# Section 3.
# Stellar structure and properties (II)

## 3.1 Luminosity of the stars

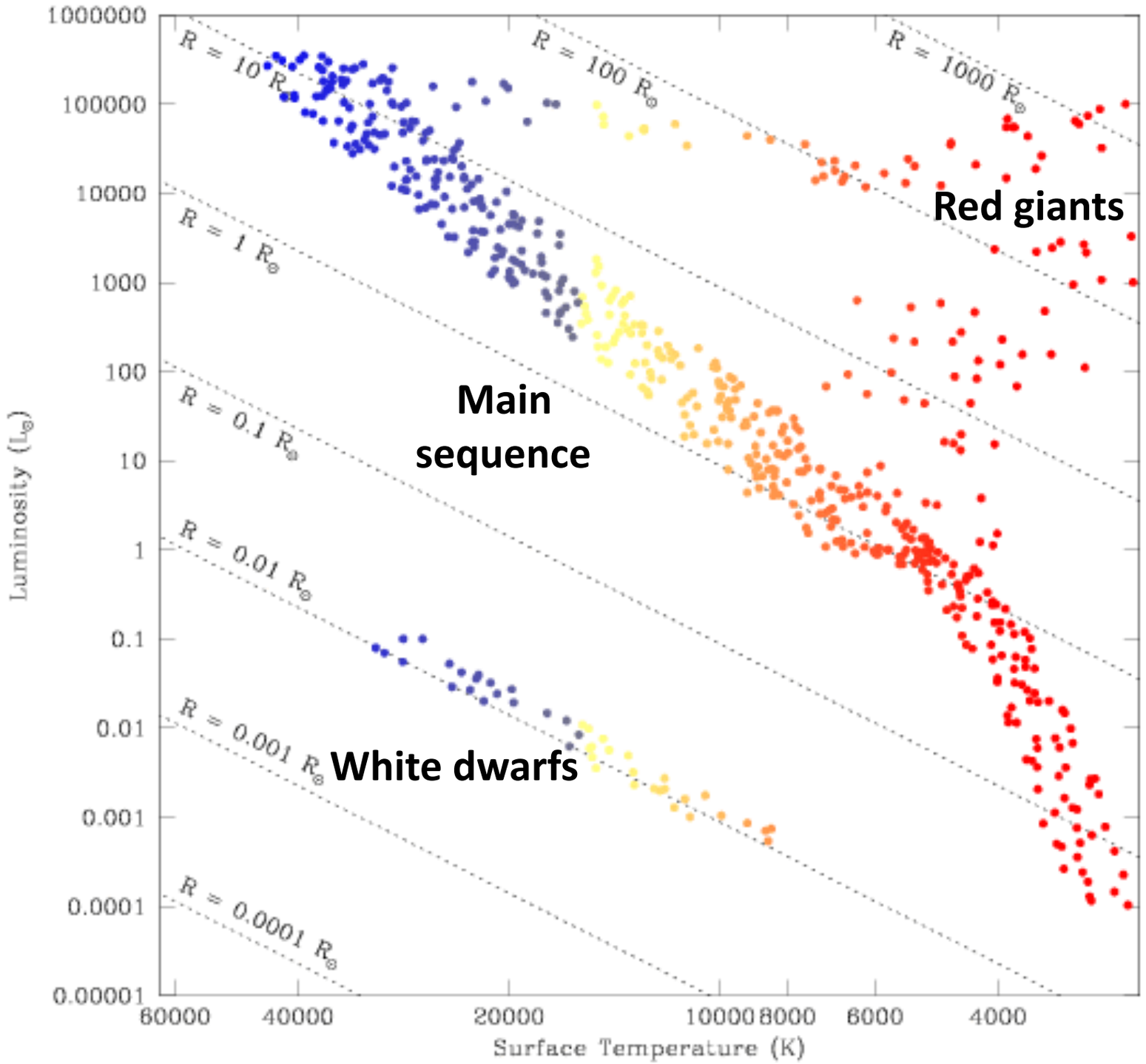
## 3.2 Opacities in the stars

# Goals of this lecture

- Standard properties of stars
  - Stellar structure and properties
  - Stellar  evolution
- Origin of the elements in the Universe
  - Nucleosynthesis in stars and supernovae
  - Explosion mechanism of supernovae
- Topics in time-domain astronomy
  - Radiation from explosive phenomena
  - Multi-messenger astronomy

