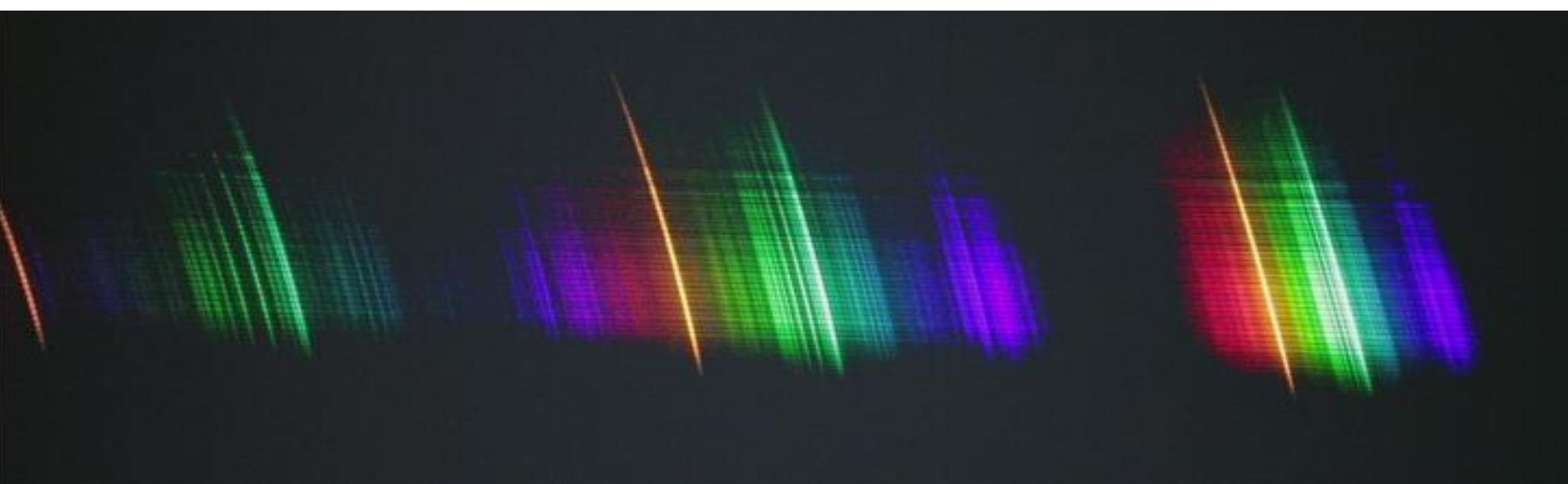


Meteor Spectroscopy, OHP 2016

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

Fachgruppe Meteorastronomie

<http://www.meteorastronomie.ch>

■ Swiss meteor network

Fachgruppe Meteorastronomie

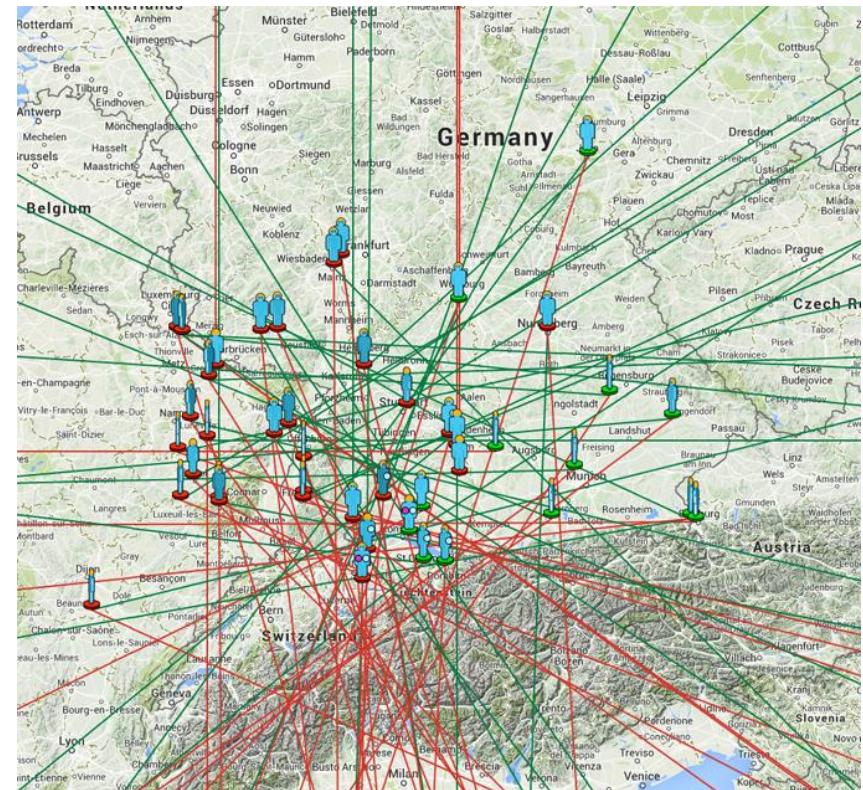
ERGEBNISSE

FEUERKUGEL-AUFZEICHNUNGEN

	Bild	Video	Pfad
13. Juli 2016, 02:21 UT Kurz und bündig			
04. Juli 2016, 23:39 UT Brillante Feuerkugel	VTE SCH	VTE	Map Zoom Daten Animation: xy xz
18. Mai 2016, 01:06 UT Zum Geniesen	BOS1, 2 VTE MAU FAL SCH SON BUE1, 2	BOS VTE MAU	Map1 , 2 , 3 , 4 Daten Lichtkurve Animation: xy
20. April 2016, 21:50 UT Klassiker	VTE BOS SON Radio: VTE BOS SON	VTE BOS Sound: BOS	Map Zoom 1, 2 Daten Lichtkurve Animation: xy xz
14. März 2016, 02:27 UT lange Leuchtdauer	FAL GNO VTE1 VTE2 EGL BAU MAU	FAL VTE1 VTE2	Map Zoom 1, 2 Daten Animation: xy
23. Januar 2016, 21:14 UT über Norditalien	FAL GNO LOC MAI Radio: ENT	FAL GNO LOC MAI Lichtkurve: MAI	Map Zoom 1, 2 Daten Animation: xy
	LOC VTE SON SCH Radio: BOS VTE MAU ENT SON	VTE Sound: VTE	Map Zoom 1, 2 Daten Animation: xy, xz
	VTE RAI I BOS	VTE	Map Zoom Daten

