

Cepheids as a DM detector

meV dark photon dark matter



CUBES 2026

Apr 26, The-K Jirisan Family Hotel, Sandong, Gurye

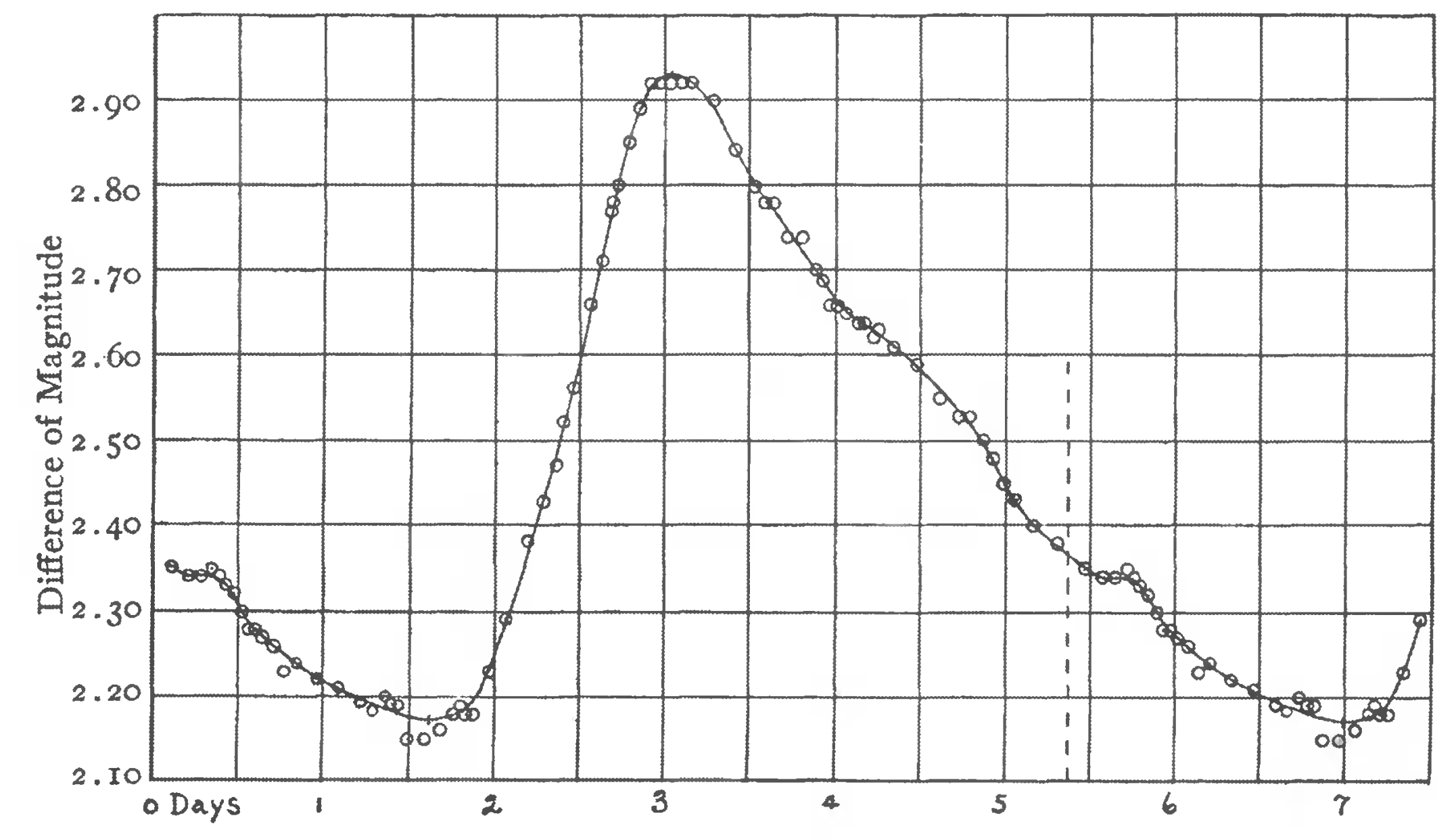
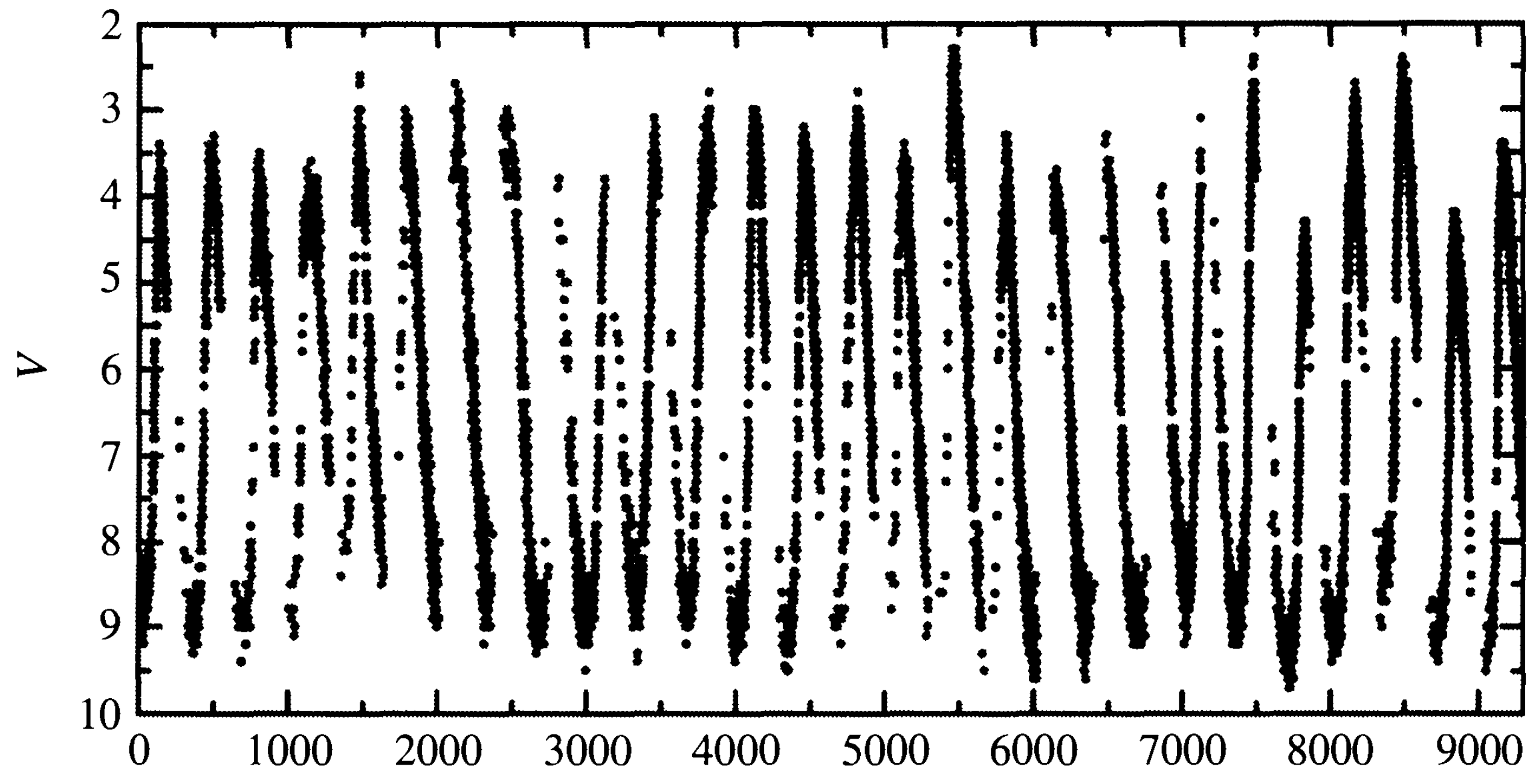
Hyung Do Kim

**with Taegyung Kang and Jaeyoung Park
(Seoul National University)**

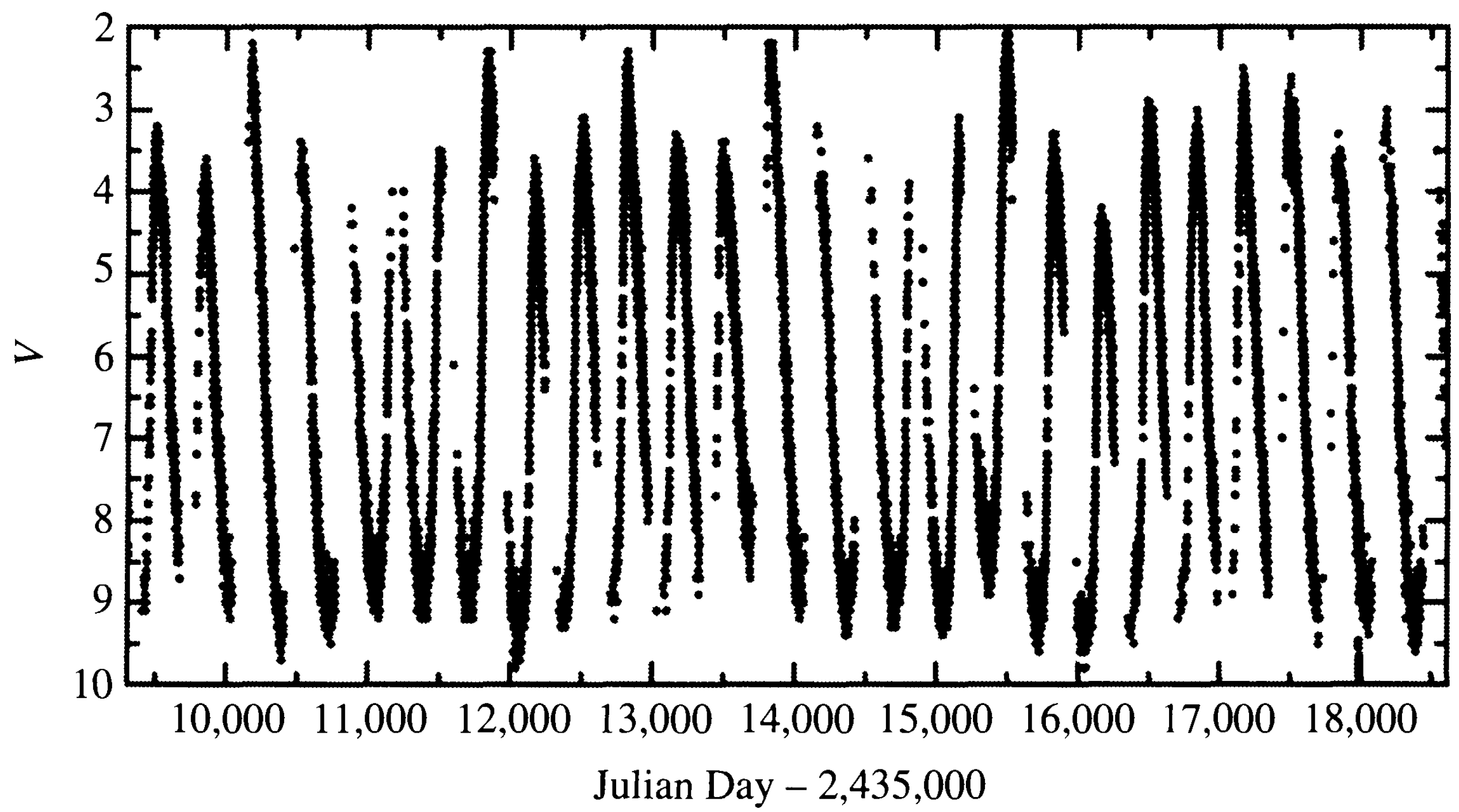
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Preliminary

