Astronomy 1 – Introductory Astronomy
Spring 2014

Review of key material from each week (building on "first six weeks") – one page (or less) of notes for each class; main points, important equations, not a comprehensive list of topics discussed in each class. The second half of the semester has less text per class, as we revisit material that's already been introduced.

Here is the syllabus:

First six weeks; posted online (Old Assignments) on Feb. 25:

Week 1: angles, scale of the solar system
Reading etc: pp. 29-31; Powers of Ten

Week 2: light, inverse square law, thermal emission distance to Sirius, temperature of the Sun and Sirius
Reading etc.: Ch. 15 first few pages; Ch. 5, secs. 1 and 2

Week 3: spectra, incl. stellar spectra, Doppler shift
Reading etc.: Ch. 5, secs. 3, 4, and 5

Week 4: gravity and orbits, Kepler's third law
Reading etc.: Ch. 4

Week 5: masses of stars, structure of stars, energy sources of stars, spectral types, main sequence
Reading etc.: Ch. 15; Ch. 14, secs. 1 & 2

Week 6: HR diagram, star clusters, evolution of stars
Reading etc.: Ch. 17

New material:

Week 7 and 8: solar system properties, formation
Reading etc.: Chs. 7 & 8

Week 9: Exoplanets
Reading etc.: Ch. 13

Week 10: Exoplanet wrap-up; telescopes and detectors
Reading etc.: Ch 6 (first five pages, skim the rest); start reading Ch. 3

Week 11: Historical development of modern astronomy
Reading etc.: Ch. 3, focusing on secs. 2 and 3; Ch. 2, sec. 4

Week 12: midterm 2 (Tue. Apr. 15); The Milky Way Galaxy
Reading etc.: Ch. 19

Week 13: More Milky Way, begin other galaxies
Reading etc.: Ch. 20, sec. 1 & 2

Week 14: the expanding Universe and the beginning of time (and space)
Reading etc.: rest of Ch. 20

Class 1 (Jan 21)

Angle-size-distance relationship

$$\theta = \frac{57.3L}{d}$$

With that constant of proportionality, the angle subtended is in degrees as long as the physical size of the object (or the separation between two objects) L and the distance d are in the same units.

Even if two stars are not the same distance from us, we can talk about the angle between them (their "angular separation").

Fist at arm's length is roughly 10 degrees.

There are 360 degrees in a full circle, and degrees are divided into 60 arc minutes, which are each divided into 60 arc seconds.

If the distance to the Moon, say, is known, then the above equation can be used to compute the Moon's size (diameter) from its apparent angular size and the distance.

Class 2 (Jan 23)

For the distance to the Sun, the A.U., we bounce radar (a pulse of light; radio waves) off of Venus when it's at its maximum elongation (angular separation from the Sun). The round trip travel time gives us the distance to Venus via:

$$v = \frac{d}{t}$$

and a little trigonometry gives us, then, the length of the A.U.

And then the measurement of the angular size of the Sun (about 0.5 degrees, nearly identical to that of the Moon) gives the size (diameter or radius) of the Sun.

Class 3 (Jan 28)

The inverse square law of light comes from the dilution of light as it expands away from a point-source, filling a greater volume with increasing distance. By considering imaginary concentric spheres, centered on the source of light, we can see that the brightness, B, for an observer a distance, d, from the light source of luminosity, L, is given by:

$$B = \frac{L}{4\pi d^2}$$

The brightness is in units of Joules/s/m^2 or Watts/m^2, where a Watt is a J/s. And the luminosity is in units of Watts, W, while the distance is in units of m.

The luminosity of the Sun can be computed from its known distance and measured brightness of B = 1360 W/m^2. That's the brightness totaled over all wavelengths.

But this equation is more often used to compute the distance to a star or other object based on an estimate of the object's luminosity, often based on similarities between the spectrum of the object and spectra of other objects, of known luminosity. For example, a star that had a spectrum very similar to the Sun could be assumed to have the same luminosity as the Sun.

The bright star Sirius can be estimated to have a luminosity 26 times higher than the Sun's. This is based on its hotter temperature and bluer color, inferred from measuring its spectrum. Given that value: $L_{sirius} = 26L_{sun}$, we can compute the distance to Sirius using the inverse square law.

