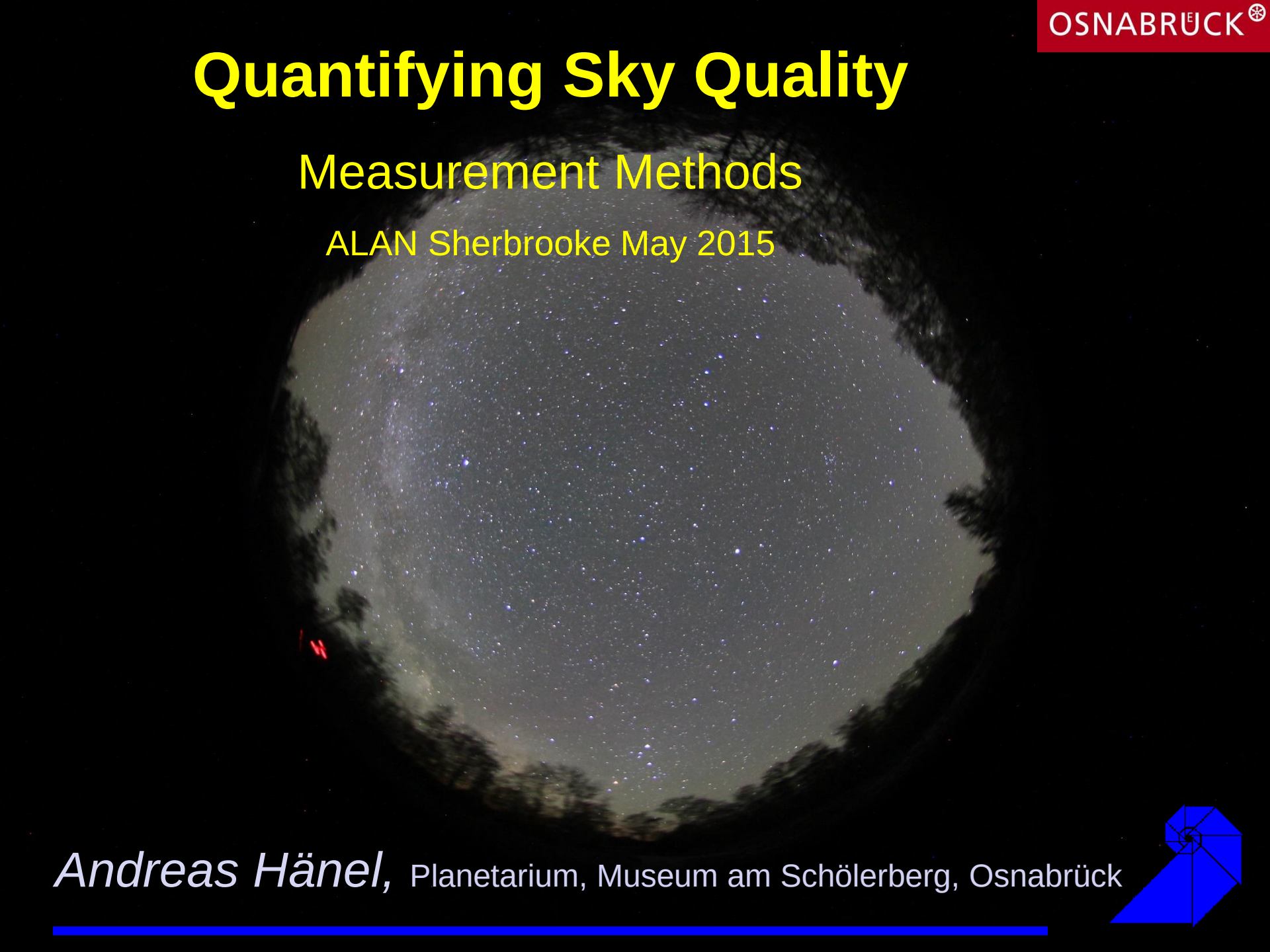


OSNABRÜCK

Quantifying Sky Quality

Measurement Methods

ALAN Sherbrooke May 2015

Andreas Hänel, Planetarium, Museum am Schölerberg, Osnabrück

Lost of the Night Network

LoNNe
ES1204
Loss of the Night Network

- Improve knowledge of the effects of increasing artificial illumination worldwide
- Influence the development of modern lighting technology, and creating guidelines for lighting concepts that are ecologically, socially, and economically sustainable

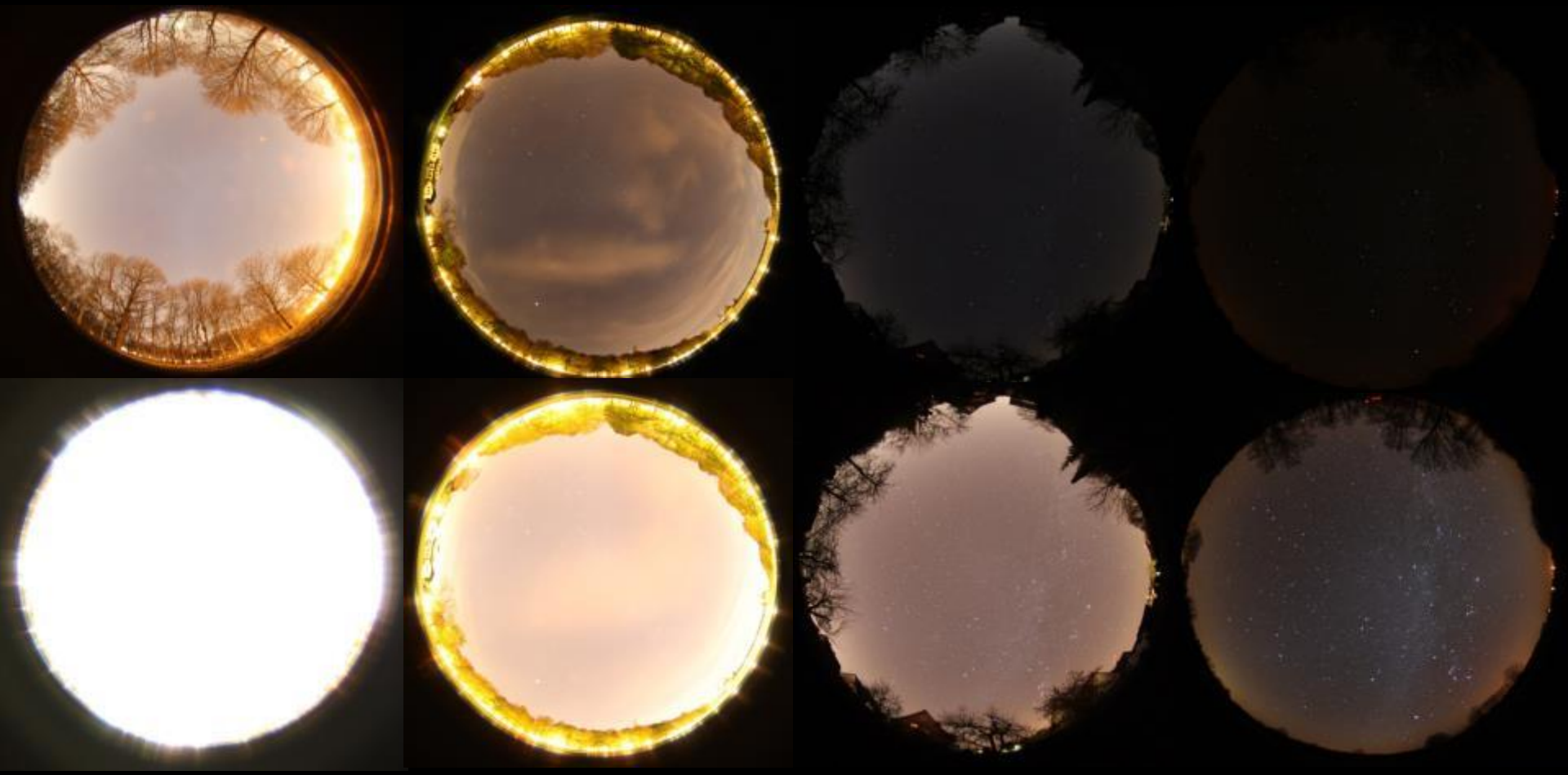
Action within COST (European Cooperation in Science and Technology)

Research – Working Groups:

- WG 1: Creating sub-networks concerning the significance of AL
- WG 2: Assembling existing data
- WG 3: Quantifying the value of nights with near-natural light conditions
- WG 4: Dissemination of research results to raise awareness of the consequences of LP

Quantify and measure light pollution (initiated *Thomas Posch*)

Night Sky (30/180 sec exp. time, 1:2,8, 800 ASA)



Berlin
18.2^{m}/arcsec^{2}
5.7 mcd/m^{2}

Bonn
19.2^{m}/arcsec^{2}
2.3 mcd/m^{2}

Osnabrück
20.6^{m}/arcsec^{2}
0.6 mcd/m^{2}

Westhavelland
21.4^{m}/arcsec^{2}
0.3 mcd/m^{2}

Necessity to measure sky brightness

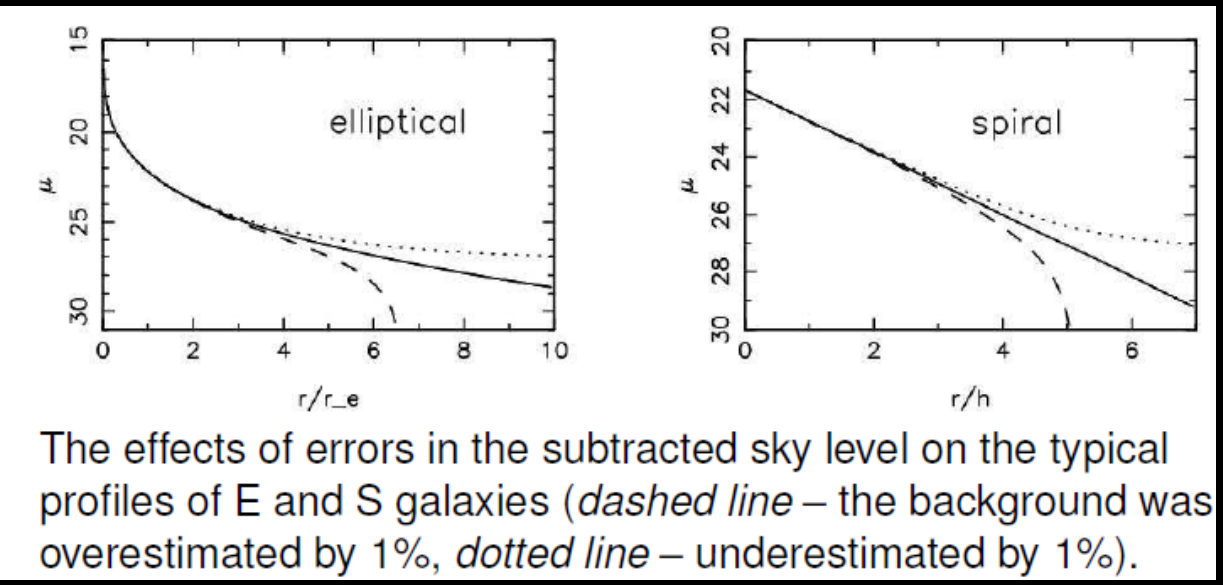
astronomy:

subtract to get object brightness

especially faint objects

- faint stars
- surface photometry of galaxies:
  mass, luminosity, evolution

ESO



The effects of errors in the subtracted sky level on the typical profiles of E and S galaxies (*dashed line* – the background was overestimated by 1%, *dotted line* – underestimated by 1%).