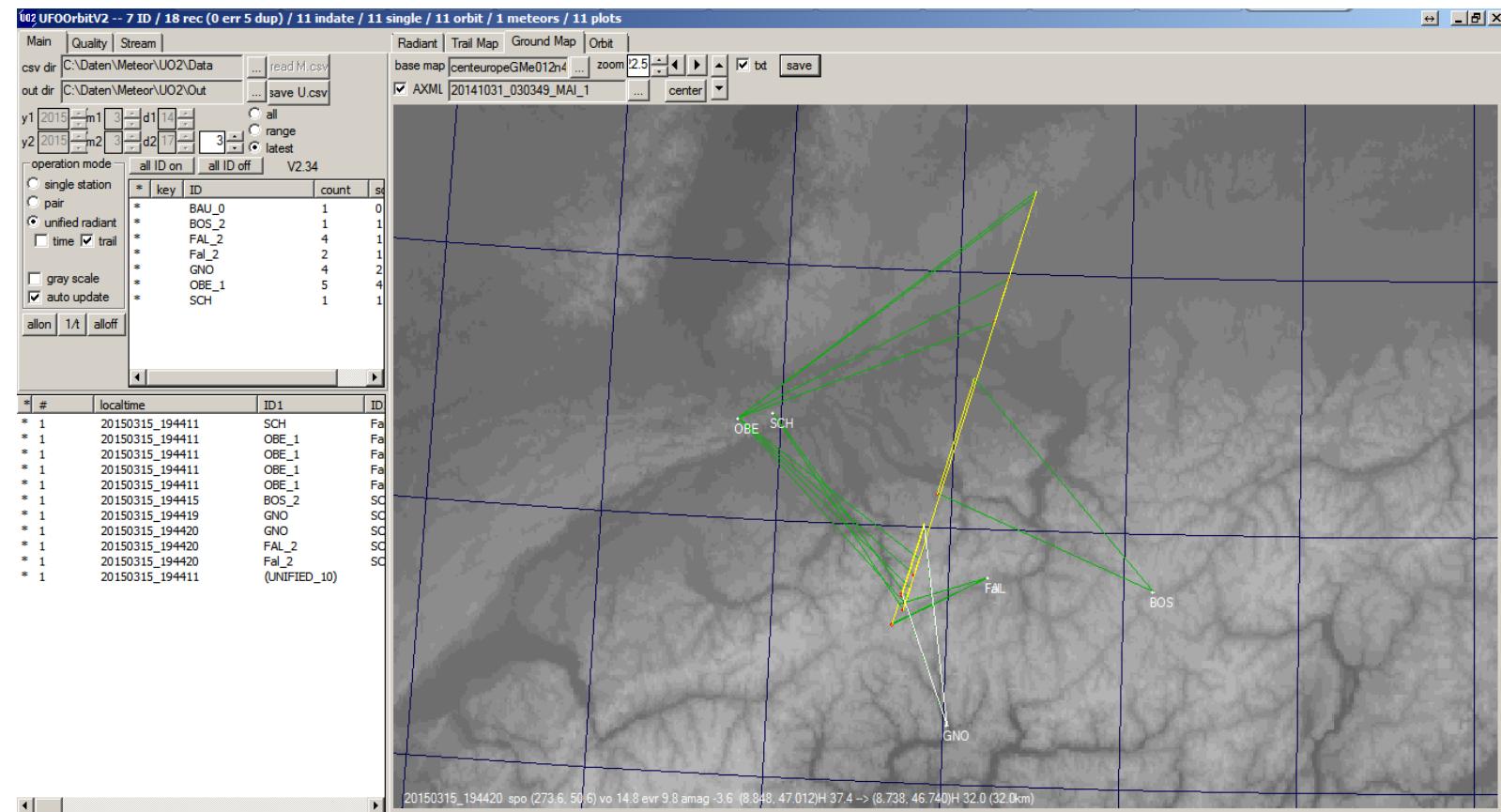
Example: Meteor 15. march 2015

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

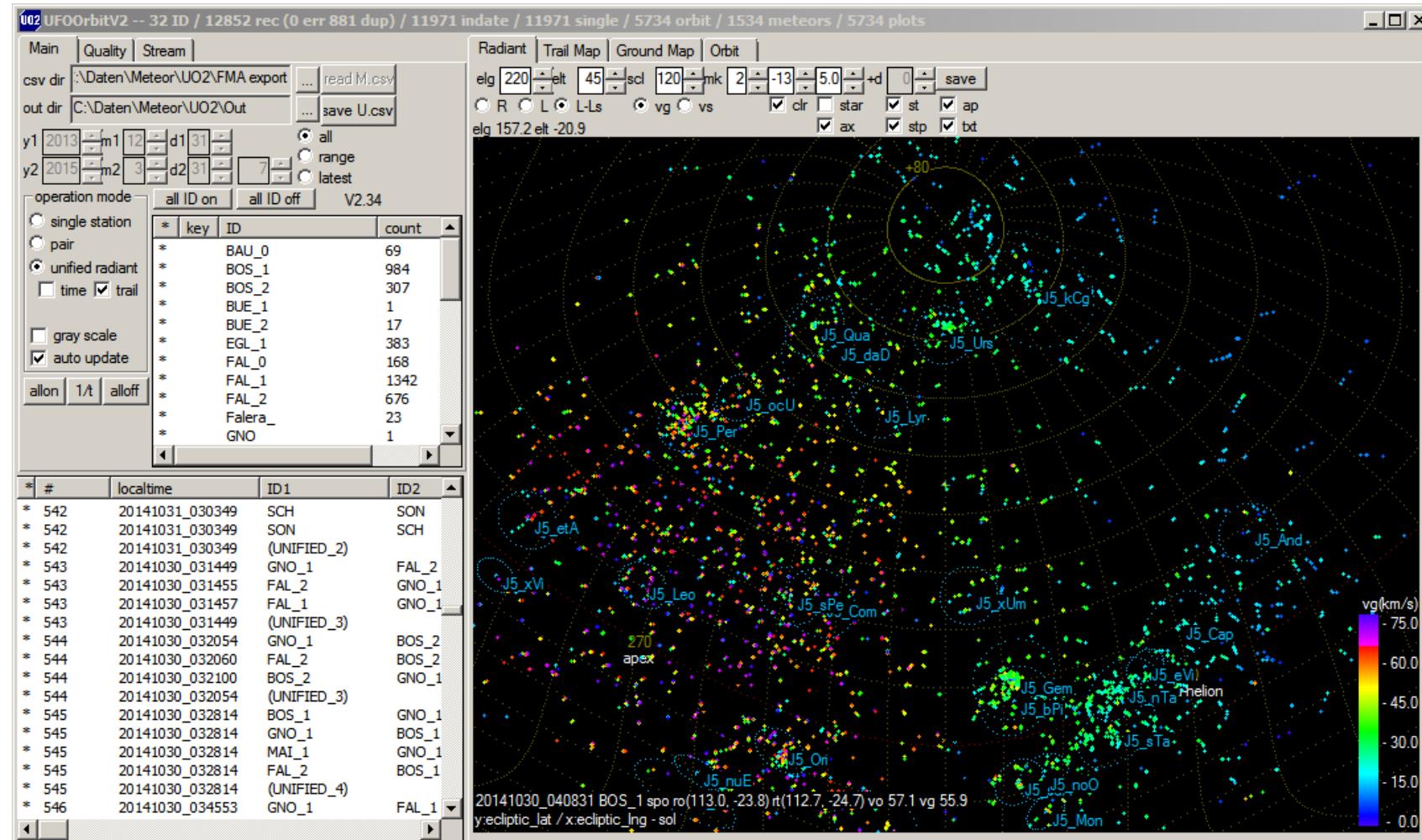


Flight path with triangulation

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

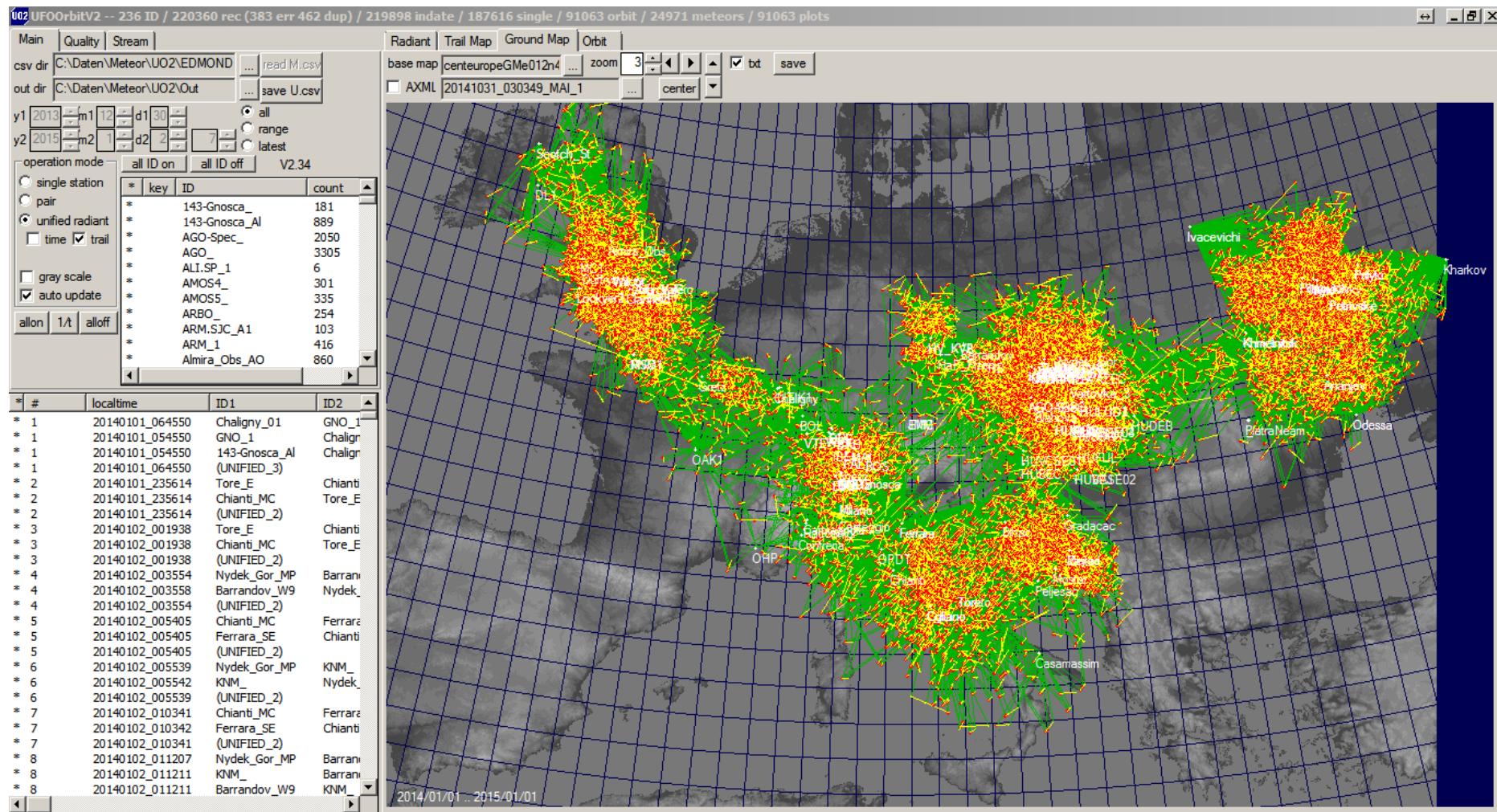


FMA Database, March 2014 – April 2015



Fachgruppe Meteorastronomie

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

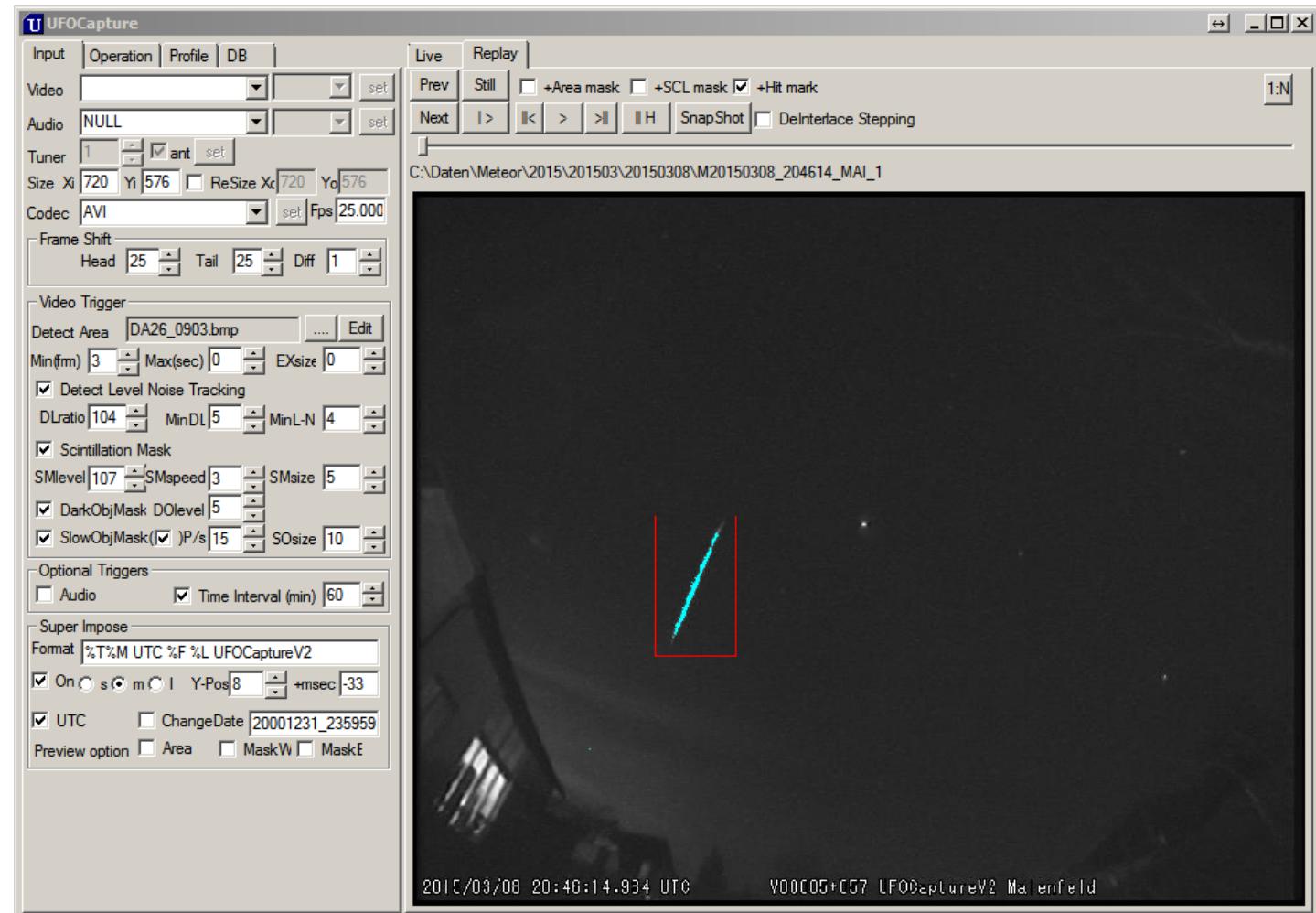


Software

- Metrec (Sirko Molau), special Hardware required
- CAMS (USA)
- 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

