LEIBNIZ-INSTITUTE OF ATMOSPHERIC PHYSICS IAP

SIMULTANEOUS OPTICAL AND METEOR HEAD ECHO MEASUREMENTS USING THE MIDDLE ATMOSPHERE ALOMAR RADAR SYSTEM (MAARSY)

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Western

Simultaneous radar/video observations

- Radars and optical instruments are valuable tools for studying meteoroids, but suffer from (different) observing biases.
- Simultaneous observations with radar and video can help constrain the true masses being detected
- Fragmentation a key issue.
- Ionization production a strong function of speed – luminous efficiency poorly known

Meteoroid radiation and deceleration

$$M = \frac{2}{\tau V^2} \int I dt$$

$$\frac{dV}{dt} = -\frac{\Gamma A}{\rho_m^{1/3} M^{1/3}} \rho_a V^2$$

I – light intensity, τ - luminous efficiency, A – shape factor,
Γ-drag coefficient, $\rho_{m,}$ ρ_a - meteoroid and atmospheric densities

Based on light production photometric mass is determined (for small meteors neglecting deceleration)

M_{ph}

Problem:
poorly known luminous efficiency

If deceleration is measured dynamic mass may be estimated

M_d

Problem:
fragmentation

To determine mass from optical observational data alone –
Need absolute luminous efficiency in your bandpass or figure out fragmentation

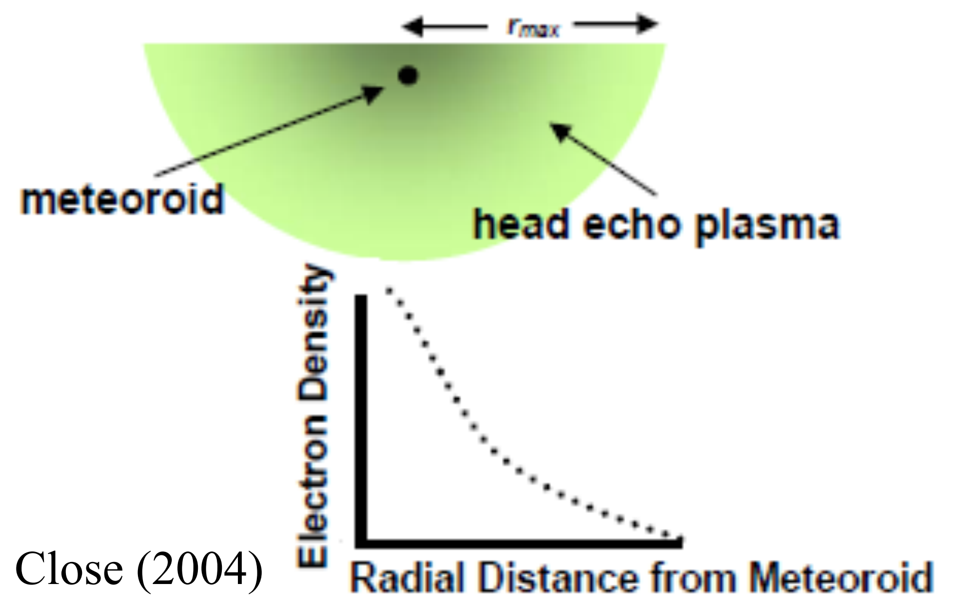
Head Echo Ionization Mass

Based on received radar power from head echo, an equivalent RCS can be measured for each returned pulse

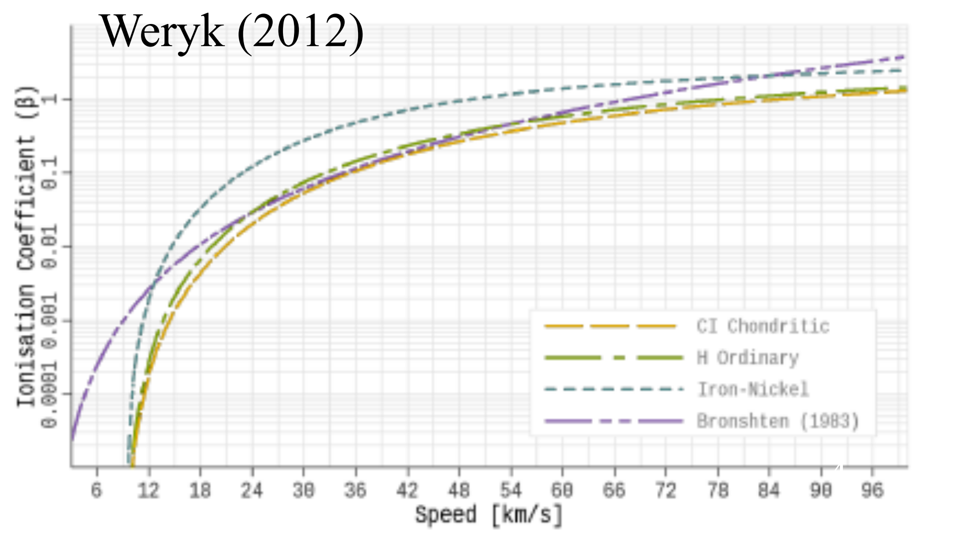
M_I

Problem:

