GaiaNIR

The GaiaNIR mission
How concepts from Theia could enhance the project

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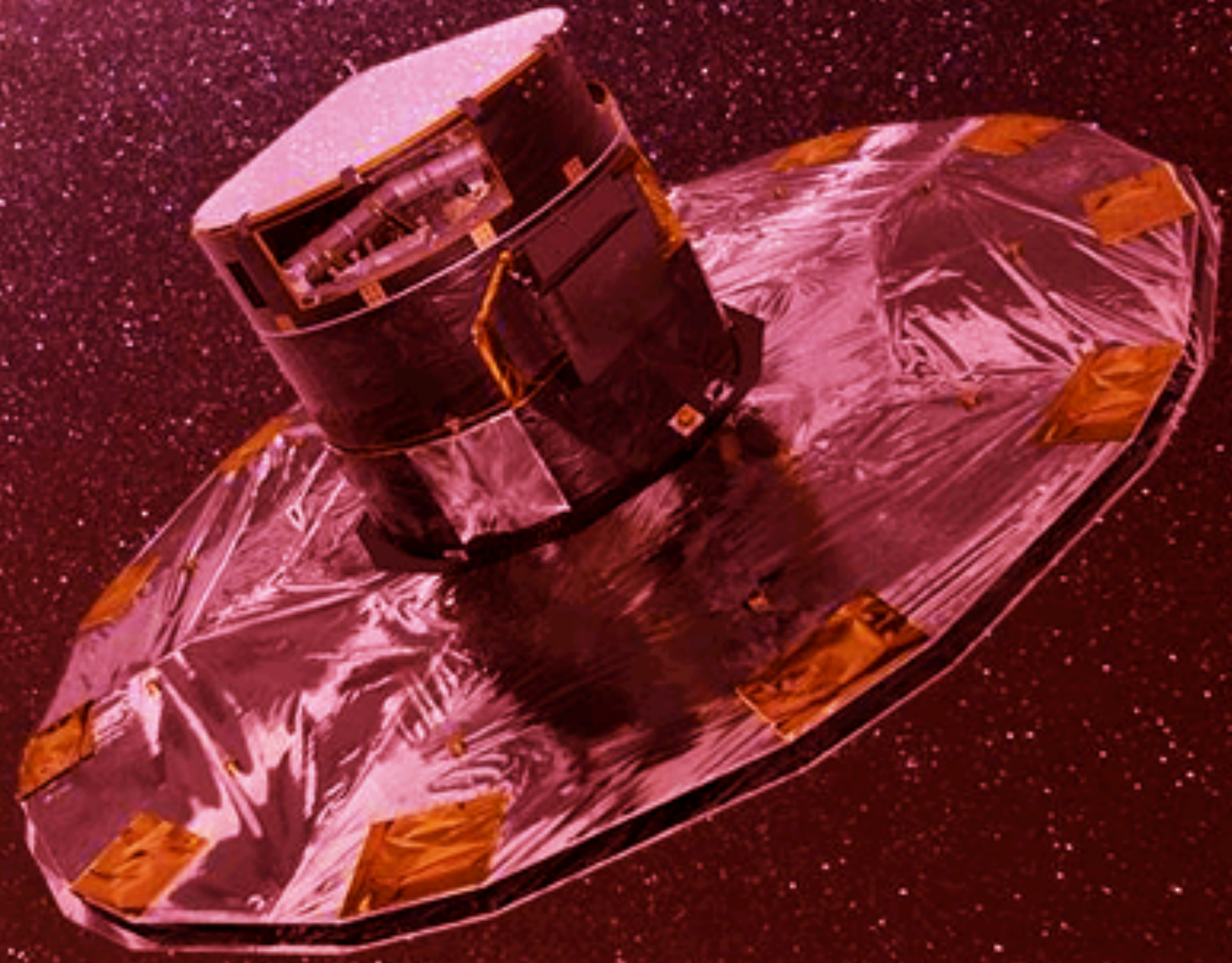
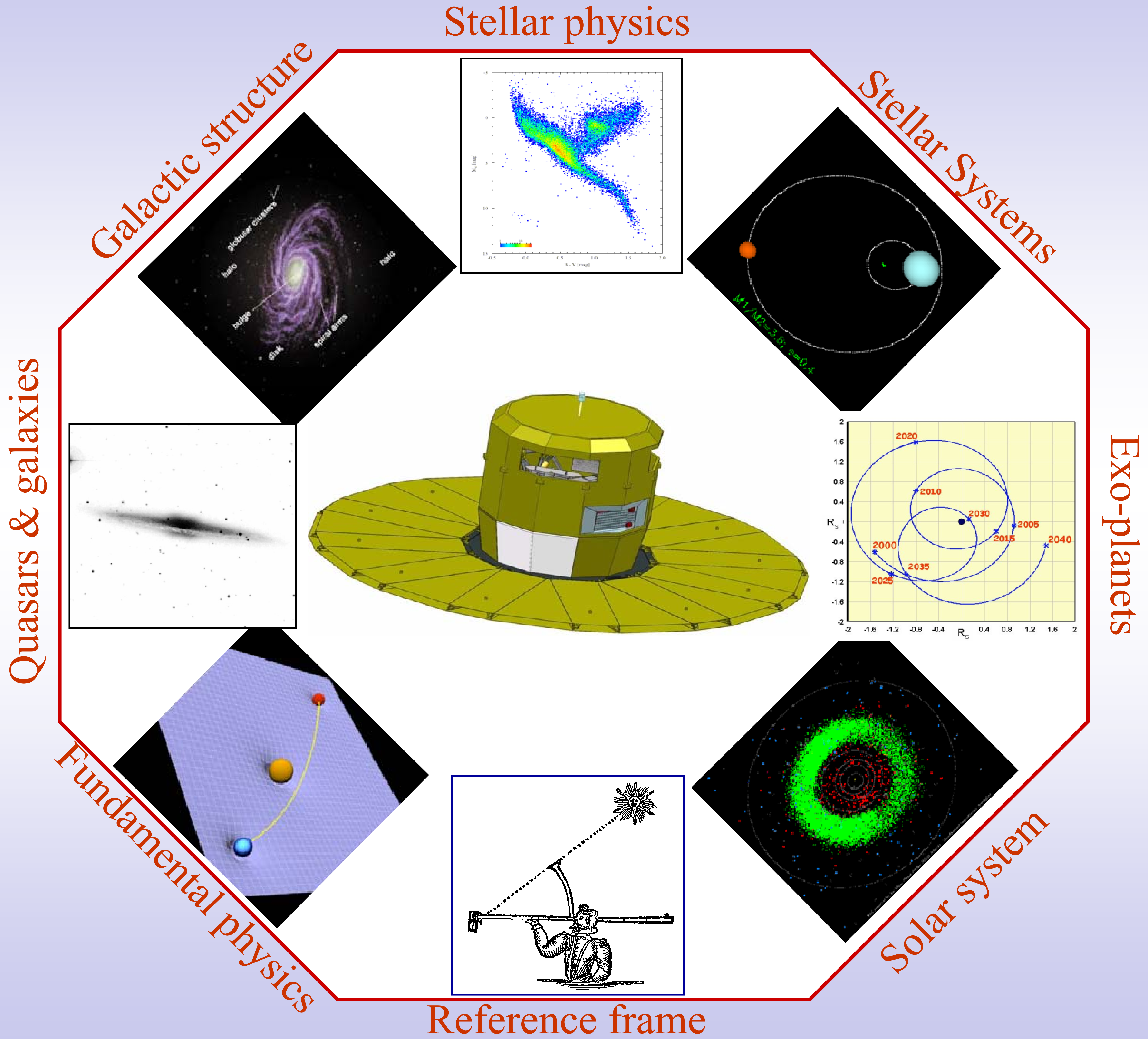


Gaia Science Objectives

GaiaNIR is similar but on a grander scale



Science Cases

- Adding NIR astrometry and photometry to probe the dynamically important hidden regions of the Galaxy giving at least 12 billion stars with a K-band cutoff
- A new mission, combined with ~2 billion common stars from Gaia with a 20 yr time gap would give PM's 15 times better and open many new science cases
- Resetting the Gaia optical RF and catalogue. Expansion of the optical RF to the NIR is super important

https://link.springer.com/article/10.1007/s10686-021-09705-z

- Adding a radial velocity spectrograph could give vast numbers of radial velocities - maybe a billion!

