木曽シュミットシンポジウム@

東大Tomo-e Gozenと京大MUレーダーによる超微光流星の同時観測

Shinsuke Abe[(1)], Ryo Ohsawa[(2)], Shigeyuki Sako[(3)]
Johan Kero[(3)], Takuji Nakamura[(4)], Yasunori Fujiwara[(4)]
Junichi Watanabe[(5)], Akira Hirota[(1)],

(1)Nihon University, Dept. Aerospace Eng., Japan
(2)Institute of Astronomy, The University of Tokyo, Japan
(3)Swedish Institute of Space Physics, Kiruna, Sweden
(4)National Institute of Polar Research, Tokyo, Japan
(5)National Astronomical Observatory of Japan, Mitaka, Tokyo, Japan

Leonid Meteor Shower by Abe, Yano, NHK, NASA Leonid MAC

Meteoroids Influx on Earth

Modified from John Plane (2012)

Mass Influx [10^6kg/year]

6
5
4
3
2
1
0

Radar

Satellite

Visual meteors

meteoroids

asteroids

Meteorites

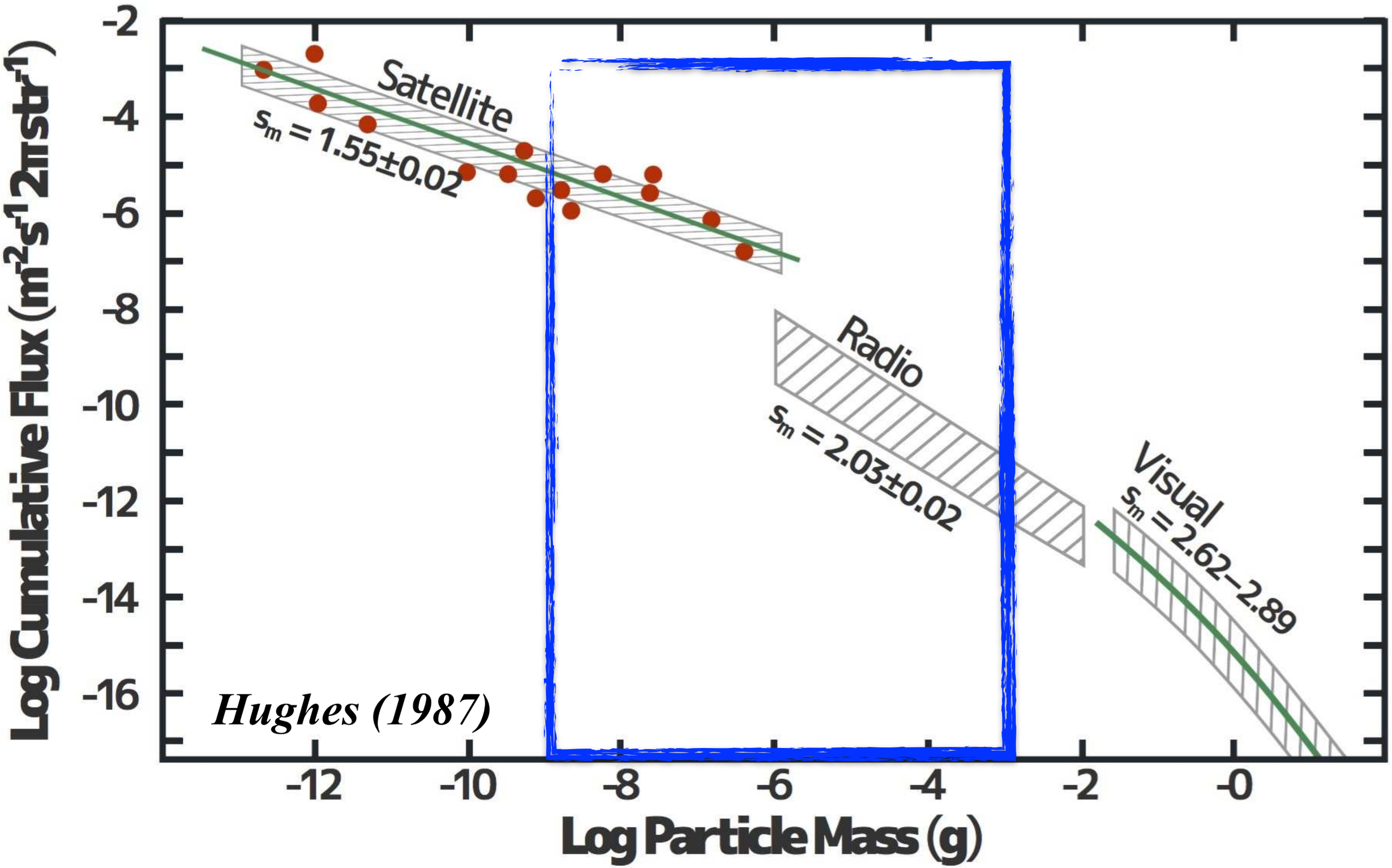
Flux of Meteoroids on Earth
100 - 300 tons/day
40,000 - 100,000 tons/year

1E-15 0.1μm
1E-10 5μm
1E-5 200μm
1E0 1cm
1E5 50cm
1E10 2m
1E5 100m

Mass[g] and Diameter of particle

assuming ρ=2.0g/cc

Sensitivity of MU Radar Meter Head-echo Observations

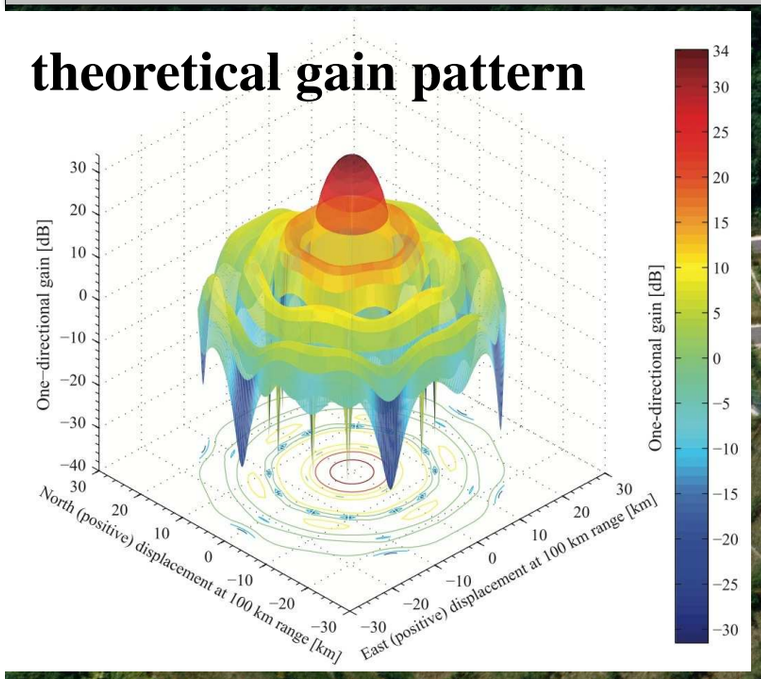


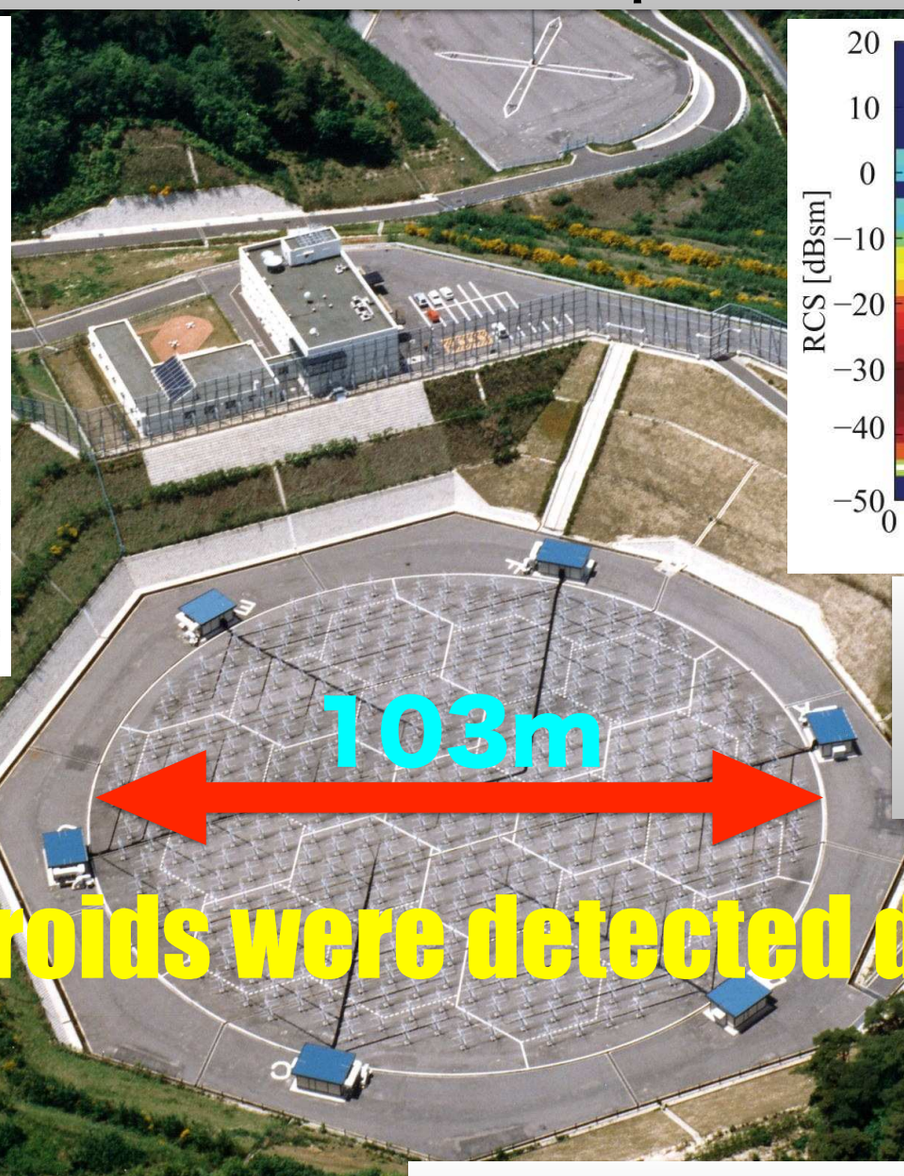
Kyoto University RISH MU Radar
Middle and **U**pper Atmosphere **Radar**

