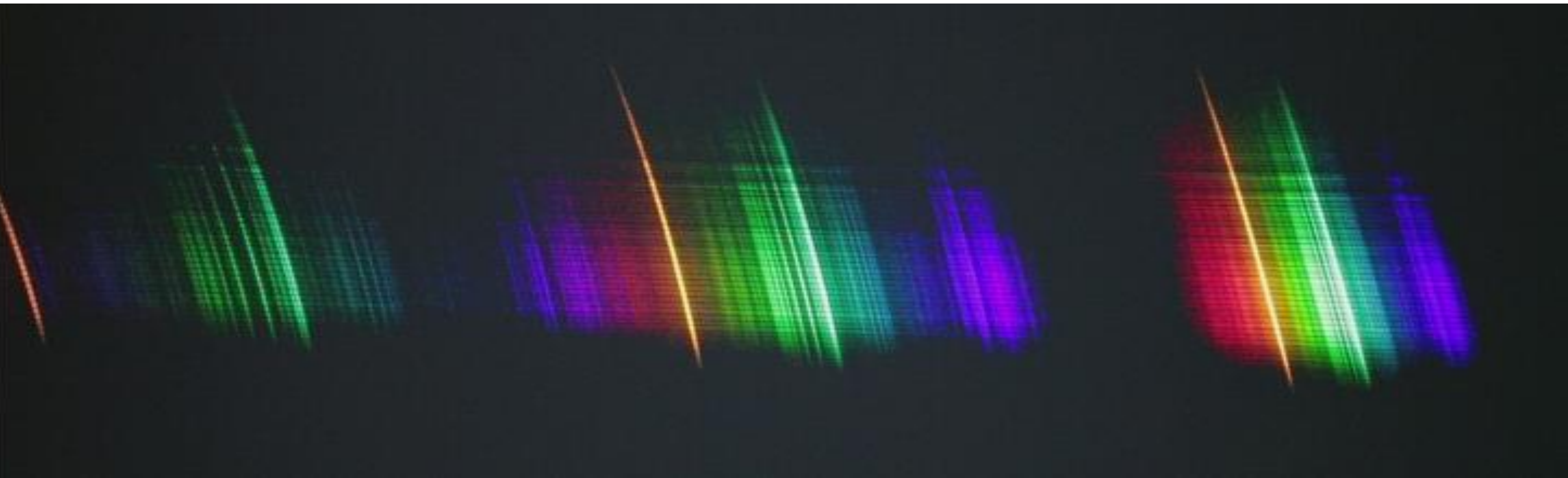
Fachgruppe Meteorastronomie

Meteor Spectroscopy, OHP 2018

Martin Dubs, images by Koji Maeda

SAG, FMA



Content

- Meteor astronomy
  - Observation
  - Network
  - Video observation: hardware and software
- Meteor spectroscopy
  - Hard- Software
  - Wavelength calibration
  - Spectrum extraction
  - Instrument response
  - Summary

Origin

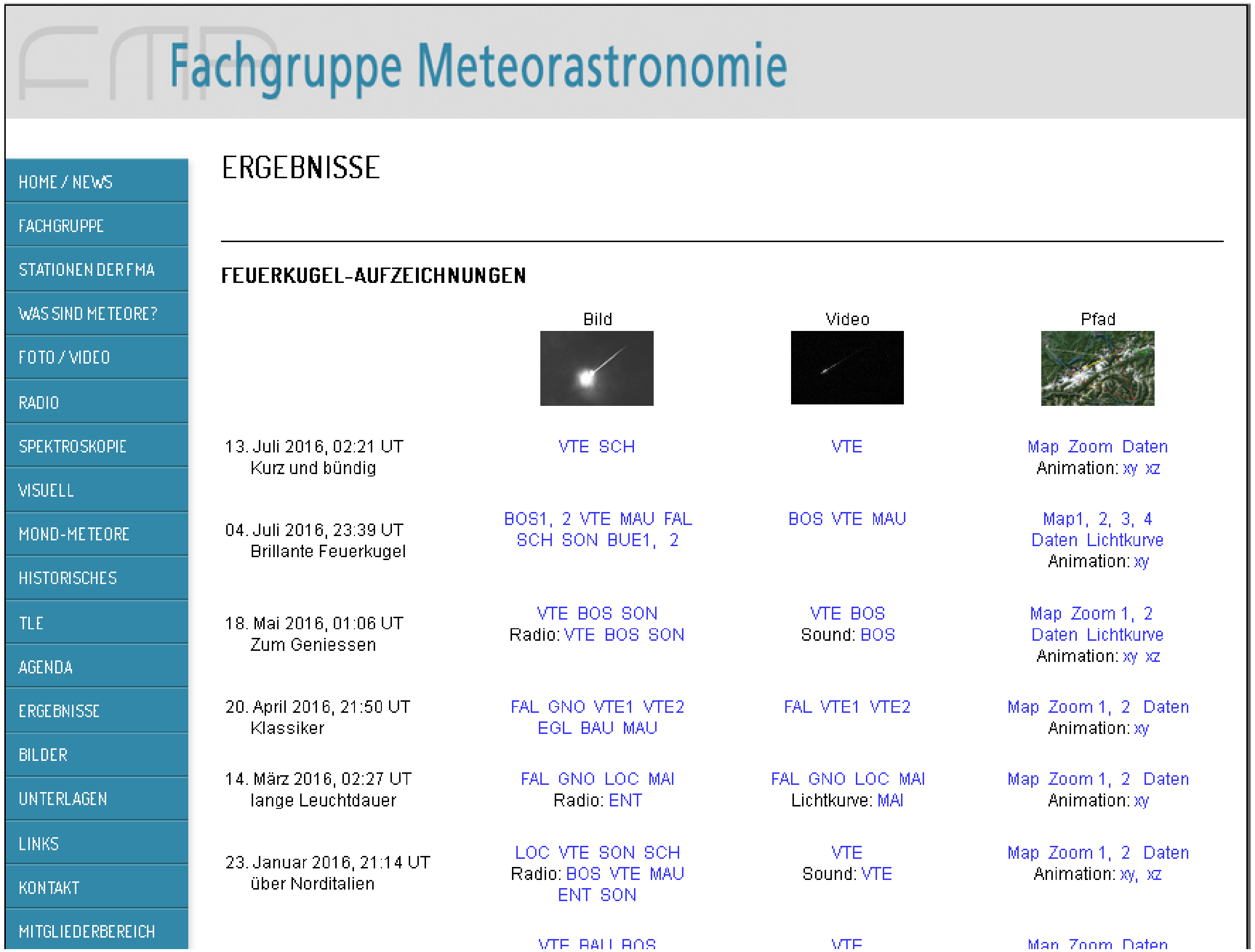
- Comets
  - Dust tail crossing earth orbit
  - Dusty snowball
  - Low density
  - Meteor streams
  - 80 – 120 km height
- Asteroids
  - Stone or iron meteorites, higher density, material strength
  - Reaches lower atmosphere
- Very old material from beginning of solar system, original state
- Space experiment for the amateur

Observation

- Visual
  - Number, brightness, direction
- Photographic
  - Radiant with simultaneous observation
- Video
  - Path, velocity with simultaneous observation
  - Origin, extrapolate backwards: Orbit elements
  - Meteorites: dark flight, extrapolate forward
    → drop or impact region

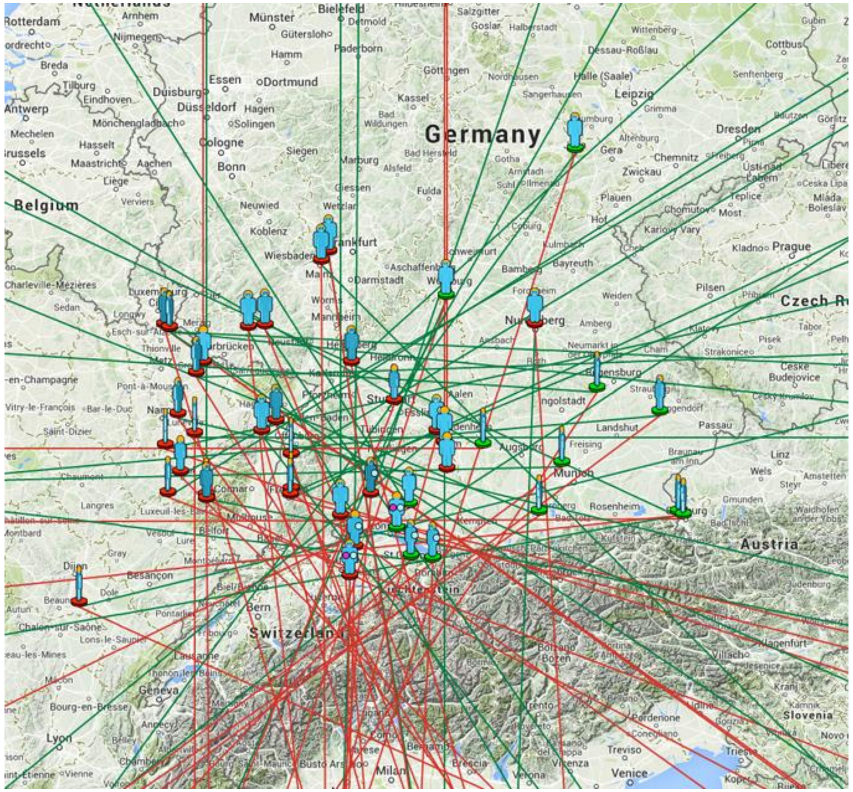
http://www.meteorastronomie.ch

- Swiss meteor network



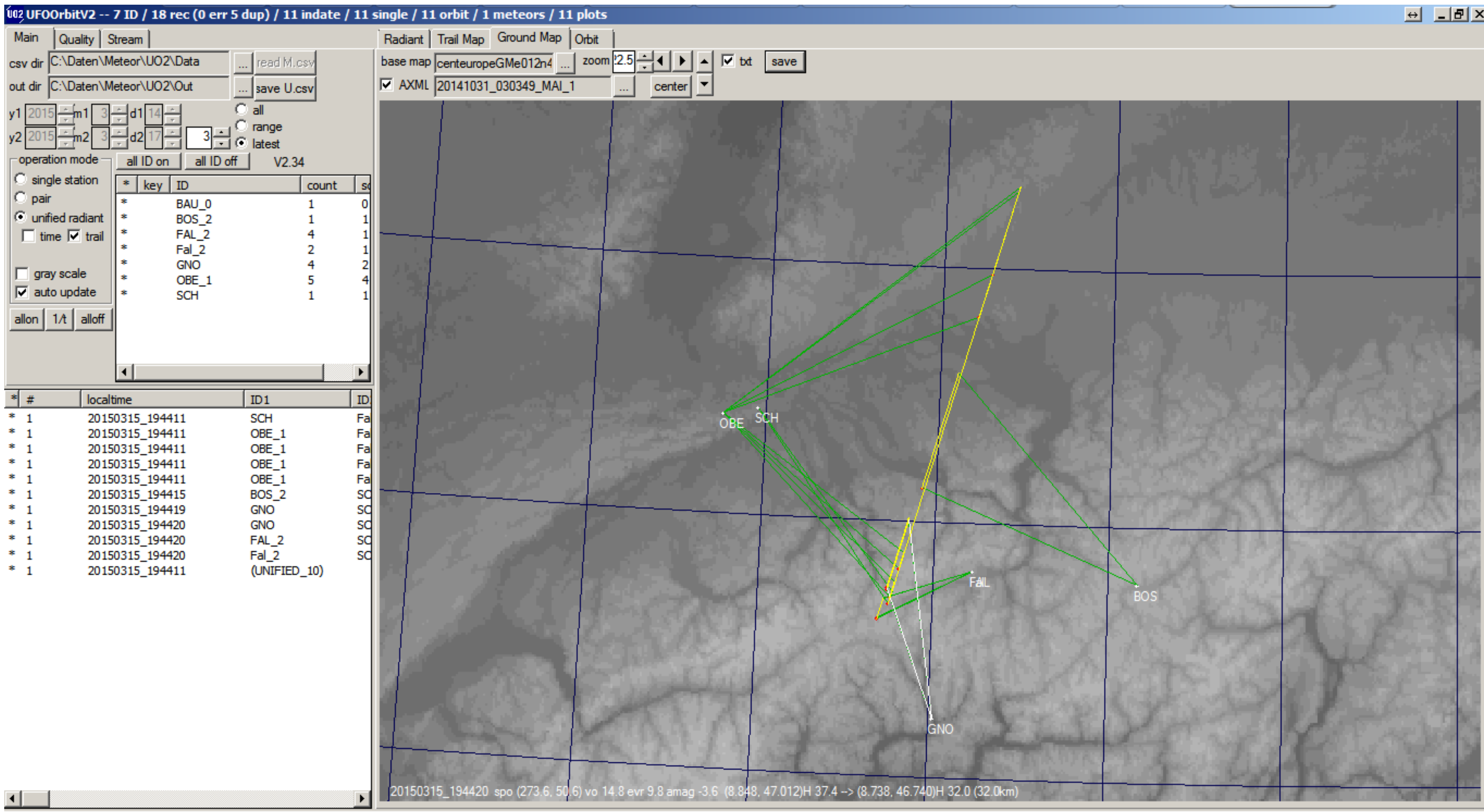
Example: Meteor 15. march 2015

- Observed over Germany and Switzerland
- Video Fredi Bachmann, Olten



Flight path with triangulation

- Data from
  - Falera
  - Oberdorf
  - Bos-cha
  - Gnosca
  - Aarau
- End point
  - h = 30 km
  - v = 4 km/s
  - Gotthard

