Division of Astronomy and Astrophysics
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Spectral properties of slow meteors: Na-rich spectra as tracers of Apollo-type meteoroids

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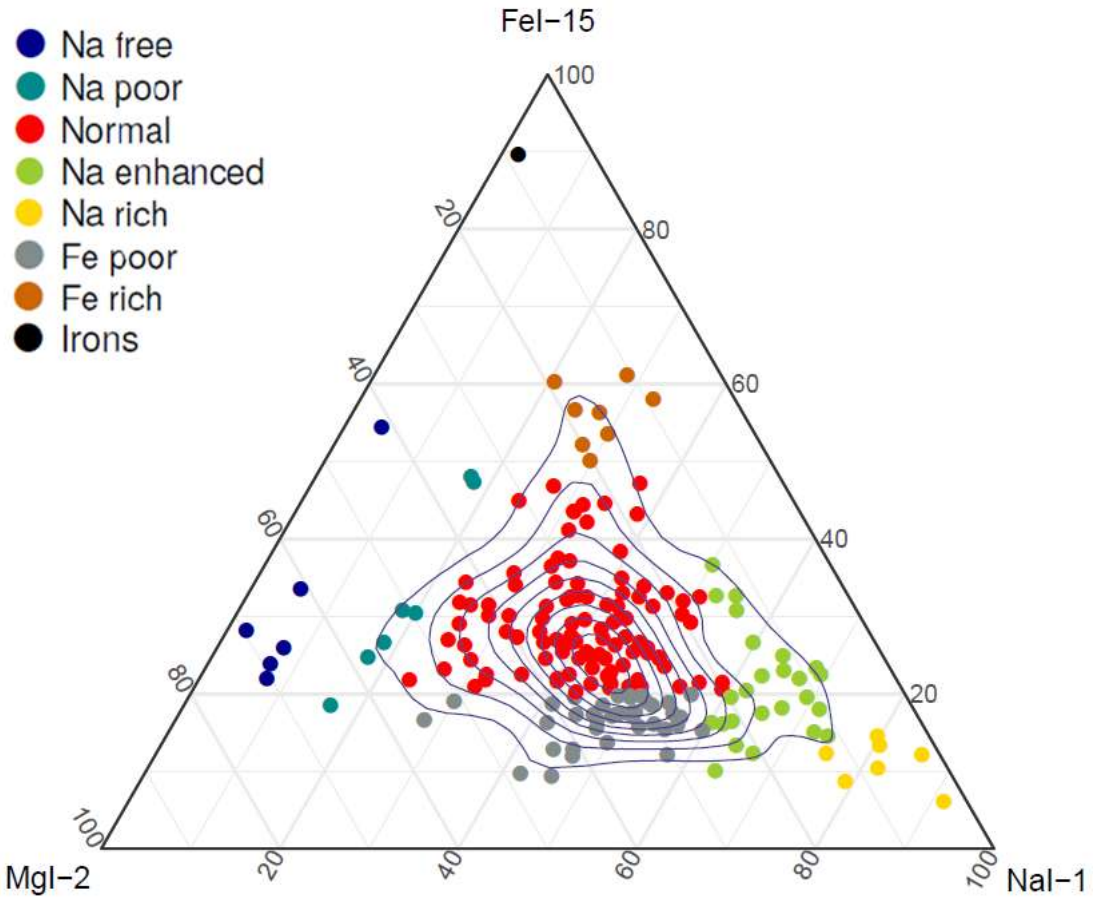
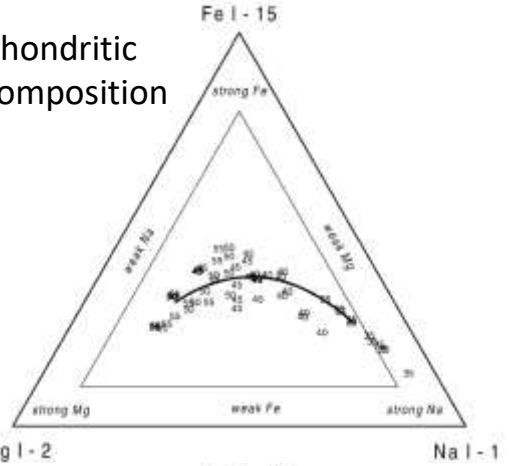
AGO Modra, Slovakia
Roque de los Muchachos, IAC
SpaceObs, Chile
Teide Observatory, IAC

Spectral classification

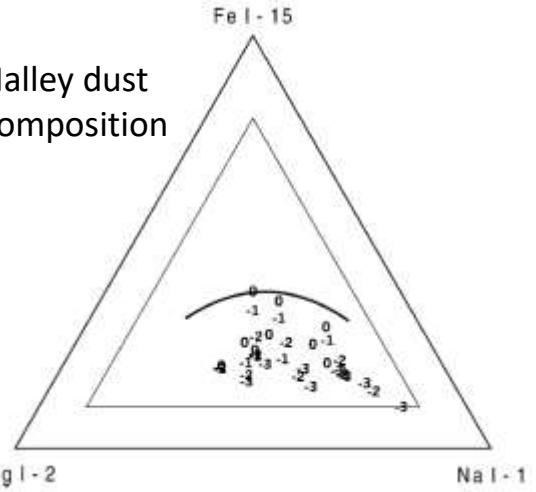
- Mainstream meteors similar to C chondrites and cometary dust
- Numerous distinct spectral classes - <u>focus on Na enhancement</u>



Chondritic composition



Halley dust composition



(Borovička+ 2005)

Sodium in meteor spectra

- Tracer of volatile phases associated with cometary origin (Trigo-Rodriguez+ 2003)
- Associated with low-boiling interstitial “glue“ joining mineral grain (Hawkes & Jones 1975)

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Na depletion

- thermal evolution, effects of space weathering: solar heating, cosmic ray irradiation (Borovička+ 2005)
- embedded: Fe-Ni bodies

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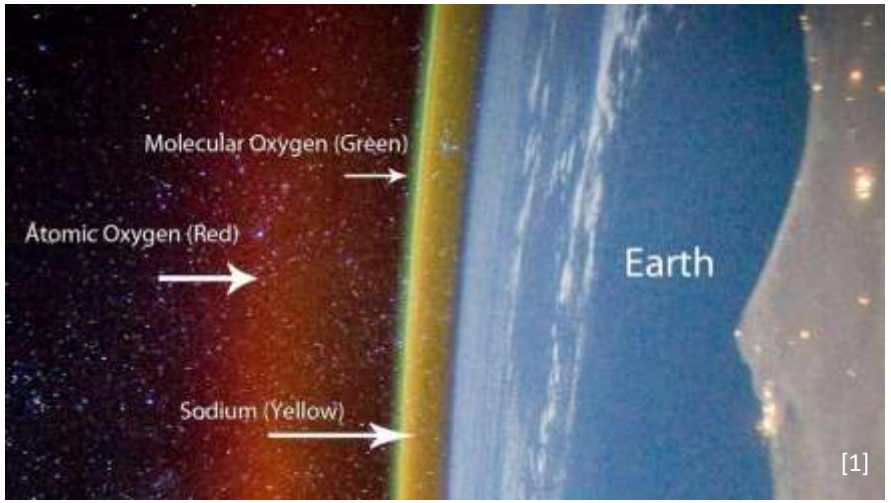
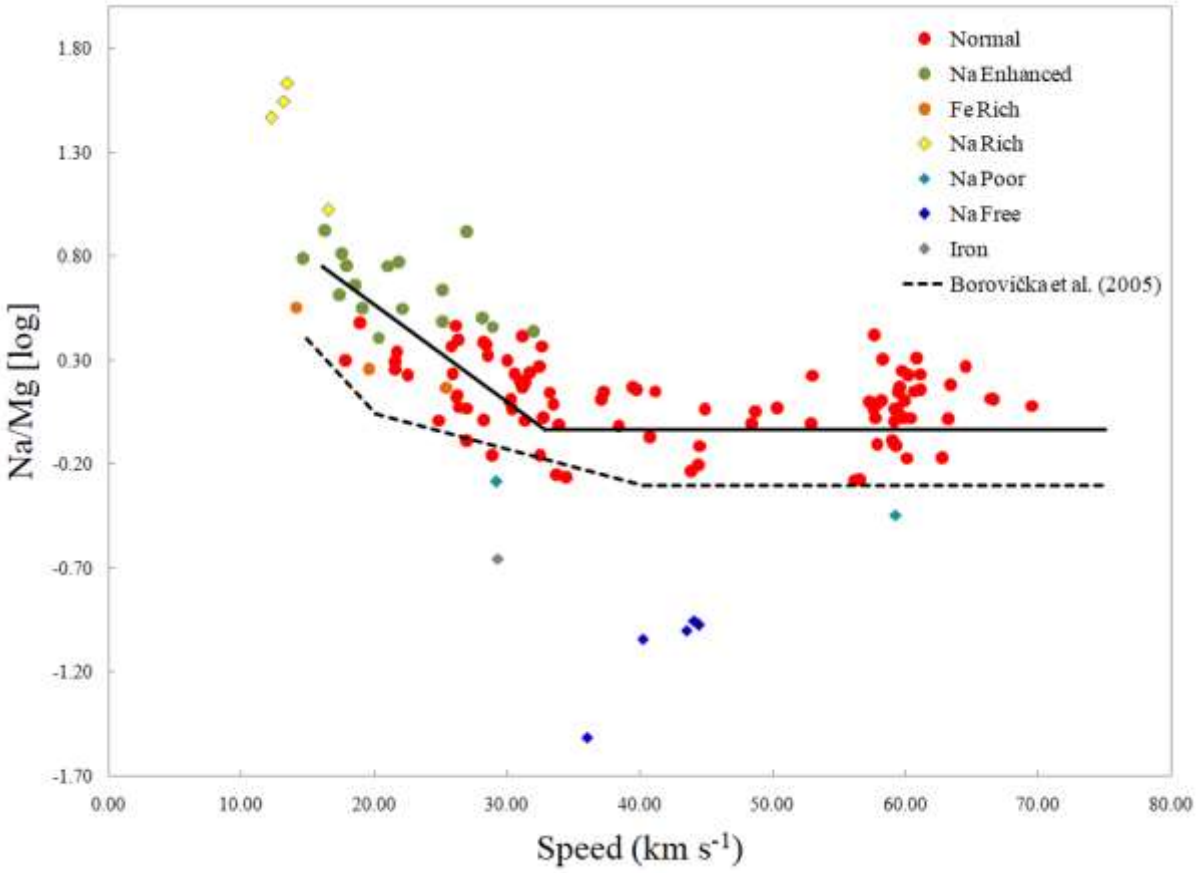
Na enhancement