# Hertzsprung-Russel diagram

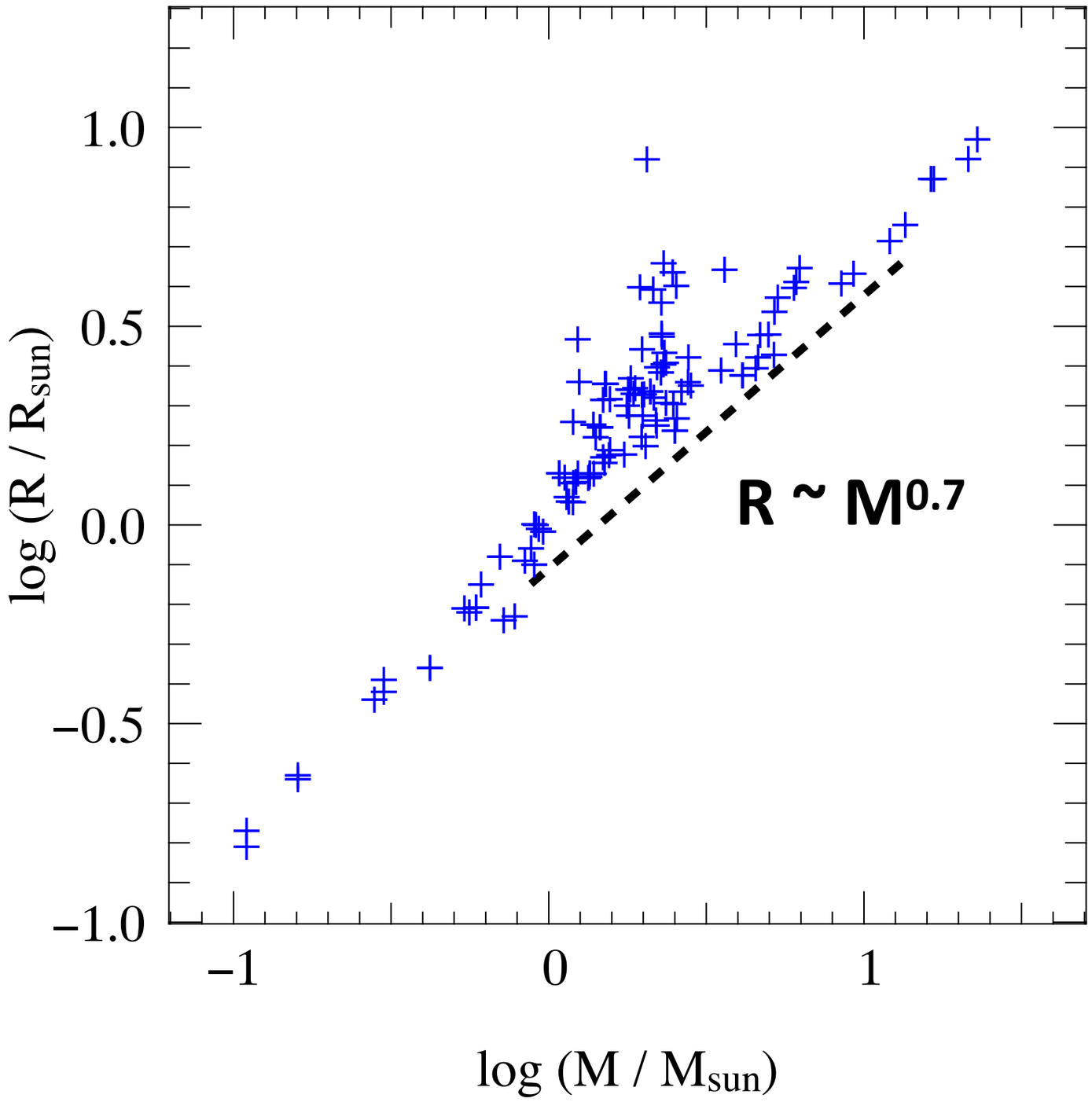
Luminosity




Temperature (K)

http://astronomy.nmsu.edu/geas/lectures/lecture23/slide04.html

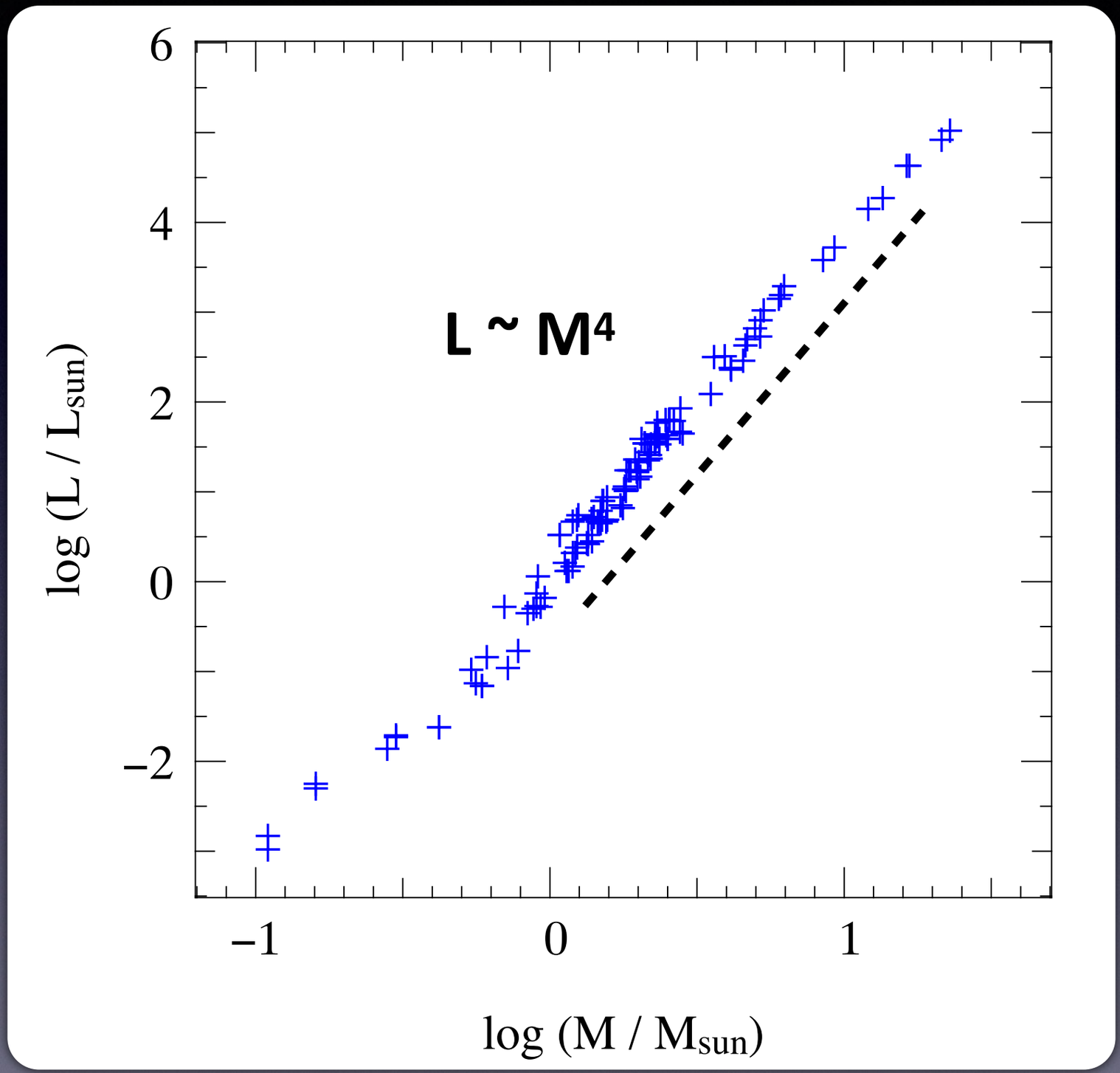
# Mass - radius relation for the main sequence




