Atmospheric calibration and simulation of the cloud cover for the LSST survey

Cécile Roucelle

31 Institutional Members of LSST

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- Carnegie Mellon University
- Chile
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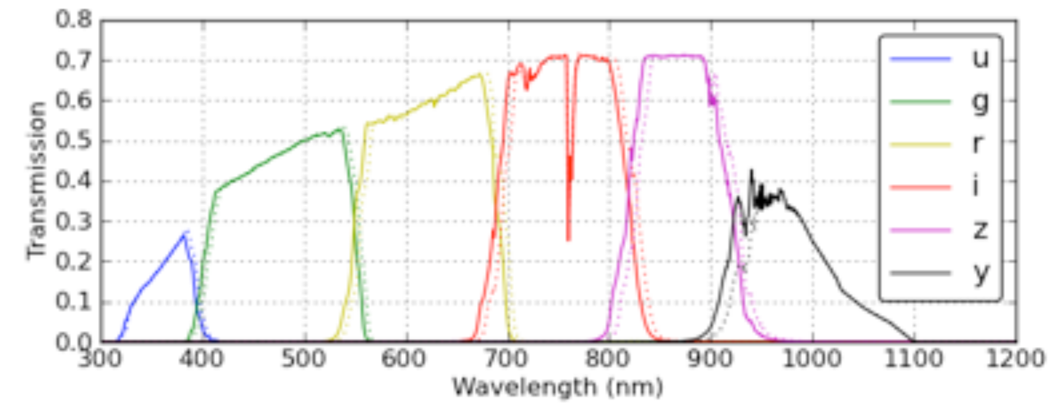
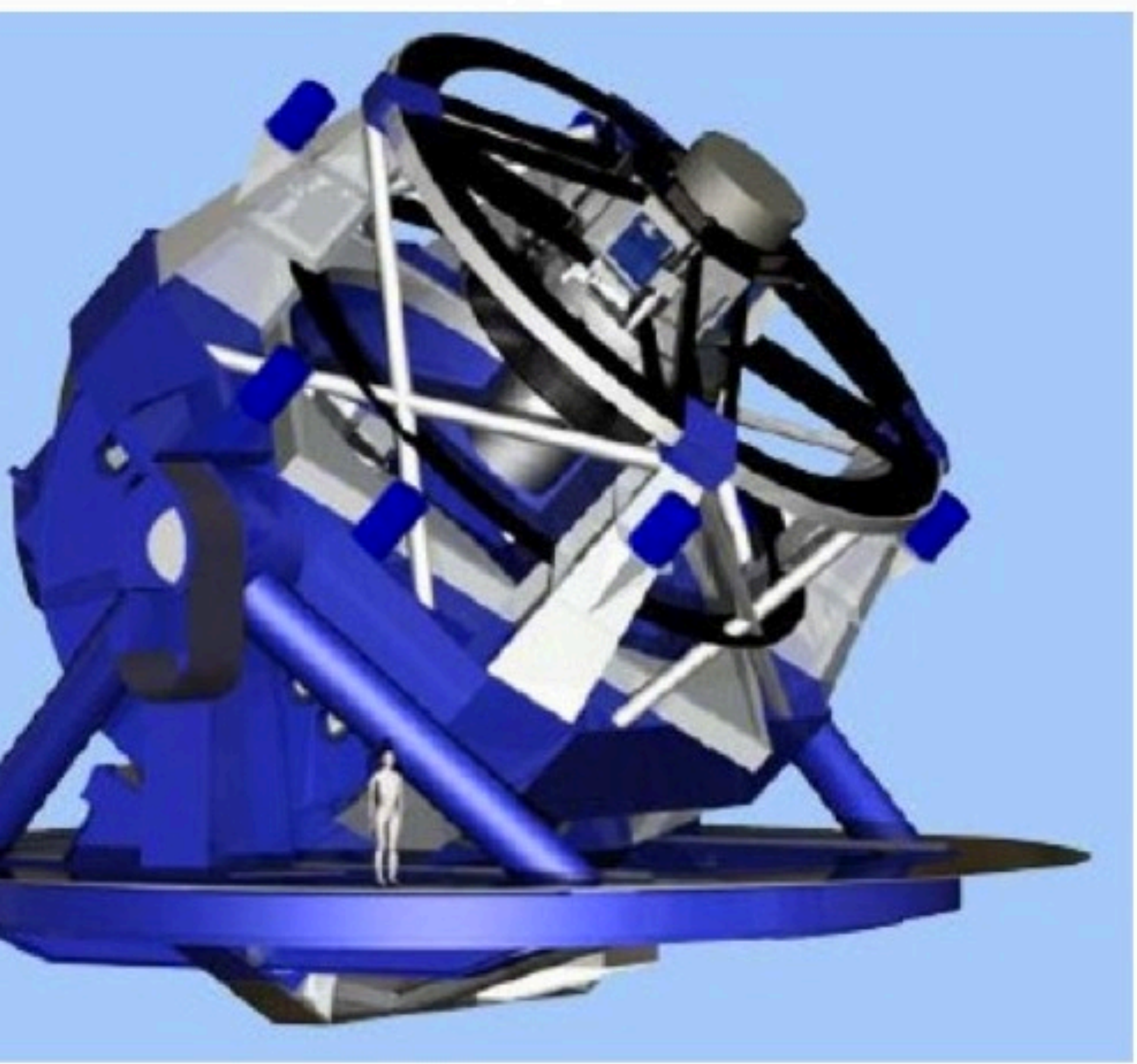
LSST facts





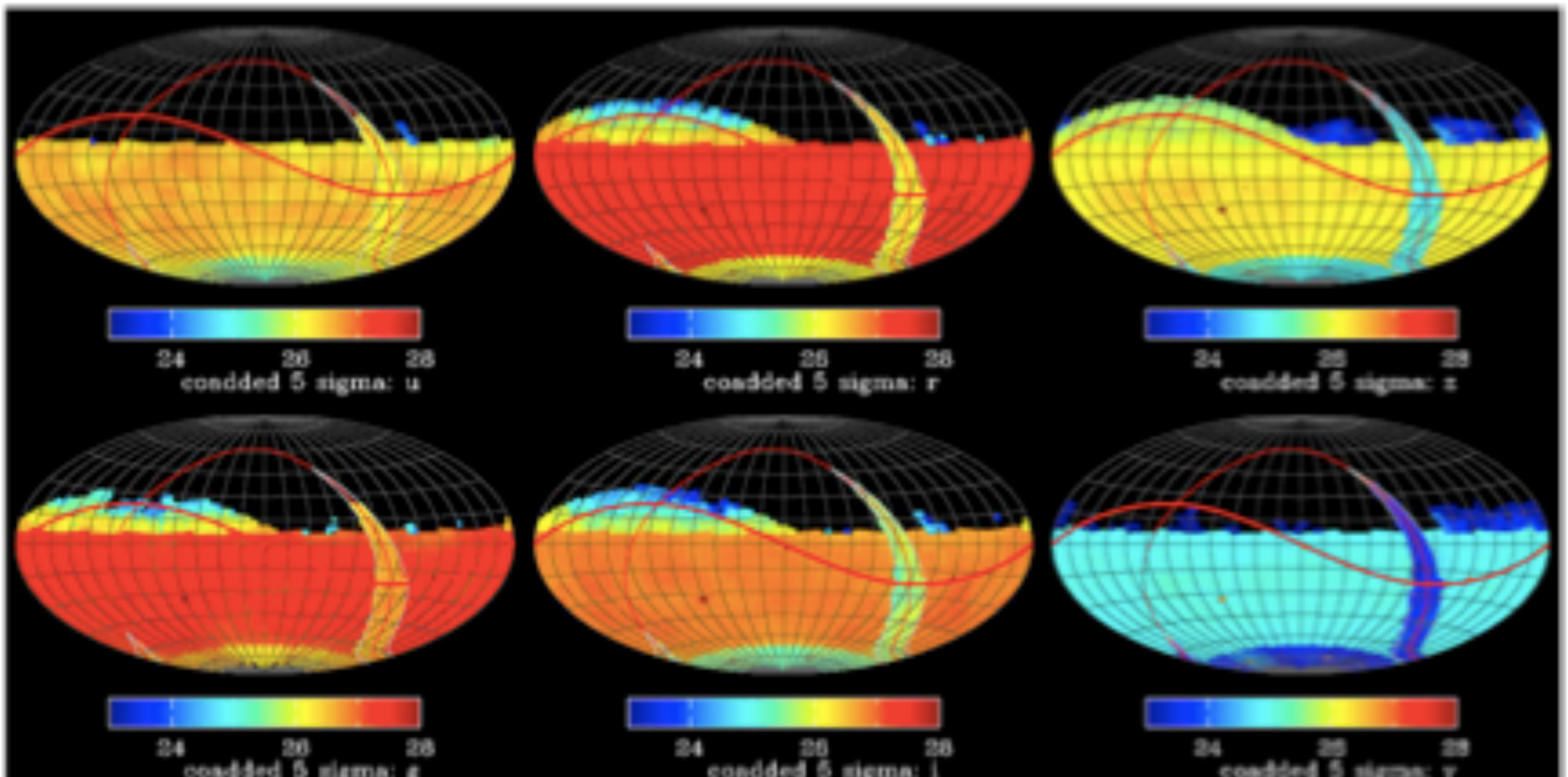
- Aperture diameter: 8.4m
- Effective aperture: 6.7m
- FOV: 3.5 deg
- Filters: u, g, r, i, z, y
- 3.2 gigapixels
- 2 sec, 5 electron noise readout
- Observing mode: pairs of 15 sec exposures, separated by 5 sec slew
- Single exposure depth: ~24.5
- Repetitively scan 20000 sq deg
- Site: Cerro Pachon, Chile
- Data flows at 0.5 GB/sec – all night
- 18 TB / night
- First light: ~2020

