Optics update

Large Synoptic Survey Telescope

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9-17-08

Camera Workshop

Optical Design: Reference Design Parameters

- Camera optical element prescription is established by V3 of the observatory optical design
  - Optical design of camera lenses and filters is integrated with optical design of telescope mirrors to optimize performance
  - 3 refractive lenses with clear aperture diameters of 1.55m, 1.02m and 0.70m
  - 6 interchangeable, broad-band, interference filters with clear aperture diameters of 0.76m
- Why are transmissive optics required?
  - L3 required as vacuum barrier (6 cm thick) for focal plane cryostat
  - Filters required for science program
  - L1 & L2 required to minimize chromatic effect of L3 and filters
- Baseline LSST optical design produces image quality with 80% encircled energy <0.3 arc-second

Camera Optical Element Design Requirements

	Lenses			Filters					
Clear Aperture Dims	**L1**	**L2**	**L3**	**u**	**g**	**r**	**i**	**z**	**y**
Surface 1 vertex to FPA	1031.950	537.080	88.500	149.500	149.500	149.500	149.500	149.500	149.500
Surface 2 vertex to FPA	949.720	507.080	28.500	123.300	128.360	131.700	133.800	135.300	136.000
Center thick.	82.230	30.000	60.000	26.200	21.140	17.800	15.700	14.200	13.500
Clear aperture rad.	775.000	551.000	346.000	375.000	375.000	375.000	375.000	375.000	375.000
Surface 1 spherical rad.	2824.000	1.000E+15	3169.000	5624.000	5624.000	5624.000	5624.000	5624.000	5624.000
Surface 2 spherical rad.	-5021.000	-2529.000	-13360.000	-5513.000	-5564.000	-5594.000	-5612.000	-5624.000	-5624.000
Sagitta of Surface 1	108.424	0.000	18.945	12.516	12.516	12.516	12.516	12.516	12.516
Sagitta of Surface 2	-60.172	-60.754	-4.481	-12.769	-12.651	-12.583	-12.543	-12.516	-12.516
Thick. at Clr Aperture	33.977	90.754	45.536	26.453	21.275	17.867	15.727	14.200	13.500

*All dimensions in mm except as noted "Approx Physical Dims" are for reference only

Optical Design: Reference Design Tolerances

- **Positioning and prescription tolerances of lenses and filters have been developed**
- **The table below shows the rigid-body and prescription tolerances resulting from the tolerance analysis studies**
  - **The remaining tolerances that are yet to be defined are non-rigid body distortion limits and allowed relative deflections of elements → this is being analyzed now**

Optical Element Positioning and Fabrication Tolerances

	Optical Element						Tol
Tolerance	L1	L2	L3	FPA	Filter	Unit	Type[+]
X	100.000	100.000	100.000		100.000	microns	2
Y	100.000	100.000	100.000		100.000	microns	2
Z	100.000	100.000	100.000	100.000	100.000	microns	2
Theta_X	0.0070	0.0100	0.0150	0.0167	0.015	degrees	2
Theta_Y	0.0070	0.0100	0.0150	0.0167	0.015	degrees	2
Surface 1 Spherical Radius	2.000		4.000		6.000	mm	1
Surface 1 Curvature		2.0E-08				1/mm	1
Surface 1 Conic			0.0020			--	1
Thickness	0.200	0.250	0.500		0.500	mm	1
Surface 2 Spherical Radius	3.000	2.000	100.000		6.000	mm	1
Surface 2 Conic		0.0002				--	1
Surface 2 A3*r^6		TBD				mm^-5	1
Wedge	20.000	20.000	30.000		30.000	arcsec	2

*All values are the half-amplitude value of a +/- tolerance

[+] Type 1: prescription errors   Type 2: rigid-body placement errors   Type 3: residuals from compensator palcemer

Filter Update

3.1 Optical Coatings

LSST camera optics require two distinct types of optical coatings:

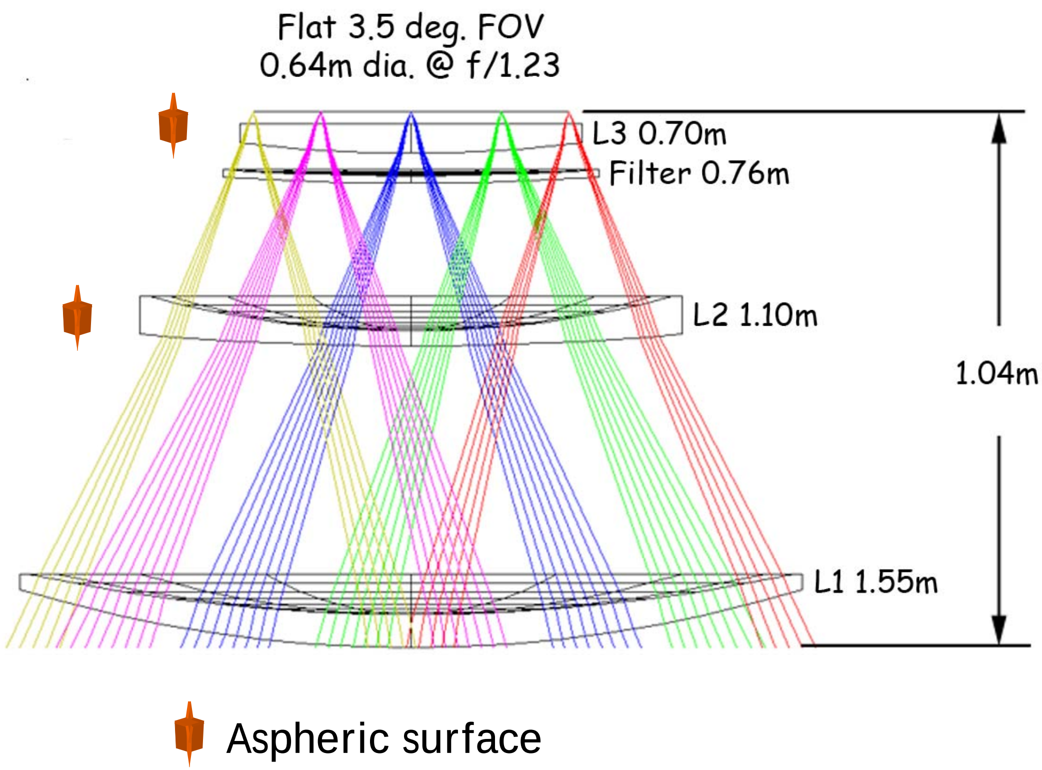
1. Anti-reflection (AR) coatings,
2. Band-pass coatings.

The filters require both types of coatings while the lenses require only AR coatings.

