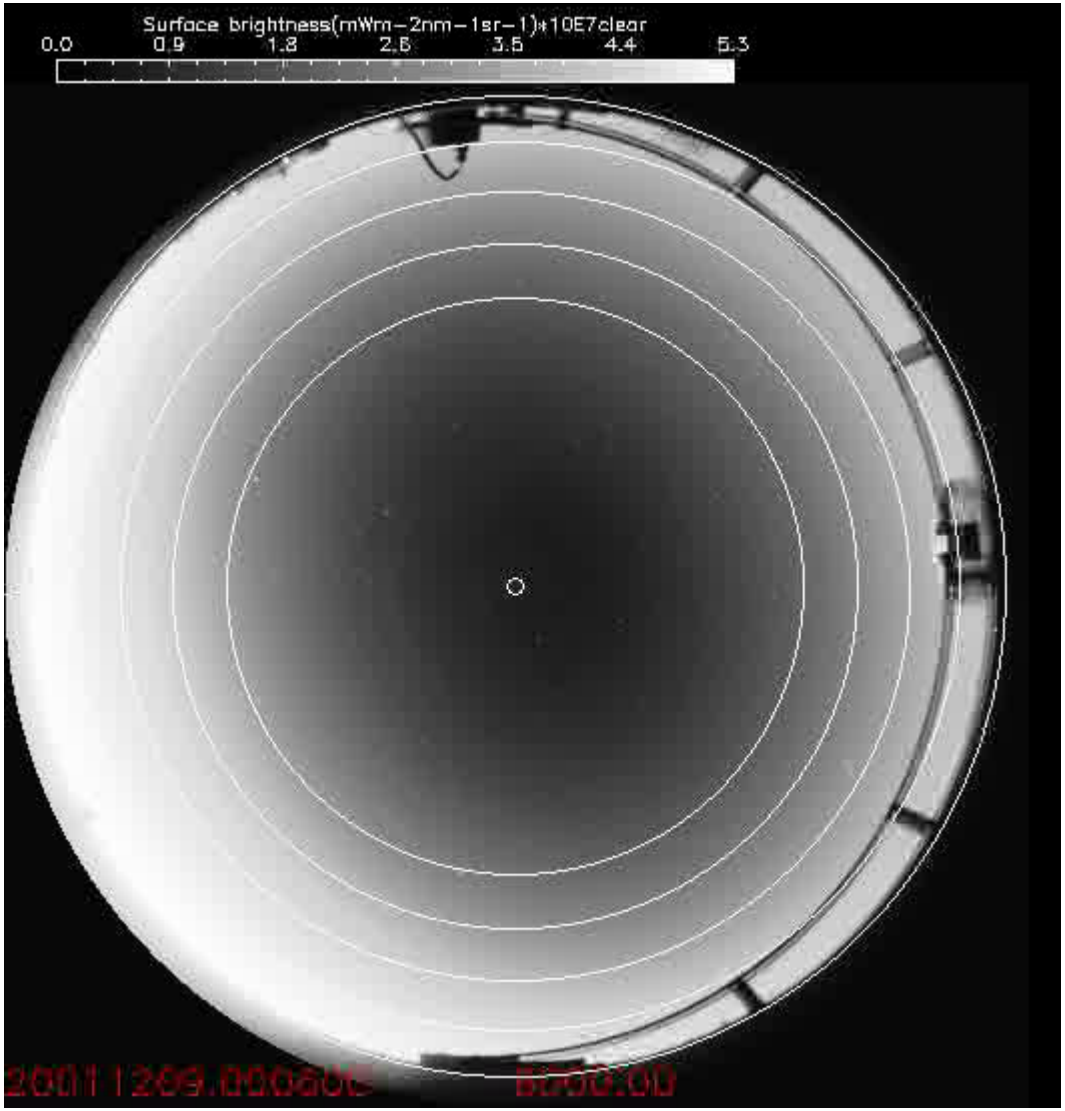
WSI night time AOD

I.C.Musat R.G.Ellingson
Florida State U.

Whole Sky Imager (WSI)



Animation 20011209

Whole Sky Imager:

Const. Zenith Distance: 50, 60, 70, 80, 90 deg.;

North is Up, East Right;

Absolute Radiances per pixel.

Entrance pupil rotates.

Absolute Calibration in lab.

CCD 512x512 pixels.

Thermoelectric cooling.

S/N >100 for stars brighter than 2.5

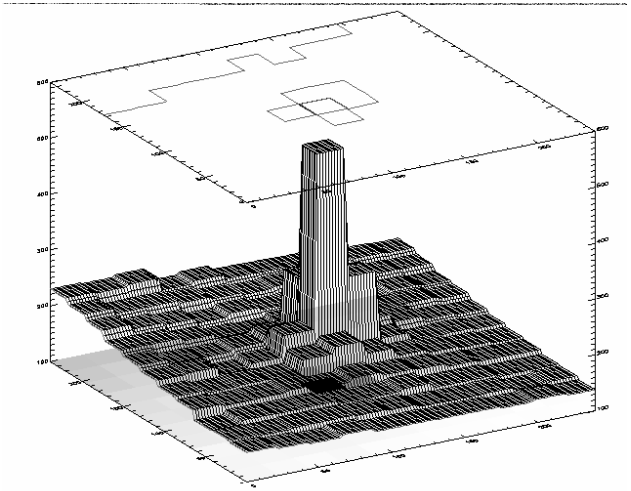
(photometric error <0.01)

Caveats:

Low angular separation

Diurnal rotation (60sec)

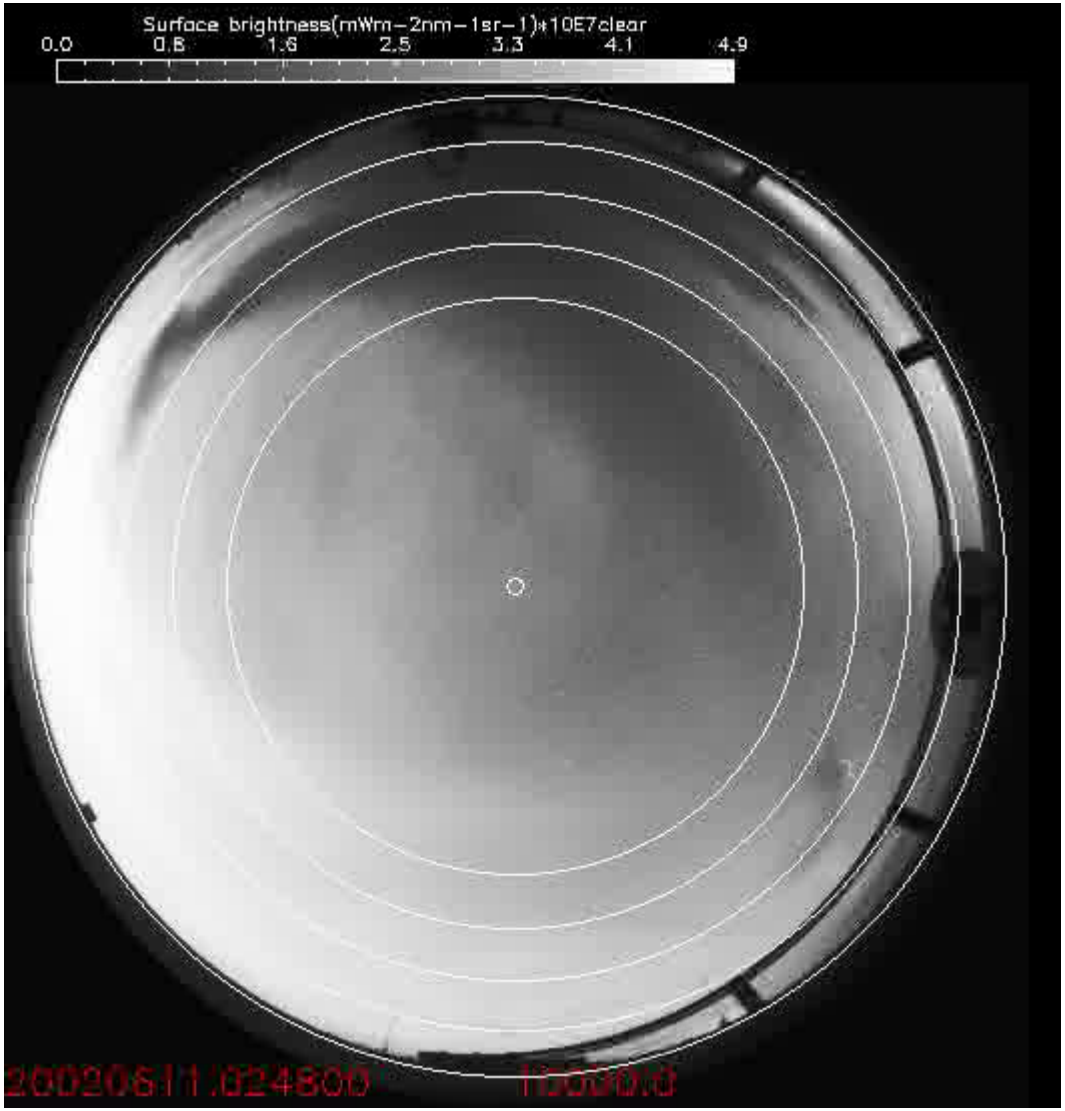
Limiting magnitude magV=6



1. Star Detection:
   Convolution

2. Star Photometry:
• Aperture photometry
Σ I(star) – Median Sky
• PSF photometry
(sigma Gaußian 0.5< 2
Undersampling)

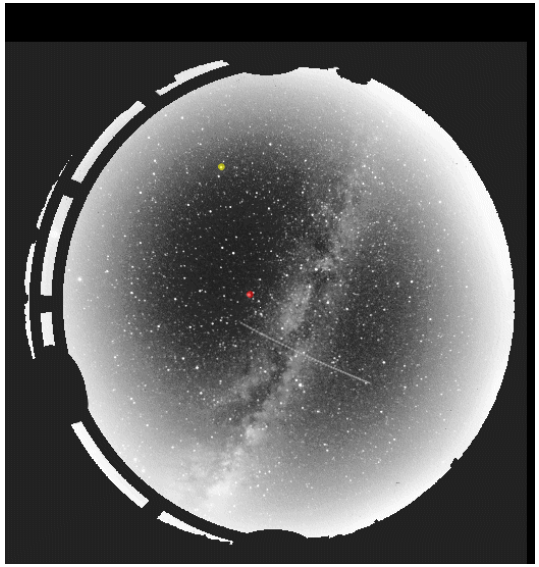
3. Sky value next to the
star



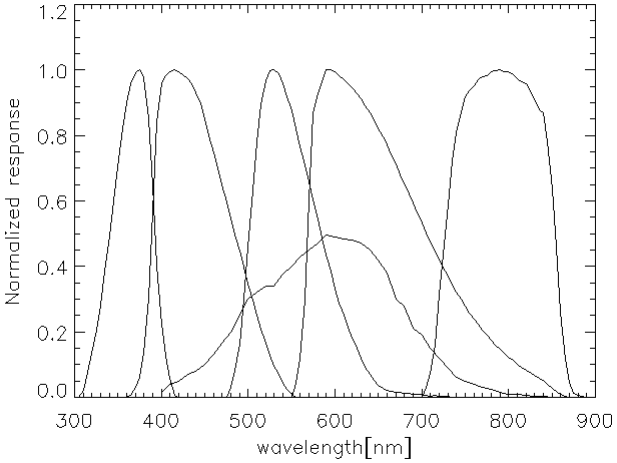
Animation 20020611 …… Vega trail on zenith

