"Observing Evolution"

This paper presents an observing list of objects, within the grasp of small amateur telescopes, which illustrate major steps in the evolution of the Universe. There are descriptions of the chosen objects and some of the physical processes associated with them. I have not personally observed all these objects and look forward to pursuing them in the coming year. I would be very happy to hear from other interested members and share observations of the objects.

The limits of a small telescope

According to Lenny Abbey FRAS (see *The Compleat [sic] Amateur Astronomer* website), the most widely used equation for finding the limiting magnitude for a given instrument is :

$$M = 6.5 - 5\log(d) + 5\log(D)$$

where, *M = limiting magnitude*
d = pupil diameter of dark-adapted eye
D = aperture of the instrument

D & d are in inches, 6.5 is the assumed naked eye limiting magnitude. The average pupil of a (young) eye will open to about 7.5mm (0.3 inches), so this equation can be simplified to :

$$M = 9.1 + 5\log(D).$$

Using this formula, the limiting magnitude for a range of common telescope apertures is presented in the following table. I have added a further column to the table showing the faintest magnitudes that may be easily observed (according to Newton & Teece [1]); the value in italics is my estimate based upon results from my own 6" reflector.

Aperture / inches	Theoretical Limiting magnitude	Faintest magnitude easily observed
4	12.1	8
4.5	12.4	-
6	13	*9.5*
8	13.6	10
10	14.1	-
12	14.5	-

Table 1 : Limiting magnitudes of small telescopes

If we assume that the 'actual' limiting magnitude for an average small instrument is about 3 magnitudes less than the theoretical value, and that the apertures of these instruments fall in the range of 4" to 10", I estimate an average actual limiting magnitude of about 10.

[1] see Newton J. & Teece P. (1995) *The Guide to Amateur Astronomy*, Cambridge, Cambridge University Press, p. 33

And so it begins …

The Big Bang has been estimated to have occurred about 13.7 billion years ago [2]. For the following 300,000 years the Universe was in the opaque state of an ionised plasma. No telescope can ever probe that stage of the Universe' evolution. By the end of that period the Universe had expanded and cooled enough (to around 10^4 K) for the state of matter to change to a neutral gas (of mostly hydrogen and helium atoms). Photons which had previously been interacting strongly with charged particles in the plasma became *decoupled* from them. These photons could then travel freely throughout the Universe and the 'epoch of observation' had begun [3]. These photons have been detected as the *Cosmic Microwave Background Radiation* (CMBR - see Figure 1) [4] but are well beyond the capabilities of amateur instrumentation.

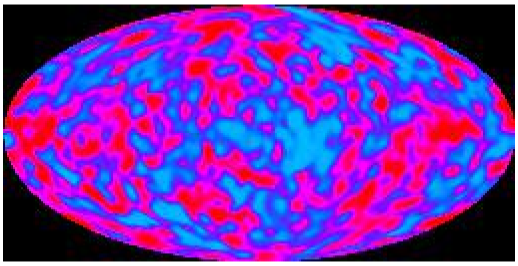


Figure 1 : Anisotropy in the cosmic background radiation, revealed by COBE [5]

Small variations in the intensity of the CMBR are believed to represent "lumpiness" in the very early Universe. These minute fluctuations in the distribution of matter in the very early Universe were the seeds for later epochs of galaxy formation.

The early Universe after 'decoupling'

Galaxies contain stars, dust and gas (both incorporated into planets and existing freely in the inter-stellar medium [ISM]). It is interesting to consider the environments needed to cause sufficient primordial gas to aggregate so that stars may form, forge heavier elements and then eject these fusion products into the ISM (via supernovae and stellar 'winds') so they can be recycled into later generations of stars and planets.

Computer modelling has shown how the density enhancements revealed in the CMBR gravitationally attracted further matter over time. These filaments of matter and the voids between them produced a structure termed the *cosmic web*. This web is now being mapped by projects like the *Two Degree Field Galactic Redshift Survey (2dFGRS)*. Many examples of the simulations can be found on the internet and cosmology books [6].

[2] For example, Freedman W.L. & Turner S.T. (2003) 'Cosmology in the New Millenium', *Sky & Telescope*, October 2003, pp. 30-41

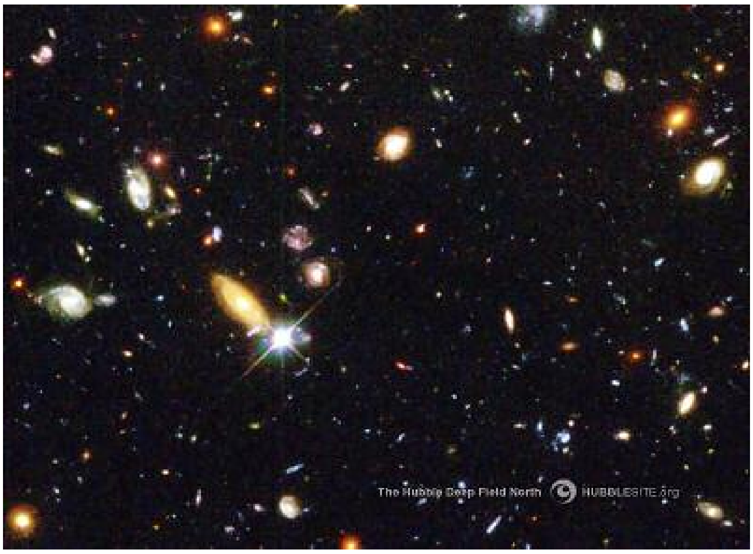
[3] See for example, Open University S281 Course Team (1994) *Cosmology*, Milton Keynes, The Open University, pp. 30-31