Class 4 (Jan 30)

Light is both a particle (a "photon") with energy given by:

$$E = hf$$

where h is Planck's constant, h = 6.63×10^{-34} Js and the photon's frequency, f, is given in Hertz or 1/s, and a wave, governed by the equation:

$$\lambda f = c$$

where λ is the wavelength of light (in meters, but commonly expressed in nanometers, nm, with 10^9 nm per m) and c is the speed of light (c = 3.0 X 10^8 m/s).

The wavelength of light is perceived by our eyes/brains as color. The shortest wavelength we can see is about 400 nm and is blue light, while red light around 700 nm is the longest wavelength we can see. This range is referred to as the *visible* range of light (or electromagnetic radiation). Shorter wavelengths are ultraviolet light, X-rays, and gamma rays. Longer wavelengths are infrared (IR) and radio.

Thermal emission is the light given off by all warm objects, according to their temperature. It has a characteristic spectral shape (the "blackbody" spectrum or Planck function). Fig. 5.19 gives an excellent summary.

Higher temperature thermal emission sources are bluer and brighter. These two laws are given as:

$$\lambda_{max} = \frac{2.9X10^6 nmK}{T}$$

and

$$B_{surf} = \sigma T^4$$

Thermal spectra are one type of continuous spectrum. There are two other types of spectra: absorption line and emission line spectra. The criteria are: continuous = hot, opaque source; emission line = hot, transparent source; absorption line = cool transparent gas in front of a hot, opaque source.

Note that room- and body- temperature objects emit mostly infrared light. The light we see emanating from most objects around us is reflected sunlight or artificial light.

Class 5 (Feb 4)

The spectral lines are due to electrons moving between orbits – or energy levels – in atoms. Each element has its own energy level structure and thus its own unique set of emission and absorption lines.

When a source of light is moving with respect to an observer, the spectral lines are seen to shift – to shorter (bluer) wavelengths if the source is moving toward the observer and (redder) longer wavelengths if it's moving away. This Doppler effect is given by:

$$\frac{v_r}{c} = \frac{\lambda_{shift} - \lambda_{rest}}{\lambda_{rest}}$$

Only the component of the velocity directly toward or away from the observer, v_r, affects the Doppler shift. Sideways motion has no effect.

Class 6 (Feb 6)

Atoms are made of neutrons and protons, which weigh about the same, in the nucleus, at the atom's center, orbited by lighter (by a factor of about 2000) electrons. The neutrons are neutral, in terms of electric charge, while the protons are positively charged and the electrons are negatively charged.

Like charges repel while opposite charges attract.

Electrons are attracted to the positively charged nucleus, so it takes energy to move them to higher orbits (or levels). These orbits are discrete – quantized – they exist only at certain energies.

Kinetic energy and potential energy are two forms of energy. There are many kinds of potential energy – all of which have to do with the position of something (a charged particle or a massive object) with respect to the source of some force (electromagnetism, gravity, the nuclear binding force).

Other types of energy include thermal energy (which is really the kinetic energy of all the random motions associated with heat) and radiant energy (light; photons).

Class 7 (Feb 11)

Forces (pushing or pulling, either physically or with electricity, magnetism, gravity) accelerate masses, make them move faster, giving them energy. Force times the distance over which the force is applied equals energy.

The acceleration due to a force is inversely proportional to the mass of the object that's being moved:

$$a = \frac{F}{m}$$

$$F = ma$$

For gravity, the force between two masses is directed toward the other mass, and for both objects is equal to:

$$F_g = \frac{GMm}{r^2}$$

Note how these two equations taken together lead to the result that the acceleration due to gravity is independent of the mass of the object.

Circular motion involves acceleration toward the center. This centripetal acceleration is given by:

$$a_{cent} = \frac{v^2}{r}$$

and there is a centripetal force associated with this acceleration that's just given by F = ma; so it's the expression above for centripetal acceleration multiplied by the mass of the object moving in a circle.

Class 8 (Feb 13)

An orbit (a circular one, at least) is simply circular motion where the central force associated with the centripetal acceleration is due to gravity. Equating them gives:

$$v^2 = \frac{GM}{r}$$

which can be recast as Kepler's third law:

$$p^2 = \frac{4\pi^2 a^3}{GM}$$

or

$$p^2 = \frac{4\pi^2 a^3}{G(M+m)}$$

if the mass of the second object is significant.

