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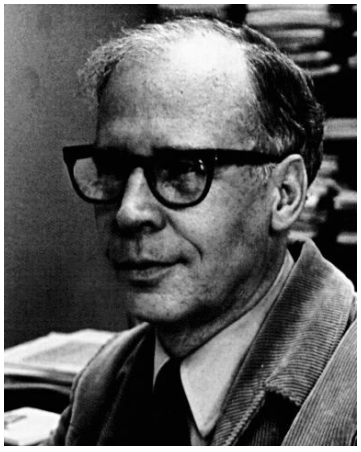
PENNSYLVANIA SCIENCE OLYMPIAD

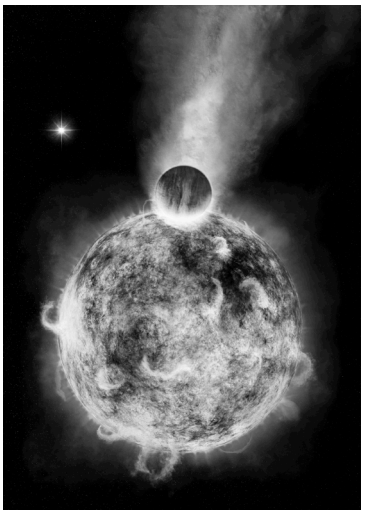
SOUTHEAST REGIONAL TOURNAMENT 2015

ASTRONOMY C DIVISION EXAM

MARCH 4, 2015



NEUMANN UNIVERSITY
VERITAS CARITAS
1965
ASTON, PENNSYLVANIA



SCHOOL:_____ **TEAM NUMBER:**_____

INSTRUCTIONS:

1. Turn in all exam materials at the end of this event. *Missing exam materials will result in immediate disqualification of the team in question*. There is an exam packet as well as a blank answer sheet.

2. You may separate the exam pages. You may write in the exam.

3. *Only* the answers provided on the answer page will be considered. Do not write outside the designated spaces for each answer.

4. Include school name and school code number at the bottom of the answer sheet. Indicate the names of the participants *legibly* at the bottom of the answer sheet. Be prepared to display your wristband to the supervisor when asked.

5. Each question is worth one point. Tiebreaker questions are indicated with a (T#) in which the number indicates the *order of consultation* in the event of a tie. Tiebreaker questions count toward the overall raw score, and are only used as tiebreakers when there is a tie. In such cases, (T1) will be examined first, then (T2), and so on until the tie is broken. There are 12 tiebreakers.

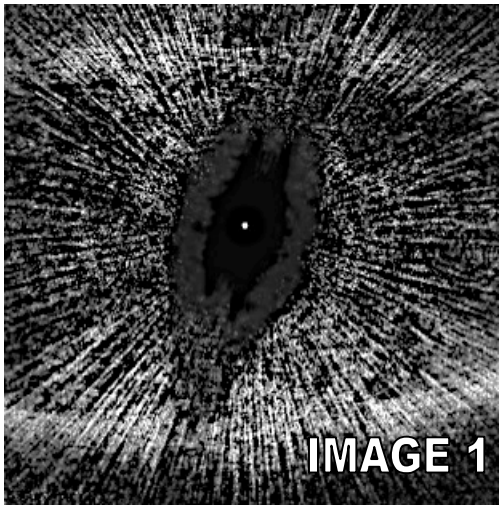
6. When the time is up, *the time is up*. Continuing to write after the time is up risks immediate disqualification.

7. In the BONUS box on the answer sheet, name the gentleman depicted on the cover for a bonus point.

8. As per the 2015 Division C Rules Manual, each team is permitted to bring "either two laptop computers OR two 3-ring binders of any size, or one binder and one laptop" and programmable calculators.

9. Nonsensical, mocking, or inappropriate answers WILL RESULT IN DISQUALIFICATION.

Questions 1-32 refer to the objects listed in section 3c, page C4, of the 2015 Science Olympiad Division C Rules Manual. "Identify, know the location and answer questions relating to the content areas for the following objects."



