Detection and Characterization of Meteoroid from Optical and Radar Observations

Space Environment and Satellite Systems

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Introduction

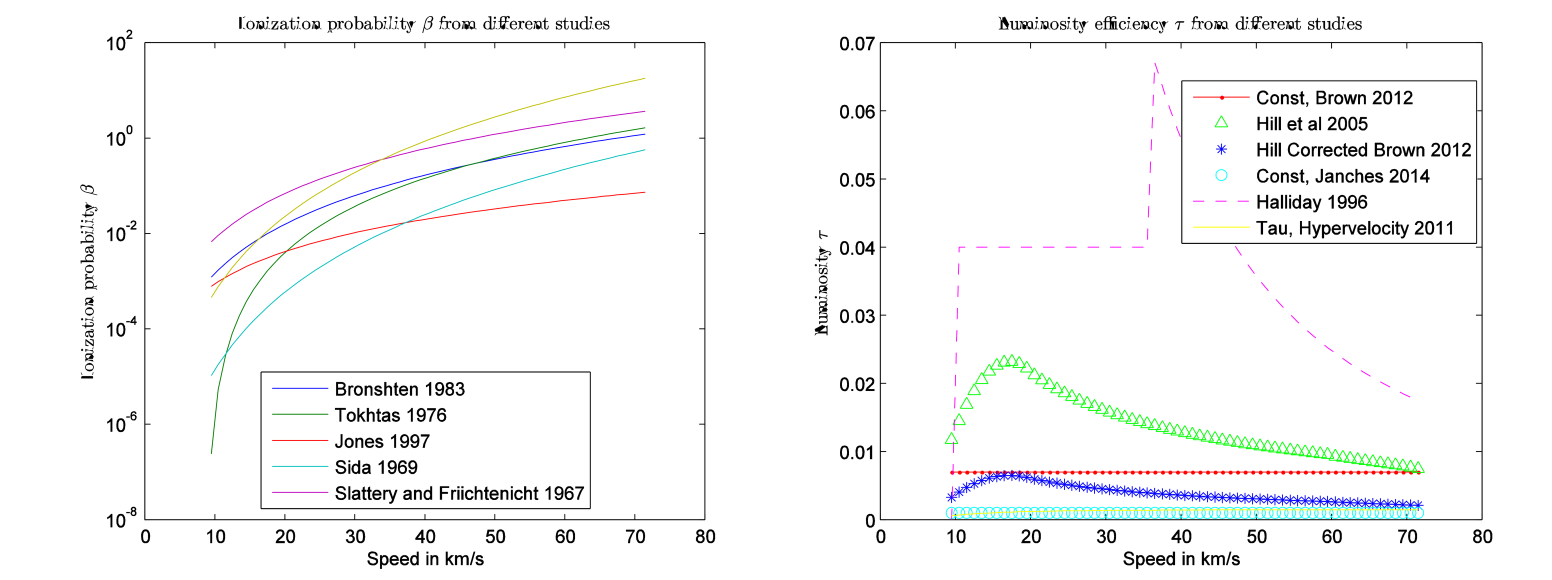
We present a method to characterize undetermined coefficients used in meteoroid mass estimation, based on data collected on March 30 2014. From the radar and optical data we can determine the Radar Cross Section (RCS) of a meteor and its luminosity power. Under the assumption that the same event is detected, we relate our measured signals to the meteoroid mass loss and then to each other, thus extrapolating the best fit among the existing model for determine which ionization coefficient (β) and luminosity coefficient (τ) parameter to use

AMSIR radar at Poker Flat

Ixon ultra camera setup

Motivation

Optical and radar mass determinations are fraught with error due to difficulty in assessing the luminous efficiency (for optical) and the ionization coefficient (for radar) parameters, both of which depend on the meteoroid velocity and composition, as well as surrounding air density. Current models for meteoroid mass distributions may differ by over an order of magnitude and do not account for the different composition of meteoroids. This discrepancy is primarily due to the large errors in models that connect a meteoroid's mass to the observation of a meteor



Existing models for the ionization probability and luminosity efficiency coefficients. The resulting mass computation can have up to one order of magnitude of difference.