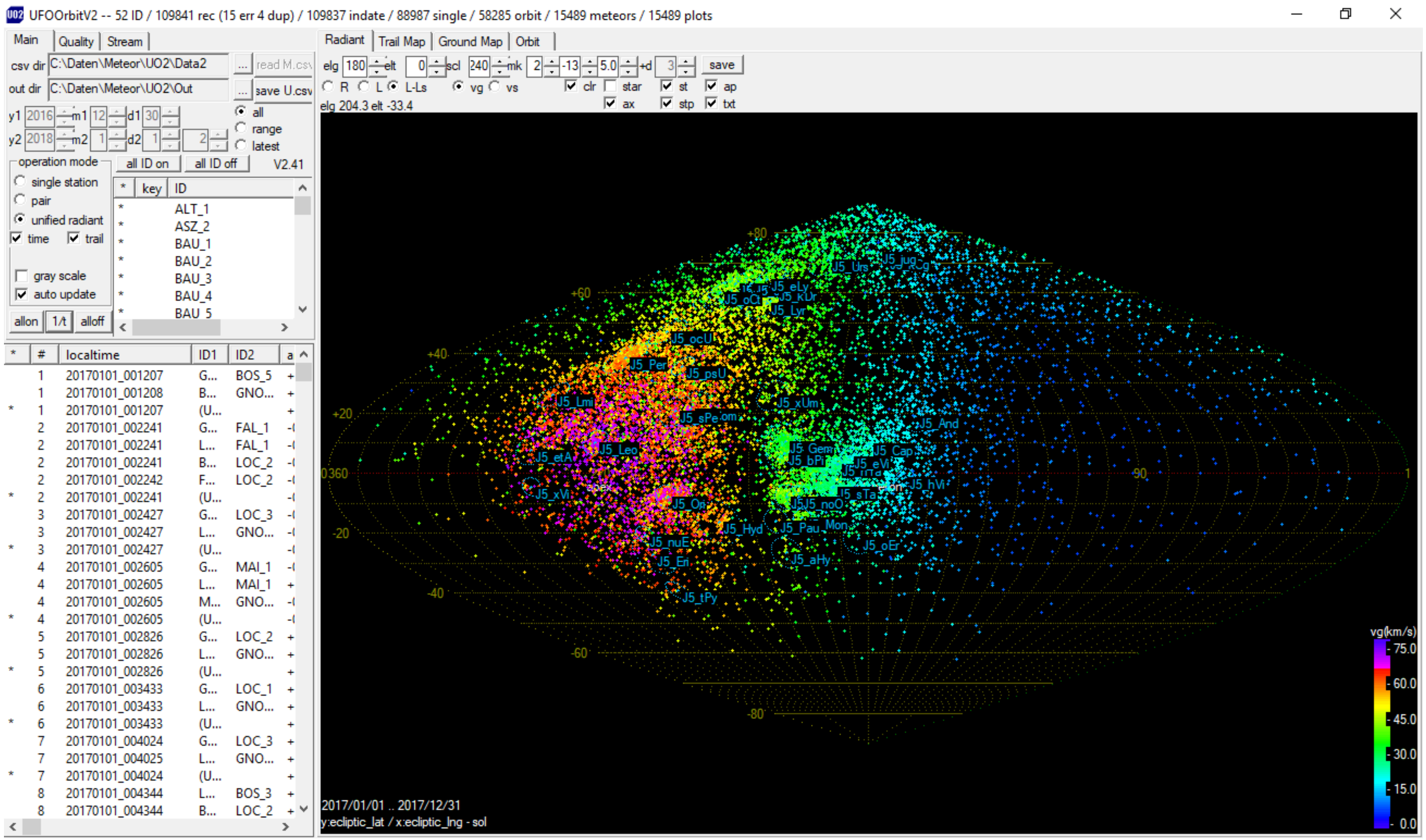


Meteor 15. march 2015

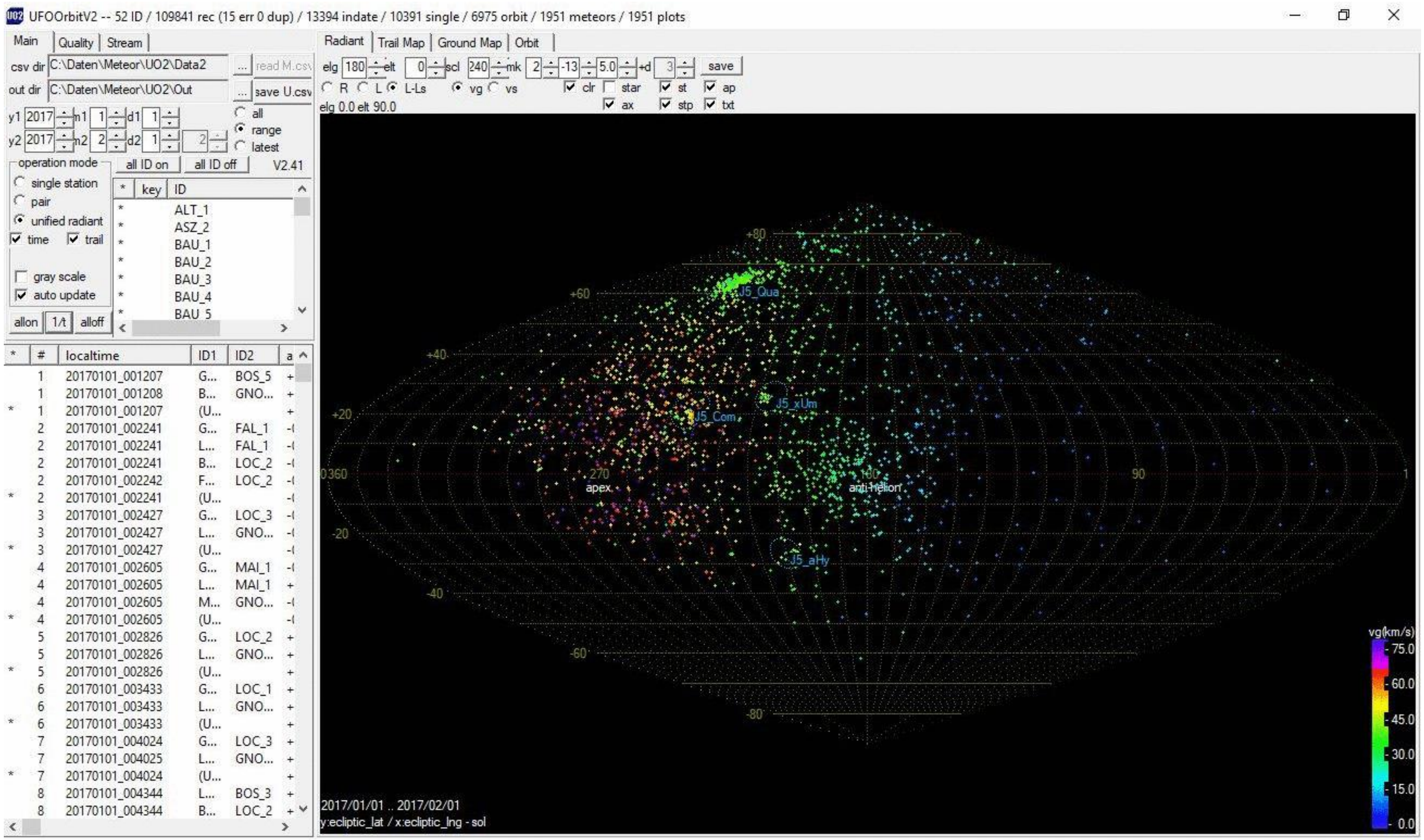
- search


Database 2017

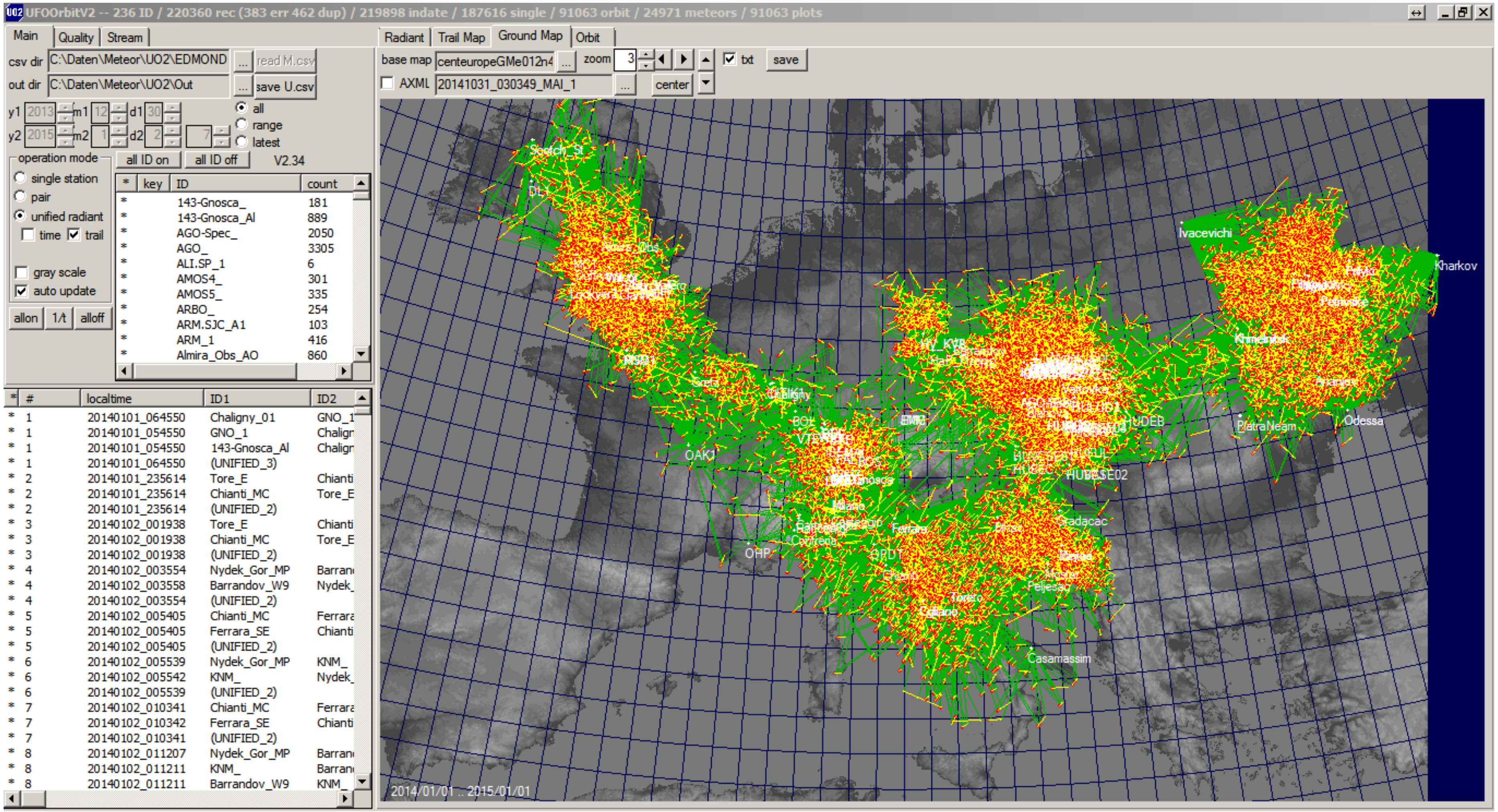
- > 100’000 observations → 15’489 orbits



2017 monthly data



Edmond Database, 2014



Hardware

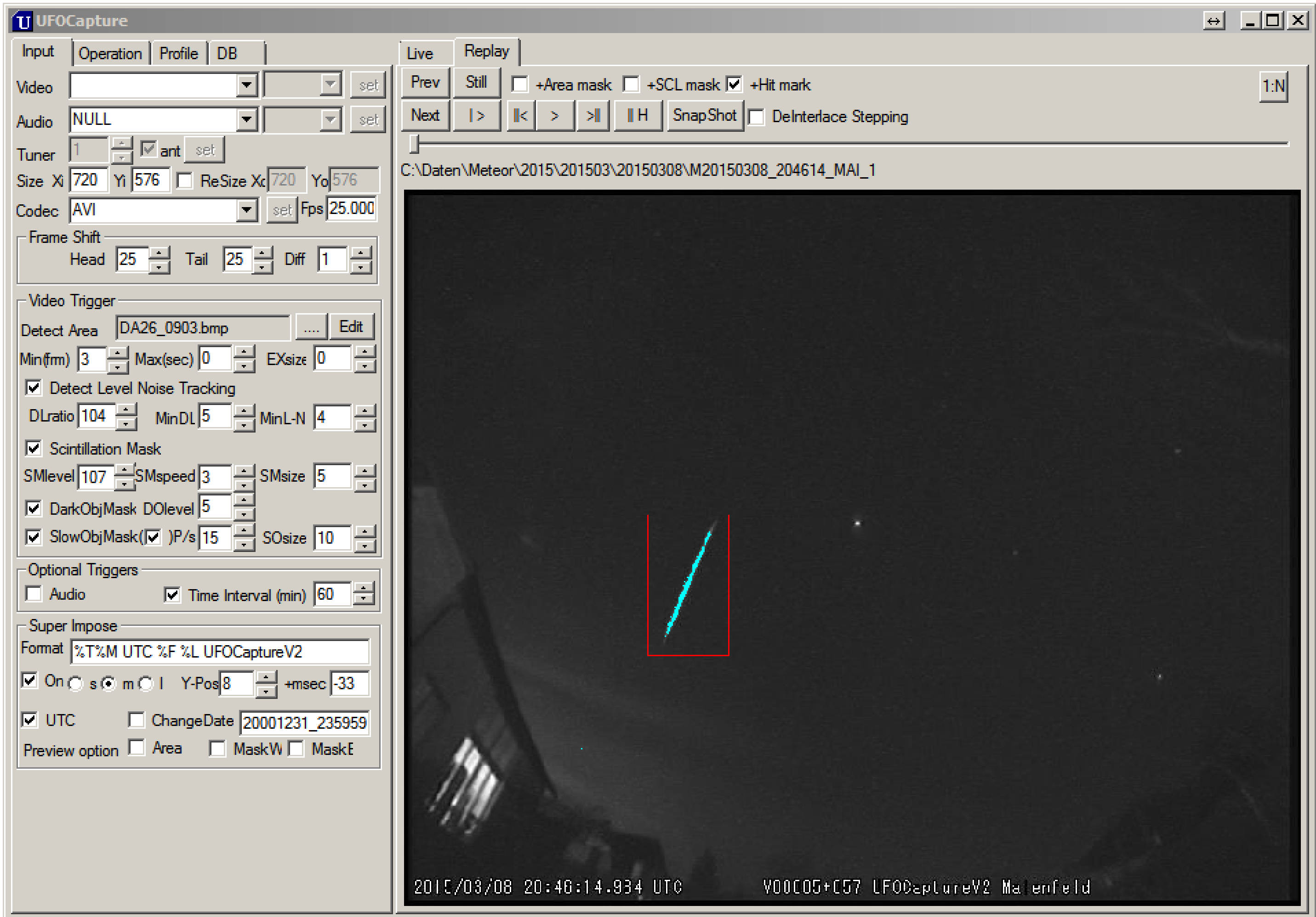
- Stefano Sposetti
  - Pressure cooker with dome
  - 4x Watec 902H2 ultimate video cameras
  - Wide angle lens f/1.0, 3 – 8 mm
  - Video grabber
  - Intel Core-i7 Computer
- 1 camera to start with

Software

- Metrec (Sirko Molau), special Hardware required
- CAMS (USA)
- FRIPON: French system, especially for bright fireballs
- UFO Tools (Sonotaco, Japan) in Europa widely used, compatible with EDMONDS database
  - UFO Capture: continuous video recording , saving of interesting events with pretrigger (for meteors, lightning, sprites, birds etc.)
  - UFO Analyzer: determination of flight path and velocity, astrometry, star coordinates, magnitude
  - UFO Orbit: determination of trajectory, velocity and orbit from simultaneous observations
  - Data from photographic observations can be used

