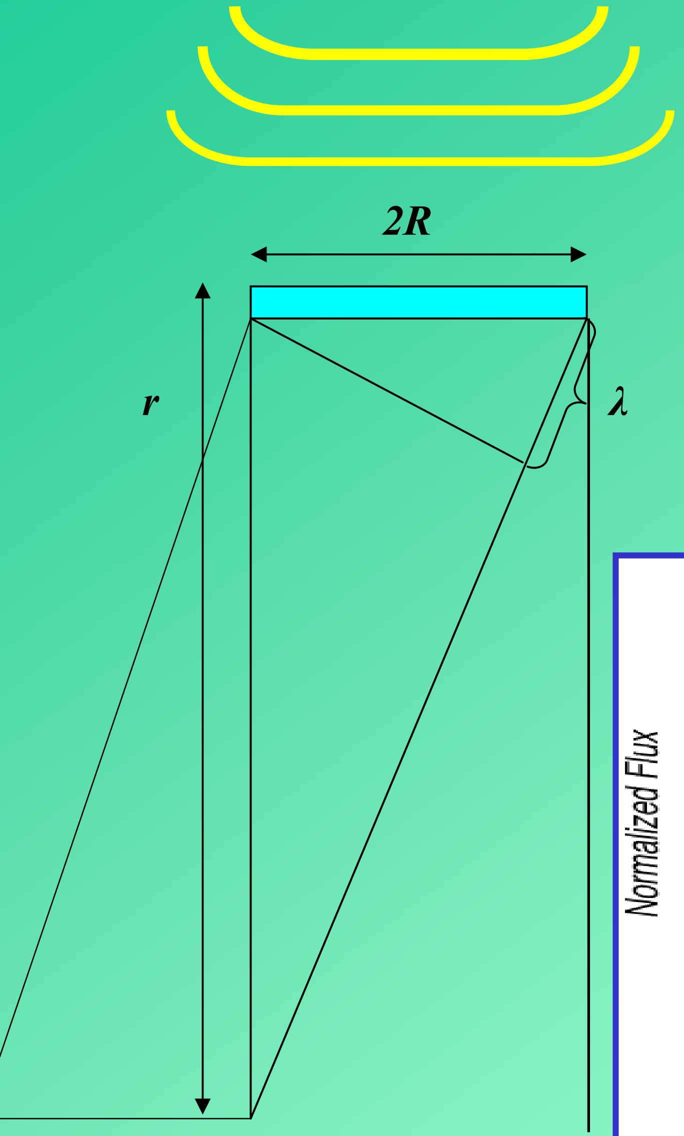
Lunar, Asteroidal and KBO occultations

Sonia Fornasier & Cesare Barbieri

Astronomy Department, Padova University

The basics of occultations

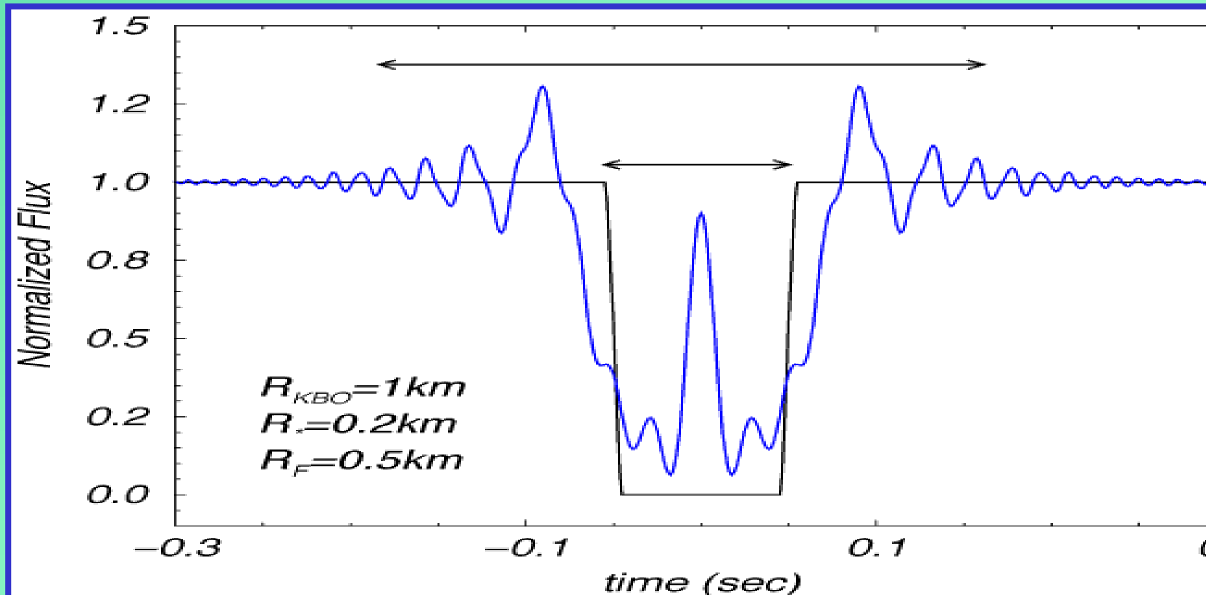
The Fresnel diffraction fringes have a typical length *x* and angle ψ of:



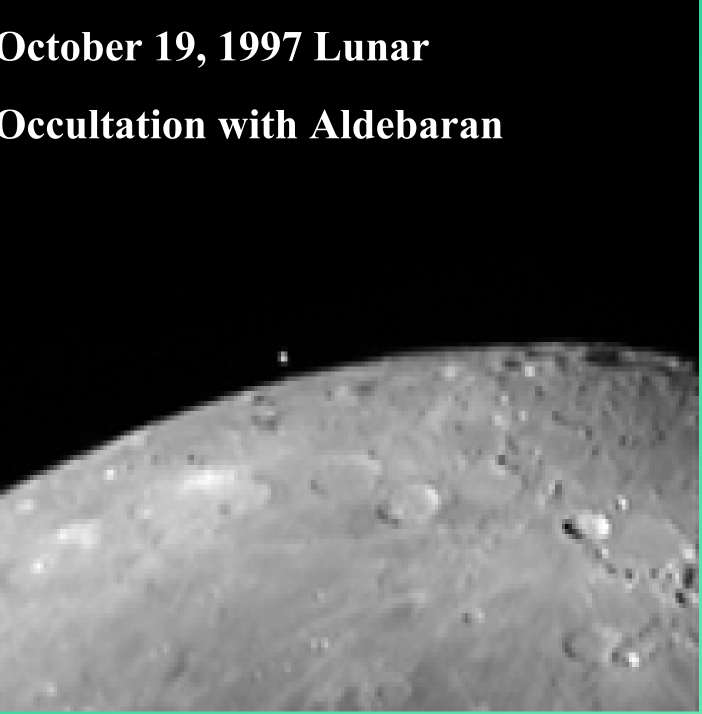
$$x = (\lambda r/2)^{1/2} \quad 1\ \mathrm{FSU}$$

