Universität Stuttgart
Institut für Raumfahrtsysteme (IRS)
Deutsches SOFIA Institut (DSI)

Upgrade of the SOFIA Focal Plane Imager FPI+

VIS & NIR Guider and Science Camera FPI++

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SOFIA Science Instrument Roadmap Workshop

June 22th, 2020

Expand the tracking capability of the SOFIA telescope into the NIR up to about 1.6 µm

- Far-infrared observations in regions of large extinction would profit from NIR tracking, as the number of available tracking stars increases towards longer wavelengths
- Increase sky coverage to 100% in dark clouds (99% all sky)

FPI+ NIR spectral coverage enables science applications requiring Y-, J- and H-band photometry

- Multi-channel capability necessary to study particle sizes and aerosol compositions during stellar occultations by atmospheres, rings or cometary coma

Motivation

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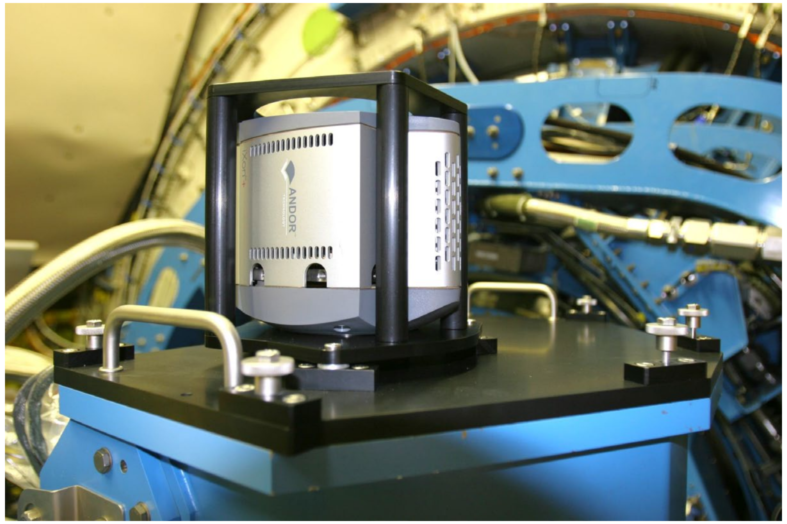
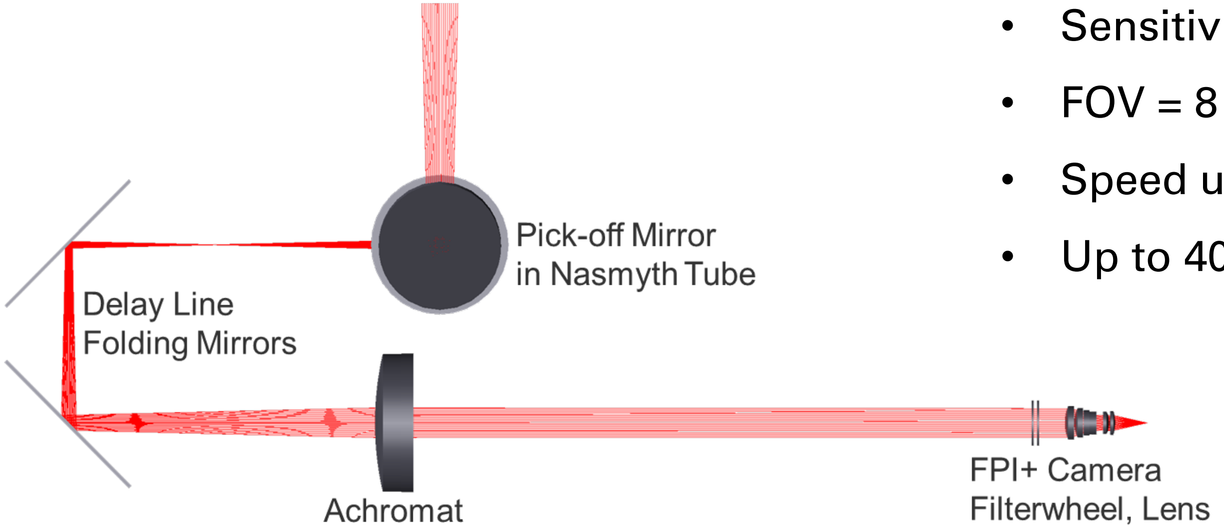


