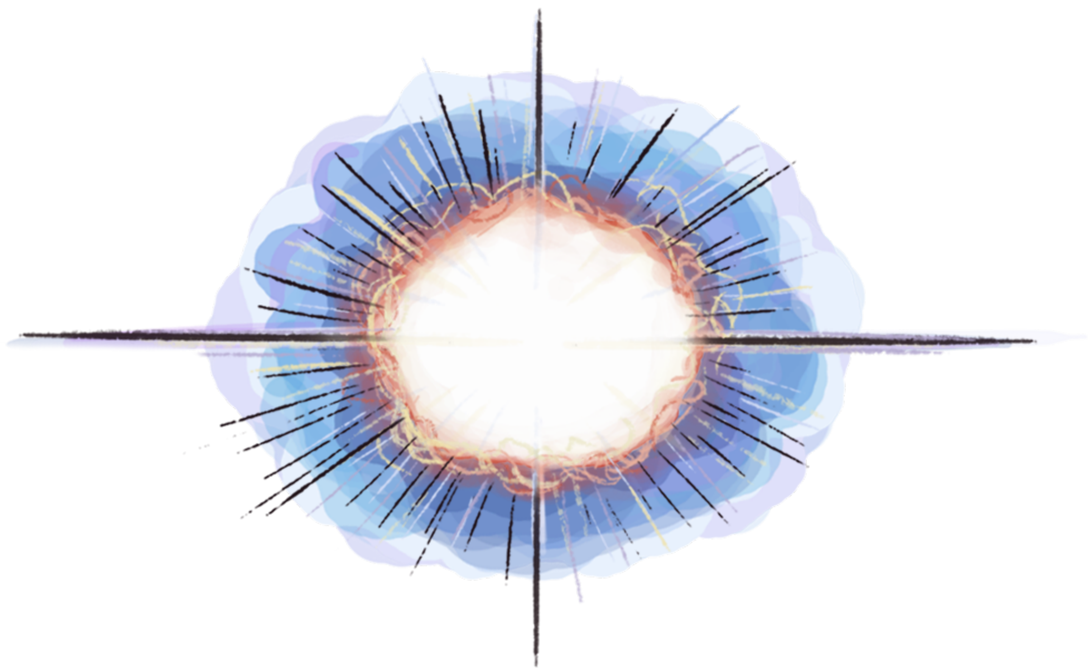
Stellar Structure and Evolution



KU LEUVEN

Pablo Marchant

Who is this guy?

Who is this guy?

Santiago de Chile
Bachelor+Master

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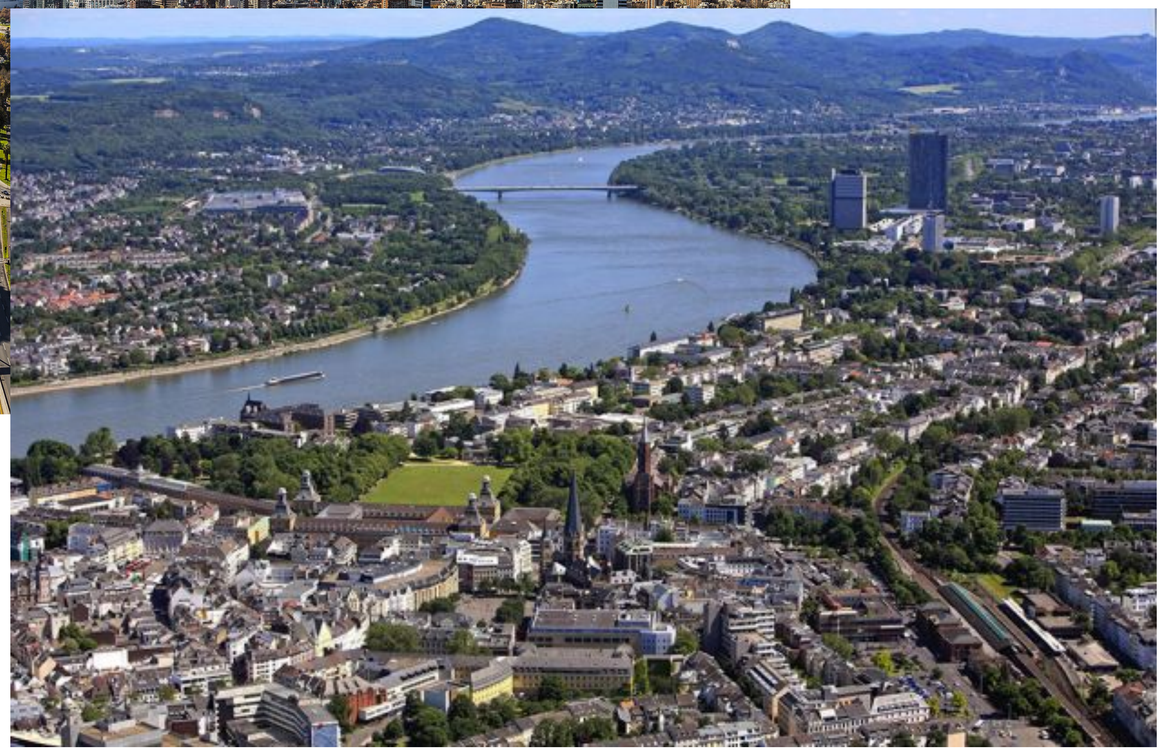


Bonn, Germany
Phd

Who is this guy?

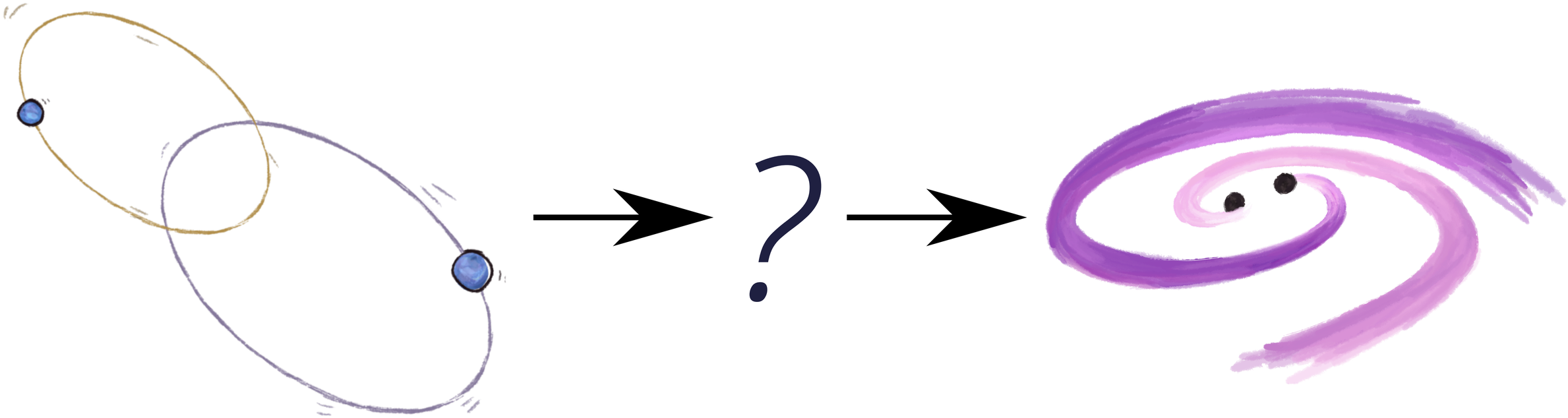
Santiago de Chile
Bachelor+Master

Bonn, Germany
Phd

Chicago, USA
Postdoc

KU LEUVEN

What do I work on?



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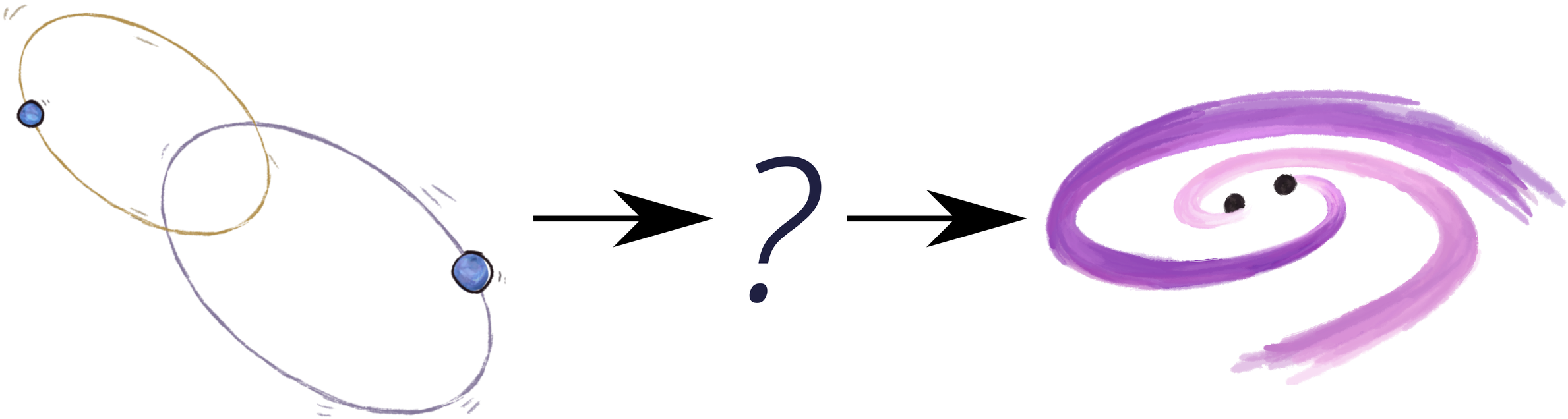
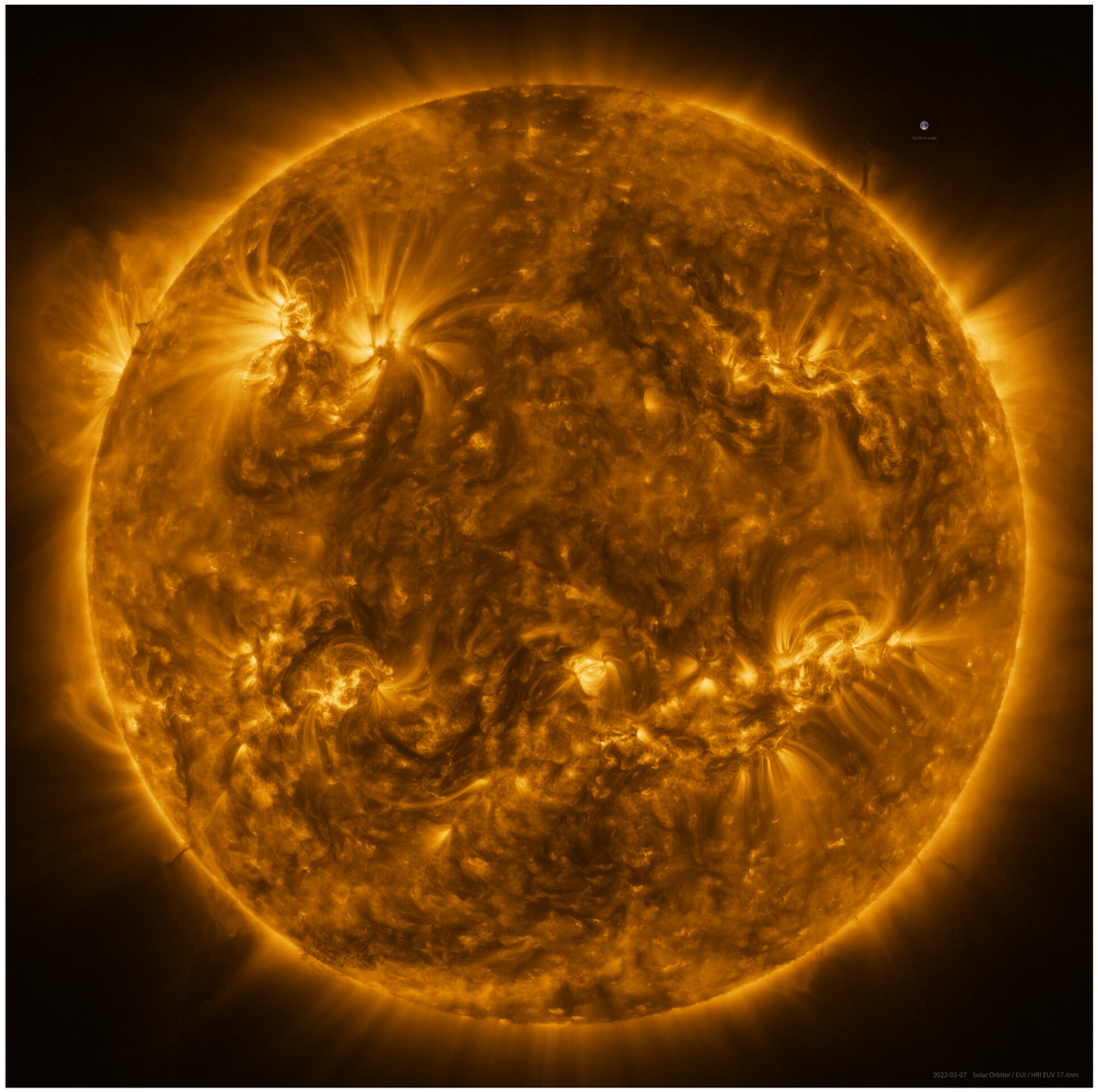


MESA

State of the art stellar evolution code

What about you?

