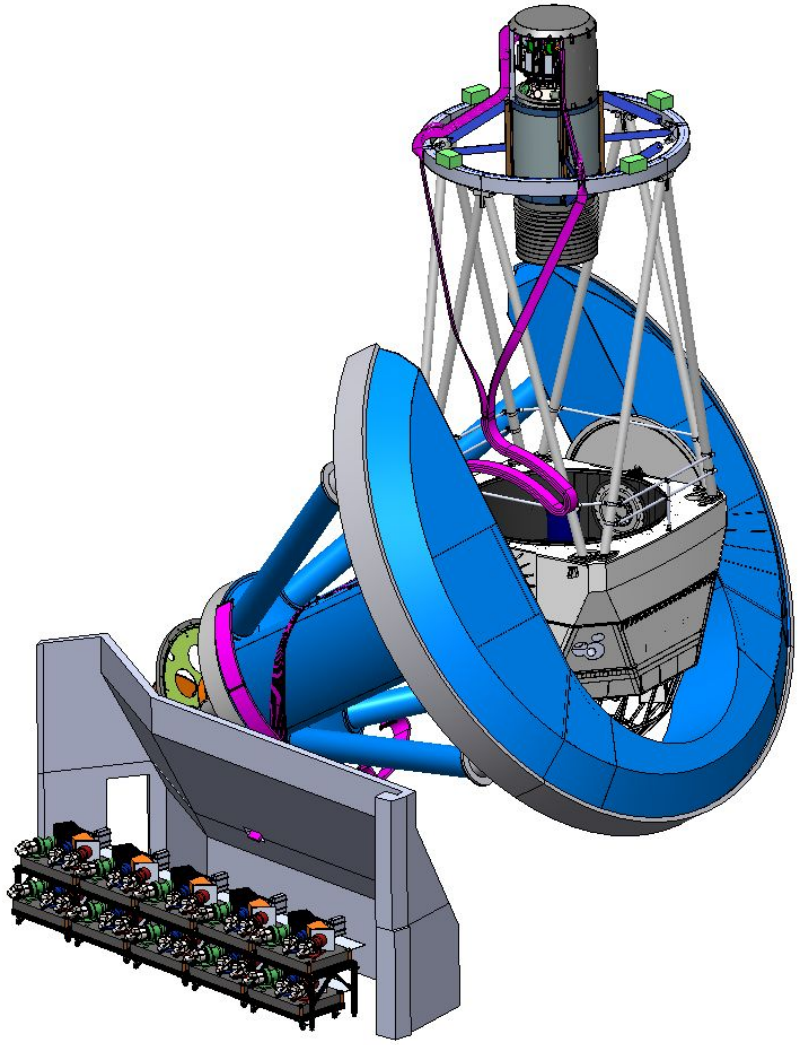


Sky Camera
Final Design Review

DESI-3985-v2

D. Kirkby, M. Lampton, P. Martini,
D. Schlegel, S.S. Tie

10 August 2018

Revision History

v2 updates:

- Add "Verification Plan" slide.

v1: Slides presented during the FDR on 10-Aug-2018.

Charge to the Committee

1. Does the design satisfy the requirements in DESI-3221?
2. Have sufficient analyses and/or tests been performed to validate the design?
3. Can the design be built, shipped, and installed safely and successfully?
4. Are the test plans sufficient to verify the requirements have been met?
5. Have all recommendations from the PDR been addressed?

Review Materials

Documents:

- DESI-3985-v1: these slides.
- DESI-3221-v3: requirements being reviewed here.
- DESI-3993-v1: interface control document.
- DESI-3422-v2: PDR slides
- DESI-3429-v1: PDR report

Spreadsheets:

- Equipment & budget (excluding fibers)
- Fibers budget
- Fiberblock layout

Review wiki page is here.

The jupyter notebook used for most of the plots and calculations is maintained in the desietc package. View it online here.

Requirements

Sky Camera requirements are DESI-3221-v3.

The main requirements flow down is:

- 4% accuracy on integrated flux in SC fibers fed to ETC [SC-1001]
  - Exposure times = 60s (BRIGHT), 200s (DARK) [SC-10010]
  - Single-exposure SNR > 10 per fiber [SC-10011]

Achieving better than 4% would be possible, but not useful since the ETC would still be limited by calibration errors due to:

- Variations in sky throughput over focal plane (plate scales, vignetting) and spatial variations in sky levels (clouds, moon, twilight).
- Errors in sky spectrum model used to extrapolate from SC bandpass to full sky continuum.

Requirements

Summary of changes since v2 (PDR):

- Added statement about two identical units [SC-10014]
- Removed statement about connectorization [SC-10021]
- Moderate increase in volume envelope [SC-10041]

Requirements that will be demonstrated in this review:

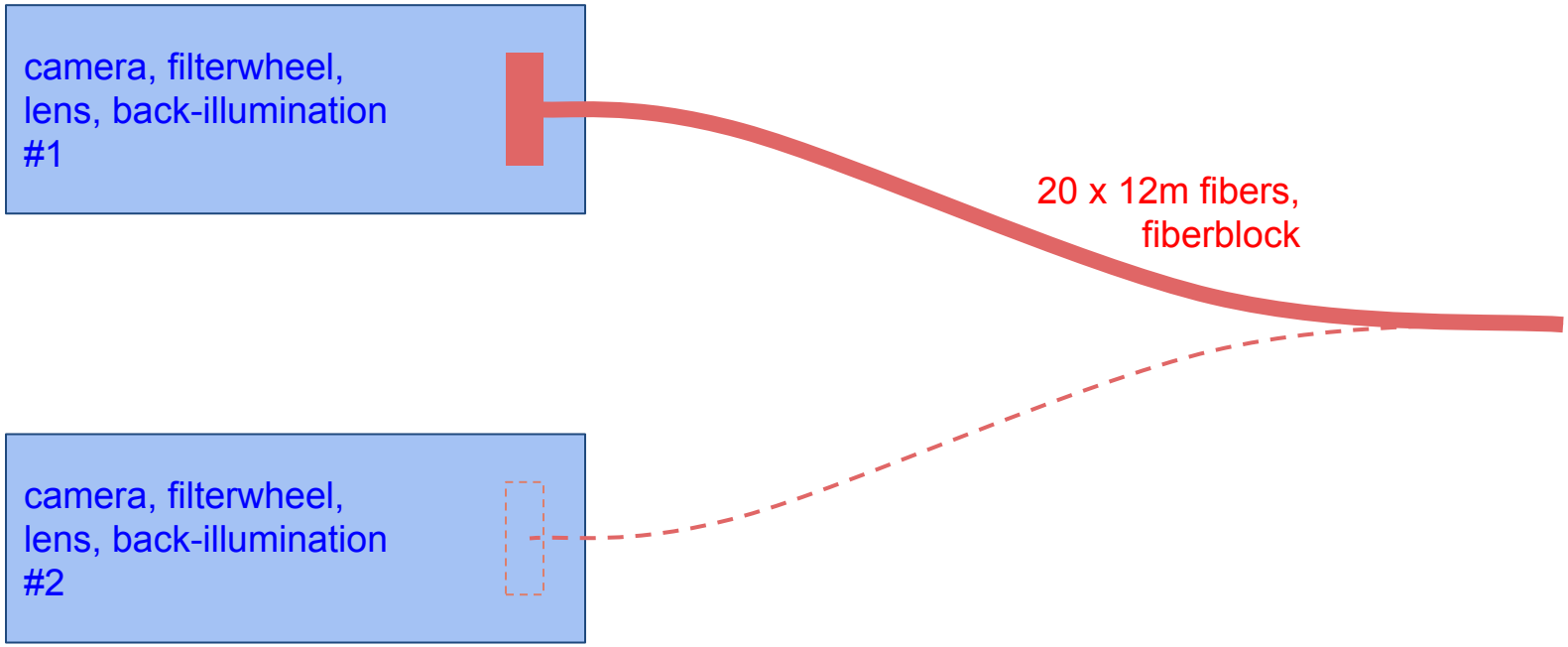
- [SC-10011] single-exposure SNR > 10 per fiber.
- [SC-10045] heat dissipation < 30W per unit.

Other responses to PDR (DESI-3429)

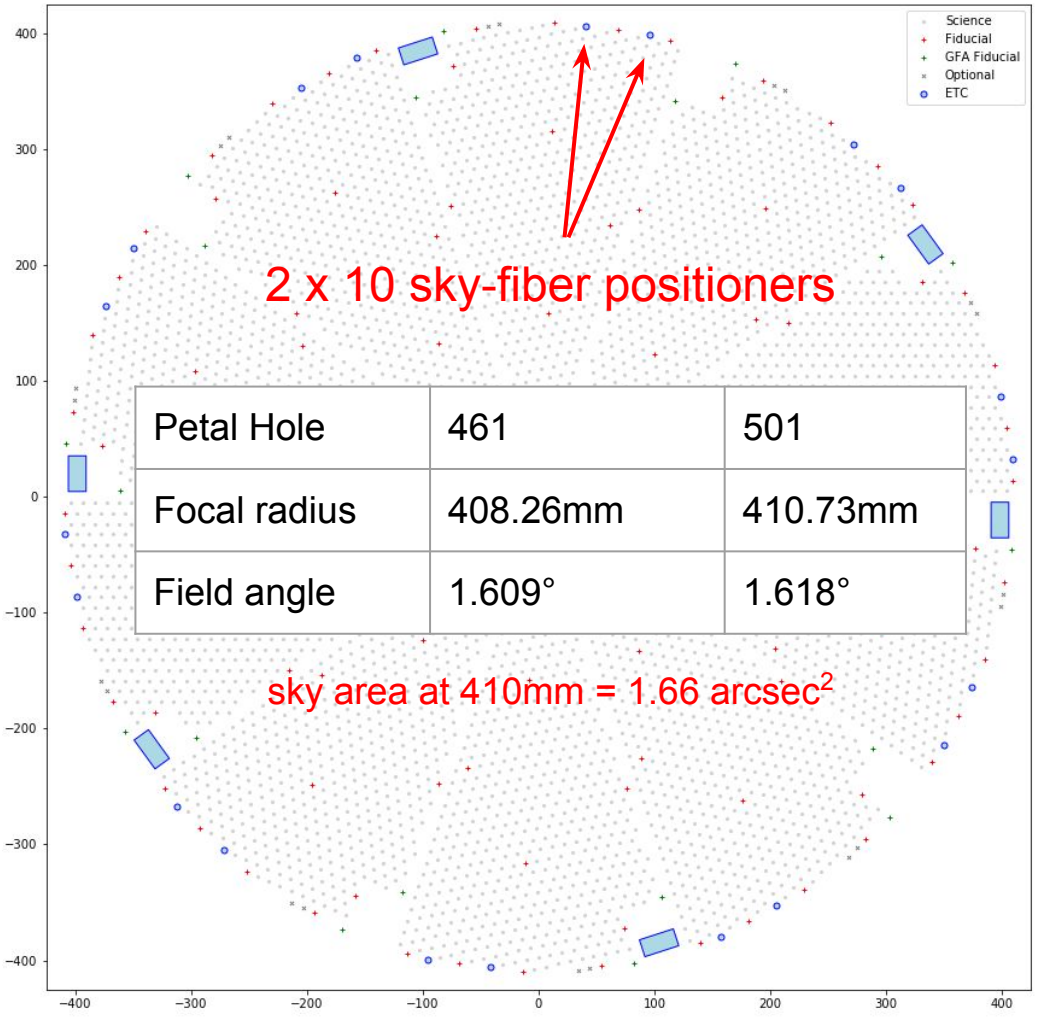
- Requirements updated (survival temperature, weight in DESI-3221)
- Interfaces better developed, ICD now exists (DESI-3993)
- Physical location established (SW corner of Shack)
- Ethernet switch removed
- SBIG STXL-6303e camera selected
- Filters selected
- Total power budget complete
- Updated throughput budget
- Plan to construct two identical units to provide redundancy

Recommendation 10: Redundancy / Spares

We recommend construction of two complete units with no spares. Should the team choose to use the 6303e camera, we recommend purchase of only one camera, and that the team incorporate one of the CI cameras into the second unit upon completion of the CI campaign. Spares would be more straightforward if all of the fibers were the same length. This also means the fiber attenuation will be about the same for all of the spots. Our expectation is that it will not be necessary to have a complete second set of fibers. We recommend that the fibers from the spool boxes terminate on a plate attached to the exterior of the unit. Should it be necessary to switch to the spare, the fiber plate would be moved to the other unit.



