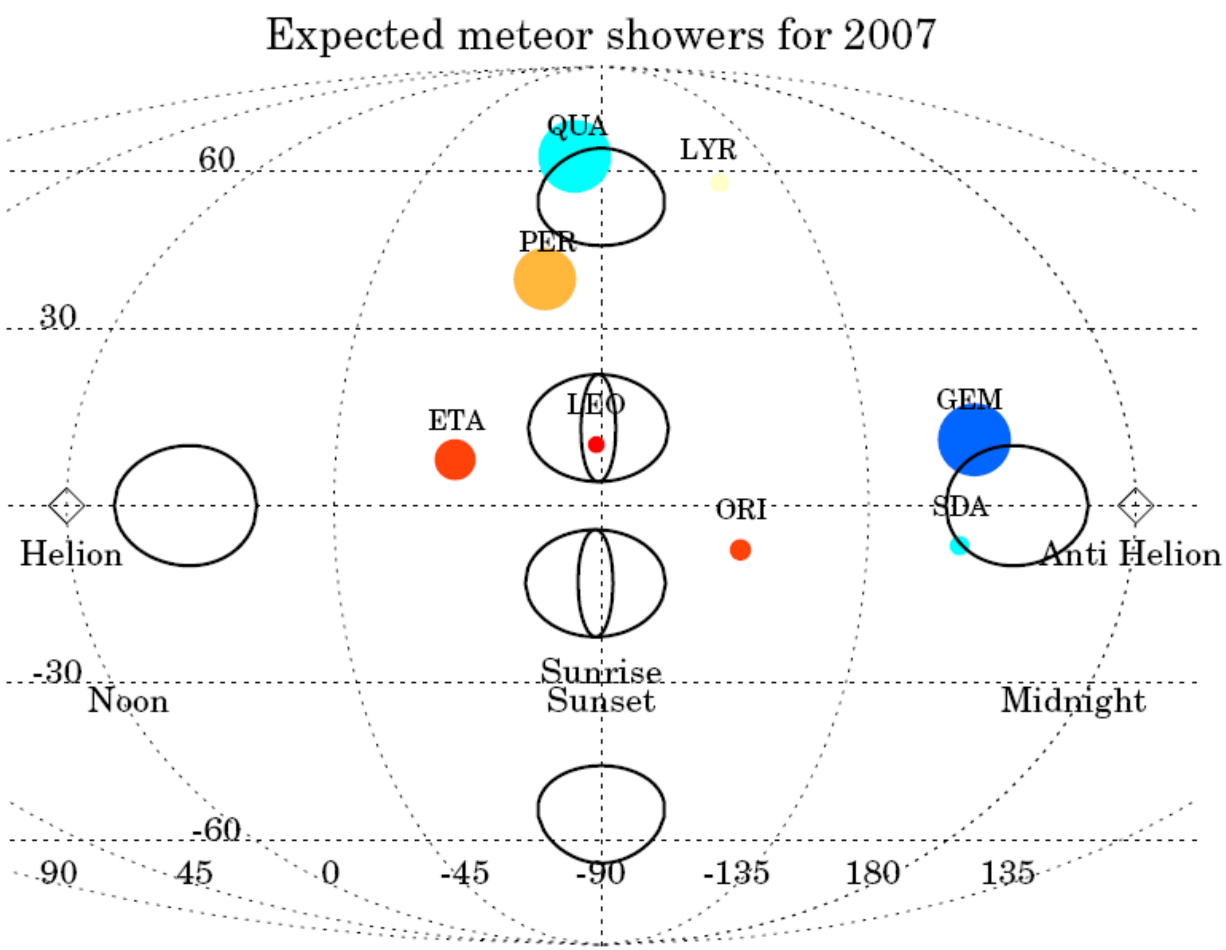
- So far HPLARs have not been able to detect meteor shower activity.
- Recall that HPLAR observe a very small volume as compared to optical instruments or SMRs, therefore the probability of being observe is much less.
- It is difficult to discriminate meteor shower signature from its velocity distribution. Sporadic population it is much larger and cover almost all velocities.
- In the case of Jicamarca, the Leonids radiant almost coincide with the Apex, making its discrimination from the sporadic population harder.
- What about other showers?



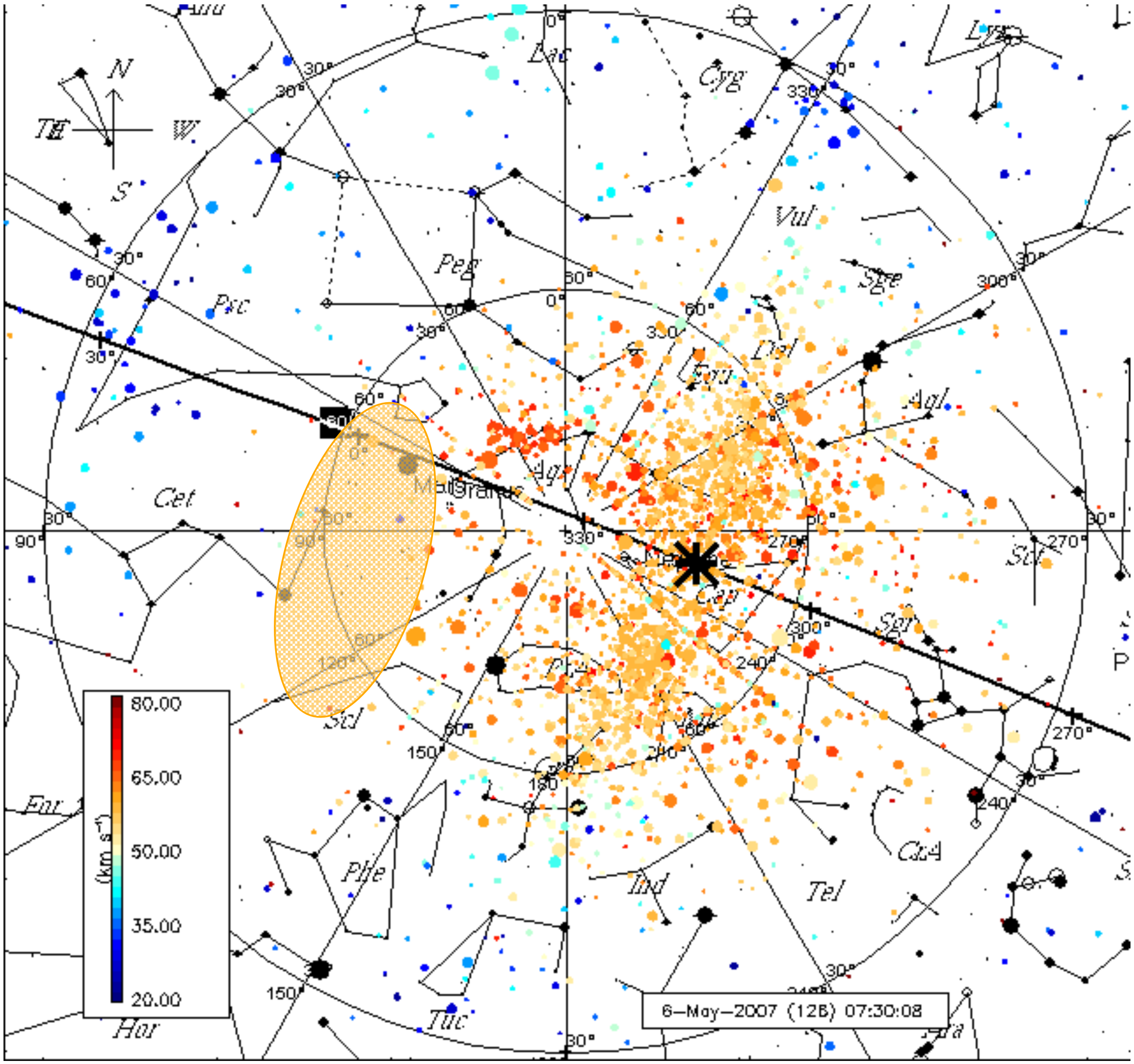
What about other meteor showers?

Radio Observatorio de JICAMARCA Radio Observatory

- First attempts
  - are limited to the nighttime, to avoid the strong electrojet echoes during the day
  - should avoid radiants that coincide with known sporadic populations.



ETA Observations: Skymap



Eta-Aquariids (May 5-6, 2007)

Radio Observatorio de JICAMARCA Radio Observatory

η-Aquarids (Visual)

