Types of Variability

I. Intrinsic Variability

Star variable "by itself" → variability caused by physical changes of star

- **pulsation variable**
- **Eruptive**
- **Rotationally induced variables**

II. Extrinsic variability

Star not variable by “itself”→ variability generated by external influences

- **Binary stars ↔ eclipsing variables**
- **Accretion disks ↔ like T Tauri**
- **binary+accretion disk ↔ cataclysmic variables, novae**

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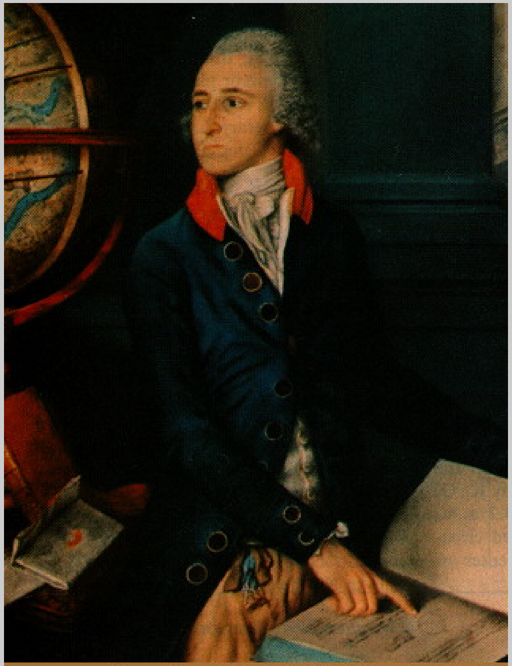
Pulsation variable - Cepheids

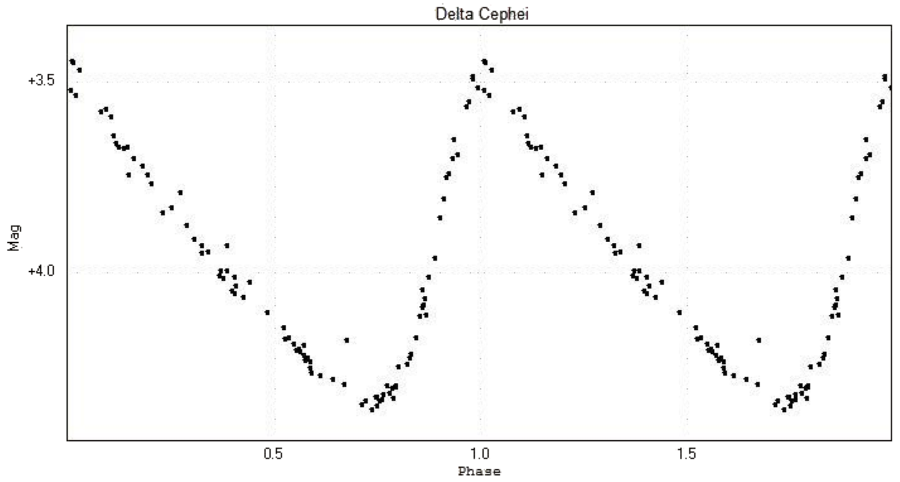
discovery & observation:

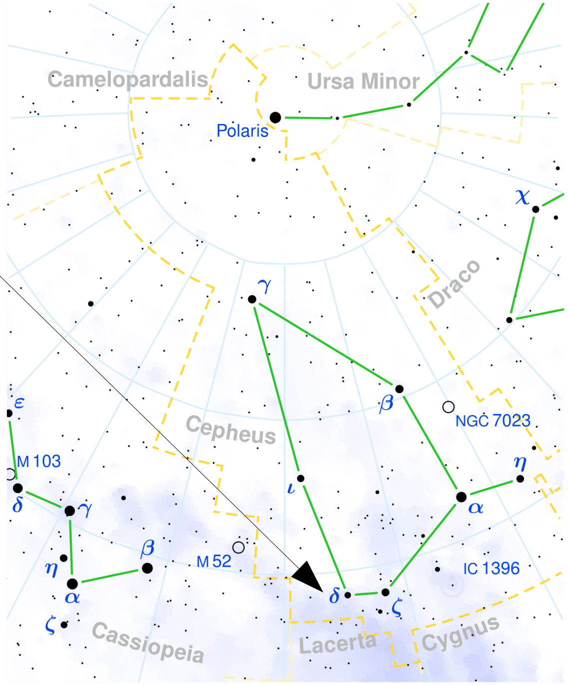
biscovered by John Goodricke in 1784 in the constellation Cepheus

δ Cephei → prototype



John Goodricke (1764-1786)
(photo from *Sky & Telescope*)





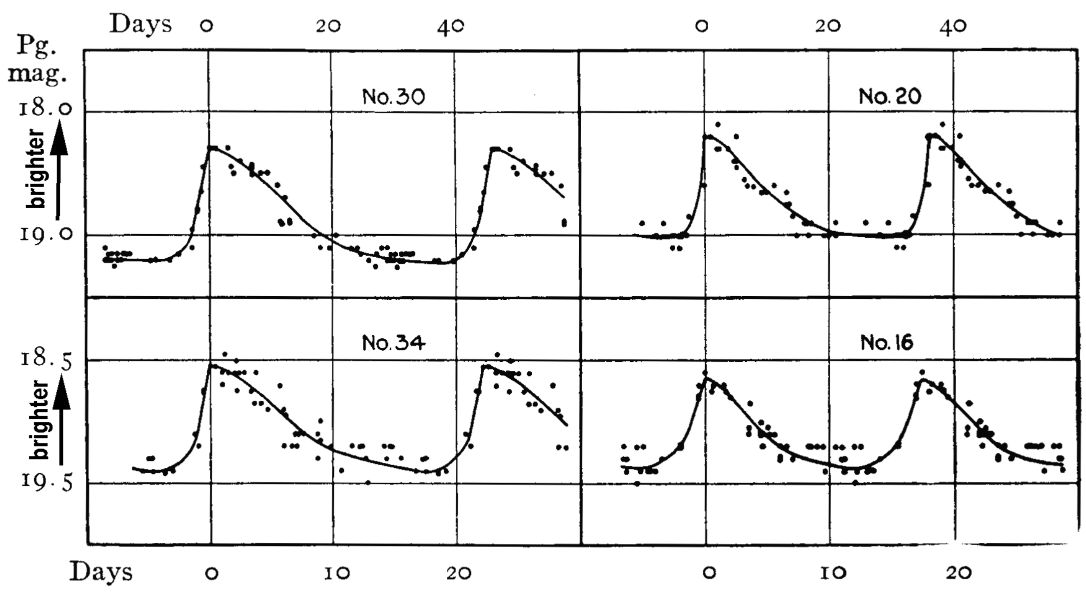
pulsation variables - Cepheids

observation:

regular photometric variability

characteristic light curve
rise and fall is asymmetric

Periods: 1 - 50 days
$\Delta m \approx$ 0.1 - 2 mag



Cepheids in M33

Cepheids are divided into the following subtypes

- δ Cephei ↔ classic Cepheids ↔ Type I Cepheids
- Type II Cepheids
- Abnormal/Uncommon Cepheid
- Bimodal Cepheids

Note that the pulsation mechanism is always the same.

Henrietta Leavitt & the Cepheids

Henrietta Leavitt (1868 – 1921)

Was at first only employed in the computer devision to do calculations

showed a lot interested in astronomy

Henrietta Leavitt & the Cepheids

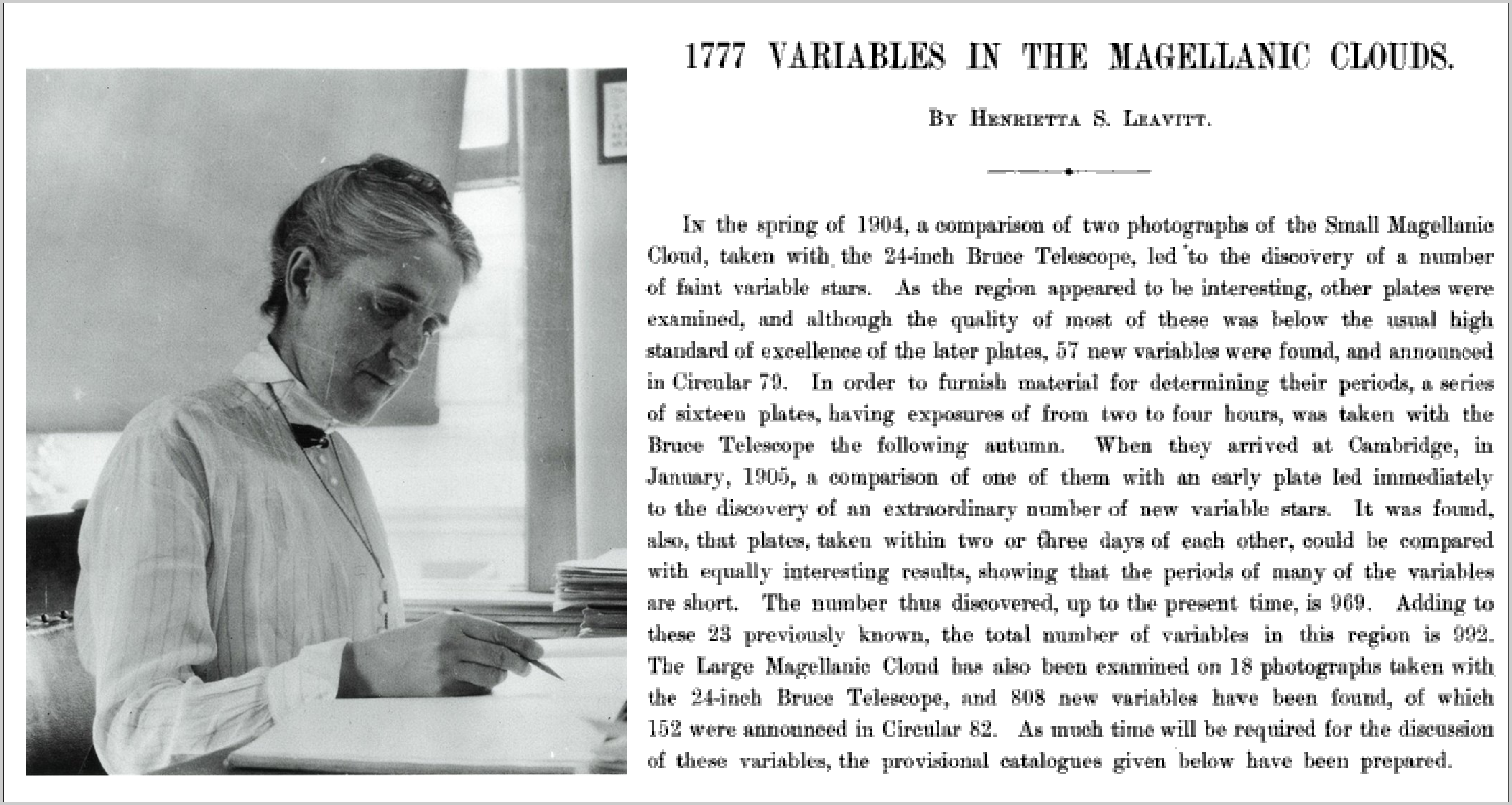
- graduated from Harvard University Radcliffe College in 1892

- Prof. E.C. Pickering gave her work at the Harvard College Observatory. Measurement of the brightness of stars on photoplates, leading to a catalog and list of variable stars.

