Topic 4: Filter Systems

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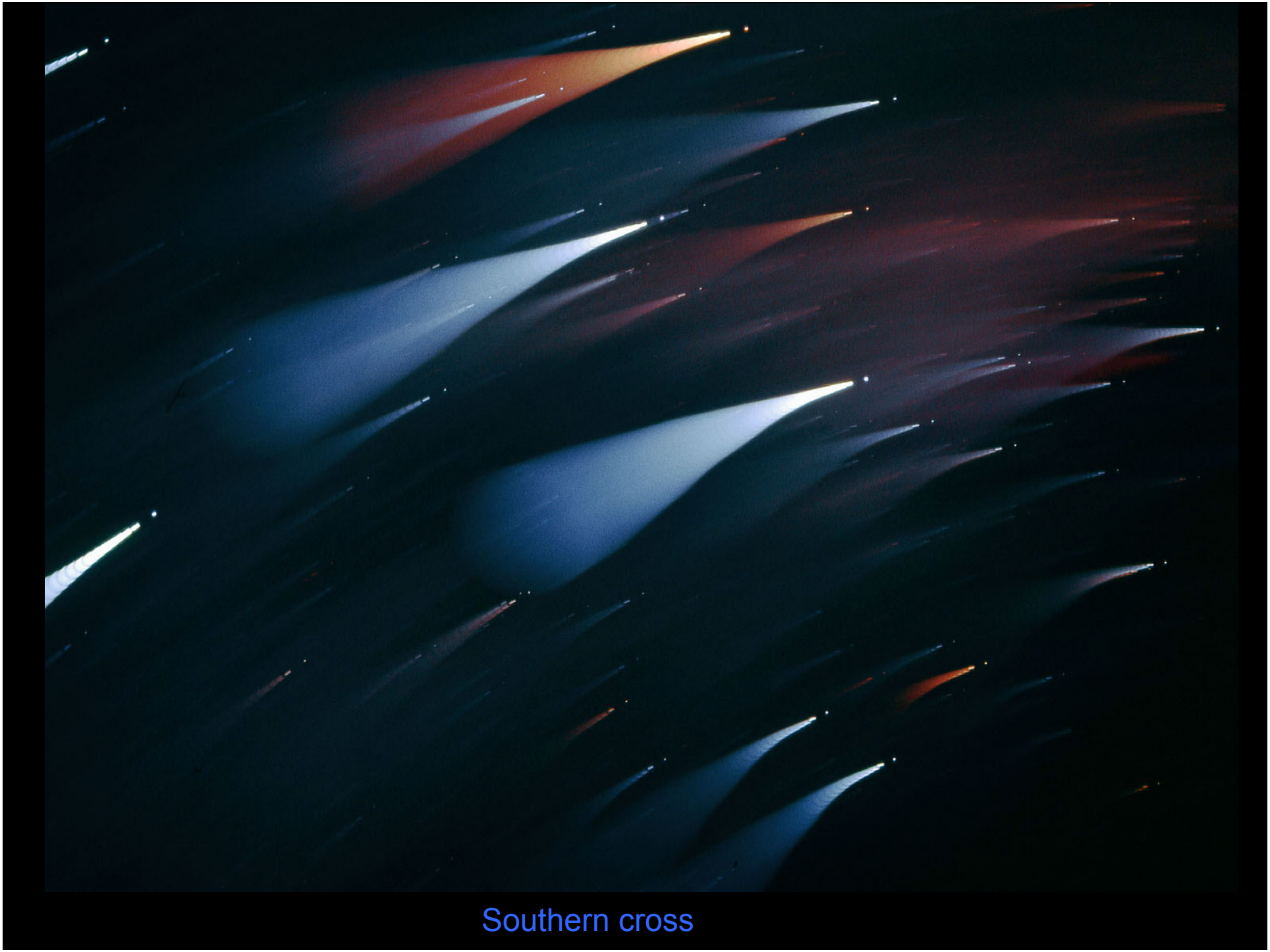


Southern cross

Filters

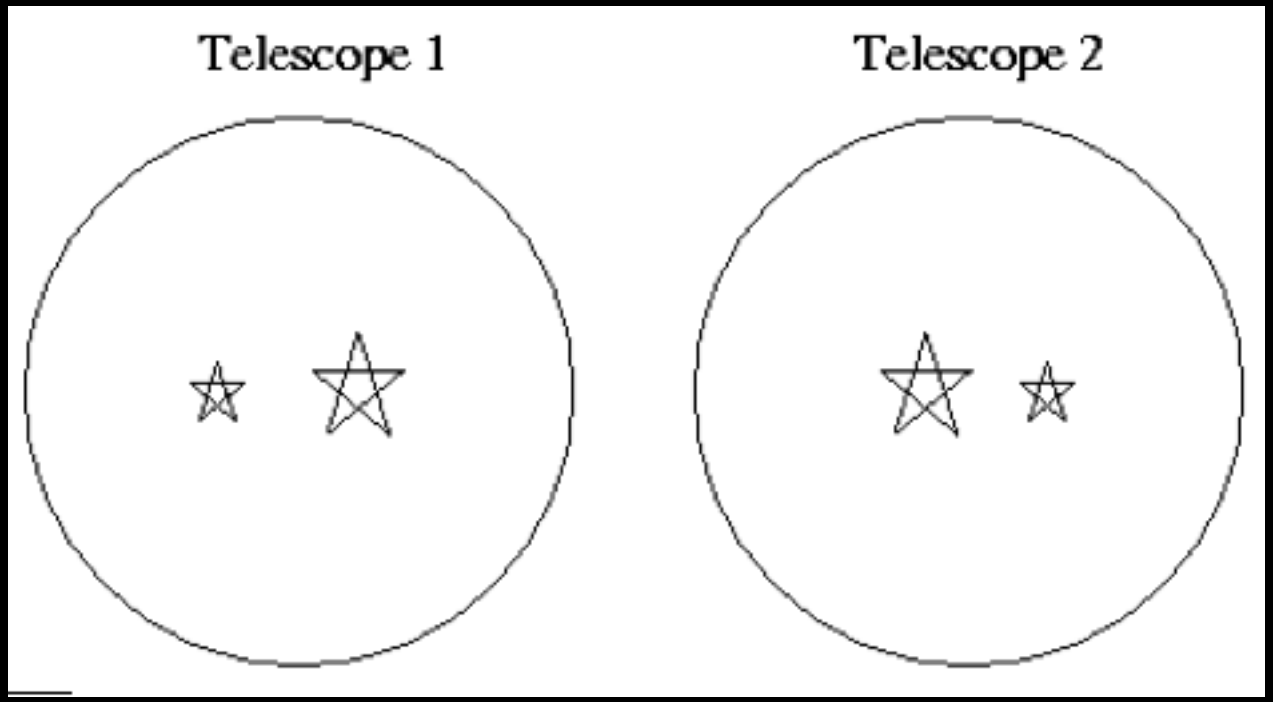
- Produce a standardized bandpass for your system
- Low-resolution spectroscopy
- Give you color information
- Can increase contrast
- Can improve seeing

Resolving power or spectral resolution

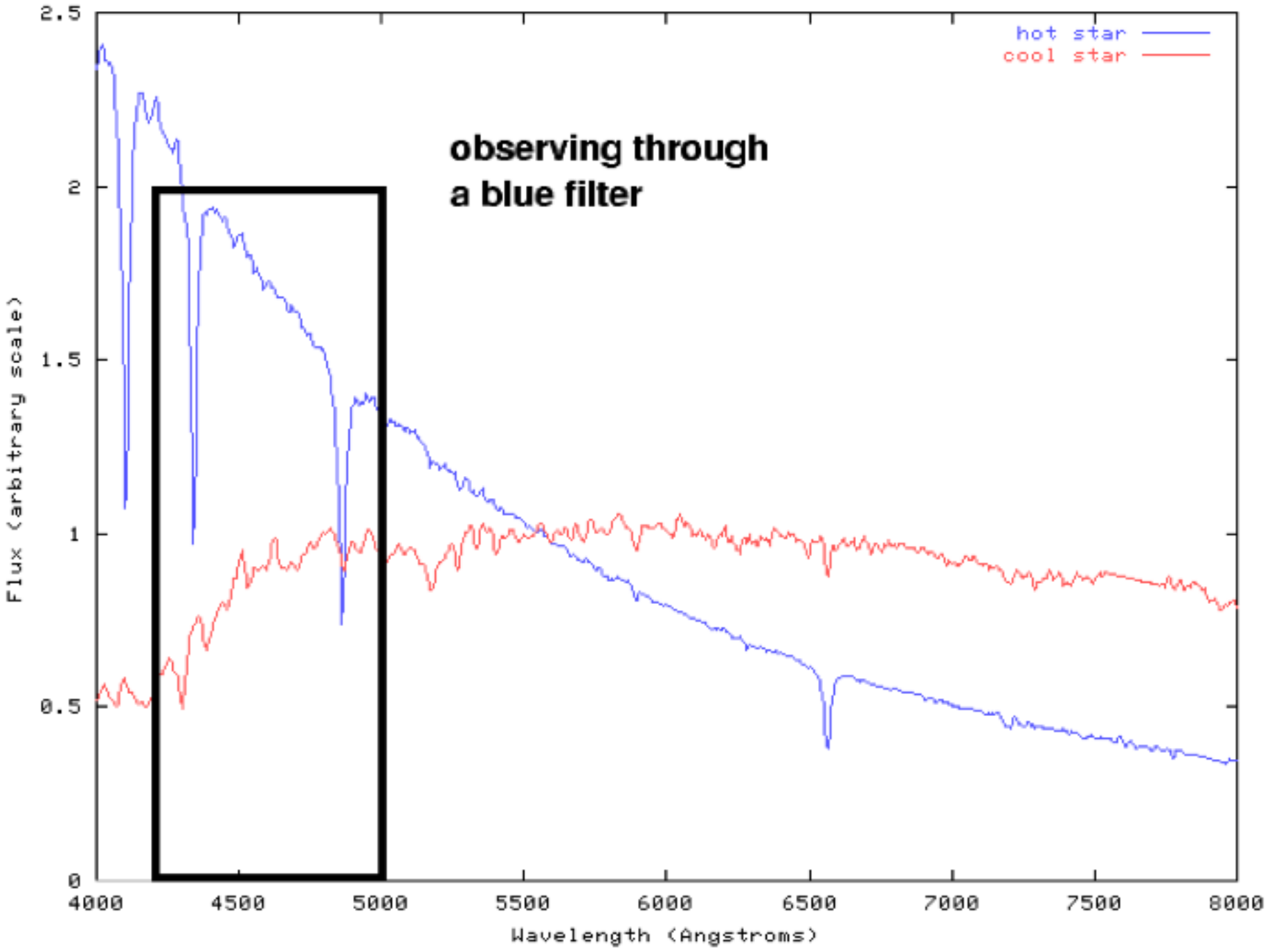
$$R = \frac{\lambda}{\Delta\lambda},$$

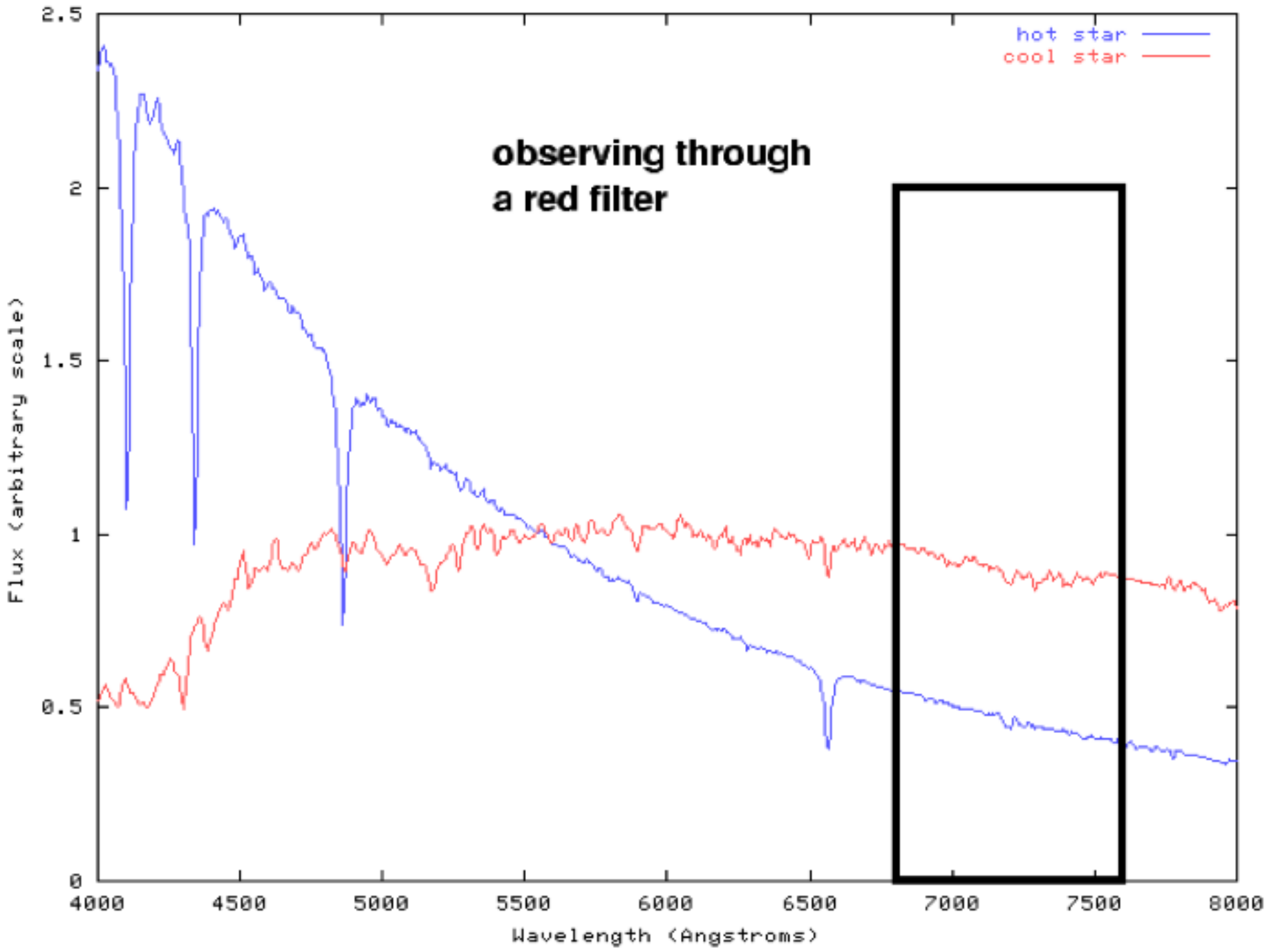
$$\text{spectral resolution} = \frac{\text{central wavelength}}{\text{width of passband}} = \text{approx } 5$$