Max. Date = May 06

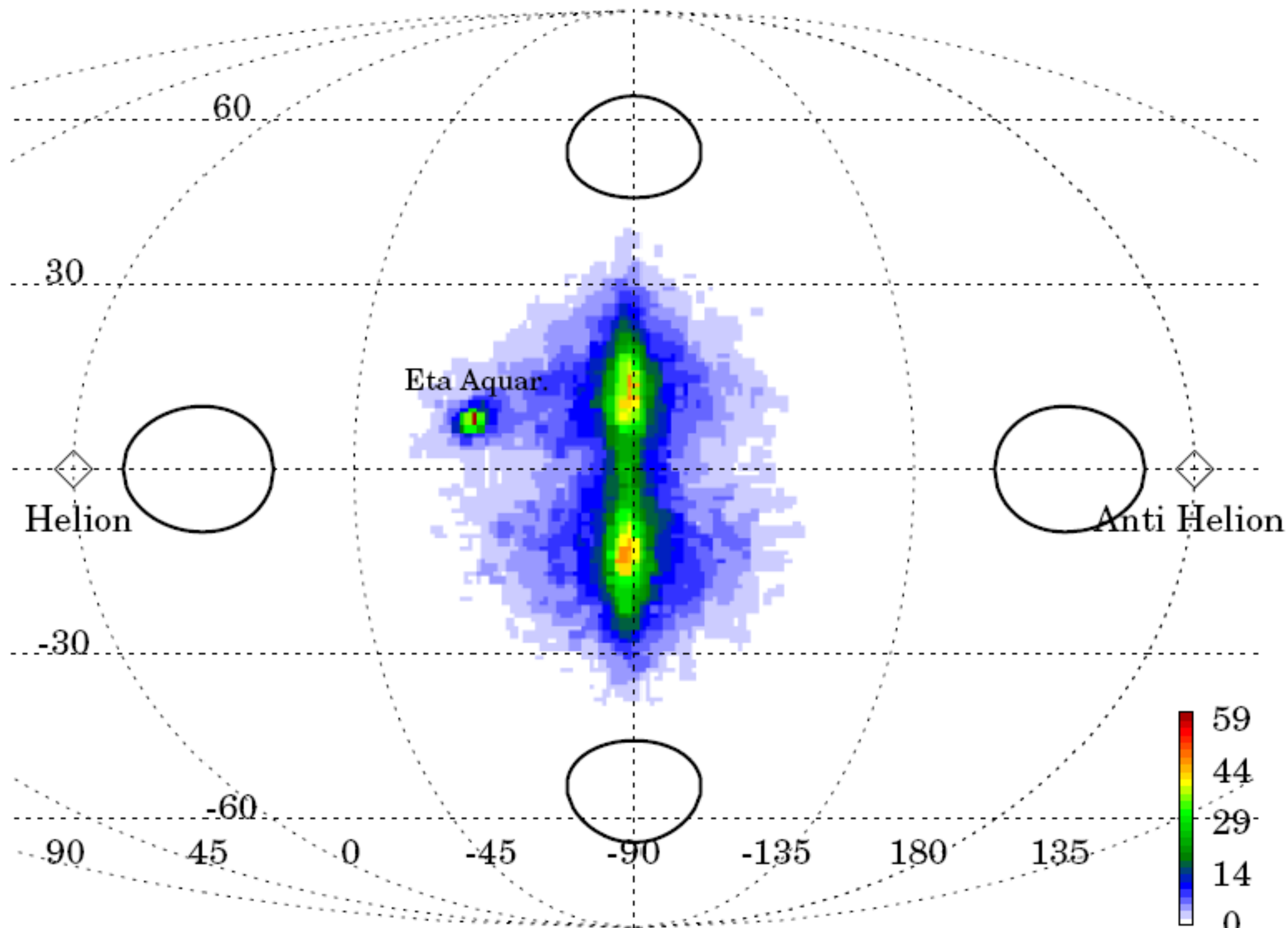
RA = ~338°

Dec = -01°

V_{inf} = 66 km/s

ZHR = 60

Distributions of all meteors before removing Earth velocity

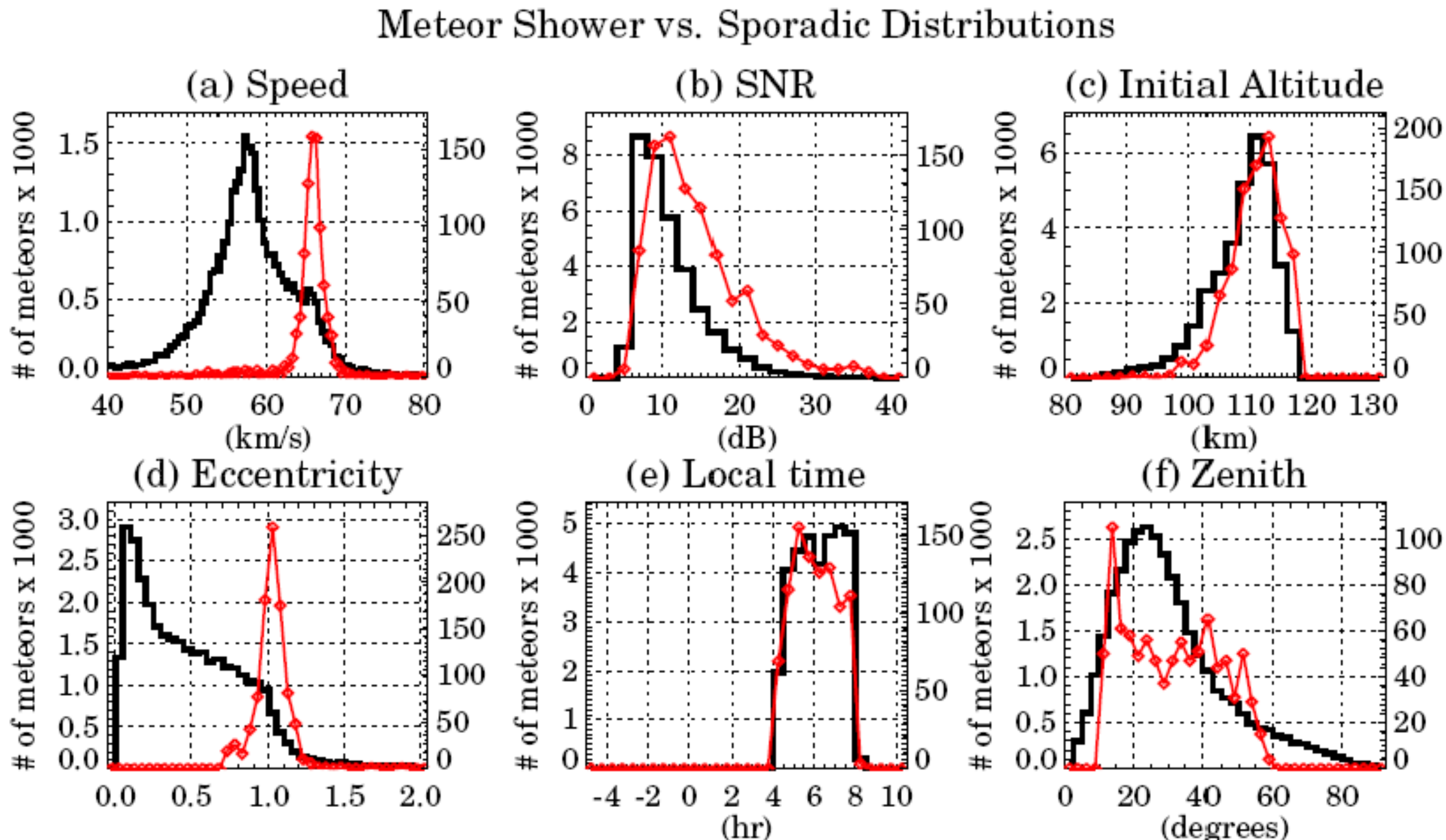


[from *Chau et al.*, 2008]

ETA parameters from Jicamarca

Radio Observatorio de JICAMARCA Radio Observatory

Apex
ETA



Eta Aquariids Shower

- There is an excellent agreement in the mean speed (65.90 vs 66 km/s) and location (fraction of a degree in both long and lat).
- Spread in velocity (1 km/s) and location (1°) within expected intrinsic results
- ETA: Mean orbits are parabolic, Halley-type orbits.
- Proportionally, there are "larger" ETA meteors than sporadic.
- ~120 ETA meteors/hour (1000 more meteors that one could observe optically in the same volume).

Perseids (August 11-12, 2005)

Radio Observatorio de
JICAMARCA
Radio Observatory

Perseids (Visual)

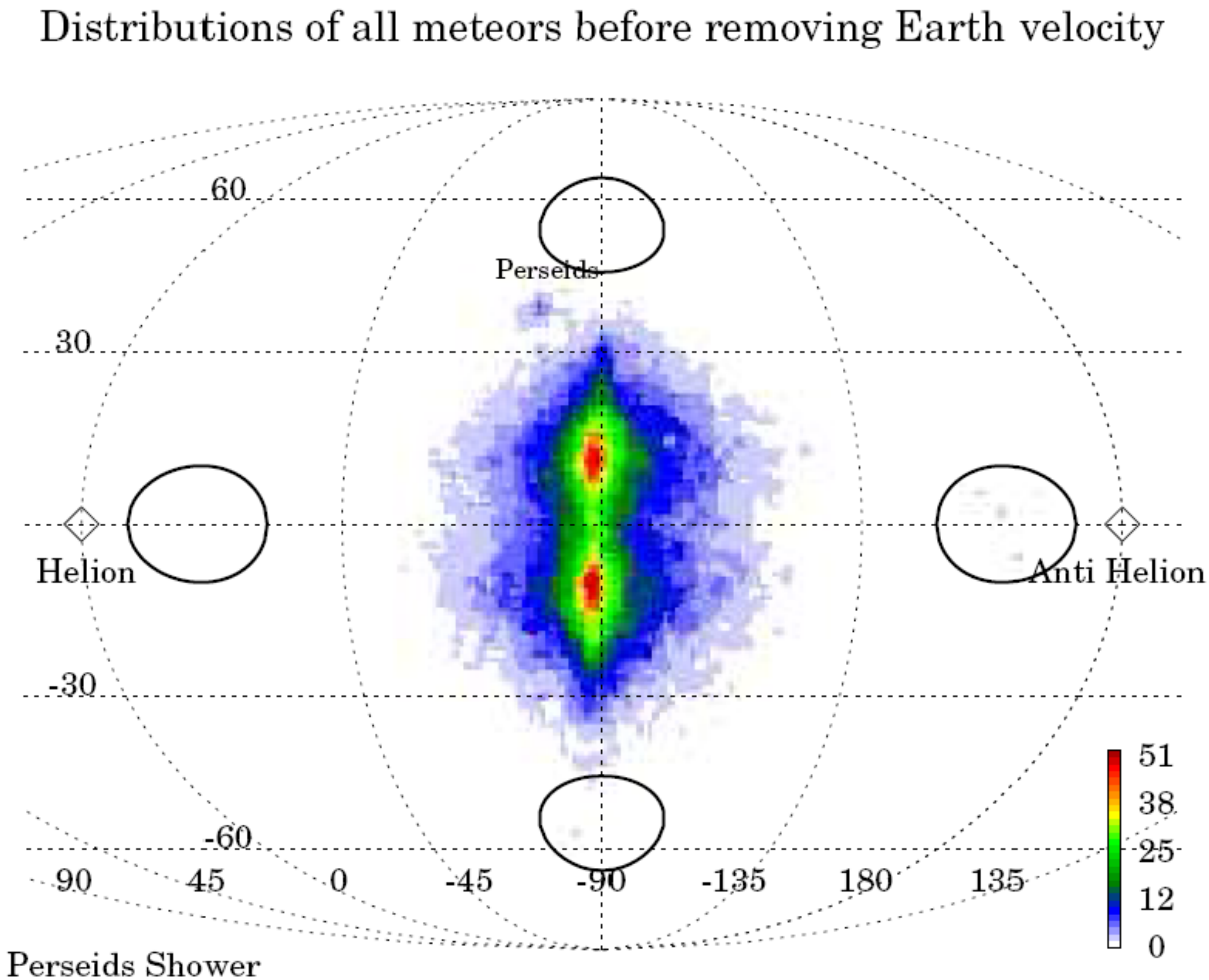
Max. Date = Aug 13

RA = ~46°

Dec = ~58°

V_{inf} = 59 km/s

ZHR = 100



Conclusions for interferometry observations of meteor-head echoes

- HPLARs observed the same population than SMRs and more.
- HPLARs are sensitive to meteor showers.
  - Some showers could be detected from velocity distributions (e.g., ETA).
  - Other shower need the combination of velocity and location distributions (e.g., PER).
  - Some of them might need, besides velocity and location, size distributions (e.g., Leonids).
- The shower parameters are obtained from meteor sizes previously not observed with any other meteor technique.

