(Extremely Simple) Radiative Transfer in a Stellar Atmosphere

ASTP-720 Final Project

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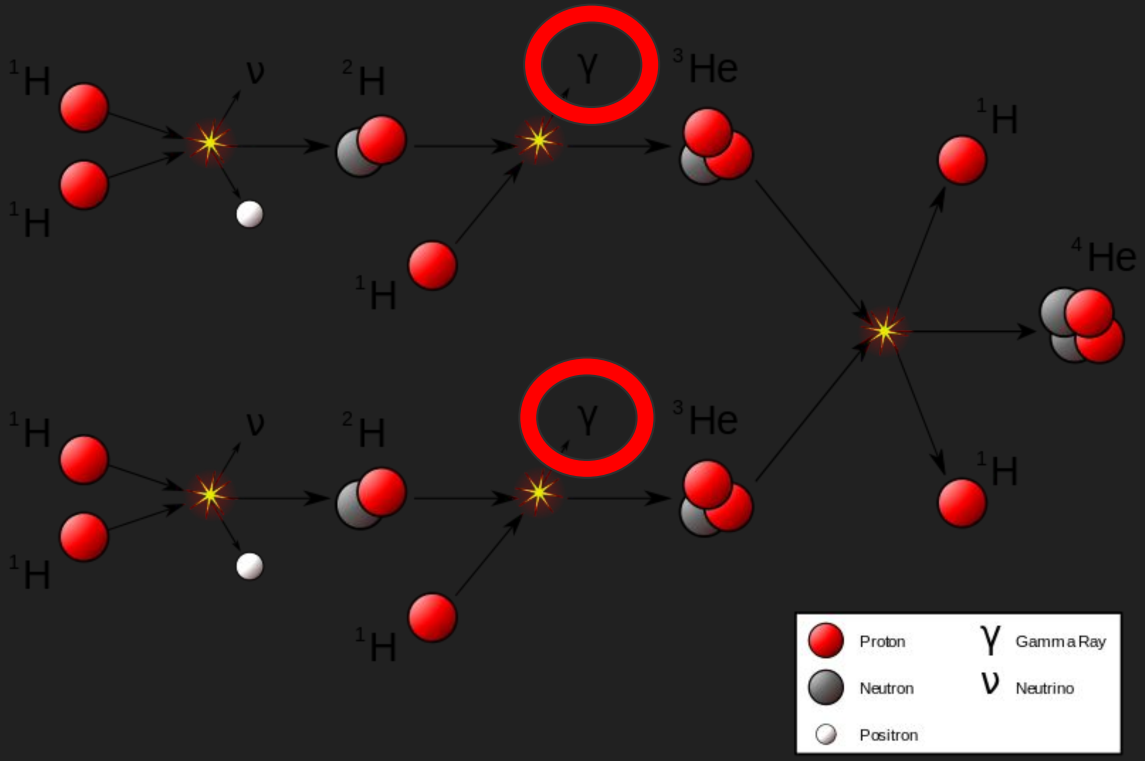
github.com/markoris/ASTP720/tree/master/FINAL

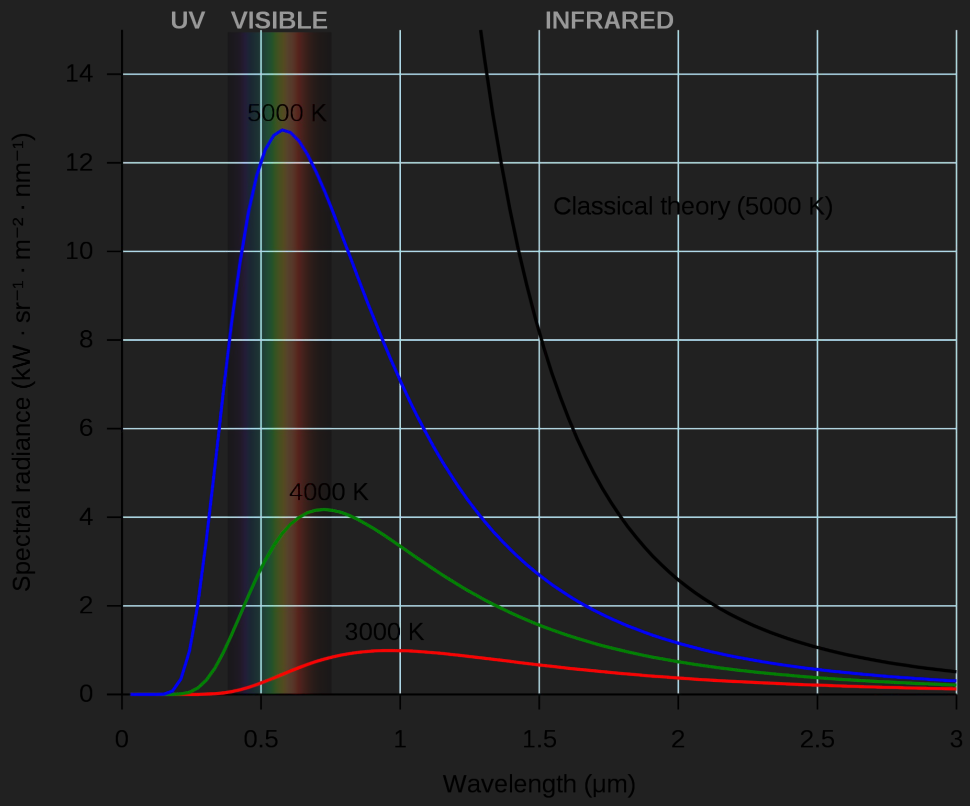
Stellar Atmospheres: proton-proton chain



Credit: Wikimedia Commons

Stellar Atmospheres: blackbody radiation

- Photon(s) could be at any temperature
- How many we see depends on the wavelength in which we observe
- Simplest case: assume photon emitted as blackbody radiation



Credit: Wikipedia

Stellar Atmospheres: plane-parallel atmosphere

- Blackbody since star is opaque as depth into atmosphere increases
- ds small enough such that stellar atmosphere is effectively plane-parallel
- Photon travels outward toward surface of the star
- Along its path, it runs into a bunch of other stuff

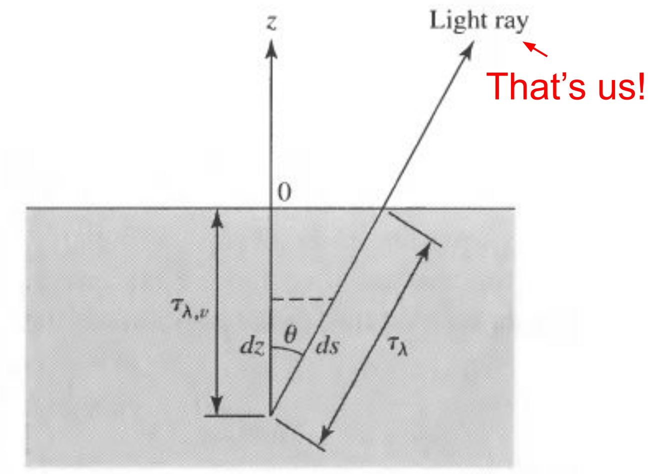


FIGURE 9.14 Plane-parallel stellar atmosphere.

Credit: An Introduction to Modern Astrophysics, Carroll & Ostlie

Radiative Transfer: a bunch of other stuff

- Main factors at play:
  - opacity
  - density
  - step size
  - current intensity
  - source function
- For simplicity:
  - opacity and density bundled together
    - new parameter alpha
      - represents all absorption/scattering effects
  - source function = Planck function

$$-\frac{1}{\kappa_\lambda \rho}\frac{dI_\lambda}{ds} = I_\lambda - S_\lambda$$

$$\frac{dI_\nu}{ds} = \alpha_\nu [S_\nu - I_\nu]$$

Computational Approach: finite differencing

- Effectively a derivative
- Replaced f'(a) with dI/ds
- Rearrange until solved for I(s+ds)