Two orbiting objects orbit from their common center of mass, given by:

$$M_1 r_1 = m_2 r_2$$

We can weigh the Sun simply from the Earth's orbital period (one year) and size (one A.U.). We can weigh the components of a binary star system by using Kepler's third law to get the combined mass and then using the center of mass equation to get the mass of each star separately.

Class 9 (Feb 18)

Pressure holds up stars against the force of their own gravity.

For most stars, this is gas pressure, given by the ideal gas law:

$$P = nkT$$

where n is the number density (particles per m^3) and k is Boltzmann's constant, $k = 1.38 \times 10^{-23}$ J/K, and T is the temperature.

The number density is related to the mass density (kg/m^3) by:

$$\rho = mn$$

where m is the average particle mass.

Pressure is a force per unit area (Newton per square meter, N/m^2), but only pressure differences – or gradients – lead to net forces. A wall or window with strong but equal air pressure on both sides won't feel a force, but if there is a pressure difference between the two sides, there will be an associated force pushing from the high pressure side to the low pressure side.

Similarly, the high pressure deep inside a star and the much lower pressure at its surface causes an outward force of gas pressure that balances the inward force of gravity.

High pressure at the center of a star is due to both high density and high temperature.

The heat at the star's center is generated by nuclear fusion – the combining of four hydrogen nuclei into one helium nucleus with the associated release of energy. The source of that energy is nuclear potential energy, like the source of the energy released in an exothermic chemical reaction is electric potential energy. One way to characterize the production of energy by nuclear fusion is by the amount of mass that's converted to energy – the difference between the helium mass and the four hydrogen masses. Using Einstein's $E = mc^2$, we can equate that mass to an energy.

Because a star uses its own mass for fuel – using up the hydrogen it's born with – the star will eventually run out of fuel.

Class 10 (Feb 20)

Types of binary stars – can use Doppler shift if two stars are too close together in angle. Such binary systems are called spectroscopic binaries. Visual binaries are binary systems where you can see the light from both stars and over time, you can see them orbiting their common center of mass. For both types of binaries, the angle at which we see the system can affect our measurements.

Distances to stars can be reliably measured using parallax – the apparent angular shift in the location of a star as viewed from the Earth at two different points in its orbit. If we define the half-angle of that apparent parallax shift as the parallax angle, p, then it is related to the distance between us and the star very simply:

$$p = \frac{1}{d}$$

where the distance, d, is expressed in parsecs (pc) where 1 pc = 3.09×10^{16} m = 3.26 light years.

The surface temperatures of stars are measured most accurately by the relative strengths of the absorption lines present in their spectra. Stars are categorized into spectral types, in decrease temperature order: OBAFGKM.

When the spectral types of stars are plotted vs. their luminosities a correlation among a majority of stars is seen – more luminous stars are also hotter. The stars that follow this trend are called main sequence stars, and the luminosity vs. spectral type plot is called a Hertzprung-Russell diagram.

Class 11 (Feb 25)

The HR diagram is the way we organize the trends (caused by the physics of stars) among the observable properties of stars. Stars' luminosities and temperatures are plotted directly on the HR diagram, but their radii can be directly computed from these two other quantities.

Most stars are on the main sequence, a narrow strip on the HR diagram that goes from low temperature and luminosity, diagonally up to high temperature and luminosity. Bigger and more massive stars are at the top and smaller and less massive stars are at the bottom.

Mass is the determining factor for the other properties – high mass stars (up to about 100 Msun have high luminosities (and temperatures and radii) because their large gravity demands a large pressure gradient. High pressure in their cores requires high temperatures which enable high fusion rates and thus the production of a lot of energy. That energy eventually makes its way to the star's surface where it is radiated into space as luminosity.

These main sequence stars are all fusing H to He in their cores.

Binary stars and orbits: all orbits are elliptical, where a circle is a special case of an ellipse. In the solar system, the Sun is at one of the foci of each planet's elliptical orbit. The planet (or other orbiting object) moves faster when it's near the Sun (or whatever it's orbiting) and slower when farther away. An ellipse is defined by its semi-major axis, which is akin to its radius, measured the long-way across the ellipse. It's that semi-major axis, a, that appears in Kepler's third law.

Class 12 (Feb 27)

The HR diagram is the "parameter space" in which we plot and try to understand stellar evolution – how stars change as they age.

