Mock exam

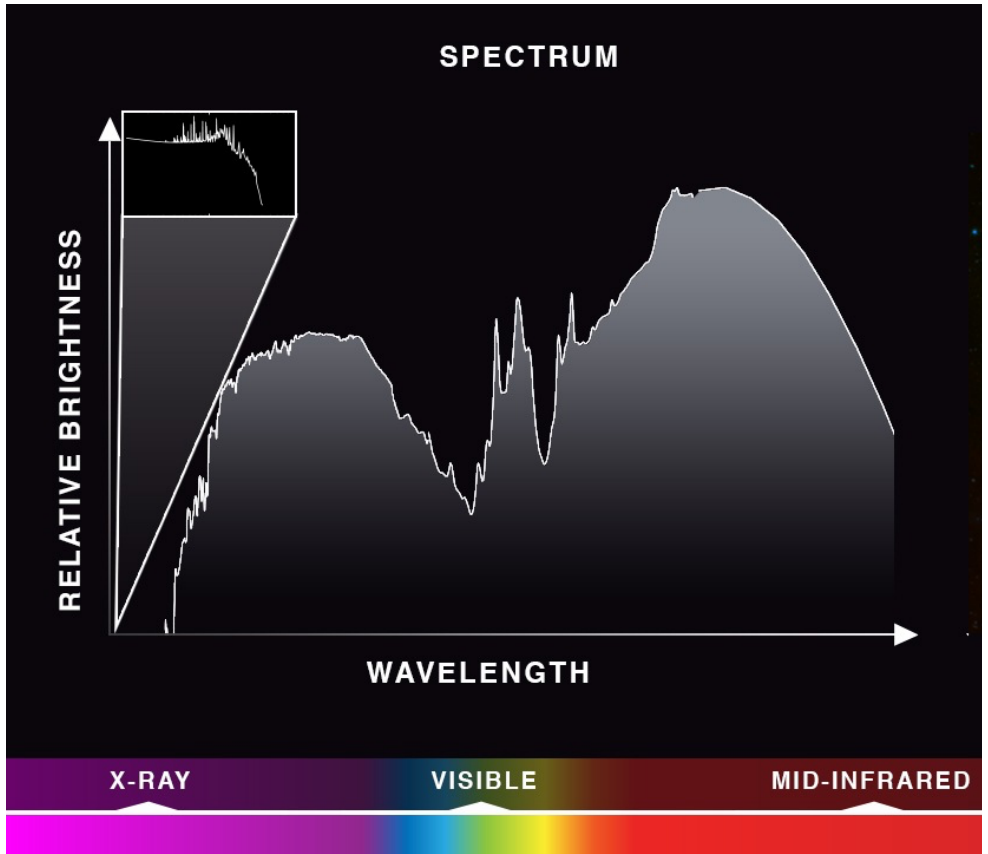
Astro-III: Galaxy Formation & Evolution

M. Hirschmann, 2024

Questions

- What is the theoretical definition of a galaxy? How can we distinguish it observationally from stars and planets?

- What is this spectrum telling you about a galaxy, which type of galaxy is it? What could you additionally learn about this galaxy if FIR and Radio would be observed?