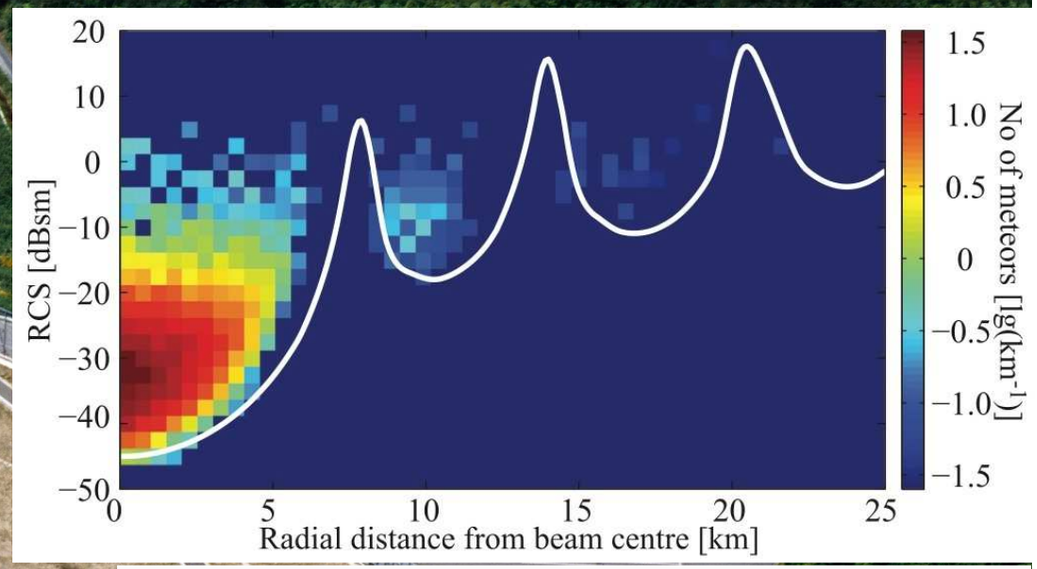
Monostatic coherent pulse Doppler radar

VHF (46.5 MHz), 1MW peak power, 475 crossed Yagi antennas

Pulse length: 1-500μs, Antenna aperture: 8330m² (D=103m)







Observed number of meteors, normalized by beam area, versus RCS (Radar Cross Section) and radial distance from beam centre.

