IMC 2024, Sep 19-22
Session5: 16:19-16:35

Annual Variation of Sodium in the Geminid Meteor Shower

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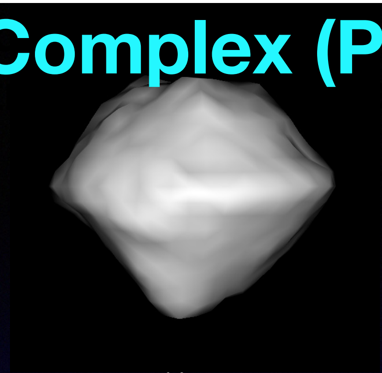
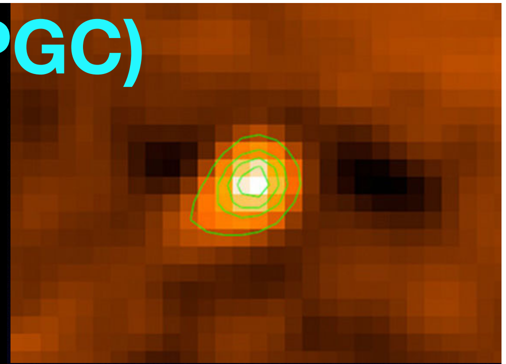
Phaethon-Geminids-Complex (PGC)





- Phaethon displays comet-like activity with a faint tail extending ~ 250,000 km from the nucleus (*Jewitt, D. et al., 2013*), and brightening near perihelion, associated with gas emission (*Jewitt, D. & Li, 2010: Zhang, Q. et al., 2023*).
- (3200) Phaethon's surface reaches temperatures up to ~750 ˚C at perihelion (0.14 au) (*e.g., MacLennan, E. et al., 2021*).
- JAXA's DESTINY+ mission; launching in 2025, fly-by in 2029 (Arai, T. et al., 2021)
- Sufficient for the thermal decomposition and volatile emission from chondritic mineral phases (*e.g., Masiero, J. R. et al., 2021*).
- The decomposition mechanism and which specific minerals are causing observed Phaethon's emissions are still unclear.
- Na in Geminids' meteoroids provides additional information on origin and evolution of PGC (*e.g., Abe, S. et al. 2020*).

Instruments

Camera

SONY α7S(ILCE-7S)

CMOS sensor 35.6 x 23.8 mm(12.2 Mpix)

HDMI output: 3840 x 2160(4K), RGB 8bit

ISO 100-102400 (extend: 128000-409600)

With IR filter, without IR filter

Lens

SIGMA 35mm/F1.4 (FOV=63.4 deg)

SIGMA & Canon 24mm/F1.4 (FOV=84.1 deg)