1. **Which object is shown in image 1?**

   A. TW Hya
   B. Kepler-7b
   C. HD 209458b
   D. Beta Pictoris
   E. Fomalhaut

2. **Which of the following most accurately describes the central object in image 1?**

   A. Pre-main sequence protostar
   B. A-class main sequence star
   C. Hot Jupiter
   D. Brown dwarf
   E. White dwarf

3. **What is the major astronomical significance of the object shown in image 1?**

   A. Its exoplanet is a hot Jupiter with the largest orbital radius yet discovered
   B. It indicated the first indirect imaging of an exoplanet
   C. It indicated a circumstellar disk around a brown dwarf
   D. Its debris disk was the first to be imaged around another star
   E. It is the closest T-Tauri star to our solar system

4. **Which object is shown in image 2?**

   A. Hr 8799
   B. TW Hya
   C. Gliese 229b
   D. LP 944-20
   E. GJ 1214b

5. **The spectrum of the object in image 2 shows:**

   A. an abundance of methane
   B. calcium II K in absorption
   C. molecular bands of titanium oxide
   D. an abundance of lithium
   E. a cubic crystalline form of ice (ice VII)

6. **What is the major astronomical significance of the object shown in image 2?**

   A. It was the first clear evidence of a brown dwarf
   B. It is the only known Gamma Doradus variable with a circumstellar disk
   C. It is the closest T Tauri star to our solar system
   D. It was the first planet of its class to be discovered – small size and low density
   E. It was the first brown dwarf to show evidence of flare activity

7. Which object is indicated by the light curve shown in image 3?

A. CoRoT-2
B. HD 189733b
C. Beta Pictoris
D. FU Orionis
E. WISE 1049-5319

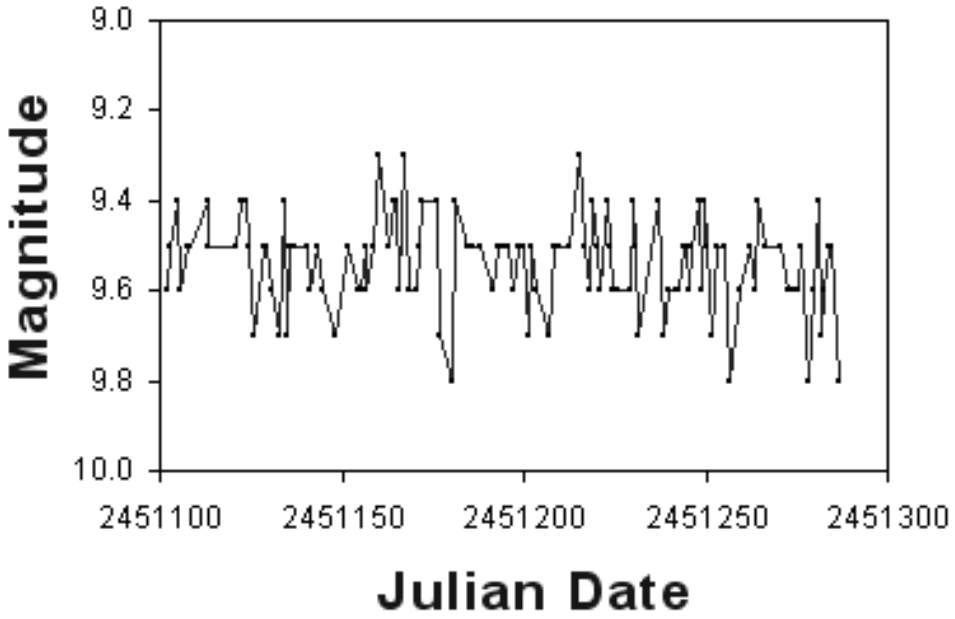
8. What phenomenon is most likely indicated by the variation in the light curve shown in image 3?

A. Perturbations of the orbit of a binary brown dwarf system
B. Pulsation of the outer atmosphere of a hot Jupiter
C. Flickering caused by fluctuations in the inner regions of an accretion disk
D. Radial pulsation of a Delta Scuti variable
E. Transits of an exoplanet

9. (T9) Which of the following is NOT commonly associated with an object of this type?

