# Photometry
# &
# Virtual Observatory

Gijs Verdoes Kleijn
Kapteyn Institute, room 147
verdoes@astro.rug.nl
050-3638326


## Concepts discussed

- The light path
- Photometric calibration
  - Standard systems
  - Calibration procedures
- Photometric calibration & VO

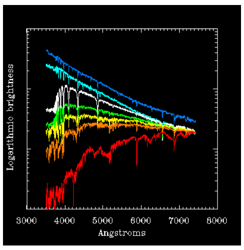
- In other words: physics of interaction over light path; calibration: quantifying interactions; sharing your photometry

## Jargon and conventions

- Flux (e.g., erg/s/cm^2, W/m^2)
- Flux density (e.g., erg/s/cm^2/Hz or /Ang)
- m(agnitude)=-2.5log$_{10}$(flux/flux0)
- m: Apparent magnitude
- M: Absolute Magnitude= apparent magnitude at 10pc
- Color: e.g., blue-red (B-R)

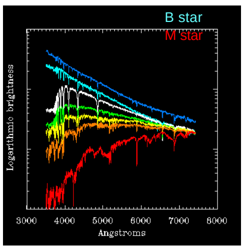
## Goal: physics via Spectral Energy Distribution (SED)

**Stellar SEDs**

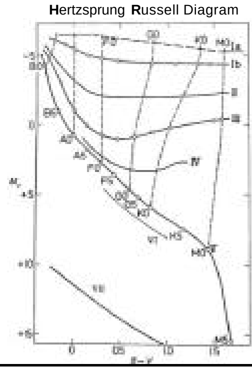



•What is required spectral resolution (?/d?) to get physics?
•Example: temperature of blackbody can be obtained from relative intensity at two wavelengths
•Spectral resolution ?
? Efficiency?
•broad-band spectroscopy =photometry

## Example: stellar colors

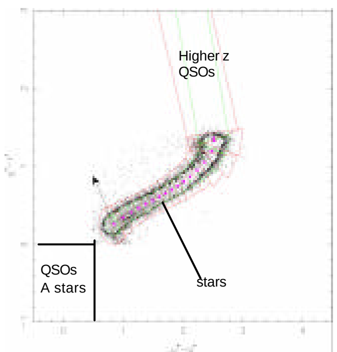



**H**ertzsprung **R**ussell Diagram



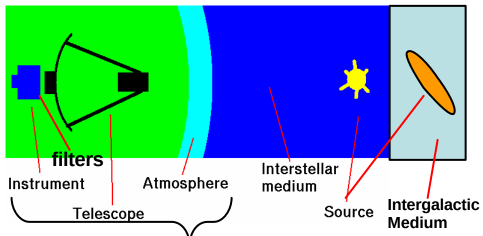
# Example Quasar colors

Richards etal AJ, 123, 2945




http://www.journals.uchicago.edu/AJ/journal/issues/v123n6/201557/201557.html

# "Maltreatment" of photons

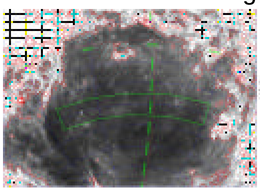


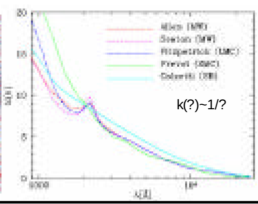

- Time/location-variability: Earth atmosphere, telescopes, filters, detectors.
- How to compare results with this variability?

http://www.sc.eso.org/~isaviane/photometry/Optical%20Photometry_files/v3_document.htm

# Galactic ISM: Interstellar extinction

- Discovery: 1930s
- Extinction=(Mie) scattering+absorption by dust particles
- Net effect: reddening