alt : 2740 m

Large Synoptic Survey Telescope

LSST survey coverage

10 yrs simulated ; 5.3 M exp



Aitoff projection of coverage on the sky representative of a simulated survey.

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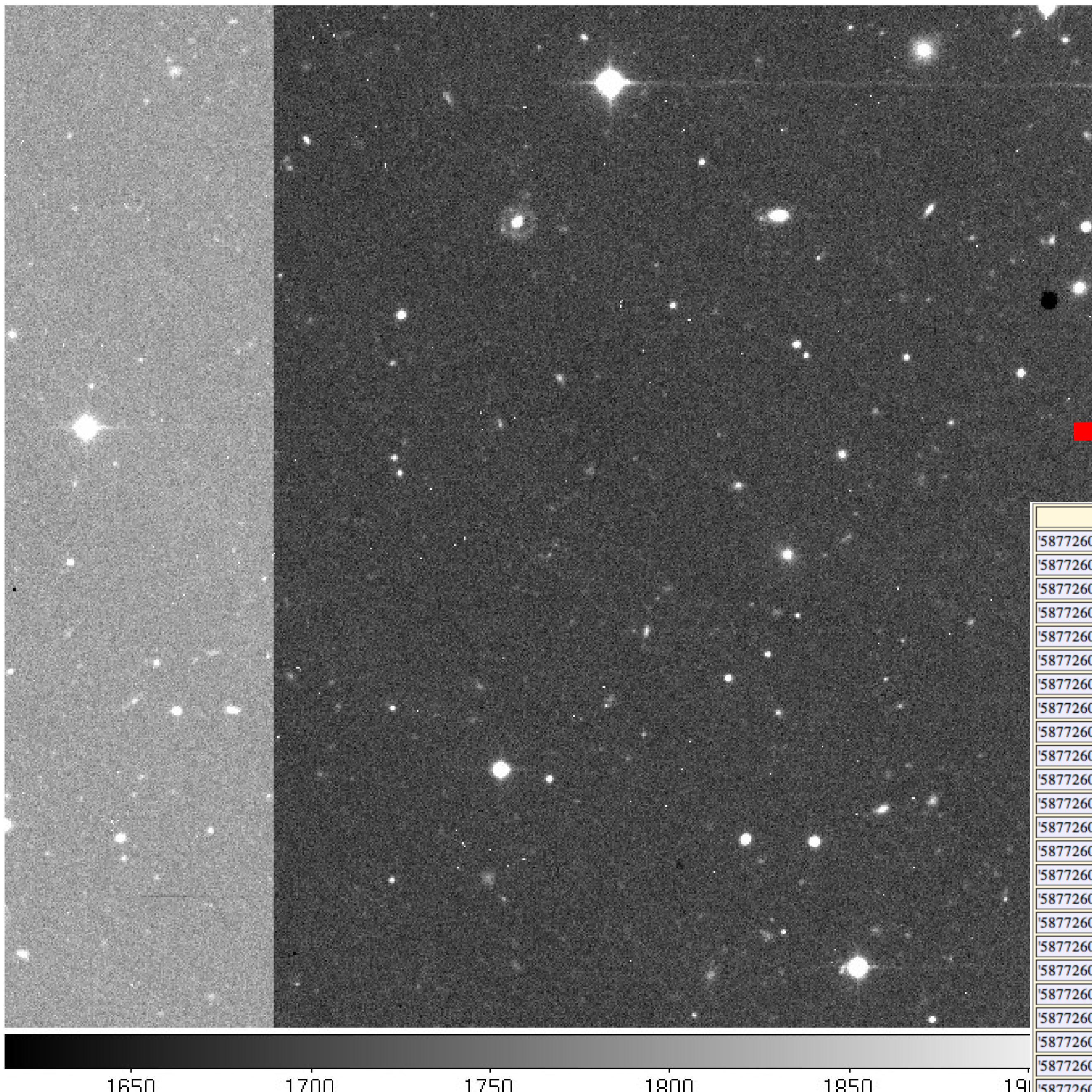
Photometric calibration of data

Translate raw ADU counts into calibrated, above-the-atmosphere magnitudes



Raw image

objID	ra	dec	u	g	r	i	z	Err_u	Err_g	Err_r	Err_i	Err_z
'587726032792191572'	195.50238391	2.50383808	23.086237	22.540611	23.234739	22.220041	23.189583	0.722462	0.178235	0.471561	0.312275	1.253866
'587726032792191560'	195.49778018	2.50480119	22.714373	22.691084	23.153305	23.400248	22.199049	0.443629	0.170543	0.365079	0.627285	0.908129
'587726032792191253'	195.50338303	2.49517596	23.126909	20.879444	19.45649	18.216761	17.550627	0.563357	0.034428	0.016544	9.686179E-3	0.01959
'587726032792191571'	195.50083602	2.49040606	24.029663	23.5137	22.521036	21.315214	21.138935	1.426794	0.428831	0.271606	0.148105	0.565282
'587726032792191161'	195.50006312	2.51001386	21.005962	19.539864	19.019932	18.812067	18.718615	0.097735	0.013818	0.012109	0.013682	0.047131
'587726032792191570'	195.50239108	2.49009506	22.047308	21.822607	21.485224	20.759323	20.428539	0.265911	0.084232	0.090651	0.072998	0.247657
'587726032792191545'	195.49349165	2.49174134	24.478592	23.055302	22.800138	22.098988	21.674263	1.235819	0.223935	0.25769	0.209802	0.937999
'587726032792191553'	195.49517009	2.50944428	22.381828	21.983875	21.66239	21.42061	21.011662	0.411743	0.110988	0.124472	0.160534	0.506803
'587726032792191283'	195.49188628	2.50686212	22.922569	21.861425	20.047256	19.121481	18.672714	0.808918	0.121613	0.037246	0.02641	0.078184
'587726032792191813'	195.50296248	2.51021467	22.811222	23.020041	21.221304	20.2631	19.962851	0.587908	0.270476	0.082926	0.055284	0.192164
'587726032792191544'	195.49191869	2.49209154	22.898981	22.268764	21.029999	20.513145	19.828917	0.671795	0.149571	0.075209	0.076365	0.191662
'587726032792191163'	195.50849958	2.50856617	19.908937	17.420572	16.17997	15.580124	15.256006	0.043291	4.951692E-3	4.107814E-3	4.403433E-3	5.968257E-3
'587726032792191564'	195.50170095	2.51223007	24.854179	21.35354	20.109291	19.536482	19.206078	1.42937	0.059345	0.029941	0.027789	0.092352
'587726032792191538'	195.48761541	2.49976257	24.984211	22.898663	22.600641	22.614235	21.334465	1.166349	0.196533	0.21838	0.32883	0.481173
'587726032792191565'	195.50190923	2.48736964	22.85474	22.217606	21.395378	20.937647	22.065811	0.574403	0.146416	0.09188	0.095091	1.011017
'587726032792191604'	195.51289941	2.50297331	22.631491	22.888988	22.298571	21.955574	20.892193	0.395867	0.192799	0.163991	0.182883	0.333513
'587726032792191600'	195.51263358	2.49508453	23.783979	22.172594	21.373093	20.727684	20.500481	0.913895	0.101758	0.072131	0.060883	0.2258
'587726032792191249'	195.49377096	2.48733034	20.529499	19.54117	19.014206	18.692968	18.443134	0.116102	0.019351	0.019358	0.022324	0.077765
'587726032792191605'	195.51355677	2.50422682	25.297295	23.347095	22.313814	22.13744	21.819094	1.168285	0.321623	0.191573	0.249649	0.78979
'587726032792191589'	195.50920718	2.48919342	25.524464	22.91293	22.859993	21.347843	20.734306	0.910661	0.199585	0.27355	0.110373	0.292632
'587726032792191603'	195.51448242	2.50365233	22.600399	21.221594	20.662912	20.638641	20.422541	0.377725	0.04651	0.040219	0.056845	0.217171
'587726032792191311'	195.49761944	2.51484817	21.240248	20.92462	20.256861	19.96217	19.880463	0.127715	0.038164	0.030391	0.034685	0.144444
'587726032792191149'	195.48343526	2.5000692	23.804209	23.013802	22.312454	21.888872	22.816216	0.894942	0.204041	0.157389	0.160374	0.908237
'587726032792191809'	195.49841889	2.51699015	23.727329	23.765503	22.453846	21.31481	20.769337	0.972352	0.421338	0.203502	0.113207	0.321724
'587726032792191800'	195.49214783	2.48449854	22.835083	23.160868	22.009319	21.786947	20.445337	0.640849	0.325503	0.177101	0.226976	0.319485
'587726032792191148'	195.48256174	2.50122622	24.072037	23.500038	21.297234	20.259172	19.899487	1.073476	0.319855	0.069453	0.041908	0.136506
'587726032792191580'	195.50572569	2.51681957	23.402885	22.360704	21.692982	21.016615	20.803389	0.857157	0.141803	0.11376	0.09582	0.362285
'587726032792191789'	195.48244918	2.50298846	23.688913	22.905945	21.788868	22.001762	20.944082	1.599668	0.341186	0.190674	0.369393	0.662273
'587726032792191581'	195.5049009	2.51723783	25.371346	24.467642	22.266394	21.366068	20.615652	0.928028	0.58941	0.15203	0.101486	0.239905
'587726032792192010'	195.49984554	2.48204269	26.330944	24.354883	22.342859	21.100237	19.83514	1.294074	1.463225	0.45473	0.26655	0.377451