Need to convert RCS to total electron content, assuming some scattering model and radial size of electron cloud and distribution of electrons. Ionization coefficient (electron production per ablated meteoric atom) also uncertain



Close (2004)



Weryk (2012)

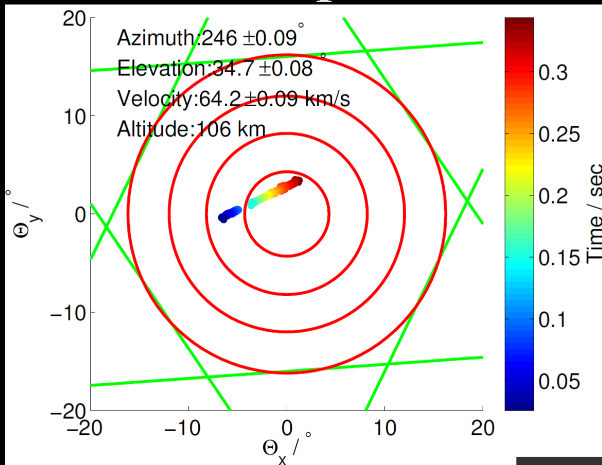
$$m = \int \frac{q\mu v}{\beta} dt$$

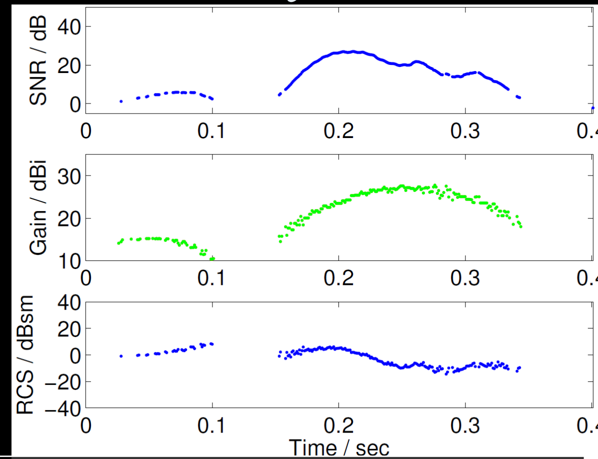
MAARSY – Optical Campaign Goals

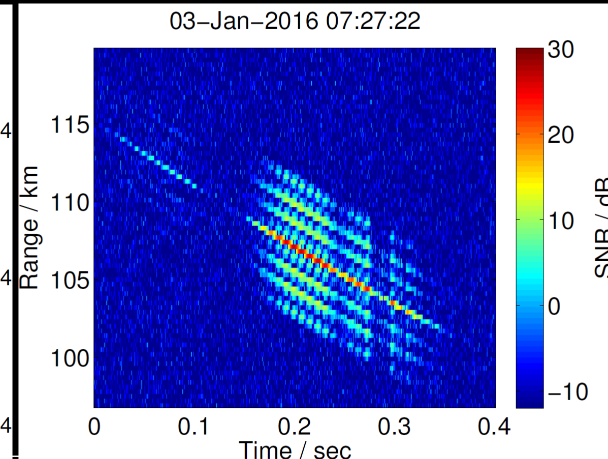
1. Compare speeds, begin/end heights and radiants measured by MAARSY and two station optical solutions for both bright (wide-field) events and fainter meteors
2. Compare photometric and dynamic mass with RCS-derived masses
   - Goal – relative intercalibration of mass scales
3. Put all metric, photometric and ionization estimates together to try and self-consistently model specific events

