Meteor Shower Flux Densities and the Zenith Exponent

Sirko Molau, *AKM, Germany*

Geert Barentsen*, University of Hertfordshire, U.K.*

Agenda

- Background
- Limiting Magnitude
- Effective Collection Area
- Flux Densities
- Zenith Exponent
- Various Showers and their Combination
- Summary

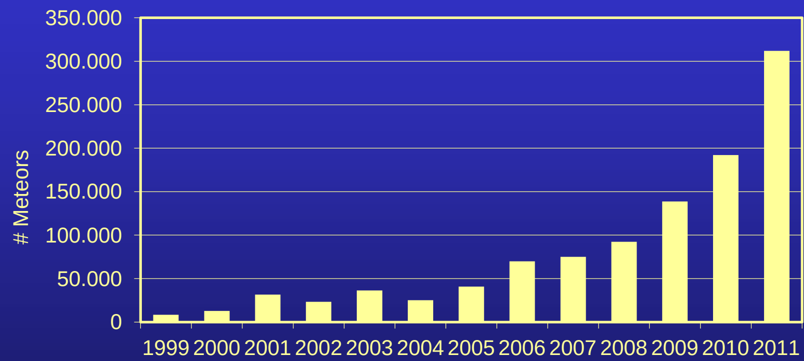
Background

- The IMO Video Meteor Network is steadily growing ...
- By the end of 2011, our meteor database contained >1 Mio single station meteor records, but there is more than just radiants and orbits!

IMO Network Cameras in Europe 2011

Recent Statistics

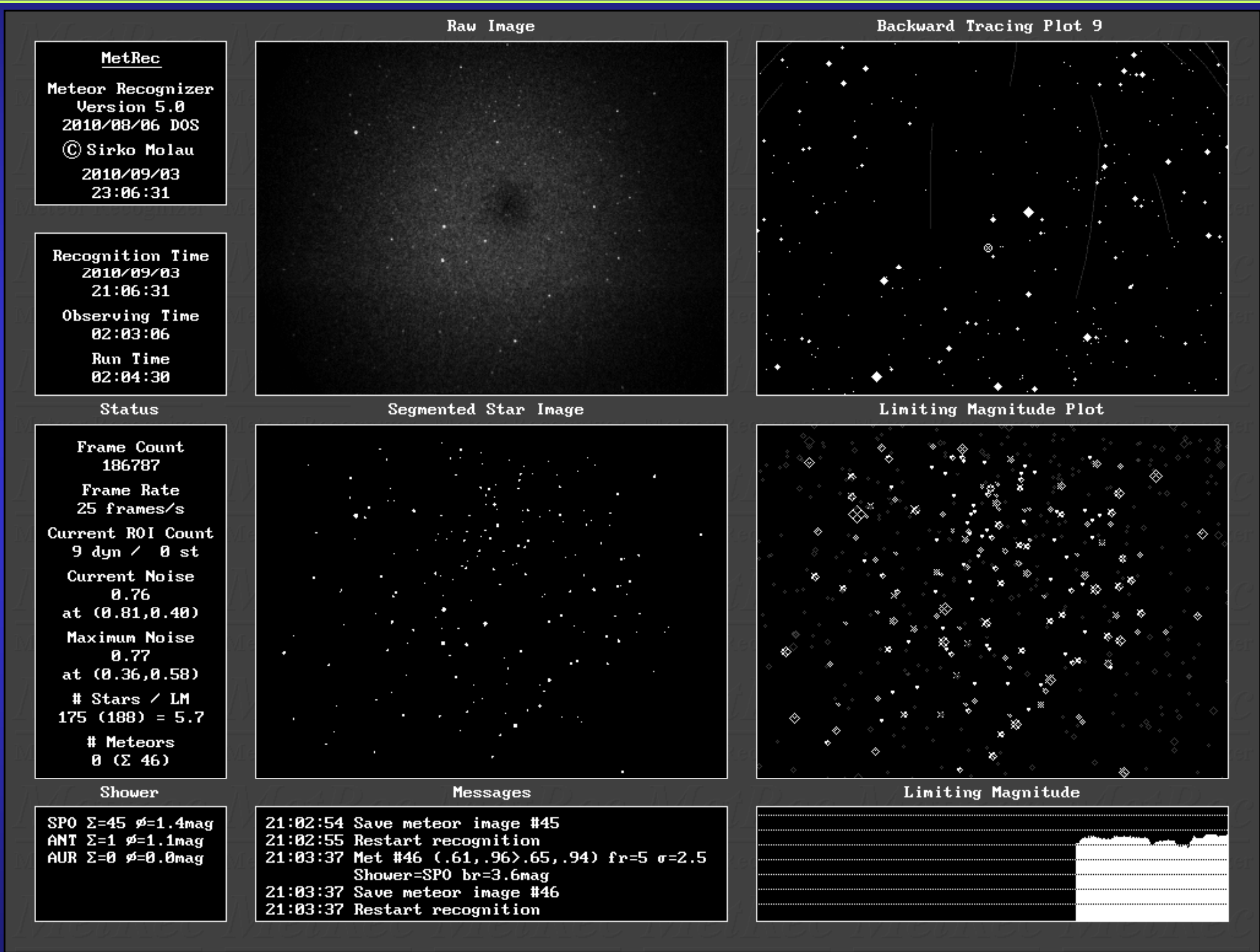
Year	Cameras	Observers	Countries
2006	28	19	9
2007	30	22	9
2008	37	24	10
2009	43	24	10
2010	57	32	12
2011	80	46	16



Limiting Magnitude (I)

- In 2010, MetRec got the functionality to measure limiting magnitudes (cf. IMC 2010):
  (1) Stars are segmented in the mean background image by a high-pass filter.
  (2) A star map is calculated from the inverse plate constants and the observing date & time.
  (3) The segmented stars are identified by matching them against the map.
  (4) The limiting magnitude is derived from the number of identified stars similar to star field counts of visual observers.
- MetRec calculates & stores the limiting magnitude each minute.

Limiting Magnitude (II)



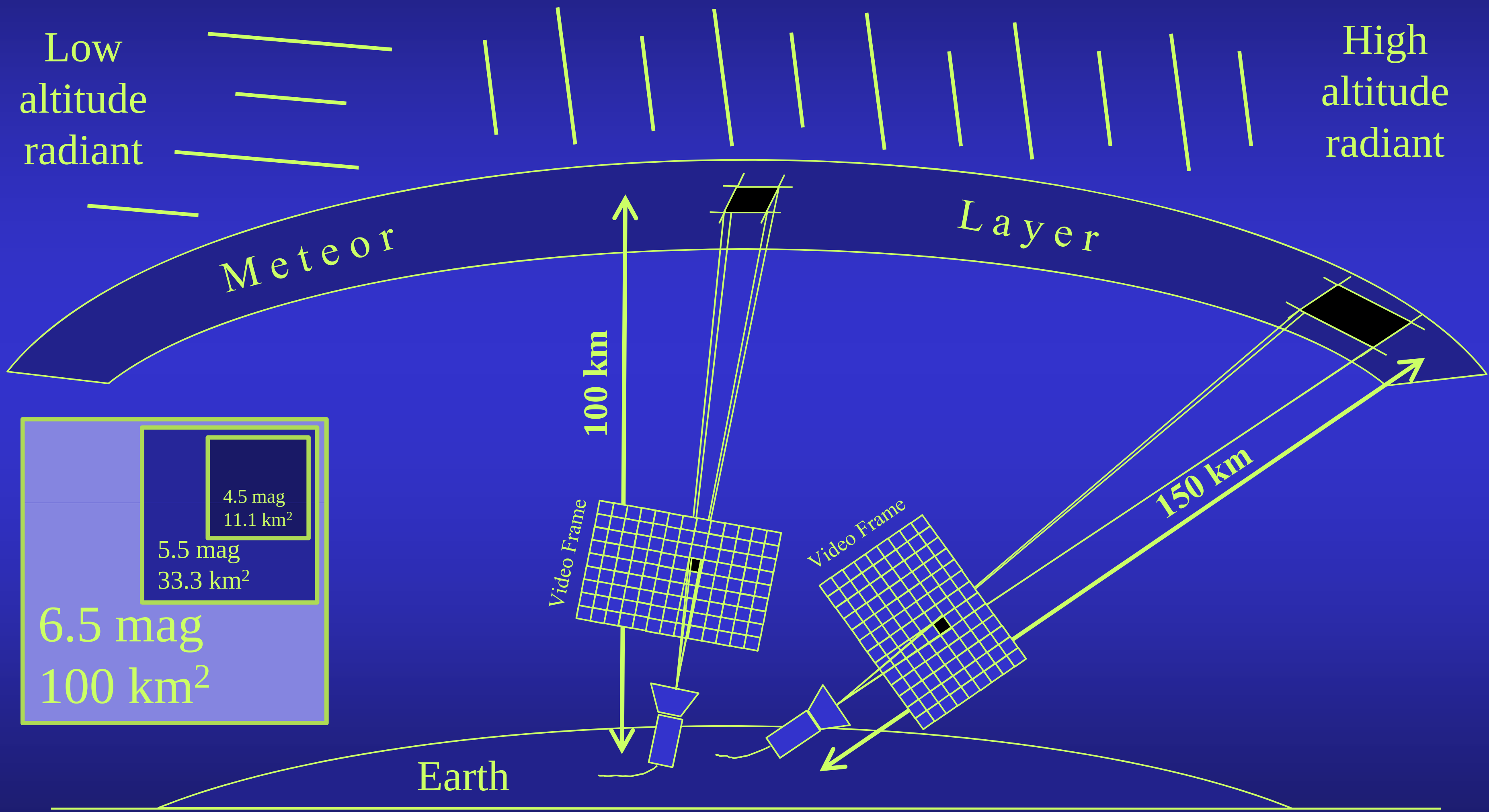
Limiting Magnitude (III)