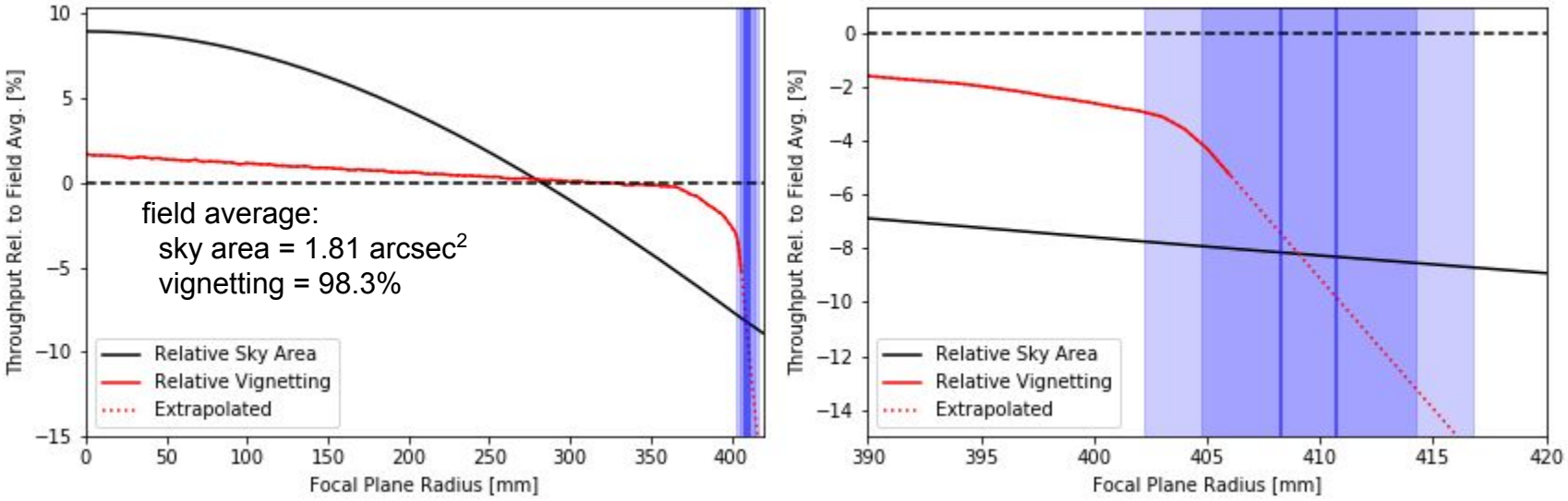
Interfaces: Focal Plane



Petal Hole	461	501
Focal radius	408.26mm	410.73mm
Field angle	1.609°	1.618°

Echo 22 Optical Design (DESI-329)

Fibers at outer edge of focal plane see less sky and are more vignetted, compared the field average.



Vignetting will vary by ~±5% over the 6mm fiber patrol radius.

Assume 90% loss relative to DESI-347 field average for SNR.

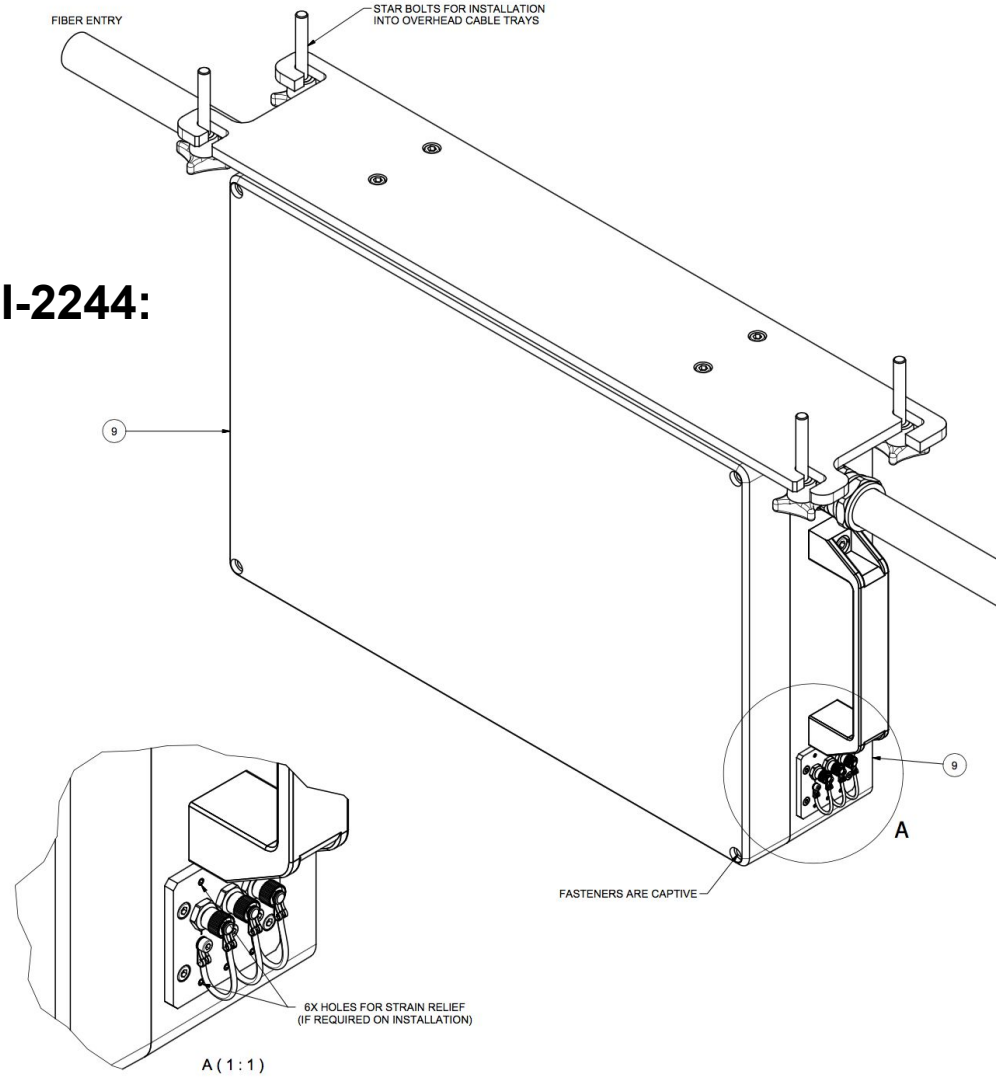
To what extent will vignetting curve depend on ADC angle?

Interfaces: Fiber System

Sky fibers terminated in SMA connecters at spool boxes (2 active + 1 spare).

Assume SMA connector throughput of 0.8 (-1dB).

DESI-2244:



Interfaces: Shack Location

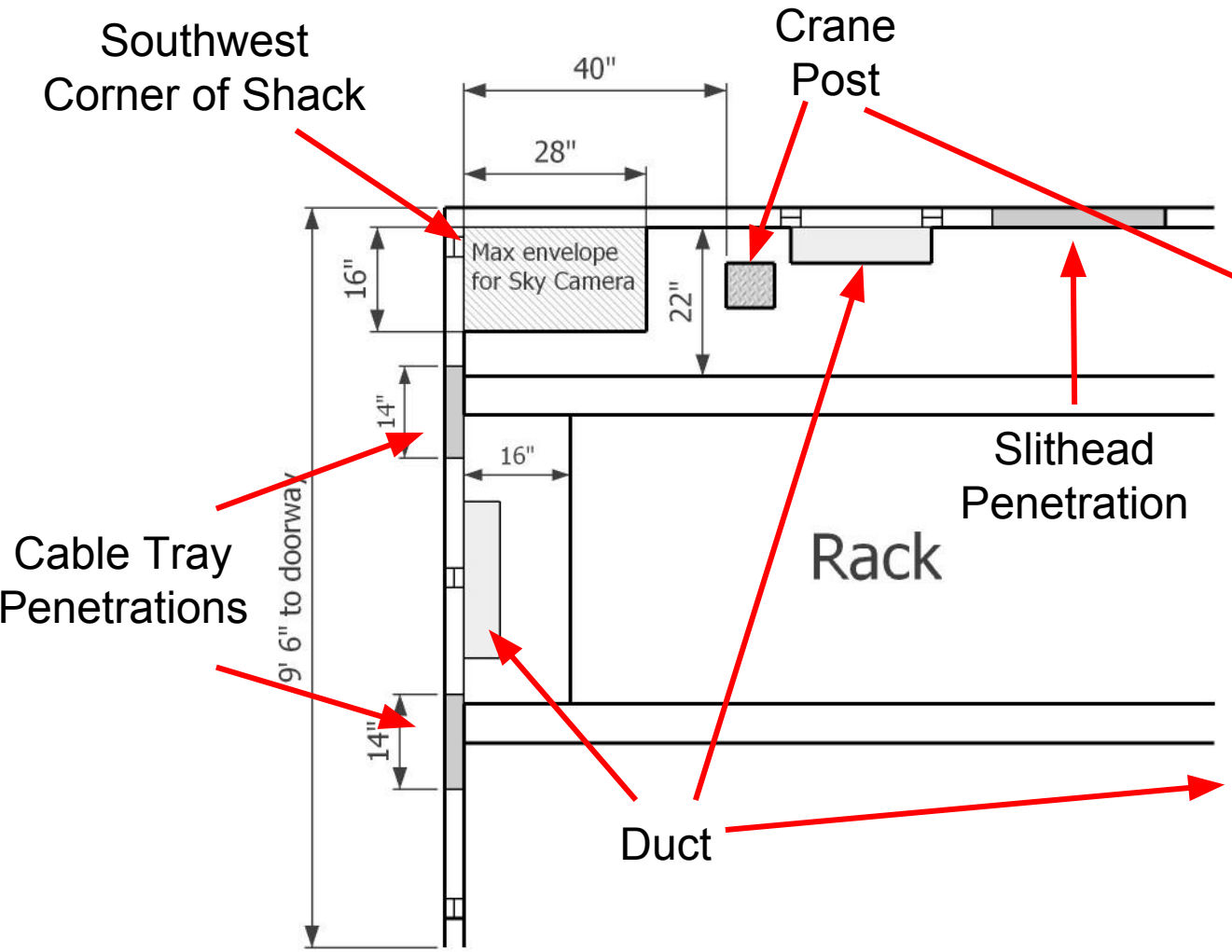
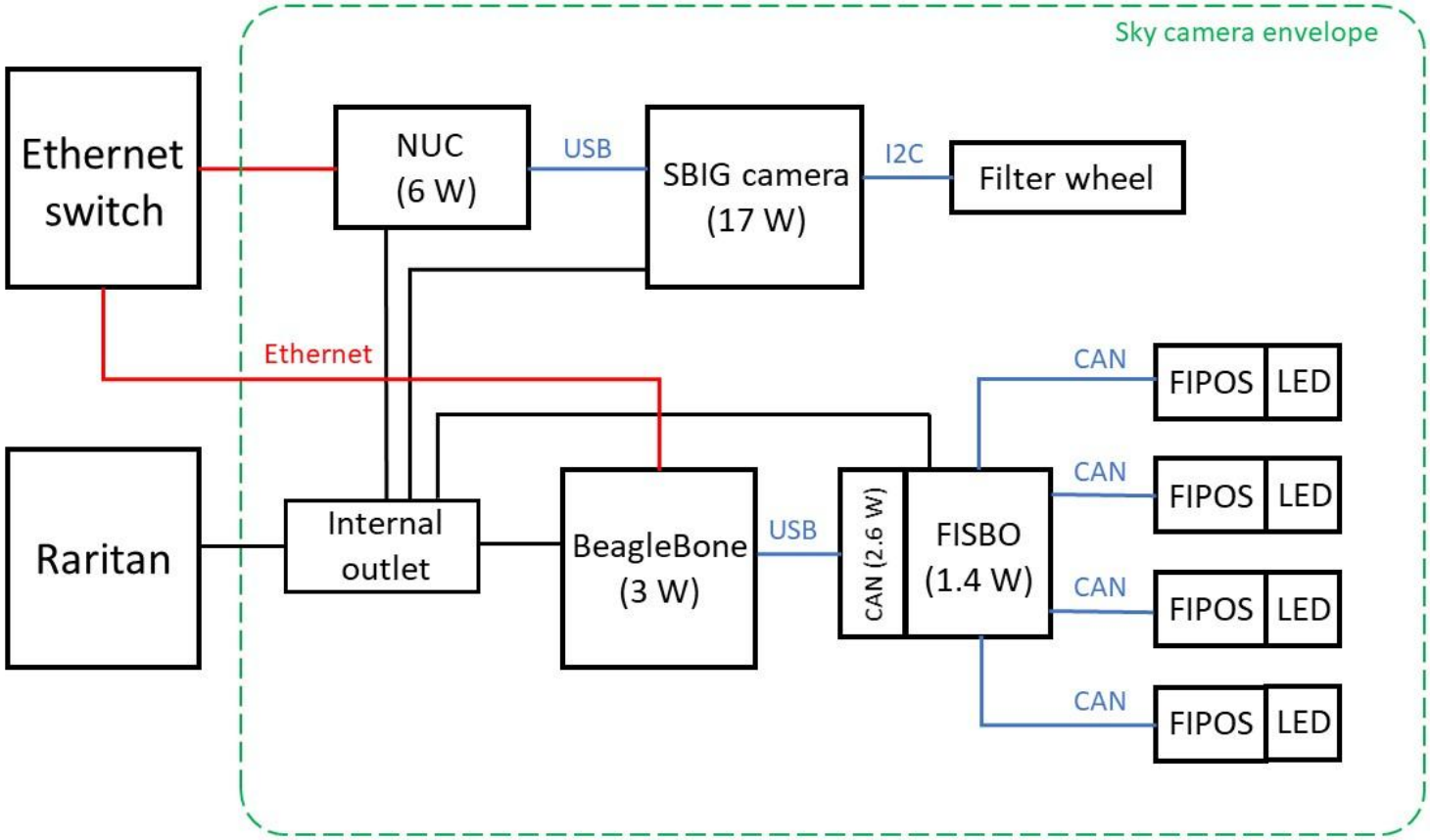