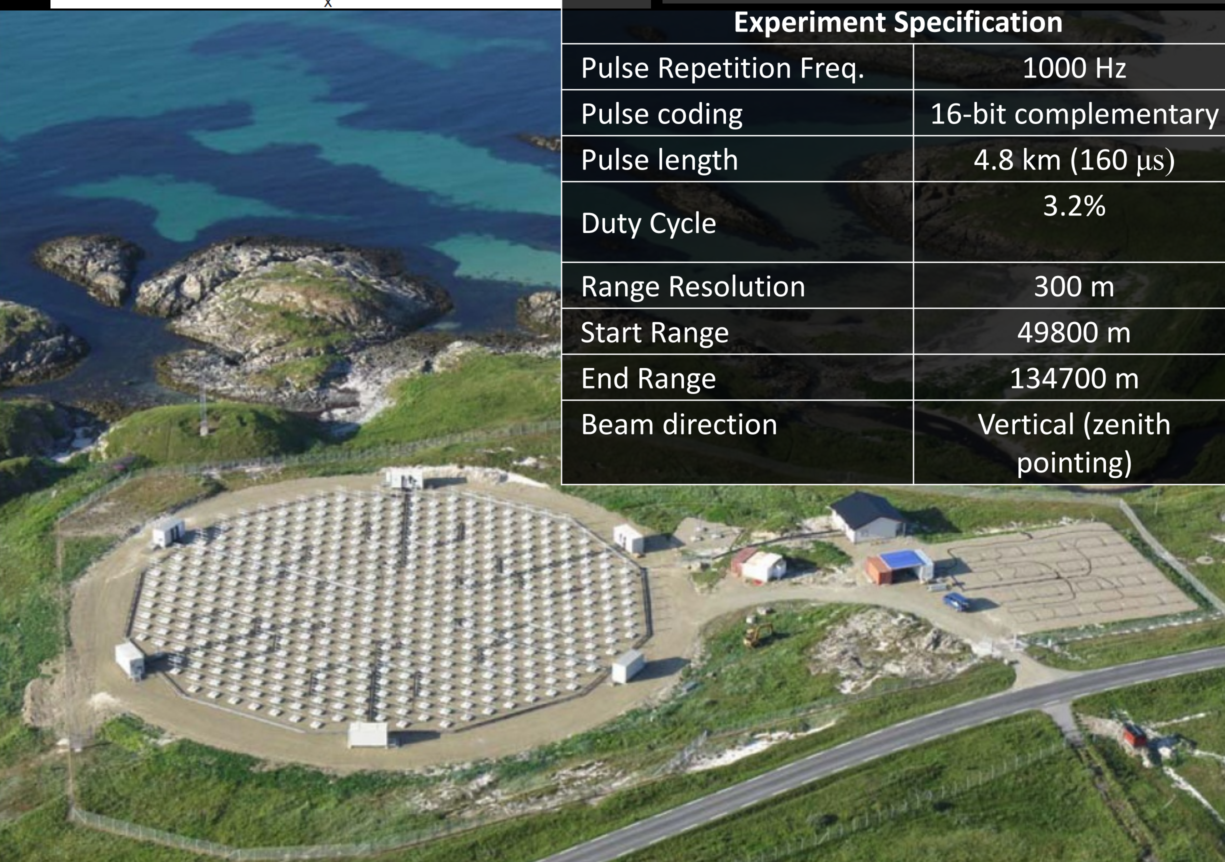

Andoya
Andenes
MAARSY RADAR
ALOMAR OBSERVATORY
Bleik
Skarstein
15 km
Stave
10 km
SAURA SITE
82
Image © 2015 DigitalGlobe
Image IBCAO
© 2015 Google
Image Landsat
Google earth
Imagery Date: 5/18/2013 lat 69.222749° lon 16.135702° elev -12 m eye alt 29.65 km

