The Yerkes 40-Inch Objective

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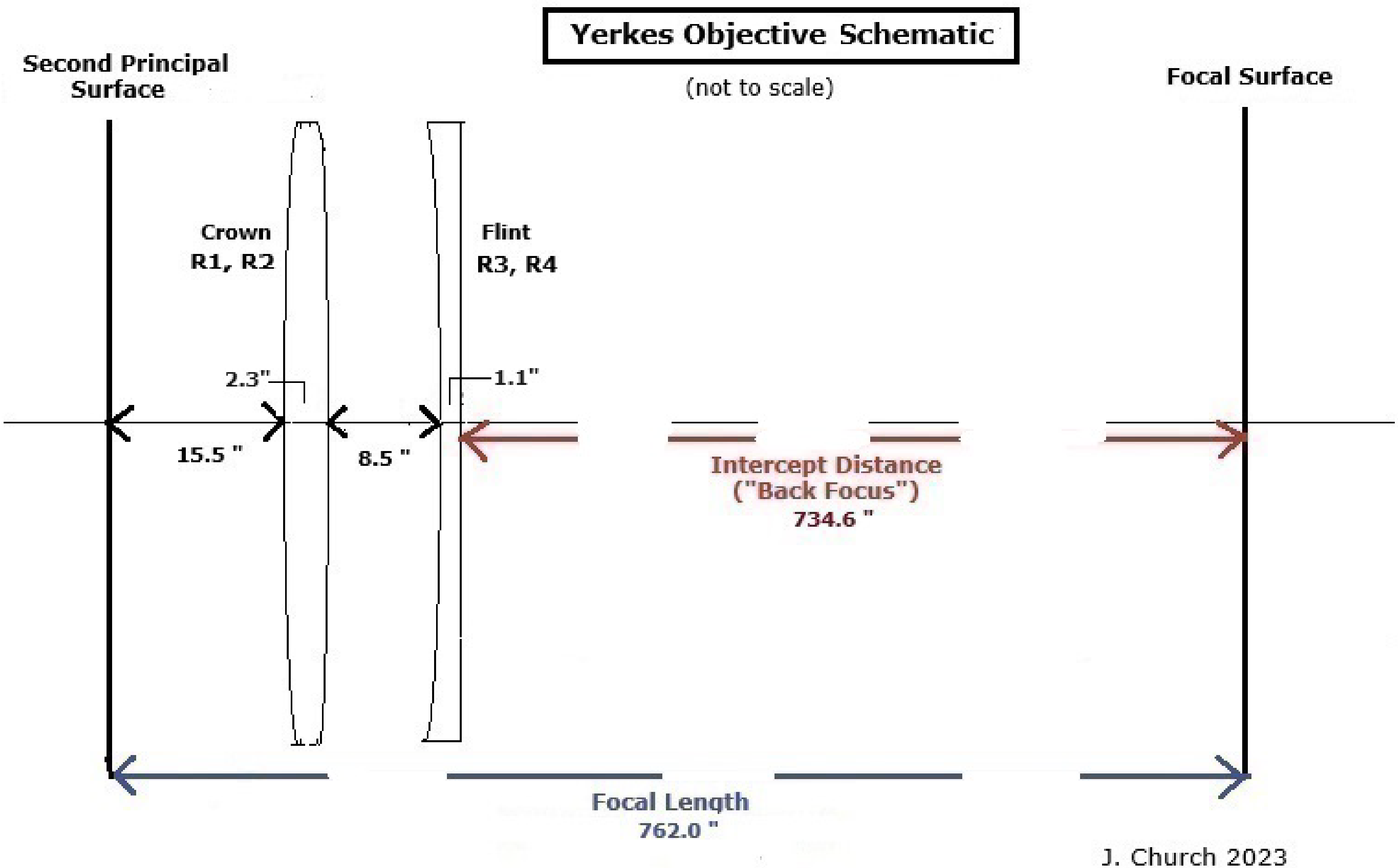
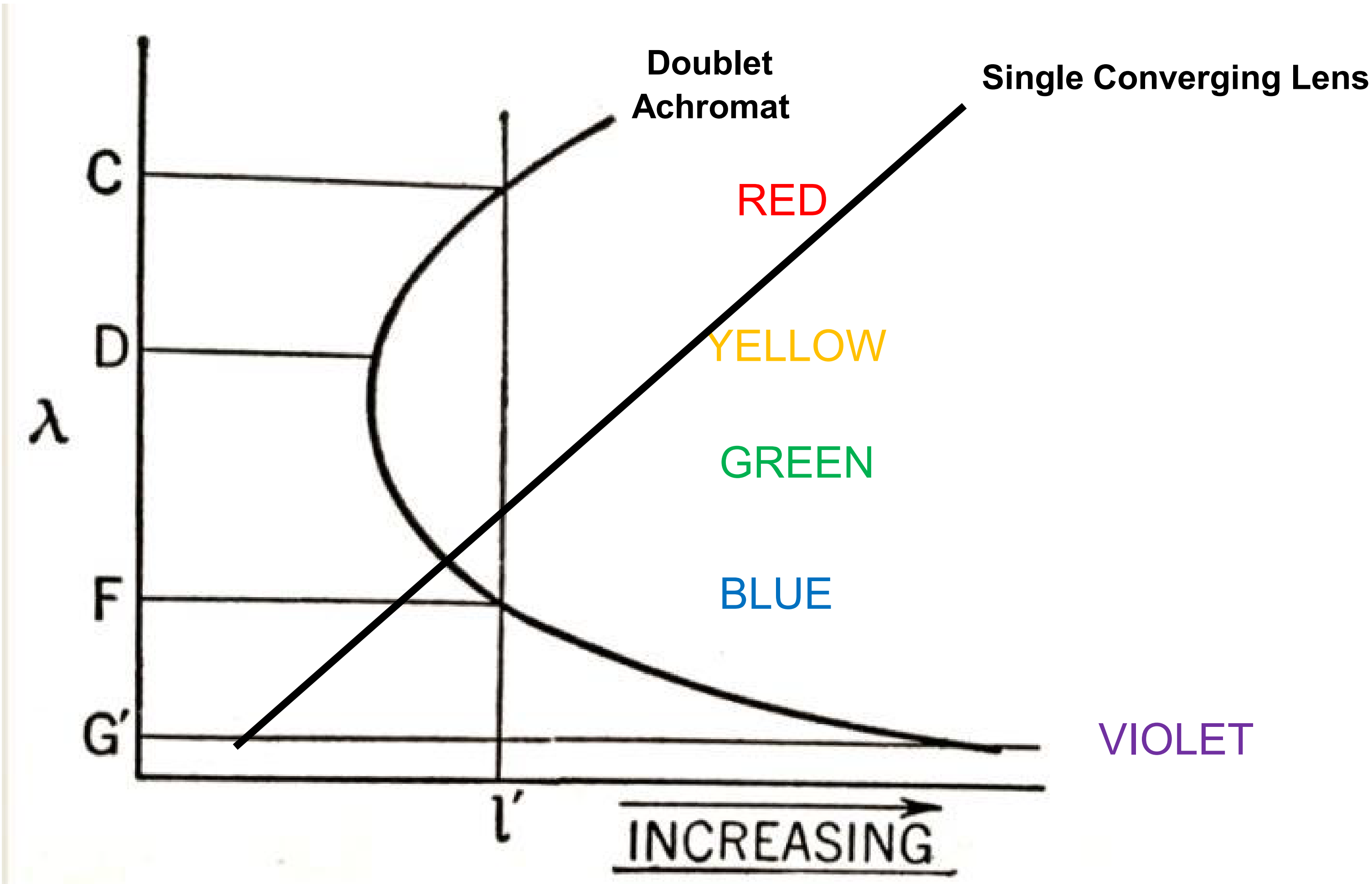