The Focal Plane Imager (FPI) is SOFIA's primary tracking camera

- Original camera upgraded in 2013 with commercial EM-CCD camera → FPI+
- SOFIA Facility Science Instrument since cycle 4
- Main application: stellar occultations by small solar system bodies (Pluto!)
- Permanently mounted at the SOFIA telescope; available in each mission in addition to any science instrument on the main flange

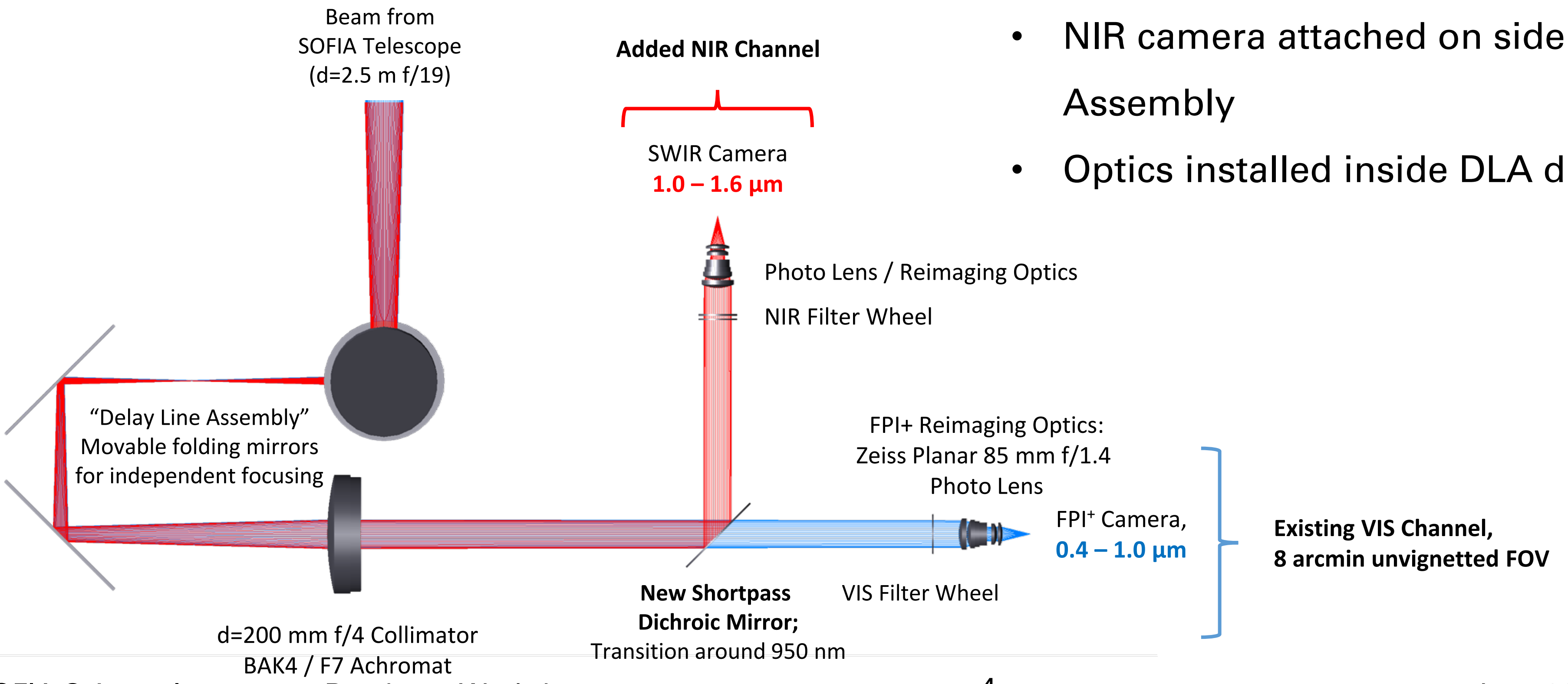


- Sensitivity: 16^{mag} with $^{S}/_{N}$ = 35 in 1 sec
- FOV = 8 arcmin diameter
- Speed up to 10 fps full frame
- Up to 400 fps with subframes / binning

FPI+ Current Capabilities

FPI+ Near-Infrared Upgrade Approach

- NIR capability for tracking 1 µm to 1.6 µm
- Retain current VIS FPI+ sensitivity with moveable dichroic mirror



- NIR camera attached on side of Delay Line Assembly
- Optics installed inside DLA distance tube

NIR Channel Upgrade

Why tracking in the NIR?

