



***Stars, Companions, and their Interactions  
A Memorial to Robert H. Koch***

***August 10-12, 2011 Villanova, PA USA***

# **The Pennsylvania Polarimeters**

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# Abstract

- This report describes the inception, development and extensive use (over 30 years) of elliptical polarimeters at the University of Pennsylvania.
- The late 60's Mark I polarimeter design utilized oriented quarter wave plates and a calcite Foster-Clarke prism as the analyzer.
- Successive generations of automation and improvements included the late-70's optical redesign to utilize a photoelastic modulated wave plate and an Ithaco lock-in amplifier – the PEMP.
- The final design in 2000 concluded with a remotely operable device.
- Extensive studies of close binaries, pulsating hot stars, and luminous late-type variables.



28-in Cassegrain dome at  
Flower & Cook Observatory

'67 U.P.  
Astro 504



# 1. The Elliptical Polarimeter Origins

- The polarimeter began in 1967 as a term-paper design by George Wolf for Bill Blitzstein's AST 504 Astronomical Instrumentation class.
- Blitzstein then spoke with Brad Wood about the possibility of building the instrument.



Bill Blitzstein

'67 U.P.  
Astro 504

1

2

3

4

5

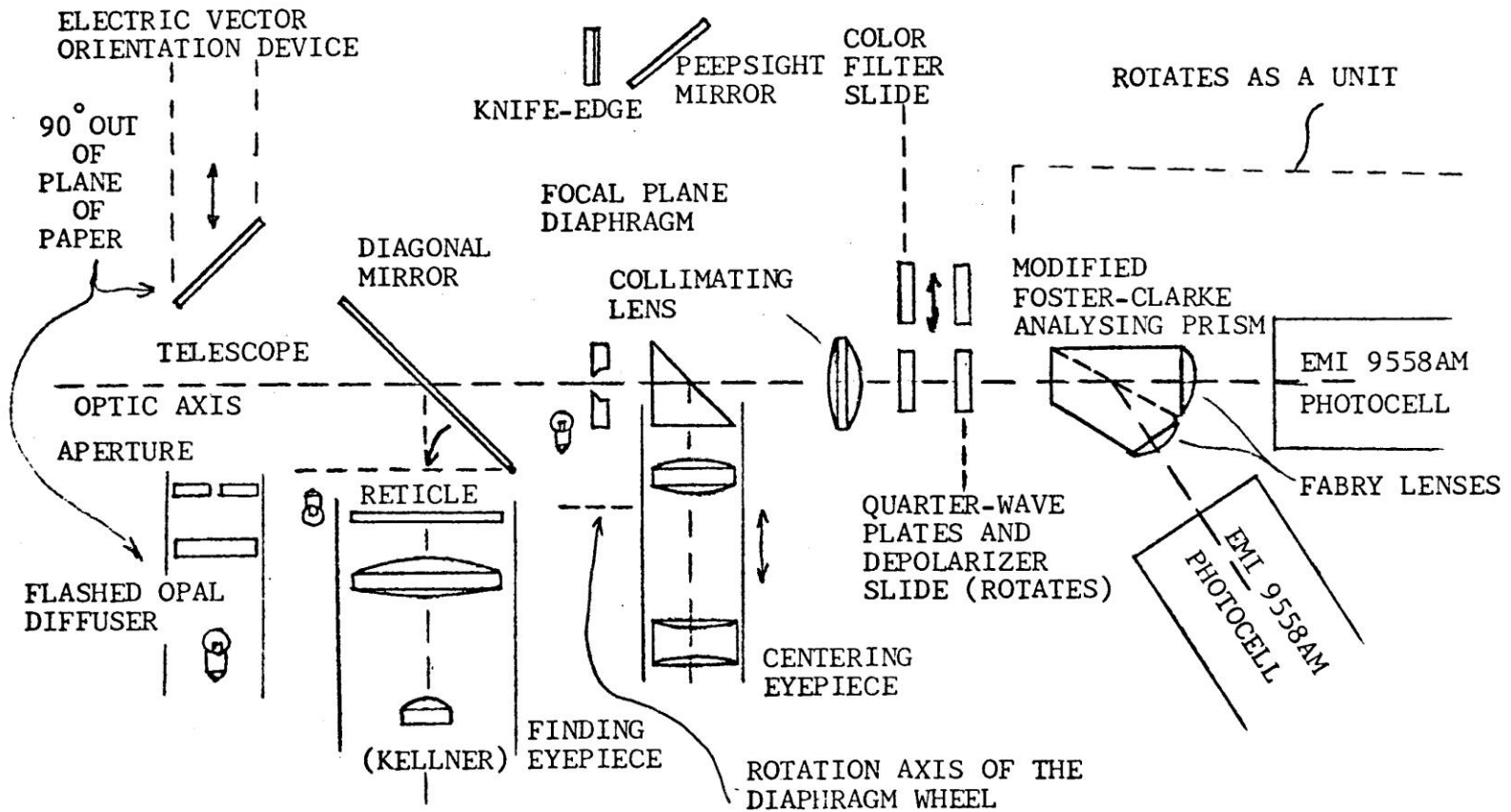
# 1. The Elliptical Polarimeter Origins (cont.)

- Wood offered Wolf the remaining funds in an expiring NSF grant to purchase all of the optics.
- All optics were quickly purchased. Then the rest of the mechanical and electronic design was put together by Blitzstein and Wolf.
- In 1968-69 Bill Barrie did the machine work, and Bob Smith did the electronics to complete the instrument construction.