>180k meteoroids were detected during 2009-2016

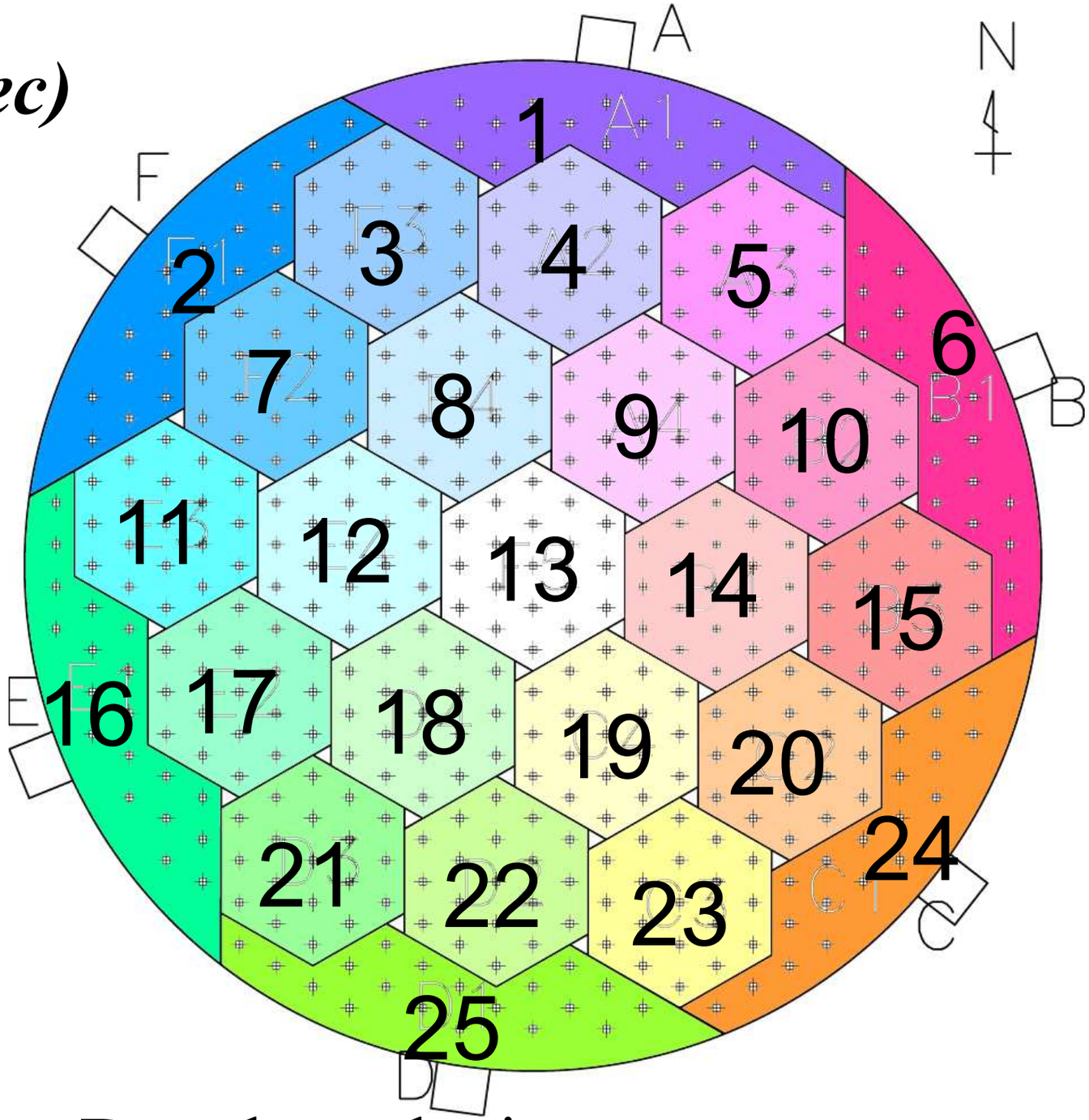
average velocity error = 0.25 km/s

average perihelion distance = 0.003 AU

3,000 - 4,000 meteor head echoes / day

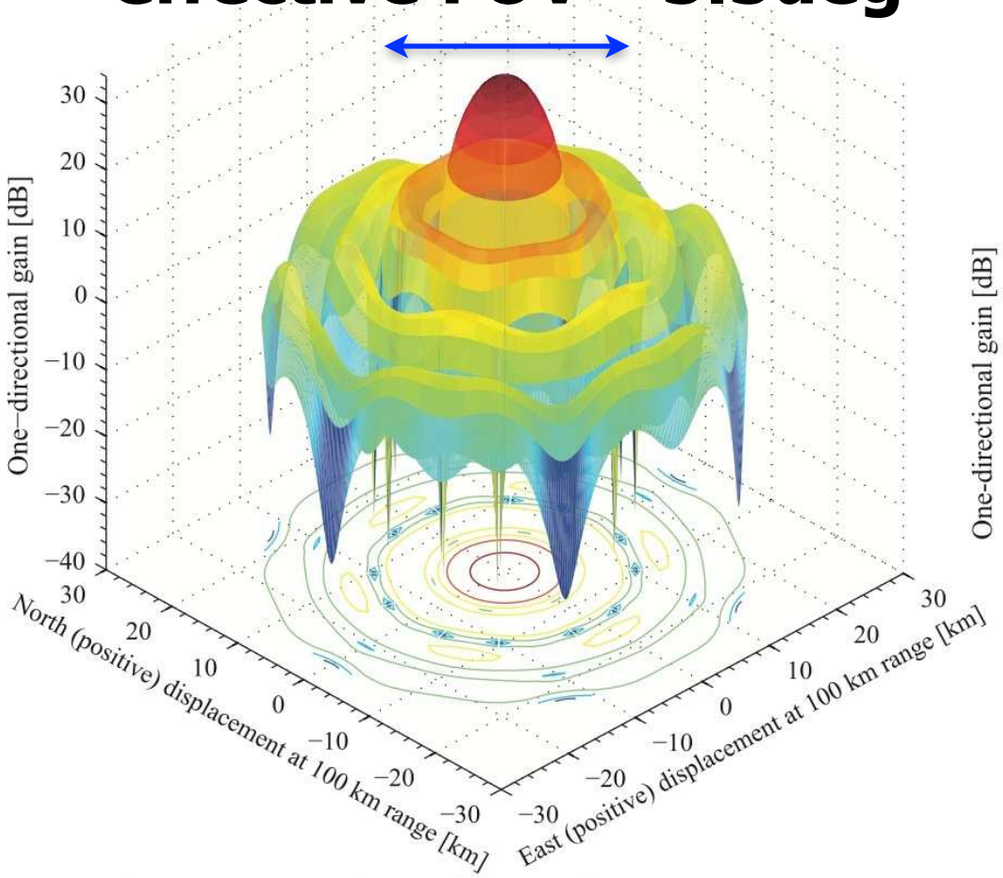
Kyoto University RISH MU Radar
Middle and **U**pper Atmosphere **Radar**

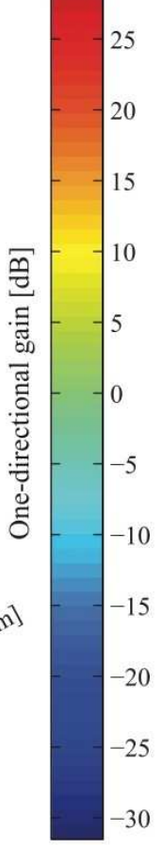
- ***Digital 25 channels***
- ***332 times per second (3 msec)***
- ***85 ranges every 3 msec***
- ***Data rate ~20 GB/hour***



