An Astrobiology Mission to Explore the 2002 Leonid Storms

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Meteors as a source of organic matter on the early Earth

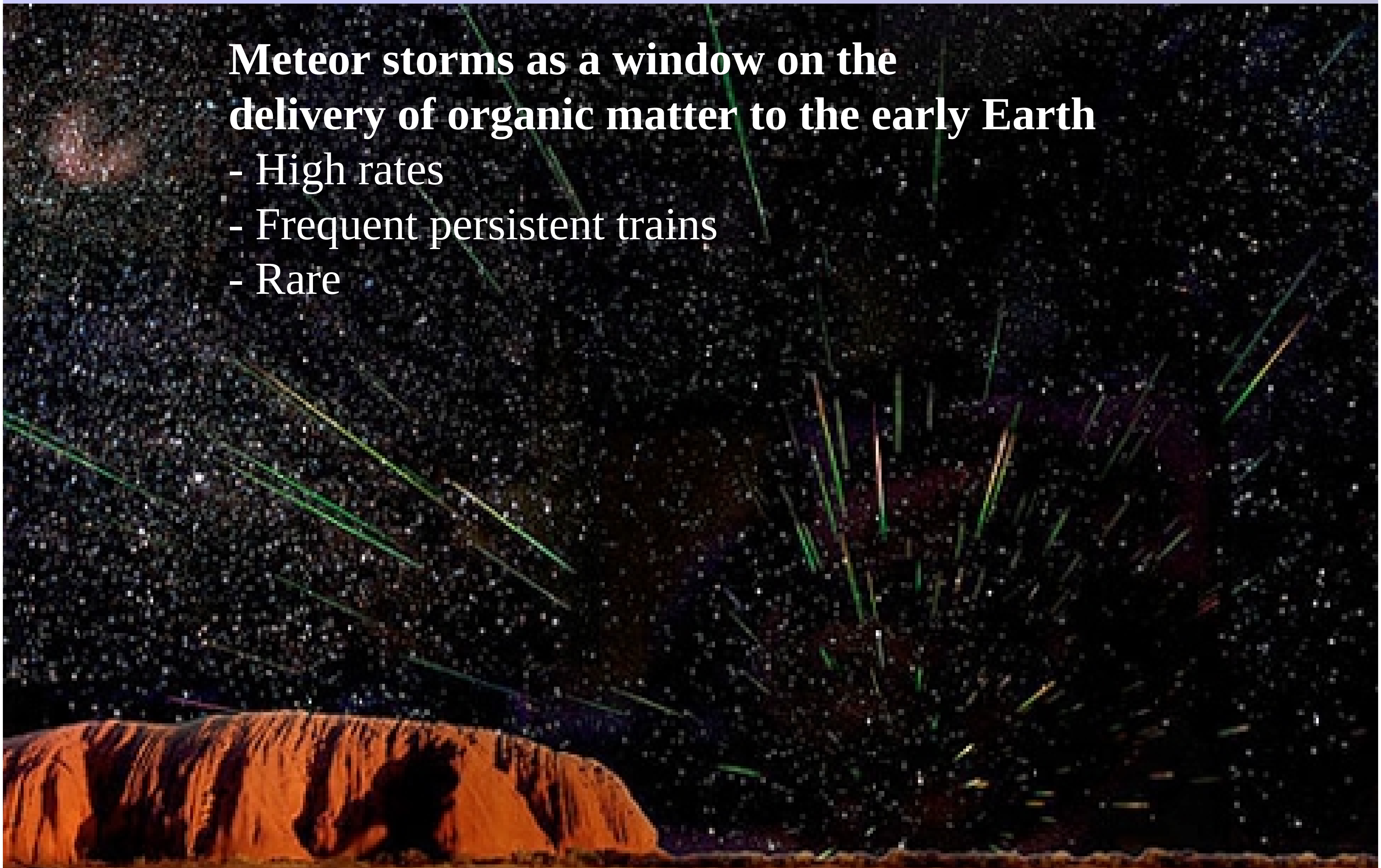
- **There is a lot of it**
  - For each molecule brought in by meteorites and interplanetary dust particles at the time of the origin of life, 20-100 are deposited in the atmosphere as a “meteor”.
- **Product is unique**
  - a chemical derivative of organic matter in comets and asteroids.
- **Chemistry is elusive**
  - non-equilibrium hot rarefied high Mach number flow, unlike any in laboratory.

Organics in meteors

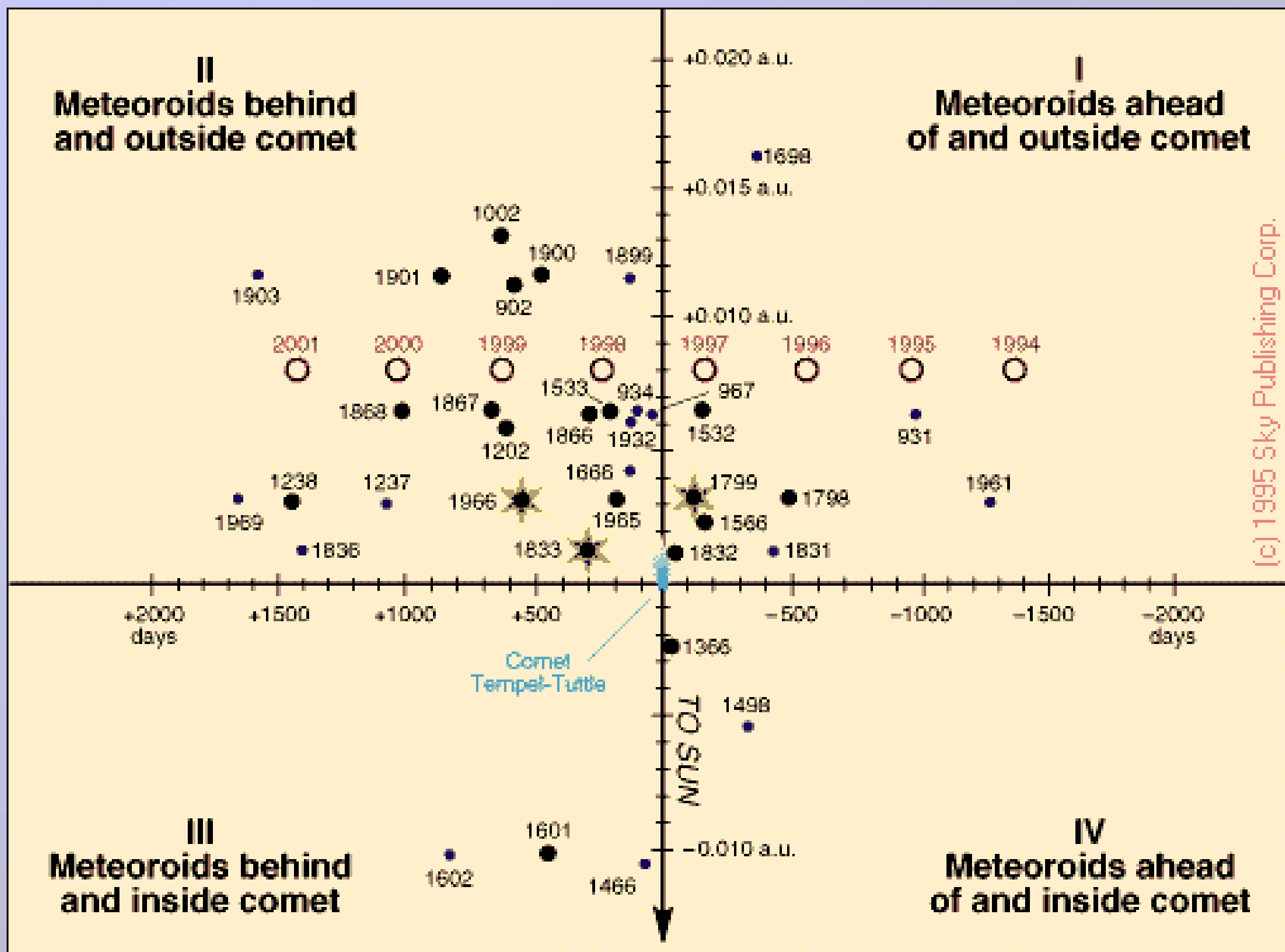
- **Electronic transitions:**
  - H, C atoms from disintegration
  - CN, CH, C_2 molecules, from partial breakup
- **Vibrational transitions**
  - C-H and C=O stretch vibration bands
- **Rotational transitions**
  - Submm lines of HCN, H_2CO, CO, O_3, H_2O, ….

Physical conditions

- How is organic matter chemically changed?
  - Plasma temperatures, cooling rates
  - Composition of the air plasma
  - Signs of non-equilibrium chemistry
- What fraction survives as solids?
  - differential ablation?
  - Signs of breakup products, dust

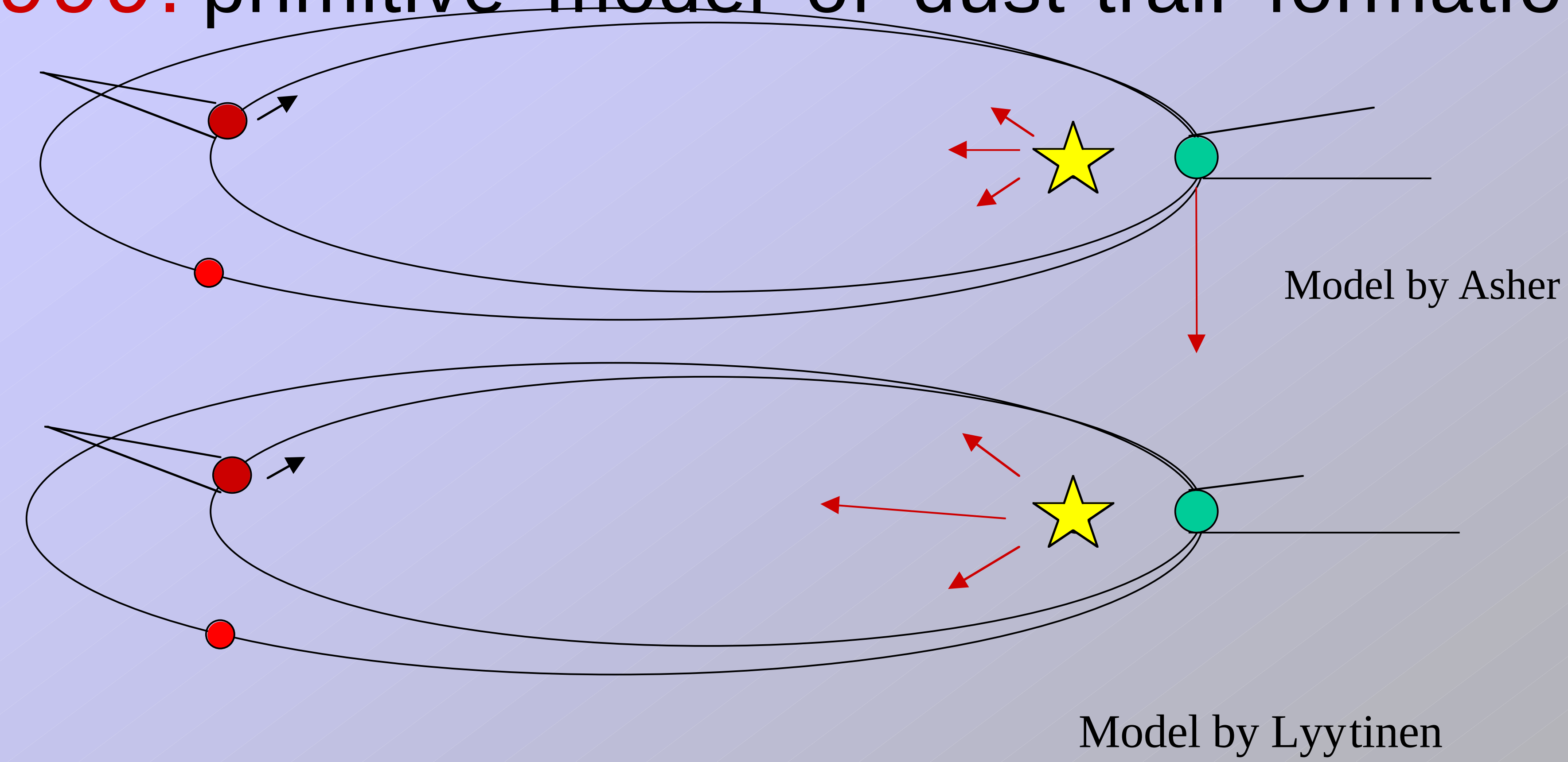

Meteor storms as a window on the
delivery of organic matter to the early Earth
- High rates
- Frequent persistent trains
- Rare