Reshetnikov

Necessity to measure sky brightness

– monitor changes of artificial lighting (light pollution)
diffuse light, light dome

Cinzano

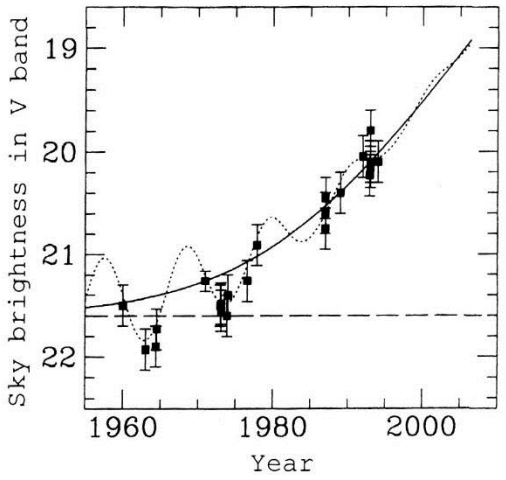


Fig. 3. All the measurements reduced to the V band (in $mag/arcsec^2$), together with the prediction obtained from (4) (continuum curve) and the prediction corrected for the effects of the solar activity (dotted curve).

– classification of
IDA Dark Sky Places

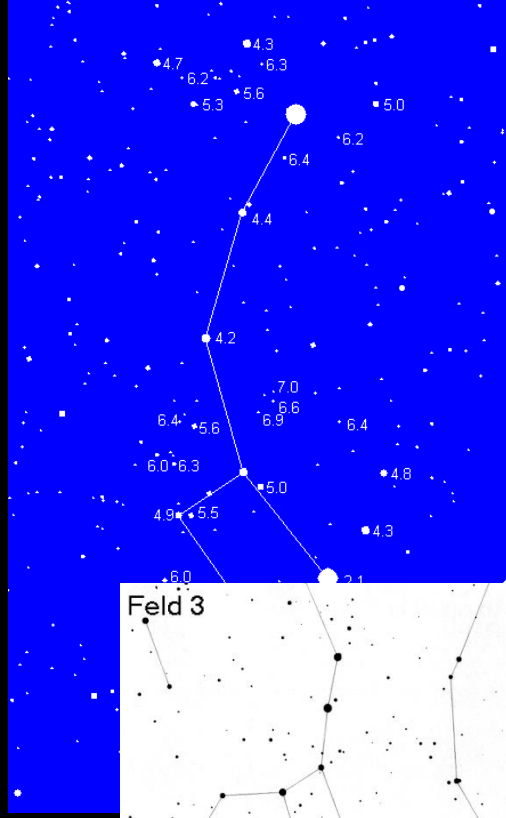
Gold >21.75

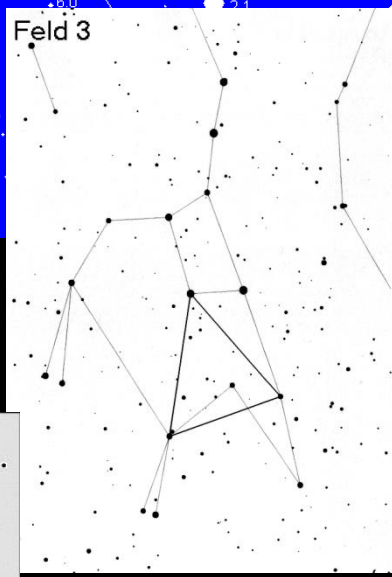
Silver >21.0

Bronze >20.0

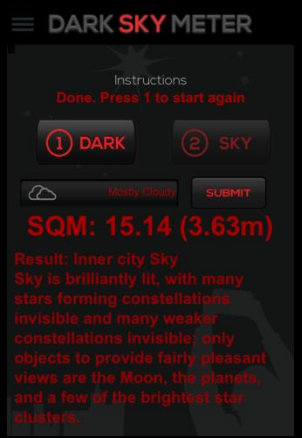
Visual measurements

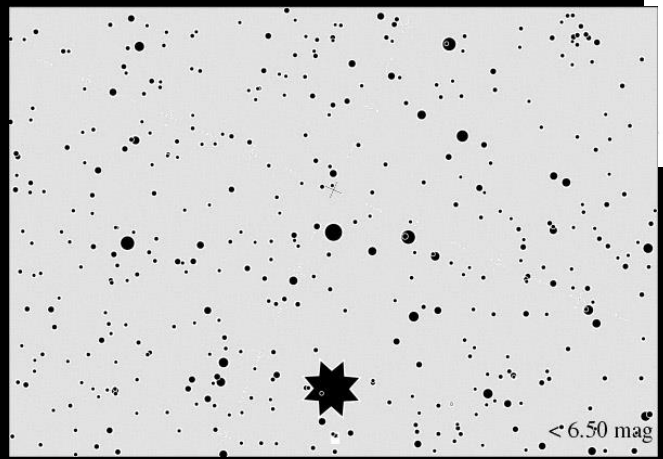
- limiting magnitude (faintest star)
  - North polar sequence
  - Counting stars (meteor observers)
  - Globe at Night
  - Comets (*Thomasz Ściężor* et al.)





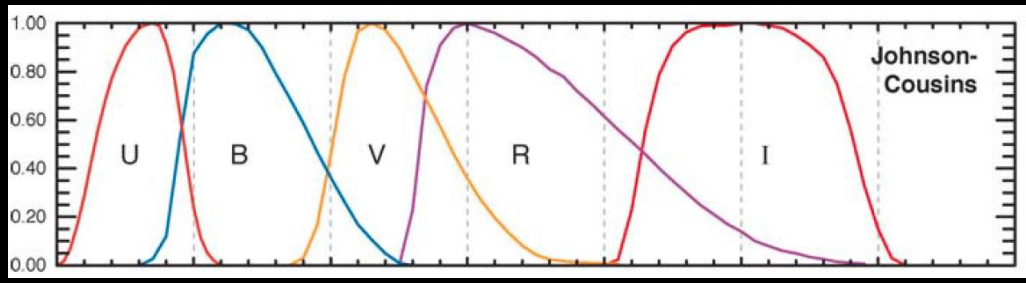
- Dark Sky Meter App (iOS)
- Lost of the Night App (Android)





Luminance measurements - Colour systems

- astronomy -> Johnson "International" (UB)V system
  - traditional **V**isual observer
  - technical filter/detector characteristics
  - λ_{max} = 545 nm, $\Delta\lambda$ = 84 nm
  - variations/modifications: uvby, HST, Tycho ...
  - stars as calibrators!