“ Pickering’s Harem”

Henrietta Leavitt & the Cepheids

Leavitt continued to analyze the variable stars, e.g. those in the Large and Small Magellanic Clouds...
and then even wrote her own publication !!!



1777 VARIABLES IN THE MAGELLANIC CLOUDS.

By Henrietta S. Leavitt.

In the spring of 1904, a comparison of two photographs of the Small Magellanic Cloud, taken with the 24-inch Bruce Telescope, led to the discovery of a number of faint variable stars. As the region appeared to be interesting, other plates were examined, and although the quality of most of these was below the usual high standard of excellence of the later plates, 57 new variables were found, and announced in Circular 79. In order to furnish material for determining their periods, a series of sixteen plates, having exposures of from two to four hours, was taken with the Bruce Telescope the following autumn. When they arrived at Cambridge, in January, 1905, a comparison of one of them with an early plate led immediately to the discovery of an extraordinary number of new variable stars. It was found, also, that plates, taken within two or three days of each other, could be compared with equally interesting results, showing that the periods of many of the variables are short. The number thus discovered, up to the present time, is 969. Adding to these 23 previously known, the total number of variables in this region is 992. The Large Magellanic Cloud has also been examined on 18 photographs taken with the 24-inch Bruce Telescope, and 808 new variables have been found, of which 152 were announced in Circular 82. As much time will be required for the discussion of these variables, the provisional catalogues given below have been prepared.

Henrietta Leavitt & the Cepheids

and then even wrote her own publication !!!
She made a very **IMPORTANT discovery**

period-luminosity relation
luminosity increases for longer periods

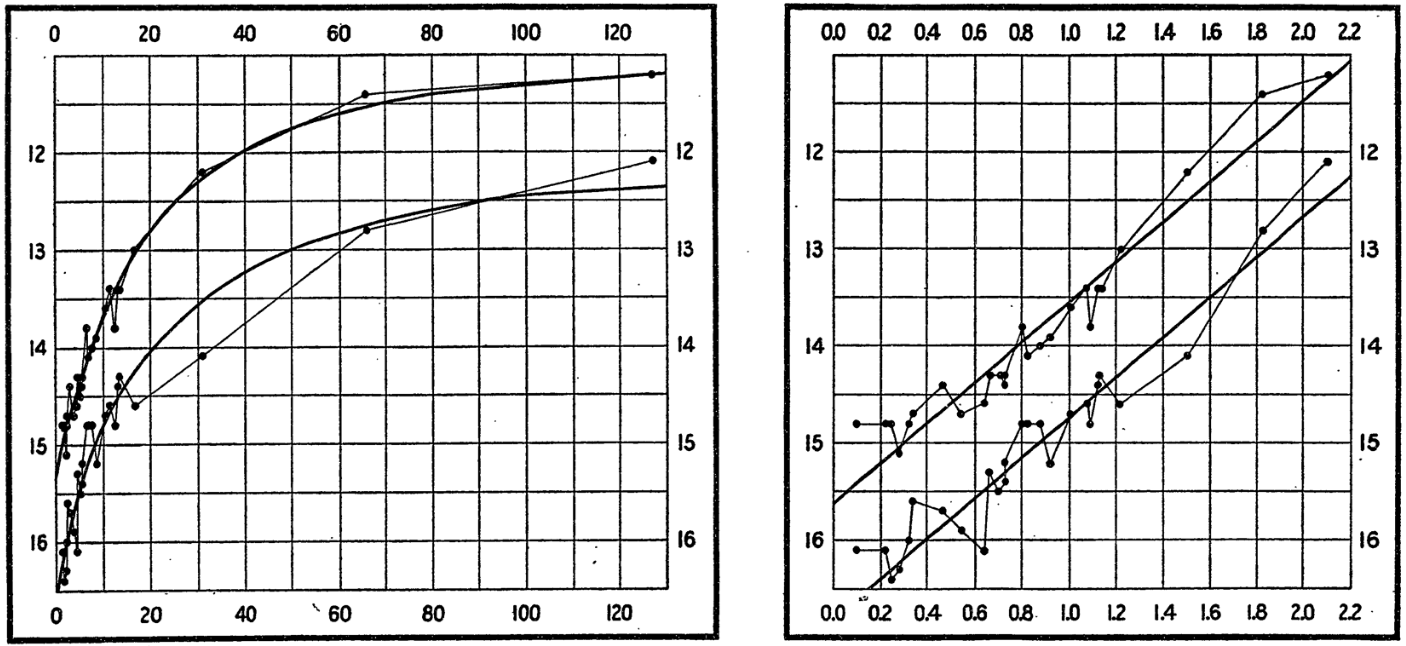


FIG. 1.

FIG. 2.

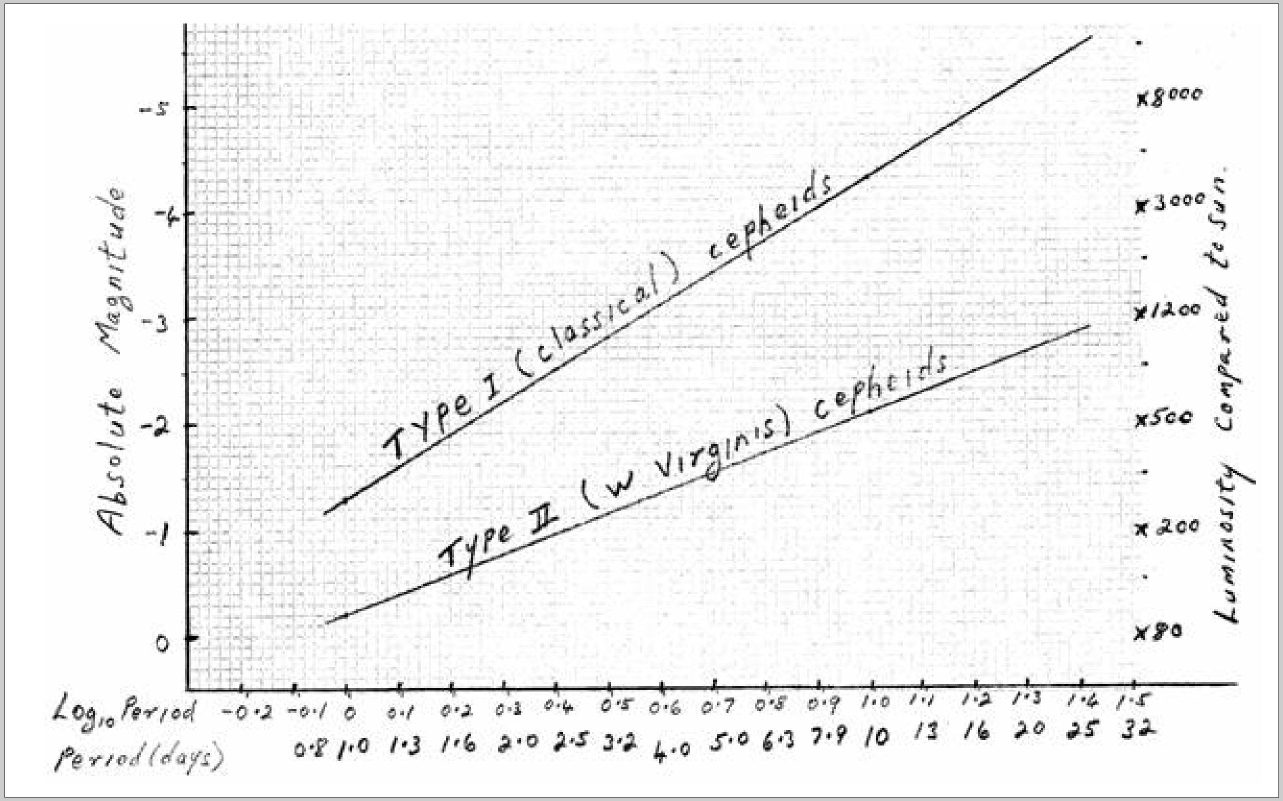
plots from Leavitt 1912 paper

Cepheiden – period-luminosity relation

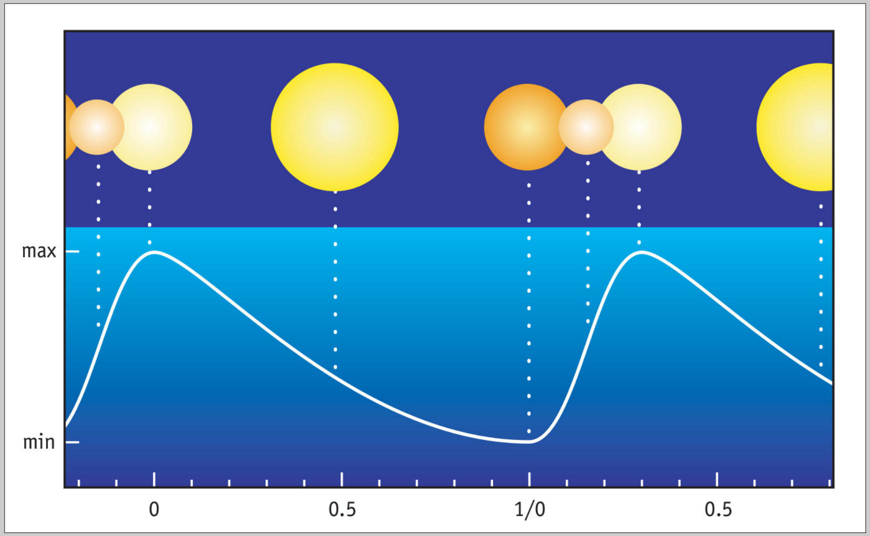
→ obvious relationship between period and luminosity of the stars with different gradient for each type. This led to the introduction of several classes of Cepheids, at that time these were

