Vesto Slipher and the Development of Nebular Spectrographs

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A TECHNICAL DISCUSSION OF EXACTLY WHAT VESTO SLIPHER DID TO MAKE HIS REVOLUTIONARY OBSERVATIONS

- Highlights of early spectroscopy (including those of Edw. Fath)
- What optical parameters make a good nebular spectrograph?
- What did Vesto Slipher do better than other astronomers?
- How did the Humason / Hubble team push to fainter galaxies?

<u>THE SPECTROGRAPH CAMERA f/RATIO IS CRUCIAL</u>

f/15 lenses : easy ! !

f/3 lenses: pretty hard to get

f/0.59 lenses: nearly impossible ! !

Early HIGH SURFACE BRIGHTNESS Spectroscopy:
[for this you only need f/15 lenses]

- Lab, Solar & Stellar spectroscopy was developed quickly by Bunsen, Kirchoff, Secchi, Angstrom, Vogel, Lewis Rutherfurd, Sir William Huggins.

- The early spectrographs required simple optics: high surface brightness sources are easy to re-image including flame spectra, sparks, Sun, stars.

- The spectrum of the first nebula was detected visually in 1864 by Huggins: a planetary nebula with an emission line spectrum. But, planetary nebulae are high surface brightness at their emission wavelengths.

Spectroscopy of LOW SURFACE BRIGHTNESS Spirals
[for this you need f/3 or f/2 optics]

- Early workers with stellar spectrographs reported spirals to have "continuous" spectra, but of course it was a low surface brightness absorption line composite of the constituent stars.

- Detection required faster optics and good photographic emulsions:

  - Spectrograph camera needed to be f/3 or f/2

  - "Wet collodian" process was used in 1860's but the "gelatine dry plate process" was introduced in 1875

Who were the Pioneers of Sprial Nebula Spectroscopy?

- Sir William Huggins: M31 but doubted his own results
- Julius Scheiner, 1899 Potsdam Astrophysical Observ.
- Dr. Edward A. Fath, 1909 Lick Ph.D. & MW 1910-1913
- Prof. Maximilian Wolf of the University of Heidellberg

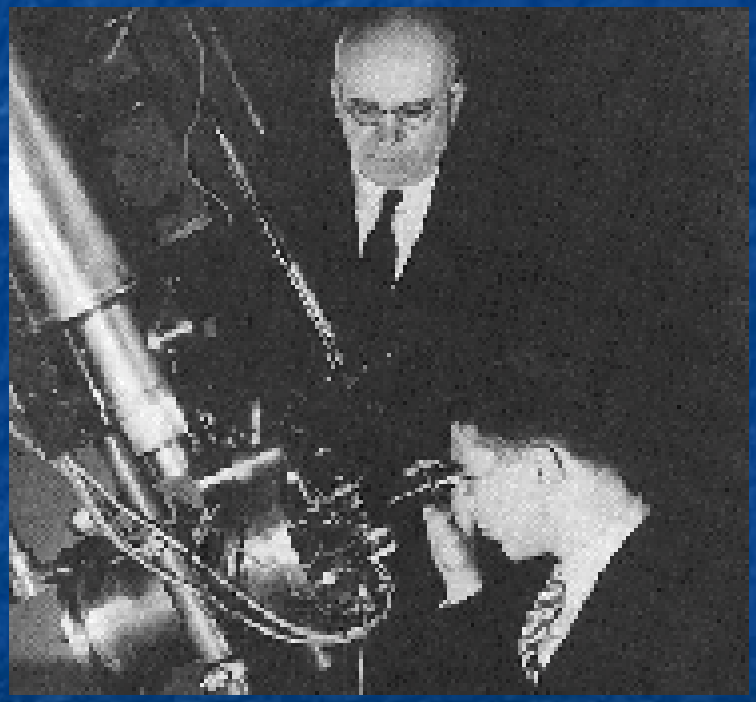
- All of these astronomers detected the spectra of spirals and saw their absorption lines.

