Addenda to Observational Cosmology, Chapter 4.

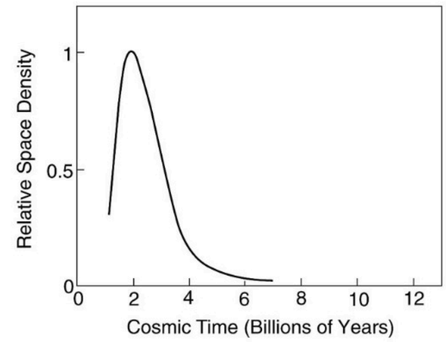
Dave 11/7/19 – 11/19/19

For meeting on December 16, 2019
{Beethoven's Birthday, 1770}

The distant optical universe

[Think about how many kinds of color filters one might use].

Figure 1: Quasar density evolution [ESO.org] →



Chapter 4 Page 121 has an important , *and opaque*, sentence that radio source counts steeper than an $S^{-5/2}$ power law counted against a steady-state ("SS") universe *(Fred Hoyle's 1948 pre-big-bang continuous-creation model – which had many believers).* { Translation: long ago and at big distances from us, source counts were unexpectedly high}.

In chapter 1, we learned that S = flux (energy seen per unit area of sky) obeyed $dN/dS \propto S^{-5/2} \propto r^5$ (where radius r is distance from us before present time). Now **quasars** and new stars and radio galaxies were dense for redshifts z >2 *but weak for z > 4* – meaning between about 4 to 1 billion years cosmic time after the big bang and peaking at 2 b years (shown in **Figure 1**). That is, there were big changes in the evolution of the universe over time. The history of the universe was decisively not steady state! Also, SS could not explain our black body CMB radiation, it was not due to old star-light scattering from galactic dust clouds. {Note for 2019: 203 quasars have now been discovered with z > 6 and defy currently accepted models. There is even a supermassive black hole at redshift z = 7.54. *"How did the first SMBHs grow so large so fast?"* Primordial BHs **[PBHs]** are being reconsidered as possibly major dark matter}.

It turns out that **Figure 4.17** on page 143 is another version of figure 1 above. Roughly, redshift z =1 means about 7.7 billion years ago (or "Ga" giga-annum before present). z =2 is 10.3 Ga and 6 is about 12.7 Ga—so the x-axis for redshift can be converted into time before us.

Similarly Figure **4.24** shows star formations peaking at z = 2, and this x-axis can also be converted to time in billions of years.

"Hot **dark matter** (HDM) candidates are relativistic particles, i.e., which move with velocities close to the speed of light, e.g. the neutrinos. Cold dark matter candidates are non-relativistic, i.e. slow moving particles." Although light weight, Axions (p.93) "are non-relativistic and therefore fall within the category of CDM." The unexpectedly high density of black holes suggests a re-thinking of that as cold DM.

Figure 4.1 on the Matter Power spectrum P(k) : Previously (on pages 60-64) we cared about the **clumpiness** of the little temperature or density variations of the CMB and noted a "Harrison-Zel'dovich" primordial $P(k) \propto k$ region {the left-most line on the plot that rises at a 45^o angle -- where $\Delta \log P(k) \sim \Delta \log k$}.

Then, at higher wavenumbers, k, the CMB P(k) rolls over and agrees with "2dF" (the "Two-degree-Field Galaxy Redshift Survey") and with galaxy clustering. The peak at roll-over is at λ_{max} = 350/ (Mpc/h, h ~ 0.7) and is related to the epoch when radiation density dominance gave way to matter density dominance.

What is the wave-length λ at the peak? 1 Mpc/h ~ 5 M ℓy. So the value 350 means 5 Mℓy/350 ~ 14,000 light years wave-length. Notice that the top lambda scale decreases to the right while the lower k scale gets bigger to the right (as it should since k = 2π/λ).

The **Cycloid equations** (exercise 4.1 p 123) describe a closed spherical Friedman matter-dominated or radiation-dominated universe from big bang expansion to a collapsing **final crunch** in terms of a time arc-angle parameter (which is usually called eta η – if ϕ and θ are space angles, why not one also for time?). Our book also uses these cycloid equations to describe the development of more local regions of "over-density" inside the universe.