Objectives of this course



ESA & NASA/Solar Orbiter/EUI team; Data processing: E. Kraaikamp (ROB)

- Derive the equations of stellar structure and evolution.

- Study the relevant microphysical ingredients of relevance (i.e., equation of state, nuclear reactions).

- Understand the different phases of evolution of a star, including its end stages.

- Compute detailed models of the structure and evolution of stars.

Course structure

Course structure

Textbook reading

+

Black board lecture

+

Pen & paper exercises

+

Computational examples

Course structure

Textbook reading

+

Black board lecture

+

Pen & paper exercises

+

Computational examples

Stellar modelling labs

MESA

Annachiara Picco

Course structure

Textbook reading

+

Black board lecture

+

Pen & paper exercises

+

Computational examples

Stellar modelling labs

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Annachiara Picco

Final written exam

Course structure

Textbook reading

+

Black board lecture

+

Pen & paper exercises

+

Computational examples

Stellar modelling labs

MESA

Annachiara Picco

8 points

Final written exam

12 points

Course schedule

Today: *History*

1/10: *Eqs. of stellar structure*

8/10: *Equations of state 1*

15/10: *Equations of state 2*

22/10: *Radiative transfer*

29/10: *Convection*

05/11: *Lab 1*

12/11: *Nucleosynthesis 1*

19/11: *Nucleosynthesis 2*

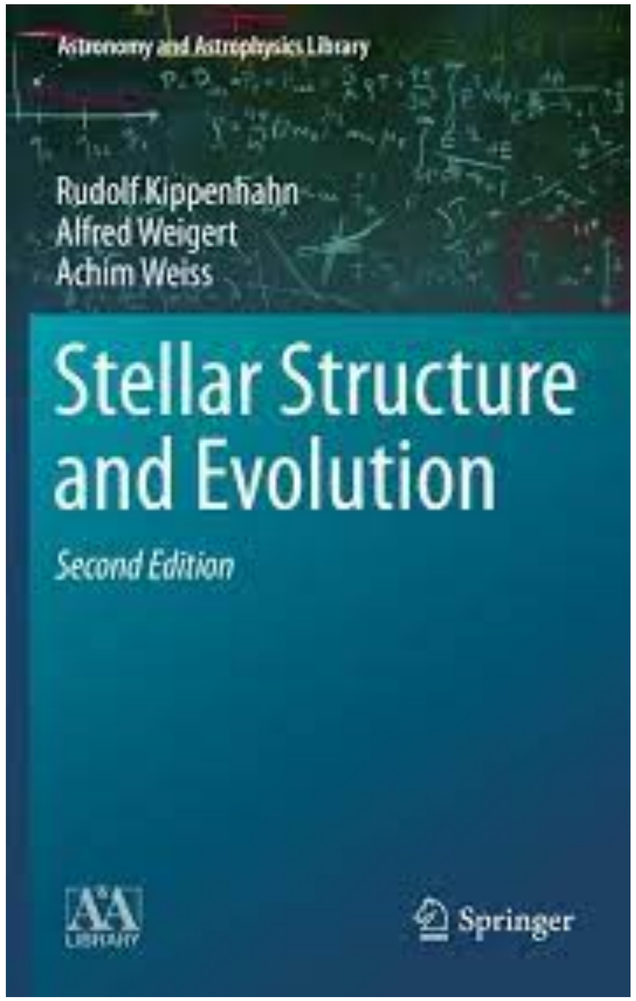
26/11: *Stellar evolution 1*

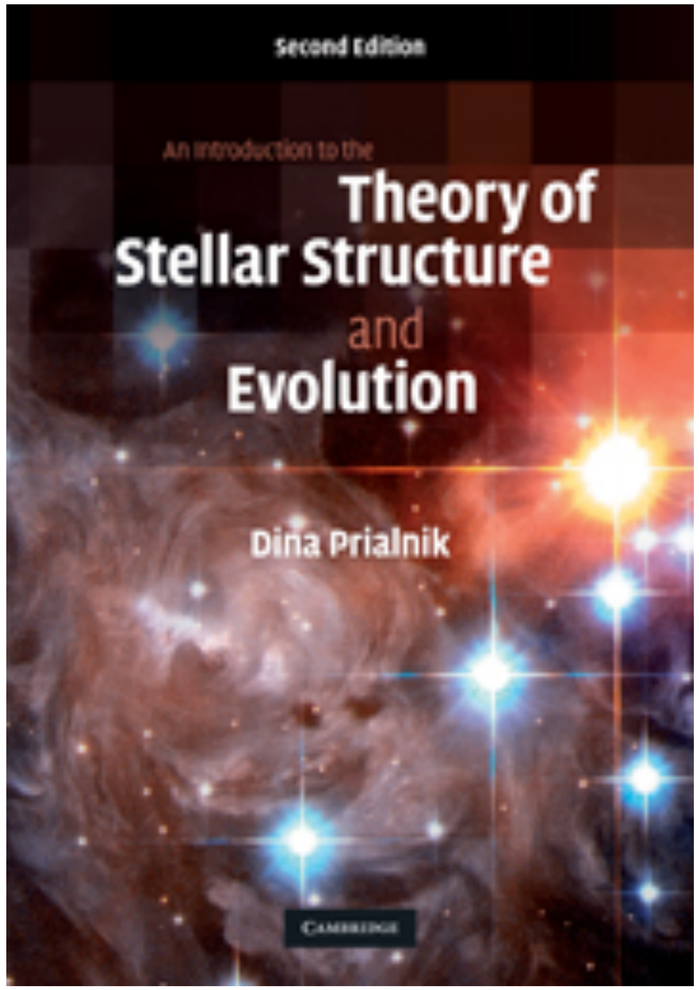
03/12: *Lab 2*

10/12: *Stellar evolution 2*

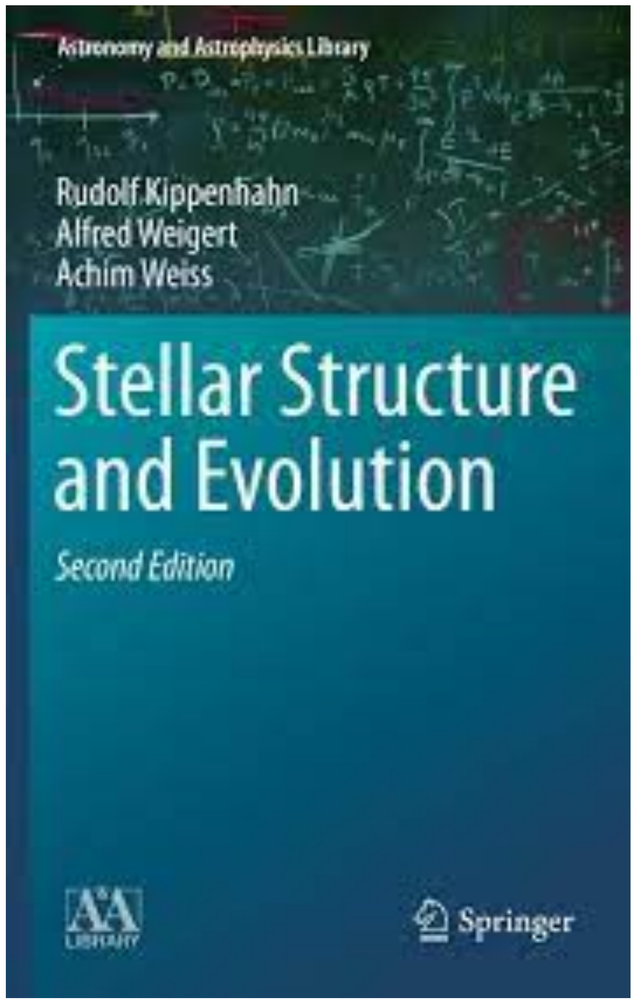
+ extra summary on **17/12**

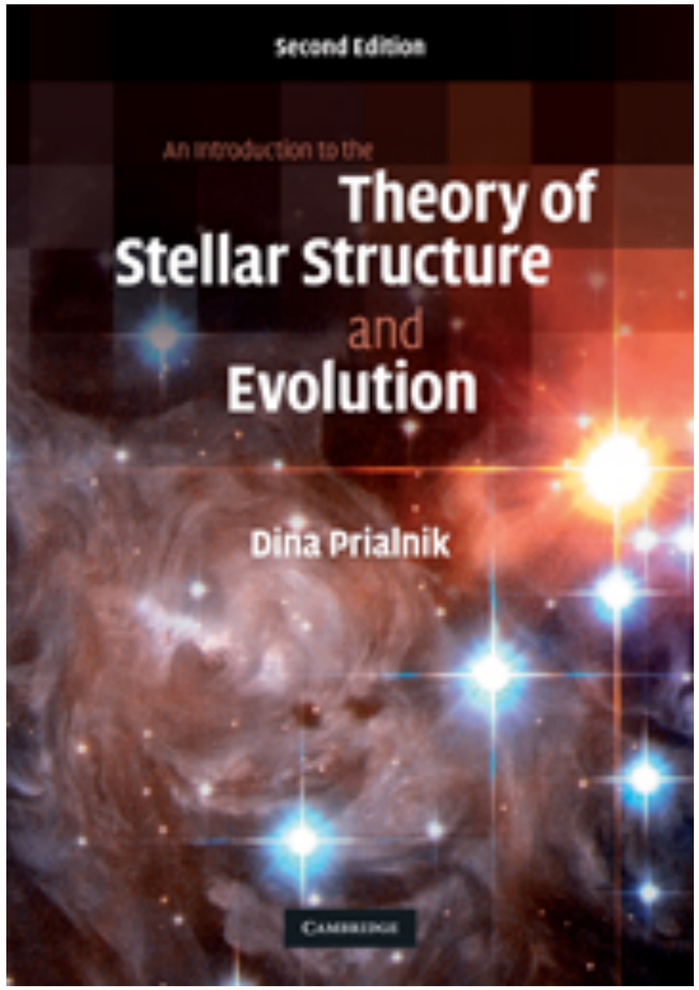
Resources

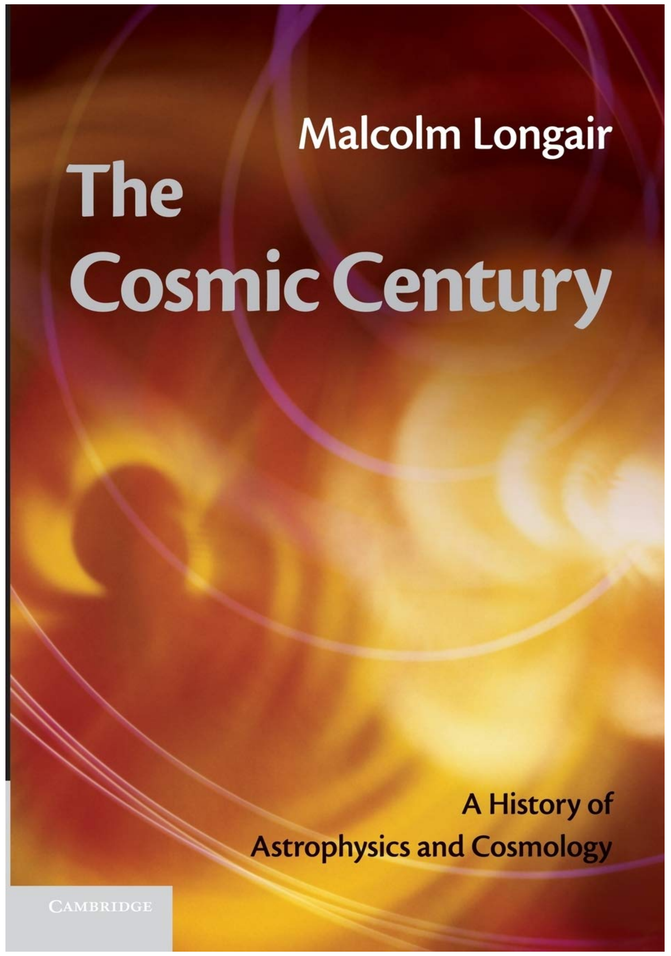

Astronomy and Astrophysics Library
Rudolf Kippenhahn
Alfred Weigert
Achim Weiss
Stellar Structure and Evolution
Second Edition
Springer


Second Edition
An introduction to the
Theory of Stellar Structure and Evolution
Dina Prialnik

Resources







Good resource on history!

