

Throughput Calculations and Limiting Magnitudes

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In order to get an estimate of the magnitude limits of the CHARA Array, a spread sheet calculator was used to list all optical components in the Array along with values for their optical efficiency in both the visible and infrared bands. These values are based on data supplied by optical companies such as Newport and Melles Griot, and by vacuum and coating companies such as Denton Vacuum. Since a spread sheet was used these estimates can be updated easily as new data comes to hand. Once the throughput for each optical subsystem is found, magnitude limits are estimated by using the approximation that 10^7 photons reach the earth per m^2 per s per Angstrom from a magnitude zero star in the visible. A different constant is used for the infrared channel. Some of the optical efficiencies are not known at this time, the fiber coupling for example, and ‘best guesses’ have been used. Experiments are underway to establish reliable values for these numbers. It is inherently difficult to produce throughput and magnitude limits for an optical instrument as complex as the CHARA Array since there are many unknowns, including the seeing quality at the site. Nevertheless the final magnitude limits predicted here should be correct to within a magnitude. A summary of the final magnitude limits found is given in Table R.1 with the details of the analysis presented on the pages following the table. Note that these magnitude limits are for active fringe tracking. Using passive openloop tracking could add another 2 magnitudes.

These calculations were repeated for aperture sizes of 2.7 m and 0.35 m. Neither the uncorrected nor the natural guide star magnitude limits changed in either case as they are both limited by the atmosphere rather than the aperture size. For the 2.7 m aperture the laser guide star extends the magnitude limit by 2 magnitudes. In the 0.35 m aperture case, adaptive optics (AO) actually reduced the magnitude limit.

TABLE R.1. Magnitude Limits as Predicted by the Spreadsheet

Seeing	AO Used	Tip/Tilt	Fringe Track	High Order AO	Imaging	Total	Infrared
Average	No AO	13.3	7.7	N.A.	8.4	7.7	13.8
	AO	12.5	11.0	9.4	7.5	9.4	13.5
	Laser	13.3	11.8	17.0	8.4	11.8	14.3
Excellent	No AO	14.2	10.1	N.A.	9.2	10.1	15.1
	AO	13.3	11.9	11.8	8.4	11.8	14.2
	Laser	14.1	12.7	17.0	9.2	12.7	15.1

THE CHARA ARRAY

OPTICAL EFFICIENCIES

	VISIBLE	INFRARED
Al Coated Mirrors	0.880	0.920
Ag Coated Mirrors	0.980	0.990
Beam Tube Windows	0.920	0.920
Anti-Reflection Coated Optics	0.950	0.950
Polarizing Beam Splitter Transmittance P	0.475	0.480
Polarizing Beam Splitter Reflectance S	0.450	0.480
Optical Fiber Coupling	0.250	0.250
Aperture Size (m)	1.000	1.000
For a zero Magnitude Star photons $\frac{4}{\pi}m^{-2}s^{-1}nm^{-1}$	7.854×10^7	4.374×10^6

INPUT OPTICS

Number	Description	Vis Eff	Vis Total	IR Eff	IR Total
1	Telescope Primary	0.980	0.980	0.990	0.990
2	Telescope Secondary	0.980	0.960	0.990	0.980
3	M3 in Coudé Path	0.980	0.941	0.990	0.970
4	M4 in Coudé Path (Wobbler)	0.980	0.922	0.990	0.961
5	M5 in Coudé Path	0.980	0.904	0.990	0.951
6	M6 in Coudé Path	0.980	0.886	0.990	0.941
7	M7 in Coudé Path	0.980	0.868	0.990	0.932
	Telescope Subsystem Total	0.868	0.868	0.932	0.932
8	Beam Tube Mirror	0.980	0.851	0.990	0.923
9	Beam Tube Window	0.920	0.783	0.920	0.849
10	Beam Tube Window	0.920	0.720	0.920	0.781
11	Beam Tube Mirror	0.980	0.706	0.990	0.773
	Beam Tube Subsystem Total	0.813	0.706	0.830	0.773
12	Input Mirror 1	0.980	0.692	0.990	0.765
13	Input Mirror 2	0.980	0.678	0.990	0.758
14	OPE Primary	0.980	0.664	0.990	0.750
15	OPE Secondary	0.980	0.651	0.990	0.743
16	OPE Primary	0.980	0.638	0.990	0.735
17	Folding Mirror 1	0.980	0.625	0.990	0.728
18	Folding Mirror 2	0.980	0.613	0.990	0.721
19	OPE Primary	0.980	0.600	0.990	0.713
20	OPE Secondary	0.980	0.588	0.990	0.706
21	OPE Primary	0.980	0.577	0.990	0.699
22	Output Mirror 1	0.980	0.565	0.990	0.692
23	Output Mirror 2	0.980	0.554	0.990	0.685
24	Output Mirror 3	0.980	0.543	0.990	0.679
	OPE Subsystem Total	0.769	0.543	0.878	0.679

