A Fast, Wide Field of View, Catadioptric Telescope for Whipple

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Abstract: We describe the optical design of a space bourn f/1.3 catadioptric telescope with a 9 degree field and 77 cm aperture that is being proposed to study objects in the Kuiper belt, Sedna Region, and Oort cloud.
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1. Introduction

Whipple will discover and characterize the populations of the Kuiper Belt (30-55 AU), Sedna region (500-2,000 AU), and Oort Cloud (5,000-100,000 AU) through the technique of blind occultation in which the observed object briefly interrupts the light from a remote star as observed by a telescope near Earth [1]. To date, our ability to probe these distributions has been severely hampered by the fact that we see objects in reflected sunlight, and thus we are limited to finding large objects that are relatively close to the Sun. Whipple will detect objects smaller than 1 km at 42 AU and 10 km at 20,000 AU.

Table 1 summarizes the driving telescope requirements. A large field of view maximizes the number of targets. A large aperture-spectral bandwidth product enables the cameras to be read out at up to 20 Hz with adequate SNR to see the small fast moving targets in front of for 14 magnitude stars. Finally, the telescope must be small and lightweight for the space application.

Table 1. Whipple telescope specifications and goals.

Parameter	Specification/Goal	Performance
Field of view (°, full)	9	Same
Focal length (cm)	103	Same
Spectral range (nm)	450-850 (uniform weighting)	Same
Collecting area (cm2)	>2,600	2867 on-axis, 2660 edge
F-number	Report	f/1.3
Encircled energy diameter (90%, μm, as-built)	36	21 (nominal)
Glass type	Radiation hard (goal)	Fused silica
Length (cm)	< 130	59
Image plane location	External (goal)	Same

Survey telescopes are typically catadioptric to cover the wide fields. Buchroeder, Ackermann, and Yudin discuss a sampling of catadioptric design forms [2-4]. The telescope described in this paper traces its roots back to a design by Hamilton in 1814 that is composed of a positive lens and a second surface mirror (also known as a Mangin mirror) to correct color [5]. Unfortunately, with only one reflection, the image is not easily accessible. In 1961, Berggren de Nygorden added a second mirror to form a Cassegrain configuration and provide an accessible image [6]. In 1966, Shimizu added a doublet field lens to improve the correction [6]. In 1979, Tamron and Minolta released telephoto SLR lenses of this form that were short and lightweight. Commercial success was elusive due to their slow speed (f/8 and f/5.6), lack of an adjustable aperture, and distracting bokeh from the annular aperture. While the preceding systems used multiple glasses, Busack designed a 43 cm aperture f/2.3 telescope with a positive lens, Mangin primary, secondary mirror, and a negative field lens with a single glass (important for astronomical applications, since few glasses are available in large diameter blanks) [8]. Riccardi and Honders independently developed a telescope similar to Busack, except the first lens is much weaker and the field lens is positive [8]. Officina Stellare commercially produces several Riccardi and Honders telescopes, the RH 300 (an f/3 astrograph with a 30 cm aperture and a 6 cm diameter focal plane) is the largest.

2. Optical design

In this section, we briefly describe a Catadioptric-Cassegrain design and the fabrication, alignment, and environmental tolerances (see Figure 1a). It features a strong first lens to reduce the length and a pair of positive field lenses. Aspheres allow operation at larger apertures, larger fields, and at faster speeds than previously reported designs. It is all fused silica. Figure 1b shows the spots are less than 13.2 µm rms. The 90% encircled energy of the nominal design is better than 20.6 µm.

Table 2 summarizes the current tolerances for an as-built 90% encircled energy of 29 µm versus the 36 µm specification (as-built wavefront error with these tolerances is less 1 wave rms at the worst field point). The tolerances are more relaxed than for comparable telescopes with dual Schmidt plates. Index inhomogeneity, either intrinsic in the material or induced by thermal gradients, are important error sources not present in reflective telescopes. The intrinsic index inhomogeneities will be partially compensated by adjusting the aspheric surface figure of the first lens and first mirror (as these null tests will be near their use conjugates).

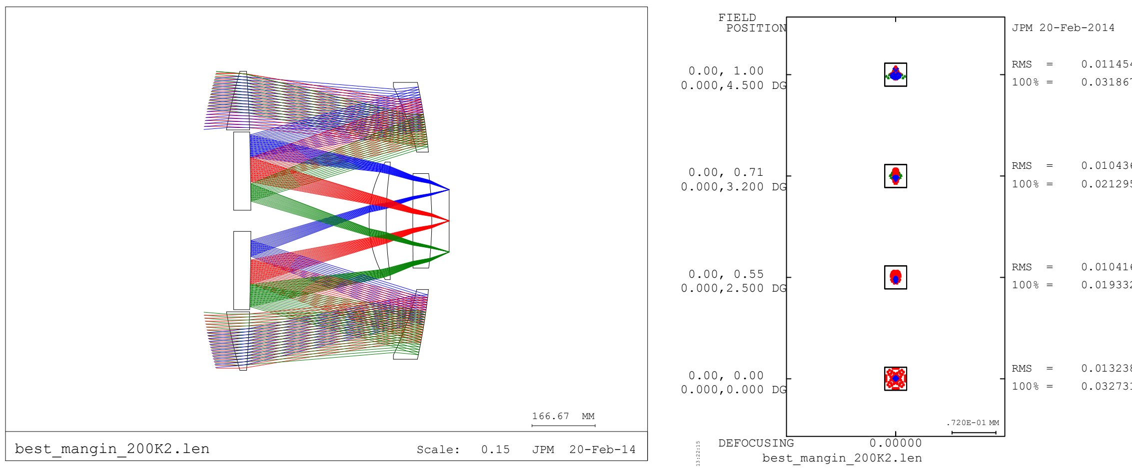

Figure 1. Layout of the telescope (a) and spot diagrams (b)

Table 2. Whipple telescope manufacturing, alignment, and thermal errors.

Tolerance	Value
Sag (mm)	0.003-0.010
Irregularity (fringes)	0.75 (Mangin) to 4 (field lenses)
Thickness (µm)	50 (airspaces), 70-200 (fused silica)
Refractive index (ppm)	10 (absolute), 3 (intra-boule)
Wedge (µm, TIR)	25-35
Tilt (µm, TIR)	17-100
Decenter (µm, TIR)	30-90
Temperature (°C, ±)	1.4 (gradients), 2 (isothermal w/o refocus)

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3. References

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