Basics of observations and data reduction: imaging and photometry

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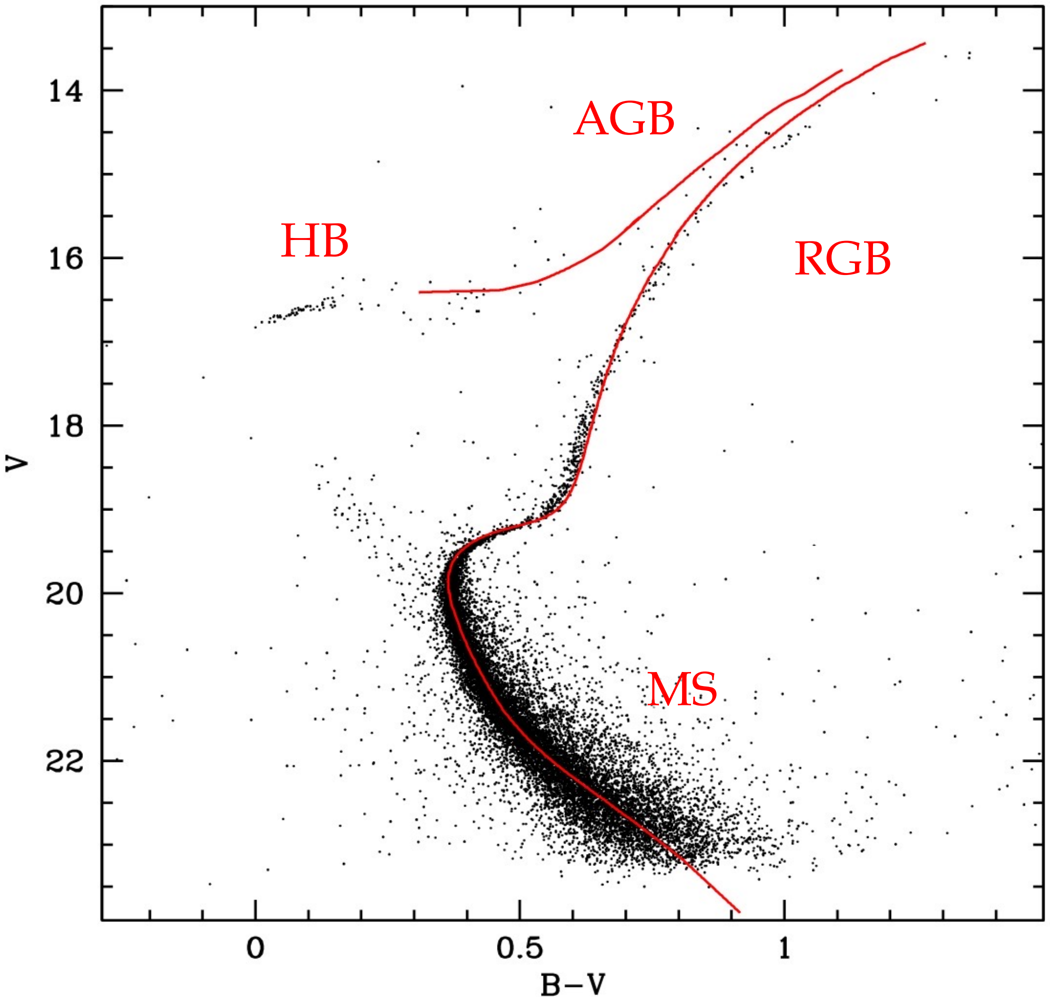
imaging and photometry?

IMAGE

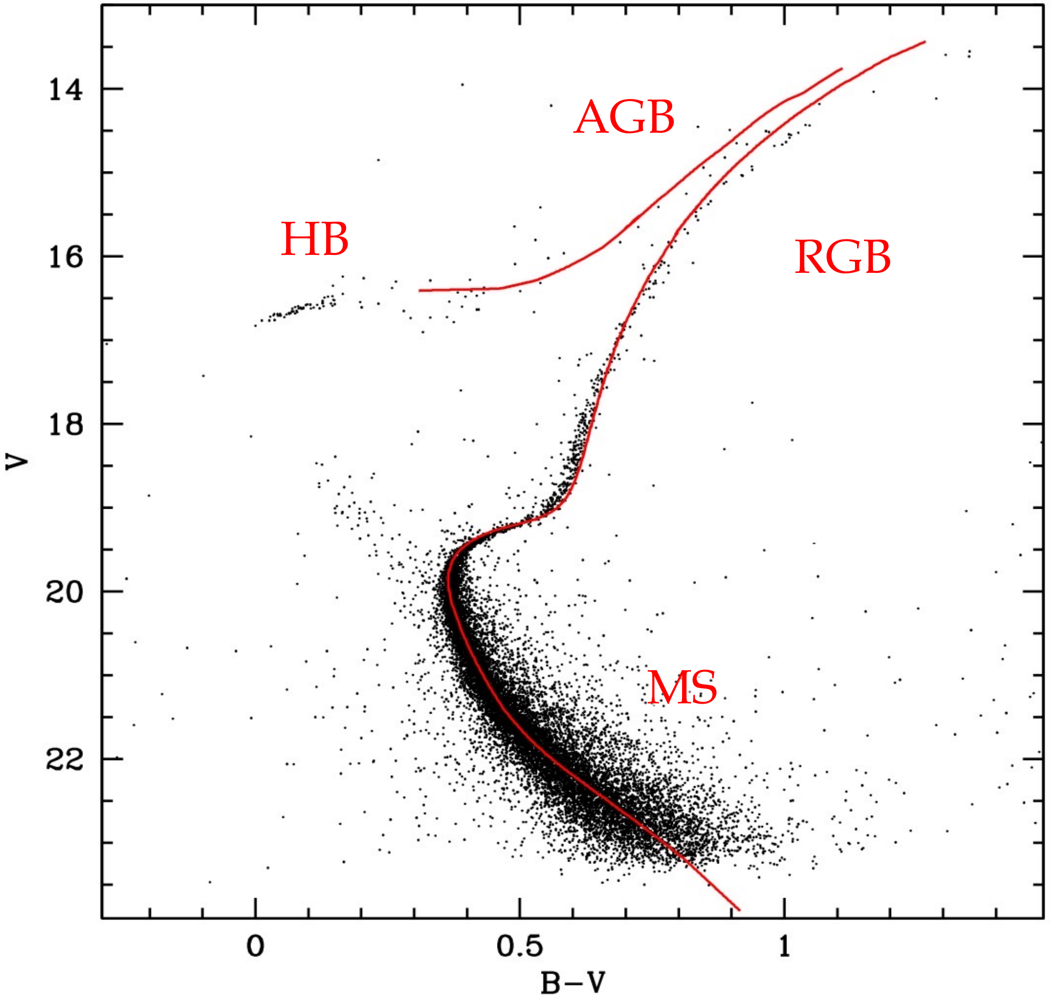
a visible impression obtained by a camera, telescope, microscope, or other device, or displayed on a computer or video screen

