x-hour Outdoor Photometric Stereo

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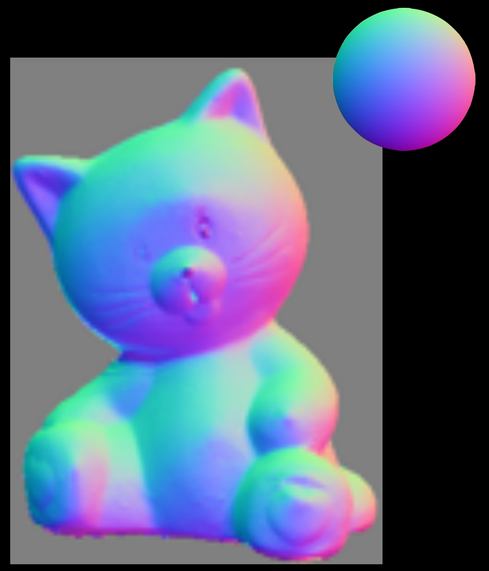
Photometric Stereo

Images of object under
different light directions (point sources)

…

Surface normals



+ albedo
(unlit color)

Images: Neel Joshi, Ira Kemelmacher, Ian Simon (CSE 455, Winter 2010)

PS - point light sources

pixel intensity

light direction

scaled surface normal

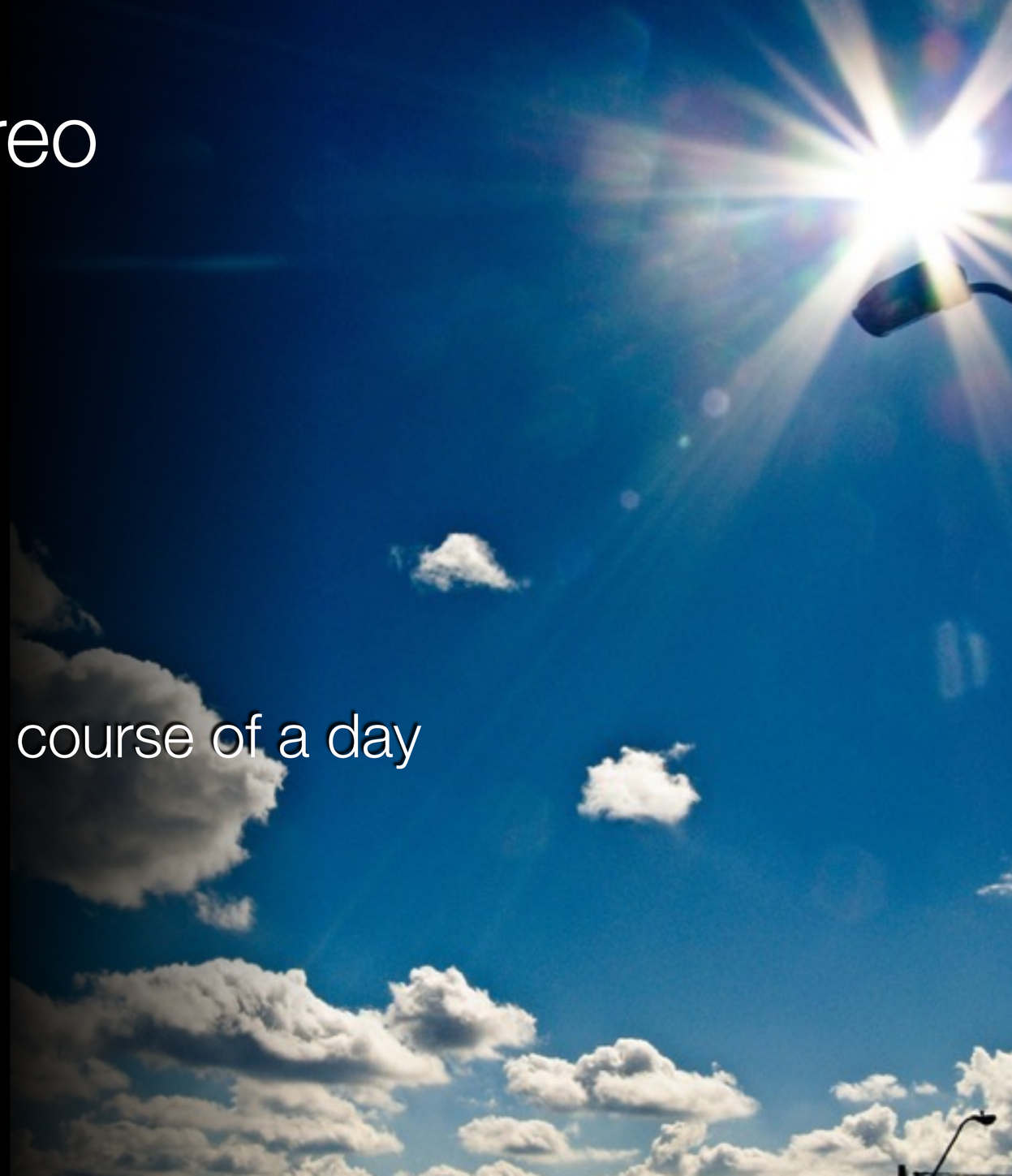
$$b_j = \mathbf{l}_j^T \mathbf{n}$$

$$\mathbf{b} = \begin{bmatrix} b_1 \\ b_2 \\ \cdots \\ b_m \end{bmatrix} = \begin{bmatrix} \mathbf{l}_1^T \\ \mathbf{l}_2^T \\ \cdots \\ \mathbf{l}_m^T \end{bmatrix} \mathbf{n} = L\mathbf{n}$$

Must be rank 3!

Outdoor Photometric Stereo

- Cannot control the sun!
- Sun moves on a plane during the course of a day



Solution #1

Months

[Abrams et al., ECCV'12]

[Ackermann et al., CVPR'12]

Solution #2

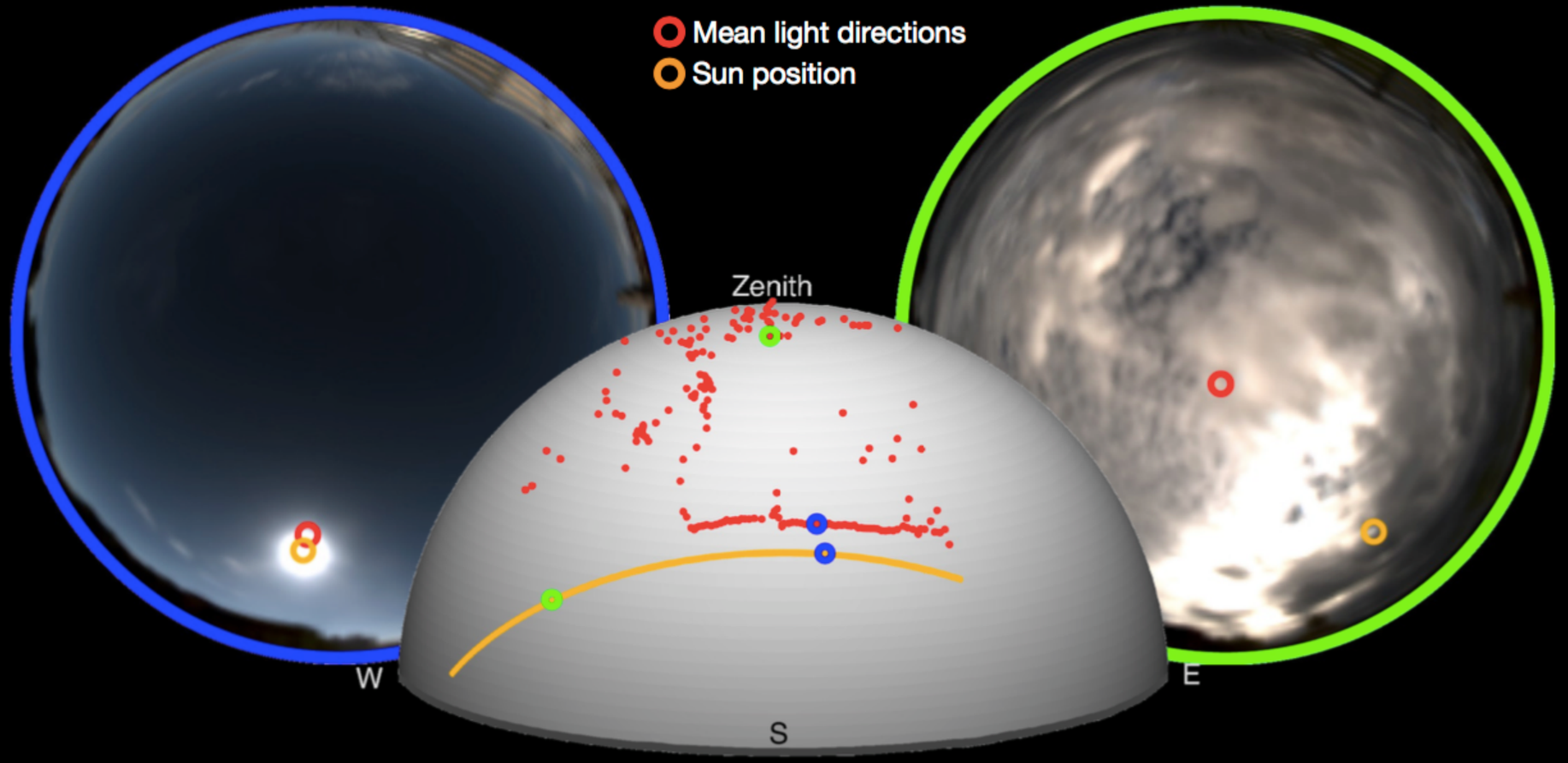
~~Months~~
Day

Yu et al., ICCP'13

Jung et al., CVPR'15

Solution #2

~~Months~~
Which day?



Hold-Geoffroy et al., ICCP'15

~~Months~~

~~Day~~

Hour(s) ?

Perform PS on small time intervals

1. Why does outdoor PS work?

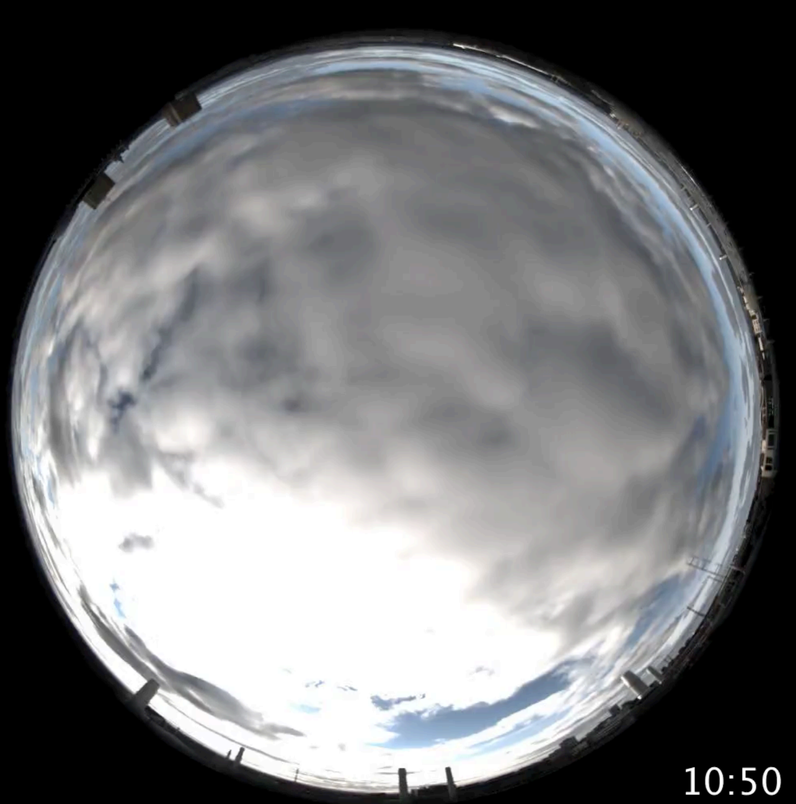
2. Can it work in x hours? ($x \leq 6$)

Environment maps

08/24/2013
light clouds
85% sun visibility

11/06/2013
mixed
41% sun visibility

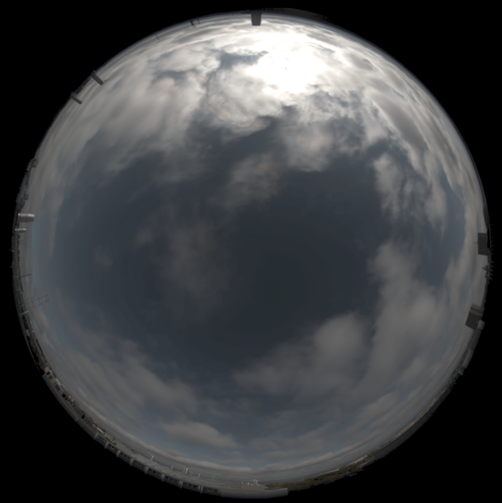
11/08/2014
overcast
16% sun visibility



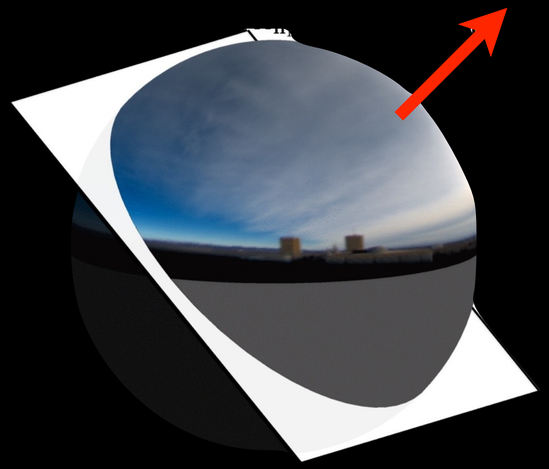
Online database: hdrdb.com

What are we going to see?

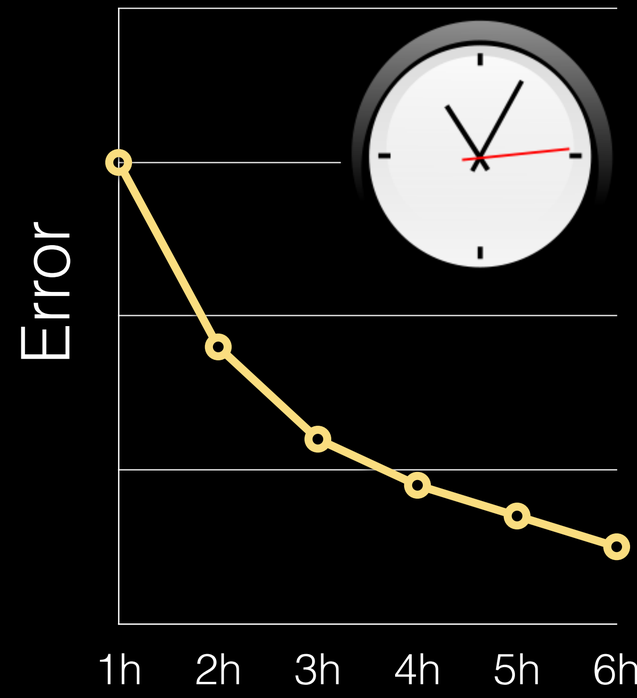
Environment maps



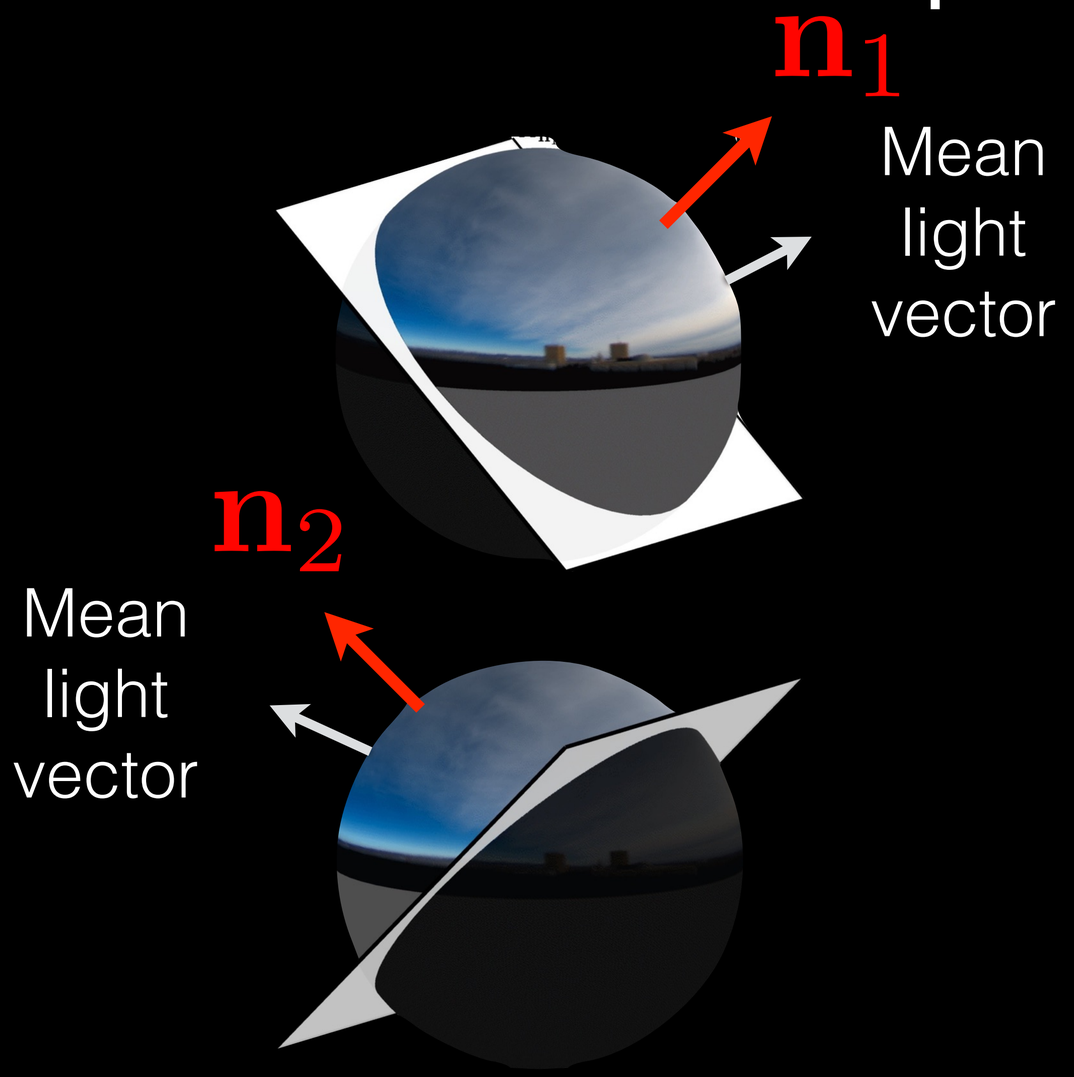
Lighting model



Fine grained analysis



PS - environment map lighting



Key points about MLVs

- An MLV is a virtual point light
- But, it depends on the surface normal

Point light source

$$\mathbf{b} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_T \end{bmatrix} = \begin{bmatrix} \mathbf{l}_1^T \\ \mathbf{l}_2^T \\ \vdots \\ \mathbf{l}_T^T \end{bmatrix} \mathbf{x} = \mathbf{L}\mathbf{x}$$