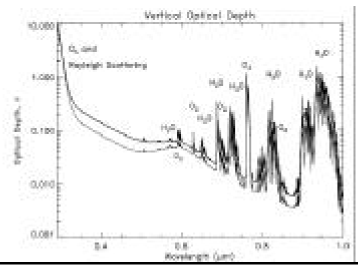





http://webast.ast.obs-mip.fr/hyperz/hyperz_manual1/node10.html

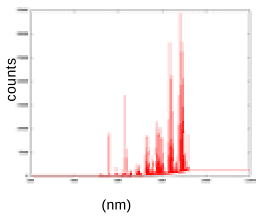
# Atmosphere: obscures+shines

- **- Extinction** by dust, aerosols, molecules




# Atmosphere: obscures+shines

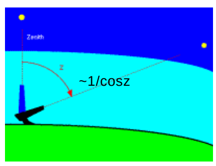
- **+Continuum+Line-Emission**




| Days from new moon | Sky Brightness | | | | | |
|---|---|---|---|---|---|---|
| | U | B | V | R | I | z |
| 0 | 22.0 | 22.7 | 21.8 | 20.9 | 19.9 | 18.8 |
| 3 | 21.5 | 22.4 | 21.7 | 20.8 | 19.9 | 18.8 |
| 7 | 19.9 | 21.6 | 21.4 | 20.6 | 19.7 | 18.6 |
| 10 | 18.5 | 20.7 | 20.7 | 20.3 | 19.5 | 18.3 |
| 14 | 17.0 | 19.5 | 20.0 | 19.9 | 19.2 | 18.1 |

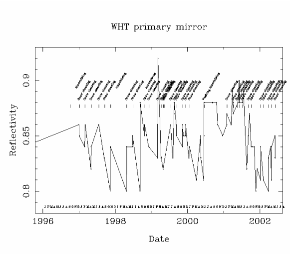
# Atmospheric extinction

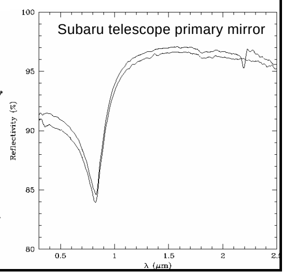
- Extinction per unit atmosphere is time/location dependent (haze, clouds, dust)
- Proportional to airmass~1/cosz



# Telescope

- Mirrors
- Lenses

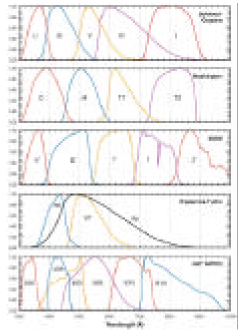


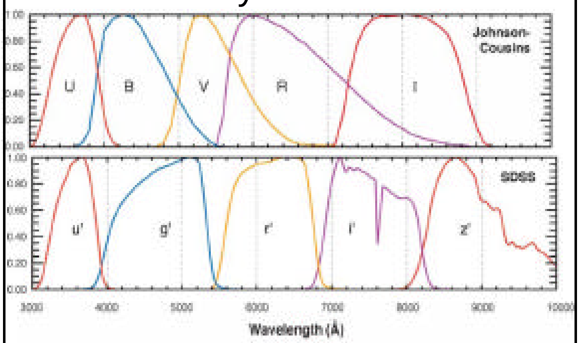

# Filters

- Filter widths ? ?/?
  - Narrow <0.02
  - Intermediate 0.02-0.1
  - Wide >0.1
- Filter materials:
  - Glass: red (IR) leaks
  - gelatin films
  - Interference

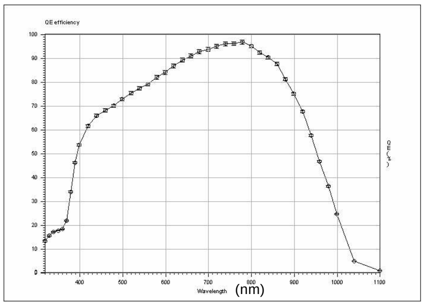
Passbands,transmission curves



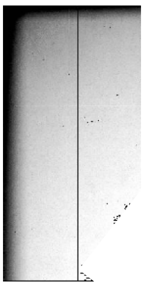
# Commonly used filter sets




# Detector effects: Quantum efficiency

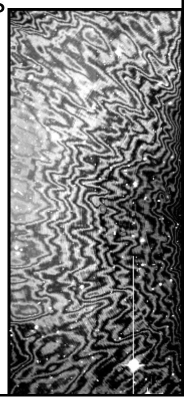



# Detector effects: pixel to pixel variation quantum efficiency: flatfield



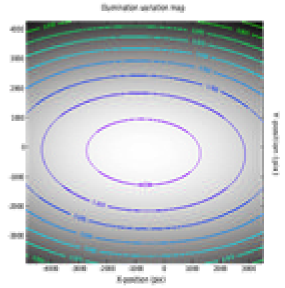
# Detector effects: fringing

Fringing= variation in background light
•Origin: Interference of nightsky lines within CCD
•More pronounced in red part spectrum
•*Only affects "background" light*