PHOTOMETRY
measuring the intensity of light by counting photons



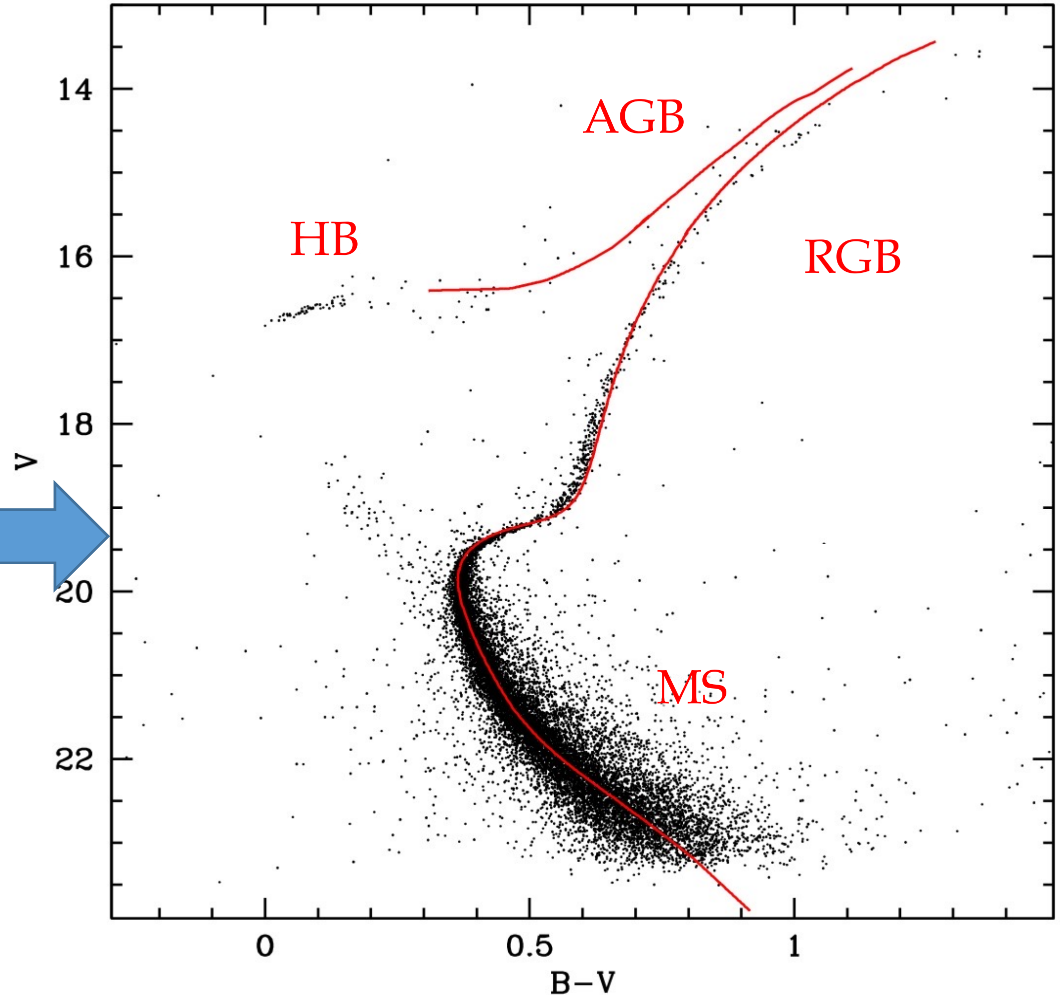
imaging

photometry

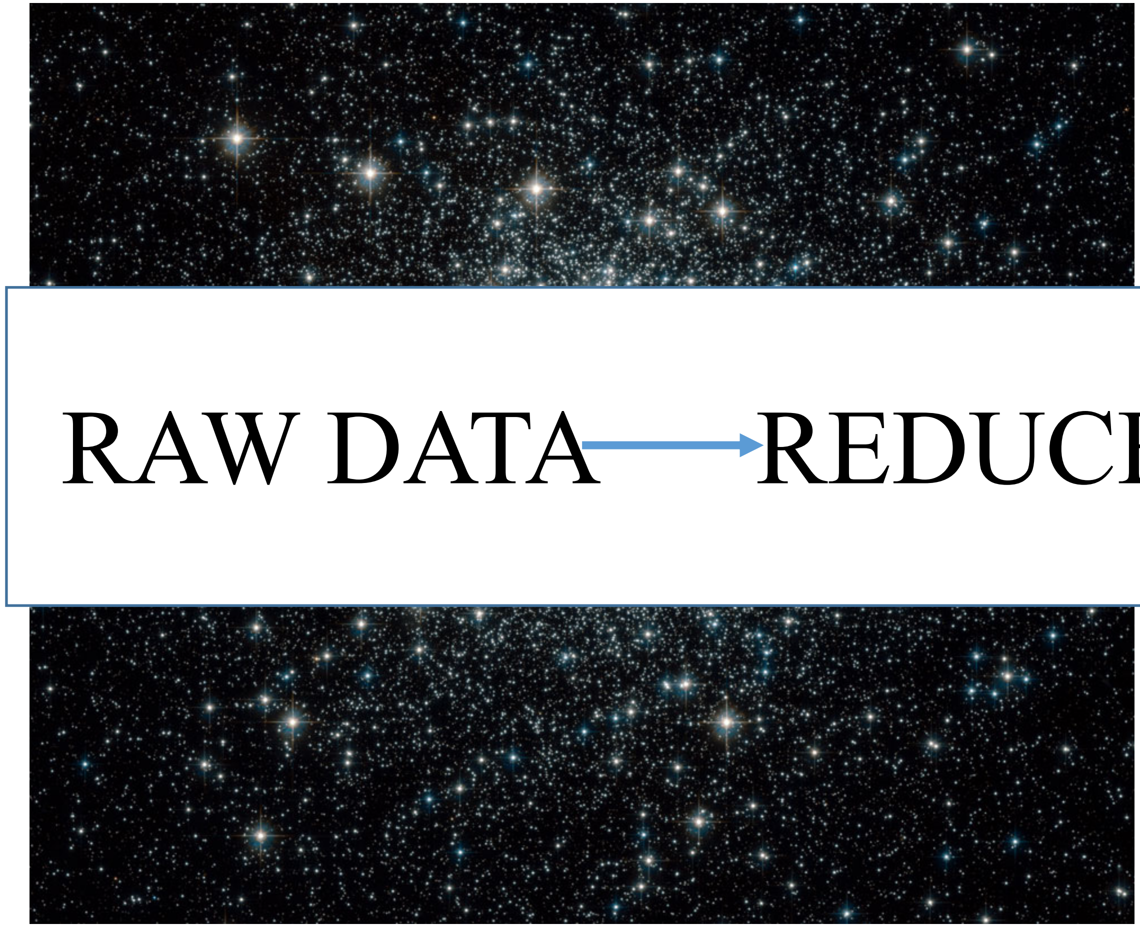


imaging

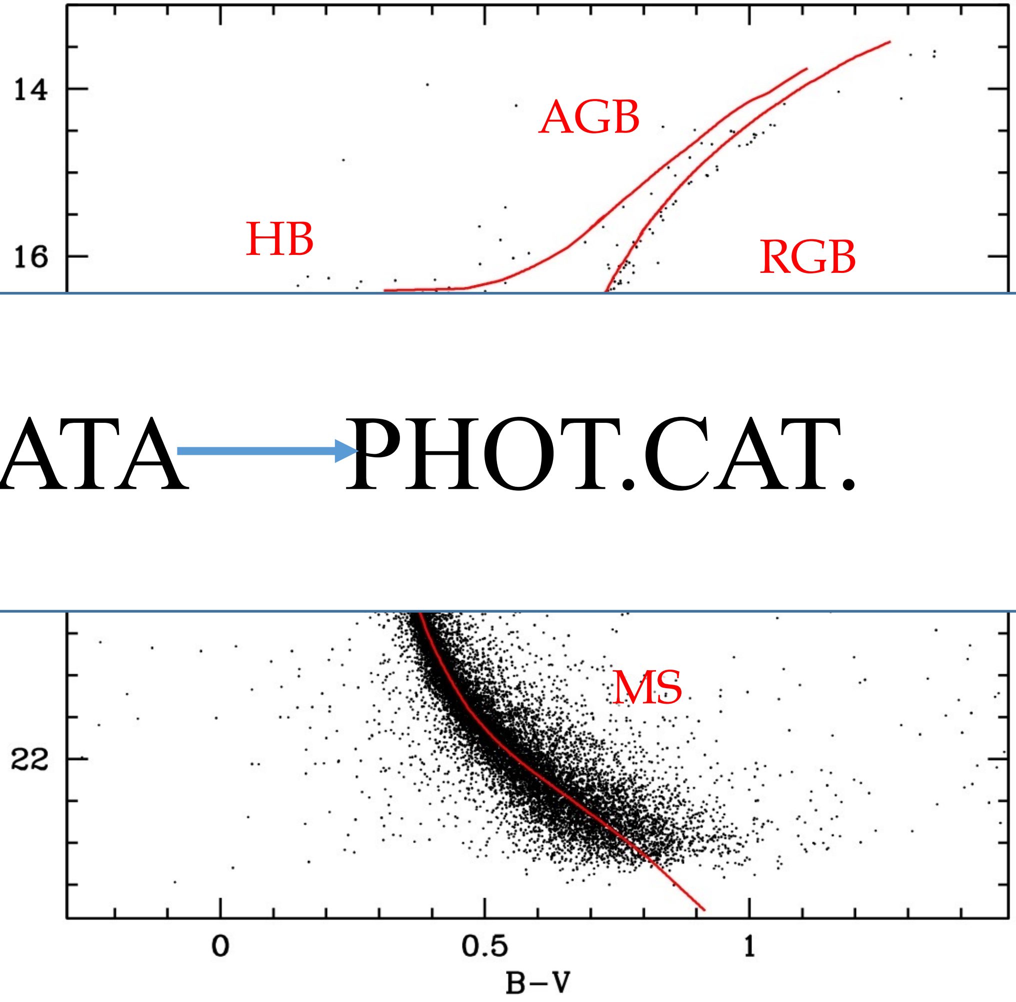
photometry



imaging



photometry



RAW DATA → REDUCED DATA → PHOT.CAT.

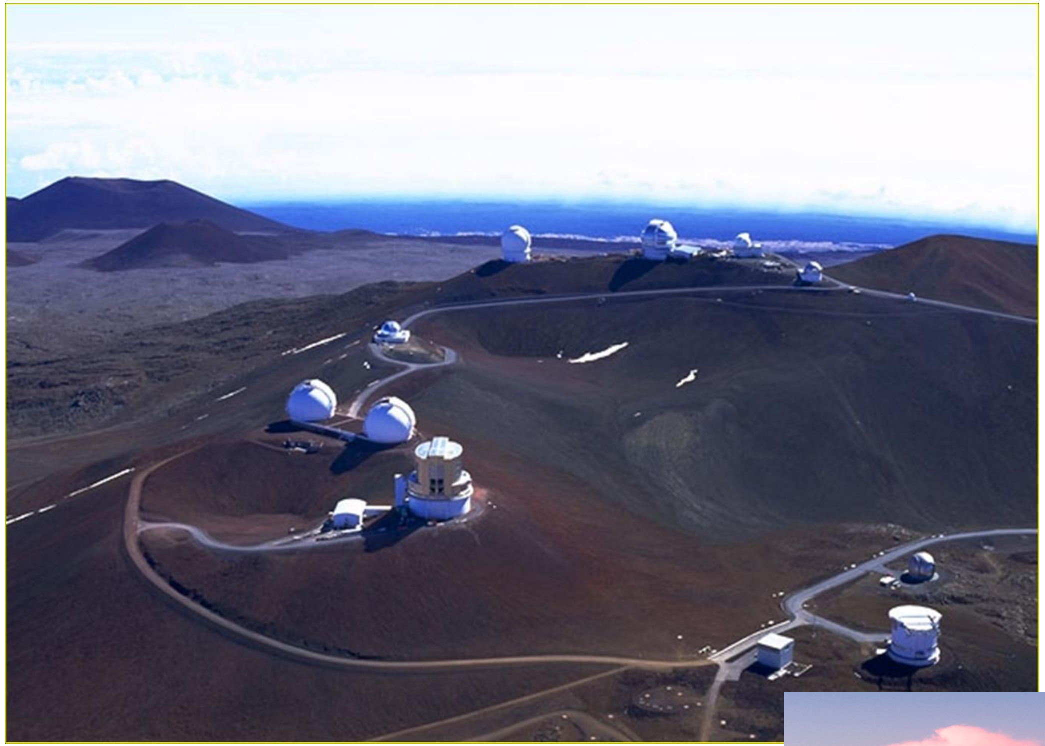
Part 1:

-RAW DATA-

The ingredients:

0. Scientific Idea
1. A telescope
2. An instrument

1. Telescopes



What makes a perfect imaging system in astronomy ?