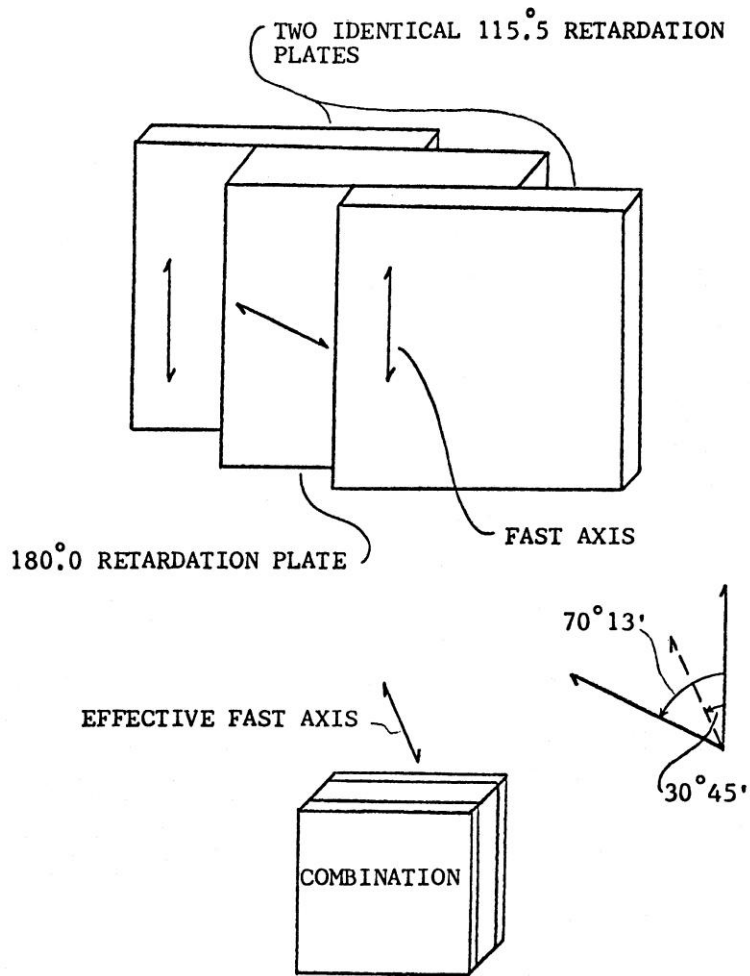


F. B. Wood

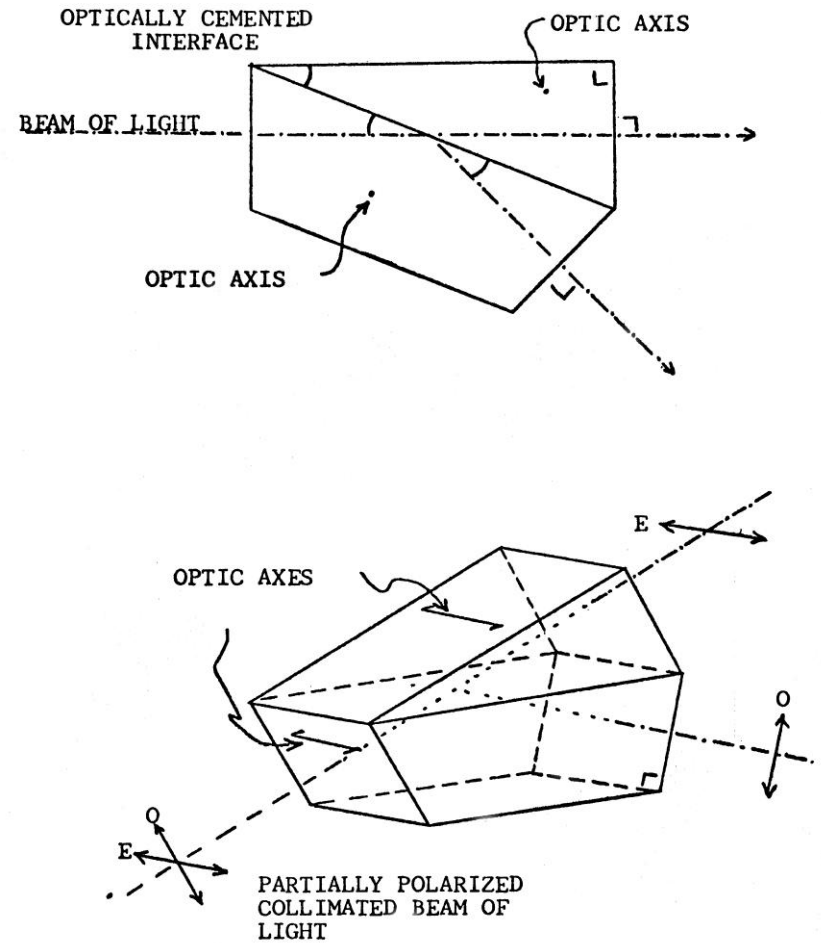
# Optical Components of the Mark I Polarimeter