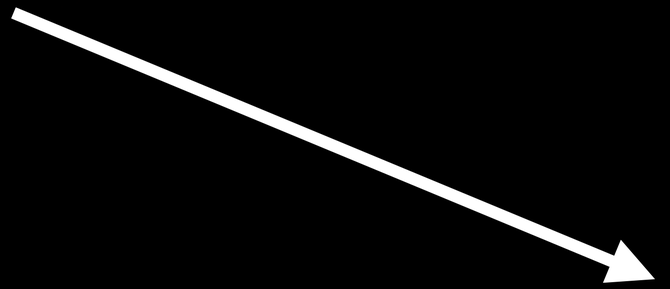
Matrix of **light directions**

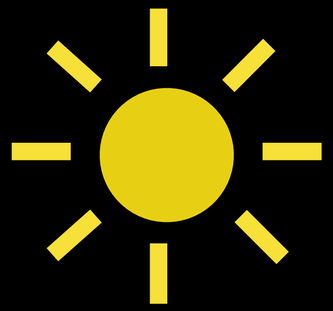
Environment map

$$\mathbf{b} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_T \end{bmatrix} = \begin{bmatrix} \overline{\mathbf{l}}_1^T \\ \overline{\mathbf{l}}_2^T \\ \vdots \\ \overline{\mathbf{l}}_T^T \end{bmatrix} \mathbf{x} = \mathbf{L}\mathbf{x}$$