Doppler velocity
19 Interferometers

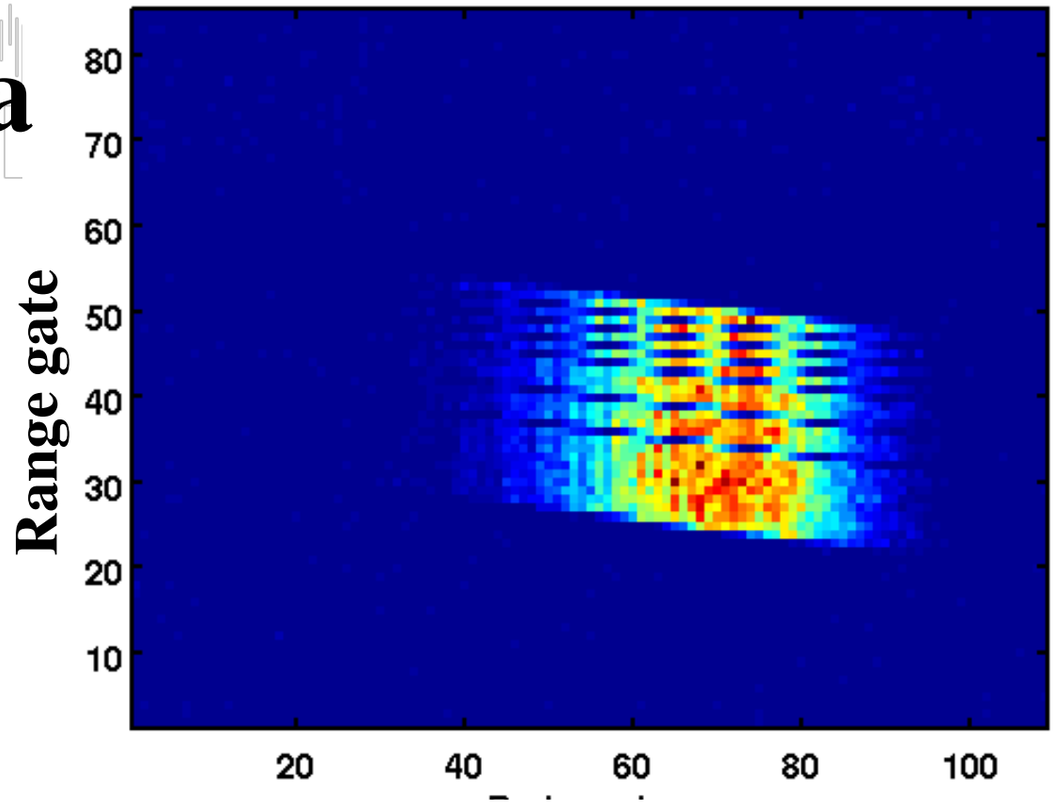
effective FOV ~5.5deg



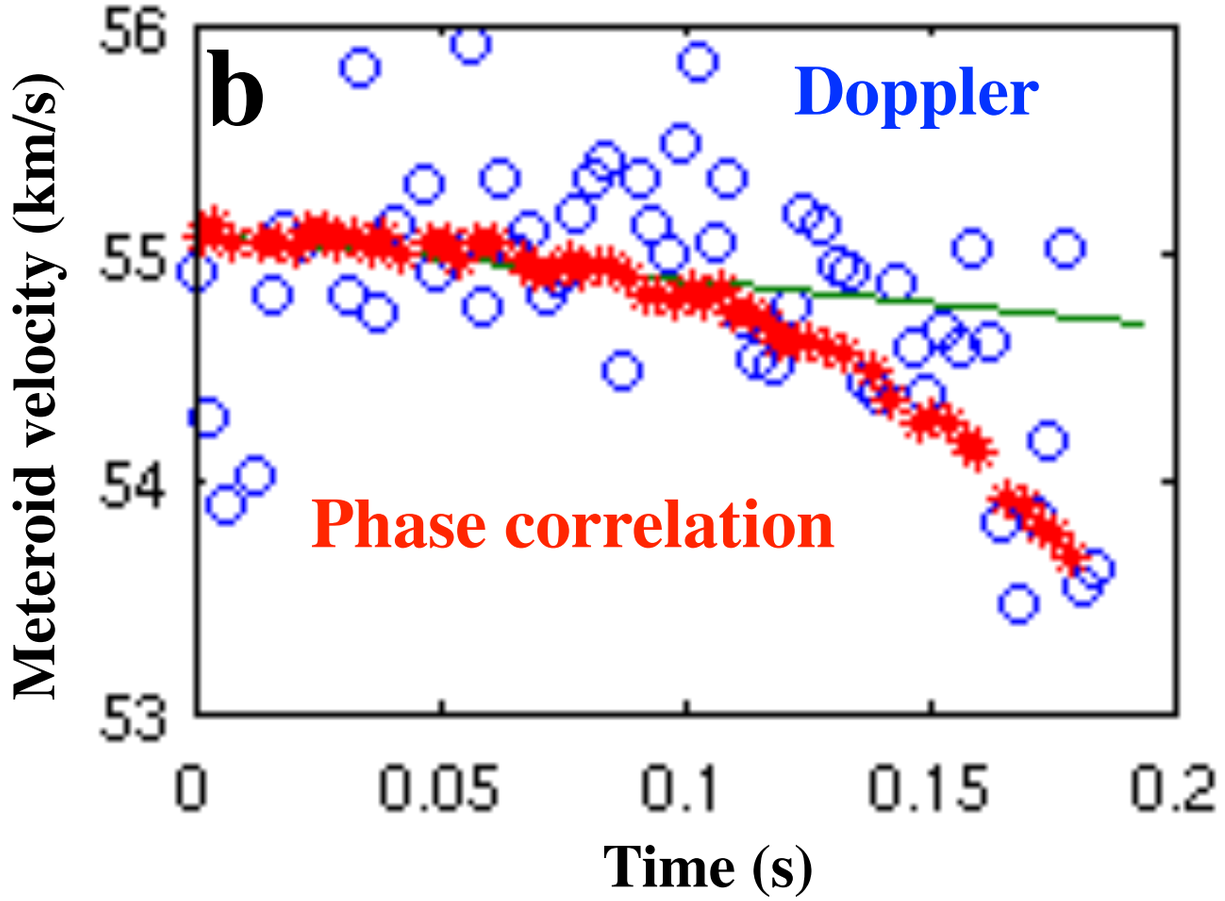


theoretical gain pattern

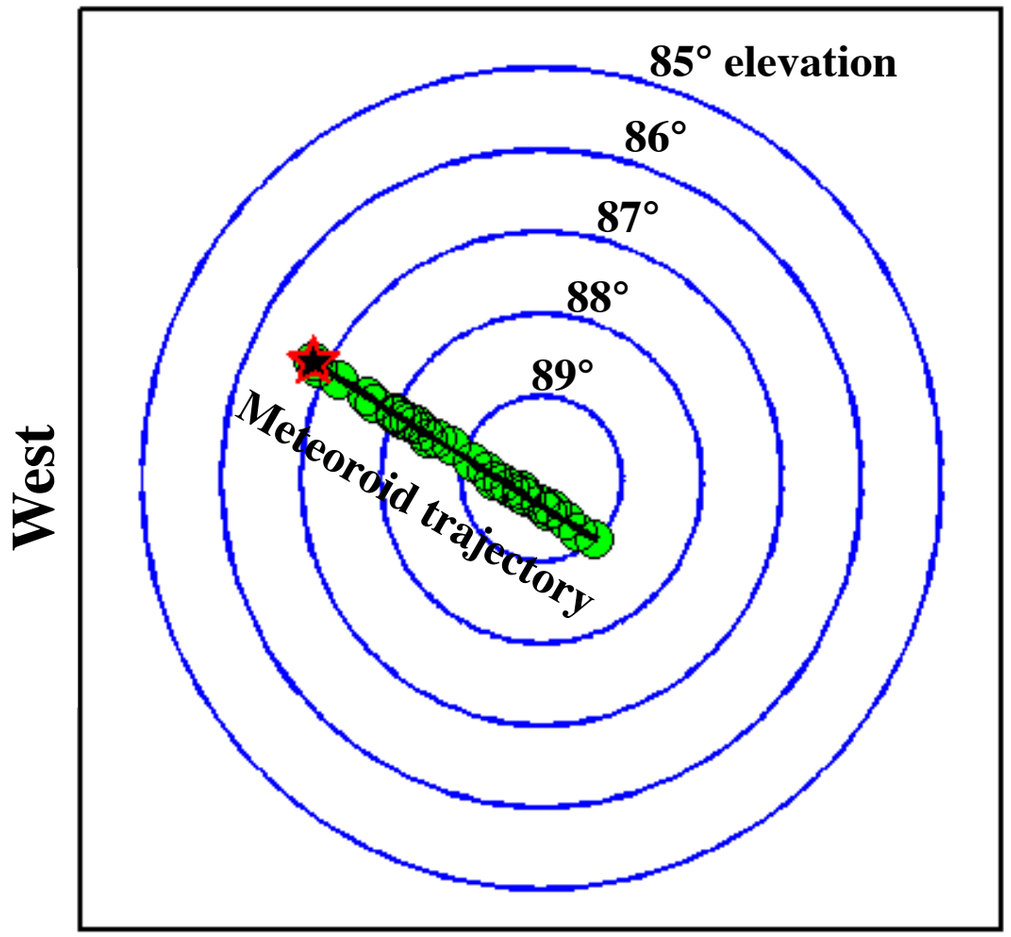
a


Range gate
80
70
60
50
40
30
20
10
20
40
60
80
100
Radar pulse

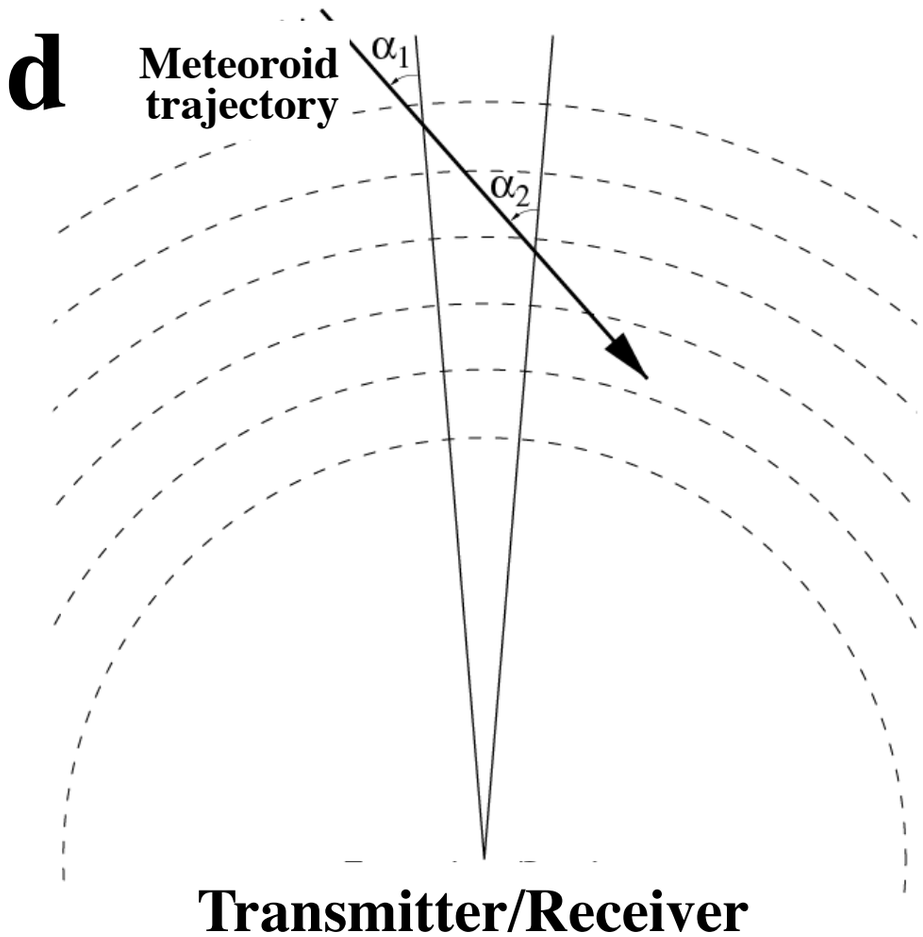
b


Doppler
Phase correlation
Meteroid velocity (km/s)
56
55
54
53
0
0.05
0.1
0.15
0.2
Time (s)

c


85° elevation
86°
87°
88°
89°
Meteoroid trajectory
West
South

d


Meteoroid trajectory
α1
α2
Transmitter/Receiver

North Toroidal

Antapex

Helion

Apex

Anti-Helion

90 60 30 0 150 120 90

-90 -60 -30 0 30 60 90

Ecliptic Latitude (deg)

10 20 30 40 50 60 70

Geocentric velocity (km/s)

Kero+ (2010)
Abe, Kero, Nakamura+, in prep

Ecliptic Longitude from Earth apex (deg)

Comparison of Orbits between MU Radar and Optical Observations

Object	$Date$	a	e	i	ω	Ω	D_{sh}
	UT	au	—	°	°	°	—
Phaethon	-	1.27	0.89	22.2	322.1	265.2	-
1-radar	Dec/14	1.27	0.89	23.6	325.1	262.6	
1-opt	15:29	1.22	0.88	23.5	325.1	262.6	0.013
2-radar	Dec/13	1.20	0.89	24.1	325.8	261.7	
2-opt	18:49	1.39	0.91	23.2	325.8	261.7	0.030
3-radar	Dec/13	1.21	0.89	22.5	324.5	261.6	
3-opt	16:14	1.26	0.88	22.7	324.5	261.6	0.037
Geminids	2010	1.30	0.899	25.0	326.1	262.3	-

