Overview of Meteor Science Research at the University of Western Ontario

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Research Focus

- Western Meteor group focusses on answering basic questions about the ***origin and evolution*** of small bodies in the solar system.
- Research program heavily obsevrational, with some theory (orbital dynamics, entry modelling, atmospheric propagation of meteor shocks)
- These include:

1. Origin of meteoroids (comets/ asteroids /interstellar and what proportion of each?)
2. Origin of meteorites (asteroid belt mostly, but where specifically?)
3. Physical structure of meteoroids (bulk density/dustballs – what does this say about their origin?)
4. Flux and interaction of larger meteoroids at Earth (meteorites, breakup in the atmosphere). Like low-cost sample-return missions.

Meteor Physics Group at UWO

FACULTY:
Dr. Peter Brown, Dr. Margaret Campbell-Brown, Dr. Paul Wiegert

ADJUNCT FACULTY:
Dr. Robert Hawkes, Dr. Douglas ReVelle

EMERITUS FACULTY:
Dr. Jim Jones, Dr. Alan Webster

DOCTORAL STUDENTS:
Wayne Edwards - Fireball airwave analysis, infrasound, seismo-acoustic coupling
Robert Weryk - Radar –Optical analysis, interstellar meteoroids
Jean-Baptiste Kikwaya - Optical observations and entry modelling; meteoroid density measurements
Alyssa Moldowan – Comet – asteroid transition objects

MASTERS STUDENTS:
Andrea Domokos – Asteroid spectral properties
David Braid – Sporadic flux measurements using electro-optical cameras
Elizabeth Sukara – Modelling meteor cylindrical line source blasts – comparison to observations

Zbigniew Krzeminski - Technical Staff

Observational Techniques

- Radar Observations
  - Sporadic/shower activity – flux, mass distribution, orbits
  - Multi-frequency characterization of biases (initial radius)
  - Observations of fireballs (head echoes and body echoes)
- All-Sky Cameras
  - Sporadic/shower activity – flux, mass distribution, orbits
  - Fireball detection/measurements
- Infrasound Observations
  - Global measurements of airwaves from large fireballs
  - Local observations of smaller events
  - Characterize energy/shock behaviour of individual large events (meteorite producers)
  - Use close range observations to refine weak shock theory
- US DoD/DoE Space-based sensors
  - Trajectory, orbits and energies for very large fireballs
  - Provides context for meteorite falls (St. Robert, Tagish Lake, Park Forest)

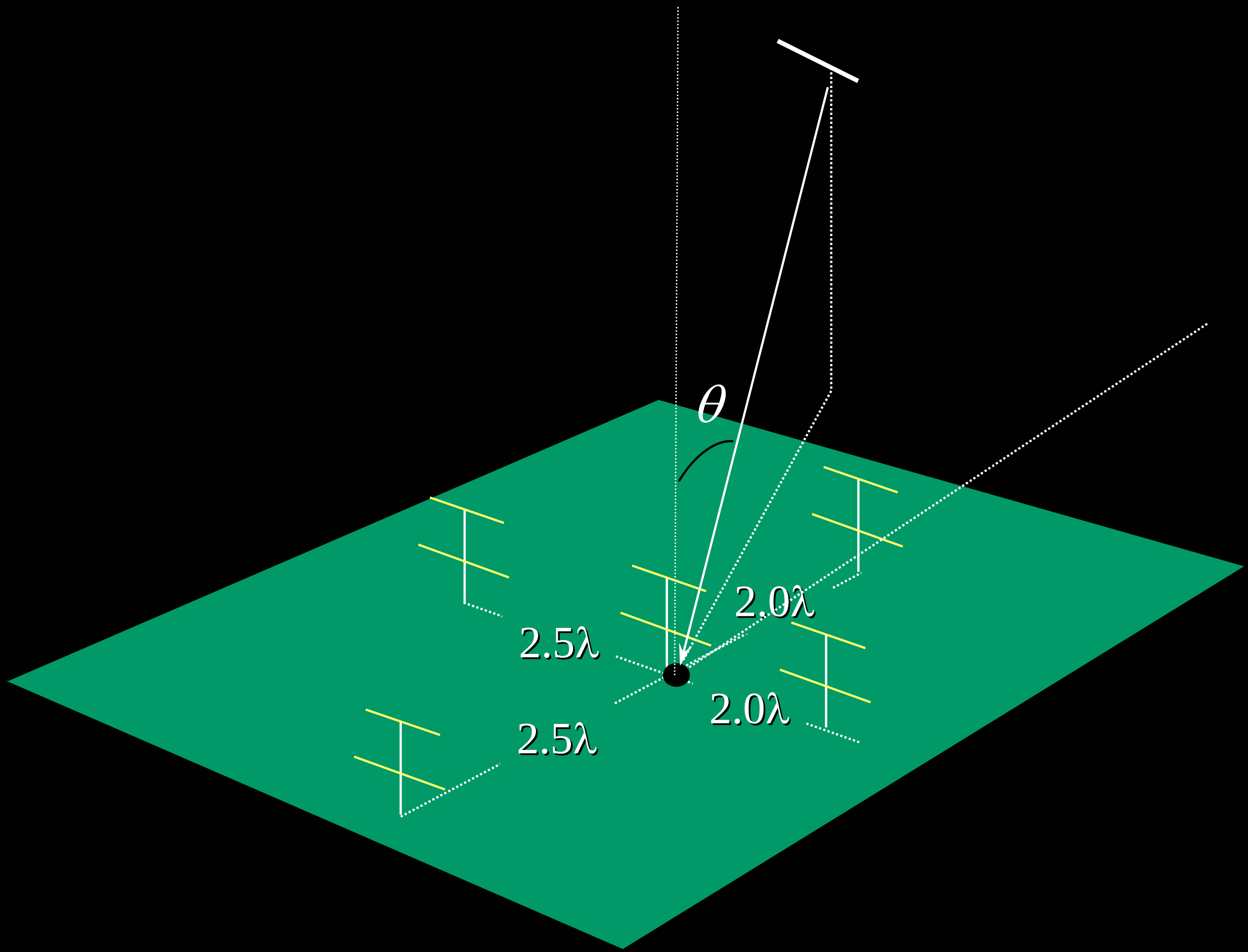
Radar – The Canadian Meteor Orbit Radar (CMOR)

Three frequency radar operating at 17.45 MHz, 29.85 MHz and 38.15 MHz

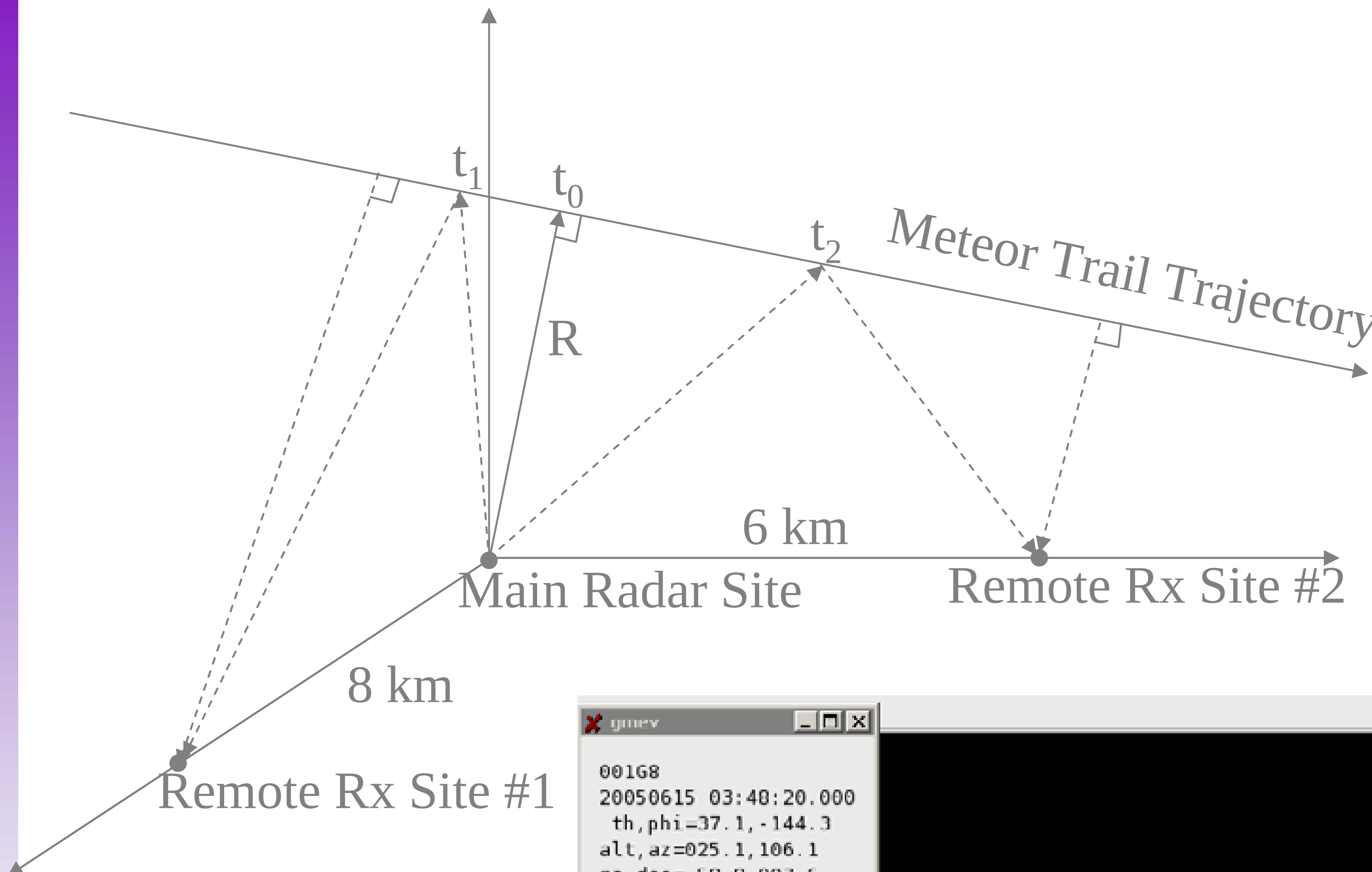
- Fully automated data collection and analysis
- All three systems collect single station meteor echo data
- The 29.85 MHz system also has two outlying stations which permits orbits for individual meteoroids to be measured
  - 4.1 million unique orbits measured to date