Calibrated data

LSST SRD requirements

Internal	Repeatability	5 mmag (0.5%) (7.5 mmag in u/z/y)	RMS in the scatter of repeat measurements of the SAME star is less than 5 mmag. Photometry can be compared over time.
	Uniformity	10 mmag (1%) (20 mmag in u/z/y)	RMS of zeropoint scatter ACROSS THE SKY is less than 10 mmag. Photometry can be compared across the sky.
External	Band-to-Band	5 mmag (0.5%) (10 mmag for colors including u)	Accuracy of zeropoint values in each band. Measurements in one filter can be tied to other filters.
	Absolute zeropoint	10 mmag (1%)	Ties LSST photometry to an external, physical scale. Measurements can be compared against models.

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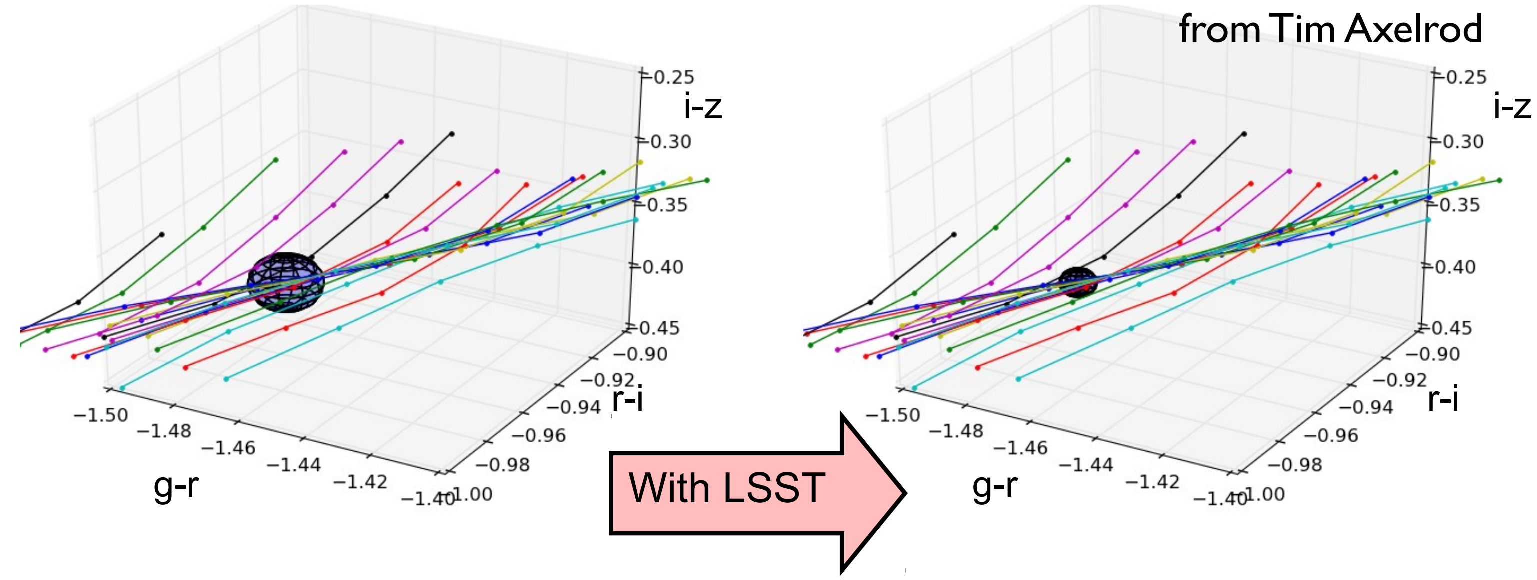
LSST requirements

Requirements on photometry driven by photo-z requirements for cosmic shear & transients; crucial to scientific objectives

from Tim Axelrod



By improving photometric errors by a factor of 2 in each of u/g/r/i/z/y, the error in 6-D color-color space is reduced by factor of 32

By calibrating data taken even in non-photometric weather, we can increase efficiency of the telescope. (From ~50% to ~85% of available time).

factor of ~2 better than previous surveys

Ambitious... but not out of reach !

- SDSS (ubercal - Padmanabhan et al. 2008) ~1-2% by simultaneous modeling of instrument, atmosphere & reference stars
- Atmospheric variations dominate residual uncertainties

...Adding LSST context

- Intensive observing campaign over 10 years => varying observational conditions on aerosols and have to deal with cirrus on non photometric nights

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Photometic calibration procedure

random error ↘ systematic error ↙ zero-points (6)

$$m_{cat} = m_{true} + \sigma + \delta_m(x, y, \phi, \alpha, \delta, SED, t) + \Delta_m$$

Reduce accumulated all-sky multi-epoch survey to a single arbitrary scale for each filter band → minimize δ_m

Determine <u>five relative</u> filter-band zero-points → fix Δ_m - Δ_n (color)

Physical scale (<u>one absolute</u> zero point) → e.g. fix Δ_r

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How can we achieve these goals?

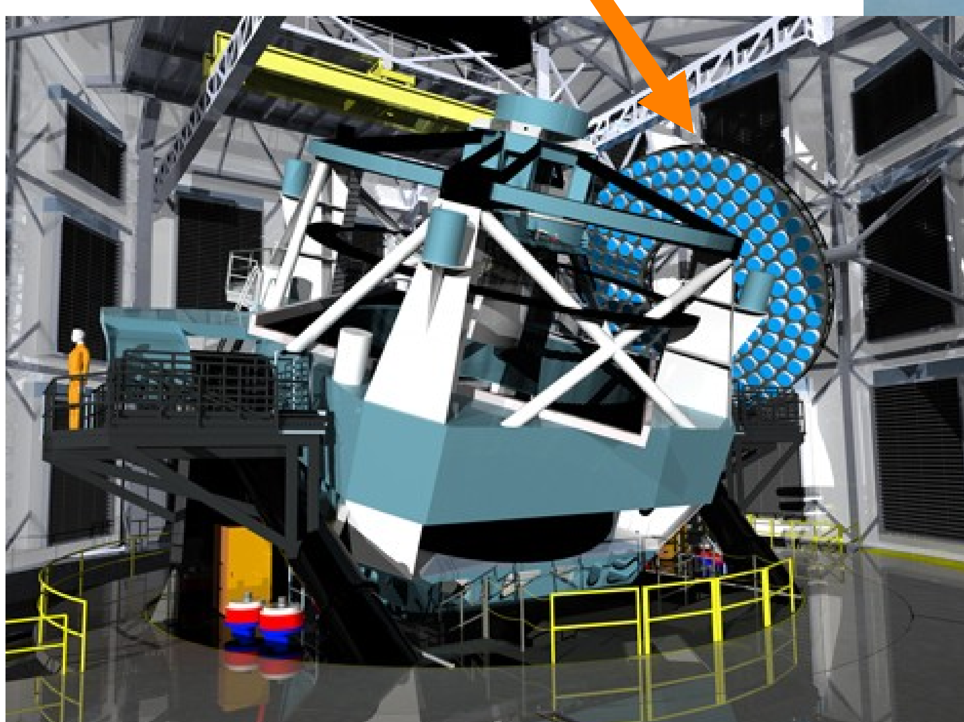
Take advantage of many observations of many stars under a wide variety of conditions

