International Radiance Workshop
Fribourg, 2008

Axel Jacobs, Stephen Wittkopf, Lars O. Grobe:

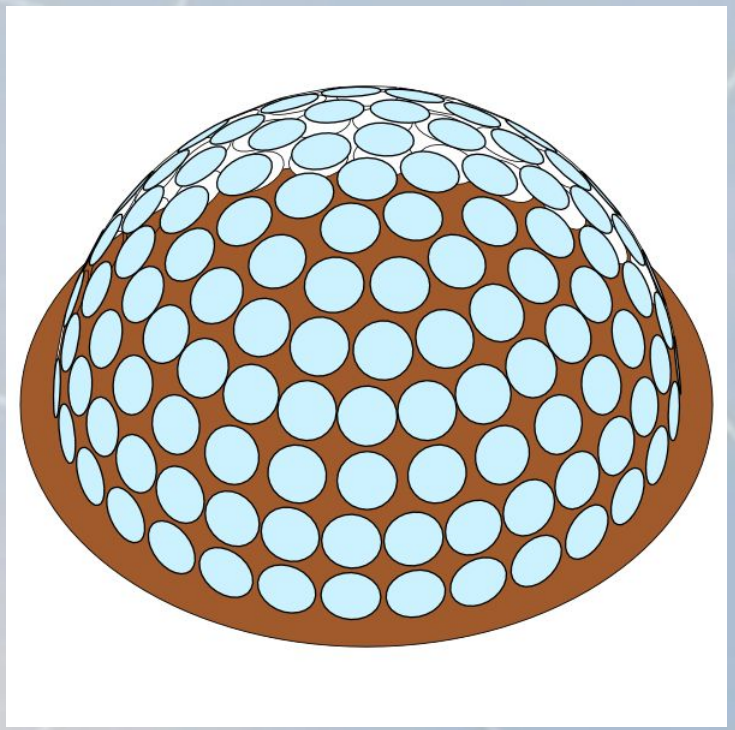
Per-pixel Sky Luminance with HDR Photography

Introduction

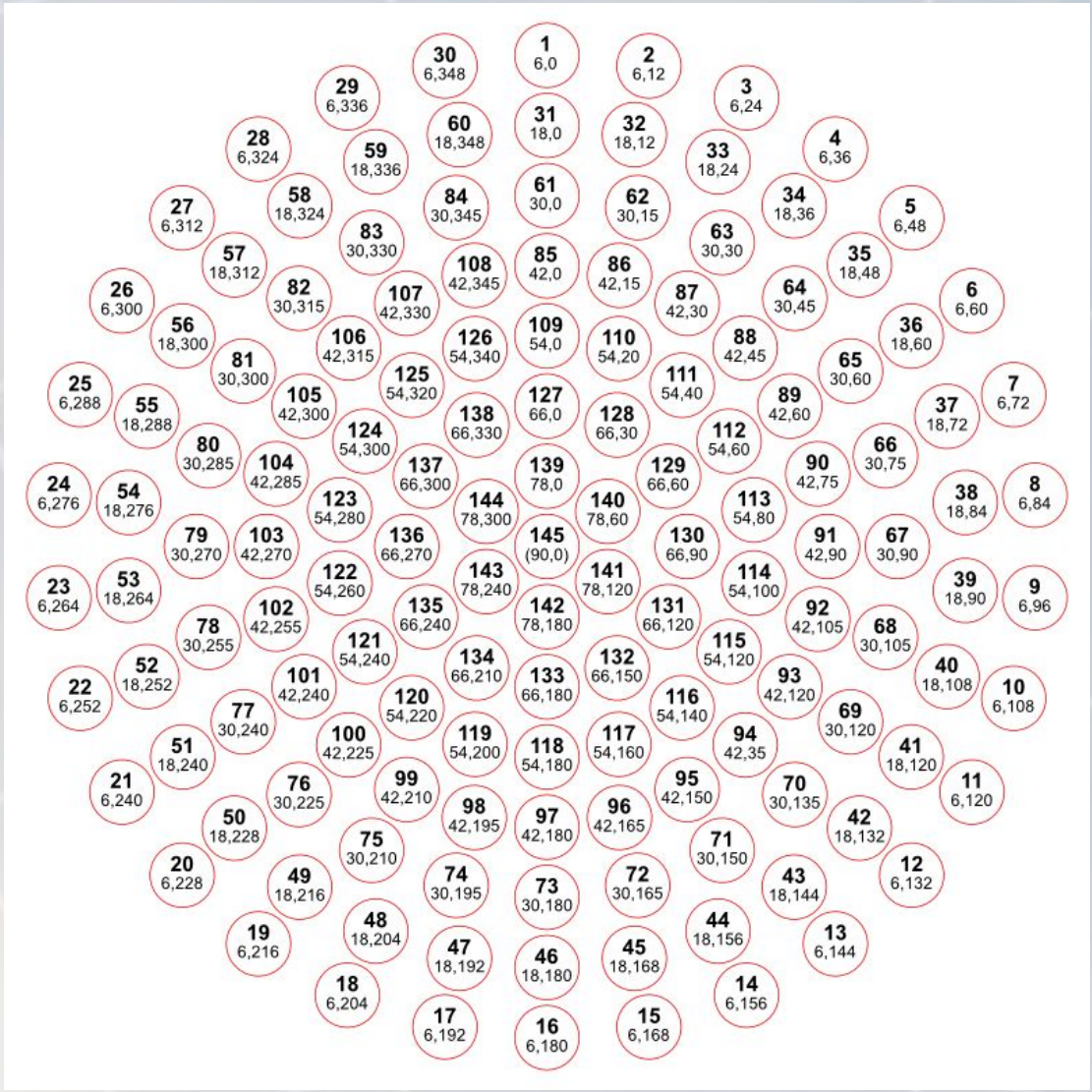
- Work in progress on HDR photography for sky luminance analysis
- Introduce the exposure settings required to capture the high luminance of tropical skies in Singapore, the HDR generation with *hdrgen*, and tools for the photometric and geometric calibration of a Nikon D200 with Sigma 4.5mm Fish-eye lens and for extracting luminance of 145 sky patches.
- Comparisons of extracted luminance vs. luminance measured with LS-100 where the average deviation is around 5%.

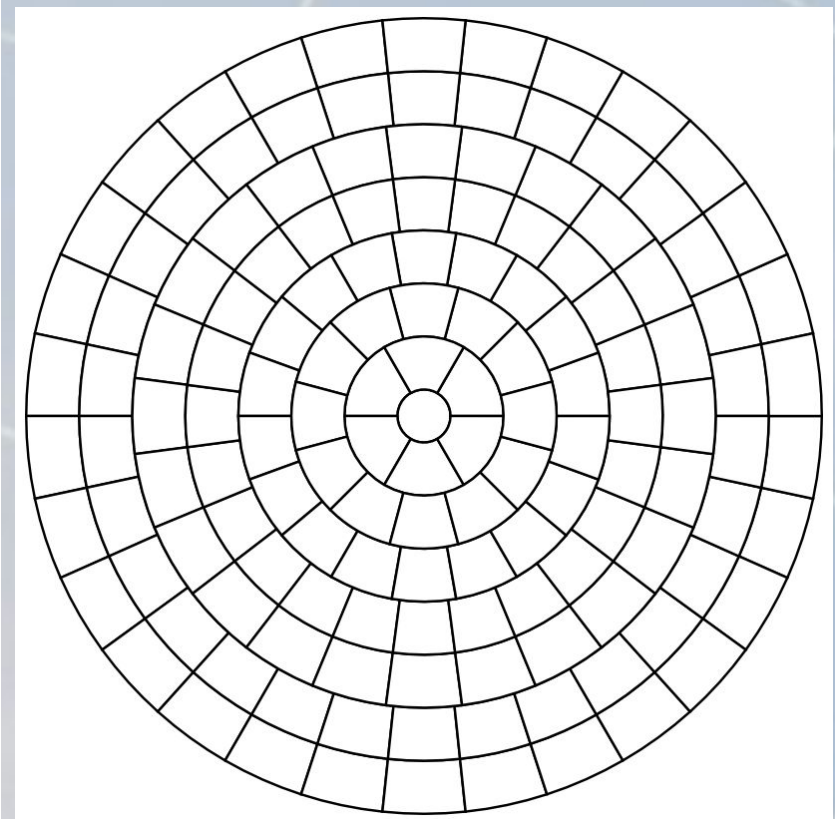
Sky Patches 1

- Peter Tregenza, 1987
- 145 patches (originally 151)
- ~11º angle of opening
- 8 bands in 12º steps,
  30-6 patches each,
  one at zenith



