Artificial Meteor and Chelyabinsk Ablation Test using Arc-heated Wind Tunnel

NIHON UNIVERSITY

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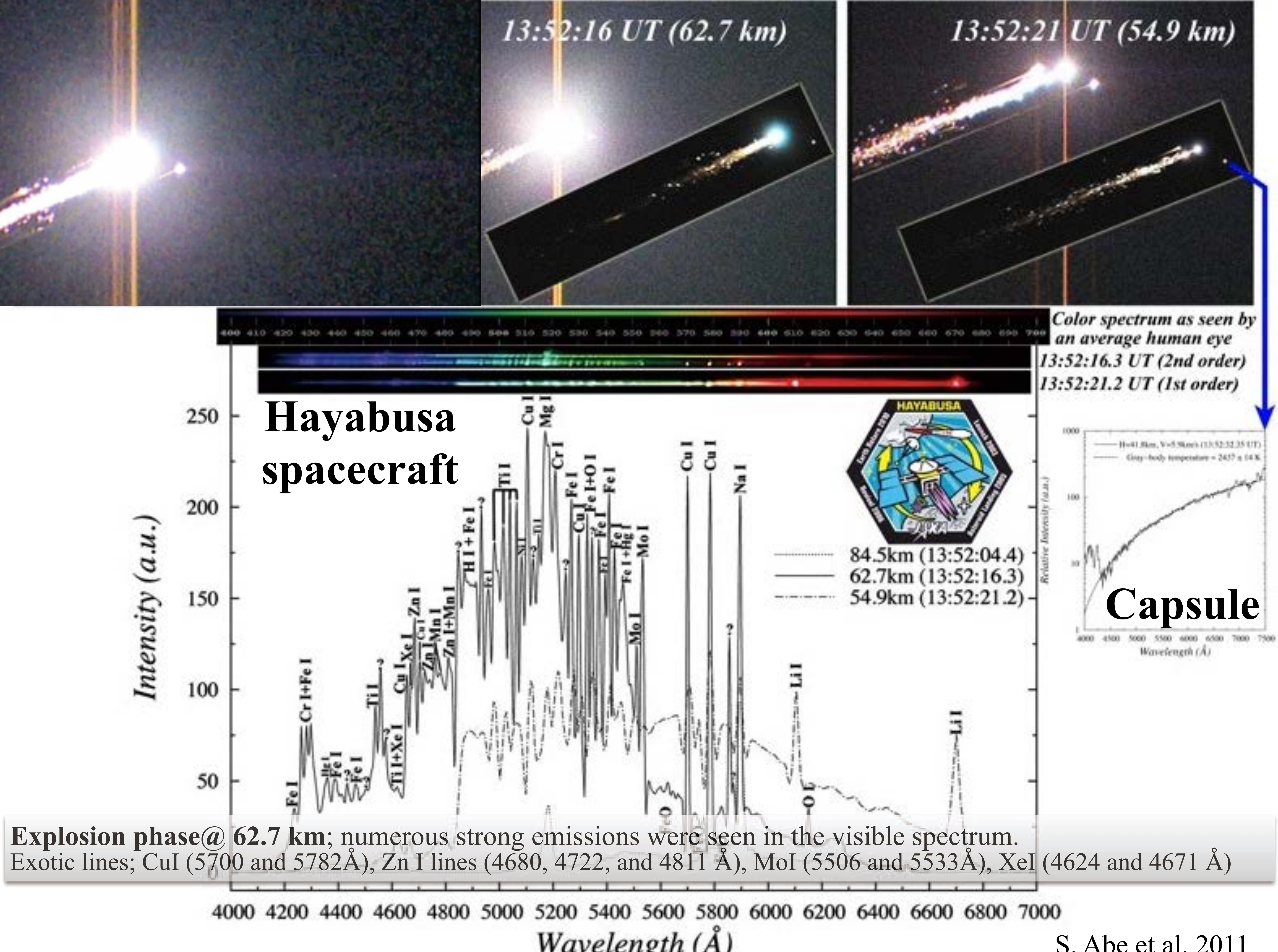


Explosion phase@ 62.7 km; numerous strong emissions were seen in the visible spectrum.
Exotic lines; CuI (5700 and 5782Å), Zn I lines (4680, 4722, and 4811 Å), MoI (5506 and 5533Å), XeI (4624 and 4671 Å)

S. Abe et al. 2011

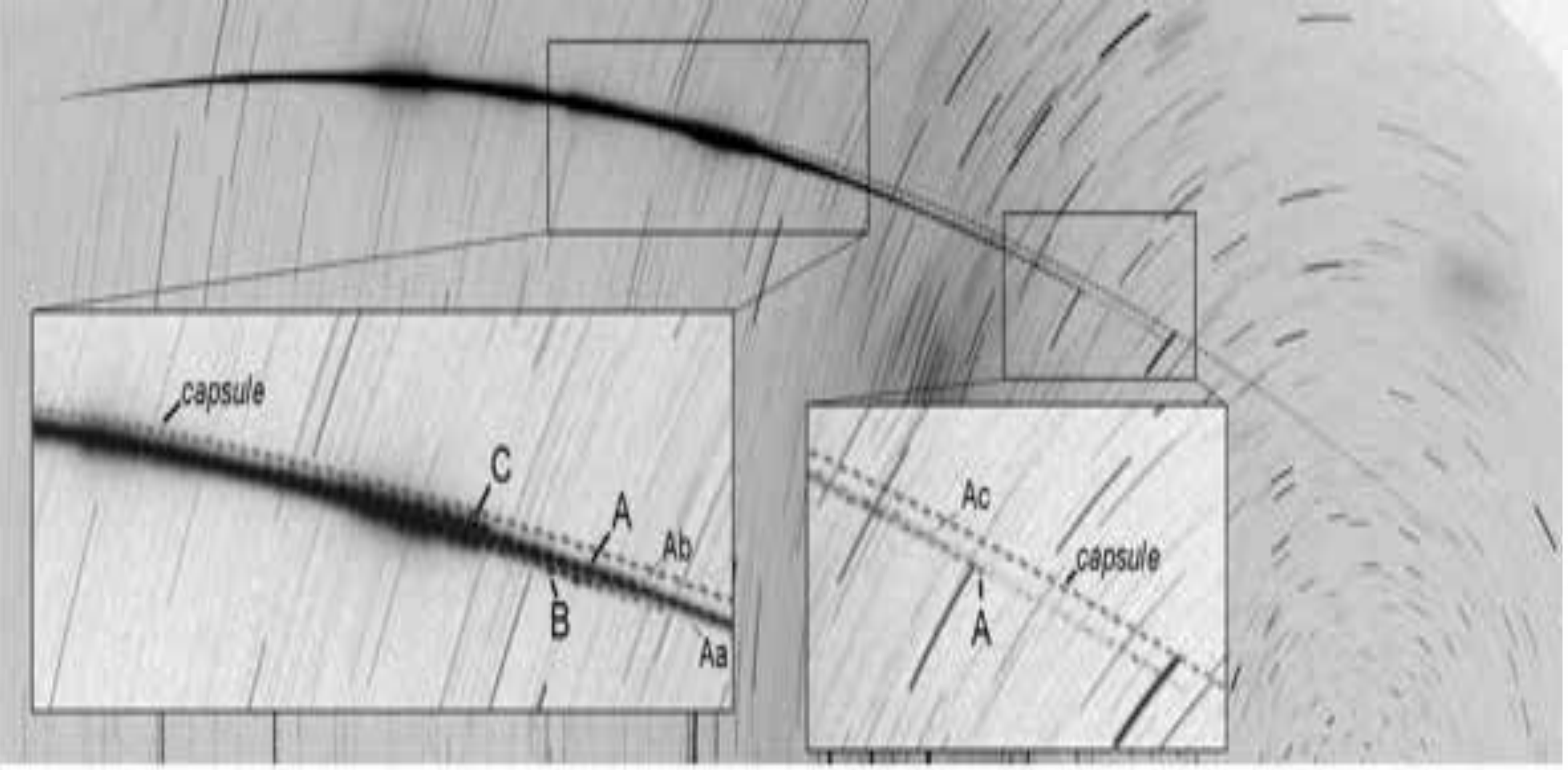
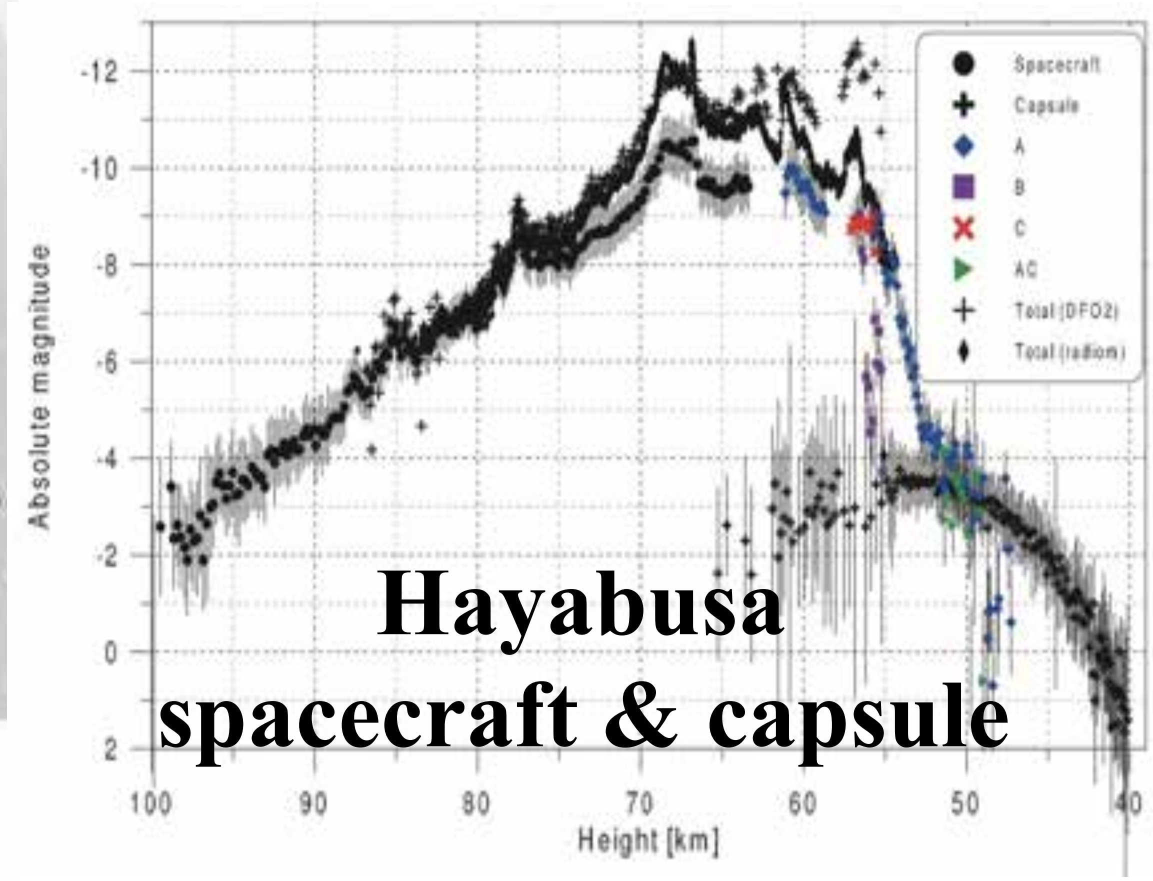


Fig. 2. Hayabusa re-entry as photographed from station GOS4. The exposure was 27 minutes long, from 13:37:00 to 14:04:00 UT. The fireball flew from left to right and was interrupted be the rotating shutter 10 times per second. The closest horizon lies upwards. The fragments mentioned in the text are identified in the insets.



- The maximum absolute magnitude of the fireball of -12.6 was reached at a height of 67 km
- The dynamic pressures acting on the spacecraft at the fragmentation points were only 1–50 kPa
- No spacecraft fragment was seen to survive below a height of 47 km
- The integral luminous efficiency of the spacecraft was 1.3% and the capsule was 0.03%

Geocentric orbit	
Eccentricity	1.32
Inclination	34.52°
Right ascension of the ascending node	7.58°
Pericenter distance	6310 km
Longitude of pericenter	255.58°
Heliocentric orbit (J2000.0)	
Semimajor axis	1.278 AU
Perihelion distance	0.9824 AU
Eccentricity	0.231
Inclination	1.59°
Argument of perihelion	145.63°
Longitude of the ascending node	82.360°

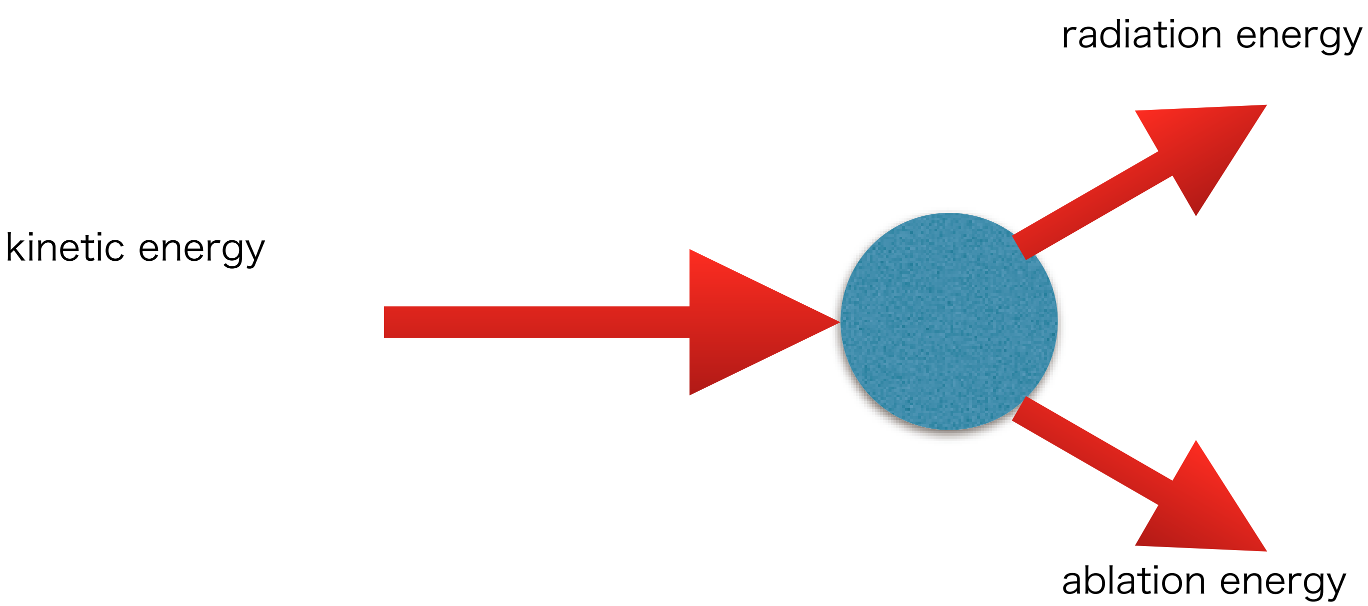
Borovická, Abe, Shrbený, Spurný, Bland, 2011

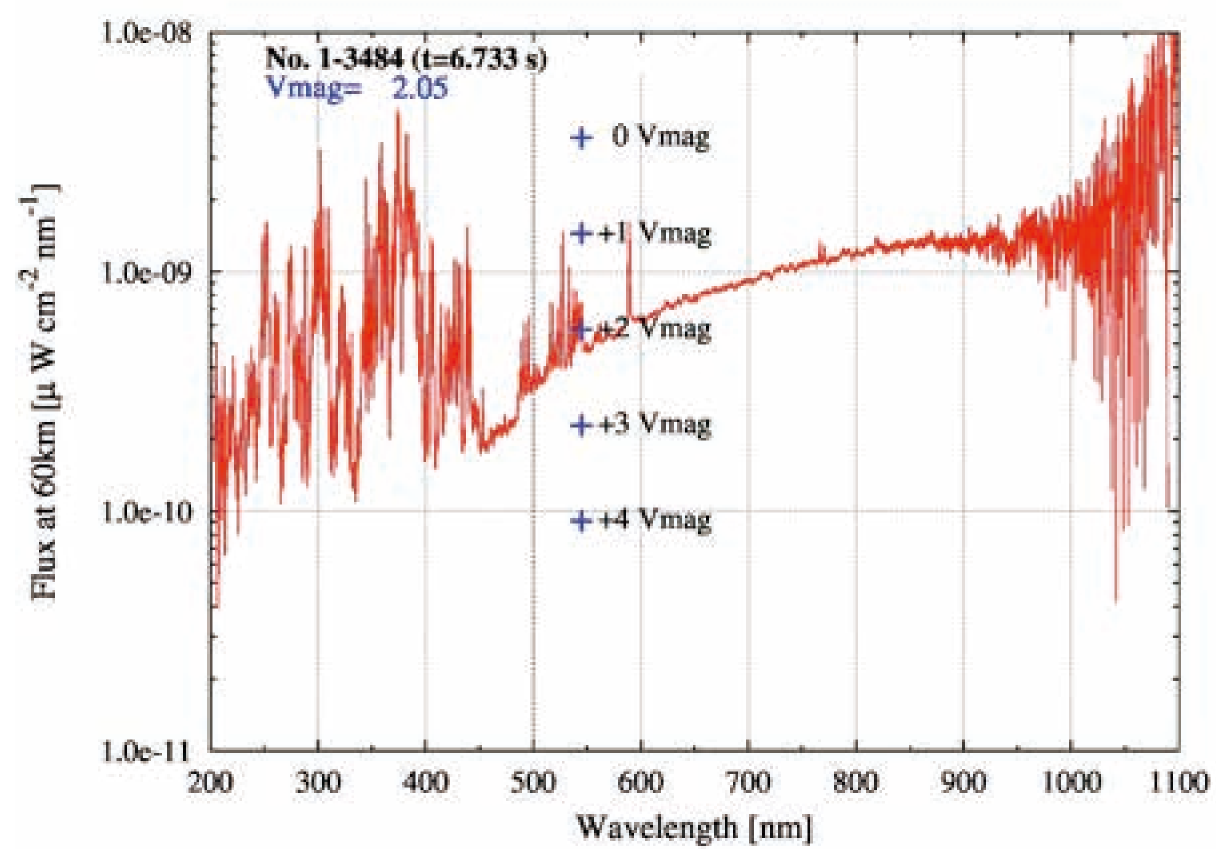
To understand ablation processes of atmospheric entry, artificial meteor test is carried out using JAXA's facility.