- LM calculation is ***most critical*** for determining flux densities.
- The calculation procedure is driven by three parameters:
  (1) The noise level that defines, how much brighter than the background a star must be for segmentation.
  (2) The limiting magnitude of the star map.
  (3) The maximum spatial distance between a segmented and a star map star.
- All three parameters are dynamically adjusted during the observation.
- The LM calculation works quite robust for a wide range of camera systems, but further improvements are implemented continuously.

Effective Collection Area (I)

- Based on the limiting magnitude, MetRec calculates the effective collection area of a camera:
  (1) The angular extend of each pixel in square degrees is computed.
  (2) From that and the observing direction of the camera, the collection area at the meteor layer (100 km) in square kilometers is obtained.
  (3) The loss in magnitude due to distance to the meteor layer (relative to 100 km) is calculated.
  (4) The difference between the actual and the nominal limiting magnitude (6.5 mag) is transformed into a reduction of the effective collection area (assuming a population index of 3.0).
- MetRec calculates & stores the effective collection area of the camera each minute.

Effective Collection Area (II)

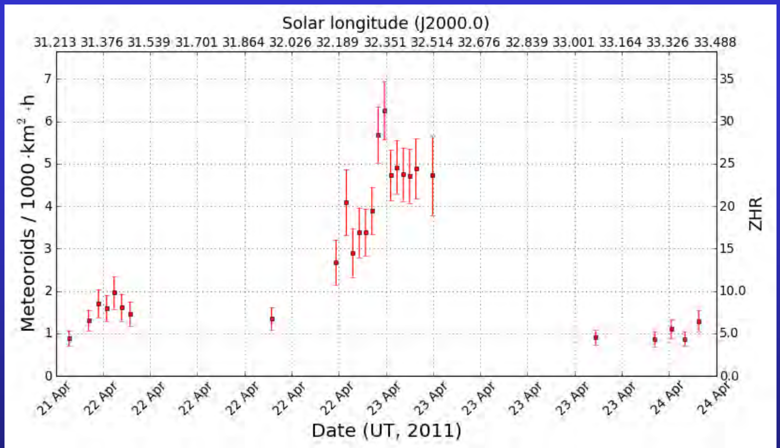


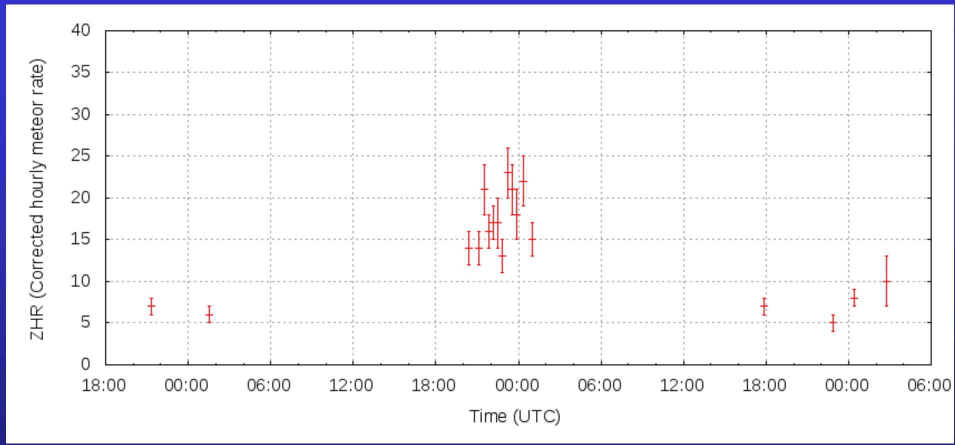
Flux densities (I)

- The flux density is the shower meteor count divided by the shower-specific eff. collection area and the eff. observing time.
- The following parameters are calculated shower-specific:
  (1) Altitude of the meteor layer (depending on the shower velocity and radiant altitude).
  (2) Population index (taken from the IMO Meteor Shower Working List).
  (3) Additional loss in limiting magnitude due to meteor motion (based on the integration time and the expected apparent meteor velocity).
  (4) Correction for the radiant altitude.
- MetRec calculates & stores the showers-specific effective collection area, the corresponding shower meteor count and the effective observing time each minute.

Flux densities (II)

- MetRec was enabled to upload flux data to the VMO server.
- G. Barentsen implemented the MetRec Flux Viewer which is similar to the well-known quick look analysis for visual obs.
- The first flux measurements by video were obtained for the 2011 Lyrids, matching well to visual results.

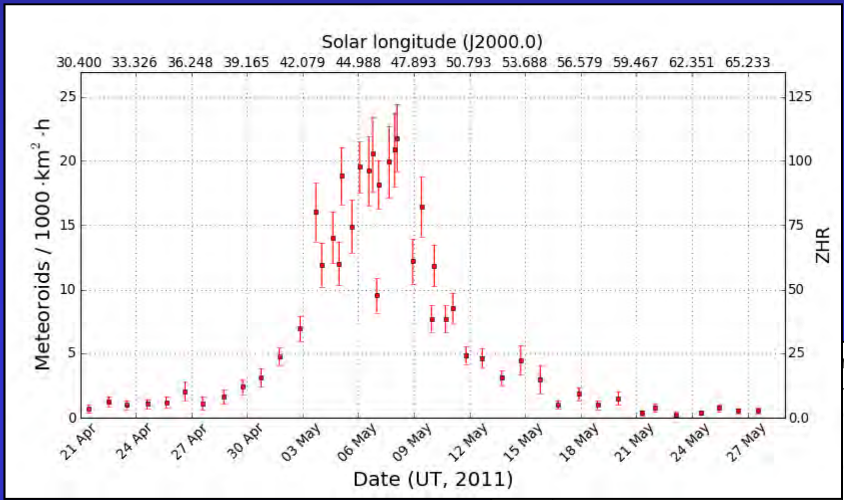




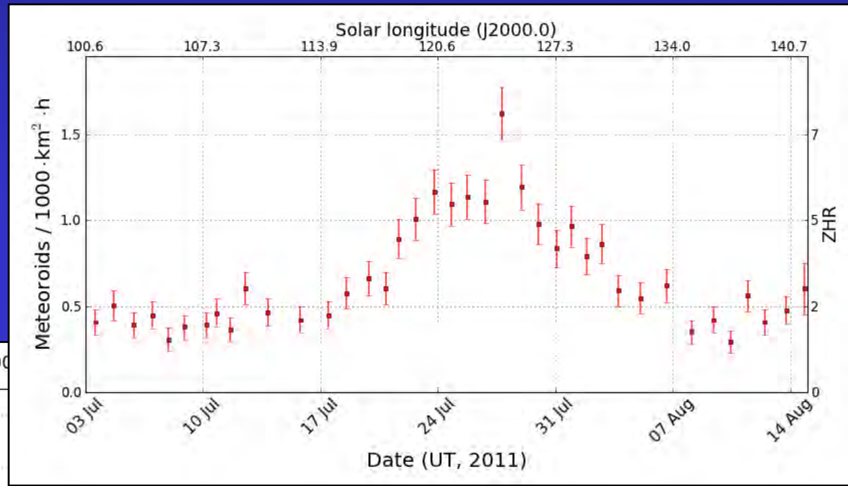
Lyrids 2011: Flux densities from IMO network video cameras (left) and visual ZHR (right)

