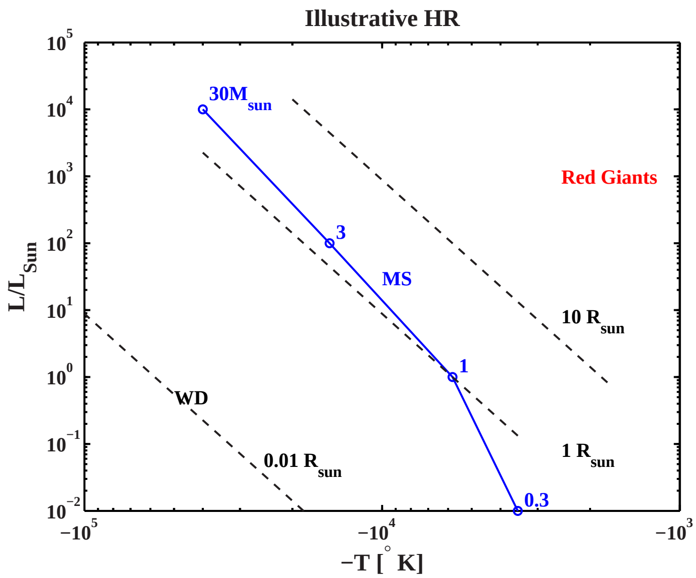
2 Overview: The content of the observable universe, Experimental techniques 2.5×[2hr]

Much of § 2.1 & § 2.2 covered in the excellent into chapter of *Galactic Dynamics* of Binney & Tremaine.

2.1 Content: In the Galaxy

- What is a star? $e^2/d < GMm/R$, $d \sim (R/N)^{1/3}$, $M = Nm$, $N > (e^2/Gm^2)^{3/2} \sim 10^{54}$, $M > 10^{-3}M_\odot$.
- The Sun: solar constant $f = 1.36 \times 10^6$erg/cm^{2}s, $d =$ 1a.u. $= 1.50 \times 10^{13}$ cm, $L_\odot = 3.90 \times 10^{33}$erg/s, $R_\odot = 6.96 \times 10^{10}$ cm, $M_\odot = dv^2/G = 1.99 \times 10^{33}$ g, $T_{\rm eff.} = 5800°$K.
- Basic distances: a.u., parallax- 1 pc= 1a.u./1" $= 3.09 \times 10^{18}$ cm, Hipparcos 0.002"- distances to $\sim 10^5$ stars, local density of stars.
- $\{U, B, V, R\} = \{0.37, 0.44, 0.55, 0.7\}\mu$, $\Delta\lambda/\lambda \approx 0.2$; $m = -2.5 \log f + const.$, mag at 10 pc: $M = m - 5\log(d/10{\rm pc})$, $m - M$ distance modulus; $M_{\odot B} = 5.48$, $M_{\odot V} = 4.83$; closest- Proxima Centauri, 1.3 pc, $m_V = 11.05$; brightest- Sirius, 2.7 pc, $m_V = -1.45$; eye: $M_V \leq 6$.
- **Slide: Hipparcos HR of local stars.**
- The HR diagram interpretation (R, T), $L \propto M^4$, $\tau_\odot \sim 10^{10}$ yr, $t_\odot \simeq 0.5 \times 10^{10}$ yr.
- **Slide: Globular clusters' HR**, age: $t_* = 14 \pm 2$ Gyr.
- Distances: Main sequence fitting- kpc, Cepheids $L = 10^3(T/1\,{\rm d})L_\odot$ for $T = 1 - 100$ d (two sequences, Z dependent)-10 Mpc.
- **Slide: Milky way**: l, b; disk $L_V \simeq 10^{10}L_{\odot V}$, $R \simeq 10$ kpc, $h \simeq 1$ kpc; spheroid $L_V \simeq 2\times 10^9 L_{\odot V}$, $R \simeq 2$ kpc; $M_G \simeq 10^{11}M_\odot$; $h_{\rm gas} \sim 0.1$ kpc, $M_{\rm gas} \simeq 10^{10}M_\odot$, 75% H, 24% He, "$Z$".
- The Sun at $r_0 = 8.5 \pm 1$ kpc, $I(r) \propto \exp(-r/3.5 \pm 0.5{\rm kpc})$, $v_c = 220 \pm 15$km/s ($2\pi r_0/v_c \sim 10^8$ yr), Sun moves at 16.5km/s in $l = 53°, b = 25°$ with respect to local standard of rest (local stars' motion).
- stellar clusters: 10^5 open in disk, 10^{2-3} stars, $\sim 10^9$ yr "Pop I"; 10^2 globular in halo, 10^{4-6} stars, $> 10^{10}$ yr "Pop II".



2.2 Content: Out of the Galaxy

- (Spirals &) Elliptical galaxies: Hubble-Reynolds $I \propto r_H^2/(r + r_H)^2$, $\sigma_v \simeq 220(L/L_*)^{1/4}$km/s.
- **Slide: Ia's Hubble's Law**, equivalent observers, $H_0 = 100\,h\,\text{km/s Mpc}$ with $100\,h = 65 \pm 8$.
- Local galaxy density $n_* \simeq 10^{-2}h^3\text{Mpc}^{-3}$, Schechter's law $dn/dL = \Phi(L) = (n_*/L_*)(L/L_*)^\alpha \exp(-L/L_*)$ with $L_{*V} = 10^{10}h^{-2}L_{\odot V}$, $\alpha = -1.25$.
- LSS. **slide: clusters**, The cosmological principle **slide: 2dF**.
- Radiaton: **slide: CMB**.
- DM: **slide: Rotation curves**.