What else has been done?

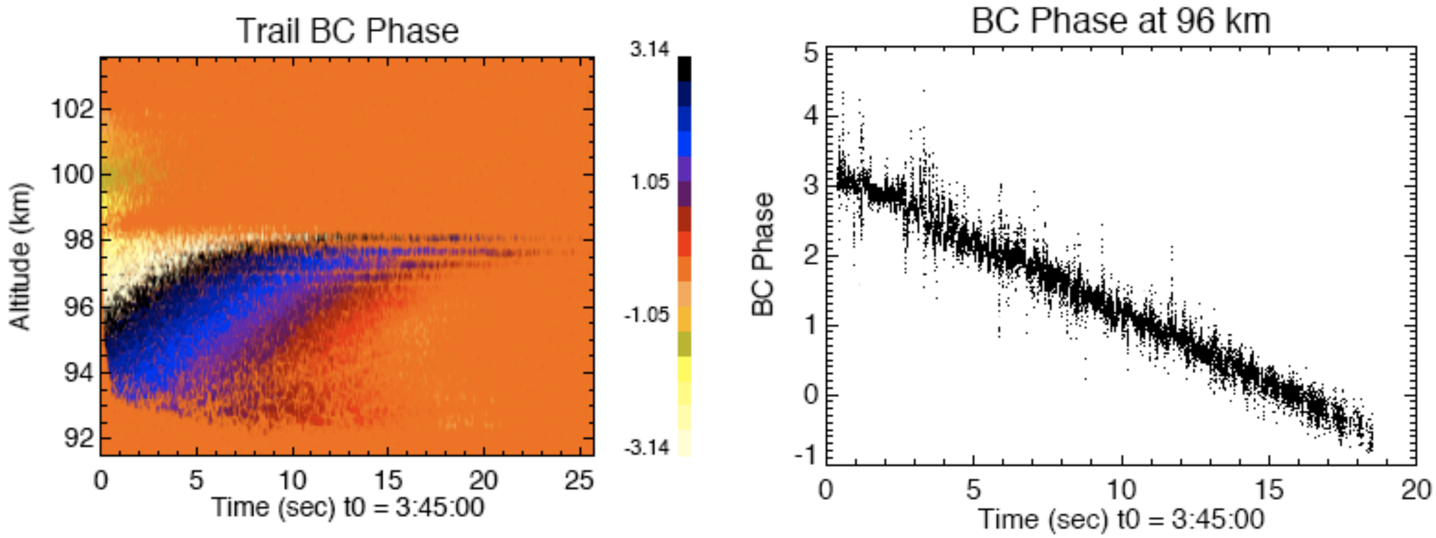
What else has been done?

Radio Observatorio de JICAMARCA Radio Observatory

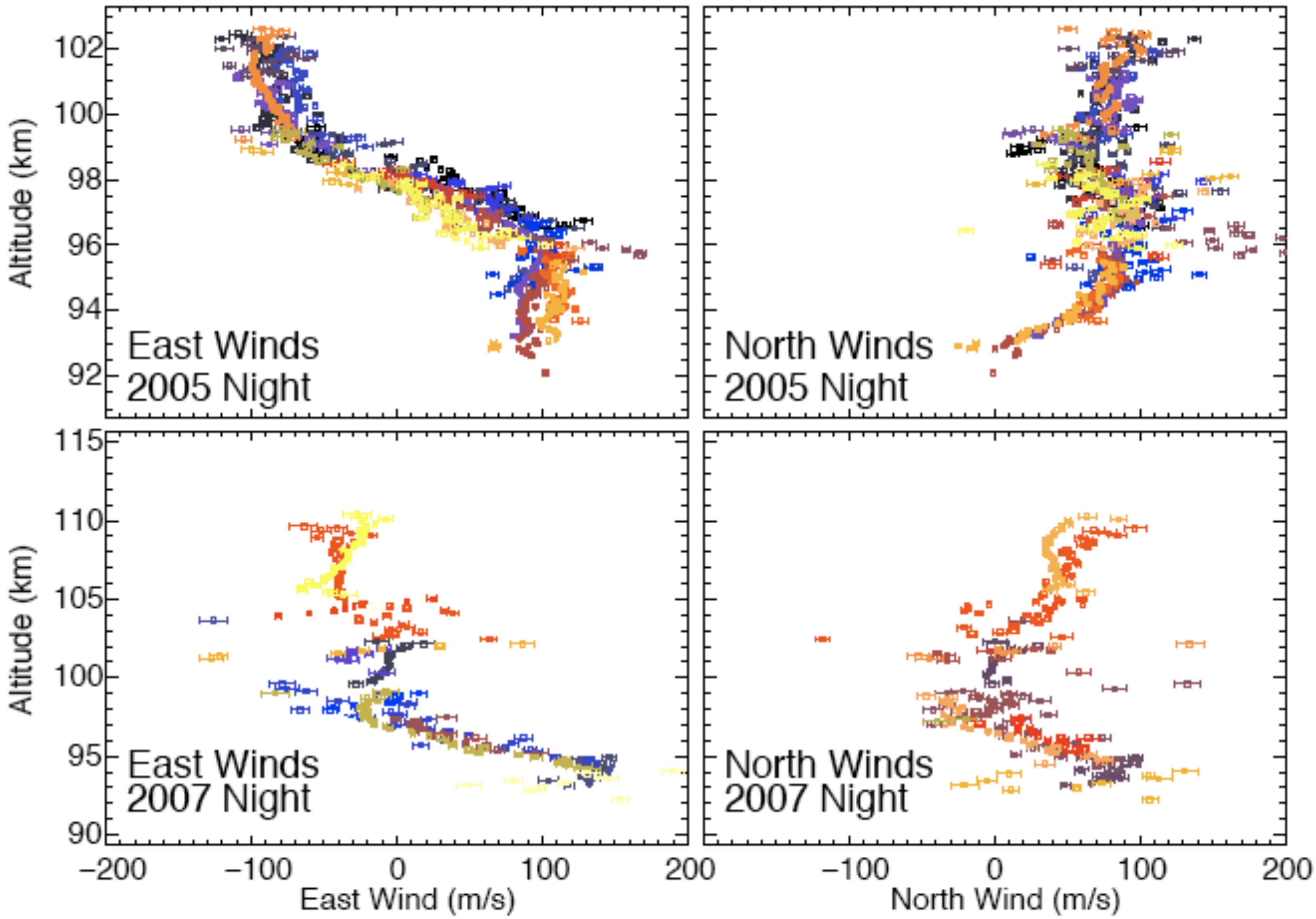
- Various field-aligned irregularity studies (Chapin and Kudeki, Dyrud et al, Oppenheim et al., Mathews et al.)
- Estimation of meteor mass from deceleration (Janches et al., Bass et al.)
- Estimation of lower thermosphere neutral winds from non-specular trails (Oppenheim et al.)
- …

Meteors LT Winds using Interferometry (1)

Radio Observatorio de JICAMARCA Radio Observatory



Meteors LT Winds using Interferometry (2)



[from *Oppenheim et al.*, 2009]

