Astronomical Observing Techniques

Lecture 12: Pink and other Colored Glasses

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Overview

1. Colored Plastic and Glass Filters
2. Interference Filters
3. UBVRI Photometry
4. Precision Photometry
5. Extreme Photometry

Broadband Color Filters

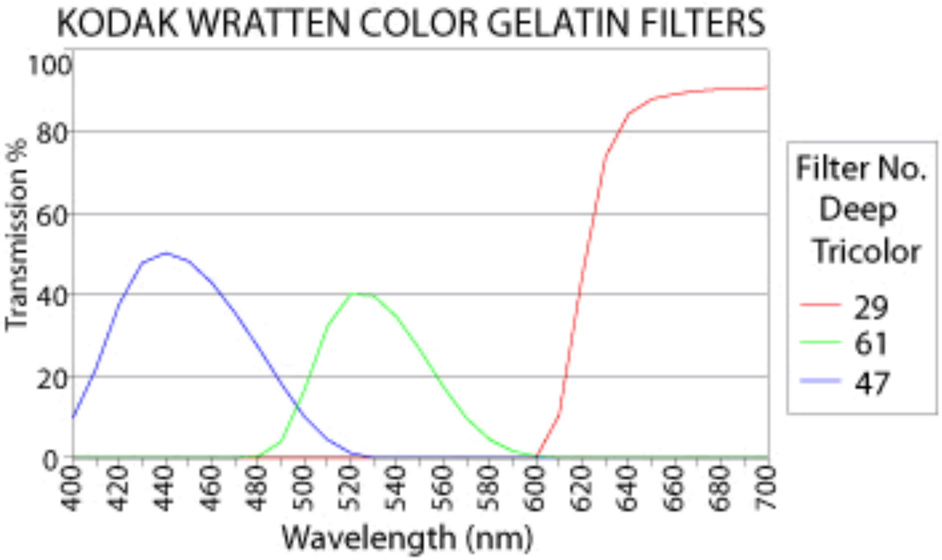
- Dyed gelatin (Kodak Wratten)
  - advantages: thin, cheap, large sizes
  - disadvantages: limited optical quality, heat-sensitive
- Colored glass (Schott, Corning)
  - advantages: stable, rugged, high transmission
  - disadvantages: limited bandpasses, limited sizes
- Interference filters
  - advantages: very narrow filters, almost arbitrary bandpass shape and wavelength
  - disadvantages: expensive, very limited sizes, temperature-sensitive, humidity-sensitive, aging

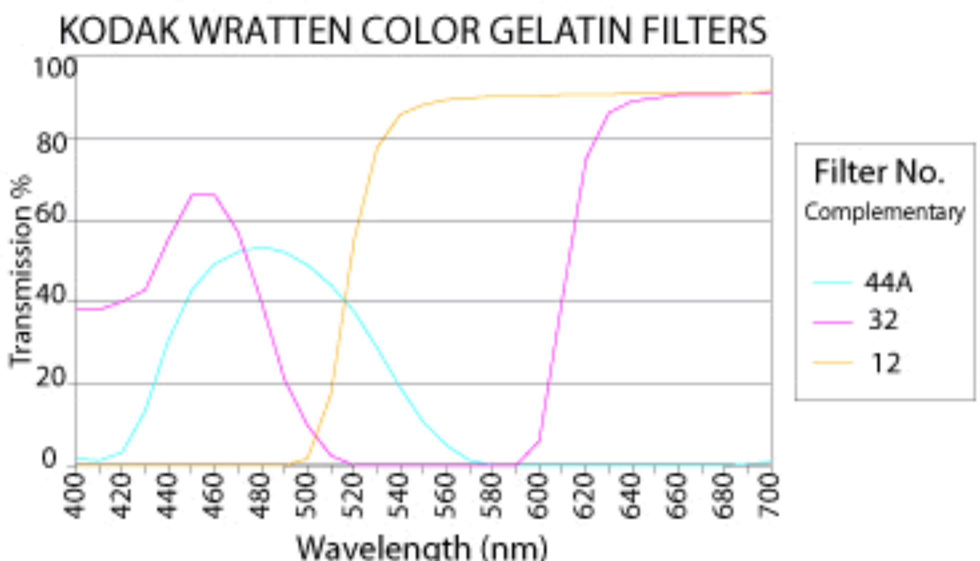
Wratten Filters

www.edmundoptics.com/onlinecatalog/displayproduct.cfm?productid=1326

- colored plastic sheets
- named after Frederick Wratten, manufactured by Kodak for about 100 years
- recently: Wratten 2
- up to 100 mm by 300 mm
- can be used for experiments
- improved performance when put between glass plates

Typical Wratten Filters



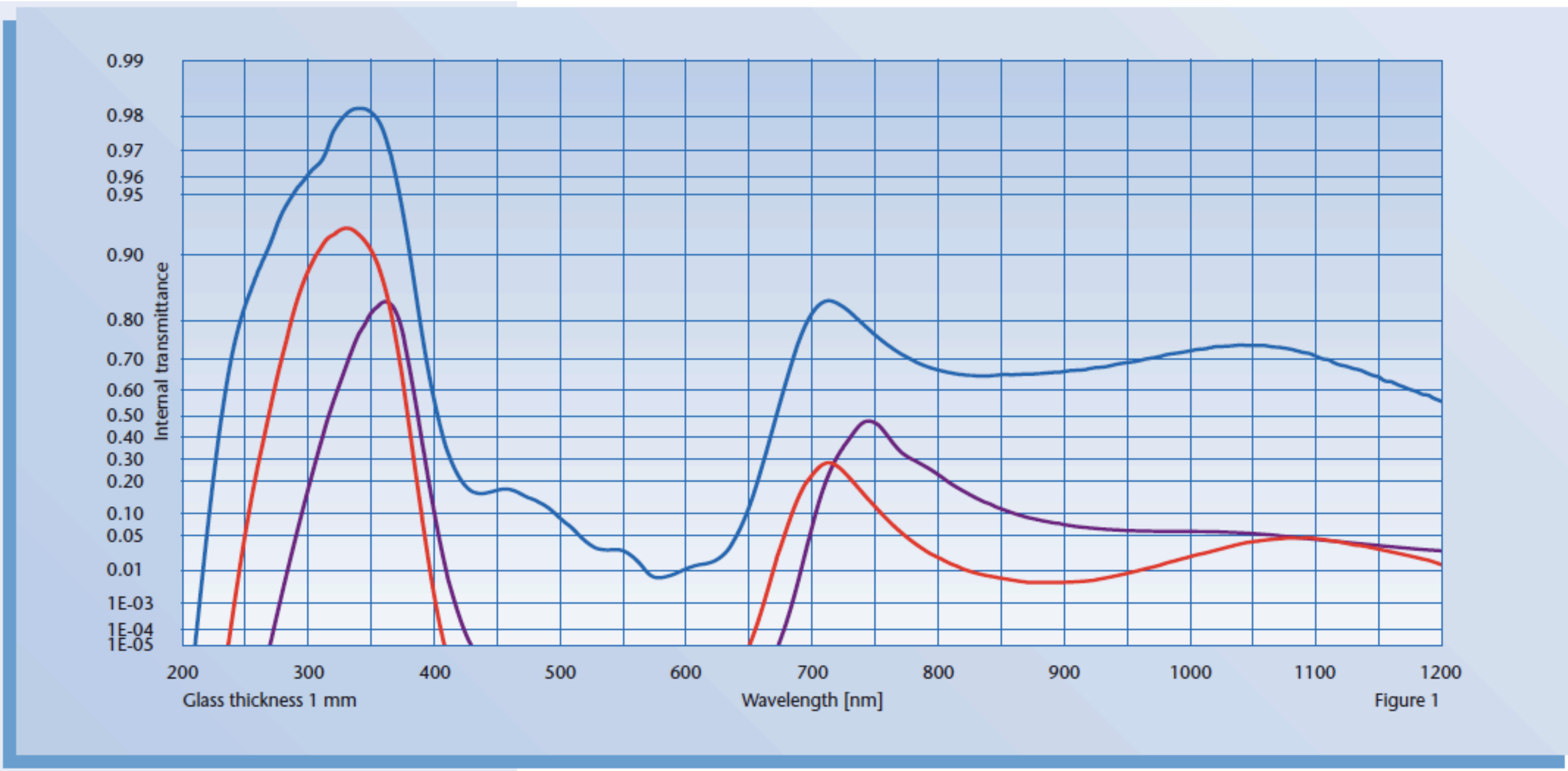


www.edmundoptics.com/onlinecatalog/displayproduct.cfm?productid=1326

Colored Glass

- typically useful from 200 - 1000 nm
- Schott
  - UG: Black and blue glasses, UV transmitting
  - BG: Blue, blue-green, and multi-band glasses
  - VG: Green glass
  - GG: Nearly colorless to yellow glasses, IR transmitting
  - OG: Orange glasses, IR transmitting
  - RG: Red and black glasses, IR transmitting
  - NG: Neutral density glasses with uniform attenuation in the visible range
  - N-WG: Colorless glasses with different cutoffs in the UV, transmitting in the visible range and the IR
  - KG: Virtually colorless glasses with high transmission in the visible and effective absorption in the IR (heat protection filters)
- other glasses from Corning, Hoya