➢ Maximize the amount of signal collected from the source

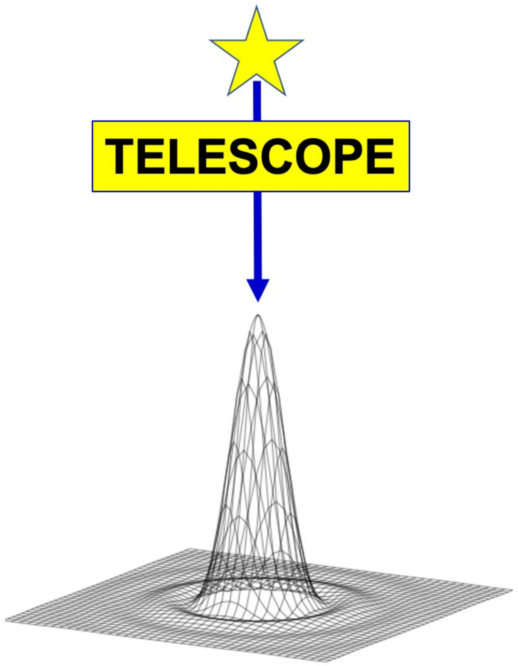
fu

Sy

nt

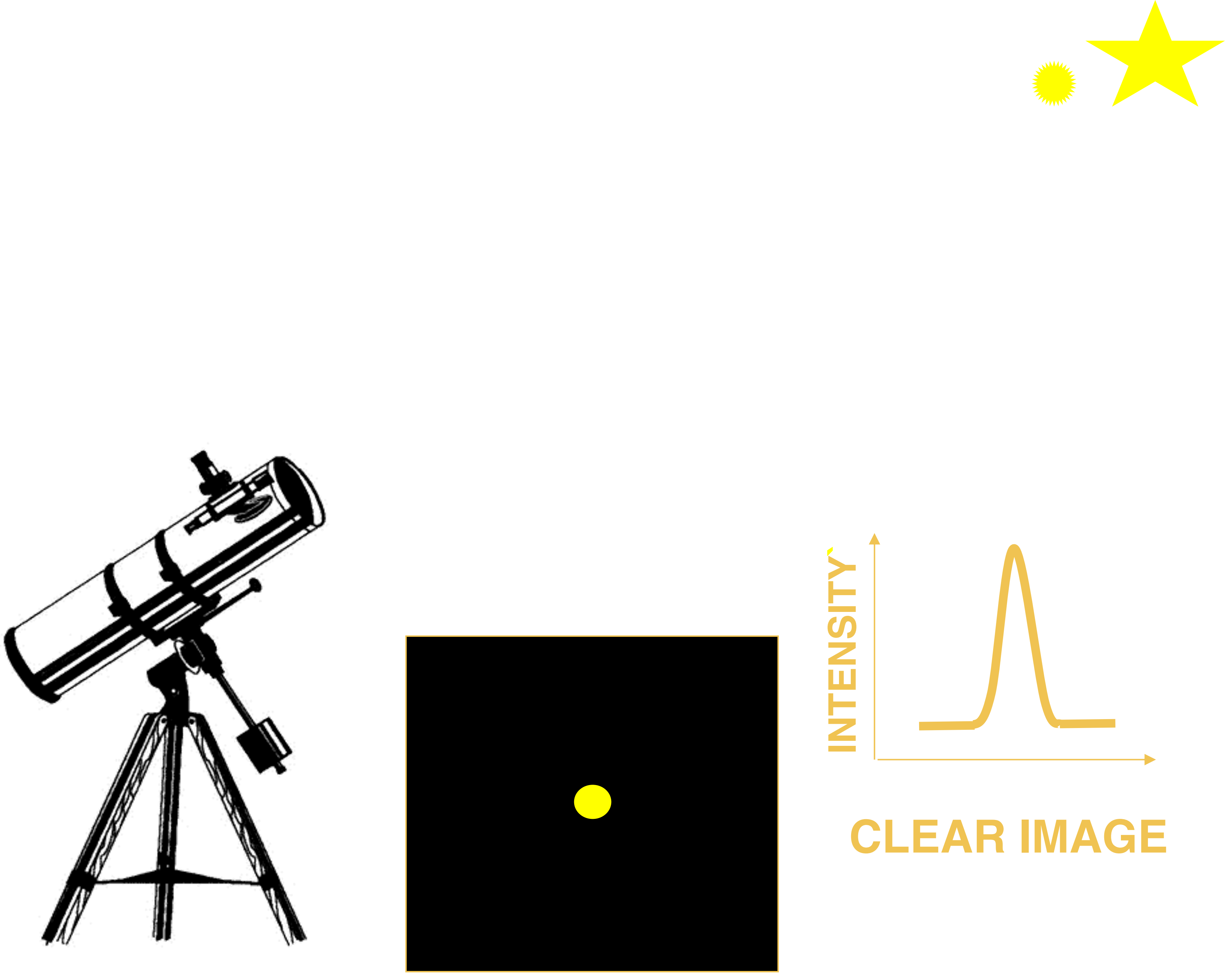
by

or

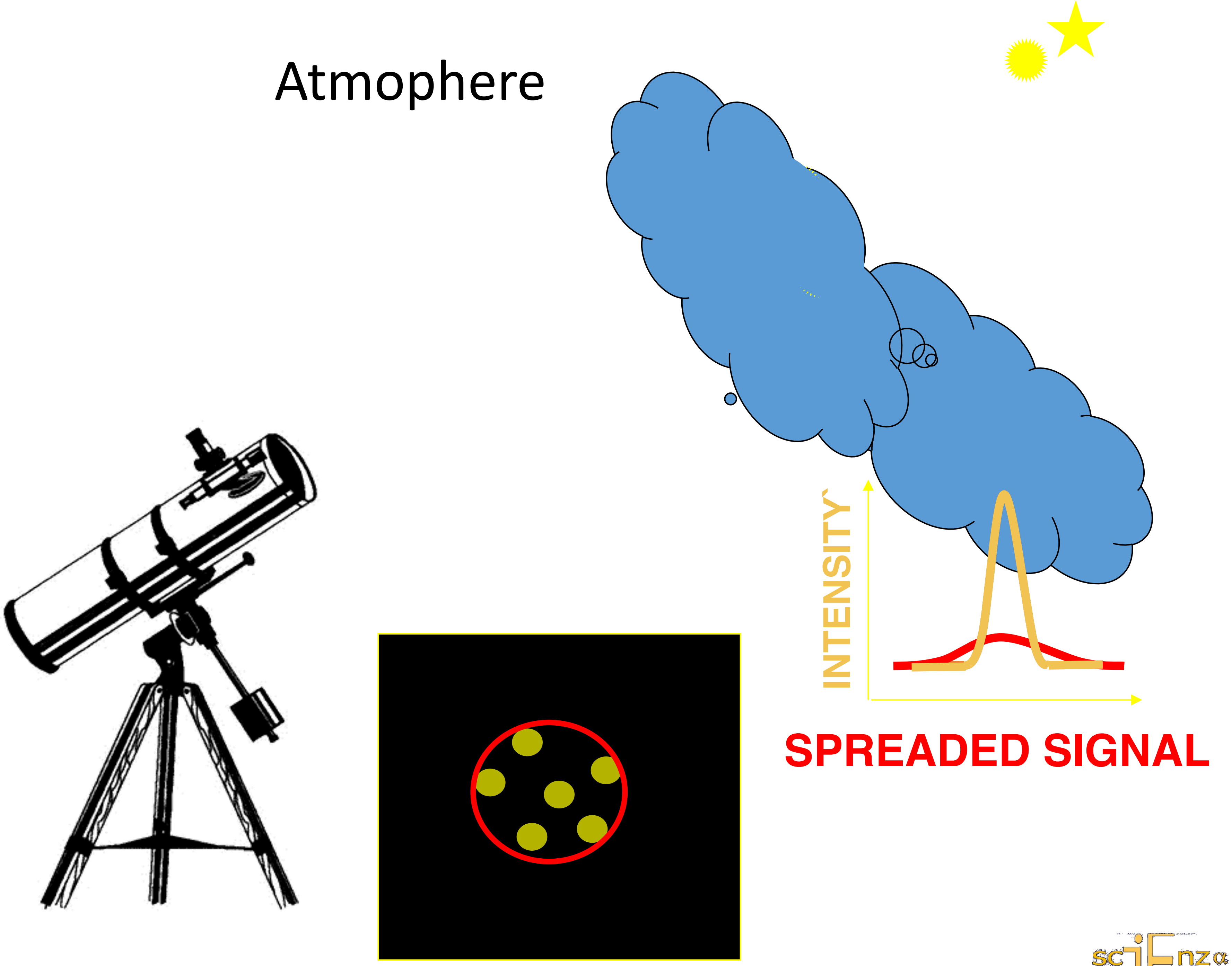


What makes a perfect imaging system in astronomy ?

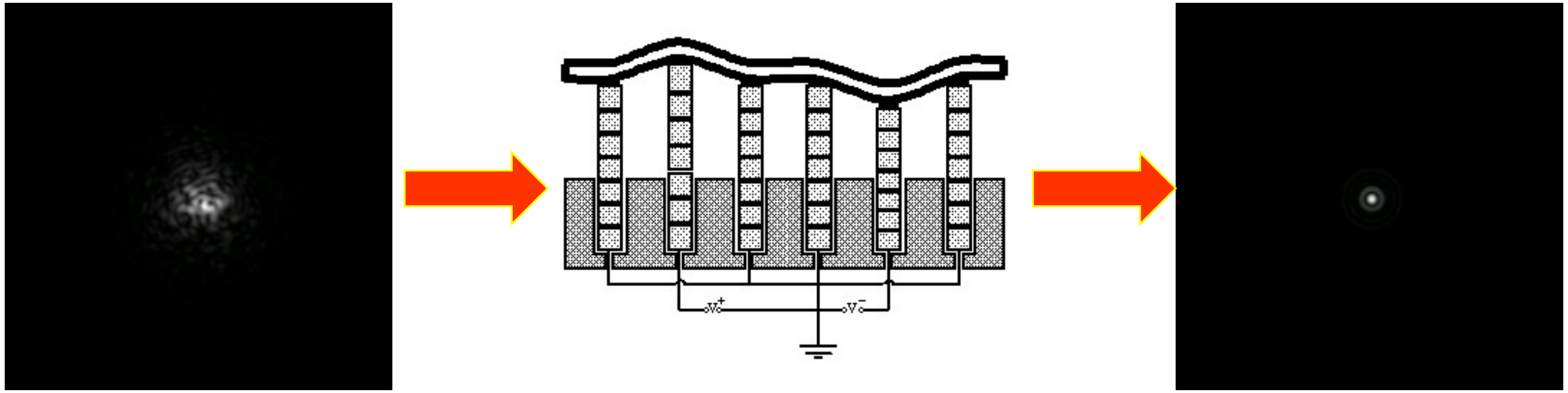
In addition to diffraction, aberrations in the optical system, the Earth’s atmosphere, and scattered light contribute to the PSF.