A. High Lithium abundance
B. P-Cygni profiles indicating mass loss
C. Reflection nebula
D. Accretion disk
E. Rapid decline in visual magnitude

IMAGE 3

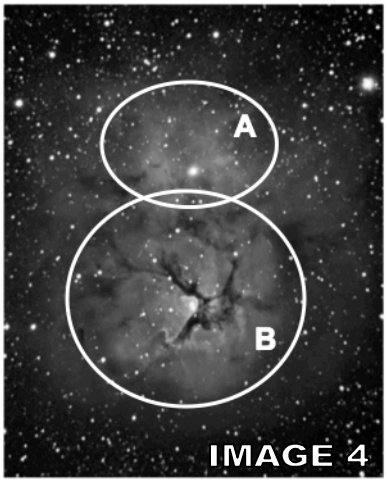


10. Which of the objects was the first exoplanet to produce a cloud map?

A. Kepler 7b
B. GJ 1214b
C. HD 189733b
D. Gliese 229b
E. CoRoT-2

11. What type of object is indicated by the circle labeled A in image 4? In color images it is bluish.

A. Molecular cloud
B. Emission nebula
C. Reflection nebula
D. Supernova remnant
E. Dark nebula



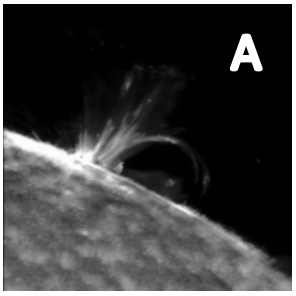
12. What type of object is indicated by the circle labeled B in image 4? In color images it is red.

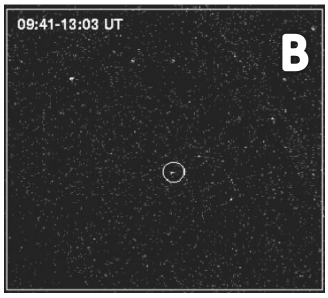
A. Herbig-Haro object
B. Emission nebula
C. Reflection nebula
D. Planetary nebula
E. Protoplanetary nebula

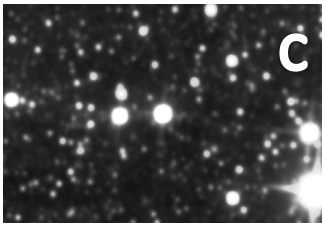
13. (T10) Part of this object was given a numerical designation in Barnard's Catalog of Dark Nebulae. What is that numerical designation?

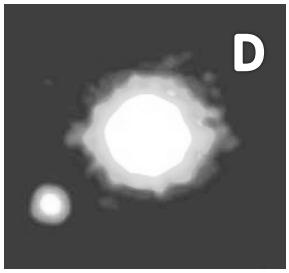
A. 85
B. 20
C. 6514
D. 30
E. 147

14. One of the objects shown below revealed to the Chandra x-ray observatory the first flare of any kind from a brown dwarf. Which image shows this object?



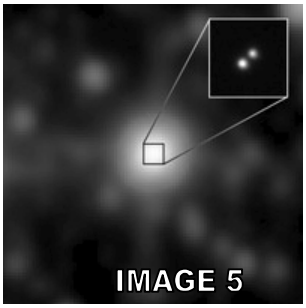






15. Which object is shown in image 5?

A. HR 8799
B. LP 944-20
C. 2M 1207
D. WISE 1049-5319
E. M20



16. Who announced the discovery of the object in image 5?

A. Christian Marois
B. Charles Messier
C. Eric Mamajek
D. Chris G. Tinney
E. Kevin Luhman

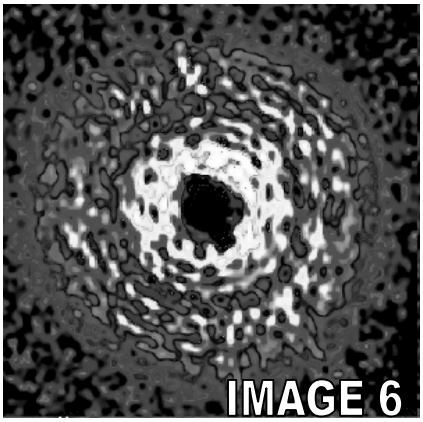
17. (T8) Which of the objects was the first exoplanet to be detected by more than one method?

A. Kepler 7b
B. CoRoT-2
C. HD 189733b
D. Gliese 229b
E. HD 209458b

18. Which methods were used to detect the object referenced in #17 and in what order?

A. Radial velocity method, then transit method
B. Pulsar timing method, then gravitational lensing method
C. Transit timing variation method, then polarimetry method
D. Relativistic beaming method, then transit duration variation method
E. Astrometric observation method, then orbital perturbation method

19. What type of object is shown in image 6?



A. H II region and emission nebula
B. Planetary nebula around a white dwarf
C. Protoplanetary disk around a protostar
D. Cloud patterns on a hot Jupiter
E. Sub-mm radiation from a brown dwarf

20. What wavelength classification was used to create this image?

A. Sub-mm
B. Radio
C. Infrared
D. Ultraviolet
E. X-ray

21. Which of the objects is thought to be the source of interstellar meteoroids in our solar system?

A. N159
B. HR 8799
C. TW Hya
D. FU Orionis
E. Beta Pictoris

22. (T1) Which of the following characteristics is NOT evident in the object referenced in #21?