Acknowledgments

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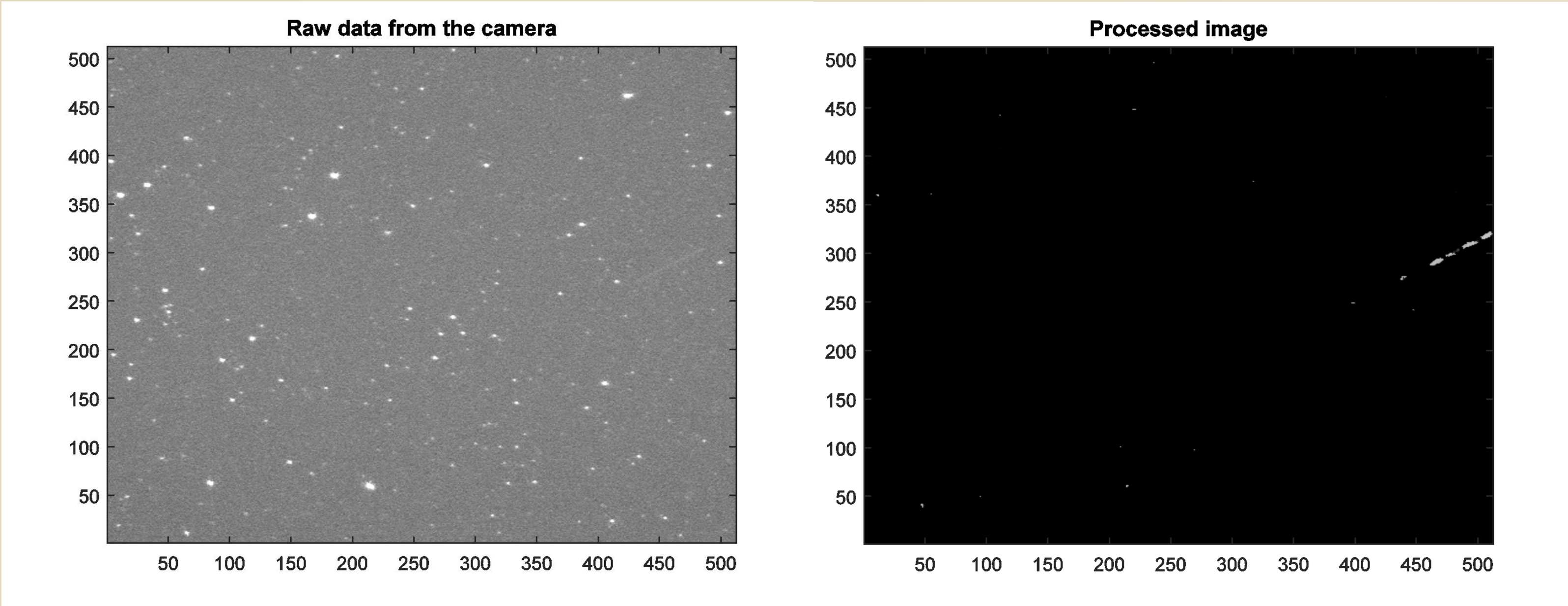
Experimental Design

We collected meteor data using PFISR, operating at 449.3MHz and an electron multiplying charge coupled device camera on three consecutive nights across end of March and beginning of April 2014. To maximize the number of coincident optical and radar observations the camera and radar were pointed at 75 deg elevation and 15 deg azimuth. PFISR was set up using two different pulses: a wide beam (~5 deg) and a narrow beam (~1 deg). The EMCCD camera had approximately ~9deg FOV.