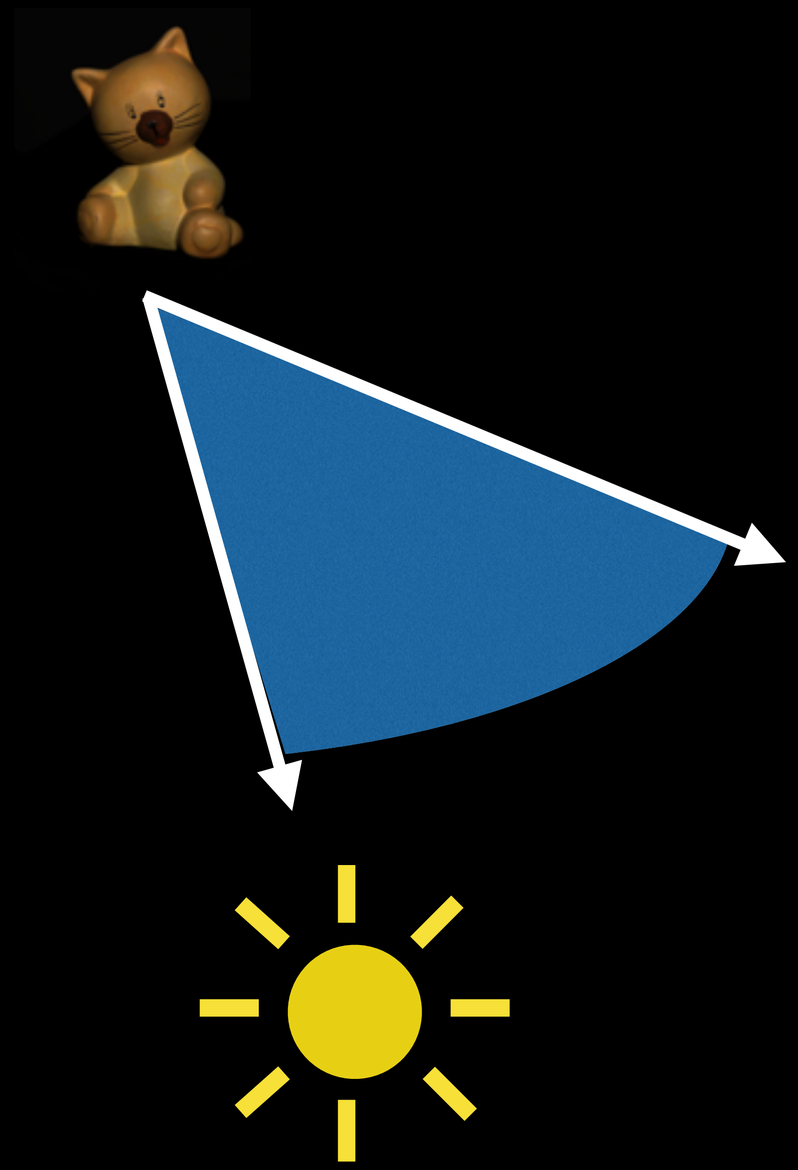
Matrix of **mean light vectors**

Mean Light Vector shifts - sunny day

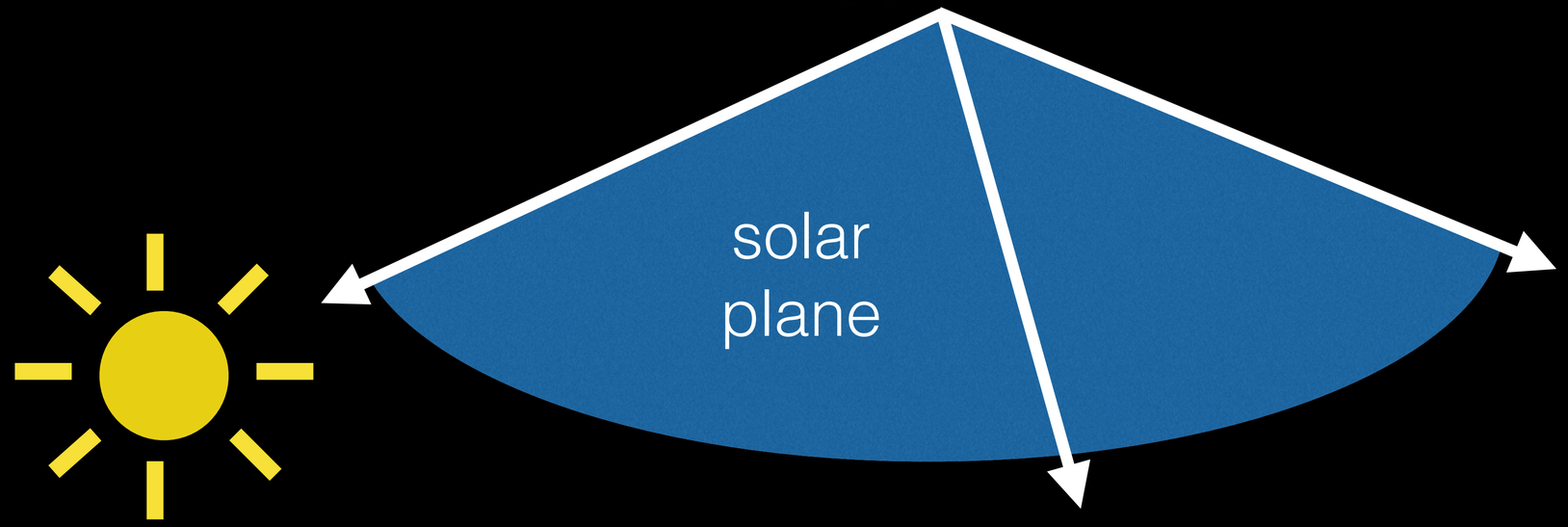




Mean Light Vector shifts - sunny day

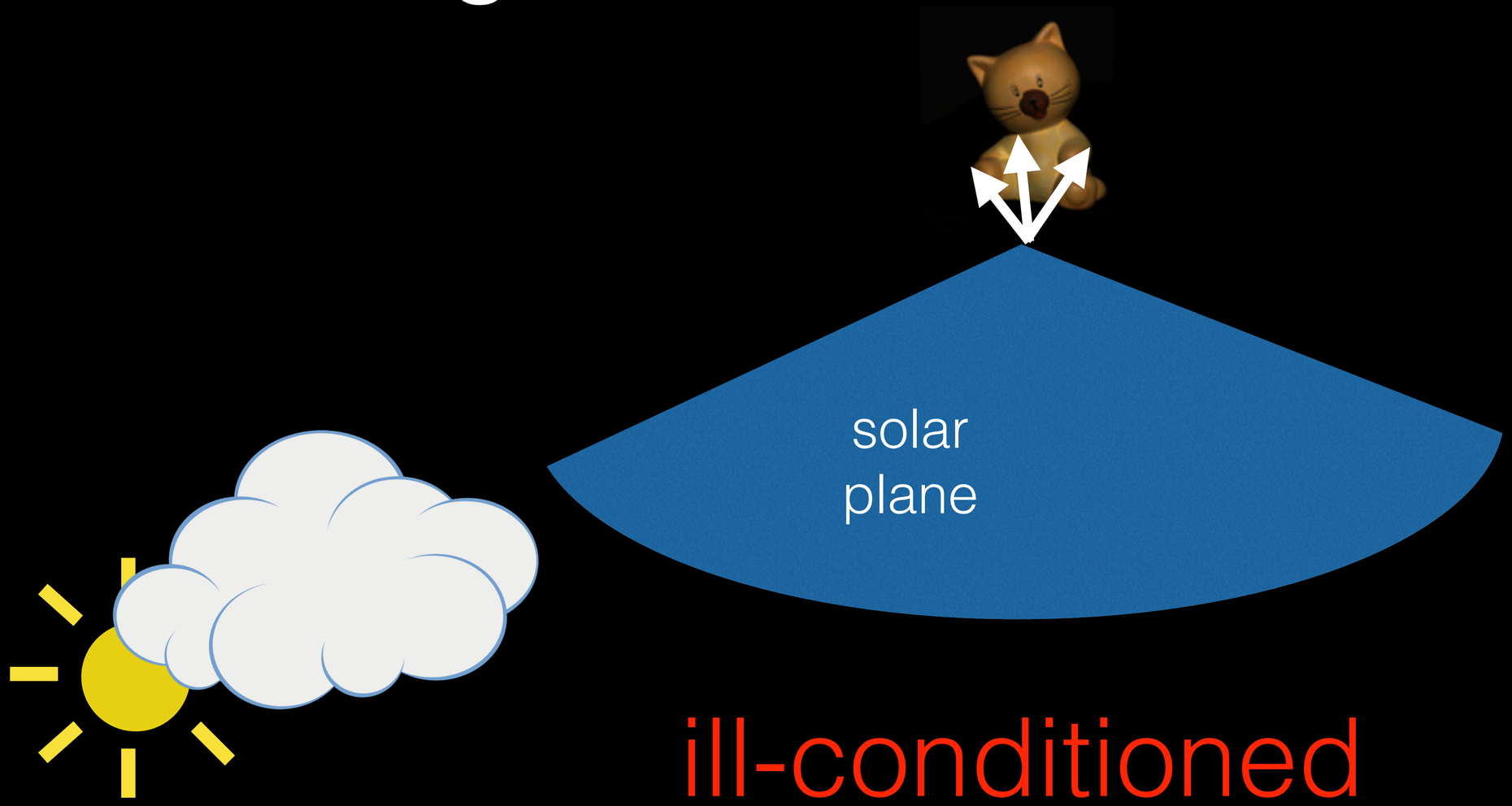


Mean Light Vector shifts



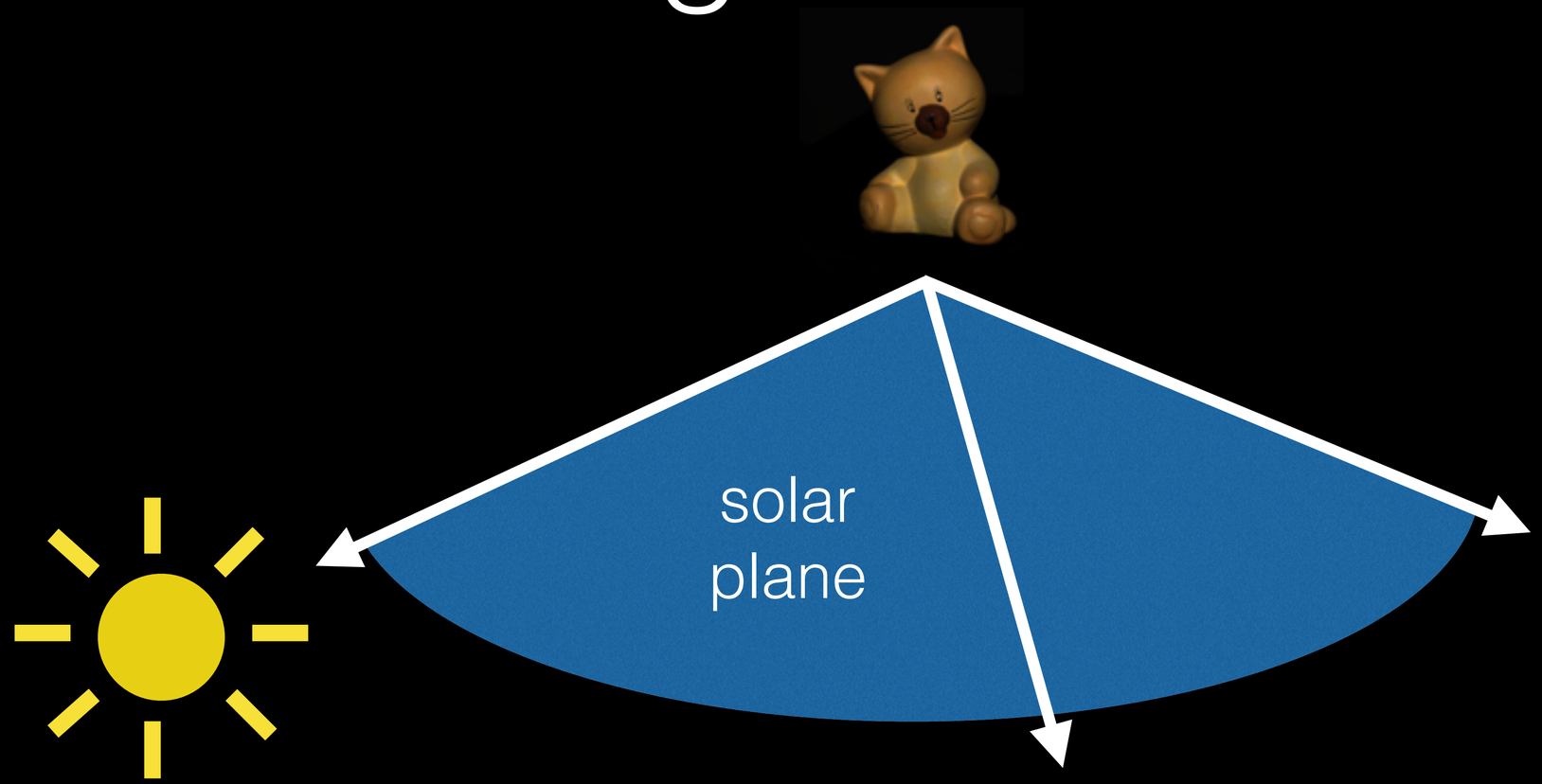
ill-conditioned

Mean Light Vector shifts - overcast day



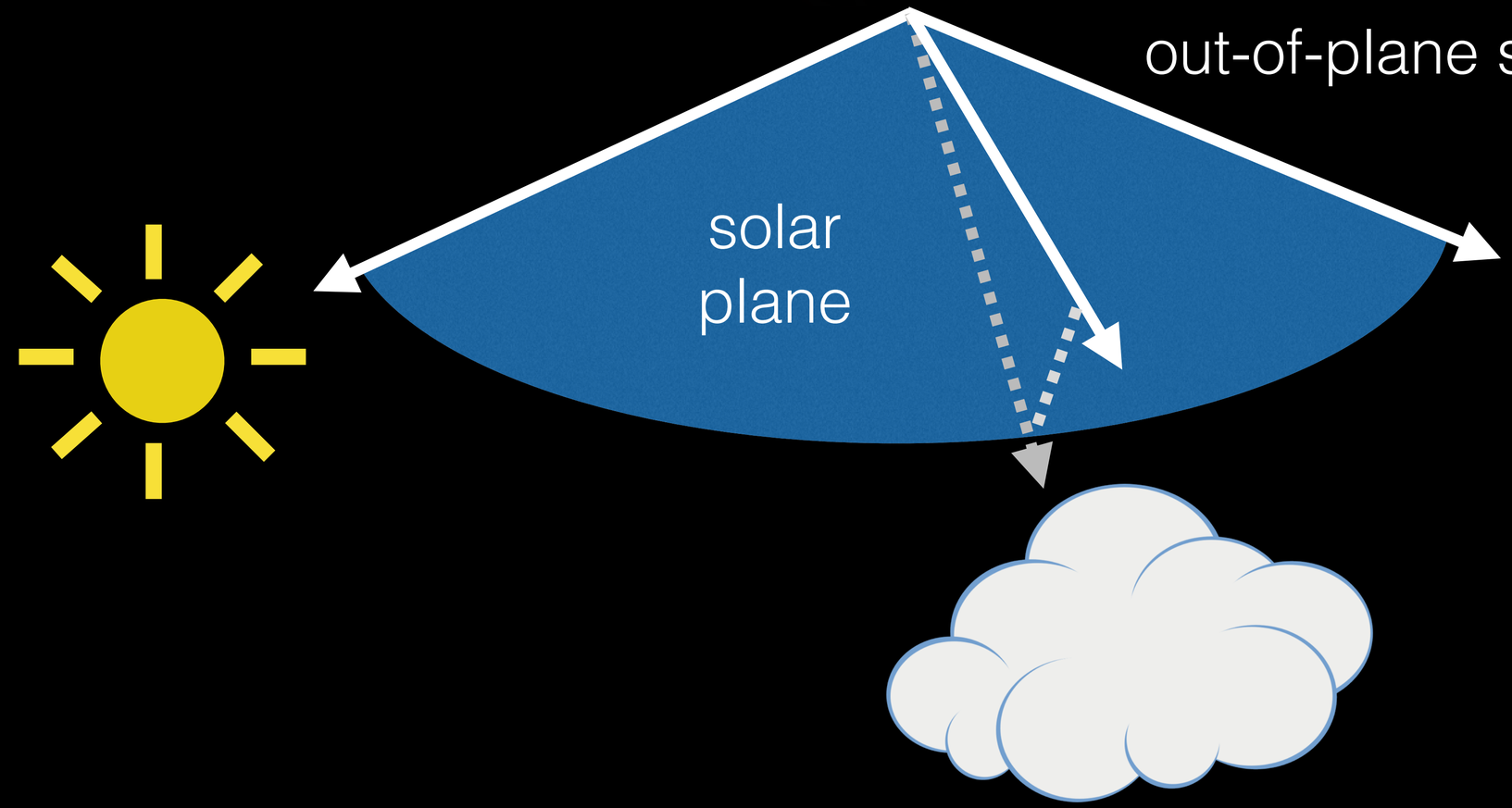
ill-conditioned

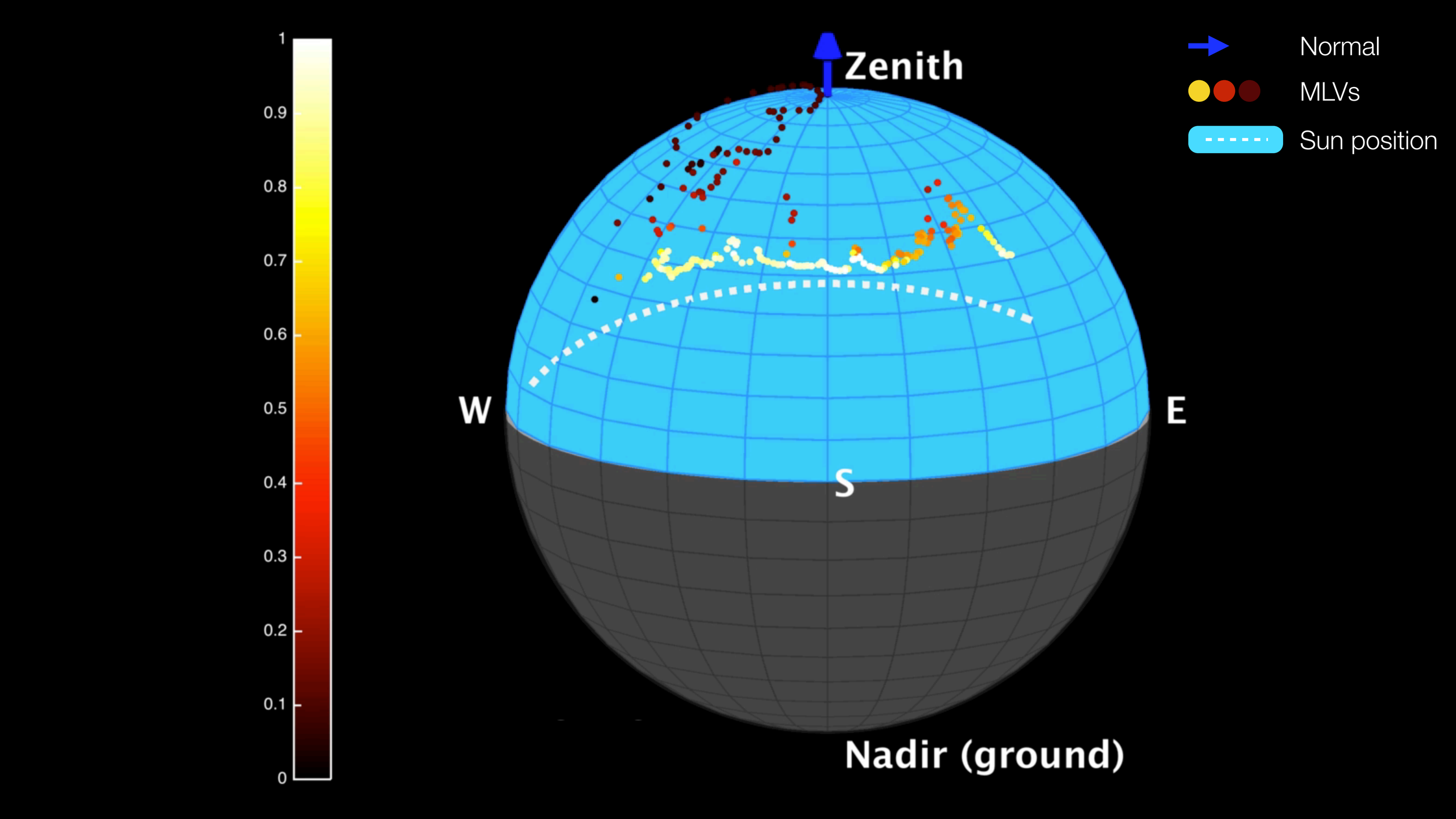
Mean Light Vector shifts

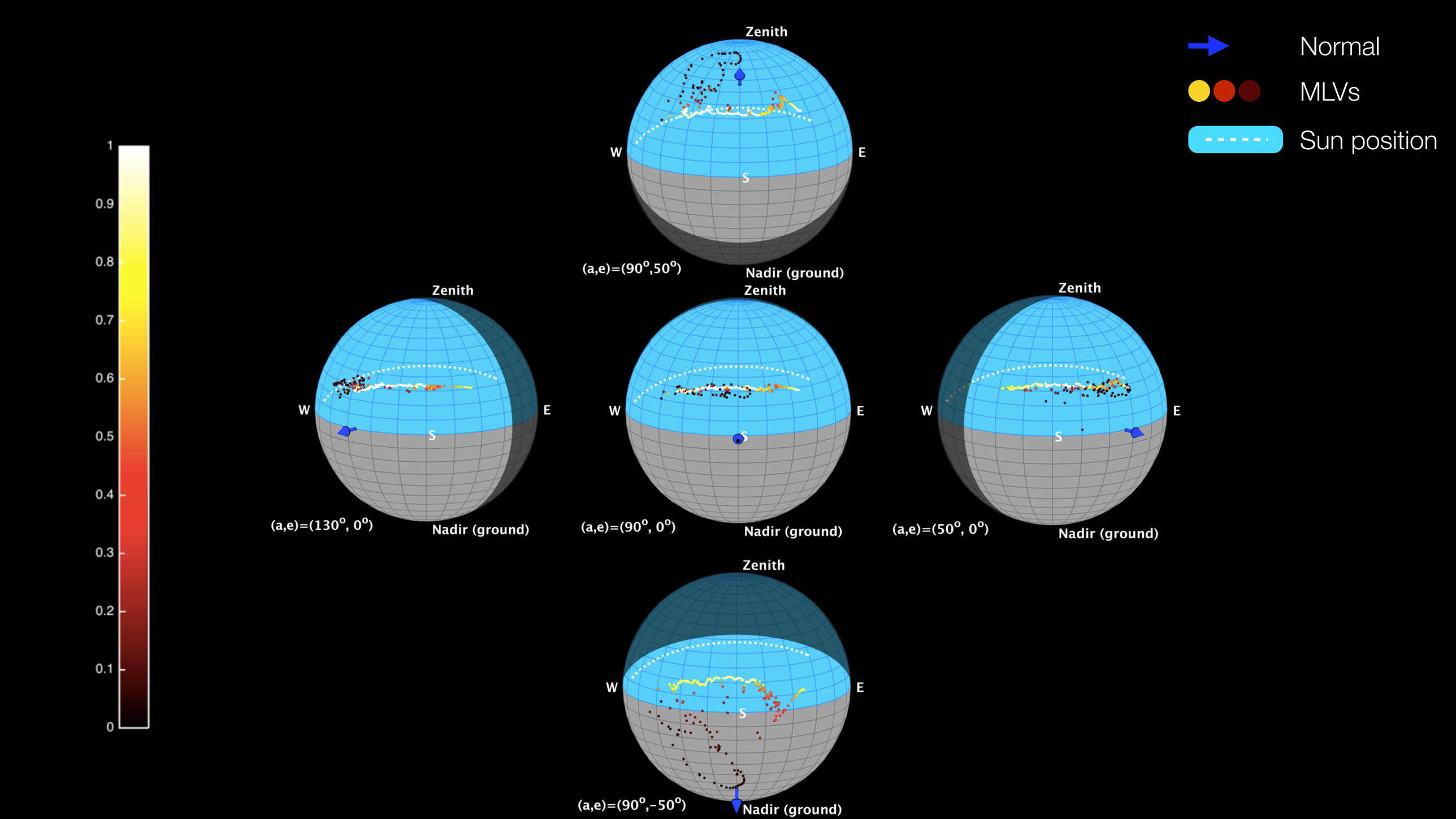


Mean Light Vector shifts - partly cloudy day

Better behaved



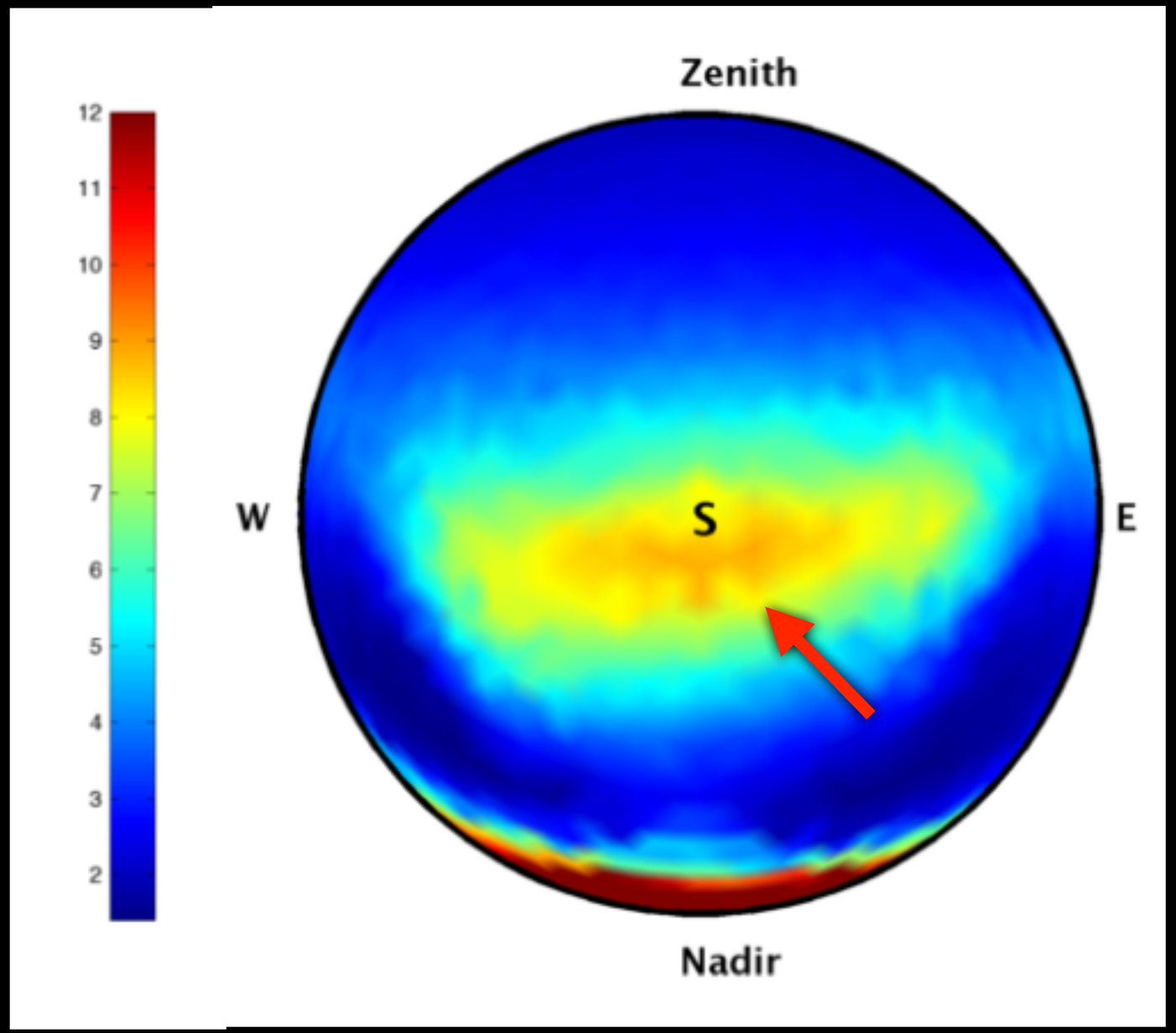

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Zenith
W
E
S
Nadir (ground)
Normal
MLVs
Sun position


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Normal
MLVs
Sun position
Zenith
W
E
S
(a,e)=(90°,50°)
Nadir (ground)
Zenith
W
E
S
(a,e)=(130°, 0°)
Nadir (ground)
Zenith
W
E
S
(a,e)=(90°, 0°)
Nadir (ground)
Zenith
W
E
S
(a,e)=(50°, 0°)
Nadir (ground)
Zenith
W
E
S
(a,e)=(90°,-50°)
Nadir (ground)