JAXA/ISAS Arc-heated Wind Tunnel

High enthalpy conditions

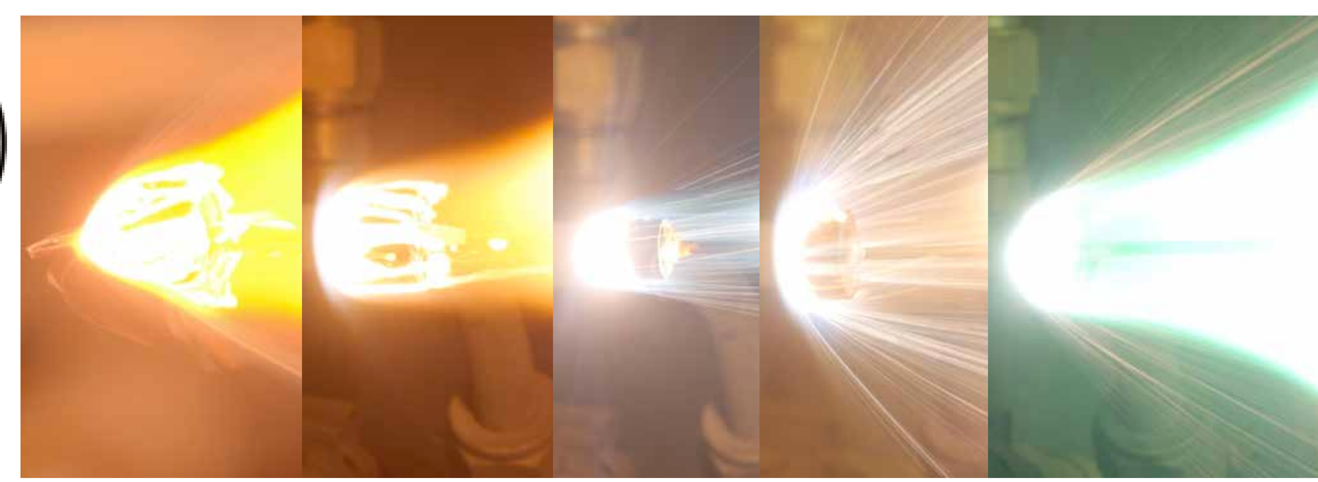
T~10,000K, V~6km/s, 0.6MPa



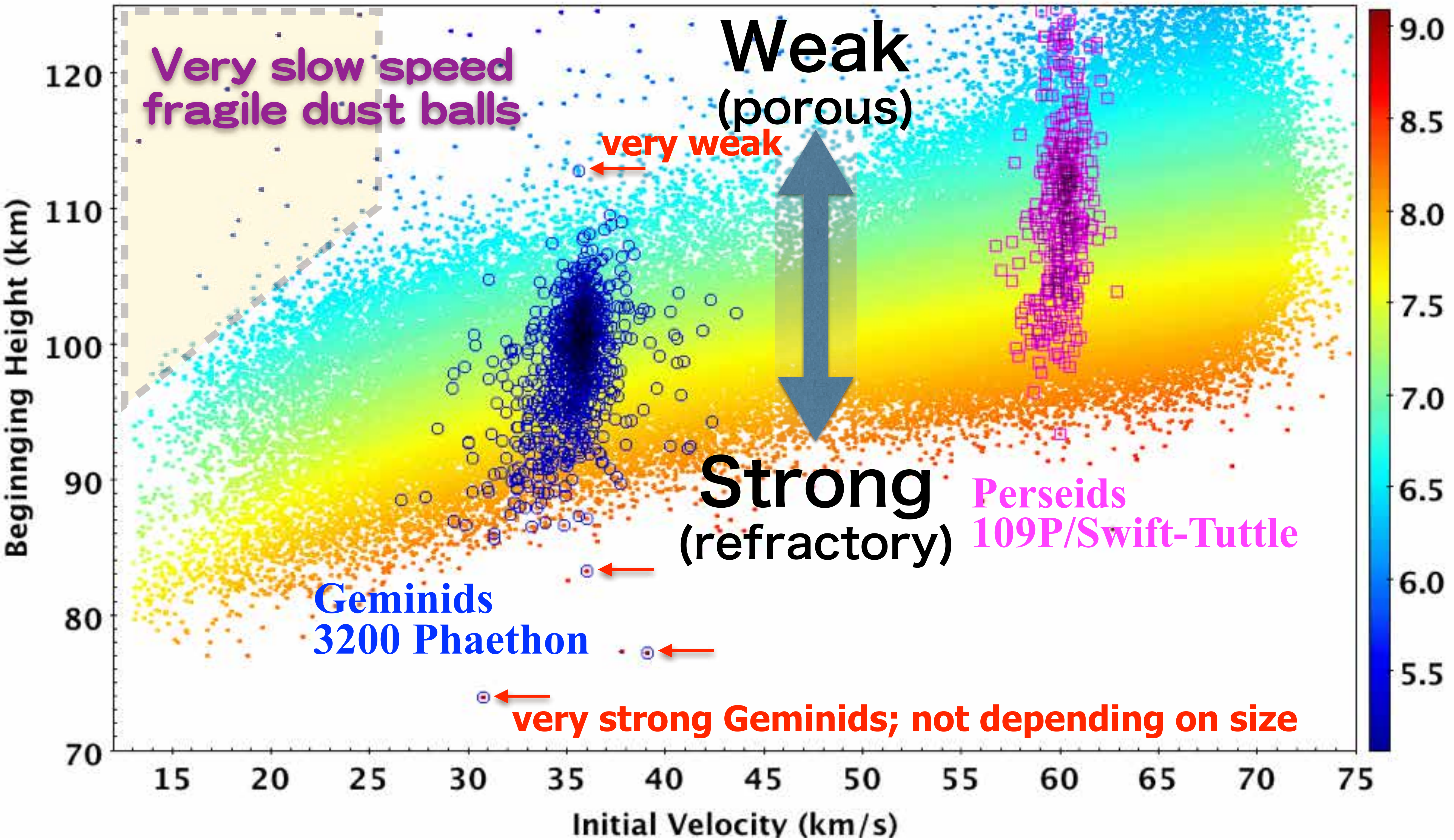


UV-VIS-NIR spectroscopy

$$\frac{dT_m}{dt} = \frac{A}{cm^{1/3}\rho_m^{2/3}}\left(\frac{C_h\rho_a V^3}{2} - 4\sigma\epsilon(T_m^4 - T_a^4) - L\frac{dm}{dt}\right)$$



Strength of Meteoroids by MU Radar Meteor head-echo



S. Abe, J. Kero, T. Nakamura et al. (in prep)


High speed camera
Phantom v711
JAXA/ISAS Arc-heated Wind Tunnel
Spectroradiometer & Spectrograph
OceanOptics QEPro, HR4000CG-UV-NIR
QEPro
Ocean Optics
HR4000CG-UV-NIR

Chelyabinsk Meteorite ; 2013/2/15

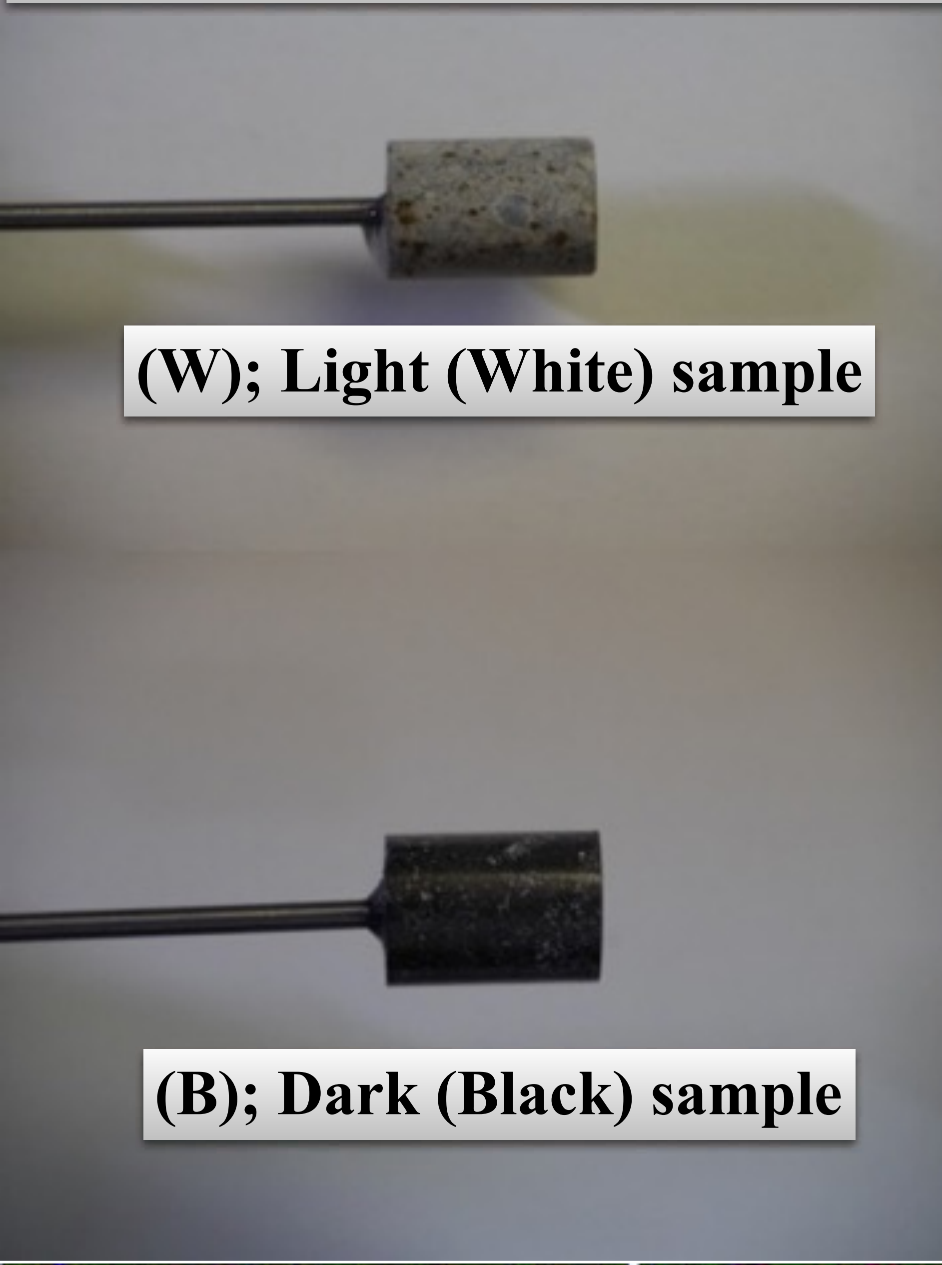
Diameter~19m, Mass~10,000ton

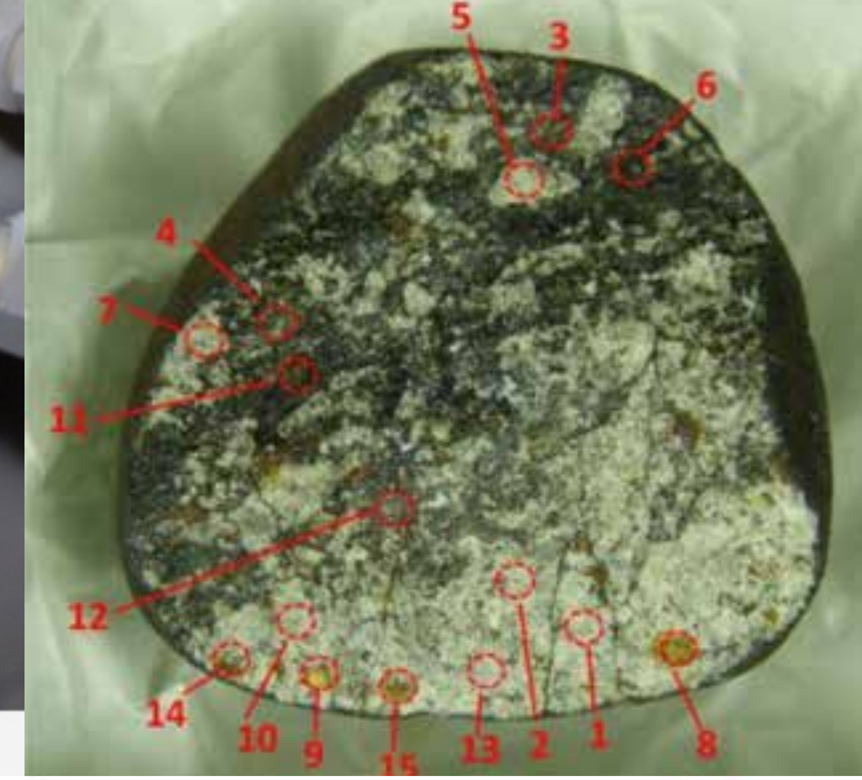
Entry velosity=19km/s

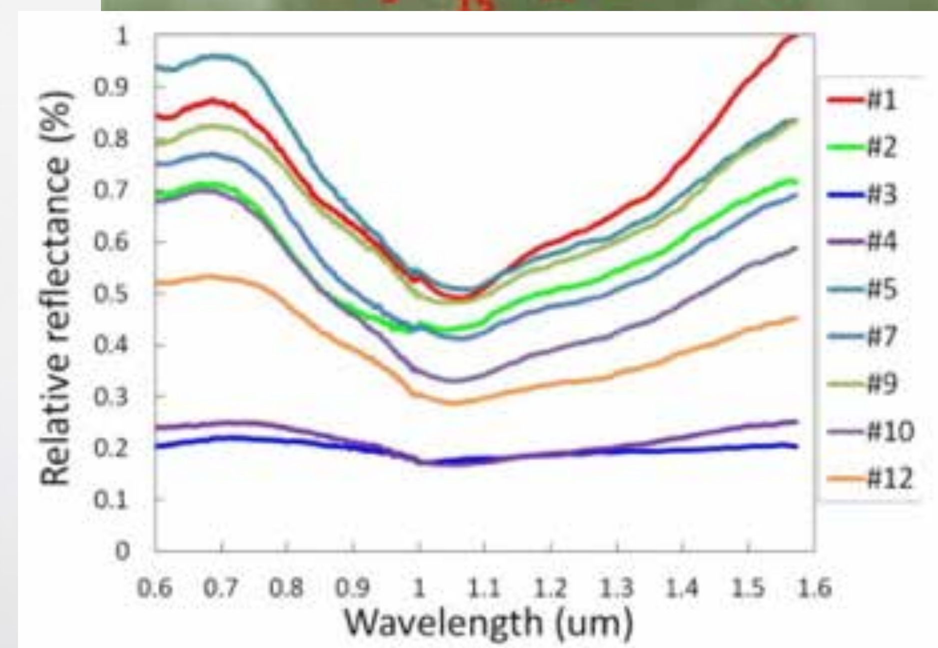
Absolute magnitude; -26〜-30Vmag (10times of Sun)