VISIBLE THROUGHPUT

25	BRT Primary	0.980	0.532	0.990	0.672
26	BRT Secondary	0.980	0.521	0.990	0.665
27	Beam Folding Mirror	0.980	0.511	0.990	0.658
28	Dichroic (IN for IR OUT for Vis)	1.000	0.511	0.900	0.593
	INFRARED SPLIT HERE				
29	ARC	0.950	0.485	N.A.	N.A.
30	LDC	0.950	0.461	N.A.	N.A.
	Beam Sampler Subsystem	0.849	0.461	0.873	0.593

TIP/TILT DETECTION

31T	Polarizing Beam Splitter Reflection	0.450	0.207	N.A.	N.A.
32T	Beam Splitter 30%	0.285	0.059	N.A.	N.A.
33T	Steering Mirror	0.980	0.058	N.A.	N.A.
34T	Achromatic Lens	0.950	0.055	N.A.	N.A.
	Tip/Tilt Subsystem Total	0.119	0.055	N.A.	N.A.

IMAGING

31I	Polarizing Beam Splitter Reflection	0.450	0.207	N.A.	N.A.
32I	Beam Splitter 70%	0.665	0.138	N.A.	N.A.
33I	Achromatic Lens	0.950	0.131	N.A.	N.A.
34I	Single Mode Fiber	0.250	0.033	N.A.	N.A.
35I	Achromatic Lens	0.950	0.031	N.A.	N.A.
36I	Dispersive Prism	0.950	0.030	N.A.	N.A.
37I	Achromatic Lens	0.950	0.028	N.A.	N.A.
38I	Cylindrical Lens 1	0.950	0.027	N.A.	N.A.
39I	Cylindrical Lens 2	0.950	0.025	N.A.	N.A.
	Imaging Subsystem Total	0.055	0.025	N.A.	N.A.

FRINGE TRACKING

31F	Polarizing Beam Splitter Transmission	0.475	0.219	N.A.	N.A.
32F	Beam Splitter 50%	0.475	0.104	N.A.	N.A.
33F	Folding Mirror	0.980	0.102	N.A.	N.A.
34F	Beam Splitter and beam combination	0.950	0.097	N.A.	N.A.
35F	Dispersive Prism	0.950	0.092	N.A.	N.A.
36F	Steering Mirror	0.980	0.090	N.A.	N.A.
37F	Achromatic Lens	0.950	0.086	N.A.	N.A.
	Fringe Tracking Subsystem Total	0.186	0.086	N.A.	N.A.

Note that there are two identical channels in the fringe tracker.

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INFRARED BEAM COMBINER

29IR	Local Delay Line Input Mirror	N.A.	N.A.	0.990	0.587
30IR	Local Delay Line Primary	N.A.	N.A.	0.990	0.581
31IR	Local Delay Line Secondary	N.A.	N.A.	0.990	0.575
32IR	Local Delay Line Primary	N.A.	N.A.	0.990	0.569
33IR	Local Delay Line Output Mirror	N.A.	N.A.	0.990	0.563
34IR	Achromatic Lens	N.A.	N.A.	0.950	0.535
35IR	Single Mode Fiber	N.A.	N.A.	0.250	0.134
36IR	Dispersive Prism	N.A.	N.A.	0.950	0.127
37IR	Achromatic Lens	N.A.	N.A.	0.950	0.121
38IR	Cylindrical Lens 1	N.A.	N.A.	0.950	0.115
39IR	Cylindrical Lens 2	N.A.	N.A.	0.950	0.109
IR Beam Combiner Subsystem Total		N.A.	N.A.	0.184	0.109

SUMMARY: NO A.O.

Telescopes	0.868	0.868	0.932	0.932
Light Pipe	0.813	0.706	0.830	0.773
OPLE	0.769	0.543	0.878	0.679
Beam Sampler	0.849	0.461	0.873	0.593
Tip/Tilt	0.119	0.055	N.A.	N.A.
Imaging	0.055	0.025	N.A.	N.A.
Fringe Tracking	0.186	0.086	N.A.	N.A.
IR Beam Combiner	N.A.	N.A.	0.184	0.109

SUMMARY: WITH A.O.

	Visible	Infrared
Amount of light sent to AO detector	0.500	0.500
Deformable Mirror	0.980	0.990
Beamsplitter for AO detector	0.475	0.475
Amount of light transmitted to system	0.466	0.470

Telescopes	0.404	0.404	0.438	0.438
Light Pipe	0.813	0.328	0.830	0.364
OPLE	0.769	0.253	0.878	0.319
Beam Sampler	0.849	0.215	0.873	0.279
Tip/Tilt	0.119	0.026	N.A.	N.A.
Imaging	0.055	0.012	N.A.	N.A.
Fringe Tracking	0.186	0.040	N.A.	N.A.
IR Beam Combiner	N.A.	N.A.	0.184	0.051

MAGNITUDE LIMITS

	Visible	Infrared
Excellent seeing r_0 (m)	0.200	1.000
Excellent seeing t_0 (sec)	0.011	0.058
Average seeing r_0 (m)	0.100	0.530
Average seeing t_0 (s)	0.005	0.029