Redshift-space Distortions (RSD's, p 125, see Wikipedia) "are an effect in observational cosmology where the spatial distribution of galaxies appears squashed and distorted when their positions are plotted as a function of their redshift {z} rather than as a function of their distance" (and there is a reference refers to our book, Serjeant). It is due to peculiar velocities outside of the usual Hubble flow. "RSDs have to be considered in any analysis that uses galaxy redshifts to make cosmological measurements."

Exercise 4.3 Magnitude apparent brightness: In modern terms, this 2000 year old Greek system uses a magnitude range of five to stand for 100 x in intensity (watts/m^2). So, one magnitude step is $100^{1/5}$ change in brightness ~ i.e., times 2.5 . We therefore express a difference of two magnitudes as $m_1 - m_2 = -2.5 \log_{10}(S_1/S_2)$ where more negative means brighter. The sun has apparent magnitude m = -27, Sirius is -1.46 (the brightest star), Vesta has m = +5. Filters can be used for transmitted color so that the filter U for ultraviolet centers at 364 nm, Blue B is 442 nm and V for Visual is 540 nm.

"Apparent magnitude" is usually understood, but there is also an "absolute magnitude M, of a star or astronomical object that is defined as the apparent magnitude it would have as seen from a distance of 10 parsecs (about 32.6 light-years). The absolute magnitude of the Sun is 4.83 in the V band (green) and 5.48 in the B band (blue).

In **figure 4.6** on page 130 (and more on page 154) focus on the top left-side of the graph where young hot galaxies emit most of their light in the ultraviolet! Notice that this bias is gone in older galaxies.

Balmer Series (1885) p. 132: There are four popular hydrogen photon emission series. If an orbiting electron from some hydrogen principle quantum number decays down to the lowest n = 1 state, we say that we have a "**Lyman**" series (e.g., Lyman alpha has n=2 → n = 1 {or orbital 2p→ 1s} emitting a UV photon with λ = 121 nm. The Lyman series is way too UV for our vision; but, after cosmic redshifting over a long distance, they can be visible (see pg 253). The more immediately visible Balmer series drops an electron from an excited state down to n = 2 as a lowest chosen level: so n = 3→ n=2 is called Balmer Hα with energy 1.89 eV or λ =656 nm (red color spectral line). A bigger drop from n = 4 → n = 2 is Hβ at 2.55 eV or 486 nm (blue). For higher numbers like n = 9→2 at λ = 383, the spectral lines become very closely spaced – a continuum called the **Balmer jump** or Balmer break (pg. 133 and Fig. 4.6).

The same thing happens with high n for the Lyman series too and is called the Lyman Jump.

Then there are the Paschen series down to n = 3 (infrared) and the Bracket series down to n = 4 as a selected lowest level. Being close to hot stars can ionize inner orbital electrons away from atoms thus creating orbital vacancies for subsequent series decays. Galactic dust absorbs the blue Hβ lines more strongly than the red Hα lines, and that provides a handle for deducing levels of dust. Exercise 4.4 is a long calculation dealing with assumptions versus estimates of dust attenuation.

Optical depth measures the attenuation of the transmitted radiant power through something, $\tau \propto A_v$ ["V" meaning visible (like green), *not Violet*]. Hα photons have a lower optical depth than Hβ or UV photons—red transmits better than blue. Flipping the wavelengths 1/λ {in microns} is near the number 2 on the x-axis of **Fig. 4.8** with more UV (and more attenuation) progressing to the right.

Luminosity pg 135: The Schechter luminosity function provides a parametric description of the space density of galaxies as a function of their luminosity. (p. 146 also mentions ϕ_*). https://en.wikipedia.org/wiki/Luminosity_function_(astronomy))

Page 137 **g-band** ? : **There are many color filter conventions**, and our book seems to assume that we might already know them. In today's astronomy, we often now refer to "**SDSS:" the "Sloan Digital Sky Survey"** – as a major reference (80 million catalogued stars and galaxies). And we sometimes wish to go beyond the colors U, B, V.

"SDSS measures magnitudes in five different colors by taking images through five color filters. A filter is a kind of screen that blocks out all light except for light with a specific color. The SDSS telescope's filters are green (g), red (r), and three colors that correspond to light not visible to the human eye: ultraviolet (u), and two infrared wavelengths (i and z). On SkyServer, the five magnitudes (through the five filters) of a star are symbolized by u, g, r, i, and z. The astronomers who planned the SDSS chose these filters to view a wide range of colors, while focusing on the colors of interesting celestial objects."
https://skyserver.sdss.org/dr1/en/proj/advanced/color/definition.asp
So, g = green. Figure 4.17 page 143 uses "i-band" infra-red.