- Difficulty to find suitable guide stars in dark clouds; Interesting IR objects „hide“ in VIS dark clouds
- There have been observations (HAWC+, FIFI-LS) that could not be scheduled due to missing guide stars

Object: L 1688
RA: 16:28:51.5, Dec: -24:17:03

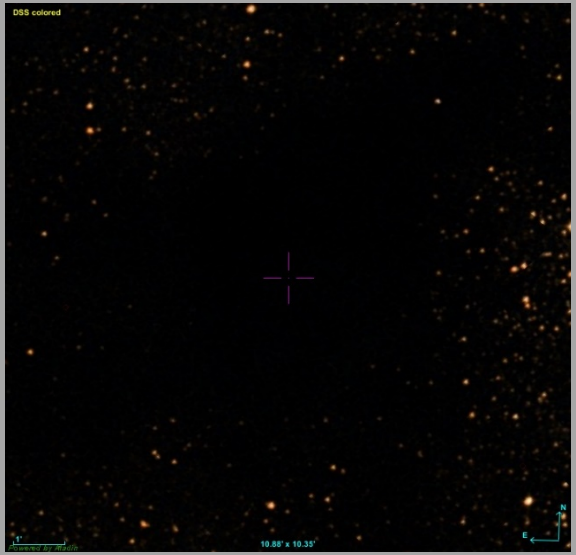
Left: VIS no stars brighter than R = 16 mag

Right: NIR star with H = 11.4 mag and about 10 stars brighter than H = 14 mag.

NIR Tracking

Dark Cloud and All-Sky Coverage Analysis

- 2892 dark clouds (Lynds, Hartley) analyzed: 96% have V=14mag guide star within FPI+ FOV (UCAC4)
  100% have H=14mag guide star (2MASS)
- Number of NIR guide stars in all dark clouds one magnitude larger than VIS guide stars
- All-sky coverage VIS 90%, NIR 99%



Object: L 483
RA: 18:17:29.9, Dec: -04:39:41

Left: no suitable VIS stars for tracking

Right: NIR star with H = 10.4 mag and about 50 stars brighter than H = 14 mag.