- overabundance in meteors vs. meteorites (Trigo-Rodriguez+ 2004)
- inhomogeneous comets? differentiated asteroids?



Speed dependency

- Na/Mg speed dependent below 35 km/s
- Effect of low excitation of Na I (2.1 eV) compared to Mg I (5.1 eV)
- Sodium better preserved in larger grains (Vojáček 2017)



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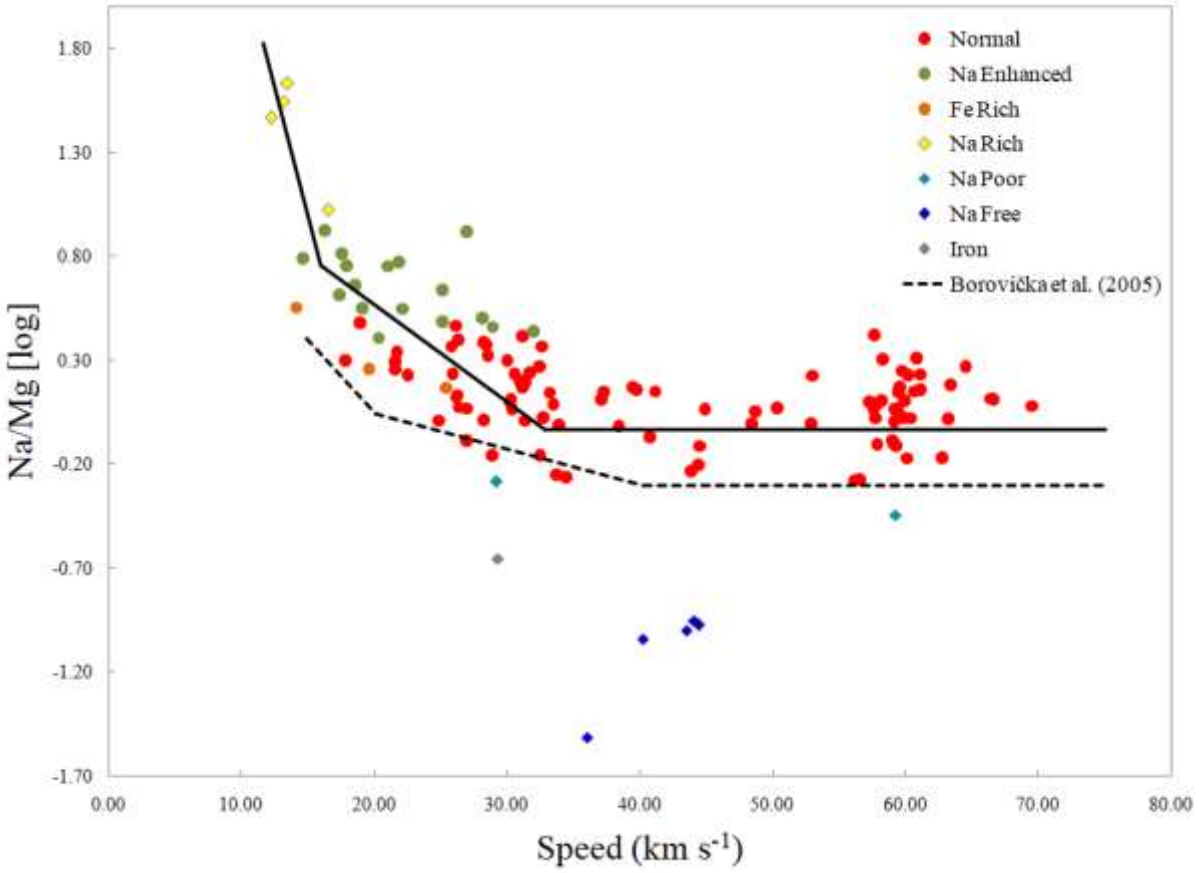
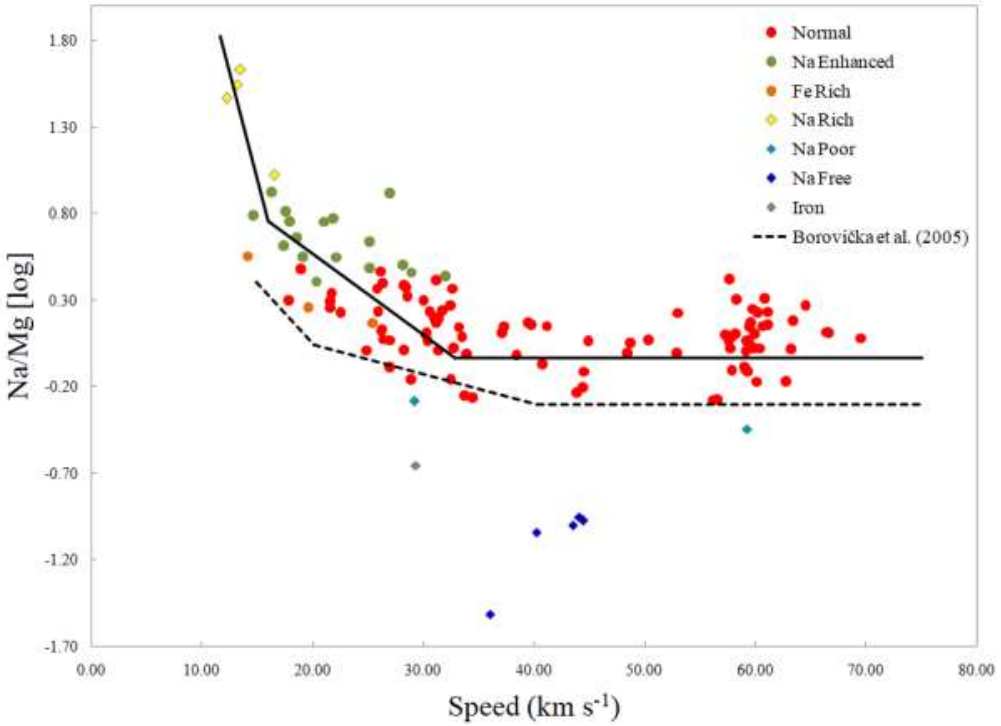
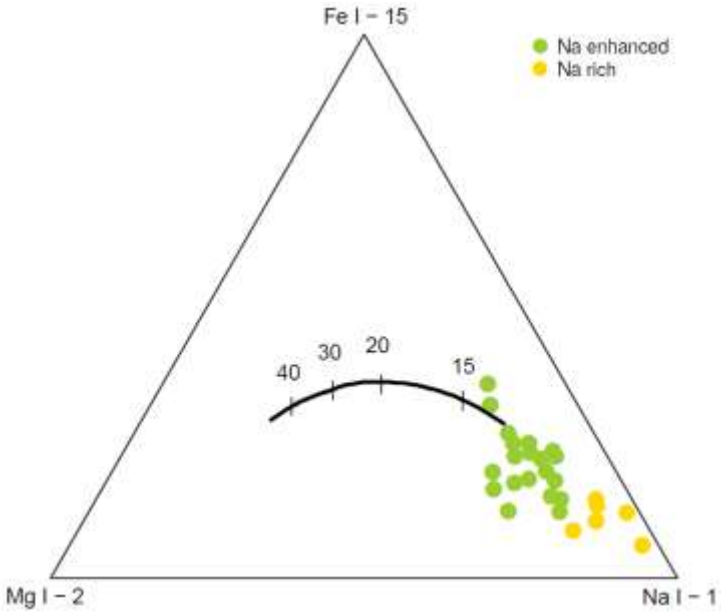