$$\Psi = (\lambda/2r)^{1/2}$$

Occultation produce diffraction phenomena



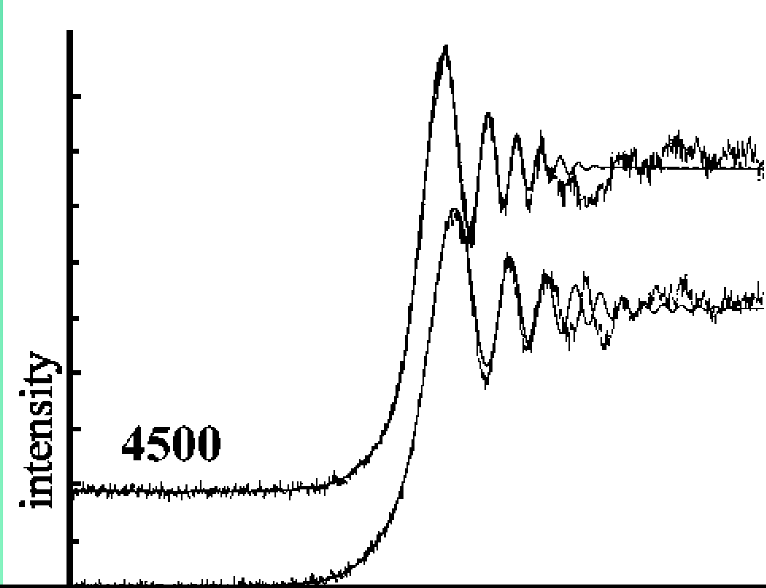
LUNAR OCCULTATIONS



October 19, 1997 Lunar Occultation with Aldebaran

Allow to derive the diameter of stars, to discover binary star systems, to investigate the disturbances of the Moon’s orbit, to find exoplanet candidates

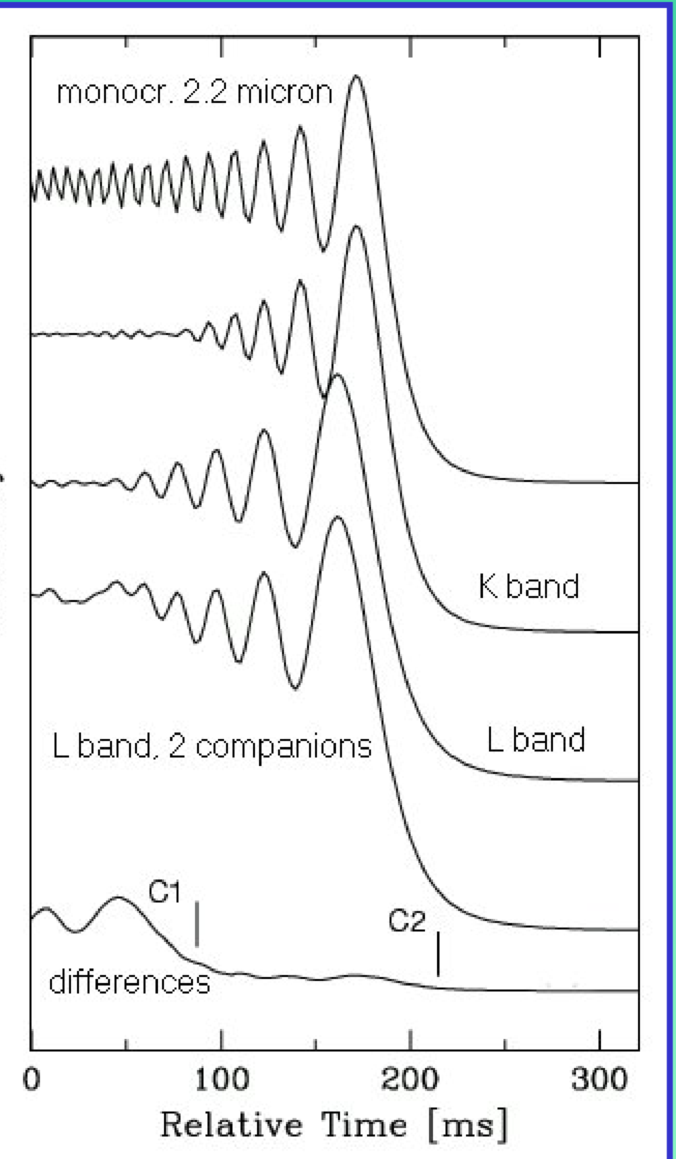
The lunar limb can be considered as a straight diffraction edge: a lunar occultation produces a series of diffraction fringes, whose contrast and frequency is related to the central wavelength and bandwidth of the filter



	0.5 μm	1.0 μm	5.0 μm	10.0 μm
x (m)	10	14	32	45
ψ (arcsec)	0”.005	0”.007	0”.016	0”.022
τ (sec)	0.012	0.017	0.038	0.053

