# Astrometry lost and regained:

## From a modest experiment in Copenhagen in 1925 to the Hipparcos and Gaia space missions

Erik Høg - 2010

*Niels Bohr Institute - Copenhagen*

*Content:*

*Only about work leading to Hipparcos/Tycho*

# Astrometry lost and regained

## The golden ages of
## Tycho Brahe and Ole Rømer

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# Quadrant 1570 Sighting the star

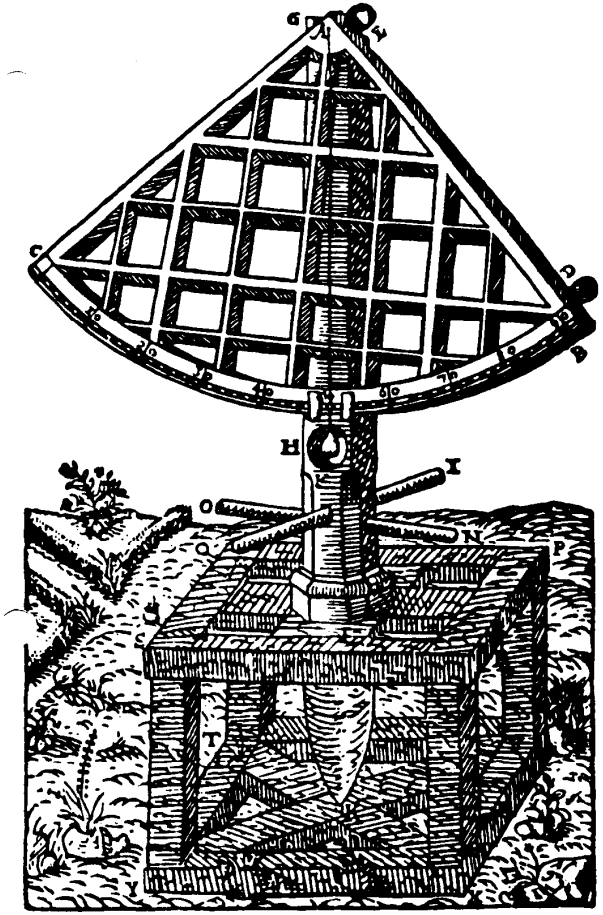


*Fig. 5: Den store kvadrant fra Augsburg, benyttet af Tycho Brahe fire år inden Uranborgs grundlæggelse. Den kunne kun måle højder (efter Astronomiae instauratae mechanica).*

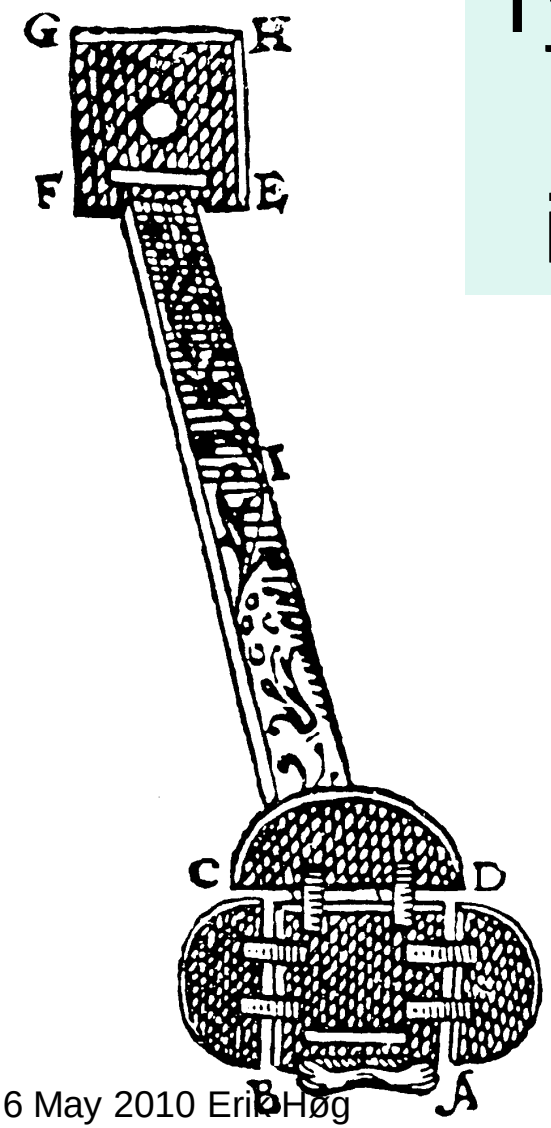
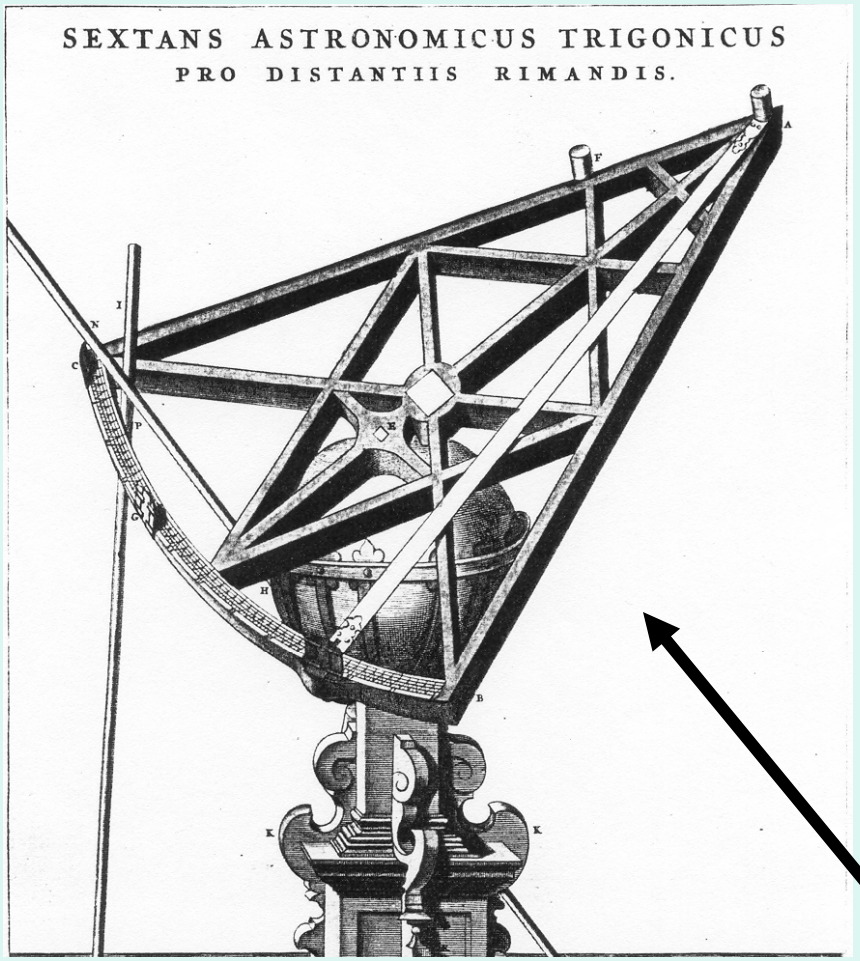



*Fig. 6: Tycho Brahes sigtemidler.*

# Tycho Brahe's *new* instruments




Tycho Brahe
on Hven
1576-97
A barrel of gold

1000 stars measured
celestial reference frame
for measurement of planets

Sextant 1580

# Tycho Brahe mural quadrant

- One observer for the star, two assistants for clocks, circle and protocol

- Diagonal division lines

# Sextant and quadrant

- With naked eye **open sight pinnules** until 1679, Johannes Hevelius

- **Telescopic sight** on quadr. and sext. 1640 by William Gascoigne 1665-, Robert Hooke a.o.

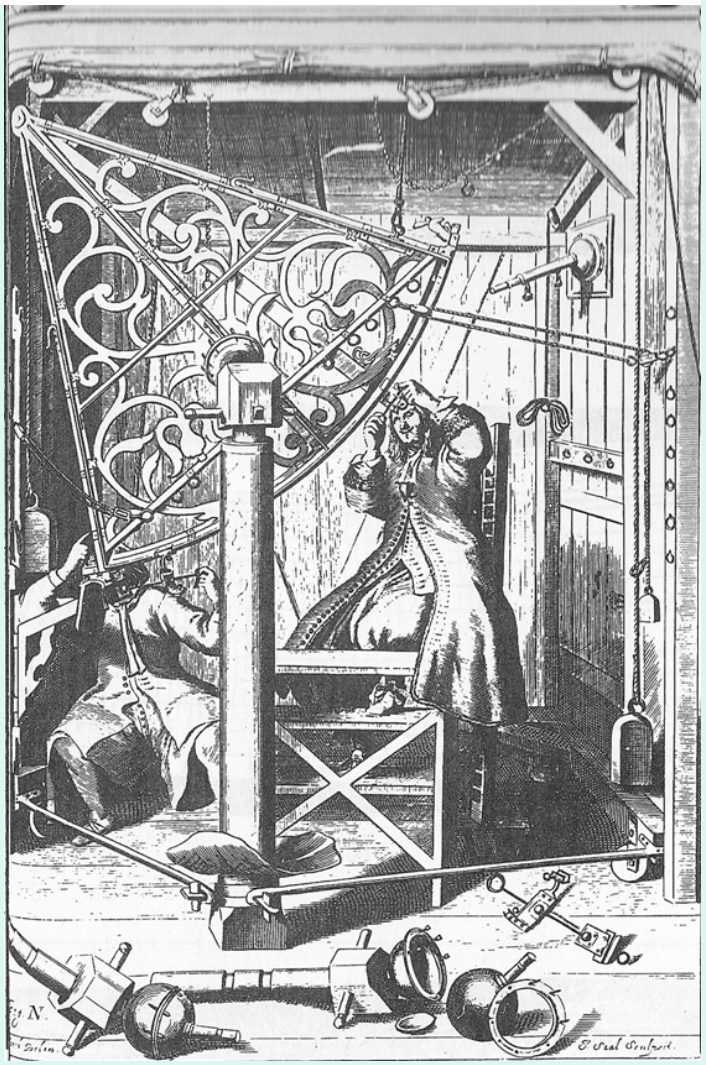
- Mural ”quadrant” of 140 deg. 1689-, John Flamsteed

- 1658 : Pendulum clock by Christiaan Huygens

- 1659 : **Wire micrometer** by Huygens Gascoigne 1641, but known only later

6 May 2010 Erik Høg

Hevelius, brass sextant



# Divided scales and circles

- 1674 Hevelius :

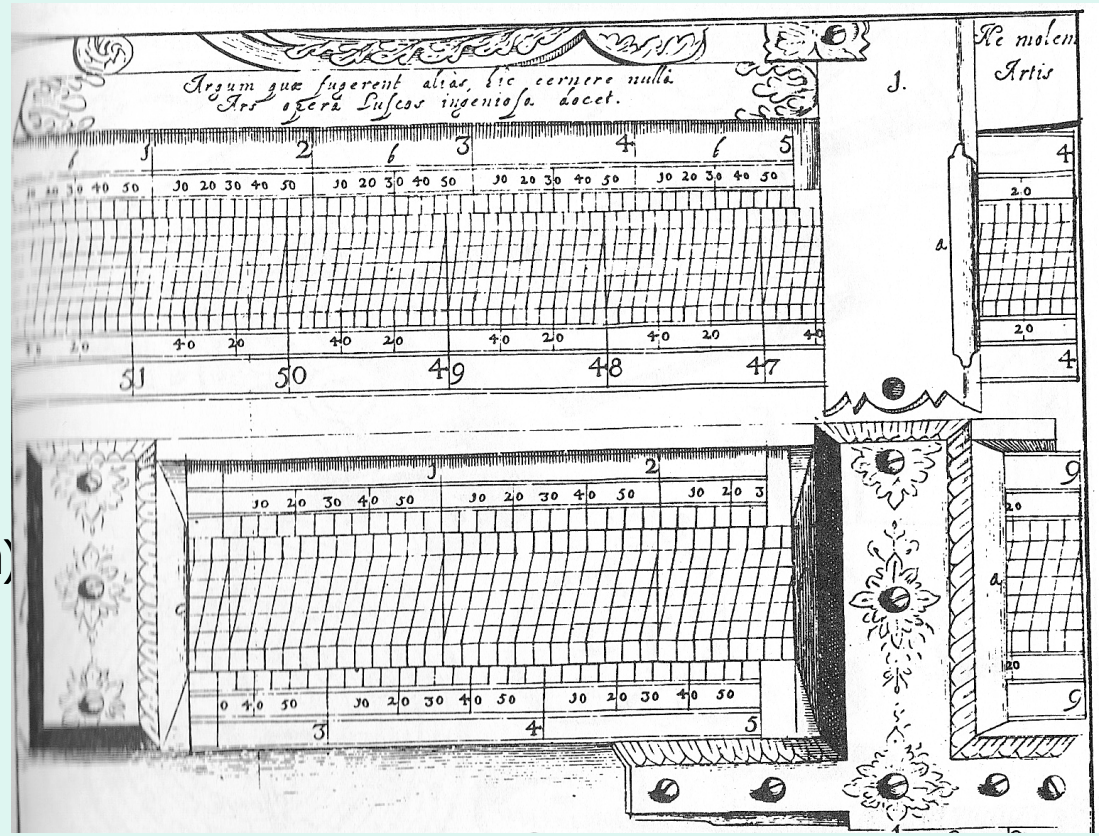
Scale with vernier

and diagonals

- The high art of

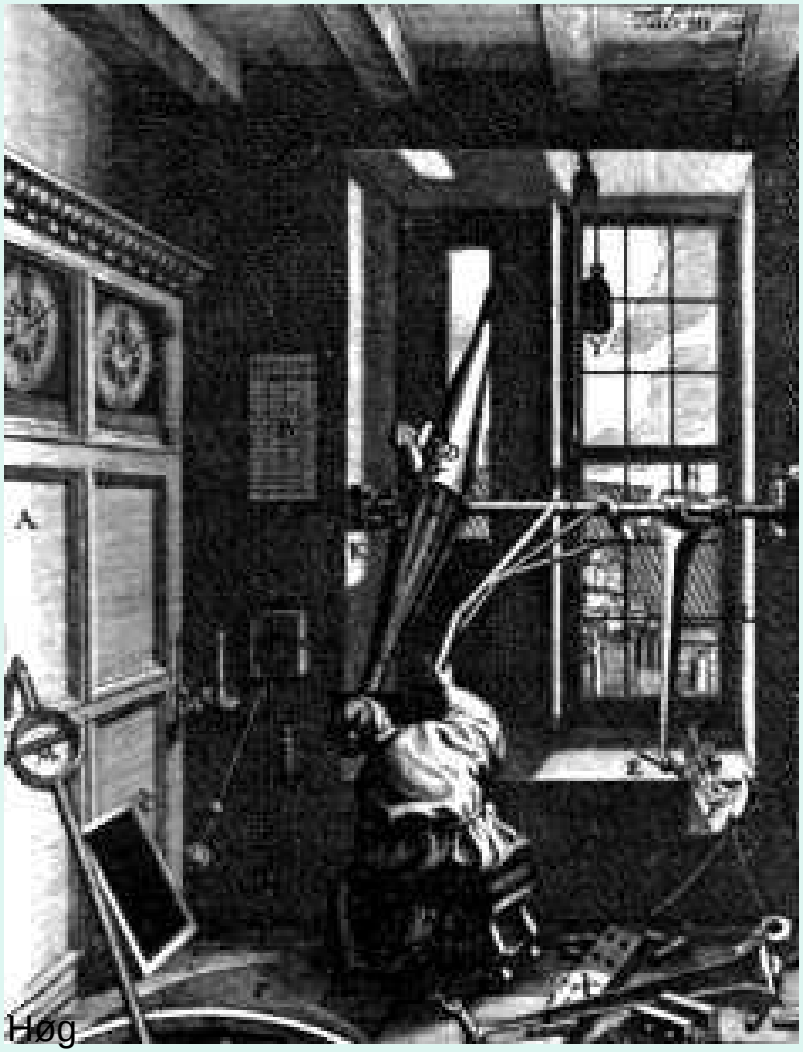
of dividing the circle

(1990 book by Allan Chapman)



