SuMIRe PFS:

A Large Multifiber Faint-Object Spectrograph for SUBARU

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Subaru UM Jan 2011

Some preliminary considerations

Wavelength range:

The HSC corrector covers the range 3800 -> 13000 A with high efficiency. We need ALL of this range:

For galaxies: 4000A break, 1.2 microns at z=2, reach H delta at z=2

Excellent spectra of L galaxies at z=2 in ~ 2 hrs*

For BAO, [OII] 3727 to z=2.5, Ly-alpha from 2.2 to 10.7

THERE IS NO REDSHIFT DESERT WITH THIS SPECTROGRAPH !!

We can work to AB ~ 24 over the whole wavelength range with reasonable exposures

Technologically not challenging; IR arm can be room temperature.

Technology: The Sky

Working in the IR is incredibly difficult because of the OH airglow, but the sky is reasonably dark between the lines. At low resolution, however, the lines overlap and there IS no `between the lines'.

IR detectors are incredibly expensive—current prices on good 4K^2 HgCdTe devices, 15 micron pixels, 70+% QE, very low dark currents, ~15 electrons read noise per nondestructive read, is ~$700K.

Wavelength coverage vs resolution is thus a crucial tradeoff. Can we cover, say, the 1.0-1.3 micron band at a resolution which does not result in a ridiculously expensive instrument?

We can model the cumulative fraction of pixels which are fainter than some limit as a function of resolving power. Will see that resolving power is dictated by detector size, camera focal ratio, and fiber size.

Resolving power and the Sky

We need high resolving power to work between the OH lines.
If we build a 3-channel spectrograph , using 1.1 arcsecond fibers and 4K x 4K detectors, we could do something like this:

	wavelength	R	50%	60%	70%
	4500	1890	22.4	22.3	22.0
blue(0.38u->0.65i)					
	5500	2380	21.6	21.5	21.4
	7000	2350	21.6	21.4	21.3
red(0.65u->1.0u)					
	9000	3200	20.7	20.4	19.8
	10500	3800	20.4	19.5	18.6
ir(1.0u-> 1.3u)					
	12500	4800	20.1	18.9	17.4

RESOLVING POWER REQUIREMENT IN RED AND IR WITH AVAILABLE DETECTORS DEMANDS A 3-CHANNEL SPECTROGRAPH

What would a system with these parameters look like?

For Subaru,

F/2.24 with HSC corrector. Scale 89μ/arcsec

Need to transform f/ratio with optics (or tapered fibers) to something significantly slower than f/2.4

100u -> 128u : 2.24 -> 2.85 (2.50 w/FRD)

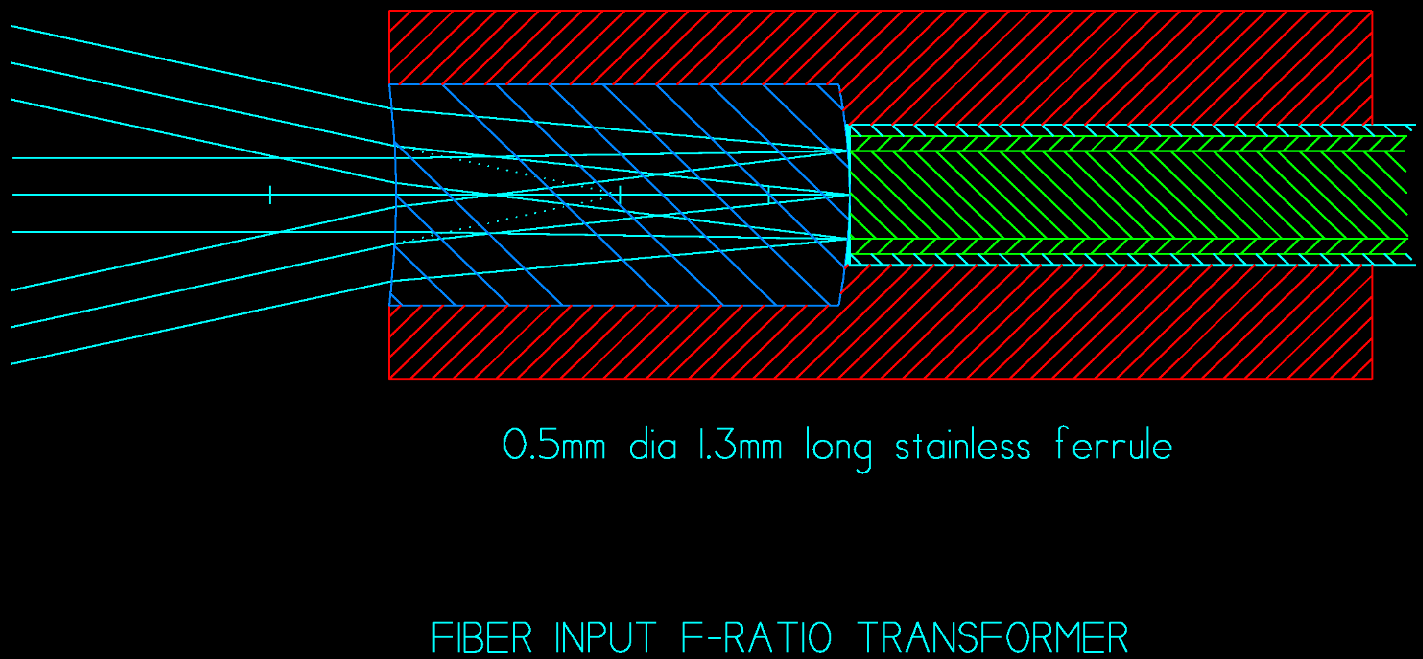
1.1 arcsec -> 9 kpc for z ~ 0.7 or greater.
SDSS has 3 arcsec fibers; z=0.12 -> 7 kpc,

f/1.05 camera, f/2.50 collimator; fiber projects to ~54u
fwhm ~ 47u, 3.13 pixels

1200 resolution elements on 4K pixel detector... sets resolution

A possible (essentially lossless) f/ratio transformer might look like this:

A negative microlens f/ratio transformer for PFS, gel-coupled to fiber, loss ~ 2%



The Spectrographs

Desiderata:

1. High Throughput

2. As wide a wavelength range as is practical

3. Sufficient resolution to
   a. Do the science
   b. Work on faint objects in the red, *between* the OH lines

4. Simple optics to keep the surface count and costs low.

5. A state-of-the-art faint object instrument. This is our chance to make the most powerful (and useful) spectrograph in the world. Let us use it. Subaru is the ONLY large telescope which has a large enough fiele for it to be effectively used. This is a unique opportunity for the Japanese astronomical community.

The Spectrograph Optics

1. Want few elements to minimize light loss, cost

2. Simplest fast camera is Schmidt. One aspheric, two refractive elements, simple spherical mirror.

3. Disadvantage: Detector is at prime focus of mirror, IN THE BEAM.
   => Beam must be large.
   How large? 4Kx4K 15u detector is 62mm square
   250mm beam has 8% obscuration, OK. Camera IS the dewar.

4. Why 250mm??

5. Kaiser can make superb 280mm VPH gratings in one shot, no bigger. Angles such that 250mm beam is OK. Cost ~$40K

Bad news: Simple Schmidt does not make good enough images.
Baker-Nunn lesson: First-order correction with aspherics on both surfaces of thick corrector is OK. Canon can make and test such surfaces.

The Spectrograph Configuration

1. Need R ~ 3000 or greater in the red (.7->1u) and 4000 or greater in the IR (1->1.3u) to work with the sky OH.

2. Science (?) says R~2000 in the blue is OK (lessons from SDSS).

3. To go from ~4000 to 1.3u requires 3 channels to meet the resolution requirements with an f/1 camera and 1" fibers with 4K^2 15u pixel detectors.