- Introduction of Cepheids
- HR diagram and physics of Cepheid variables
- PLC relation to PLZ relation
- Cosmic distance ladder
- Vector dark matter : dark photon as a dark matter
- Dark photon to photon conversion at the partially ionizing zone of Cepheids
- Summary



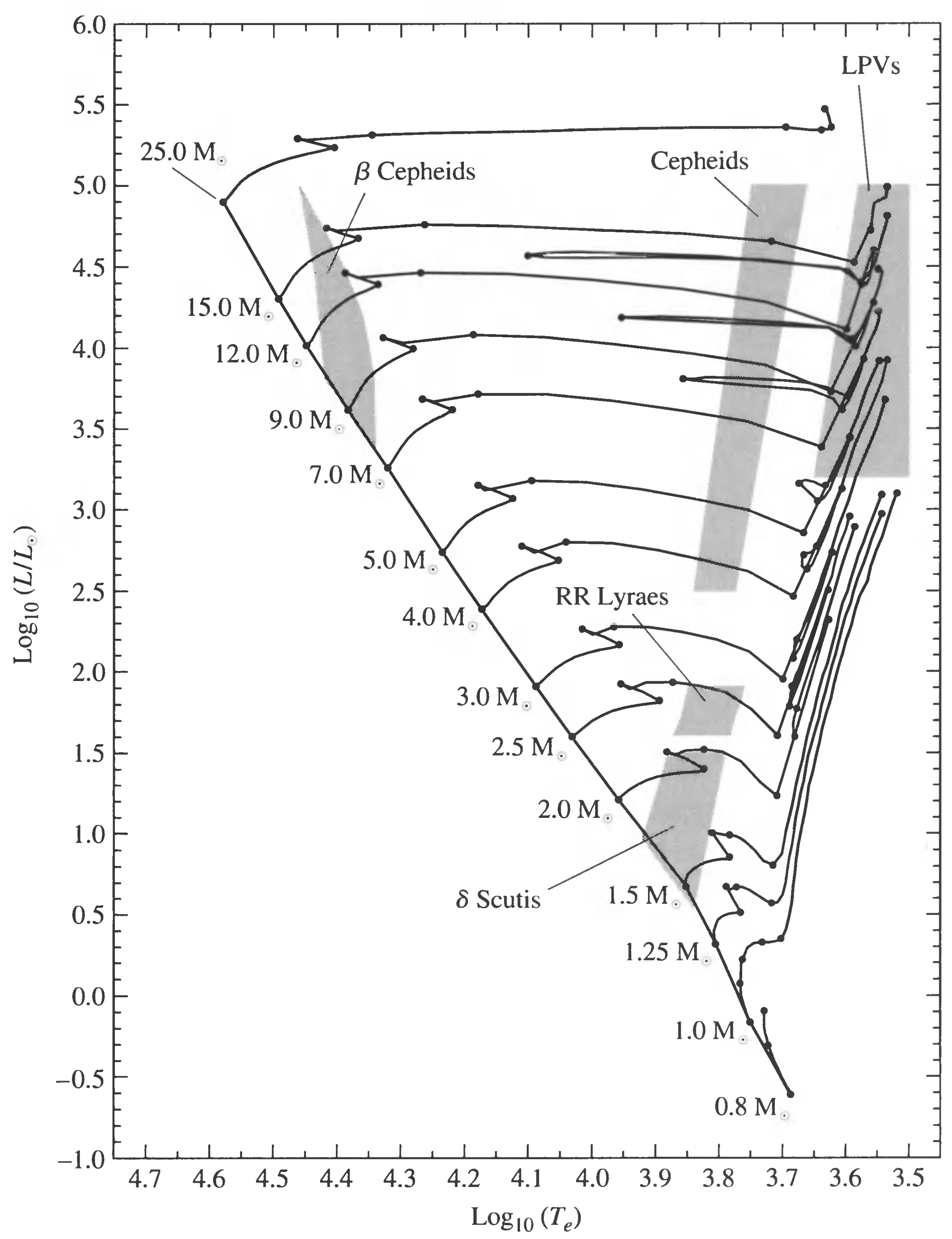
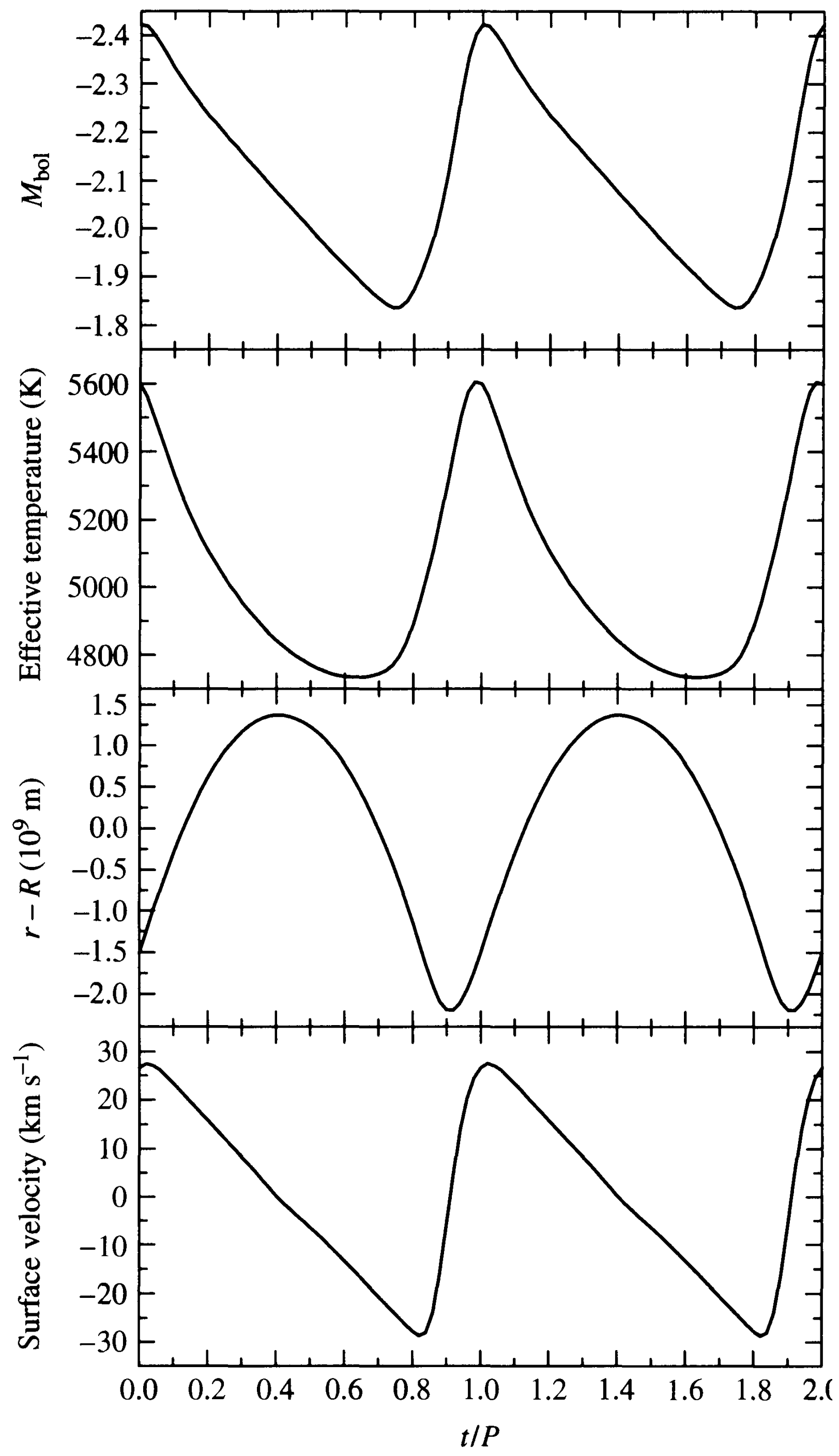
δ Cephei



Mira

Henrietta
Swan
Leavitt
(1868-1921)