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  - Gravitationally bound collection of dark matter stars, dust & gas
  - NO noticeable motion over short timescales (as for planets),
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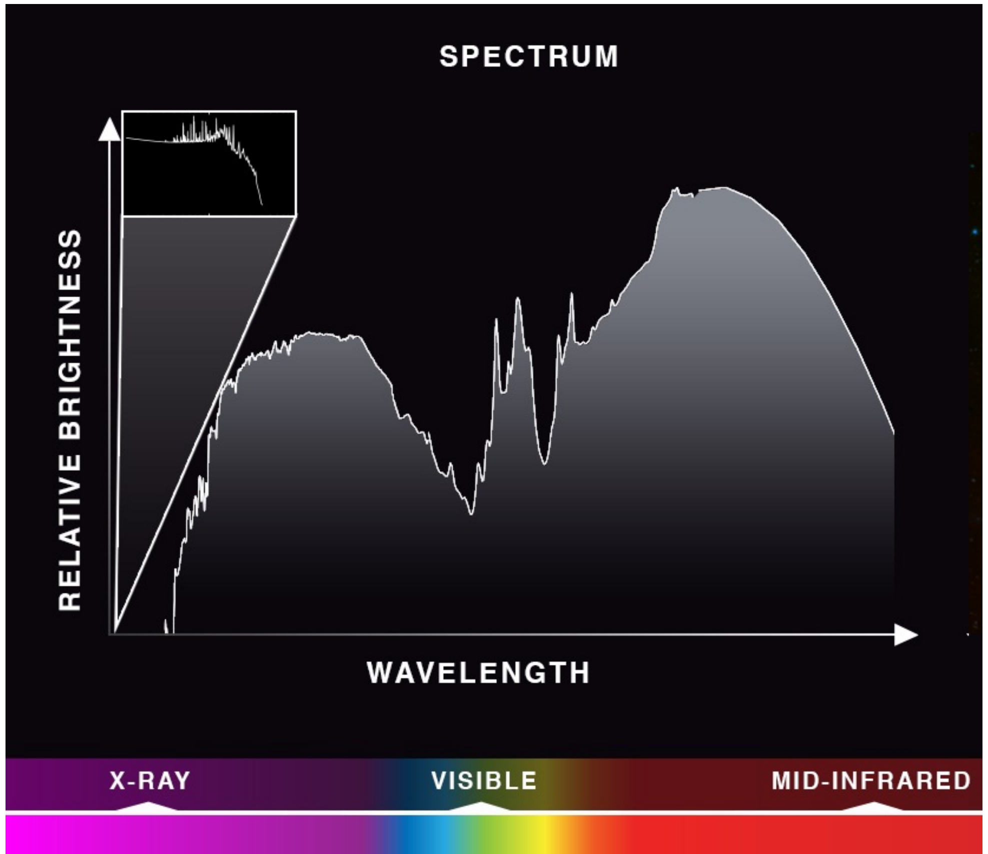

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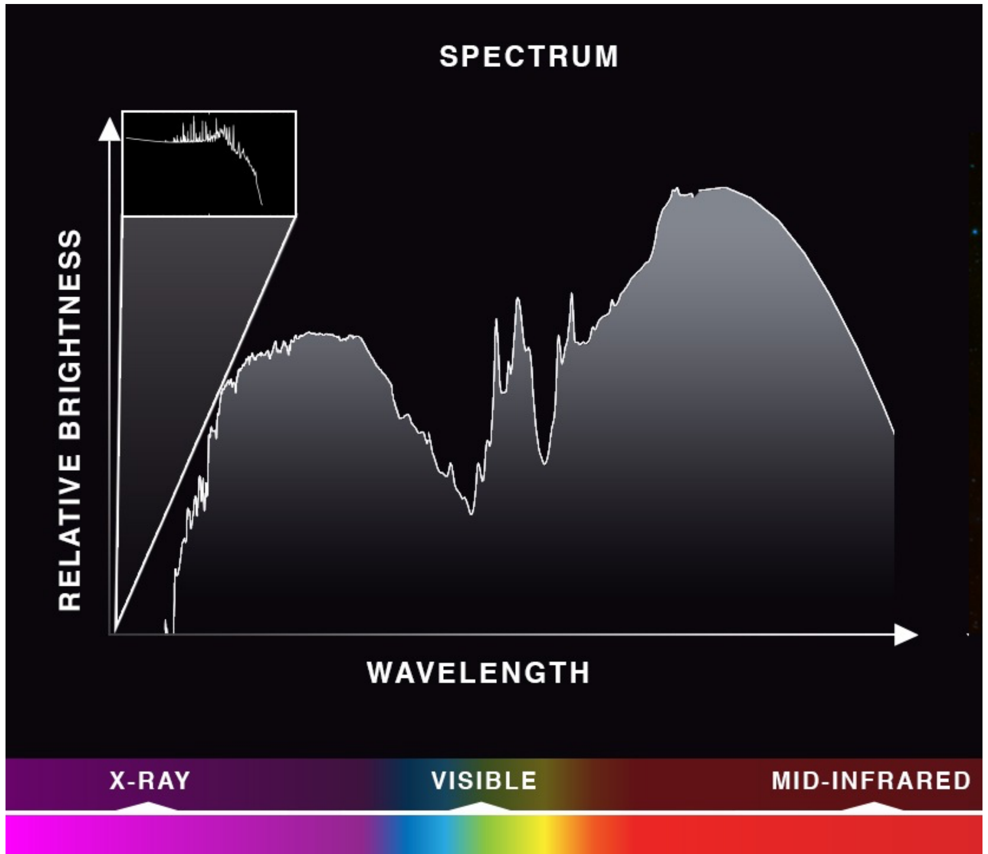
- What is this spectrum telling you about a galaxy, which type of galaxy is it? What could you additionally learn about this galaxy if FIR and Radio would be observed?
  - Lots of emission from dust —> large dust content and high SFR —> Star-bursting galaxy
  - FIR: molecular lines, radio: 21cm (neutral H), AGN jets (via synchrotron)