Middle Atmosphere Alomar Radar System-MAARSY









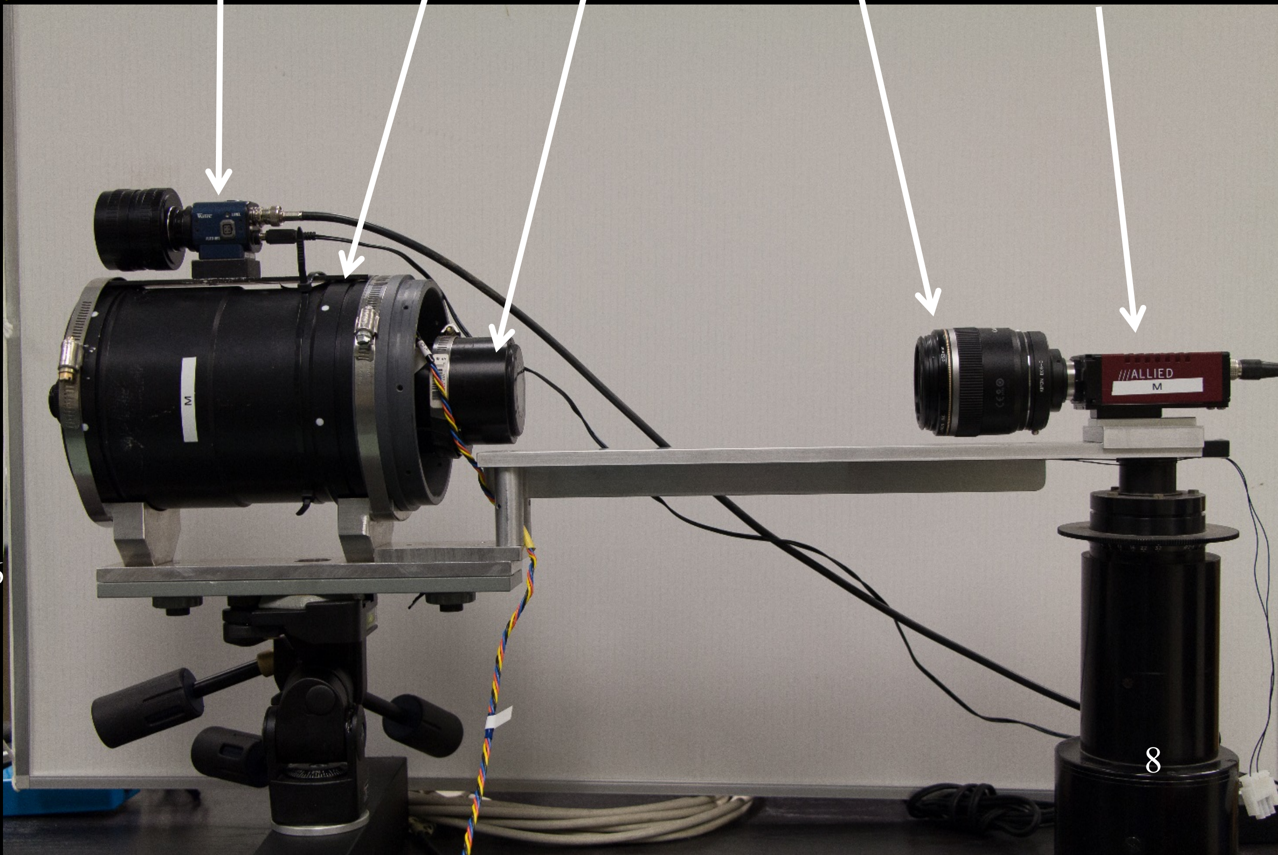
Experiment Specification	
Pulse Repetition Freq.	1000 Hz
Pulse coding	16-bit complementary
Pulse length	4.8 km (160 μs)
Duty Cycle	3.2%
Range Resolution	300 m
Start Range	49800 m
End Range	134700 m
Beam direction	Vertical (zenith pointing)

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

Optical System at each sit

- Narrow field (Gige) intensified systems have a 6° diameter field of view
- 50 fps
- 1k x 1k 12 bit
- Limiting peak meteor magnitude +7 - +8^M
- Limiting stellar magnitude +10^M
- Median meteoroid mass ~10^{-7} kg

- WATEC FOV 14° x 11° with 25mm f0.85 Fujinon lens
- 30 fps
- 640x480 8-bit
- Limiting peak meteor magnitude +4
- Limiting stellar magnitude +6^M
- Median meteoroid mass ~10^{-6} kg



Data collection in 2014-2015

- Cameras and radar observed simultaneously from Oct 3, 2014 – Apr 14, 2015
- Total "clear" and dark (no LIDAR) skies in this interval
  - Alomar 73 hours
  - Saura 116 hours
- 236 multi-station meteors detected automatically with WATEC
- 108 WATEC events also detected by MAARSY