4. Propose 3 channels:

3800 – 6700A	R=2050 at center
6500 – 10000A	R=2950 at center
9700 – 13000A	R=4350 at center

f/1.05 camera f/2.5 collimator

The Spectrograph Configuration

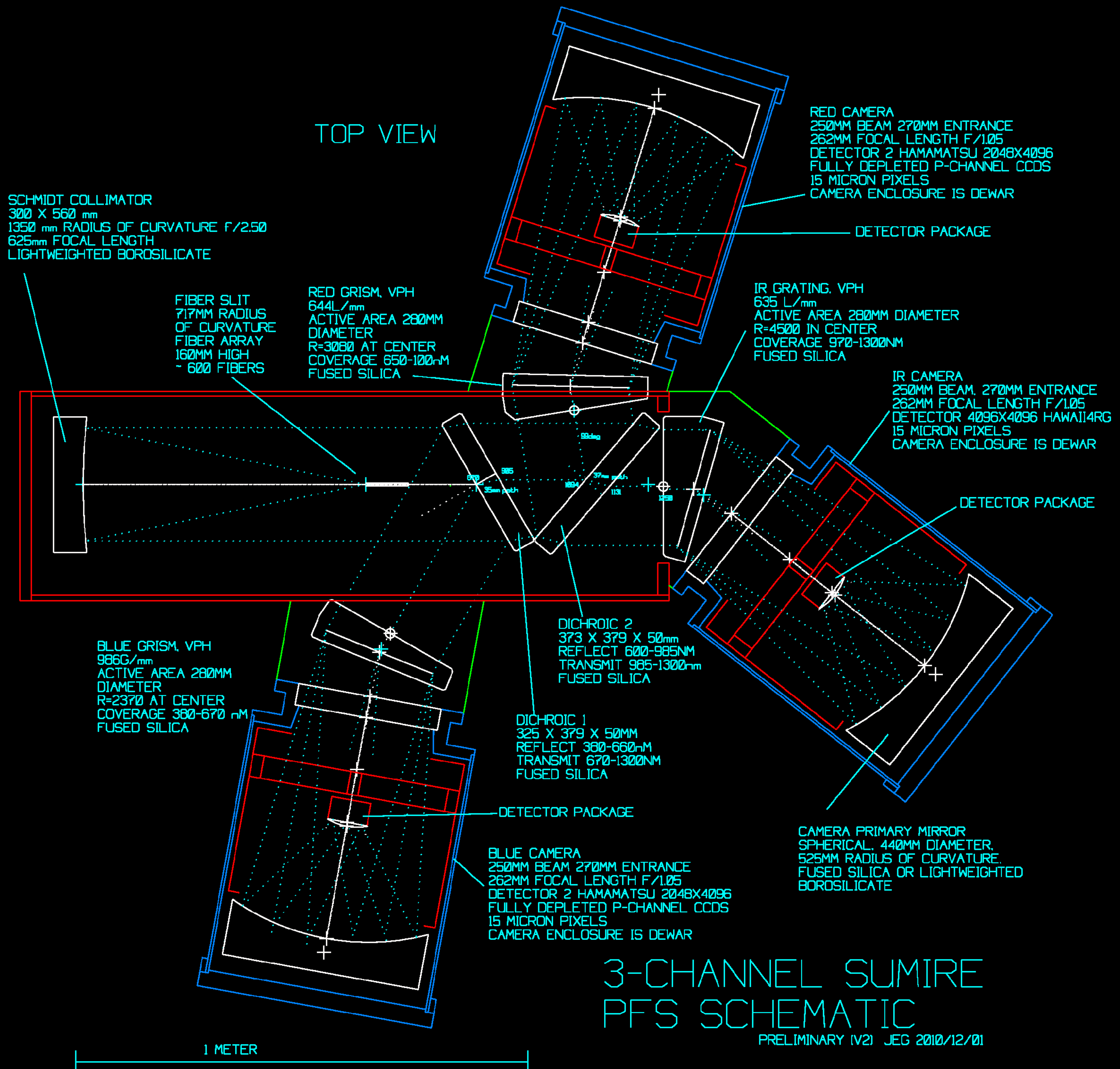
These 3 cameras, optically almost identical

Schmidt collimator, f/2.5 from fiber with ideal f/ratio 2.8. Microlens f/ratio transformer, 100u at telescope focus, 128u in long harness and in spectrograph. (Use SDSS connectors at PFU)

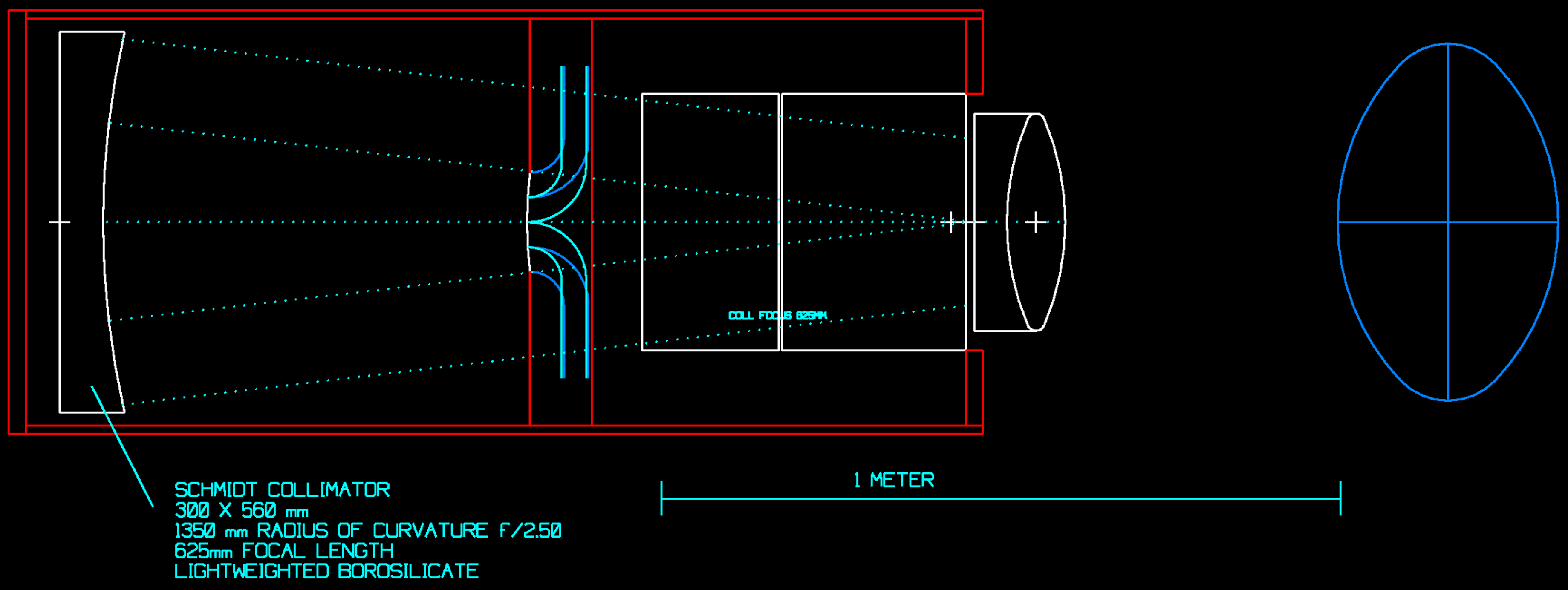
Two dichroic splitters:

first at 6600A, reflects 3800 – 6600, trasmits longer
second at 9850A, reflects 6600 – 9850, transmits longer