$$f'(a) \approx \frac{f(a+h) - f(a)}{h}$$

$$\frac{dI_\nu}{ds} = \alpha_\nu [S_\nu - I_\nu]$$

$$\alpha_\nu \left[S_\nu - I_\nu(s)\right] = \frac{I(s+ds) - I(s)}{ds}$$

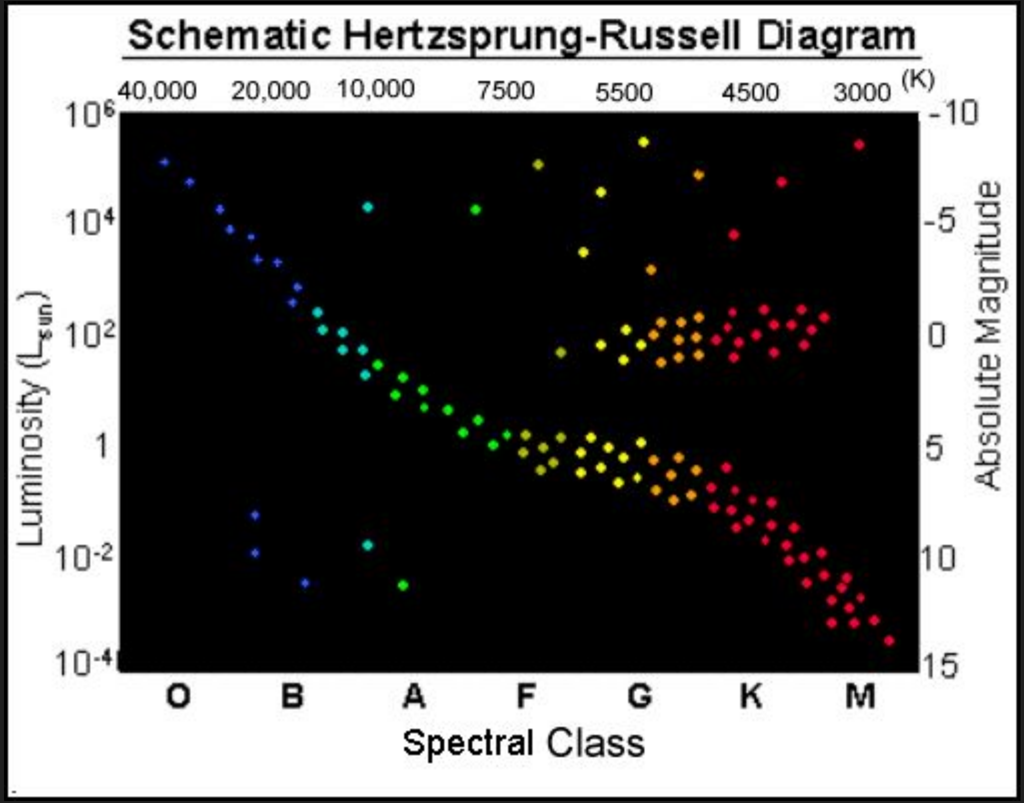
$$I(s+ds) = \left(\alpha_\nu \left[S_\nu - I_\nu(s)\right]\right) ds + I(s)$$

Credit: An Introduction to Modern Astrophysics by Carroll & Ostlie, C. P. Dullemond

Code Assumptions

- Blackbody emission of photons
- Photon moving out of star radially (not Monte Carlo)
- Simple absorption term which scales as 1/r
- Very simple quantum efficiency for camera
- Three camera viewing filters

