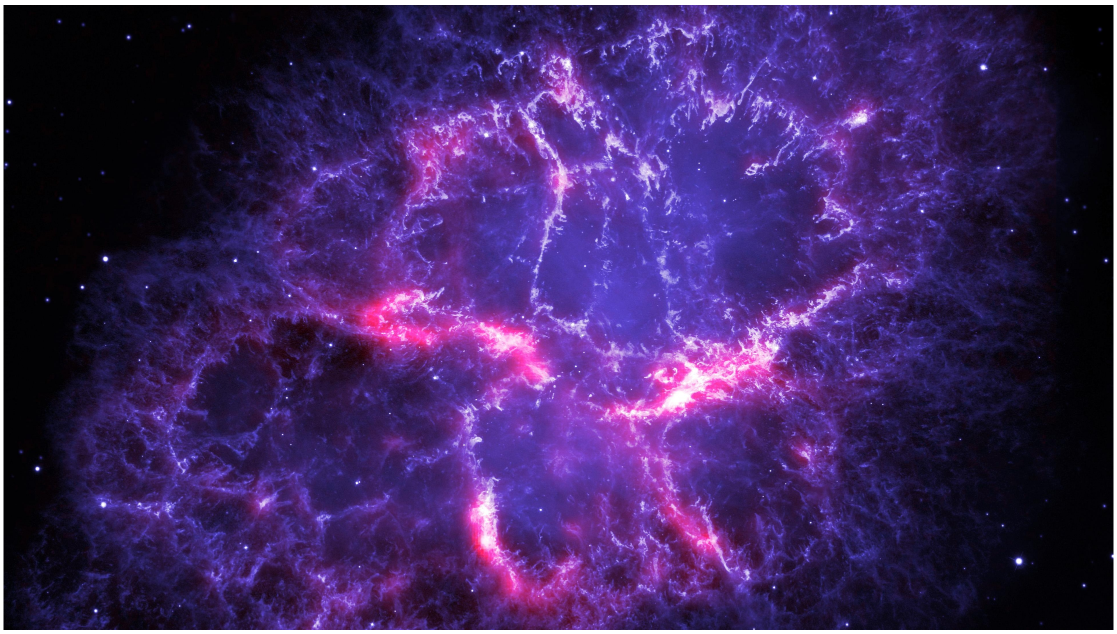
Science Olympiad
Boyceville Invitational
December 7, 2024

Astronomy C



Directions:

- Each team will be given **50 minutes** to complete the exam.
- There are four sections: **§A** (General Knowledge), **§B** (JS9), **§C** (DSOs), and **§D** (Astrophysics).
- **Do not write on the exam or image sheet**. Only write on your answer sheet.
- For calculation questions, **work will be graded**. Please show all your work.
- The use of AI tools (e.g. ChatGPT) are expressly forbidden.
- Tiebreakers, in order: §A6–8, §C1–10, §D1, §C13, §B, §A.
- After the tournament, the exam will be available online at `robertyl.com/scioly`
- Good luck! And may the stars align for you.

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Section A: General Knowledge

This section consists of a mix of multiple choice and free-response questions about general astronomy concepts. Each question is worth 2 points, for a total of 40 points.

1. A main-sequence star of $2\,M_\odot$ will eventually evolve to become which of the following?
   A. Red dwarf
   B. Red giant
   C. Red supergiant
   D. Brown dwarf

2. At what point does a star leave the main sequence?
   A. When it initiates hydrogen burning.
   B. When it runs out of hydrogen fuel.
   C. When it initiates helium burning.
   D. When it runs out of helium fuel.

3. A pre-main sequence star typically has a spectral class that is ____ than it will be when the star reaches the main sequence.
   A. Bluer
   B. Redder
   C. Brighter
   D. Dimmer

Two stars, A and B, have apparent magnitudes $m_A = 5$ and $m_B = 8$.

4. Which of these stars appears brighter from Earth?
   A. Star A
   B. Star B
   C. They have the same brightness.
   D. Not enough information.

5. Which of these stars is intrinsically brighter?
   A. Star A
   B. Star B
   C. They have the same brightness.
   D. Not enough information.

An H–R diagram is shown in Image 1.

6. Order these points by increasing temperature (coldest object first).

7. All of these points fall roughly on the evolutionary track of a $1\,M_\odot$ star. Arrange these points in order of the lifetime of this star.

8. At which one of these points on this track would the $1\,M_\odot$ star be shedding its envelope?

Consider the object in Image 4, which was taken in the optical band.

9. What is the term for the dark region indicated in this image?
   A. Absorption nebula
   B. Diffuse nebula
   C. Emission nebula
   D. Reflection nebula

10. This object primarily obscures light from which of the following regions of the EM spectrum?
    A. Radio
    B. Microwave
    C. Infrared
    D. Optical

11. Obscuring light in this band implies that the dust particles in the nebula are (on order) how large?
    A. 500 nm
    B. 100 µm
    C. 50 mm
    D. 10 m

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12. A protostar that forms with a mass of less than ________ is likely to become a brown dwarf.
    A. $0.008\,M_\odot$
    B. $0.08\,M_\odot$
    C. $0.8\,M_\odot$
    D. $8\,M_\odot$
13. What key process in stars are objects below this mass unable to complete?
14. A very young brown dwarf primarily generates energy through which of the following reactions?
    A. p–p chain hydrogen fusion
    B. CNO cycle hydrogen fusion
    C. Deuterium fusion
    D. Helium fusion

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15. Which of the following planets is most easily detected using the radial-velocity method?
    A. Neptune-like
    B. Hot Jupiter
    C. Terrestrial
    D. Sub-Neptune
16. List two key properties of this planet type that make it easier to detect with radial velocity.

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17. The mass of a Super-Earth planet falls in what mass range?
    A. Less massive than Earth
    B. More massive than Earth, less massive than ice giants
    C. More massive than ice giants, less massive than Jupiter
    D. More massive than Jupiter
18. We can get a general idea of the elemental composition of an exoplanet based on the elemental composition of its star. Why would the composition of these objects be linked?

Taken by JWST, Image 5 displays an intense process of stellar evolution.

19. What is the term for the object in this image?
    A. Circumstellar disk
    B. Relativistic jet
    C. Stellar wind
    D. Herbig–Haro object
20. Briefly (1–2 sentences) describe the process occurring at the “ends” of the objects (indicated by arrows) that cause them to emit light.

Section B: JS9

This section consists of a lab using the JS9 imaging software. Unless otherwise specified, each question is worth 2 points, for a total of 15 points.

On the provided laptop, JS9 should be open, showing **a white dot in the middle of a black screen**. If you do not see this, or need the file re-opened, raise your hand.

For questions 1-3, do not add a region to perform this analysis!
This object dominates the image, so adding regions will be time-consuming and unnecessary.