Measuring light

Apparent magnitude:

$$m_1 - m_2 = -2.5 \log_{10} \left(\frac{S_1}{S_2} \right)$$

Absolute magnitude, magnitude object would have at a distance of 10 pc:

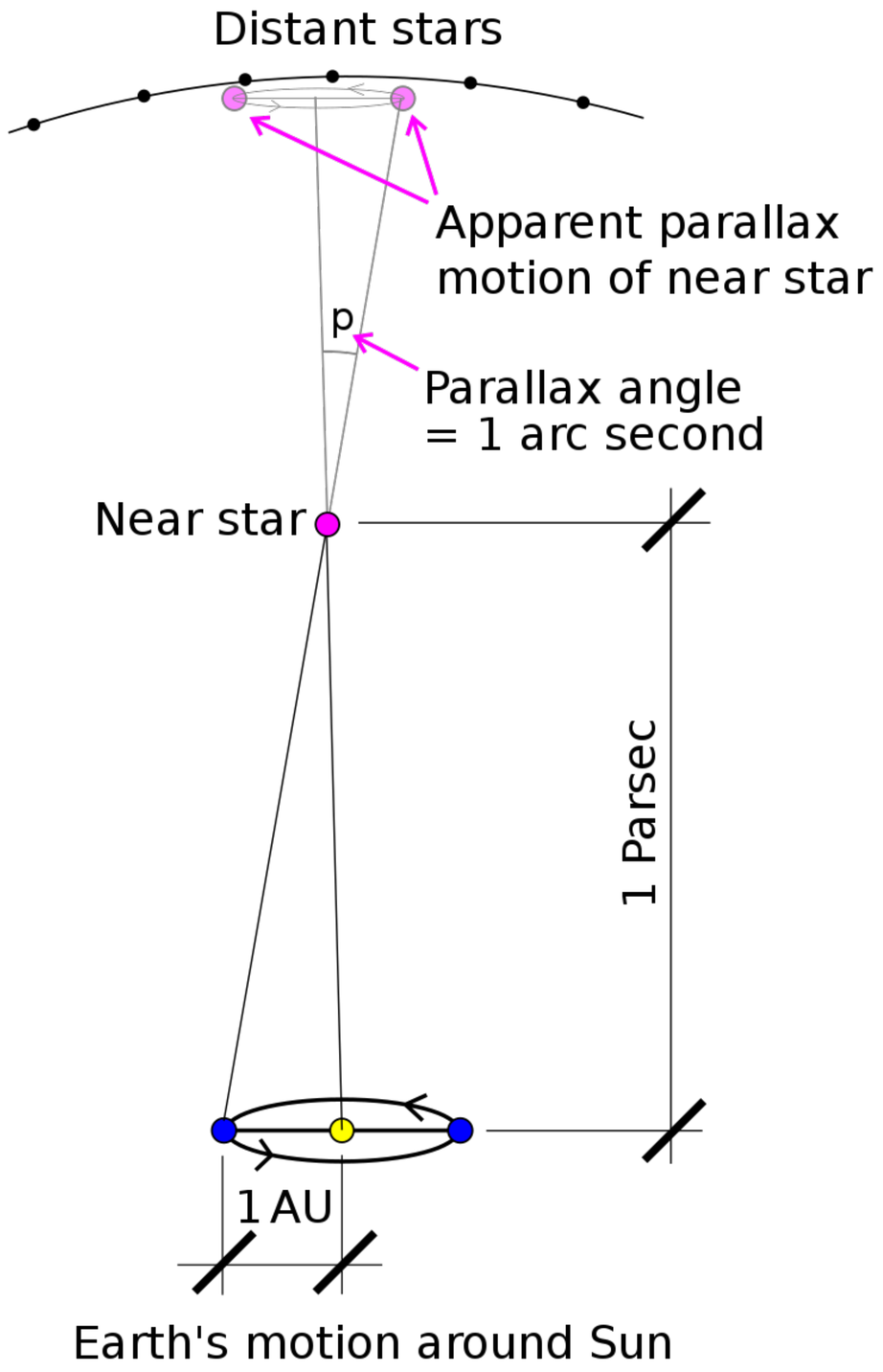
$$S = \frac{L}{4\pi d^2} \rightarrow M - m = 2.5 \log_{10} \left(\frac{10\mathrm{pc}}{d} \right)^2$$

Beware this does not define the zero point!

What is a parsec?

One parsec is the distance at which a star exhibits a parallax of one arcsecond.

$$\frac{d}{1\mathrm{pc}} = \frac{1}{p/1''}$$



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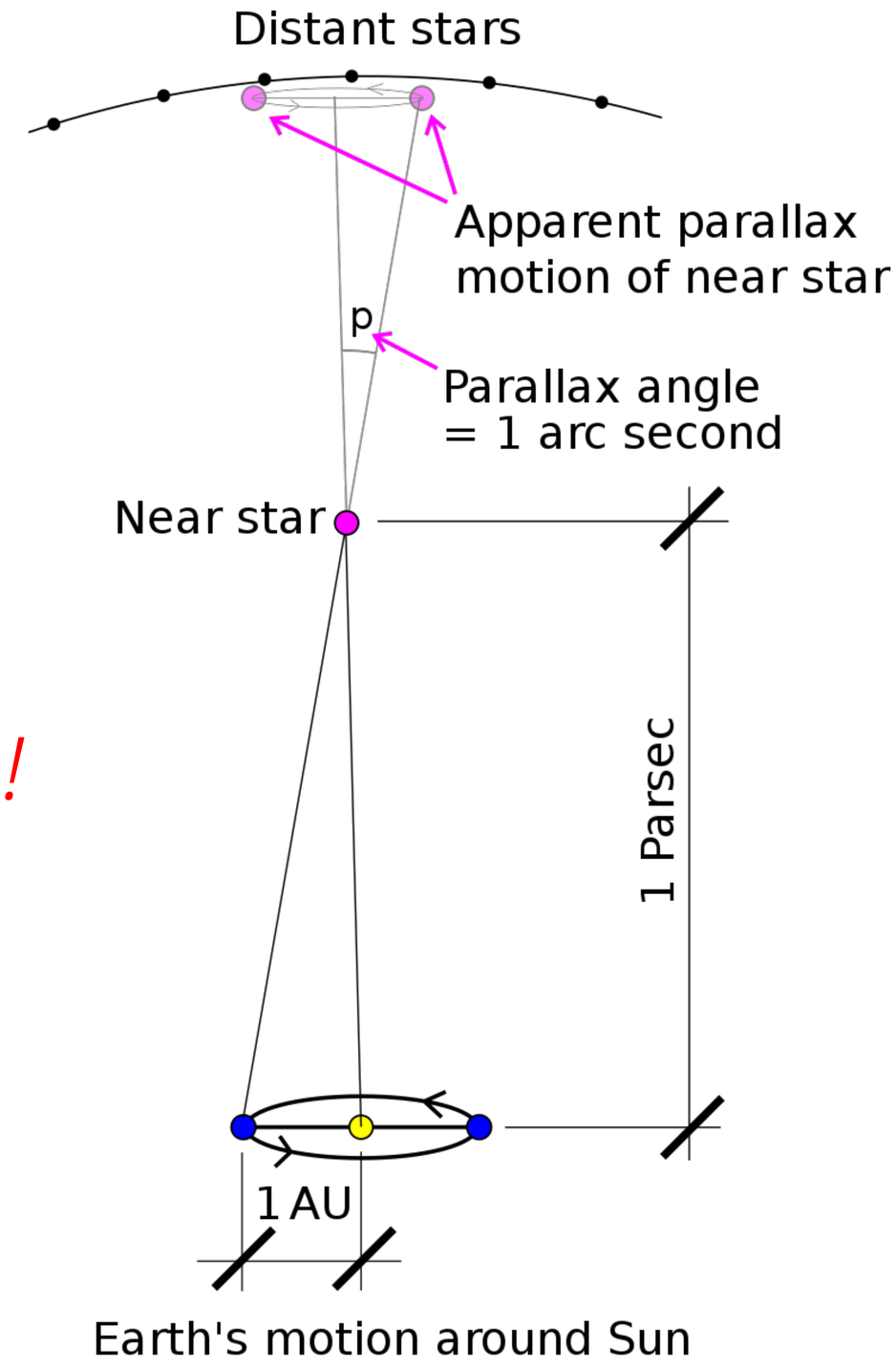
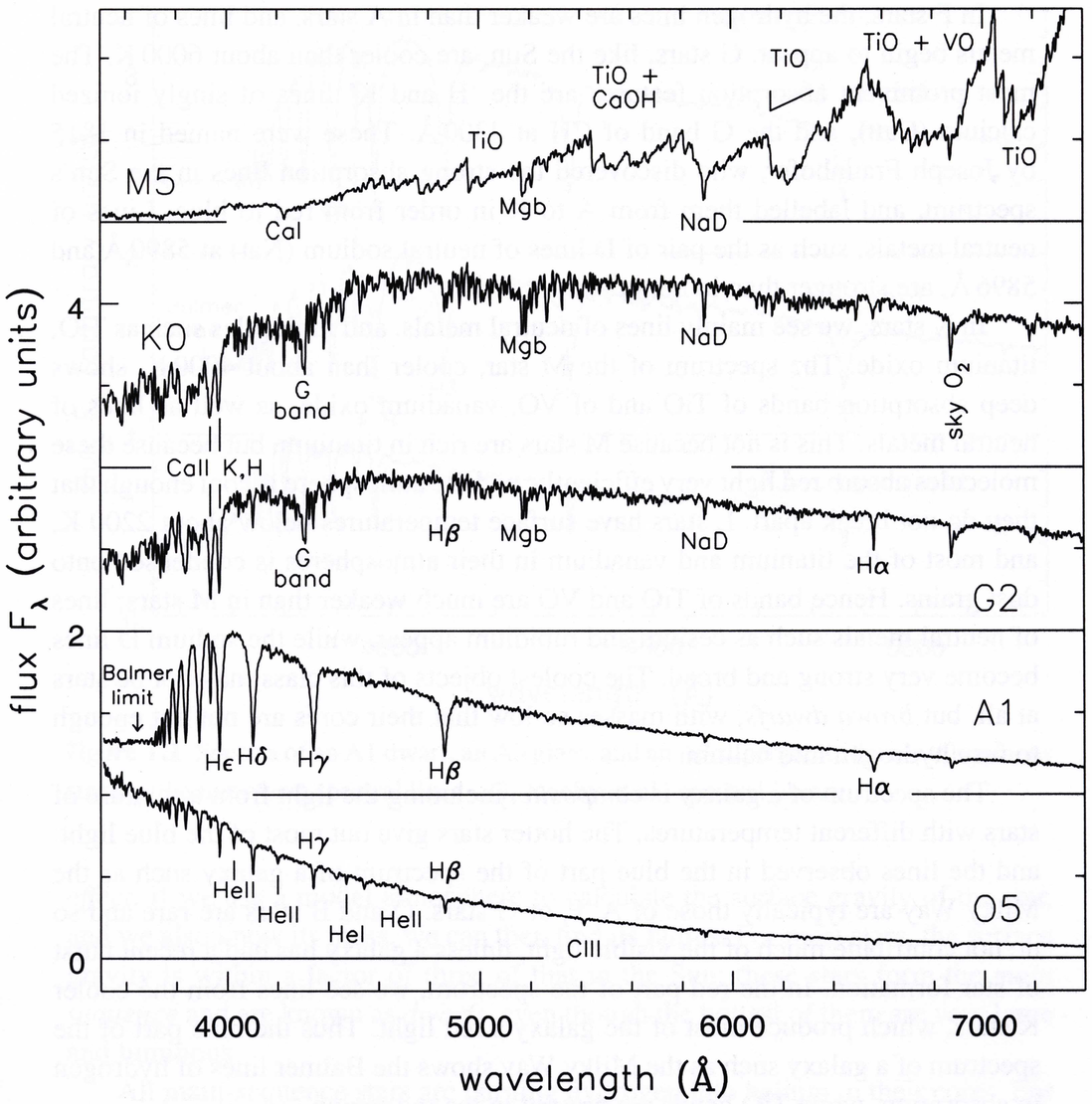
Astronomers use the CGS system!

$$1\mathrm{pc} = 3.1 \times 10^{18}\ \mathrm{cm}$$
$$1\mathrm{au} = 1.5 \times 10^{13}\ \mathrm{cm}$$
$$R_\odot = 7 \times 10^{10}\ \mathrm{cm}$$
$$R_\oplus = 6.4 \times 10^{8}\ \mathrm{cm}$$