# Special Optical Component Details

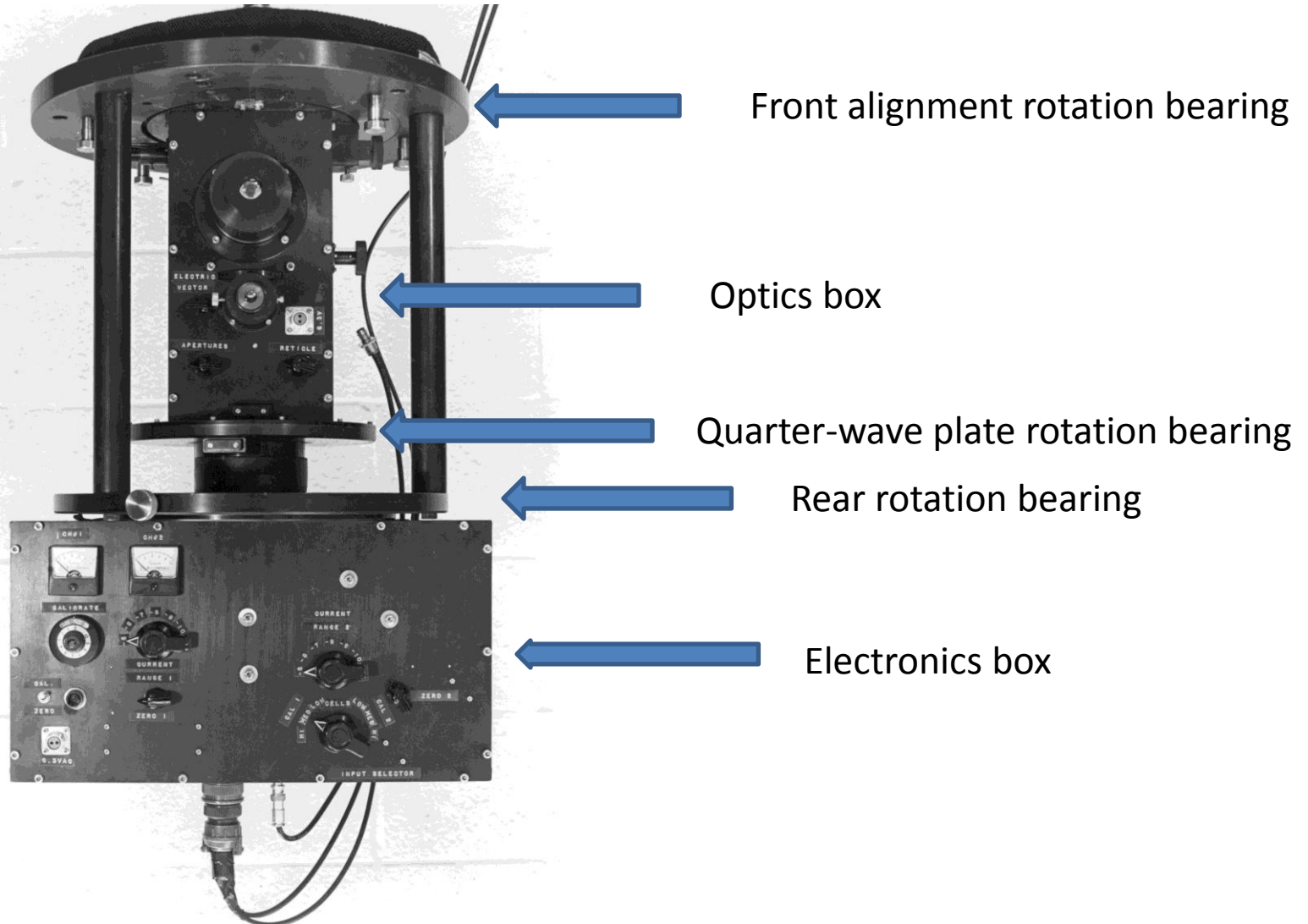


Achromatic Quarter-wave Plates

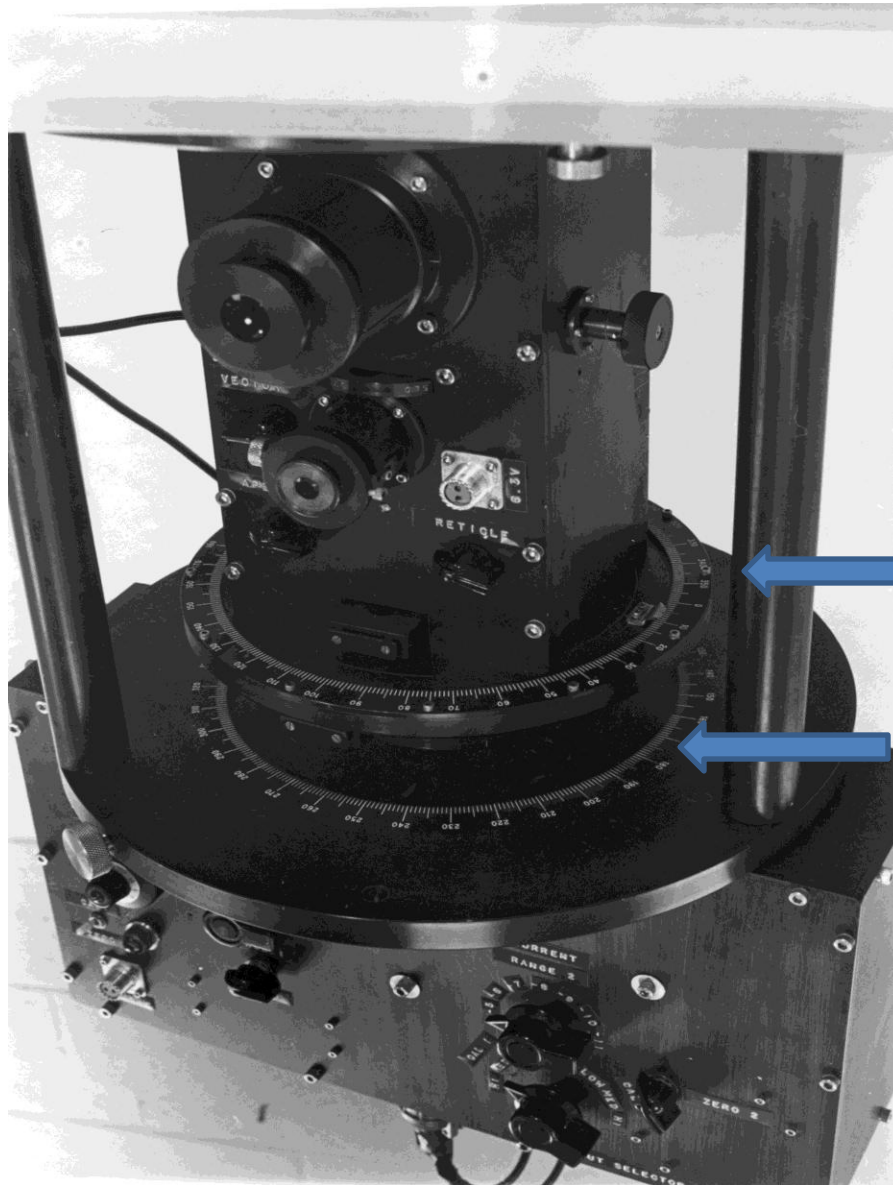


Calcite Foster-Clarke Prism

# The Completed Elliptical Polarimeter - 1969



# Polarimeter Setting Circles

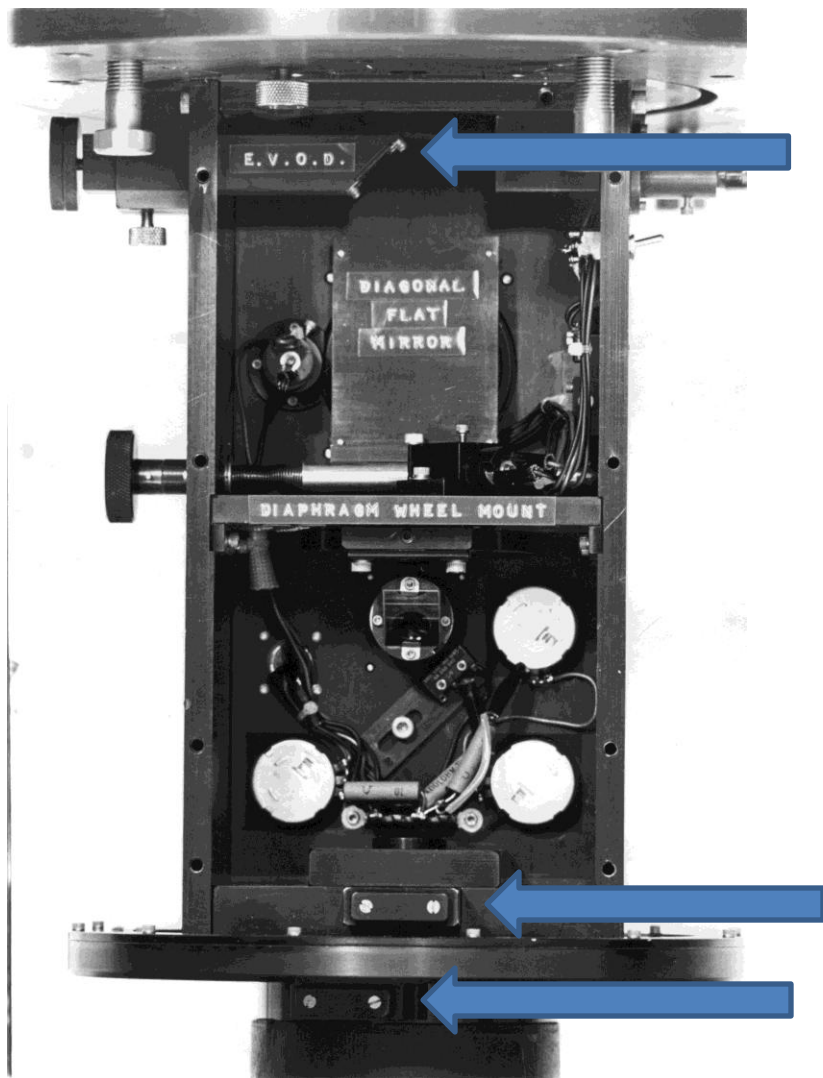


Quarter wave plate circle

Analyzing prism and electronics box circle



# Optics box - inside

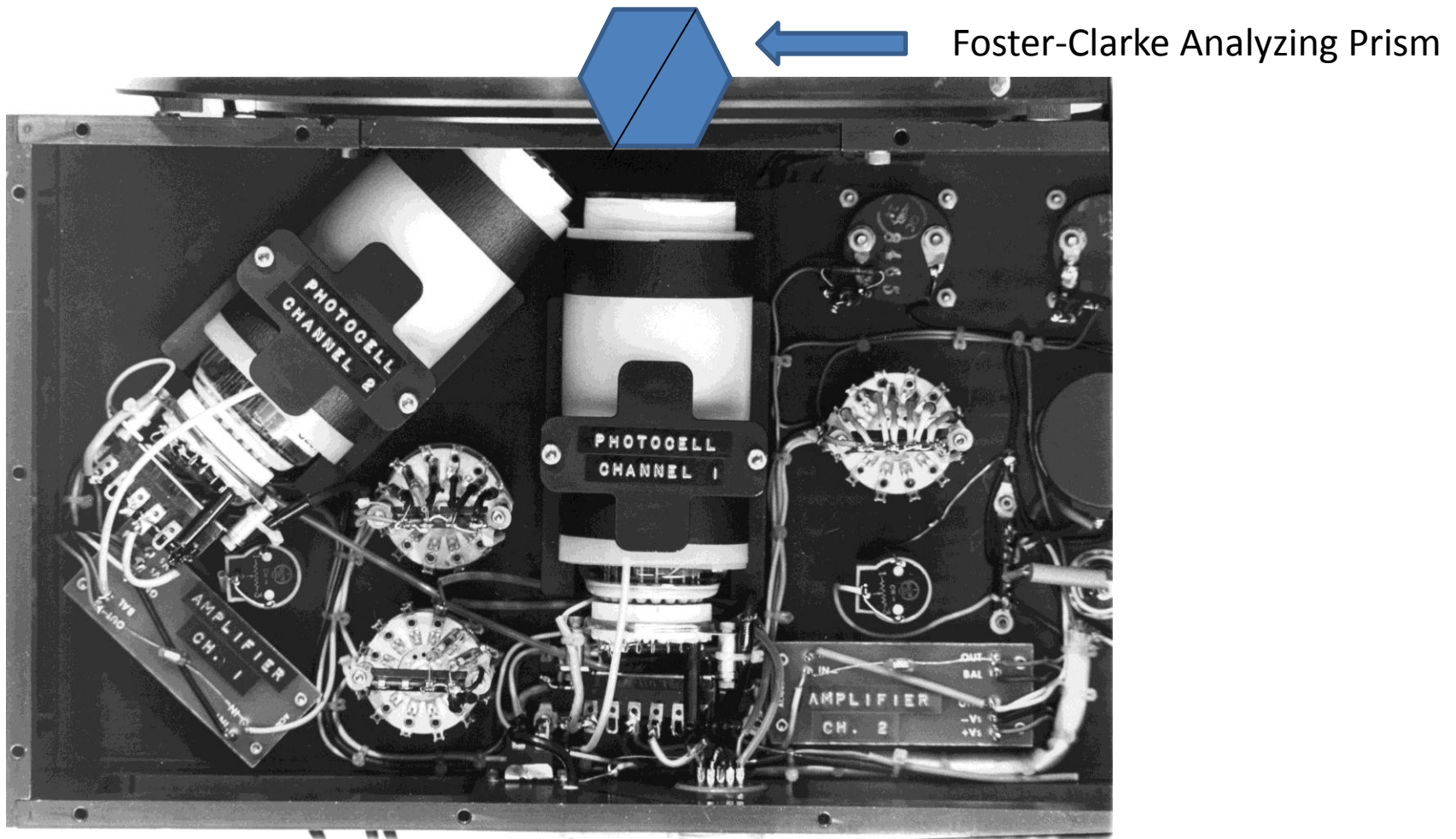


Electric -vector orientation device

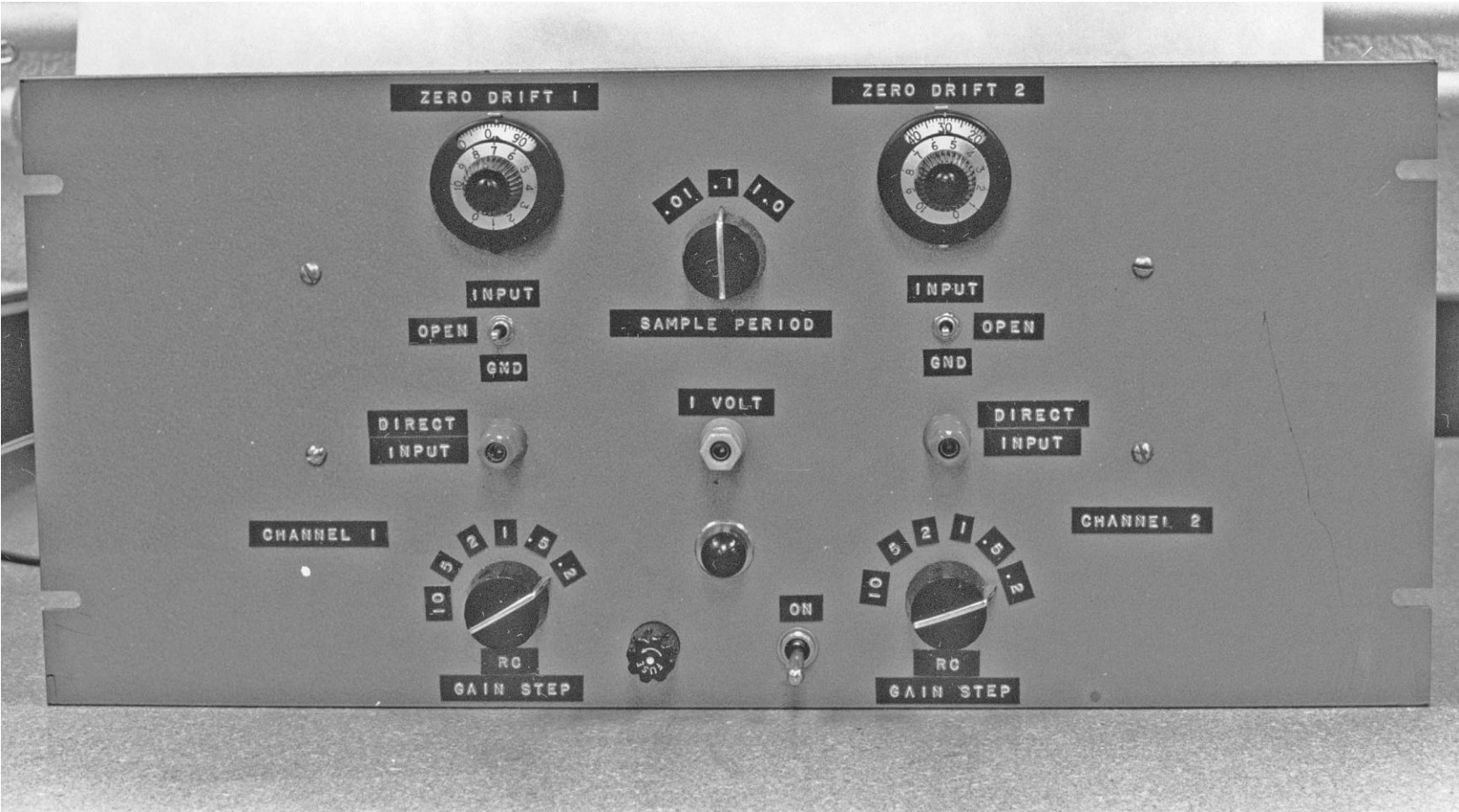
Filter slide

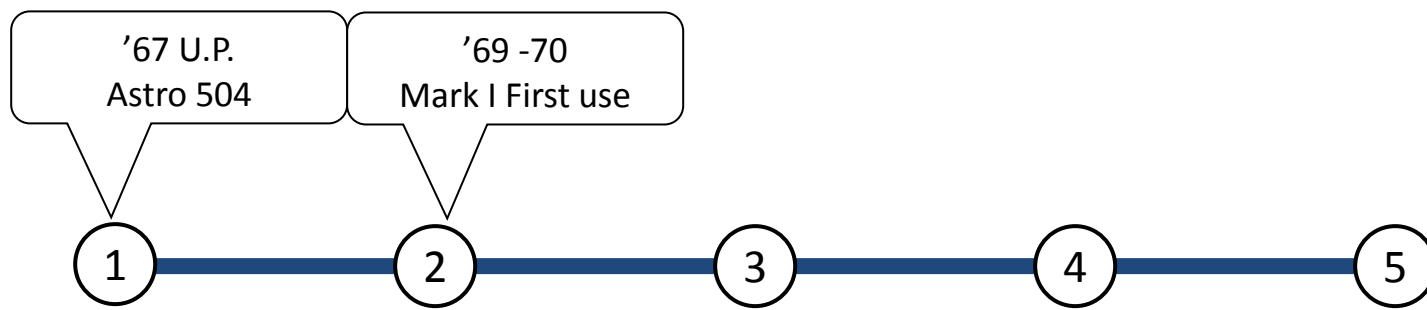
Rotating quarter-wave plate slide