1. Run `[Analysis > Server-side Analysis: Energy Spectrum]`.

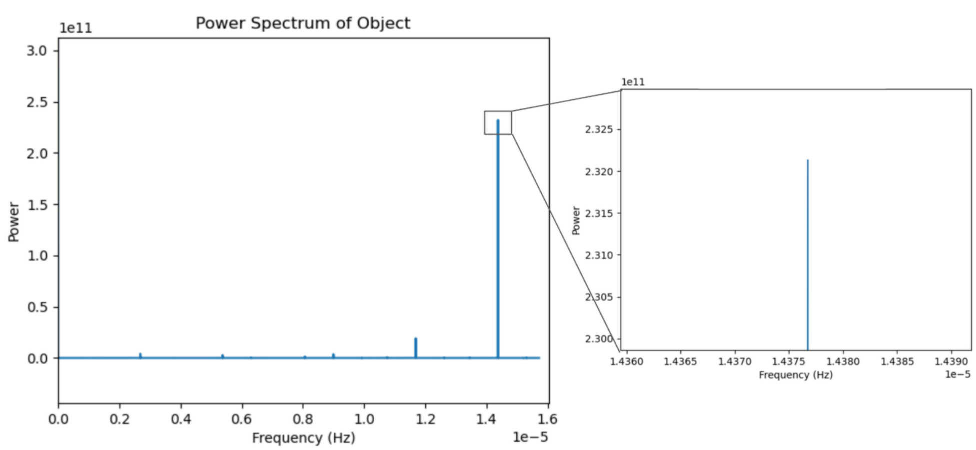
   What major spectral features does this object exhibit? Briefly describe these, and give the wavelengths of any peaks.

2. The lowest energy (farthest left) spectral line is a Neon line, and has a natural width of 0.24 eV. By what factor has this line been broadened?
   (Note: The number that we get will be off, because of the reality of analyzing this raw spectral data. However, it won't be a bad estimate.)

3. This object is a protostar. What is the most likely reason for the broadening of these lines?

This object also has an interesting light curve!

4. The power spectrum of this object is given below. Estimate this object's period, in hours. Be careful with the x–axis—notice that it is scaled by 1×10^{-5}.
   (Hint: Remember the power spectrum x-axis is a frequency, so take its reciprocal to get the period.)



5. What is the exposure of this image, in hours? How does the object's period compare with the exposure?
   (Hint: The FITS header beckons. . .)

6. [3 pts] Encircle the bright central point in a region, with `[Regions > circle]`. Use `[Analysis > Server-side Analysis: Light Curve]` to generate this object's light curve.

   Roughly sketch the resulting waveform. Label the y-axis with the amplitude of any major peaks, and the background.

7. List one mechanism that can result in periodic emission from a protostar.

Section C: Deep-Sky Objects

This section consists of a mix of multiple choice and free-response questions about this year's DSOs. Unless otherwise specified, each question is worth 2 points, for a total of 45 points.

Match the following ten (10) statements with the corresponding deep-sky object in the list below. Each choice may be used once, more than once, or not at all.

A. Orion Nebula	F. TOI-270d
B. HD 80606b	G. WD 1856+534
C. WASP-121b	H. 55 Cancri
D. LTT 9779b	I. Kepler-62
E. K2-18b	J. AU Microscopii

1. This Messier object contains an open cluster, notable for its four young OB stars.
2. A red dwarf with two confirmed Neptune-like planets detected by TESS.
3. Hubble detected a stratosphere (i.e. an atmospheric layer with a temperature inversion) in this ultra-hot Jupiter.
4. This binary system is located just 41 light-years away, with its primary star named after the astronomer who placed the Sun at the center of the universe.
5. JWST detected methane, carbon dioxide, and water vapor in the atmosphere of this planet, which resides in a system with two other confirmed planets.
6. A planetary system with five confirmed exoplanets with the innermost one being a super-Earth.
7. A highly eccentric gas giant in the constellation Ursa Major.
8. Image 2 depicts the spectra of this object.
9. This object is part of a triple star system.
10. A high albedo planet with a G-type main sequence host star.
11. The central region of 30 Doradus is shown in Image 6.
    (a) What process formed the cavity in the bottom left of the image?
    (b) [3 pts] Is the blue star in the cavity younger or older than the stars in the colored regions. Explain your answer.
    (c) What instrument produced this image?
12. WASP-17b is a gas giant tidally locked to its host star.
    (a) Explain what it means to be "tidally locked." Give an example of this occurring in the Solar System.
    (b) What type of silicate was discovered in its atmosphere?
    (c) What observational technique was used to make this discovery?
13. Image 3 shows two light curves.
    (a) Name the wavelengths these two curves are observed in.
    (b) What type of event is occurring in this light curve?
    (c) A typical simplification in the analysis of these curves leads to the bottom of the curve being flat. Give two possible reasons why we don't observe this.
14. Image 7 highlights a star found in the southern hemisphere, located less than 11 light-years from Earth.
    (a) Identify this star.
    (b) A planet was detected orbiting about this star. What method was used to do so?
    (c) What property of the star impacted the validity of the exoplanet's detection?

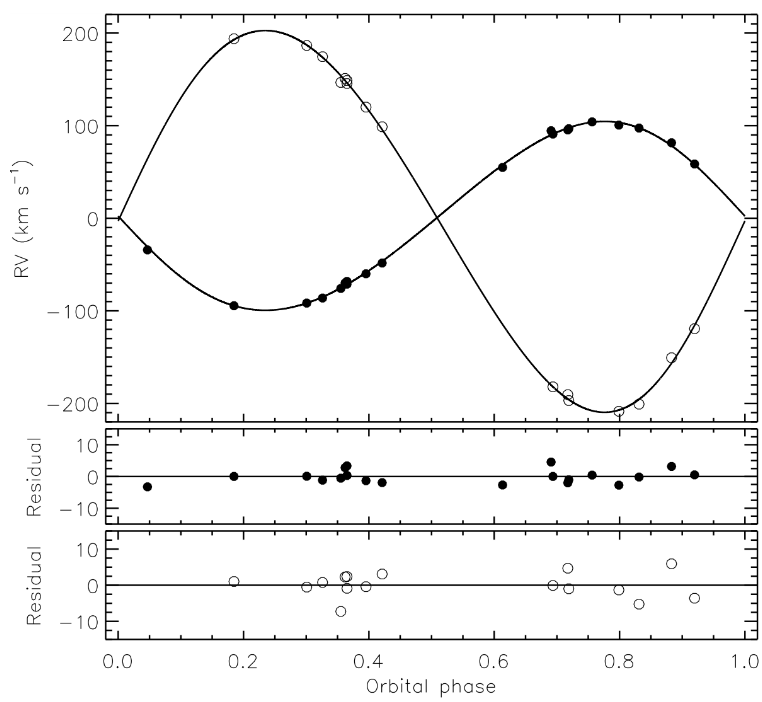
Section D: Astrophysics

This section consists of astrophysics calculations and free-response questions. Points are shown for each sub-question, for a total of 40 points. Numerical answers must be provided to 3 significant figures. Please show your work: no work, no points. Partial credit may be awarded for correct work.