Photo of SW Corner

Block Diagram and Power, Ethernet Interfaces



See also the Sky Camera ICD (DESI-3993)

System Overview

Camera: SBIG STXL-6303e + 50mm f/1.2 lens

Filters: 610 ± 10 nm (DARK), 450 ± 80 nm (BRIGHT)

Fibers: (20 + 2) x 12m, mounted in custom fiber block.

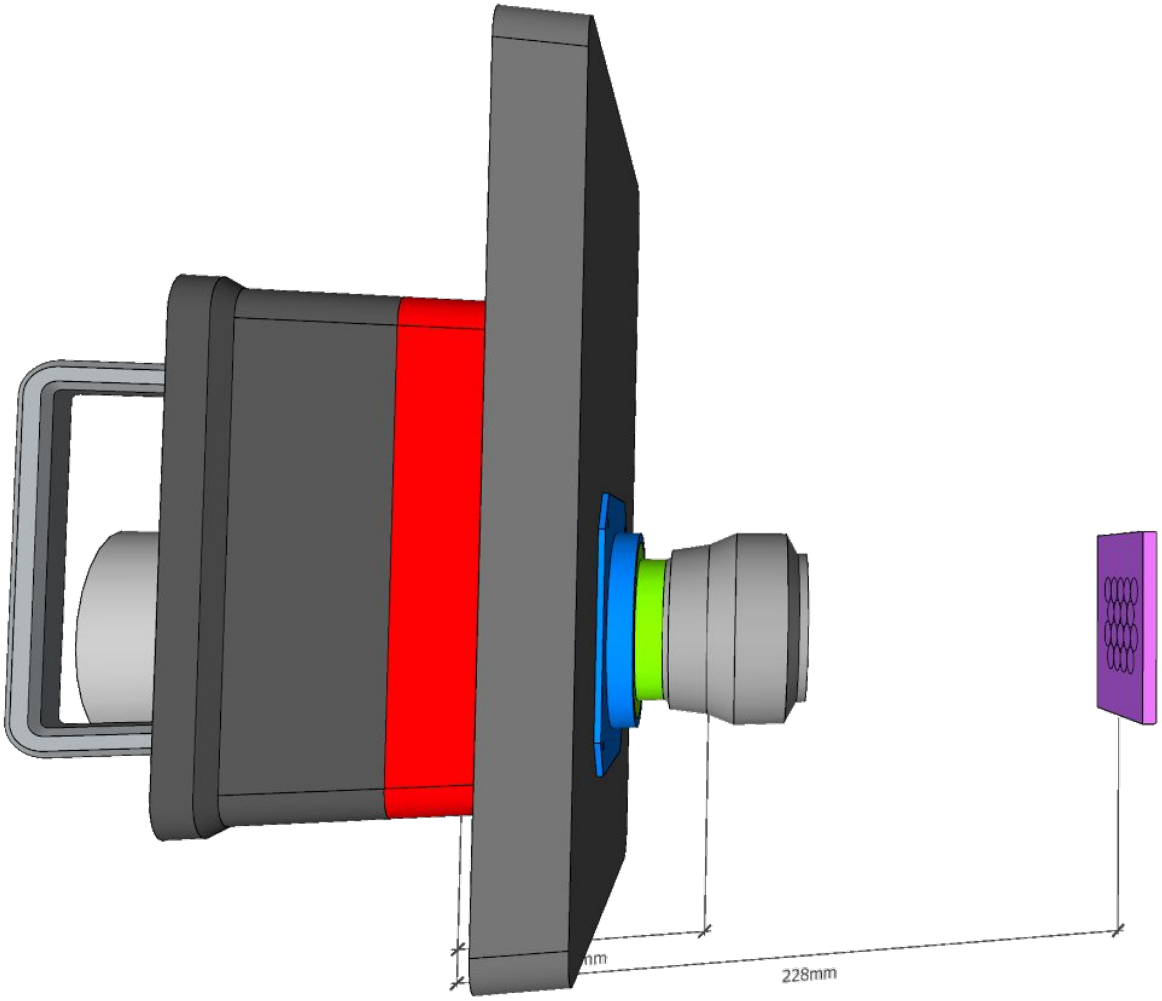
Back illumination: fiberblock LEDs reflected off mirrored ND filter.

Control: Intel-NUC + BeagleBone + FISBO + FIPOS

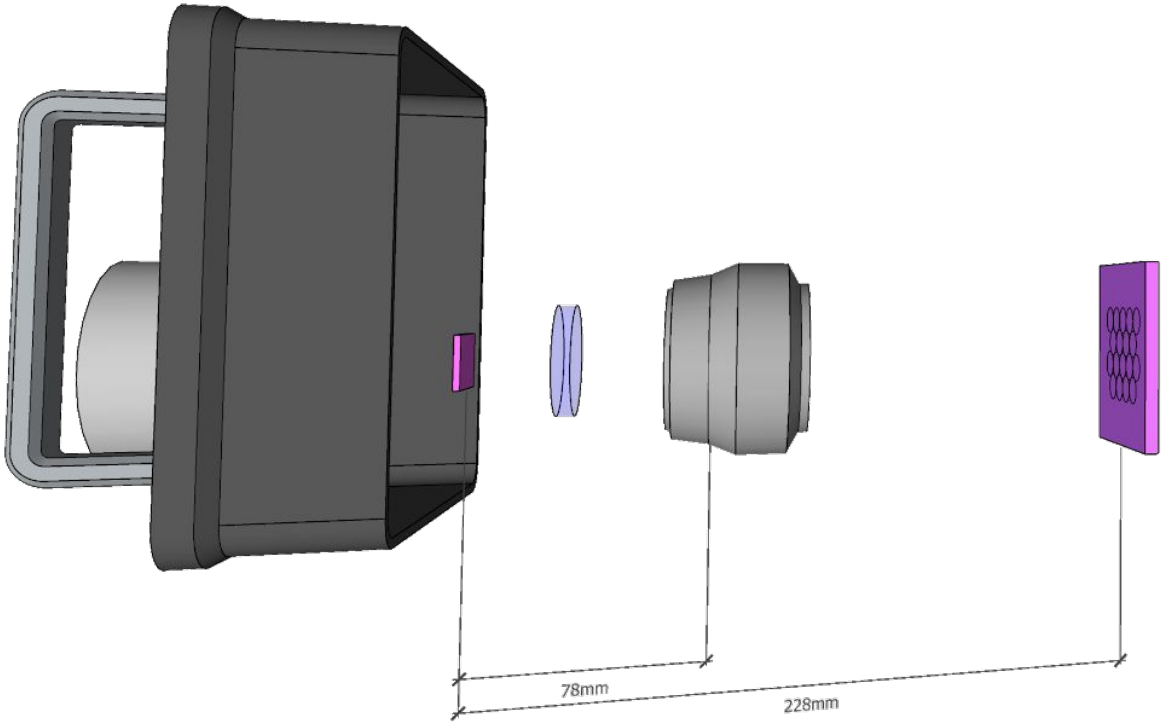
Power: 12VDC, 30W max.

Mechanics: breadboard with light-tight enclosure, adjustable focus.

System Overview



System Overview



Camera: STXL 6303e

Same as Commissioning Instrument.

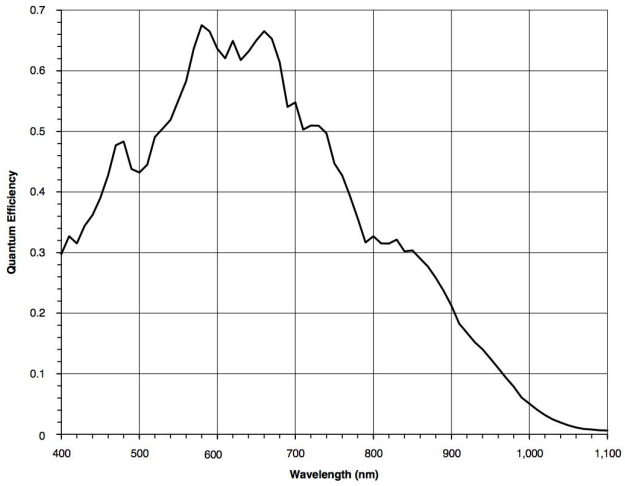
Kodak KAF-6303E sensor:

- 3072 x 2048 x 9μm pixels
- Dark current ~ 0.5 elec/s
- Read noise ~ 12 elec (1x1)

Supports 2x2 readout binning:

- Read noise ~ 16 elec
- ~20% improvement in SNR.

17W at 12VDC. Vents and exhaust fan on back side of housing (so want to keep this outside light-tight housing).



Lens: 50mm f/1.2

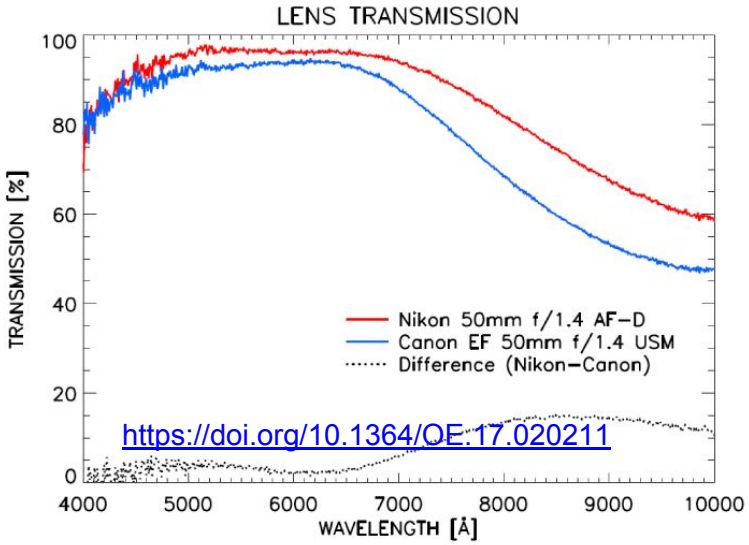
Nikkor AI-s series, manual focus.

When attached to camera body:

- Max reproduction ratio 1 / 7.9
- Min. focal distance 500mm.