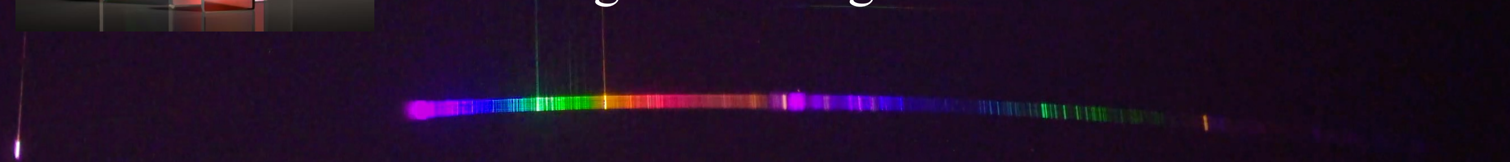
Spectrograph

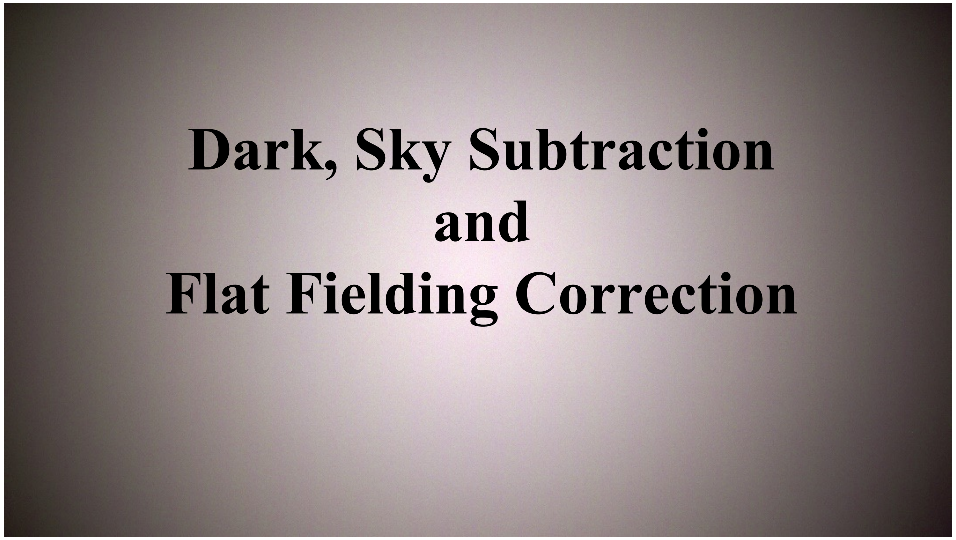
Transmission Grating（Edmmund VIS 600）

Grooves: 600/mm

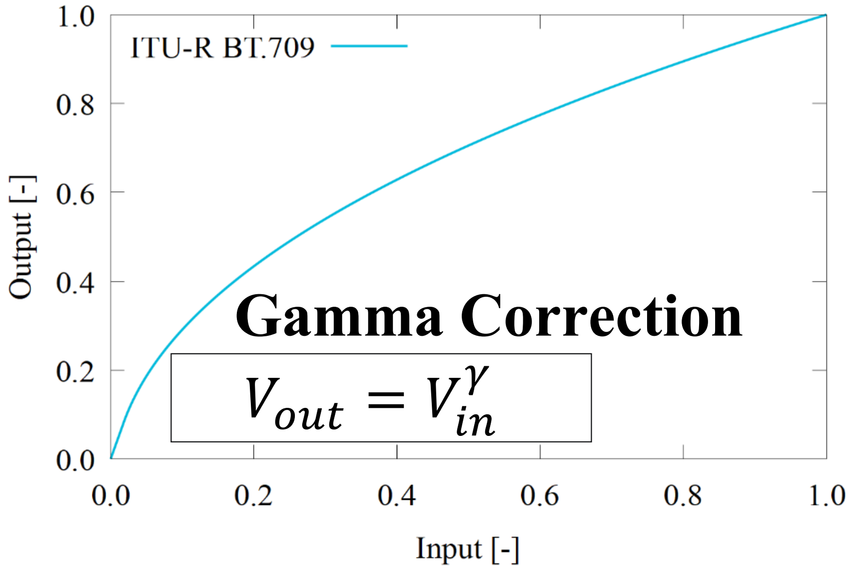
Size: 50 x 50 mm

Blazed angle: 28.7 deg

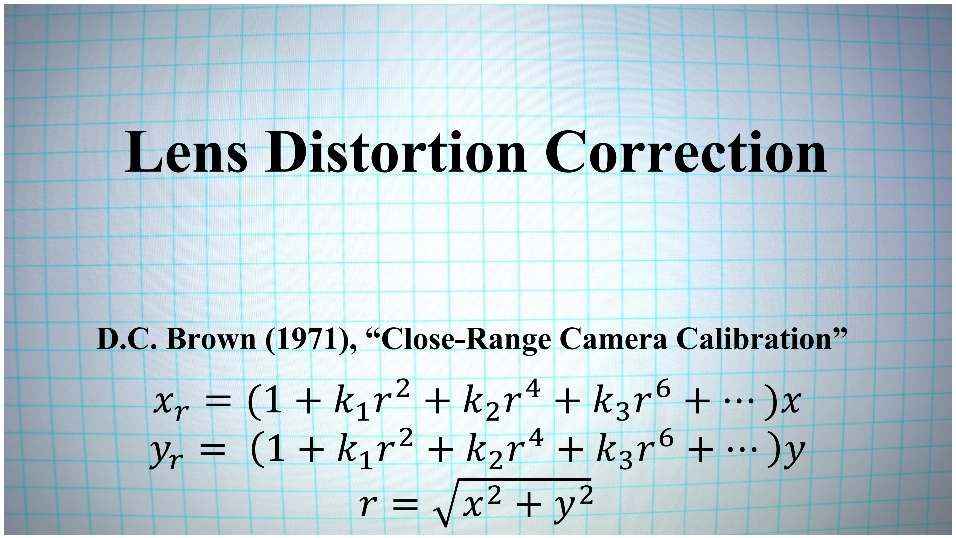




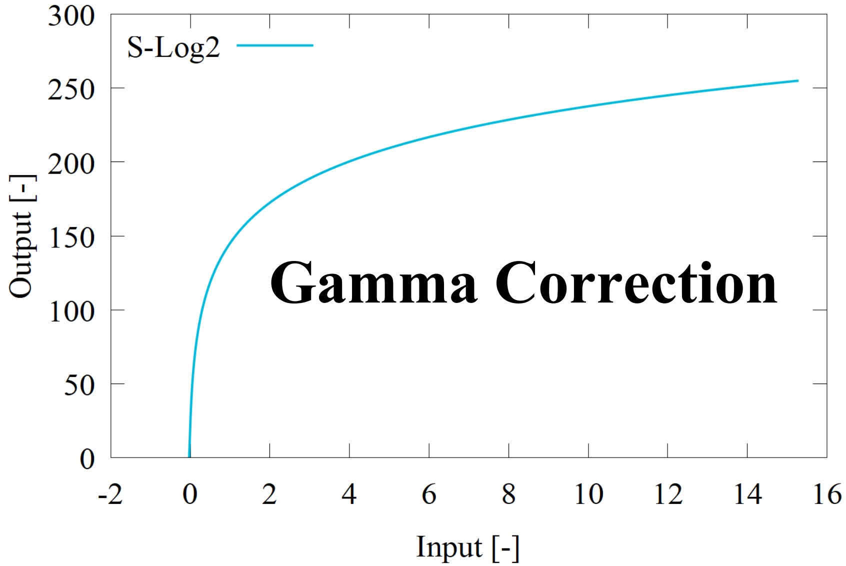
Dark, Sky Subtraction
and
Flat Fielding Correction



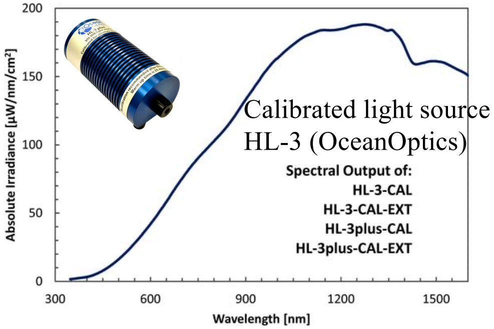
1.0
0.8
0.6
0.4
0.2
0.0
Output [-]
ITU-R BT.709
Gamma Correction
$V_{out} = V_{in}^{\gamma}$
0.0
0.2
0.4
0.6
0.8
1.0
Input [-]



Lens Distortion Correction
D.C. Brown (1971), "Close-Range Camera Calibration"
$x_r = (1 + k_1 r^2 + k_2 r^4 + k_3 r^6 + \cdots)x$
$y_r = (1 + k_1 r^2 + k_2 r^4 + k_3 r^6 + \cdots)y$
$r = \sqrt{x^2 + y^2}$

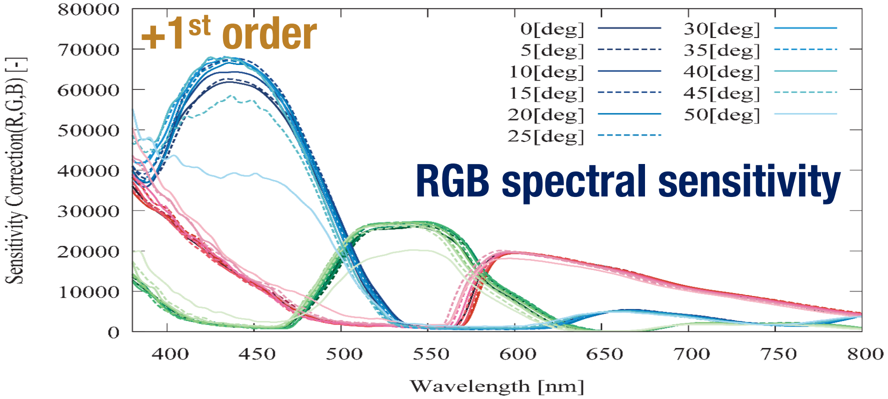


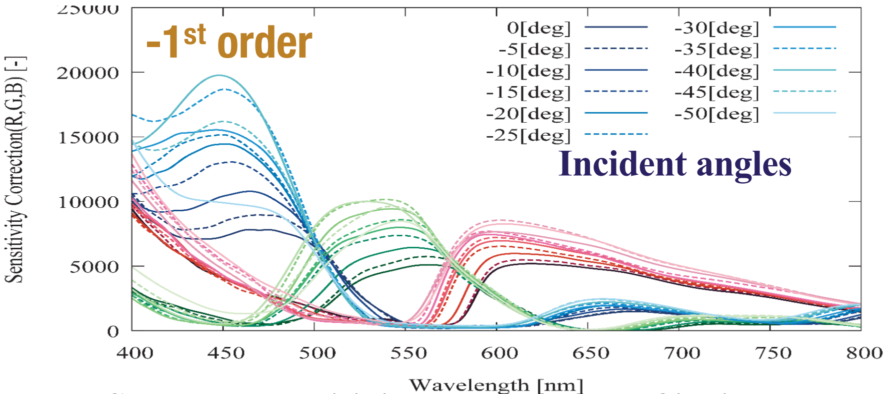
300
250
200
150
100
50
0
Output [-]
S-Log2
Gamma Correction
-2
0
2
4
6
8
10
12
14
16
Input [-]