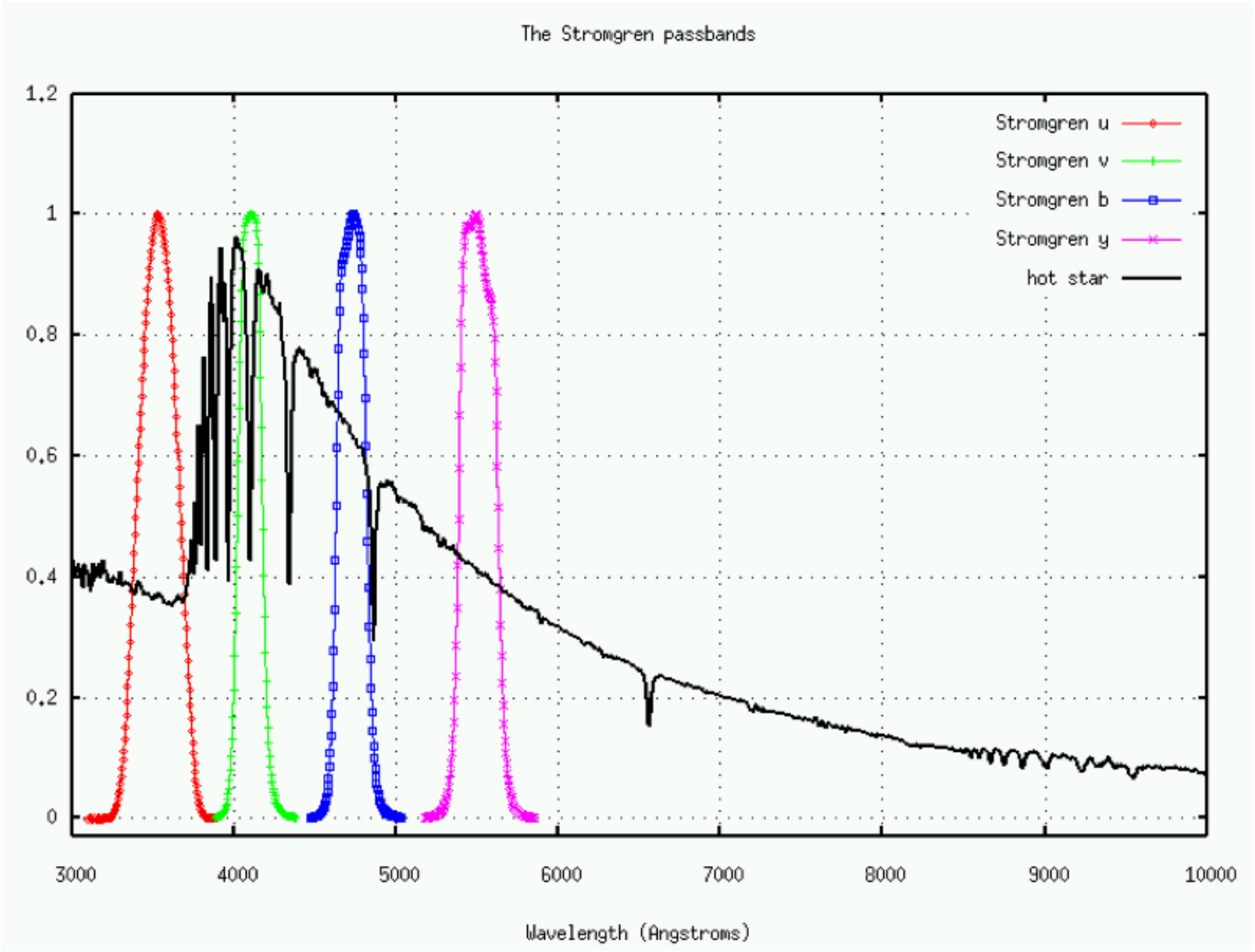
$$\text{spectral resolution} = \frac{\text{6563 Angstroms}}{\text{20 Angstroms}} = \text{approx } 330$$



Different appearance, depending on filter


observing through
a blue filter
hot star
cool star
Flux (arbitrary scale)
Wavelength (Angstroms)
0
0.5
1
1.5
2
2.5
4000
4500
5000
5500
6000
6500
7000
7500
8000

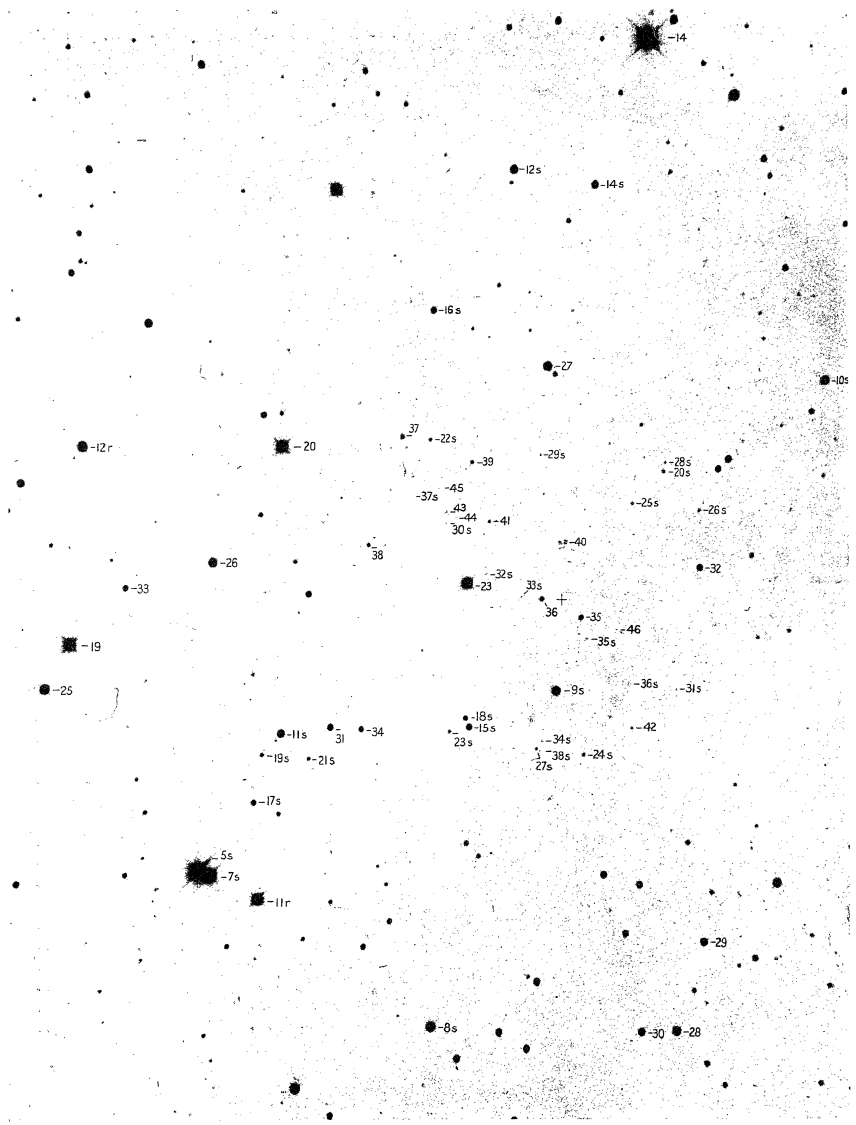

hot star
cool star
observing through
a red filter
Flux (arbitrary scale)
Wavelength (Angstroms)
0
0.5
1
1.5
2
2.5
4000
4500
5000
5500
6000
6500
7000
7500
8000


The Stromgren passbands
Stromgren u
Stromgren v
Stromgren b
Stromgren y
hot star
1.2
1
0.8
0.6
0.4
0.2
0
3000
4000
5000
6000
7000
8000
9000
10000
Wavelength (Angstroms)

North Polar sequence

- Defined in 1912-1917 by Pickering and Leavitt
- 96 stars near north pole (including Polaris), visible all night by most obs
- Blue magnitudes to match photographic plates
- Green magnitudes to match visual

1912HarCi.170....1P



STANDARD NORTH POLAR SEQUENCE

SCALE 5″=1 mm. MT. WILSON 60-INCH REFLECTOR

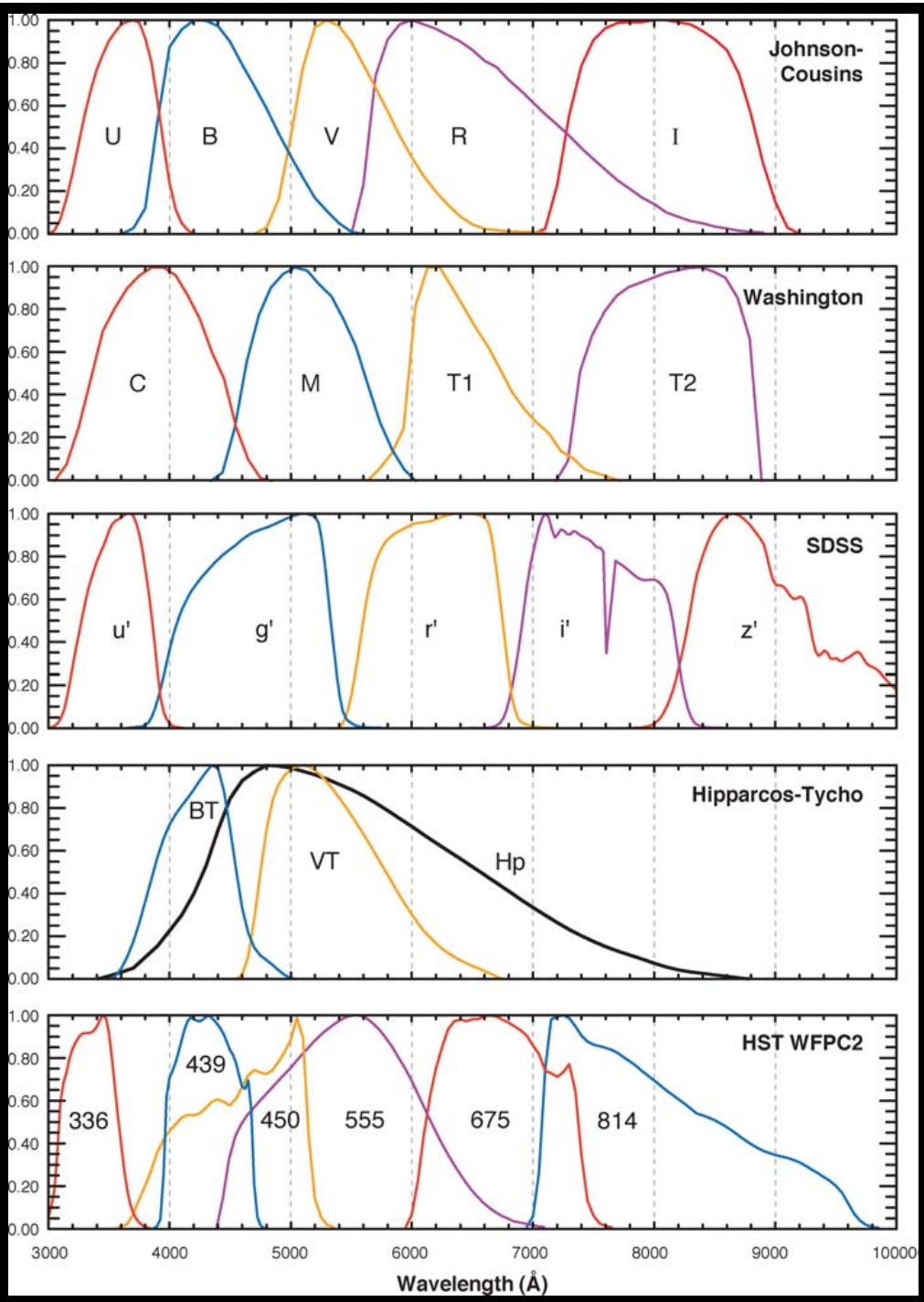
John G. Wolbach Library, Harvard-Smithsonian Center for Astrophysics • Provided by the NASA Astrophysics Data System

North polar sequence

Filter classification

- Wide-band (R~5)
- Intermediate band (R~50)
- Narrow-band (R~500)
- Not restricted to optical (NIR)

Wide-band


Johnson-
Cousins
U
B
V
R
I
Washington
C
M
T1
T2
SDSS
u'
g'
r'
i'
z'
Hipparcos-Tycho
BT
VT
Hp
HST WFPC2
336
439
450
555
675
814
1.00
0.80
0.60
0.40
0.20
0.00
3000
4000
5000
6000
7000
8000
9000
10000
Wavelength (Å)

Narrow-band

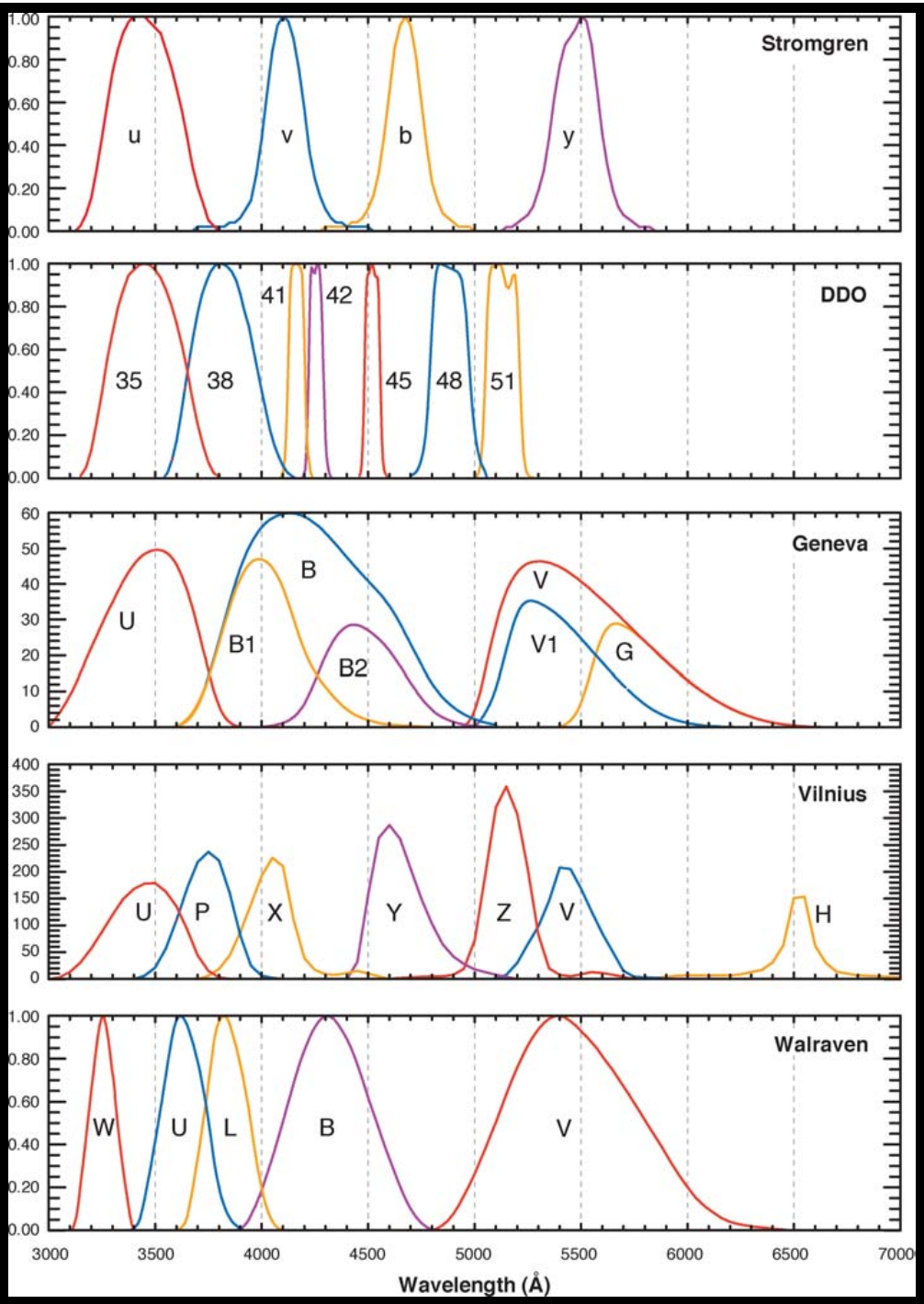

Stromgren
u
v
b
y
DDO
35
38
41
42
45
48
51
Geneva
U
B
B1
B2
V
V1
G
Vilnius
U
P
X
Y
Z
V
H
Walraven
W
U
L
B
V
Wavelength (Å)