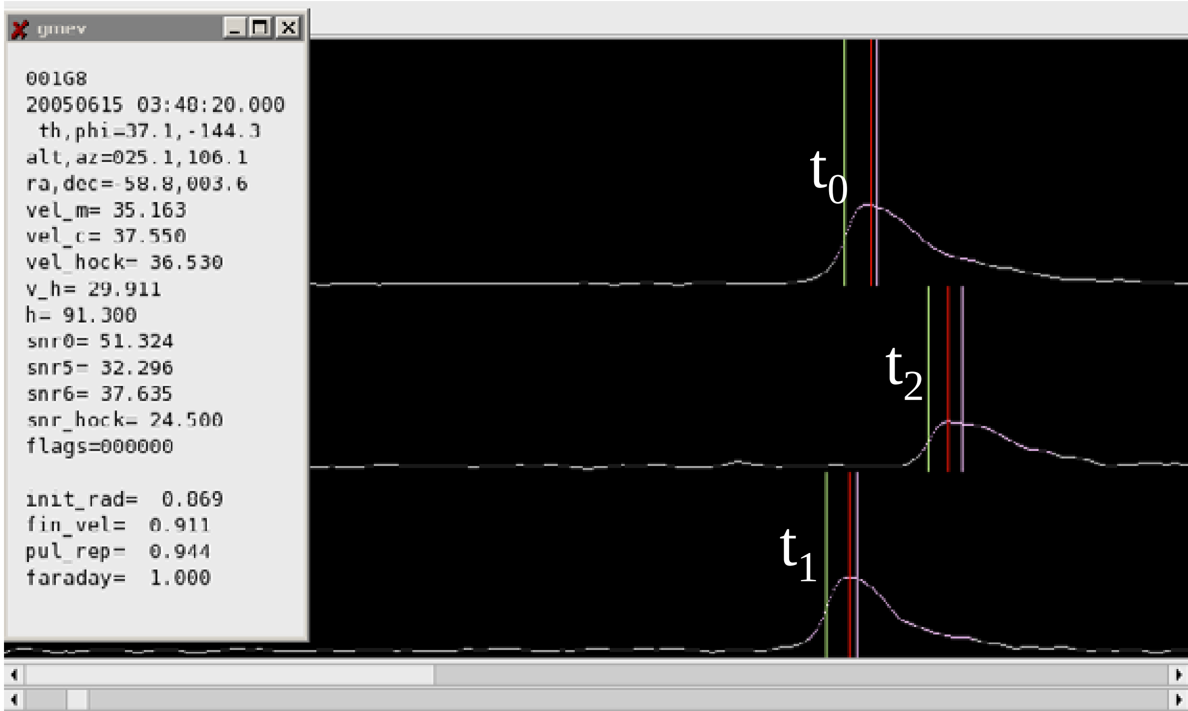
Frequencies ……………….17.45, 29.85 & 38.15 MHz
Peak power ………………. 6kW
P.R.F. ……………………... 532pps
Sampling rate ……………..... 50ksps
Range increment …………3kms
Bandwidth ……………….. 28kHz
Pulse length ………………. 75μs
Remote link Freq.…………450 MHz

Magnitude limit ……………+8
Minimal Detectable Mass….10^{-5} g
(velocity dependent)
Minimal Detectable
Meteoroid Size……………..0.1 mm
Height range ………………. 70-120 km
Range interval………..……..70-250 km
Effective Instantaneous Atmospheric
Collecting Area……………..~100 - 300 km^2