Spectral energy distribution



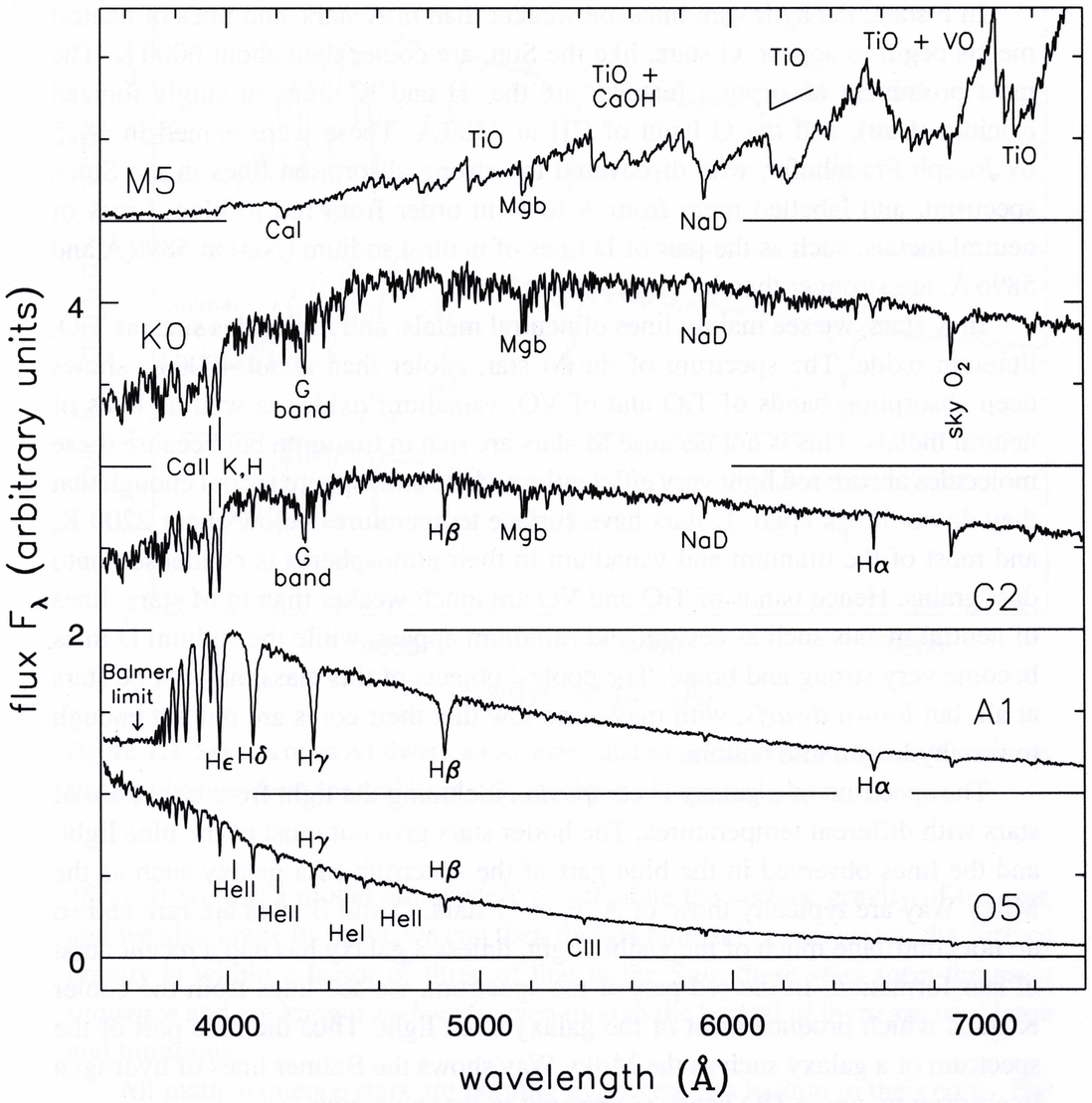
Spark & Gallagher (2000)

To first order, the spectrum of most stars can be approximated as a black body with a specific effective temperature:

$$S_\lambda = \frac{R^2}{d^2}\frac{2hc^2\pi}{\lambda^5}\frac{1}{\exp(hc/\lambda k_B T)-1}$$

$$S = \int_0^\infty S_\lambda d\lambda = \frac{R^2}{d^2}\sigma T^4$$

Spectral energy distribution



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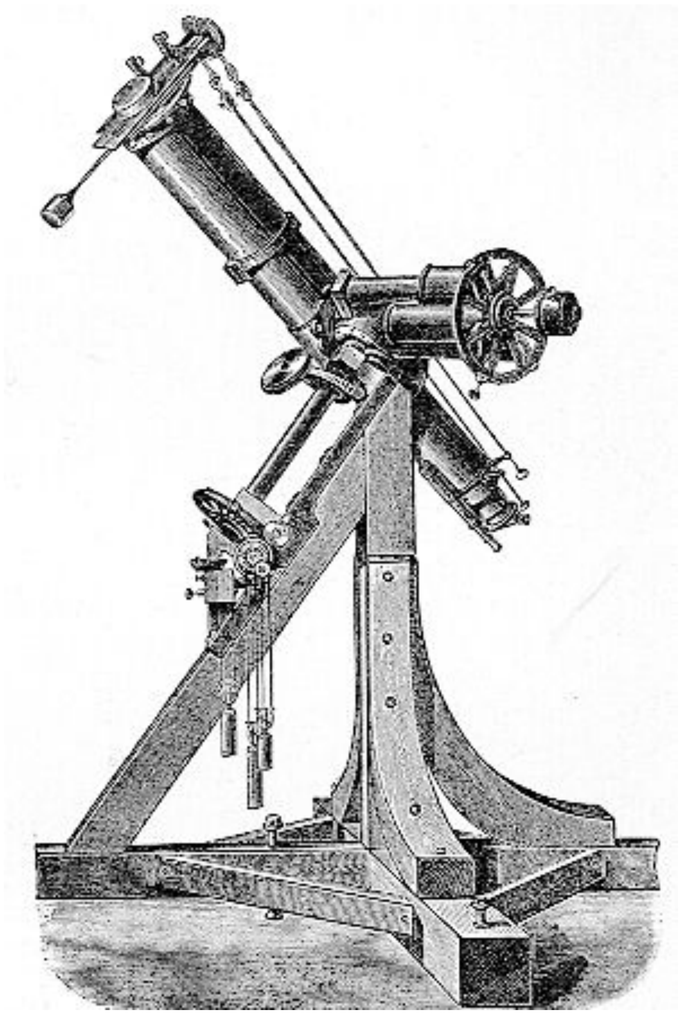
In practice, we only measure a fraction of this flux!

$$S_{\rm obs} = \int_0^\infty S_\lambda \varphi(\lambda) d\lambda$$

The initial drivers of astrophysics

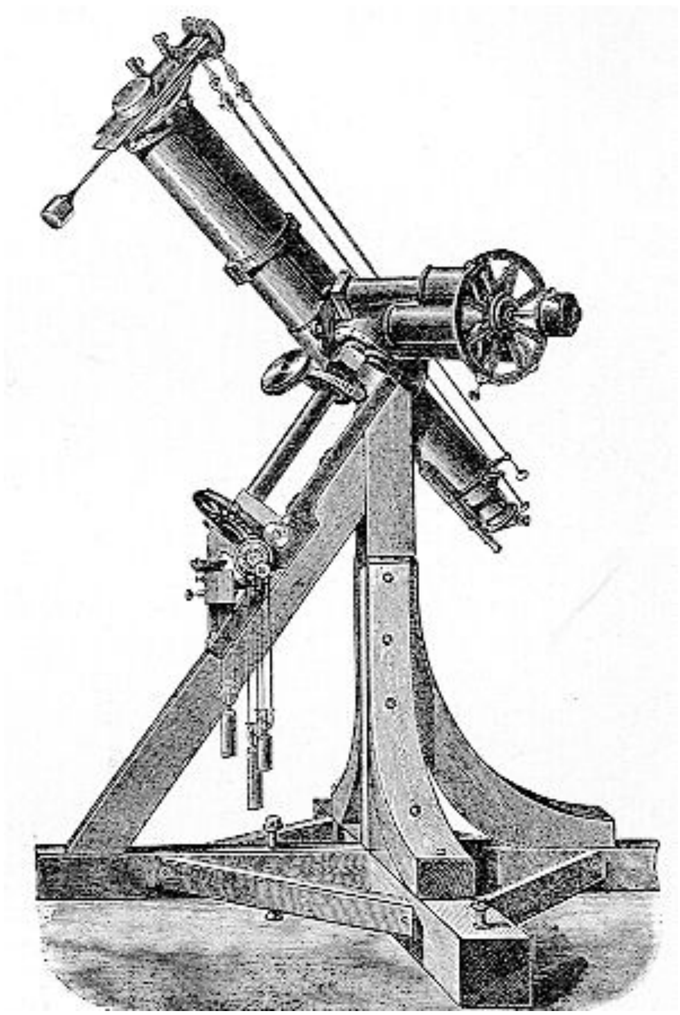
Parallaxes



Bessel (1839), Henderson (1840), Struve (1840)

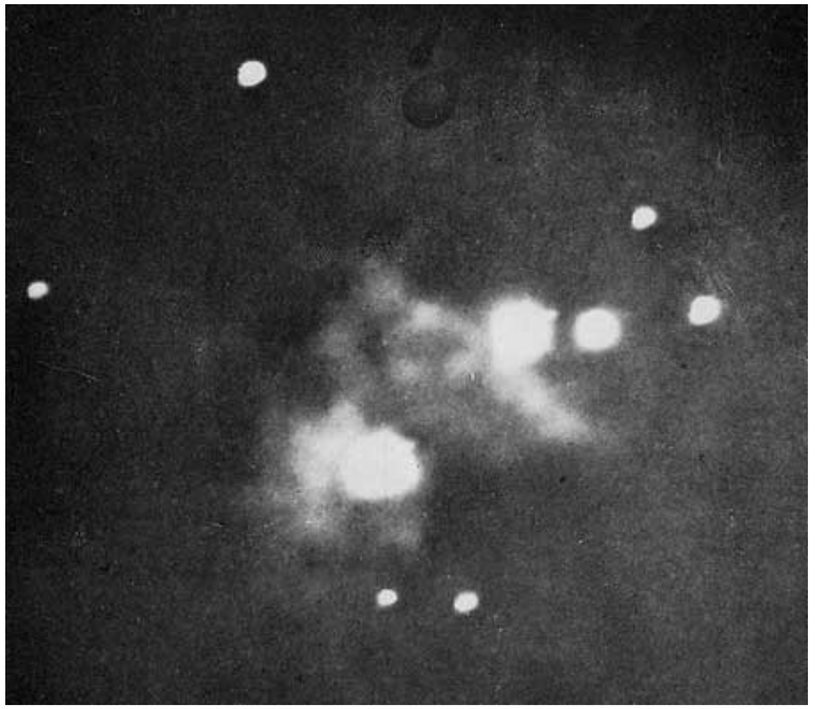
The initial drivers of astrophysics

Parallaxes



Bessel (1839), Henderson (1840), Struve (1840)

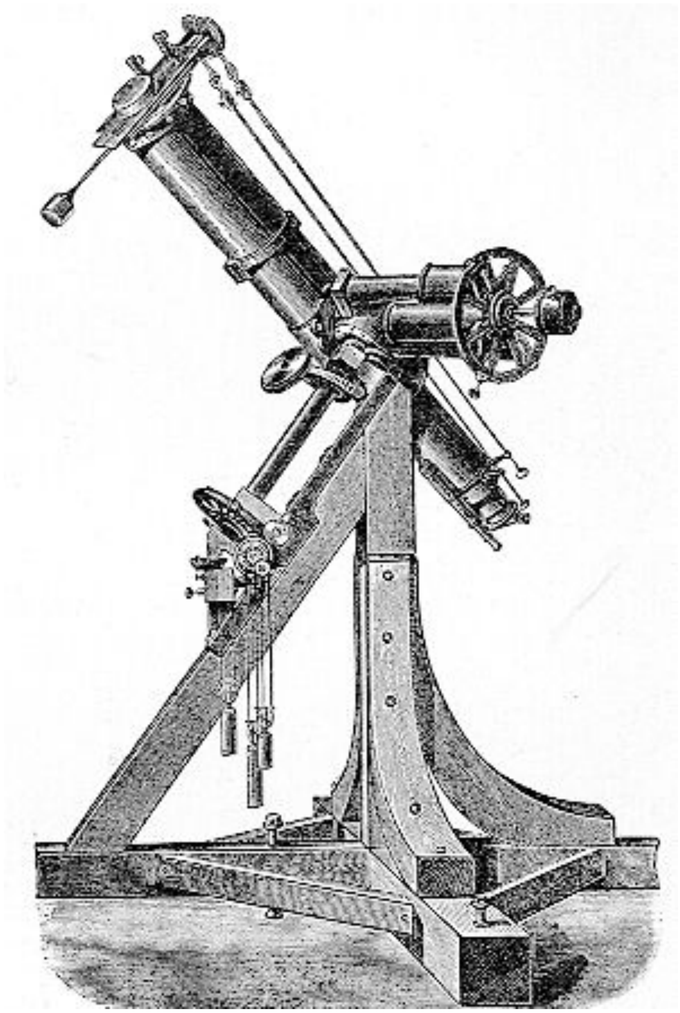
Photography



Great Orion Nebula, by Henry Draper (1880)

The initial drivers of astrophysics

Parallaxes



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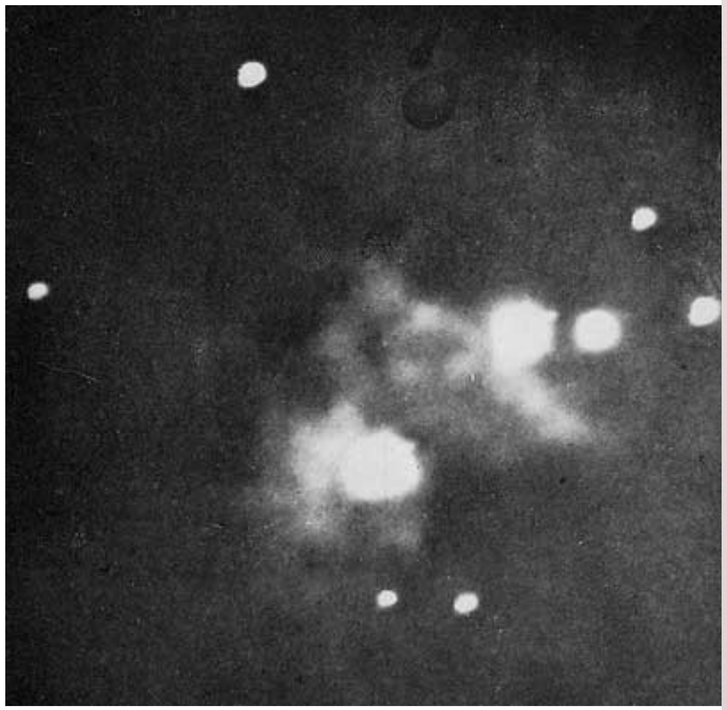