Conversions and constants you may find helpful:

$1\,\text{au} = 1.496 \times 10^{11}\,\text{m}$	$1\,\text{R}_\odot = 6.957 \times 10^{8}\,\text{m}$	$G = 6.674 \times 10^{-11}\,\text{N}\,\text{m}^2\,\text{kg}^{-2}$
$1\,\text{ly} = 9.461 \times 10^{15}\,\text{m}$	$1\,\text{M}_\odot = 1.989 \times 10^{30}\,\text{kg}$	$b = 2.898 \times 10^{-3}\,\text{m}\,\text{K}$
$1\,\text{pc} = 3.086 \times 10^{16}\,\text{m}$	$M_\odot = +4.74$ (Abs. mag.)	$\sigma = 5.670 \times 10^{-8}\,\text{W}\,\text{m}^{-2}\,\text{K}^{-4}$

1. **Binary Stars.** You come across a binary star system containing two main-sequence stars: **A** and **B**. As a generally lucky astronomer, you assume the system is approximately edge-on and measure the radial-velocity of the system over some time, as seen below. Assume star **A** is more massive than star **B**, and all orbits are circular.



(a) [2 pts] This system has a parallax of 0.001″; how far away is it, in light-years?

(b) [2 pts] Is the binary system moving relative to the observer? Why or why not?

(c) [2 pts] What does our assumption—that the system is viewed edge-on—allow us to conclude?

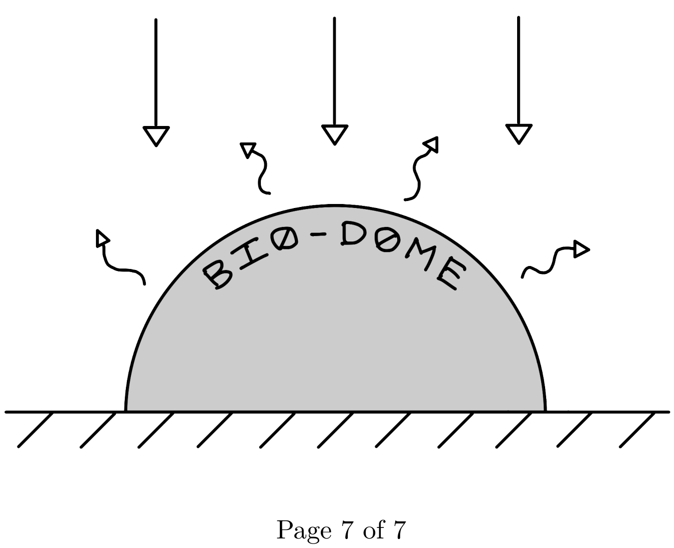
(d) [3 pts] Given the period of the stars is 3 days, find the radius of each star's orbit from the center of mass of the system, in meters.

(e) [3 pts] Find the mass of the entire binary system, in solar masses.

(f) [2 pts] Find the mass of star **A**, M_A, and star **B**, M_B, individually in solar masses.

2. **A Little Shifty.** Continuing with the same scenario as the previous question, after more careful observation, you estimate that one of the stars has a surface peak wavelength emission at 300 nm.
   (a) [2 pts] What is the surface temperature of the star, in Kelvin?
   (b) [2 pts] Identify the spectral type and subclass of this star. *(Hint: It's a letter, then a number.)*
   (c) [1 pt] Which star is more likely to have this surface temperature?
   (If you couldn't derive the masses of the stars, assume $M_A = 6\,\mathrm{M}_\odot$ and $M_B = 2\,\mathrm{M}_\odot$.)
   (d) [2 pts] What parts of the orbital phase in the radial-velocity curve (from question 1) should we observe the stars to get the most accurate surface temperature estimates?
   (e) [3 pts] Another astronomer makes an observation and finds the star has a peak wavelength 0.04 nm less than the original 300 nm, which is your (perfectly accurate) measurement. What was the radial velocity of the star at this time? Is it moving towards or away from Earth?
   (f) [2 pts] Assuming your measurement was made at the optimal time, how long after your observation (in days) was their observation made? As a reminder, the total orbital period is 3 days.
   (Note: There are multiple valid answers, but you need only list one of them.)

3. **Resolution!** A planet that was previously thought to have orbited a single host star is found to be orbiting a very compact set of binary stars.
   (a) [2 pts] If the planet was discovered using direct imaging, what common tool would have been used to blot out the central stars?
   (b) [3 pts] If the diameter of your space telescope is 10 meters and you are observing the system at a wavelength of 10 micrometers, what is the limiting angular resolution of your telescope (by diffraction), in radians?
   (c) [2 pts] The wavelength used by the telescope in part (b) is often used for direct imaging. Why?
   (d) [3 pts] The stars have an absolute magnitude of +1 and +4, respectively. When viewed together, what is their combined absolute magnitude?
   (e) [4 pts] In the far future, astro-neers land and settle on this planet. They find it orbits at a distance of 7 au and is tidally locked to its host stars. More importantly, it lacks an atmosphere!
   So, they construct a bio-dome 2 km in diameter at the planet's substellar point. The shell of the bio-dome is designed to replicate the thermal properties of Earth, having a bond albedo of 0.3 and an emissivity of 0.9. For simplicity, we'll assume the bio-dome is an opaque hemisphere.
   (Note: Use +4.74 for the absolute magnitude of the Sun.)
   What is the temperature in the bio-dome, in Celsius? Is it habitable?



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Astronomy C Image Sheet

Directions:

- Do not flip until the exam begins.