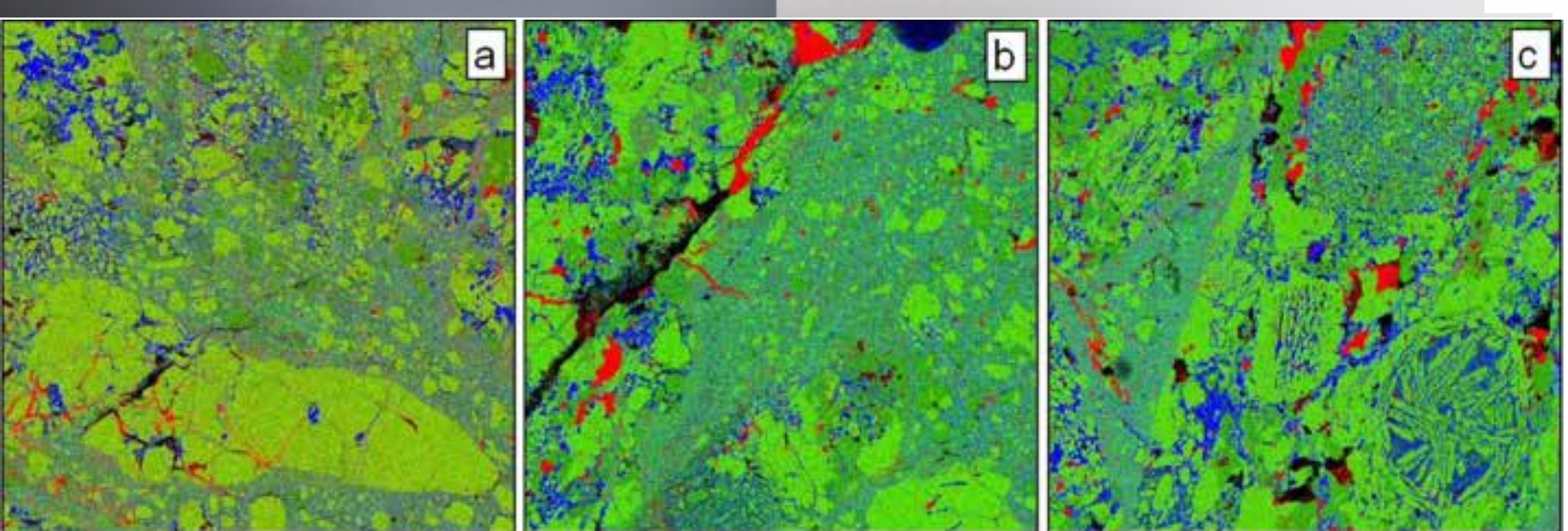
Kinetic energy; 500Kton TNT=33xHirosima

Chelyabinsk samples
light and dark lithology in the cm scale.









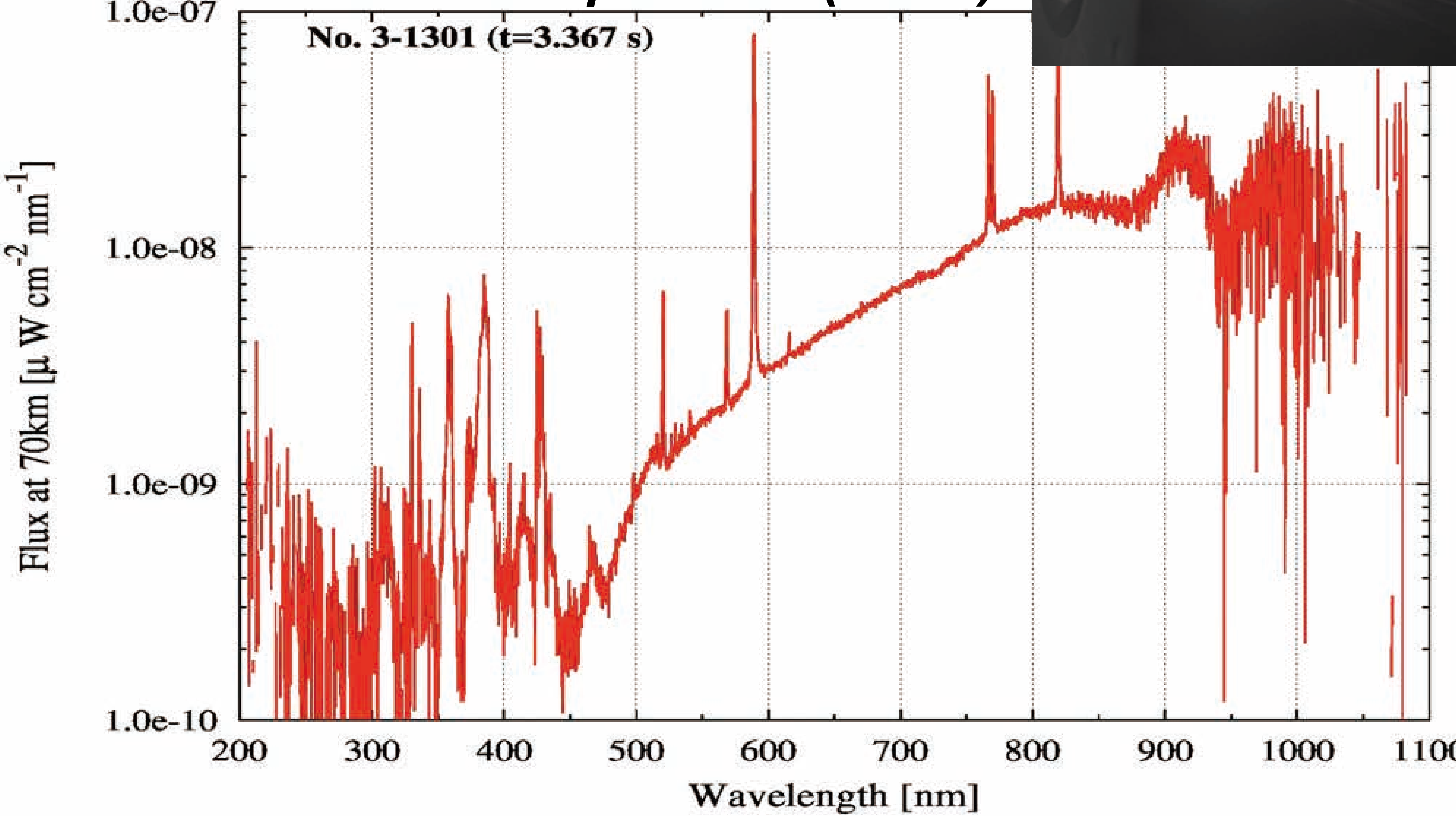
T. Arai, S. Abe et al.

LPI (2014) 2860.

Artificial Meteor Test using
JAXA Arc-heated wind tunnel

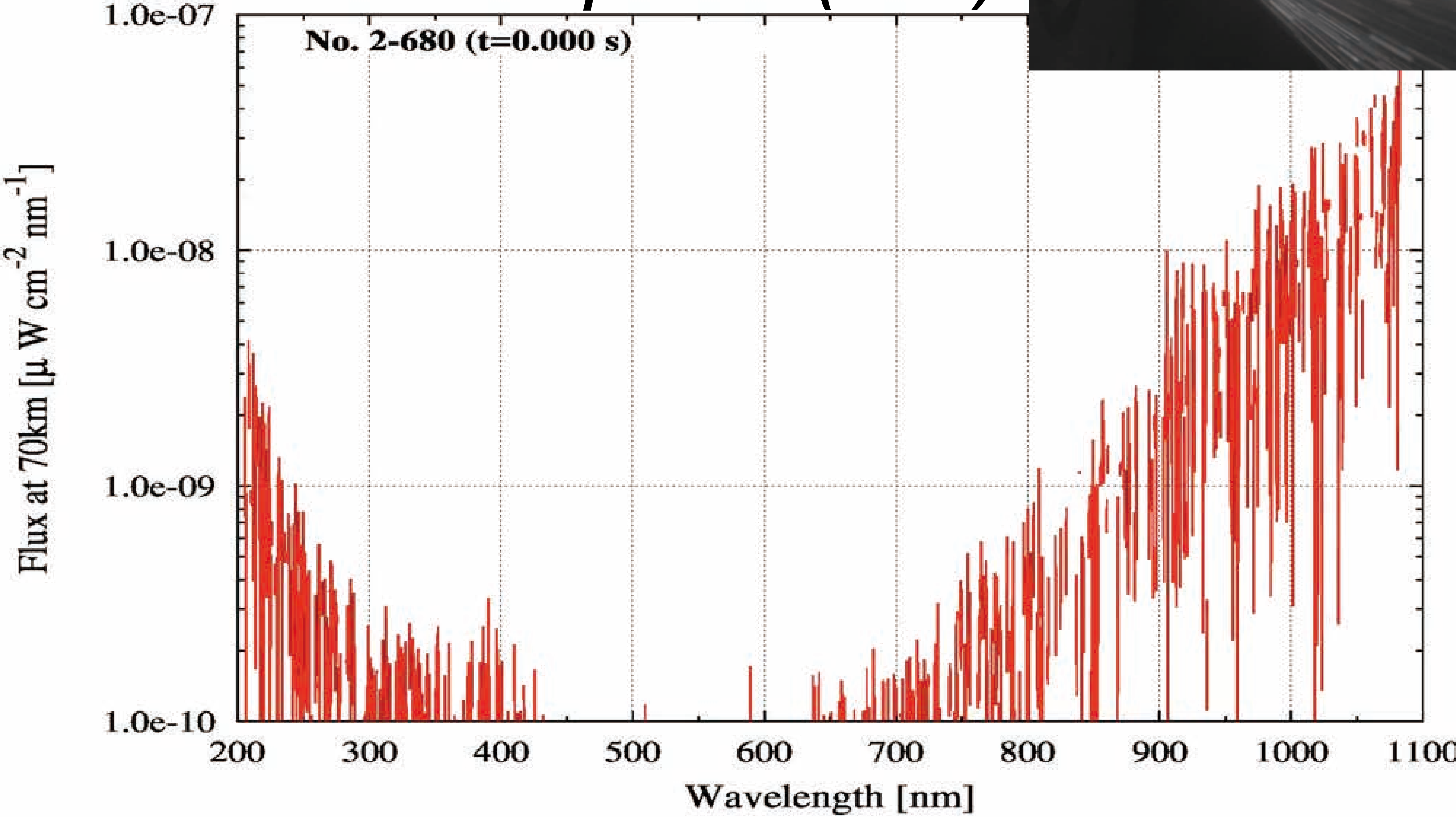
Chelyabinsk (LL5)

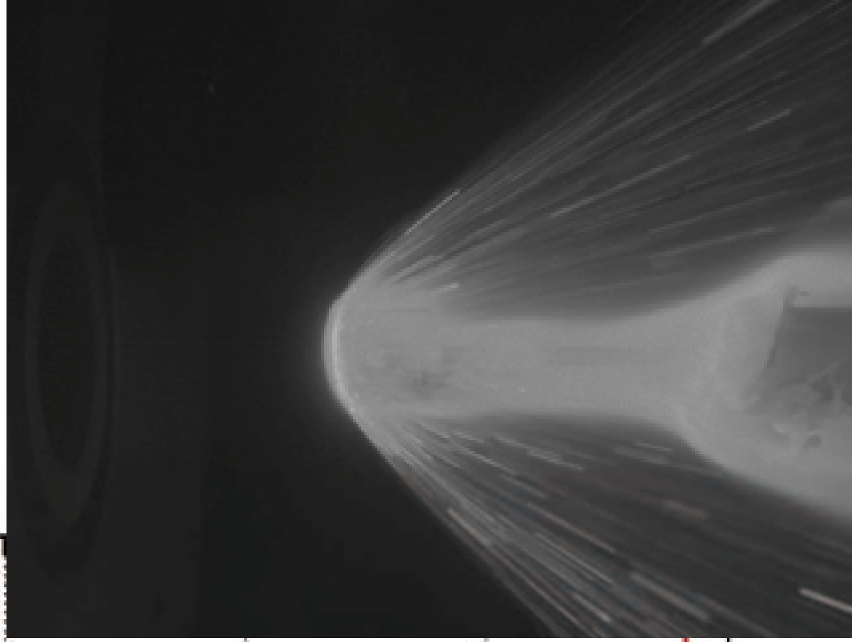
UV-VIS Spectrum (1/30s)



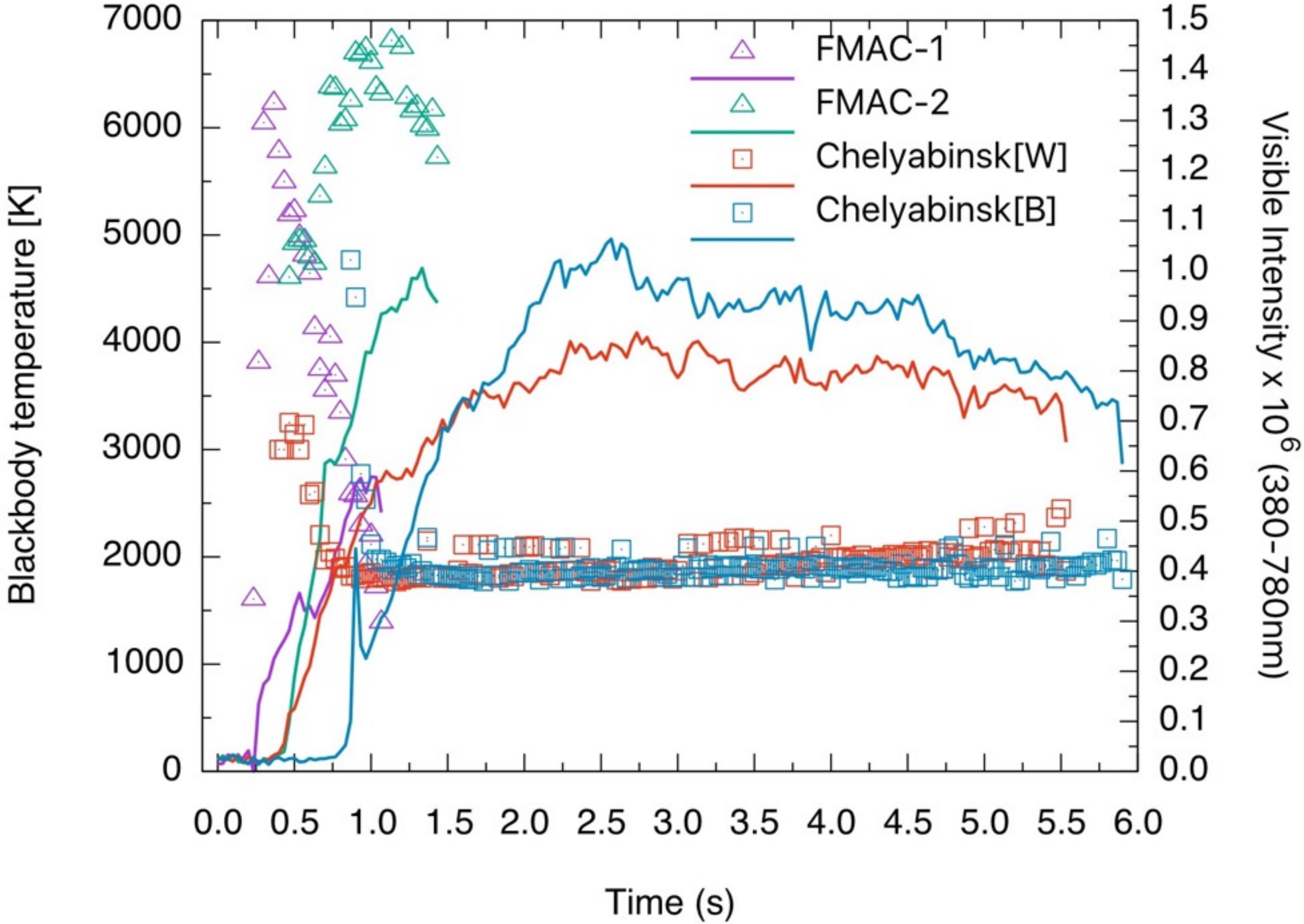
Fe+Mg+Al+C (FMAC) with Sabo

UV-VIS Spectrum (1/30s)