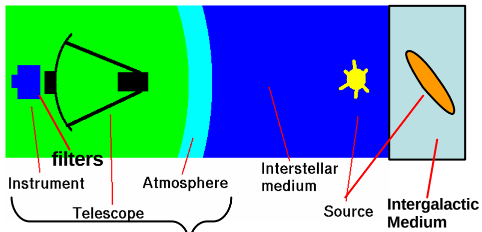


## Detector effects: illumination variation

•due to internal scattering of light in instrument
•*Affects both source and background light*




## “Maltreatment” of photons

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http://www.sc.eso.org/~isaviane/photometry/Optical%20 Photometry_files/v3_document.htm

## Solution: relative measurements

- Measure relative to flux $I_0$ of reference object:

$$m\text{-}m_0 = -2.5 \log_{10} ( I/I_0)$$

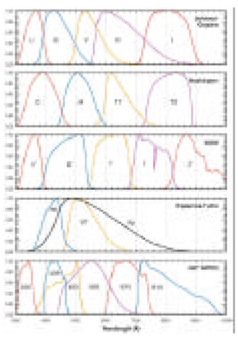
  - i.e., measure $(I/I_0)$ instead of I: constants cancel
- Unitless system
- $m_0 = -2.5 \log_{10} (I_0/I_0) = 0$ by definition
- $I_0$ proportional to flux, but can have arbitrary units:
  - $m = -2.5\log_{10}$ (countrate) +zeropoint

## What one observes

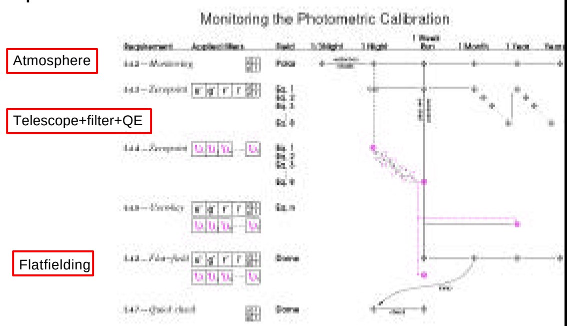
- Effects of ism, atmosphere, telescope, filter and detector QE and flatfielding are multiplicative gains:
  - $I_{obs} = I^*g_{ISM}(a,d) * g_{atm}(k,z_0) * g_{tel}{}^*g_{filt1}{}^* g_{det1}(x,y)$
  - $I_{0,obs} = I_0{}^*g_{ISM}(a_0,d_0) * g_{atm}(k,z) * g_{tel1}{}^*g_{filt1}{}^* g_{det1}(x_0,y_0)$
- Neglected fringing and illumination correction: discussed in werkcollege
- For telescope2,filter2,detector2:
  - $I_{obs} = I^*g_{ISM}(a,d)^*g_{atm}(k,z)^*g_{tel2}{}^*g_{filt2}{}^*g_{det2}(x,y)$
  - $I_{0,obs} = I_0{}^*g_{ISM}(a_0,d_0)^*g_{atm}(k,z_0)^*g_{tel2}{}^*g_{filt2}{}^*g_{det2}(x_0,y_0)$

## Photometric standard systems

- Goal: putting mags on common scale
- Standard system=
  - telescope+filter+detector
- Natural system=
  - Your telescope+filter+detector
- Convert your measurements as if observed with standard system
- Example standard systems:
  - Johnson-Cousins
  - Sloan
  - Stroemgren
  - Walraven



## Integrating up-link and down-link: Determining gains translate into procedurized observations



Reflecting on design->deliver slides from previous lectures….

## from Design-> deliver

- Scientific requirements - SRD
  - Science goals (e.g., determine temperature of stars out to 10kpc)
- User requirements - URD
  - Shalls: what photometric accuracy is needed for science
- Architectural design - ADD
  - Designing a data model to capture the physics of photometric calibration
- Detailed design – DDD
  - Working out the details and writing the code
- Quantify
- Build
- Qualify – unit tests

## New approaches new balances

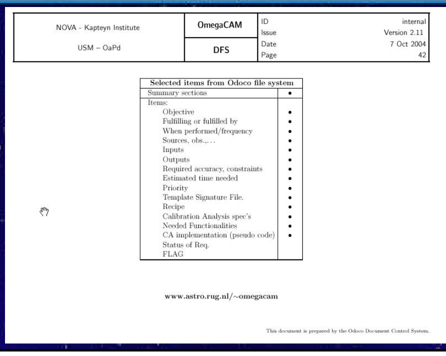
Anarchy ← →coordinated
Freedom ← → fixed system