Electro-optical system
(CCD Charge-Coupled Device+FishEyeLens)

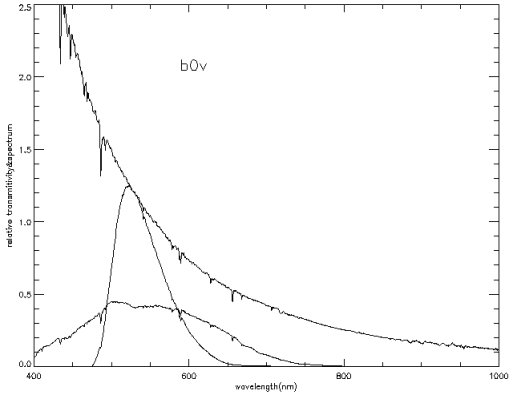
Optics	Principal lens: F=46cm, f/2.8 Nikkon lens, 21 cm diameter; Moon/Sun ocultor; Fiber-optics transducer; 16-bit A/D converter
Detector	CCD Frontal Illuminated, Thomson CCD 512x512pixels, 19μm pixel Quantum Efficiency peak 40% (in red), filter passband [400; 850] nm, Dark signal 0.5e-/px/s at -40C.
Image	Image size 9.73x9.73 mm; Optical Image size reduced 2.47 times; Field of view 180deg, Plate angular scale ≈34μsr / pixel
Electronics	Unit 4: gain 4.92e-/DN; flatfielded; read noise 6.05e-rms. Unit10: gain 4.37e-/DN; flatfielded before deployment; read noise 6.90 e-rms. Bias 997e-…1017e-.
Calibration	Transmission curve determined for optics-filter system: in lab and in-situ. Tu lamps (NIST standard). Number of geometrical calibrations: 14. Number of absolute radiance calibrations: 4 (Bias subtraction, Noise subtraction, Readout noise correction, Flatfielding, Absolute calibration for all combinations of neutral and spectral filters).

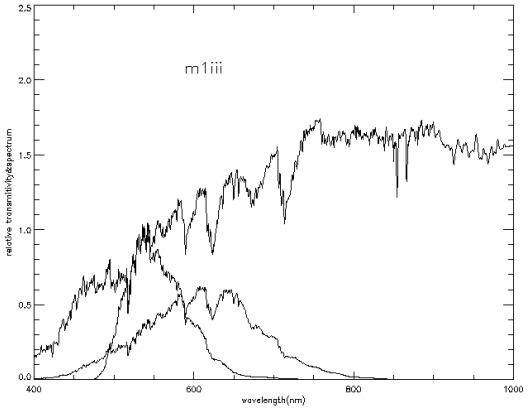


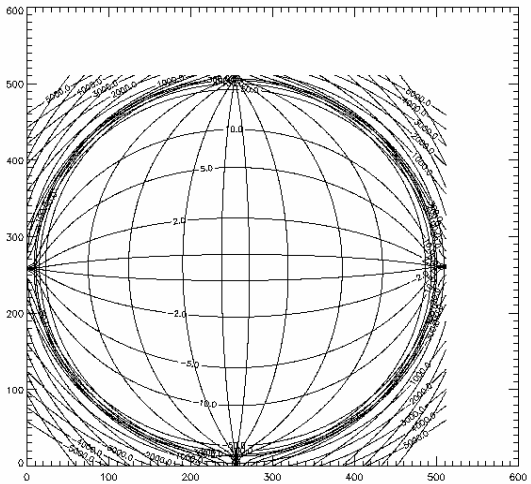
Johnson Filters UBVRI and WSI broadband

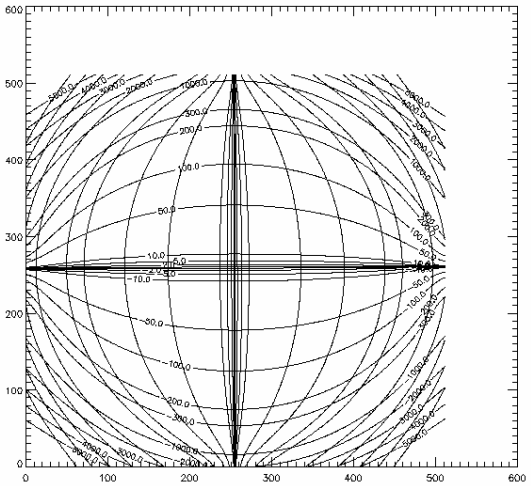


O B A F G K M R N S
Morgan-Keenan luminosity and spectral classes

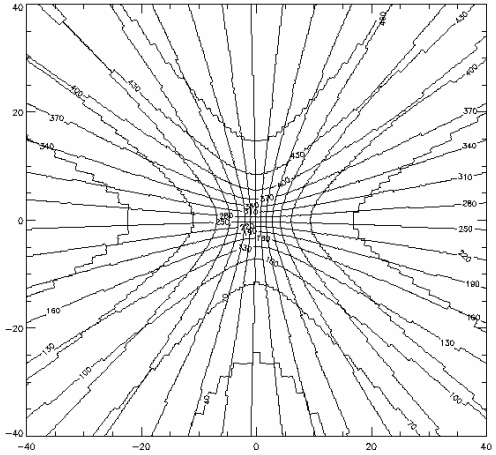


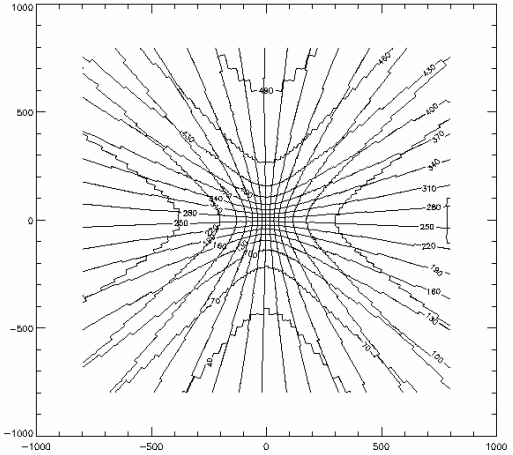




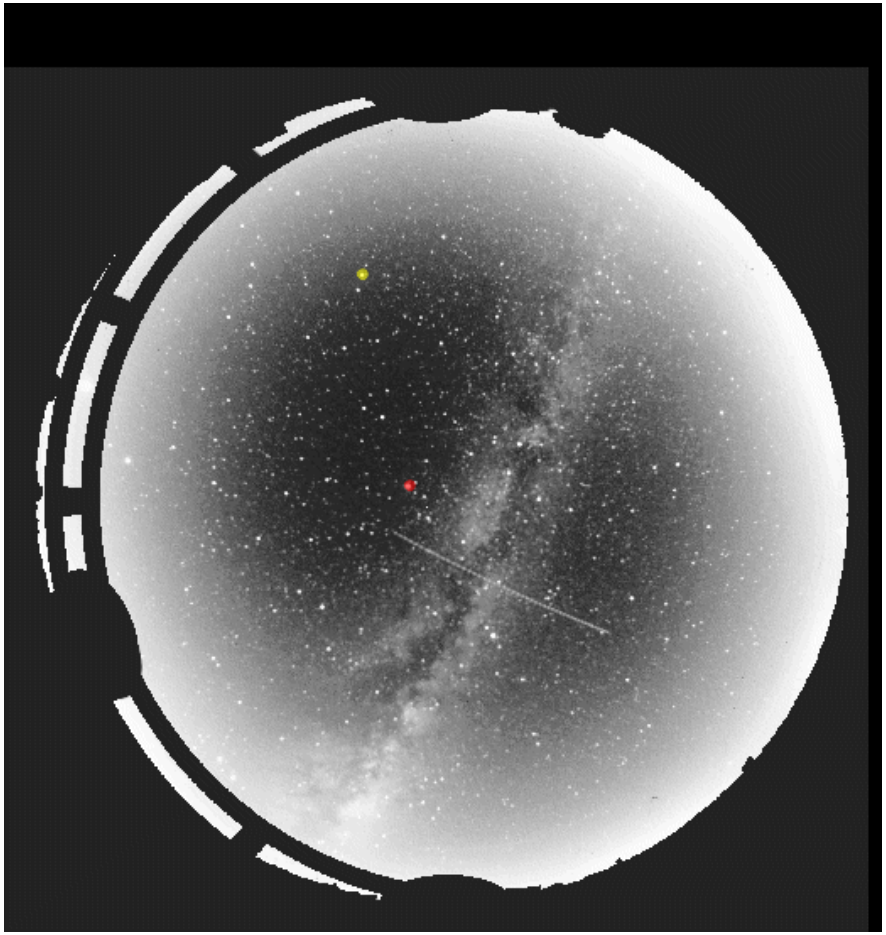


Polar fisheye view on a 512 x 512 pixels detector of a uniform spherical grid layer at 5 and 96km altitude