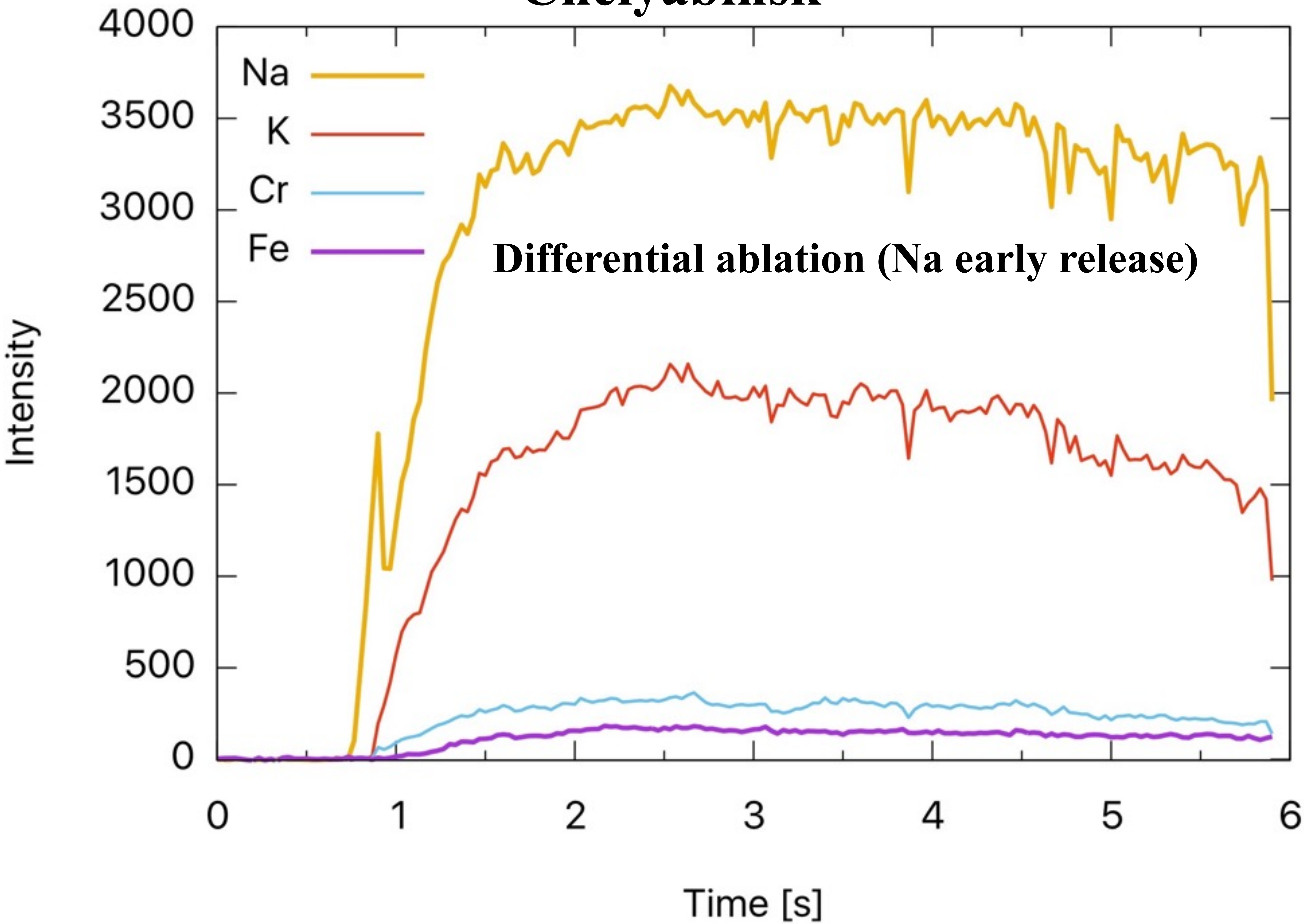




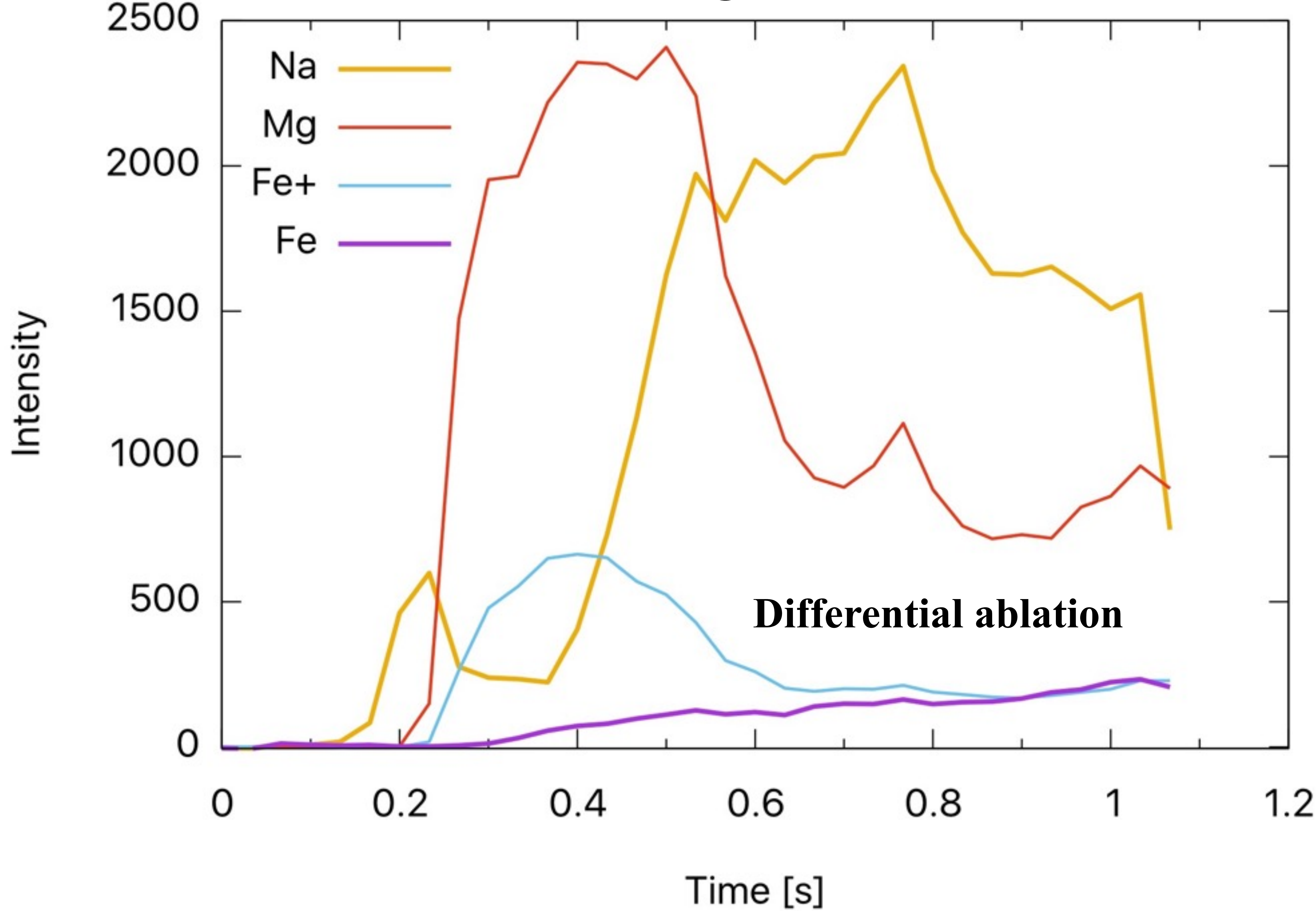
Blackbody is dominant for low-velocity meteors



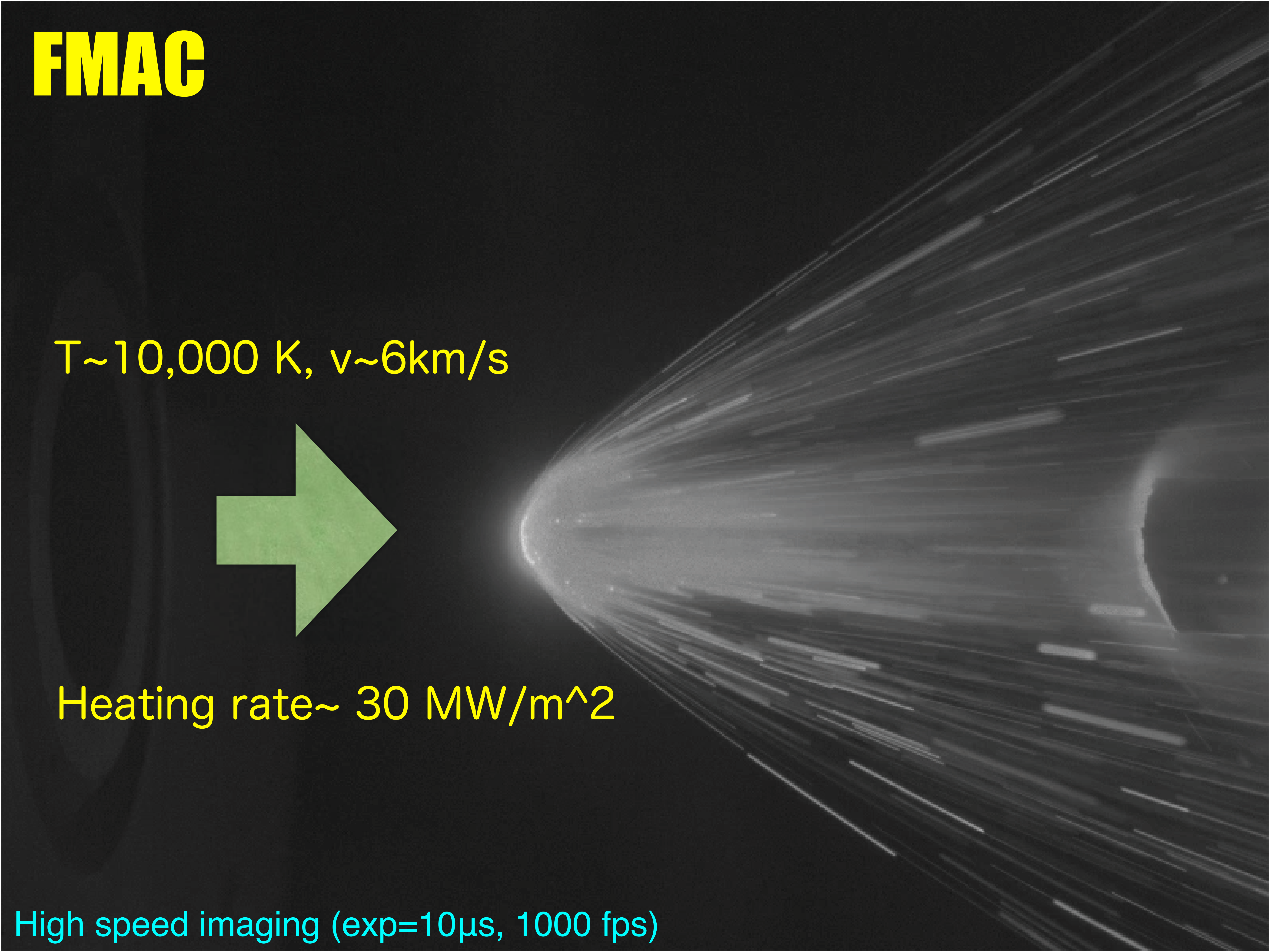
Chelyabinsk

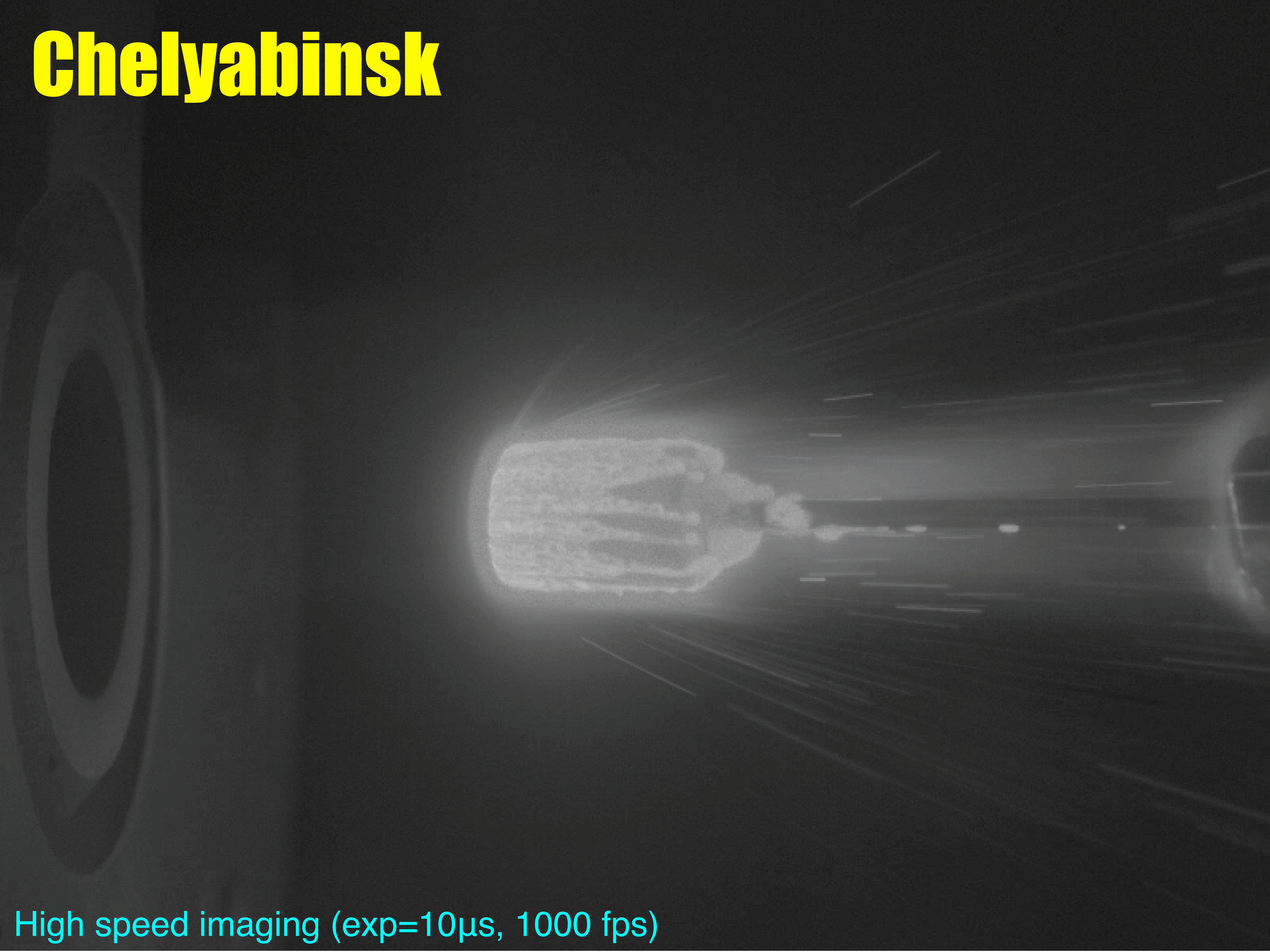


FMAC



Na
Mg
Fe+
Fe
Intensity
Time [s]
0
500
1000
1500
2000
2500
0
0.2
0.4
0.6
0.8
1
1.2
Differential ablation