**Outcome of the central property of the star**

Lecture Note by Pols

# Mass - luminosity relation of the main sequence stars




Star with M = 10 Msun

=> L ~ $10^4$ Lsun

=> Lifetime

~ 1/$10^3$ of the Sun

~ $10^{10}$ yr (100億年)/$10^3$

~ $10^7$ yr (1000万年)

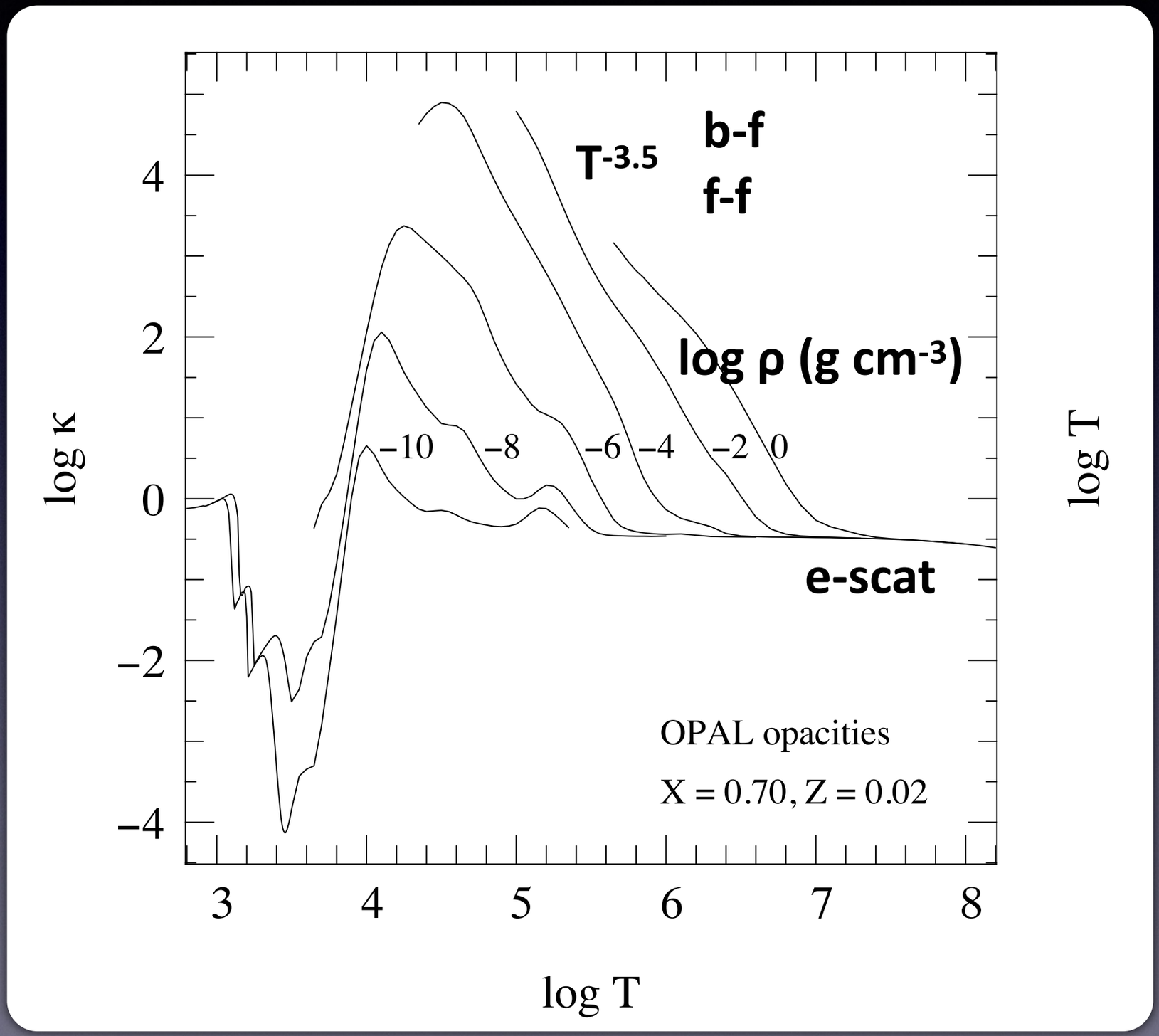
More massive stars have shorter lifetime