- Edward Fath was, by far, the most important contributor/competitor. He tested fast camera lenses, and by the time Vesto Slipher had detected M31, Fath had detected absorption (and emission) lines in Andromeda and 10 other spiral galaxies & had published his work in 3 papers in the Astrophysical Journal.

Prof. Edward Fath received his Ph.D. at Lick Observatory in 1909. He worked 3 years at Mt. Wilson and then moved first to Beloit College in Wisconsin and then to Carleton College in Minnesota.

Fath detected absorption lines in the spectrum of Andromeda, numerous globular clusters, and the following spiral galaxies:

NGC 650-651
NGC 1023
NGC 1068
NGC 3031
NGC 4594
NGC 4725
NGC 4736
NGC 4821
NGC 5194
NGC 7331



Fath acknowledged the support of Director Campbell for Resources and helpful interest in the work.

August 29 – September 3, 1910
4th Conference of the International Union for Cooperation in Solar Research, Mt. Wilson, California

Left to right:
Mr. McBride,
Frank Brasket,
Jacobus Kapteyn,
Edwin Frost,
Karl Schwarzschild,
Vesto M. Slipher

Credit: U. Chicago Library

What ideas did Slipher and Fath exchange?

- Slipher traveled to MWO in 1910 for a meeting, talked directly with Fath about nebular spectroscopy, and began a 3 year correspondence with him.

- Their correspondence is available in the Lowell Obs. archives. Lauren Amundsen, Lowell Observatory Librarian provided copies of 10 such letters.

- Slipher wanted to know: How does the exposure time change when observing with the Lick 36-inch Crossley reflector as compared with the MWO 60-inch?

- Slipher eventually told Fath on Feb. 8, 1911 that the telescope diameter and telescope f/ratio do not matter but that the spectrograph camera f/ratio is all-important.

What did Vesto Slipher do that made his work better?

- Slipher identified the key factors:
  - Telescope aperture and f/ratio do not matter all that much in nebular spectroscopy
  - Spectral dispersion does not matter IF the spectrograph slit is adjusted accordingly
  - THE CAMERA f/RATIO increases the signal level above the "threshold of detection"
- Vesto Slipher was a VERY CAREFUL experimentalist
  - Temperature stabilized his spectrograph
  - Measured radial velocity standard stars
  - Sensitized his photographic emulsions
  - Applied lab reference arc spectra often (using Leyden jar capacitors)
  - Repeated his detections

