Team name: _____ Team Number: _____

Answer Key: Section A (1 point each, 81 total)

1. 20, 5, 1, 4
2. 47 Tucanae, SN 2014J, NGC 4993
3. D, E, K, L
4. (a) M51
   (b) X-rays, optical
   (c) White
   (d) Image 1
5. (a) They have unusually high rates of star formation
   (b) X-ray
   (c) Our view is obscured by gas and dust because it is near the plane of the Milky Way
6. (a) Image 20
   (b) Center
   (c) Gravity
   (d) Color-magnitude diagrams
   (e) Image 35
7. (a) Image 4
   (b) Type Ia
   (c) It will not because the Sun does not have a binary companion to accrete mass from
   (d) Q
   (e) Image 10
8. (a) Phoenix Cluster
   (b) X-ray
   (c) Powerful jets of high-energy particles emanating from near a supermassive black hole in the central galaxy of the cluster
   (d) Outer cavities
   (e) Image 15
   (f) Optical and radio
9. (a) Image 23
   (b) ALMA
   (c) Gas and dust block our view
   (d) Molecular cloudlets
10. (a) Centaurus A (Cen A)
    (b) Image 22
    (c) Hubble Space Telescope
    (d) Image 17
    (e) Inner lobes
11. (a) Abell 400
    (b) Radio
    (c) The galaxy's very high speed as it moves through the surrounding gas and dust in the cluster.
    (d) Supermassive black holes
    (e) Image 11 and Image 13
    (f) Image 11
12. (a) Image 19
    (b) Lack of x-rays or radio waves
    (c) It has a very high star formation rate (i.e. it is a starburst galaxy)
    (d) Image 21
13. (a) NGC 4038 and NGC 4039
    (b) Corvus
    (c) Image 14
    (d) Pink or red
    (e) 656.28 nm

(f) Elliptical

(g) X-ray

(h) Matter falling onto black holes and neutron stars

14. (a) Image 25

(b) 10^7 seconds

(c) They grow mainly in bursts

15. (a) ESO 137-001

(b) Towards the top left

(c) Gravity holds it together

(d) It'll get worse

(e) As ESO 137-001 moves through space, much of its gas get stripped away (as part (c) of the question tells us!) A galaxy needs gas to form stars, so this process helps form stars outside the galaxy, but makes it harder to form stars within the galaxy.

16. (a) Image 7

(b) M81

(c) Image 4

(d) Type IIb

(e) E

17. (a) NGC 4993

(b) Lenticular

(c) It was observed by both LIGO and Virgo

(d) Image 26

18. (a) M100

(b) Hubble's corrective optics had not been installed when Image 31 was taken

(c) Image 39

(d) F

19. (a) GALEX

(b) VLA

(c) Subrahmanyan Chandrasekhar

(d) James Webb Space Telescope

(e) Very Large Array

(f) Fermi, Chandra, GALEX, Hubble, Spitzer, and VLA

(g) The big one

Team name: _____ Team Number: _____

Answer Key: Section B (3 points each, 90 total)

20. 5800 Kelvin

21. 4.96 degrees

22. (a) 1.6 solar masses
    (b) 1.2 solar masses
    (c) 2.5 AU

23. (a) $4L$
    (b) $2^{1/4}T$ Note: the decimal approximation $1.189T$ is perfectly fine as well :)
    (c) $4L$

24. (a) 18.2 Mpc
    (b) 3×10^{15} times brighter

25. (a) 25 parsecs
    (b) 81.5 years
    (c) 119.45 km/s
    (d) 36.57 km/s
    (e) 124.92 km/s
    (f) 508,000 parsecs
    (g) This star is too close for Hubble's Law to be useful. Its motion through the galaxy and gravitational interactions with nearby objects will be more significant than the recession velocity caused by the expansion of the universe. The distance found using parallax will be more accurate.

26. (a) B
    (b) C
    (c) The rate at which energy is emitted from the central regions of the star is indeed greatest when the star is at its minimum radius, but the opacity of the gases in the stars outer layers impede the flow of energy to the surface.
    (d) For stars on the high-temperature (left) side of the instability strip, helium ionization occurs too close to the surface and involves only an insignificant fraction of the star's mass. For stars on the cool (right) side of the instability strip, convection in the star's outer layers prevents the storage of the energy needed to drive the pulsations.
    (e) At longer wavelengths, the brightness changes are due primarily to changes in the radius of the star; at shorter wavelengths, they are due primarily to changes in the temperature of the star. Small increases in the temperature results in the Cepheid emitting much more violet light than red light.

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27. (a) Hydrogen and helium

    (b) Answer should include **one** of the following to get credit: it displays strong lines in the optical portion of the EM spectrum, it is only weakly depleted onto dust grains, or it is significantly more common than iron in the ISM

    (c) More massive galaxies have higher metallicities

    (d) Less massive galaxies have shallower potential wells, making it easier for galactic winds to strip them of their metals.

28. (a) E

    (b) 211,200 km/s

    (c) As time goes on, the metallicities of galaxies increase.

    (d) Newer stars are formed from gas clouds that are "seeded" with heavy elements from previous giant stars.