Recent progresses on a Second World Atlas of the Night-Sky Brightness

LPTRAN/LPDART realistic models, Tomography of light pollution, accurate validation methods and extended satellite data analysis

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www.lightpollution.it/dmsp/

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in collaboration with

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[3]NOAA National Geophysical Data Center, Boulder

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Italian Space Agency
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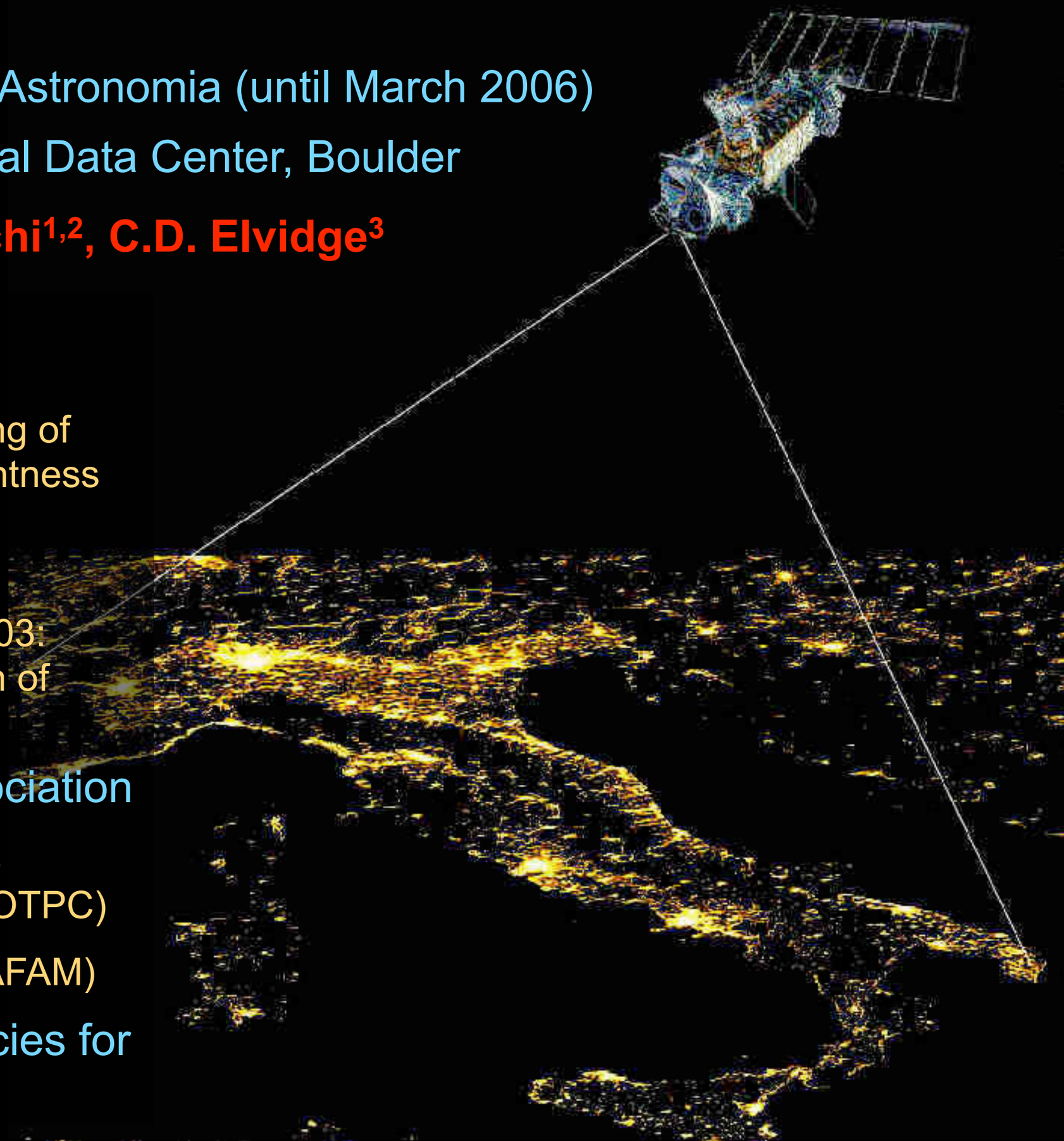
Università di Padova
(Young Researcher's Project 2003: Light pollution and the protection of astronomical sites)

International Dark-Sky Association

Astronomical Observatories
(NOAA/CTIO, VAT, Lowell, IAC/OTPC)

Other organizations (CfDS, AFAM)

National and regional agencies for environmental protection



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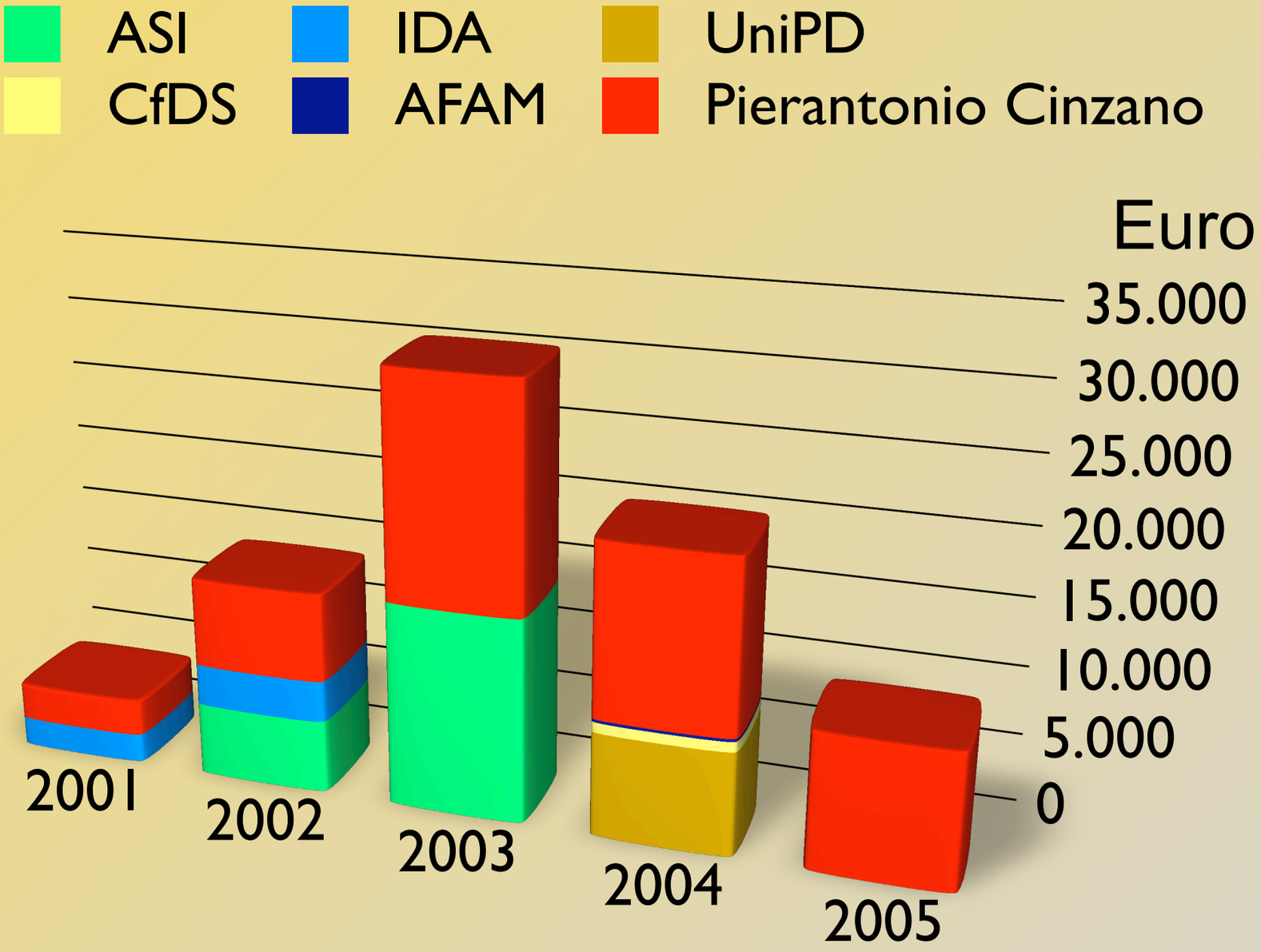
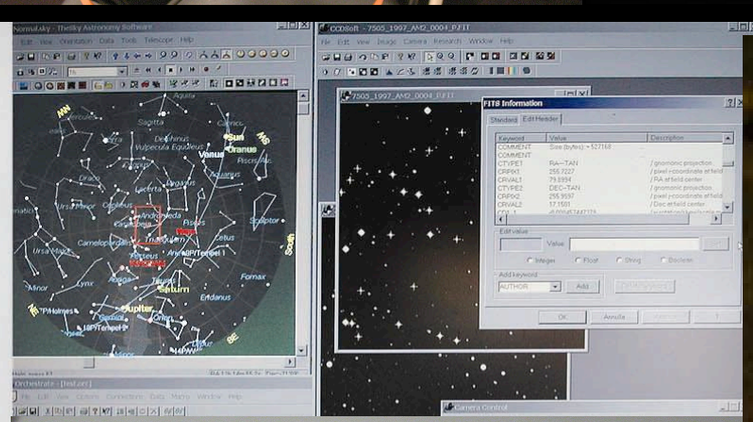


LPLAB: Laboratory of Photometry and Radiometry of Light Pollution

www.lplab.it



Cinzano 2003, Mem. Soc. Astron. It. Suppl., 3, 312-315

Main steps

OLS-DMSP UPDATED

Reduction of radiance data UPDATED

Data analysis UPDATED

Geographical and spatial distribution of upward light emission

Atmos- UPDATED
phere

Modelling of light pollution propagation UPDATED

Map computation UPDATED

Earth-based measurements UPDATED

Validation of results UPDATED

Night sky brightness

Stellar visibility

Changes with time

Correlation with the geographical distribution of population

New Computational techniques

Cinzano

New output products and indicators

Cinzano

New methods for validation of results and new observational campaigns

Cinzano
Falchi
Falchi & Cinzano

New methods in satellite data analysis

Elvidge
Cinzano
Cinzano, Falchi & Elvidge
Falchi, Cinzano & Elvidge

New Computational techniques

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New methods in satellite data analysis

Recent methods to map artificial night sky brightness and stellar visibility across large territories or their distribution over the entire sky at any site, are based on the computation of the propagation of light pollution with Garstang models, a simplified solution of the radiative transfer problem in atmosphere which allows a fast computation by reducing it to a ray-tracing approach. They are accurate with clear atmosphere, when a two-scattering approximation is acceptable, which is the most common situation.

I present here up-to-date **Extended Garstang Models** (EGM) which provides a more general numerical solution for the radiative transfer problem applied to the propagation of light pollution in atmosphere.

(Cinzano, in prep.)

I also present the **LPTRAN software package**, an application of EGM to DMSP-OLS radiance measurements and to GTOPO30 digital elevation data, which provides an up-to-date method to predict the artificial brightness distribution of the night sky at any site in the World at any visible wavelength for a broad range of atmospheric situations and the artificial radiation density in atmosphere across the territory.

EGM account for:

- multiple scattering
- wavelength from 250 nm to infrared
- earth curvature and its screening effects
- sites and sources elevation
- many kinds of atmosphere or custom setup (e.g. thermal inversion layers)
- mix of different boundary layer aerosols and tropospheric aerosols or custom
- up to 5 aerosol layers in upper atmosphere including fresh and aged volcanic dust and meteoric dust
- variations of the scattering phase function with elevation
- continuum and line gas absorption from many species, ozone included
- up to 5 cloud layers
- wavelength dependant bidirectional reflectance of the ground surface from NASA/MODIS satellites, main models or custom data (snow included)
- geographically variable upward emission function given as a three-parameter function or a Lagrange polynomial series
- atmospheric scattering properties or libraries of light pollution propagation functions from other sources

A more general solution, too heavy at present time, allows to account for:

- mountain screening
- geographical gradients of atmospheric conditions, including localized clouds
- geographic distribution of ground surfaces and asymmetric sources

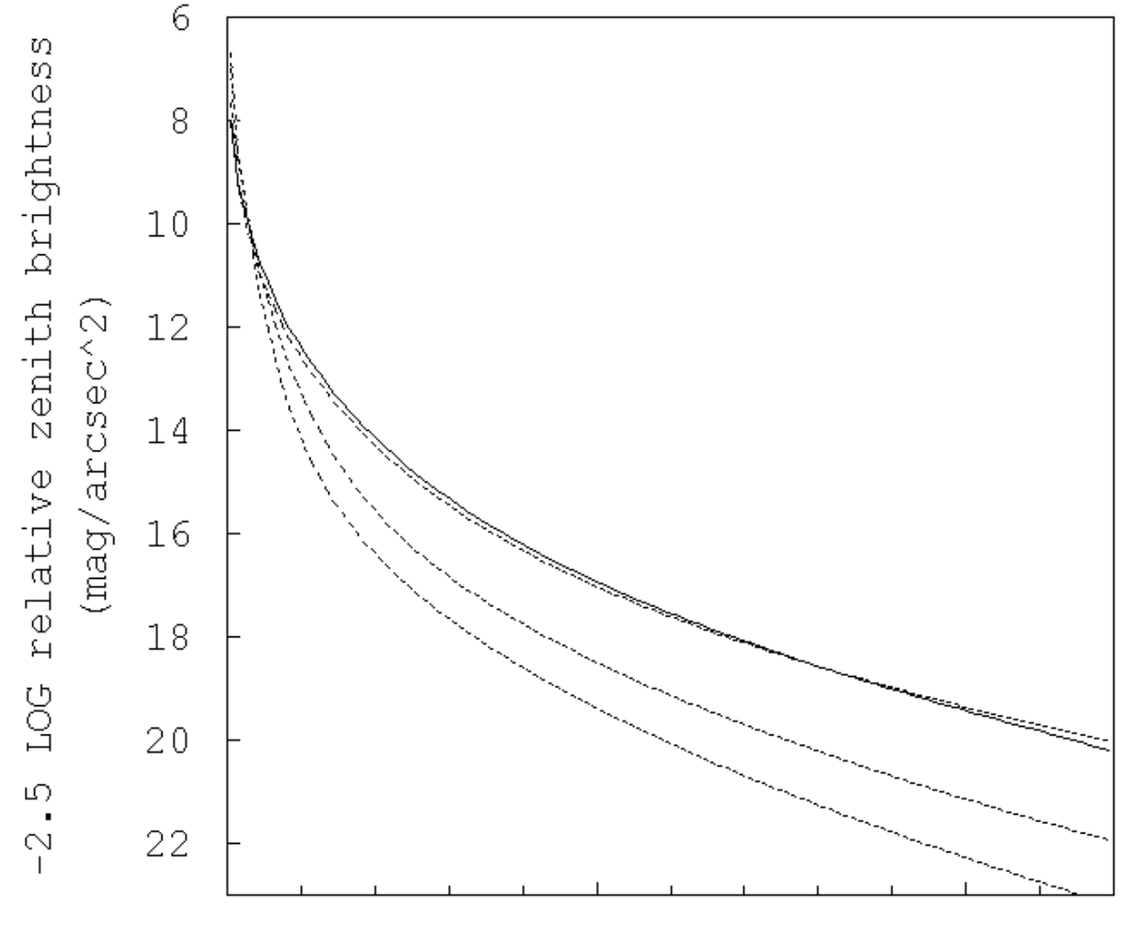
Approach

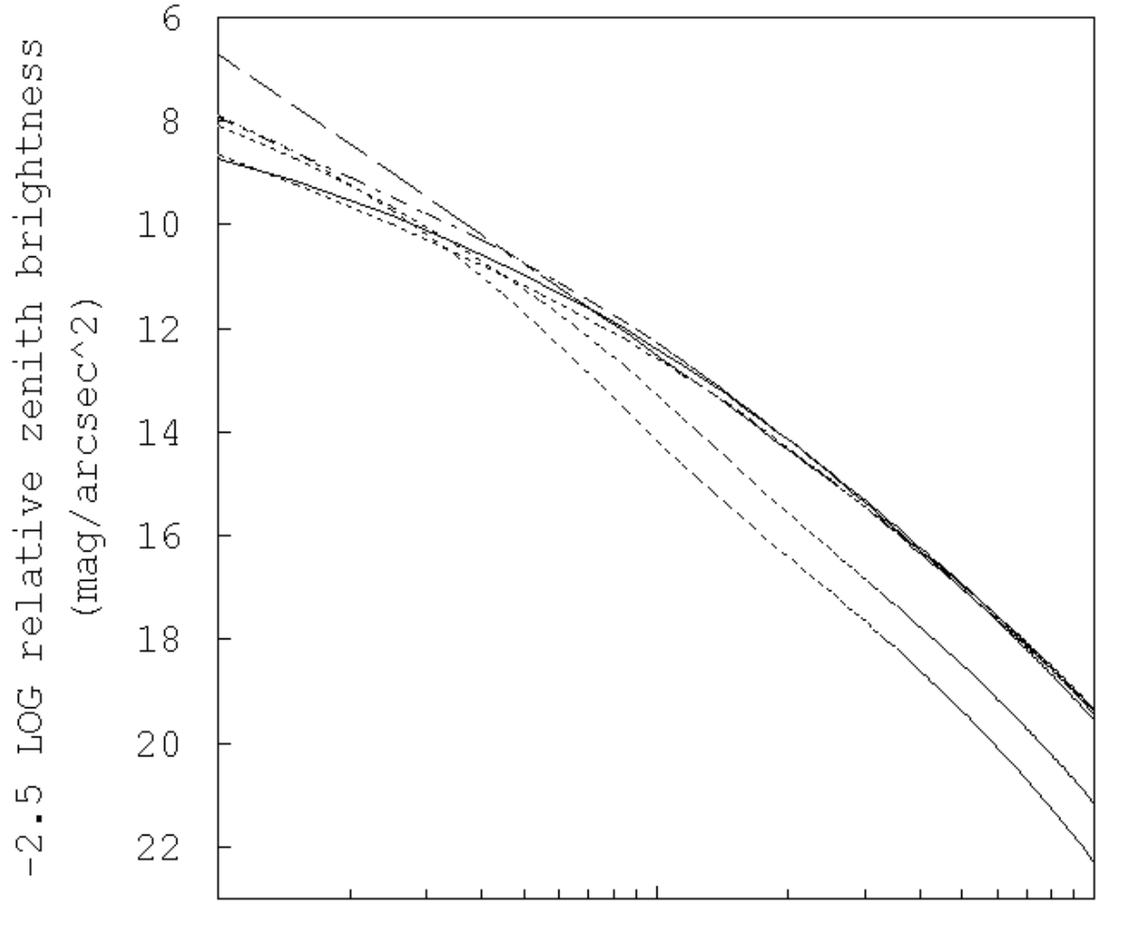
- atmosphere divided in 3D grid
- surface in a corresponding 2D grid
- atmospheric situation and scattering functions of each volume from up-to-date models of atmospheric physics
- the source has a given upward intensity function
- Garstang-like ray-tracing approach
- irradiance from the source on each atmospheric volume is calculated (accounting for extinction, absorption, etc.)
- intensity of the light scattered in each direction by each volume (numerical approximation) based on detailed scattering properties
- irradiance on each surface area from each atmospheric volume and intensity of the light scattered in each direction
- start iterations: irradiance on each atmospheric volume and on each surface area is calculated, due to light coming from other volumes, other surface areas and the source. The intensity of the light scattered in each direction is added. Then another iteration.
- at the end, the intensity of light scattered by each volume in each direction is known, and also the radiation density, etc.
- brightness obtained from simple integration along the line-of-sight

The software package **LPTRAN (Light Pollution radiative TRANsfer)**, written in Fortran-77, applies the method for the case of axial symmetry of sources.