Optical Coatings Proposal Schedule:

July 28, 2008	RFP Issued
Aug 04, 2008	All questions due
Sep 15, 2008	Proposal Submittal date
Oct 30, 2008	Anticipated Award date
Mar 30, 2010	Prototype contract deliverables sent to LSST (LLNL) for evaluation
Sep 1, 2010	Science Contract negotiations with vendors to begin

The camera optical design produces a flat focal plane



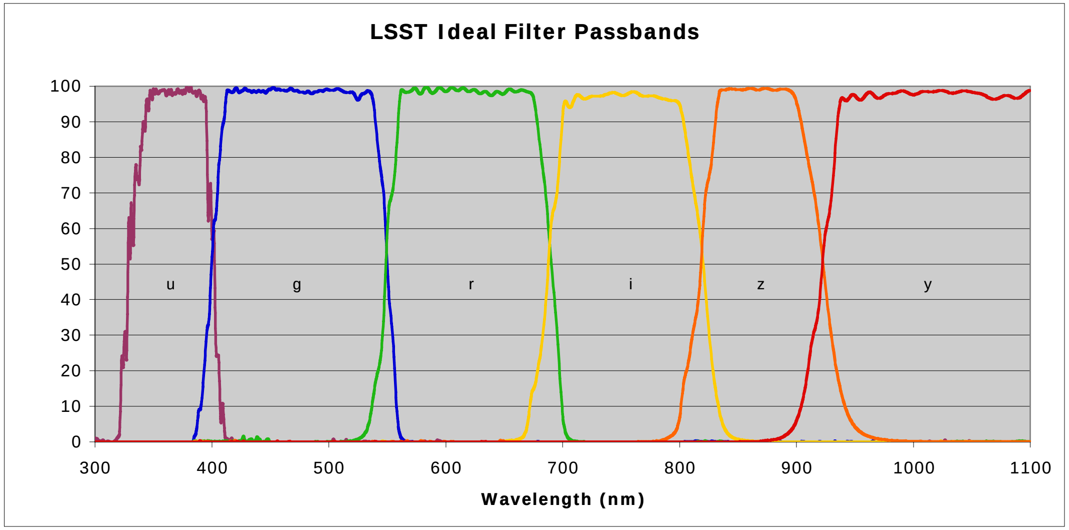
- **LSST camera optical design includes, 3 large lenses and a set of 6 large transmission filters**
- **Integrated design of lenses improves design**
  - **For example, adding asphericity to L2 simplifies testing and helps to reduce asphericity on secondary mirror**

Filter band-pass is based on a combination of scientific considerations

Specs

Half-Maximum Transmission Wavelength			
	Blue Side	Red Side	Comments
U	350	400	Blue side cut-off depends on AR coating
G	400	552	Balmer break at 400 nm
R	552	691	Matches SDSS
I	691	818	Red side short of sky emission at 826 nm
Z	818	922	Red side stop before H_2O bands
Y	948	1060	Red cut-off before detector cut-off

- 75 cm dia.
- Curved surface
- Filter is concentric about the chief ray so that all portions of the filter see the same angle of incidence range, 14.2º to 23.6º



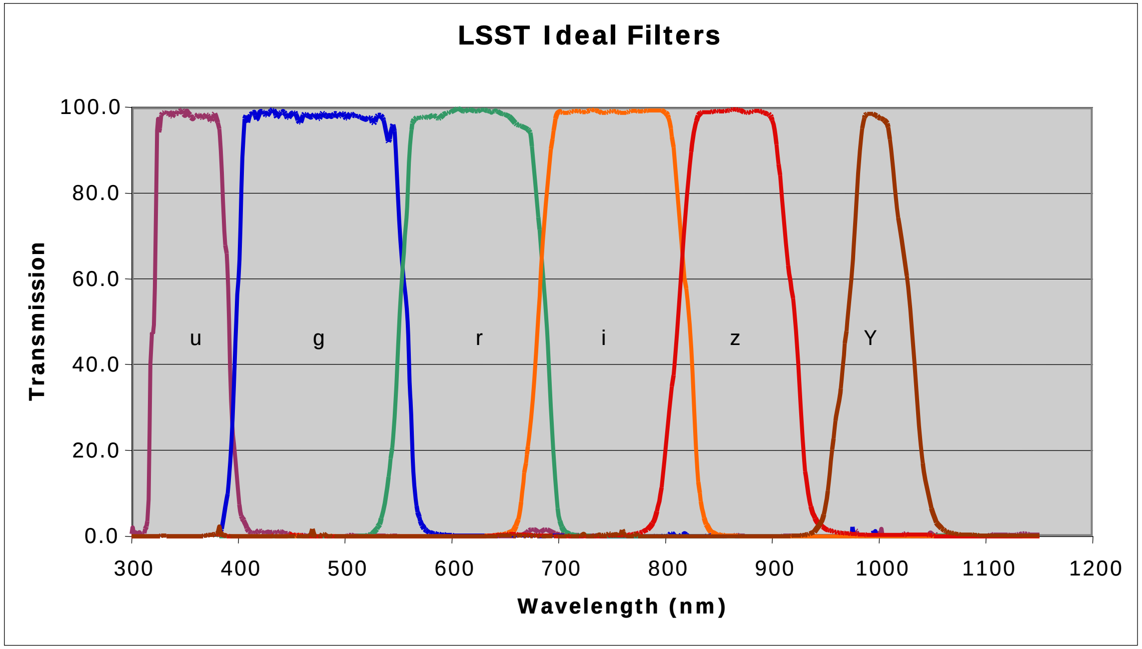
Uniform deposition required at 1% level over entire filter

Filter Band Pass Transitions

Optical Design: Filter Reference Design

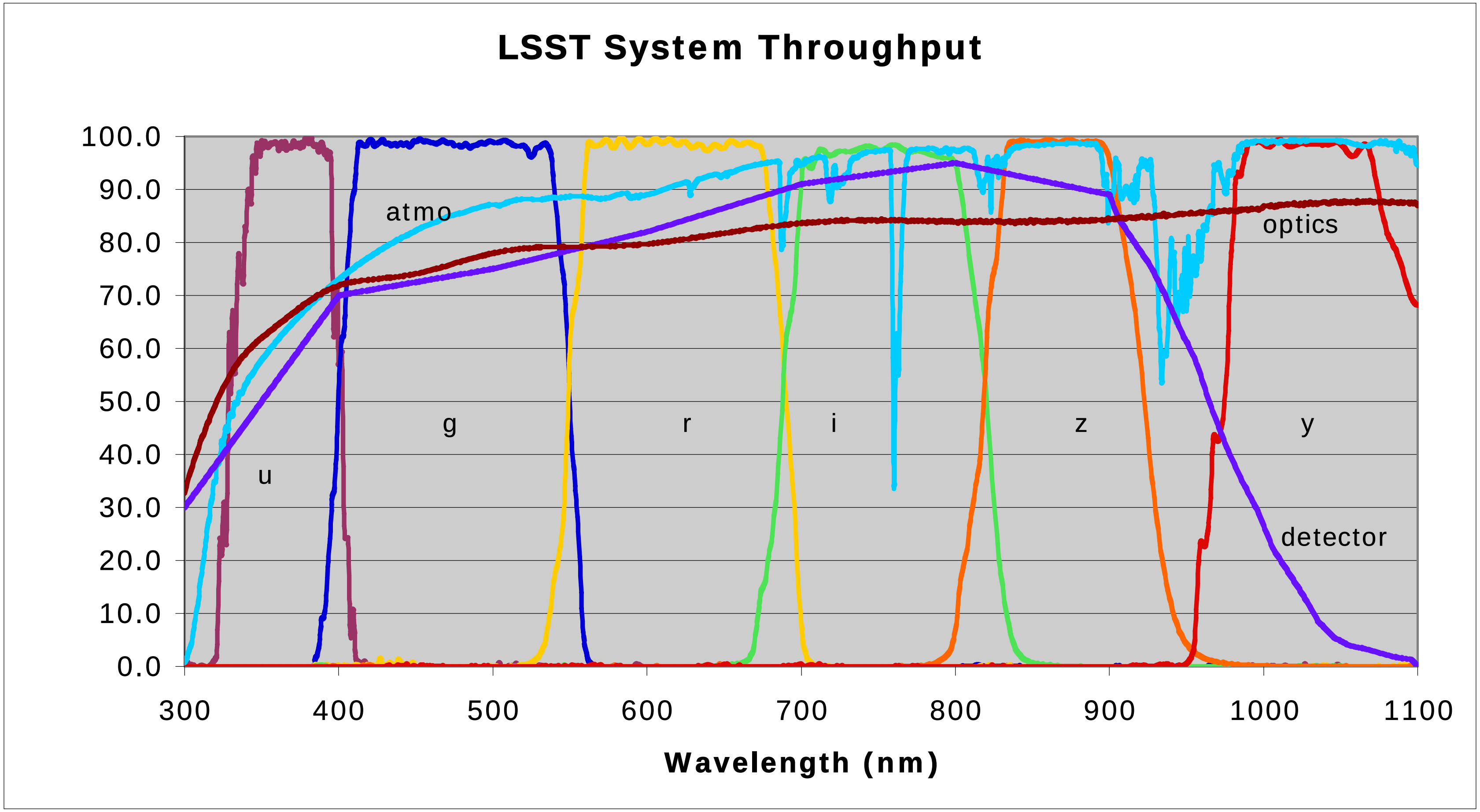
- **Filter band-pass characteristics are defined based on a combination of scientific considerations**