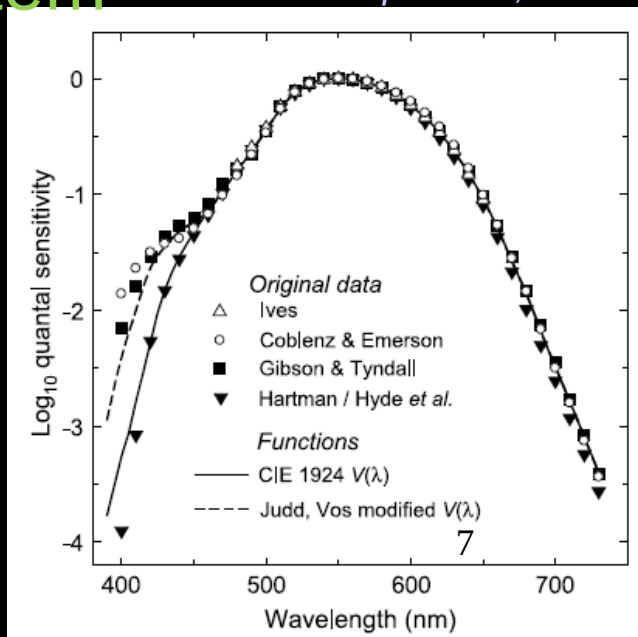


Bessell, 2005

- photometry -> V(λ) photometric system

Sharpe et al., 2005

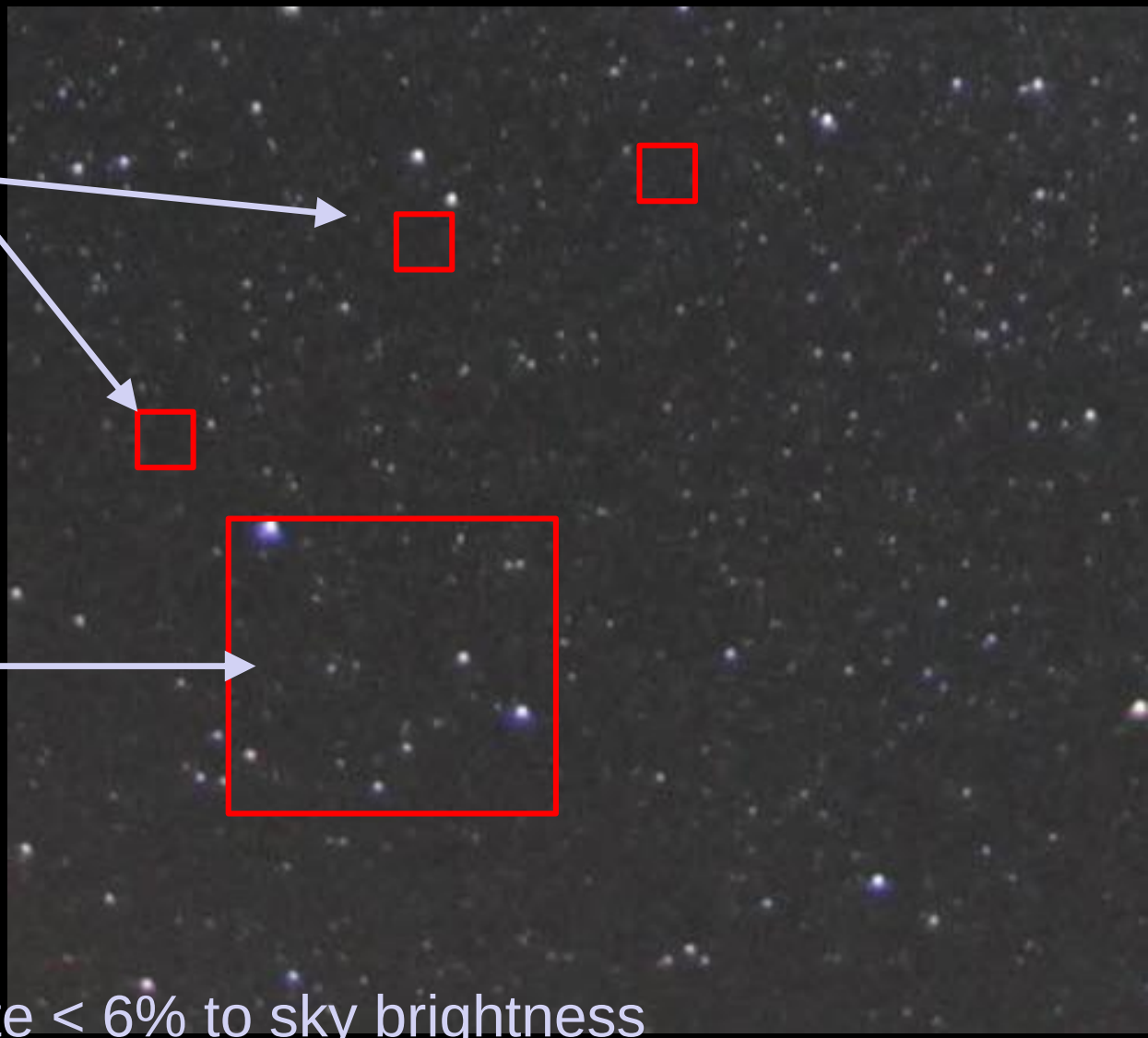
  - CIE 1924
  - mean value from different studies
  - λ_{max} = 555 nm, $\Delta\lambda$ = 100 nm
  - laboratory integrating/Ulbricht sphere



- transformation:

$I\ [cd/m^2] = 108\,000 \times 10^{-0.4\ m\ [mag/arcsec^2]}$

- Sky background brightness
- Sky brightness



Cinzano:

stars <5 mag contribute < 6% to sky brightness

- **1 dimensional (spot, single channel)**
  - classical star photometry with lightelectical photometer

    diaphragm (typically 15" – 2')
    photomultiplier tube PMT RCA1P21 + filter GG495
    solid state photometers (Optec)
  - Sky Quality Meter SQM
  - luminance meters

Mt. John

- **2 dimensional (panoramic, imaging)**
  - classical photography with film (not linear)
  - CCD
  - CMOS (DSLR)

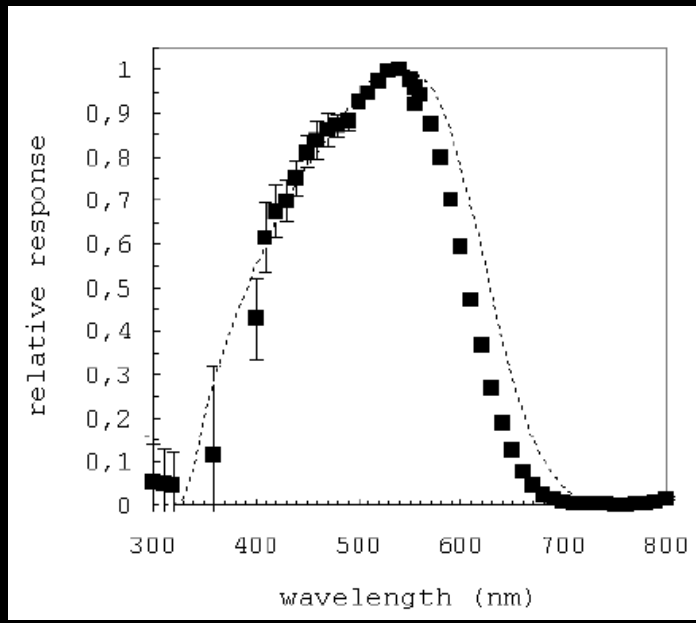
Instruments that are generally readily available

1dim: Sky Quality Meter

- Unihedron
- Detector: TAOS TSL237
- Filter: Hoya CM-500
- λ_{max} = 520 nm, $\Delta\lambda$ = 230 nm
- FOV: SQM: 84° (FWHM)
- SQM-L, -LE, -LR, -LU, -LU-DL: 20° (FWHM)
- Roadrunner (with GPS)

- not V, not V(λ): own brightness system m_{SQM}!
- V = m_{SQM} -0.17 mag/arcsec² (*Cinzano*)
- deviations below 20 mag/arcsec² (later)
- add filters (*Cinzano, Spoelstra*)

Cinzano

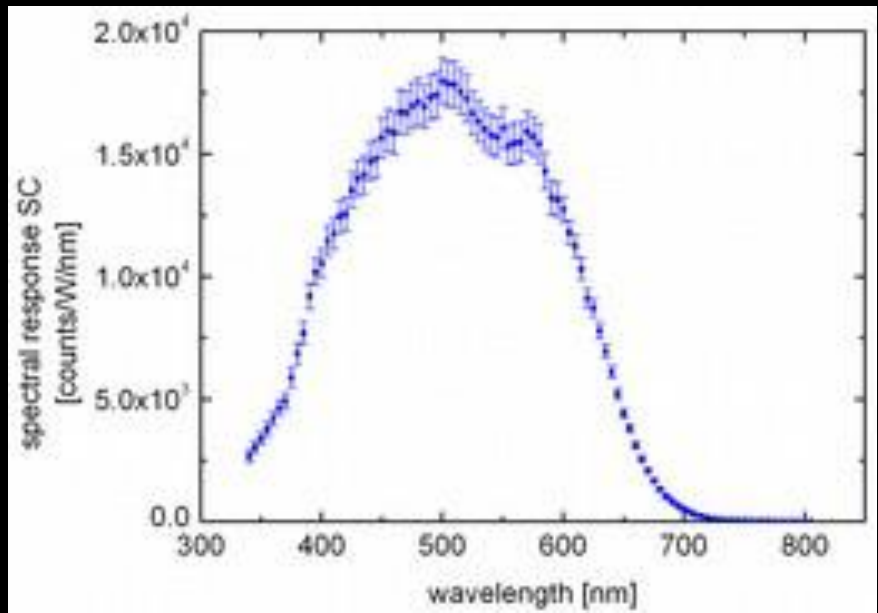


1dim: Lightmeter – illuminance!

- K2WLights, *Wuchterl*
- Detector: photo cell
- Filter: -
- λ_{max} = 500 nm, $\Delta\lambda$ = 250 nm
- FOV: Lambertian 120° (FWHM)
- no calibration

- not V, not V(λ): own brightness system!

Wuchterl



1dim: Luminance Meter

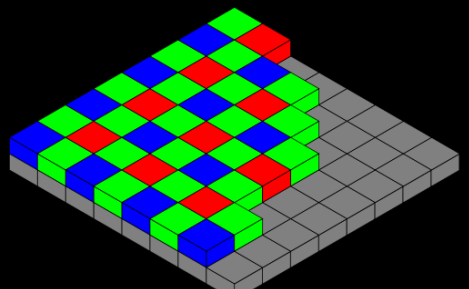
- different providers: LMT, Konica-Minolta, Gossen
- limit 0.001 cd/m² ?
- V(λ) calibrated (CIE)
- FOV: 0.3 – 5°

- DigiLum (Optronik, *Spoelstra*)
- limit 0.0001 cd/m²
- FOV: 5°

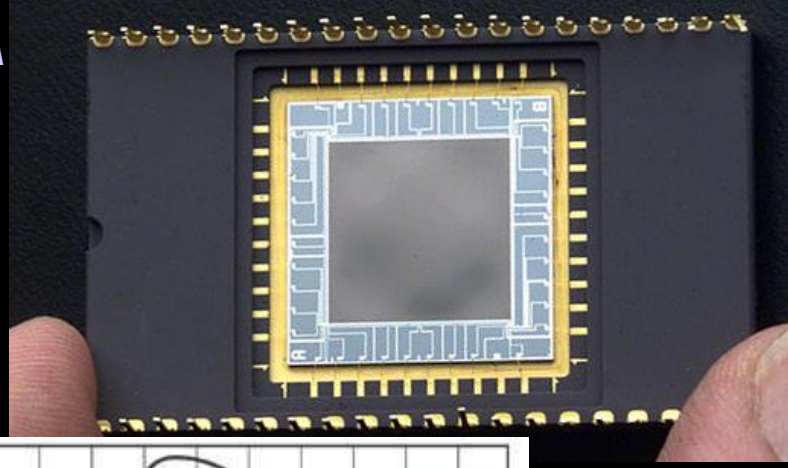
2dim

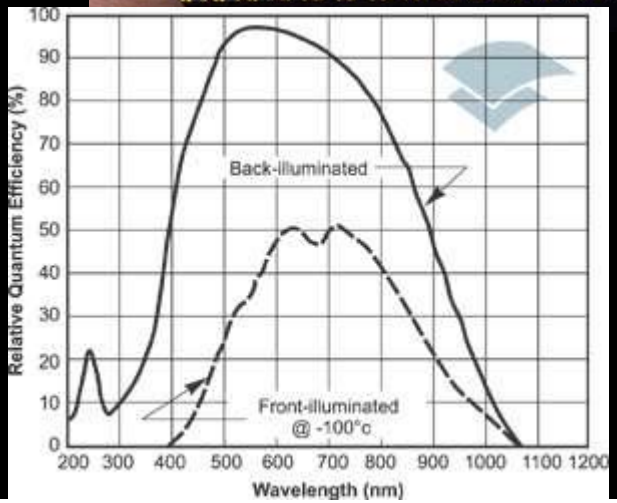
- CCD
  - spatial resolution
  - large pixel numbers (>1024 x 1024)
  - high dynamics (<=16 bit)
  - cooling (low noise)
  - broad spectral range -> filtering colour corrections!