LUNAR OCCULTATIONS

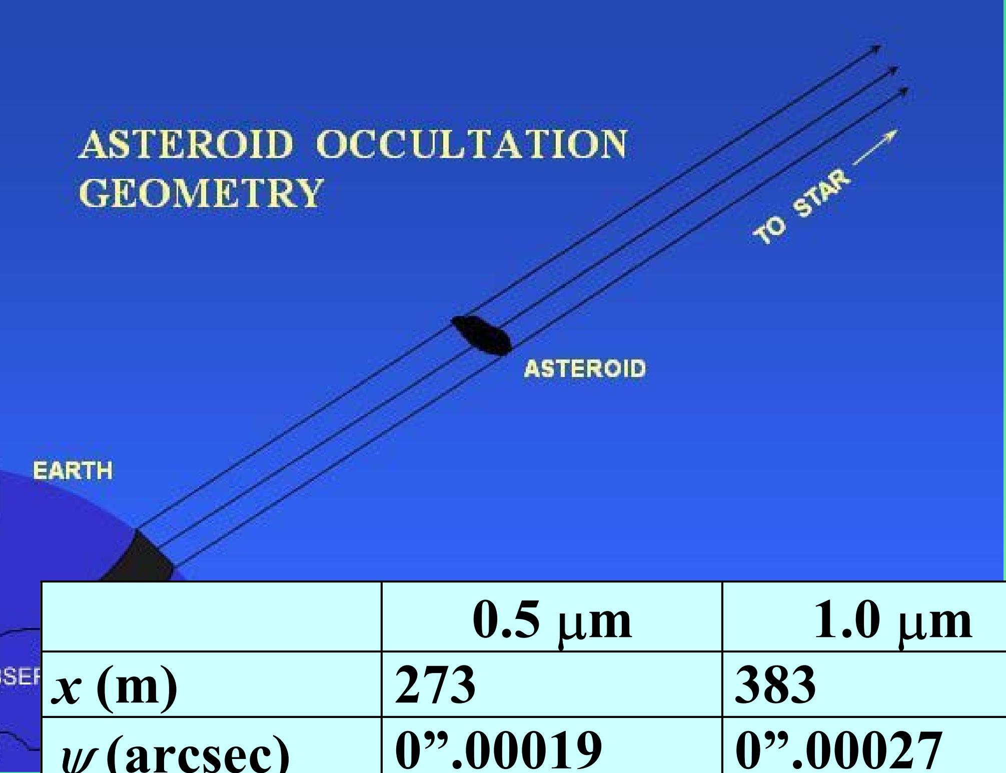
lunar occultations can be a powerful instrument for astrophysical considerations:



- Gies et. al. (1990), who obtained low-resolution spectra with a time sampling rate of 7 ms of the H-alpha emission line in the spectrum of the Be star Pleione.

•Richichi (1993) propose to use lunar occultation for the detection of very faint companions of a star (exoplanet or brown dwarfs) : the presence of one or more faint companions re s in a superposition of diffracti patte

OWL will allow to detect star companions 13-15 magnitudes fainter than the central star.

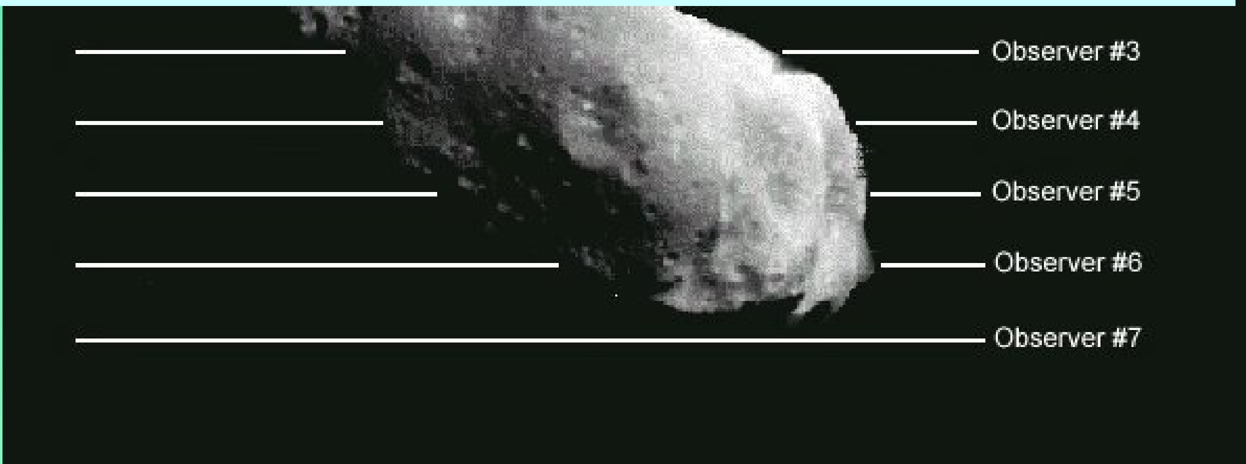


The duration of time that the star vanishes is usually less than one second (near the edge of the shadow) to several seconds near to the center. Since the star vanishes for several seconds as the dark asteroid moves in front of it, its size and shape can be determined from analysis of different observations

	0.5 μm	1.0 μm	5.0 μm	10.0 μm
x (m)	273	383	857	1210
ψ (arcsec)	0".00019	0".00027	0".00059	0".00084
τ (sec)	0.018	0.0256	0.058	0.081

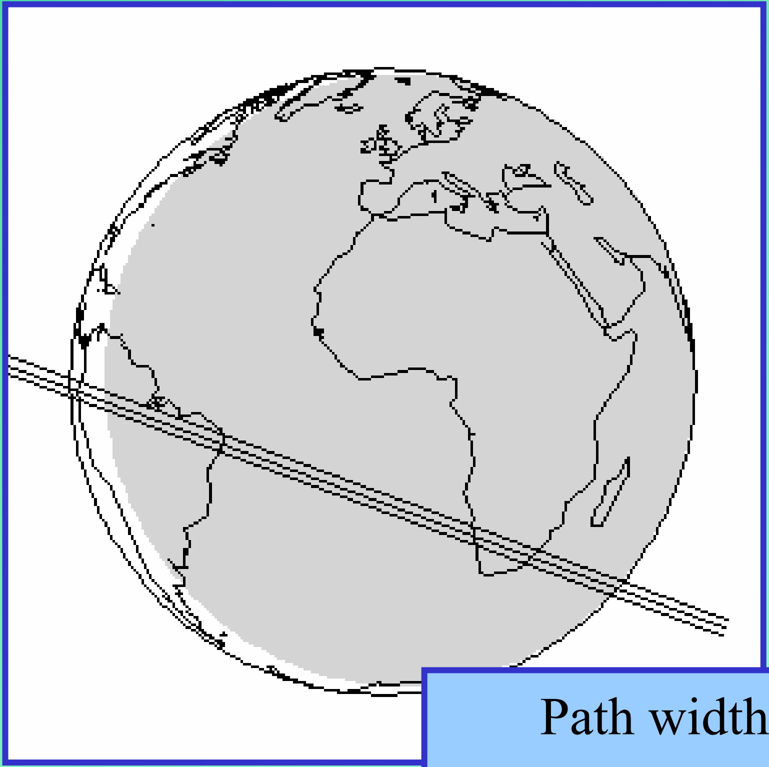
C

the occultation at a different time than Observer # 6, caused by the orientation angle of the asteroid. Observer # 7 will not see an occultation, thus he has a "miss".