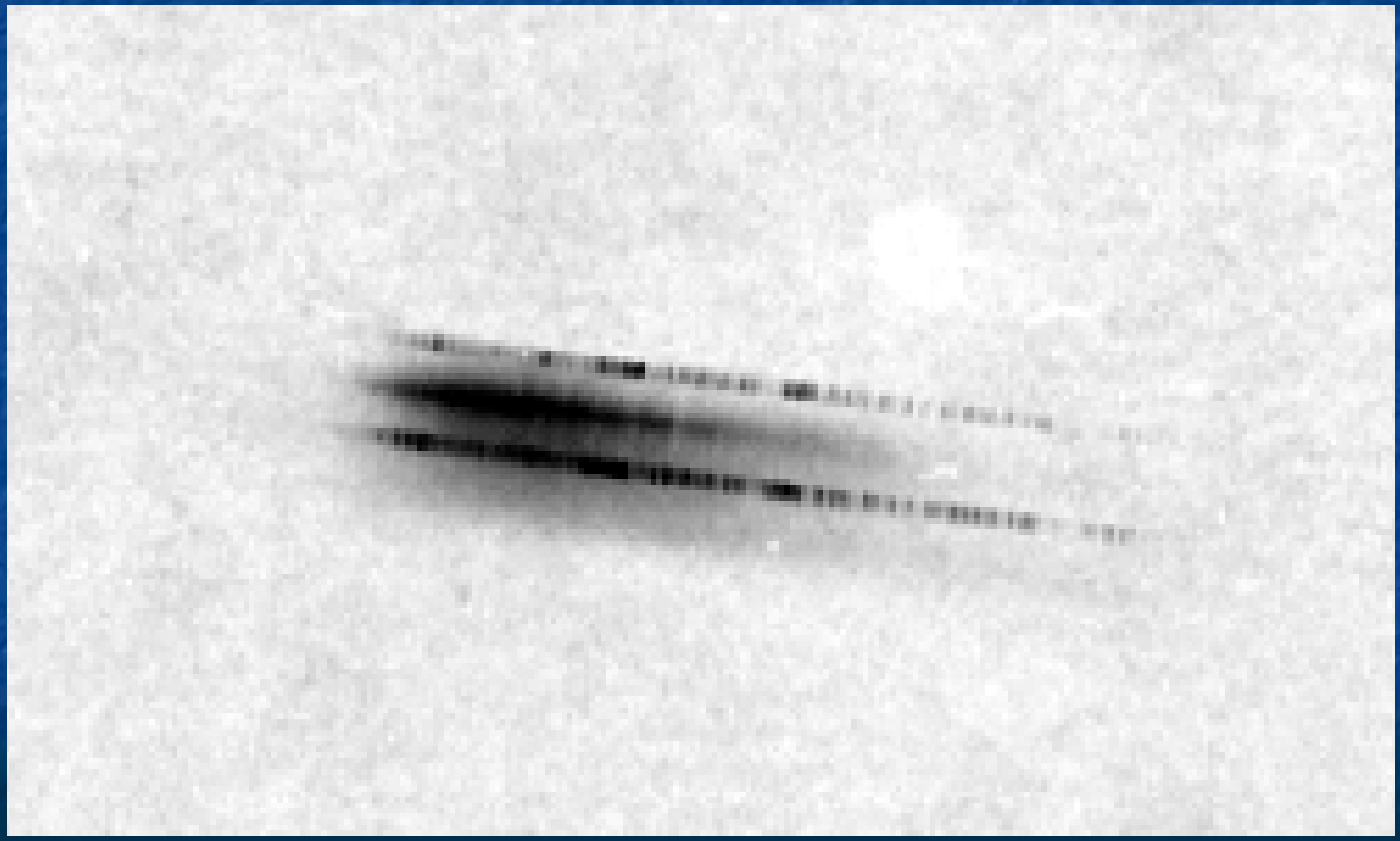
Key Nebular Spectrograph Parameters

Vesto Slipher states verbally these conclusions in his papers both in 1915 and 1917. Ira Bowen (1952) was the first to algebraically derive and publish this result:

"speed" = energy / cm^2 per second at the detector

$$\text{"speed"} = \frac{\text{surface brightness} \times \text{slit width} \times \text{dispersion}}{(\text{spectrograph camera f/ratio})^2}$$

Slipher's best spectrum of Andromeda



Spectrograph Camera Development:

- Fath (1909) started with f/3 and by 1911 had changed to a camera with f/2 (under VM Slipher's influence).

- Slipher (1906) started with the Brashear spectrograph camera at f/14.2 and went to a commercial Voightlander f/2.5 camera lens for all of his historic work.

- Humason began his work in ~1928 with an f/1.43 spectrograph camera lens, but it produced poor images. Soon the Mt. Wilson/Palomar observatory developed the f/0.59 Rayton lens for him to use for his best work.