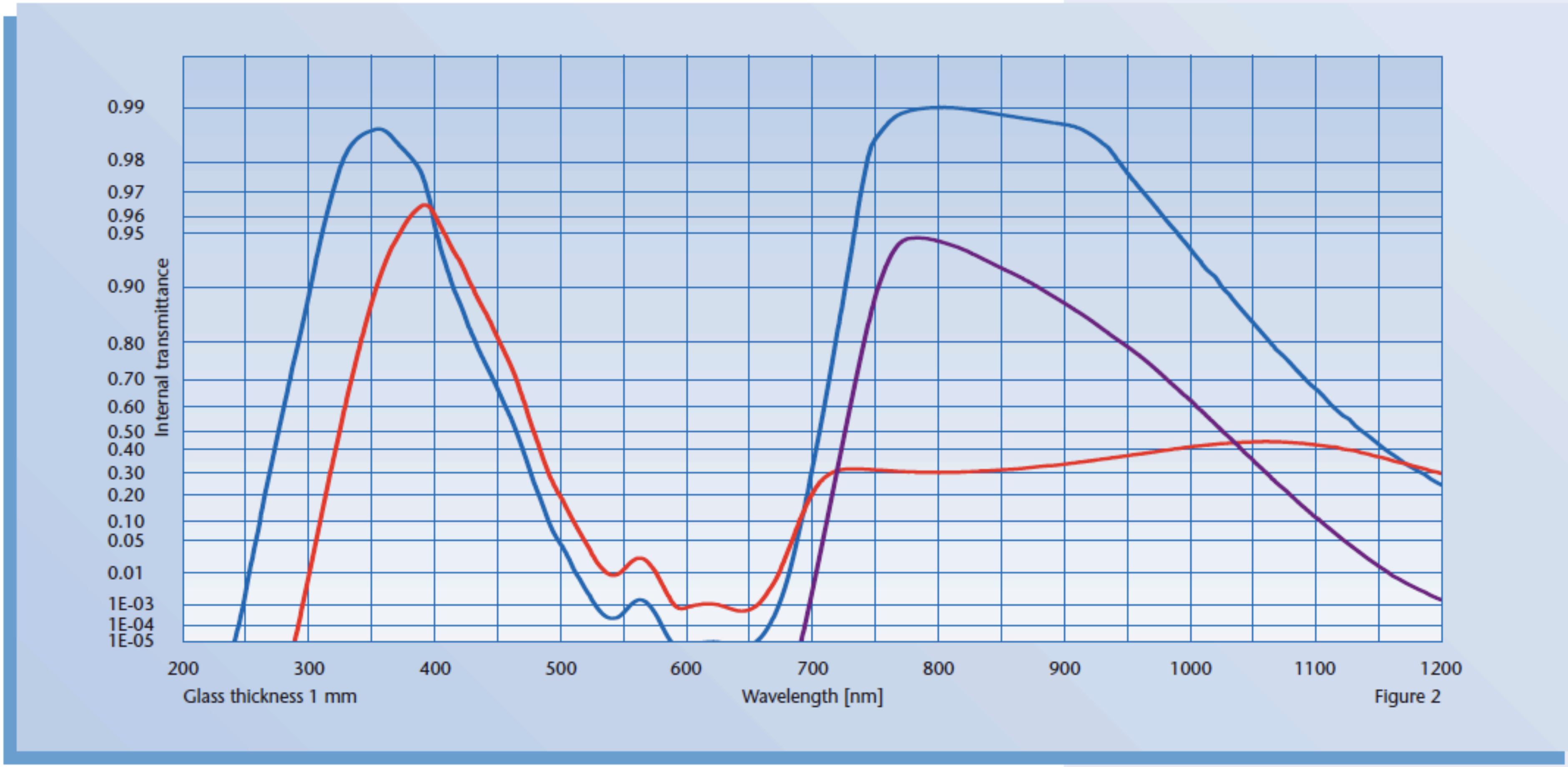
Schott Colored Glass 1



Color: dark violet-black (UG1)
dark violet (UG5)
dark red-black (UG11)