Half-Maximum Transmission Wavelength			
	Blue Side	**Red Side**	**Comments**
U	330	400	Blue side cut-off depends on AR coating
G	400	552	Balmer break at 400 nm
R	552	691	Matches SDSS
I	691	818	Red side short of sky emission at 826 nm
Z	818	922	Red side stop before H_2O bands
Y	930	1070	Red cut-off before detector cut-off

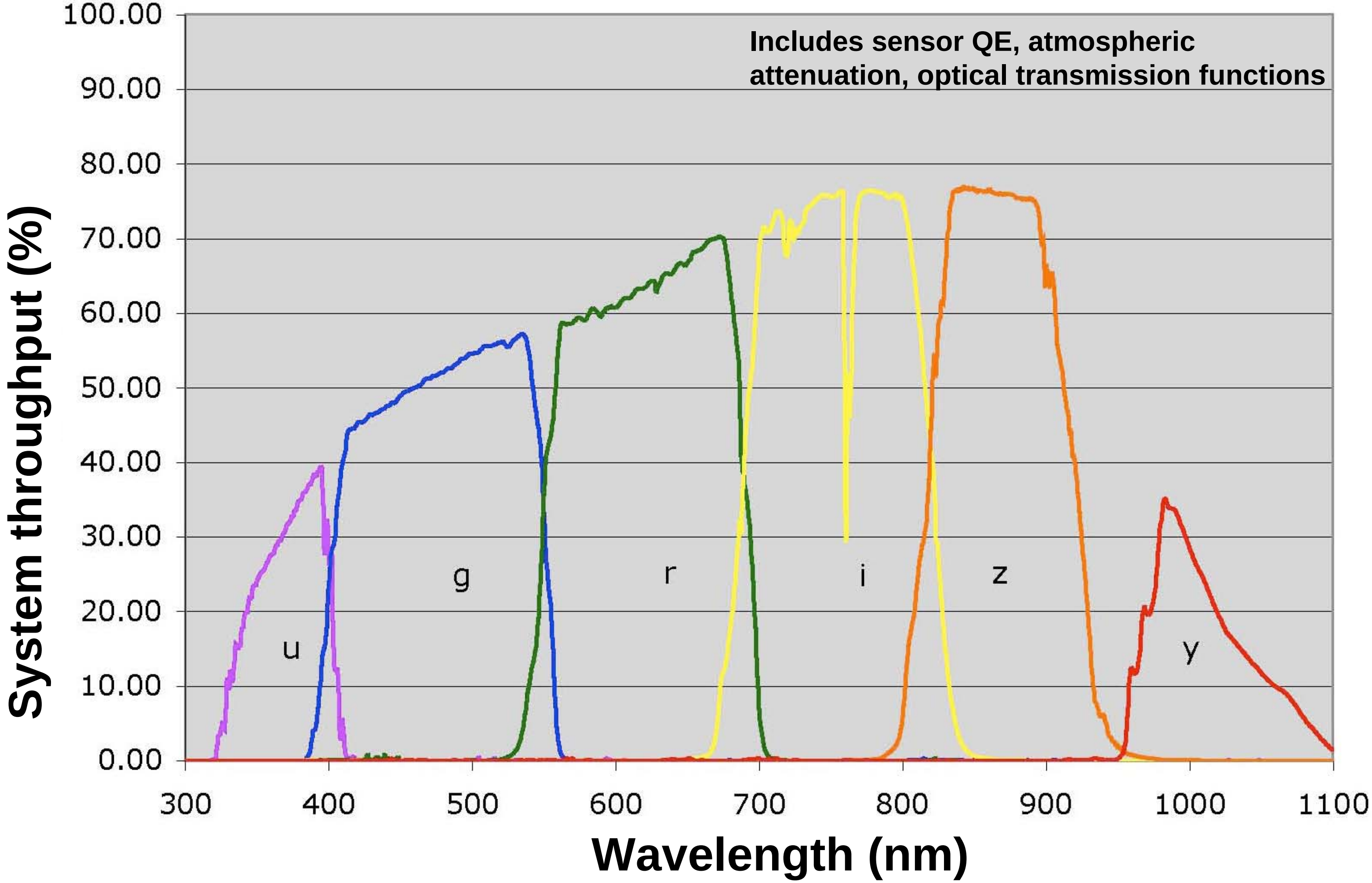


Filter Band Pass Transitions

LSST system throughput parameters



LSST system spectral throughput in the six filter bands



Design Considerations

Leak Update

QuickTime™ and a
decompressor
are needed to see this picture.