Speed dependency: Na-enhanced bodies

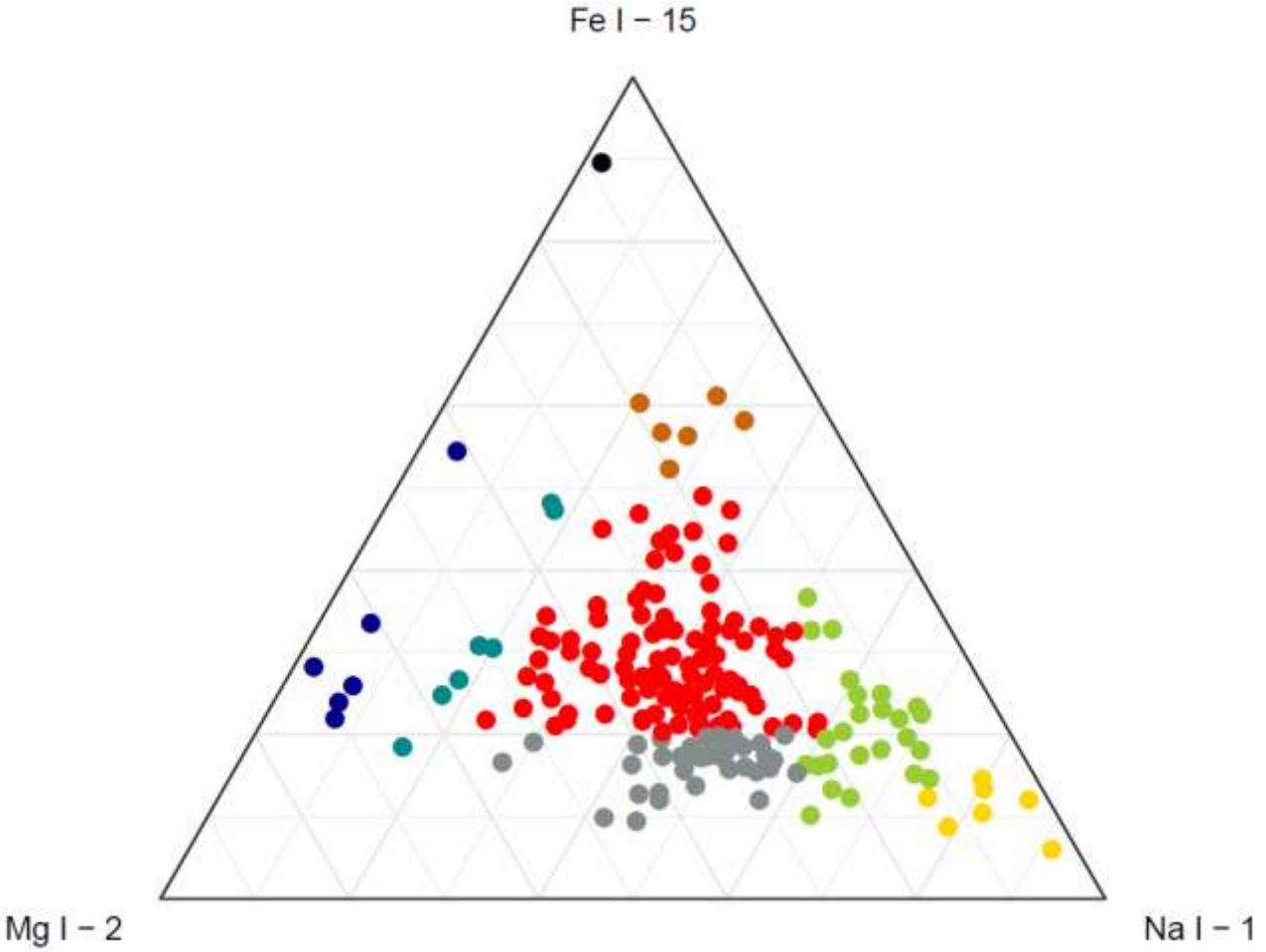
- Distinction between normal and Na-enhanced bodies not clear
- Strong effect of meteor speed, deviations related to lower brightness