KBO OCCULTATIONS

- **Objectives**
  - Establish accurate diameters
  - Search for close companions
  - Search for atmospheres
- **Approach**
  - Brightest KBOs as targets
  - Three strategies (portable, airborne, large fixed)
- **Needs**
  - Discovery of more bright KBO’s in dense star fields
    - Star density in the galactic plane ~ 10 times the average
  - Improved orbits, high astrometric precision
    - 17 orbits better than 0.1"; 79 better than 1"
    - How much large telescope time to use for predictions vs. observations?



Path width!

KBO:230-1000k

(2300 km Pluto)

KBO occultation

- **Density distribution of KBO is poorly known**: current estimations give **10^{11}** objects larger than 1 km located between 30 and 50 AU. The size distribution varies as ρ^{-q}, with $3 < q < 4$

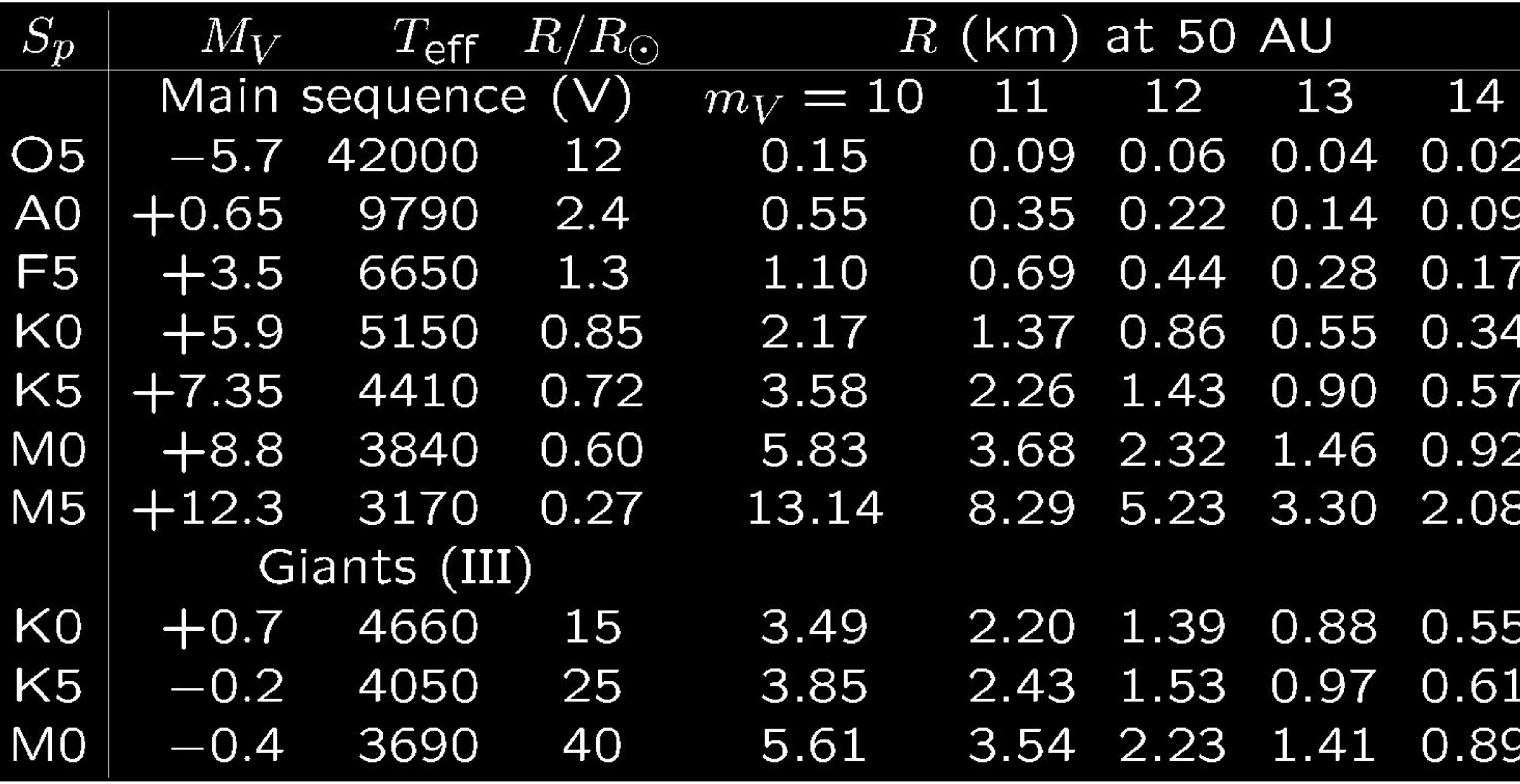
- **Diffraction is very important**, reduces the depth of the event but increase the size of the shadow (it is larger than the geometrical one)