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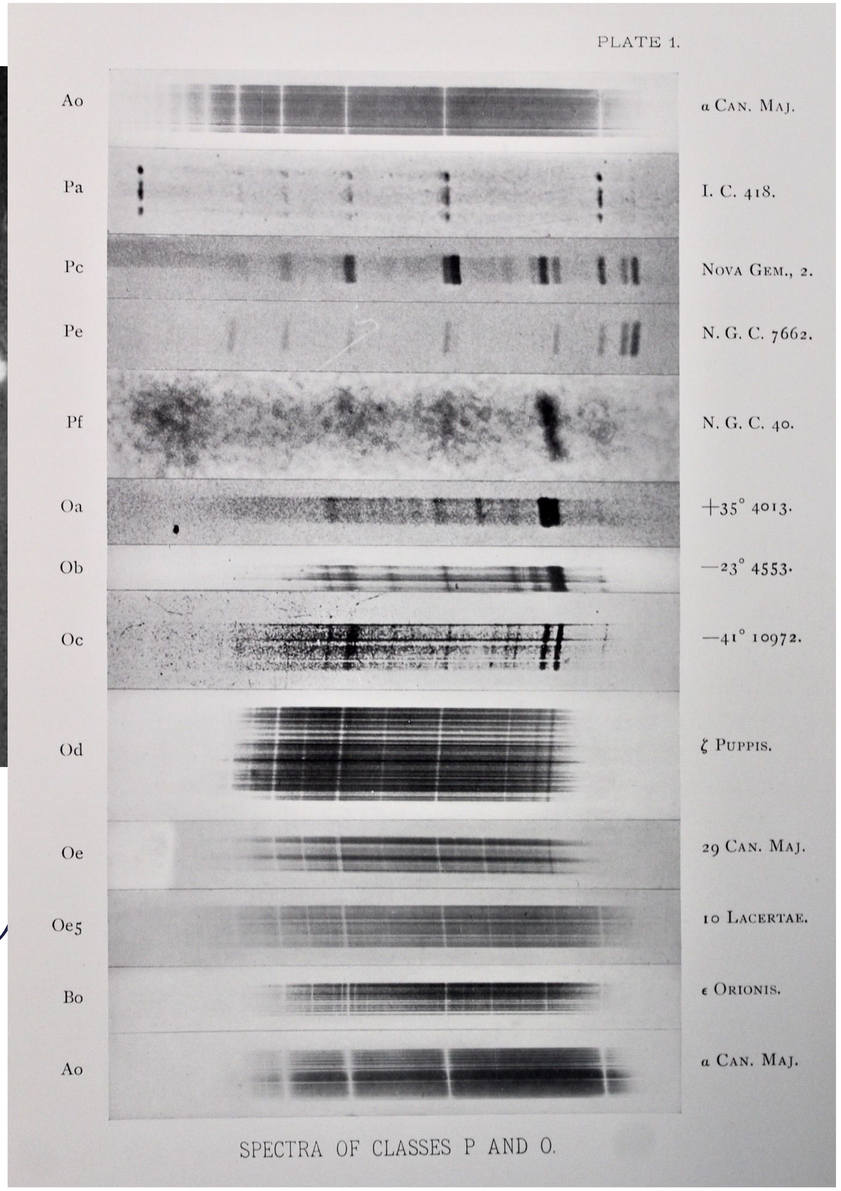
Spectra



Sample of spectra from A. Cannon

The Harvard computers

Draper memorial catalogue (Pickering, 1890)
Including classification of 10351 stars

The Harvard computers

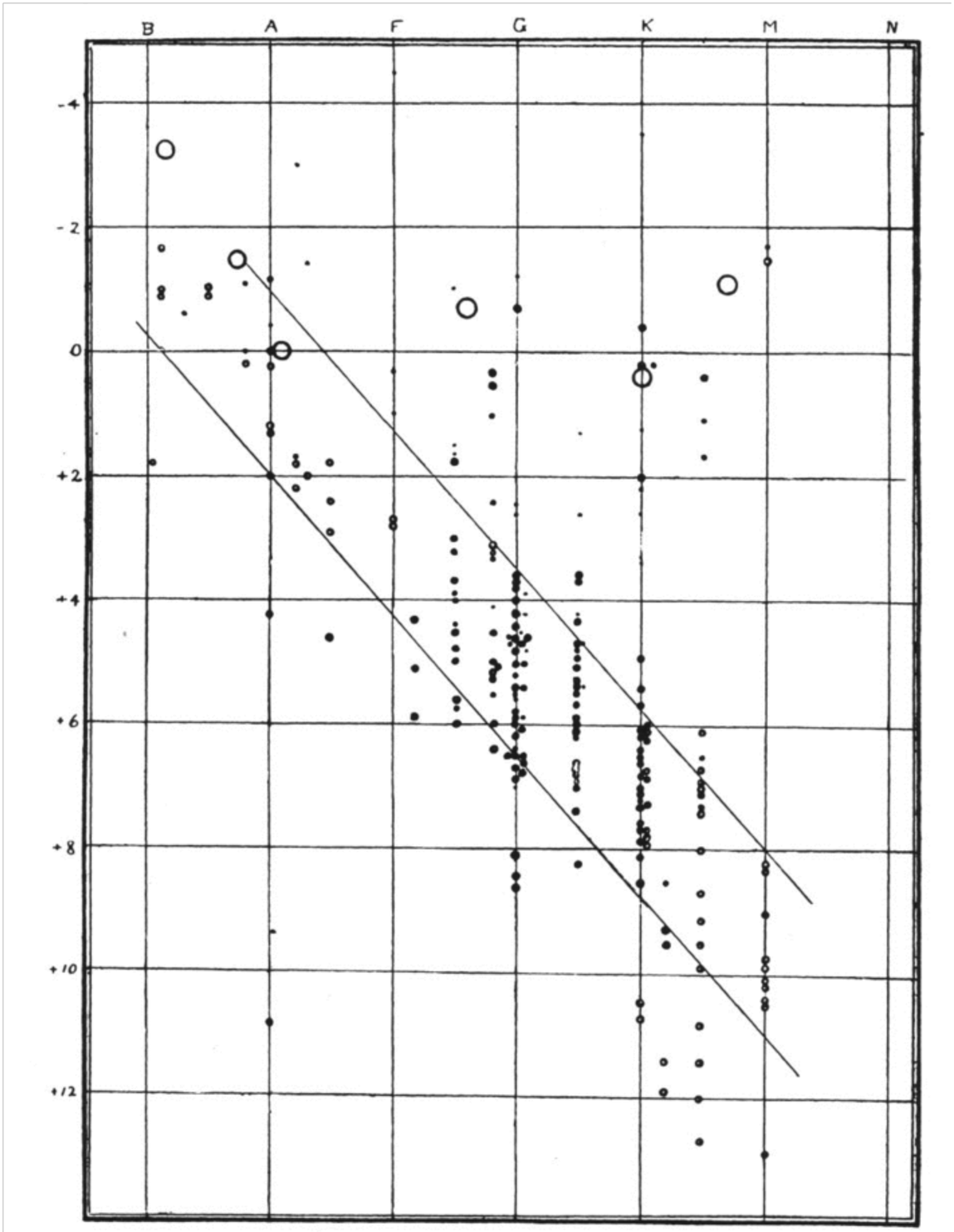
Williamina Fleming

Antonia Maury

Annie Cannon

Developers of the **OBAFGKM** *classification.*
Annie Cannon classified hundreds of thousands of spectra, forming the Henry Draper (HD) catalogue.

The Hertzsprung-Russell diagram



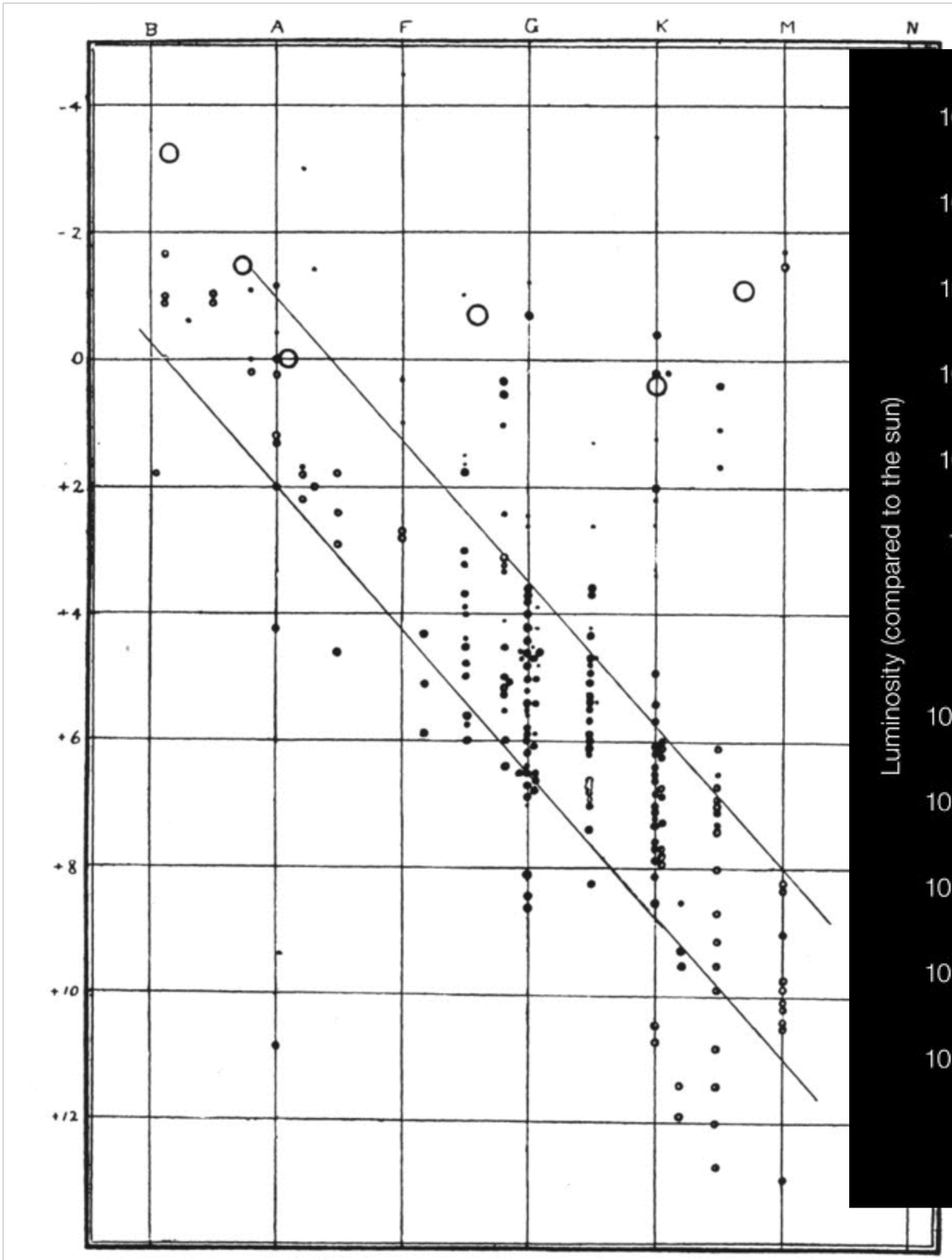
Russell (1914)

- Developed independently by Ejnar Hertzsprung and Henry Norris Russel.