Image 1

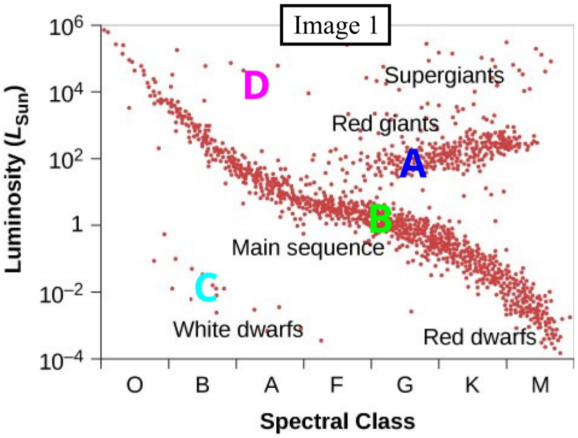


Image 2

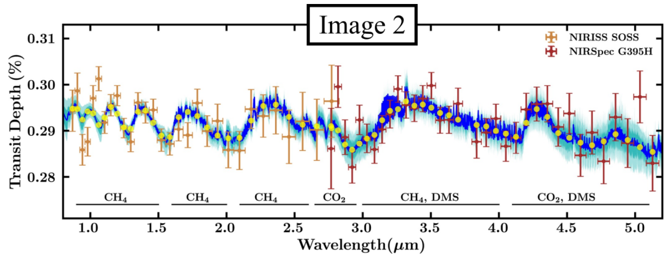


Image 3

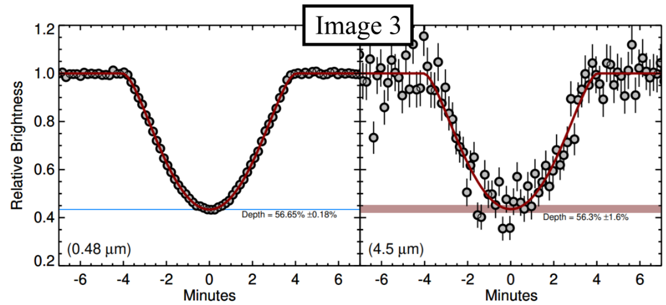


Image 4

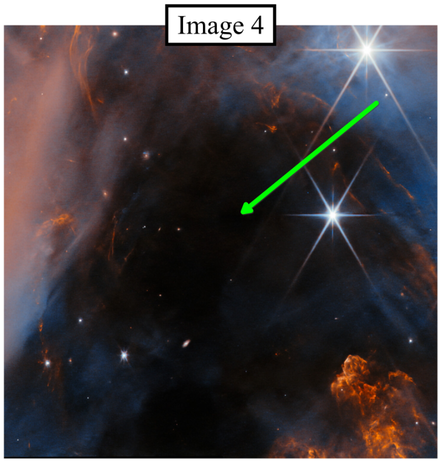


Image 5

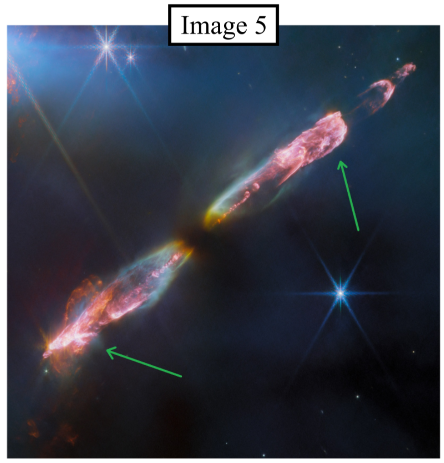


Image 6

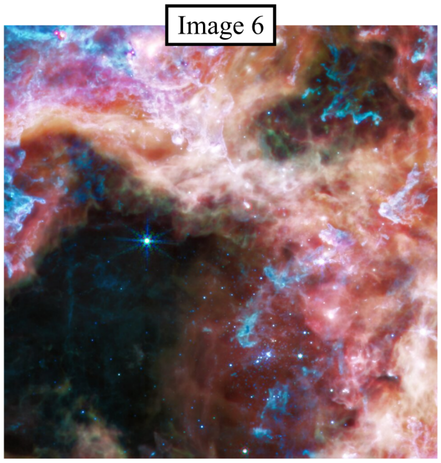
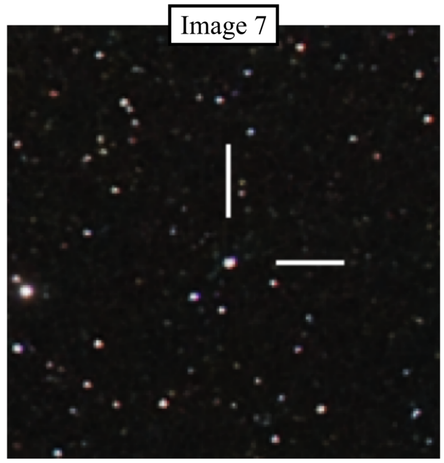