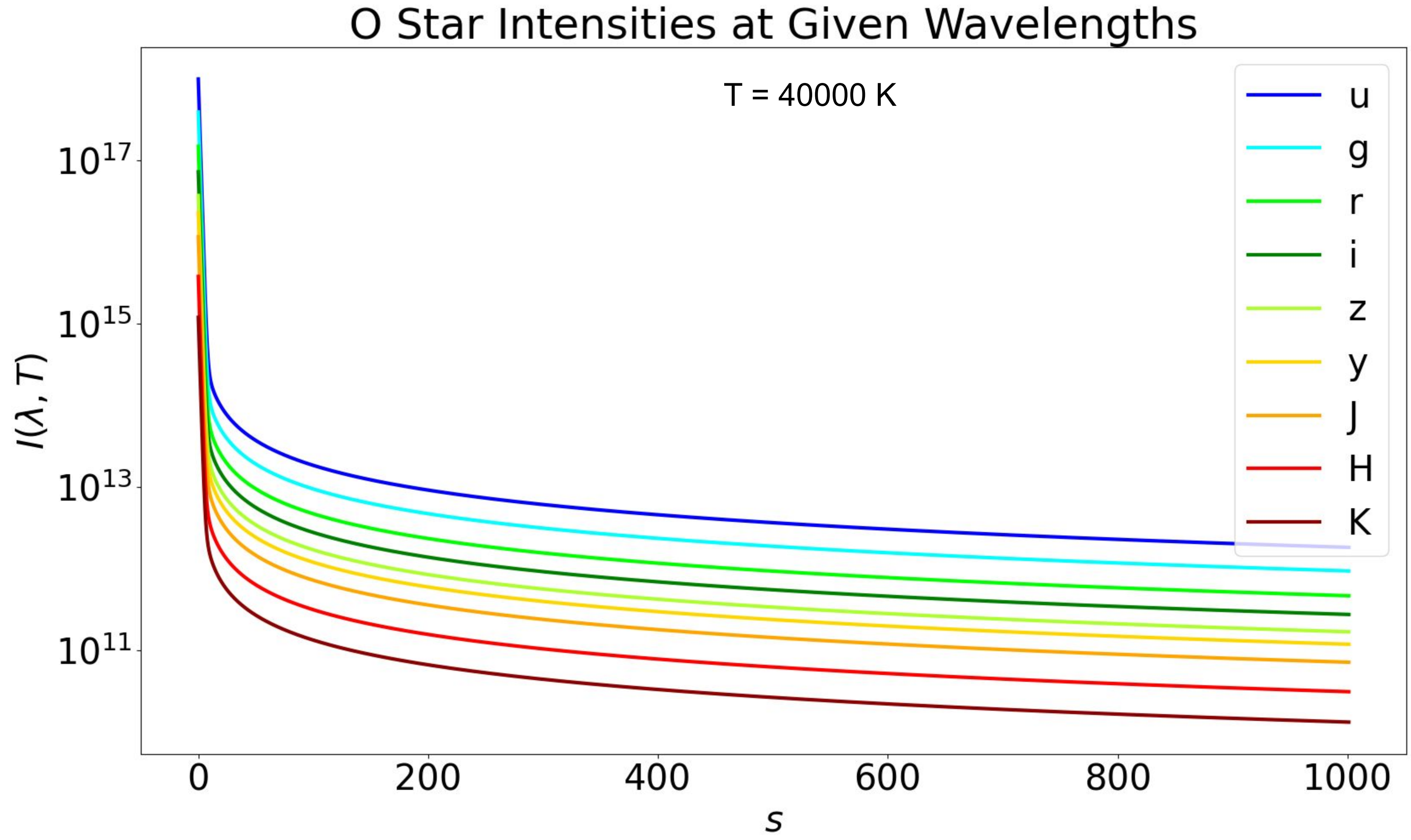
Physics Example

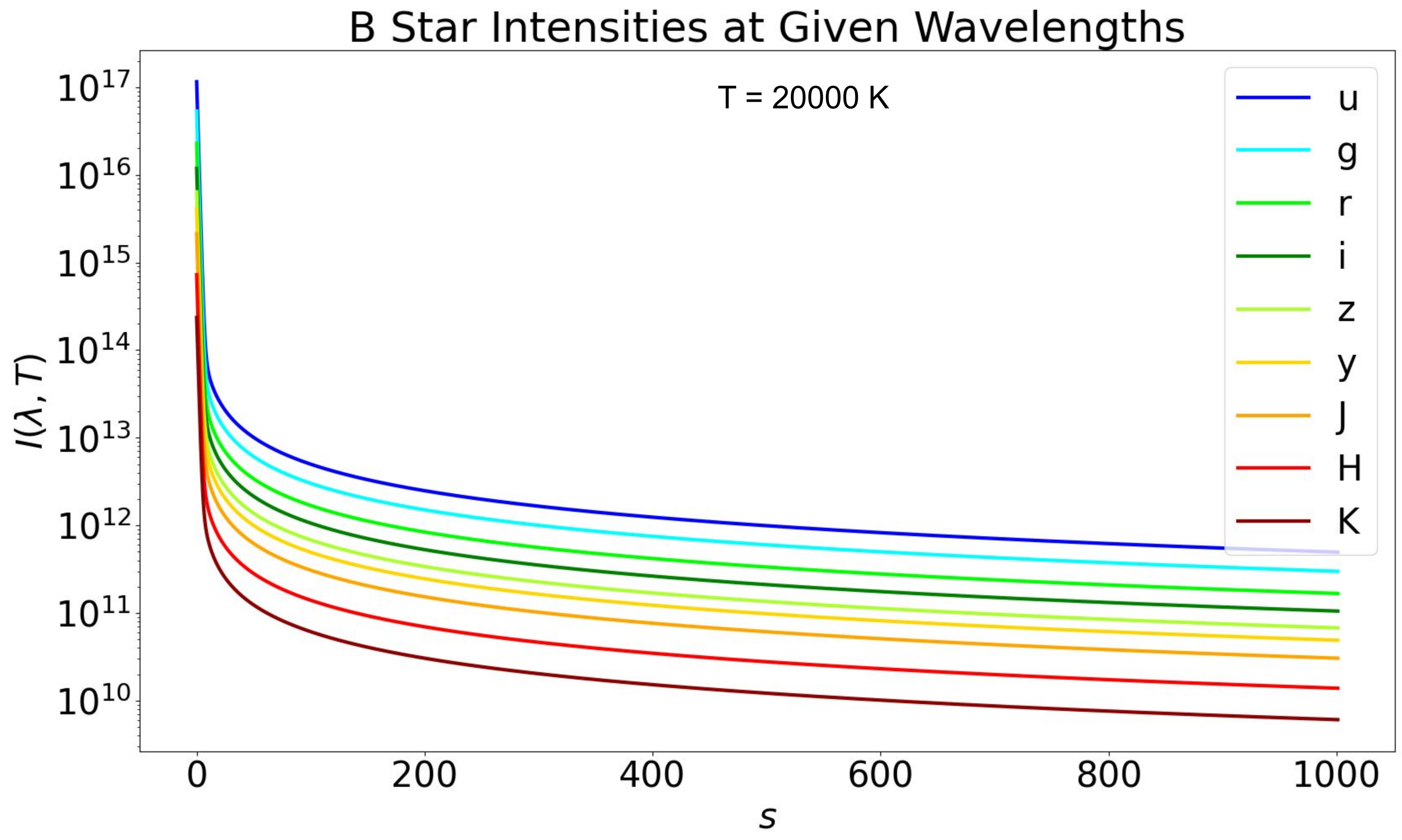


Credit: Cornell Astronomy

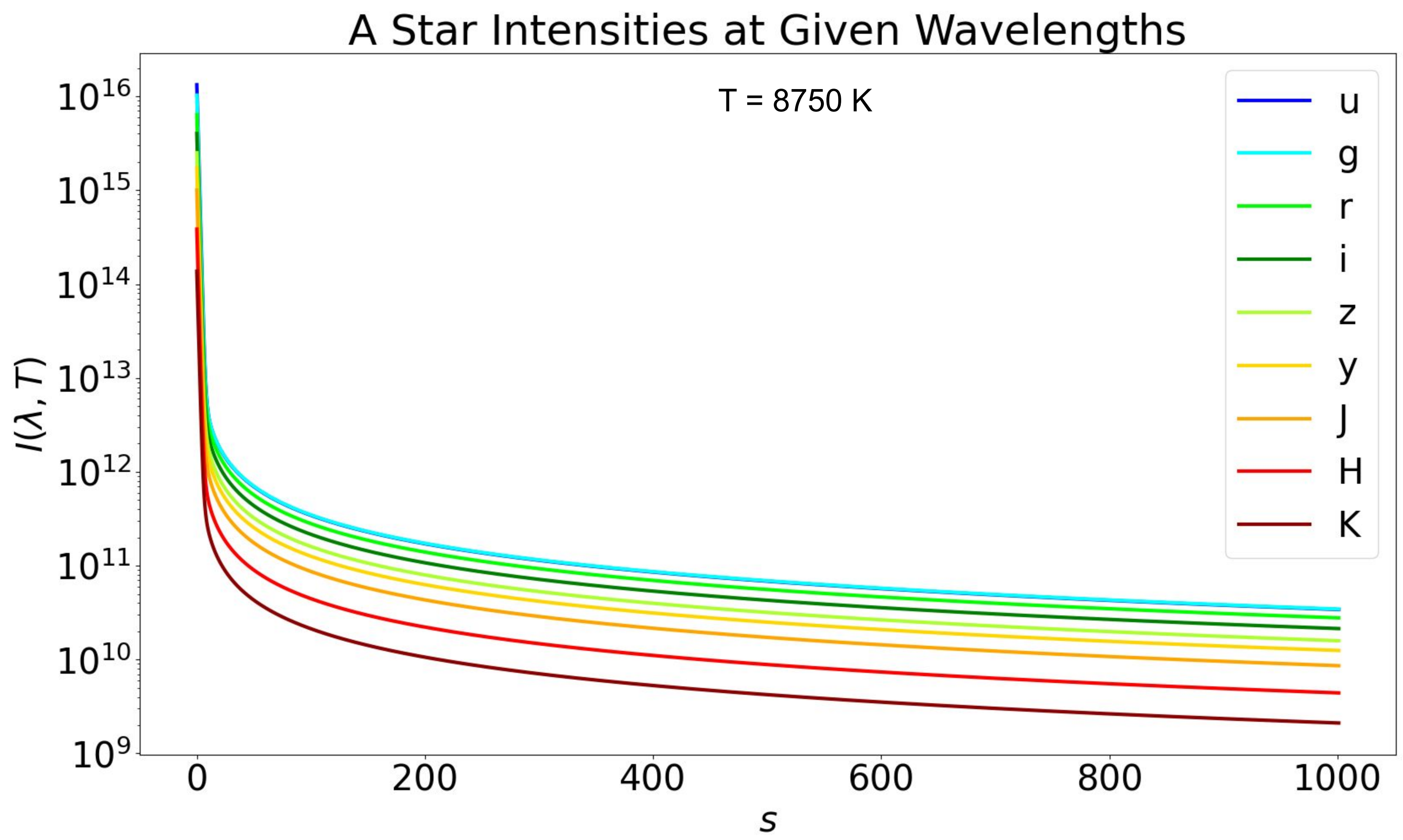
Parameters Considered

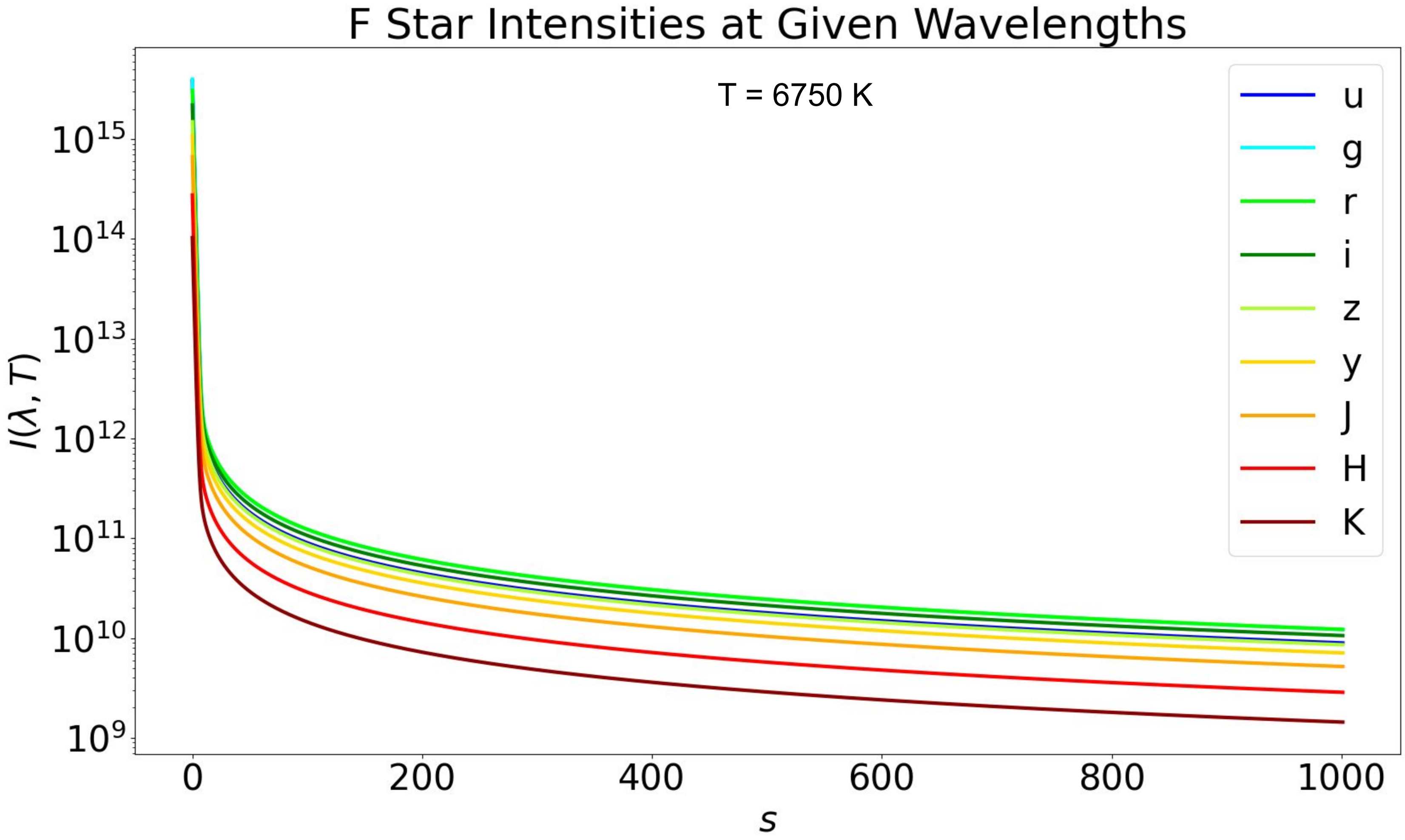
	U	G	R	I	Z	Y	J	H	K	
λ (nm)	365	476	621	754	900	1020	1220	1630	2190	
T (K)	40000	20000	8750	6750	5600	4450	3050	1850	1000	600
	O	B	A	F	G	K	M	L	T	Y