Flux densities (III)

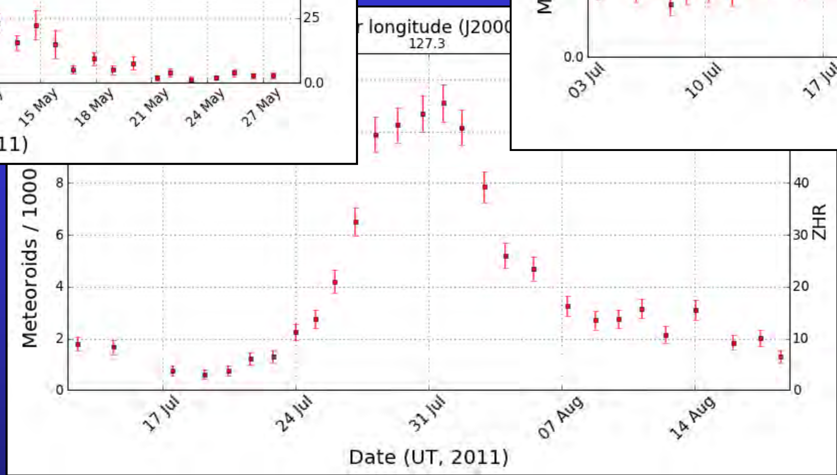
- Flux densities were derived for further showers in 2011 ...



eta Aquariids 2011



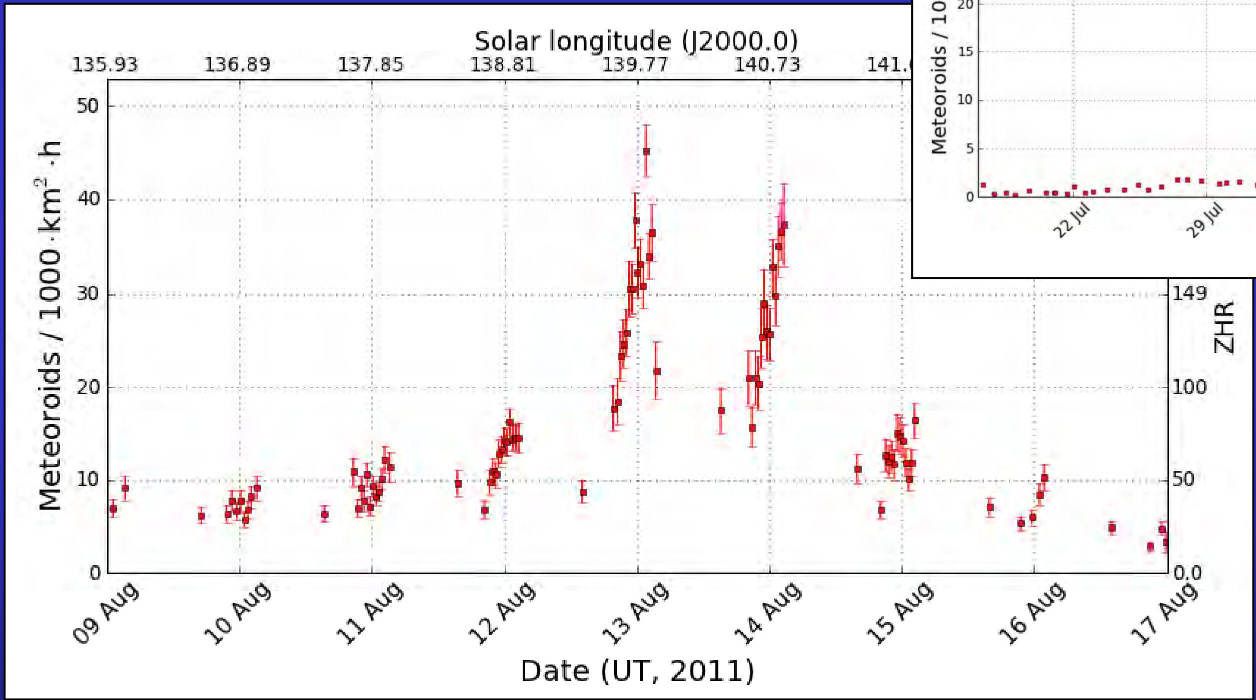
alpha Capricornids 2011



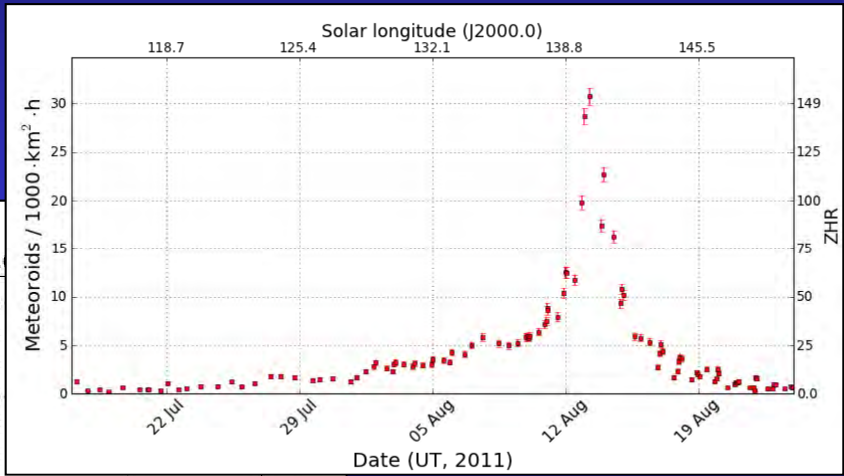
Southern delta Aquariids 2011

Flux densities (IV)

- But then came the Perseids 2011 ...



Detailed flux density profile of the 2011 Perseid peak



Overall flux density profile of the Perseids 2011

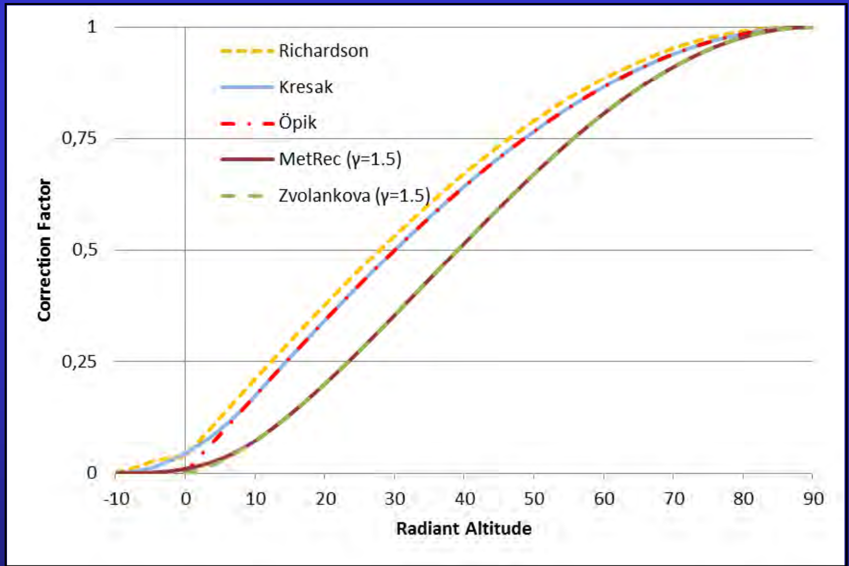
Zenith Exponent (I)