Yerkes Objective Schematic
(not to scale)
Second Principal Surface
Focal Surface
Crown
R1, R2
Flint
R3, R4
2.3"
1.1"
15.5 "
8.5 "
Intercept Distance
("Back Focus")
734.6 "
Focal Length
762.0 "
J. Church 2023

REFRACTOR CONSIDERATIONS

- Aperture and focal ratio
- Color correction (chromatic aberration)
- Spherical aberration
- Coma
- How to mount it, house it, and operate it !

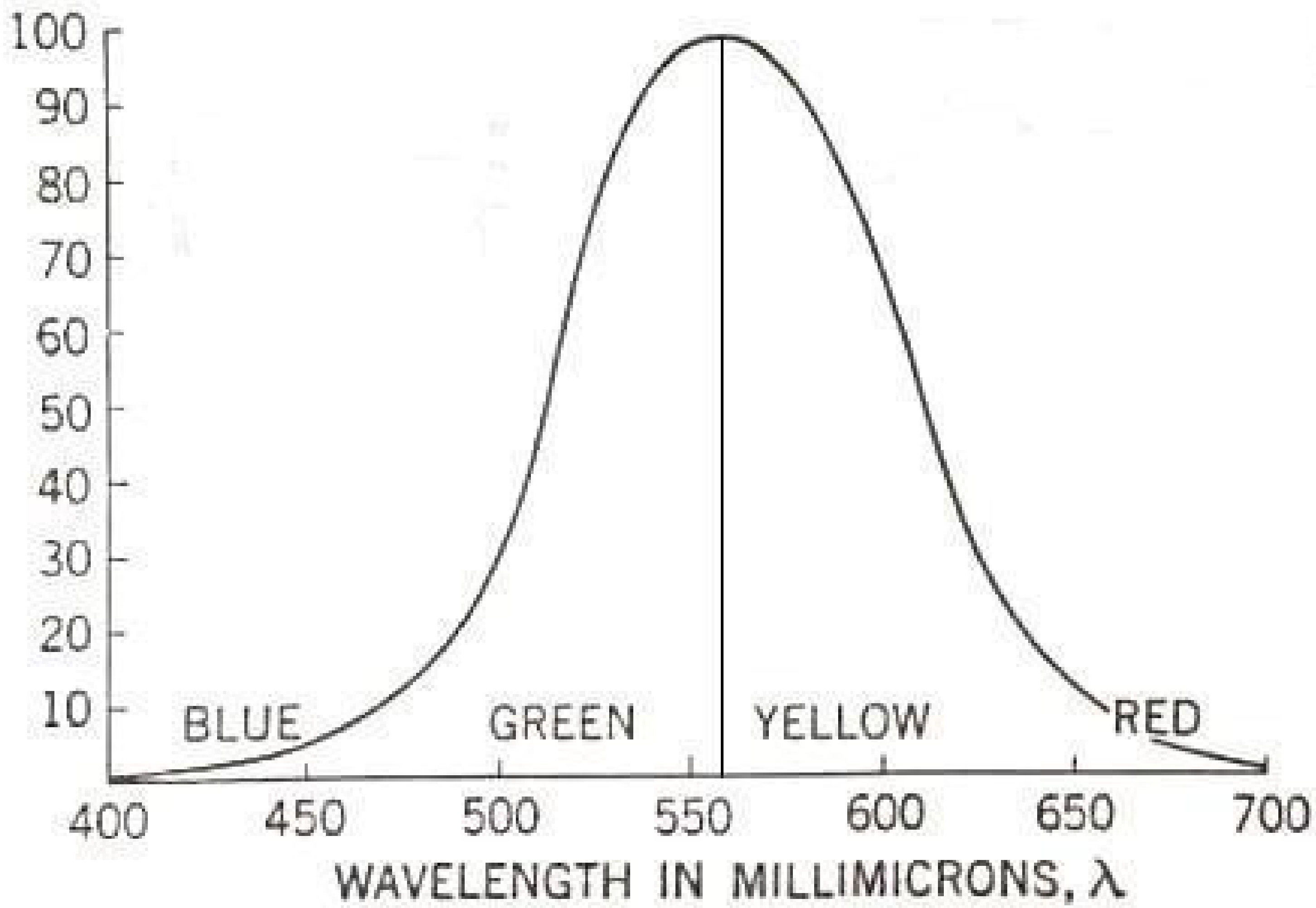
CHROMATIC ABERRATION



Wavelength vs. intercept distance for a doublet achromat corrected for the C and F spectral lines.

[D. Jacobs]