[4] For examples see the results from COBE (Mather & Boslough's *The Very First Light* is a good read) and the Wilkinson Microwave Anisotropy Probe (WMAP)

[5] This image was obtained from the NASA LAMBDA website.

[6] See Rees M. (2001) *Our Cosmic Habitat*, London, Weidenfeld & Nicolson, figure 5.3, for example

After the *decoupling* event the first big epoch of galaxy formation occurred between 300,000 and 1 billion years after the Big Bang [7]. However, objects of this age reside at redshifts of between about 10 to 4, way beyond the capabilities of amateur 'scopes !. To explain this let us consider the *Hubble Deep Field* image [8] (Figure 2). This resolved objects down to magnitude 30, much fainter than images from other redshift surveys and below the light-grasp of even the Keck telescopes for spectroscopy. Since the brightness of observed objects changes at the rate of $2.512^{\mathbf{m}}$ (where m is the difference in magnitude between two objects - see footnote [9]), it is clear that the magnitude 30 objects observed in the HDF are approximately 100 million times too faint to be observed in a small telescope.



<u>Figure 2 : Hubble Deep Field North [10]</u>

The first objects within the grasp of a small amateur telescope

It is not clear whether the formation of stars preceded that of galaxies, or visa versa. However, it is accepted that stars form through the gravitational collapse of matter within cold molecular clouds [11]. Although we cannot observe the first of these structures in the cosmos, we can find corresponding equivalents within the grasp of small telescopes.

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[7] Eicher D.J. (1999) 'Galactic Genesis', *Astronomy*, May 1999, pp. 38-47

[8] Hubble Deep Field (HDF) - 10 day exposure of the sky near the Plough using the Hubble Space Telescope, taken in 1995. Much information about this image can be found on the internet, as well as the following references : Hook R. (1996) 'A window into the young universe', *Astronomy Now,* June 1996, pp. 21-24 … Dickinson, M. (1997) 'A multitude of faint galaxies', *Astronomy Now*, September 1997, pp. 47-49 … Wilkie T. & Rosselli M. (1998) *Visions of Heaven : The mysteries of the universe revealed by the Hubble Space Telescope*, London, Hodder & Stoughton

[9] In 1865 N.R. Pogson proposed that a 5 magnitude difference in brightness equated exactly to a brightness ratio of 100:1. Two stars differing by one magnitude hence differ in brightness by a ratio of $\sqrt[5]{100}$: 1 = 2.512 :1 - this is *Pogson's ratio*. Stars whose magnitudes differ by *m* have a brightness ratio of $(2.512)^m$: 1. - see Illingworth V. (ed) (1994) *Collins Dictionary of Astronomy*, Glasgow, HarperCollins, for a fuller description.

[10] This image was obtained from the HubbleSite Newsdesk on the internet, ref STScI-PRC1996-01a. Credit: Robert Williams and the Hubble Deep Field Team (STScI) and NASA

One example of such a cloud, and the first object on our observing list, is *Barnard 33*, the “Horsehead Nebula” (IC 434) near zeta (ζ) Orionis. This is a popular target for astro-imaging, however Levy says “… it can be quite difficult to see, usually requiring a dark sky and at least an 8-inch telescope” [12]. This nebula is a dark cloud seen against a bright emission (HII) nebula. Should the right circumstances arise in the future, it is one site where star formation could occur.

The second object in this category is the dark cloud *Barnard 68* [13] , classified as a Bok globule. These are small clouds of gas (containing 20 to 200 solar masses of matter) thought to be in the late stage of contraction. IRAS [14] detected some protostars in Bok globules. B68 contains about one solar mass of material.

The final example in this category is an old favourite, *M42* in Orion. The Orion Nebula is the “nearest significant giant molecular cloud complex” [15]. Stars have recently formed in this nebula and certain “infrared brightspots” mark the sites of Young Stellar Objects (YSO’s - stars in the process of formation). The stars of the Trapezium form a very young open cluster of hot objects (O and B spectral classes); their intense radiation has “eroded” the surrounding nebula and revealed them to us.

A star for every occasion

Stars form in varying environments; their ‘birth clouds’ contain differing masses of gases and dust. This distribution is driven by the original seeding of matter across the Universe by the Big Bang, the gravitational attraction of further matter and its concentration into molecular clouds, and its later modification by stellar evolution (winds and supernovae). A discussion of the track of protostars across the H-R diagram [16] is outside the scope of this paper. However, this evolutionary period includes a variety of interesting objects including those exhibiting bipolar outflow (revealed in radio observations of IRS5 in dense cloud L1551, near The Trapezium, for example) and T-Tauri variables.