Orig Design

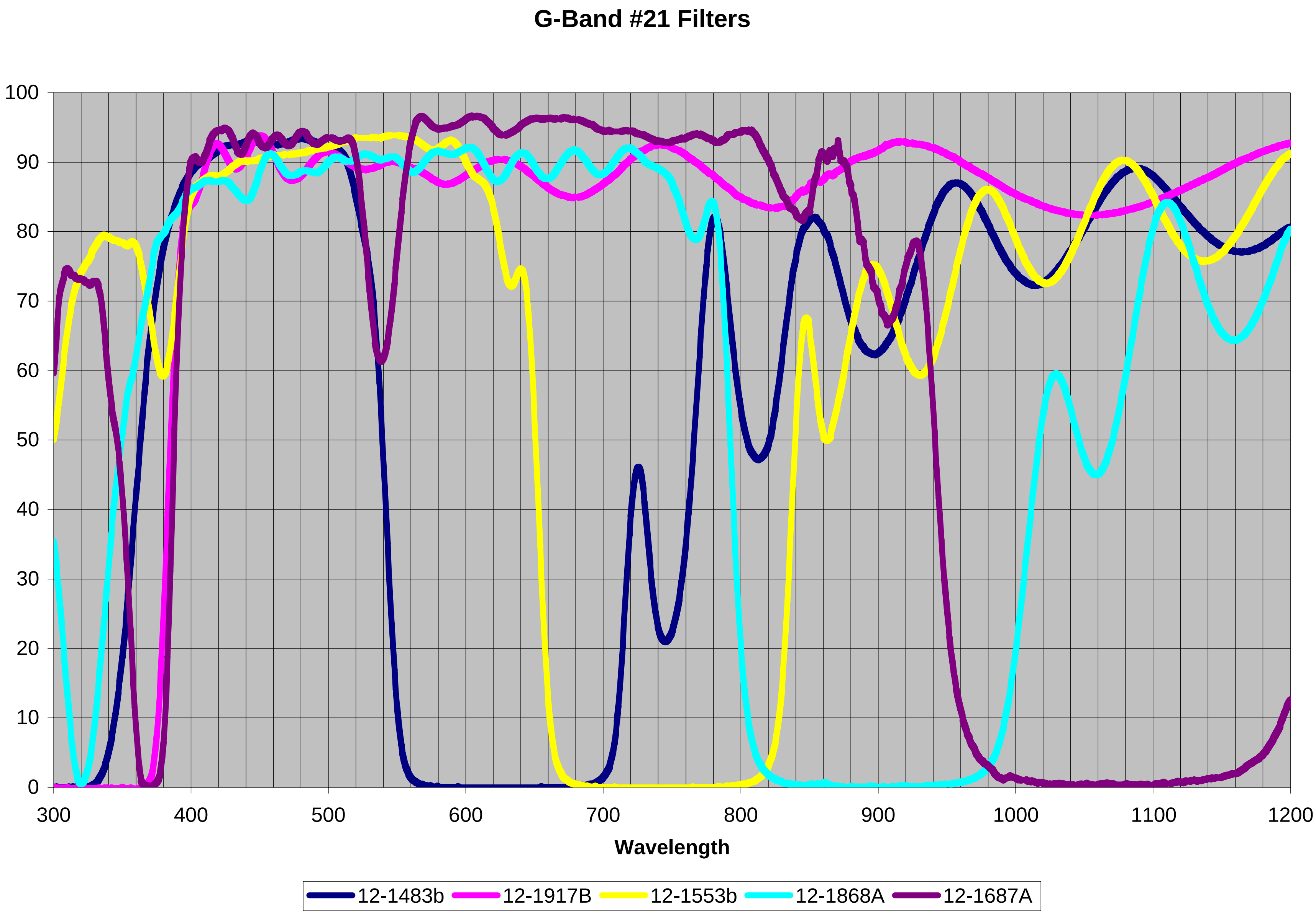
Updated
Design

QuickTime™ and a
decompressor
are needed to see this picture.

Y-Band Options (Y2, Y3 and Y4)

QuickTime™ and a
decompressor
are needed to see this picture.

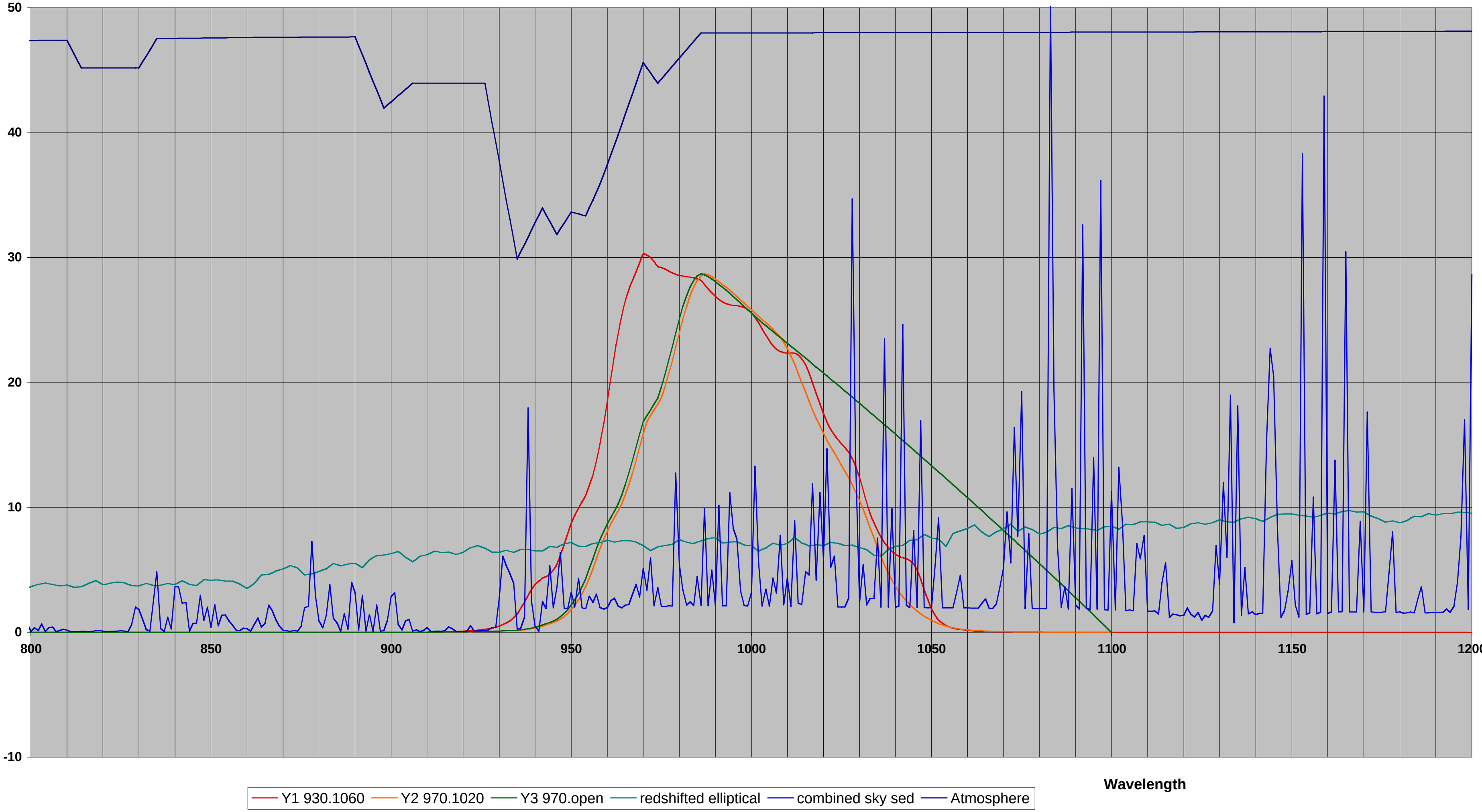
QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.


G-Band #21 Filters
100
90
80
70
60
50
40
30
20
10
0
300
400
500
600
700
800
900
1000
1100
1200
Wavelength
12-1483b
12-1917B
12-1553b
12-1868A
12-1687A

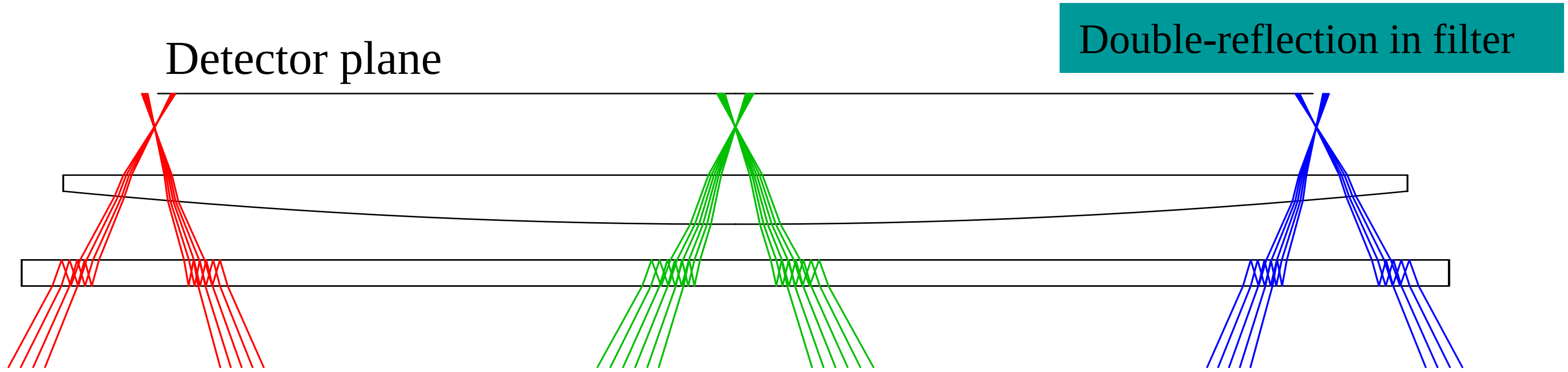
OH Emission

- Source - Bright airglow produced by a chemical reaction of hydrogen and ozone in the Earth's upper atmosphere
- Band system is due in part to emission from vibrationally excited OH radicals produced by surface interactions with ground-state oxygen atoms.
- Emission can vary 10-20% over a 10 minute period
- Ramsey and Mountain (1992) have reported measurements of the nonthermal emission of the hydroxyl radical and examined the temporal and spatial variability of the emission.