Image 7




File Edit View Zoom Scale Color Regions WCS Analysis Help
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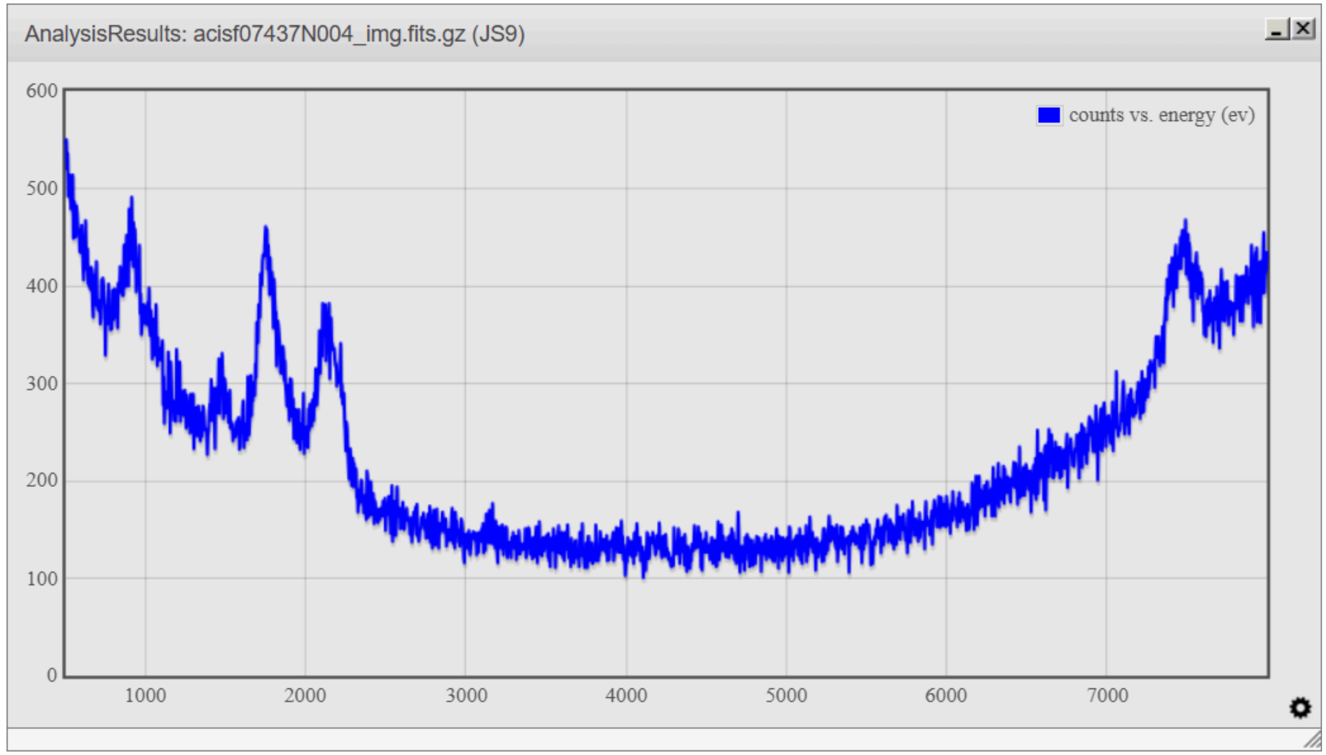
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400
300
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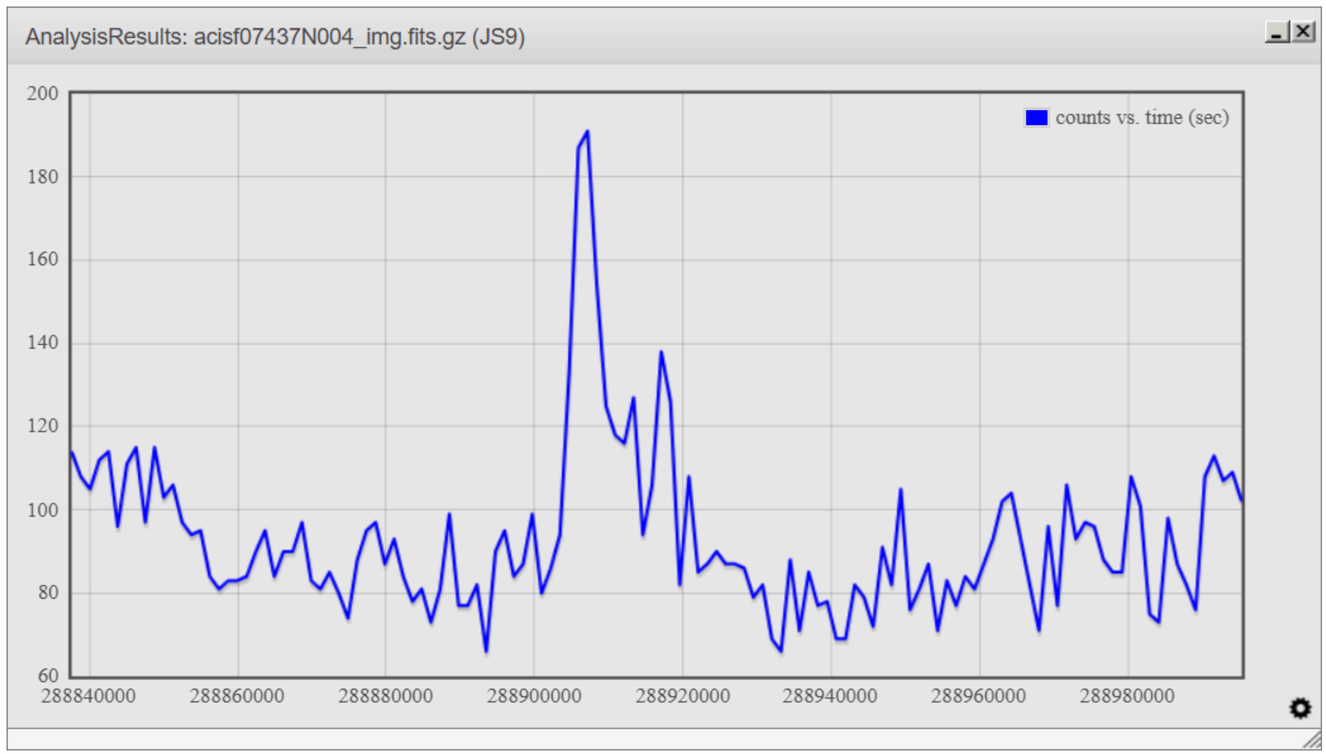
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counts vs. time (sec)
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180
160
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NAXIS2  =                 1024 / y axis dimension
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COMMENT                               | AXAF FITS   File |
COMMENT                               +------------------+
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COMMENT  >    This file is written following certain AXAF-ASC    <
COMMENT  >    conventions which are documented in ASC-FITS-2.0   <
COMMENT  **********************************************************
COMMENT
COMMENT                        / Configuration control block--------------------
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COMMENT character at the end of a string which is then continued
COMMENT on subsequent keywords whose name = 'CONTINUE'
COMMENT
COMMENT                        / Time information block-------------------------
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DATE-END= '2007-02-27T20:43:26' / Observation end date
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TIMEUNIT= 's       '           / Time unit
BTIMNULL=  2.8648251009781E+08 / Basic Time offset (s)
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TIERABSO=  5.0000000000000E-05 / default
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STARTOBT=  0.0000000000000E+00 / On-Board MET close to STARTMJF and STARTMNF
TIMEPIXR=  5.0000000000000E-01 / default
DATACLAS= 'OBSERVED'           / default
RADESYS = 'ICRS    '           / default
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COMMENT
COMMENT                        / Observation information block------------------
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GRATING = 'HETG    '           / Grating
DETNAM  = 'ACIS-456789'        / Detector
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DEC_PNT = -3.4711154867771E+01 / [deg] Pointing Dec
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COMMENT
COMMENT AXAF FITS File ACIS specific keywords
COMMENT
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ACSYS3  = 'DET:ASC-FP-1.1'     / reference for focal plane coord system
ACSYS4  = 'SKY:ASC-FP-1.1'     / reference for sky coord system
ACSYS5  = 'GDP:ASC-GDP-1.1'    / Grating coordinate system
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COMMENT Product specific keywords are inserted here
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COMMENT
COMMENT                        / Column format information block----------------
COMMENT
COMMENT
COMMENT                        / History information block----------------------
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HISTORY  PARM  :template=/vobs/ASC_DR_TLM/src/dr/tlm/template_dir/acis_fASC00006
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HISTORY  PARM  :template=/vobs/ASC_DR_TLM/src/dr/tlm/template_dir/acis_cASC00008
HISTORY  CONT  :onfig_file.dat@@/main/2                                 ASC00009
HISTORY  PARM  :template=/vobs/ASC_DR_TLM/src/dr/tlm/template_dir/acis_gASC00010
HISTORY  CONT  :roup_info.dat@@/main/12                                 ASC00011
HISTORY  PARM  :template=/vobs/ASC_DR_TLM/src/dr/tlm/template_dir/acis_dASC00012
HISTORY  CONT  :p_info.dat@@/main/21                                    ASC00013
HISTORY  PARM  :template=/vobs/ASC_DR_TLM/src/dr/tlm/template_dir/acis_dASC00014
HISTORY  CONT  :eahk_dp_info.dat@@/main/1                               ASC00015
HISTORY  PARM  :template=/vobs/ASC_DR_TLM/src/dr/tlm/template_dir/acis_cASC00016
HISTORY  CONT  :ommon_dp_info.dat@@/main/9                              ASC00017
HISTORY  PARM  :template=/vobs/ASC_DR_TLM/src/dr/tlm/template_dir/acis_cASC00018
HISTORY  CONT  :al_info.dat@@/main/2                                    ASC00019
LONGSTRN= 'OGIP 1.0'           / The HEASARC Long String Convention may be used.
COMMENT   This FITS file may contain long string keyword values that are
COMMENT   continued over multiple keywords.  The HEASARC convention uses the &
COMMENT   character at the end of each substring which is then continued
COMMENT   on the next keyword which has the name CONTINUE.
TITLE   = 'Accretion or a Corona? Definitive Observations of the Young Accreti&'
CONTINUE  'ng Star TW Hydrae'  / Proposal title
OBSERVER= 'Dr. Nancy Brickhouse' / Principal investigator
OBJECT  = 'TW Hya  '           / Source name
DS_IDENT= '10.25574/07437'     / Dataset Identifier: DOI
OBS_ID  = '7437    '           / Observation id
SEQ_NUM = '200448  '           / Sequence number
HISTORY  TOOL  :acis_format_events   2020-12-16T11:31:32                ASC00020
HISTORY  PARM  :infile=@/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_ASC00021