Projection of the detector's 30 x 30 square pixels each on layer at 5 and 96 km altitude
(surface of layer seen 80x80 sq.km and 1600x1600 sq km)



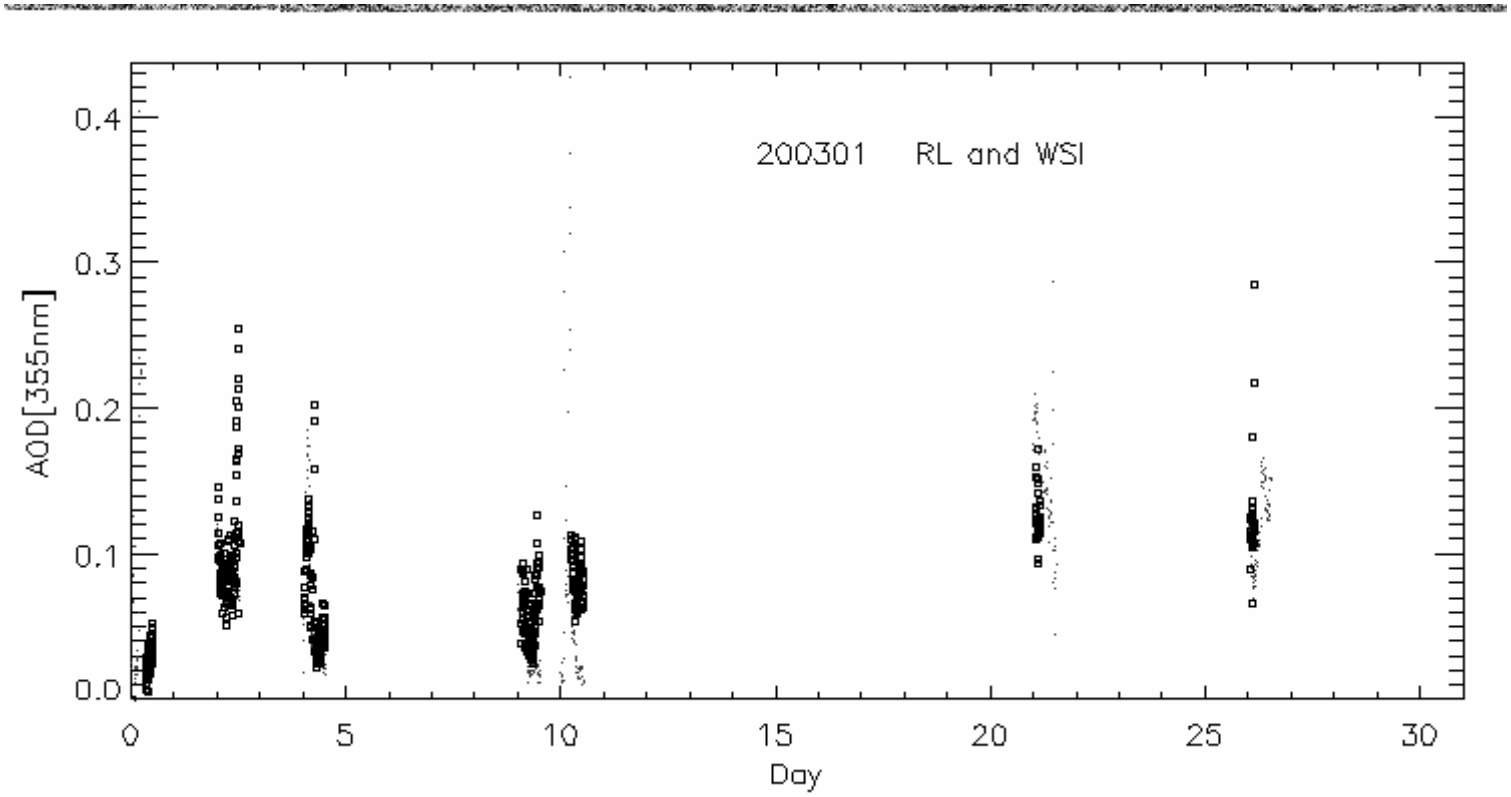
19990914.0212

Assume a missing AOD from known total optical thickness as a power law of wavelength (alpha Angstroem exponent, beta turbidity)
Known optical depths: molecular absorption, RAYLEIGH scattering, absorption in PWV and O3 from MWR, balloon soundings, TOMS ozone spectrometer.

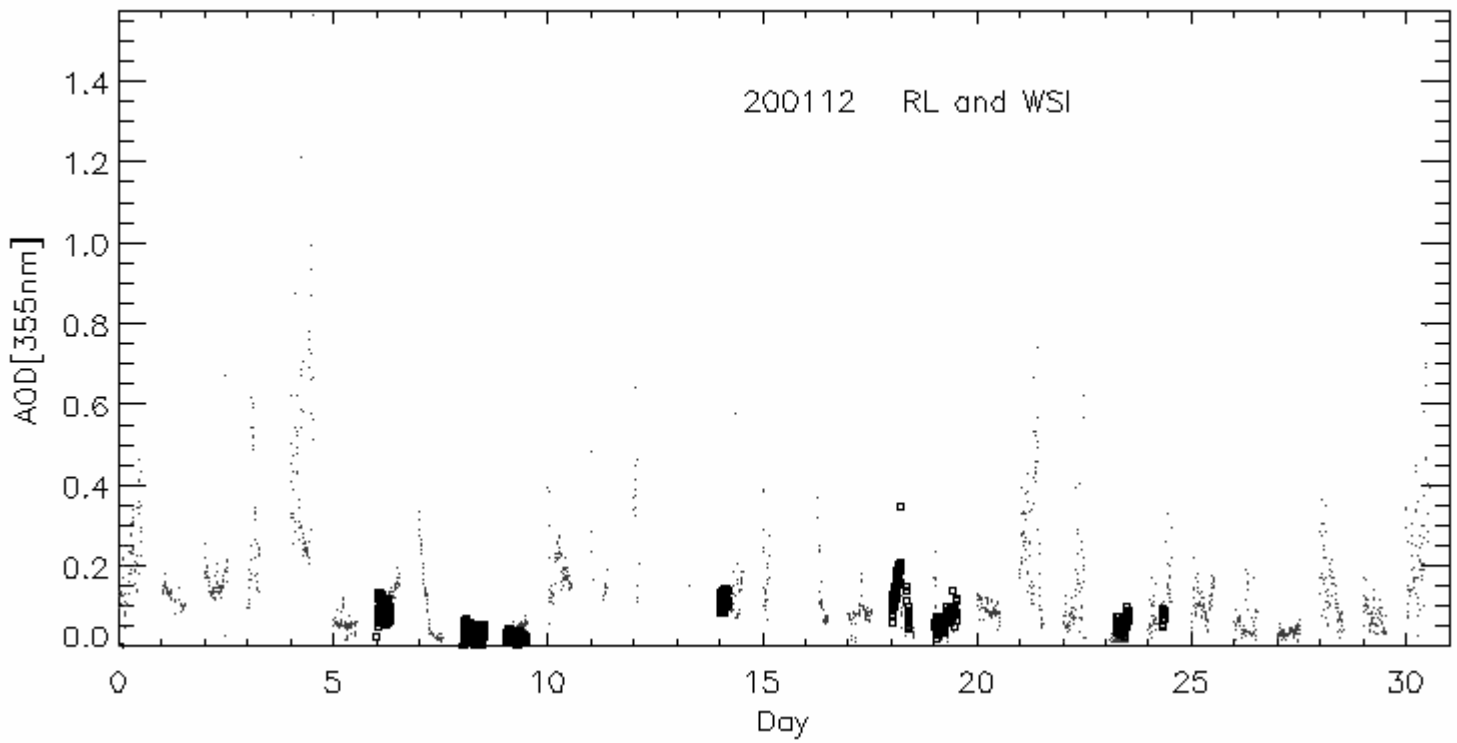
Compare Colors of Pairs:
Beta UMi (Kocab) K4
Alpha Lyr (Vega) A0V

Solve by iterations for the same AOD for different zenith angles and colors.