Stars are categorised, according to the temperatures of their photospheres, into *spectral classes* [17] :

Spectral class	Temperature / K	Colour	Notes

[11] See Snow T.P. & Brownsberger K.R. (1997) *Universe - Origins and Evolution*, London, Wadsworth Publishing Company, pp. 285-290 or Open University S281 Course Team (1994) *The Stars and the Interstellar Medium*, Milton Keynes, The Open University, pp. 94-104, for example

[12] Levy, D. (1995) *Skywatching - The Ultimate Guide to the Universe*, London, Collins, p. 195

[13] See Croswell K. (2003) ‘The black cloud’, *Astronomy*, December 2003, p. 51

[14] **I**nfra**R**red **A**stronomy **S**atellite - operated during 1983

[15] see Snow & Brownsberger (listed above) p. 281

[16] The Hertzsprung-Russell diagram is the most important diagram in stellar astronomy. It illustrates the relationship between luminosity and photospheric temperature and shows the evolutionary track of stars.

[17] Using elements whose abundance does not vary much from star to star, we can measure the strength of spectral absorption lines. In “cool” stars these lines from ionised atoms will be weak.

O	40,000	Blue	
B	17,000		
A	9,000		
F	7,000		
G	5,500		The Sun is a G2 star
K	4,500		
M	3,000	Red	
C			Red Giants with carbon-based molecules in their surface layers
S			Red Giants with zirconium oxide (ZrO) in their surface layers

Table 2 : Spectral classes

On the main sequence, the more massive a star is the more rapidly nuclear reactions proceed in its core and the hotter it will be. However, more massive stars use their fuel at faster rates and hence have shorter lifetimes. The lifetime of a star can be estimated as $10^{10}(M / M_{sun})^{-3}$ years, where M is the mass of the star and M_{sun} is the mass of the Sun.

At the end of their lives very low mass stars (between 0.1 M_{sun} and 0.5 M_{sun}) start to evolve towards the red giant phase. However, since they possess insufficient mass for helium burning to begin, they cool rapidly.

Low mass stars (< 8 M_{sun}) evolve through the red giant stage before becoming white dwarfs. According to their mass, these stars produce intermediate nuclides through carbon burning and s-process reactions driven by neutrons released by other reactions. At the end of the red giant phase many of them become variable due to expansion and contraction of their outer layers [18]. Perhaps during this variable phase, or maybe through helium shell flashes during the giant phase and stellar winds, such stars eject sufficient material (forming planetary nebulae) to bring their mass down to the 1.4 M_{sun} *Chandrasekhar limit.* Red Giants may exhibit an excess of carbon vs. oxygen in their outer layers (as compared to normal stars where carbon is constrained within a shell around the core), these are the *carbon stars* (C stars). The carbon excess is due to convection currents pushing carbon towards the exterior of the star [19]. An example C-star is *W Orionis*.

White dwarfs actually exhibit a range of colours from white through red, before ending as cold, *black dwarfs*. Spectroscopic classification of them by spectral type is inadequate because of the variety of their surface compositions. A separate classification scheme is used[20] and will not be discussed further. A

[18] This includes the Cepheid variables and RR Lyrae stars.
[19] see English N. (2002) 'The Carbon Drenched Universe', *Astronomy Now*, April 2002, pp. 50 - 53, for example.
[20] This is E. Sion's scheme, introduced in 1983.

white dwarf at the Chandrasekhar limit may also undergo a Type I supernova if it gains mass, from a close binary companion perhaps.

At the end high-mass end of the scale, (8 to 50 M_{sun}) stars evolve into supergiants after leaving the main sequence. Increasingly heavy nuclides are produced until a shell of iron (A = 56) has built around the core. Rather than releasing energy, both the fusion and fission of iron consume it. Once the reactions that produce iron have finished the cores of these heavy stars contract. This collapse may be halted by neutron degeneracy pressure; in which case a shock wave rebounds off the core and travels through the overlying material which is still falling inwards - the result is a *supernova*. A Type I supernova occurs when hydrogen is deficient, perhaps because the hydrogen envelope has been shed through stellar winds (this is the case for stars in the 30 - 40 M_{sun} class). Type II supernovae exhibit hydrogen spectral lines. It is r-process reactions in supernovae which forge the elements heavier than iron. Those stars which are too massive for their supernova remnants to be supported by neutron degeneracy pressure, or which acquire mass after the explosion, will collapse to form *black holes*. Table 3 gives an observing list for stars of each major spectral type.