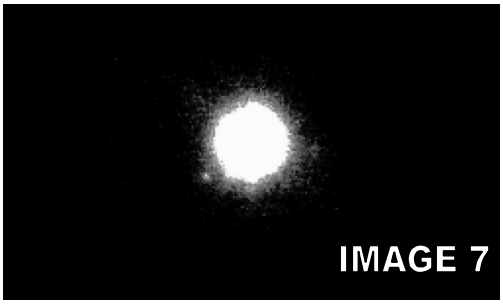
A. Spectral features of carbon monoxide
B. Planetesimal belts
C. A young Delta Scuti-class central star
D. A hot Jupiter-class exoplanet
E. An asymmetrical debris disk

23. The object referenced in #21 shows evidence of comet activity. The comets are considered to have two distinct populations based on which of the following criteria?

A. The density of the comet nucleus
B. The eccentricity of the comet orbits
C. The amount of gas evaporating from the comet
D. The reflectance and albedo of the comet surface
E. The length of the comet's orbital period

24. What is the spectral class of the object shown in image 7?

A. F
B. L
C. Y
D. T
E. M



25. Which of the following correctly describes the two objects shown in image 7?

A. Brown dwarf with planetary companion
B. Protostar with accretion disk
C. T Tauri star with Herbig-Haro object
D. Young massive star with debris disk
E. Main sequence star with hot Jupiter companion

26. What is the significance of the object(s) shown in image 7?

A. The objects suggest planetesimal conglomeration in the debris disk
B. It suggests the possibility of lithium burning in the Hayashi track contraction phase of T Tauri stars
C. It is the youngest A-class protostar with a suspected planetary companion
D. It is the first known planetary companion to a brown dwarf
E. The hot Jupiter is the first to be detected via the transit timing method

27. GJ 1214b is a planet orbiting a red dwarf star about 40 light years away. What classification best describes GJ 1214b?

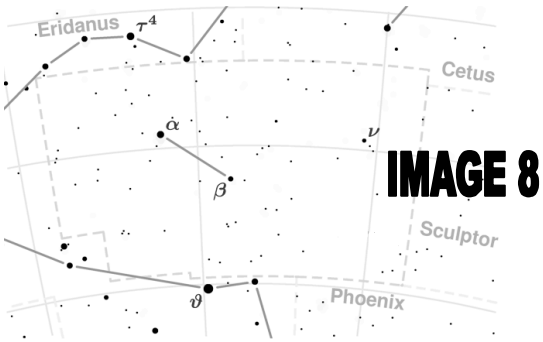
A. Mesoplanet
B. Rogue planet
C. Ice giant
D. Super-Earth
E. Hot Jupiter

28. (T5) What recent discovery was made regarding GJ 1214b?

A. It has a high-mean-molecular mass atmosphere, most likely water, methane, or carbon dioxide
B. It has most likely migrated inward, losing much of its gas in the process
C. It has a density close to that of polystyrene foam
D. Its orbital inclination allows the transit to be viewed from Earth
E. It formed at the same time as the planet, condensing from the same molecular cloud

29. Which object appears in the constellation shown in image 8?

A. LP 944-20
B. N159
C. TW Hya
D. 2M1207
E. Beta Pictoris



30. What is the classification of the object referenced in #29?

A. White dwarf
B. Red dwarf
C. Brown dwarf
D. Hot Jupiter
E. Super-Earth

31-40: Match the numbered exoplanet detection method with its description in the lettered column.