Sky Patches 2





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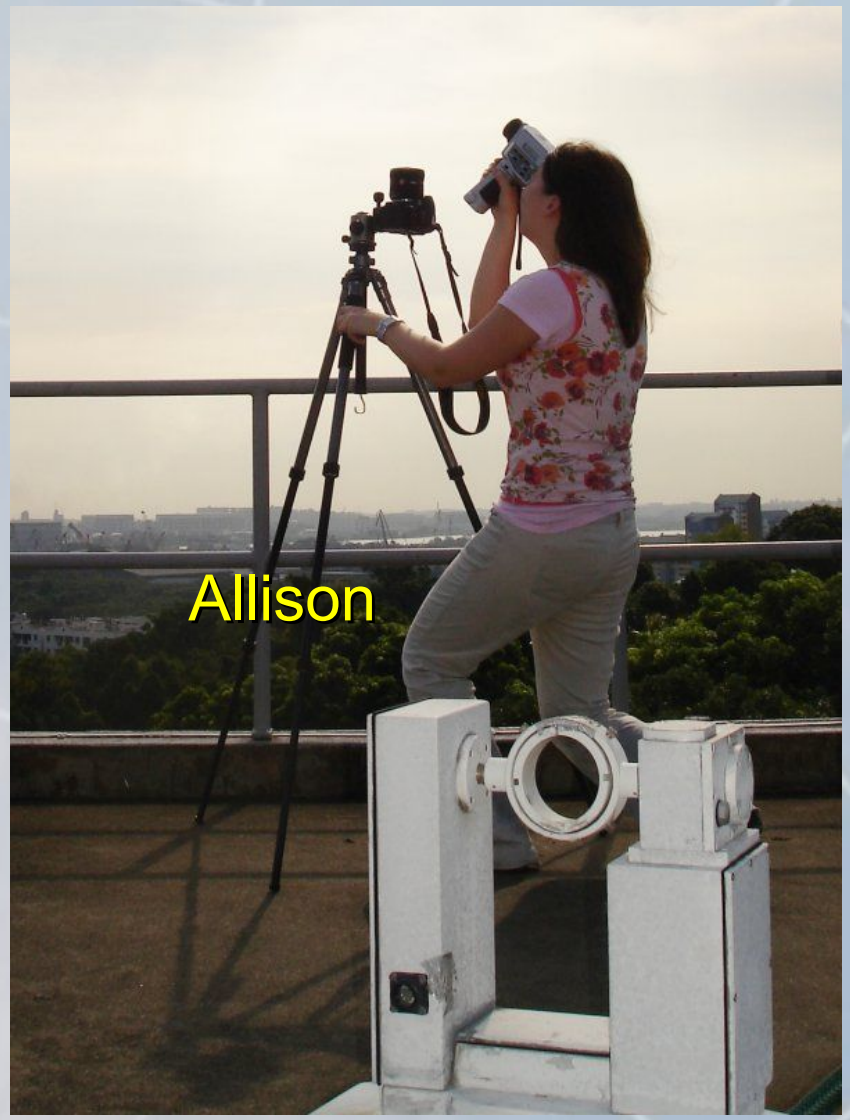
IDMP

- International Daylight Measurement Programme, 1991
- Sky scanners in many countries
- Analysis of results led to 15 new CIE standard skies: Standard Sky Luminance Distribution, SSLD



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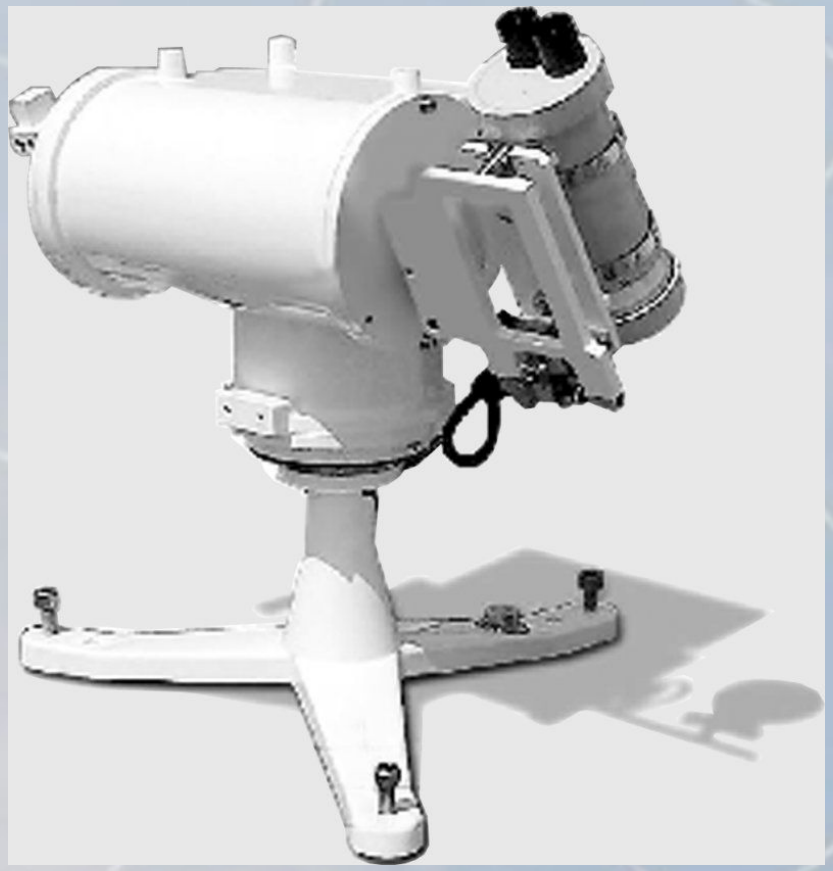
Sky Scanner

- Sophisticated equipment for measuring sky luminance distribution based on Tregenza patches
- Very expensive
- Not widely available
- Most IDMY ones no longer work



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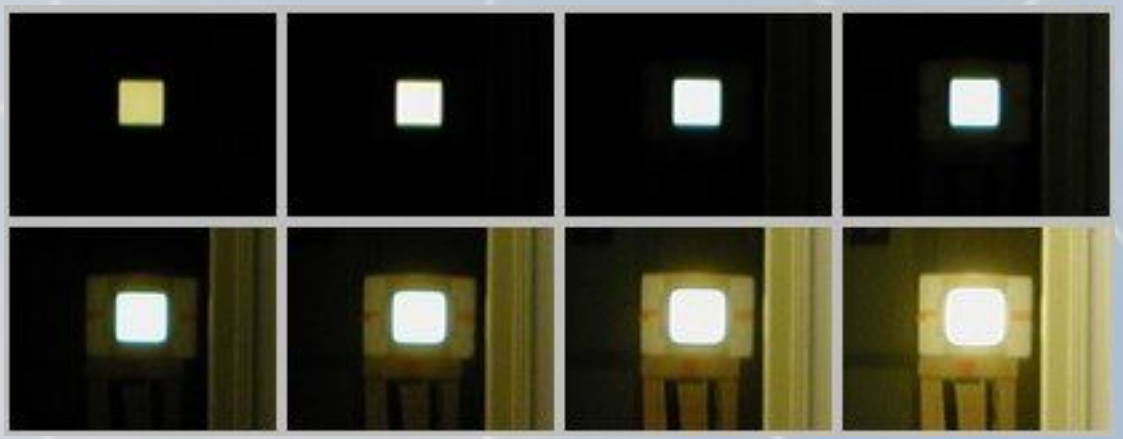
High Dynamic Range Imagery

1. Take exposure-bracketed sequence, covering the entire dynamic range of the scene
2. Combine sequence into an HDR image
3. Calibration routines and EXIF header result in accurate photometric information

Luminance Camera



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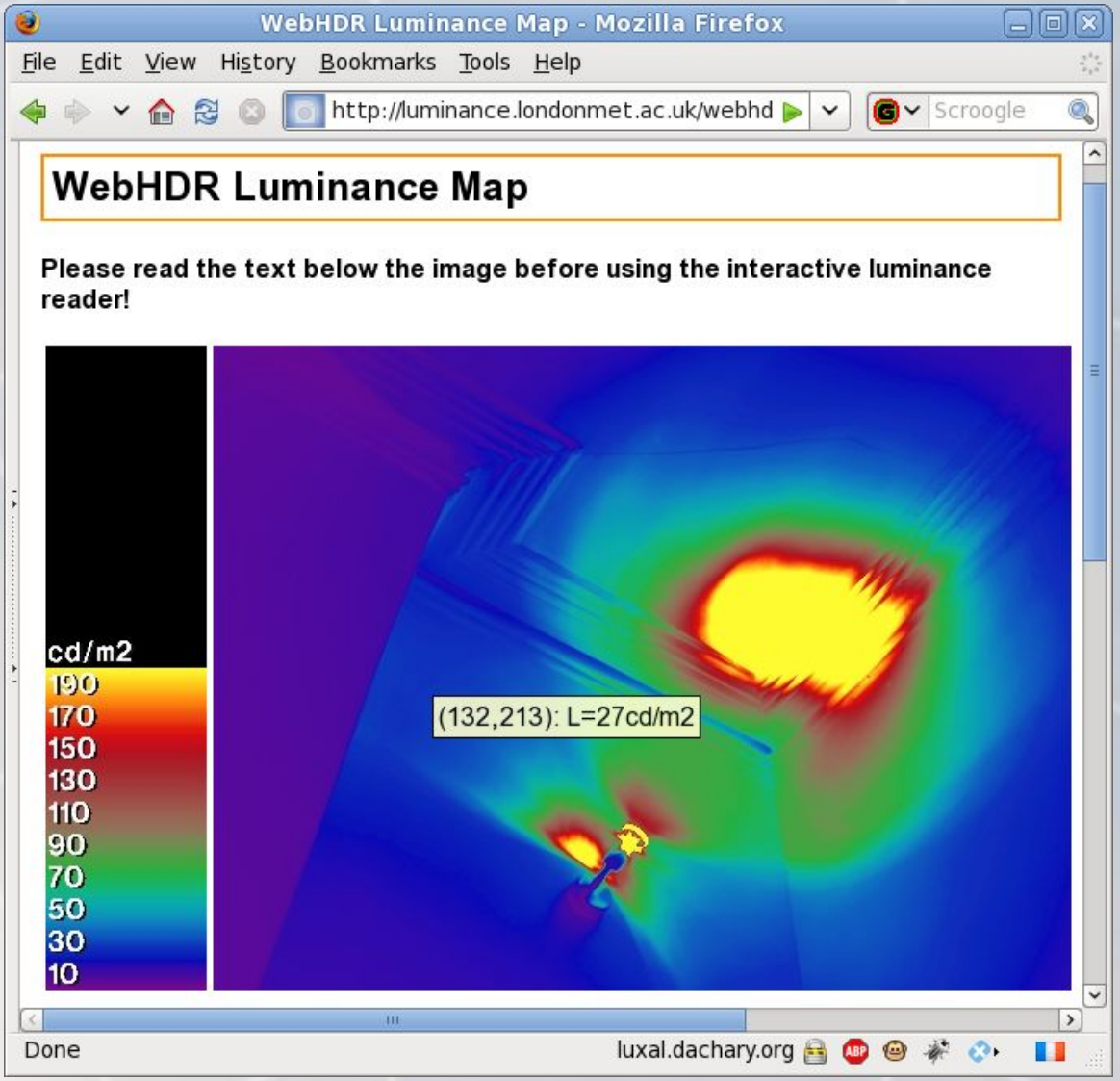
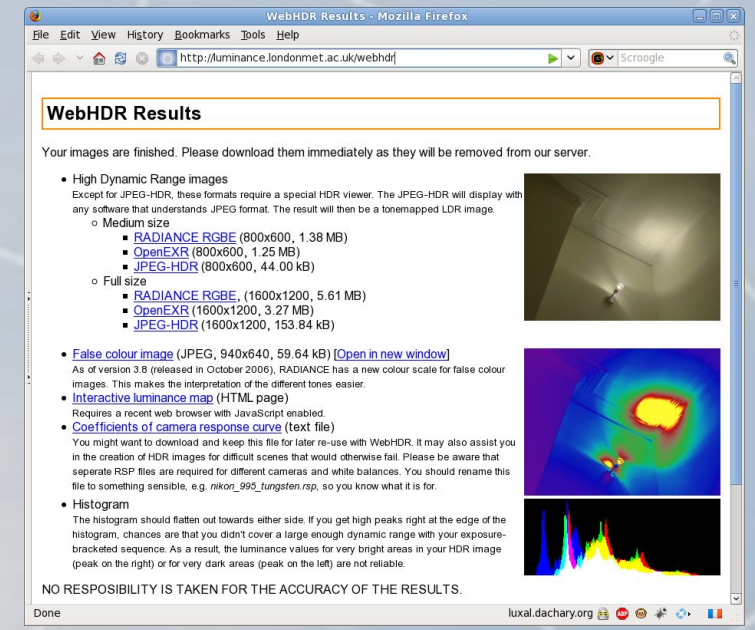
WebHDR