Typ I or **classical Cepheids**

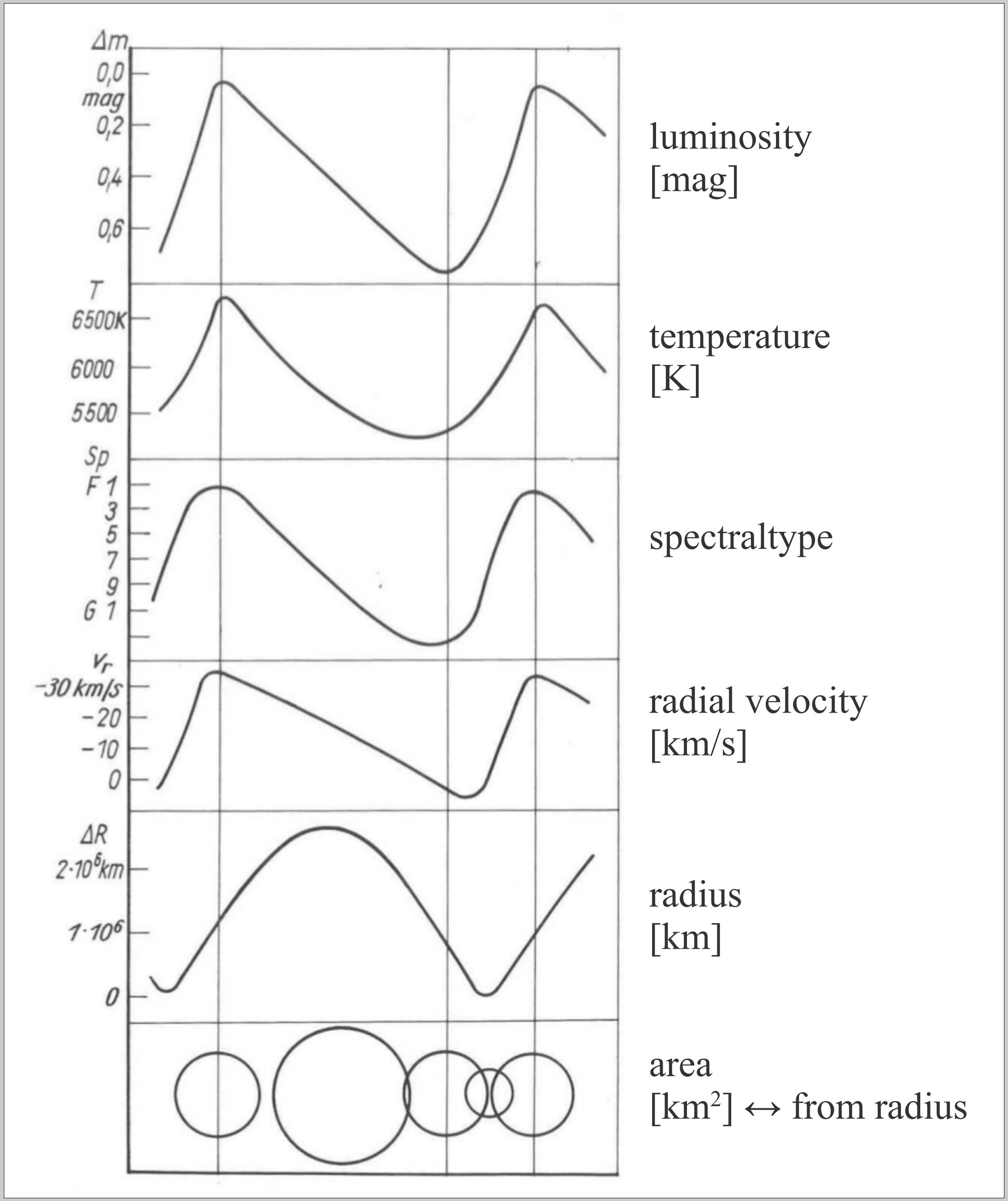
Typ II or according to the prototyp **W Virginis Sterne**



Pulsation – Cepheids



Parameters that change within a Pulsation cycle



pulsation variables - Cepheids

Theorie:

variability due to a regular pulsation of the star

↔ need a mechanism that leads to pulsation

↔ what causes the star to change its structure
more precisely its **radius**

TIME FOR THE

KAPPA MECHANISM

κ-mechanism

Remember star structure equations

- **Energy transport** in the star **radiative** or **convective** depends on temperature, density, ... and κ ↔ **opacity** ↔ transmissivity of radiation

Energy Transport Equations

$$\frac{dT}{dr} = -\frac{3}{4ac}\,\frac{\kappa\rho}{T^3}\,\frac{Lr}{4\pi r^2}$$

$$\frac{dT}{dr} = -\left(1-\frac{1}{\gamma}\right)\frac{\mu m_H}{k}\,\frac{GM}{r^2}$$

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κ opacity ↔ radiation Transmittance

Radiation transmittance is **essential** for the **stability** of a **star!**

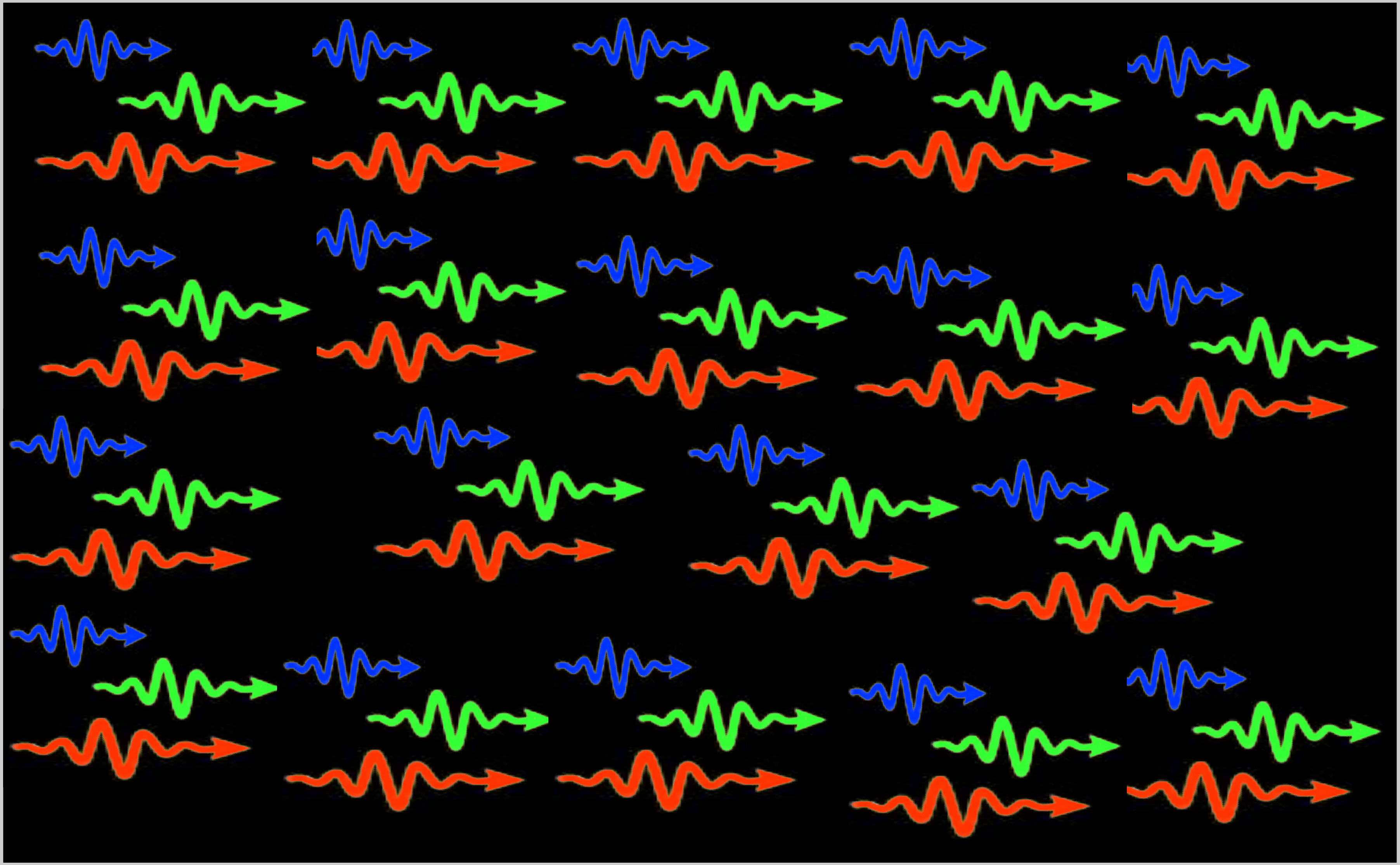
if the radiation transmission is reduced, the star reacts

Heat accumulation = pressure increase ≠ hydrostatic equilibrium

So what changes the transmissivity of radiation the opacity in the star?

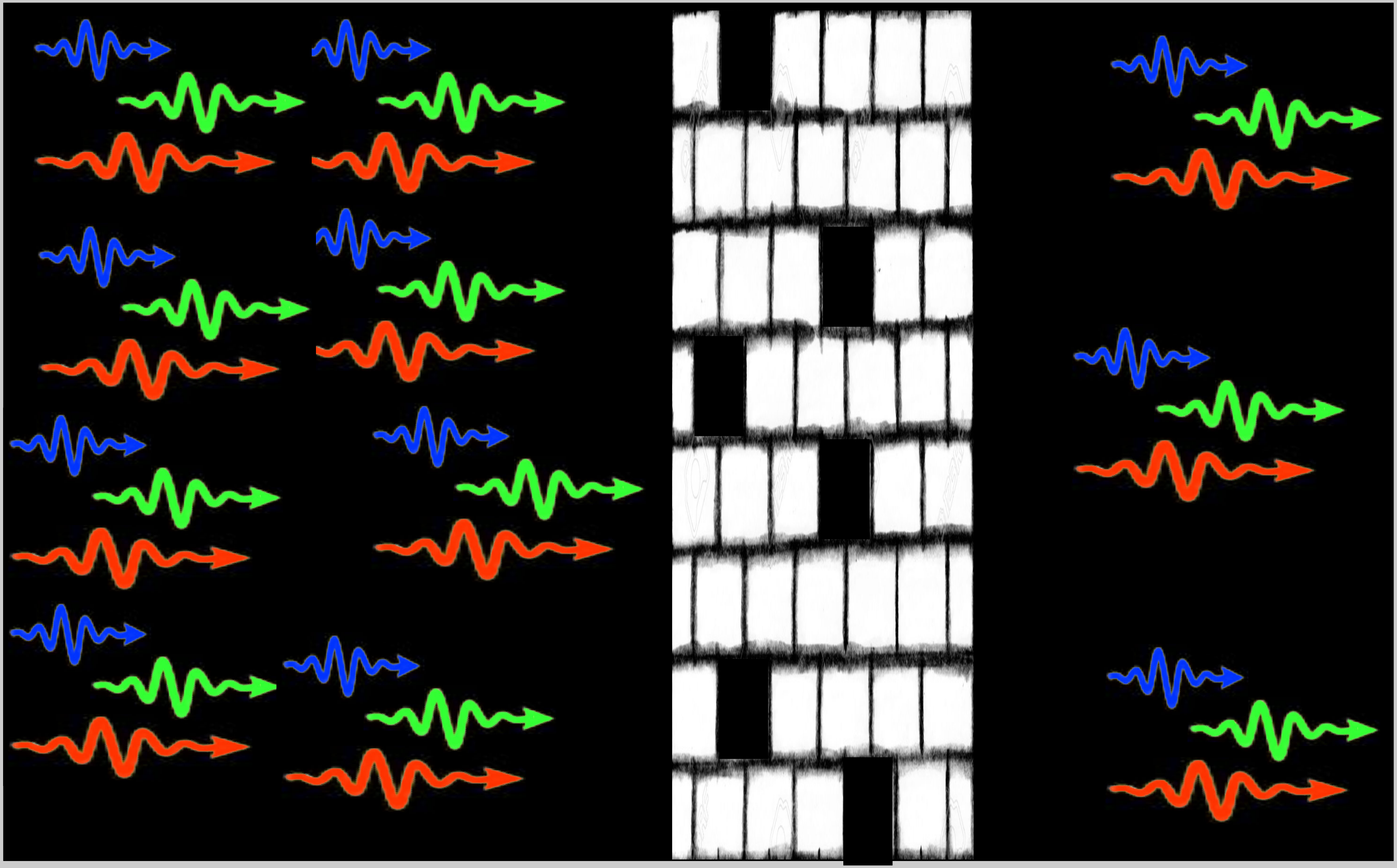
What is and what determines the opacity in stars?