TABLE 5 Characteristics of the Wing bands

Band	λ_{eff} Å	FWHM Å	Primary function	Contaminant
	6880	60	CaH, KM dwarfs	
1	7120	60	TiO $\gamma(0,0)$	CN
2	7540	50	Continuum, K4-M6	wk CN
3	7810	40	Continuum, G,K,C	TiO M
4	8120	50	CN $\Delta\nu = +2$	wk TiO
	9910	50	FeH, late M dwarfs	
5	10395	50	Continuum, all	
6	10540	60	VO	
7	10810	60	Continuum	HeI
8	10975	70	CN (0,0)	

temp

Interference filters

- When tilted: wavelength shifts to blue, peak transmission decreases, width broadens

$$\lambda = \lambda 0 \sqrt{1 - \frac{\sin^2 \alpha}{n^2}}$$

$$\lambda_m = \lambda 0 \left(1 - \frac{\beta^2}{4\, n^2}\right)$$

$$\sin \beta \approx \frac{1}{2\, No}$$

Temperature dependence

- When heated: layer thicknesses increase; layer indices of refraction change.
- Net effect: peak transmittance shifts to longer wavelengths (typically 0.02nm per degree C)

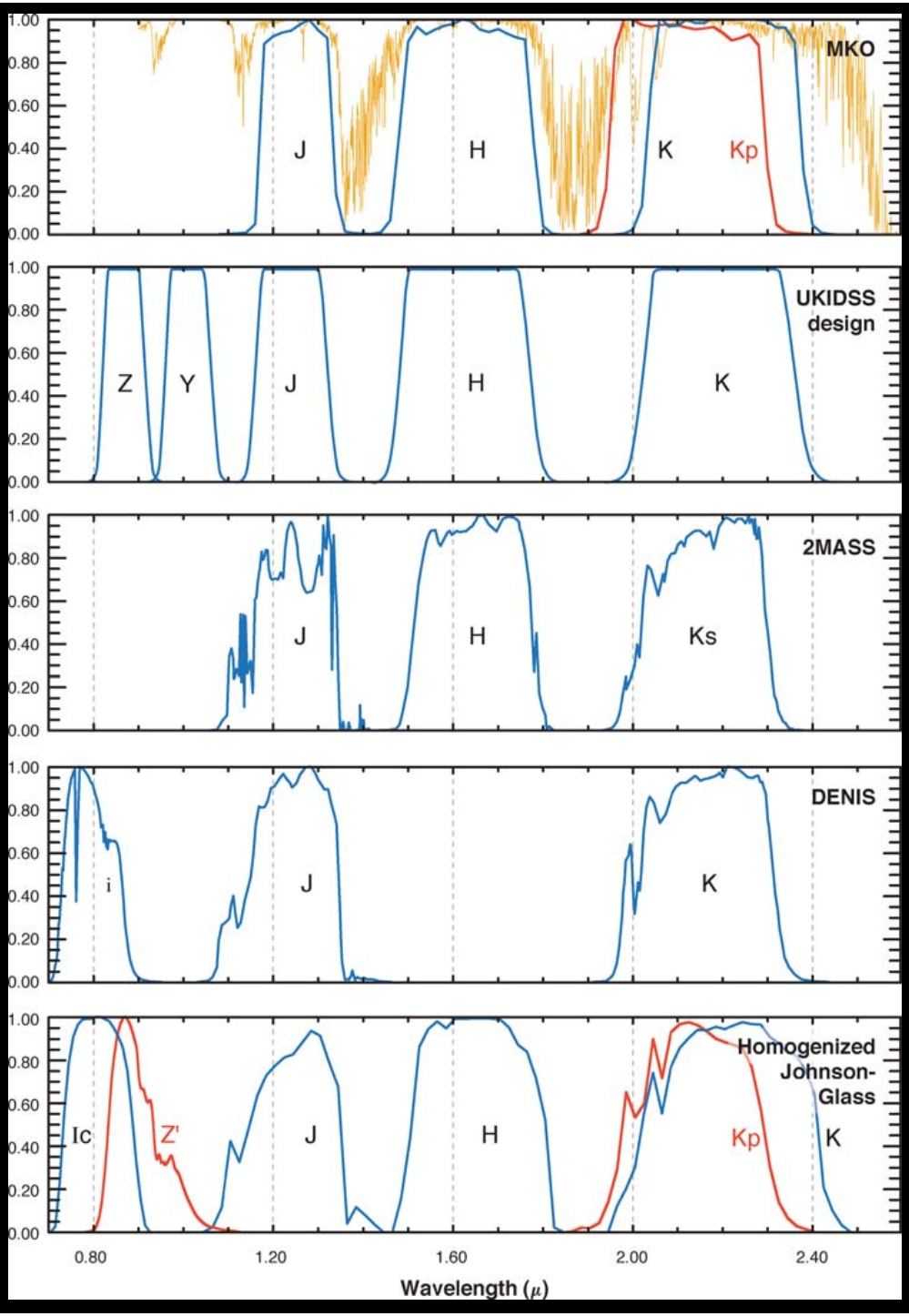
Filter orientation

- From Melles Griot: orient so that shiniest (metallic) and most nearly colorless side faces towards the incoming light. Minimizes thermal load of the absorbing-glass blocking components.
- Either orientation has same transmittance and passband

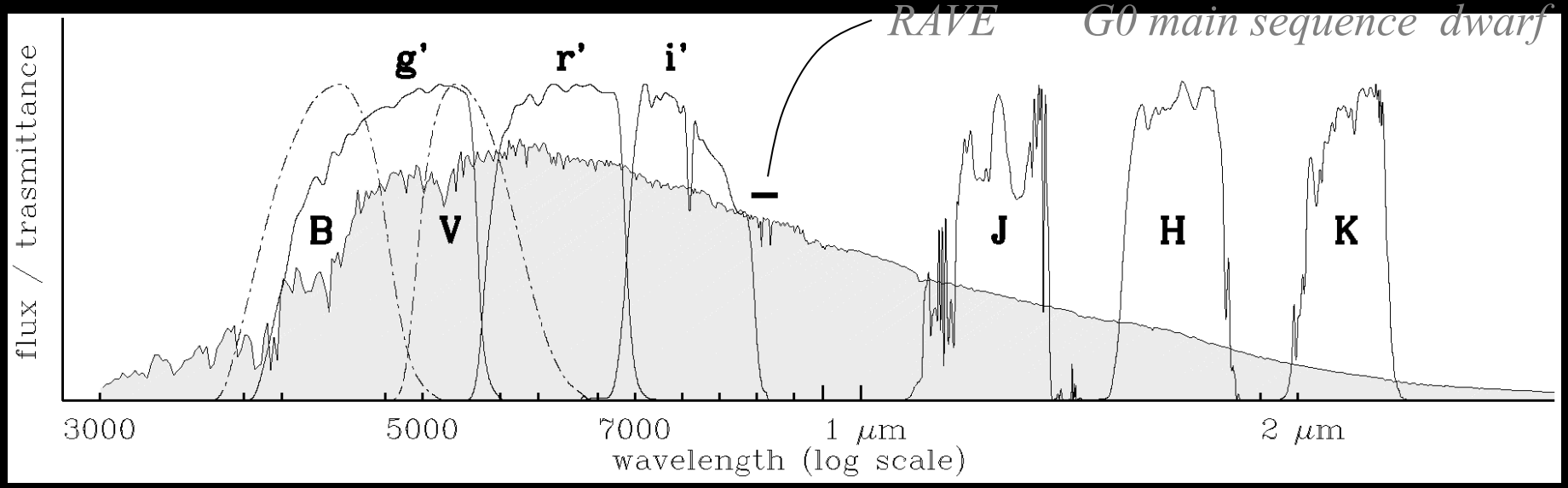
Manufacturing details

- Get edge blackened – cuts down reflections
- Get filter AR coated – improves transmission, cuts down on reflections

Near-infrared

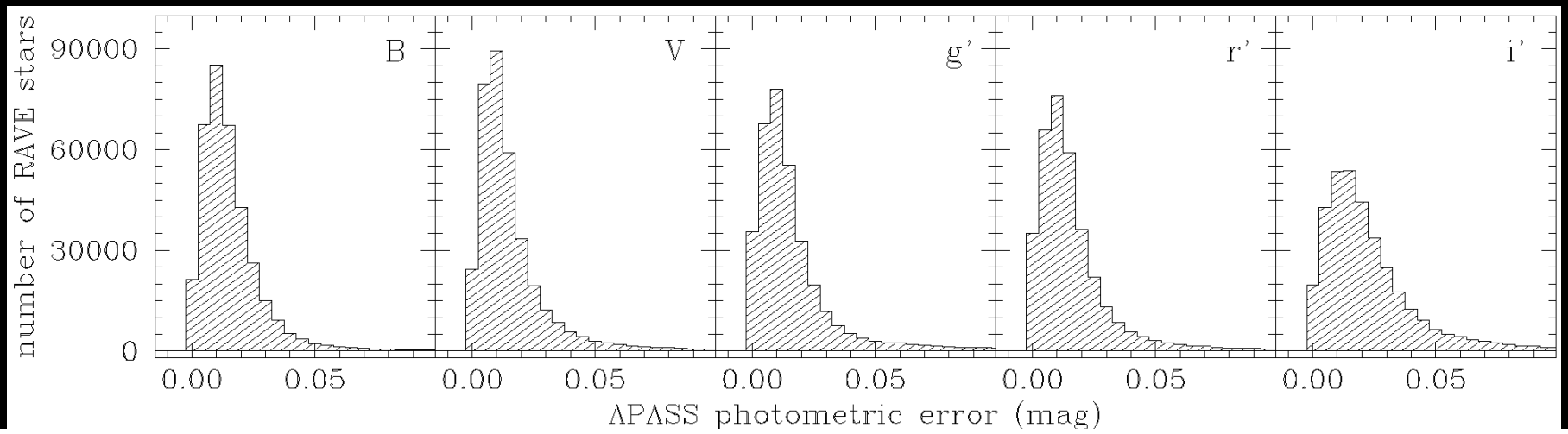


to date, 358,963 RAVE stars have been observed by APASS
on at least 2 distinct epochs in the Landolt B,V and Sloan g'r'i' bands.



median of internal errors of the mean on RAVE stars:

0.013 0.011 0.012 0.013 0.018 mag



Johnson UBVRI system

- Defined in 1953 paper
- B to match photographic
- V to match visual
- Vega defined to have same magnitude in all filters “Vega system”

Original paper

1953ApJ...117..313J

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME 117 MAY 1953 NUMBER 3

FUNDAMENTAL STELLAR PHOTOMETRY FOR STANDARDS OF SPECTRAL TYPE ON THE REVISED SYSTEM OF THE YERKES SPECTRAL *ATLAS**

H. L. JOHNSON AND W. W. MORGAN
Yerkes and McDonald Observatories
Received November 29, 1952

ABSTRACT

A system of photoelectric photometry is outlined which utilizes the revised zero point of the visual magnitude scale of the North Polar Sequence and which returns to the original definition for the zero point of color indices in terms of main-sequence stars of class A0; the interval A0–gK0 is 1 mag. The revised Yerkes *Atlas* system (MK) of spectral classification is taken as standard. The latter is described briefly, and a list of standard stars is included.

Magnitudes and color indices from measures in three wave-length bands are given for stars selected by spectral type and luminosity class to be representative of the principal regions of the H-R diagram. A few white dwarfs are also included.

A standard main sequence is defined for the new color–absolute magnitude diagram by the use of stars of large parallax, together with the galactic clusters NGC 2362, the Pleiades, the Ursa Major nucleus, and Praesepe. A standard main sequence is also defined for the relationship between the two systems of color index.

A purely photometric method for determining spectral types and space reddening for B stars in galactic clusters is described.

TERMINOLOGY

y. Deflection through yellow filter, corrected for sky.
b. Deflection through blue filter, corrected for sky.
u. Deflection through ultraviolet filter, corrected for sky.
C_y. Observed blue-yellow color index, reduced to outside the earth's atmosphere.
C_u. Observed ultraviolet-blue color index, reduced to outside the earth's atmosphere.
V. Observed magnitude through yellow filter, reduced to outside the earth's atmosphere. This is approximately equivalent to the photovisual magnitude on the International System.
B. Observed magnitude through blue filter, reduced to outside the earth's atmosphere and including a zero-point correction to satisfy the condition

$$B - V = 0$$

for main-sequence stars of class A0 on the MK system.
U. Observed magnitude through ultraviolet filter, reduced to outside the earth's atmosphere and including a zero-point correction to satisfy the condition

$$U - B = 0$$

for main-sequence stars of class A0 on the MK system.

* *Contributions from the McDonald Observatory, University of Texas,* No. 216.