- CMOS (DSLR)
  - large pixel numbers
  - high dynamics (14 bit)
  - RGB filters: Bayer matrix: G ~ V
  - RAW data not really raw



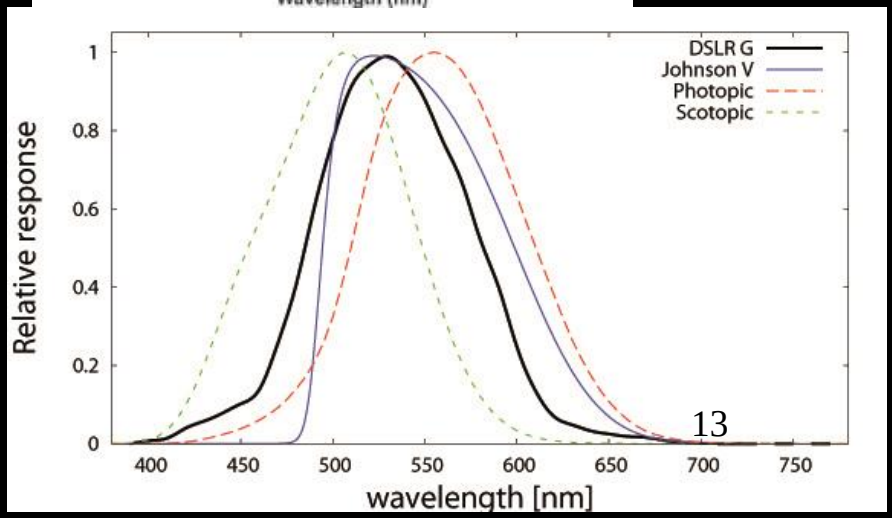
NASA



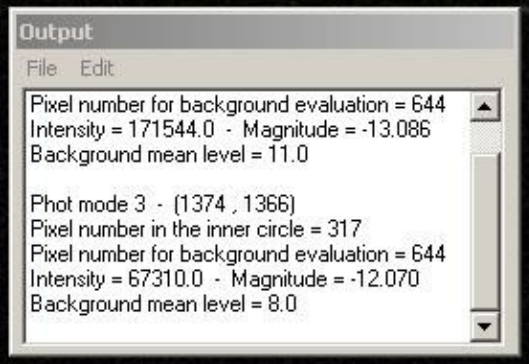


Andor

Kollath?



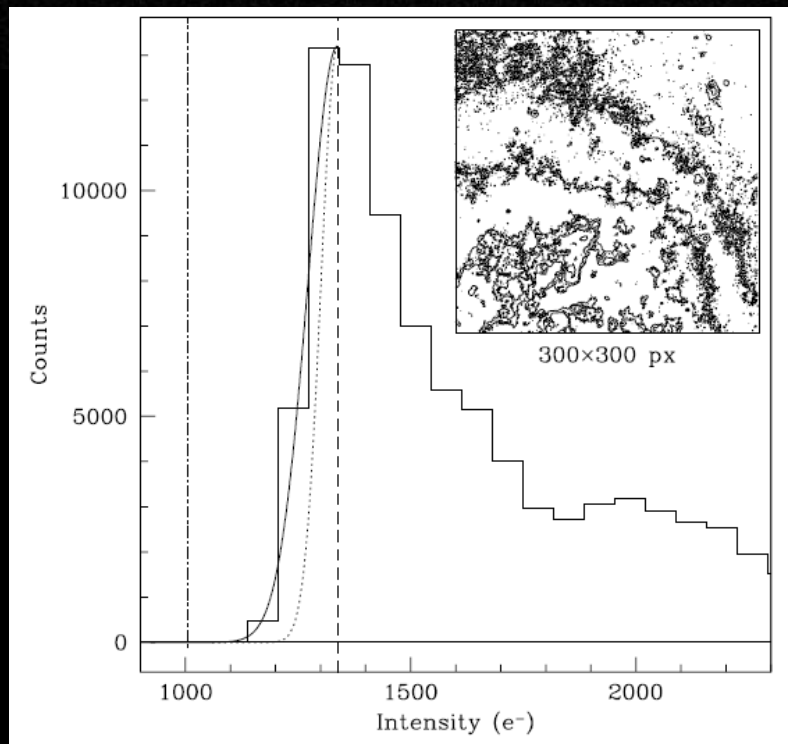
Calibration with stellar photometry



- classical photometry
- stars with well known brightness (e.g. Tycho)
- annular diaphragmas
- point spread function

- background from ring

- more elaborate:
  optimal binning technique
  OBT (*Patat, 2003*)



Patat, 2003

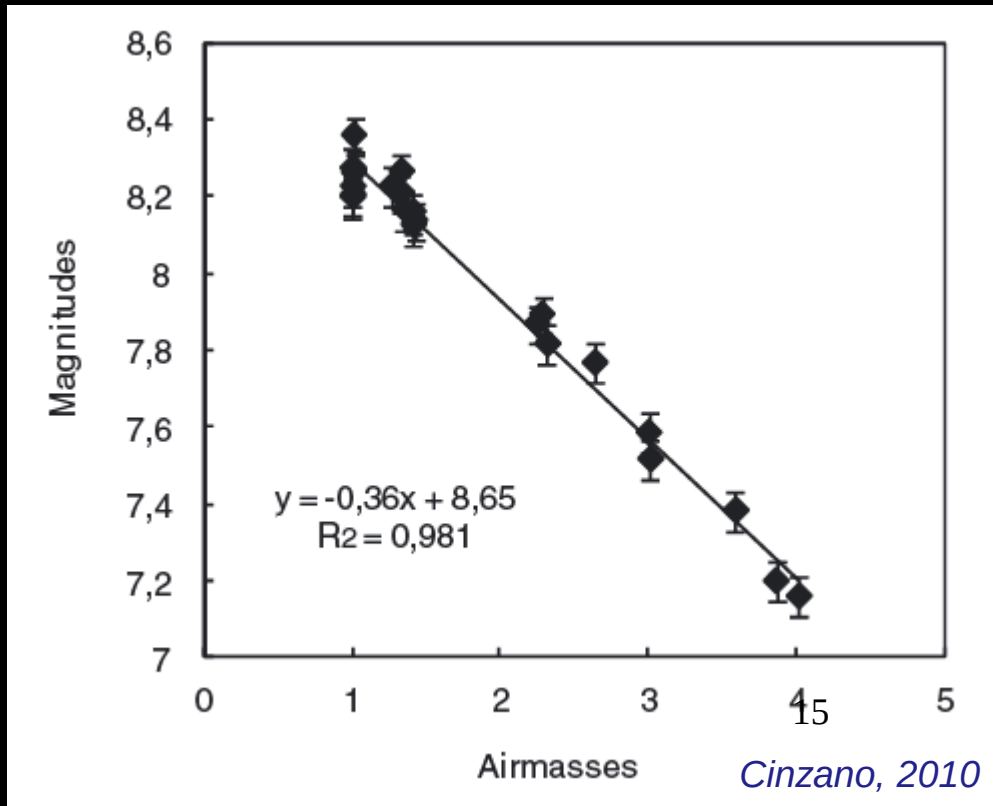
Calibration with stellar photometry

- colour corrections (spectral mismatch)
- correction for extinction + calibration (Bouguer method)

$V = -2.5 \log_{10} (ADU) + \varepsilon (B-V) - k_v X + V_0$

V	star magnitude
ADU	instr. intensity
ε	colour constant
k_v	extinction coefficient
X	air mass
V_0	instr. const.

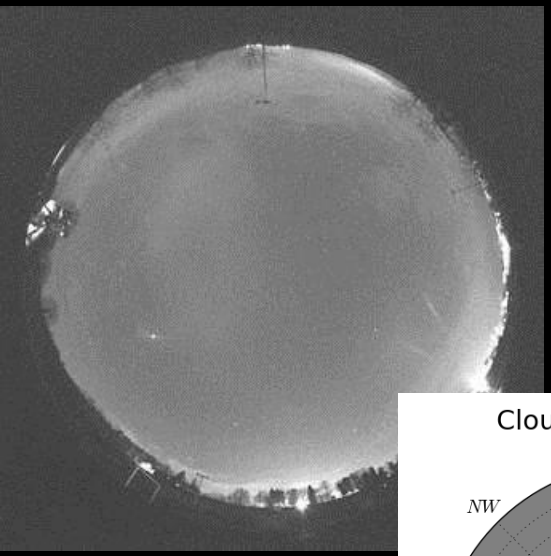
- rôle of extinction on sky brightness?



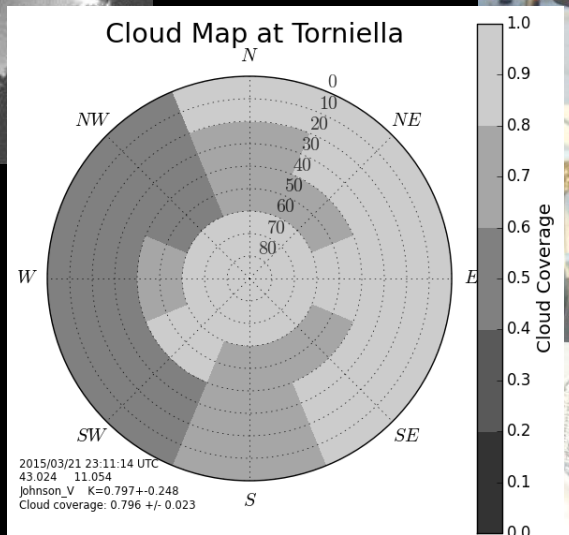
Cinzano, 2010

2dim: AstMon

- Calar Alto obs. (*Aceituno et al*.)
- Lens: 4.5mm/2.8 fisheye
- detector: Kodak KAF-8300 CCD
- scale: 3.8'/px



e shows the internal view of the system: (1)
ectrical breakers. (2) Main fan. (3) Anti-
CCD head with filter wheel. (5) Servo-motor
(6) Servomotor controller. (7) Thermostats.
ower supply. (9) PIC I/O controller. (10)
ic dome.