# Transit instrument by Ole Rømer

- 1675 - Transit instrument in Copenhagen

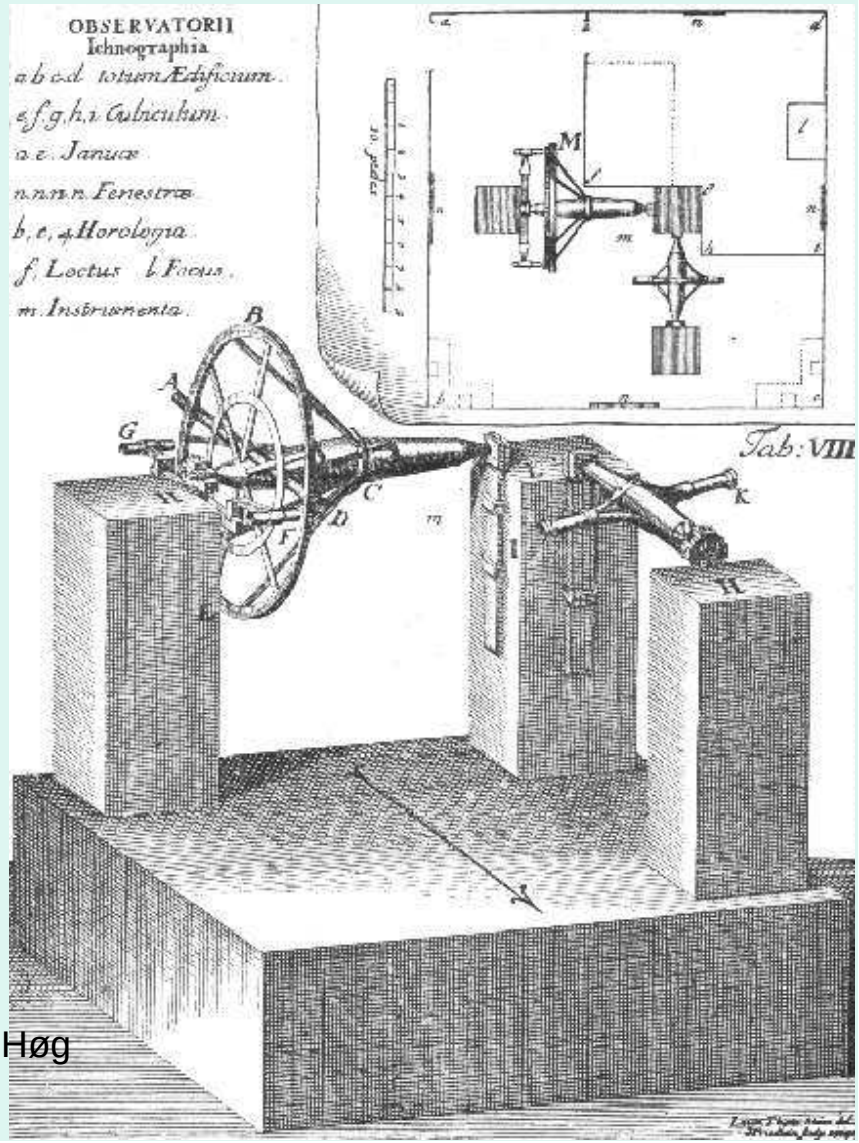


# Meridian circle by Ole Rømer

- 1705 - Meridian circle

full circle and microscopes

Only after 1800 were quadrants out of business

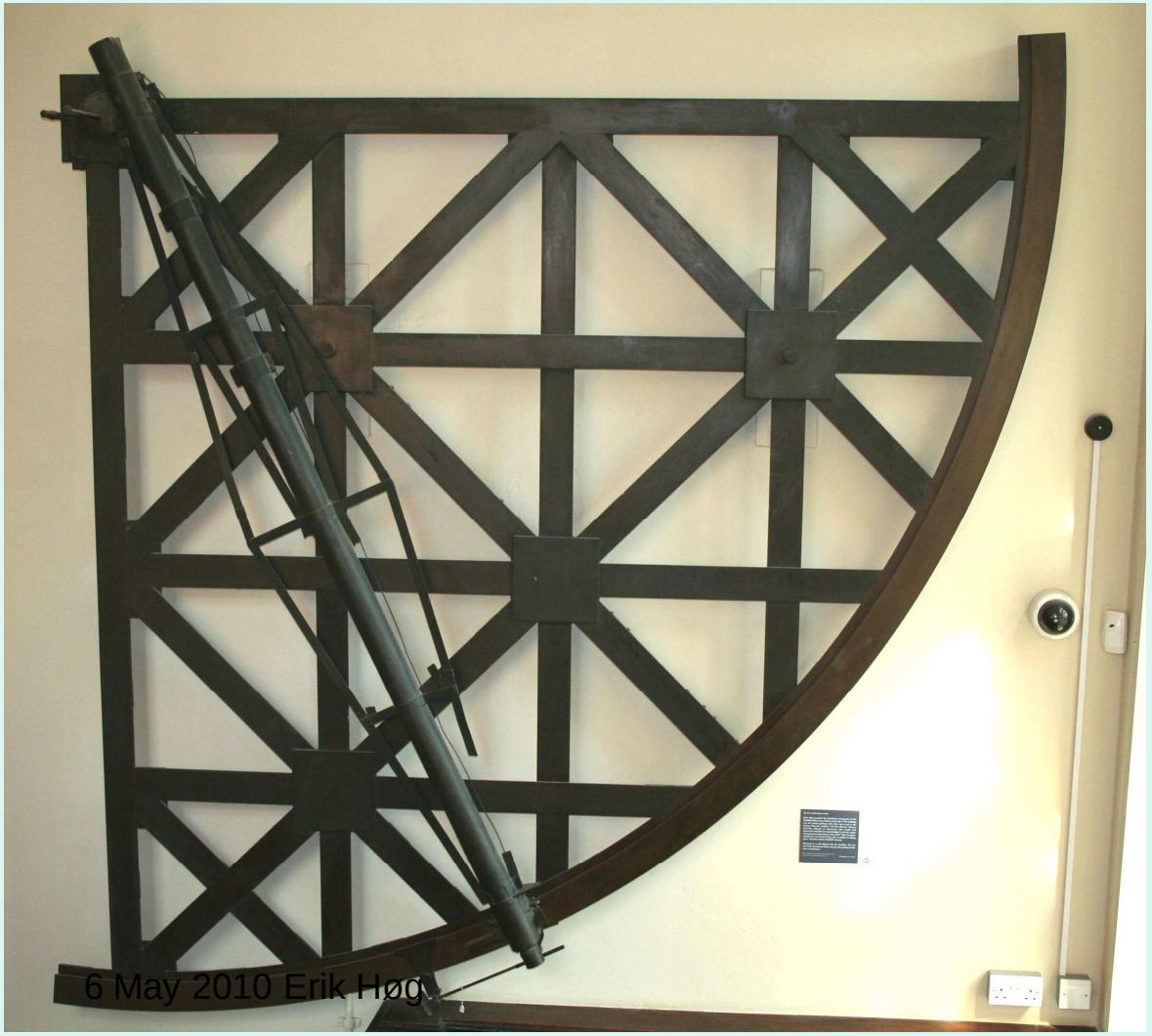


# Mural quadrant – John Bird - 1773

- Critical issues :

Divisions

Planarity of circle



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*Content:*

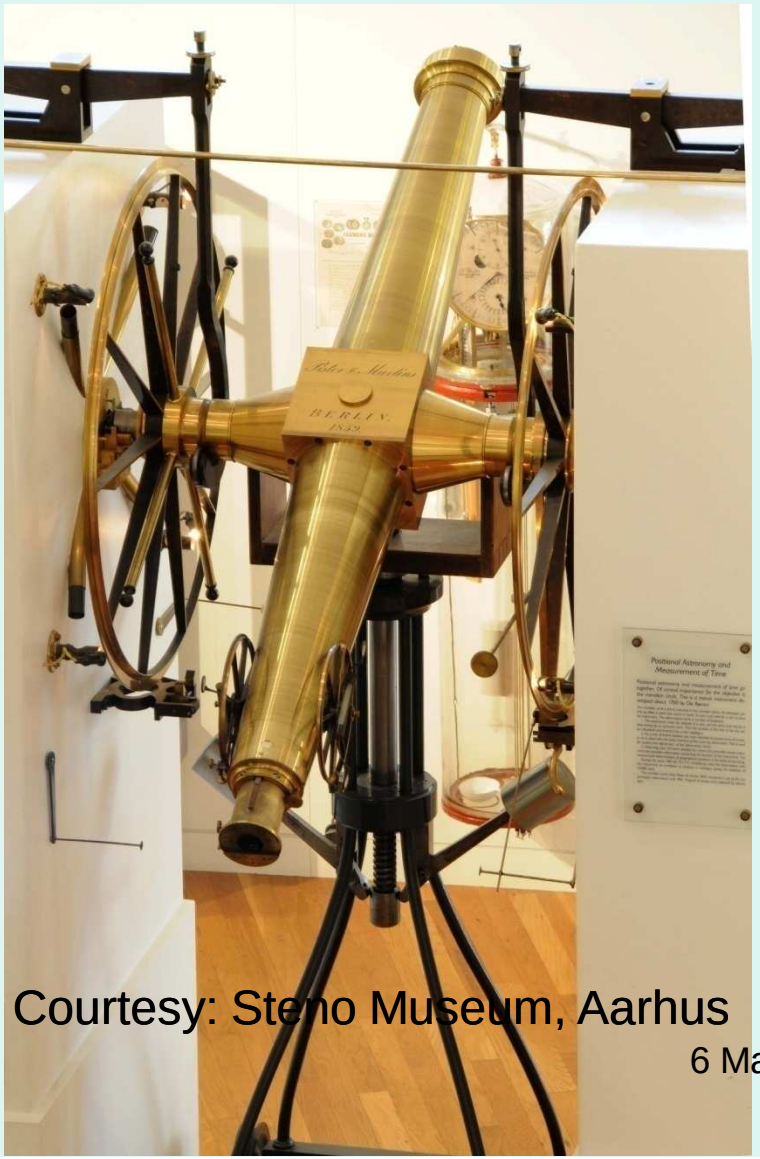
*Only about work leading to Hipparcos/Tycho*

- *Photoelectric effect, Bengt Strömgren*
- *Meridian circles in Brorfelde, Hamburg and Perth*
- *Hipparcos mission, including the Tycho experiment*

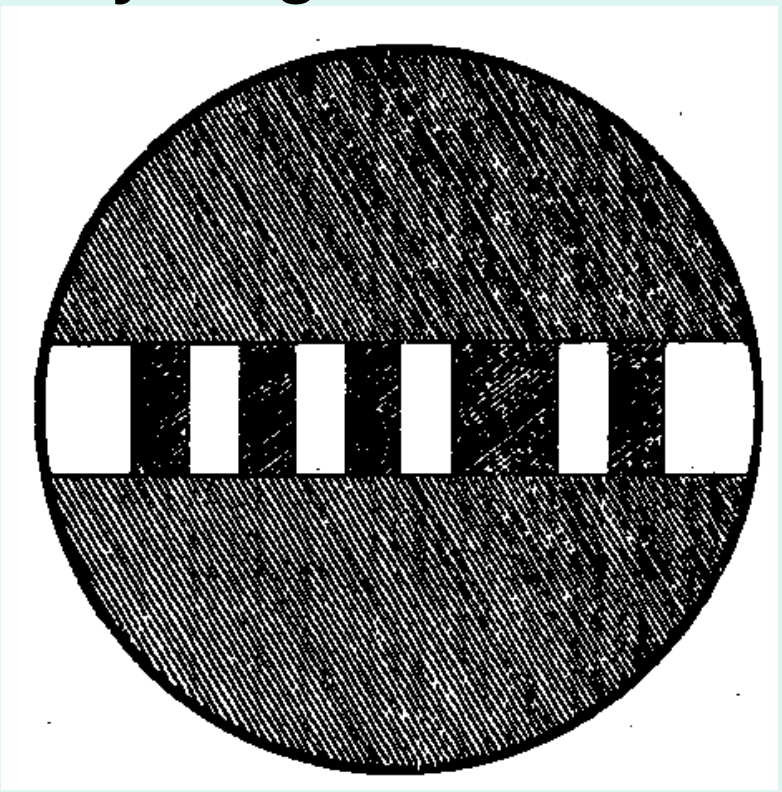
# The photoelectric effect

- An atom emits an electron when hit by light with sufficiently high frequency, i.e. high energy
- *CCD:  NOT photoelectric effect*
- Experimental discovery:
- In 1887 by *Heinrich Hertz* (Germany, 1857-1894) while discovering radio waves; but he did not fully realize!
- In 1887 by *Wilhelm Hallwachs* (Germany, 1859-1922) on a zinc plate
- Named the *Hallwachs effect*
- Explained 1905 by *Albert Einstein*; Nobel prize 1921