1998: Possible storms in 1998 and 1999



Yeomans 1981

1999: primitive model of dust-trail formation

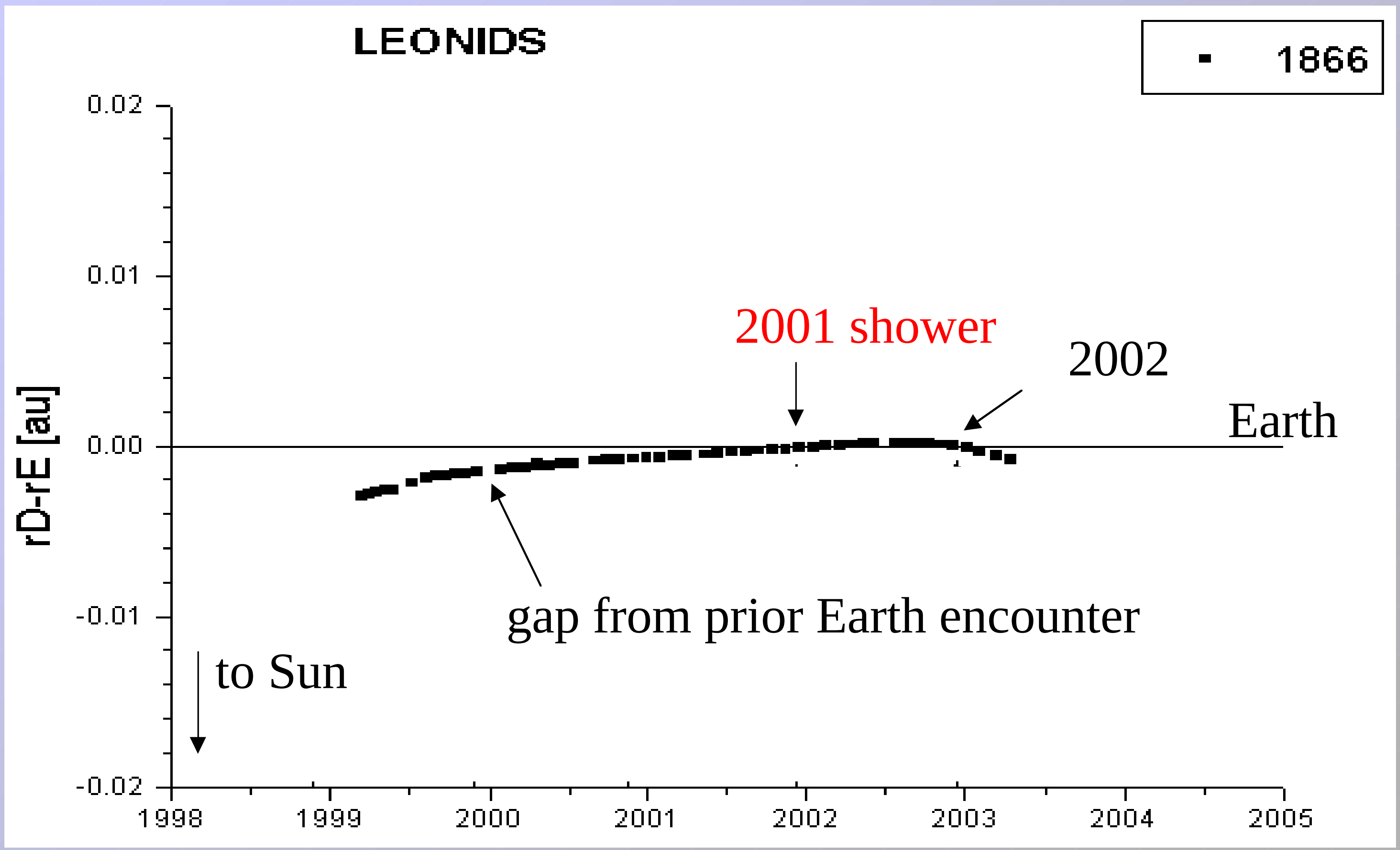


Different assumptions about

ejection+radiation pressure

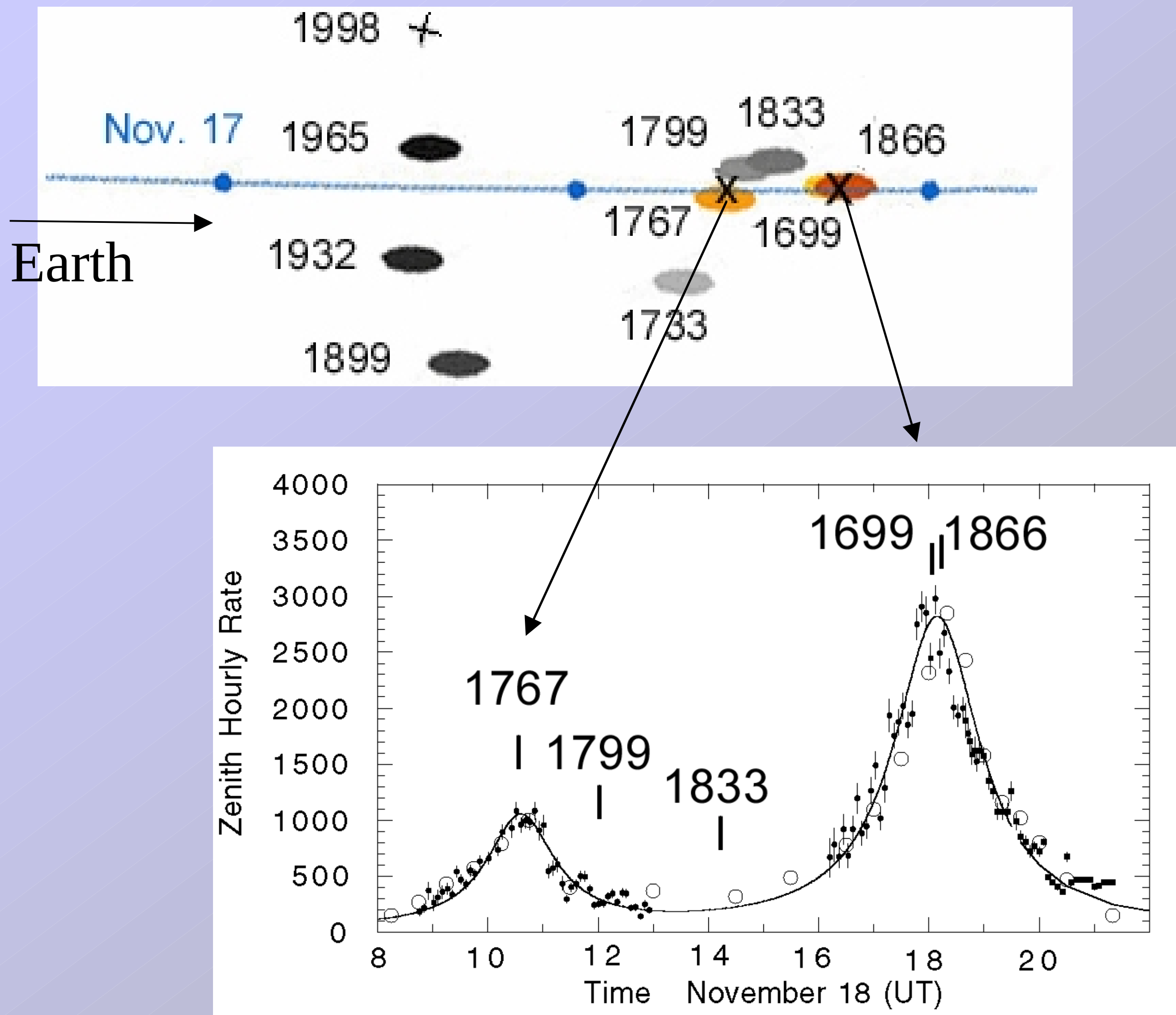
but similar results (same orbit to match encounter time)