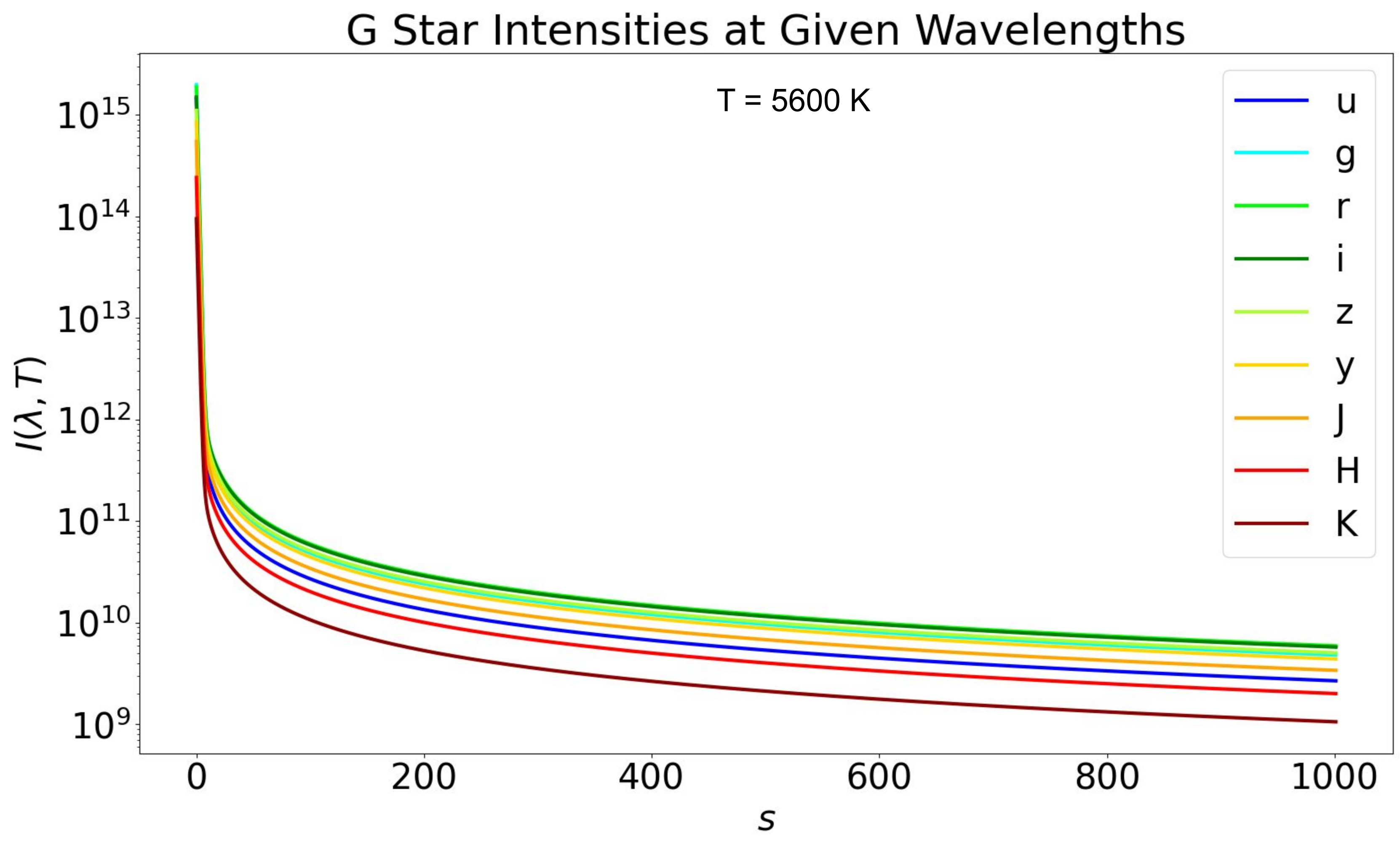

O Star Intensities at Given Wavelengths
T = 40000 K
u
g
r
i
z
y
J
H
K
10^{17}
10^{15}
10^{13}
10^{11}
$I(\lambda, T)$
0
200
400
600
800
1000
s

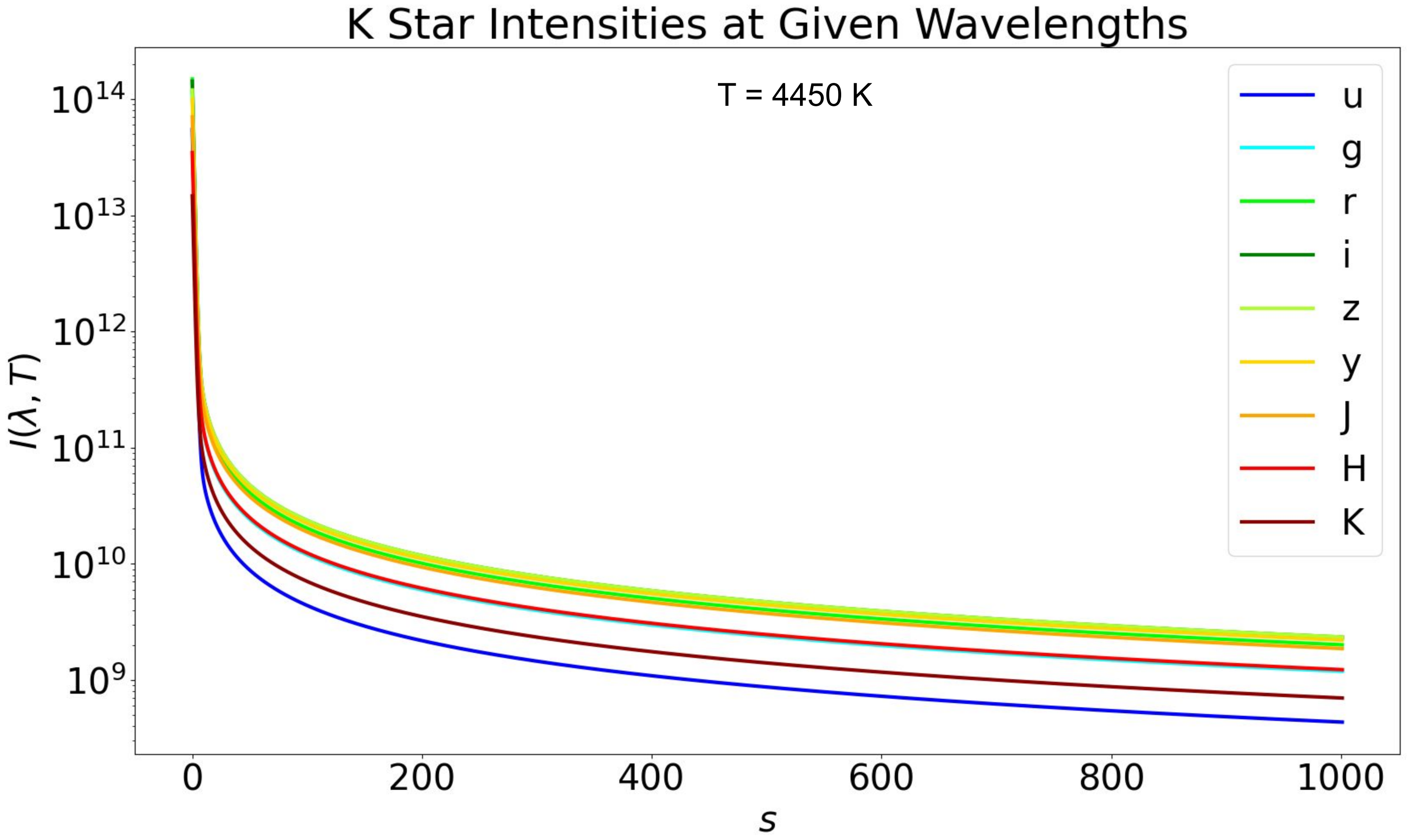


B Star Intensities at Given Wavelengths
T = 20000 K
u
g
r
i
z
y
J
H
K
$I(\lambda, T)$
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
0
200
400
600
800
1000
s