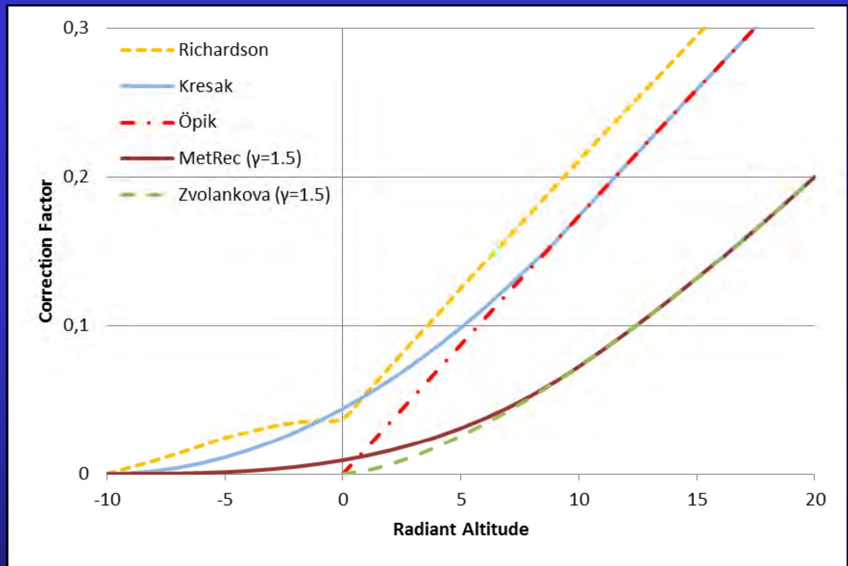
- What went wrong? The flux densities grew continuously by more than a factor of two in from dusk till dawn.
- Linking the phenomenon to the radiant altitude of the Perseids (which also grows from dusk till dawn) was straight forward.

- In 1955, Öpik proposed to use the sine of the radiant altitude $sin(h_r)$ (resp. cosine of the zenith distance) for correction.
- Kresák suggested in 1954 a refinement of that basic formula for low radiant altitudes $h_r<10°$.
- In 1983, Zvolánková revivided the zenith exponent γ: $sin^{\gamma}(h_r)$, from 17,000 visual Perseids she derived γ=1.47.
- Richardson derived 1999 a fully geometric solution.

Zenith Exponent (II)

- MetRec uses a combination of the low altitude correction from Kresák and the zenith exponent of Zvolánková.
- As gamma is unknown and may vary for different showers, it is set to 1.0 and only introduced in the MetRec Flux Viewer.

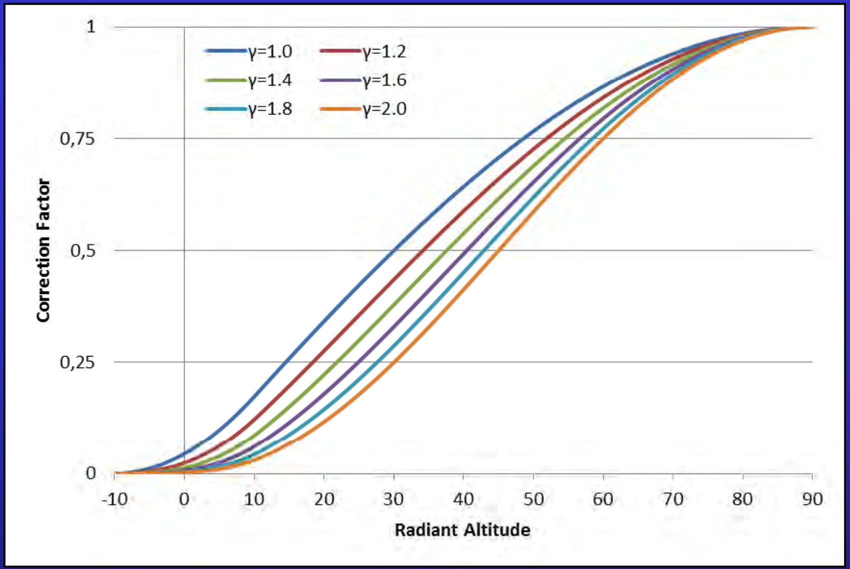




Radiant altitude correction functions

Zenith Exponent (III)

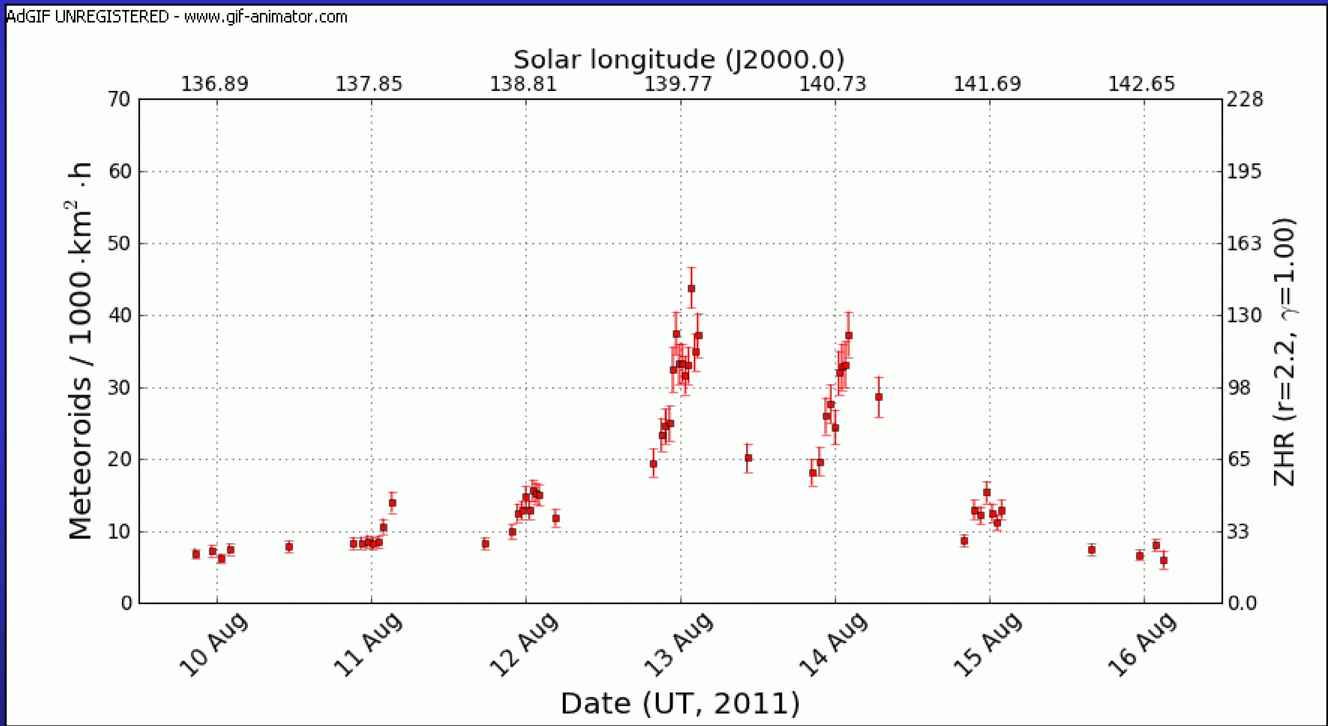
- Previously the zenith exponent was determined using data from the same time but different locations / radiant altitudes, or the data was normalized by a mean ZHR profile.
- For the Perseids 2011, we found empirically a value of γ=1.6 using a similar approach.
- For the Orionds 2011 the same γ=1.5 to 1.6 was found.
- γ>1 increases the overall flux density systematically.



