Extragalactic Distance Scale lect. II

Grzegorz Pietrzyński CAMK
pietrzyn@camk.edu.pl

In general critical review of different methods

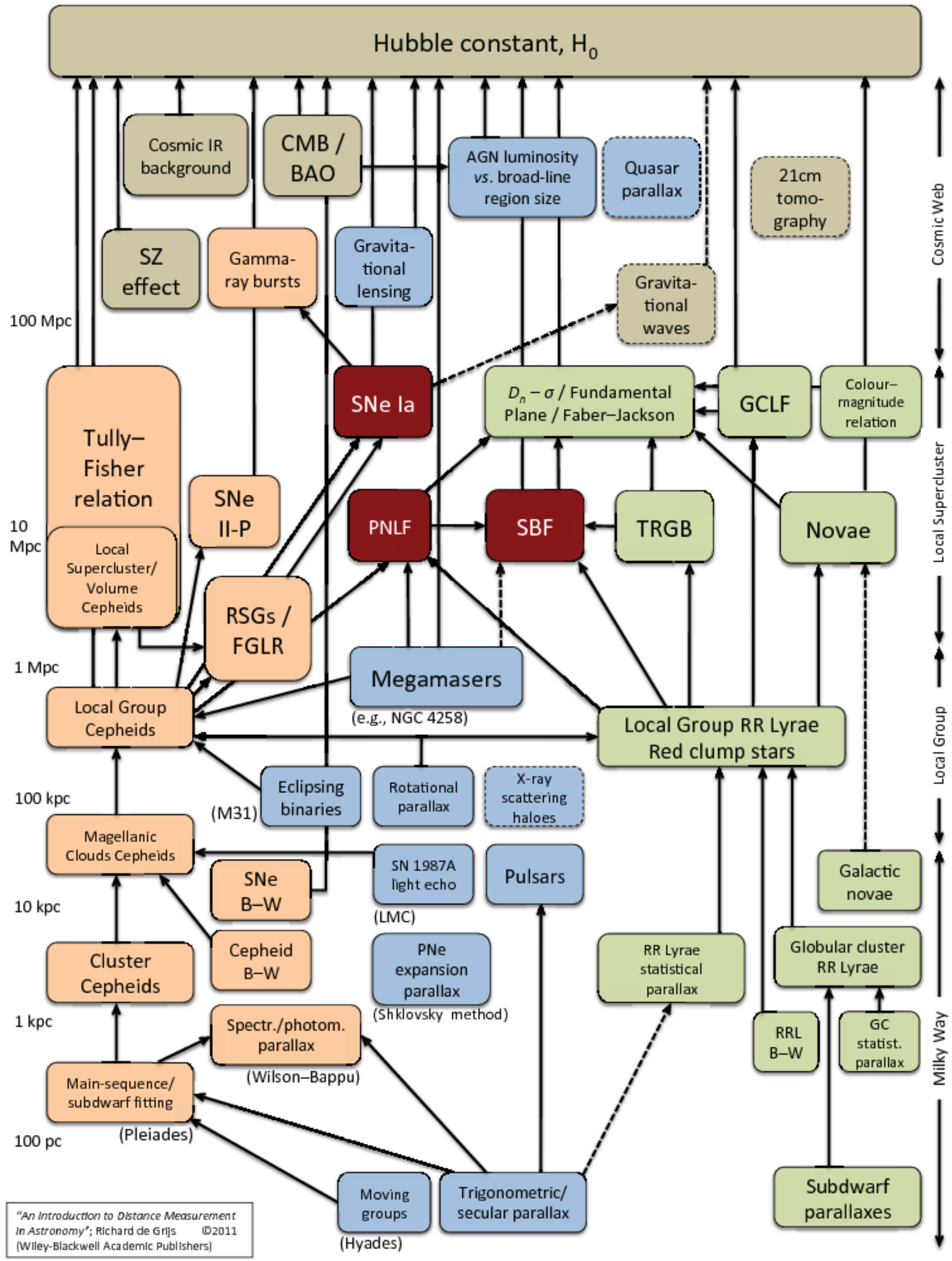
To show the limits of different techniques (no only H_0)

To understand better different errors

To discuss several problems

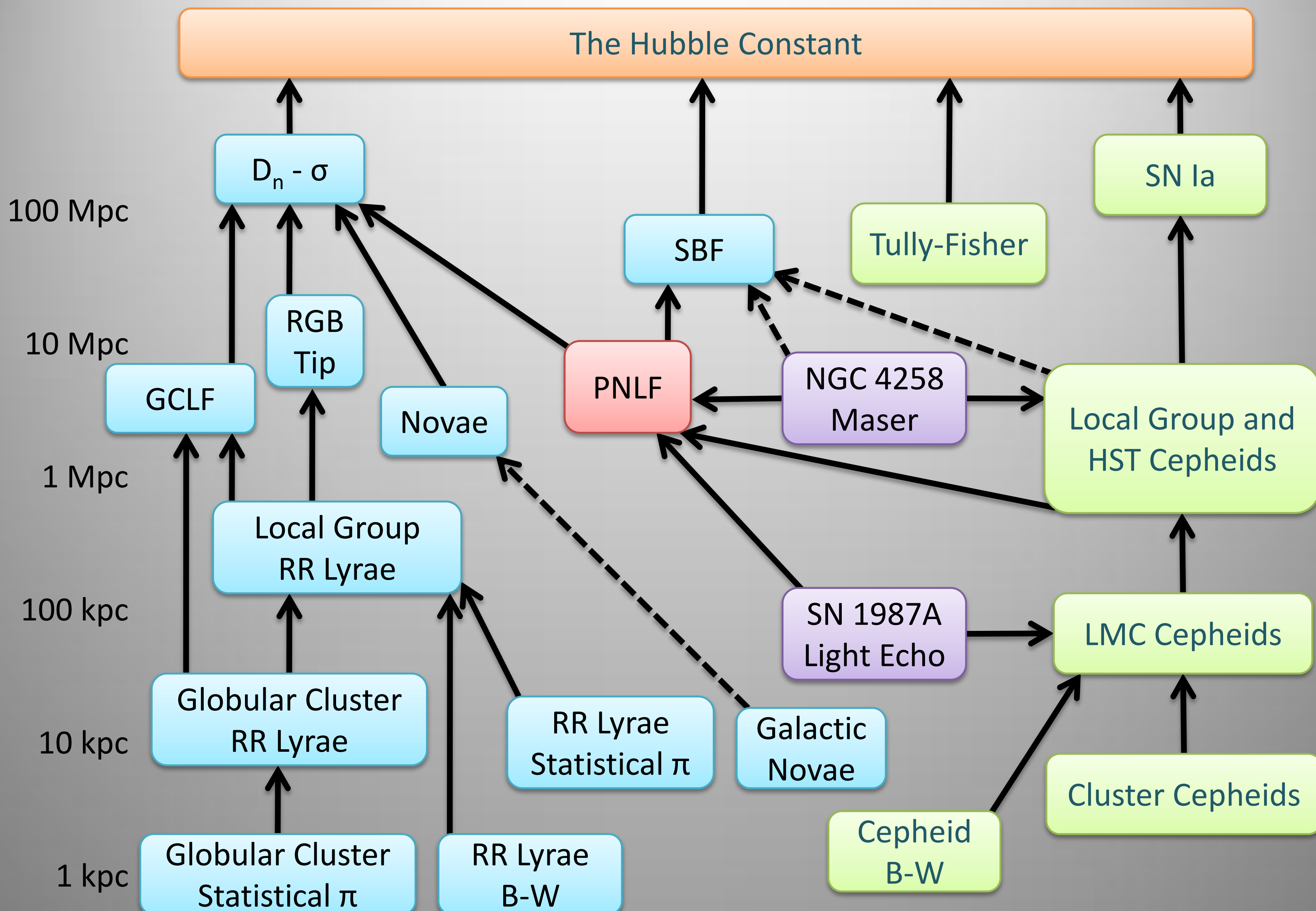
To encourge you to investigate furter

To hope you will help to solve some problems



Hubble constant, H_0
Cosmic IR background
CMB / BAO
AGN luminosity vs. broad-line region size
Quasar parallax
21cm tomography
SZ effect
Gamma-ray bursts
Gravitational lensing
Gravitational waves
100 Mpc
Tully–Fisher relation
SNe Ia
$D_n - \sigma$ / Fundamental Plane / Faber–Jackson
GCLF
Colour–magnitude relation
SNe II-P
PNLF
SBF
TRGB
Novae
10 Mpc
Local Supercluster/ Volume Cepheids
RSGs / FGLR
Megamasers
(e.g., NGC 4258)
1 Mpc
Local Group Cepheids
Local Group RR Lyrae Red clump stars
100 kpc
(M31)
Eclipsing binaries
Rotational parallax
X-ray scattering haloes
Magellanic Clouds Cepheids
SNe B–W
SN 1987A light echo
(LMC)
Pulsars
Galactic novae
10 kpc
Cluster Cepheids
Cepheid B–W
PNe expansion parallax
(Shklovsky method)
RR Lyrae statistical parallax
Globular cluster RR Lyrae
1 kpc
Spectr./photom. parallax
(Wilson–Bappu)
RRL B–W
GC statist. parallax
Main-sequence/ subwarf fitting
(Pleiades)
100 pc
Moving groups
(Hyades)
Trigonometric/ secular parallax
Subdwarf parallaxes
Cosmic Web
Local Supercluster
Local Group
Milky Way
"An Introduction to Distance Measurement in Astronomy"; Richard de Grijs ©2011 (Wiley-Blackwell Academic Publishers)

Extragalactic Distance Ladder



Classical method via extragalactic ladder

1) Firmly sticked to the ground

(basic physics of distance indicators,

 glabular clusters etc)

2) Many opportunities for cross-check and trace systematic errors

4) We know mostly well the errors and we can mitigate / reduce them.