Looks roughly like this


TOP VIEW
SCHMIDT COLLIMATOR
300 X 560 mm
1350 mm RADIUS OF CURVATURE F/2.50
625mm FOCAL LENGTH
LIGHTWEIGHTED BOROSILICATE
FIBER SLIT
717MM RADIUS
OF CURVATURE
FIBER ARRAY
160MM HIGH
~ 600 FIBERS
RED GRISM, VPH
644L/mm
ACTIVE AREA 280MM
DIAMETER
R=3080 AT CENTER
COVERAGE 650-100nM
FUSED SILICA
RED CAMERA
250MM BEAM 270MM ENTRANCE
262MM FOCAL LENGTH F/1.05
DETECTOR 2 HAMAMATSU 2048X4096
FULLY DEPLETED P-CHANNEL CCDS
15 MICRON PIXELS
CAMERA ENCLOSURE IS DEWAR
DETECTOR PACKAGE
IR GRATING, VPH
635 L/mm
ACTIVE AREA 280MM DIAMETER
R=4500 IN CENTER
COVERAGE 970-1300NM
FUSED SILICA
IR CAMERA
250MM BEAM, 270MM ENTRANCE
262MM FOCAL LENGTH F/1.05
DETECTOR 4096X4096 HAWAII4RG
15 MICRON PIXELS
CAMERA ENCLOSURE IS DEWAR
DETECTOR PACKAGE
BLUE GRISM, VPH
986G/mm
ACTIVE AREA 280MM
DIAMETER
R=2370 AT CENTER
COVERAGE 380-670 nM
FUSED SILICA
DICHROIC 2
373 X 379 X 50mm
REFLECT 600-985NM
TRANSMIT 985-1300nm
FUSED SILICA
DICHROIC 1
325 X 379 X 50MM
REFLECT 380-660nM
TRANSMIT 670-1300NM
FUSED SILICA
DETECTOR PACKAGE
BLUE CAMERA
250MM BEAM 270MM ENTRANCE
262MM FOCAL LENGTH F/1.05
DETECTOR 2 HAMAMATSU 2048X4096
FULLY DEPLETED P-CHANNEL CCDS
15 MICRON PIXELS
CAMERA ENCLOSURE IS DEWAR
CAMERA PRIMARY MIRROR
SPHERICAL, 440MM DIAMETER,
525MM RADIUS OF CURVATURE,
FUSED SILICA OR LIGHTWEIGHTED
BOROSILICATE
3-CHANNEL SUMIRE
PFS SCHEMATIC
PRELIMINARY (V2) JEG 2010/12/01
1 METER

SIDE VIEW, MAIN BOX STRUCTURE ONLY



Blue Channel: Higher Resolution?

Room to swing dewar to larger angles. Can replace grating with higher density one to reach R~5000 or perhaps even 8000 over blue range 3800-6500 but with restricted wavelength range.

But SDSS-SEGUE has been very successful with the proposed PFS resolution in the blue for stellar parameters.

The Spectrograph

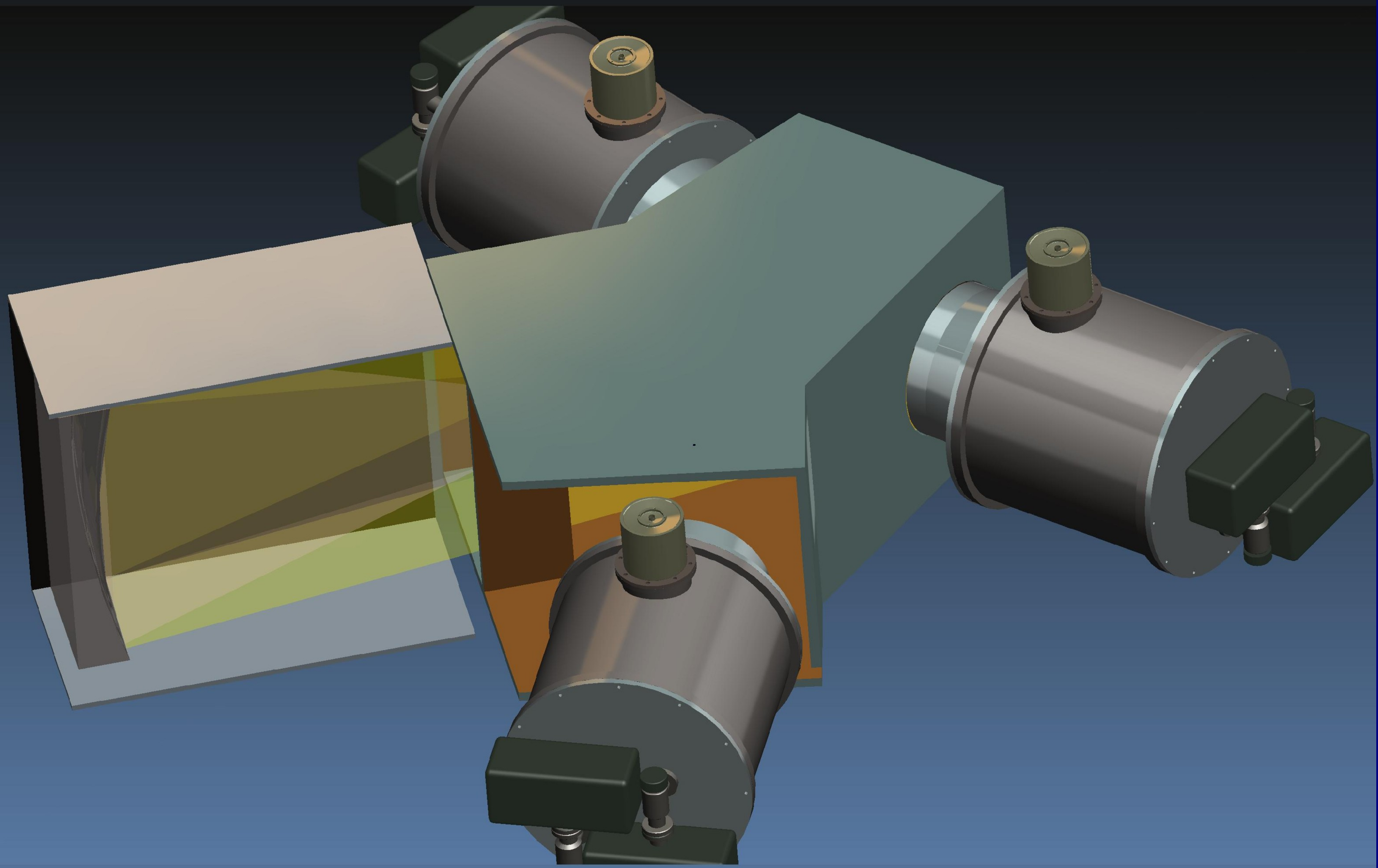
Want 2400 fibers

600 fibers per spectrograph with 3 pixel (45u) spacing

So 4 spectrographs.

Simple bolted or welded rectangular aluminum box with internal baffles/gussets.

Might look like this physically:

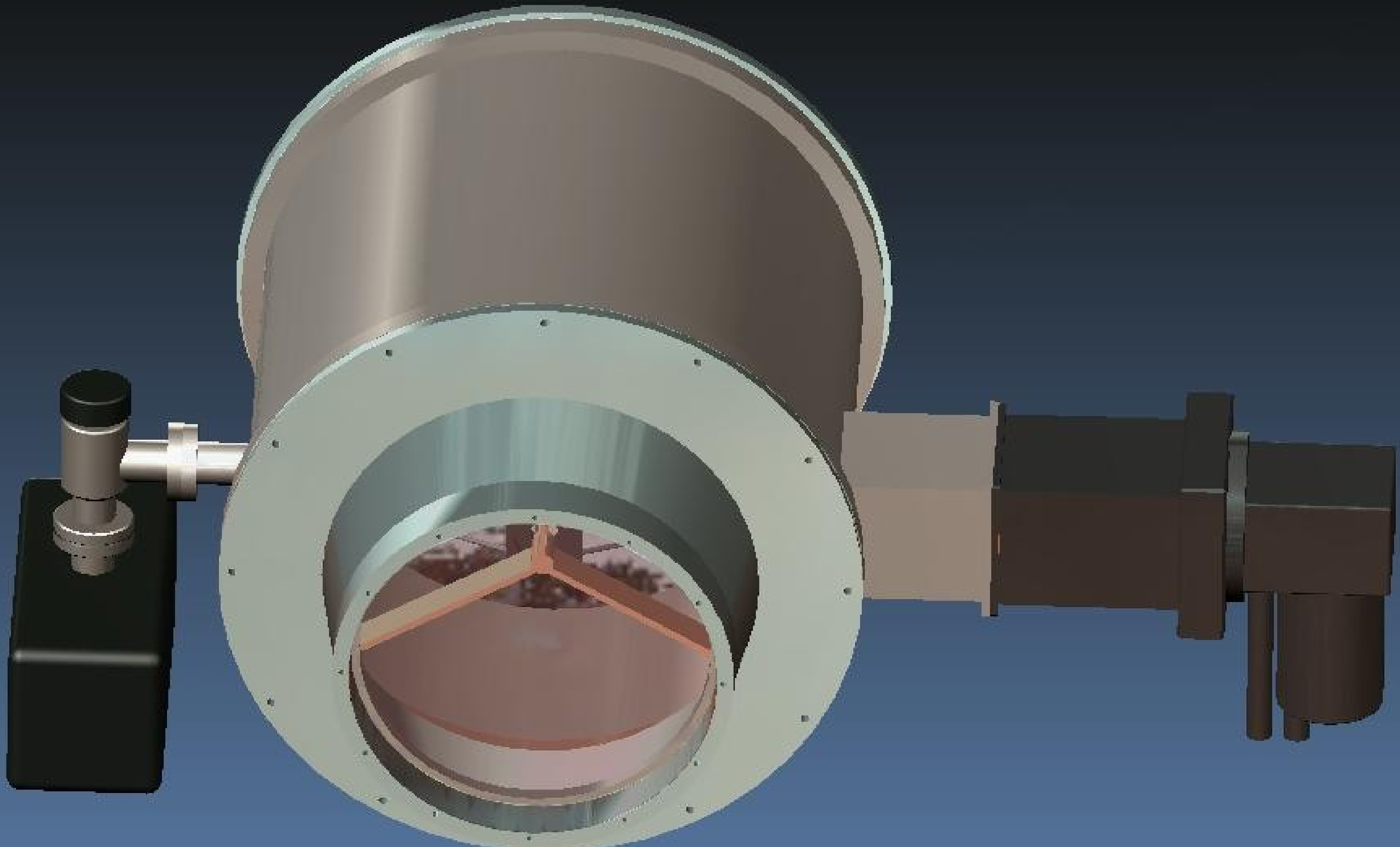


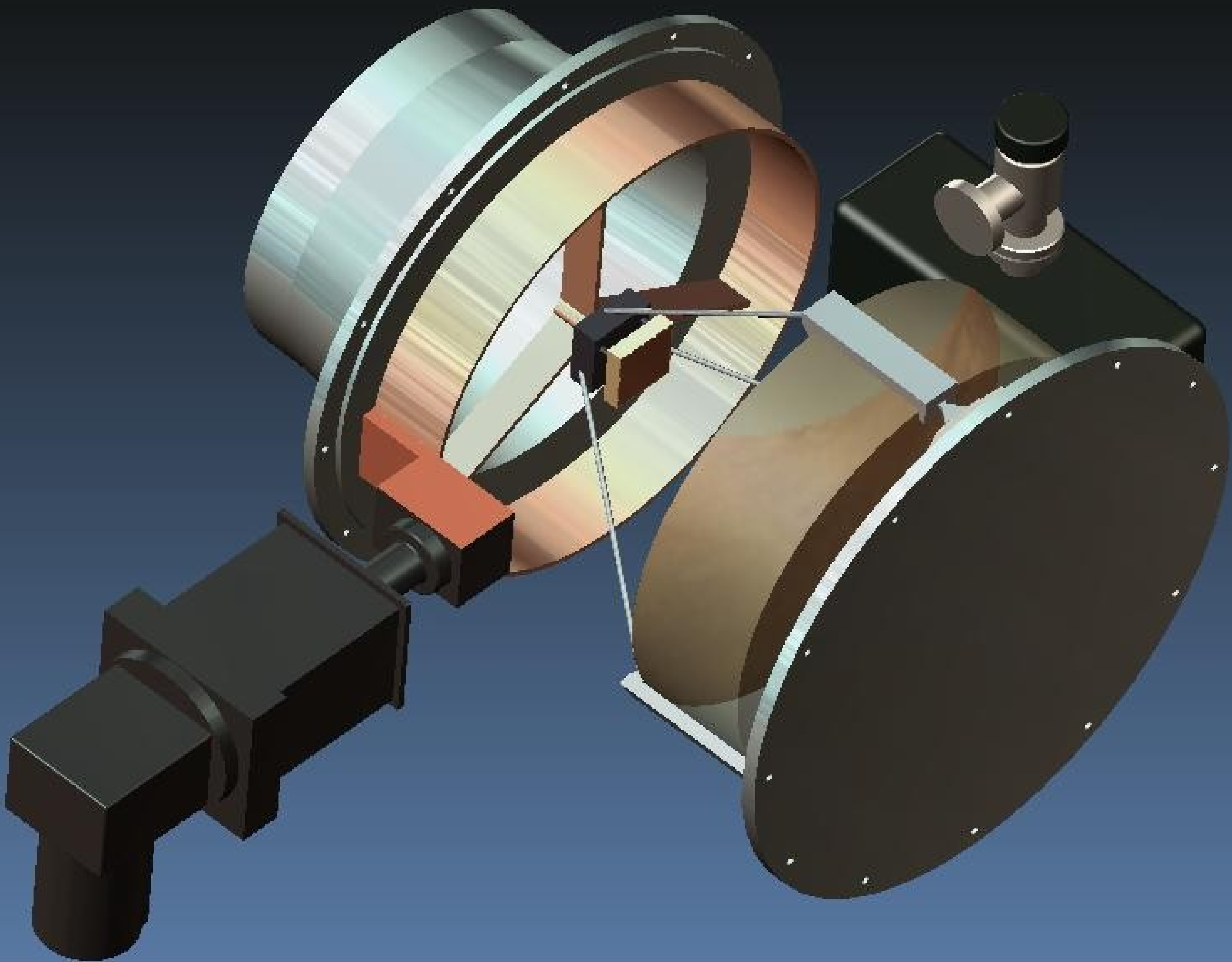
The Cameras/Dewars

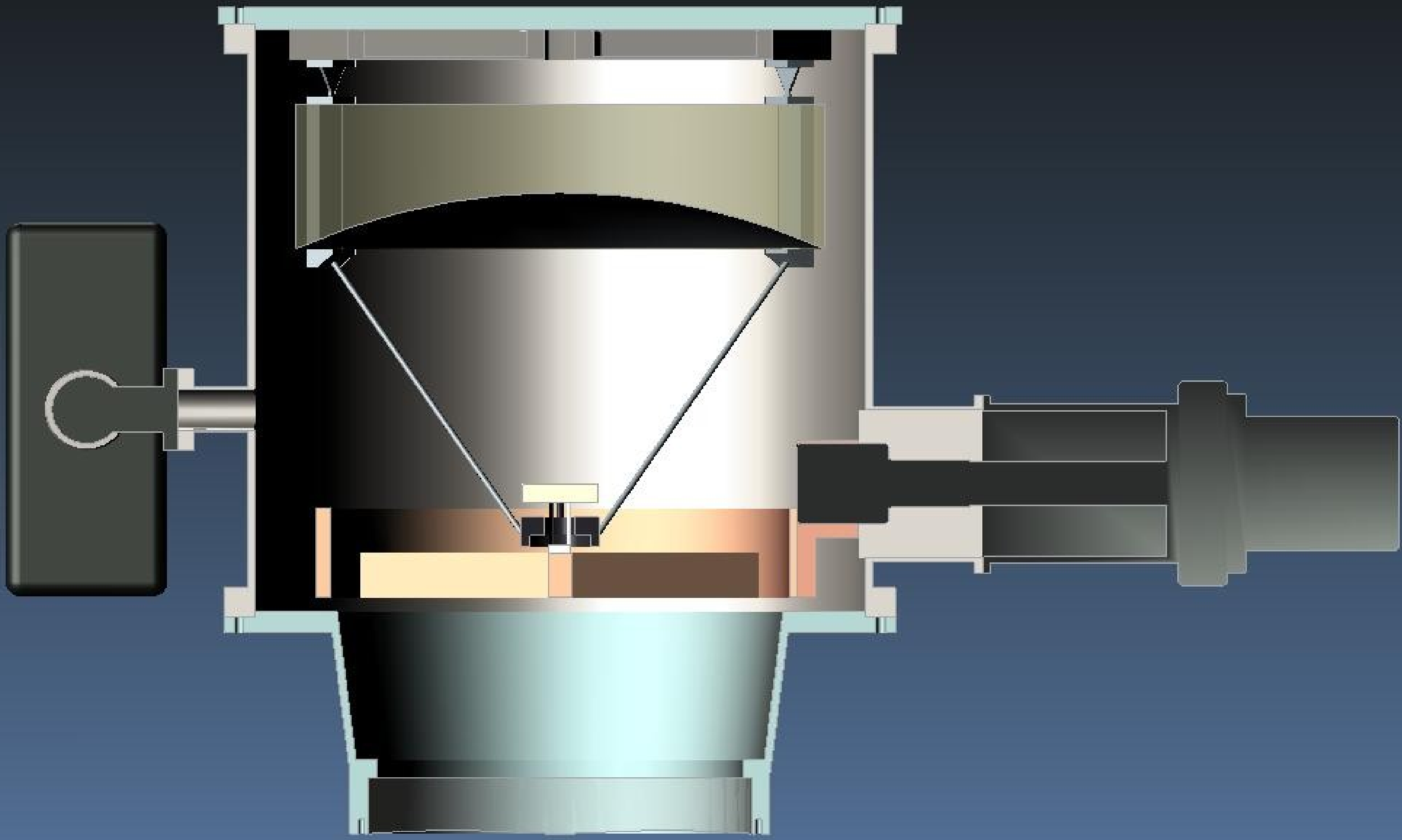
Performance: 25u images with crude hand optimization. Baker-Nunn gives 12u images over curved field, no reason to expect worse here.