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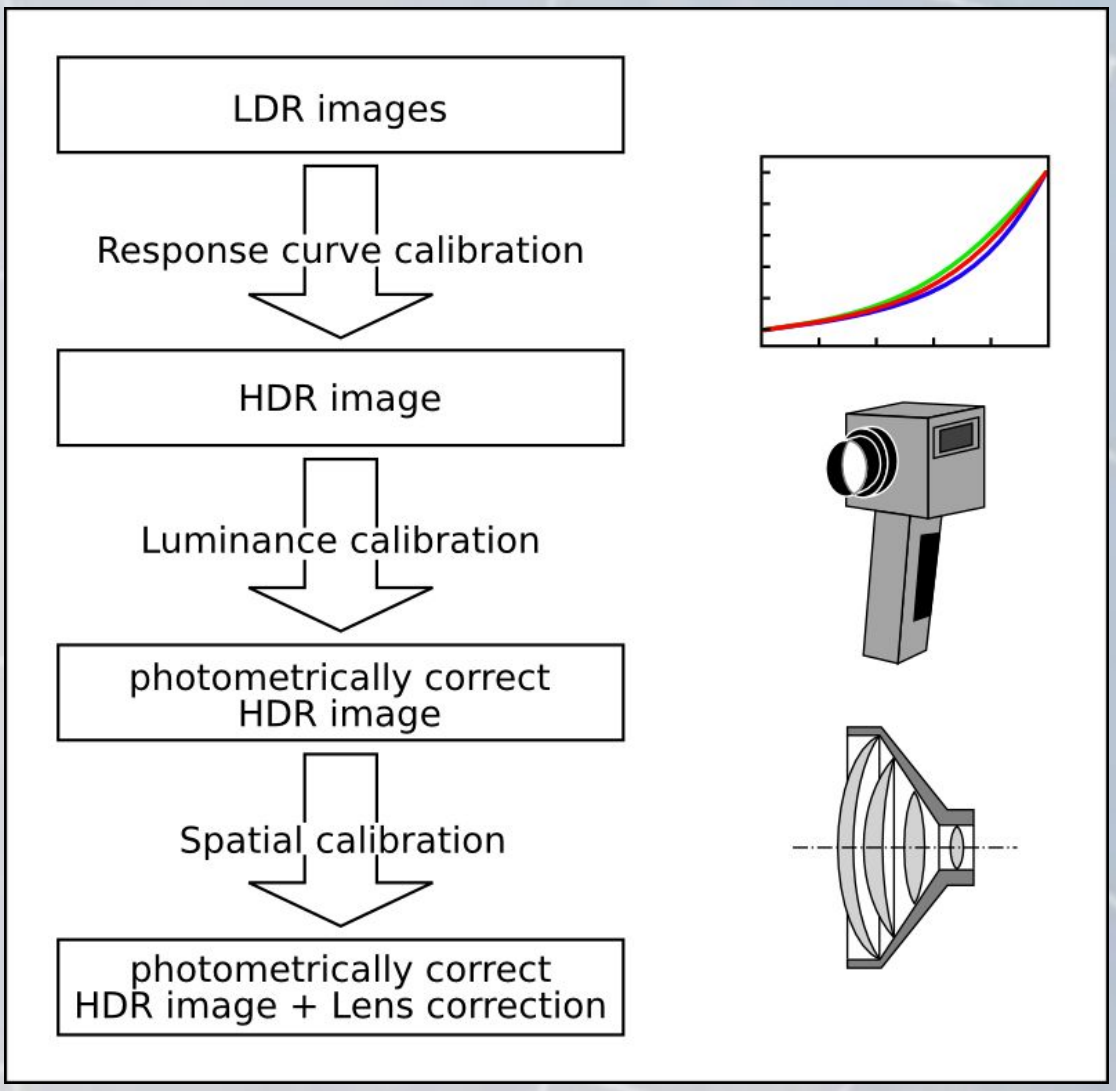
Calibration



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Vignetting

- Drop-off of image brightness towards the edges of the image
- Characteristic for a particular lens
- Depends also on aperture setting
- Theoretically proportional to $\cos^4$

Source: Wikipedia

Projection 1

- Should be about equiangular:
  Distance of pixel from the image centre is proportional to angle away from optical axis
- But is it?

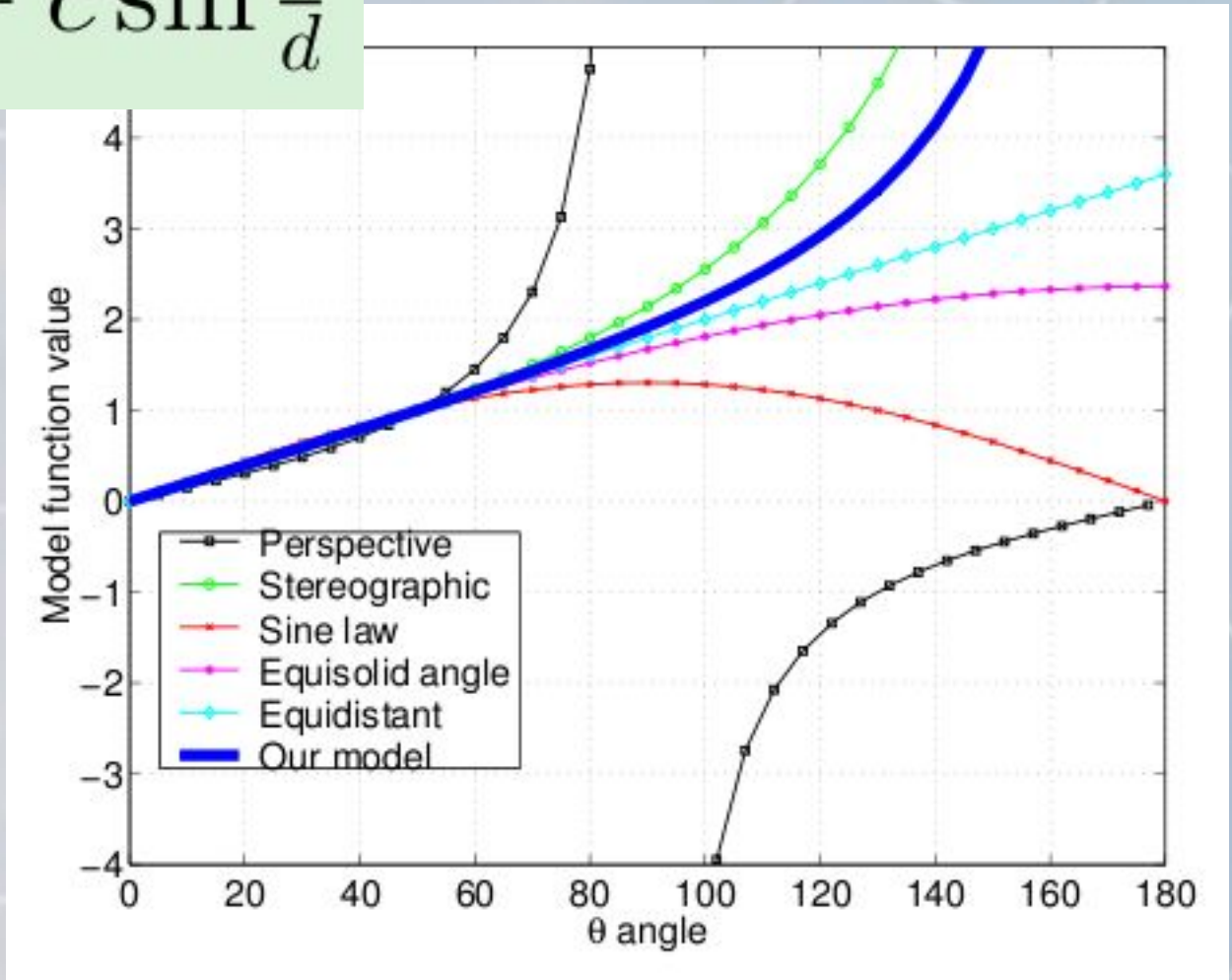
Projection models [Fleck, 1995]:

- perspective $r = k \tan\theta$
- stereographic $r = k \tan\frac{\theta}{2}$
- equidistant $r = k\theta$
- equisolid angle $r = k \sin\frac{\theta}{2}$
- sine law $r = k \sin\theta$

Projection 2

$$r = a \tan \frac{\theta}{b} + c \sin \frac{\theta}{d}$$

Nikon FC-E8



Bakstein and Pajdla: "Calibration of a fish eye lens with field of view larger than 180º"; Proceedings of the CVWW 2002, p276–285, Feb 2002.