# The Electronics Box - inside



# The Integrator – Power Supply – Relay Logic Unit

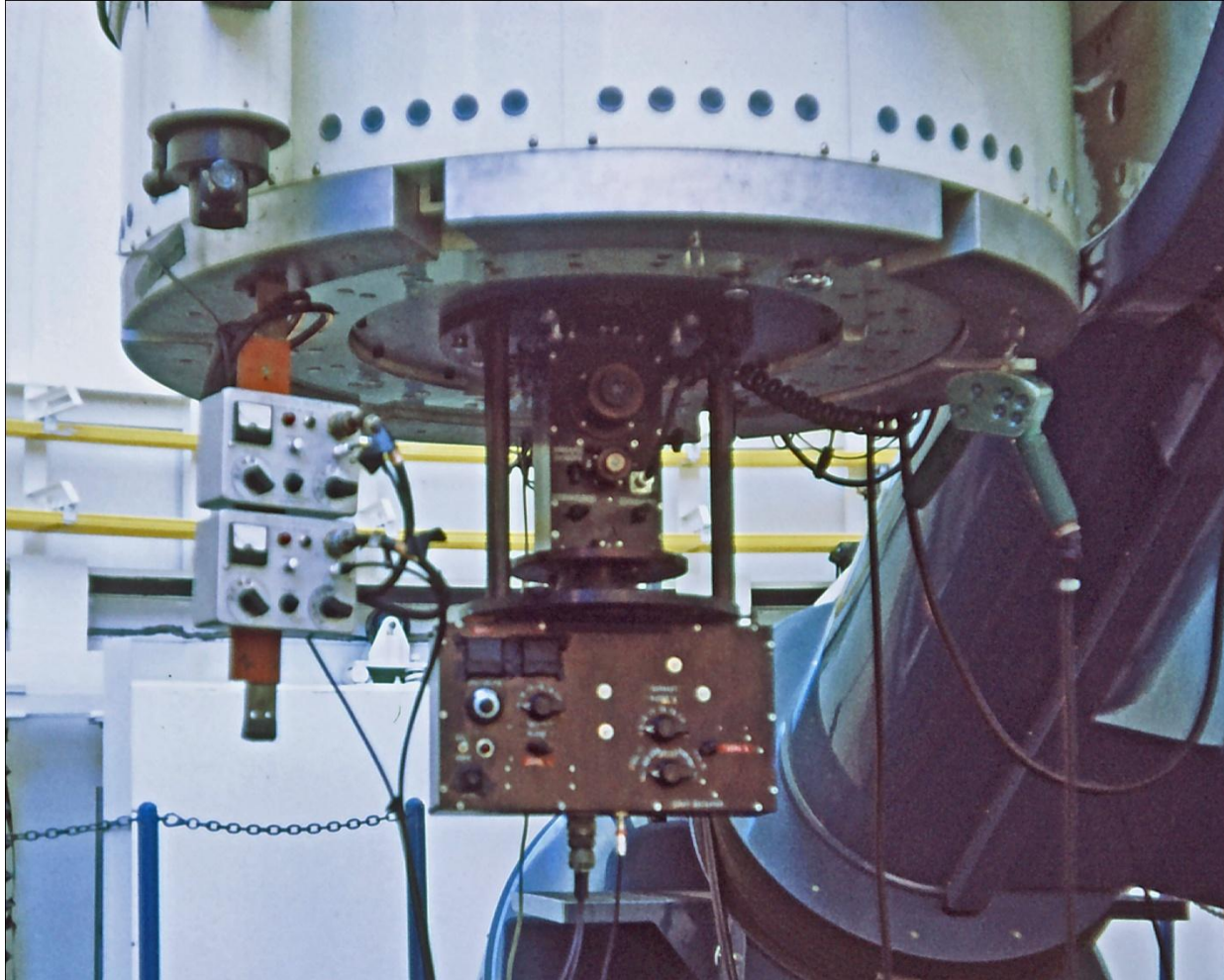




## 2. Initial Use of the Mark I Polarimeter

- First use of the polarimeter was supposed to be a Southern Sky elliptical-polarimetry survey by George Wolf on the 24 inch Optical Craftsman Telescope at Mt. John Observatory in New Zealand during 1969.
- However, because of design and mechanical problems, that telescope was not delivered to New Zealand until 1970.
- This delay caused a change in venue to Kitt Peak National Observatory for a Northern Sky elliptical-polarimetry survey by Wolf during December 1969 and January 1970.