# Copenhagen meridian circle
# Photoelectric astrometry begins in 1925



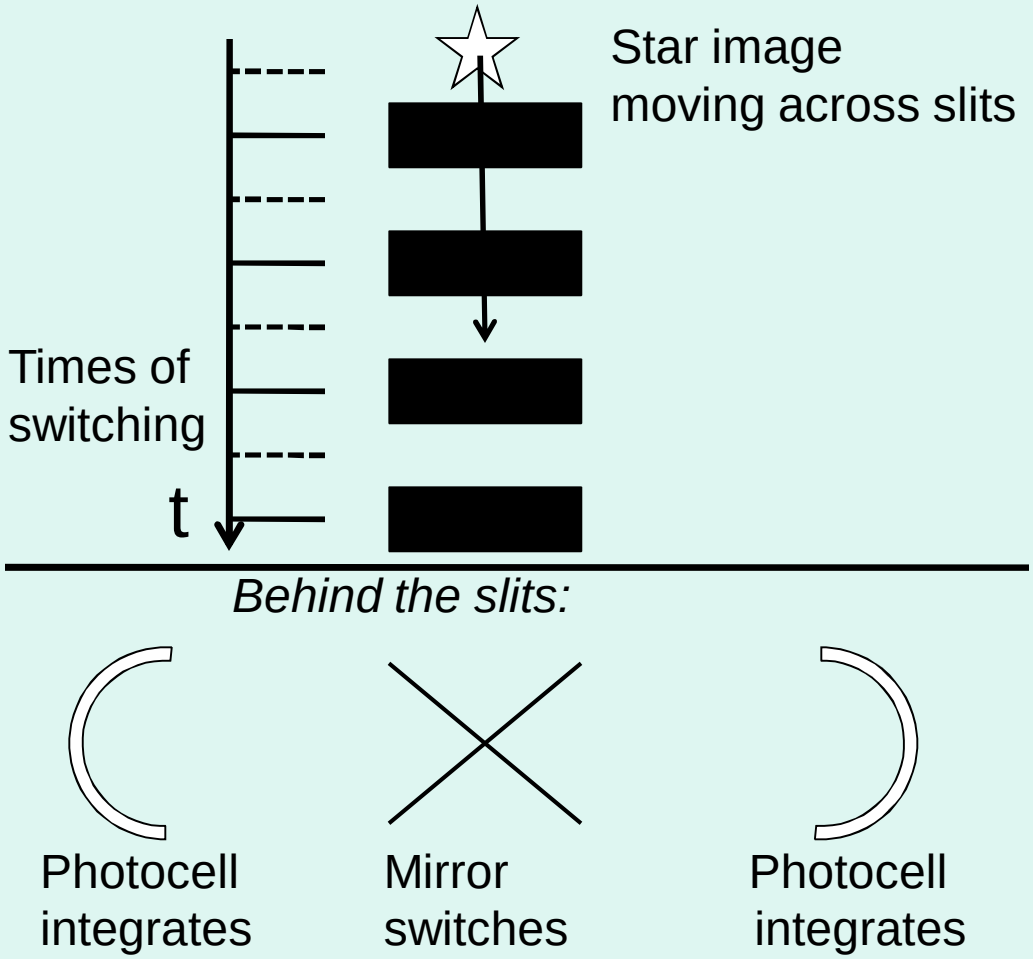

Courtesy: Steno Museum, Aarhus



Bengt Strömgren 1925 and 1933
Experiments with
photoelectric recording of transits

# Switching mirror and integration

## proposed 1933



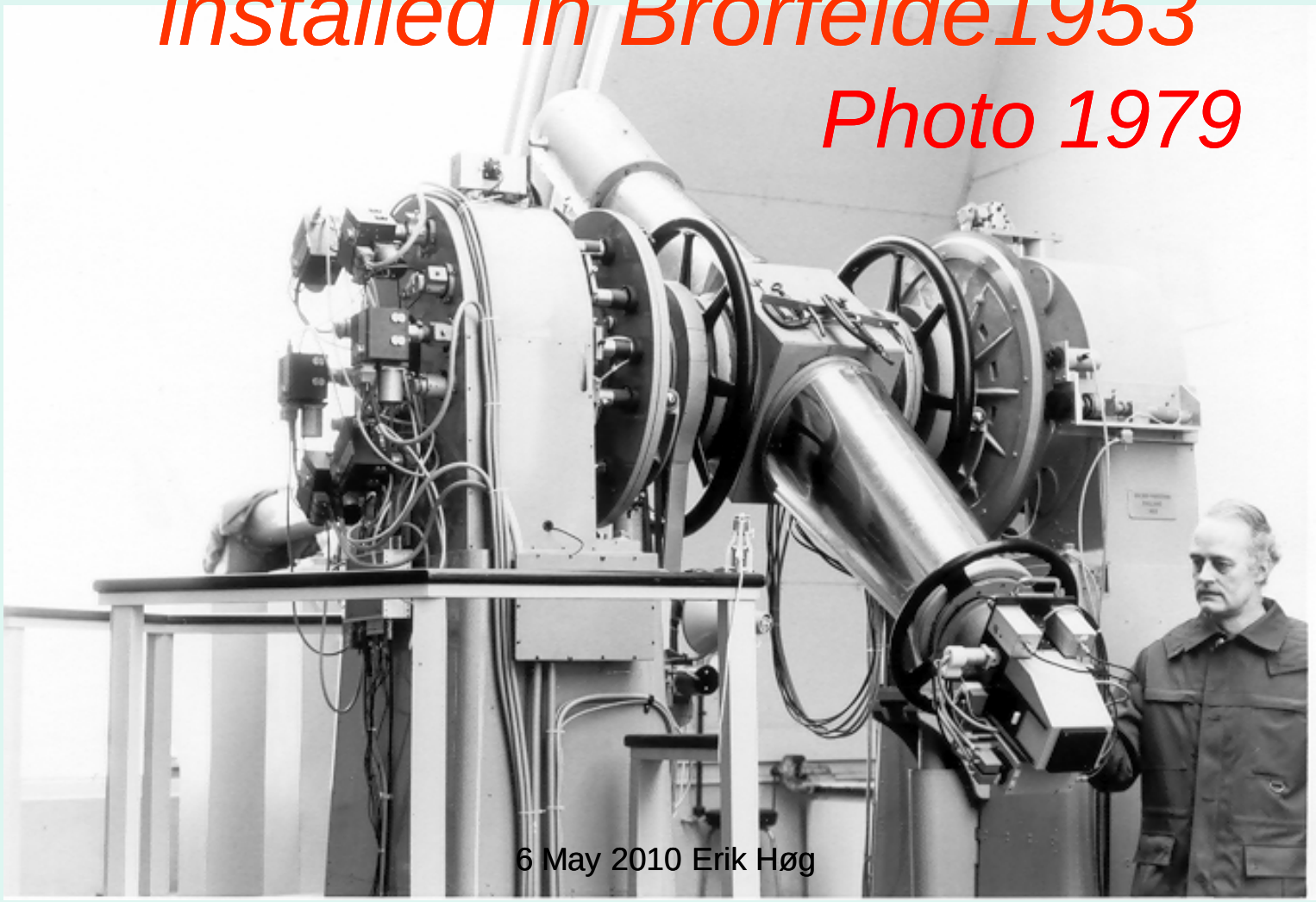

**Bengt Strömgren (1957)**

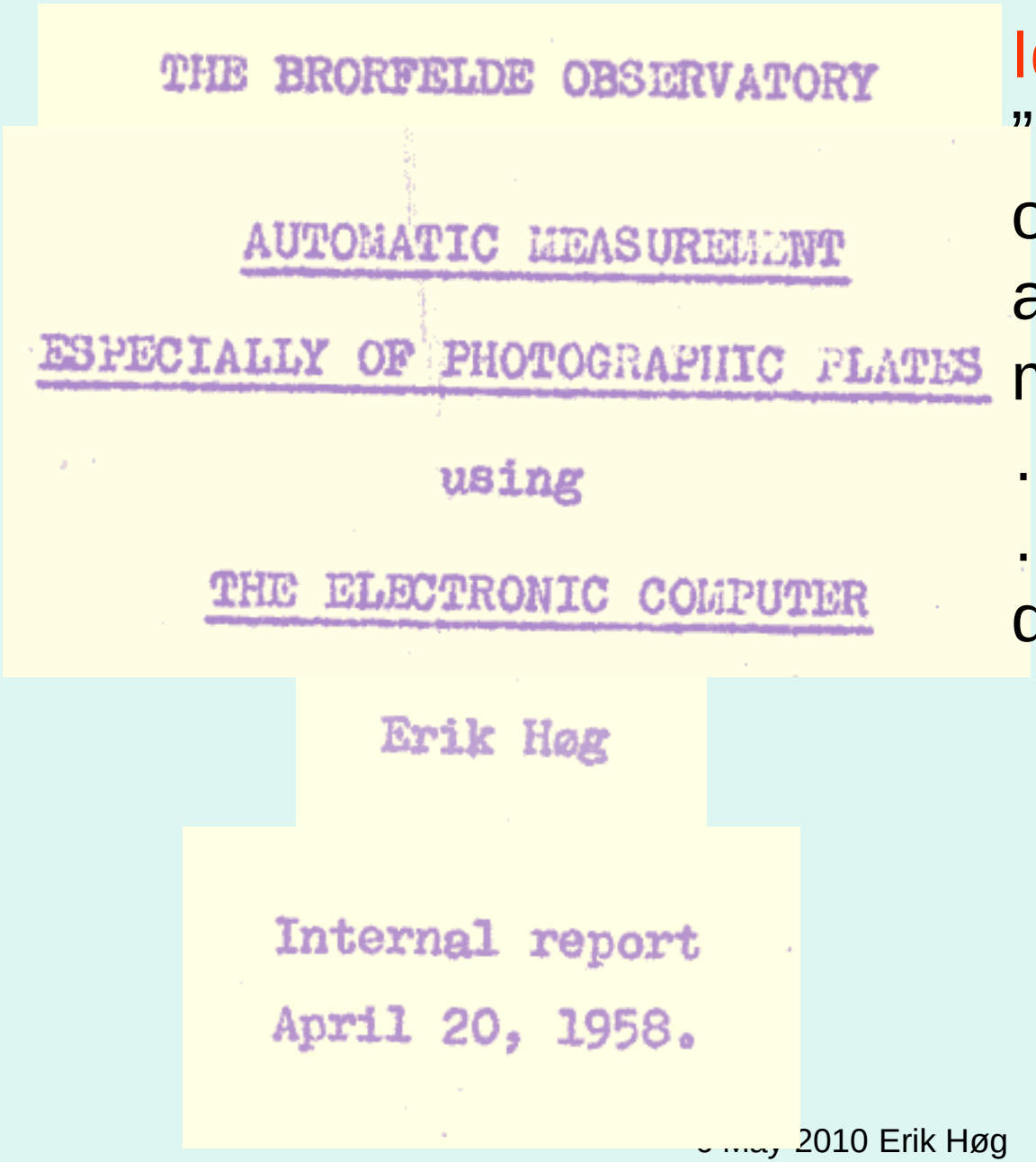
# *New meridian circle*

initiated by Bengt Strömgren 1940

*installed in Brorfelde1953*

*Photo 1979*




THE BRORFELDE OBSERVATORY

AUTOMATIC MEASUREMENT

ESPECIALLY OF PHOTOGRAPHIC PLATES

using

THE ELECTRONIC COMPUTER

Erik Høg

Internal report

April 20, 1958.

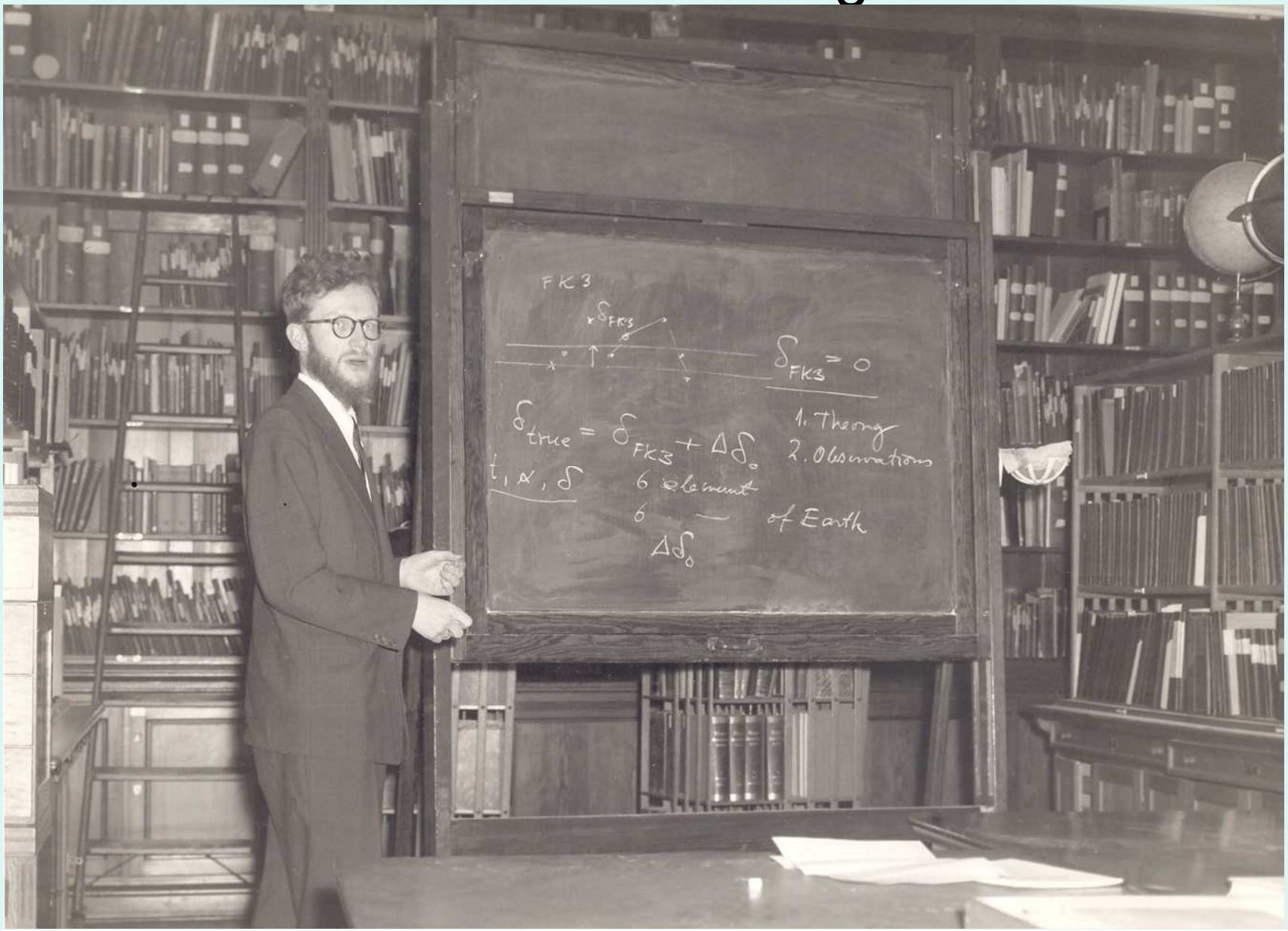
Idea 1958:

"… general principles of a new type of automatic measuring machine …

…to magnetic tape

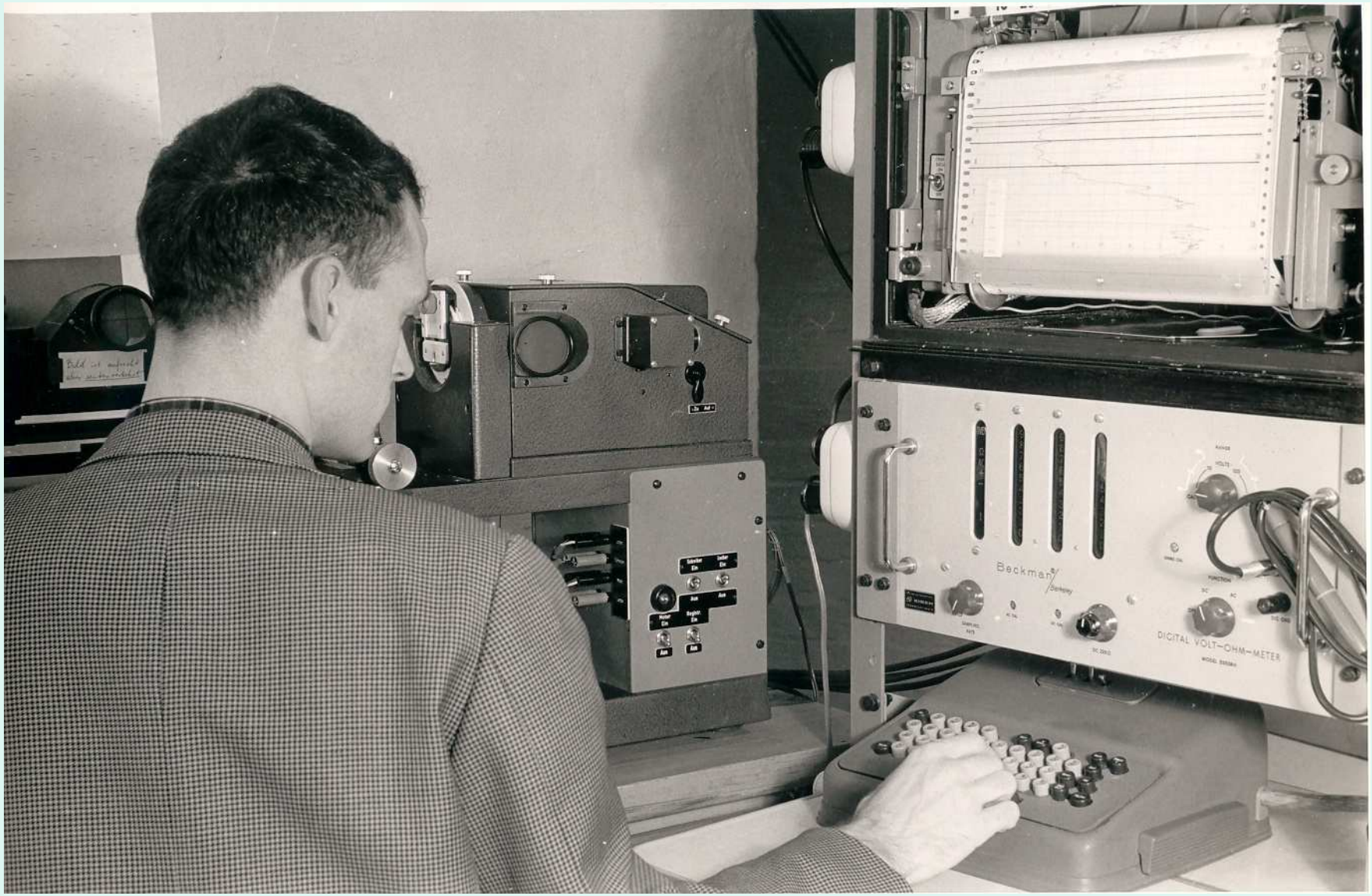
…to high speed digital computer…"

# Peter Naur – my teacher in Copenhagen at a lecture in Hamburg ~1959



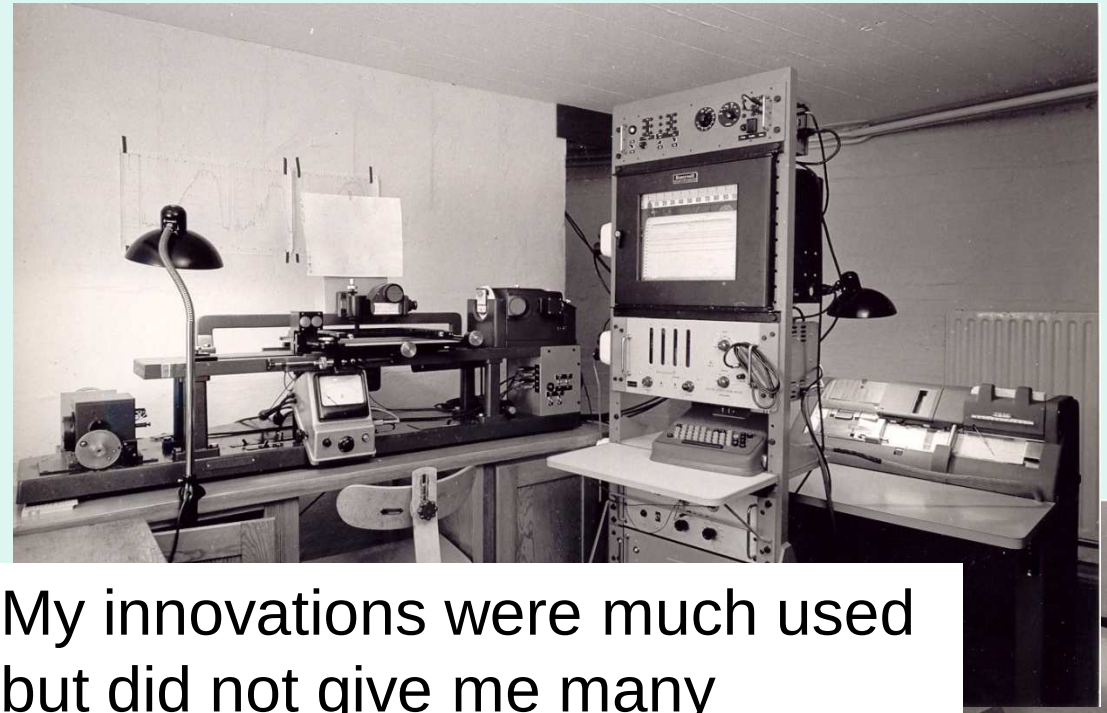
# E. Høg 1960:

## Scanner for photographic plates with spectra



# Hamburg 1960: Recording on punched cards

## Scanning spectra

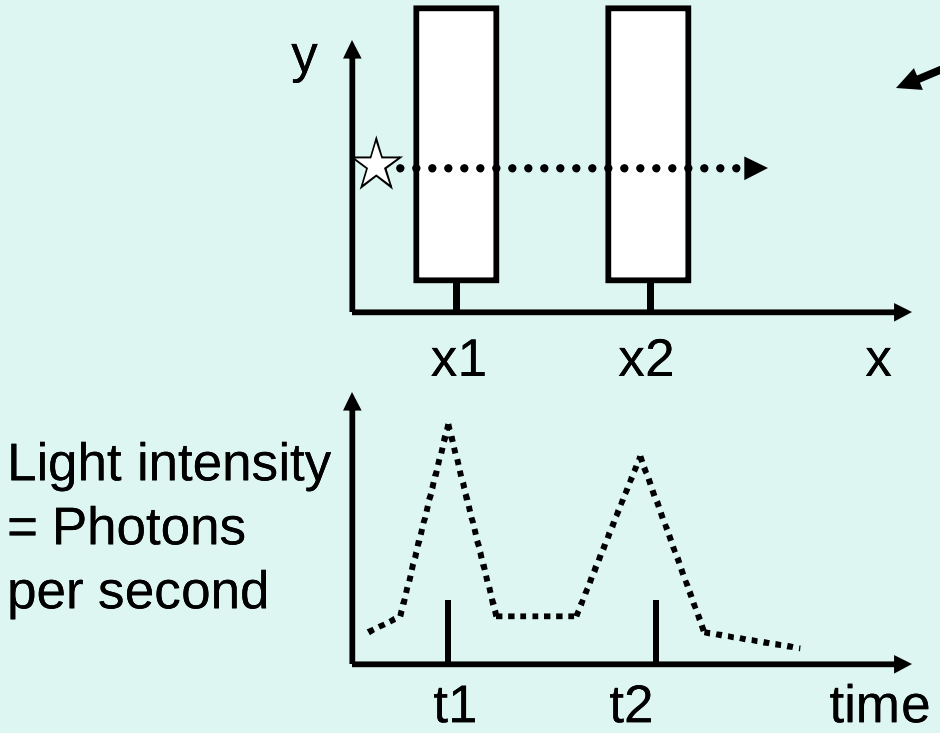


Otto Heckmann

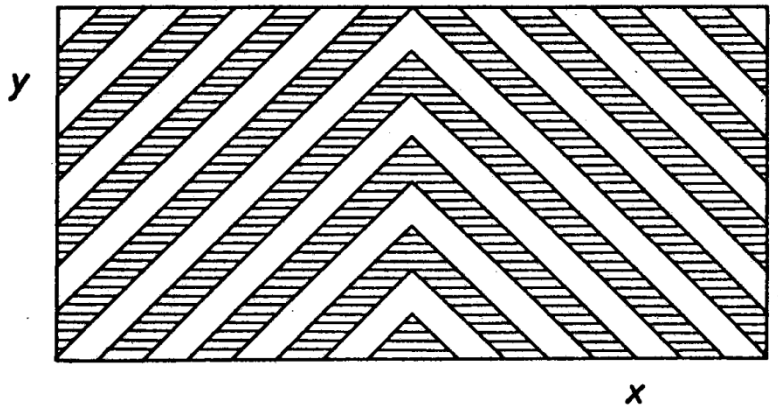
## Iris Photometer

My innovations were much used but did not give me many publications. I won, however, the director Otto Heckmann's sympathy and his confidence that I had even more to offer.

**Slits + Photon counting vs. Time**
**=> Astrometry + Photometry**



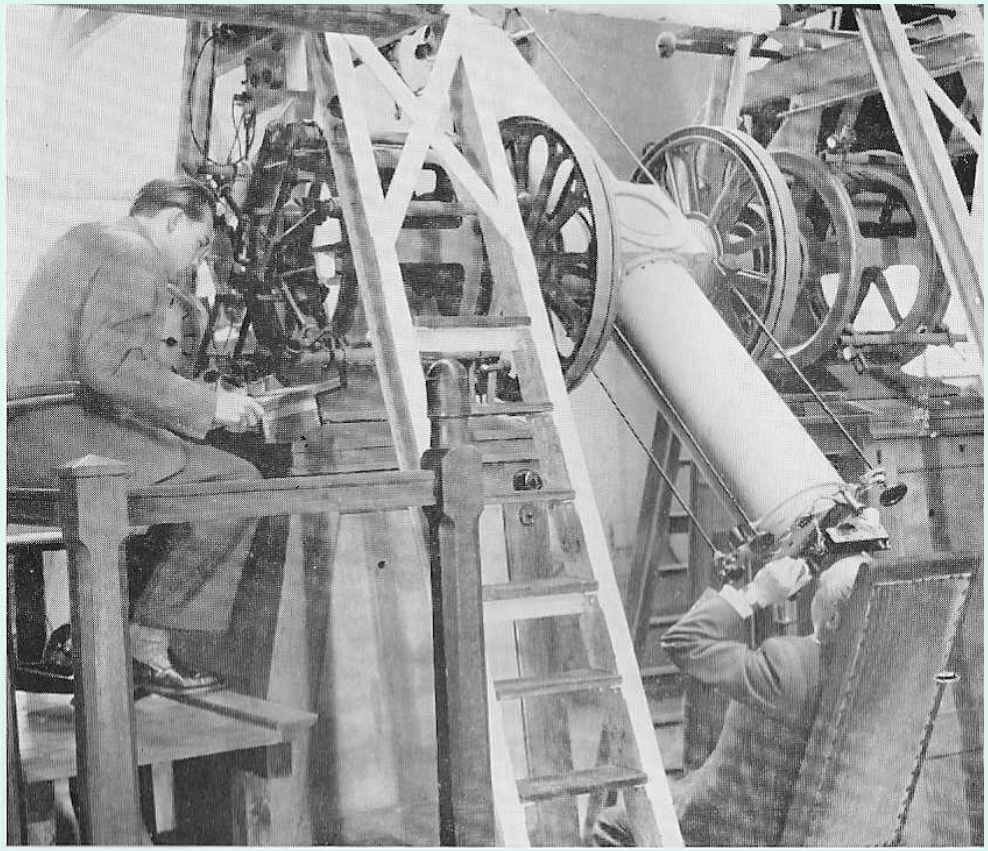

Ideas 1960




In France called: *Une grille de Høg*

B. Strömgren 1933: slits + switching mirror
1930s: Photomultiplier Tube (PMT) and Image Dissector (IDT) developed
Atomic bombs 1957 : Counting techniques
E. Høg 1960 : Slits + counting >>> implementation on meridian circles