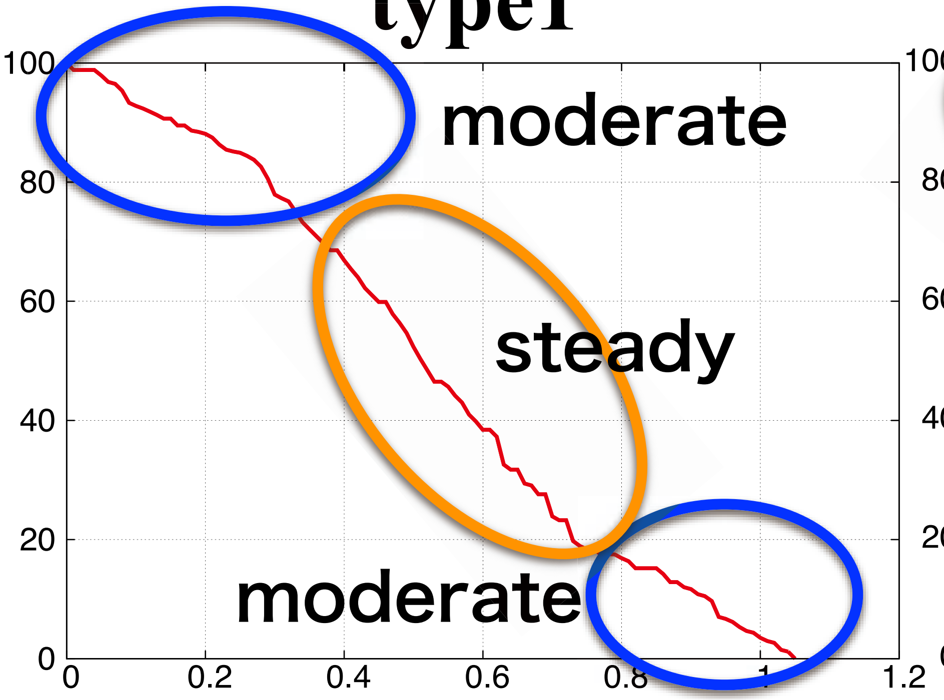

FMAC
T~10,000 K, v~6km/s
Heating rate~ 30 MW/m^2
High speed imaging (exp=10μs, 1000 fps)


Chelyabinsk
High speed imaging (exp=10µs, 1000 fps)

Mass Loss Rate , dm/dt

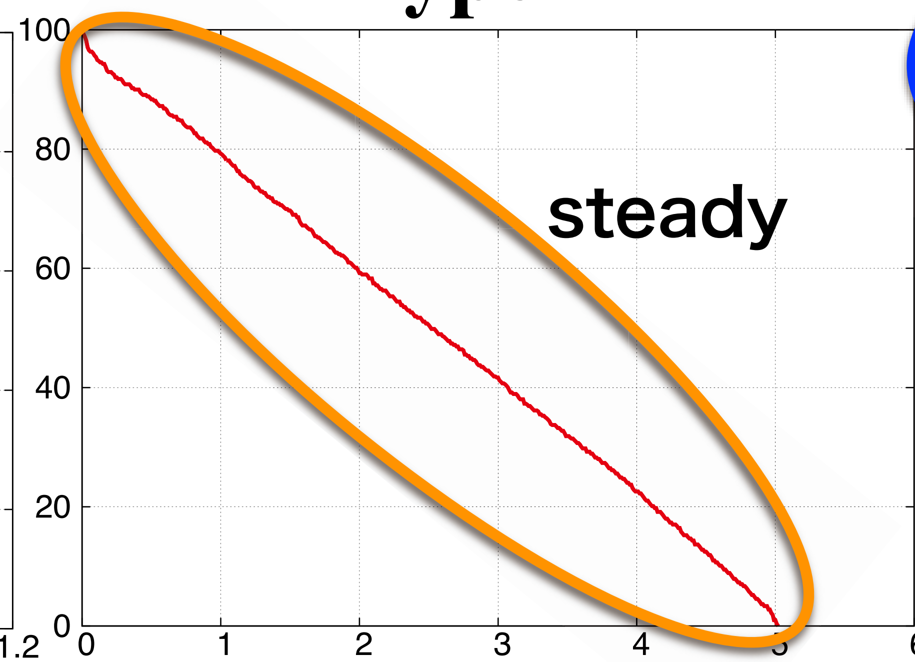
Y-axis：Rest of mass [%]　X-axis：Time [s]

type1



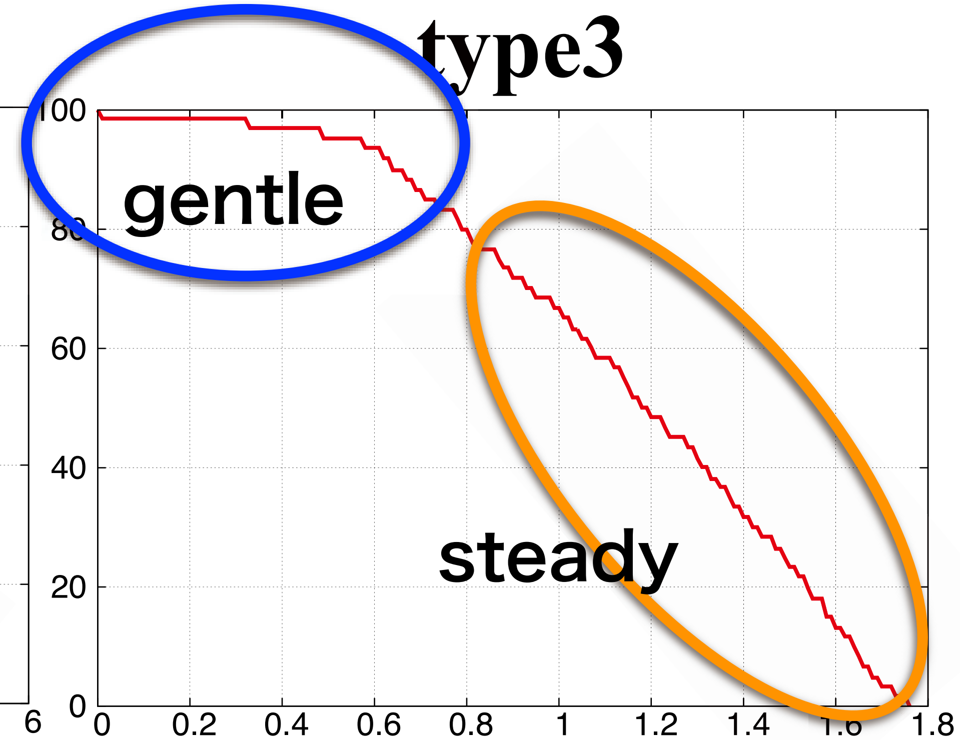
Fe+Mg+Al+C (17.7%)

type2

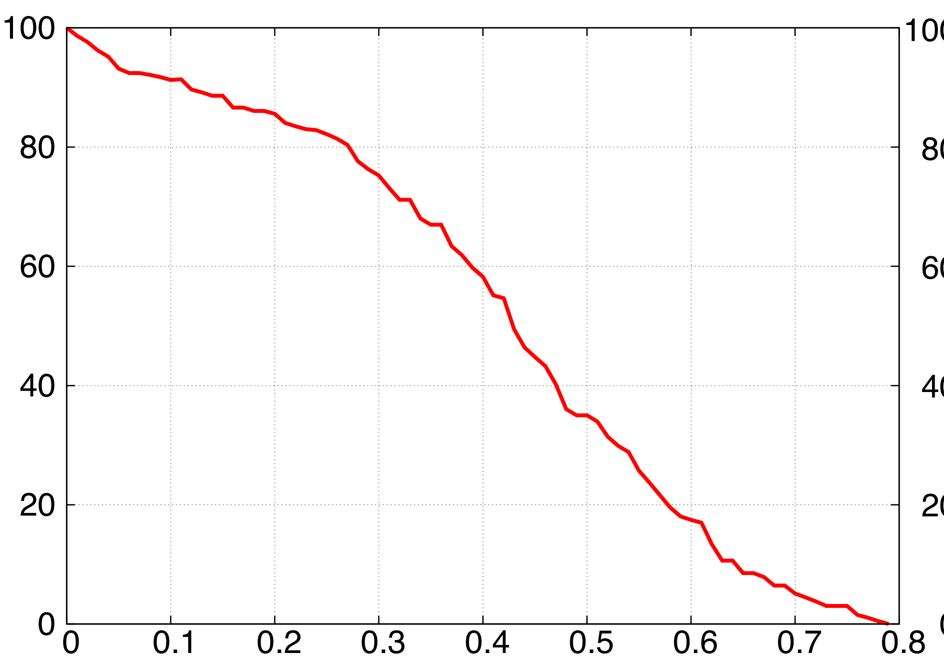


Chelyabinsk (W)

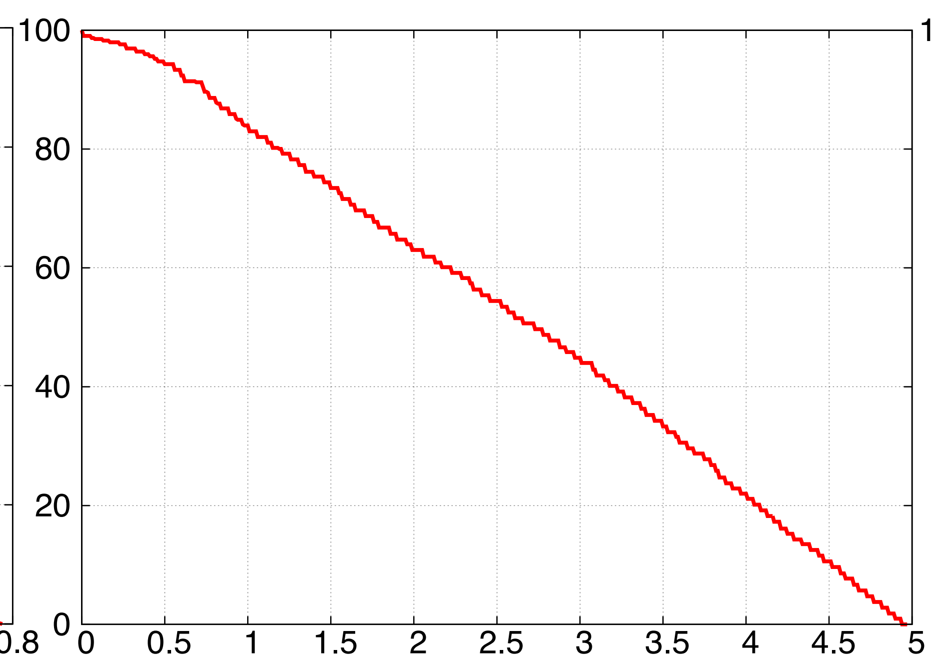
type3



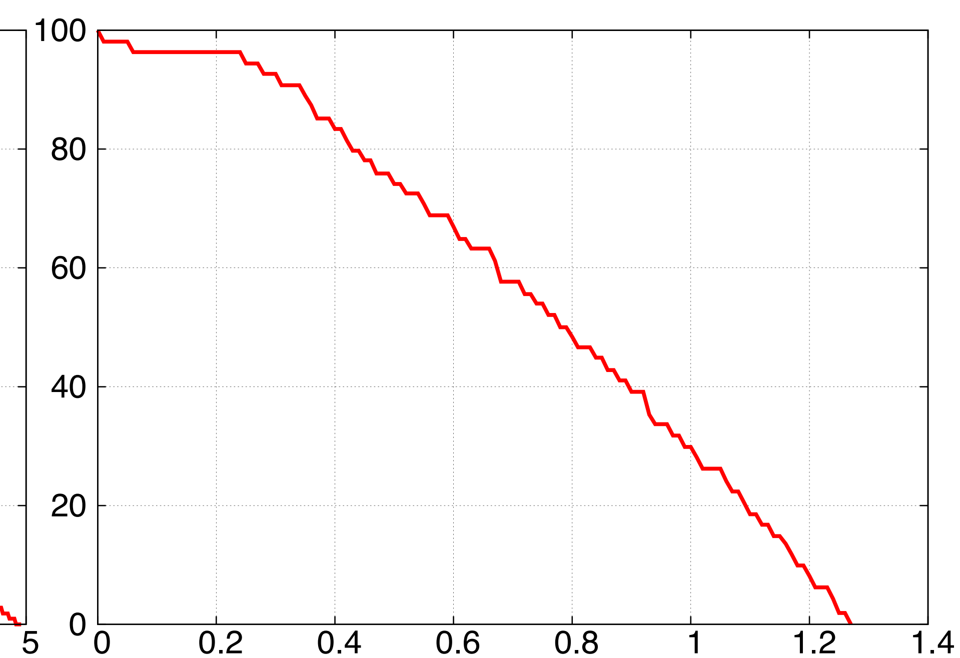
3D printer (10.0%)



Fe+Mg+Al+C (29.2%)

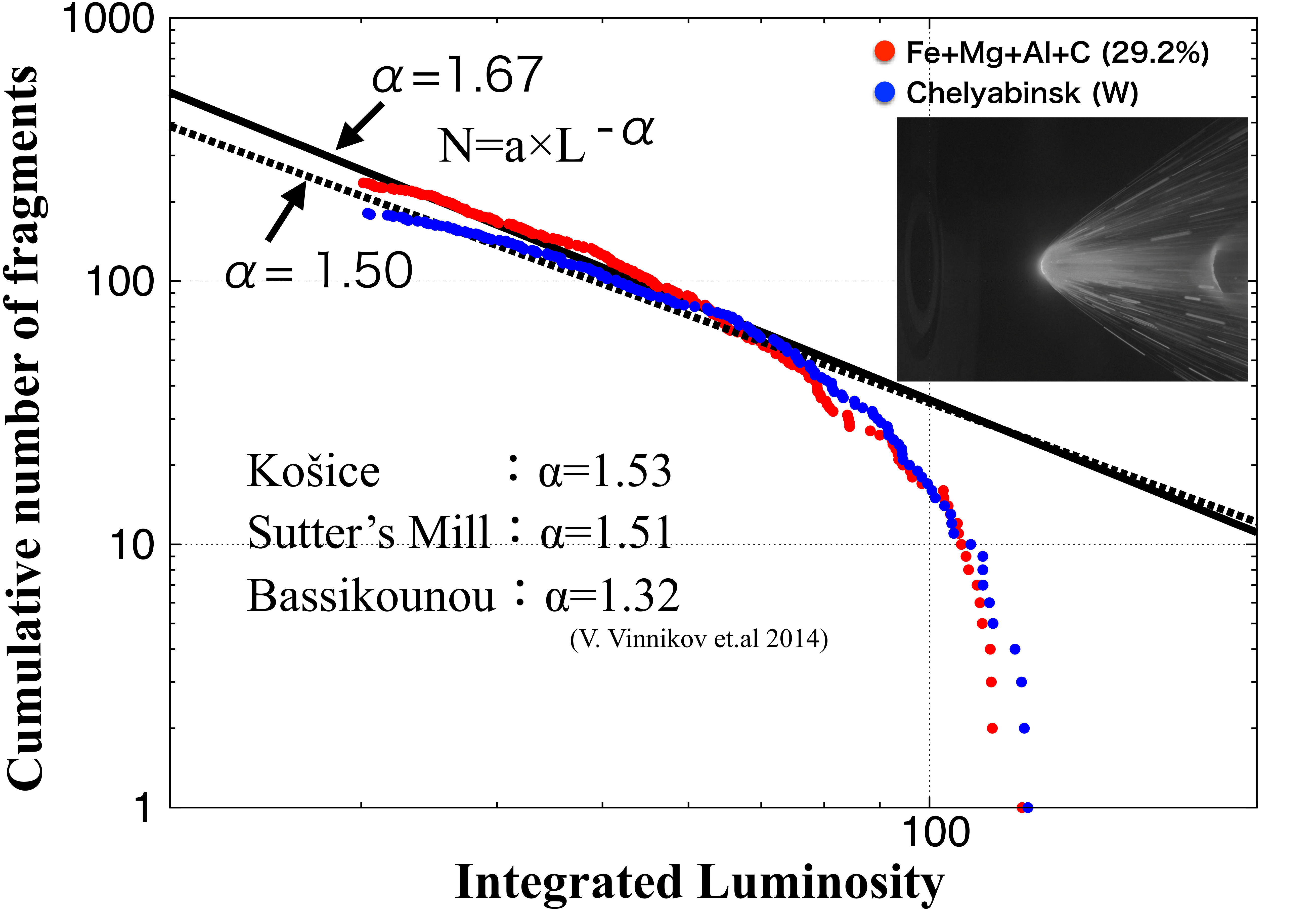


Chelyabinsk (B)