Lecture Note by Pols

**Why do stars show $L \sim M^4$?**

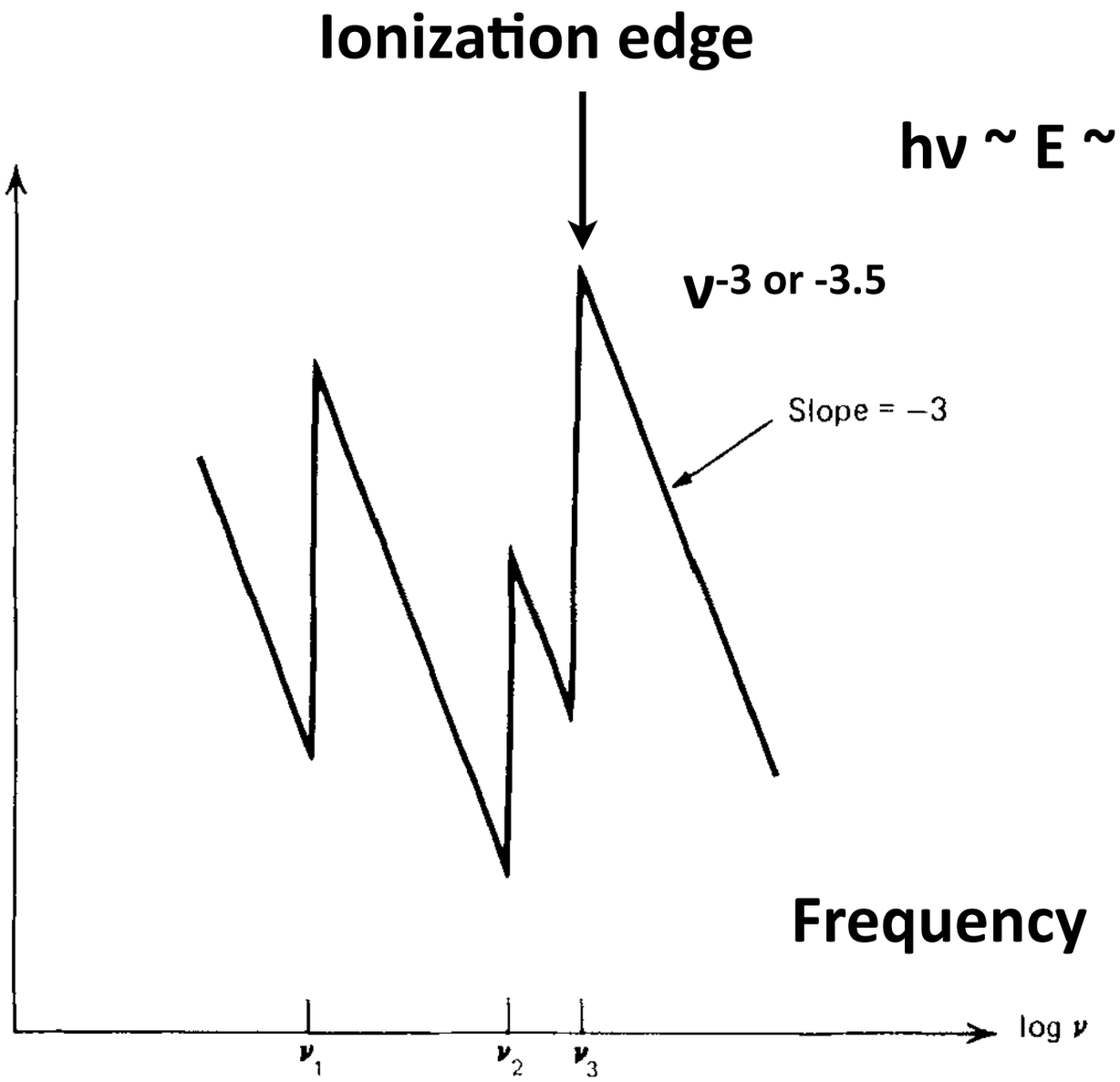
**Why do more massive stars have higher temperature?**

# Opacity inside the stars




Lecture Note by Pols

# Bound-free opacity




Rybicki & Lightman

# Assignment 1

Derive that the dependence of free-free opacity in stellar interior can be approximated as $\kappa \sim \rho T^{-3.5}$

Hint: In equilibrium, the rate for free-free absorption matches with that of free-free emission (thermal bremsstrahlung), i.e. $j_\nu = \alpha_\nu B_\nu(T)$
* Kirchhoff's law