# Visual meridian observations Hamburg ~1962



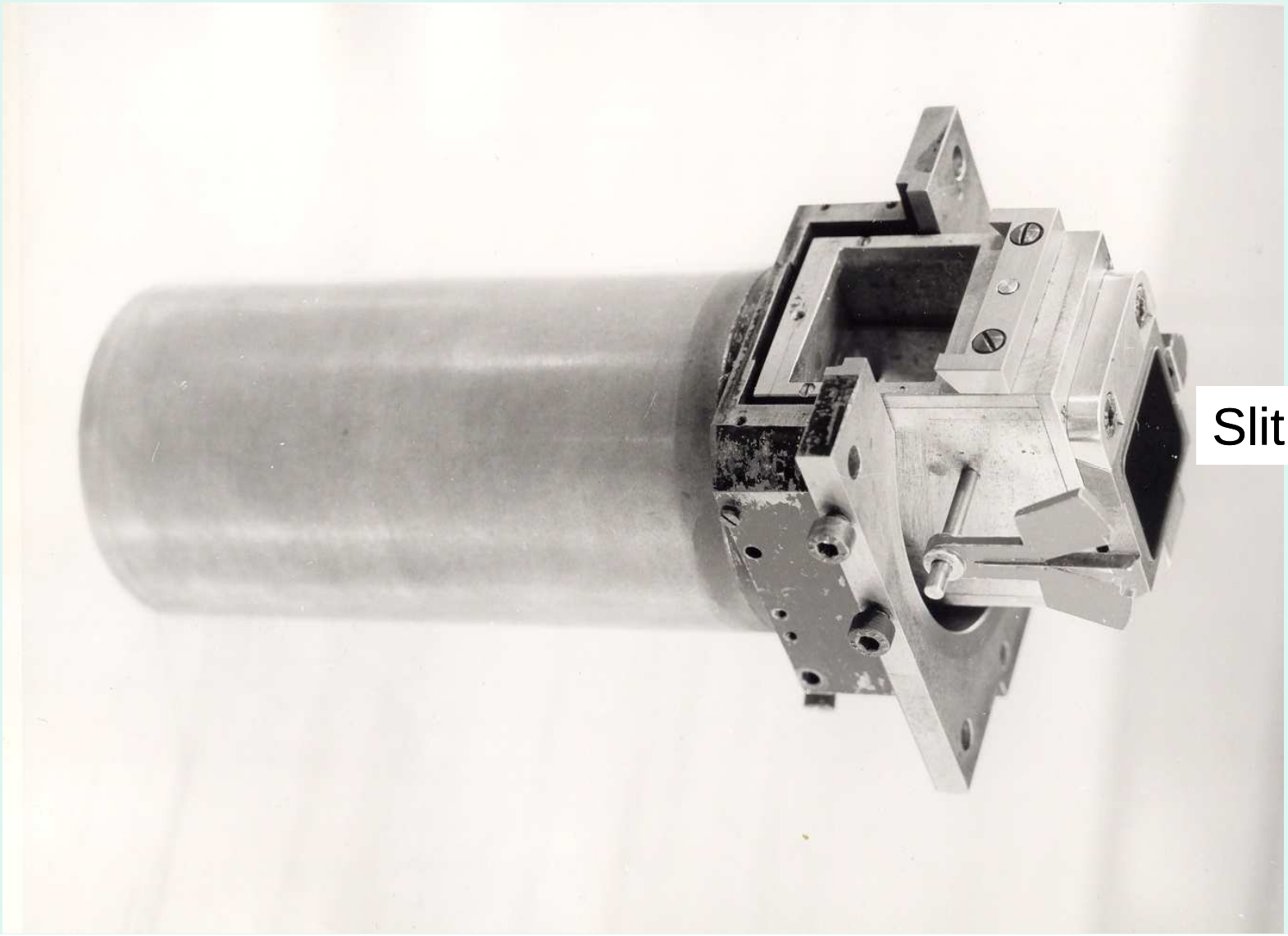
G. Holst reading the declination circle

J. von der Heide observing the star

# Aase and Erik – 1963 in Hamburg

# **First photoelectric slit** micrometer for a meridian circle ~1964

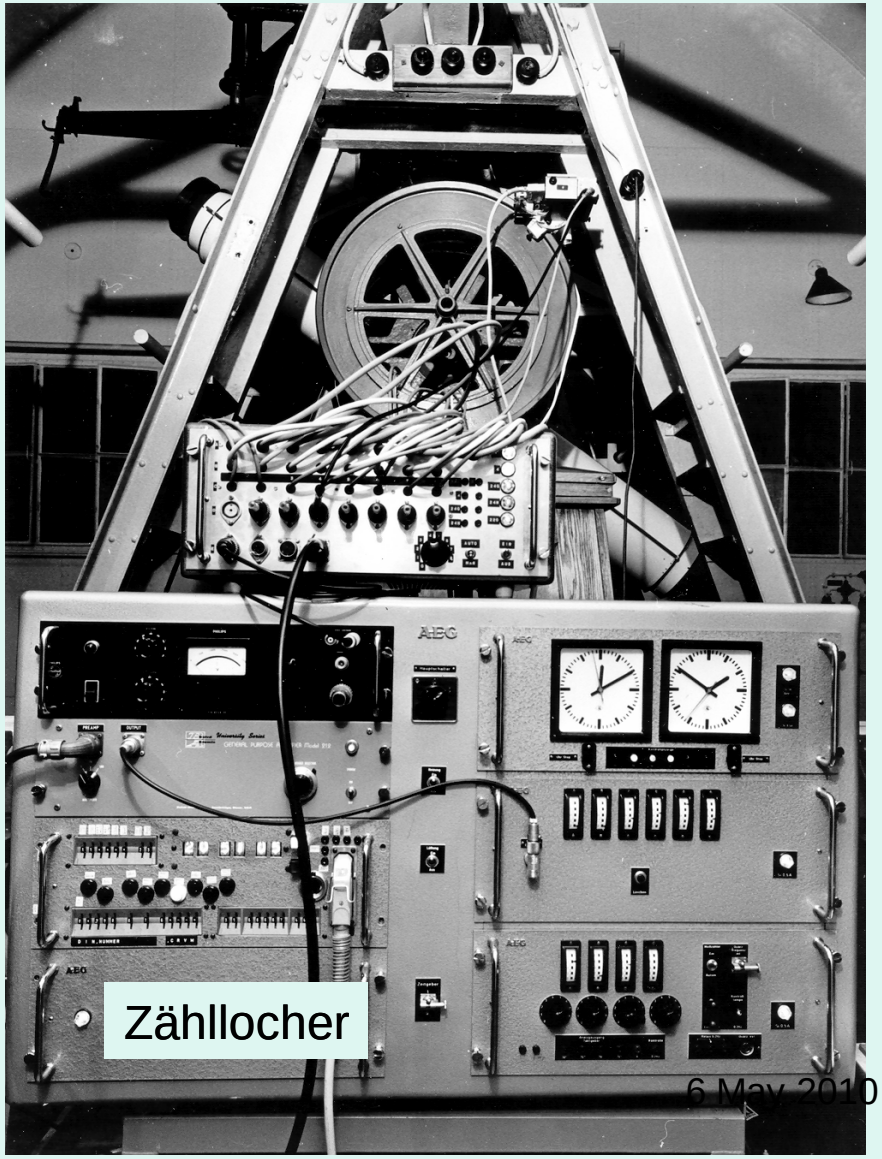
Developed for the Hamburg Expedition to Perth 1967-1972



Slit plate

# Hamburg – Meridian Circle 1966

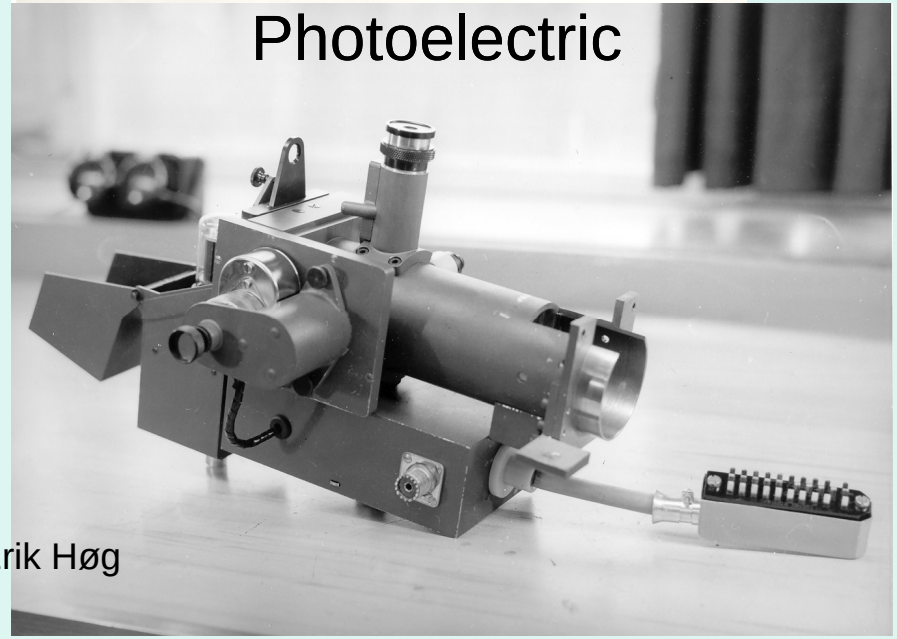
## Reading of the declination circle



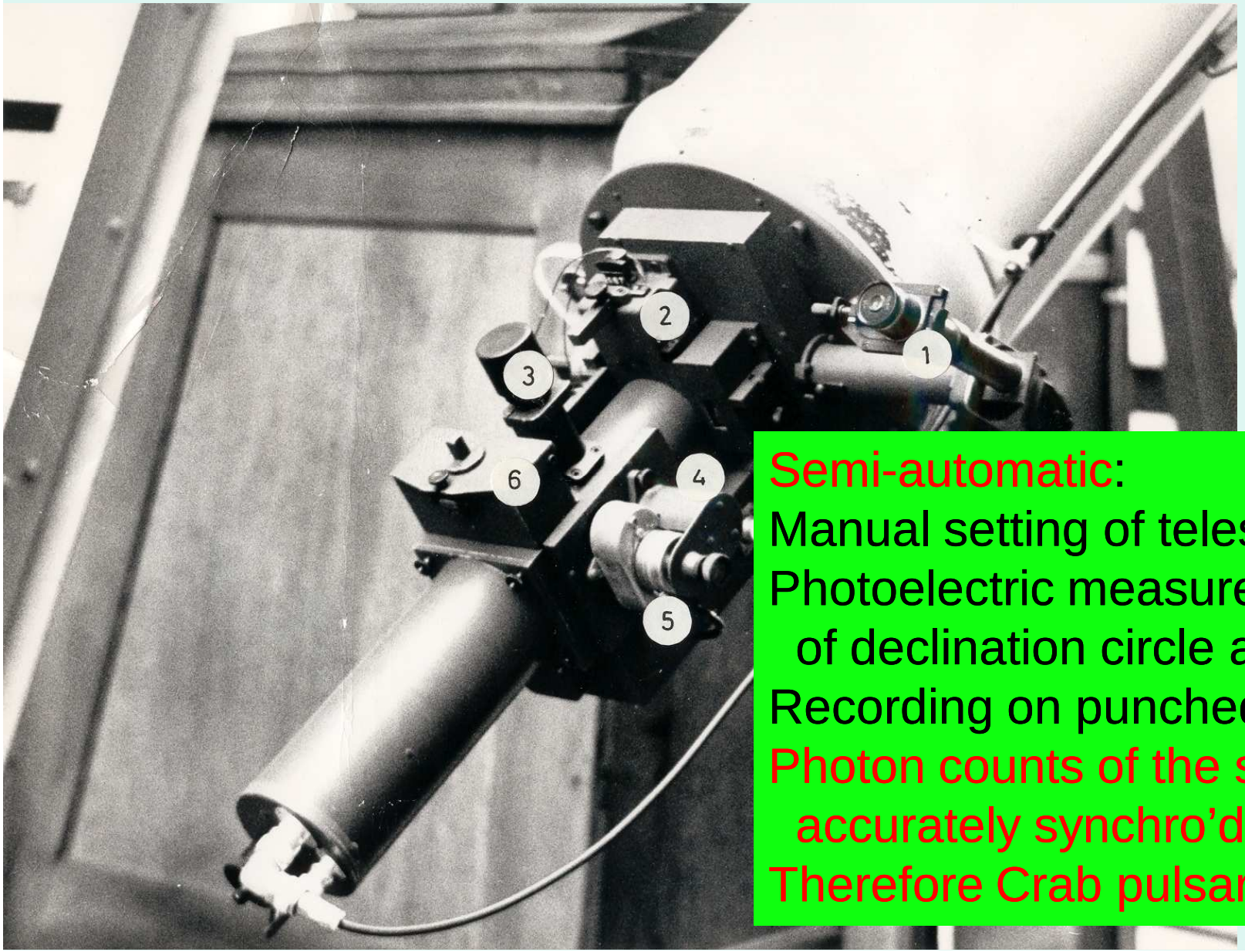

Zähllocher

Visual micrometer

Photoelectric

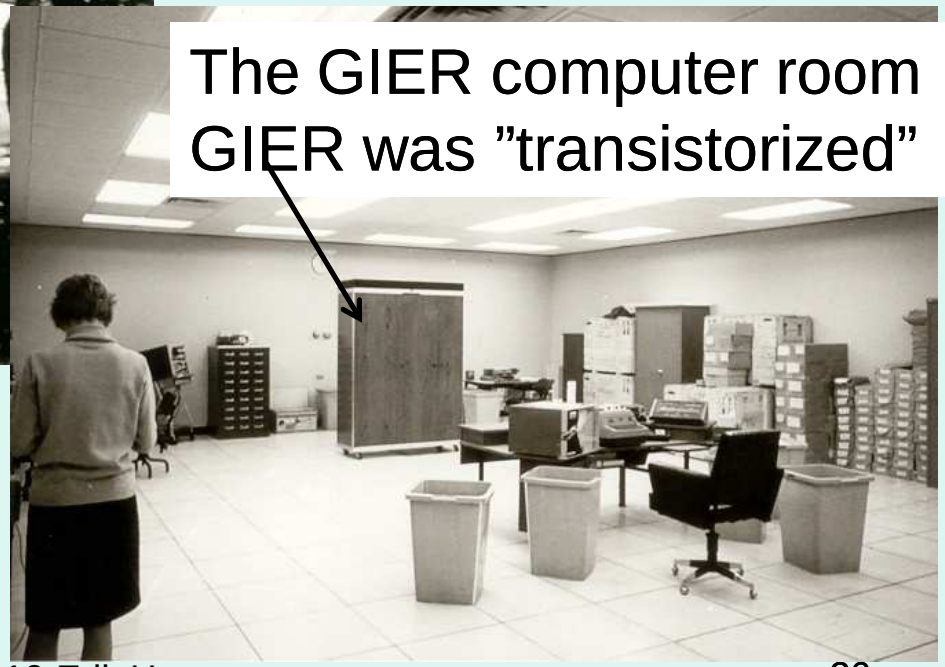


# Hamburg – First slit micrometer on a meridian circle 1966




Semi-automatic:
Manual setting of telescope
Photoelectric measurement of declination circle and star
Recording on punched tape
Photon counts of the star are accurately synchro'd to UT.
Therefore Crab pulsar 1969