GaiaNIR is a discovery mission designed to unveil the nature of our Galaxy - Voyage 2050

Nano-arcsec yr^{-1} PMs

The numbers 17.6=0.8σ_π and 15.4=0.7σ_π μas are the sky averaged position components of Gaia DR4 after ~5 years and $\sqrt{2}$ is extrapolation to 10 years

$$\sigma_\mu = \frac{\sqrt{\left(\frac{\sigma_{\mathrm{pos}_G}}{\sqrt{2}}\right)^2 + \left(\frac{\sigma_{\mathrm{pos}_N}}{\sqrt{2}}\right)^2}}{t_N - t_G}$$

$$\sigma_{\mu_{\alpha^*}} = \frac{\sqrt{\left(\frac{17.6}{\sqrt{2}}\right)^2 + \left(\frac{17.6}{\sqrt{2}}\right)^2}}{20+10} = 0.59\ \mu\mathrm{as\ yr}^{-1}$$

$$\sigma_{\mu_\delta} = \frac{\sqrt{\left(\frac{15.4}{\sqrt{2}}\right)^2 + \left(\frac{15.4}{\sqrt{2}}\right)^2}}{20+10} = 0.51\ \mu\mathrm{as\ yr}^{-1}$$

Euclid, Roman, and JASMINE provide NIR stars

A 20 year gap

An earlier launch will decrease the PM accuracy

2055

2050

2045

2025

2020

2015

Second Epoch GaiaNIR 10yr (2050)

First Epoch Gaia 10yr (2020)

$\sigma_\mu = 0.54\sigma_\varpi$ μas yr^{-1} is estimated at G = 15 for Gaia DR4

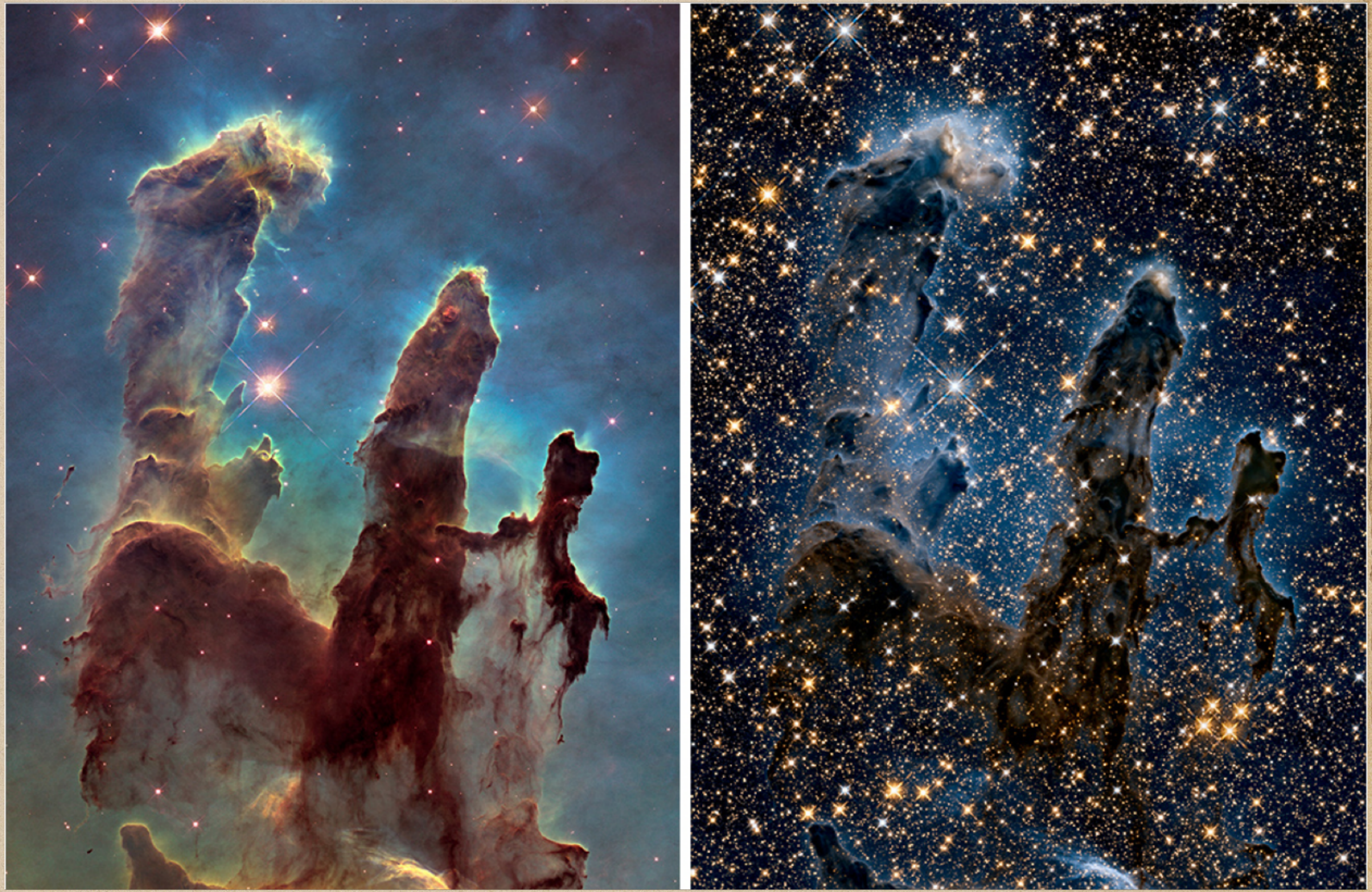
An order of magnitude improvement (factor of 15) in PM's compared to Gaia DR4 giving nano-arcsec PMs for common stars.

The big science question!

- A new mission can measure the hidden stars not seen by Gaia for the entire sky!
- The most important NIR science cases lie in the Galactic plane (bulge/bar) and star forming regions. E.g.
  - PMs of galactic streams and in clusters can probe halo DM;
  - Detect IMBH's in globular clusters;
  - Bulge/bar dynamics, etc.
  - Long period binaries and exoplanets (solar system analogues);
- Like Gaia it will answer big science questions in many areas of astronomy!

Gaia
(Hubble Visible)

GaiaNIR
(Hubble NIR)



The Pillars of Creation in the Eagle Nebula. Image NASA.

ESA's GaiaNIR Design

GaiaNIR is based on a off-axis f=35m Korsch telescope as is Gaia, but differs in:

- The mirror surfaces are simple conics to simplify manufacturing, alignment and test.
- Entrance pupil is at a flat folding mirror in front of the primary instead of on the primary mirror itself.

