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Neutral density measurement from simultaneous radar observation of meteors

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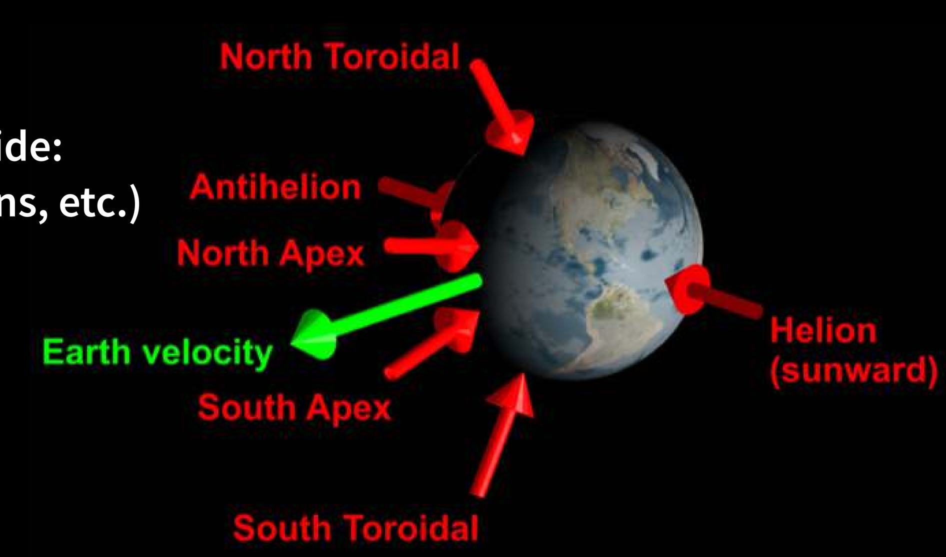
Introduction

- Thermospheric neutral density difficult to measure directly
- Space-based in situ measurements down to ~360 km
- What is coming into the Earth system and what is it passing through?
- Meteoroids provide information on the properties and phenomena of the lower thermosphere

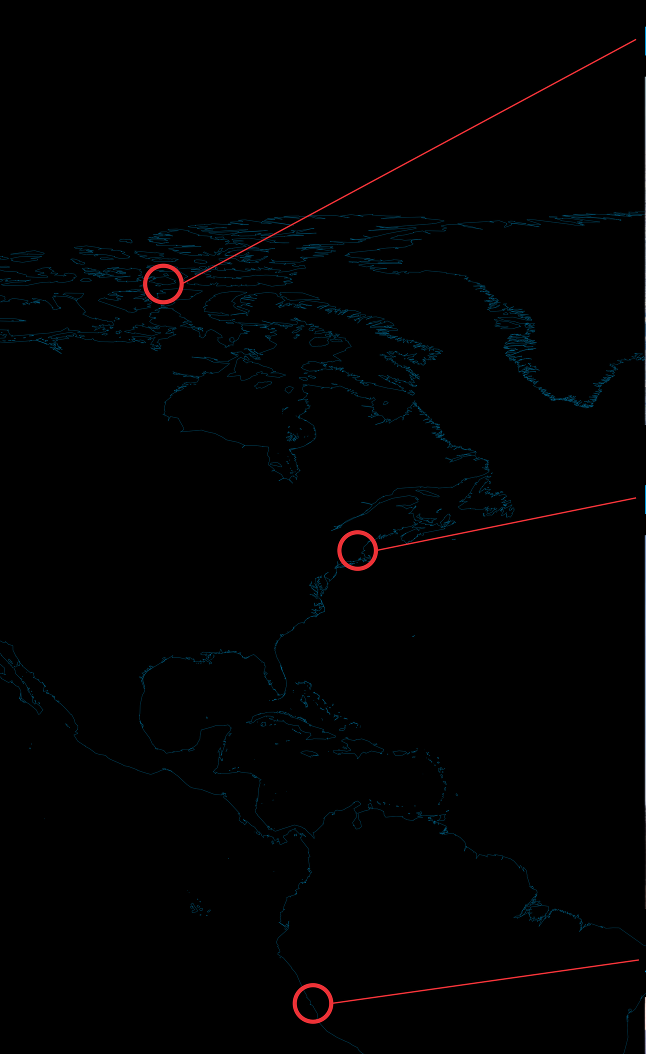
Meteoroids

- Plasma interactions throughout meteoroid lifetime
- Sporadic meteoroids entering the Earth's atmosphere provide:
  - A source function of extraterrestrial material (metallic ions, etc.)
  - A probe into the atmospheric conditions being traversed
- Ablation of meteoroids in atmosphere produces meteor plasma, which is detectable by ground-based radar



