Q Exam Notes

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1 PHYS 7680: Computational Physics

Not much to review here, we know most of it or it's too low level

- CFL conditions, von Neumann Analysis.
- Spectral methods (exponential conv, low numerical viscosity).
- What is numerical viscosity, how does it arise?
- Convergence of various numerical schemes, higher order than RK4.
- Runge Phenomenon vs Gibbs Phenomenon, non-sinusoidal expansions.

2 ASTRO 6578: Planet Formation

- Protostellar disks: Coolers stars have more complex lines, young stars don't support planets. OBAFGKM (Oh be a fine gal, kiss me) stars.
- Lol: Peak power generation of the core $\ll$ human power generation (recall Eddington luminosity as well from Ph101).
- Disk formation must be driven by eddy viscosity in order for the only timescale $t = \frac{L^2}{\nu}$ to be less than a Hubble time.
- Shakura-Sunyaev discs $\nu = \alpha c_s H$ viscosity parameterization.
- In a disc w/ gas and dust, gas orbits sub-Keplerian if polytrope $P \propto r^{-n}$ profile.
- Planet formation: Isochron dating.
- Gravitational focusing $\propto R^2/R^4$ for small/large objects, favors runaway accretion.
- Pebble accretion for gas giants, ice line means smaller inner planets. Dynamical friction speeds up smaller bodies and counteracts gravitational focusing, preventing runaway accretion and inducing oligarchal growth but no big planets. Pebble accretion solves because pebbles ($\sim$ 10 cm) feel gas drag, further magnifying gravitational focusing.

- Minimum Mass Solar Nebula constructed by replenishing all planets up to solar abundances (makes up for photoevaporation, though not ejecta from early Sun).
- Planetary migration: Grand Tack model uses Jupiter/Saturn resonances to form small Mars. Also produces *Late Heavy Bombardment*.
- Lindblad resonances spaced unevenly on either side of planet, Type I migration until planet opens a permanent gap immune to disc viscosity replenishing (Saturn-sized).
- Giant planet interiors: molecular hydrogen envelope, metallic hydrogen mantle and diffuse core in Jupiter.

3 AEP 6060: Introduction to Plasma Physics

- Electron plasma frequency $\omega_{pe} = \sqrt{\frac{n_0 e^2}{\varepsilon_0 m_e}}$ (derivation: oscillating box of charges).
- Debye length is bottom end for plasmas.
- $\frac{\mathrm{d}f}{\mathrm{d}t} = 0$ Vlasov equation/kinetic theory, produces fluid equations.
- The world is Maxwellian $f(\vec{v}) \propto e^{-(\vec{v}-\vec{v}_0)^2}$ or $f(v) \propto v^2 e^{-(v-v_0)^2}$.
- Alfvén speed $v_A = B/\sqrt{\mu_0 \rho}$. Two-fluid yields more waves than MHD unless introduce thermal/-pressure terms.
- Instabilities: streaming instability, Landau damping.
  - Plane wave ansatz gets dispersion relation of form $1 + \chi_e = 0$ where χ_e the electron susceptibility consists of an integral over a singular value.
  - Careful IVP analysis + Landau prescription deforming contour above the singularity in χ_e shows that the correct way to interpret the dispersion relation is to deform the integral (equivalent).
- Infinite cold plasma waves (instead of permitting pressure/temp terms, use source term in Ampère's Law, dielectric tensor).
- Geometric optics for waves, magnetic reconnection.

4 ASTRO 6531: Astrophysical Fluids

- Boundi radius (1D accretion), Bondi-Lyttleton Accretion (moving BH accretion) for *barotropic flow* $P \propto \rho^\gamma$.
- Waves in self-gravitating fluid have $\omega^2 = a^2 k^2 - 4\pi G \rho_0$. Extra term is self gravitation, *Jean's Mass*.

- Surface gravity waves (deep vs shallow). Coarse treatment of steepening, just "increased height makes faster velocity."
- Atmospheric waves, $N^2 > 0$ is *Schwarzchild criterion*. Nonradial spherical atmospheric waves = my research.
- Sommerfield quantization condition for modes in irregular cavities.
- Kelvin-Helmholtz Instability: two fluid streaming. Extension: shear flow instability, Richardson criterion.
- Rotating flows, Rossby waves, can source Chandrasekar-Friedman-Schutz Instability (major GW source for quadrupole moment).
- Viscous flows, high/low Re drag, Stokes flow. Boundary layers, Ekman layer in rotating flow.
- Kolmogorov turbulence, similarity.
- Discs: Shakura-Sunyaev discs, radial-epicyclic frequencty. Toomre Q stability, Lindblad resonance, corotation resonance.
- Shocks, Rankine-Huginot conditions continuity. Blast waves, Sedov-Taylor = radial shocks and self-similarity.
- MHD, Alfvén speed, magnetorotational instability.