Nikon F-mount designed for flange-CCD distance of 46.5mm.

Needs extension of ~22mm to achieve baseline magnification M=0.5.

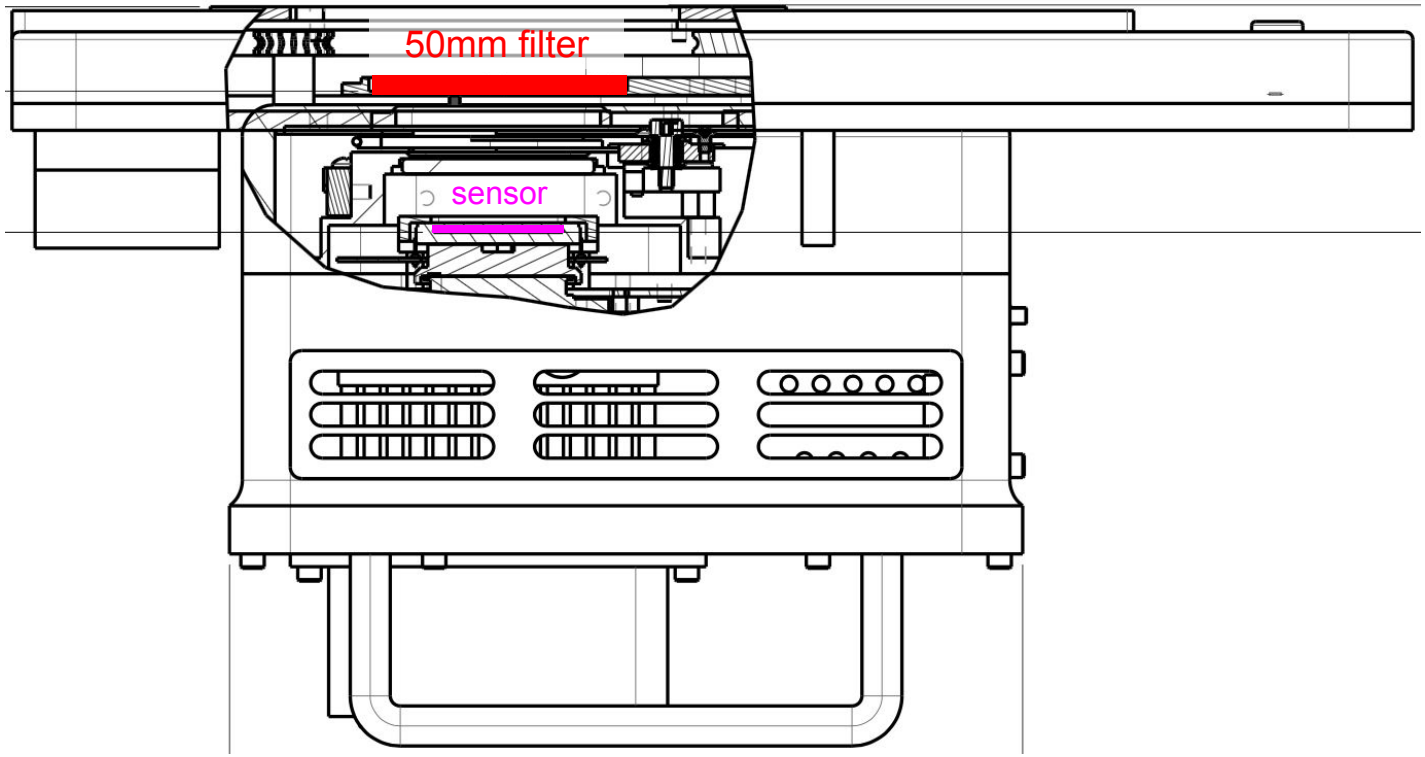


Filter wheel: FW8S-STXL

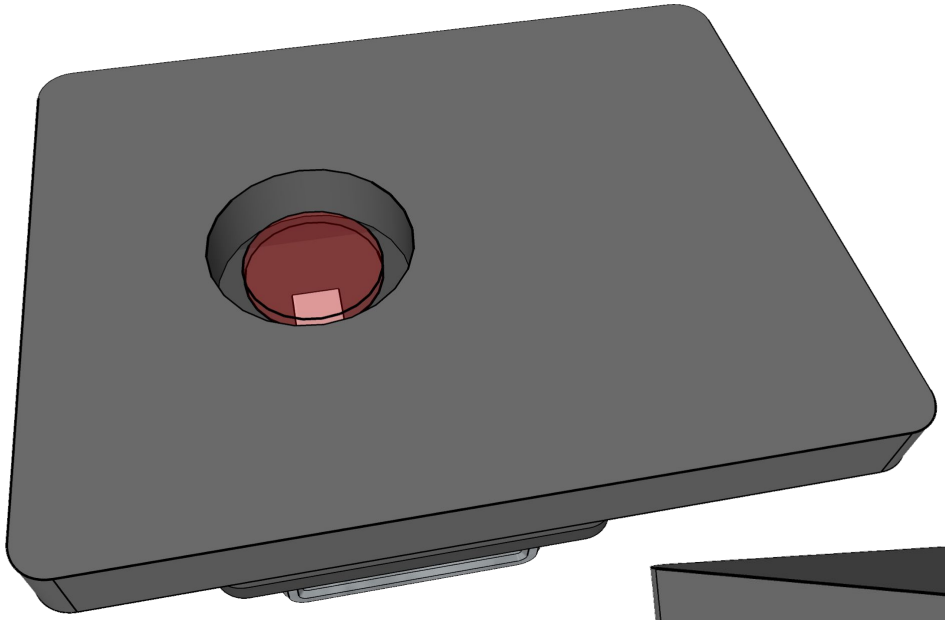
8-position carousel for 50mm round filters.

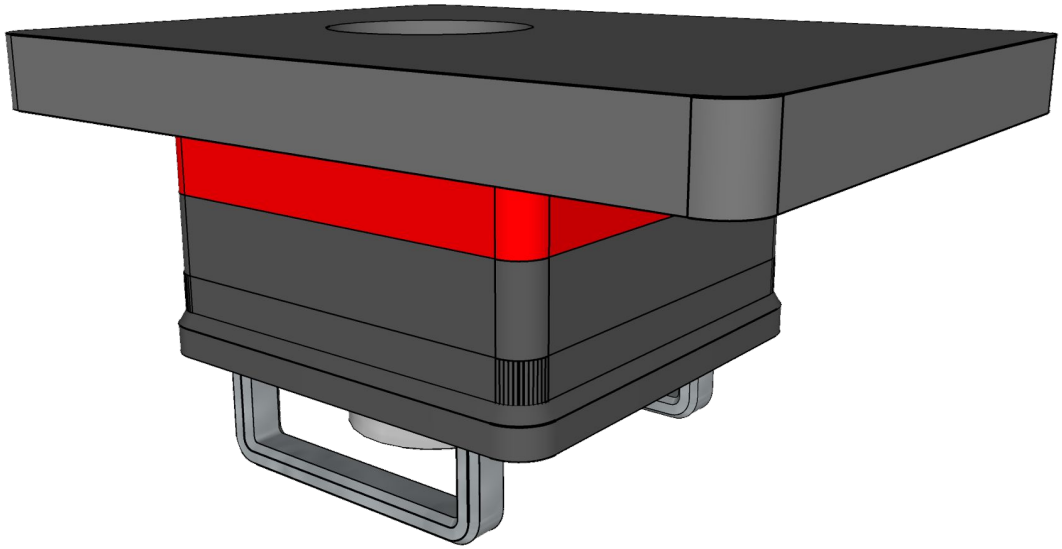
Powered and controlled via camera I2C.

Mounts directly to camera (⇒filter between sensor & lens)



Camera + Filter Assembly





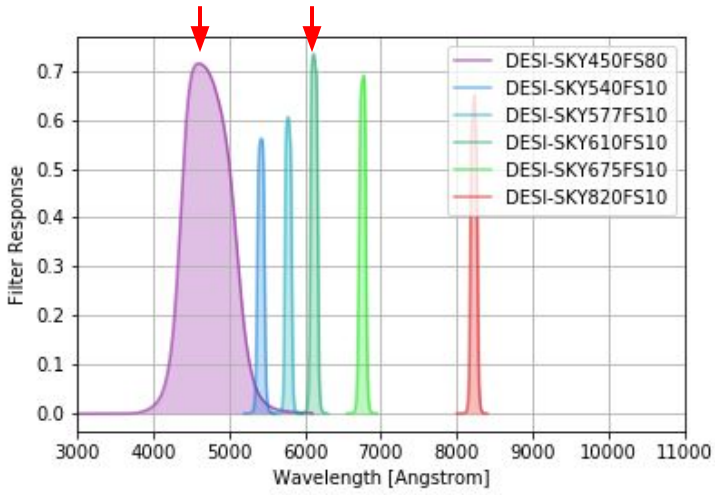
Filters: Andover Standard Bandpass 50mm

Andover standard bandpass series:

- Thickness 5.9mm, index *n = 2.05*
- Large selection of optical ±10 nm bandpasses, $232, in stock.
- Displaces focus in baseline design by ~3.1mm with ~3μm blur.

Bandpasses suitable for sky monitoring:

- Cover wavelengths of redshifted [OII] (3727A) & 4000A.
- Minimize sensitivity to variable emission & extinction lines.
- 450 ± 80 nm BRIGHT baseline
- 540 ± 10 nm
- 577 ± 10 nm
- 610 ± 10 nm DARK+GRAY baseline
- 675 ± 10 nm
- 820 ± 10 nm



https://www.andovercorp.com/products/bandpass-filters/standard

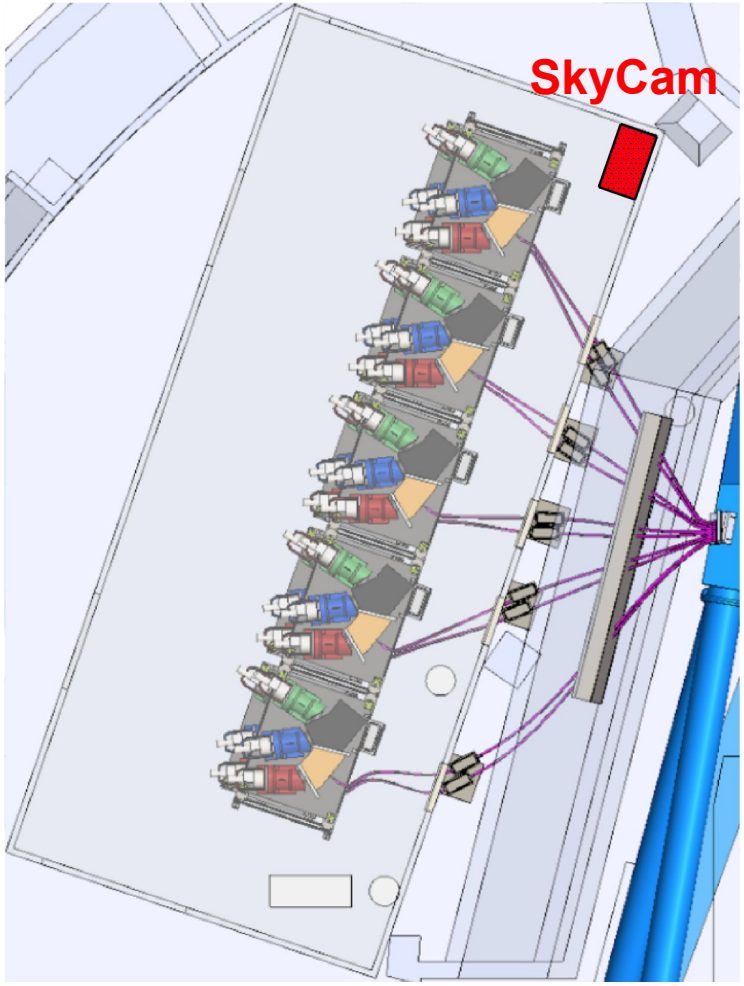
Fiber Length

Pat Jelinsky estimates 3.54 - 8.76m with no margin:

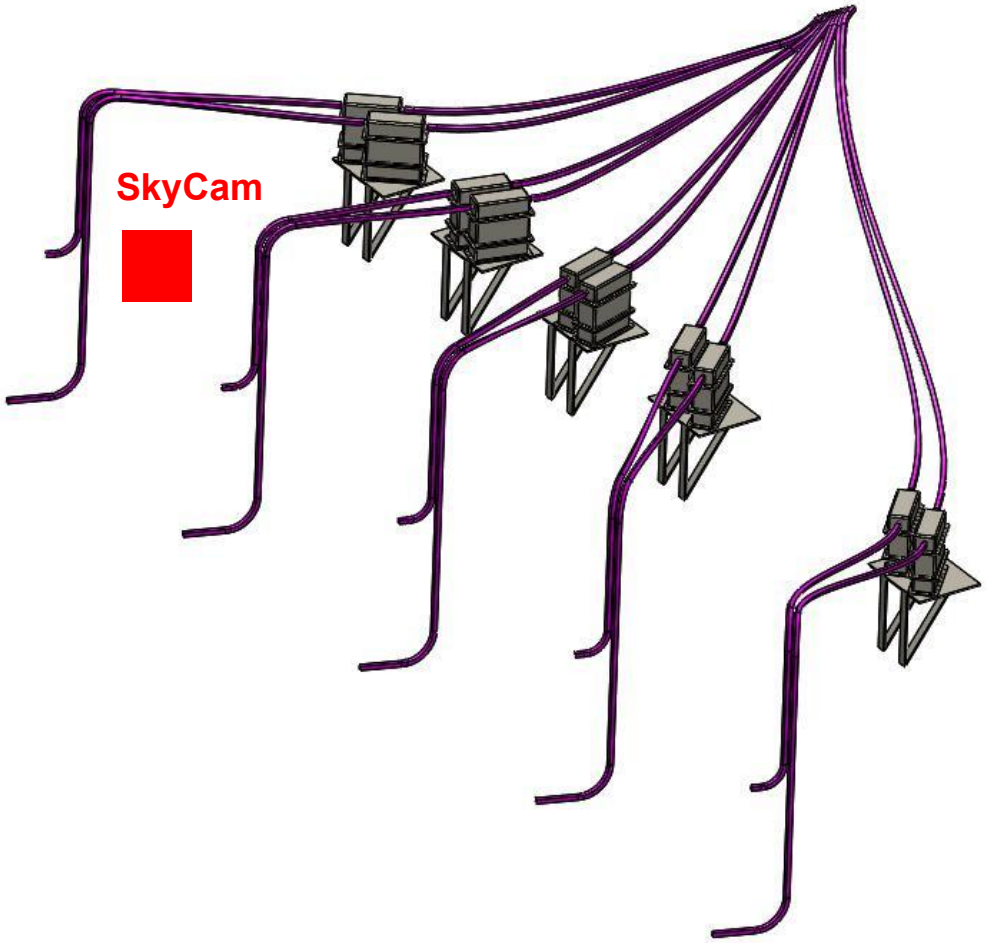
1) I assumed that the sky cables routed through the penetrations near the spectrograph cables.
2) I assumed that the entrance into the sky monitor box was 1000 mm off the floor, 200 mm from the wall that the fibers penetrated, and 500 mm from the wall with the spectrograph electrical feedthoughs. (in other words the sky monitor box in the corner behind the spectrograph kitty corner from the annex.
3) I assumed that the cables had a bend radius of 100 mm.
4) I assumed that the cables had a 200 mm length in the sky monitor box.
5) I assumed that the spool boxes were mounted horizontally.

Use 12m for all fibers to provide some margin, fewer spares, and more uniform throughput.

Extra 5m relative to spectrographs reduces transmission by few %.



Fiber Length



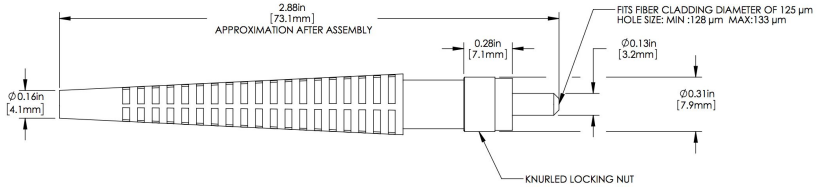
Fiber Termination

SMA connector at spoolbox already finalized.

Two options at fiberblock.

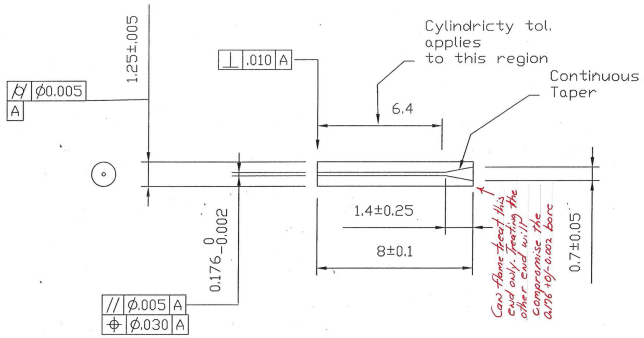
Baseline option:

- PFA ferrules, glued into fiberblock.
- Claire Poppett estimates $1550 for materials.
- 5 working days to assemble.



Alternate fiberblock termination:

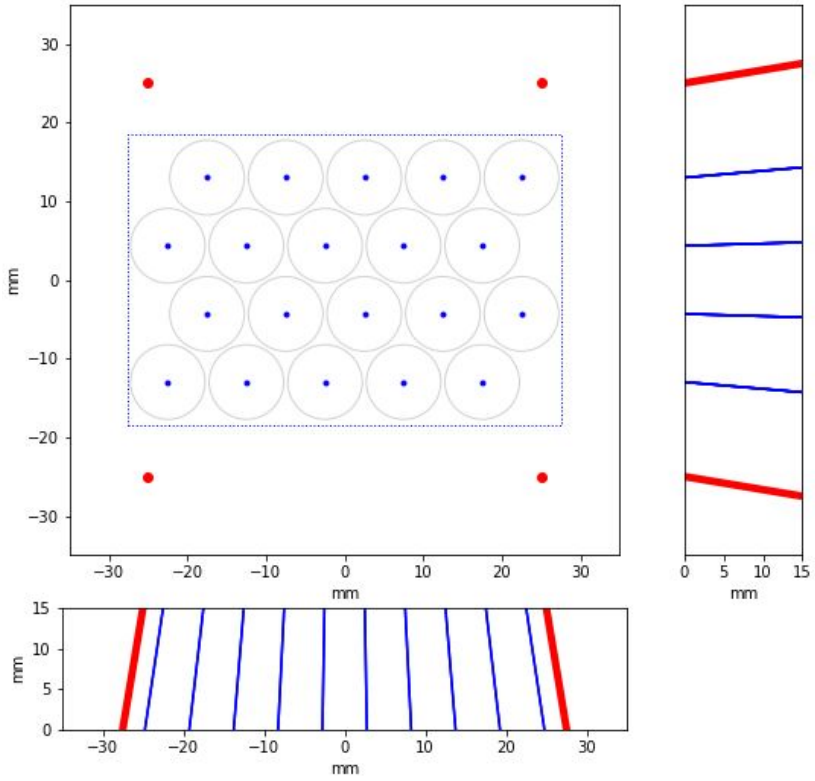
- SMA905 connectors with long ferrules.
- Constructed by ThorLabs using DESI fibers.
- $308/fiber, $4.3K total.
- 6 weeks lead time.



Fiber block assembly

Distribute 4 x 5 fibers at 10mm center-center (5mm at CCD, M=0.5) using triangular packing:

Use same layout with either termination option.

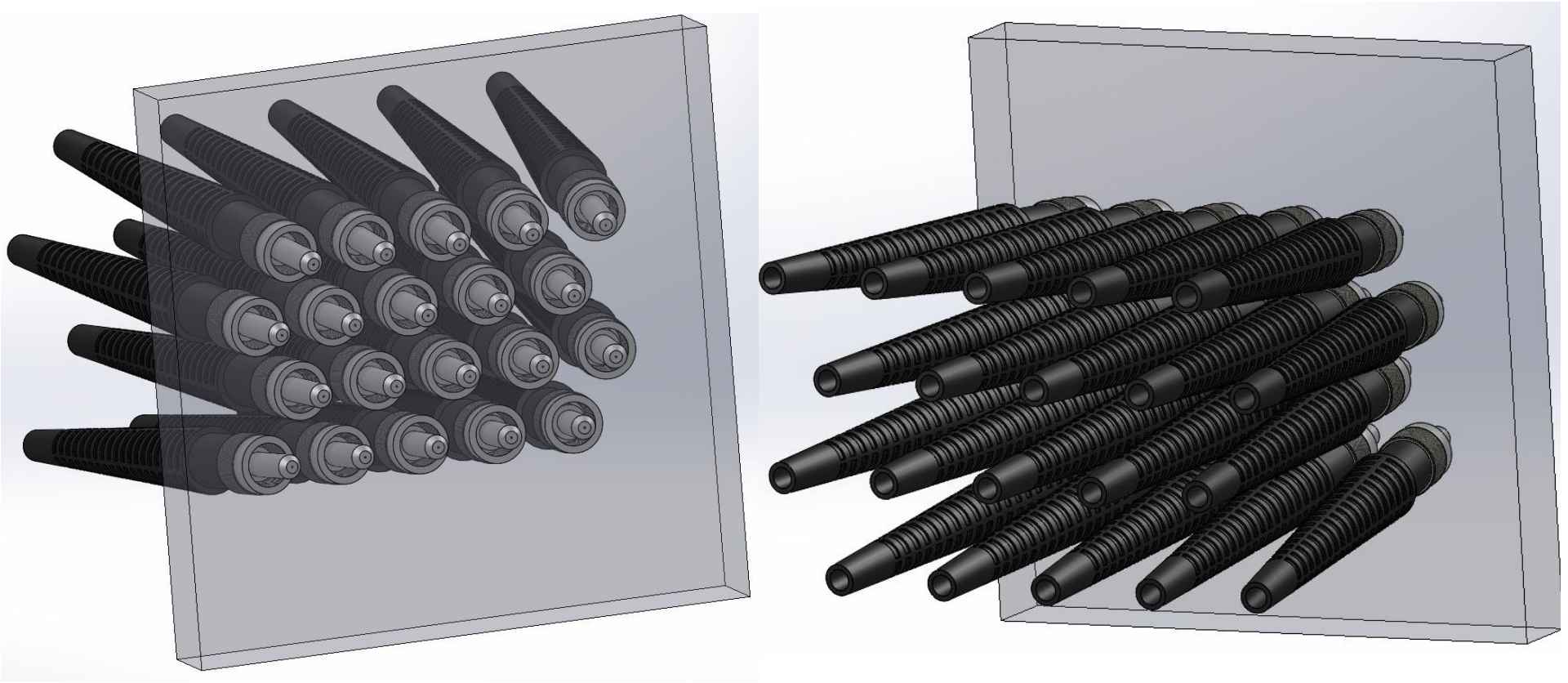


Off-axis fibers aimed at lens center, 150mm from fiber tips.

Also holds 4 collimated LEDs for back illumination.

Fiber block assembly

10mm spacing provides sufficient space for SMA905 option:



Back Illumination

LEDs powered by standard FIPOS+FISBO chain (1.4W + 2.6W CAN).

LEDs illuminate filter wheel with stacked:

- 99.9 / 0.1 mirrored neutral density filter.
- ground-glass diffuser.

0.1% of illumination transmitted to camera provides:

- flat-field calibration.
- LED monitoring / diagnostics.

LEDs must not leak light into the shack [SC-10021].

Design not very advanced yet, but should have plenty of SNR margin.
Will prototype implementation in next phase to finalize details.