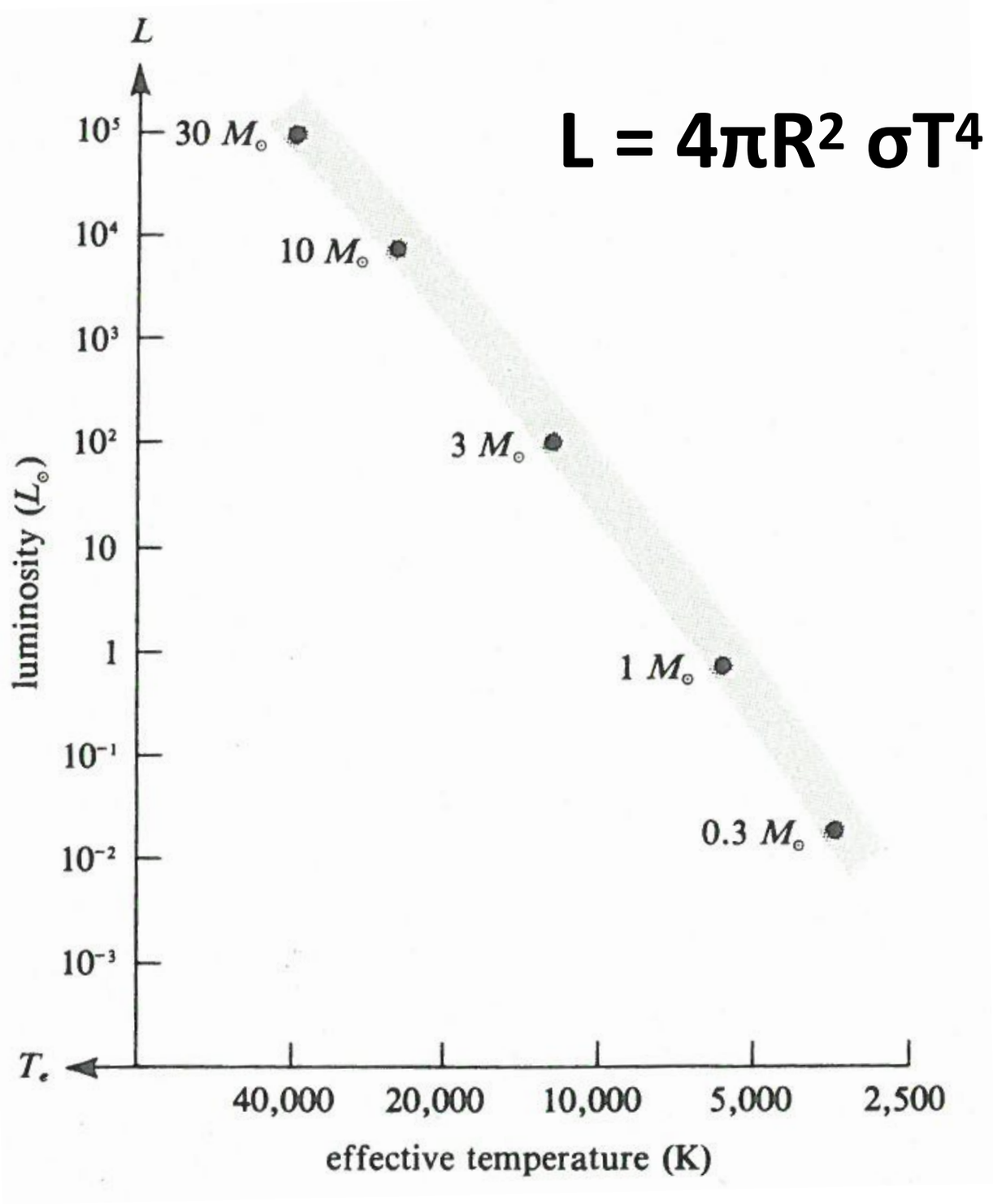
# レポート課題 1

恒星内部における自由-自由吸収の密度・温度依存性が
近似的に次のように表せられることを示せ $\kappa \sim \rho T^{-3.5}$

ヒント：平衡状態では自由-自由吸収のrateと自由-自由放射 (熱的制動放射)のrate
はつり合う $j_\nu = \alpha_\nu B_\nu(T)$
* キルヒホッフの法則

