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Tether-Cor:

Tethered Formation-Flying Coronagraph

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by:

Silvano Fineschi

DOCUMENT CHANGE RECORD

Sheet: 1 of 1

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0.0 Abstract

This document describes the proposal of a formation-flying coronagraph to be implemented on a space platform consisting of two tether-connected nano-satellites – Tether-Cor. The Tether-Cor optical concept comprises an occulter installed on one nano-satellite (Occulting Satellite) and a simple telescope hosted on the other satellite (Observing Satellite). The telescope's entrance pupil is in the shadow cast by the 0.38-m diameter occulter, 30 m away, towards the Sun. The optical system consists of a simple CCD-based web-camera with an objective lens and an afocal telescope for the suppression of the diffraction off the occulter.

1.0 Introduction

Externally occulted coronagraphs are telescopes whose entrance pupil is in the shadow of a screen ("external occulter") blocking the direct sunlight. This allows the observation of the solar corona that is several orders of magnitude fainter than the Sun (cfr. Figure 1). The distance between the external occulter (EO) and the Entrance pupil (EP) is the parameter that determines how close to the solar limb the corona can be observed. The longer this distance, the smaller is the view angle from the sun-center direction. Also, the longer is the EO-EP distance, the smaller is the EP vignetting. This improves the spatial resolution by reducing the diffraction.

In single-bench coronagraphs, the EO-EP distance is limited to 1-2 m. By separating the EO and the telescope on two different space platforms in formation flying, the EO-EP baseline can be extended to tens of meters. While the formation flying concept has already been proposed for coronagraphs, the use of tether-connected nano-satellites for a formation flying coronagraph (Tether- Cor) is a novel approach. In this concept, the limited attitude control available in nano-satellites is compensated by the tether connection that helps maintaining the relative attitude between the two satellites (i.e., formation flying). In the following, the Tether-Cor optical concept and implementation is described (Fineschi, 2009).

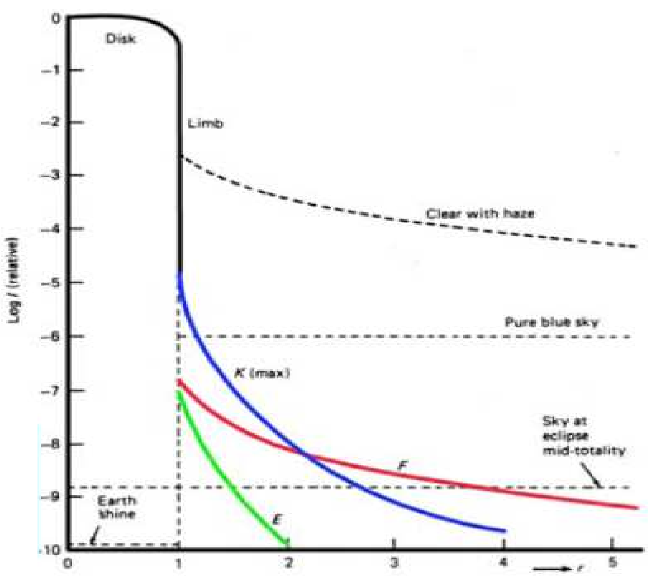
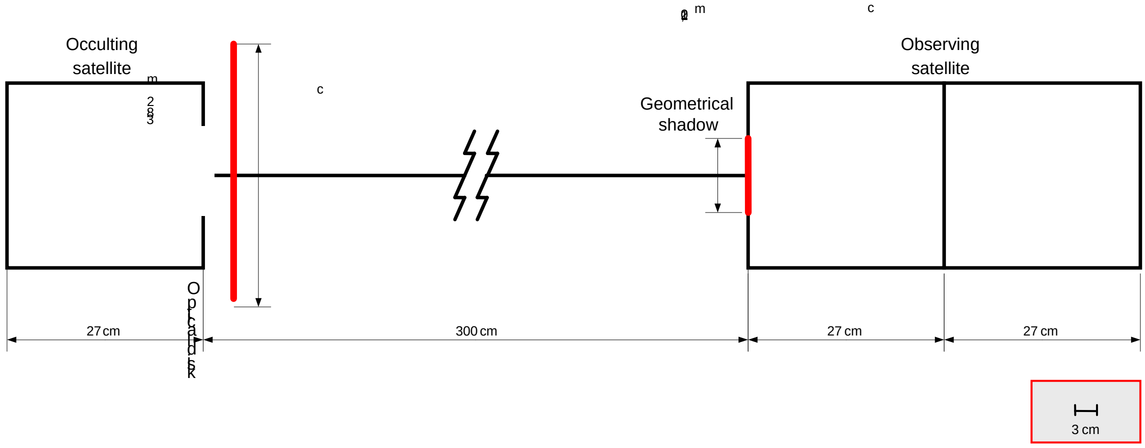