Mt. Wilson & Palomar's Rayton Camera Lens

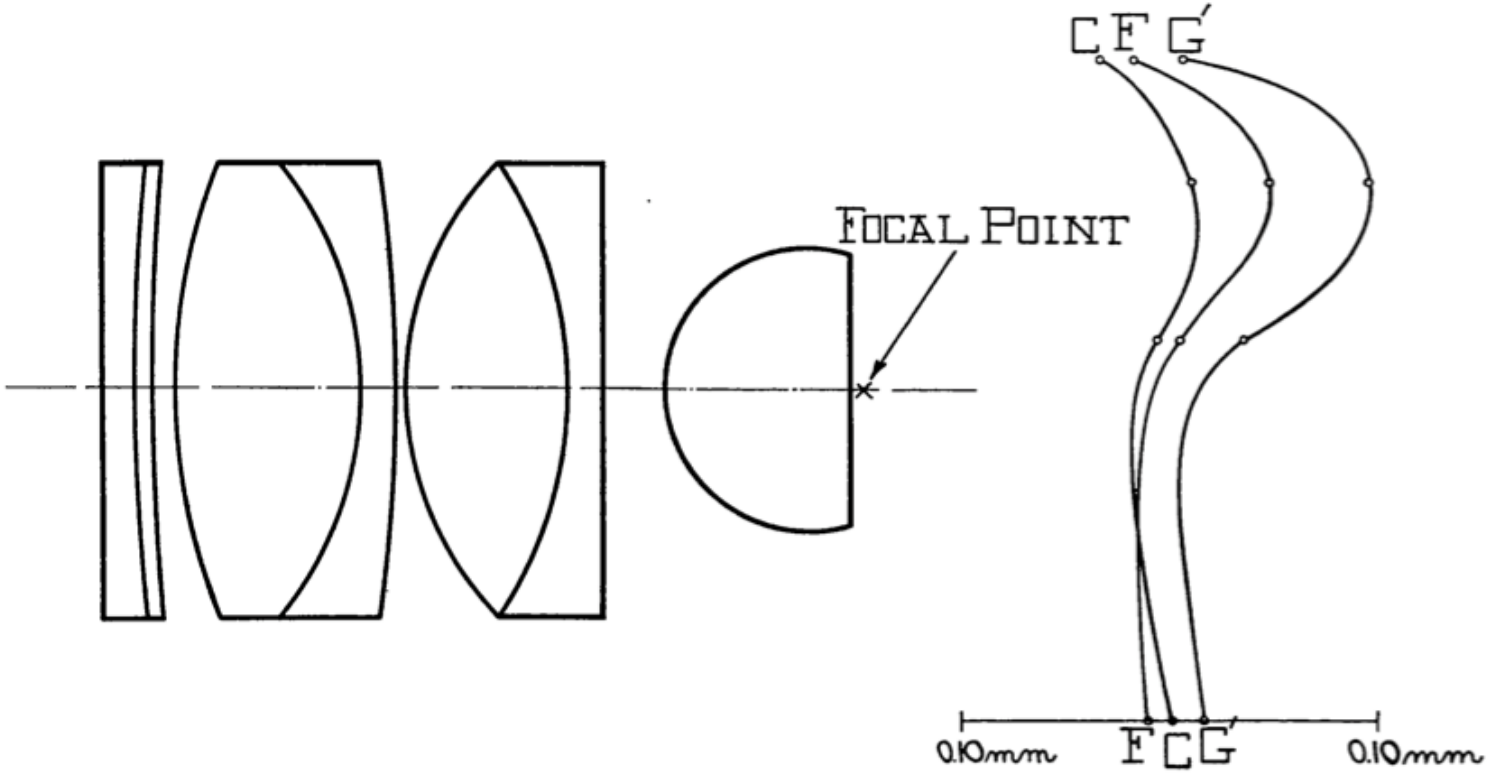
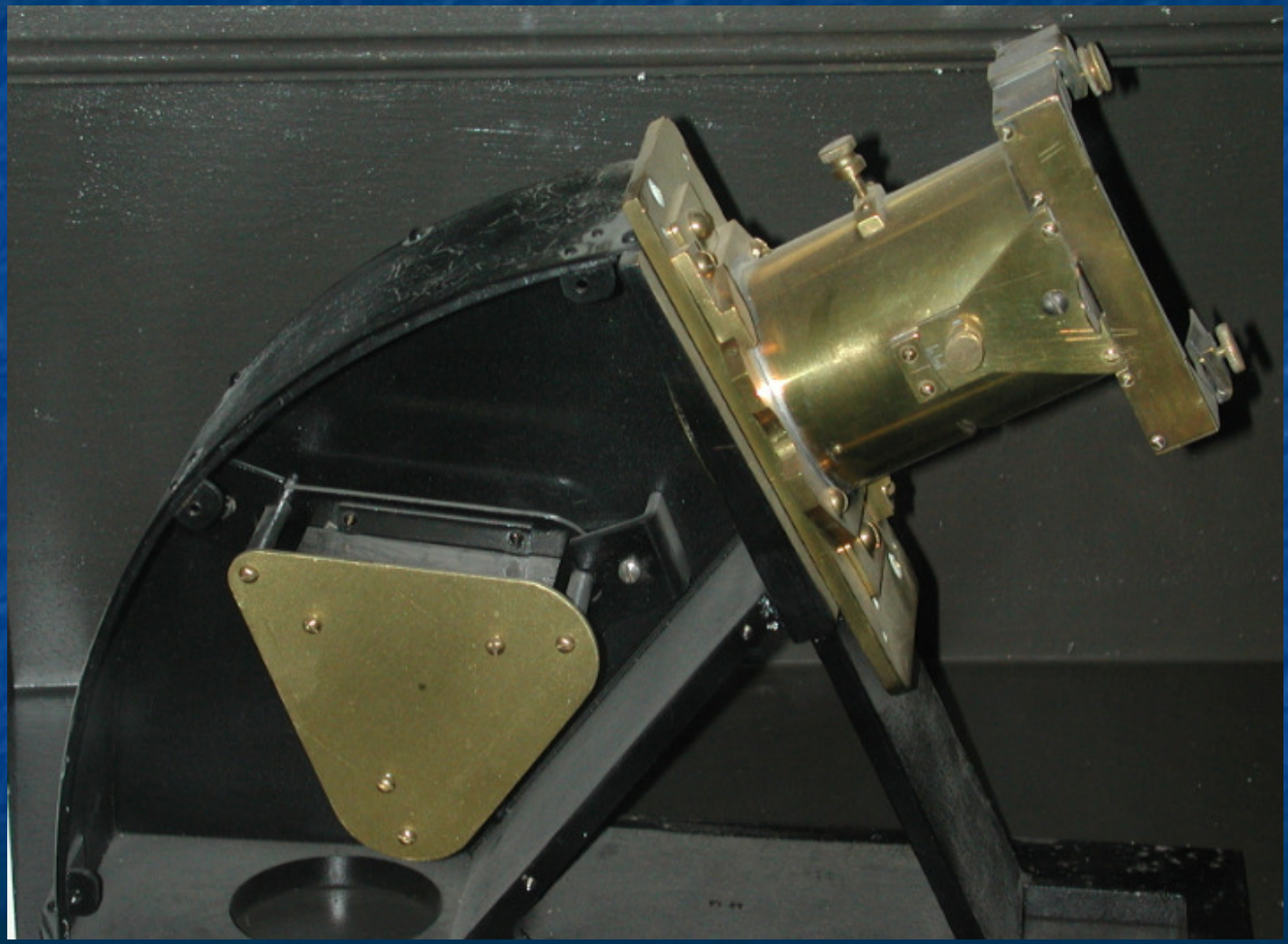