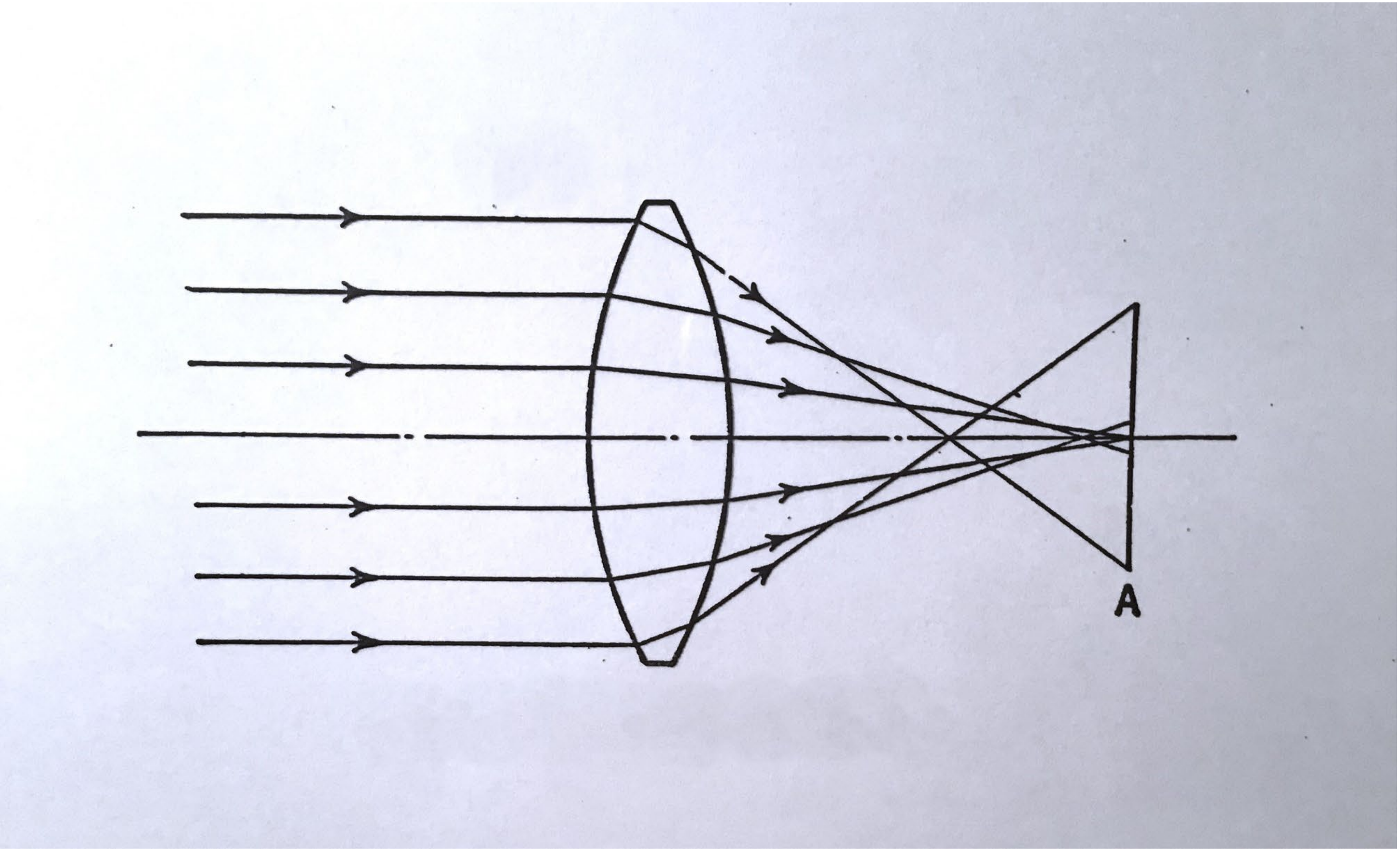
Adapted by J. Church



Relative brightness sensitivity of human eye.

[Adapted from D. Jacobs]

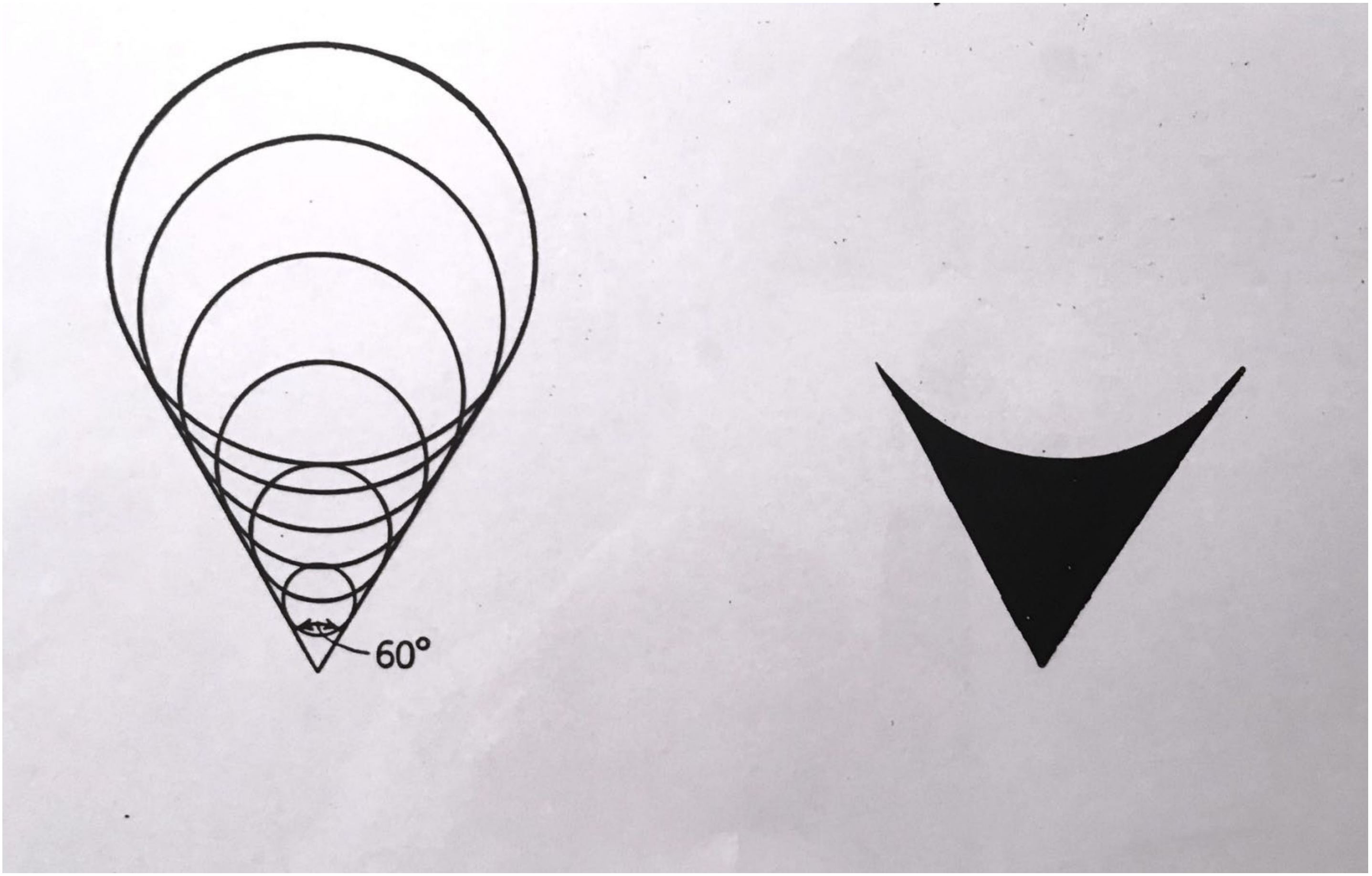
SPHERICAL ABERRATION



[D. Jacobs]

S.A. of one element can be minimized by the reverse effect of the other one.
Drawing shows <u>positive</u> S.A.