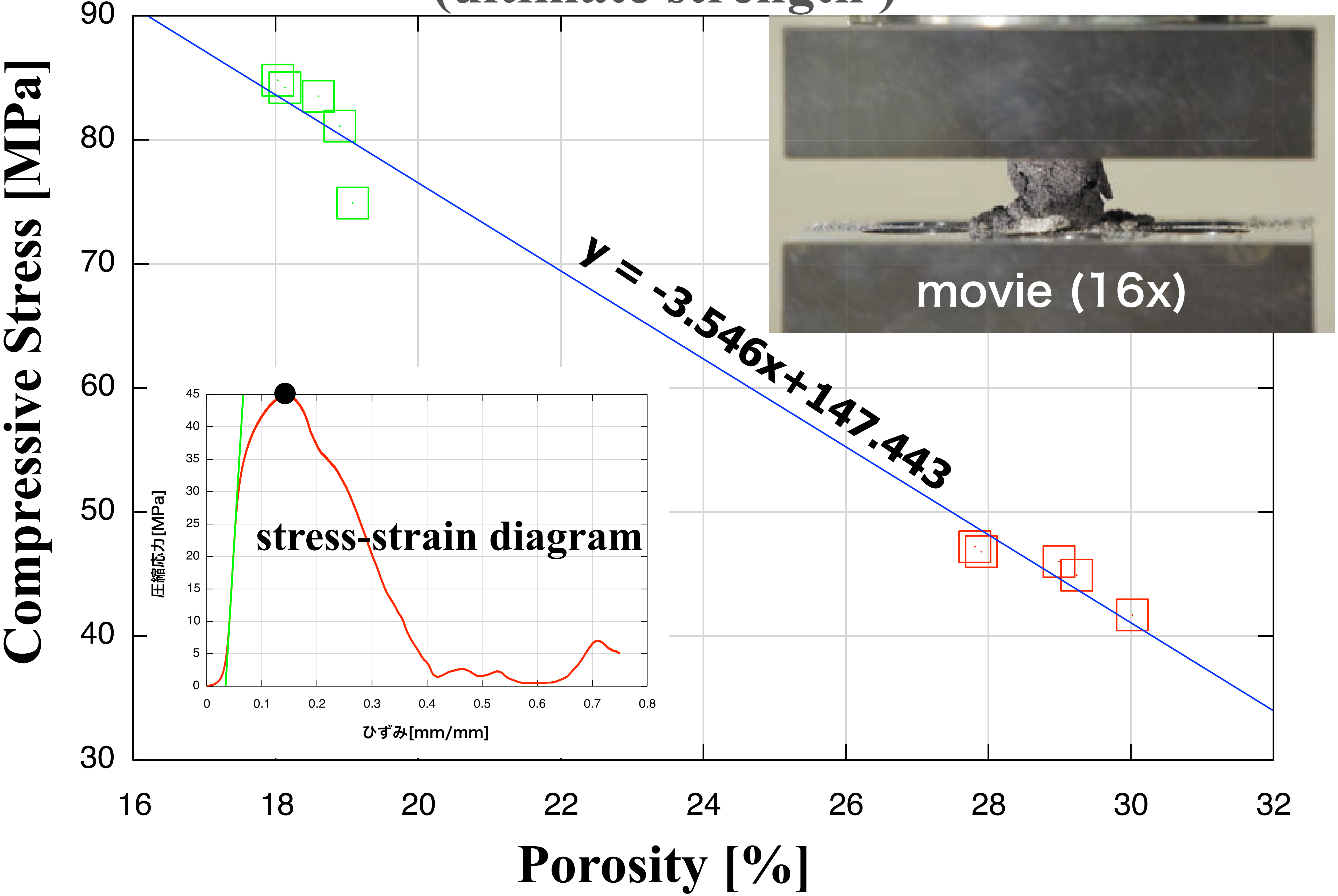


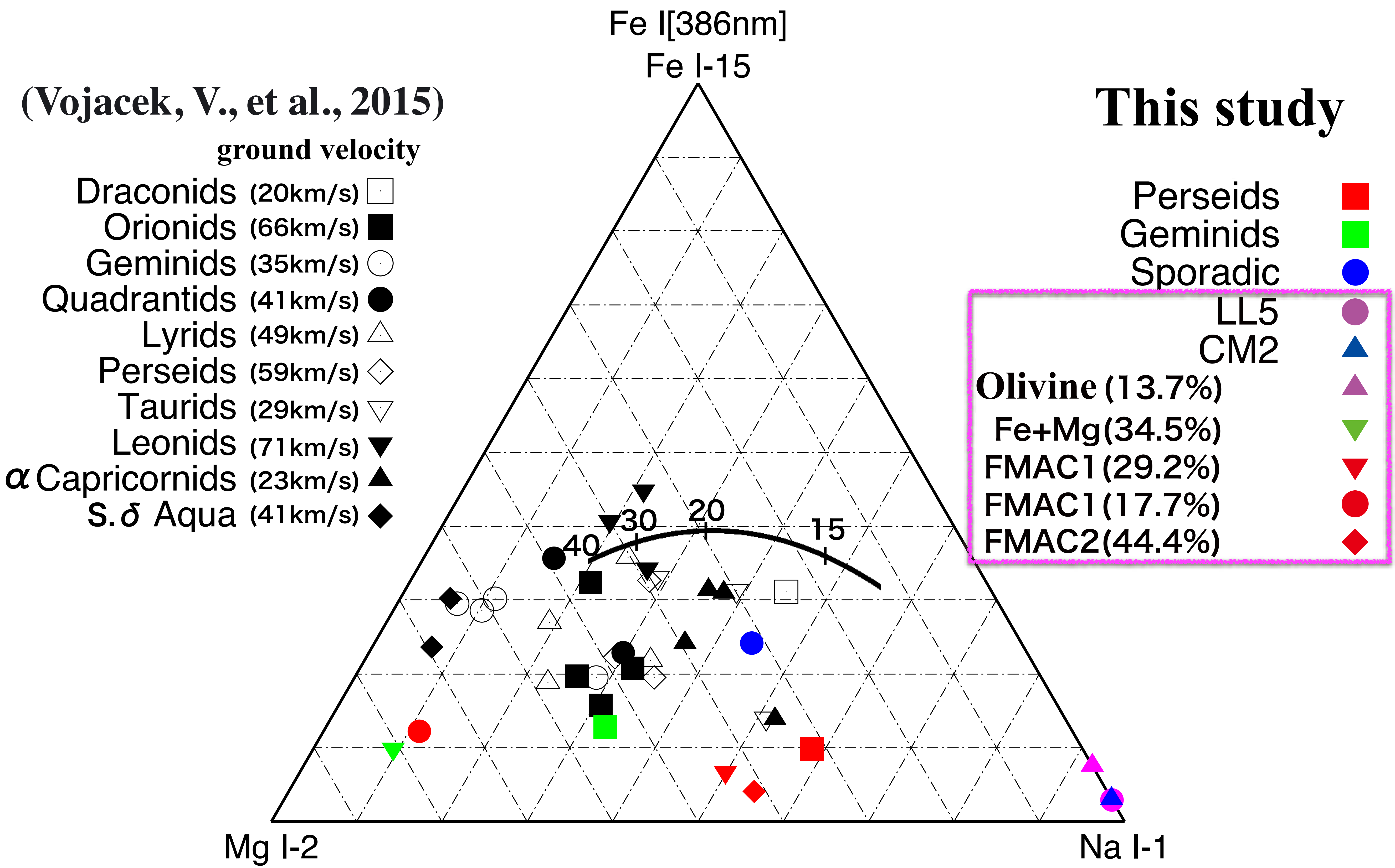
3D printer (20.0%)

Fragmentation

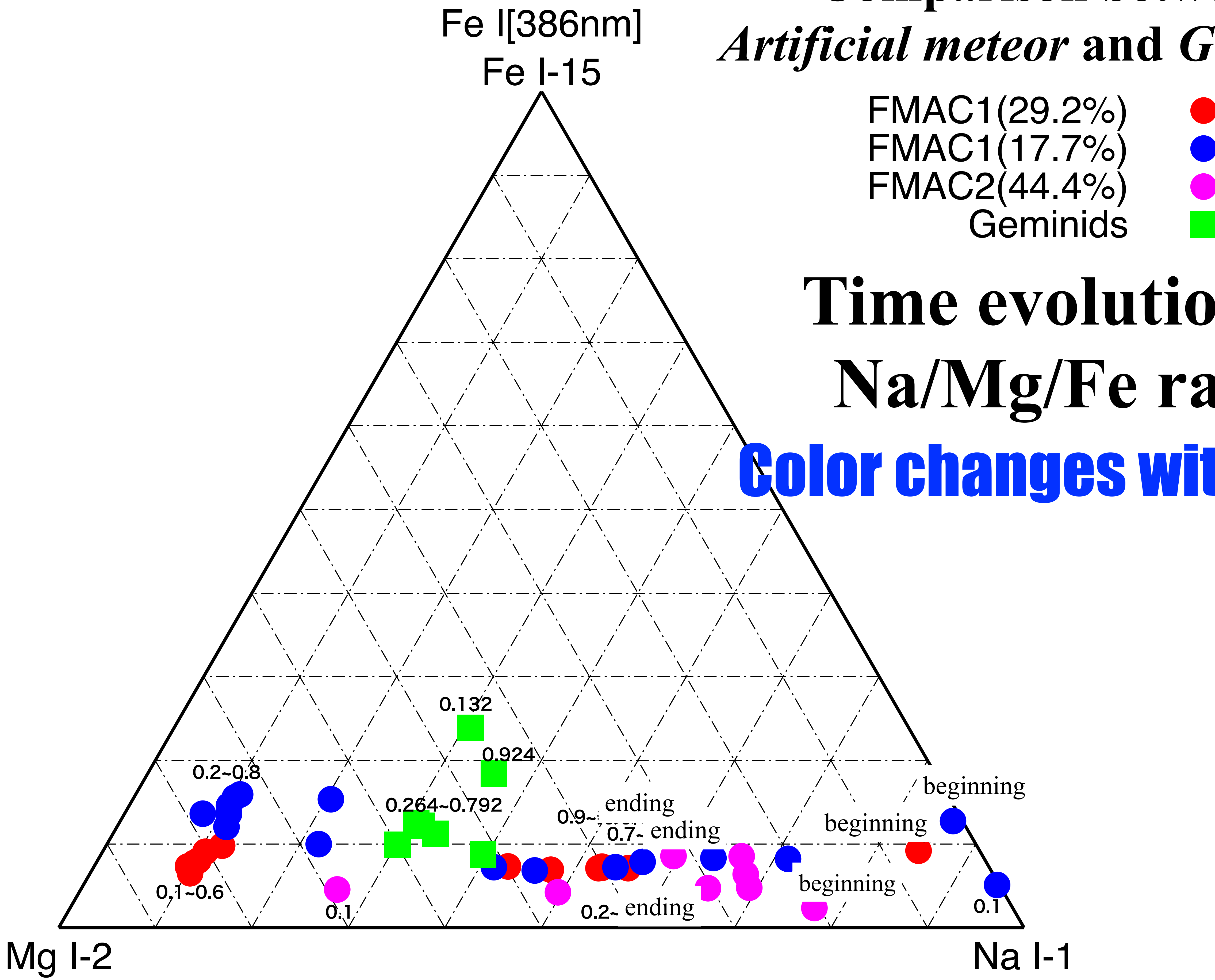


Fe+Mg+Al+C (FMAC)：Maximum compressive stress as a function of Porosity (ultimate strength)




Fe I[386nm]
Fe I-15
(Vojacek, V., et al., 2015)
ground velocity
Draconids (20km/s)
Orionids (66km/s)
Geminids (35km/s)
Quadrantids (41km/s)
Lyrids (49km/s)
Perseids (59km/s)
Taurids (29km/s)
Leonids (71km/s)
α Capricornids (23km/s)
S.δ Aqua (41km/s)
This study
Perseids
Geminids
Sporadic
LL5
CM2
Olivine (13.7%)
Fe+Mg(34.5%)
FMAC1(29.2%)
FMAC1(17.7%)
FMAC2(44.4%)
40
30
20
15
Mg I-2
Na I-1

Comparison between *Artificial meteor* and *Geminids*



Time evolution of Na/Mg/Fe ratio

Color changes with time.

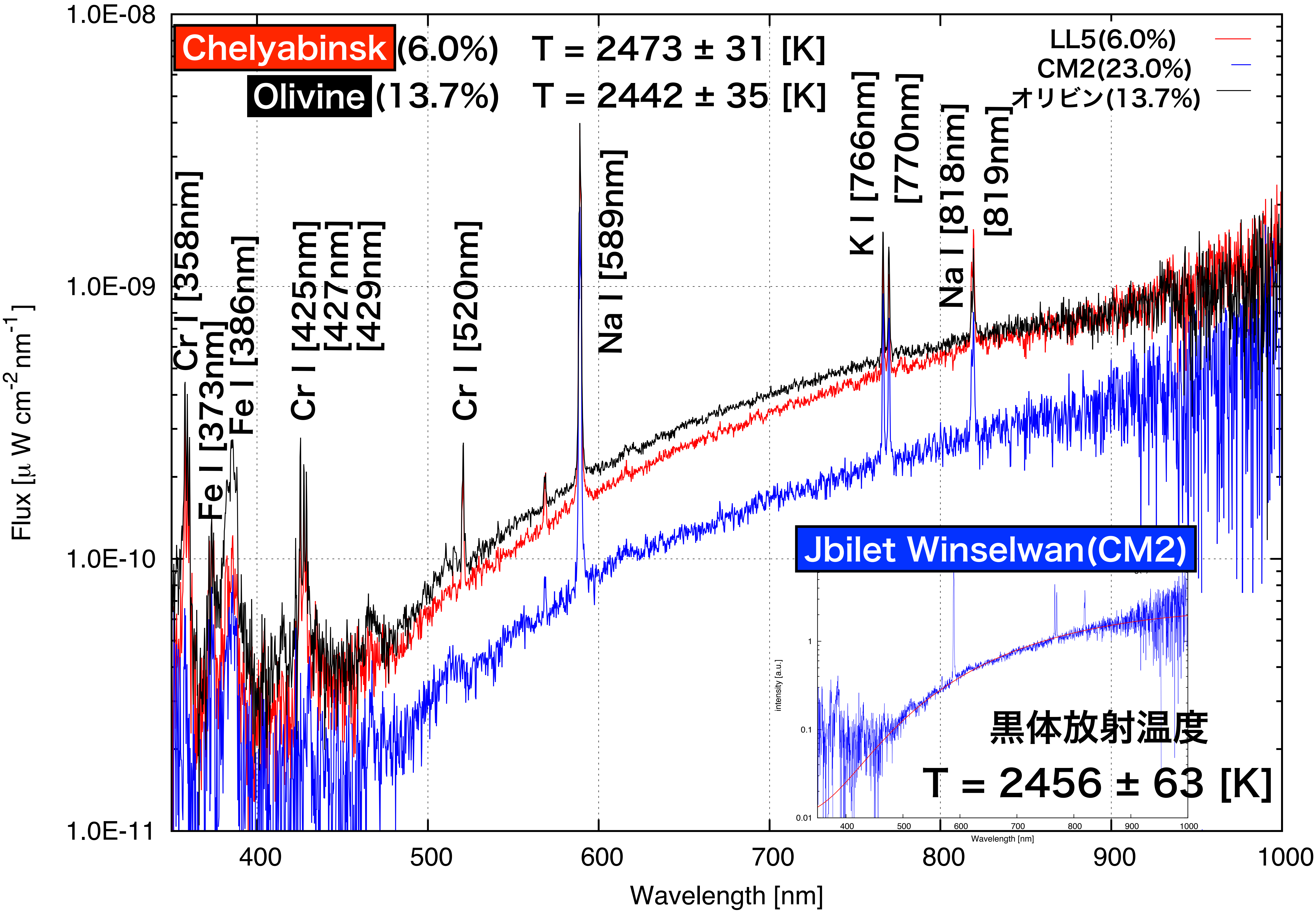
Artificial Meteors for Business & Science

ALE Co. Ltd., Tokyo Metropolitan Univ., Nihon Univ., Teikyo Univ.