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- How are galaxies ordered along the Hubble sequence? What is the difference between elliptical and spiral galaxies (in addition to the obviously different morphology)?

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  - thin and thick disk, bulge, stellar halo

    —>different position of stars, distance to the galactic centre, orbits/velocities, ages and Z

    —> thin+thick disk: circular orbits, older and more metal-poor stars have large scale heights for the thick disk

    —> bulge: random motions, spatially compact (a few kpc only), bulge stars young & metal-rich

    —> stellar halo: random motions, a large distance from centre (100kpc), very metal-poor and old stars

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    —Ellipticals according to their ellipticity, the rounder the "farer away" from spirals (little cold gas, old stars, red, often quiescent, hot gas halos, higher Z, more massive)

    —Lenticulars bridging element between spirals and ellipticals

    —Spirals: with and without barred structure, then further distinction according to the opening angle of spiral arms, & clumpiness (lots of cold gas, SF, blue, young stars, lower Z, less massive)

    —Irregulars

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- Which large-scale structures do we observe in our Universe, what makes these environments particular? How can these structures be reconciled with the cosmological principle?

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  —relations between different properties of galaxies

  —mass-SFR, mass-size, fundamental plane of Ellipticals (size, luminosity, velocity dispersion), mass metallicity, Tully-Fisher relation, etc.

  —Understanding Underlying Physics: For example, the Tully-Fisher relation suggests a link between the mass of a galaxy (inferred from its luminosity) and its rotation speed, implying a connection between visible matter and dark matter.

  —Testing Theoretical Models: Galaxy scaling relations provide benchmarks for testing and refining theoretical models and simulations of galaxy formation and evolution. A successful model must be able to reproduce these observed relations and predict their evolution over time.

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  —galaxy groups and clusters

    —> additional processes: ram pressure stripping of gas, tidal stripping of gas and stars, harassment, galactic cannibalism etc.

    —> on sufficiently large scales, matter is still distributed homogenously and isotropically…

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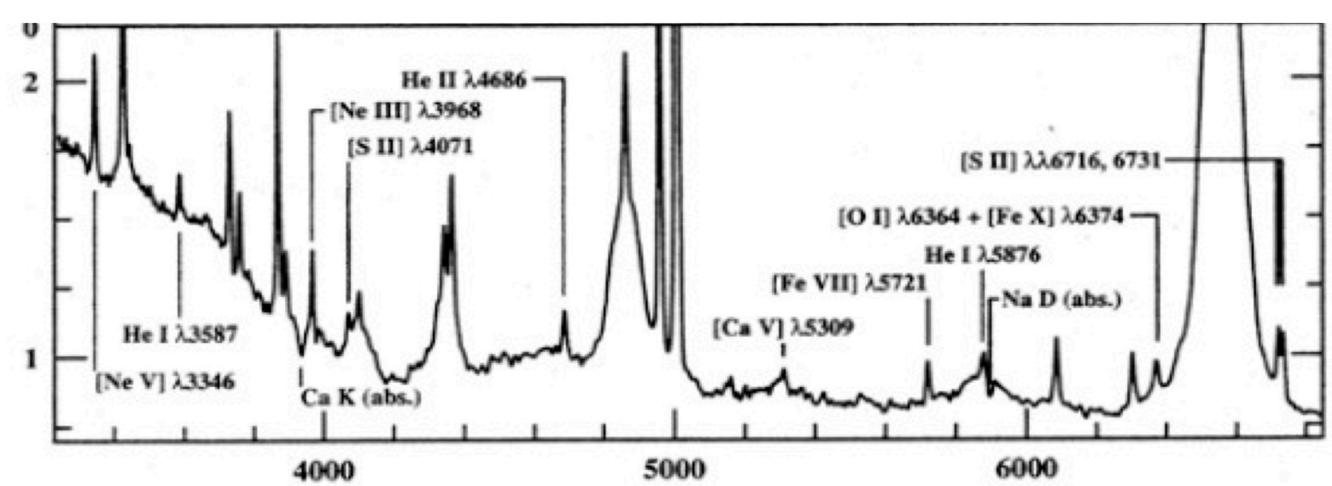
- What are AGN? How can they be observationally identified? Which types do exist and how are they characterised? Which AGN type is shown by the spectra below and why?