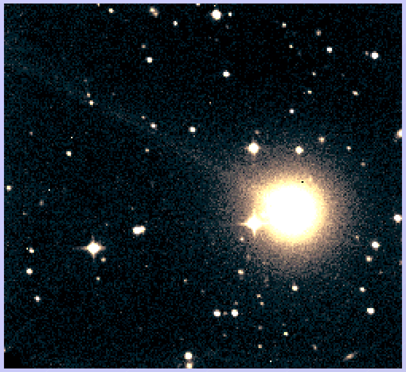
PLANETARY PERTURBATIONS



Hartwig Leuten

2001 Leonid storm encounter

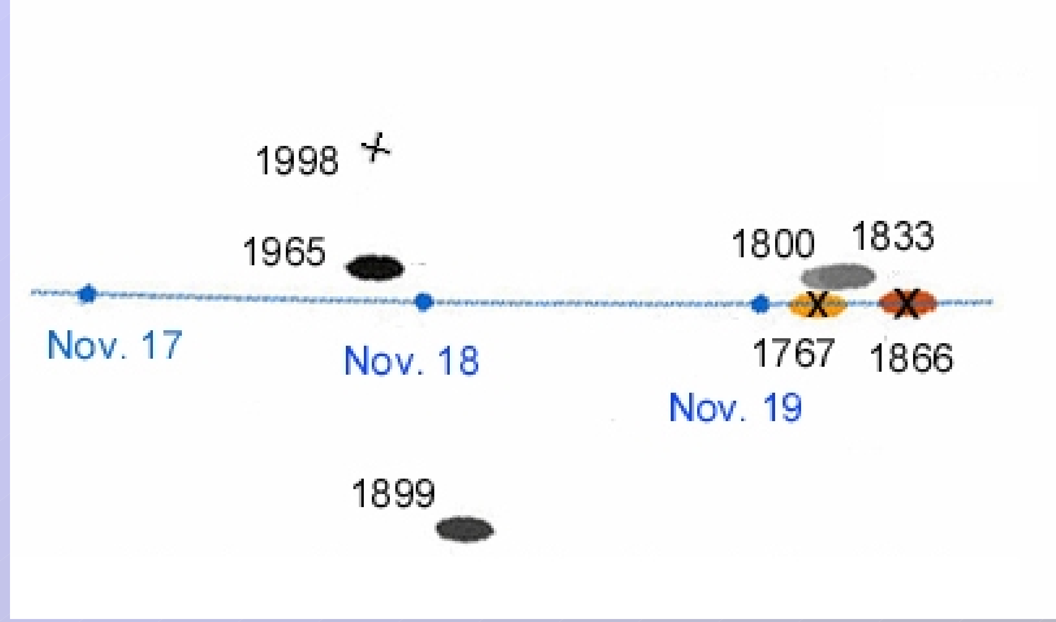




Dust trail of comet 55P/Tempel-Tuttle

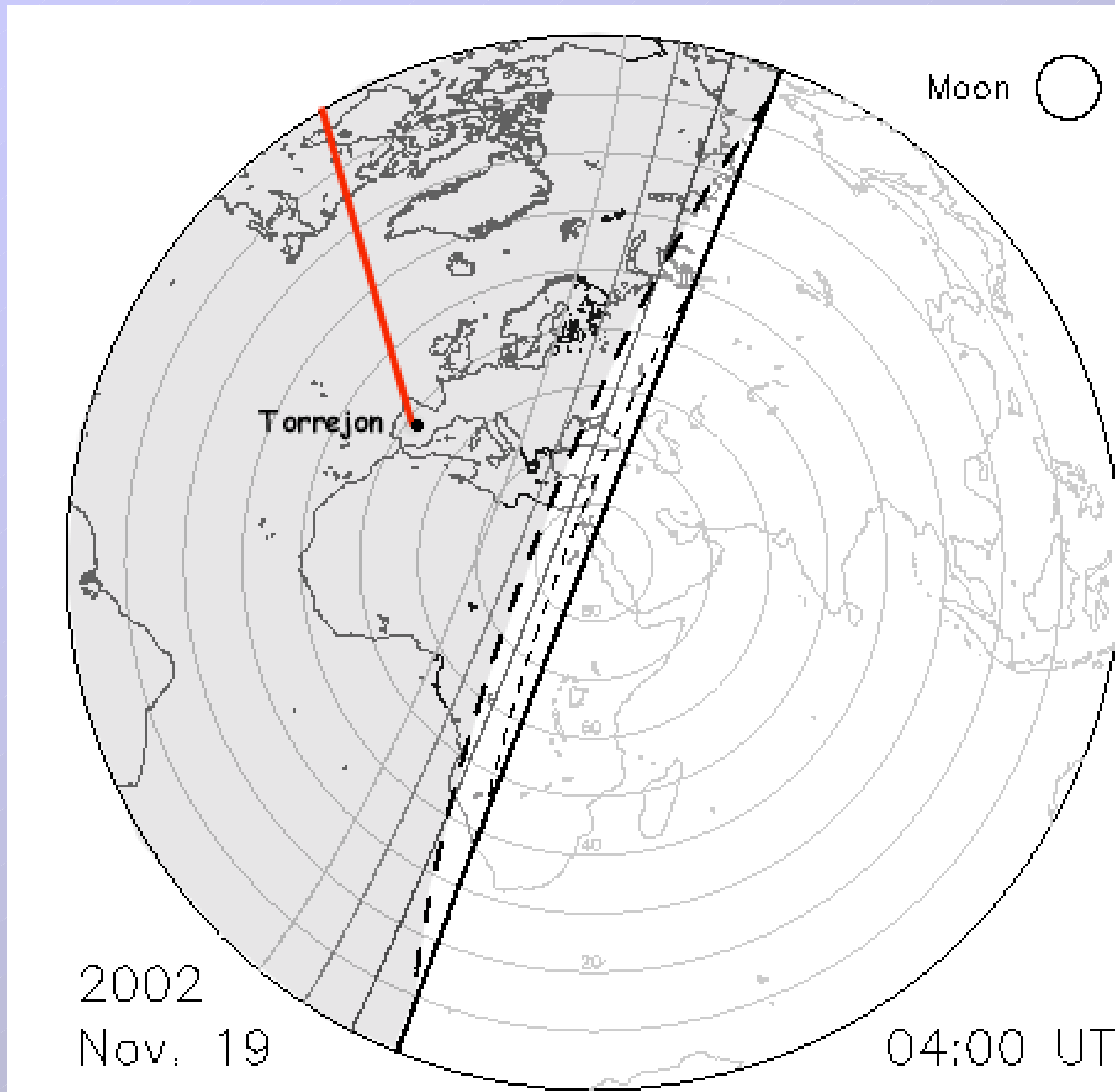
- Dust trail size: 30,000x90,000 km at node
  (factor 3 wider in heliocentric in-plane direction)
- Dust grain density: 0.97±0.13 g/cm^3 (from β)
- Size distribution: $s = 1.64 \pm 0.05$ for $M > 2 \times 10^{-3}$ g
  $s = 1.97 \pm 0.07$ for $M < 5 \times 10^{-4}$ g
- Total mass loss: $2.6 \pm 0.7 \times 10^{10}$ kg/return
- Dust/gas ratio: 2.4 ±1.7 (or larger if less gas lost)
- Ejection velocities: 9.1±1.8 m/s at perihelion
  Large grains appear to fragment more efficiently in the comet coma near perihelion

2002 Leonid forecast

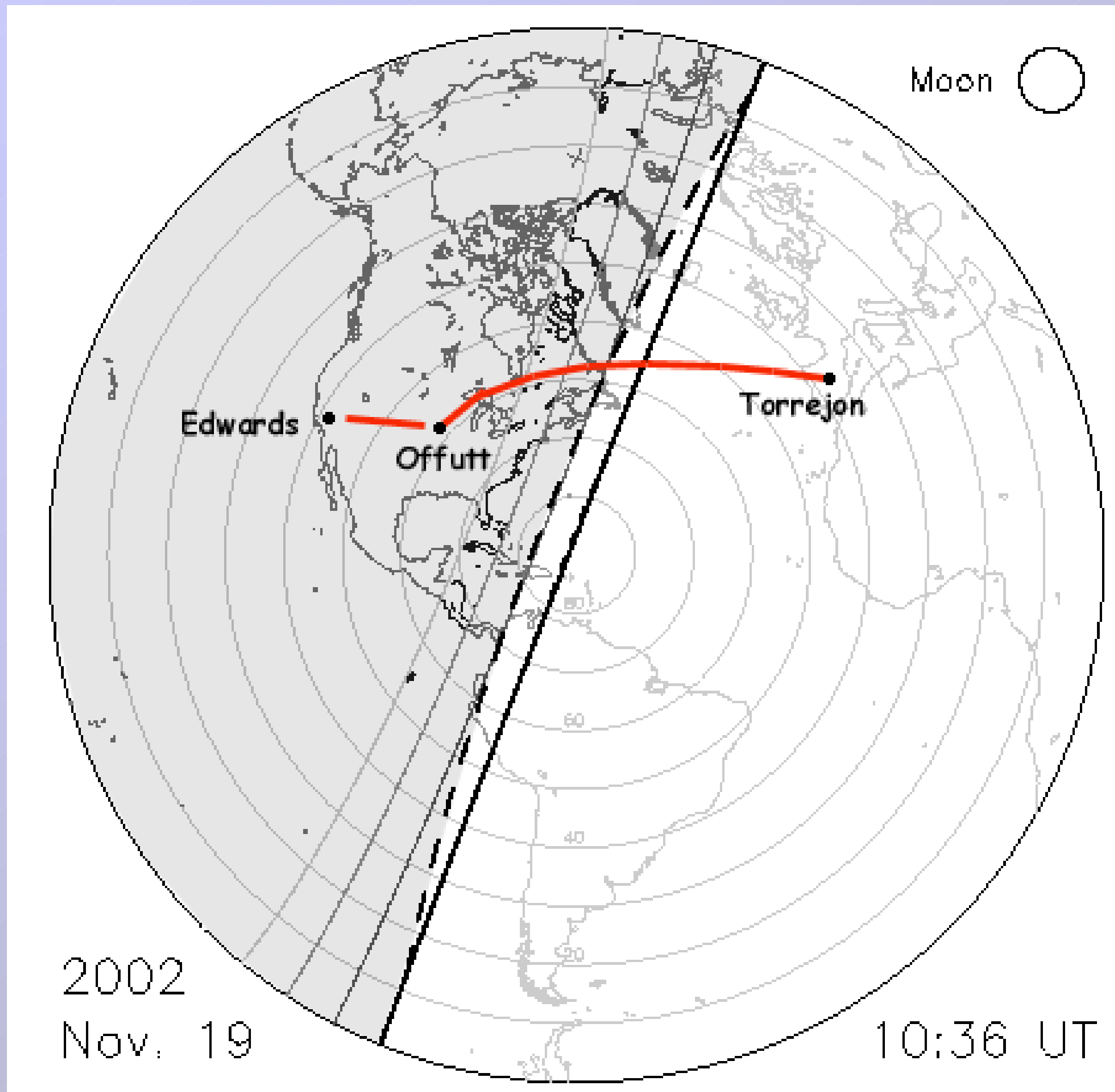


- Two storm peaks Nov. 19 (UT):
  - 1767 trail: 03:58±15 UT (Europe)
  - 1866 trail: 10:36±15 UT (USA)
- Peak rates comparable to rates in 2001
- Full Moon (15 days)

2002 Leonid Multi-Instrument Aircraft Campaign

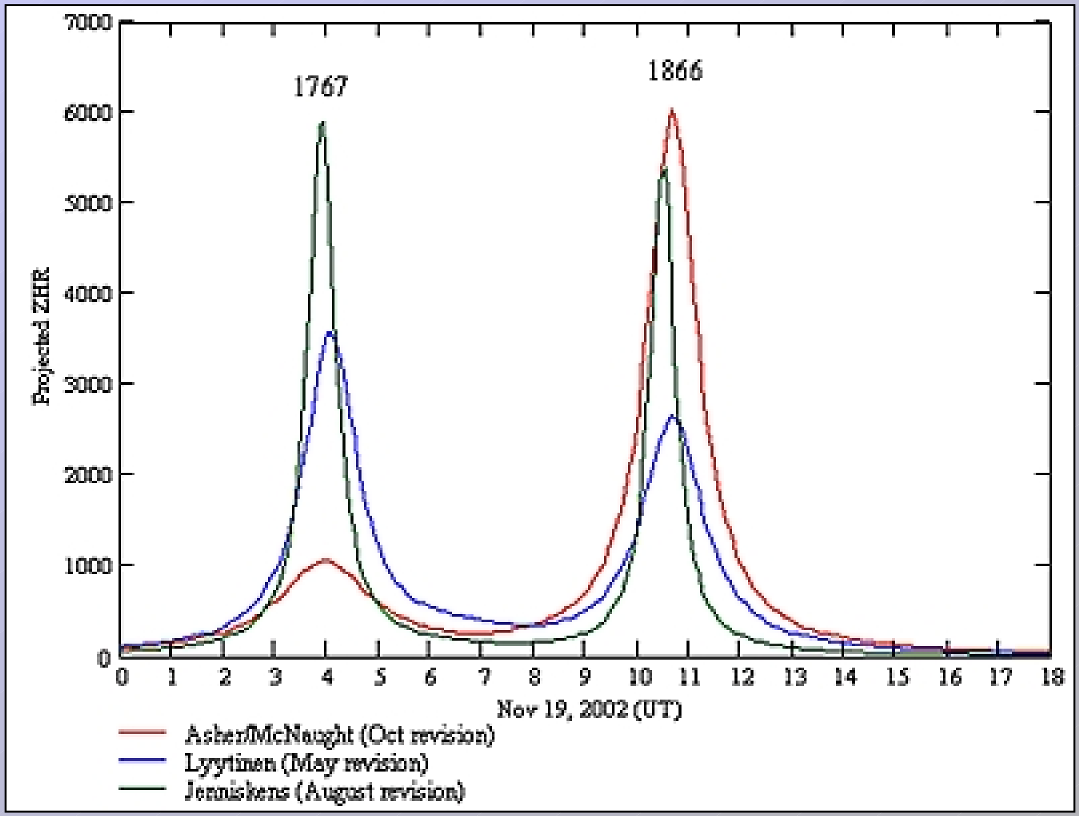


R. McNaught


Moon
Edwards
Offutt
Torrejon
2002
Nov. 19
10:36 UT

http://leonid.arc.nasa.gov/estimator.html

2002 Leonid forecast (ground)



Summary by Cooke 10/9

In-cabin view "FISTA"

40^o elevation
12" flat
special glass

12^o
12" flat
horizon

Low weight cameras: tripod mounted

More elaborate equipment: trainable eyeball assembly (±20^o)
or custom mount

40^o

12^o

Certificate of Appreciation

NASA

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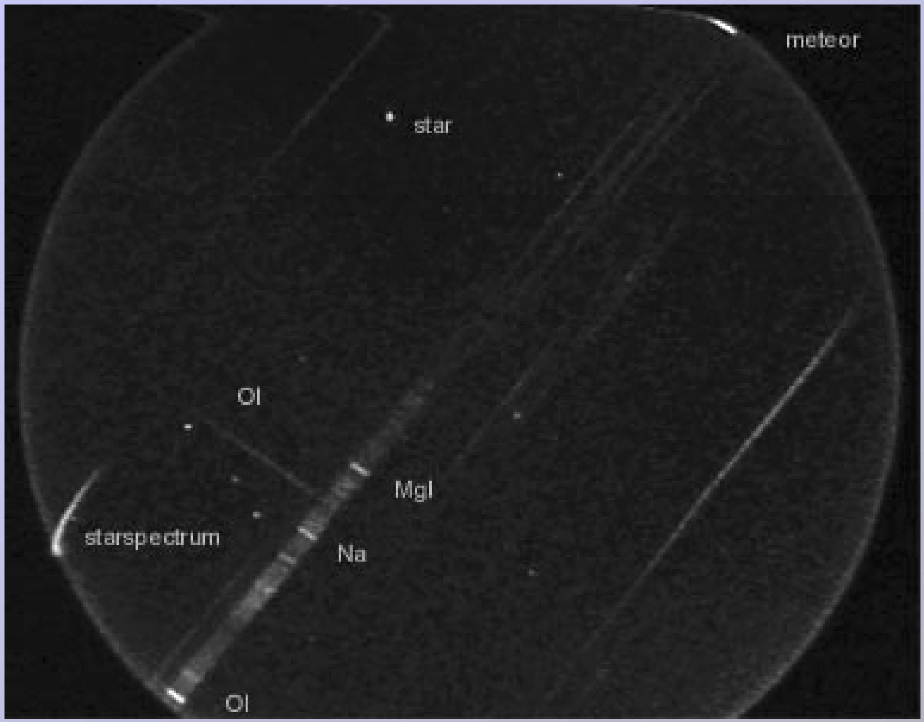
In recognition of your contribution to the success of the