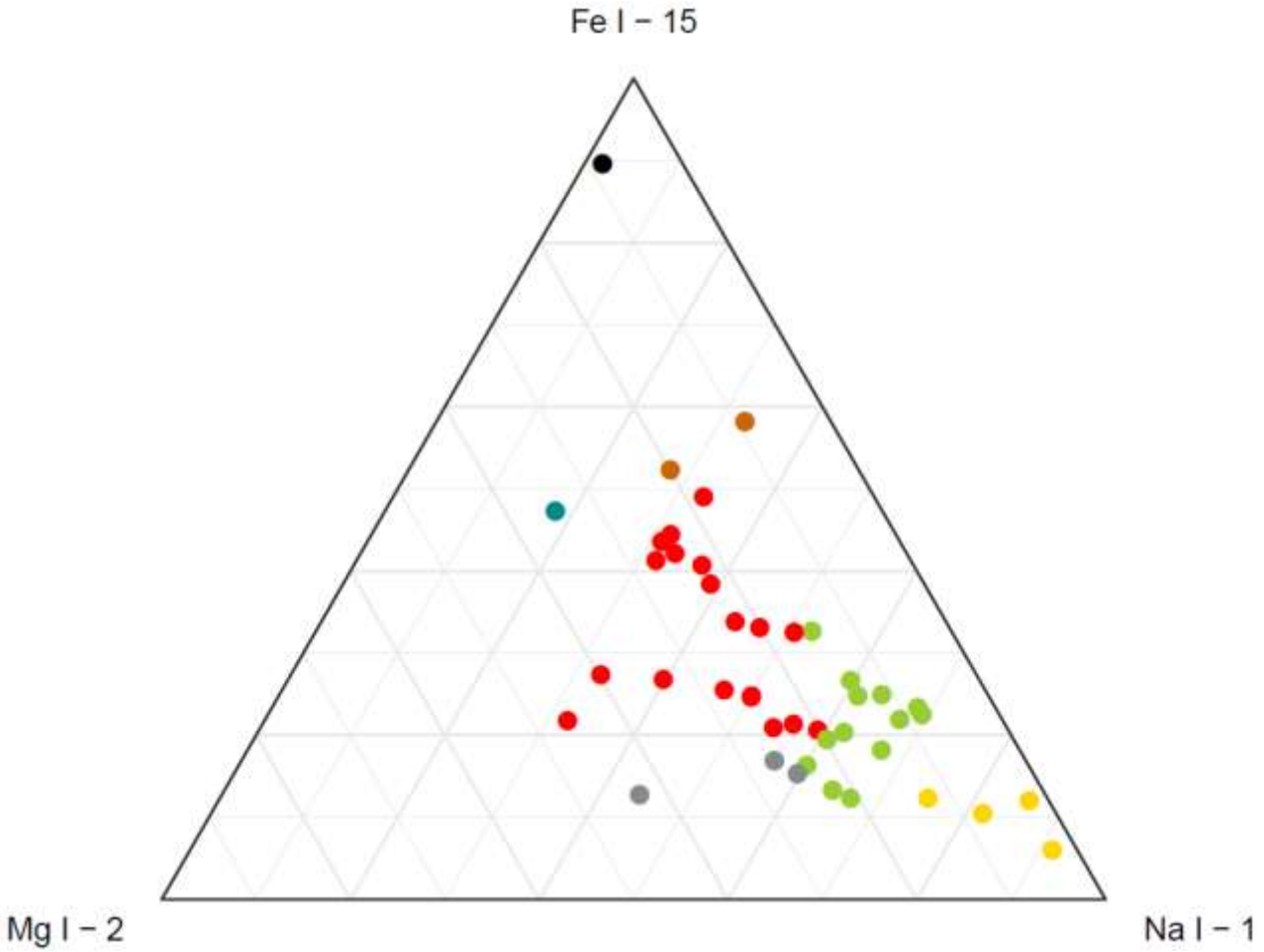
Spectral classification: slow meteors

- $v_i < 72$ km/s



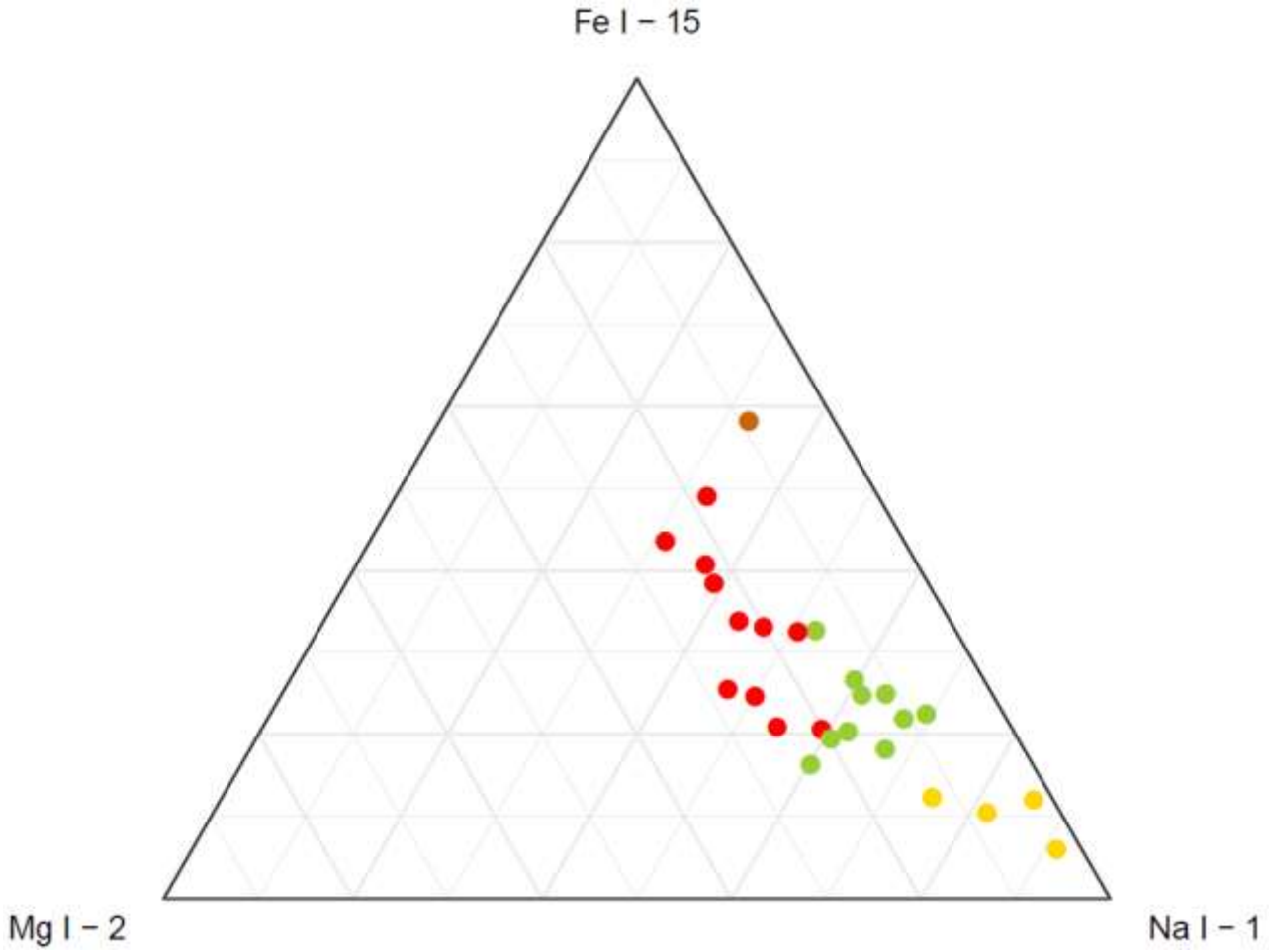
Spectral classification: slow meteors

- $v_i < 30$ km/s



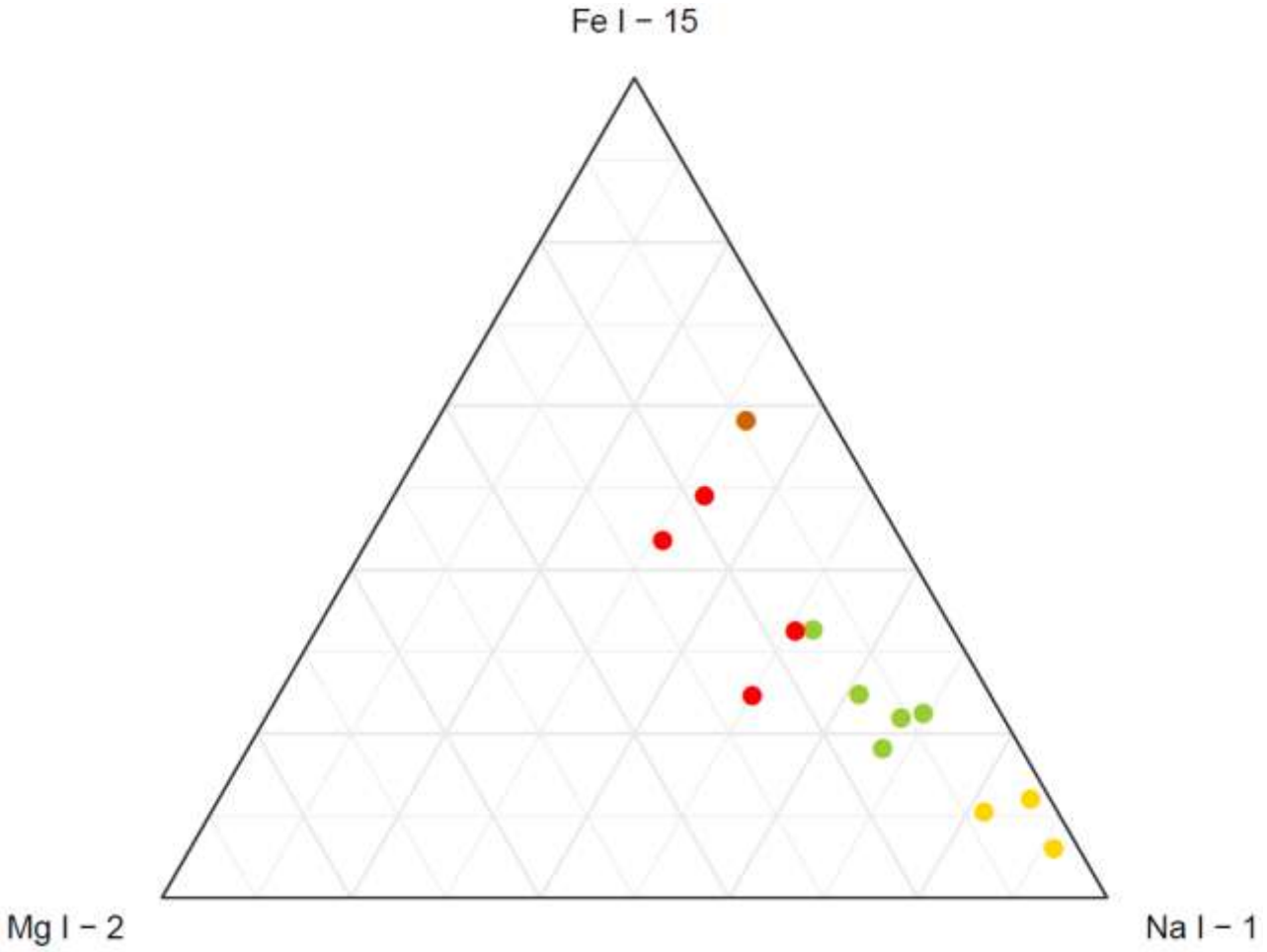
Spectral classification: slow meteors

- $v_i < 25$ km/s



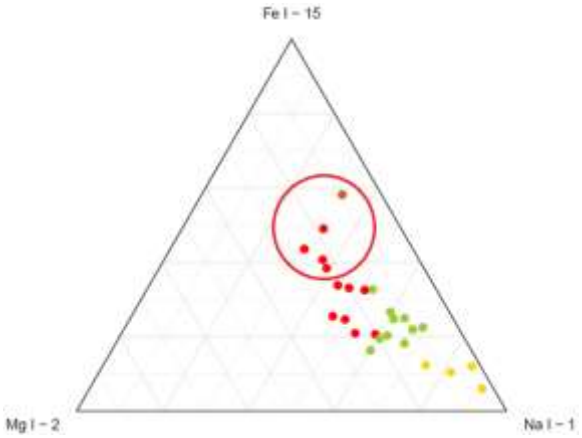
Spectral classification: slow meteors

- $v_i < 20$ km/s