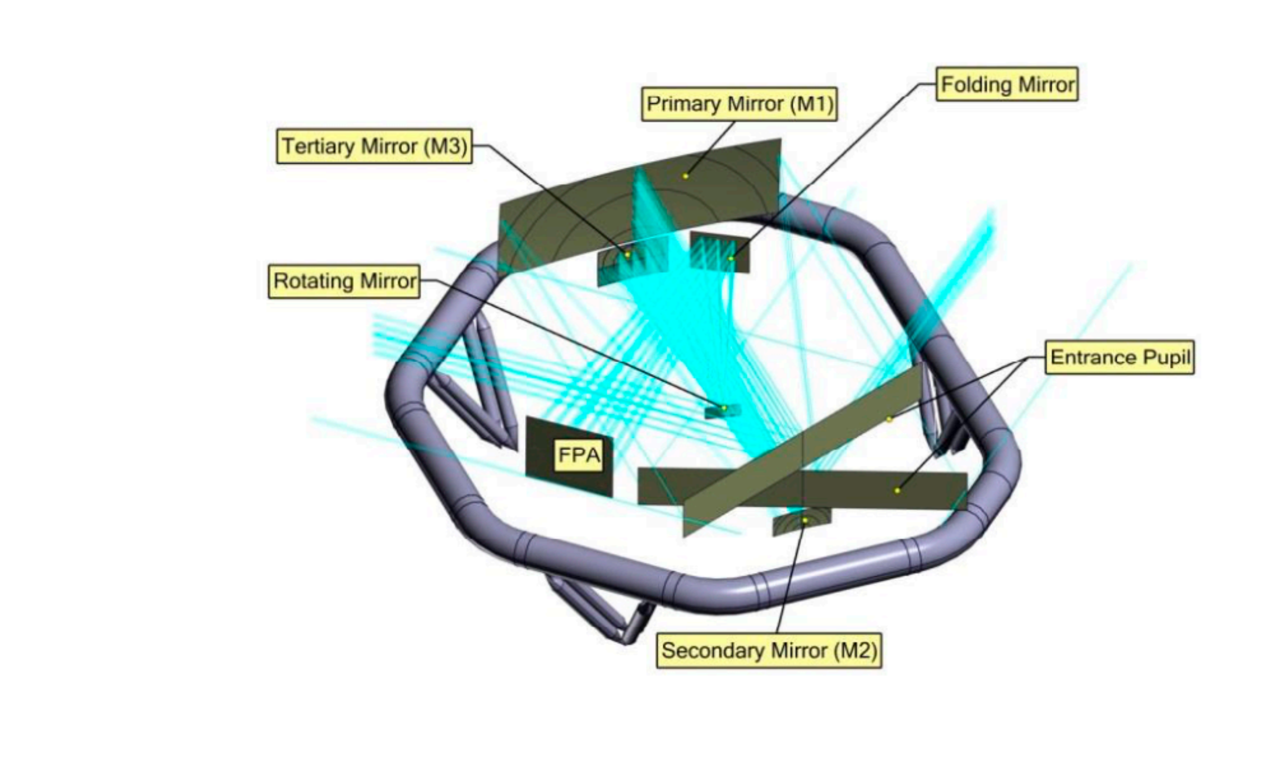


Figure 5-34: GaiaNIR optical surfaces and the light path

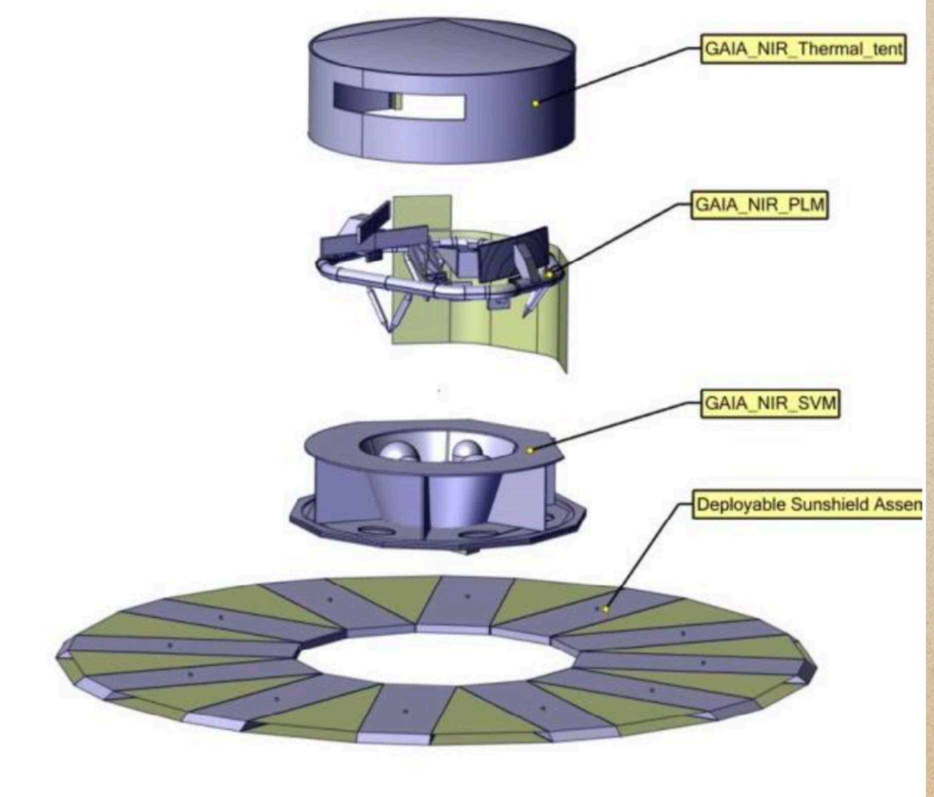
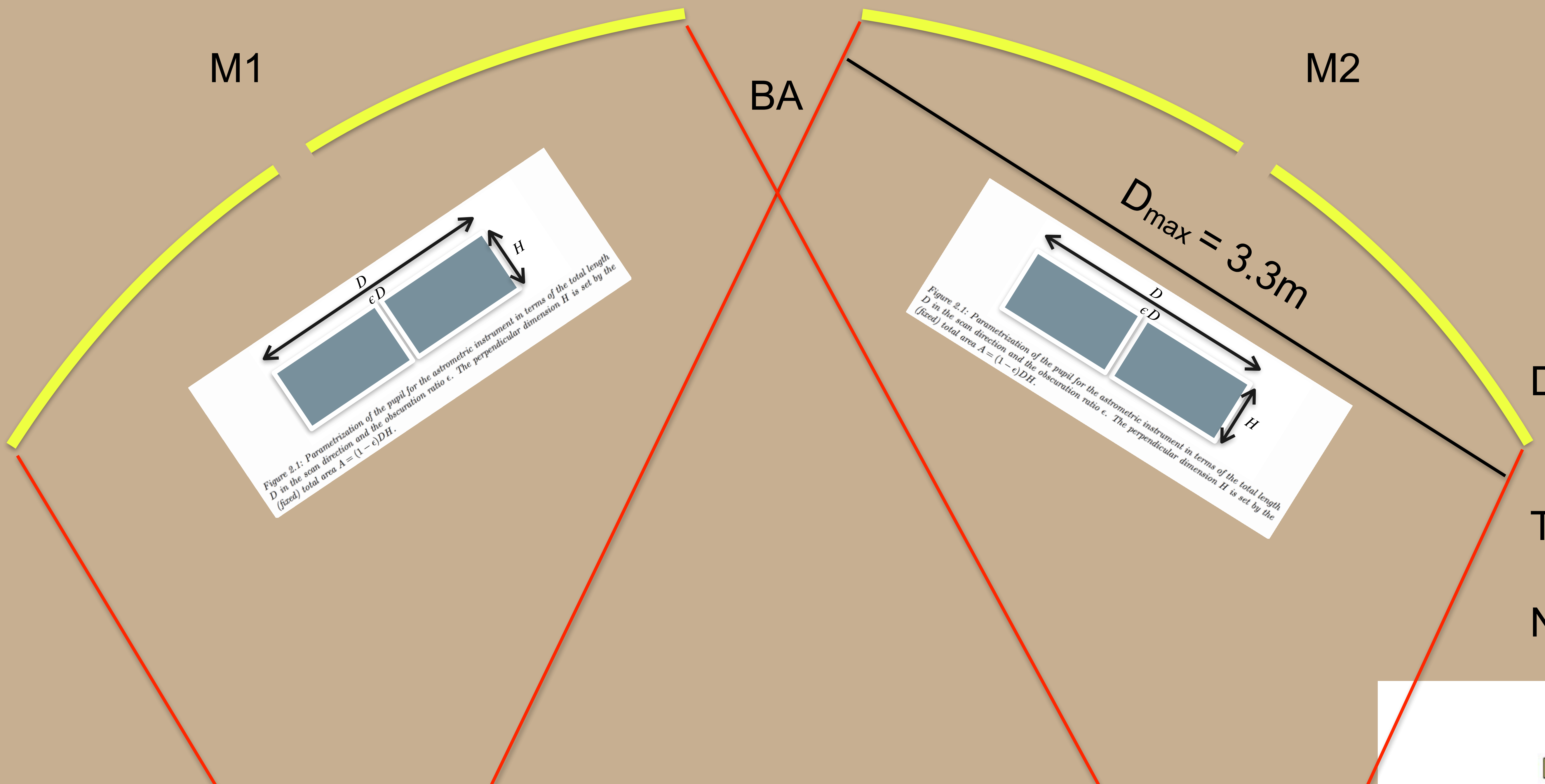


Figure 6-2: Gaia-NIR Spacecraft main elements

- The optical path of the telescope is composed of:
- Primary mirror
- Secondary mirror
- Tertiary mirror
- 4x Flat mirrors:
  1. At the entrance pupil (2 defining the BA)
  2. Folding mirror (after the exit pupil)
  3. At the exit pupil