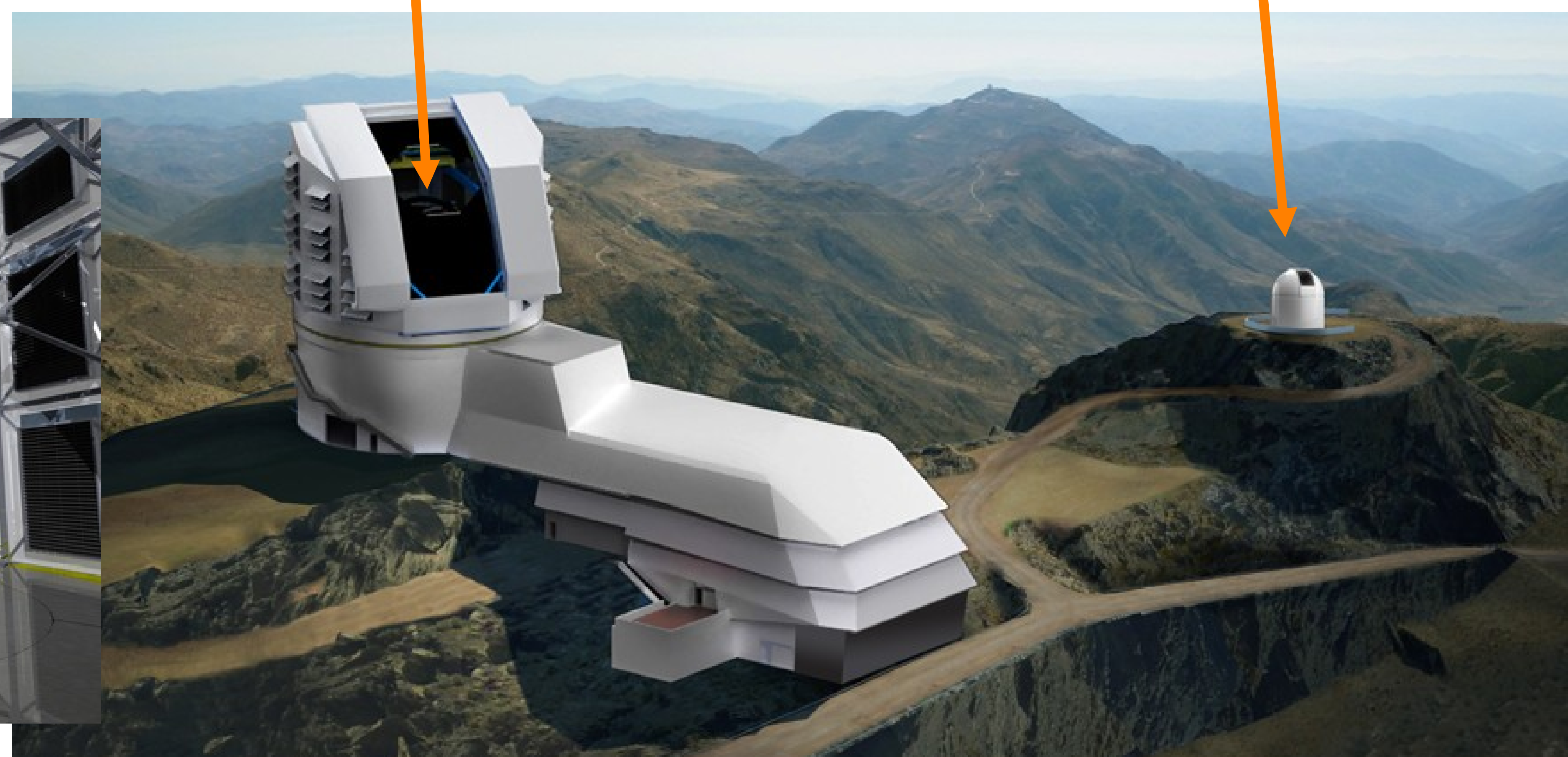
Use optimized methods to measure hardware throughput and atmospheric throughput separately (as well as measure wavelength-dependent and independent effects separately)

Dome screen capable of generating both broad-band and narrow-band flat fields

The survey images + self-calibration procedure

Auxiliary telescope with spectrograph





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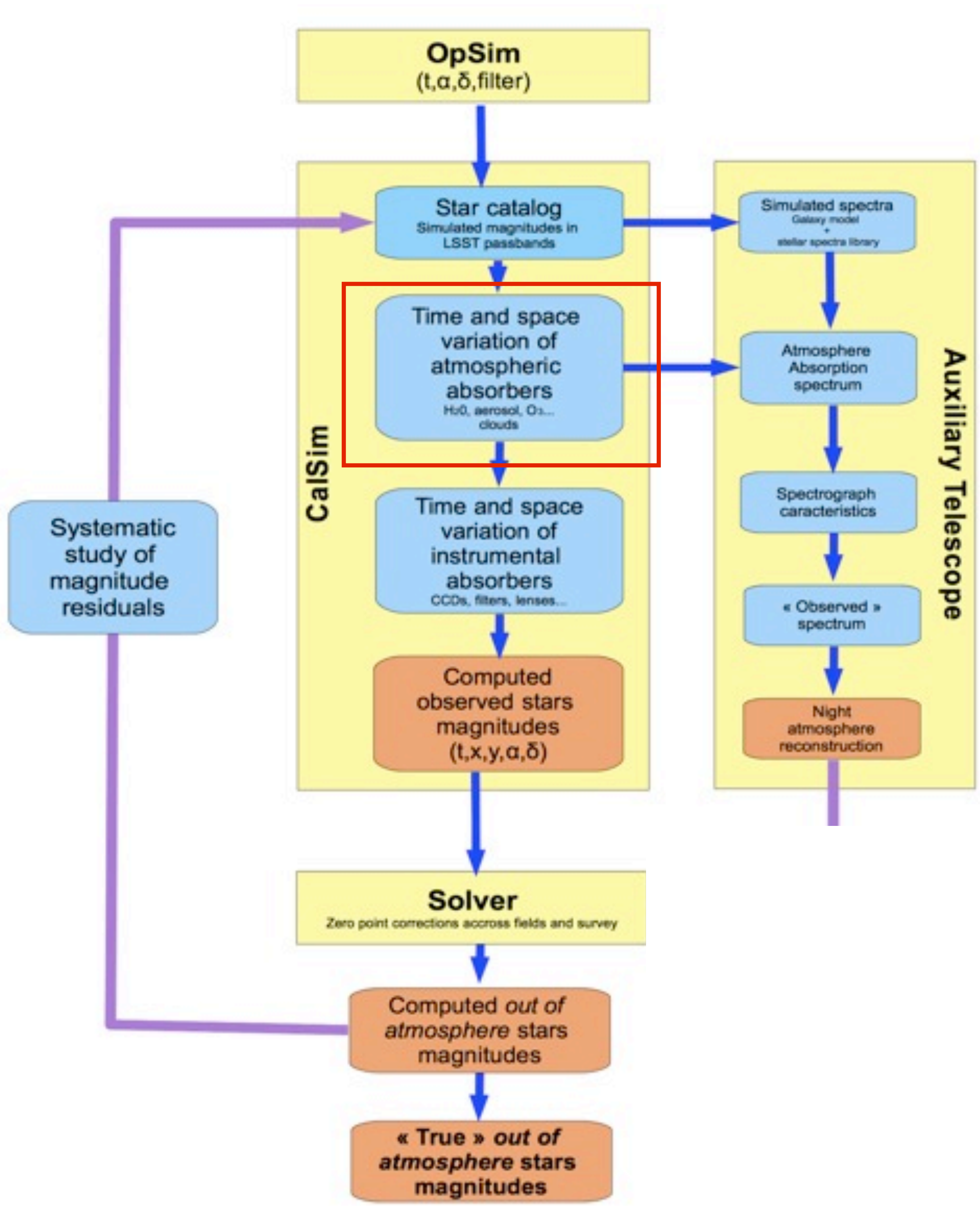
Simulations are essential for the benchmarking of methodologies !