Standard data products ←→user tuned products
Data releases ← → user defined hunting

DESIGN

5 Essential STEPS:

## 1- calibration plan integrated up-link /down link



| NOVA - Kapteyn Institute<br>USM – OaPd | OmegaCAM | ID: internal<br>Issue: Version 2.11 |
|---|---|---|
| | DFS | Date: 7 Oct 2004<br>Page: 42 |

| Selected items from Odoco file system | |
|---|---|
| Summary sections | • |
| Items: | |
| Objective | • |
| Fulfilling or fulfilled by | • |
| When performed/frequency | • |
| Sources, obs.,… | • |
| Inputs | • |
| Outputs | • |
| Required accuracy, constraints | • |
| Estimated time needed | • |
| Priority | • |
| Template Signature File. | • |
| Recipe | • |
| Calibration Analysis spec's | • |
| Needed Functionalities | • |
| CA implementation (pseudo code) | • |
| Status of Req. | |
| FLAG | |

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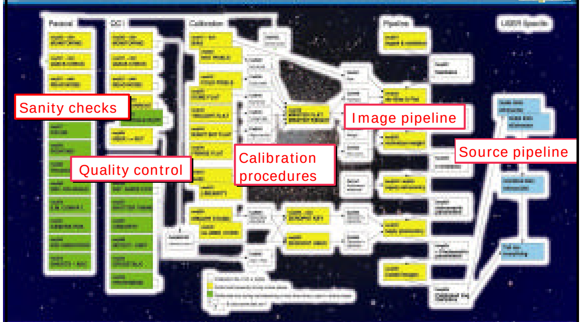
## 2 -Procedurizing

- Procedurizing
  - Data taking at telescope for both science and calibration data - Templates
    - Observing Modes: —Stare —Jitter —Dither —SSO
    - Observing Strategies: —Stan —Deep —Freq —Mosaic
  - Full integration with data reduction
  - Design- ADD
  - Data model (classes) defined for data reduction and calibration
  - View pipeline as an administrative problem

## 3 Data Model



## 4 Integrated archive and Large Data Volume

- Handling of the data is non-trivial
  - Pipeline data reduction
  - Calibration with very limited resources
  - Things change in time:
    - Physical changes (atmosphere, various gains)
    - Code (new methods, bugs)
    - Human insight in changes
  - Working with source lists

Science can only be archive based

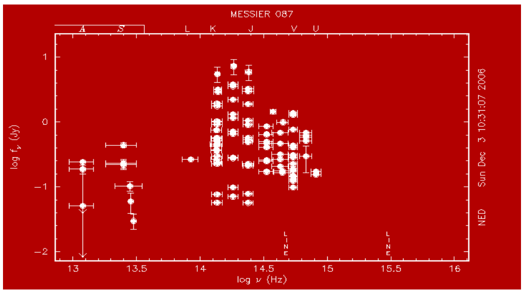
## Photometric calibration and the VO

- Now you have your result and you want to share it…..=VO
- Describing photometry universally: UCDs
  - Properties measurement: aperture…..
  - Value and error

## Photometric calibration & VO UCDs for photometry

- E | phot | Photometry
- E | phot.antennaTemp | Antenna temperature
- Q | phot.calib | Photometric calibration
- C | phot.color | Color index or magnitude difference
- Q | phot.color.excess | Color excess
- Q | phot.color.reddFree | Dereddened, reddening-free color
- E | phot.count | Flux expressed in counts
- E | phot.fluence | Fluence
- E | phot.flux | Photon flux
- Q | phot.flux.bol | Bolometric flux
- E | phot.flux.density | Flux density (per wl/freq/energy interval)
- E | phot.flux.density.sb | Flux density surface brightness
- E | phot.flux.sb | Flux surface brightness
- E | phot.limbDark | Limb-darkening coefficients
- E | phot.mag | Photometric magnitude
- Q | phot.mag.bc | Bolometric correction
- Q | phot.mag.bol | Bolometric magnitude
- Q | phot.mag.distMod | Distance modulus
- E | phot.mag.reddFree | Dereddened magnitude
- E | phot.mag.sb | Surface brightness in magnitude units

## How to compare magnitudes of extended sources…




NED: http://nedwww.ipac.caltech.edu