What needs to be done

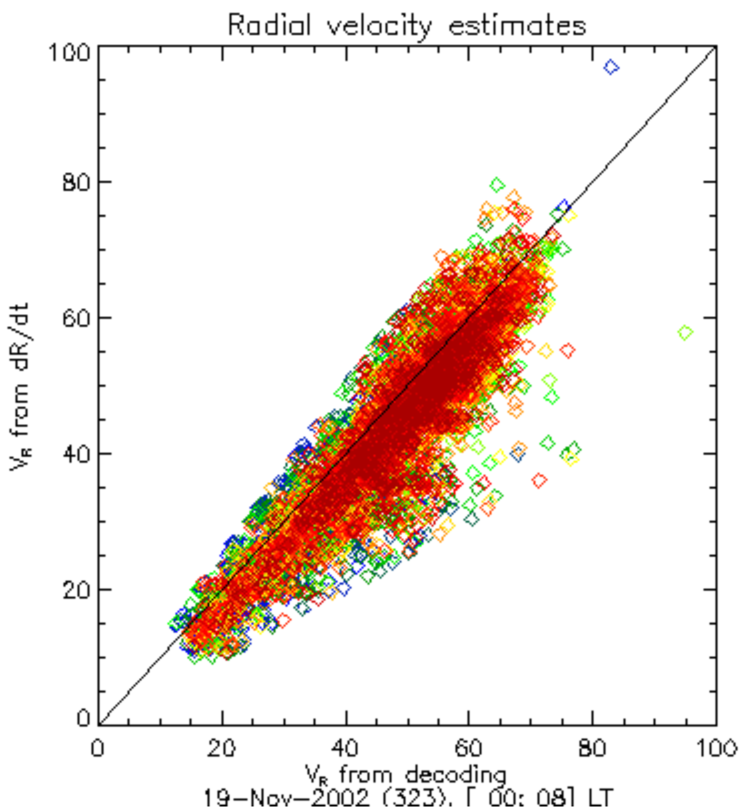
What needs to be done

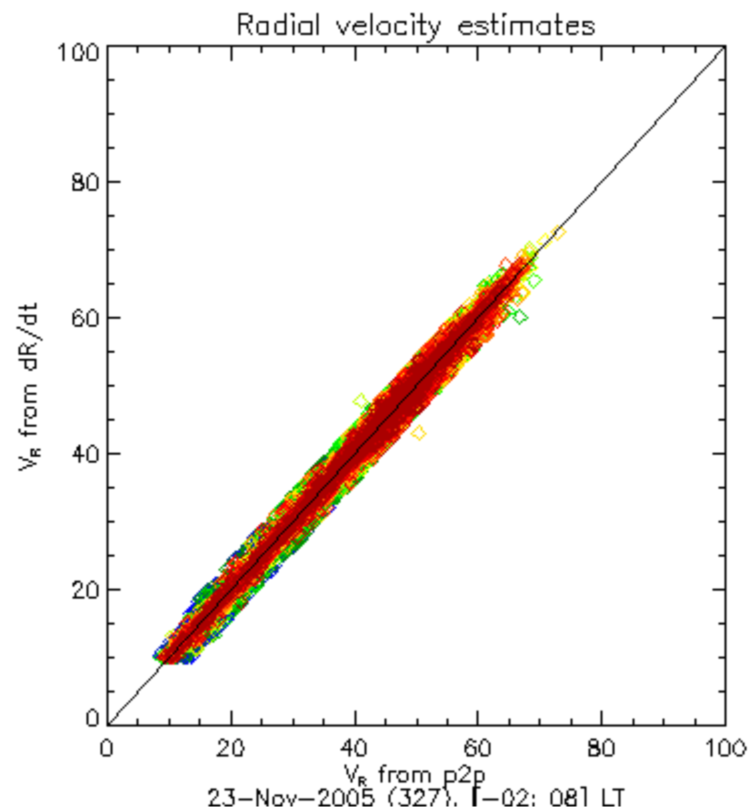
Radio Observatorio de JICAMARCA Radio Observatory

- Meteoroid vs. "plasma" speed.
- Meteoroid mass from RCS. How is the antenna beam pattern taking into account? From PFISR results at least 20% of the echoes were observed with sidelobes!
- What is the cause of non-smooth power profiles?
  - Fragmentation, Differential ablation, Instrumental effects, Polarization issues, other
- Comparison of different mass estimates, including visual masses.
- Improved radar experiments (EEJ rejection, better time/altitude resolution, better angular determination, …)

Meteoroid vs. "plasma" velocity

Radio Observatorio de
JICAMARCA
Radio Observatory





- In 2002, comparing dR/dt vs the Doppler from the decoding process, there was a 3-5 km/s difference.
- In 2005, comparing dR/dt vs Doppler from pulse to pulse (after removing the ambiguity using dR/dt), the previous difference is not there! Note that the Nyquist Doppler is 7 km/s.
- **Is the velocity of the plasma in front of the meteoroid faster than the meteoroid velocity?**

Multiple-pulse Experiment

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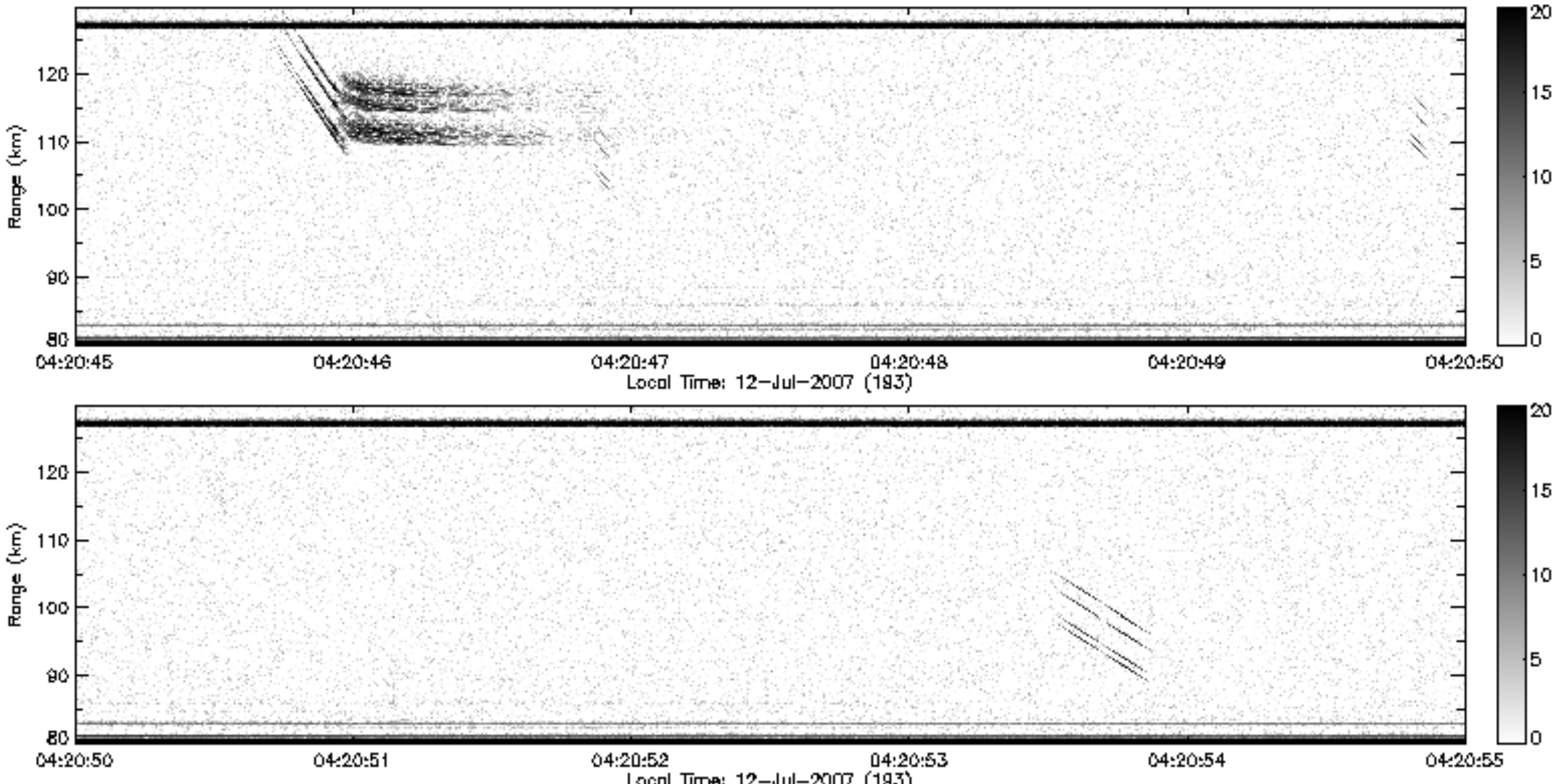
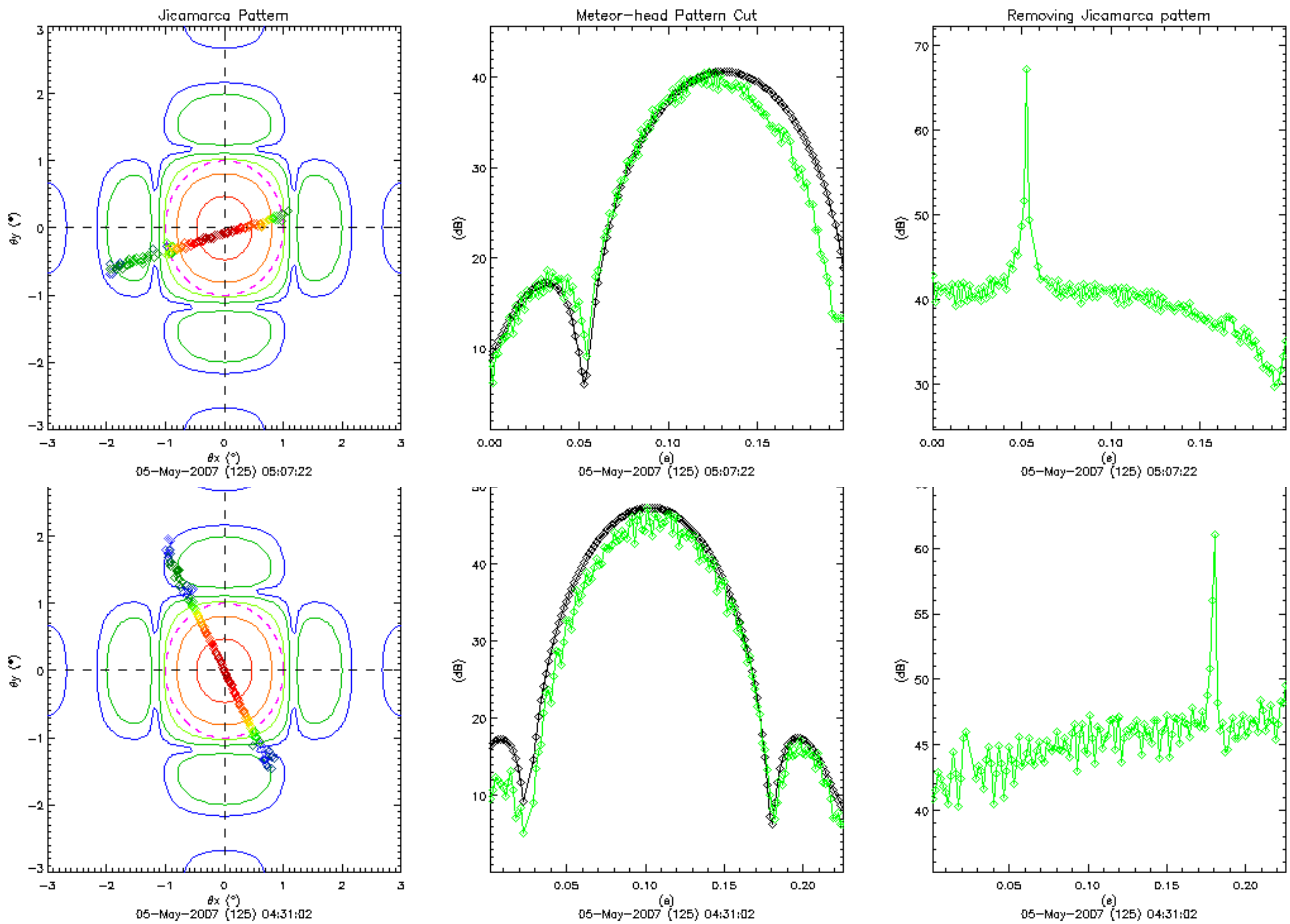