5) Direct method without additional assumptions

6) Determination of the Hubble constant (e.g. H_0) not just H

7) Potentially precise and accurate ! Reference for other methods.

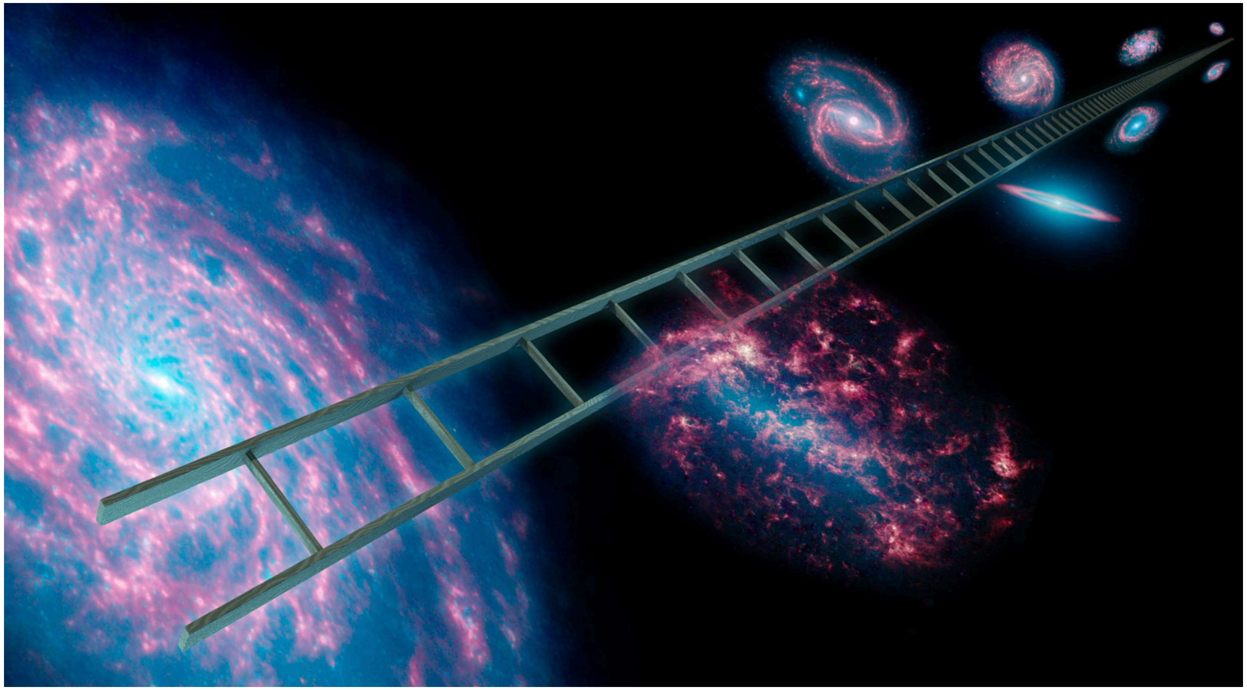
Cosmological methods

Very attractive based on „early universe”

Additional asumptions needed

Do not deliver H_0

Very precise but it is difficult to contraint accuracy



Other methods

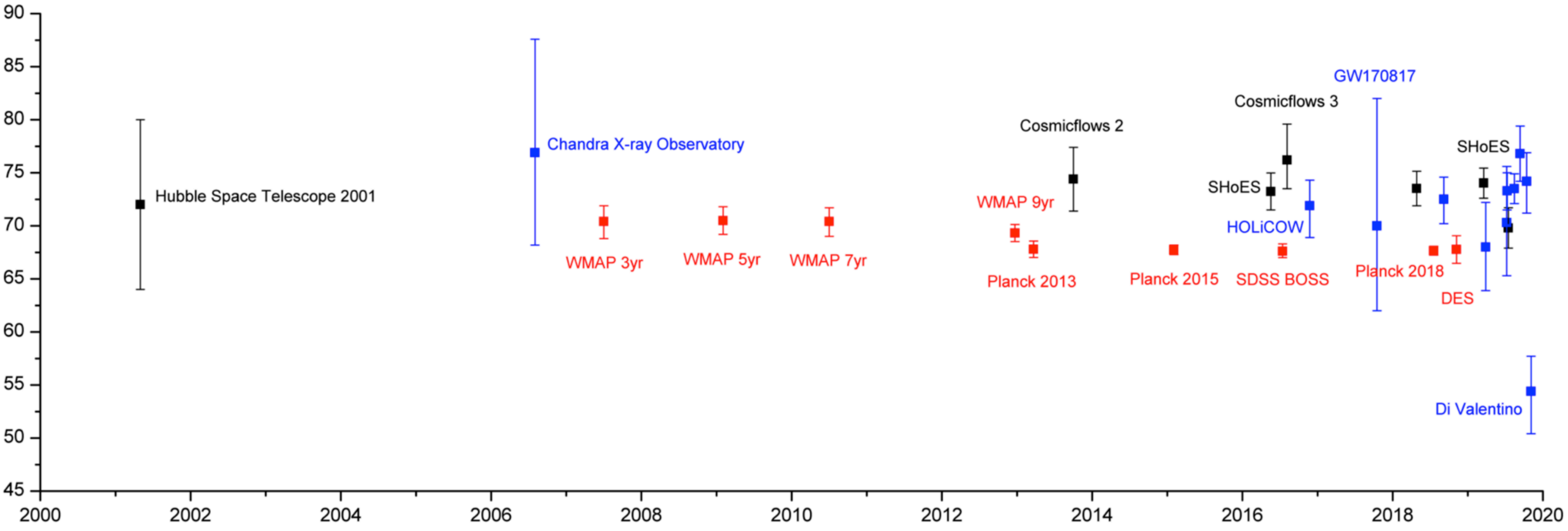
Gravitational waves, Quasars, mazers

Precision and accuracy is uknown

All of them rely on averaging many different determinations and different z

How about systematics ??

"



$$H^2 \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2} + \frac{\Lambda c^2}{3},$$

$$t_H \equiv \frac{1}{H_0} = \frac{1}{67.8(\mathrm{km/s})/\mathrm{Mpc}} = 4.55 \cdot 10^{17}\mathrm{s} = 14.4 \text{ billion years.}$$

Crucial for all fields of modern astrophysics ...

Sources of errors in data

Noise sources

Reduction procedures

Observational techniques

Calibrations

Origin of noise

- Poisson fluctuations in counting photons
- Pixel-pixel gain variations
- Cosmic Rays
- CCD RON
- Charge transfer efficiency
- Scattered light
- Wrong reduction algorithms

Noise Reduction

- What phenomenon produce the noise (e.g. cosmic rays) ?
- How does it manifest itself ?
- Is this noise seriously affecting the data ?
- Can it be or should it be corrected ?
- What algorithm should be applied to minimize it ?

Poisson noise

If the mean number of photons if X then the uncertainties related to counting photons is $\sqrt{X}$, so $S/N = X / \sqrt{X} = \sqrt{X}$

If we increase the exposure time by 2 we gain just $\sqrt{2}$ in S/N

Note: the Poisson noise is irreducible; the S/N corresponds to the upper limit; no reducing method can yield higher S/N

Saturation and linearity

Linearity limit (20 000 – 60 000 ADU)

Now deep depletion chips (350 000)

Saturation of the first kind happens when the signal in one pixel goes higher than the full well capacitance allows.

Often ghost images, charge bleeding (double check the field before observations !)

RON

Each time a pixel is read by the amplifier, a noise is added to the signal.

Modern CCDs have RON ~ few electrons

Gain is chosen the lab to resolve RON.

RON is assumed to be:

1) independent of position on the CCD

2) representable as a simple Gaussian error dist.

Overscan and BIAS

Many CCDs have various lines or columns of pixels which are not exposed. Those pixels allow to estimate the pedestal (BIAS) of an image (overscans, prescans). Usually it is OK to take the mean of the column or line and subtract it from the image. After such correction, the remaining noise should be Poissonian. It also helps to monitor for potential problems (electronic, high temperature)

To check for a possible structure it is necessary to obtain a series of 0 sec (BIAS) images. The distribution of pixel values in a mean BIAS (overscan subtracted) must have Gaussian form with a mean of 0 and FWHM ~ $RO / \sqrt{N}$

In the case of IR detectors no BIAS exposure !!

Cosmic Rays

Problems with long exposures

Several images help !

May be a very important issue – expresso !!

Dark current and hot pixels

The additive DARK current is produced by:

1) A weak signal composed of thermal electrons

2) Electrons produced by hot pixels

When cooling with N the dark current is very small (no correction needed)

Hot pixels (preparing a map and subtraking)

Flatfield

Correction for pixel to pixel variation of quantum efficiency.