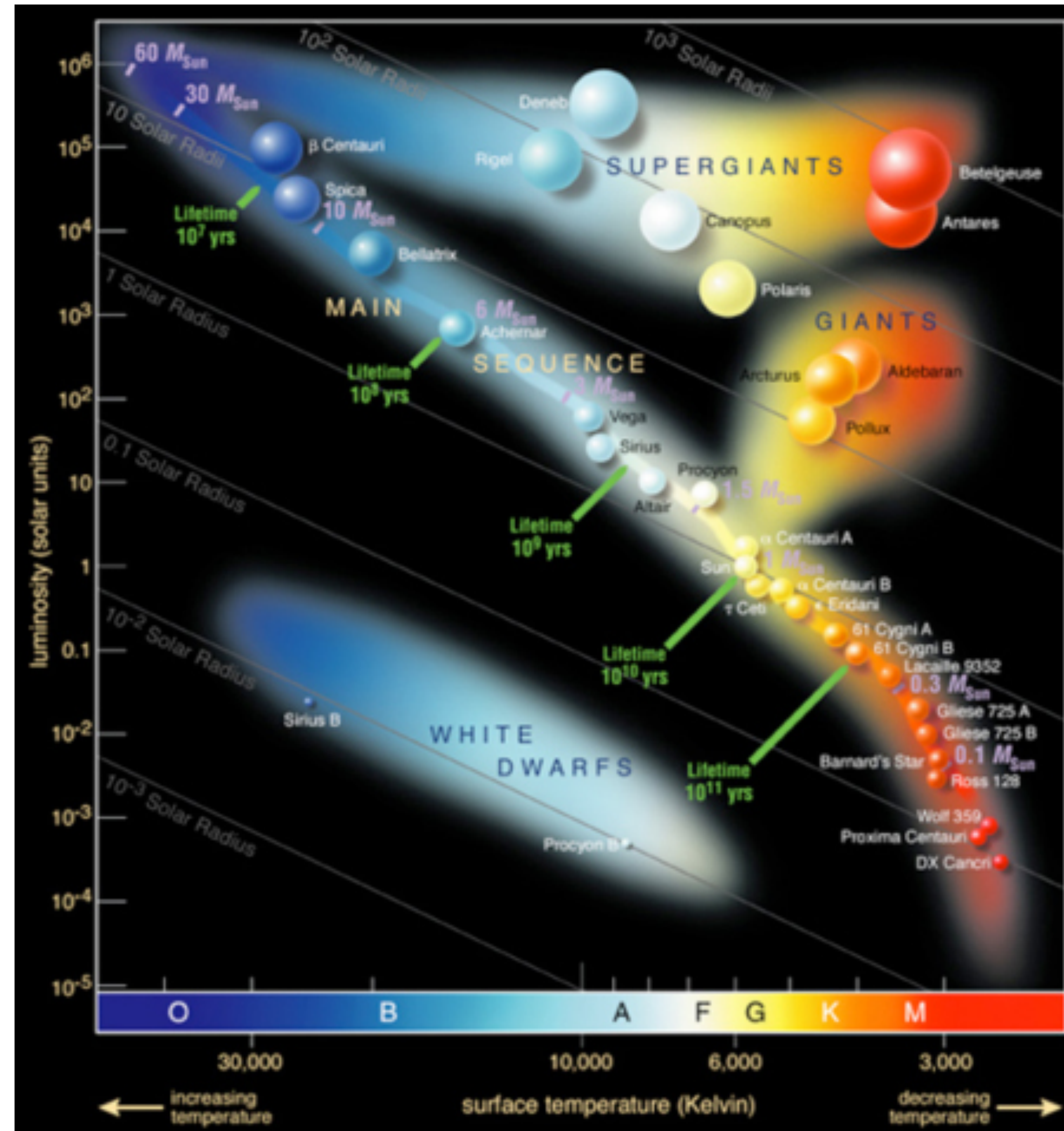




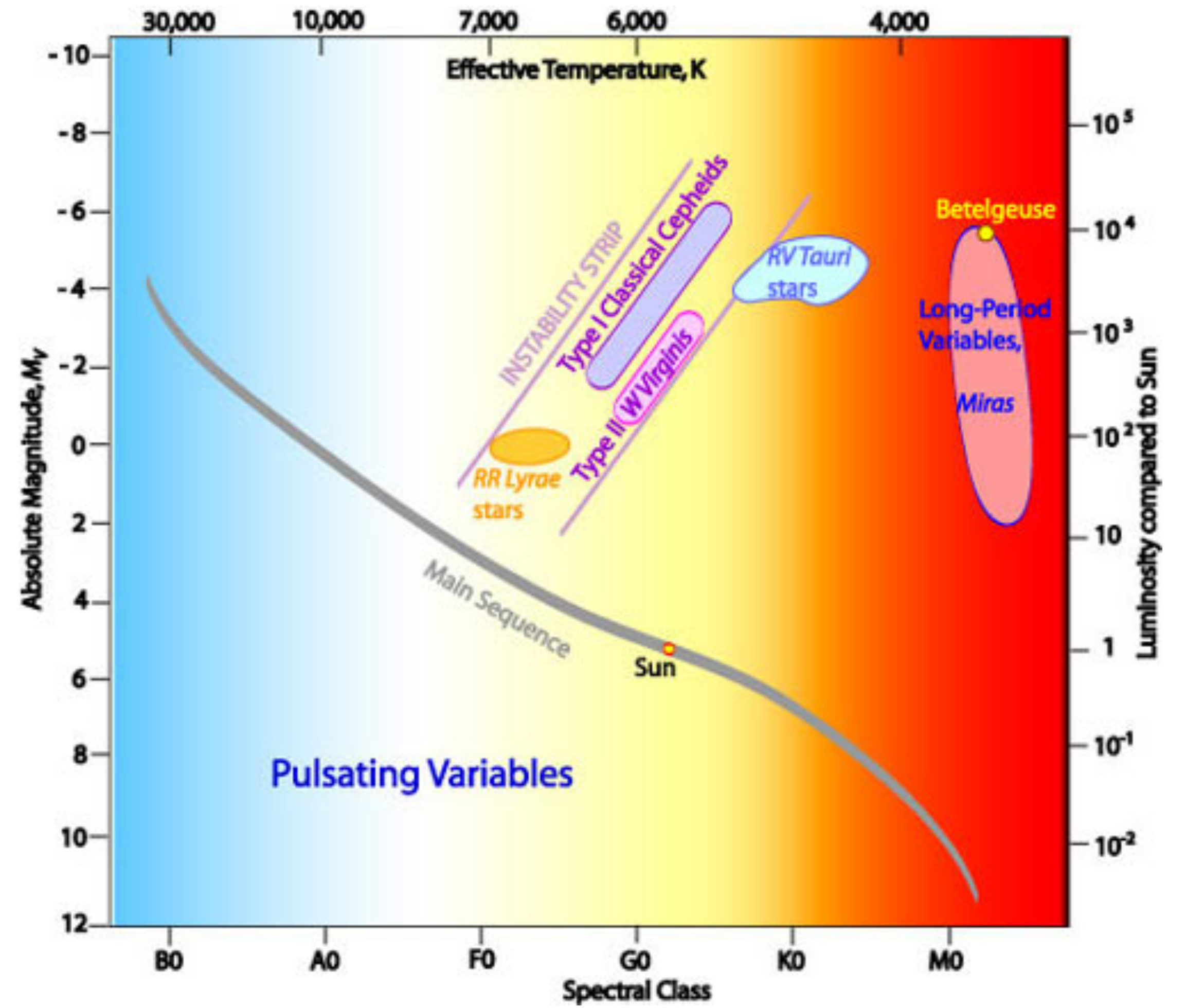
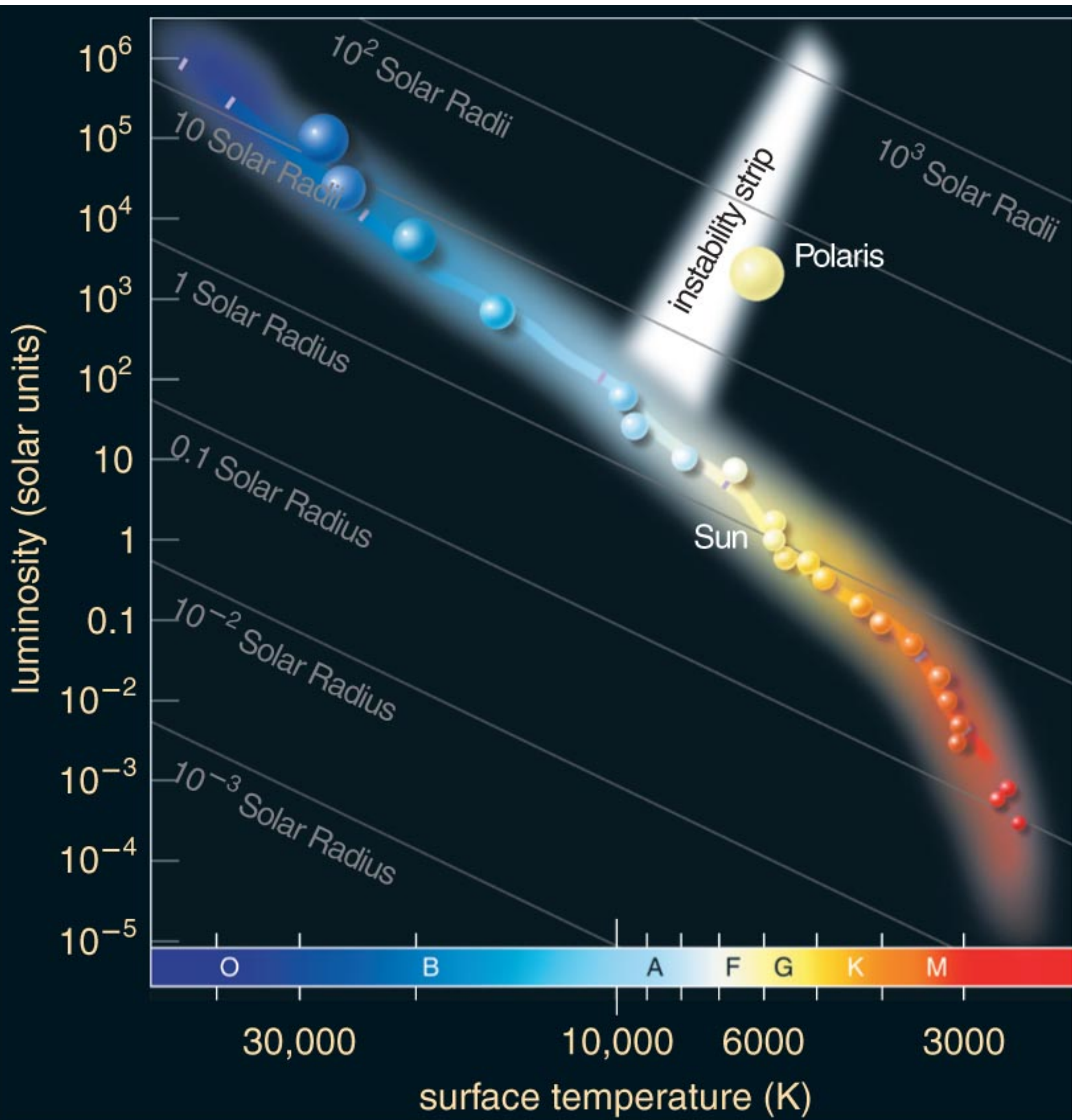
Herzsprung-Russell Diagram

Luminosity

Mass



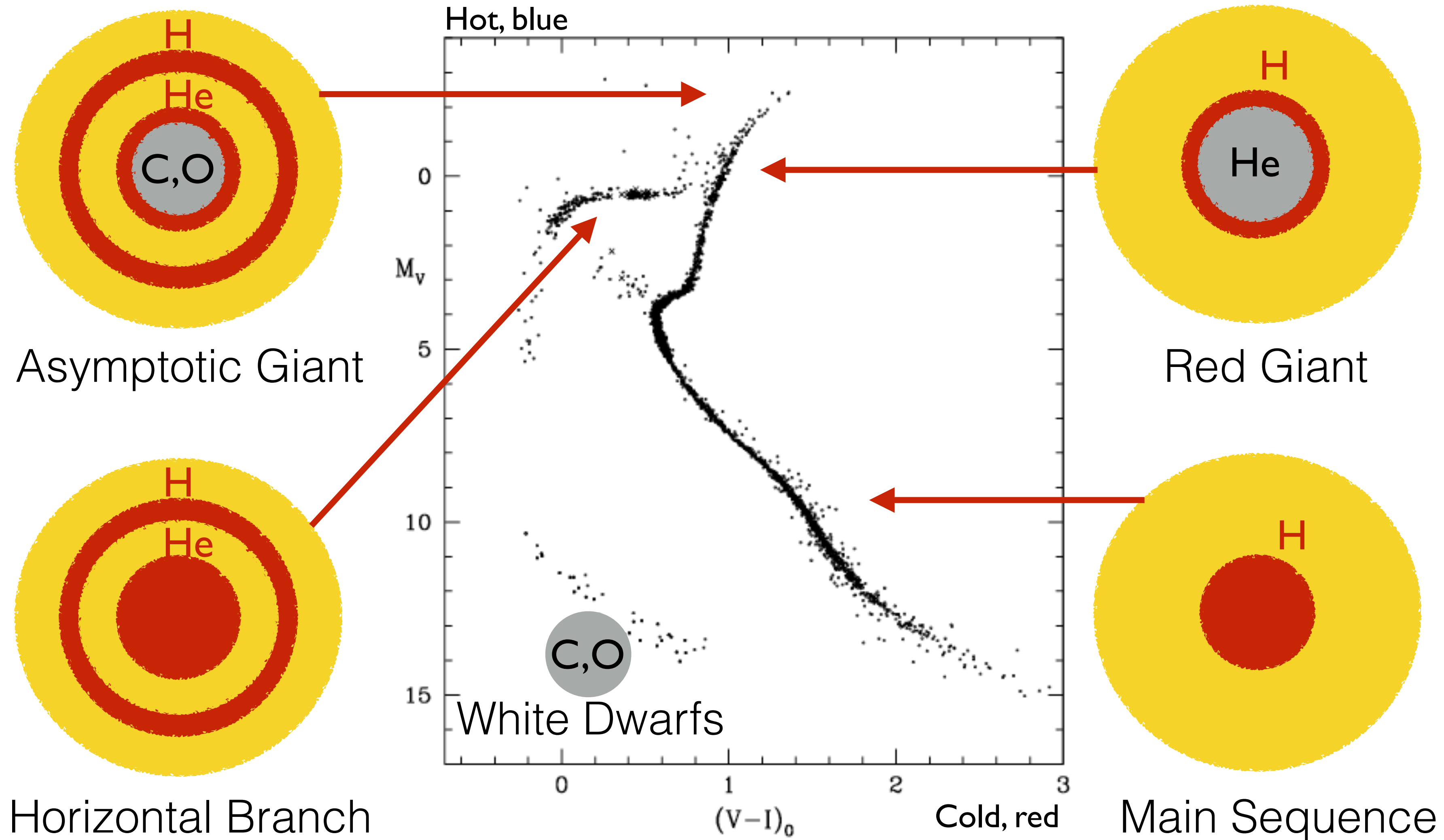
Color
(Temperature)