Name / Catalogue No.	**RA / dec (2000 epoch)**	**Spectral class**	**Visual magnitude**
Mintaka / δ Orionis Bright giant	5h 32 m / -0° 18’	O	2.23
Rigel / β Orionis Bright supergiant	5h 14 m / 8° 12’	B	0.12
Sirius /α Canis Majoris Main sequence (A star) White Dwarf (B star)	6h 45 m / -16° 43’	A	-1.46
Procyon / α Canis Minoris Sub-giant / main sequence	7h 39m / 5° 13’	F	0.38
Capella A / α Aurigae Yellow Giant	5h 16 m / 46° 00’	G	0.08
Arcturus / α Boötis Red Giant	14h 15 m / 19° 11’	K	-0.04
Betelgeuse / α Orionis Red Supergiant	5h 55m / 7° 24 ‘	M	0.0 to 0.9 [variable]
W Orionis Carbon star - Red Giant	5h 05m / 1° 10’	C	8.2 - 12.4 [variable]

Table 3 : Observation targets for stars of each major spectral class [21]

At late stages of their lives many giant stars become pulsating variables. It is thought that this represents a period of instability in the structure of their outer layers, which alternately compress and expand. Such stars cluster together in the *instability strip* area of the H-R diagram. They include Cepheid variables, RR

[21] Objects selected from Moore P. (1996) *Brilliant Stars*, London, Cassell Publishers Limited. Magnitudes taken from this book, co-ordinates taken from HNSky v 2.1.2c by Han Kleijn.

Lyrae type stars and Mira type stars. Thus we can add *RR Lyrae* (19h 25m RA / 42° 47' Dec), *delta (δ) Cephei* (22h 29m RA / 58° 25' Dec) and *Mira* (2h 19m RA / -2° 58' Dec) to the observing list.

Moving towards the final chapter of stellar evolution, *Sirius B* is an example of a white dwarf star. According to Patrick Moore [6] this object is difficult to see due to its close proximity to the Sirius A. At the higher mass end we find planetary nebulae and supernova remnants. *M57* (the Ring Nebula) is a fine example of a planetary nebula and *M1* (the Crab Nebula) is a famous supernova remnant which harbours a pulsar [22] at its core (and is the only such object in Messier's catalogue).

It is not possible to "see" a black hole with a small amateur telescope. However, we can look in the direction of the nearest suspect and wonder at what might be happening there. Studies of the radial motion of stars near the centre of the Milky Way suggest that our Galaxy harbours a massive black hole. One can gaze towards it through *Baade's Window* (18h 3m RA / -30° 1' Dec, near NGC6522 in Sagittarius [23]).

Galaxies

The Hubble Space Telescope (HST) has shown in dramatic detail the immense variety of structures that galaxies may exhibit. Back in 1925 Edwin Hubble introduced a galaxy classification scheme which is still widely used today (the Hubble 'Tuning Fork' diagram). In this scheme a galaxy may be classified as an 'elliptical', 'spiral', 'barred spiral' or 'irregular'. Elliptical galaxies do not have spiral arms and range from type E_0 (nearly circular) to E_7 (highly elliptical). Spiral galaxies have spiral arms which join directly to the nuclear bulge (no bar present between the arms and the bulge); according to how tightly the arms wind around the bulge they are categorised between types Sa (tight) and Sc (open). Barred-spirals have a central bar which links the arms to the nuclear bulge; again, according to how tightly the arms wind around the bulge they are categorised between types SBa (tight) and SBc (open). There is an intermediate S_0 type which resemble the spirals in shape but lack arms. Irregular galaxies are those which cannot be assigned to the other categories. Although astronomers do not generally believe that galaxies evolve from one type to another across the 'tuning fork' diagram, the HST has returned images suggesting that mergers of spiral galaxies may lead to the formation of ellipticals or S0 types [24].

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[22] A pulsar is probably a rotating neutron star which channels a flow of electrons within an intense magnetic field. These rapidly moving electrons emit synchrotron radiation and are especially concentrated near the magnetic poles.

[23] For example see http://www.ast.cam.ac.uk/AAO/images/captions/aat093.html, http://www.bpcs.com/lcas/Articles/baade.html and http://www.astrosurf.com/jwisn/ngc6522.htm

[24] For example NGC 4038 & NGC 4039 in Corvus - see 'Fireworks in the Antennae', Astronews (Feb 1998), *Astronomy*, February 1998, p. 24 or Wilkie T. & Rosselli M. (1998) *Visions of Heaven: The Mysteries of the Universe Revealed by the Hubble Space Telescope*, London, Hodder & Stoughton …. also see Snow T.P. & Brownsberger K.R. (1997) *Universe - Origins and Evolution*, London, Wadsworth Publishing Company, pp. 459-461

An observing list for each major galaxy type given in table 4. At my home in Ramsgate (latitude 51° 19' N) it is not possible to see an object with a declination of 38° 41' South or less [25] and close to it they will be hard to see. I have marked those objects which will require a southerly holiday with an asterisk !