UG5 UG11
UG1

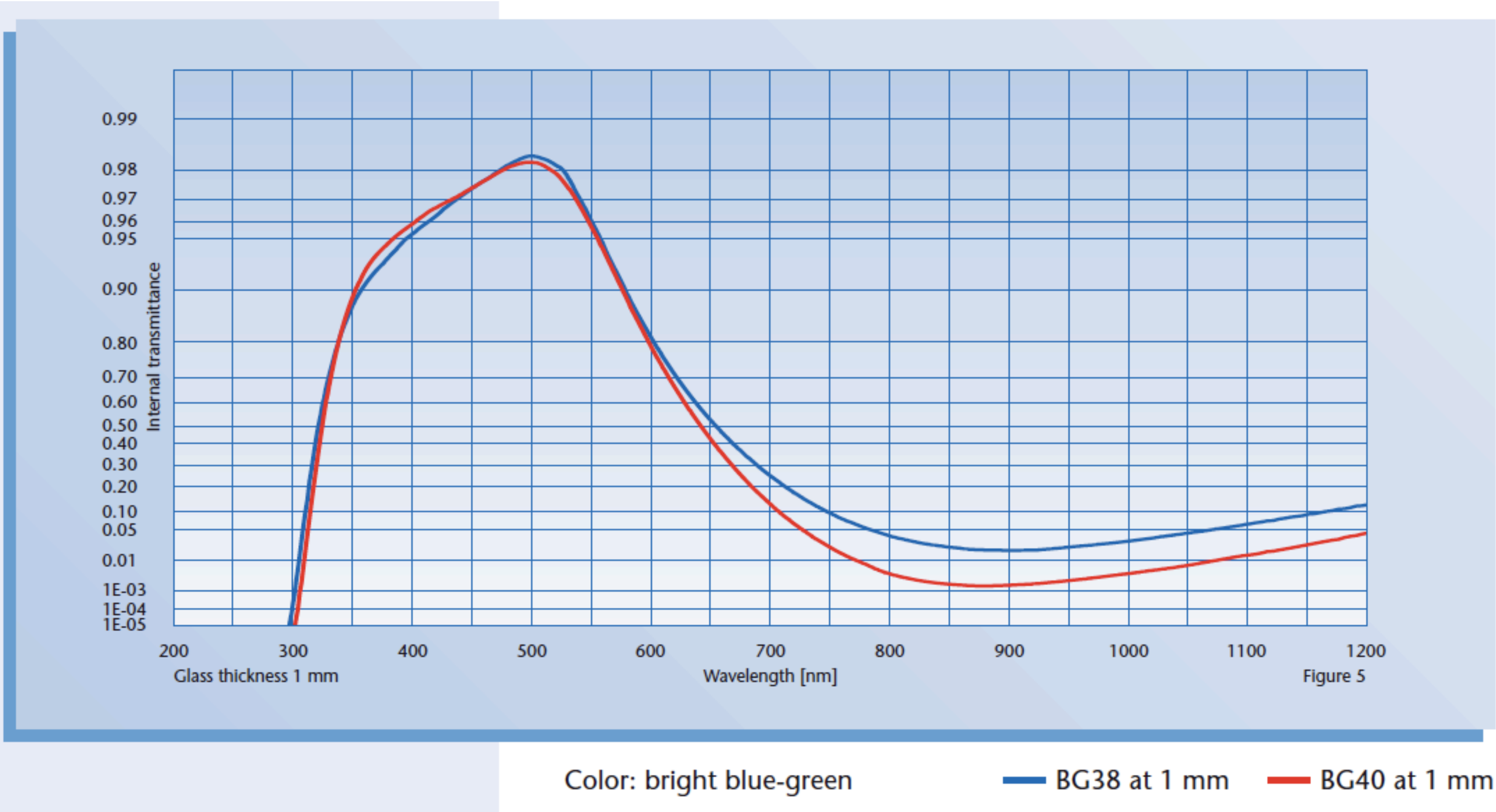
Schott Colored Glass 2



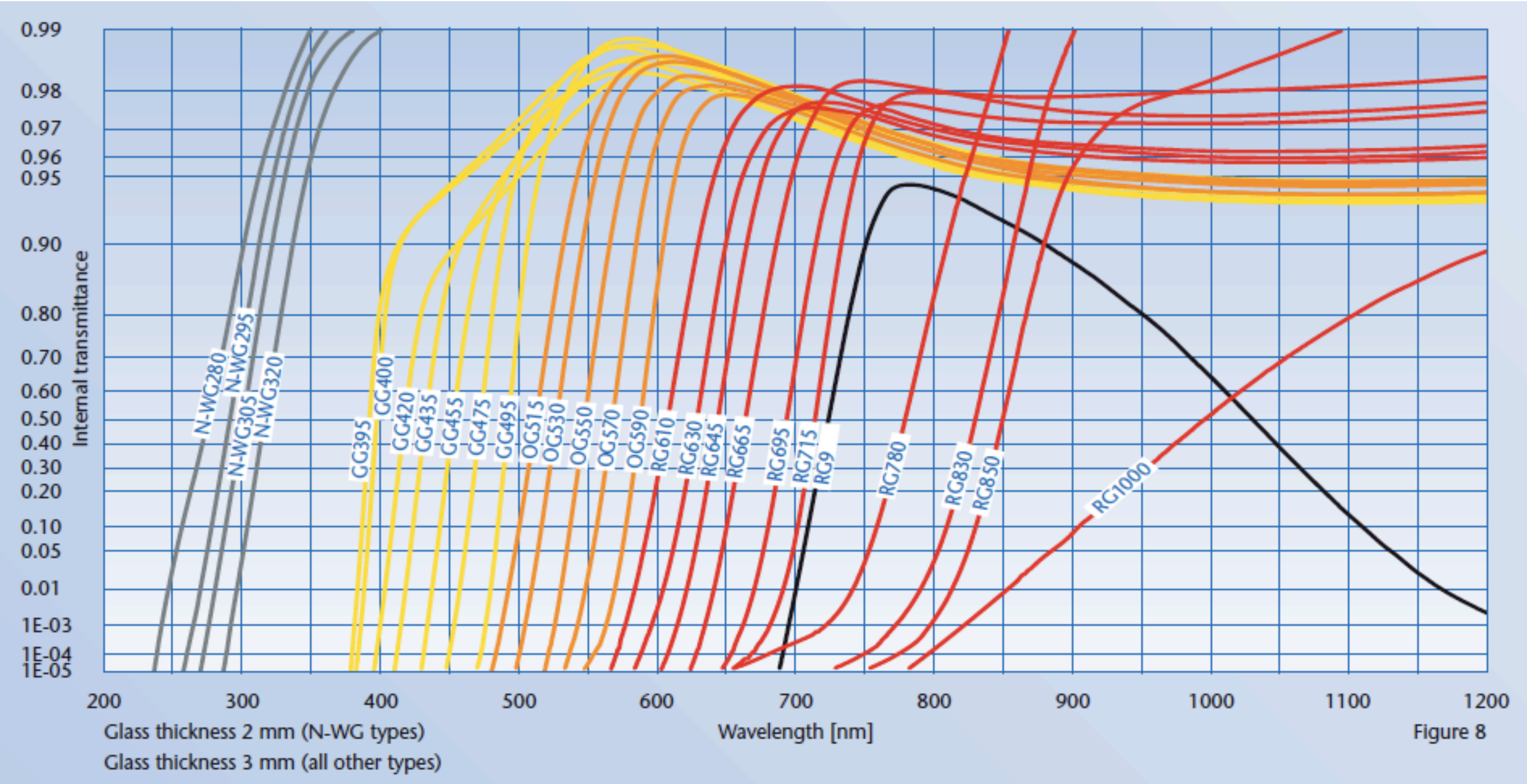
Color: blue

BG3 at 1 mm
BG25 at 1 mm
RG9 at 3 mm

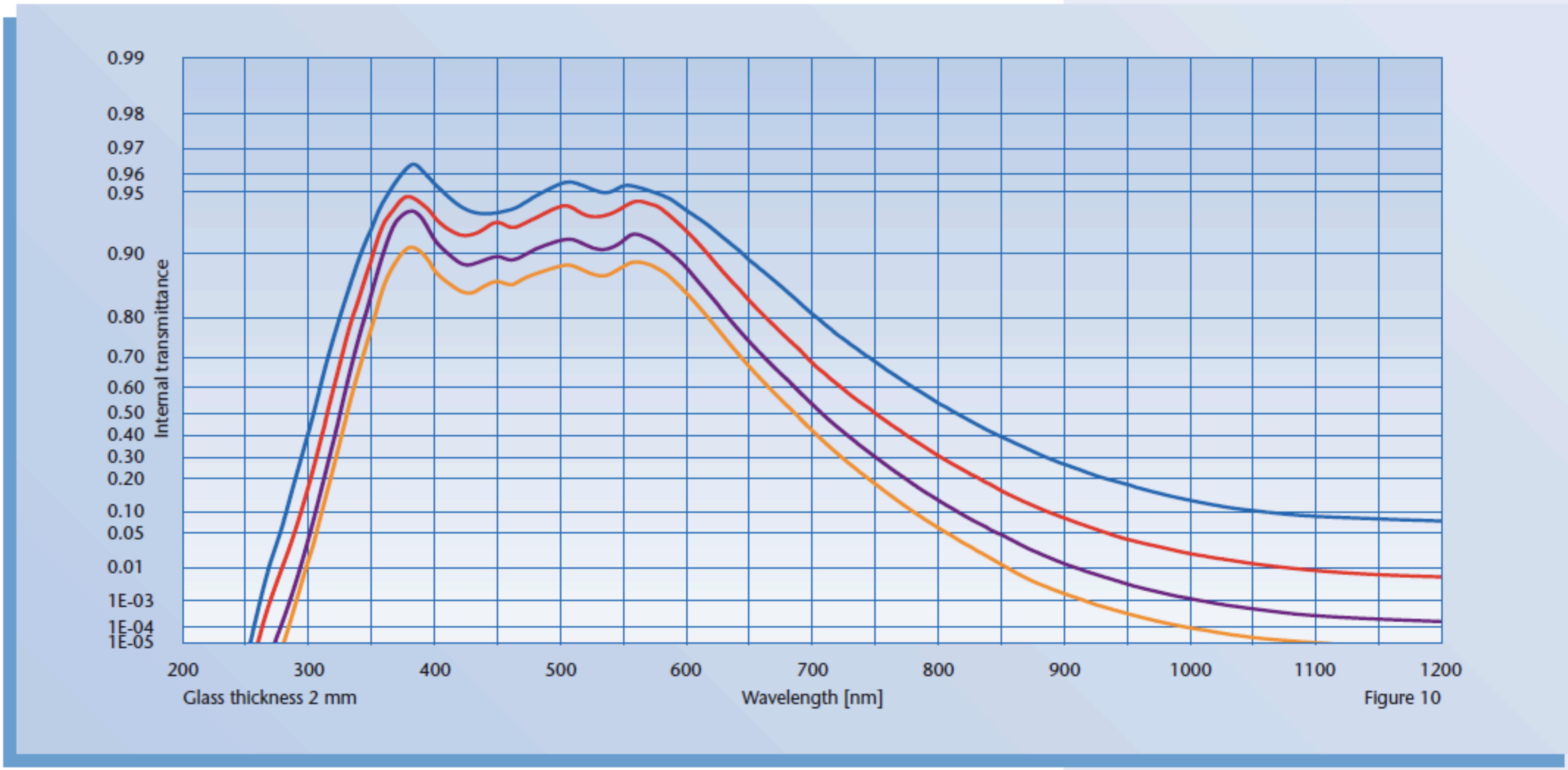
Schott Colored Glass 3



Schott Colored Glass 4



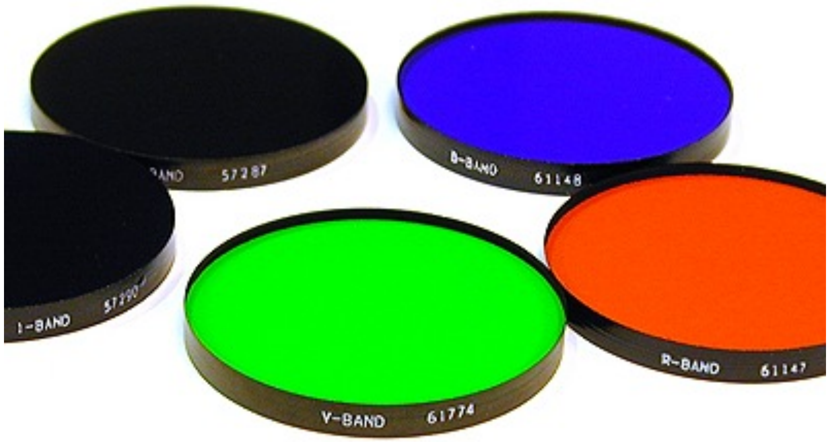
Schott Colored Glass 5



Color: nearly clear
(light greenish tint)

KG2 KG1
KG3 KG5

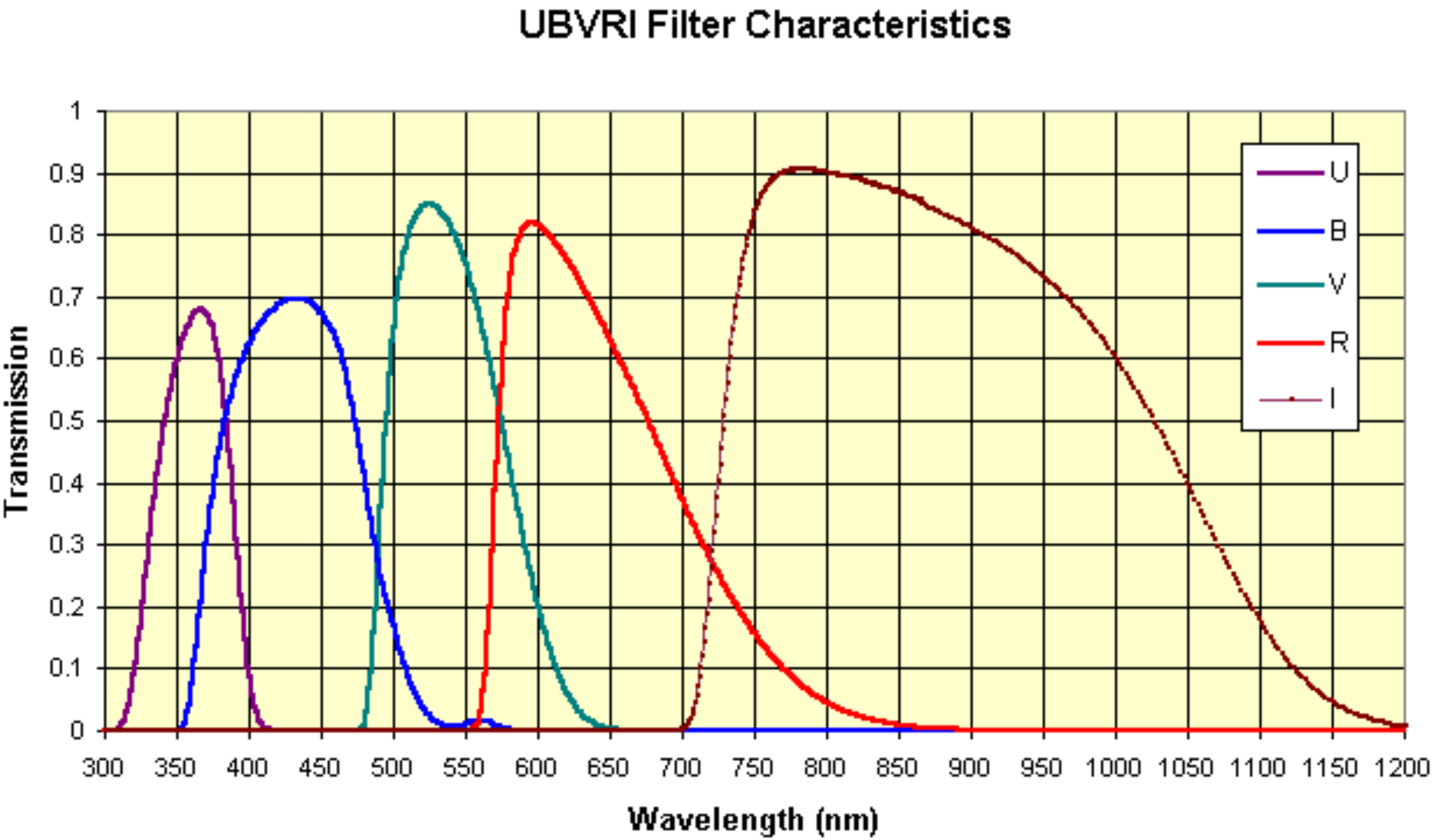
UBVRI



www.sbig.com/products/filters.htm

- UBV by Johnson and Morgan (1953)
- VRIJKLMNQ (infrared) by Johnson (1960)
- (combinations of) glass filters
- invented to classify stars with photomultipliers
- zero point of B-V and U-B color indices defined to be zero for A0 V stars

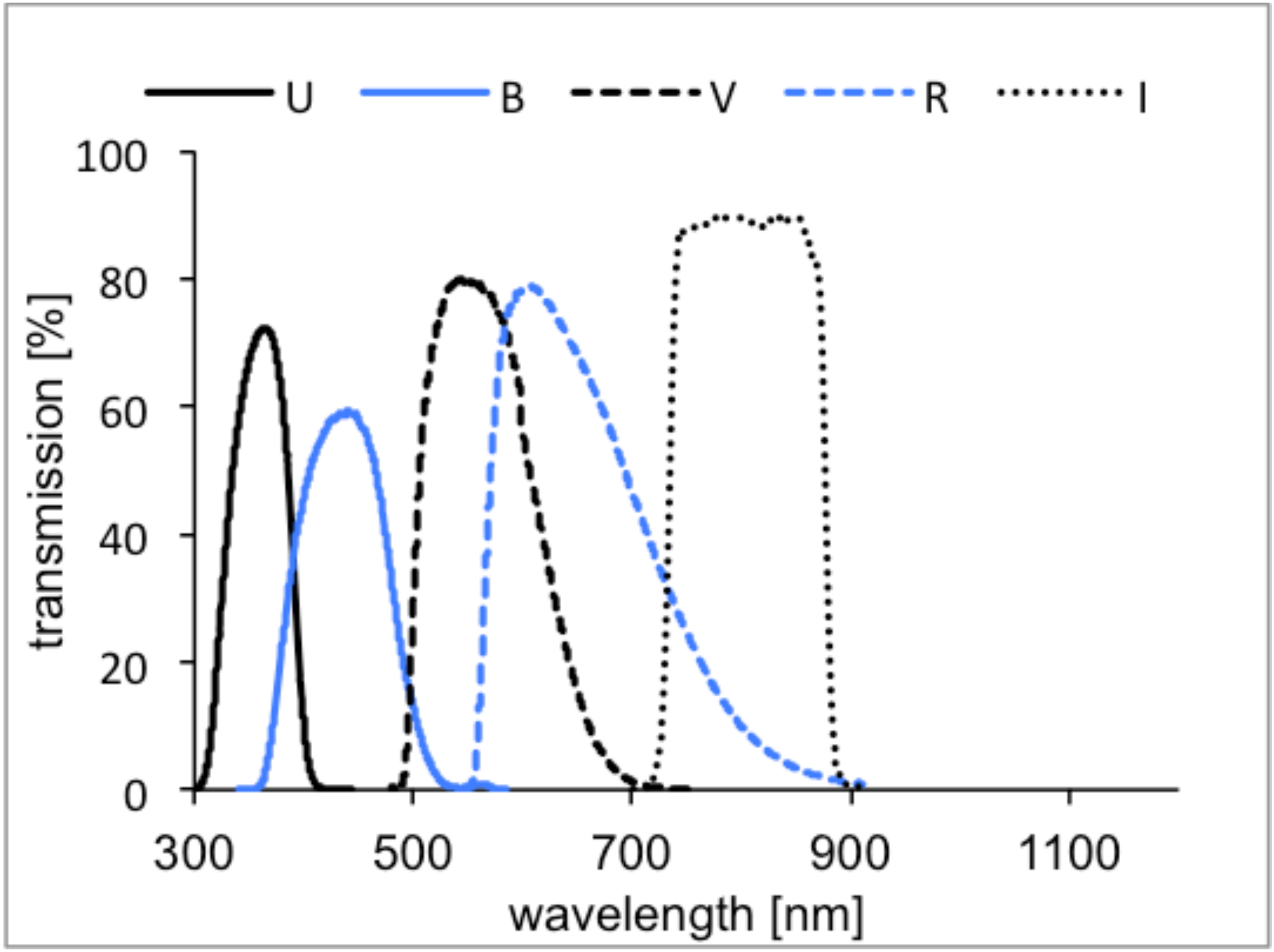
(Old) UBVRI


UBVRI Filter Characteristics
Transmission
Wavelength (nm)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
U
B
V
R
I