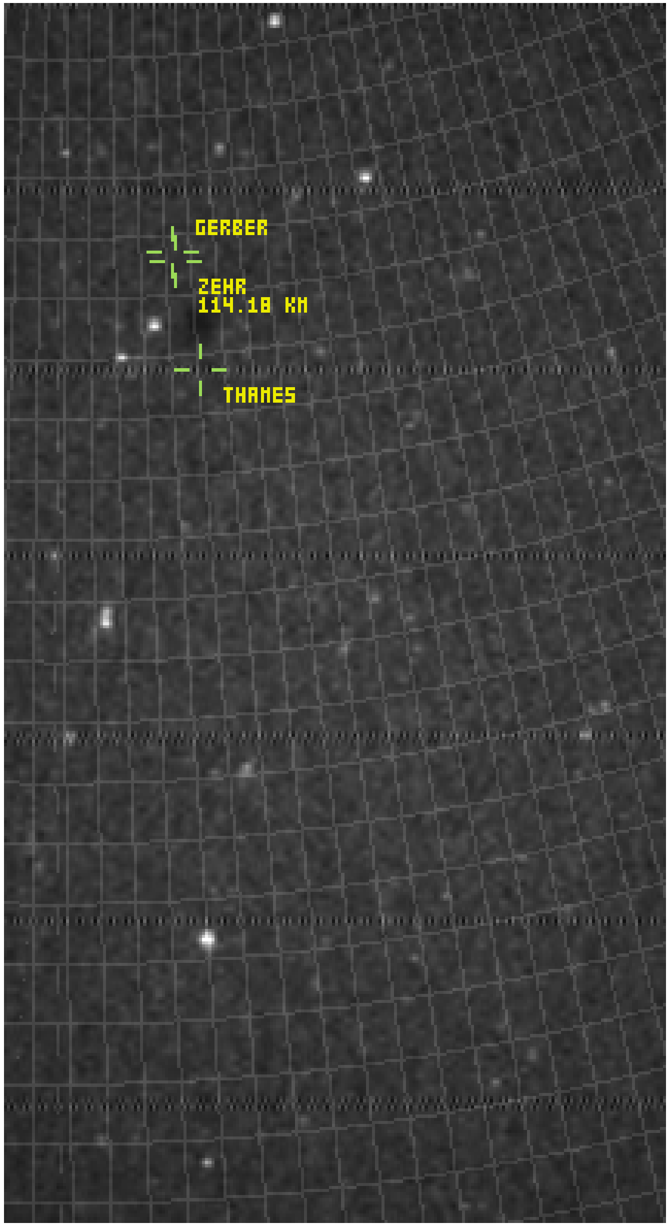


Main Site Receiving Antenna Layout

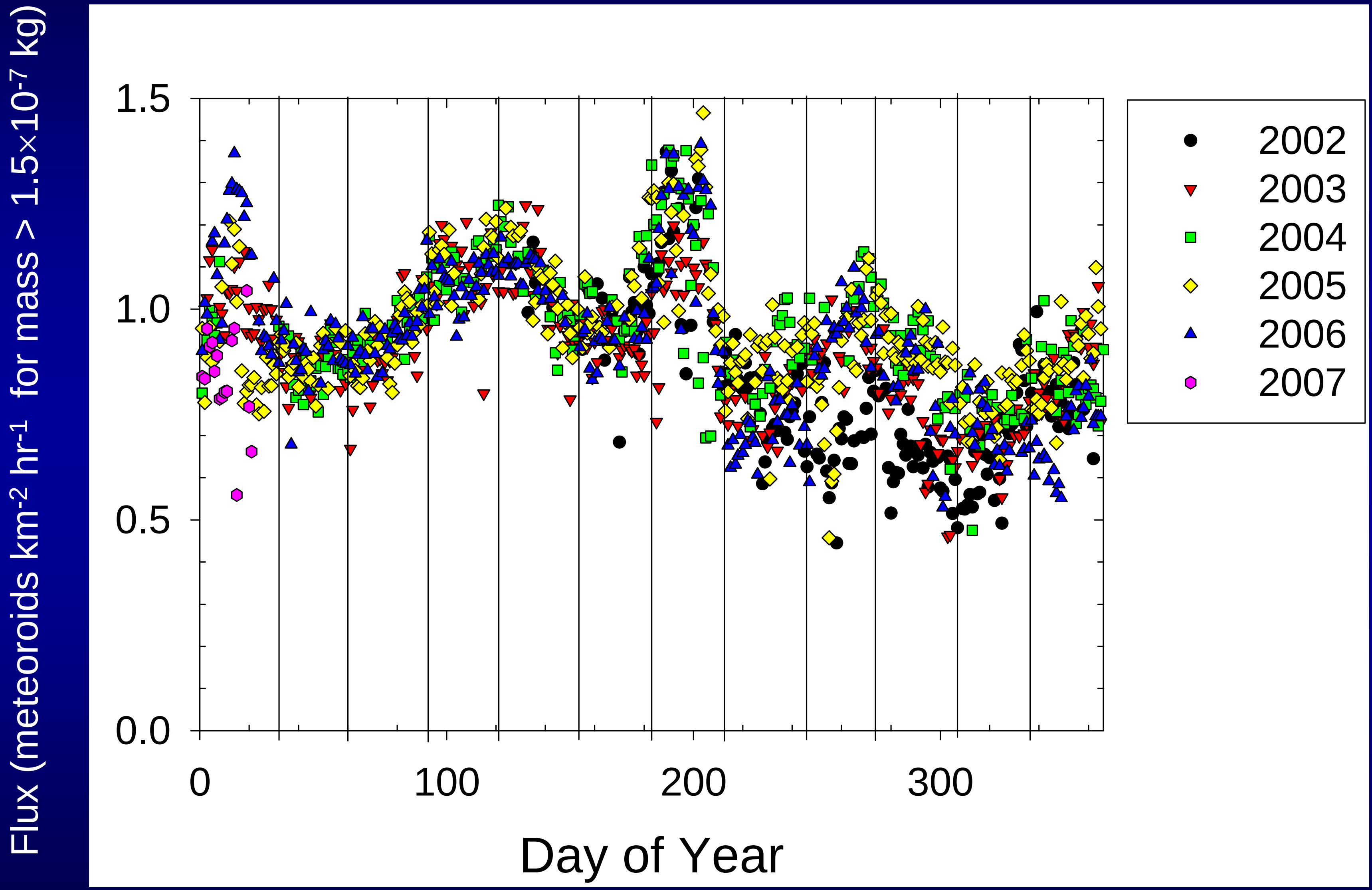

Meteor Trail Trajectory
t_1
t_0
t_2
R
6 km
8 km
Main Radar Site
Remote Rx Site #2
Remote Rx Site #1


00168
20050615 03:40:20.000
th,phi=37.1,-144.3
alt,az=025.1,106.1
ra,dec=-58.8,003.6
vel_m= 35.163
vel_c= 37.550
vel_hock= 36.530
v_h= 29.911
h= 91.300
snr0= 51.324
snr5= 32.296
snr6= 37.635
snr_hock= 24.500
flags=000000
init_rad= 0.869
fin_vel= 0.911
pul_rep= 0.944
faraday= 1.000
t_0
t_2
t_1

- Calibration of radar through two station EO observations
- Time synchronization and spatial calibration allow redundant checks on radar measured quantities:
  - Range accuracy (~300 m)
  - Interferometry (<0.2 degs)
  - Velocity (~5-10% error depending on geometry)
  - Radiant direction (1-2 degrees typical measurement error)
- Ultimately relate EO mass scale to radar scale