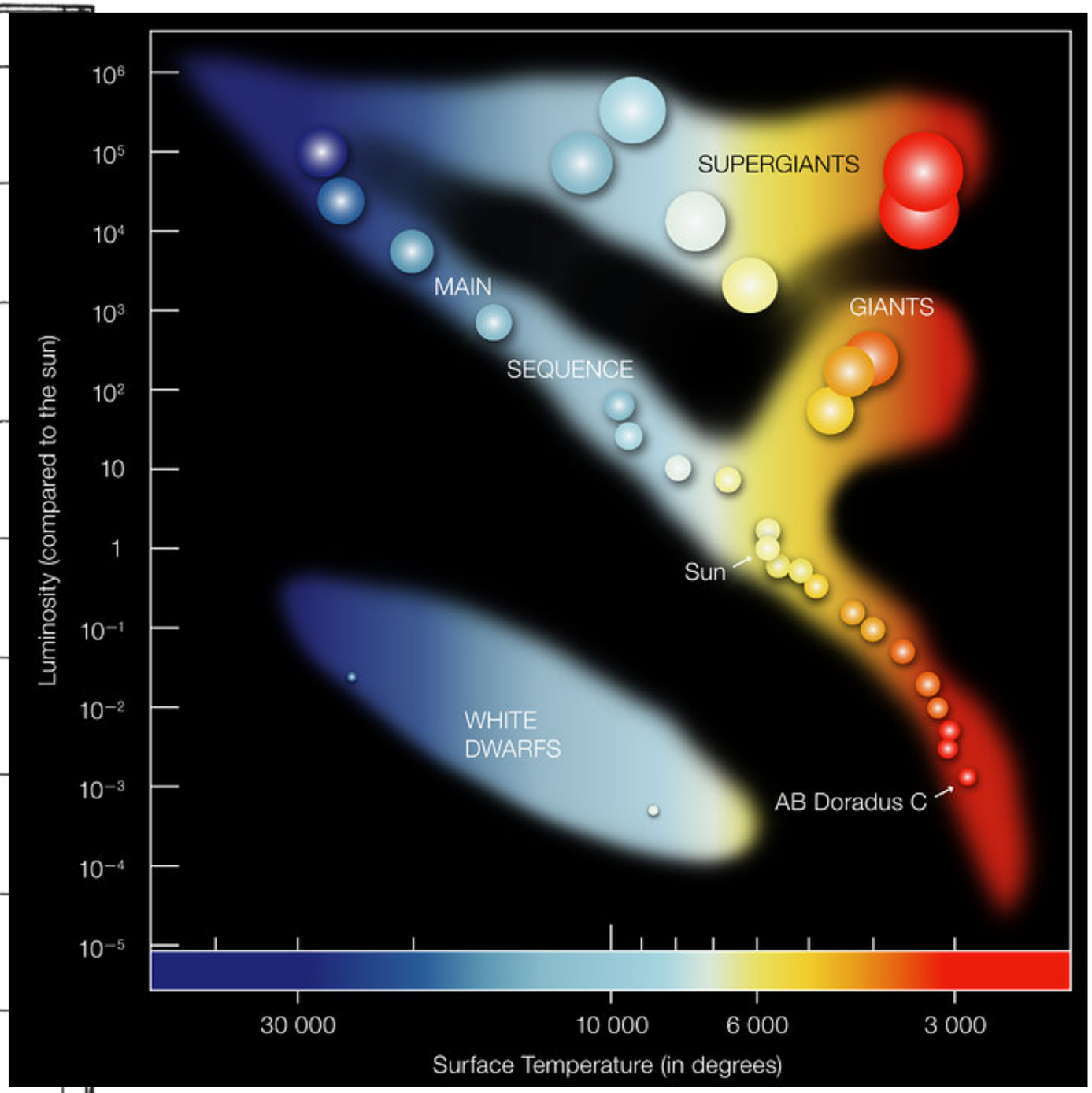
- Strong correlation between spectral type/color and absolute magnitude.
Main Sequence!

- Large range of luminosities despite narrow range in masses.

The Hertzsprung-Russell diagram

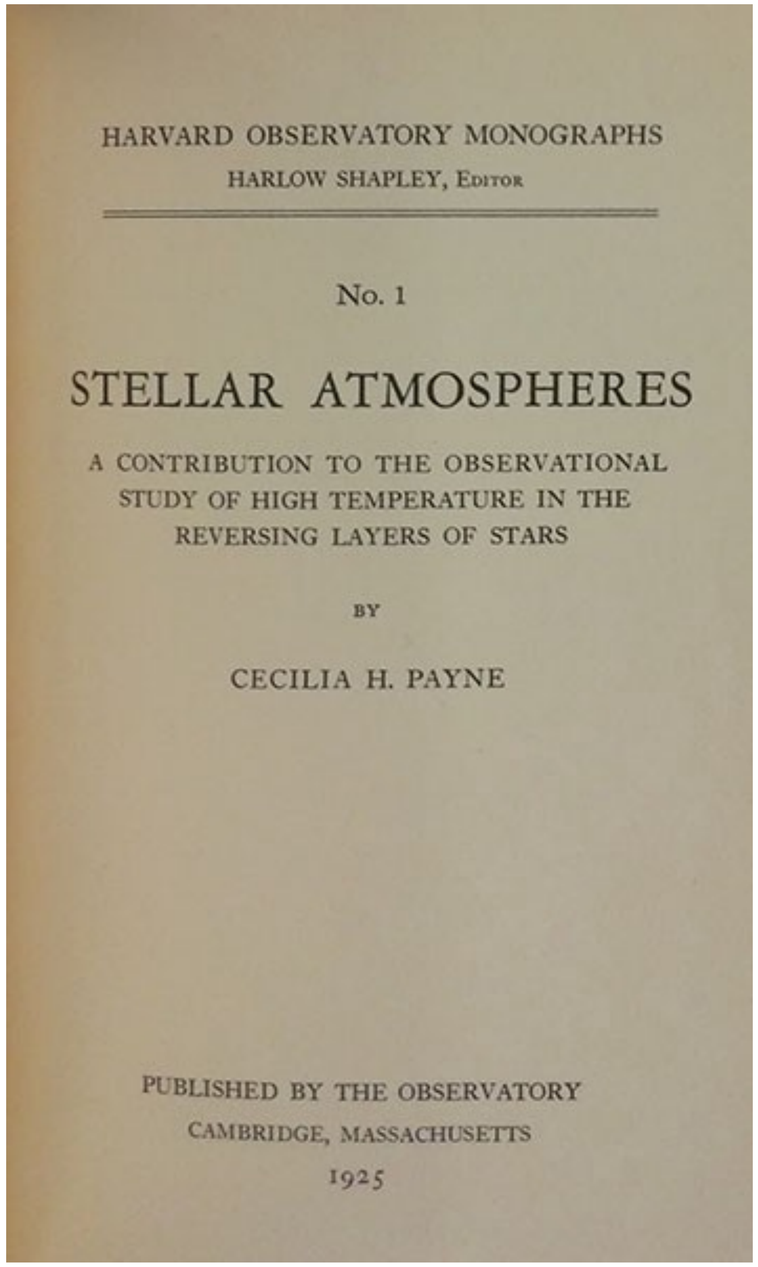


Russell (1914)



Credit: ESO

Stellar atmospheres



HARVARD OBSERVATORY MONOGRAPHS

HARLOW SHAPLEY, EDITOR

No. 1

STELLAR ATMOSPHERES

A CONTRIBUTION TO THE OBSERVATIONAL STUDY OF HIGH TEMPERATURE IN THE REVERSING LAYERS OF STARS

BY

CECILIA H. PAYNE

PUBLISHED BY THE OBSERVATORY

CAMBRIDGE, MASSACHUSETTS

1925

Cecilia Payne-Gaposhkin

Stellar atmospheres

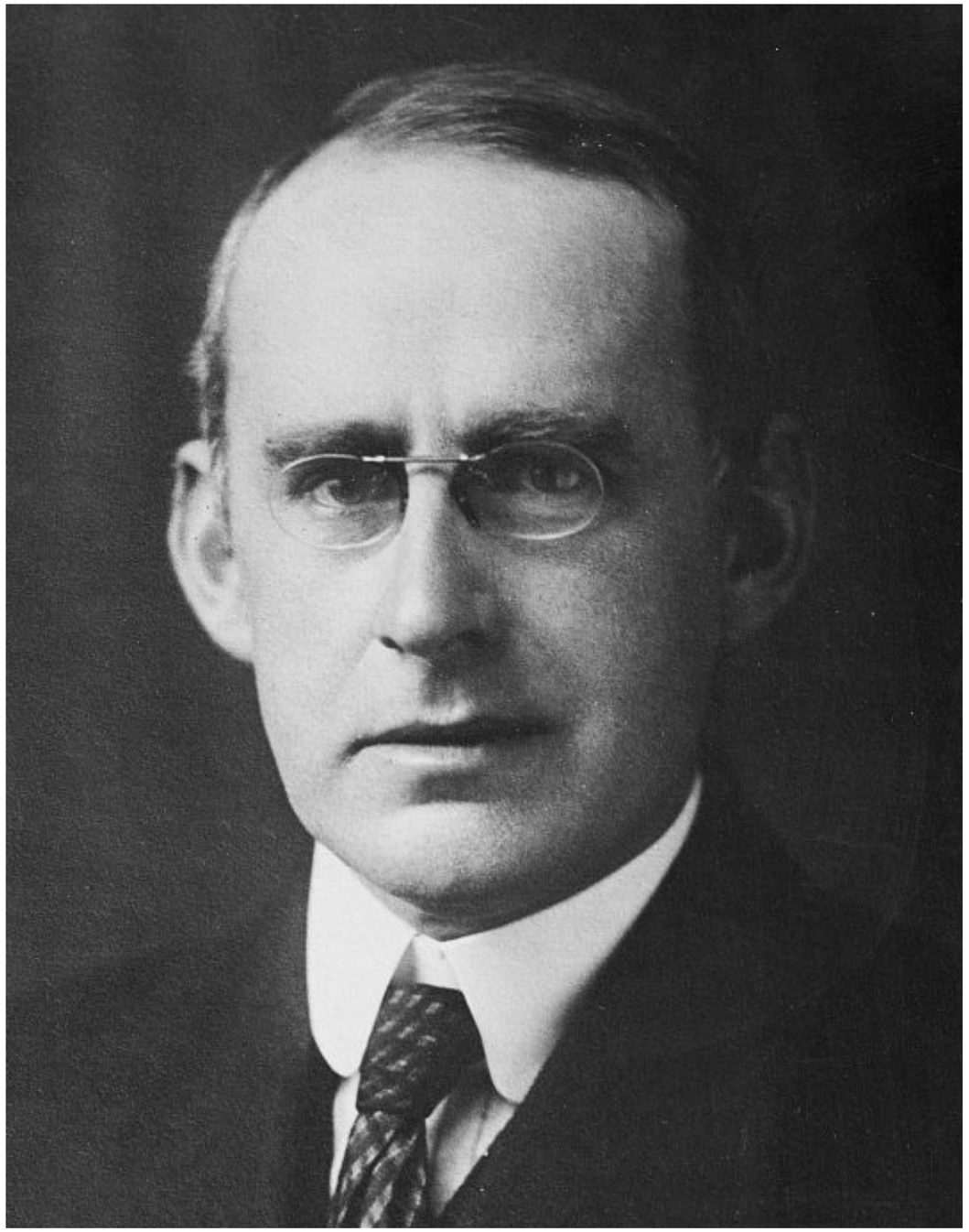
- Spectral classes form a sequence in effective temperature.

- Quantified the dependence between line-strengths and abundances.

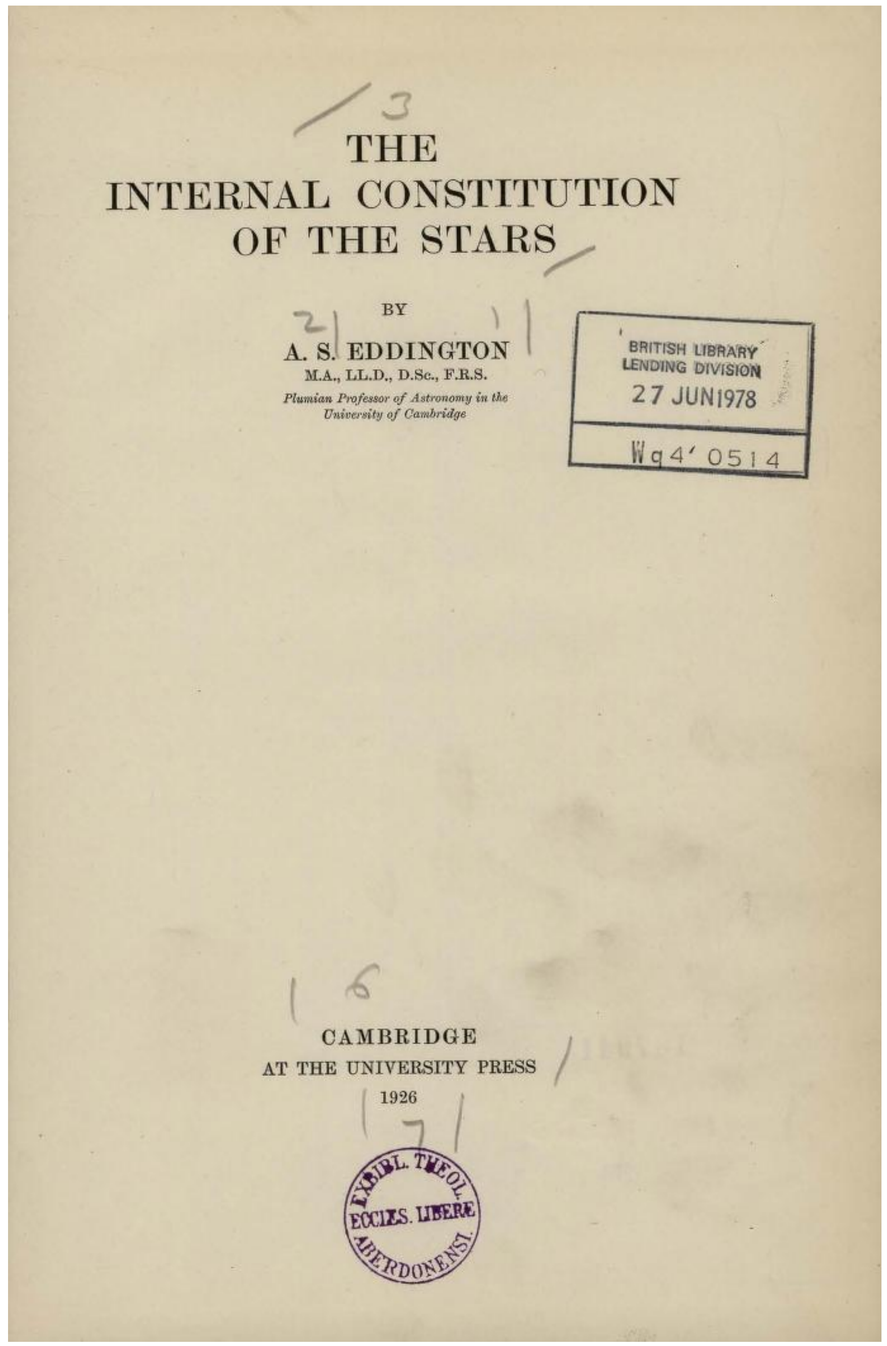
- Found hydrogen to be the prominent component of stars