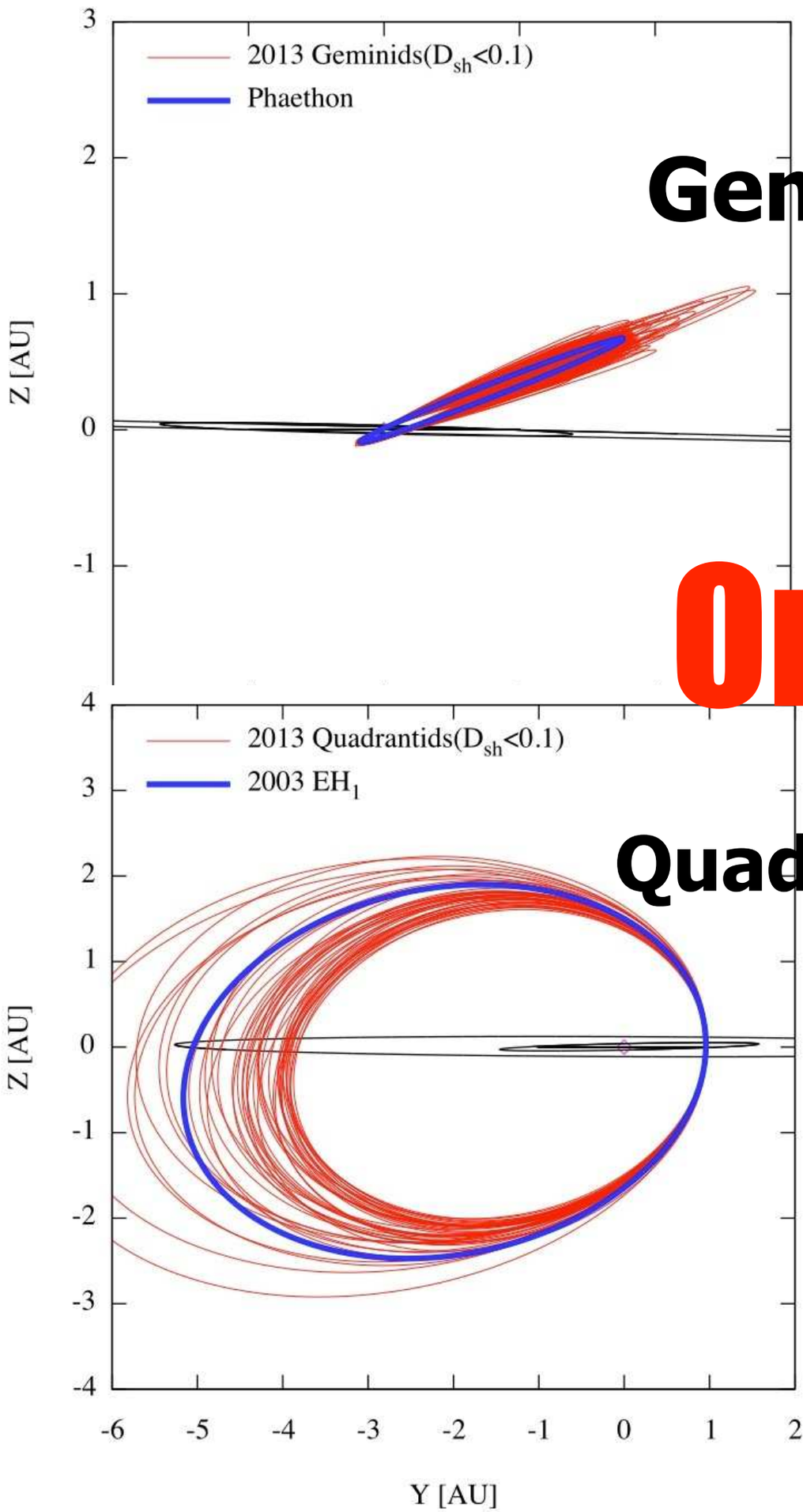
Orbital determination by Meteor Head-echo and optical observation is comparable.

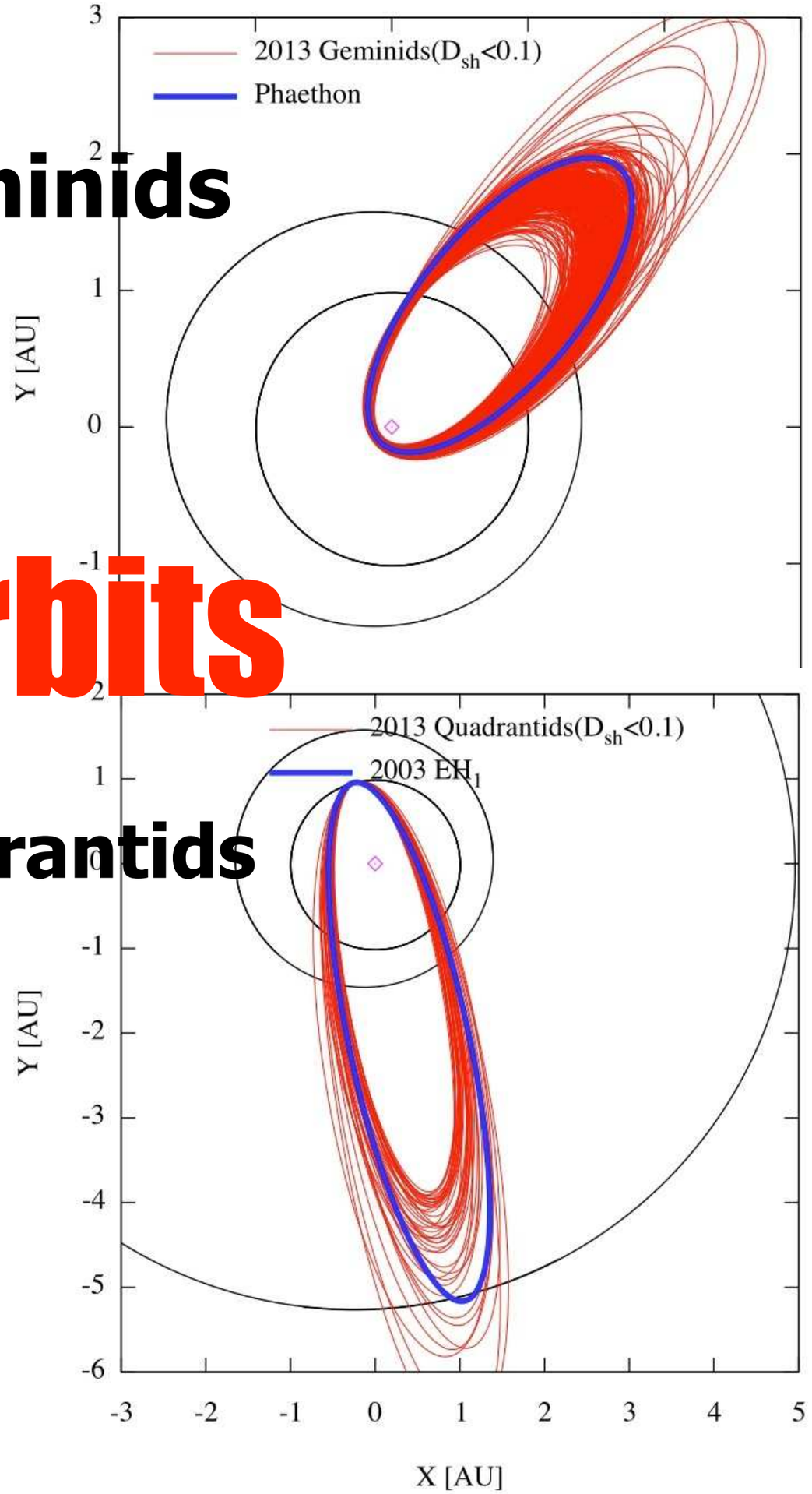
Abe et al. Proc. ISTS (2015)