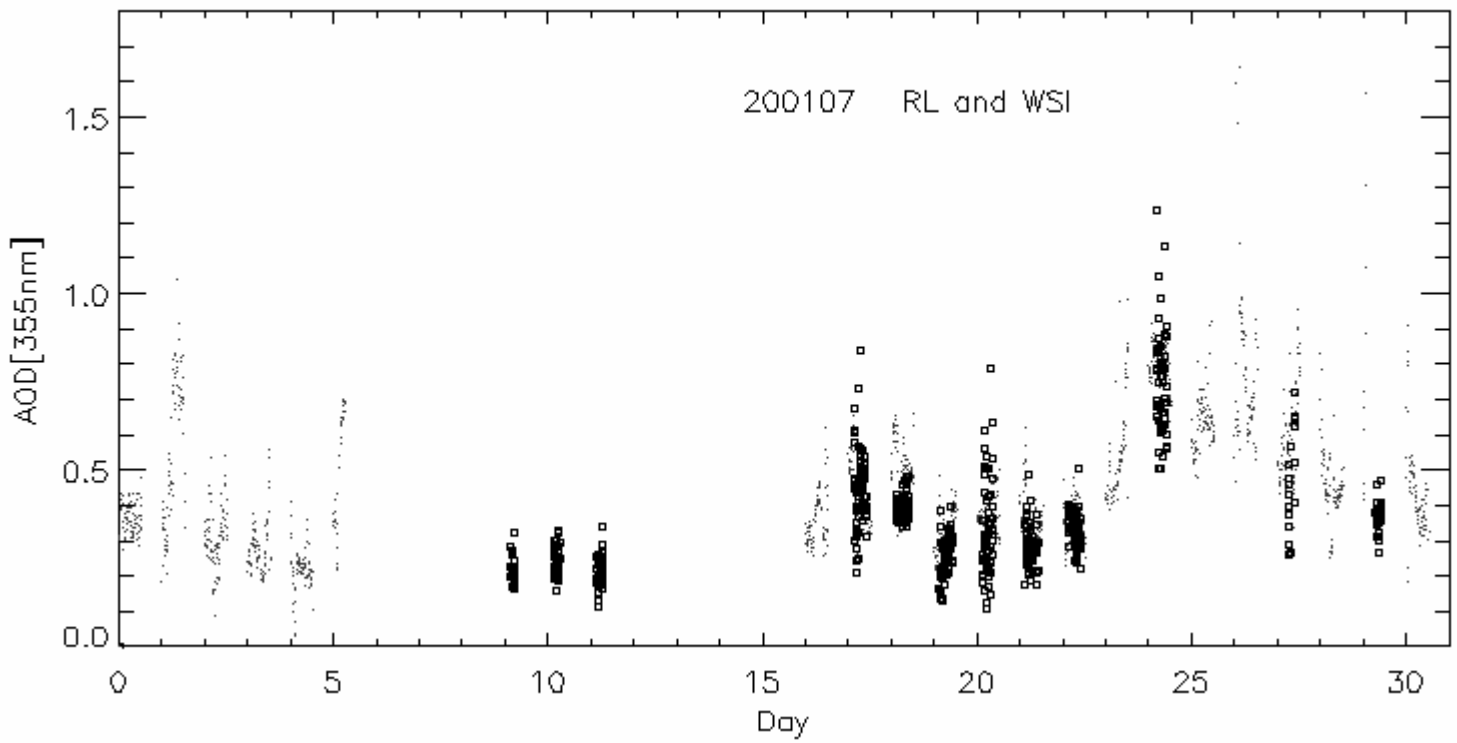
AOD from WSI and RL



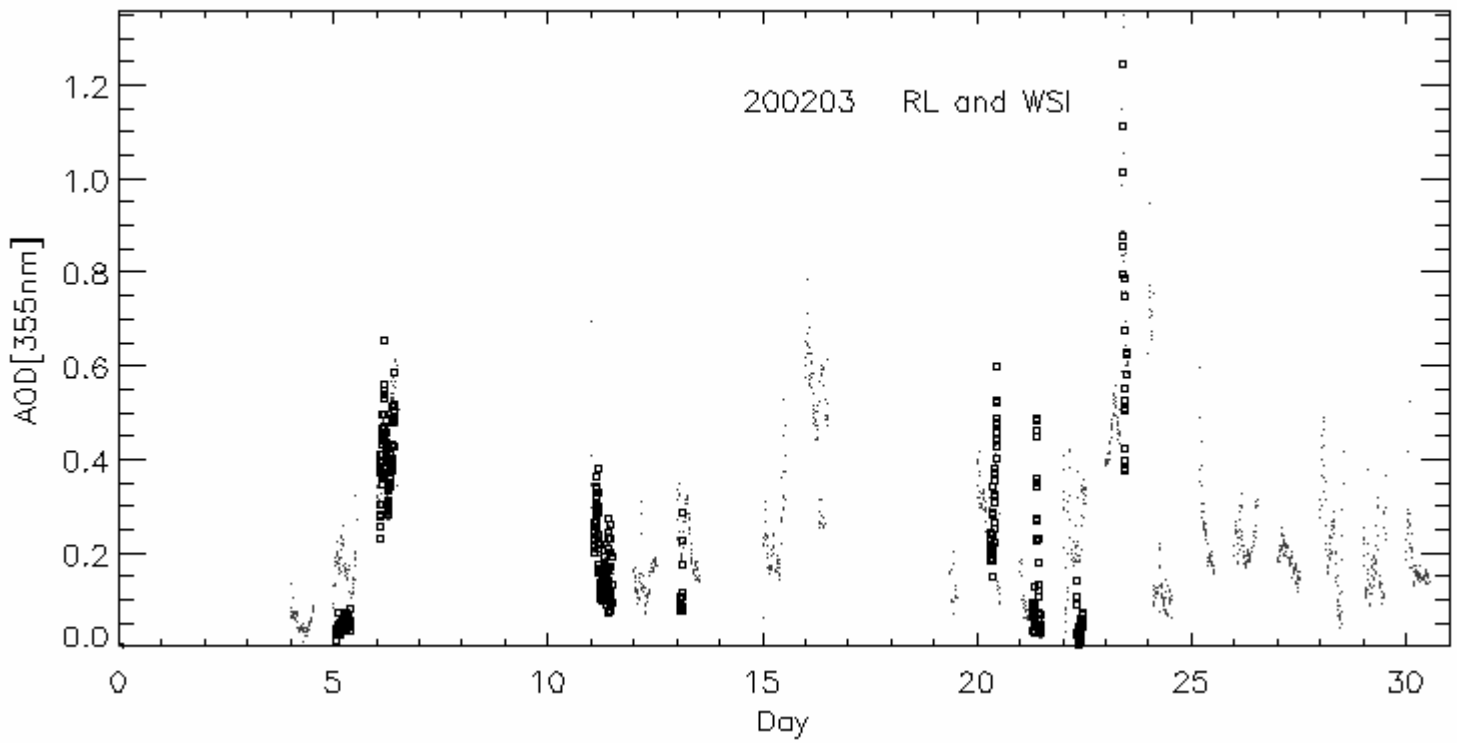
AOD from WSI and RL

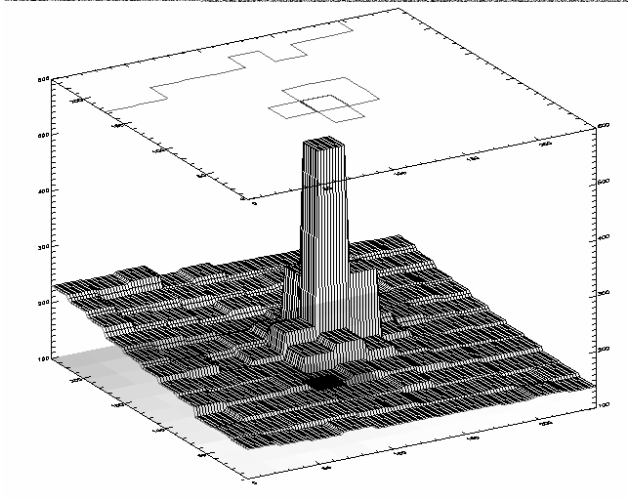


AOD from WSI and RL



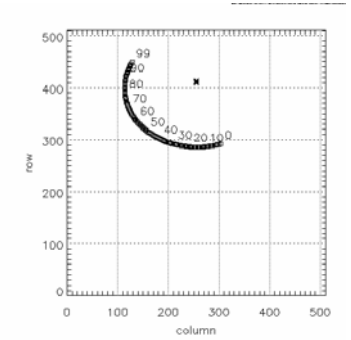
AOD from WSI and RL





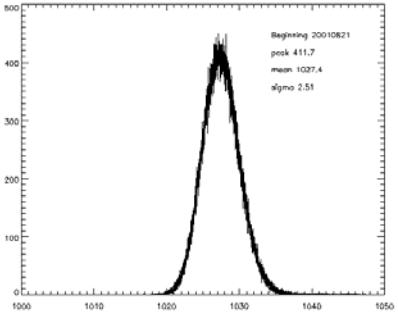
Star Capella 19990124,
Position 99 on trail.
Error in flux calculation
is 1/(S/N):

$$\frac{S}{N} = \frac{N_{star}}{[N_{star} + n_{star}(1 + \frac{n_{star}}{n_{sky}})(N_{sky} + n_{dark} t_{\exp} + n_{read}^2 + g^2 \sigma_f{}^2 + P)]^{1/2}}$$



Trail on CCD

Median sky from 48 pixels,
for ellipse sky tangent with local constant
Zenith circle