- **Fast photometry needed** (> 15 Hz) as occultation events are brief

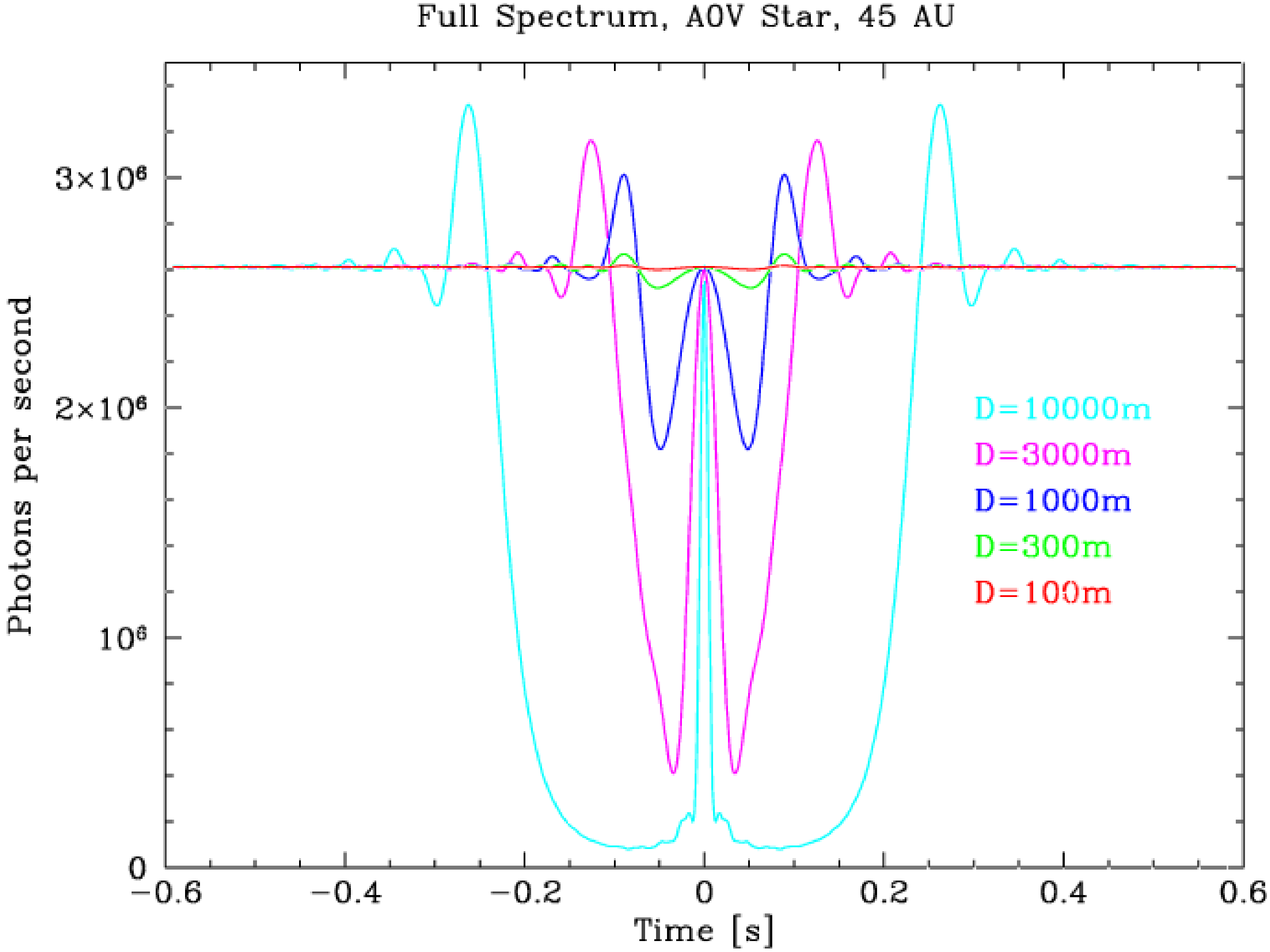
- **S/N noise** of the light-curve limits the detection: increase with big telescopes; atmospheric intensity scintillation is a limiting parameter!

- **Star size is a critical parameter**: star must have small angular diameter to search for small KBO, but it must be bright enough to preserve high S/N. Blue stars are good candidates (at a given mag. they have smaller angular diam.)

