Lecture 19: Revision Summary

Lec. 1: Radiation

1.1 Basic Definitions

- be familiar with units of specific intensity: $[I_\nu] = \mathrm{W\,m^{-2}\,sr^{-1}\,Hz^{-1}}$
- be familiar with defns of mean intensity and flux in plane-parallel geometry: $J_\nu = \frac{1}{2}\int_{-1}^{+1} I_\nu\, d\mu$ and $F_\nu = 2\pi \int_{-1}^{+1} I_\nu\, \mu\, d\mu$
- don't need to remember defns of other moments of I_ν

1.2 Blackbody Radiation

- **ADV only**: understand origin of terms in Planck fcn:

$$B_\nu(T) = c \times \text{energy density} = c \times (\text{density of states}) \times (\text{average energy per state})$$

- be familiar with: Stefan-Boltzmann law, $\sigma T_{\rm eff}^4 = F$; Rayleigh-Jeans law, $I_\nu^{\rm RJ} \simeq \frac{2\nu^2}{c^2}\,kT$, when $h\nu \ll kT$; and Wien's law, $I_\nu^{\rm W} \simeq \frac{2h\nu^3}{c^2}\exp\left(-\frac{h\nu}{kT}\right)$ when $h\nu \gg kT$

Lec. 2: Radiative Energy Transport

2.1 Emission and Extinction Coefficients

- be familiar with units of emissivity and extinction: $[j_\nu] = \mathrm{W\,sr^{-1}\,Hz^{-1}\,m^{-3}}$, $[k_\nu] = \mathrm{m}^{-1}$
- be familiar with defn and concept of optical depth: $d\tau_\nu = k_\nu ds$

2.2 The Equation of Radiative Transfer

- be able to write down the RTE: $\frac{dI_\nu}{ds} = j_\nu - k_\nu I_\nu$ and understand what it means
- be able to re-write RTE in terms of source fcn, $S_\nu = j_\nu / k_\nu$

2.3 Simple solutions to the RTE

- Kirchoff's law implied by TE: no net change in I_ν, so $j_\nu = k_\nu B_\nu$

2.4 Formal solution to the RTE

- know how to derive the formal soln using the I.F. e^{τ_ν}, giving $I_\nu(\tau_2) = I_\nu(\tau_1)e^{-(\tau_2-\tau_1)} + \int_{\tau_1}^{\tau_2} S_\nu(\tau) e^{-(\tau_2-\tau)}\, d\tau$
- derive & explain soln for a uniform slab in optically-thin & optically-thick limits
- understand difference between TE & LTE

Lec. 3: Stellar Atmospheres

Nothing from this lecture will be explicitly examined.

Lec. 4: Radiative Processes I

4.1 Radiative Processes

- understand difference between bound-bound, bound-free, free-free, scattering processes

4.2 The Einstein Coefficients

- don't need to remember explicit formalism for E-coefficients, but should be familiar enough with A-coefficient to know that it represents rate $[\mathrm{s}^{-1}]$ of spontaneous emission
- understand radiative equilibrium: true absorption = spontaneous + stimulated emission (in units no. of transitions per unit vol per unit time)

4.3 Thermodynamic and Statistical Equilibrium

- know the Maxwell, Boltzmann & Saha LTE relations for velocities, populations of bound states, & populations of ionisation states, but the equations for these relations are non-examinable

Lec. 5: Radiative Processes II

5.1 LTE Line Transition Rates

Nothing explicitly examinable.

5.2 Spectroscopic Notation

- electronic configurations and spectroscopic terms will not be explicitly examined
- know the difference between allowed and forbidden transitions: allowed radiative transitions obey the selection rules for changes in quantum numbers (don't need to remember the rules), whilst forbidden radiative transitions do not, resulting in a transition probability that is effectively zero (don't need to remember details of assumptions in LS coupling scheme)

5.3 Fine Structure

Nothing explicitly examinable.

5.4 Hyperfine Structure

- understand the origin of the HI 21 cm transition as hyperfine splitting of ground state due to interaction between electron spin states and nuclear spin state

- understand that hyperfine transitions are technically forbidden, but the 21 cm transition is observable because: (i) hydrogen is so abundant, esp. in the Galactic disk; and (ii) the collisional rate for 21 cm is much faster than the (forbidden) radiative rate (c.f. Lec. 6, Sec. 6.3), so the transition proceeds collisionally

Lec. 6: Radiative Processes III

6.1 LTE Continuum Transition Rates

- be able to explain *qualitatively* the origin of absorption & emission edges in spectra: photoionisation & recombination only occur above a threshold energy corresponding to the bound-free/free-bound potential
- no detailed derivations or calculations of continuum transitions are examinable

6.2 Scattering Effects

Nothing explicitly examinable.