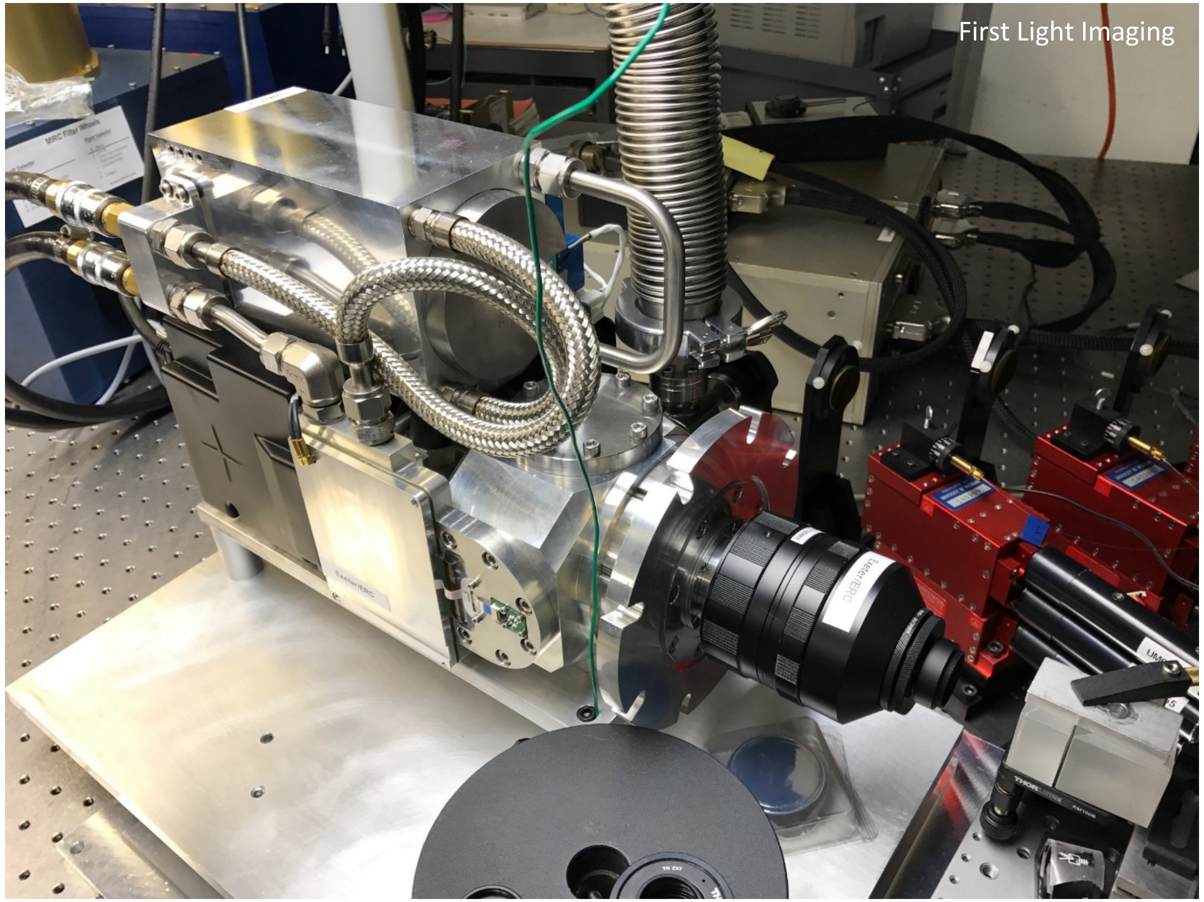
NIR Tracking

Promising commercial solution for NIR upgrade

First Light Imaging „C-RED One“ Camera

- Leonardo Saphira e-APD HgCdTe Array
- 320 x 256 pixel, 24 µm pitch – sweet spot for existing FPI+ optics and shear layer seeing
- Pulse tube cooled to 80 K = no consumables
- Very low noise figures
- Optimized towards high frame rates

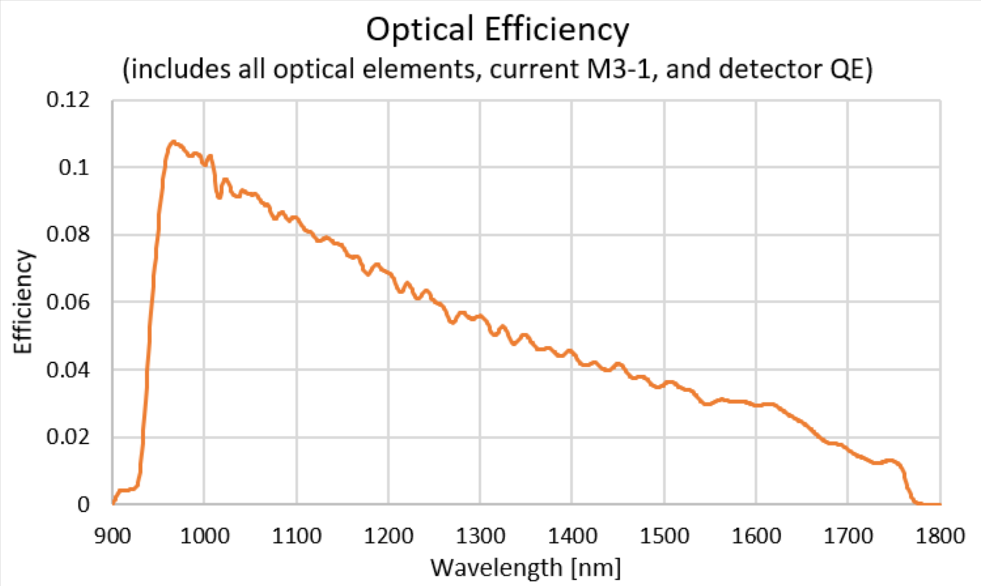
Plate scales 1.3 … 1.6 arcsec/pixel appear feasible