5 PHYS 6562: Statistal Mechanics

- The diffusion equation, probability current.
- Microcanonical Ensemble: ensemble of all states at fixed energy E.
- Entropy is uncertainty, log number of accessible states. Is a thermodynamic potential like chemical potential (derivatives of thermo potentials = observables), $T^{-1} = \frac{\partial S}{\partial E}, \frac{\mu}{T} = -\frac{\partial S}{\partial N}$.
- Bunch of free energy stuff. Bosons (condensation)/Fermions (Fermi sea).
- Markov chains (detailed balance).
- Ising model, phase changes (discontinuities in order parameters).
- Correlation functions show power laws in continuous phase transitions.
- Abrupt transitions require often some small activation energy past the critical value.
- Scale invariance, renormalization.

6 ASTRO 6516: Galaxies

- Milky Way: $10\,\text{kpc} \times 0.5\,\text{kpc}$, $\sim 10^{11} L_\odot$. Rotation curve flattens 220 km/s (implies mass is not dominated by SMBH at center). Galaxy spacing $\sim$ Mpc.
- *Cold* regions = dominated by Keplerian motion, *warm* dominated by many-body gravitational interactions.
- Plummer law for galactic density distribution $\rho(r) = \frac{\rho_0}{(1+x^2)^{5/2}}$, $x = r/r_c$, simply looks like $\Phi = \frac{GM}{r}\frac{1}{\sqrt{1+x^2}}$ smoothing.
- Quasars are AGNs, very bright compared to rest of galaxy. Standard model of AGNs is that viewing angle and dustiness produce varying kinds of emission (broader IR lines if obscured e.g. DSFGs).
- Universe age $t = 0.3\,\text{s}(T/\,\text{MeV})^{-2}$. Early universe is radiation dominated, then hydrogen formation/recombination when photons drop below photodissociation (photon decoupling releases photons as new atoms decay, CMB). Then eventually Population III stars, galaxies, large scale structure.
  - Recombination $z = 1100$.
  - Dark ages (no stars).
  - Reionization $z = 20$–6 as stars and galaxies form, ionizing radiation.
  - Only now can clusters form, lasts until present day.
- Lyman-α forest: high redshift light passes through many different redshift absorbing media. Largely happens before reionization since much more hydrogen.
- Lyman-α emitters are very old galaxies that have mostly neutral hydrogen. Lyman-break galaxies have lower redshifts $z \sim 3, 4$ whose redshift can be pinpointed by the 912 Å dropoff in radiation.
- Metallicity tracks how many stars have already formed in the galaxy.
- 21 cm line is important since one of only transitions possible in neutral Hydrogen.
- Collisionless Boltzmann Equation is the Vlasov equation, with Maxwellian energy distribution allows solving density distributions in galaxies.

7 MATH 6270: Applied Dynamical Systems

- Homoclinic tangles: stable and unstable manifolds intersect transversely!

- Melnikov's Method predicts when a system pertubed from a homoclinic orbit exhibits chaos (whether the stable + unstable manifolds cleanly untangle or homoclinic tangle/chaos). Can also use to predict topological changes in behavior.
- Symbolic dynamics to describe objects in the invariant set of a map.
- Center manifold theory! Dynamics near a center manifold. Fast-decaying variable is slaved to motion along the center manifold. Can predict e.g. XY model topological nature of phase transition.
- Normal forms: find spanning subset of a degenerate linearization about a fixed point.
- "Find a global bifurcation by blowing up a local analysis on a rescaled system." Melnikov's Method again.
- Kuramoto oscillators synchronization.
- Fermi-Pasta-Ulam-Tsingou solitons, Kortweg de Vries.
- Henon-Heiles arises from studying star motion around galactic center; for sufficiently high level curves, Hamiltonian invariant tori break down into chaos. Can study via a map, though I missed this part of lecture.

8 ASTRO 6530: Astrophysical Processes

- Radiative transfer equation! $\frac{\mathrm{d}I_\nu}{\mathrm{d}\tau_\nu} = -I_\nu + S_\nu$.
- Einstein coefficients, stimulated emission key (detailed balance).
- In isotropic radiation, expanding in small multipoles gives closure relation, plus two-stream approximation relates I_ν to J_ν.
- Polarization: Stokes parameters!
- Thomson scattering is non-relativistic limit of Compton.
- Bremsstrahlung is when a charged particle moves through a plasma, bunch of scatterings means acceleration and radiation. Mostly spectrally flat in the R-J regime.
- Coherent vs incoherent radiation (groups of particles generally incoherent $\sim N$ unless population inversion, cascade $\sim N^2$).
- Cyclotron radiation when electron in magnetic field, L-W potential gives radiation field $\sim r^{-1}$,
- Synchrotron radiation: particle blips $\Delta t \propto \gamma^{-3}$, power laws over all frequencies.
- Propagation through a plasma, AEP 6060.