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Project

- What:
  - Use HDR for analysis of sky luminance distribution
  - RGBE sky map for Radiance rendering (image-based lighting)
- How:
  - Capture exposure-bracketed fisheye images of sky vault
  - Process into HDR image
  - Analyse HDR with Radiance tools
  - Perl as 'glue'

Funding

- NUS

  - Development of zero-energy building with advanced PV and Daylight systems; PI: Stephen Wittkopf
  - Funding available for equipment: D200, computers, light meter, etc
  - Lars (8-week visiting researcher)
  - Xiaoming (part-time)

- MIT

  - Building a campus in SG with focus on environmental sensing and modelling (http://censam.mit.edu)
  - Censam PI Leslie Norford collaborates with NUS
  - Sigma Fisheye lens, other equipment
  - Allison Dee (MIT exchange student)
  - Chiew Wai (full-time)

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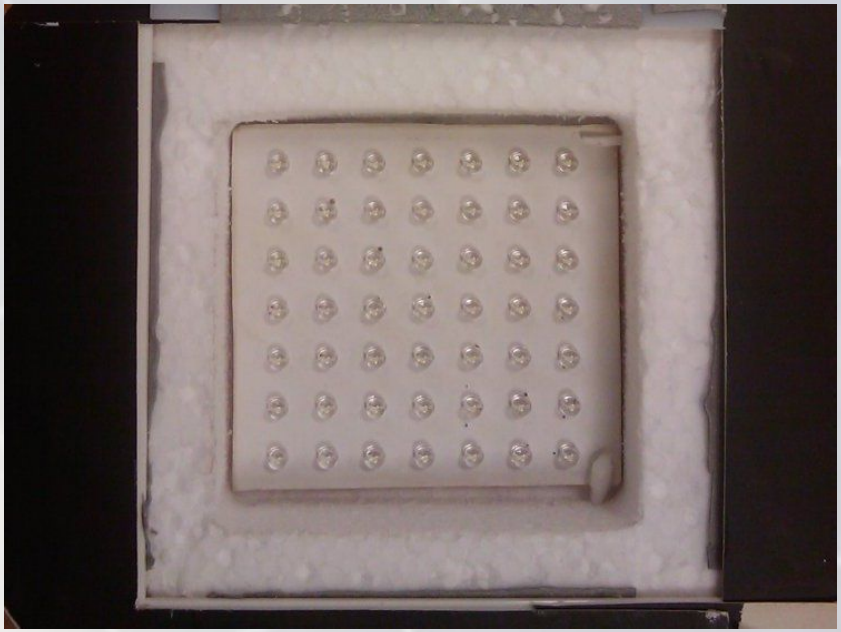
Players

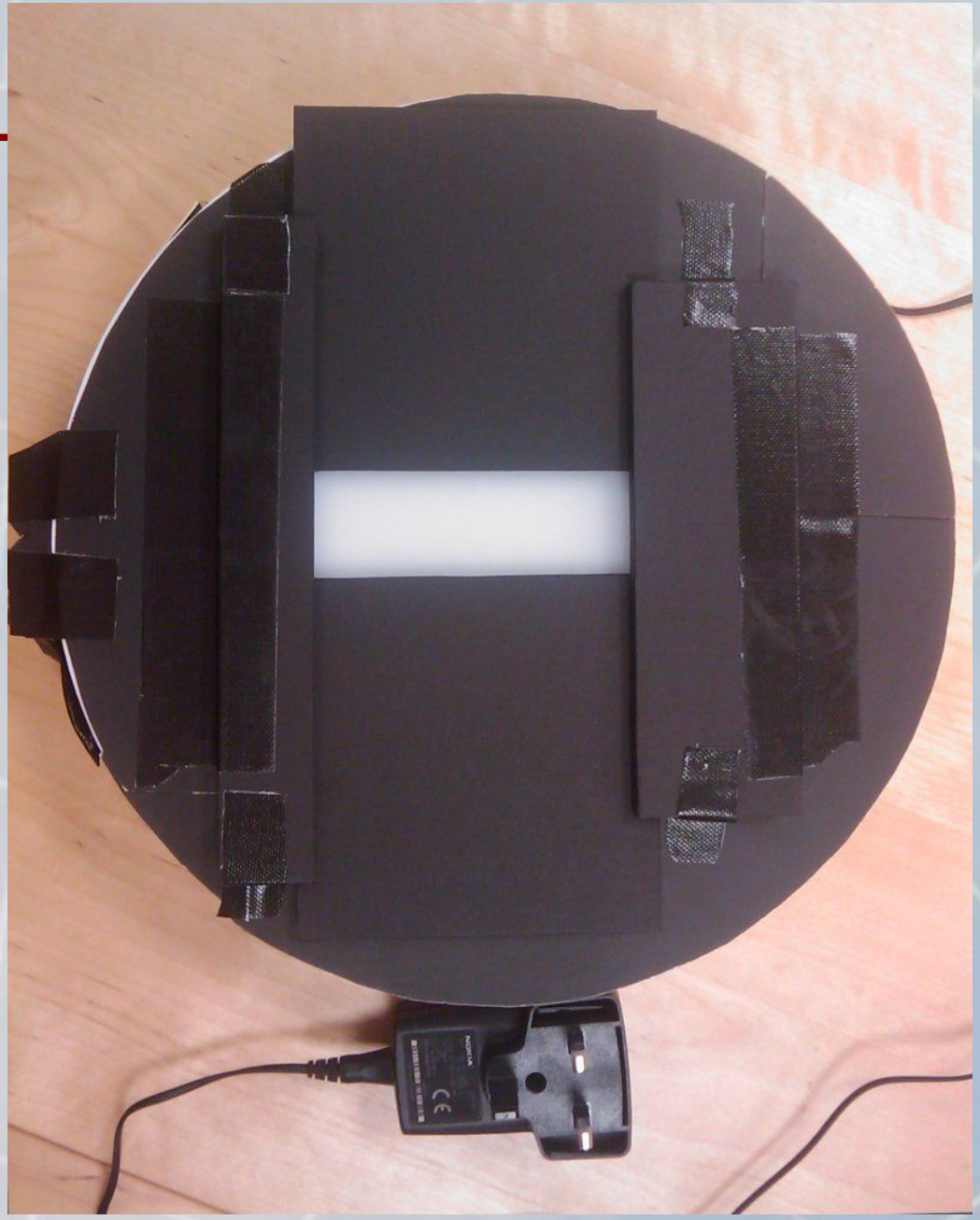
Camera

- Nikon D200
- Sigma 4.5mm fisheye lens with 180° view
- Connected to laptop

Light Source 1

- DIY Array of LEDs





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Procedure

- Fixed camera
- Positions marked on floor
- Light source moved around the camera
- One HDR for each position
- 6º steps: 16 images over 90º