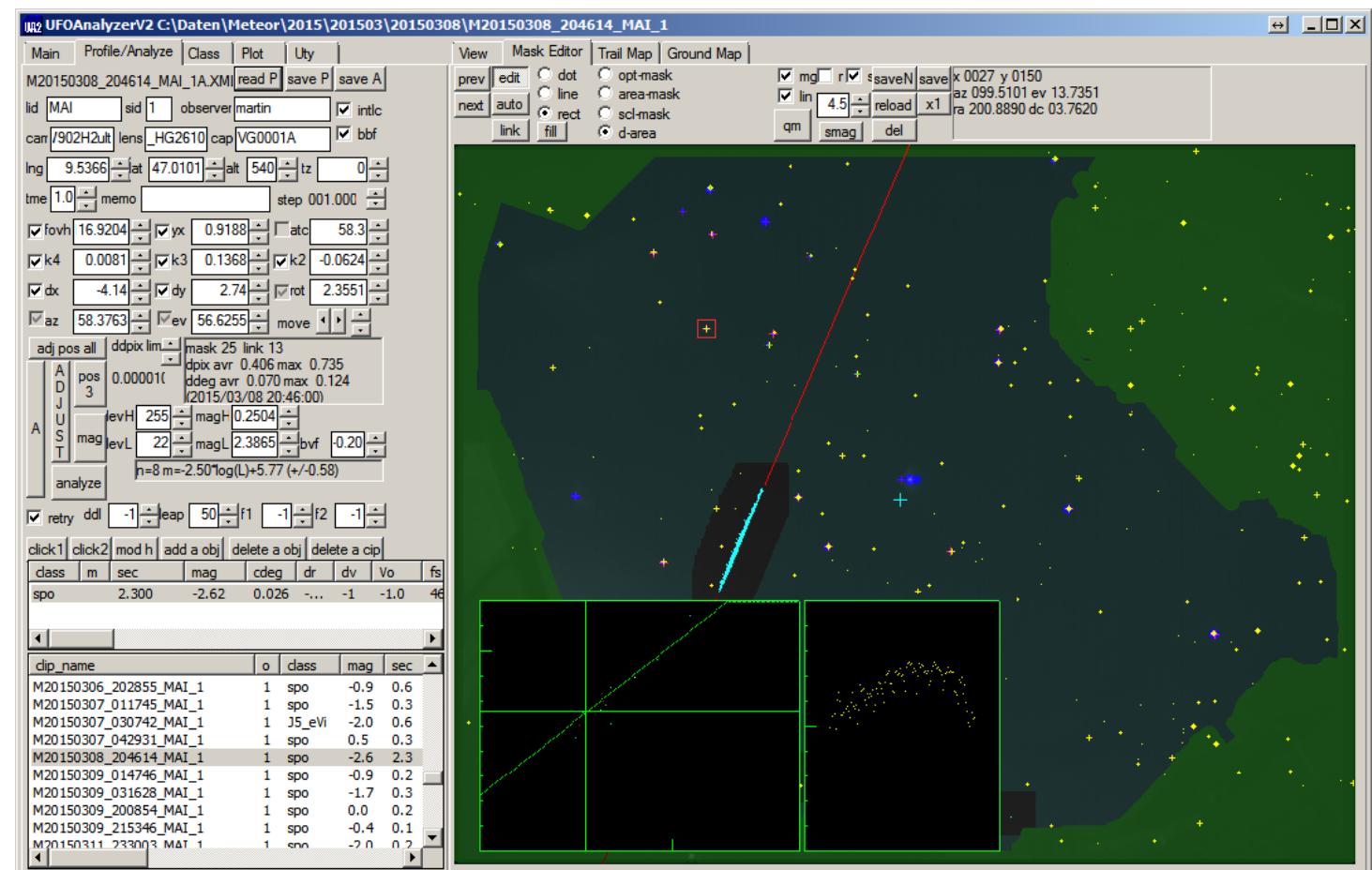
UFO Capture

- Detection
- Capture
- Pretrigger



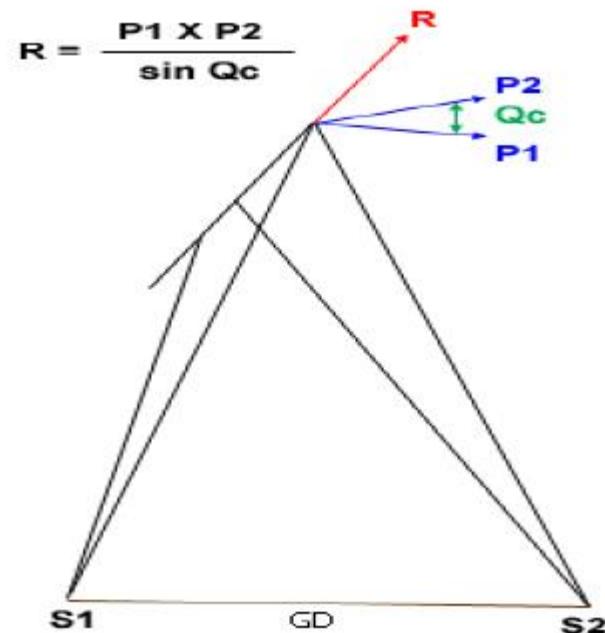
UFO Analyze

- Astrometry
- Flight path
- Magnitude
- Velocity



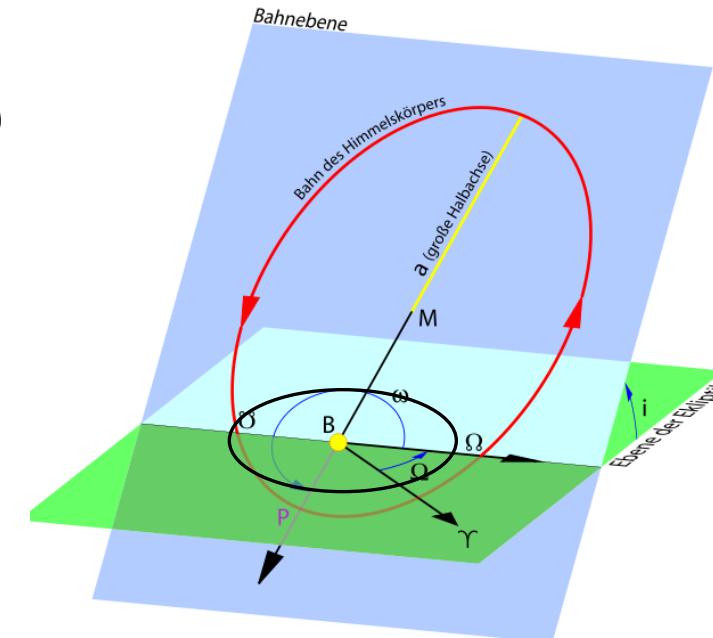
Orbit calculation with UFO Orbit

- Terrestrial observer
 - Radiant and velocity observed
 - Correction for deceleration in atmosphere
 - Correction for earth rotation:
 $0.456 \cdot \cos(\varphi)$ km/sec, rund 300 m/sec $\rightarrow v_g$
 - Velocity correction for gravitational potential:
 $v_0^2 = v_g^2 - 125.4$
 (v in km/sec)
 - Correction zenithal attraction
 $\Delta z = 2 \cdot \text{ARCTAN}((v_g - v_0) / (v_g + v_0) \cdot \tan(z/2))$
- \rightarrow 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 (\rightarrow eccentricity e),
 - Orbit plane (inclination i , node Ω)
 - → position of perihel ω , T_{perihel}



Fachgruppe Meteorastronomie



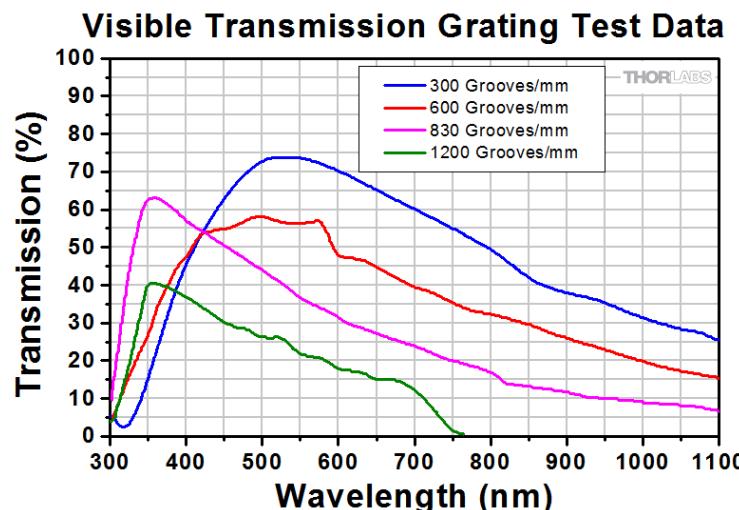
<http://www.eso.org/public/images/potw1414a/>

Meteor spectroscopy

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

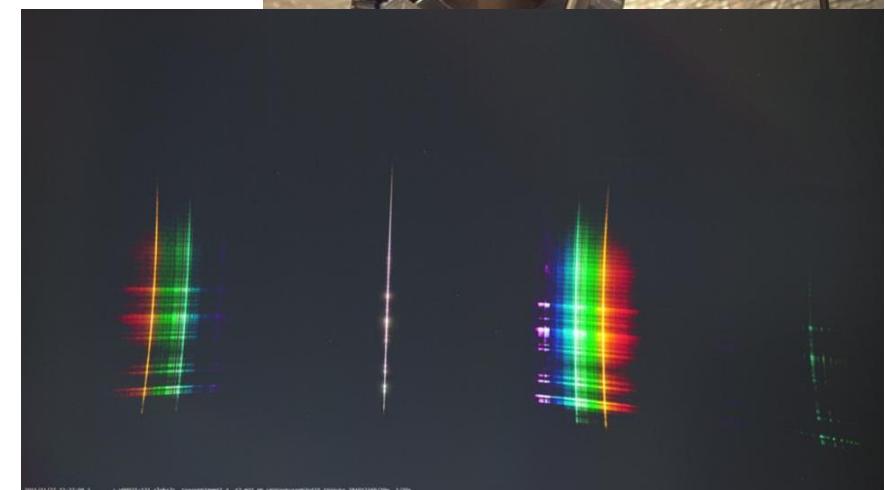
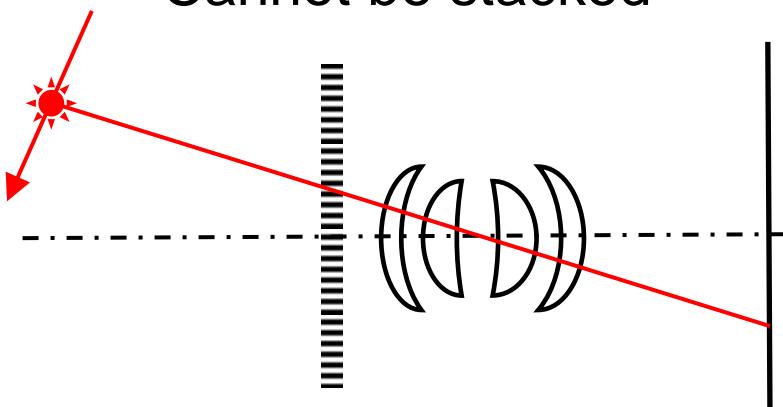
Hardware