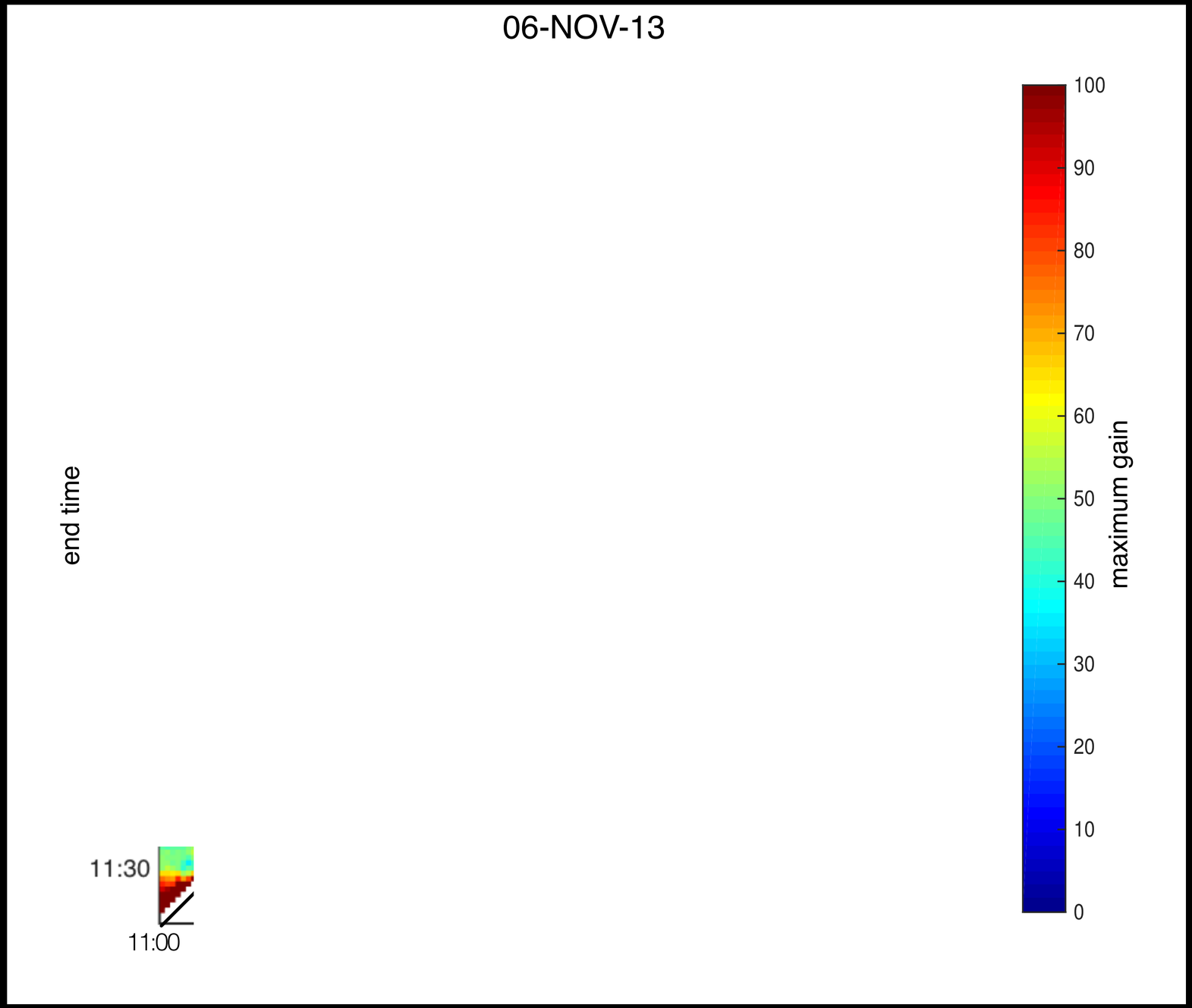
Measure: maximum uncertainty

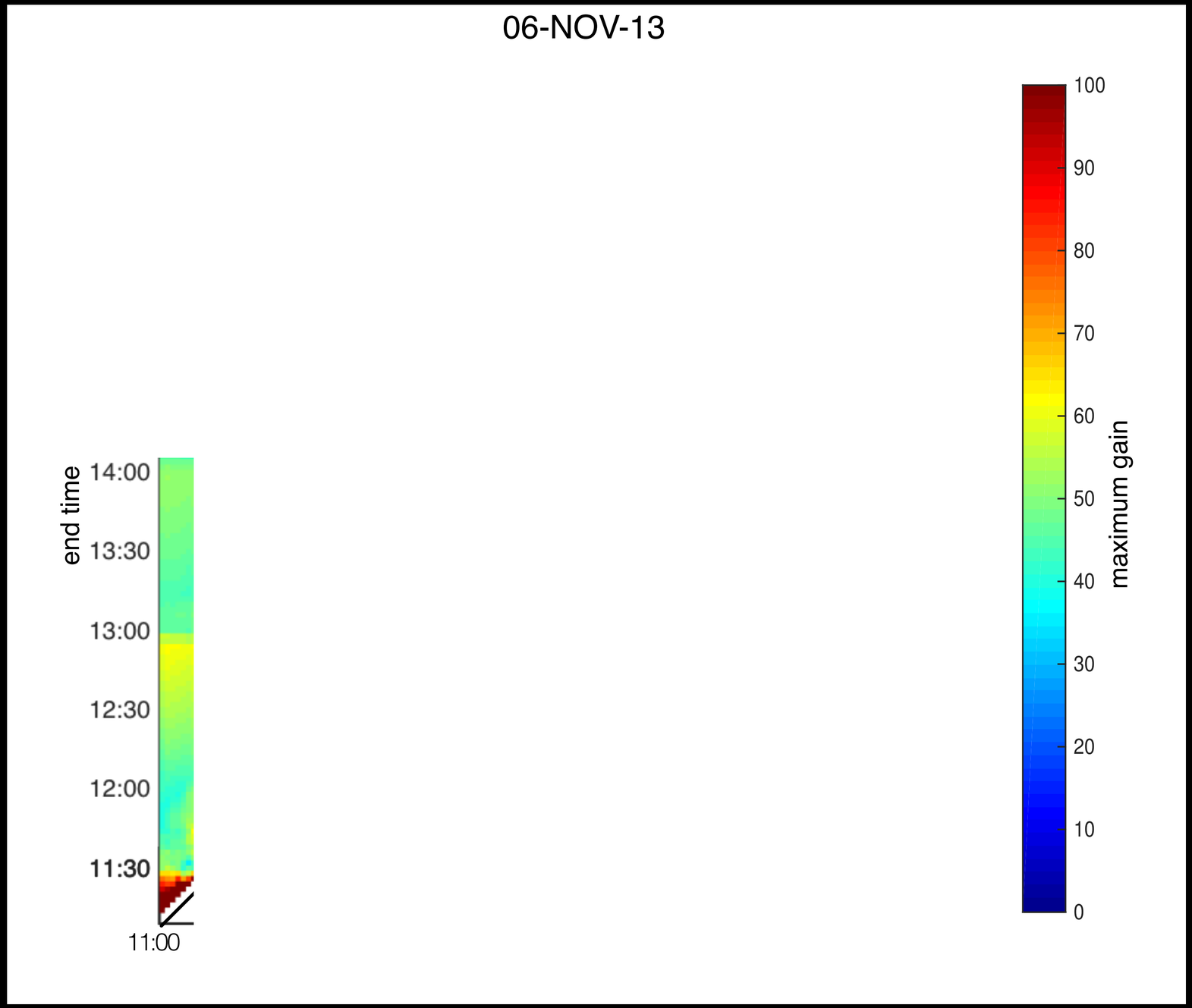
$$L = \begin{bmatrix} \bar{\mathbf{l}}_1^T \\ \bar{\mathbf{l}}_2^T \\ \dots \\ \bar{\mathbf{l}}_m^T \end{bmatrix}$$

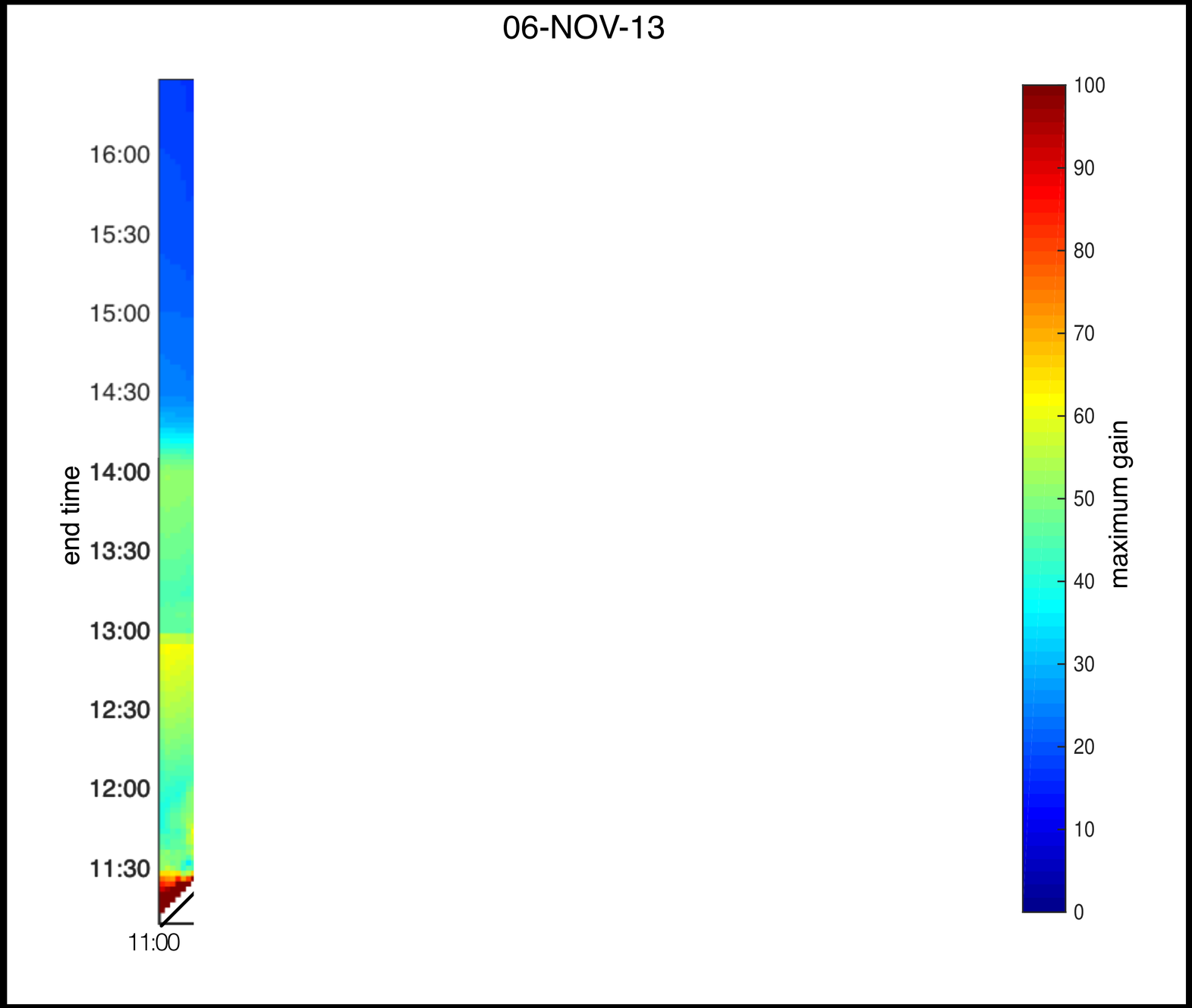
Uncertainty is higher for nearly horizontal normals

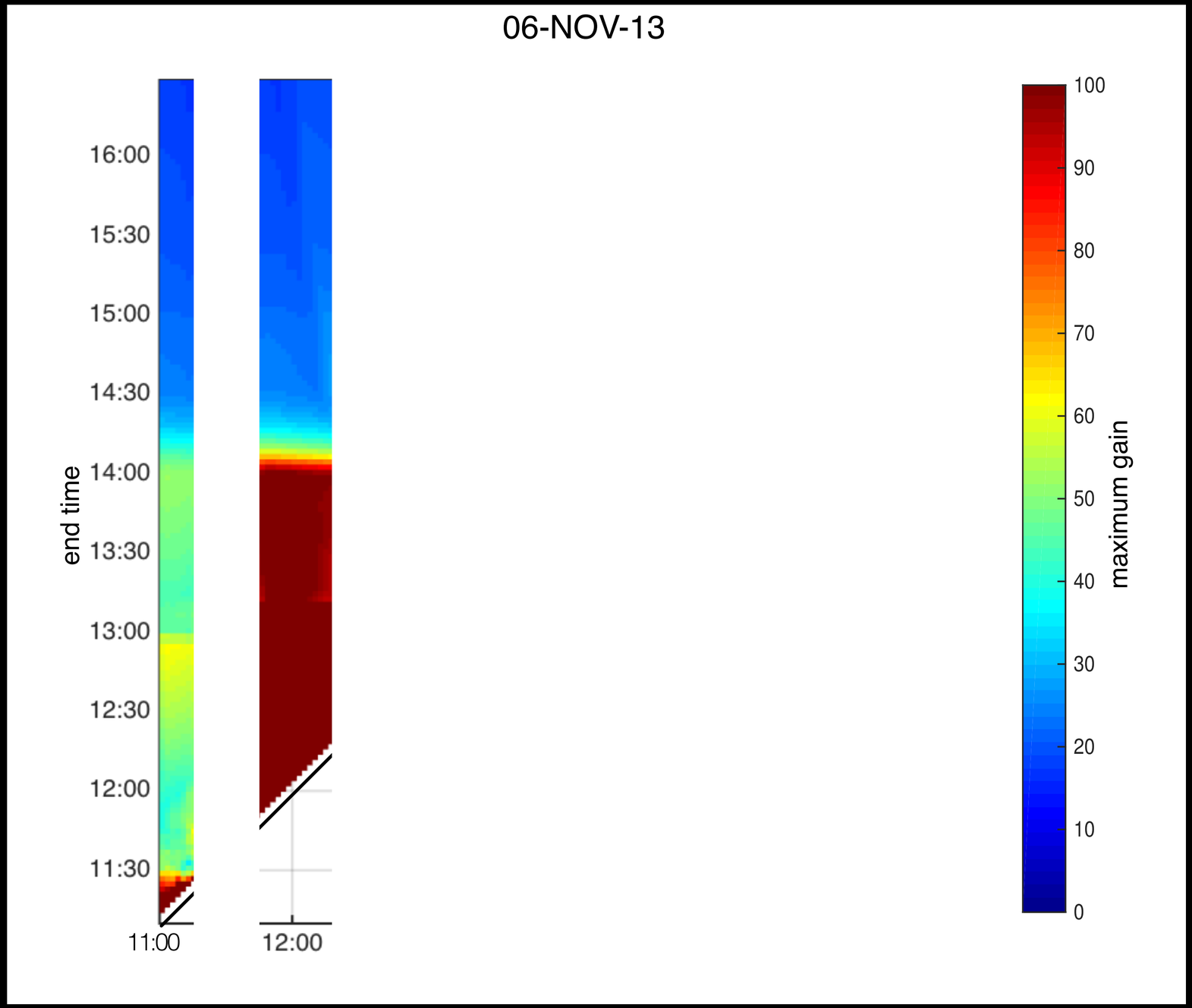


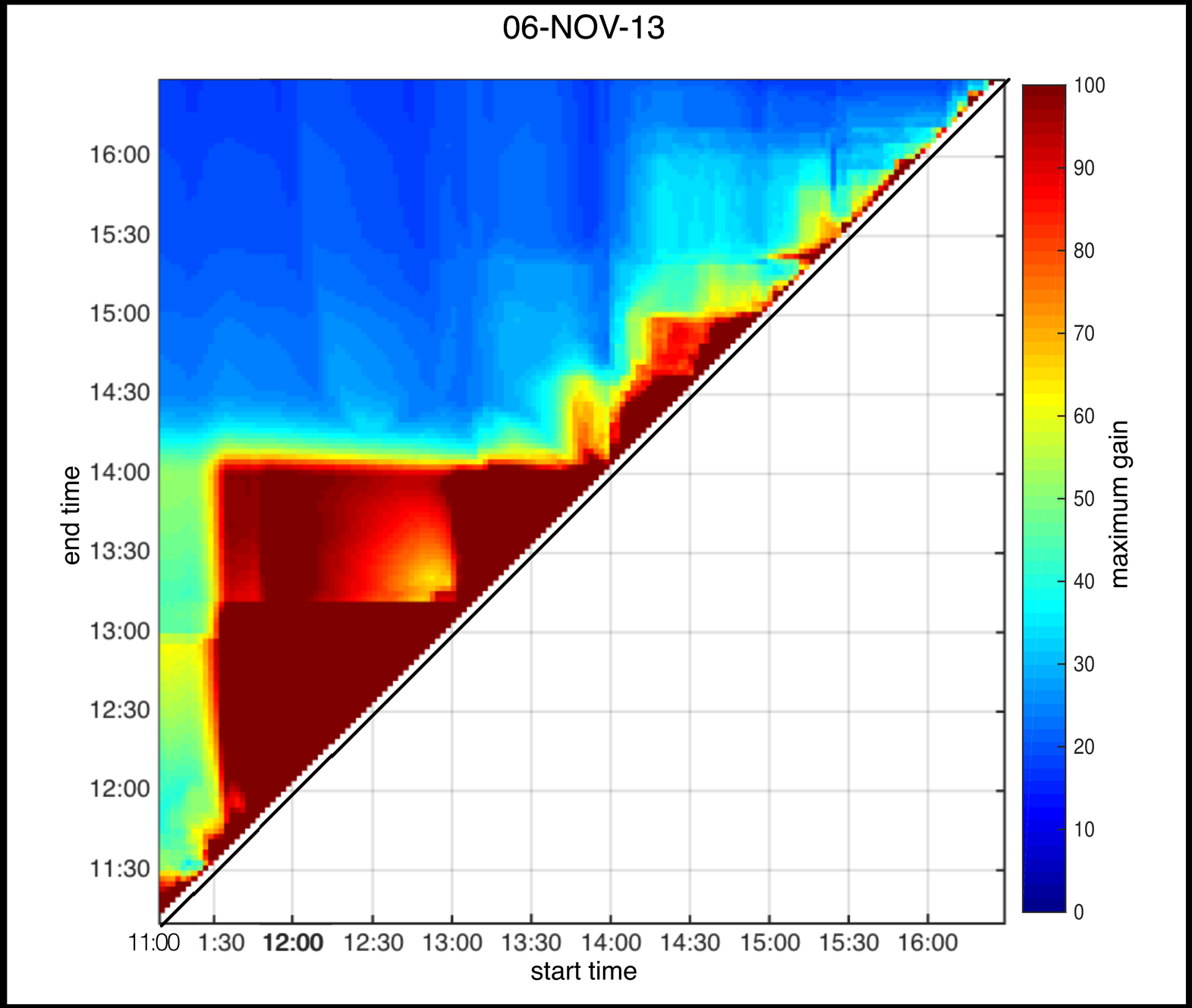
Is MLV shifting observable within x hours?