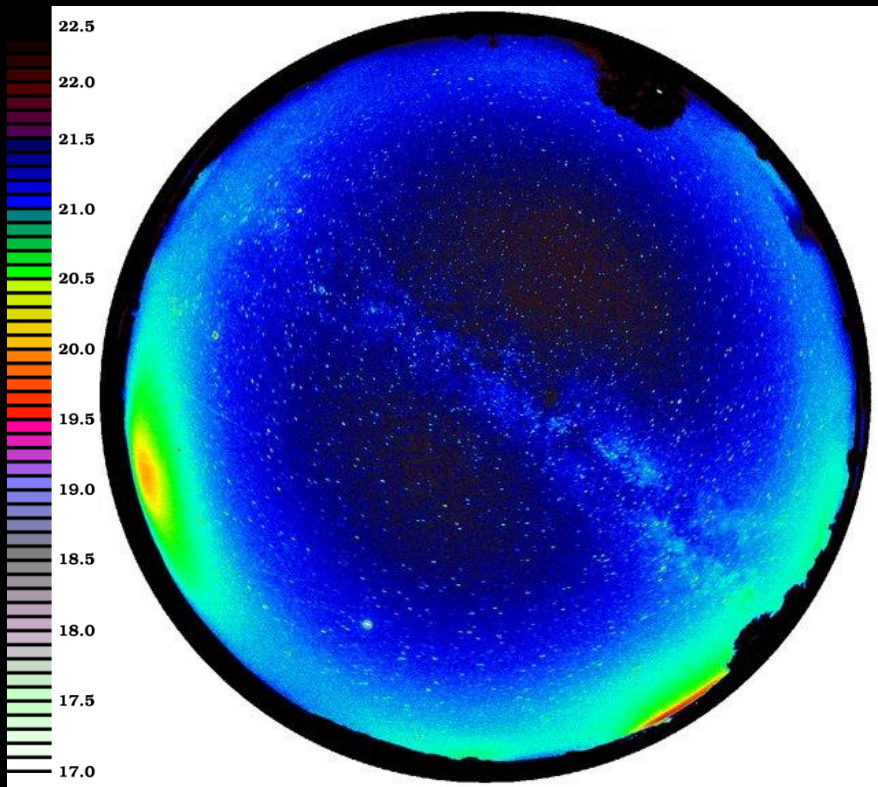
2dim: DSLR

- APS format:
- Lens: 4.5mm/2.8 fisheye
- detector: e.g. Canon
- scale: 4.5'/px

- Full format:
- Lens: 8mm/3.5 fisheye
- detector: e.g. Canon
- scale: 2.8'/px

- astronomical (stars): AstMon
  photometric (lab) calibration

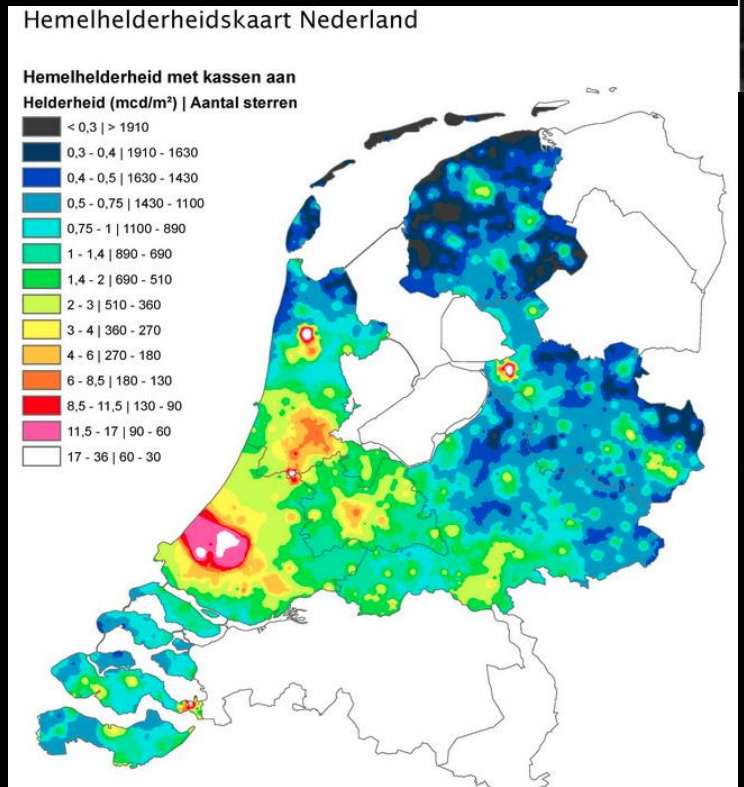
- *Kollath, Schmidt, Hänel, Mohar ...*

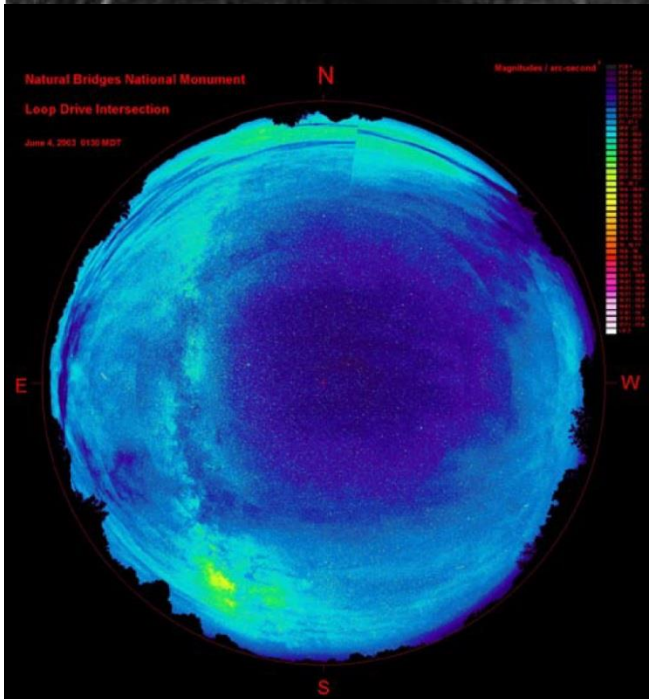


Kollath - Hänel

2dim: Mosaics, Stellar photometry

- National Park Service (*Duriscoe*)
- Mosaic, lens: 35 mm, 50mm/1:2
- detectors: KAF261E, 1001E
- scale: 1.5'-3.8'/px
- similar:
  Sotto le Stelle NL (*Wim Schmidt*)
  Falchi

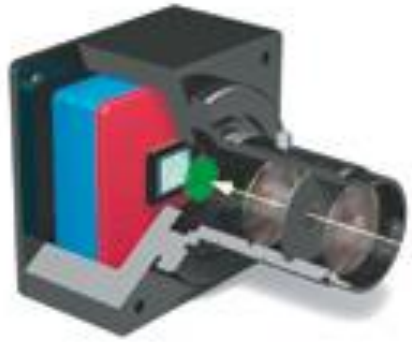




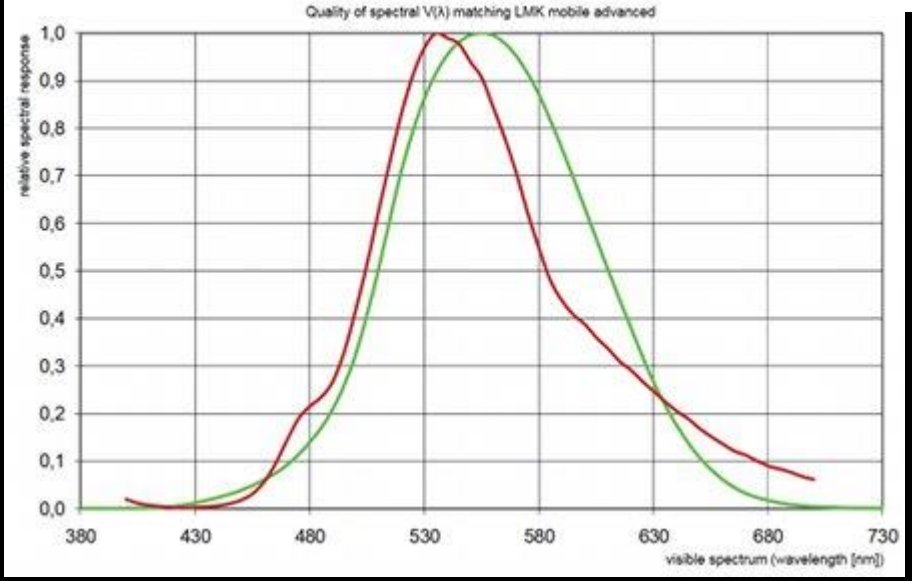
Schmidt, Sotto

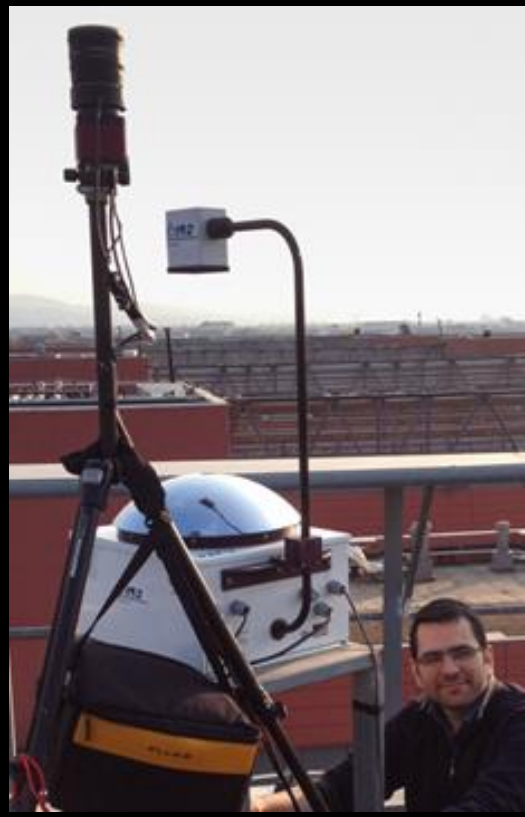
2dim: Photometry

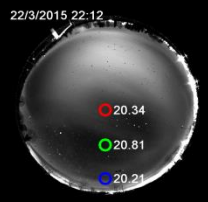
- TechnoTeam
- Costas Bouroussis

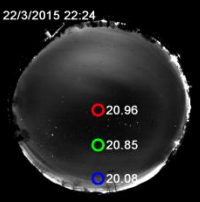


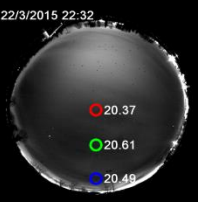
numerical transformation from R,G,B – sensor data

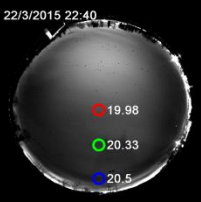












What is natural sky background brightness?