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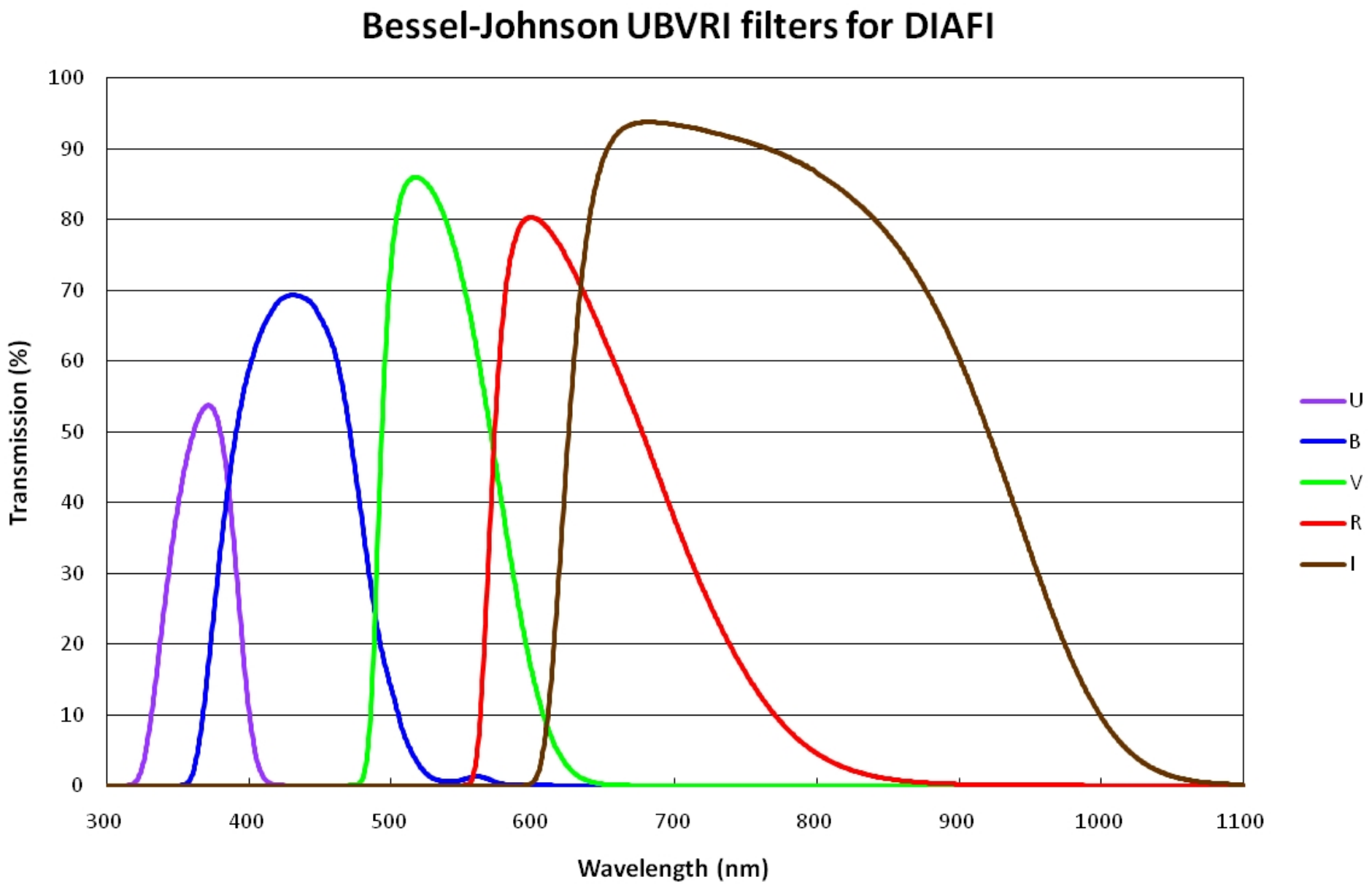


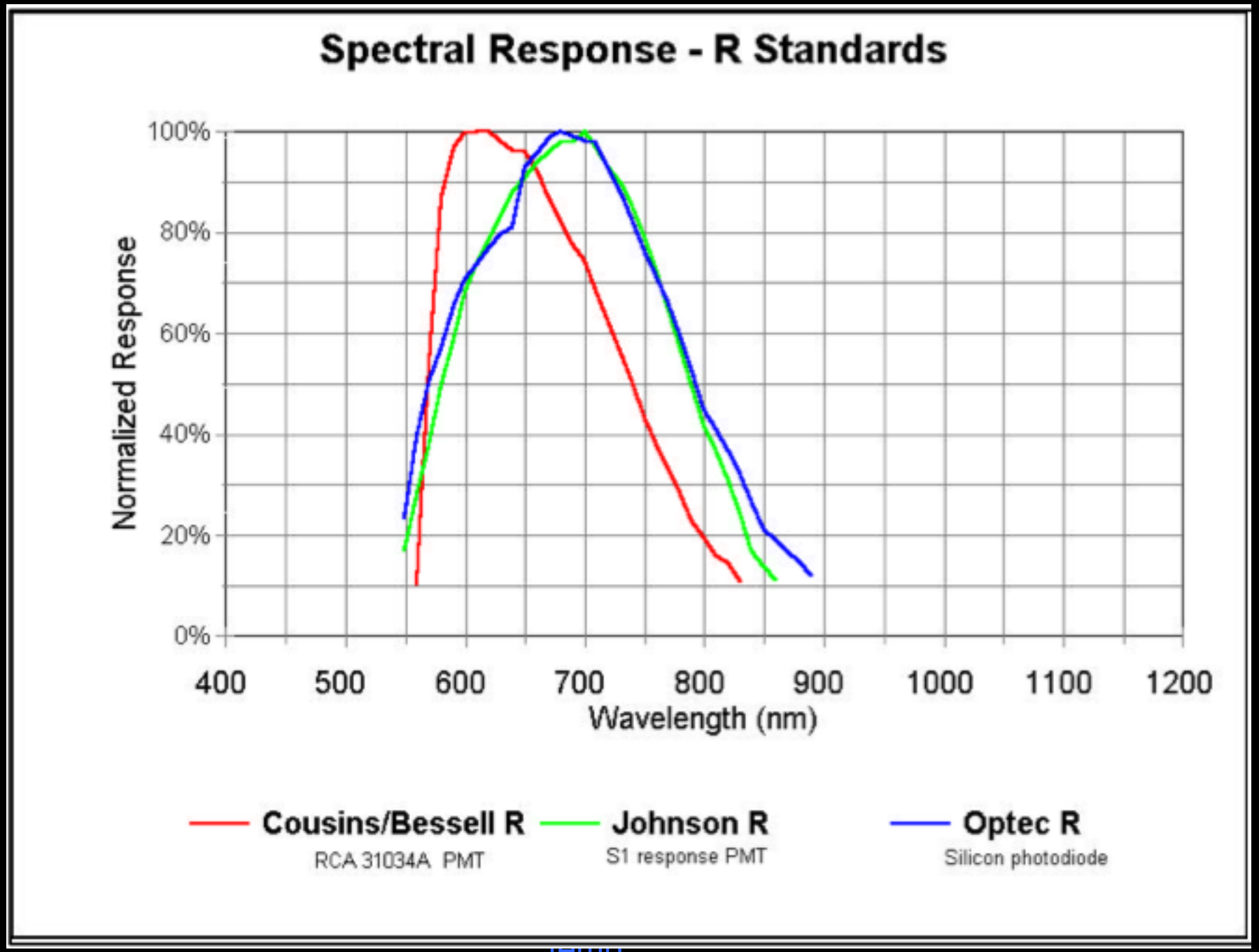
UBVRI filter curves

Johnson UBVRI system

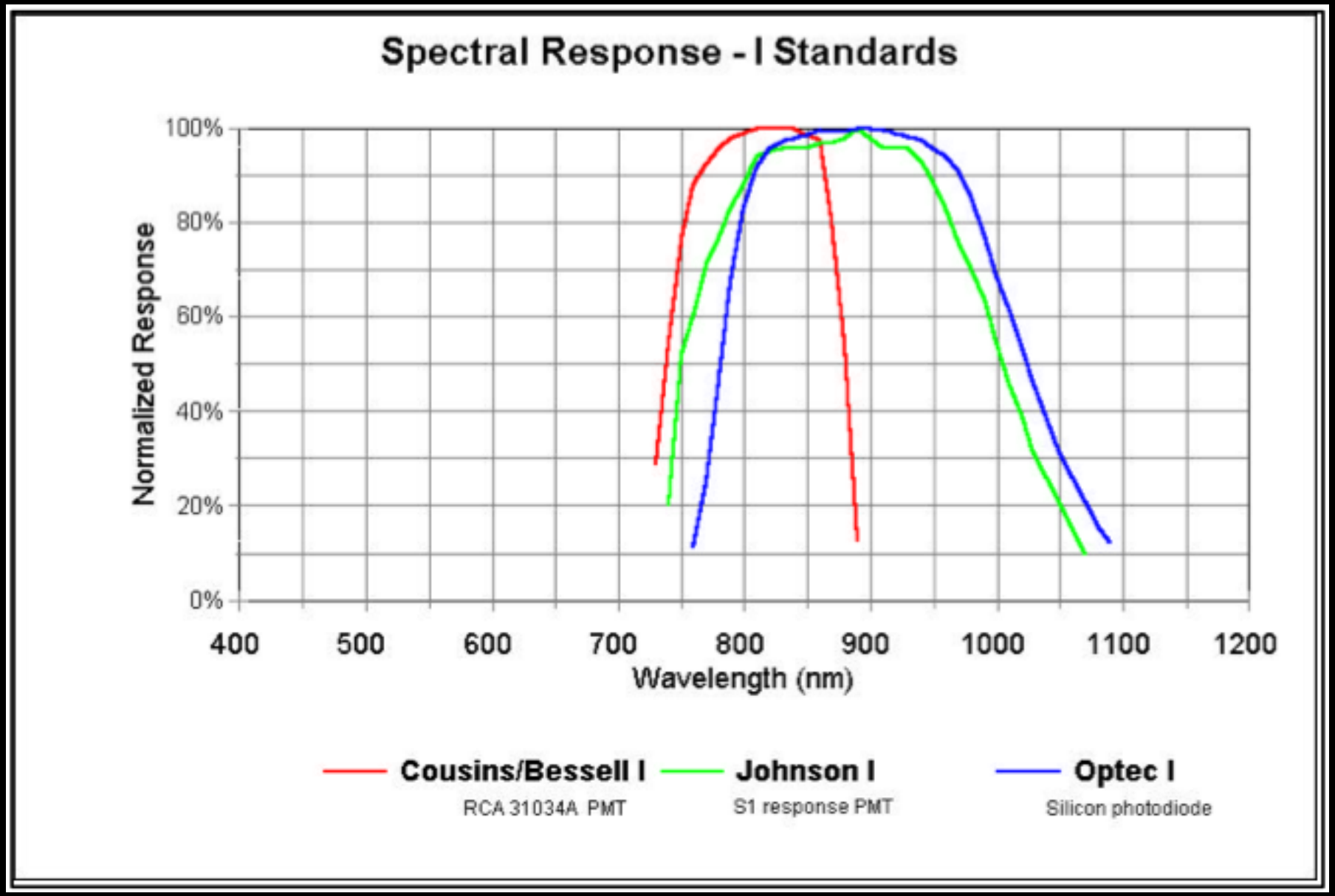
- U filter blue side defined by atmosphere
- UBV from 1P21; RI from EMI9863
- I-band red side defined by PMT FW-118 (S1 cathode)
- U straddles Balmer jump, not best
- UBVRI Tontantzintla catalog 1966

Kron-Cousins

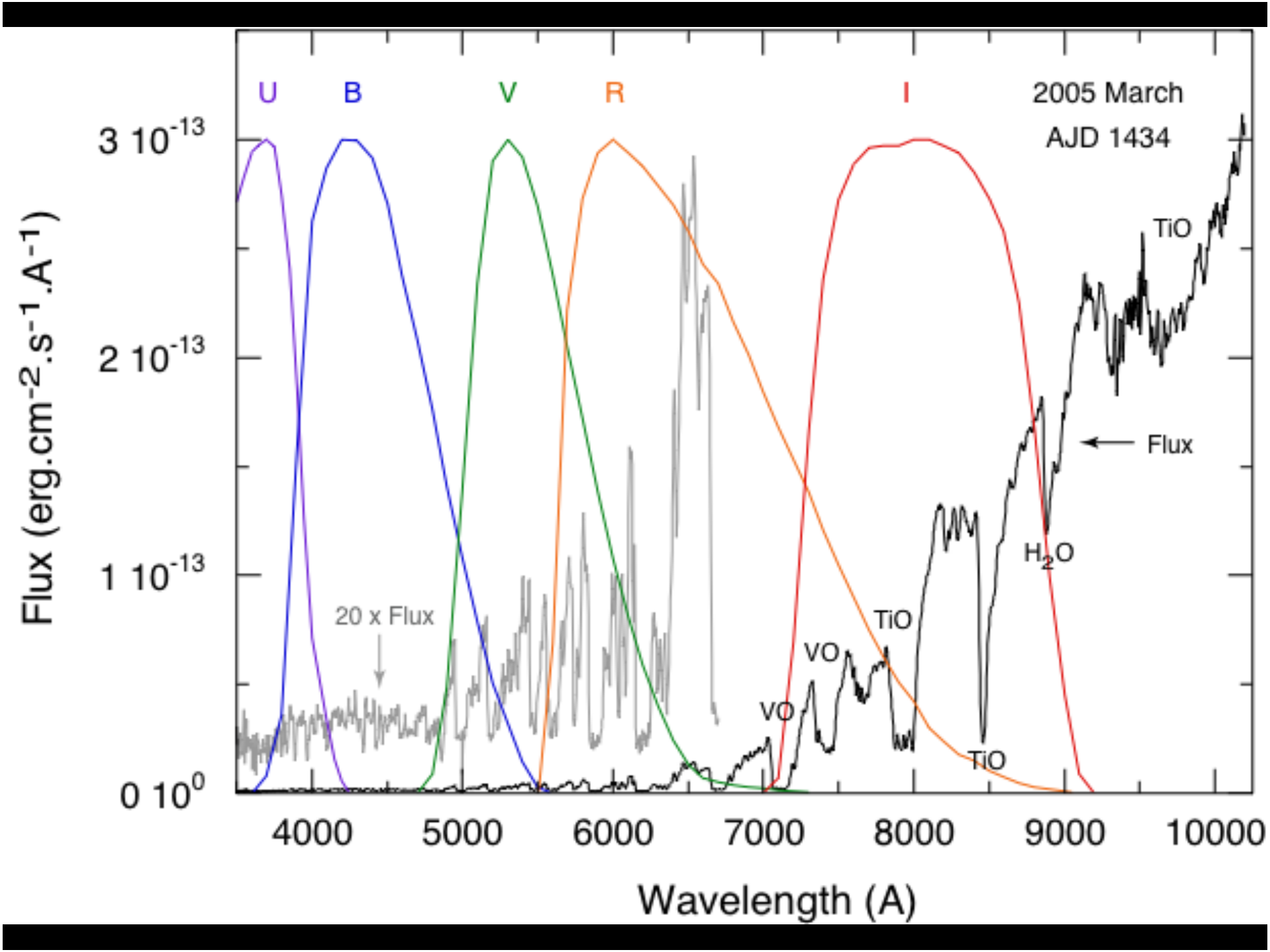
- Kron (north), Cousins (south), came up with slightly different R,I bandpasses from Johnson.
- For some reason, these were adopted by the professional community, so we have UBVRcIc