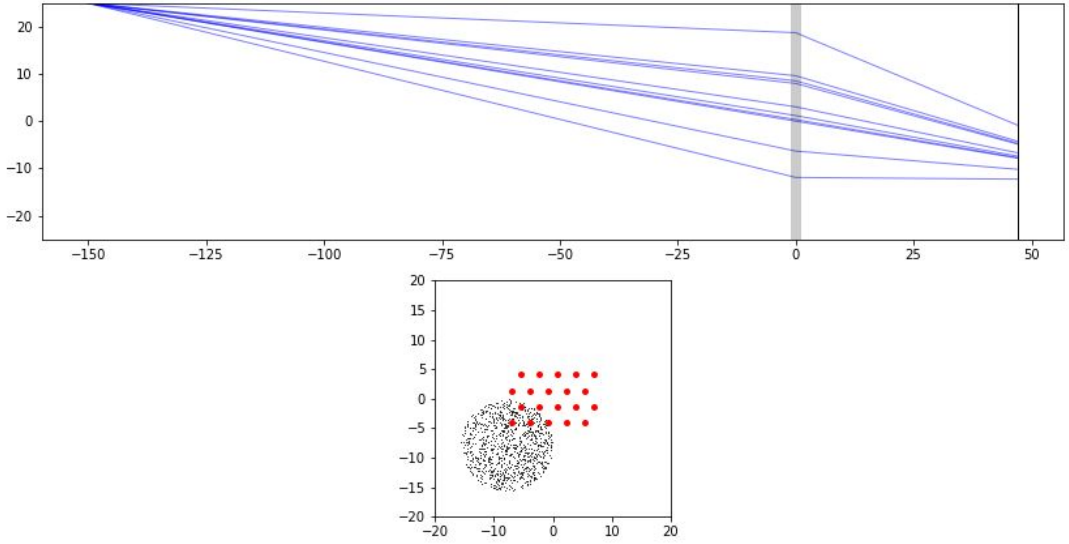
Back Illumination: Update

The initial concept for locating the LEDs in the fiberblock is flawed:

It provides ~uniform illumination of the fibertips into an f/3.8 acceptance, but the FVC has a much smaller acceptance.

The current LED locations do not illuminate the chief rays of several of the central fibers in the fiberblock array:

A different LED location should address this, but this still needs to be confirmed.



End-to-end performance

Sky surface brightness:

- DARK / GRAY / BRIGHT (use minimum DARK for SNR forecast).

DESI throughput:

- optics-to-fiber
- fiber transmission & FRD (54m vs 49m).
- corrector vignetting (r=410mm vs field average)

Sky Camera throughput:

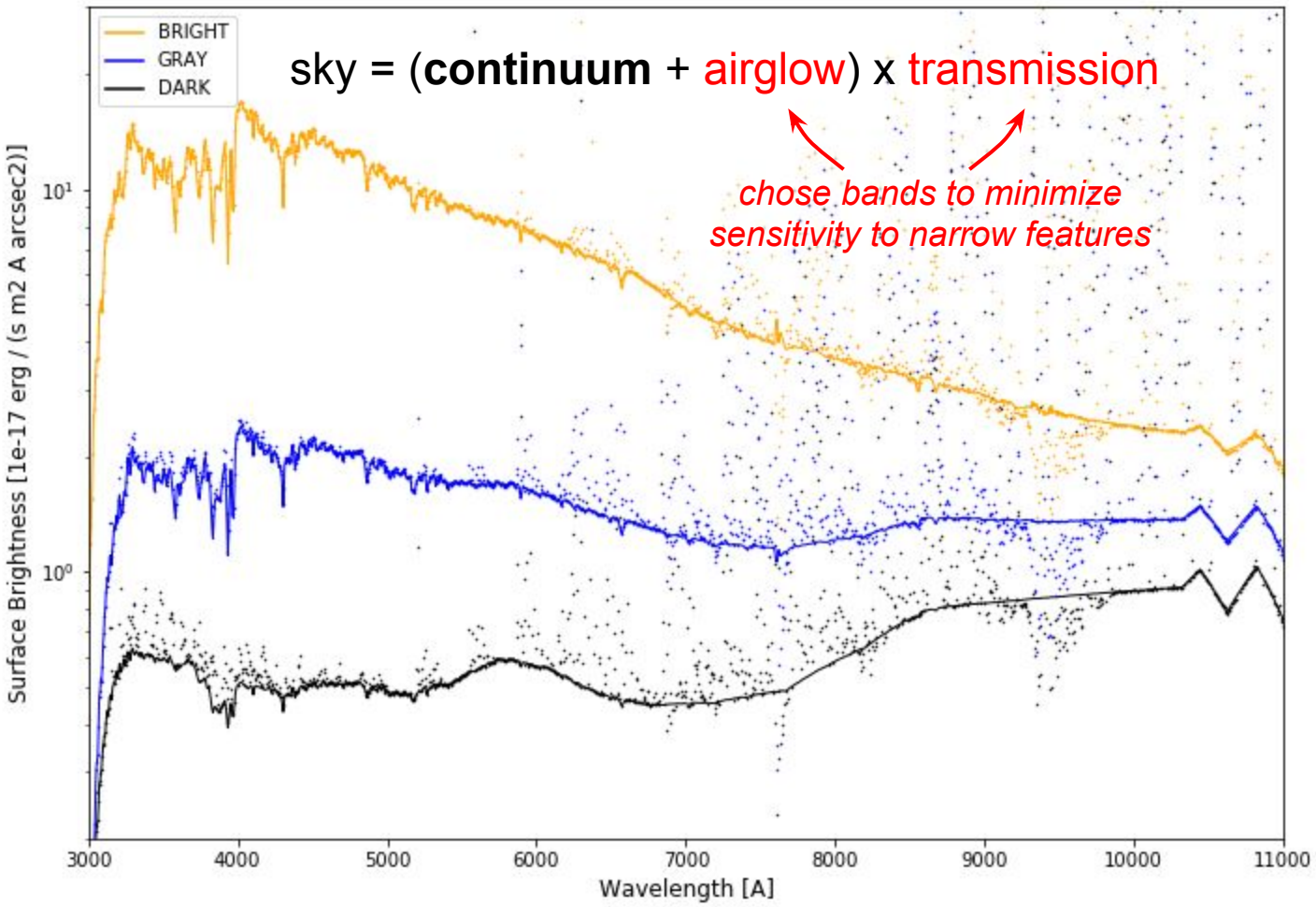
- filter & lens
- lens vignetting
- CCD QE

Sky Camera noise:

- sky shot noise
- dark current
- read noise (reduce with 2x2 binning)

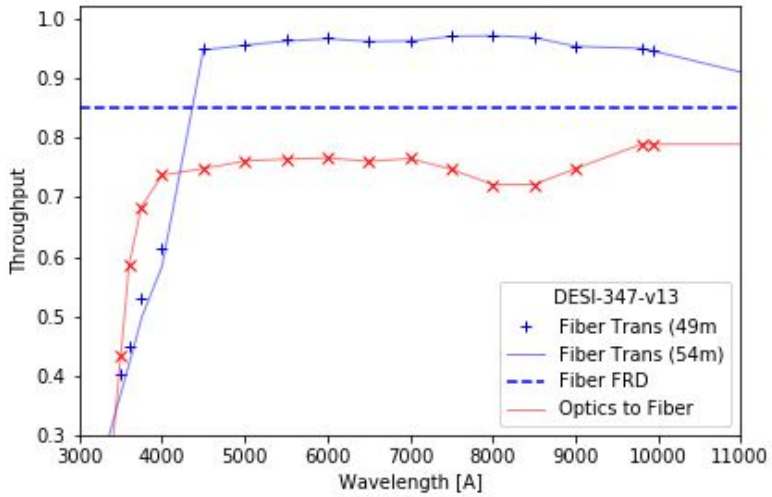
Min. requirement is single-exposure SNR > 10 per fiber.

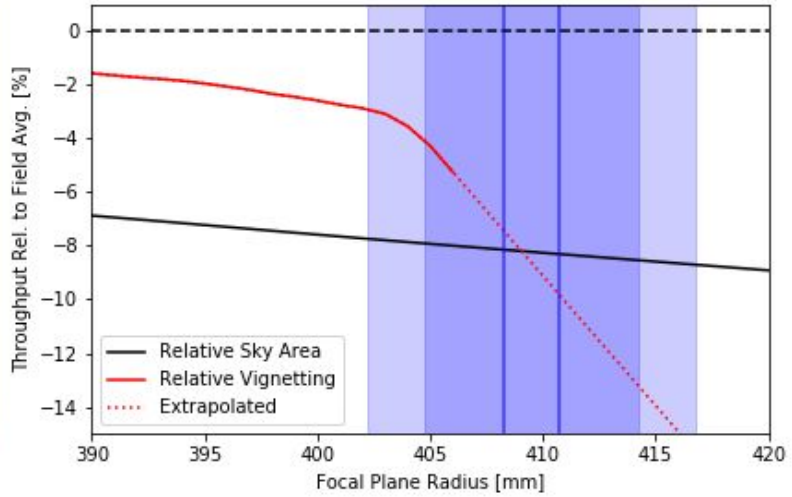
Sky Surface Brightness

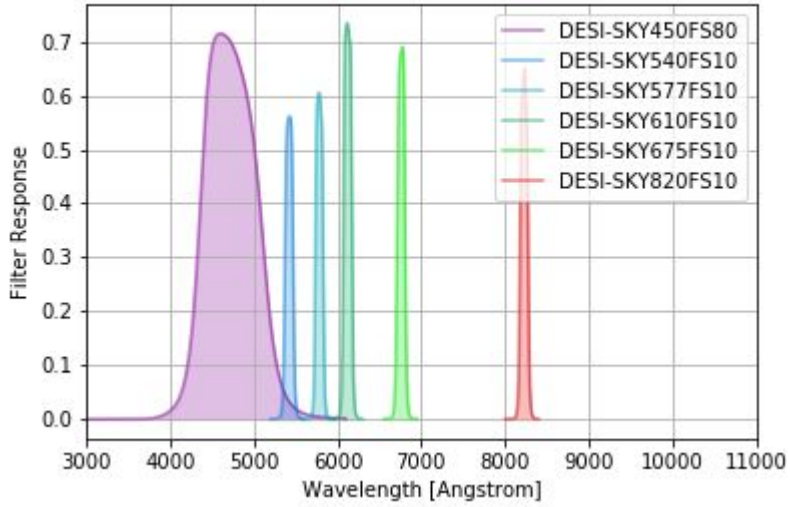


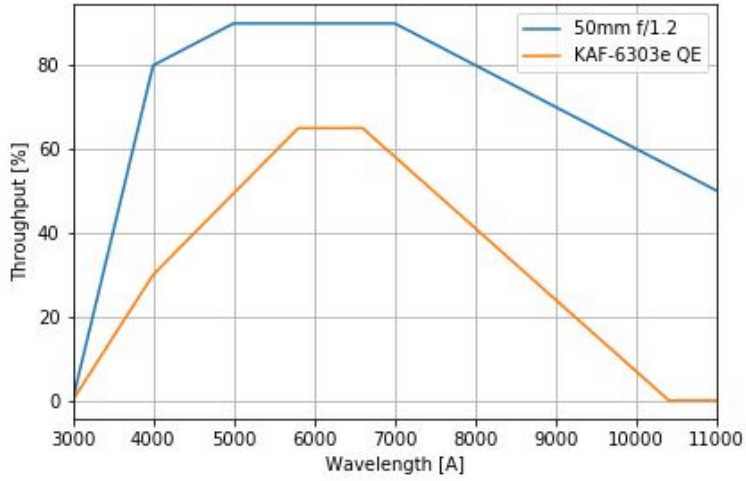
Predictions from ESO SkyCalc based on models in Noll 2012.