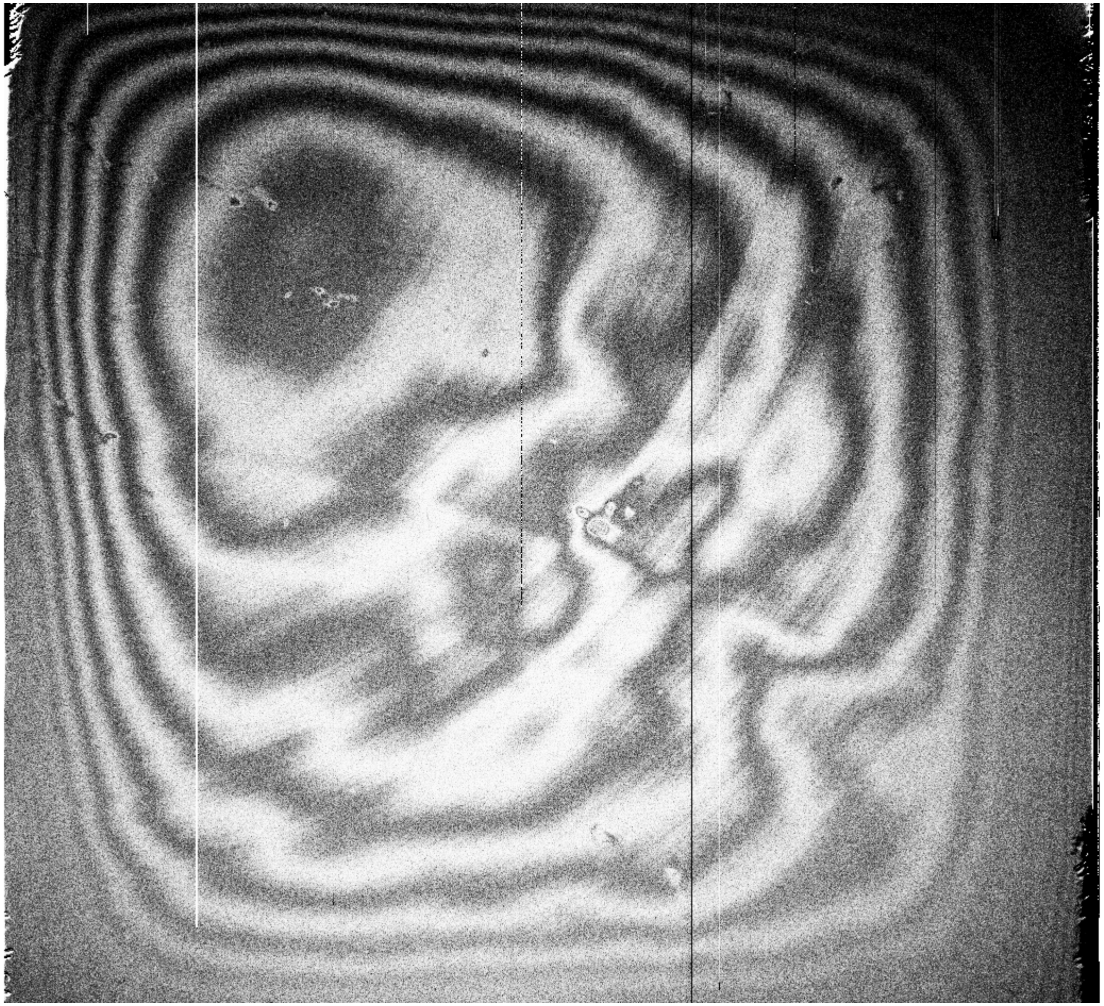
dome flat (few %)

sky flat (1 %)

empty field (0.1 %) - time consuming

real challenge for near IR and spectroscopy

Fringing



Other problems

Poor ground – additional noise (call for technician)

otherwise Fourier filter

Scattered light – must be subtracted before flatfielding

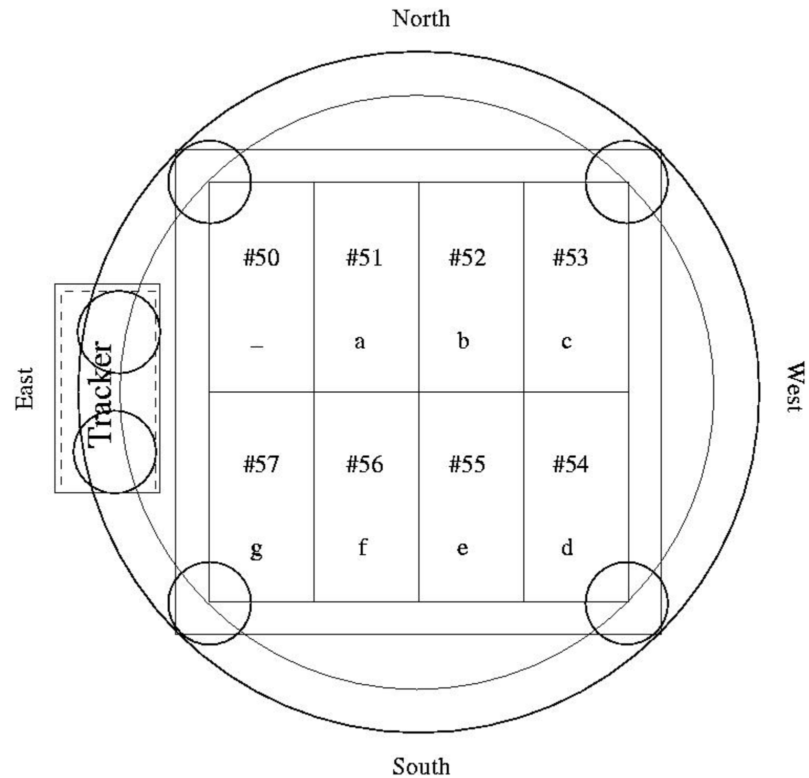
Crosstalk

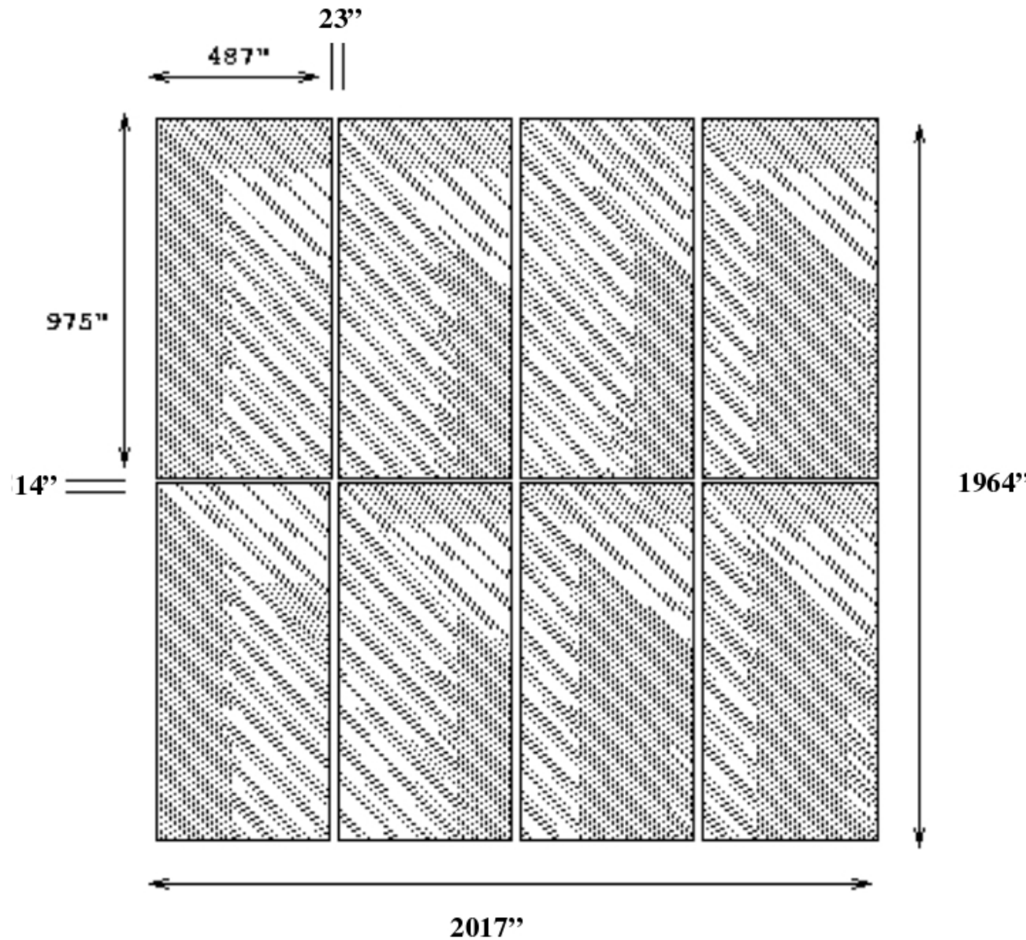
Possible contaminations (quite often)