opazity high



opazity low

Weakening of the transmissivity → fewer photos pass the area
here as an example of a holes in the wall



κ opacity

κ ↔ opacity
Is the transmittance of radiation ↔

$$\frac{dI}{ds} = -\kappa\rho\, I \qquad \text{or} \qquad d\tau = \kappa\,\rho\, I\, ds$$

τ ↔ optical depth

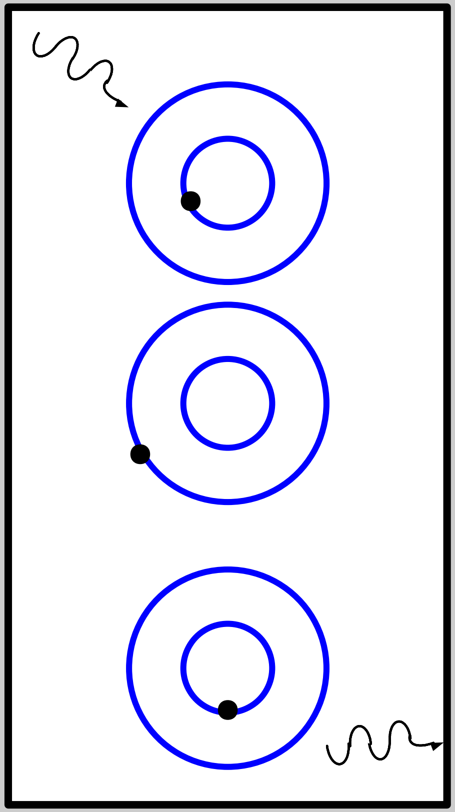
τ = 1 opaque
impassable

The radiation transmittance: The effective cross section of radiation with matter depends strongly on the physical process. A rough distinction is made between 2 classes

- **scattering processes**
  ↔ Loss from "Changing Direction" & "Annihilation"

- **absoption processes**
  ↔ loss from "Annihilation"

κ opacity – physical mechnism



- **Scattering bound - bound**

photon is absorbed → electron to higher energy state

changes the direction of the photon
→ not necessarily in the direction to the surface

Line transitions → concrete energies/transitions
→ strongly dependent on wavelength !!!

<u>Temperature T</u>
- determines number of transitions
  fully ionized → no more transitions
- dtermines the radiation field (UV or IR → number of transitions)

<u>Metallicity Z</u>
- determines number of transitions(iron versus helium)

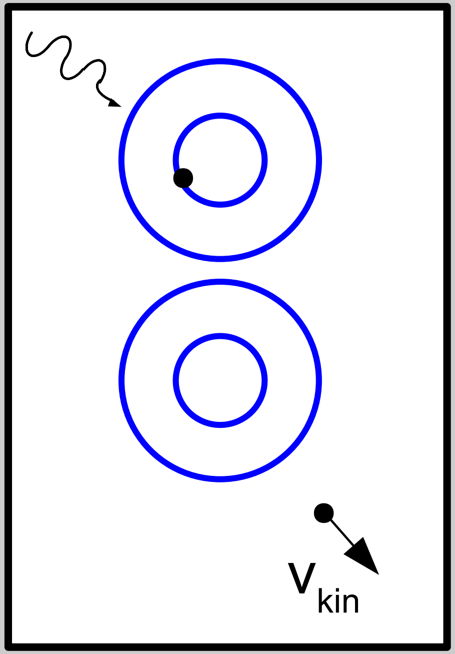
at T > 10^4 K, the transitions of the metals are the most important contribution → very strongly dependent on metallicity !!!

κ opacity – physical mechnism

- **Scattering bound - free**

  annihilation of the photon
  → Energy goes into ionization and motion
  → wide range of energies possible
  → continuum

  dependent but less strongly than "bound bound" on temperature T and metallicity Z



κ-mechanism – instability

But how does pulsation come about?

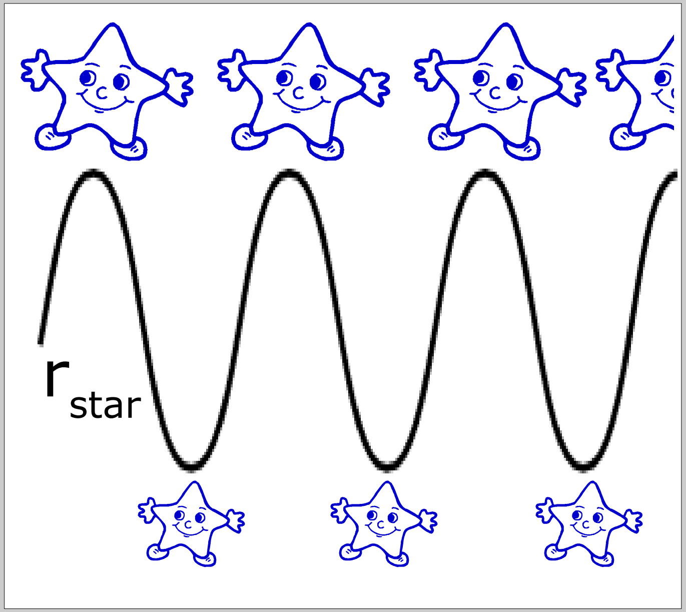
If the **temperature**, **composition**, **ionization state**, **density** and/or **pressure** changes → the **opacity changes**

$$L = 4 \pi\sigma r^2 T^4$$

→ lower transmittance ↔ leads to heat accumulation
→ expansion = temperature and radius larger → star brighter
→ expansion also → reduction of heat accumulation
→ temperature and radius decreases again and star brightness decreases
→ this changes the opacity

... the game starts all over again

→ pulsation



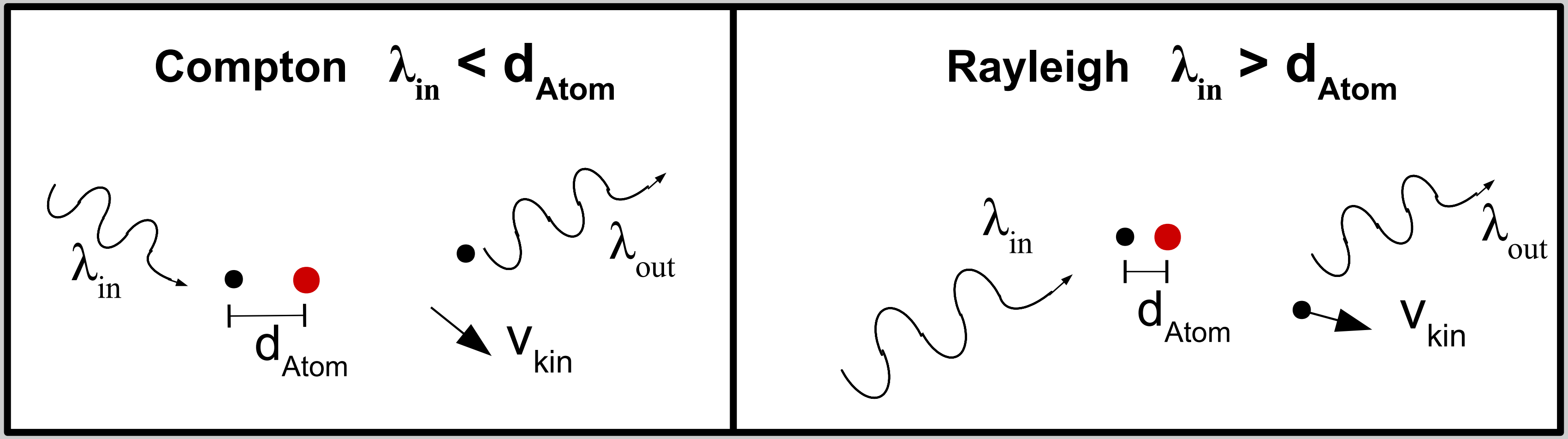
κ opacity – physical mechnism

- **electron Scattering – Compton Scattering $\lambda_{in} < d_{Atom}$**
- **electron Scattering – Rayleigh Scattering $\lambda_{in} > d_{Atom}$**

Photon scattering with electron that is 'weakly bound to nucleus'

Photon has less energy and longer wavelength,electron receives kinetic energy, de facto goes with 'every photon' → continuum

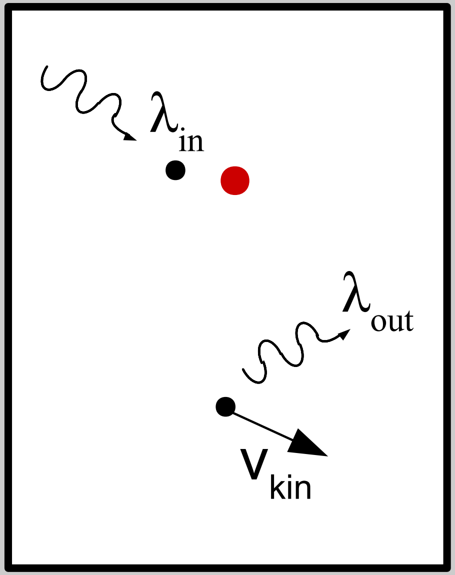
slightly dependent on temperature T ↔ since it determines the energies of the incident photons



Compton $\lambda_{in} < d_{Atom}$

Rayleigh $\lambda_{in} > d_{Atom}$

κ opacity – physical mechnism



d) free free absorption

photon scattering with a unbound electron
in the vicinity of a proton/ion

Photon transferes energy to the electron
→ photon lower in energy and longer wavelength,
→ electron receives kinetic energy

also works de facto with 'every photon' → continuum

Slightly dependent on the Temperature T ↔ something since it reflects the energies of the incident photons (λ_{in})

Rossland mean Opazity

All of these processes prevent radiation from reaching the stellar surface. The individual amounts are different and dependent on

temperature (↔ radiation field),

Composition,

ionization state

↔ thus also **density** and **pressure**.