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



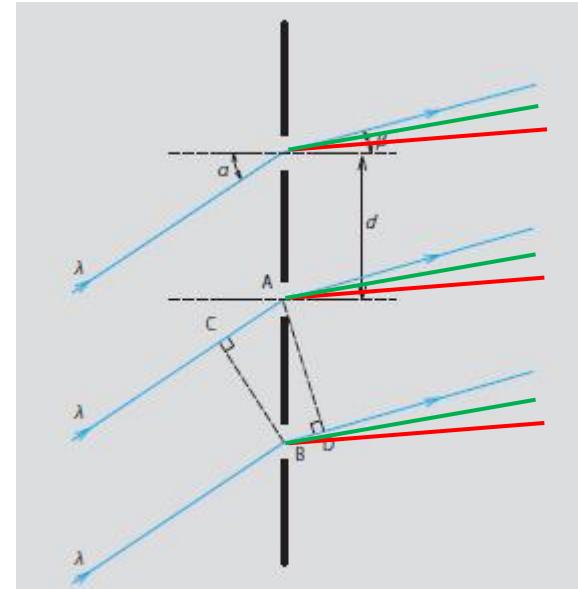
Starting point

- 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:
 - $m * \lambda * G = (\sin \alpha - \sin \beta) * \cos \gamma$
 - 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:
 $d\lambda/dx = (\cos \beta \cos \gamma)/(m * G * f) * p$ (p: pixel size)
 - Example: $f = 7 \text{ mm}$, $p = 8.6 \mu\text{m}$, $G: 300L/\text{mm}$ $\beta = 0 \rightarrow d\lambda/dx = 41\text{A}/\text{pixel}$



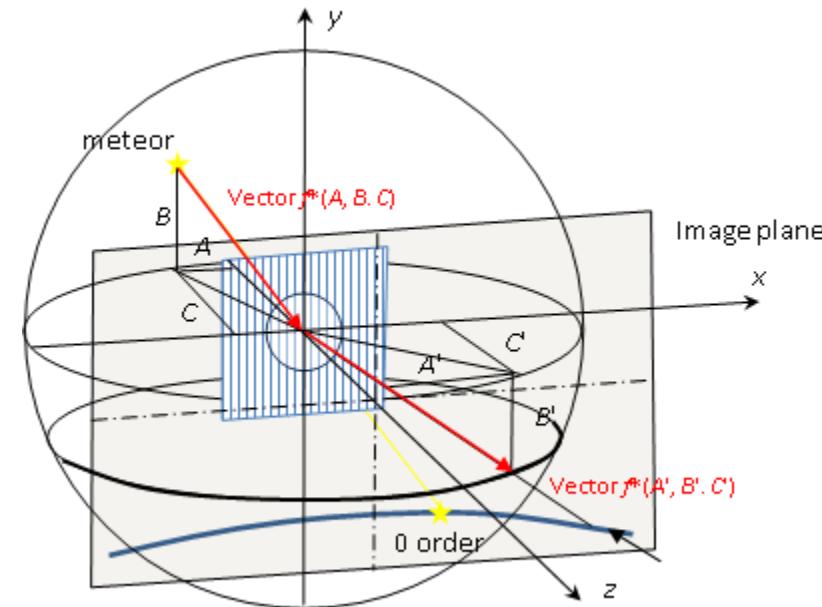
Vector theory wavelength calibration

- Grating in front of lens perpendicular to optical (z)-axis
- Unit vector (A B C) for incident direction
- Diffracted beam

$$A' = A + m\lambda G \quad (\text{x-axis})$$

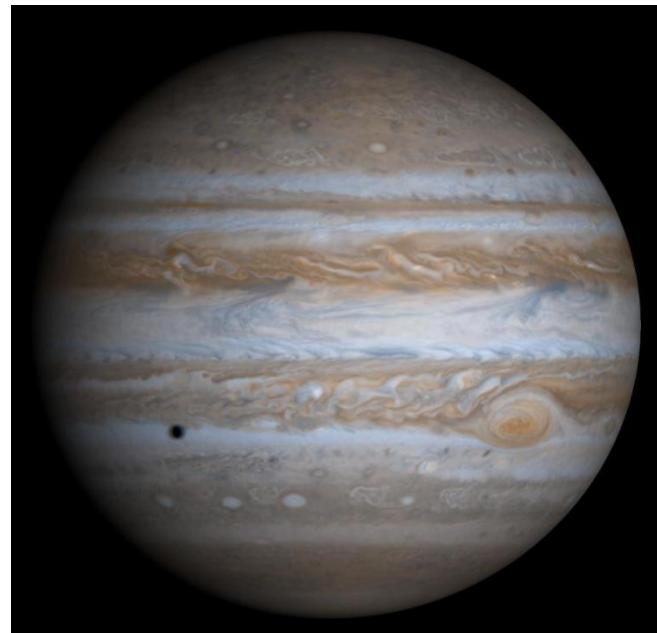
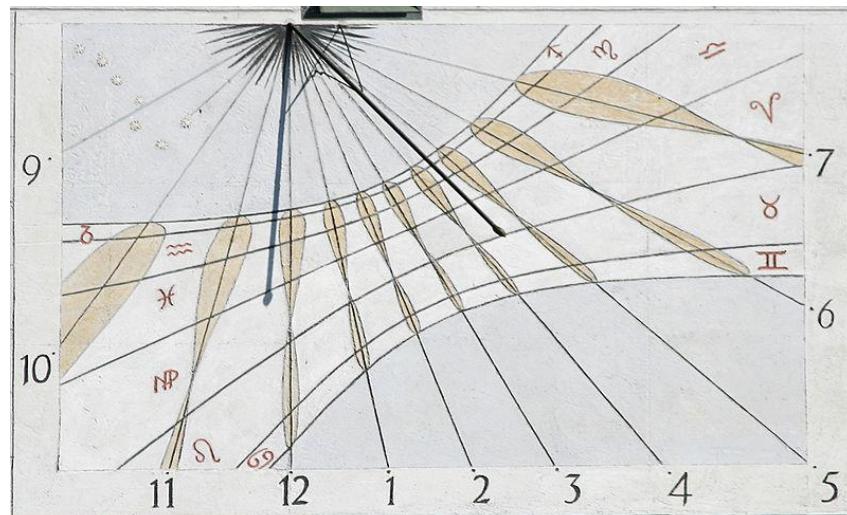
$$B' = B \quad (\text{y-axis})$$

$$C' = \sqrt{1 - A'^2 - B'^2}$$
- Spectrum on CCD plane
 - Nonlinear dispersion
 - Hyperbolic curvature
- Spectrum straight linear in A', B'



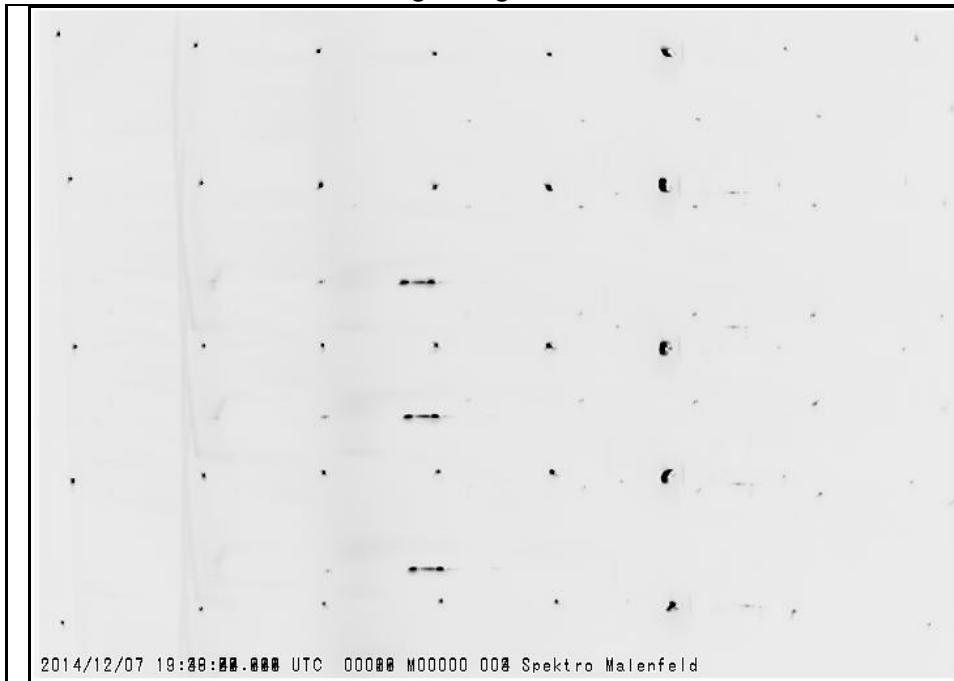
Gnomonic and orthographic projection

- Gnomonic, TAN
 - $R = f * \tan(\rho)$
 - Great circles \rightarrow straight
 - Optimum for path, radiant
 - Latitude circles \rightarrow hyperbola
- Orthographic, SIN
 - $R = f * \sin(\rho)$
 - Great circles \rightarrow ellipses
 - Latitude circles \rightarrow straight
 - Optimum for spectroscopy

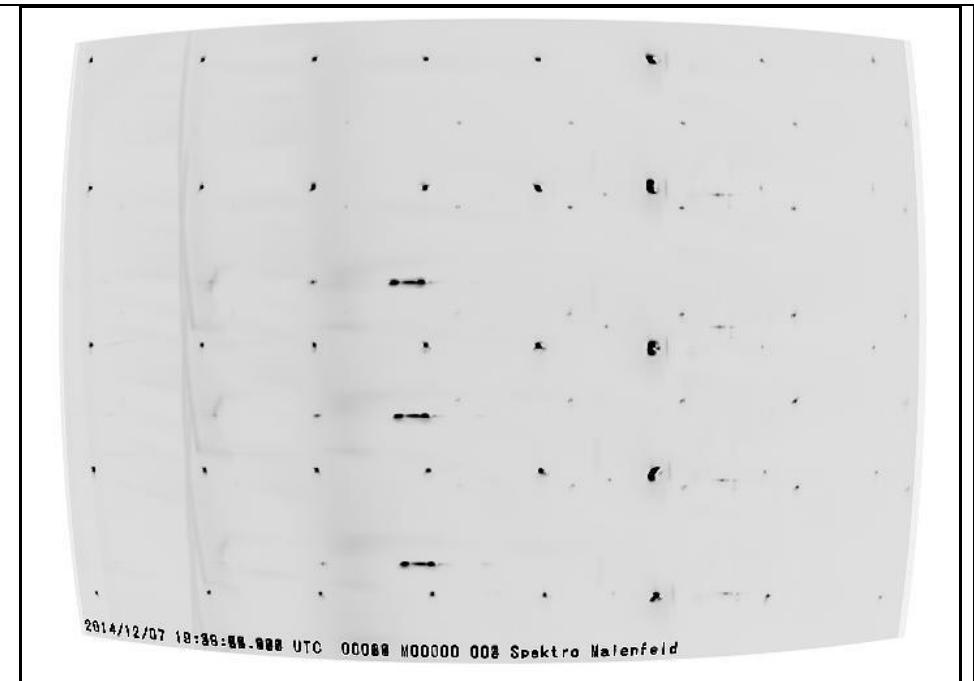


Calibration spectrum HeNe laser

- HeNe laser $\lambda = 633 \text{ nm}$, $f = 4 \text{ mm}$
- Fit with polynom $r = r' * [1 + 3.94E-07 * r'^2 + 2.01E-12 * r'^4]$
- Fit center x_0, y_0