2.3 Observational techniques

Atmospheric "windows": Optical/IR $\sim 0.3 - 10\,\mu$ limited (below & above and bands within) by molecular absorption, Radio $\sim 1 - 10^3$ cm (30 MHz-30 GHz) limited below by molecular absorption and above by ionosphere reflection.

Optical telescopes. Transmitting lens f, D, $\Delta\theta = 1.22\lambda/D = 0.2"\lambda_\mu/D_{\rm m}$, diffractive scintillation-seeing-$\sim$ 1", $\Delta h \sim \Delta\theta f = 1(\Delta\theta/1")f_{\rm m}\mu$. 1" $= 5\times10^{-6}$. Reflector/transmitter advantages: optical surface/medium, mass-weight (support, distortions) & thermal inertia, adaptive O. **slide: Keck**.

25th mag$\simeq 2\times10^{-30}$erg/cm^{2}s Hz $\simeq 10^{-3}$ph/cm^{2}s; sky brightness 23-22 mag/(")^2 U-R, implying, for a detector with efficiency q and no internal noise ($AT = 10^6$cm^{2}s for $D = 1$ m and $T = 1$ min),

$$f_{\rm Opt,5\sigma} \simeq 10^{-3}\left(\frac{qAT}{10^6{\rm cm^2s}}\right)^{-1/2}\frac{\Delta\theta}{1"}\frac{\rm ph}{\rm cm^2s} \simeq 10^{-15}\left(\frac{qAT}{10^6{\rm cm^2s}}\right)^{-1/2}\frac{\Delta\theta}{1"}\frac{\rm erg}{\rm cm^2s}, \tag{1}$$

i.e. 25th mag for $AT = 10^6$cm^{2}s. For PSF contained in one (e.g. $\sim$ 1") pixel with few e^- per sec per pixel "dark",

$$f_{\rm Opt,5\sigma} \simeq 10^{-1.5}\left(\frac{qAT}{10^6{\rm cm^2s}}\frac{10e^-/{\rm s}}{\dot{n}_e}\right)^{-1/2}\frac{\rm ph}{\rm cm^2s}, \tag{2}$$

i.e. 21st mag for $AT = 10^6$cm^{2}s- CCD cooling may improve sensitivity significantly.

Ground: Keck 10 m, seeing 0.5", High res spectro $\lambda/\Delta\lambda \sim 10^{4.5}$; Space (reaching eq. (1) limit) O/UV: Hubble 2.4 m, 0.1"; UV: GALEX ~ 50cm^2 effective area, 5"; IR: Spitzer, 0.85 m, 3-180 μ, cryogenically cooled (near 0°K). FOV's $< 1^\circ \times 1^\circ$.

Radio telescopes. Arecibo (Puerto Rico) single large dish, 300 m; VLA (NM) 27 $D = 25$ m array, max. spread 27 km (0.1" at 1 GHz), VLBI reach 10^{-3}", sensitivity reaches 1mJy$= 10^{-26}$erg/s cm^{2}Hz.

X-ray telescopes. Micro channel plates, gas proportional counters, CCDs. Grazing incidence $\sim 3^\circ$ mirrors. Crab: $\varepsilon^2 I_\varepsilon = 10^{-8}$erg/cm^{2}s. XRB (1-100 keV) $\varepsilon^2 I_\varepsilon \sim 10$keV/cm^{2}s sr.

The most advanced X-ray sat', Chandra, has a high resolution camera (HRC, 16M 10 μ diameter MCPs) with $A_{\rm eff} \sim 10^{2.5}$cm^2 and $\Delta\theta \sim 1"$, 0.5 deg×0.5 deg FOV, 0.5-10keV,

$$f_{X,5\sigma} \simeq 10^{-13.5} \left(\frac{AT}{10^6\mathrm{cm}^2\mathrm{s}}\right)^{-1/2} \frac{\Delta\theta}{1"} \frac{\mathrm{erg}}{\mathrm{cm}^2\mathrm{s}} \simeq 10^{-4} \left(\frac{AT}{10^6\mathrm{cm}^2\mathrm{s}}\right)^{-1/2} \frac{\Delta\theta}{1"} \frac{\mathrm{ph}}{\mathrm{cm}^2\mathrm{s}}. \quad (3)$$

HR grating spectrograph provides $\lambda/\Delta\lambda \sim 10^{2.5}$, ACIS CCD provides imaging plus $\lambda/\Delta\lambda \sim 10^{1.5}$.

Wide field: MAXI on the space station with gas-slit camera & solid-state slit camera (SSC), the SSC is $A \sim 10^2\mathrm{cm}^2$ with 90 deg×2 deg FOV and $\Delta\theta \sim 1$ deg giving ~ 10 mCrab (at ~ 1 keV) for $AT = 10^6\mathrm{cm}^2\mathrm{s}$ (BeppoSAX was intermediate with similar FOV, $A \sim 10^2\mathrm{cm}^2$ and $\Delta\theta \sim 1'$ giving 10^2 times better sensitivity).

Will appear later:

- γ-ray satellites
- ν detectors
- CR detectors
- HE γ Cerenkov telescopes