Size of different spectral type stars at KBO distance

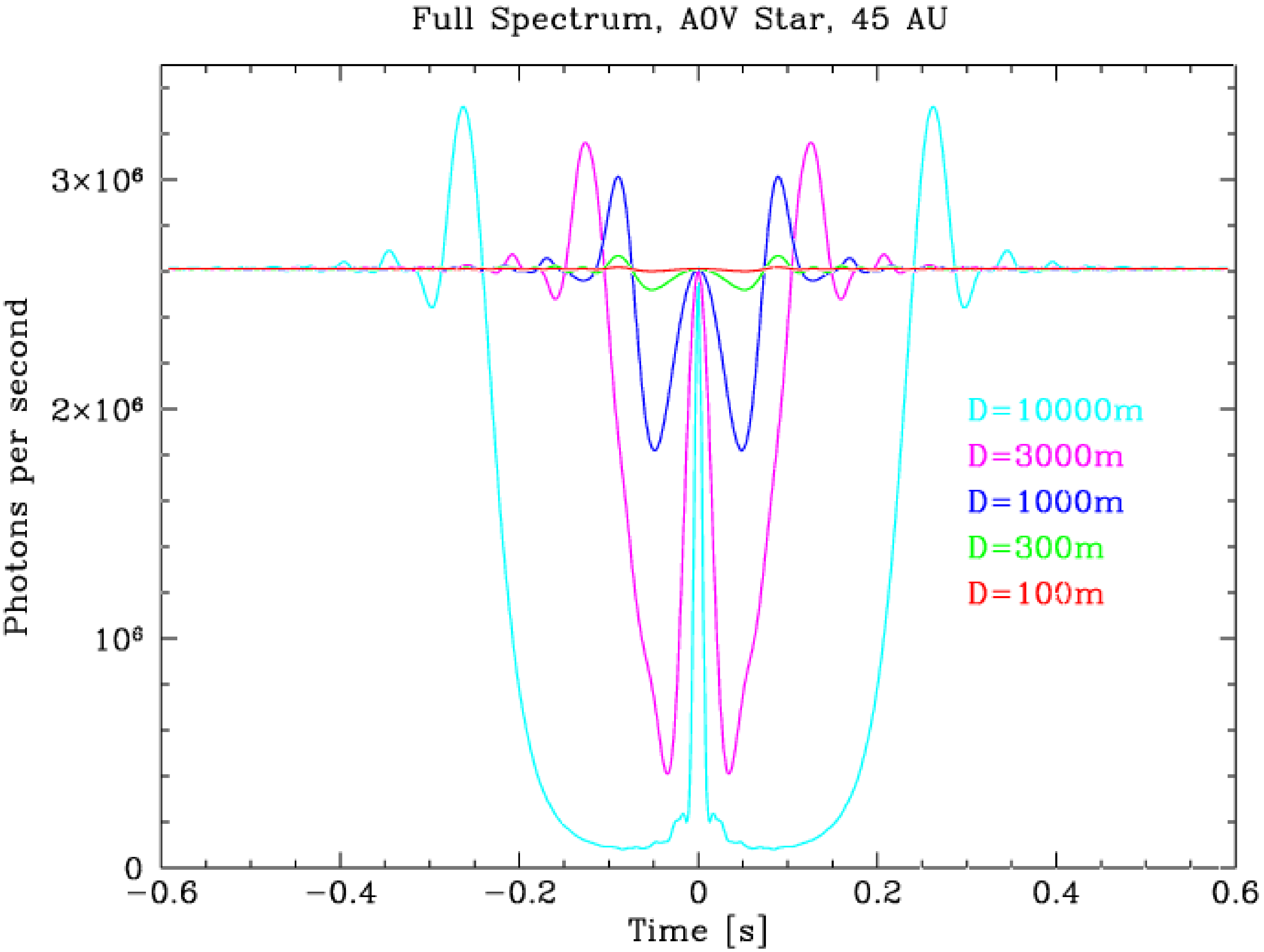


S_p	M_V	$T_{\rm eff}$	$R/R_\odot$	R (km) at 50 AU				
	Main sequence (V)			$m_V = 10$	11	12	13	14
O5	−5.7	42000	12	0.15	0.09	0.06	0.04	0.02
A0	+0.65	9790	2.4	0.55	0.35	0.22	0.14	0.09
F5	+3.5	6650	1.3	1.10	0.69	0.44	0.28	0.17
K0	+5.9	5150	0.85	2.17	1.37	0.86	0.55	0.34
K5	+7.35	4410	0.72	3.58	2.26	1.43	0.90	0.57
M0	+8.8	3840	0.60	5.83	3.68	2.32	1.46	0.92
M5	+12.3	3170	0.27	13.14	8.29	5.23	3.30	2.08
	Giants (III)							
K0	+0.7	4660	15	3.49	2.20	1.39	0.88	0.55
K5	−0.2	4050	25	3.85	2.43	1.53	0.97	0.61
M0	−0.4	3690	40	5.61	3.54	2.23	1.41	0.89



Full Spectrum, A0V Star, 45 AU

	0.5 μm	**1.0 μm**	**5.0 μm**	**10.0 μm**
x (m)	**1220**	**1710**	**3833**	**5411**
ψ (arcsec)	**0”.000043**	**0”.000060**	**0”.00013**	**0”.00018**
τ (sec)	**0.048**	**0.068**	**0.153**	**0.216**



Chromaticity: Information on the Fresnal scale, then, on the distance of the KBO wo occultation chords needed

EVENTS PER YEAR

Need accurate prediction (miss is expensive!)
Second occultation chord or astrometry (from other te

Telescope Strategy (aperture, m)	Limiting Stellar R Mag	Events per Year per KBO, γ_R	Location Factor, f_l	Weather Factor, f_w	Combined Factor, ε	Observable Events per Year[b], N_{obs}
Portable (0.36)	16.2	1	0.17	0.75	0.13	~6
Airborne (2.5)	18.4	12	0.58	0.95	0.55	~200
Fixed (6.5)	19.3	30	0.0067	0.60	0.0040	~4
OWL	25	≈400	0.0067	0.60	0.0040	≈ 50

[b] for a single tel. and the current sample of 29 KBOs brighter than an *H* mag. of 5.2.

Initial prediction accurate to 0.025 arcsec (=> 1/5 success rate)
Single occultation chord & astrometry with the same telescope

Occultations rates

- The noise is due to scintillation: $\sigma = S_0 . d^{-2/3} . X^{3/2} . e^{-h/H0} . (2\ \tau)^{-1/2}$

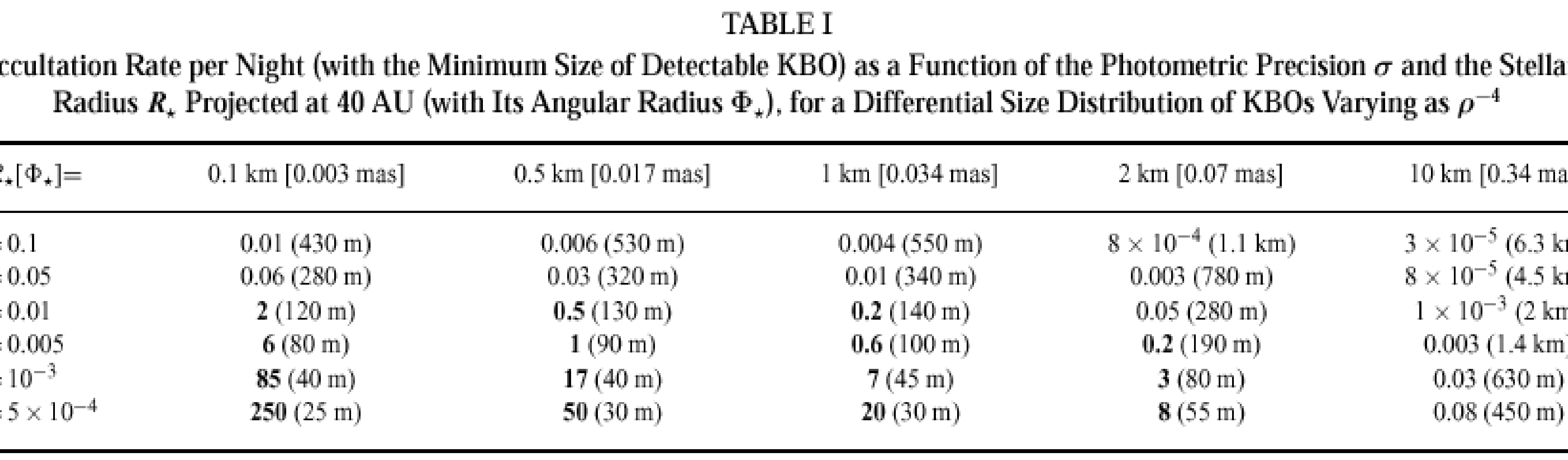
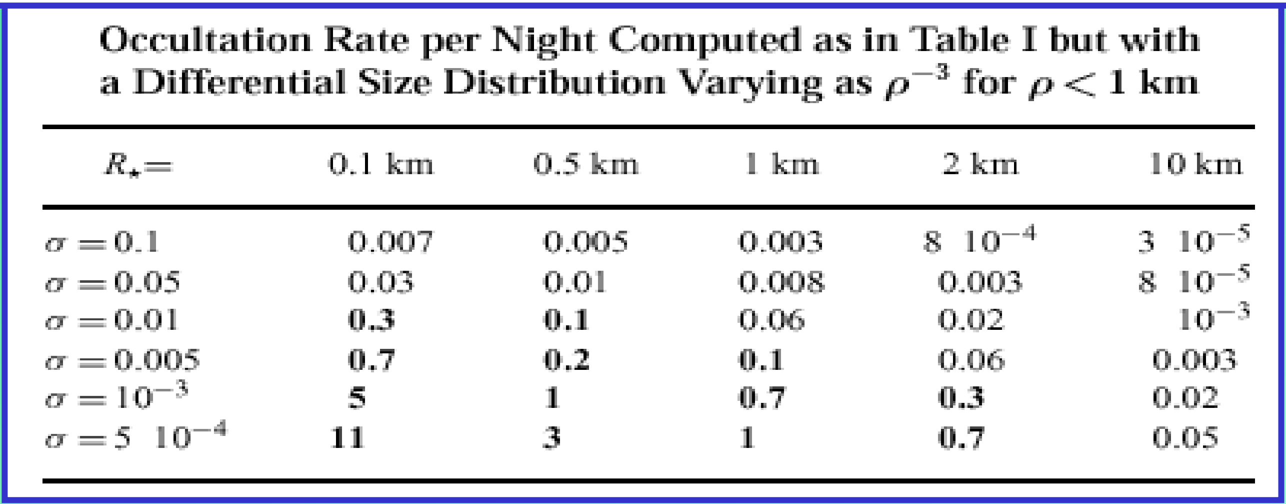