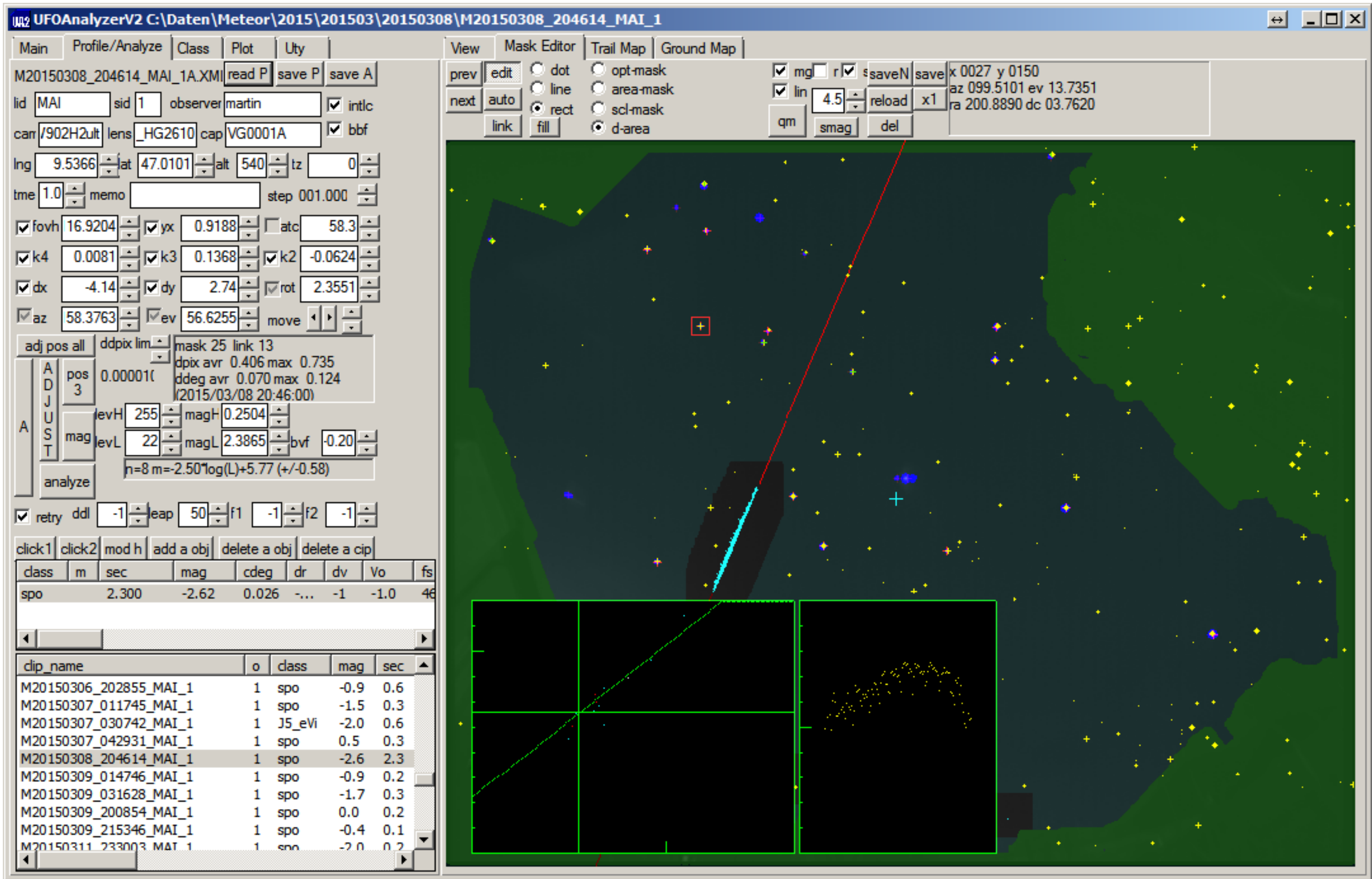
UFO Capture

- Detection
- Capture
- Pretrigger



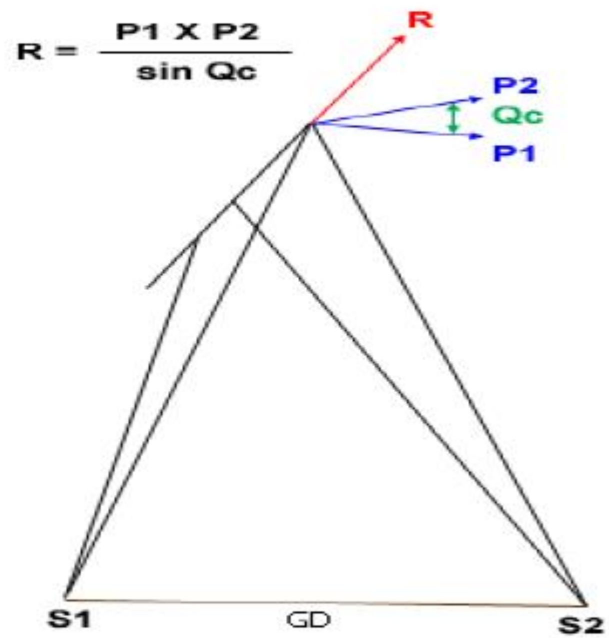
UFO Analyze

- Astrometry
- Flight path
- Magnitude
- Velocity



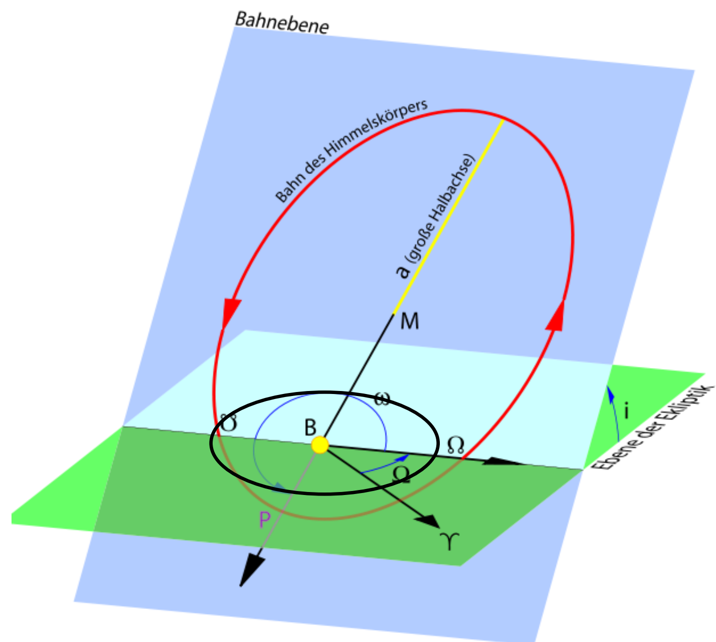
Orbit calculation with UFO Orbit

- Terrestrial observer
  - Radiant and velocity observed
  - Correction for deceleration in atmosphere
  - Correction for earth rotation:
    0.456*cos(φ) km/sec, rund 300 m/sec → v_g
  - Velocity correction for gravitational potential:
    $v_0^2 = v_g^2 - 125.4$
    (v in km/sec)
  - Correction zenital attraction
    $\Delta z=2*ARCTAN((v_g-v_0)/(v_g+v_0)*TAN(z/2))$
- → velocity relative to earth outside gravitational potential



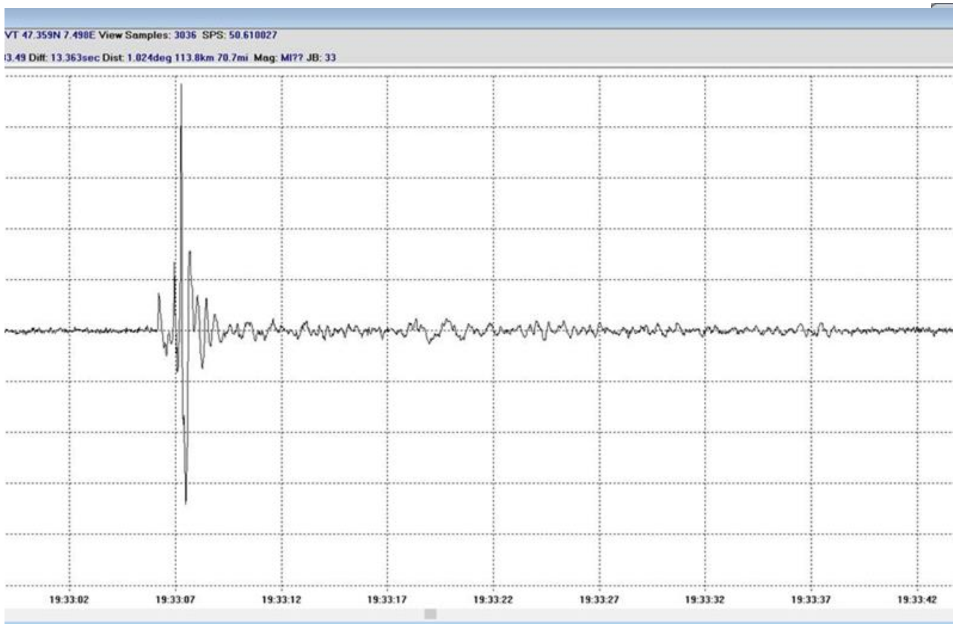
Orbit calculation with UFO Orbit 2

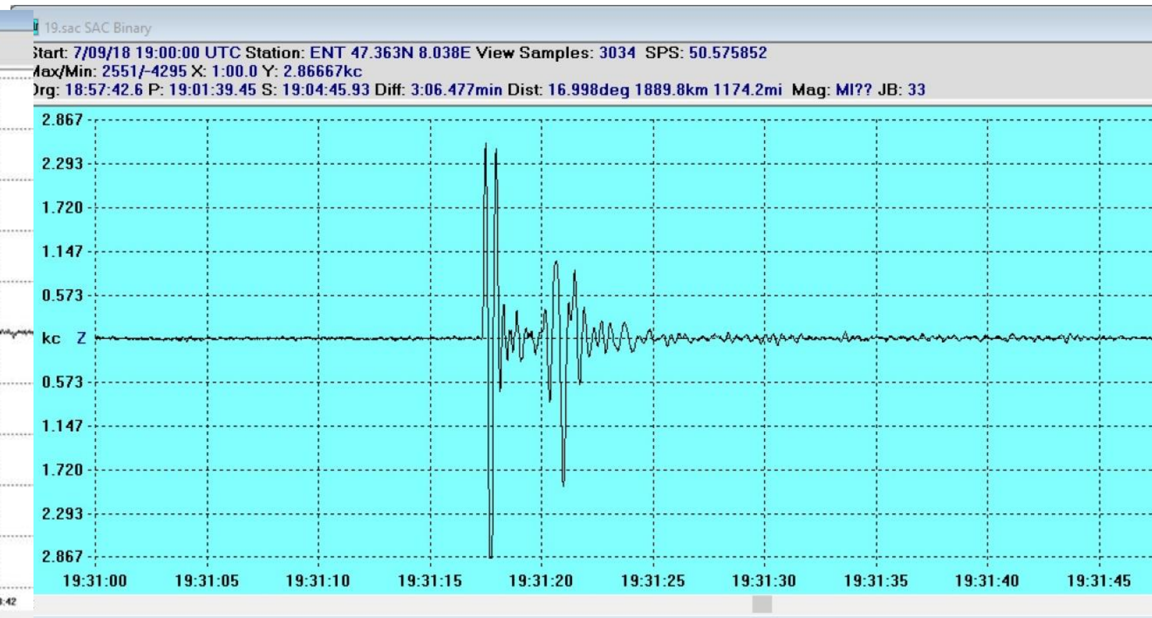
- Velocity relative to earth
  - (Vector-) addition earth orbit velocity (approx. 30 km/sec) →
  - Heliocentric meteor velocity (x, y, z, v_x, v_y, v_z)
  - From distance (1AE) and velocity → semi major axis a → orbit time of revolution (3rd law of Kepler)
  - Vector v and r (Vector sun – meteor) → angular momentum (→ eccentricity e),
  - Orbit plane (inclination i, node Ω)
  - → position of perihel ω, T perihel



Other activities in meteor observations

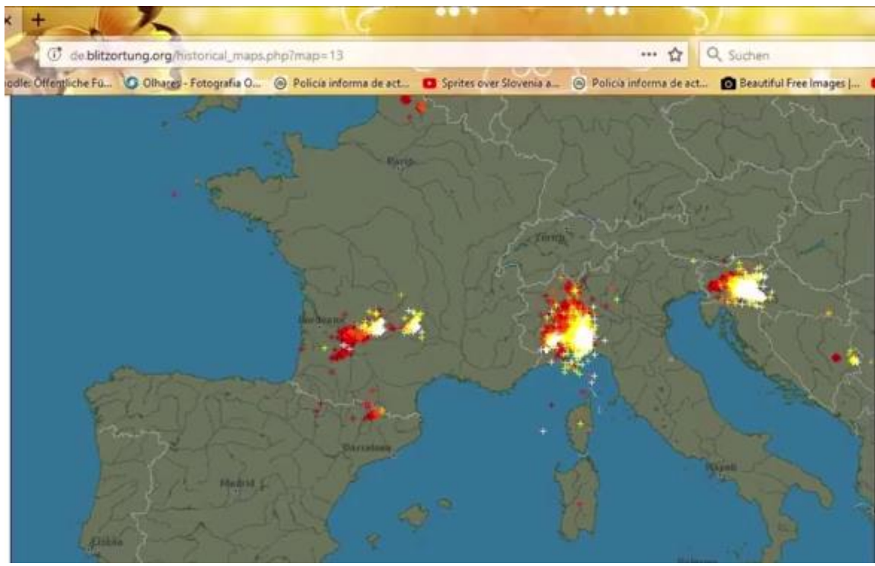
- Radio detection
- Infrasound measurements
- Detection of transient luminous events (TLE) in the upper atmosphere





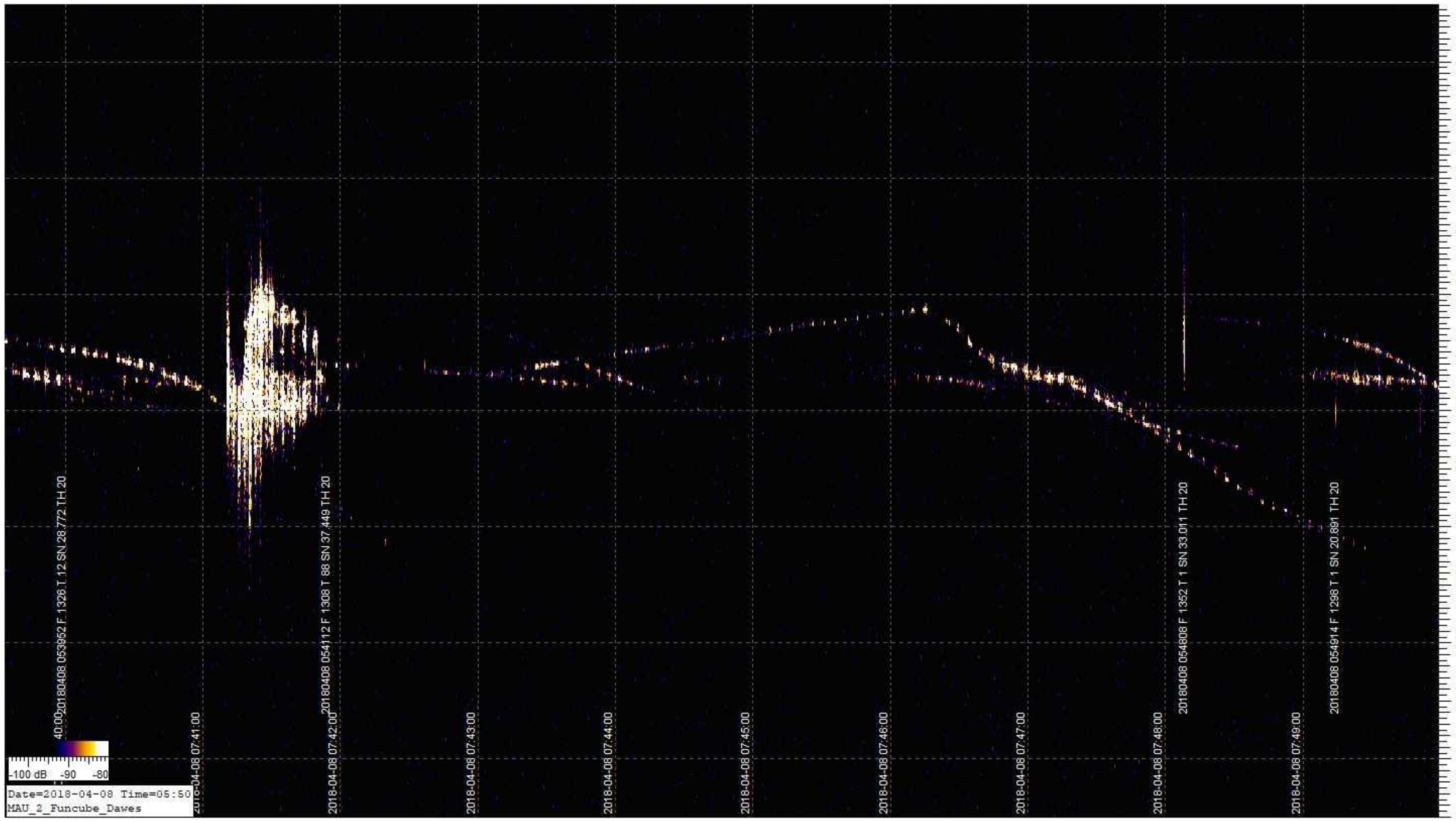
TLE, sprite

- First detection at Maienfeld



Radio detection, echo from Graves 143.05 MHz

- Daylight event R20180408_054130 UT



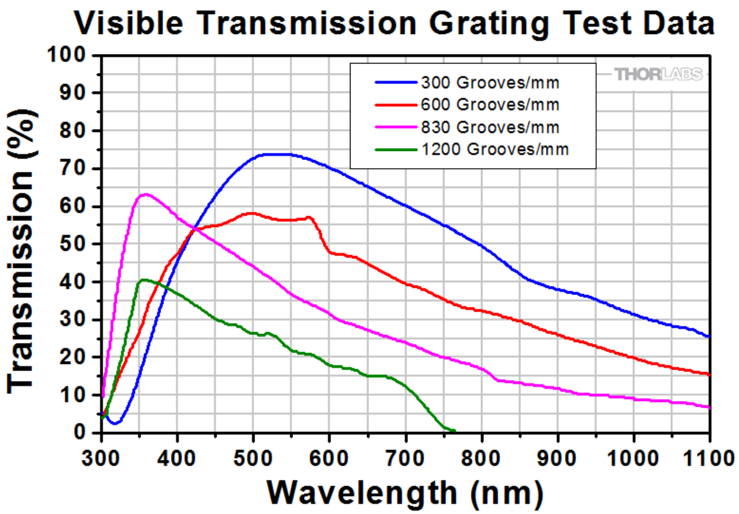

http://www.eso.org/public/images/potw1414a/

Meteor spectroscopy

- Hard- Software
- Wavelength calibration
- Spectrum extraction
- Instrument response
- Summary