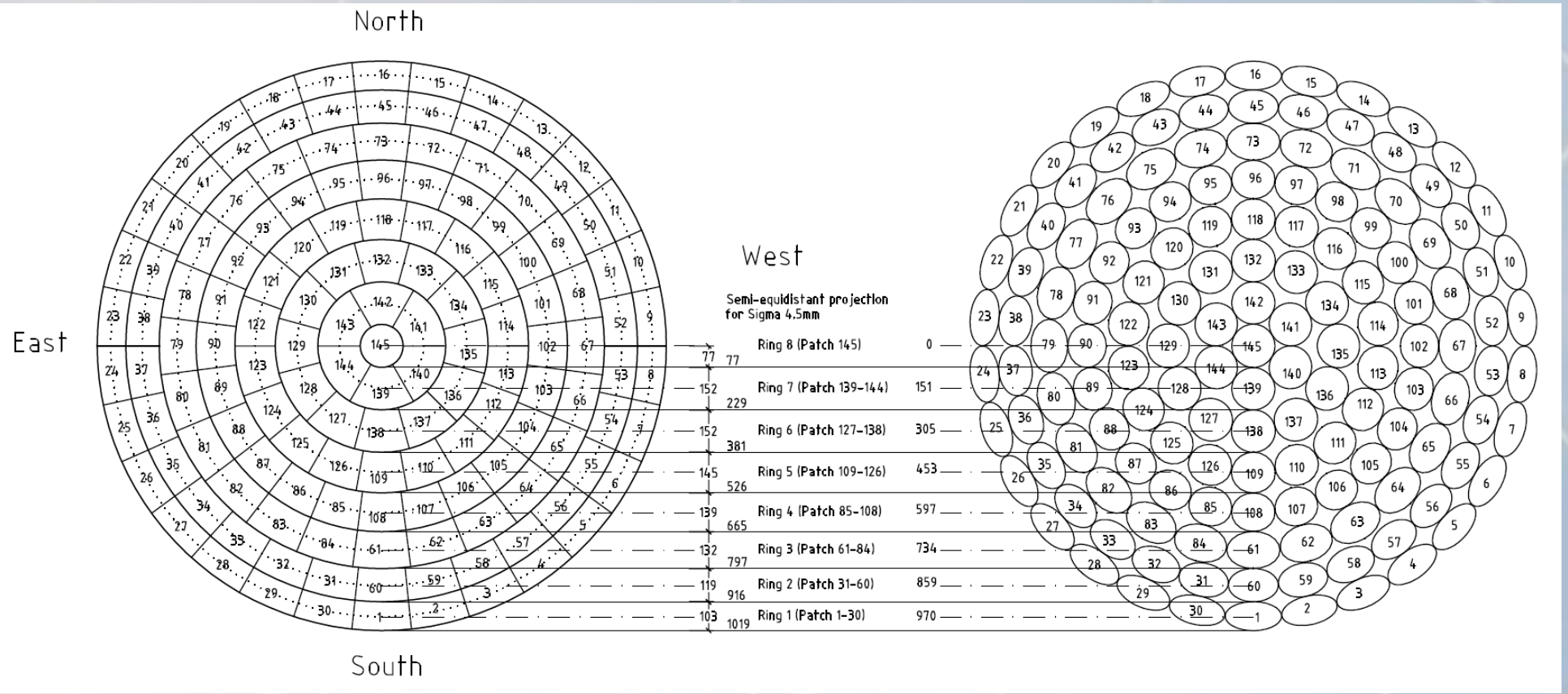
Outcome

6º steps, from 0º to 90º

Software picks out average luminance and (x, y) pixel position of each sample area

Projection 3

- Distance of pixel from the image centre is not proportional to angle away from optical axis



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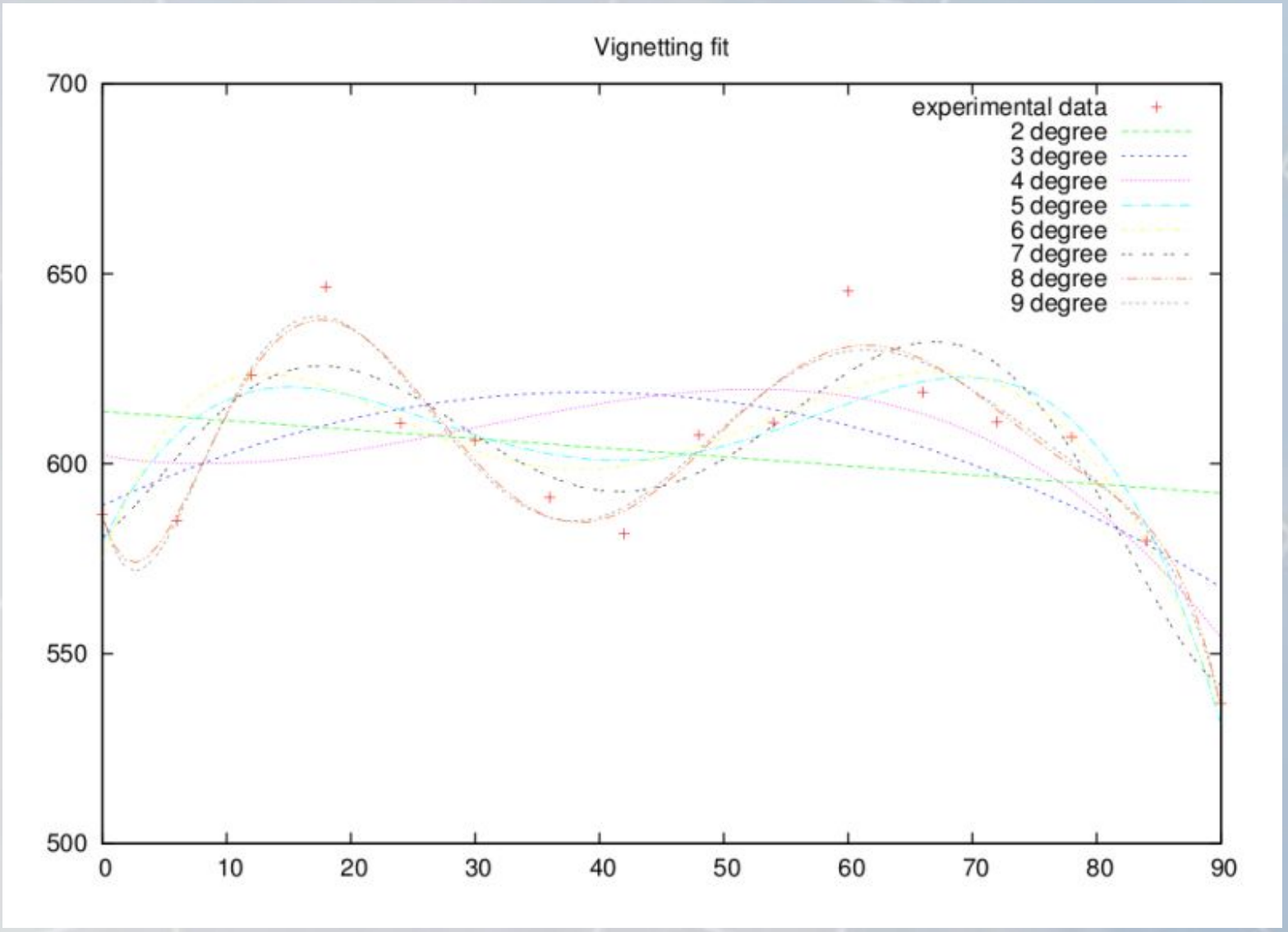
Strangeness



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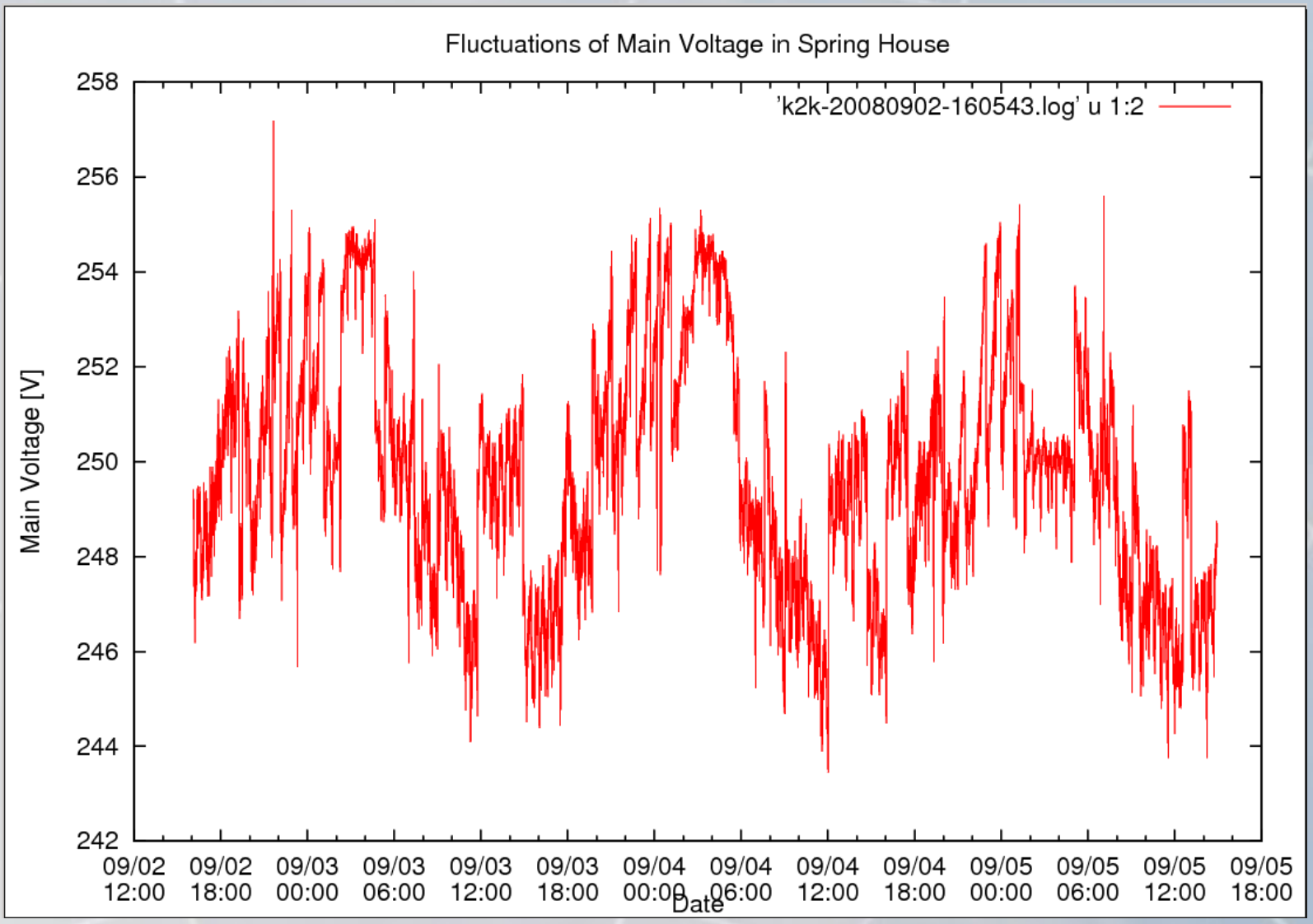
Problem 1