- The polarimeter was then moved to Flower and Cook Observatory in 1971.

# The Mark I Polarimeter on Kitt Peak 0.9 meter

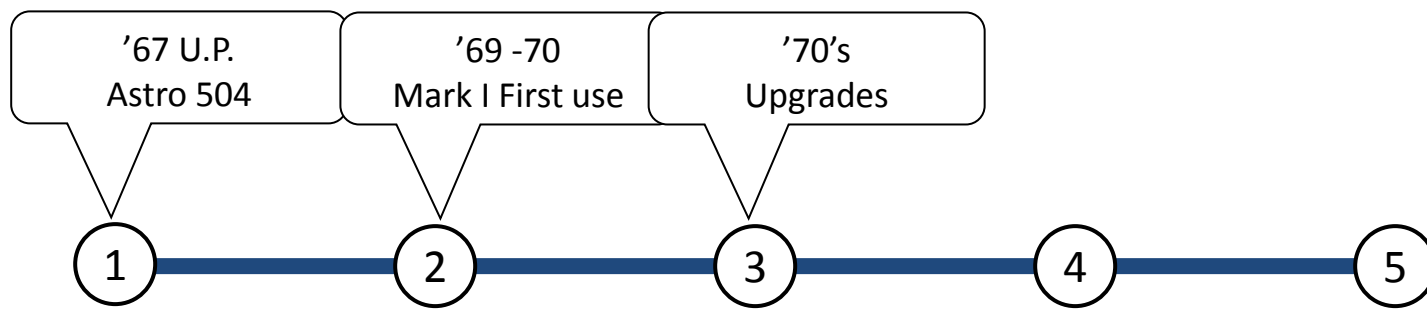


December 1969

# The Initial Mark I Polarization Survey

The initial elliptical-polarization survey (all four stokes parameters) at Kitt Peak of approximately 70 objects included:

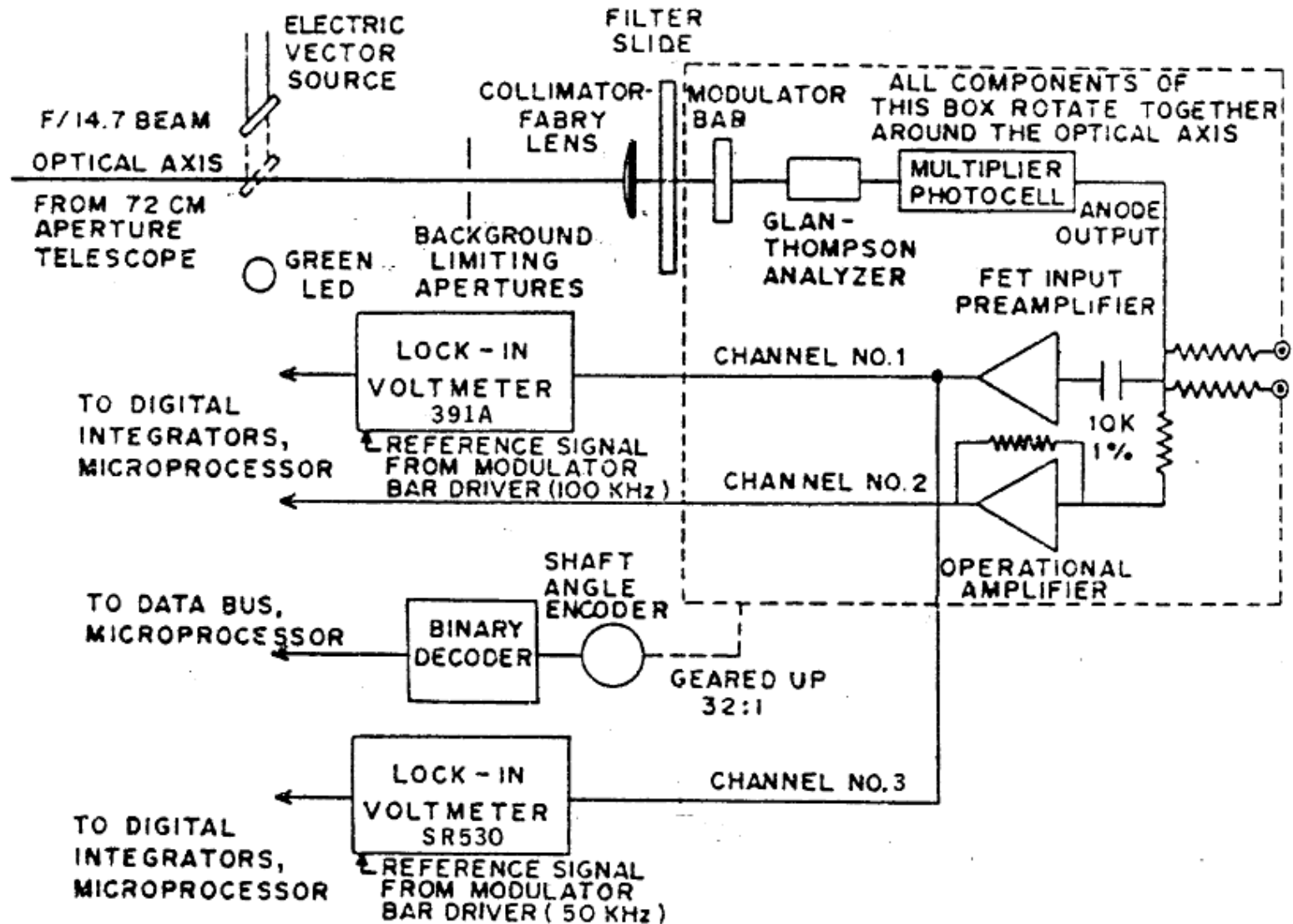
- Magnetic A stars
- Polarized O and B stars
- Highly polarized stars of other spectral types
- Stars with peculiar spectra
- Intrinsic variable stars
- Galactic and extragalactic objects with known synchrotron radiation
- Comet Tago-Sato-Kosaka
- Unpolarized standard stars
- Polarized standard stars