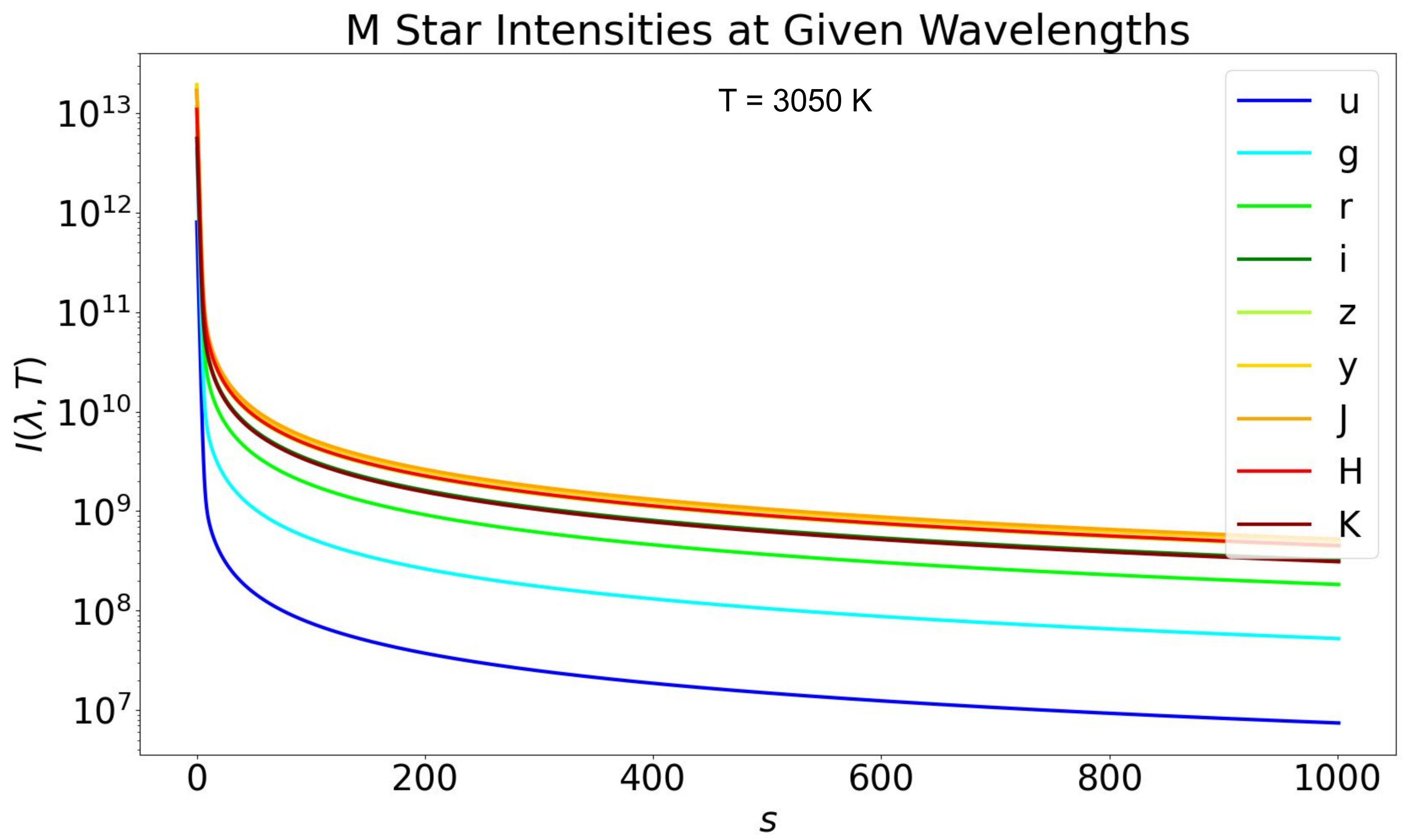

A Star Intensities at Given Wavelengths
T = 8750 K
u
g
r
i
z
y
J
H
K
$I(\lambda, T)$
s
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
0
200
400
600
800
1000

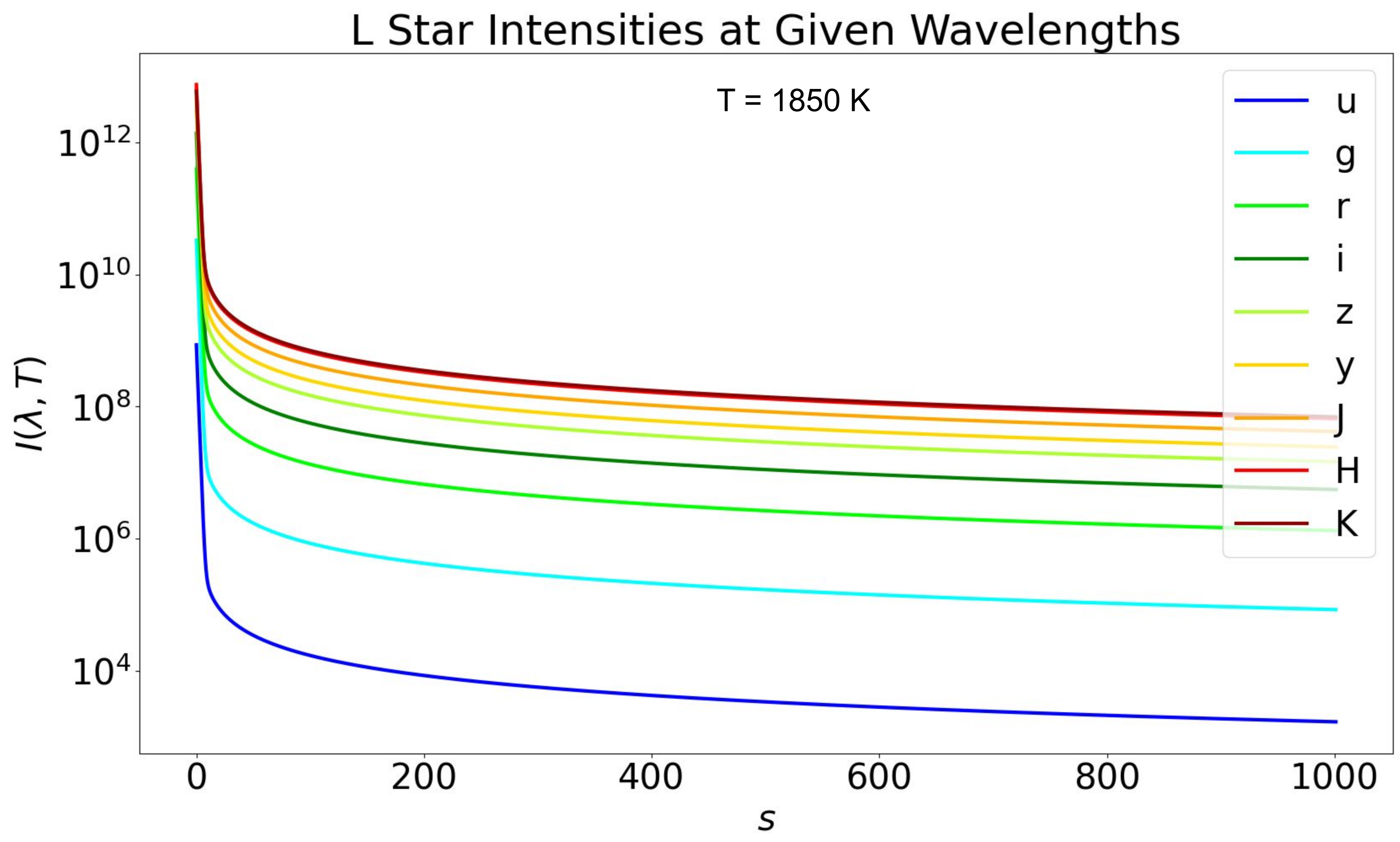

F Star Intensities at Given Wavelengths
T = 6750 K
$I(\lambda, T)$
s
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
0
200
400
600
800
1000
u
g
r
i
z
y
J
H
K