Galaxy Catalogue Number	**Galaxy Type**	**Magnitude**	**RA / Dec (Epoch 2000)**	**Constellation**
M89 NGC 185	E_0	10.5 9.2	12h 35m / 12° 33' 0h 39m / 48° 20'	Coma Berenices Cassiopeia
M60 M84	E_1	8.8 9.3	12h 43m / 11° 33' 12h 25m / 12° 53'	Virgo Virgo
M32	E_2	8.2	0h 42m / 40° 52'	Andromeda
M59 NGC 4406	E_3	9.8 9.2	12h 42m / 11° 39' 12h 26m / 12° 57'	Virgo Virgo
M49	E_4	8.4	12h 30m / 8° 0'	Virgo
NGC 2768	E_5	10.0	9h 11m / 60° 2'	Ursa Major
M110	E_6	8.0	0h 40m / 41° 41'	Andromeda
NGC 3384	E_7	10.0	10h 48m / 12° 38'	Leo
NGC 5102 * NGC 5128 * NGC 1553 *	S_0	9.7 7.0 9.5	13h 22m / -36° 38' 13h 25m / -43° 01' 4h 16m / -55° 47'	Centaurus Centaurus Centaurus
M64	Sa	8.5	12h 56m / 21° 41'	Coma Berenices
M81 M31	Sb	6.9 3.9	9h 55m / 69° 04' 0h 42m / 41° 16'	Ursa Major Andromeda
M33 M51	Sc	5.7 8.4	1h 34m / 30° 39' 13h 30m / 47° 11'	Triangulum Canes Venatici
NGC 1808 * NGC 1433 *	SBa	9.9 10.0	5h 7m / -37° 31' 3h 42m / -47° 13'	Columba Horologium
M95 M109	SBb	9.7 9.8	10h 44m / 11° 42' 11h 57m / 53° 22'	Leo Ursa Major
NGC 6221 *	SBc	11.0	16h 53m / -59° 13'	Ara
M82	Irr	8.4	9h 56m / 69° 41'	Ursa Major

Table 4 : Galaxies of each type in the Hubble Classification

The oldest stars in a galaxy are often found in globular clusters. Globular clusters are typically found in galactic halos, moving in highly eccentric elliptical orbits about galactic centre. The stars in these clusters are low-metal objects with similar chemical compositions. A variety of easily observable globular clusters can be found in Messier's catalogue including *M2* in Aquarius, *M3* in Canes Venatici and *M4* in Scorpius.

By contrast to the globular clusters, the stars in open clusters (aka galactic clusters) tend to be young objects. These systems are found in or close to the plane of the galaxy, they are more loosely gravitationally bound than globular clusters and modelling suggests they may not survive more than a few

[25] This is determined by the colatitude of the observing site, which is given by (90° - observing site latitude) - see Scagell R. (1998) 'Making the Position Clear', *Astronomy Now*, Aug 1998, pp. 54 - 56 for example

orbits about the galaxy. It is possible that star formation is still happening in some of these systems. Examples of open clusters include *M67* in Cancer, *M103* in Cassiopeia and *M29* in Cygnus.

There is evidence that star formation in clusters is the norm for certain types, including the hottest **O** and **B** types. These stars are commonly found together in loosely bound systems called *OB Associations*. Such high-mass objects have short lifetimes and are strong indicators of sites of star formation; the stars of the Trapezium are O and B types for example.

Stars are of course found throughout a galaxy and are not confined to clusters. By using the inferred age of stars we can group them into *populations*. Halo Population II stars are the oldest (an example is the type II Cepheid *W Virginis*). Continuing contraction of the galaxy's gas produces an extended disc in which the Intermediate Population II and Disc Populations of stars form (this includes *RR Lyrae* for example). The youngest stars tend to be concentrated in the plane of the galaxy's disc (in the spiral arms). They include the Older Population I objects (like the *Sun*) and Extreme Population I stars (the youngest, like *T-Tauri* for example).

Returning to a theme from the beginning of this paper, a galaxy's stars form from the gravitational collapse of clouds of gas. Some stars form alone, others in binary (or higher) systems and clusters (it is possible that parts of a cloud may collapse at different rates and hence proceed to form stars at differing rates). Where stars form together there is a good chance of them being gravitationally bound and becoming *physical doubles*. There are many attractive double-stars in the sky including the objects selected in table 5.

Object	**RA / Dec (Epoch 2000)**	**Visual magnitudes / star a - star b**	**Position angle**	**Separation**
55 Piscium	0h 40m / 21° 26’	5.4 - 8.7	194°	6.6 “
γ Andromedae	2h 4m / 42° 19’	2.3 - 4.8	63°	9.8 “
Mizar / ζ Ursae Majoris	13h 24m / 54° 55’	2.3 - 4.0	152°	14.4”
66 Ceti	2h 12m / -2° 23’	5.7 - 7.7	234°	16.5”

Table 5 : Selected physical double stars

It is also possible to find entire *galaxies* which are gravitationally bound and orbiting a common centre of mass. Such objects are known as *binary galaxies*, an example is the Magellanic Clouds which orbit each other whilst travelling around our galaxy (they are unfortunately not visible from the UK).