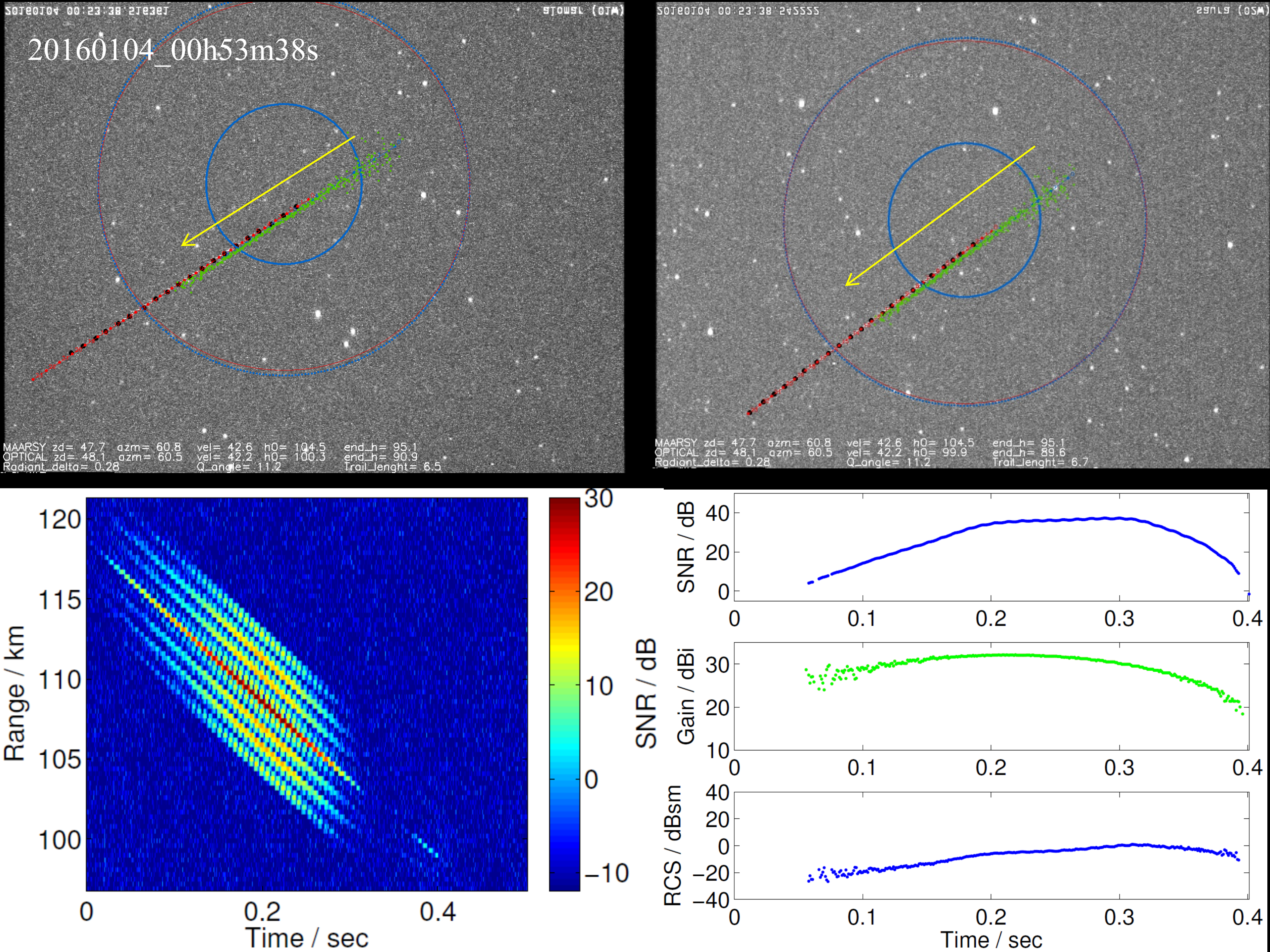
Data collection in 2015-2016

- Cameras and radar observed simultaneously from Sep 15, 2015 – Apr 08, 2016
- Total "clear" and dark (no LIDAR) skies in this interval
  - Alomar 242 hours
  - Saura 368.8 hours
  - Including 2016 Quadrantid peak (multiple optical-HE Quadrantids detected)
- 140 multi-station meteors detected with WATEC and detected by MAARSY. This includes:

  - 14 four camera detection (2 WATEC and 2Gige)