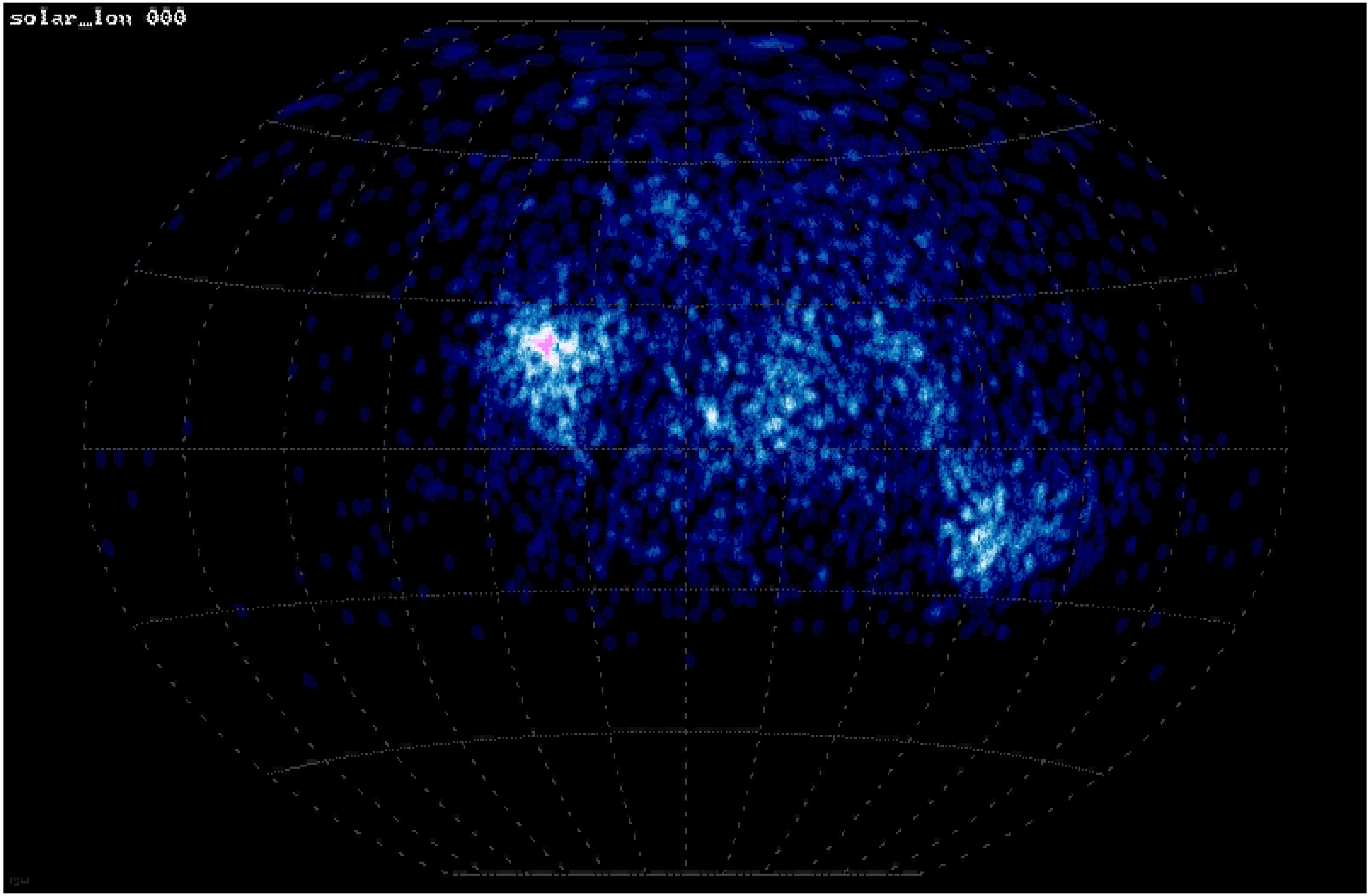
Sporadic meteor activity



Sporadic meteor activity measured by CMOR

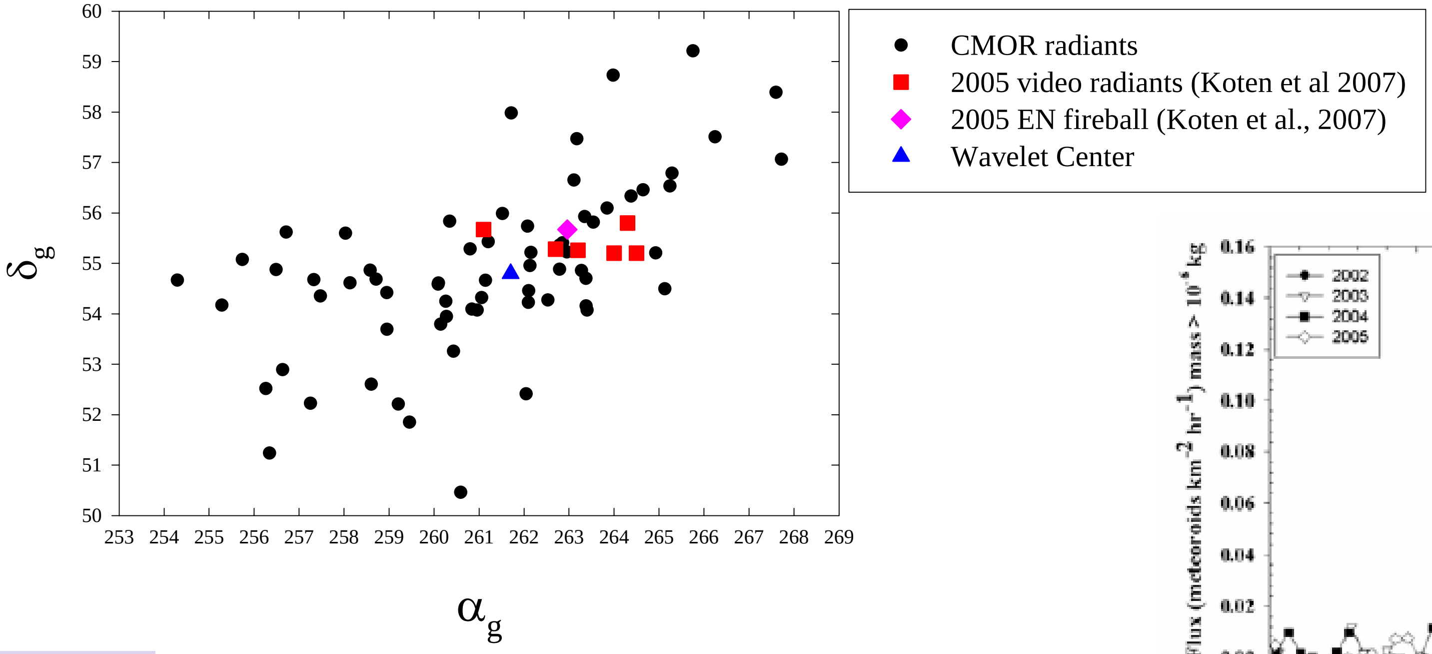
Movie of individual radiants

Declination

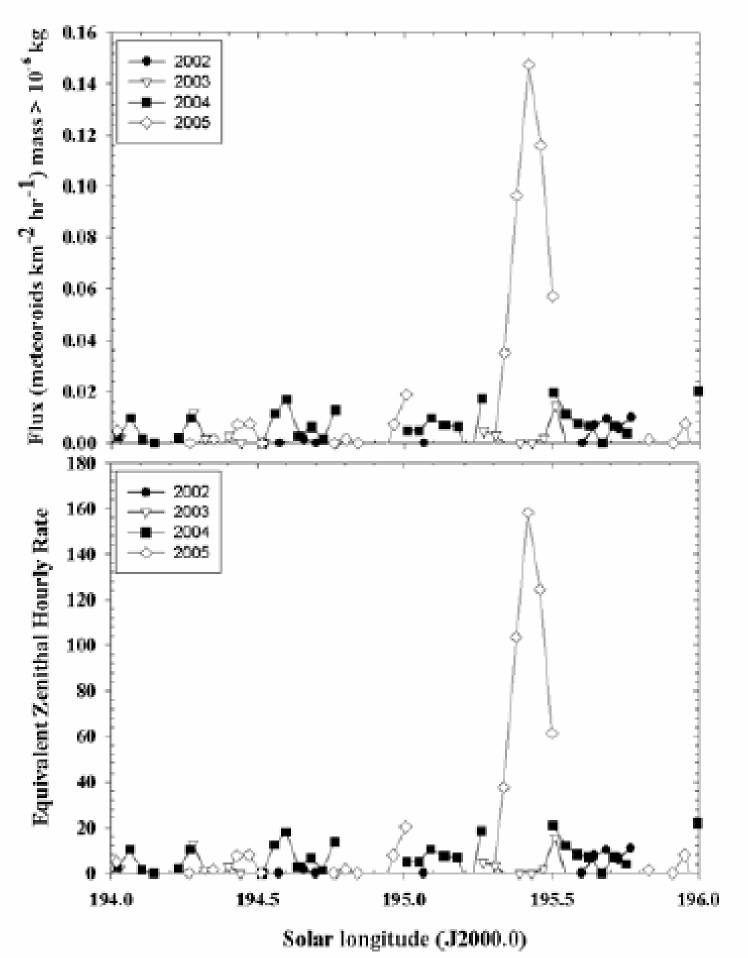


Right Ascension

2005 Draconid Outburst

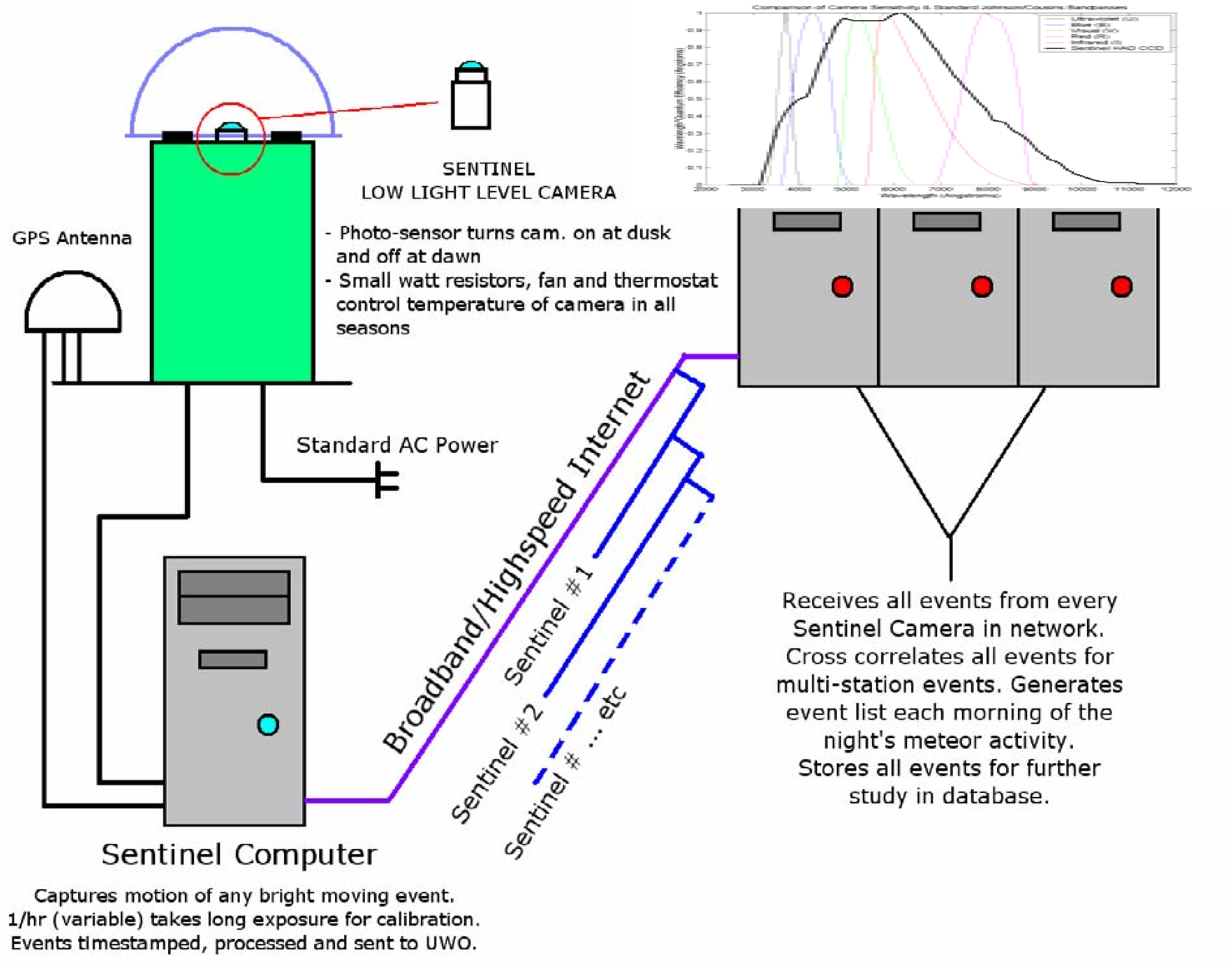


Total of 67 Draconid Orbits measured during outburst
from 11 UT – 18:30 UT, Oct 8, 2005