Throughput

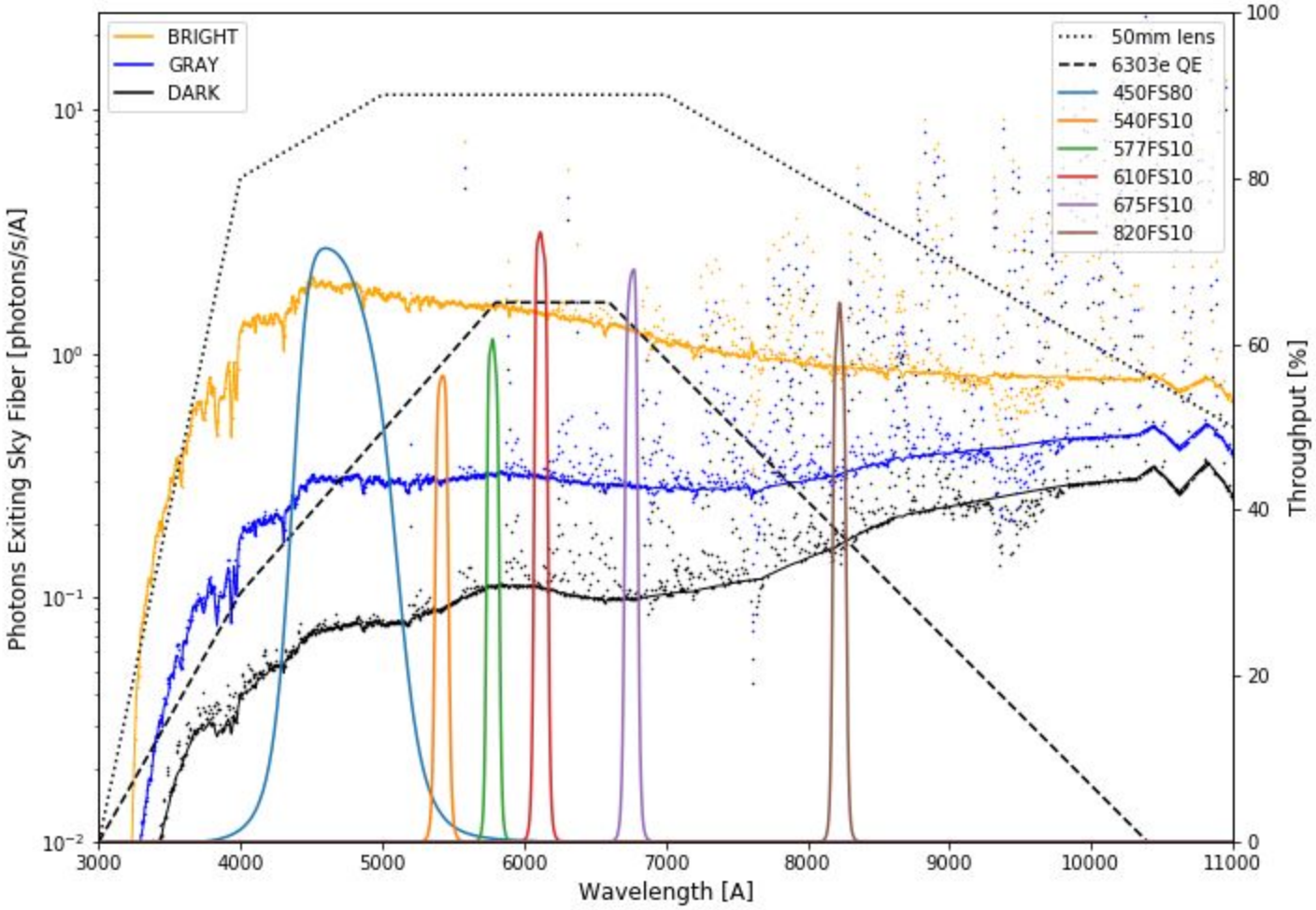

Throughput
Wavelength [A]
DESI-347-v13
Fiber Trans (49m
Fiber Trans (54m)
Fiber FRD
Optics to Fiber


Throughput Rel. to Field Avg. [%]
Focal Plane Radius [mm]
Relative Sky Area
Relative Vignetting
Extrapolated


Filter Response
Wavelength [Angstrom]
DESI-SKY450FS80
DESI-SKY540FS10
DESI-SKY577FS10
DESI-SKY610FS10
DESI-SKY675FS10
DESI-SKY820FS10


Throughput [%]
Wavelength [A]
50mm f/1.2
KAF-6303e QE

Photon Rates Exiting Fiber



Sky Camera Detected Electron Rates

Nominal contribution of OH airglow emission

Filter	DARK	Airglow	Absorp.	GRAY	Airglow	Absorp.	BRIGHT	Airglow	Absorp.
450FS80	16.33 Hz	3.2%	0.0%	62.91 Hz	1.0%	0.0%	378.26 Hz	0.2%	0.0%
540FS10	2.73 Hz	0.4%	0.0%	9.08 Hz	0.2%	0.0%	48.30 Hz	0.0%	0.0%
577FS10	3.73 Hz	0.3%	0.0%	10.73 Hz	0.1%	0.0%	52.17 Hz	0.0%	0.0%
610FS10	5.12 Hz	4.8%	0.0%	14.13 Hz	2.1%	0.0%	64.87 Hz	0.5%	-0.0%
675FS10	3.99 Hz	4.7%	0.0%	11.22 Hz	2.0%	0.0%	48.04 Hz	0.5%	0.0%
820FS10	3.63 Hz	21.0%	4.3%	6.41 Hz	14.3%	5.2%	16.08 Hz	6.1%	5.1%

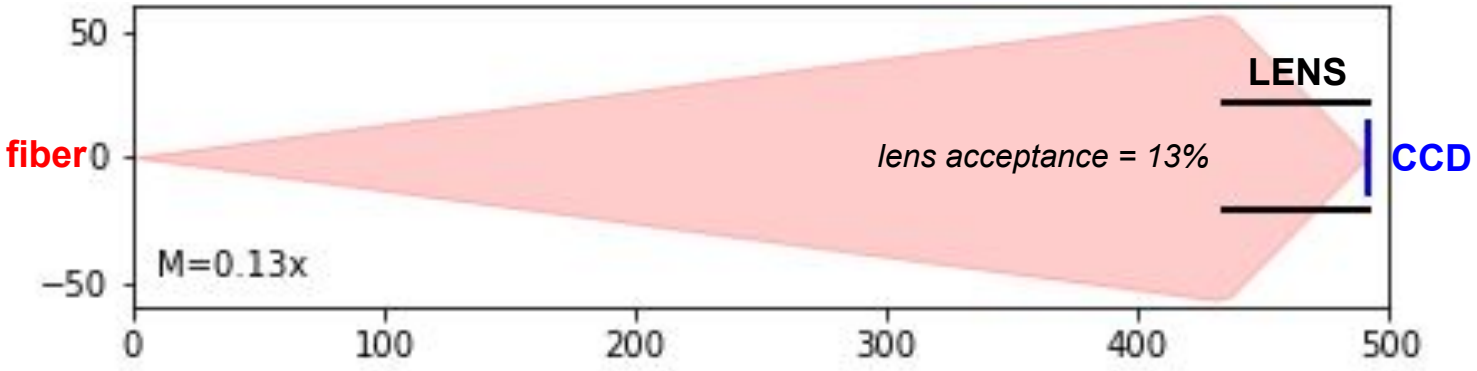
Nominal fraction lost to molecular absorption

Baseline filters are 610FS10 (DARK+GRAY) and 450FS80 (BRIGHT)

Lens Magnification

Magnification > 0.13 requires an extension tube.

Magnification < 0.5 vignettes f / 3.8 fiber.

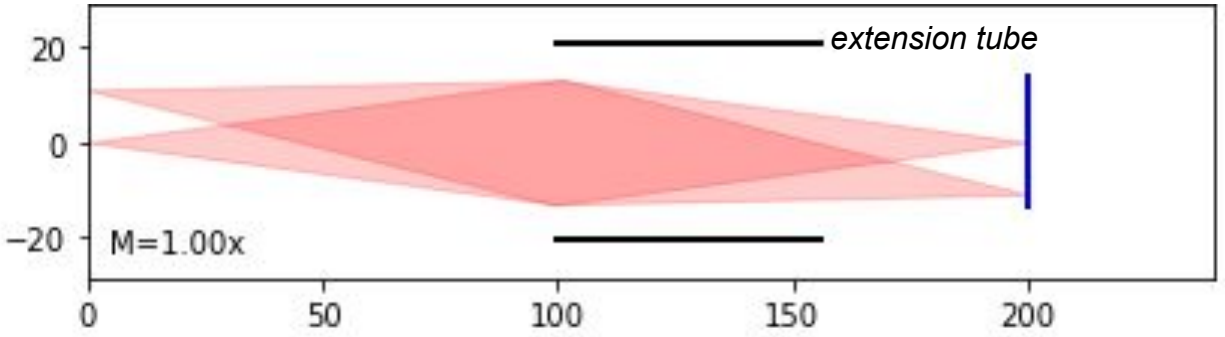


Lens Magnification

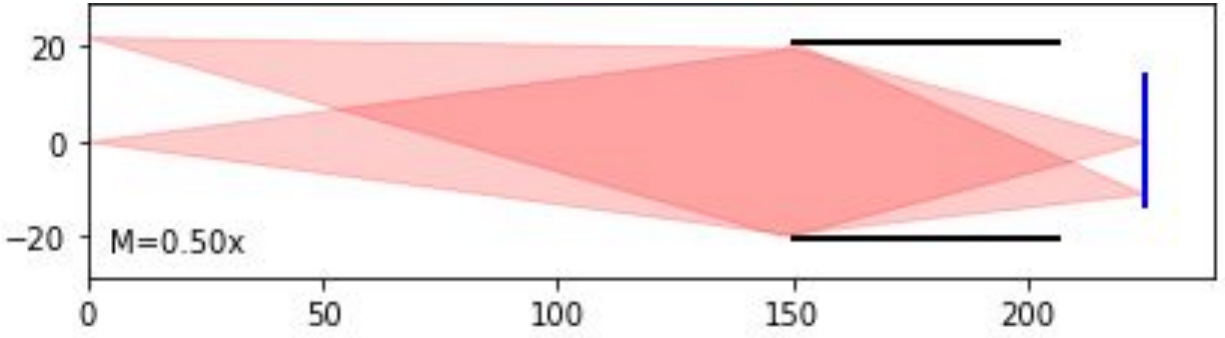
Smaller magnification:

- reduces number of signal pixels ⇒ lower pixel noise
- reduces depth of field ⇒ tighter assembly tolerances
- reduces fiber packing density
- increases overall length

aim off-axis fibers at lens center to minimize vignetting

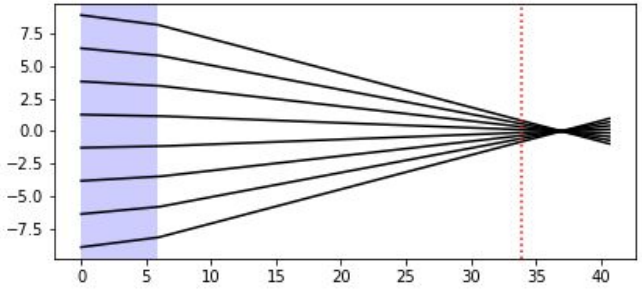


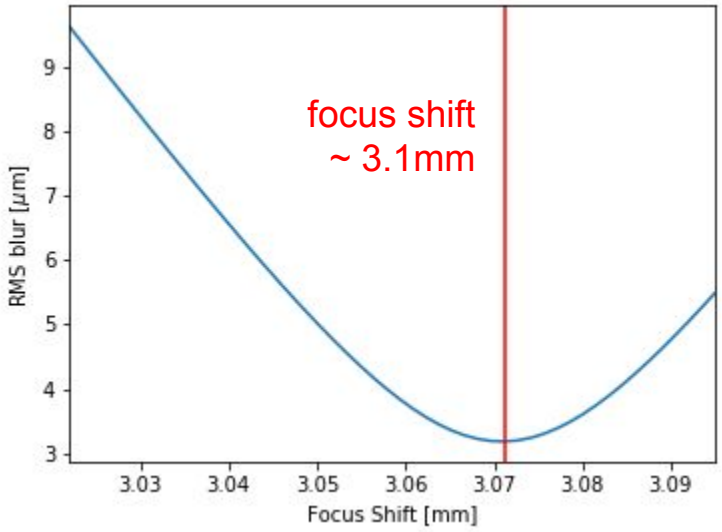
Baseline: M=0.5

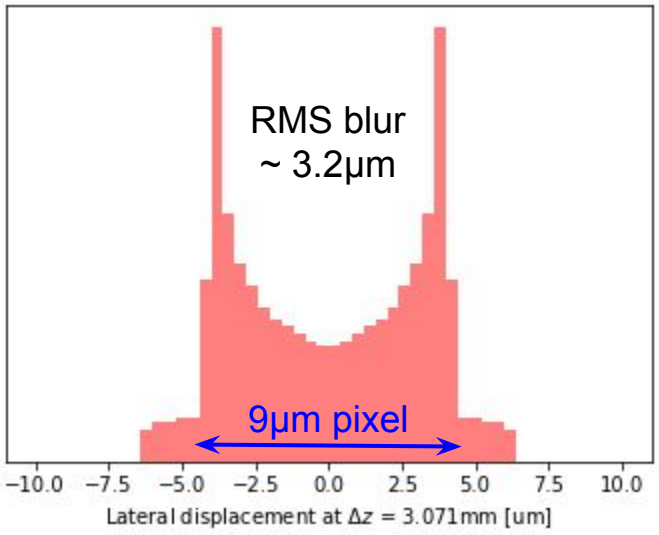


Filter Refraction

Filters are 5.9mm thick with n=2.05. Since they are between lens and camera, they refract f/1.9 beam.







