# "Obtaining meteoroid orbits and physical properties by the SPMN: the case of Villalbeto de la Peña"

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***(IEEC, ICE-CSIC))***

**Villalbeto de la Peña meteorite fall, January 4, 2004.**

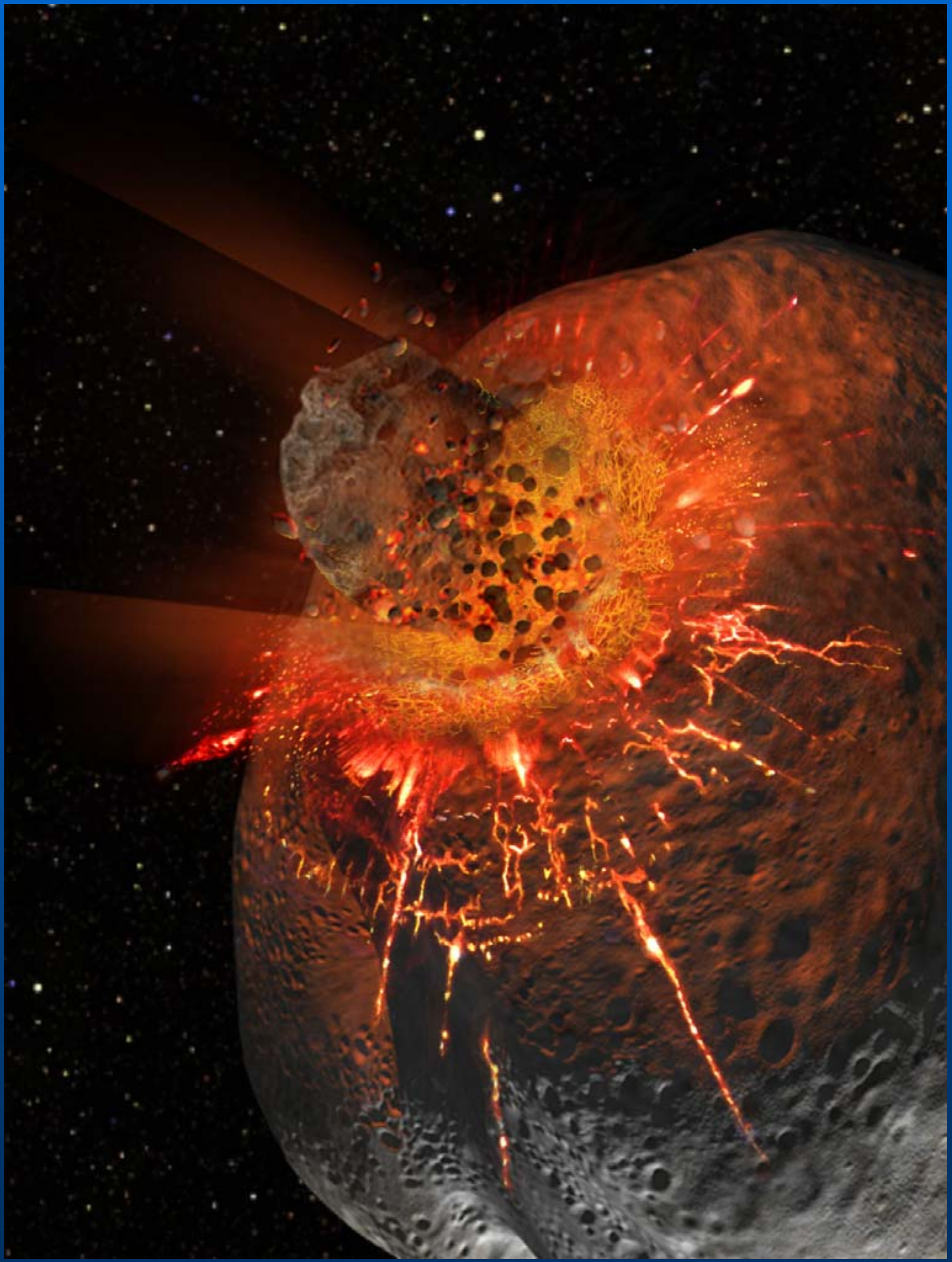
**Perseid CCD fireball spectrum, August 12, 2004.**

# OUTLINE

- Differences between cometary and asteroidal streams
- Why study meteoroids, meteors and meteorites?
- The atmospheric interaction: meteors and fireballs
- Physical properties of meteoroids derived from meteors
- The role of fireball networks. First results of the SPMN:
  - **Jan 27, 2003 Nador superbolide**
  - **Jan 04, 2004 Villalbeto de la Peña meteorite fall.**
  - **Jun 30, 2005 Ceuta superbolide**
- Fireball classification vs. recovered meteorites
- Chemical abundances from meteor spectroscopy
- Conclusions

# ASTEROIDAL STREAMS

- Are "one-off" events produced during an impact with other asteroid.
  - The meteoroids are in a cluster that will be dispersed over time along the orbit
    - Typical decoherence timescales are a few million years.
  - A "hot topic" is the possible existence of meteoroid streams producing "meteorite-dropping" events
- Usually these impacts are more likely close to the aphelia:
  - Lesser relative velocities among bodies.
  - Proximity to the main asteroid belt.
- The meteoroids are carried out by the gas outflow produced during partial vaporization of the asteroidal surface:
  - Large rocks remain as regolith

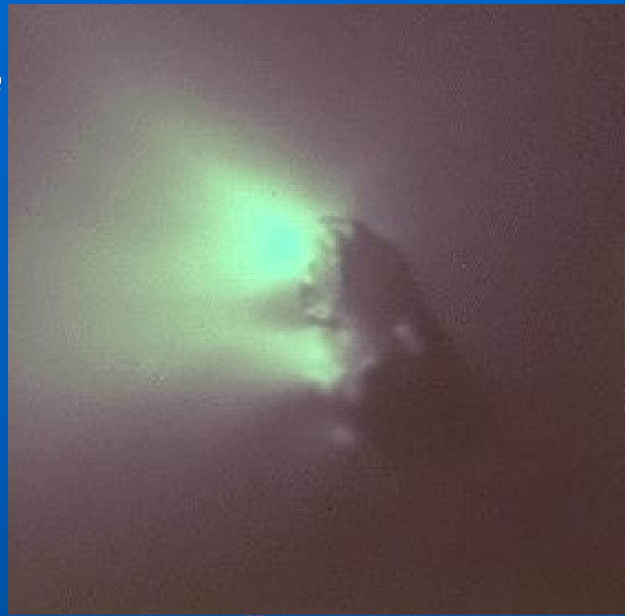


Don Dixon

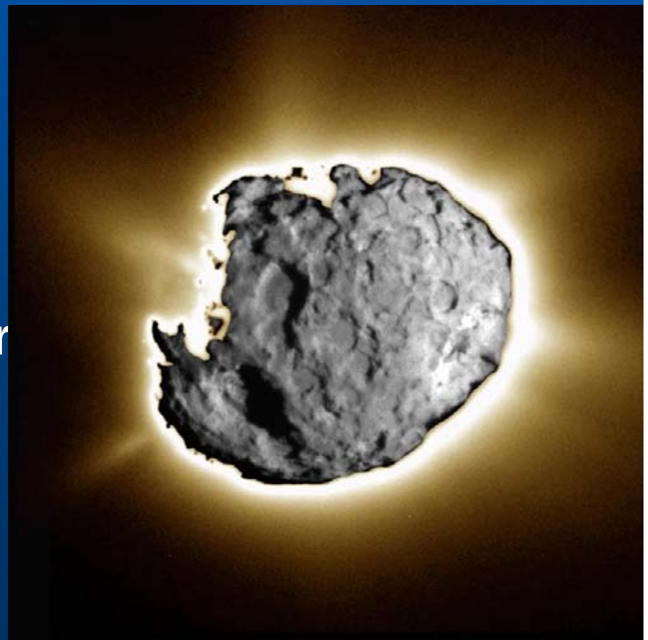
# COMETARY STREAMS

Cometa 19P/Borrelly (Deep Space)

- Whipple (1950) proposed the notion of dust embedded on the icy cometary matrix.
  - Preferentially close to perihelion the ice will be sublimed and dust released
  - Small grains produce the dust tail
  - Large grains produce dust trails in similar orbits to the comet
- Meteoroids are dispersed in their orbits by the radiation pressure (P-R effect) or during collisions
- Usually after 10.000-100.000 years the particles lose their orbital similitude with the comet
  - Origin of sporadic meteoroids
  - Zodiacal dust cloud

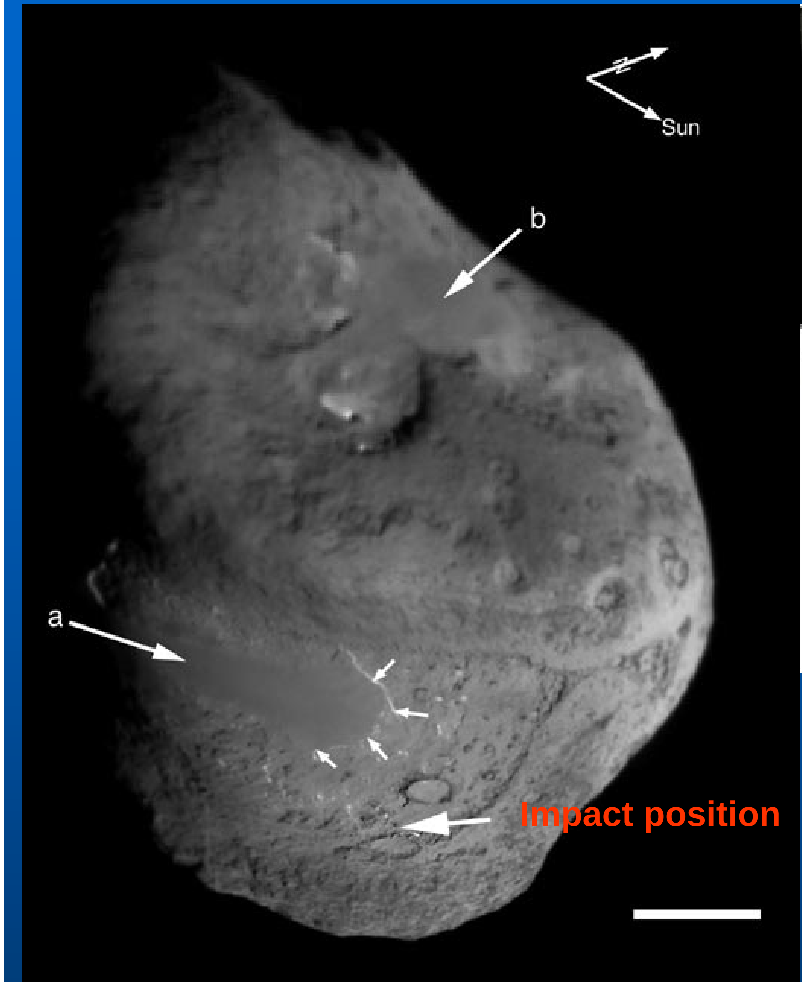


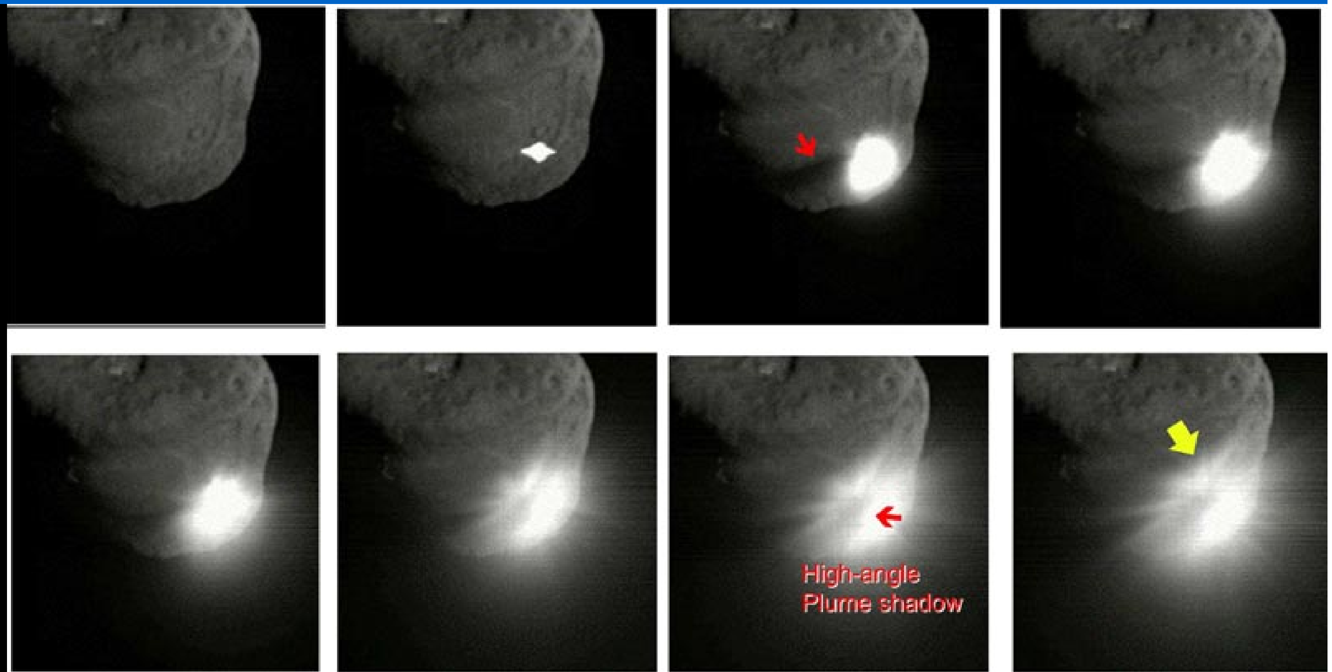
1P/Halley (Giotto, ESA)



Cometa 81P/Wild 2 (Stardust)

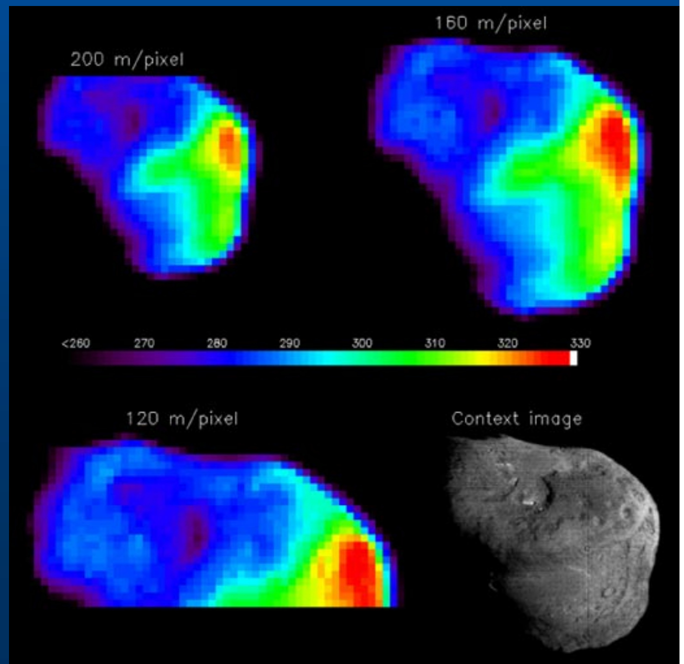
# DEEP IMPACT AT TEMPEL 1




Tempel 1 impact (0.84 s among frames)
(Deep Impact, NASA)