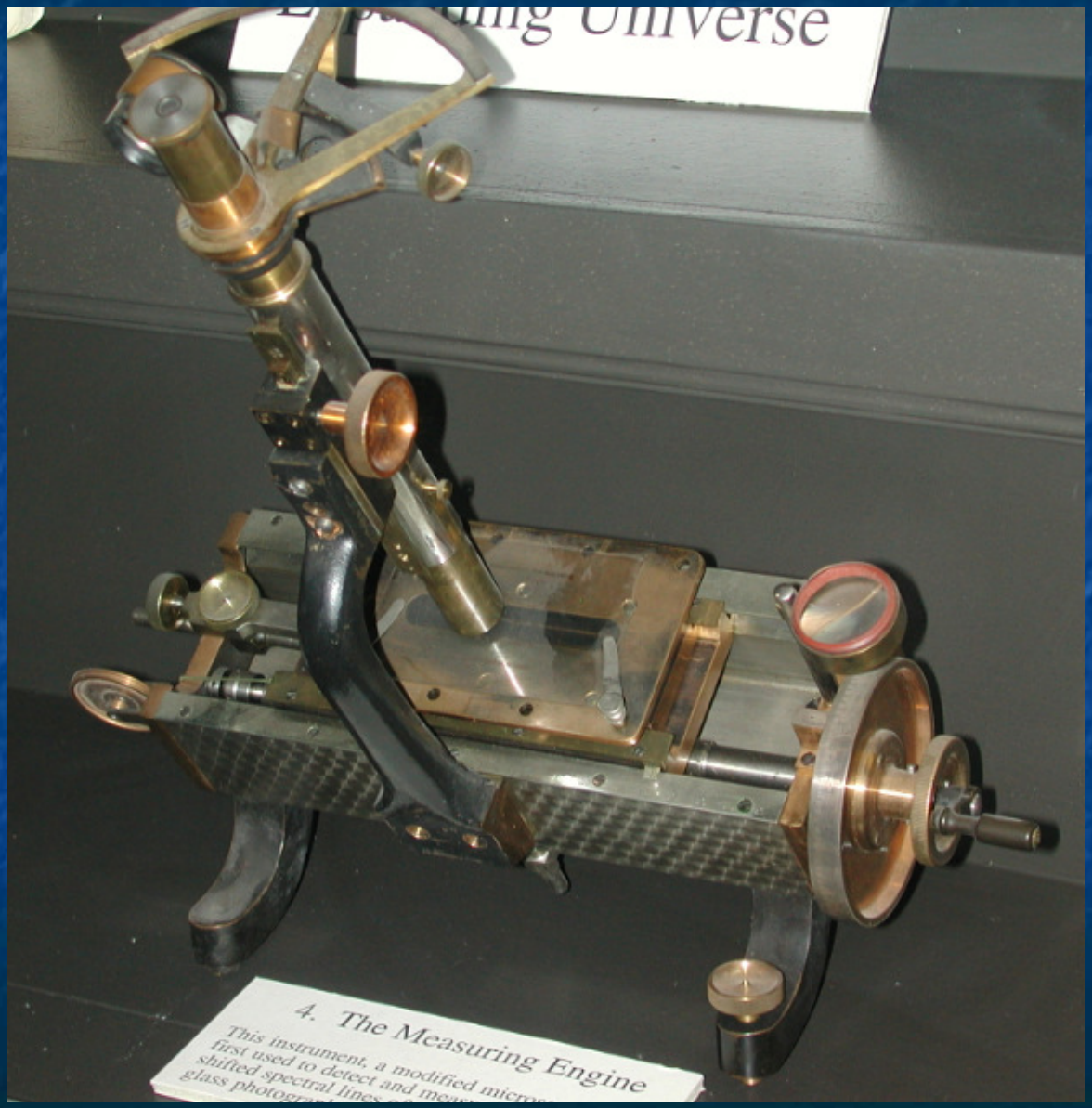