Stars have to change because they use up their fuel (turning H into He), so they eventually run out of H in their cores. This leads the star to tap into a series of different energy sources and each one leads to a different configuration (radius, luminosity, temperature) for the star. So, the star moves around in the HR diagram.

For a low-mass star like the Sun, H to He fusion not in the core but in a shell above the core, is the next fusion source, and the star is a red giant at this stage. Eventually He starts fusing to C in the core, and then the He in the core runs out and He starts fusing in a shell above the core. But that releases so much energy that the outer layers of the star are ejected into space. The star dies, leaving behind a small, dense, hot (but not generating any new energy) core – a white dwarf.

For massive stars, the process of fusing heavier and heavier elements continues up to the point that the core is composed of iron. As these later stages of fusion occur, the star moves horizontally across the HR diagram (becoming a red supergiant and then back to a blue supergiant), before it explodes as a supernova, leaving behind not a white dwarf but a neutron star or black hole.

Star clusters: all the stars in a cluster are the same age (more or less). So clusters are a good place to study stellar evolution. The key concept is the main-sequence lifetime. Stars live their main sequence lives only so long as they have H left in their cores. Massive stars start with more, but use it up faster, so they live short lives. Low mass stars live much longer lives (because they are so much less luminous). By seeing what the most massive star left on the main sequence of a cluster is, we can estimate the age of the cluster.

(after the midterm) :

Class 14 (Mar 6)

Solar system properties:

Nearly all the mass in the Solar System is in the Sun. Jupiter is 1/1000 the mass of the Sun.

The planets orbit in more-or-less the same plane and all in the same direction around the Sun. The inner four planets are smaller, denser, and made of rock and metal. Only the Earth has a substantial moon among these four planets. The outer planets are bigger, more massive, composed primarily of gas (with icy and rocky/metallic cores).

The solar system also has numerous smaller objects: Asteroids which are rocky and metallic and mostly orbit the Sun in the same plane as the planets, and are located between Mars's and Jupiter's orbits; Comets which are in a spherical distribution called the Oort cloud, beyond the most distant planets. They are icy and the ones that enter the inner solar system are on highly eccentric orbits. The third category is Kuiper belt objects, which are comets and even bigger "dwarf planets" that orbit beyond Neptune but are in the same plane as the planets (unlike objects in the Oort cloud).

Class 15 & 16 (Mar 18, 20)

The "Nebular Theory" explains the key properties of the Solar System (two kinds of planets, their location, motion, and composition and the exceptions to these rules).

Nebular Theory says that the planets (asteroids and comets) formed out of the material in the flattened disk that orbited the forming Sun. Such an orbiting disk is a natural consequence of gravitational contraction of a rotating cloud.

The temperature in this protoplanetary disk decreased with distance from the Sun. Planets formed from smaller, solid objects – planetessimals – which themselves formed from small solid objects sticking together. Since only solid objects can participate in this process, locations with more solids have bigger planets. Here the "condensation sequence" is key – in the colder regions of the disk, hydrogen compounds were in solid form (ices) so the Jovian planets are bigger and lower density because they are made of ices as well as rock and metal.

As the planets were finishing their formation, there were still a lot of planetessimals orbiting around the Solar System. This was the "era of heavy bombardment" during which collisions or near collisions between such objects caused the exceptions to the patterns we see: the backwards spin of Venus, the existence of the Earth's Moon, Uranus and its moons being tipped over.

Understanding radioactive dating and applying the half-life concept is relatively important, too.

Class 17 (Mar 25)

We begin the topic of exoplanets – planets around other stars. We'll keep the topic of binary stars in mind (a lot of the same concepts and also observational/measurement techniques) and also we'll keep the Nebular Theory of the formation of our own Solar System in mind, since it basically predicts that planetary systems will be common (since they're a natural aspects of star formation and stars are common) and it predicts their basic properties (e.g. coplanar, two types of planets).

Direct imaging of exoplanets is very difficult. They are dim and are situated very close to bright stars. A couple of such systems have been discovered and more will be in the future, but until we have better instruments, this won't be a fruitful technique for discovering exoplanets. And even if an image of an exoplanet can be taken, very little specific information about the planet can be learned from such an image, anyway.