INTENSITY
CLEAR IMAGE

Atmophere

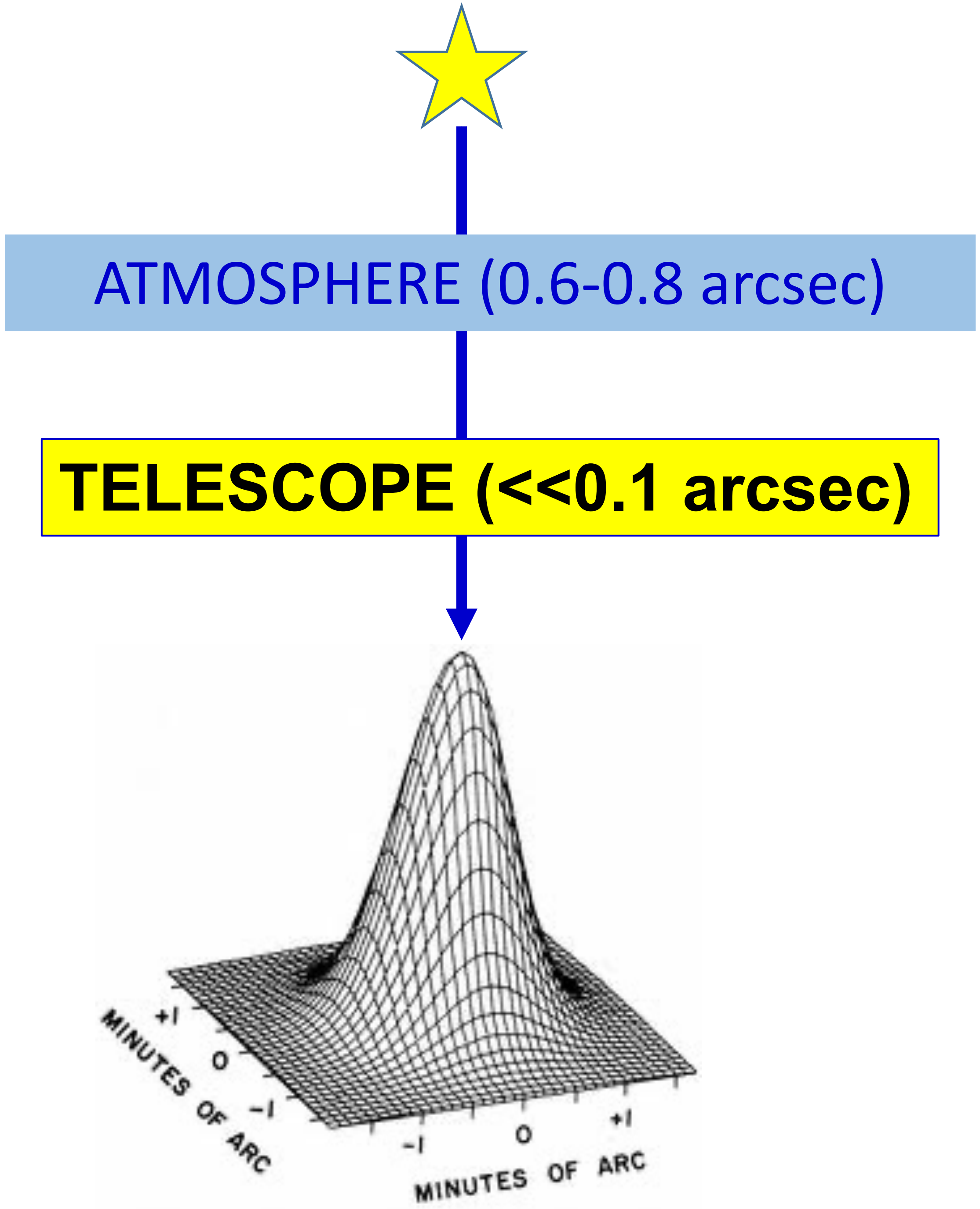


Atmospheric turbolences: Adaptive Optics

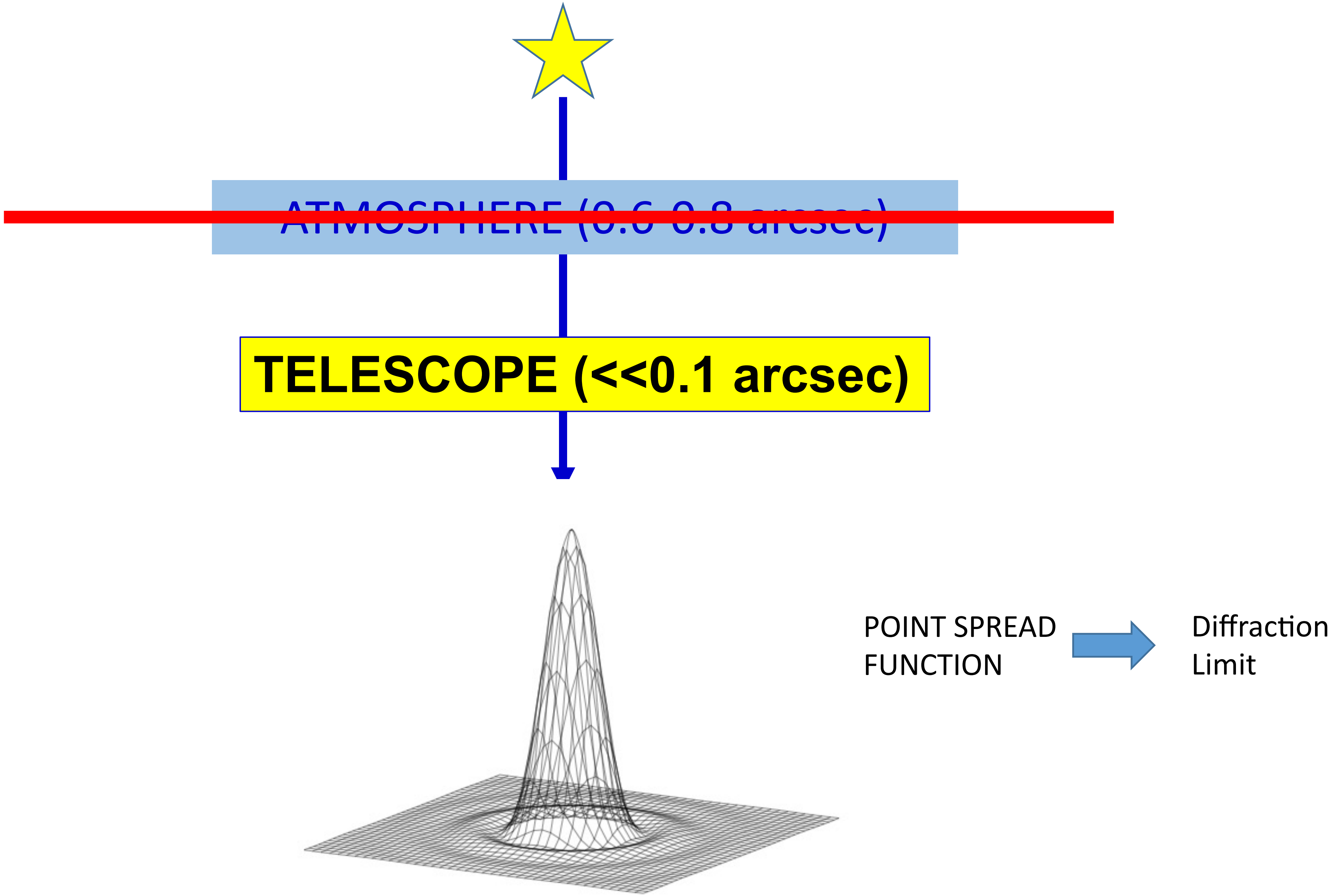


ATMOSPHERE (0.6-0.8 arcsec)

TELESCOPE (<<0.1 arcsec)



POINT
SPREAD
FUNCTION


~~ATMOSPHERE (0.6-0.8 arcsec)~~
TELESCOPE (<<0.1 arcsec)
POINT SPREAD FUNCTION
Diffraction Limit

Omega Centauri

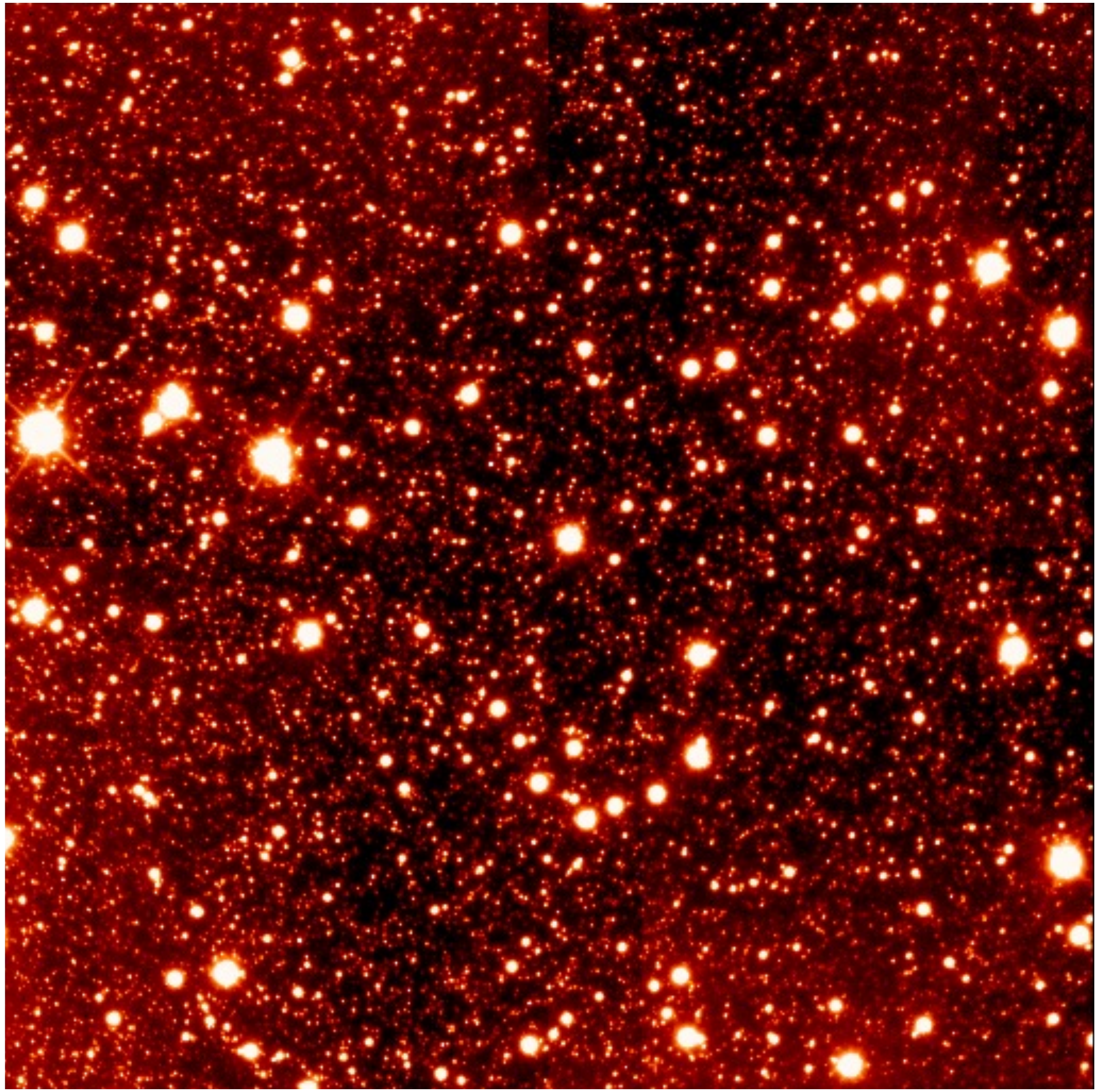
MAD

T_{exp}[Ks]: 600s

FWHM: 100mas

K~20.5

DIMM: 0.69”



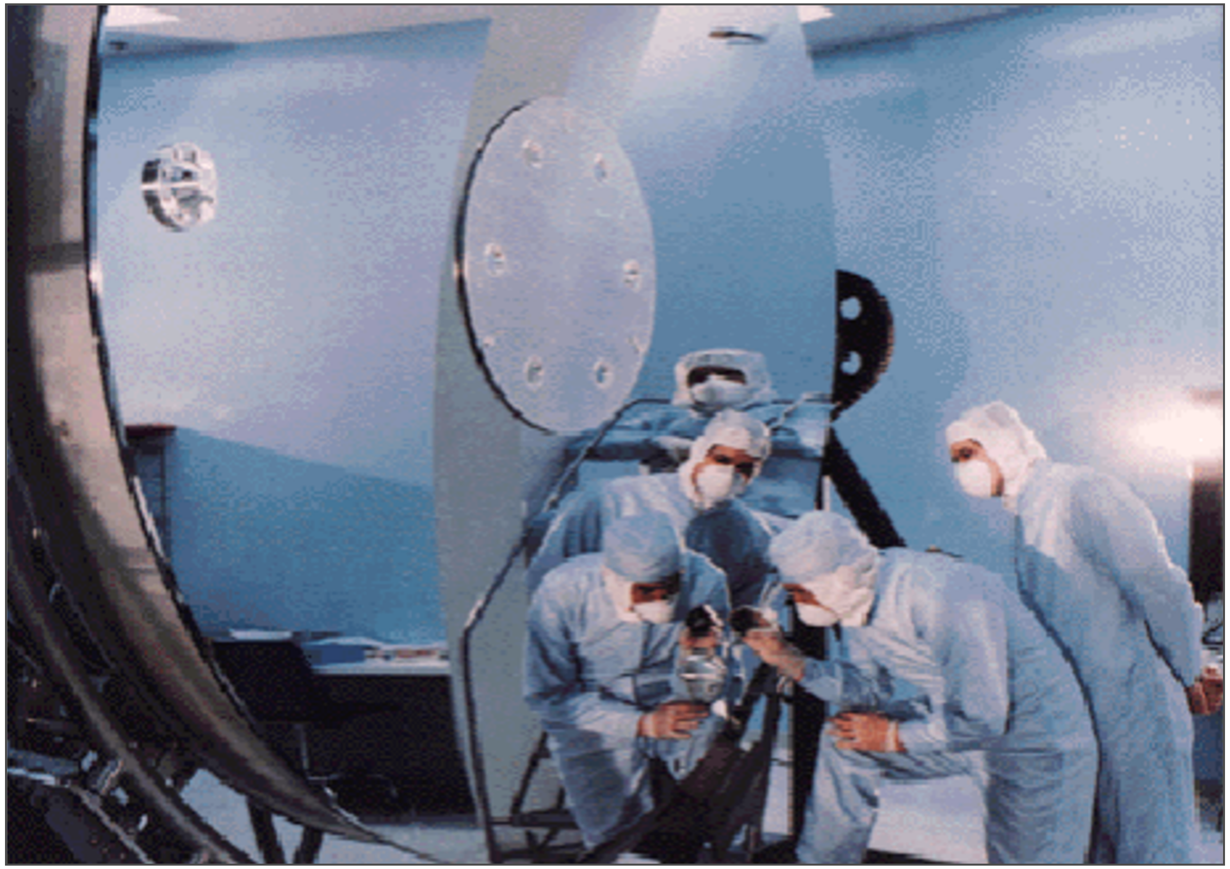
1 arcmin

1990 – Hubble Space Telescope

“Houston, we have a problem...”