Figure 1 Sun-disk normalized brightnesses of the coronal visible-light continuum (K) and emission lines (E).

2.0 Optical concept of the tethered formation-flying coronagraph

The optical concept calls for an occulter to be installed on one nano-satellite (Occulting Satellite) and for a simple telescope to be hosted on the other nano-satellite (Observing Satellite). The optical payload consists of a simple CCD-based web-camera and an afocal telescope for the suppression of the diffraction off the occulter.

Figure 2 Conceptual layout of the tether-connected coronagraph



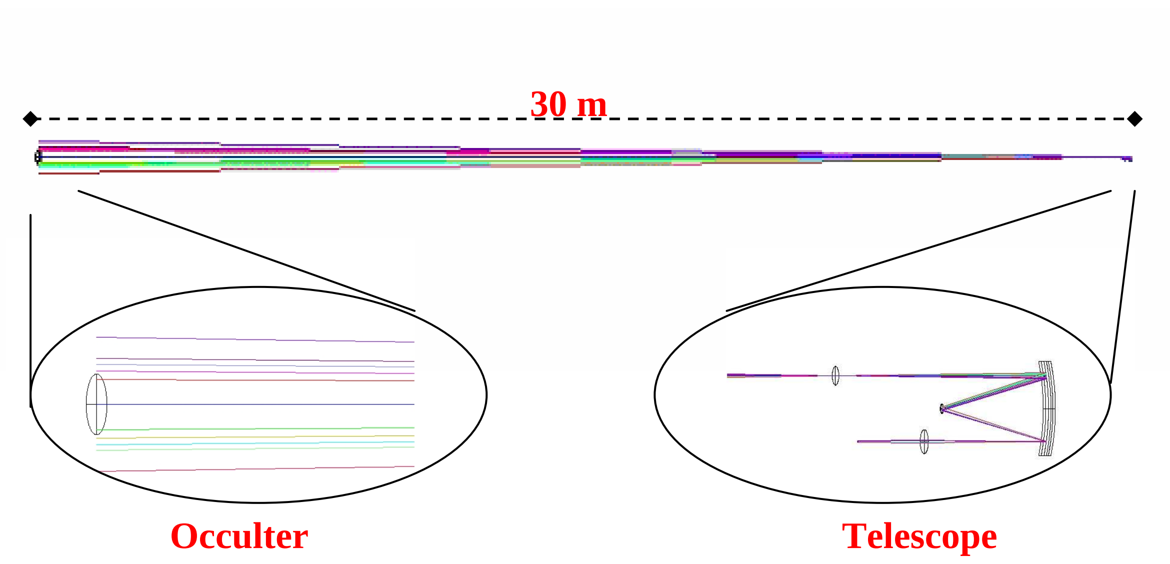


Figure 3 Coronagraph's occulter and telescope on the two tether-connected nano-satellites.

3.0 Nano-satellites platform for tethered formation-flying

The nano-satellites platform for tethered formation-flying and its specifications are described in Chiesa, S., Corpino, S., Viola, N., 2008.

4.0 Tether-Cor implementation

Table 1 shows the main characteristics of the Tether-Cor.