Limitations of UBVRI Photometry

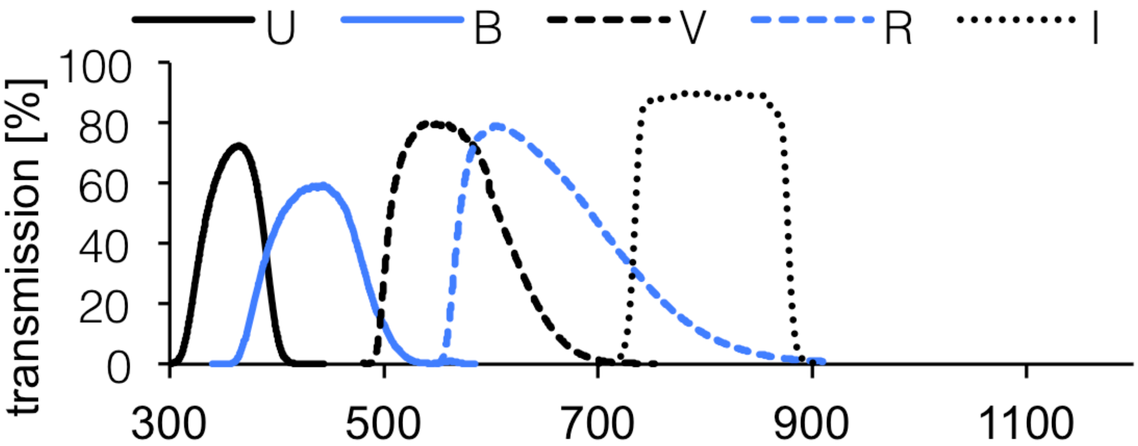
- limited spectral resolution
- effective central wavelength changes with color of star
- star's magnitudes and color depend on the star's color
- short-wavelength side of U filter extends below atmospheric transmission cutoff
- properties of sky define width of bandpass, not filter
- no clean separation of information from different filters
- different detectors have different sensitivities
- today: Bessel or Cron/Cousins UBVRI with CCDs

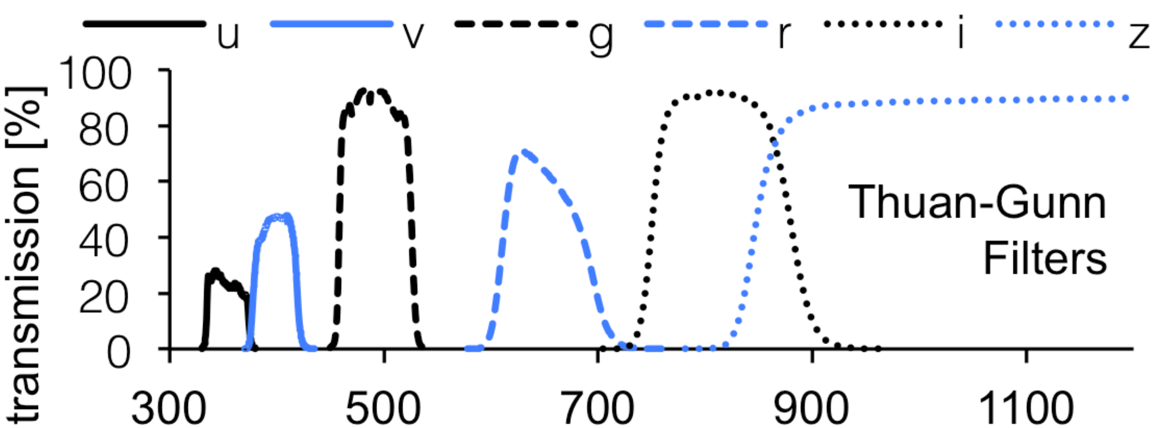
UBVRI



U
B
V
R
I
100
80
60
40
20
0
transmission [%]
300
500
700
900
1100
wavelength [nm]

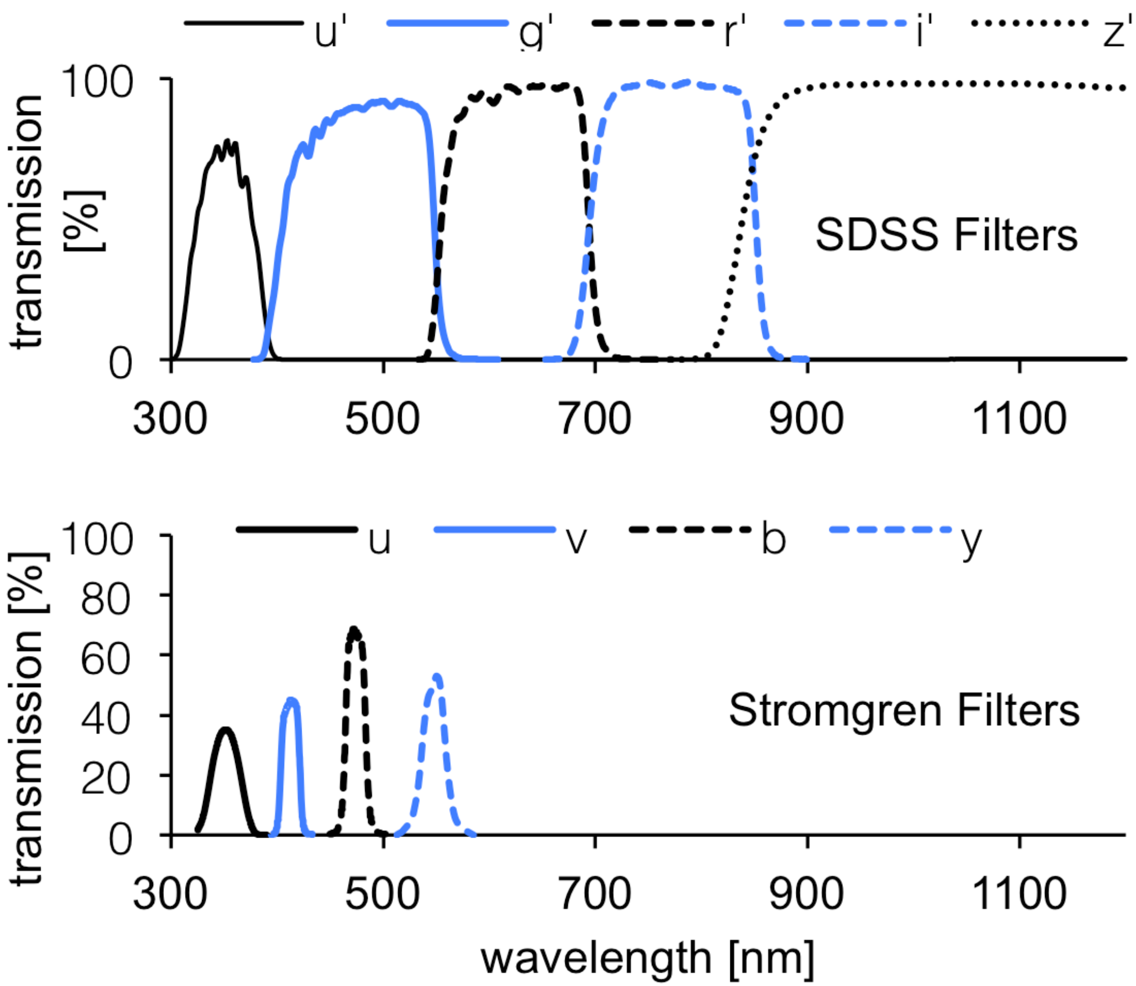
Other Filter Systems





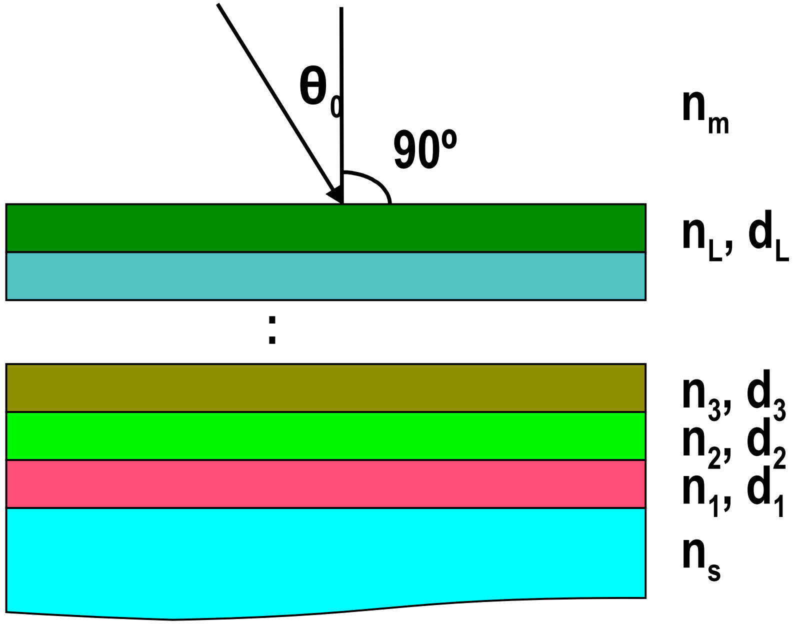
- have less overlap and/or higher transmission
- Johnson system for stars
- Thuan-Gunn filters for faint galaxy observations