Fluctuations of Main Voltage in Spring House
'k2k-20080902-160543.log' u 1:2
Main Voltage [V]
258
256
254
252
250
248
246
244
242
09/02 12:00
09/02 18:00
09/03 00:00
09/03 06:00
09/03 12:00
09/03 18:00
09/04 00:00
09/04 06:00
09/04 12:00
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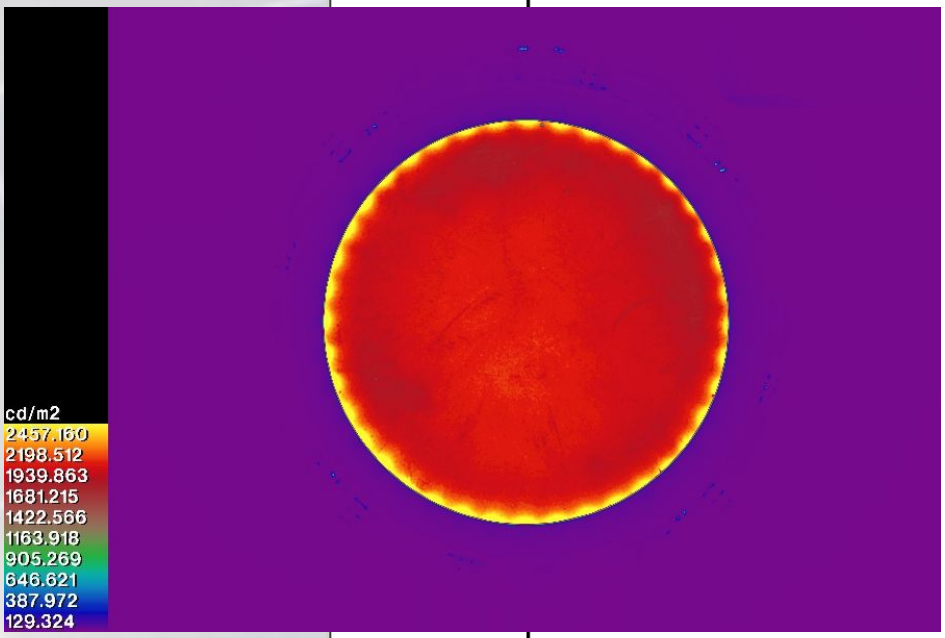
09/05 12:00
09/05 18:00
Date

Problem 2



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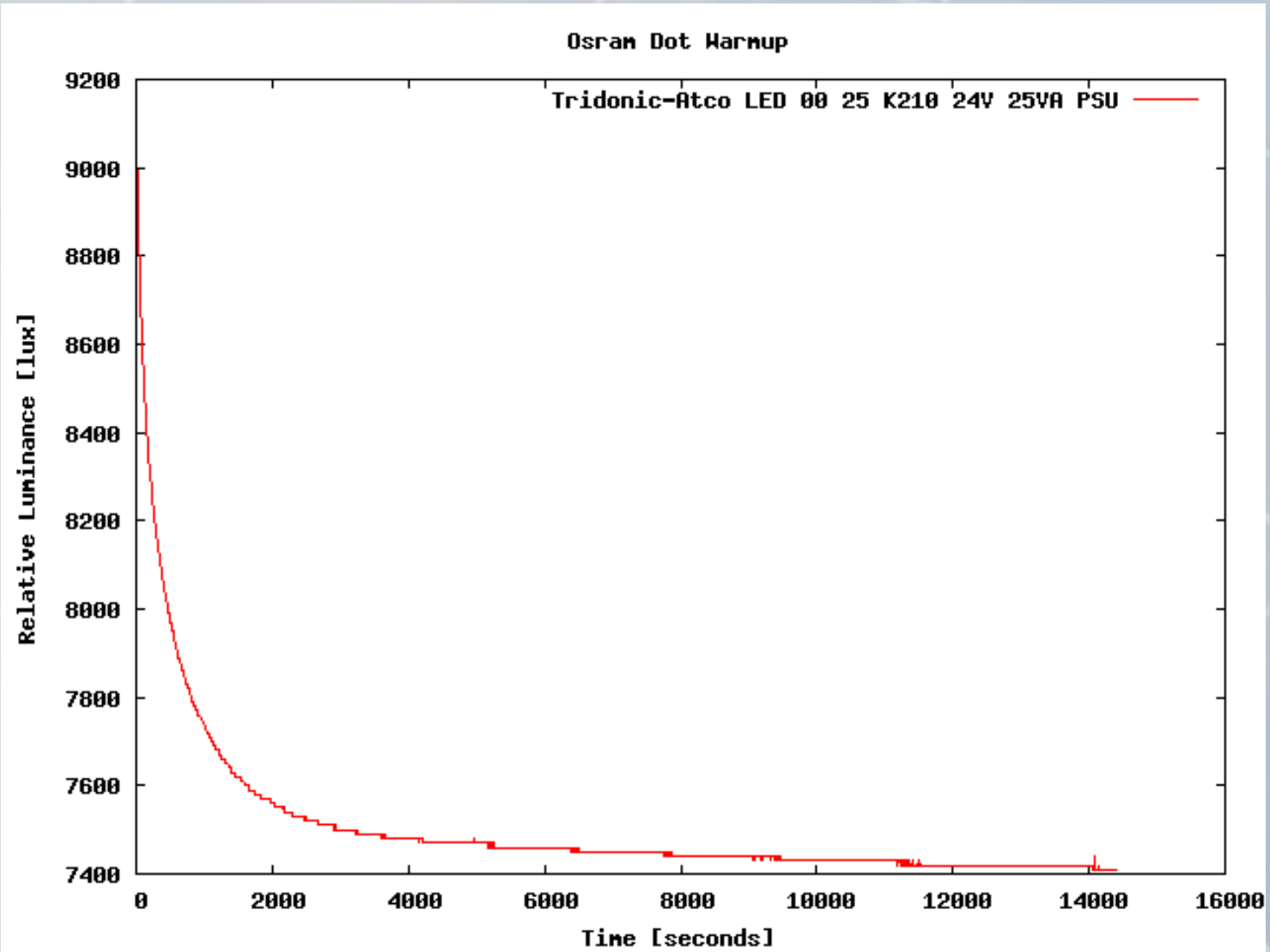
Problem 3



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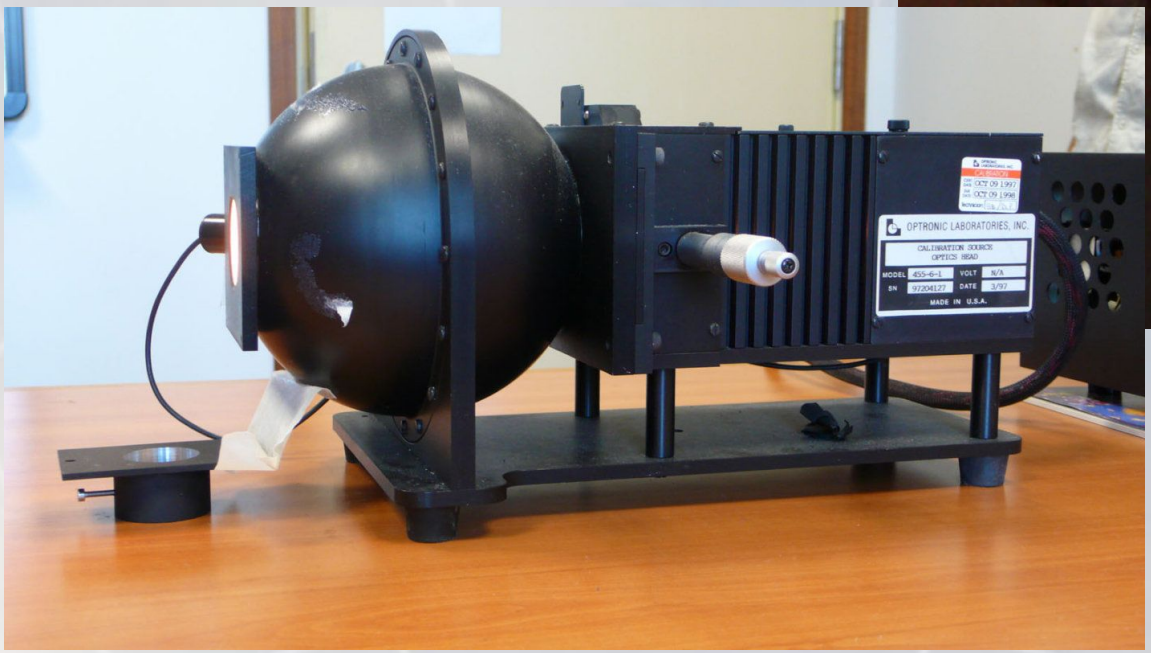
Light Source 2

- Optronic Labs, Inc.