31. Direct imaging	**A. Useful for detecting multiple planets in one system, particularly when one of the planets is more massive than the others**
32. Pulsar timing	**B. Also called Doppler spectroscopy, this method observes changes in a star's velocity toward or away from Earth**
33. Relativistic beaming	**C. Periodicity in the offset of observed versus predicted minima due to the perturbations of a planet**
34. Radial velocity	**D. This method works best in systems that are relatively near the sun, have significant star/planet separation, and a hot planet**
35. Transit photometry	**E. This method is capable of detecting planets far smaller than any other method, but planets found using it are very rare**
36. Transit timing variation	**F. Effective for detecting planets around stars that have left the main sequence, as they are more susceptible to tidal distortion**
37. Gravitational microlensing	**G. Also called "Doppler Boosting," this is when the light from a star appears brighter because it is moving towards Earth**
38. Astrometry	**H. Measuring the star's position in the sky with precision over time; this method is severely limited by atmospheric distortion**
39. Ellipsoidal light variations	**J. Depends on a chance alignment of a star (with a planet) almost directly in front of a distant star (from Earth perspective)**
40. Eclipsing binary minima timing	**K. The observed brightness of a star drops perceptibly when a planet passes in front of it**

41 – 50: Match the numbered exoplanet species with its description in the lettered column.

41. Gas giant	**A. A planet without a host star that orbits the galaxy directly**
42. Terrestrial planet	**B. A planet composed mainly of hydrogen and helium**
43. Super-Earth	**C. A planet with a large radius but very low density**
44. Mini-Neptune	**D. Defined exclusively by mass with upper and lower limits**
45. Hot Jupiter	**E. Also known as a gas dwarf or transitional planet**
46. Ice giant	**F. A planet that orbits a rapidly rotating neutron star**
47. Pulsar planet	**G. A gas giant that orbits very close to its host star**
48. (T6) Goldilocks planet	**H. A planet that falls within the star's habitable zone**
49. Rogue planet	**J. Composed primarily of silicate minerals or metals**
50. Puffy planet	**K. Composed primarily of volatile substances heavier than helium**

51. A particular astronomical body is seen to have a mass of 7 M_J. What is its most likely classification?

A. Brown dwarf
B. Red dwarf
C. Gas giant
D. Protostar
E. Mini-Neptune

52. (T11) A brown dwarf:

A. can fuse hydrogen and helium
B. can fuse hydrogen but not helium
C. can fuse deuterium and lithium
D. can fuse deuterium but not lithium
E. can fuse lithium but not hydrogen

53. Where on the H-R diagram would one find a brown dwarf?

A. Above and to the right of the white dwarf region
B. Just below the horizontal branch
C. Below the main sequence in the instability strip
D. Below and to the right of the main sequence
E. In the region characterized by luminosity class 0

54. Which of the following features is NOT associated with FU Orionis stars?

A. Rapid decline to pre-outburst luminosity
B. Strong Lithium absorption lines
C. Reflection nebulae
D. Thermal instabilities in the accretion disk
E. Jets producing radio emission

55. T Tauri stars exhibit P-Cygni profiles in their spectra. What does this indicate?

A. Circumstellar disk instability
B. Synchrotron radiation
C. Magnetic field variation
D. Mass loss
E. Convection in the stellar atmosphere

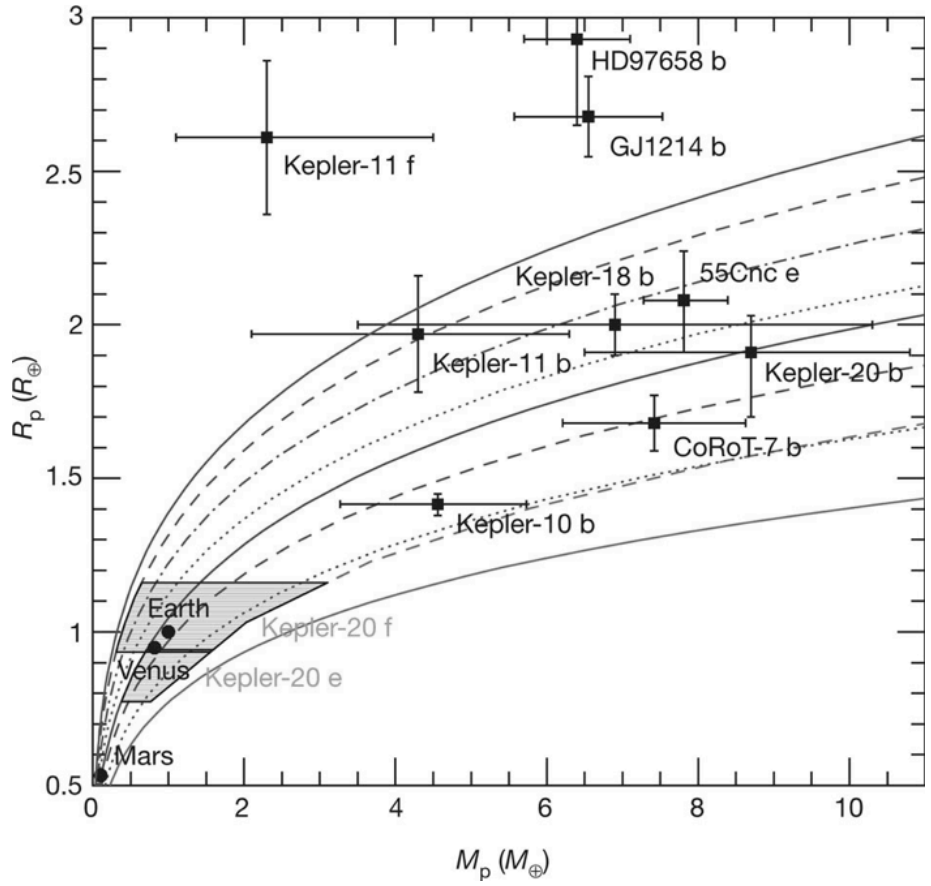
56. A particular star has [Fe/H] = 0.3. What is its fractional metal content, compared to the sun?