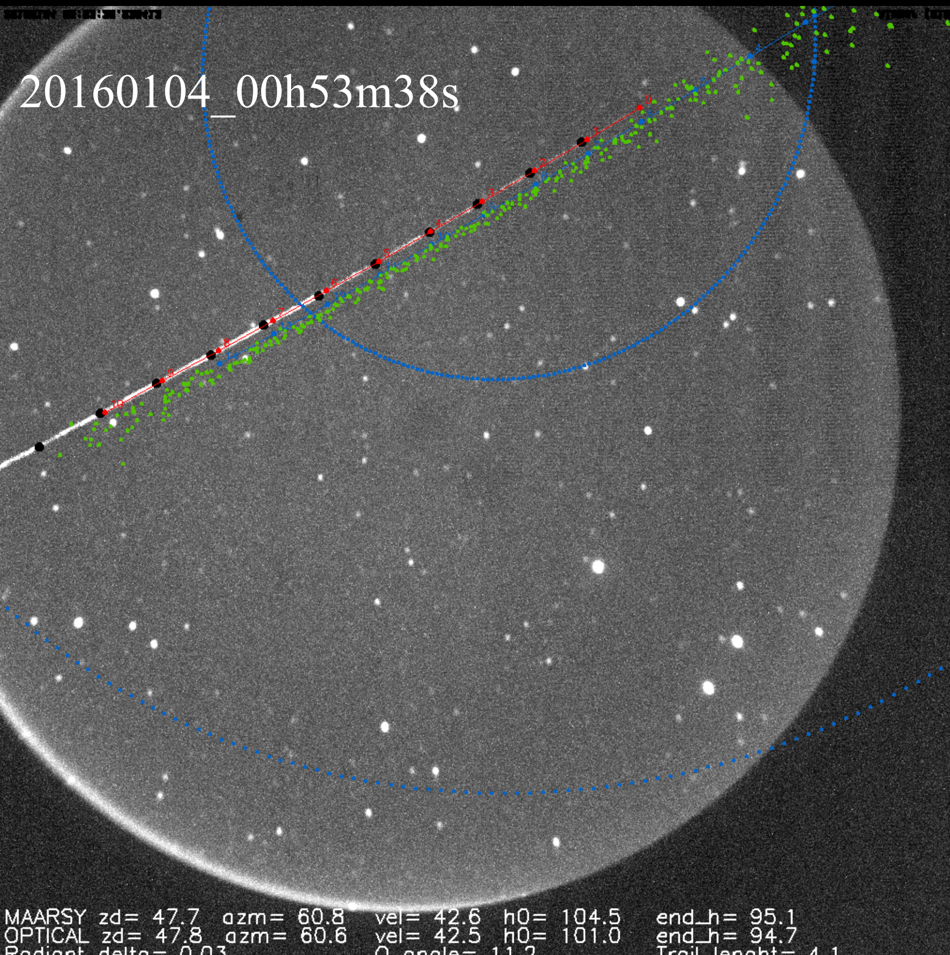
Ongoing Work

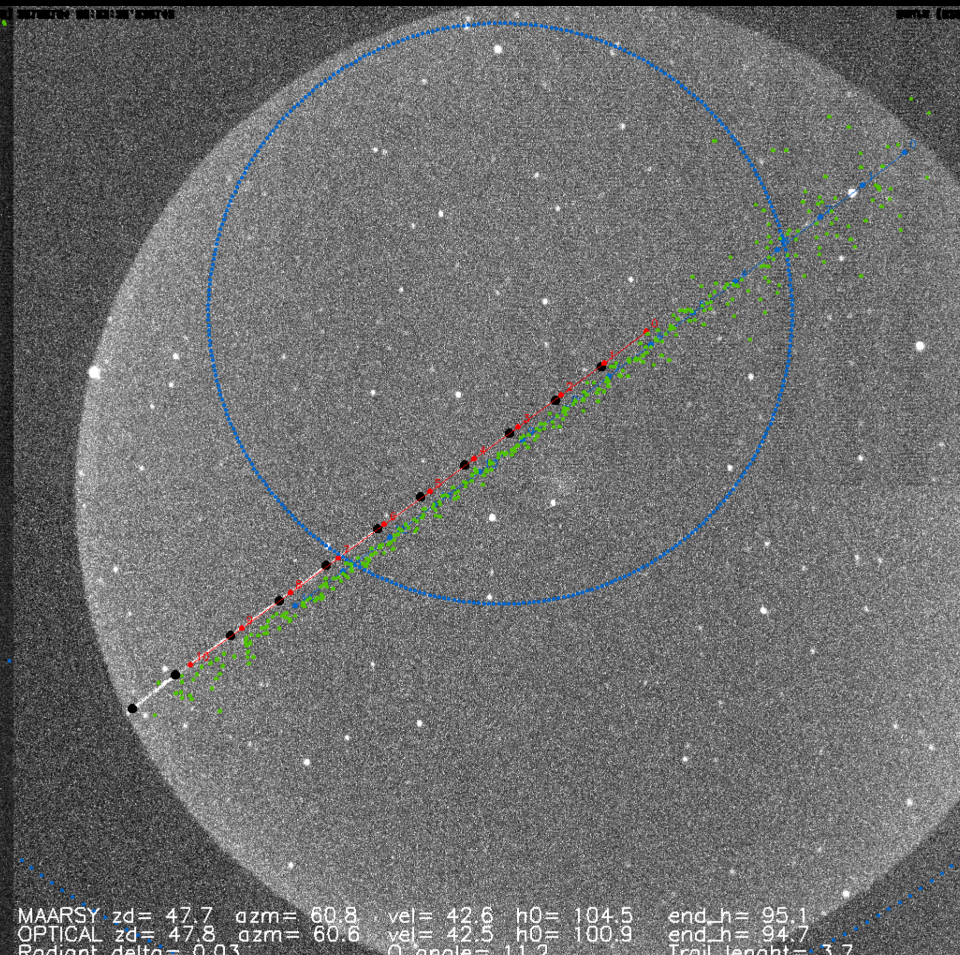
- Third campaign season (Sept, 2016-Apr, 2017) now complete
- Several hundred additional simultaneous events
- Handful of events with MAARSY-optical and EISCAT simultaneous measurements