The two most fruitful techniques are the Doppler method, which measures the Doppler shift due to the orbital reflex motion of the host star as it orbits the common center of mass. The inclination angle of the orbit (edge-on vs. face-on) leads to ambiguities in interpreting data from such systems. But in principle, the orbital period can be directly measured from the periodic variation of the star's Doppler shift. And the star's velocity is proportional to the planet's mass, so the planet's mass can be measured (if the orbit's inclination is known) and the properties of the host star can be estimated. The key equations are:

$$v_p = \frac{2\pi a_p}{p_p}$$

$$M_p = \frac{M_s v_s P_p}{2\pi a_p}$$

Note that the center of mass equation and Kepler's third law are steps/concepts on the way to deriving this last equation.

Class 18 (Mar 27)

The transit method is the second very useful method of detecting and characterizing exoplanets. This involves measuring the decrease in a star's observed brightness when the exoplanet passes in front of it. The key equation, that gives the exoplanet's size, is:

fraction of light blocked = $(R_p/R_s)^2$

This technique has the added benefit that detecting a transit guarantees that you're seeing the exoplanet's orbit edge-on, which enables you to better-use the Doppler technique.

A transiting exoplanet can have its atmosphere studied via spectroscopy, as the starlight shines through the atmosphere during times when the planet is transiting.

Class 19 (Apr 1)

Results of exoplanet searches thus far have yielded about a thousand exoplanets, all discovered in the last twenty years. Roughly equal numbers have been discovered by the Doppler method and by the transit method. Once discovered by the transit method, the Doppler method can also be used to give both the mass and the radius of the planet. In combination, these give the planet's average density, which can provide clues about its composition.

Many exoplanets discovered so far are Jovian-like, but close to their host stars – they are "hot Jupiters." It seems likely that they formed farther from their host stars, beyond the "snow line" in their protoplanetary disks and later moved (migrated) inward.

We started the topic of telescopes and detectors at the end of this class. Telescopes, like cameras, collect light from an area that's potentially bigger than your eye, enabling you to see dim light sources, and then focuses that light into a clear image some distance behind the lens. The basic physics of lenses involves refraction, the bending of light as it passes from one medium to another.

Class 20 (Apr 3)

We can quantify the ability of a large telescope to collect light from a dim source via

$$\text{telescope collecting area} = \pi(D/2)^2$$

where D is the diameter of the telescope lens or mirror. Note that this is just the formula for the area of a circle. Note also that we refer generically to the mirror, lens, or just the light-accepting opening of an optical system (telescope, camera, human eye) as the "aperture."

The second thing a telescope does, in addition to sensing light from dim sources, is to form clear images. This ability is characterized by the spatial resolution of an image – the minimum angle between two light sources that can be measured (and so enables you to tell that there are two sources, not one). A key fact to know is that the Earth's atmosphere limits this resolution to typically 1 arc second. This is the main reason we put telescopes into space.

The other reason is that the Earth's atmosphere blocks most electromagnetic radiation (only optical light and radio waves make it through easily). So to observe X-rays, infrared light, ultraviolet light, etc. telescopes must be in space.

Finally, we saw how a camera, in conjunction with a telescope can further enhance our ability to see dim objects because a camera shutter can be kept open for a long time (whereas the naked eye has an effective exposure time of 1/30 to 1/20 of a second) and because modern electronic detectors have excellent sensitivity (i.e. they detect close to 100% of the photons that strike them whereas the human eye detects only a few percent). Putting all this together we have:

signal = brightness*exposure time*collecting area*sensitivity

Class 21 (Apr 8)

Historical development of modern astronomy: based on observing patterns in the sky. (This would be a good place to review your understanding of the cause of the seasons – see the lab where you explored this concept.)

We focused first on the overall motion of the sky caused by the Earth's rotation and then added in the additional motion due to the Earth's orbit, the Moon's orbit, and, importantly, the orbits of the planets. For the latter, we focused on retrograde motion.

We compared the Greek (Ptolemaic) and modern (Copernican) models of the Solar System and saw how the former can explain retrograde motion only in a very contrived way, using epicycles, whereas the Copernican system explains it naturally, when the Earth passes or is passed by a planet in its orbit.