## 3. 70's Polarimeter Upgrades & Redesigns

- 1972: Added a dual channel HP integrating digital voltmeter and digital clock.
- Closed circuit TV camera was trained on the digital displays of the clock and voltmeter.
- 1972-1973: An IBM key punch was interfaced with the digital voltmeter and clock.
- 1977? – 1981 Polarimeter was redesigned. One photomultiplier tube, Photo Elastic modulator bar, internal polarization sources, Ithaco lock-in amplifier.

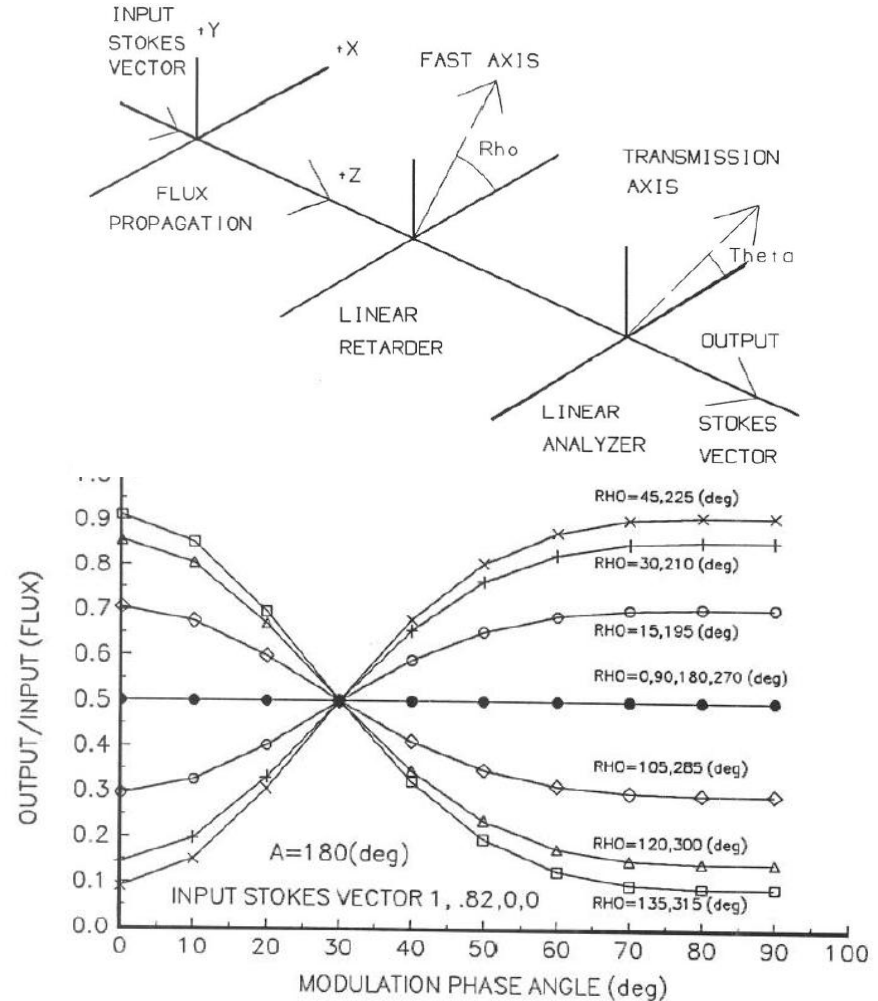
# Electro-Optical Components of the PEMP





# PEMP Special Optical Component Details

## Hinds Photoelastic Variable Retarder & Controller

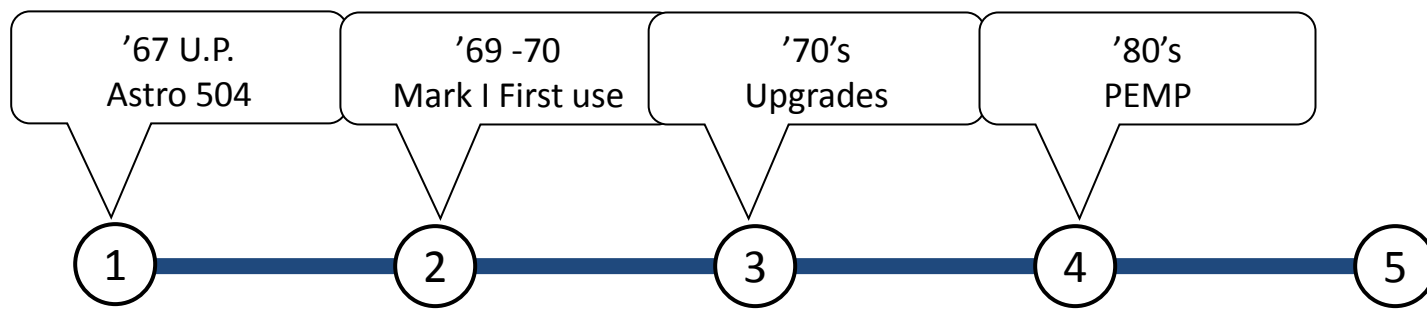


$$I_d(\Phi, t) = \frac{1}{2}I_T + \frac{1}{2}P_I \cos(2\Phi) \cos(2\Psi) + \frac{1}{2} \sin(2\Psi) \bullet$$

$$\{ (P_I \sin(2\Phi) \cos\alpha + V \sin\alpha) [J_0(\beta) + 2 \sum_{n=1}^{\infty} J_{2n}(\beta) \cos(2n\omega t)]$$

$$+ (V \cos\alpha - P_I \sin(2\Phi) \sin\alpha) [2 \sum_{n=0}^{\infty} J_{2n+1}(\beta) \sin((2n+1)\omega t)] \},$$