It is composed by a number of programs **(Cinzano, in prep.)**:

- the main program **LPTRAN** (the same name of the package) computes the radiative transfer and light pollution propagation based on an input atmospheric and surface model for the given wavelength
- **LPDART** evaluates light pollution and night sky brightness on the grid and writes a library of light pollution propagation functions (brightness vs. distance)
- **lpskymap_lptran** computes night sky brightness in a site based on DMSP-OLS radiance data, a Digital Elevation Map and the lptran library.
- **lpskyalt**, **lpskydens** and **lpskyfrzh** compute across a territory the artificial night sky brightness at any chosen azimuth and elevation, the radiation and scattered flux densities in atmosphere and their fractionary contribution to the zenith night sky brightness at sea level.
- **lpskymap package** (Cinzano & Elvidge 2004) allow to obtain polar plots and other indicators for individual sites.
- **lpmap package** (Cinzano, Falchi & Elvidge 2001) allows to obtain the maps of limiting magnitudes across the territory.





Comparisons between predictions of classic Garstang models and LPTRAN predictions show close agreement for US62 standard clear atmosphere and typical upward emission function. (Cinzano, in prep.)

New Computational techniques

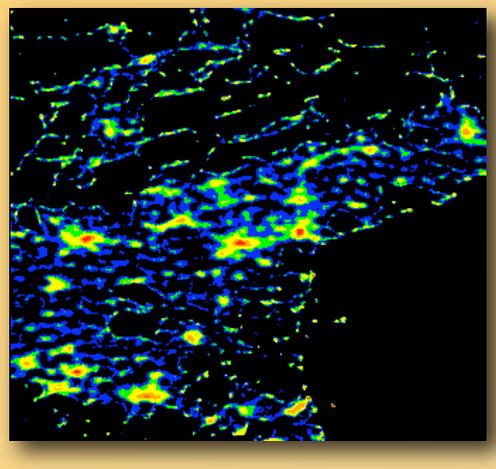
New output products and indicators

Cinzano

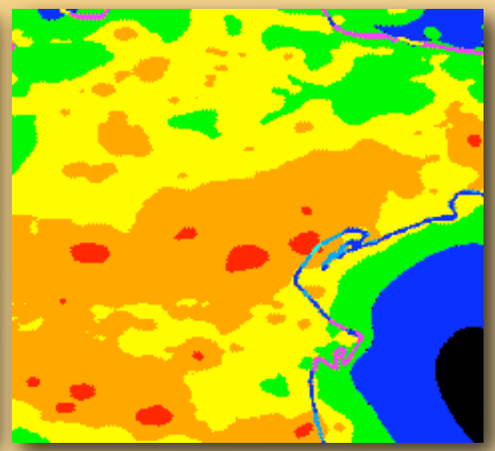
New methods for validation of results and new observational campaigns

New methods in satellite data analysis

Our classic products and indicators

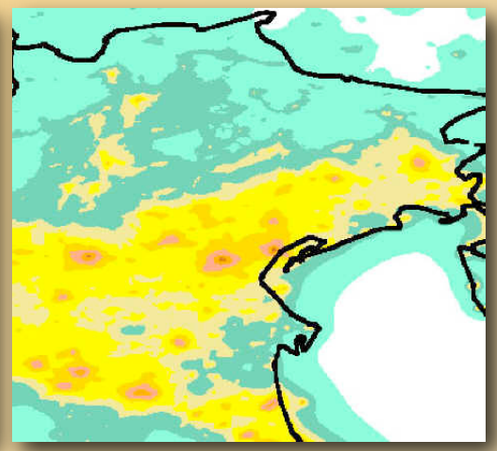


upward flux



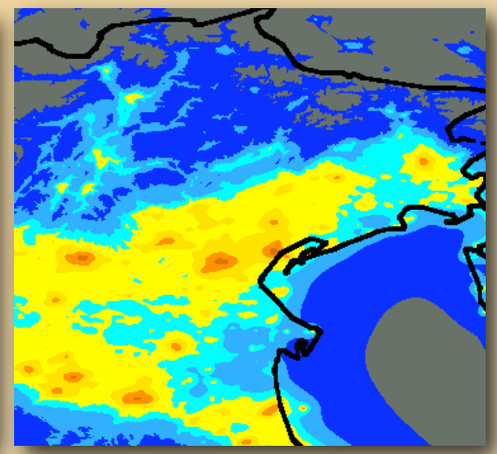
sea level artificial night sky brightness

Cinzano, Falchi, Elvidge, Baugh 2000, MNRAS, 318, 641-657

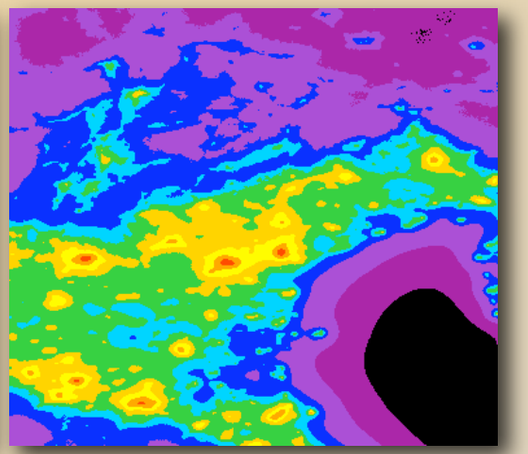


total night sky brightness

Cinzano, Falchi, Elvidge 2001a, MNRAS, 323, 34-46

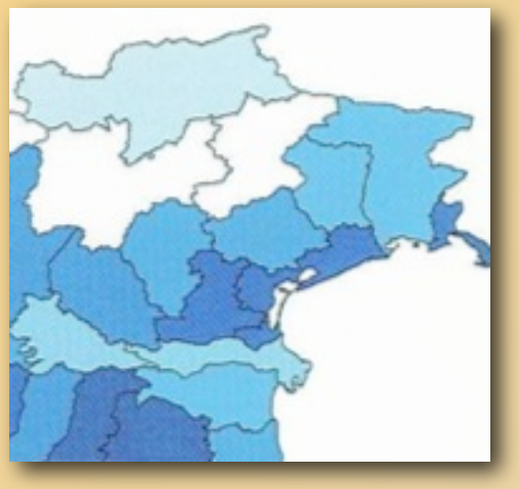


stellar visibility (limiting magnitude)



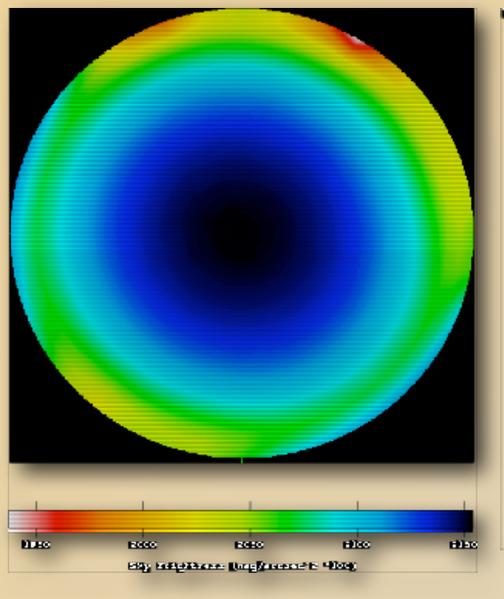
loss of stellar visibility

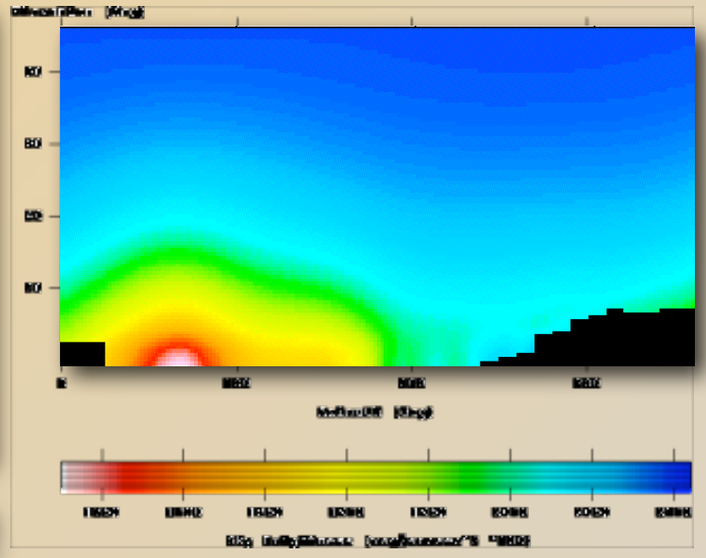
Cinzano, Falchi, Elvidge 2003, IAUWG, Sidney



statistical indexes (e.g fraction of population or surface under a sky of given luminosity)

Cinzano, Falchi, Elvidge 2001b, MNRAS, 328, 689-707

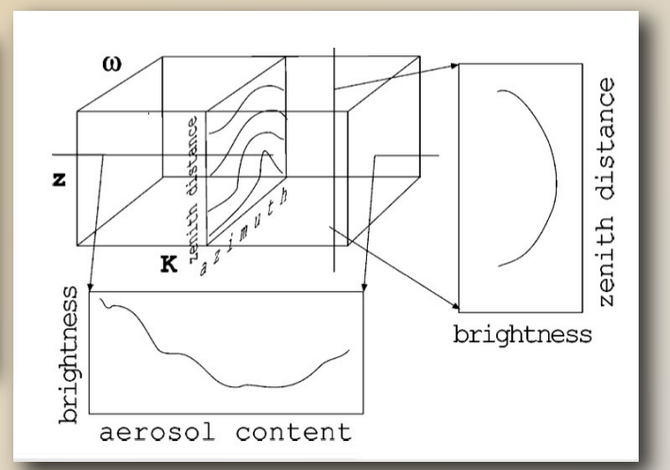




night sky brightness and stellar visibility at individual sites

polar maps cartesian maps hypermaps

Cinzano, Elvidge 2004, MNRAS, 353, 1107-1116



New indicators of light pollution:

(i) the **sky irradiance** (or the illuminance) **on the earth surface**, which has effects on the luminosity of the ground surface and on the luminosity of the night environment as perceived by animals, plants and the man (where direct irradiance by nearby lighting installations is not overwhelming);

(ii) the **radiation density in the atmosphere**, which is the energy (or the light or the number of photons) per unit volume of atmosphere in course of transit, in an unit time, in the neighborhood of the point (x, y, z). UNITS: photon density in ph m^{-3}, luminous density in Tb m^{-3}, where Talbot (lm * s) is the unit of luminous energy.
It can be split in **upward and downward radiation densities**, which quantify approximately the light coming back toward the soil and going toward the outer Space. The **radiation density due to direct illumination** by the sources, gives the *direct* light travelling through a unit volume of atmosphere.

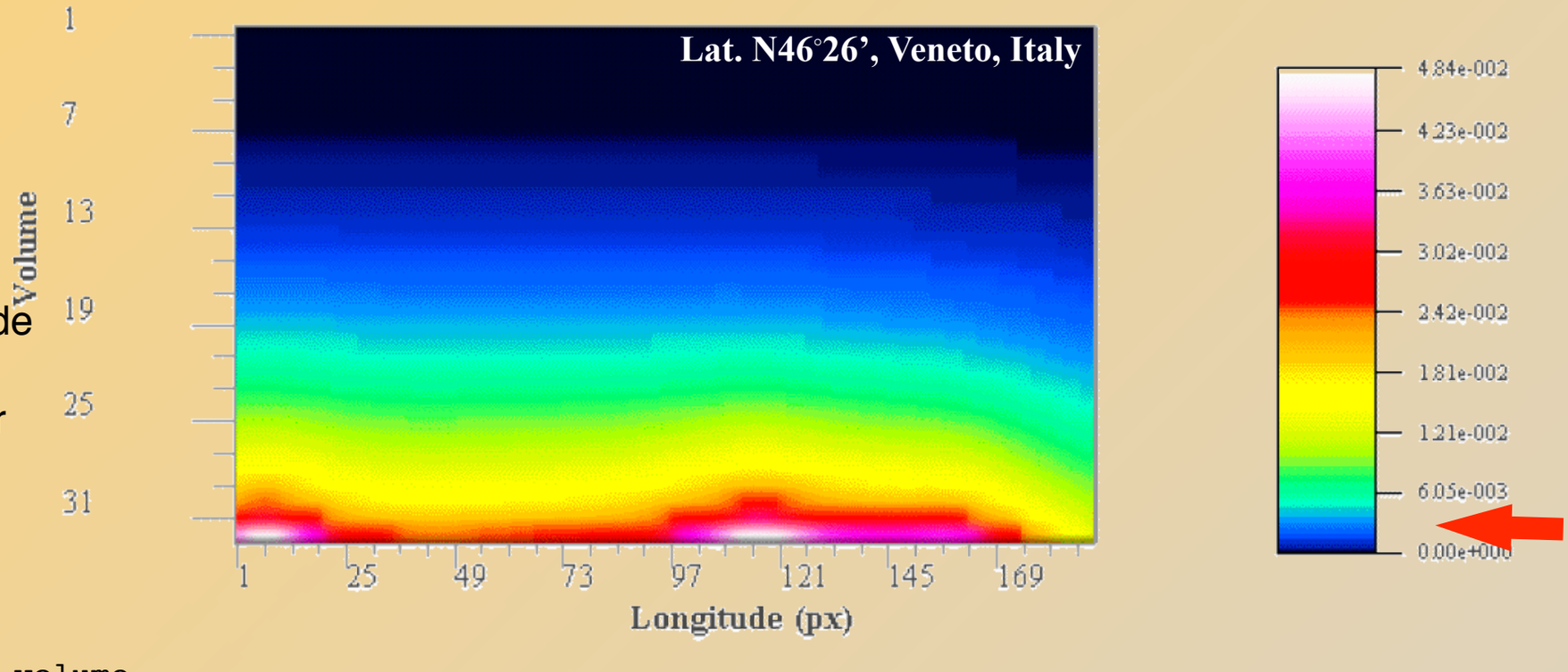
(iii) the **upward and downward scattered flux densities**, which are the flux density of the scattered radiation; the downward one, in particular, quantifies the ”strength” of the unit volume of atmosphere at position (x, y, z) as secondary source of light pollution when subjected to the considered light polluting action. UNITS: density of flux in ph s^{-1} m^{-3} or lm m^{-3}.

These integrated quantities are useful only as generic indictors of the alteration of the atmosphere. The effects of the atmosphere as secondary source of light pollution must be evaluated based on the intensity of light at each position $I_\lambda(x, y, z, \theta, \phi)$.