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  - —**Lyman-Break Technique:** UV radiation from young, hot stars in distant galaxies is absorbed by the neutral H in and around the galaxy and in the intergalactic medium —> distinctive "break" in the galaxy's spectrum at the Lyman limit (912 Angstroem). Photometric observations can identify this break via the drop-out technique (in bluer bands), as the break gets redshifted to longer wavelengths for high-z galaxies.
  - —**Photometric Redshift Estimation** via fitting SSP model spectra to observed data —> not very accurate
  - —**Gold standard of identifying high-z galaxies via spectra** and their absorption or emission lines in their spectra —> redshifted line allows for exact redshift determination
  - —High-z galaxies are more gas-rich, more SF/star-bursty, clumpier, often more AGN activity, smaller in size, compact and dense, more metal-poor…

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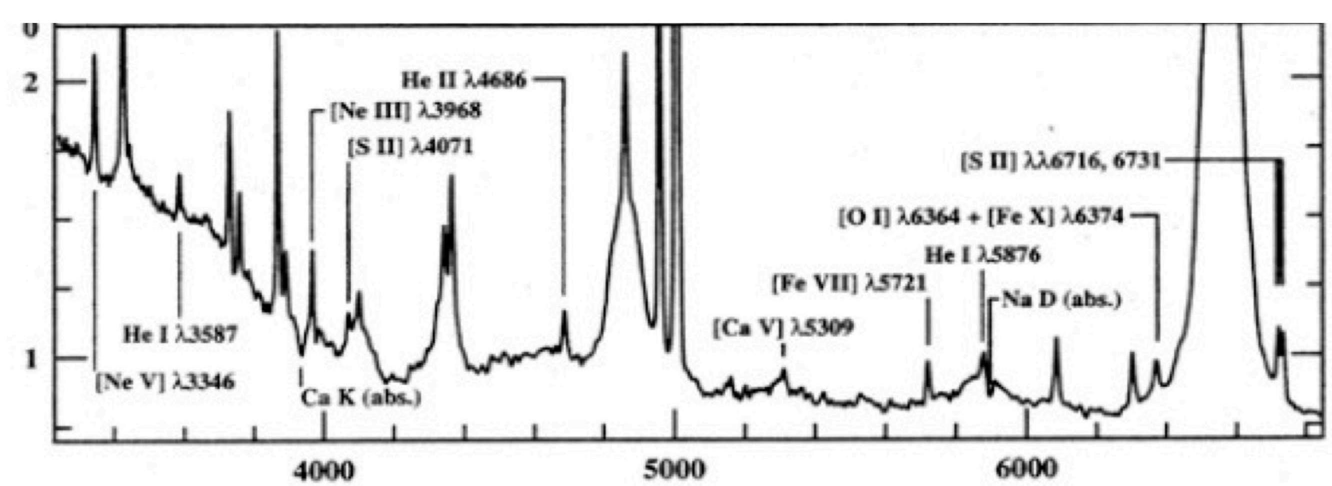