Other Filter Systems



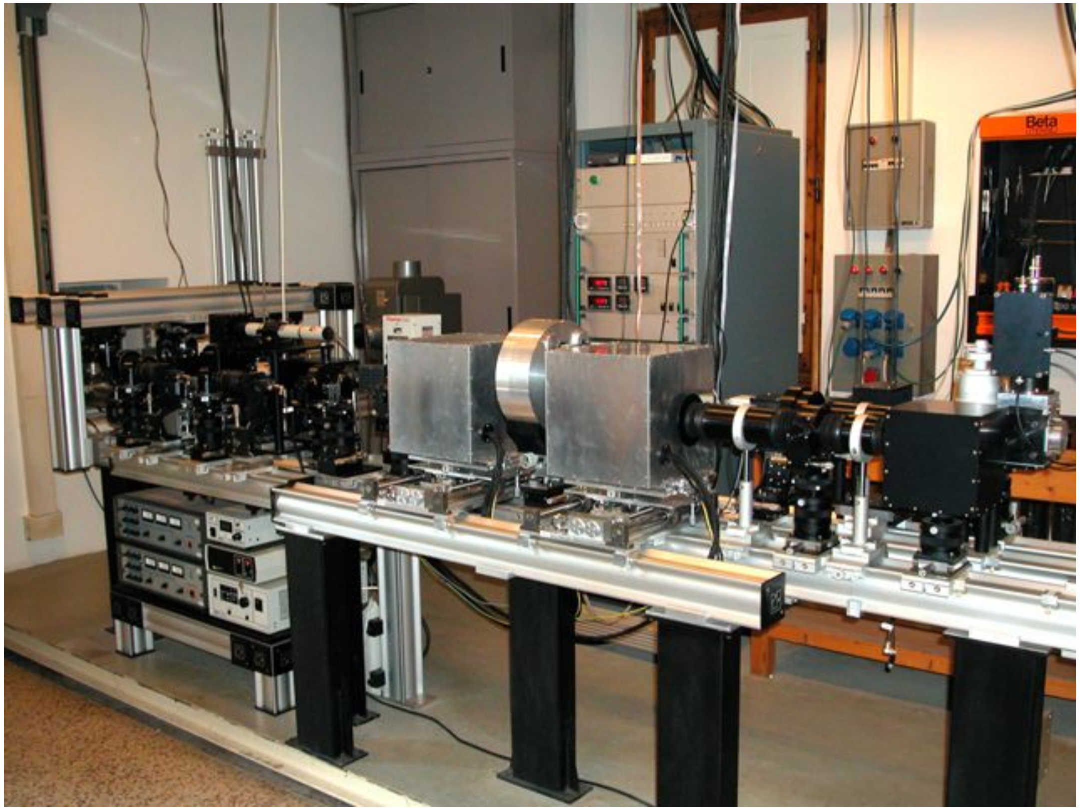
- Sloan Digital Sky Survey (SDSS) for faint galaxy classification
- Stromgren for better sensitivity to stellar properties (metallicity, temperature, surface gravity)

Interference Filters



- thin film:
  - layer with thickness ≤ λ
  - extends in 2 other dim. >>λ
- reflection, refraction at all interfaces
- layer thickness d_i≤λ -> interference between reflected and refracted waves
- *L* layers of thin films like Fabry-Perots: thin film stack
- substrate (index n_s), incident medium (index n_m) have infinite thickness
- can be tailored to almost any specifications
- sensitive to temperature, humidity, angle of incidence
- tune in wavelength with temperature, angle of incidence

Fabry-Perot Tunable Filter



www.arcetri.astro.it/science/solare/IBISphoto.jpeg

- main ingredient is Fabry-Perot with tunable plate separation
- stability of cavity spacing is critical
- often combine two or more tunable elements
- always need interference prefilter

Photometry

- goal: determine flux of an astronomical object in well-defined wavelength range
- problems:
  - seeing
  - extinction
  - sky background
  - telescope, instrument, detector
- calibration with (standard) stars
- all-sky photometry: compare objects all over the sky
- differential photometry: compare objects on same CCD exposure

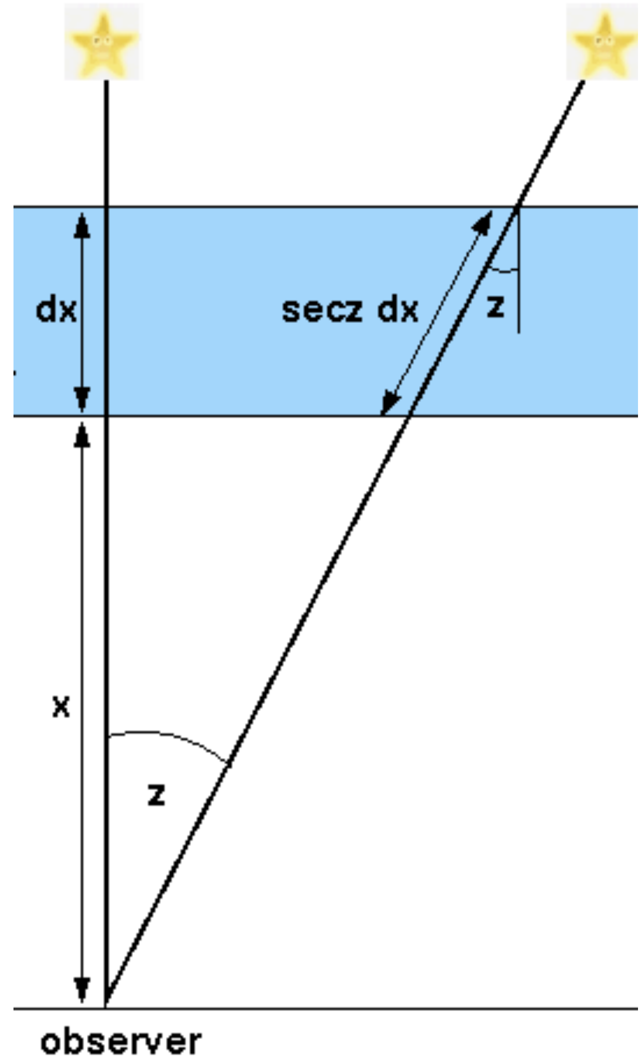
Sky over La Palma

Atmosphere

- photometric night = uniform, stable sky conditions
- thin clouds and cirrus are hard to see at night
- bright, grey and dark observing time
- seeing defines size of stellar image for large telescopes
- image = convolution of source and Point-Spread Function (PSF)
- integral over image = integral over source

Air Mass

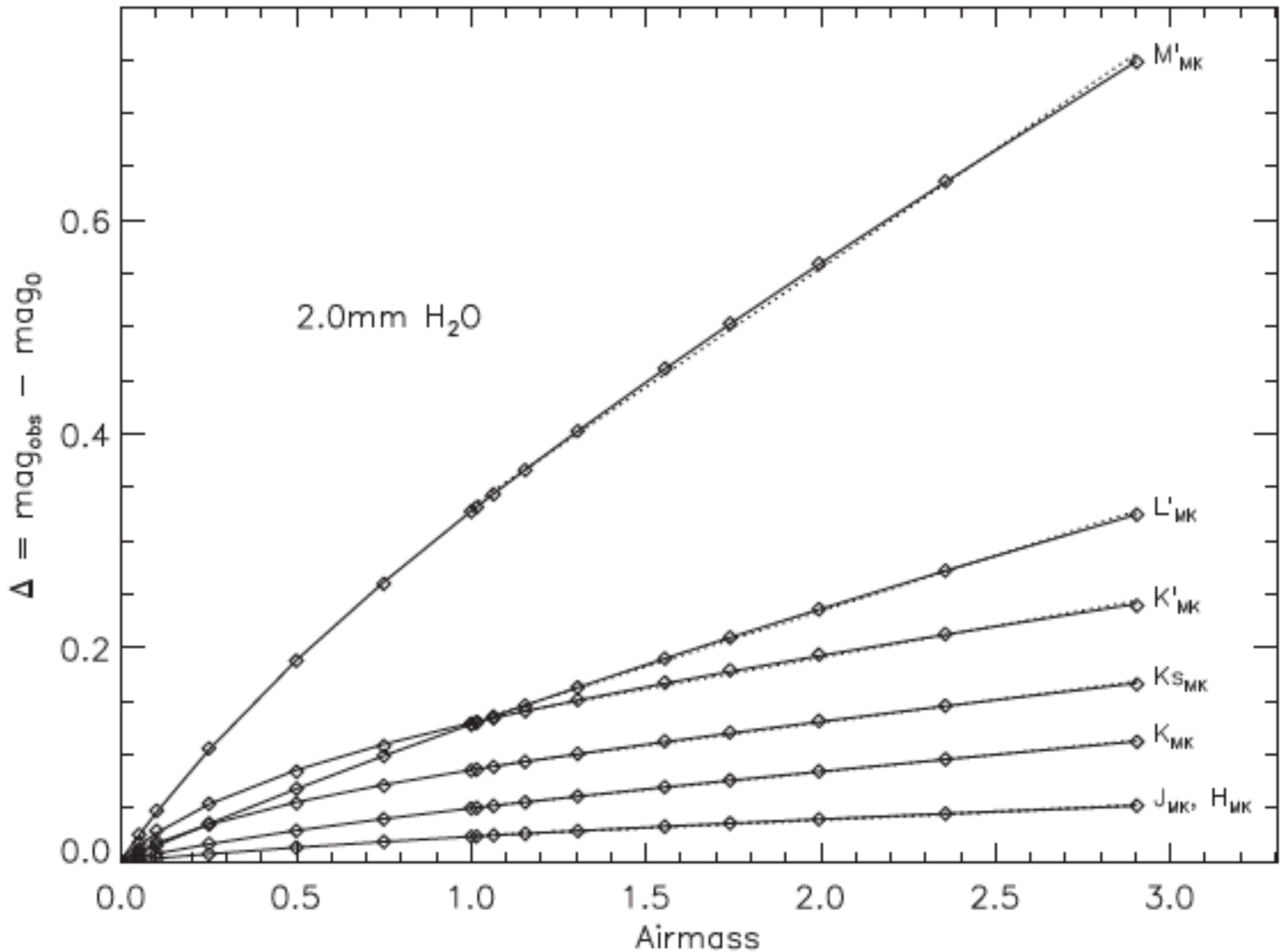
- extinction due to atmosphere along line-of-sight
- *airmass* = amount of air one looks through
- at zenith (*z=0*): airmass X=1.0
- at zenith distance *z*, airmass $X \approx \sec z = 1/\cos z$
- $X(z=60°) \approx 2$



Air Mass

- absorption coefficient $K=2.5$ log$(f(z)/f(z=0))$, where $f(z)$ is measured flux as function of zenith distance z
- $K\Delta X = \Delta m$ change in magnitude is absorption coefficient times change in airmass
- measure magnitude for different airmasses and extrapolate to zero airmass (no atmosphere!)
- linear extrapolation does not work in the infrared due to saturated/overlapping molecular lines