Camera body is cryostat; Double-sided Schmidt corrector is vacuum window. Proven design.

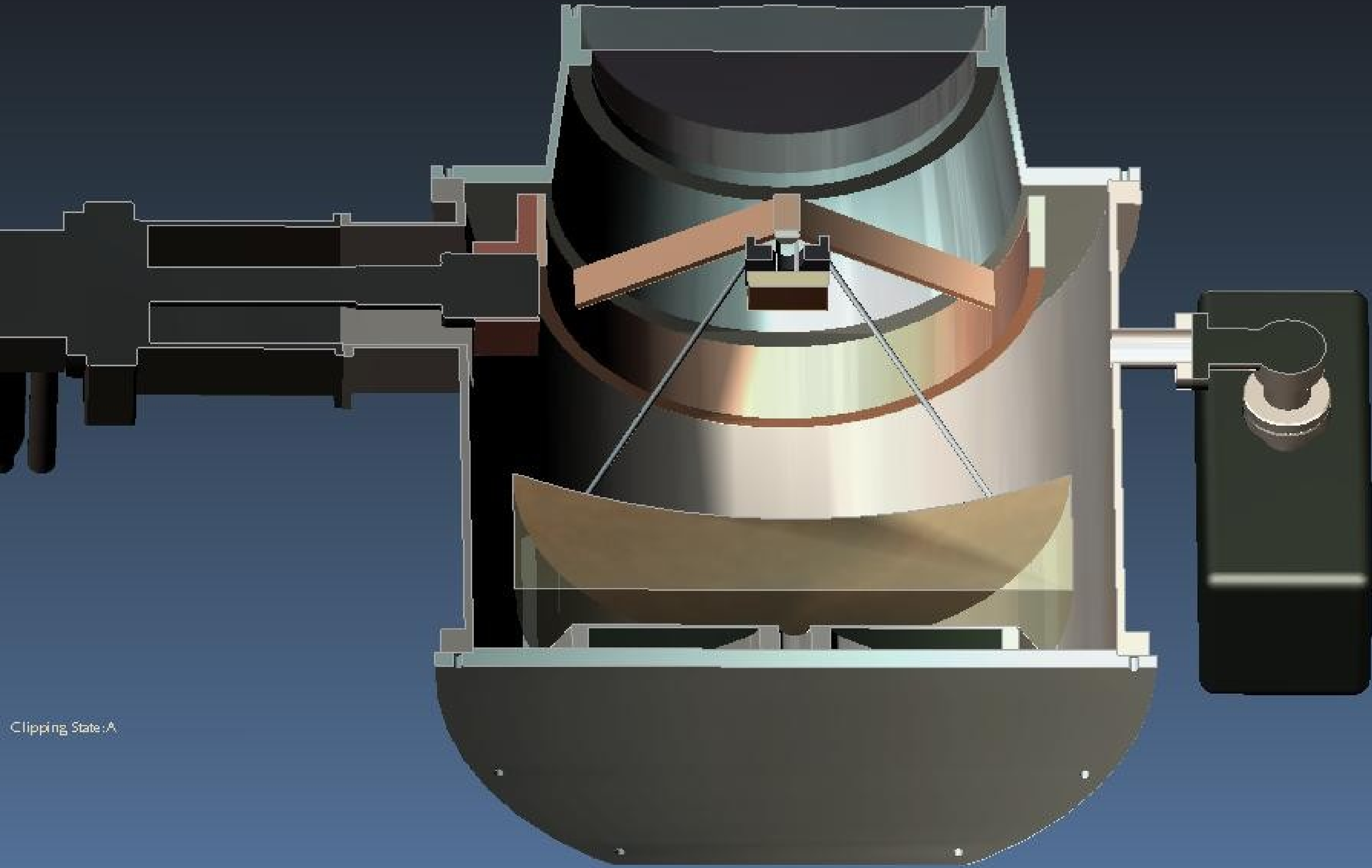
Looks like this



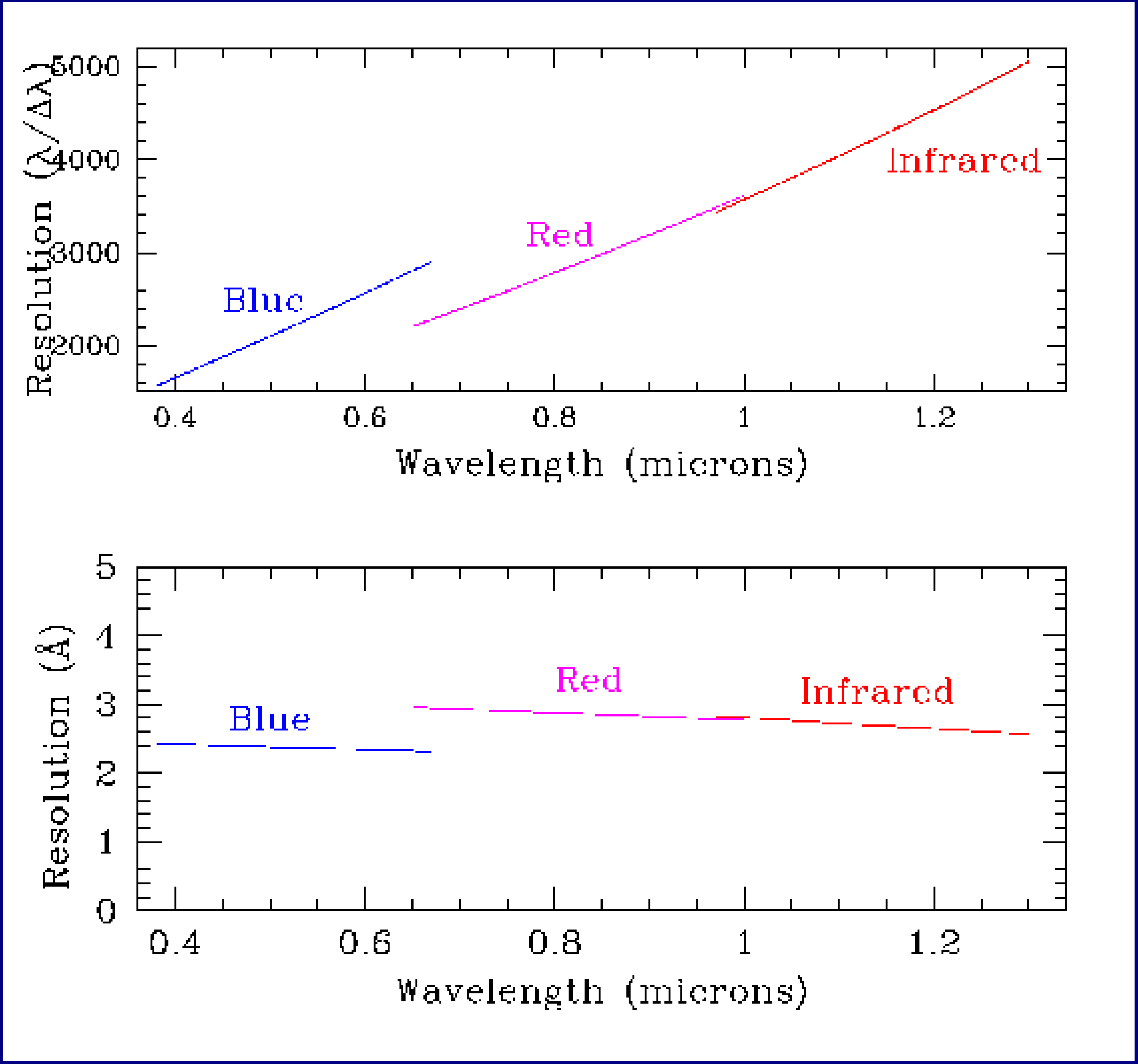




Clipping State:A

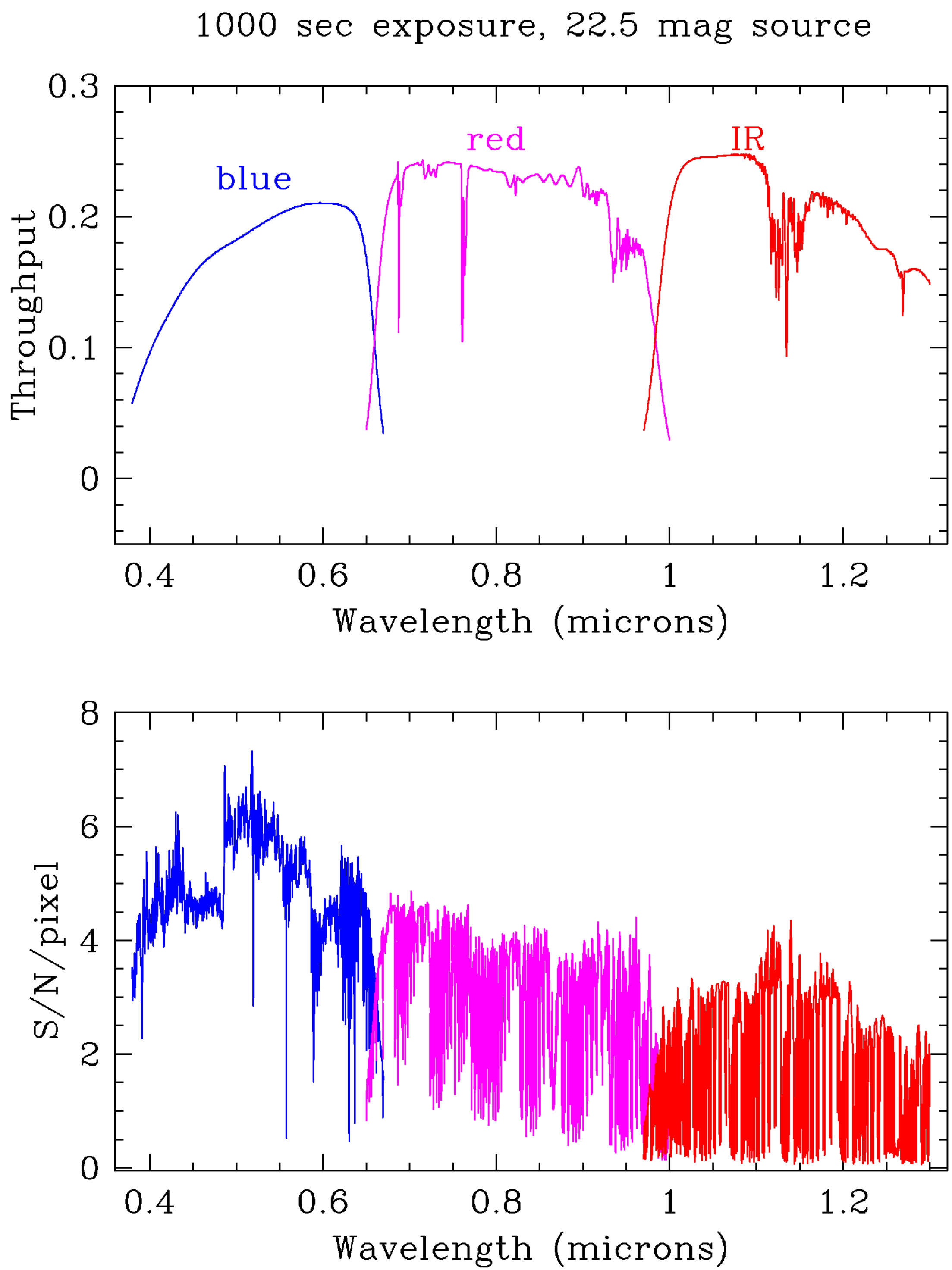

Clipping State:A

Resolving Power vs Wavelength for 3-channel PFS



Point-source throughput with all instrumental losses and seeing loss at input in 0.7" seeing (29%). Fiber size is near optimal for S/N for small sources.

Per-pixel S/N in 1000s at 22.5 (R=500 is ~30 pixels in IR)



Sensitivity

Assume throughput of 25%. Normalize to AB=22.5, 1 hr (3x1000s) exposures

In BLUE, (R=2400) get 300 electrons per V pixel,
400 electrons from sky; S/N ~ 14 per pixel
For GALAXIES, degrade to R=1000, S/N ~ 20, 5 at AB=24

In RED, (R=3100) get 300 electrons per V pixel
800 electrons from sky, S/N ~ 8.5 per pixel
For GALAXIES, at R=500, S/N ~ 20 , 5 at AB=24

In IR, (R=4500) get 160 electrons per V pixel
300 electrons from sky, S/N ~ 5 per pixel
For Galaxies, at r=300, S/N ~ 20, 5 at AB=24