Velocity from multiple-pulses (< 100 us)

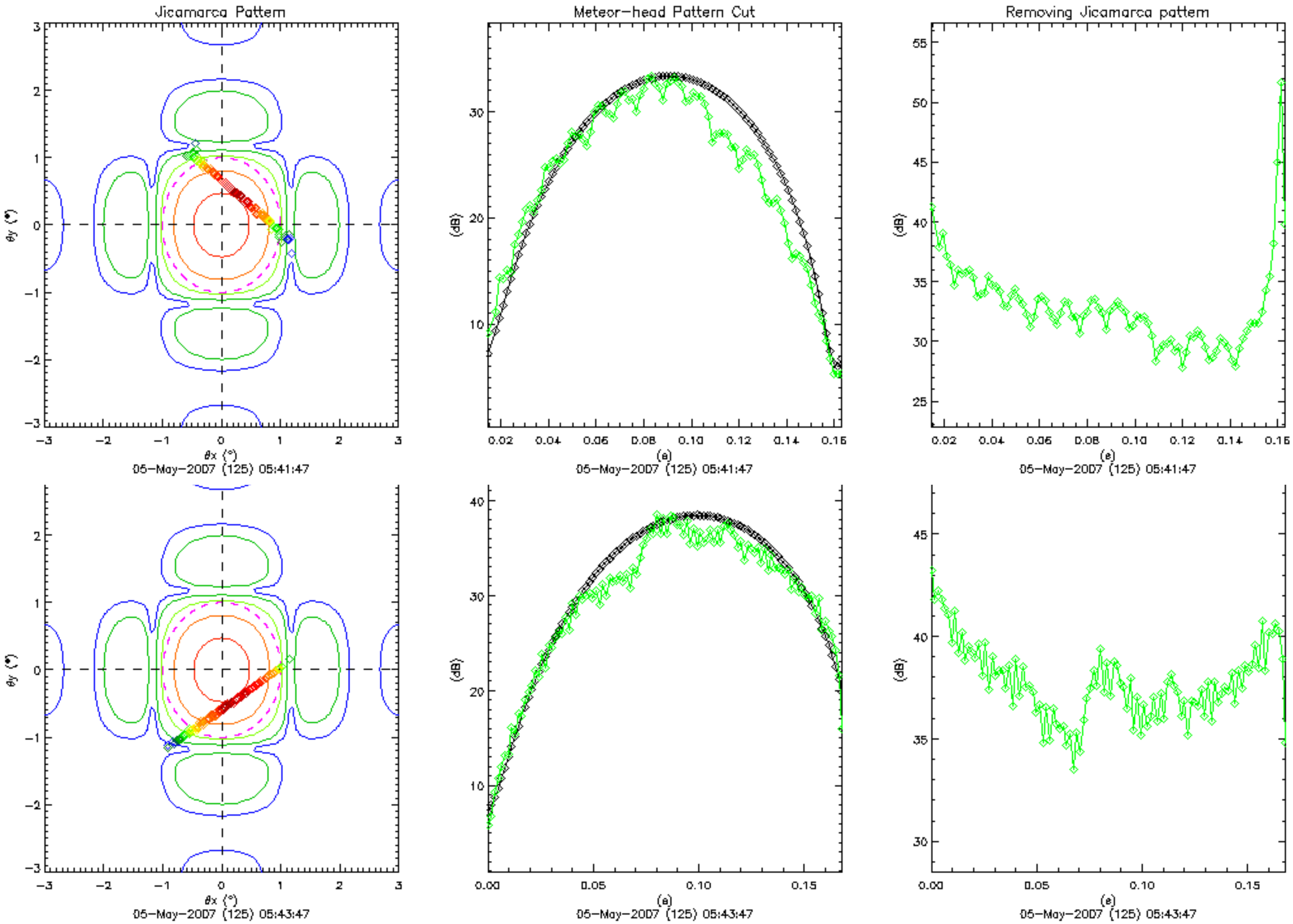
vs

velocity from pulse-to-pulse (>0.5 ms)

RCS: Increasing/decreasing?



RCS: How do we work with non-smooth power profiles?



Meteor "ablation" over JRO

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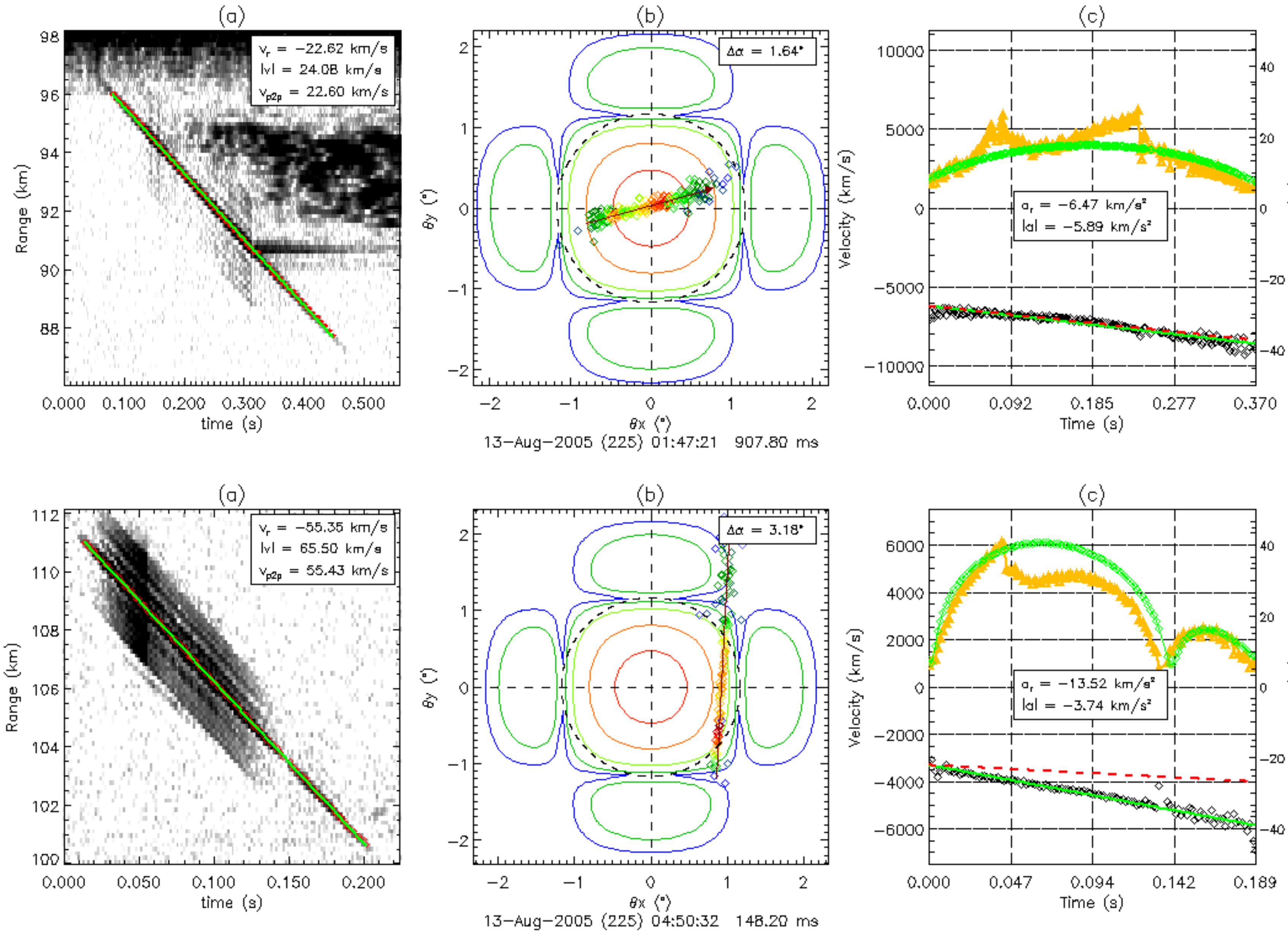