Zero point stability - luminosity correction

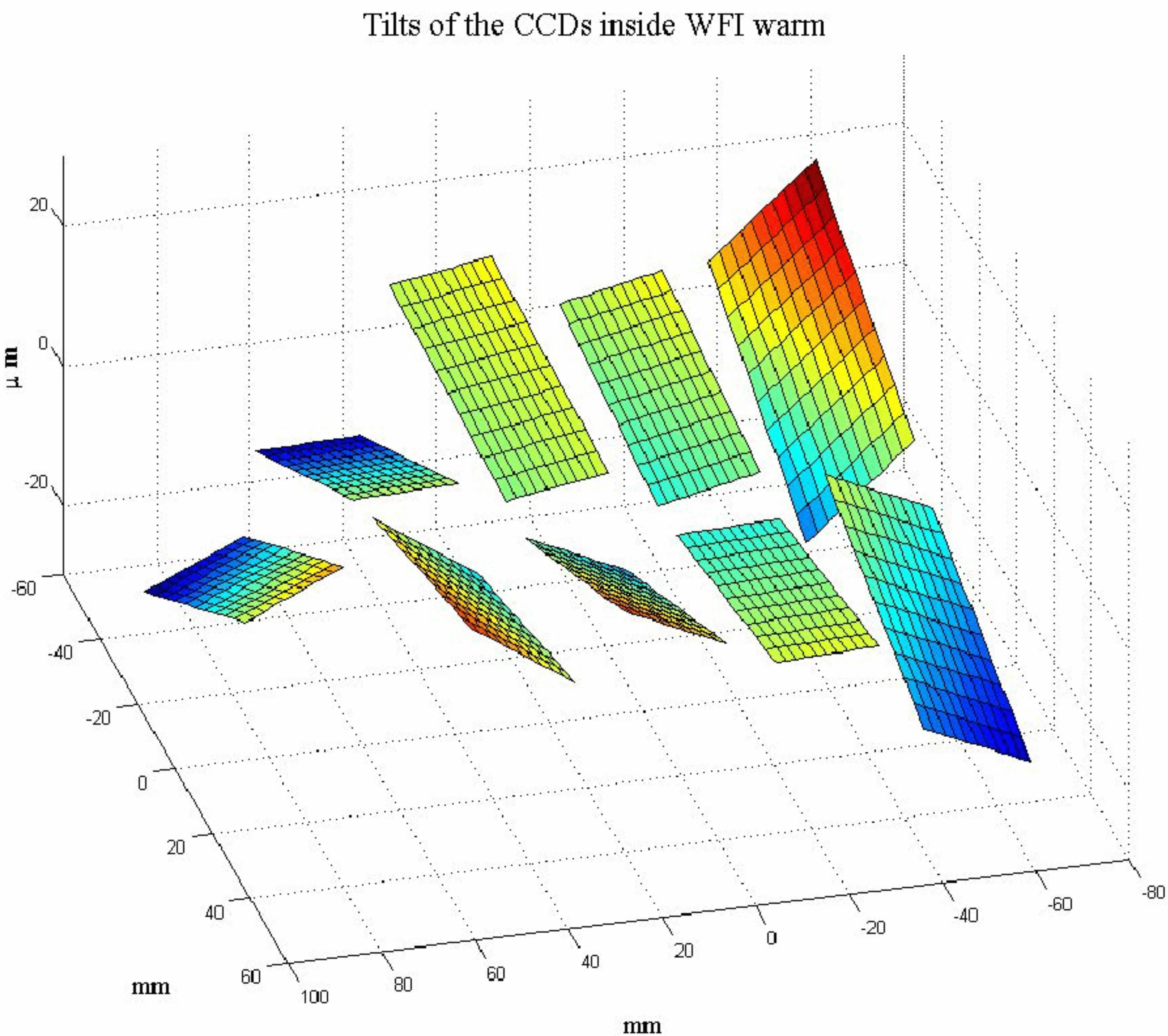
Mosaic CCDs

- Field of view 34'x33'
- Pixel scale 0.238 arcsec/pixel
- Detector 4x2 mosaic of 2kx4k CCDs
- Filling factor 95.9%
- Read-out time 27 seconds
- Read-out noise 4.5 e-/pixel
- (Inverse) gain 2.0 e-/ADU
- Geometrical distortions <= 0.08%





Coverage: 0.56x0.54 deg^2 (0.238 "/pix)


Tilts of the CCDs inside WFI warm
μ m
20
0
-20
-60
-40
-20
0
20
40
60
mm
100
80
60
40
20
0
-20
-40
-60
-80
mm

Variable Pixel Scale

The basic assumptions about the uniform pixel scale is now not valid ! In the case of Mosaic, the pixel scale decreases approximately quadratically from the field center, with the pixels in the field corners being 6% smaller in the radial direction, and 8% smaller in area.

IRAF: mscred package

Other issues

Distorsions: correction maps

Bad columns: masking

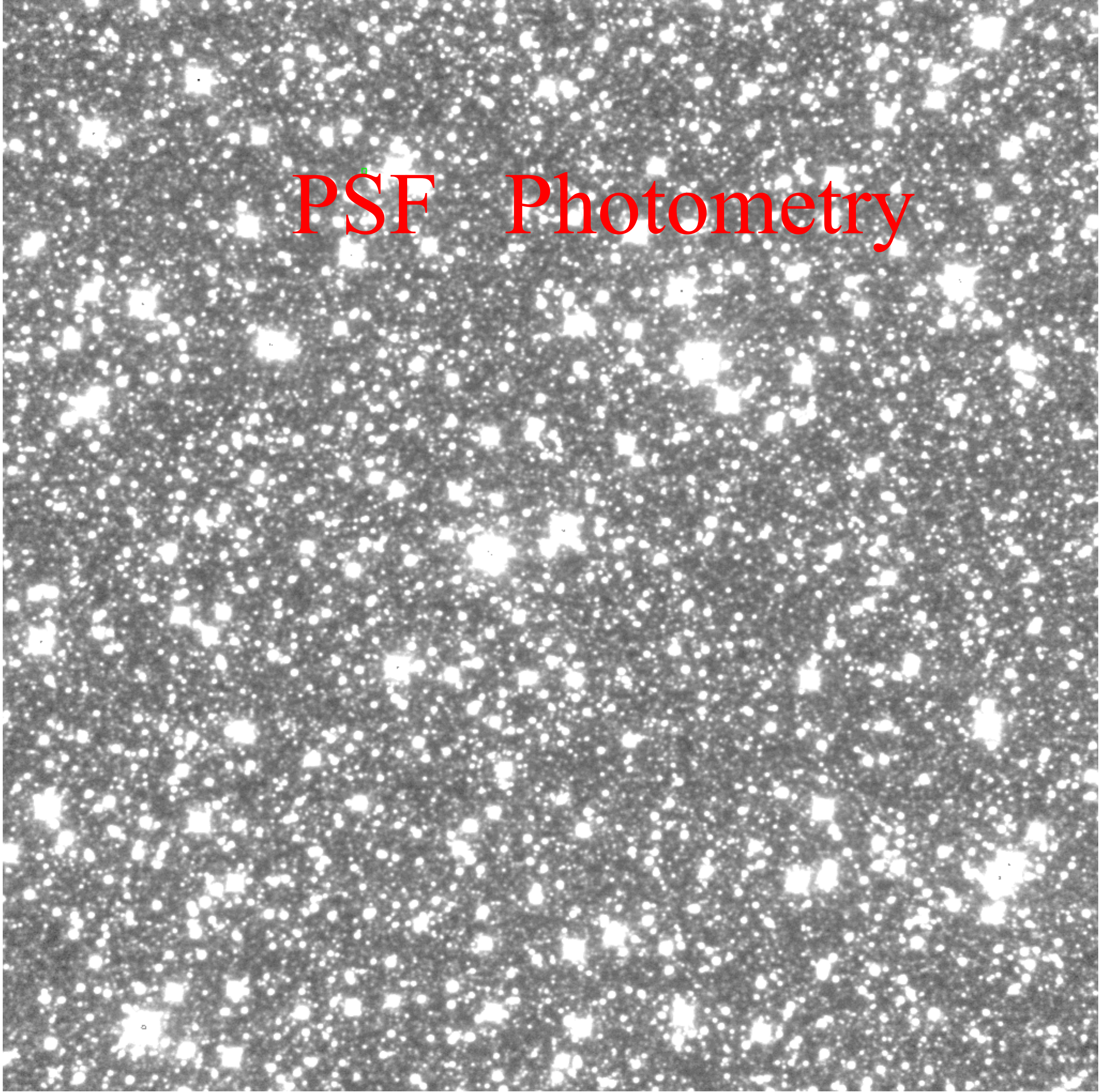
Dead pixels: correction maps (interpolating)