- A 370 kg projectile impacting at 10.2 km/s

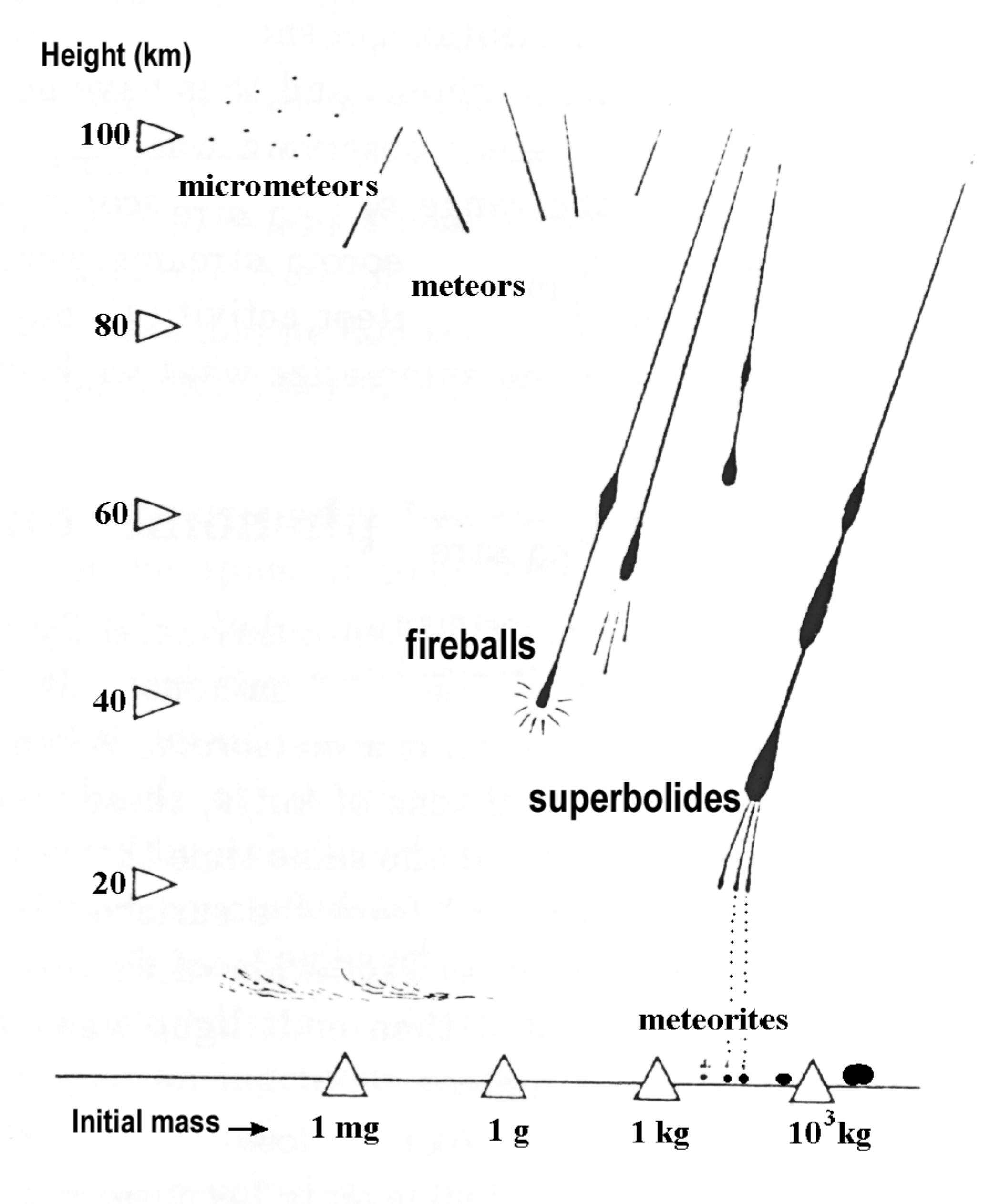



Thermal conductivity is very low (temperature in K)
Preferential release of gas

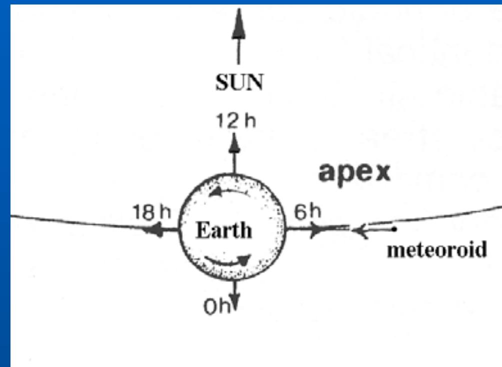
# ATMOSPHERIC INTERACTION

-10 absolute magnitude Perseid fireball, August 12, 1993 (Trigo-Rodriguez, 1994)

# TERMINOLOGY



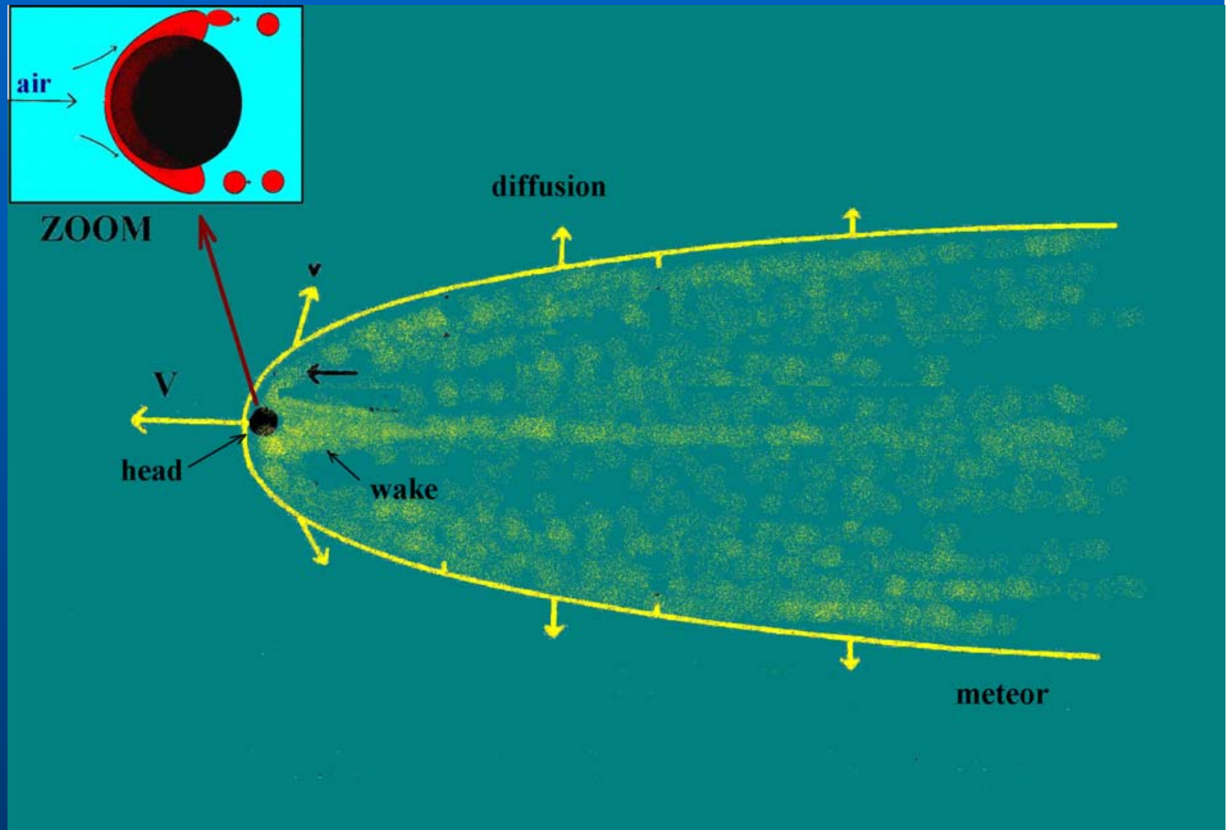

- **Meteoroid**
  - Particle orbiting the Sun
- **Luminosity α $E_k$**
  - $E_k = ½\ m·v^2$




  - Meteor (-4 < $M_v$<+6 )
  - Fireball or bolide ($M_v$≤-4)
  - Superbolides ($M_v$≤-17):
    - Recorded from DoD and DoE military satellites.
  - Meteorites: rare surviving samples
    - Typically a 95-98% of the initial mass is loss during atmospheric entry

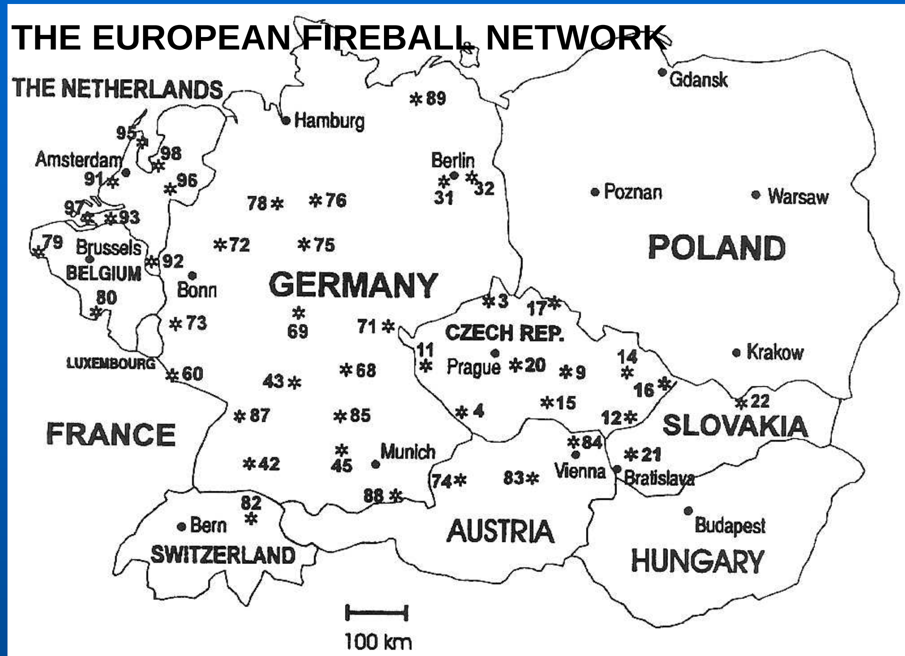
# HOW IS A METEOR PRODUCED?

- **Meteoroid melting starts when T>1500 K**
  - Ablation process.
- **Radiation regions:**
  - Main spectra:
    - Origin in the HEAD
    - T≈ 4500 K
  - Second component:
    - COLLISION FRONT
    - T≈ 9500 K
  - The ablation column forms the METEOR.
- **Sinks of energy:**
  - **IR and UV radiative mechanisms still unknown.**
  - **Fragmentation and sputtering effects.**



# FIREBALL NETWORKS' ROLE

- European Fireball Network:
  - Recovery of Pribram meteorite in 1959. First orbital determination.
  - 2002 Neuschwanstein puzzle.
- Prairie Network (1964-1974):
  - 16 stations around Nebraska.
  - Recovery of Lost City meteorite (H5) in 1970 .
- Canadian Photographic Network (1971-1985):
  - Recovery of Innisfree in 1977 (LL5).
- Direct  and unique orbital and spectral information (!):
  - Most bodies are not recovered.
- Two networks in development:
  - Spain (first stations starting in 2004)
  - Australia (starting in 2006)



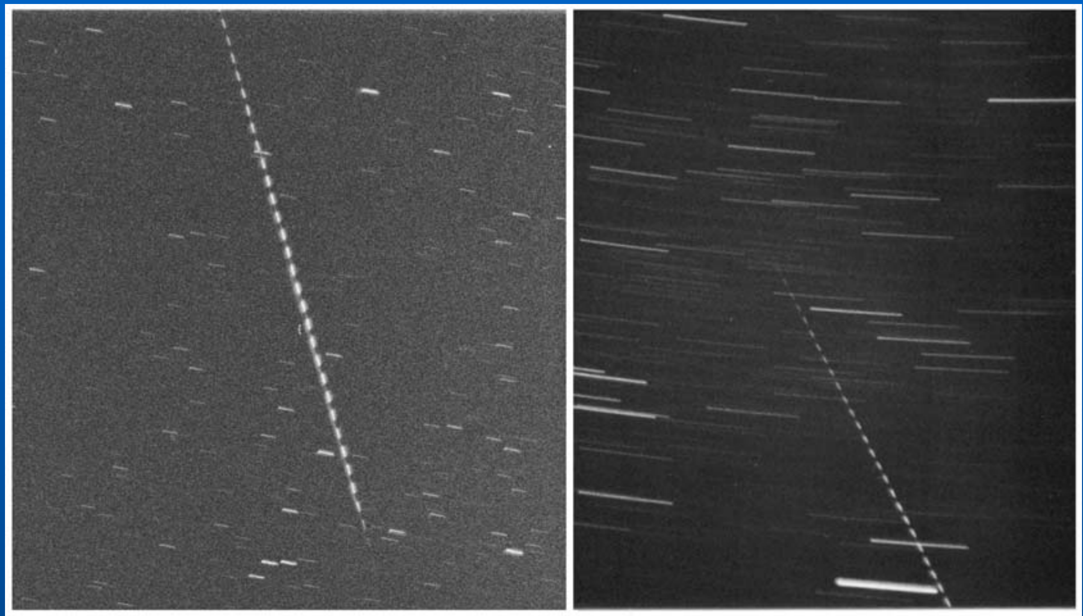

# SPANISH FIREBALL NETWORK

- SPanish Meteor Network (SPMN):
  - First campaigns: 1999
  - First all-sky images 2002.
  - Double-station operations: Since June 2004.
    - La Mayora and El Arenosillo (BOOTES)
  - Present all-sky station in Montseny
  - Future two stations in Valencia.
- Homepage:
  - Participation of public.
  - Popularization of this field in Spain.
    - Creation of social interest
  - Homepage: www.spmn.uji.es
- Some initial results:
  - 3 superbolides studied in two years.
  - Research on meteor storms: Leonid and Perseid studies

# CCD ALL-SKY CAMERAS

- All-sky CCD image of a Perseid fireball, Aug.12, 2004 (Spanish Fireball Network)
- World's first developed high-res all-sky CCD detector.

