Digital Imaging Photometry with Common Cameras – Methods, Results and Perspectives

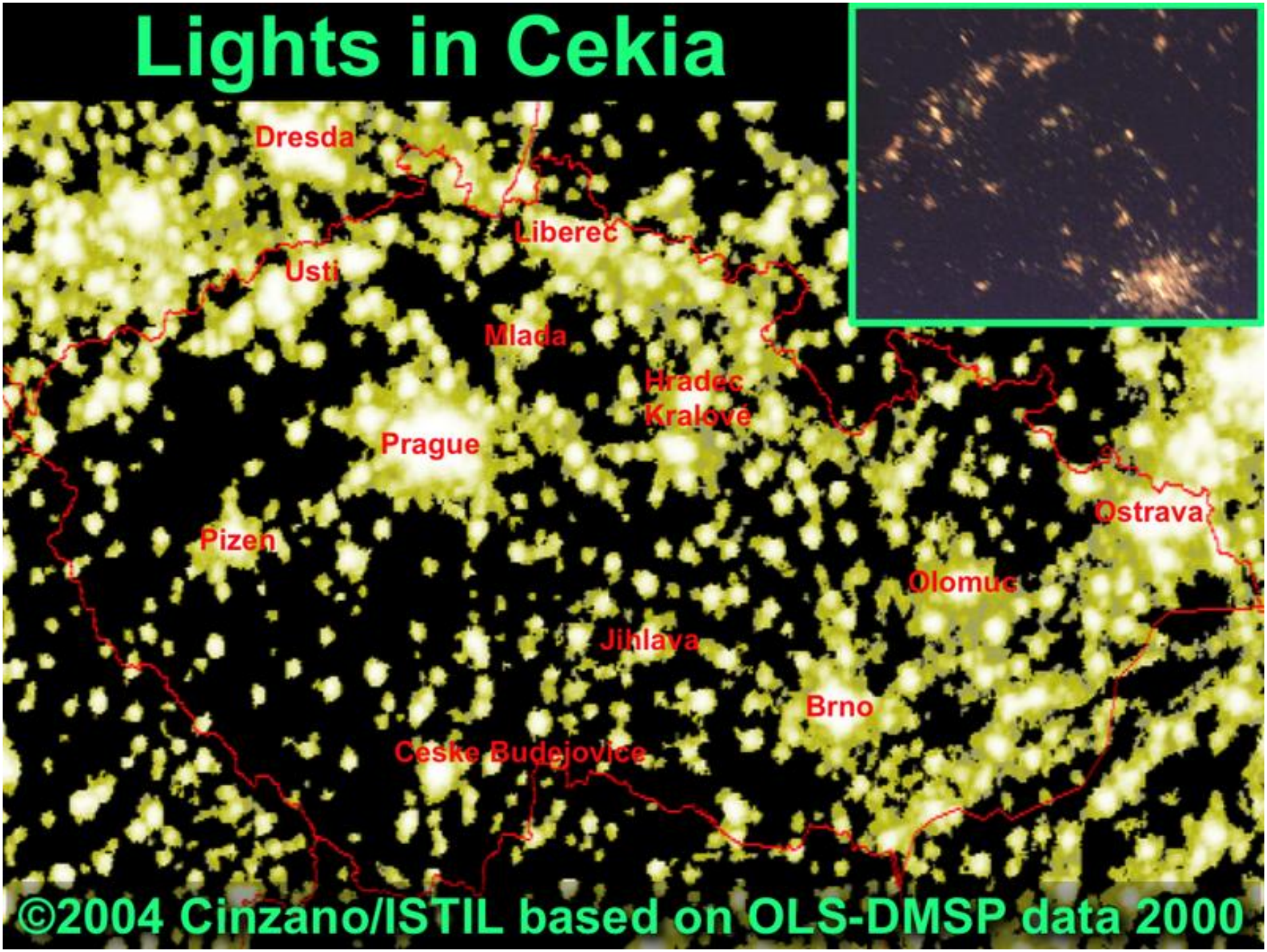
J. Hollan, N. Copernicus Observatory and Planetarium in Brno

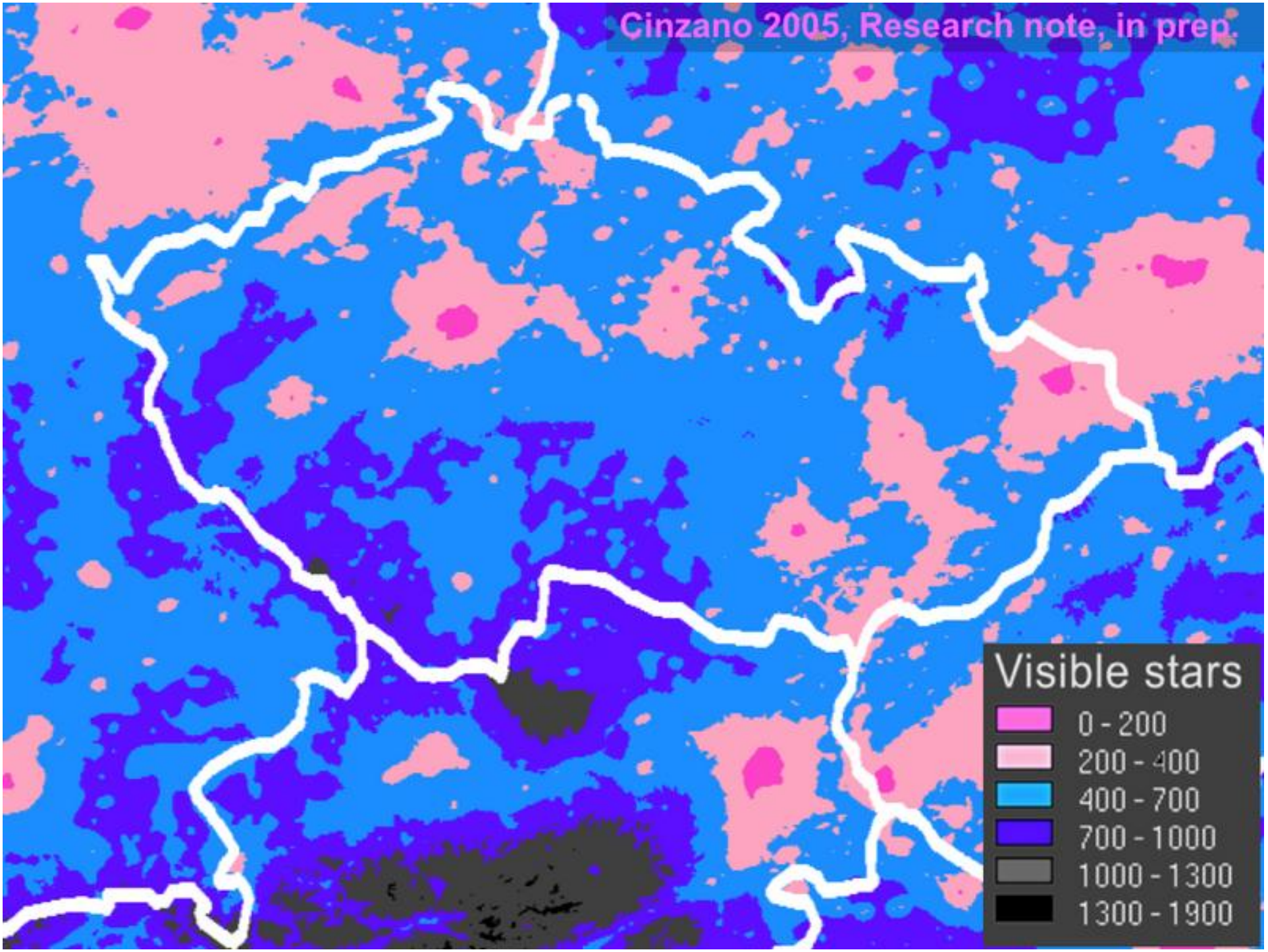
IAU commission 50 meting, Prague 2006

Natural Darkness: A prime attribute of the night

A need to quantify:

- How much light, man-made and natural is there and from where it comes?
- How it was decades ago?
- How much does it vary with time and weather?
- How much do various individual anti-LP measures help, like adhering to the 0 cd/klm limit?


Lights in Cekia
Dresda
Liberec
Usti
Mlada
Hradec Kralove
Prague
Pizen
Ostrava
Olomuc
Jihlava
Brno
Ceske Budejovice
©2004 Cinzano/ISTIL based on OLS-DMSP data 2000


Cinzano 2005, Research note, in prep.
Visible stars
0 - 200
200 - 400
400 - 700
700 - 1000
1000 - 1300
1300 - 1900

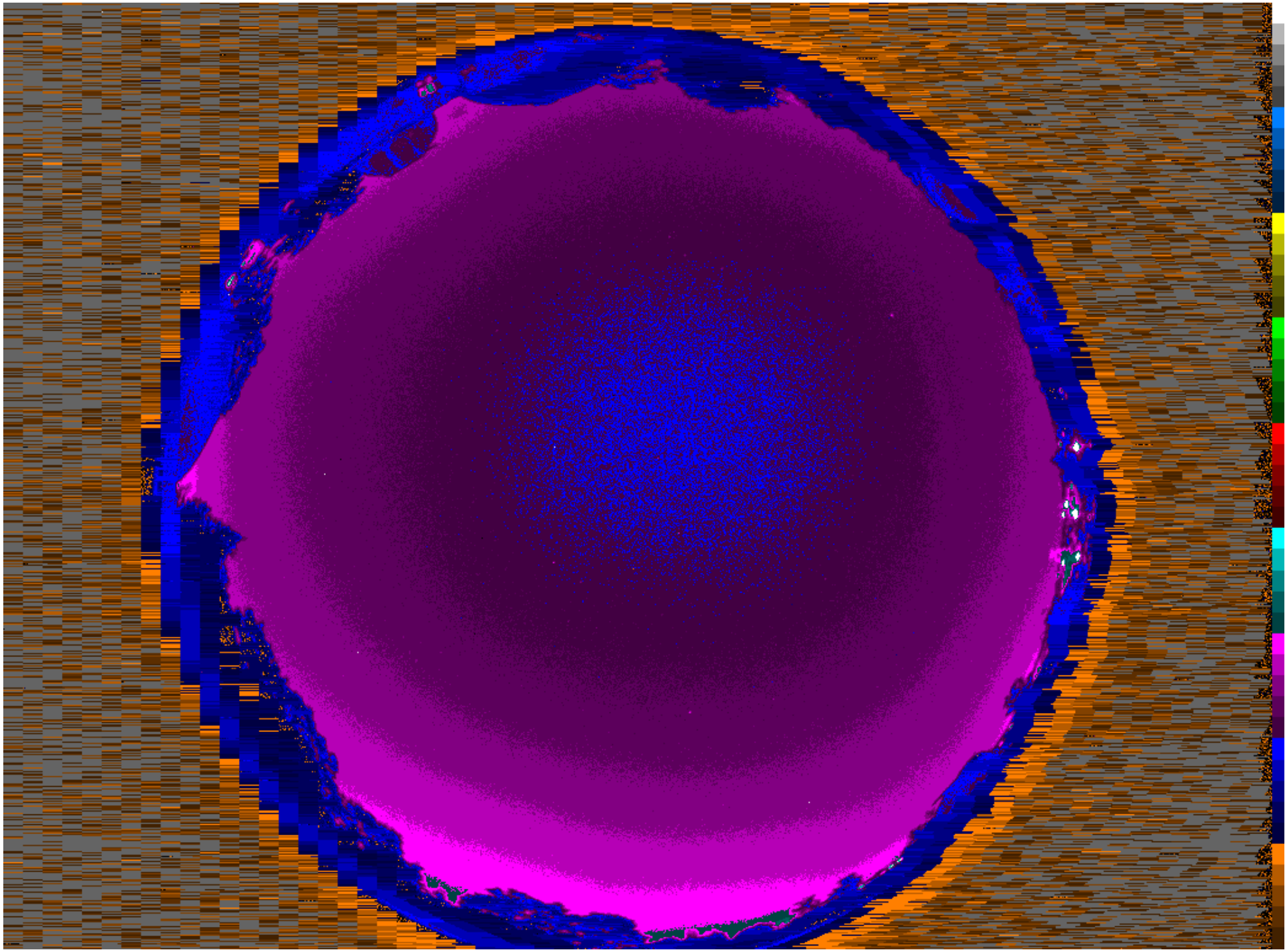
Satelite images and old instruments don’t answer:

- complete angular distributions of light emissions
- amounts of unuseful light from luminaires
- amounts of light from lit vertical surfaces and from lit terrain
- imissions to bedroom windows, gardens, protected nature areas
- their most harmful proportion – direct light from luminaires

SQM – Sky Quality Meter helps a lot.

Modern digital cameras
– offering raw data, manual control and many second exposures –
can give all answers.

Full fish-eye view – an ideal. Two examples:



– sky above Brno Observatory, 2005-8-12 22:32:33

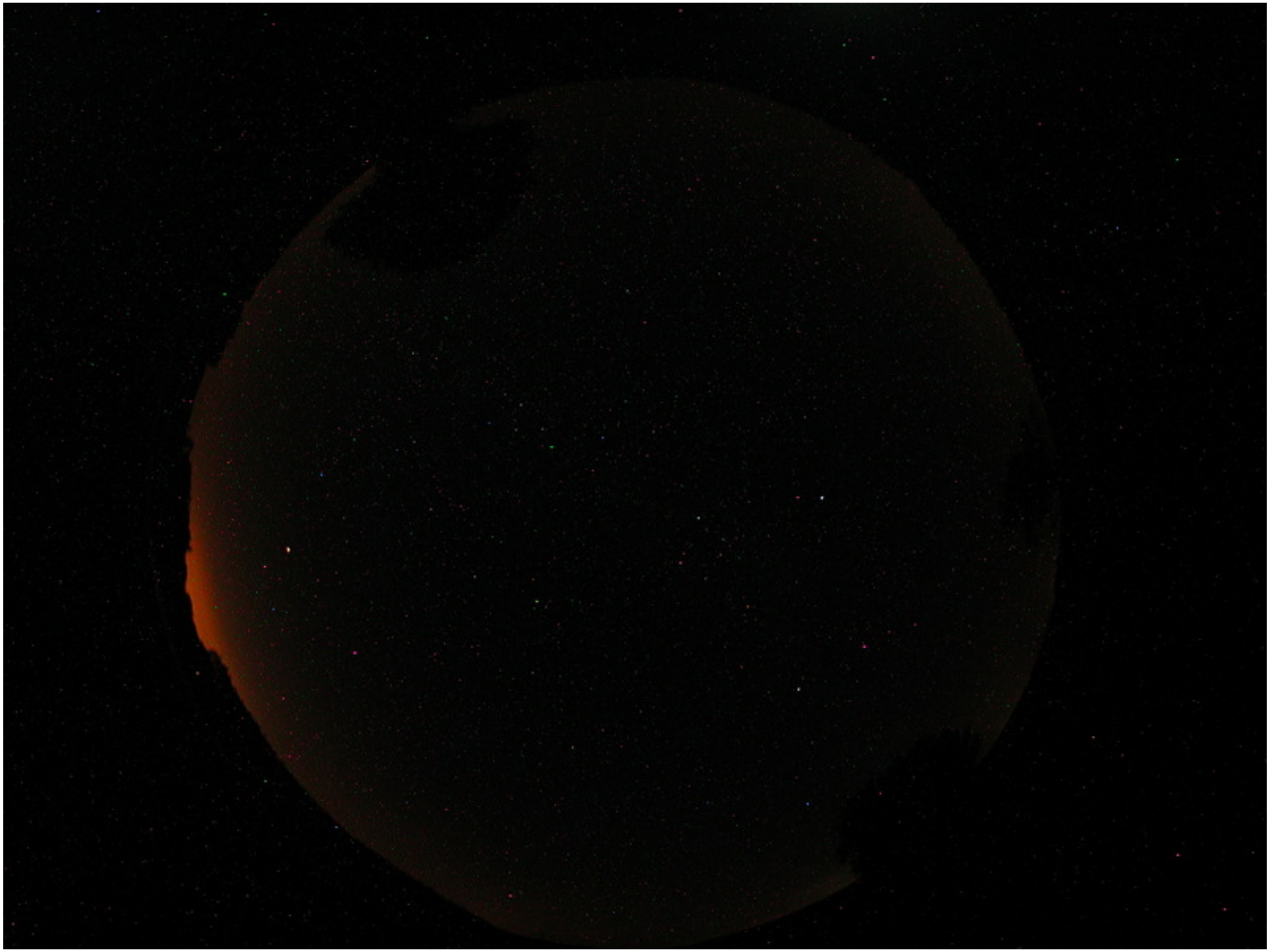
(Perseid maximum, beginning of astronomical night)