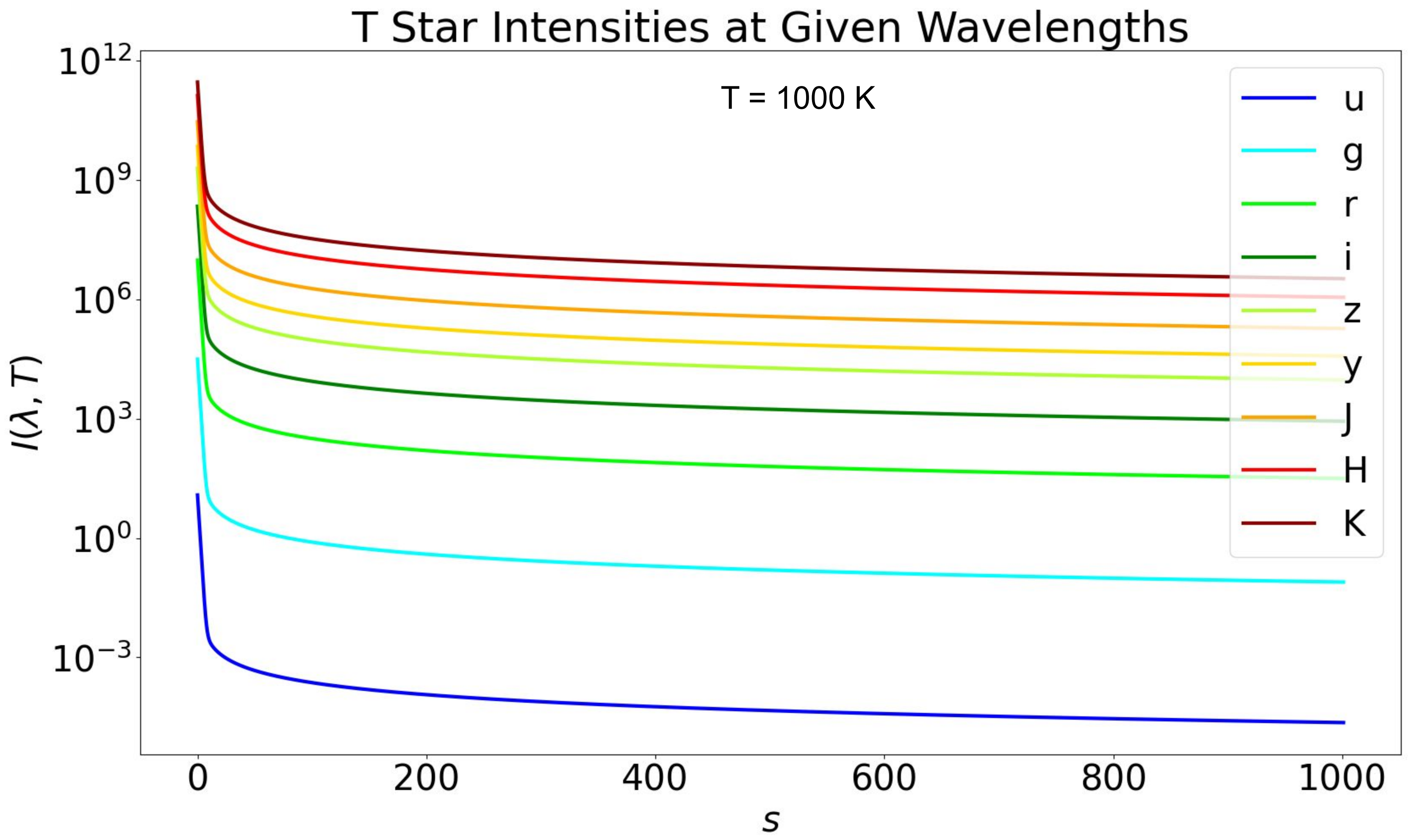

G Star Intensities at Given Wavelengths
T = 5600 K
$I(\lambda, T)$
s
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
0
200
400
600
800
1000
u
g
r
i
z
y
J
H
K

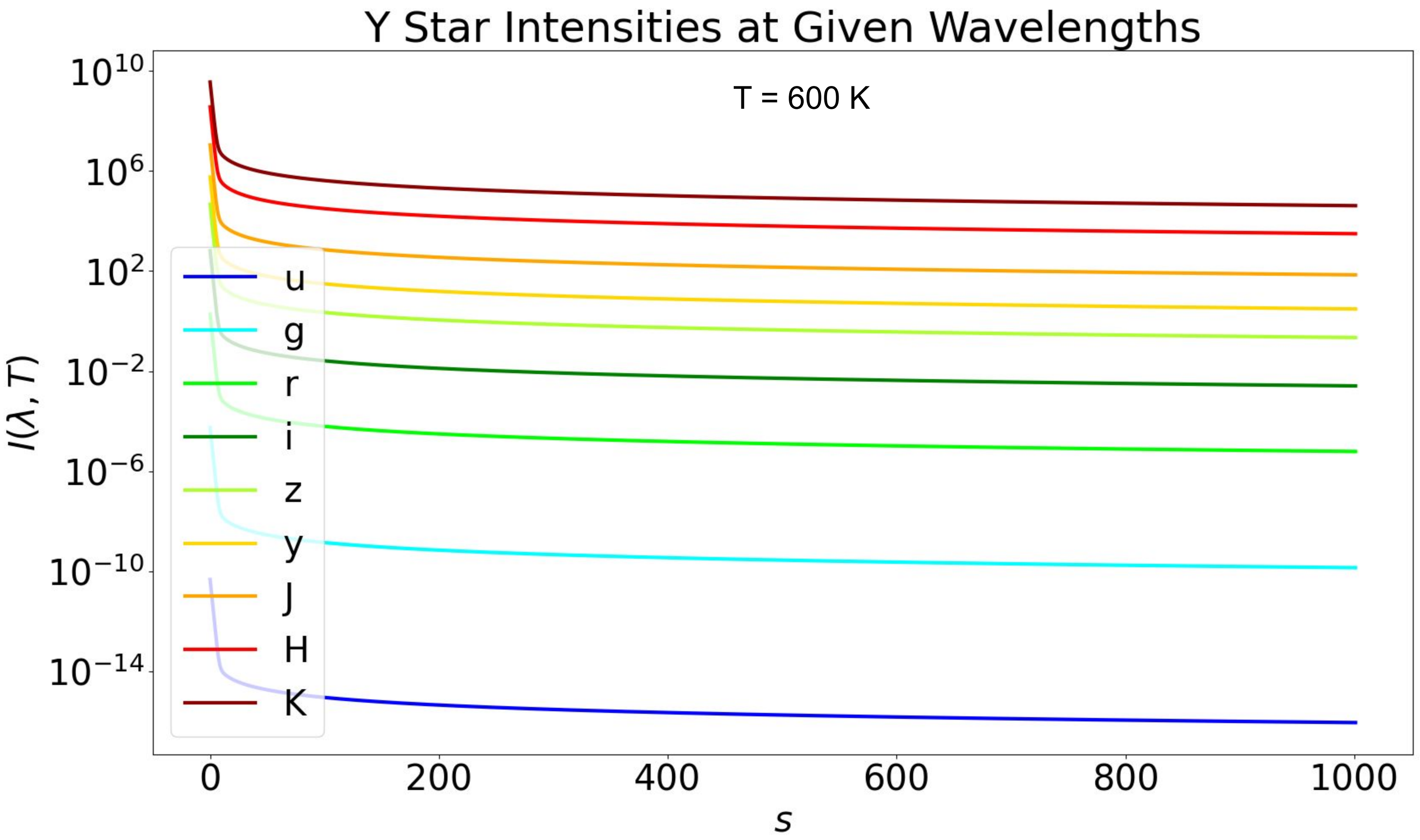


K Star Intensities at Given Wavelengths
T = 4450 K
u
g
r
i
z
y
J
H
K
$I(\lambda, T)$
s
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
0
200
400
600
800
1000


M Star Intensities at Given Wavelengths
T = 3050 K
u
g
r
i
z
y
J
H
K
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
$I(\lambda, T)$
0
200
400
600
800
1000
s


L Star Intensities at Given Wavelengths
T = 1850 K
u
g
r
i
z
y
J
H
K
10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
$I(\lambda, T)$
0
200
400
600
800
1000
s


T Star Intensities at Given Wavelengths
T = 1000 K
$I(\lambda, T)$
s
u
g
r
i
z
y
J
H
K
10^{12}
10^{9}
10^{6}
10^{3}
10^{0}
10^{-3}
0
200
400
600
800
1000



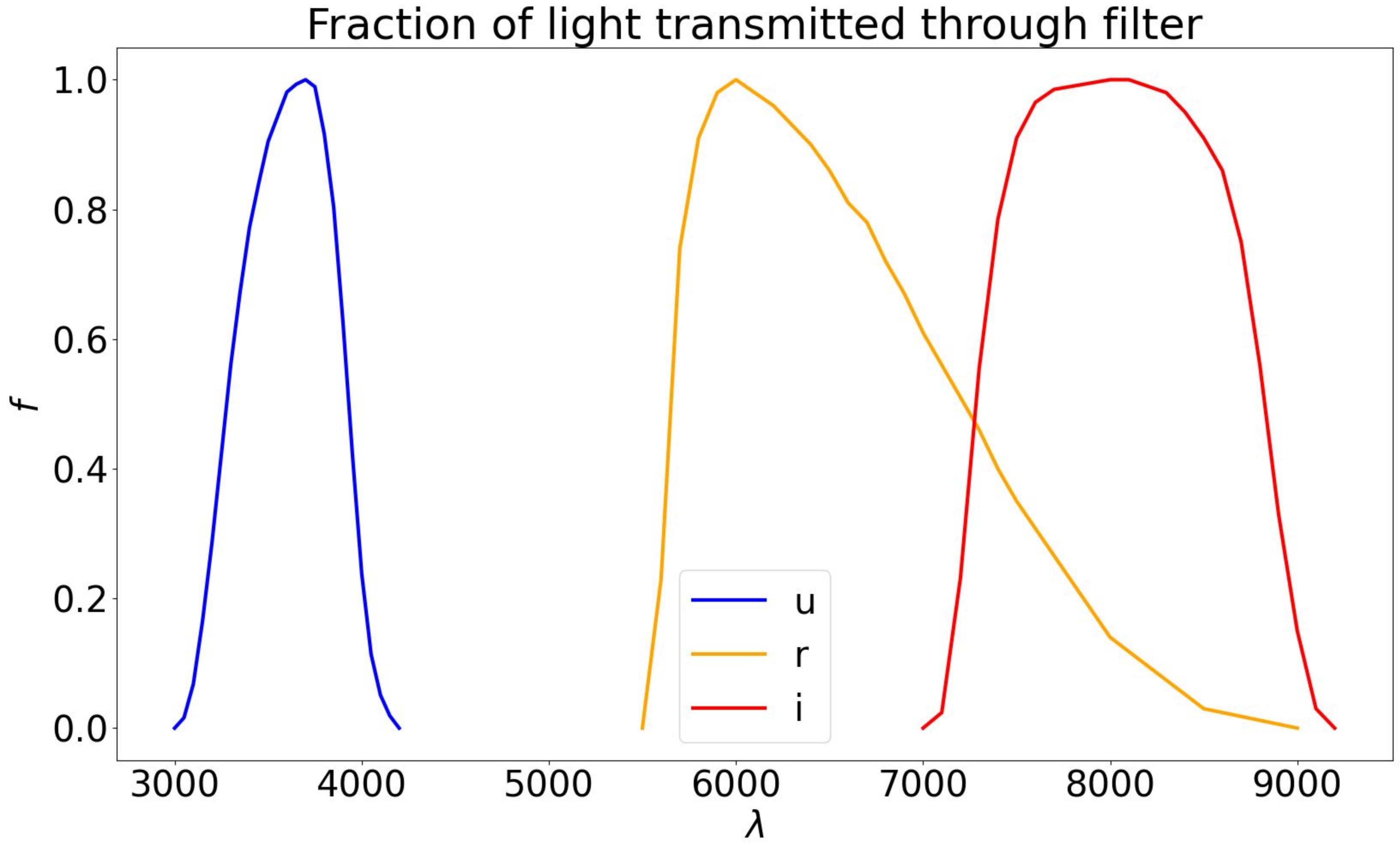
Y Star Intensities at Given Wavelengths
T = 600 K
10^{10}
10^{6}
10^{2}
10^{-2}
10^{-6}
10^{-10}
10^{-14}
$I(\lambda, T)$
0
200
400
600
800
1000
s
u
g
r
i
z
y
J
H
K