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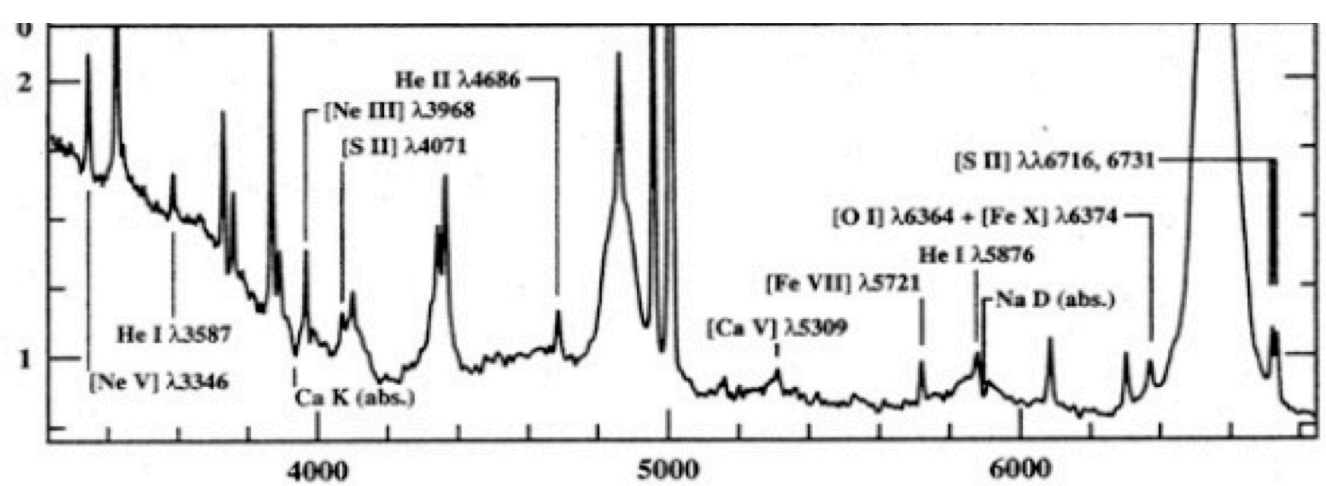
  - AGN are actively accretion supermassive BHs releasing energy so that become visible as AGN
  - Via radio, via X-ray, via IR (dusty torus), via optical and UV narrow and broad emission lines
  - Spectrum shows a BLR/Type-1 AGN



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  — Via radiation and fast particle winds from gas accretion disk and via relatistics particle stream in form of jets

  — the state of galaxies impact the gas fuel/supply onto the BH and in turn the energy release from the supermassive BH may be affecting the further evolution of the host galaxy.

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- Which role plays general relativity when describing the evolution of our Universe?

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  - Perhaps DM could be a bit “warmer”, but not much
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- How do we think that galaxies have started to form in our Universe? Why did they emerge at all?
  —Emerged from small density fluctuations present in the early Universe (likely inflated quantum fluctuations during the phase of inflation)
  —Overdense regions become denser until they de-couple from expansion and start to collapse
    —> driven by DM, forming virialised DM halos
  —Gas follows the evolution of DM due to gravity, falls into DM halo potential wells, cools and condenses so that stars, and thus, first galaxies, can form.

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- If we want to model the evolution of galaxies, how can we do that? What is needed?
  - Assume a cosmological model and create initial conditions
  - Model the evolution of DM via N-body simulations, just assuming gravitational interactions
  - Model the evolution of gas via Hydrodynamics (continuity, euler and energy equations), add cooling and heating terms
  - Add sub-resolution models for star formation, stellar feedback, BH growth, AGN feedback, chemical enrichment etc.
  - Efficient algorithms, Parallelisation of codes, and High-performance super-computing facilities

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    - Needed to explain observational trends (e.g. scaling relations)
    - Besides obvious processes like star formation and gas cooling, feedback processes from stars and AGN turned out crucial to obtain realistic properties of galaxy populations
    - Anti-hierarchical trend in galaxy (and BH) evolution
    - Morphologies and sizes of spiral and elliptical galaxies, build-up of the Hubble sequence
    - Solution to some initial tension with LambdaCDM predictions (missing satellite problem, too-big-too-fail problem, flat rotation curves, etc.)