Simulated Near-Infrared Absorption



from Tokunaga et al. 2002, adsabs.harvard.edu/abs/2002PASP..114..180T

Dark Sky in Alps

Bright Sky in the Netherlands

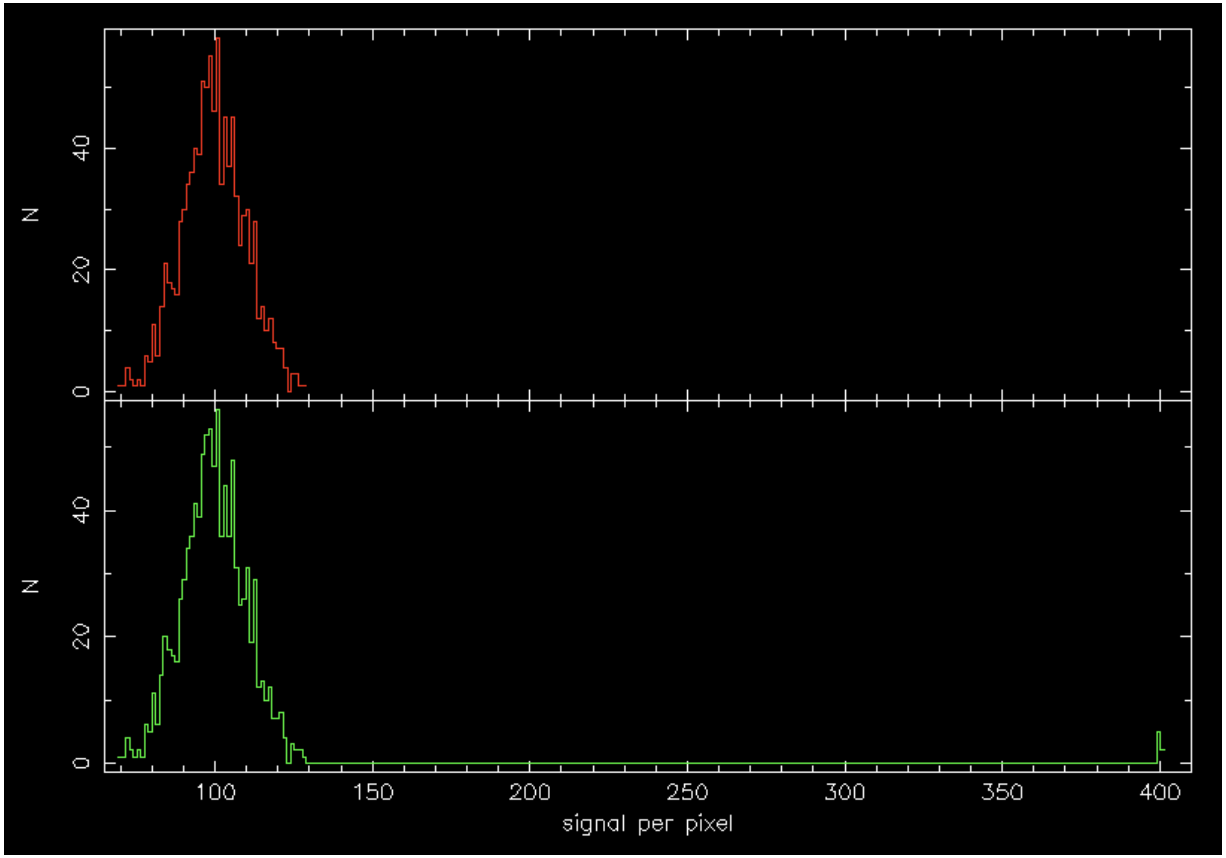
Photometric Observations (1)

- observe object and standard stars with different colors
- observe standard stars at low and high airmass to determine their (color-dependent) extinction coefficients
- reduce images with bias, dark, flat field
- measure fluxes with aperture photometry
- calculate instrumental magnitudes:
  $m_{inst} = -2.5\log(f_i/t_{exp})$

Photometric Observations (2)

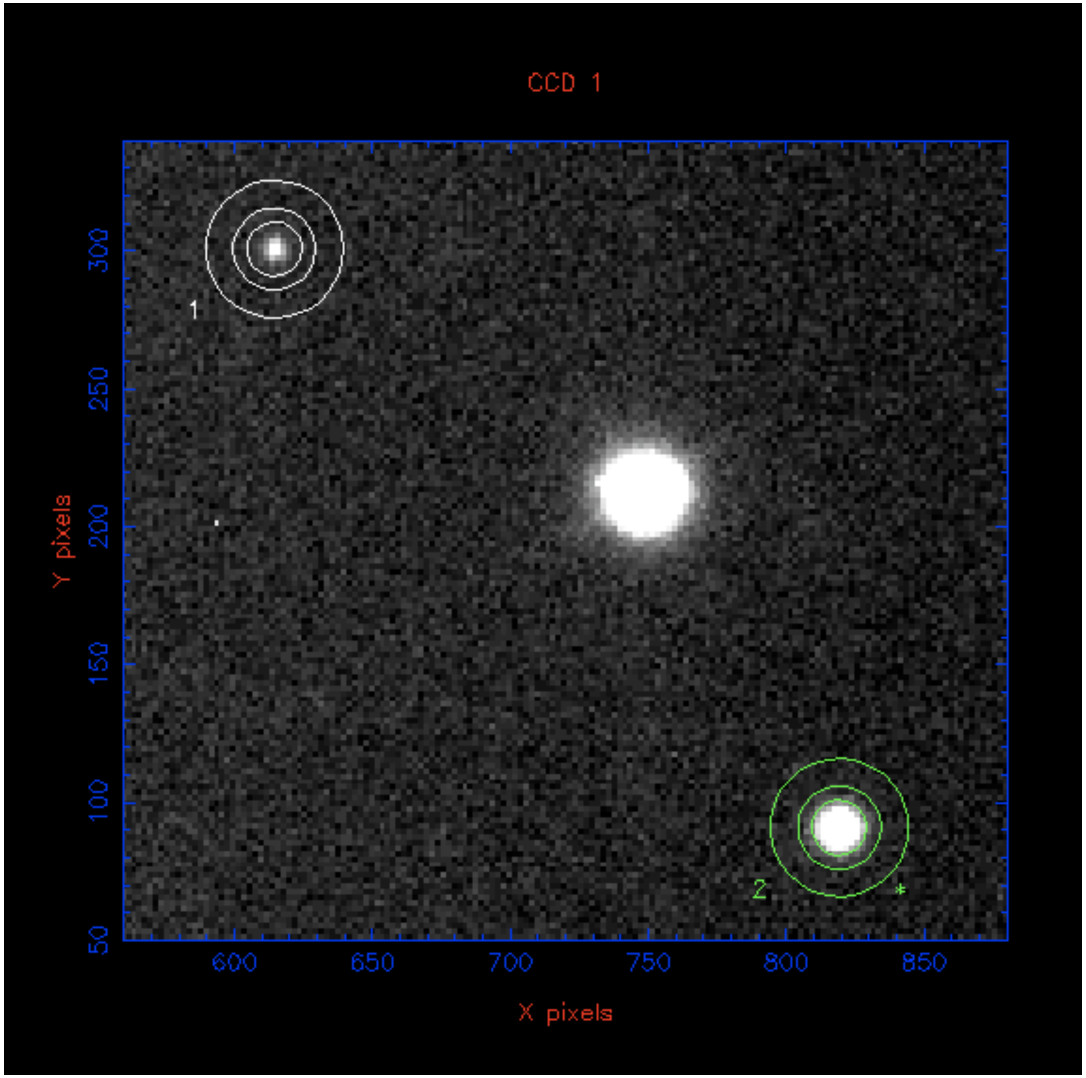
- calibrate instrumental magnitude for zero airmass: $m_0 = m_{inst} - K \sec z$
- zero point from standard stars: $m_{zp} = m_{std} - m_{std,inst}$
- remove zero point: $m = m_{zp} + m_{inst}$
- absolute photometry: determine actual magnitudes with calibrations derived from standard stars
- differential photometry: does not require calibrations

Sky Background



- use annulus around star
- use median instead of mean to neglect cosmic rays

Aperture Photometry



- determine location of star by fitting 2-D Gaussian or Moffat PSF model
- determine and remove sky background

Aperture Photometry (continued)

- best aperture size depends on brightness of star
- trade-off between capturing more starlight and adding noise from sky background, detector etc.
- plot result as function of increasing aperture and estimate asymptotic value
- for variability measurements (e.g. exoplanet transit) with differential photometry (standard star in same image):
  - use fixed and identical apertures for target and reference star(s)
  - optimum aperture minimizes scatter in constant parts of mtarget-mstd

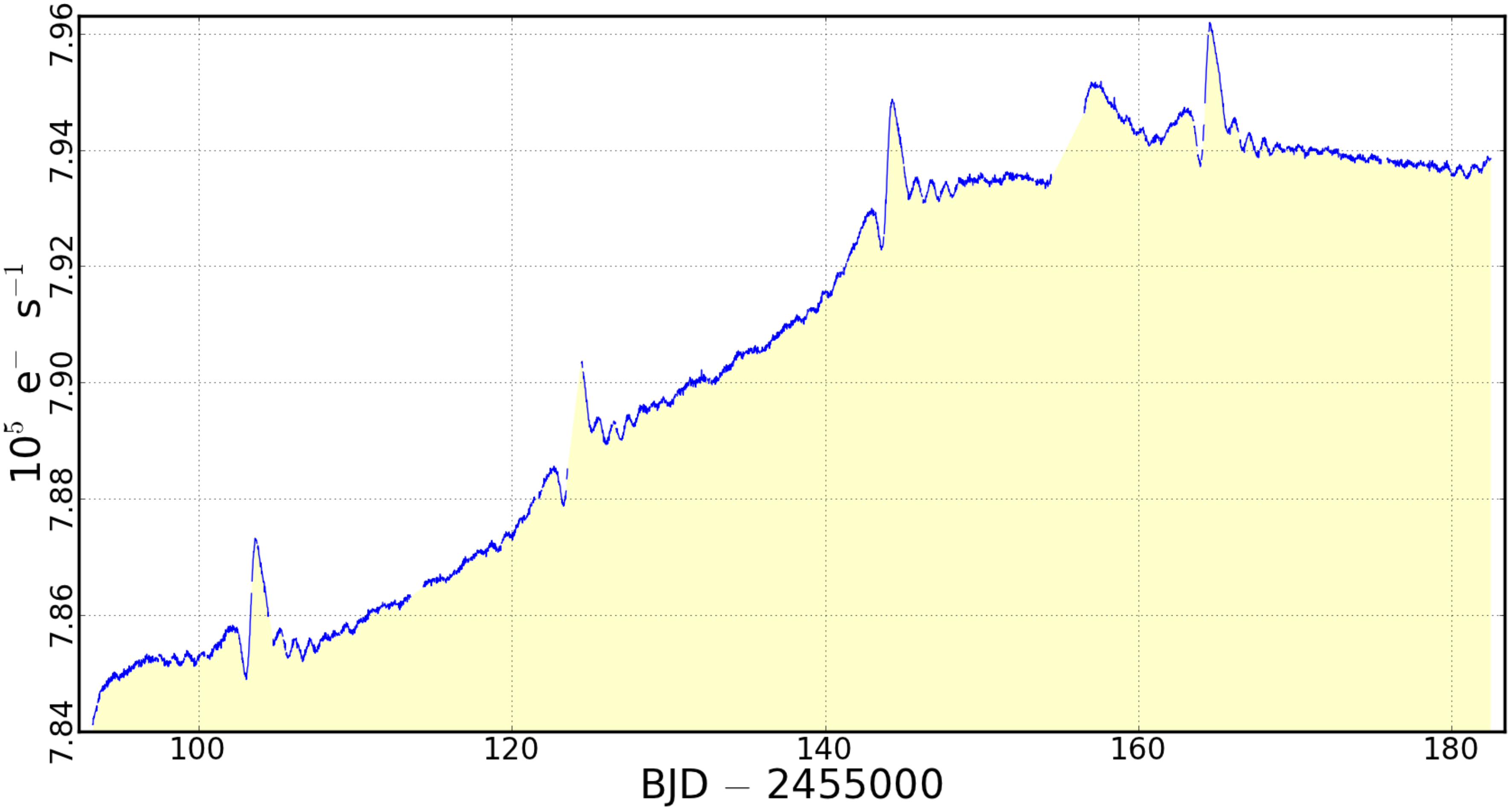
Color Correction

- extinction depends strongly on wavelength (color)
- measured flux through broad filter depends on stellar spectrum
- additional correction