From 1998 to 2009, "SDSS used a dedicated 2.5 meter wide-angle optical telescope and observed in both imaging and spectroscopic modes. The imaging camera was retired in late 2009, since then the telescope has observed entirely in spectroscopic mode."

A list of conventional "bands" is found at;
https://en.wikipedia.org/wiki/Apparent_magnitude

Astronomical Ionized Spectral Lines: pg 141 mentions **OIII** which is doubly ionized oxygen. Singly ionized oxygen is O II and singly ionized nitrogen is N II. There is also an O I at 630nm (not ionized uses Roman numeral I). The classification of stellar spectra uses the temperature hierarchy **O B A F G K M** (Annie Jump Cannon at Harvard) – "from the hottest blue O stars to the coolest red M stars." "The visible spectral lines of singly ionized calcium (Ca II) are most intense for K0 stars (T_e = 5250 K)" {from my Astrophysics textbook}.

[And even more special color filters] **Page 146 BzK galaxy**: "A set of broad-band and narrow-band **infrared filters** was required for use with the 8.2-m Subaru Telescope and the 8.0-m Gemini North Telescope" (2001). "**BVRIzJHK imaging** with B, z, R, I, Js , Ks , K filters." "In infrared astronomy, the K band is an atmospheric transmission window centered on 2.2 μm (in the near-infrared 136 THz range)." The center for the J filter is 1.25 microns. Broadband Z is 1.033 microns. "J-band" and "H-band" are mentioned in Figure 4.23. In astrophysics, a BzK galaxy is a galaxy that has been selected as star-forming or passive based on its photometry in the B, z, and K photometric bands [WIK] **"The AB magnitude system** is an astronomical magnitude system. Unlike many other magnitude systems, it is based on flux measurements that are calibrated in absolute units, namely spectral flux densities." https://en.wikipedia.org/wiki/AB_magnitude

Page 149 (and p 154) refers to the Fundamental Plane (from 1987. First glance back to page 98). Out of 4 measureable variables: Luminosity L, effective radius r_e, mean surface brightness $\mu = \langle I_e \rangle$, and velocity variation σ_{vel} , only three are independent. So, for example, $r_e \propto \sigma^{1.34}/\mu^{0.82}$, or $L \propto \sigma^{3.5}/\mu^{0.7}$.

Page 151: There was a time when astronomers did not know about huge superclusters and big voids in the fractal structuring of the cosmic web. **Pencil beam** analysis of redshifts in a sub-degree-squared area of the sky revealed a big void in 1981 and later studies: the Bootes SuperVoid (330 million light years diameter).

Page 154: The **Hertzprung-Russel** Color-Magnitude diagram is usually drawn as Luminosity Magnitude on the y-axis and spectral type or color on the x-axis. It shows main sequence lifetimes increasing with cooling down to the right.

Originally, the x-axis was the sequence OBAFGKM with hot "O" blue left and cool "M" red on the right. That means that the x-axis could also be laid out as temperature decreasing to the right. Still other plots use color index (B-V) from B-V=0 to about B-V = +1.5 or so. {Why positive? – because the magnitude scale appears to work 'in reverse', with objects with a negative magnitude being brighter than those with a positive magnitude}. See:
https://en.wikipedia.org/wiki/Hertzsprung%E2%80%93Russell_diagram

Figure **4.30** reverses the axes: the up y-axis is color "U – V" (instead of $B\text{-}V_{visual}$) and the x-axis is magnitude with the main interest now being population shifts with **redshift** z.

In history, spectral types began logically with a "type A" having the strongest broadest hydrogen lines. This was followed by "type B" with weaker lines. And then somehow "O" was the weakest. But then it was discovered that this weakness was due to ionization of hydrogen due to high temperatures, and a more natural order was by temperature from hot to cold. So, temperature O > B > A .

Note: A reviewer of Serjeant's book called it "a graduate school level presentation of the topic… geared to giving research level descriptions of the topics researchers in those areas would understand." This was not Serjeant's stated intention. He says it is "fully self-contained" for (what we call undergraduate seniors) interested in future PhD study but that students should look at his suggested reading sources. He assumes some previous general background in astronomy and astrophysics without which supplemental outside readings would then be necessary.