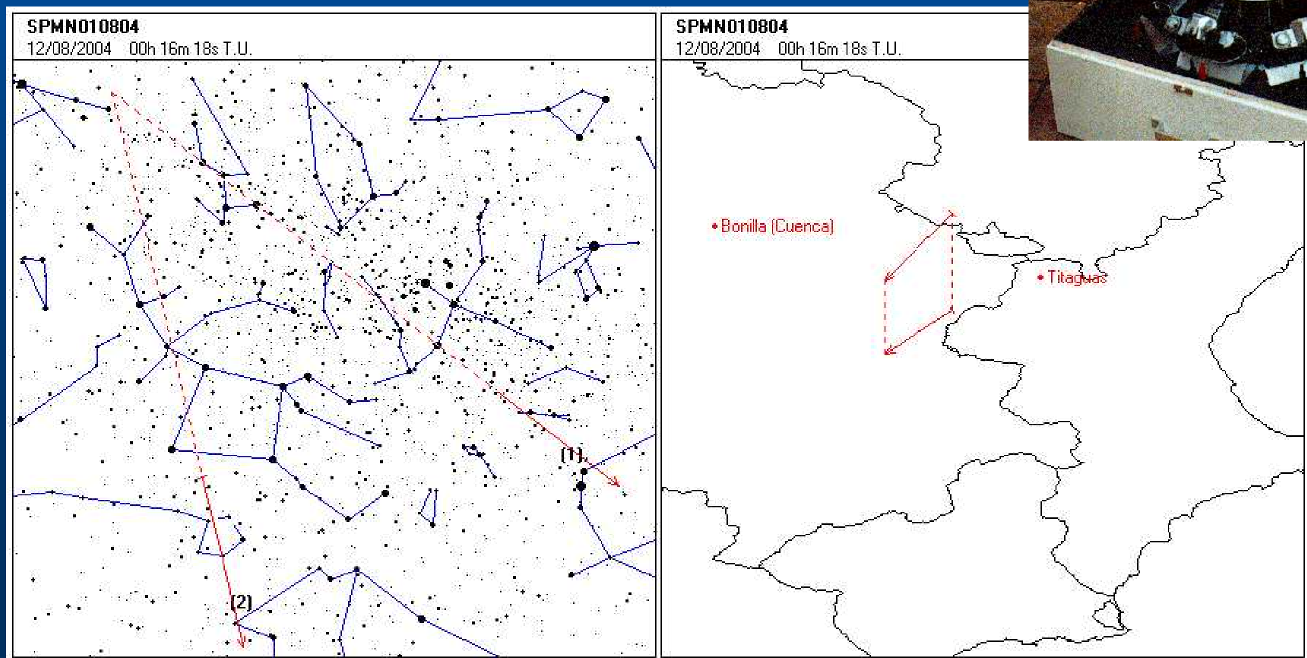
# AN EXAMPLE OF TRAJECTORY AND ORBIT



- Fireball "INIESTA" (SPMN010804)
- 2004 Aug. 12, 0h16m18s UTC
- -8 absolute magnitude event
- Associated with comet 109P/Swift-Tuttle.

Batteries of cameras

Apparent trajectory of the fireball projected on the sky from both Stations.
Images Paco Ocaña and Angela del Castillo (Trigo-Rodríguez et al., 2005)




Location of both stations and atmospheric trajectory of the fireball

# TRAJECTORY AND ORBITAL DATA: INIESTA FIREBALL

**SPMN010804 "Iniesta"**
**2004 August 12, T= 0h16m18±1s UT**

**Atmospheric trajectory data**

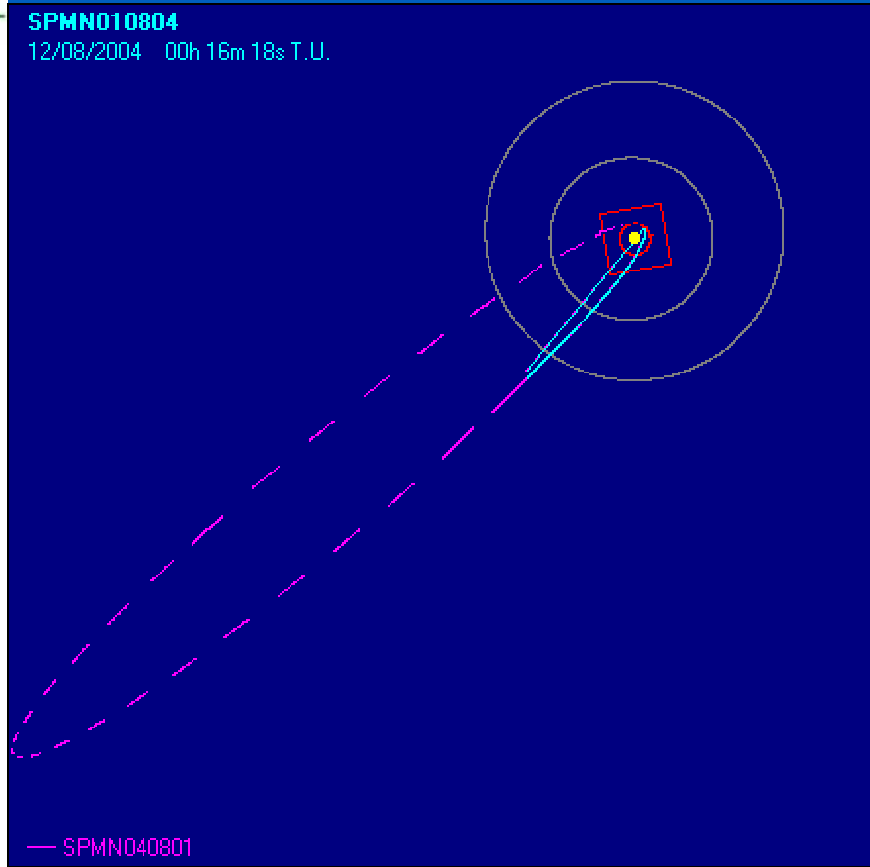
| | Beginning | Max. light | Terminal |
|---|---|---|---|
| Velocity (km/s) | 60.7 ± 0.2 | 60.5 ± 0.2 | 59.7 ± 0.2 |
| Height (km) | 123.85 ± 0.07 | 104.34 ± 0.07 | 86.13 ± 0.06 |
| Longitude (° W) | 1.479 ± 0.002 | 1.677 ± 0.002 | 1.862 ± 0.001 |
| Latitude (° N) | 39.651 ± 0.001 | 39.477 ± 0.001 | 39.314 ± 0.001 |
| Photometric mass (g) | $8 \cdot 10^{-6}$ | 9.8 | $2 \cdot 10^{-5}$ |
| Absolute magnitude | +6 | -8 | +5 |
| Total length (km) | | 39.5 | |
| Slope (°) | | 72.7±0.1 | |
| Duration (s) | | 0.65 | |
| SPMN stations: | | Titaigües (Valencia) and Bonilla (Cuenca) | |

**Radiant data (J2000.0)**

| | Observed | Geocentric | Heliocentric |
|---|---|---|---|
| Right ascension (°) | 44.90±0.02 | 45.61±0.02 | - |
| Declination (°) | 57.55±0.02 | 57.67±0.02 | - |
| Ecliptical Longitude (°) | - | - | 79.44±0.09 |
| Ecliptical latitude (°) | - | - | 63.37±0.06 |
| Initial velocity (km/s) | 60.7±0.1 | 59.5±0.1 | 41.47±0.09 |

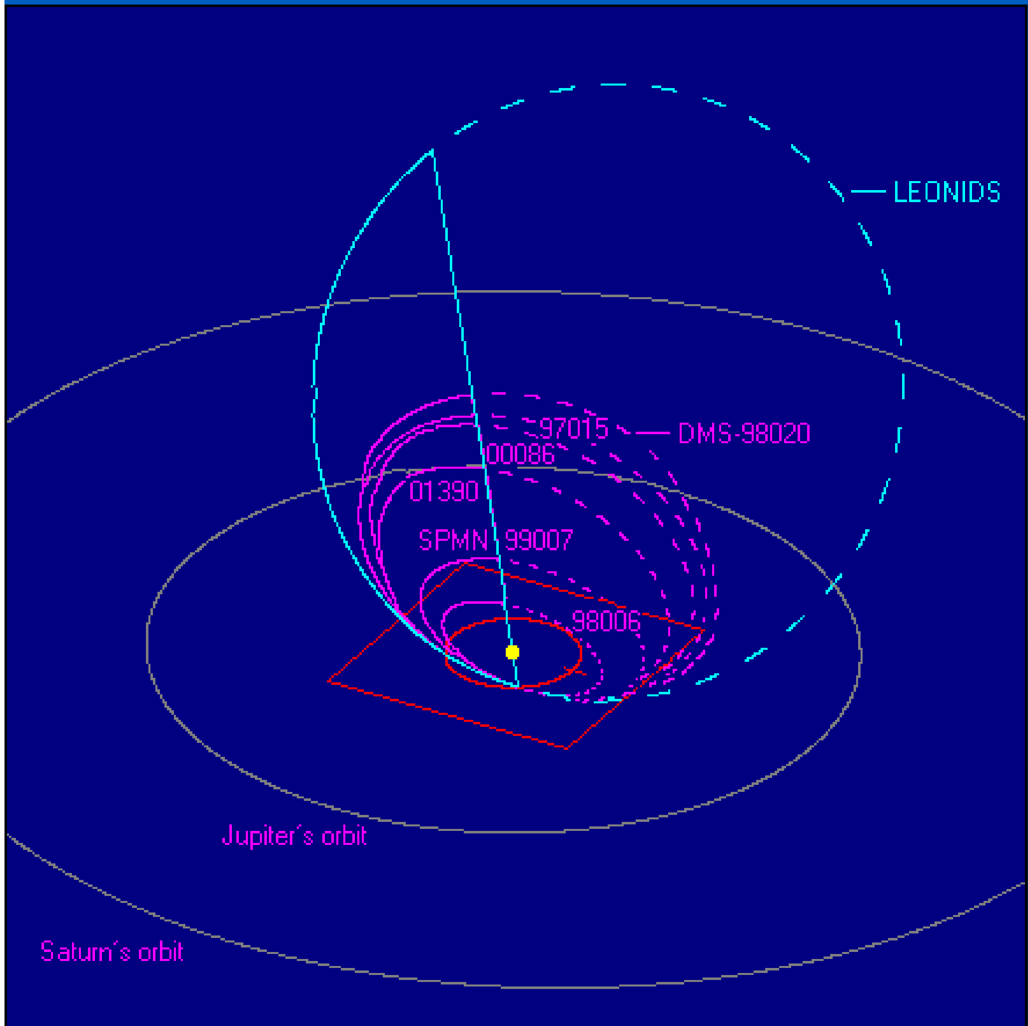
**Orbital data (J2000.0)**

| | | | |
|---|---|---|---|
| a (AU) | 29 ± 7 | ω (°) | 153.75 ± 0.13 |
| e | 0.966 ± 0.008 | Ω (°) | 139.57728 ± 0.00001 |
| q(AU) | 0.9620 ± 0.0003 | i (°) | 113.51 ± 0.07 |
| Q(AU) | 56 ± 14 | | |



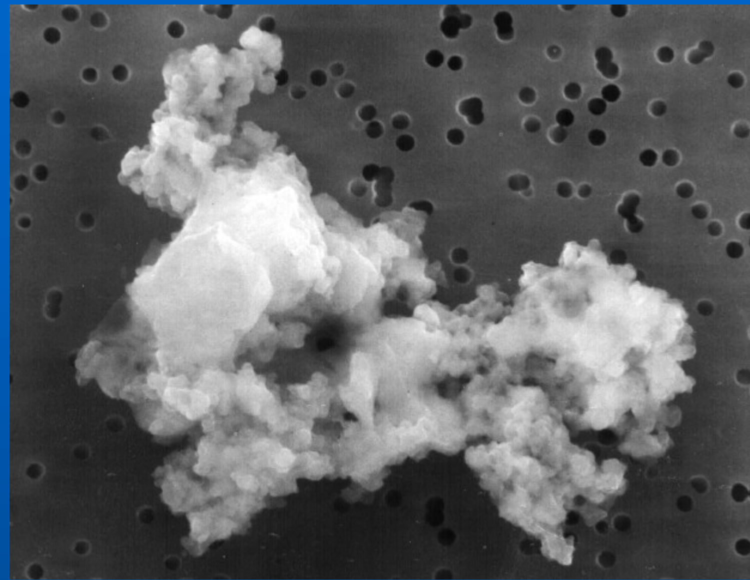
# COLLISIONS ON FLUFFY PARTICLES

Short period Leonid orbits



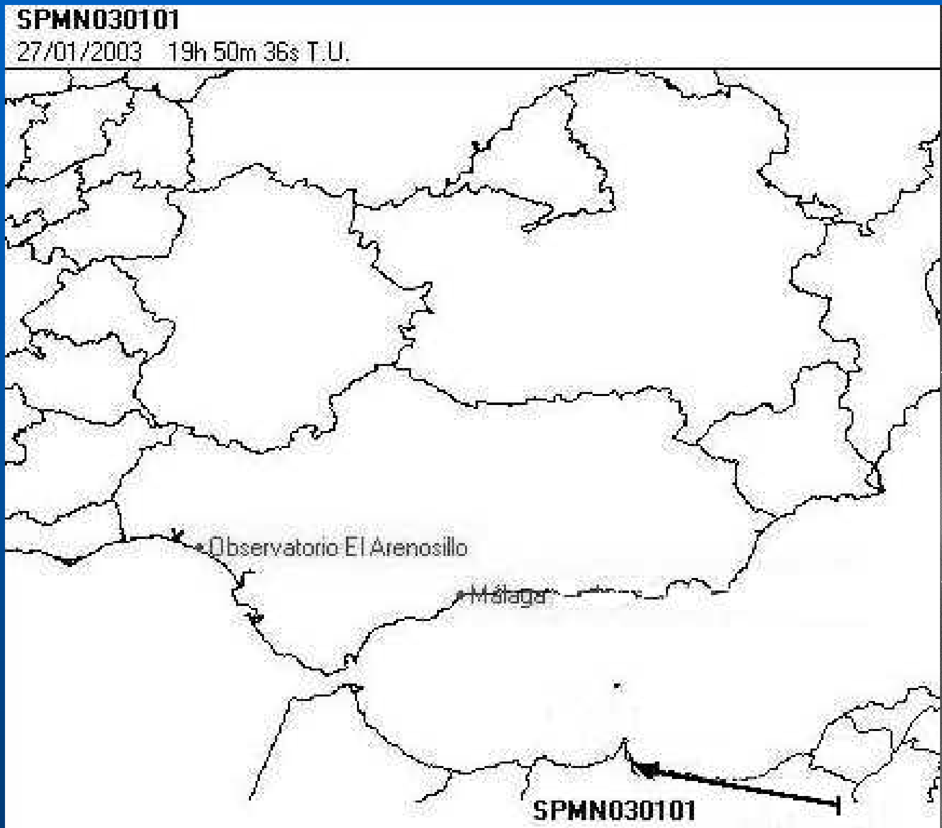

(Trigo-Rodriguez, Betlem & Lyytinen, Ap J 621, 2005).