Sky subtraction

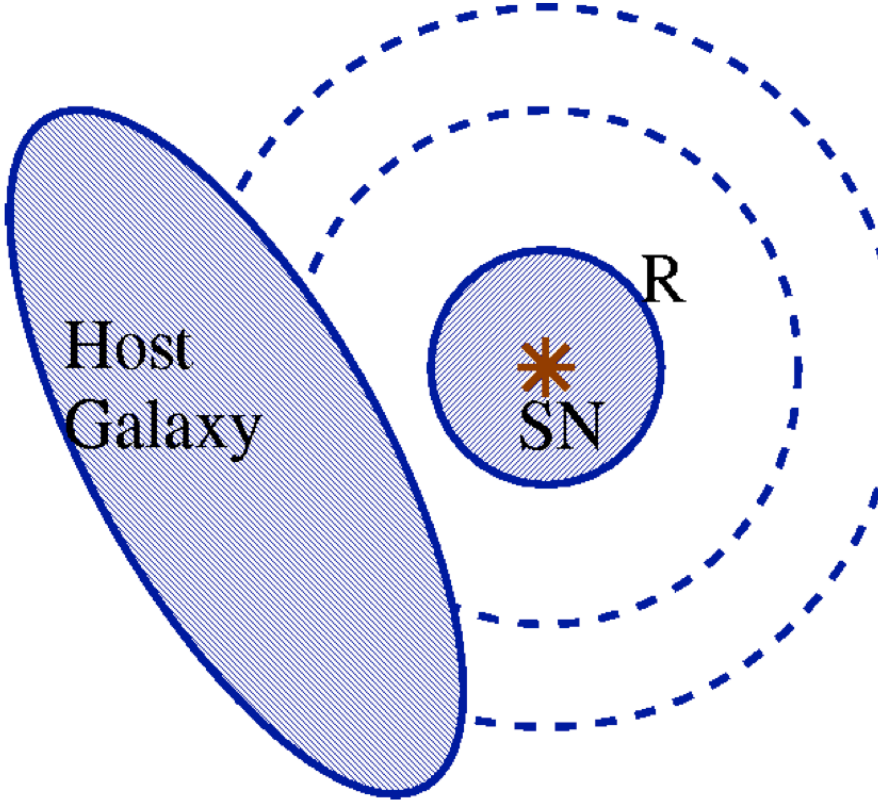
Binning (improve S/N, saturation, PSF sampling etc).

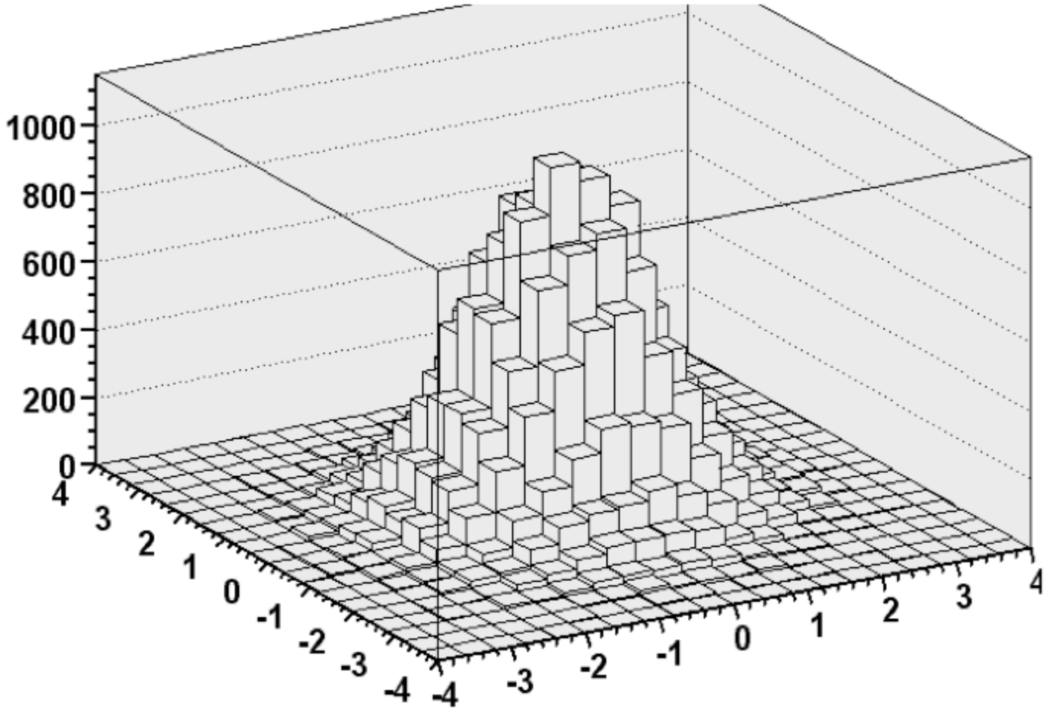
Dithering and stacking images

Different CCDs different characteristics …

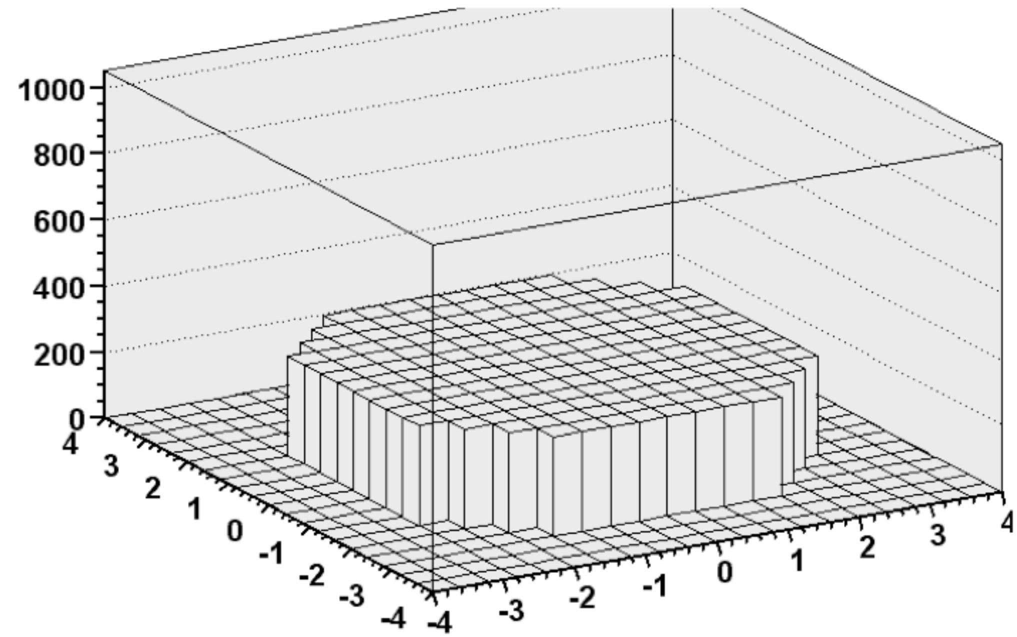

PSF Photometry

Why PSF ?





2D Gaussian weight function



Aperture photometry weight function

PSF shape dependence

For the ground-based telescopes, the PSF shape mostly depends on seeing – variable atmospheric condition.

For a space-based mission, the seeing is non-existent => the following factors are more apparent:

1) color
2) pointing jitter (telemetry info)
3) optical aberrations
4) field dependence

Sampling is crucial for centering, width determination, algorithmic processing, etc.
Undersampled / critically sampled (FWHM 1-2 pix) / oversampled.

PSF modelling

Can use *analytical* shapes:

1) 2D Gaussian $A * \exp(-r^2/\sigma^2/2)$

2) Lorentz $A/(r^2/\sigma^2+1)$

3) Moffat $A/(r^2/\sigma^2+1)^\beta$

May need sub-pixel integration if not well sampled. Hard to model tails, non-circularity.

***Empirical* modelling off the bright field stars:**
can templetize PSF(x,y) => "any shape"
But:

- **noisy,**
- **centering,**
- **interpolation,**
- **may not have enough field stars.**

***Hybrid* approach:**
use analytical models for the fast-varying core, then model the (tail) residuals empirically.

"Standard" PSF-fitting packages

Things to be cautious about:
a standard package is a just piece of software, which somebody wrote, and somebody else uses. Domains of applicability vary!

Differences:
- PSF shape,
- background,
- bad pixels.

All for stars photometry.

None accounts for custom errors.

ROMAFOT (Buonanno 1983) – developed at Rome Observatory, originally for photographic plates. Gaussian or Moffat PSF.