Blitzstein, et. al 1993



## 4. Later PEMP Operations and Improvements

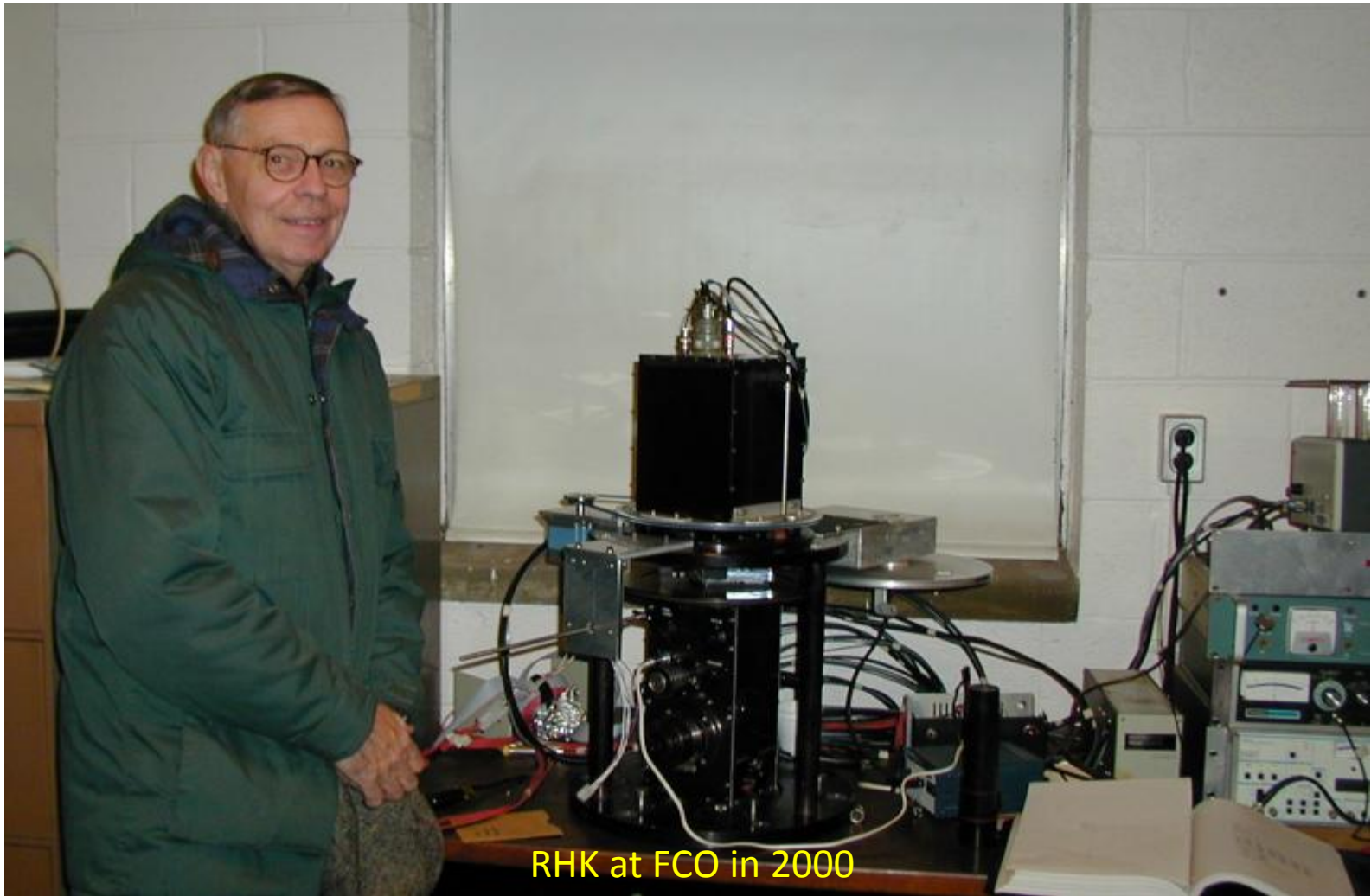
- 1981 Ohio Scientific microcomputer installed.
- 1981 Dave Bradstreet wrote first OSI polarization data reduction program.
- 1981 (August) PEMP Operations began
- 1982 Encoder added to Polarimeter to read and record azimuth.
- 1986 Ohio Scientific computer replaced with IBM AT and new interface.
- 1986 Stanford SR530 lock-in added for simultaneous  $Q$ -,  $U$ -, and  $V$ -Stokes vector operation.
- 1987 Temperature sensors installed into the Polarimeter and Lock-in.
- 1990's-2000 Remote operation completed: filter slide, PEMP orientation