Cecilia Payne-Gaposhkin

The theory of stellar structure and evolution



Arthur Eddington



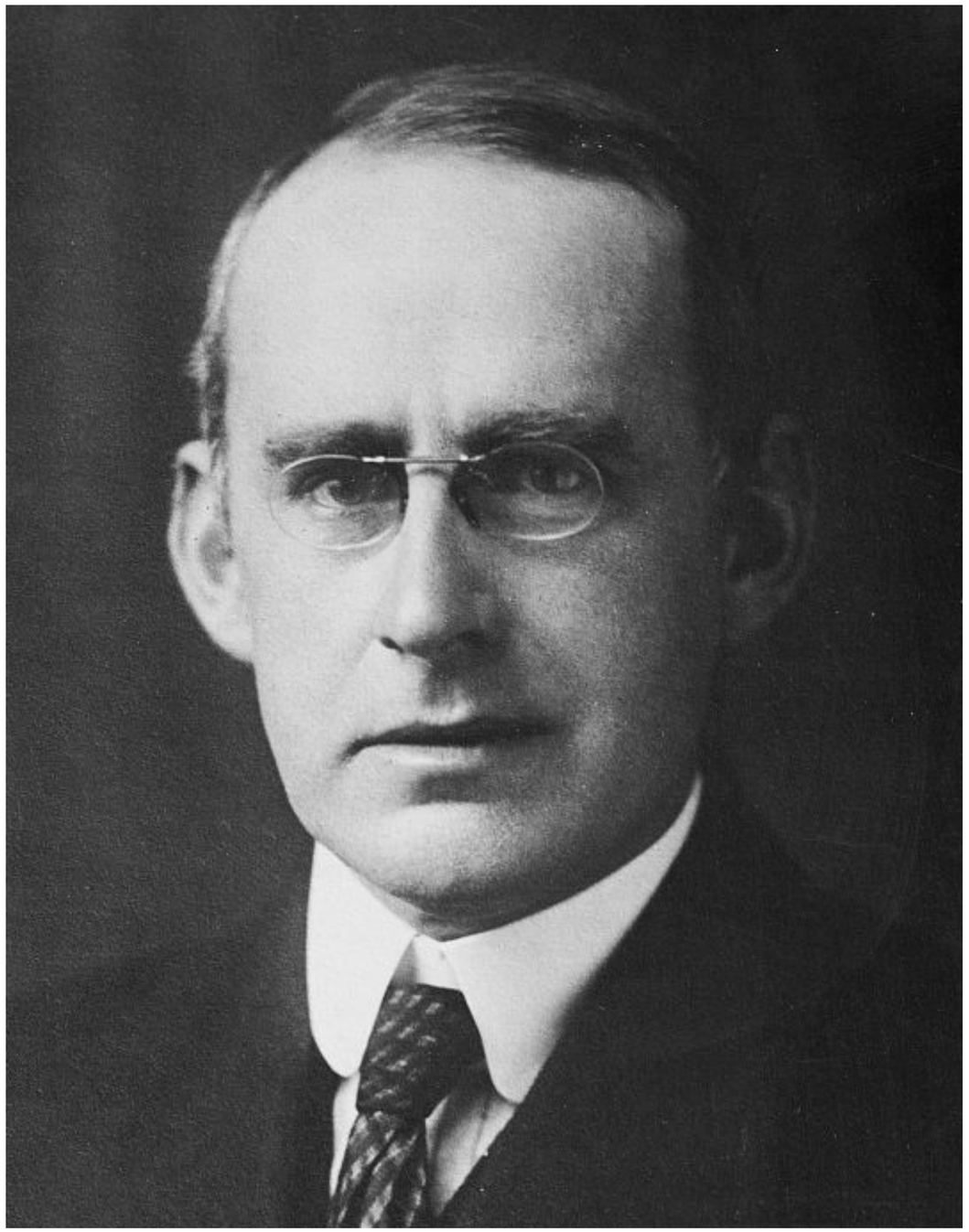
THE
INTERNAL CONSTITUTION
OF THE STARS

BY

A. S. EDDINGTON
M.A., LL.D., D.Sc., F.R.S.
Plumian Professor of Astronomy in the University of Cambridge

CAMBRIDGE
AT THE UNIVERSITY PRESS
1926

The theory of stellar structure and evolution



Arthur Eddington

- Importance of radiative energy transport.

- Burning of hydrogen into helium as the energy source of the Sun (precise processes discovered by von Weizsacker, Bethe and Critchfield).

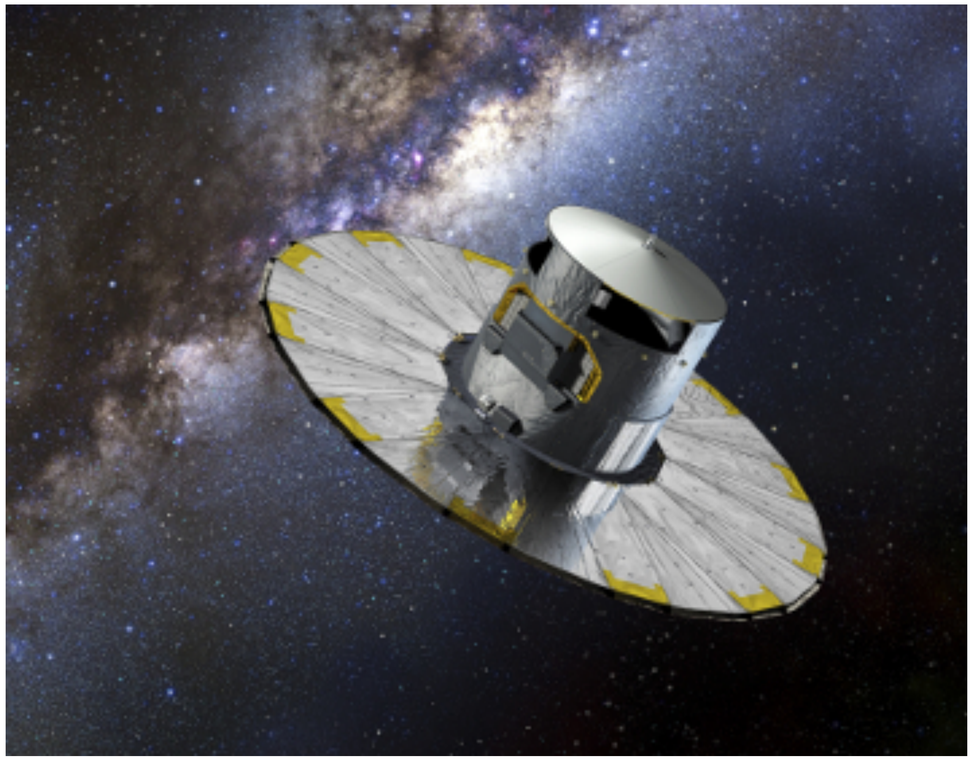
- Understanding of the origin of the main sequence.

Where are we now?

Parallaxes *Photography* *Spectra*

Where are we now?

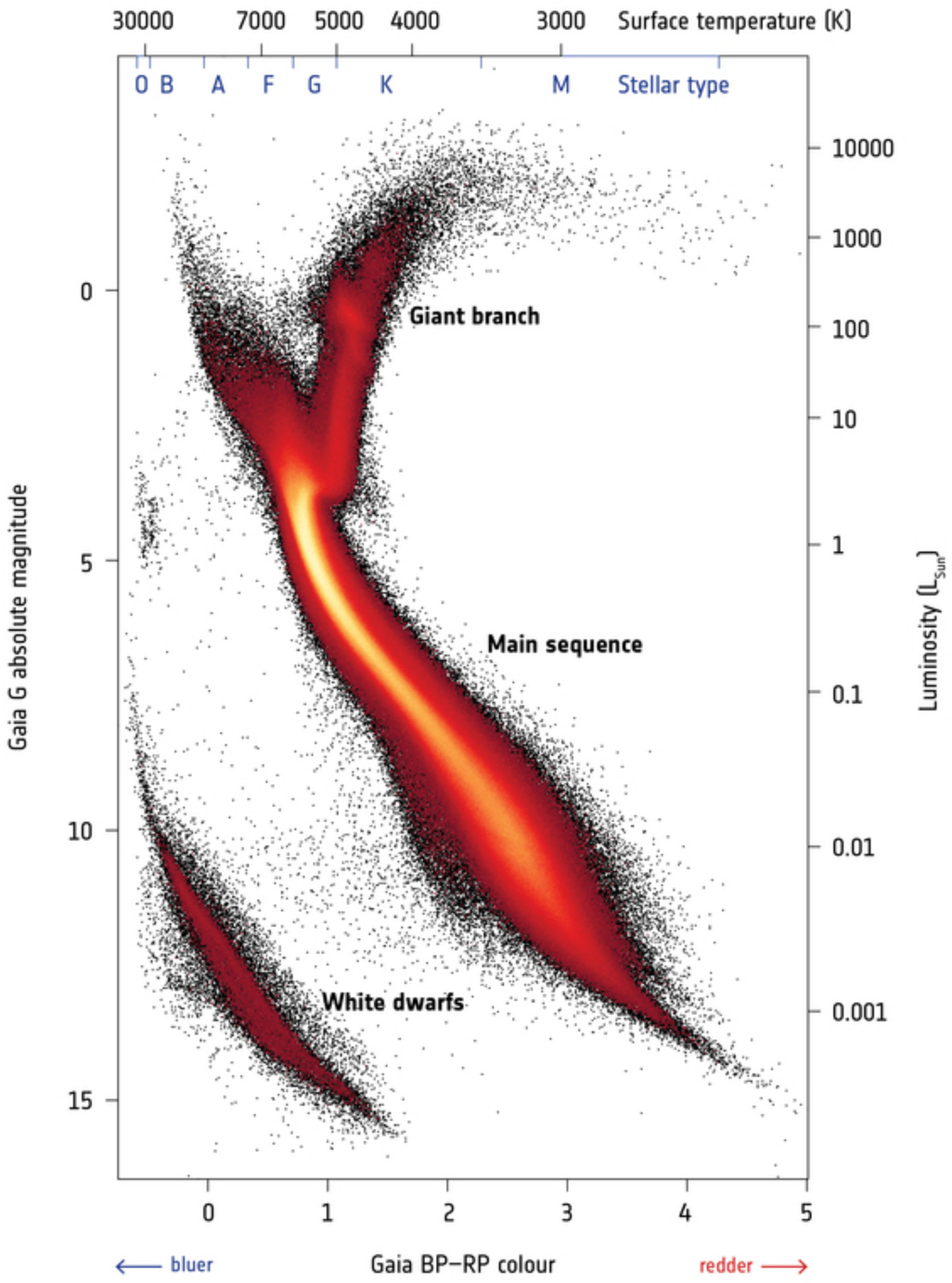
Parallaxes *Photography* *Spectra*



Gaia Mission
Parallaxes for over a billion stars!

