

# The stray light baffle for the ARRAKIHS mission

L. Clermont <sup>\*1</sup>, E. Lallemand<sup>1</sup>, J.Y. Plesseria<sup>1</sup>, S. Serrano<sup>2</sup>, C. Kintziger<sup>1</sup>

<sup>1</sup> Centre Spatial de Liège, STAR Institute, Université de Liège, Avenue du Pré-Aily, 4031 Liège, Belgium

<sup>2</sup> Satlantis, 48940 Leioa, Bizkaia, Spain

\* lionel.clermont@uliege.be

## ABSTRACT

ARRAKIHS is an ESA mission dedicated to observing dwarf galaxies and stellar streams. Its objective will be to test the standard cosmological model, particularly regarding the nature of dark matter. It will use four telescopes operating in the visible and near infrared spectral ranges. As they will observe ultra-low brightness objects, an extreme level of stray light control is necessary. A large external baffle is necessary to prevent out-of-field light from entering the telescope, with an extreme stray light rejection down to  $10^{-11}$ . This paper will discuss the design of this baffle. We will present the design trade-offs, as different possible baffle architectures were considered. Ultimately, the selected architecture consists in developing one baffle for two telescopes, hence a total of two baffles are used on the payload. A multi-stage baffle is developed, in the heritage of the CoRoT baffle which is seen as one of the best ever designed. Moreover, we will discuss the reflections on the test setup which will be implemented for validating the design on a prototype.

ARRAKIHS, Stray light, baffle

**Keywords:** Times Roman, image area, acronyms, references

## 1. INTRODUCTION

The “Analysis of Resolved Remnants of Accreted galaxies as a Key Instrument for Halo Surveys” (ARRAKIHS) mission will image 50 square degrees of the sky per year down to an unprecedented ultra-low surface brightness (SB) simultaneously in two visible bands (HST F475X: 380 to 630 nm and Euclid VIS: 550 to 900 nm) and two infrared bands (Euclid Y: 920 to 1230 nm and Euclid J: 1169 to 1590 nm). These images will allow us to address major outstanding issues in the  $\Lambda$ -Cold Dark Matter ( $\Lambda$ CDM) cosmological model. In particular, if Dark Matter in our Universe deviates from the cold and collision-less model as for the standard  $\Lambda$ CDM, then it is expected that the satellite mass functions, satellite merger rates, and prevalence of stellar streams around dwarf galaxies would all be greatly suppressed.

These observational tests could not yet be carried out because a wide field-of-view survey, imaging down to ultra-low SB limits is extremely difficult to achieve from the ground due to the atmospheric background. Instead, ARRAKIHS will use an innovative binocular telescope assembly on board a mini satellite in Low Earth Orbit. This survey will result in a first-of-its-kind catalog of ultra-low SB extragalactic images for a volume-limited and mass-limited sample of galaxies like the Milky Way in the nearby universe. The defining and unique characteristic of the ARRAKIHS mission is that it will image these systems down to an unprecedented surface brightness of 31 mag/arcsecond<sup>2</sup> with a resolution of 0.8 arcsec (FWHM) in visible wavelengths, and 30 mag /arcsecond<sup>2</sup> with 1.25 arcsec (FWHM) in the near infrared.

ARRAKIHS fits perfectly within ESA’s “Cosmic Vision” scientific priorities. In particular, ARRAKIHS will advance our knowledge in two of the four key questions at the heart of the “Cosmic Vision” Program: “What are the fundamental physical laws of the Universe?” and “How did the Universe originate and what is it made of?” In addition, ARRAKIHS will complement the new generation of giant ground- and space-based observatories. JWST will observe the earliest stages of galaxy formation and evolution at the highest redshift. The Rubin Observatory, Roman, and Euclid will provide images and spectra for millions of galaxies at intermediate and high redshifts. ARRAKIHS will complement these in-depth, wide-area observations of the distant universe by pioneering an unprecedented systematic exploration of the nearby universe at ultra-low SB with excellent spatial resolution from visible to infrared wavelengths.