Iron enhanced slow meteors

- $v_i \approx 25.4$ km/s



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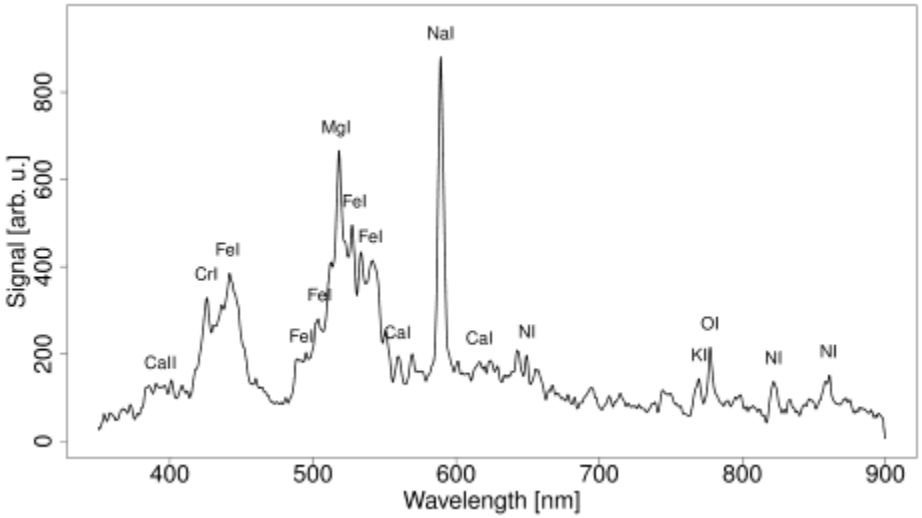

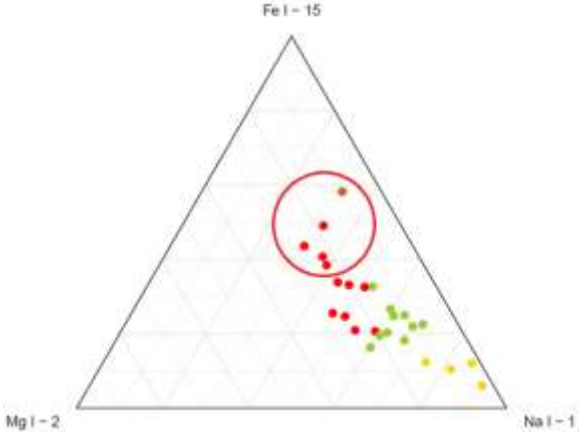

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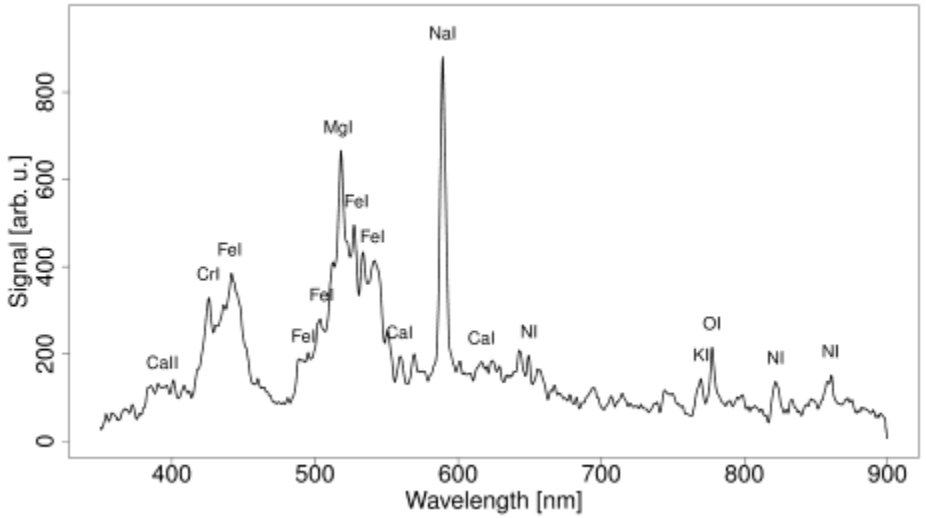
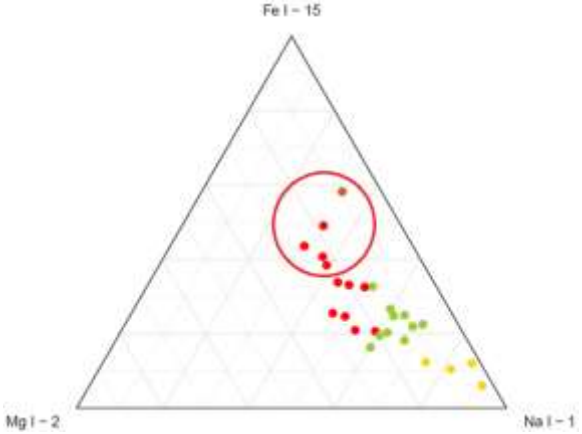
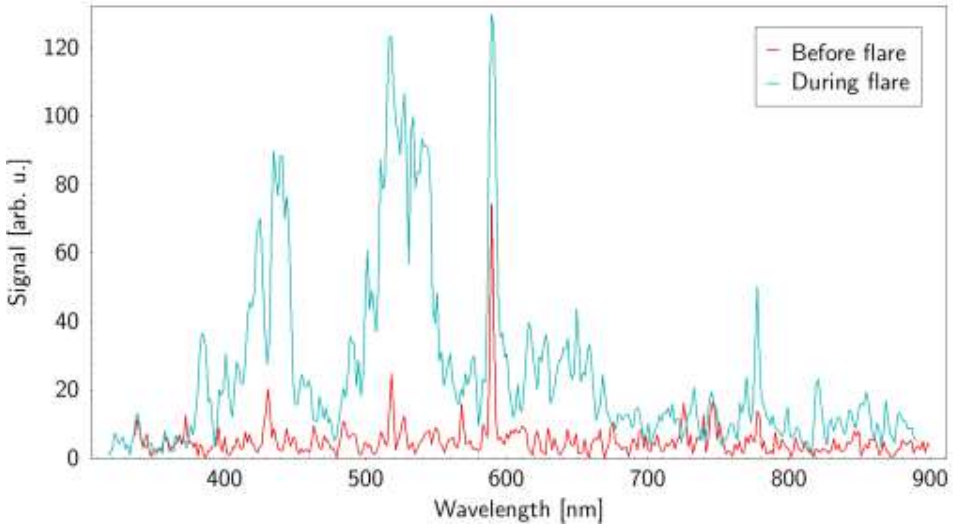
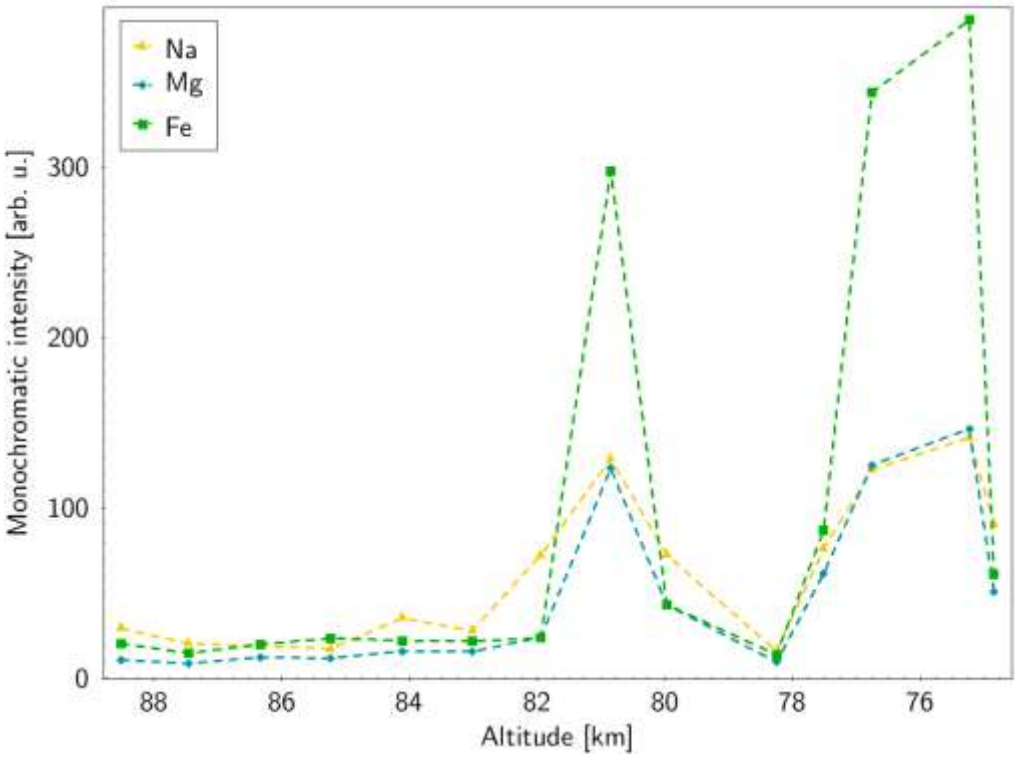