Radiant altitude correction for different zenith exponents

Zenith Exponent (IV)

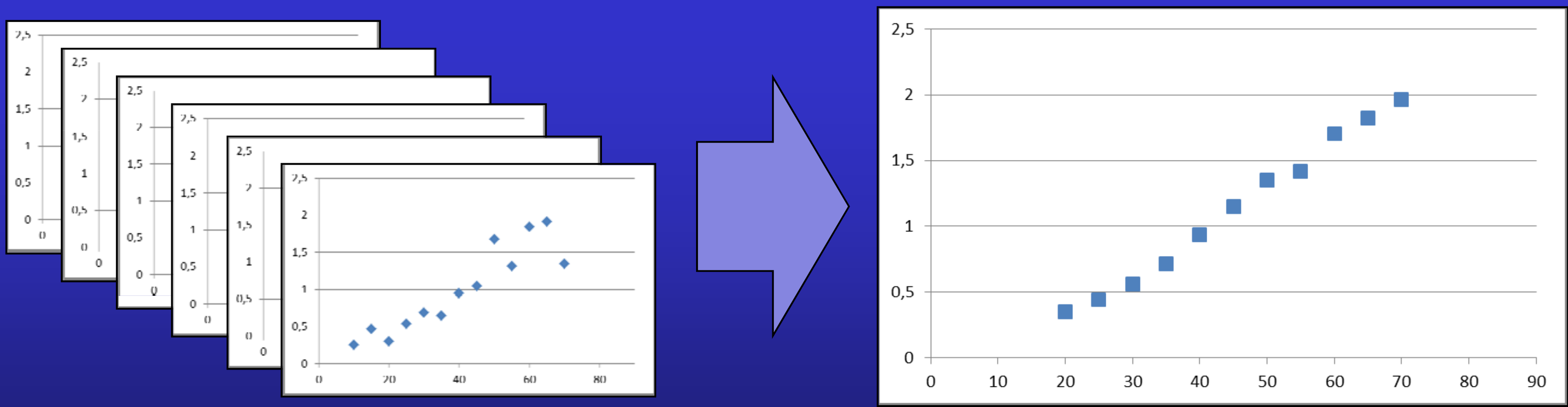
- Zenith exponent visually explained using real observations: Dependency of the flux density profile from the zenith exponent γ.



Detailed flux density profile from the Perseid 2011 peak

Perseids 2012 (I)

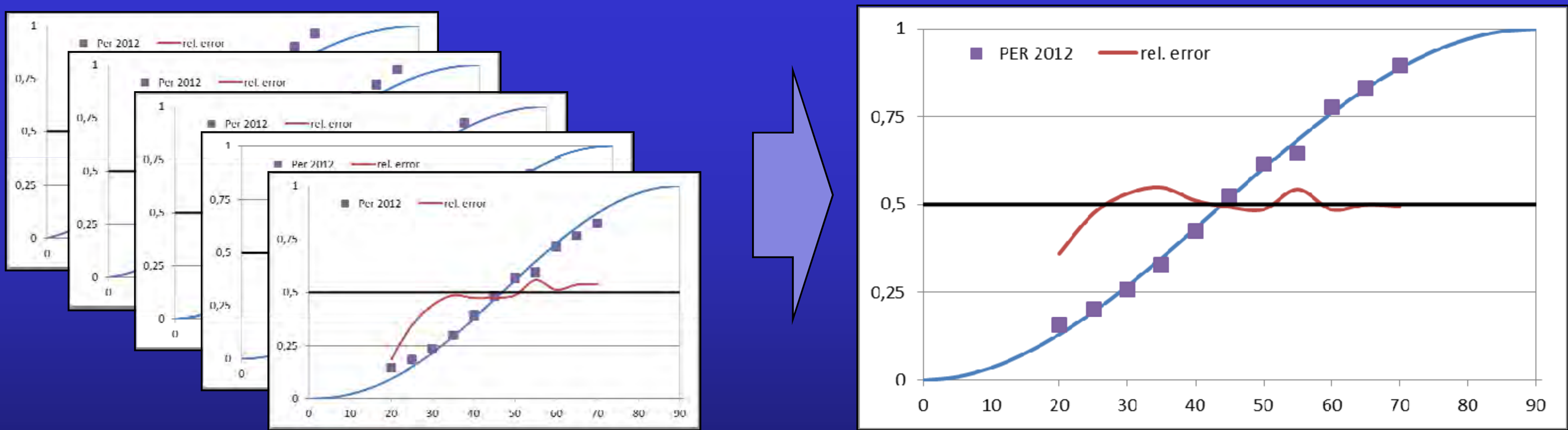
- Based on 18,500 Perseids recorded in 2012, the effect of the zenith exponent was re-analysed with a new method:
  - (1) The existing radiant altitude correction was reverted in the flux data.
  - (2) The dependency of the flux density from the radiant altitude was determined in 5° altitude bins for individual nights between Aug 1-21.
  - (3) The data set was normalized and averaged over all nights.



Mean flux density vs. radiant altitude for the 2012 Perseids

Perseids 2012 (II)

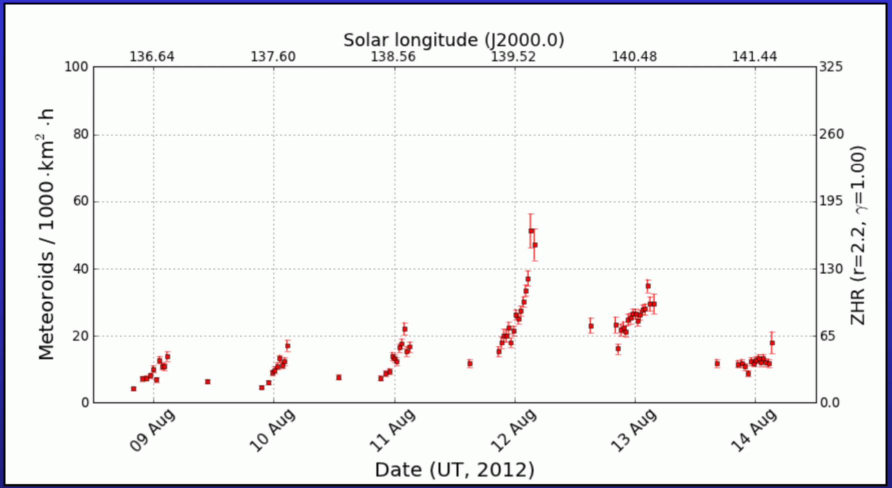
- Best averaging procedure → the eff. collection area and meteor count were accumulated for each altitude bin over all nights.
- We tested whether near-maximum nights with variable flux density would introduce a systematic shift → all nights were used.
- Determining the zenith exponent with a least squares fit.



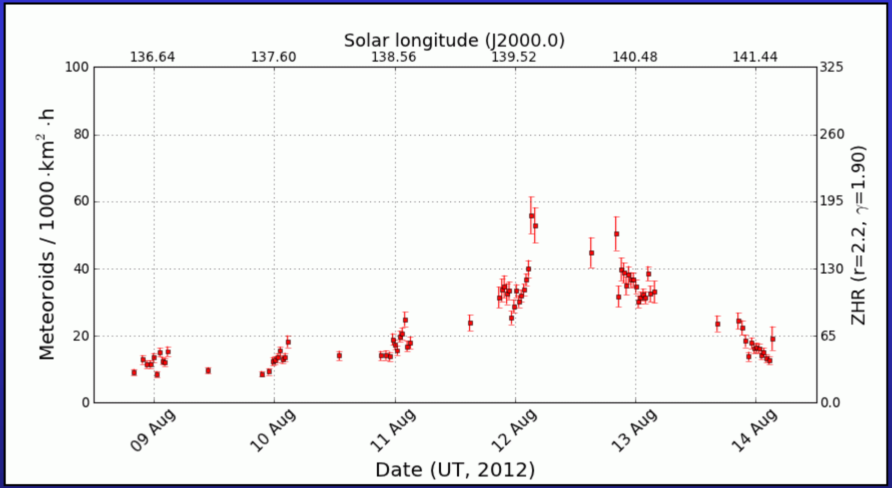
Looking for the best γ in the radiant altitude correction function $\sin^{\gamma}(h_r)$

Perseids 2012 (III)

- A sine function with exponent γ=1.9 fits best to the data set.
- For the accurate estimation of the zenith exponent, a large altitude range needs to be covered.
- The new flux density graph is not perfect, but clearly improved.
- The procedure was repeated for other showers of 2011/12.