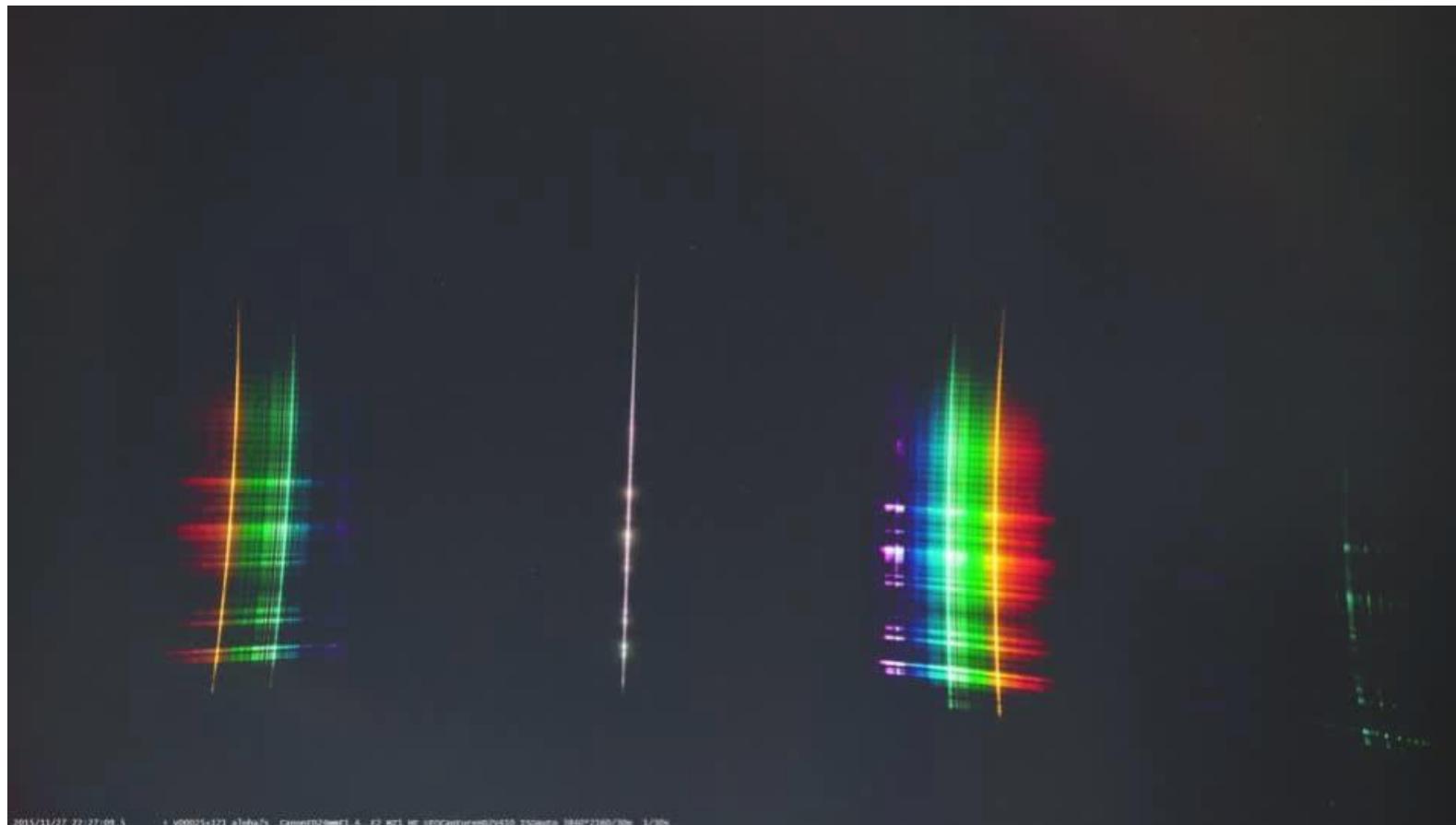


Composite spectra original

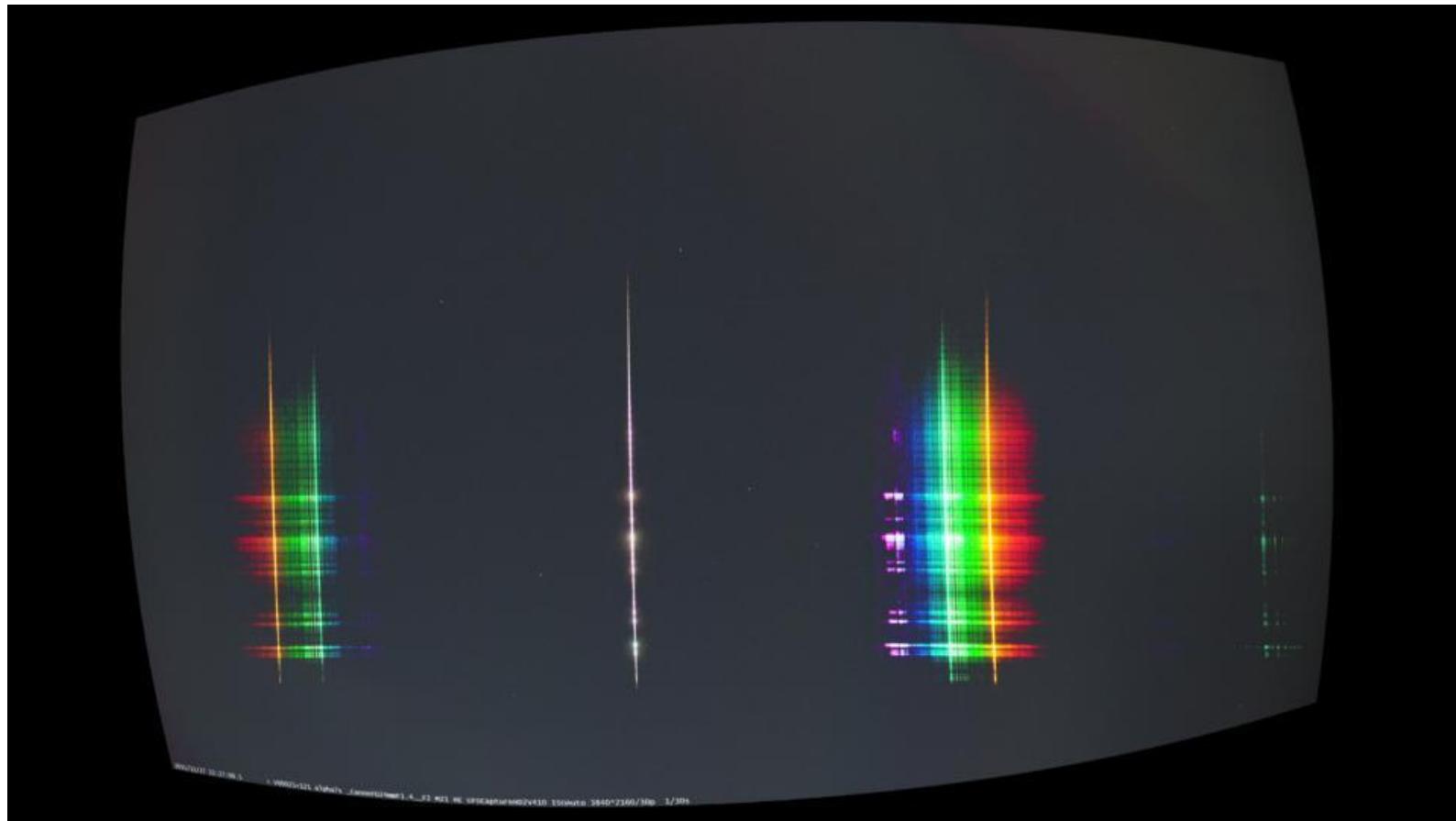


After applying transformation

Orthographic transformation



Orthographic transformation, result



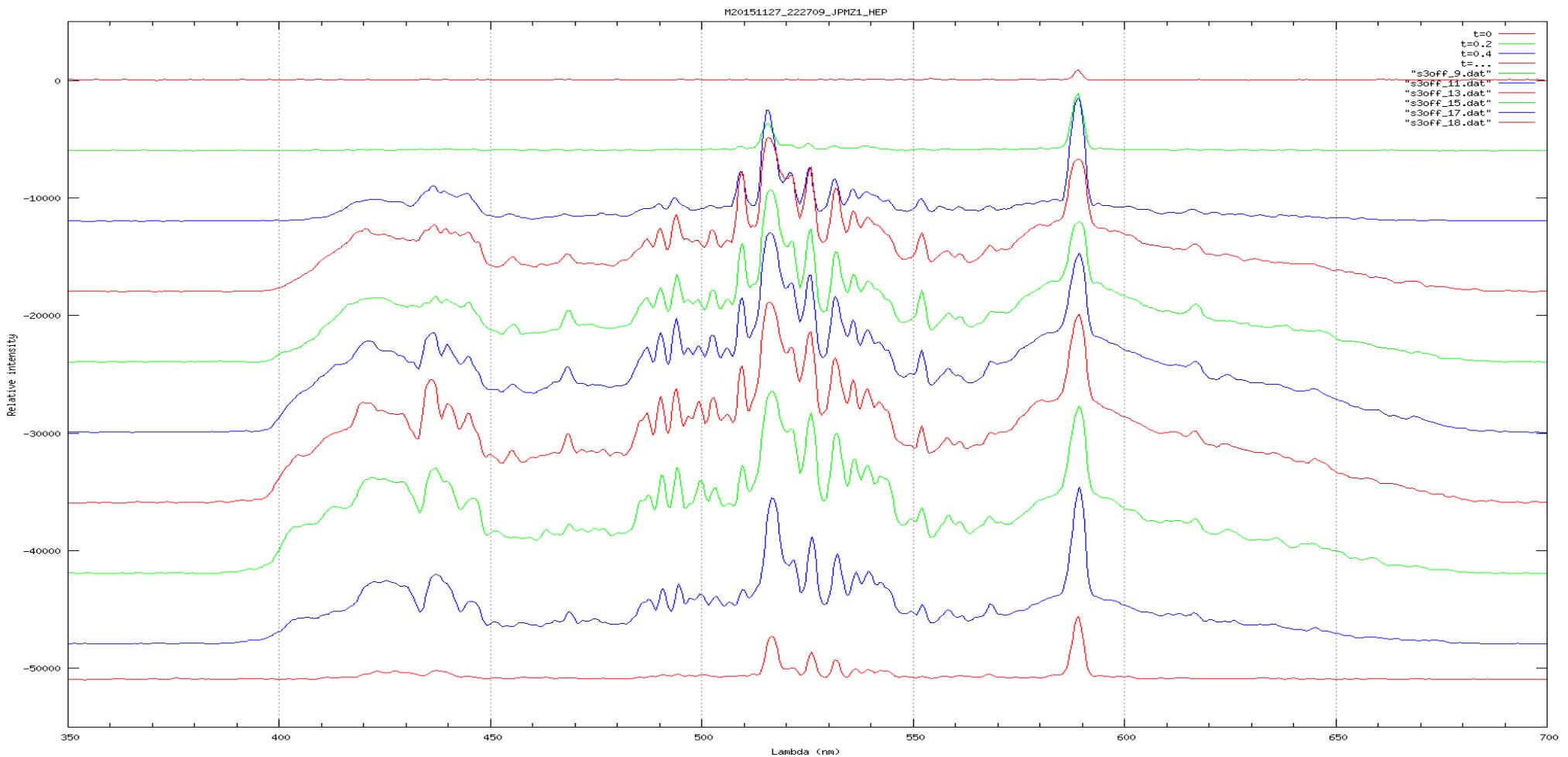
Orthographic transformation, result

- 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

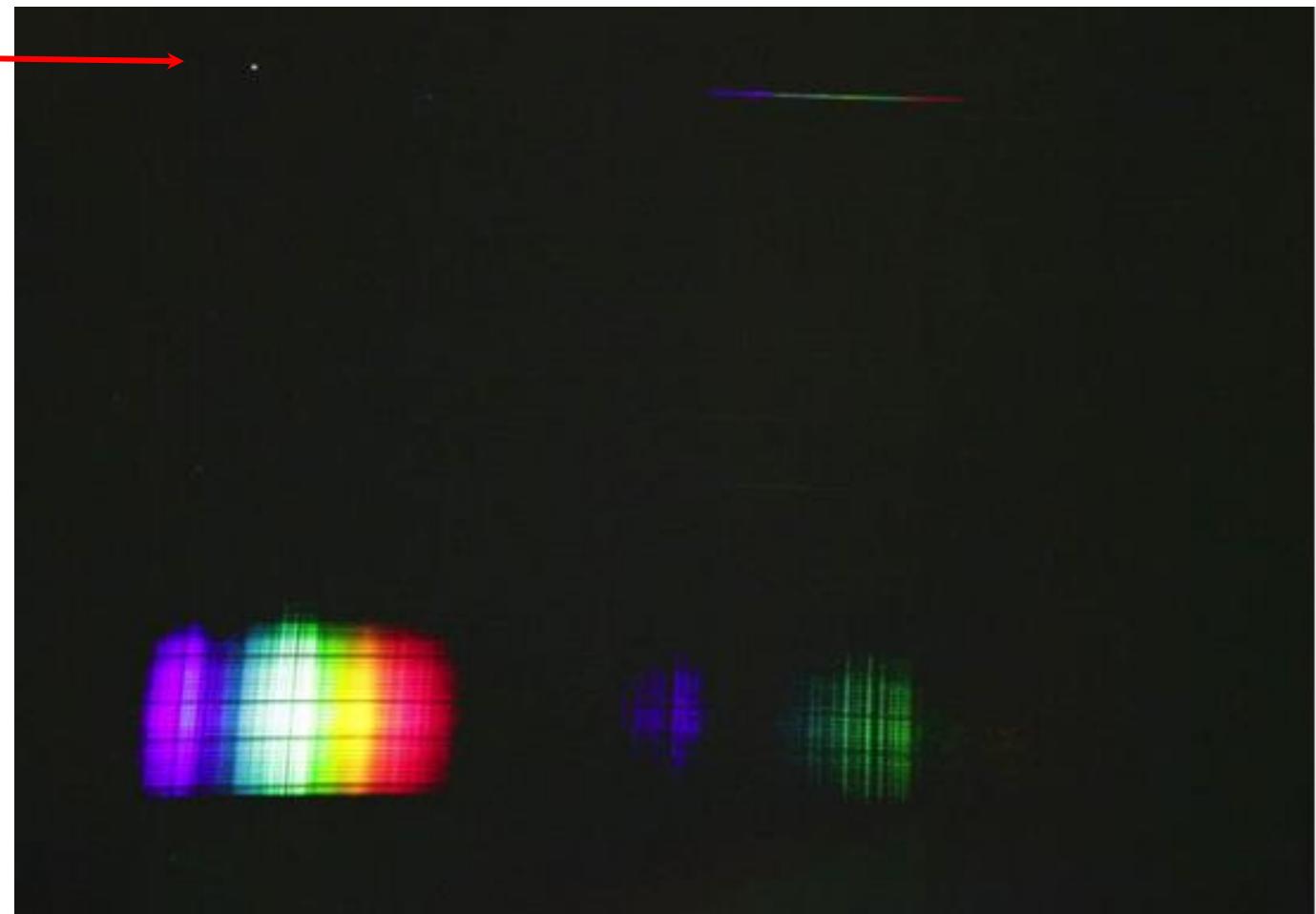
} flat field correction
in pre-processing

- Instrument response
 - Grating efficiency
 - Camera spectral sensitivity (lens, CCD)
 - Atmospheric transmittance