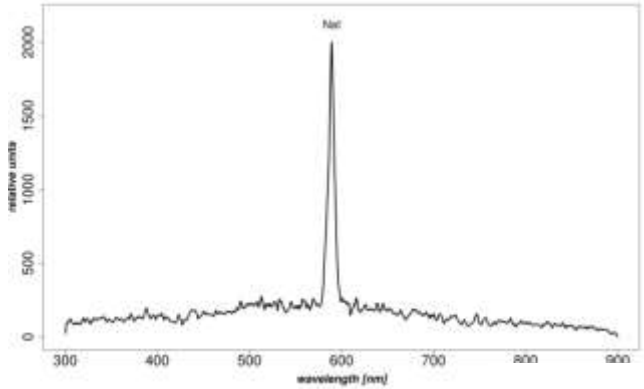


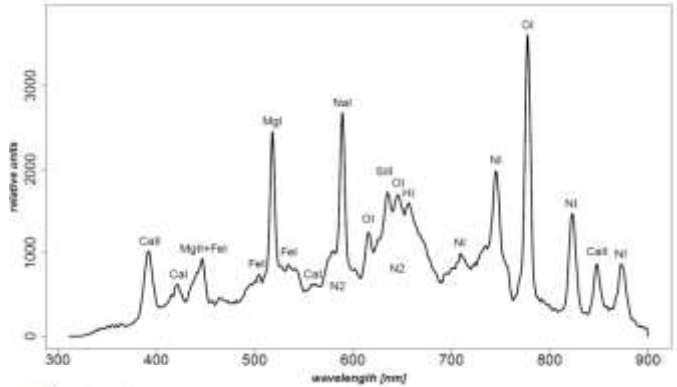
Iron enhanced slow meteors

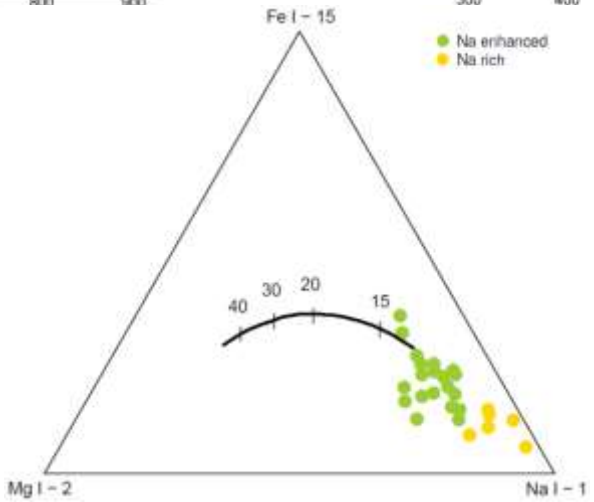
- Na enhancement at the beginning and end of the flight
- Other spectral lines, particularly Fe visible during flares
- Saturation, optically thick plasma during flares



Na-enhanced and Na-rich meteors: observations



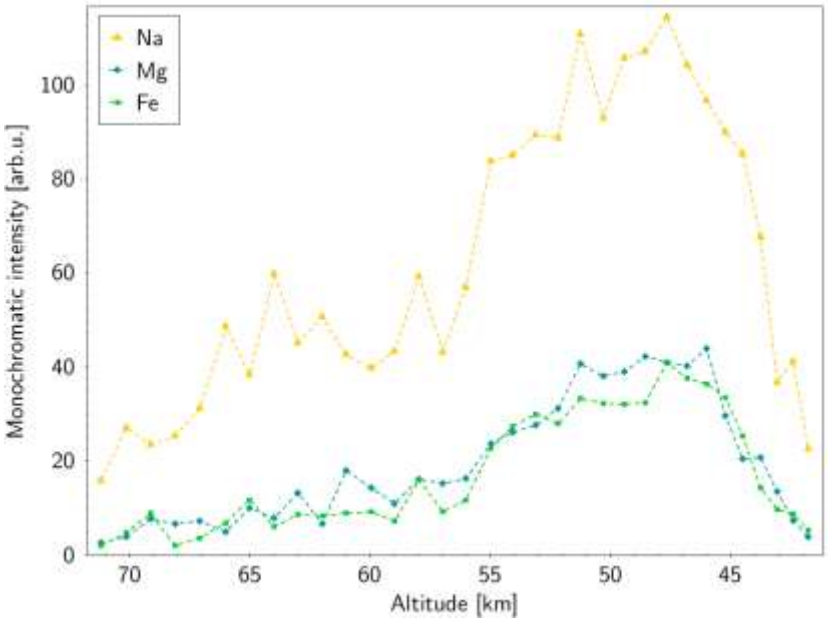


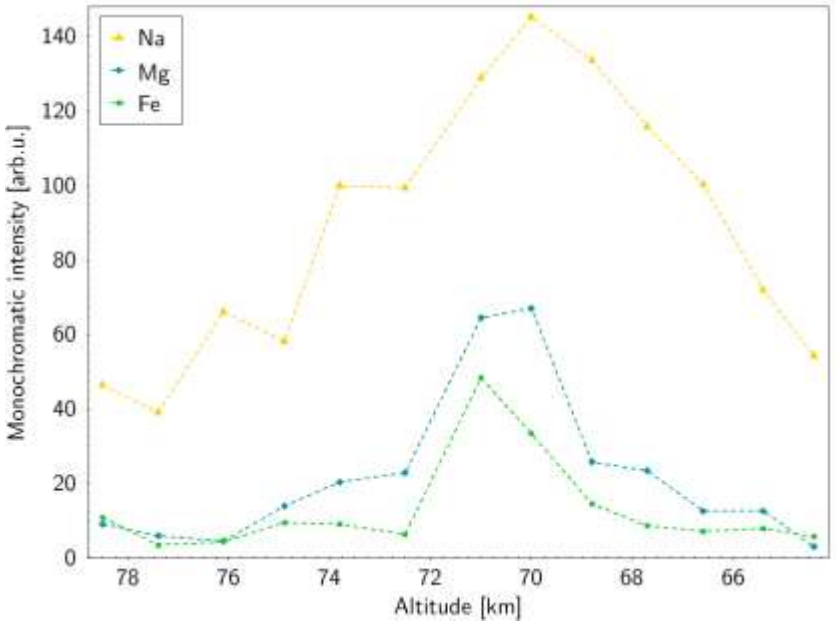


Na-enhanced meteors: results

Discovery of two distinct groups:

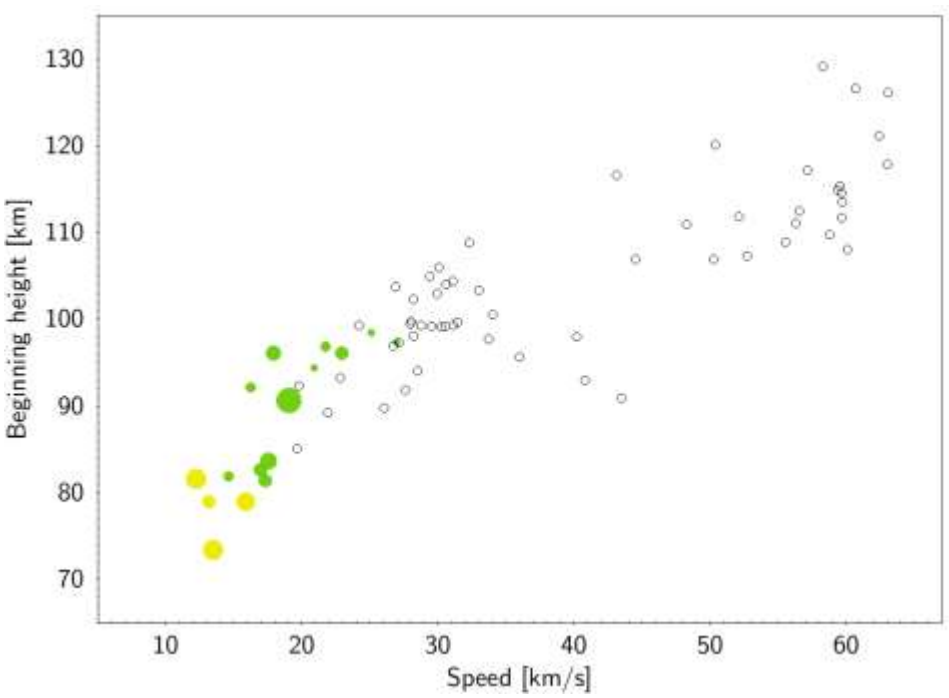
- Fragile cometary bodies from short-period, dormant comets
  - material strength IIIA/C1, density $\delta_m \approx 2.0$ g cm^{-3}
  - two Alpha Capricornids from comet 169P/NEAT
- Stronger asteroidal bodies from near-Earth Apollo asteroids
  - q > 0.8 AU, Q < 2.5 AU, material strength I/A

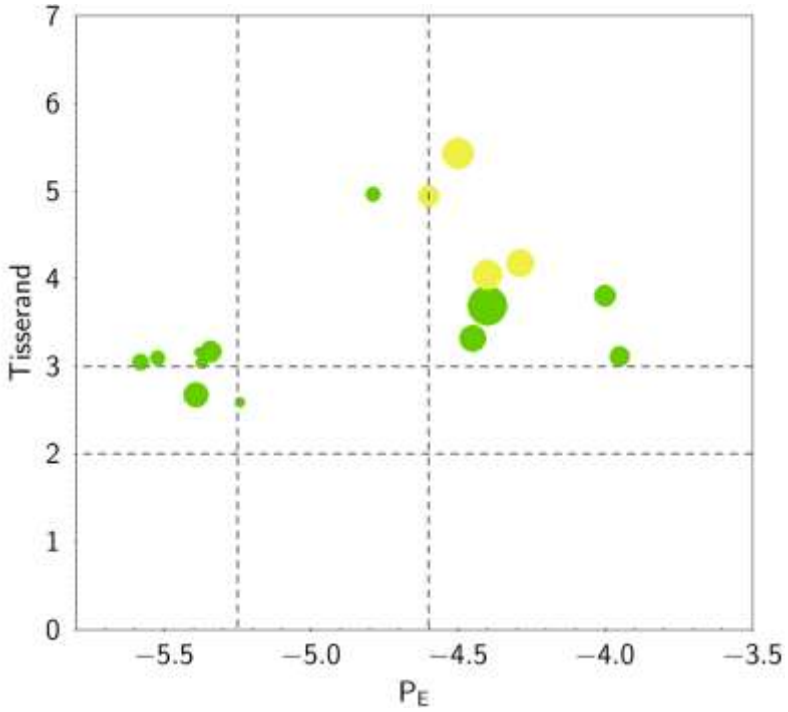




Na-enhanced meteors: structure

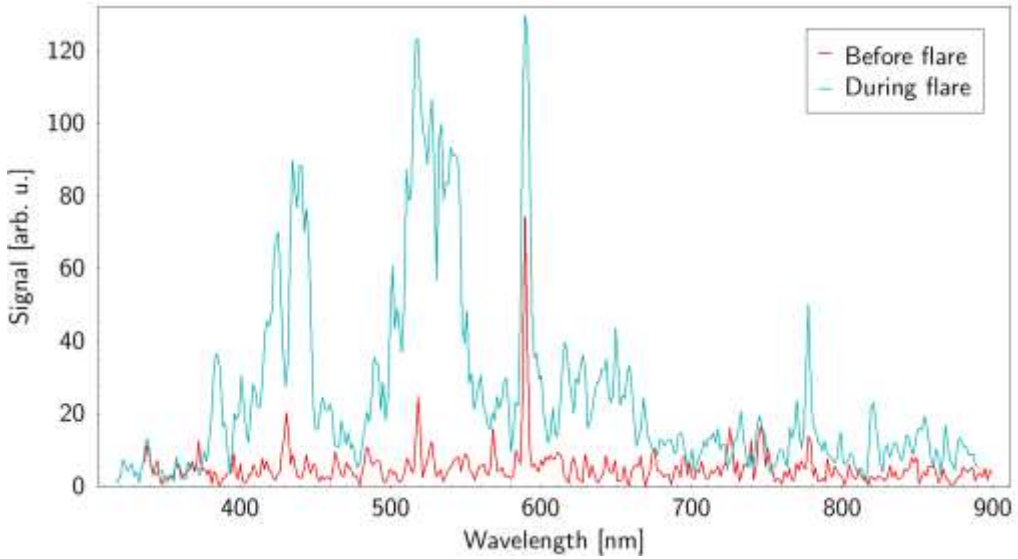
- Distinction between fragile cometary and stony NEA meteoroids