Simulating the atmosphere for calibration



Dedicated pipeline for calibration testing purposes

Simulation at the object level

Needs to be fast to allow a large number of runs

Include auxiliary telescope

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Atmospheric simulation

Calculate extinction curve for each visit using MODTRAN

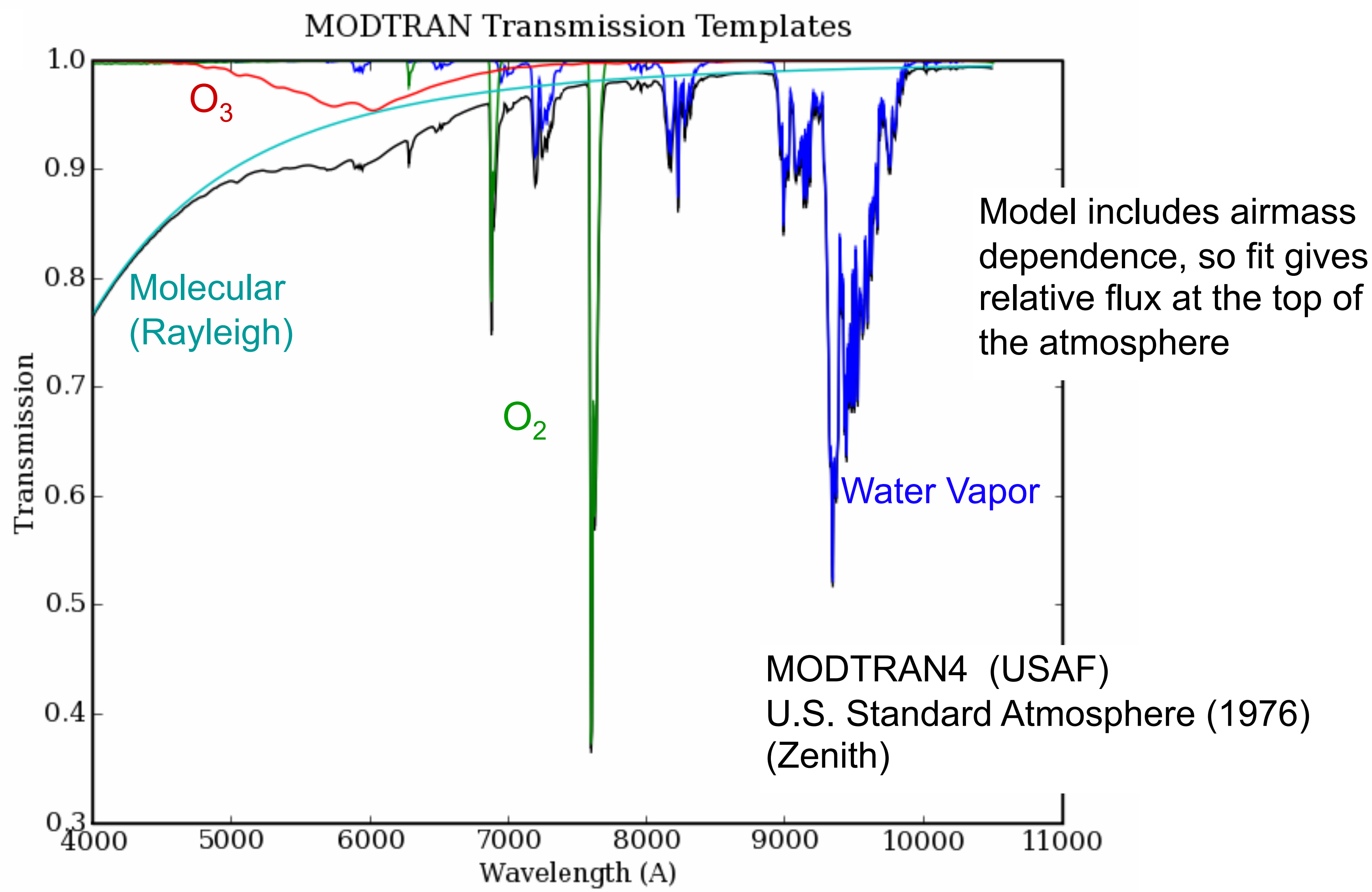
5 components

Uniform

1. Rayleigh+O_2
2. O_3
3. Water

Spatially varying

1. Aerosols
2. Gray (cloud) term



See Alexandre's talk

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Objectives of cloud cover simulation

- Obtain a realistic simulation of the cloud cover during non strictly photometric nights for the simulated observing campain
- Mandatory scale for the simulation : LSST CCD scale so ~ arcmin
- Answer to the time variability of structures at this scale (and how the average over ~30s)
  - Production of 2D maps in the simulation chain using realistic data

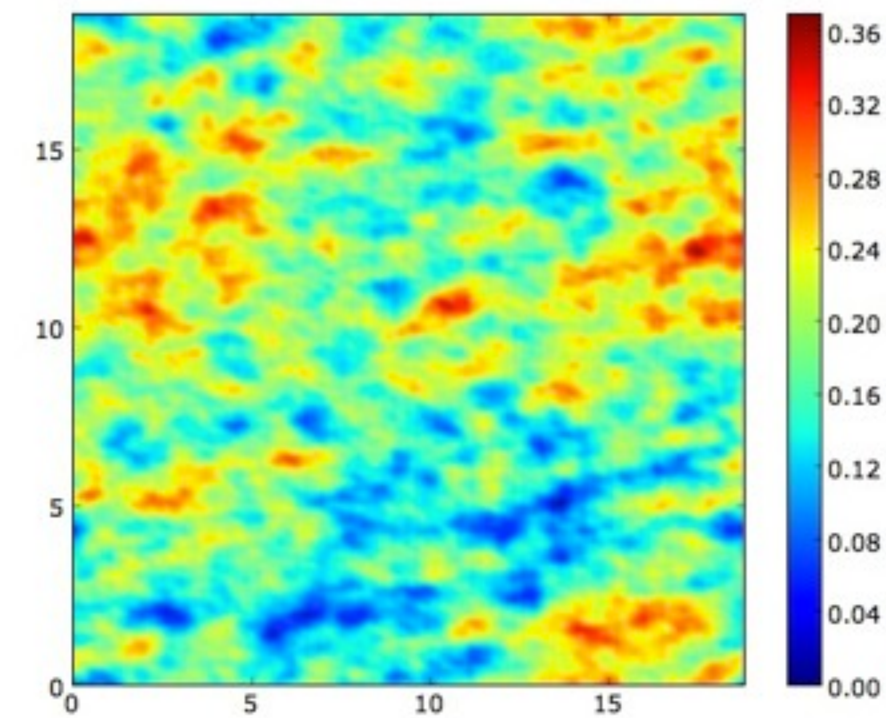
Generating gray extinction maps

- Based on a GRF

$$\tau(\vec{r}) = \frac{1}{(2\pi)^3}\int d^3k \; \tau(\vec{k})e^{-i\vec{k}\cdot\vec{r}}$$

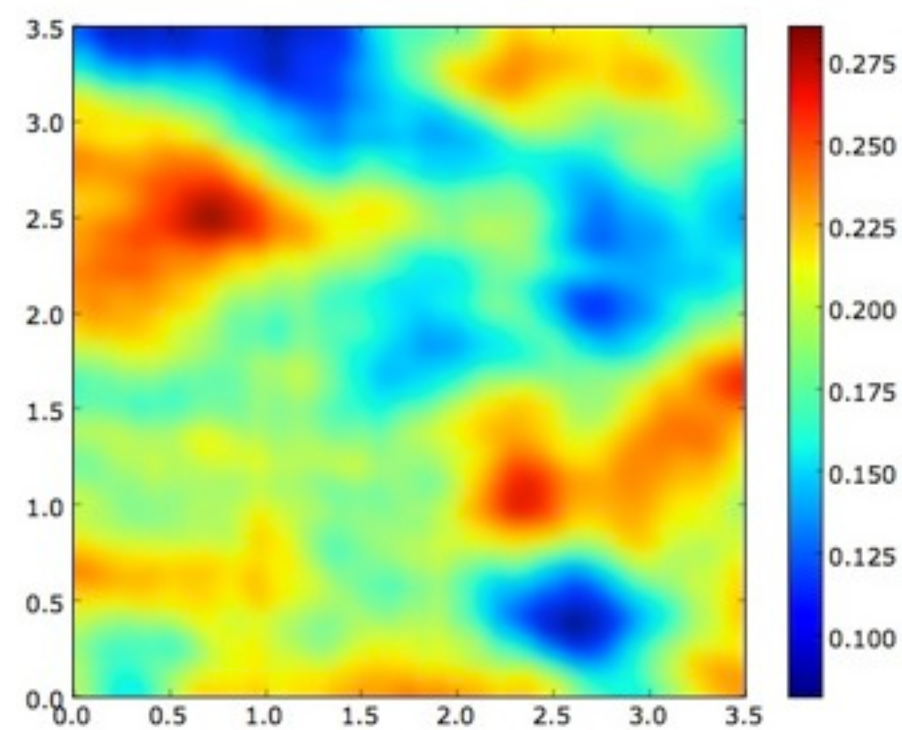
- Structural information derived from the power spectrum of RASICAM images to pull the simulated cloud field parameter

$$\tau(\vec{k})$$



RASICAM (IR cam sur calypso 10-12 μm wavelength
Fov : 25°x18.8° - pixel size 4.7 $arcmin^2$)