Hardware

- Watec 902H2 ult. Computar HG2610AFCS-HSP F/1 2.6mm fl
- 902H2 ultimate (spectroscopy) Tamron 12VG412ASIR F/1.2, ≈7mm fl
- 2nd camera with transmission grating for spectroscopy Thorlabs
  300 L/mm → 600 L/mm

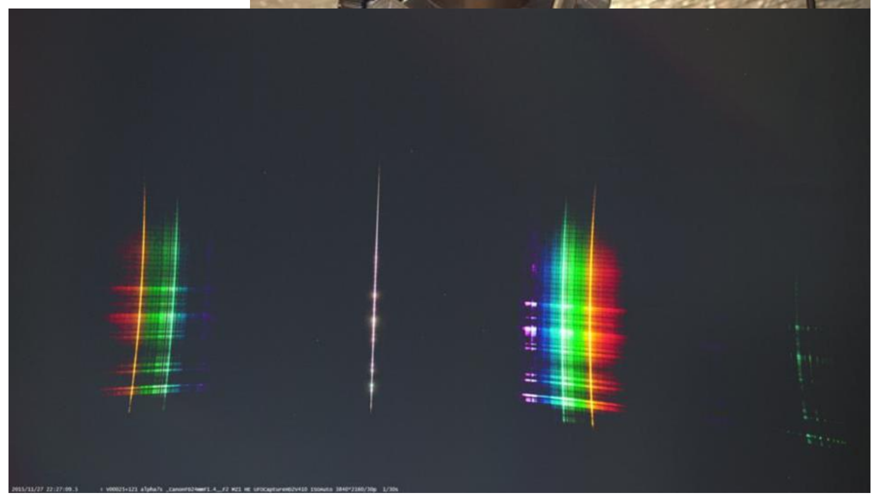


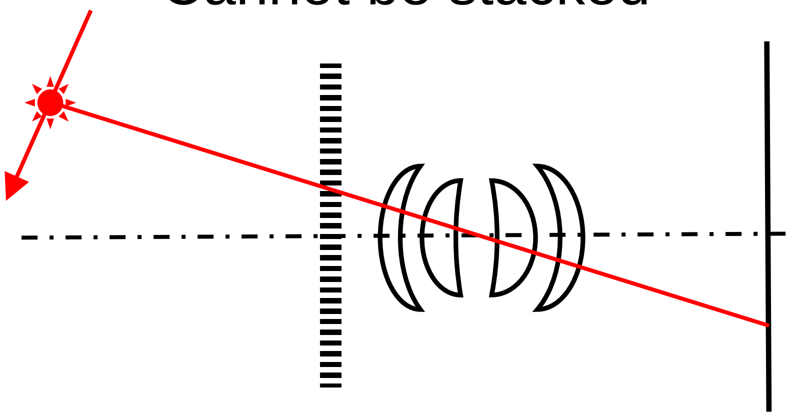
OHP 2017

- Mobile setup

Starting point

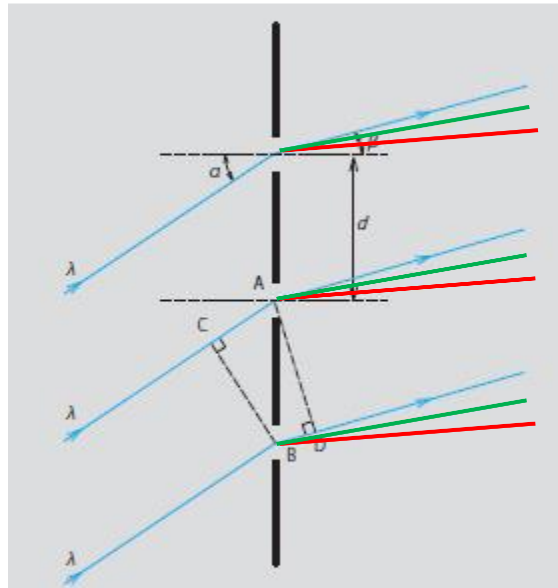
- Camera with wide angle lens
- Transmission grating
  - mounted perpendicular to optical axis!
- Problem:
  - Moving meteor
  - Curved spectra with nonlinear dispersion
  - Cannot be stacked





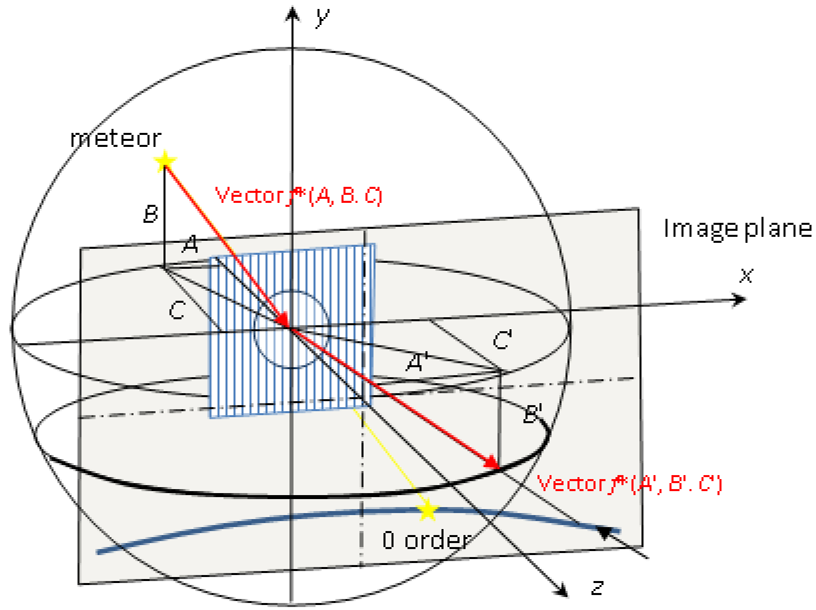
Spectrograph, theory

- Video camera with transmission grating in front of lens
- Grating equation:
  - **m * λ * G = (sin α - sin β) * cos γ**
  - m: grating order, G: grating lines / mm
  - λ: wavelength
  - α, β: angle of incidence, transmitted beam
    γ: cross, out of plane angle
- Inverse dispersion per pixel:
  dλ/dx = (cos β cos γ)/(m*G*f)*p (p: pixel size)
  - Example: f = 7 mm, p = 8.6 µm, G: 300L/mm β = 0 → dλ/dx = 41A/pixel



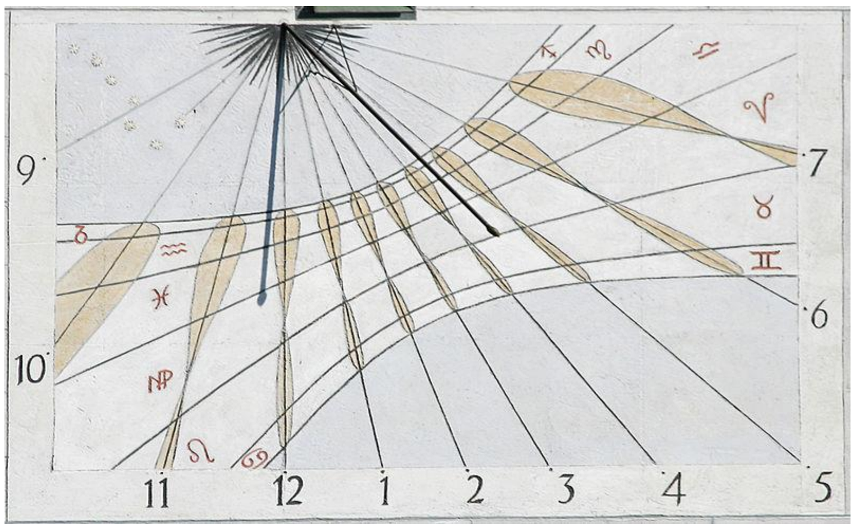
Vector theory wavelength calibration

- Grating in front of lens perpendicular to optical (z-)axis
- Unit vector (A B C) for incident direction
- Diffracted beam
  $A' = A + m\lambda G$ *(x-axis)*
  $B' = B$ *(y-axis)*
  $C' = \mathrm{sqrt}(1 - A'^2 - B'^2)$
- Spectrum on CCD plane
  - Nonlinear dispersion
  - Hyperbolic curvature
- Spectrum straight linear in A',B'

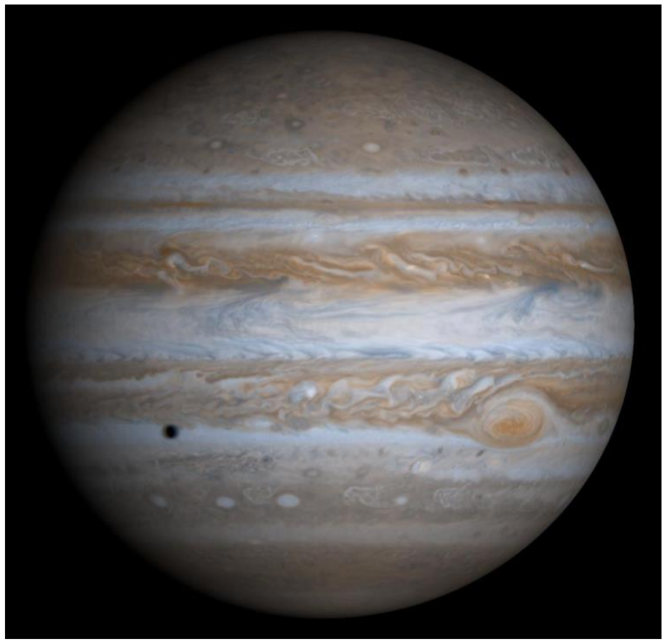


Gnomonic and orthographic projection

- Gnomonic, TAN
  - R = f*tan(ρ)
  - Great circles → straight
  - Optimum for path, radiant
  - Latitude circles → hyperbola

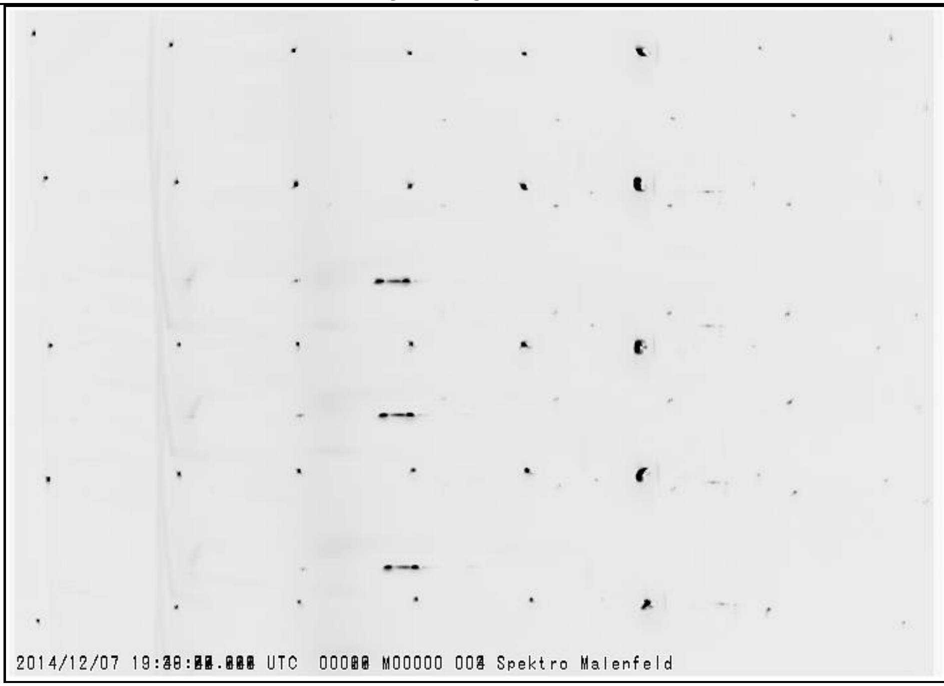


- Orthographic, SIN
  - R = f*sin(ρ)
  - Great circles →ellipses
  - Latitude circles → straight
  - Optimum for spectroscopy

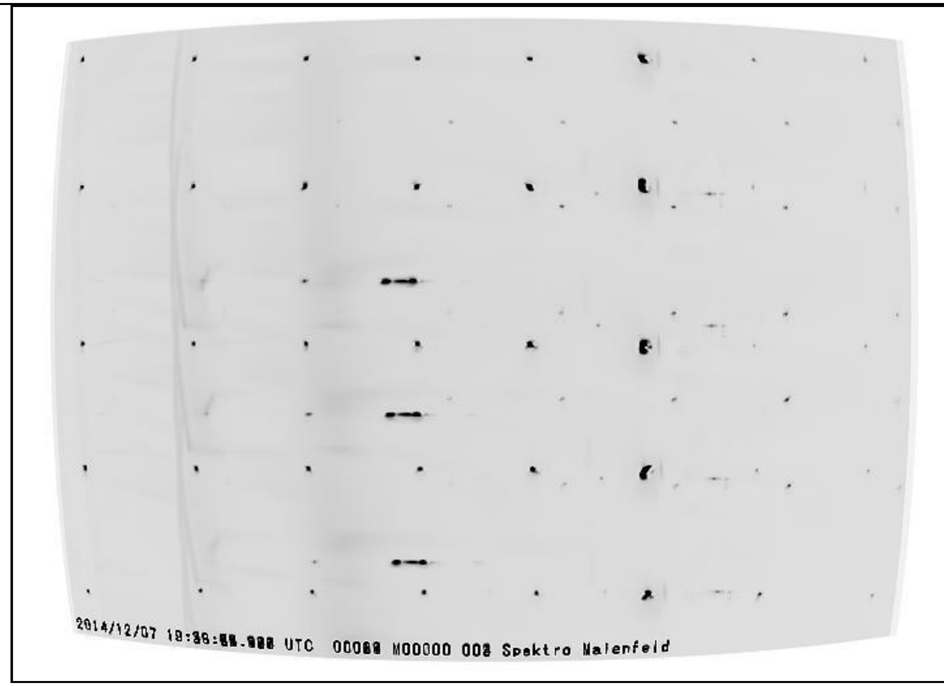


Calibration spectrum HeNe laser

- HeNe laser λ = 633 nm, f = 4 mm
- Fit with polynom r = r' * [1 + 3.94E-07*r'2 + 2.01E-12*r'4]
- Fit center x_0, y_0