FIG. 2.—Camera objective $f=32$ mm, $f/a=0.59$, after design of 4-mm microscope objective.

Slipher's prism+camera attachment for the Brashear Spectrograph



Lowell Dual-Plate Spectro-Comparitor



The following three slides show the spectrograph used by Milton L. Humason at the Mt. Wilson Observatory to collect galaxy spectra in the period 1928 – 1936.

"Trombone-shaped" optical mount for the Mt. Wilson 100-inch nebular spectrograph.

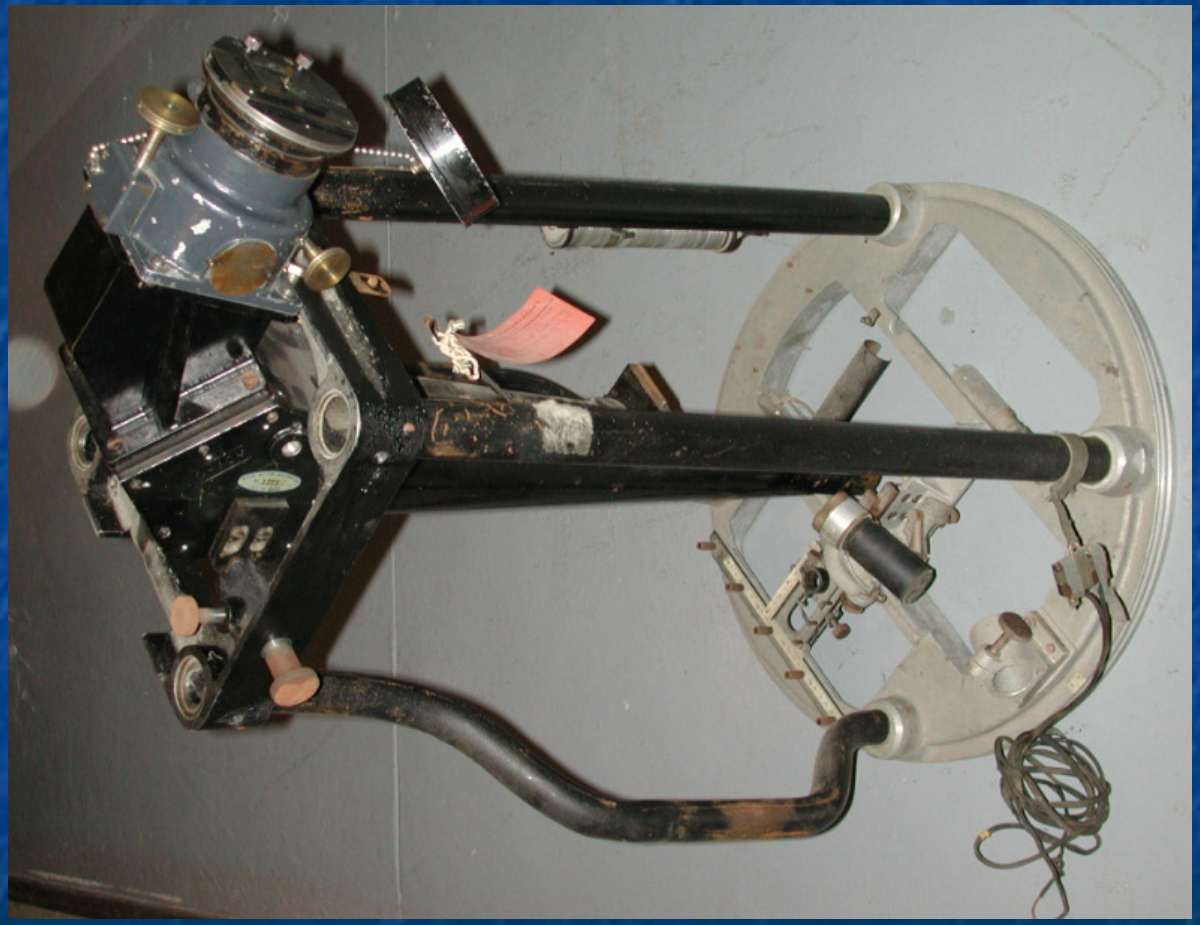
In the next slide, this optical mount sits in its "instrument cage" ready to be placed on the telescope.

A long focal length collimator lens sits at the narrow end at the bottom of the picture, the prism is mounted in the white curved central section, and at the top right is the spectrograph camera lens and the photographic plate holder.

A 1 foot wooden ruler is shown for scale.

Mt. Wilson 100-inch nebular spectrograph on its mounting frame

Light enters the spectrograph from the right, and the large round disk on the right mounts to the telescope.