VISIBLE THROUGHPUT

AVERAGE SEEING CASE

Tip/Tilt Aperture (m)	1.000	N.A.
Tip/Tilt Sample Time	0.010	N.A.
Tip/Tilt Bandwidth (nm)	300.000	N.A.
Tip/Tilt DQE	0.800	N.A.
Number of counts required	50.000	N.A.
Fringe Tracking Aperture (m)	0.150	N.A.
Fringe Tracking Sample Time (sec)	0.005	N.A.
Fringe Tracking Bandwidth (nm)	200.000	N.A.
Fringe Tracking DQE	0.800	N.A.
Number of counts required	100.000	N.A.
Adaptive Optics Subaperture (m)	0.100	N.A.
Adaptive Optics Sample Time (sec)	0.005	N.A.
Adaptive Optics Bandwidth (nm)	200.000	N.A.
Adaptive Optics DQE	0.800	N.A.
Number of counts required	50.000	N.A.
Imaging Aperture (m)	1.000	N.A.
Imaging Sample Time (sec)	0.005	N.A.
Imaging Bandwidth (nm)	15.000	N.A.
Imaging Optics DQE	0.150	N.A.
Number of counts required	10.000	N.A.
Infrared Aperture (m)	N.A.	0.795
Infrared Sample Time (sec)	N.A.	0.029
Infrared Bandwidth (nm)	N.A.	1000.000
Infrared DQE	N.A.	0.700
Number of Counts required	N.A.	20.000
<u>No Adaptive Optics</u>		
Tip/Tilt Magnitude Limit	13.293	N.A.
Fringe Tracking Magnitude Limit	7.708	N.A.
Imaging Magnitude Limit	8.376	N.A.
Infrared Magnitude Limit	N.A.	13.714
No A.O. Magnitude Limit	7.708	13.714
<u>With Adaptive Optics</u>		
Adaptive Optics Magnitude Limit	9.440	N.A.
Tip/Tilt Magnitude Limit	12.462	N.A.
Fringe Tracking Magnitude Limit	10.997	N.A.
Imaging Magnitude Limit	7.545	N.A.
Infrared Magnitude Limit	N.A.	13.393
A.O. Magnitude Limit	9.440	13.393

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Guide Star Adaptive Optics

Adaptive Optics Magnitude Limit	17.000	N.A.
Tip/Tilt Magnitude Limit	13.293	N.A.
Fringe Tracking Magnitude Limit	11.827	N.A.
Imaging Magnitude Limit	8.376	N.A.
Infrared Magnitude Limit	N.A.	14.212

Guide Star Magnitude Limit	11.827	14.212
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EXCELLENT SEEING CASE

Tip/Tilt Aperture (m)	1.000	N.A.
Tip/Tilt Sample Time	0.022	N.A.
Tip/Tilt Bandwidth (nm)	300.000	N.A.
Tip/Tilt DQE	0.800	N.A.
Number of counts required	50.000	N.A.
Fringe Tracking Aperture (m)	0.300	N.A.
Fringe Tracking Sample Time (sec)	0.011	N.A.
Fringe Tracking Bandwidth (nm)	200.000	N.A.
Fringe Tracking DQE	0.800	N.A.
Number of counts required	100.000	N.A.
Adaptive Optics Subaperture (m)	0.200	N.A.
Adaptive Optics Sample Time (sec)	0.011	N.A.
Adaptive Optics Bandwidth (nm)	200.000	N.A.
Adaptive Optics DQE	0.800	N.A.
Number of counts required	50.000	N.A.
Imaging Aperture (m)	1.000	N.A.
Imaging Sample Time (sec)	0.011	N.A.
Imaging Bandwidth (nm)	15.000	N.A.
Imaging Optics DQE	0.150	N.A.
Number of counts required	10.000	N.A.
Infrared Aperture (m)	N.A.	1.000
Infrared Sample Time (sec)	N.A.	0.058
Infrared Bandwidth (nm)	N.A.	1000.000
Infrared DQE	N.A.	0.700
Number of Counts required	N.A.	20.000

No Adaptive Optics

Tip/Tilt Magnitude Limit	14.149	N.A.
Fringe Tracking Magnitude Limit	10.069	N.A.
Imaging Magnitude Limit	9.232	N.A.
Infrared Magnitude Limit	N.A.	14.965

No A.O. Magnitude Limit	10.069	14.965
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VISIBLE THROUGHPUT

With Adaptive Optics

Adaptive Optics Magnitude Limit	11.801	N.A.
Tip/Tilt Magnitude Limit	13.318	N.A.
Fringe Tracking Magnitude Limit	11.853	N.A.
Imaging Magnitude Limit	8.401	N.A.
Infrared Magnitude Limit	N.A.	14.146
A.O. Magnitude Limit	11.801	14.146

Guide Star Adaptive Optics

Adaptive Optics Magnitude Limit	17.000	N.A.
Tip/Tilt Magnitude Limit	14.149	N.A.
Fringe Tracking Magnitude Limit	12.683	N.A.
Imaging Magnitude Limit	9.232	N.A.
Infrared Magnitude Limit	N.A.	14.965
Guide Star Magnitude Limit	12.683	14.965