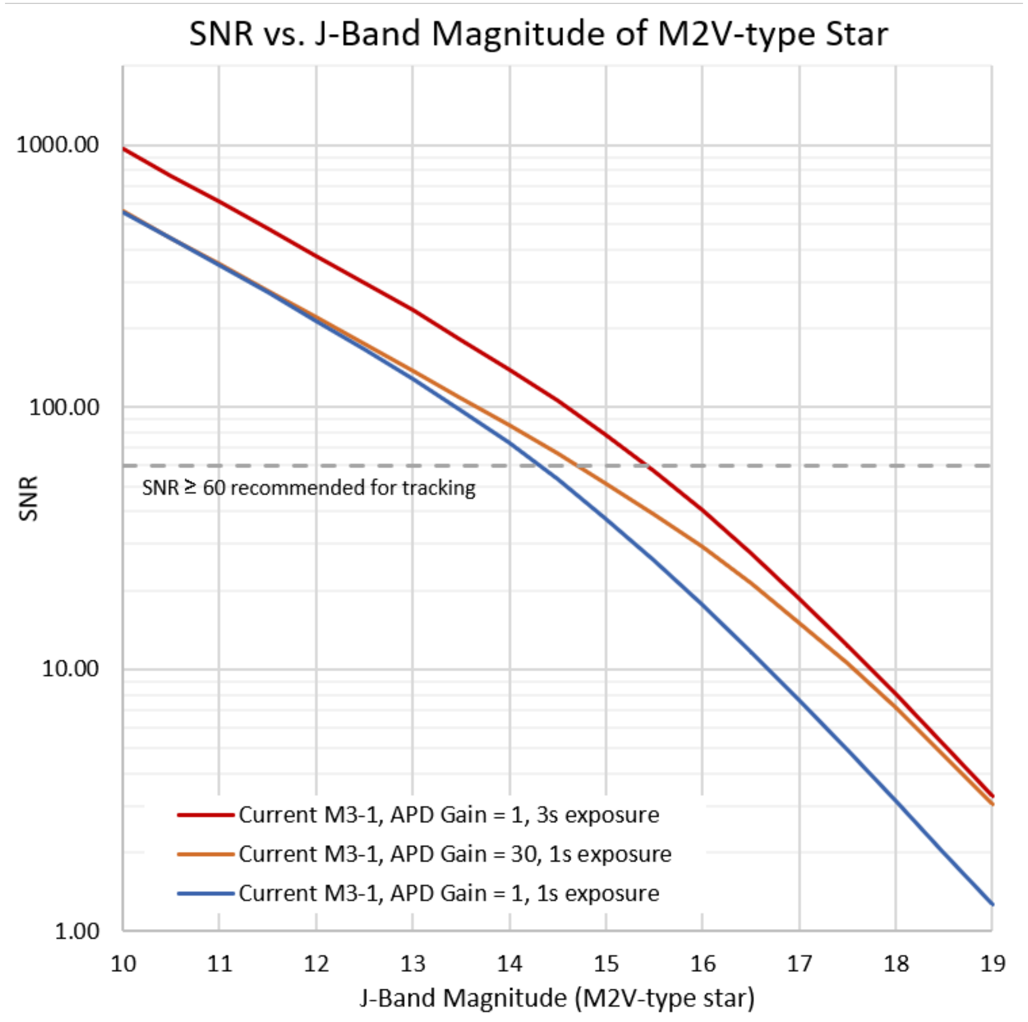


Sensitivity analysis of proposed NIR channel

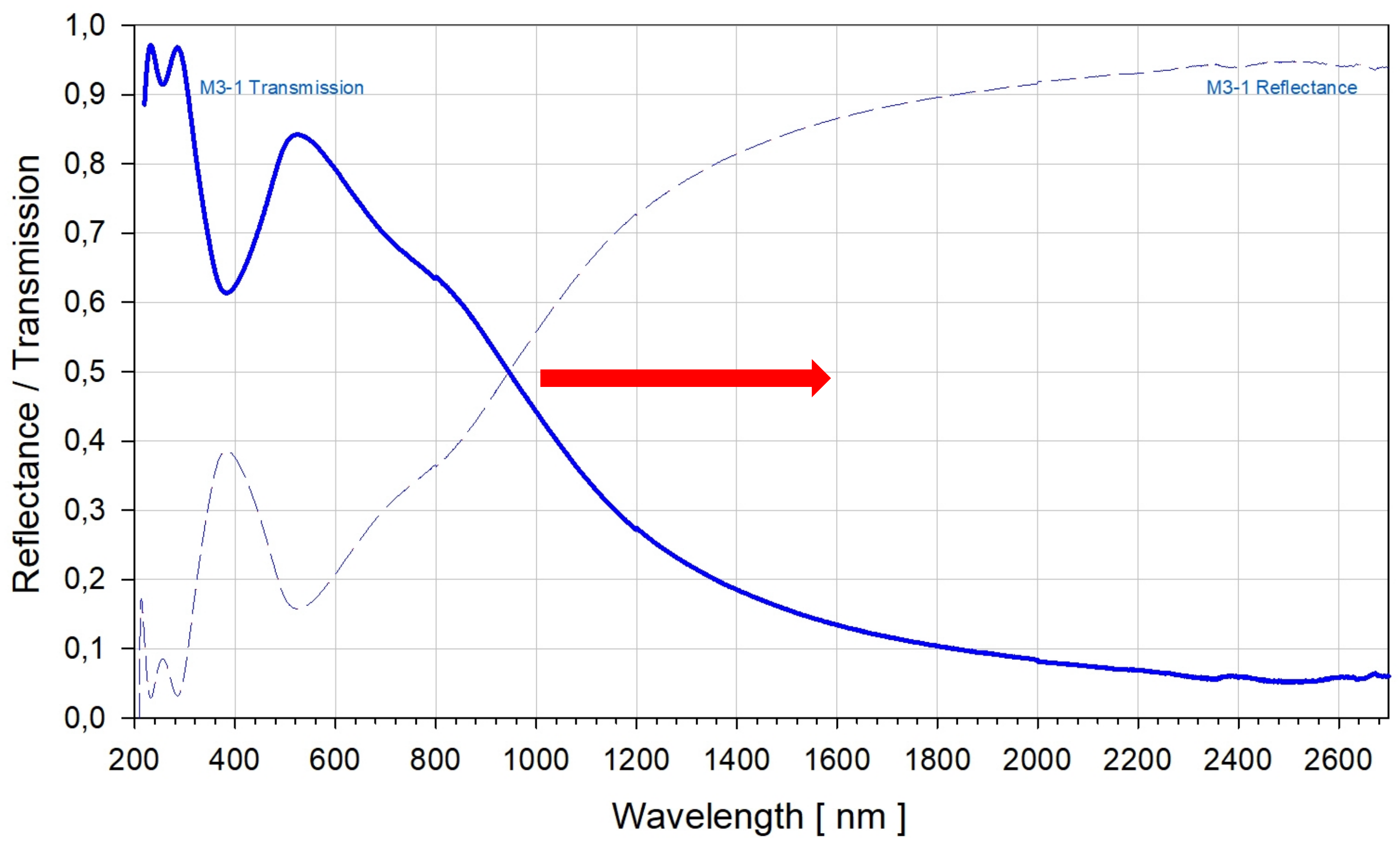
	SNR = 60 (tracking limit)	SNR = 10 (detection limit)
1 s exposure	J=14.0 mag	J=16.3 mag
3 s exposure	J=15.1 mag	J=17.4 mag