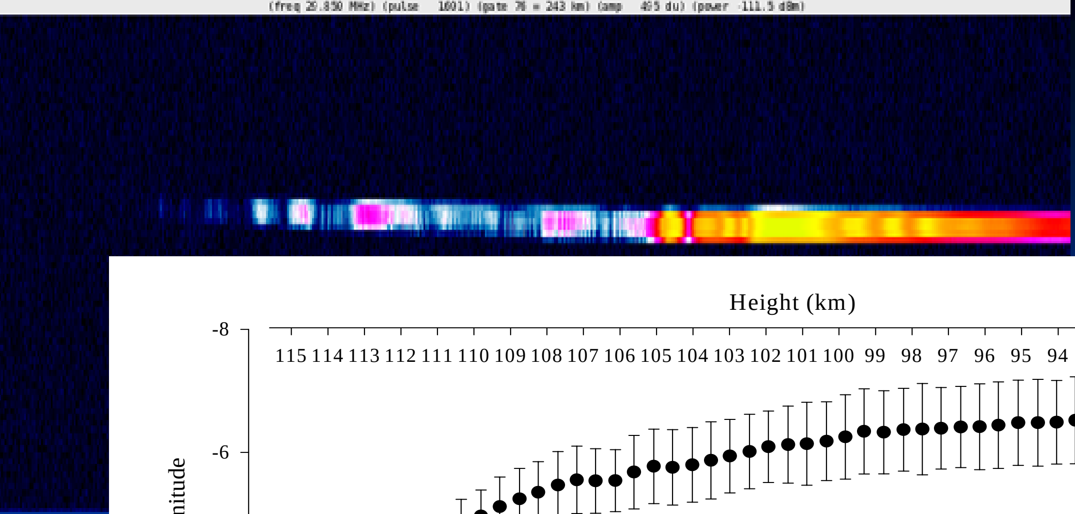


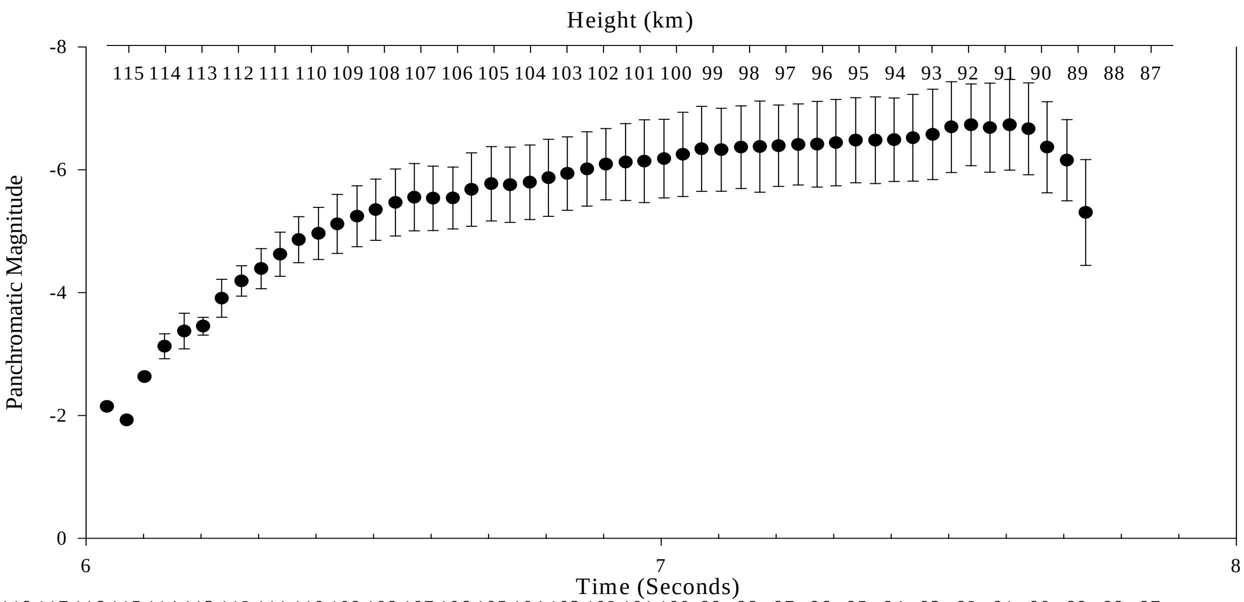
All-Sky Cameras

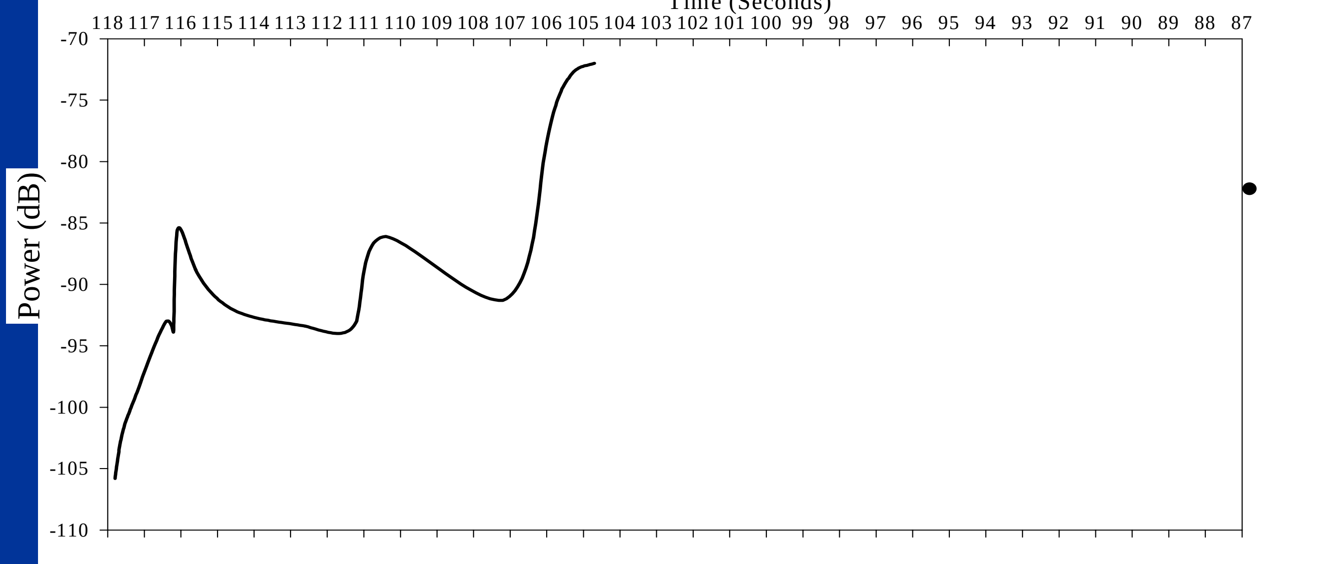
- Five video systems (all-sky) with sentinel detection units
- All connected by high-speed internet
- Locations:
  - UWO (testbed –ongoing)
  - Elginfield
  - Radar site
  - McMaster University
  - Collingwood (RASC Toronto Center Observatory)
  - Robosky (Orangeville)
  - High resolution CCD camera (Elginfield)
- Sensitivity ~ -2 for meteor events at 30 fps



SENTINEL
LOW LIGHT LEVEL CAMERA
- Photo-sensor turns cam. on at dusk and off at dawn
- Small watt resistors, fan and thermostat control temperature of camera in all seasons
GPS Antenna
Standard AC Power
Broadband/Highspeed Internet
Sentinel #1
Sentinel #2
Sentinel # ... etc
Receives all events from every Sentinel Camera in network. Cross correlates all events for multi-station events. Generates event list each morning of the night's meteor activity. Stores all events for further study in database.
Sentinel Computer
Captures motion of any bright moving event.
1/hr (variable) takes long exposure for calibration.
Events timestamped, processed and sent to UWO.


(freq 29.850 MHz) (pulse 1601) (gate 76 = 243 km) (amp 495 du) (power -111.5 dBm)


Height (km)
115 114 113 112 111 110 109 108 107 106 105 104 103 102 101 100 99 98 97 96 95 94 93 92 91 90 89 88 87
Panchromatic Magnitude
-8
-6
-4
-2
0
6
7
8
Time (Seconds)


118 117 116 115 114 113 112 111 110 109 108 107 106 105 104 103 102 101 100 99 98 97 96 95 94 93 92 91 90 89 88 87
Power (dB)
-70
-75
-80
-85
-90
-95
-100
-105
-110

Infrasound

- Low frequency sound waves
  - Below the range of human hearing (<20 Hz)
  - Above the atmospheric Brunt-Vaisala frequency (>0.017 Hz)
- Signals may be detectable for thousands of kilometers
  - Low attenuation at low acoustic frequencies

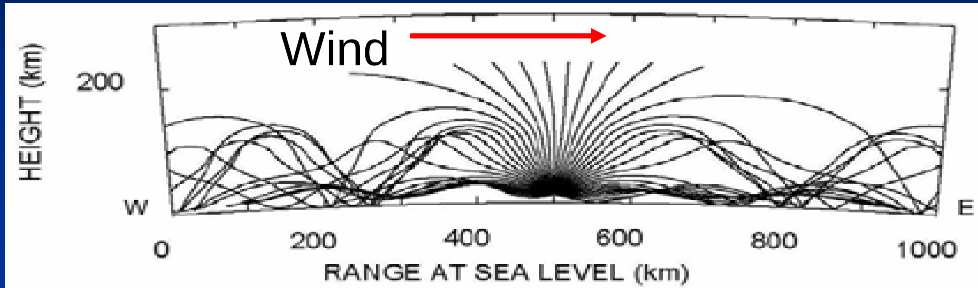
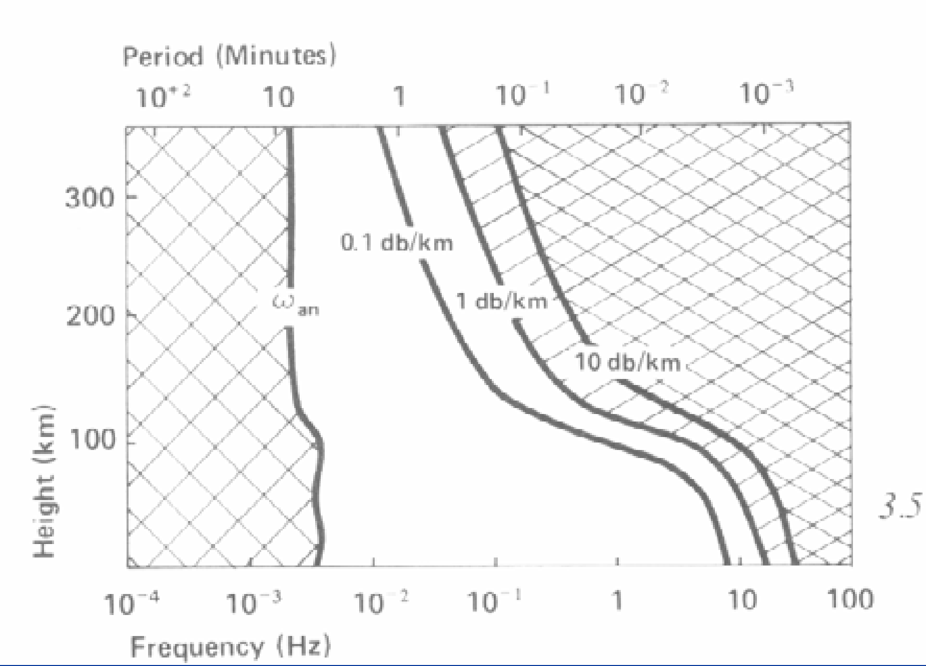
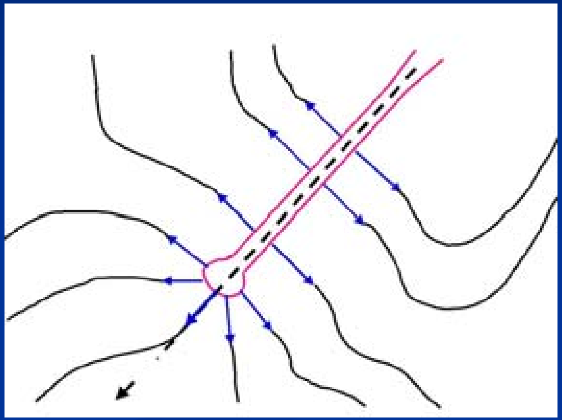


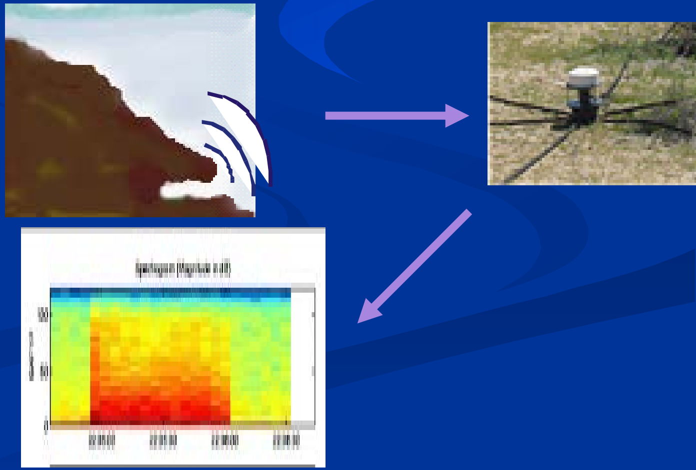
FIG. 3. Propagation with a standard temperature profile and 5 ms^{-1} wind.