Spectral Response - R Standards
Normalized Response
100%
80%
60%
40%
20%
0%
400
500
600
700
800
900
1000
1100
1200
Wavelength (nm)
Cousins/Bessell R
RCA 31034A PMT
Johnson R
S1 response PMT
Optec R
Silicon photodiode

temp


Spectral Response - I Standards
Normalized Response
100%
80%
60%
40%
20%
0%
400
500
600
700
800
900
1000
1100
1200
Wavelength (nm)
Cousins/Bessell I
RCA 31034A PMT
Johnson I
S1 response PMT
Optec I
Silicon photodiode

temp


U
B
V
R
I
2005 March
AJD 1434
3 10-13
2 10-13
1 10-13
0 100
Flux (erg.cm-2.s-1.A-1)
20 x Flux
TiO
Flux
H2O
VO
VO
TiO
TiO
4000
5000
6000
7000
8000
9000
10000
Wavelength (A)

Bessell Filter Prescriptions

- Bessell 5mm
- U 1UG1+2S8612+2WG295
- B 2GG385+1BG1+2BG39
- V 2GG495+3BG40
- R 2OG570+3KG3
- I 3RG9+2WG295

- Bessell 4mm
- U 1UG1+2SG8612+1WG295
- B 1GG385+1BG4+2BG39
- V 2GG495+2BG39
- R 2OG570+2GK3
- I 2RG9+2WG295

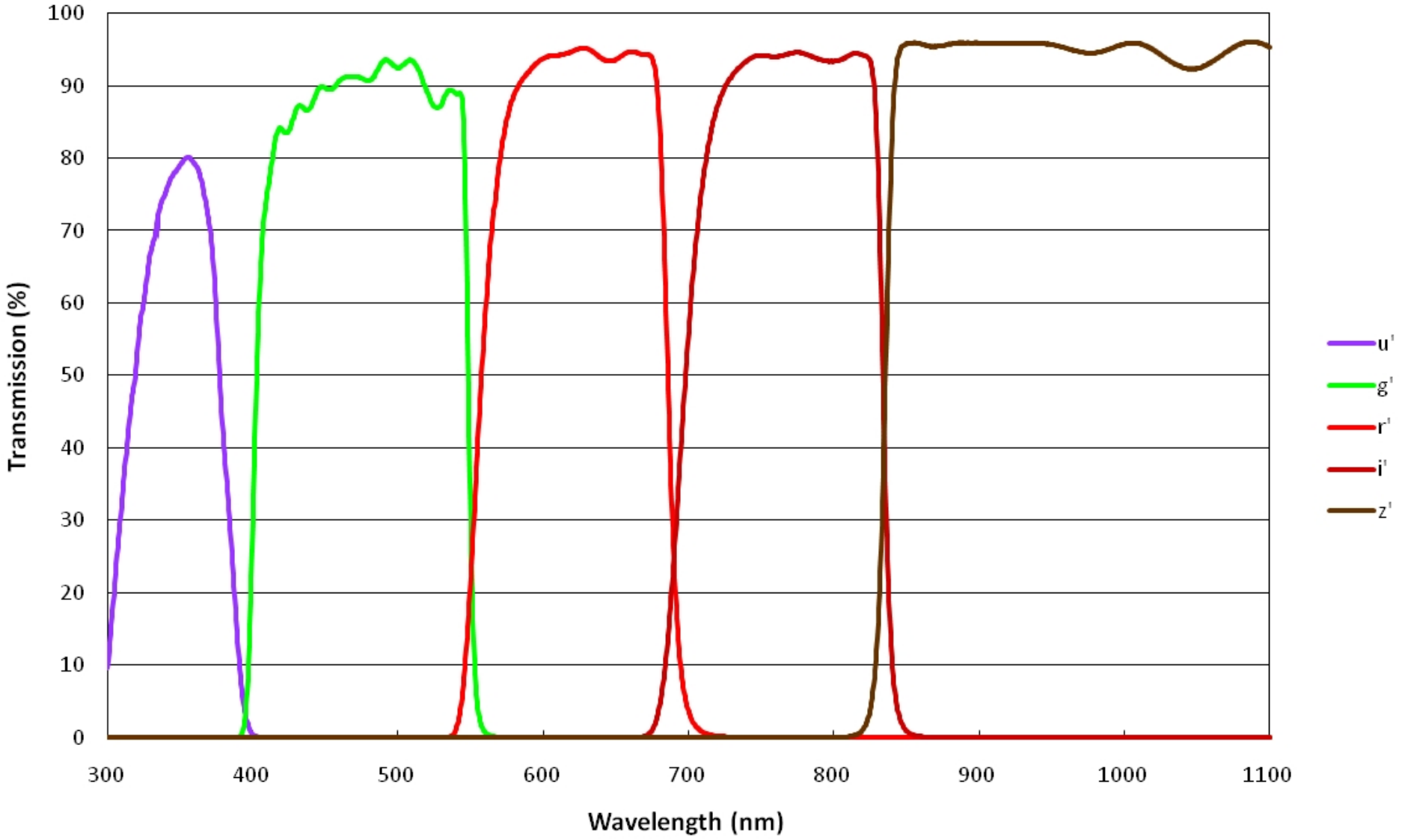
It is essential for those doing standardized CCD photometry to understand that photoelectric standard star photometry was necessarily obtained using apertures with diameters of 14 arcsec (Landolt 1992), 16–27 arcsec (Landolt 1983), and 40 arcsec (Cousins 1983). If 14-arcsec apertures cannot be used for the Landolt (1992) standards, then those standards with background stars evident within a 7-arcsec radius should be rejected, or the Stetson (2000) values for those stars used. Stetson's CCD photometry was obtained using small synthetic apertures or via profile fitting. Inversely, those using Tycho and Hipparcos photometry to standardize ground-based photometry need to check for nearby companions in the Tycho catalog that would be combined under ground-based seeing conditions.

The SDSS passbands are likely to become the new standard for optical broad-band photometry. As mentioned above, the placement and width of the *u* and *g* bands are not ideal for stellar work and steps are underway to design two or three different bands in the ultraviolet and blue that will enable the Balmer Jump, the metallicity and the hydrogen lines to be better measured. The passbands for the Global Astrometric Interferometer for Astrophysics (GAIA) satellite are also under active consideration and their finally adopted passbands will also greatly influence others.

Aperture sizes

Sloan Digital Sky System

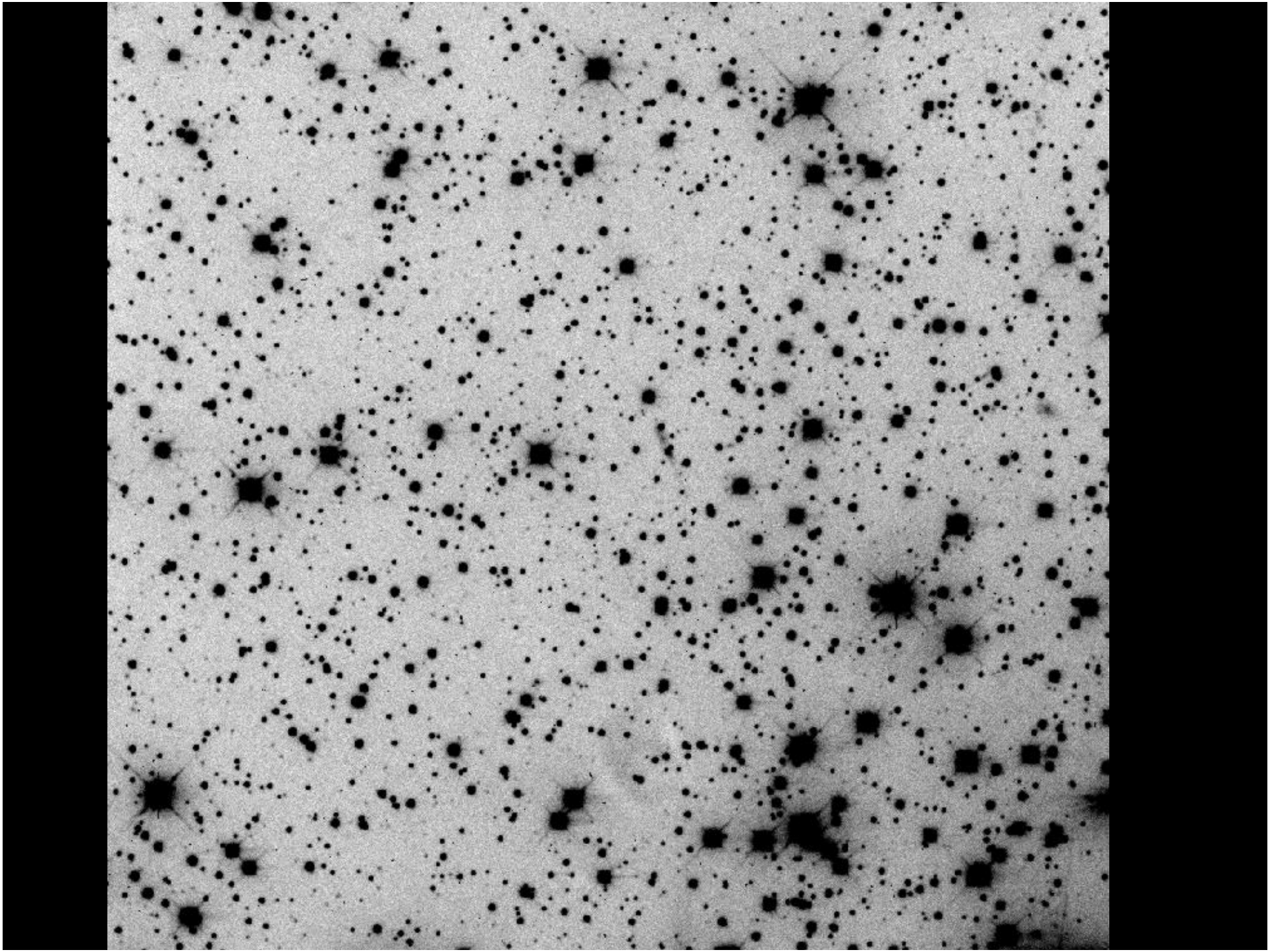
- SDSS ugriz magnitudes based on earlier filter system described by Gunn
- Defined to best separate stars from galaxies
- Note: u'g'r'I'z' are Standard. Ugriz are catalog
- SDSS is "AB" system

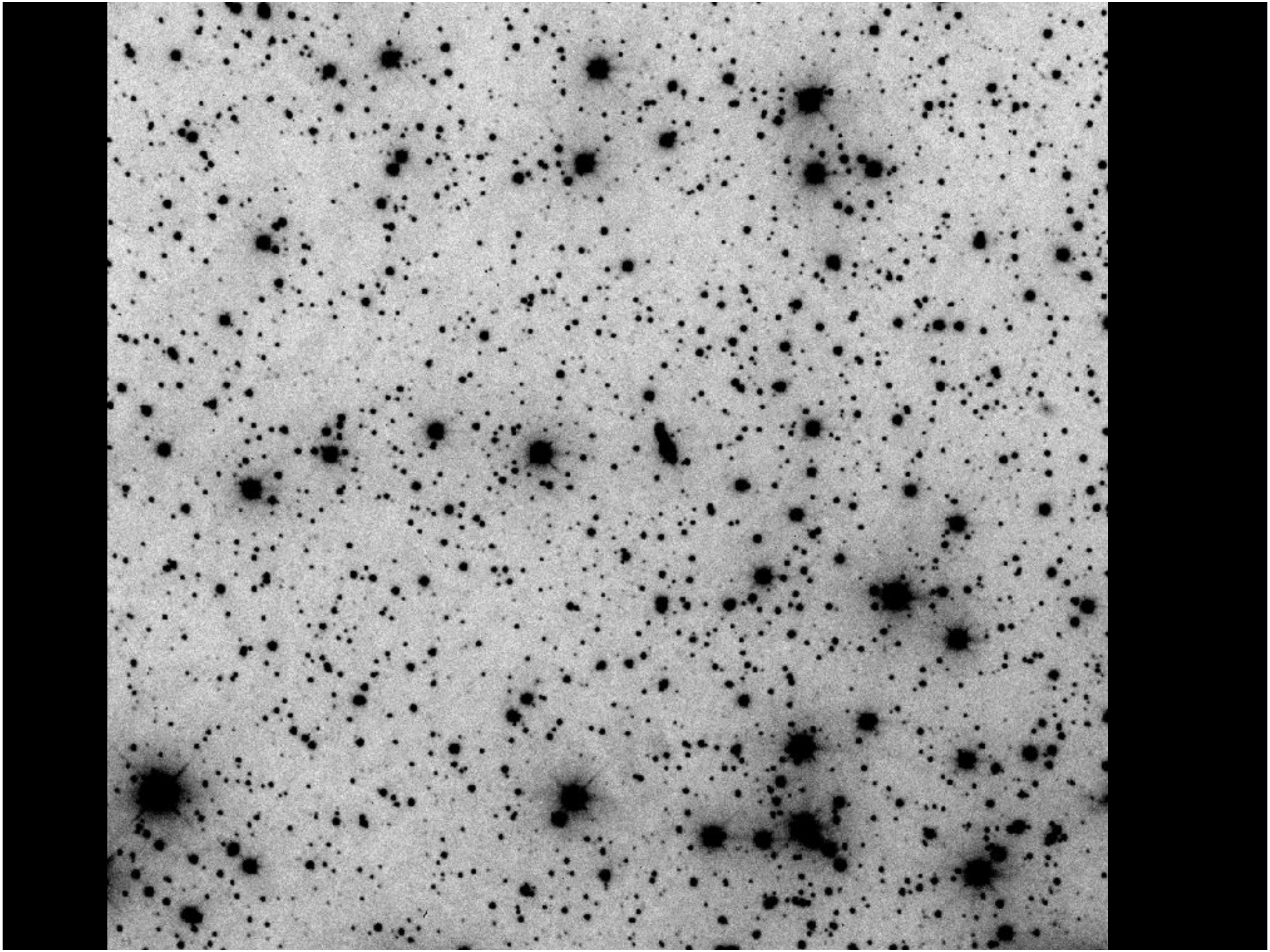


Sdss filters

The Oke spectrophotometric system is specified on a relative absolute (AB) flux scale, AB $= -2.5 \log F\nu + 48.60$ (Oke 1965, Oke & Gunn 1983). The system is based on the absolute flux of α Lyrae. There were some uncertainties concerning standard lamps and horizontal extinction correction in the earliest measurements of the absolute flux of α Lyrae (Hayes, Oke & Schild 1970; Tüg, White & Lockwood 1977). The original standards were a set of bright A and B stars (Oke 1964) with measurements made over 50 Å bands at 30 wavelengths between 3390 Å and 10,800 Å avoiding the hydrogen lines. These were later supplemented by fainter FG subdwarfs and white dwarfs (Oke & Gunn 1983, Oke 1990) measured over 40 Å bands at 68 wavelengths between 3080 Å and 12,000 Å.