HISTORY  CONT  :724400982n381/input/acisf07437_000N004_evt0.lis         ASC00022
HISTORY  STCK  :/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_72440098ASC00023
HISTORY  CONT  :2n381/input/acisf288836947N003_0_evt0.fits[time=28883600ASC00024
HISTORY  CONT  :5.5346600:288996206.8922700]                            ASC00025
ONTIME  =  1.5902719940764E+05 / [s] Sum of GTIs
ONTIME7 =  1.5902719940764E+05 / [s] Sum of GTIs
ONTIME4 =  1.5901747644645E+05 / [s] Sum of GTIs
ONTIME5 =  1.5902719940764E+05 / [s] Sum of GTIs
ONTIME6 =  1.5902071739697E+05 / [s] Sum of GTIs
ONTIME8 =  1.5902719940764E+05 / [s] Sum of GTIs
ONTIME9 =  1.5902395840734E+05 / [s] Sum of GTIs
LIVETIME=  1.5701350125405E+05 / [s] Livetime
LIVTIME7=  1.5701350125405E+05 / [s] Livetime
LIVTIME4=  1.5700390141086E+05 / [s] Livetime
LIVTIME5=  1.5701350125405E+05 / [s] Livetime
LIVTIME6=  1.5700710132251E+05 / [s] Livetime
LIVTIME8=  1.5701350125405E+05 / [s] Livetime
LIVTIME9=  1.5701030129326E+05 / [s] Livetime
EXPOSURE=  1.5701350125405E+05 / [s] Exposure time
EXPOSUR7=  1.5701350125405E+05 / [s] Exposure time
EXPOSUR4=  1.5700390141086E+05 / [s] Exposure time
EXPOSUR5=  1.5701350125405E+05 / [s] Exposure time
EXPOSUR6=  1.5700710132251E+05 / [s] Exposure time
EXPOSUR8=  1.5701350125405E+05 / [s] Exposure time
EXPOSUR9=  1.5701030129326E+05 / [s] Exposure time
DTCOR   =  9.8733739787229E-01 / Dead time correction
HISTORY  STCK  :/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_72440098ASC00026
HISTORY  CONT  :2n381/input/acisf288836947N003_1_evt0.fits[time=28883600ASC00027
HISTORY  CONT  :5.5346600:288996206.8922700]                            ASC00028
HISTORY  STCK  :/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_72440098ASC00029
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HISTORY  CONT  :2n381/input/acisf288836947N003_2_evt0.fits[time=28883600ASC00030
HISTORY  CONT  :5.5346600:288996206.8922700]                            ASC00031
HISTORY  STCK  :/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_72440098ASC00032
HISTORY  CONT  :2n381/input/acisf288836947N003_3_evt0.fits[time=28883600ASC00033
HISTORY  CONT  :5.5346600:288996206.8922700]                            ASC00034
HISTORY  STCK  :/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_72440098ASC00035
HISTORY  CONT  :2n381/input/acisf288836947N003_4_evt0.fits[time=28883600ASC00036
HISTORY  CONT  :5.5346600:288996206.8922700]                            ASC00037
HISTORY  STCK  :/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_72440098ASC00038
HISTORY  CONT  :2n381/input/acisf288836947N003_5_evt0.fits[time=28883600ASC00039
HISTORY  CONT  :5.5346600:288996206.8922700]                            ASC00040
HISTORY  PARM  :biasfile=@/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_LASC00041
HISTORY  CONT  :1_724400982n381/input/acisf07437_000N004_bias0.lis      ASC00042
HISTORY  STCK  :/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_72440098ASC00043
HISTORY  CONT  :2n381/input/acisf288835629N003_0_bias0.fits             ASC00044
HISTORY  STCK  :/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_72440098ASC00045
HISTORY  CONT  :2n381/input/acisf288835629N003_1_bias0.fits             ASC00046
HISTORY  STCK  :/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_72440098ASC00047
HISTORY  CONT  :2n381/input/acisf288835629N003_2_bias0.fits             ASC00048
HISTORY  STCK  :/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_72440098ASC00049
HISTORY  CONT  :2n381/input/acisf288835629N003_3_bias0.fits             ASC00050
HISTORY  STCK  :/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_72440098ASC00051
HISTORY  CONT  :2n381/input/acisf288835629N003_4_bias0.fits             ASC00052
HISTORY  STCK  :/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_72440098ASC00053
HISTORY  CONT  :2n381/input/acisf288835629N003_5_bias0.fits             ASC00054
HISTORY  PARM  :exrfile=/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_ASC00055
HISTORY  CONT  :724400982n381/output/acisf288836947N003_0_deltexr0.fits ASC00056
HISTORY  CONT  :/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_72440098ASC00057
HISTORY  CONT  :2n381/output/acisf288836947N003_1_deltexr0.fits /dsops/rASC00058
HISTORY  CONT  :epro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_724400982n381/ouASC00059
HISTORY  CONT  :tput/acisf288836947N003_2_deltexr0.fits /dsops/repro5/sdASC00060
HISTORY  CONT  :p.1/opus/prs_run/tmp//ACIS_F_L1_724400982n381/output/aciASC00061
HISTORY  CONT  :sf288836947N003_3_deltexr0.fits /dsops/repro5/sdp.1/opusASC00062
HISTORY  CONT  :/prs_run/tmp//ACIS_F_L1_724400982n381/output/acisf288836ASC00063
HISTORY  CONT  :947N003_4_deltexr0.fits /dsops/repro5/sdp.1/opus/prs_runASC00064
HISTORY  CONT  :/tmp//ACIS_F_L1_724400982n381/output/acisf288836947N003_ASC00065
HISTORY  CONT  :5_deltexr0.fits                                         ASC00066
HISTORY  PARM  :outfile=/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_ASC00067
HISTORY  CONT  :724400982n381/output/acisf07437_000N004_epr1.fits       ASC00068