Sources of Infrasound

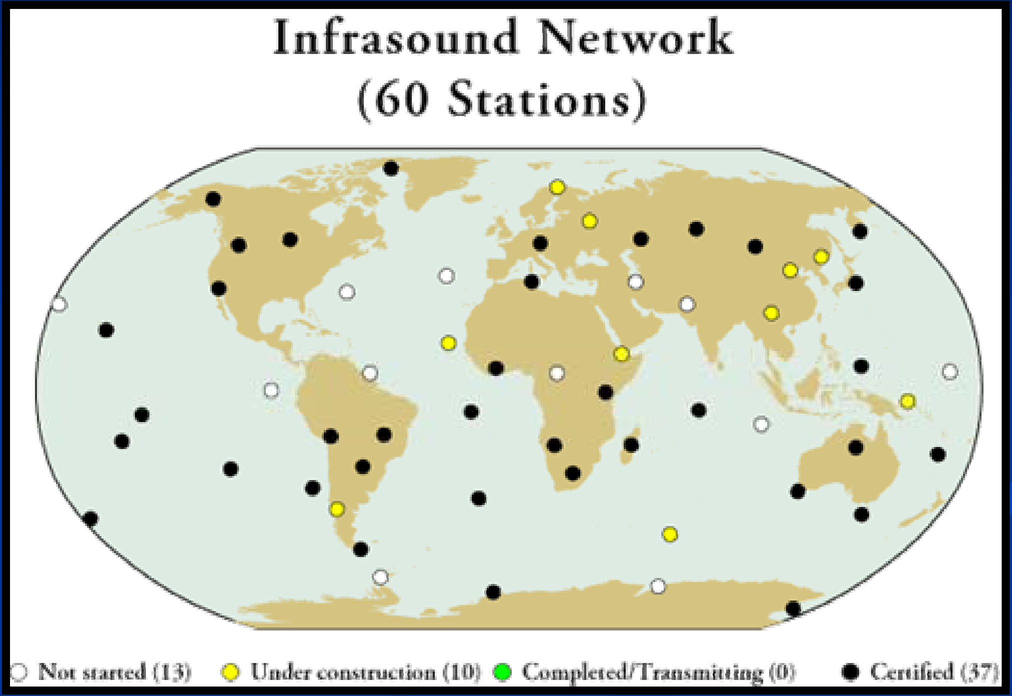
- **Natural sources:**
  - Meteors
  - Ocean Waves
  - Volcanic eruptions, earthquakes
  - Weather – Thunder, tornadoes
  - Aurora
- **Man made activities:**
  - Nuclear/chemical explosions
  - Spacecraft Re-Entry
  - Airplanes, trains, industrial noise
  - Missile launches





Global Infrasound Meteoroid Observations

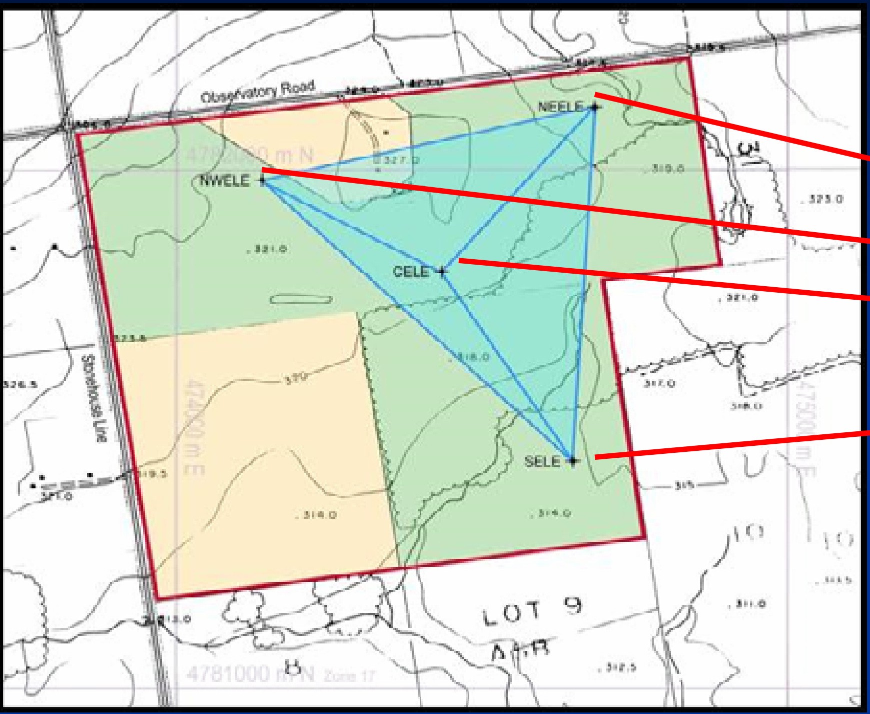
- Global network of microbarometer arrays monitoring ~0.01 – 10 Hz for explosive sources.
- CTBTO IMS Network
- Equally proficient at recording long range (1000's km) infrasound from meteors/bolides.
- Kinetic energy estimates from these signals provide constraints as to their size
  - Edwards et al. (2005/2006)



Currently 37 out of 60 stations have been completed to date, 10 more are currently under construction.