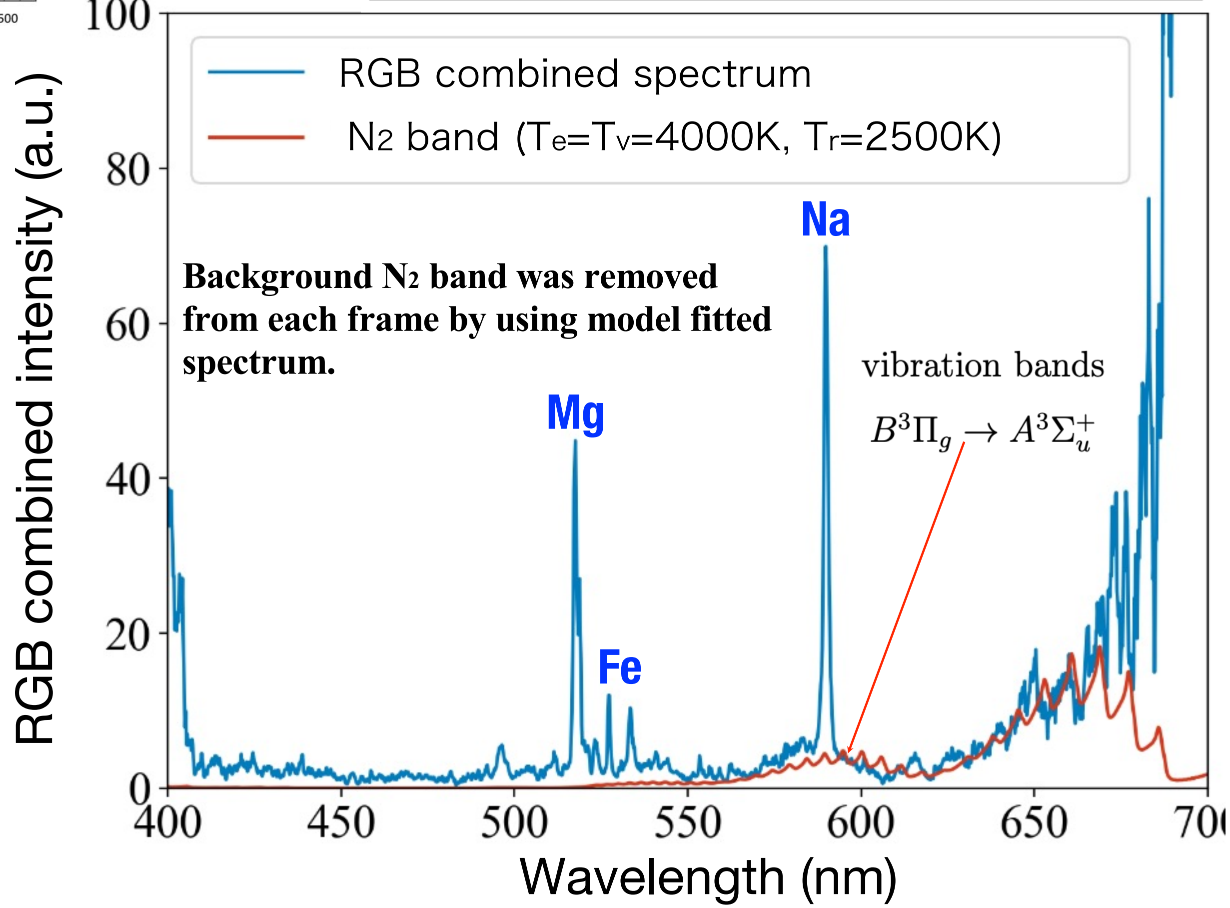
Analyzed meteor spectral lines.

Wavelength (nm)	Chemical elements	Multiplet
Meteor lines		
518.2	Mg I	2
526.9, 532.8, 537.1, 540.4, 543.1, 544.9	Fe I	15
589.2	Na I	1
Atmospheric lines		
500.0–700.0	N_2	vibration bands $B^3\Pi_g \rightarrow A^3\Sigma_u^+$



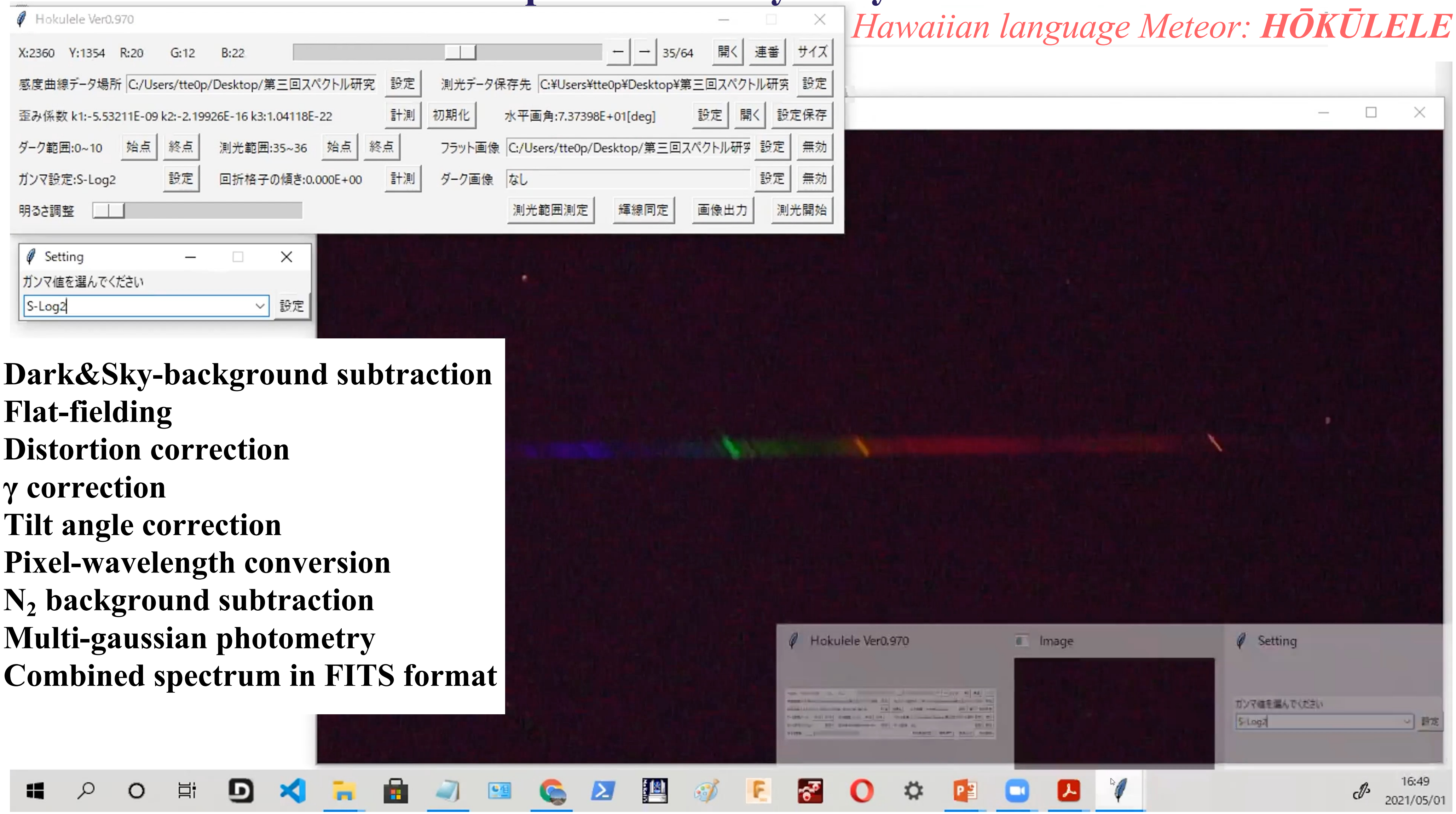


Spectrum sensitivity as a function of incident angle was adopted for ±1 order spectra.