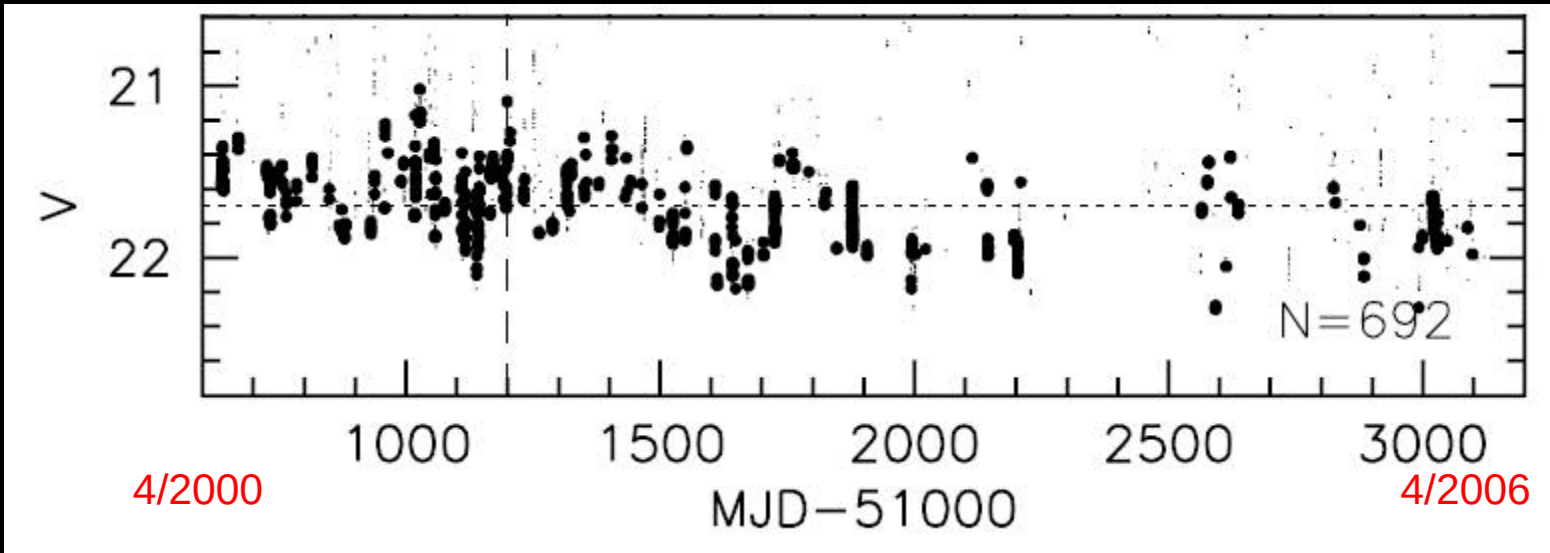
Teneriffa OT	21.4 mag/arcsec²
Calar Alto	21.8
La Palma ORM	21.9
Kitt Peak	22.01
Hawaii	22.05
La Silla	21.9
Paranal	21.7 21.0 .... 22.3
HST	22.1 – 22.7 – 23.3 (zodiacal light)
Gaia	22.5

Ref.: Leinert et. al.: AASS 127, 1998; Patat, HST Users Hdb.

SQM-L values >21.9 - 22 mag/arcsec² ?

Variations: What is the natural background????

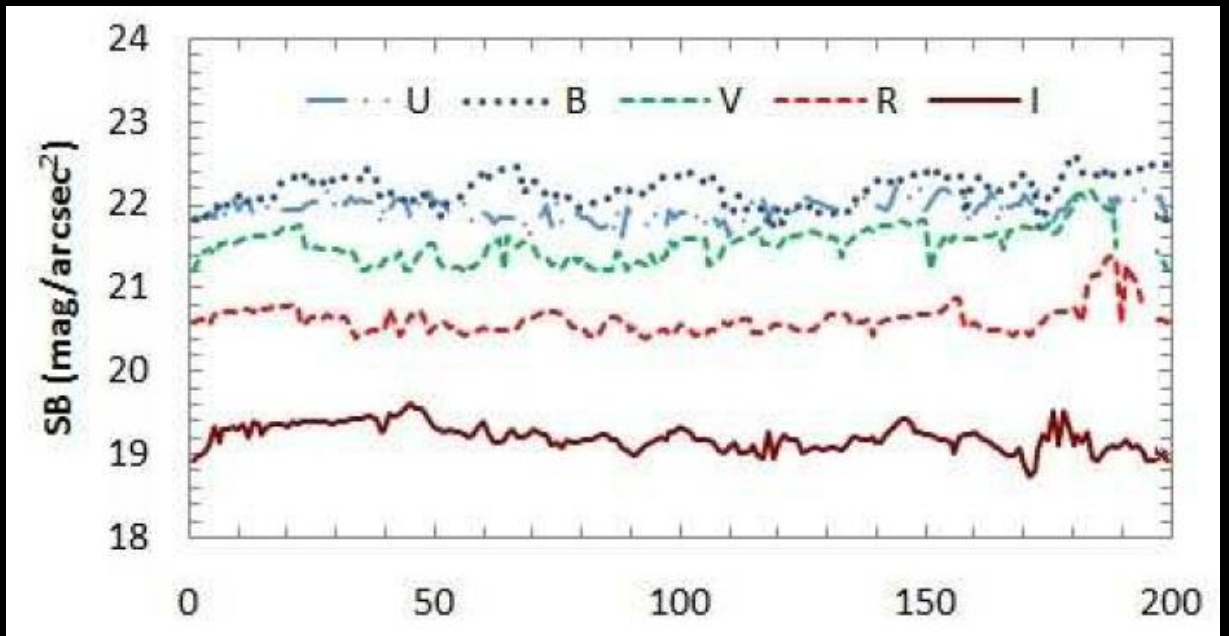
Paranal
(Patat)



Patat, 2008

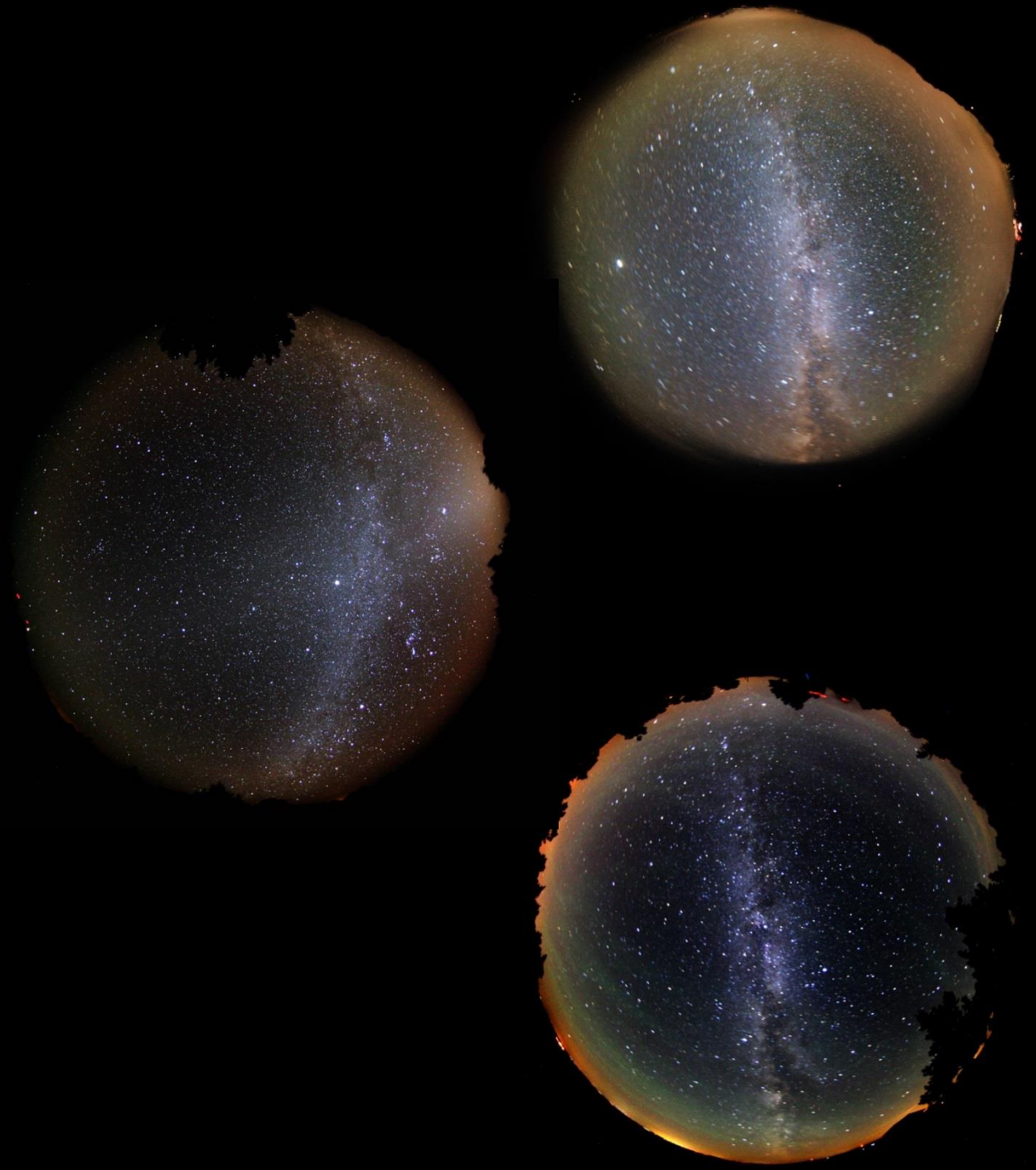
Scattering
1 mag/arcsec²!