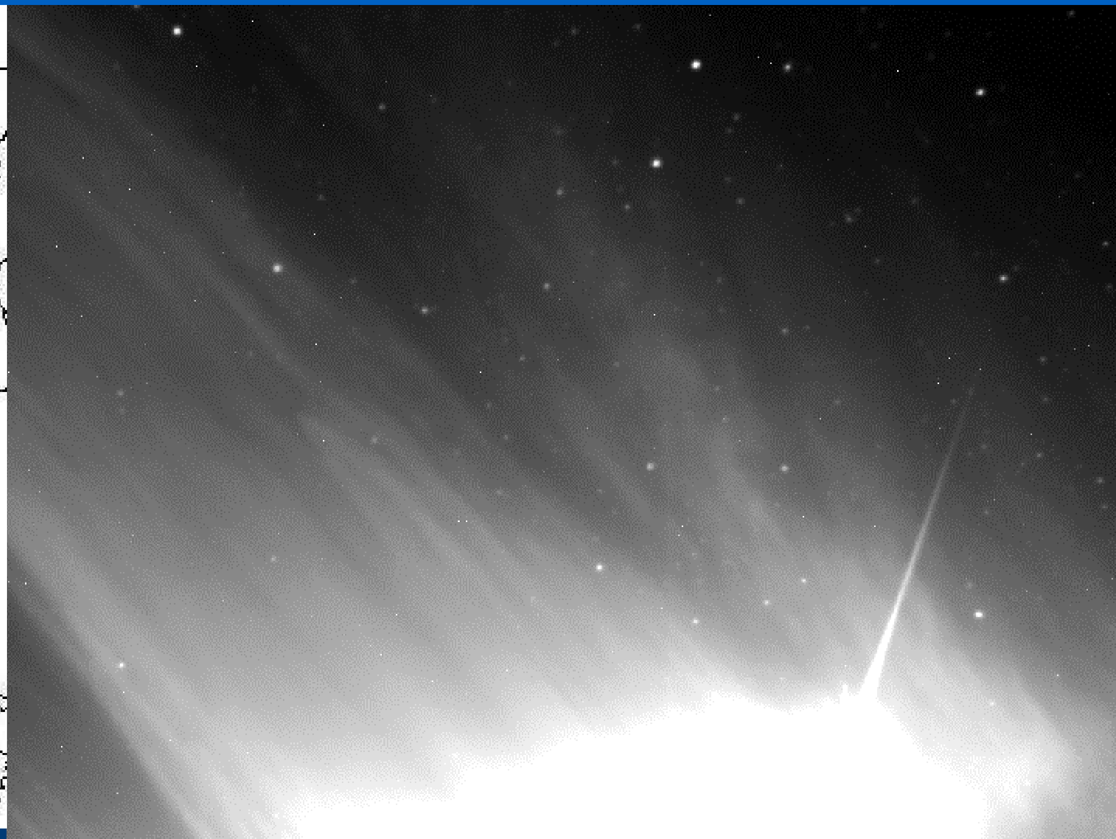
Interplanetary Dust Particle or IDP (NASA)



- **Are fluffy cometary particles able to survive collisions?**
  - – **Yes, but it depends on size. We have discovered short-period Leonids.**
    - **It can be explained by collisions with interplanetary dust.**
    - **Loss of energy close to the ecliptic plane**
    - **Typical mass of zodiacal dust: $10^{-6}$ grams**
  - – **In short time-scales large particles are fragmented and the dust trail spatial density decreases.**

# 27 JAN 2003 SUPERBOLIDE



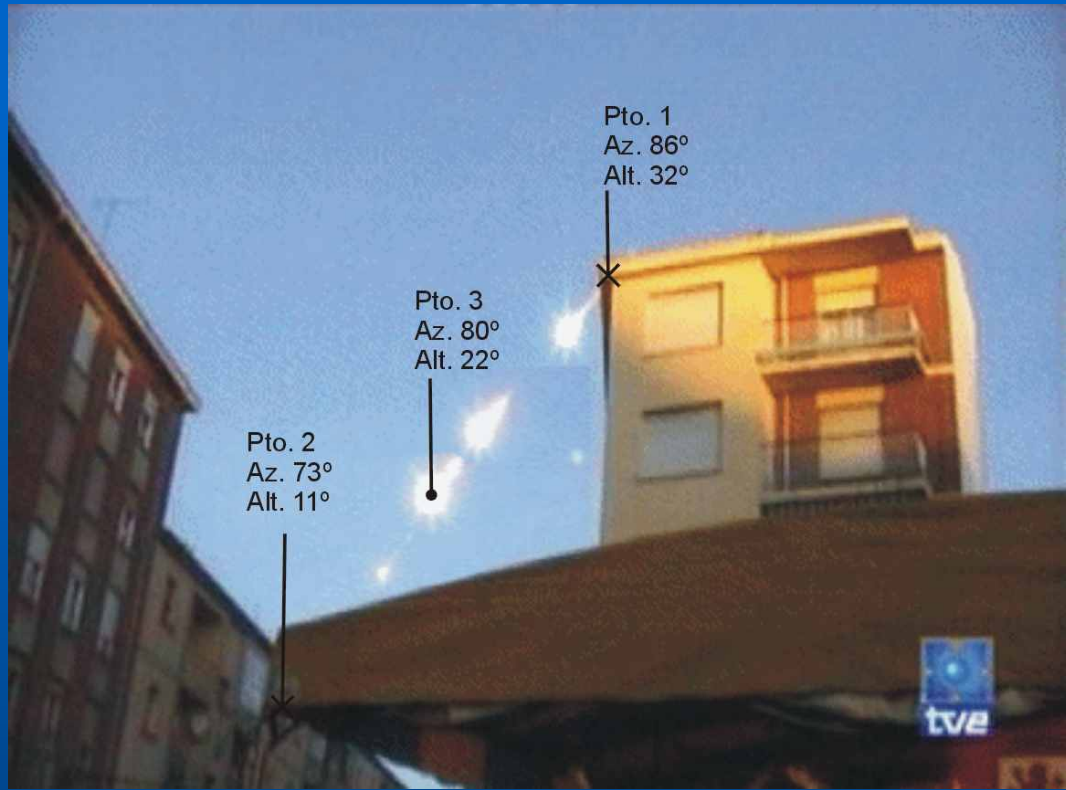
- Role of public in detecting fireballs and providing information through our homepage.
- Probable meteorite fall in Morocco

Medium field image recorded over the Argel and Morocco border, Mv=-17 ± 1, 0.3 s

El Arenosillo Observatory (LAEFF, INTA)

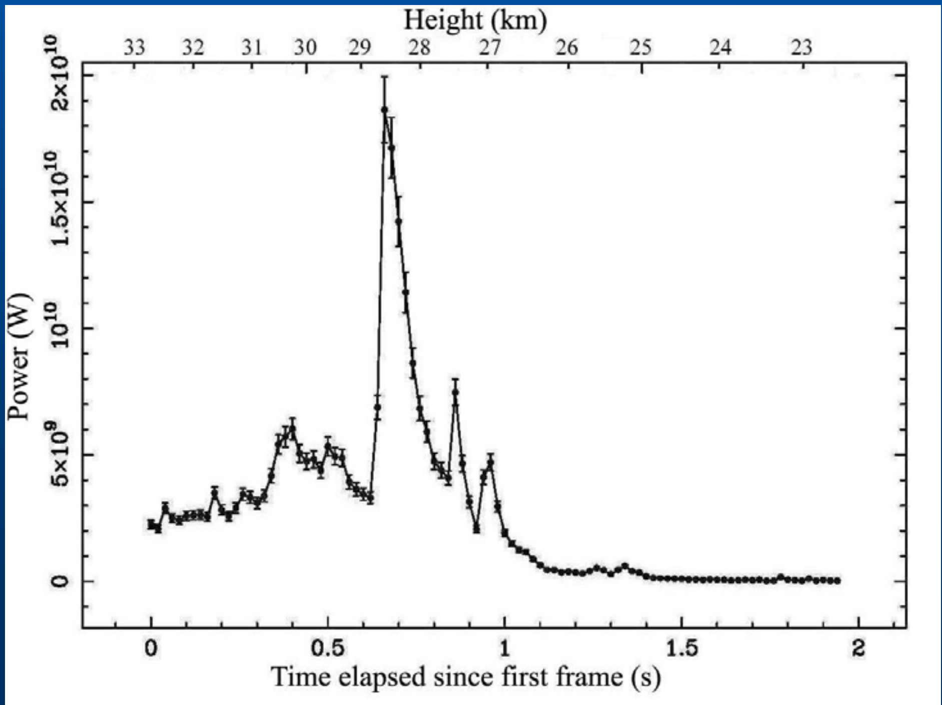
# VILLALBETO DE LA PEÑA FALL

- Daylight bolide of magnitude -18±1
- January 4, 2004 at 16h46m45s UTC
- Initial meteoroid mass: 760 ± 150 kg
- Trajectory slope: 29.0 ± 0.2º
- Trajectory length: 130 ± 10 km



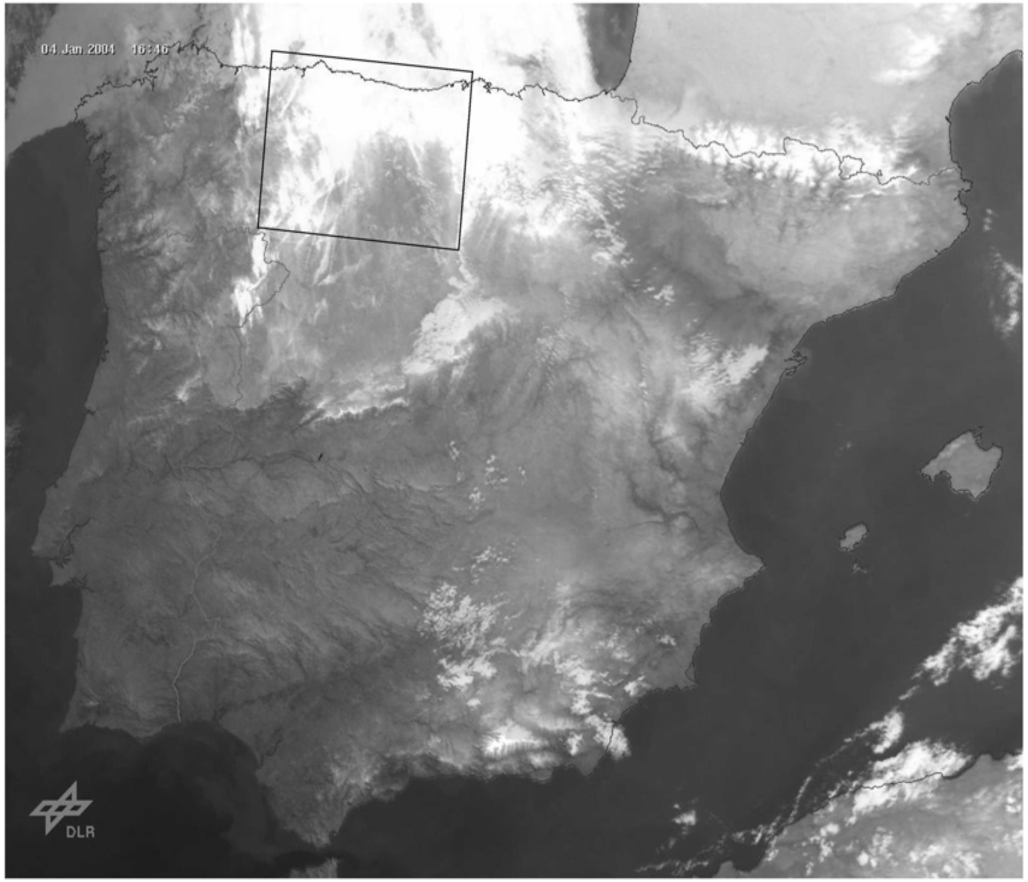

Composite frame sequence of the video recorded from Leon.

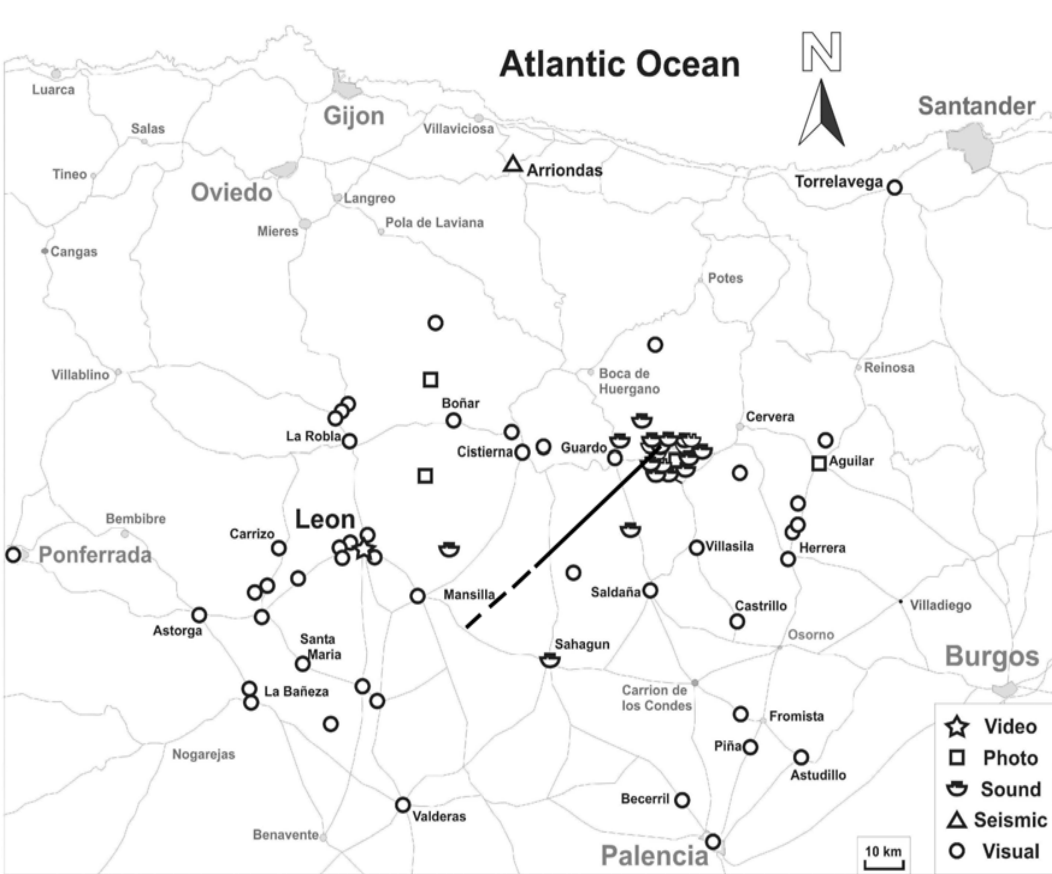
**Papers will be published in MAPS.**




- Total light emission: $5.7\times10^{9}$ J from the analysis of the video
- Energy: ~0.022 kilotons
  - Consistent with photometric, seismic, and infrasonic data.