- First version of the simulation :
- Arbitrary choice of the reference image
  - ➡ Integrate a weather scenario information
  - ➡ Relate with modtran parameters

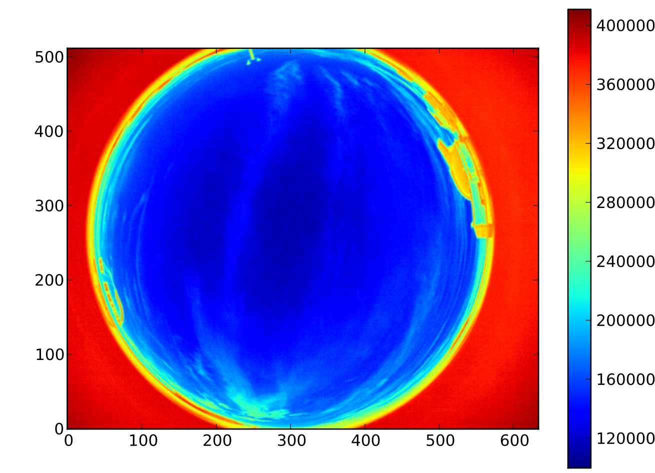


- Only two pointings available for this campaign
- Too few images accessible : no follow up on different night

- Other data necessary to answer our different questions

Using CFHT IR camera

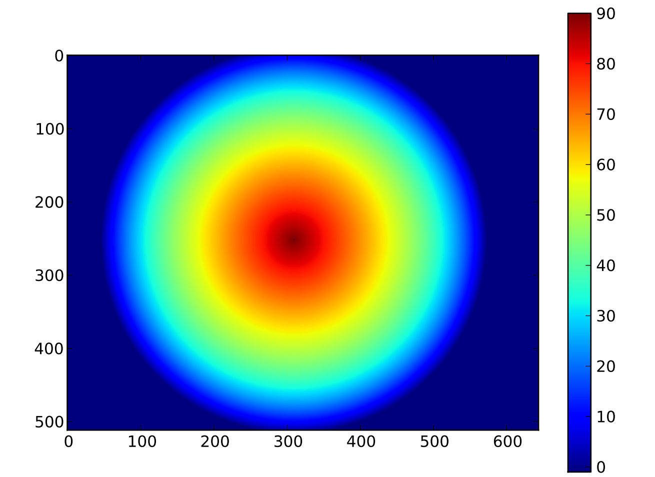
All sky IR camera ASIVA - FLIR cmera Photo 640
640x512 pix - 10-13 microns
averaged image every 3 min (raw images accessible)

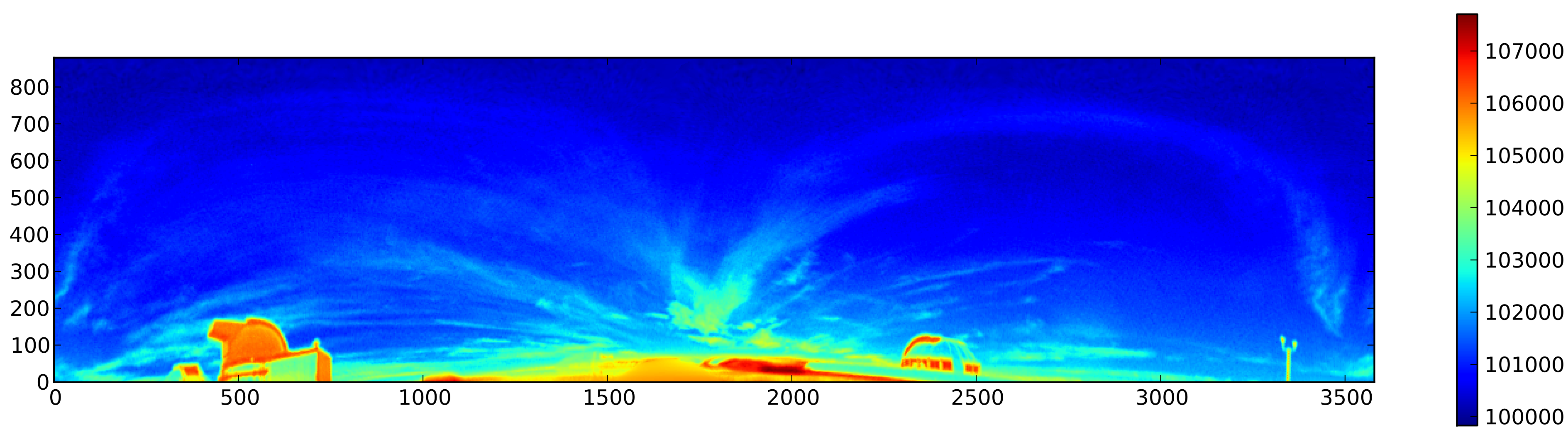


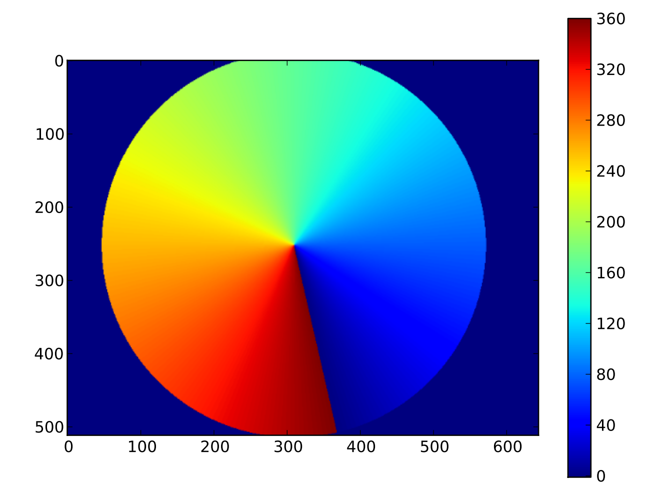
Ex : 1700 images over 14h

Ideal for cloud cover determination
(use in CFHT)

Used here for structures study
Similar camera will be on site







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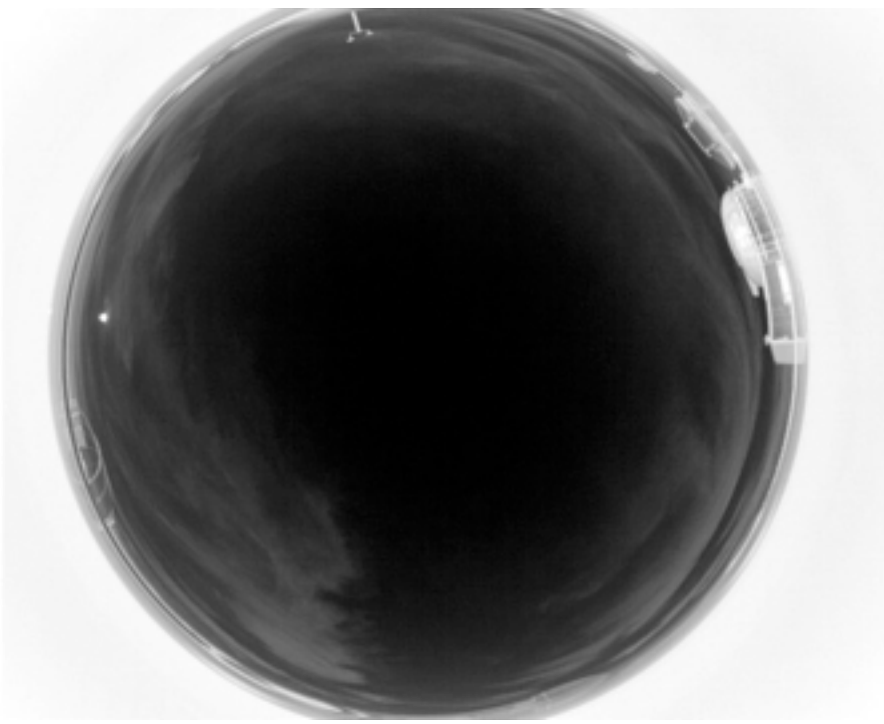