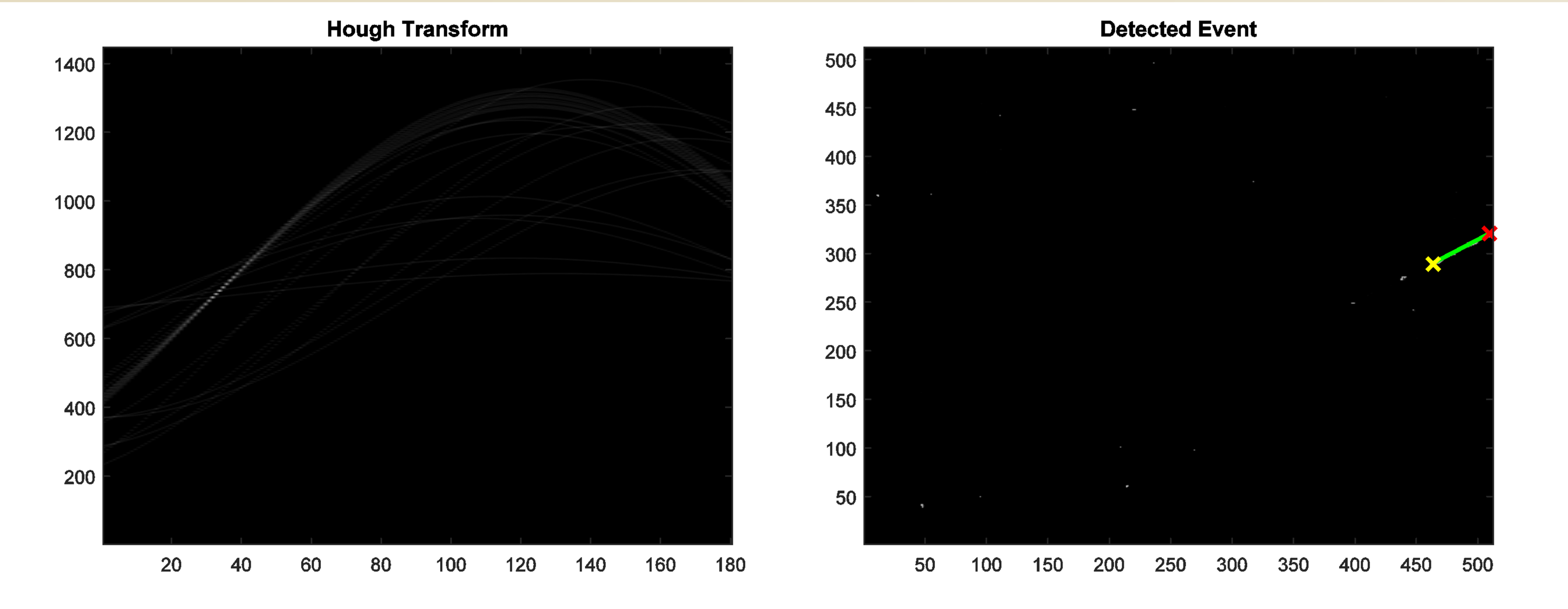
Methodology

An automated detection algorithm based on the Hough transform has been developed to discover meteors in the optical instruments. Once an event is identified, we confirm its existence in the radar signal and then proceed to extract the meteor properties (velocity, luminosity, RCS and altitude of the event).

Detection Algorithm



Raw data from the camera Processed data



Hough transform Detected strike

Detected Events

	03/30/2014	03/31/2014	04/01/2014	Percentage
Identified Objects	49	95	136	100
True positive	43	88	94	80.36
False Positive	6	7	42	19.64
False Negative	N/A	N/A	N/A	N/A
Common Events	13	11	N/A	N/A

Coefficients best fit

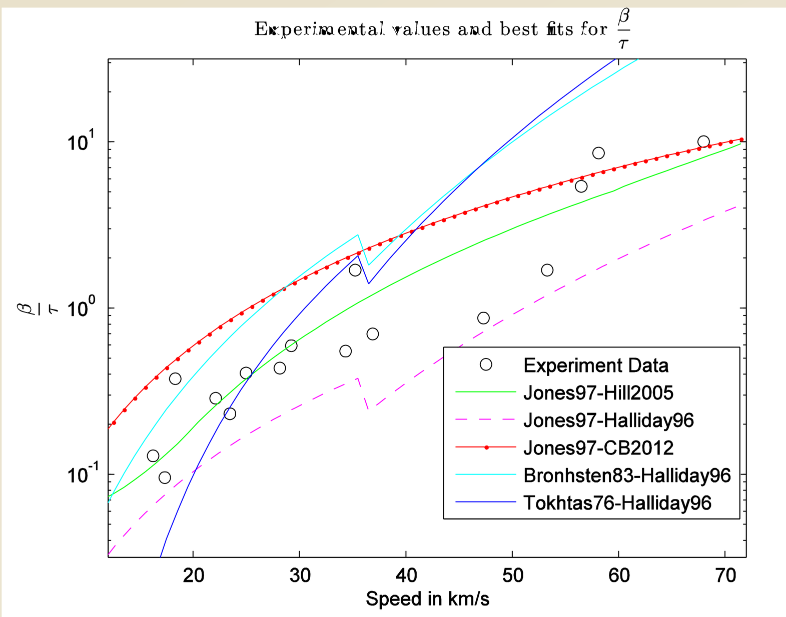
Given this information -- under the reasonable assumption of a negligible change in velocity -- we can directly relate the mass loss to the meteor luminosity and RCS.