$$m=m_0+K \sec z + k_2 C \sec z$$

where C is color index (e.g. C=B-V)

Extreme Photometry

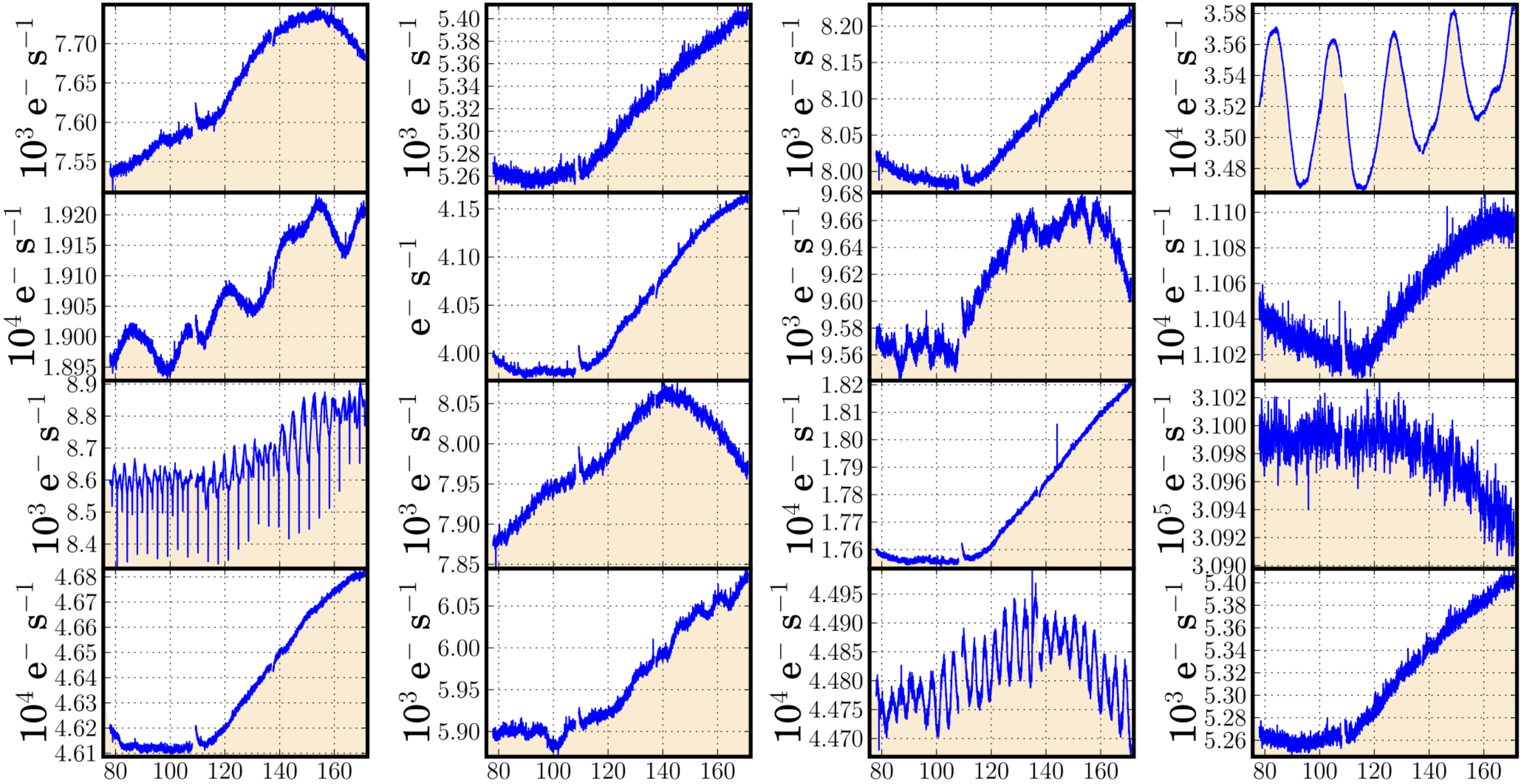


keplerscience.arc.nasa.gov/PyKEprimerWalkthroughC.shtml
90-day long-cadence Kepler SAP light curve of KIC 3749404.

Subtle Instrumental Effects

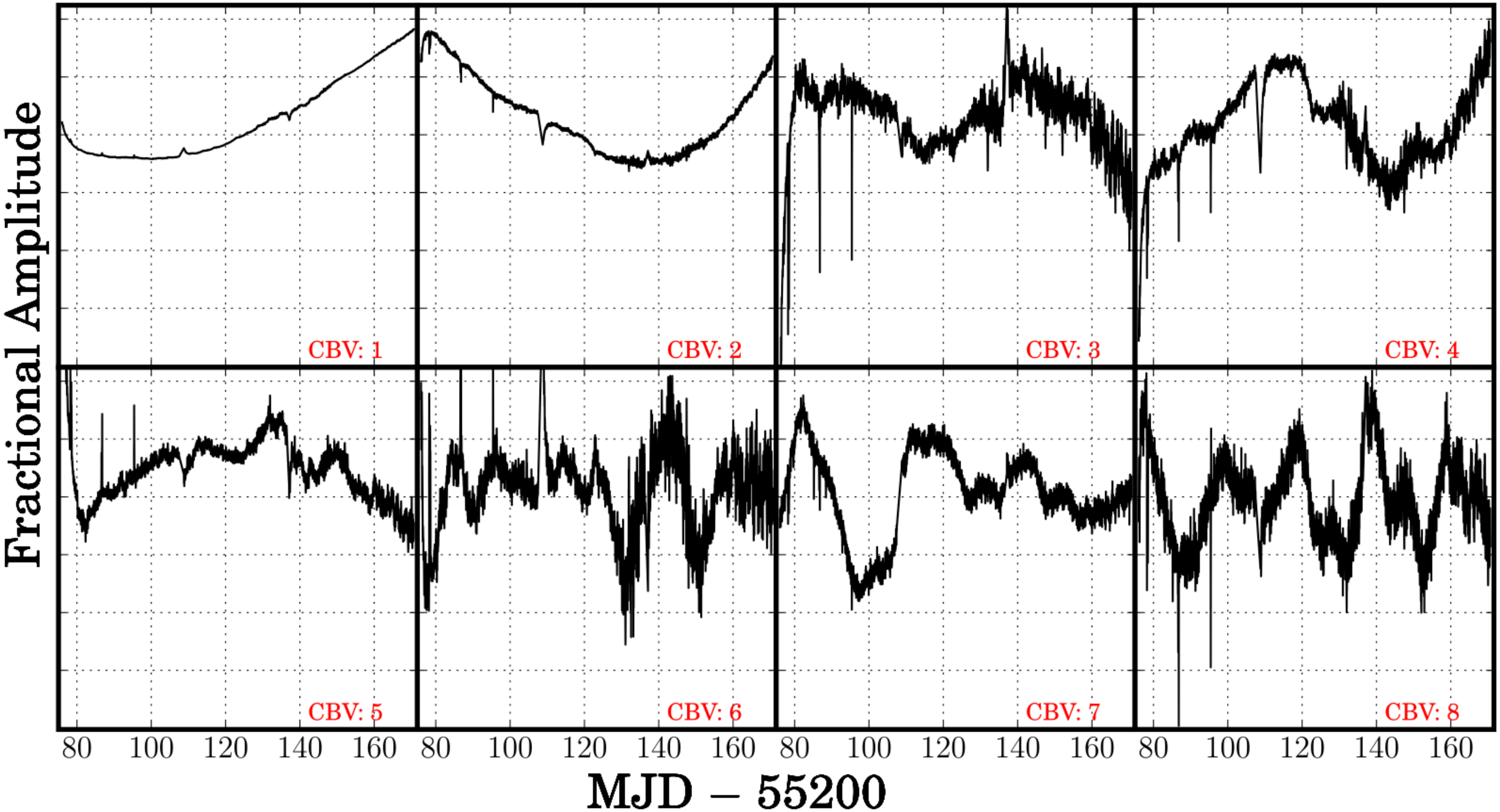
- Thermal changes in optics, electronics
- Small guiding errors coupled with sub-pixel gain variations
- Cotrending Basis Vectors (CBV): Instrumental parameters that have been shown to correlate with photometry of standard stars