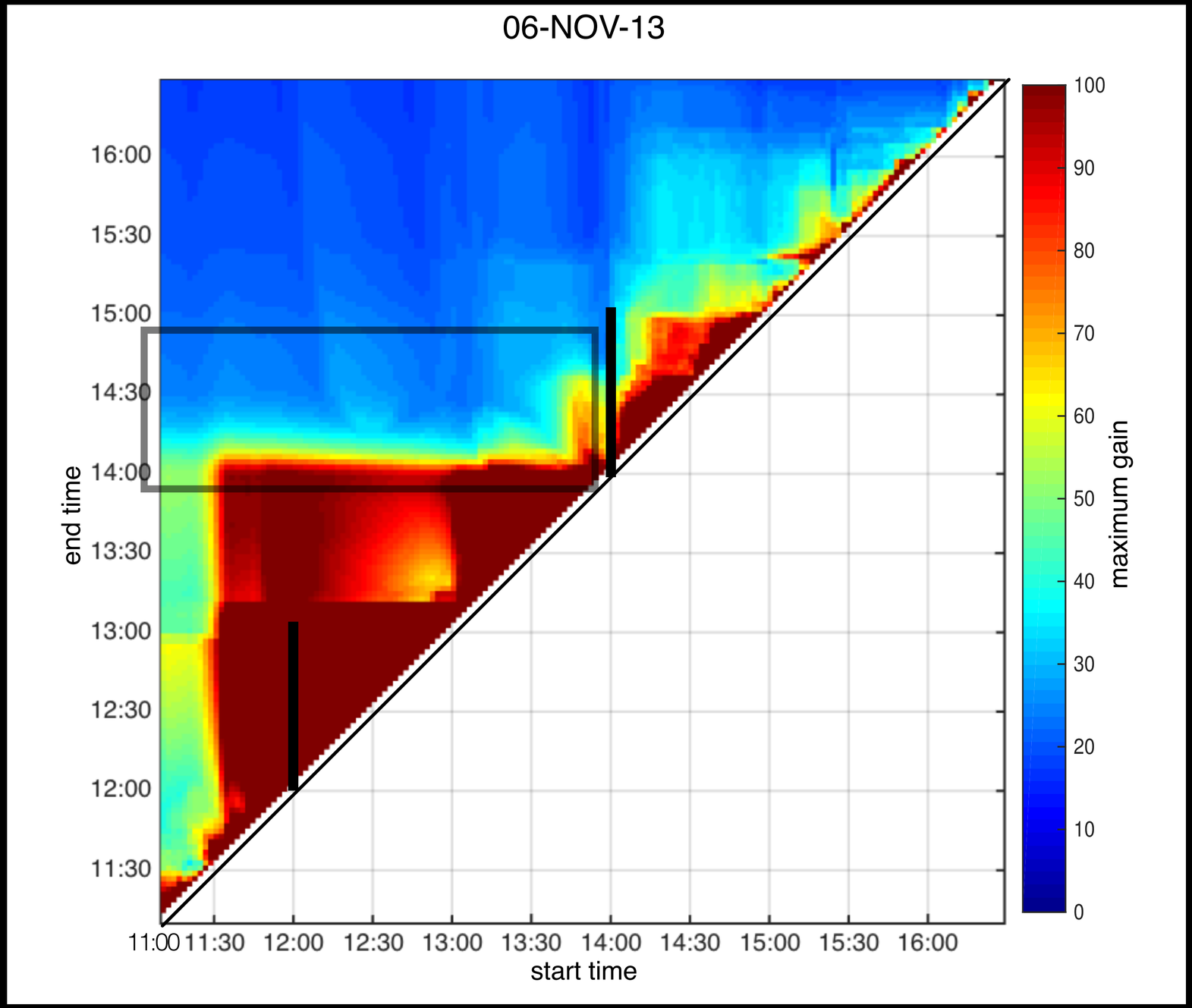

06-NOV-13
end time
11:30
11:00
maximum gain
100
90
80
70
60
50
40
30
20
10
0

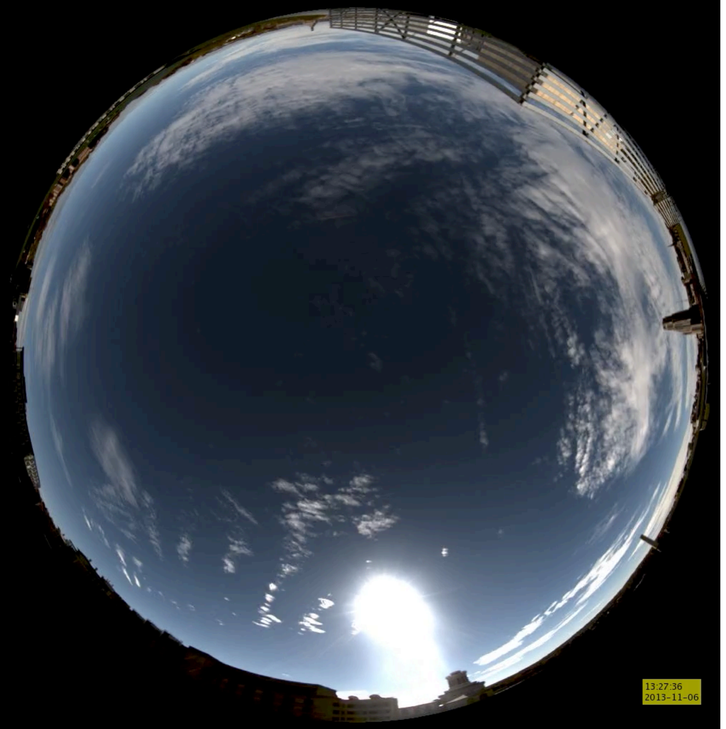

06-NOV-13
end time
14:00
13:30
13:00
12:30
12:00
11:30
11:00
maximum gain
100
90
80
70
60
50
40
30
20
10
0

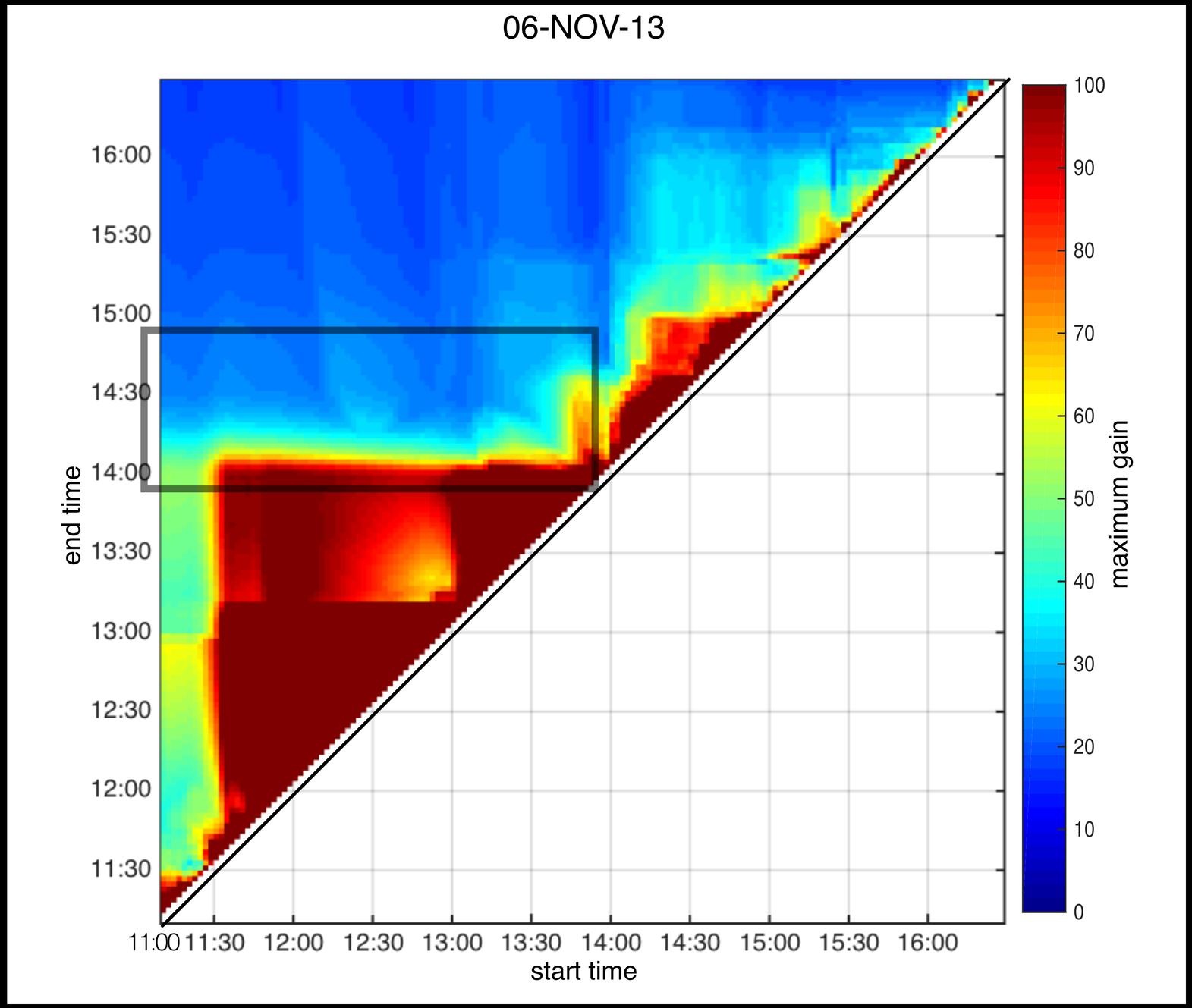

06-NOV-13
end time
16:00
15:30
15:00
14:30
14:00
13:30
13:00
12:30
12:00
11:30
11:00
maximum gain
100
90
80
70
60
50
40
30
20
10
0

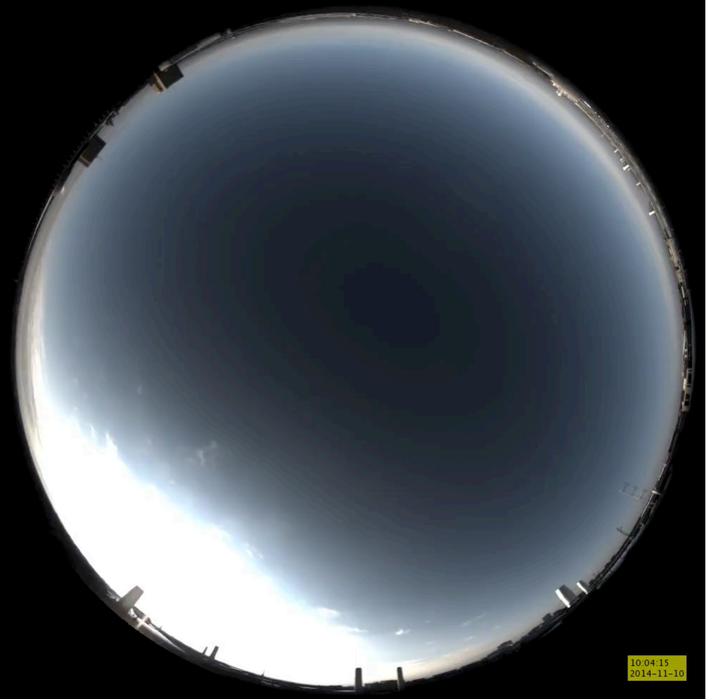

06-NOV-13
end time
16:00
15:30
15:00
14:30
14:00
13:30
13:00
12:30
12:00
11:30
11:00
12:00
maximum gain
100
90
80
70
60
50
40
30
20
10
0

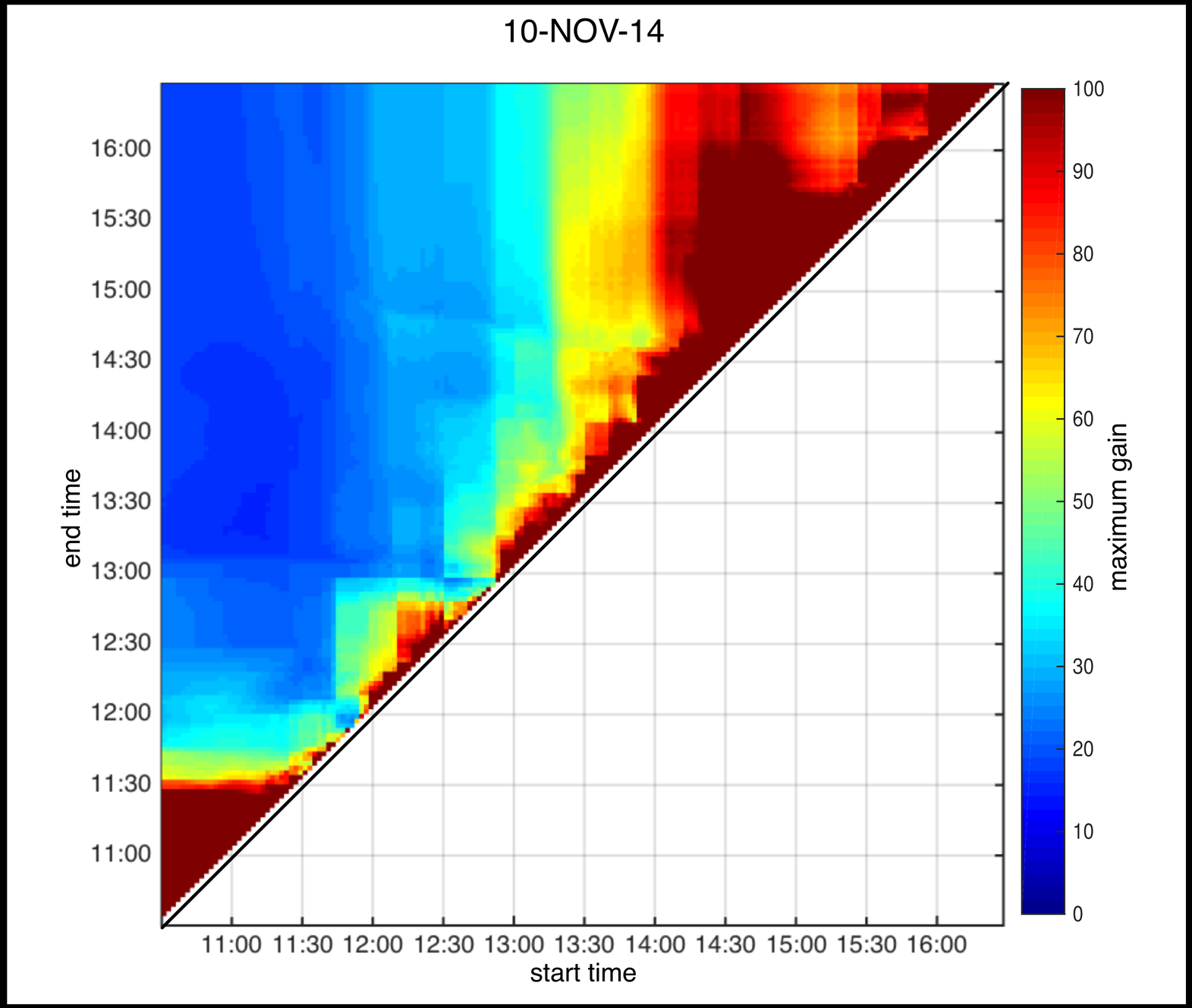

06-NOV-13
end time
16:00
15:30
15:00
14:30
14:00
13:30
13:00
12:30
12:00
11:30
11:00
1:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
start time
maximum gain
100
90
80
70
60
50
40
30
20
10
0

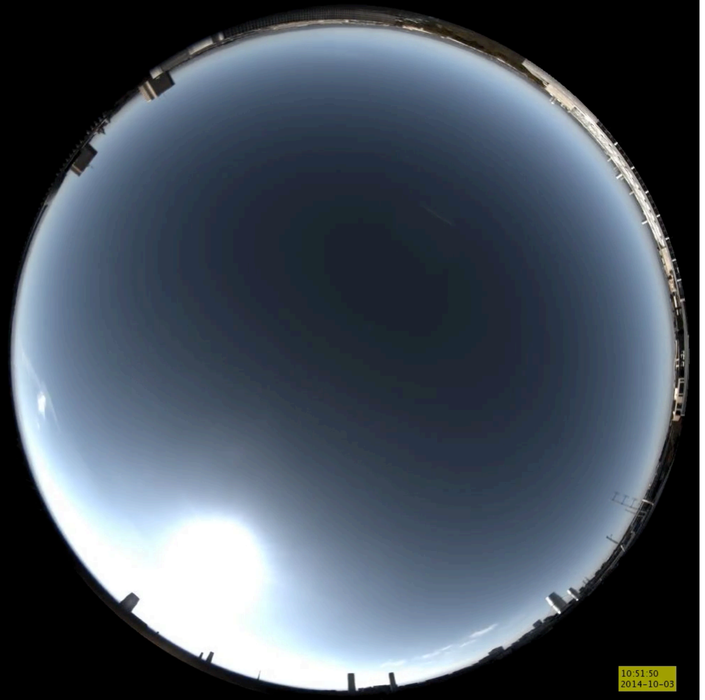

06-NOV-13
16:00
15:30
15:00
14:30
14:00
13:30
13:00
12:30
12:00
11:30
end time
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
start time
100
90
80
70
60
50
40
30
20
10
0
maximum gain