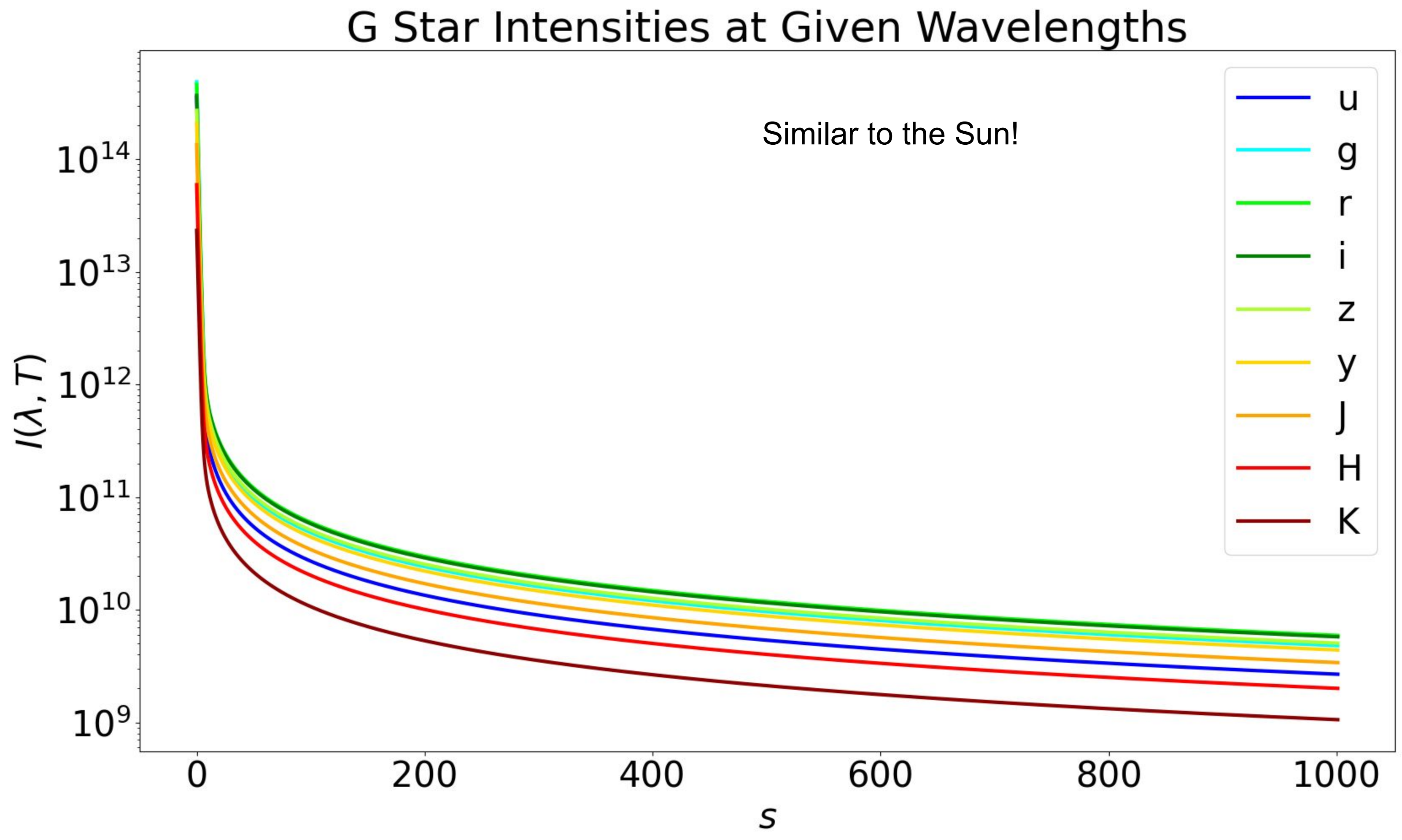
Camera + Filters

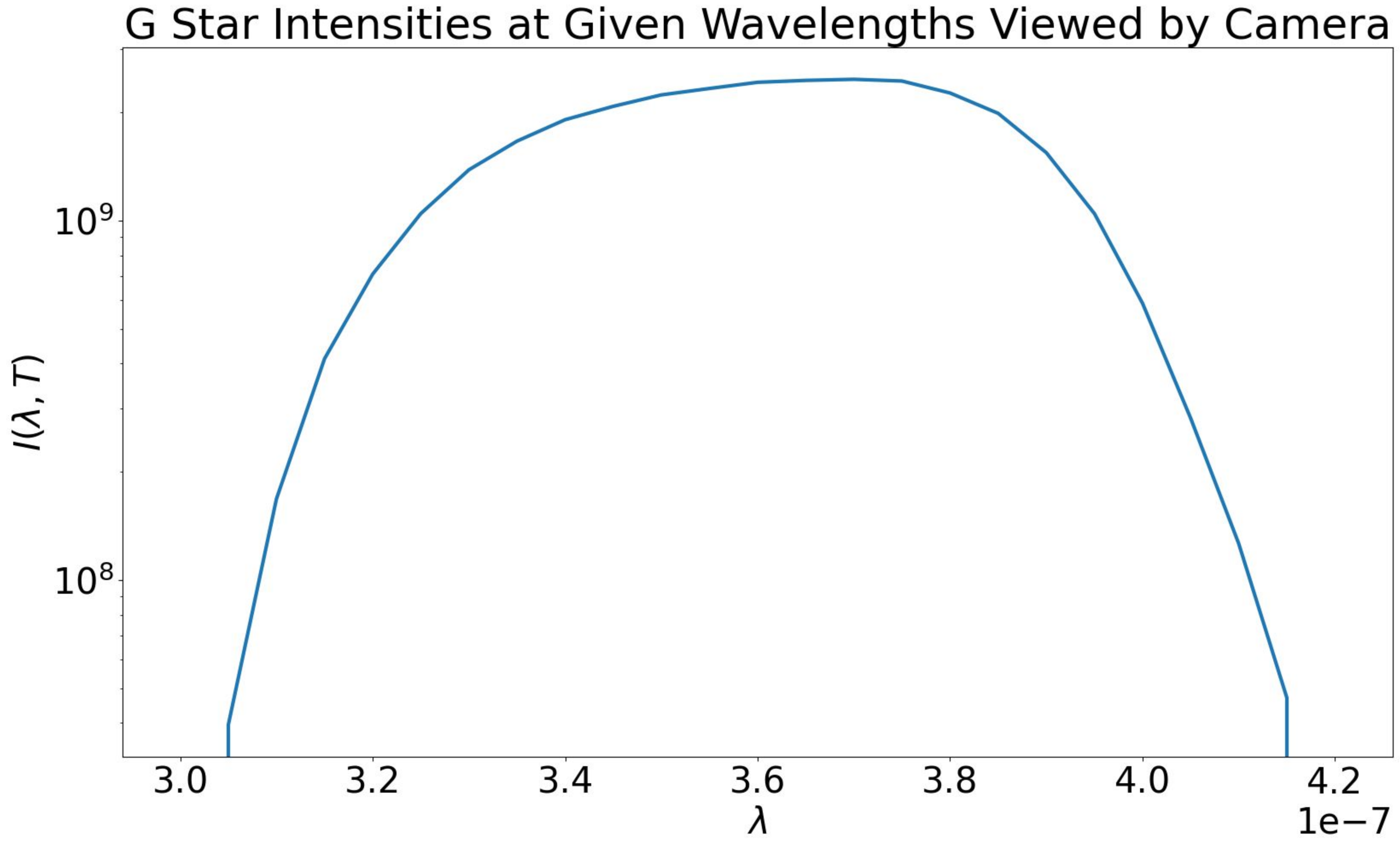
- Suppose you wanted to know how your CCD and selected filters would affect the recorded intensity