HISTORY  PARM  :outbias=/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_ASC00069
HISTORY  CONT  :724400982n381/output/acisf07437_000N004                 ASC00070
HISTORY  PARM  :expstatsfile=/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_ASC00071
HISTORY  CONT  :F_L1_724400982n381/output/acisf07437_000N004_stat1.fits ASC00072
HISTORY  PARM  :obsfile=/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_ASC00073
HISTORY  CONT  :724400982n381/input/axaff07437_000N001_obs1.par         ASC00074
HISTORY  PARM  :logfile=/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_ASC00075
HISTORY  CONT  :724400982n381/output/acis_format_events.log             ASC00076
HISTORY  PARM  :pbkfile=@/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1ASC00077
HISTORY  CONT  :_724400982n381/input/acisf07437_000N004_pbk0.lis        ASC00078
HISTORY  STCK  :/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_F_L1_72440098ASC00079
HISTORY  CONT  :2n381/input/acisf288836947N003_pbk0.fits[time=288836005.ASC00080
HISTORY  CONT  :5346600:288996206.8922700]                              ASC00081
HISTORY  PARM  :bias_correct=yes                                        ASC00082
HISTORY  PARM  :oc_correct=yes                                          ASC00083
HISTORY  PARM  :badoclkfile=/dsops/repro5/sdp.1/opus/prs_run/tmp//ACIS_FASC00084
HISTORY  CONT  :_L1_724400982n381/output/acisf07437_000N004_badoclk1.fitASC00085
HISTORY  CONT  :s                                                       ASC00086
HISTORY  PARM  :geompar=geom                                            ASC00087
TIME_ADJ= 'NONE    '           / time adjustment algorithm
ASPTYPE = 'KALMAN  '
HISTORY  PARM  :eventdef={d:time,i:expno,s:chipx,s:chipy,s:phas,s:ccd_idASC00088
HISTORY  CONT  :,s:node_id,x:status}                                    ASC00089
HISTORY  PARM  :telev1={d:time,i:expno,s:chipx,s:chipy,s:phas,s:ccd_id,sASC00090
HISTORY  CONT  ::node_id,x:status}                                      ASC00091
HISTORY  PARM  :vflev1={d:time,i:expno,s:chipx,s:chipy,s:phas,s:ccd_id,sASC00092
HISTORY  CONT  ::node_id,x:status}                                      ASC00093
HISTORY  PARM  :cclev1={d:time,i:expno,s:chipx,s:chipy,s:phas,s:ccd_id,sASC00094
HISTORY  CONT  ::node_id,x:status}                                      ASC00095
HISTORY  PARM  :tegrflev1={d:time,i:expno,s:chipx,s:chipy,l:pha,s:fltgraASC00096
HISTORY  CONT  :de,s:corn_pha,s:ccd_id,s:node_id,x:status}              ASC00097
HISTORY  PARM  :ccgrlev1={d:time,i:expno,s:chipx,s:chipy,l:pha,s:fltgradASC00098
HISTORY  CONT  :e,s:corn_pha,s:ccd_id,s:node_id,x:status}               ASC00099
HISTORY  PARM  :verbose=0                                               ASC00100
HISTORY  PARM  :tempbias=no                                             ASC00101
HISTORY  PARM  :clobber=no                                              ASC00102
HISTORY  PARM  :PIXLIB Version: 4.0.0                                   ASC00103
HISTORY  PARM  :******     PIXLIB Parameter File      *****             ASC00104
HISTORY  PARM  :/dsops/repro5/sdp.1/opus/prs_run/tmp/ACIS_F_L1_724400982ASC00105
HISTORY  CONT  :n381/output/param/geom.par:                             ASC00106
HISTORY  PARM  :instruments  = /data/chandra_caldb/sdp/data/chandra/defaASC00107
HISTORY  CONT  :ult/geom/telD1999-07-23geomN0006.fits(CALDB)            ASC00108
HISTORY  PARM  :aimpoints    = /data/chandra_caldb/sdp/data/chandra/defaASC00109
HISTORY  CONT  :ult/aimpts/telD1999-07-23aimptsN0002.fits(CALDB)        ASC00110
HISTORY  PARM  :tdet         = /data/chandra_caldb/sdp/data/chandra/defaASC00111
HISTORY  CONT  :ult/tdet/telD1999-07-23tdetN0001.fits(CALDB)            ASC00112
HISTORY  PARM  :sky          = /data/chandra_caldb/sdp/data/chandra/defaASC00113
HISTORY  CONT  :ult/sky/telD1999-07-23skyN0002.fits(CALDB)              ASC00114
HISTORY  PARM  :shell        = /data/chandra_caldb/sdp/data/chandra/defaASC00115
HISTORY  CONT  :ult/sgeom/telD1999-07-23sgeomN0001.fits(CALDB)          ASC00116
HISTORY  PARM  :obsfile      = 2007-02-26T00:13:25(/dsops/repro5/sdp.1/oASC00117
HISTORY  CONT  :pus/prs_run/tmp//ACIS_F_L1_724400982n381/input/axaff0743ASC00118
HISTORY  CONT  :7_000N001_obs1.par)                                     ASC00119
HISTORY  PARM  :******     PIXLIB System Configuration      ******      ASC00120
HISTORY  PARM  :Telescope = axaf                                        ASC00121
HISTORY  PARM  :Focal Length (mm) = 10070.000                           ASC00122
HISTORY  PARM  :Detector = ACIS                                         ASC00123
HISTORY  PARM  :Focal Plane Sys. = FP-1.1                               ASC00124
HISTORY  PARM  :Tiled Detector Plane Sys. = ACIS-2.2                    ASC00125
HISTORY  PARM  :SIM Offset (mm) = (0.684 0.75 236.552)                  ASC00126
HISTORY  PARM  :Aim Point(AI1) (mm) = (-0.782348 0 -237.5)              ASC00127
```

Science Olympiad
Boyceville Invitational
December 7, 2024

Astronomy C Answer Sheet

Team Name and Number: ____________________

Participant Name(s): ____________________