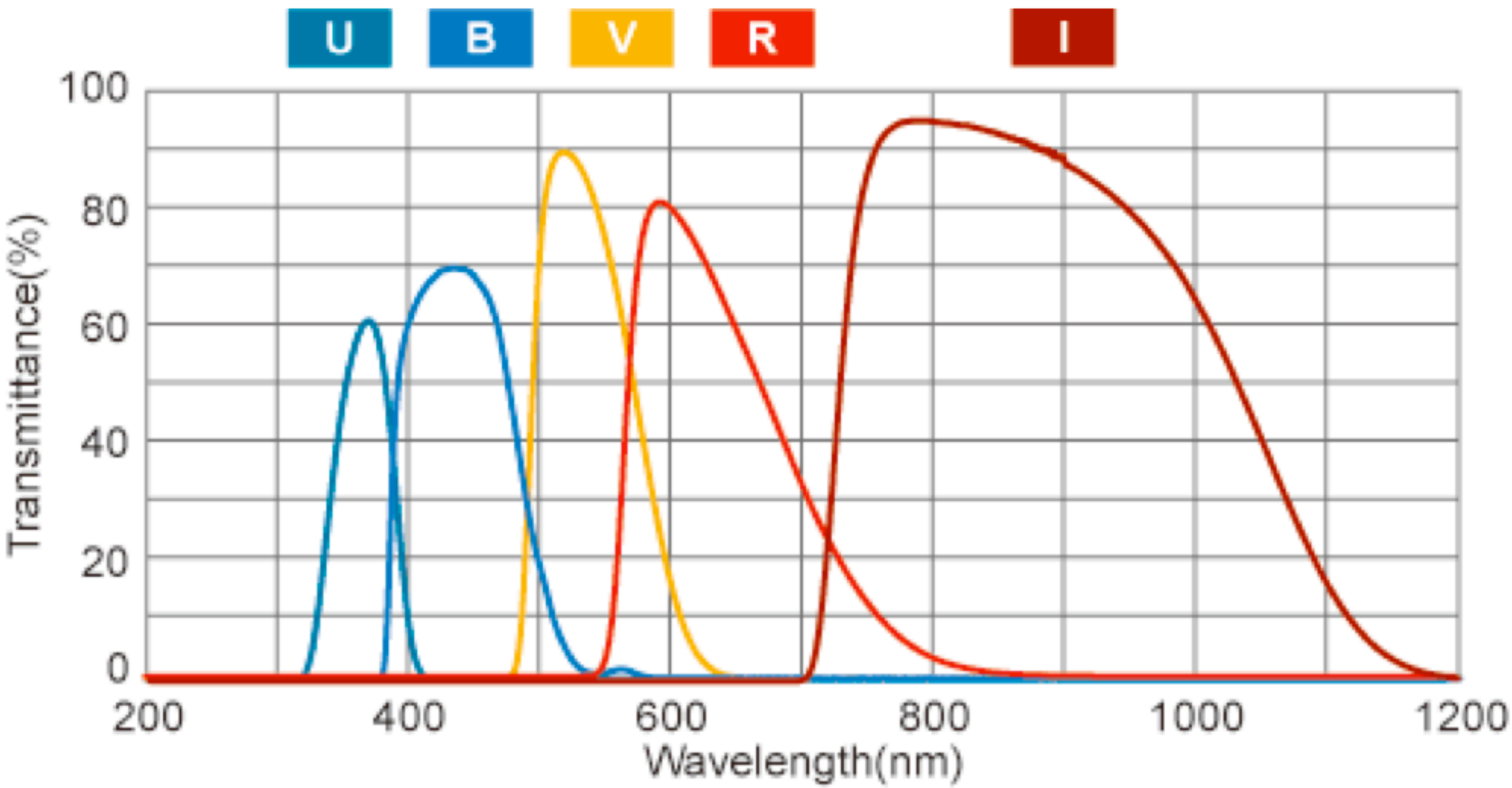
STARMAN (Penny 1995) – a stand-alone program from UK. Hybrid Lorentz-Gaussian-empirical profile. Can deal with very crowded and very undersampled images, as well as field-variable PSF.

DAOPHOT (Stetson 1987) – probably the most famous package, included in IRAF. Uses a hybrid approach to PSF building (Gaussian/Moffat/Lorentz). Has bad pixel thresholds.

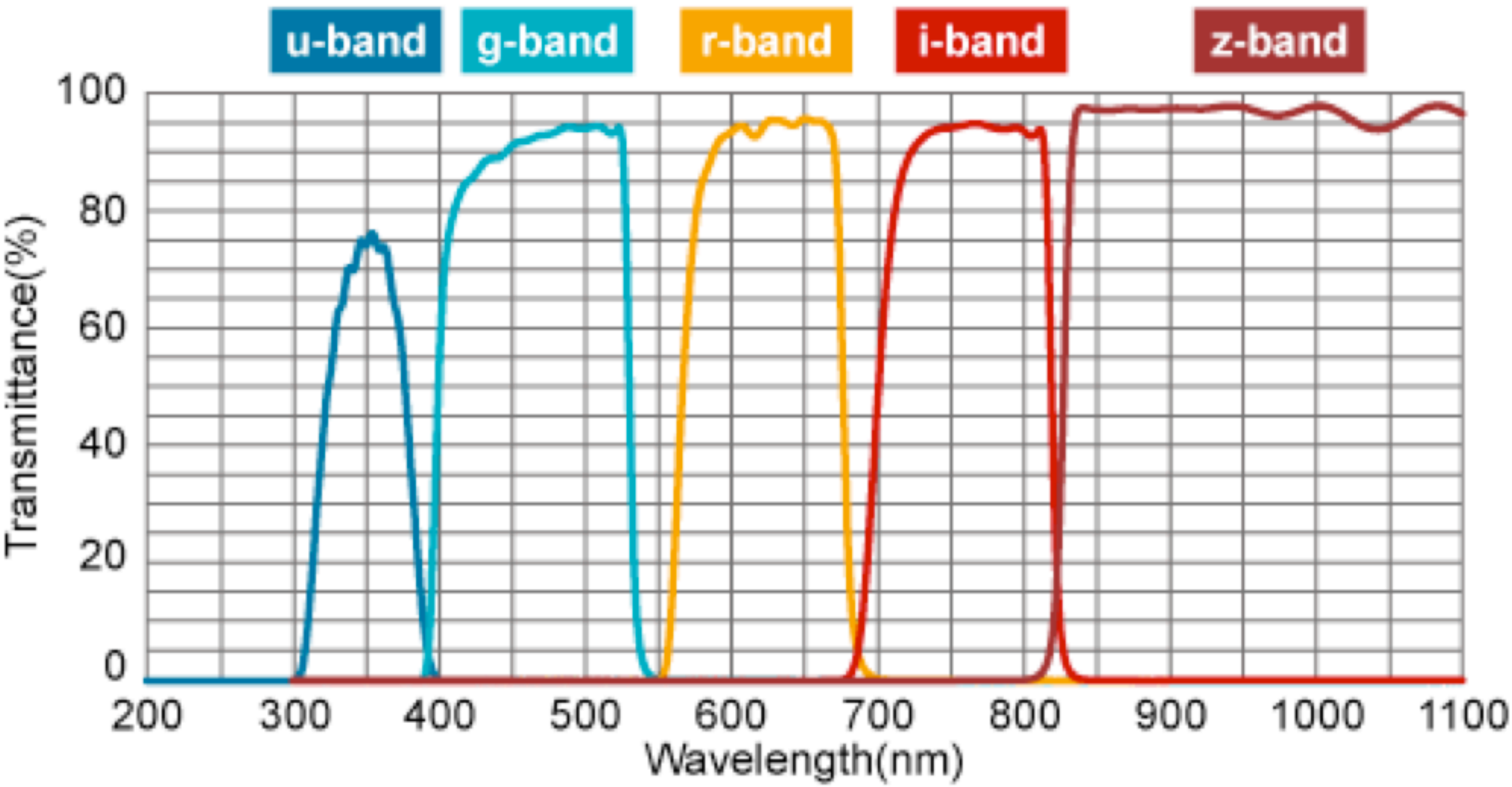
DoPHOT (Schechter 1993) – written with automated processing in mind. Analytical or empirical PSF. Capability to detect CRs and saturated pixels.

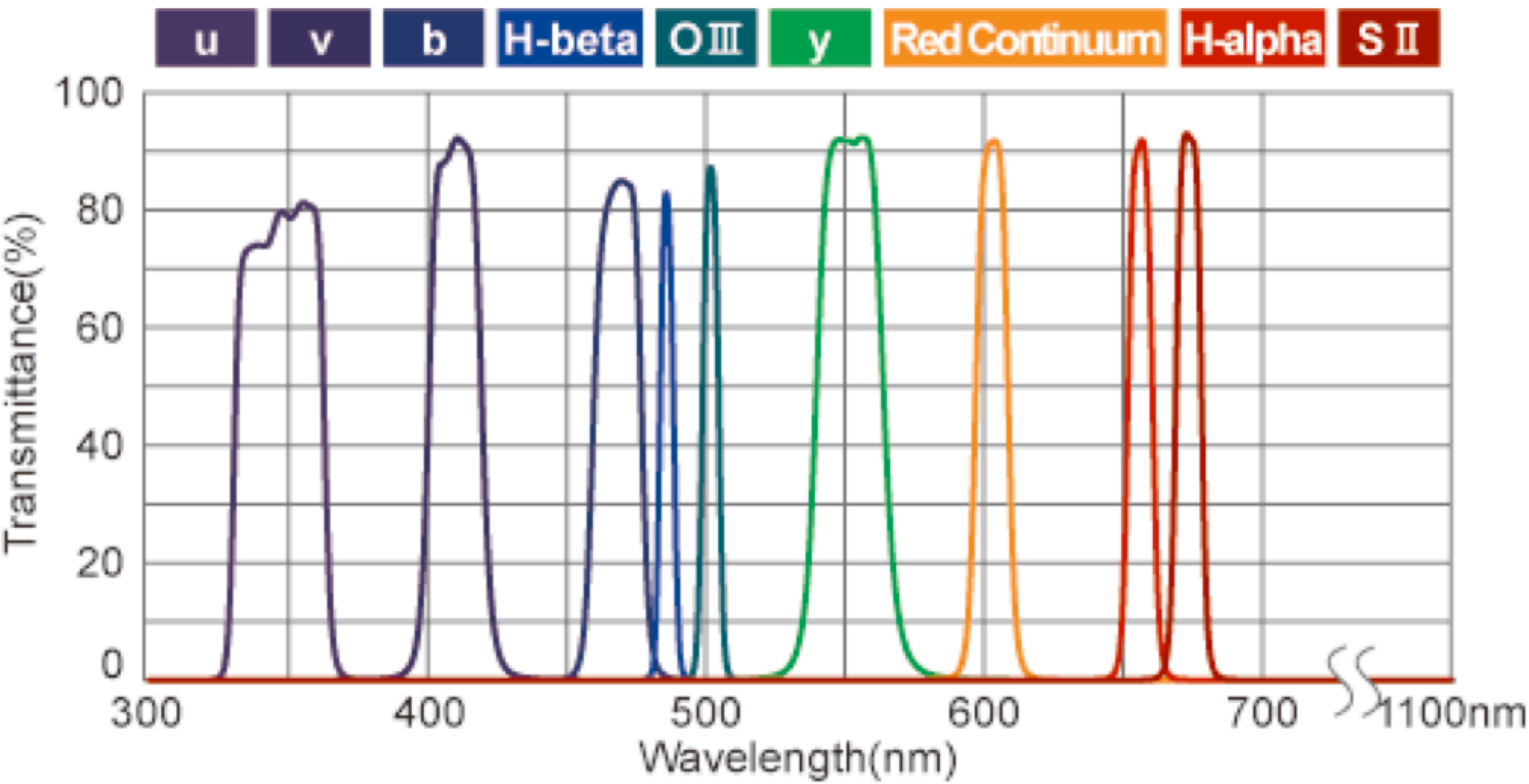
Errors returned by daophot by some 20% lower than real ...