2001 LEONID Multi-Instrument Aircraft Campaign

Gregory K. Schmidt
Lead, Astrobiology Integration Office
NASA

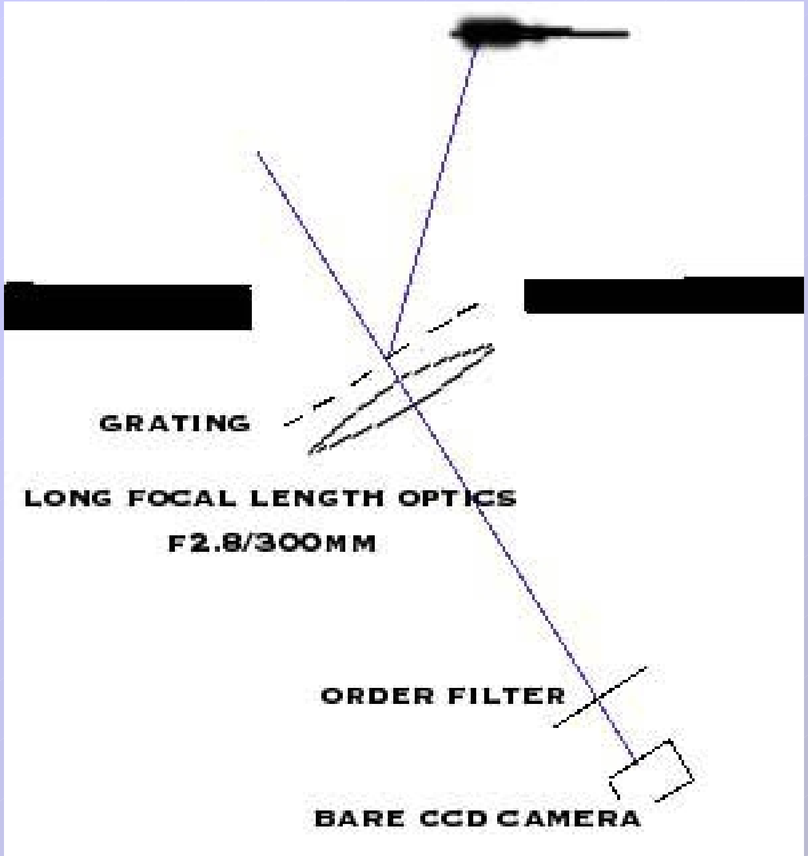
Dr. Peter Jenniskens
Principal Investigator

Optical slit-less spectroscopy



Borovicka et al. 1999
1998 Leonid MAC

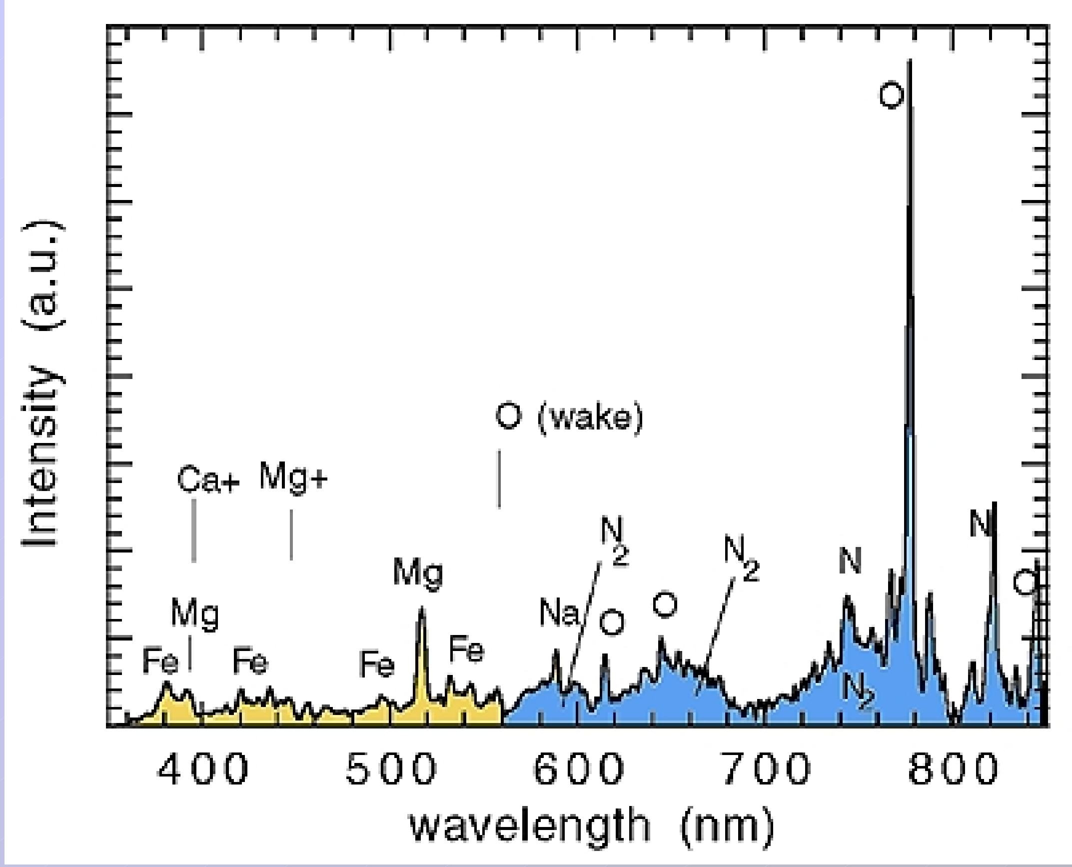
- Old tool (Millman, Harvey, Ceplecha, Borovicka, …)
- In need of quantitative analysis
- Few good spectra only describe physics of bright fireballs



Solution:

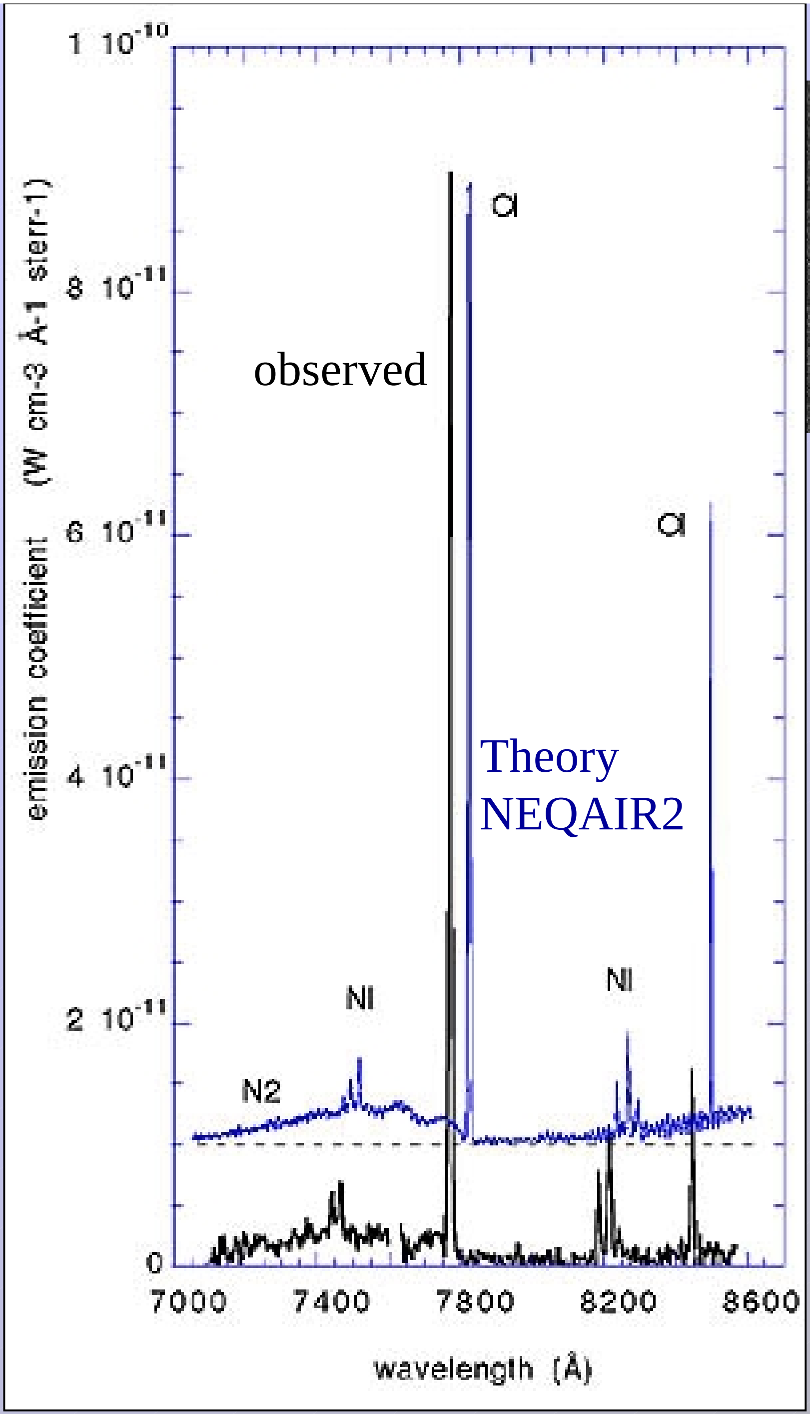
- Highest possible resolution
- C ooled CCD (not intensified)

Typical Leonid meteor spectrum

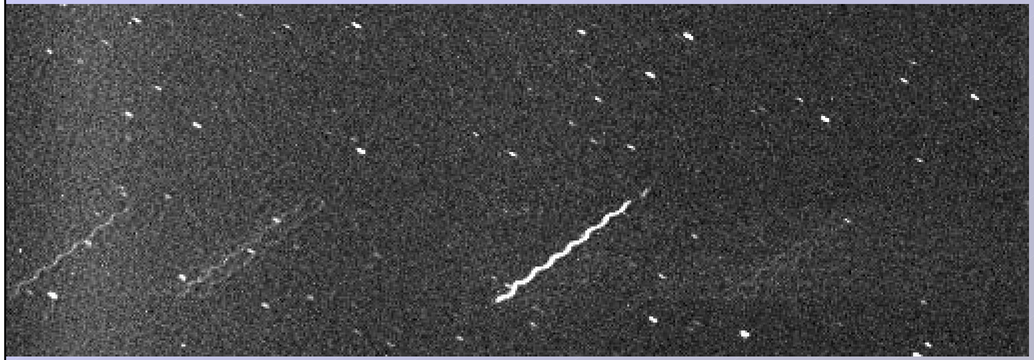


Abe et al. 2000
HDTV, 1999 Leonid MAC)

Region of interest: 550-900 nm



17:47:06 UT



1998 Leonid MAC Spectrum I

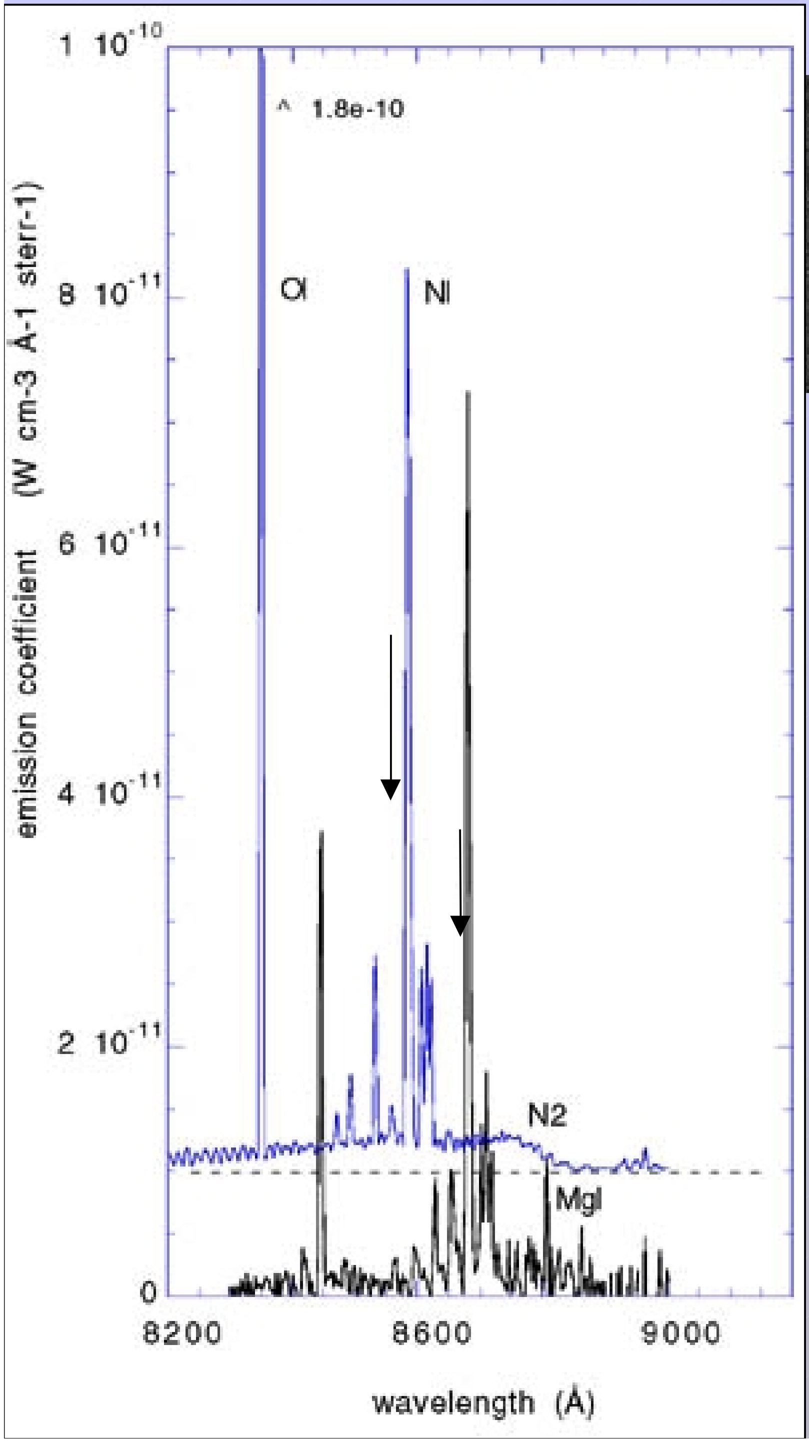
Borovicka (1994):

