## Introductory Astronomy NAME:

**Homework 30: Cosmology:** Homeworks and solutions are posted on the course web site. Homeworks are **NOT** handed in and **NOT** marked. But many homework problems ($\sim$ 50–70 %) will turn up on exams.

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001 qmult 00007 1 4 1 easy deducto-memory: reading-homework-self-testing done 2

1. Did you complete reading-homework-self-testing for the Introductory Astronomy Lecture (IAL) by the weekly due date?

   a) YYYessss! b) Jawohl! c) Da! d) Sí, sí. e) OMG no!

   **SUGGESTED ANSWER:** (a),(b),(c),(d)

   **Wrong answers:**
   e) As Lurch would say AAAARGH.

   **Redaction:** Jeffery, 2008jan01

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030 qmult 00100 1 1 5 easy memory: cosmology defined

**Extra keywords:** physci

2. The science of the universe as a whole is called:

   a) proctology. b) universology. c) cosmetology. d) inflation. e) cosmology.

   **SUGGESTED ANSWER:** (e)

   **Wrong answers:**
   a) A very important science which is difficult to discuss in polite society.
   d) Inflation is an idea in modern cosmology; we stole the word from economics.
   c) Many people say this. Actually, both cosmetics and cosmos are derived from the same Greek word meaning something like ornamentation.

   **Redaction:** Jeffery, 2001jan01

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030 qmult 00120 1 1 3 easy memory: general relativity in cosmology

**Extra keywords:** cosmology

3. By the reckoning of almost any cosmologist, the main physics theory ingredient to cosmology is:

   a) planetary systems. b) stellar physics. c) general relativity.
   d) the quantum theory of solids. e) helioseismology.

   **SUGGESTED ANSWER:** (c)

   **Wrong answers:**
   e) Oh, c'mon.

   **Redaction:** Jeffery, 2001jan01

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030 qmult 00200 1 1 1 easy memory: cosmology concerns itself with nature of

**Extra keywords:** cosmology

4. Modern physical cosmology concerns itself primarily with the universe in regard to:

   a) nature of. b) purpose. c) meaning. d) mythology. e) consciousness.

   **SUGGESTED ANSWER:** (a)

   **Wrong answers:**
   e) We may come to this one day.

   **Redaction:** Jeffery, 2001jan01

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030 qmult 00330 1 4 4 easy deducto-memory: Democritus and Democritian cosmology

5. "Let's play *Jeopardy*! For $100, the answer is: The Pre-Socratic philosopher who proposed a universe full atoms moving in an infinite, eternal void. Occasionally, vortices formed by chance in the void. In brief, the evolution of a vortex is as follows. The vortex developed a membrane surrounding a region where an up-and-down axis developed (not necessarily aligned with the axis of rotation of the vortex). The lower part of the vortex became solid ground and ocean and the upper part air. Stars rotated with

the membrane and planets (including maybe moons, and suns) moved relative to the rotation in some way. The vortex worlds or cosmoses were not eternal, they came and went. Humankind lives in a vortex cosmos with one moon, one sun, and a rotation axis not aligned with the up-and-down axis."

Who was _____, Alex?

a) Hesiod (circa late 8th century BCE) b) Anaximander (c.610–c.546 BCE)
c) Socrates (c.469–399 BCE) d) Democritus (c.460–c.370 BCE)
e) Aristarchos of Samos (c.310–c.230 BCE)

**SUGGESTED ANSWER:** (d) Democritus counts as a Pre-Socratic philosopher even though he was younger than Socrates because he did Pre-Socratic philosophy and his writings mostly preceded the writing Plato's Socratic dialogues.

**Wrong answers:**
c) Socrates counts as a Pre-Socratic philosopher since he was interested in Pre-Socratic philosophical questions before giving up on them.

**Redaction:** Jeffery, 2008jan01

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030 qmult 00450 1 1 3 easy memory: Hubble's law
**Extra keywords:** physci

6. Given $v$ as recession velocity and $r$ as cosmological physical distance, Hubble's law is:

a) $r = Hv$. b) $r = H/v$. c) $v = Hr$. d) $v = H/r$. e) $v = Hr^2$.

**SUGGESTED ANSWER:** (c)

**Wrong answers:**
e) As Lurch would say: "Aaaarh." But someone if I recall correctly thought they had found evidence for such a law.