COMA



[D.Jacobs]

Coma occurs when different zones of an objective have different off-axis focal lengths. One measure is called "offense against the sine condition" (OSC). This is the ratio of the size of the coma patch to the distance of the patch from the center of the field of view. If coma is present, stars farther from the center of the field will get progressively more "comet-shaped."

Glasses in the Yerkes Objective

Indexes of Refraction (n)

	C	D	F	G’		
Wavelength, A	6563	5893	4861	4341	V - no.	Type
Crown Element	1.513193	1.515797	1.522032	1.527065	58.35	Feil 1219 ?
Flint Element	1.610092	1.614866	1.626824	1.636989	36.75	Feil 1406 ?

Frank E. Ross, *Ap. J.* 76: 187 (1932). Prisms supplied by the Clarks. Types hypothetical.

The V-number is a measure of how much the glass disperses light of different wavelengths. The lower the number, the more dispersive the glass. V # = (nD – 1)/(nF – nC).

Yerkes Radii and Spacings (mm)

"The published data on the 40-inch lens are exceedingly meager." – Ross, 1932

Crown Element		Flint Element					
R1	**R2**	**R3**	**R4**	**t1**	**Air Space**	**t2**	**Notes**
+ 6950	- 6950	- 6754	+ 1,219,000	?	?	?	(1)
+ 6887	- 6887	- 6090	+ 1,209,290	58	215.2	28	(2)
?	?	?	?	63	213	38	(3)
+ 6910	- 6910	- 6504	+ 96,000	58	215.2	28	(4)

(1) C. Lundin, letter to E. Frost 6/28/1907; J. Church, *Sky & Telescope* March 1982, pp. 303, 308. English units converted to metric. R3 wrong due to typographical error (Ross).

(2) Lundin radii recalculated by Ross to give correct FL and color curve. High spherical aberration.

(3) Thicknesses and air space from G. Hale, *Ap. J.* 6:43 (1897). Inches converted to mm. No radii given.

(4) Church, p. 308. These radii would have achieved correct focal length, color curve, and spherical aberration consistent with other evidence. Maintains Ross spacings.

Positive radii are convex to the sky; negative concave. Both crown surfaces are *physically* convex; both flint surfaces are *physically* concave.

Aberrations of the 40-Inch at W.L. 5893 A.

	Spherical Aberration, mm	OSC
Ross calculations	- 49.8	n/a
Recomputed from Ross radii	- 48.9	- 0.0008
With suggested radii	- 4.9	- 0.0006
Observed *	- 4 to - 8	n/a
Tolerance (Rayleigh ¼ wave S.A.)	+/- 3.4 Jacobs**, p. 445	+/- 0.0025 Jacobs**, p. 418

* P. Fox, *Ap.J.* 27:240-1 (1908), Fig. 2.

** "Fundamentals of Optical Engineering" (McGraw-Hill, 1943).

Effects of Changing the Air Space *

Assume suggested radii. Increase air space 1 inch.

Reduces focal length 5.7 inches and image scale 0.75%.

Back focus shortened 8.4 inches.   Major tailpiece work needed.

The next two slides show the effect this would have on spherical aberration and the color curve. No noticeable change in coma.