# PEMP on 28-in. Cassegrain at FCO

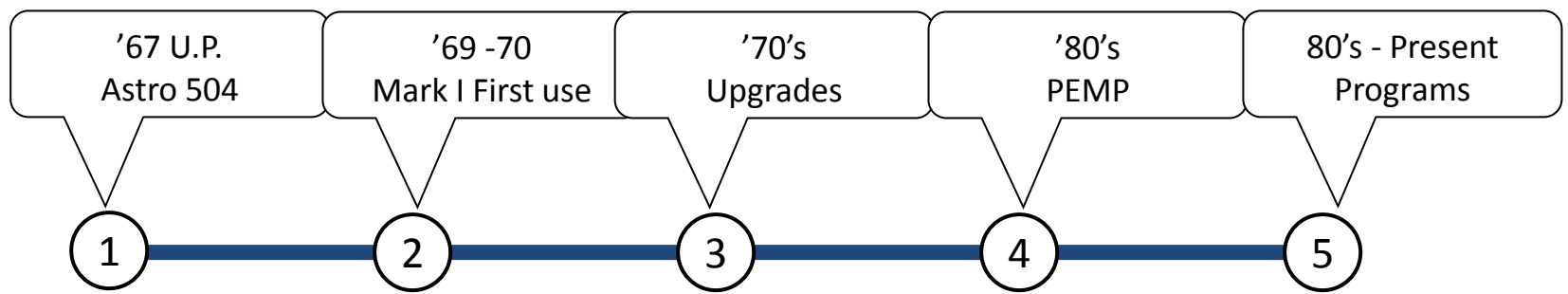


Early 1980's

# Remote Operation PEMP



RHK at FCO in 2000



## 5. 80's-Present Observational Programs

**Productivity: August, 1984 to October, 1992**

**Close Binary Systems 1673**

**Luminous Late-Type Variables 621**

**Beta Cepheid Variables 263**

**Polarization Standards 772**

**Miscellaneous 57**

**Total Observations 3386**

Source: Blitzstein, *et. al.* 1993

# PEMP Calibration

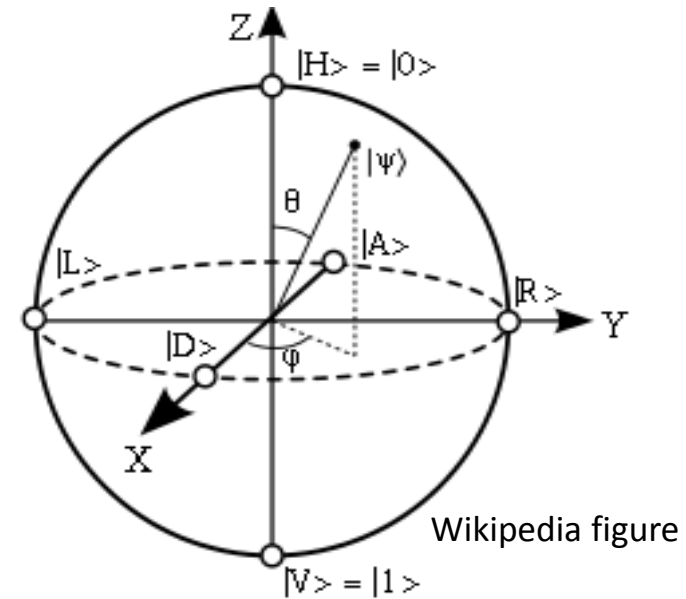
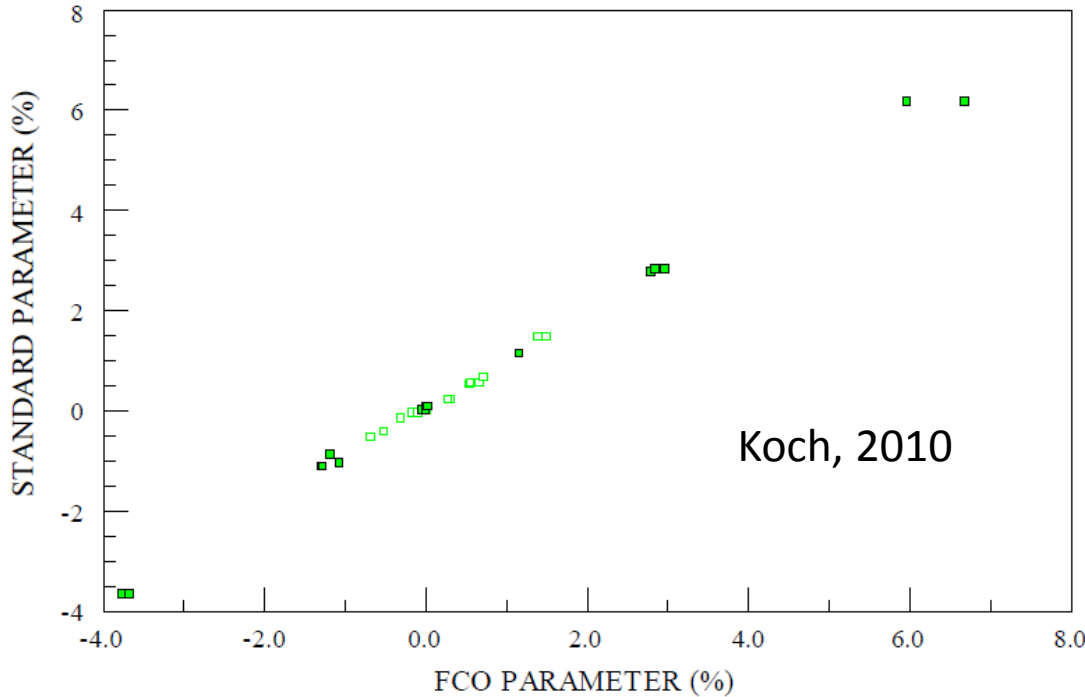
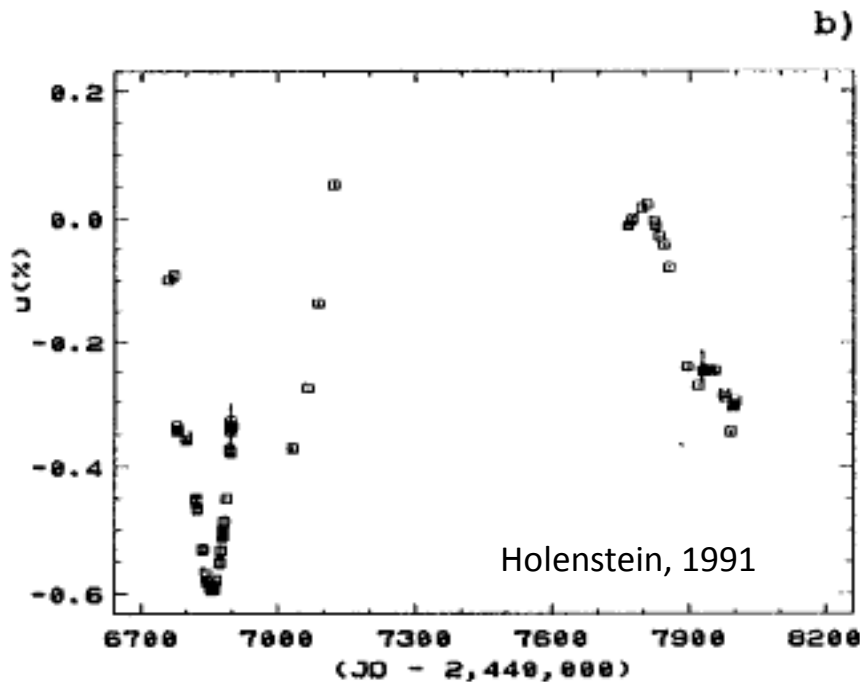
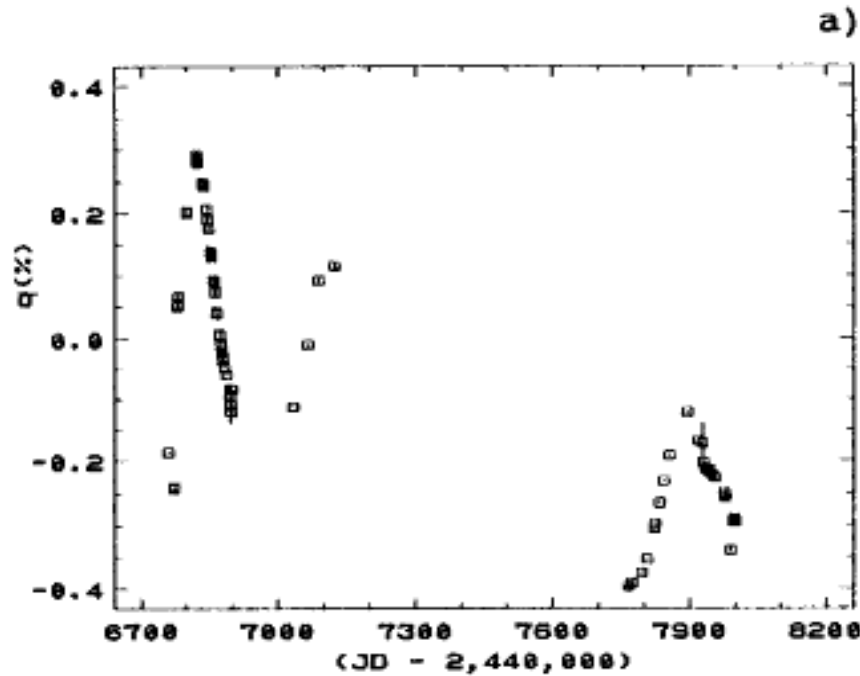


Fig. 52. The calibration of the FCO values of the green  $Q$  and  $U$  polarization parameters over the interval, July 1983 through May 1984. Filled symbols refer to  $Q$  and open ones to  $U$ . Linear regressions lead to:  $Q(\text{std}) = +0.0301 + 0.9668Q(\text{FCO})$ ,  $U(\text{std}) = +0.0176 + 0.9293U(\text{FCO})$ .

**Null and non-null standard stars for linear calibration**

**Null standards and rotation of the Poincaré sphere for circular calibration**

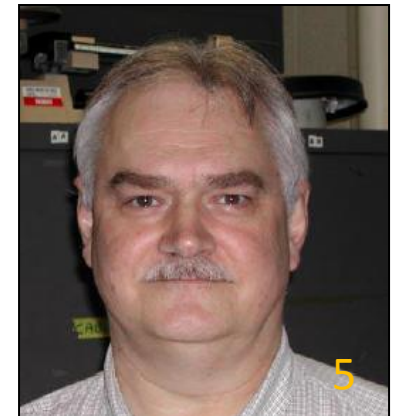
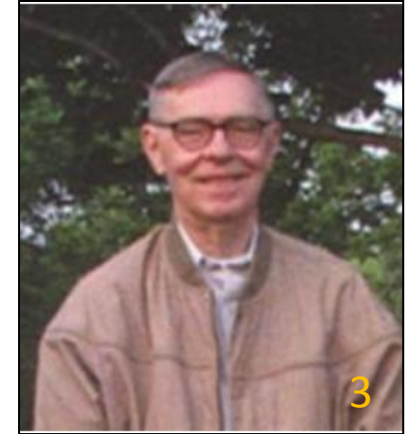
# Luminous Late-Type Variables



- Alpha Ori (R-bandpass shown)
- Others: 119 CE Tau, 6 BU Gem,  $\Psi^1$  Aur, 72 Leo, V CVn,  $\alpha$  Sco,  $\alpha^1$  Her,  $\mu$  Cep, VV Cep,  $\beta$  Peg

# Other key Penn Polarimeter Contributors

1. Bill Barrie
2. Dave Bradstreet
3. Robert H. Koch
4. Robert E. Smith
5. Richard J. Mitchell





# Summary

- Penn Polarimeters evolved over 30 years and made use of the best available technology during that time.
- Product of a collaboration of many Penn astronomers and staff from 1967 to 2000.
- Elliptical polarimetry, using a photoelastic modulated bar, was a productive activity at Flower and Cook Observatory, a location near a major US city.
- Objects all over the HR diagram down to about 11<sup>th</sup> magnitude were studied polarimetrically.
- The precision in latter years of better than  $\pm 0.01\%$  for a 7<sup>th</sup> magnitude star.