WHAT HAPPENED?

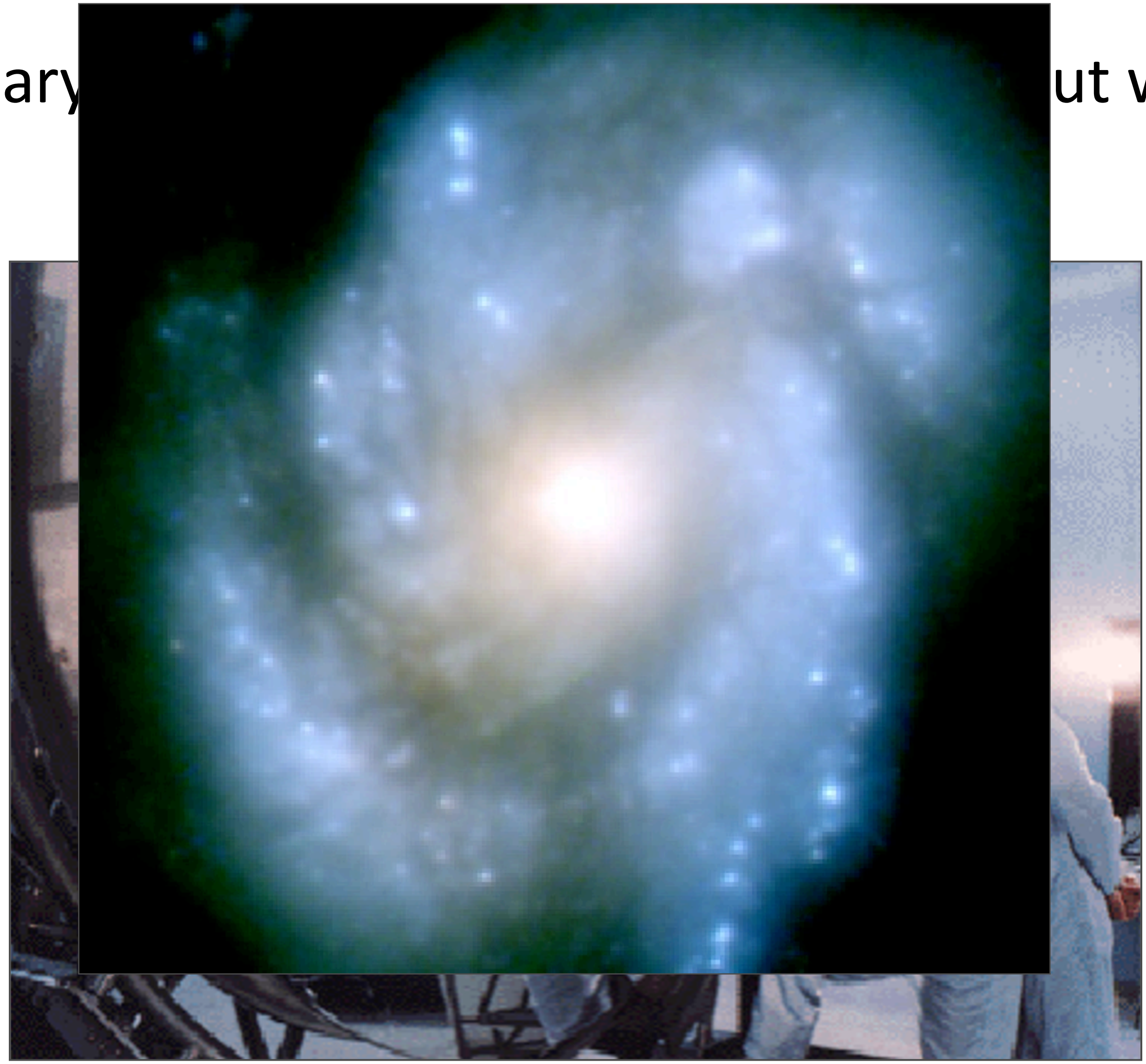
The primary mirror was PERFECTLY polished but was built with WRONG shape!



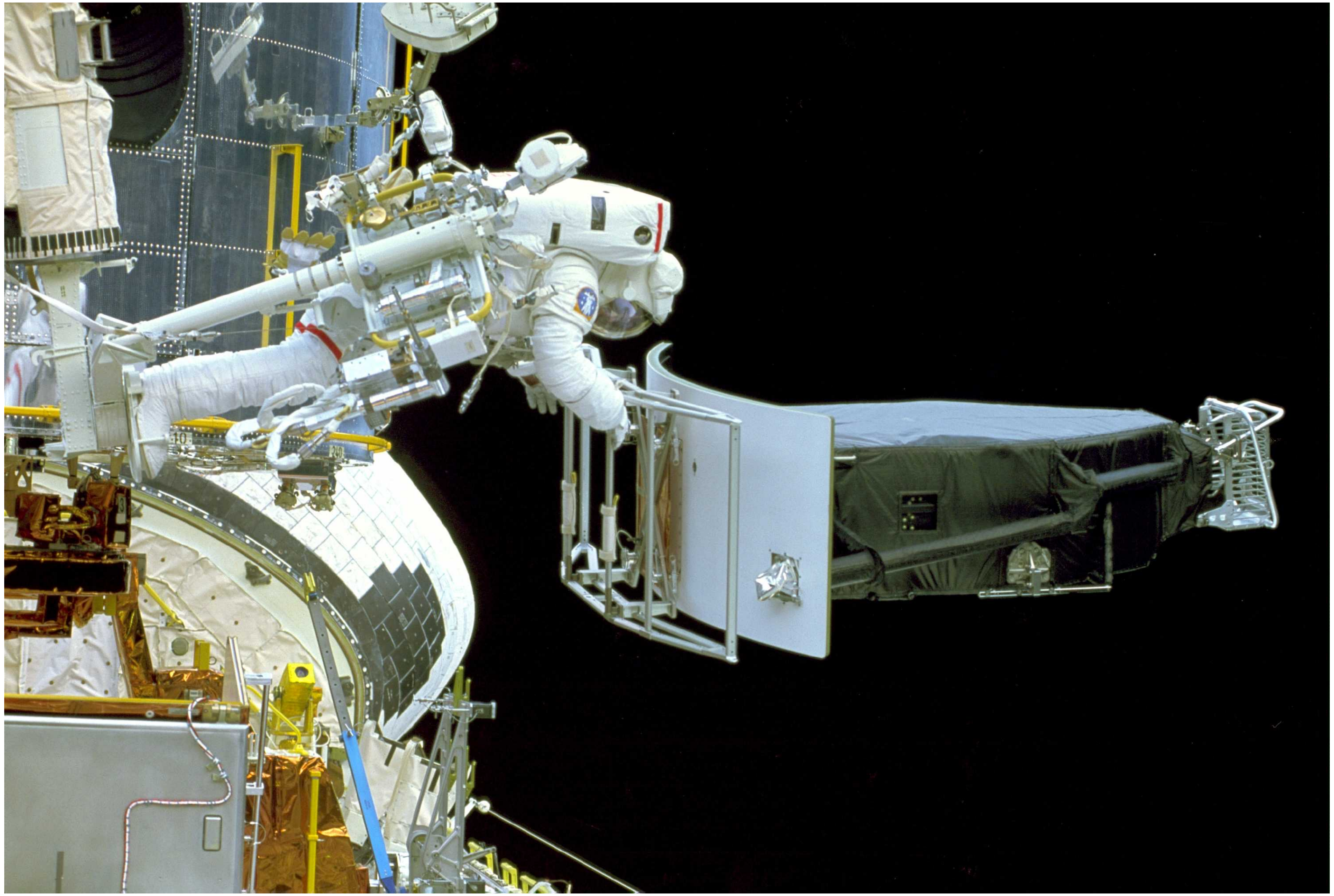
“Houston, we have a problem...”

WHAT HAPPENED?