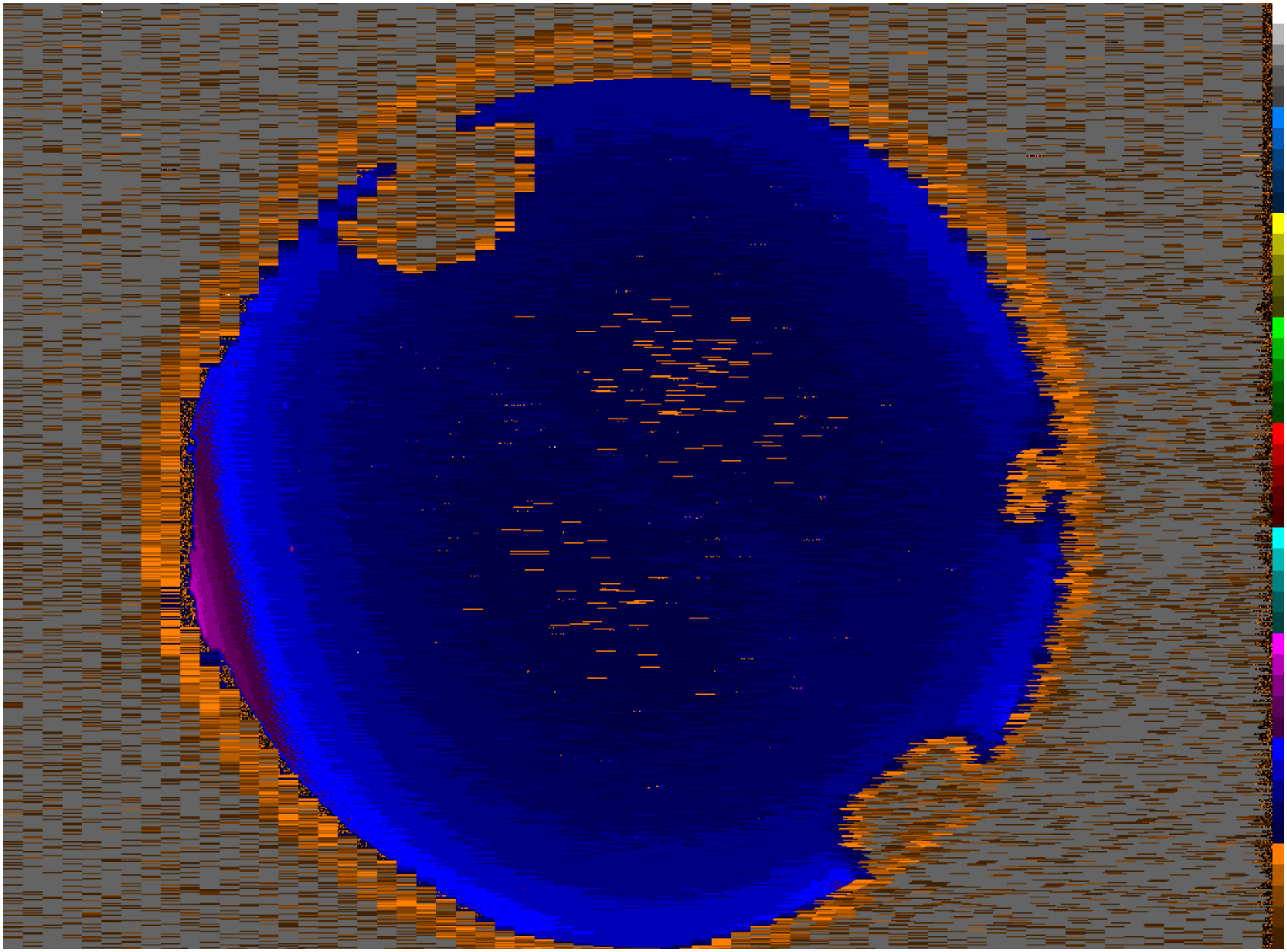
Nikon 990 with FC-E8 fish-eye converter, 60 s exposure

Horizontal illuminance 0.018 lx

Computed SQM 0.0041 $\mathrm{cd/m^2}$, 18.54 mag

Fine steps: 0.2 mag, middle red: 1 $\mathrm{cd/m^2}$, middle magenta: 0.01 $\mathrm{cd/m^2}$





– 22 km to the WNW, three hours later

Horizontal illuminance 0.0020 lx

Computed SQM 4.79E-4 $\mathrm{cd/m^2}$, 20.88 mag

Middle blue: 0.001 $\mathrm{cd/m^2}$

2003: first results presented (Ecology of the Night conference).

2004: software published (GPL), report for the Czech Ministry of environment, poster at Cancer and Rhythm conference

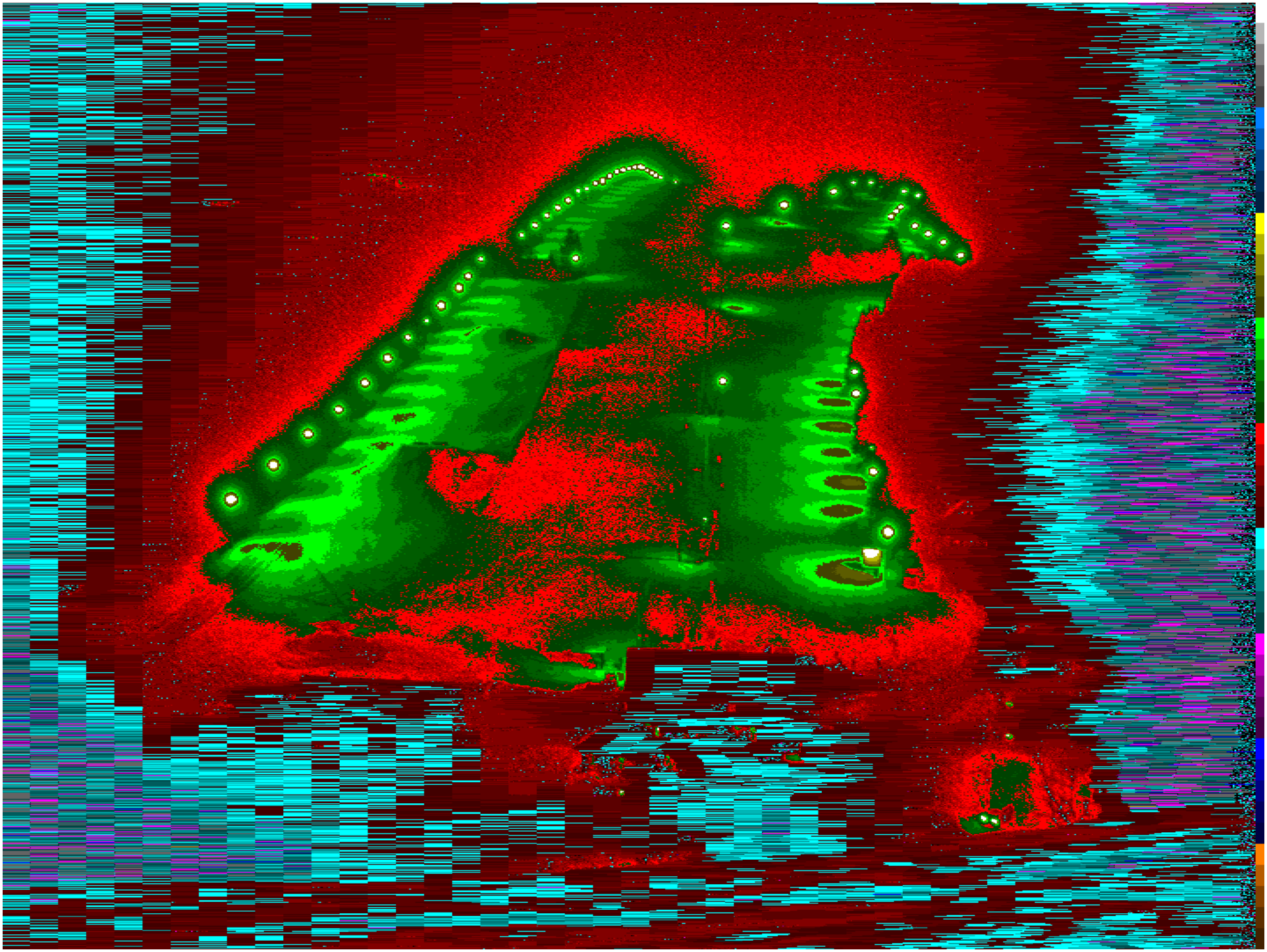
2005 and 2006: Giant Mountains Natural Park exploration

The Park's winter night environment:

$2\times$ to $10000\times$ more light than in nature

natural dominants disappear, lamps reign the landscape

two strongly lit ski slopes add more light than the rest of the world



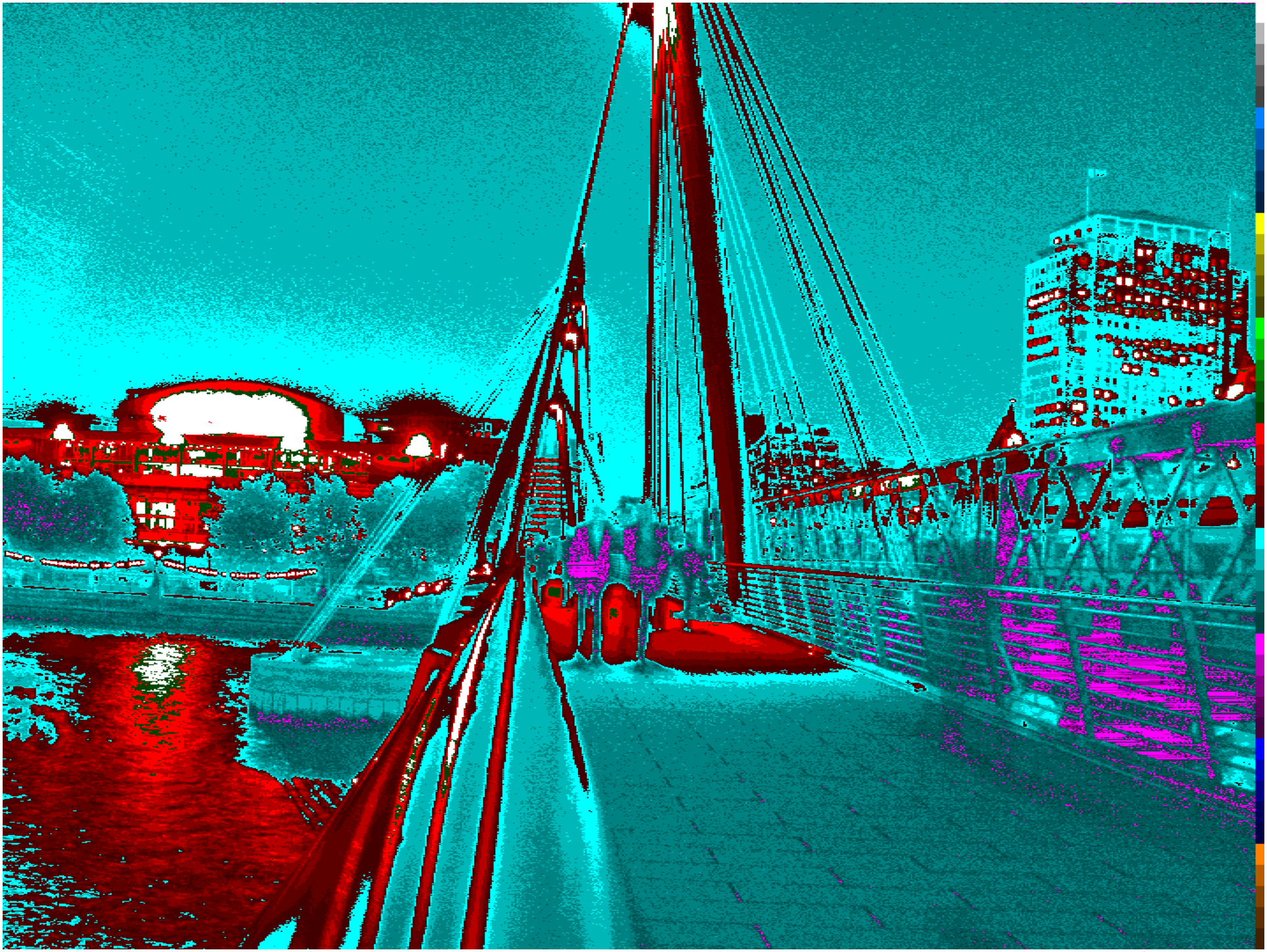
	0	1	2	3	4	5	6	7	8	9
1	8	22	34	50	76	96	87	64	33	2
	0.315	0.420	0.524	0.719	1.04	1.24	1.15	0.888	0.565	0.277
2	14	27	44	68	124	158	131	90	40	0
	0.339	0.444	0.602	0.927	1.61	1.98	1.64	1.18	0.602	0.215
3	15	30	52	98	276	314	241	141	42	0
	0.363	0.505	0.794	1.36	6.89	6.50	4.33	2.60	0.624	0.120
4	15	33	65	160	649	360	385	284	38	0
	0.344	0.521	0.937	2.70	9.52	5.48	6.02	7.57	0.614	0.0906
5	17	36	89	663	513	313	428	78	27	0
	0.329	0.547	1.23	10.7	7.24	4.71	6.16	1.38	0.441	0.0961
6	16	49	168	1088	340	329	764	58	14	0
	0.325	0.704	3.58	14.3	4.95	4.92	11.8	0.850	0.342	0.0688
7	18	77	587	820	290	452	1082	64	9	0
	0.345	1.23	11.1	12.3	3.78	5.96	15.3	1.06	0.280	0.0716
8	21	131	1283	393	253	380	1152	101	13	0
	0.362	4.24	15.3	5.50	3.05	4.98	17.5	3.16	0.317	0.0680
9	23	166	1102	357	294	446	944	155	16	0
	0.423	4.14	15.2	4.76	3.51	6.09	18.8	5.02	0.339	0.0693
10	29	120	191	232	342	230	251	172	31	0
	0.533	1.67	2.91	2.77	4.87	2.56	3.08	2.30	0.575	0.0434
11	4	58	34	51	75	30	43	80	41	0
	0.196	0.868	0.698	0.963	2.69	0.706	0.841	1.09	1.13	0.0777
12	0	11	20	31	71	26	26	88	106	0
	0.0838	0.255	0.348	0.508	1.25	0.518	0.564	1.49	1.85	0.0692
13	0	0	12	26	38	29	22	56	50	24
	0.0727	0.108	0.278	0.419	0.691	0.552	0.418	1.69	1.16	0.463
14	16	27	28	30	28	36	40	32	24	18
	0.405	0.474	0.507	0.530	0.519	0.616	0.638	0.564	0.445	0.414

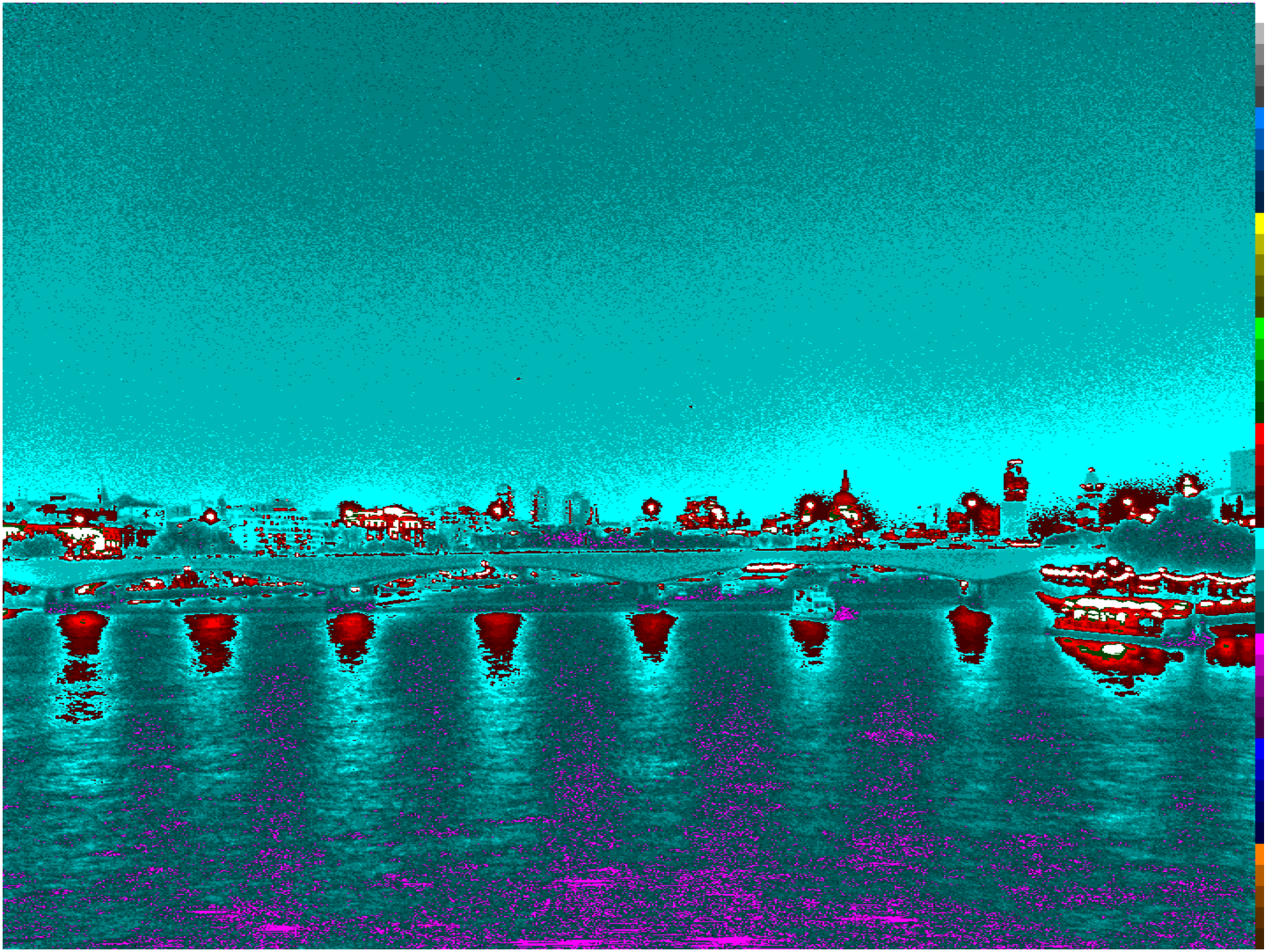
– maxima over 200 lx

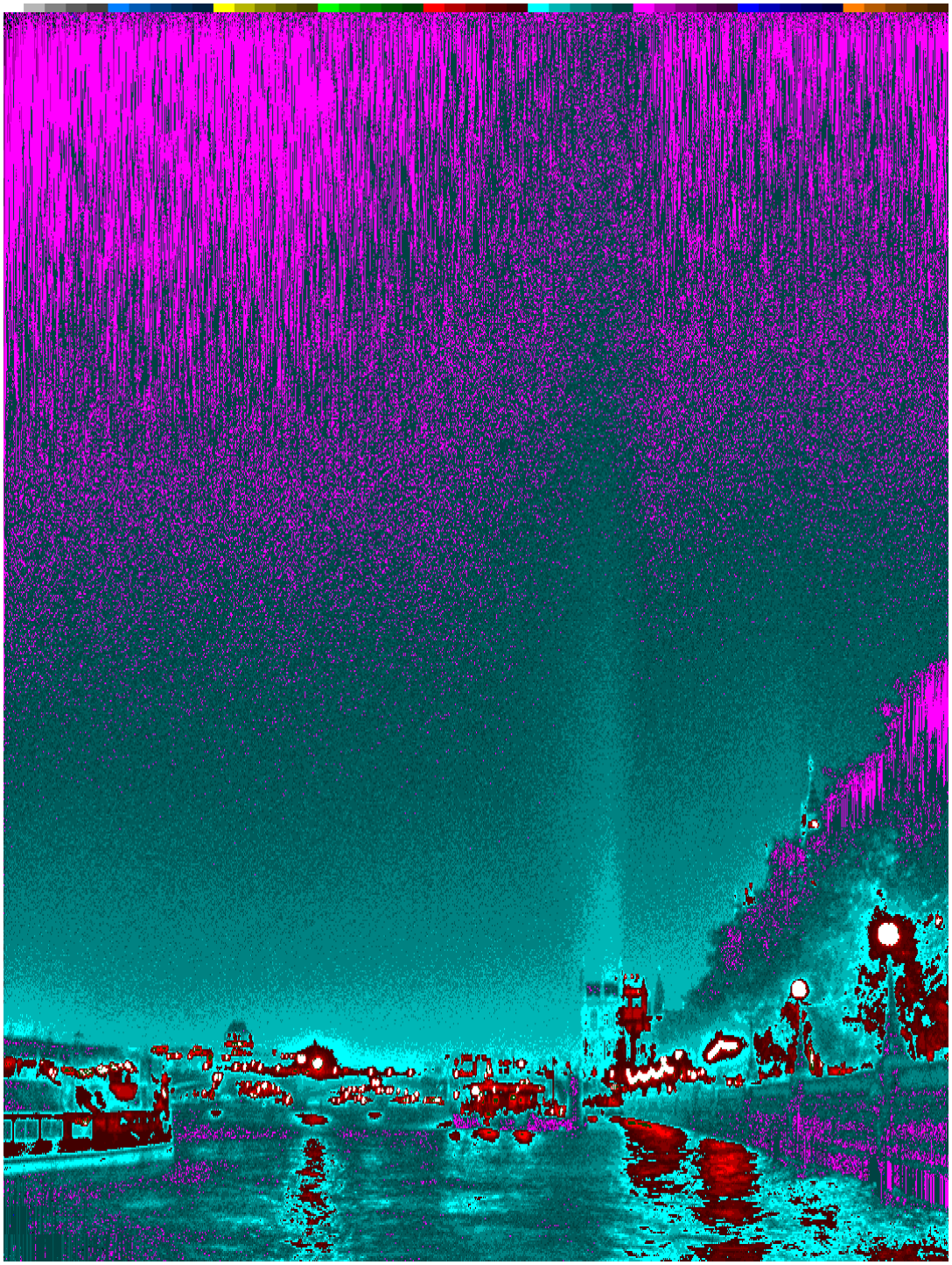
half of the light to the camera comes directly from luminaires