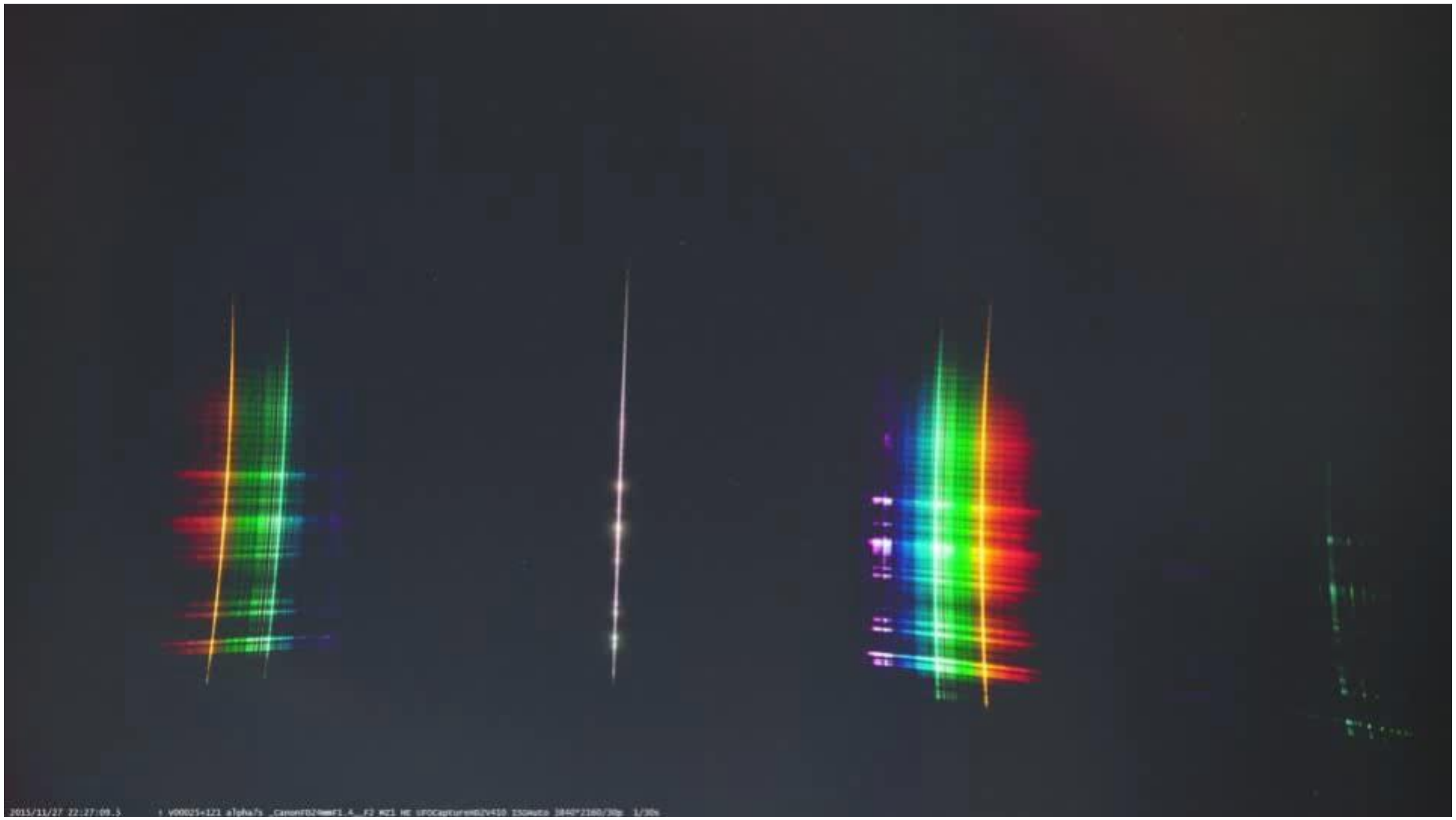


Composite spectra original

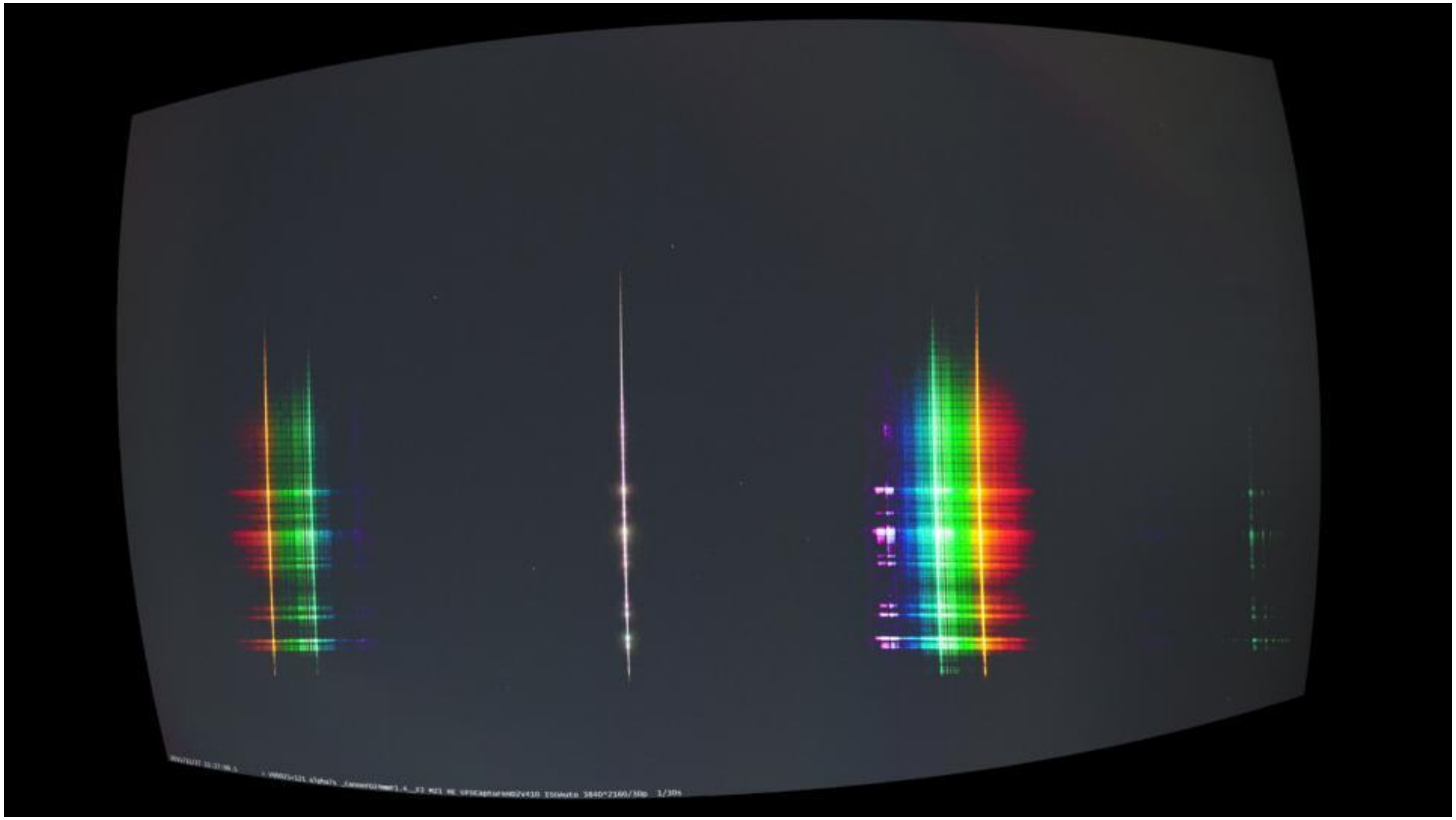


After applying transformation

Orthographic transformation, original

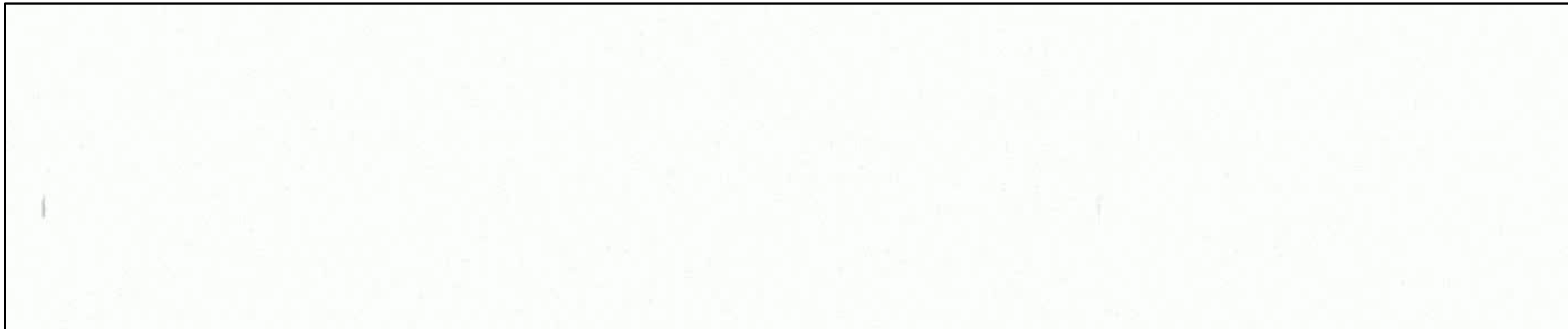


Orthographic transformation, result



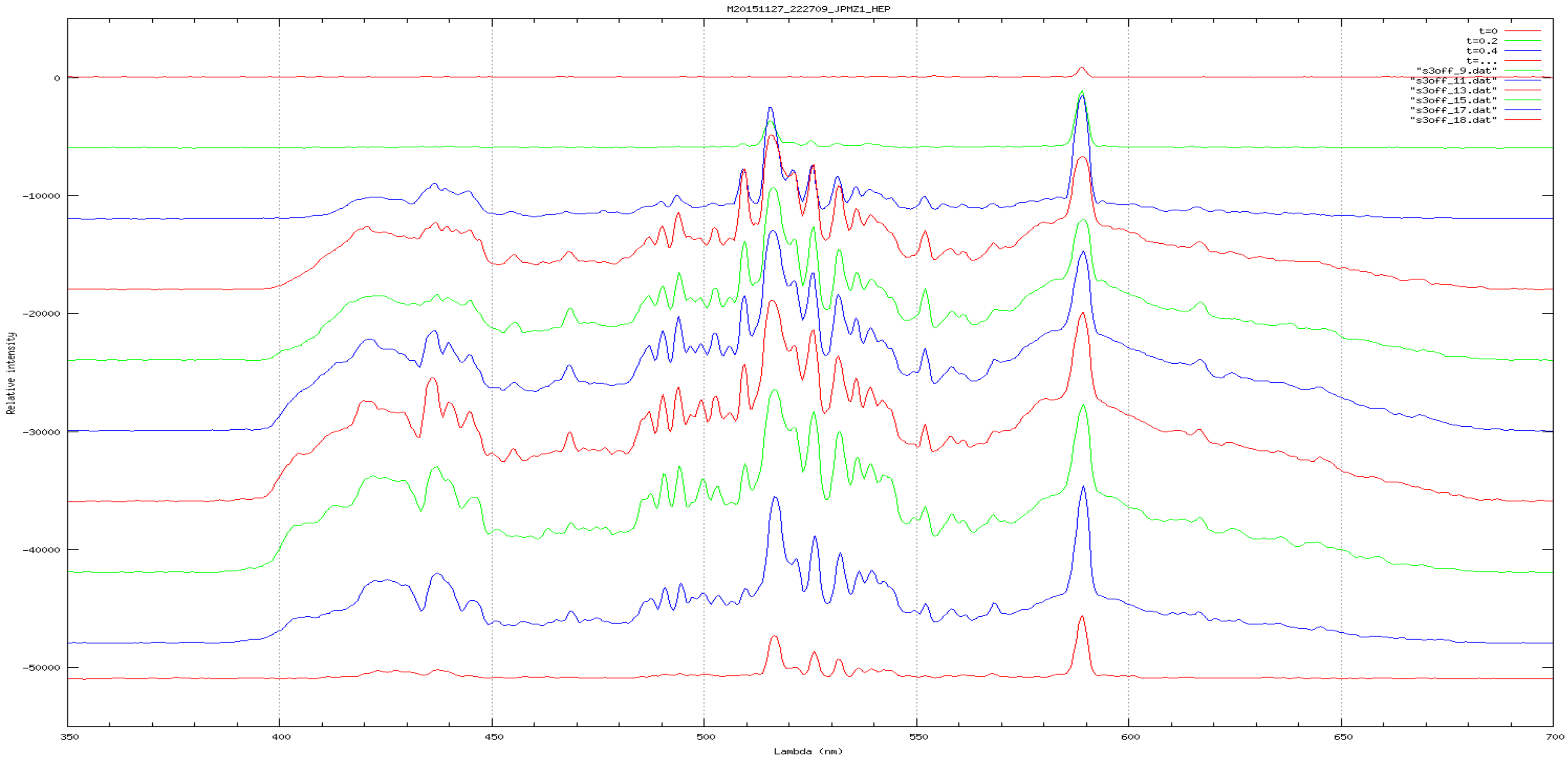
Orthographic transformation, result

- Frames converted to b/w, linearized,registered, M20151127_222709



- color

Extraction of spectra



Full processing

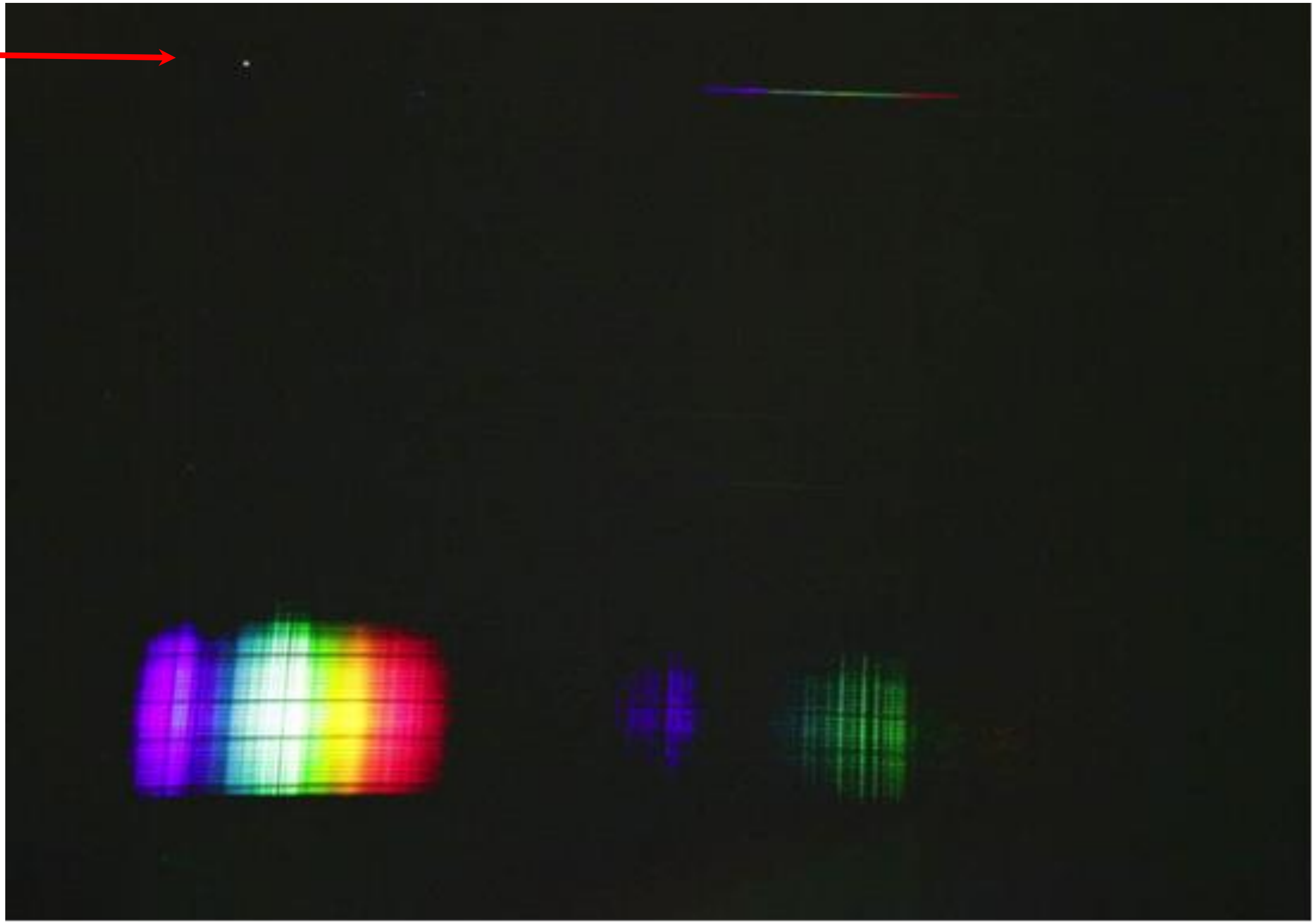
- Wavelength calibration √
- Flux calibration
  Correct for:
  - Background subtraction!
  - Vignetting, field of view
  - Correction for image transformation
    - Apply image transformation
    - Extract spectrum, calibrate wavelength

  } flat field correction in pre-processing
- Instrument response
  - Grating efficiency
  - Camera spectral sensitivity (lens, CCD)
  - Atmospheric transmittance