New Design



Drawing not to scale

Two primary segmented mirrors

No flat mirrors at entrance pupil

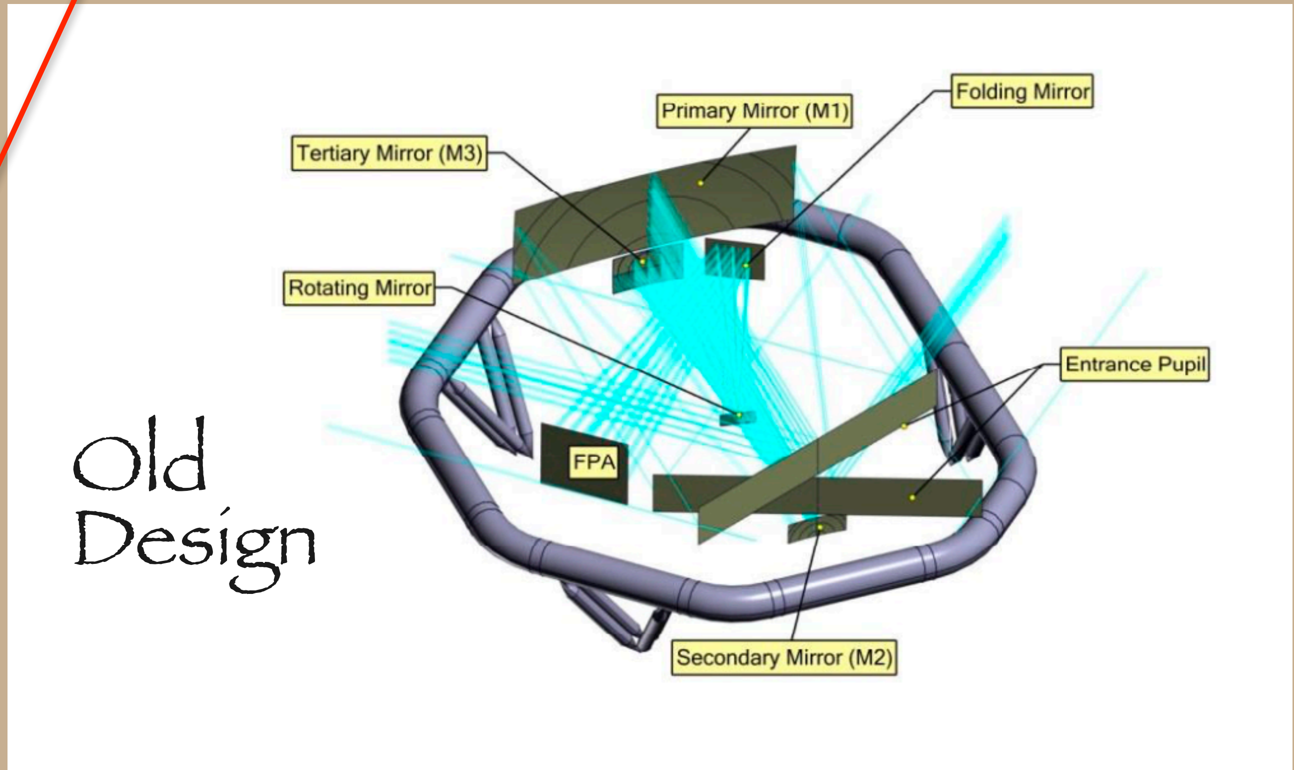


Figure 5-34: GaiaNIR optical surfaces and the light path

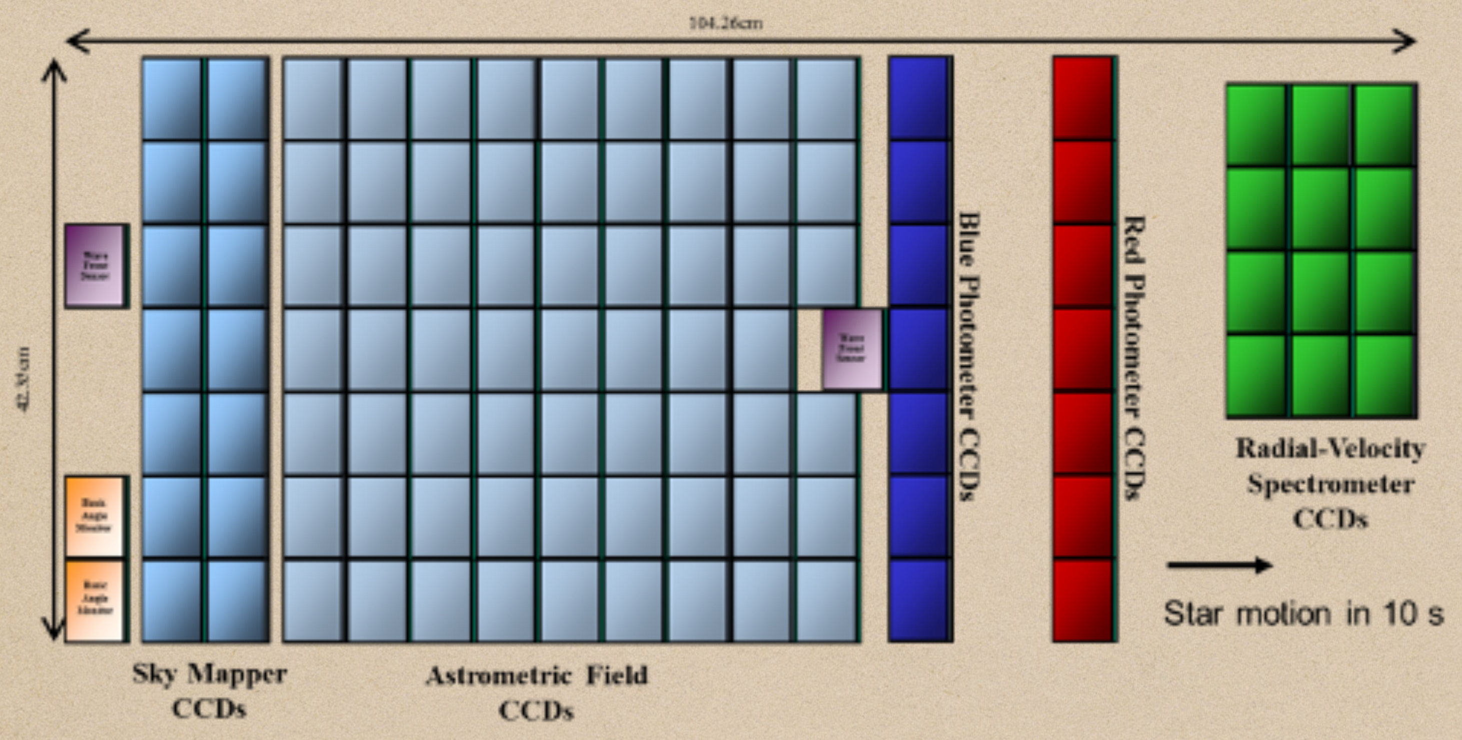
The resolution and parallax errors are inversely proportional to the length of the primary mirror D

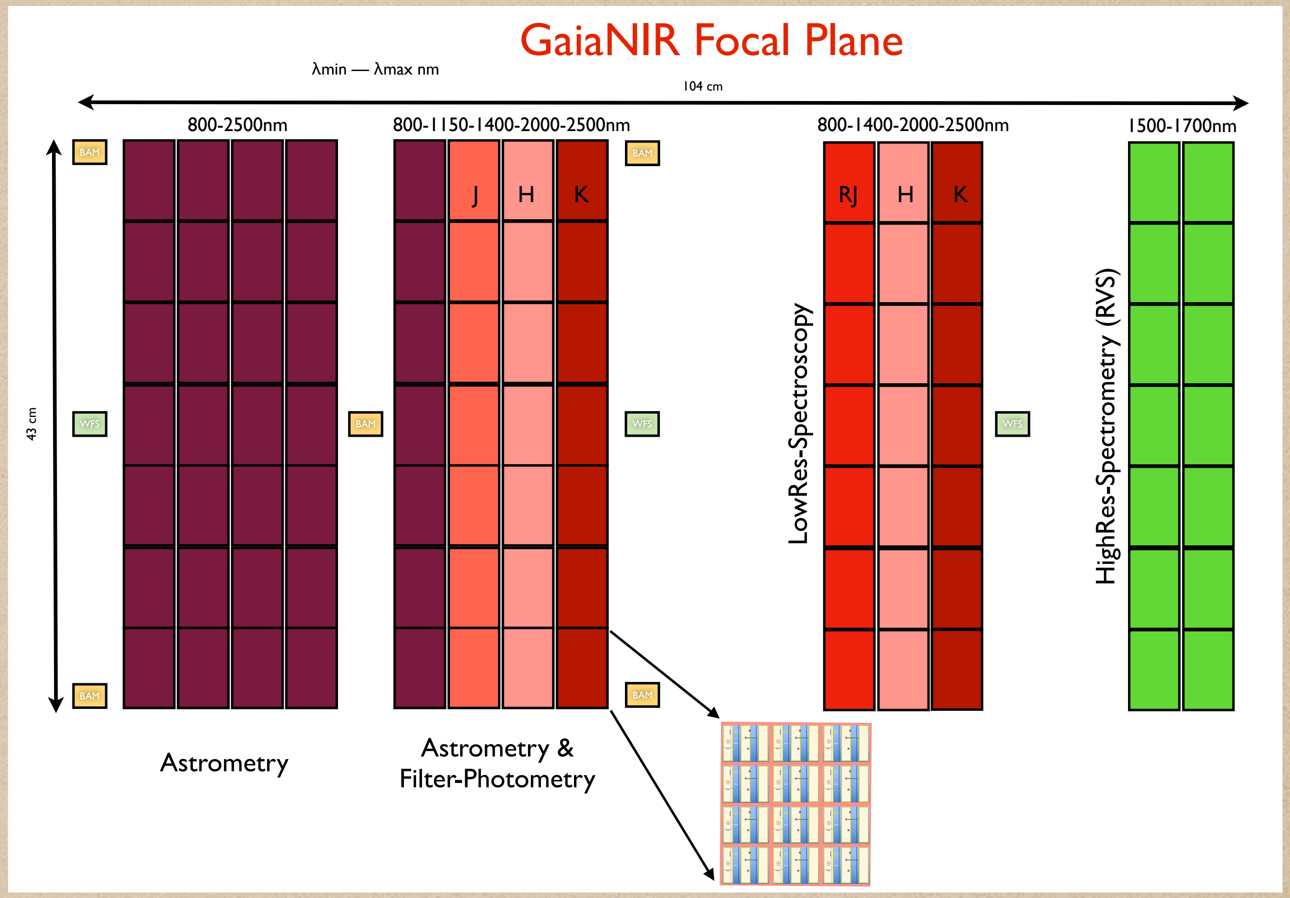
$$\sigma_{\varpi} \propto \frac{\lambda}{D\sqrt{N}\sin\xi}$$

Mission	Resolution
Gaia (λ_{mid}=700nm)	0.12“ with D=1.45
GaiaNIR (λ_{mid}=1600nm)	0.24” with D=1.6
GaiaNIR x2 (λ_{mid}=1600nm)	0.12” with D=3.3

The Focal Plane & Filters

Gaia Focal Plane

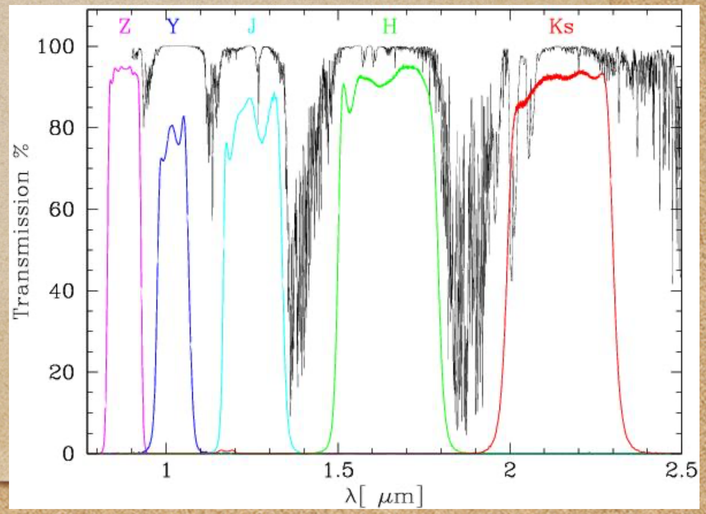




4x3= 12 APDs (TBD)

A modular concept uses small detectors to form larger ones

- Linear Mode APDs are the most promising detector for GaiaNIR
- Cooling strategy must be passive (~90K)
- Max wavelength ~ 2500 nm, blue stars (<800nm) are more challenging
- No SMs - track motion of stars instead to determine the FoV
- Filter photometry on astrometric field by depositing filter material on detectors
- Low resolution spectra on a dedicated field for astrophysical parameters
- An RVS Spectrograph is a great opportunity?



Example from VVV

End Of Mission Accuracy

$$\sigma_\varpi = m g_\varpi \left[\frac{\tau_1}{N_i \tau p_{\mathrm{det}}(G)} \left(\sigma_\xi^2 + \sigma_{\mathrm{cal}}^2\right) \right]^{1/2}$$

p_{det} is the detection probability in a single transit;
σ_ξ angular uncertainty AL from one CCD transit [rad];
σ_{cal} accuracy of astrometric or photometric calibration [rad];
N_i is the number of instruments and m is a safety factor of 20%.