Calar Alto
Aceituno et.al, 2011



limitations

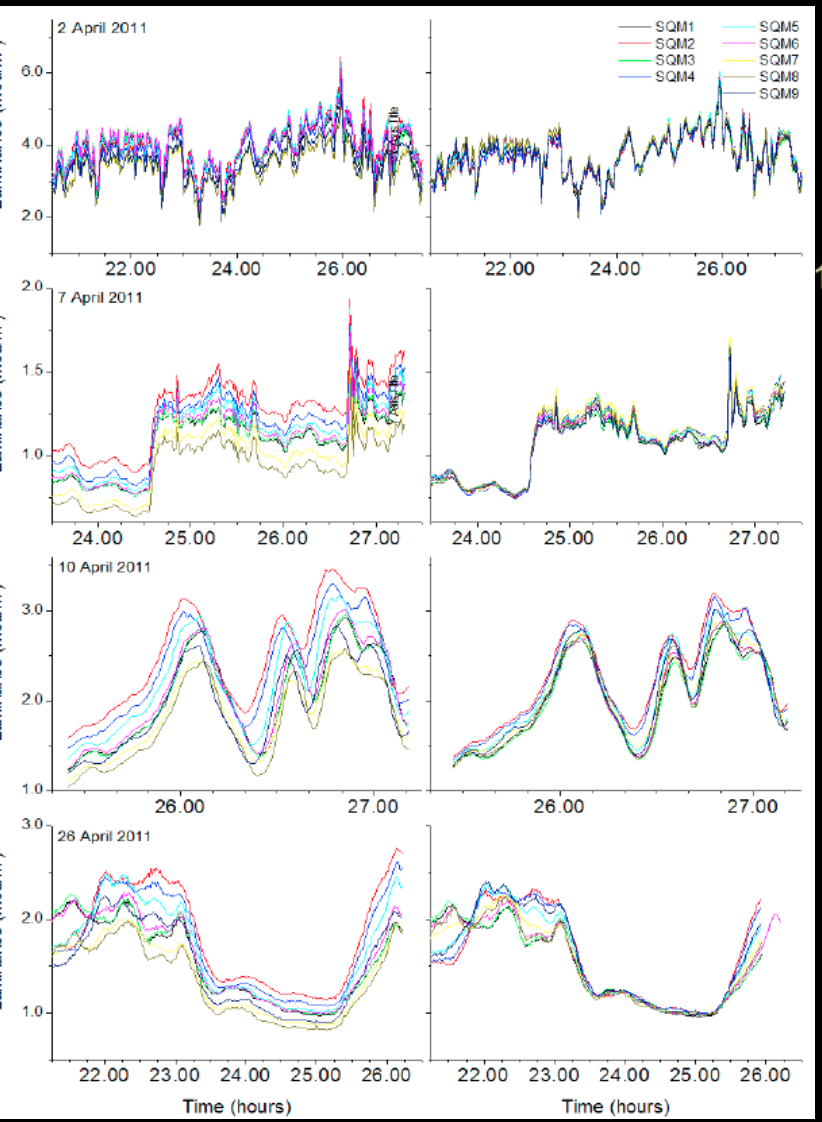
- Milky Way
- zodiacal light
- airglow

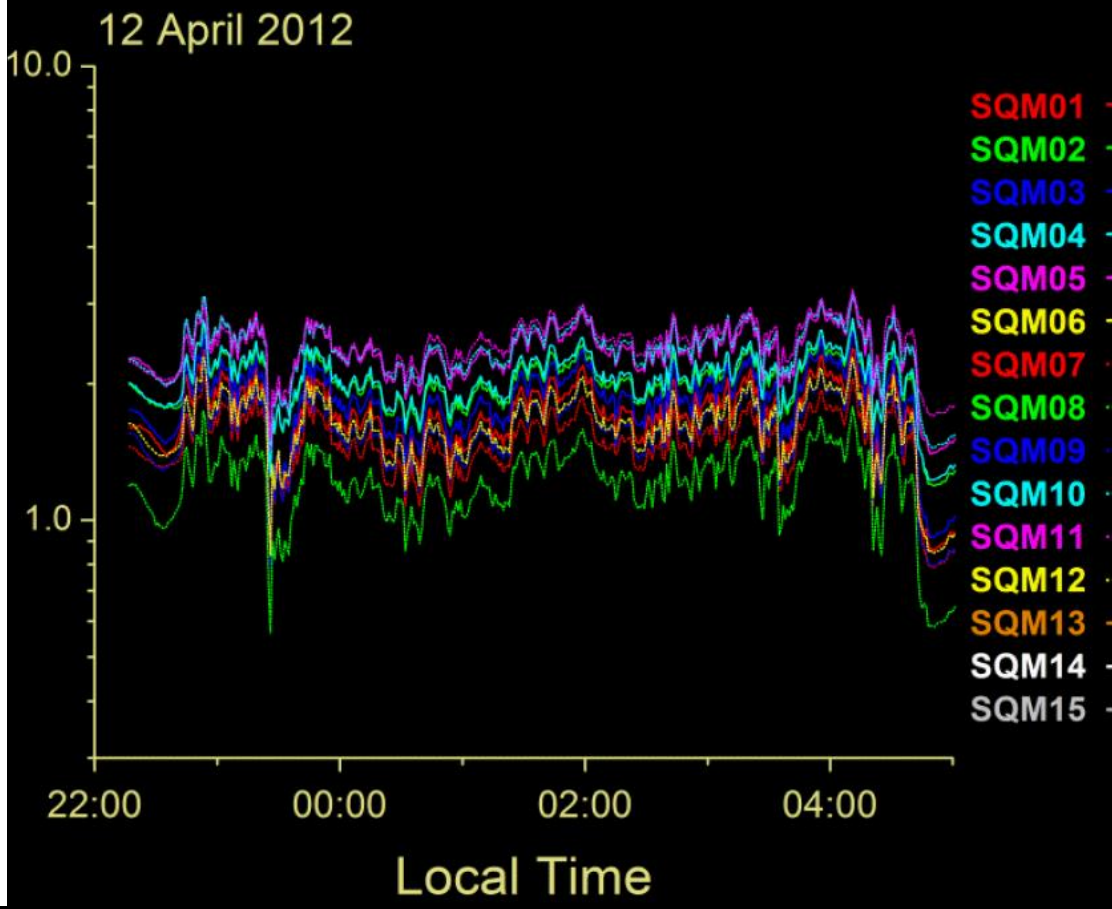


Accuracy - comparisons

variation SQM-L with version number (2.17 –> 2.18: -0.1–0.15 mag/arcsec²?)