20160104_00h53m38s
MAARSY zd= 47.7 azm= 60.8 vel= 42.6 h0= 104.5 end_h= 95.1
OPTICAL zd= 48.1 azm= 60.5 vel= 42.2 h0= 100.3 end_h= 90.9
Radiant_delta= 0.28 Q_angle= 11.2 Trail_lenght= 6.5
MAARSY zd= 47.7 azm= 60.8 vel= 42.6 h0= 104.5 end_h= 95.1
OPTICAL zd= 48.1 azm= 60.5 vel= 42.2 h0= 99.9 end_h= 89.6
Radiant_delta= 0.28 Q_angle= 11.2 Trail_lenght= 6.7
Range / km
Time / sec
SNR / dB
Gain / dBi
RCS / dBsm

Gige Camera (Image Intensified)

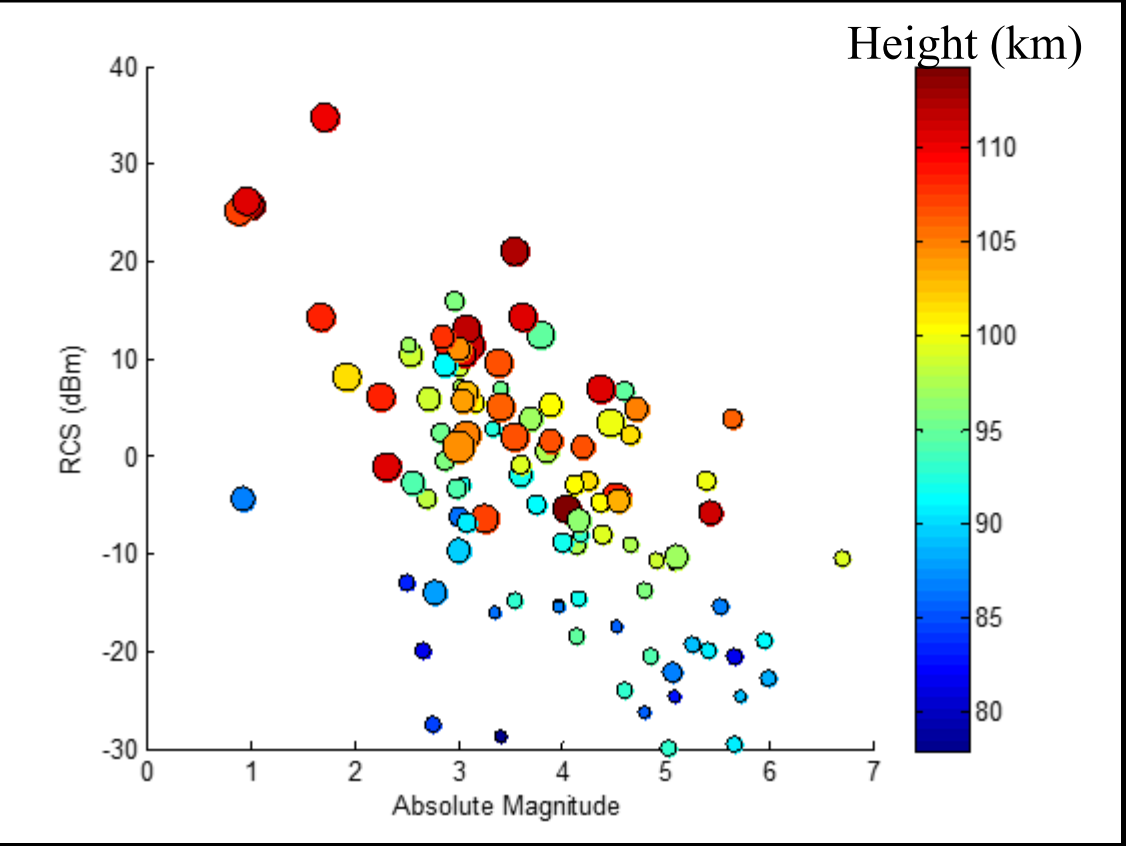
Alomar Saura





RCS vs Magnitude and Height

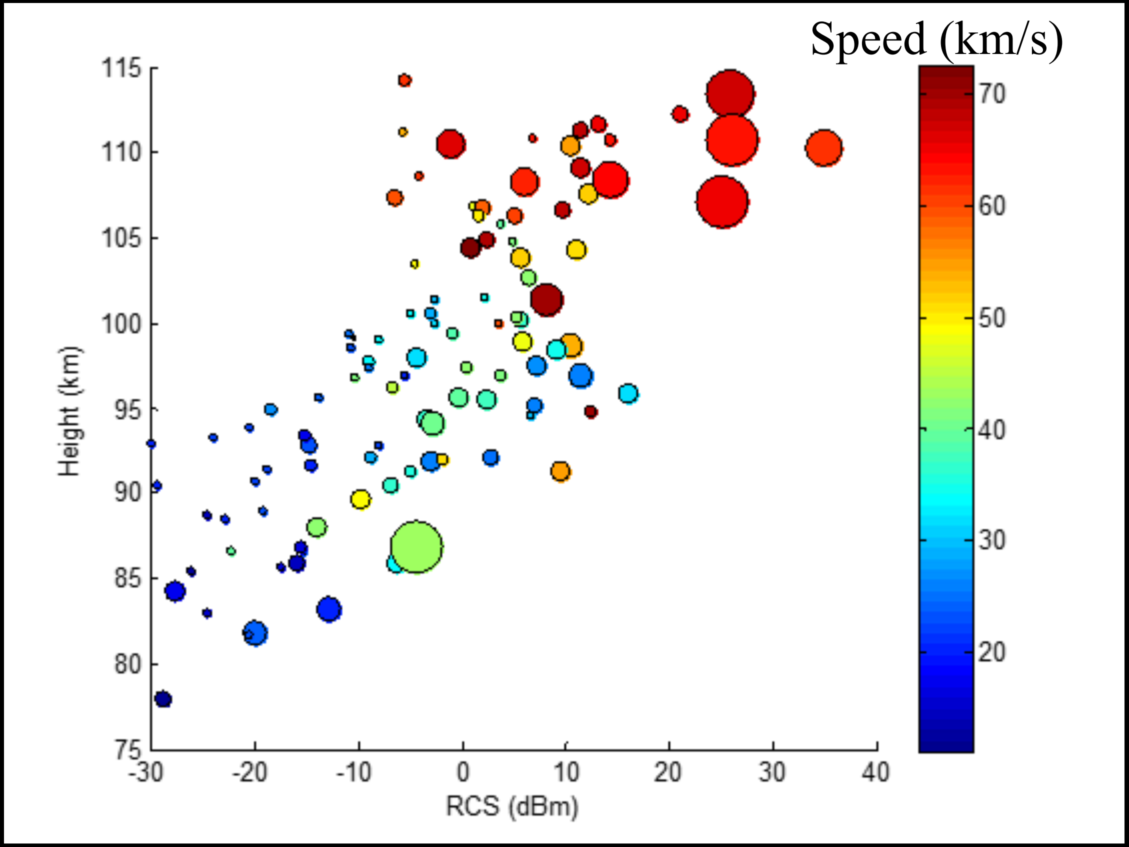
Peak radar cross section (in units of dB relative to a 1 m^2 target) versus the observed magnitude at the same height as the peak RCS measurement for the common head echo. Symbol size proportional to speed and color coding by height (in km).



Height vs RCS showing luminous intensity and speed

Height versus peak radar cross section (in units of dB relative to a 1 m^2 target) as a function of speed (color coding in km/s) with symbol sizes representing peak meteor absolute brightness in watts at the height of the peak RCS.

Larger symbols for a given speed (color) represent larger masses



Metric Results 2014-2016 campaign

Watec – MAARSY quality events (Q>3°, rad dev < 10°) [94 total events]

Gige – MAARSY quality events [12 total]

All differences are optical - radar

Dataset		Δh_{beg}	**ΔHend**	**ΔVel**	**Δrad**
Watec	Mean	-2.3 ± 0.5	-1.4± 0.4	-0.9± 0.2	1.9 ± 0.2
	Median	-1.9	-1.0	-0.7	1.4
Gige	Mean	-2.4 ± 1.2	-0.4± 0.9	-1.5± 0.7	2.9 ± 0.9
	Median	-3	-0.6	-1	1.6

Conclusions - I