Color/B&W Meteor Spectrum Analysis Python Software *HOKULELE*

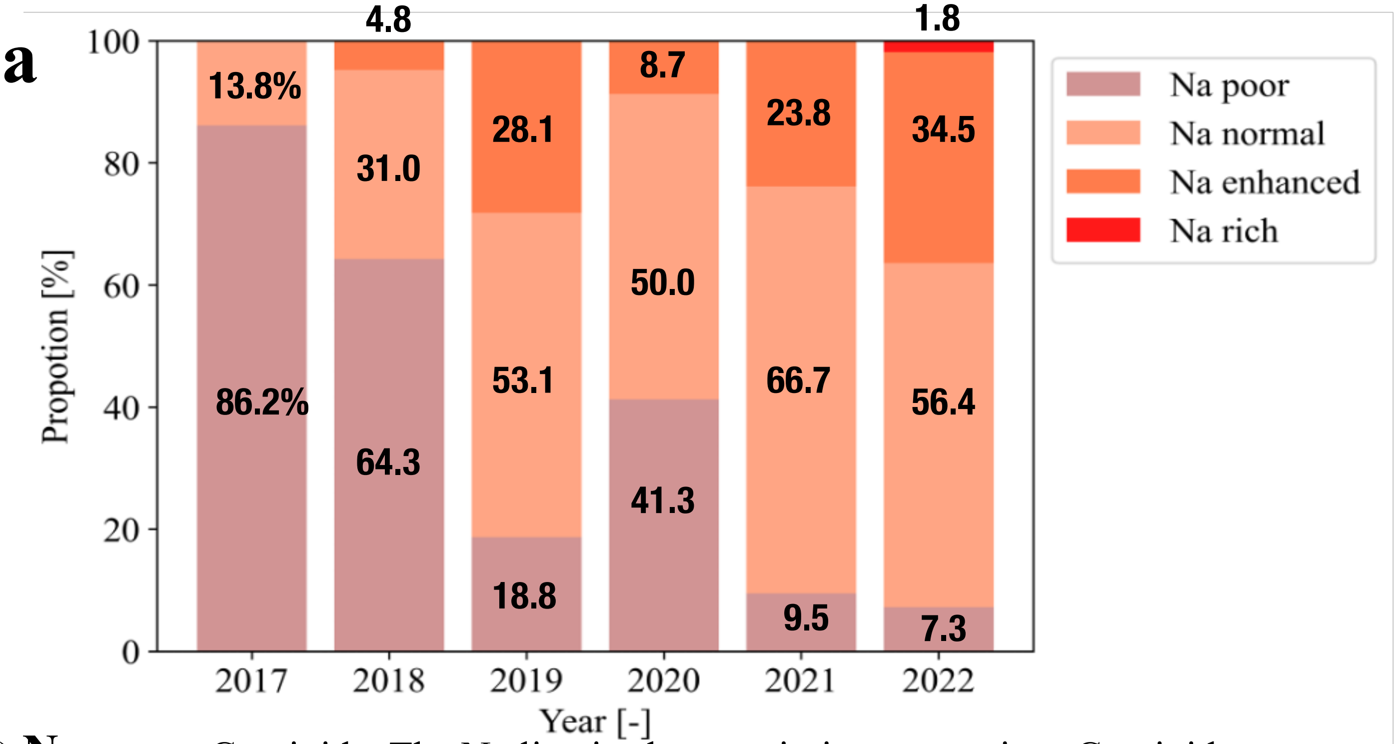
Hawaiian language Meteor: ***HŌKŪLELE***



- ✓ **Dark&Sky-background subtraction**
- ✓ **Flat-fielding**
- ✓ **Distortion correction**
- ✓ **γ correction**
- ✓ **Tilt angle correction**
- ✓ **Pixel-wavelength conversion**
- ✓ **N_2 background subtraction**
- ✓ **Multi-gaussian photometry**
- ✓ **Combined spectrum in FITS format**

Annual variation of Na

Year	Num. of Spectrum
2017	65
2018	84
2019	32
2020	46
2021	84
2022	220
Total	531



(a) **Na-poor** Geminids; The Na line is almost missing except iron Geminids.

Na < 10%, while Fe/Mg ratio varies widely.

(b) **Na-normal** Geminids; The Na line is similar to the expected chondritic value.

10% < Na < 30%

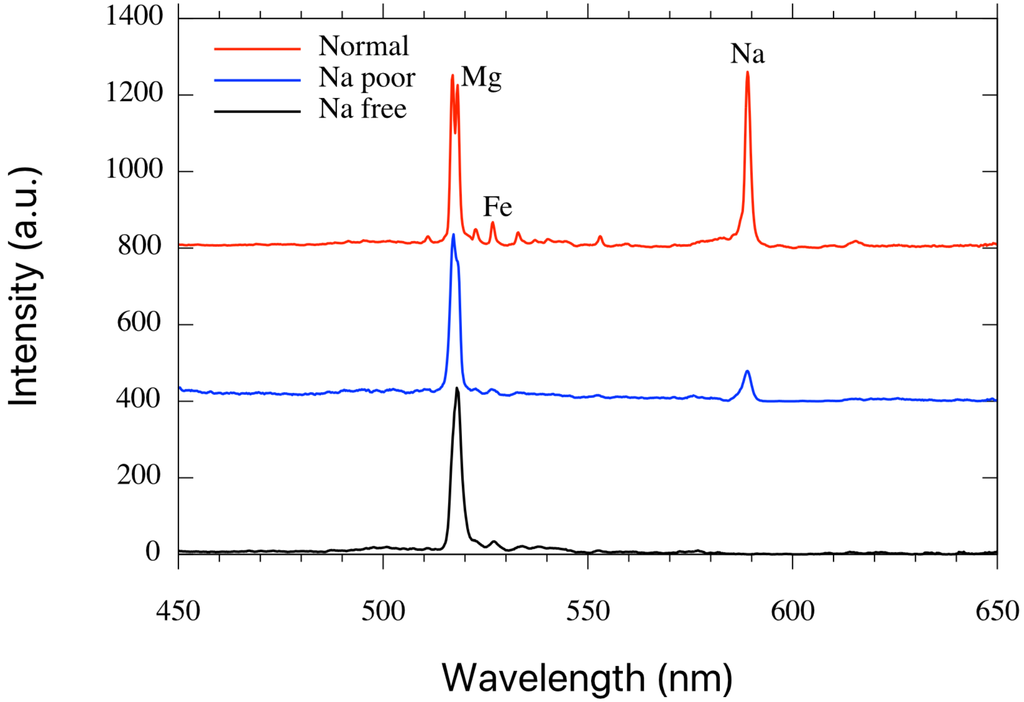
(c) **Na-enhanced** Geminids; The Na line is stronger than the expected chondritic value.

30% < Na < 80%

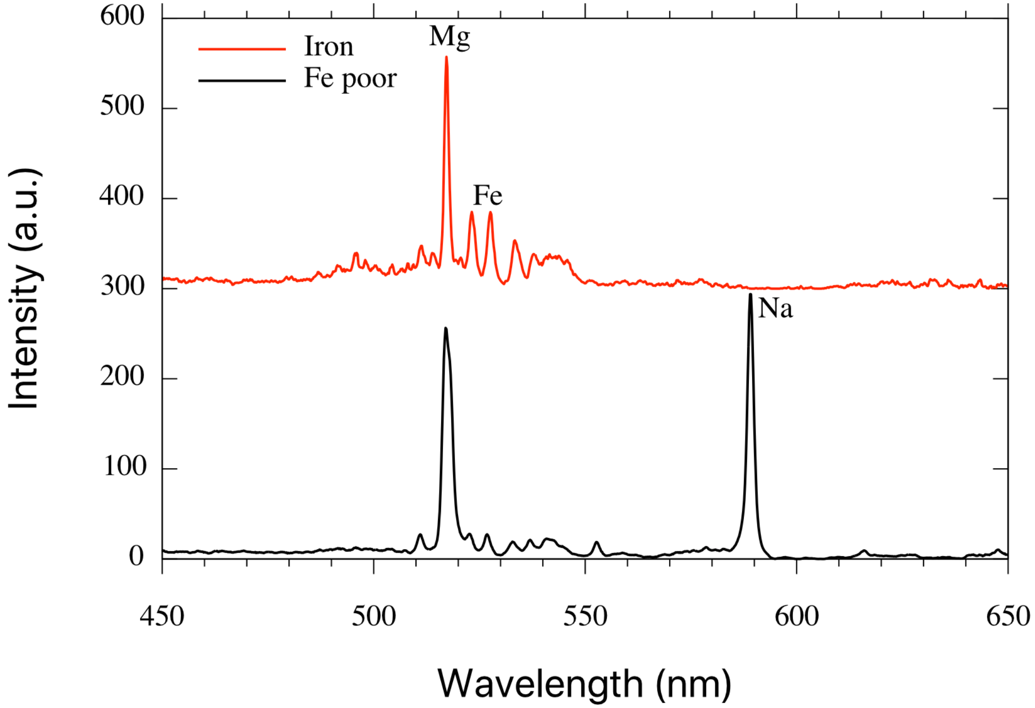
(d) **Na-rich** Geminids; The Na line is much stronger than the expected chondritic value.