Galaxies are not quiet, slow-moving homes for stars. In many cases new stars are forming whilst old ones may expire quietly or go out in a supernova “blaze of glory”. Galaxies exhibiting massive bursts of star formation are termed *starburst galaxies* and include *M82* in Ursa Major (the BAA describes this as "the best irregular galaxy of the Northern hemisphere" [26]). Other interesting objects include the "active galaxies" : this category includes Seyfert galaxies, quasars, BL-Lac objects and radio galaxies. These are all thought to represent the 'active galactic nucleus' (AGN) of very similar objects, the observed differences being line of sight effects. The idea is that each is powered by an accreting super-massive black hole (the *engine*) surrounded by a torus of gas and dust. The varying types observed all depend on angle of observation between the Earth and the engine of the AGN [27].

Seyfert galaxies have exceptionally bright nuclei, emitting most of their output in the infrared, but also being active at X-ray and ultraviolet wavelengths. Their energy output is variable, sometimes on the scale of months. Type 1 Seyferts exhibit both broad Balmer line hydrogen emission in their spectra, as well as narrow lines of ionised metals. Type 2 Seyferts only exhibit narrow lines. An example of a Seyfert galaxy within the grasp of a small telescope is the magnitude 8.6 object *M87* in Virgo (12h 30mRA 12° 23' Dec [epoch 2000], class E1). We can also consider NGC4395 (12h 25m RA 33° 33' Dec, magnitude 10.2 - described by Keel as "a very disorganised spiral galaxy", see footnotes) in Canes Venatici which harbours a Type 1 Seyfert AGN.

Quasars ("quasi-stellar" objects) are seen as point sources in the optical and radio wavebands. They exhibit highly redshifted emission spectra for hydrogen and other elements found in astronomical sources. They show excess emission in various wavelengths (including the infrared) and many have broad emission lines and variable output. There are no known quasars anywhere near the Local Group of galaxies [28 and 29].

BL-Lac objects appear as point sources but do not exhibit emission lines in their spectra. On the basis of the redshift of spectral lines in the galaxies in which they are believed to lie, BL-Lacs are believed to lie at great distances (like quasars). They show rapid variability of their output. BL Lacertae itself is "too faint to be of interest to the user of a small telescope" [30].

Radio galaxies are always elliptical galaxies which exhibit enormous lobes of radio emission (normally in pairs) well beyond the extent of their visible parent galaxies. The galactic centres have a point-like radio

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[26] See British Astronomical Association (1996) *Deep Sky Section Handbook No. 2 : A Messier Catalogue*, London, British Astronomical Association, p. 57

[27] For example, see Open University S281 Course Team (1994) *Galaxies*, Milton Keynes, The Open University, pp. 108-114 and Snow T.P. & Brownsberger K.R. (1997) *Universe - Origins and Evolution*, London, Wadsworth Publishing Company, chapter 19, and an excellent article in *Astronomy* - Keel W. (2003) 'Quasars Explained', *Astronomy*, February 2003, pp. 34-41

[28] Moore P. (1994) *Philip's Atlas of the Universe*, London, Philips, p. 186

[29] There was a good recent article on the Local Group : Villard R. (2003) 'Order out of Chaos', *Astronomy*, November 2003, pp. 38 - 43

nucleus coincident with the visible nucleus. *M87*is a radio galaxy and has the designation 3C 274 in the Cambridge Catalogue of radio sources [31]

The home straight …

We are nearing the end of this journey across space and time. Having formed matter, clouds, stars and galaxies, we are left searching for our own home.

The standard theory of planet formation within our solar system asserts that the material which comprises the planets was 'left over' from the processes which formed the Sun. As the cloud which would give birth to the Sun collapsed, the left over material was spun into a disc of gas and dust called the *solar nebula*. In general it is believed that the planets started to form once the solar nebula had passed the peak temperature generated by the formation of the proto-Sun. Substances condensed out of the cooling nebula according to an interplay between their stability and the rate at which they could form at the prevailing temperatures. The most volatile minerals and compounds condensed at the lowest temperatures.

The idea is that dust grains in the solar nebula stuck together to form pebble-sized objects. These then collided to form larger rocks, boulders and ultimately planetesimals (the basic planetary building blocks). When enough matter had aggregated to form the planetesimals they started to gravitationally dominate their surroundings, attracting increasing amounts of matter. The largest planetesimals then 'slugged it out', until only the bodies that constitute the planets were left. That was largely the end of the story for the 'terrestrial planets'. However, in the region on the gas giants the solar nebula was cool enough for volatiles to condense as solids and enable larger planetesimal formation. These more massive cores were able to sweep up much more gas from the nebula and retain it in their atmospheres. Mars and Jupiter are easy objects to observe as examples of the terrestrial planets and gas giants.

The basic process of agglomeration of dust grains in the solar nebula was beautifully tested on board the Space Shuttle Discovery in October 1998 via the CODAG (*Cosmic Dust Aggregation*) [32] experiment. In this experiment micron-sized SiO_2 spheres (silica is a basic building block of non-biogenetic rocks) were dispersed into a low gas pressure atmosphere, where they rapidly agglomerated into open structures.