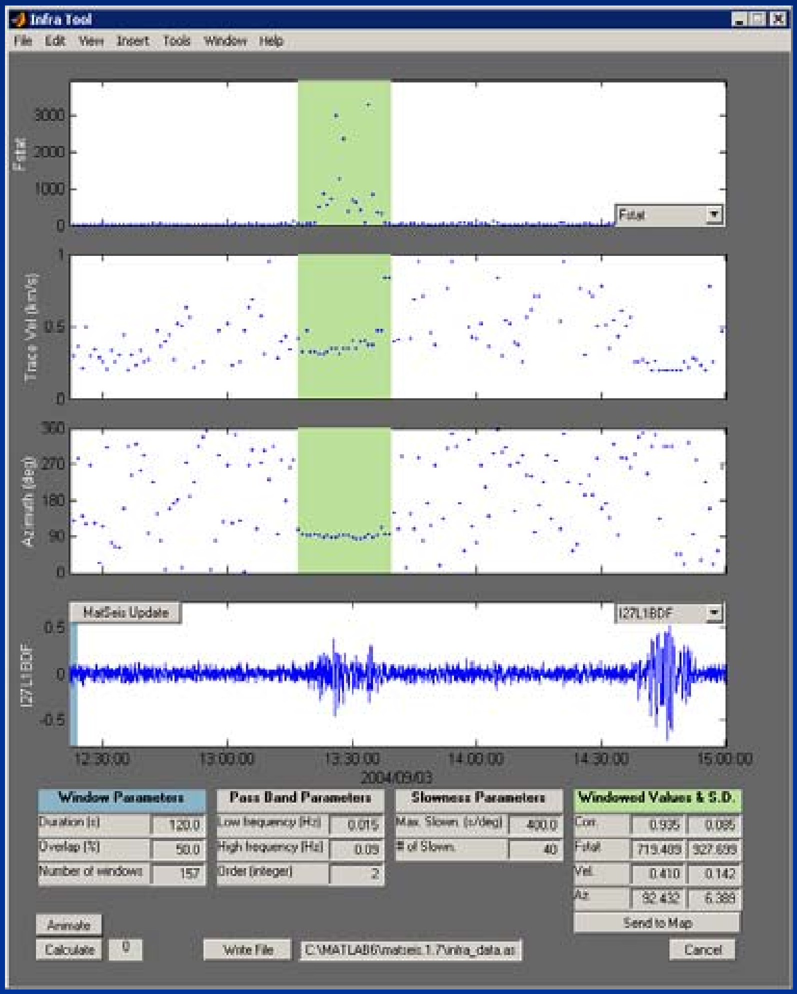
ELFO Infrasonic Array

How Infrasound is Measured



Top View

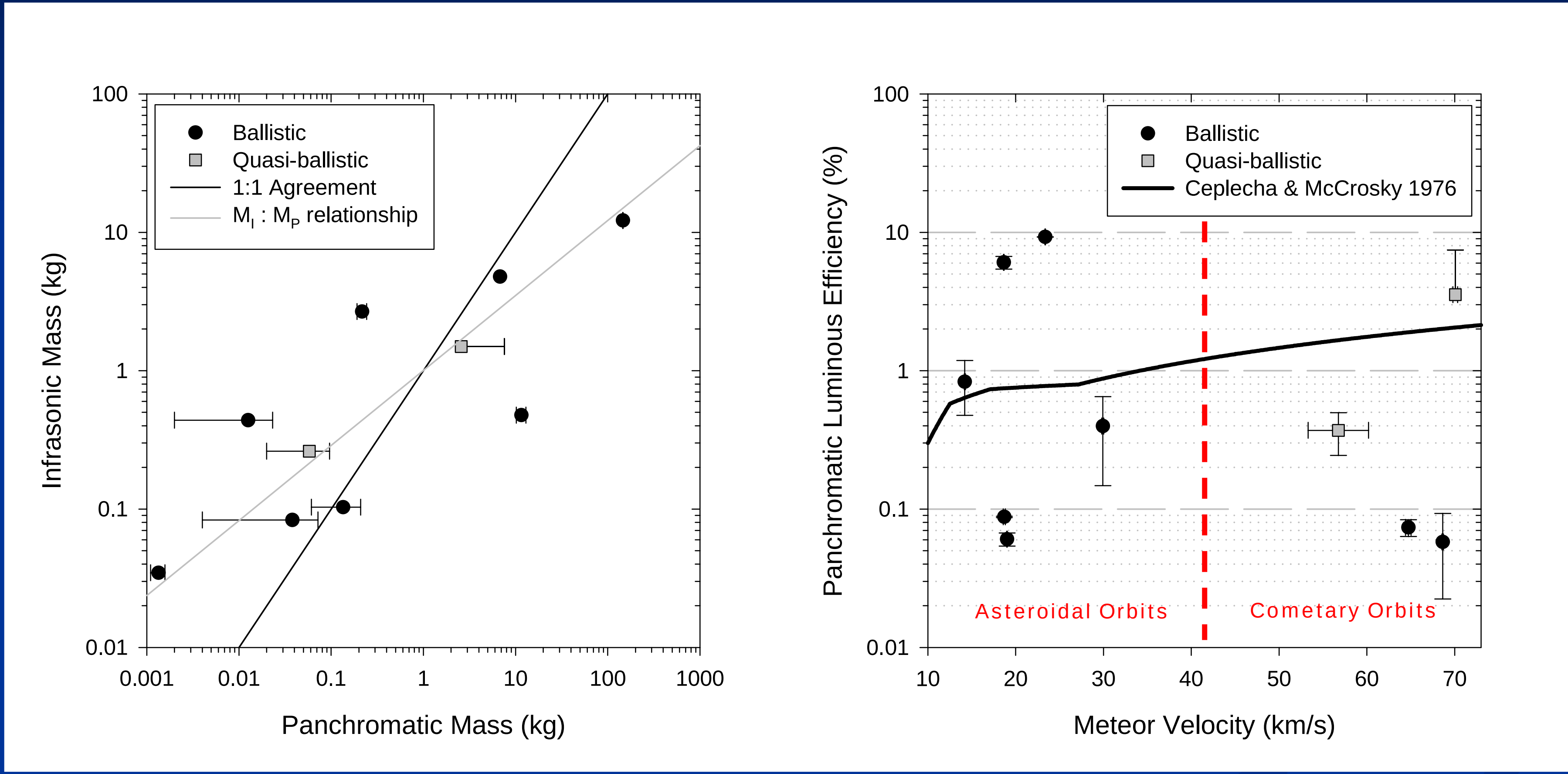
Meteor Infrasound



- Infrasound provides meteor shock angle of arrival and azimuth
- Comparison with radar/optical data establishes point on trajectory where shock emanates
- Allows energy measurements/shock characterization

#	Event	Time	Arrival	Duration	Δp	Frequency
	UTC	UTC	UTC	(Sec.)	(Pa)	(Hz)
1	00602213	08:49:25	08:53:33.8	3 – 4	0.212	3.37
2	20060302	06:28:14	06:41:54.5	3 – 4	0.107	1.68
3	20060305	05:15:37	05:21:27.8	8 – 9	0.156	6.70
4	20060405	03:03:27	03:10:01.6	4 – 5	0.166	5.29
5	20060419	04:21:28	04:27:17.9	~1	0.061	3.44
6	20060419b	07:05:57	07:10:34.8	~0.5	0.137	9.28
7	20060805	08:38:50	08:46:00.0	45	0.650	0.658
8	20060901	06:44:49	06:48:19.7	15	0.096	2.61
9	20061021	03:42:07	03:56:05.0	30	0.044	1.22
10	20061101	06:46:12	06:55:00.7	10	0.037	0.958
11	20061104	03:29:30	03:35:25.0	~0.5	0.084	5.69
12	20061121	10:45:46	10:54:22.5	20	0.028	0.920
13	20061223	06:27:26	06:37:33.5	32	0.058	1.73
14	20070102	10:42:03	10:51:42.7	~3	0.041	1.20
15	20070125	10:02:05	10:08:42.2	5	0.036	0.829
16	20070129	00:49:51	00:55:27.0	1.5	0.316	2.15
17	20070421	09:21:01	09:31:38.6	1.5	0.015	1.55
18	20070511	07:41:14	07:48:34.7	~3.5 – 4	0.012	1.42

Infrasonic Mass & Luminous Efficiency

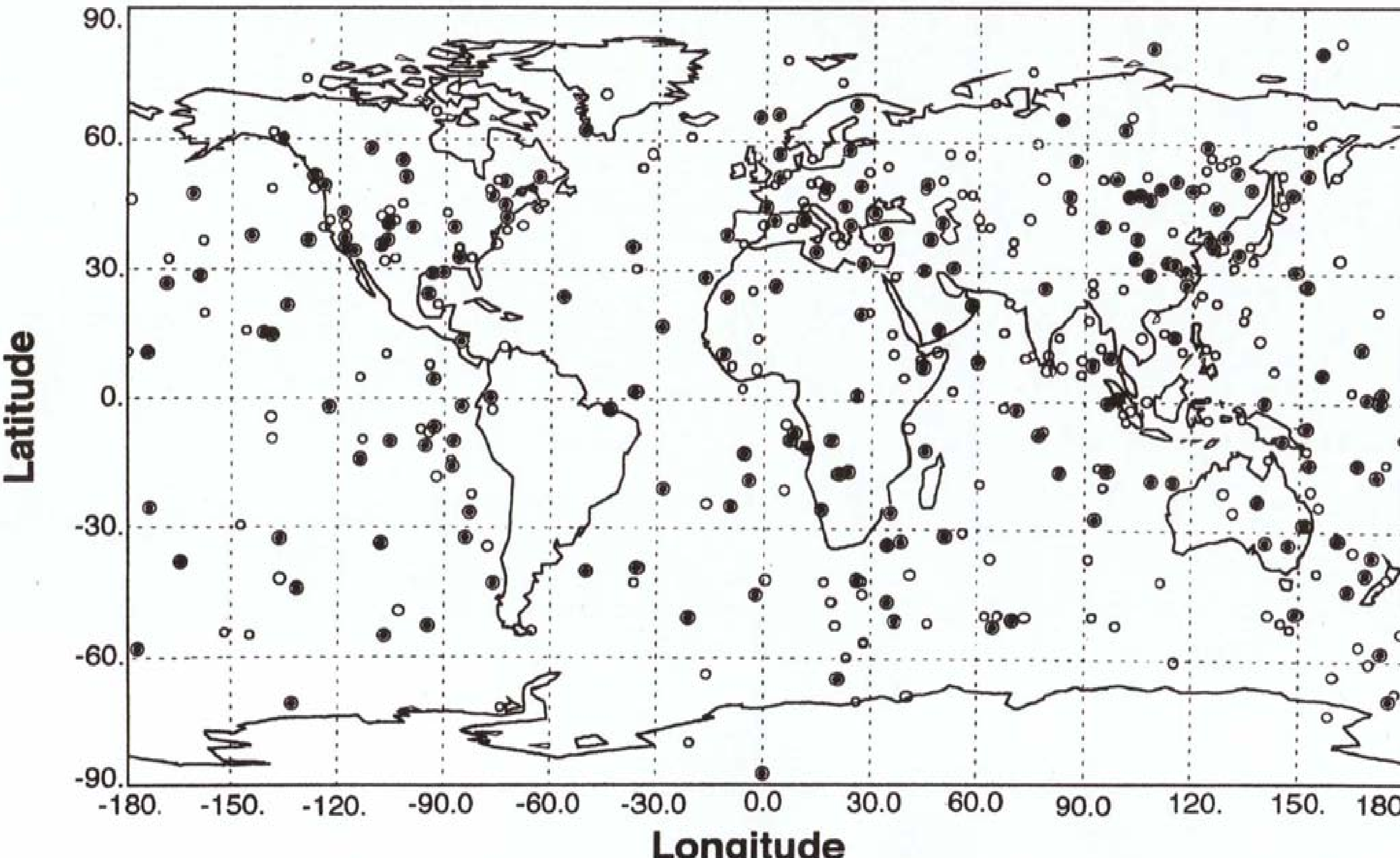


Given meteor's trajectory & velocity → Forward model to fit ΔP & Period.
Using this "Infrasonic mass" we compute the integral luminous efficiency.