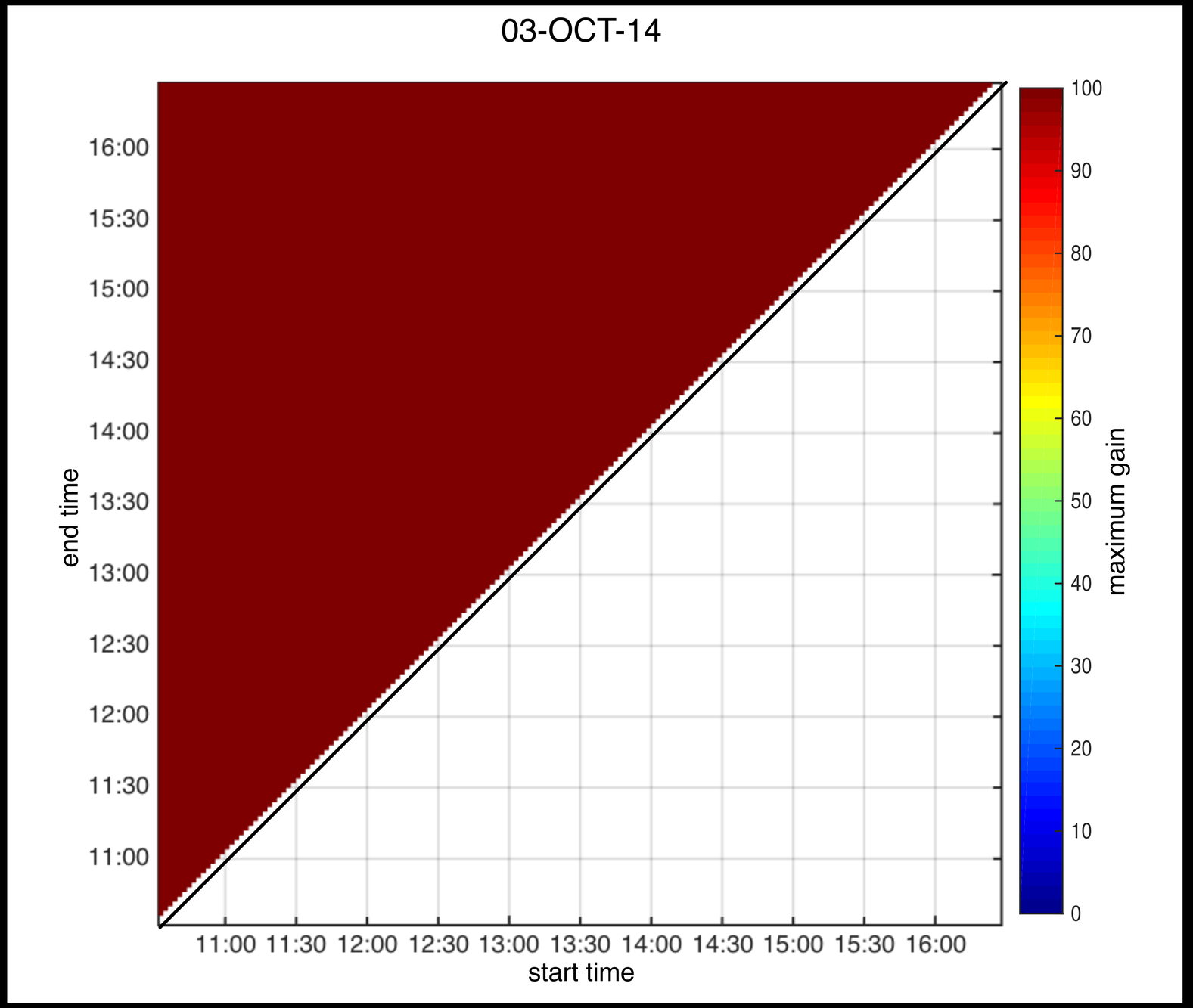

13:27:36
2013-11-06


06-NOV-13
end time
16:00
15:30
15:00
14:30
14:00
13:30
13:00
12:30
12:00
11:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
start time
maximum gain
100
90
80
70
60
50
40
30
20
10
0


10:04:15
2014-11-10


10-NOV-14
end time
16:00
15:30
15:00
14:30
14:00
13:30
13:00
12:30
12:00
11:30
11:00
start time
11:00 11:30 12:00 12:30 13:00 13:30 14:00 14:30 15:00 15:30 16:00
maximum gain
100
90
80
70
60
50
40
30
20
10
0


10:51:50
2014-10-03

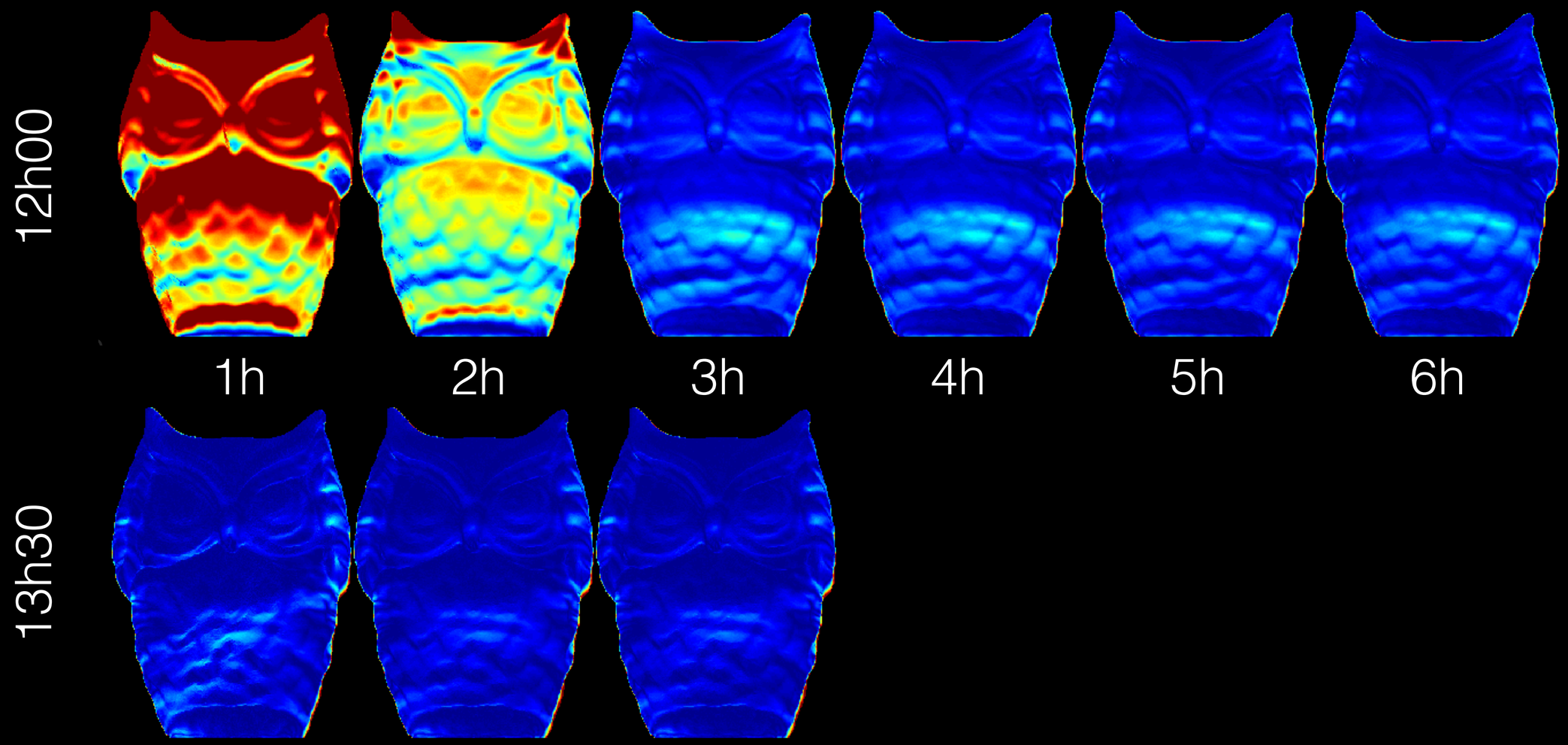

03-OCT-14
end time
16:00
15:30
15:00
14:30
14:00
13:30
13:00
12:30
12:00
11:30
11:00
start time
11:00 11:30 12:00 12:30 13:00 13:30 14:00 14:30 15:00 15:30 16:00
maximum gain
100
90
80
70
60
50
40
30
20
10
0

How often does it happen?