  } instrument response

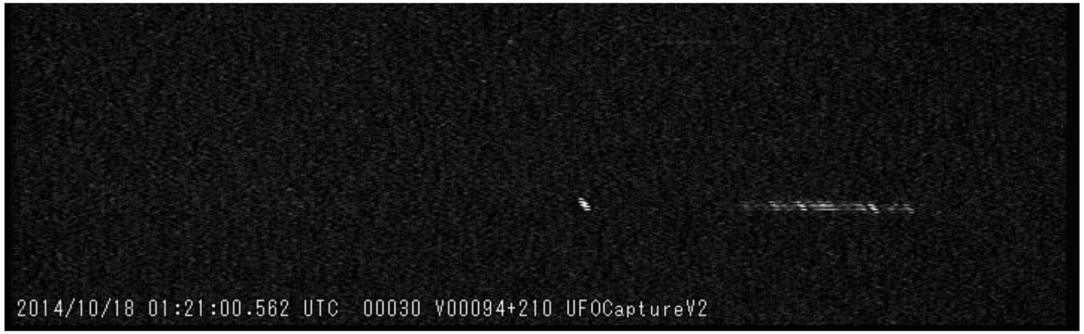
M20160107_225526_JPMZ1_HDP, iron meteor

- Sirius
- Koji Maeda
- Canon EOS6D
  Sigma 35mm/f1.4
- zero order missing

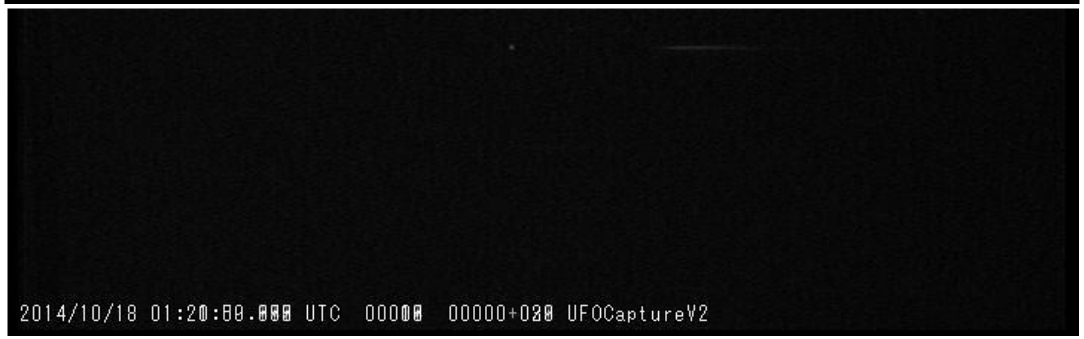


Preprocessing

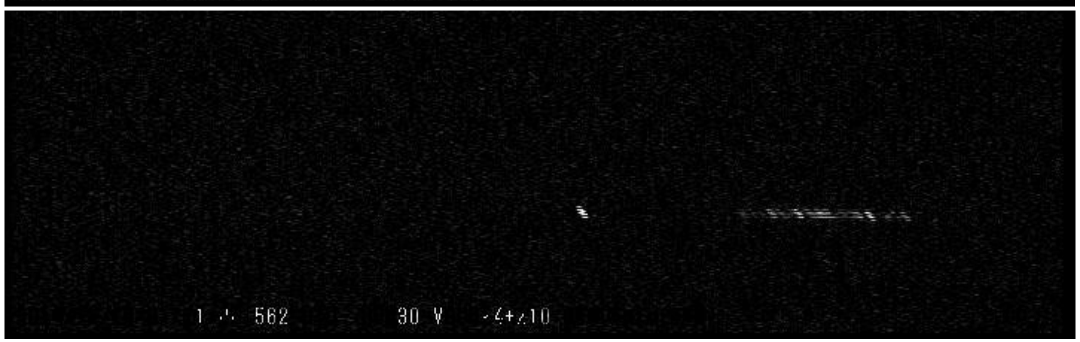
- Extract image (i30)



- Background ADD_MEAN < I1 … I20 >

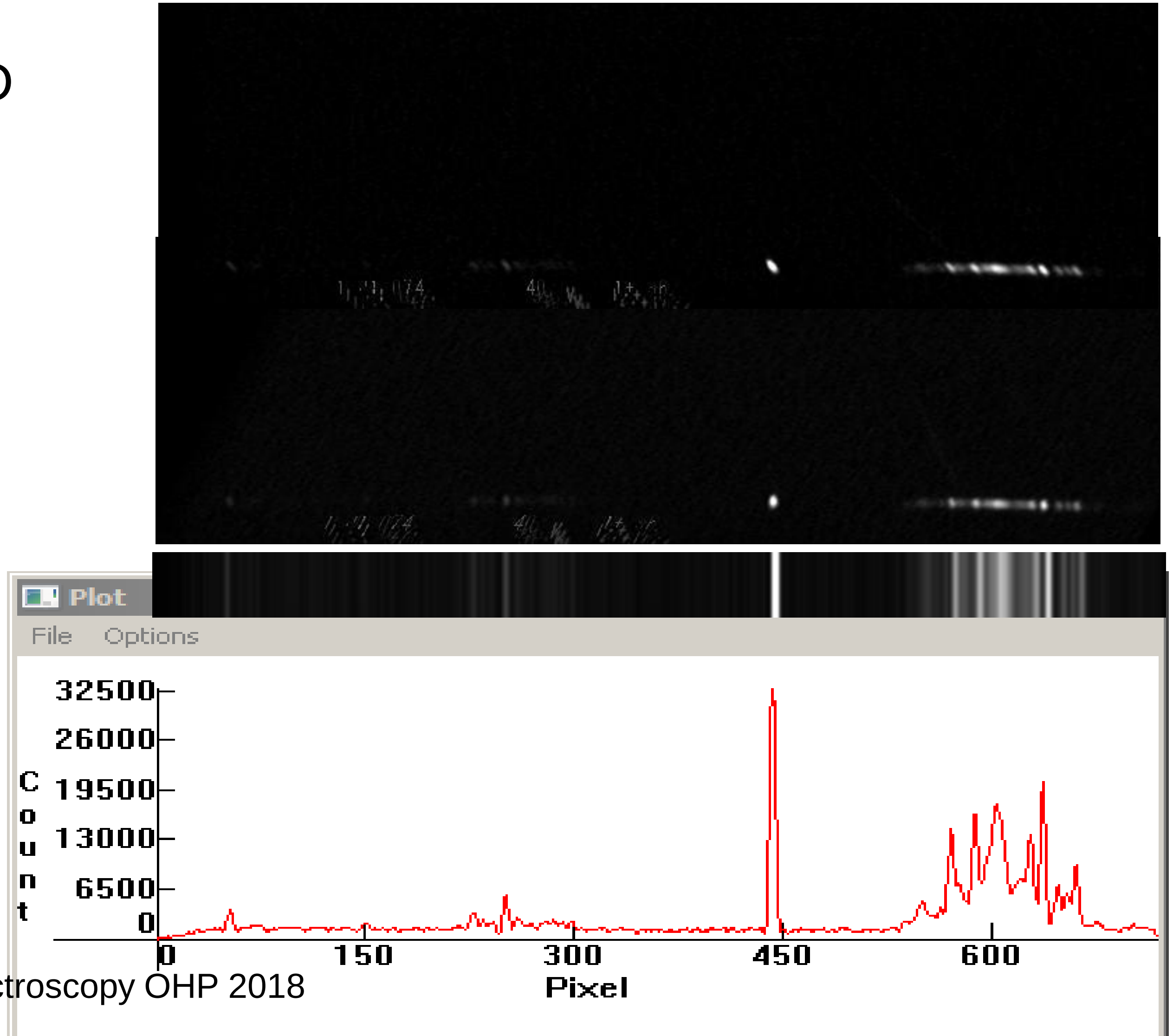


- Subtraction SUB2



Processing 2

- Add
  TRANS, ADD
  ib34-ib40
- Slant 28 30
- L_ADD
- L_PLOT
  save file.dat

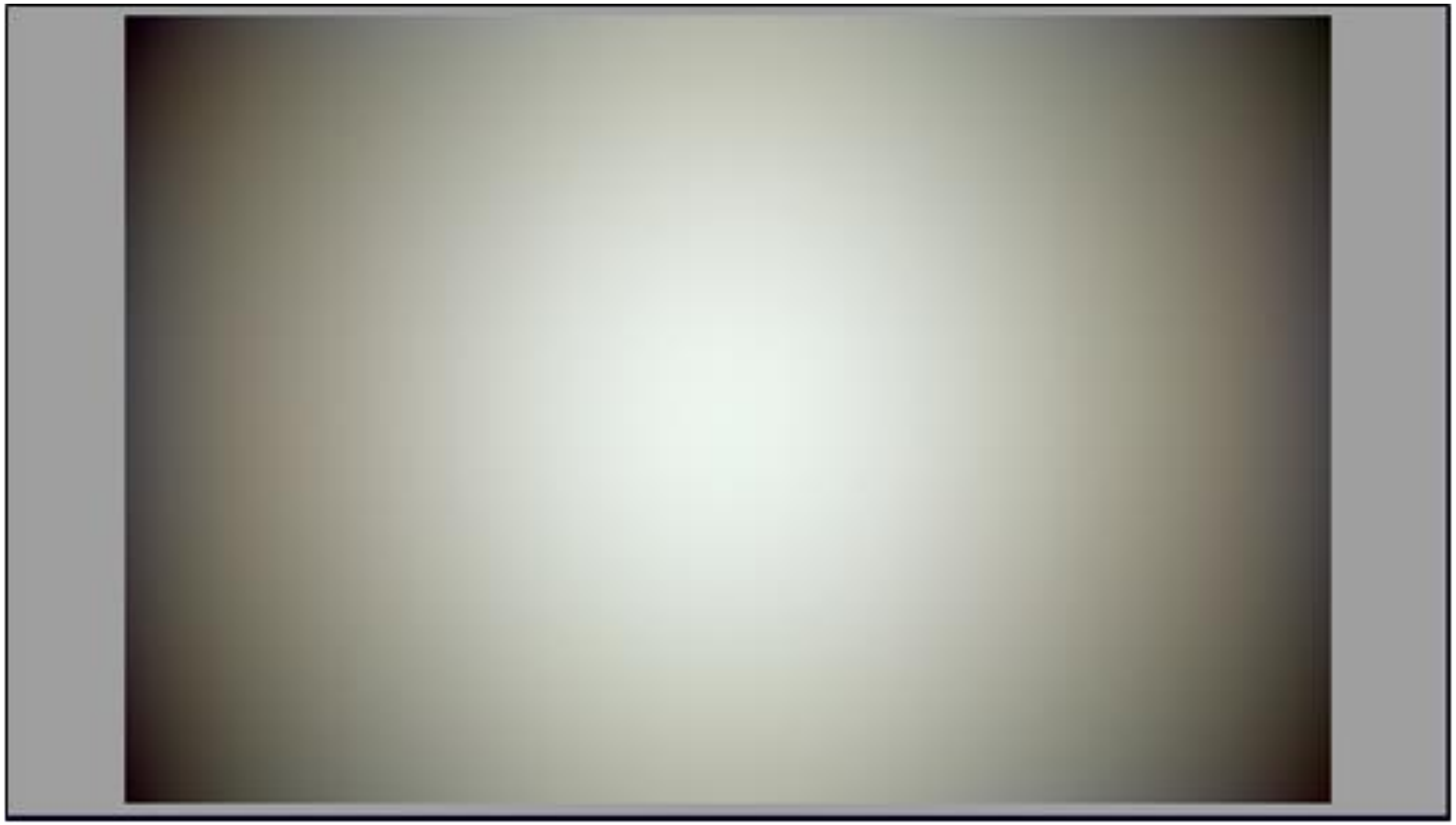


Background subtraction with IRIS

- Pretrigger → no meteor visible, used for background
  - M_BACK.PGM
    CONVERTBMP24bw $1 @b $3
    *CONVERTBMP24 $1 @b $3
    ADD2 @b $3
    MULT $4
    SAVE $2
    REMOVE@
- Background subtraction: M_DARK.PGM
  - SETBASE $4
    CONVERTBMP24BW $1 @m $5
    *CONVERTBMP24 $1 @m $5
    SUB2 @m $2 $3 0 $5
    REMOVE@
    SETBASE 1