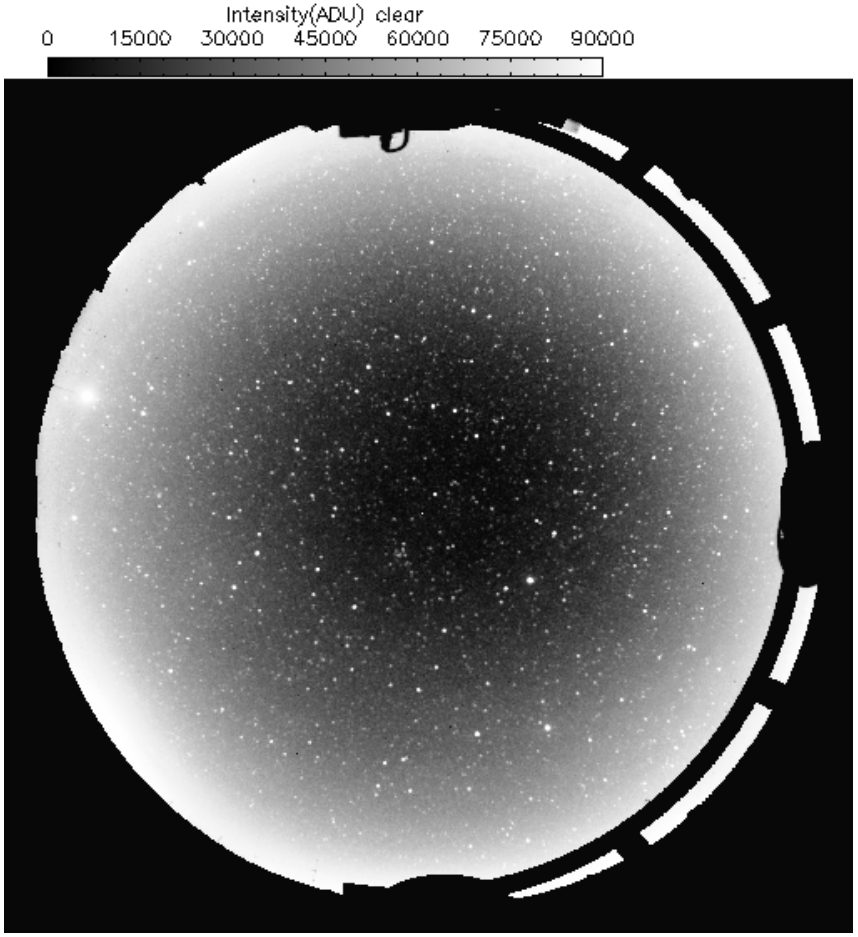
Ndark*texp

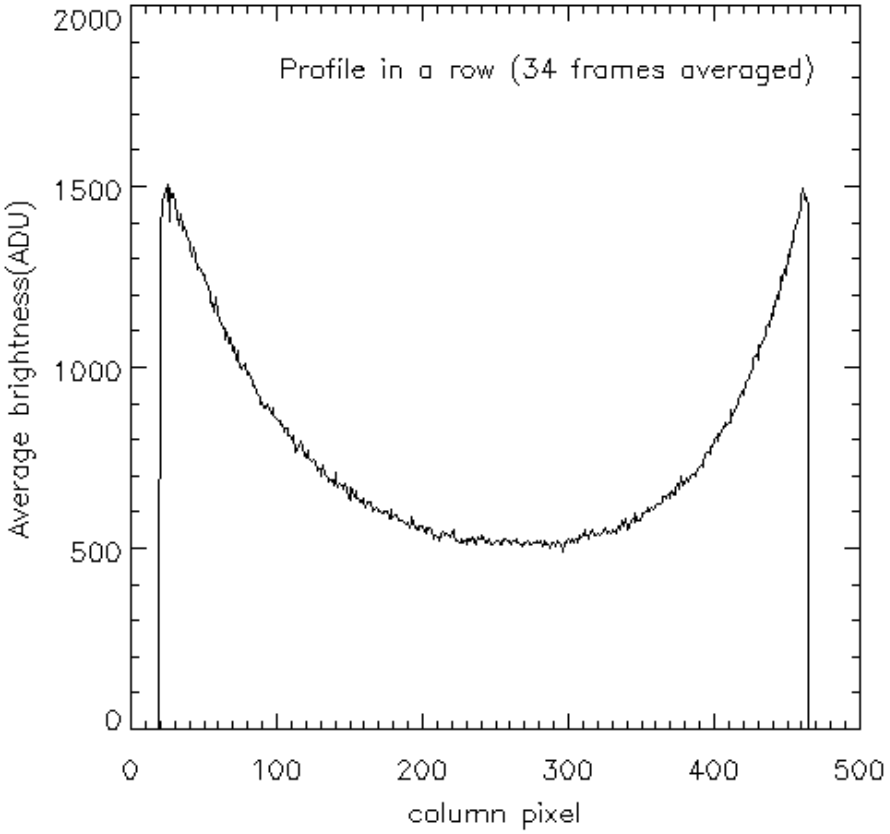
AOD from stars (error estimation)

- Absolute calibration constant 0.5%
- Sistematic uncertainty in the absorption and molecular scattering model (MODTRAN): 0.72%
- Random uncertainty in absolute monochromatic flux of the standard star (0.02 x 10-7 mW m-2 nm-1) rms
- Sist.uncertainty in absolute monochr. flux of nonstandard star 1%
- Star calibrated measurement uncertainty 1.11 -1.37 %
- Catalog magnitude uncertainty 0.01 mag
- Uncertainty per iteration from calibrated measurement and extinction model: 1.32 – 1.55 %
- Linear relaxation: after 4 iterations (linear relaxation): 2.6 – 4. %

The sky value as error source

North Galactic Pole direction:
SKY ~ { Isca Rayleigh(AG) + AG_0 exp(-tau)}; ISL=0; ZL low