Radar facilities

- High-power large-aperture (HPLA) radar typically uses higher frequencies and narrower beams than dedicated meteor radar
- Track head plasma to determine deceleration of meteoroid subject to drag and ablation



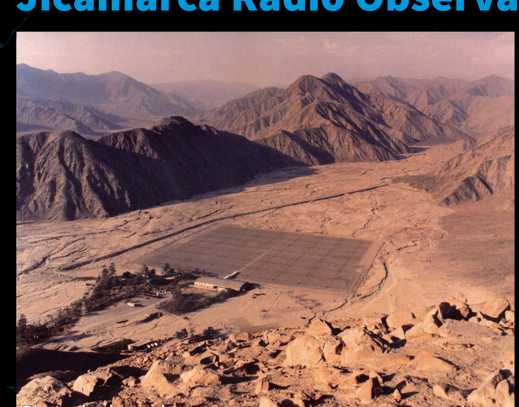
Resolute Bay Incoherent Scatter Radar North face (RISR-N)

Location:	74.7296° N, 94.9058° W, 145 m
TX Frequency:	442.5 MHz
Antenna:	30 m x 30 m square array
Orientation:	26° azimuth, 86° elevation
Waveform:	MinSideLobe-51 1μs baud
Inter-pulse period:	1.4 ms
Sample frequency:	2 MHz

MIT Haystack Observatory (MHO)

Location:	42.6195° N, 71.4917° W, 146 m
TX Frequency:	440 MHZ
Antenna:	46 m steerable dish
Orientation:	270° az, 45° el
Waveform:	Barker-7 6 μs baud
Inter-pulse period:	2 ms
Sample frequency:	1 MHz (10 minutes at 25 MHz)

Jicamarca Radio Observatory (JRO)



Location:	11.9515° S, 76.8745° W
TX Frequency:	49.9 MHz
Antenna:	300 m x 300 m square array
Orientation:	90° elevation
Waveform:	MinSideLobe-51 1μs baud
Inter-pulse period:	1.25 ms
Sample frequency:	1 MHZ

Neutral density estimation

- Simultaneously estimate relative neutral density profiles and meteoroid parameters
- Use order statistics with known meteoroid distribution to anchor density profiles to absolute density value
- Prior work by Li and Close [2016] using ALTAIR meteor data

Drag: $$\frac{1}{v^2}\frac{dv}{dt} = -\frac{3}{8}\frac{C_D \rho_a}{\rho_m R}$$

Ablation: $$\frac{dm}{dt} = -\frac{1}{2}\frac{C_H}{H^*} A \rho_a v^3$$

Combined: $$D = \frac{C_H}{6 C_D H^*}$$

Matrix formulation:

$$\ln\left(\frac{a_2^2}{v_2^2}\right) - \ln\left(\frac{a_1^2}{v_1^2}\right) = D(v_1^2 - v_2^2) + \ln\left(\frac{\rho_{a2}}{\rho_{a1}}\right)$$

$$F_{i,j} = \ln\left(\frac{a_{i,j+1}}{v_{i,j+1}^2}\right) - \ln\left(\frac{a_{i,j}}{v_{i,j}^2}\right) \qquad W_{i,j} = v_{i,j}^2 - v_{i,j+1}^2 \qquad \rho_{rj} = \frac{\rho_{a,j+1}}{\rho_{a,j}}$$

$$\begin{bmatrix}F_{i,1}\\ F_{i,2}\\ \vdots\\ F_{i,m}\end{bmatrix} = \begin{bmatrix}I_{i,j=1} & 0 & \cdots & 0 & W_{i,1}\\ 0 & I_{i,j=2} & \cdots & 0 & W_{i,2}\\ \vdots & \vdots & \ddots & \vdots & \vdots\\ 0 & 0 & \cdots & I_{i,j=m} & W_{i,m}\end{bmatrix}\begin{bmatrix}\ln(\rho_{r1})\\ \ln(\rho_{r2})\\ \vdots\\ \ln(\rho_{rm})\\ D_i\end{bmatrix}$$