# Hertzsprung-Russel diagram

L

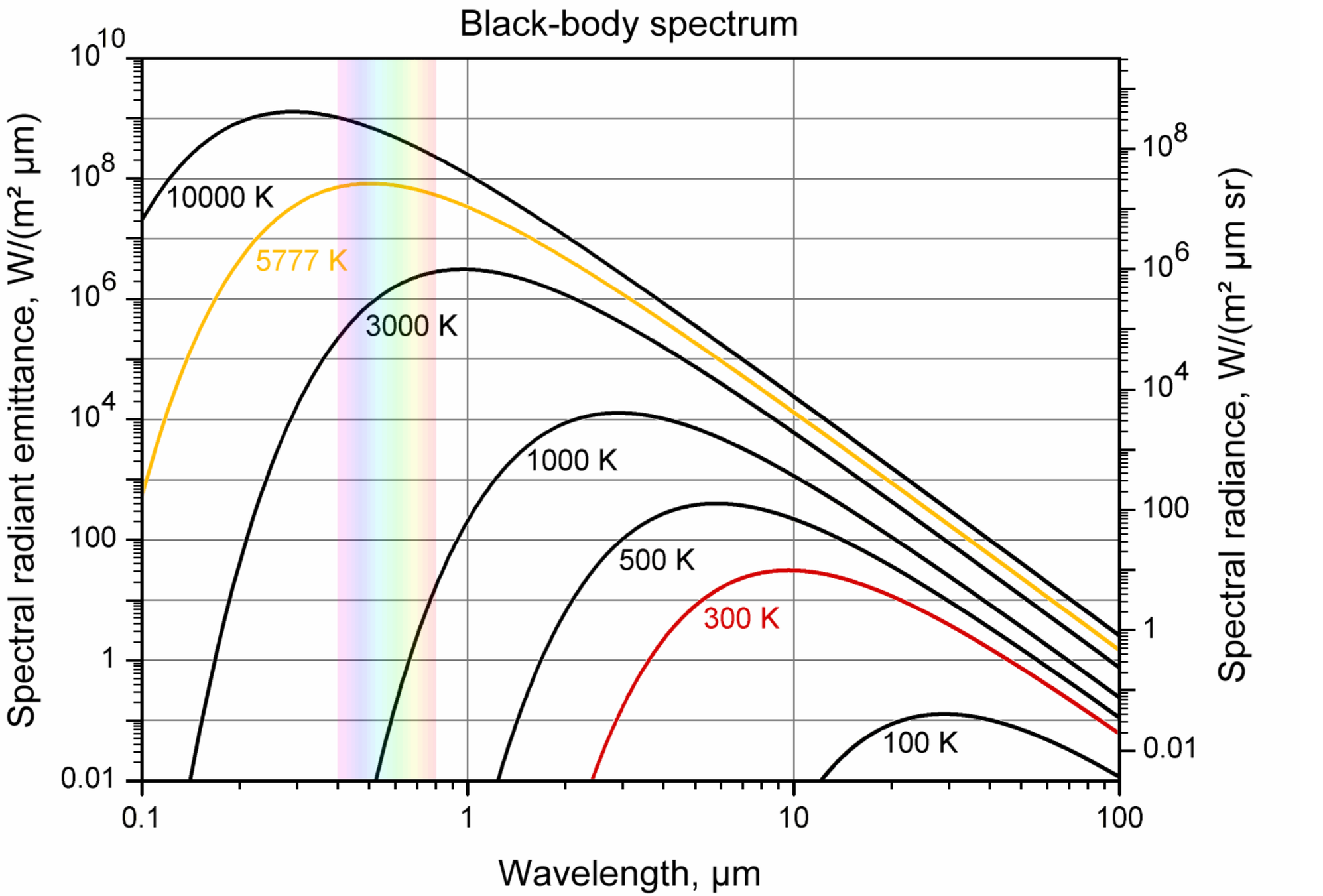



$$L = 4\pi R^2 \sigma T^4$$

T (K)

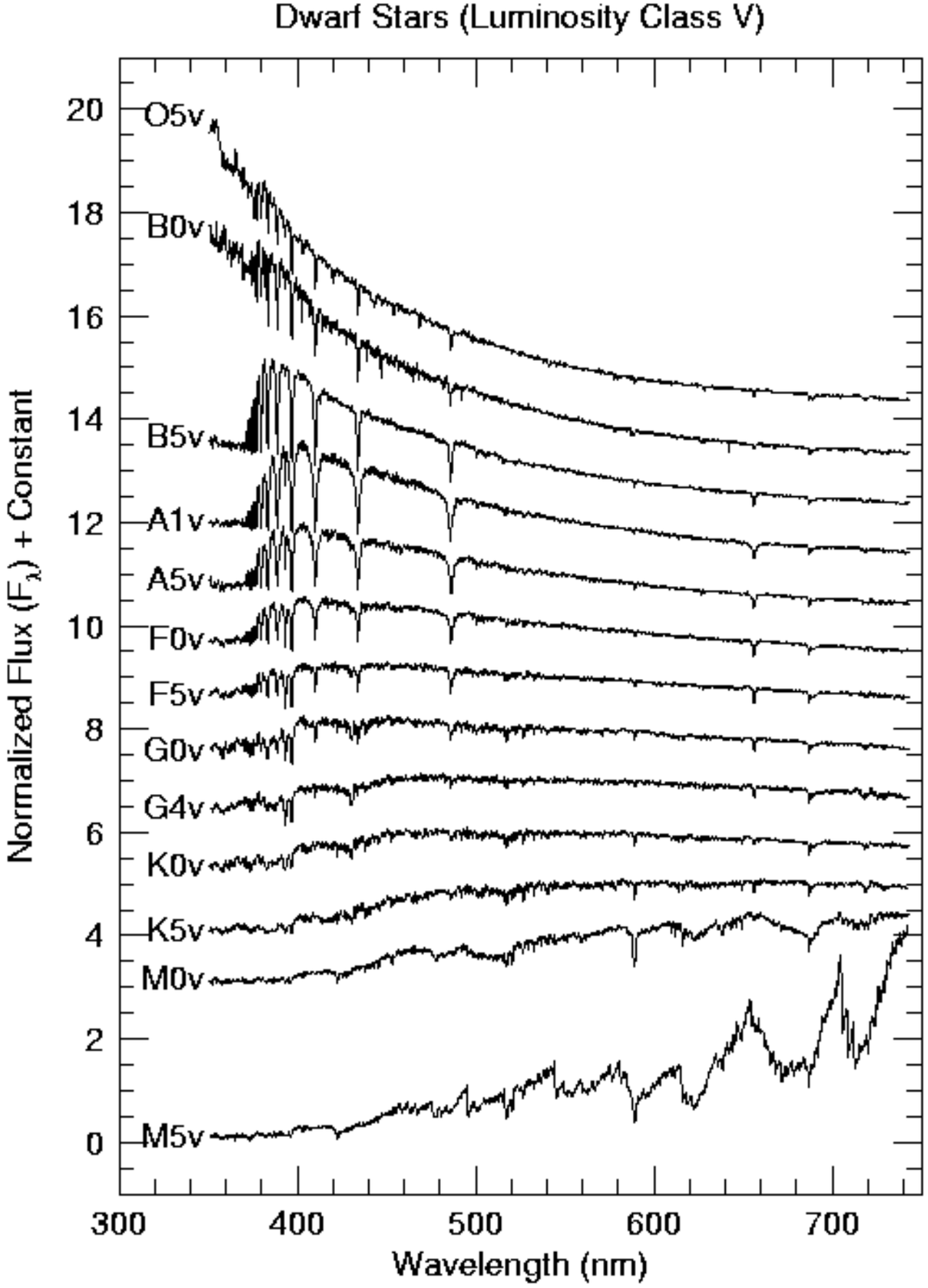
Introduction to Astronomy (F. Shu)