Class 22 (Apr 10)

Concepts from the historical development of astronomy: Greek ideas about motion and about atomism; Copernicus's model (including its deficiencies, like its adherence to circular orbits); Tycho's precise (but naked-eye) observaitons of planetary positions (and also his observation of a supernova, which violated Greek dogma about the perfection of the heavens). Kepler's synthesis of Tycho's data and his three laws; and Galileo's telescopic observations (including the Milky Way being made up of numerous individual stars, Jupiter's moons, and Venus's phases).

(After the second midterm:)

Class 24 (Apr 17)

The Milky Way and its basic properties. How we know the size and shape of the Milky Way including where its center is (via the distribution of globular clusters). A key point is the confusing role played by interstellar dust's obscuration of starlight.

Class 25 (Apr 22)

Disk vs. halo properties: heavy element abundances, spatial distribution, nature of orbits, presence of gas and dust.

Using Kepler's third law to weigh the galaxy:

$$M_{enclosed} = \frac{rv^2}{G}$$

The star-gas-star cycle: stars are formed from interstellar gas, they turn light elements to heavy ones in their cores as a by-product of nuclear fusion energy production (while their surfaces show their original chemical makeup), and then when stars die they deposit some fraction of their material – enriched in heavy elements – back into the interstellar medium.

The central massive black hole as revealed by the orbits of nearby stars (and the use, again, of Kepler's third law).

The overall picture of the formation of the Milky Way involves the collapse of a huge cloud of gas. Early on, it was spherical, and stars formed at that stage became halo stars. Later, a flattened disk of material formed, and stars formed after that point are disk stars.

Class 26 (Apr 24)

Other galaxies include spirals like the Milky Way, ellipticals (which are kind of like the halo of the Milky Way, but without any disk component), and irregular galaxies. Star formation, the presence of gas, and of young stars all go together.

We discussed spiral structure as a wave phenomenon that propagates through the galaxy, compressing gas and forming stars. Spiral arms are bright because that's where the star formation is, not so much because there are *more* stars there.

Galaxies tend to be found in big clusters, often with a giant elliptical galaxy at their center. These clusters are filled with hot, X-ray emitting gas, stripped out of the component galaxies.

Even outside of clusters, galaxies can interact with each other. Galaxies, including the Milky Way, are constantly being built up by the cannibalization of smaller, nearby galaxies.

Class 27 (Apr 29)

The universe is expanding, uniformly (i.e. the same amount of expansion everywhere). This was discovered in the 1920s by Edwin Hubble who showed that galaxies contain lots of stars and that they are very far away and, more specifically, that there is a correlation between the distance to a galaxy and its speed moving away from us:

$$v = H_o d$$

The constant of proportionality is called the Hubble Constant and its best-determined observational value is:

H_o = 22 km/s/Mly

The velocities of galaxies are easily measured from their Doppler shifts, which are basically always red shifts, since galaxies are all moving away from each other.

redshift, $z = \frac{v}{c} = \frac{\lambda_{observed} - \lambda_{rest}}{\lambda_{rest}}$

$$1 + z = \frac{\lambda_{observed}}{\lambda_{rest}}$$

Class 28 (May 1)

Distances to galaxies are harder to determine. Most techniques for doing this involve the inverse square law applied to luminous objects whose luminosity can be assumed or determined. Good examples include Cepheid variable stars that show regular variations in brightness, the period of which is directly proportional to their luminosity (so, observe the variability period, assume the luminosity from that, use the inverse square law to compute the distance from that and the measured brightness).

Recently, a subset of supernova explosions – referred to as White Dwarf Supernovae – have been shown to have relatively uniform peak luminosities and so they are now used as standard candles. Their very high luminosities enable us to see them at huge distances.

An associated concept here is the lookback time: we see distant objects as they were in the past.

And we can think of the cosmological redshift as being due to the expansion of the universe – of space – as the light from distant galaxies is traveling toward us. Similarly, we can use that exact same redshift equation to see how much closer objects like galaxies were to each other at some point in the past.

Finally, once the Hubble law was established, and the Hubble constant – the rate of expansion – was measured, it became possible to estimate the age of the universe simply by asking how long would the expansion of the universe have to go on in order to give the separations between galaxies that we see today:

age = $1/H_o$

Using the best-determined value of the Hubble constant this gives an age of the universe that's 13.6 billion years, which seems to be consistent with our knowledge of the age of the oldest stars (the very oldest stars are slightly younger than the universe as a while, which is what you'd expect).