**Redaction:** Jeffery, 2001jan01

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030 qmult 00460 1 4 3 easy deducto-memory: discoverer of Hubble's law
**Extra keywords:** physci

7. "Let's play *Jeopardy*! For $100, the answer is: He/she is the person who observationally discovered Hubble's law."

Who is _____, Alex?

a) Henrietta Swan Leavitt (1868–1921) b) Knut Lundmark (1889–1958)
c) Edwin Hubble (1889–1953) d) Georges Lemaître (1894–1966)
e) Adriaan van Maanen (1884–1946)

**SUGGESTED ANSWER:** (c)

The story of the discovery of the expansion of the universe and Hubble's law (which is the form of the expansion) is complex. Some form of universal expansion was gradually becoming apparent to astronomers from 1912 on, starting from Vesto Slipher's work on the redshifts of galaxies.

But convincing observational evidence of the expansion of the universe and Hubble's law came with Hubble in 1929. Knut Lundmark deserves some credit for getting partway to it. Theoretically, the expansion was first suggested by Willem de Sitter (1872–1934) in 1917 and Lemaître first demonstrated Hubble's law as a theoretical consequence of the Friedmann-equation models of the expanding universe in 1927 though it was little known till some years later. Lemaître, using published data in the literature, even obtained a value of Hubble's constant that was not much worse than Hubble's own value which was about 7 times too large due an overall calibration error. Note Lemaître did not observationally discover Hubble's law, but only showed that if did apply observationally then his value of Hubble's constant may have applied.

**Wrong answers:**
a) She was the discoverer of the period-luminosity relation for Cepheid variable stars (No-488) while working at Harvard College Observatory. Distance determinations by Hubble using this relation established the extragalactic nature of the galaxies.

e) His mistaken observations of movement of the spiral arms of the spiral nebulae worked against the acceptance of the extragalactic nature of these objects (No-495).

**Redaction:** Jeffery, 2001jan01

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030 qmult 00470 1 4 1 easy deducto-memory: Hubble time

**Extra keywords:** physci KB-668-26

8. The current value of the Hubble time and the Λ-CDM model (AKA the concordance model) value for the age of the universe are both about:

a) 14 Gyr. b) $10^{100}$ yr. c) 10 years. d) 4.6 Gyr. e) 0.

**SUGGESTED ANSWER:** (a)

**Wrong answers:**

d) This is the age of the Solar System as determined by radioactive dating.

e) As Lurch would say: "Aaaarh."

**Redaction:** Jeffery, 2001jan01

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030 qmult 00480 1 1 4 easy memory: Hubble length observable universe

**Extra keywords:** physci KB-670-22

9. The Hubble length is $4.283h_{70}^{-1}$ Gpc (where $h_{70}$ is the reduced Hubble constant: it is equal to 1 to within a few percent). It is a characteristic size scale for the:

a) quantum of the inflaton. b) Milky Way. c) total universe. d) observable universe. e) Solar System.

**SUGGESTED ANSWER:** (d)

**Wrong answers:**

a) As Lurch would say: "Aaaarh."

Fortran-95 Code

```
          print*
          print*,'Hubble quantities, Hubble values'
          ckms=2.99792458d5                 ! speed of light in km/s
          yearsec=365.25d0*86400.d0         ! Jyr in seconds
          gly=ckms*yearsec*1.d9             ! Gly in km
          au=1.49597870700d8  ! https://en.wikipedia.org/wiki/Astronomical_unit in
km
          con=2.*acos(-1.)/(3600.d0*360.d0) ! Arcseconds to radians
          parsec=au/con                     ! Parsec in km
          xmpc=parsec*1.d6                  ! Mpc in km
          gpc=parsec*1.d9                   ! Gpc in km
          pclyr=gpc/gly                     ! pc in ly
          gyr=1.d9*yearsec                  ! Gyr in seconds
          h0=70.d0                          ! Fiducial value
          t=(xmpc/h0)/gyr                   ! Hubble time in Gyr
          dly=t                             ! Hubble length in Gly
          dgpc=dly/pclyr                    ! Hubble length in Gpc
          print*,'pclyr,t,dly,dgpc'
          print*,pclyr,t,dly,dgpc
    !    3.2615636864061552        13.968459921017748        13.968459921017748
4.2827493999999993
```