Total Score: ____ / 140 **Rank:** ____

Directions:

- Read the directions on the exam cover.

Section A (40 points)

1. ______ 2. ______ 3. ______ 4. ______

5. ______ 6. ______ 7. ______ 8. ______

9. ______ 10. ______ 11. ______ 12. ______

13. ______

14. ______ 15. ______

16. ______

17. ______

18. ______

19. ______

20. ______

Section B (15 points)

1.

2.

3.

4.

5.

6.

7.

Section C (45 points)

1. ______ 2. ______ 3. ______ 4. ______ 5. ______

6. ______ 7. ______ 8. ______ 9. ______ 10. ______

11. (a)

(b)

(c)

12. (a)

(b)

(c)

13. (a)

(b)

(c)

14. (a)

(b)

(c)

Section D (40 points)

1. (a)

(b)

(c)

(d)

(e)

(f)

2. (a)

(b)

(c)

(d)

(e)

(f)

3. (a)

(b)

(c)

(d)

(e)

Science Olympiad
Boyceville Invitational
December 7, 2024

Astronomy C Answer Key

Exploring the World of Science

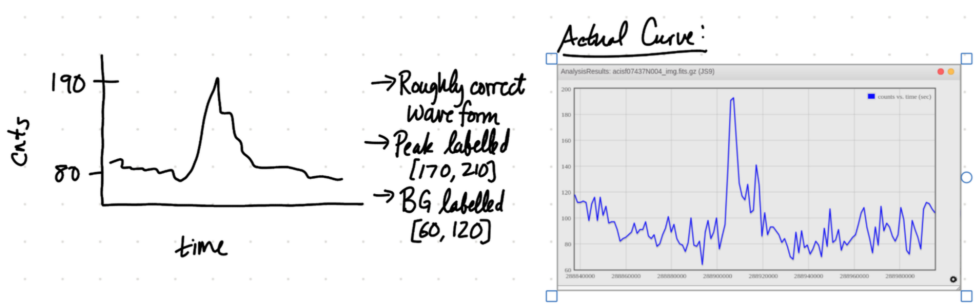
ANSWER KEY ANSWER KEY
ANSWER KEY ANSWER KEY
ANSWER KEY ANSWER KEY
ANSWER KEY ANSWER KEY
ANSWER KEY ANSWER KEY
ANSWER KEY ANSWER KEY
ANSWER KEY ANSWER KEY
ANSWER KEY ANSWER KEY

Section A (40 points)

1. B
2. B
3. B
4. A
5. D
6. ABDC
7. BADC
8. D
9. A
10. D
11. A
12. B
13. Hydrogen fusion
14. C
15. B
16. High mass and small orbit distance
17. B
18. The exoplanet and its star form from the same material.
19. D
20. High velocity ejecta hit dense pockets of interstellar medium and form shocks. The shocked material is ionized and excited which then produces emissions.

Section B (15 points)

1. Five spectral peaks at 915 eV, 1480 eV, 1750 eV, 2130 eV, and 7480 eV. (Accept within ±10 %)
   Don't deduct for omitting 1480 eV or 7480 eV peaks.
2. Accept 300 to 800.
3. Rotation of the accretion disk.
4. 19.4 h (Accept 18.8–19.7). Half credit for 69 000 s (Accept 68 000–71 000).
5. 43.6 h. Half credit for 1.57×10^5 s. Exposure is greater than object's period.
6. [3 pts]



7. Rotation from brightness variations. For instance, clumps in the disk or envelope transiting the star, or dark sunspots on the star rotating in and out of view.

Section C (45 points)

1. A
2. J
3. C
4. H
5. F
6. H or I
7. B
8. E
9. G
10. D

11. (a) Stellar wind from young stars pushes gas and dust out
    (b) [3 pts] The blue star is older (1). Its stellar wind has had enough time to clear out the material it formed in. The stars in the colored regions are newly forming protostars still shrouded in dust. Any justification based on the presence of the cavity (2).
    (c) Near-Infrared Camera (NIRCam)
    Only (1) if mentions infrared or JWST.
12. (a) Rotational period equals orbital period (1). Moon, Phobos, Deimos, Pluto/Charon, etc. (1)
    (b) Quartz
    (c) Transmission spectroscopy
13. (a) Optical (left), infrared (right) (1 each)
    (b) Transit
    (c) Limb darkening, grazing/high impact factor (1 each)
14. (a) Epsilon Eridani
    (b) Radial-velocity
    (c) Magnetic activity led to doppler jitter

Section D (40 points)

Award up to half credit for correct work with incorrect answer

1. (a) [2 pts] $d = 1/p$. $d = 3260\,\text{ly}$ (Accept 3250–3270)
   (b) [2 pts] No, the system is stationary (1). When both of the curves "meet", the orbital component of their radial velocity is 0 so we get the radial velocity of the system (1).
   (c) [2 pts] The maximum radial velocity represents the true velocity of the star.
   (d) [3 pts] $vP = 2\pi r$. $r_A = 4.13 \times 10^9\,\text{m}$ (Accept 3.71–4.54) and $r_B = 8.25 \times 10^9\,\text{m}$ (Accept 7.42–9.08)
   Only (2) if r_A and r_B flipped.
   (e) [3 pts] $a = r_A + r_B$ and $G(M_A + M_B)/(4\pi^2) = a^3/P^2$. $M_A + M_B = 8.35\,\text{M}_\odot$ (Accept 7.51–9.19)
   (f) [2 pts] $M_A r_A = M_B r_B$. $M_A = 5.57\,\text{M}_\odot$ (Accept 5.00–6.13) and $M_B = 2.78\,\text{M}_\odot$ (Accept 2.50–3.06)
   Only (1.5) if M_A and M_B flipped.

2. (a) [2 pts] $T = b/\lambda$. $T = 9660\,\text{K}$ (Accept 8700–10 600)
   (b) [2 pts] A (1), 0 or 1 (1)
   (c) [1 pt] Star B
   (d) [2 pts] When radial velocity is zero (2). (Also accept $\phi = 0, 1$ (1) and $\phi = 0.5$ (1))
   (e) [3 pts] $v_r/c = \Delta\lambda/\lambda_0$. $v_r = 40\,\text{km}\,\text{s}^{-1}$ (Exact) (2). Moving towards Earth (1).
   (f) [2 pts] $v \sin\phi = v_r \Rightarrow \phi = 23.6^\circ$ or 156°. Multiple answers accepted: 0.20, 1.30, 1.70 and 2.80 d.

3. (a) [2 pts] Coronagraph
   (b) [3 pts] $1.22(\lambda/d) = \sin\theta_R \approx \theta_R$. $\theta_R = 1.22 \times 10^{-6}\,\text{rad}$ (Exact)
   (c) [2 pts] Planets are primarily bright in infrared and, more importantly, the brightness ratio between the planet and its star is highest for infrared. (Accept either justification)
   Only (1) if mentions infrared.
   (d) [3 pts] $M = -2.5\log_{10} L$. $+0.933$ (Exact)
   (e) [4 pts] Identify expression for:
   - absorbed heat $[\dot{Q}_{\text{in}} = L \times (\pi D^2/4)/(4\pi d^2) \times (1-\alpha)]$ (1)
   - and emitted heat $[\dot{Q}_{\text{out}} = \varepsilon\sigma T_{\text{eq}}^4 \times (\pi D^2/2)]$ (1).

   $T_{\text{eq}} = 282\,\text{K} = 9.29\,^\circ\text{C}$ (Accept 0–20) (1.5). Yes, it is habitable (0.5).
   Only (1) if using "standard" equilibrium temperature formula.