High excitation levels:
N, O lines originate in
hot T ~ 10,000 K plasma

We find:

- N/N_2 ratio: T = 4350±100 K

Temperature similar to metal atom ablation lines T ~ 3900-5000 K

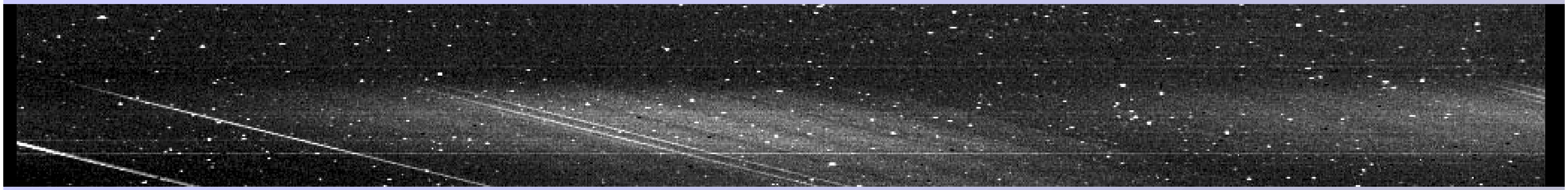


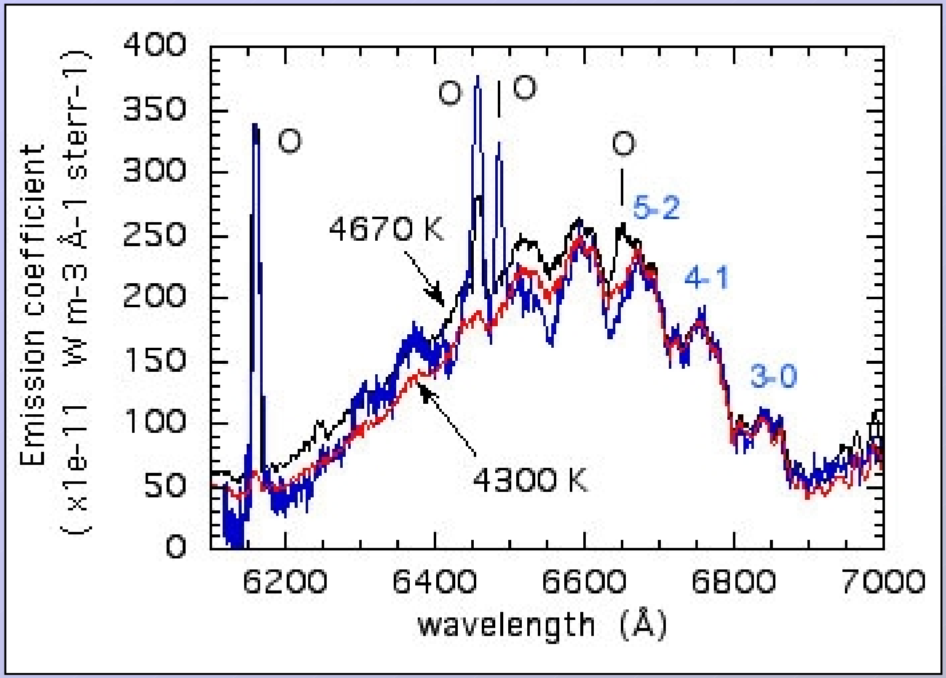
06:08:47 UT

1998 Leonid MAC Spectrum II

Emitting volume of plasma:
Initial train radius predicts
volume of $3x10^7$ cm^3

- Intensity implies emitting volume of $1x10^{13}$ cm^3.
- Non-LTE?
  - O I 8446 Å factor 3 too faint
  - N I 8656 Å too strong





1999 Perseids (ground):

First fit of N_2 band profile with theoretical model.

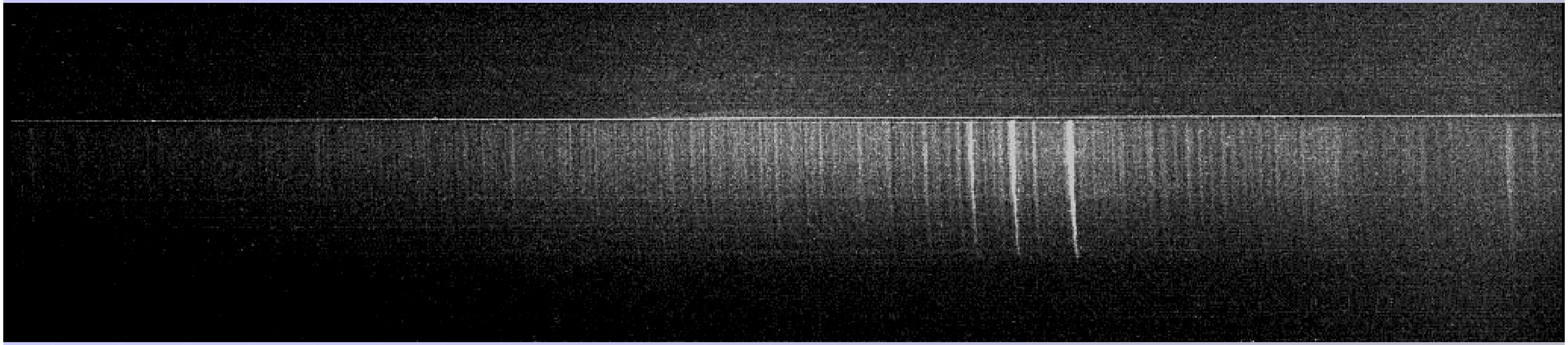
- N_2 contour: T = 4,300±40 K
- Excess Δν = 10-9 and 9-8

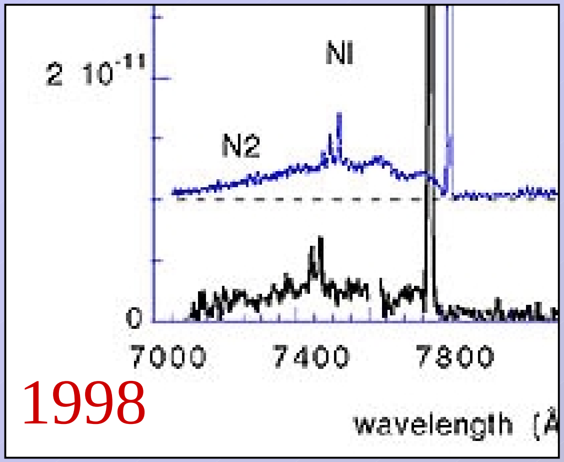
evidence of recombination:

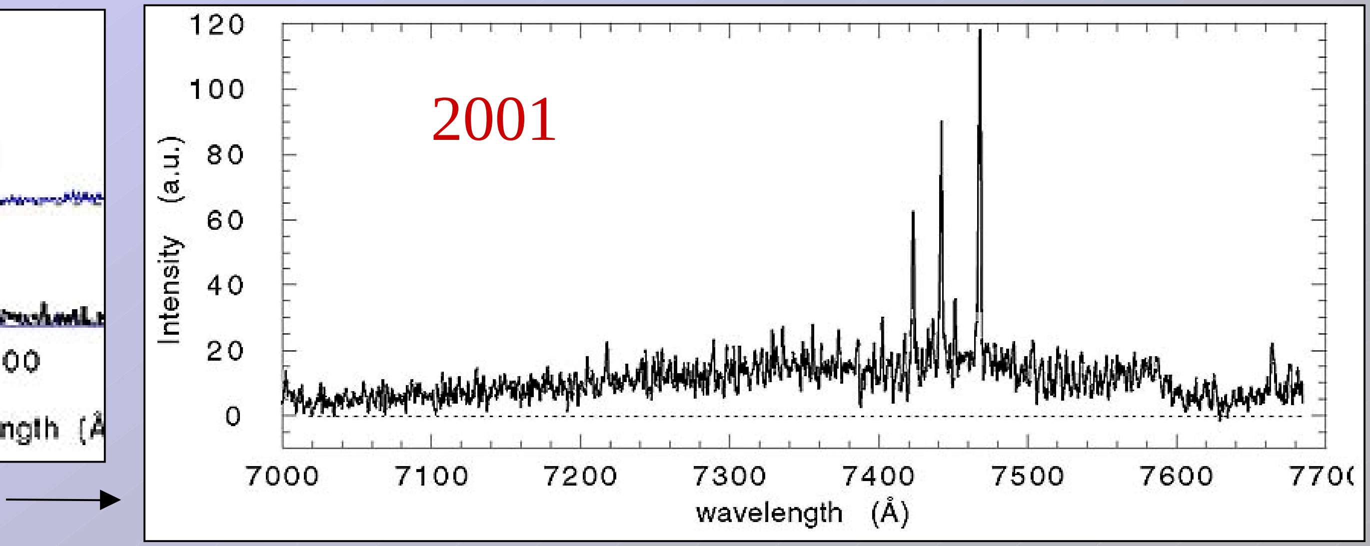
N + N <—> N_2

- New line at 648 nm (OI ?)