Thank You

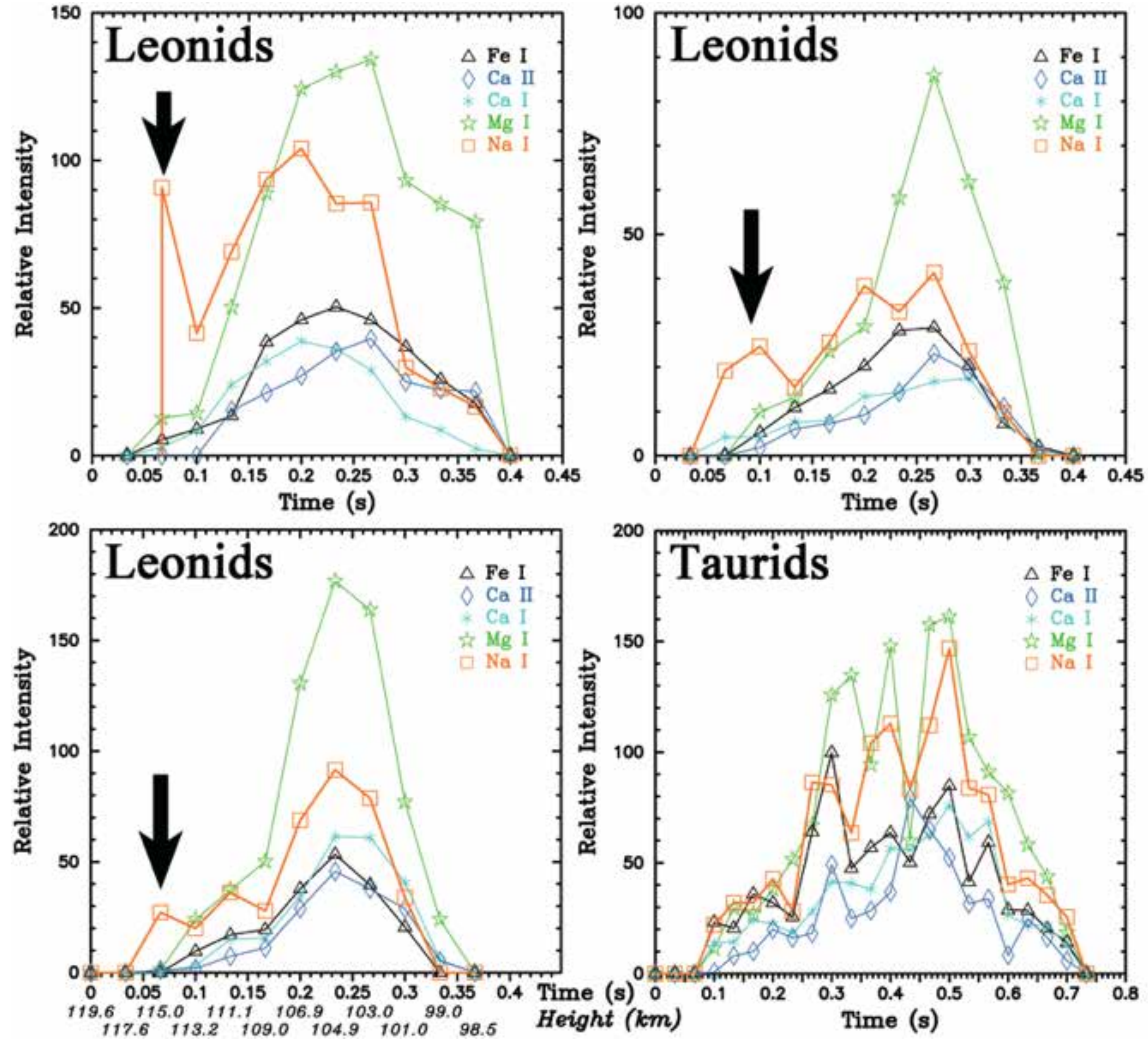
On-demand Meteor Shower

First test in 2018



Chelyabinsk (6.0%) T = 2473 ± 31 [K]
Olivine (13.7%) T = 2442 ± 35 [K]
LL5(6.0%)
CM2(23.0%)
オリビン(13.7%)
Cr I [358nm]
Fe I [373nm]
Fe I [386nm]
Cr I [425nm]
[427nm]
[429nm]
Cr I [520nm]
Na I [589nm]
K I [766nm]
[770nm]
Na I [818nm]
[819nm]
Jbilet Winselwan(CM2)
黒体放射温度
T = 2456 ± 63 [K]
Flux [μ W cm⁻² nm⁻¹]
Wavelength [nm]
1.0E-08
1.0E-09
1.0E-10
1.0E-11
400
500
600
700
800
900
1000

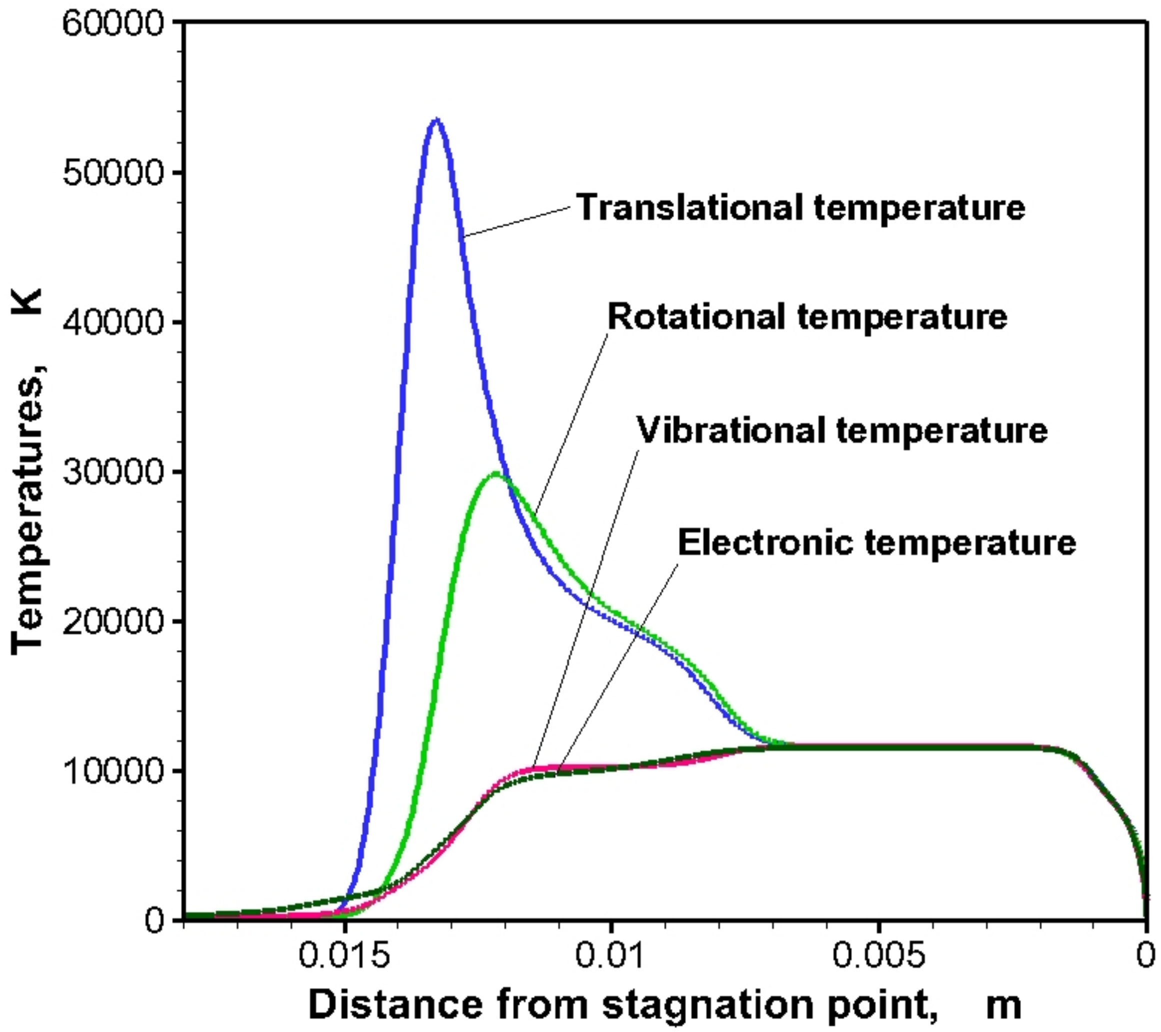
Differential ablation (Na early release) signature of structure & volatility of meteoroids

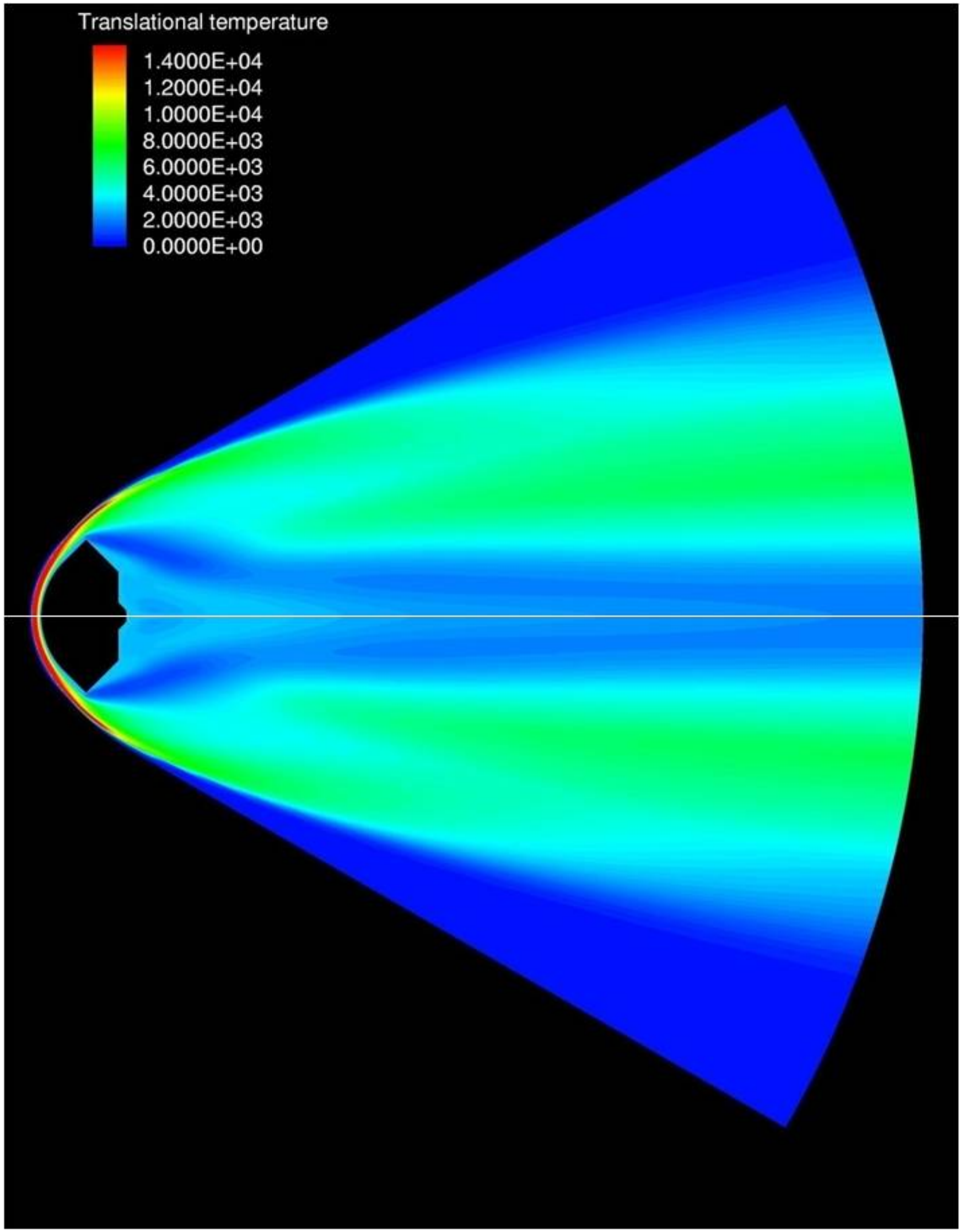


S. Abe (2009), Meteoroids and Meteors - observations and connection to parent bodies, Springer

CFD simulation of HAYABUSA capsule

Vibration-rotation temperature of ~13,000 K for $N_2^+ (1^-)$ and CN is reasonable.





Fujita, Abe et al. (2013)

- The vibration temperature of molecular $N_2^+(1^-)$ has dramatically changed from 4,000 K @ 92.5km to 13,000 K @ 82.9km.
- The observed spectra are a superposition of the post shock plasma radiation which is mixed with a shock layer heating and downward plasma. Thus, it is logical to understand that the high temperature region was induced by a shock layer of the spacecraft which rapidly grew between 92.5 km and 82.9 km in height.
- $N_2^+(1^-)$ bands originated from the spacecraft was much stronger than CN bands originated from the capsule in which Carbon was the major erosion product of the Carbon-Phenol heat shield of the capsule as seen by the Stardust capsule (Jenniskens 2010; Winter & Trumble 2011).