} instrument response

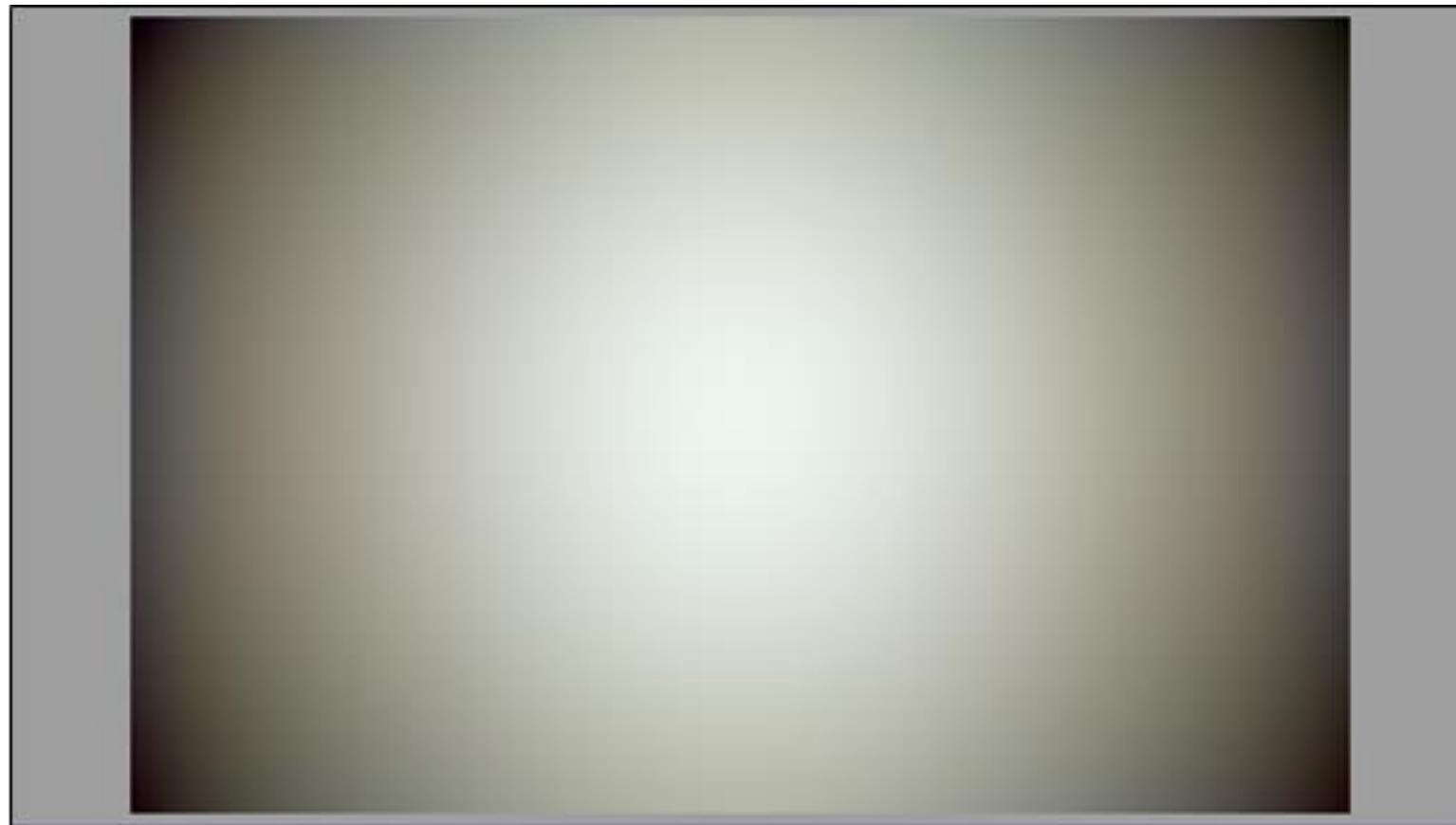
M20160107_225526_JPMZ1_HDP, iron meteor

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



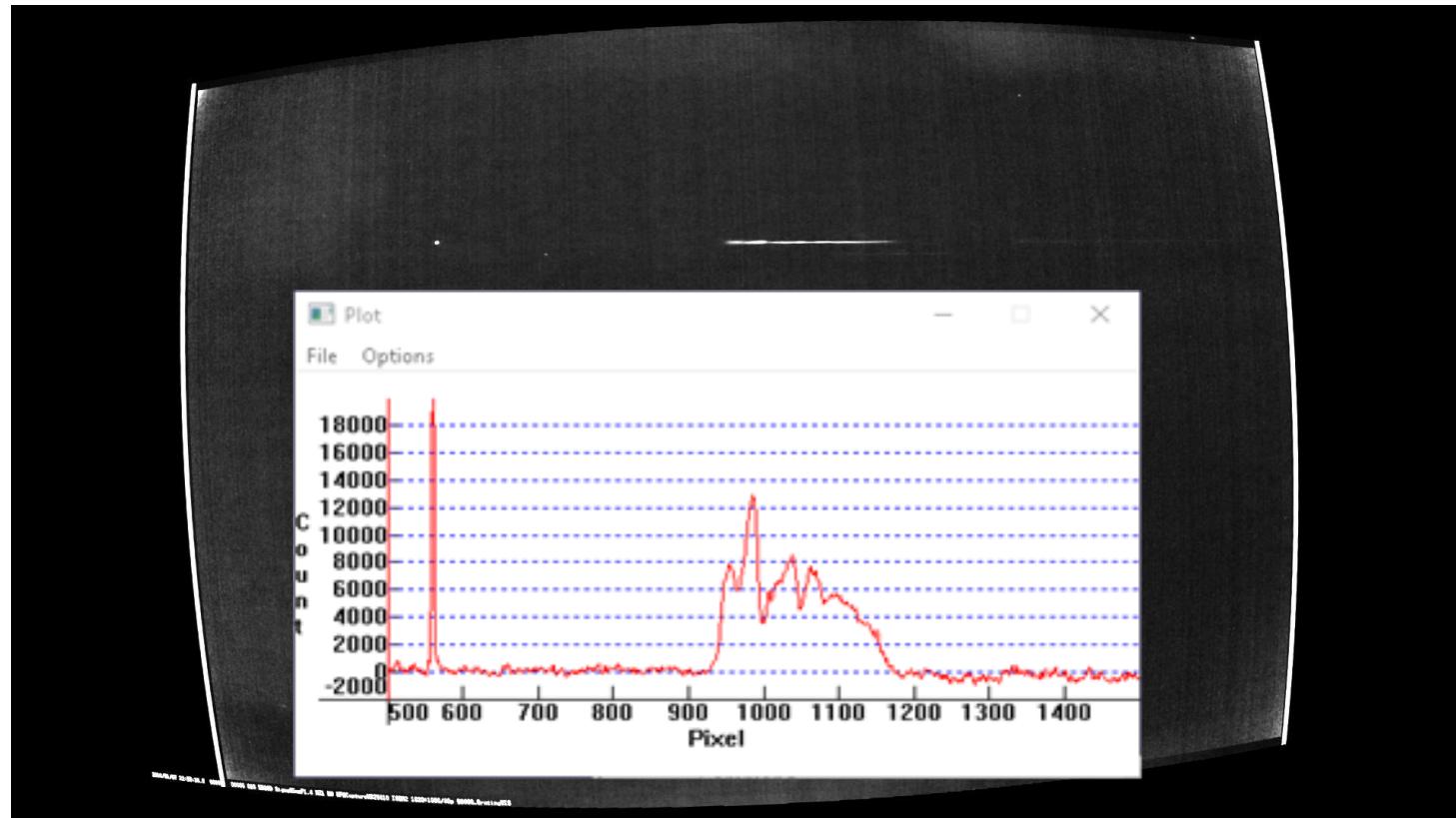
Flat field

- Border not illuminated



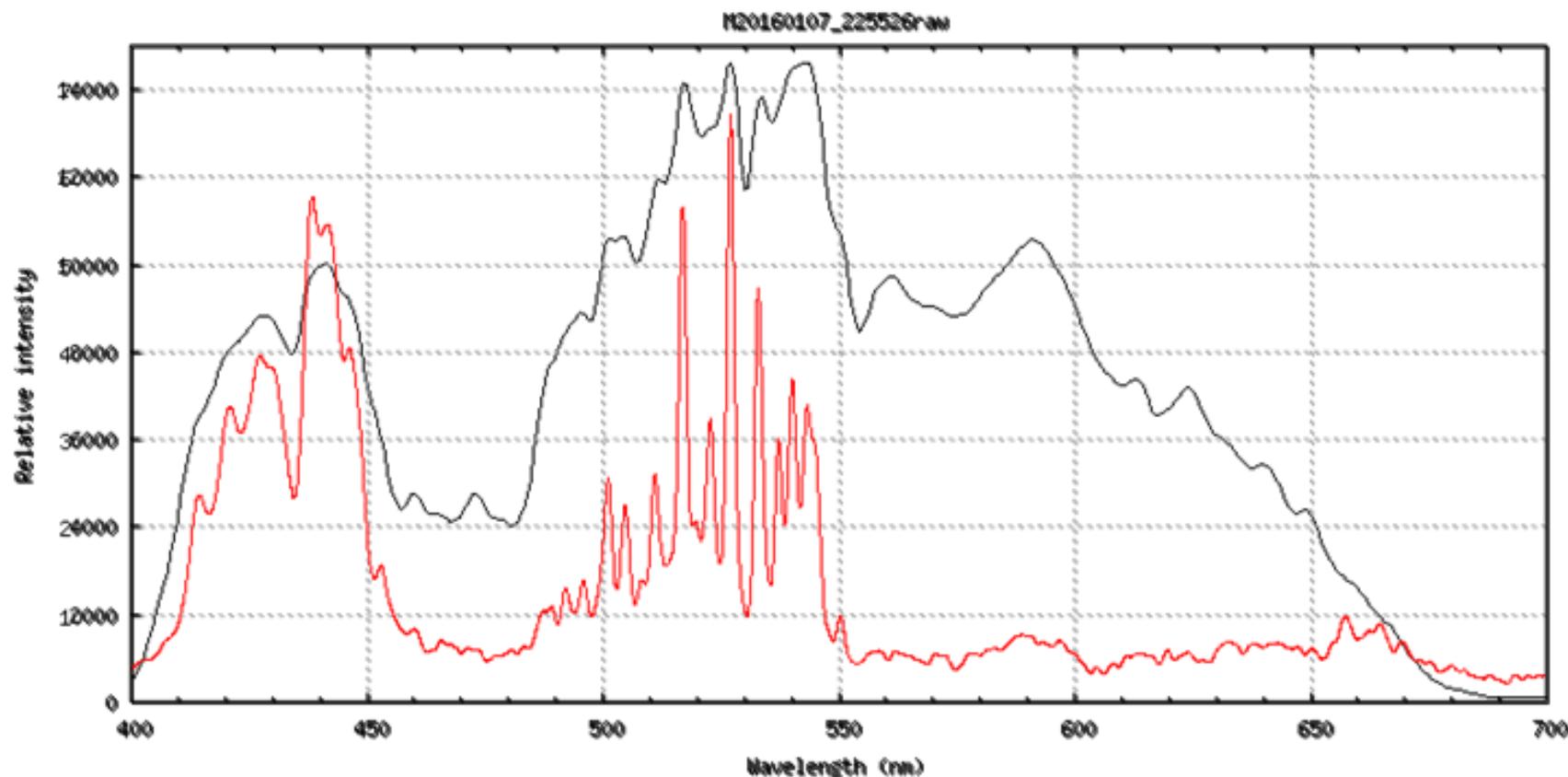
Reference spectrum (alp Cma)