80% < Na

Geminids categorized by Na intensity

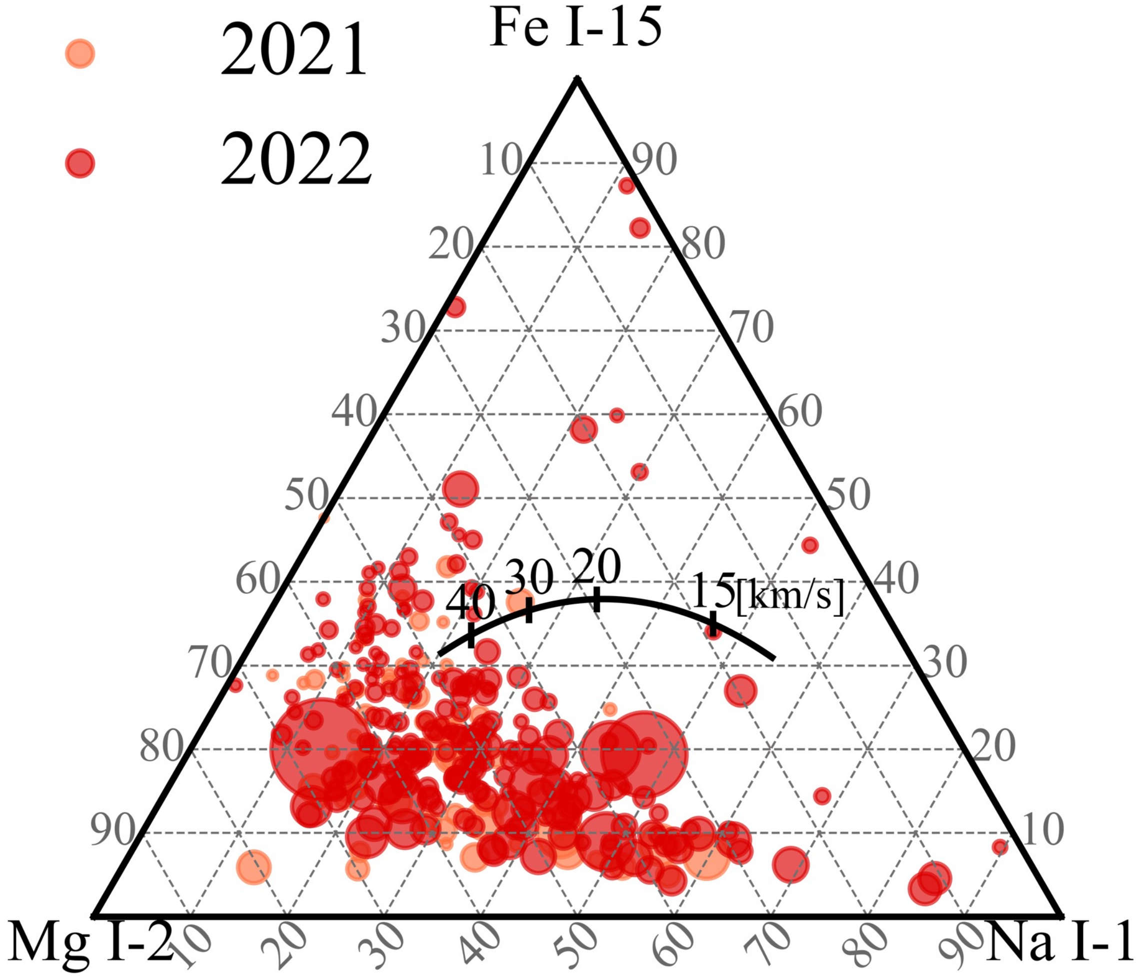


Extraordinary Geminids spectrum



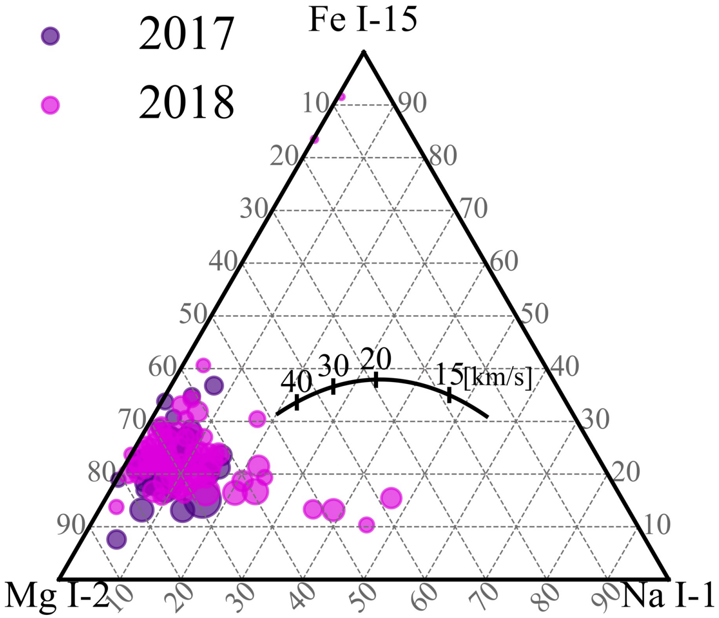
Iron Geminids

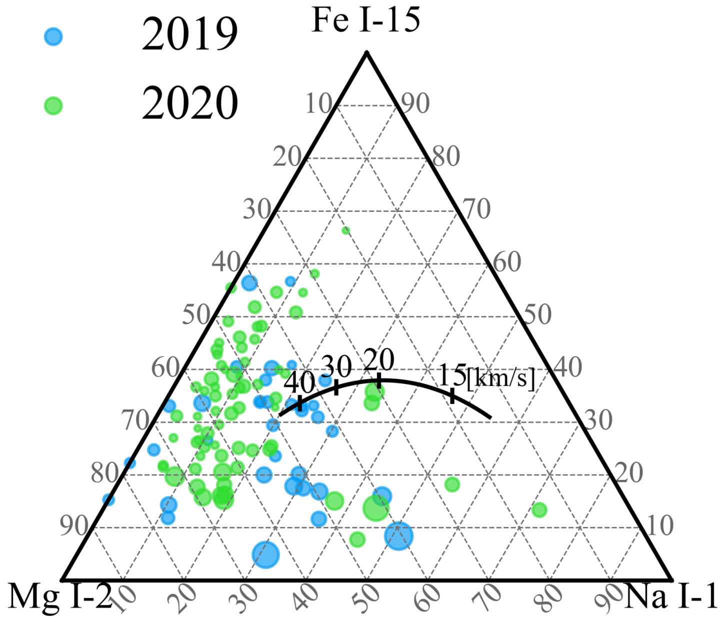
Ternary diagram of Geminids

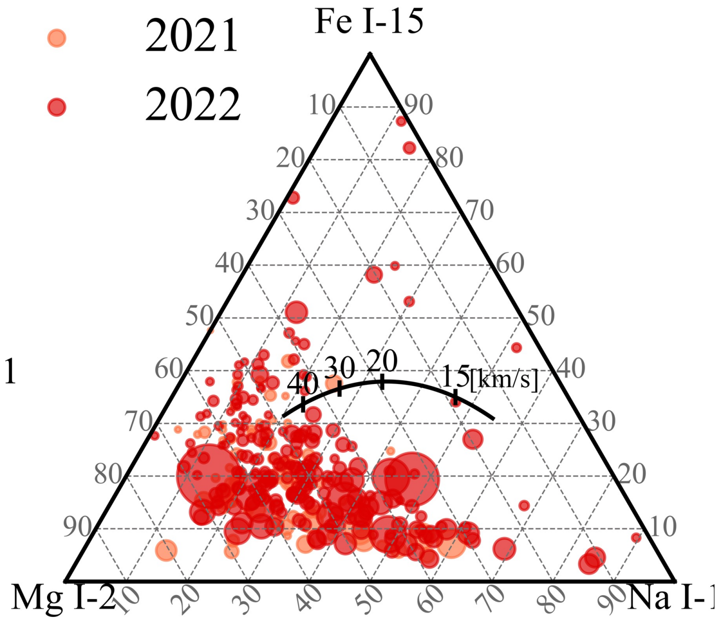


[1] Abe, S. et al., (2020) Planet. Space Science 194.
[2] Abe, S. et al., (2024) in prep.