Tomography of light pollution

LPTRAN/LPDART Preliminary Data **© Cinzano/ISTIL 2004**

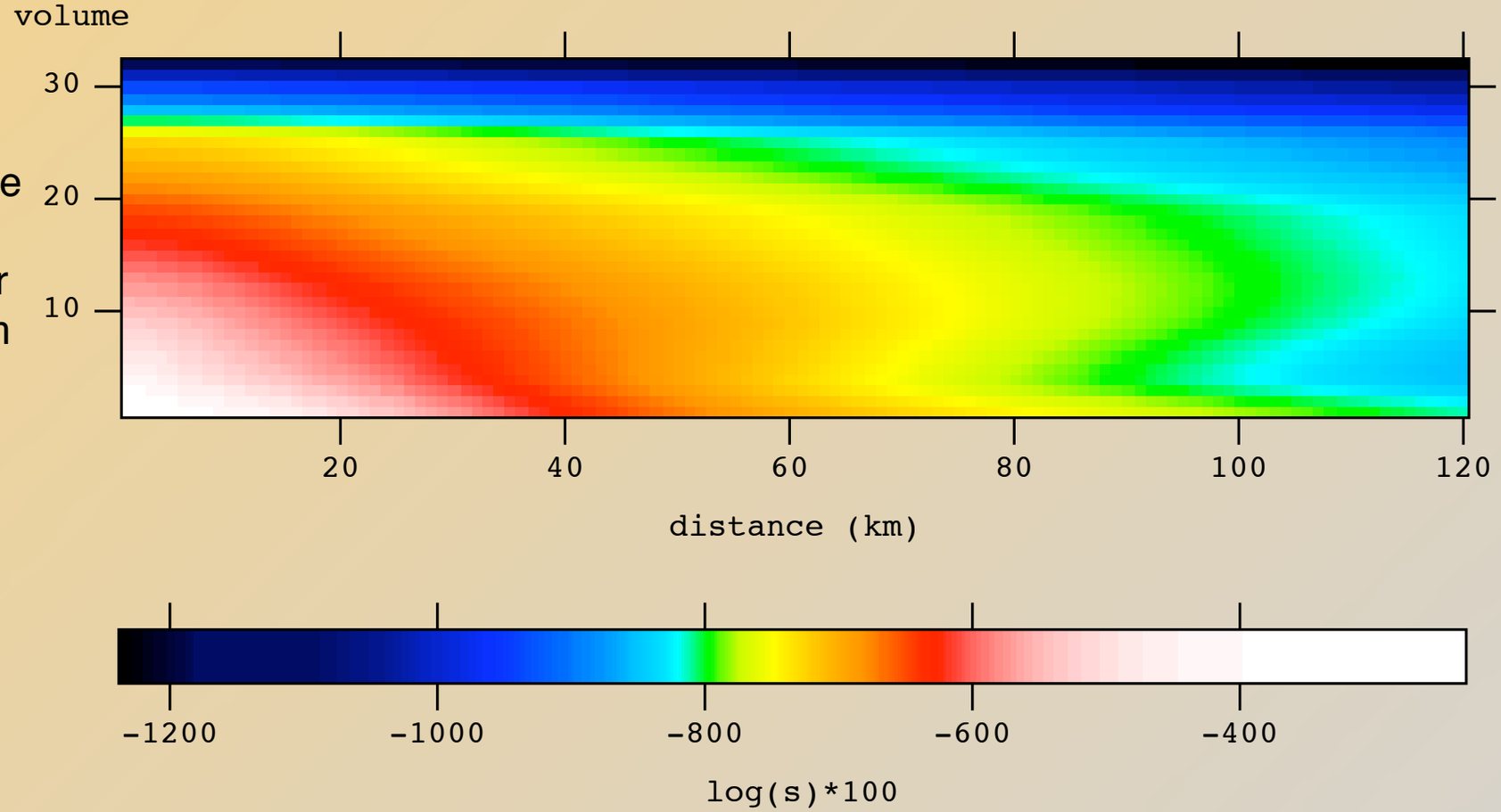
Downward radiation density in the atmosphere above a line at constant latitude in function of the volume index number and the position.



Tb/km^3

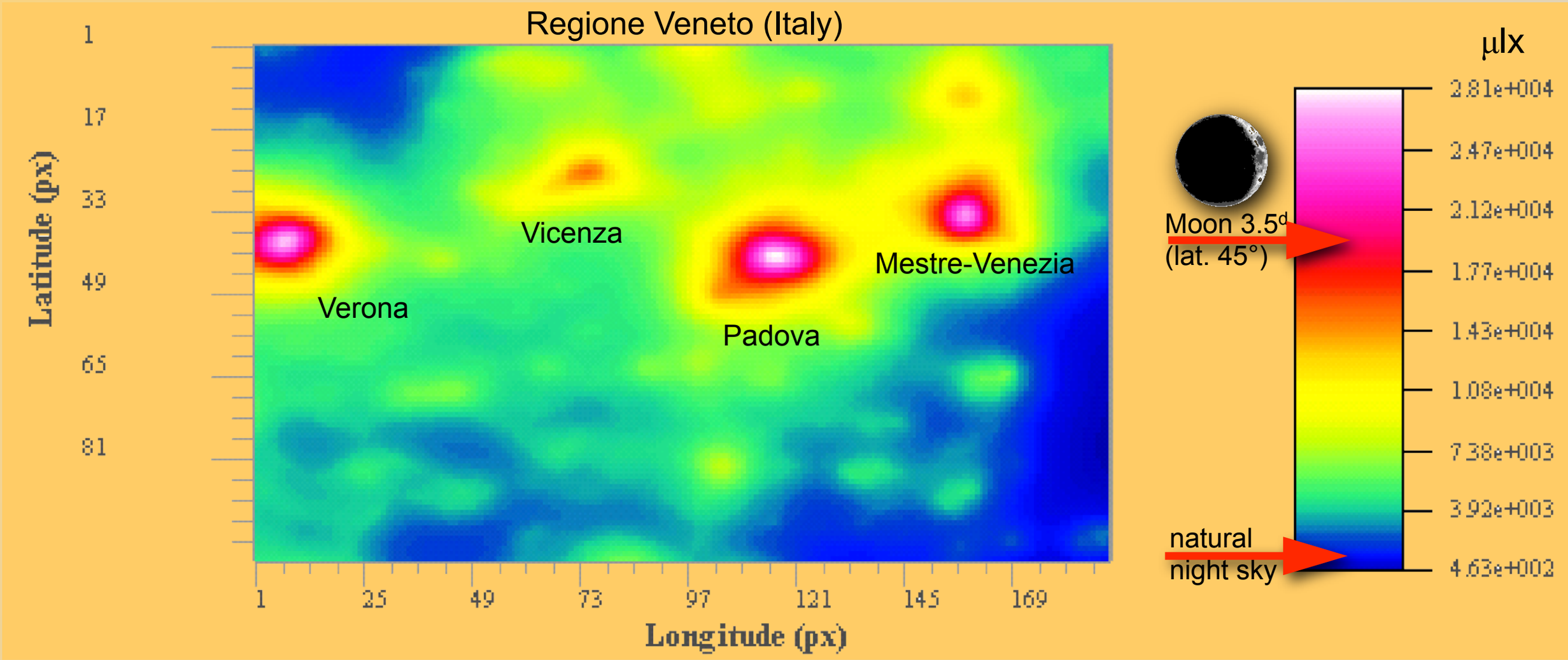
The natural luminous density is approximately of the order of $3 \cdot 10^{-3}$ Tb/km^3

Light flux scattered downward by an unit volume of atmosphere in function of the volume index number and the distance from an unit source.



Illuminance/irradiance at soil from scattered light

LPTRAN/LPDART Preliminary Data



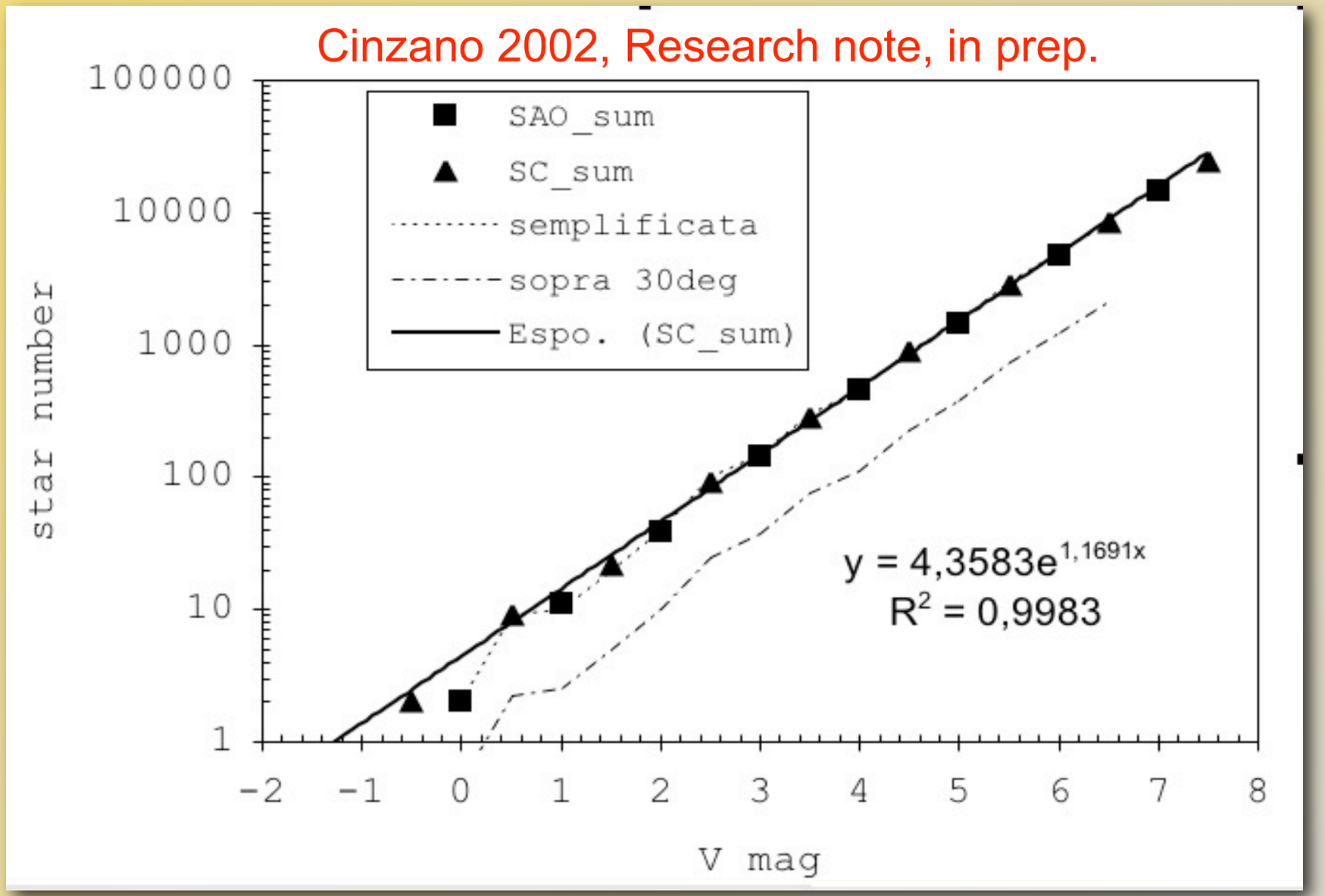
Visible stars

- 0 - 200
- 200 - 400
- 400 - 700
- 700 - 1000
- 1000 - 1300
- 1300 - 1900

Cinzano 2002, Research note, in prep.

No biunivocal relation between the number of visible stars and the zenith limiting magnitude:

- V mag vs. star number is not exactly exponential and not well defined in catalogues
- sky brightness changes with the direction of observation: required integration over the visible emisphere or modelling
- extinction and star apparent magnitude change with elevation



New Computational techniques

New output products and indicators

New methods for validation of results and new observational campaigns

Cinzano
Falchi
Falchi & Cinzano

New methods in satellite data analysis

We want improve the validation with Earth-based observations of the night sky brightness computed from OLS-DMSP data

Cinzano, Elvidge 2004, MNRAS, 353, 1107–1116

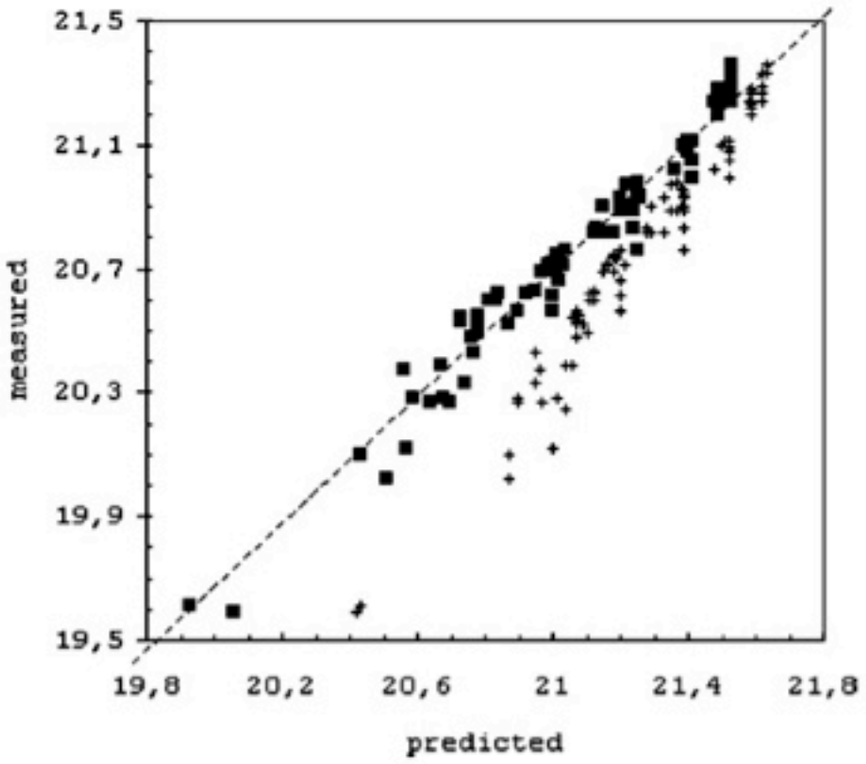


Figure 4. Comparison between predictions and V-band measurements at Sunrise Rock for atmospheric clarities $K' = 0.5$ (squares) and $K' = 3$ (crosses). Units are mag arcsec^{-2}.

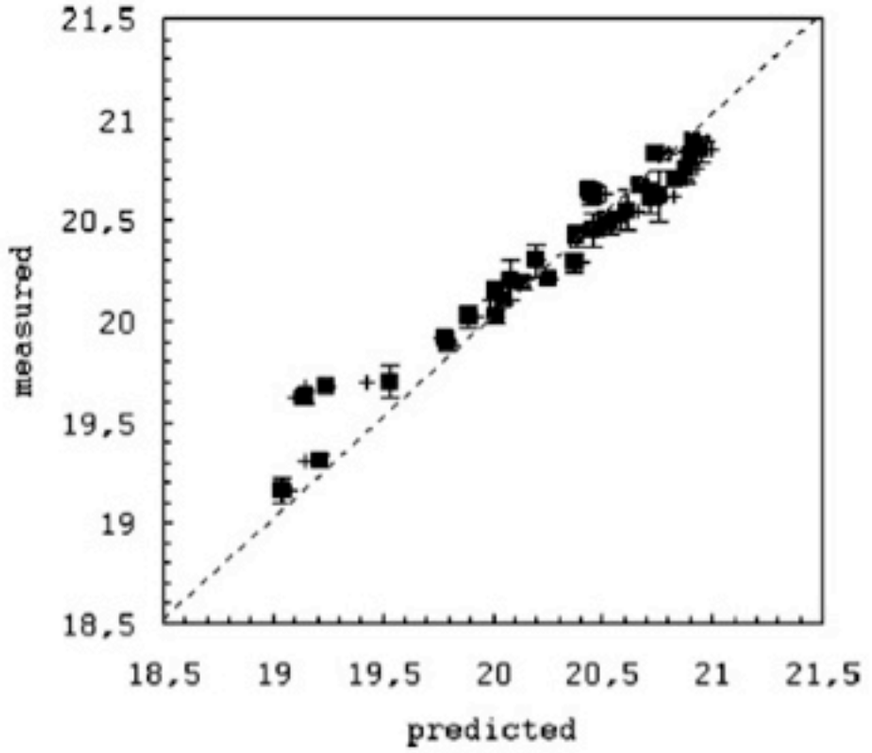
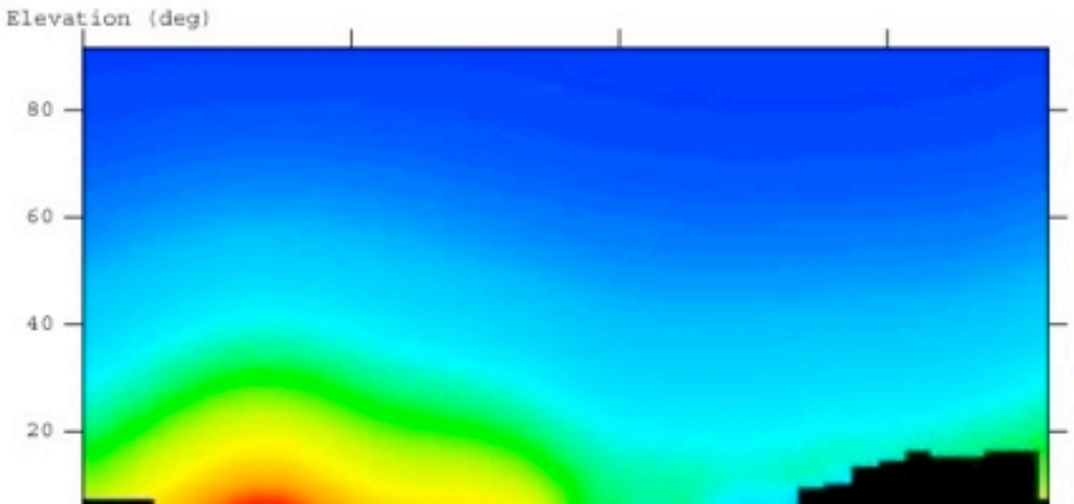
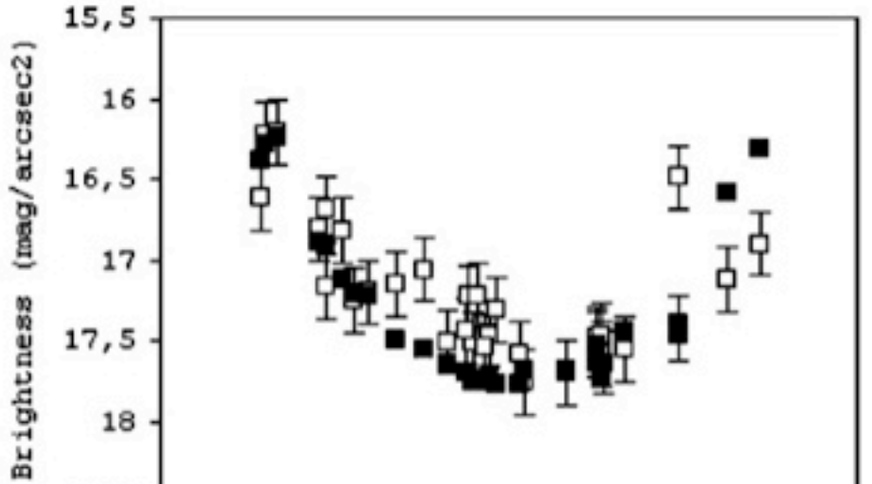


Figure 6. Comparison between predictions and V-band measurements at Serra la Nave Observatory for atmospheric clarities $K' = 1$ (squares) and $K' = 2$ (crosses). Units are mag arcsec^{-2}.