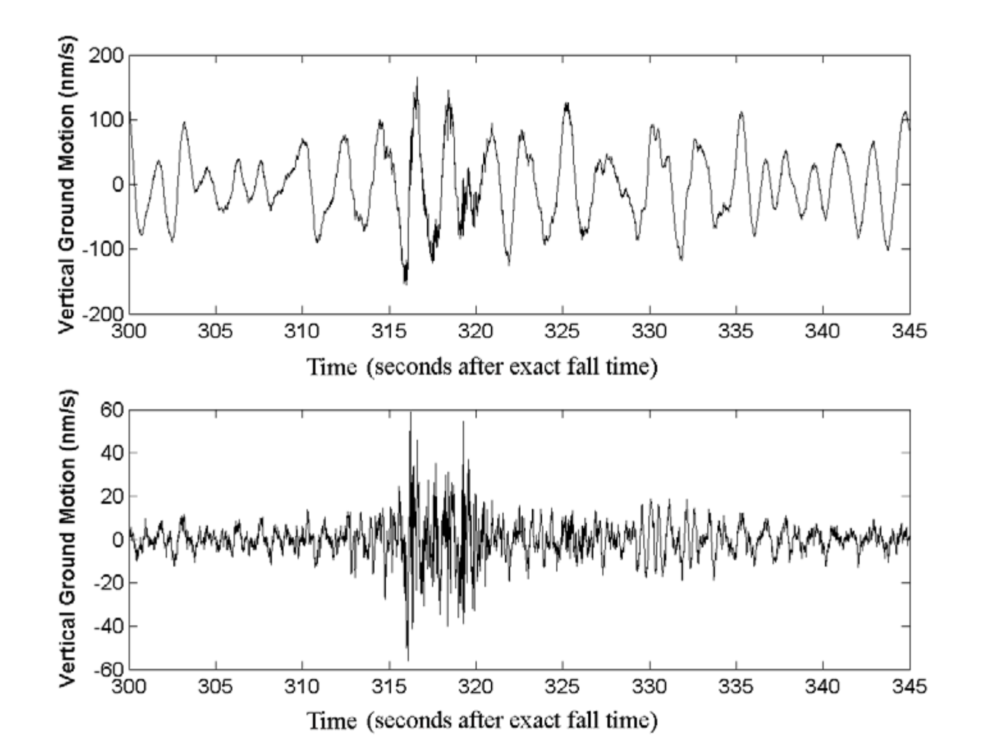
# VILLALBETO OBSERVING CONDITIONS



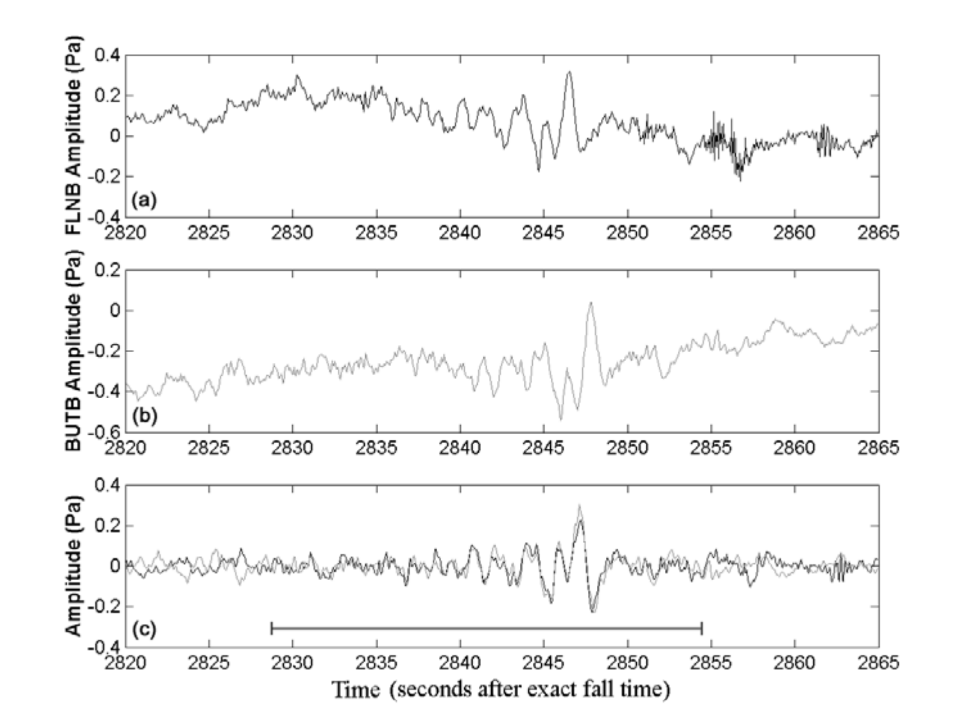




- The Earth receives ~10 impacts with such energy every month:
  - Appeared in broad daylight when thousands of people were attending diverse festivities in the northern part of the Iberian Peninsula.
  - Increasing availability of digital cameras makes it possible for eyewitnesses to obtain valuable records of daylight fireballs.

# SEISMIC AND INFRASOUND DETECTIONS




Infrasound detection from Le Fleurs (France)

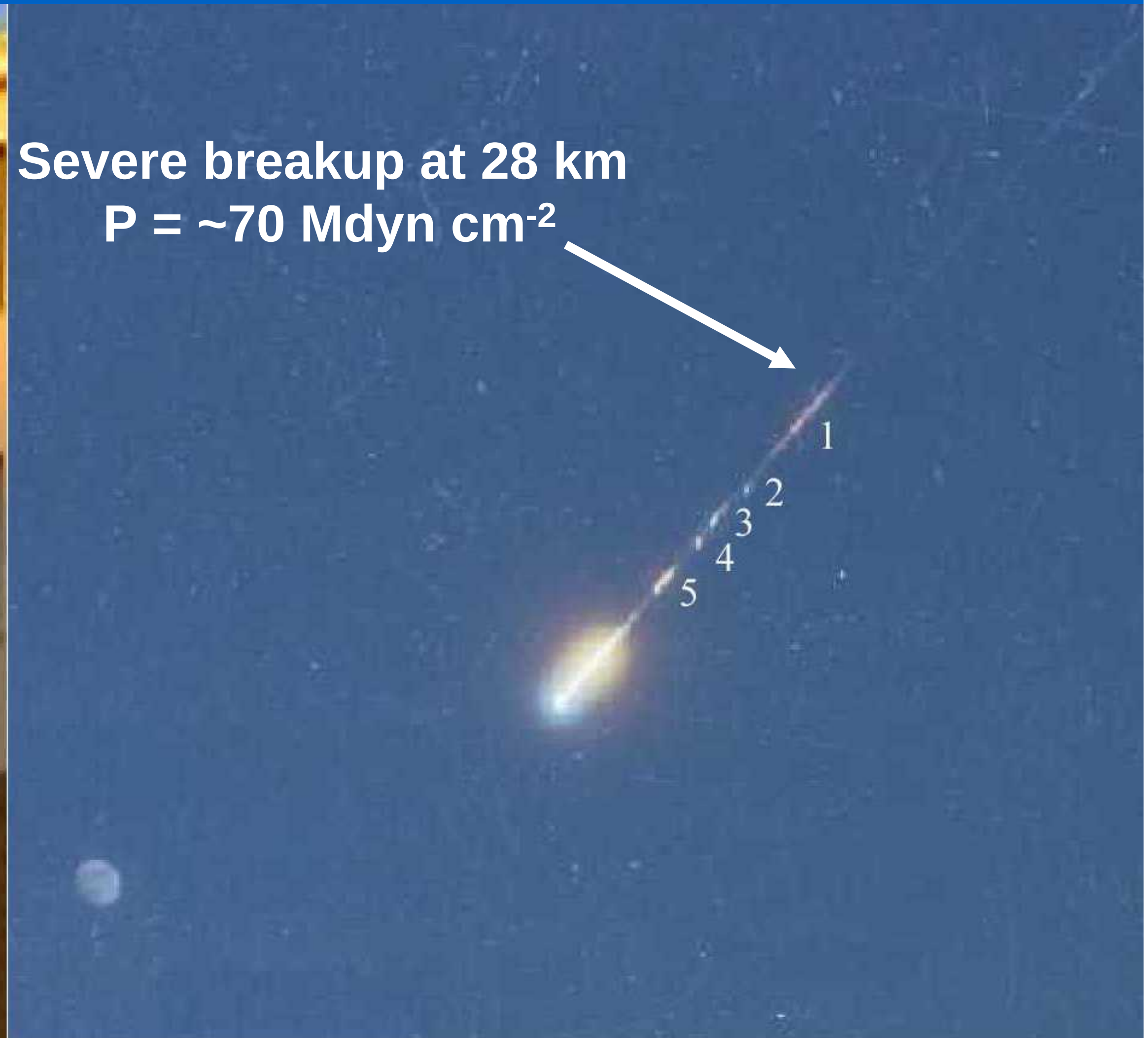



Seismic detection of the airblast during massive fragmentation at an height of 28 km. Arriondas seismic station (Asturias)

Llorca et al., MAPS 40-6, (2005)

Picture taken before main fragmentation from Las Hoces (León). Image Salvador Díez

# VILLALBETO FALL: FRAGMENTATION EVENTS


- Video frame at the same moment from León
- Picture of the bolide obtained from Santa Columba de Corueño (León). Image Maria Robles
- And the Moon appears for calibration of both pictures !!!

# TRAJECTORY DETERMINATION


- 65 calibration points were selected in every frame (right). In the 110 frames, a total of ~7,000 points were accurately measured.
- Calibration images were obtained for all locations where the fireball was imaged. Astrometric reduction was made by following the procedures of Borovicka et al. (2003).
- On the right is a calibration picture containing stars from constellations of Boötes, Hercules and Draco.

From Trigo-Rodríguez et al., MAPS (2006)

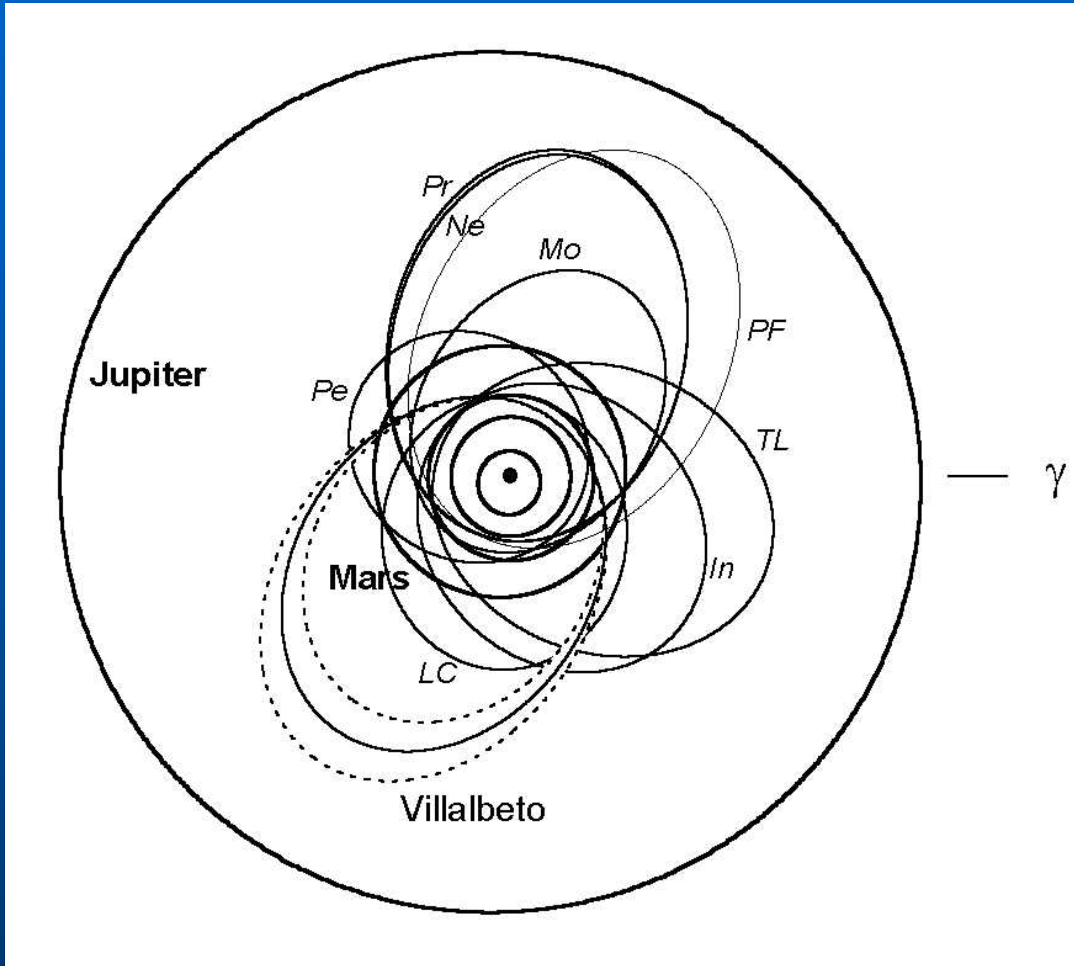
# VILLALBETO FALL: ORBITAL DATA

Villalbeto de la Peña is the ninth meteorite with a known heliocentric orbit.

MAIN DATA:

- Initial velocity: 16.9 ± 0.4 km/s
- Heliocentric velocity: 37.7 ± 0.5 km/s

- Orbital period: 3.5 ± 0.5 yr
- Aphelion distance: 3.7 ± 0.4 AU
- Eccentricity: 0.63 ± 0.04
- Semimajor axis: 2.3 ± 0.2 AU
- Inclination: 0.1 ± 0.2 º
- Argument of perihelion: 132.3° ± 1.5°
- Perihelion distance: 0.860 ± 0.007 AU
- Longitude of perihelion: 56.0° ± 1.5°




Orbit of Villalbeto (considering the uncertainty in the orbital elements) compared with previously determined orbits of meteorites. (Trigo-Rodríguez et al., MAPS, 2006)

# VILLALBETO'S ORIGIN

- Using the source-region model for NEAs of Bottke et al. (2001), and taking into account the uncertainties in the orbital elements, Villalbeto de la Peña could have originated in four regions:

  - The 3:1 jovian resonance,
  - The $\nu_6$ resonance,
  - The Mars-crossing region,
  - The outer main belt.

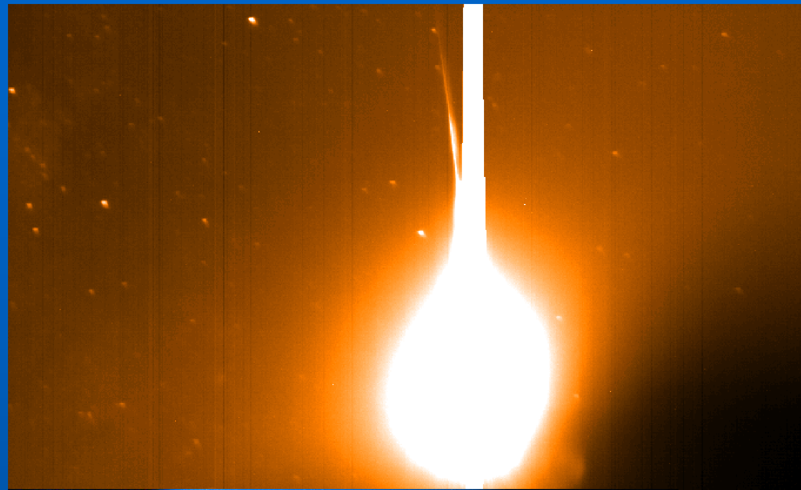
However, the similar probabilities for these four regions make it difficult to determine the exact source of the meteorite.