# Blackbody radiation



# Stellar spectrum

| Type | M (Msun) |
|---|---|
| O | 20-60 |
| B | 3-18 |
| A | 2-3 |
| F | 1.1-1.6 |
| G | 0.9-1.05 |
| K | 0.6-0.8 |
| M | 0.08-0.5 |



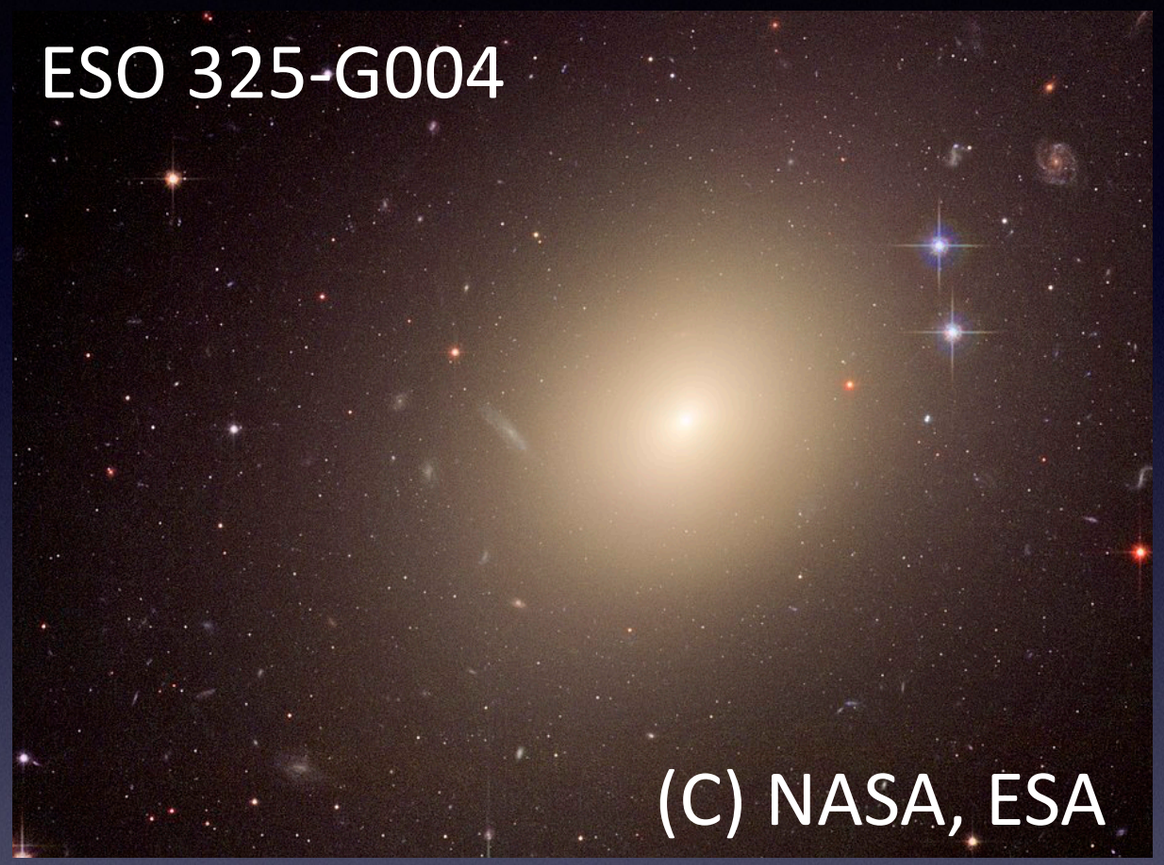

http://www.astronomy.ohio-state.edu/~pogge/Ast162/Unit1/SpTypes/index.html

# Applications to galaxy studies

## Spiral galaxy


- Star forming
- More “young" stars
- More massive stars
- Blue (high T radiation)