To find the total opacity

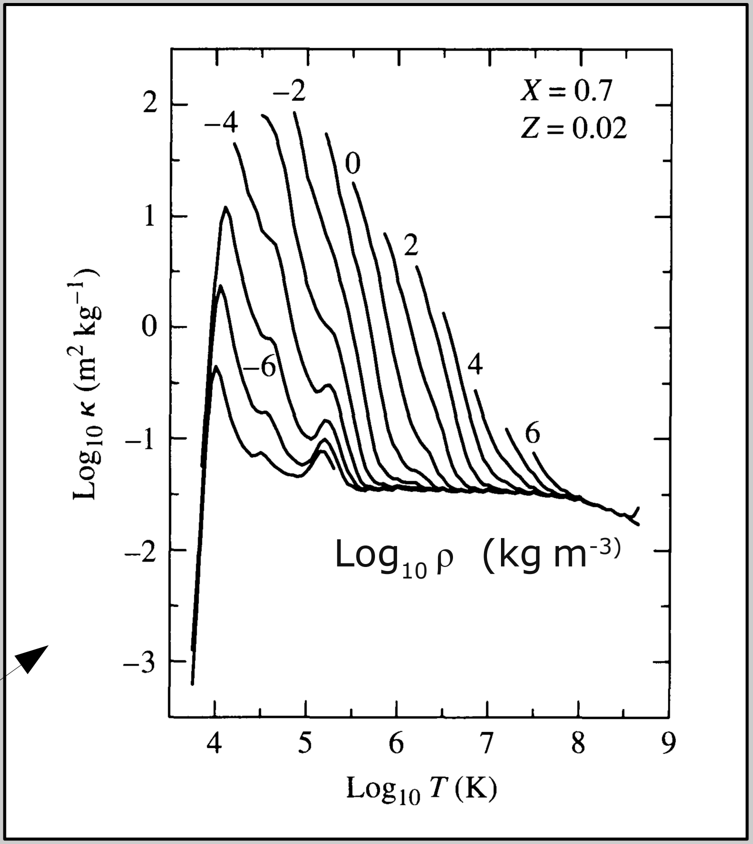
$$\kappa_{\text{Gesamt}} = \kappa_{\text{gebgeb}} \,\&\, \kappa_{\text{gebfrei}} \,\&\, \kappa_{\text{elektron}} \,\&\, \kappa_{\text{freifrei}}$$

calculate a weighted mean is derived

= **Rossland mean free opacity**

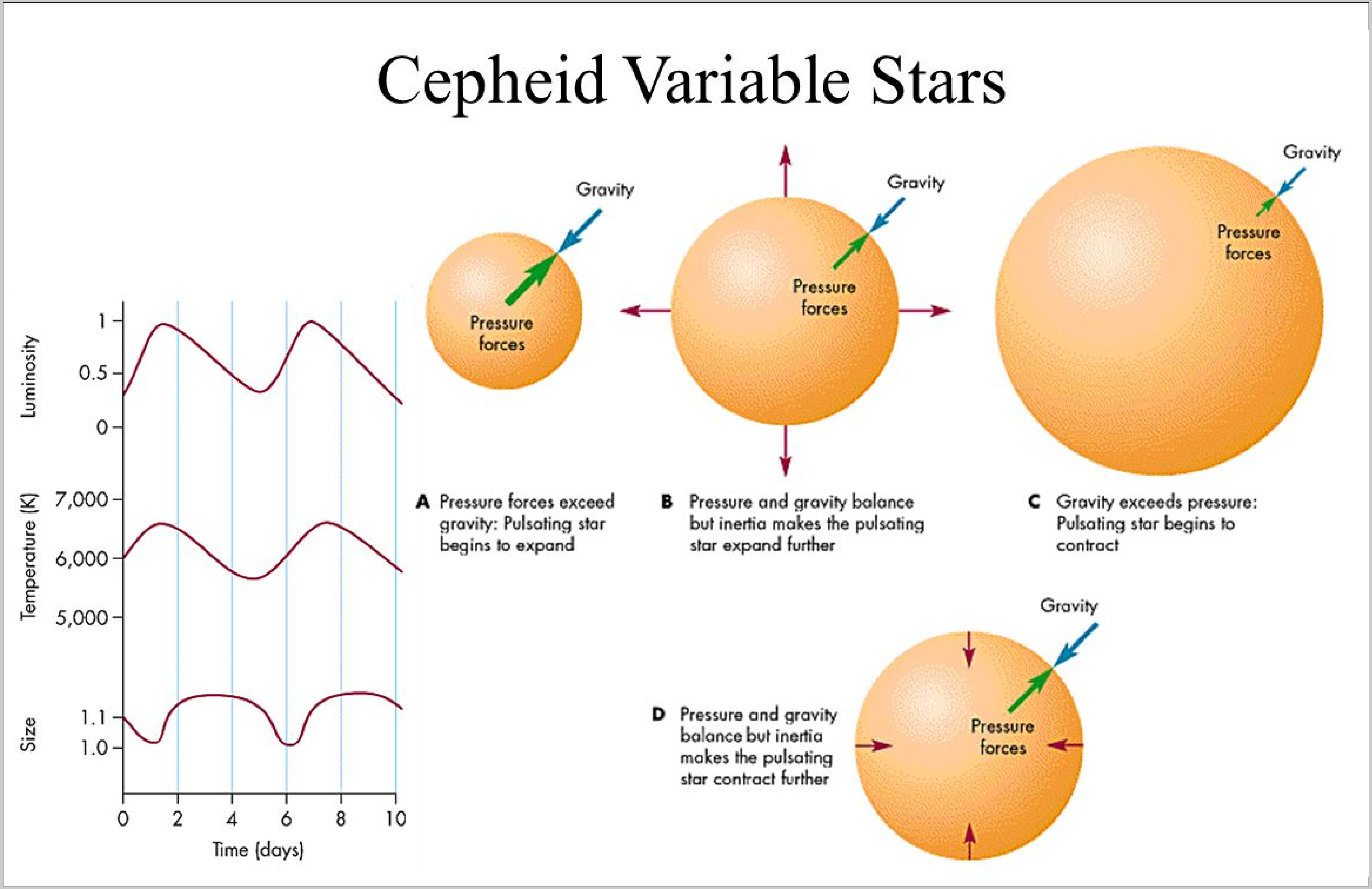
$$\frac{1}{\kappa} = \frac{\int_0^\infty \kappa_\nu^{-1} u(\nu,T)d\nu}{\int_0^\infty u(\nu,T)d\nu}$$

$$u(\nu,T) = \partial B_\nu(T)/\partial T$$



it depends on T, Z and ρ

Pulsation – Cepheids



graphic version of my words

κ-Mechanismus – die Instabilität

The **depth structure** is **important**, i.e. how deep in the star does the accumulation of heat occur

too deep
→ shell above too massive → hardly moved and quickly dampened

too high
→ shell above too light hardly any mass that is moved
→ possibly leave the gravitational field at the very first oscillation

What changes the opacity ?
Mechanisms known to date are based on a change in the ionization state.

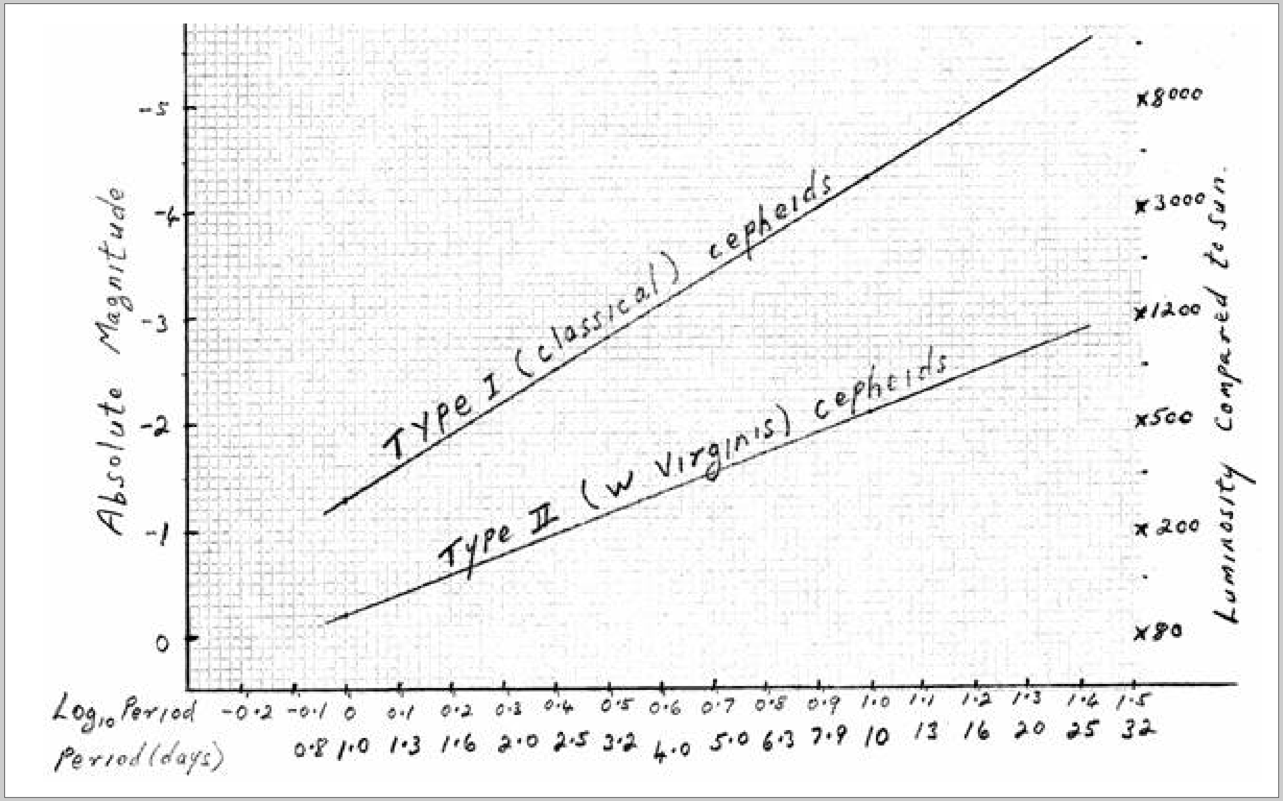
→ Change in free electrons ↔ free free
→ Changing the transitions ↔ bound bound & bound free

Cepheiden – Perioden-Leuchtkraft Relation

→ obvious **relation** between **period** and **luminosity** with different gradient for each type. This led to the introduction of several classes of Cepheids, at that time these were