Fig. 1 shows one of the telescopes of the binoculars for the ARRAKIHS mission. To ensure mission success, the telescope must have a strict stray light control, allowing for the observation of faint objects and small variations of

amplitude. This is fundamental as stray light limits the image quality and contrast [1][2], therefore in optical systems the design must be optimized for minimizing its quantity[3]. The stray light requirement is defined in terms of the NDI, which is the stray light irradiance at the detector normalized to the input irradiance at the entrance of the instrument. Fig. 2 shows the performance requirement, specifically the maximum value of the NDI due to stray light in the system. In this paper, we describe the design trade-offs for the ARRAKIHS baffle. The selected configuration is a multi-stage configuration baffle, in the line of baffles such as the one of CoRoT mission[4][5][6][7].

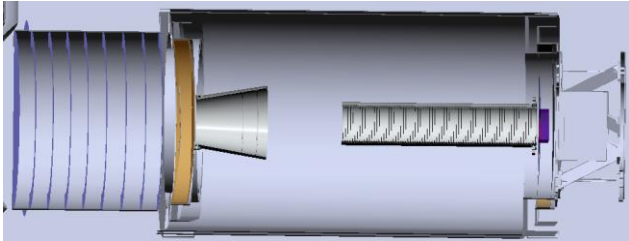


Figure 1. Telescope for the ARRAKIHS mission

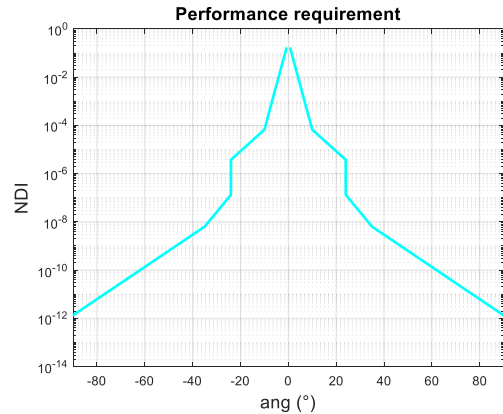


Figure 2. ARRAKIHS stray light performance requirement

## 2. PRELIMINARY DESIGN CONCEPTS

To fulfill the performance requirement, various configurations of optical baffling were considered. Fig. 3 shows the sketch of the main configurations. The first case, (a), consists in using no additional baffle, except the internal baffle from the telescope itself. This is the configuration giving the largest SL as the baffle is very small, bringing a lot of light inside the telescope. The second configure, (b), consists in building a multi-stage baffle, with a first stage for each telescope, but a second stage common for four telescopes (i.e. two binoculars). This configuration was shown to produce an acceptable SL. Finally, the third configuration, (c), was selected. It uses a multi-stage baffle, with the second stage being common for two telescope, or one binocular. This is a very similar concept to (b), however here we have the baffle placed further from the telescope and with a fold mirror in between.