temp

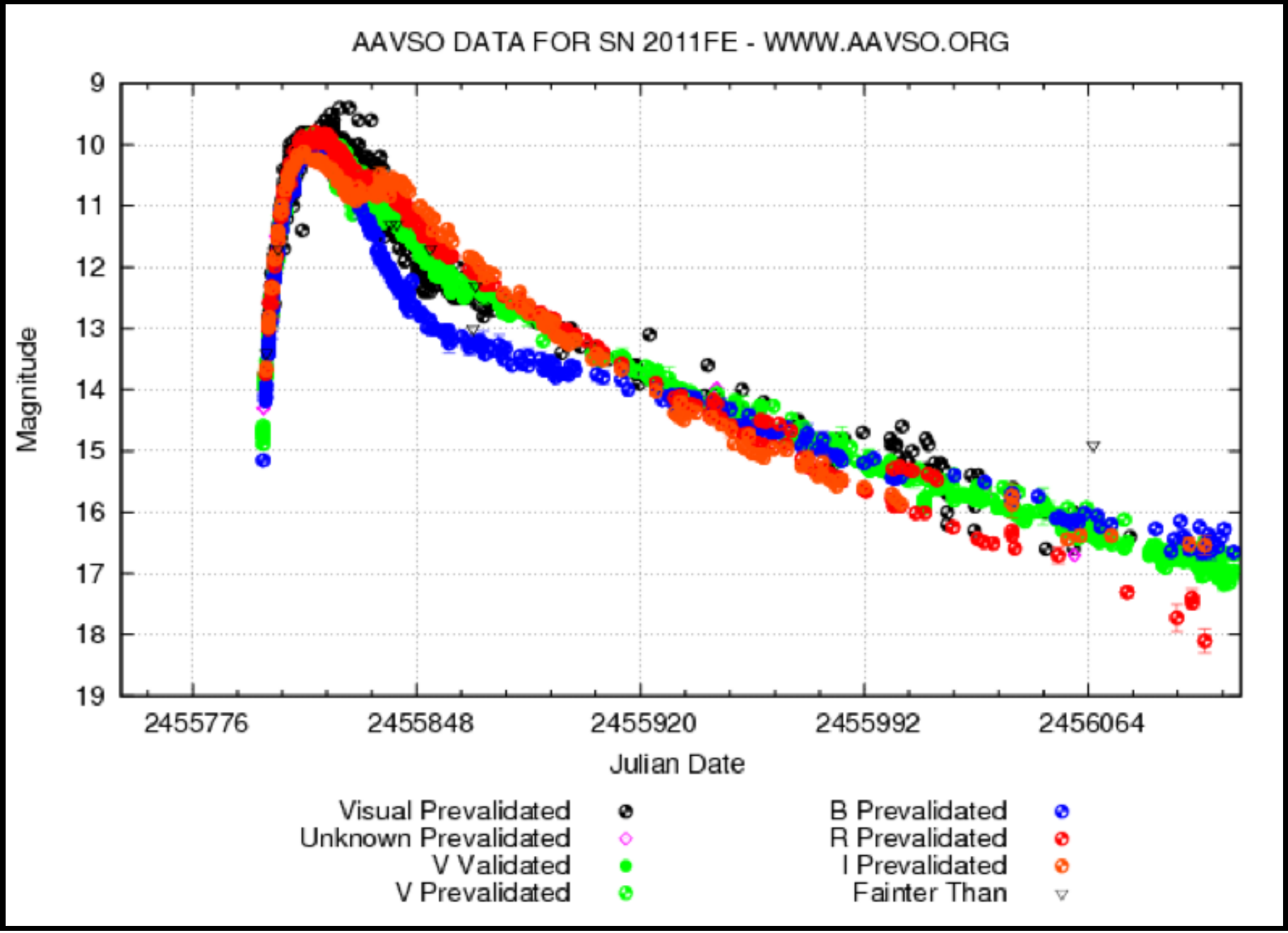


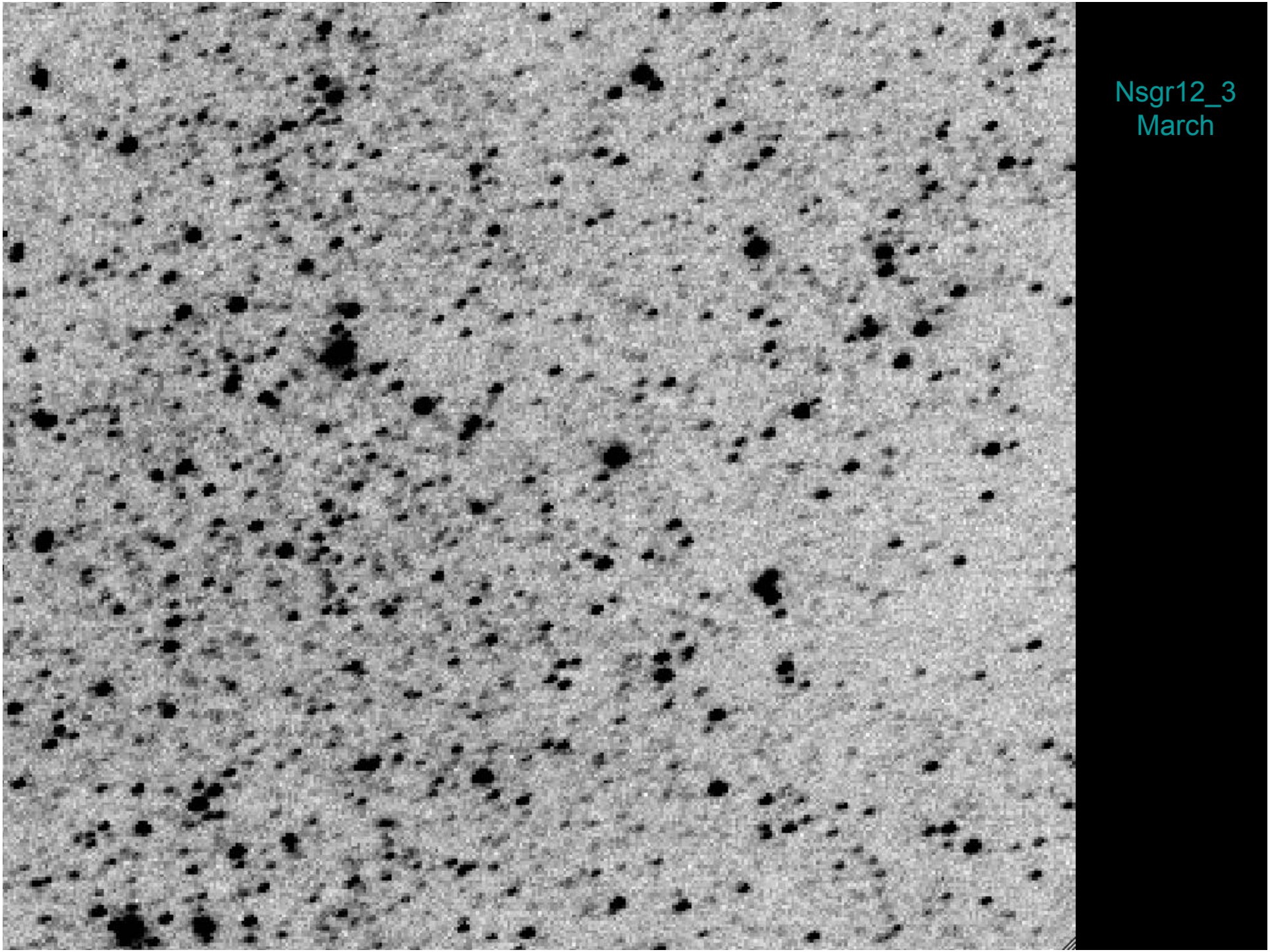


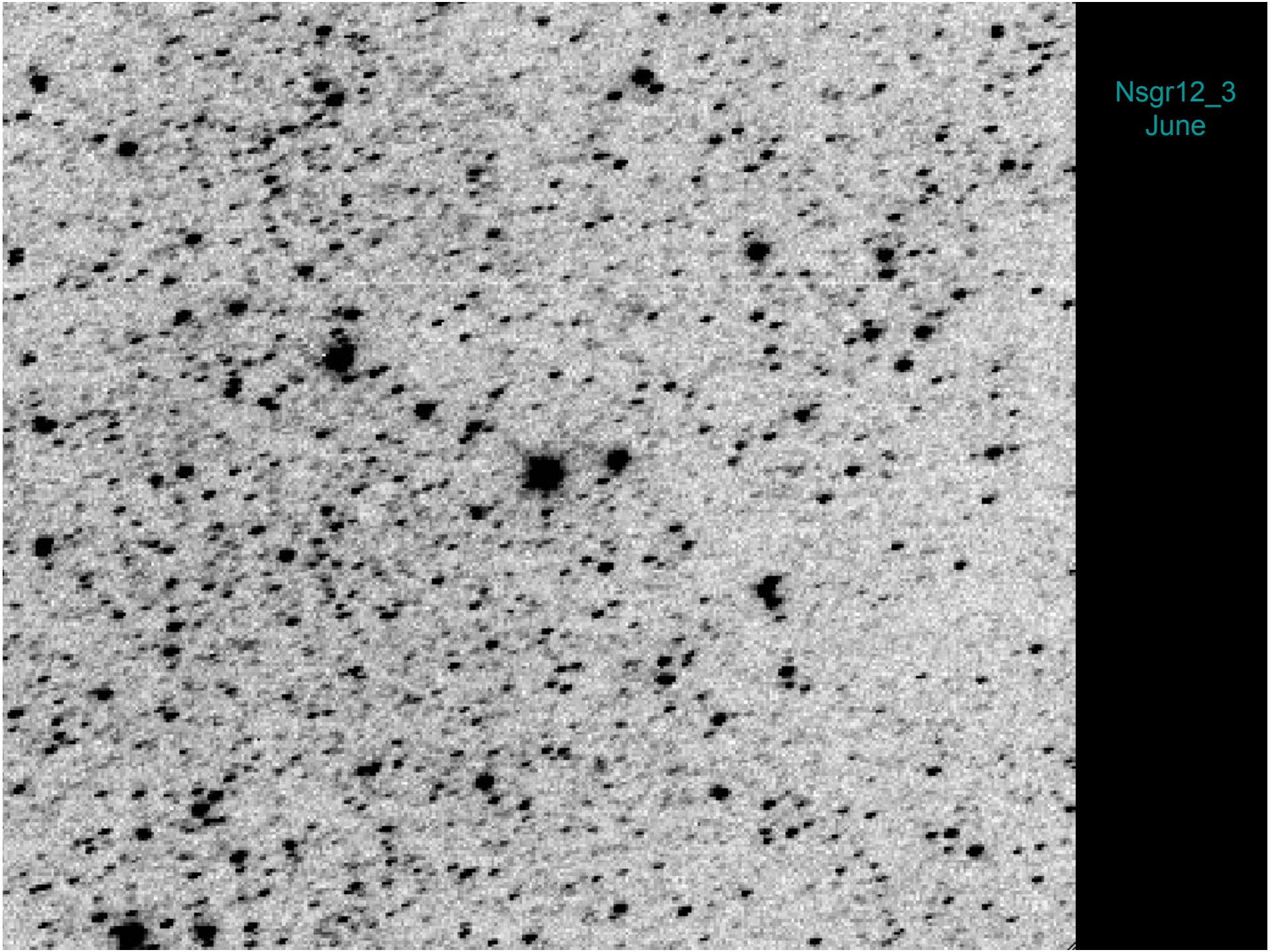
M101 + SN2011fe
outburst: 8/23/2011

Credit: Albert Duin

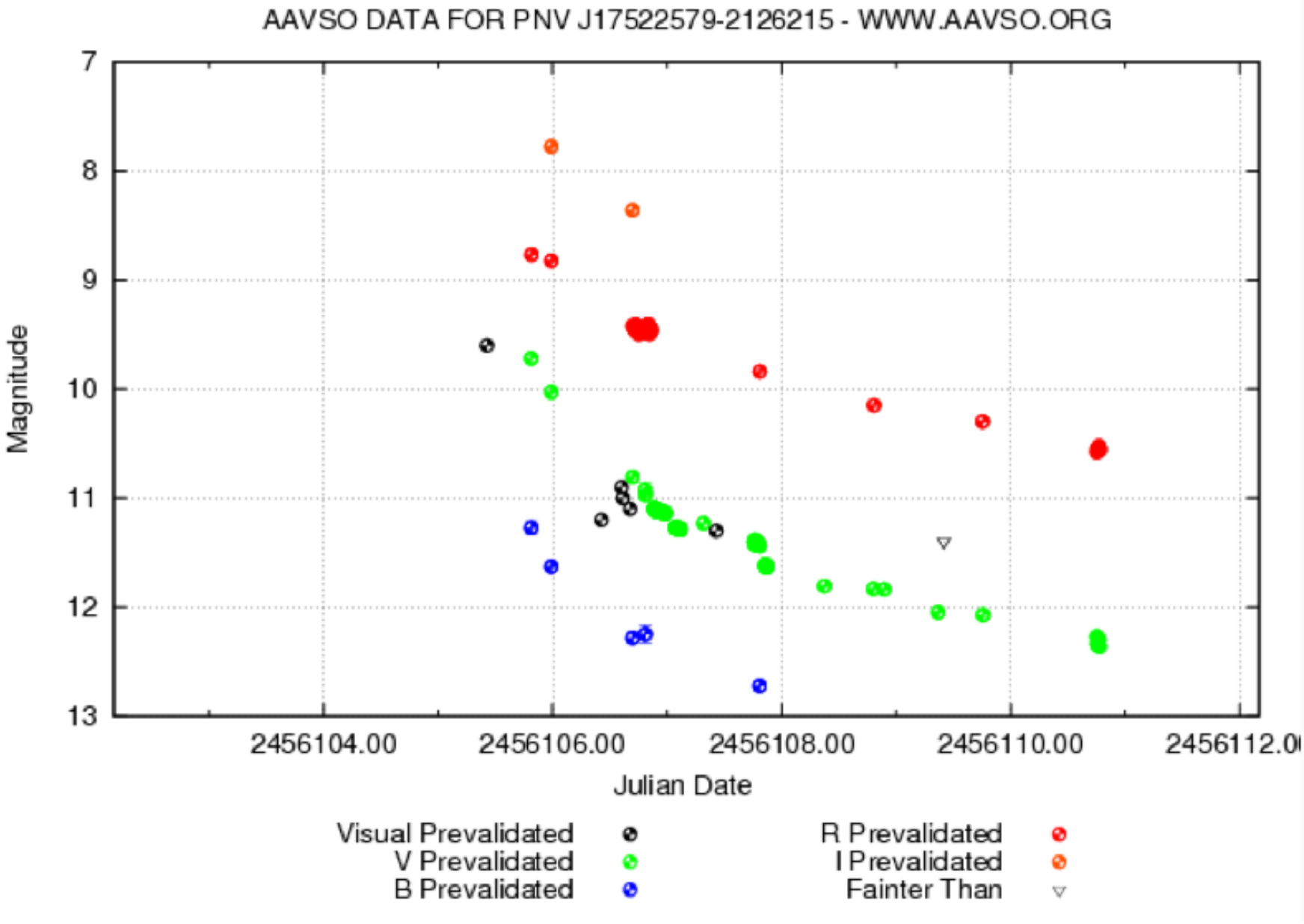
SN2011fe light curve

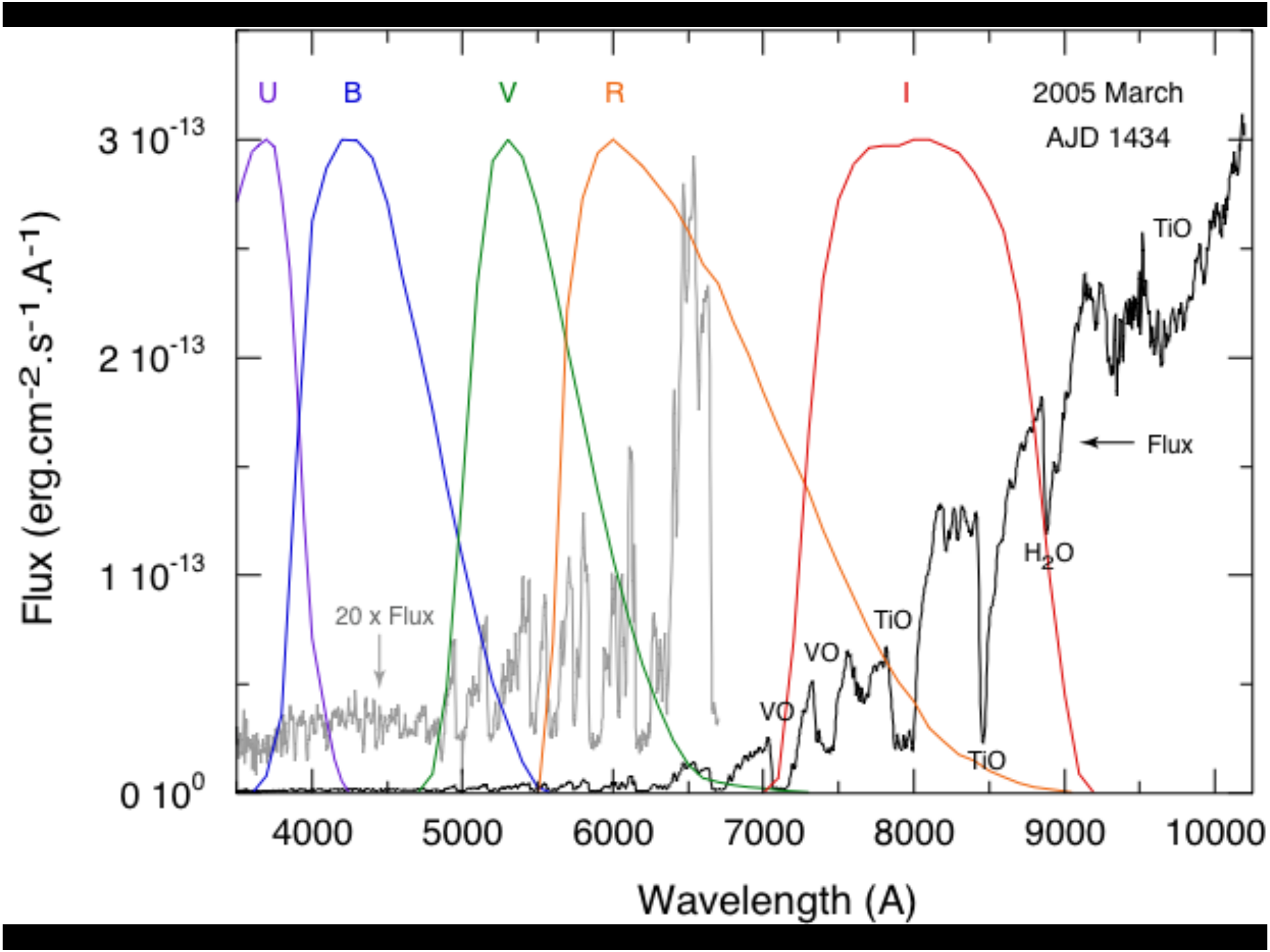



Nsgr12_3
March


Nsgr12_3
June

Nova Sgr 2012 n. 3 light curve




U
B
V
R
I
2005 March
AJD 1434
3 10-13
2 10-13
1 10-13
0 100
Flux (erg.cm-2.s-1.A-1)
20 x Flux
TiO
Flux
H2O
VO
VO
TiO
TiO
4000
5000
6000
7000
8000
9000
10000
Wavelength (A)

Red Leaks

- U-band very difficult to IR block; often see red-leaks
- B dielectric filter from Astrodon had red leak…