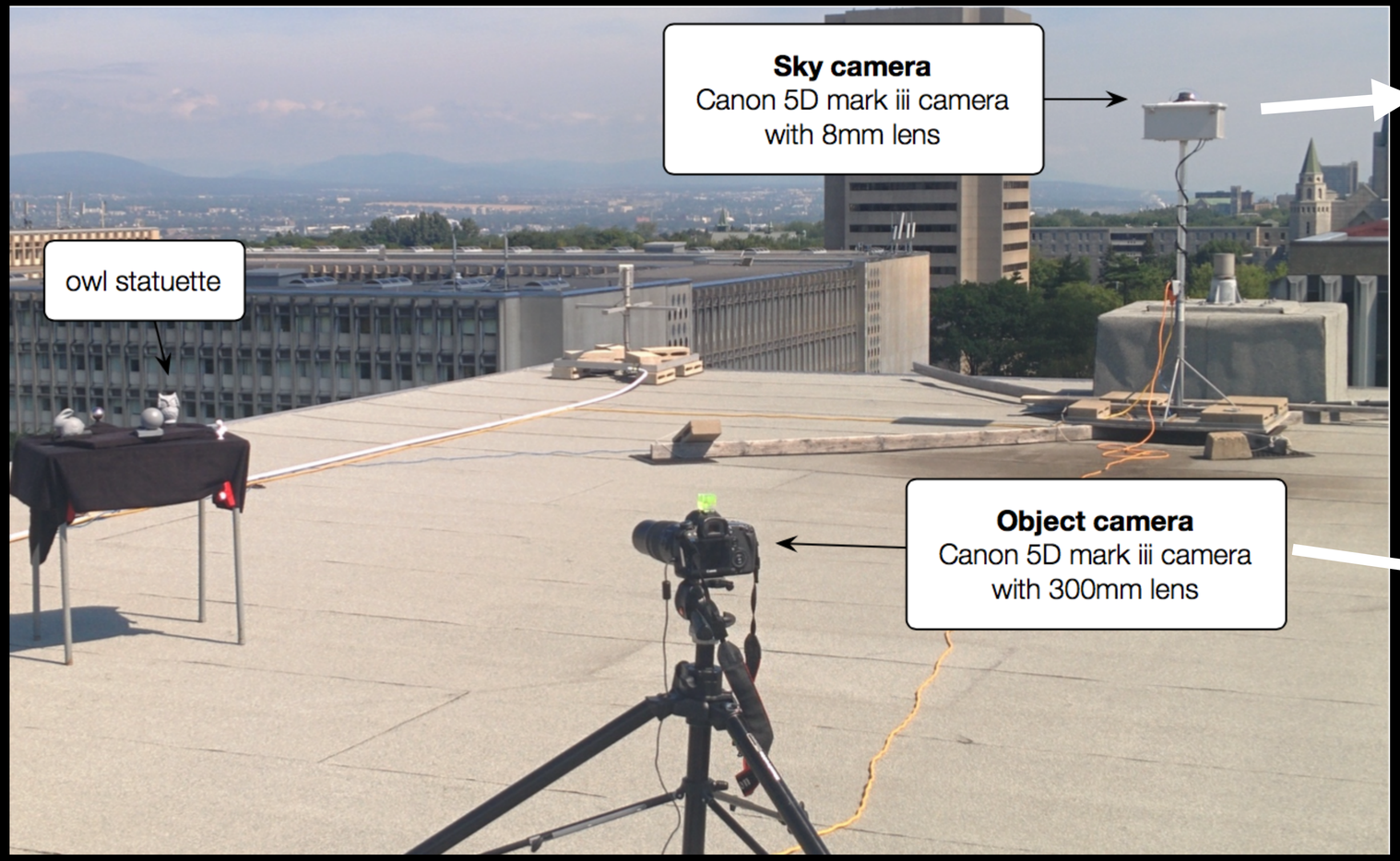
50% half days < 2x full day

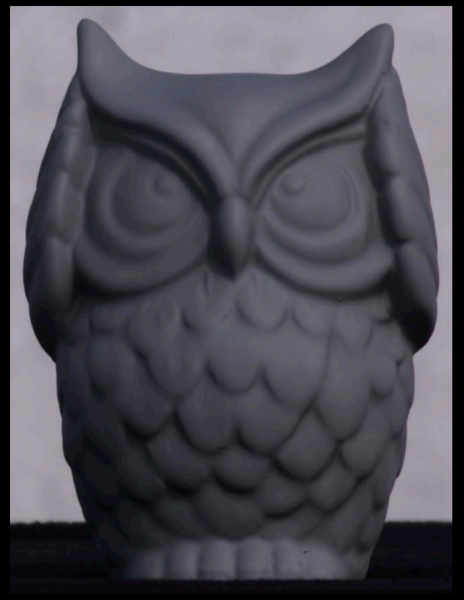
PS reconstruction on synthetic images

Real sky probes, no inter-reflections, highlights or cast shadows

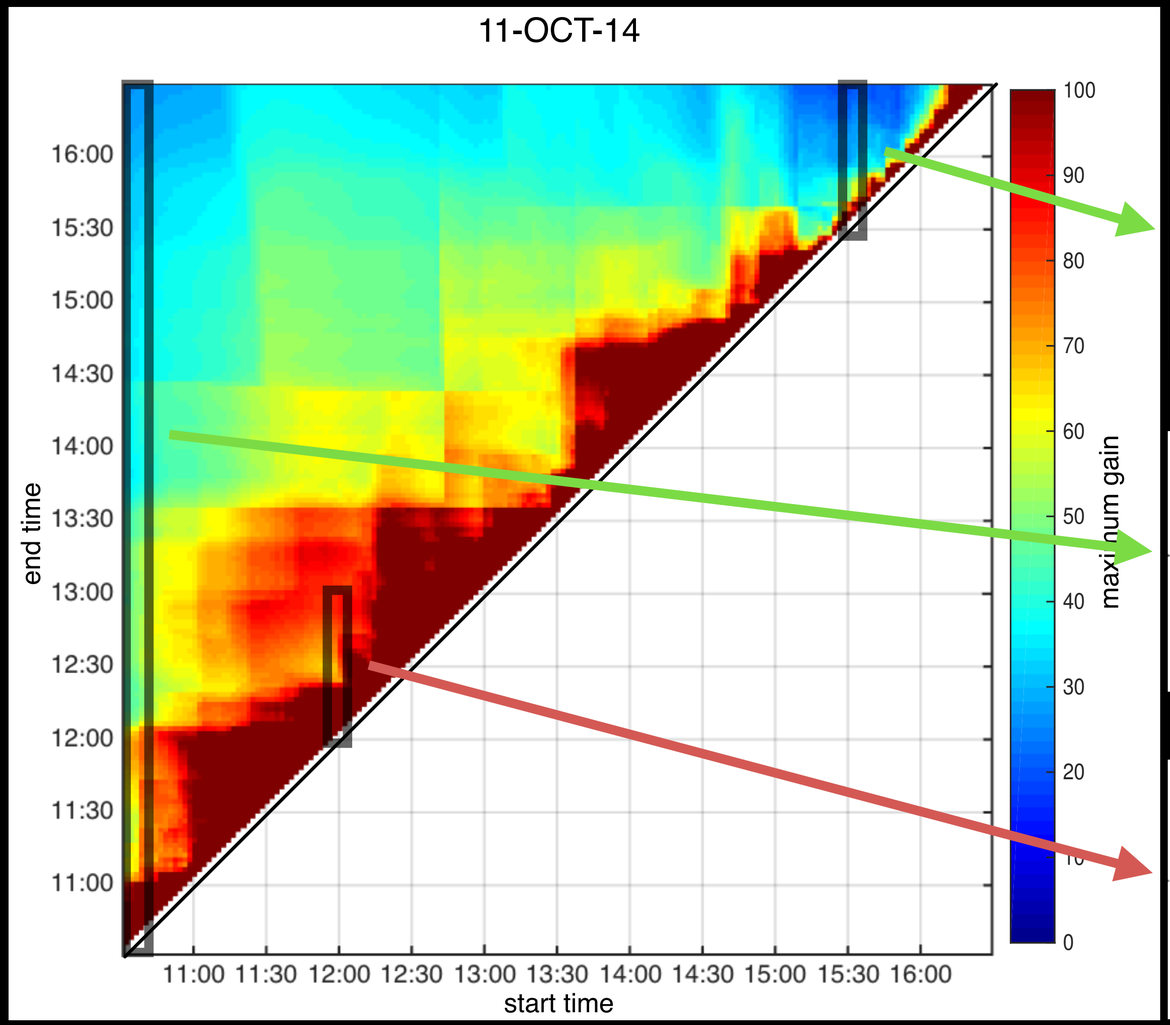


Real data—setup

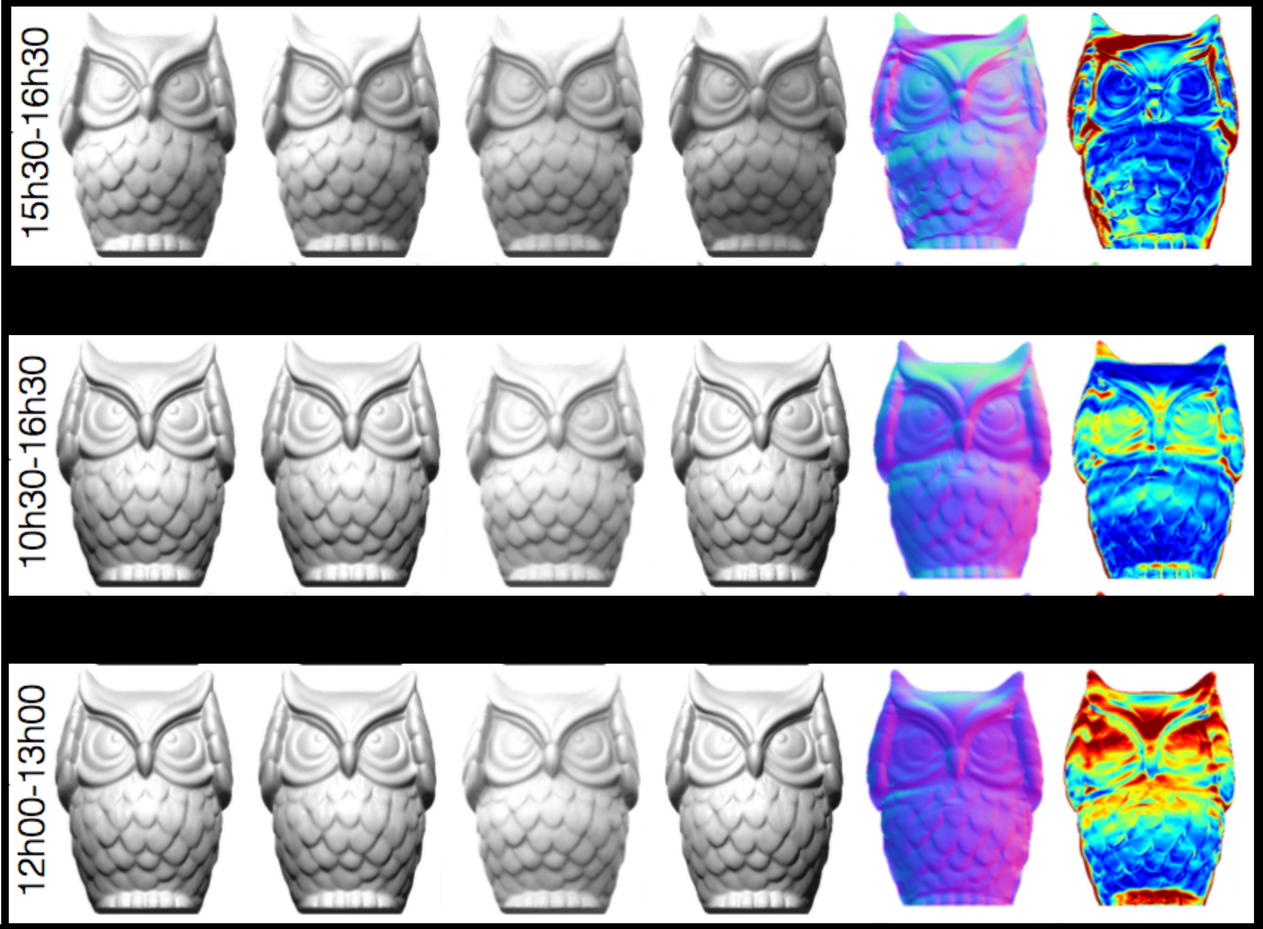




Analysis of the real owl images



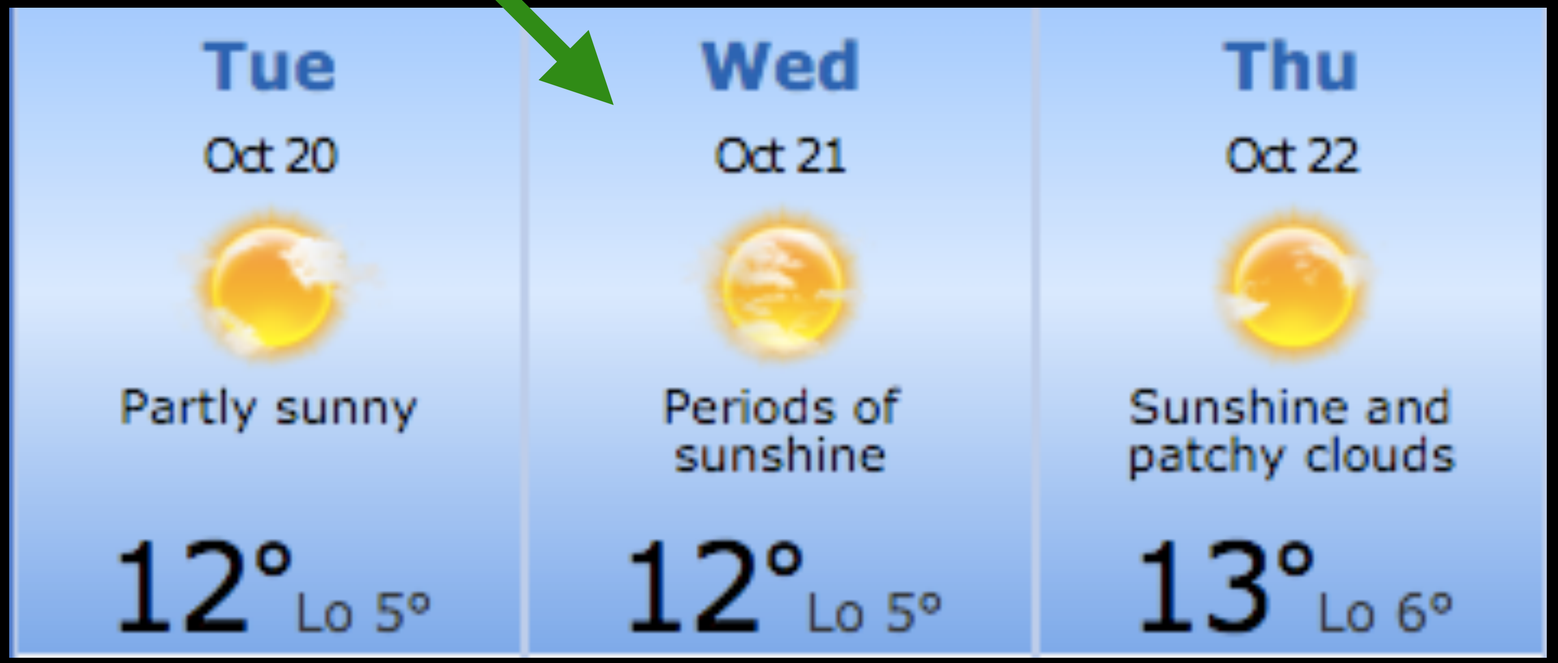
Ground Truth normals



Recap

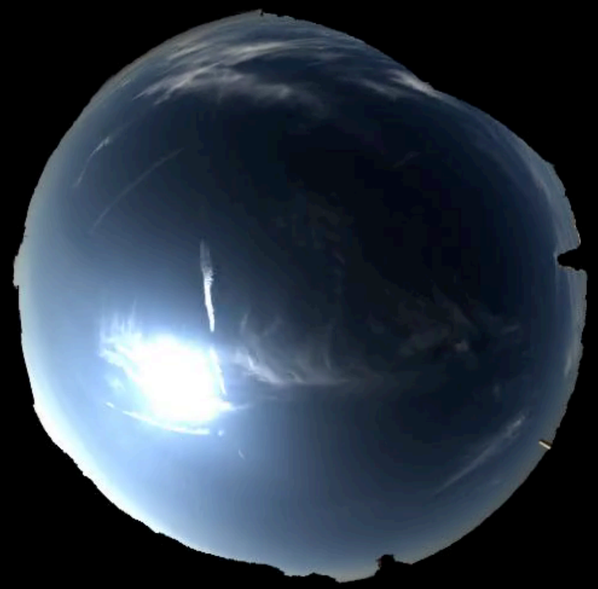
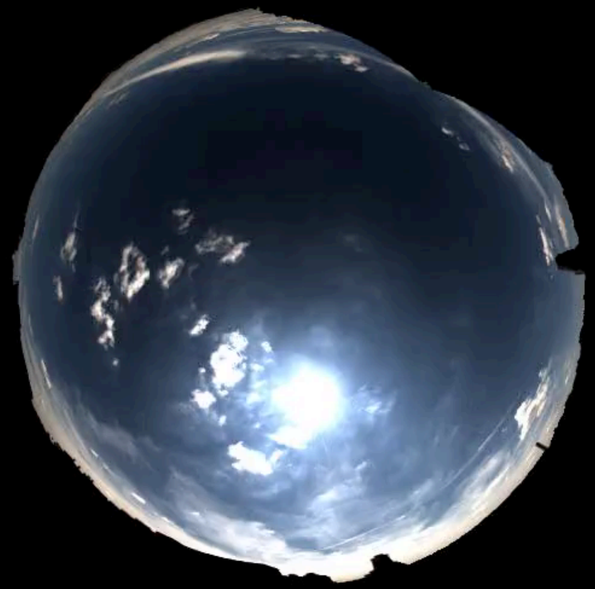
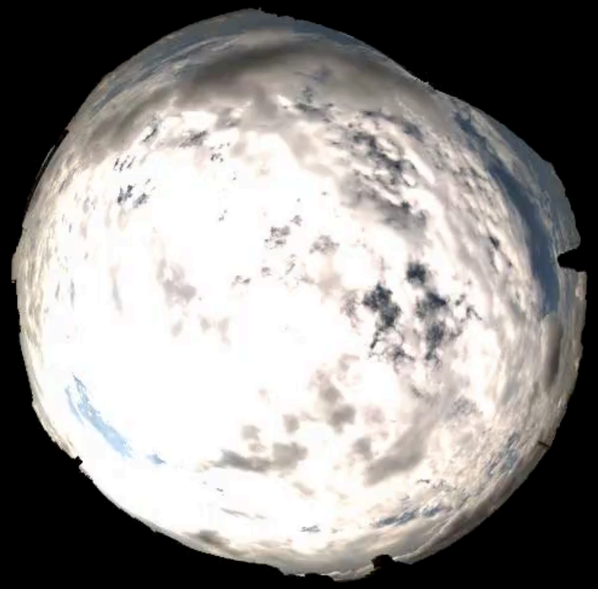
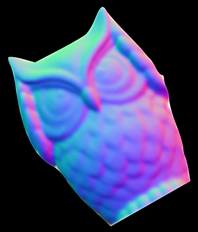
- What needs to happen for PS to work?
  - Mean Light Vector shifts
- Can it happen during less than a day?
  - Yes, MLV shifts happen in small time intervals (i.e., < 6 hours)
  - 50% of the time, 3 hours intervals have similar performance

Want to perform PS in Lyon?



Wednesday

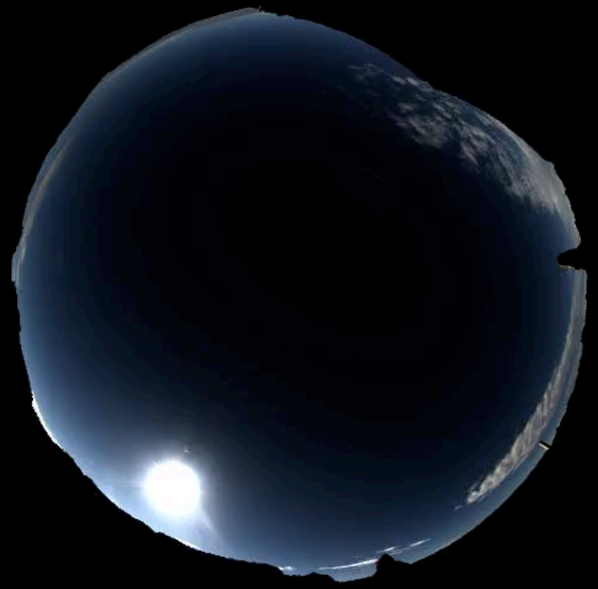
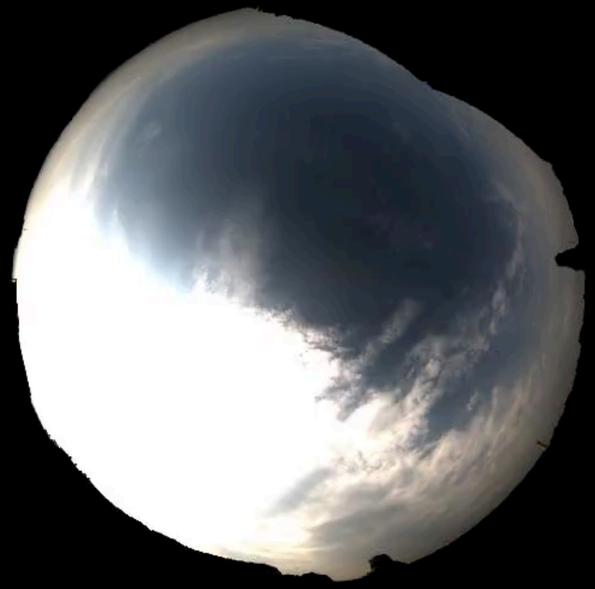
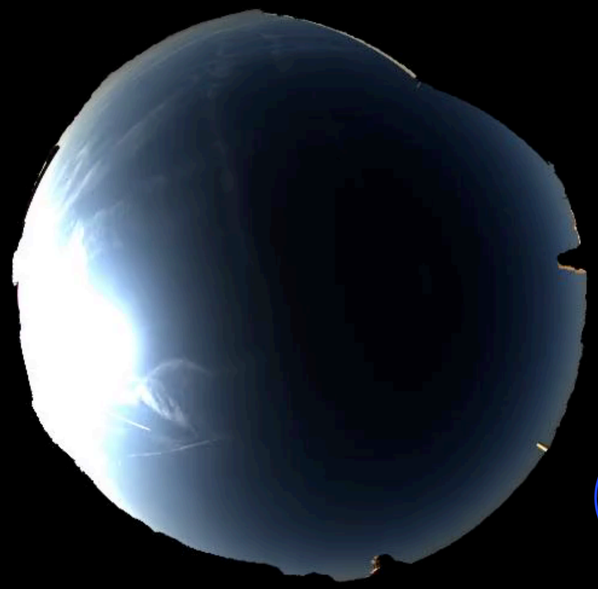
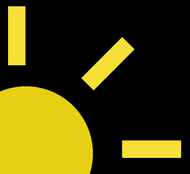
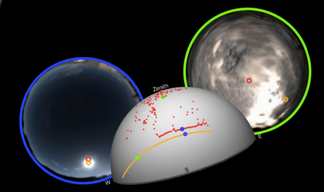
	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
Wind (km/h)	13 N	15 N	17 N	17 N	18 N	18 N	18 N	20 N
UV Index	1	2	2	2	2	2	1	0
Cloud Cover	46%	46%	46%	46%	46%	46%	46%	46%

Thank you!

hdrdb.com

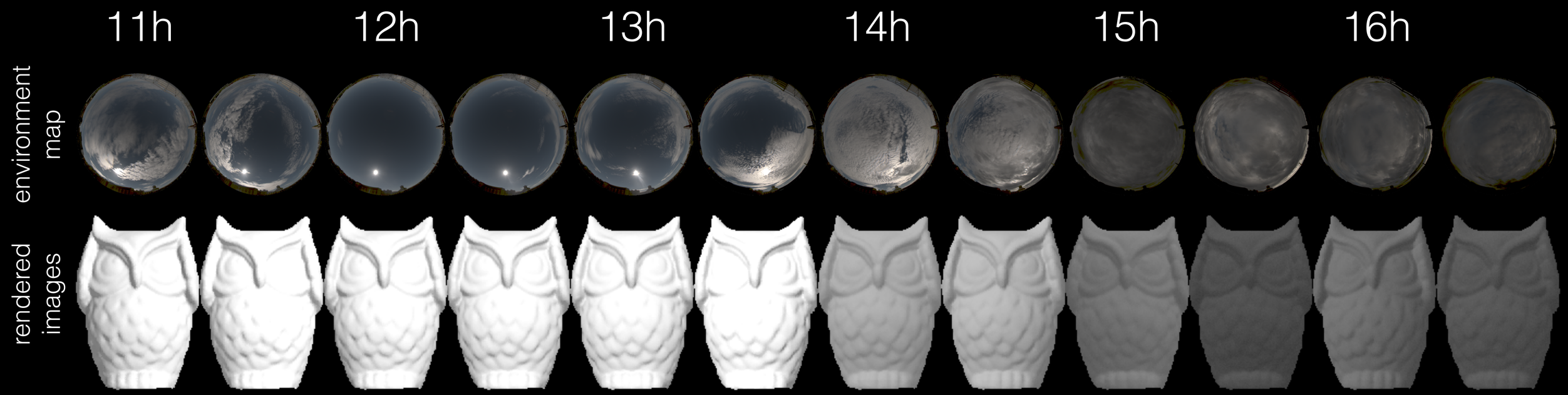
http://vision.gel.ulaval.ca/~jflalonde/projects/xHourPS

Extra slides

PS reconstruction on synthetic images

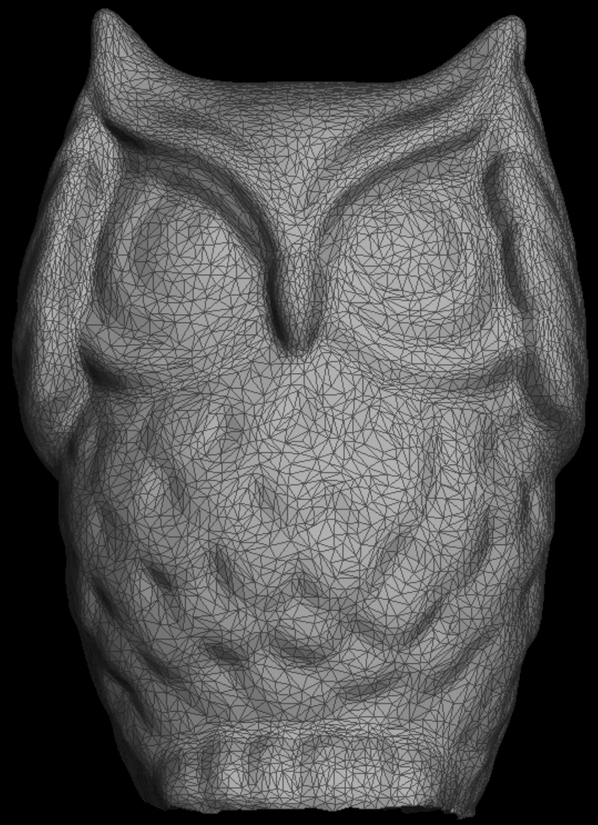
Real sky probes, no inter-reflections, highlights or cast shadows