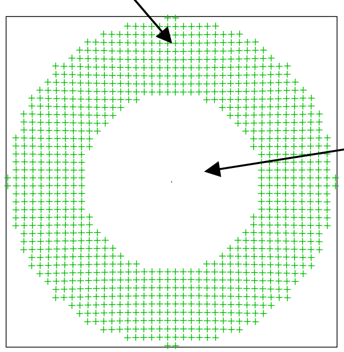
Comparison of Y1, Y2, and Y3



Ghost analysis shows worst case is double-reflection from thinnest spectral filter



Ghost halo: 14 mm ϕ



Relative intensity of ghost image to primary image

$I = [\,S / G\,]^2 R_1 R_2$, S = image diameter = 0.020 mm

G = ghost image diameter = 14 mm

R = surface reflectivities = 0.01

$I = 2.0 \times 10^{-10}$ = ~ 24 visual magnitude difference

S/N Calculations in Y-band

By Seeing

Seeing = 0.500

n	source type	z	Y1	Y2	Y3
400	elliptical-galaxy	0	16.51	14.26	17.11
400	elliptical-galaxy	1	16.55	14.30	17.36
400	elliptical-galaxy	2	15.88	14.15	17.54

Seeing = 0.750

n	source type	z	Y1	Y2	Y3
400	elliptical-galaxy	0	11.08	9.59	11.49
400	elliptical-galaxy	1	11.11	9.62	11.65
400	elliptical-galaxy	2	10.65	9.52	11.78

Seeing = 1.000

n	source type	z	Y1	Y2	Y3
400	elliptical-galaxy	0	8.32	7.21	8.63
400	elliptical-galaxy	1	8.34	7.23	8.75
400	elliptical-galaxy	2	8.00	7.15	8.85

Seeing = 1.250

n	source type	z	Y1	Y2	Y3
400	elliptical-galaxy	0	6.66	5.77	6.91
400	elliptical-galaxy	1	6.68	5.79	7.01
400	elliptical-galaxy	2	6.41	5.73	7.08

By Num of Exposures

n	source type	z	Y1	Y2	Y3
25	elliptical-galaxy	1	2.09	1.81	2.19
50	elliptical-galaxy	1	2.95	2.56	3.10
75	elliptical-galaxy	1	3.61	3.13	3.79
100	elliptical-galaxy	1	4.17	3.62	4.38
125	elliptical-galaxy	1	4.66	4.04	4.89
150	elliptical-galaxy	1	5.11	4.43	5.36
175	elliptical-galaxy	1	5.52	4.78	5.79
200	elliptical-galaxy	1	5.90	5.11	6.19
225	elliptical-galaxy	1	6.26	5.42	6.57
250	elliptical-galaxy	1	6.60	5.72	6.92
275	elliptical-galaxy	1	6.92	6.00	7.26
300	elliptical-galaxy	1	7.22	6.26	7.58
325	elliptical-galaxy	1	7.52	6.52	7.89
350	elliptical-galaxy	1	7.80	6.77	8.19
375	elliptical-galaxy	1	8.08	7.00	8.48
400	elliptical-galaxy	1	8.34	7.23	8.75

By Source

n	source type	z	Y1	Y2	Y3
400	elliptical-galaxy	0	8.32	7.21	8.63
400	elliptical-galaxy	1	8.34	7.23	8.75
400	elliptical-galaxy	2	8.00	7.15	8.85
400	spiral-galaxy	0	8.34	7.21	8.61
400	spiral-galaxy	1	7.74	7.30	7.75
400	spiral-galaxy	2	8.25	7.20	8.66
400	G5V	0	8.39	7.25	8.48
400	G5V	1	8.33	7.22	8.65
400	G5V	2	7.86	7.12	9.00

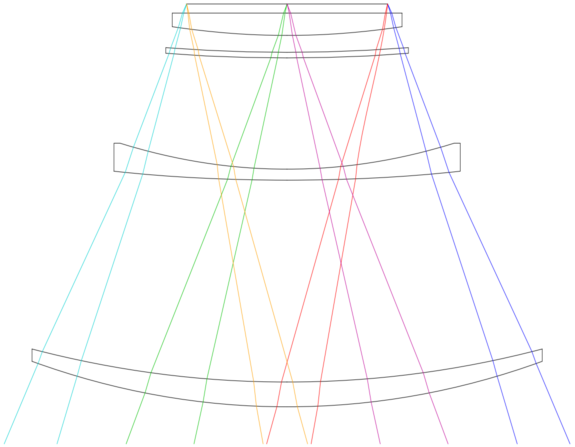
Lab/Telescope Dewar for filter and detector evaluation

QuickTime™ and a
decompressor
are needed to see this picture.

Vendor Considerations

We have identified qualified vendors for the fabrication of large, thin, transmissive optics

- **Discussions initiated with multiple vendors**
  - **L3-Brashear**
  - **Goodrich**
  - **Tinsley**
  - **ITT**
- **Substantial industrial base exists to fabricate large, thin optics**
- **Industry estimates of cost and schedule to fabricate these large, thin optics have been used as input for LSST camera optics schedule and budget**



Optics Fabrication

- **Corning manufacturing process for fused silica can produce glass of the required size and quality**

- **Corning estimates of cost and schedule to produce the required fused silica glass have been used as input for LSST camera optics schedule and budget**

We have identified qualified vendors for coating of large, thin, transmissive filters

- Discussions initiated with multiple vendors
  - JDS Uniphase
  - Infinite Optics
  - SAGEM
  - Asahi Spectra
- Substantial industrial base exists to coat large, thin filters
- Industry estimates of cost and schedule to coat these large, thin optics have been used as input for LSST camera optics schedule and budget
  - These estimates include a risk reduction study during the R&D phase

120-inch coating chamber

NOVA Laser Fusion Optics

Filter Procurement Process

Design Study
- Define performance tradeoffs including shape coating designs, uniformity, repeatability
- Define possible parameters to relax without compromising science (Reduction in cost)

Risk Reduction Study
- Engineering proof of concept.
- Required uniformity and spectral performance developed and tested
- Fabrication risks identified and addressed
- Create witness samples – Develop final cost/schedule estimates

Production of Filters
- Create handling tools – AR coat filters

Vendor R & D Tasks

1. Establish procedures to distribute a uniform coating over the entire filter surface. This includes evaluating several coating techniques to determine best method of coating.