Optics Summary

The baseline design has:

- magnification M=0.5
- readout binning = 2x2
- total optical path length of ~228mm.
- extension length of 18.7mm.
- DOF = 72μm (for 5μm circle of confusion).
- 3.2μm RMS blur from filter.

Meets SNR > 10 per fiber requirement with:

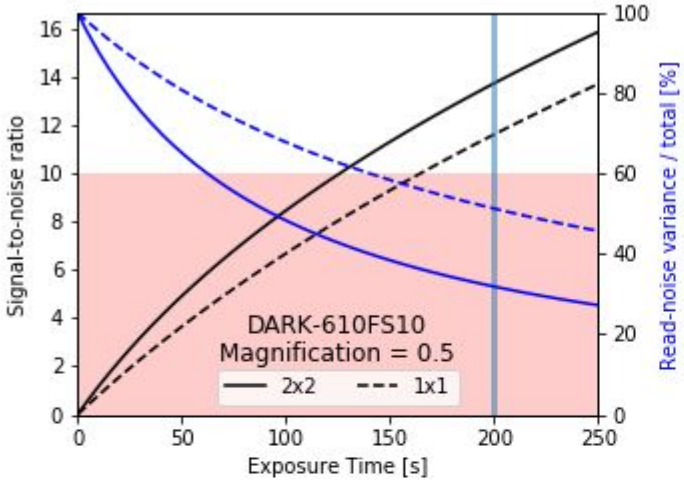
- 200s exposure with 610FS10 filter (DARK + GRAY)
- 60s exposure with 450FS80 filter (BRIGHT).

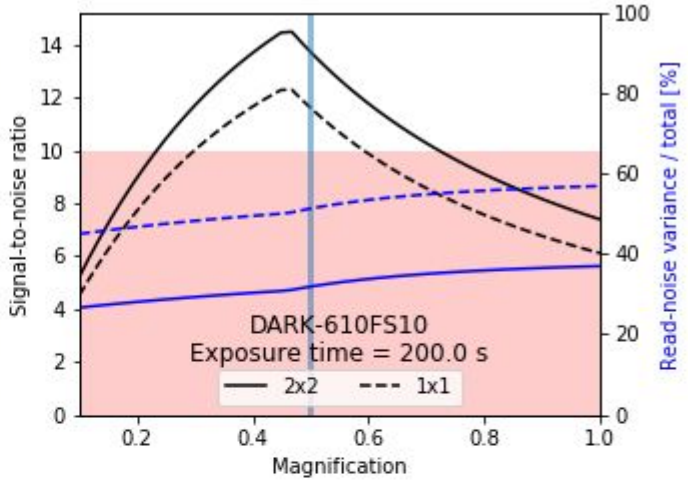
Throughput Summary

Component	Throughput at 610nm
Field-averaged optics to fiber	76.5%
Extra vignetting at r=410mm	90.0%
Fiber transmission (54m)	96.5%
Fiber FRD	85.0%
Spoolbox connector	80.0%
50mm f/1.2 lens	90.0%
610FS10 filter	72.7%
Sensor QE	65.0%
TOTAL	**19.2%**

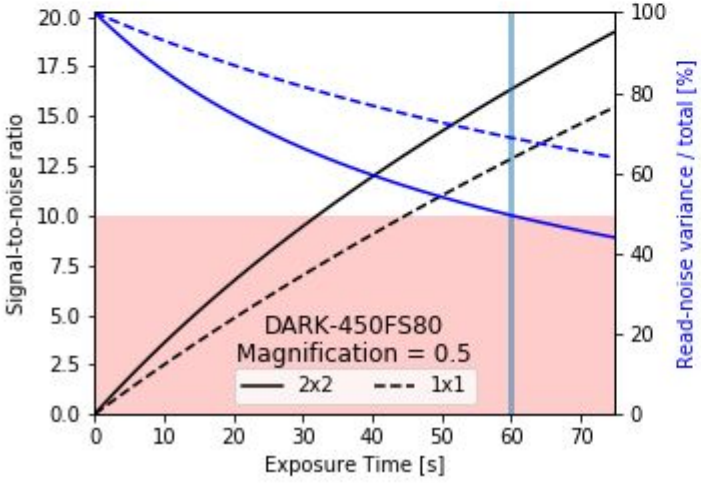
SNR Forecast vs exposure time & magnification

200s of darkest sky with DARK+GRAY filter 610FS10





60s of darkest sky with BRIGHT filter 450FS80



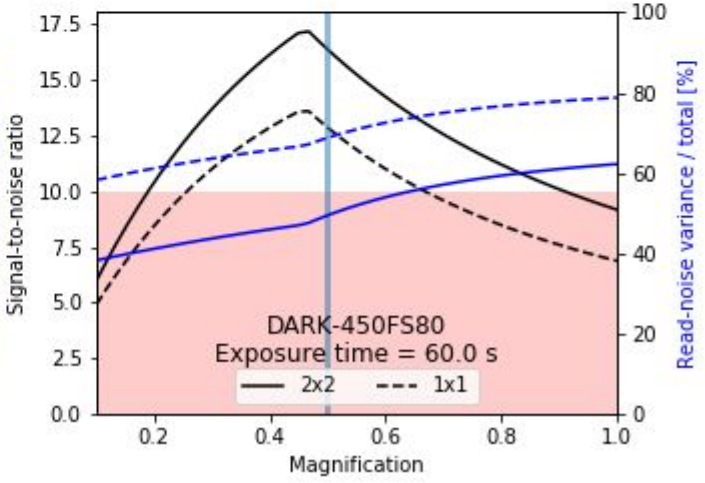
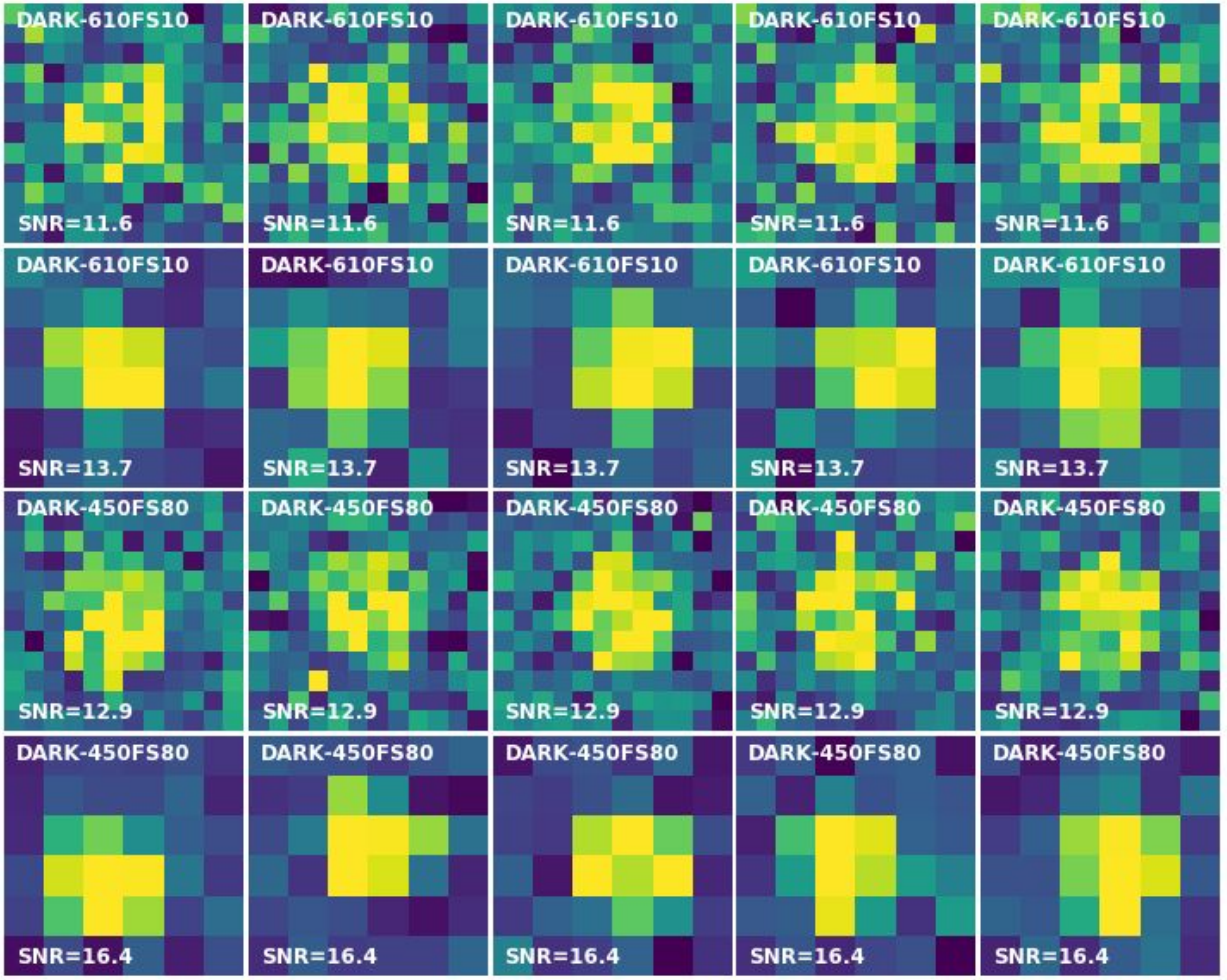


Image Simulation

200s of darkest sky with DARK+GRAY filter 610FS10

60s of darkest sky with BRIGHT filter 450FS80



Build Plan

LBL to send OSU one SBIG, filter wheel, and filter:

- OSU to assemble one system, verify optics layout and focus.
- Prototype back illumination and measure fiber illumination levels.
- Finalize mounting and enclosure scheme.

LBL purchase 2 fibers from Thorlabs with SMA connectors:

- Measure FRD and throughput.
- Decide which fiber option to use.

UCI finalize flux measurement algorithm and ETC/ICS integration:

- Validate with simulations and bench data.
- Specify and simulate commissioning plan.

Schedule Milestones

Date	Task
Aug 2018	Order camera, filter wheel, and other components for tests at OSU
Oct 2018	Select fiber termination scheme (SMA / ferrule), manufacture fibers
Nov 2018	Complete prototype tests at OSU, remaining detail design, have MRR
Dec 2018	Fiberblock fabricated at LBL, order components for second unit
Dec 2018	Finalize software integration with ETC / ICS
Jan 2019	All components integrated and tested at OSU
Feb 2019	Ready to ship to Mayall, install once spool boxes are in place
May 2019	Start of level-2 commissioning
Sep 2019	Start of survey validation

Verification Plan

Prototype Tests (Aug-Nov 2018)

OSU to assemble SBIG, filter wheel, filters, lens+extender, fiber block, several test fibers, LEDs

- Measure best focus for fiber block with both filters
- Determine best back-illumination strategy
- Develop/test filter wheel driver
- Process raw images with SkyCam software

System Tests (Dec 2018-Feb 2019)

OSU to assemble both units

- Verify focus, measure fiber block position repeatability
- Measure total power
- Develop/test ICS control
- Measure light tightness of enclosure
- Use raw images to test SNR calculation

SkyCam in Commissioning

Level 2: Spectroscopy (16 nights)

- 6.1: OCS software can control all parts of DESI system

Level 3: Full-System Functionality (31.5 nights)

- C5.8: Measure sky background S/N with sky fiber camera

Level 4: System Characterization & Survey Ops Tools (30.5 nights)

- Dynamic exposure-time calculator

Budget Overview

Assume two identical camera systems with shared fibers + fiberblock.

Only spares are 4 additional fibers.