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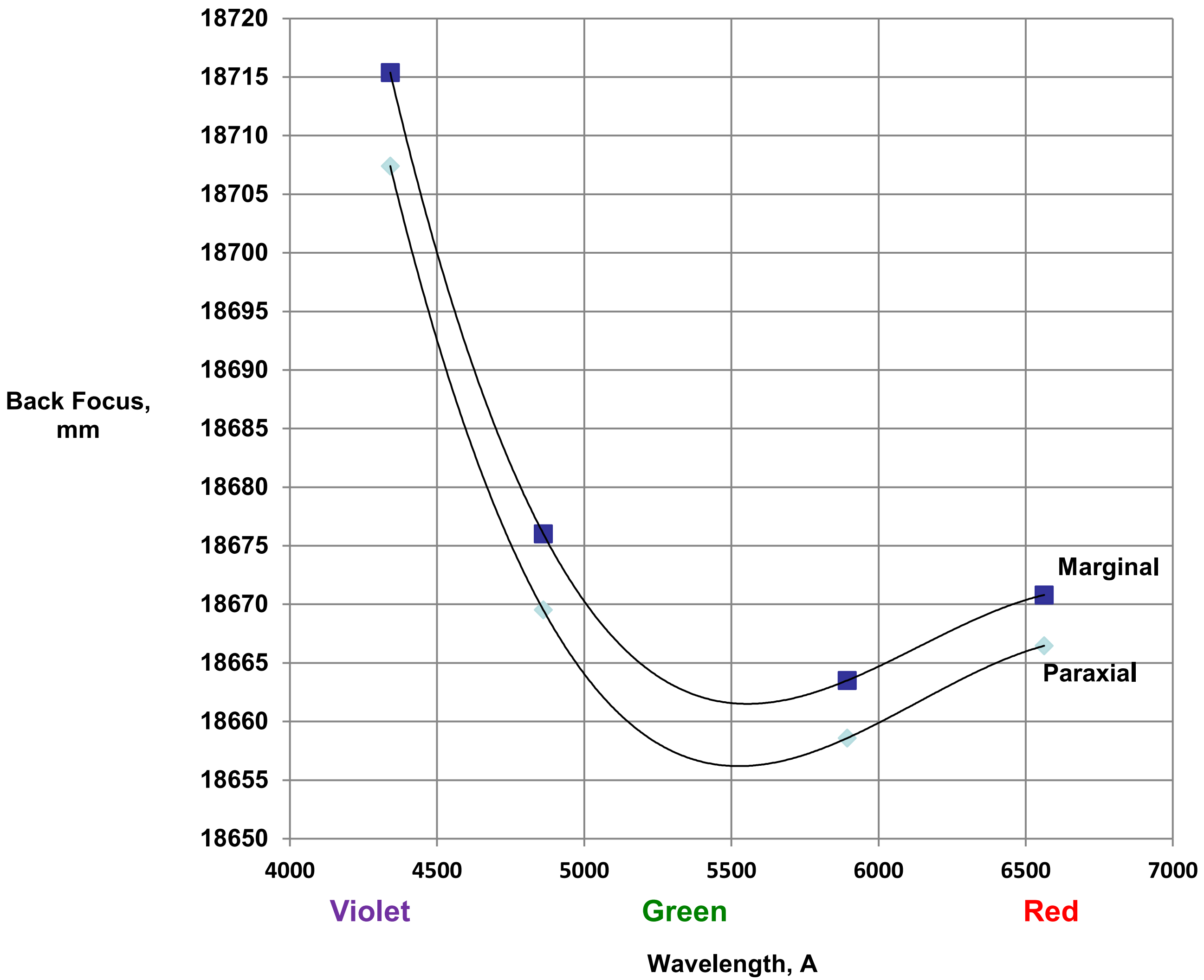
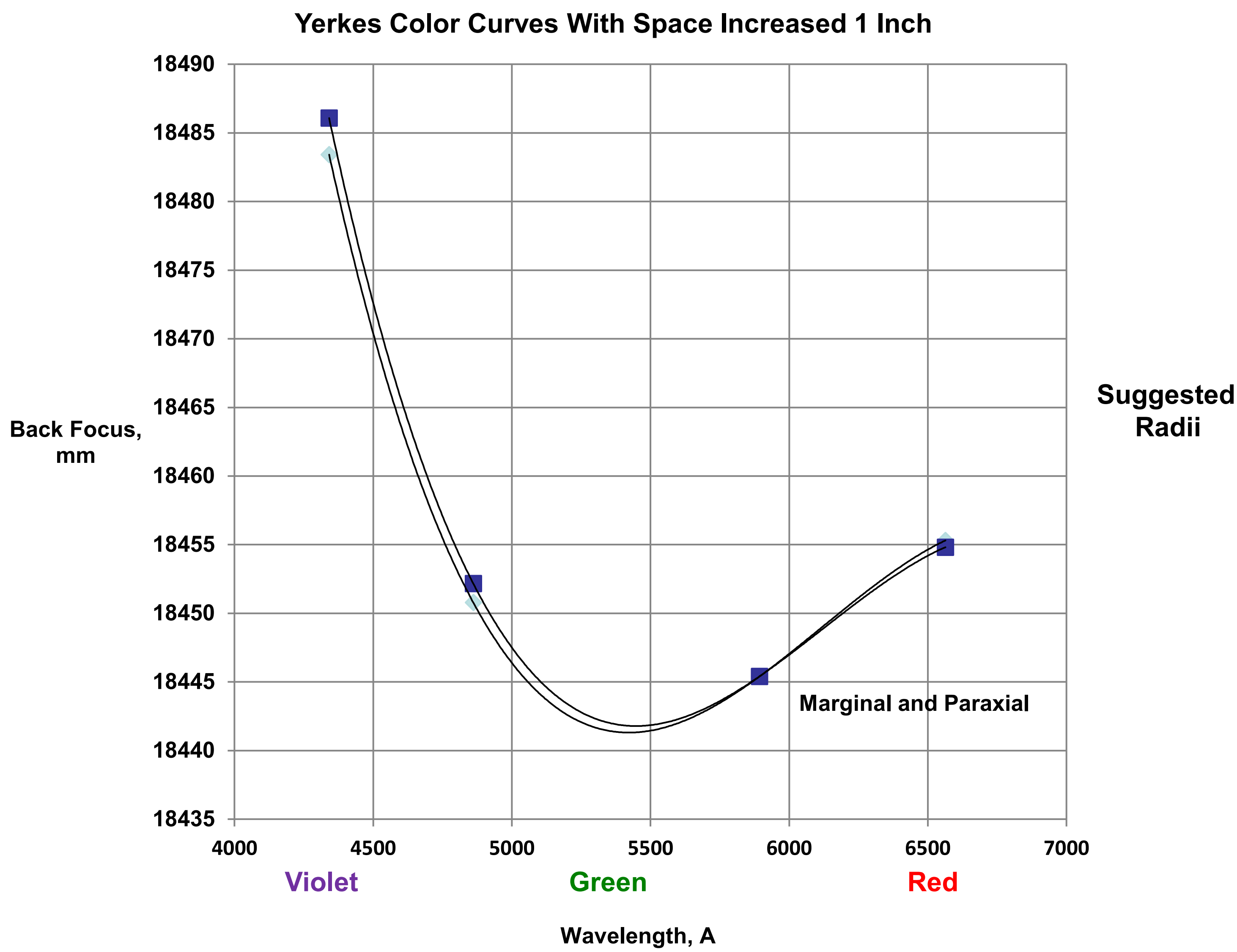
* See Jacobs, *op. cit.*, p. 429 for a general discussion of this subject.