09:44:53 UT



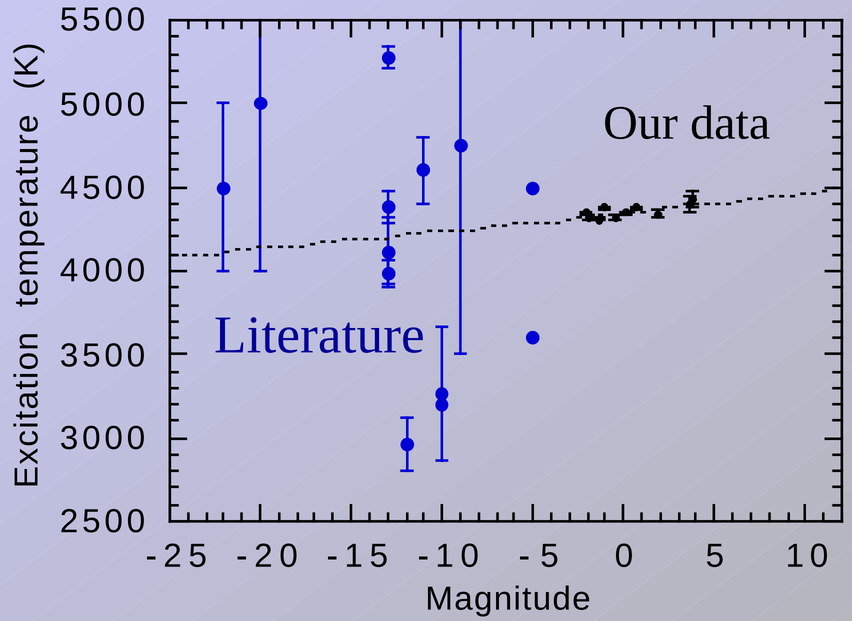

2 10-11
NI
N2
0
7000
7400
7800
1998
wavelength

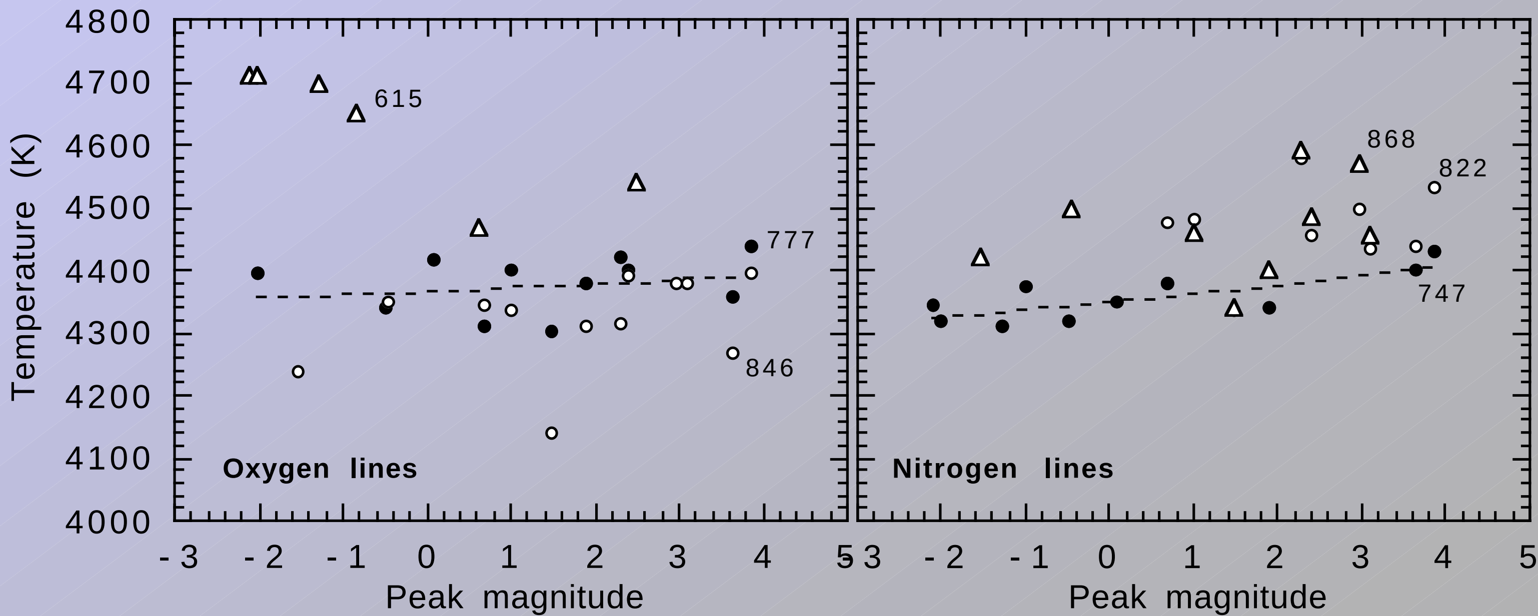

120
100
80
60
40
20
0
Intensity (a.u.)
2001
7000
7100
7200
7300
7400
7500
7600
wavelength (Å)

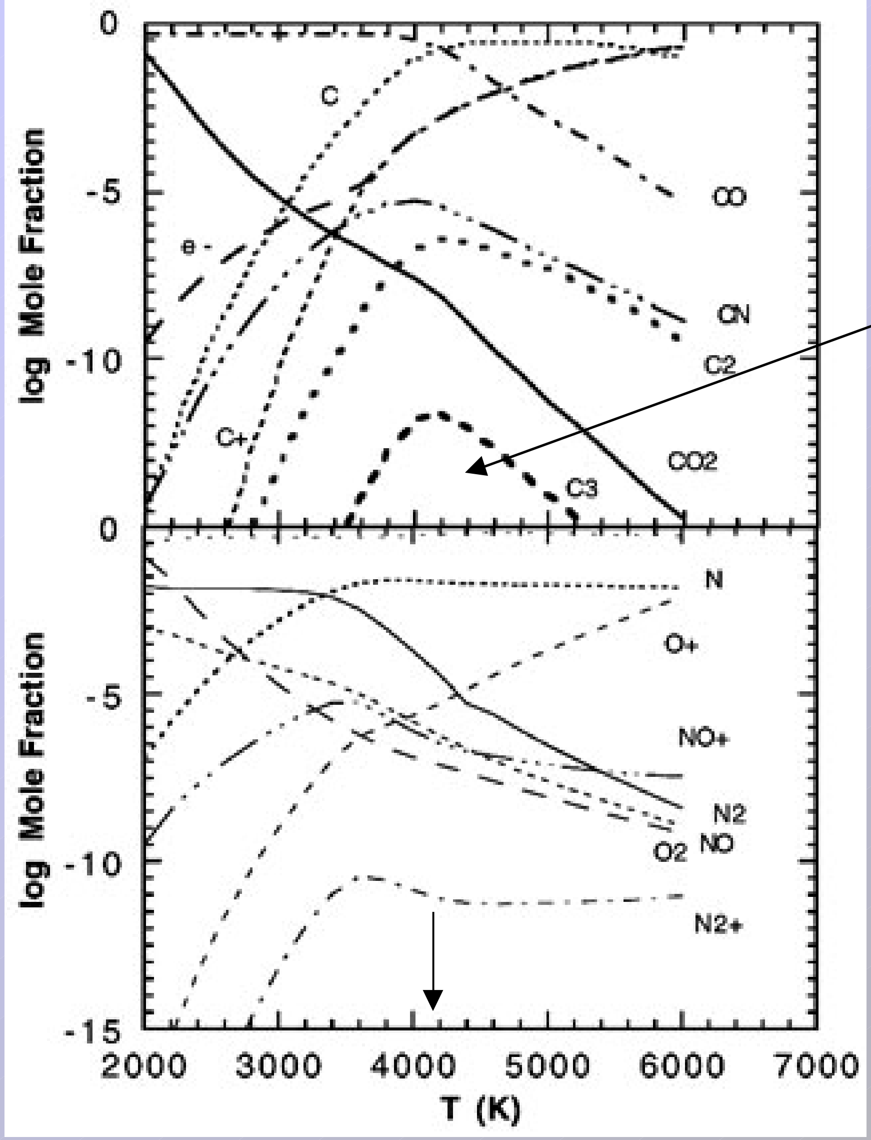
Air plasma temperature

(almost) NO dependence on meteor mass or speed

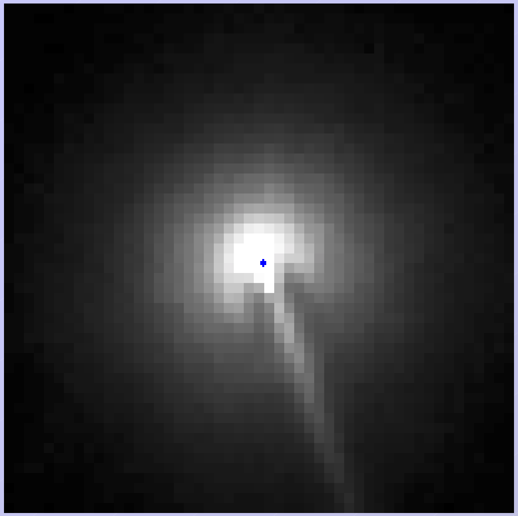
T = 4,500 K for small meteoroids

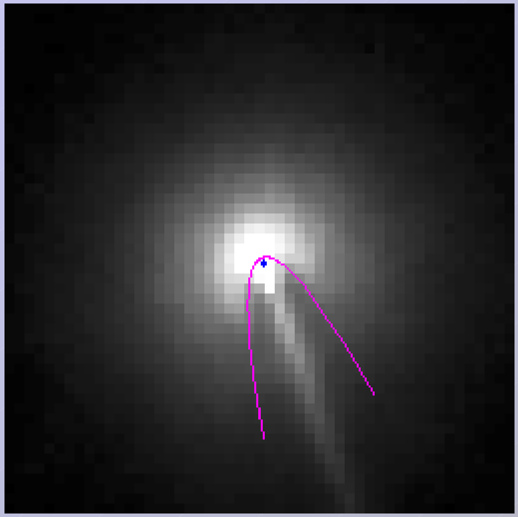






4150 K:
Interesting chemistry
in CO_2 rich atmosphere





Leonid 1000 frames/s

Hans Stenbaek-Nielsen, University of Alaska

Discovery of a "Shock"

Interpretation (ongoing work):

- Diffuse glow: (instrumentally?) scattered light from bright pointsource
- Circular bright area with "cut-out": predissociation by UV photons
- Parabolic shock with meteoroid in focal point. Region behind shock where air is fully dissociated.

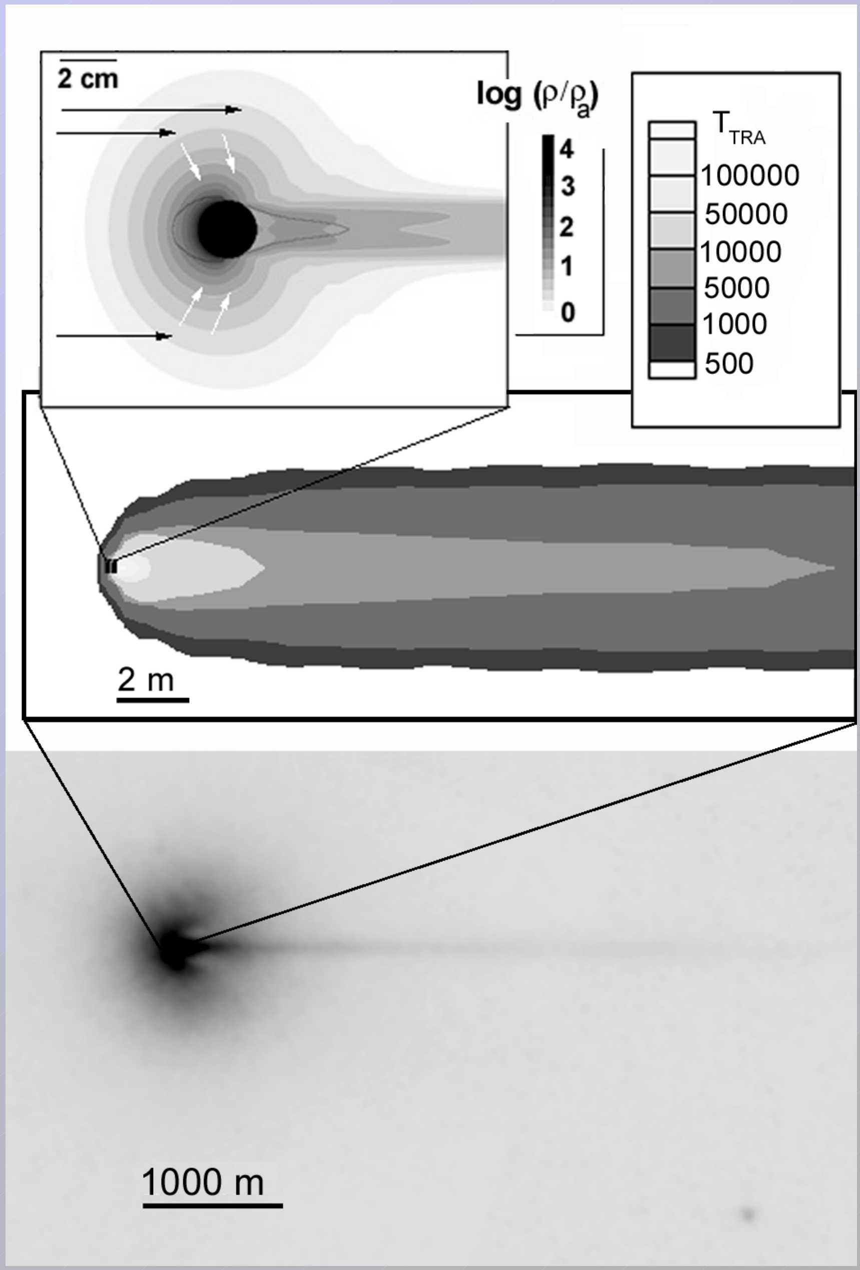
Meteor model

• Single air collision releases cloud of products: “Meteoric Vapor Cloud”

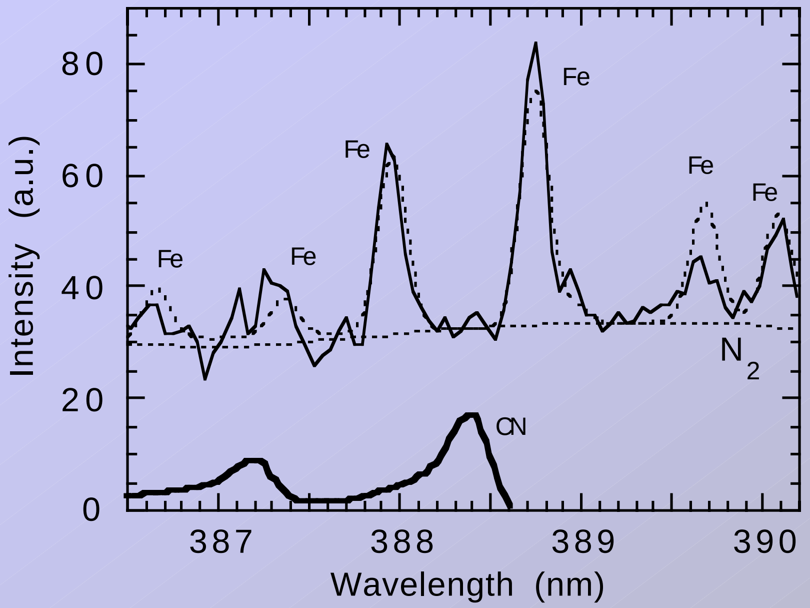
• Air interacts with cloud to form warm wake with dimensions of mean free path.