Typ I or **classic Cepheiden**

Typ II or according to the prototype **W Virginis Sterne**



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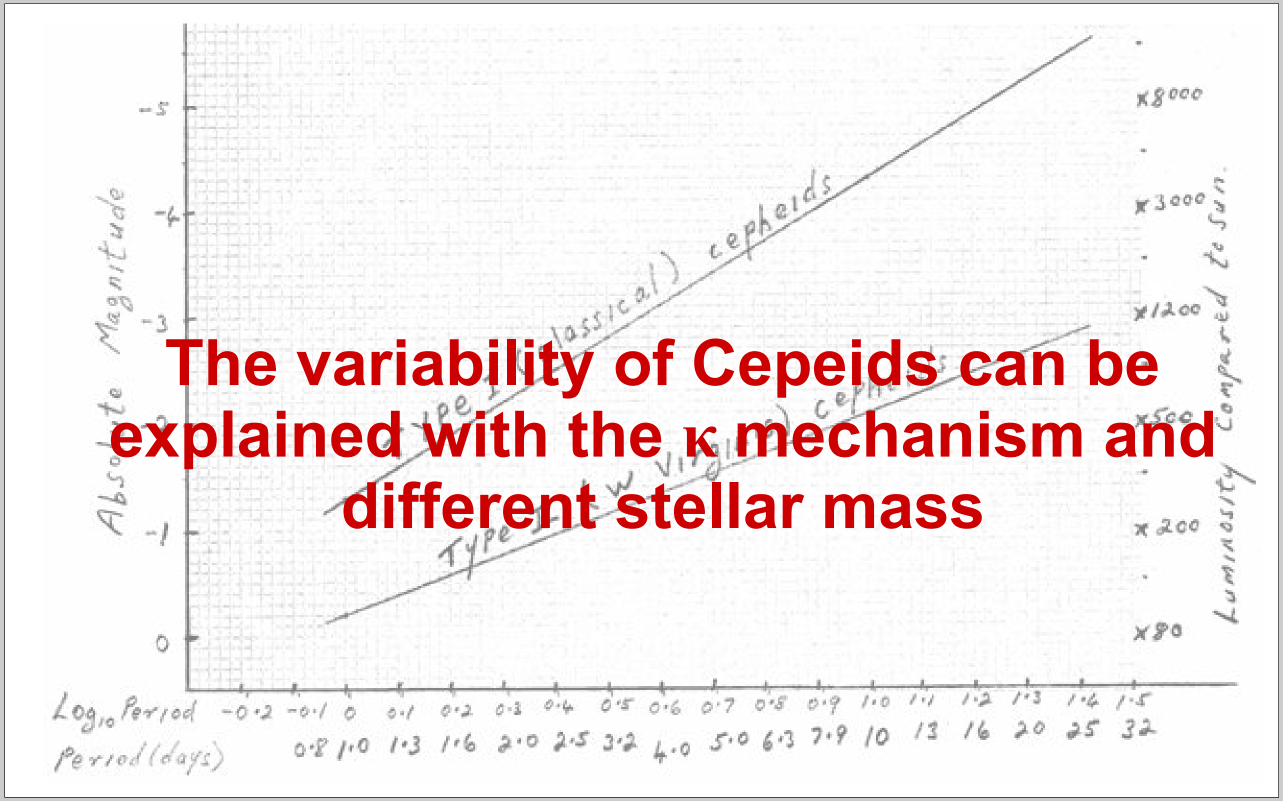
Typ I or **classic Cepheiden**

Typ II or according to the prototype **W Virginis Sterne**

… today we know more class



The variability of Cepeids can be explained with the κ mechanism and different stellar mass

Cepheiden – Perioden-Leuchtkraft Relation

Depending on how deep the layer is, a more or less strong pulsation starts (↔ temperature structures in the star ↔ HRD).

- a lot of mass above (↔ star more massive)
  → small change in radius → short period → Luminosity change weak

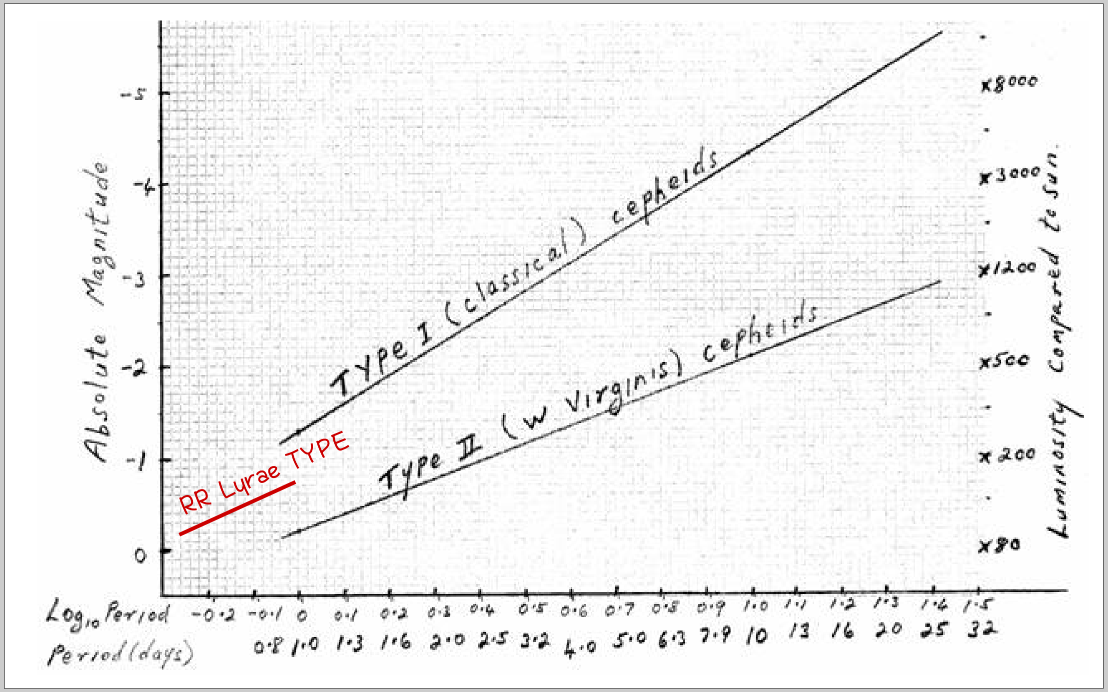
  → relation between period and luminosity can be explained by different stellar masses.

Therfore

δ Cepheids
Typ I massive stars

W Virginis stars
Typ II low mass stars

RR Lyrae stars
Horizontal branch stars



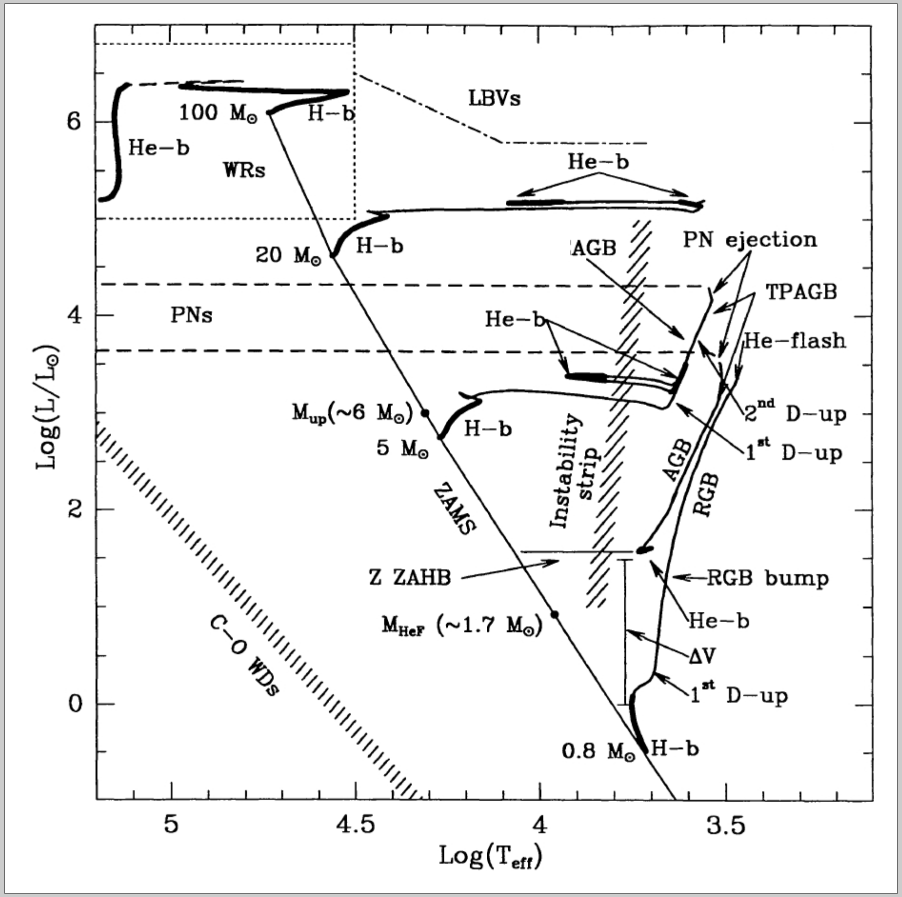
κ-Mechanismus – Cepheiden

Why does the pulsation start? What triggest the mechnism

Stellar evolution
→ changes in the stellar structure
→ changes in temperature, density & ionization state and hence the **opacity**

For Chepheids it's a temperature change that leads Helium to go from a single Ionized to double ionized state
(He I→HeII)

→ this changes the opacity κ
→ starts the κ mechanism
→ initiates the pulsation of the star



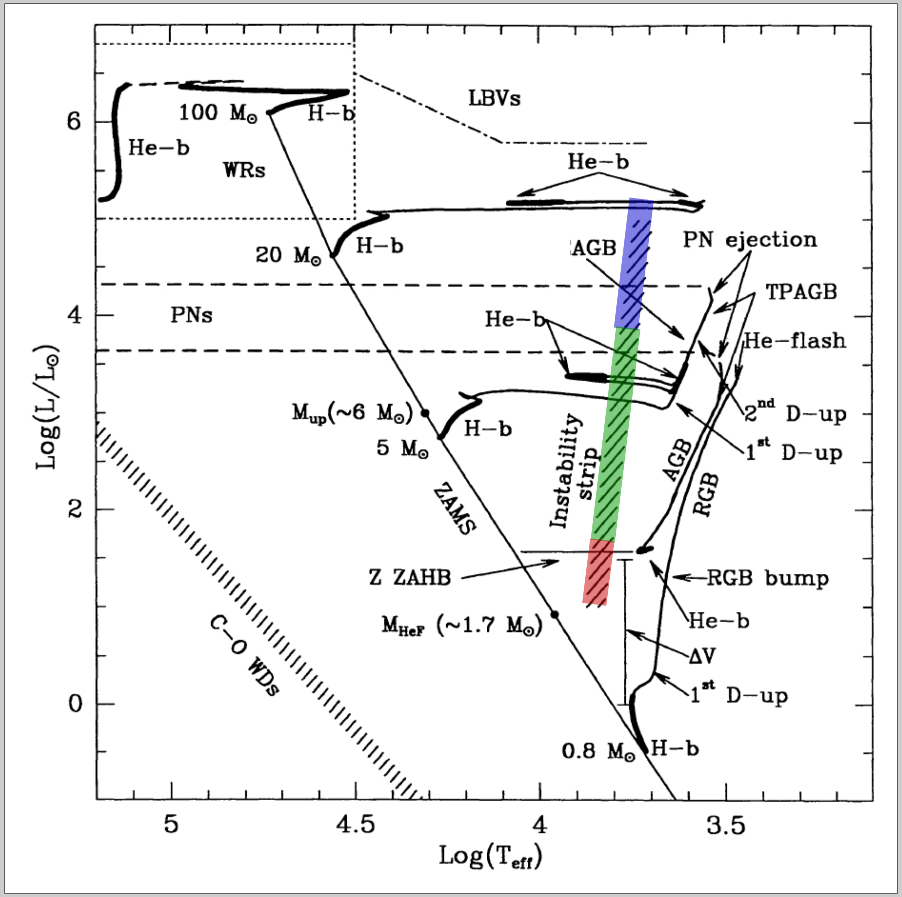
Chepheids stars therefore all have similar **temperatures** when the pulsation starts – but have different **masses**