- With flat correction, black/white
- Transformed to orthographic projection, rotated



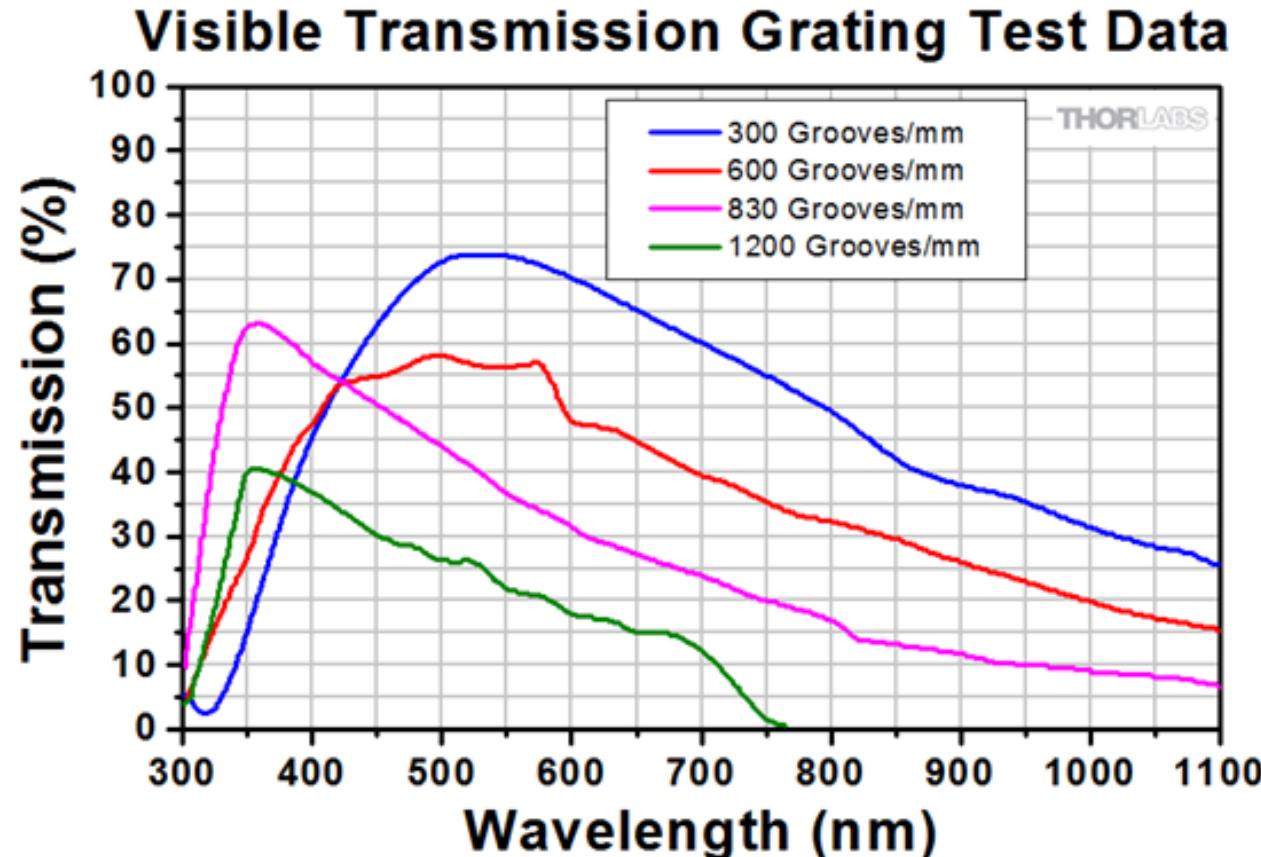
Saturation

- 1st and 2nd order on same wavelength scale



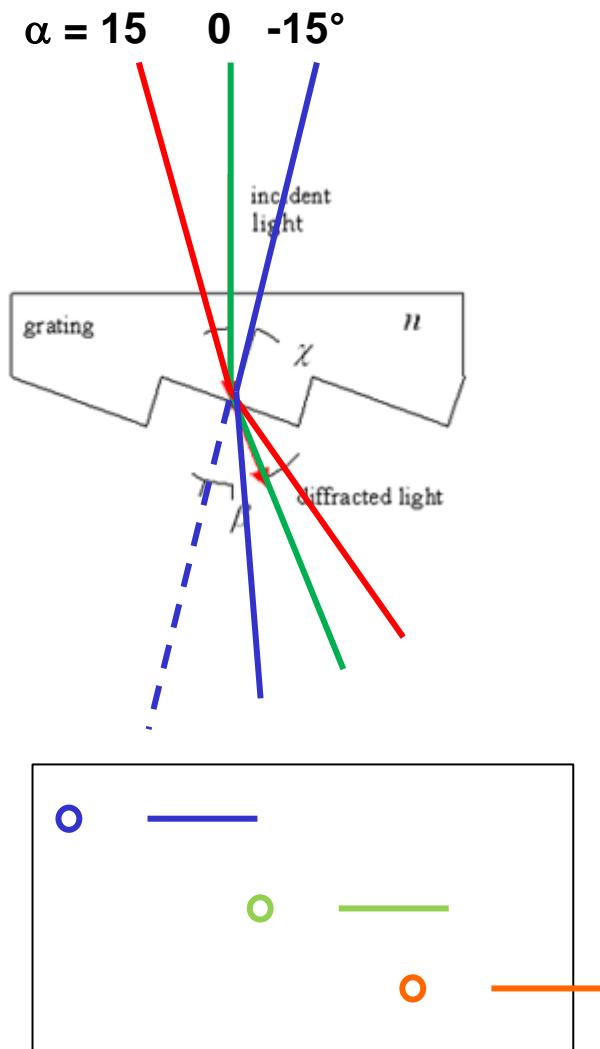
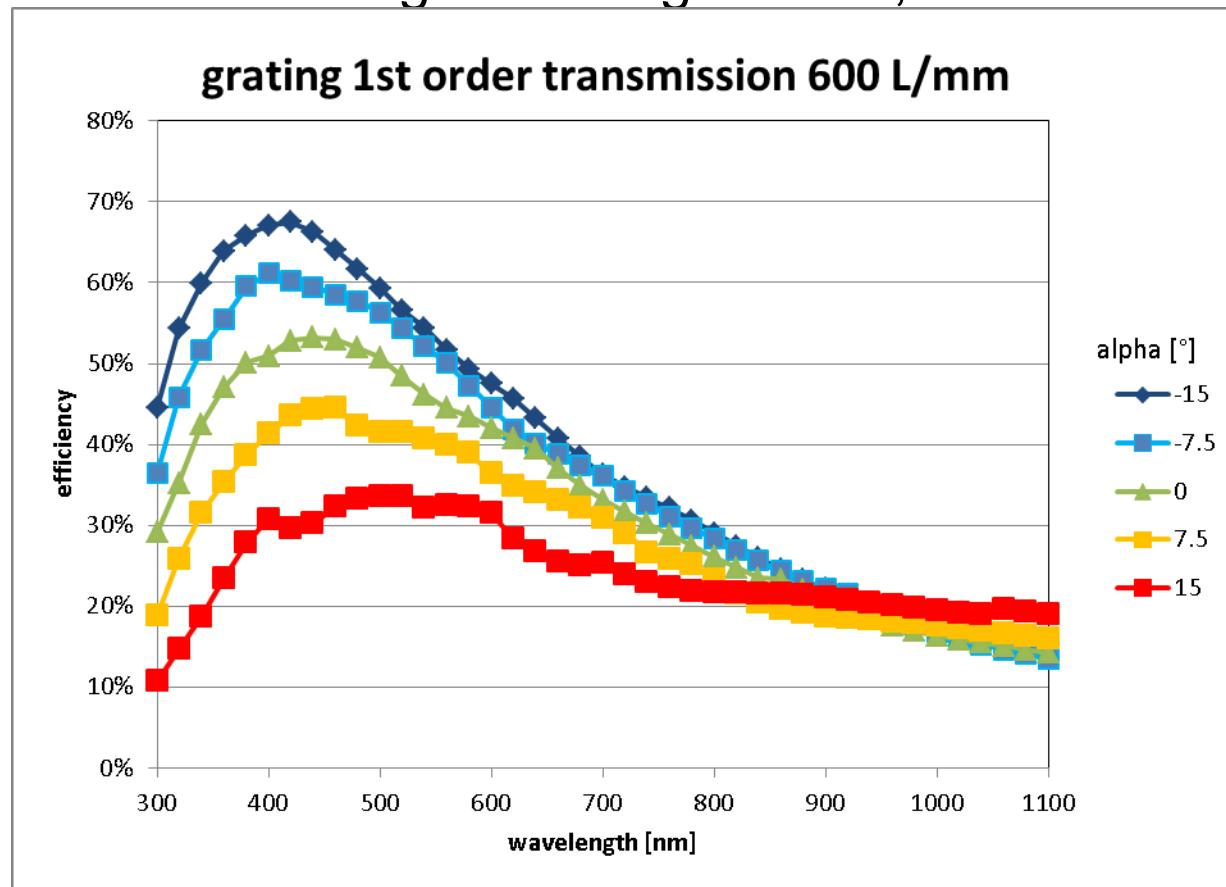
Grating efficiency