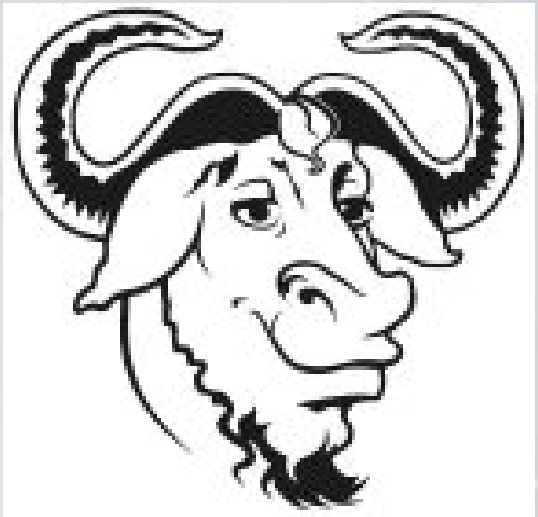


Perls

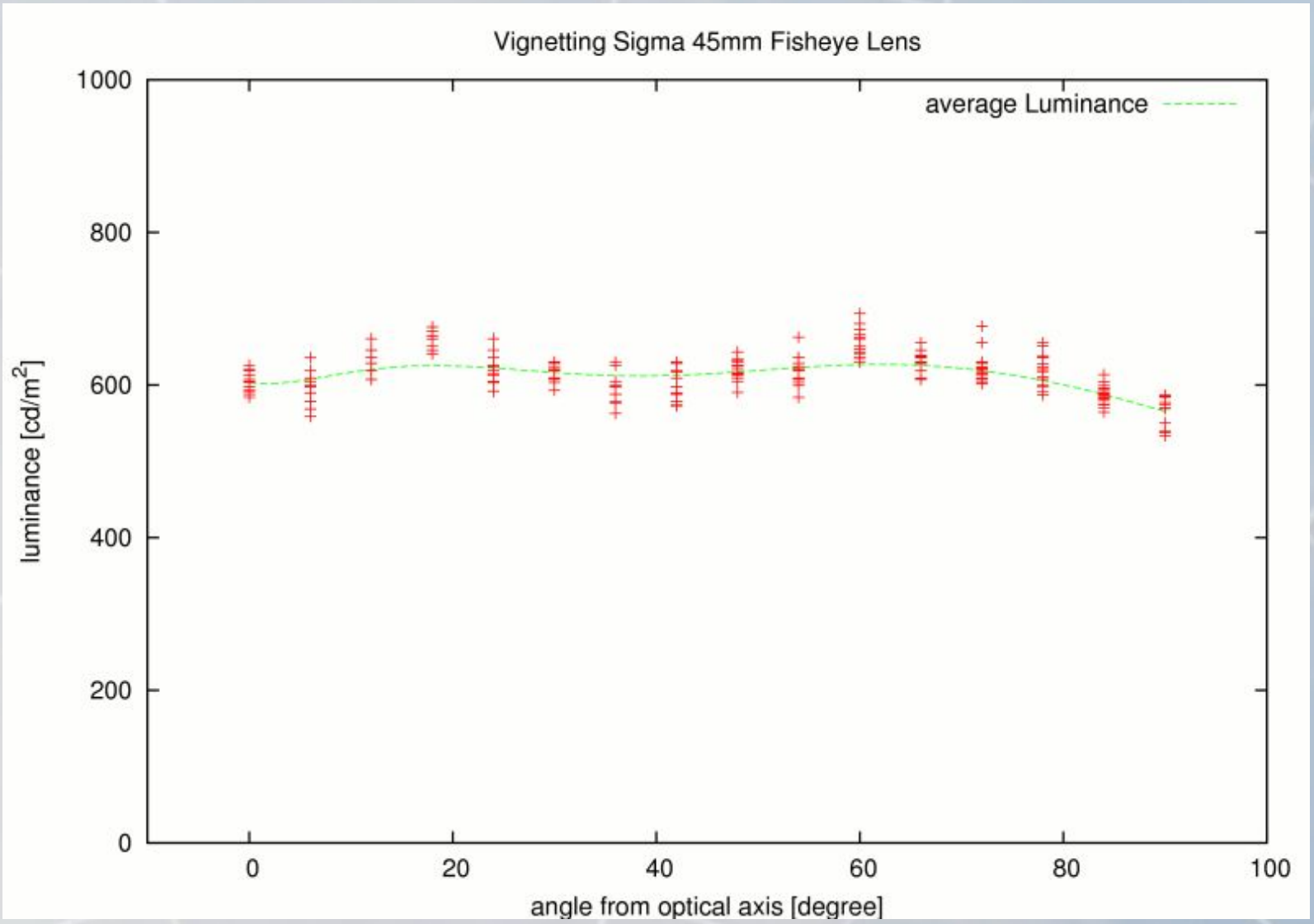
- *vsd_ldr2calib*: Create calibration data from a directory of JPGs.
- *vsd_ldr2hdr*: Assemble HDR image from a set of JPGs
- *vsd_hdr2patchlum*: Read out patch luminances from an HDR sky capture
- *vsd_csv2histogram*: Create histograms from given csv-files
- *vsd_image2graph3d*: Generate a 3d-chart showing sky luminance mapped to z-axis, including isolines
- *vsd_fit*: Calculate a set of polynomial approximations for a given set of values

Software

- Software will be published under an Open Source licence
- Expect a project web site in early 2009
- Possible integration with WebHDR



Vignetting



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Validation 1

- Minolta LS-100 mounted on a telescope

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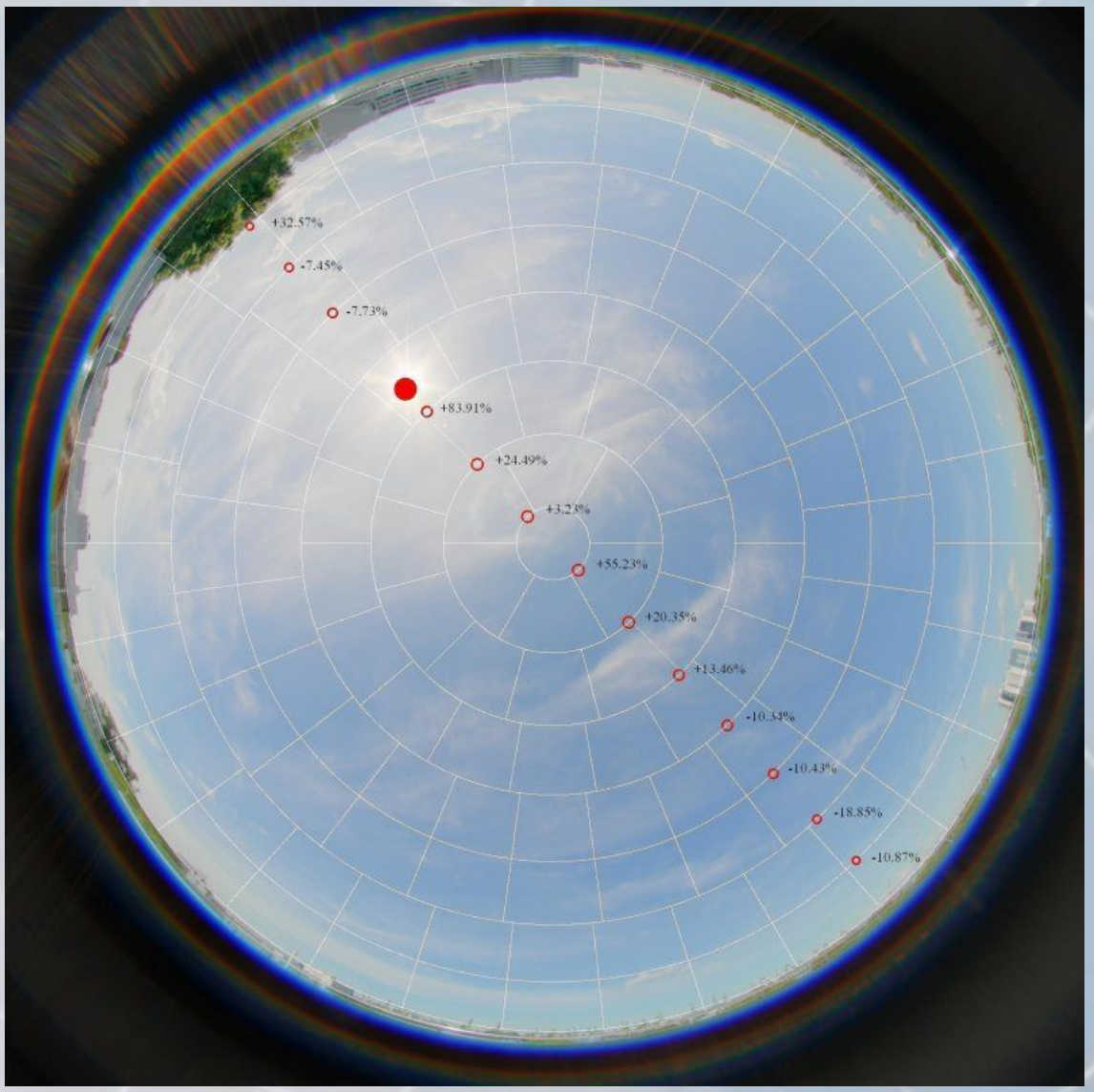
Accuracy 1