1) search for better instruments and procedures

the goal is the situation of the light pollution in the territory, then a lot of measurements in many different sites, each clean night, are needed. **Main requirements:**

- **fast movements of the observer across the territory**, possibly returning at the same site at different times in the same night, so the number of measured sites in a night should depend almost exclusively on the transfer times from one site to the following one
- measurements should be taken *each* night resulting clean over the entire territory for long times (because they are not many). This interact with private life of the observer so the **measurement process should be not awkward** or the observer will give up

Needed fast "point-and-shot" mobile instrument with short setup times, easy to manage, portable, accurate, not requiring awkward data reduction

Choices:

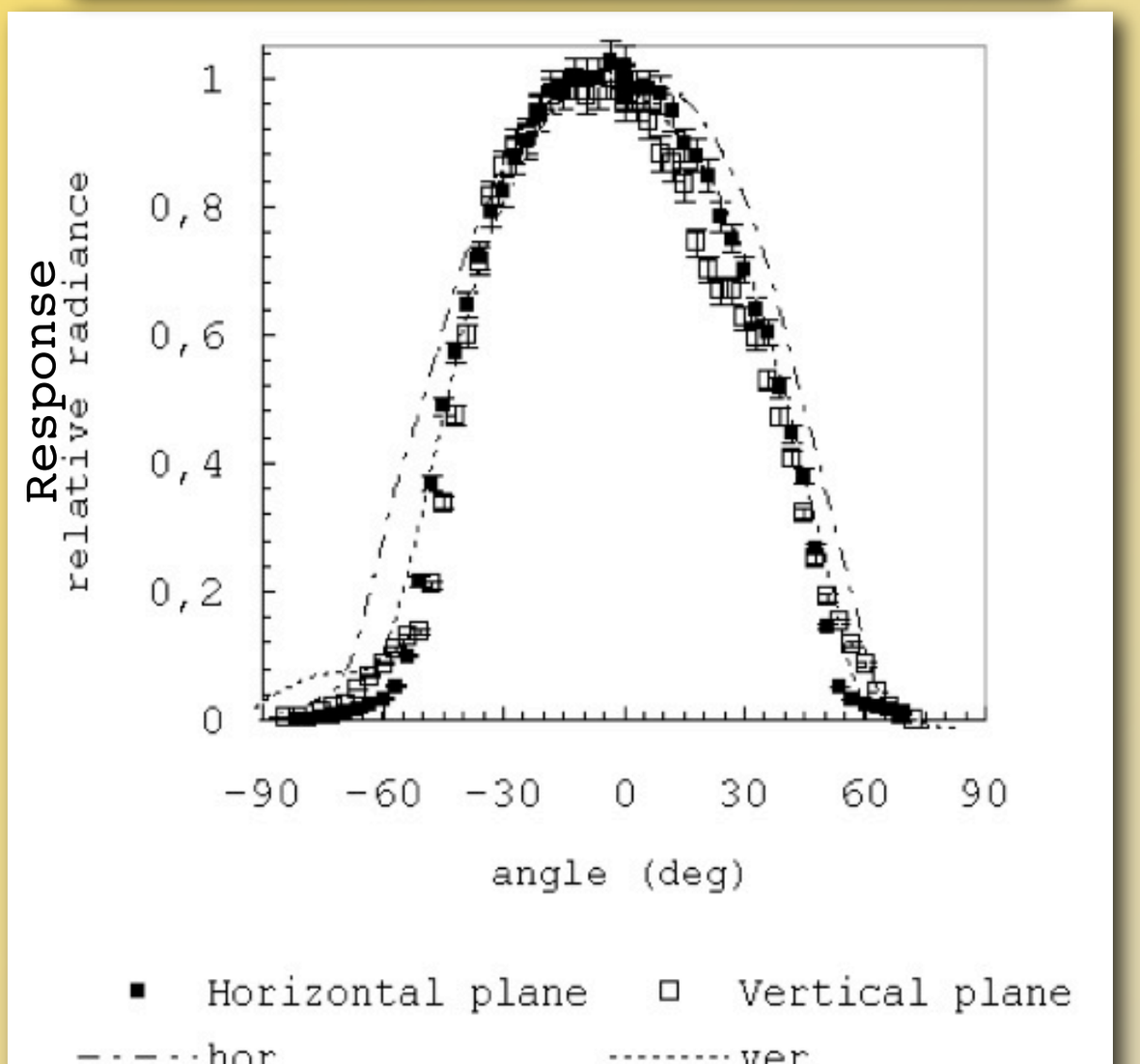
- **automatized portable CCD imagers:** accurate measurements of both brightness and aerosol content (extinction) but not so quick setup, professional data reduction required (e.g. WASBAM and WASBAM-SSH with spectrographic capabilities, Cinzano, Falchi 2003, Mem. Soc. Astron. It., 74, 458-459; Cinzano 2004, Mem. Soc. Astron. It. Suppl., 5, 395-398)
- **mobile fish-eye CCD cameras pointed at zenith:** fast setup, professional data reduction required, geometric corrections, some limitations (e.g. Duriscoe 2004, IDA Meeting, Tucson; see also CONCAM webcam network, Nemiroff & Schwarz 2003, AAS; Hollan, this meeting)
- **portable research radiometers:** point-and-shoot, very accurate, continuous sampling, but no measure of the atmospheric situation so external data are needed (e.g. LPLAB radiometer, Cinzano 2003, Mem. Soc. Astron. It. Suppl., 3, 312-315)
- **sky quality meters:** super-quick but not best accuracy, atmospheric data needed; they require accurate characterization and that the user “understand” the instrument (Cinzano 2005, Night sky photometry with Sky Quality Meter, ISTIL Internal Report, 9)

Sky Quality Meter

Characterization:

Cinzano 2005, Night sky photometry with Sky Quality Meter, ISTIL Internal Report, 9

http://www.lightpollution.it/download/sqmreport.pdf



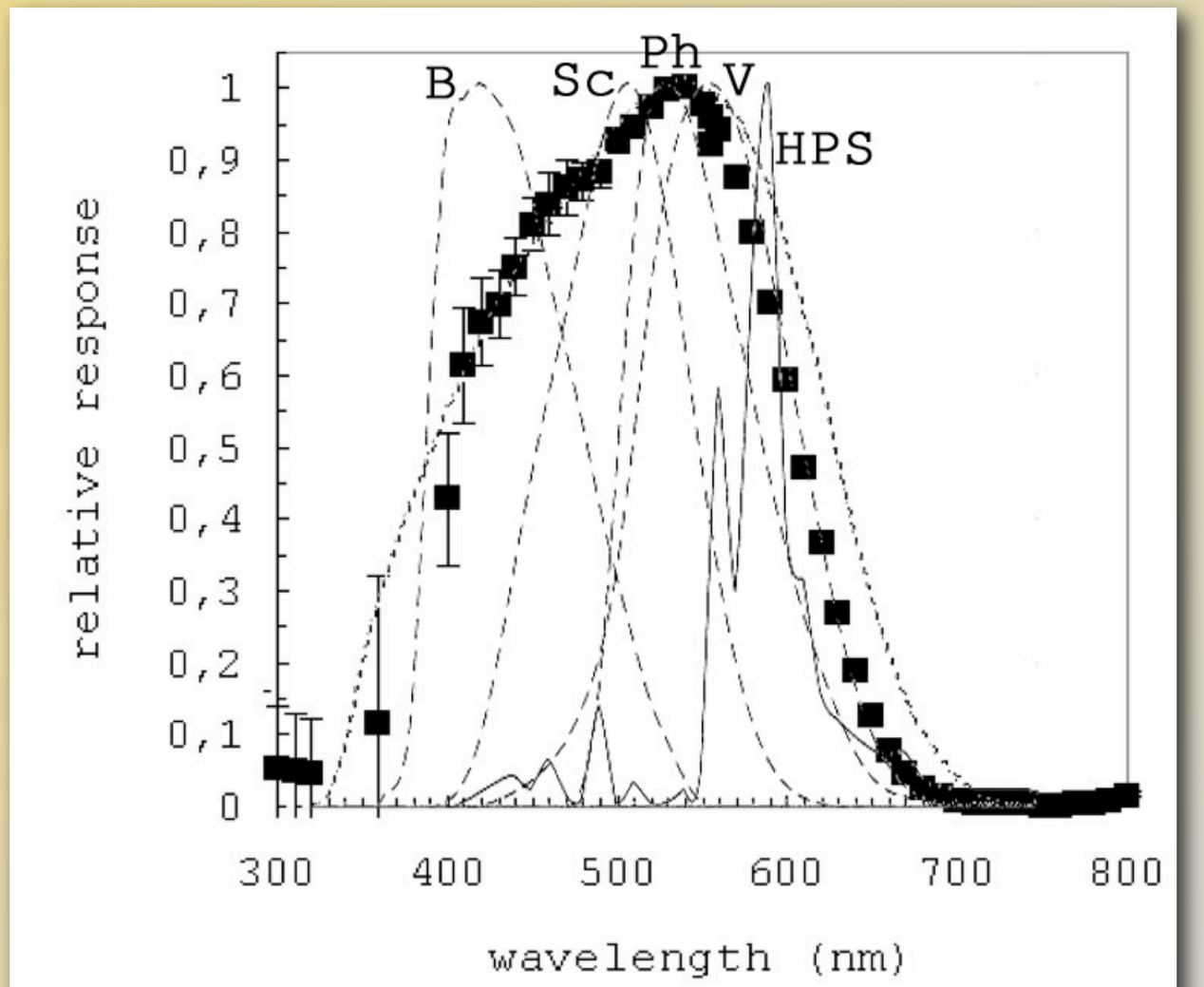


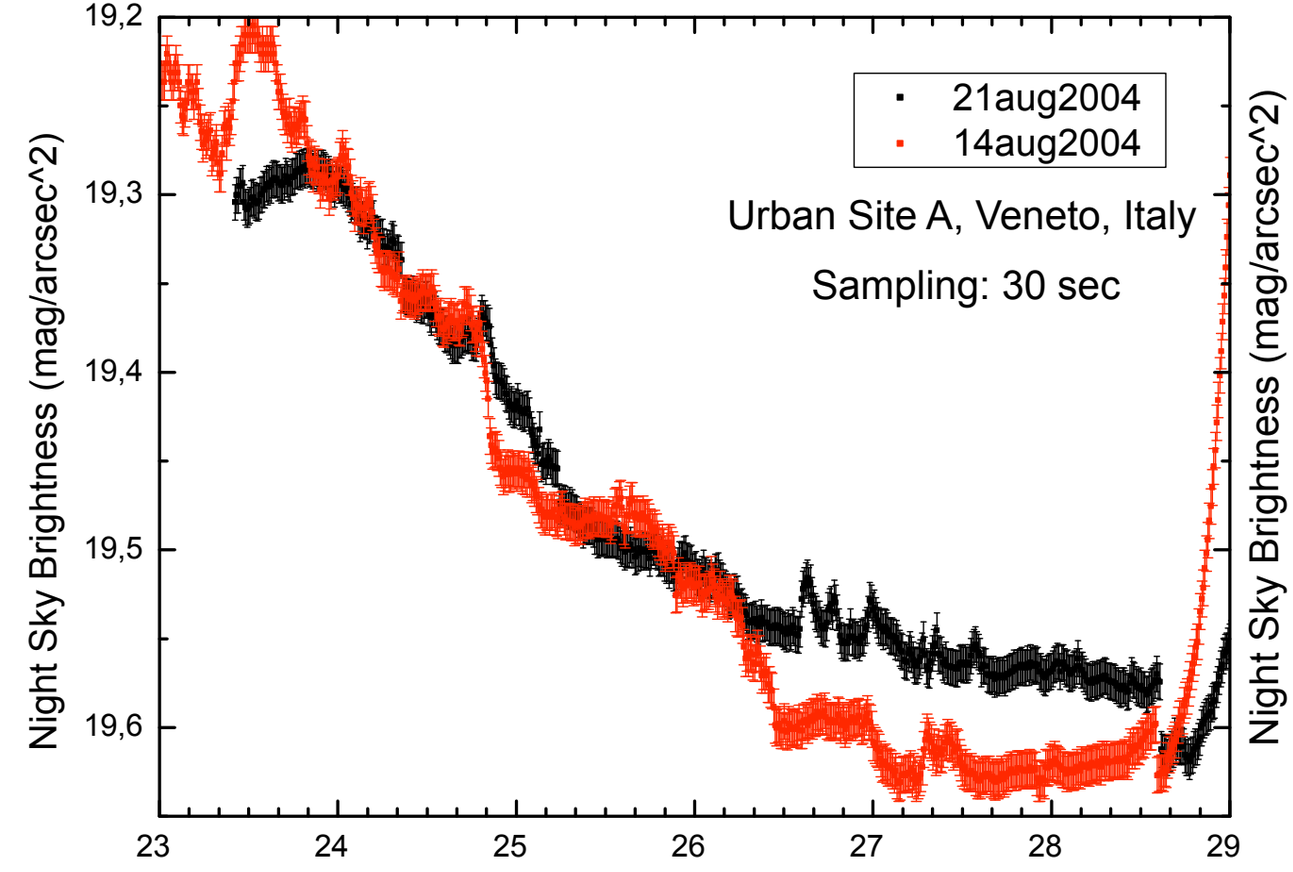
Fig. 9.— Measured SQM responsivity (squares) and calculated SQM responsivity (line).

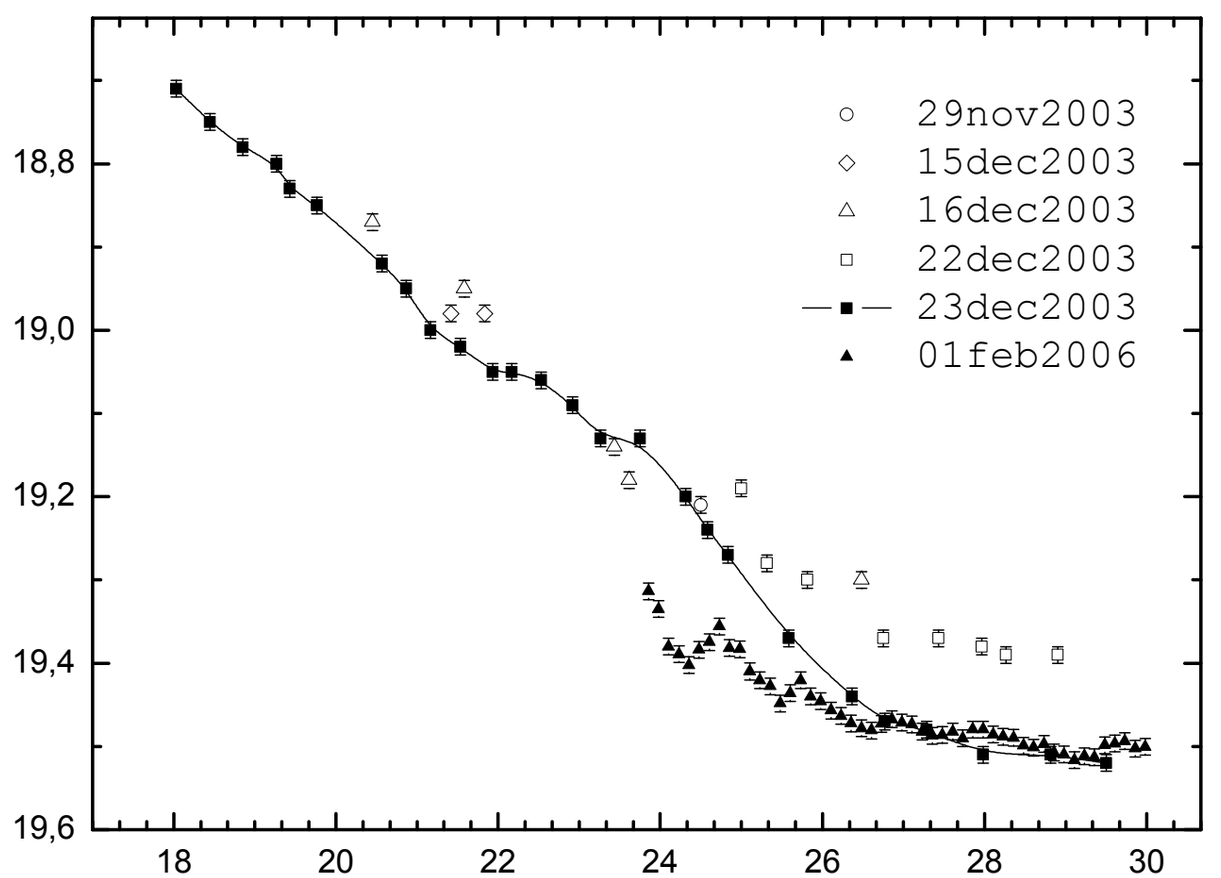
2) improvements of method of measure

(Cinzano, Falchi, various papers in prep.)