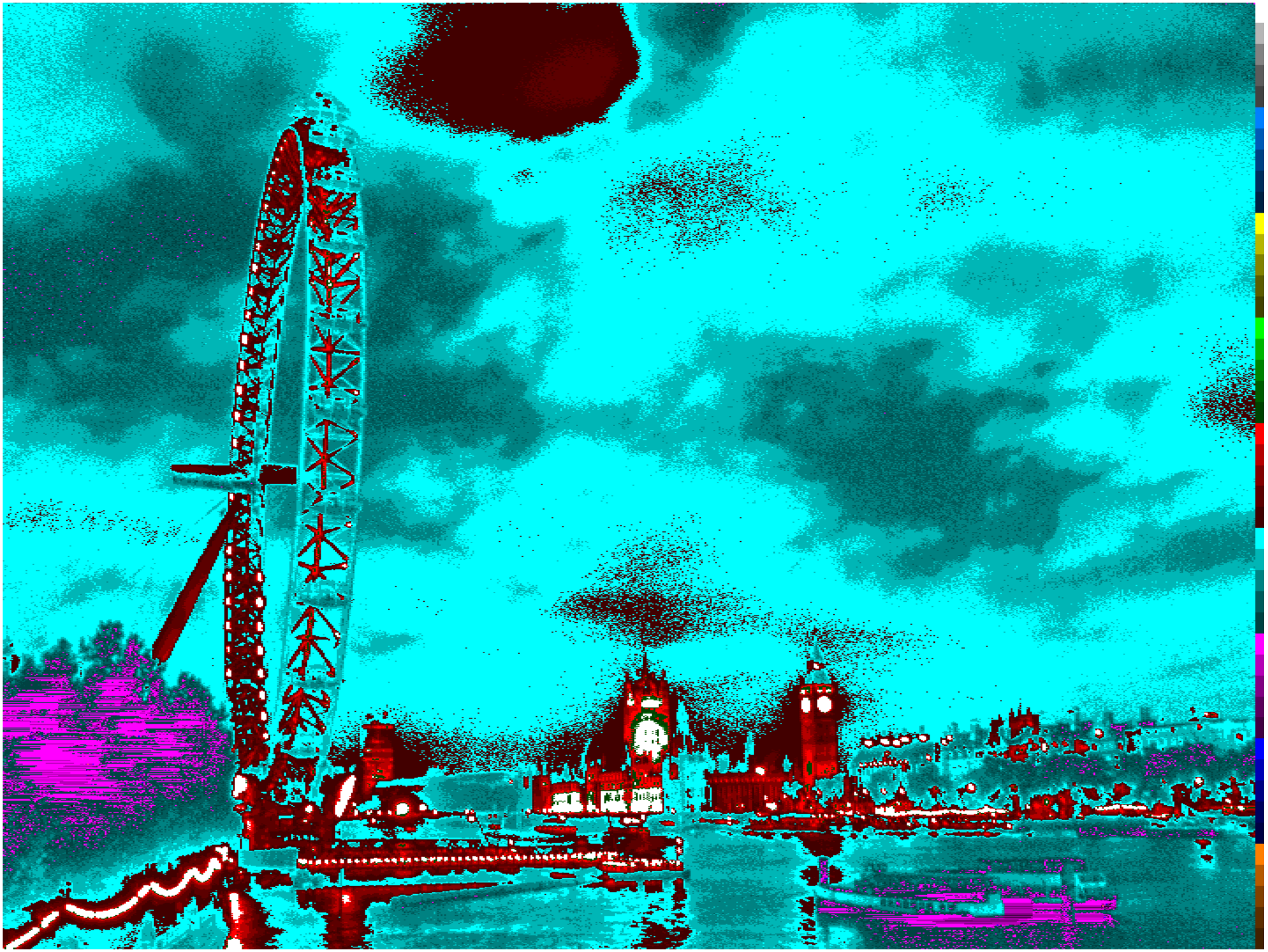
(luminances are given at the bottom of the grid tiles,
median pixel readings in the centre)

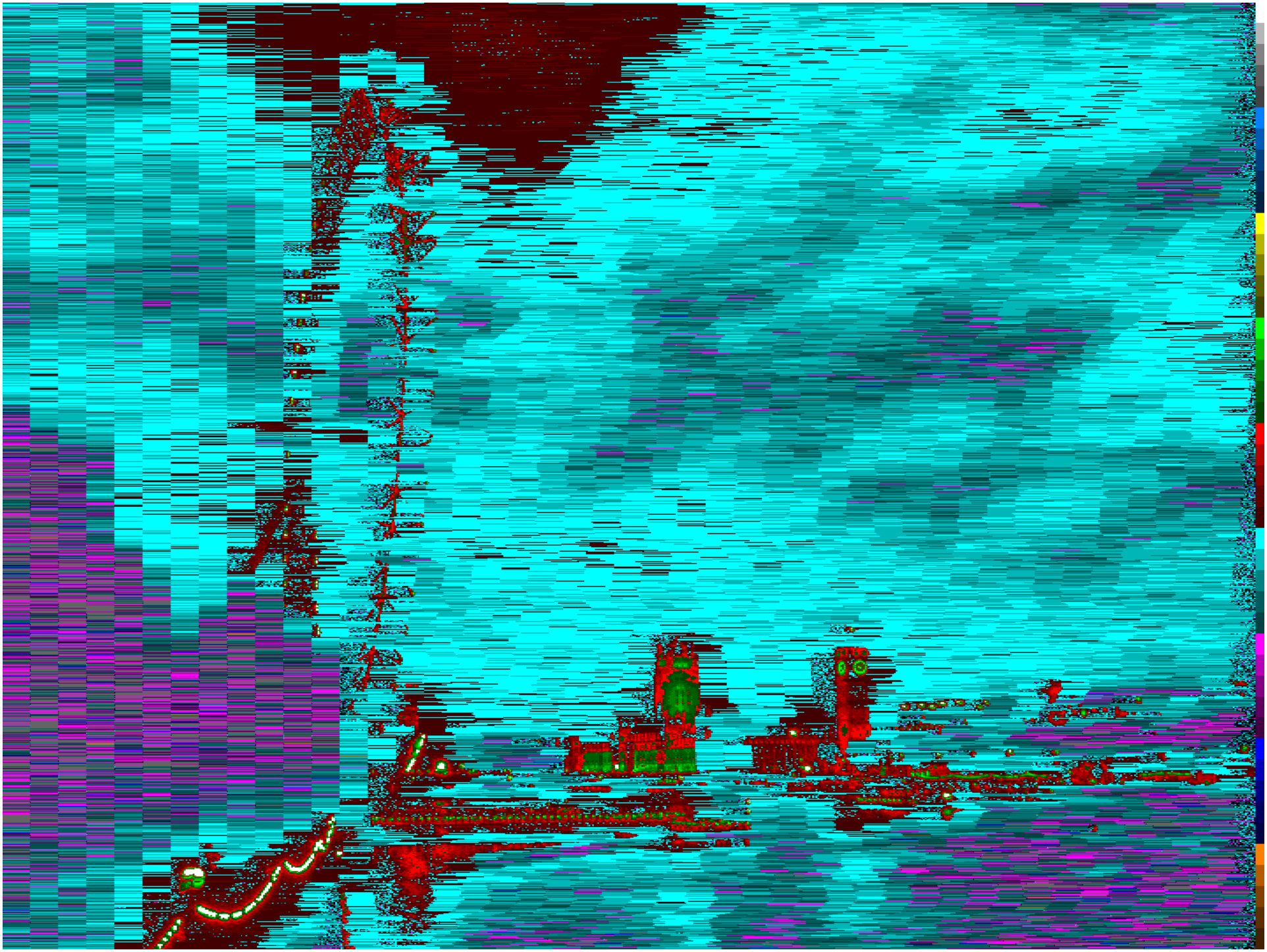
London views:

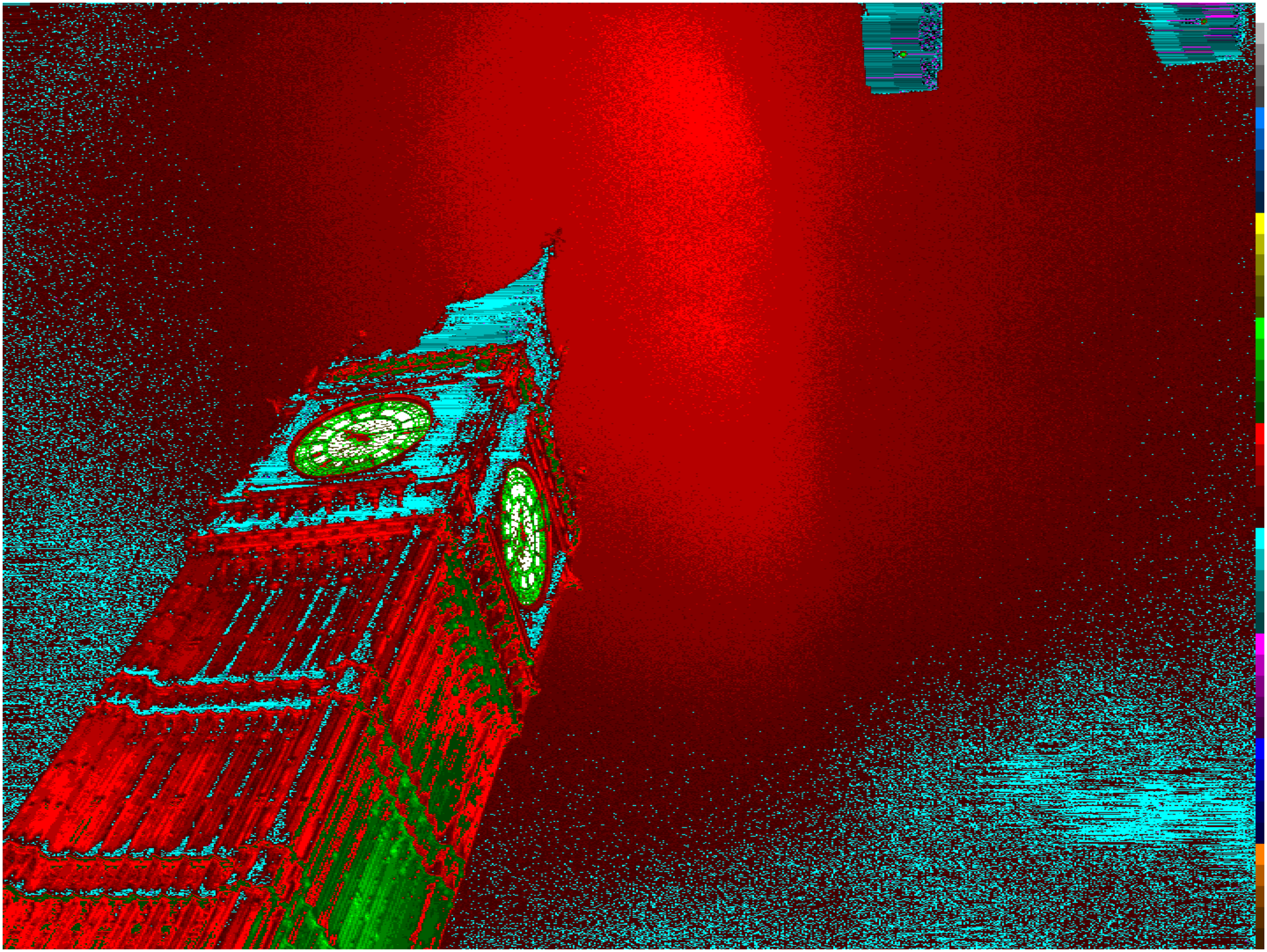


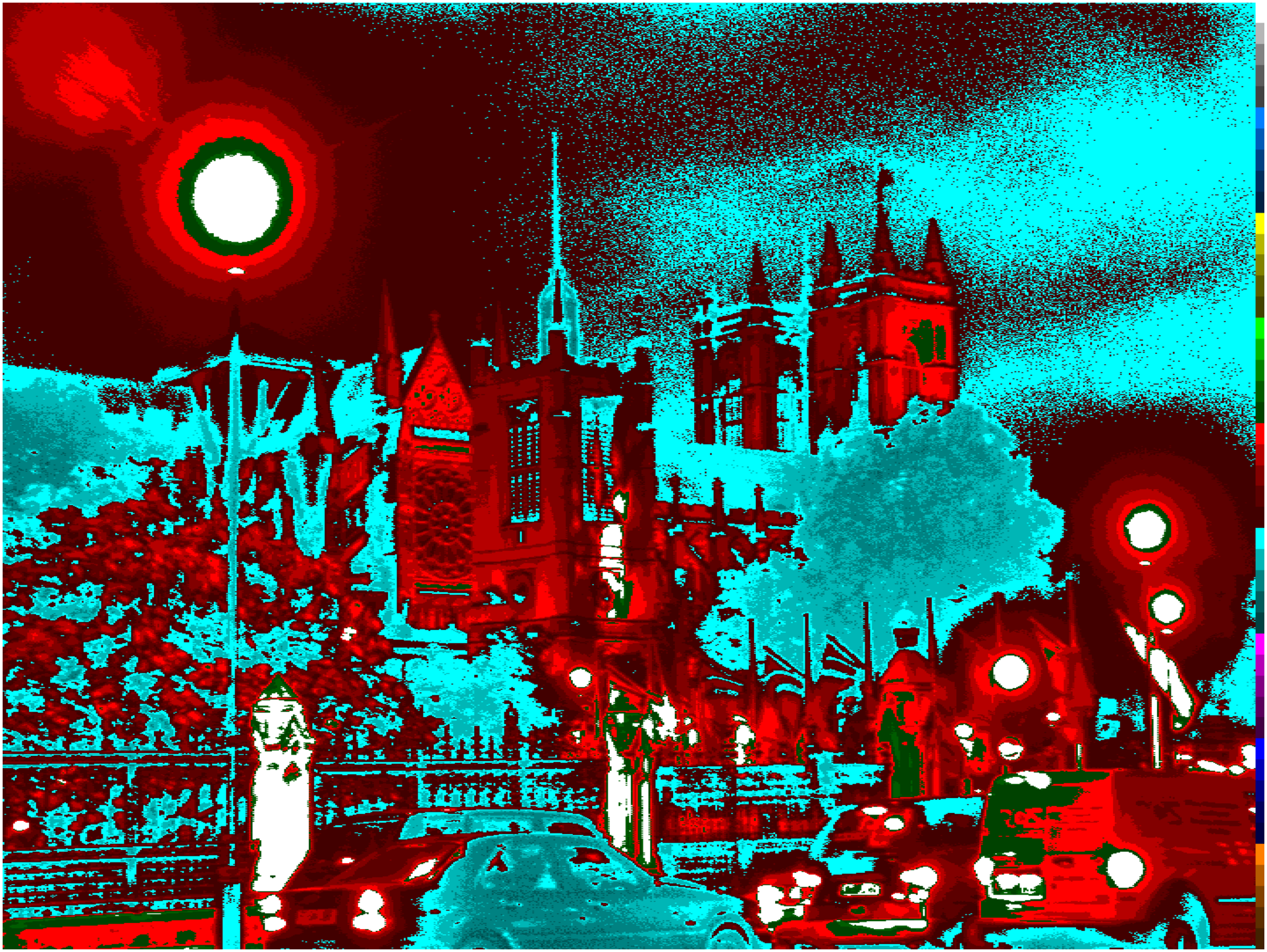


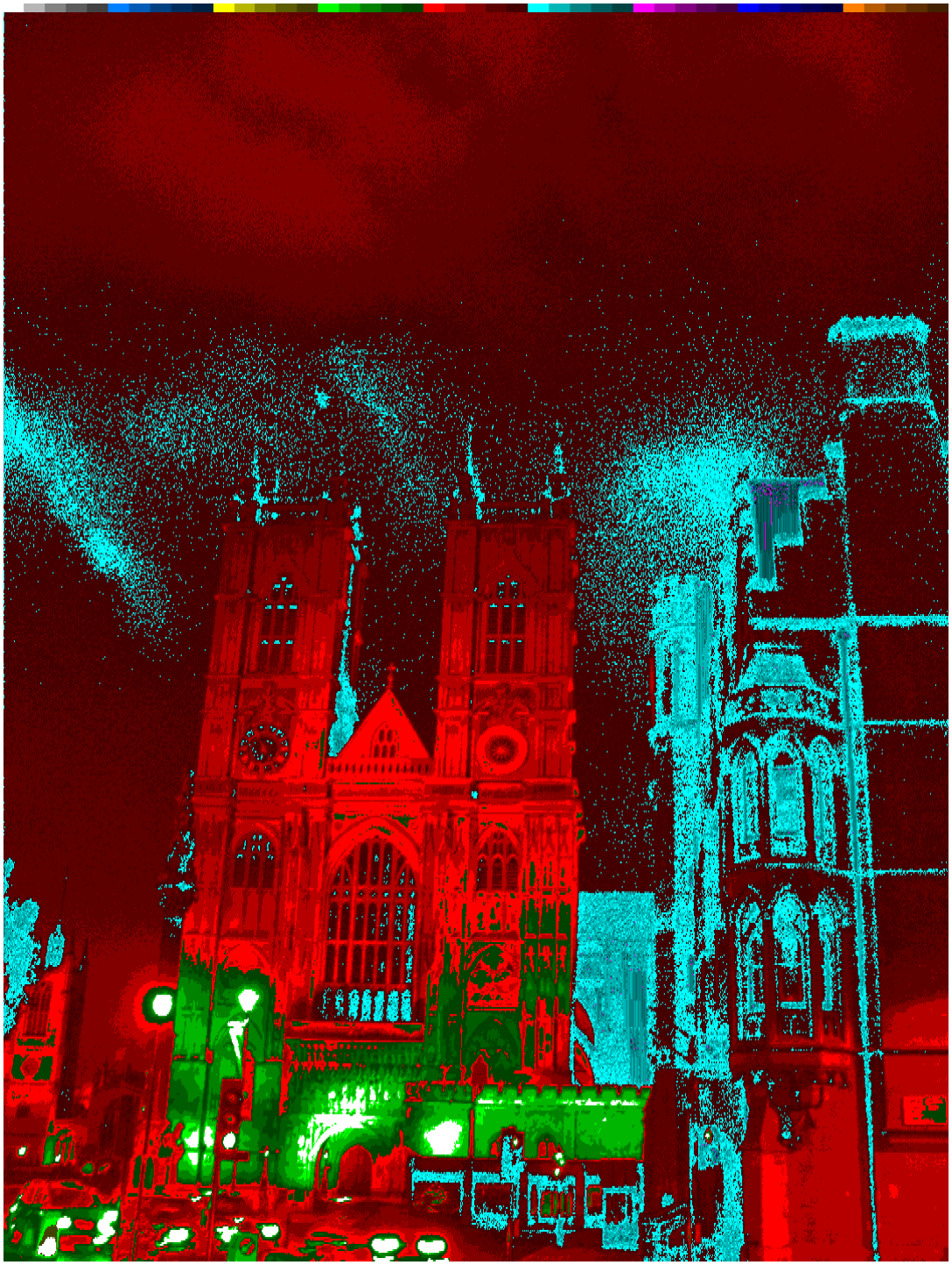


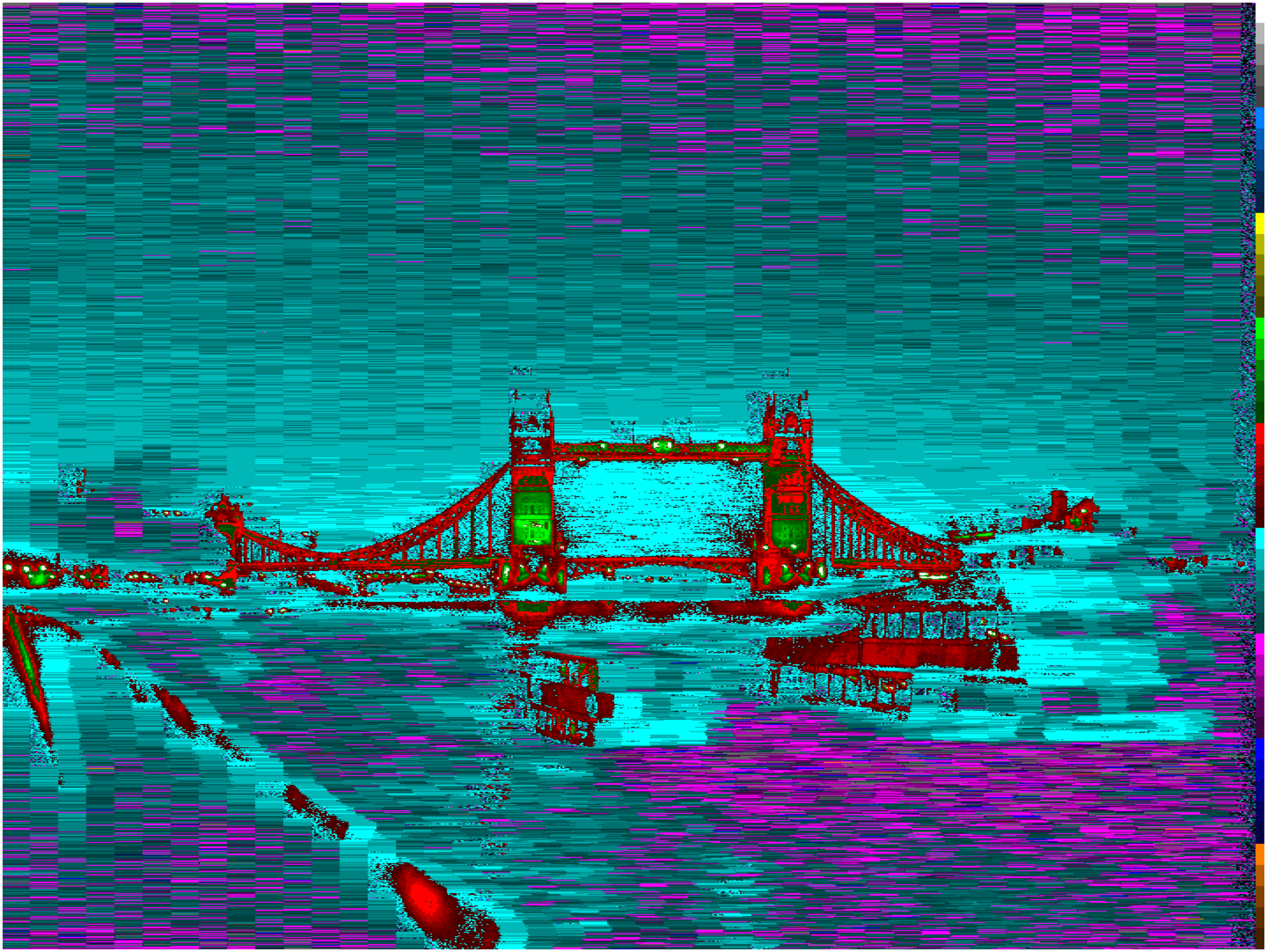




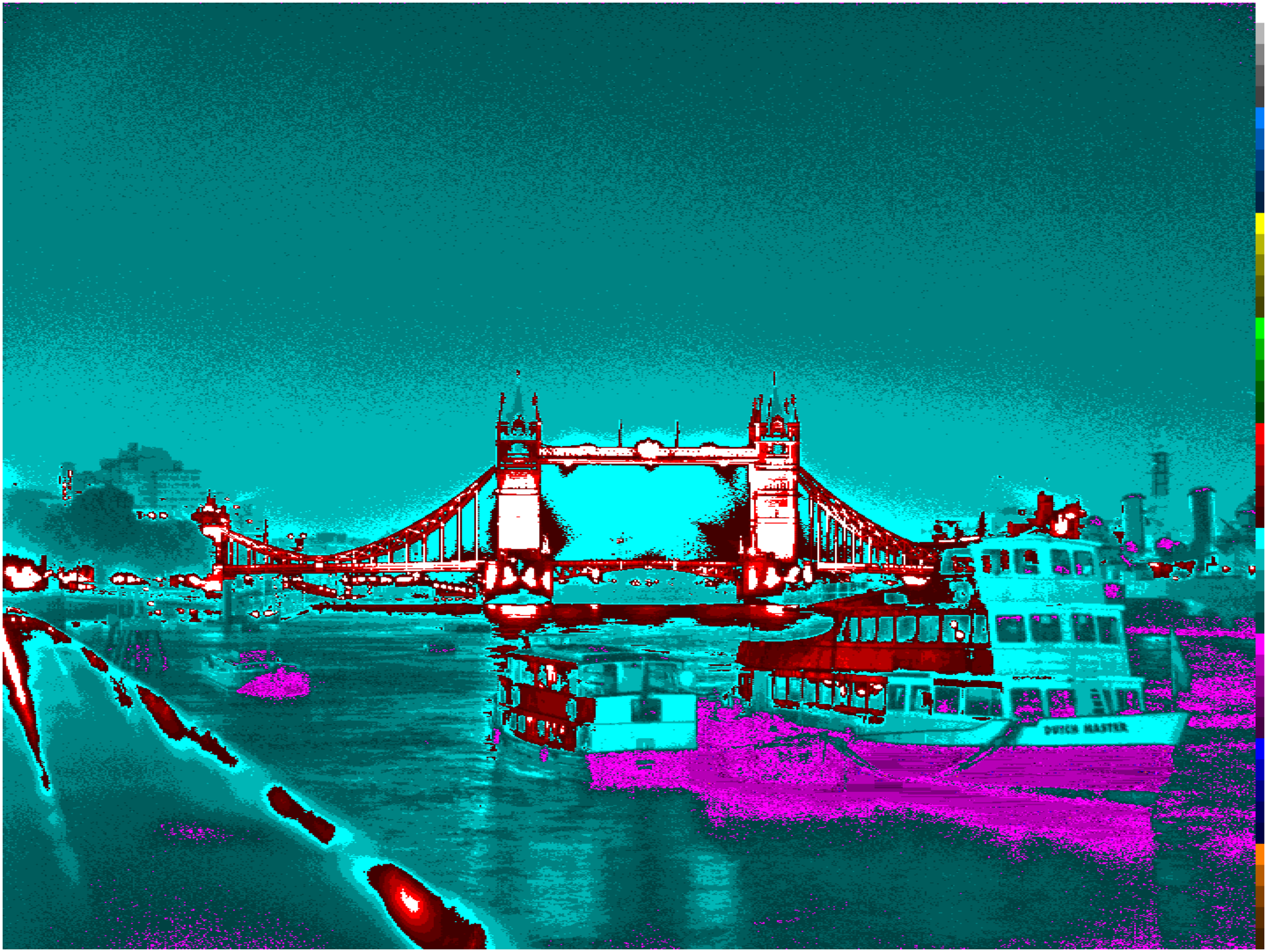


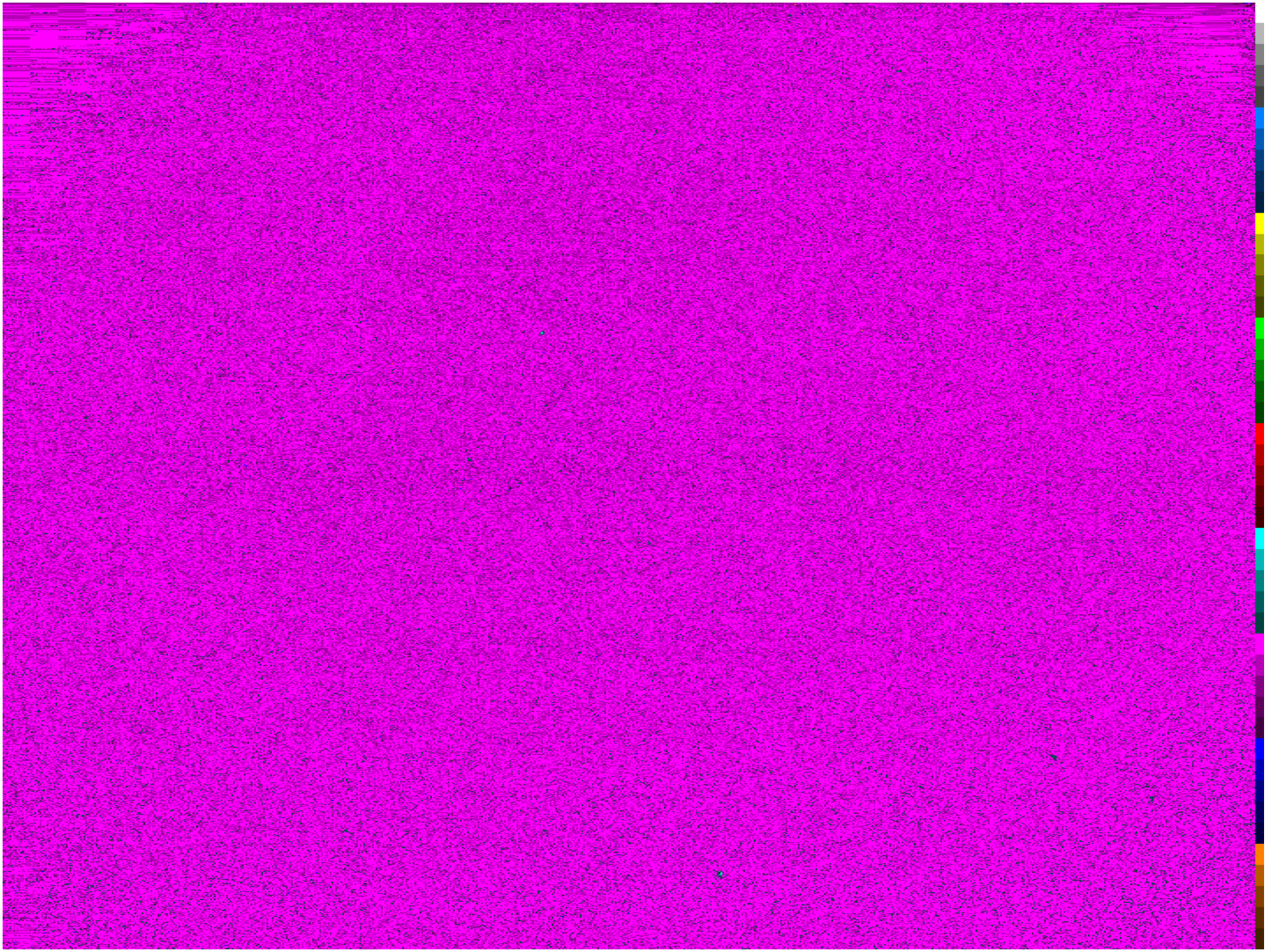






DUTCH MASTER


DUTCH MASTER



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2 0 84 0.0237	2 1 104 0.0235	2 2 107 0.0231	2 3 108 0.0232	2 4 107 0.0228	2 5 111 0.0232	2 6 114 0.0239	2 7 116 0.0243	2 8 117 0.0251	2 9 102 0.0248
3 0 95 0.0239	3 1 108 0.0234	3 2 108 0.0234	3 3 109 0.0233	3 4 108 0.0228	3 5 110 0.0232	3 6 113 0.0236	3 7 115 0.0242	3 8 118 0.0246	3 9 114 0.0255
4 0 99 0.0232	4 1 108 0.0230	4 2 109 0.0235	4 3 107 0.0227	4 4 107 0.0225	4 5 109 0.0227	4 6 111 0.0232	4 7 113 0.0234	4 8 116 0.0240	4 9 116 0.0249
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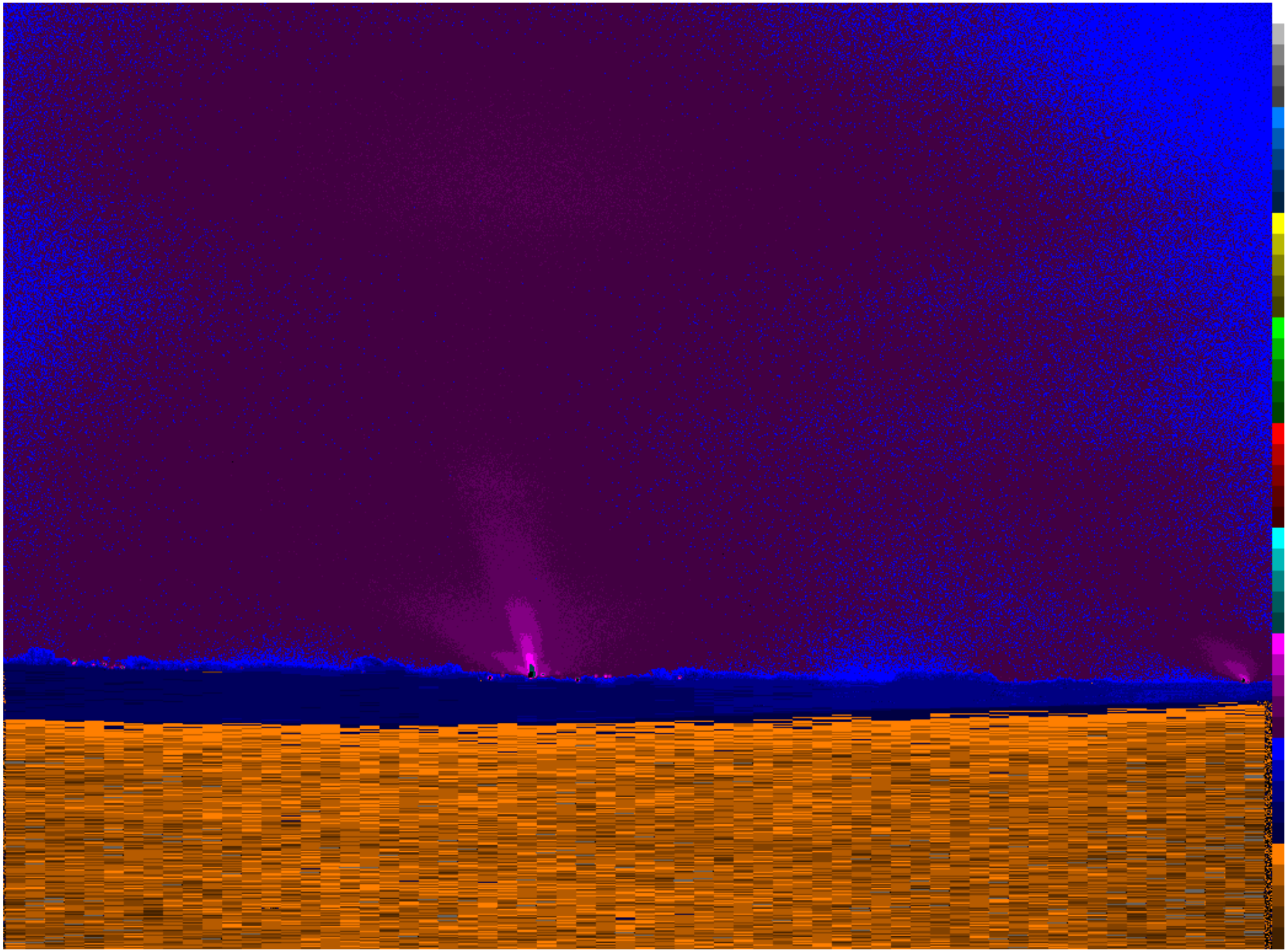
6 0 108 0.0238	6 1 112 0.0238	6 2 111 0.0237	6 3 111 0.0231	6 4 112 0.0232	6 5 114 0.0234	6 6 114 0.0237	6 7 114 0.0237	6 8 116 0.0242	6 9 119 0.0248
7 0 106 0.0233	7 1 112 0.0236	7 2 111 0.0232	7 3 110 0.0229	7 4 111 0.0232	7 5 112 0.0233	7 6 113 0.0233	7 7 114 0.0235	7 8 114 0.0236	7 9 117 0.0242
8 0 108 0.0235	8 1 111 0.0236	8 2 108 0.0229	8 3 110 0.0229	8 4 112 0.0231	8 5 115 0.0233	8 6 114 0.0234	8 7 113 0.0236	8 8 115 0.0237	8 9 114 0.0240