**Redaction:** Jeffery, 2001jan01

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030 qmult 00500 1 1 3 easy memory: Einstein universe defined

10. The Einstein universe presented by Einstein in 1917 is a/an _____ universe model.

a) contracting, hyperspherical b) expanding, hyperspherical c) static, hyperspherical d) static, hypercritical e) expanding, hypercritical

**SUGGESTED ANSWER:** (c) See No-520.

**Wrong answers:**
e) As Lurch would say: "Aaaarh."

**Redaction:** Jeffery, 2001jan01

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030 qmult 00524 1 1 1 easy memory: Einstein's reason for doing cosmology

11. One of the reasons and probably the main reason for Einstein starting to do cosmology in 1917 was to add support to general relativity as a universally true theory. After all, if general relativity was a universally true theory and gravity determines the largest scale structures of the universe, then general relativity should be able to account for the:

    a) largest scale structure of the universe. b) universe in part. c) universe not at all.
    d) Big Bang. e) the cosmic microwave background.

**SUGGESTED ANSWER:** (a)

**Wrong answers:**
c) Oh, c'mon.

**Redaction:** Jeffery, 2008jan01

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030 qmult 00600 1 4 2 easy deducto-memory: de Sitter universe defined

12. "Let's play *Jeopardy*! For $100, the answer is: It is an eternal, exponentially expanding cosmological model with no mass-energy content, but only a cosmological constant."

    What is the _____, Alex?

    a) Einstein universe (1917) b) de Sitter universe (1917) c) Lemaître universe (1931?)
    d) Eddington-Lemaˆ itre universe (1925) e) Einstein-de Sitter universe (1932)

**SUGGESTED ANSWER:** (b)

**Wrong answers:**
a) As Lurch would say AAAARGH.

**Redaction:** Jeffery, 2008jan01

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030 qmult 00700 1 4 4 easy deducto-memory: Friedmann-equation models

13. "Let's play *Jeopardy*! For $100, the answer is: These models were the first plausible universe models (in that they contained mass-energy) to predict the expansion of the universe."

    What are the _____ models, Alex?

    a) Alpher-Behte-Gamow b) Einstein-Lemaître c) Einstein d) Friedmann-equation
    e) Gamow

**SUGGESTED ANSWER:** (d)

**Wrong answers:**
a) There was a famous Alpher-Behte-Gamow paper in the development of Big Bang cosmology.

**Redaction:** Jeffery, 2001jan01

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030 qmult 00730 1 4 5 easy deducto-memory: Omega in Friedmann-equation models

14. "Let's play *Jeopardy*! For $100, the answer is: In the Friedmann-equation models, it is the symbol for density parameter which is the parameter that that specifies the geometry of the universe: if less than 1, the universe is hyperbolic and infinite; if equal to 1, the universe is flat and infinite; if greater than 1, the universe is hyperspherical and finite. The symbol name is often used as synonym for density parameter."

    What is _____, Alex?

    a) $\Lambda$ (spelt Lambda) b) $\Psi$ (spelt Psi) c) $\Delta$ (spelt Delta) d) $\Gamma$ (spelt Gamma)
    e) $\Omega$ (spelt Omega)

**SUGGESTED ANSWER:** (e)

**Wrong answers:**
a) This is the symbol for the cosmological constant.
b) This is the symbol for the wave function in quantum mechanics.
c) This is the symbol for change in.
d) I don't think $\Gamma$ has a standard use in physics, although we do use it for various things.

**Redaction:** Jeffery, 2001jan01

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030 qmult 00800 1 1 5 easy memory: accelerating universe
**Extra keywords:** physci KB-668-28 but note their answer is wrong.

15. According to observations of several kinds beginning in 1998, it is almost certain that the universal expansion is currently:

a) decelerating. b) stopped. c) negative: i.e., the universe is contracting. d) in doubt. e) accelerating.

**SUGGESTED ANSWER:** (e)

**Wrong answers:**
a) Exactly wrong, but this is what was believed to be the case before 1998.

**Redaction:** Jeffery, 2001jan01

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030 qmult 00810 2 4 5 mod. deducto memory: cosmological constant
**Extra keywords:** physci

16. The simplest explanation considered for the accelerating expansion of the universe is:

a) planet explosions. b) supernovae. c) stellar winds. d) green energy. e) a cosmological constant.