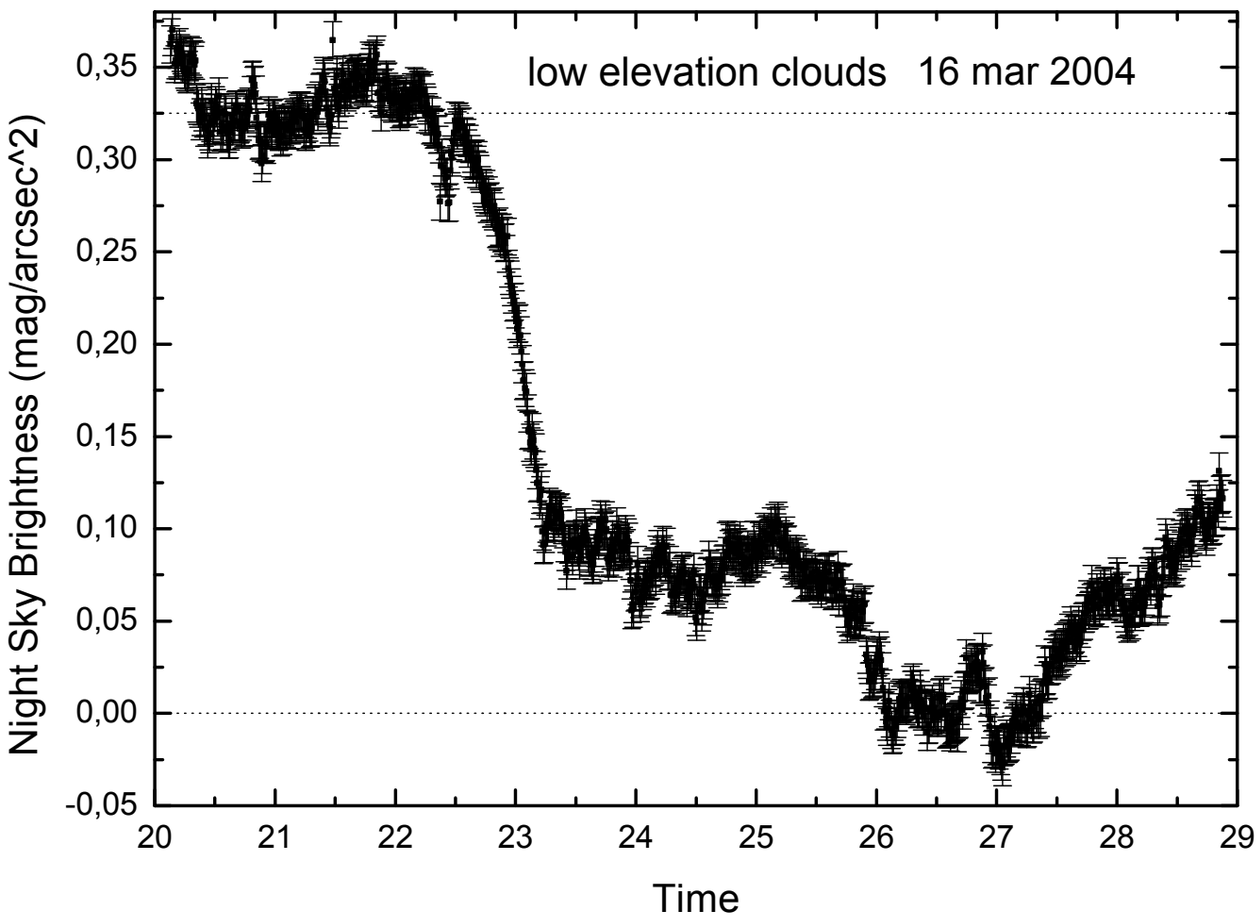
Measurements needs to be:

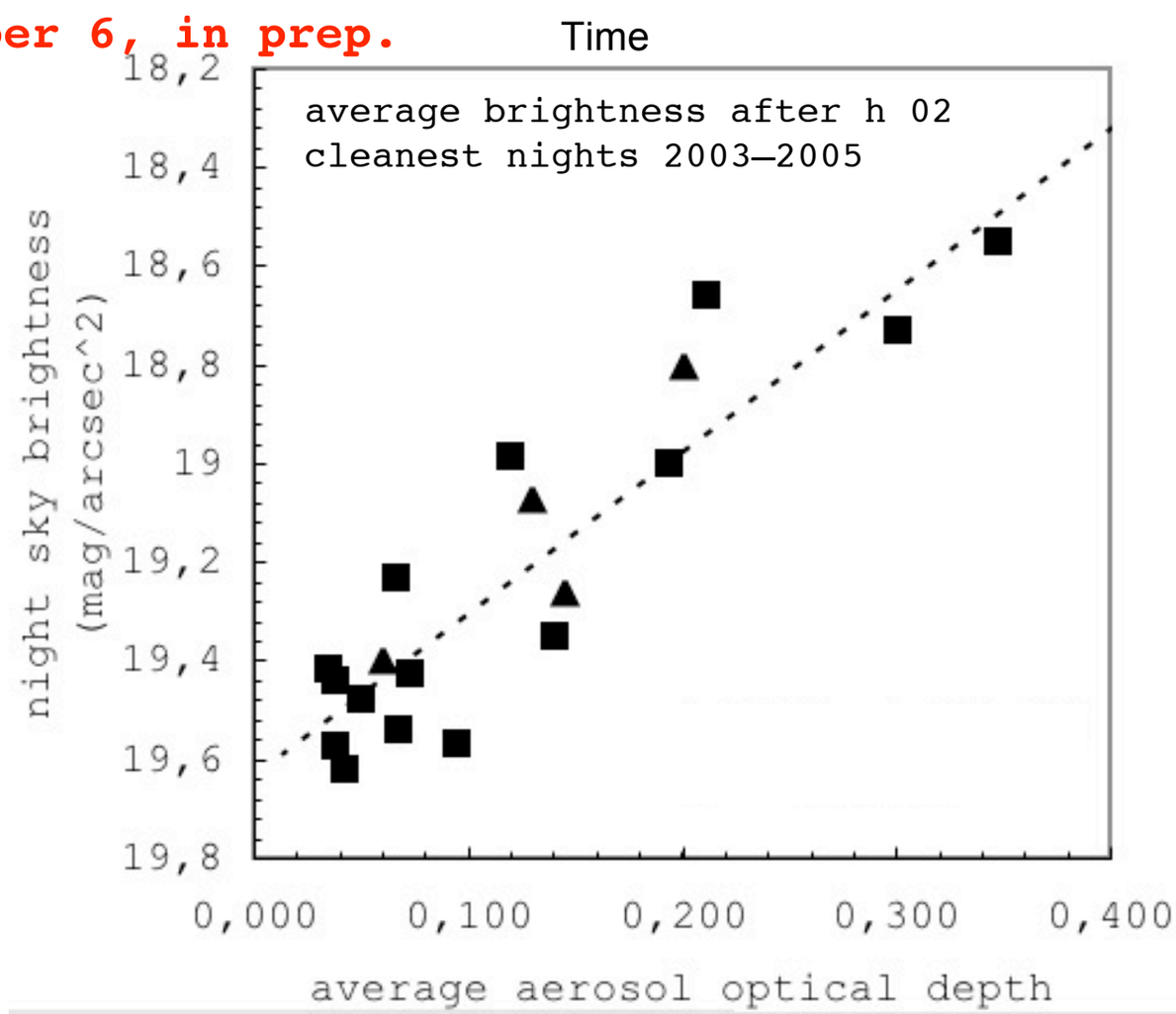
- accurate (high accuracy and stable instrument with accurate calibration)
- taken in an accurately shaped passband (wide-field instruments are calibrated over a laboratory source rather than over stars so proper filters need to be fitted to the detector response or passband mismatch correction)
- independent from the time of the night (they should be taken all at the same time of the night - first or second part of the night - frequent sampling allow minimizing atmospheric fluctuations by averaging e.g. over 1 hour)
- independent from atmospheric conditions (to obtain an atmospheric independent measurement requires a large sample of data from the same site taken in many clean nights along one or more years with contemporary measurements of atmospheric aerosol optical depth (stellar extinction or lidar measurements taken inside the polluting area)





Cinzano 2005, paper 6, in prep.

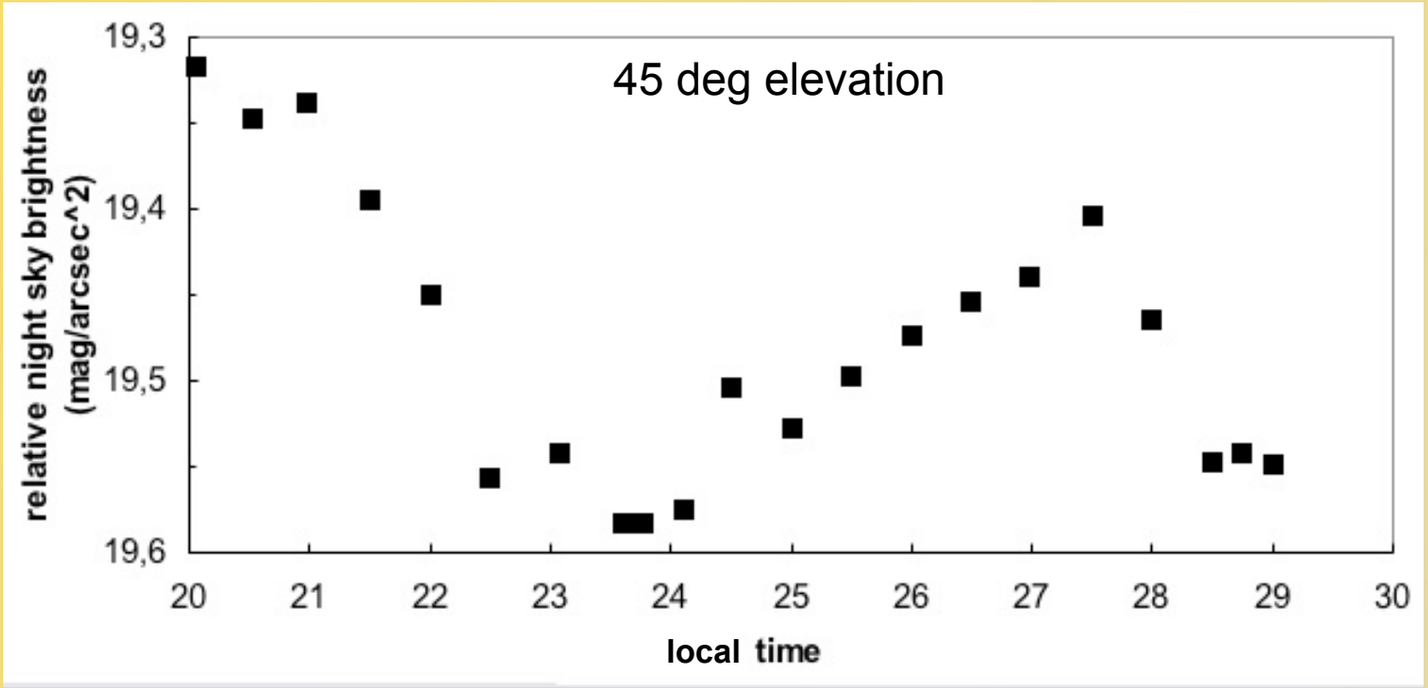


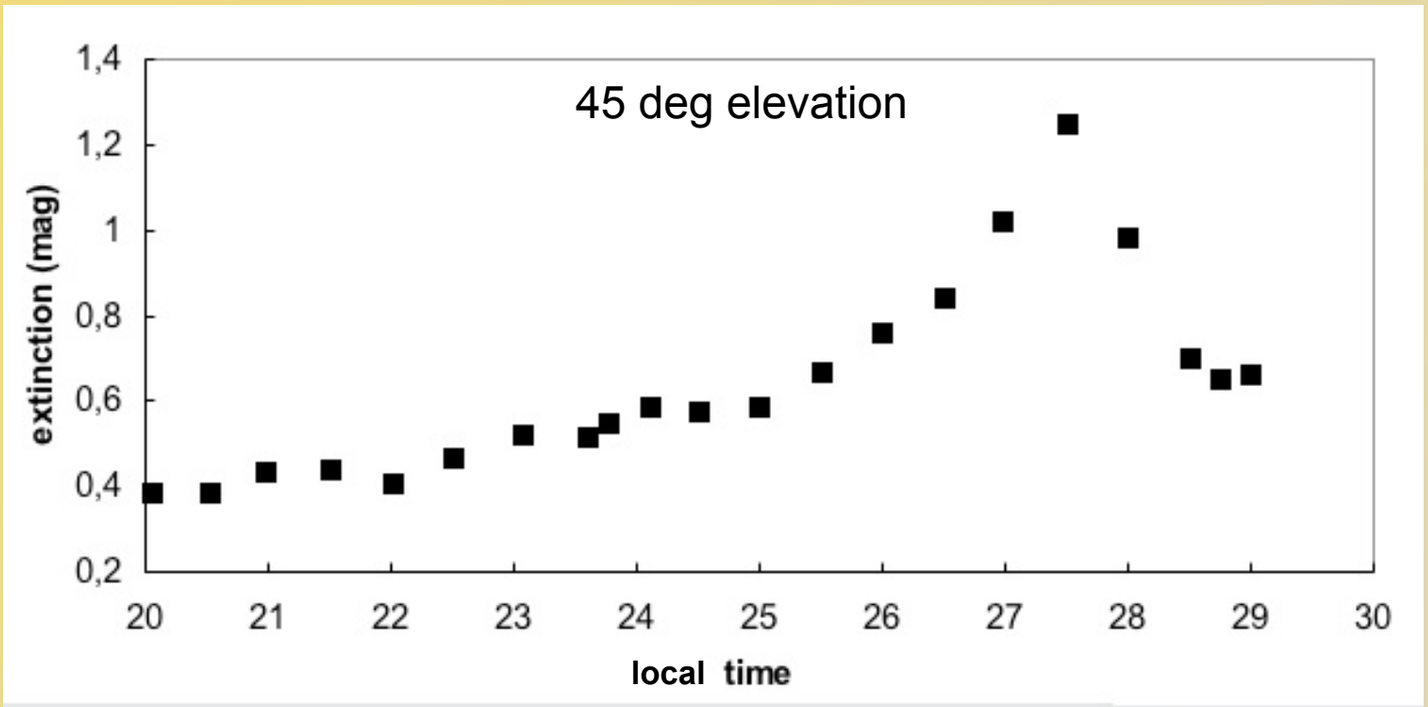


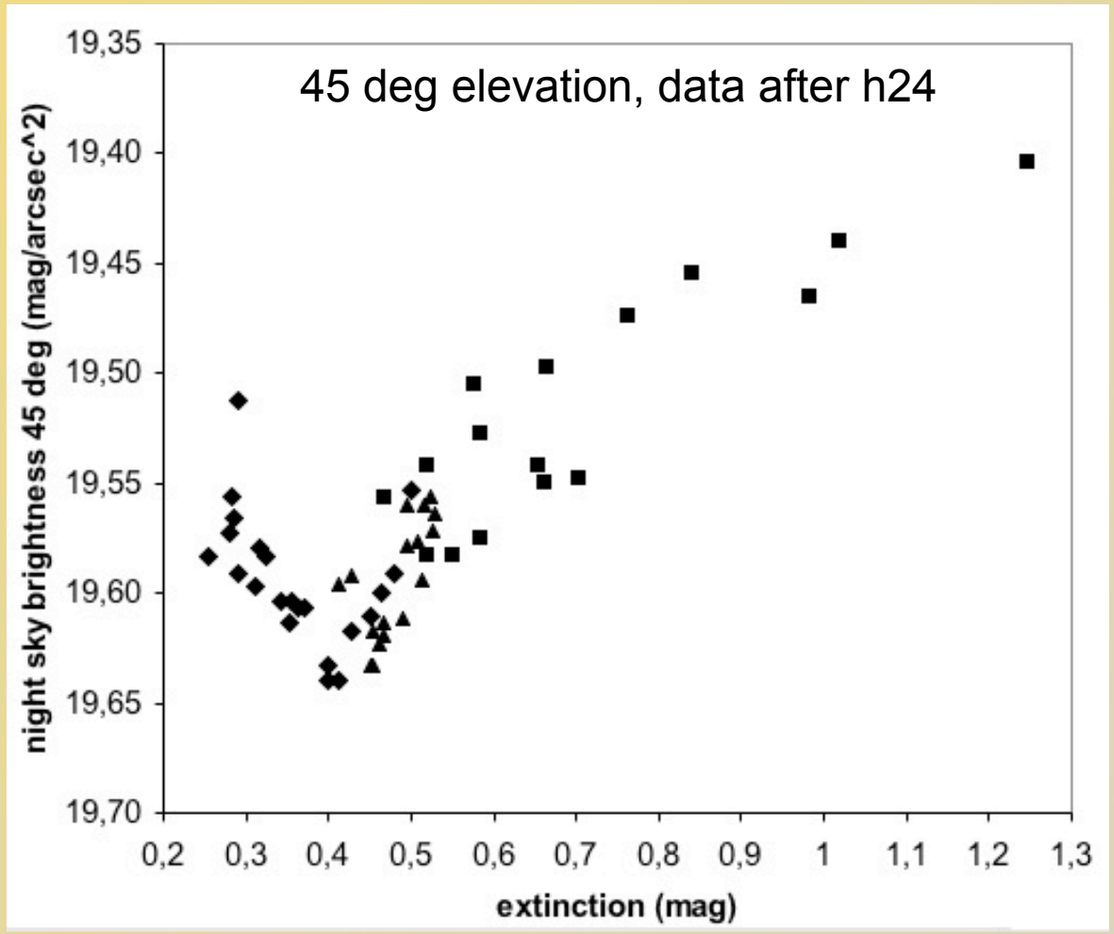
Quantification of the atmospheric aerosol content is mandatory