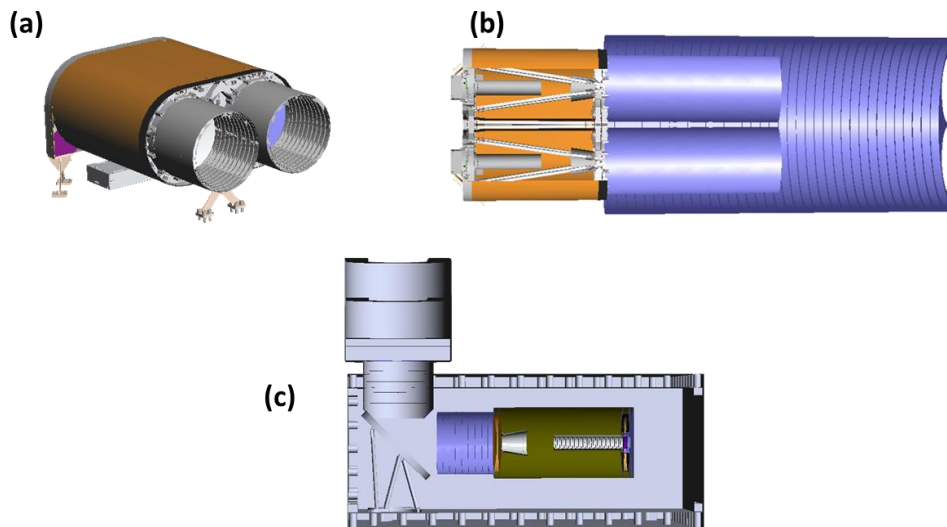


Figure 2. Preliminary study for baffling configurations

### 3. OPTICAL PERFORMANCE EVALUATION METHOD

The performance is evaluated by ray tracing, using the FRED software. For that, we estimate the SL irradiance at the detector focal plane as a function of the input angle. We consider the input angle in the short and long axis, with a reference frame illustrated on fig. 3. We consider SL from scattering in the mechanical system, as well as the ghosts inside the telescope. Inside the baffle, we consider scattering up to the third level. This includes scattering between the various walls and vanes of the baffle, but also scattering on the edges of the vanes, which are known to contribute for a significant proportion of the SL [8]. On the fold mirror, we consider scattering at order 1 for direct illumination. Furthermore, we consider up to a fourth order a scattering on the mirror to scatter toward the telescopes the light which is previously scattered in the baffle. All rays are stored at the input of the telescope and their ancestry level is brought back to zero for each ray. Then, the propagation of rays is continued inside the telescope and internal stray light effects are computed for all rays. Ultimately we measure the stray light at detector level. We decompose the stray light coming from various contributors:

- Stray light from the front baffle (including an additional fourth level of scattering on the fold mirror)
- Direct scattering on the mirror
- Internal stray light of the telescope (labelled the payload)

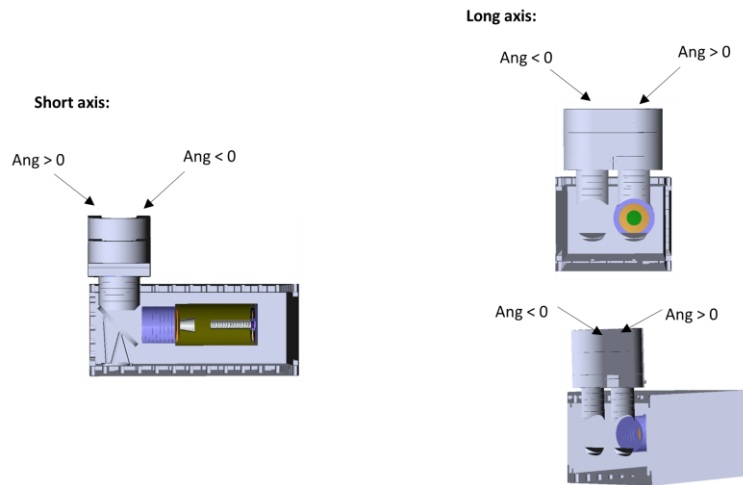


Figure 3. Reference frame definition

### 4. TRADE-OFF ON TELESCOPE POSITION WITH RESPECT TO THE BAFFLE

We study the impact of the telescope position. We consider two extreme situations, shown on Fig. 4. In the first case, the telescope is at the nominal position and we have an internal fore baffle before the telescope. The second case have the telescope shifted toward the fold mirror, with no internal fore baffle.

Fig. 5 show the NDI, as a function of the short or long axis angle, for the two different positions of the telescope. On each graph, we show the NDI coming from three different contributors: payload, fold and baffle. The payload contribution is the SL generated inside the telescope when direct light enters inside it. The fold contribution is the first order scattering occurring when direct light is incident on the fold mirror. This contribution can either arrive directly at the FPA, or through an additional SL effect occurring inside the telescope. The baffle contribution is the SL generated by the baffle. It reaches the focal plane either through an additional scattering effect on the fold mirror, or through an additional stray light effect inside the telescope. Additionally, the graph show the performance specification to reach. Fig. 6 compares the NDI for the two configurations of the telescope position. The curve shows the total NDI coming from the sum of each contributor.

From these results we deduce that configuration 2 and 1 are equivalently acceptable. The only deviation from requirement is for very large angles, due to scattering inside the front baffle. The interest of configuration 2 compared to the 1 is the reduced volume of the payload. Ultimately, the selected configuration is in-between, pushing the telescope toward the fold mirror up to the limit where illumination can reach directly from the output the telescope.