A. Roughly 30% of the fractional metal content of the sun
B. Roughly twice the fractional metal content of the sun
C. Roughly three times the fractional metal content of the sun
D. Roughly half the fractional metal content of the sun
E. Roughly 70% of the fractional metal content of the sun

57. What is the mass range of Herbig Ae/Be stars?

A. $13M_\odot < M < 80M_\odot$
B. $M < 2M_\odot$
C. $8M_\odot < M < 13M_\odot$
D. $13M_\odot < M < 65M_\odot$
E. $2M_\odot < M < 8M_\odot$

Consider the following graph of exoplanet radius versus exoplanet mass for questions 58 - 62. The curves are theoretical constant-temperature mass–radius relations for various planetary compositions.



58. Based on its position on the graph, what would be the likely classification of Kepler-11f?

A. hot Jupiter B. ice giant C. terrestrial planet D. gas dwarf E. gas giant

59. What is the approximate density of Kepler-11f?

A. 5.51 g/cm^3 B. 6.37 g/cm^3 C. 0.706 g/cm^3 D. 7.81 g/cm^3 E. 1.42 g/cm^3

60. Kepler-11f orbits a star (Kepler 11) in the Cygnus constellation. The planet's orbital radius is 0.25 AU and its orbital period is 46.7 days. What is the mass of the star in solar masses?

A. 13$M_\odot$ B. 2.6$M_\odot$ C. 2.25$M_\odot$ D. 0.95$M_\odot$ E. 1.16$M_\odot$

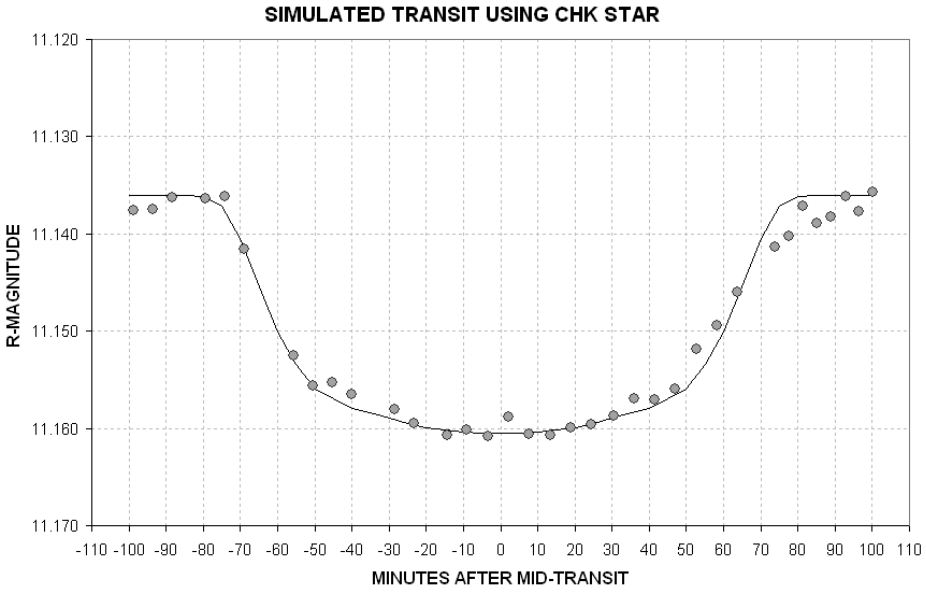
61. Which of the planets listed is most Earth-like in its composition?