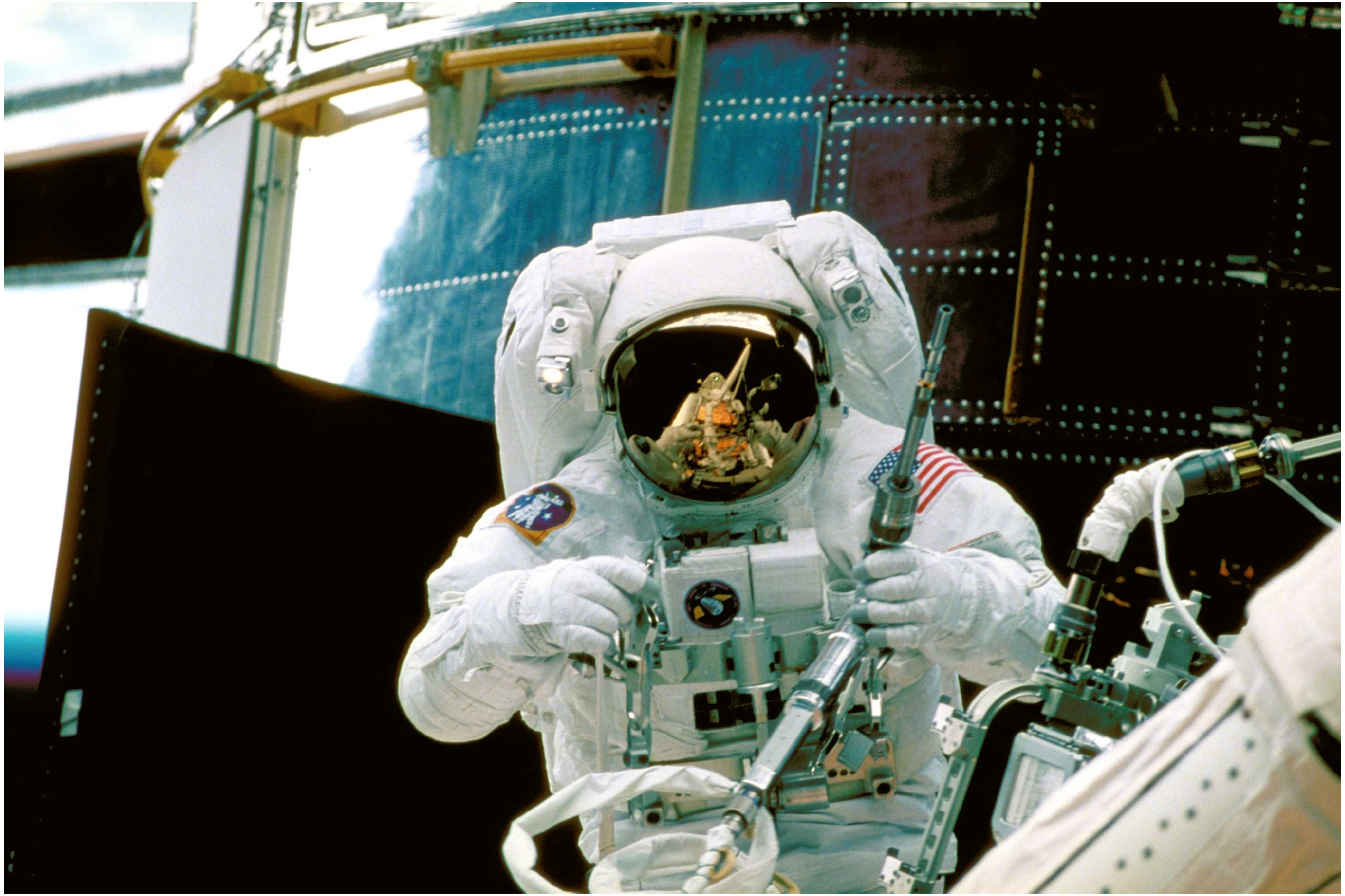
The primary … ut was built



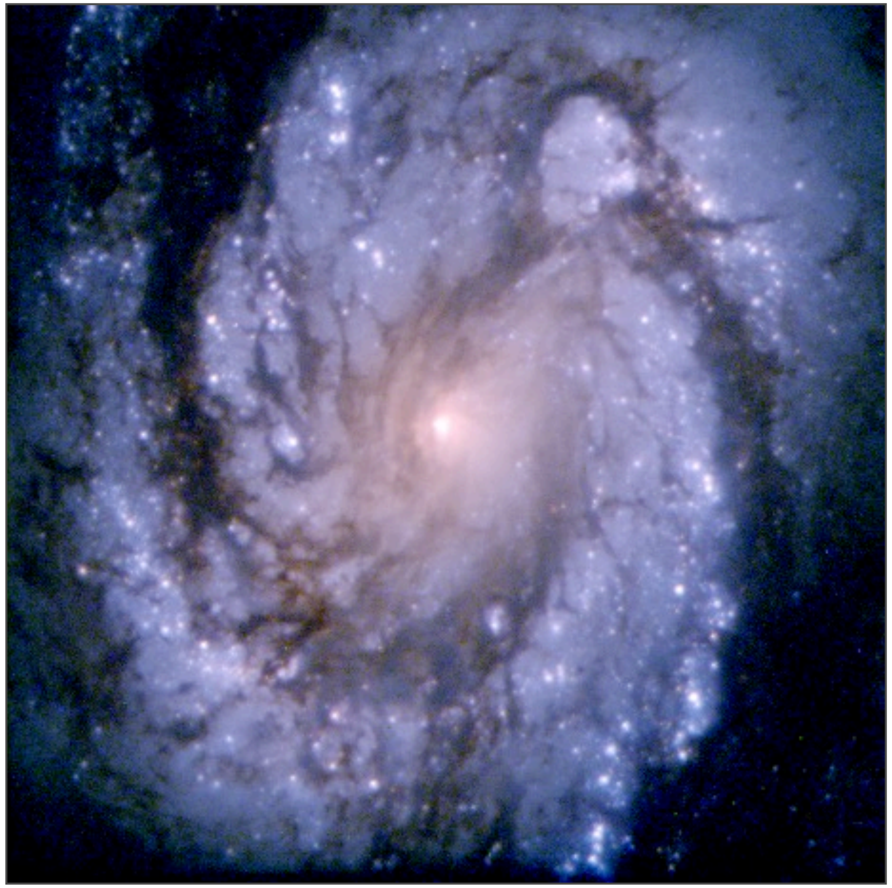
Hubble's servicing mission, December 1993



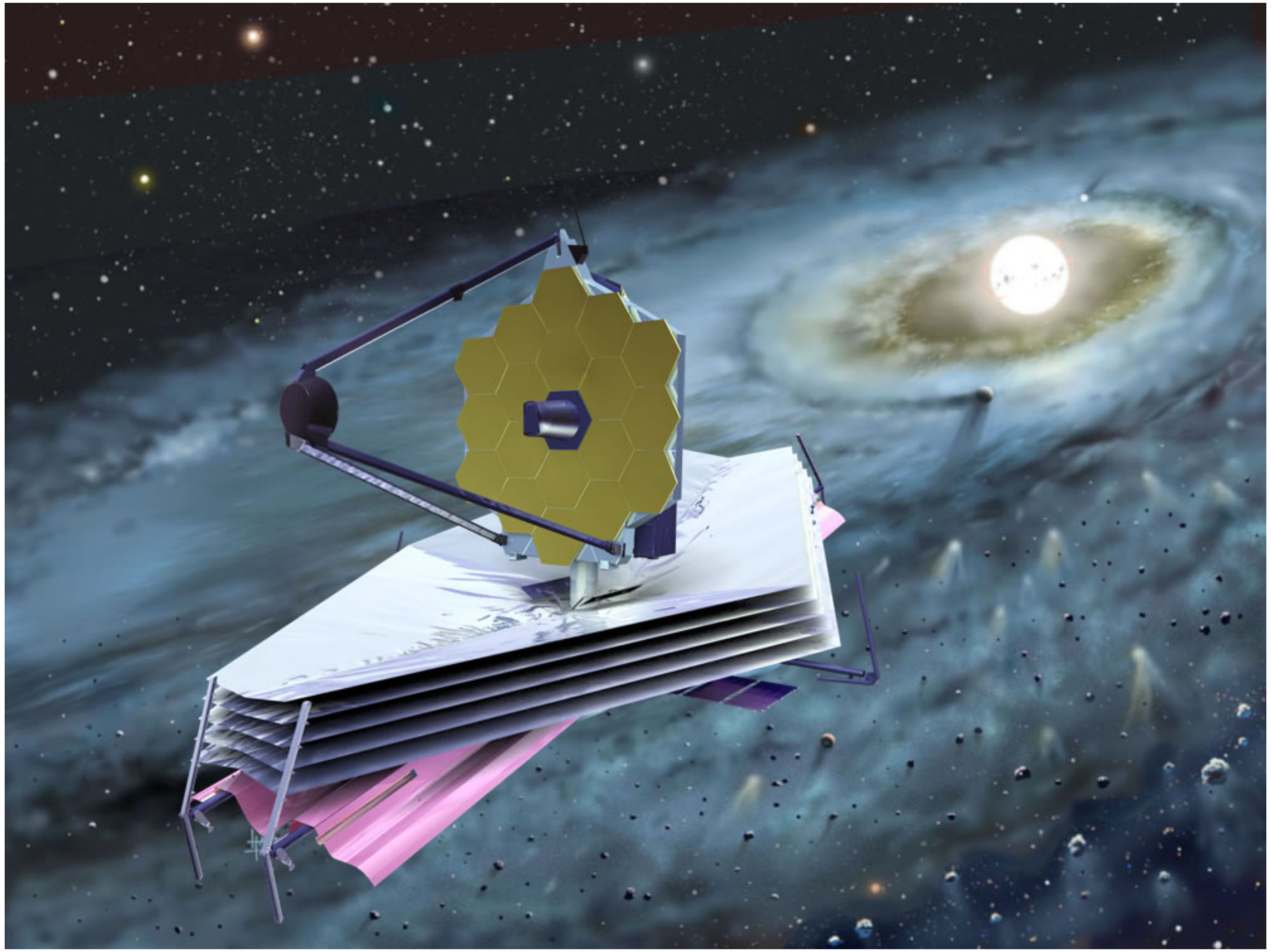
Mechanics in the Space



“The Hubble problems is solved!”