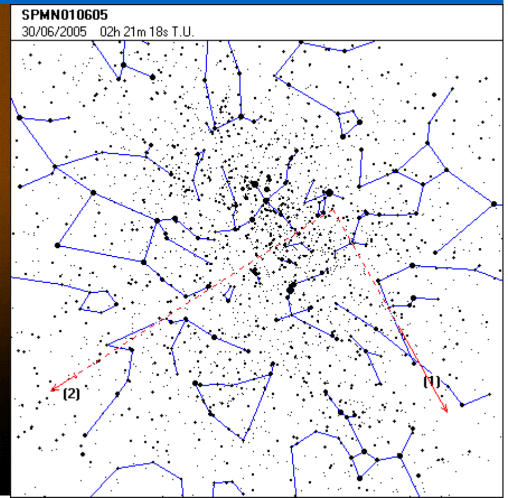
# CEUTA SUPERBOLIDE

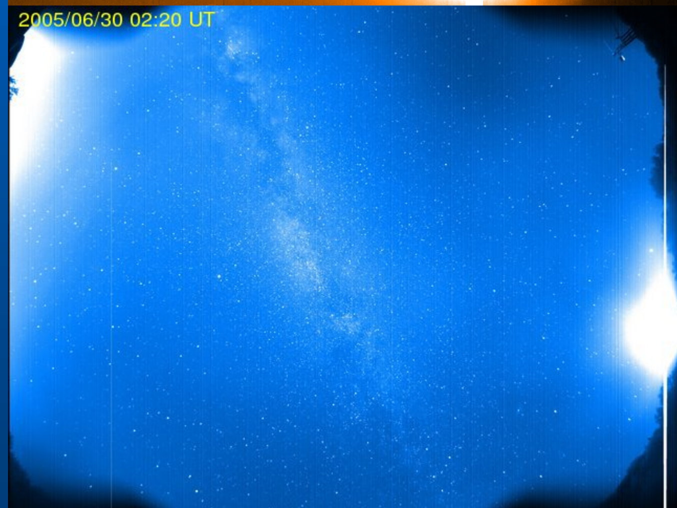
- First superbolide recorded from double-station monitoring from Spain
- Appeared on June 30, 2005 at 2h21m22s±8s UTC
- Absolute magnitude -17±2
- Complete disintegration of the meteoroid at an height of 62±2 km
- Luminous trajectory of 51±3 km

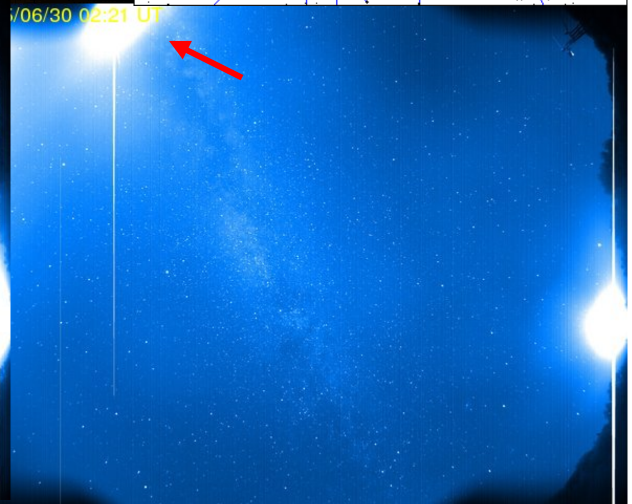
- Active radiants:
  – June Lirids minor shower.
  – June Bootids radiant associated with 7P/Pons-Winnecke.

- The fireball was of cometary type IIIB, as suggested by its light curve and early fragmentation





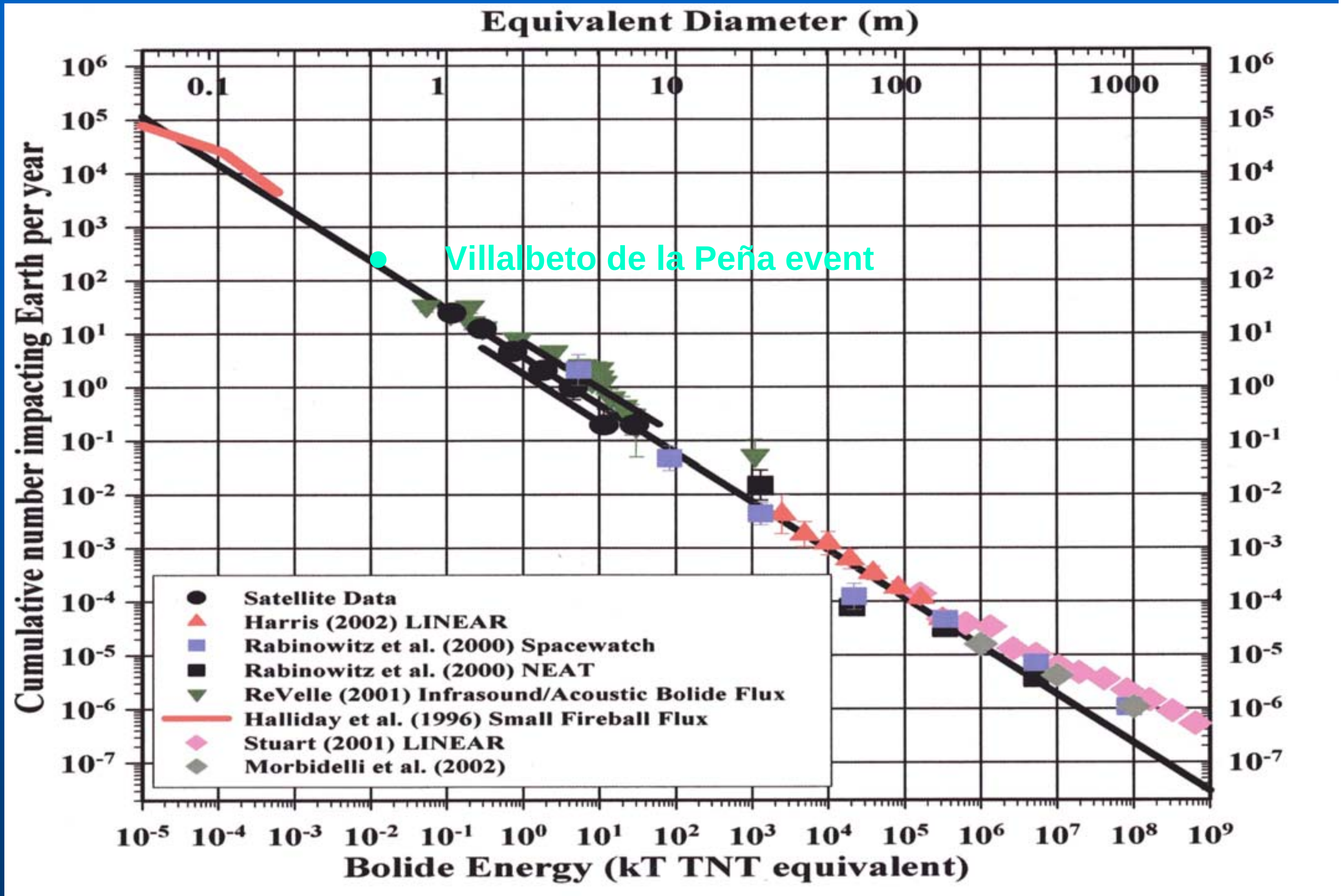




# THE PRESENT FLUX OF BODIES

Brown et al., (2002)

- In the mass range: $0.1 \leq M_{\infty} \leq 2 \times 10^3$ kg
- Fireball network studies provide information on bodies that are not detectable with telescopes.
  - Direct estimations of the energy released in impacts
- Evidence for weak interplanetary materials that are unable to survive atmospheric interaction

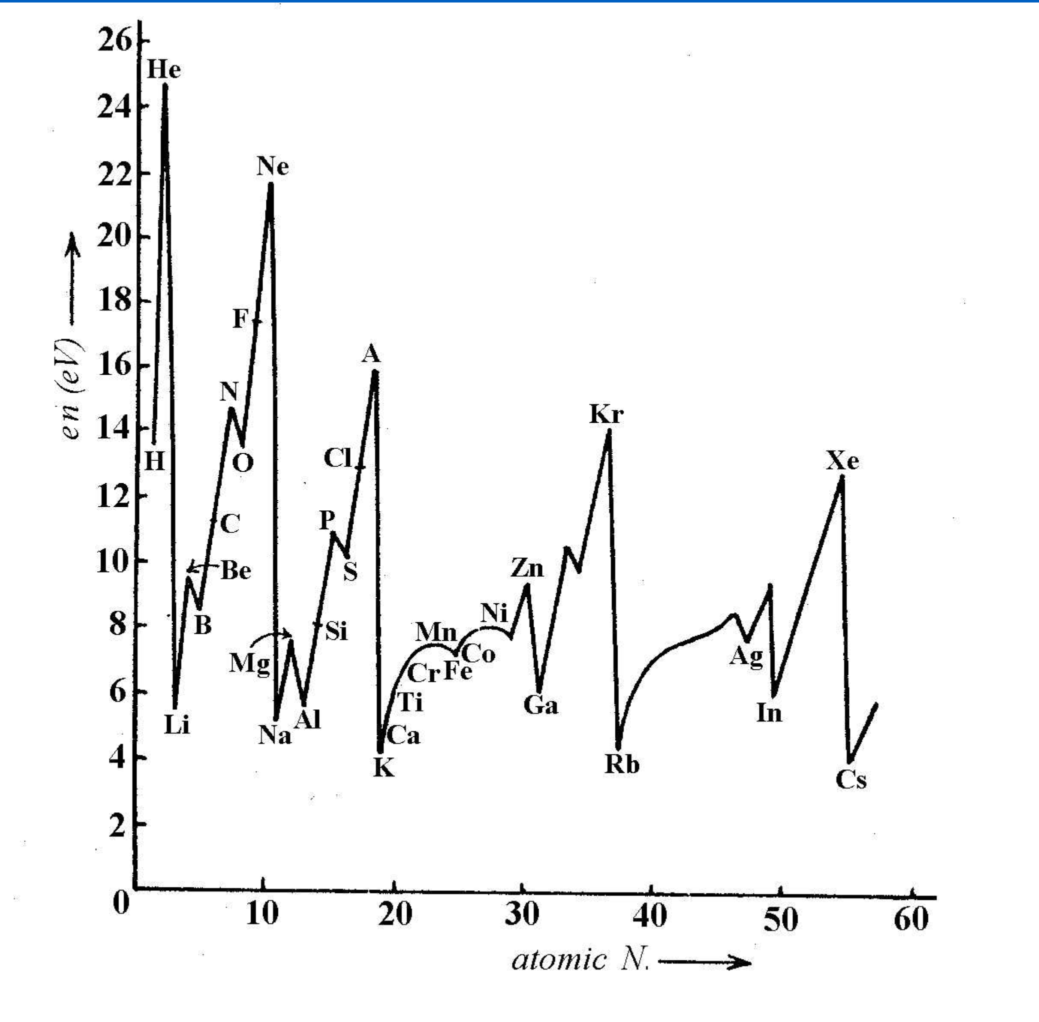


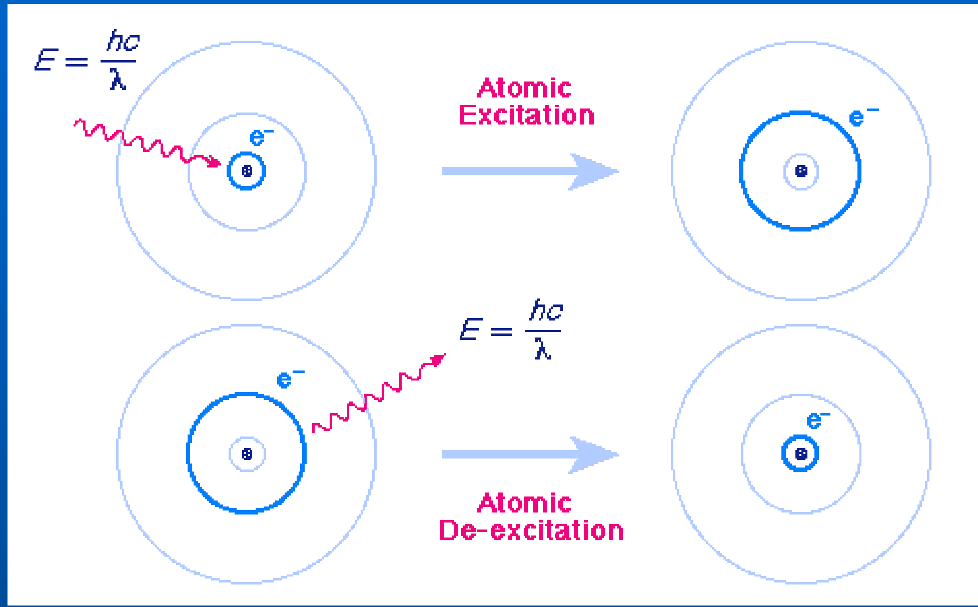

The Earth receives one impact in the range of 2 to 10 ktons annually and one impact of 0.3 ktons monthly.

# FIREBALL SPECTRA: A VALUABLE LINK WITH METEOROID CHEMISTRY


Leonid fireball spectra, Ondrejov Observatory, Nov. 18, 1980.