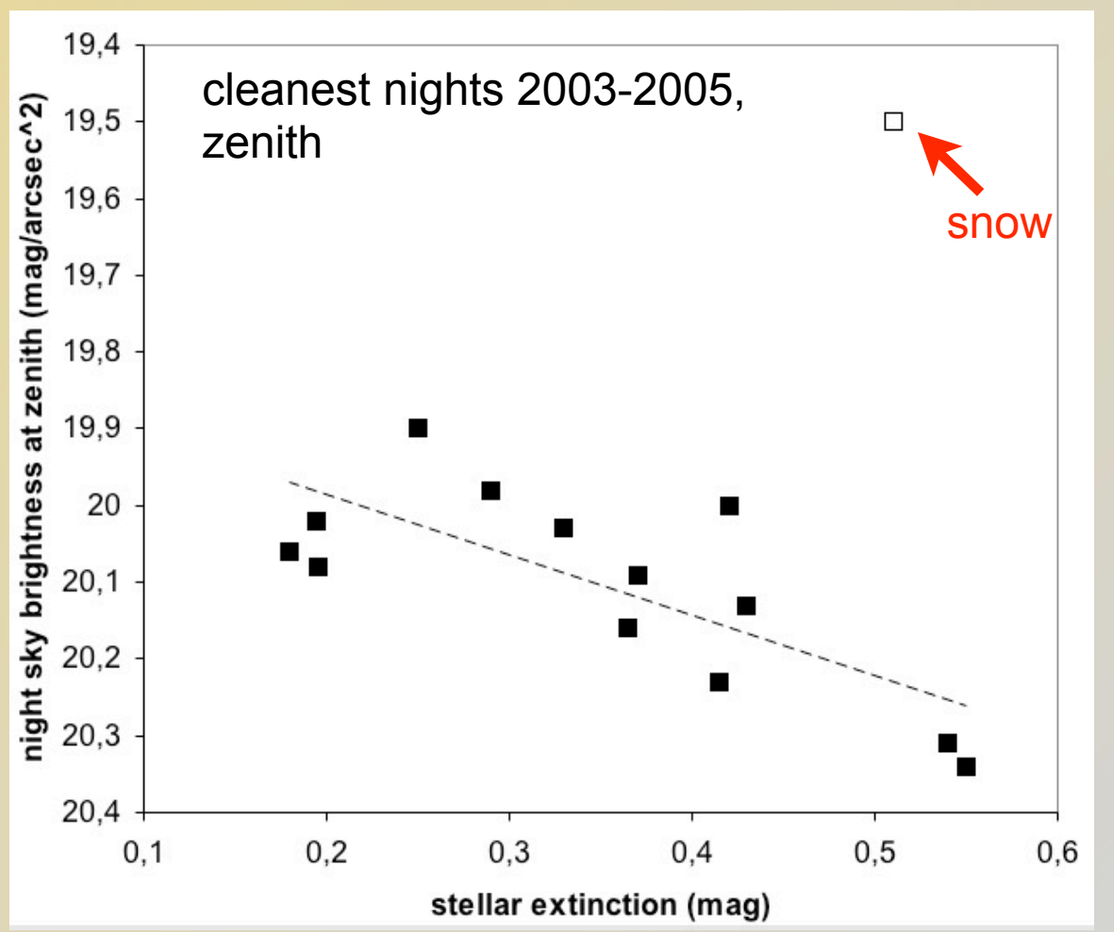
here another example

Falchi, Cinzano 2006, in prep.





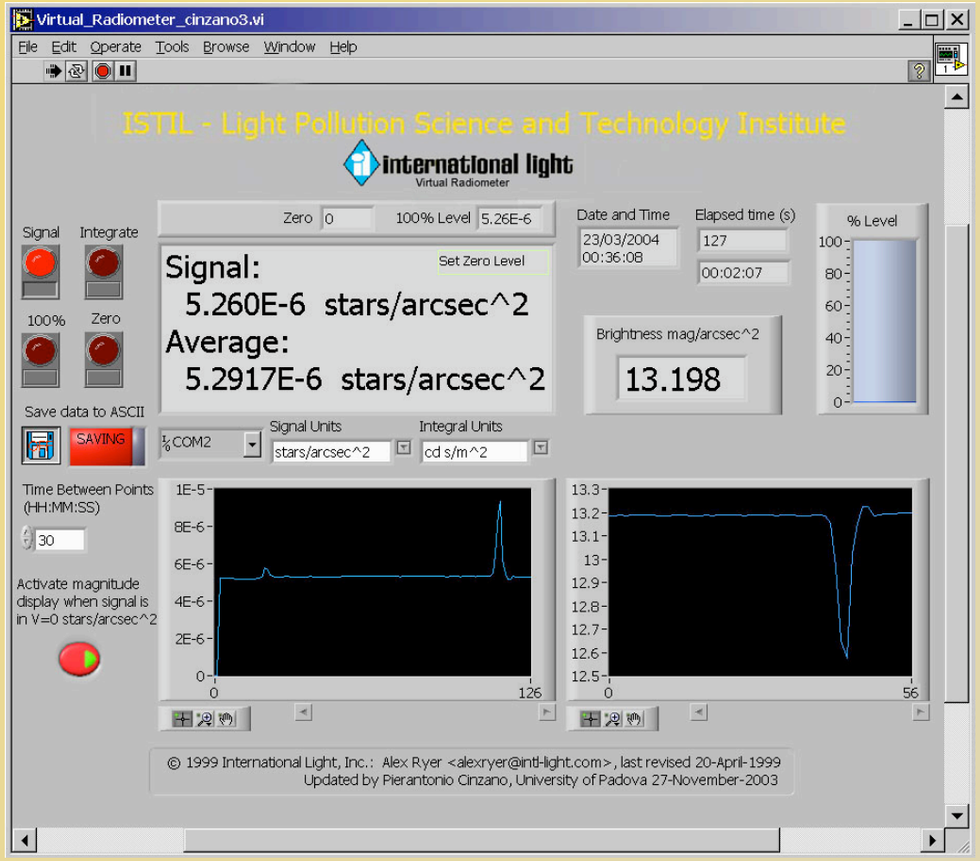




3) solution of primary issues of photometry and radiometry of light pollution at LPLAB (Cinzano, various papers in prep.)

- ☑ Procedures for characterization and testing of instruments
- ☑ Procedures for calibration of instruments
- ☑ Calibration of a TTL luminance-meter over the Moon
- ☑ Laboratory calibration of large-field radiometers in V band
- ☑ Conversion between CIE photopic and astronomical V band
- ☑ Effects and correction of passband mismatch
- ☑ Procedures for photometrical and spectral data reduction

☑ Development of software for instruments management (LABVIEW)



4) New observational campaigns

- **Campaign for photometric measurements of night sky brightness and atmospheric extinction**
- Dip. Astronomia, Università Padova (5/2003-11/2005)
- ISTIL, Thiene (after 11/2005)
- observer: Fabio Falchi
- wide field automatic CCD camera (like WASBAM)
- B,V night sky brightness and stellar extinction
- aim: map validation and brightness-aerosol relationship
- 1600 frames, more than 1000 brightness measurements on a 37 points grid in 22 clean nights from 8 Italian sites
- <u>contemporaneity with low gain DMSP measurements</u>

- **Light pollution measurements in urban areas**
- ISTIL, Thiene (2003-2006)
- observer: Pierantonio Cinzano
- portable research radiometer
- V night sky brightness at zenith from an urban site
- aim: measurement in urban areas and relationship brightness-atmospheric content
- 39 nights with 30^{s} sampling or random sampling
- <u>aerosol optical depth measurements in the same day</u>

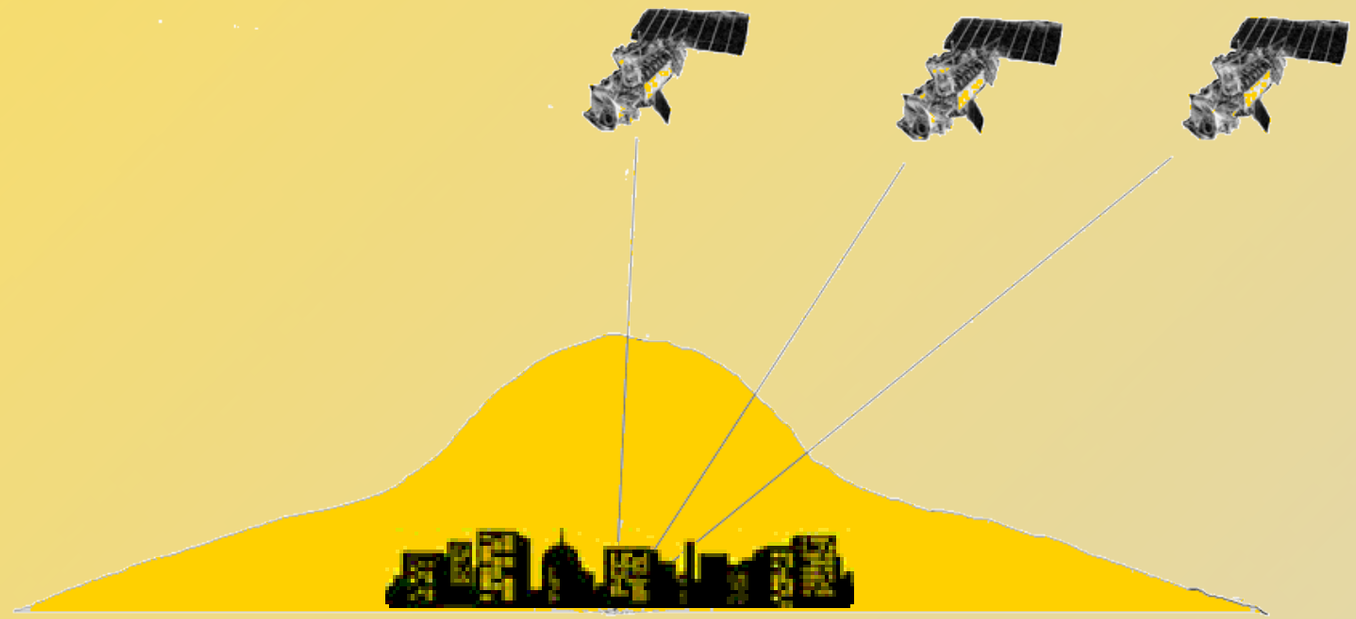
New Computational techniques

New output products and indicators

New methods for validation of results and new observational campaigns

New methods in satellite data analysis

Elvidge
Cinzano
Cinzano, Falchi & Elvidge
Falchi, Cinzano & Elvidge

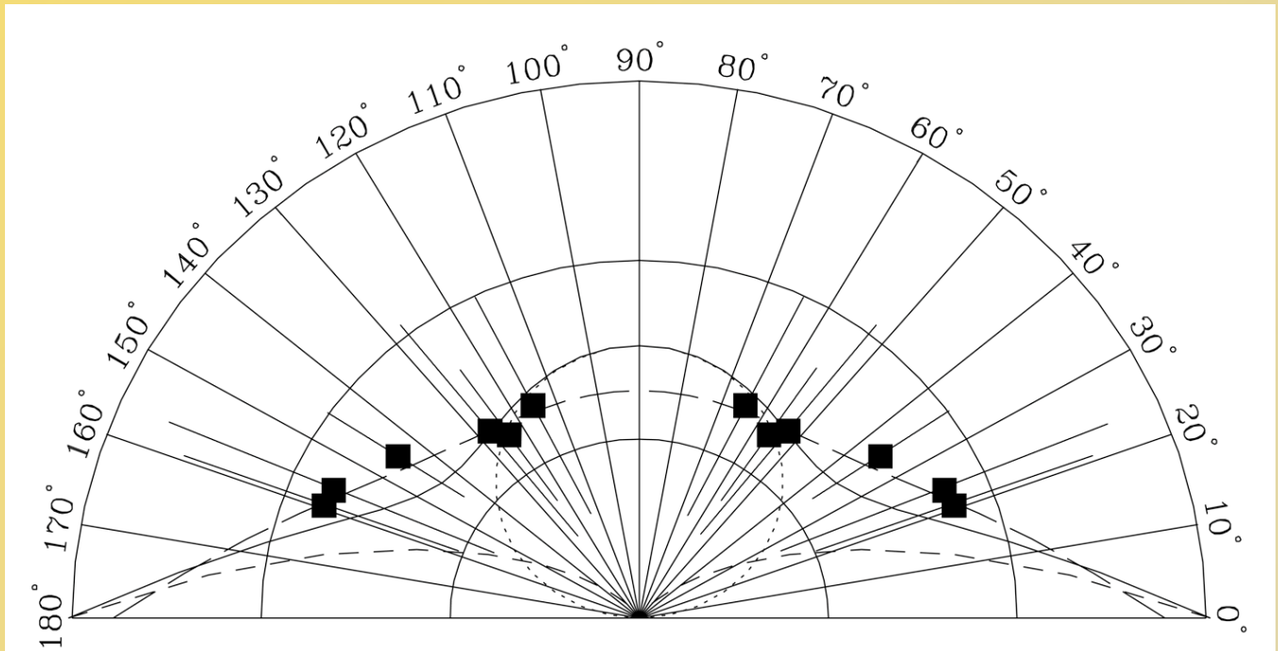


maps of light emission near zenith ⇔ OLS-DMSP ⇒ upward emission function (normalized intensity)

New extended data sets (Falchi, Elvidge) and improved reduction (Elvidge)

- visible band geolocated images in 30 arc second grids with both low gain and high gain, extended to large view angles (~80° from nadir)
- scan angles from the OLS toward the Earth
- times of observation of each scan line
- thermal band images
- thermal band brightness temperature difference from NCEP surface
- temperature model
- flags (data quality labels, clouds, snow, etc.)
- lunar illuminance

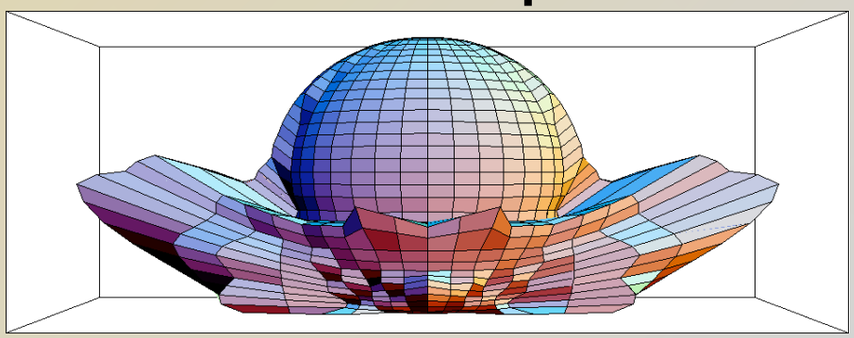
We want improve our knowledge of the upward emission function of cities