Yerkes Color Curves With Original Space



Suggested Radii

S.A. ~ 6 mm for brightest light



S.A. < 1 mm for brightest light

<u>Evaluating the 40-Inch Refractor</u>

Performed well visually [H. C. King, "The History of the Telescope," 316-18 (Dover edition, 1979)]. Reached theoretical resolving power.

Photographic performance enhanced with corrector lens to flatten the color curve in the blue-violet area (King, Ross).

S.A. may have been reduced by hand-figuring (Ross).

<u>Proposal</u>: Measure R1. Assume R2 = – R1. Find R3 and R4 values that would achieve known color correction, focal length, and S.A.

"It is a pity that some of the large refractors have residual coma. This situation is by no means necessary and is a result of inadequate design." – Baker, *Applied Optics* 2: No. 2, 125 (2/63).

M51 (Yerkes Observatory, 1902)

Clark Refractors at Princeton

- 23-inch Halstead – 1882 to 1960's.
- Transferred to USNO. Shipped to southwest, never used.
- Installed at Roper Mountain Science Center, Greenville, SC, 1980's.
- 9.5-inch, 1877. Tube in dome, lens in storage.
- (?) 4-inch owned by William Peyton. Formerly used at open houses.

For more on the Clarks, see D.J. Warner and R. Ariail, "Alvan Clark & Sons: Artists in Optics" (2nd edition, Willman-Bell, Inc., 1995). Extensive catalog of known Clark telescopes and other instruments.

Refractor Design

- Correcting spherical aberration and coma
  - Clairaut and d'Alembert ,1760's *
  - Four different surface radii
  - Fraunhofer, 1820's
  - Our 6-1/4 inch Hastings objective

- Alvan Clark Company
  - Equiconvex crown elements
  - Gauss objective to correct SA for two colors (Young, Princeton)
  - Local correction
  - Optimize central performance

- Achromatization
  - Minimum focus 5500 A. for visual use
  - Better glasses now available for smaller refractors

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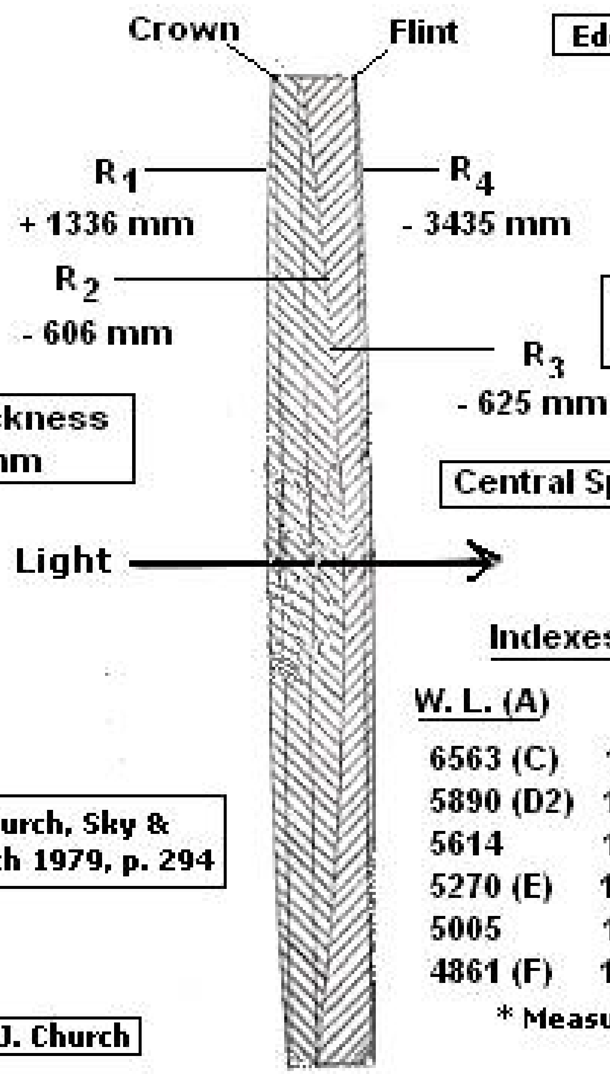
* J. Church, *Sky & Telescope* September 1983, p. 259; November 1984, p. 450.