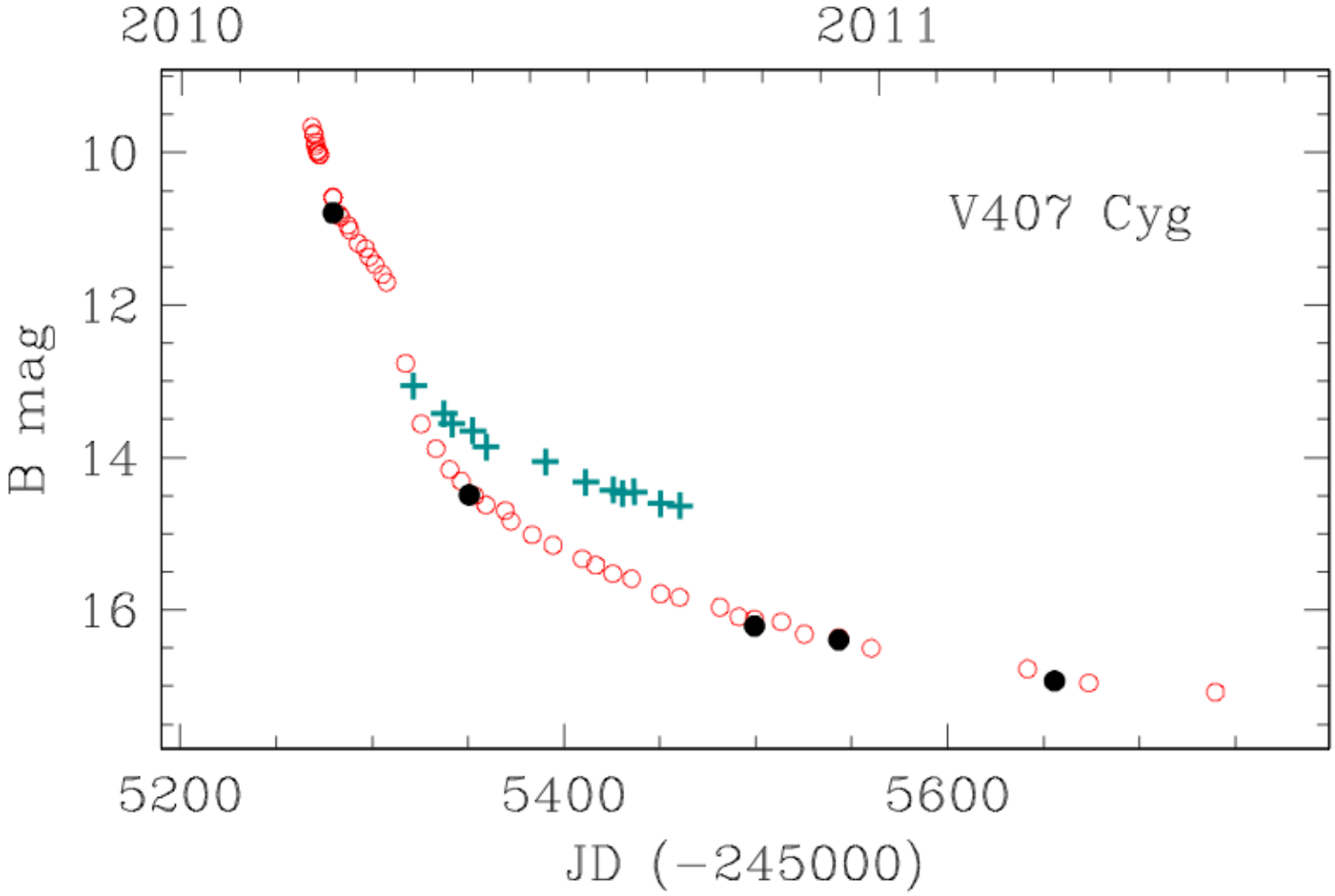


Fig. 8. The effect of the red leak of multi-layer filters when observing very red stars, like V407 Cyg during the return to quiescence following its 2010 outburst. B magnitudes from ANS Collaboration telescope R061 (crosses), equipped with Astrodon filters, became deviating from those of telescopes equipped with classical colored glass filters (open and filled circles) when $V-I_C$ turned $\geq$3.8.

Filter red leak problem

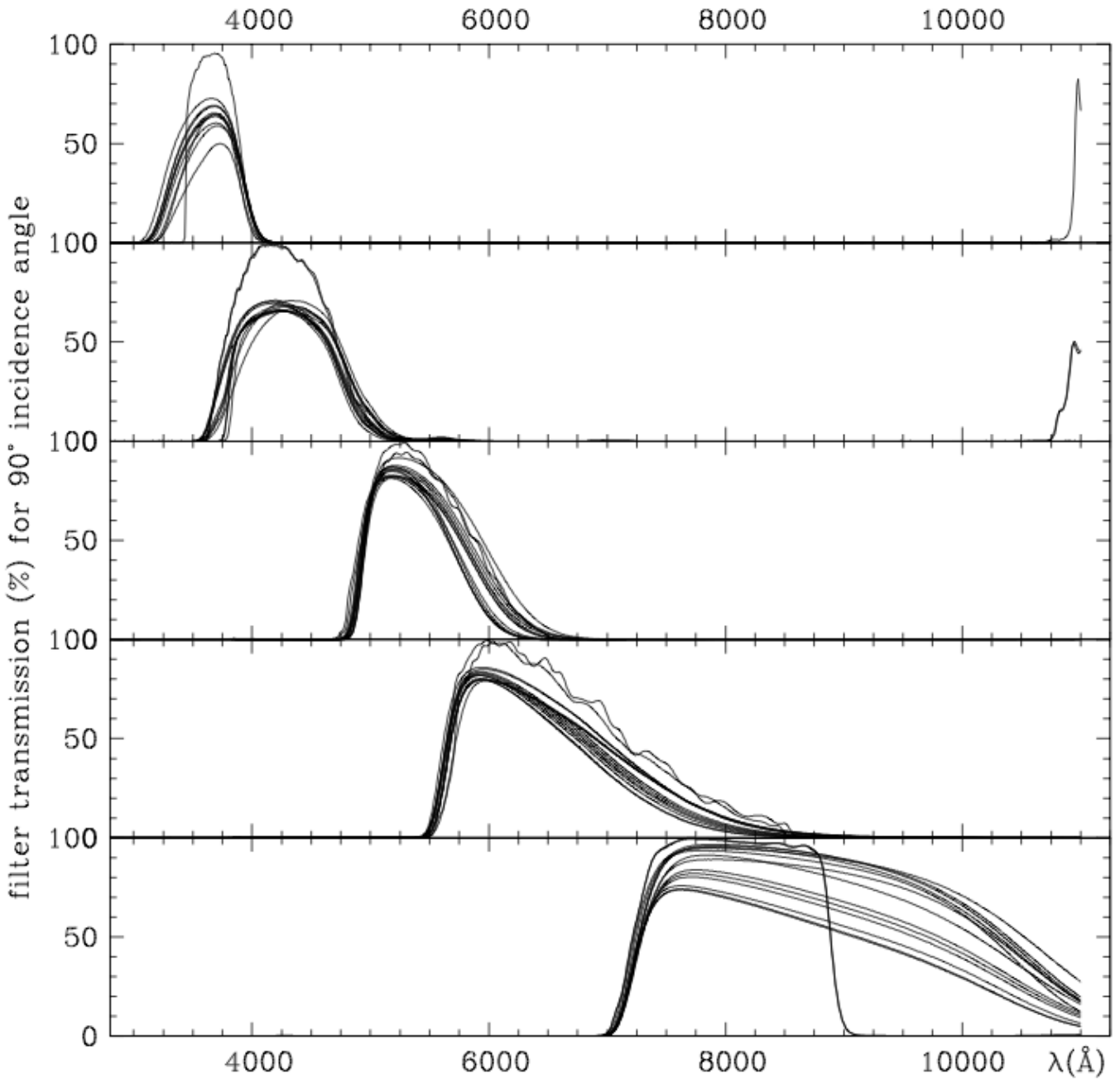


Fig. 1. The transmission curves we have measured for a sample of the photometric filters in use with ANS Collaboration telescopes.