• Shock forms surrounding wake, predissociation air by UV photons

Latest result



FATE OF ORGANICS IN ABLATION



Halley: N/Fe = 0.79±0.02

Leonids: CN/Fe < 0.03

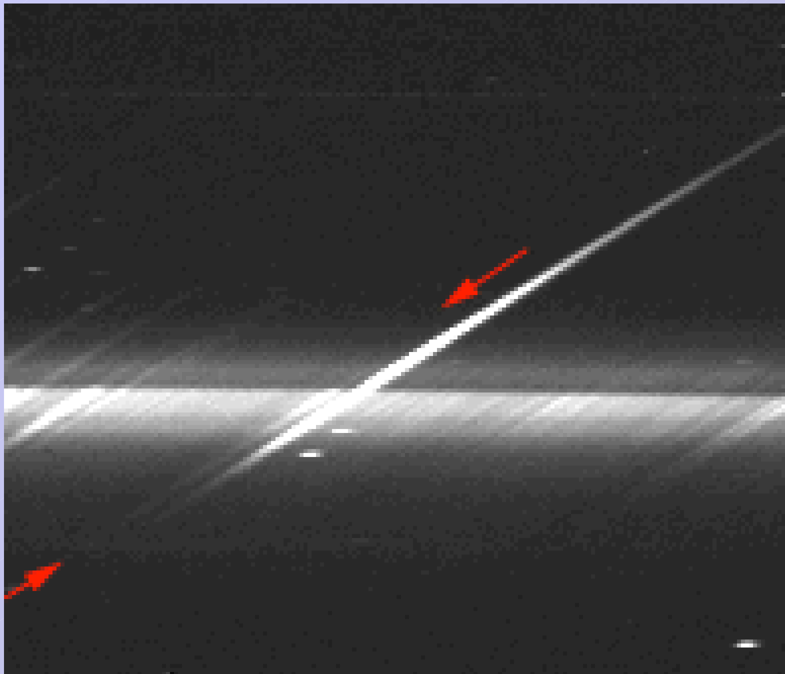
(upper limit factor 10
better than after
1999 campaign)

Latest result

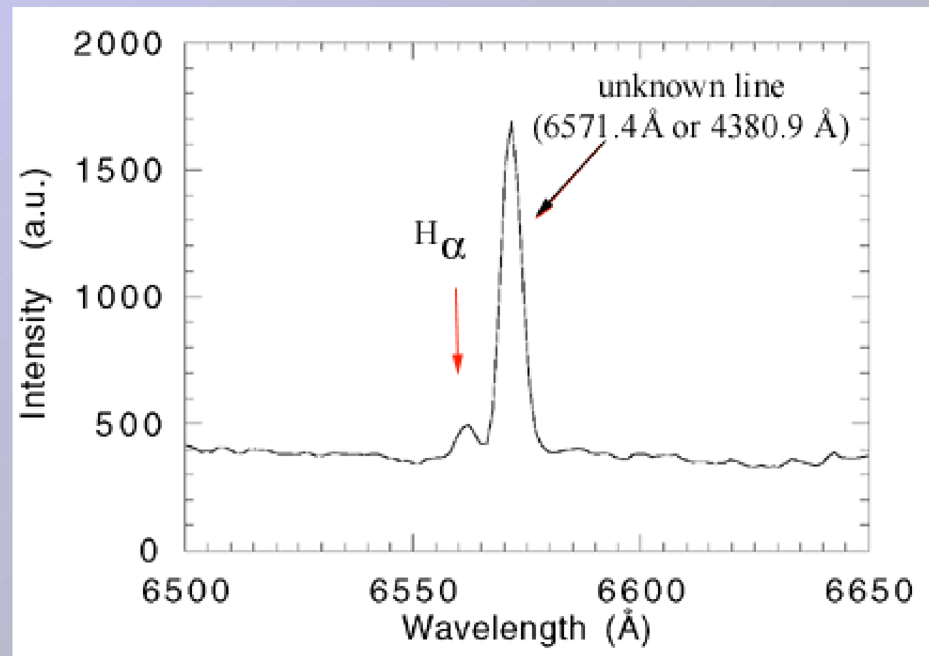
Organics do not break up in di-atoms

(P. Jenniskens et al., 2002 Astrobiology, submitted)

Loss of functional groups (H)

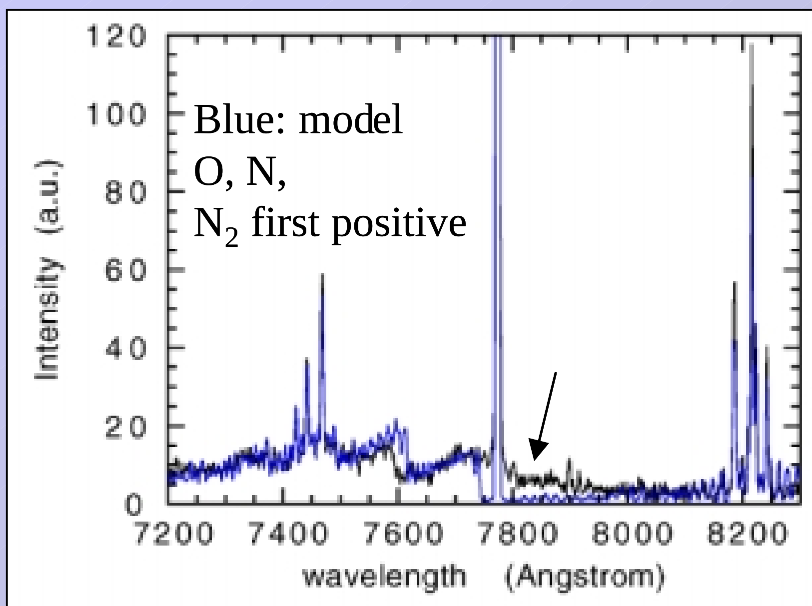


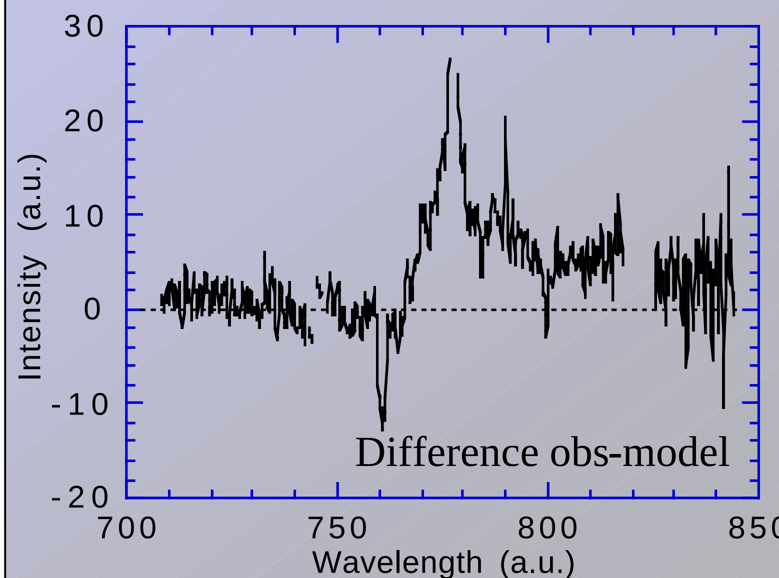
10:54:59 UT



- Sharp flare termination (deposition debris)
- Detection of H_α - probable source H: organics

(in preparation)

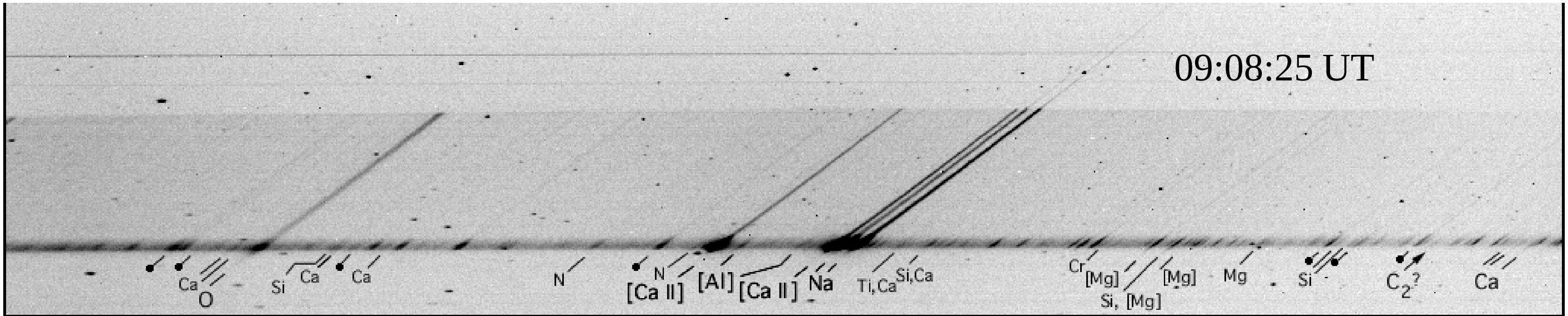




Search for C_2: detection of OH Meinel band?

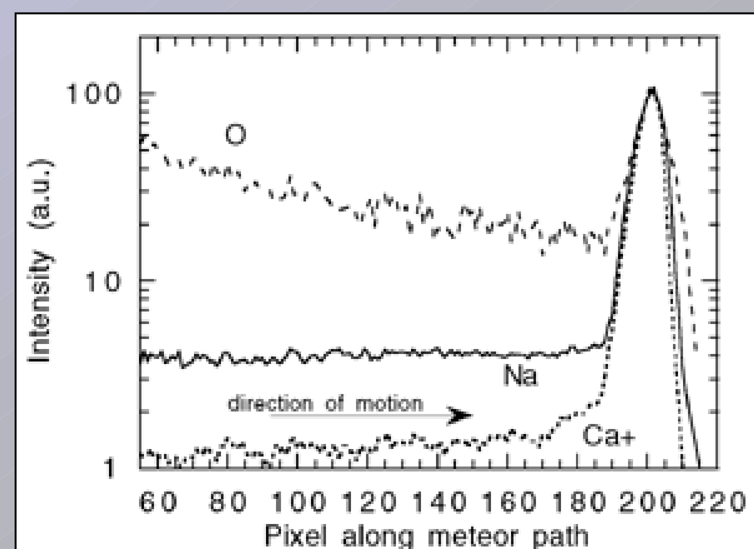
P. Jenniskens et al., 2002 (Astrobiology, submitted)

New result

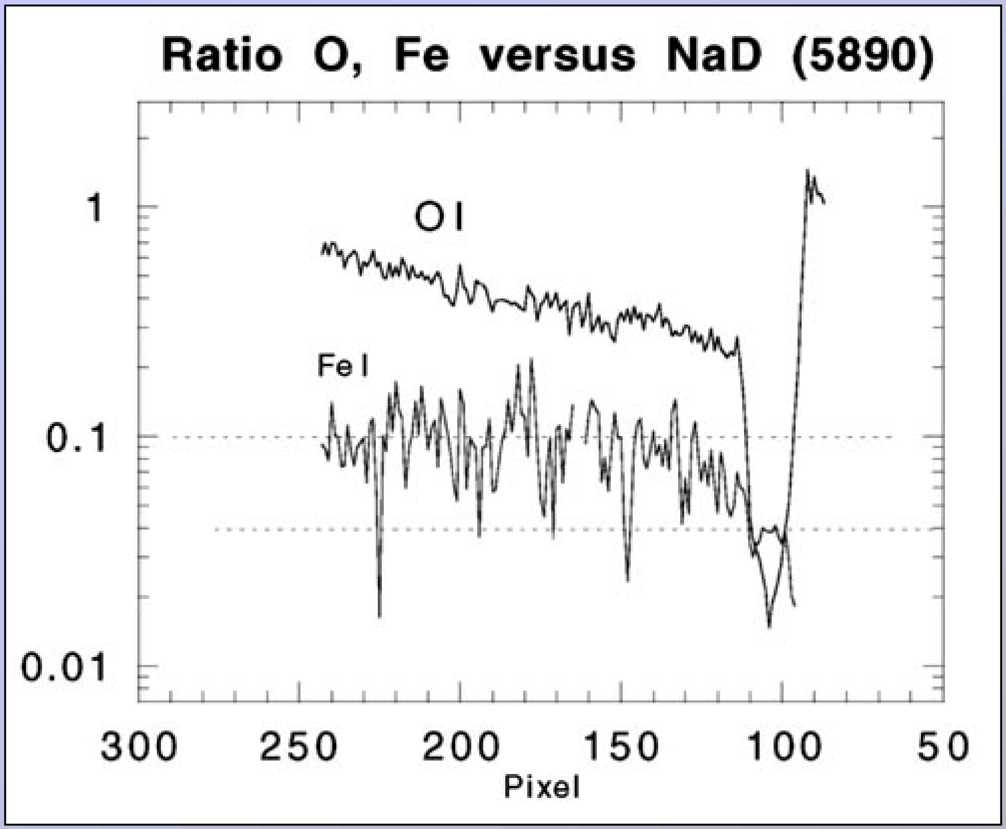


Three components (Borovicka 1993)