Ternary diagram of Geminids







[1] Abe, S. et al., (2020) Planet. Space Science 194.
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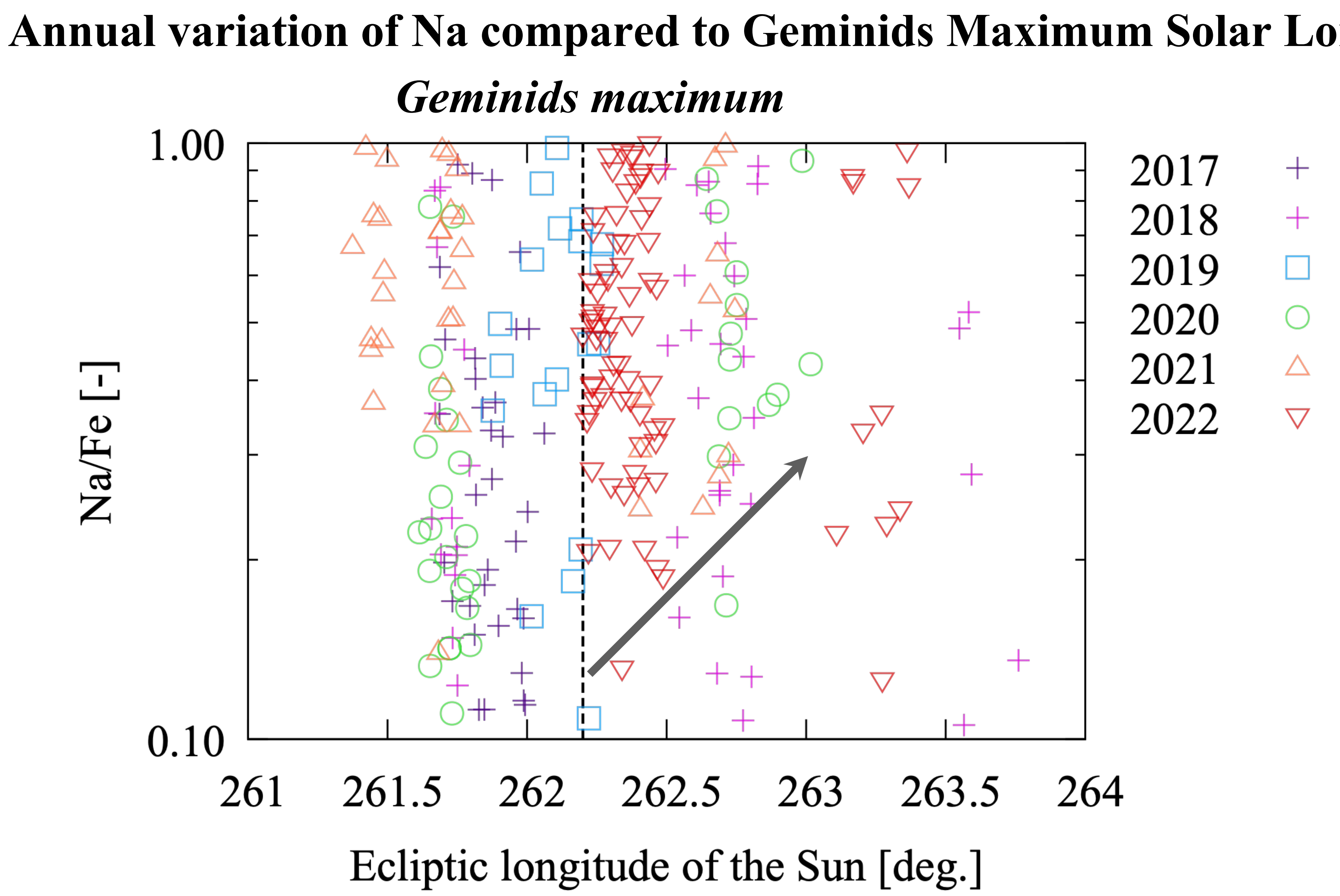
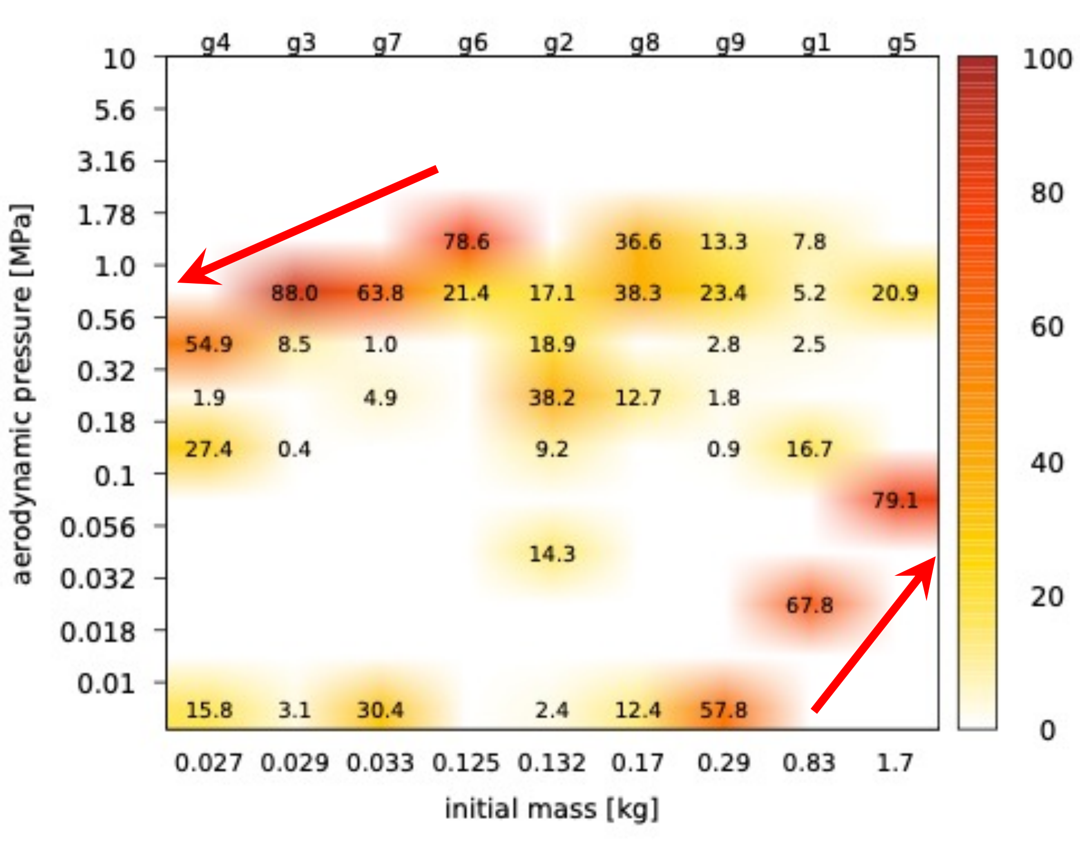
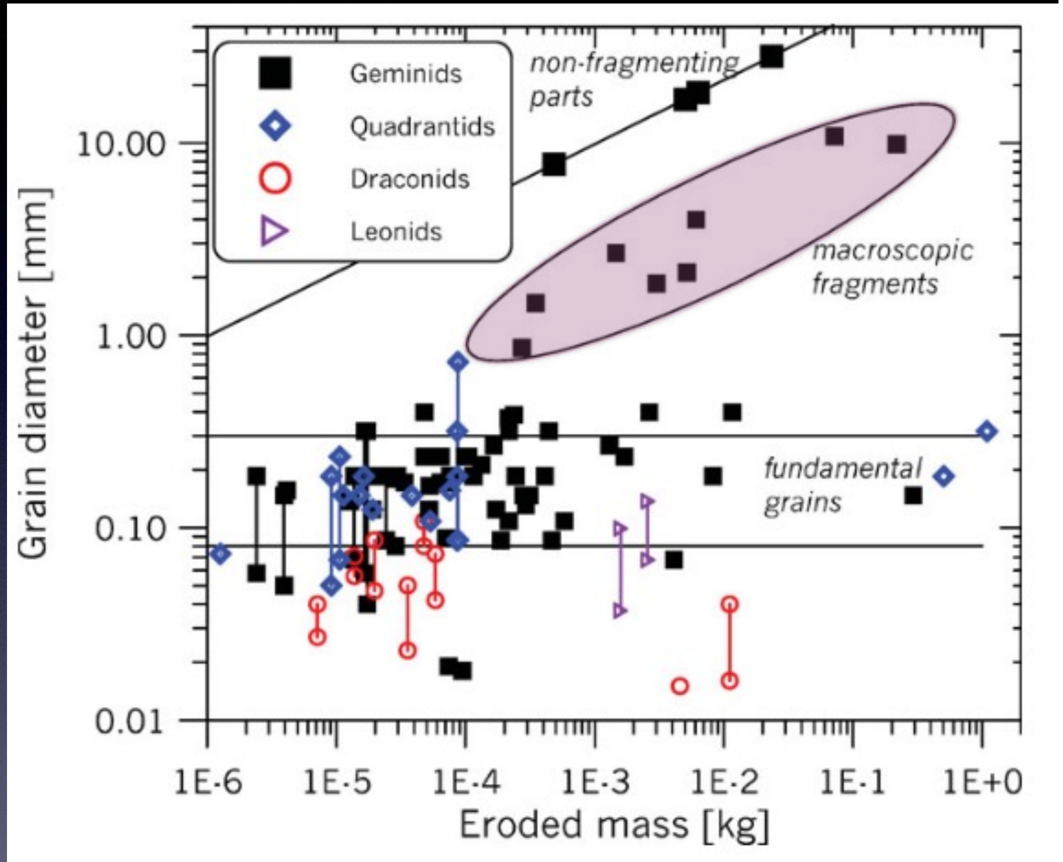