Meteor “fragmentation” over JRO

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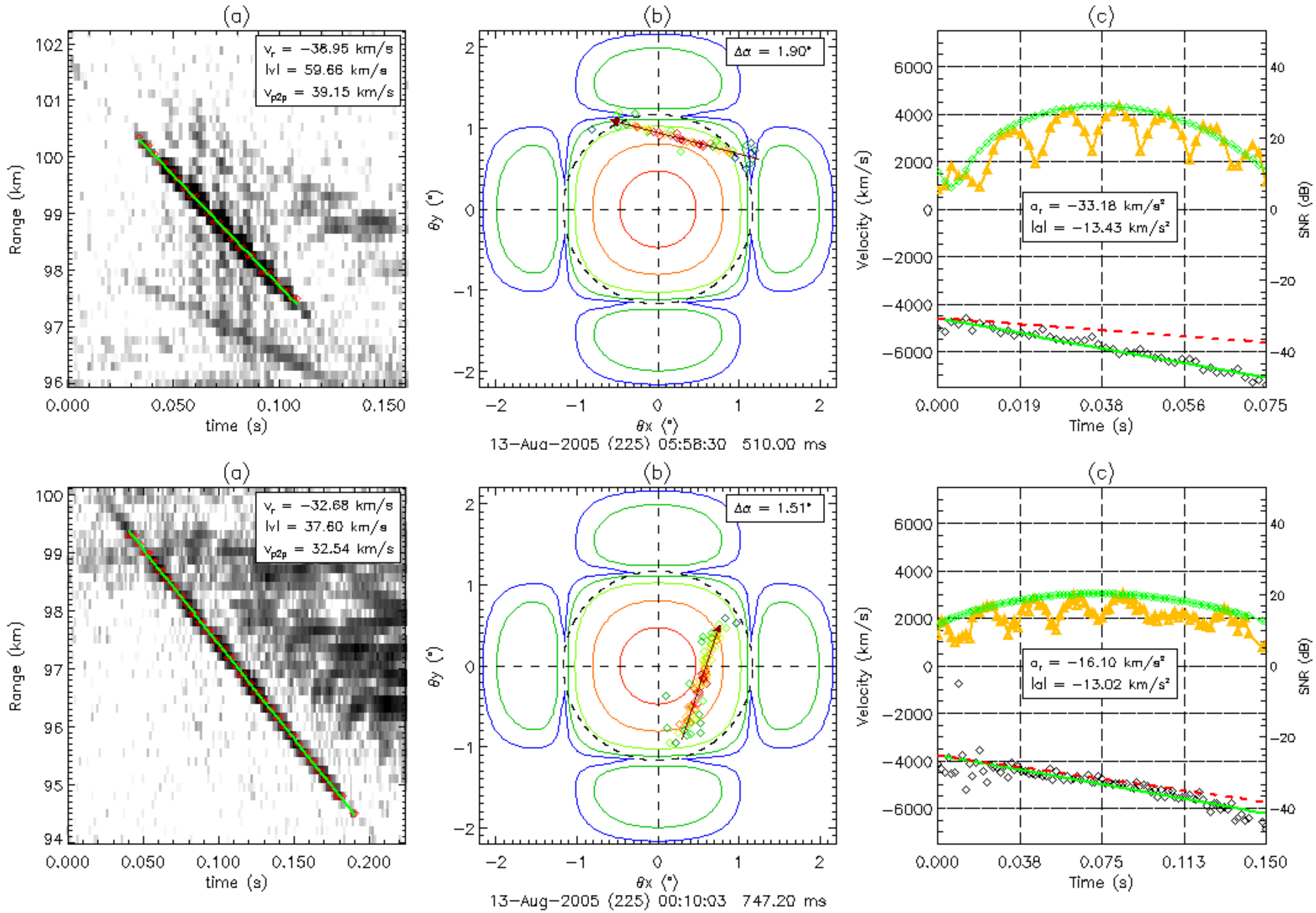

Instrumental effects: Changes in power correlate with changes in range.

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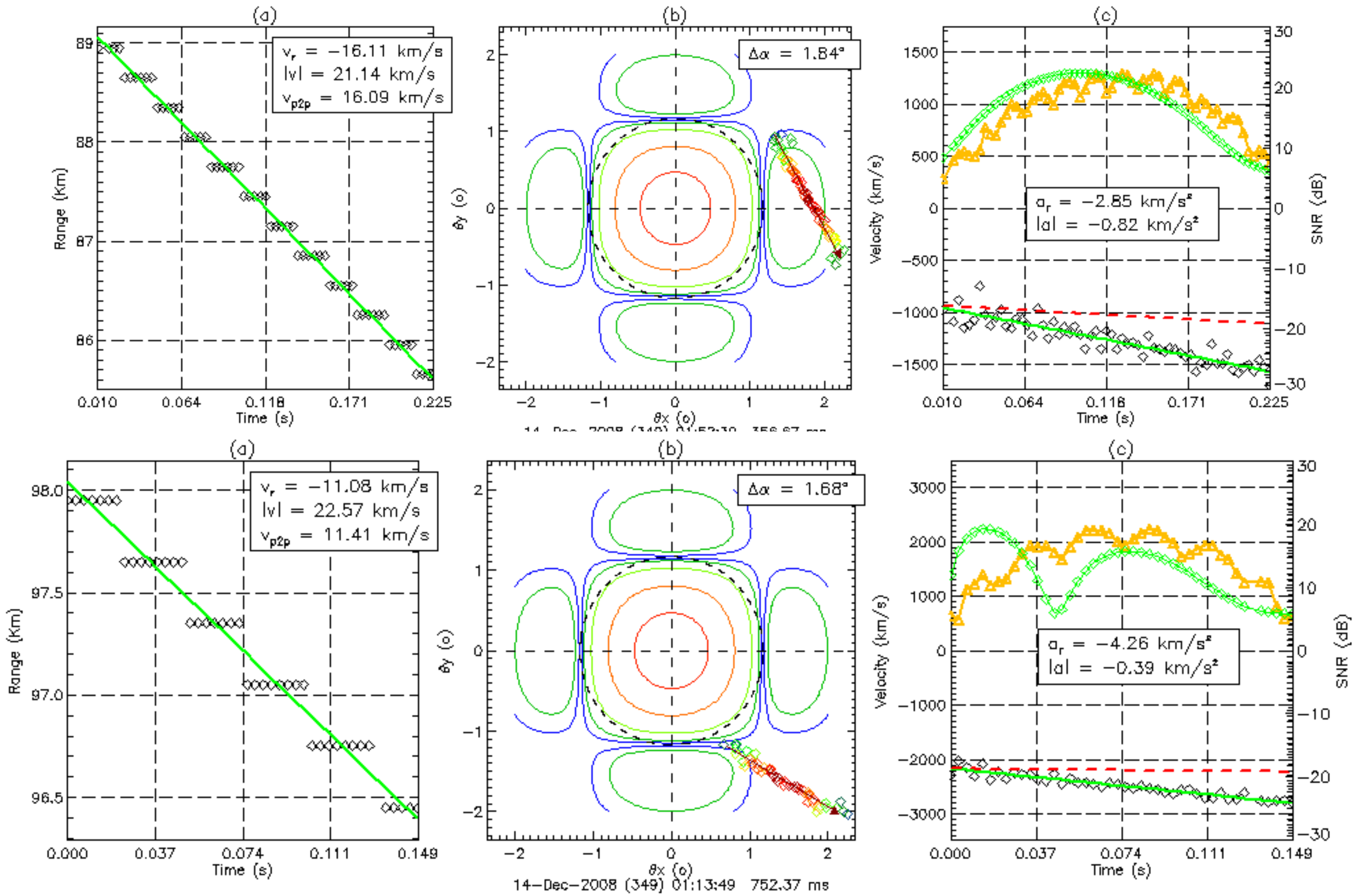
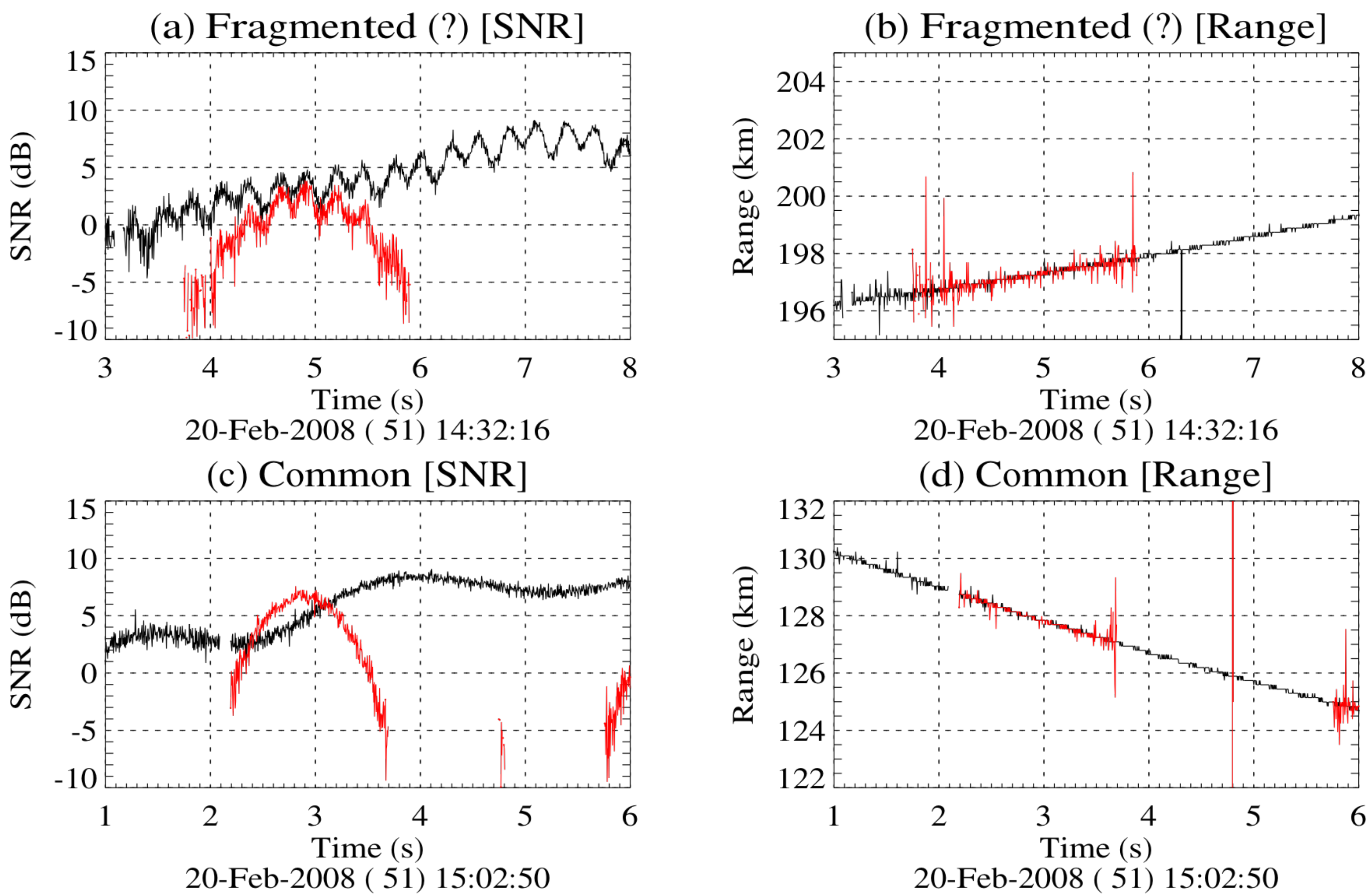


Instrumental effect: Other radars?