Assumptions: EM off (APD gain = 1), M2V type star





Limiting NIR transmission of dichroic tertiary mirror M3-1



Improved M3-1 requirements:

- Shift 50% transmisison to λ > 1.6 μm
- Keep FIR reflectance > 95%

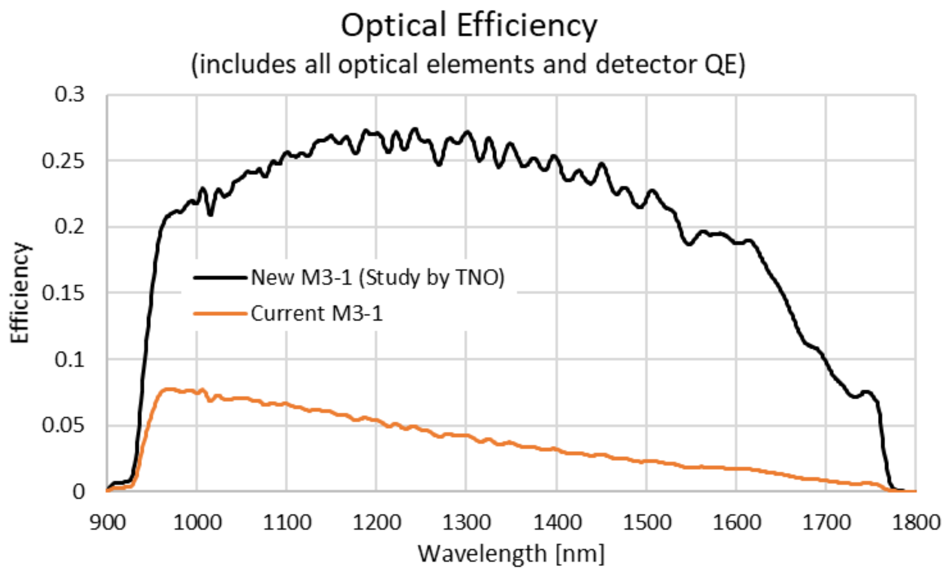
Very promising new coating is under investigation