9 0 110 0.0238	9 1 113 0.0241	9 2 112 0.0235	9 3 113 0.0233	9 4 114 0.0235	9 5 116 0.0238	9 6 115 0.0239	9 7 115 0.0240	9 8 114 0.0239	9 9 117 0.0245
10 0 110 0.0240	10 1 115 0.0244	10 2 113 0.0238	10 3 114 0.0235	10 4 114 0.0235	10 5 116 0.0238	10 6 117 0.0239	10 7 116 0.0242	10 8 116 0.0243	10 9 118 0.0248
11 0 109 0.0242	11 1 115 0.0245	11 2 114 0.0241	11 3 114 0.0238	11 4 116 0.0239	11 5 118 0.0240	11 6 120 0.0244	11 7 119 0.0245	11 8 119 0.0249	11 9 122 0.0254
12 0 109 0.0246	12 1 117 0.0246	12 2 117 0.0248	12 3 119 0.0245	12 4 119 0.0246	12 5 120 0.0249	12 6 122 0.0251	12 7 123 0.0253	12 8 123 0.0256	12 9 125 0.0261
13 0 105 0.0247	13 1 117 0.0248	13 2 117 0.0249	13 3 118 0.0246	13 4 119 0.0249	13 5 121 0.0251	13 6 122 0.0253	13 7 124 0.0255	13 8 125 0.0259	13 9 122 0.0261
14 0 100 0.0253	14 1 118 0.0254	14 2 118 0.0254	14 3 119 0.0253	14 4 121 0.0252	14 5 121 0.0260	14 6 125 0.0259	14 7 126 0.0261	14 8 127 0.0265	14 9 118 0.0267

– clear sky with (top of) Northern Cross and Vega

$0.024\,\mathrm{cd/m^2}$ – almost hundred times the natural value

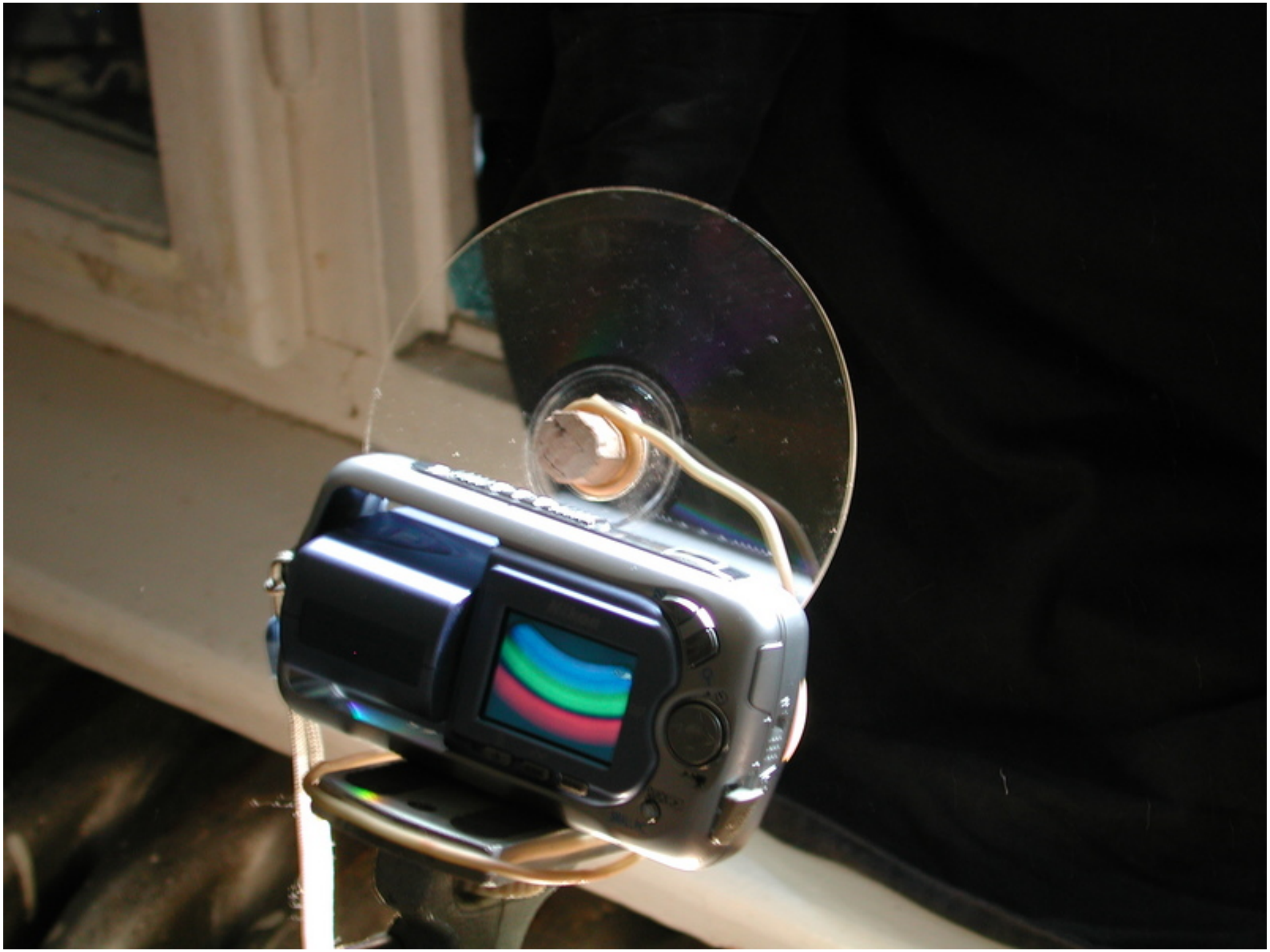
(2s exposure, 2004-09-09 22:53)

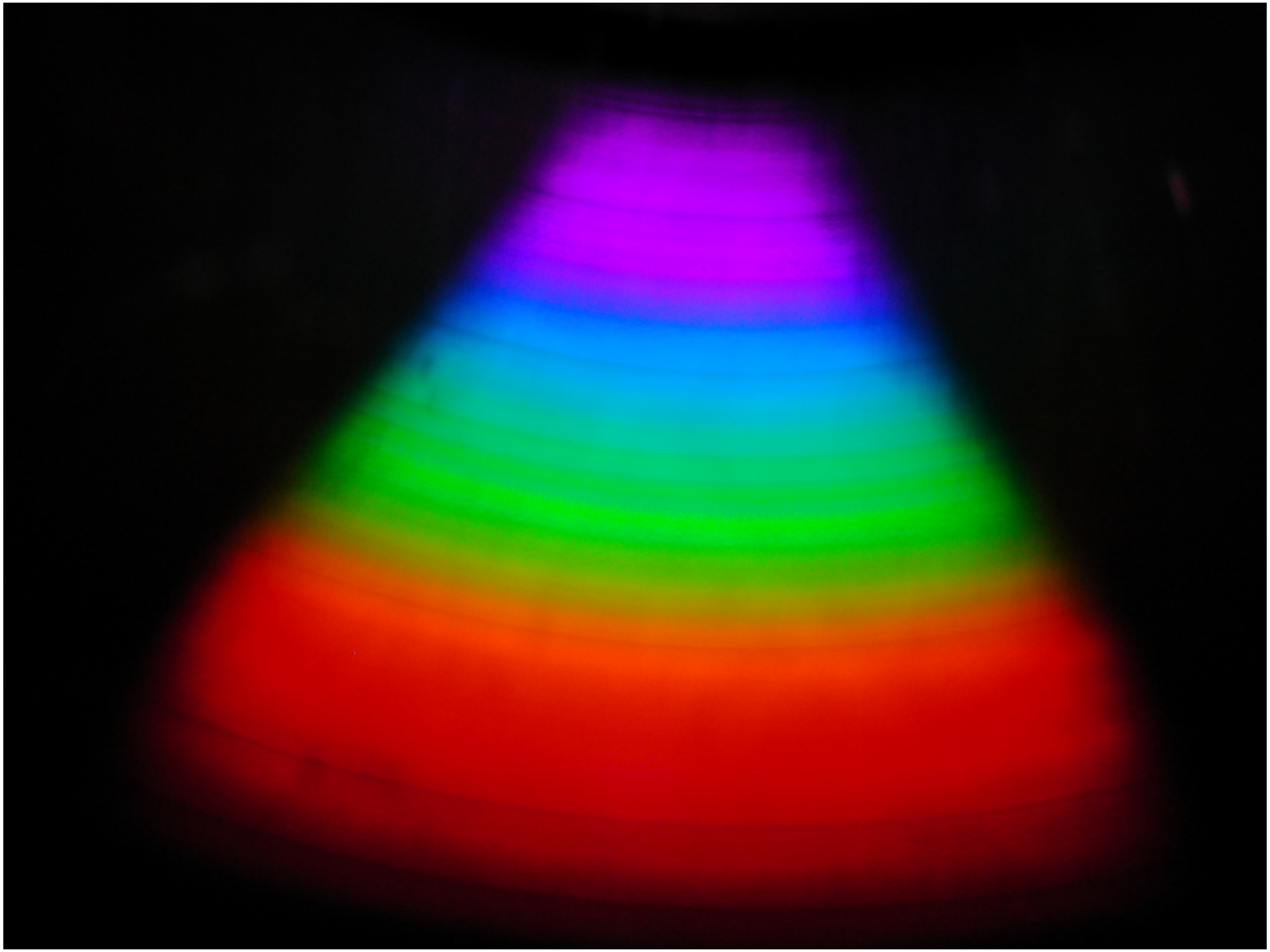
Anonymous Czech (celestial) churches:

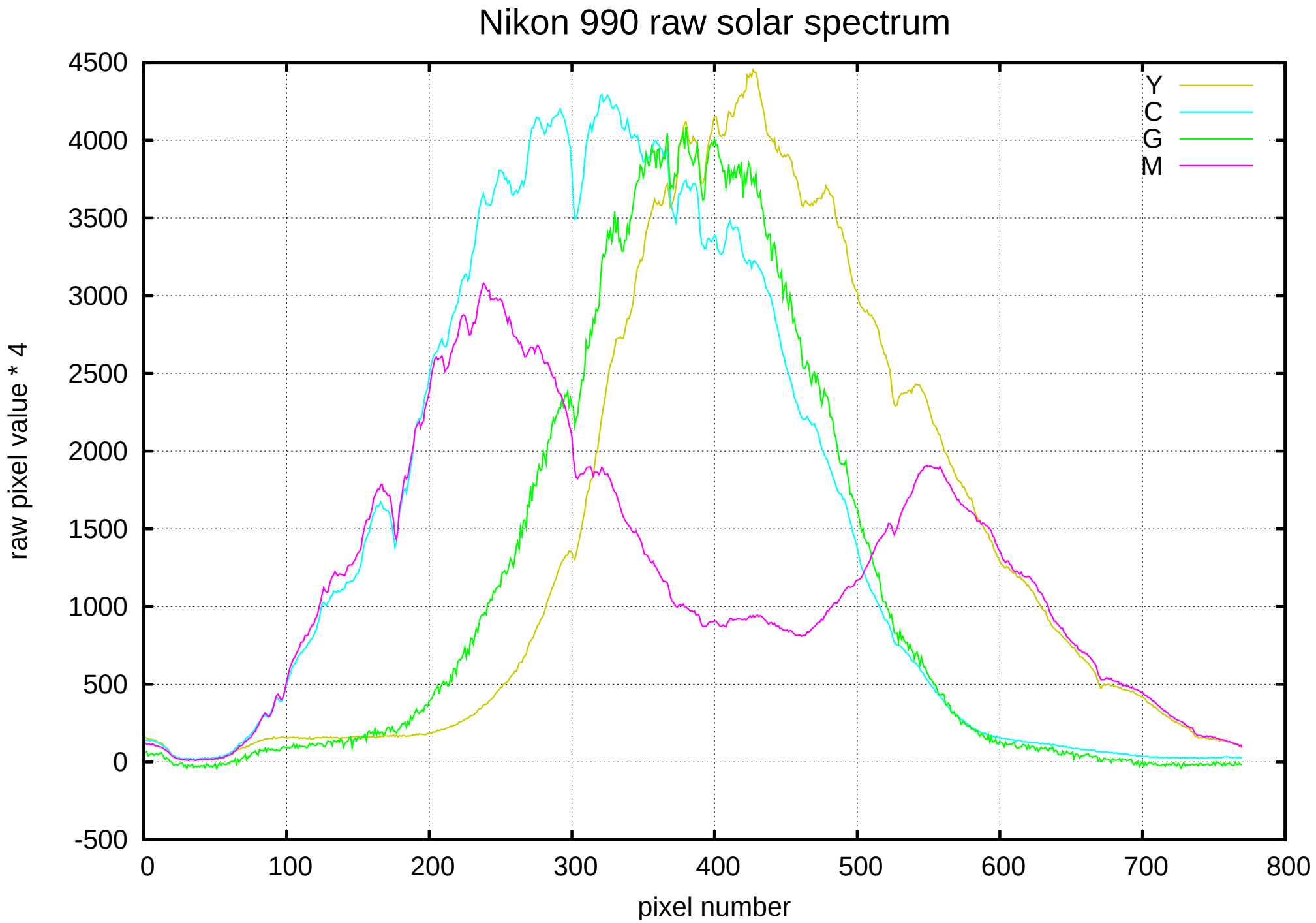


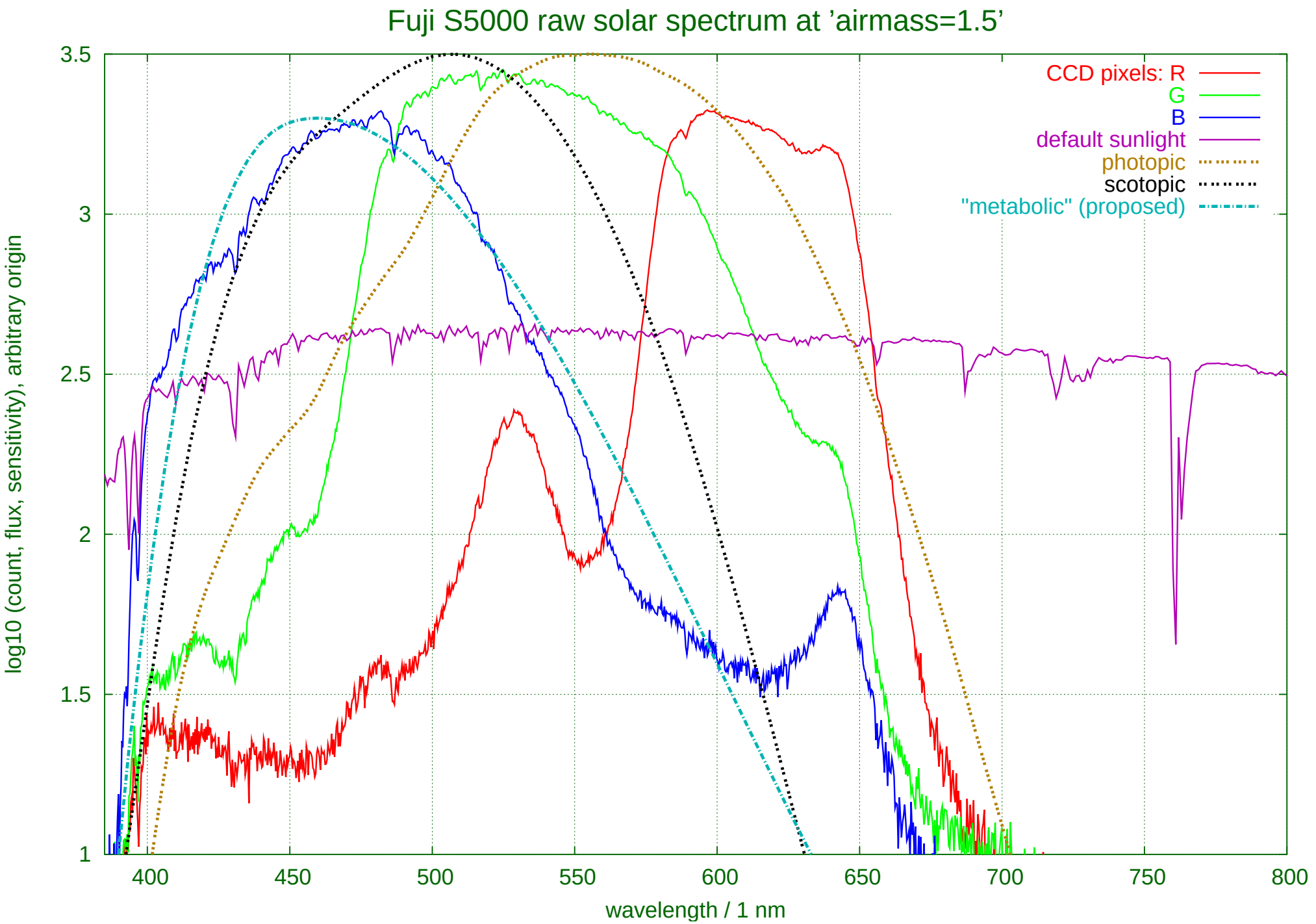
Calibration

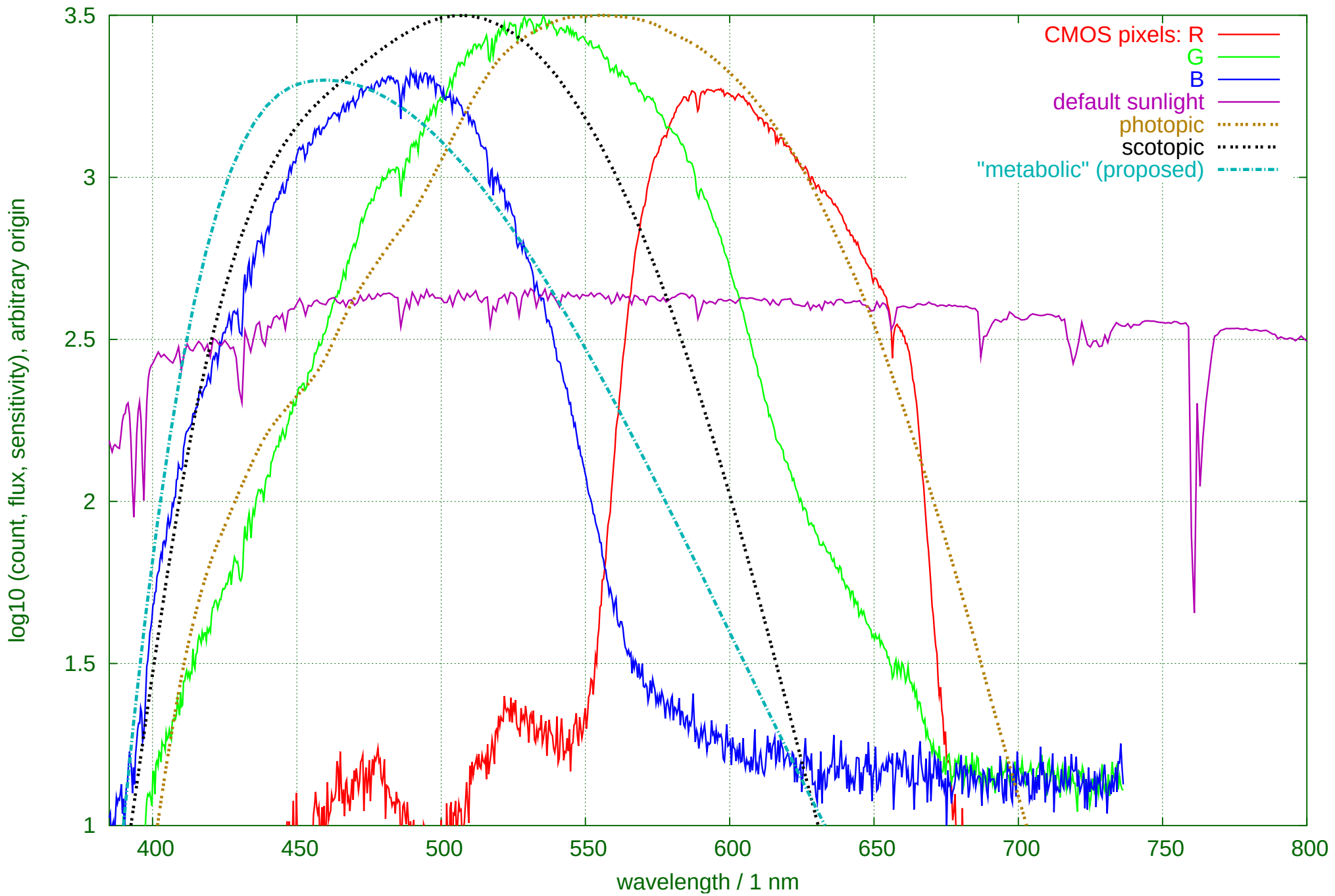
- “some” luminance: sunlit/moonlit paper (or white standard)
- spectral sensitivity
- vignetting
- image geometry
- ... good luminances, or even illuminance

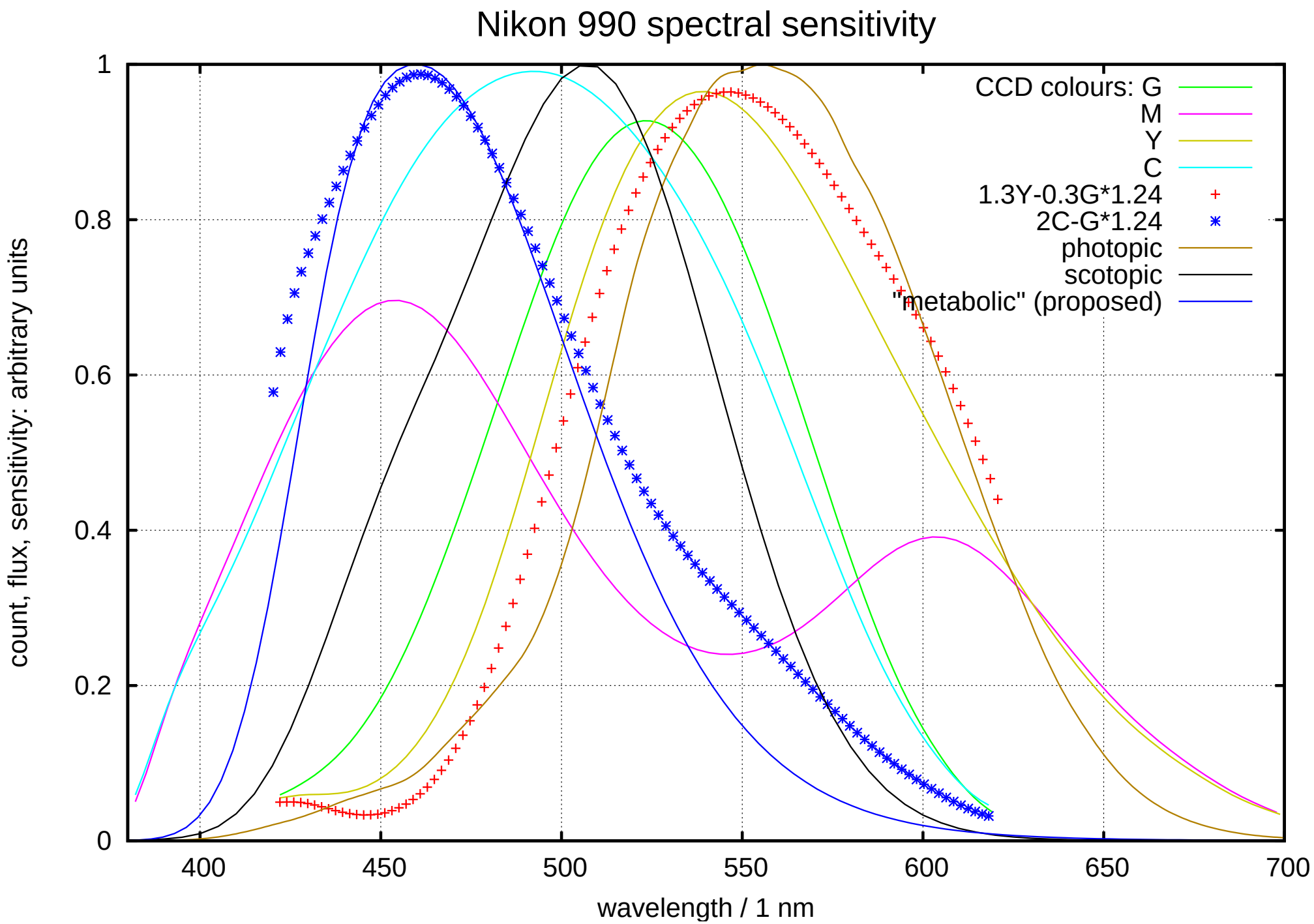


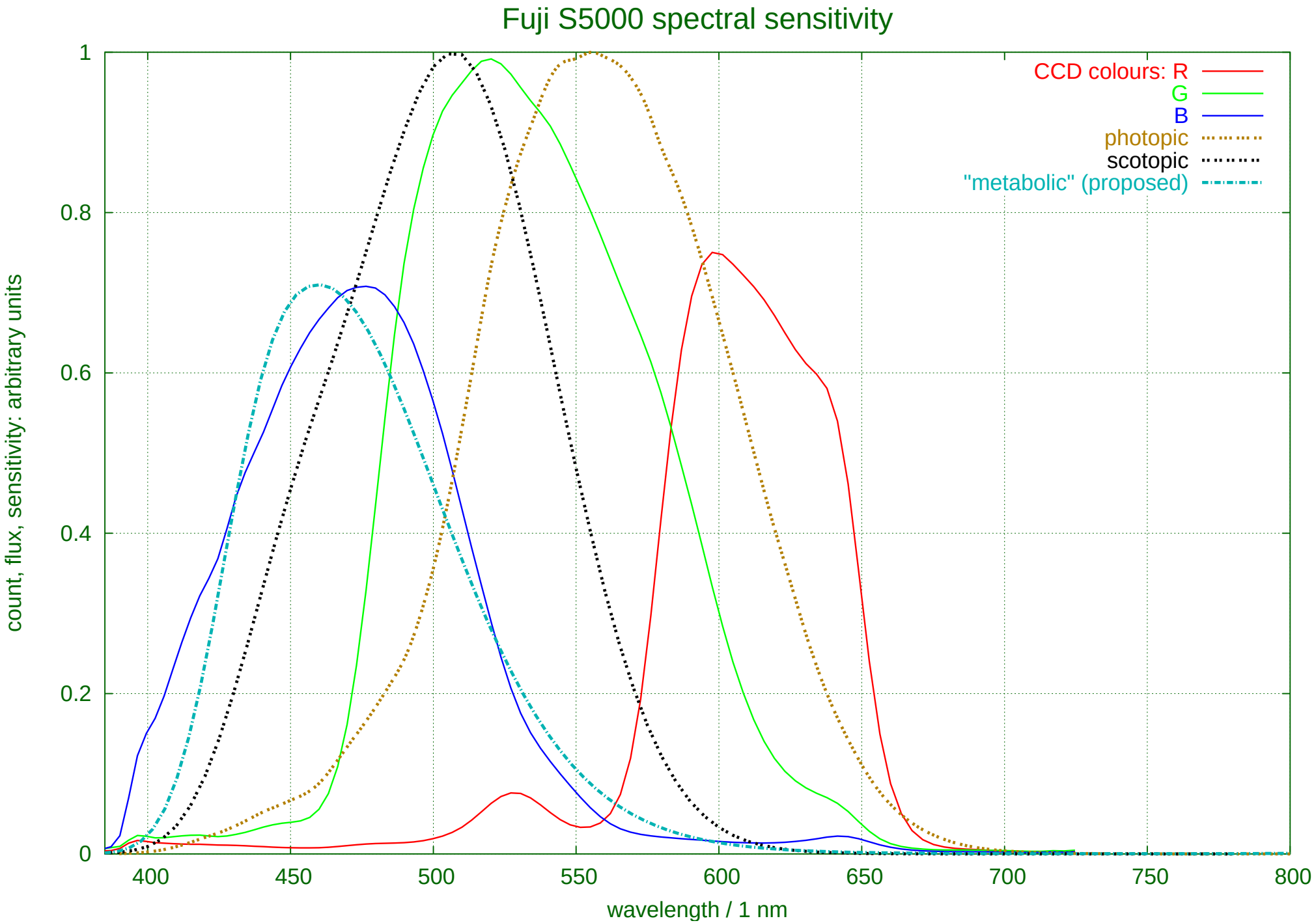


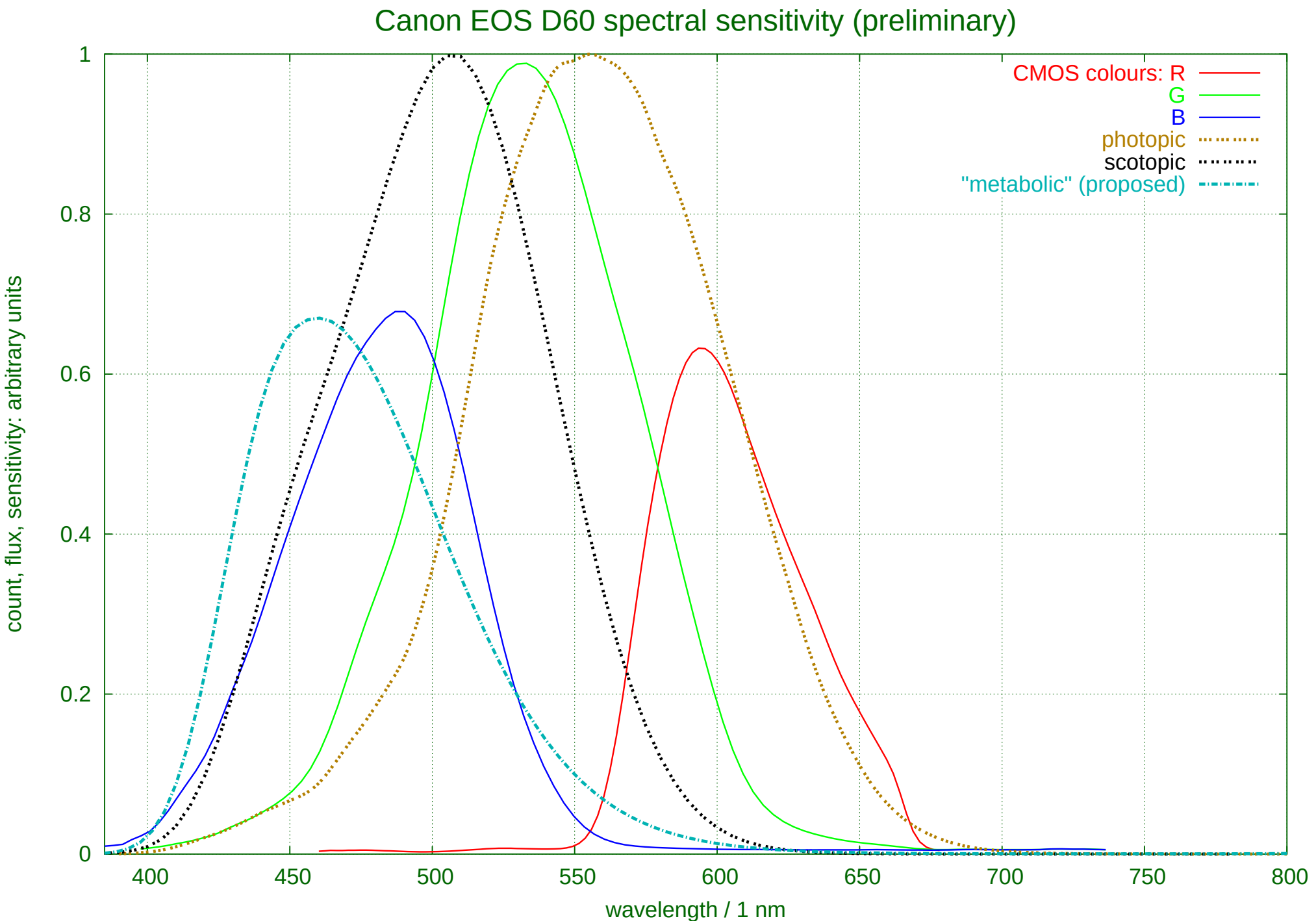

Nikon 990 raw solar spectrum
raw pixel value * 4
pixel number
Y
C
G
M
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
0
100
200
300
400
500
600
700
800


Fuji S5000 raw solar spectrum at 'airmass=1.5'
log10 (count, flux, sensitivity), arbitrary origin
wavelength / 1 nm
3.5
3
2.5
2
1.5
1
400
450
500
550
600
650
700
750
800
CCD pixels: R
G
B
default sunlight
photopic
scotopic
"metabolic" (proposed)


Canon EOS D60 raw solar spectrum at airmass=1.5
CMOS pixels: R
G
B
default sunlight
photopic
scotopic
"metabolic" (proposed)
log10 (count, flux, sensitivity), arbitrary origin
wavelength / 1 nm
3.5
3
2.5
2
1.5
1
400
450
500
550
600
650
700
750
800


Nikon 990 spectral sensitivity
CCD colours: G
M
Y
C
1.3Y-0.3G*1.24
2C-G*1.24
photopic
scotopic
"metabolic" (proposed)
count, flux, sensitivity: arbitrary units
wavelength / 1 nm
0
0.2
0.4
0.6
0.8
1
400
450
500
550
600
650
700


Fuji S5000 spectral sensitivity
CCD colours: R
G
B
photopic
scotopic
"metabolic" (proposed)
count, flux, sensitivity: arbitrary units
wavelength / 1 nm
0
0.2
0.4
0.6
0.8
1
400
450
500
550
600
650
700
750
800


Canon EOS D60 spectral sensitivity (preliminary)
CMOS colours: R
G
B
photopic
scotopic
"metabolic" (proposed)
count, flux, sensitivity: arbitrary units
wavelength / 1 nm
0
0.2
0.4
0.6
0.8
1
400
450
500
550
600
650
700
750
800

Vignetting (light fall-off from the image center)

from images of the same strip, taken at various angles:

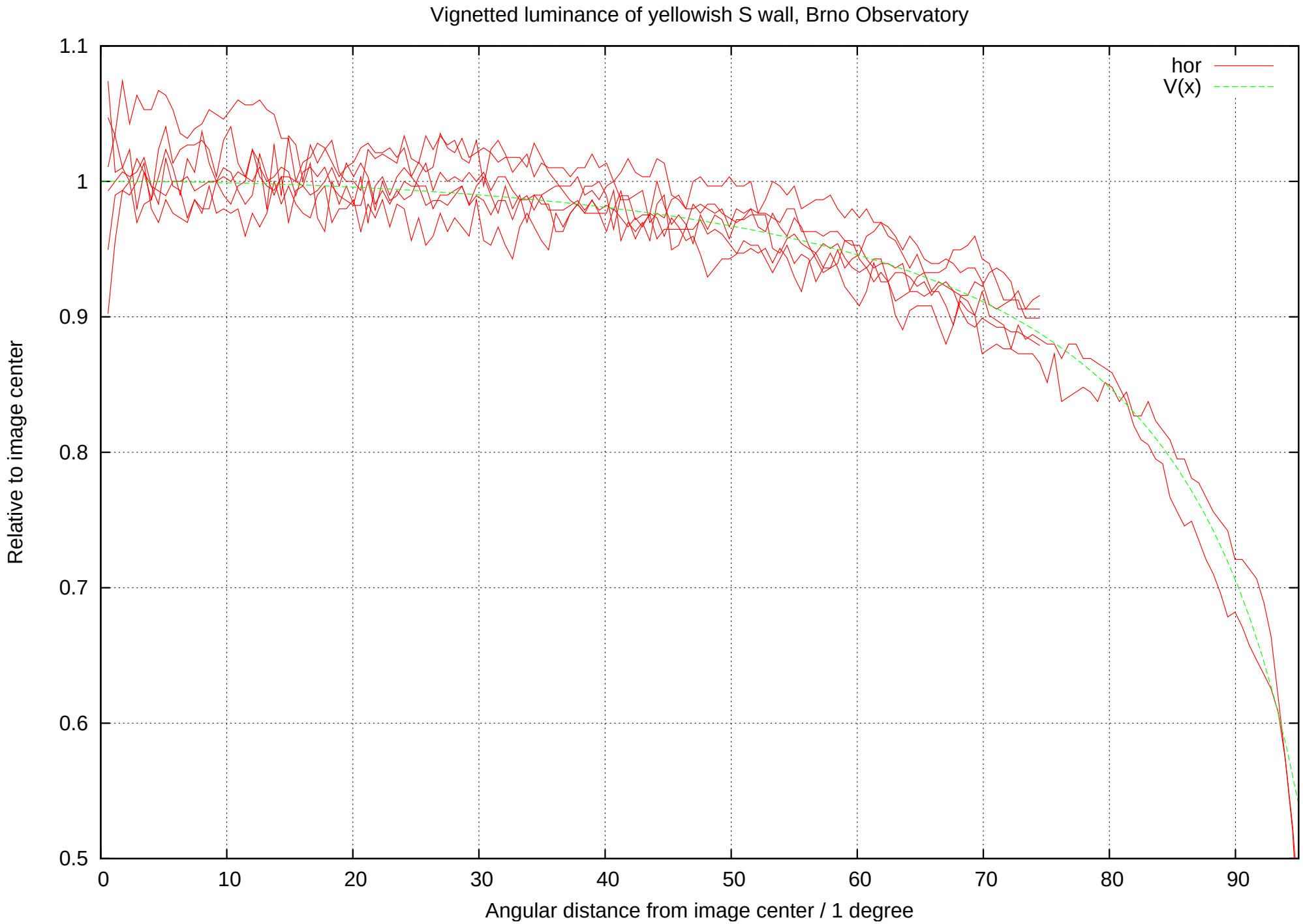
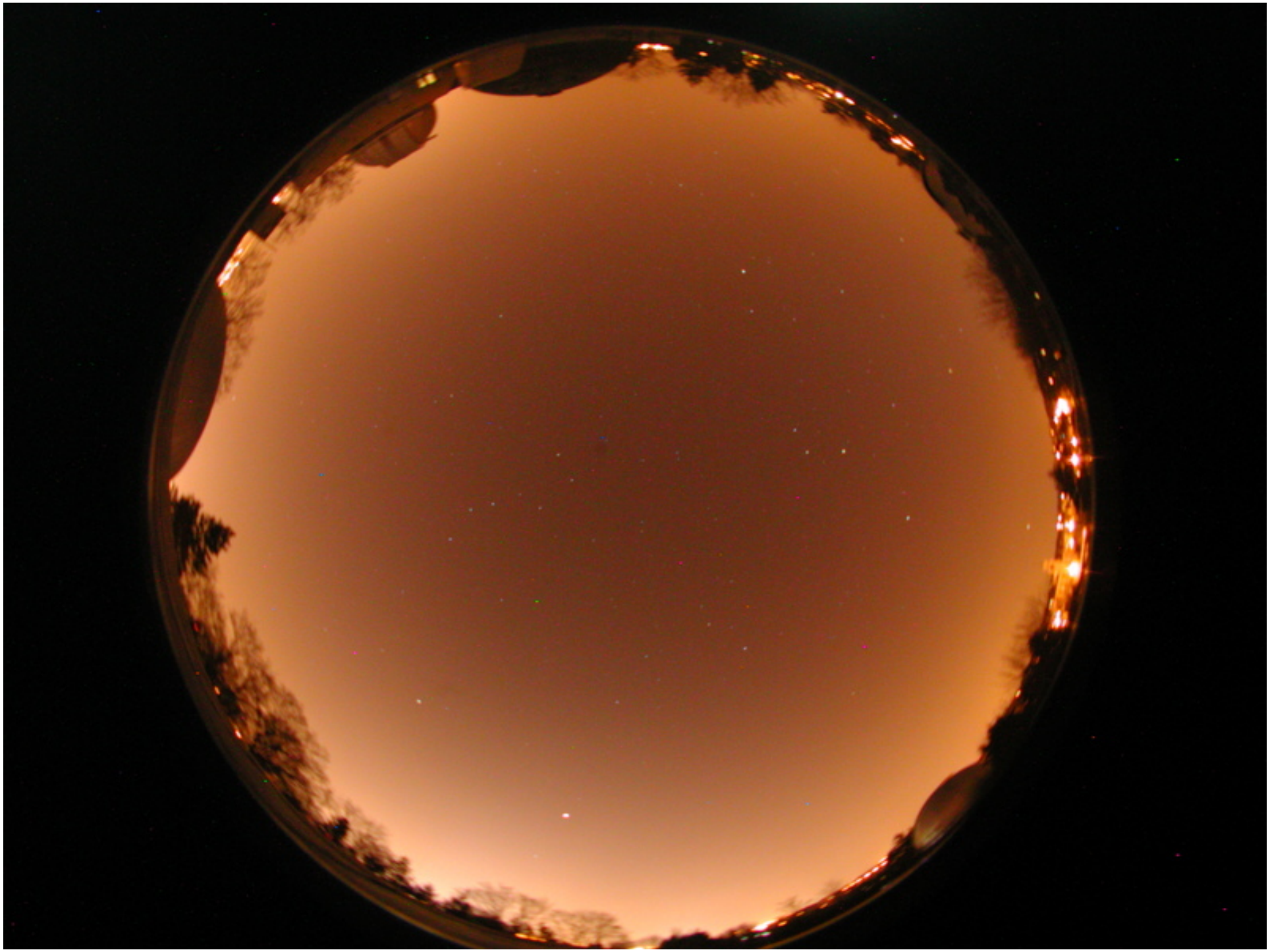
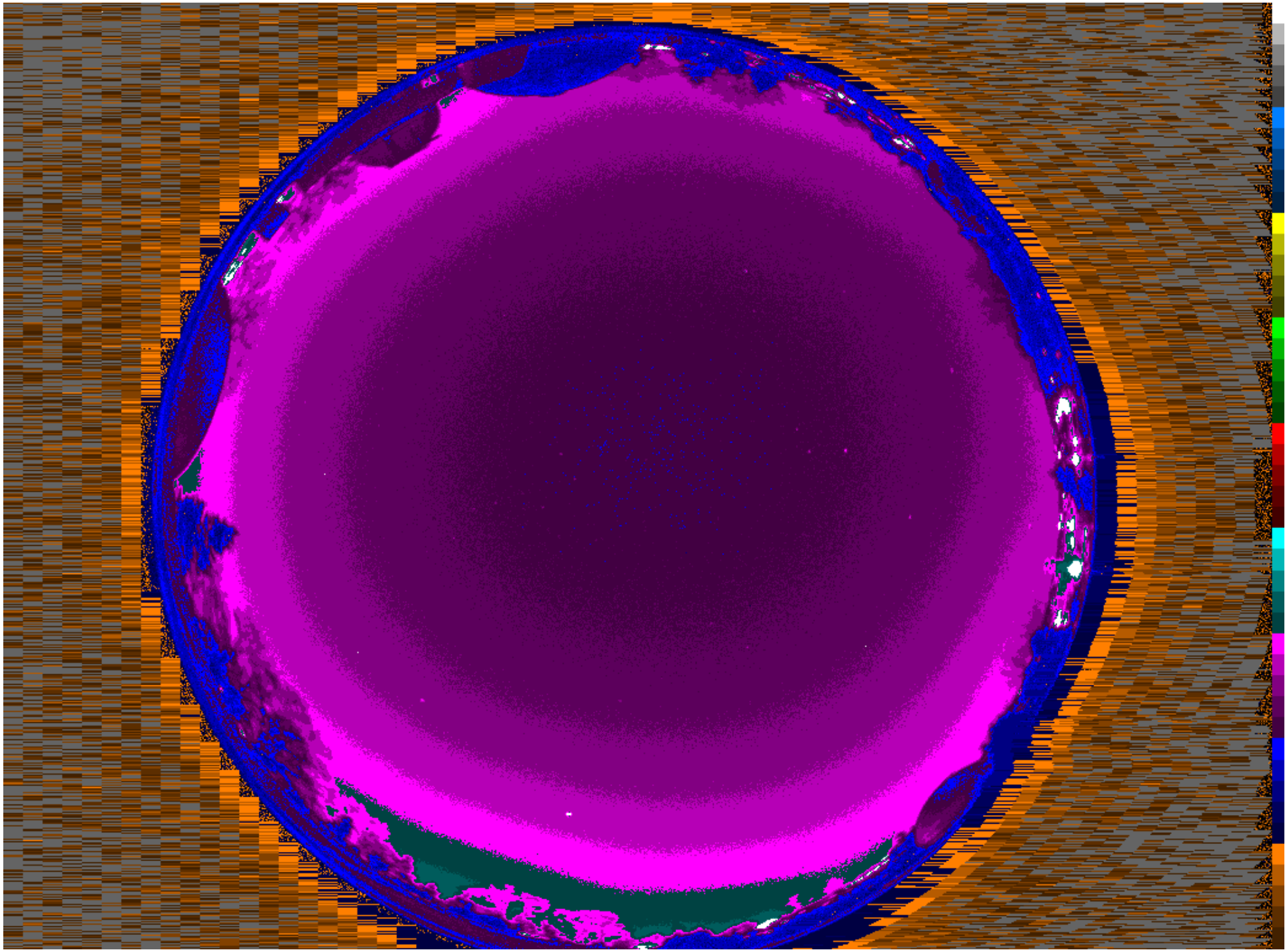
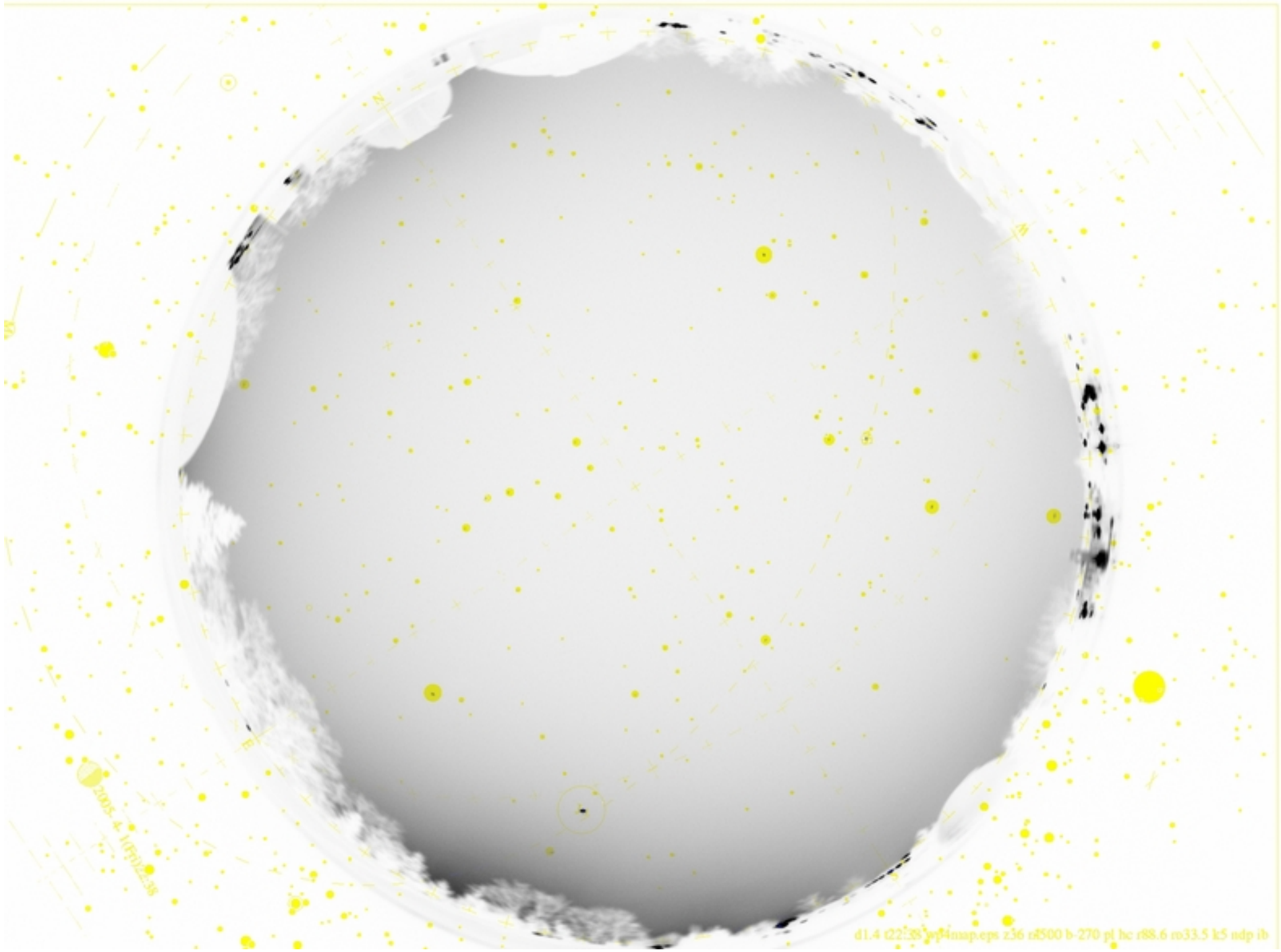

Vignetted luminance of yellowish S wall, Brno Observatory
Relative to image center
Angular distance from image center / 1 degree
hor
V(x)
1.1
1
0.9
0.8
0.7
0.6
0.5
0
10
20
30
40
50
60
70
80
90

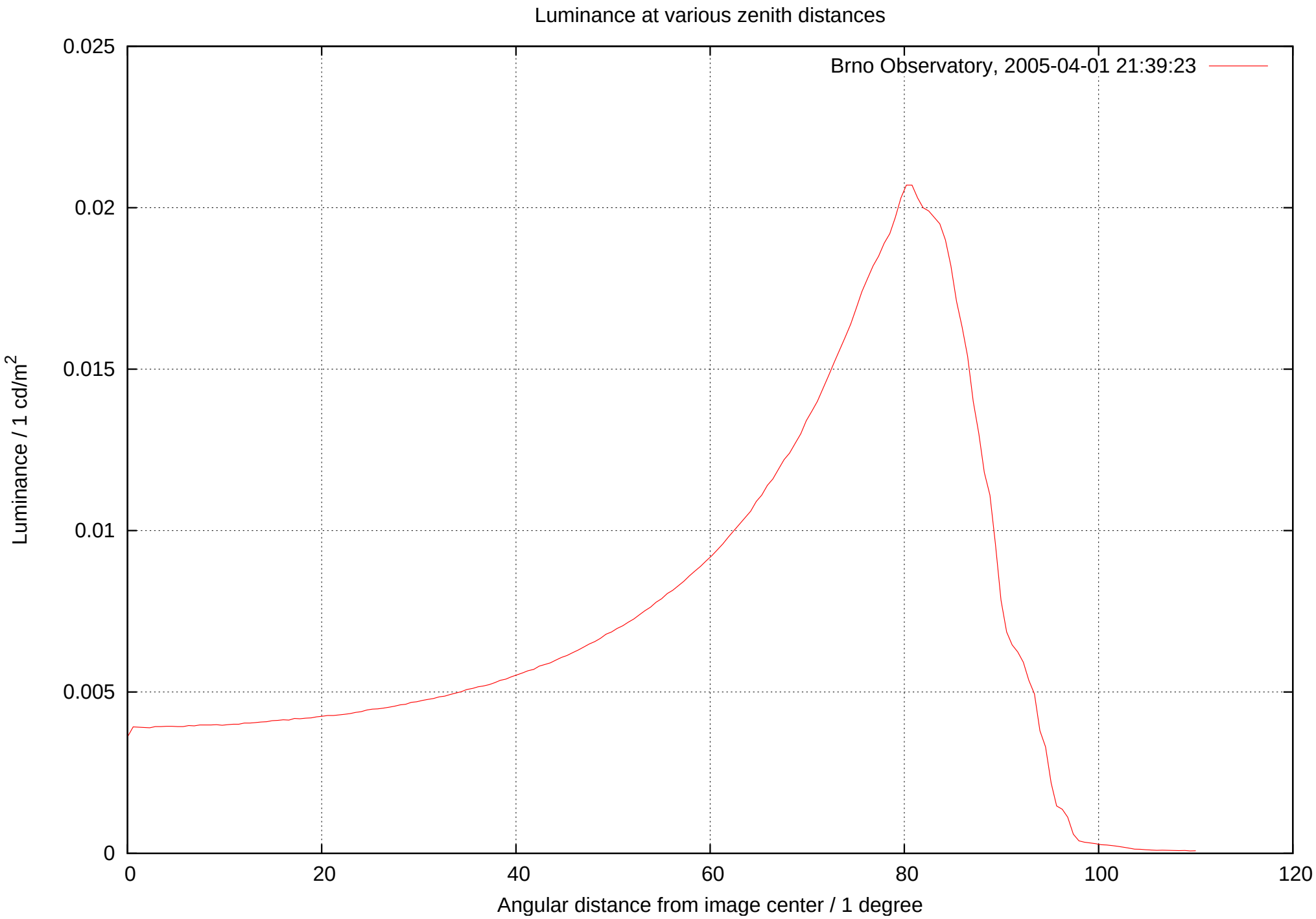
Image geometry from fitting a star map with a suitable projection:

(Brno Observatory, 2005-04-01 21:39:23, 60 s exposure)



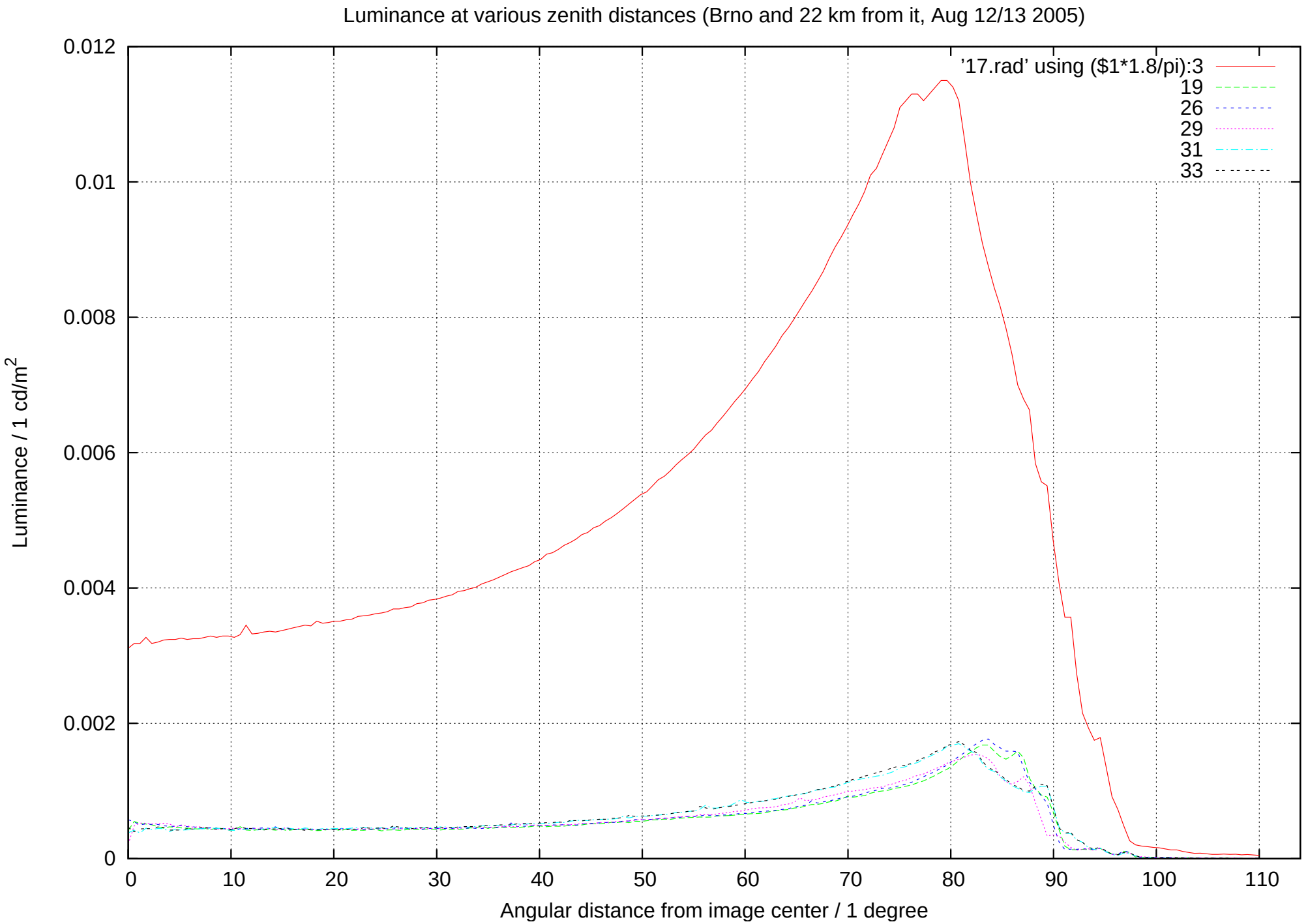


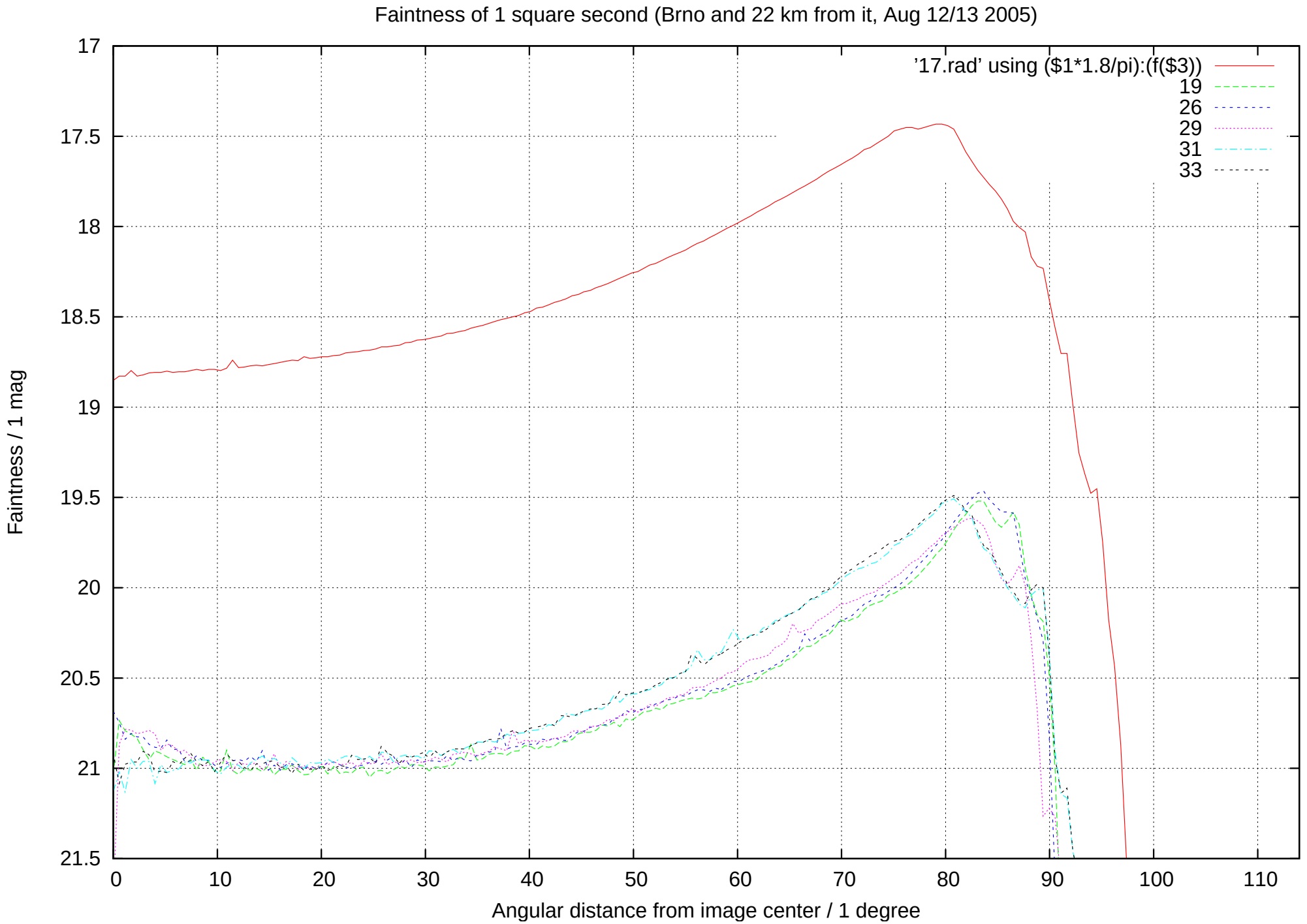

d1.4 t22:38 wp4map.eps z36 r4500 b-270 pl hc r88.6 ro33.5 k5 ndp ib


Luminance at various zenith distances
Brno Observatory, 2005-04-01 21:39:23
Luminance / 1 cd/m2
Angular distance from image center / 1 degree
0.025
0.02
0.015
0.01
0.005
0
0
20
40
60
80
100
120

Knowing vignetting and geometry, sky luminance profiles can be made

(again the 2005 Perseid maximum night):


Luminance at various zenith distances (Brno and 22 km from it, Aug 12/13 2005)
'17.rad' using ($1*1.8/pi):3
19
26
29
31
33
Luminance / 1 cd/m2
Angular distance from image center / 1 degree
0.012
0.01
0.008
0.006
0.004
0.002
0
0
10
20
30
40
50
60
70
80
90
100
110

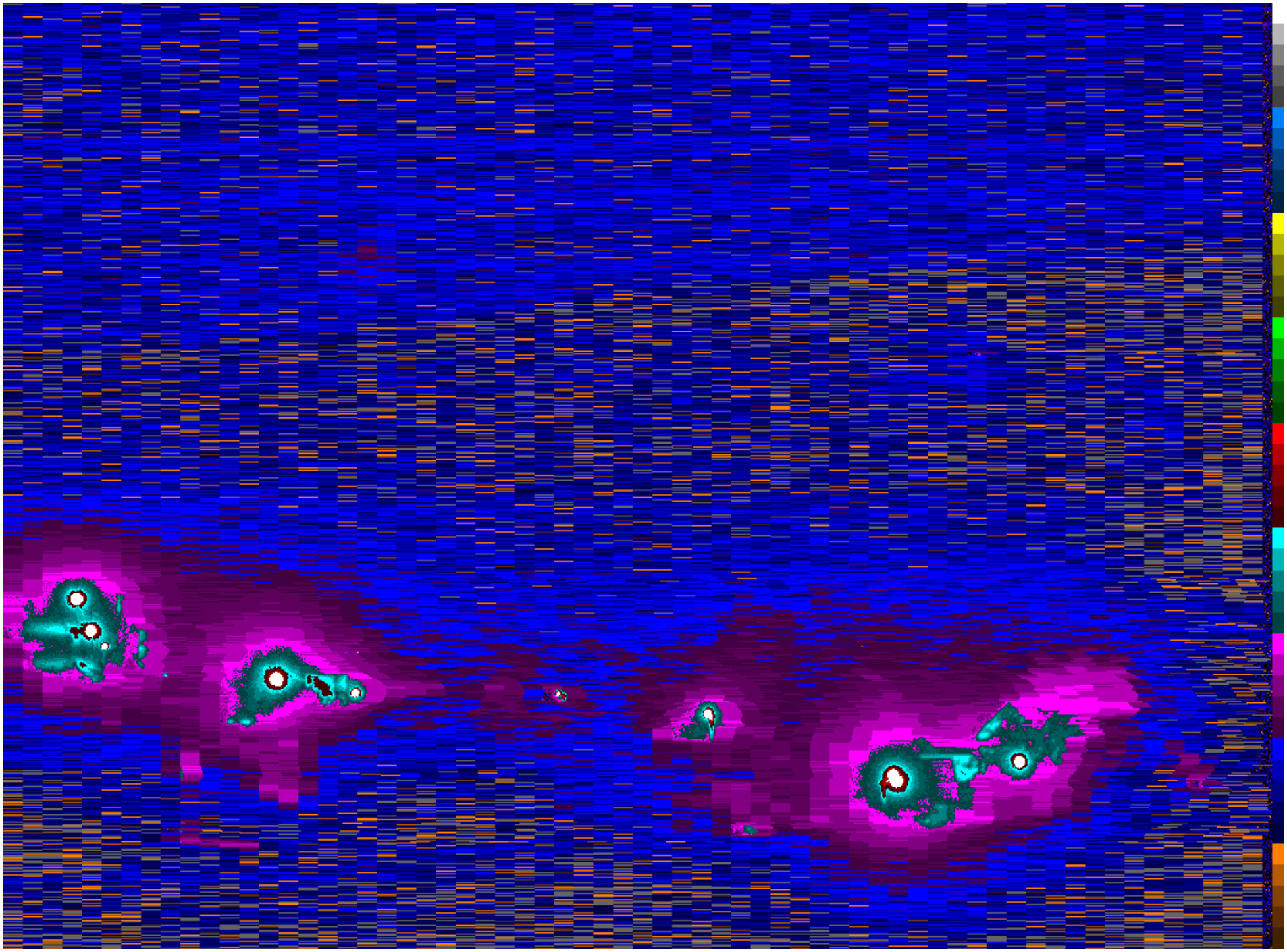

Faintness of 1 square second (Brno and 22 km from it, Aug 12/13 2005)
'17.rad' using ($1*1.8/pi):(f($3))
19
26
29
31
33
Faintness / 1 mag
Angular distance from image center / 1 degree
17
17.5
18
18.5
19
19.5
20
20.5
21
21.5
0
10
20
30
40
50
60
70
80
90
100
110

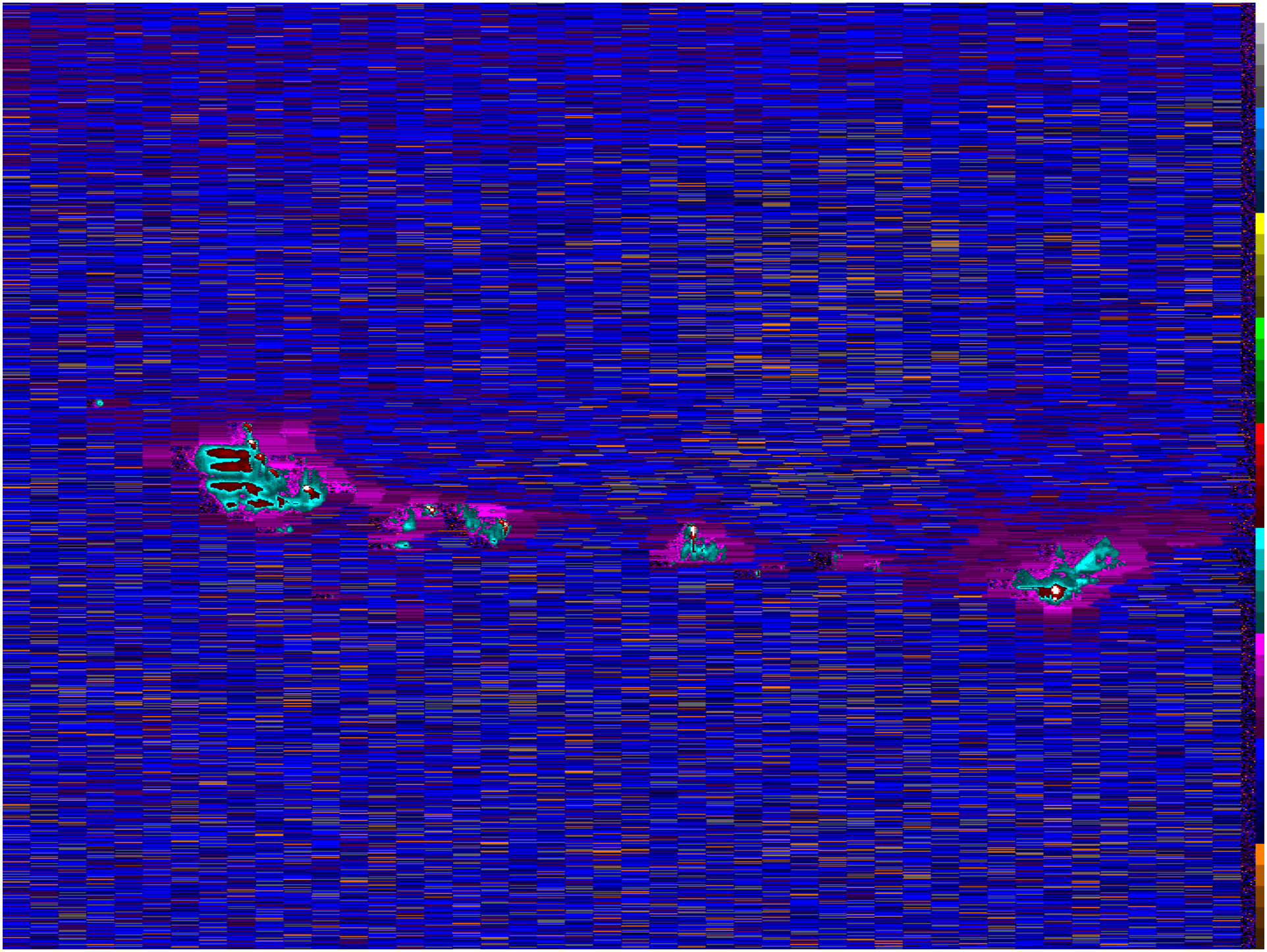
Direct comparison with a luxmeter reading is possible:

Nikon
EXTECH
Easy View 30
3462
RANGE
MAX/MIN
PEAK
REL
Nikon

Good retrofit in Hostetin

(Images before by Nikon 990, after by Fuji S5000)





– vast improvement:

10$\times$ lower imissions,

25$\times$ less “direct” light (coming mostly just from illuminated masts now)

even with 3$\times$ more light onto the road...

The tools:

series of exposures (2 s, 1/8 s, 1/125 s, 1/2000 s)

an adapted David Coffin’s dcraw

raw2lum

Which camera is the best one?

Any which outputs almost all darkframe pixels as non-zero.

(If many pixels are 0, low-light photometry is less accurate.)

Future tasks:

Automated stellar photometry (to arrive at air transparency),

two-component vignetting model (for any aperture and focal length),

use of archived jpeg images (with their black-box magic) to document changes over years.

Some interesting all-sky projects:

- Whole Sky Imager (closed; there were attempts to get night sky radiances)
- National Park Service Night Sky Team
- ISTIL (emerging monitoring)

www.astro.cz/darksky