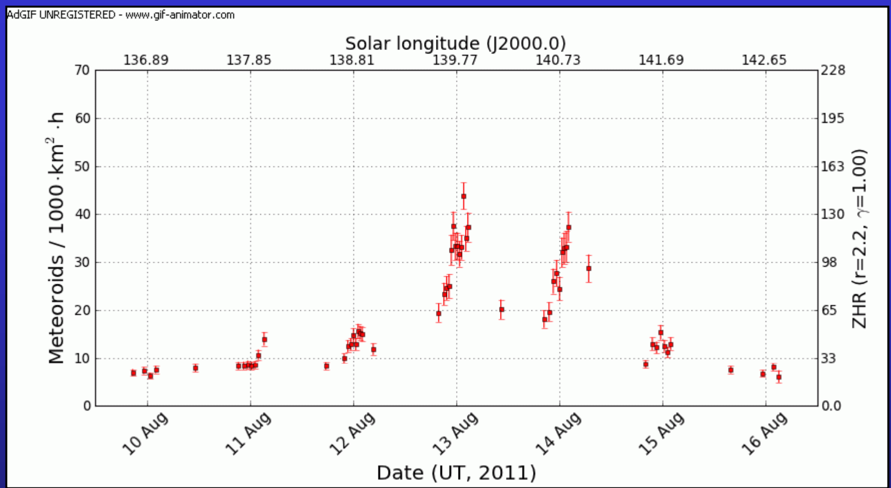
PER 2012 radiant altitude correction with γ=1.0



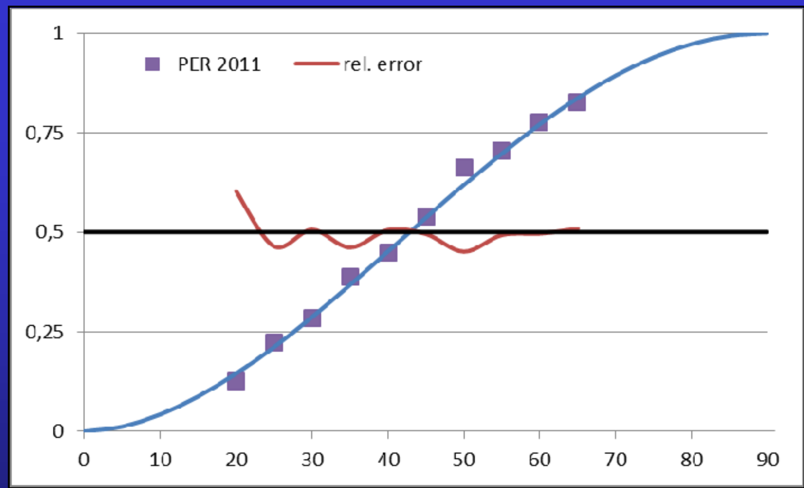
PER 2012 radiant altitude correction with γ=1.9

Perseids 2011

- 10,500 Perseids from 2011 give a best fitted with γ=1.8.
- Reliable estimate thanks to large altitude range.
- Almost the same zenith exponent as for 2012.



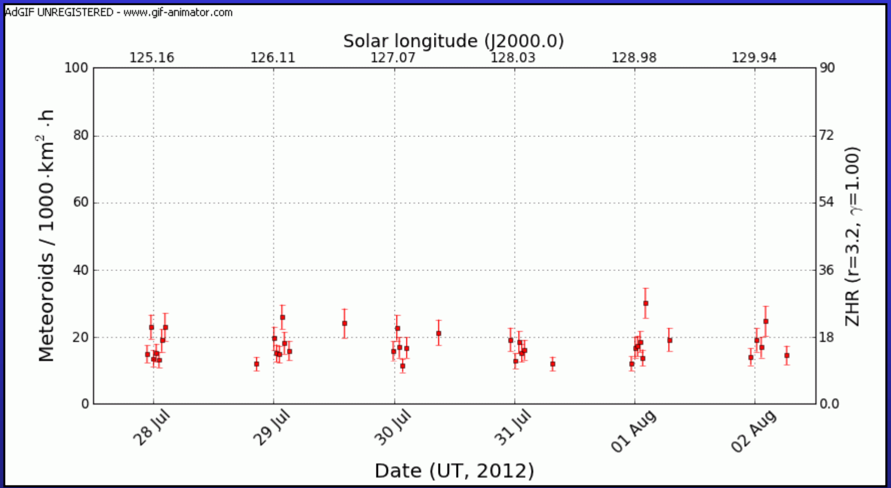
Detailed PER 2011 flux density profile



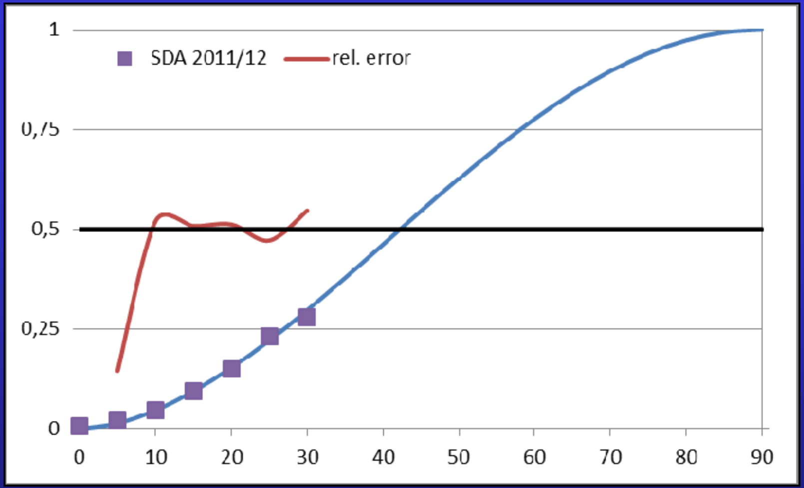
Radiant altitude correction with γ=1.8

Southern delta Aquariids 2011/12

- 2011/12 data sets were combined to get 4,000 shower meteors.
- Only European data were used (smaller altitude range, but the single Australian camera introduced too much scatter).
- The estimate of the zenith exponent of γ=1.75 is less reliable, as the function is fitted to only a few data points.



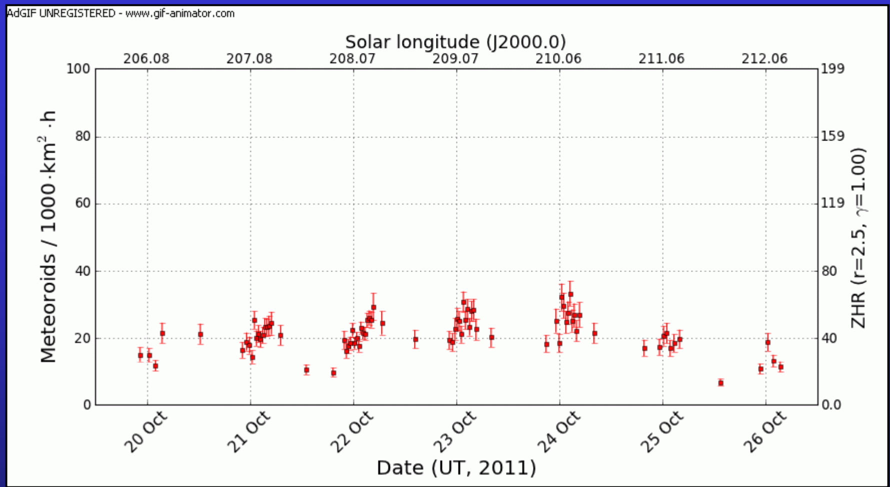
Detailed SDA 2012 flux density profile



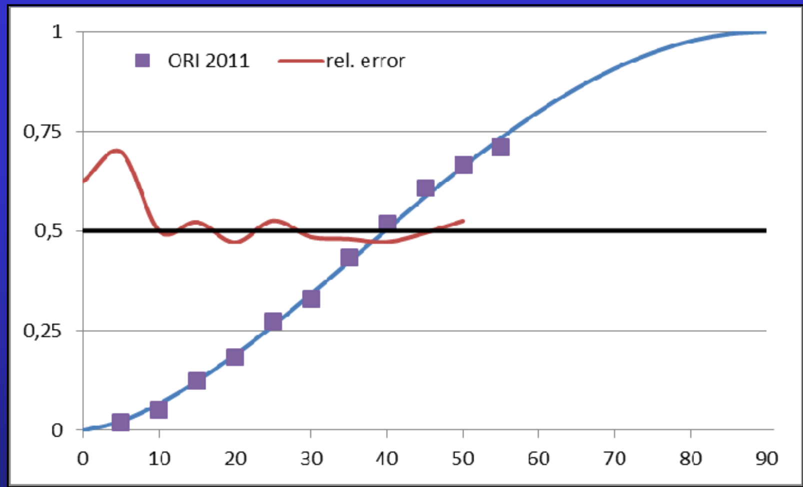
Radiant altitude correction with γ=1.75

Orionids 2011

- Almost 10,000 Orionids from 2011were analysed.
- The large altitude range yields a more reliable fit.
- A smaller value of γ=1.55 gives best results.