Stars as laboratories

see e.g. Raffelt's excellent book

Pradler's talk 2015



Globular Cluster color-magnitude diagram

Cepheid Variable

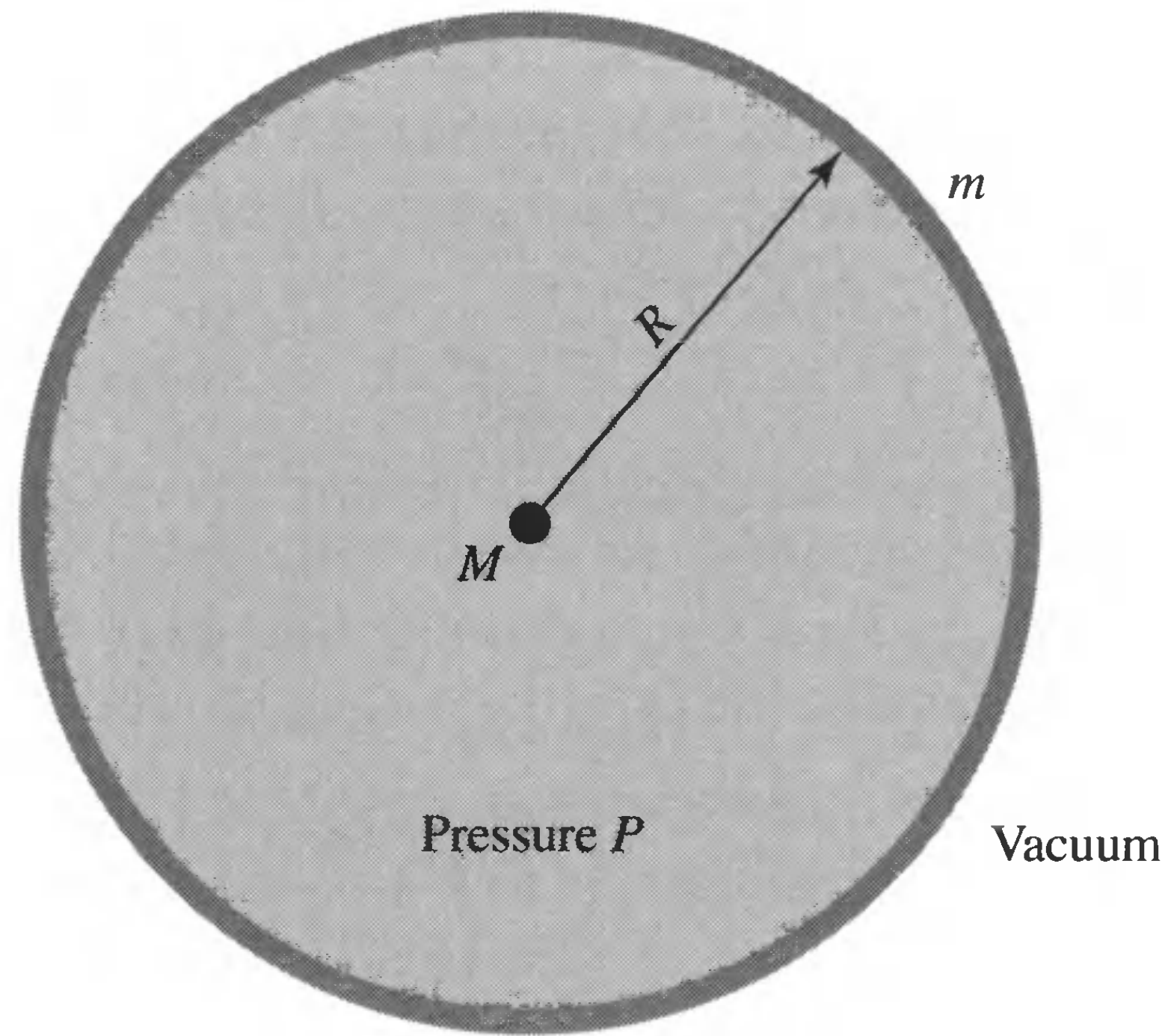
$$\rho \frac{d^2 r}{dt^2} = -G \frac{M_r \rho}{r^2} - \frac{dP}{dr}$$

$$\frac{\delta P}{P_0} = -3\gamma \frac{\delta R}{R_0} \quad PV^\gamma = \text{constant}$$

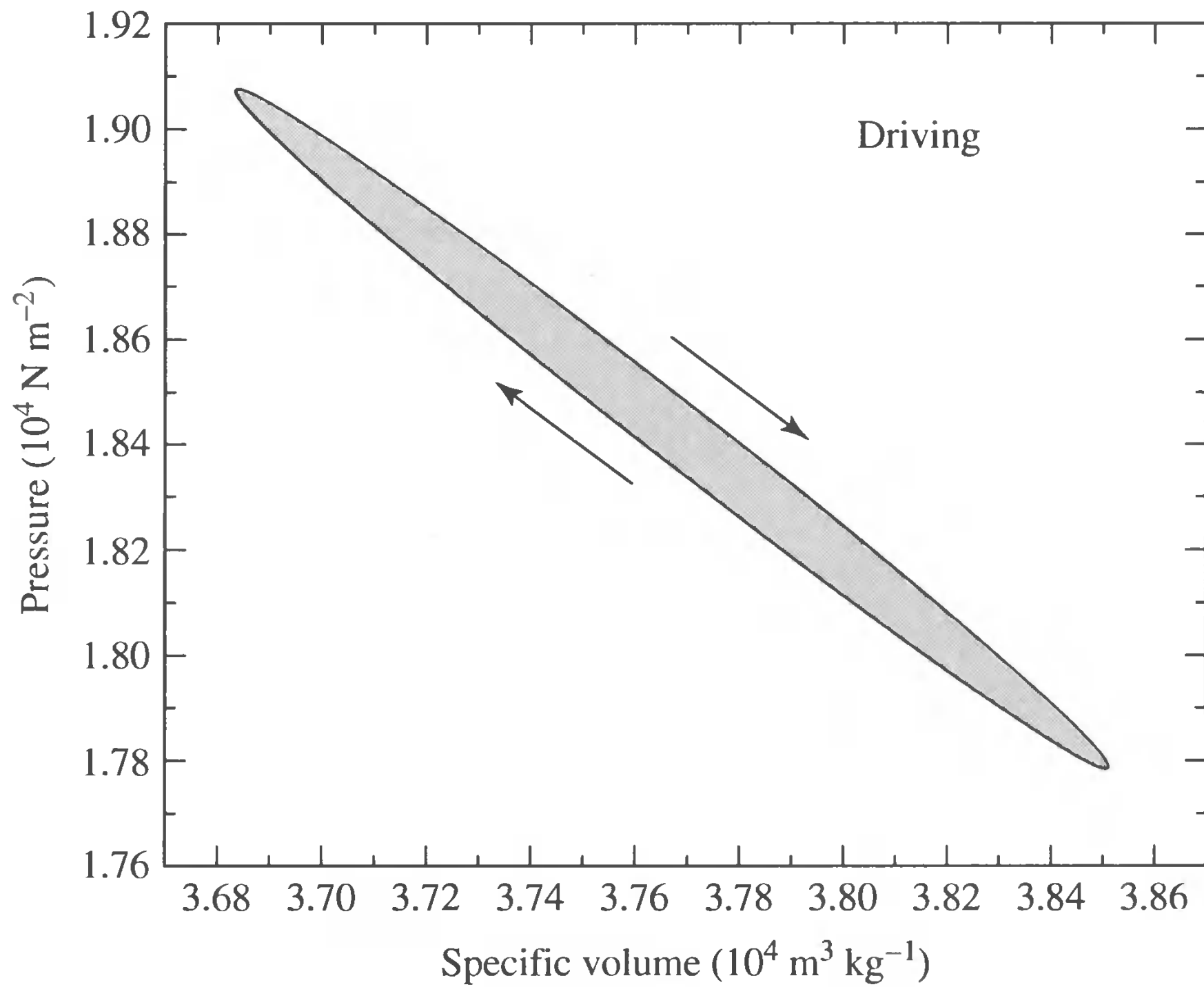
(adiabatic)

$$\frac{d^2(\delta R)}{dt^2} = -(3\gamma - 4) \frac{GM}{R_0^3} \delta R$$

$$\omega^2 = (3\gamma - 4) \frac{GM}{R_0^3} \quad \Pi = \frac{2\pi}{\omega} \propto \frac{1}{\sqrt{\rho}}$$



One-zone model



$$\kappa \propto \frac{\rho}{T^{3.5}}$$

The opacity increases with compression

$$\oint P dV > 0$$

The gas does work during the cycle.

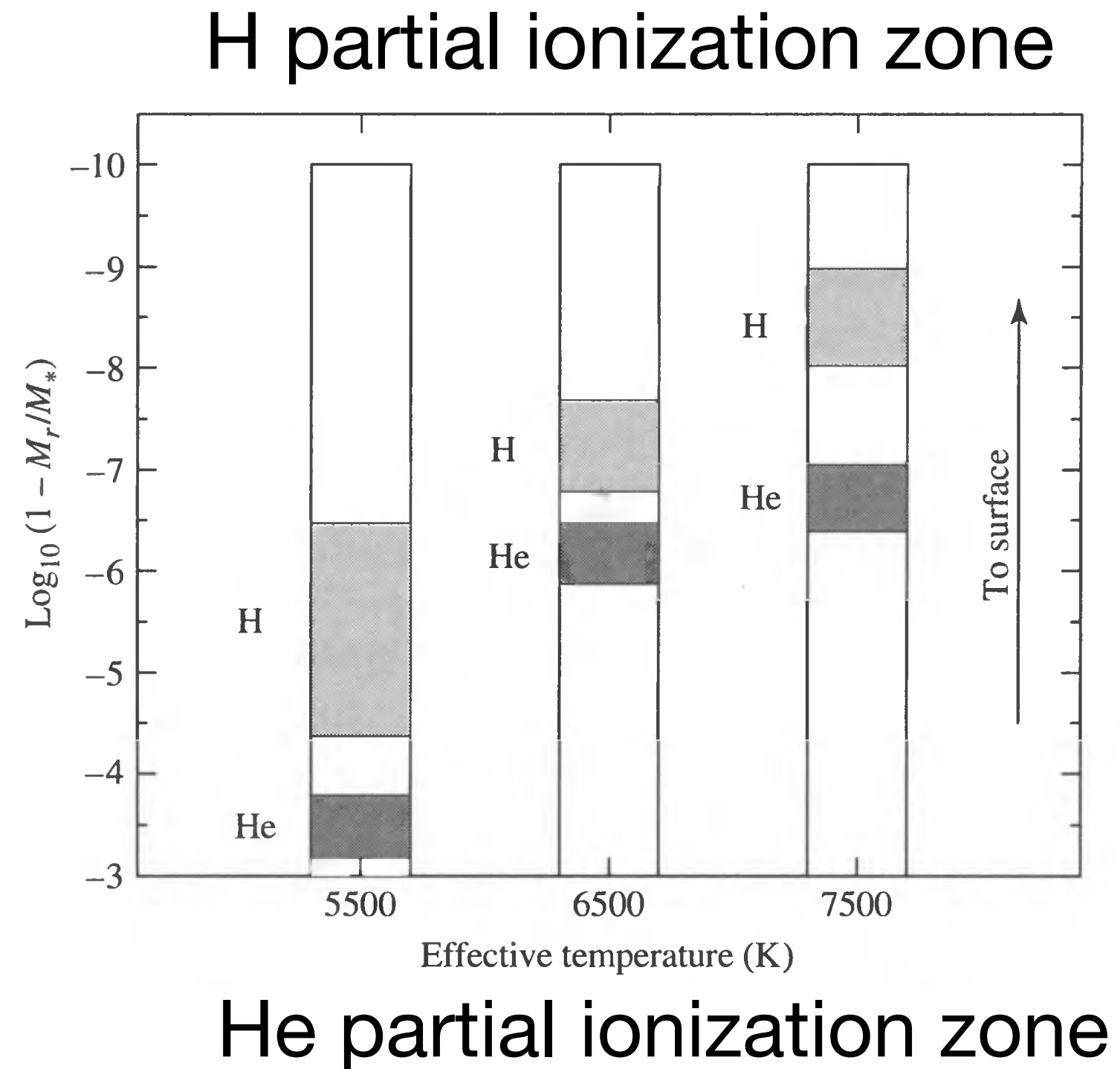
$$\oint P dV < 0$$

The gas dampens the oscillation.