$\tau = \frac{L\Omega}{4\pi}$ = Total integration time on object per source[s]

$\tau_1 = \frac{N_\xi \Delta\xi}{\omega}$ = Integration time per CCD[s]

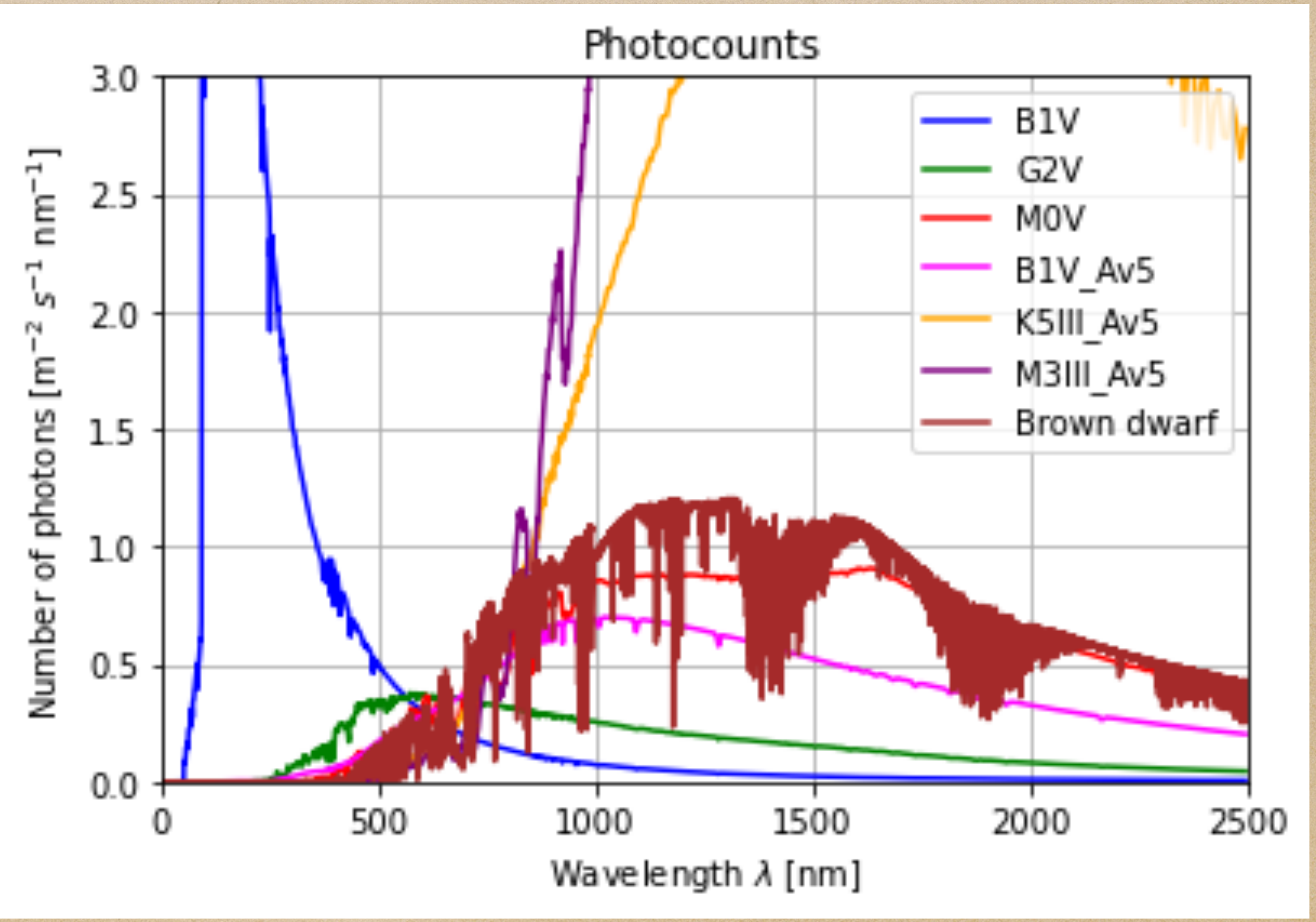
where

ω is the scan speed [rad s^{-1}];
$\Delta\xi$ is the angular pixel size along scan [rad] and;
N_ξ is the number of pixels per CCD in the scan direction [e−].

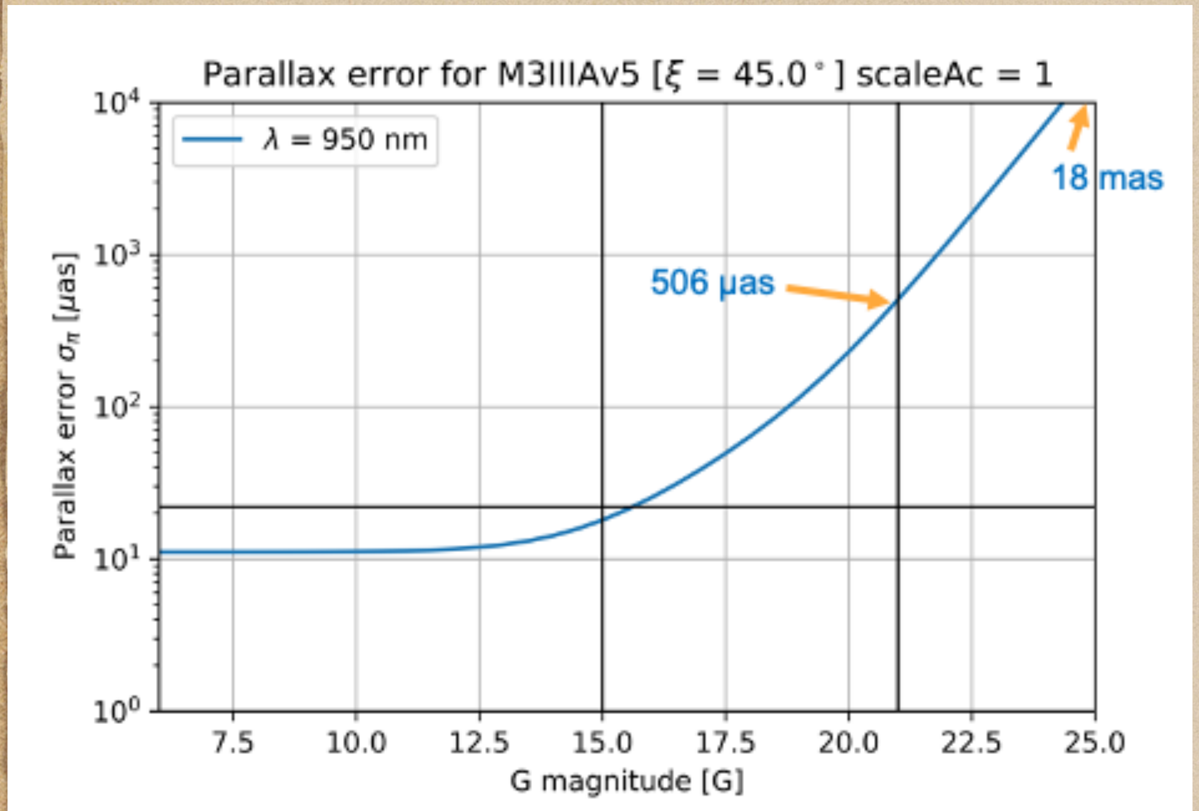
L = effective mission length (i.e. excluding dead time);

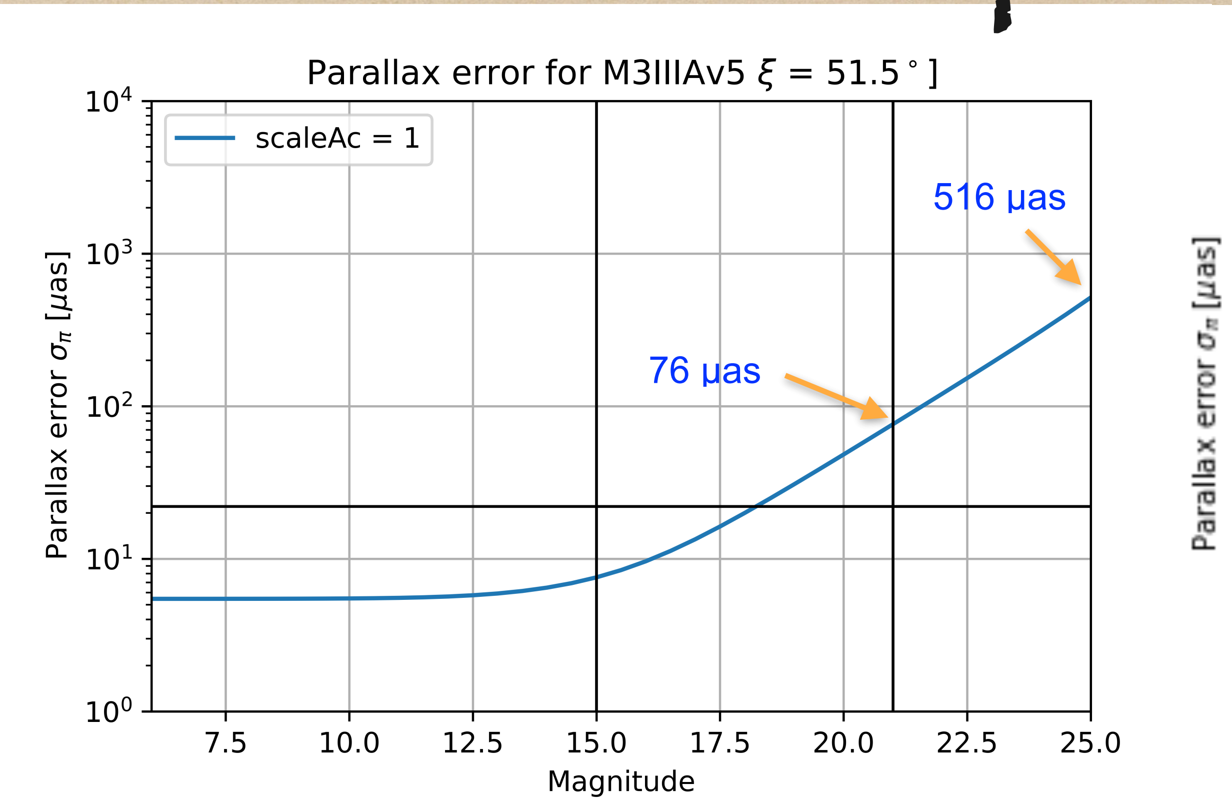
$\Omega = 1.2\ \mathrm{deg}^2$ = detector solid angle per instrument