Geminids

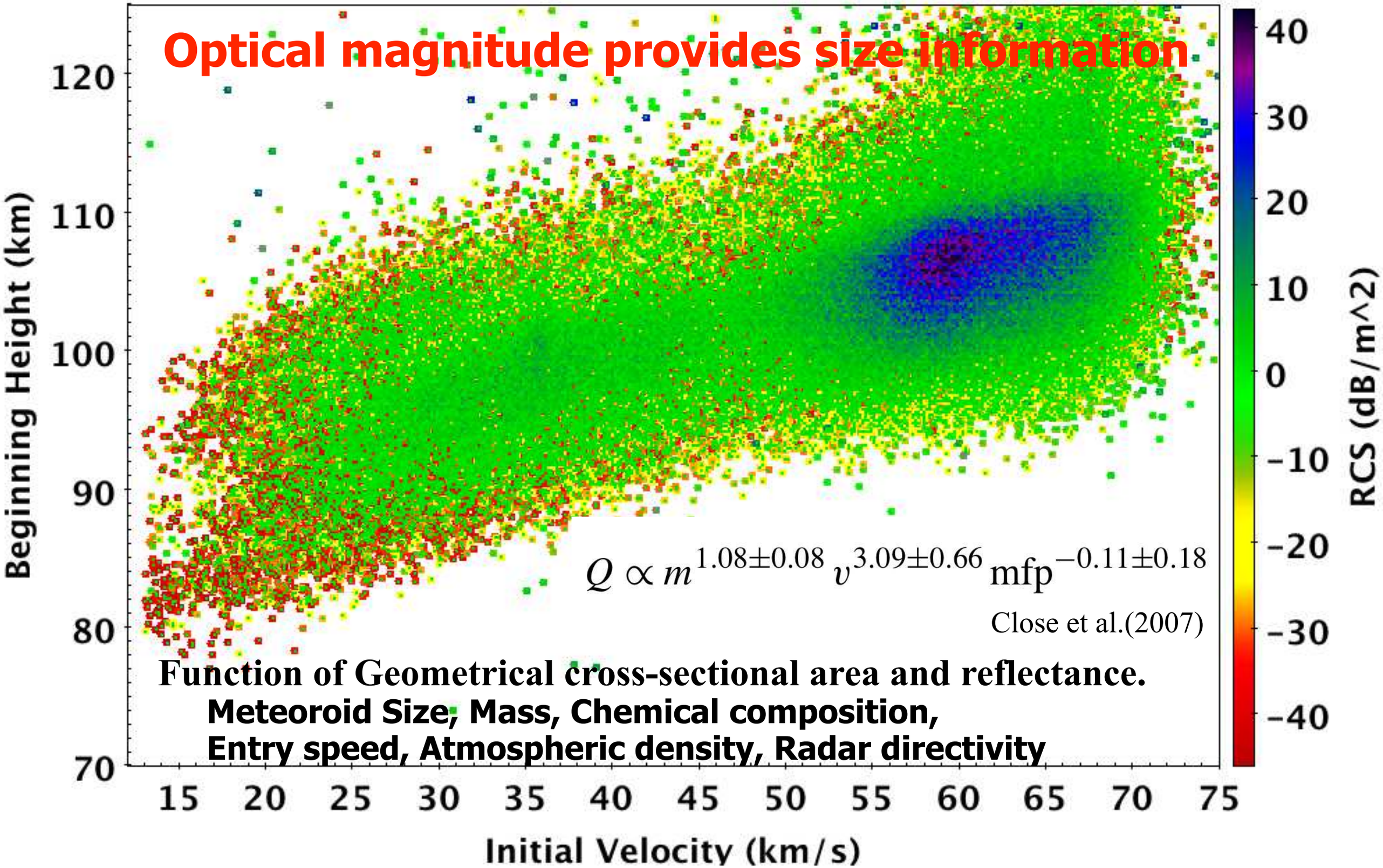
Orbits

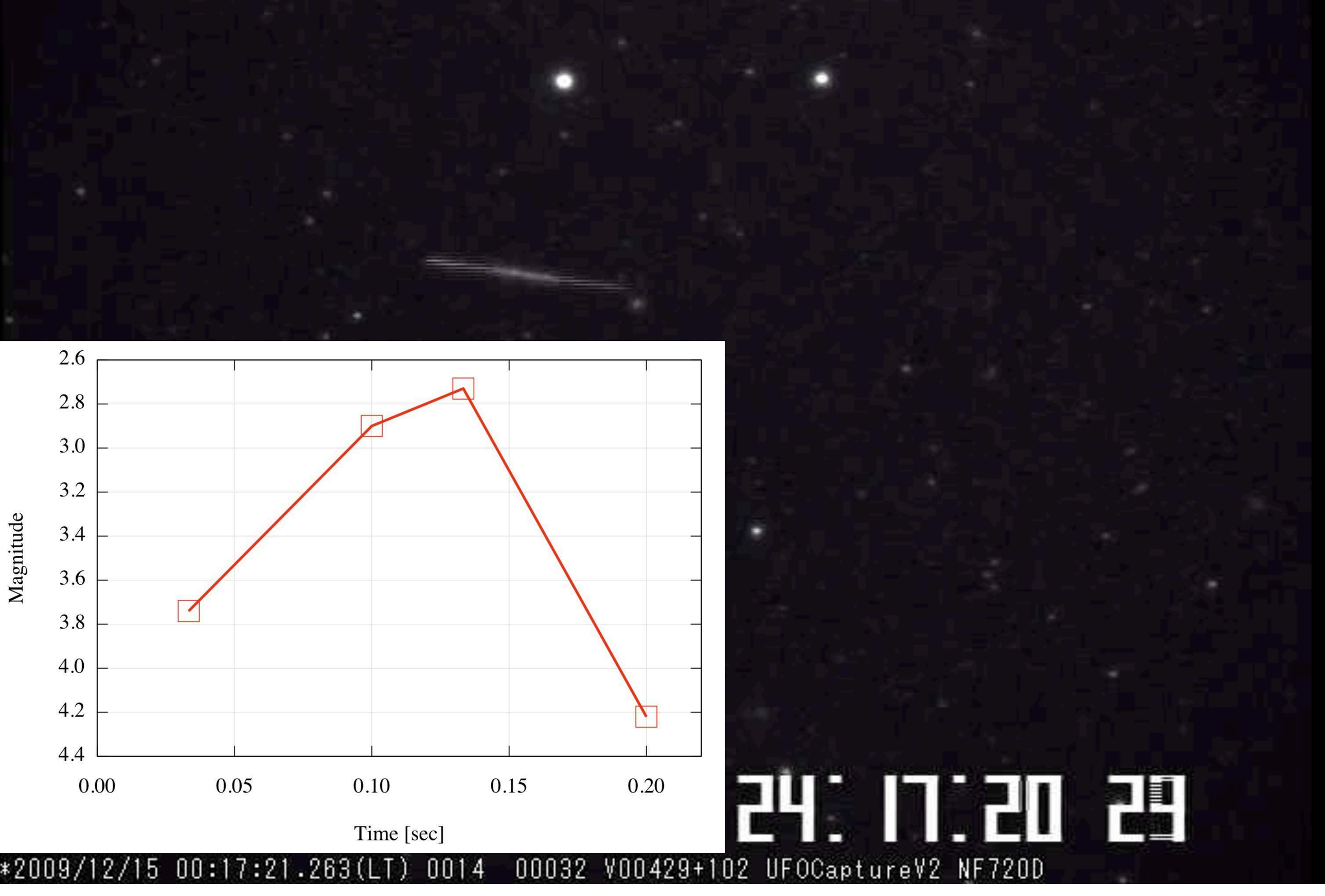
Quadrantids





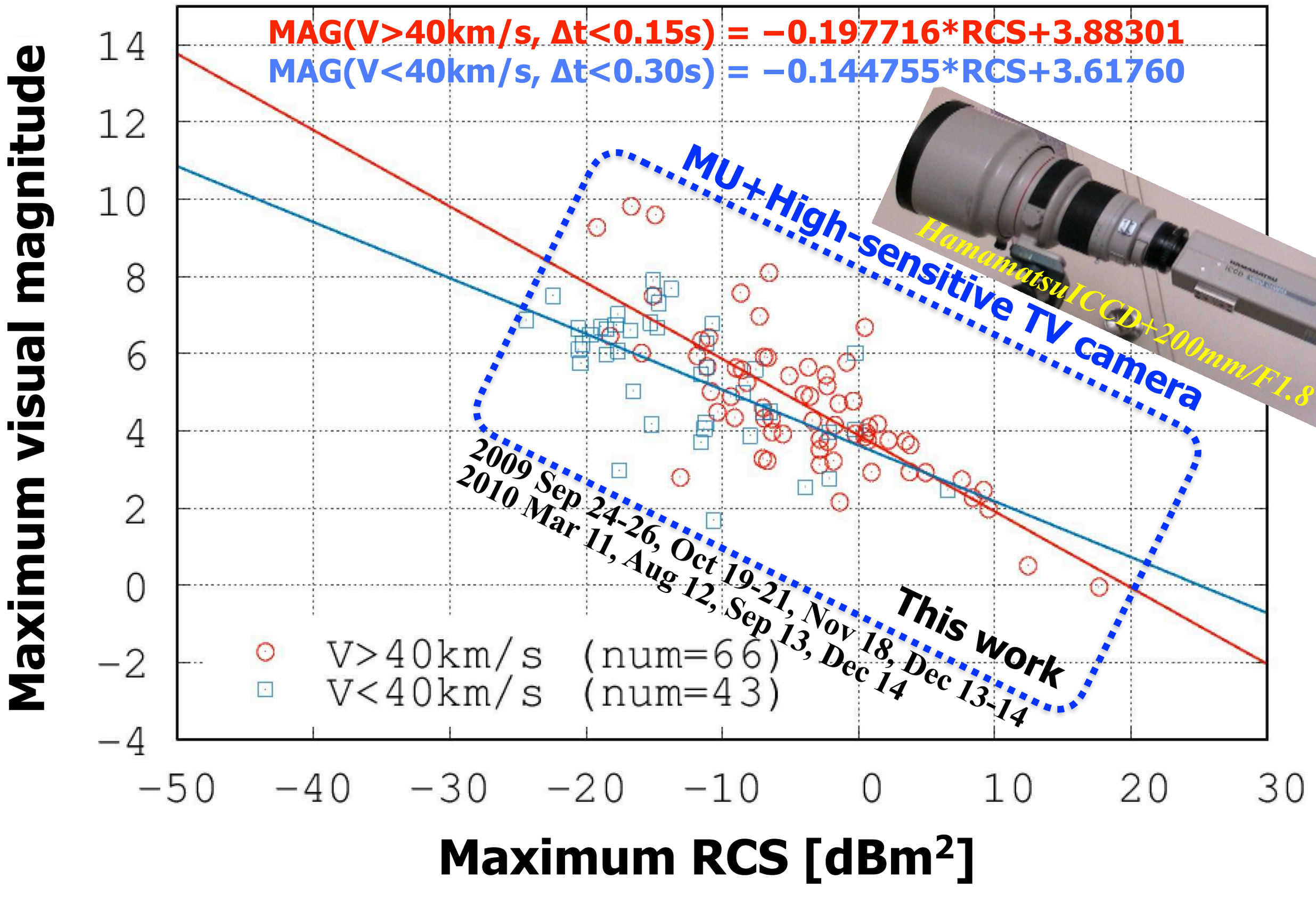
RCS (Radar Cross Section) controversy





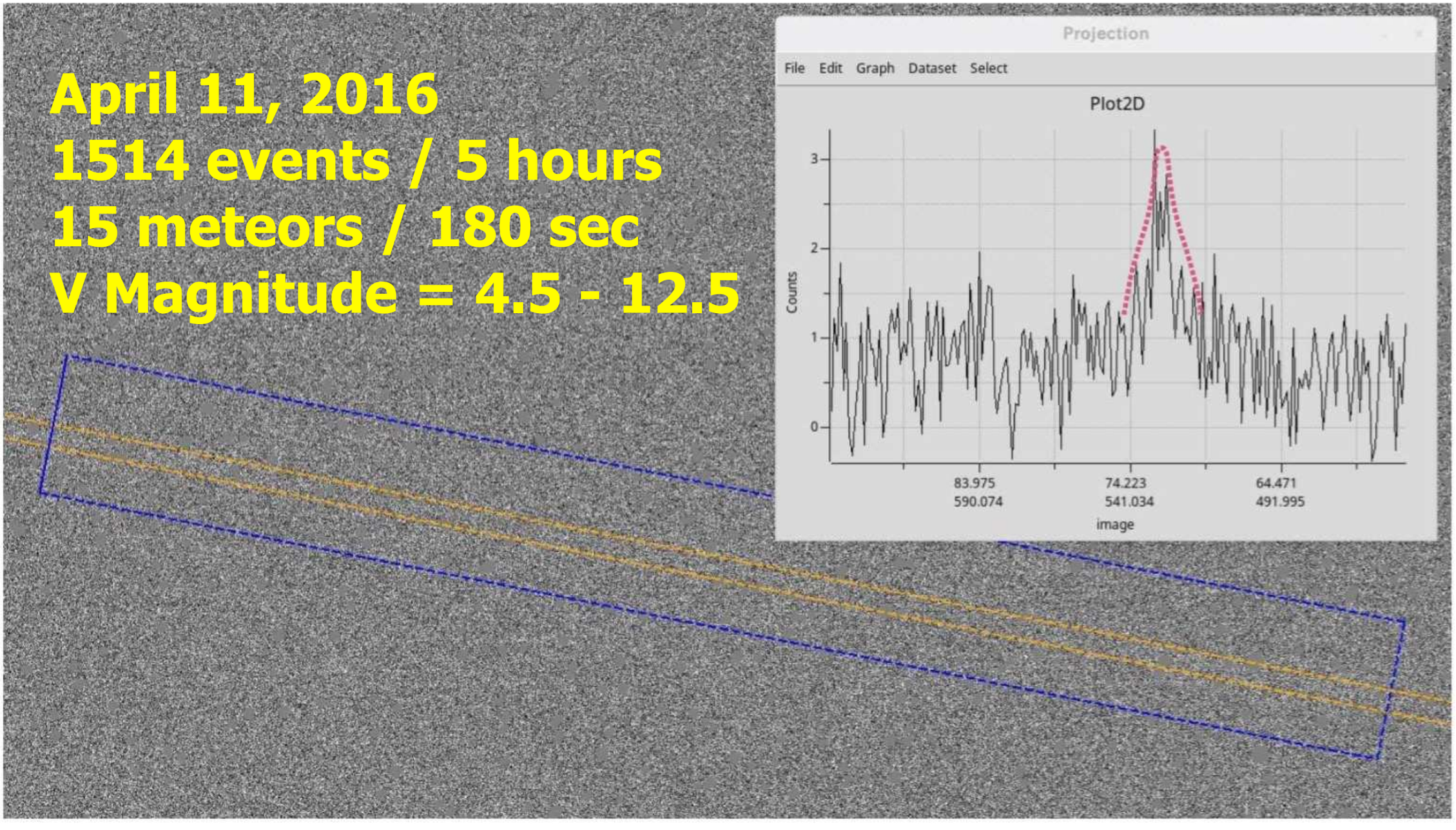
Simultaneous observation with MU Head-echo and TV

Visual magnitude as functions of RCS



Faint Meteors Imaging ~13th magnitude

An Image containing a faint meteor (stellar sources are masked)



Detected Faint Meteors by Hough transform algorithm

Osawa, Sako, et al. (Univ. Tokyo)

Visual magnitude as functions of RCS

MAG(V>40km/s, Δt<0.15s) = −0.197716*RCS+3.88301

MAG(V<40km/s, Δt<0.30s) = −0.144755*RCS+3.61760

MU+Tomo-e GOZEN

Future work

MU+High-sensitive TV camera

2009 Sep 24-26, Oct 19-21, Nov 18, Dec 13-14