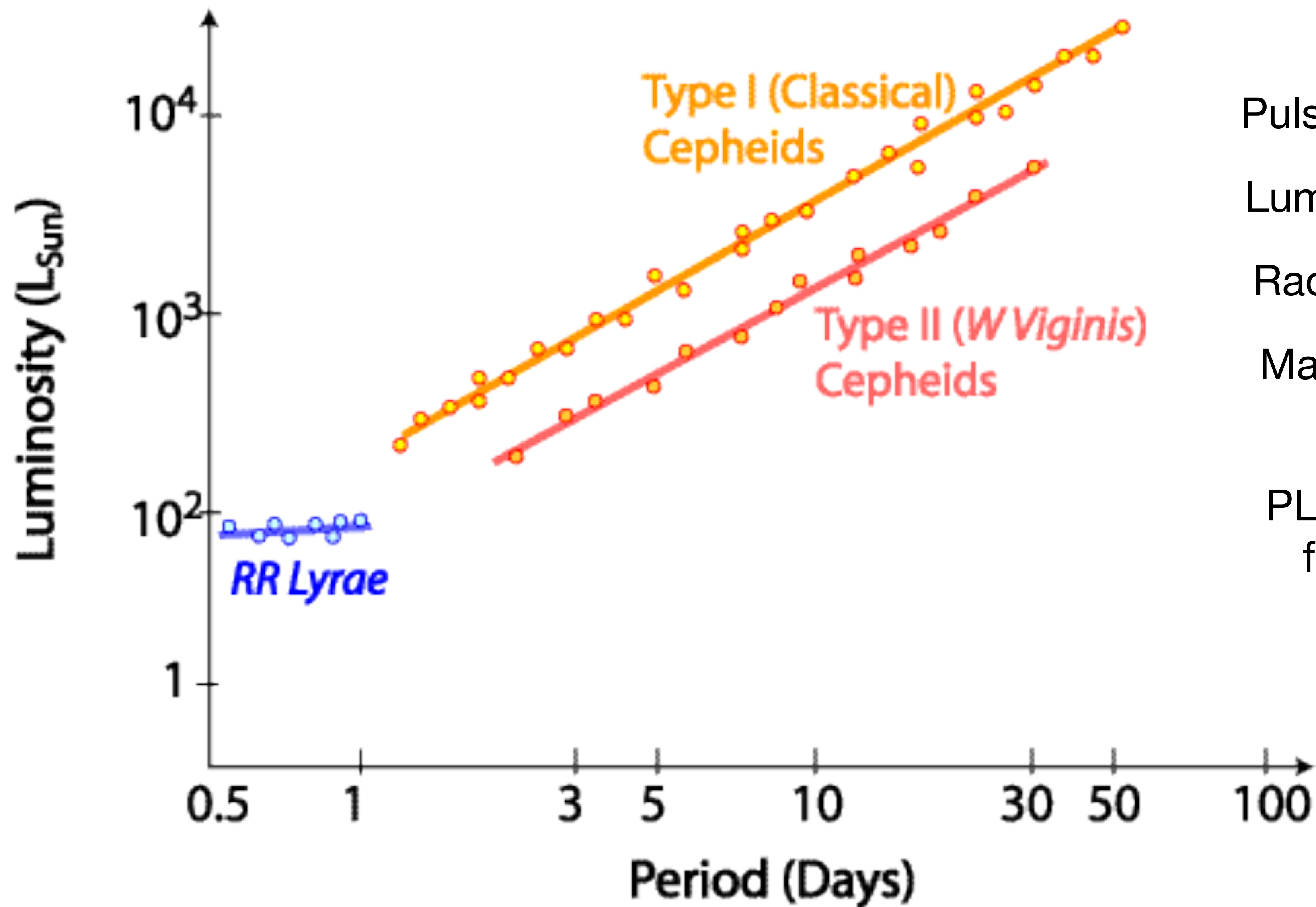
$$\oint P dV = 0$$

Equilibrium is reached.

Pulsation is observed only one in 10^5 stars



PERIOD - LUMINOSITY RELATIONSHIP



Pulsation Period : 1 - 50 days

Luminosity (L) : 300 - 26,000 L_{sun}

Radius (R) : 14 - 200 R_{sun}

Mass (M) : 3.7 - 14 M_{sol}

PL relation of Cepheids is used for measuring the distance.

Standard candle

PL(C) relation of Cepheids

$$L \propto R^2 T^4$$

Stefan-Boltzmann

$$\log L \propto 2 \log R + 4 \log T$$

$$\propto \frac{4}{3} \log P + 4 \log T$$

Magnitude and Distance Modulus

$$\frac{F_{10}}{F} = 100^{\frac{m-M}{5}} = \left(\frac{d}{10\text{pc}}\right)^2$$

absolute
magnitude

apparent
magnitude

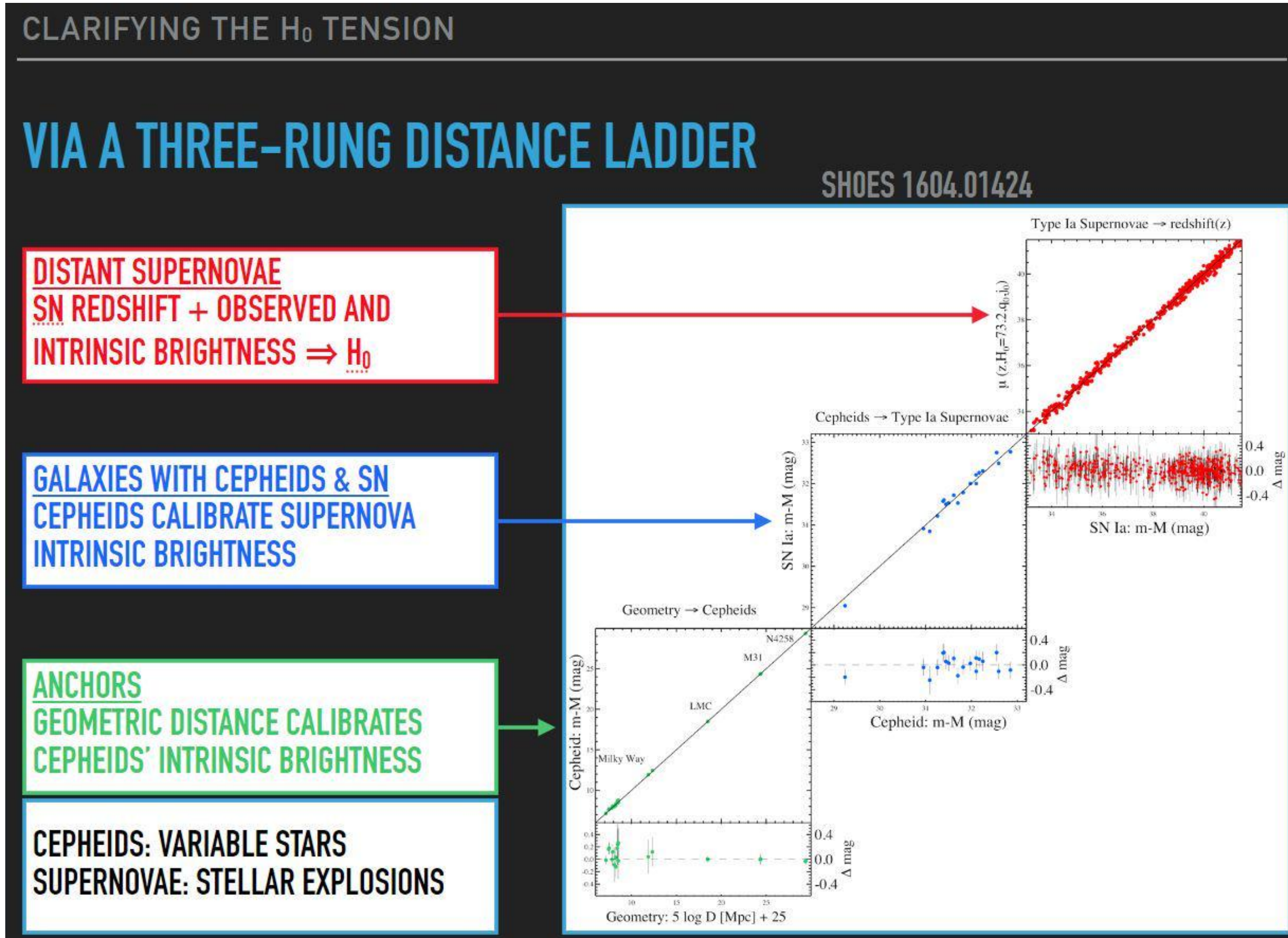
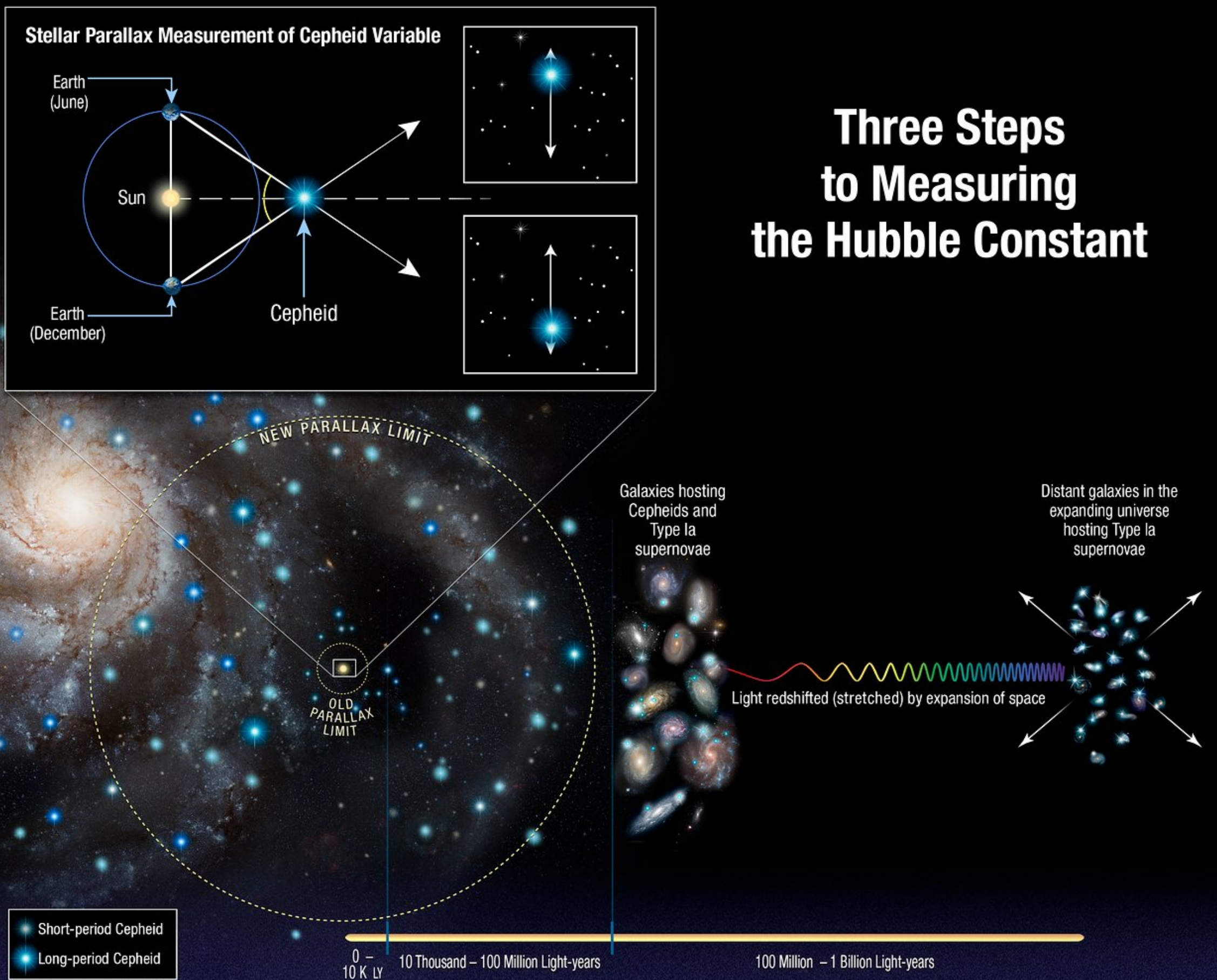
distance