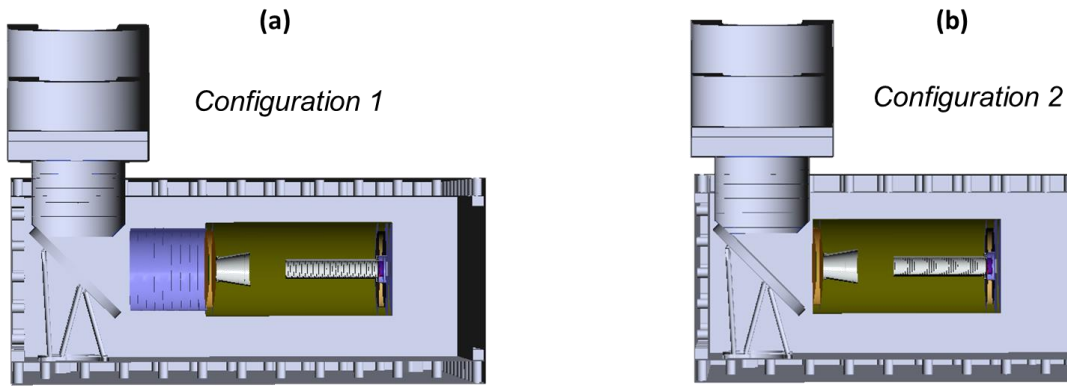


Figure 4. Configuration with the telescope placed at nominal position, including an internal fore baffle, or with the telescope shifted toward the fold mirror excluding the internal fore baffle

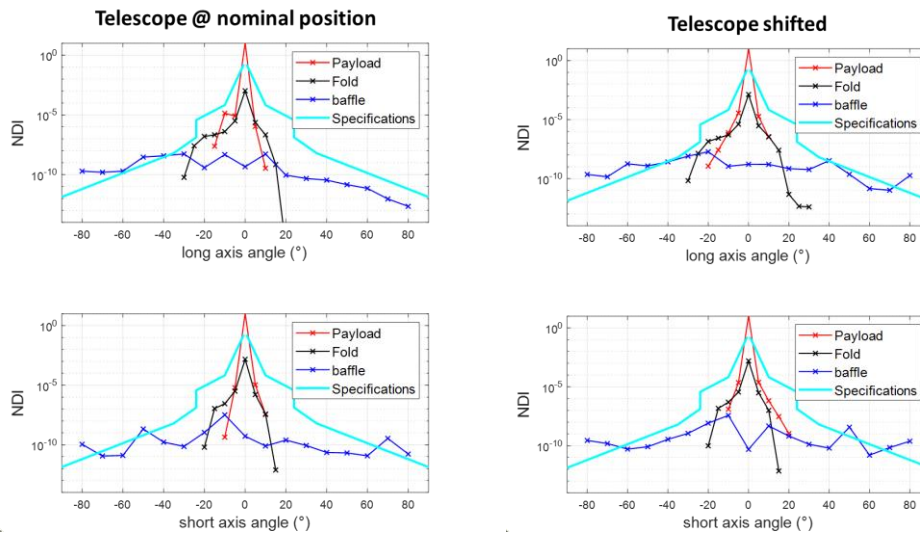


Figure 5. NDI as a function of the long or short axis angle, with the telescope shifted toward the fold mirror

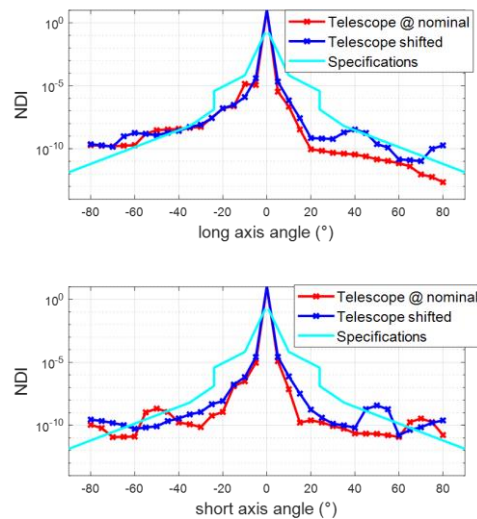


Figure 6. Comparison of the NDI as a function of the long or short axis angle, with the telescope shifted toward the fold mirror or at nominal position