TABLE I

ccultation Rate per Night (with the Minimum Size of Detectable KBO) as a Function of the Photometric Precision σ and the Stella
Radius $R_\star$ Projected at 40 AU (with Its Angular Radius $\Phi_\star$), for a Differential Size Distribution of KBOs Varying as ρ^{-4}

$_\star[\Phi_\star]=$	0.1 km [0.003 mas]	0.5 km [0.017 mas]	1 km [0.034 mas]	2 km [0.07 mas]	10 km [0.34 ma
0.1	0.01 (430 m)	0.006 (530 m)	0.004 (550 m)	8×10^{-4} (1.1 km)	3×10^{-5} (6.3 k
0.05	0.06 (280 m)	0.03 (320 m)	0.01 (340 m)	0.003 (780 m)	8×10^{-5} (4.5 k
0.01	**2** (120 m)	**0.5** (130 m)	**0.2** (140 m)	0.05 (280 m)	1×10^{-3} (2 km
0.005	**6** (80 m)	**1** (90 m)	**0.6** (100 m)	**0.2** (190 m)	0.003 (1.4 km
10^{-3}	**85** (40 m)	**17** (40 m)	**7** (45 m)	**3** (80 m)	0.03 (630 m)
5×10^{-4}	**250** (25 m)	**50** (30 m)	**20** (30 m)	**8** (55 m)	0.08 (450 m)



Occultation Rate per Night Computed as in Table I but with a Differential Size Distribution Varying as ρ^{-3} for $\rho < 1$ km

$R_\star=$	0.1 km	0.5 km	1 km	2 km	10 km
$\sigma = 0.1$	0.007	0.005	0.003	$8\ \ 10^{-4}$	$3\ \ 10^{-5}$
$\sigma = 0.05$	0.03	0.01	0.008	0.003	$8\ \ 10^{-5}$
$\sigma = 0.01$	**0.3**	**0.1**	0.06	0.02	10^{-3}
$\sigma = 0.005$	**0.7**	**0.2**	**0.1**	0.06	0.003
$\sigma = 10^{-3}$	**5**	**1**	**0.7**	**0.3**	0.02
$\sigma = 5\ \ 10^{-4}$	**11**	**3**	**1**	**0.7**	0.05