$$M = m - 5 \log_{10} \left(\frac{d}{10\text{pc}} \right)$$

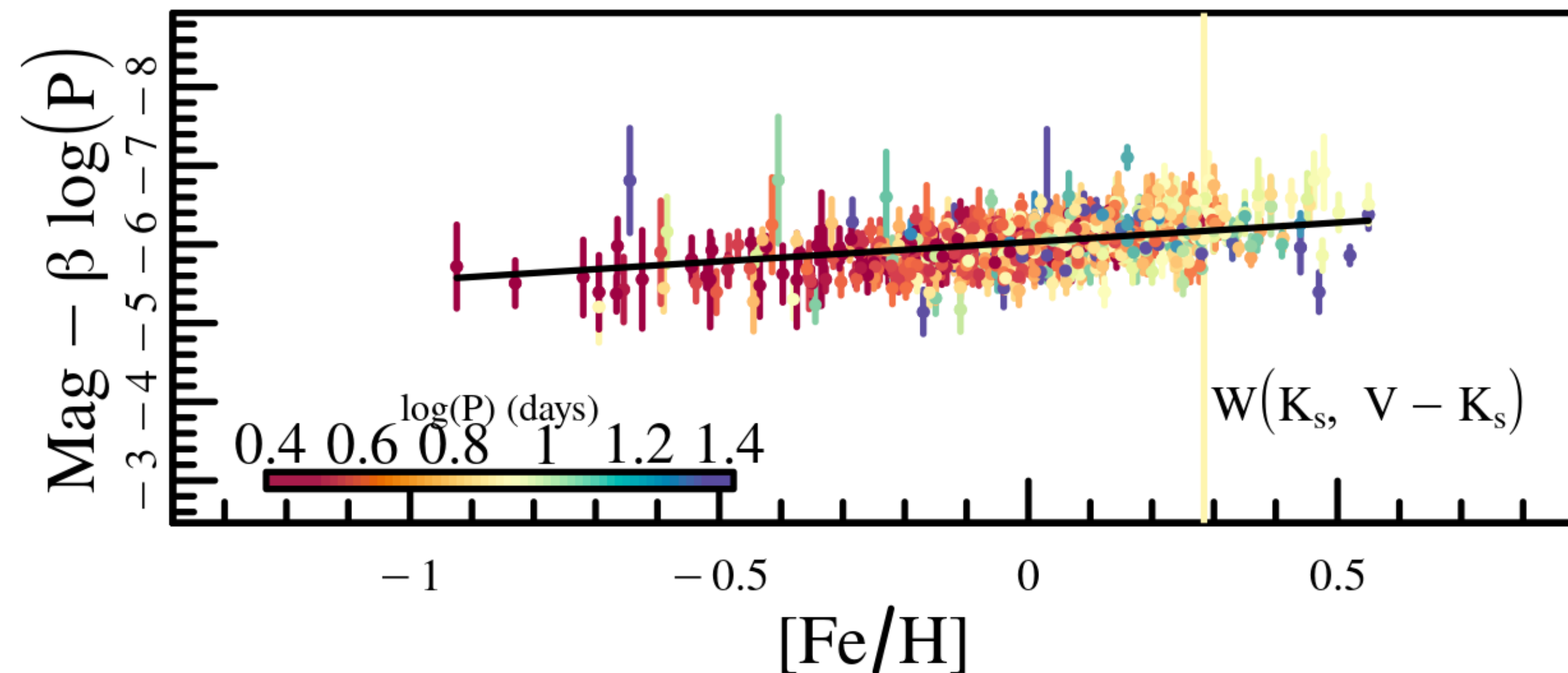
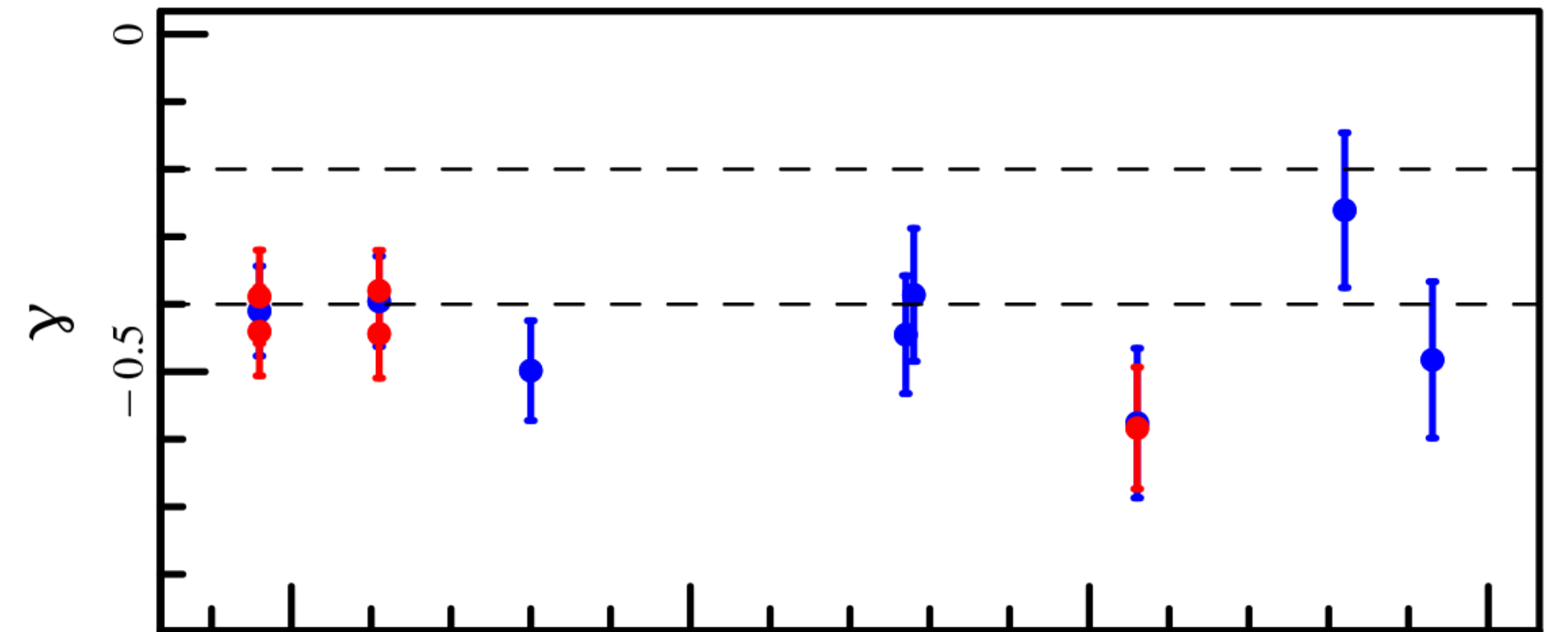
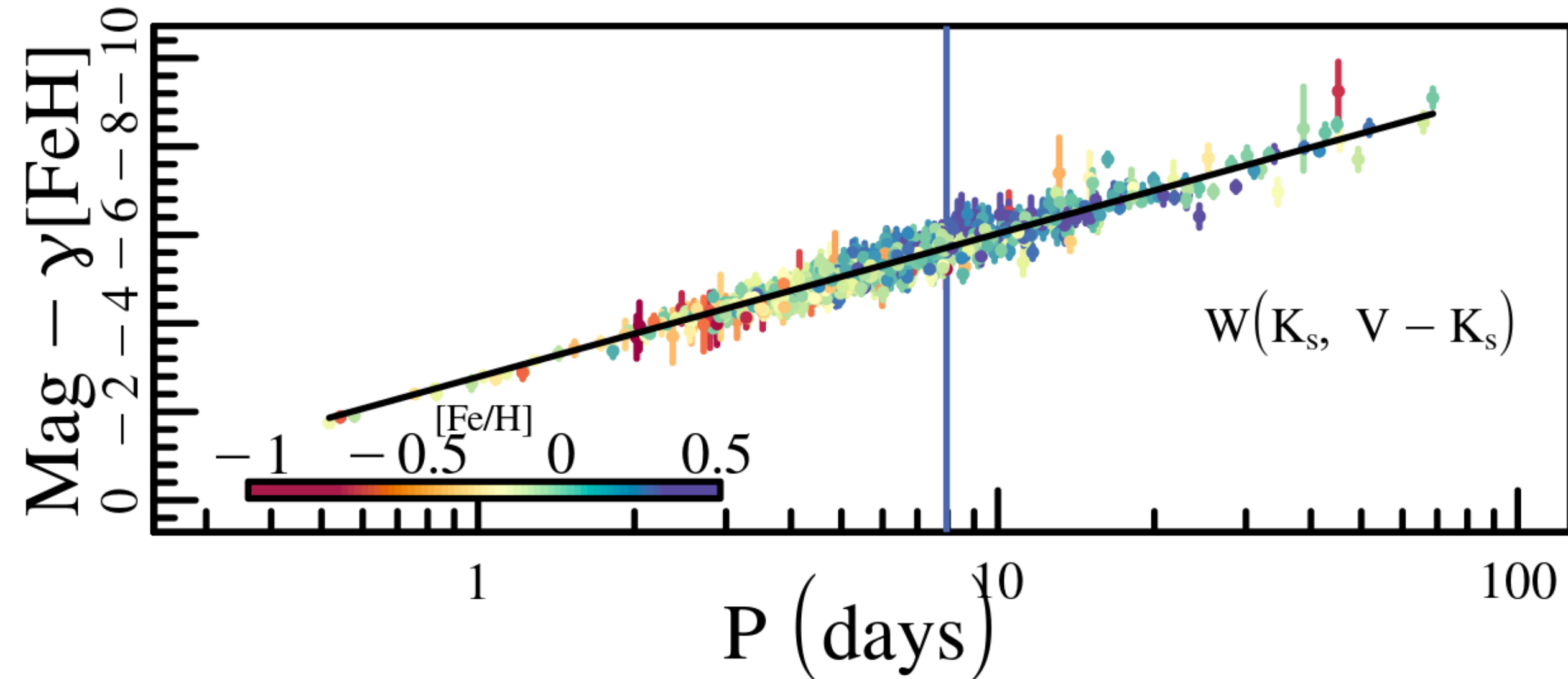
distance modulus