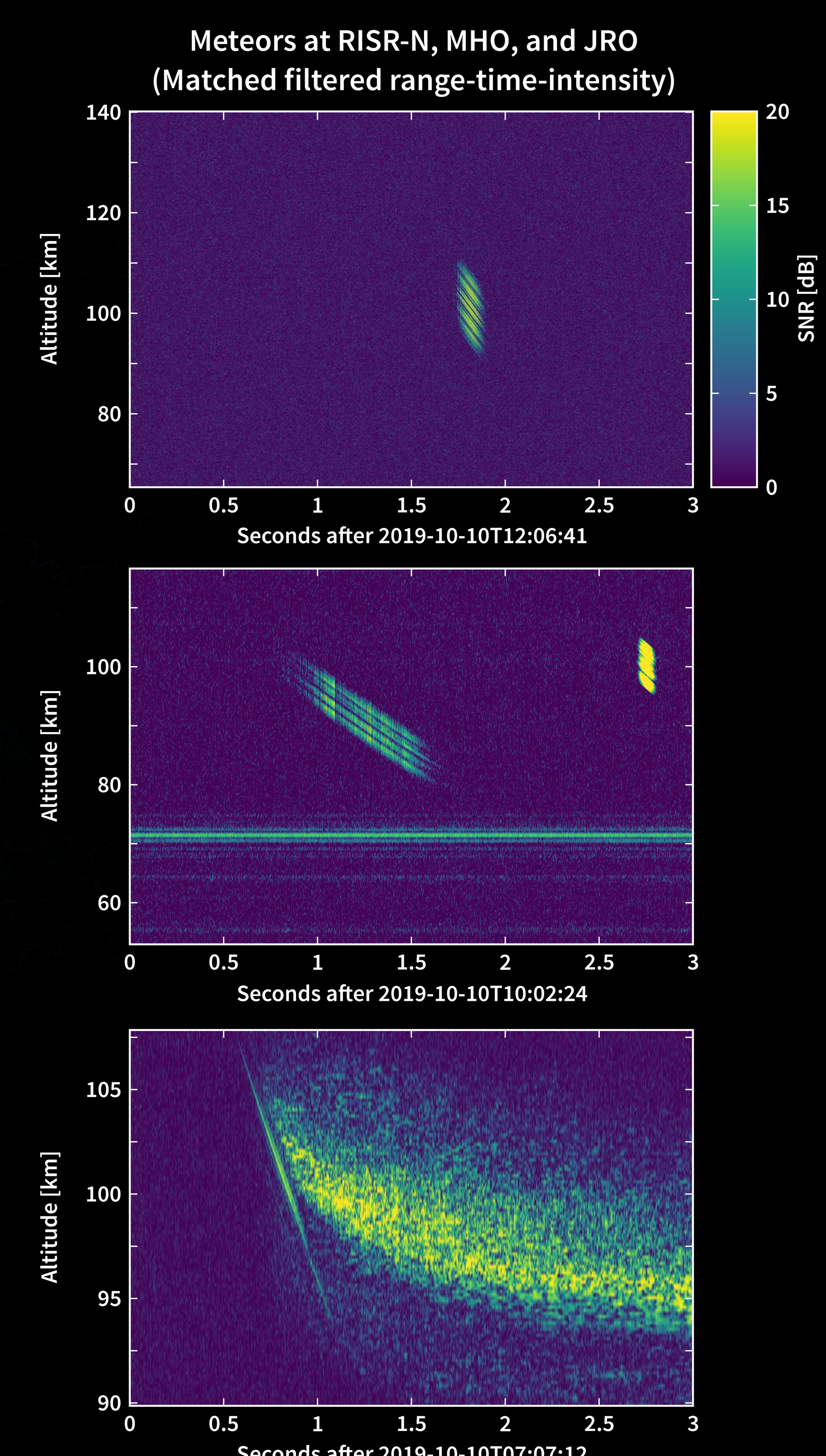
Convex optimization problem:

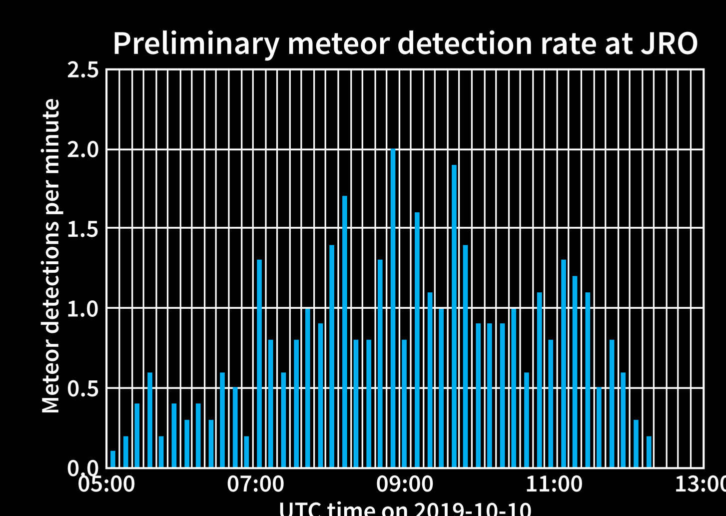
Minimize $$\sum_{i,j} \left|F_{i,j} - D_i W_{i,j} - \ln(\rho_{rj})\right|$$

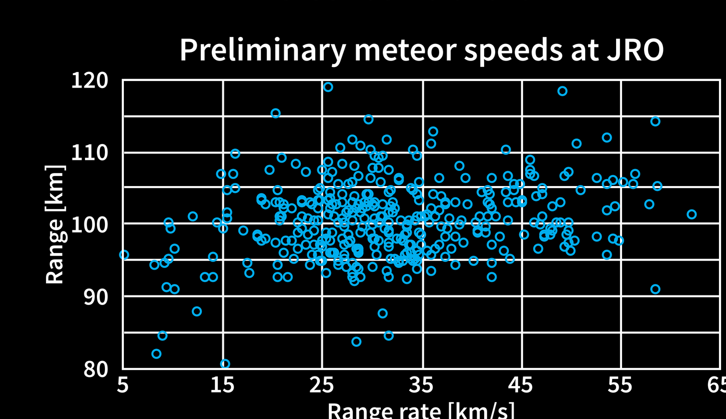
Subject to $D_i > 0$

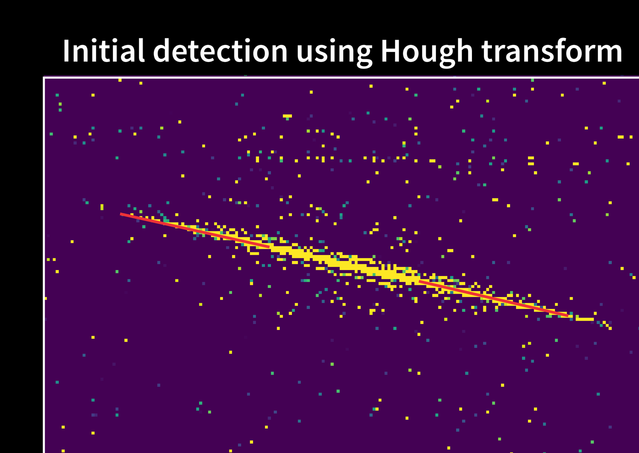
Meteor campaign

- Simultaneous measurement from multiple facilities spanning equatorial to polar latitudes
- Four-hour windows spanning period of maximum sporadic meteoroid flux:
  - 2019-10-10T09:00Z to 2019-10-10T13:00Z
  - 2019-10-11T09:00Z to 2019-10-11T13:00Z
- Binary phase coded pulse compression selected based on Volz and Close [2012]









Conclusion

- Meteor-derived atmospheric density measurements provide a technique for continuous monitoring using existing facilities that complements measurements of other atmospheric parameters
- Upcoming/ongoing meteor radar campaigns will yield new data set of meteor trajectories for population studies

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References

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