κ-Mechanismus – Cepheiden

Chepheids stars therefore all have similar **temperatures** when the pulsation starts

→ in the HRD all are on the instability strip

but have different **masses**



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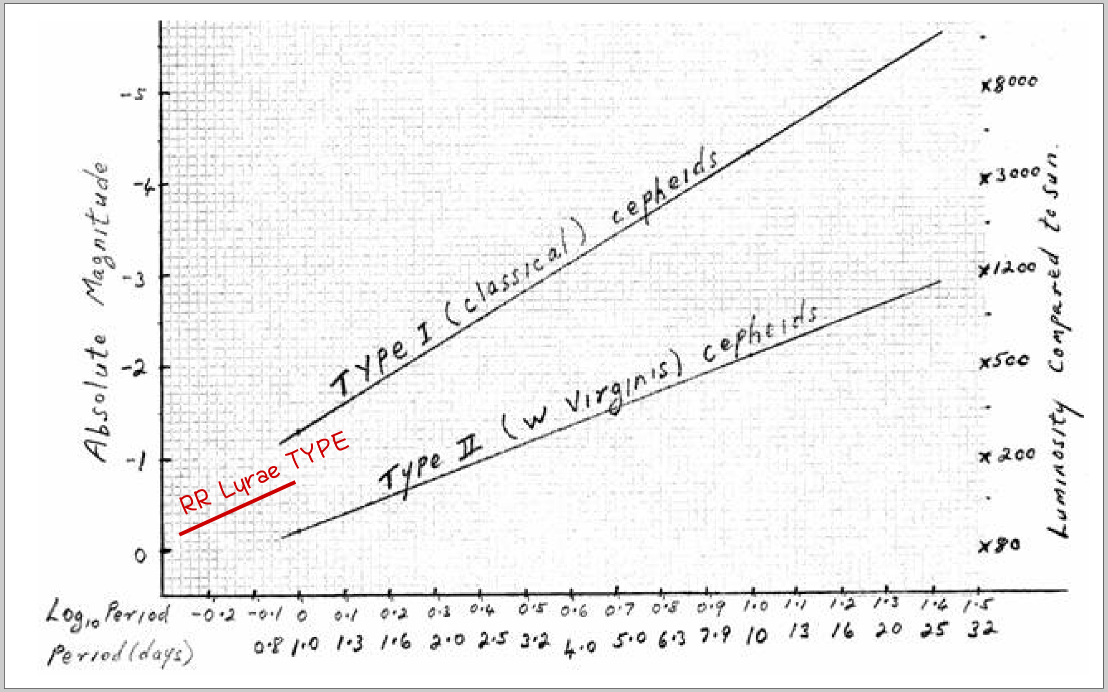

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Cepheiden – Entferungsbestimmung

→ Cepheids can be used for distance determinations

Measurement: Cepheid type, period, luminosity/brightness

Method: Comparison the 'actual brightness' with the brightness that is expected for period that was measured
From the difference and the distance module

$$m - M = 5\,\mathrm{mag} \cdot \log_{10}\left(\frac{r}{10\,\mathrm{pc}}\right)$$

→ distance r

δ Cepheids
Typ I massive stars

W Virginis stars
Typ II low mass stars

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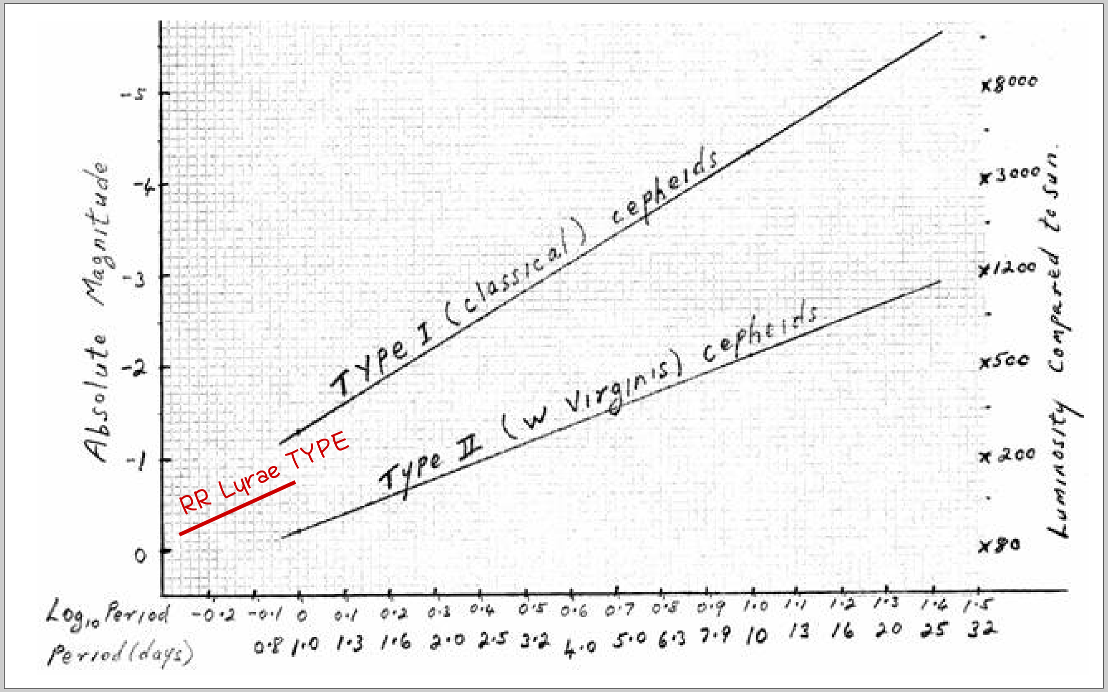
Horizontal branch stars



Baade – Populationen I & II

Walter Baade (1893-1960)

- studied in Munich and Göttingen
- worked at the observatory in Hamburg
- Mt. Wilson Observatory & Mt. Palomar
- Work on variable stars and structure of the Milky Way and galaxies
- found Cepheids in M31
- has divided the Cepheids (according to the gradient of the period luminosity function) into two populations Population I and II, therefore often the term Population I and II Cepheids instead of Type I and II

Population I ↔ massive young star

Population II ↔ low mass old stars

Baade – Population I & II

Walter Baade (1893-1960)

- Work on variable stars and structure of the Milky Way and galaxies

  Population I ↔ massive young star

  Preferentially located in spiral arms

  Population II ↔ low mass old stars

  Preferentially located in the bulge

- Motivated and pursued the idea of a European observatory
  → therefore an originator (father) of ESO

Baade – and ESO

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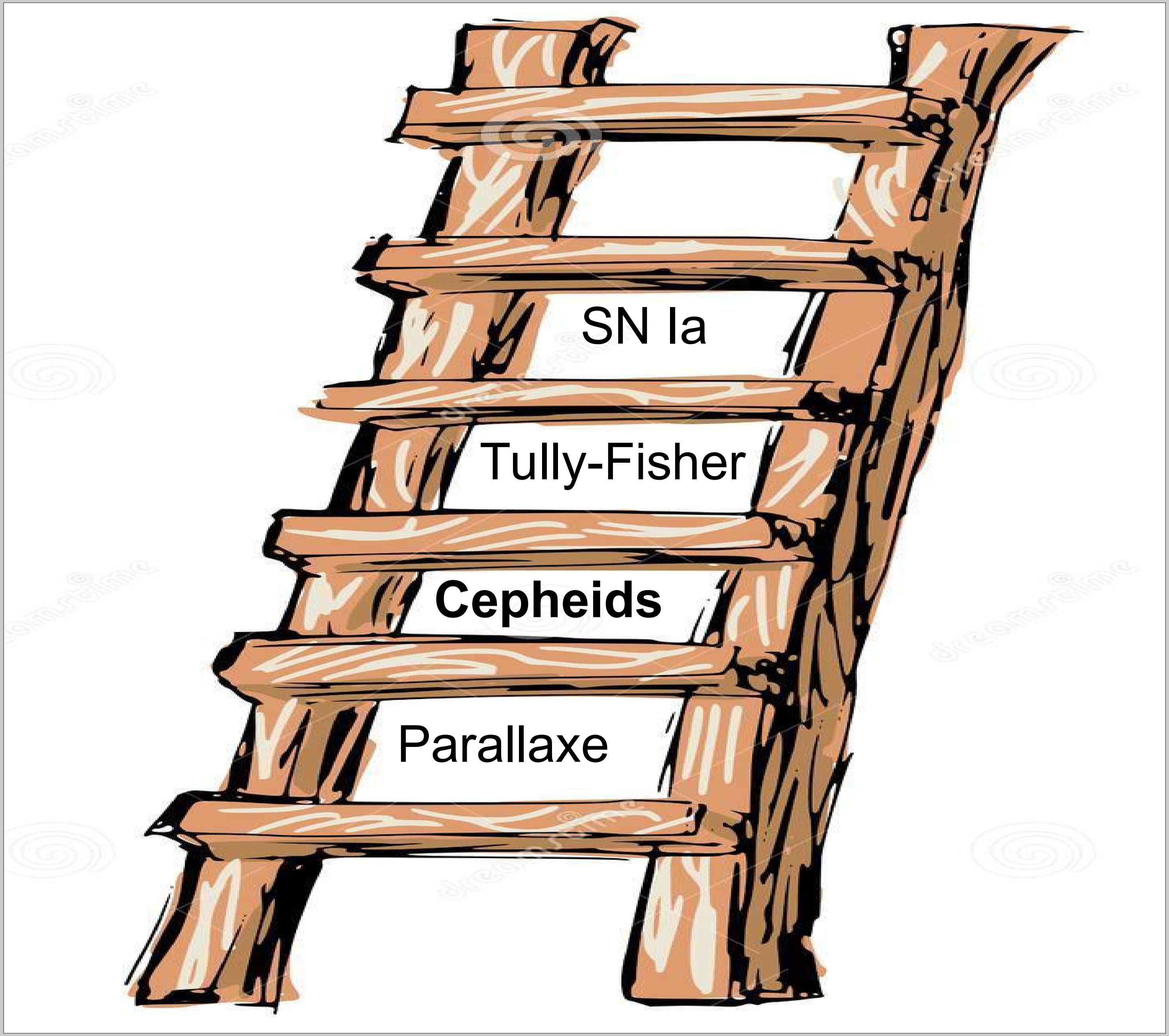
Cepheids - important step of the distance ladder



But I am as constant as the northern star,
Of whose true-fix'd and resting quality
There is no fellow in the firmament.

in William Shakespeare, Julius Caesar

Constant as the northern star...