## 5. EVALUATION OF IMPACT OF CONTAMINATION

We evaluate the impact of contamination on the stray light [9], considering various conditions of cleanliness from class 300 to class 600. Fig. 7 shows the BSDF for contamination scattering in these different conditions. On-axis, total integrated scattering, or hemireflectance, is 0.052% for a contamination level CL300. It increases to 0.2017 % contamination level CL400, and up to 1.52% at contamination level 600.

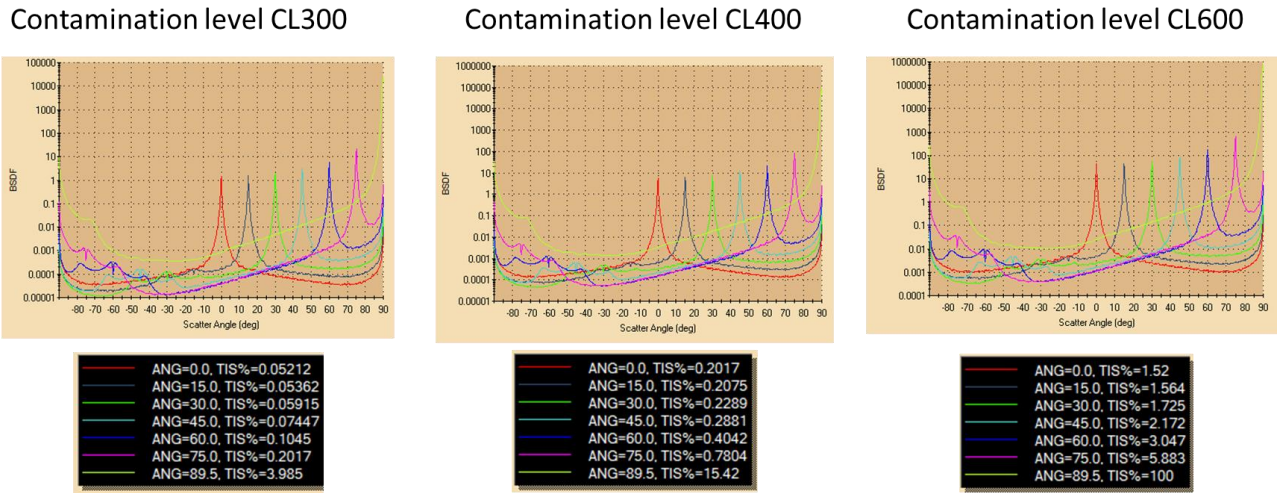


Figure 7. BSDF for scattering in the case of various contamination levels

Fig. 8 shows the NDI as a function of the long or short axis angle, for various contamination levels. The different contributors are shown individually. The impact of contamination is only considering on the fold mirror, thus the observed differences are the following:

- Fold contribution: is fully dependent on the contamination level. When the contamination is increased, the first order scattering on the fold is increased accordingly, thus we observe a significant variation of that contribution when considering different contamination levels
- Baffle contribution varies only when considering the part of the baffle SL which is brought back to the telescope through an additional scattering on the fold mirror. This is only a portion of the baffle SL, as a significant proportion of the baffle SL enters the telescope directly without an additional scattering on the fold mirror. Therefore, the variation of the baffle contribution is less obvious and we are mostly within ray tracing noise.
- Telescope contribution is unchanged when the contamination level is varied, as the contamination only impacts the fold mirror

Fig. 9 shows the total NDI, combining all contributors. It compares the result for the various contamination levels. As it shows, the NDI close to 0 increase significantly when the contamination level increases. For large angles, the variation is mostly within the noise.