$$\mu = m - M$$

Cosmic Distance Ladder



Cepheid Metallicity in the Leavitt Law (C-MetaLL) survey

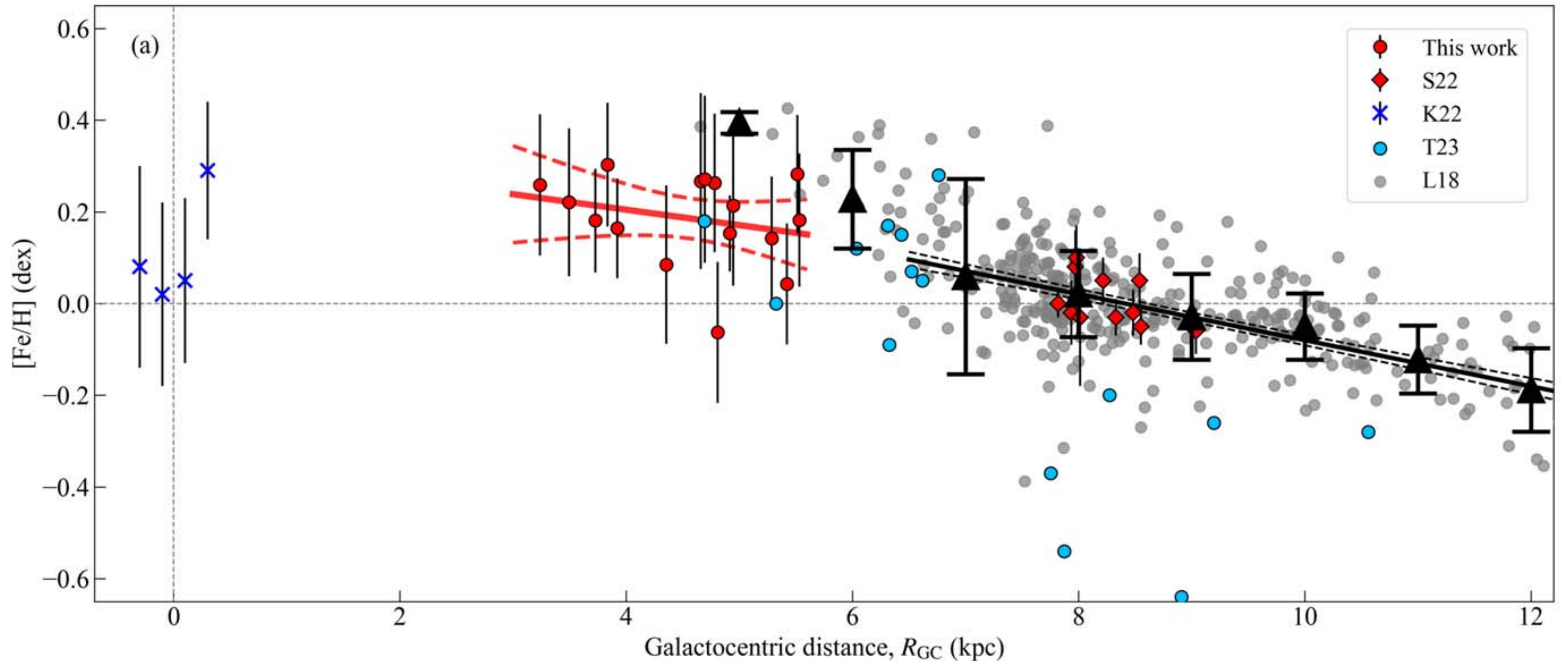
V. New multiband (*grizJHK_s*) Cepheid light curves and period–luminosity relations

Cepheids and SN Ia
:Standizable candle

Metallicity vs Galactocentric distance

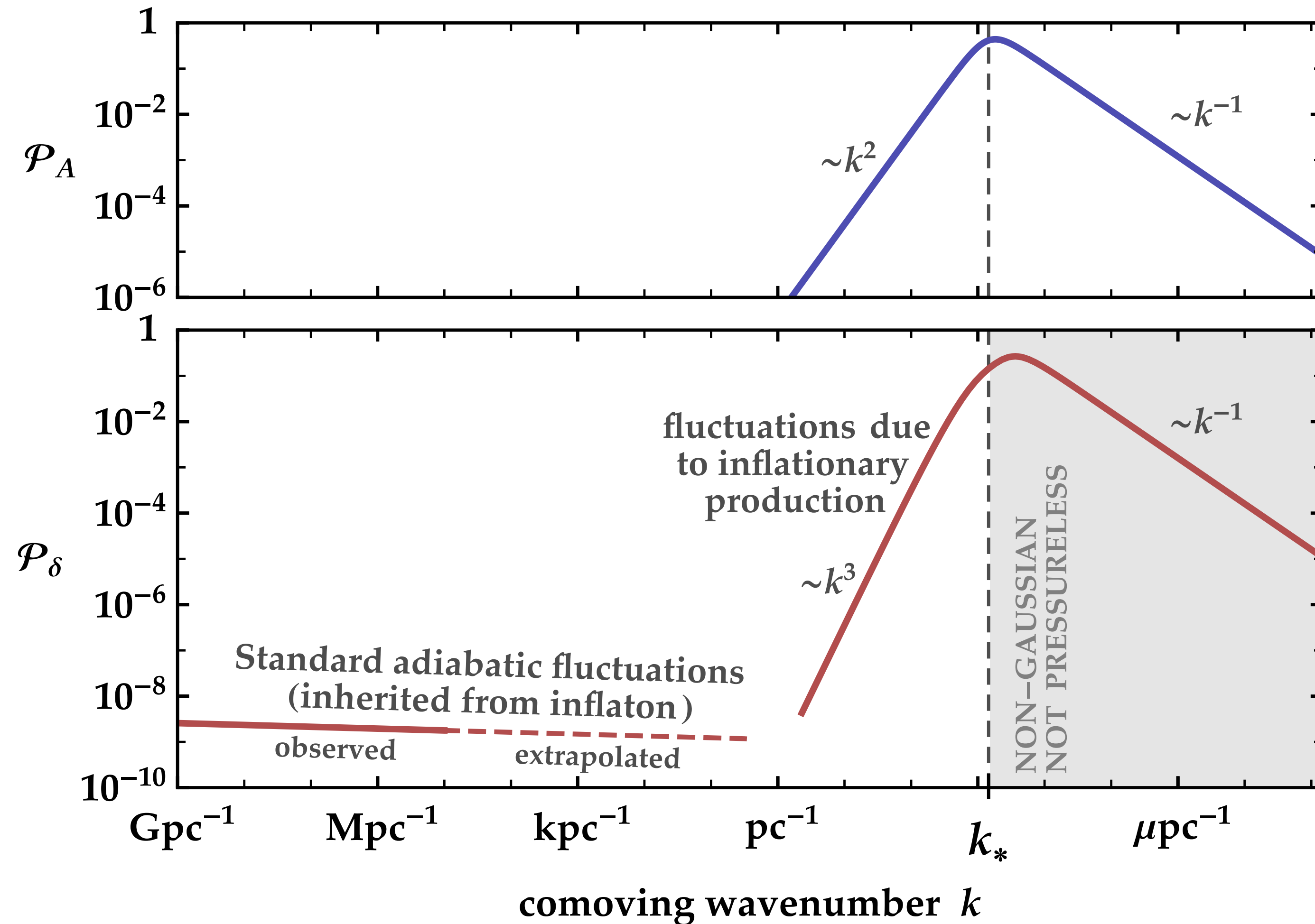
THE ASTROPHYSICAL JOURNAL, 954:198 (8pp), 2023 September 10

Matsunaga et al.



Vector dark matter from inflation (longitudinal)

arXiv:1504.02102



$$\frac{1}{k_*} \sim 10^{-10} \text{ Mpc} \times \sqrt{\frac{10^{-3} \text{ eV}}{m}}$$