$g_\varpi = 1.47 (sin\ \xi)^{-1}$ Sky averaged parallax factor

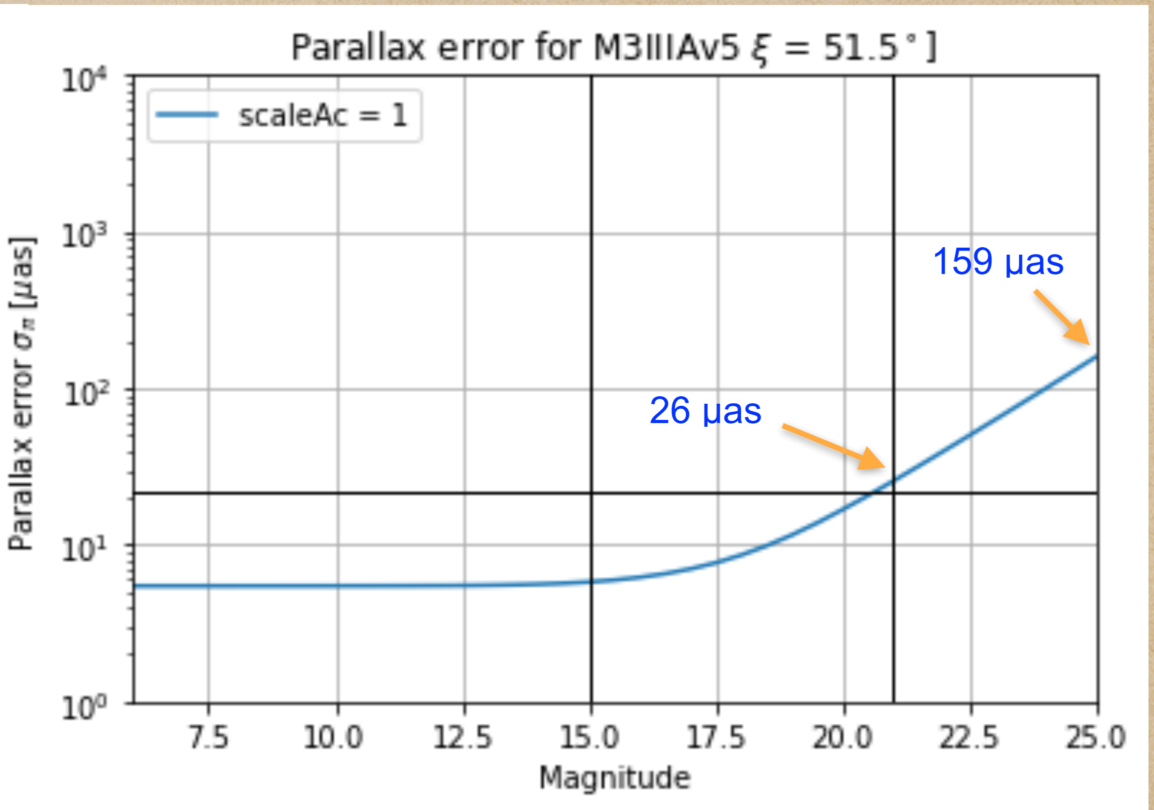


Detector Comparison

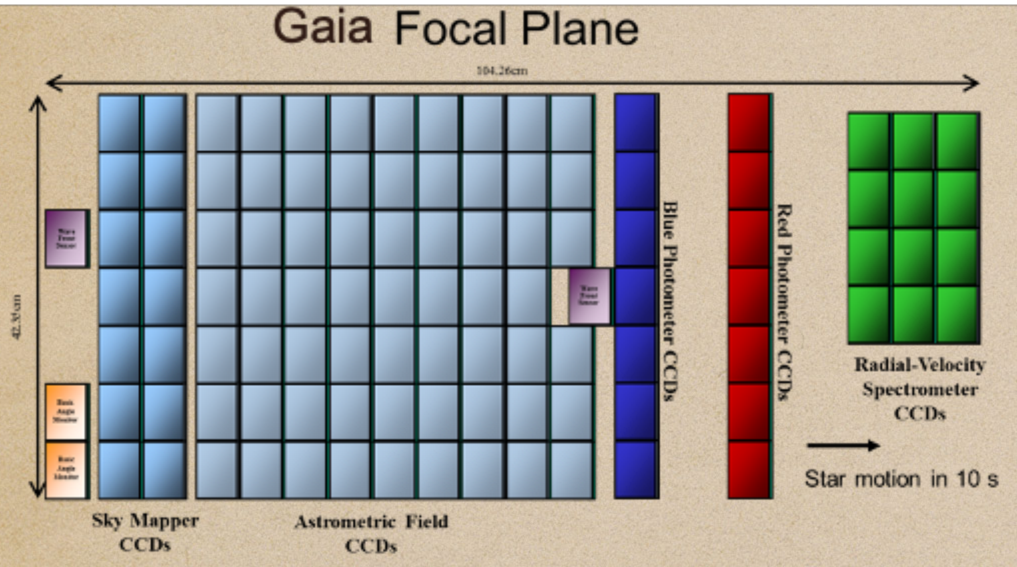


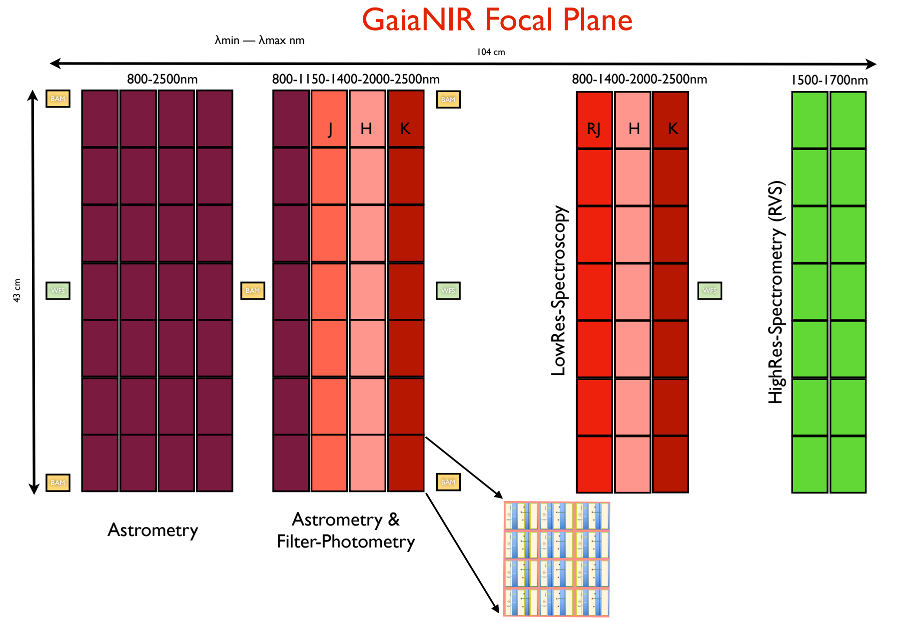


Old Optics



New Optics

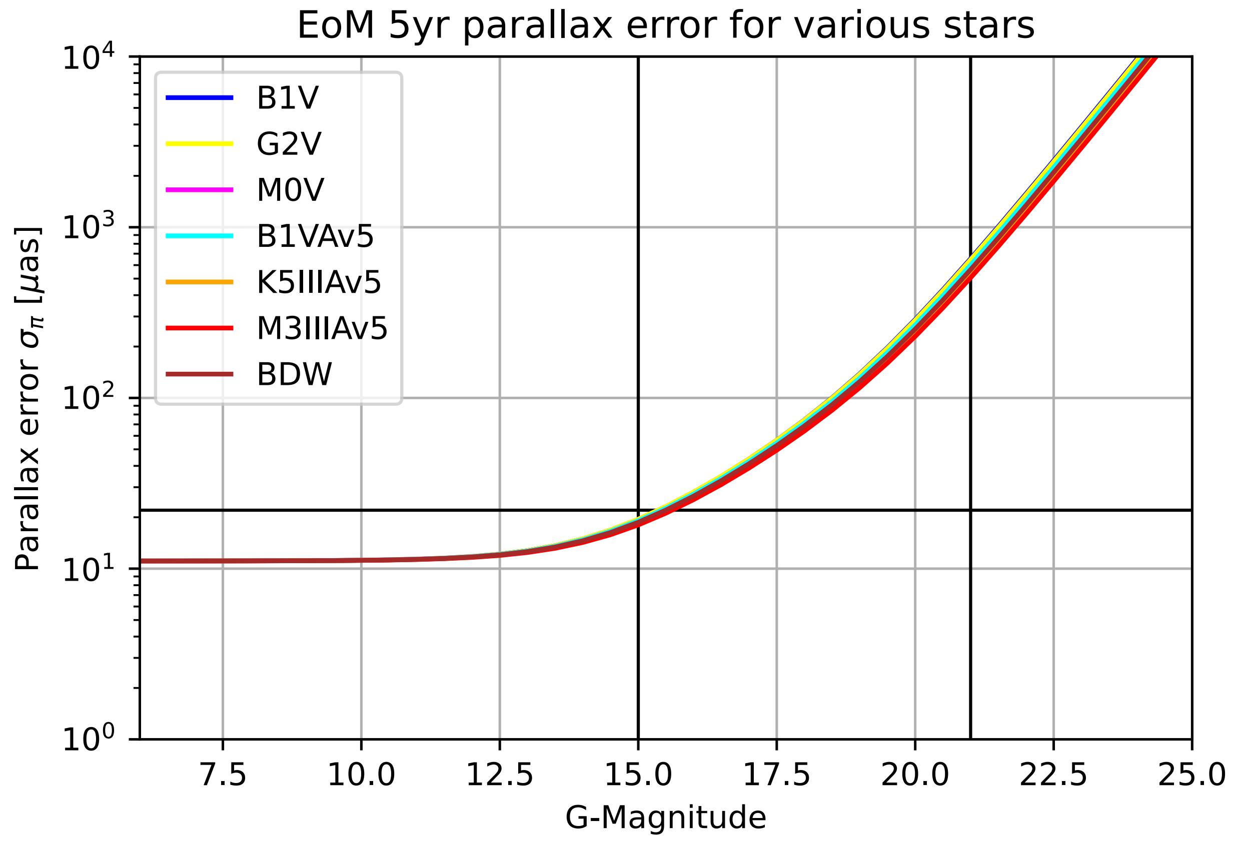




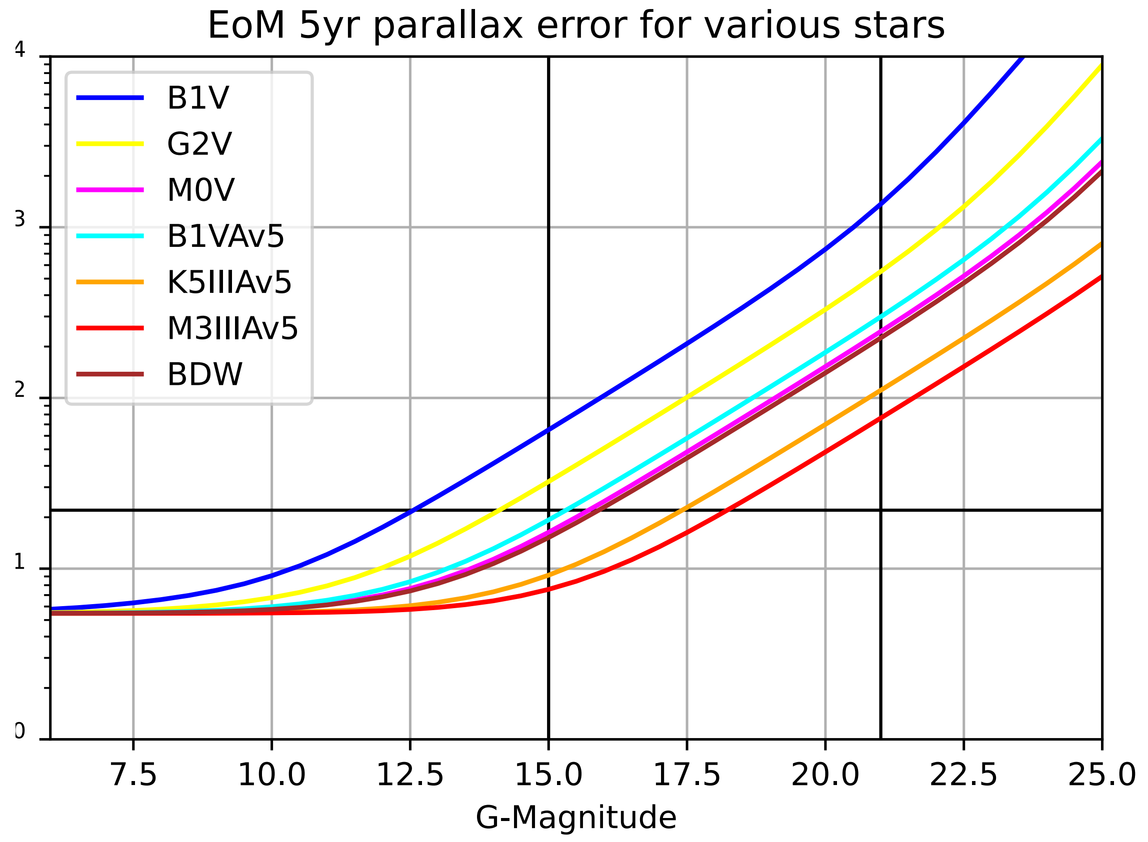
- Identical runs for M3III_Av5_T_{eff}3500_logg2.0_feh red giant giving a comparison between Gaia CCDs and GaiaNIR APD's
- APDs shows a linear (log) increase in error with magnitude compared with an exponential increase in CCDs