A. CoRoT-7b B. Kepler-11f C. Kepler-11b D. Kepler-10b E. 55Cnc e

62. Which of the following correctly interprets the designation Kepler-11f?

A. It was the 11th planet discovered by Johannes Kepler
B. It is the 5th planet (radially outward) in the planetary system orbiting Kepler-11
C. It was the 6th planet discovered to orbit Kepler-11
D. It was the 66th planet detected by the Kepler spacecraft
E. It was the 11th planet detected orbiting Kepler

Consider the following transit light curve for questions 63-68.



63. What is the duration of the transit?

A. 50 minutes B. 2 hours 30 minutes C. 2 hours D. 75 minutes E. 3 hours 20 minutes

64. What is the change in the star's apparent magnitude?

A. 0.16 mag B. 0.136 mag C. 0.024 mag D. 11.16 mag E. 11.136 mag

65. (T4) The center of the transit is not quite flat. What is the reason for this?

A. Limb darkening of the stellar disk
B. The planet does not transit across the center of the stellar disk
C. The orbit of the planet is highly eccentric
D. The orbit of the planet is inclined to the plane of the sky
E. The planet surface has a low albedo

66. How much of the star's flux is lost at mid-transit?

A. 2.19% B. 0.216% C. 1.05% D. 2.69% E. 0.744%

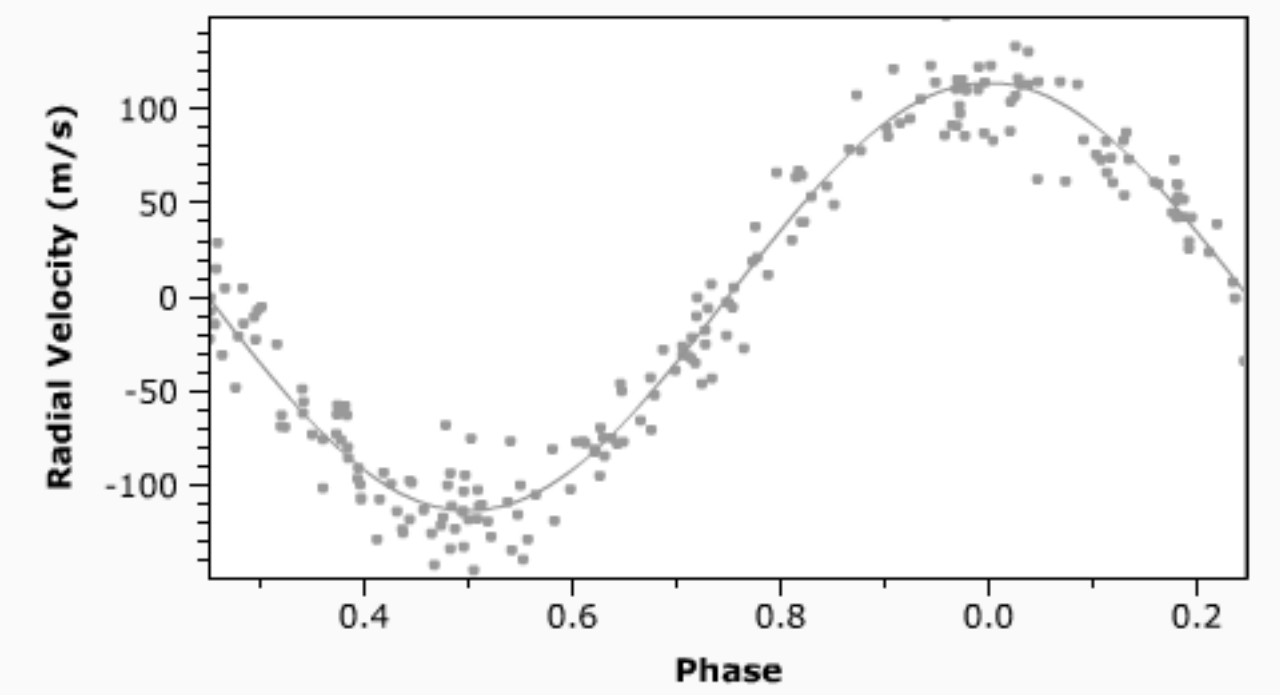
67. What is the term for the sky-projected distance between the center of the stellar disk and the center of the planetary disk at conjunction?