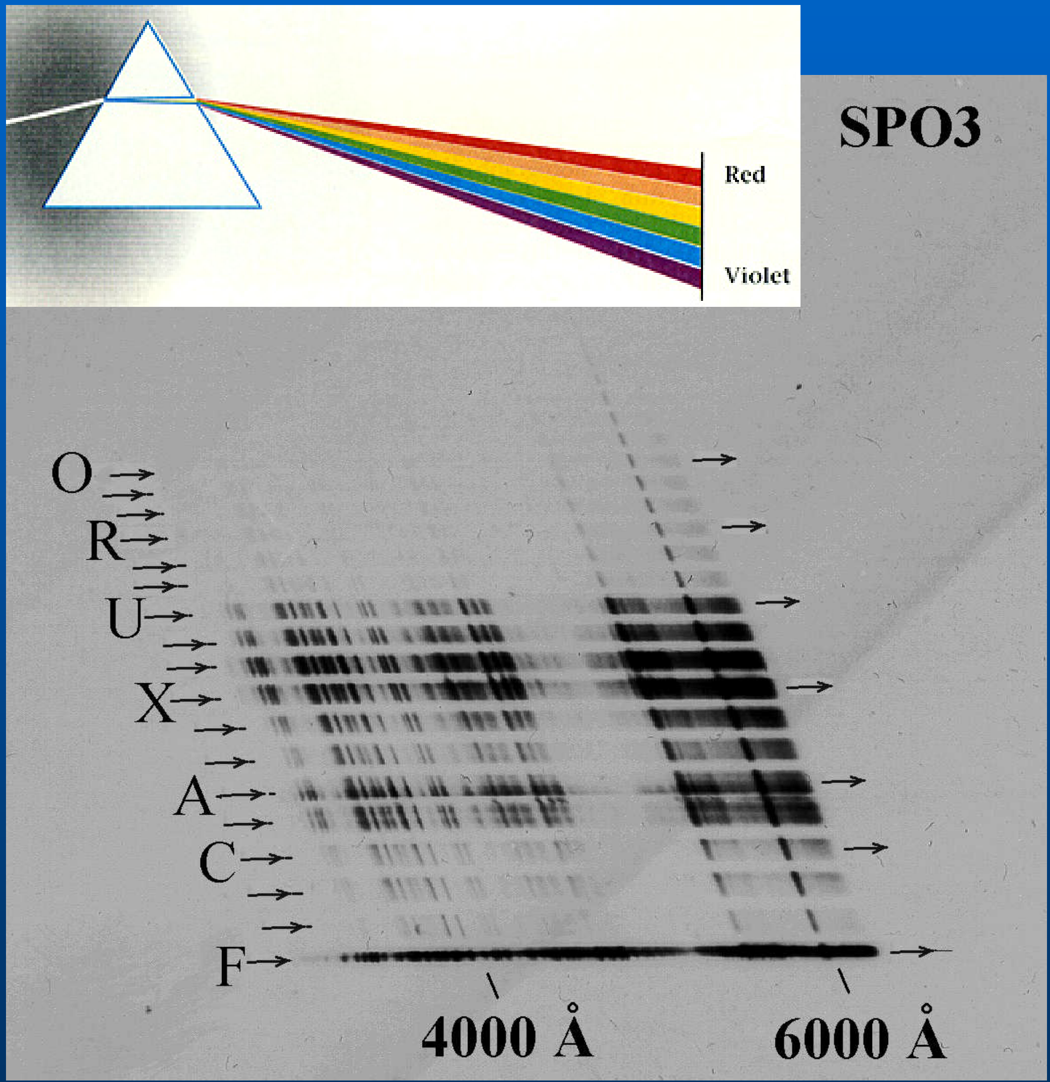
# THE ORIGIN OF METEOR RADIATION




- Atomic collisions produce excitation and ionization.
- De-excitation produces light
  - Between UV and near IR.
- Depending of the binding energy some atoms contribute to meteor light more than others.
- But the presence of one element in meteor spectra also depends on its relative abundance in the meteoroid.

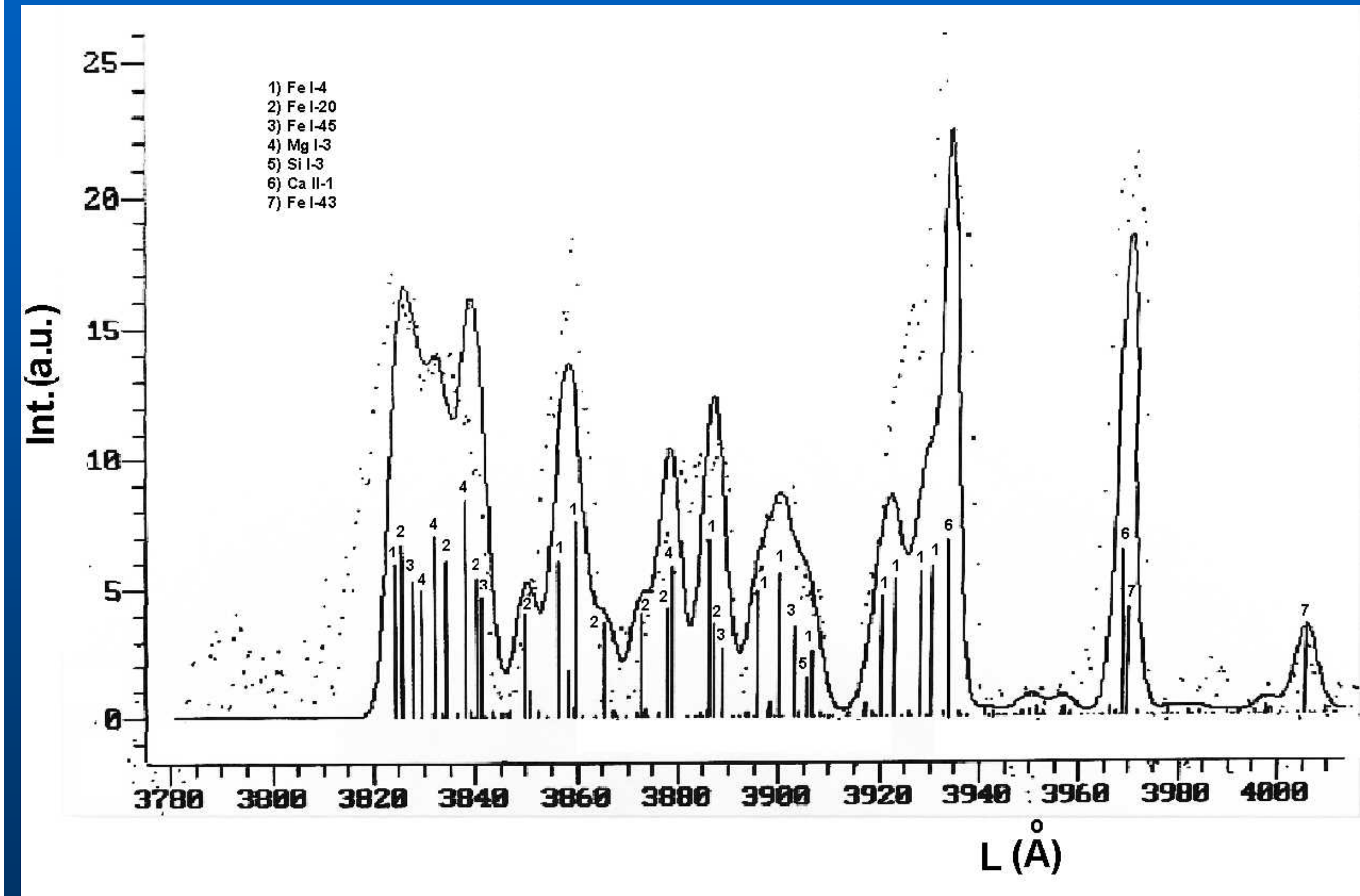
# REDUCTION PROCEDURE




Sporadic fireball of Vg=25.6 km/s (Trigo-Rodriguez et al., 2003).

- **The spectra are scanned along different segments in the trajectory:**
  - **Chemical abundances were estimated averaging all parts.**
- **First step: Identification of main spectral lines to calibrate the wavelength along the spectrum.**

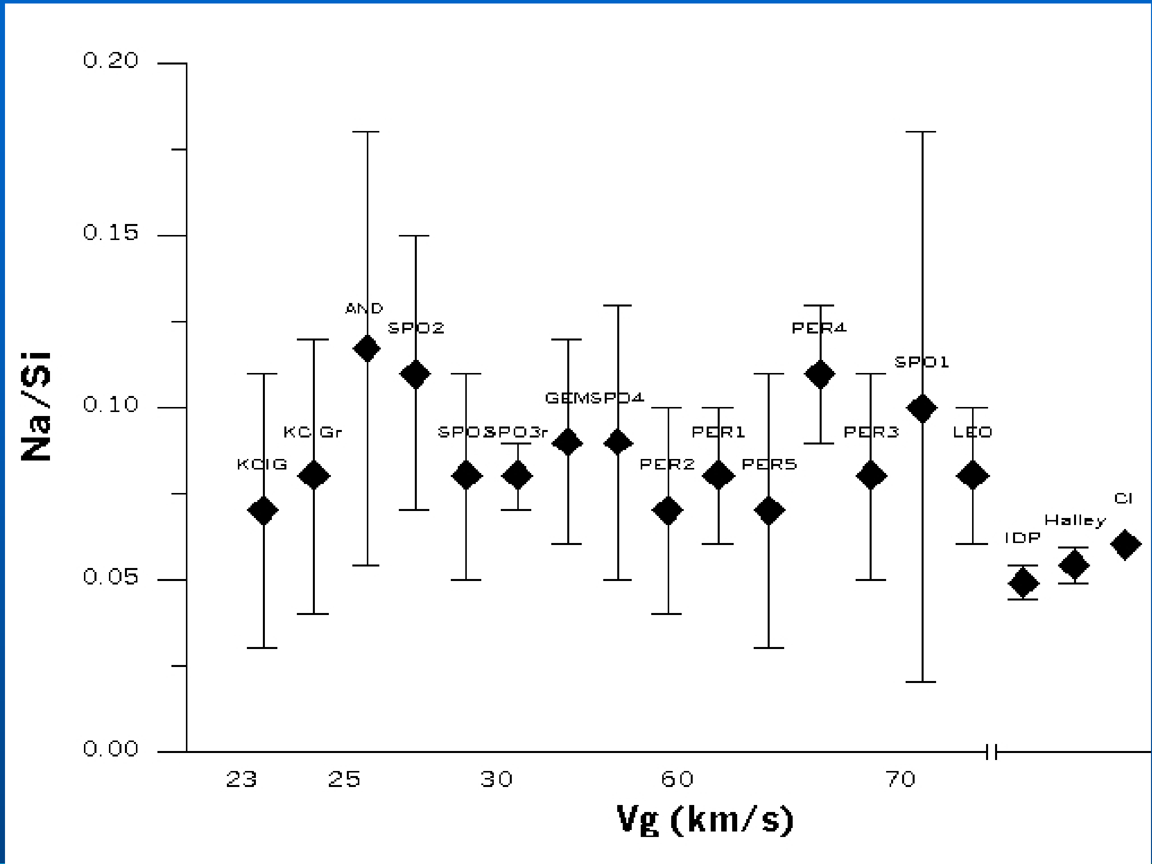
# DETERMINING CHEMICAL ABUNDANCES




(Trigo-Rodríguez., 2002).

- **The synthetic spectrum vs. the observed one (discontinuous).**
- **3 free parameters to fit meteor spectra:**
  - **Density of atoms in column**
  - **Temperature (K)**
  - **Radiating area**
- **Chemical abundances are adjusted by matching the synthetic to the observed one.**

# SODIUM OVERABUNDANCE

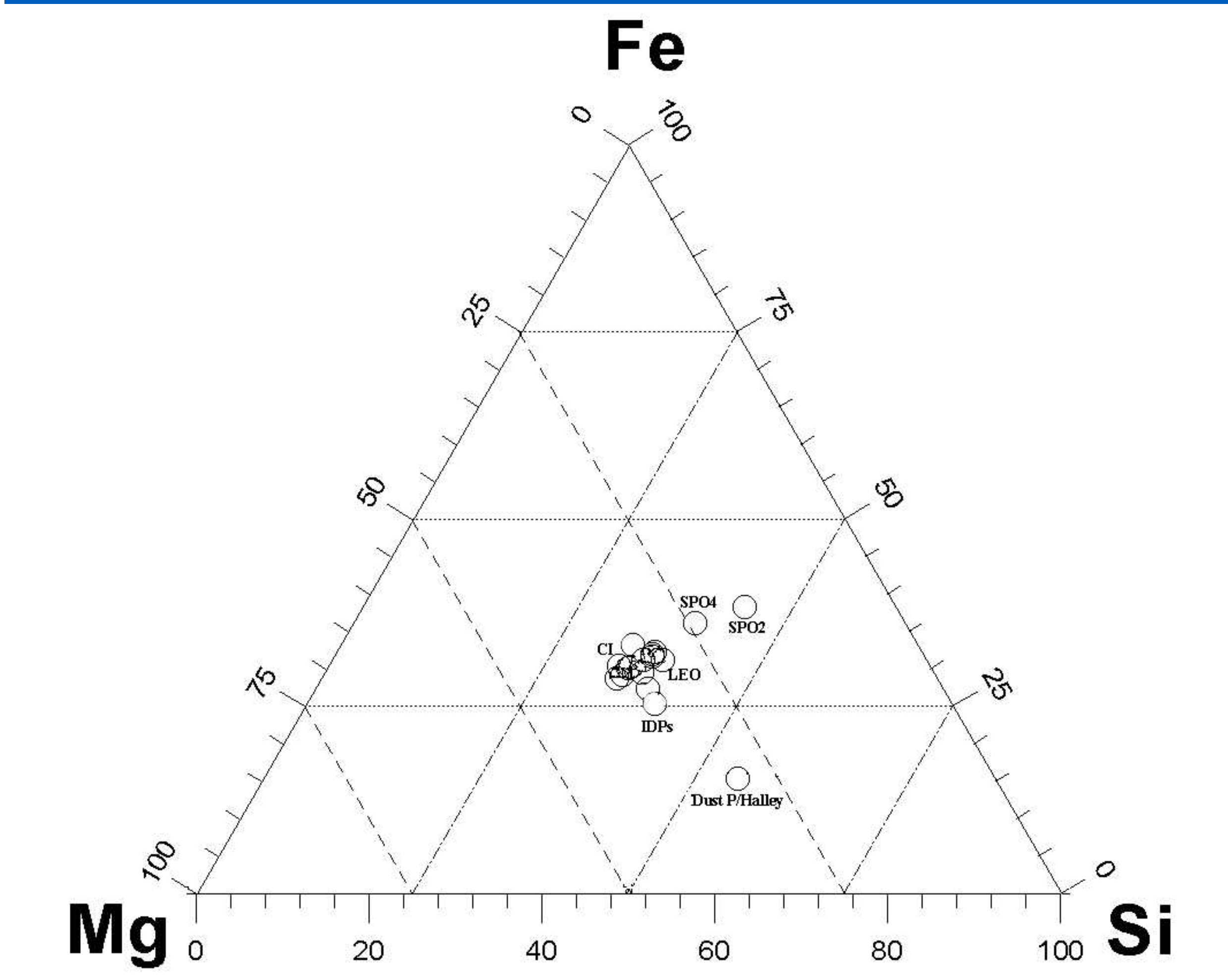



| Source of Na | Segments | Vg (Km/s) | Density Na ($cm^{-3}$) Max | Min |
|---|---|---|---|---|
| AND | A y H | 24 | $7{,}5\cdot10^{11}$ | $1{,}3\cdot10^{11}$ |
| SPO3 | A y N | 29 | $1{,}6\cdot10^{12}$ | $3{,}7\cdot10^{11}$ |
| GEM | J y D | 38 | $1{,}3\cdot10^{11}$ | $7{,}1\cdot10^{10}$ |
| SPO4 | A y Z | 57 | $6{,}5\cdot10^{11}$ | $3{,}3\cdot10^{11}$ |
| PER1 | A y D | 60 | $4{,}9\cdot10^{11}$ | $2{,}3\cdot10^{11}$ |
| LEO | A y N | 72 | $6{,}5\cdot10^{11}$ | $1{,}6\cdot10^{11}$ |
| [Na] in the atmosphere (Plane, 1991) | - | - | $10^{3}$ | $10^{4}$ |

(Trigo-Rodriguez. et al., 2004, MNRAS)

- Na relative abundance plotted as a function of the geocentric velocity (Vg).
- Na/Si ratio is higher than expected.
- Na overabundance not related to the Na atmospheric layer (see table)
  - Sodium abundance is between 7 to 8 orders of magnitude higher than in the meteoric columns.
- Is this evidence that comets have higher abundances of many volatiles than the Sun?