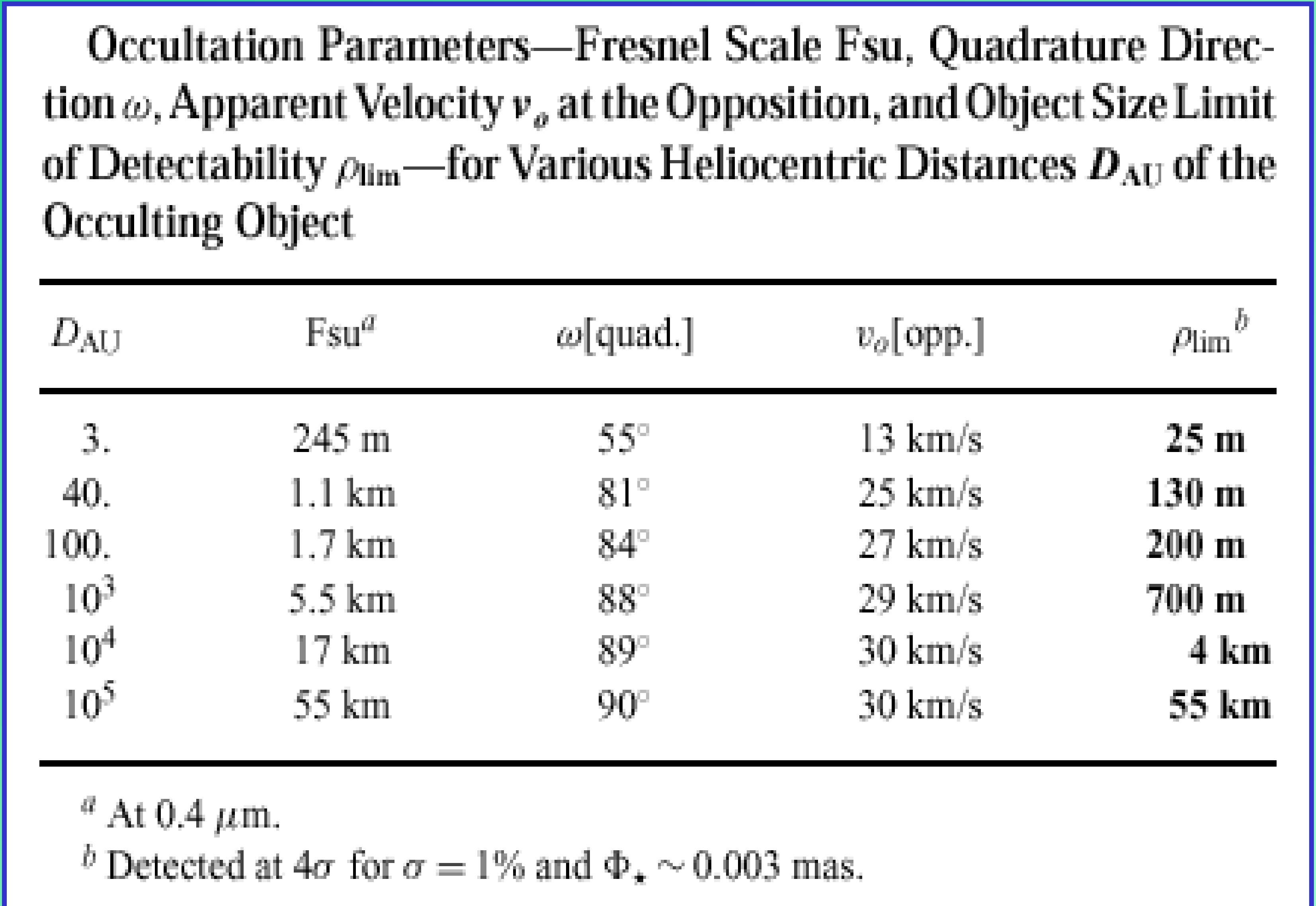
TAOS

T4M

T8M
space

OWL: $\sigma \approx 3{*}10^{-4}$ (τ =1s)! but $\sigma \approx 2{*}10^{-3}$ (τ =0.01s) ...

Prospective
Distants objects : Oort cloud

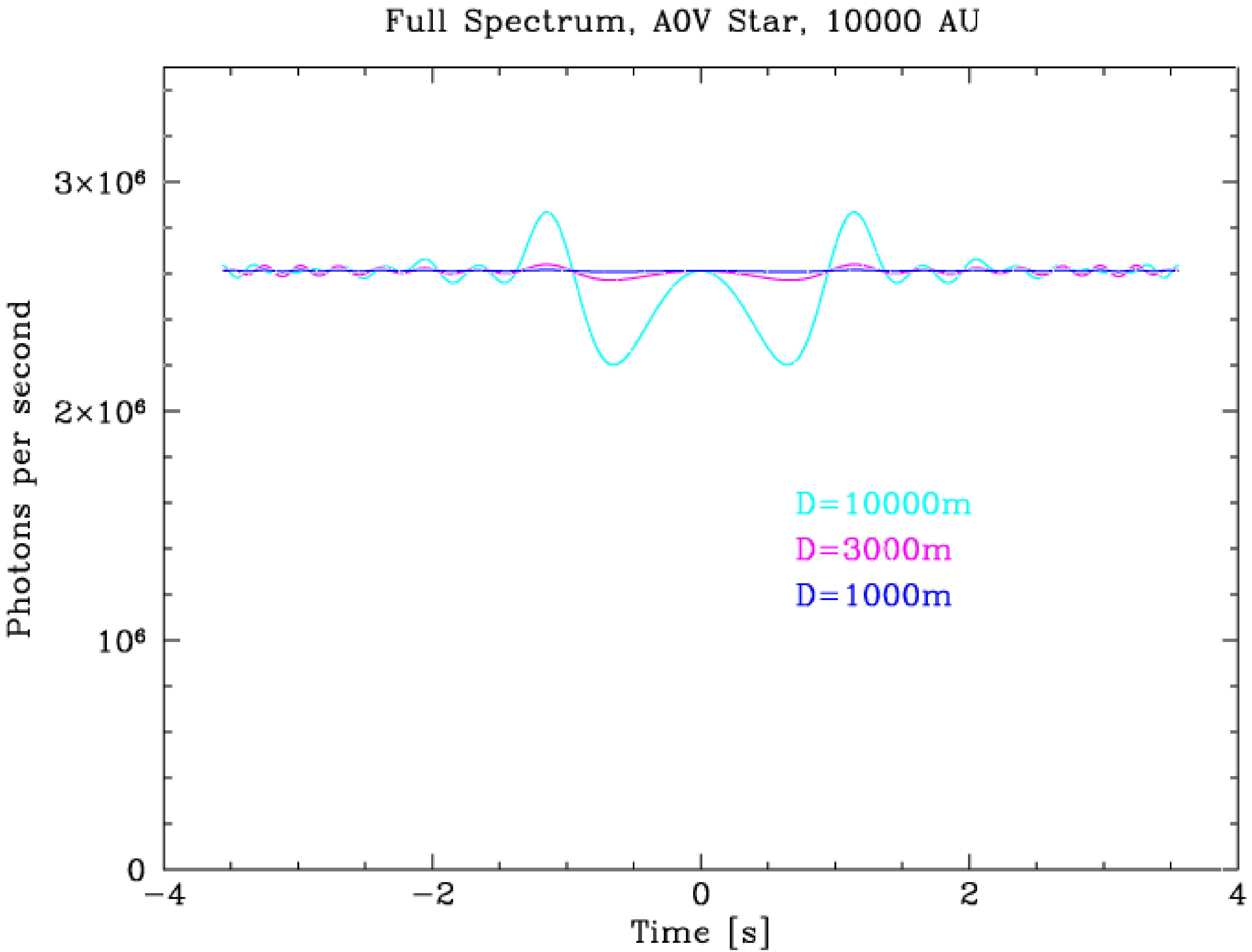


Occultation Parameters—Fresnel Scale Fsu, Quadrature Direction ω, Apparent Velocity v_o at the Opposition, and Object Size Limit of Detectability $\rho_{\rm lim}$—for Various Heliocentric Distances $D_{\rm AU}$ of the Occulting Object

$D_{\rm AU}$	Fsu[a]	ω[quad.]	v_o[opp.]	$\rho_{\rm lim}$[b]
3.	245 m	55°	13 km/s	**25 m**
40.	1.1 km	81°	25 km/s	**130 m**
100.	1.7 km	84°	27 km/s	**200 m**
10^3	5.5 km	88°	29 km/s	**700 m**
10^4	17 km	89°	30 km/s	**4 km**
10^5	55 km	90°	30 km/s	**55 km**

[a] At 0.4 μm.

[b] Detected at 4σ for $\sigma = 1\%$ and $\Phi_* \sim 0.003$ mas.



Full Spectrum, A0V Star, 10000 AU