James Webb Space Telescope (JWST)
Launch: 22 December 2021 07:20 EST



James Webb Space Telescope (JWST)
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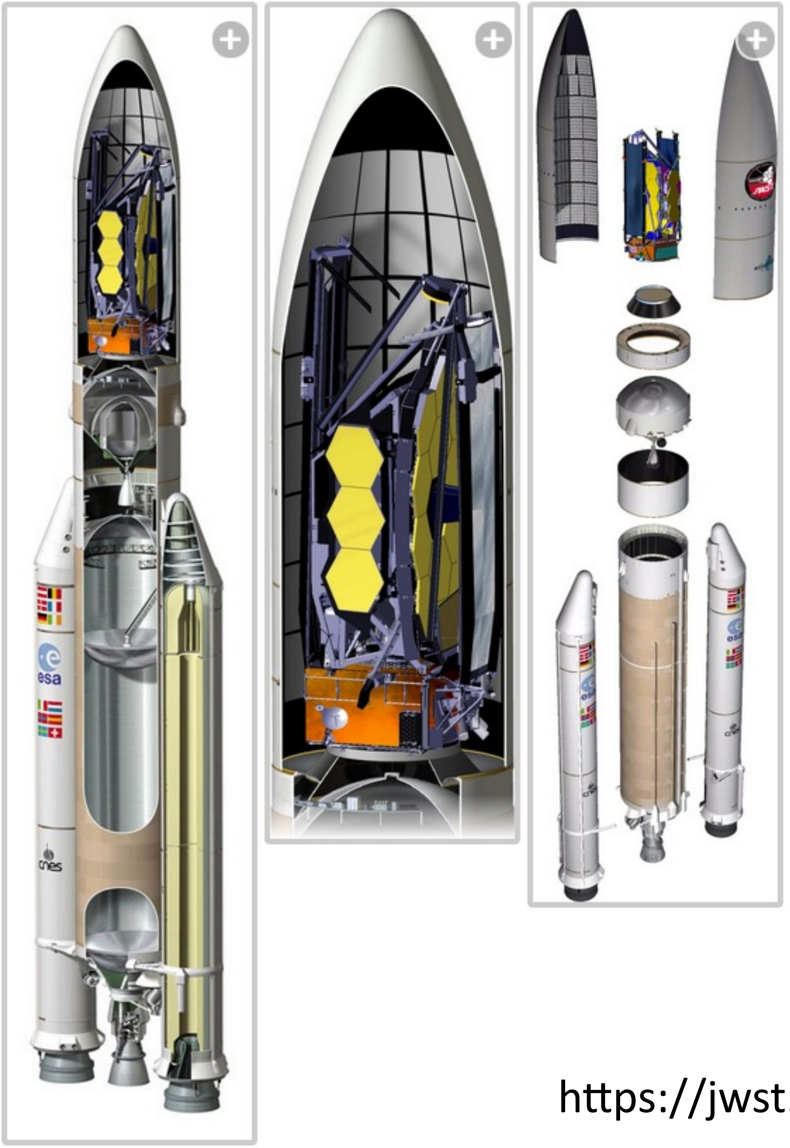
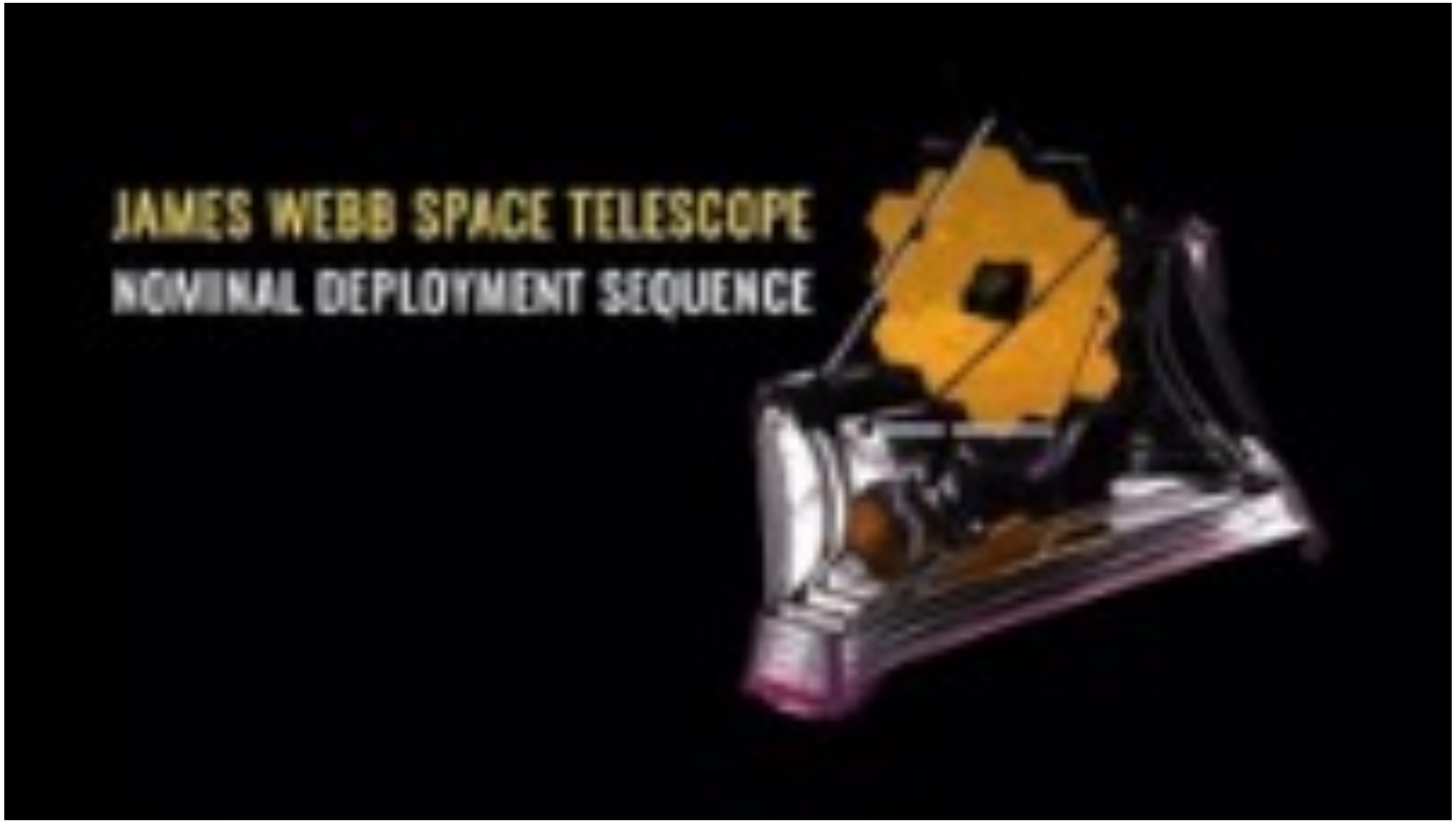
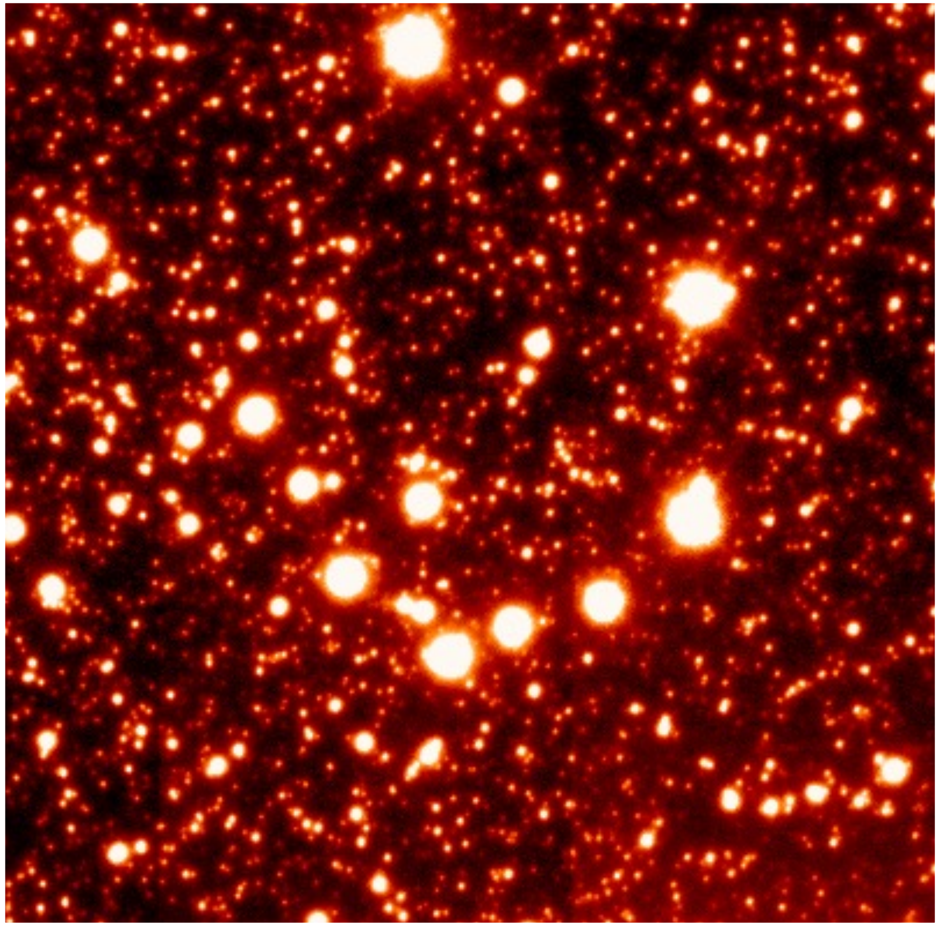


https://jwst.nasa.gov/content/about/launch.html

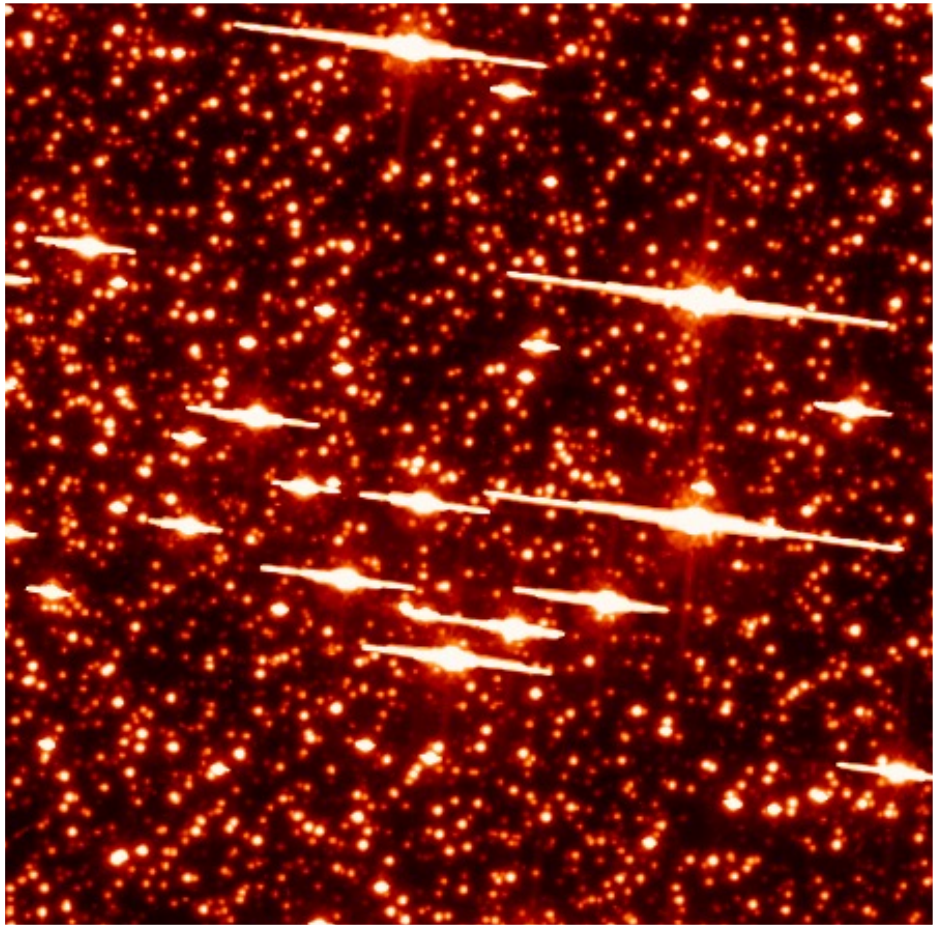
James Webb Space Telescope (JWST)
Launch: 22 December 2021 07:20 EST (13:30 CET)



Credit: NASA's Goddard Space Flight Center
see also https://svs.gsfc.nasa.gov/20339



MAD [Ks] (0.028”/px) DIMM: 0.69”
FWHM: 100mas – T_{exp}: 600s



HST/ACS [F435W] (0.050”/px)
FWHM: 100mas – T_{exp}: 340s

Electromagnetic radiation

Light

Multi-Wavelength

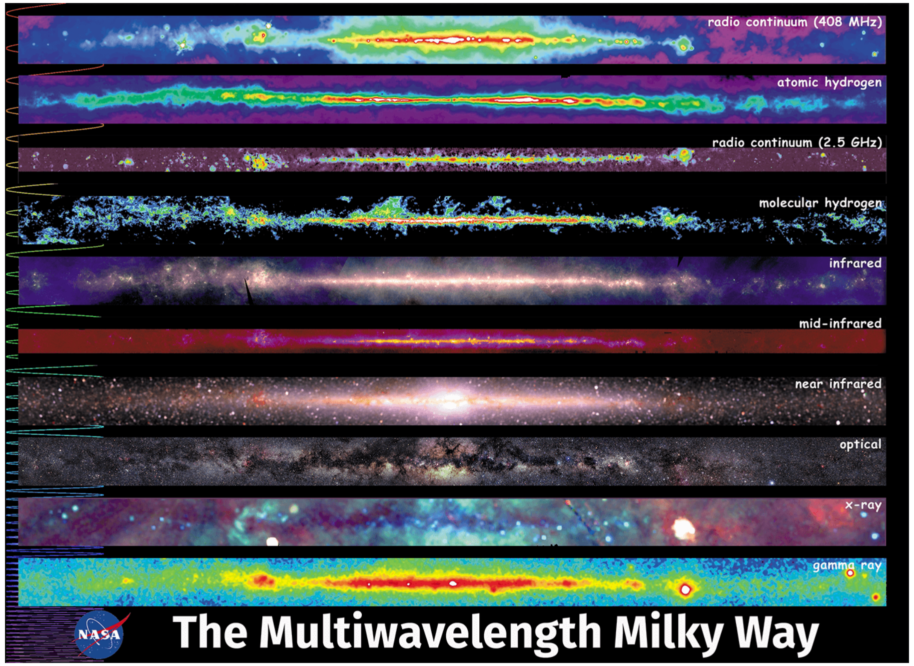
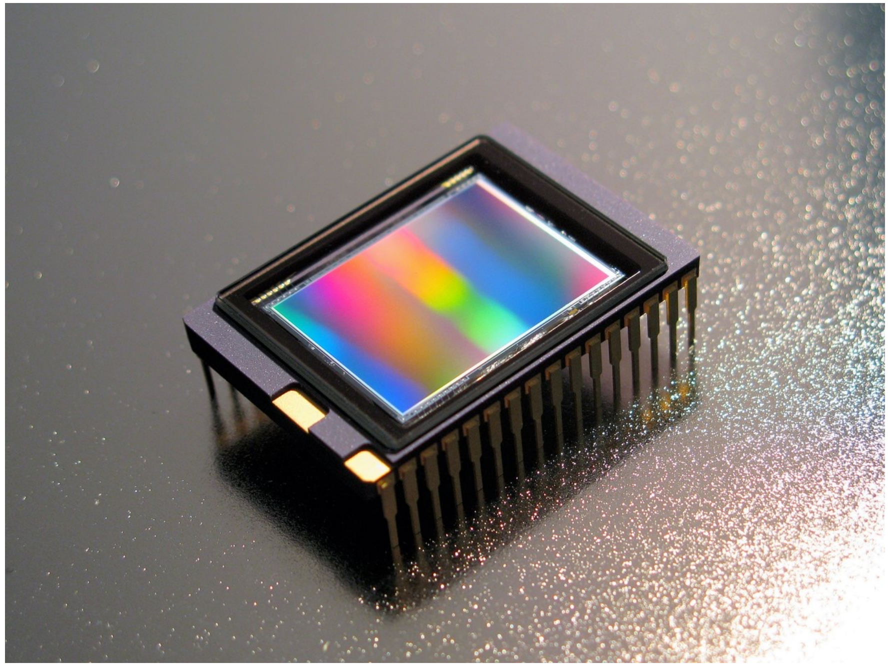