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[30] Moore P. (1994) *Philip's Atlas of the Universe*, London, Philips, p. 207

[31] There is a good description of M87 in *Burnham's Celestial Handbook Vol 3*.

[32] See Blum J. *et al* (2000) 'Growth and Form of Planetary Seedlings : Results from a Microgravity Aggregation Experiment', Physical Review Letters, Vol 85 No 12, pp. 2426 - 2429

Of course, if this model of planet formation is correct one would expect planets to be common features of the Universe. In recent years professional astronomers have discovered around 115 so-called ‘exo-planets’ [33] including the now famous systems around Vega, Beta Pictoris (Southern sky) and Tau Boötis.

Name / Catalogue No.	RA / dec (2000 epoch)	Visual magnitude
Vega	18h 37m / 38° 47’	0
β Pictoris	5h 47m / -51° 04’	3.9
τ Boötis	13h 47m / 17° 27’	4.5

Table 6 : Stars with planetary systems

Finally, one may wish to observe the Moon and wonder about its origin; there are a number of possible scenarios [34]:

1. It may have originated elsewhere and been gravitationally captured by the Earth
2. A passing body may have been disintegrated upon capture and then re-accreted
3. The Earth may have split and ejected the Moon
4. The Earth and Moon may have formed *in situ* as a binary system
5. A giant impact on the proto-Earth may have ejected debris into orbit, which then coalesced into the Moon

Comparing the crust and mantle of the Earth and Moon reveals the Moon to be depleted in volatile substances (and enriched in refractory ones). This tends to discount options 3 and 4 wherein the compositions would be very similar. Analysis of meteor compositions has shown that the ratios of stable isotopes vary according to where (and when) they formed in the solar nebula. Ratios of the three stable oxygen isotopes (^{16}O, ^{17}O and ^{18}O) are very similar in rocks found on the Earth and Moon; this tends to discount options 1 and 2. Collisions between boulders and planetesimals in the early solar system tends to discount option 4, since surely the Moon would have been accreted by the Earth ? Option 3 seems particularly fanciful if we believe the model of planetesimal growth through accretion; why should a spinning proto-Earth throw off sufficient mass to form the Moon ?

So we are left with option 5 which is the current generally accepted theory. If this theory is correct then the Moon is the “smoking gun” of a blow from a large planetesimal late in the Earth’s formation. That such giant impacts can occur was confirmed by the collision of comet Shoemaker-Levy 9 and Jupiter on 16th July 1994. The G-fragment had kinetic energy equivalent to that of the mile-sized objects which are thought to pose the greatest danger to our civilisation [35]. There is also evidence that groups of comet-fragments can impact bodies other than Jupiter. For example, Voyager revealed a chain of 20 craters on

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[33] for example see Nicolson I. (2003) ‘Homing in on Extrasolar Planets’, *Astronomy Now*, December 2003, pp.36 - 39
[34] See S281 Course Team (1994) *The Planets*, Milton Keynes, The Open University, pp. 56-58.
[35] See Spencer J.R. and Mitton J. (1995) *The Great Comet Crash*, Cambridge, Cambridge University Press, p. 106.

Callisto which are thought to have been formed in that way [36]. Also, the crater *Herschel* on Mimas (satellite of Saturn) indicates that collisions with objects on the scale of 10 km are possible [37].

The impact theory accounts for how the Moon came to be our satellite, its relative depletion of volatiles (which could have been vaporised by the impact and then escaped) and the presence of a relatively small lunar core (since it was formed from Earth's mantle material there was little heavier material to differentiate into a core). There are problems with the theory but it seems to be the best available so far.

I have summarised the objects selected for observation in this paper in the appendix.

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[36] See Rothery D.A. (1999) *Satellites of the Outer Planets : Worlds in their own right*, Oxford, Oxford University Press, figure 5.16.

[37] Figure 2.3 in Jones B.W., Lambourne R.J.A. and Rothery D.A. (1994) *Images of the Cosmos*, Milton Keynes, The Open University illustrates this well.

Appendix : Summary of objects to view when 'observing evolution'