**SUGGESTED ANSWER:** (e)

**Wrong answers:**
a) As Lurch would say: "Aaaarh."

**Redaction:** Jeffery, 2001jan01

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030 qmult 00910 1 1 3 easy memory: dark energy and cosmological constant

17. The acceleration of the universe can most simply be accounted for by a (nonzero) cosmological constant. Alternatively, one can use a constant _____. The two are conceptionally different, but have exactly the same effect on the time evolution of the cosmic scale factor $a(t)$: i.e., they are effectively the same. Because they are effectively the same, the cosmological constant and constant _____ are often used as if they were synonyms—which is fine as long as you know what you mean.

a) dark matter b) grey matter c) dark energy d) grey energy e) dark grey

**SUGGESTED ANSWER:** (c)

**Wrong answers:**
e) A nonsense answer.

**Redaction:** Jeffery, 2008jan01

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030 qmult 01000 1 1 1 easy memory: Lambda-CDM or concordance model defined

18. The Friedmann-equation $\Lambda$ model (i.e., the Friedmann-equation model with a nonzero cosmological constant $\Lambda$ or nonzero dark energy but still using the letter $\Lambda$ since one knows what one means) with parameters adjusted to fit current observations was once often called the concordance model, but nowadays is more usually nowadays called the:

a) $\Lambda$-CDM model. b) $\Omega$-CDM model. c) $\Lambda$-HDM model. d) $\Omega$-HDM model. e) discord model.

**SUGGESTED ANSWER:** (a)

**Wrong answers:**
e) Exactly wrong.

**Redaction:** Jeffery, 2001jan01

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030 qmult 01030 1 4 2 easy deducto-memory: dark matter
**Extra keywords:** physci KB-669-34

19. After the dark energy (whatever that is and assuming it's not just an effect of a true cosmological constant), the most abundant form of mass-energy in the universe is apparently some form of matter known only (at least to circa 2020) through its gravitational effects. We call this matter:

a) luminous matter. b) dark matter. c) baryonic matter. d) invisible matter. e) mirror matter.

**SUGGESTED ANSWER:** (b)

**Wrong answers:**
e) There is something called mirror matter, but I forget what and it probably doesn't exist anyway.

**Redaction:** Jeffery, 2001jan01

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030 qmult 01100 1 1 4 easy memory: cosmological redshift direct observable distance measure

20. The only direct observable cosmological distance measure (except those that are only direct observables asymptotically as distances go to zero) is:

a) physical or proper distance. b) luminosity distance. c) recession velocity. d) the cosmological redshift. e) lookback time.

**SUGGESTED ANSWER:** (d)

**Wrong answers:**
a) A nonsense answer.

**Redaction:** Jeffery, 2008jan01

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030 qmult 01300 1 1 3 easy memory: Big Bang in brief defined
**Extra keywords:** physci KB-668-27

21. The Big Bang, in brief, is the:

a) explosion of a supernova. b) explosion of a star. c) origin of the observable universe. d) explosion of a quasar. e) end of the observable universe or our pocket universe.

**SUGGESTED ANSWER:** (c)

**Wrong answers:**
e) Exactly wrong. The big crunch (which is a sort of big bang in revese) is one of the theoretical ends of the universe.

**Redaction:** Jeffery, 2001jan01

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030 qmult 01330 1 1 2 easy memory: H and He from Big Bang nucleosynthesis
**Extra keywords:** physci KB-669-29

22. In Big Bang nucleosynthesis, the two most abundant products are:

a) hydrogen and iron in about a 1:1 mass ratio. b) hydrogen and helium in about a 3:1 mass ratio. c) hydrogen and helium in about a 1:1 mass ratio. d) hydrogen and iron in about a 3:1 mass ratio. e) helium and iron in equal amounts by mass.

**SUGGESTED ANSWER:** (b)

**Wrong answers:**
e) As Lurch would say: "Aaaarh."

**Redaction:** Jeffery, 2001jan01

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030 qmult 01332 1 4 1 easy deducto-memory: origin of the heavy elements
**Extra keywords:** physci KB-669-30

23. Most of the elements in the observable universe heavier than lithium were formed in:

a) stars and supernovae. b) black holes. c) the Big Bang. d) nuclear reactors.
e) planets.