Johnson / Bessell Filters (U,B,V,R,I)

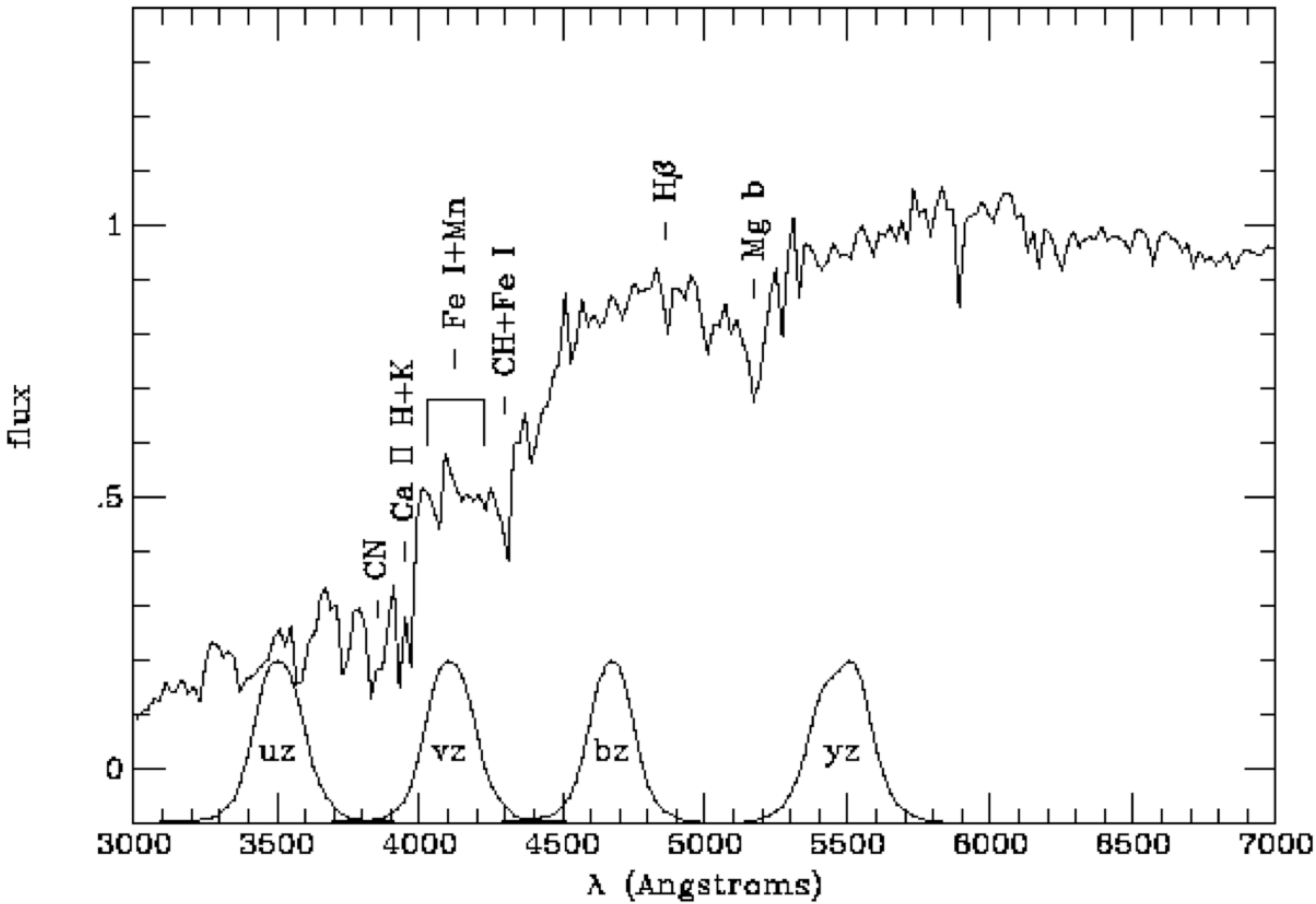


SDSS Filters (u,g,r, i,z-band)





u
v
b
H-beta
OIII
y
Red Continuum
H-alpha
SII
100
80
60
40
20
0
Transmittance(%)
300
400
500
600
700
1100nm
Wavelength(nm)



flux
λ (Angstroms)
CN
Ca II H+K
Fe I+Mn
CH+Fe I
Hβ
Mg b
uz
vz
bz
yz
0
.5
1
3000
3500
4000
4500
5000
5500
6000
6500
7000

Standard systems

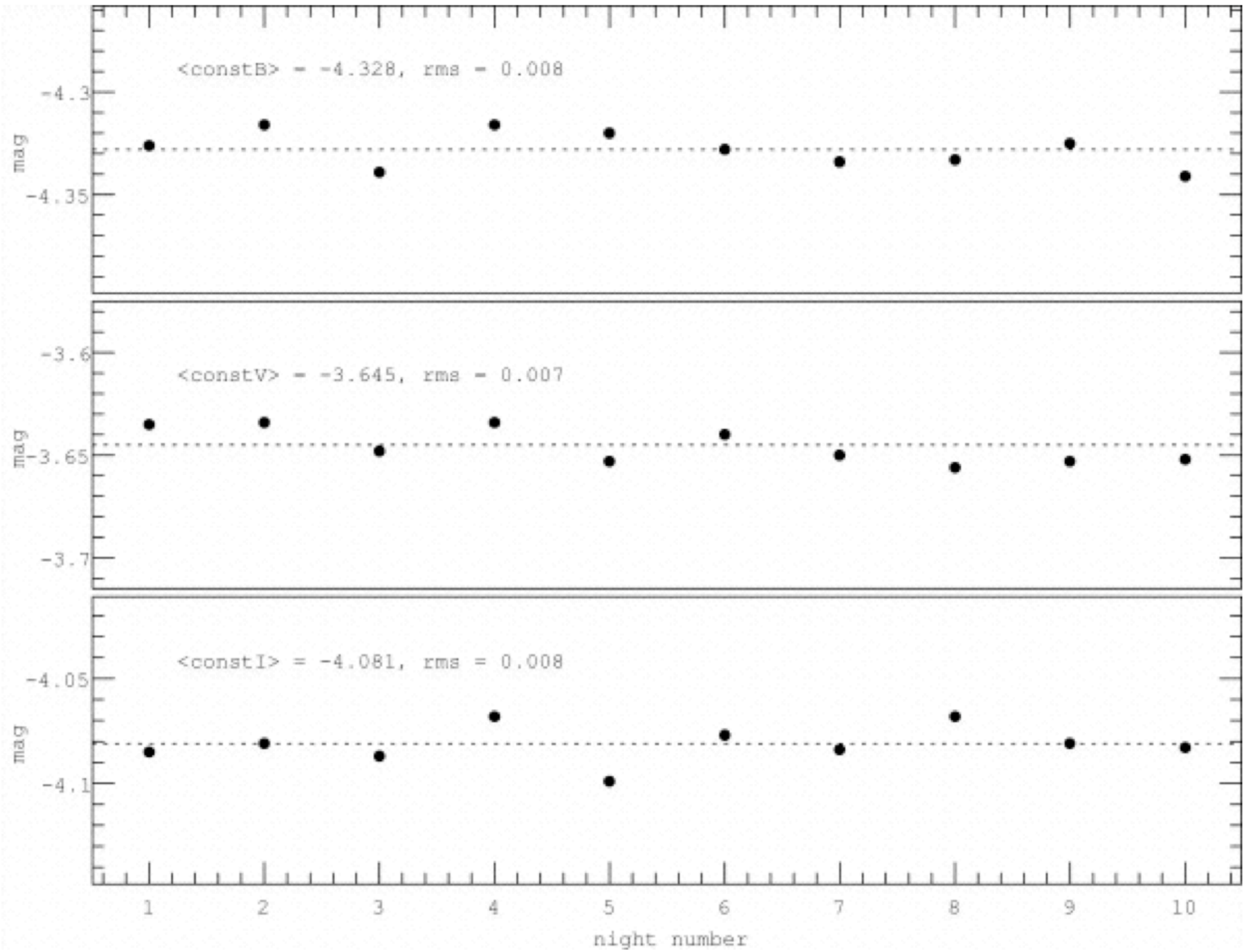
$$B = b - 0.041(B - V) + \text{const}_B,$$

$$V = v - 0.002(V - I) + \text{const}_V,$$

$$I = i + 0.029(V - I) + \text{const}_I,$$

$$B - V = 0.959(b - v) + \text{const}_{B-V},$$

$$V - I = 0.969(v - i) + \text{const}_{V-I},$$



<constB> = -4.328, rms = 0.008
-4.3
-4.35
mag
<constV> = -3.645, rms = 0.007
-3.6
-3.65
-3.7
mag
<constI> = -4.081, rms = 0.008
-4.05
-4.1
mag
1
2
3
4
5
6
7
8
9
10
night number