Cabauw/NL: initial scatter +/- 14%, intercomparison -> 0.5 %



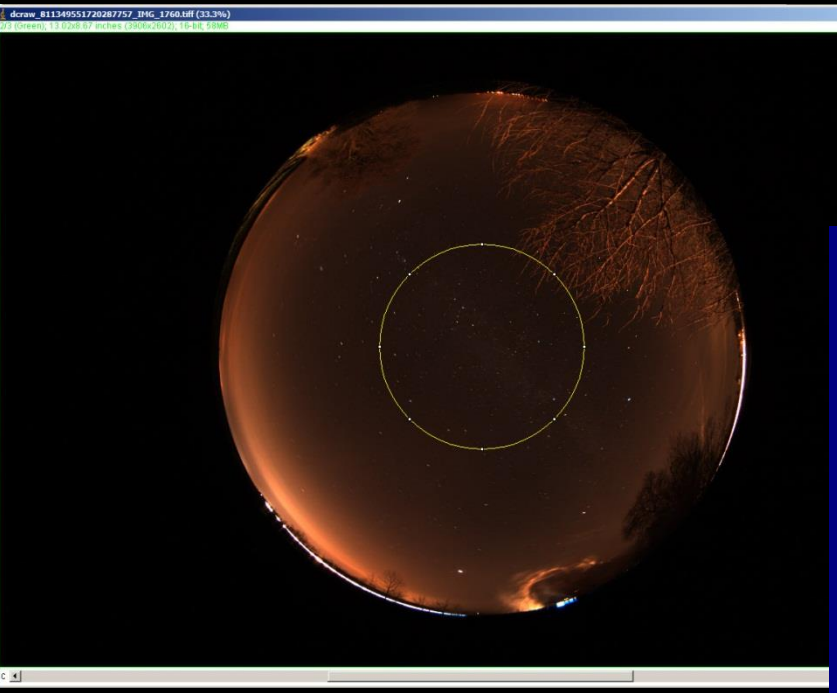


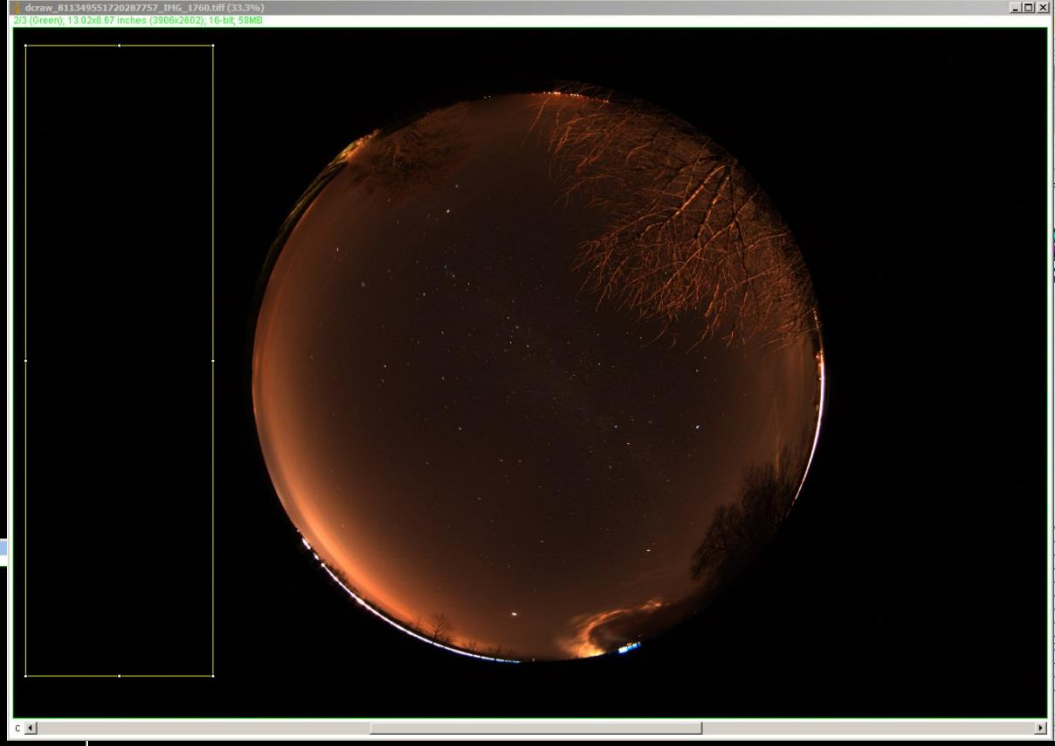
Measuring Allskies

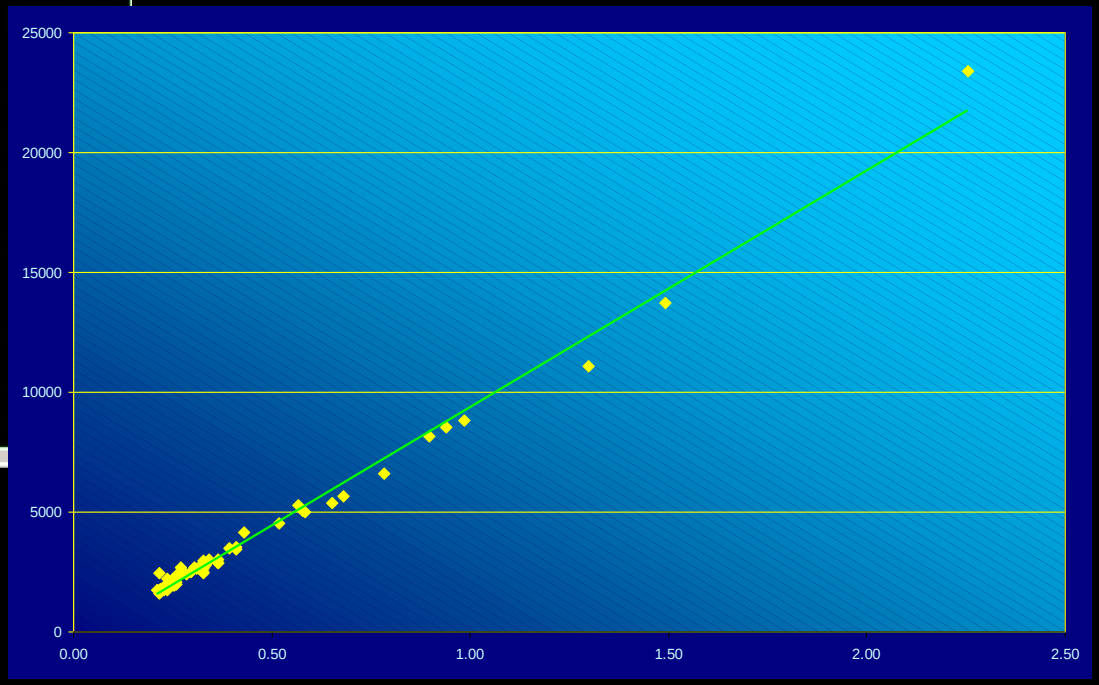
with ImageJ

measuring dark

simulation of the 40°
measurement cone of the SQM-L



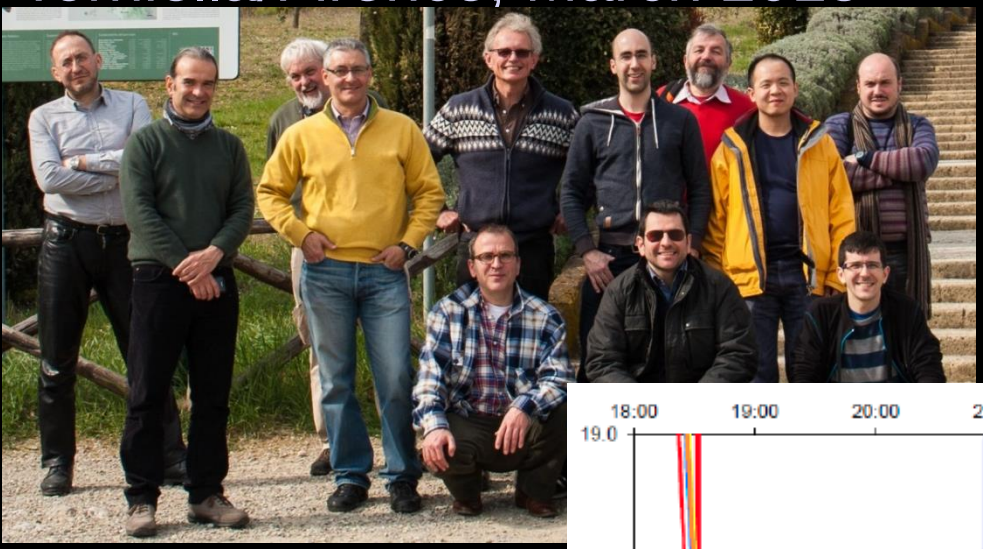




accuracy 0.1 mag/arcsec²

intercomparison campaigns

Torniella/Firence, March 2015



LoNNe
ES1204
Loss of the Night Network

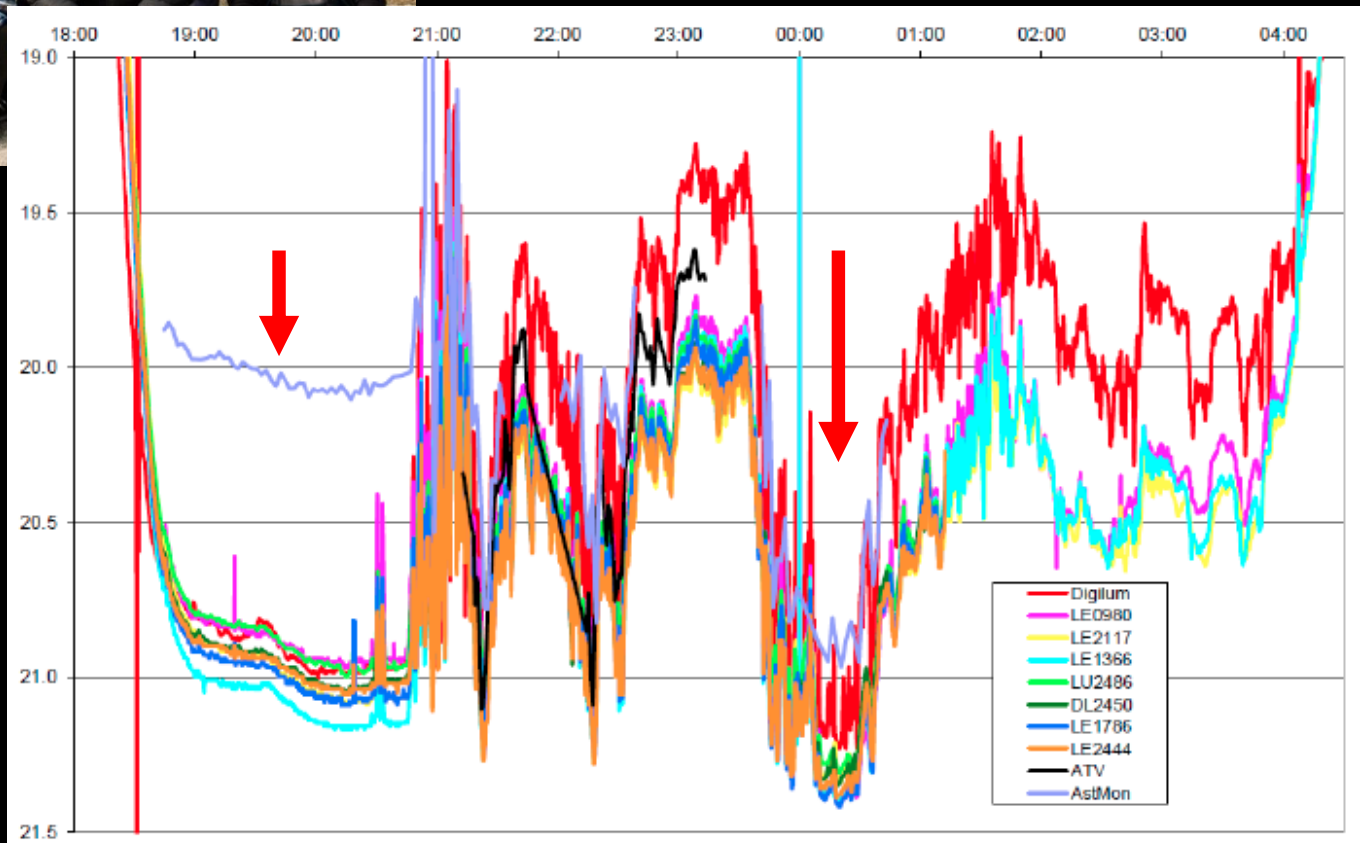


Figure 18: SQM measurements from stationary devices on the night of March 22-23

comparisons

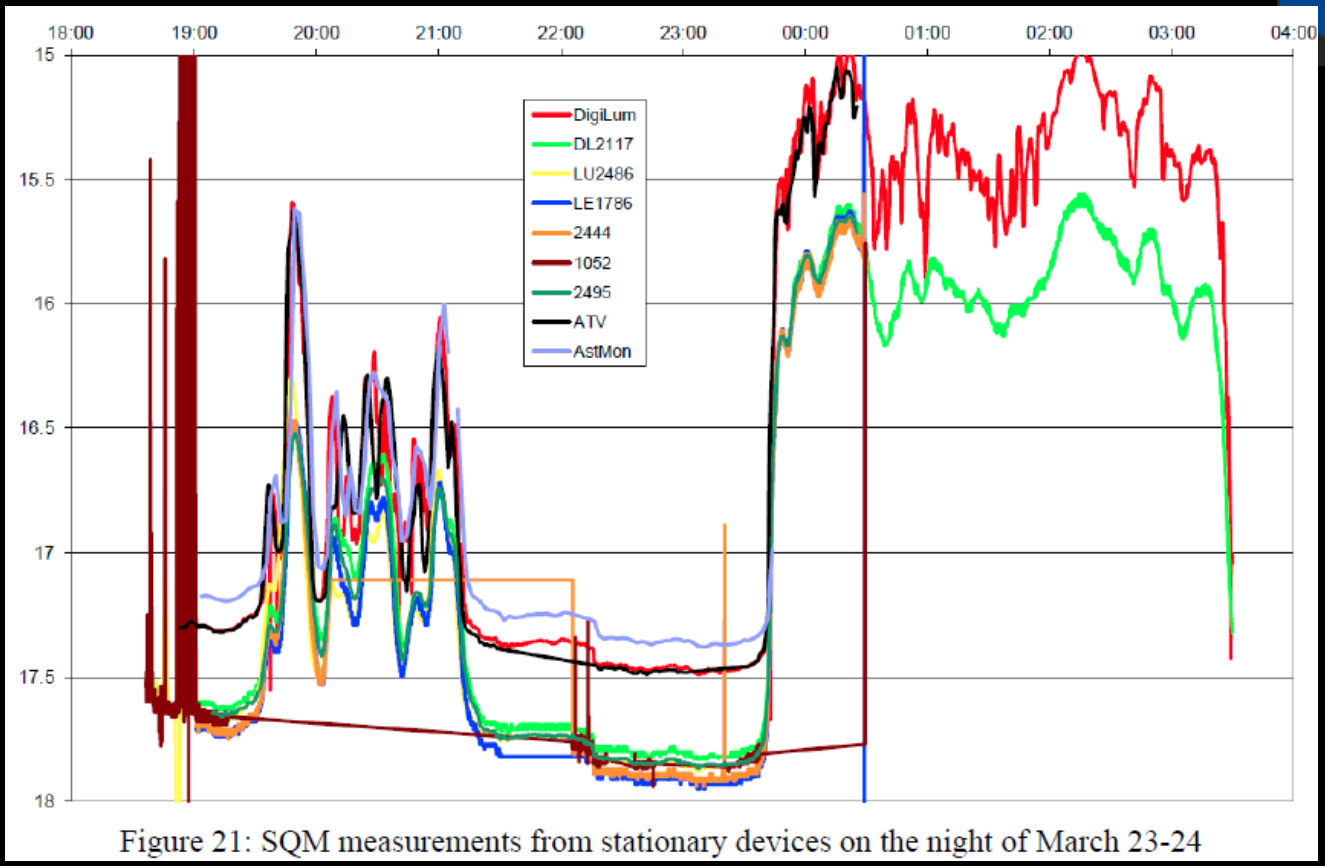
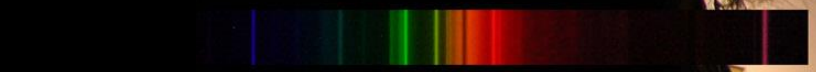


Figure 21: SQM measurements from stationary devices on the night of March 23-24

- SQM offsets - intercalibration
- SQM – Digilum: small at low, 0.5 mag at higher brightness
- Digilum – ATV (*Bouroussis*) small (photometric calibrated)
- Astmon 0.1 mag brighter Digilum?

Colour and spectral resolution

- changes at continuum (LED)
- difficult due to low intensity



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Thank you!