16 Kepler Light Curves



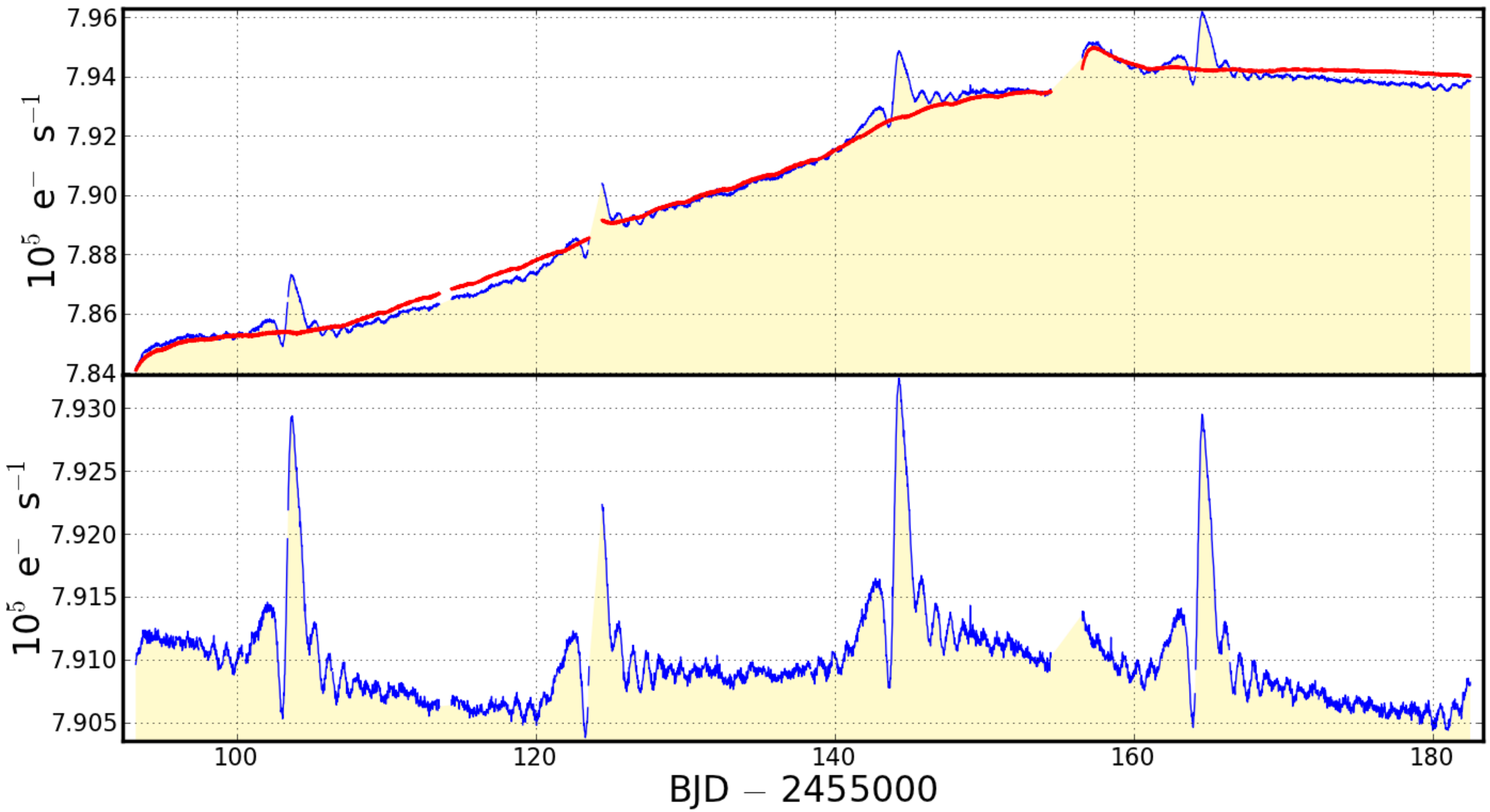
keplerscience.arc.nasa.gov/images/PyKE/PyKEprimerFig4.png

Cotrending Basis Vectors



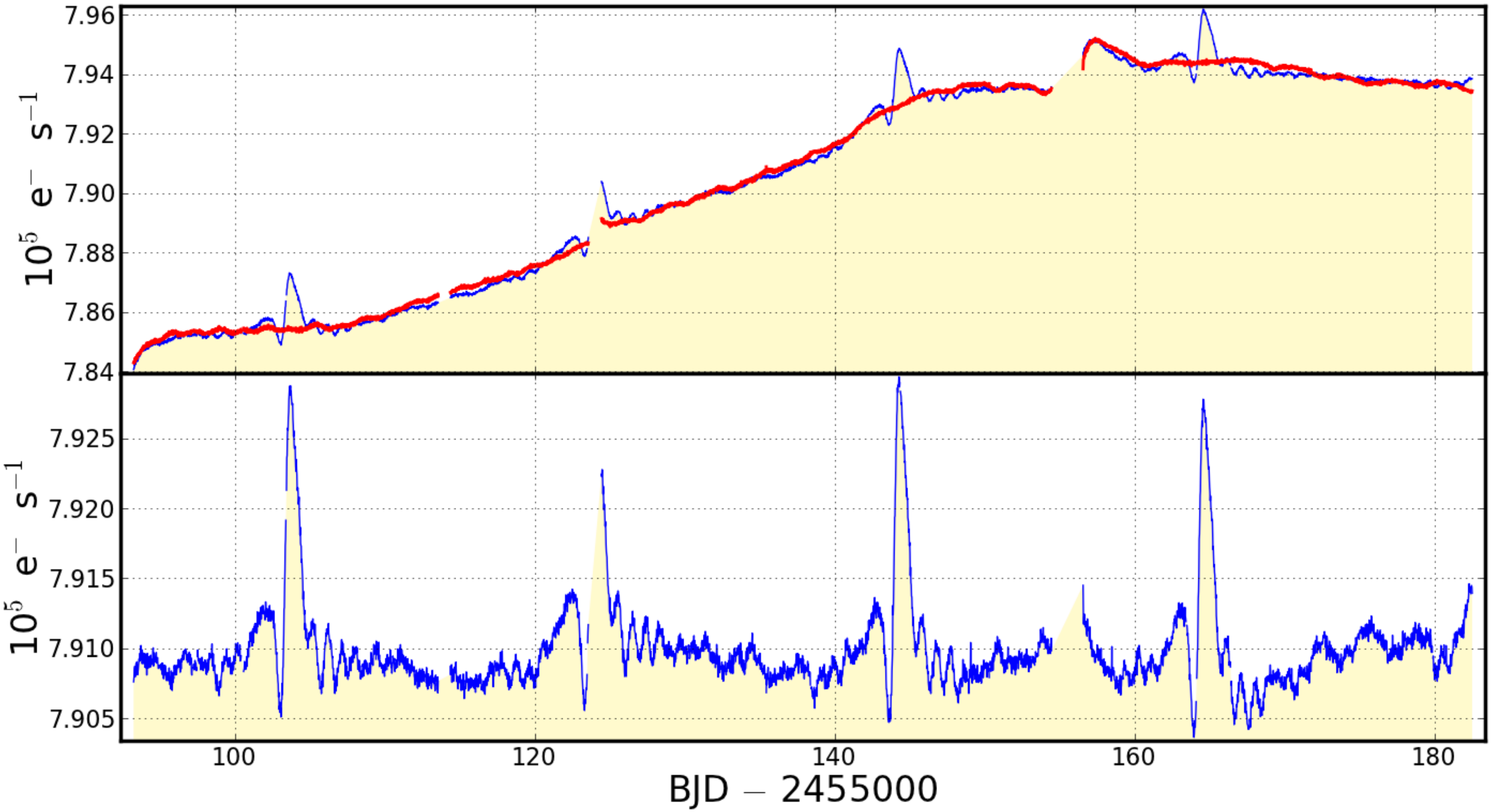
keplerscience.arc.nasa.gov/images/PyKE/PyKEprimerFig3.png

Subtraction of 2 CBVs



keplerscience.arc.nasa.gov/PyKEprimerWalkthroughC.shtml
90-day long-cadence Kepler SAP light curve of KIC 3749404.

Subtraction of 8 CBVs



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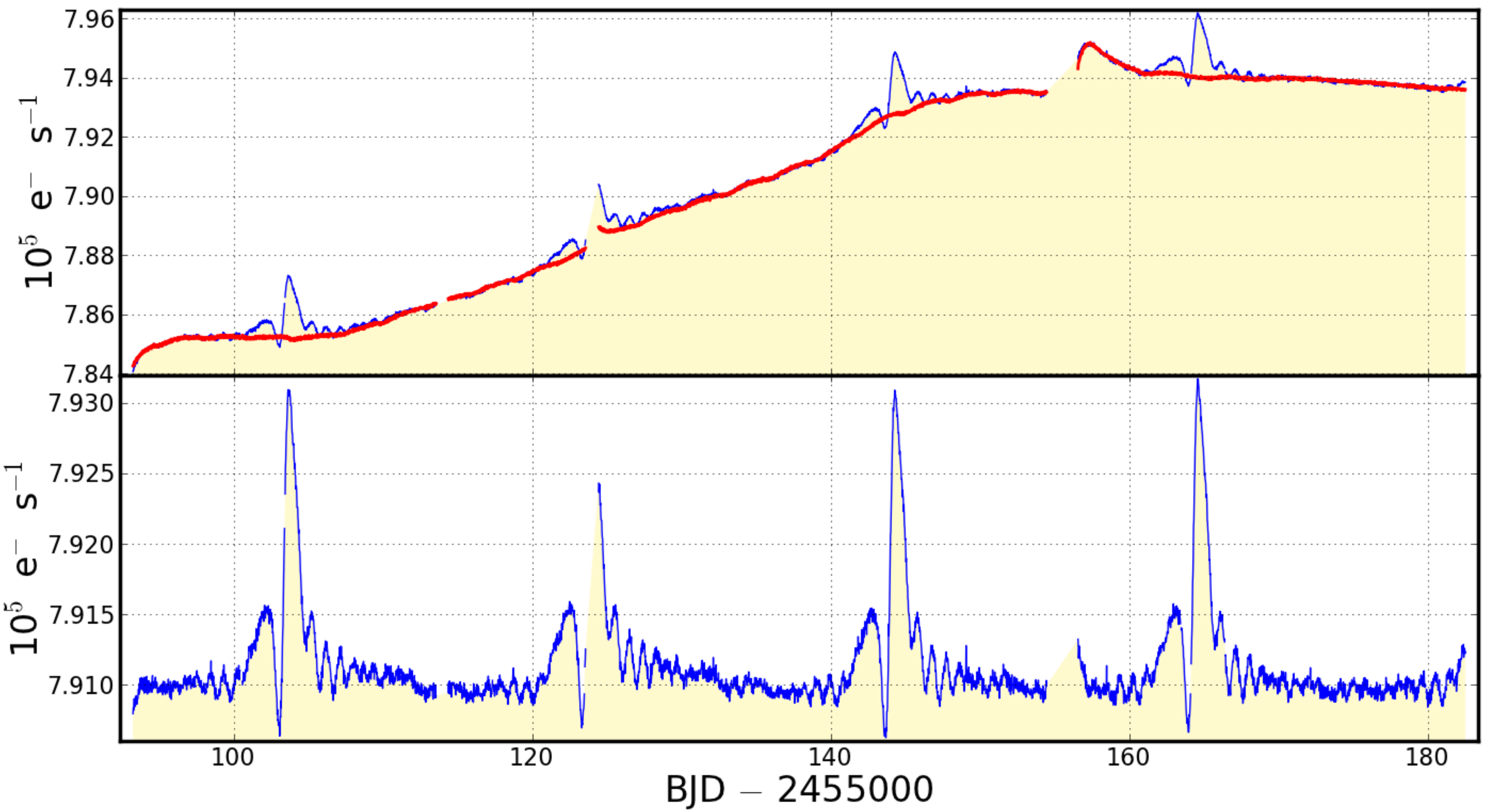
90-day long-cadence Kepler SAP light curve of KIC 3749404.

No CBV Fitting During Eclipses



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