- Separating AF and CF is better for astrometry and astrophysics!

Eom Results For Various Stars

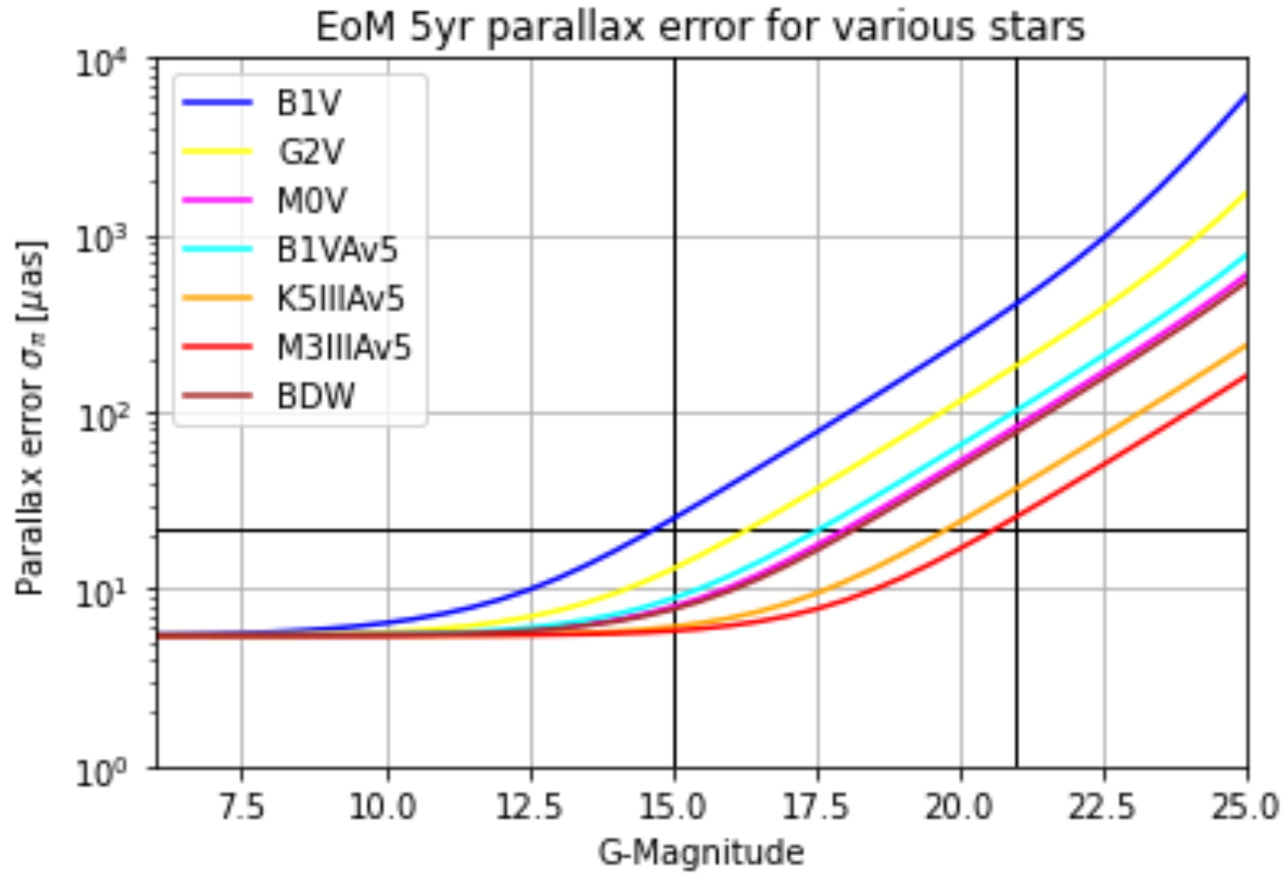
Gaia



GaiaNIR Old Optics



GaiaNIR New Optics



Can Theia Metrology Help GaiaNIR?

Gaia BA variations were unexpectedly large (~1 mas) and the BA monitor focused on one small area.

Complex self-calibration for Gaia is needed for each detector and pixel over different time scales.

Multiple WFS and BA monitors on GaiaNIR would allow interpolation across the FPA

However, the metrology being developed for Theia might replace this!