Polaris ↔ α Ursae Minoris → Polaris A

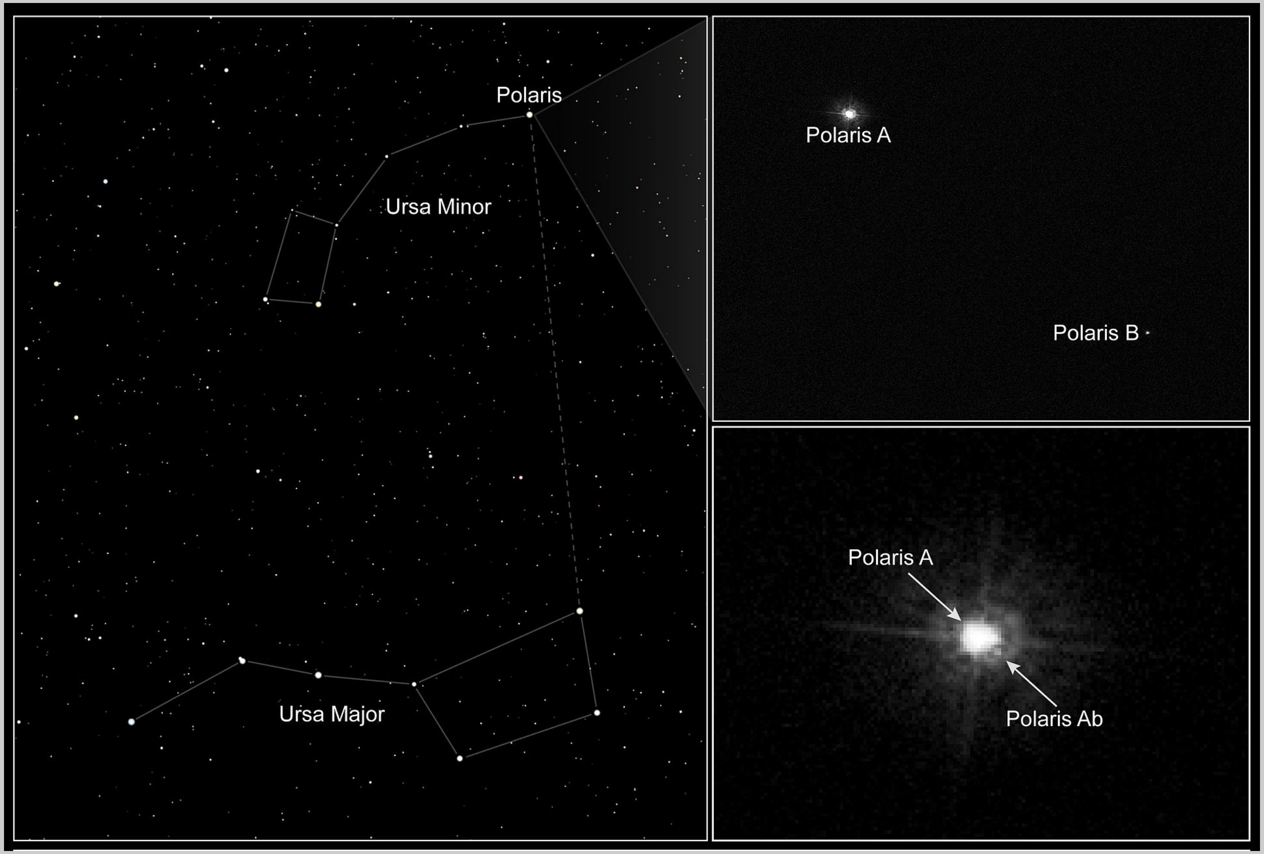
- visuel **binary** Polaris A and B (1780 Wilhelm Herschel)
- apparent distance from Polaris B (F3 V) is 18.4"
- **Polaris A** itself is also a **binary:** Polaris Aa (F7 Ib) and Polaris Ab (F6 V) distance 0.17"

UND

- **Polaris Aa** is a **Typ I Cepheid** with m = 1.92 – 2.07^{mag} a period of 3.9 days, but the **Pulsation amplitude is declining**!

constant as the northern star

!!!



©HST

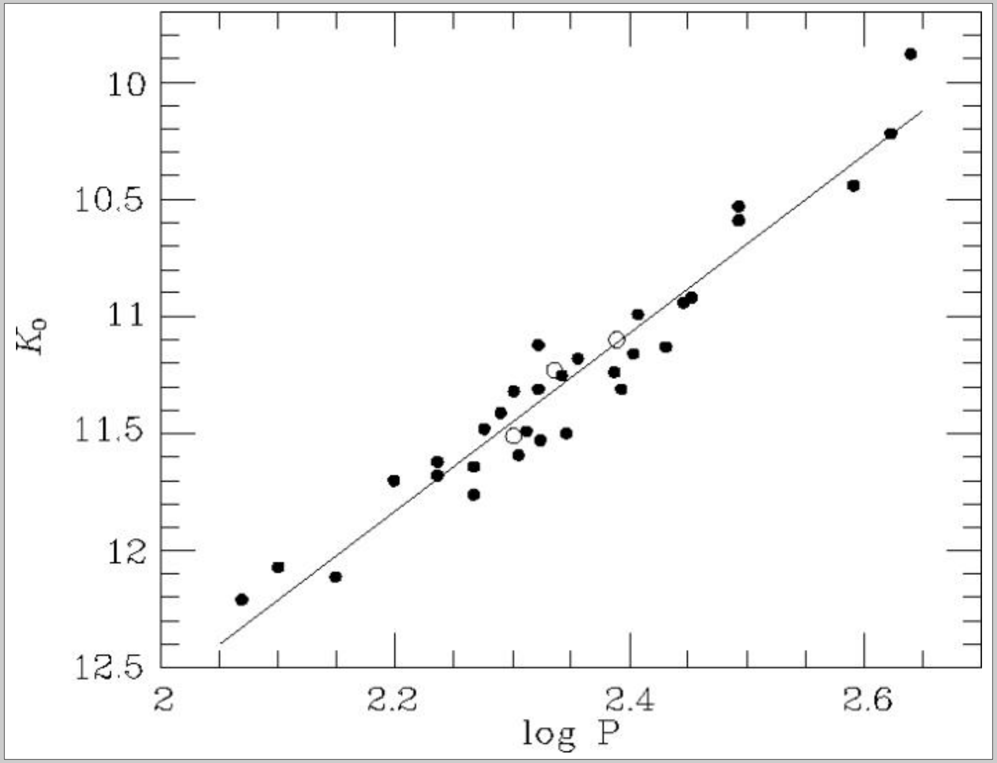
Other pulsation variables

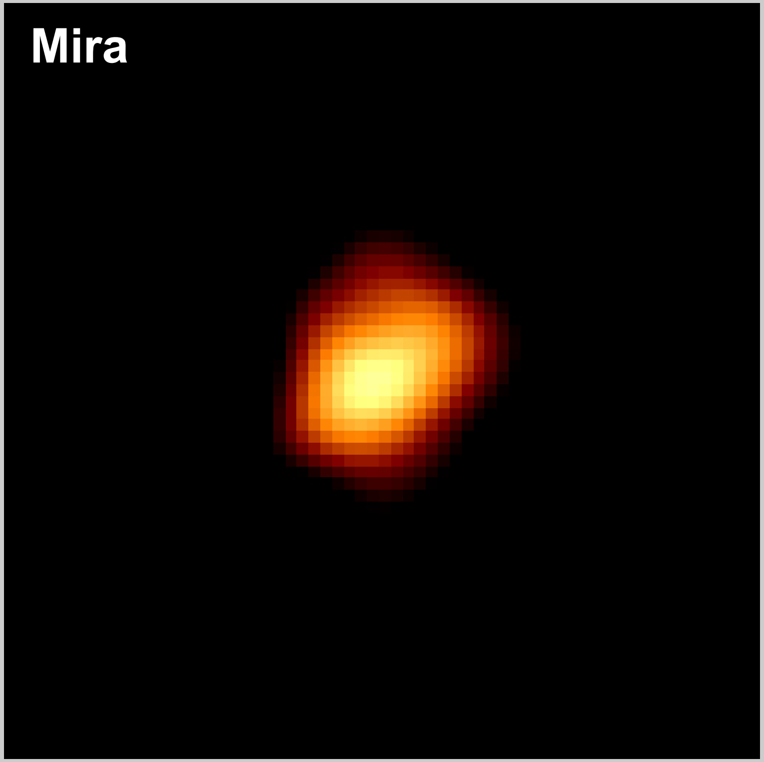
Mira Variable

Variability Mechanism:
Pulsation of **low-mass stars** in **AGB** phase
κ-mechanism here change in the **opacity** of e.g. He, titanium oxide

Long-**p**eriod **v**ariable → LPVs

As with Cepheids luminosity periods relationship
(for AGB in the red and IR range can be easily observed)
↓





Weiter Pulsationsvariable mit κ-Mechnismus

α Cygni
supergiant stars
periods days to weeks and brightness changes around 0.1 mag

β Cephei
also knonwn as **β Canis Majoris** bekannt.
Periods 0.1 – 0.6 days, brightness changes 0.01 – 0.3 mag

RV Tauri ↔ not T Tauri !!!
Yellow supergiants
Periods often 2 maxima 30 – 100 days, brightness changes 3-4 mag
Existence of additional long-periodic (years) changes

Weiter Pulsationsvariable mit κ-Mechnismus

δ Scuti
also known as Dwarf Cepheids.
like Cepheids with shorter periods 0.01 – 0.02 days and smaller magnitude changes 0.003 – 0.9 mag, spectral type A0 - F5

SX Phoenicis
Similar to δ Scuti, often in globular clusters
Periods 1 – 2 hours, brightness changes 0.7 mag = ~ 100%
Spectral type A2 - F5

Ap Variable
A subclass of δ Scuti, main sequence A Stars with strong rotation
Periods therefore in the range of a few minutes, change in brightness 0.001 mag

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