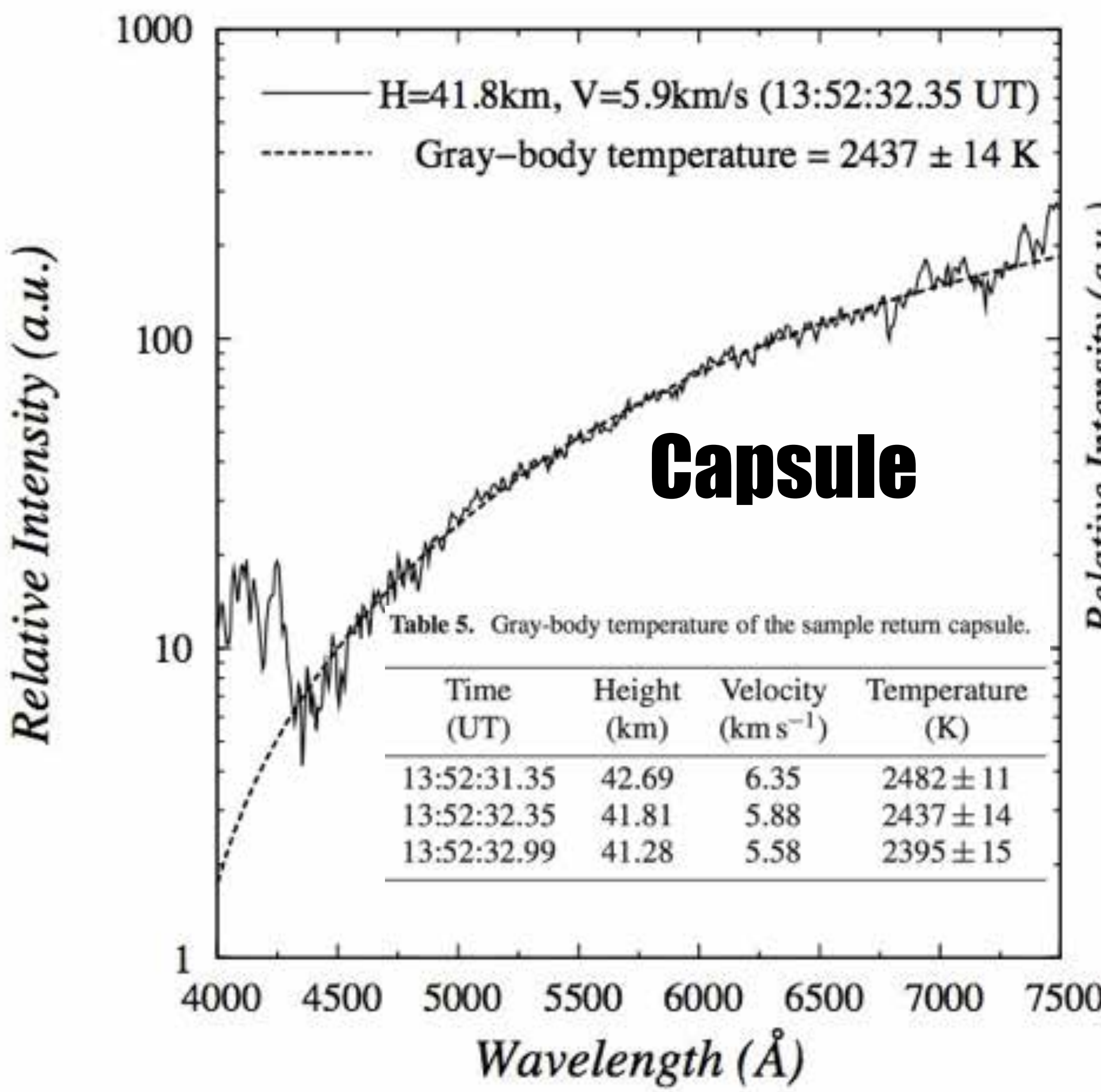
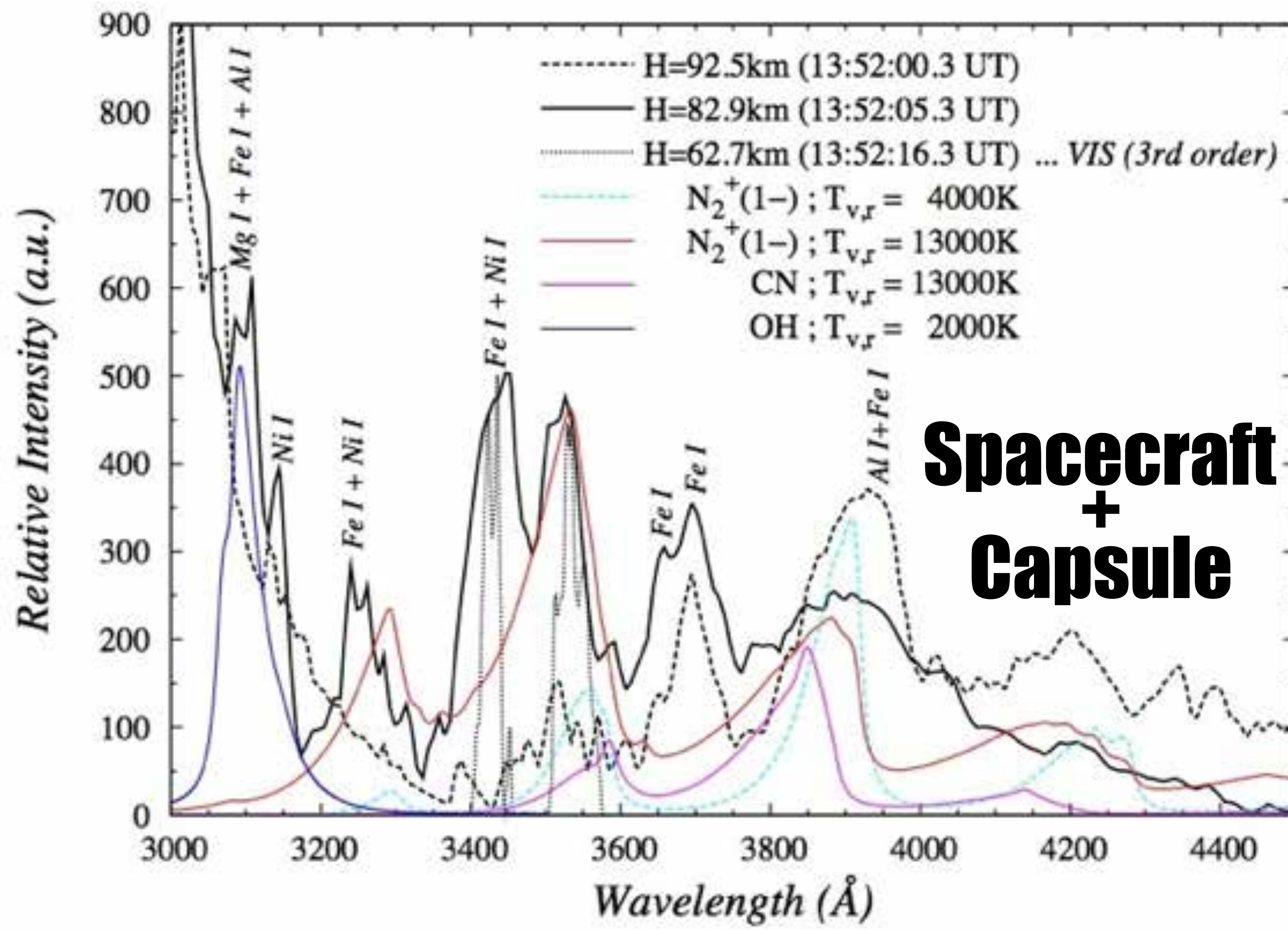
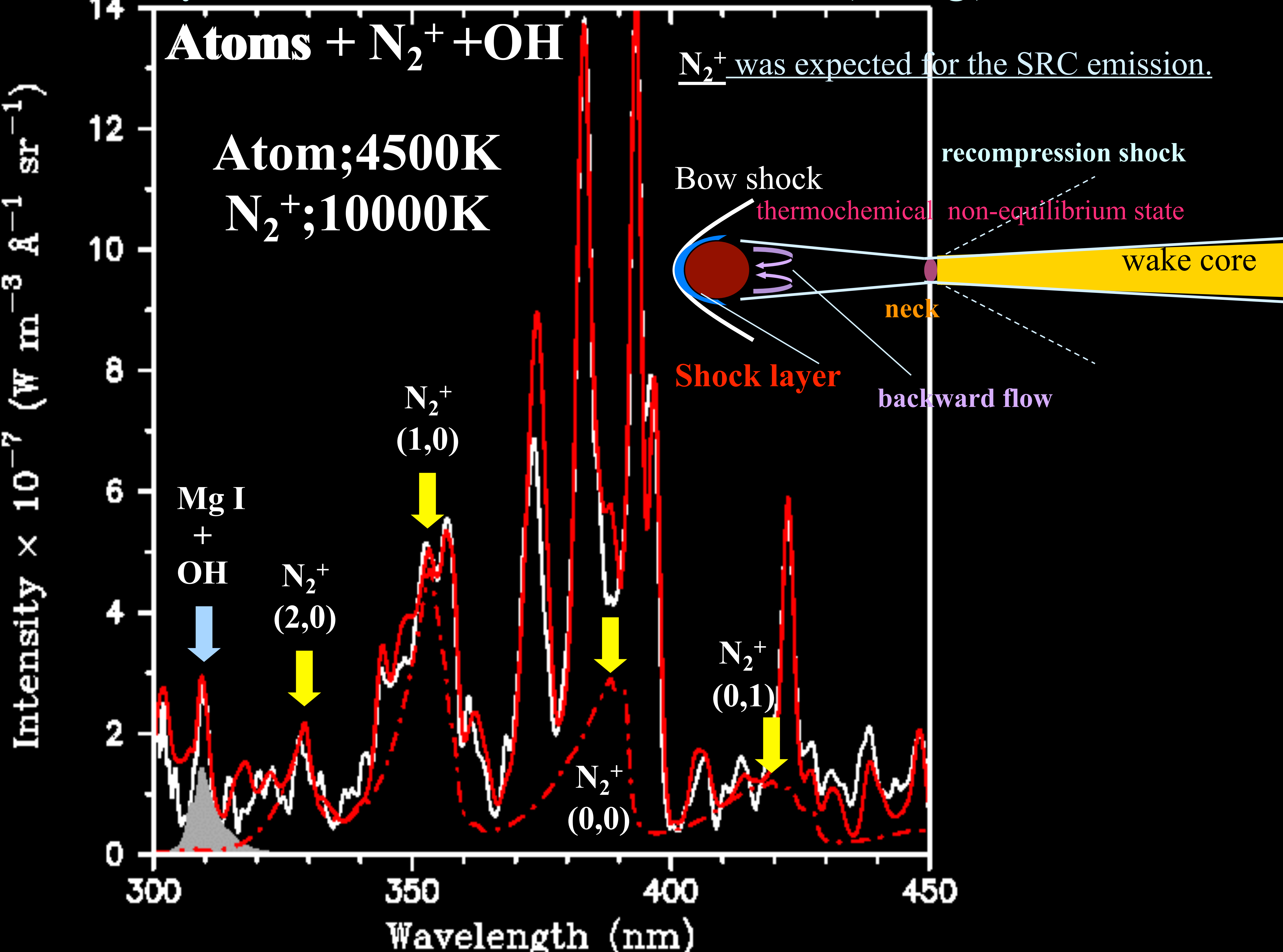


Table 5. Gray-body temperature of the sample return capsule.

Time (UT)	Height (km)	Velocity ($km\,s^{-1}$)	Temperature (K)
13:52:31.35	42.69	6.35	2482 ± 11
13:52:32.35	41.81	5.88	2437 ± 14
13:52:32.99	41.28	5.58	2395 ± 15



Discovery of Molecular Bands in Leonid Fireball(-5 mag.)



Abe, et al. ApJ *618*, L141-L144, 2005.

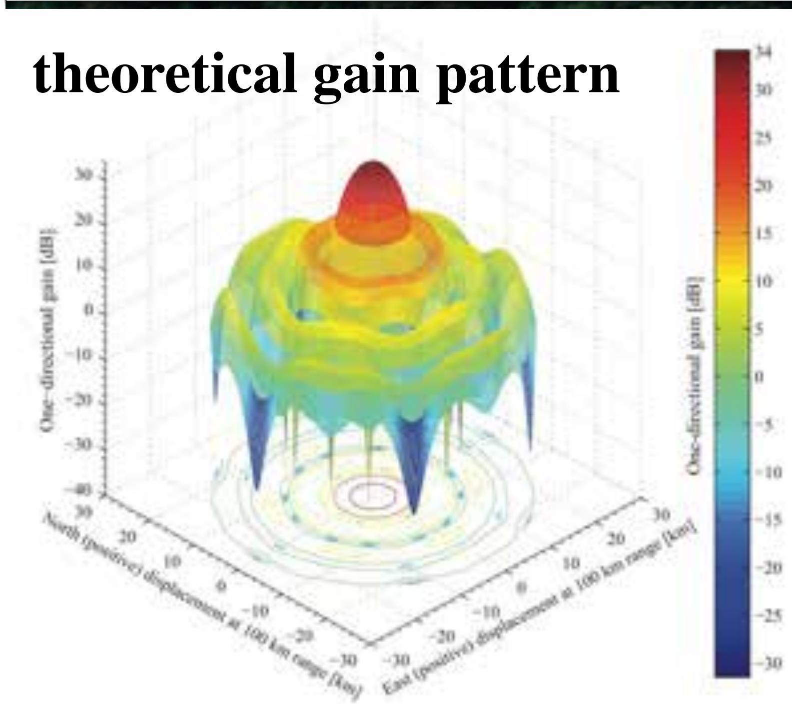
Kyoto University, RISH

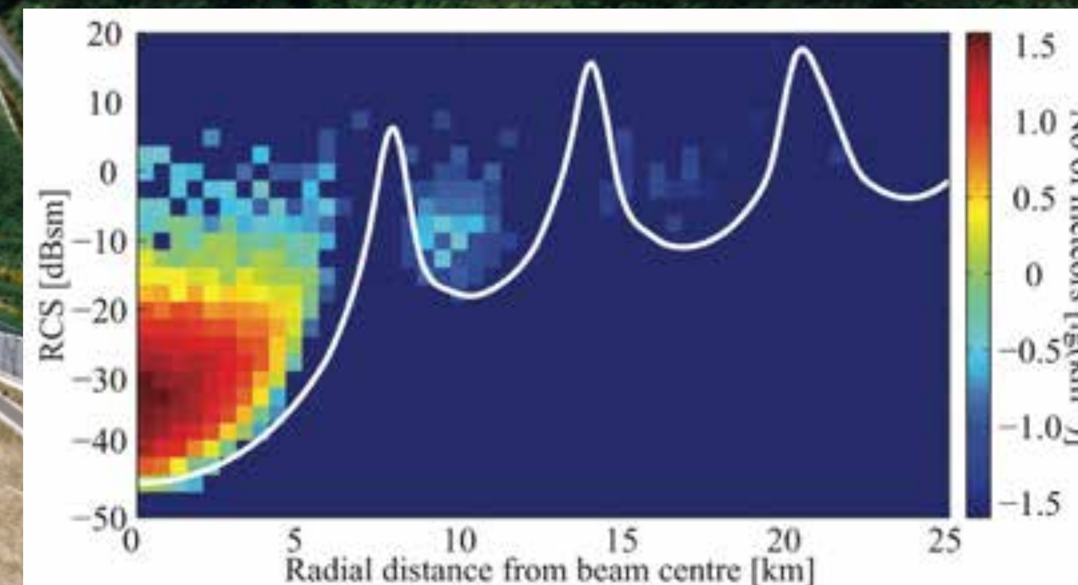
Middle and Upper Atmosphere Radar

Monostatic coherent pulse Doppler radar

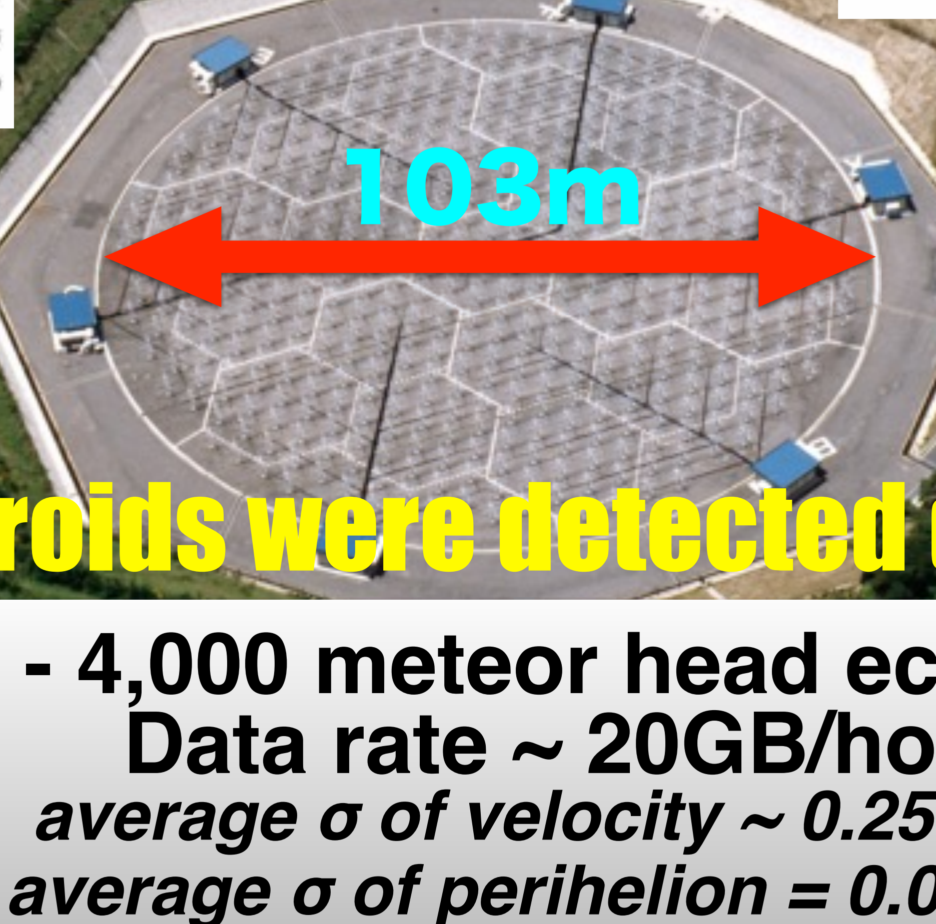
VHF (46.5 MHz), 1MW peak power, 475 crossed Yagi antennas

Pulse length: 1-500μs, Antenna aperture: 8330m^2 (D=103m)





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



>150k meteoroids were detected during 2009-2015

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

Data rate ~ 20GB/hour

average σ of velocity ~ 0.25 km/s

average σ of perihelion = 0.003 AU