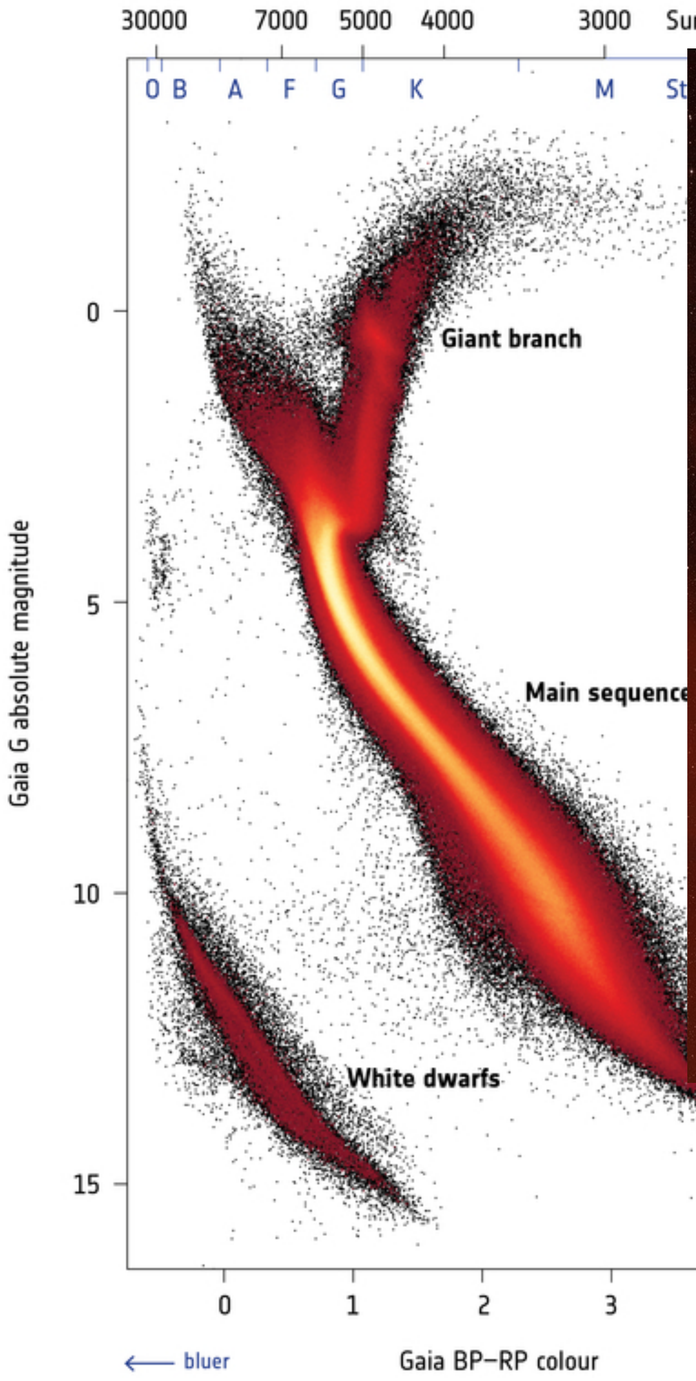
Where are we now?

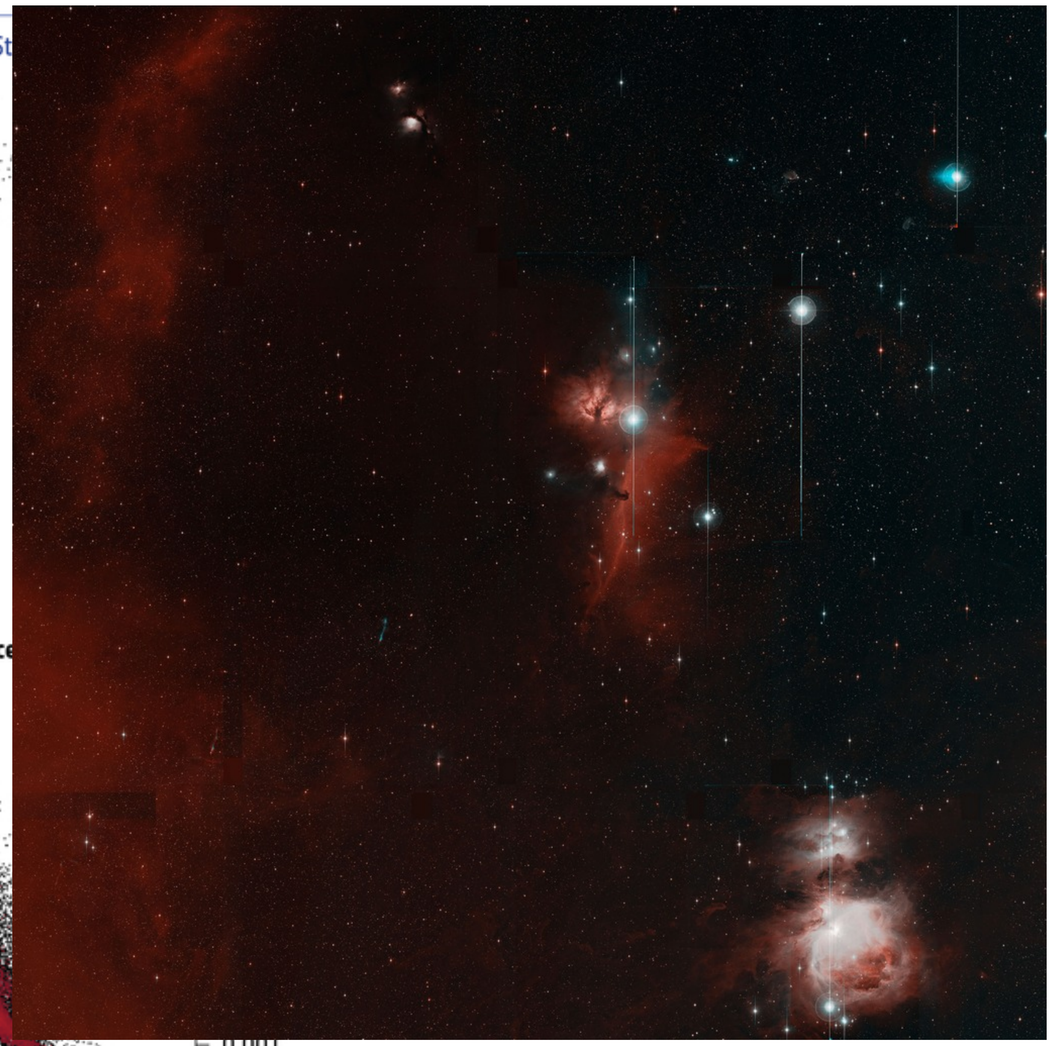
Parallaxes *Photography* *Spectra*



Where are we now?

Parallaxes *Photography* *Spectra*

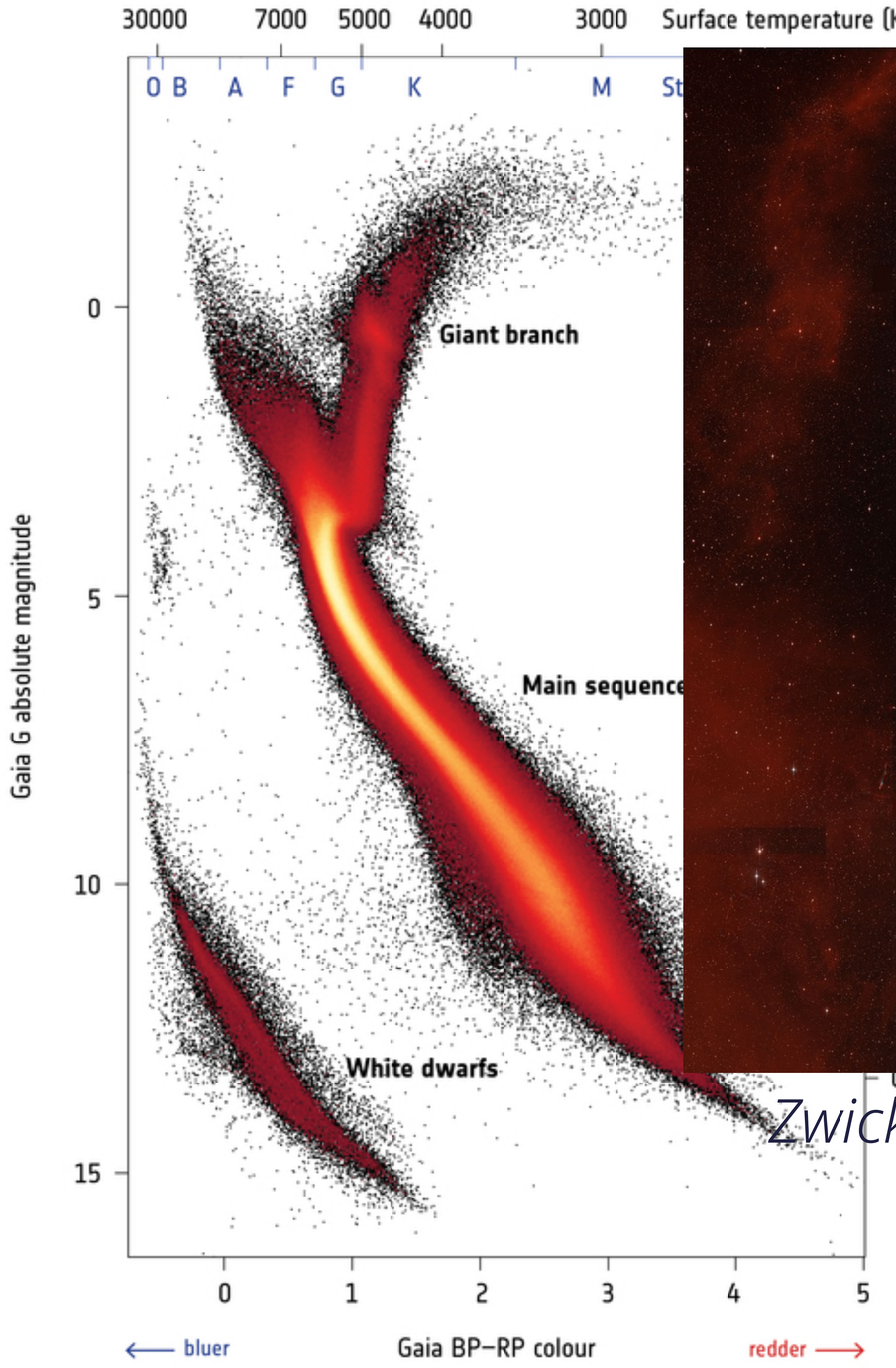




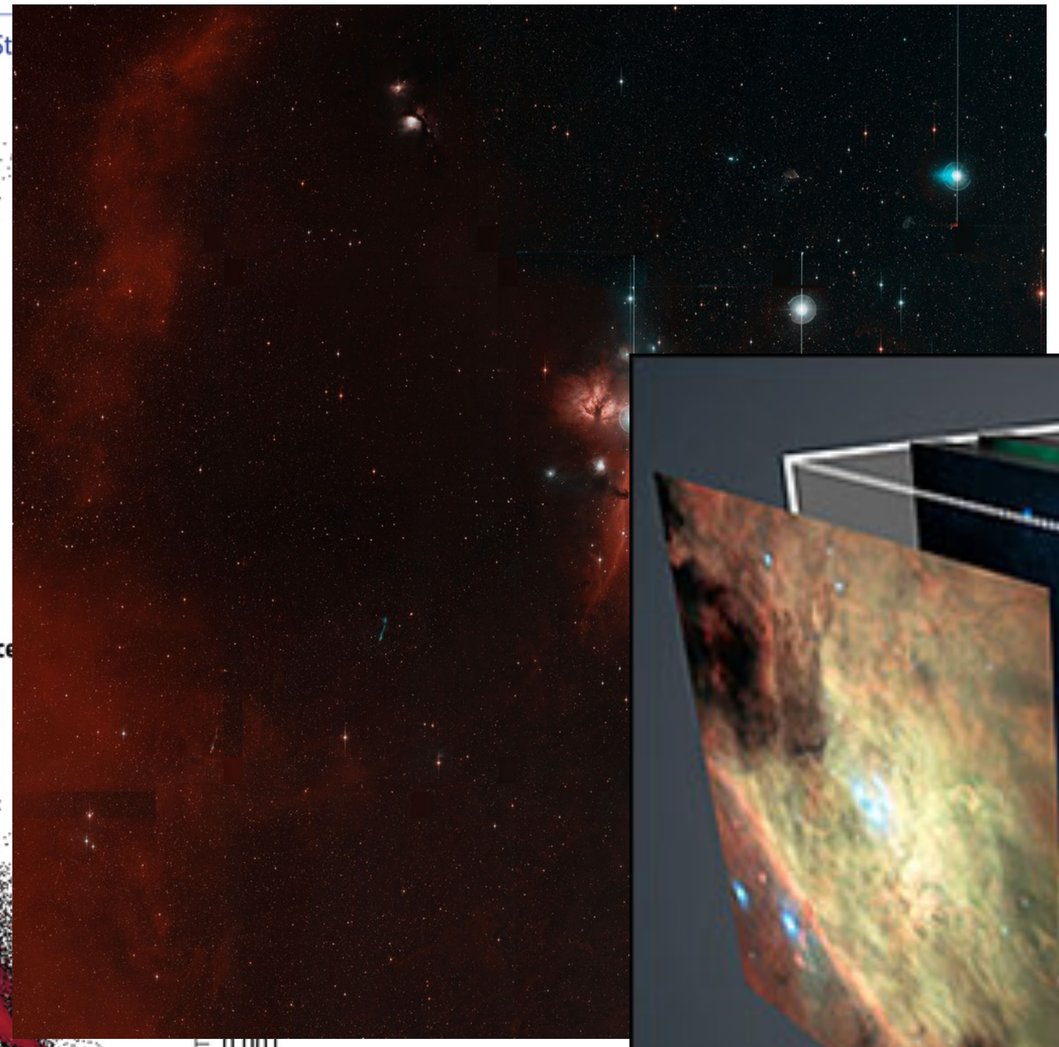
Zwicky Transient Facility first light, Orion Nebula

Where are we now?

Parallaxes



Photography



Zwicky Transient Fac

Orion Neb

Spectra

Muse view of Orion.
Instrument at the VLT (ESO).
Each pixel is a spectrum!