Instrument effect: Simple modeling

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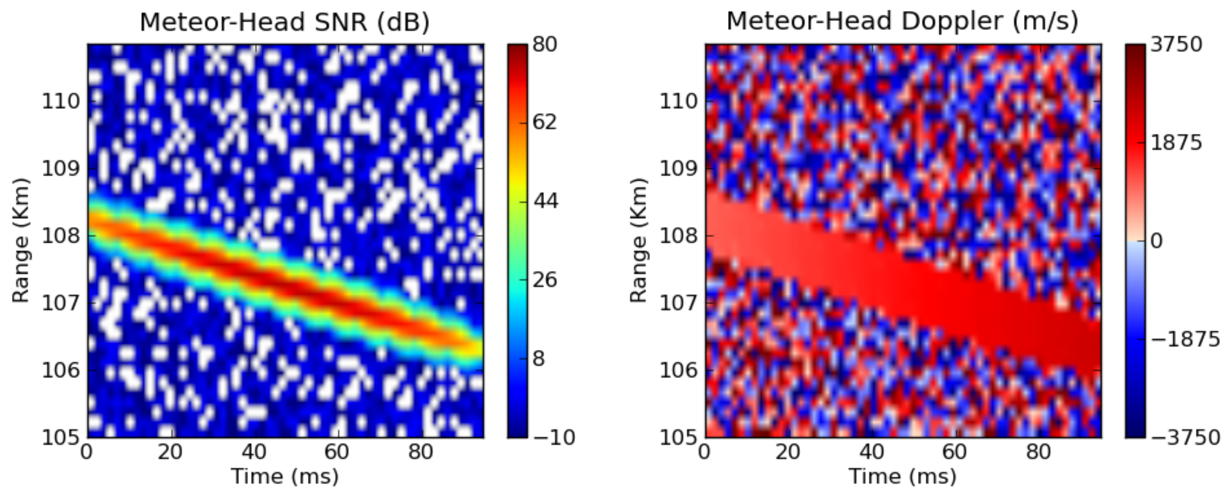
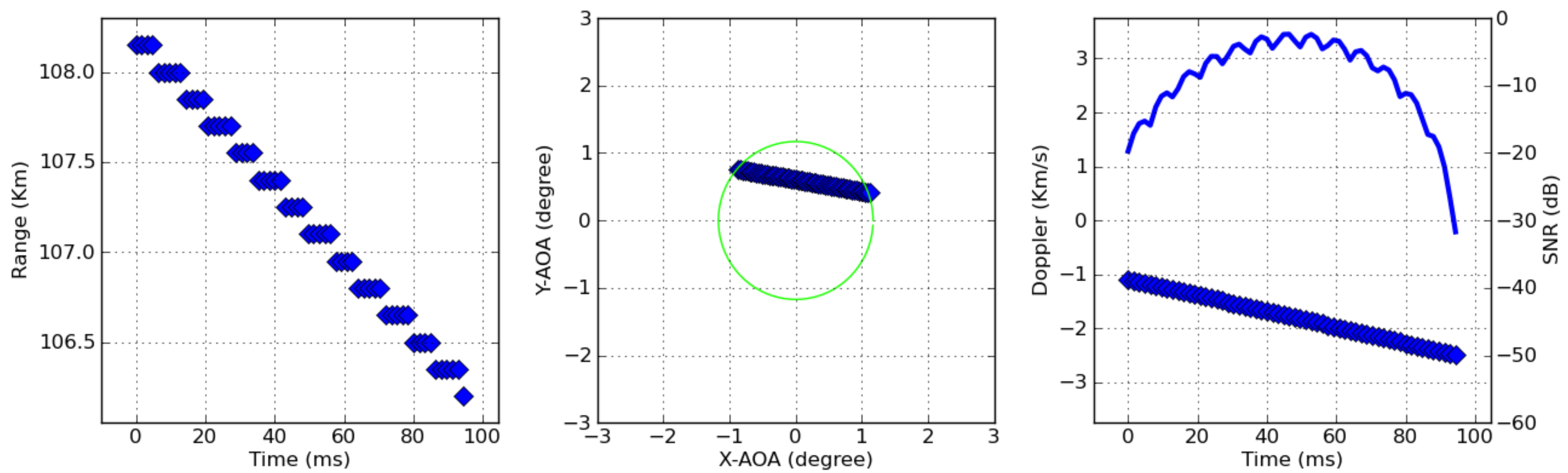
Head echo simulation:

- $(V_x,V_y,V_z) = (39.2, -7.0, -20.8)$ Km/s
- Pulse Repetition Time = 60 Km
- Pulse Width = 0.15 Km
- Sampling rate = 0.15 Km





[from *Galindo et al.*, 2010]

Instrument effect: Observations vs. Simulations

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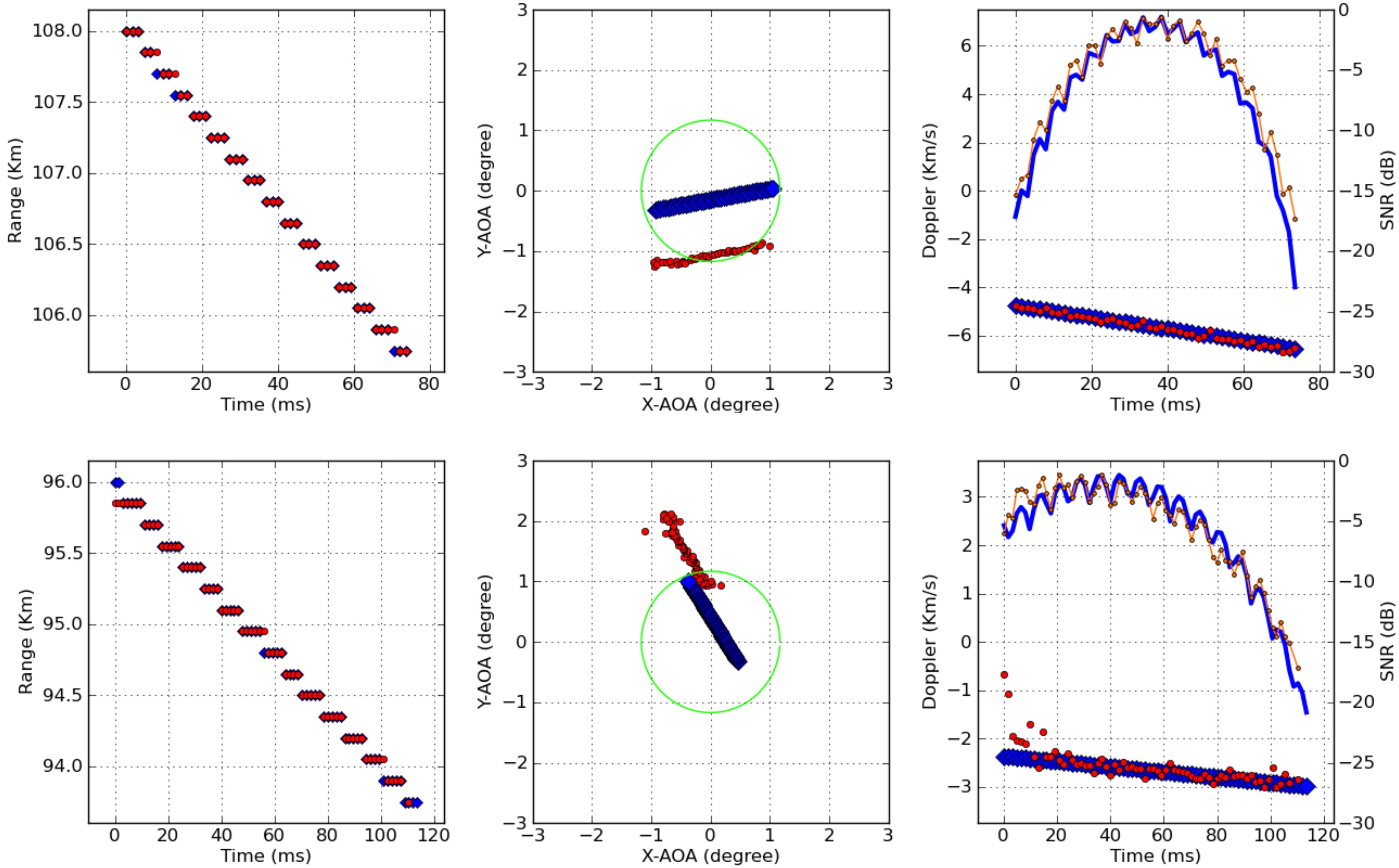
Observations: red, Simulations: blue



Orthogonal polarization results

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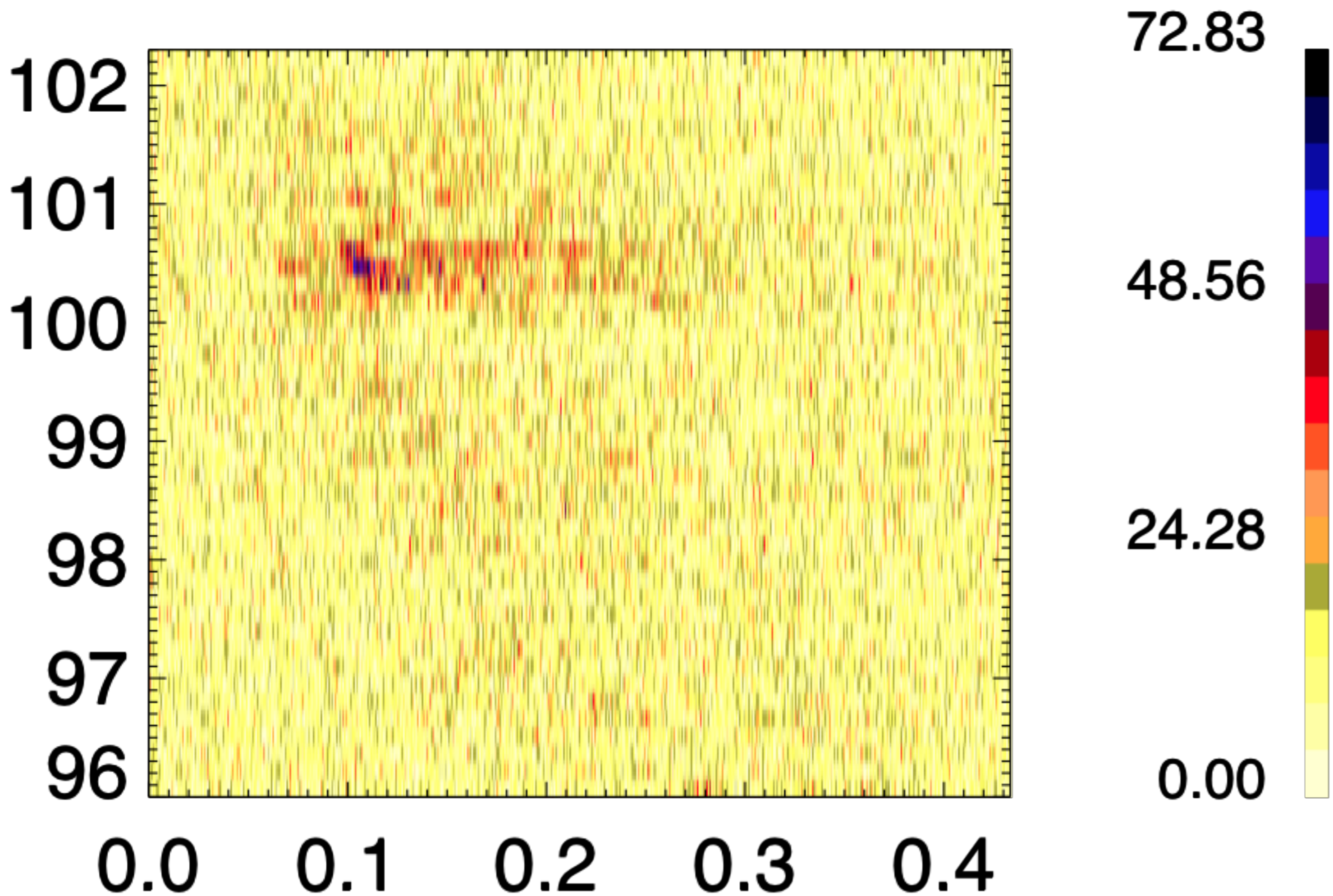