Nano-satellites distance	30 m
External occulter diameter	380 mm
Optical payload dimension	250 mm × 110 mm × 50 mm
Coronagraph Fiel-of-View	1.65 Ro – 5 Ro

Table 1 Tether-Cor main characteristics.

4.1 Occulter's diffraction

The occulter's diffraction has been calculated from the Fresnel integrals for a circular disk at 20 m (Figure 4) and 30 m (Figure 5) distance.

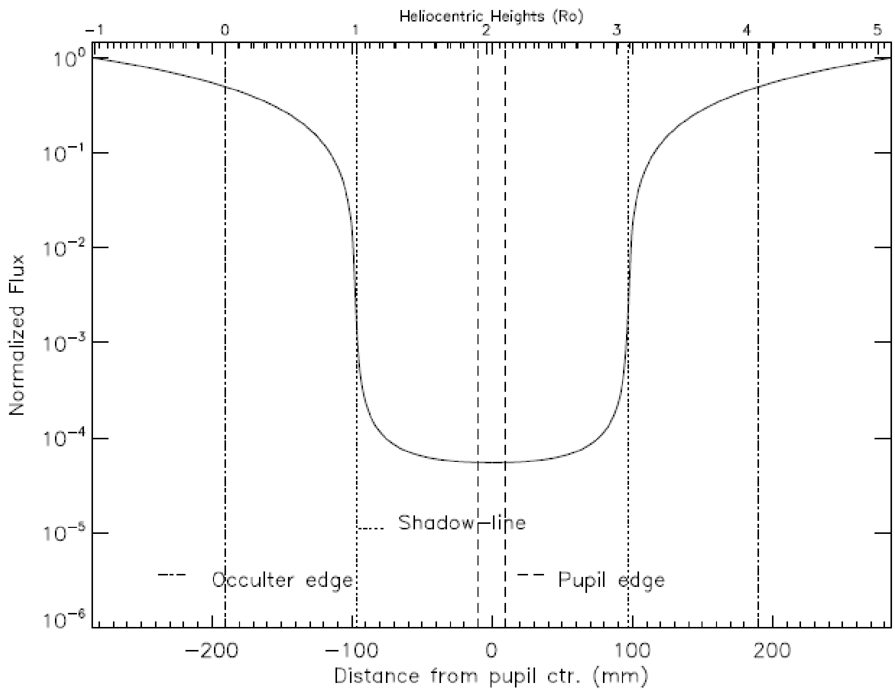


Figure 4 Diffraction profile off a 38-cm diameter occulter on 20-m tether

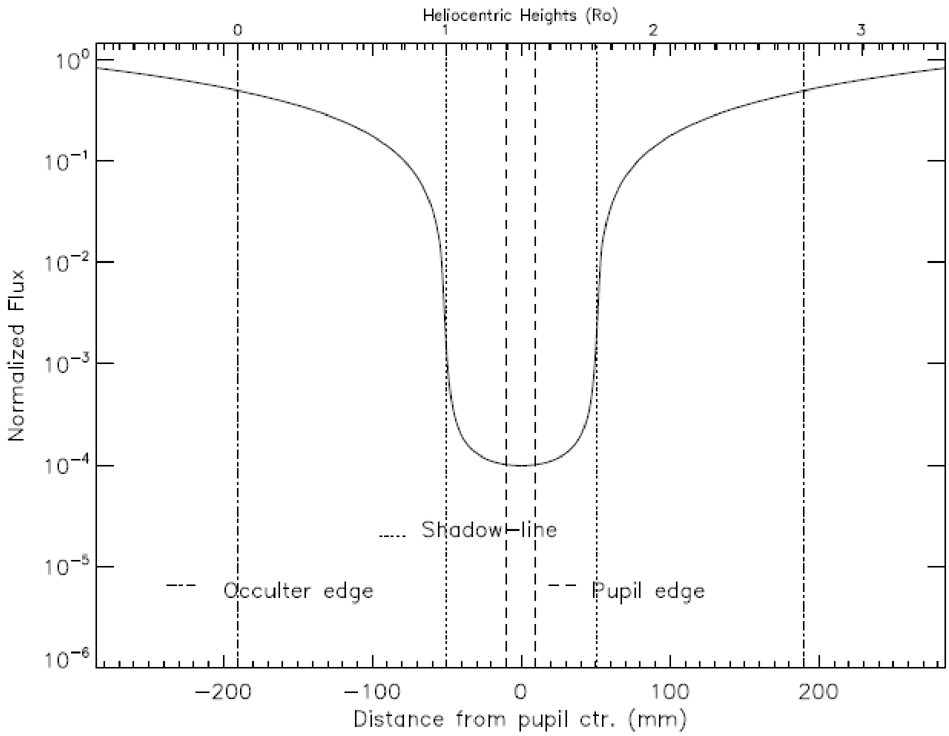


Figure 5 Diffraction profile off a 38 cm diameter occulter on a 30-m tether

4.2 Telescope's Optical Design

The optical specifications of the coronagraph's telescope are reported in Table 2. Figure 6 shows the optical layout.

Telescope Overview	
Overall dimensions	250 mm × 110 mm × 50 mm
Entrance aperture dia.	20 mm
Effective focal length	100 mm (F/# = 5)
Afocal Diffraction-suppressing Optical System (ADOS)	
Parabolic mirror focal length	120 mm
Parabolic mirror dimensions	30 mm × 100 mm
Parab. mirror rms roughness	0.7 nm (0.5 nm goal) in sp. freq. 0.1-0.01 μm^{-1}
Flat reflector dimensions	10 mm × 10 mm
Internal occulter hole dia.	1.04 mm (0.9mm w/o ± 0.07° max disalignm.)
Imaging System	
Objective lens dia.	24 mm
Objective focal length	100 mm (F/# = 4)
CCD sensing area	3.6 mm × 2.7 mm
CCD pixel format	510 × 492 (7 μm pixels)
Plate scale	14 arcsec/pixel
Fiel-of-View	1.45 Ro (1.65 Ro) – 4 Ro