Annual variation of Na compared to Geminids Maximum Solar Longitude
Geminids maximum
1.00
0.10
Na/Fe [-]
261
261.5
262
262.5
263
263.5
264
Ecliptic longitude of the Sun [deg.]
2017
2018
2019
2020
2021
2022

Grain Size of Geminids' Meteoroids



Aerodynamic pressure distribution vs. the initial mass of the meteoroid for Geminid fireballs in predefined bins. Numbers and colors designate the percentage of the entry mass destroyed at a certain aero-dynamic pressure. (Henych, T. et al., 2024)



A majority of grain sizes of Geminids : 80 – 300 μm
Some large Geminids: macroscopic pieces : ~ 1 – 10 mm
No fragmentation : Cm-sized
(Borovička, J. et al., 2010)

Grain Mineralogy of Geminids' Meteoroids

Deep insight of Na variation

- It is suggested that Phaethon regolith is composed of olivine, Fe-sulphides, Ca-sulphates and Hematite(Fe_2O_3).
- Simulating conditions on Phaethon demonstrate that rapid heating rates combine with the low permeability, resulting in reactions between volatile gases and decomposing minerals.

Suttle, M.D. et al., "Rapid heating rates define the volatile emission and regolith composition of (3200) Phaethon", Nat. Commun. (2024)15:7178.

- Na ions in Phaethon's tail and Gemimids' meteoroids are resulted from the decomposition of Na-bearing minerals?

Nepheline (Na,K)$AlSiO_4$ in CM chodrite

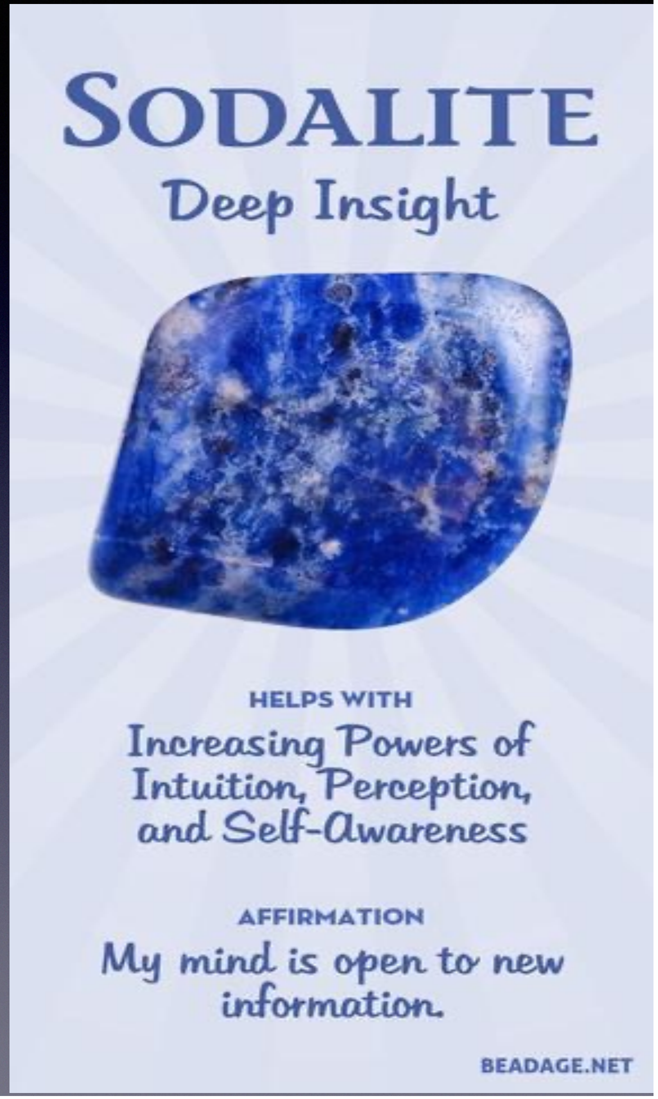
Sodalite $Na_8Al_6Si_6O_{24}Cl_2$ in CM chodrite

Albite $NaAlSi_3O_8$ common in chodrite

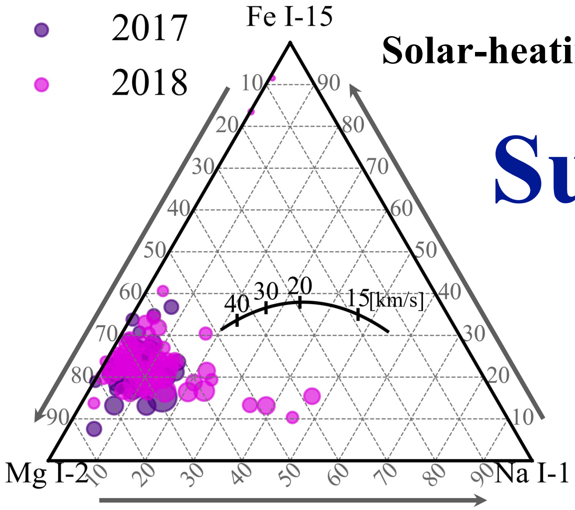
Sodium pyroxene

Jadeite ($NaAlSi_2O_6$) in some chondrites and Achondrites

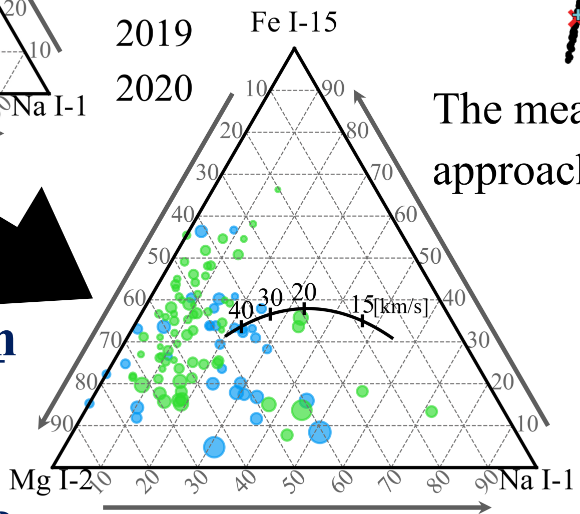
Aegirine ($NaFe_3$+Si_2O_6) especially in enstatite chondrites