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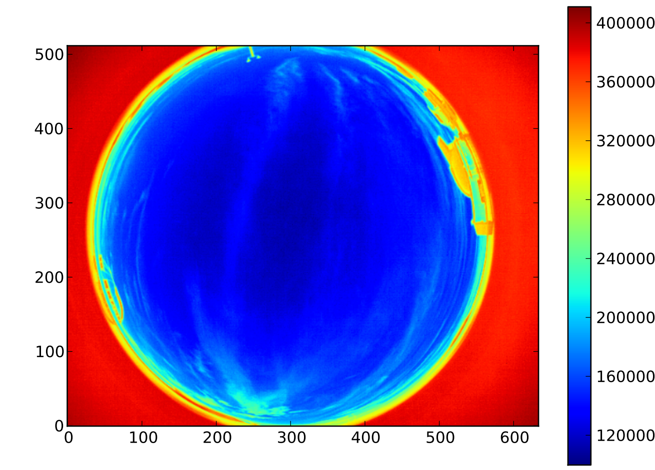
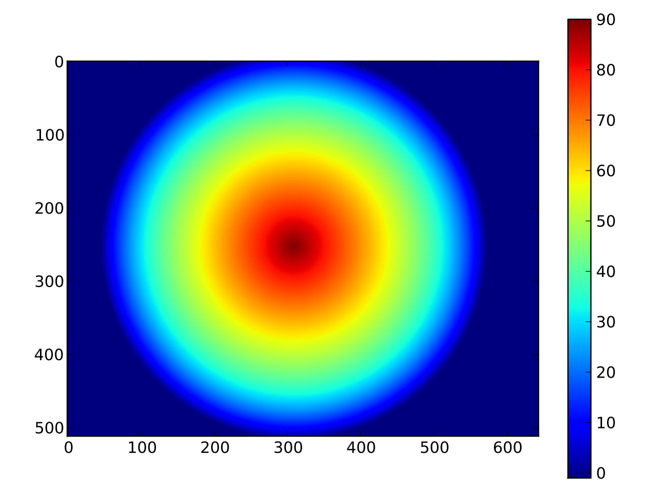
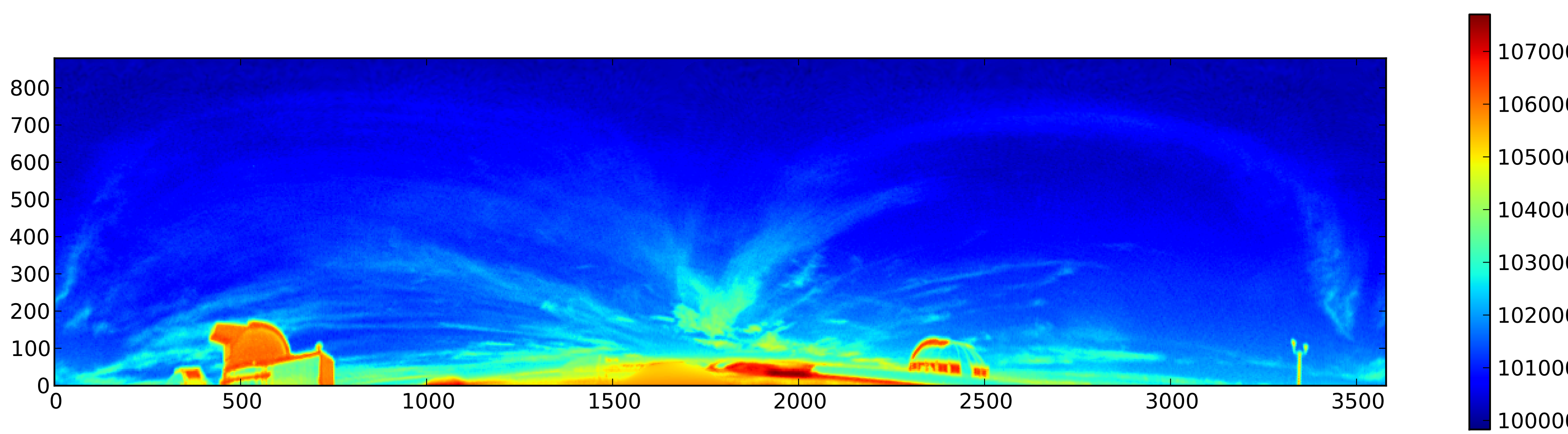
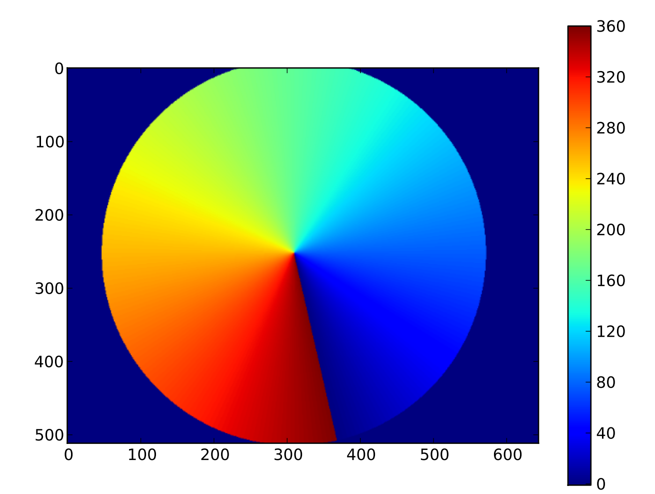
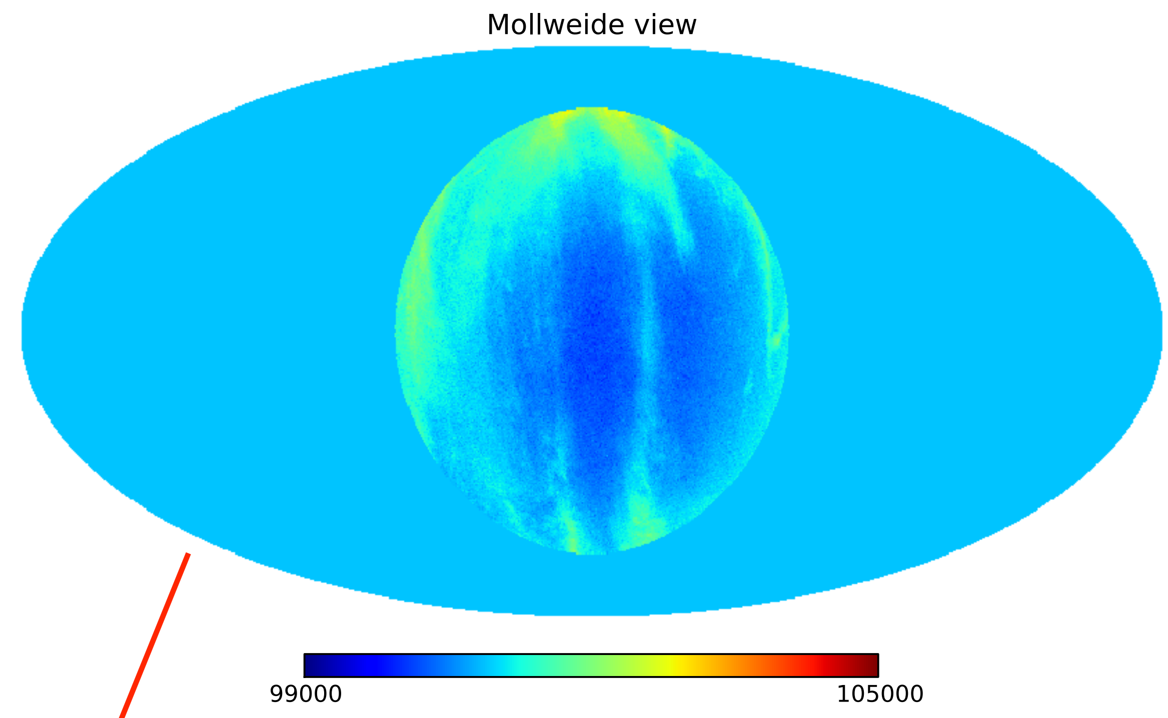