2. Set-up test procedures to measure optical performance of filters.

3. Determine optical quality of glass and coatings necessary for rejecting out-of-band transmissions.

4. Develop techniques to ensure wavelengths of pass band edges are met.

5. Establish ability to coat on two sides for spectral performance.

6. Determine exact substrate thickness to achieve desired performance goals.

7. Monitor techniques to reduce variations.

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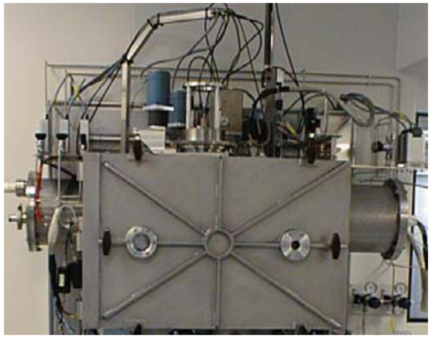
LMA Effort

LMA IBS (Ion Beam Sputtering) deposition Facilities

- Small IBS coater
  - Able to coat homogeneously up to 3“ substrates
    - ✓ Continual upgrades since 199
  - Very flexible machine ⇒ ideal for prototyping

Small IBS coater



- Large IBS coater
  - ✓ 2,4 m X 2,4 m X 2,2 m inner deposition chamber
  - ✓ Designed to coat substrates up to 1 meter diameter
  - ✓ Used for VIRGO large mirrors since 2001
    - ❖ Periodic quarter wave doublet stacks (Ta_2O_5 and SiO_2)
    - ❖ Between 120 and 180 nm layer thickness

350 mm diameter VIRGO mirrors

Large IBS Coater

LSST Filters uniformity

- **LSST filter shape (clear aperture of 750 mm and 12,5 mm of sagitta**
  - **⇒ use of**

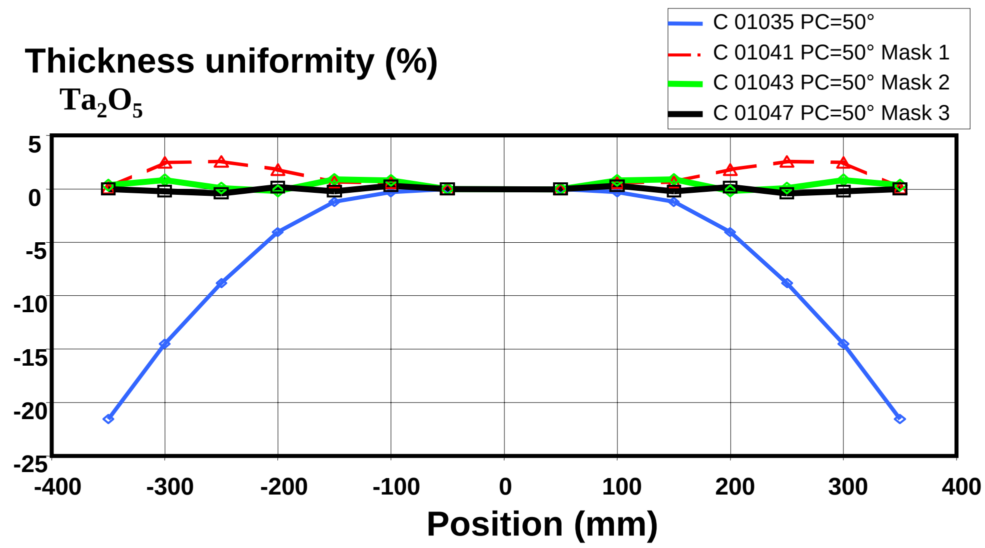
Corrective mask technique

To have the required uniformity

✓

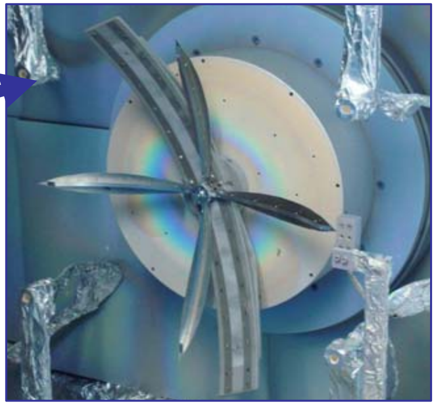
✓ **Previous LMA successfull works**

- **Uniformity thickness control for large VIRGO mirrors**
- **Gradient index profile on aspherical mirrors : diameter 550 mm and 120 mm sag**



Iterative masking process (3 steps)

⇒ Final uniformity : 3.10^{-3} over ∅ 700 mm



LSST filter design

Optical stack for the R band (552 – 691 nm) optimized with TFCalc software

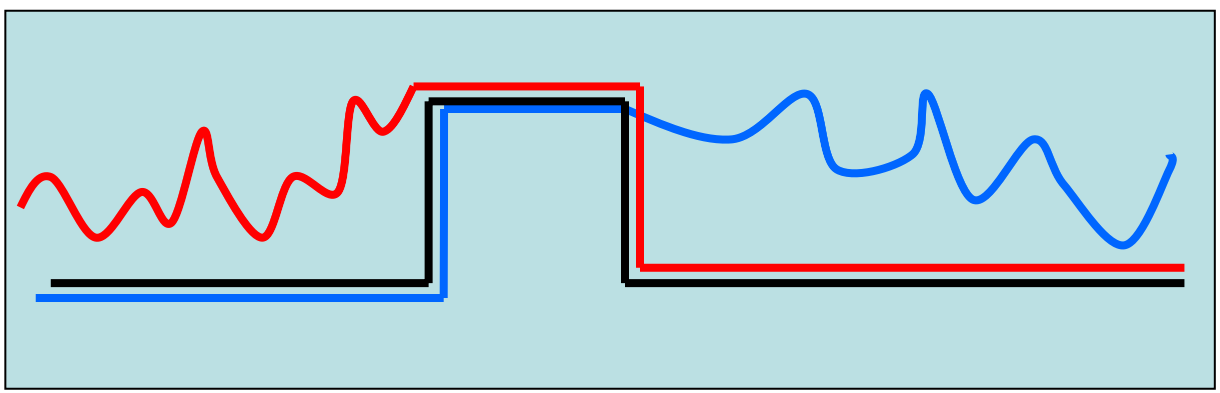
at 18.9 ° (average angle of incidence)

- **The first optimizations with different materials show that the stack thickness needed for such filters is >> to 15 µm**

  ⇨ problem of stress and adhesion

⇩

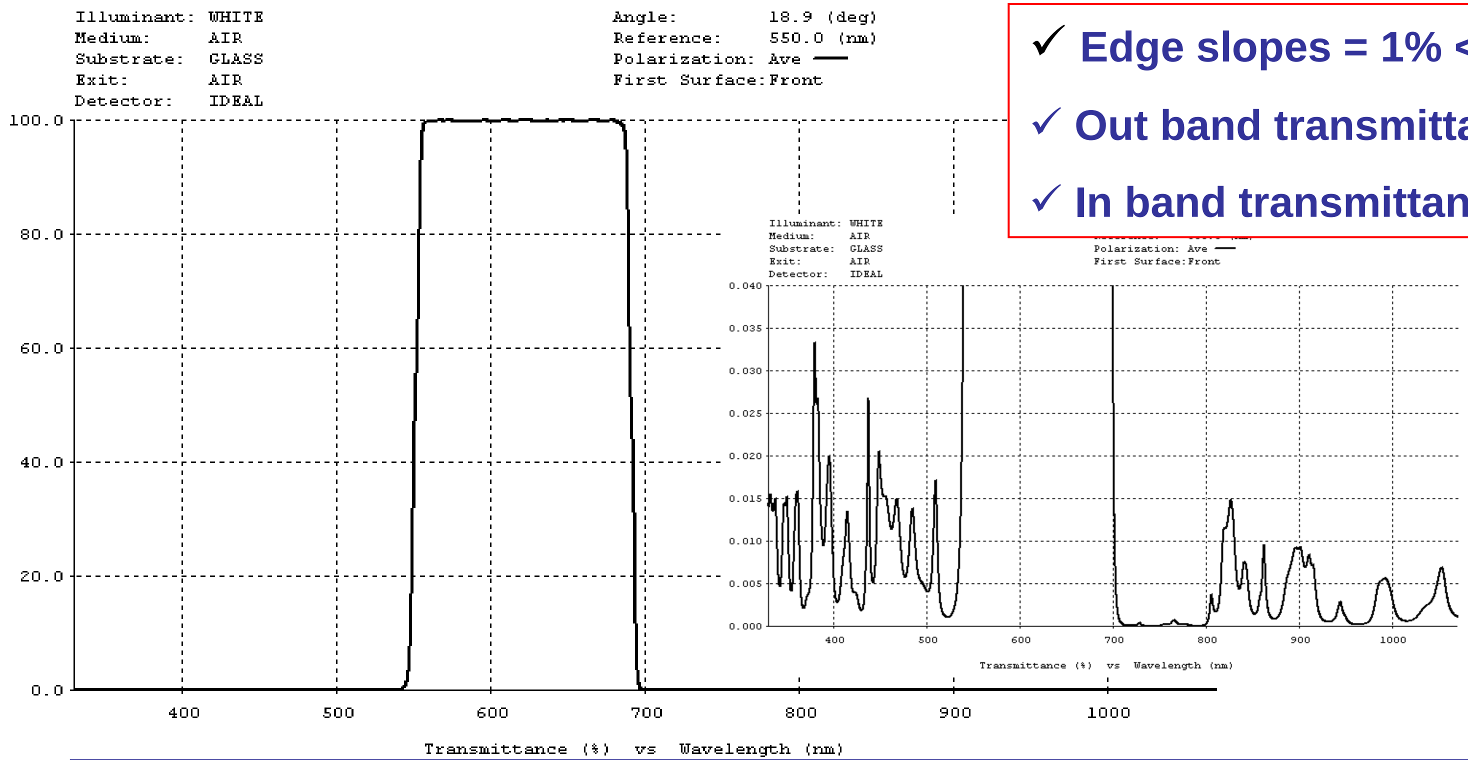
Solution : pass band = low-pass band + high-pass band