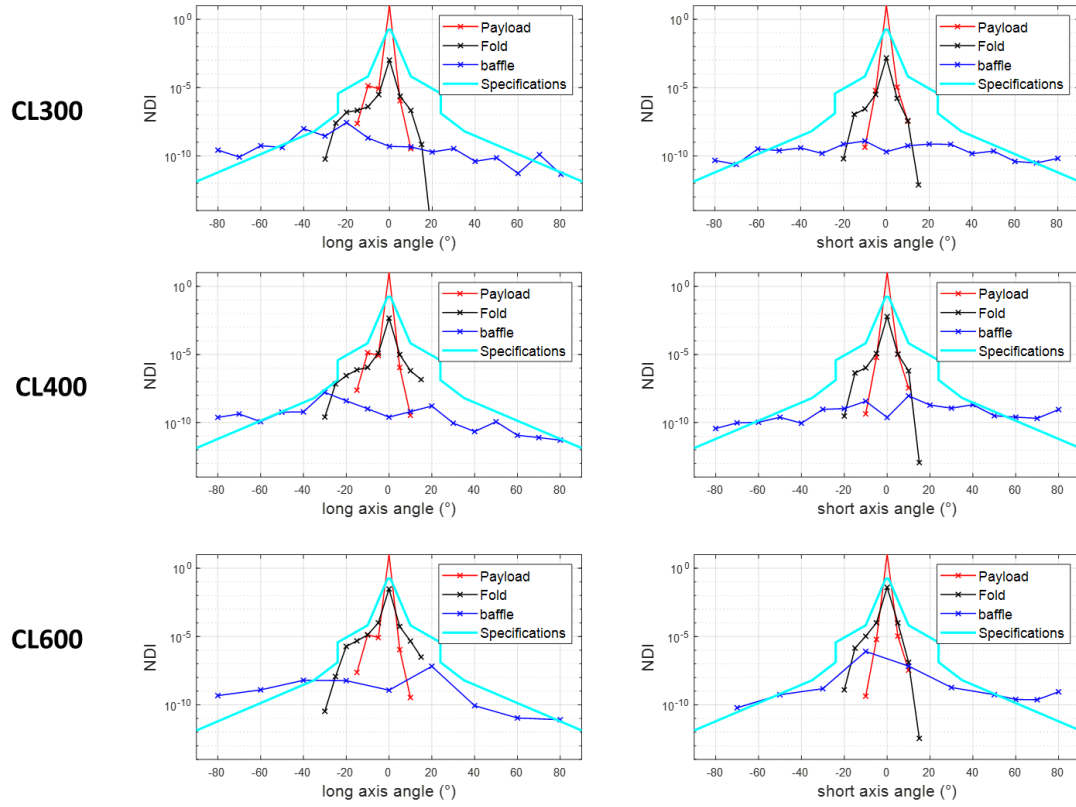


Figure 8. NDI decomposed by contributor, for various conditions of contamination level