A. inclination B. semi-major axis C. ingress D. impact parameter E. transit depth

68. Transit light curve A has an orbital inclination of 90^{o}, while transit light curve B has an orbital inclination of less than 90^{o}. All other characteristics of the systems are identical (star temperature, planet size, orbital period, etc.). Which of the following comparisons is accurate?

A. Light curve A will have shorter transit duration and larger transit depth than light curve B
B. Light curve A will have longer transit duration and smaller transit depth than light curve B
C. Light curve A will have the same transit duration and a larger transit depth than light curve B
D. Light curve A will have shorter transit duration and smaller transit depth than light curve B
E. Light curve A will have longer transit duration and larger transit depth than light curve B

Consider the following radial velocity curve of a star with an orbiting exoplanet. The star is an A6V with a mass of 1.70$M_\odot$ and the period of the planet's orbit is 7.07 days. There is no inclination and the eccentricity of the orbit is zero. Use this graph for questions 69-73.



69. (T2) What is the orbital radius of the planet, assuming its mass is much less than the planet?

A. 0.086 AU B. 0.041 AU C. 0.179 AU D. 0.032 AU E. 2.03 AU

70. (T7) What is the orbital velocity of the planet, in km/s?

A. 110 km/s B. 220 km/s C. 261 km/s D. 132 km/s E. 347 km/s

71. What is the mass of the planet, in Jupiter masses?

A. 0.56 M_J B. 1.49 M_J C. 7.07 M_J D. 2.21 M_J E. 5.00 M_J

72. What is the most likely classification for this planet?

A. Ice giant B. Hot Jupiter C. Mini-Neptune D. Terrestrial planet E. Super-Earth

73. Which of the following descriptions most likely applies to this planet?

A. The planet condensed from the same cloud as the star in its present position
B. The planet coalesced from gas and dust in the accretion disk when the star was a protostar
C. The planet formed beyond the frost line and migrated inward to its present position
D. The planet formed far away from the star and was pulled inward by the star's gravity
E. The planet formed from a different cloud and was captured by the star

74. H II regions of star formation contain large amounts of:

- **A. Molecular hydrogen**
- **B. Neutral atomic hydrogen**
- **C. Ionized atomic hydrogen**

75. (T12) What defines the "habitable zone"?

- **A. The region around a star within which a planet could sustain liquid water**
- **B. The region on a planet where the insolation is maximal**
- **C. The region on the H-R diagram where stars with long main-sequence lifetimes reside**
- **D. The region on a planet in an eccentric orbit where tidal heating warms the surface**
- **E. The inner part of an accretion disk where heavy elements like silicon gather into terrestrial planets**

76. In a transiting exoplanet orbit, when does the secondary eclipse occur?

- **A. During the transit**
- **B. At inferior conjunction of the planet**
- **C. At superior conjunction of the planet**
- **D. At the periastron of the planet's orbit**
- **E. At the apastron of the planet's orbit**

77. Who pioneered the separation of gas giants into five classes?

- **A. Edouard Roche**
- **B. Richard Alfred Rossiter**
- **C. Wilhelm Gliese**
- **D. George Herbig**
- **E. David Sudarsky**

78. What is the classification of gas giants referenced in #77 based on?

- **A. Orbital parameters such as eccentricity and inclination**
- **B. Temperature and albedo**
- **C. Distance from the host star**
- **D. Metallicity**
- **E. Transit impact parameter**

79. (T3) The first exoplanet ever discovered orbits around which of the following?

- **A. a brown dwarf**
- **B. a pulsar**
- **C. a T-Tauri protostar**
- **D. a main-sequence sun-like star**
- **E. a red dwarf**

80. What is the term for the shifting of radial velocity profiles due to a transiting exoplanet?

- **A. Doppler shift**
- **B. Herbig-haro object**
- **C. Rossiter-McLaughlin effect**
- **D. Foucault bias**
- **E. Wolszczan effect**