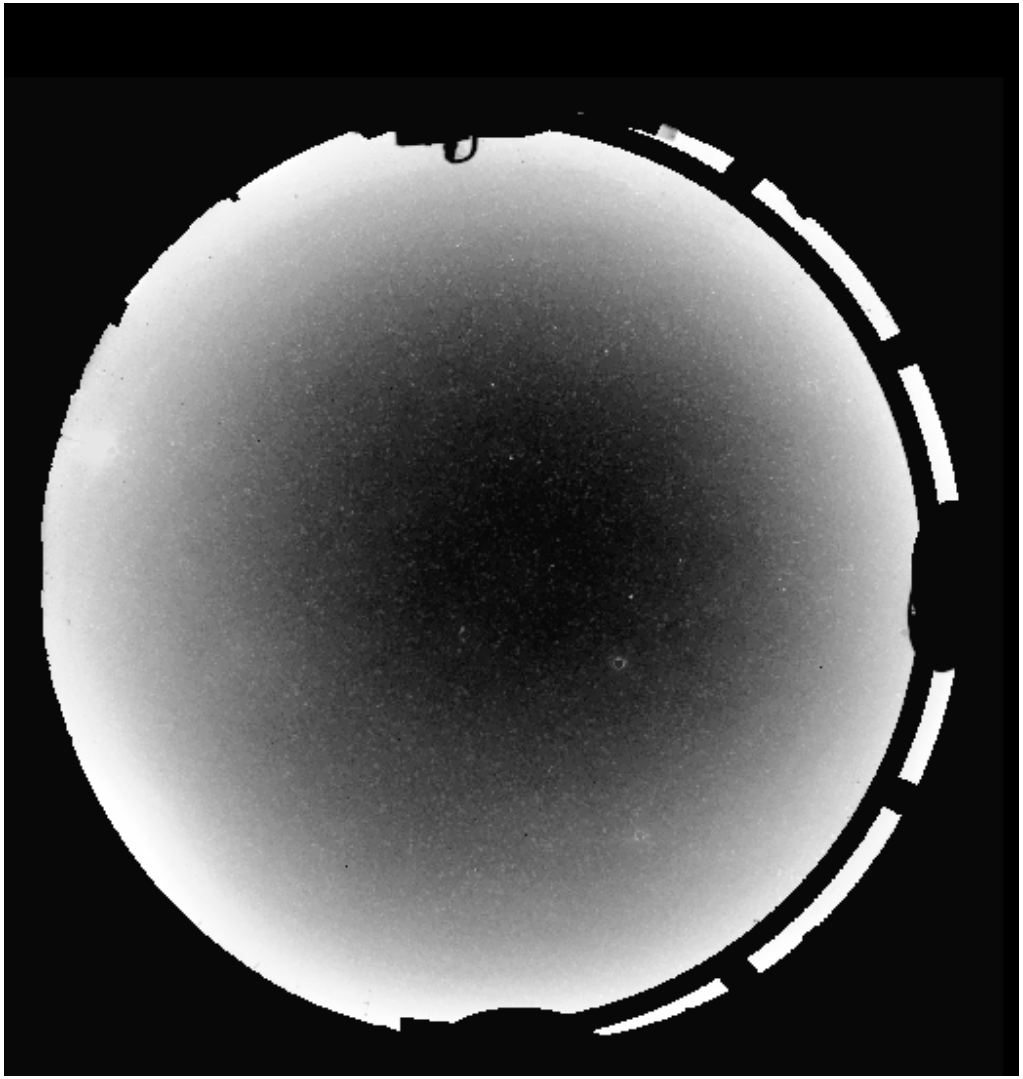




AOD=0.04

Feb.1999

The sky value as an error source

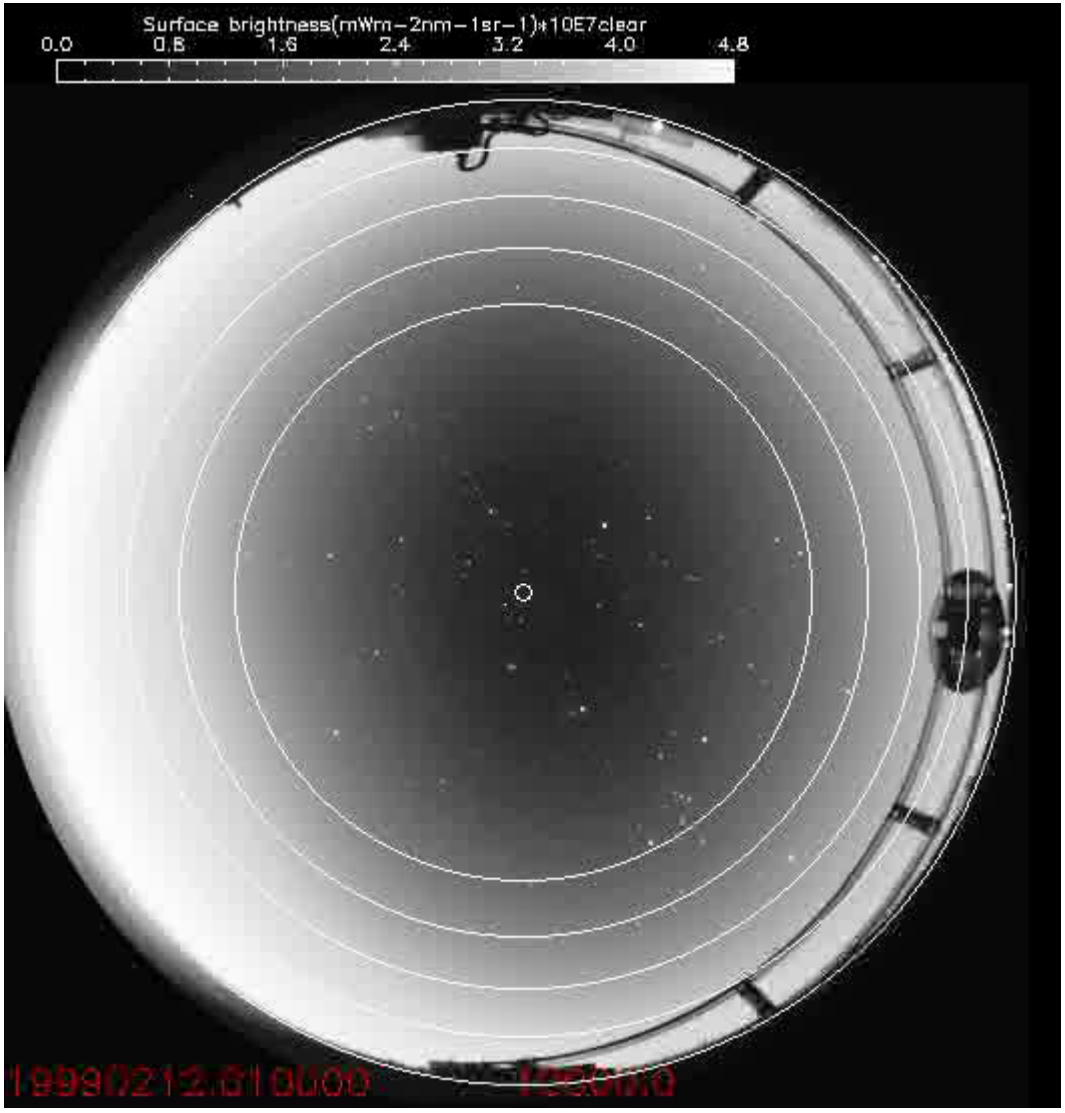


Feb.1999

AOD=0.04

SKY ~ { Isca R&M (AG) + AG_0 exp(-tau)}

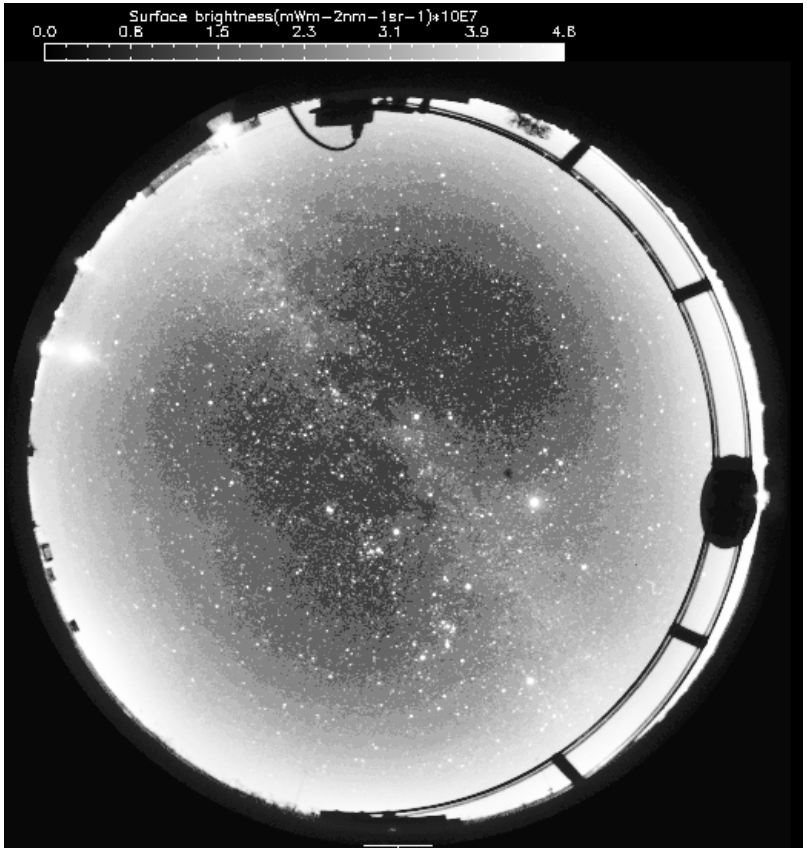
The sky value as an error source



Animation Feb,1999, Last part: Example of NGP (no ISL, no ZL)

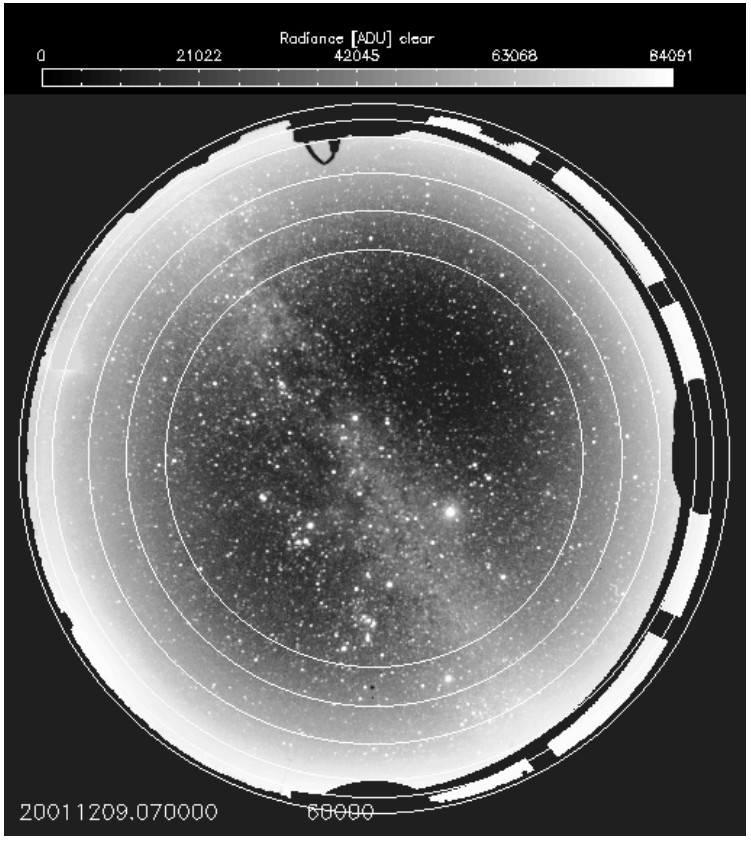
SKY = (ZL+ISL)+ Isca(ZL+ISL+AG)+AG

AOD=0.10



Oct.2001

AOD=0.05

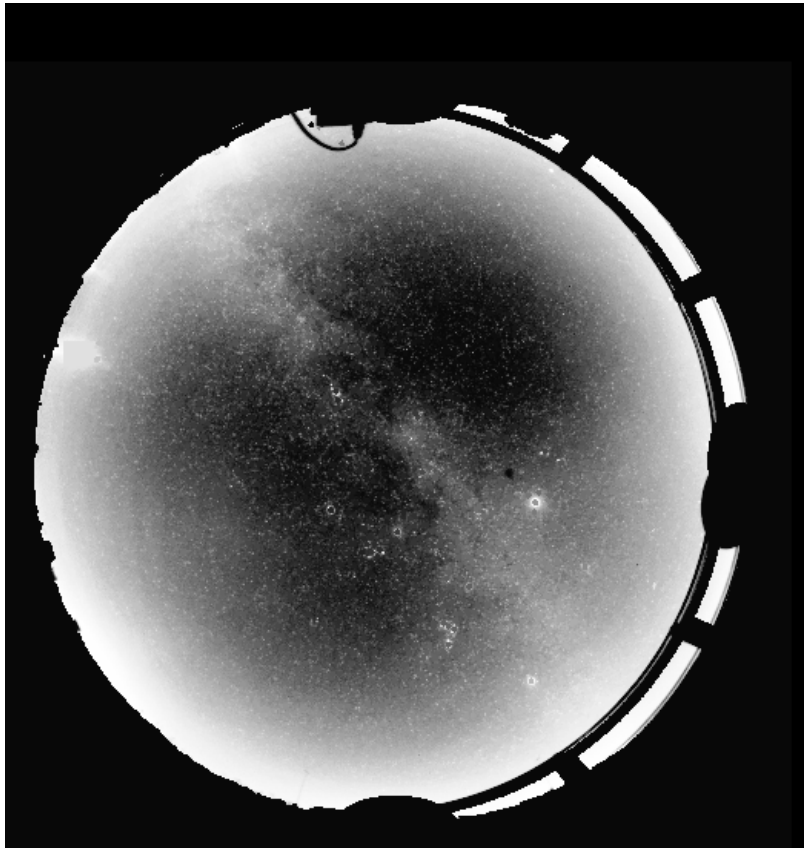


Dec.2001

The sky value as an error source

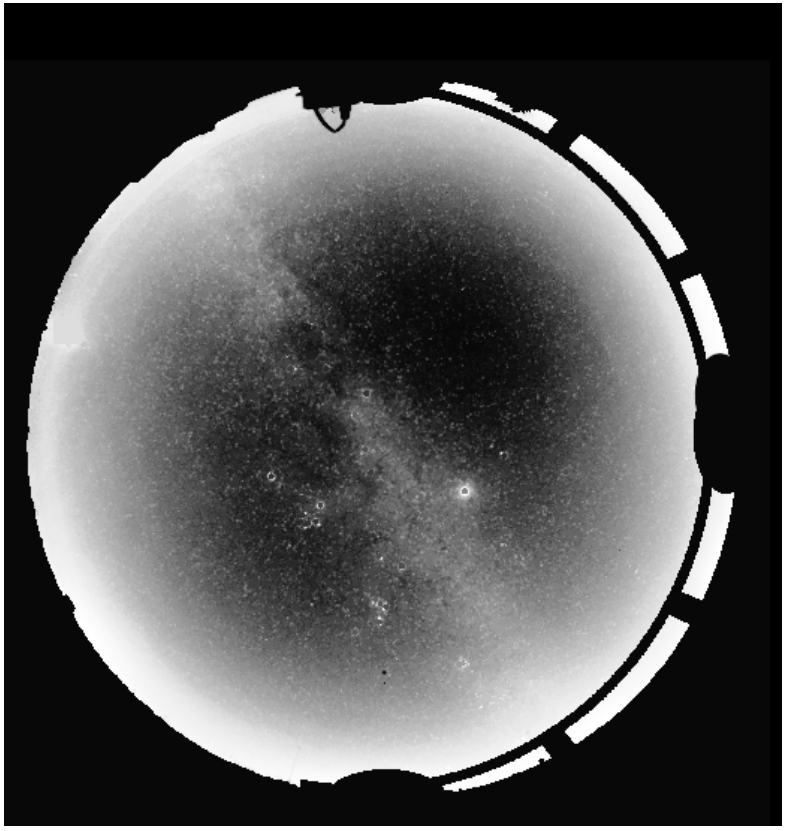
Stars=0; SKY = (ZL+ISL)+ Isca(ZL+ISL+AG)+AG