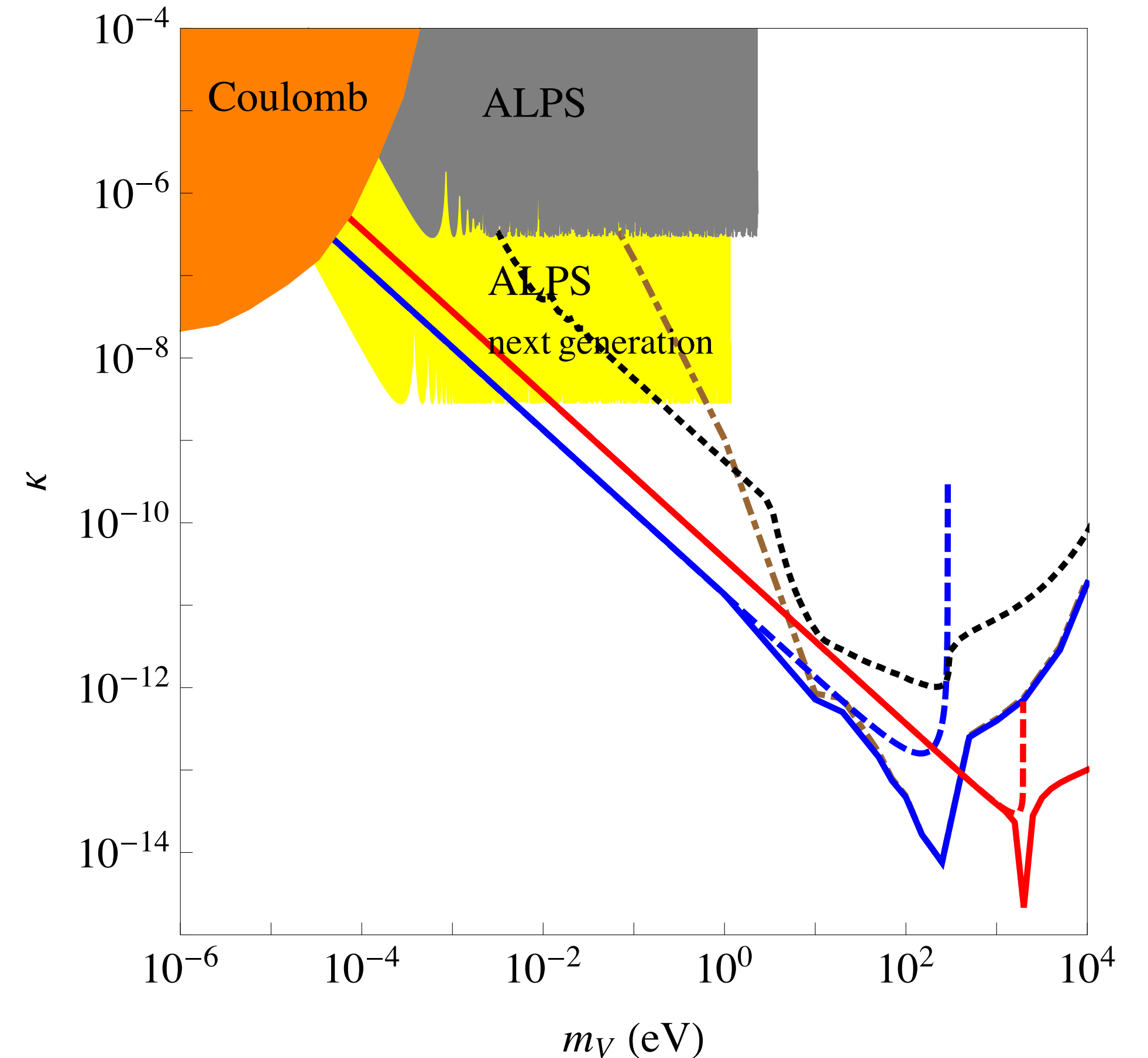
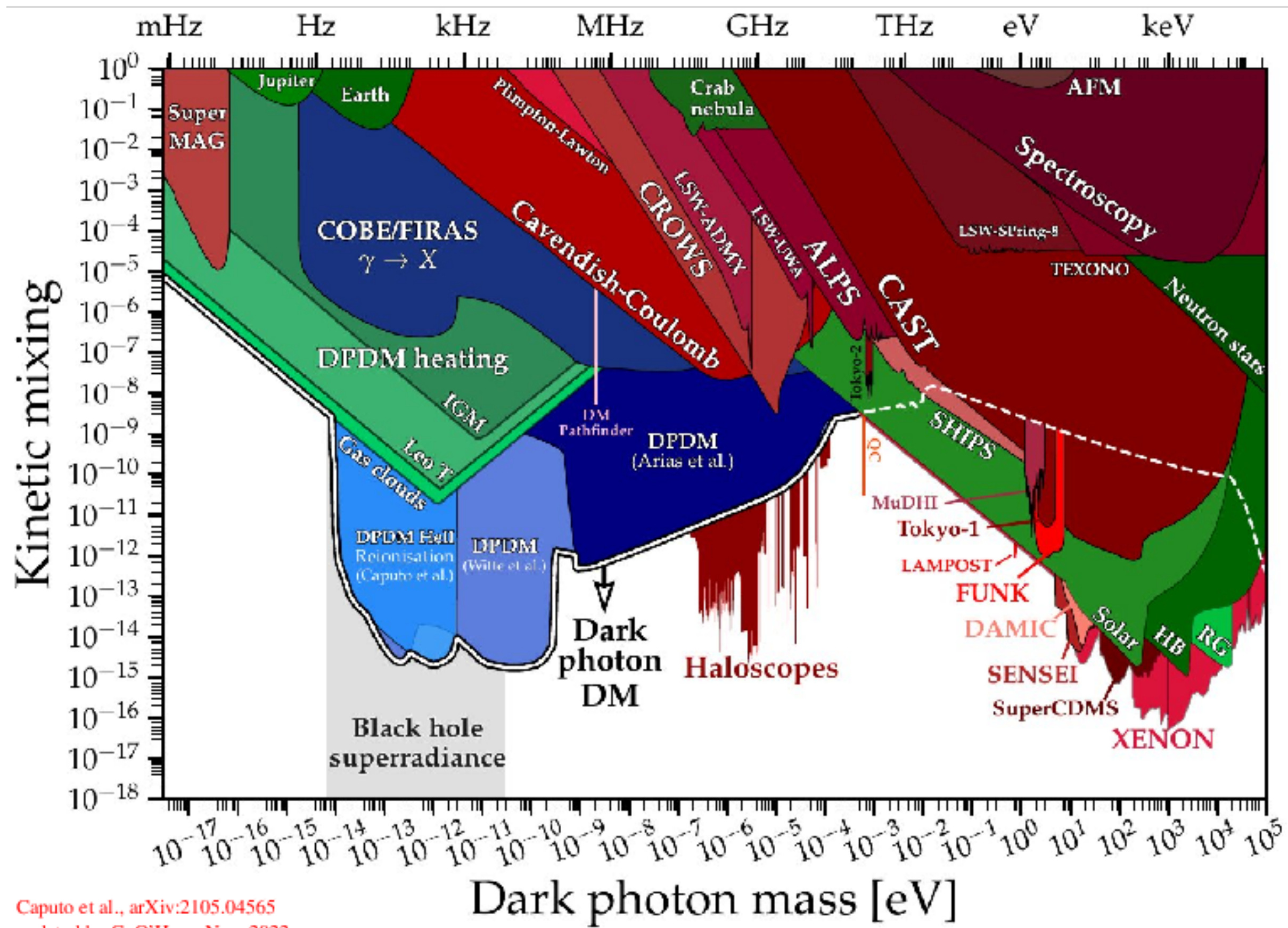
$$\frac{\Omega_{\text{vector}}}{\Omega_{\text{cdm}}} = \sqrt{\frac{m}{10^{-3} \text{ eV}}} \left(\frac{H_I}{3 \times 10^{13} \text{ GeV}} \right)^2$$

$$\mathcal{P}_\phi = \left(\frac{H_I}{2\pi} \right)^2 \longrightarrow \mathcal{P}_{A_0} = \left(\frac{kH_I}{2\pi m} \right)^2$$

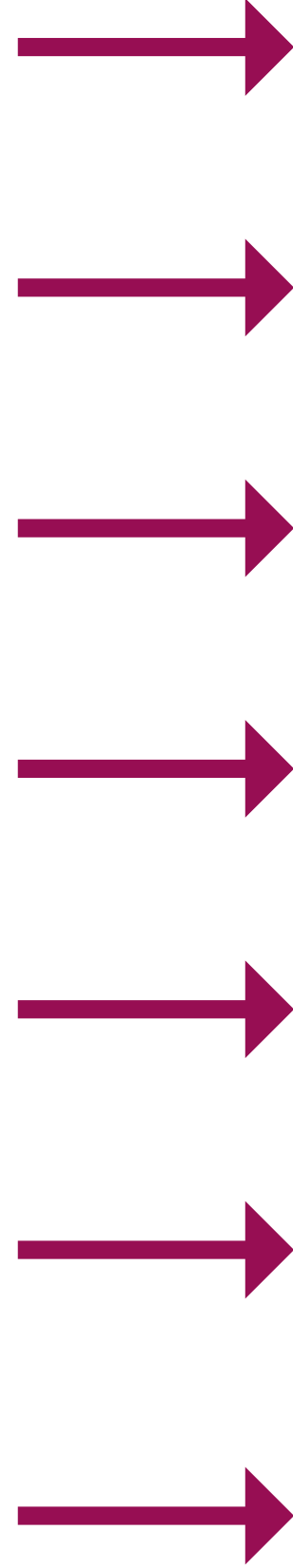
$$\phi \simeq \frac{m}{k} A_L$$

Kinetic mixing of DPDM with photon

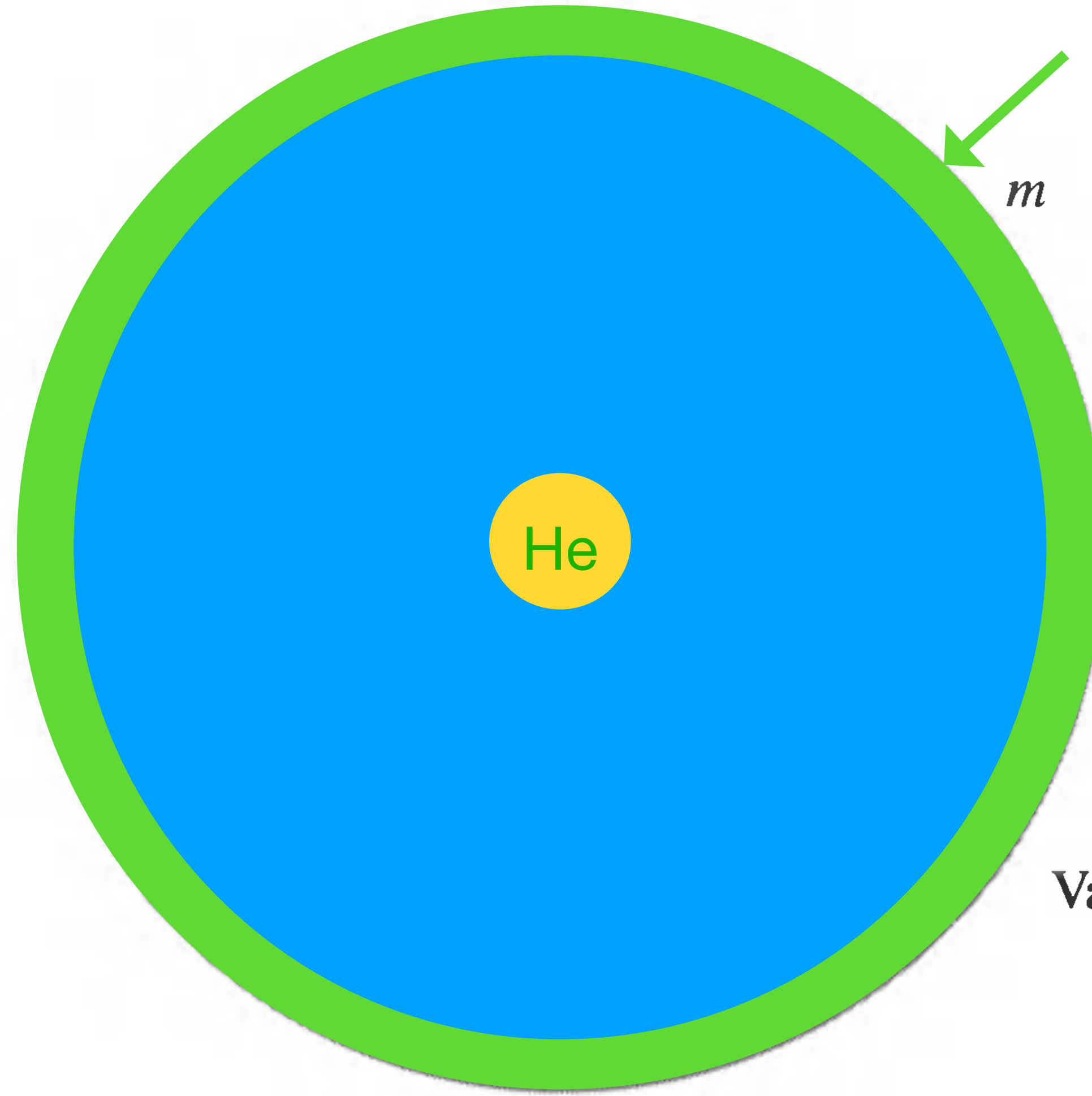
$$\mathcal{L} \supset \frac{\epsilon}{2} F_{EM}^{\mu\nu} F'_{\mu\nu}$$



Dark Photon
Dark Matter



Cepheid



Resonance Conversion



m

Vacuum

Back of envelope calculation

$$\Gamma(\gamma' \rightarrow \gamma) = \frac{\pi \epsilon^2 m_{\gamma'}}{v \left| \frac{\partial \log \omega_p^2}{\partial \log r} \right|} \quad \frac{\omega_p^{-1}}{L_{\text{shell}}} \sim \frac{\text{mm}}{10^8 \text{km}} \sim 10^{-14}$$

Cepheid data

$$L = 10^3 L_{\odot} \sim 4 \times 10^{36} \text{ erg/s}$$

$$R = 40 R_{\odot} \sim 2 \times 10^7 \text{ km}$$

He II shell

$$n_e \sim 10^{16} \text{ cm}^{-3}$$

$$T \sim 10^4 \text{ K}$$

$$\omega_p = \frac{4\pi\alpha n_e}{m_e} \sim \text{meV}$$

$$\Phi_{\text{DM}} \Gamma_{\gamma'} A = \frac{\rho_{\text{DM}}}{m_{\gamma'}} v \Gamma_{\gamma'} \pi (40 R_{\odot})^2$$

$$\sim \epsilon^2 \times 10^5 \text{ GeV/cm}^3 \times 10^{15} \times 10^{25} \text{ cm}^2 \times 10^{10} \text{ cm/s}$$

$$\sim \left(\frac{\epsilon}{10^{-9}} \right)^2 \left(\frac{\rho_{\text{DM}}}{10^5 \text{ GeV}} \right) 10^{34} \text{ erg/s}$$

Summary

Preliminary

- New era of dark matter astrophysics
- Dark matter beyond the gravitational source
- Many things to be understood in the stand(izable) candle stellar objects