The pink tag says "Jan 20, 1936. Please do not take any of the optical parts of this spectrograph. M.L.H." (Milton L. Humason)

Plate Holder for the 100-inch Nebular Spectrograph

END OF PRESENTATION

Origins of the Expanding Universe
Flagstaff, Arizona
September 15, 2012

From: "Kodak Plates and Films for Science and Industry" ca. 1962

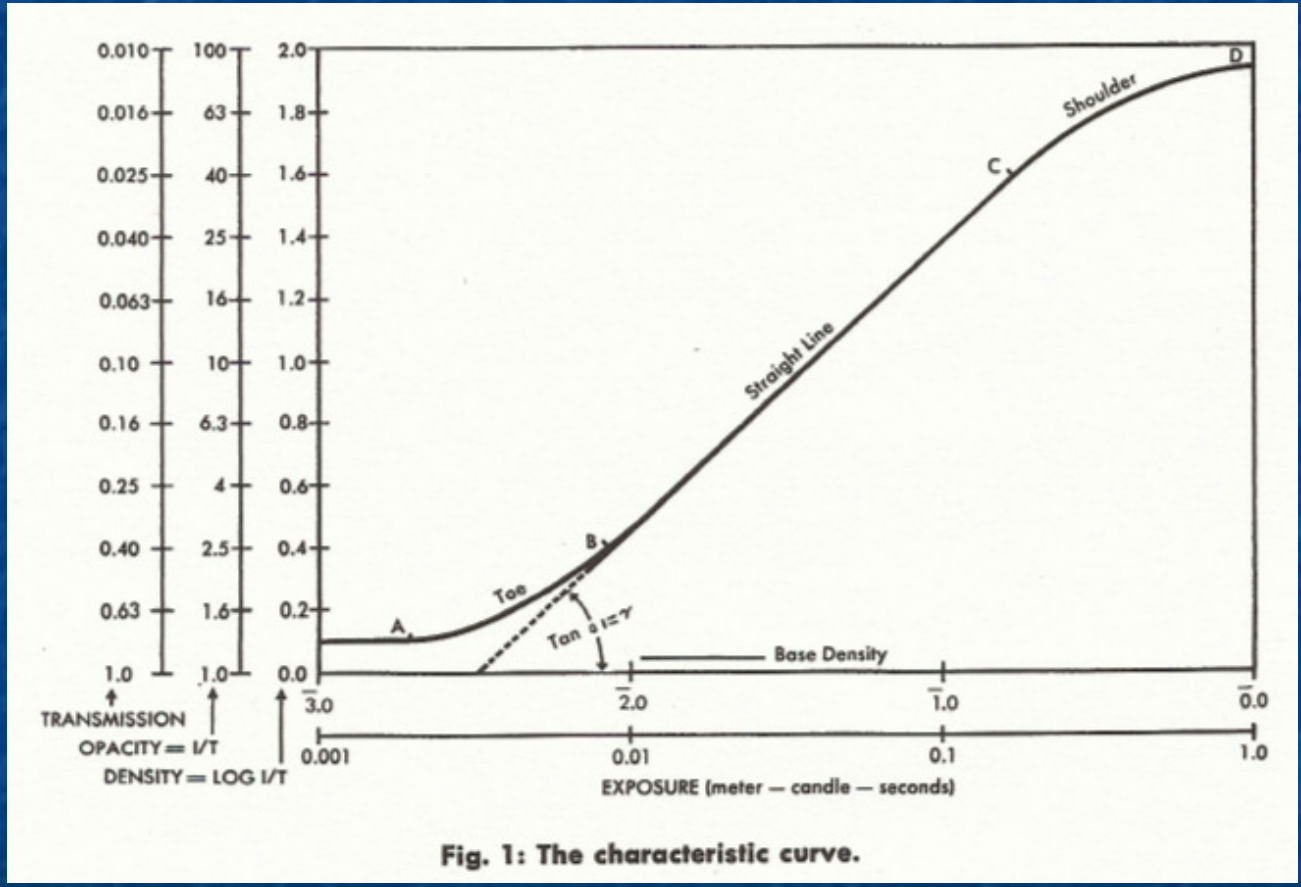


Fig. 1: The characteristic curve.