"Differential Ablation"

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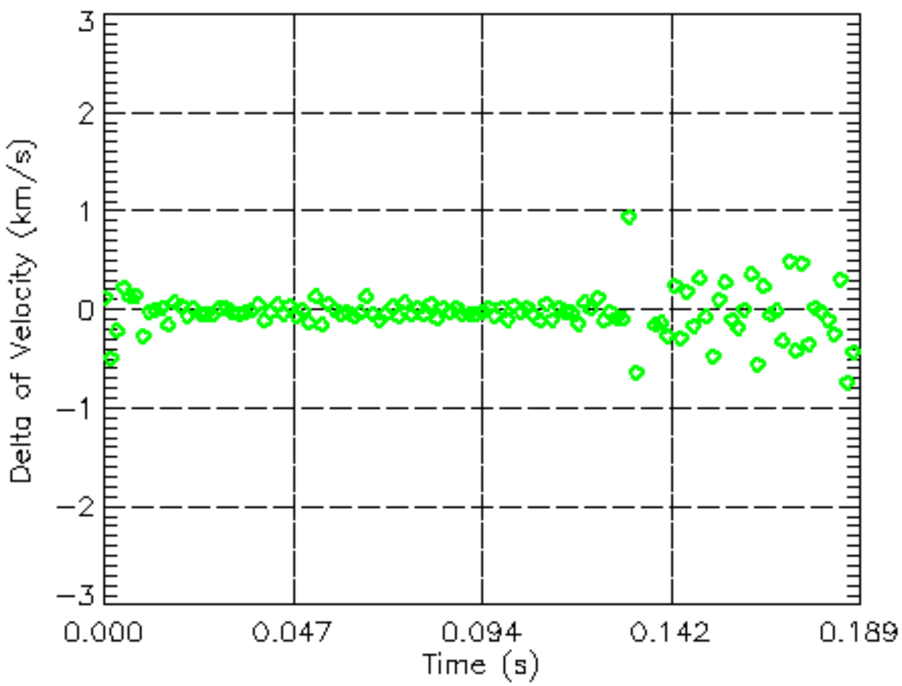

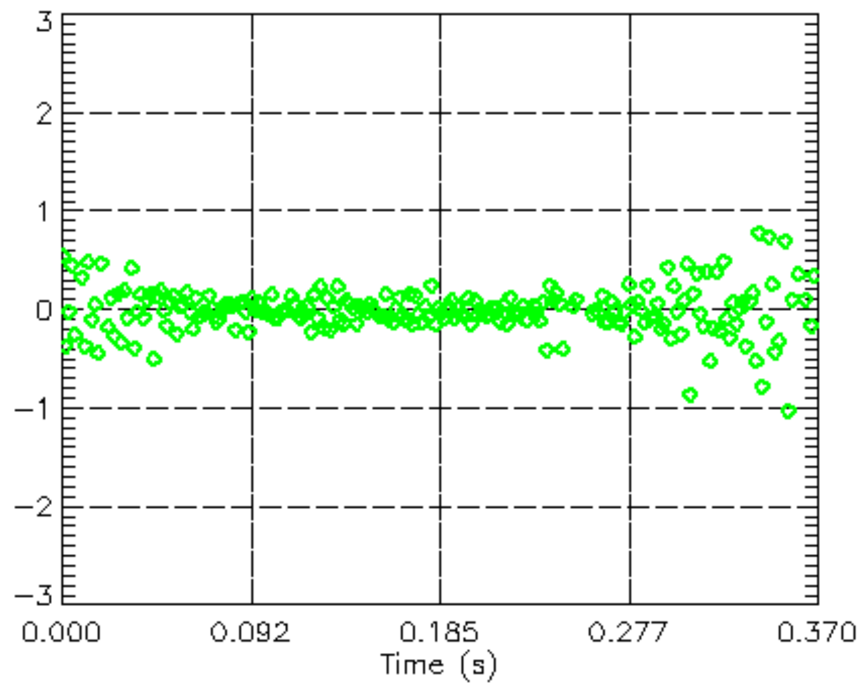

“Fragmentation”

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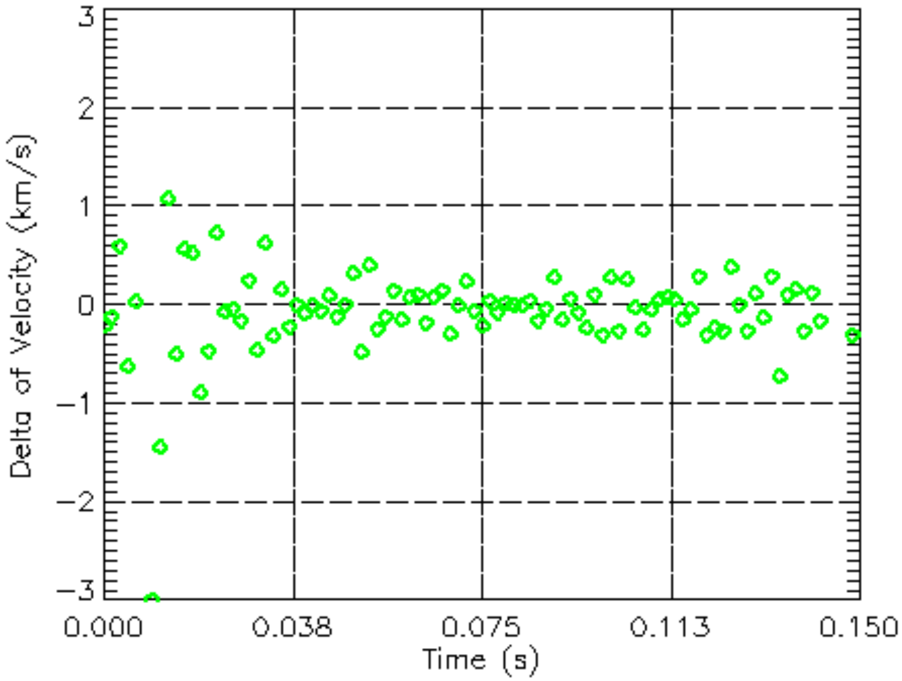

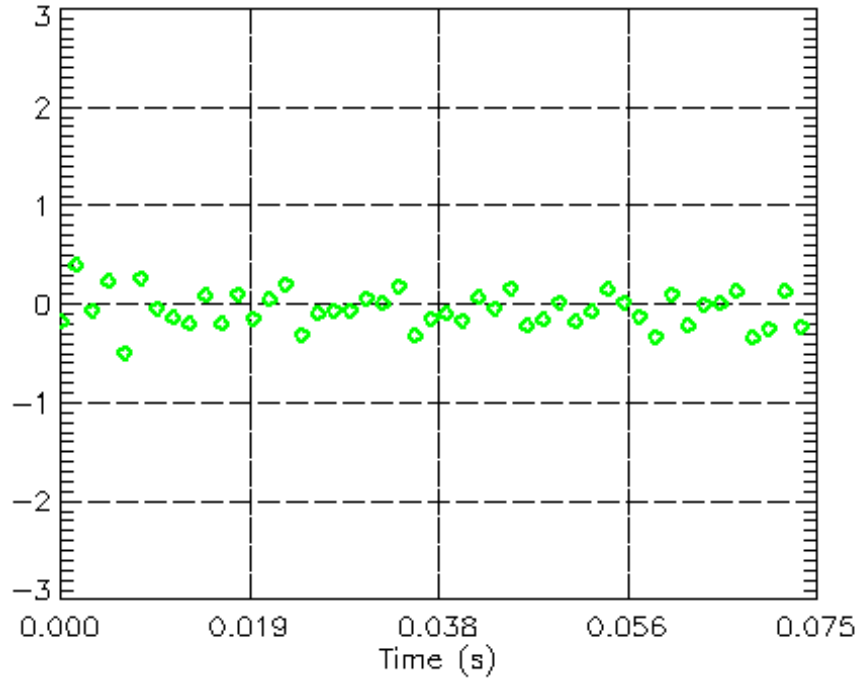

Trainee "Summer" Program (1)

Radio Observatorio de JICAMARCA Radio Observatory

- When? June-August
- How long? 10-12 weeks
- Where? Jicamarca Radio Observatory, Peru
- Who should apply? Undergraduates (3rd, 4th year), Graduates (1st, 2nd year)

http://jro.igp.gob.pe/jirep/

Trainee “Summer” Program (2)

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