AOD=0.10



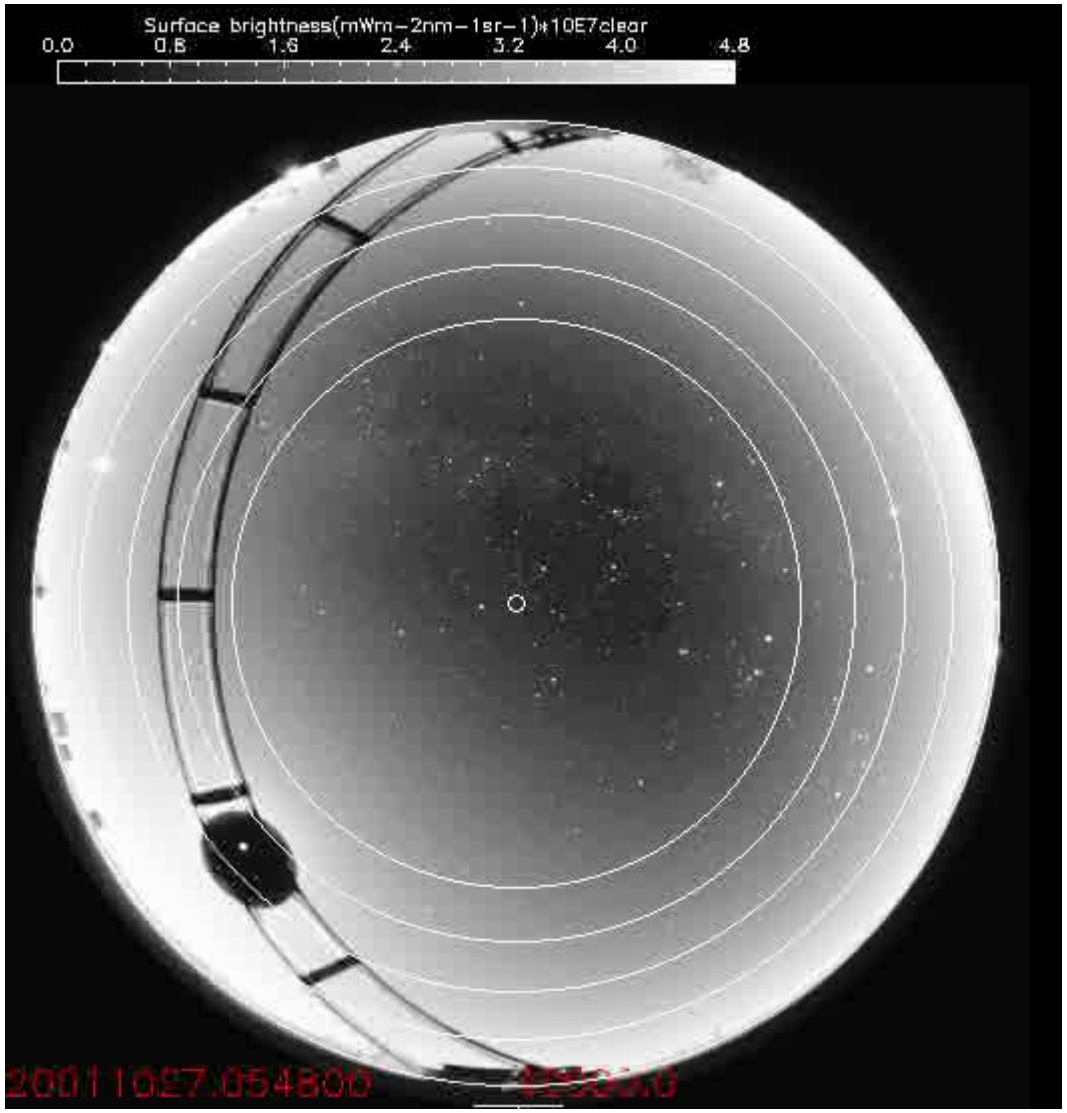
Oct2001

AOD=0.05,
Isca(ZL) low



Dec.2001

The sky value as an error source



Animation Oct.2001

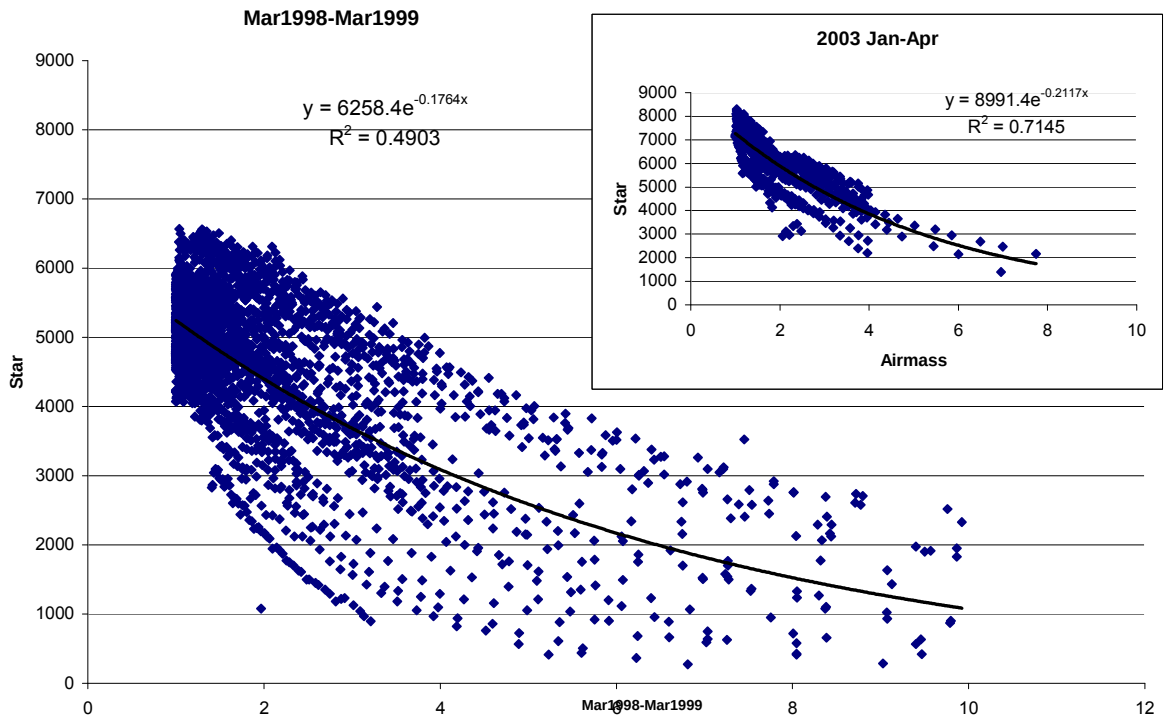
The sky value as an error source

Date	Calibration of Unit 4 (then Unit 10)	Calibration Constant
19970404	Unit 4: installation of new camera dome	0.000398693
19971010	addition of nir filter and replacement of the camera	0.000398693
19981007	movement of unit because broken platform	0.000398693
19981020	movement after repair	0.000398693
19990217	new instrument stand	0.000398693
19990302	rotation on stand	0.000398693
2000506	Unit 10 replaces Unit 4	0.000822440
20010821	New camera lens	0.000785403
20011128	Cleaning the sensor	0.000783696

Updates geometric calibration function, but not the calibration constant?
Was the integrating sphere (for flat fielding etc.) deployed in the field?

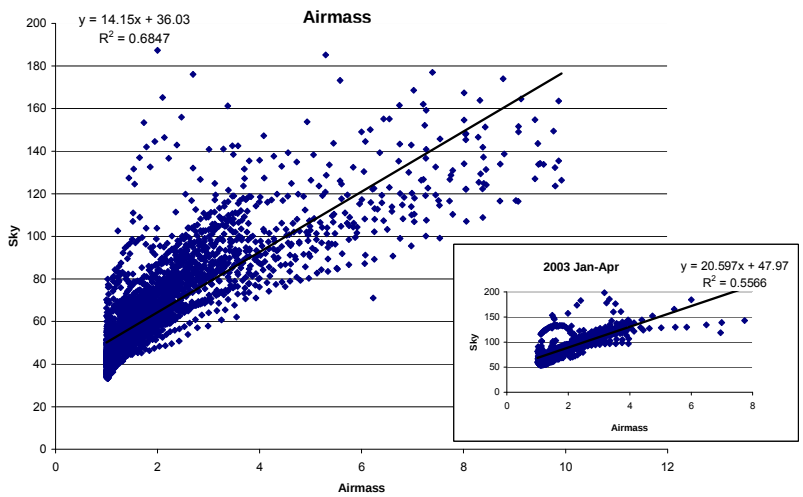
Sky spectrum (Leinert'95) @ Palomar 1974 in WSI:
38 x 10-7 mW m-2 sr-1 nm-1
(above the scattering layer, astron.site)
Sky WSI minimum value 1998 = **29** (same units)