Real data

Owl statuette

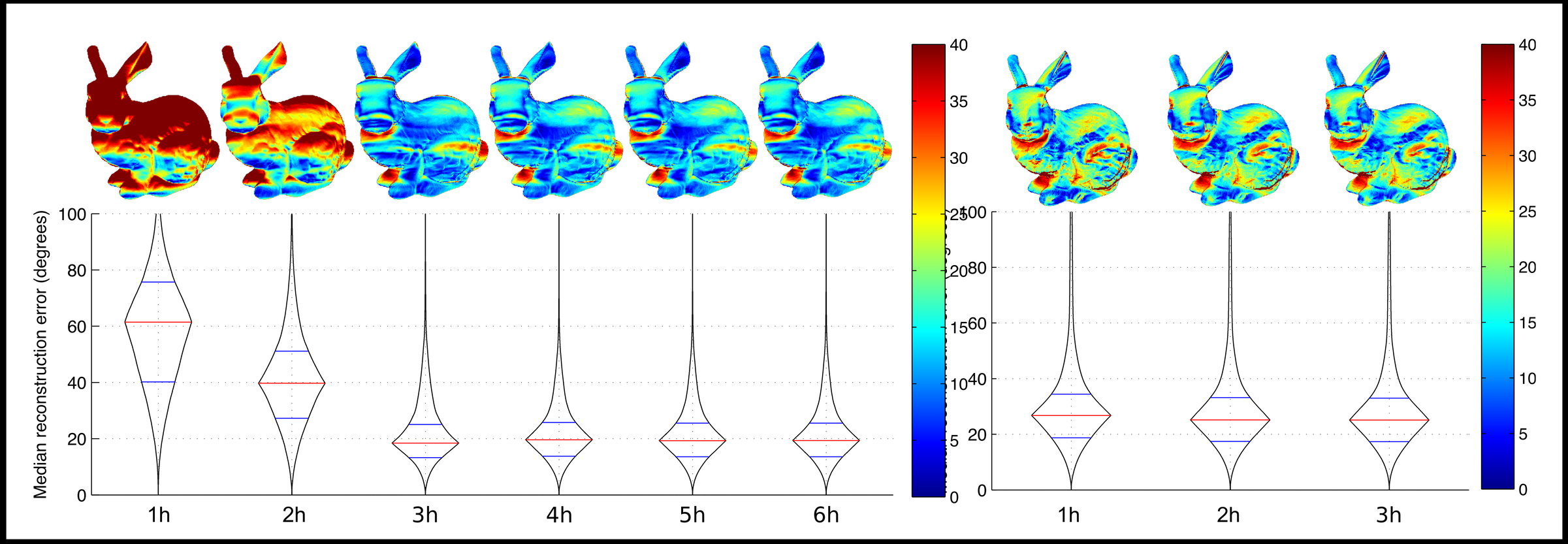
3D scan



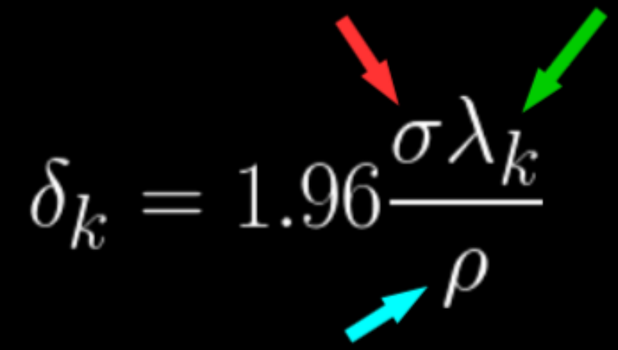
Normal map

Results on synthetic bunny images

Real sky probes, with inter-reflections, highlights and cast shadows

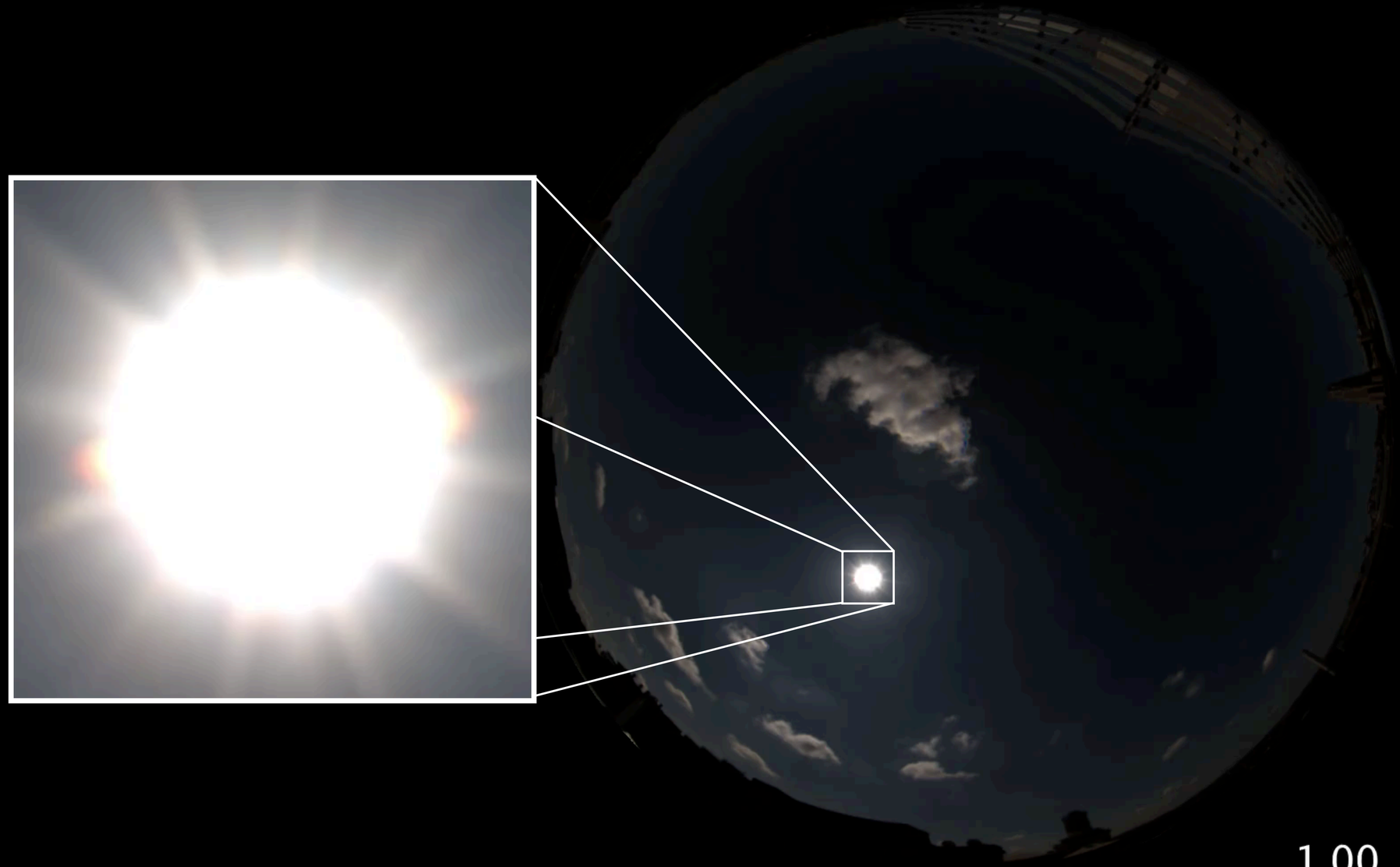


Metric: maximum uncertainty



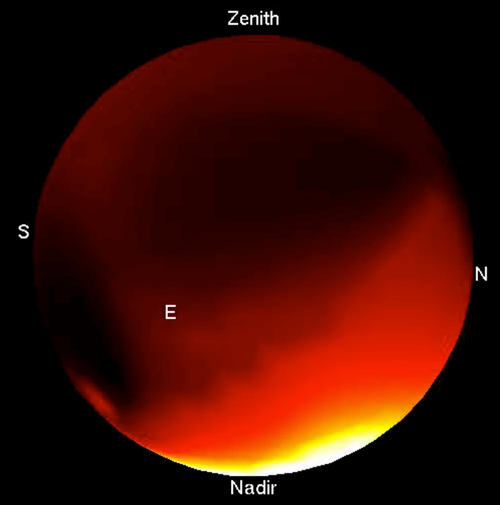
$$\delta_k = 1.96 \frac{\sigma \lambda_k}{\rho}$$

- We now focus on the conditioning of matrix L (**noise gain factor**)
- Independent of albedo and sensor noise

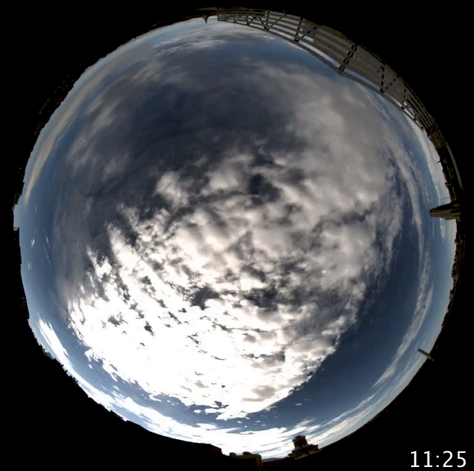


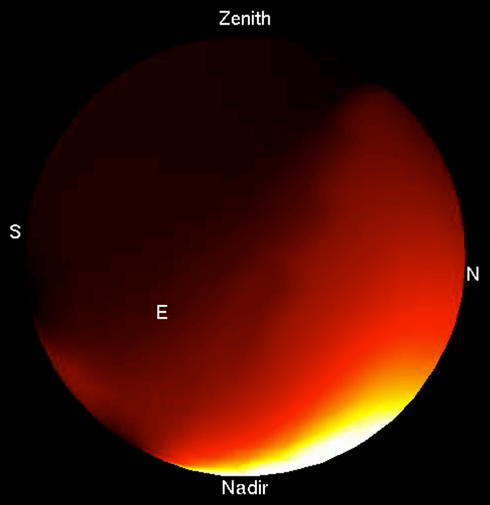
1.00

08/24/2013
light clouds
85% sun visibility

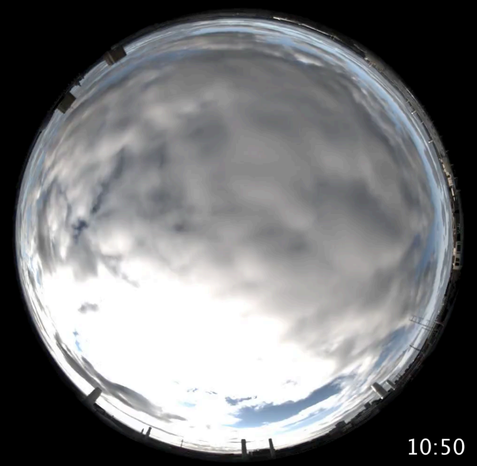


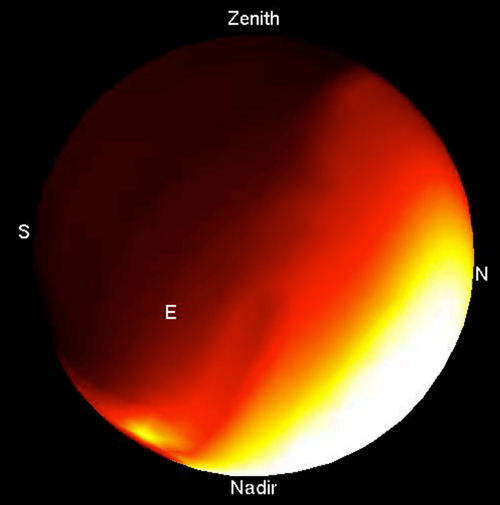
11/06/2013
mixed
41% sun visibility

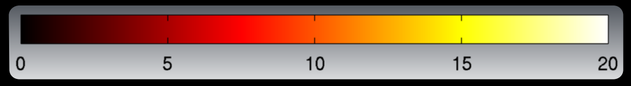




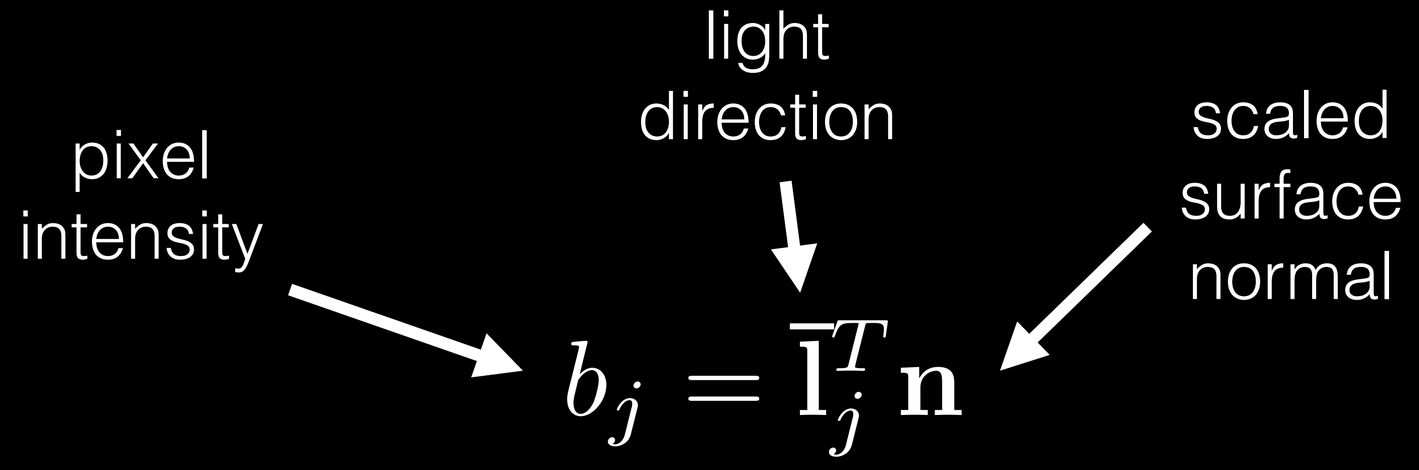
11/08/2014
overcast
16% sun visibility





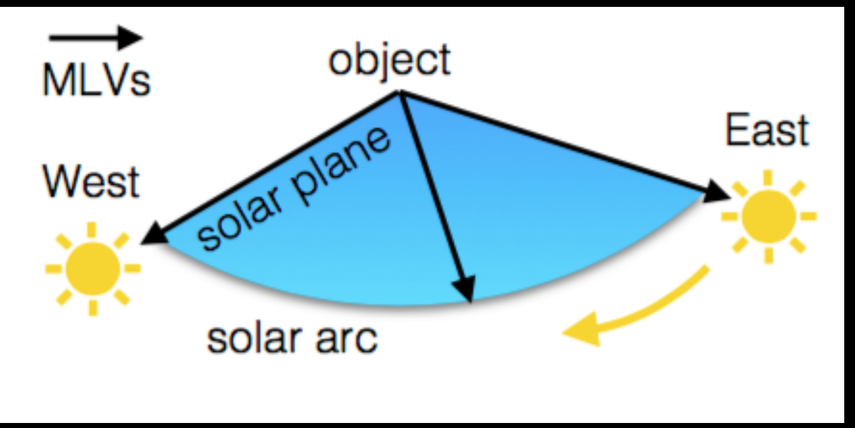


How?

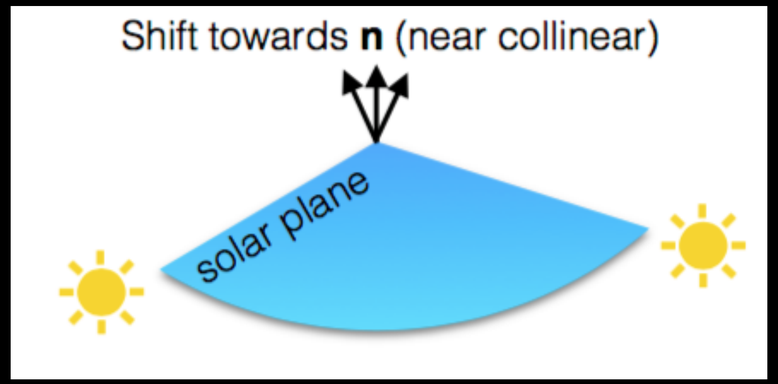


- Online database: hdrdb.com

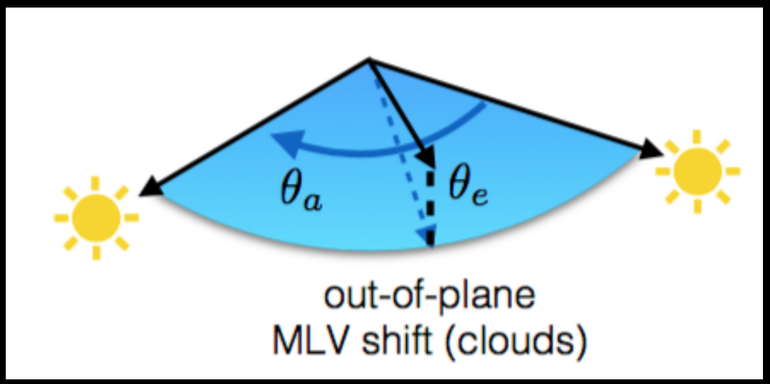
Mean Light Vector shifts



Overcast

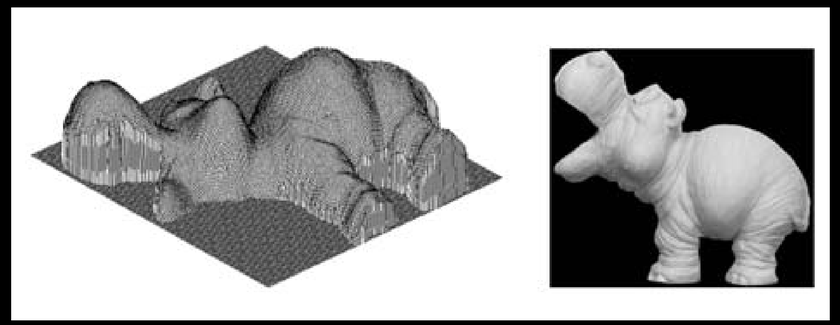


Partly cloudy



Photometric Stereo in the lab

Unknown, smooth lighting
(Spherical Harmonics)



[Basri et al., IJCV ’07]

Non-parametric,
spatially-varying reflectance

[Alldrin et al., CVPR ’08]

Robust estimation of
complex BRDF models

[Ikehata et al., CVPR ’12]