# Perth Observatory - 1967



The GIER computer room
GIER was ”transistorized”

# Perth – meridian pavilion

~200 star observations per night
~20 000 per year !!!
Fantastic for 1970

# Final catalogue in 1976 by E. Høg and J. von der Heide

ABHANDLUNGEN AUS DER HAMBURGER STERNWARTE

BAND IX

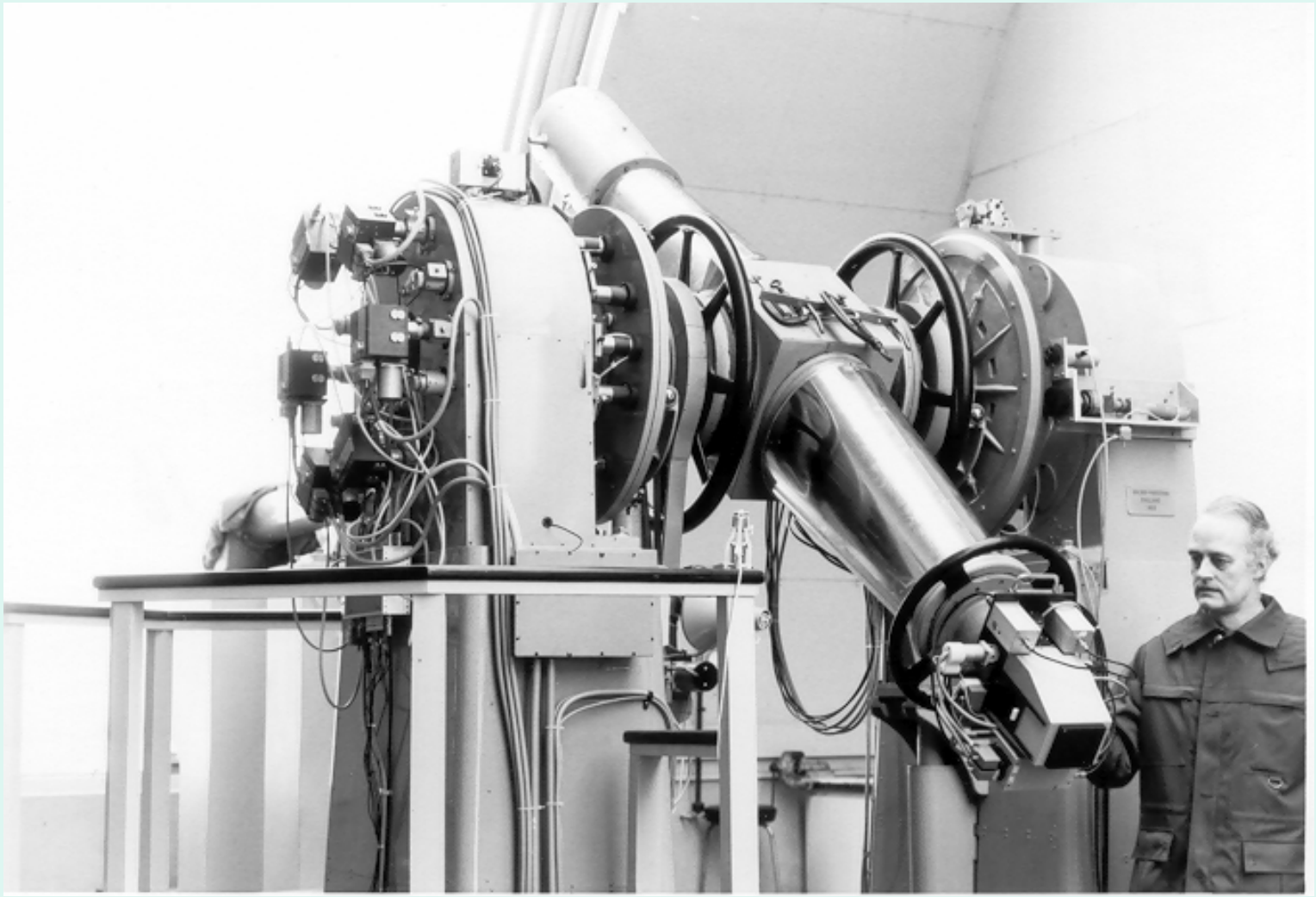
5 years observing by a staff of 10

**PERTH 70**

A CATALOGUE OF POSITIONS

OF 24900 STARS

# Denmark – automatic meridian circle Feb. 1979



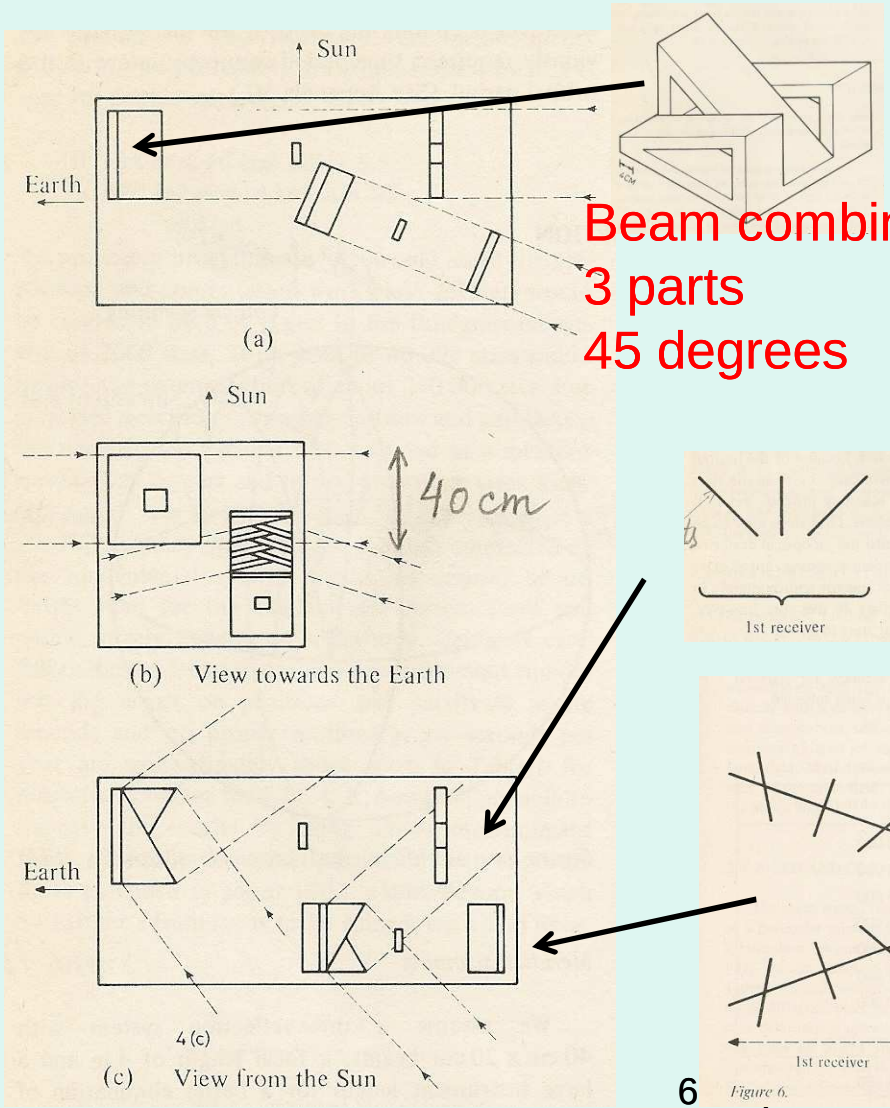
# Space astrometry in France

- Ideas and work in France 1964-74 Nice, Grasse, Paris, Lille: Pierre Bacchus, Strasbourg, and CNES in Toulouse; there was no space astrometry activity outside France in this period
- Pierre Lacroute 1967: Presentation in Prague
- Jean Kovalevsky 1974: European project

Pierre Bacchus & Pierre Lacroute (1985)

Jean Kovalevsky (2005)

# Design of a scanning satellite

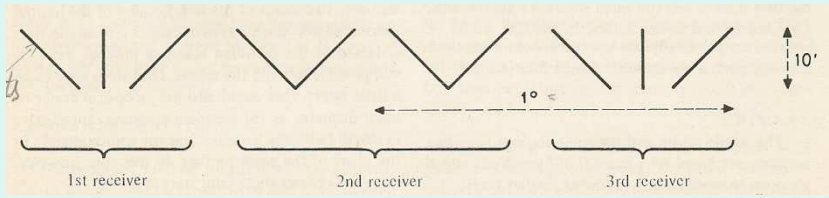


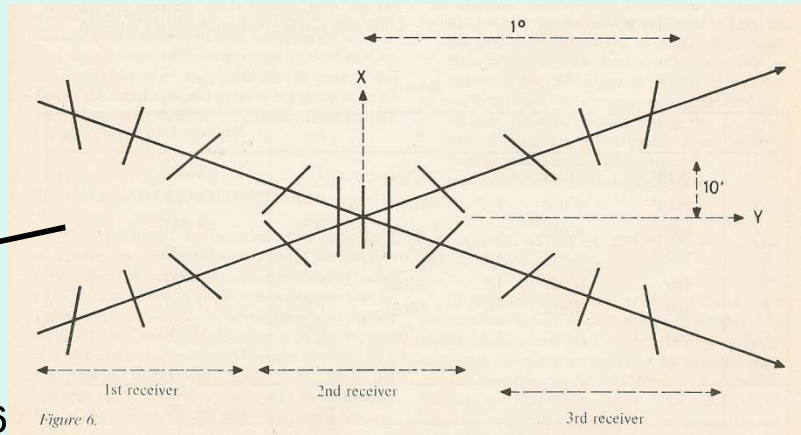



Beam combiner
3 parts
45 degrees

- Lacroute 1974:

Expected 300 000 stars ~3 mas
with 40x40 + 30x30 cm apertures
Two-dimensional measurement
6 Photomultiplier tubes




Frascati 1974 in ESRO SP-108

# Beam combiners and mission

Features later adopted for Hipparcos are in red

- Lacroute 1965-1974:

Scanning satellite

with a beam combiner

Two-dimensional measurement

Beam combiner of 16, 5 or 3 parts

Slit systems

Only photomultiplier tubes (PMs)

Passive attitude control

Spin axis related to orbit

Lacroute also considered

a Spacelab option

First meeting of the study group in Paris on 14 October 1975

- Høg 3 Dec. 1975:

One-dimensional measurement

Beam combiner of 2 parts

Change its angle from 45 deg

Modulating grid

Image dissector tube

Active attitude control

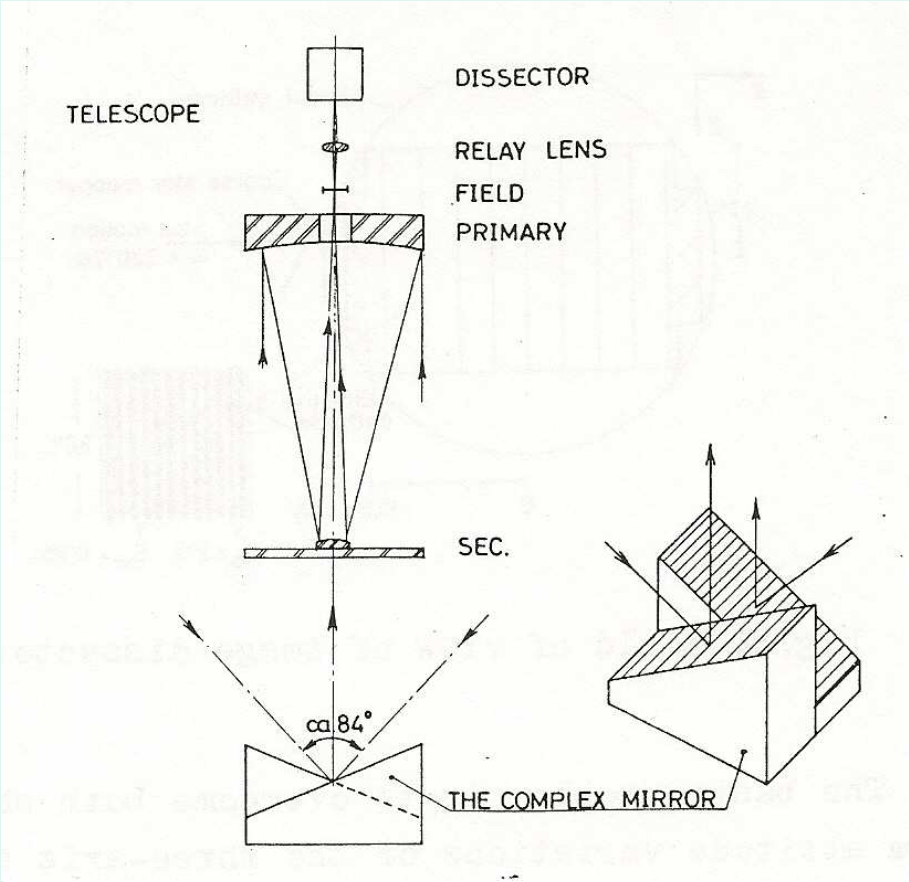
Spin axis revolves around sun

Star mapper with one PM

Input catalogue

The best I ever did for astronomy

# Design of a scanning satellite




IAU GA 1976, Highlights of Astr., p.361

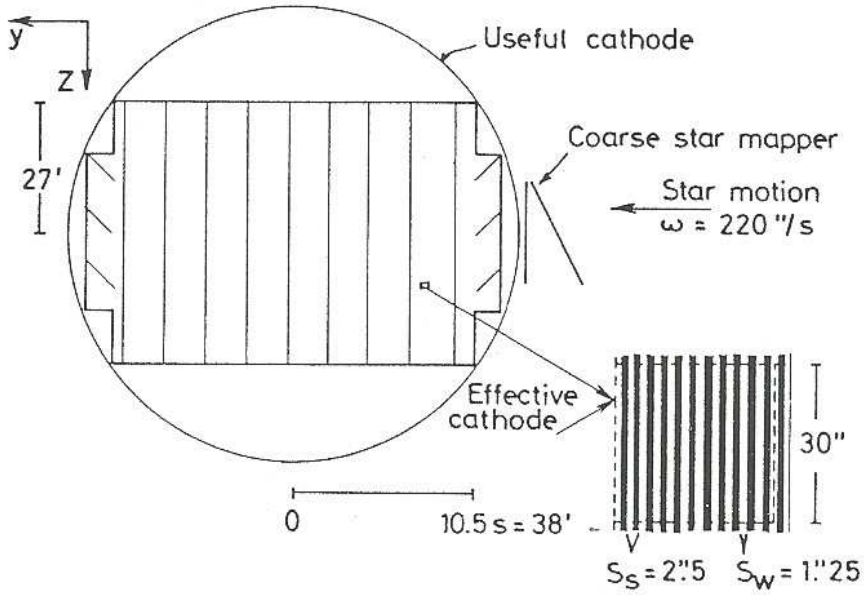
- Høg 1975-1976:

Expected 100 000 stars ~4 mas

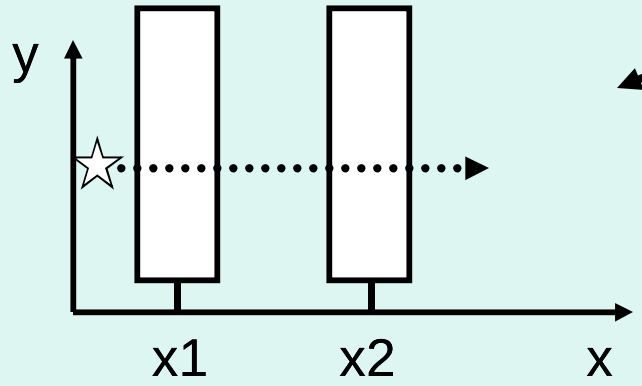
with 16x16 cm aperture

One-dimensional measurement

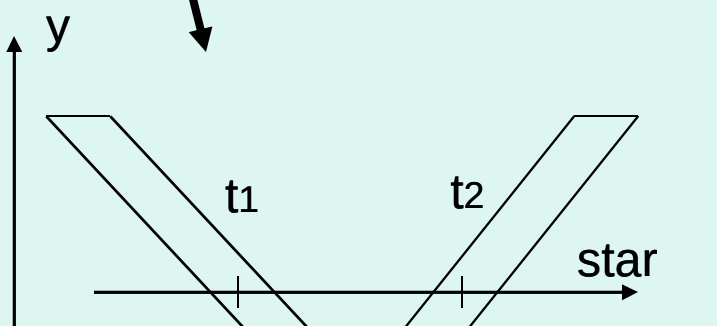
One image dissector tube + one PM



**Slits + Photon counting vs. Time**
**=> Astrometry + Photometry**




Ideas 1960

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B. Strömgren 1933: Slits + switching mirror
E. Høg 1960: Slits + counting

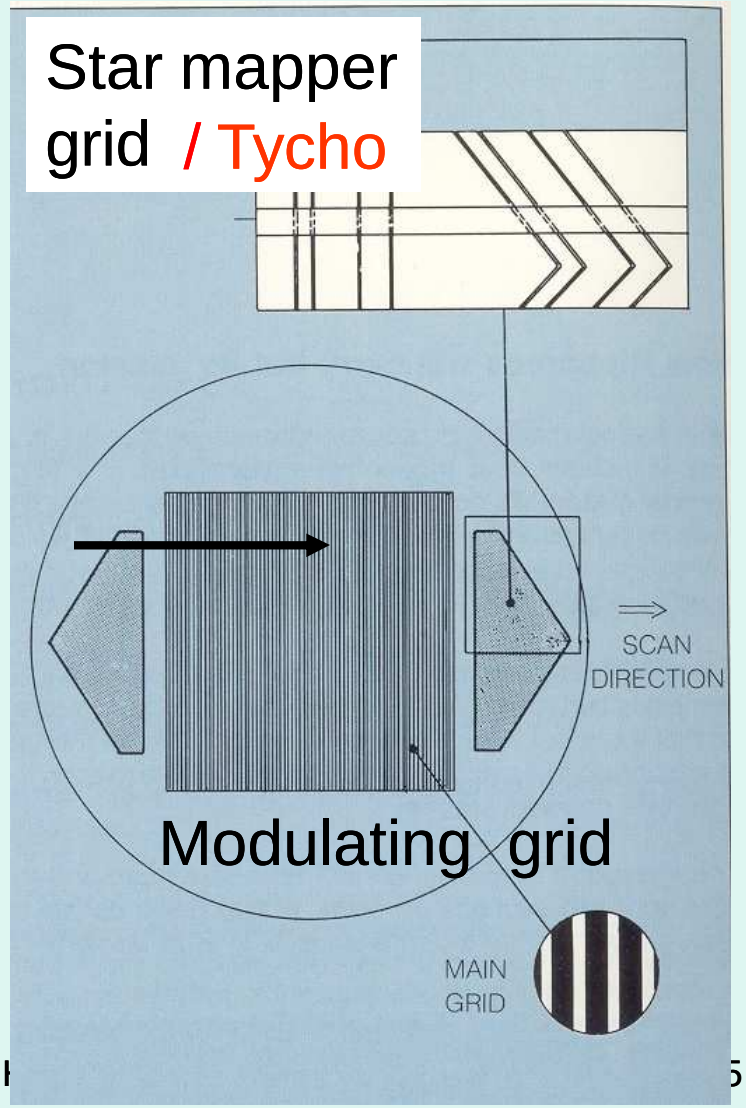
P. Lacroute 1967: Go to space
J. Kovalevsky 1974: European project
E. Høg 1975: New design of mission
L. Lindegren 1976: Data reduction
Studies during 4 years led to:
ESA 1980: Hipparcos approval
*www.astro.ku.dk/~erik/History.pdf*

Hipparcos mission: 1989-93
Final results 1997:
16 volumes + 6 CD ROMs

# Hipparcos and Tycho 1975-2007

- Focal plane of
  Hipparcos – Tycho:

- New mission design Høg 1975
- Mission approval Feb 1980
- Tycho proposal Høg 1981
- Launch 1989
- Catalogues 1997 & 2007
- Tycho-2 Catalogue in 2000
  2.5 million stars
  600 citations by 2009



# Hipparcos mission 1981-1997
# Science leaders

**Catherine Turon (2005)**

**Jean Kovalevsky (2005)**

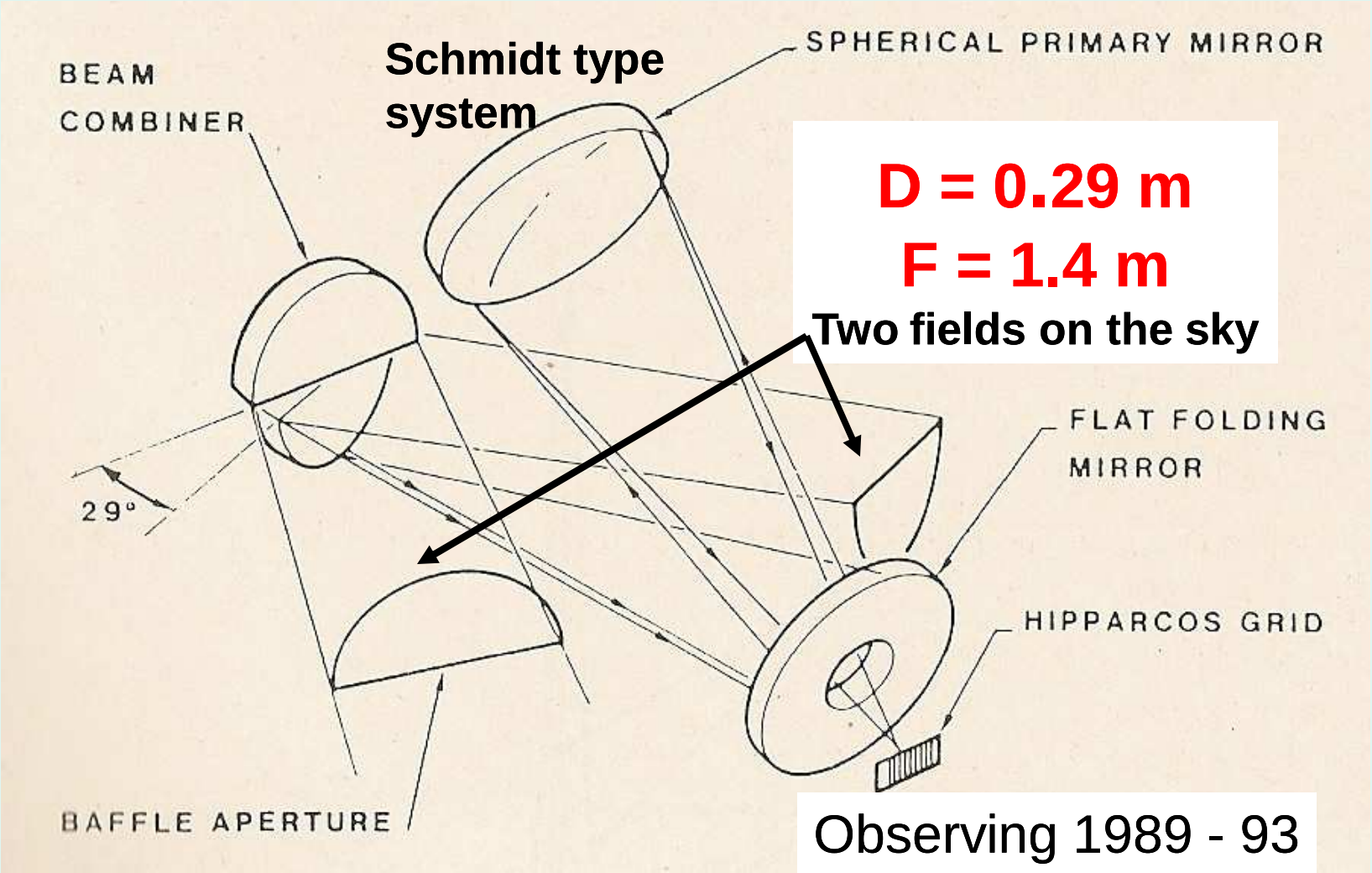
**Michael Perryman (2009)**
**The project scientist and his four consortia leaders**

**Lennart Lindegren (2003)**

**Erik Høg (2009)**

Hipparcos mission
owes a thank you
to all the
hard working
scientists and ESA staff
industry and tax payers

# Telescope of Hipparcos



# Telescope and payload of Gaia

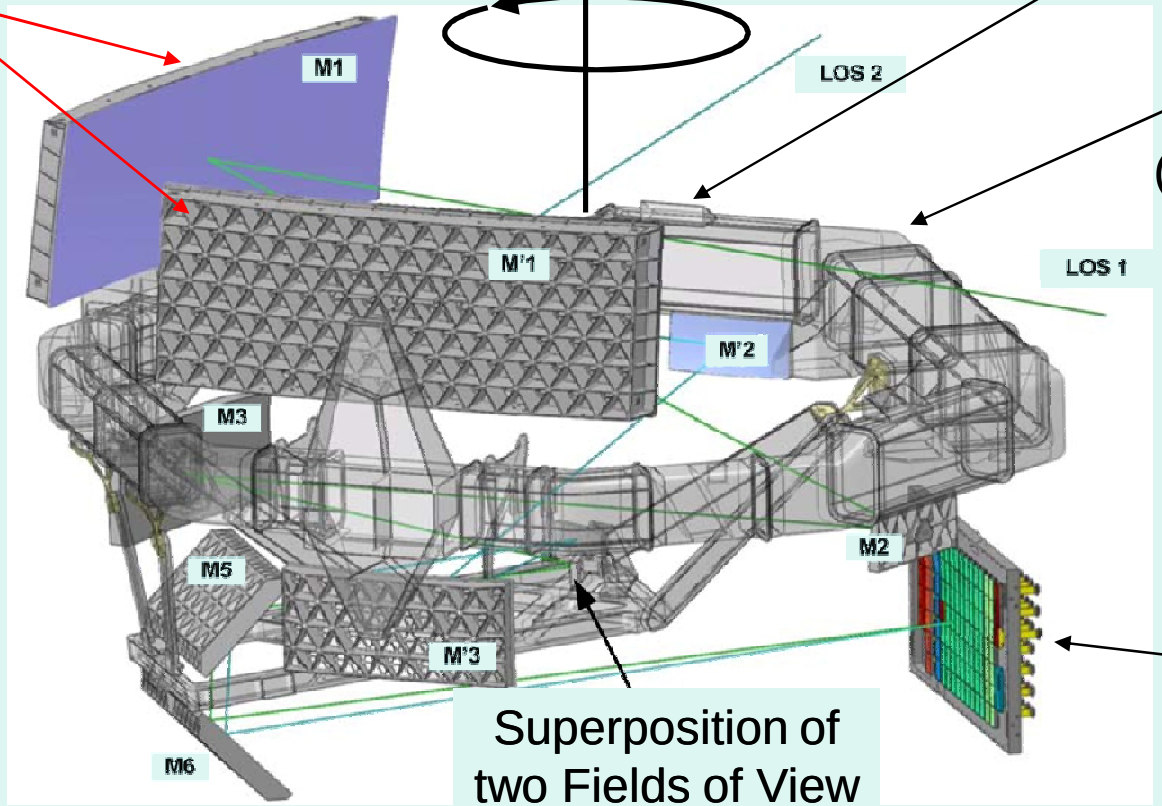
## Launch 2012

Two SiC primary mirrors

$1.45 \times 0.50\ m^2$ at 106.5°

Rotation axis (6 h)