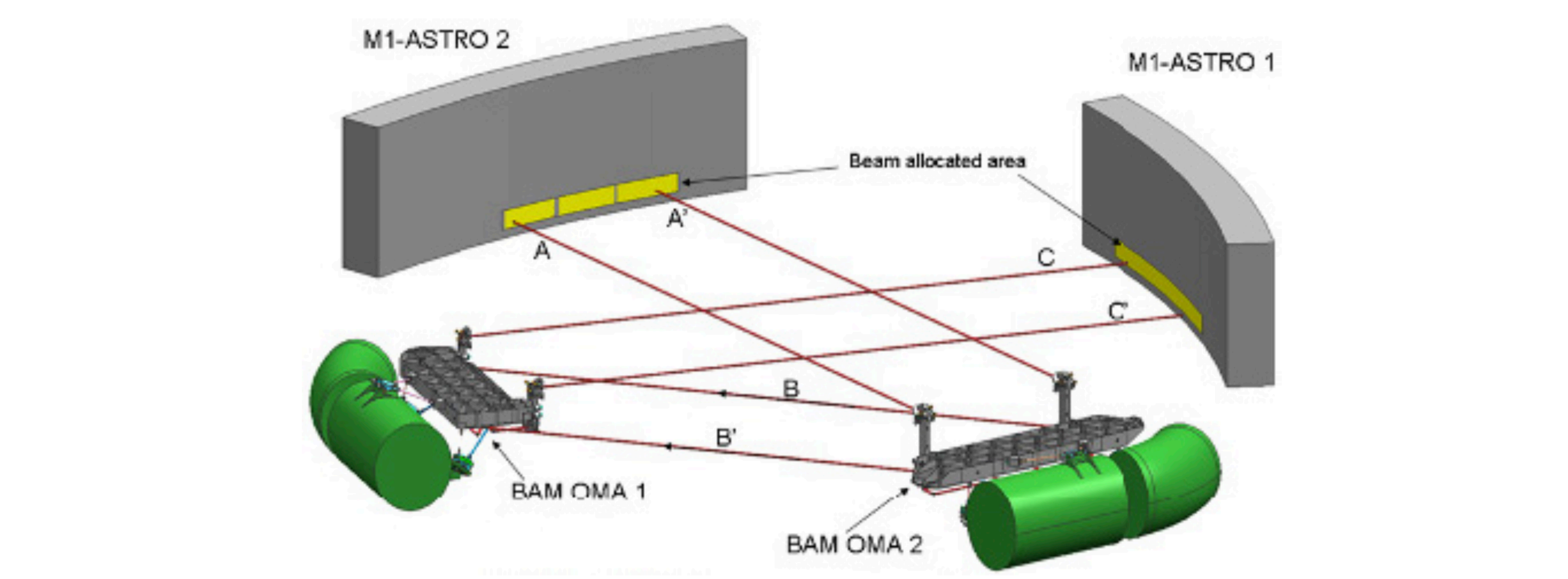
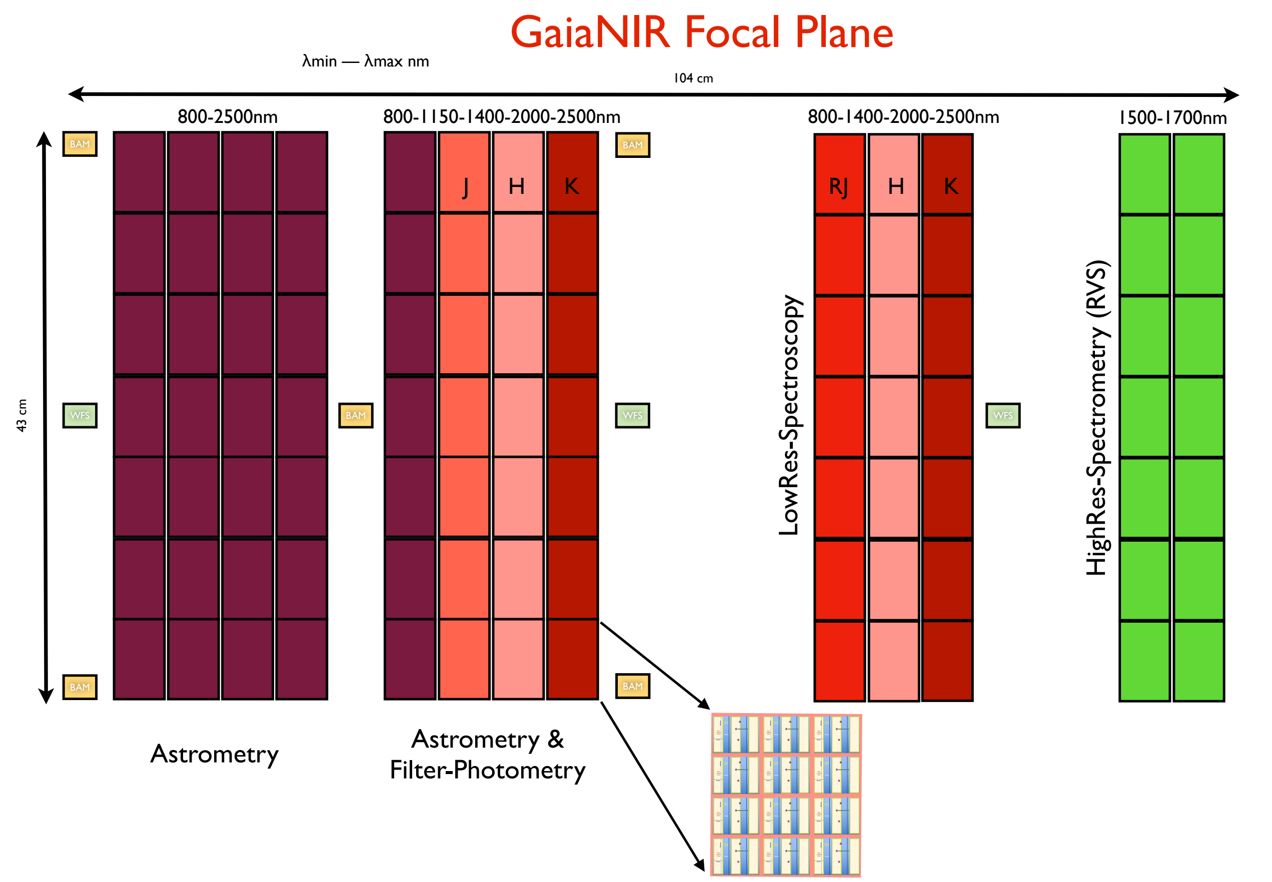


Figure 2.9: The BAM is a laser interferometer that injects two beams in each telescope entrance pupil. In this way, an interference pattern is produced for each telescope in the common focal plane. The relative shift of the patterns at the CCD level is related to changes in the basic angle between the telescopes. Credit: Airbus Defence and Space and TNO. This figure also appears as Figure 17 in Fabricius et al. (2016).



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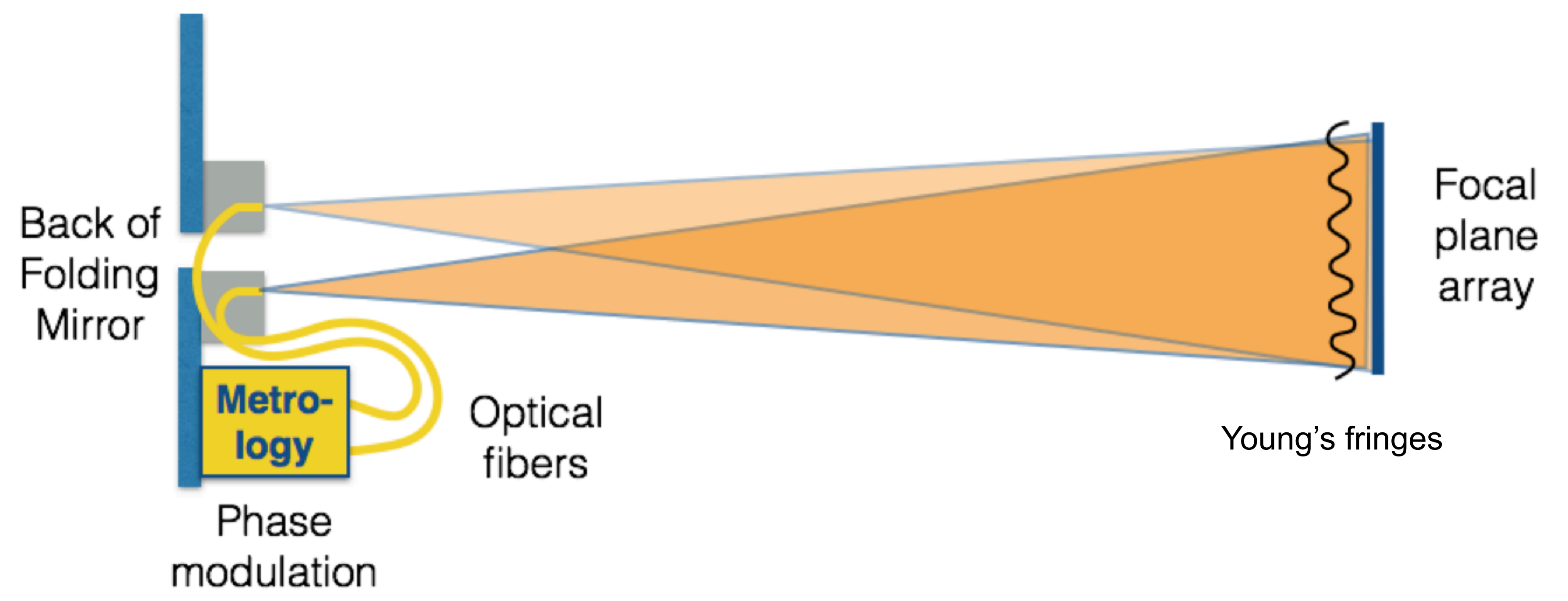

Fig. 4.27: Focal-plane metrology system concept: pairs of optical fibers on the back of the folding mirror (M3) produce interference fringes on the focal plane detectors. One line is offset in frequency by a few Hz with respect to the other line, producing a continuous scan of the metrology fringes on the detectors at a rate of 10 fringes per second.

To Think About!

Years of lab *work developing metrology for Theia could be waisted if Theia is not select.*

Applying Theia metrology to GaiaNIR would increase the chances of success.

How do we start this? - a technical discussion is needed!

The Theia concept uses Youngs fringes which allow to solve the XY position of each detector and pixel.

To measure the QE, the light beams have their phase modulated by optical modulators. The arrays are read at 50 Hz providing many frames yielding high accuracy.

Which direction Next?

Future space astrometry can move in several directions:

1. All-sky optical and NIR (Gaia-like μas/nas) - GaiaNIR.
2. Pointed relative astrometry in NIR (e.g. JASMINE - $H_w < 15$ mag) to add important regions in the Galactic plane.
3. Pointed relative astrometry missions (SIM, NEAT, Theia, ...), targeted ultra accurate (nas), aimed at specific questions on dark matter, exoplanets (e.g. exo-earths), etc.

Clearly there is overlap between science cases above but global Gaia-like astrometry in the NIR can do more!

Politics will also play a role - will two astrometry missions get selected?