6.3 Collisional Processes

- understand that collisional transition rates exceed radiative transition rate above a critical density, so transitions that are radiatively forbidden can proceed collisionally if the density is above the critical value; this is the case for HI 21 cm in our Galaxy

Lec. 7: The Interstellar Medium

7.1 Overview

- don't need to remember all the details of physical properties of ISM components, but should know the main components are: neutral gas (molecular, cold, warm), ionised gas (diffuse, HII, coronal), and dust
- observational evidence for dust: interstellar extinction (strongest in optical/UV wavebands); re-radiation in IR (prominent around star-forming regions)
- understand difference between emission, reflection and dark nebulae
- don't need to know about interstellar absorption lines

7.2 Molecular Clouds

Not explicitly examinable.

Lec. 8: Radiative Processes in the ISM I

8.1 Atomic Neutral Gas

- understand that main tracer is 21 cm line in either emission or absorption, but detailed calculations will not be examinable
- don't need to know about interstellar absorption lines

Lecture 9: Radiative Processes in the ISM II

9.1 Diffuse Warm Gas

- only important piece of info here is that continuum processes (ie free-bound, free-free) are important, since gas is ionised; emission is optically-thin and $\propto \int N_{\mathrm{e}}^2 \, ds$ – the emission measure
- don't need to know about dispersion measure

9.2 HII Regions

- should be able to explain what a Strömgren sphere is and its properties: approximately spherical HII region surrounding a hot, massive O/B star; size (radius) of region is determined by photoionisation equilibrium (photoionisation and recombination rates balance); recombination lines produced as recombinations to high energy states cascade down to Balmer levels $\Longrightarrow H\alpha, H\beta, H\gamma$ optical line emission (and some due to He, depending on the ionising stellar flux)

- should be able to derive an algebraic expression for the Strömgren radius, $r_{\rm s}$, for a given ionising flux $S_\star$ (s^{-1}), recombination coefficient α ($\rm m^3\,s^{-1}$), and hydrogen number density $N_{\rm H}$ (m^{-3}). Think about the units.
- **ADV only**: you should be able to derive $S_\star$ for a given $T_\star$ and $R_\star$. Use $S_\star = 4\pi R_\star^2 F$, where $F = \int_{\nu_1}^{\infty} F_\nu \, d\nu \simeq \int_{\nu_1}^{\infty} B_\nu \, d\nu$ using the Wien limit to simplify the integral over all frequencies of photons capable of ionising hydrogen (i.e. all $h\nu \geq h\nu_1 = 13.6$ eV).

9.3 Coronal Gas

Not explicitly examinable.

9.4 Dust Extinction

- know what interstellar extinction is: absorption and scattering by dust grains leads to obscuration and reddening $\Longrightarrow$ correction to magnitudes is A
- don't need to know about photometric wavebands, colour index, reddening, or colour excess

9.5 Dust Emission

- should know that dust re-radiates absorbed starlight into the IR with approximately blackbody spectrum over a distribution of $T \Longrightarrow$ traces star forming regions

Lec. 10: ADV/REG Split

Non-examinable. But ADV students should do worked problems done by the REG class in this lecture.

Lecture 11: The Milky Way

11.1 The Milky Way as a galaxy

- omit historical overview
- be familiar with disk, bulge, halo components of our galaxy and know difference between PopI/PopII stars; don't need to know all the differences in physical properties – metal rich/poor distinction is most important
- omit spiral arms & star formation
- know that flat rotation curves provide strong evidence for a dark matter halo in our galaxy – don't need to know details of mass estimates

11.2 The Galactic Centre

Not explicitly examinable.

Lecture 12: Galaxies I

12.1 The Morphological Classification System

Not explicitly examinable.

12.2 Distance Scales

- know distance modulus: $m - M = 5\log\left(\frac{d}{10\,\mathrm{pc}}\right)\,(+A)$
- know Hubble's law: $v = H_0 d$ (for $z \ll 1$)

Lecture 13: Galaxies II

Nothing from this lecture will be explicitly examined.

Lecture 14: Galaxies III

14.1 Mass and Luminosity Functions

Not explicitly examinable.

14.2 Star Counts

Not explicitly examinable.