MUCH shorter times for BAO using 3727

$SFR=(t/t_0)exp(-t/t_0)$

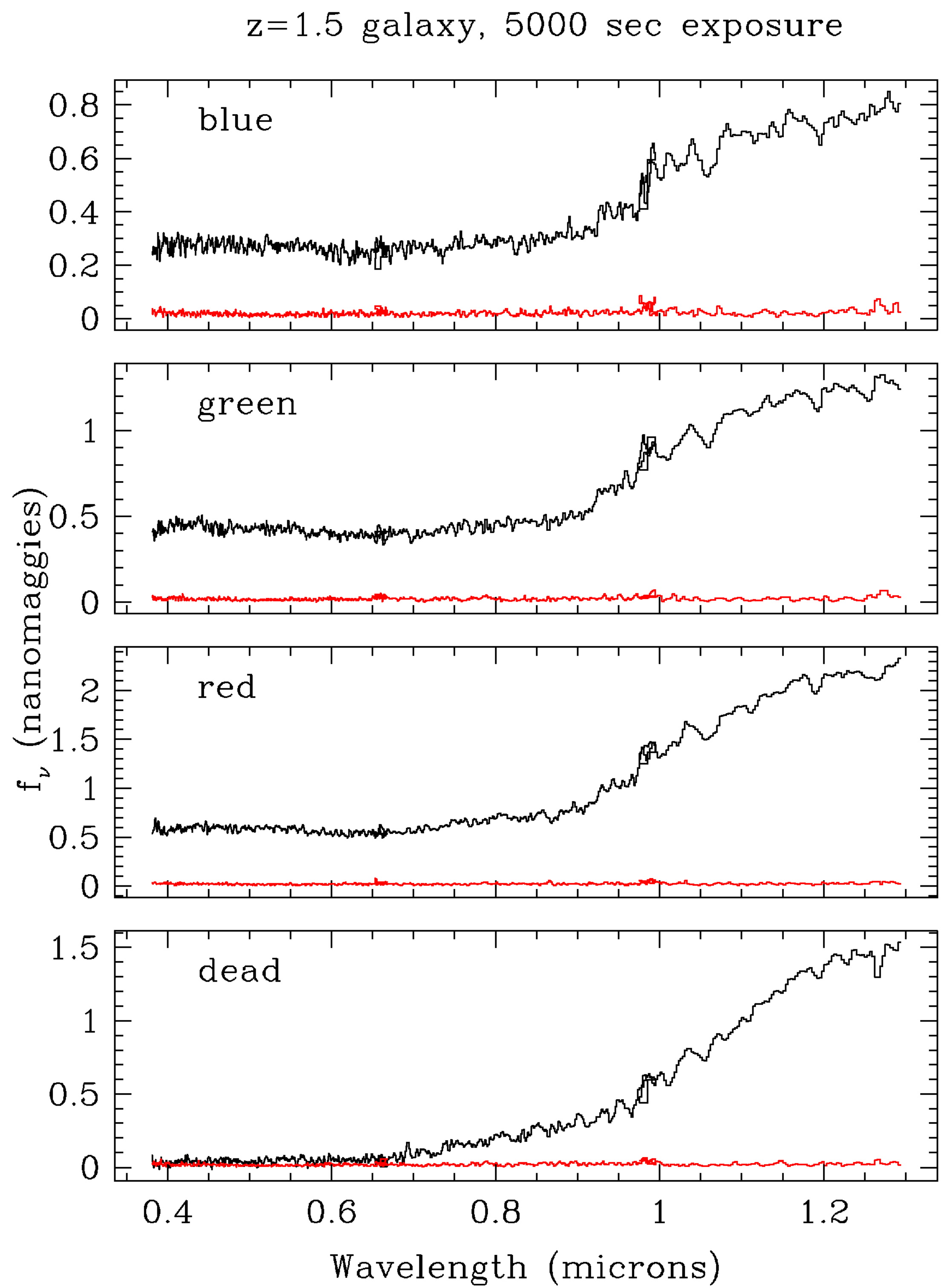
t_0= 4Gyr

t_0= 2.8Gyr

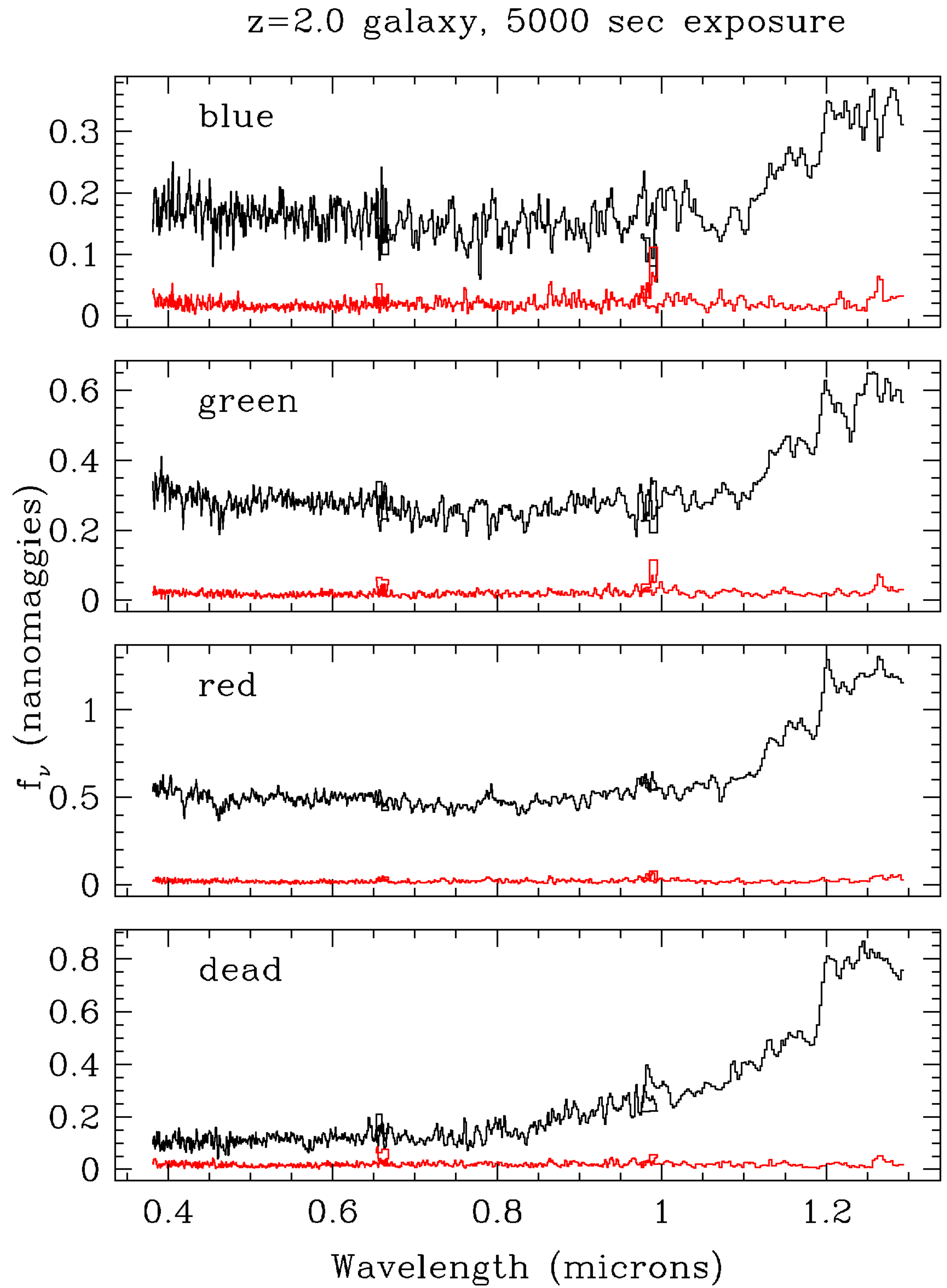
t_0= 1.6Gyr

t_0= 0.5Gyr

R=400,300,200 B, R, IR



SFR=(t/t$_0$)exp(-t/t$_0$)