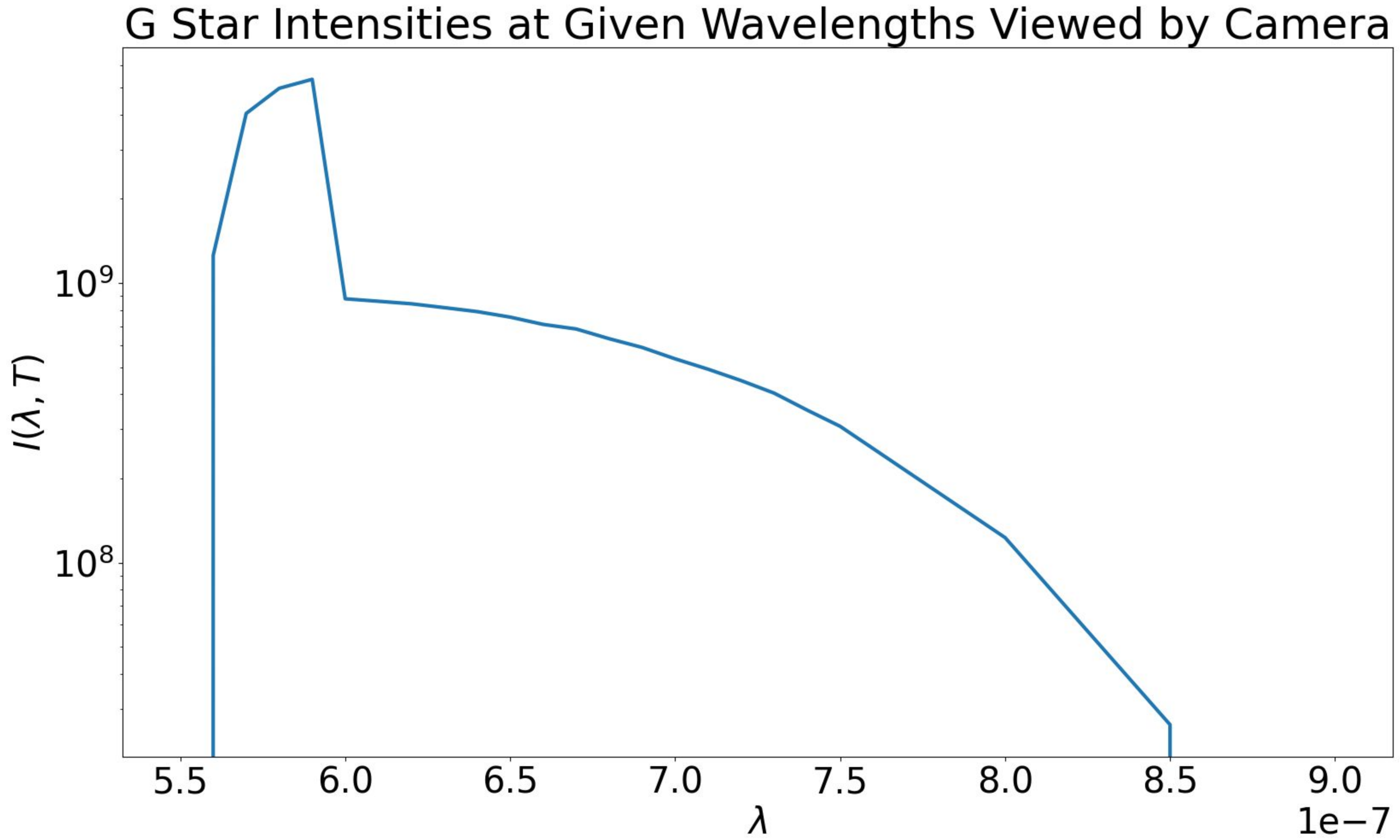
- Johnson U, R, and I filters

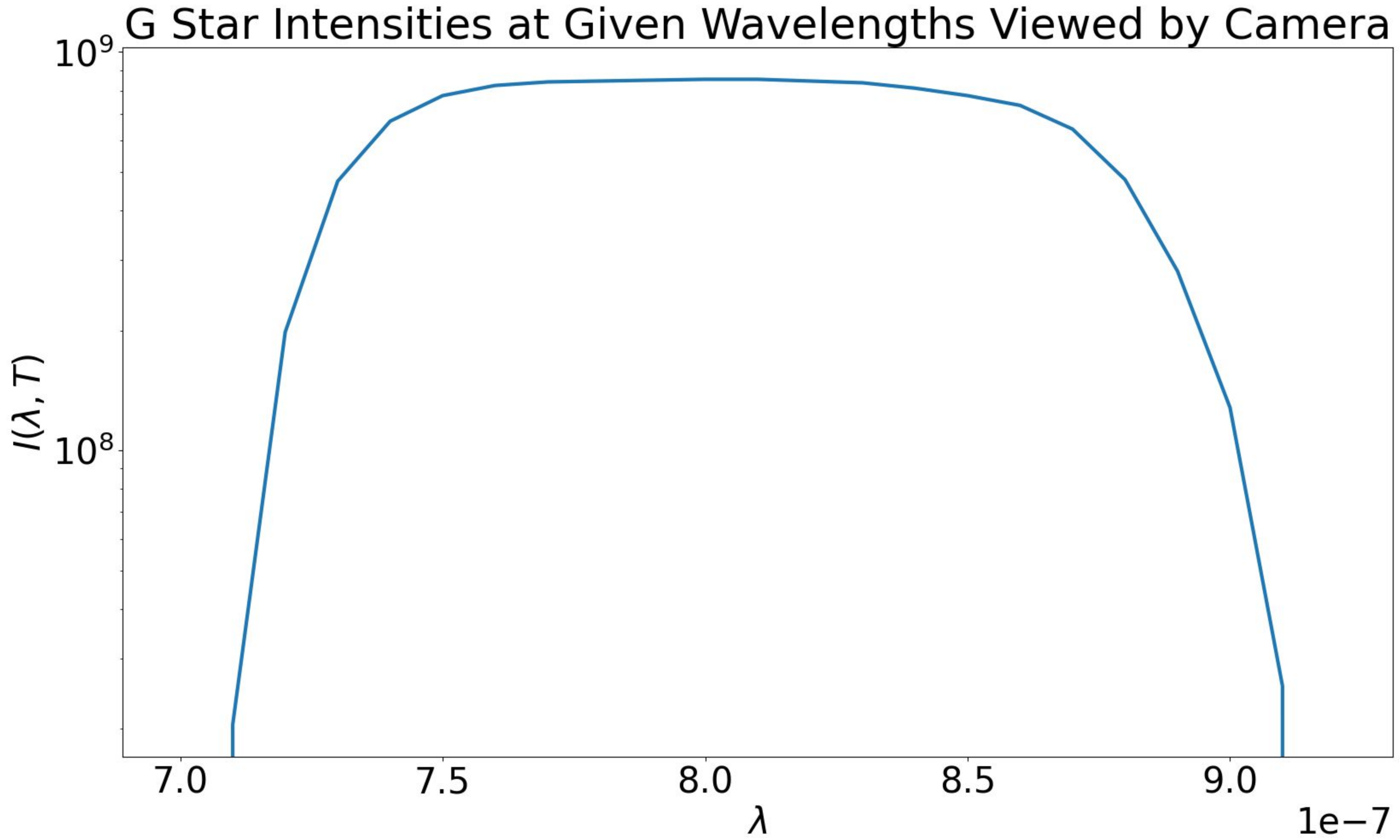
- Camera with piece-wise quantum efficiency
    - Very efficient under a wavelength threshold
        - Much less efficient above that wavelength
            - (why? who knows, probably some grad student’s fault)


Fraction of light transmitted through filter
1.0
0.8
0.6
0.4
0.2
0.0
f
3000
4000
5000
6000
7000
8000
9000
λ
u
r
i


G Star Intensities at Given Wavelengths
Similar to the Sun!
u
g
r
i
z
y
J
H
K
$I(\lambda, T)$
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
0
200
400
600
800
1000
s


G Star Intensities at Given Wavelengths Viewed by Camera
$I(\lambda, T)$
10^9
10^8
3.0
3.2
3.4
3.6
3.8
4.0
4.2
λ
1e−7


G Star Intensities at Given Wavelengths Viewed by Camera
$I(\lambda, T)$
10^9
10^8
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
λ
1e−7



G Star Intensities at Given Wavelengths Viewed by Camera
10^9
10^8
$I(\lambda, T)$
7.0
7.5
8.0
8.5
9.0
λ
1e−7

Possible Future Additions

- Include Monte Carlo approach with some constant wind
- Consider a more complex source function
- Consider a more complex absorption term with wavelength dependency
  - Not a grey opacity
- Expand from 1D to 3D

Conclusion

- Radiative transfer is really hard
- Treat everything as a blackbody
- Finite differencing is great (once you actually realize in what form your differential equation needs to be)
- Don’t let grad students make CCDs