Basic angle monitoring system




SiC toroidal structure (optical bench)

Combined focal plane (CCDs)

F = 35 m

Superposition of two Fields of View

# Two anastigmatic off-axis telescopes



Figure courtesy EADS-Astrium

# Astrometry besides of Gaia and beyond

- High-precision parallaxes of very faint stars:

  Ground-based, Hubble, JASMINE, J-MAPS, SIM
- Black hole at the Galactic Center
- Astrometric all-sky surveys beyond 20 mag

  including multi-colour photometry

  See: *www.astro.ku.dk/~erik/AstrometricSurveys.pdf*

# Carlsberg automatic meridian circle on La Palma from 1984

**Photoelectric**
**during 14 years**

**Then from 1998**
**CCD micrometer :**
**20,000,000 star observations per year**
**100 mas per obs.**

**4000 x better than 1970 in Perth**

# USNO – US Naval Observatory

**UCAC: CCD Astrograph Catalog**

4 k x 4 k pixels CCD 1 sq.deg

2000: UCAC2: 48 million stars

70 mas at limit R=16 mag

20 mas 10-14 mag

2009: UCAC3: 100 million stars, all sky

70 mas at limit R=16 mag

15 mas 10-14 mag

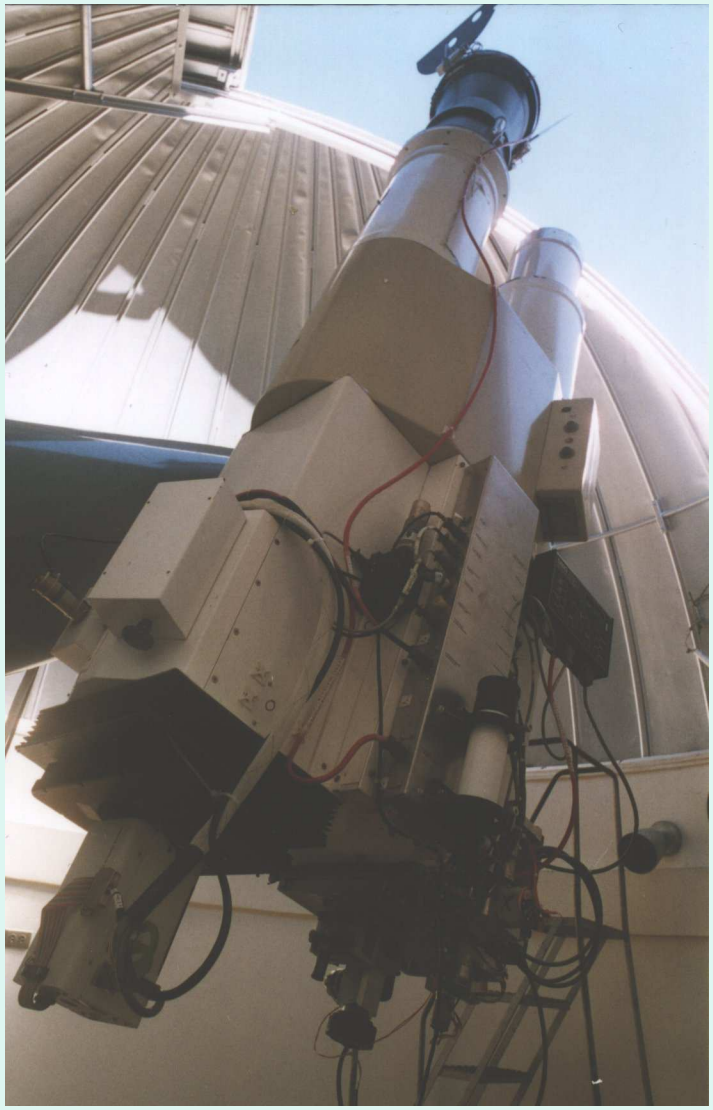
**URAT: 20 cm, f= 2m Astrograph, same as UCAC**

10 k x 10 k CCD 4x = 28 sq.deg

2009-2015: 400 million stars, all sky

30 mas at R=18 mag

5 mas 10-15 mag



# Astrometric performance 1800-2000

- 1st class position catalogues
- Weight = $N \sigma^{-2}_{star} 10^{-6}$

| Publ year | Name | Obs. years | N stars | $\sigma_{star}$ arcsec | Weight |
|---|---|---|---|---|---|
| 1814 | Piazzi | 21 | 7646 | 1.4 | 0.0034 |
| 1908 | Küstner | 10 | 10663 | 0.34 | 0.092 |
| 1952 | USNO | 8 | 5216 | 0.15 | 0.23 |
| 1997 | Hipparcos | 3 | 118 000 | 0.001 | 120 000 |
| 2000 | Tycho-2 | 3 | $2.5\ 10^6$ | 0.06 | 700 |

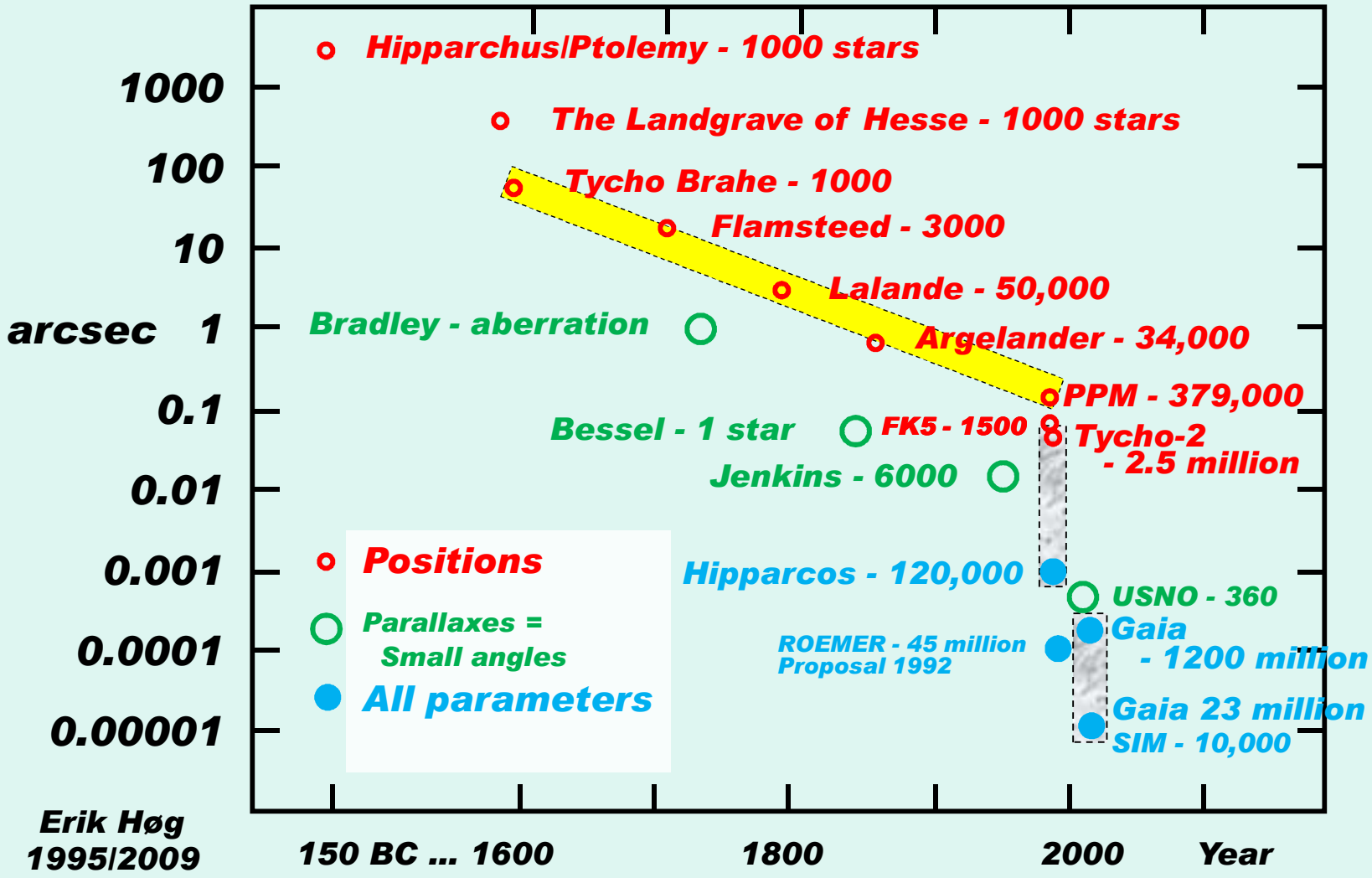
# Some results from astrometry 1900-2007

- By 1900 : 539 stars 0.01”/a motions Decl. > -10 deg
- 1905 : Hertzsprung discovers dwarfs/giants using motions for distances
  100 stars 0.04” relative parallaxes
- By 1950 : 33,342 stars 0.01”/a motions,
  5822 stars 0.01” relative parallaxes
  500 stars with <10% error on distances

❖ 1970 - : Radio astrometry : accurate absolute positions, reference system by quasars, Earth rotation

- 1997 : Hipparcos satellite : accurate large & small angle
  120,000 stars 0.001” ann. motions (N & S) & abs, parallaxes
  21,000 stars with <10% error on distances
  2007 : 30,000 stars with <10% error on distances
  2000 : Tycho-2 : 2.500,000 stars 0.002”/a motions
  USNO : 1,000,000,000 stars to 20th mag

# Astrometric Accuracy versus Time



# After Gaia
## what then ? ? ?

# How Gaia began

- *August 1989: Hipparcos launched*
- 1990-91 dialogue with Russian colleagues
- *Proposal 1992: Scanning mission with* ***CCDs***

# From the Roemer mission to Gaia

by Erik Høg, Copenhagen

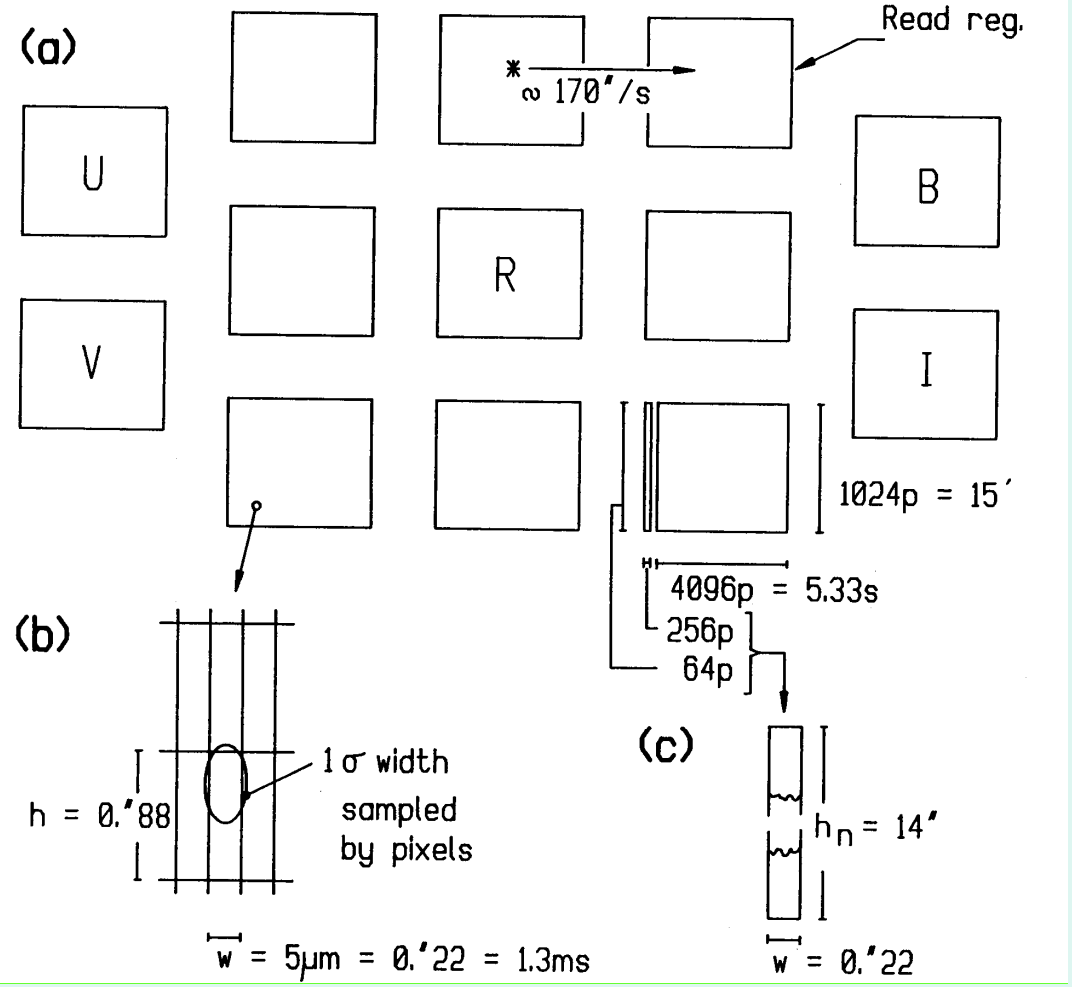
- *August 1989: Hipparcos launched*
- 1990-91 dialogue with Russian colleagues
- *Proposal 1992 at IAU Symposium in Shanghai:*

  Satellite in scanning mode with CCDs

  Direct imaging for astrometry and photometry

  0.1 mas at 12 mag from a 5 year mission
- Roemer proposal for ESA M3 mission in 1993
- Later enhancements: *0.01 mas mission goal; Input catalogue dropped; Interferometry studied and dropped; Radial velocities added; Prism photometry instead of filters.*
- *Other missions: SIM, DIVA, FAME*
- *Get the 6-page poster at [www.astro.ku.dk/~erik](http://www.astro.ku.dk/~erik) in the section Gaia*

# Fig. 1. Focal plane of Roemer - 1992





# *The F.G.W. Struve medal*

***awarded for the great contribution to development of ground-based and space astrometry by***

# Erik Høg

*Scientific Council of the*
*Central Astronomical Observatory of the*
*Russian Academy of Sciences*

*Director of the CAO RAS* *A.V. Stepanov*

*Pulkovo Observatory*
*2009*