- MAARSY and optical two station solutions show comparable trajectories and speeds
  - median deviation in radiants between radar and optical determinations of 1.5 degrees, with 1/3 of common events having radiant agreement to better than one degree
- MAARSY detects meteors higher and earlier than optical
  - MAARSY tends to record average speeds roughly 0.5 km/s and 1.3 km higher than optical records, in part due to the higher sensitivity of MAARSY as compared to the optical instruments.
- From optical comparisons, we estimate MAARSY limiting meteoroid mass is in the 10^{-9} kg to 10^{-10} kg (astronomical limiting meteor magnitudes of +11 to +12) appropriate to speeds from 30-60 km/s.

Conclusions - II

- Clear trend of higher peak RCS for brighter meteors between 35 and -30 dBsm.
- For meteors with similar magnitudes, the MAARSY head echo radar cross-section is larger at higher speeds. Brighter meteors at fixed heights and similar speeds have consistently, on average, larger RCS values, in accordance with established scattering theory.
- Most events show a smooth variation of RCS with height broadly following the light production behavior
  - A significant minority of meteors show large variations in RCS relative to the optical light curve over common height intervals, reflecting fragmentation or possibly differential ablation
- No optically detected meteor occurring in the main radar beam went unrecorded by MAARSY.
  - Thus there does not appear to be any large scale bias in MAARSY head echo detections for the (comparatively) larger optical events, even at very low speeds.