- **We coat the low band on one side of the filter substrate**
- **We coat the high band on the other side**

LSST filter design

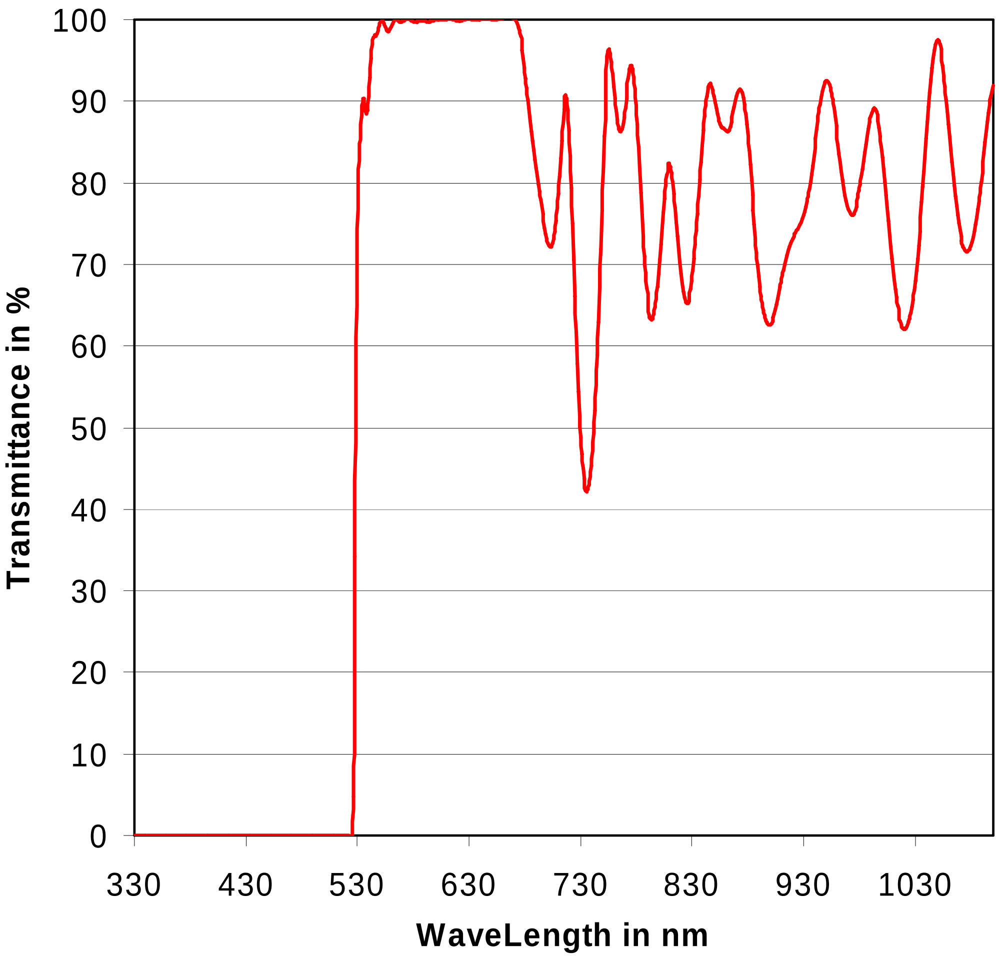
- R Pass band (552 nm -691 nm) optimization with tantala Ta_2O_5 and silica SiO_2



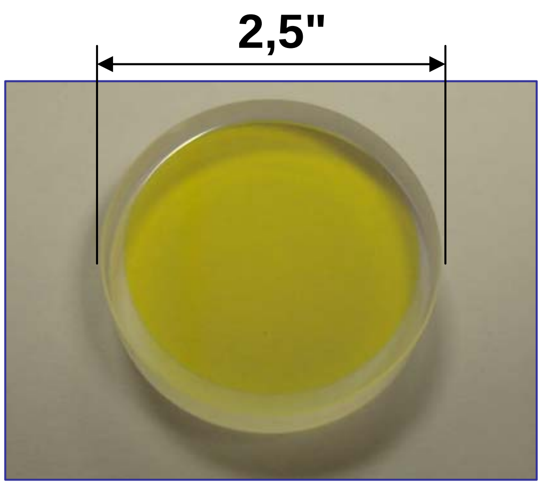
- ✓ Edge slopes = 1% < 5%
- ✓ Out band transmittance = 0.01 %
- ✓ In band transmittance = 99.75 %

- ➢ More than 100 layers on each substrate side
- ➢ Single layer thickness between few 10’s nm and few 100’s nm
- ➢ Total thickness = 20 µm (>> 5 µm VIRGO mirrors)
- ➢ No periodicity in the stack (not the case for VIRGO mirrors)