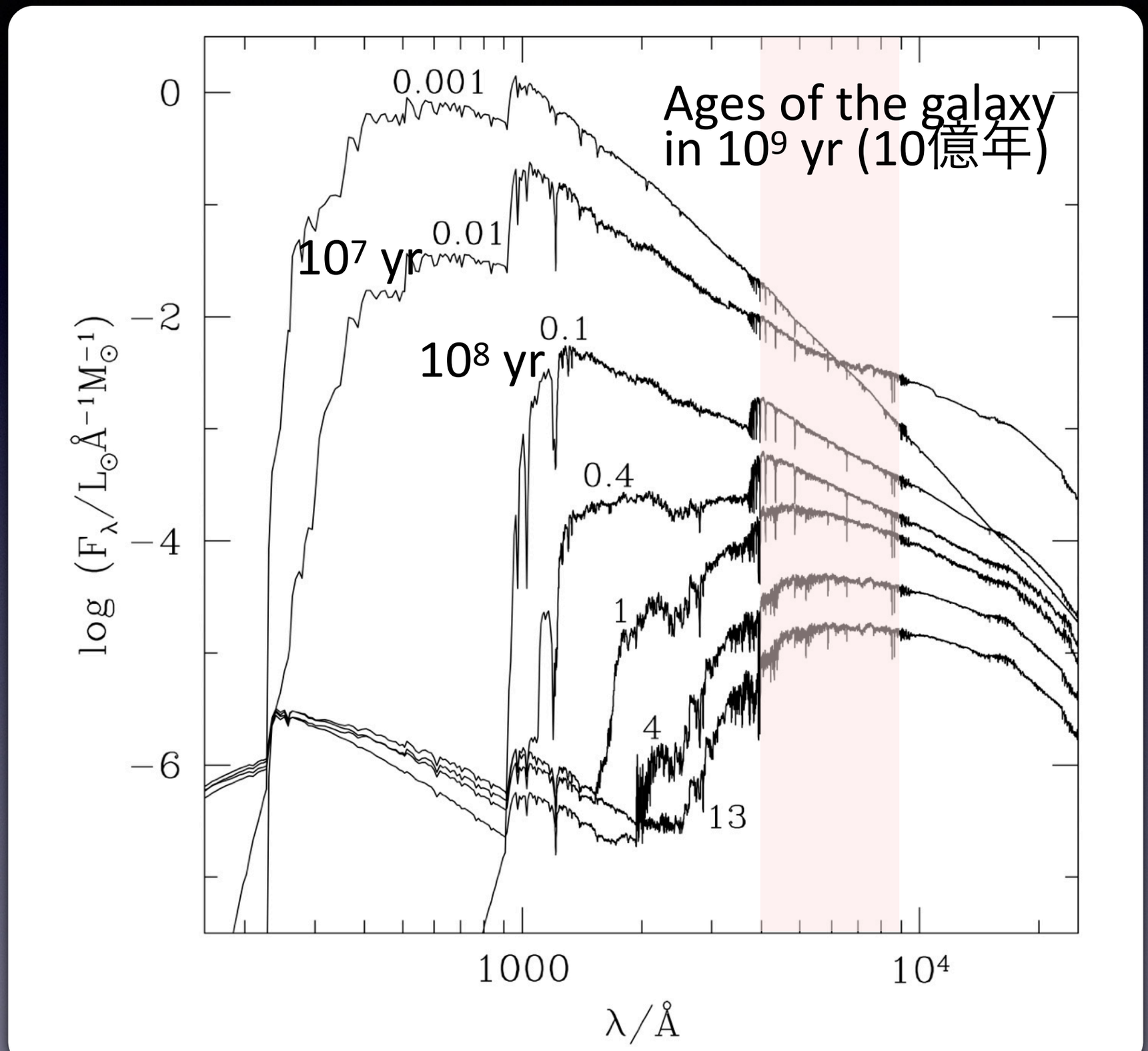
## Elliptical galaxy




- No star formation
- Old stars
- Less massive stars
- Red (low T radiation)

# Spectral models for galaxies

Bruzual & Charlot 2003



# Summary: Stellar structure and properties (I)

- Opacities in the stars
  - Thomson scattering
  - free-free and bound-free absorption
- Luminosity of the stars
  - $L \sim E/t_{esc}$, where $t_{esc} \sim (R/c)\,\tau$ (<== $\tau = \kappa\rho R$)
  - $L \sim M^{3\text{-}5}$
- Stellar properties
  - More massive stars have
    - Higher luminosity $L \sim M^4$ (shorter lifetime $t \sim M^{-3}$)
    - Higher temperature $T \sim M^{0.5}$
  - Foundation to determine the galaxy spectra

Let’s understand these questions
with the word of physics

Knowing ≠ Understanding

- **Why do some stars explode?**
- **Why don’t normal star explode?**
- **Why do stars show $L \sim M^4$?**
- **Why do stars evolve?**
- **Why does the destiny of stars depend on the mass?**
- **Why does stellar core collapses?**
- **Why is the energy of supernova so huge?**
- **…**

Thermodynamics

Electromagnetism

Classical mechanics

Statistical mechanics

Astrophysics

Hydrodynamics

Quantum mechanics

Relativity

Nuclear physics