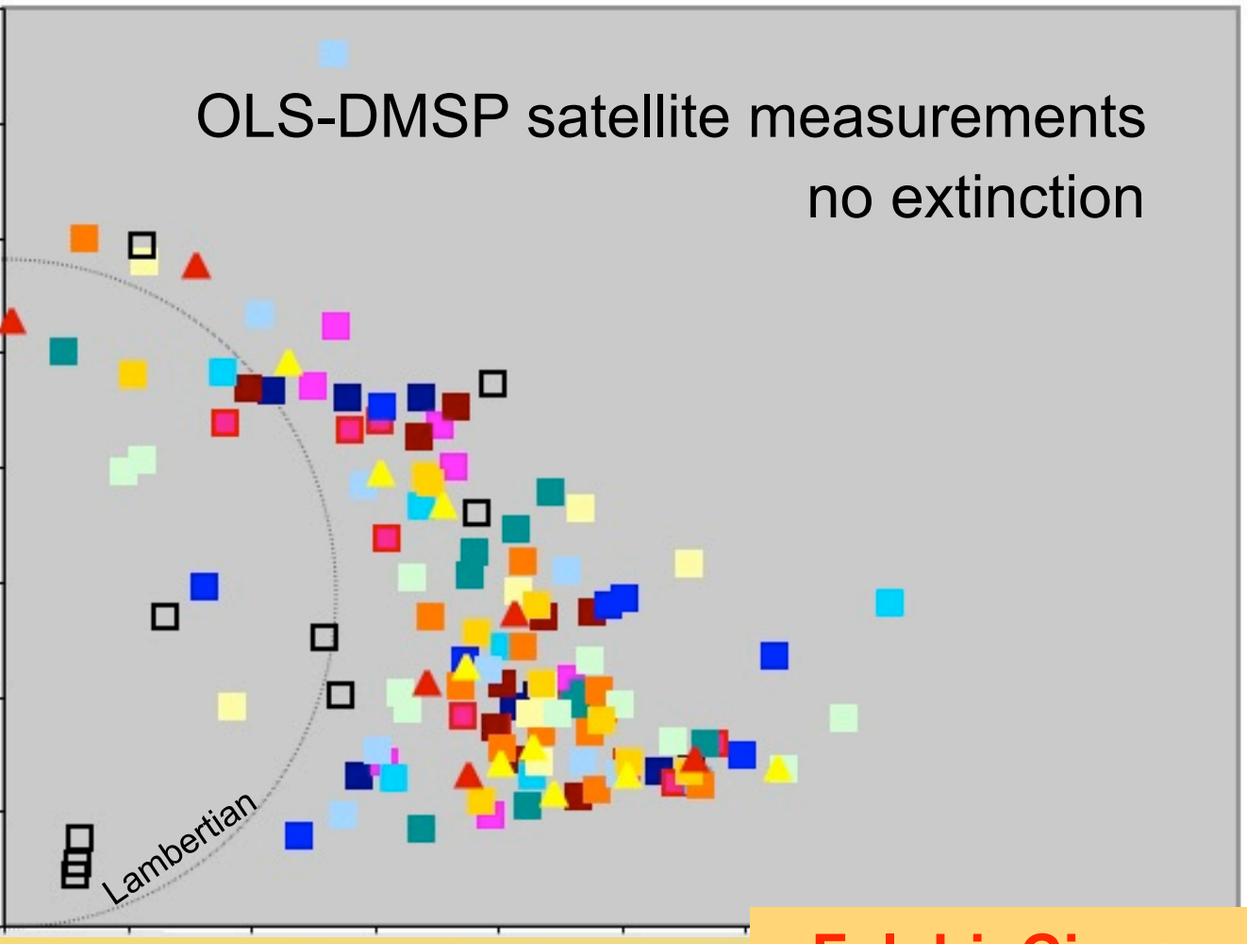


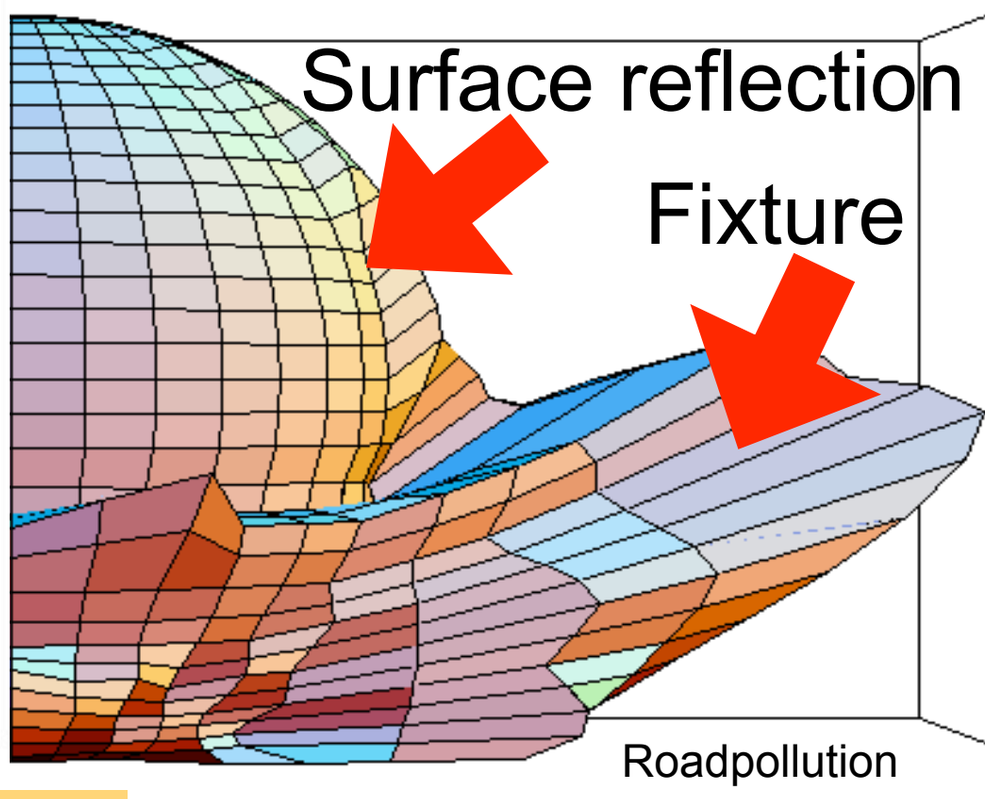
Cinzano, Falchi, Elvidge, Baugh, 2000, MNRAS, 318, 641–657

Three methods, in progress:

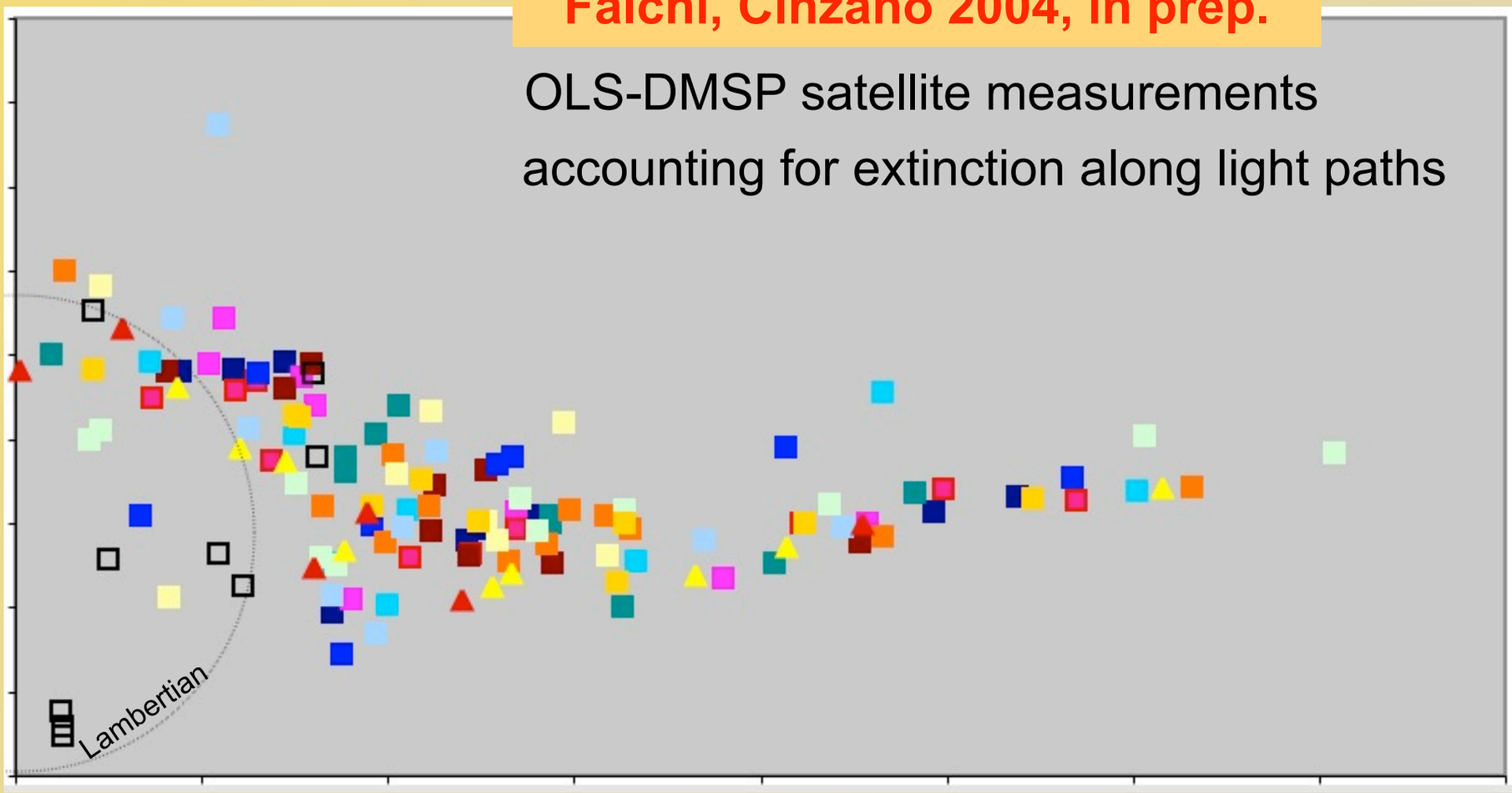
- satellite measurements (analysis software under testing, required OLS angular response i.e. "standard sources" on Earth surface, Moon illuminance software done) (Cinzano, Falchi, Elvidge, in prep.)
- earth-based measurements with inversion of models (software under testing, some revision planned) (Cinzano, in prep.)
- modelling of cities by summing the functions of a sample of lighting installations randomly oriented (extension of *Roadpollution* software, models required for the city lighting and its environment) (Cinzano, to be done)





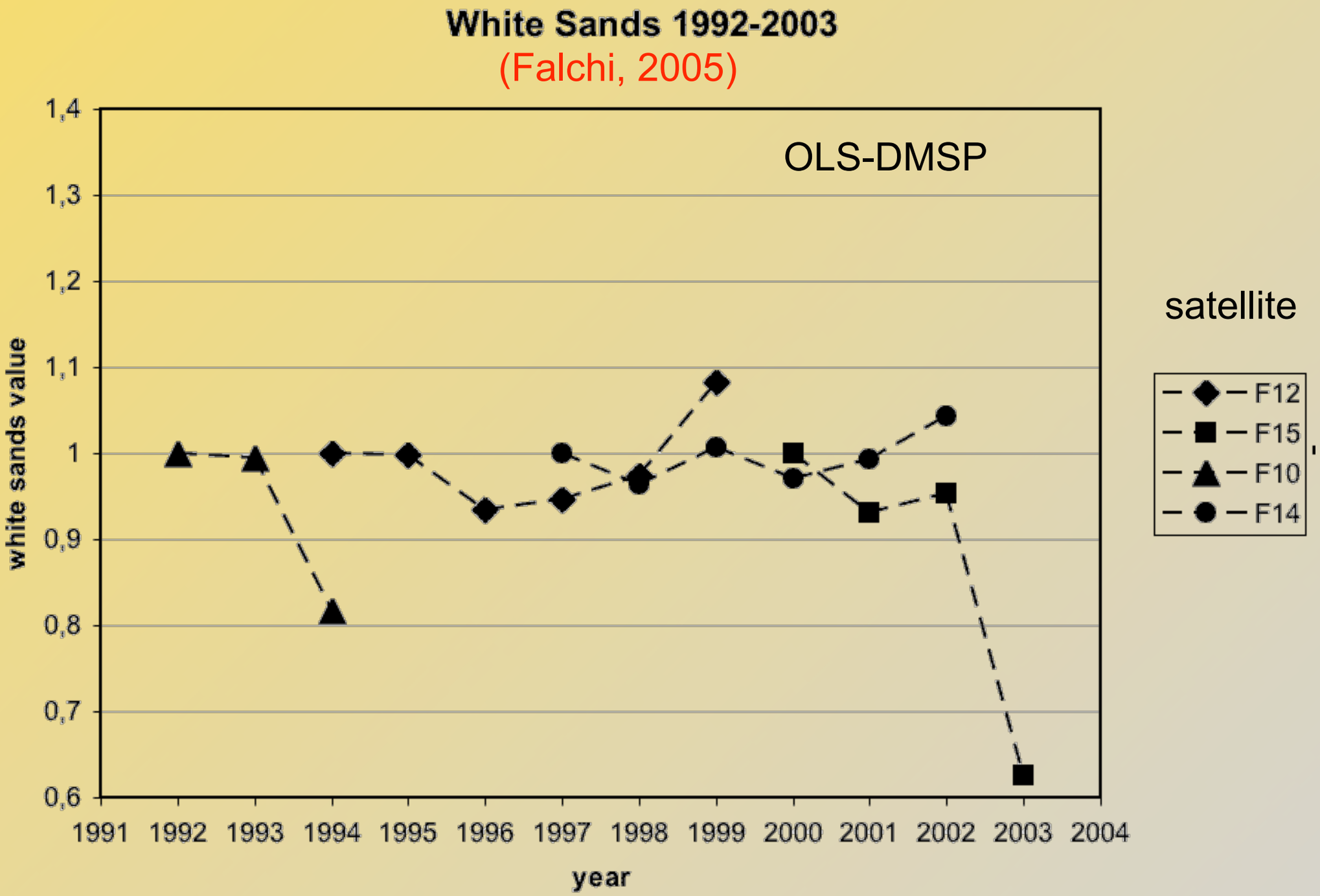


Falchi, Cinzano 2004, in prep.