Benefits:
- 2 stellar magnitudes improvement of FPI++ NIR sensitivity
- M3-1 spare part

Improved Tertiary M3-1 Mirror

Sensitivity analysis of proposed NIR channel

Current M3-1	SNR = 60 (tracking limit)	SNR = 10 (detection limit)
1 s exposure	J=14.0 mag	J=16.3 mag
3 s exposure	J=15.1 mag	J=17.4 mag
Upgraded M3-1	**SNR = 60 (tracking limit)**	**SNR = 10 (detection limit)**
1 s exposure	J=15.8 mag	J=18.1 mag
3 s exposure	J=16.9 mag	J=19.2 mag



- matches or exceeds Andor iXon 888 at comparable V-mag
- does not even consider further sensitivity improvements using avalanche multiplication

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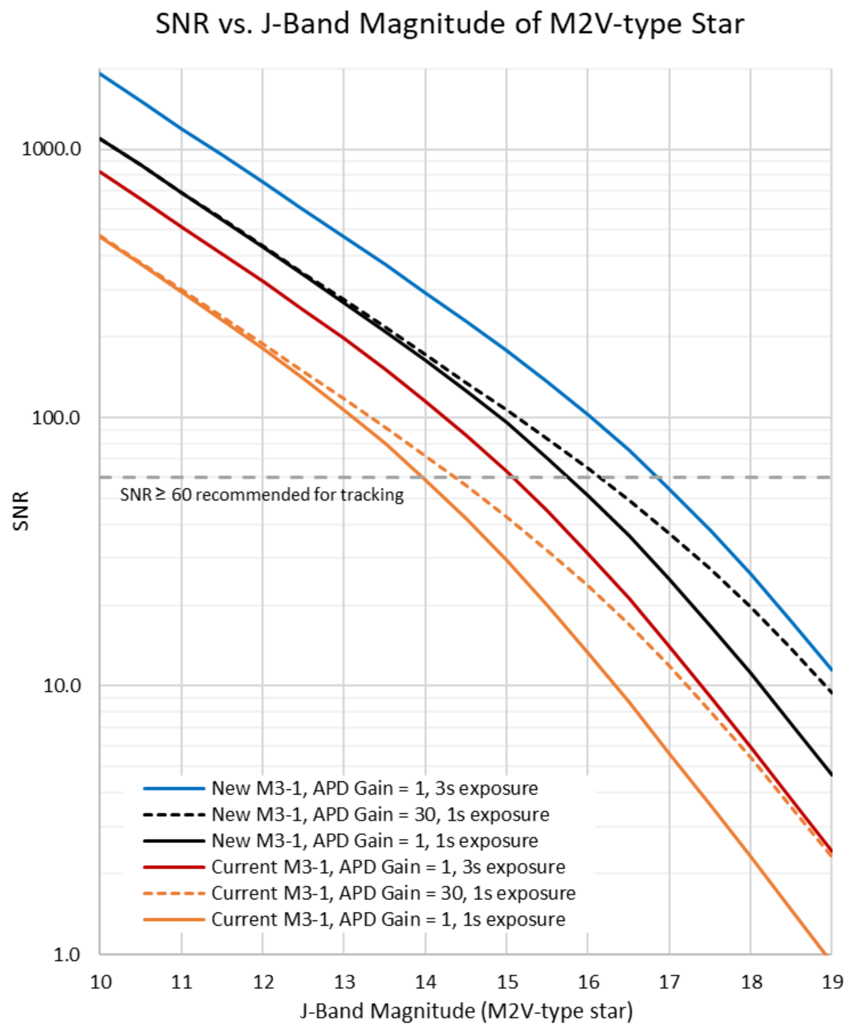
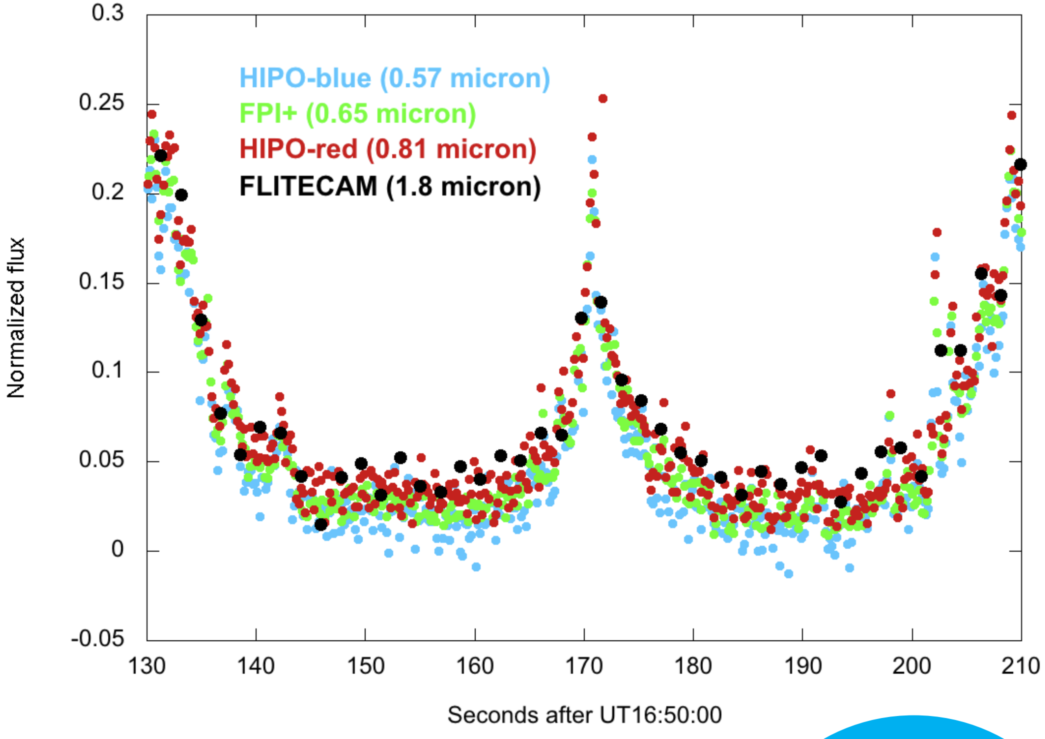


Science Applications of NIR-upgraded FPI++

- The upgraded FPI++ will partially restore the capabilities of the former instrument combination FLIPO (HIPO + FLITECAM)
- Allows for high-speed observations at two wavelengths simultaneously (VIS & NIR)
- Critical for stellar occultations by bodies with an atmosphere, e.g. Pluto, Triton, Titan
  - Atmospheric extinction is wavelength dependent
  - VIS and NIR light is therefore scattered differently in atmospheres
    - Existence/Depth of hazes can be shown
    - Aerosol particle sizes can be determined
    - Temperature gradients can be verified

Person, et al., 2020



Multi-Wavelength Occultations

- The upgraded Focal Plane Imager FPI++ will enable tracking in the NIR, up to ~ 1.6 µm
- This results in practically 100% sky coverage with usable guide stars even in dark clouds
- The upgraded Focal Plane Imager FPI++ will enable dual wavelengths observations (VIS, NIR) particularly usefull for stellar occultations by solar system bodies with atmospheres

A two-step approach is possible:

Step1

Mechanical and optical design for a second VIS camera
Possible benefit for tracking with deep depletion CCD (~ 1 µm)
Would fully prepare the installation of the NIR camera and enable dual wavelength observations (VIS red & VIS blue)
Development time < 2 years

Step 2

Replace the second VIS camera with NIR camera when available (~1 year lead time) and characterized in the lab

Summary

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Thank you!