t$_0$= 4Gyr

t$_0$= 2.8Gyr

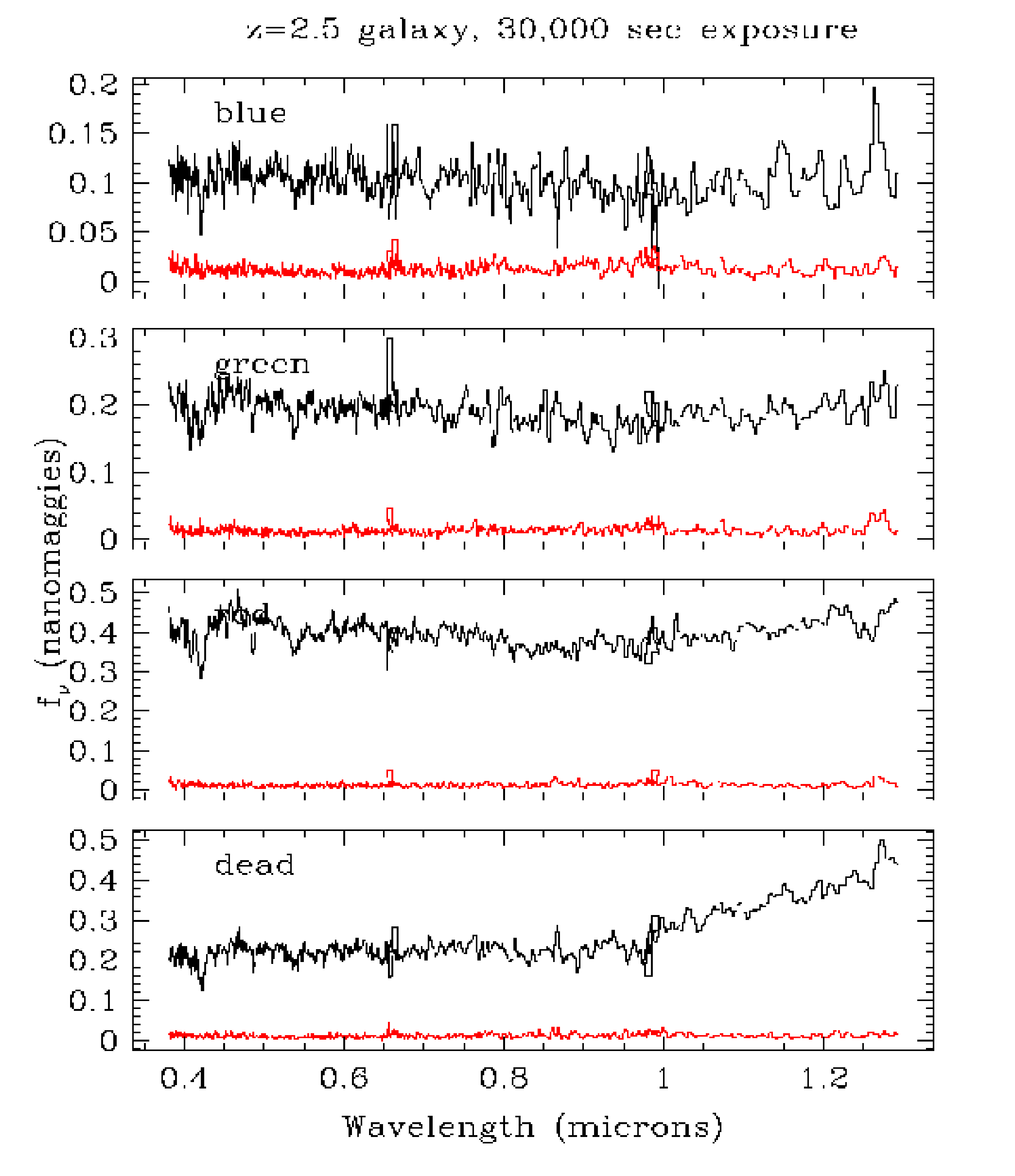
t$_0$= 1.6Gyr

t$_0$= 0.5Gyr

R=400,300,200 B, R, IR

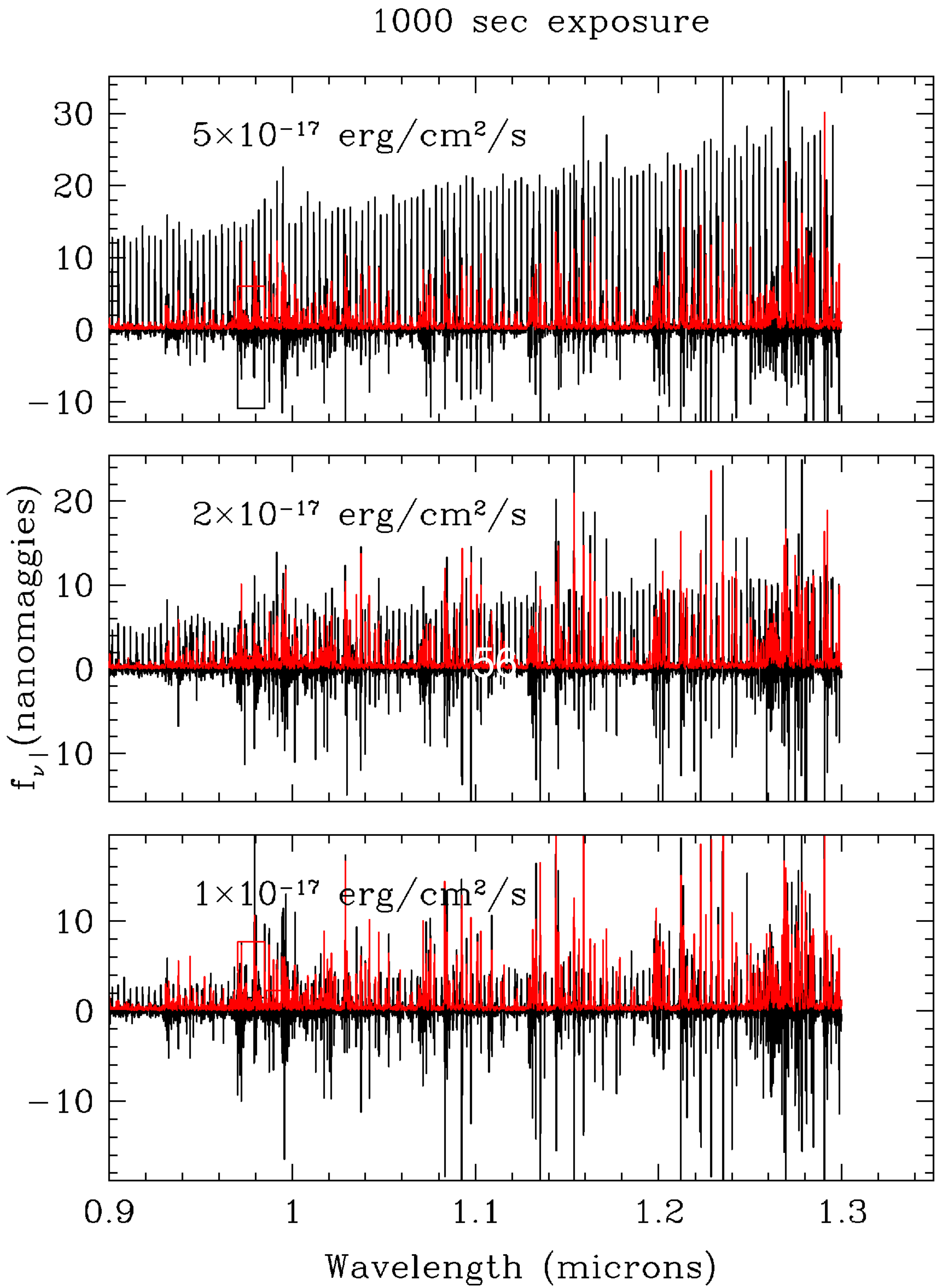
z=2.5; 4000A break beyond end of FSR; must rely on emission

3727 at 1.30u, Ly-a at 4250



These are simulated spectra with lines of constant cgs flux every 33 A through the spectrum

At z~2, the space density of 3737 sources with L~1e42 erg/sec is comparable with L galaxies; the flux is 4e-17*



How Long? How Many Fields?

SDSS-like survey in 5 redshift slices with <z> = 0.7, 0.9, 1.2, 1.5, 1.8

~.02h^{-3} Gpc^3, L* galaxies. 500,000 spectra, 2 hr exposures

Targetting from HSC deep survey and same area

16 PFS fields, 30 sq. degrees (Deep Survey area)

200 pointings, 13 visits per field. 80 allocated nights

BAO survey?

Shorter; brighter objects, 1 visit per field, 30min exposures,

2000 sq degrees, targetting from HSC wide survey, 500 hours,

100 allocated nights, ~2 million spectra,

~4 $h^{-3}Gpc^3$

Cost

Spectrograph only:

Box	30K
Slit assy and fiber hdwe	30K
Collimator	40K
Dichroics	20Kx2
Gratings	40K x 3
Grism/wedge/corrector	40K x 3
	380K

Cameras:

Primary mirror	20K
Corrector	40K
Field Flattener	2K
Pump	2K
Cooler	150K
Dewar	30K
	240Kx3

Detectors:

CCDs	40K(?)x4	
IR	700K	
	860K	total $2.0M per spectrograph

The Beginning

BAO and 3727

Number density of 3727 emitters, L>1e42 erg/sec is 3e-4 at z=1, 8e-4 at z=1.5, probably ~2e-3 at z=2. Number density of L galaxies is 3e-3*

Detection:

z	λ3727	R	f42	fph42	ndet/s	SkyAB	nsky/s
0.7	6335	2700	9.1e-16	2.9e-4	40	21.5	0.7
1.0	7455	2600	3.6e-16	1.3e-4	18	21.0	1.2
1.4	8945	3300	1.6e-16	7.2e-5	10	20.3	1.8
1.8	10435	3800	8.7e-17	4.6e-5	6.4	19.7	2.7
2.2	11925	4500	5.3e-17	3.2e-5	4.5	19.2	3.6
2.5	13045	5200	3.9e-17	2.5e-5	2.5	18.7	3.3