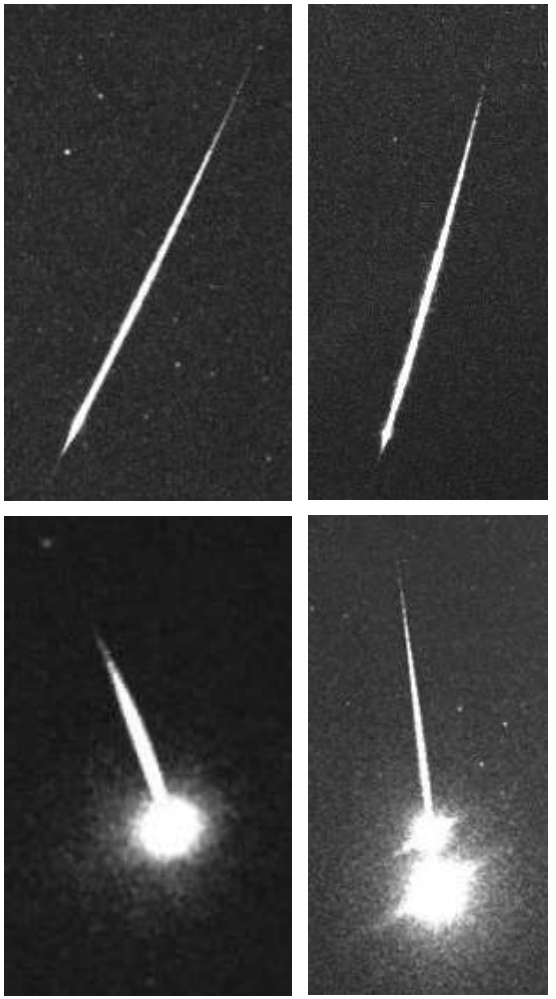




example: Alpha Capricornids

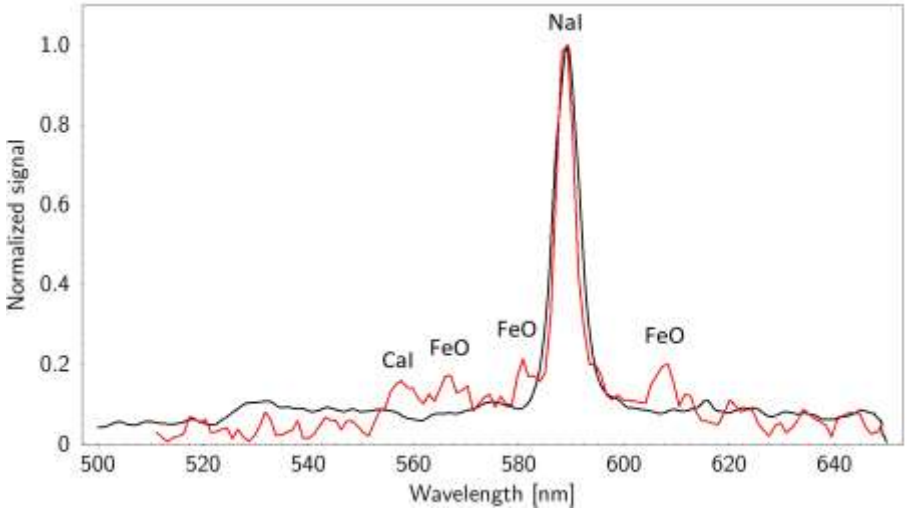
- Parent 169P/NEAT (former 2002 EX_{12}) (Jenniskens & Vaubaillon, 2010)
- Spectra:
  - representing cometary Na-enhanced bodies (C1/IIIA fireballs)
  - normal / Fe-enhanced spectra during flares
- Assuming homogeneous composition of 169P, clear effect of physical conditions

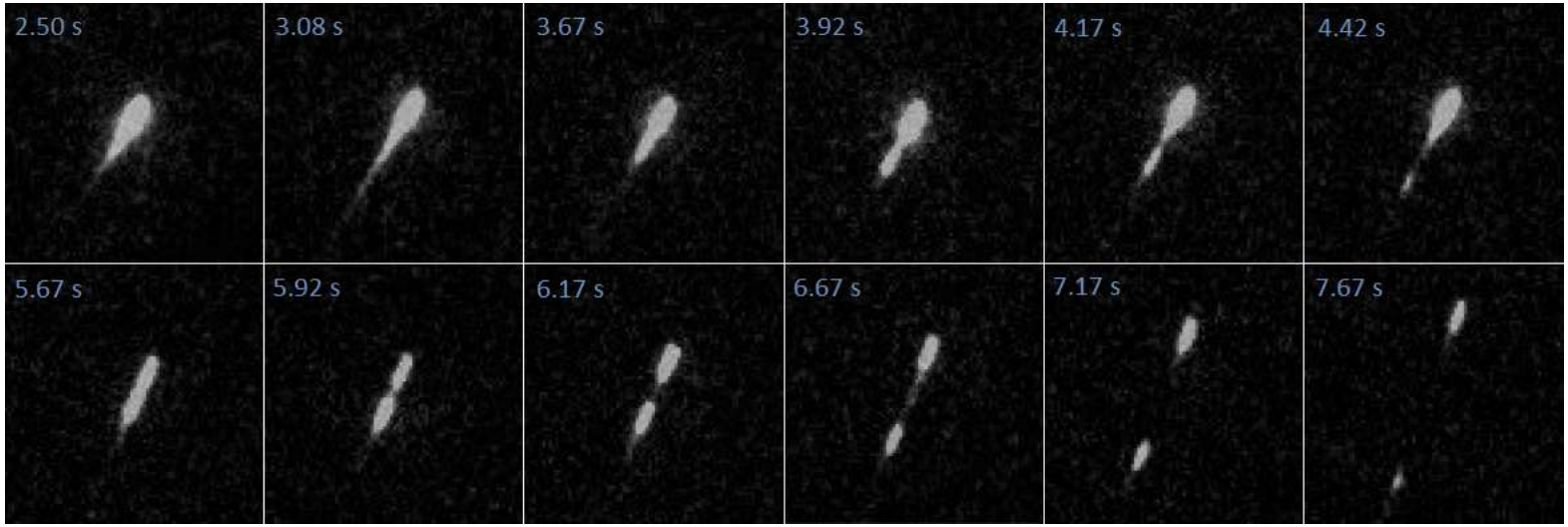




Na-rich meteors: results

- Low level emission of refractory Ca and FeO
- Specific fragmentation patterns
  - separation at p < 0.2 MPa (fracture)
- Apollo-type orbits:
  a < 1.8 AU, Q < 2.5 AU
- Structure similar to strong Na-en.

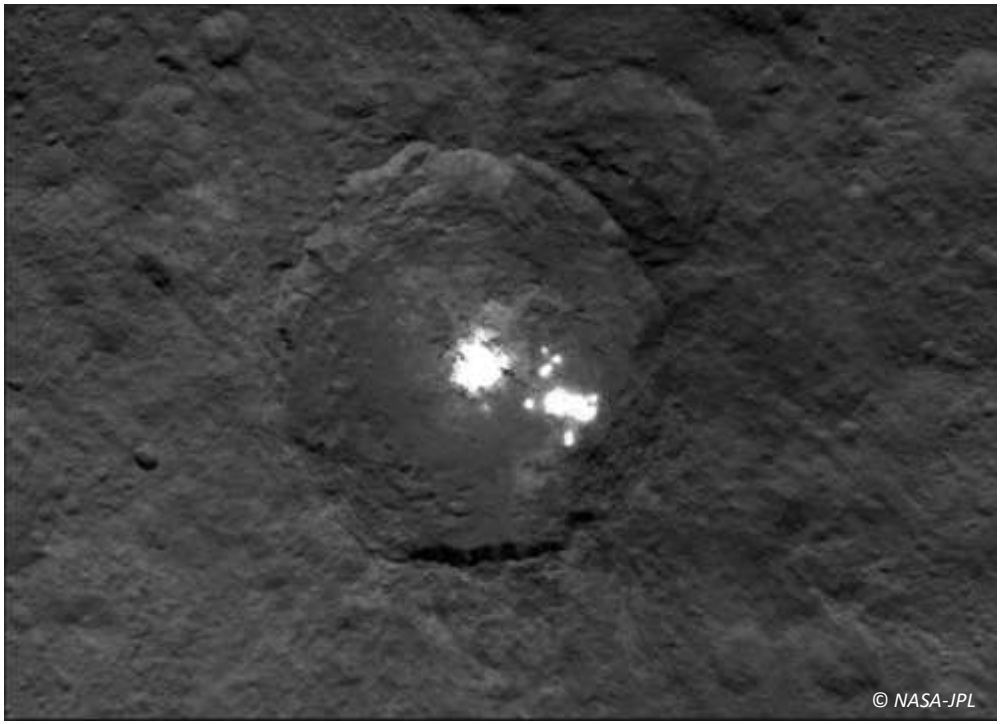




Real enhancement of Na?

- Relation to differentiated C/D asteroids
  - discovery of Na_2CO_3 on Ceres (salt spots): early formation beyond snow-line
- Martian / lunar origin - rare SNC meteorite samples
  - composition rich in low-anorthosite plagioclase minerals (Na-Ca)$AlSi_3O_8$

Sarafian (2017): volatiles, including water delivered to Earth by diff. meteorites



Conclusions and discussion

- Slow meteors dominated by Na-enhanced bodies (at our sensitivity, resolution)
- Na depletion - compositional effect

  Na enhancement - dominantly physical effect
  - related to achieved temperature (speed) and brightness
- Na-rich and part of Na-enhanced meteoroids related to fragments of Apollo-type near-Earth asteroids
- Significant contribution of short-period and dormant comets
- Side product:
  Strong spectral and structural heterogeneity of Alpha Capricornids
  (169P/NEAT - previous large disruption)