- Air plasma (O, N, N_2)
  - T ~ 4,400 K
- Metal atoms (Fe, Mg, Na, K, Al, Ca, Mn, …)
  - T ~ 4,400 K
  - anomalous excitation
- Hot (Ca^+, Mg^+)
  - T ~ 10,000 K



NO differential ablation



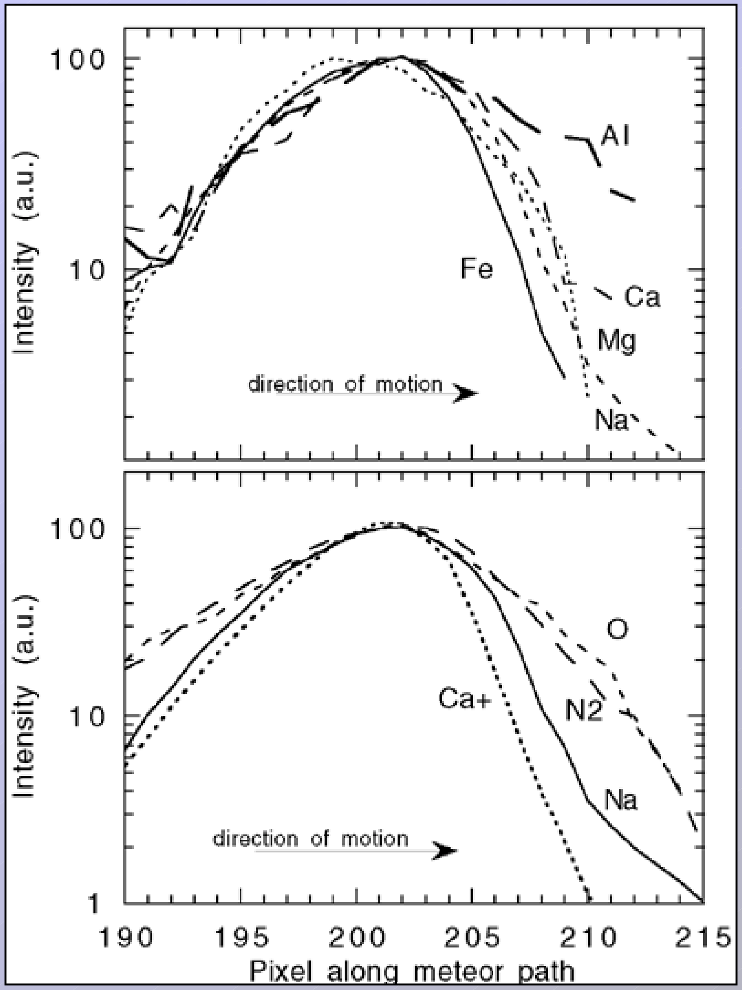
As a rule:
NO differential ablation

< Fe/Na = constant

But: in fragile Leonids volatile Na minerals start ablation earlier (Borovicka et al. 1999)

< At end: Na nearly gone.

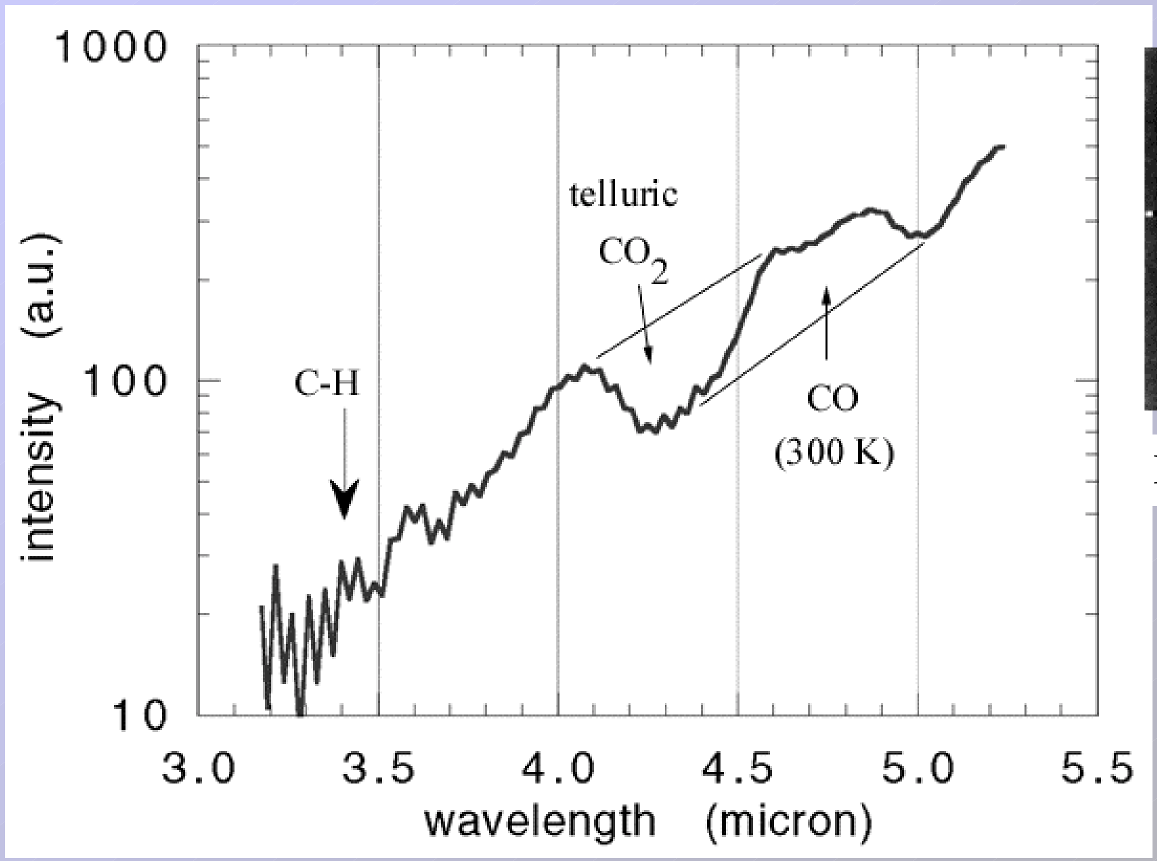
Survival of debris



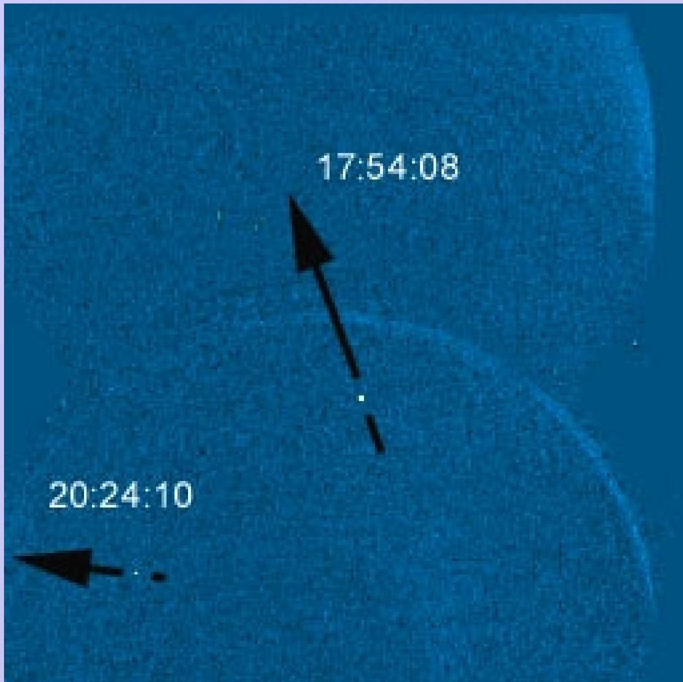
Some material rich in Ca, Mg, and Al survives flare (debris).

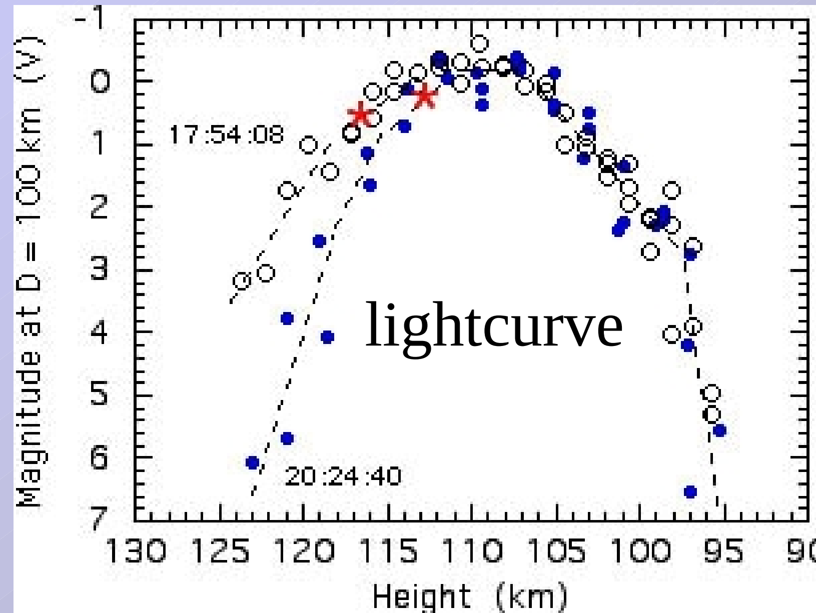
• C-H stretch vibration band in persistent train emission

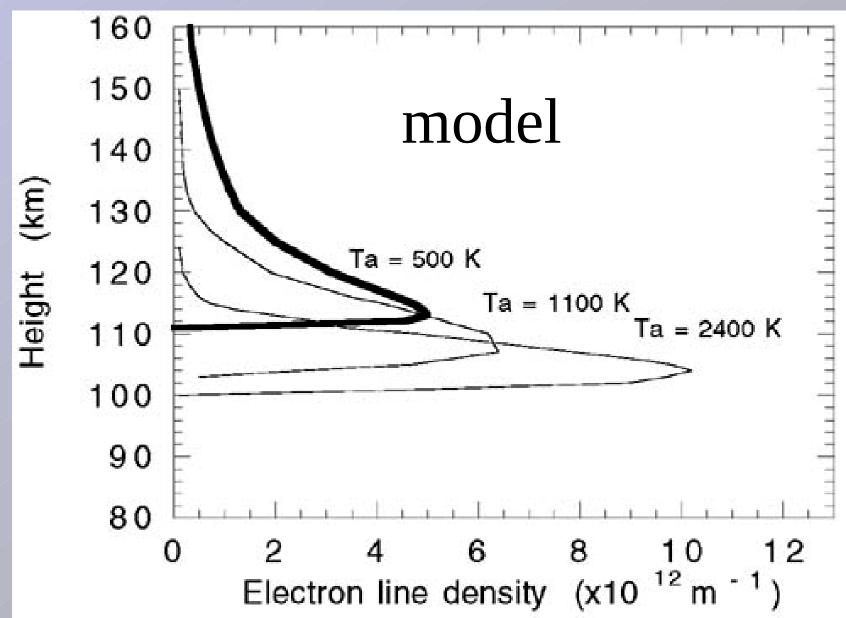
Ray Russell & George Rossano et al., The Aerospace Corporation



Nov. 18, 1999 - 04:00:29 UT







Mid-IR (3-5.5 μm) emission peak

George Rossano et al.,
The Aerospace Corporation

Release of organics
At altitude ~ 117 km?

Conclusions

- Organics appear to survive ablation
  - Large molecules
  - Solid debris (soot)
- Volume of atmosphere affected by meteors is orders of magnitude larger than thought before
- Much work and opportunity remains