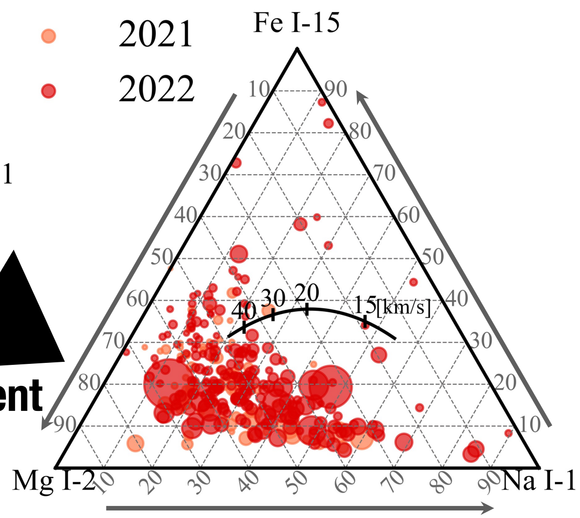
Summary



Depleted in ~80 %

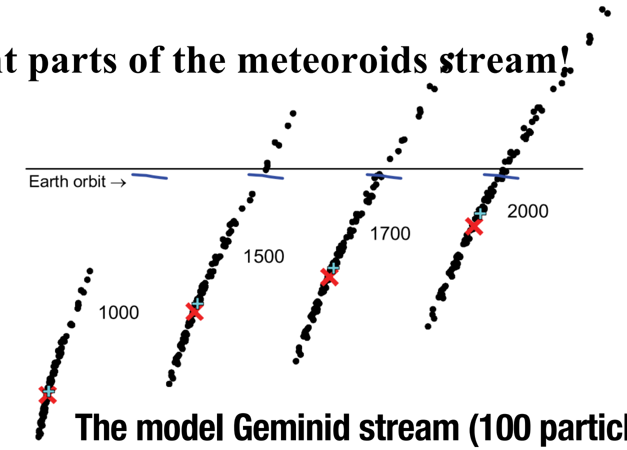


More variations



Increasing & enhancement

Solar-heating age across the different parts of the meteoroids stream!



The model Geminid stream (100 particles, mass=0.02g)[4]

The mean orbit of the Geminids' stream are gradually approaching the Earth's orbit.

The annual variability of sodium

- ➢ **Size bias?**
- ➢ **Different age of dusts?**
- ➢ **Different part in dust stream?**

References

[1] Borovička, J. et al., (2005) Icarus 174.

[2] Abe, S. et al., (2020) Planet. Space Science 194.

[3] Čapek, D. and Borovička, J. (2009) Icarus 202.

[4] Ryabova, G. O. and Rendtel, J. (2018) MNRAS 475.

Phoenicids Spectroscopic Observing Campaign

JAXA's next sample return target : 289P/Blanpain

JAXA needs compositional information.

Parent: Comet 289P/Blanpain

P=5.3yr (JFC), a=3.05, e=0.69, i=5.9

Meteor shower in 1956

Medium activity in 2014, 2019

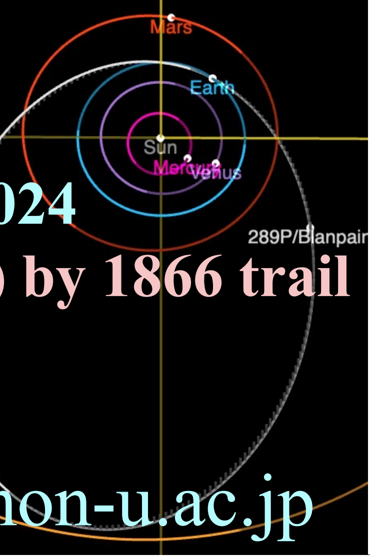
Weak activity is predicted in 2024

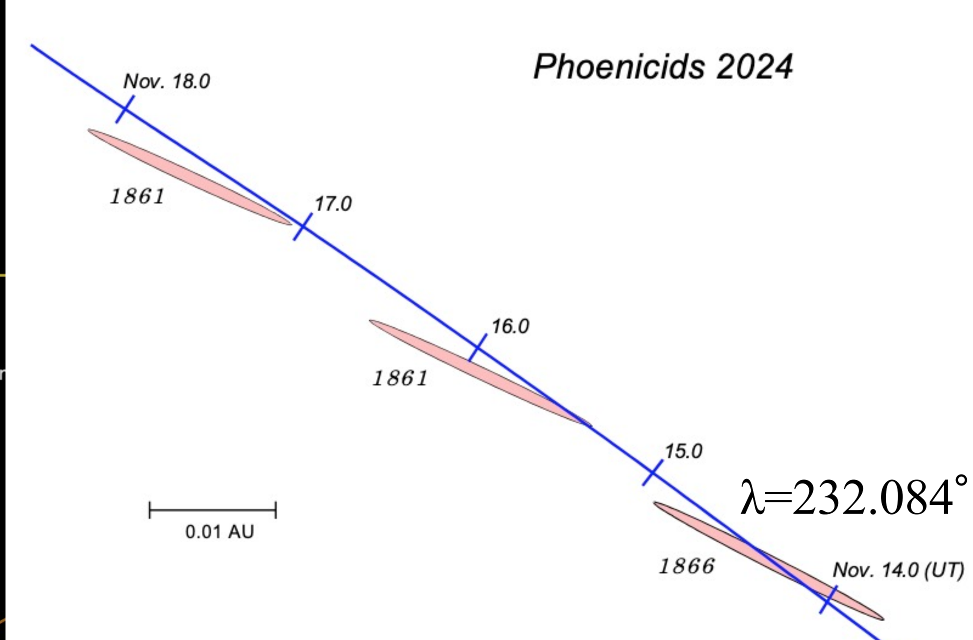
Peak: Nov. 14, 2024, 07:37(UT) by 1866 trail

V_∞=15 km/s; r = 2.8 (?)

Radiant: $\alpha = 7^\circ$, $\delta = -8^\circ$ (ι Cet)

Contact: abe.shinsuke@nihon-u.ac.jp





Prediction by Mikiya Sato

Ejected year	Date (UT)	Expected peak time Time	JST		LS(2000.0)	Δr (AU)	Ejection Velocity (m/s)	fM	Expected position of radiant α(deg.)	δ(deg.)	Vg (km/s)	Notes
1866	2024/11/14.32	07:37	11/14	16:37	232.084	-0.000081	-12.37	0.0019	6.99	-7.83	10.66	
1861	2024/11/15.92	22:07	11/16	07:07	233.698	-0.0015	-14.79	0.0020	6.80	-8.78	10.49	
1861	2024/11/17.57	13:36	11/17	22:36	235.357	-0.0018	-15.24	0.0012	6.75	-10.00	10.31	