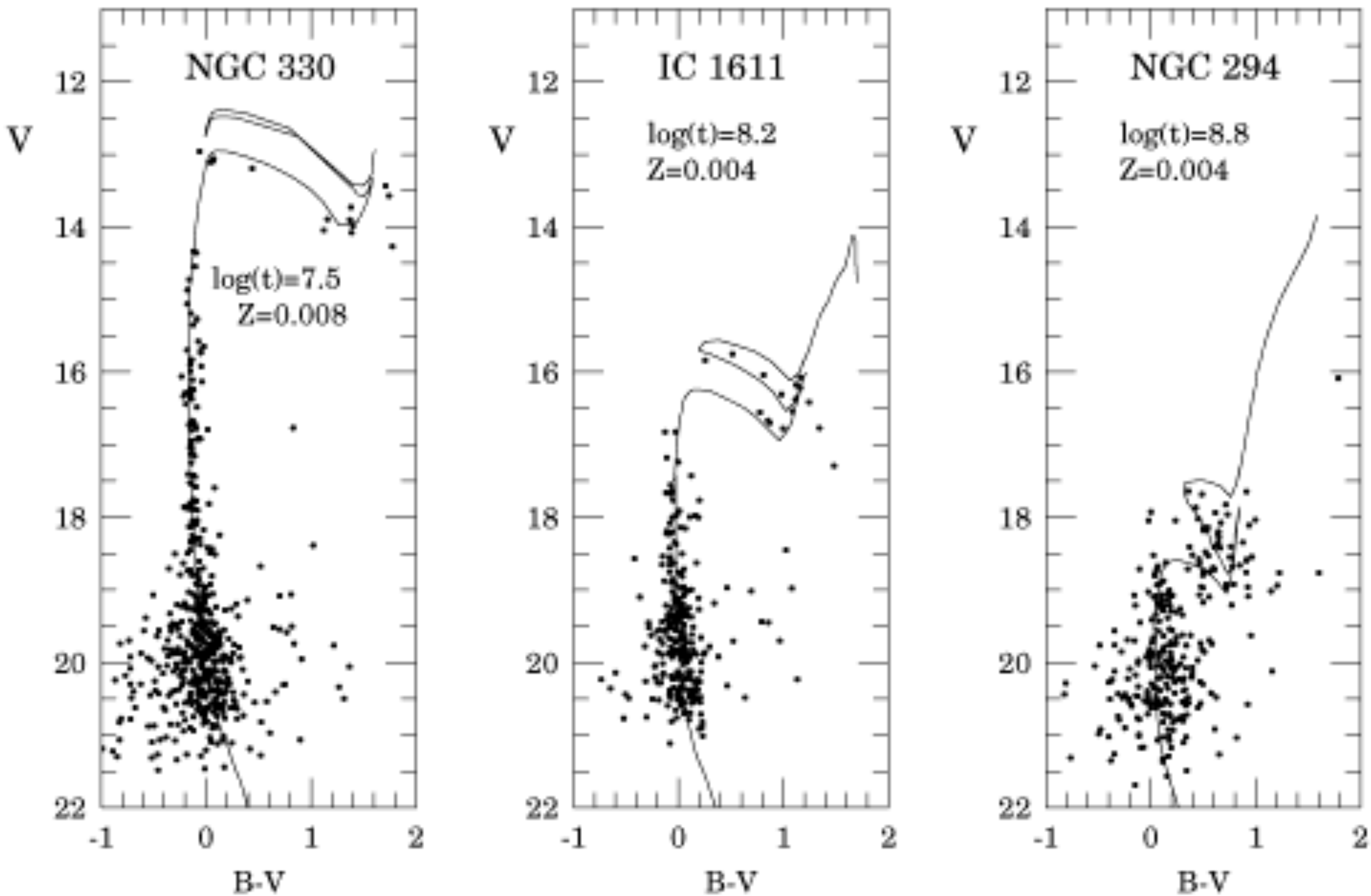
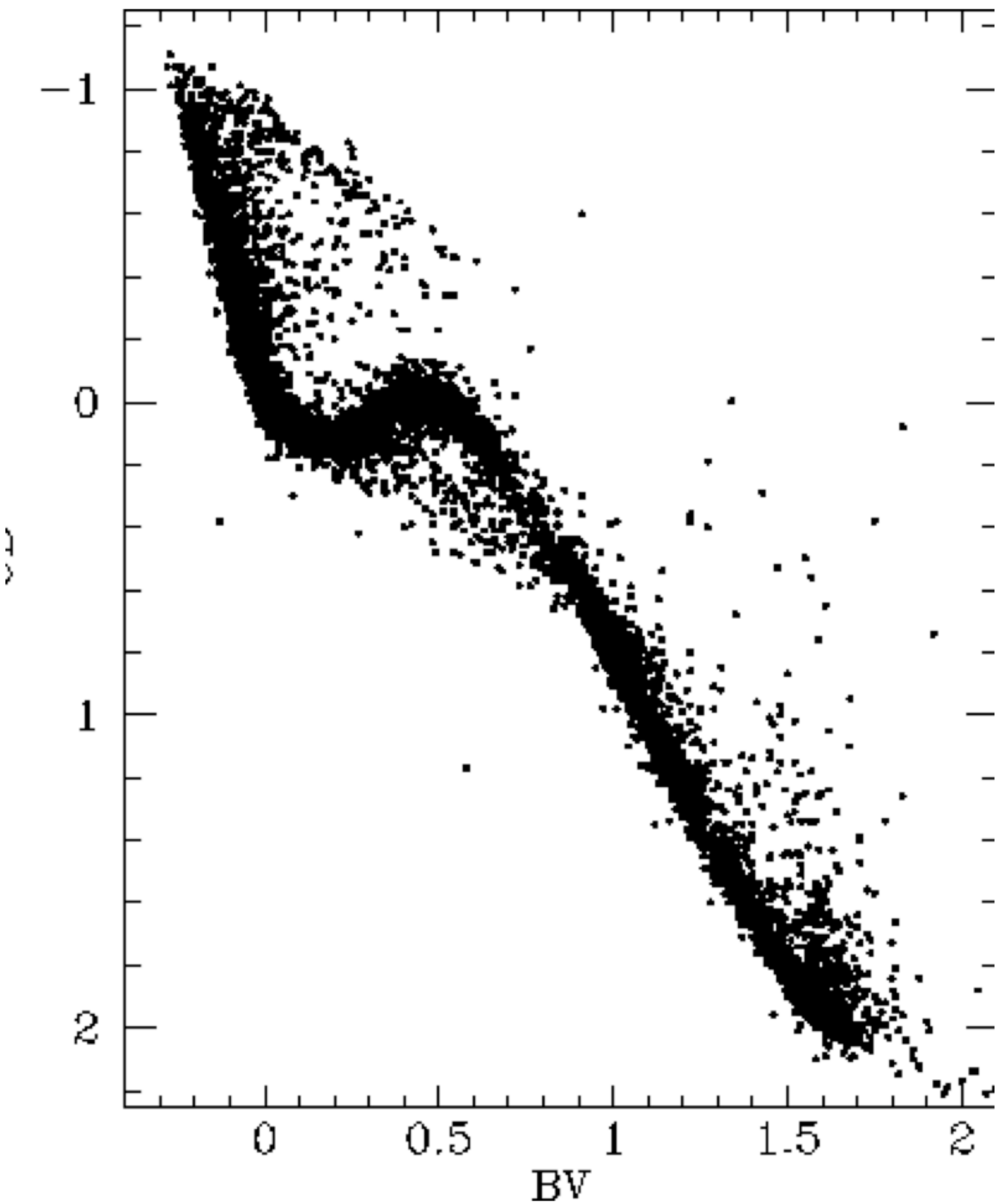


Fig. 2. CMDs with fitted isochrone for three clusters of different age.

U-B vs B-V diagram



Photometric multicolor data:

1) age, distance
2) Reddening
3) Metallicity
4) Gravity
5) Effective temperature
6) Surface brightness (angular diameter)