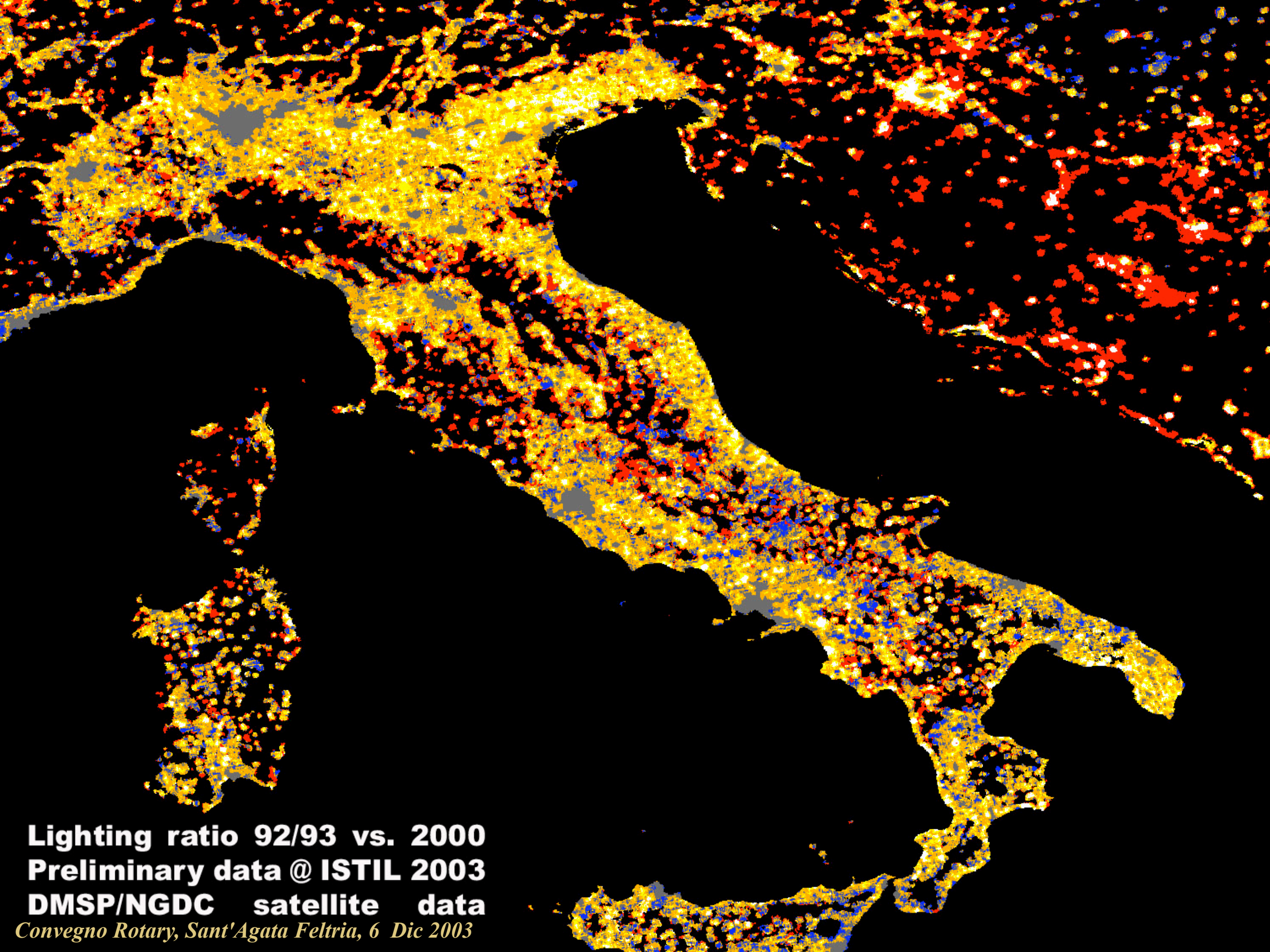
study of growth of light pollution

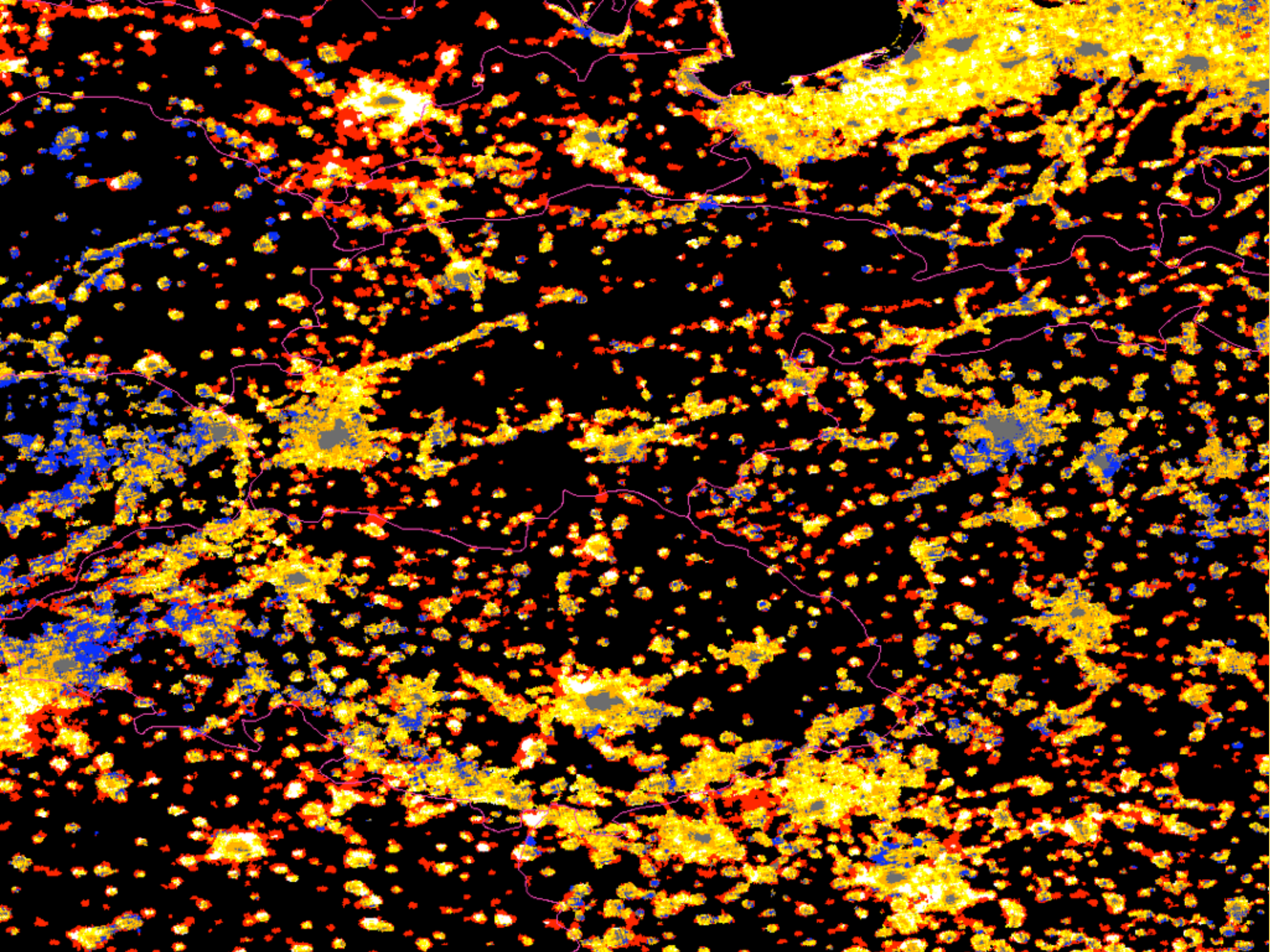
➡ requires accurate calibration of DMSP-OLS



Growth of lighting in Italy 92/93-00
Preliminary Map @ ISTIL 2003
DMSP/NGDC satellite data

Convegno Rotary, Sant'Agata Feltria, 6 Dic 2003


Lighting ratio 92/93 vs. 2000
Preliminary data @ ISTIL 2003
DMSP/NGDC satellite data
Convegno Rotary, Sant'Agata Feltria, 6 Dic 2003



Conclusions

we authors have a lot of works to complete

Planned deadline: one year to complete papers and another year to compute the world atlas

Realistic deadline: two years to complete draft papers, one year to complete further details and one/two years to compute the atlas

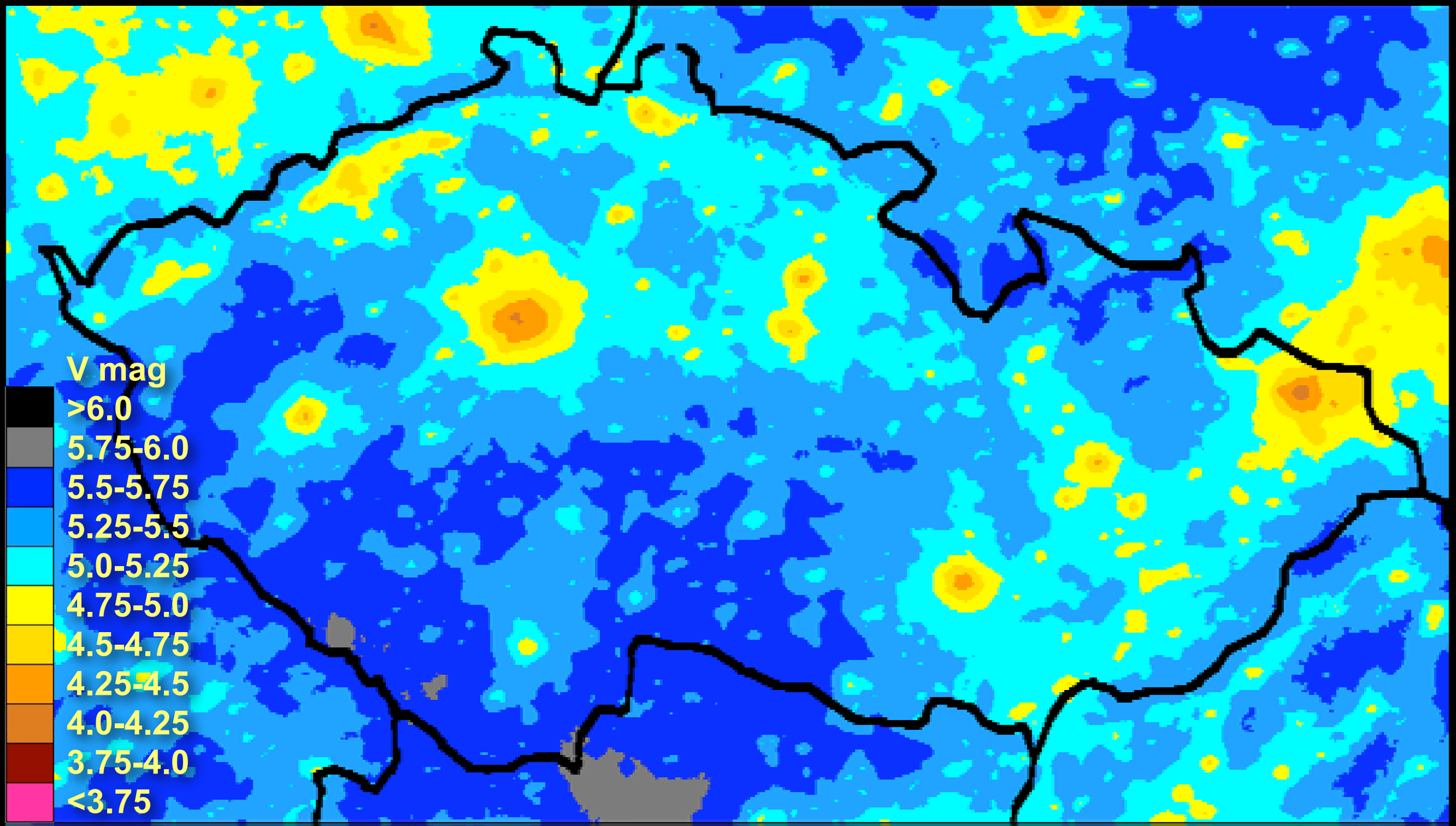
This talk on the web:
www.lightpollution.it/download/iau06cinzano.pdf
www.lightpollution.it/download/iau06slides.pdf

Photo G. Barcheri

Lights in Cekia

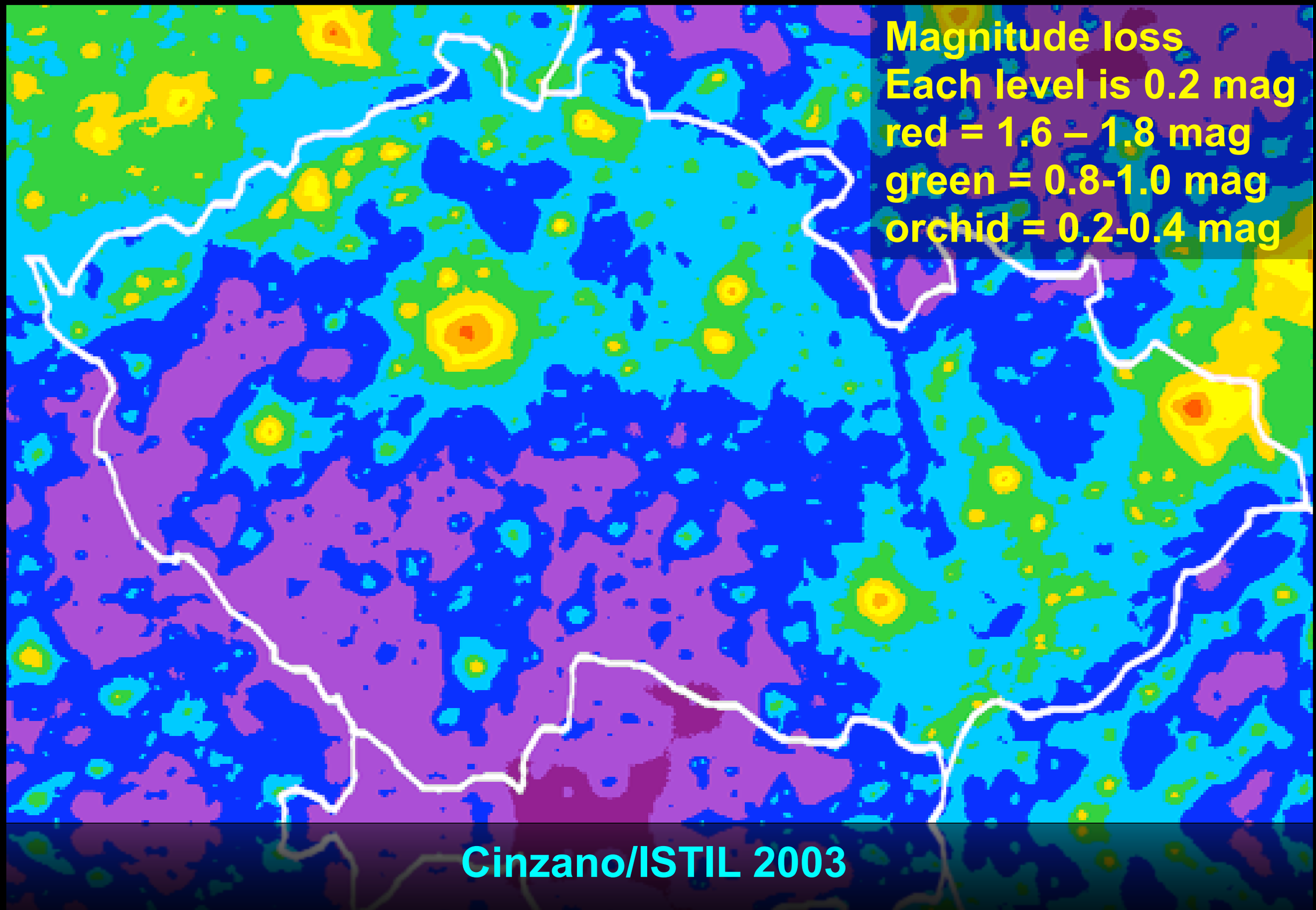
Dresda
Liberec
Usti
Mlada
Hradec Kralové
Prague
Ostrava
Pizen
Olomuc
Jihlava
Brno
Ceske Budejovice

Stellar visibility in Cekia



Cinzano, Falchi, Elvidge 2001, MNRAS, 323, 34-46

Magnitude loss in Cekia



Cinzano/ISTIL 2003

Cinzano 2005, Research note, in prep.

Visible stars

0 - 200

200 - 400

400 - 700

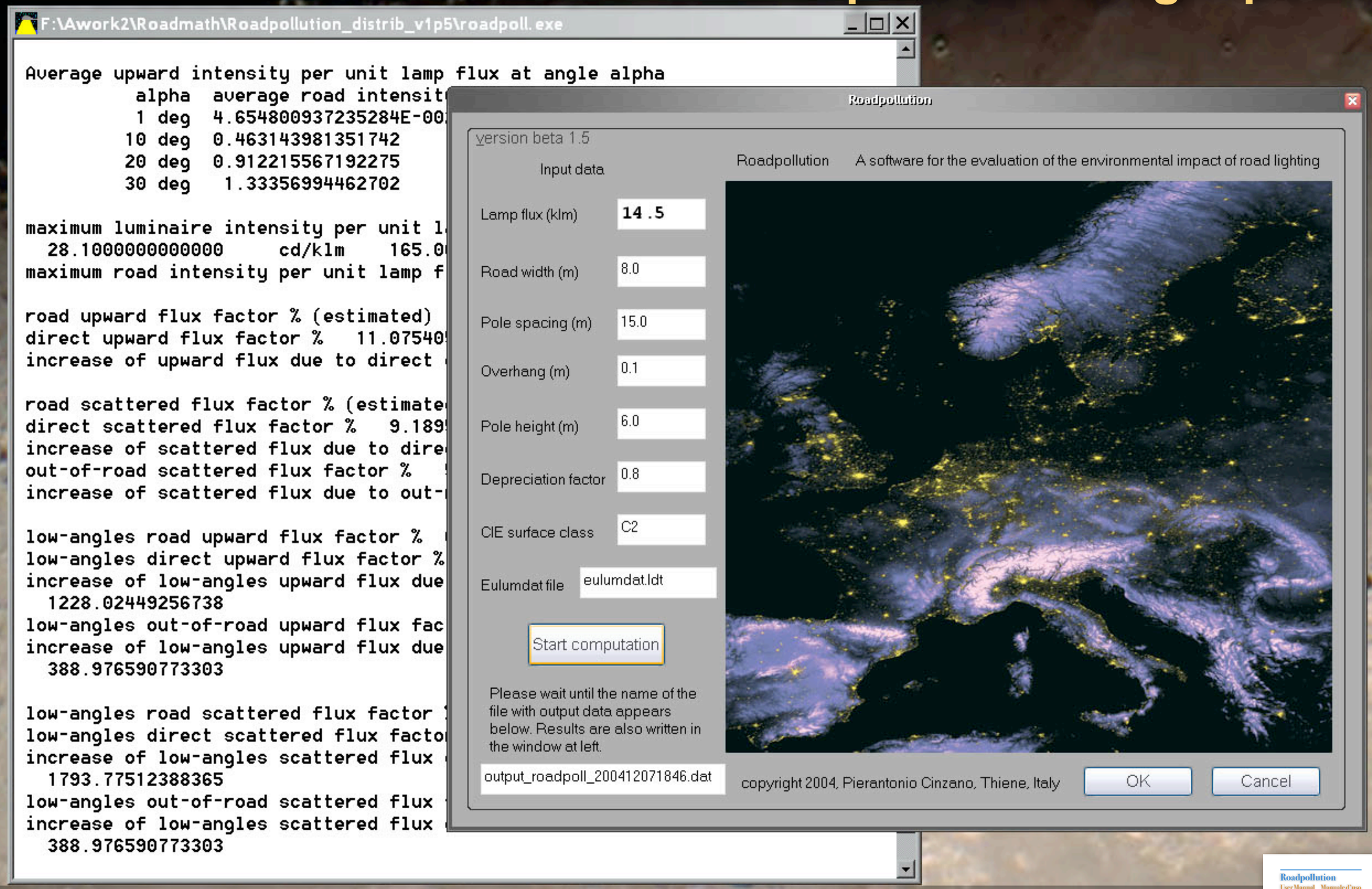
700 - 1000

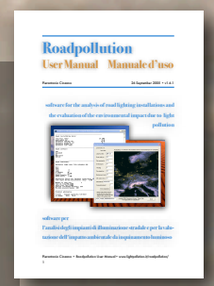
1000 - 1300

1300 - 1900

Roadpollution v. beta 1.5

a free software for the analysis of road lighting installations and the evaluation of the environmental impact due to light pollution





Downloadable from www.lightpollution.it/roadpollution/

Users MUST read the user manual

EasyLight free optimization software

ing. Diego Bonata www.savethesky.eu