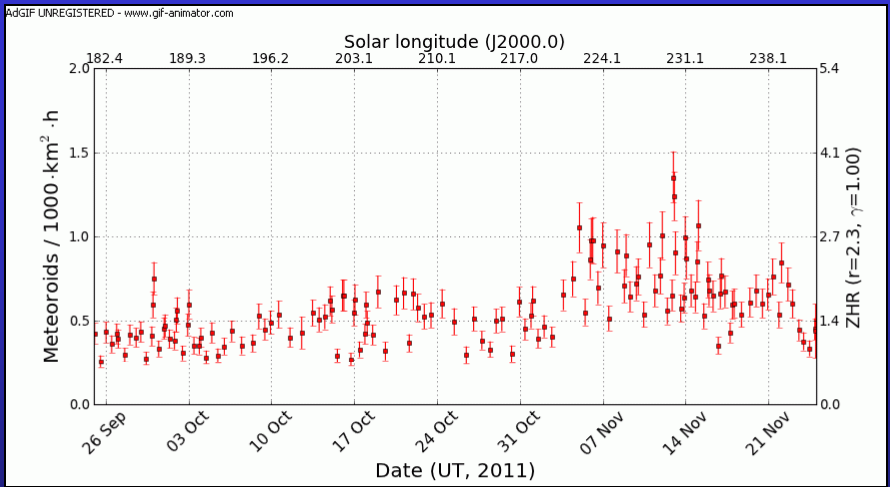
Detailed ORI 2011 flux density profile



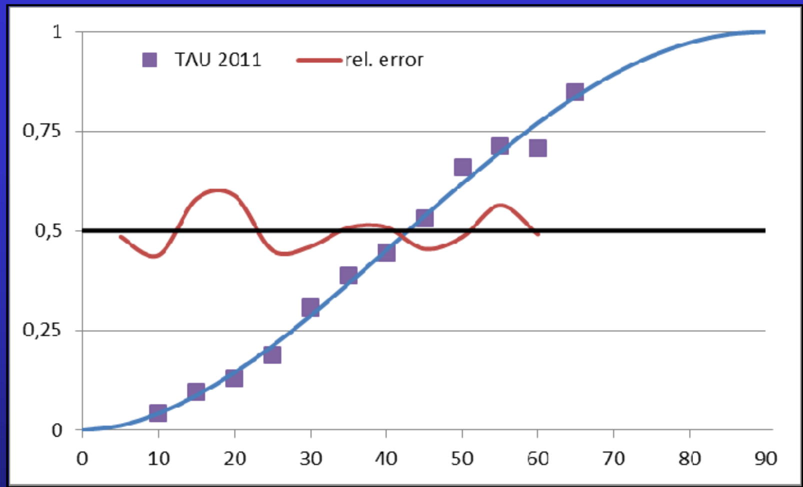
Radiant altitude correction with γ=1.55

Taurids 2011

- Perfect data set with over 13,000 shower meteors (NTA and STA) yields a best fit with γ=1.8.
- Perfect conditions because of an almost complete altitude range, many nights, almost constant activity → but still large scatter towards high radiant altitudes.



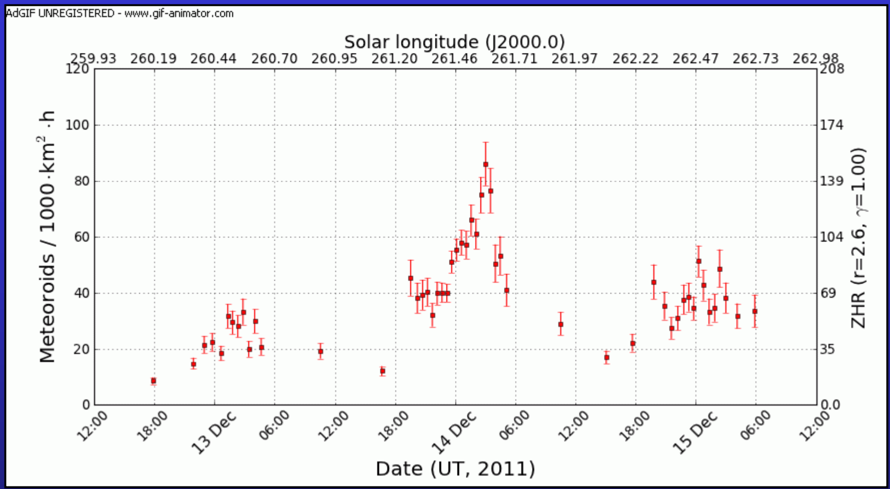
NTA 2011 flux density profile



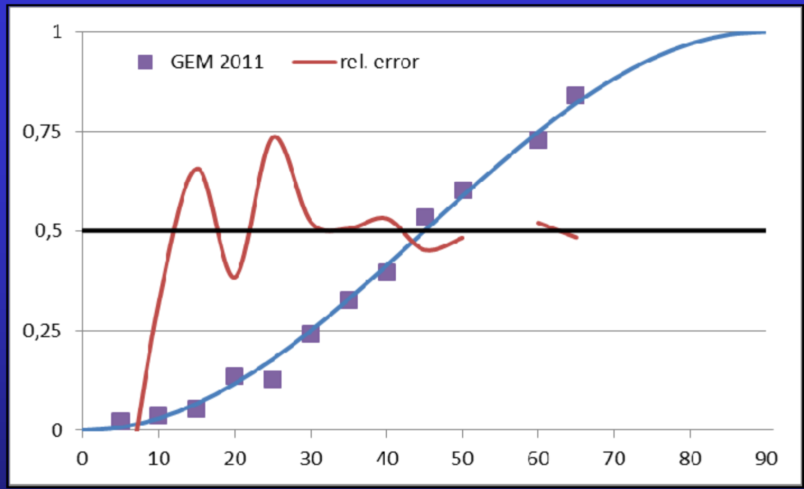
Radiant altitude correction with γ=1.8

Geminids 2011

- Small data set with only 1,500 shower meteors (mediocre weather) results in large scatter.
- Some nights and altitude bins had to be omitted.
- Best results with γ=2.0, but less reliable.