Table 2 Optical specifications of the coronagraphic optics

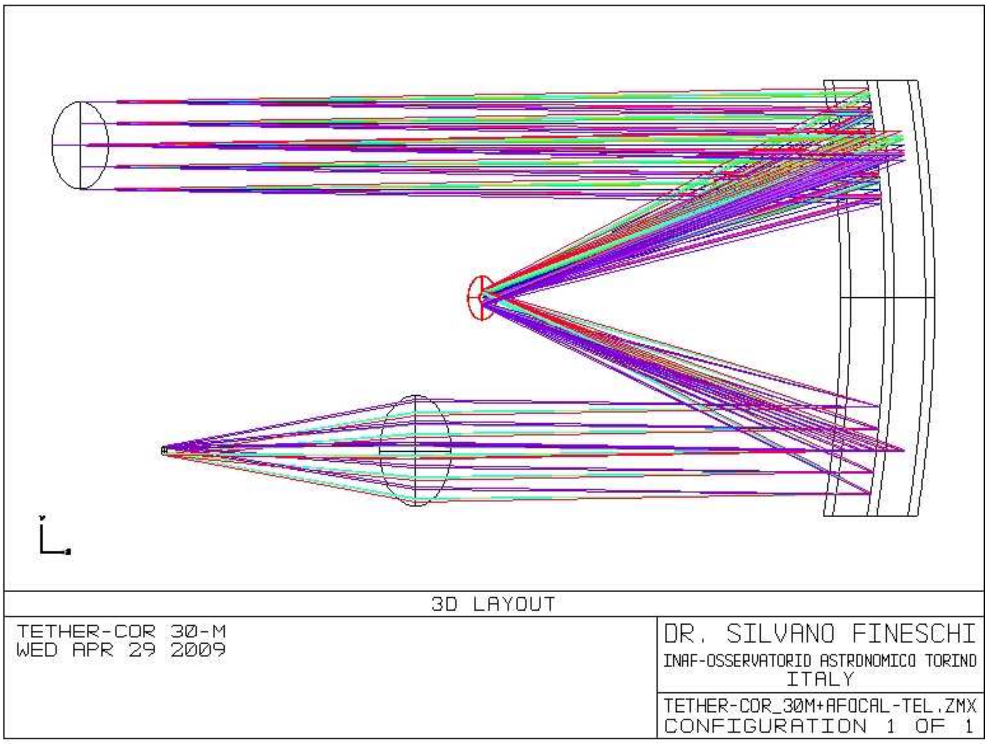


Figure 6 Optical layout of the coronagraph's telescope

4.2.1 Optical Performances

Figure 7 shows that the telescope's optical performances are diffraction limited.

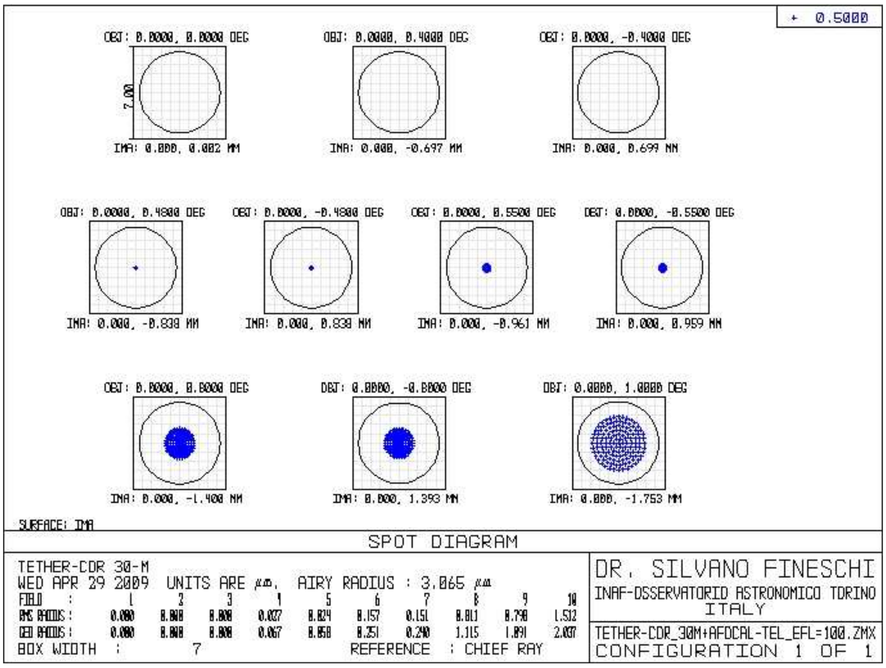


Figure 7 Spot diagram of the coronagraph system.

Figure 8 Vignetting function of the coronagraph. The lower field-of-view limits correspond to the case with (1.65 Ro) and without (1.45 Ro) margin in the satellite alignment.