R Band test in the small IBS coater (july 2008) : Blue side



Spectrophotometer Data



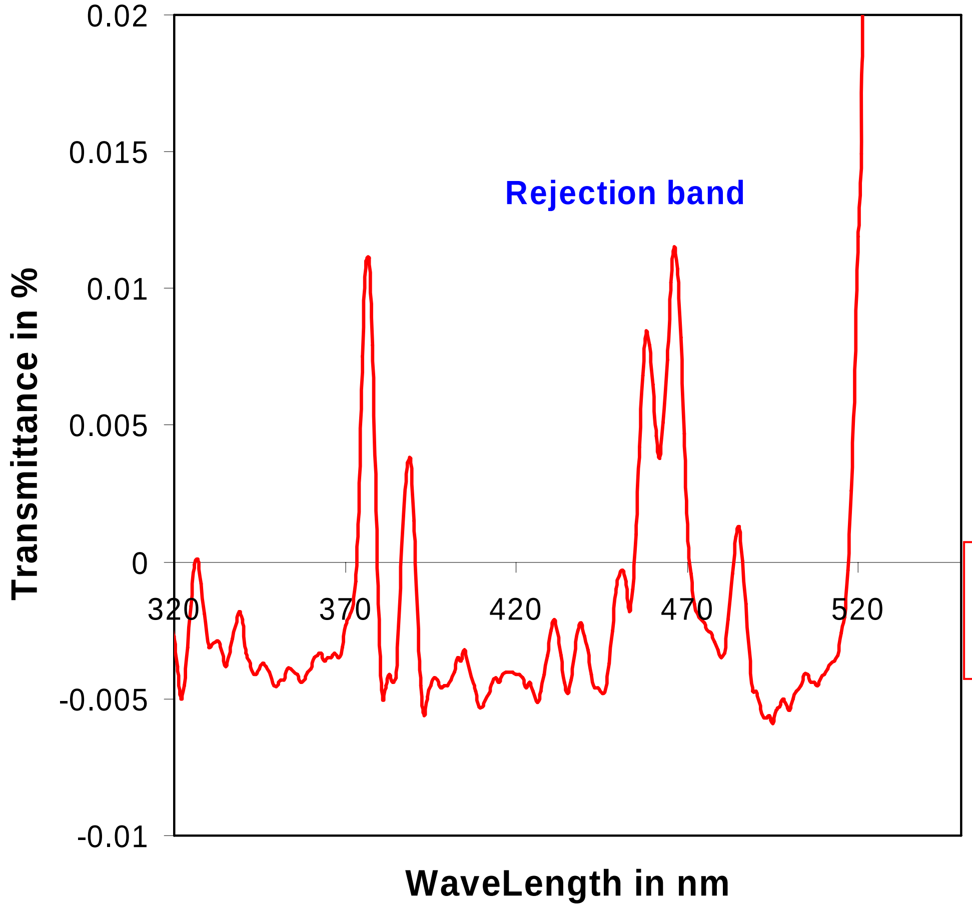
✓ **transmittance ~ 100 % OK**

✓ **edge slope = 2,5 % OK**

✓ **edge position : 20 nm redshift compare to the ideal R band filter**

- ➢ **better control of the layer thickness needed**
- ➢ **instability of the filament ion source, life time of the filament limited to 40 hours**

R Band test in the small IBS coater (july 2008) : Blue side



Spectrophotometer Data

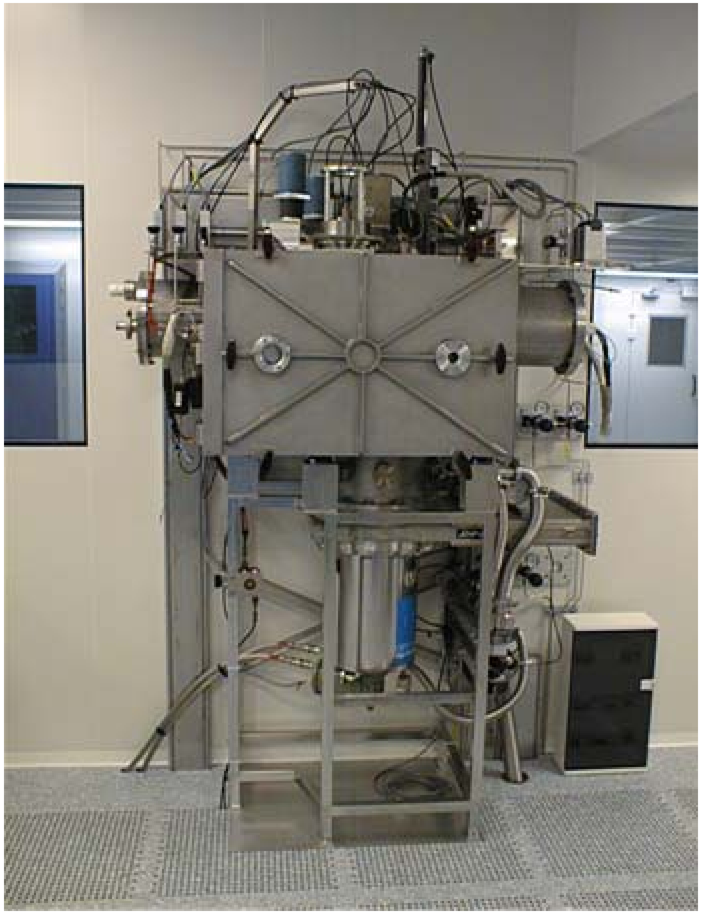
✓out of band transmission : ~OK

- ➢ Problem of the actual spectro-photometer sensitivity ⇒ on going purchase of a new one

Some 2,5“ test samples for the choice of a more sensitive spectrophotometer

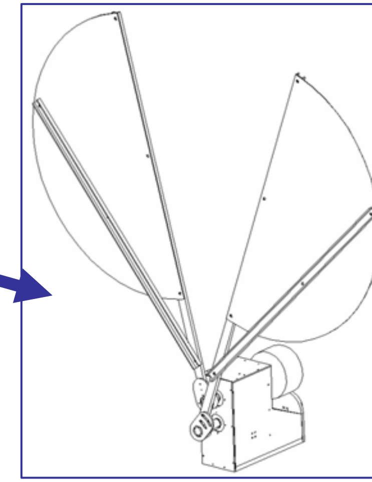
Scheduled works in the small IBS coater

- **In the small IBS coater :**
  - ✓ **Replacement of the filament ion source by a more stable RF ion source**
  - ✓ **Test of new quartz for the QCM (Quartz crystal microbalance) more suitable for the thickness control of dielectric coatings**
    - ➢ Continue coating R band filters on 1"substrates with new configuration (first try scheduled at end 2008)



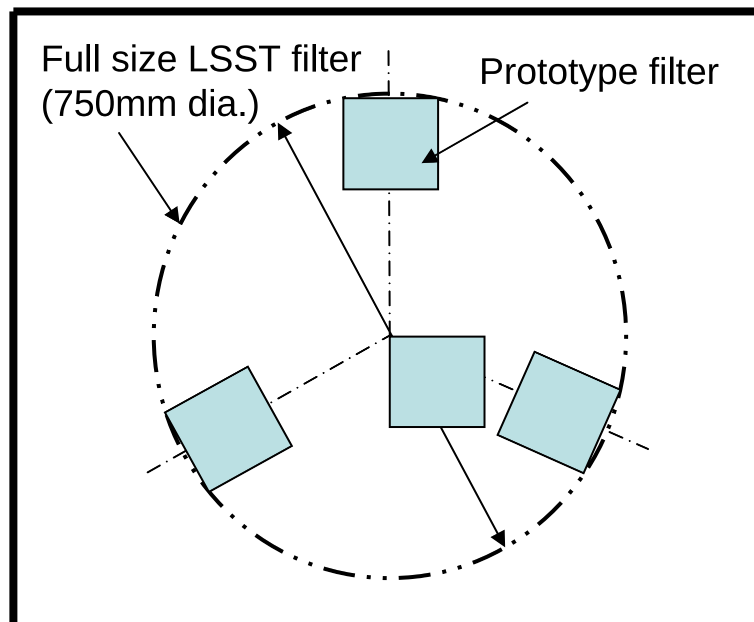
Scheduled work in the Large IBS coater

- **In the large IBS coater : (waiting for financial support)**
  - ✓ **Faster shutter (screen hiding the substrate during the transition between two different layers)**
    - ➢ Design conception : OK
    - ➢ Realisation and mounting in the coater : to be done
  - ✓ **Increase substrate rotation speed : new motor**



New faster shutter design

All this new equipment will boost the thickness control accuracy



Goal : Realisation of 4 R-band filter prototypes on squared silica substrates (around 100 mm by 100 mm)