$$\text{Optical: } \frac{dm}{dt} = \frac{2I}{v^2\tau}$$

$$\text{Radar: } \frac{dm}{dt} = \frac{\mu q v}{\beta}$$

Observing a common event implies that the mass loss computed with the two different equations must be the same, allowing us to compare directly the two coefficients of interest from experimental results with real data. This leads to

$$\frac{\beta}{\tau} = \frac{\mu q v^3}{2I}$$



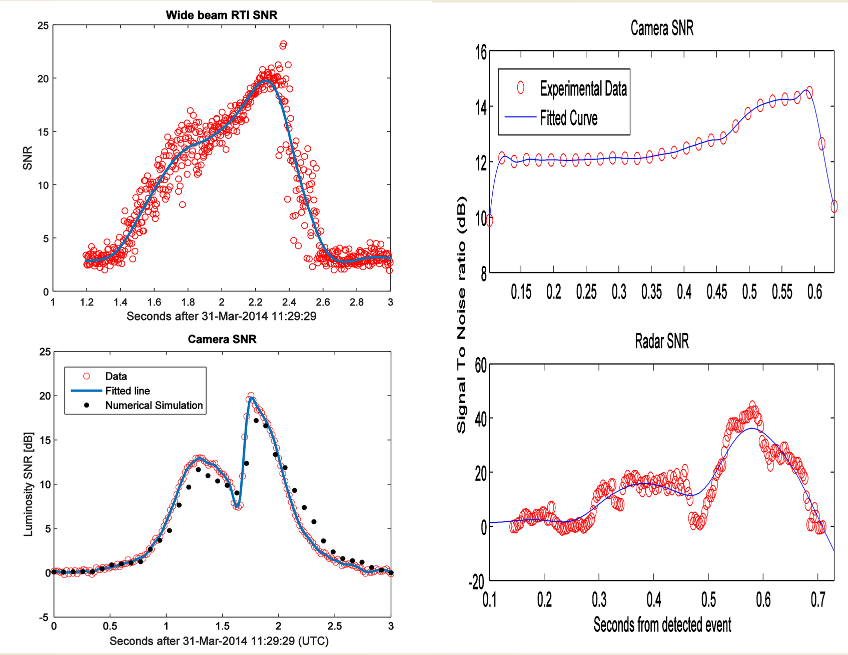
We show the combination of Ratio empirical equation with present the minimum distance to our observations in our given metric

In order to equally weight the events at all speeds our error estimate is given by

$$\min ||\max(\frac{\frac{\beta}{\tau}|_{equ}}{\frac{\beta}{\tau}|_{obs}}, \frac{\frac{\beta}{\tau}|_{obs}}{\frac{\beta}{\tau}|_{equ}})||_{inf}$$

β-τ Combination	Error
Jones 1997 – Hill 2005	**24.82**
Jones 1997 – Halliday 1996	41.16
Jones 1997 – Cons, Campbell-Brown 2012	42.31
Bronshten 1983 – Halliday 1996	54.44
Tokhtas 1976 – Halliday 1996	59.98

Interesting Meteor Signal



In both situation we observe an interesting response in our recorded data, we note a progressive increase in SNR due either to fragmentation or differential ablation. A more in-depth analysis of the Radar alongside a numerical simulation seems to suggest the latter

Conclusion and Future Work

The work here presented brought forward two important points: firstly – according to our observations – Jones1997 and Hill 2005 are the best pair of coefficients the community should use in order to obtain consistent measurements across different instruments for mass estimation. Secondly we observed events that may support the existence of meteoroid differential ablation. Nonetheless the incongruity of some data require further inquiry to characterize them. Future experiment of this sort should thus incorporate additional instruments (e.g. camera filter, lidar), to resolve probable irregularity in the collected data.