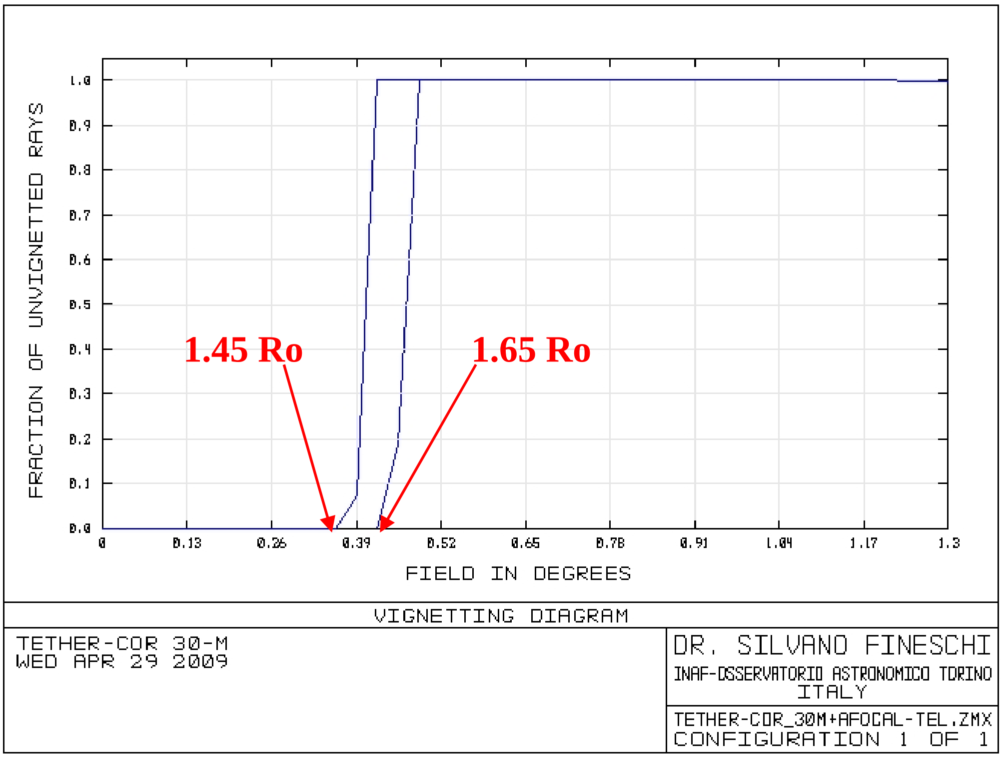


Figure 8 Vignetting function of the coronagraph. The lower field-of-view limits correspond to the case with (1.65 Ro) and without (1.45 Ro) margin in the satellite alignment.

References

1. Chiesa, S., Corpino, S., Viola, N., 2008, "Tethered Nano-satellites to Observe the Solar Corona", *IAC-08-B4-2-08*

2. Fineschi, S., 2009, "Reflecting Coronagraphs: New Concepts for Future Space Missions", *Proc. SPIE*, **7438** (in press)

APPENDIX A Abbreviations/Acronyms

Abbreviation/ Acronyms	DEFINITION
ADOS	Afocal Diffraction-suppressing Optical System
EO	External Occulter
EP	Entrance Pupil
FOV	Field-of-view

APPENDIX B Web-Cam Characteristics

Edmund optics worldwide

home : online catalog : imaging : cameras : board level cameras

Color Micro Standard-Res Board Level CCD Cameras

- Small Color Version
- Models With 3.8mm or 6mm Lens, or CS-Mount

Designed for direct system integration, Edmund Optics board level cameras provide a variety of solutions for machine vision, image processing, and surveillance applications. These cameras yield the performance and benefits of traditional boxed units, but without the added weight and size. Our selection includes standard and high resolution micro monochrome cameras, and some of the smallest color cameras currently available.

Signal Format	NTSC
Interline Transfer CCD	1/4" format
Pixels (H x V)	510 x 492
Horizontal Resolution	330 TV Lines
Sensing Area (H x V)	3.6 x 2.7mm
Video Output	Via 10" wire leads
Lens Mount	CS-Mount or M13 x 1mm
Back Flange Distance	12.5mm (CS-Mount)
Sync System	Internal Only
Minimum Sensitivity (f/1.2)	<1.0 lux
S/N Ratio	>50dB
Electronic Shutter Speed	1/60 - 1/20,000 sec
Gamma	0.45
Auto Gain Control	on 12dB
Operating Temperature	-10°C to 50°C (14°F to 122°F)
Power Requirement	12V DC, 130 mA
Power Supply	#53-256
Dimensions	32mm W x 32mm H x 20mm L
Weight	30g

Lens Options	**3.8mm**	**6.0mm**	**CS-Mount**
Aperture (f/#)	f/2	f/2.5	no lens
Field of View	55° x 40°	35° x 26°	no lens
Minimum Working Distance	0.20m	0.25m	no lens
Stock No.	#53-314	#53-315	#53-316