**R.T.J McAteer** **CUME #444** **12 Sept 2020**

This CUME is motivated by the science drivers and instrumental capabilities of the Daniel K. Inouye Solar Telescope. The questions are based on the accompanying pdf, "*An Introduction to Science with the DKIST*". This document was written by the DKIST team as an introduction to the DKIST science and DKIST telescope for the professional astrophysics community.

- At the end of your exam time, photograph your written solutions and send them directly to me (mcateer@nmsu.edu). I will check your submitted document for clarity and completion and reply to acknowledge your submission.
- There are 45 total points available. A total of 32 points is *expected* to be a passing grade.
- Take a new page for each question. This makes it much easier to award partial credit for incorrect answers.
- Be careful with your time management. Do not allow yourself to get stuck on any one question. If you find yourself spending a long time at one question without success, move on and come back to it later. In particular I suggest you try to get through all questions inside the first ~90 minutes (so do about 2 minutes per point) and then use the remaining ~30 minutes to go back and complete any parts you have skipped.
- Calculators are only to be used for calculations. You may not store equations.
- You may not use your cell phone at any time. You may not use the internet. You may not consult any notes from classes.
- Show all work for full points. Attempt all parts of all questions. Unless informed otherwise, use cgs units in your calculations.
- Show the derivation of any constants not provided.
- Adopt the following values for constants
    - Mass of a proton, $m_p = 1.7 \times 10^{-24}$ g
    - Boltzmann constant, $k_B = 1.4 \times 10^{-16}$ erg $K^{-1}$
    - For the Sun, surface gravity $g = 2.7 \times 10^4$ cm $s^{-2}$
    - For the Sun, photospheric temperature T ~ 5800K
    - 1 solar radii = $7 \times 10^{10}$ cm
    - The Sun subtends an angle of $0.5^o$ at 1AU

1. This blurb is intended for an astrophysics audience, so define the following terms *from an astrophysics perspective*. Use 2-3 sentences for each one and include a brief sketch if that helps you in your definition.

- “non-linear dynamics” (page 1)
- “highly ionized magnetic plasma” (page 1)
- “adaptive optics” (page 1, 2, 3, 5, 6)
- “angular resolution” (page 2)
- “photon mean free path” (page 2, 3)
- “flux tubes” (page 2, 3)
- “thermal bifurcation” (page 4)

**2 points each**

**2.** The equation for angular resolution is

$$\theta = 1.22\frac{\lambda}{D}$$

NOTE: θ is in radians.

**(a)** Describe why this equation has a prefactor of 1.22

**2 points**

**(b)** Calculate the angular resolution of DKIST (4m diameter) in arcsec. Use a typical wavelength from the article, and give your answer in arcsec. (Note, the article states several typical values for expected resolution, so use these to guide your answer)

**2 points**

**(c)** Starting from a hydrodynamic, gravitationally stratified atmosphere

$\nabla P \quad + \rho g \quad = 0$ ,

For an ideal gas, $P = 2n_e\, k_B\, T$

Derive the following equation for scale height, H

$H = (2k_BT / m_pg)$

**5 points**

**(d)** Determine the vertical scale height in the solar photosphere and thereby show that this is resolved by the expected angular resolution of DKIST.

**3 points**

**3.** When observing a star of apparent magnitude, m, the equation for expected signal , S, from any telescope is given as

$S = 0.7\ N_0\ 10^{-0.4m}\ \tau\ D^2\ \Delta\lambda$

Where $N_0 = 10^4$ photons / (sec cm$^2$ nm), $\tau$ is the system transmission factor, D is mirror diameter, $\Delta\lambda$ is spectral resolution. Let's now look at each of the components one by one.

**(a)** *Consider τ, system transmission, for DKIST*
The system transmission factor (between 0 and 1) accounts for photon losses.The equation to calculate $\tau$ for DKIST is as follows

$$\tau = 0.7 \text{ X } (0.9)^{23} = 0.062$$

By considering this calculation for $\tau$, discuss the two main contributing factors to system transmission. In your discussion, consider each of the following.
- What does the 0.7 component represent?
- What does the 0.9 represent?
- Why is there a 23 exponent?
(HINT: system transmission factor incorporates everything from the top of the atmosphere to the detector, and DKIST has no refracting optics).
- Finally, how did the DKIST team go about making sure $\tau$ for DKIST is as large as possible?

**4 points**

**(b)** *Consider Δλ, spectral resolution for DKIST*
The spectral resolution for Fe I (630nm) is about 3.5 picometers, so the basic equation for spectral resolving power is then $R = \lambda / \Delta\lambda = 180{,}000$. State two problems with directly comparing this number to R calculated from other nighttime spectroscopy instruments.

**2 points**

**(c)** *Consider $N_0\ 10^{-0.4m}$ for DKIST*
For solar telescopes, this component in the equation has to be altered to $N_0\ 10^{-0.4B}\ \phi^2_{px}$ where B is surface brightness at the chosen wavelength ($B_{\lambda=630nm}$=-9.48 mag/arcsec$^2$) and $\phi$ is accumulation area (arcsec$^2$).
Why do we have to use this new equation for observations for solar telescopes?
Why is this value of B smaller (closer to 0) than the apparent magnitude of the Sun (-26.74)?
State which types of nighttime observations require the same substitution, and explain your answer.

**3 points**

**4.** The equation for the resulting signal to noise ratio is given as

$SNR = (SQt_{exp})^{0.5}$

Where Q is quantum efficiency (about 0.8 for DKIST cameras), and $t_{exp}$ is exposure time

**(a)** Lets consider the effect of feature smearing. Show that for a photospheric acoustic velocity of 7 km $s^{-1}$, $t_{exp}$ must be around 5 seconds for $\phi \sim 0.1$ $arcsec^2$.

**4 points**

**(b)** Spectropolarimetry requires a signal to noise ratio of SNR $\sim 5 \times 10^4$
Using all parts of Q2 and Q3, show this SNR requires a 4m mirror

**6 points**

4.