14.3 Mass-to-Light Ratios

- know that $M/L > 1$ always $\Longrightarrow$ faint sources + dark matter

14.4 Galactic Dynamics

- be familiar with 2 methods for estimating mass of galaxies & clusters :
  1. velocity dispersion method (ellipticals & clusters)
  2. rotation curves method (spirals)
- both methods assume virial theorem holds (i.e. assume gravitationally bound systems): $\boxed{2T + \Omega = 0}$, where T = random (translational) KE + rotational (orbital) KE and Ω = gravitational potential; generally, use $v^2 \simeq \frac{GM}{r}$, where exact relation depends on geometry of system and relative importance of random and rotational motions.
- be aware that for velocity dispersion method, both random and rotational velocities are important, but we can only measure the radial component v_r (which corresponds to the rotational component when we look at a spiral edge-on) so $\langle v^2 \rangle$ is estimated by assuming other velocity components have the same magnitude
- for rotation curves method, don't have this problem since KE is all rotational, so $\langle v^2 \rangle \simeq \langle v_r^2 \rangle$

Lecture 15: Active Galaxies I

15.1 Introduction to AGN

- know at least a few observational properties of AGN that distinguish them from normal galaxies (e.g. broadband SEDs, very broad optical emission lines, extremely high luminosities, rapid spectral variability across short light-crossing times, relativistic jets)

15.2 AGN Classification

- know 4 types of AGN: Seyferts, radio galaxies, quasars, blazars; don't need to know names or properties of sub-classes
- know difference between type I & type II Seyferts: type I exhibit both broad and narrow emission lines, type II only narrow (this is relevant to unification schemes)

Lec. 16: ADV/REG Split

Non-examinable.

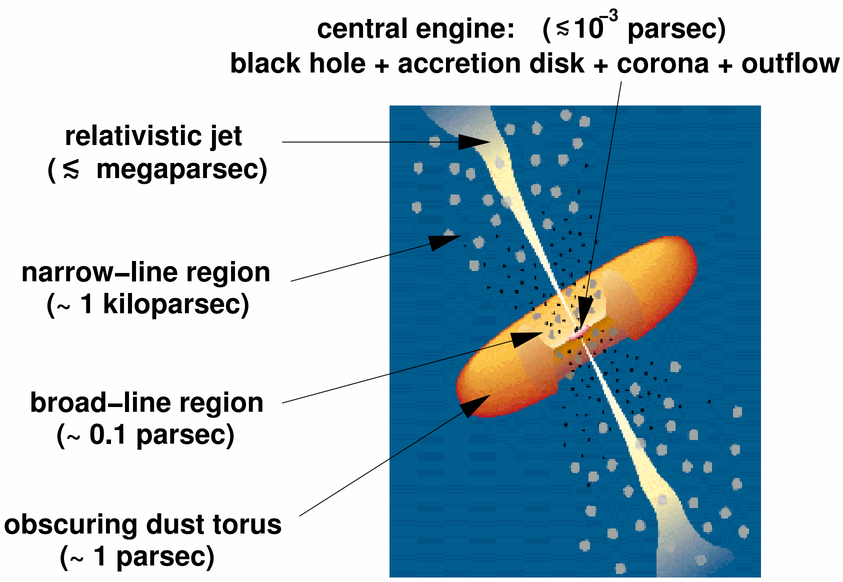
Lecture 17: Active Galaxies II

17.1 The Black Hole Paradigm for AGN

- be familiar with arguments for a BH based on energetics and dynamics, but don't need to derive anything here; key argument is need a lot of mass in a v. small space
- understand that the ultimate power source behind AGN is gravitational potential energy of matter accreting via a disk, converting potential to other forms of energy (radiative, kinetic)
- 2 key parameters in accreting BHs: M and $\dot{M}_{\rm a}$

17.2 The Unification Model for AGN

- orientation-based model is evidenced by: anisotropic structure (e.g. jets/outflows along the disk axis); possible obscuration of broad-line region in Sy 2's $\Longrightarrow$ what we see depends strongly on the orientation of the AGN w.r.t. our l.o.s.
- be able to sketch components of AGN: accretion disk (emits mostly optical/UV continuum), corona (X-ray, γ-ray continuum emission), jets (radio $\longrightarrow$ X-ray broadband synchrotron emission), fast-moving clouds (broad optical emission lines & narrow emission lines further out), dust torus (absorbs nuclear continuum + line emission, re-emits in IR)



Lecture 18: Quasars

18.1 Introduction

- understand that cosmological redshift is not due to the Doppler effect
- understand that mass estimates of supermassive black holes in distant quasars are obtained from the broad emission lines: assuming emission line widths are due to Doppler broadening, then $\Delta\nu/\nu_0 = \lambda_0/\Delta\lambda \simeq v/c$ and assuming the line-emitting clouds are gravitationally bound, the virial theorem gives $v^2 \simeq GM/r$, where an upper limit on r can be obtained from the instrument angular resolution and distance d, which is obtained from z using a cosmological model.

18.2 Quasar Absorption Lines

- know the difference between the 3 main absorption systems: damped $Ly\alpha$ systems (strong absorption in the $Ly\alpha$ by an intervening system at some z); $Ly\alpha$ forest (strong absorption of the Ly continuum by many intervening absorption systems); broad absorption lines (strong absorption lines blueward of corresponding high-ionisation emission lines, consistent with absorbing clouds intrinsic to the quasar, but being driven outward by radiation pressure)