	Object	Type	RA / Dec [epoch 2000]	Magnitude
1	*Barnard 33* / IC 434 The "Horsehead Nebula"	Dark molecular cloud	5h 41m / -2° 24'	/
2	*Barnard 68*	Dark molecular cloud	17h 22m / -23° 49' (approx)	/
3	*M42* The Trapezium	Star forming region in molecular cloud	5h 25m / -5° 27'	/
4	*Mintaka* / δ Orionis	Bright Giant	5h 32 m / -0° 18'	2.23
5	*Rigel* / β Orionis	Bright Supergiant	5h 14 m / 8° 12'	0.12
6	*Sirius* /α Canis Majoris	Main Sequence (A star) White Dwarf (B star)	6h 45 m / -16° 43'	-1.46
7	*Procyon* / α Canis Minoris	Sub-giant / main sequence	7h 39m / 5° 13'	0.38
8	*Capella A* / α Aurigae	Yellow Giant	5h 16 m / 46° 00'	0.08
9	*Arcturus* / α Boötis	Red Giant	14h 15 m / 19° 11'	-0.04
10	*Betelgeuse* / α Orionis	Red Supergiant	5h 55m / 7° 24 '	0.0 to 0.9 [variable]
11	W Orionis	Carbon star - Red Giant	5h 05m / 1° 10'	8.2 - 12.4 [variable]
12	RR Lyrae	Variable star	19h 25m / 42° 47'	7.1 - 8.1 [variable]
13	delta (δ) Cephei	Variable star Cepheid	22h 29m / 58° 25'	3.5 - 4.4 [variable]
14	*Mira*	Variable star	2h 19m / -2° 58'	1.6 - 10.1 [variable]
15	*M57*	Planetary nebula	18h 54m / 33° 02'	9.0
16	*M1*	Supernova remnant + pulsar	05h 35m / 22° 01'	8.4
17	*Baade's window*	Unobstructed view towards centre of Milky Way and probable Black Hole	18h 3m / -30° 1'	/
18	*M89*	E_0 Galaxy	12h 35m / 12° 33'	10.5
19	*NGC 185*	E_0 Galaxy	0h 39m / 48° 20'	9.2
20	*M60*	E_1 Galaxy	12h 43m / 11° 33'	8.8
21	*M84*	E_1 Galaxy	12h 25m / 12° 53'	9.3
22	*M32*	E_2 Galaxy	0h 42m / 40° 52'	8.2
23	*M59*	E_3 Galaxy	12h 42m / 11° 39'	9.8
24	*NGC 4406*	E_3 Galaxy	12h 26m / 12° 57'	9.2
25	*M49*	E_4 Galaxy	12h 30m / 8° 0'	8.4
26	*NGC 2768*	E_5 Galaxy	9h 11m / 60° 2'	10.0
27	*M110*	E_6 Galaxy	0h 40m / 41° 41'	8.0
28	*NGC 3384*	E_7 Galaxy	10h 48m / 12° 38'	10.0
29	*NGC 5102* *	S_0 Galaxy	13h 22m / -36° 38'	9.7
30	*NGC 5128* *	S_0 Galaxy	13h 25m / -43° 01'	7.0
31	*NGC 1553* *	S_0 Galaxy	4h 16m / -55° 47'	9.5
32	*M64*	Sa Galaxy	12h 56m / 21° 41'	8.5

33	*M81*	Sb Galaxy	9h 55m / 69° 04’	6.9
34	*M31*	Sb Galaxy	0h 42m / 41° 16’	3.9
35	*M33*	Sc Galaxy	1h 34m / 30° 39’	5.7
36	*M51*	Sc Galaxy	13h 30m / 47° 11’	8.4
37	*NGC 1808* *	SBa Galaxy	5h 7m / -37° 31’	9.9
38	*NGC 1433* *	SBa Galaxy	3h 42m / -47° 13’	10.0
39	*M95*	SBb Galaxy	10h 44m / 11° 42’	9.7
40	*M109*	SBb Galaxy	11h 57m / 53° 22’	9.8
41	*NGC 6221* *	SBc Galaxy	16h 53m / -59° 13’	11.0
42	*M82*	Irr Galaxy	9h 56m / 69° 41’	8.4
43	*M2*	Globular cluster	21h 34m / -0° 49’	6.5
44	*M3*	Globular cluster	13h 42m / 28° 23’	6.4
45	*M4*	Globular cluster	16h 24m / -26° 32’	5.9
46	*M67*	Open cluster	08h 50m / 11° 49’	6.9
47	*M103*	Open cluster	01h 33m / 60° 42’	7.4
48	*M29*	Open cluster	20h 24m / 38° 32’	6.6
49	W Virginis	Type II Cepheid variable	13h 23m / -3° 07’	9.5 - 10.6
50	Sun	G-type star / Older Population 1 star	/	-26.8
51	T Tauri	Extreme Population I star	04h 22m / 19° 32’	8.4 - 13.5
52	55 Piscium	Double star	0h 40m / 21° 26’	5.4 - 8.7
53	γ Andromedae	Double star	2h 4m / 42° 19’	2.3 - 4.8
54	Mizar / ζ Ursae Majoris	Double star	13h 24m / 54° 55’	2.3 - 4.0
55	66 Ceti	Double star	2h 12m / -2° 23’	5.7 - 7.7
56	*NGC 4395*	Type 1 Seyfert AGN	12h 25m / 33° 33’	10.2
57	*M87* / 3C 274	Syfert galaxy	12h 30m / 12° 23’	8.6
58	Vega	Exo-planetary system	18h 37m / 38° 47’	0
59	β Pictoris	Exo-planetary system	5h 47m / -51° 04’	3.9
60	τ Boötis	Exo-planetary system	13h 47m / 17° 27’	4.5
61	Mars	Terrestrial planet	/	/
62	Jupiter	Gas giant	/	/
63	The Moon	Earth satellite. Probable debris from planetesimal impact on proto-Earth	/	/