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



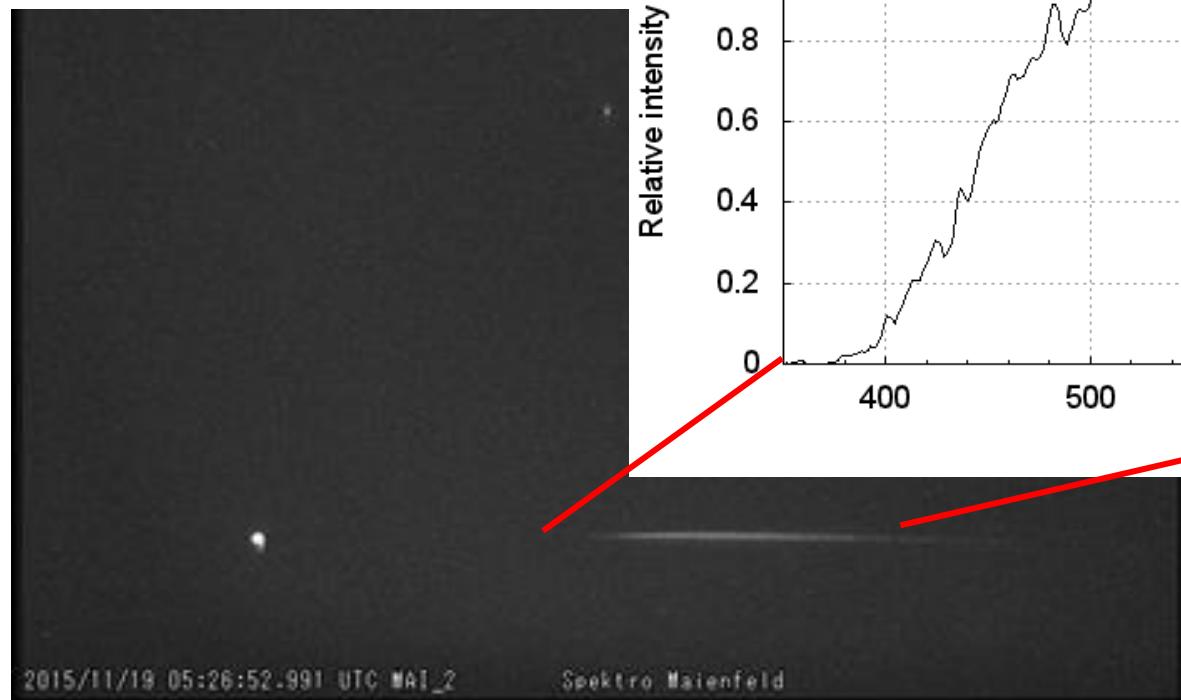
Grating efficiency 2

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



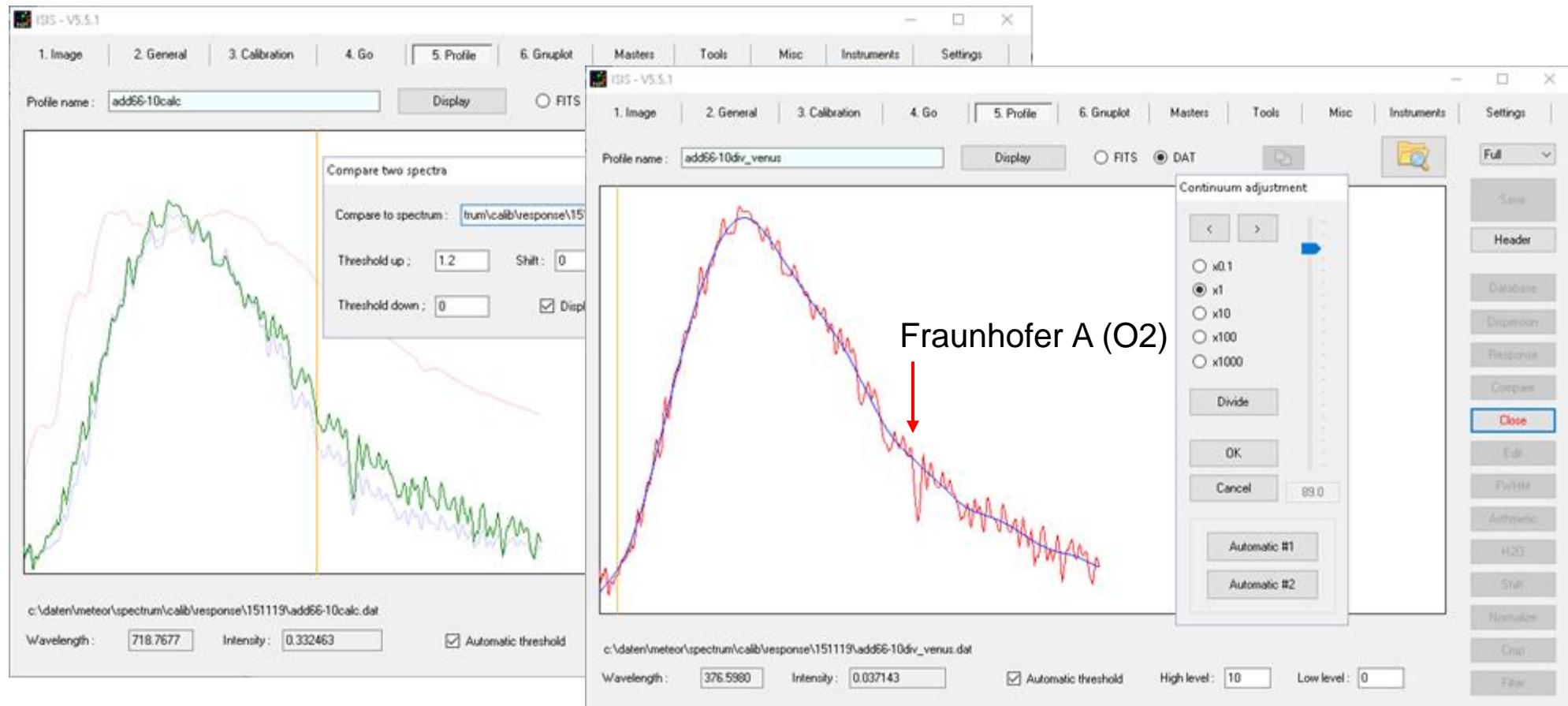
Measured spectrum, Watec 902H2ultimate

- Venus spectrum



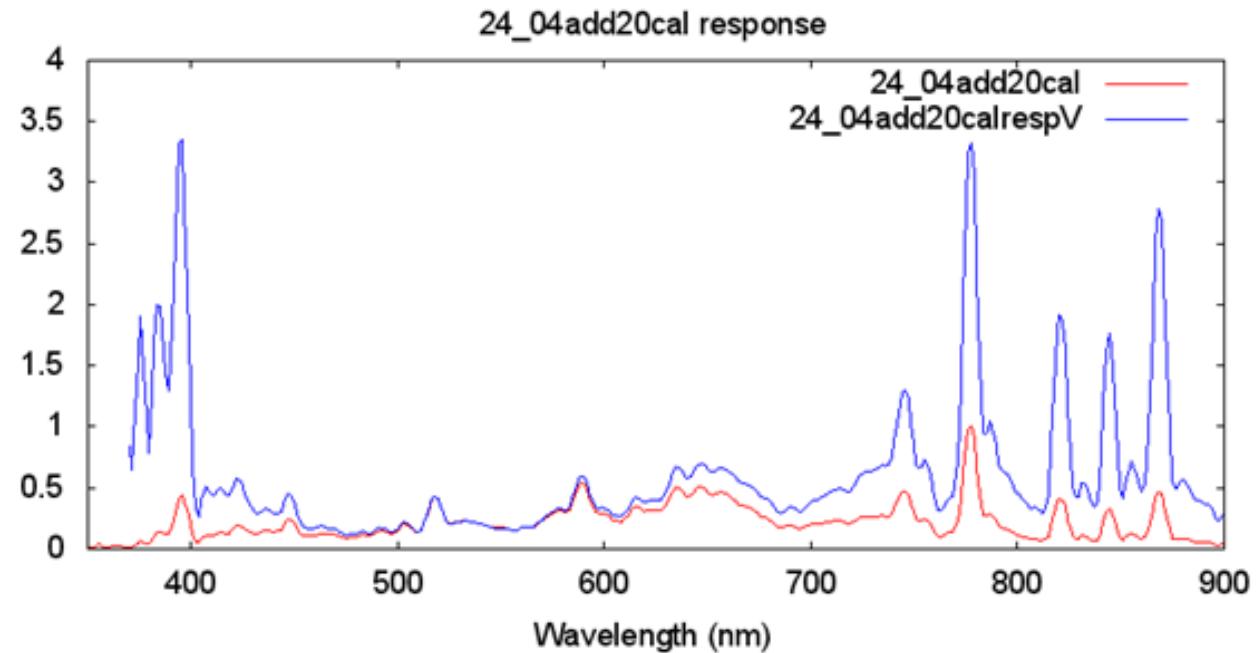
Instrument response

- 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



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

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
- Linear wavelength calibration: <http://arxiv.org/abs/1509.07531> or
http://www.meteorastronomie.ch/images/Meteor_Spectroscopy_WGN_43-4_2015.pdf
- FMA Spectroscopy page (with papers and presentation from IMC 2016):
<http://www.meteorastronomie.ch/spektroskopie.html>

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!