Average deviation of >15% without calibration



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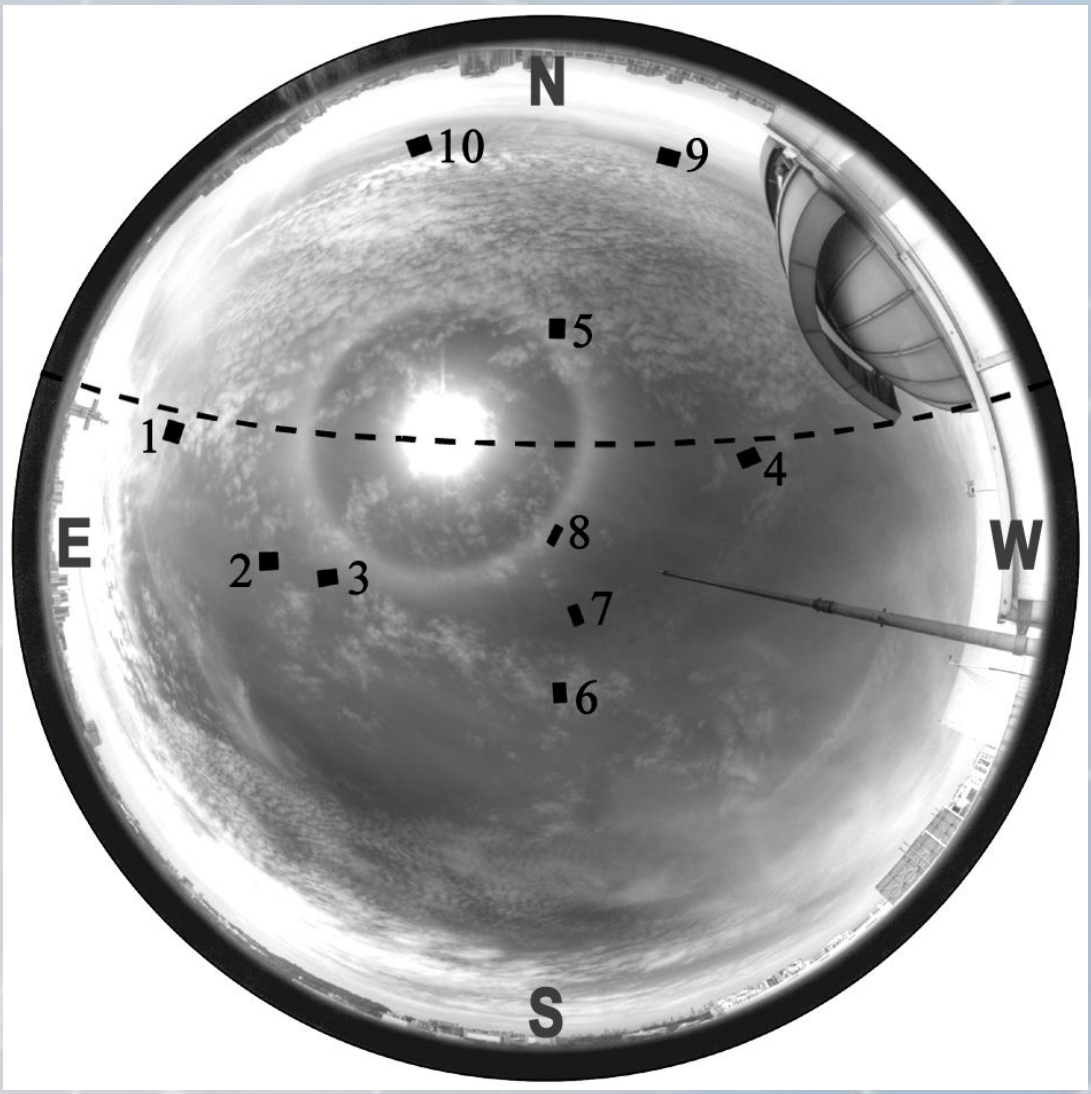
Calibration 1

- HDR of sky vault
- Dashed line shows sun path
- 10 randomly selected areas measured with LS-100 and compared to HDR
- Each box is 3x3 circular patches of 1º field of view



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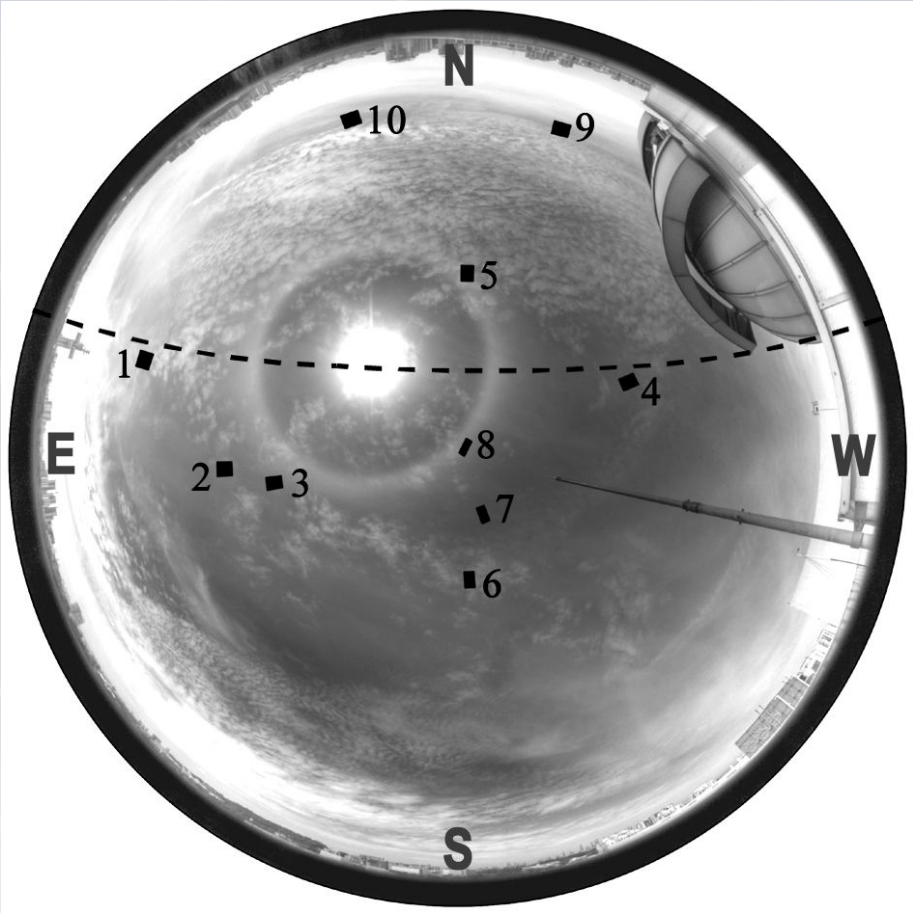
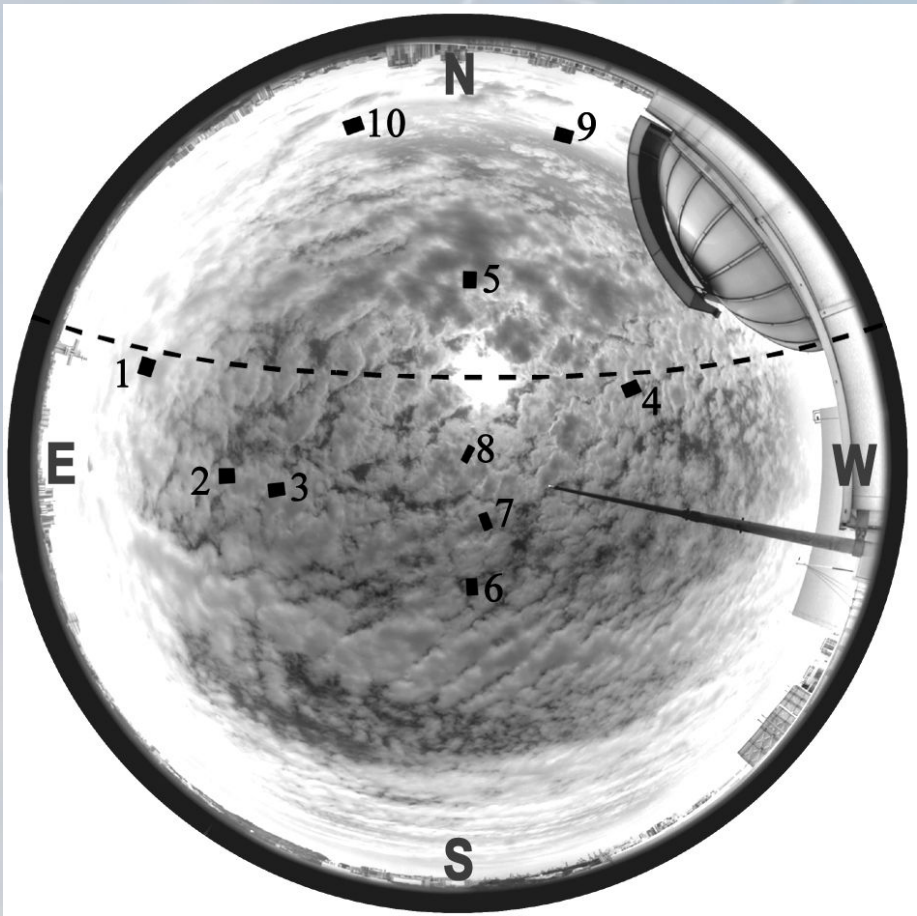
Calibration 2

Change of cloud cover over 90 minutes



Area 1: 12:01:40 on 28th July 2008



Area 10: 13:33:26 on 28th July 2008

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Accuracy 2

Average deviation of less than 5% after calibration

Area	Time	Sun Alt	Sun Azi	Meter Alt	Meter Azi	Meter (cd/m2)	HDR (cd/m2)	Error
1	12:05:38	66.1	41.4	21	73	10,690	10,045	6.0%
2	12:10:49	67.0	39.2	43	92	10,505	10,914	3.9%
3	12:17:27	68.0	36.1	52	97	16,443	16,572	0.8%
4	12:30:14	69.7	29.2	53	295	7,553	7,867	4.2%
5	12:38:16	70.6	24.3	53	359	10,953	10,805	1.4%
6	12:44:44	71.2	20.0	65	185	16,047	15,748	1.9%
7	12:55:45	72.0	12.1	78	201	19,535	19,051	2.5%
8	01:05:23	72.3	4.7	87	335	22,447	28,636	27.6%
9	01:22:24	72.2	351.5	18	344	12,570	11,854	5.7%
10	01:33:26	71.6	343.3	15	18	10,843	10,735	1.0%

Large error in circumsolar region

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Outdoors

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Future

- Investigate sky distribution in non-visible spectrum with FujiFilm FinePix S3 Pro UVIR DSLR
- Use HDR captures for image-based lighting in Radiance

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You!

- NUS is looking for visiting scholars to continue on this project. Monthly payment is SGD 2,000. The candidate must have knowledge in Radiance, programming, and lighting engineering. This exchange would ideally be within the framework of an existing PhD or Msc.
- Also: Coding of Radiance, ESP-r, EnergyPlus and Sketchup. Posts as Research Fellow, or within a PhD. Funding is available.

Shoulders of Giants

- HDR papers
  - Jessi Stumpfel et al
  - Mehlika Inanici
  - Greg Ward
  - Paul Debevec
  - Santiago Torres
  - Axel Jacobs
- Sky analysis papers
  - Kittler/Darula
  - Danny Li
  - Edward Ng
  - Stephen Wittkopf

Paper with all the gory details to follow in Solar Energy...


End
Thank you