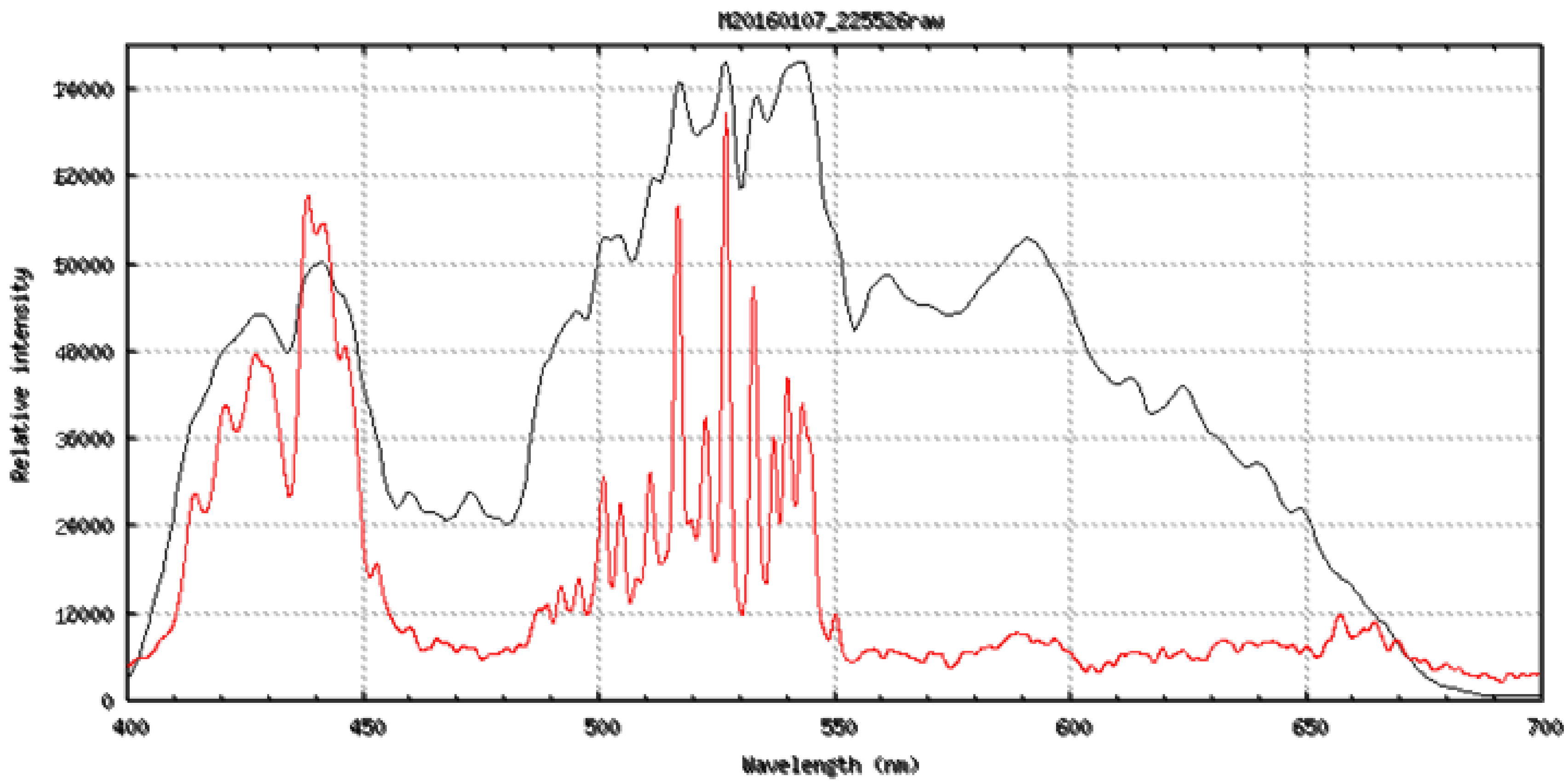
Flat field

- Border not illuminated



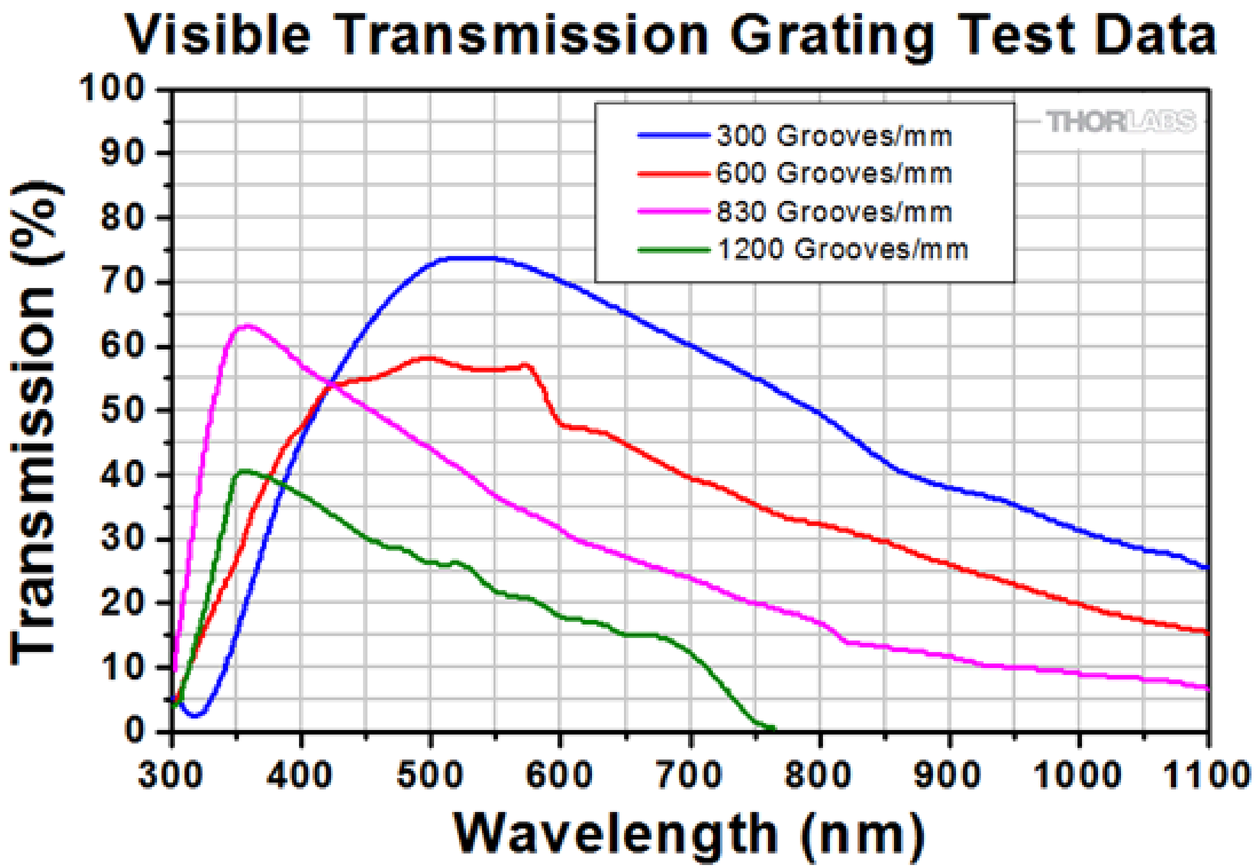
Saturation

- 1st and 2nd order on same wavelength scale



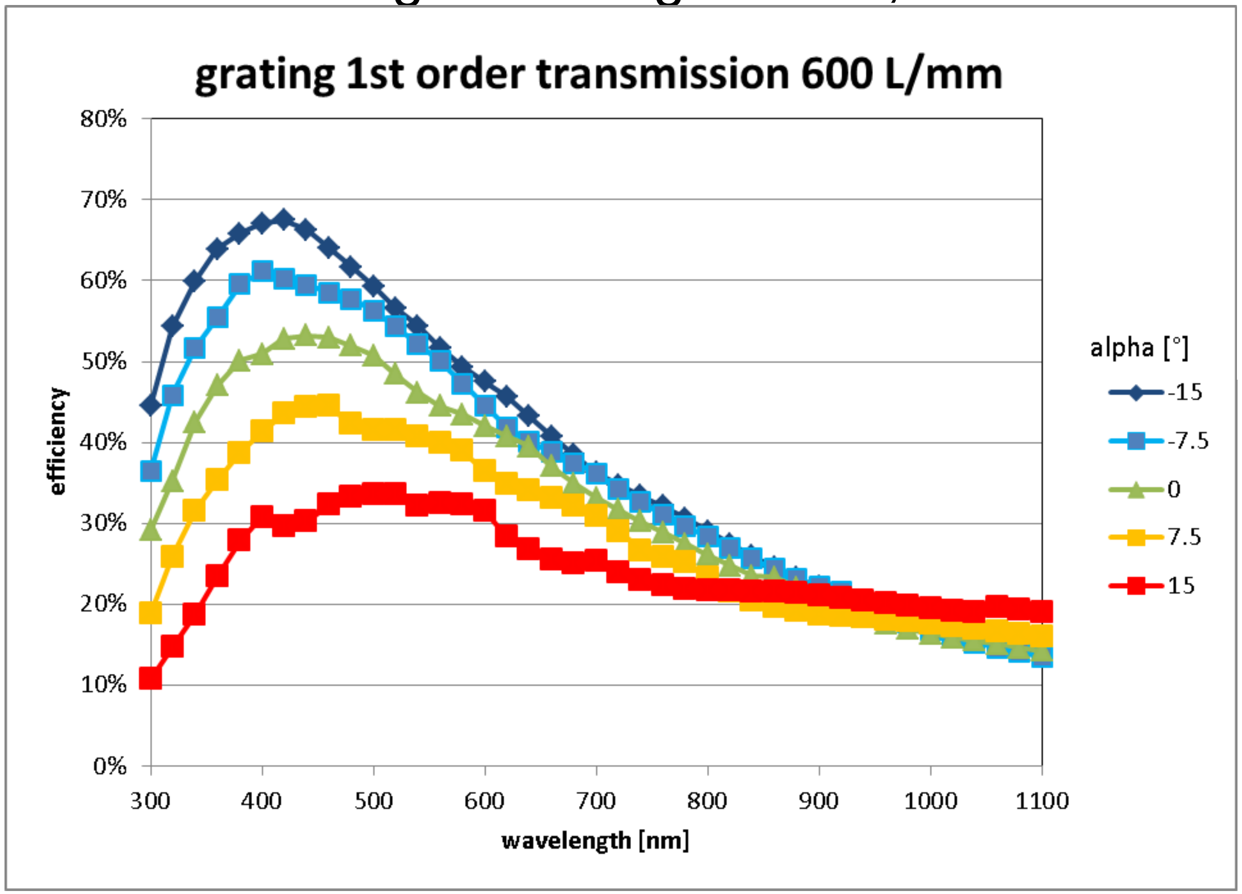
Grating efficiency

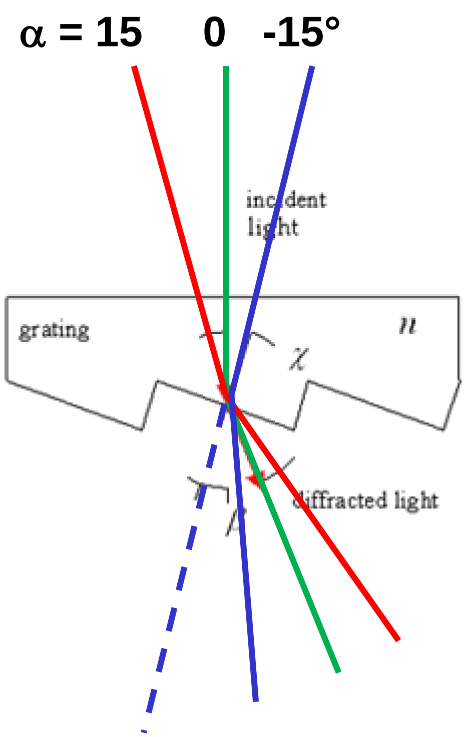
- Depends on grooves/mm and groove angle
- Thorlabs:

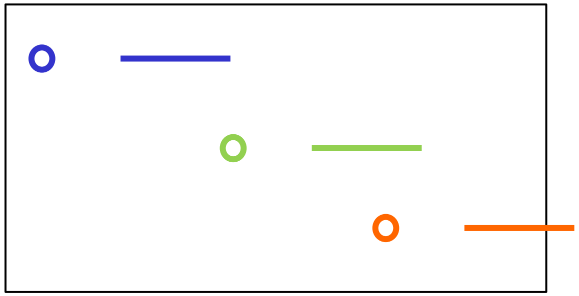


Grating efficiency 2

- Grating efficiency dependent on incident angle!
  Calculated for groove angle 28.7°, n = 1.52

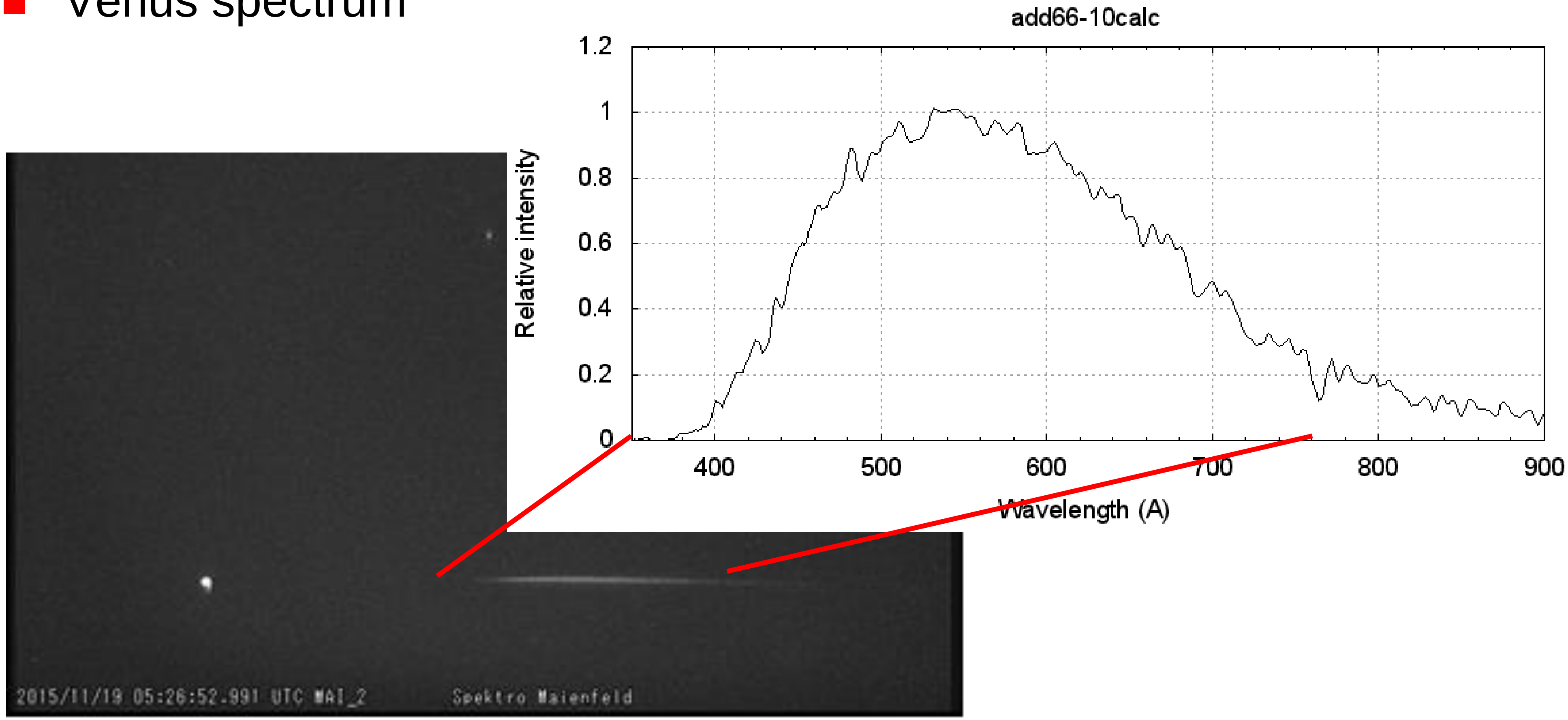






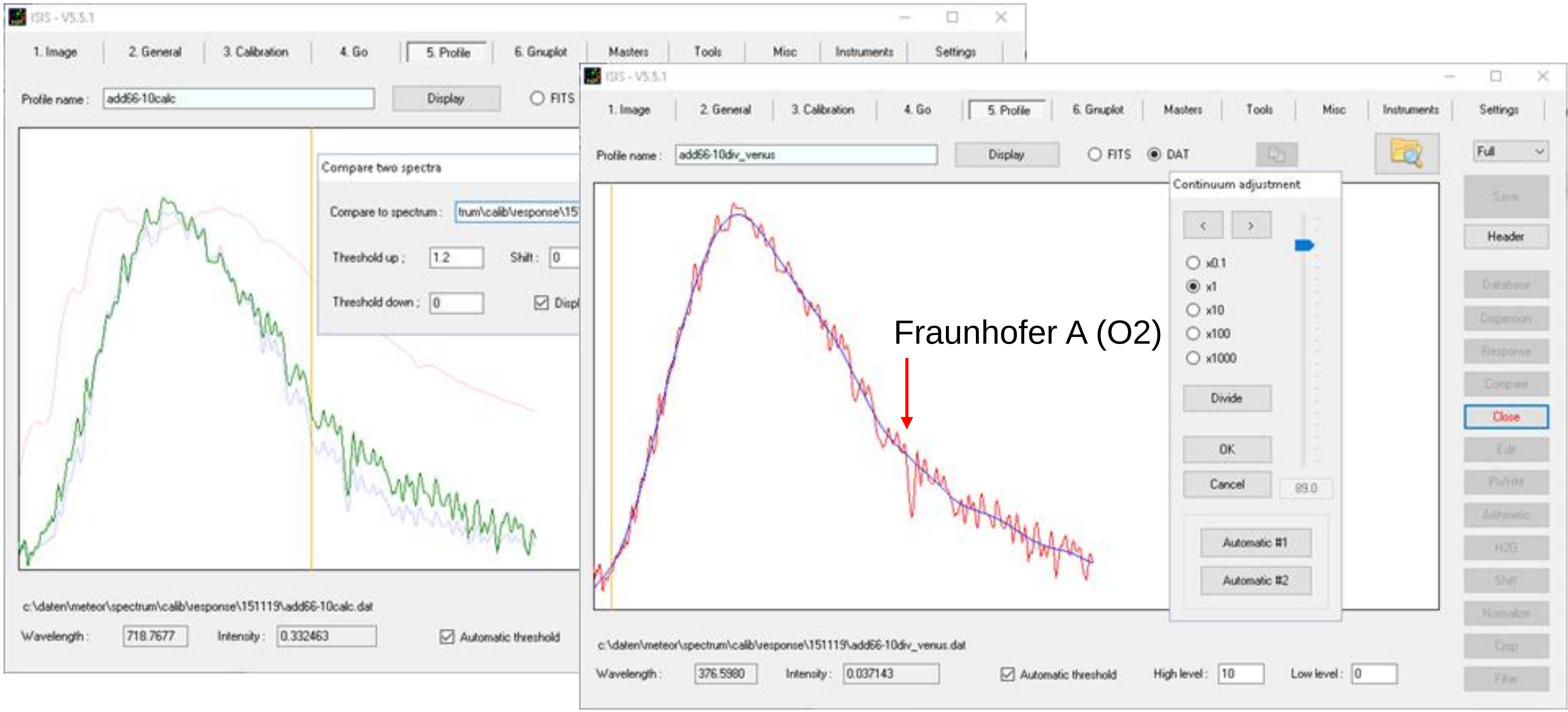
Measured spectrum, Watec 902H2ultimate

- Venus spectrum



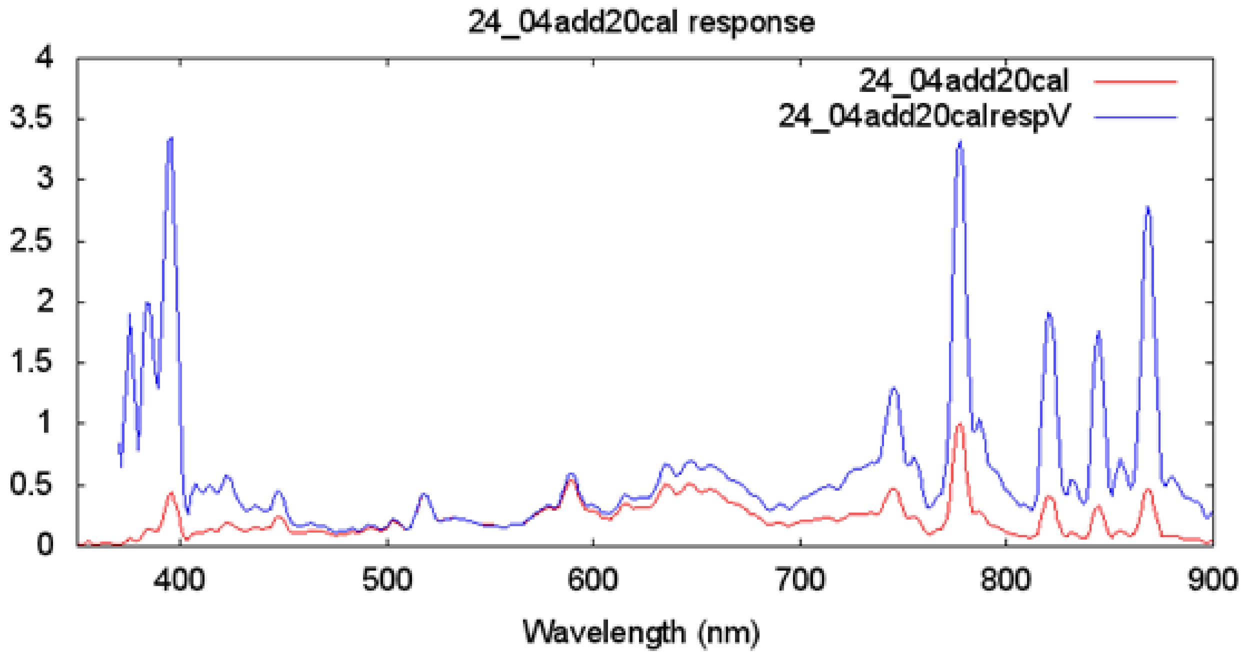
Instrument response

- Measured spectrum / reference spectrum



Instrument response

- Spectrum of known object (Venus)
- Instrument response = measured spectrum / reference spectrum
- Meteor spectrum, wavelength calibrated
- Corrected spectrum = meteor spectrum / instrument response