2010 Mar 11, Aug 12, Sep 13, Dec 14

This work

V>40km/s (num=66)
V<40km/s (num=43)

Maximum visual magnitude

Maximum RCS [dBm²]

14 12 10 8 6 4 2 0 −2 −4

−50 −40 −30 −20 −10 0 10 20 30

V>40km/s (number~13K)
V≦40km/s (number~2.7K)
Geminids (number = 1023)
Cumulative Number
1e5
1e4
1000
100
10
1
-5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Magnitude

V>40km/s (number~13K)

V≦40km/s (number~2.7K)

Individual observations by Radar and Optical methods

Tomo-e GOZEN

April 11, 2016
1514 events / 5 hours
15 meteors / 180 sec
V magnitude = 4.5 - 12.5

2016-04-11
2016-04-14

Cumulative Number

1e5
1e4
1000
100
10
1

10^3
10^2
10^1
10^0

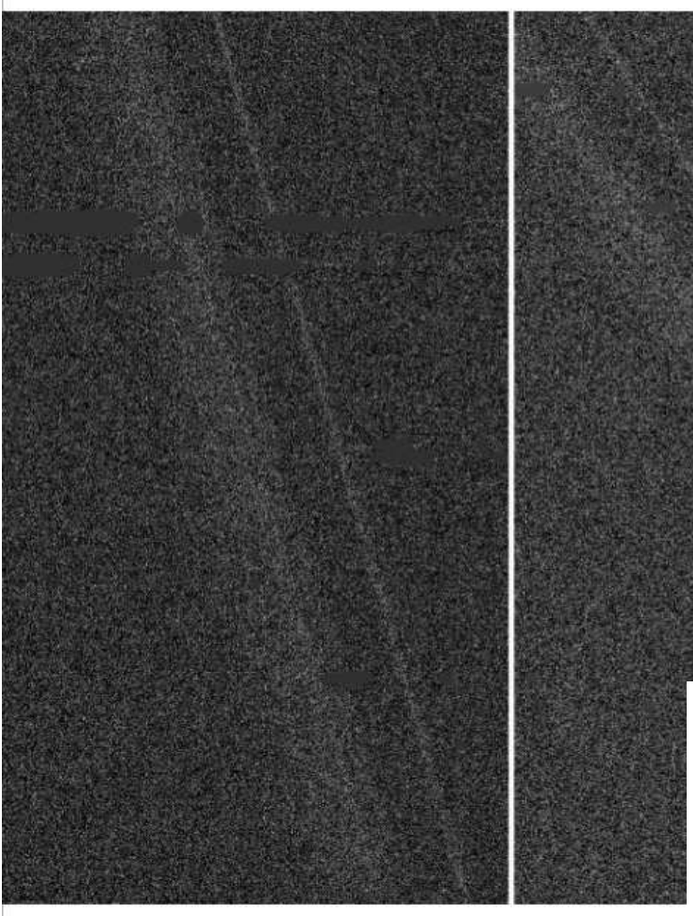
-5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