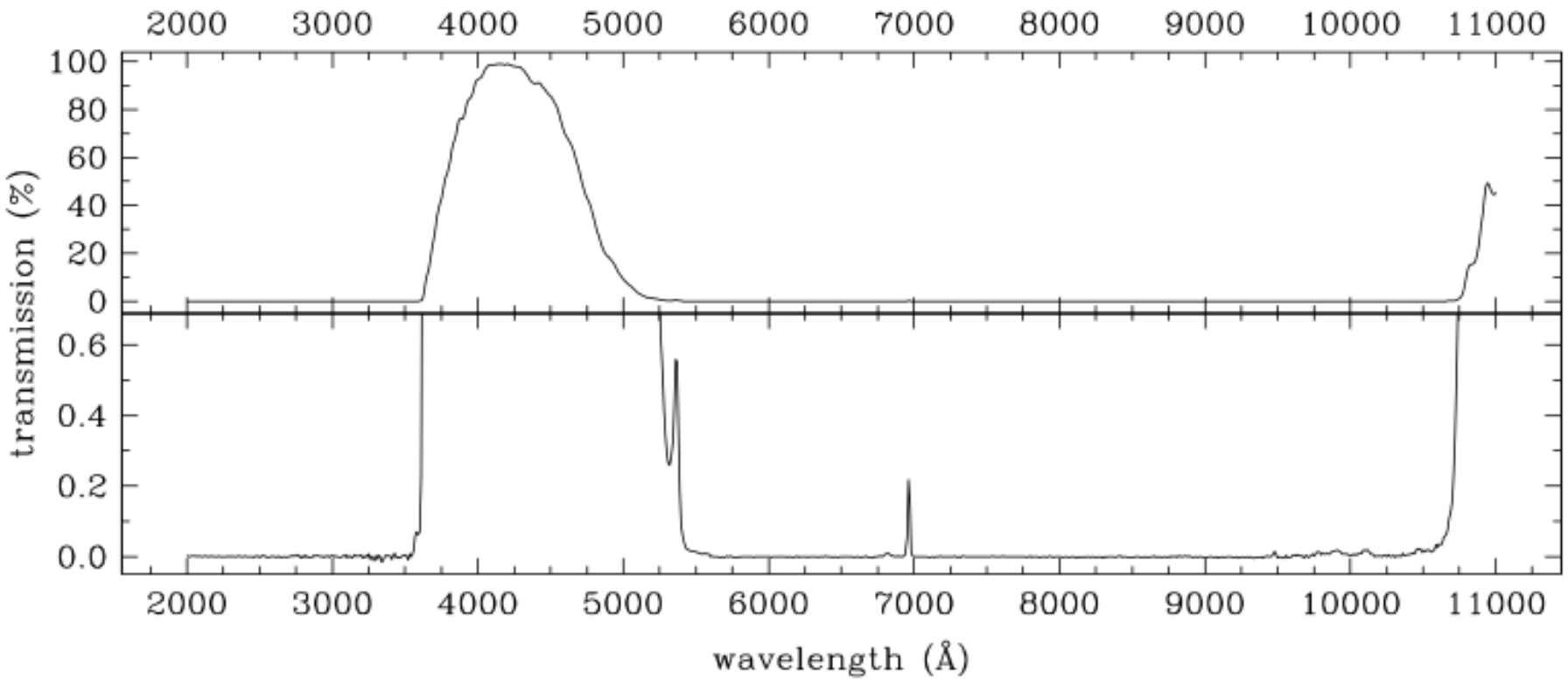


Fig. 1: *Transmission profiles (measured on May 2010) under 90° incident light, for an old Astrodon Johnson B filter in use since December 2009 at ANS Collaboration telescope R122.*

temp

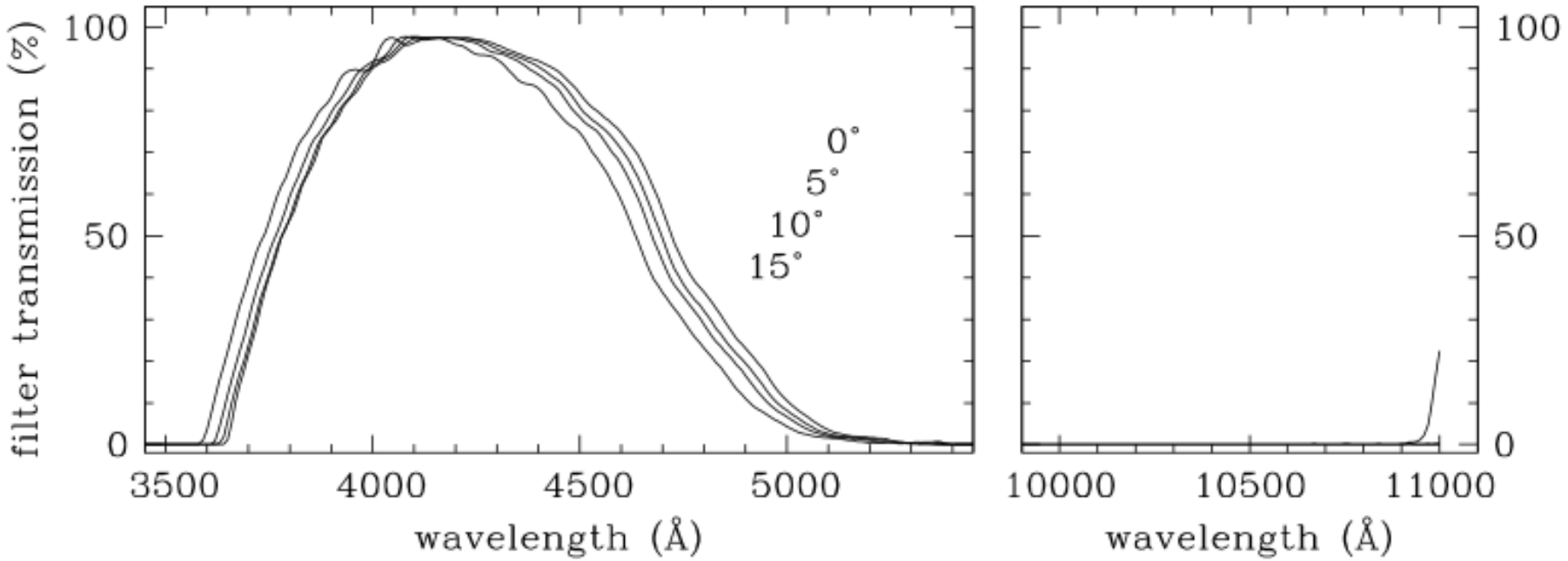


Fig. 4: *Similar to Fig. 3 for a test article of the new Astrodon Johnson B filter (red-leak suppressed) measured on April 2012.*

temp

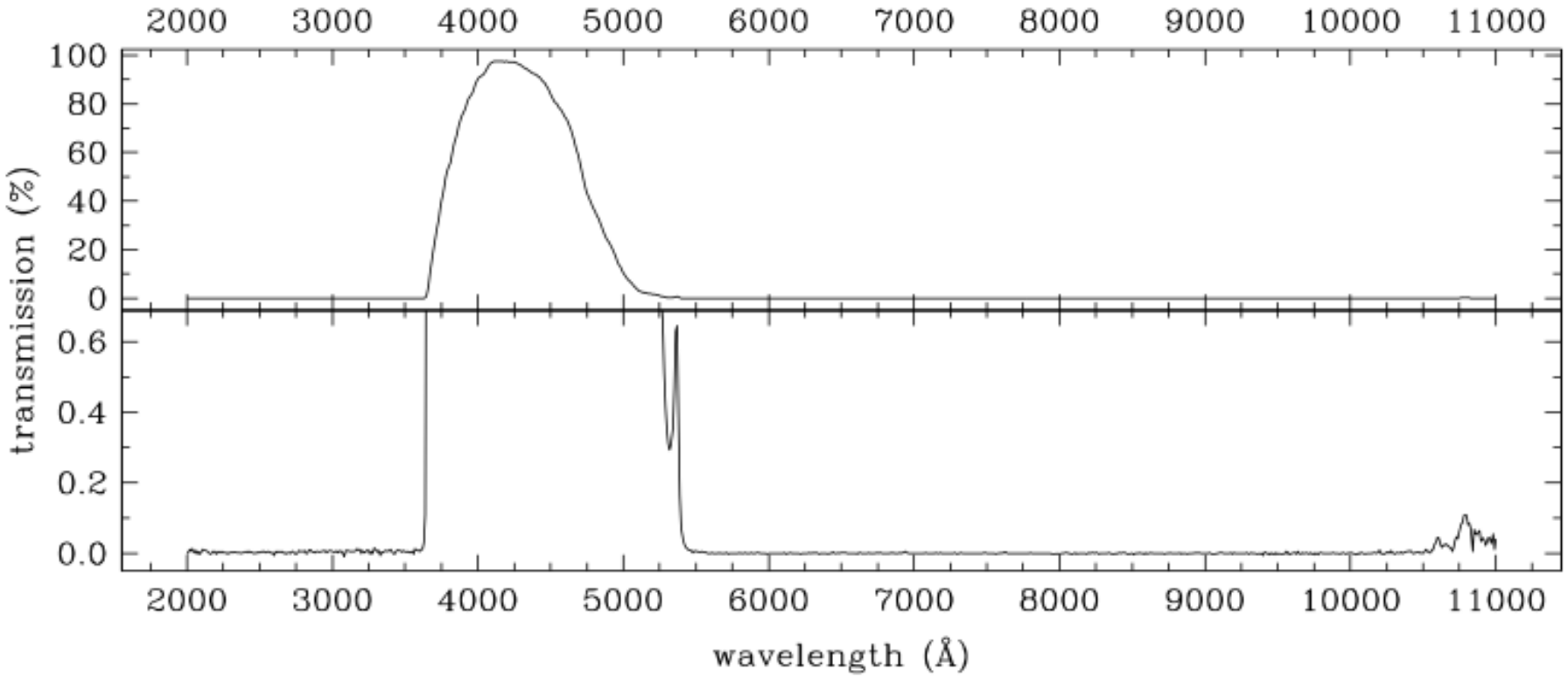


Fig. 2: *Transmission profiles (measured on April 2012) under 90° incident light, for a test article of the new Astrodon Johnson B filter (red-leak suppressed).*

temp

Recommendations

- Always use a filter unless the object just can't be imaged in any other way; uniquely defines your observation
- However, wide-band filters decrease your throughput by about 5x
- Watch out for red leaks
- Dielectric filters don't work well in fast beams

Astrodon Filters - 1

- Original glass filters used Bessell prescription colored glass
- V filter has a hygroscopic glass: BG39. Needs to be sandwiched to keep from frosting. Schuler prescription does not do this. Can clean for a while with cerium oxide

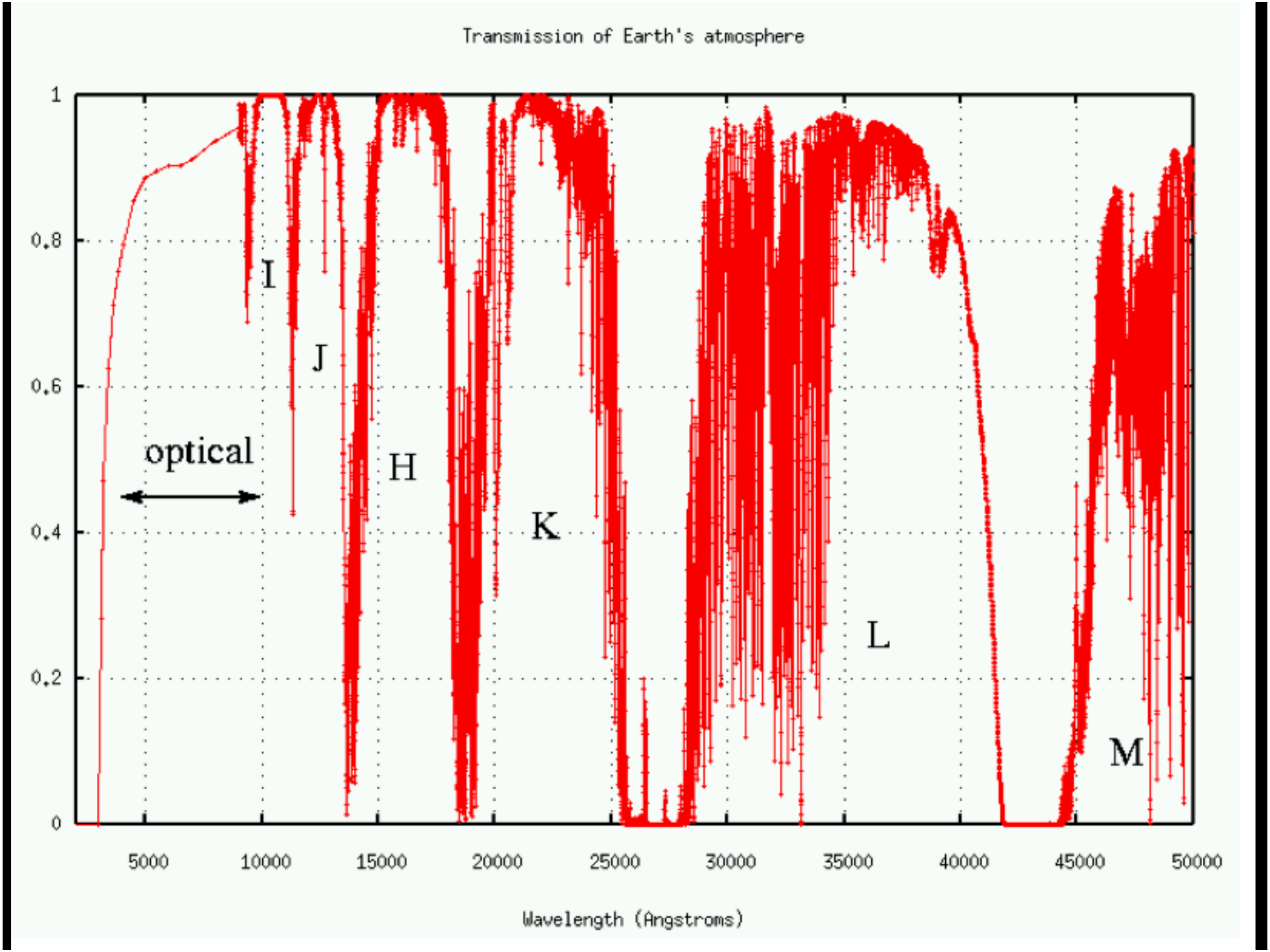
Astrodon Filters - 2

- Dielectric filters excellent match to J/C system
- B filter in particular has far better transmission
- B filter has red leak, as mentioned. New version has improved blocking, works fine – available as of June

Filter Vendors

- Omega Optical Inc.
  210 Main Street
  Brattleboro, VT 05301
  phone: 802-254-2690
  web: http://www.omegafilters.com
- Custom Scientific Inc.
  3852 N. 15th Ave.
  Phoenix, AX 85015
  phone: 602-200-9200
  web: http://www.customscientific.com
- Schuler AstroImaging
  now Don S. Goldman/Sacramento CA
  web: http://www.astrodon.com

  2789 Northpont Pkwy
  Santa Rosa, CA 95407-9809
  web: http://www.ocli.com
- SBIG (CSI)
- Optec Inc.
  199 Smith Street
  Lowell, MI 49331
  ph: 888-488-0381
- Optical Coating Laboratory Inc.
  web: http://www.optecinc.com


Transmission of Earth's atmosphere
1
0.8
0.6
0.4
0.2
0
optical
I
J
H
K
L
M
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Wavelength (Angstroms)