The Hastings 6-1/4 inch objective
in its cell and tube by John Byrne

(1879-80)

The Hastings 6-1/4 Inch Objective

Edge spacers omitted



Flint Thickness
4.82 mm

Crown Thickness
11.97 mm

Central Spacing 0.02 mm

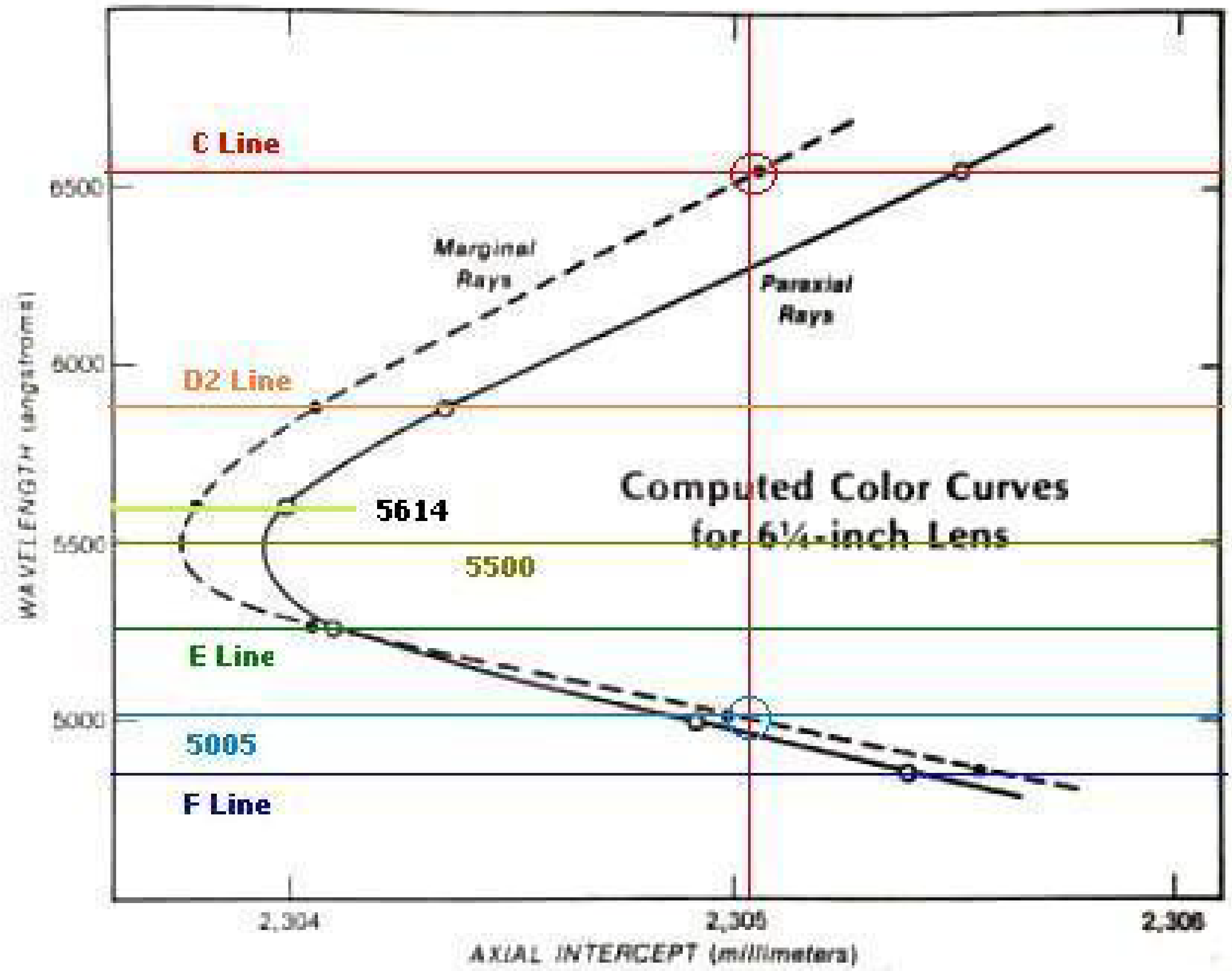
Indexes of Refraction *

W. L. (A)	Crown	Flint
6563 (C)	1.512580	1.609041
5890 (D2)	1.515288	1.613843
5614	1.516673	1.616333
5270 (E)	1.518719	1.620103
5005	1.520564	1.623604
4861 (F)	1.521696	1.625751

* Measured by Hastings

Details: J. Church, Sky & Telescope, March 1979, p. 294

Rendering: J. Church



March 1979 article, showing chromatic aberration corrected for marginal rays at the C Line and 5005 A as per Hastings.

OSC = - 0.00010 (5614)

Sky & Telescope **March 1979, p. 299. Annotations: J. Church.**

J. Church 2001

Galileo’s Tomb, Santa Croce, Florence