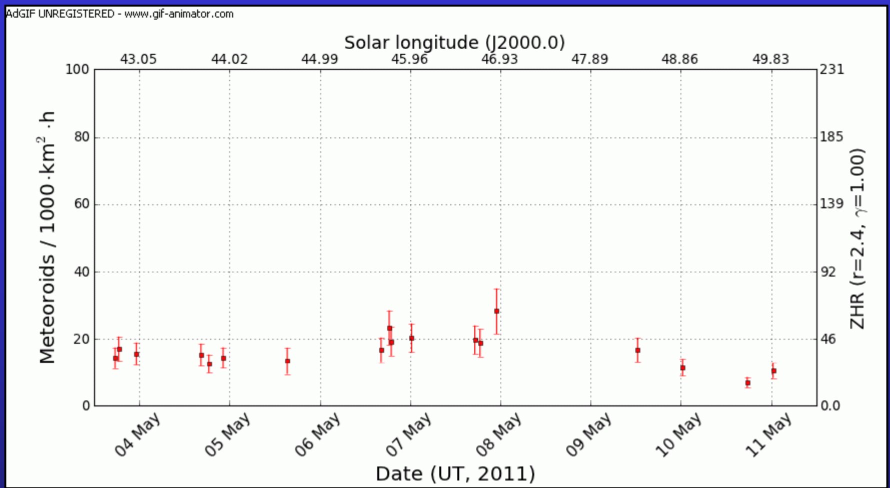
Detailed GEM 2011 flux density profile



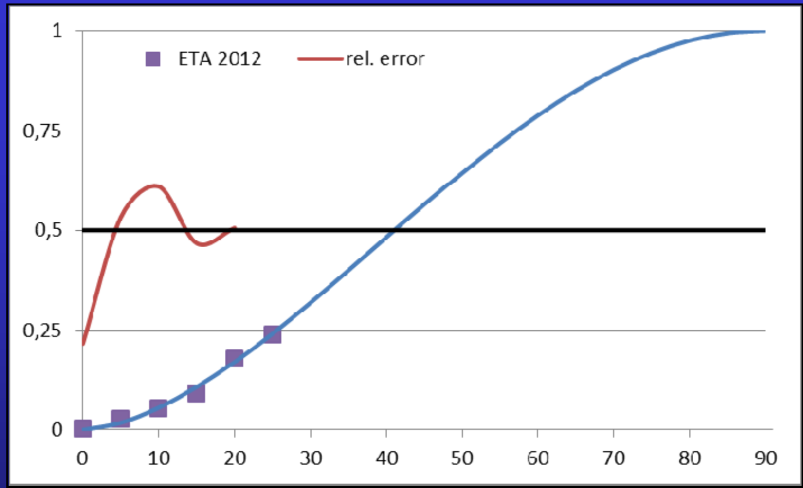
Radiant altitude correction with γ=2.0

Eta Aquariids 2012

- Once more only data from European cameras used (500 shower meteors).
- Special case with low altitude observations only, but still a good fit with γ=1.65



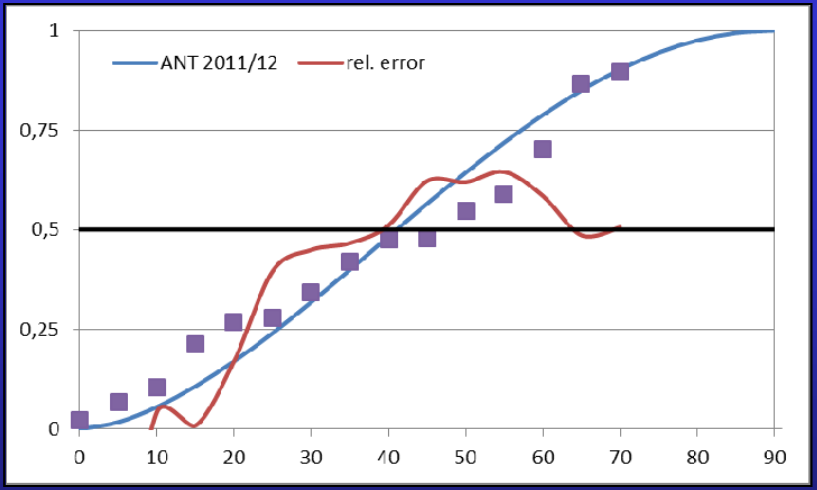
Detailed ETA 2012 flux density profile



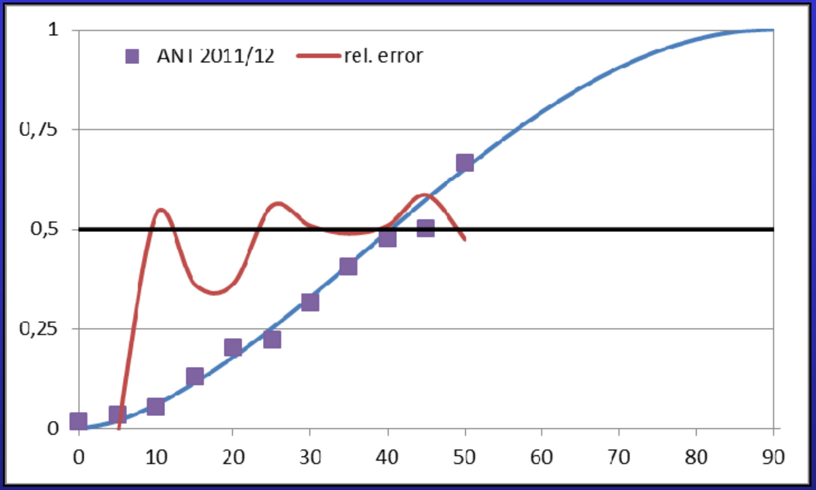
Radiant altitude correction with γ=1.65

Antihelion 2011/12

- Active all year long (except during TAU) and full altitude range.
- Combining all nights yields systematic errors, because of variable activity at different altitude ranges.
- Analysing Feb-Apr and Aug-Sep data separately and merging the results of 8,300 shower meteors yields a value of γ=1.65.



ANT radiant altitude correction all year

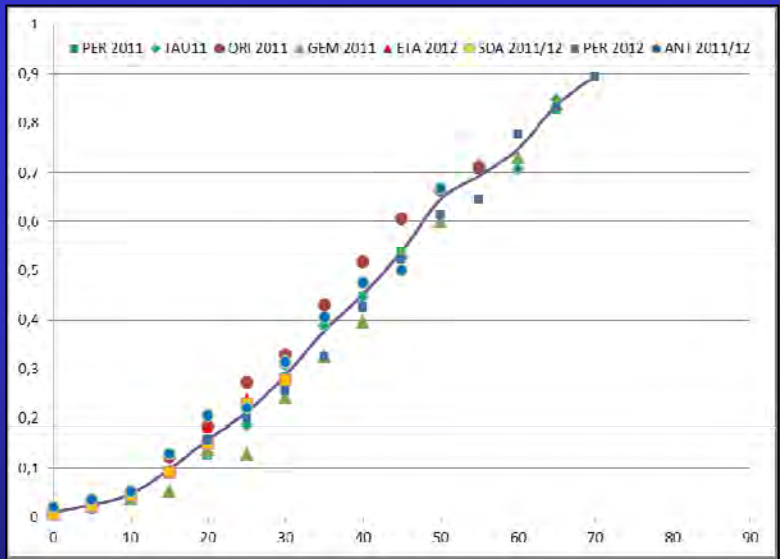


Radiant altitude correction Feb-Apr / Aug-Sep

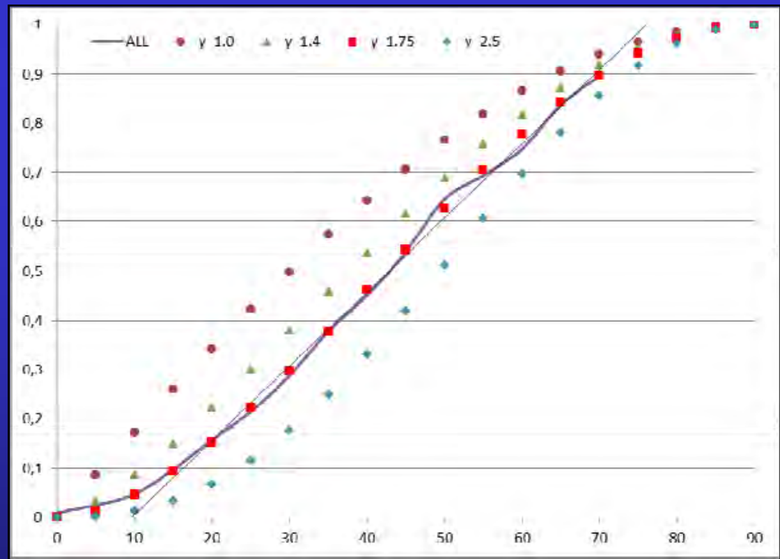
Combination

- Combining the results of all analysed showers yields an average zenith exponent of γ=1.75.
- Between 15° and 75° altitude, the dependency is almost linear.
- With γ=1.47, Zvolánková was closest to our result.

In 1871, Schiaparelli proposed the correction function *sin*$^{1.6}$*(h*$_r$*)*!!!



Combination of all showers



Radiant altitude correction with γ=1.75

Summary

- The dependency of the flux density from the radiant altitude can be well described by a sine function with zenith exponent γ.
- In order to determine the zenith exponent properly, a large altitude range must be covered.
- The flux density should ideally be constant during each night.
- The zenith exponent varies for different showers, the mean values of all analysed meteor showers so far is $\gamma=1.75$.
- Introducing a zenith exponent $\gamma>1$ increases systematically the flux density, so be careful when comparing data with different γ.
- Low altitude observations should be omitted from flux density calculation, as too large correction factors are introduced.

Thanks for your Attention

Questions?