Vega(Alpha Lyr) Flux and (below) the Sky around



CCD 10

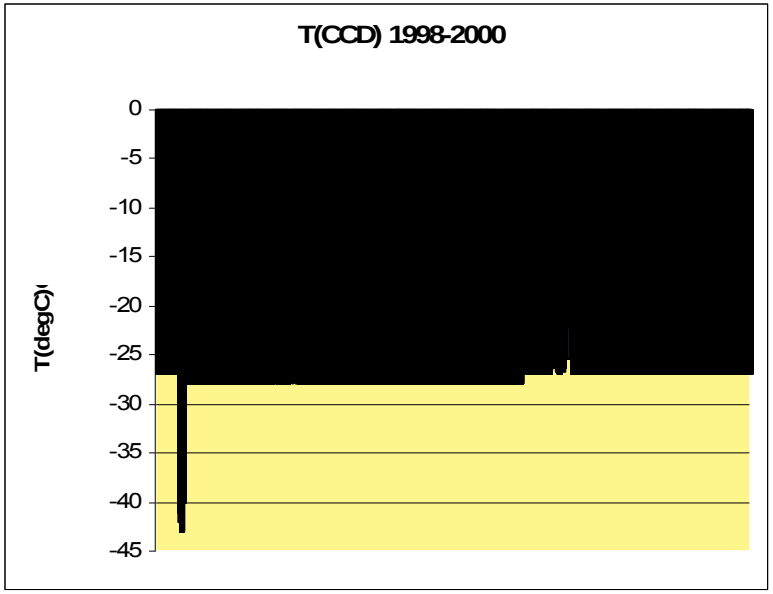
CCD 4



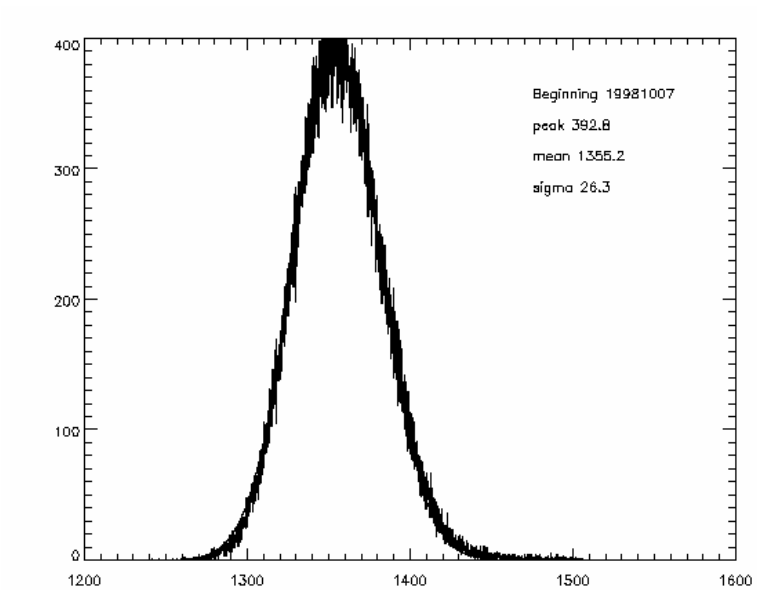
CCD 10

CCD 4

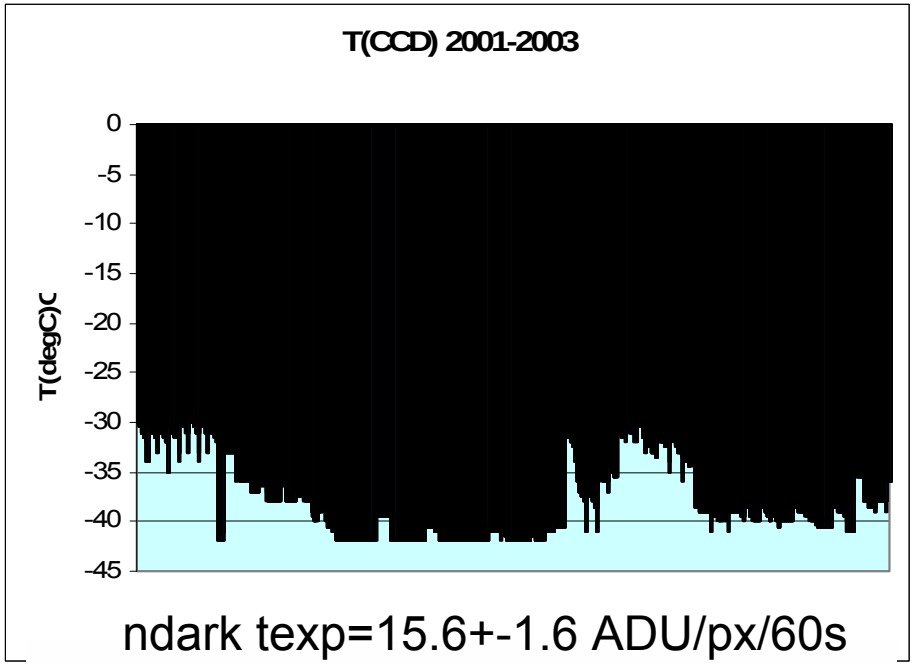
Unit 4 (1998-apr2000)



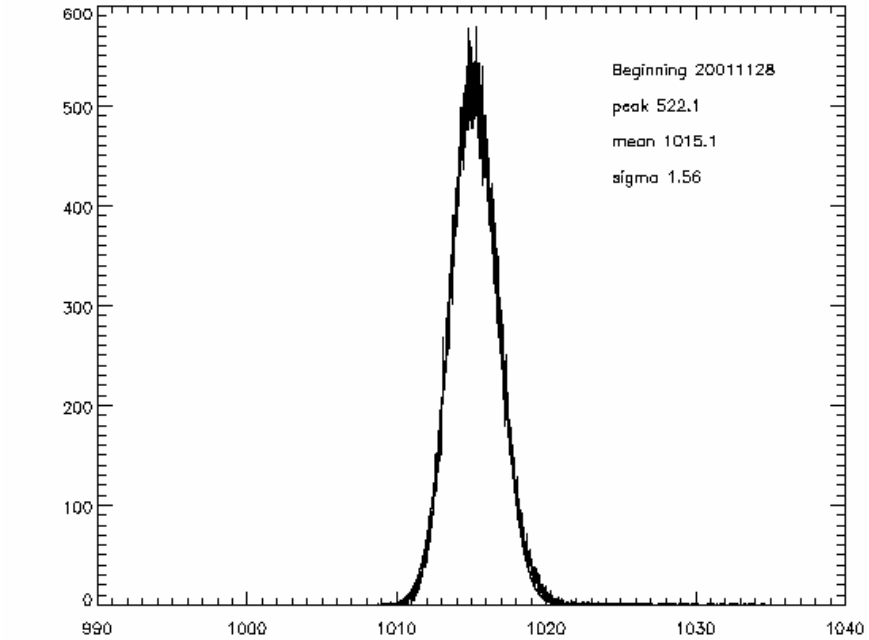
ndark texp=348+-26 ADU/px/60s



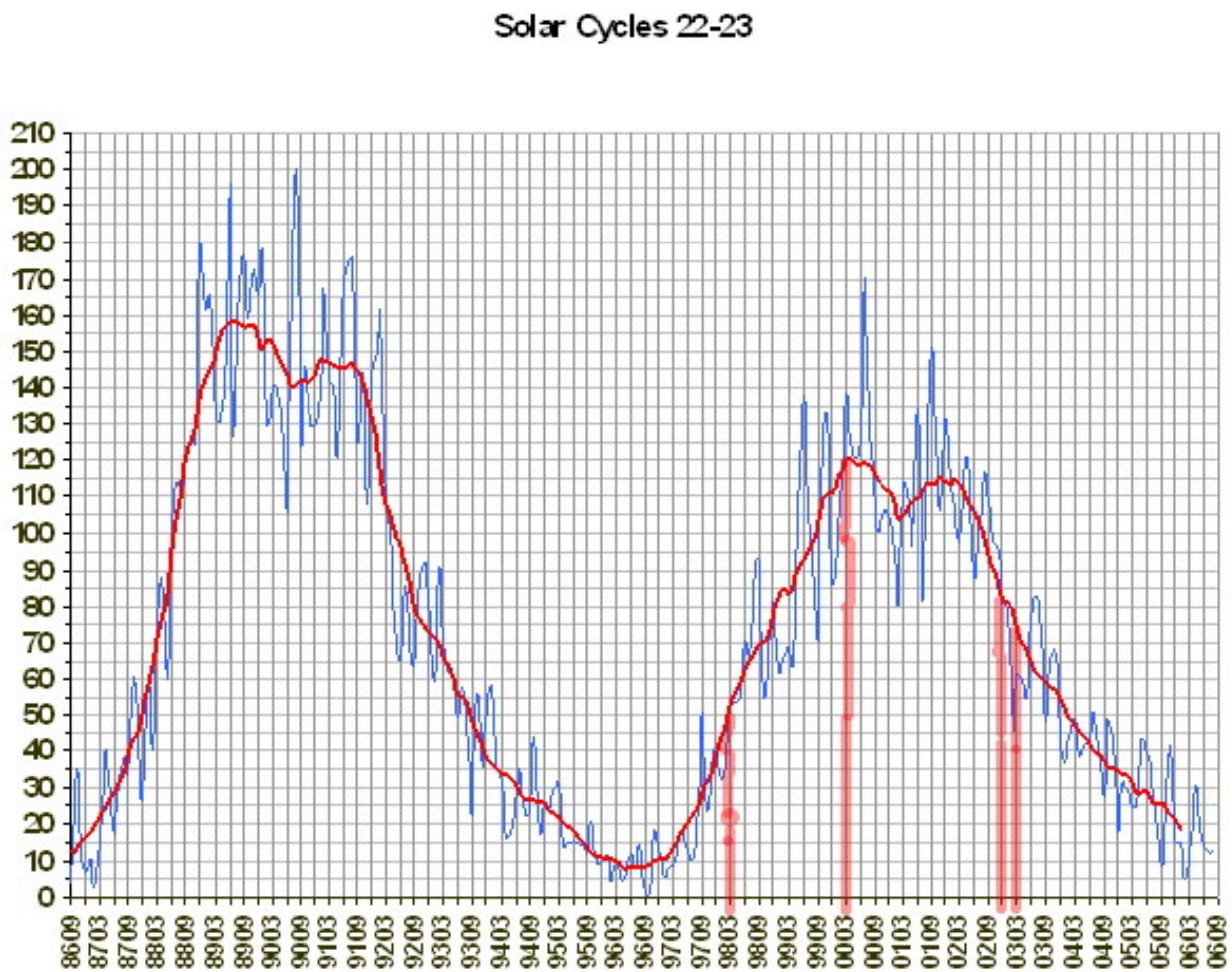
Unit 10 (apr2000-apr2003)



ndark texp=15.6+-1.6 ADU/px/60s



AG ~ solar flux 10.7 cm cycle



Source: Brussels Observatory

- True Star = Flux (aperture or PSF fitting) – True Sky

- Sky in Image = True Sky + Extended Sources + Isca(Extended Sources),

  where Extended Sources = (ZL + ISL) known + (AG) unknown

- Eliminate (ZL + ISL)exp(-tau) using astronomical maps

- Residual Sky left contains still the atmospheric scattered Extended Sources light, which can't be known until AOD is known.

- But AOD is the unknown to begin with!!

Solution (future work):
Every pixel of sky (not only those containing stars) could be a radiometer for AOD measurement.
Extract from the image, in the first approximation, the stars, ZL, ISL; model the remaining scattered light dependence upon zenith. Use a model for aerosols SS+MS, with a non-collimated, non-uniform spherical source.
Use the value of the sky at the zenith in the image as approx. for Absorption + Single Scattering of the unknown and highly variable AG.