Satellite Sensors - IR

- Scanning arrays of IR sensors
  - cover entire Earth several times per minute
  - limited photometry of bright events
- IR is positional indicator
  - may also provide velocity and atmospheric trajectory
  - sensors tend to detect dust cloud via reflected sunlight
- IR detections: 639 Aug, 1972 – Dec, 2000
  - 100+ have both IR and optical information

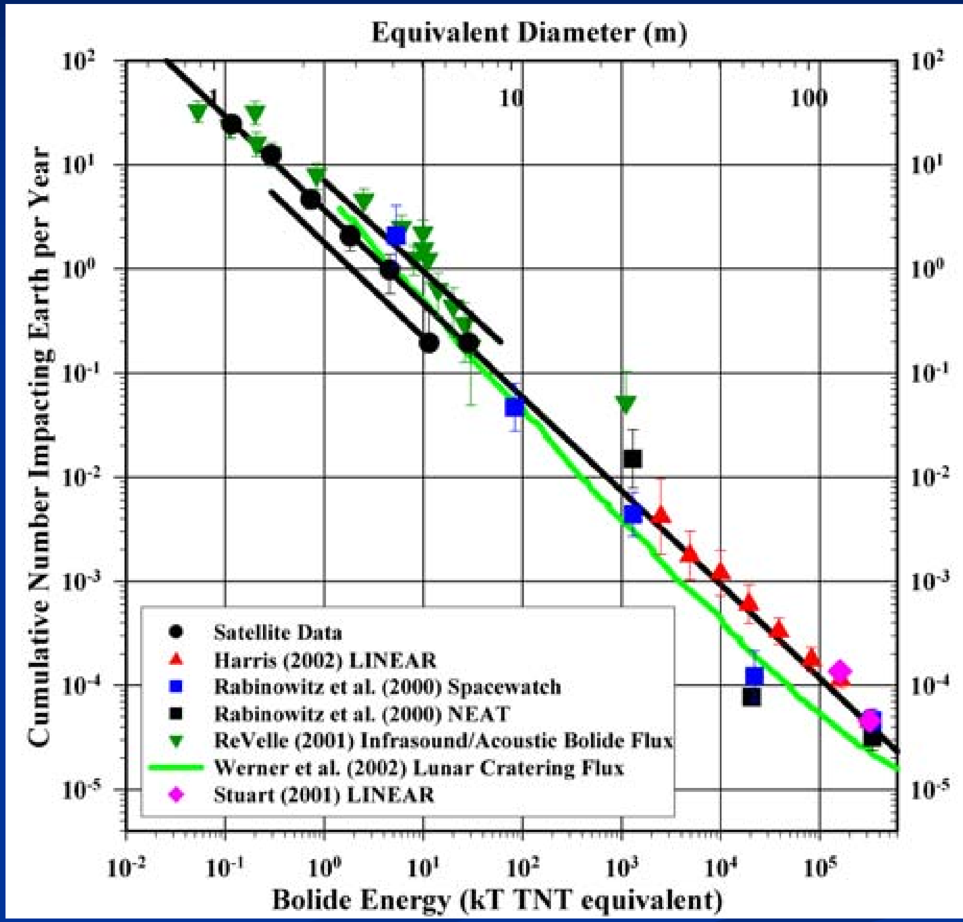
Geographic Locations is Meteoroid Impacts Detected by Space Based IR Sensors August 1972 - December 2000



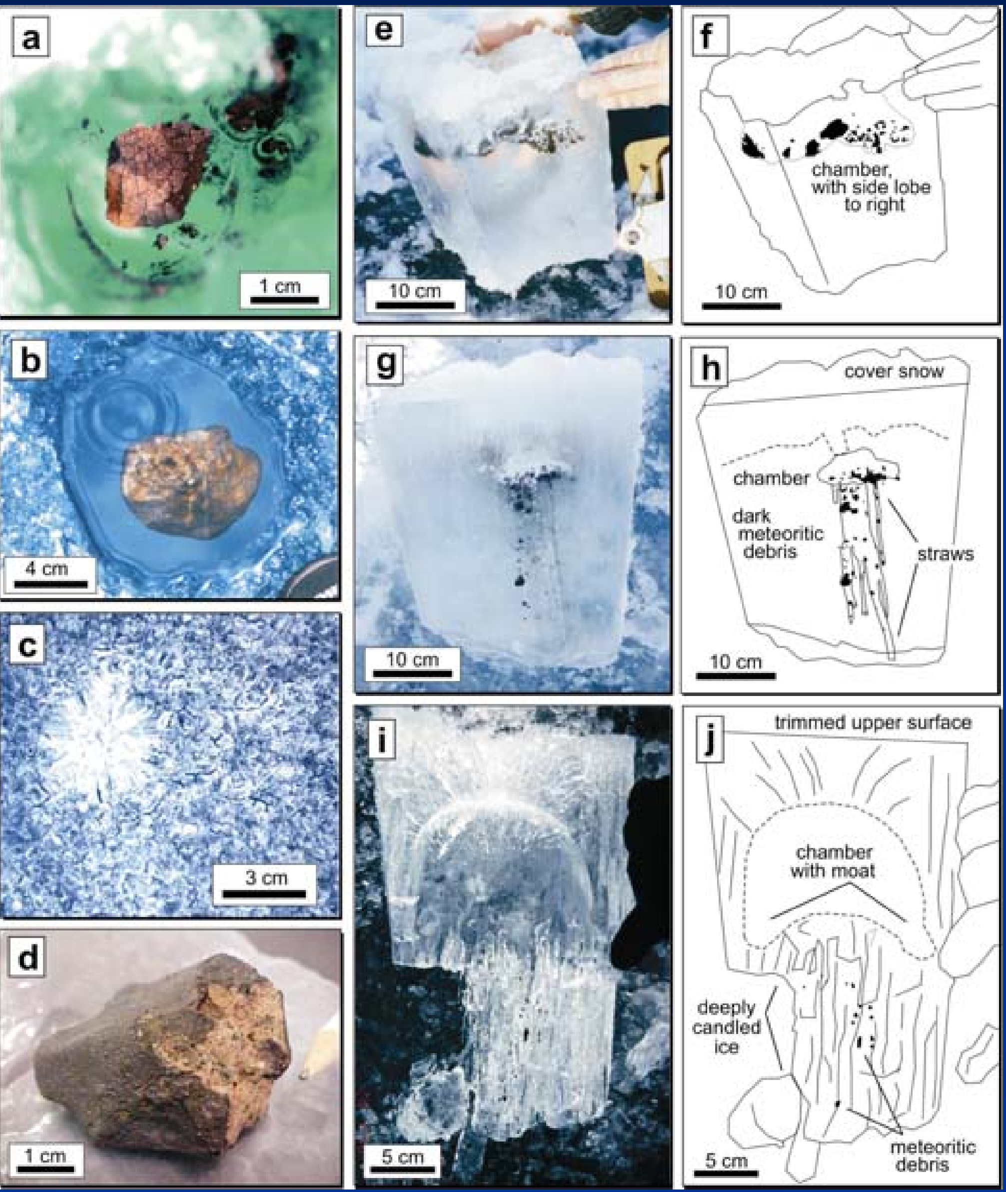
Solid circles represent night time detections, open circles daytime detections.

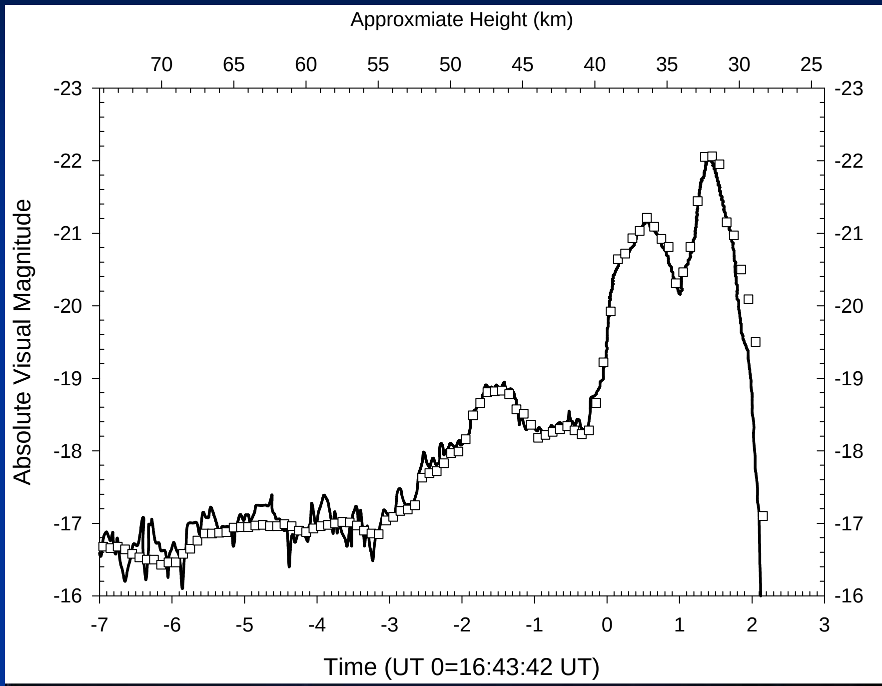
Satellite Sensors - Optical

- Broadband unfiltered Silicon, peak sensitivity at 9000 nm
- "Stare" continuously at large portion of Earth
  - Photometry of bolide detonations, no positions
- Effective limiting magnitude ~(-17.5 M_v)
  - Most sensitive to transient flashes
  - If brightness builds too slowly (>0.5 second), sensitivity diminishes
- Used for timing and energy for events, particularly meteorite producing fireballs



Tagish Lake Meteorite : January 18, 2000





Summary

- Wide variety of meteor projects underway with the Western Meteor Group
- One thrust of observational meteor research work at Western involves fusion of different observational techniques and comparison with theory.
- Many opportunities for students!

Thanks for your attention