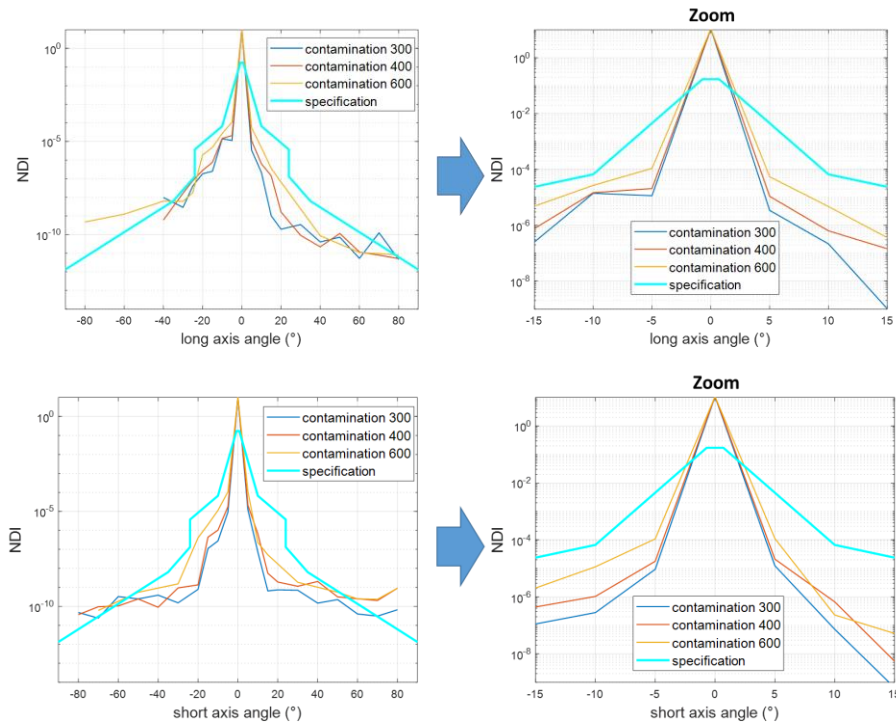


Figure 9. Total NDI for different conditions of contamination level

## 6. TEST SETUP CONCEPT

Once manufactured, the baffle will undergo experimental testing to ensure that the performance is as expected from theory. This is fundamental, as stray light analysis necessarily rely on assumptions which might omit certain contributors, also manufacturing tolerance might add unexpected stray light to the system [10]. The test principle consists in illuminating the baffle under test with a collimated beam, formed with an off-axis parabola with fiber injection. The full entrance aperture should be illuminated, either at once or by scanning, effectively illuminating the full “stray light entrance pupil” [11]. The angle of illumination is varied with two rotation wheels, evaluating the SL under various conditions. Optical densities are used to perform measurements over a dynamic range over 10-10, and a monitoring device is used to compensate for source instability. NDI is eventually derived and compared to performance requirement.

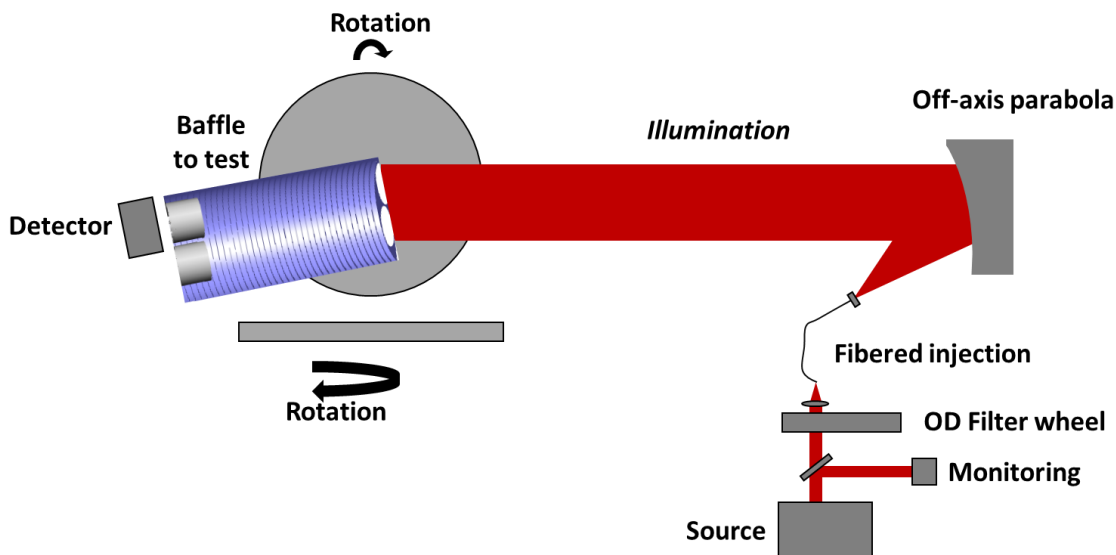


Figure 10. Sketch of the test setup

## 7. CONCLUSIONS

We described the stray light baffle for the ARRAKIHS, including the trade-off between various designs. This includes the use of a single stage baffle, or the use of an external large multi-stage baffle. The latter was selected, in particular with a fold mirror before the telescope entrance. We study the impact of the position of the telescope with respect to the fold mirror, showing small impact on the stray light level, thus the closest distance possible is selected, though we limit to the distance such that no direct illumination from out-of-field angles can hit directly the telescope. We study the impact of contamination on the stray light, showing in particular an impact from the direct scattering on the fold mirror. Finally, we describe the test setup that will be used for experimentally testing the prototype.

## ACKNOWLEDGEMENTS

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