Characteristic meteor spectra

- Catalogue of meteor spectra: V. Vojacek et. Al.
  http://adsabs.harvard.edu/abs/2015A%26A...580A..67V

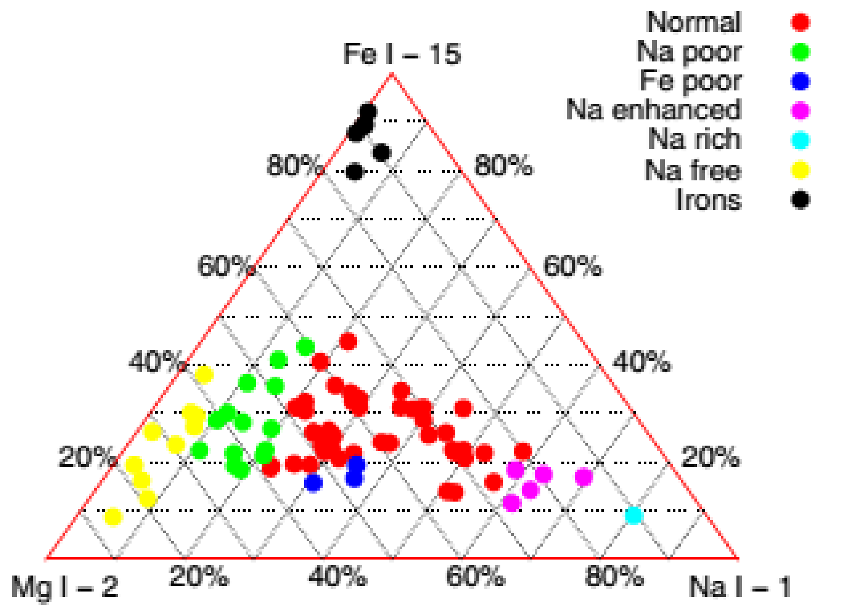


Fig. 8. Classification of meteor spectra. The ternary graph of the Mg I (2), Na I (1), and Fe I (15) multiplet relative intensities. Every group of meteoroids is represented with a different symbol.

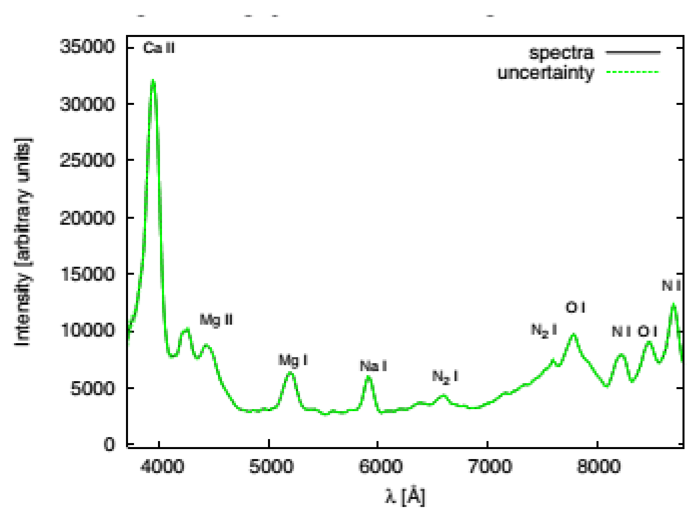


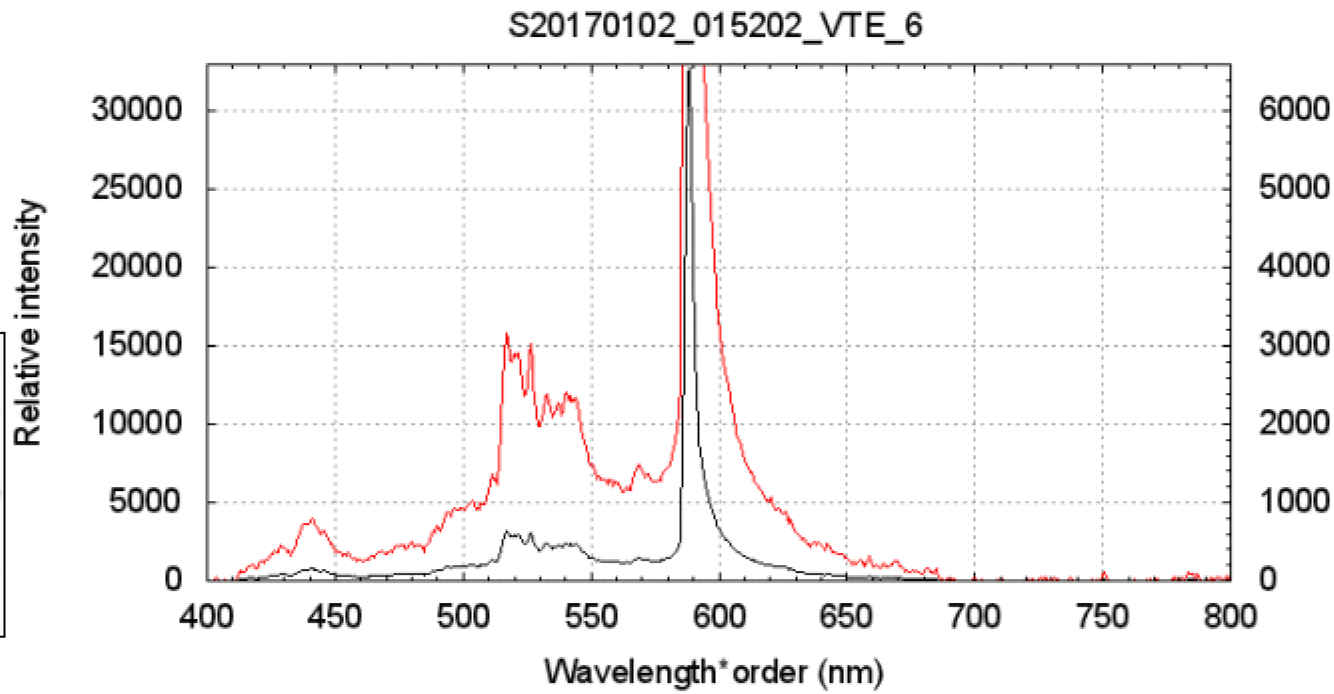
Fig. 5. Spectrum SX1837 of a bright Perseid. The meteor had a maximum brightness of −9.2 mag. Because the spectra were oversaturated on the video frames around the brightness maximum, one frame of the sequence was chosen. The brightness of the meteor in this frame was −7.5 mag.

Slow meteor

- https://meteorspectroscopy.org/blog/two-slow-meteors-with-spectra/
- Strong Na-lines

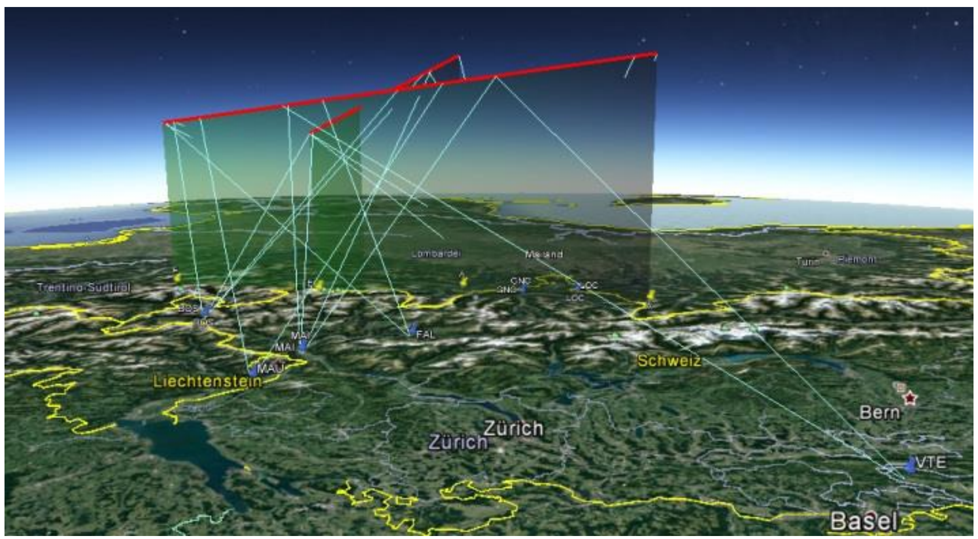
MAI_2 with meteor train

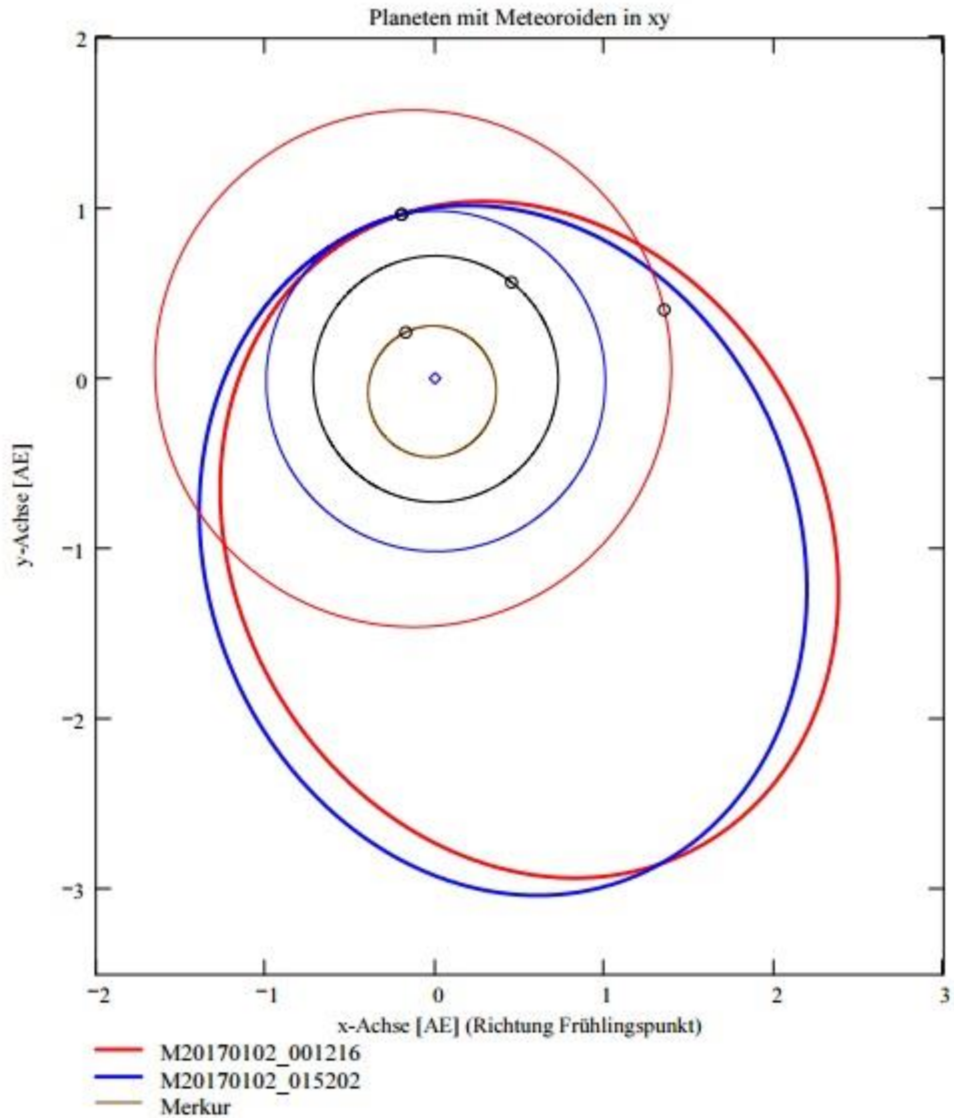
Zero order first order



2 slow meteors

- v_0 = 13 – 14 km/sec
- 20170102_001216
  20170102_015158
- Similar orbits





Conclusion

- Grating mounted perpendicular to camera axis
- Orthographic image transformation gives linear spectra!
- Precise flux calibration depends on many factors, approximations used
- Looking for low cost, sensitive, high resolution, high dynamic range video camera
- Full format colour camera (e.g. Sony)
  - \+ Color → easy interpretation
  - \+ Orders can be separated
  - \+ High resolution
  - – Bayer matrix lower sensitivity
  - – Difficult to analyse (Instr. Resp.)
  - – cost
- Video camera (e.g. Watec)
  - \+ High sensitivity
  - \+ Spectral range
  - \+ Low cost
  - – Small field of view or
  - – Low spectral resolution
  - – Overlapping orders
  - – Low dynamic range

Spectrum recording and processing software

- UFO Capture for trigger and record video (http://sonotaco.com/e_index.html)
- IRIS (http://www.astrosurf.com/buil/us/iris/iris.htm) astronomical image processing and spectroscopy software http://www.astrosurf.com/buil/iris/nav_pane/CommandsFrame.html
- ISIS (http://www.astrosurf.com/buil/isis/isis_en.htm) advanced (more specialized) spectroscopy software
  - Both by Christian Buil
- ImageTools by Peter Schlatter (private communication)
- SpectroTools by Peter Schlatter http://www.peterschlatter.ch/SpectroTools/

Links

- SonotaCo Forum
  http://sonotaco.jp/forum/viewtopic.php?t=3065
- Thorlabs grating
  http://www.thorlabs.de/newgrouppage9.cfm?objectgroup_id=1123
- FMA Spectroscopy page
  http://www.meteorastronomie.ch/spektroskopie.html
- Italian Meteor Network: http://meteore.uai.it/

- All documentation on calibration: https://meteorspectroscopy.org
  (personal website, with papers and presentation from IMC 2016):

Acknowledgment

- FMA (division of Swiss (Amateur) Astronomical Society) for data, discussion
  - Jonas Schenker, Roger Spinner (website, database)
  - Network of stations (Photo, Video, All sky fireball detection, Radio, Seismic), complementing Spectroscopy
  - Linked with EDMOND database
- Peter Schlatter (Image tools)
- Koji Maeda (HD color videos)

Thank you!