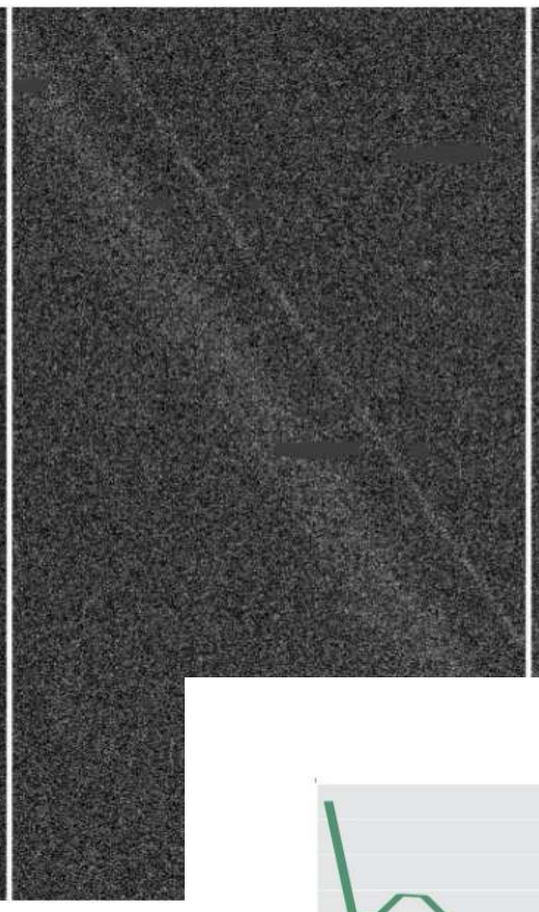
4 6 8 10 12

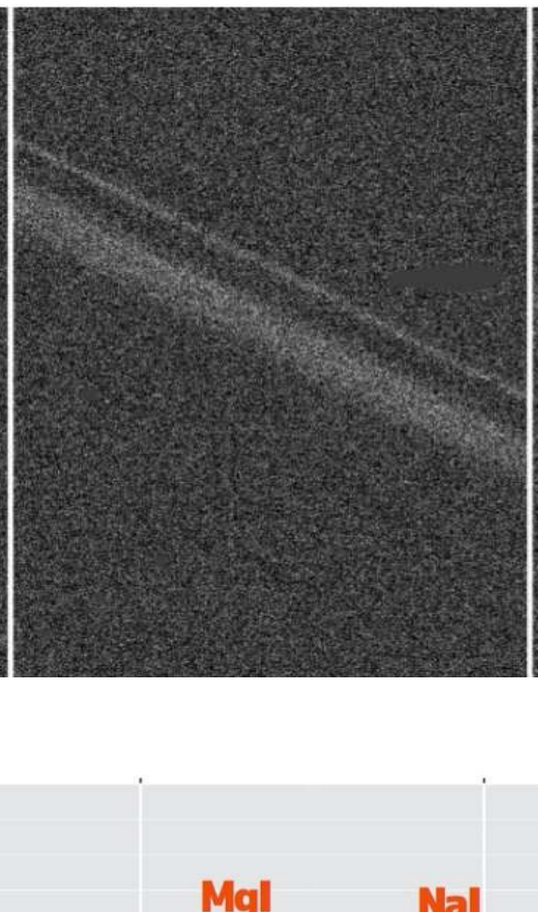
Magnitude

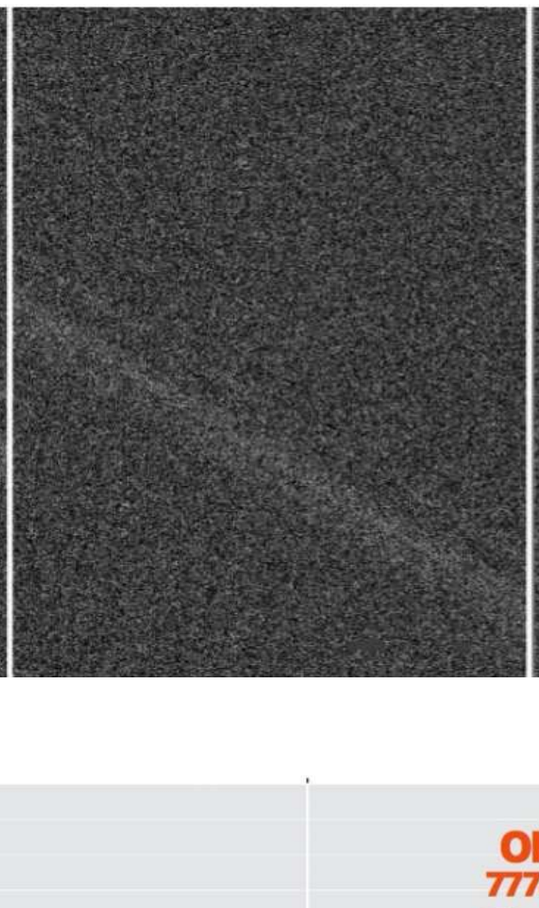
Faint Meteors Spectroscopy

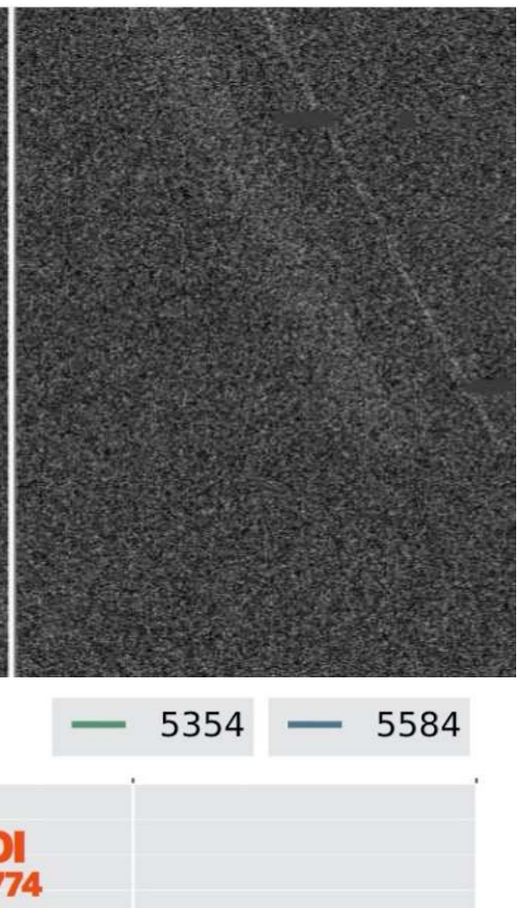
~8-9th magnitude with R=10

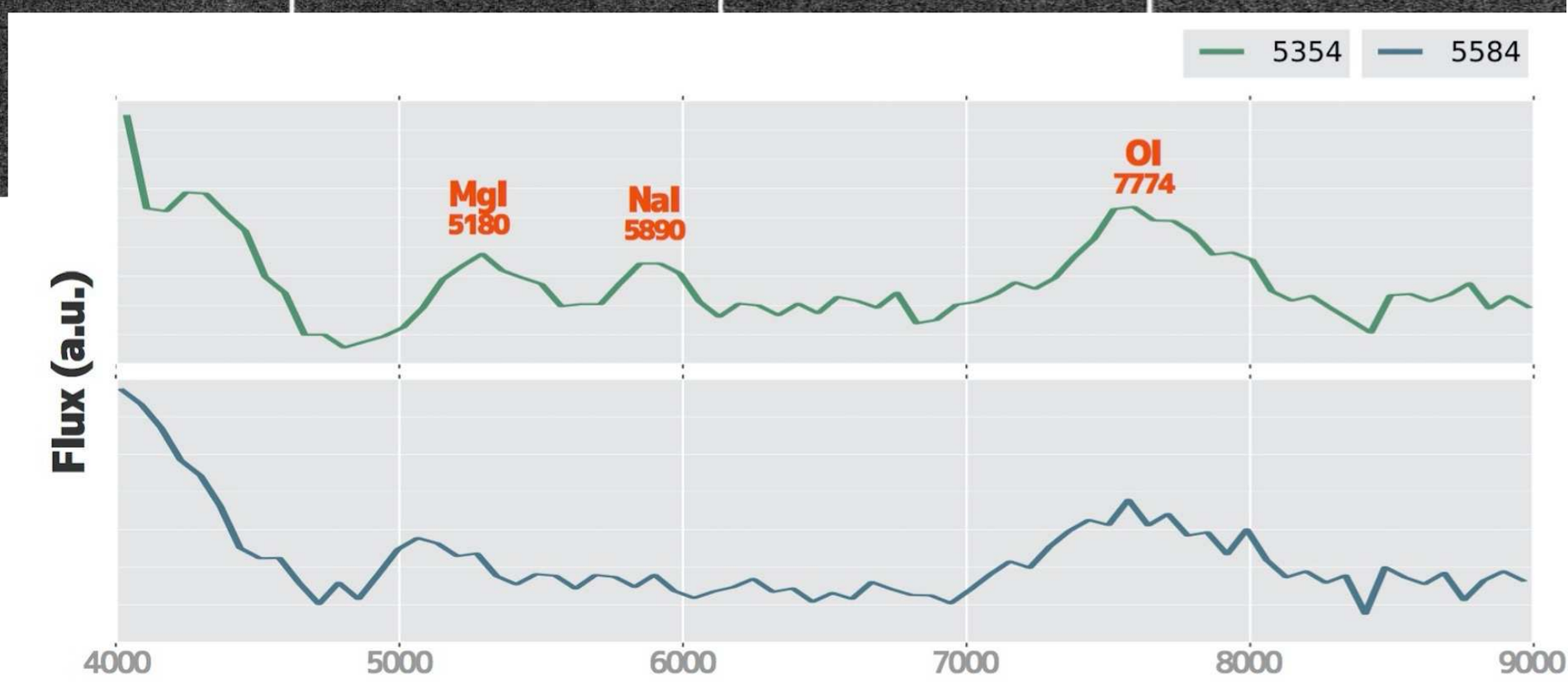












Osawa, Sako, et al. (Univ. Tokyo)

~1000 orbits and size distribution per night (5hrs)
~100 spectroscopy with orbit per night (5hrs)

Future Plan

Meteoroid

Meteor head
Dense plasma

12-72km/s
Meteoroid's motion

meteor wake

Limiting magnitude for stars
~19mag. (2Hz at V-band)

332Hz
D=103m
FOV~Φ4deg
46.5MHz, 1MW

faint meteors ~13th mag.

2Hz
D=1.05m
FOV~Φ9deg
400-700nm

Height; 70-130km

19 Interferometers

Distance~173km

MU Radar

Schmidt telescope

木曽観測所と京都大学MUレーダの位置関係

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