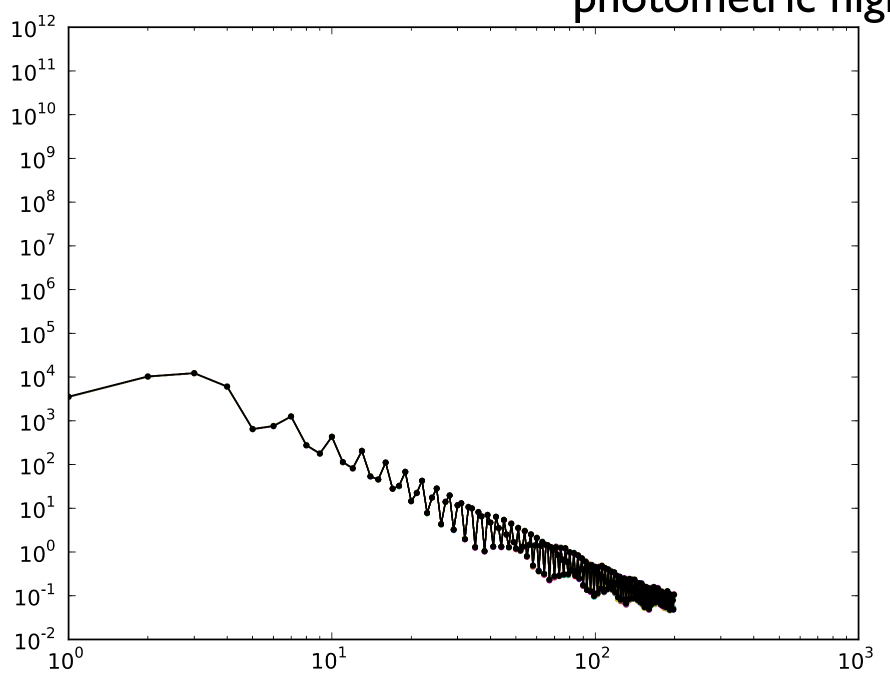
Using CFHT IR camera



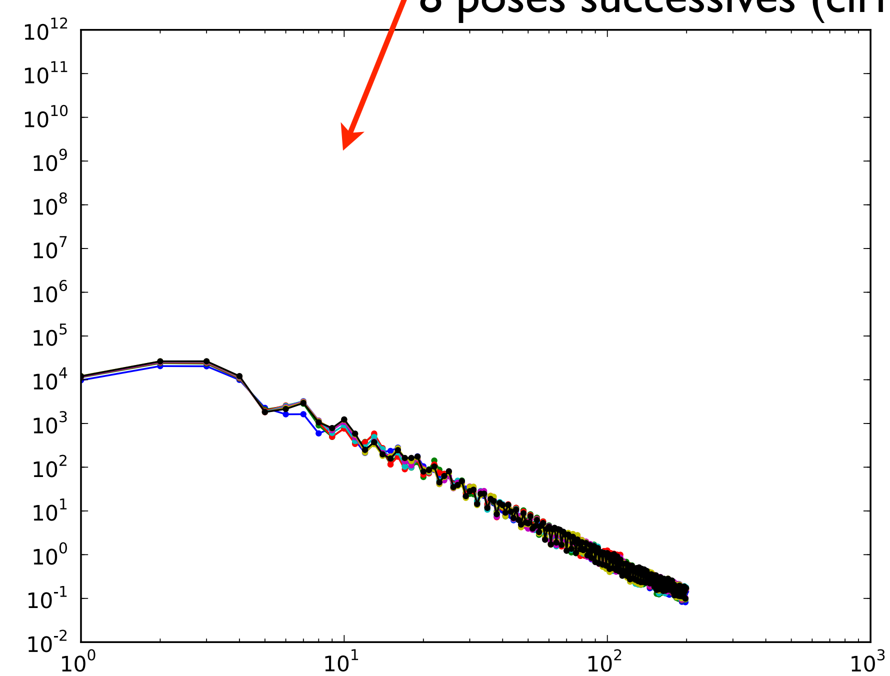
Cut in elevation at 65 deg
Using pixellisation on the sphere

Study of the power spectrum of the partial sky

photometric night



8 poses successives (cirrus)



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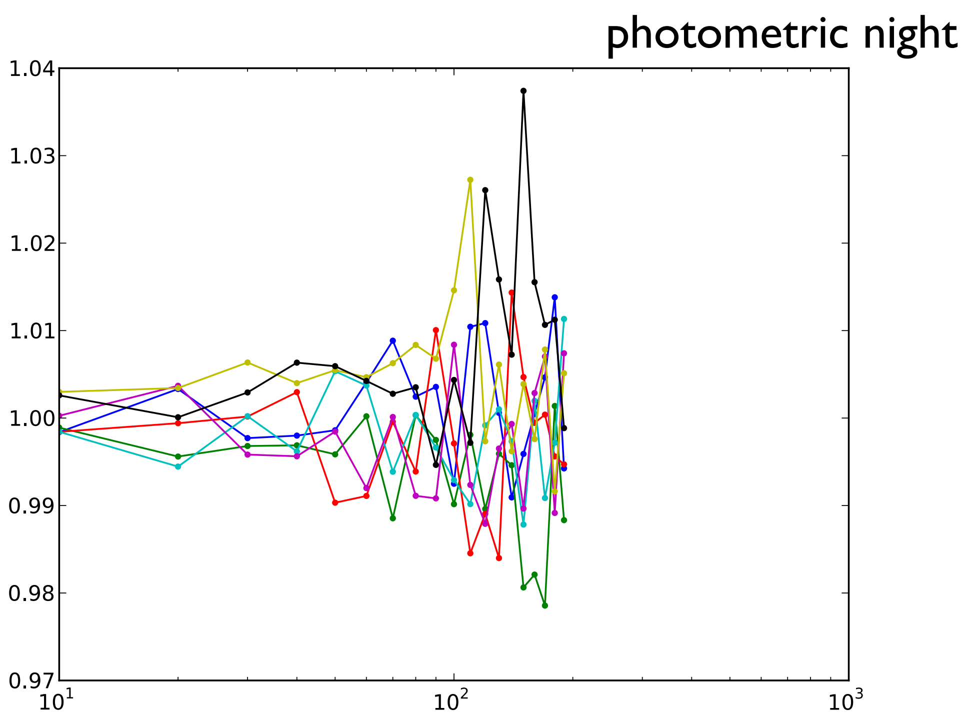

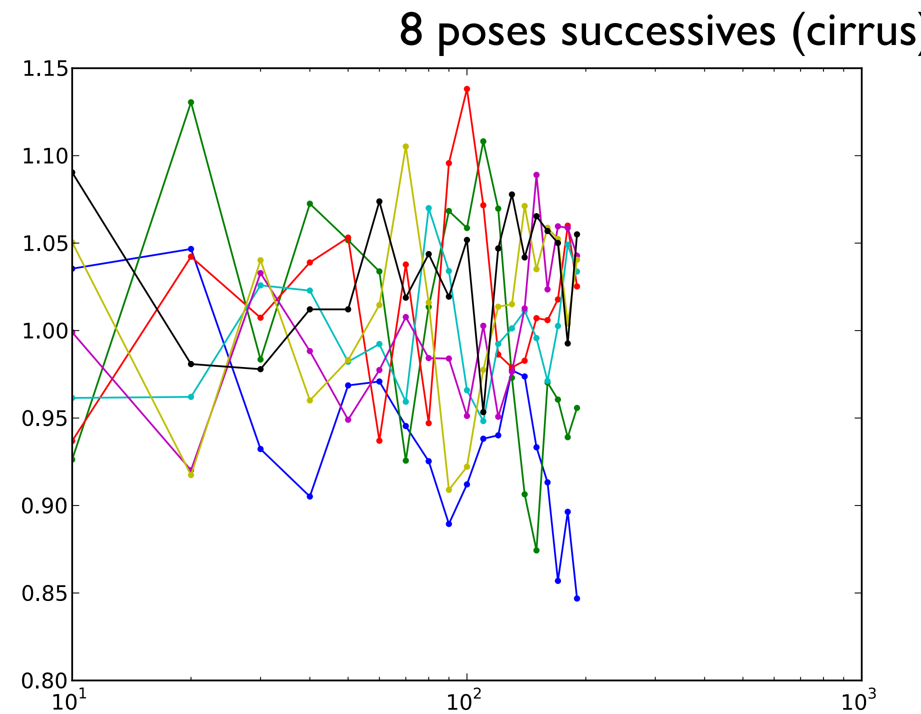

- Variability can be studied at the large scales; possibility of characterization of the general «cloudiness» of an almost clear night

- We can include follow-up (numerous images are available); one can simulate a scenario related to the other parameters of atmospheric simulations

- These cannot be used above l ~ 100 ; pixel size on all sky cameras way too large !

- Small angular scales problem needs the use of an extra instrument : small FoV IR camera needed and will soon be included (FLIR camera FoV 7.6 × 5.7deg 1.3 arcmin 3180 pixels)

Summary

- LSST has to achieve unprecedented quality for photometric calibration even using non strictly photometric nights to achieve its scientific objectives.
- The follow up of the atmospheric conditions to characterize wavelength dependant and gray extinction is key : use of the auxilliary telescope and external information have to be assessed properly.

- Simulations dedicated for the calibration procedure are being built
- knowledge of the cloud cover structure is needed
- Atmospheric monitoring data have been included for cloud cover and better characterisation of the cloud effect at the pixel scale of LSST will be added
- Study of aerosols also needed to assess the use of monitoring tools and methods for calibration of wavelength dependant effects

Thank you !

LSST
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