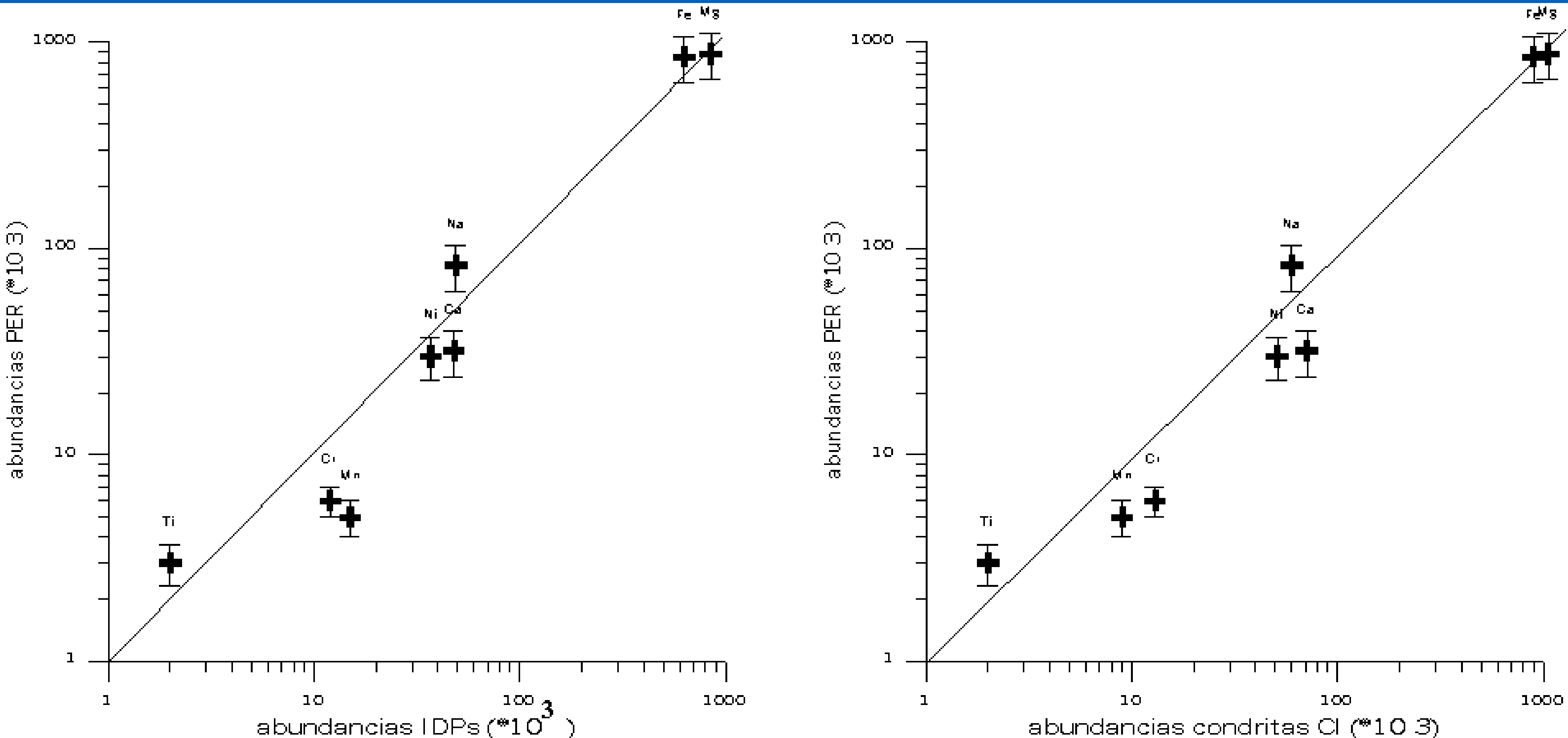
# TERNARY Fe-Mg-Si DIAGRAM




(Trigo-Rodriguez. et al., 2003, MAPS)

- Fe-Mg-Si are the main constituents of silicates.
- The location in the diagram of meteoroids is lined up with the average for IDPs and chondrites.
- Two sporadic meteoroids are especially poor in Mg.
- We see important compositional differences with the deduced Giotto values for 1P/Halley dust (Jessberger et al., 1988)

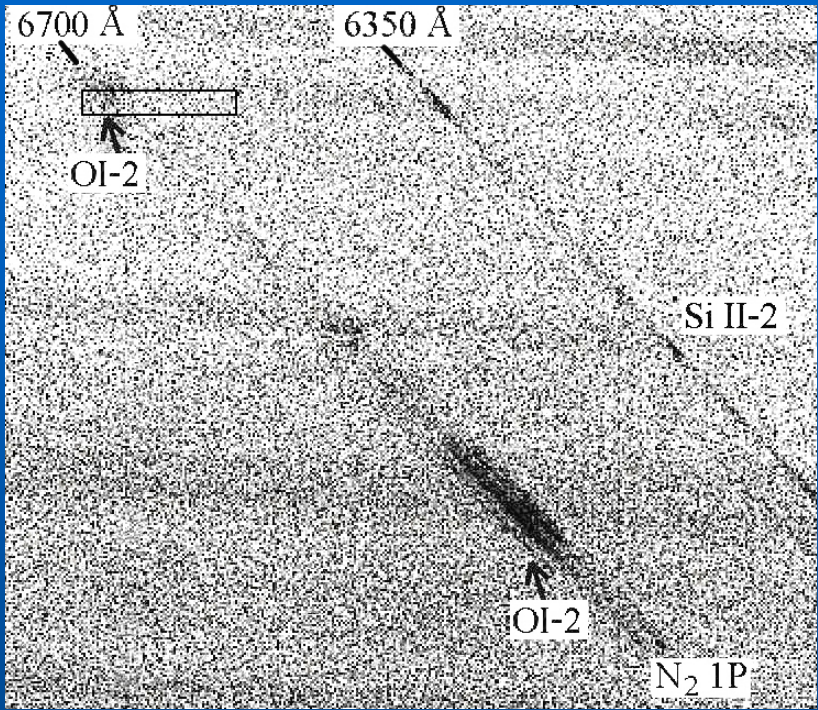
# PERSEIDS VS. IDPs & CHONDRITES

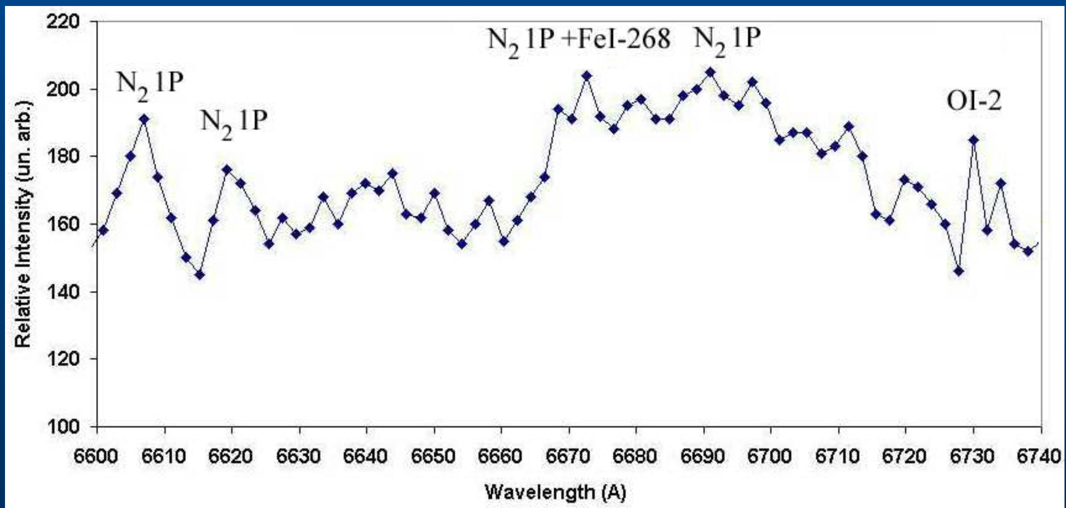



Five spectra associated with 109P/Swift-Tuttle (Perseid meteor shower).

Averaged chemical abundances are close to those of IDPs and chondrites.

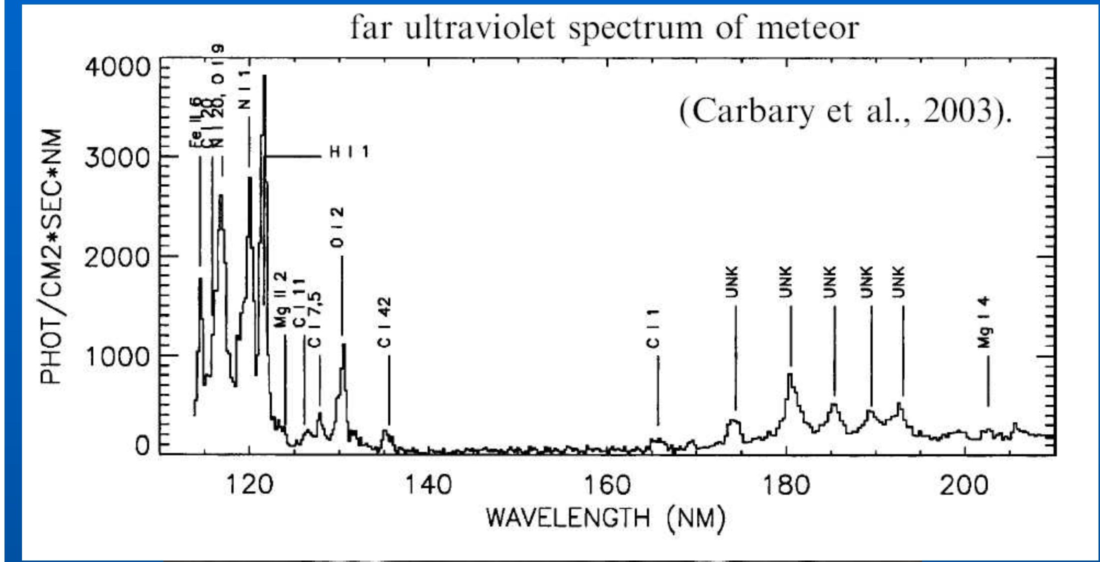
# WATER IN COMETARY METEOROIDS

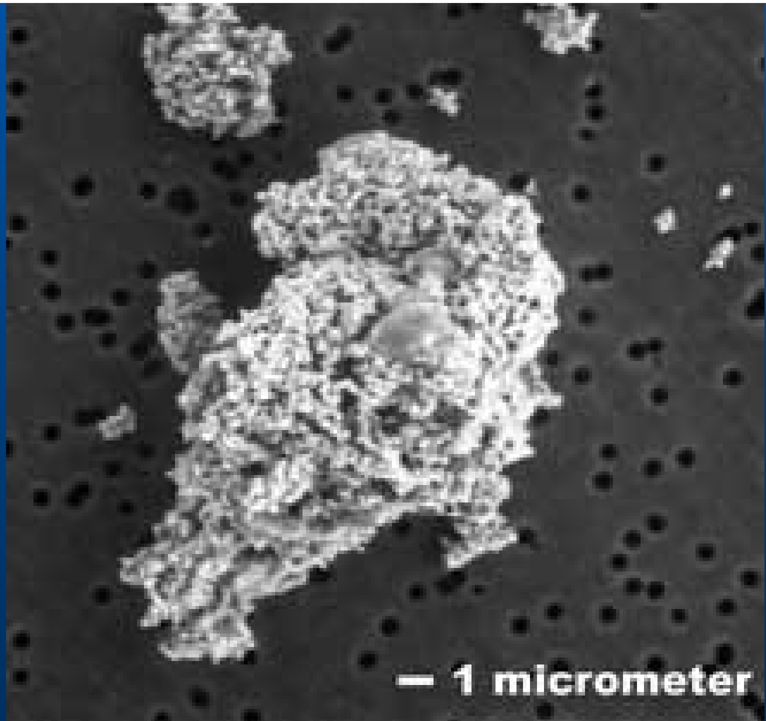



- **A high resolution spectrum obtained of a Perseid fireball by the Spanish Fireball Network reveals the presence of O and H lines.**
  - **Evidence of decomposition of $H_2O$ or OH present in the meteoroid into radicals O and H:**
    - **It can be associated with clay minerals where water would be surviving for long periods in the interplanetary medium.**
    - **Evidence of water in cometary meteoroids although, in fact, it must be widely present in comets.**
  - **Importance of the development of meteor spectroscopy**
  - **Additional evidence: Jenniskens et al. (2004) in Astrobiology 4-1 and Abe et al. (2005) detection of OH**
  - **Hydrated minerals must be frequent in cometary meteoroids (Rietmeijer et al., MAPS, 2004)**

# CARBON IN METEOROIDS




**Interplanetary Dust Particle (NASA)**

- High-resolution IR and UV spectroscopy can confirm if organic molecules are able to survive ablation.
- First detection of C lines and unidentified lines from MSX satellite detectors in a far UV Leonid spectrum:
  - Cometary origin because of the negligible amount of C I at 100 km.
- Flynn et al. (2004) give new estimates of the amount of C preserved in collected IDPs: ~12 wt%.
  - Is the carbon and volatile content of collected IDPs representative of the incoming particles?
  - We can use meteor spectra temperature data to constrain numerical models for low-velocity meteoroids.

# CONCLUSIONS AND FUTURE WORK

- Importance of the study of interplanetary matter from fireball networks:
  - Casual imaging of fireballs provide valuable information, but require a devoted research framework to collect and reduce all available data
  - Fireball networks can provide accurate trajectory data in shorter time
  - New technology is available: CCD and video cameras can patrol the skies
  - From these data the flux of meter-sized bodies to the Earth can be estimated

- Orbital data provide information:
  - On the sources of meteorites: asteroidal and cometary (?) parent bodies.
  - By knowing more orbits we could improve our knowledge of delivery mechanisms
- Meteor Spectroscopy:
  - It offers the chemical composition of meteoroids coming from a large variety of sources
  - It is a complementary source of chemical data compared to expensive sample-return missions

    HOT QUESTIONS WE TRY TO ANSWER:
    - Are cometary meteoroids efficiently delivering organics and water to the Earth?
    - Do comets evolve into asteroids? 3200 Phaeton and Geminids.
    - Exist important chemical differences among comets?
    - Is cometary matter able to survive atmospheric interaction producing meteorites?

If you are interested in these fields just feel free to contact me: trigo@ieec.uab.es