**SUGGESTED ANSWER:** (a)

**Wrong answers:**
c) Exactly wrong.
e) As Lurch would say: "Aaaarh."

**Redaction:** Jeffery, 2001jan01

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030 qmult 01370 1 4 4 easy deducto memory: CMB defined
**Extra keywords:** physci KB-669-33

24. The relic primordial electromagnetic radiation field which decoupled from matter in the recombination era circa 400,000 years after the Big Bang when hydrogen became neutral making the observable universe transparent and which has since free streamed through space and cooled off because of the expansion of the universe is called the:

a) Cosmic Gamma-ray Background (CGB). b) Cosmic X-ray Bare Ground (CXBG).
c) Cosmic X-ray Foreground (CXF). d) Cosmic Microwave Background (CMB).
e) Cosmic X-ray Background (CXB).

**SUGGESTED ANSWER:** (d)

**Wrong answers:**
b) As Lurch would say: "Aaaarh."

**Redaction:** Jeffery, 2001jan01

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030 qmult 01390 1 4 1 easy deducto memory: 5 evidences for Big Bang
**Extra keywords:** physci-670-28

25. Five observational evidences are:

1. the expansion of the universe.
2. the abundances of the light elements: H, D, He, and Li.
3. the existence of the cosmic microwave background (CMB).
4. that the fluctuations in the CMB are accounted for by primordial density fluctuations that account adequately so far for the initial conditions for the large-scale structure of the universe.
5. that the oldest stars ( $\gtrsim 13.6\,\mathrm{Gyr}$) are not older than the observable universe.

These evidences strongly support:

a) Big Bang cosmology. b) the steady-state universe. c) little bang cosmology.
d) the hierarchical universe. e) Democritean cosmology.

**SUGGESTED ANSWER:** (a)

**Wrong answers:**
b) Actually, 2–5 are evidence against the steady-state model of the universe.
c) This was proposed by Gary Larsen in a cartoon which is an unusual location for a scientific theory.
d) The hierarchical universe was a possibility at one time but seems ruled out by observations of the large-scale structure (CL-55).
e) Democritus (460?–370? BCE) was the 2nd proponent of the atom theory in ancient Greece. He, or he and his older colleague Leucippus, had a very interesting cosmology that in some respects anticipates the eternal inflation cosmology model of our own time.

**Redaction:** Jeffery, 2001jan01

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030 qmult 01450 1 4 4 easy deducto-memory: Hubble tension

26. The Λ-CDM model is in almost all respects a very adequate cosmological model for the observable universe. But there is one major discrepancy at present. The Hubble constant measured directly from the local universe and the Hubble constant measured indirectly using the cosmic microwave background (and relying on the Λ-CDM model itself) do not agree within observational error. Either one or both measurements are wrong if the Λ-CDM model is correct. However, it seems likely that both

measurements are correct, except the indirect measurement cannot actually be a measurement of the Hubble constant if they are both correct as measurements: it must be a measurement of something else. This means the Λ-CDM model probably needs to be revised perhaps to the extent that we need a new name for the revision. The disagreement in the two Hubble constant measurements is called the:

a) Hubble anomaly. b) Hubble dispute. c) Hubble-Lemaître dispute.
d) Hubble tension. e) Hubble X problem

**SUGGESTED ANSWER:** (d)

**Wrong answers:**
a) A better name in my view

**Redaction:** Jeffery, 2008jan01

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030 qmult 01500 1 4 5 easy deducto-memory: inflation defined
**Extra keywords:** CK-446

27. "Let's play *Jeopardy*! For $100, the answer is: It is name for the super-rapid expansion that the observable universe and maybe beyond may have undergone at very early times.

What is _____, Alex?

a) inoculation b) infestation c) hybridization d) hydration e) inflation

**SUGGESTED ANSWER:** (e)

**Wrong answers:**
d) Hydration is to chemically combine with water (Ba-591).

**Redaction:** Jeffery, 2001jan01

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030 qmult 01690 1 4 1 easy deducto-memory: golden age of cosmology

28. "Let's play *Jeopardy*! For $100, the answer is: The popular name (among astronomers anyway) for the period in cosmological research since circa 1992."

What is the _____ of cosmology, Alex?

a) golden age b) silver age c) bronze age d) iron age e) dawn age

**SUGGESTED ANSWER:** (a)

**Wrong answers:**
b) As Lurch would say AAAARGH.

**Redaction:** Jeffery, 2008jan01