Image Credit: ESA/NASA/Felix Mirabel

Particle

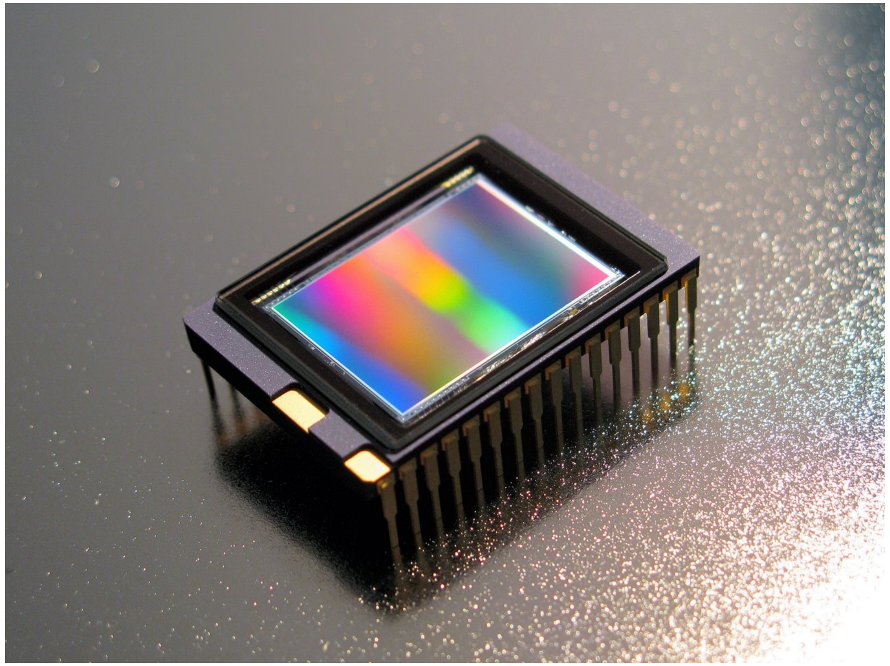


Credit: Moravian Instruments

Electromagnetic radiation

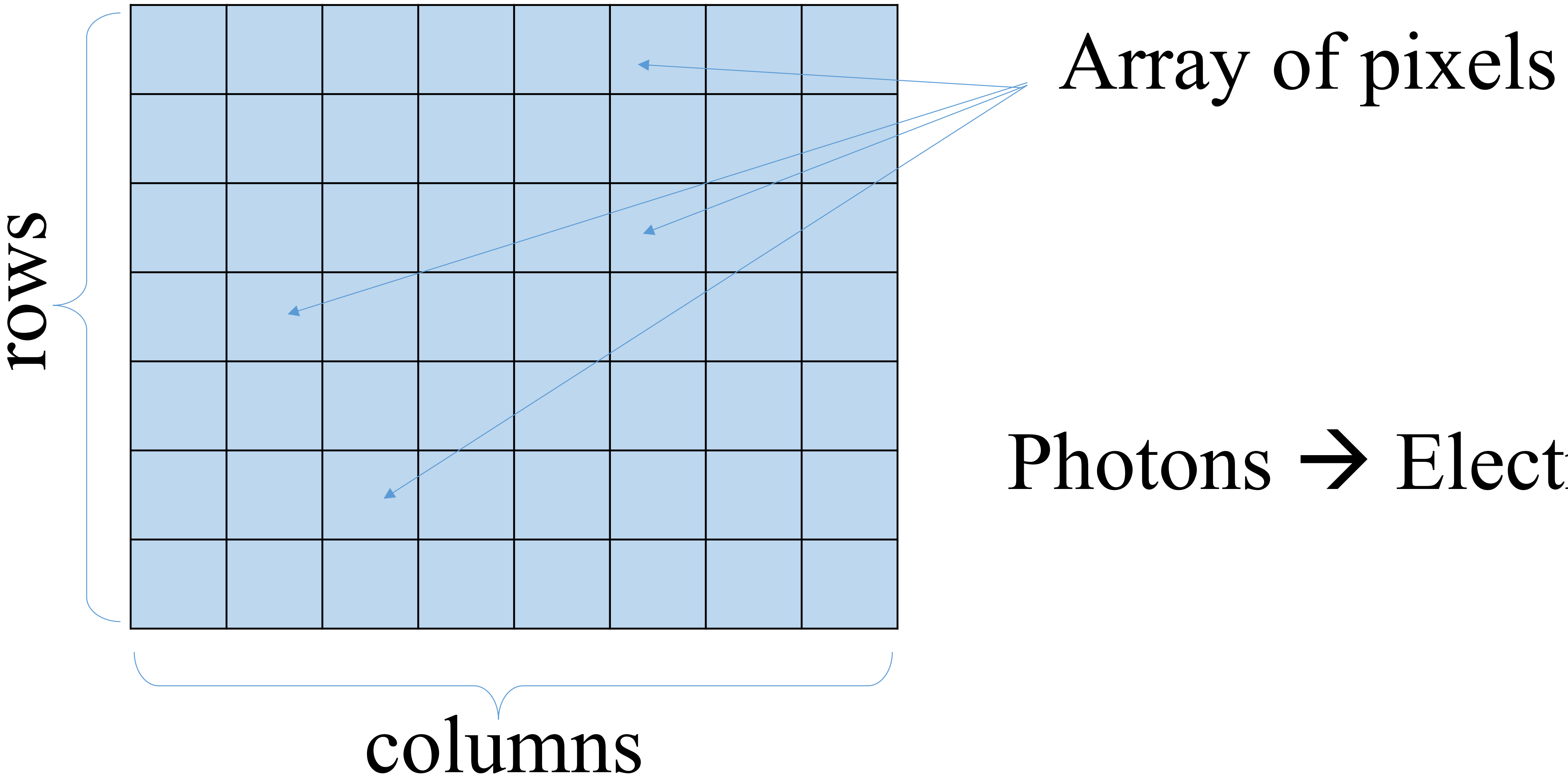
Light

Particle



Credit: Moravian Instruments

Charge Coupled Device (CCD)



Photons → Electrons

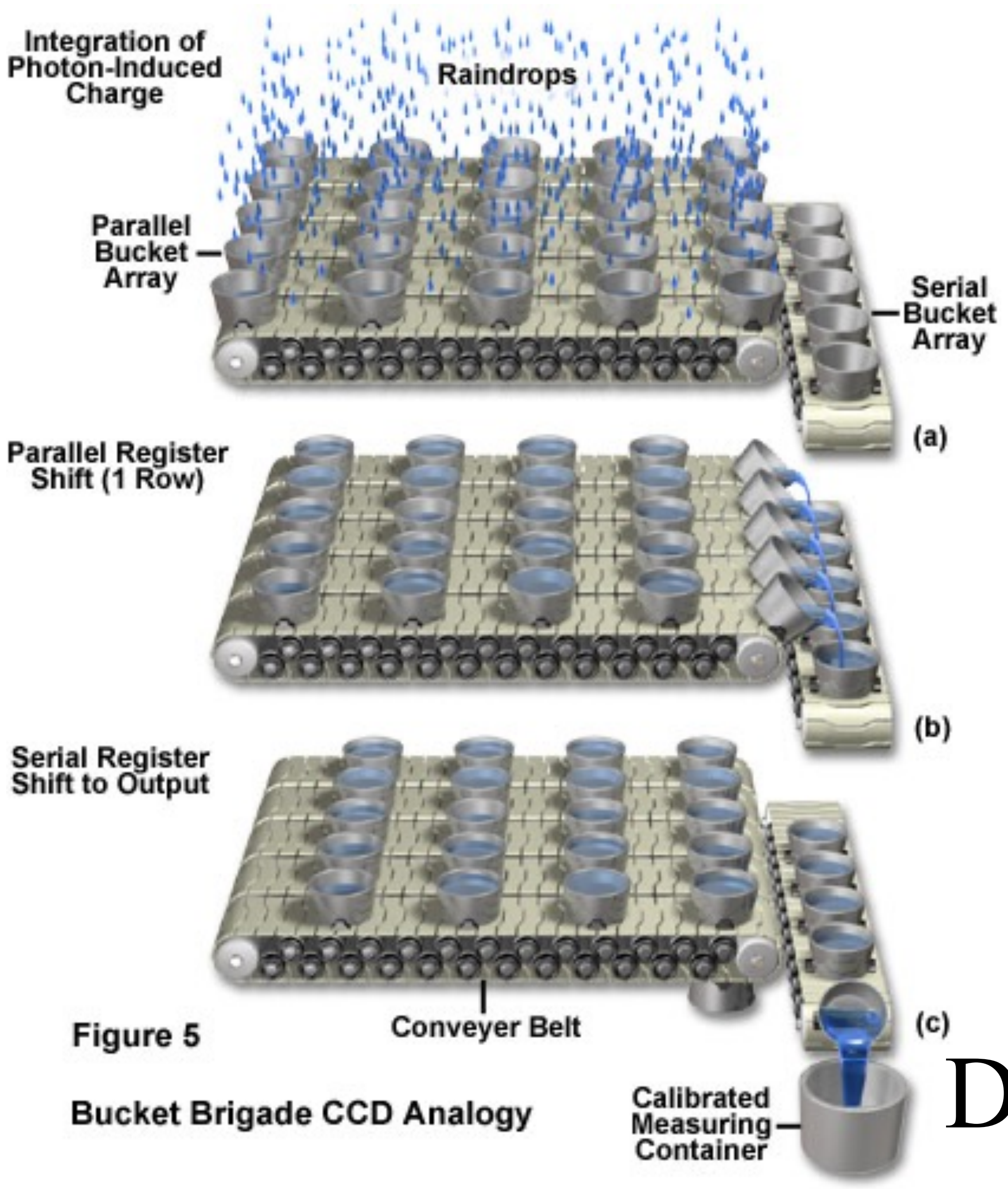


Figure 5

Bucket Brigade CCD Analogy

Array of pixels
The Buckets

Rain Drops = Photons

Buckets = Pixels

Water = Charge

Saturation = Max. capac.

Dynamic range = tot. capac.

The most striking characteristic of CCD is the fact that the digital counts LINEARLY INCREASES with the exposure CCDs are LINEAR

		2		
	2	5	2	
		2		

$T_{exp} = 1$ sec

The most striking characteristic of CCD is the fact that the digital counts LINEARLY INCREASES with the exposure CCDs are LINEAR

		20		
	20	50	20	
		20		

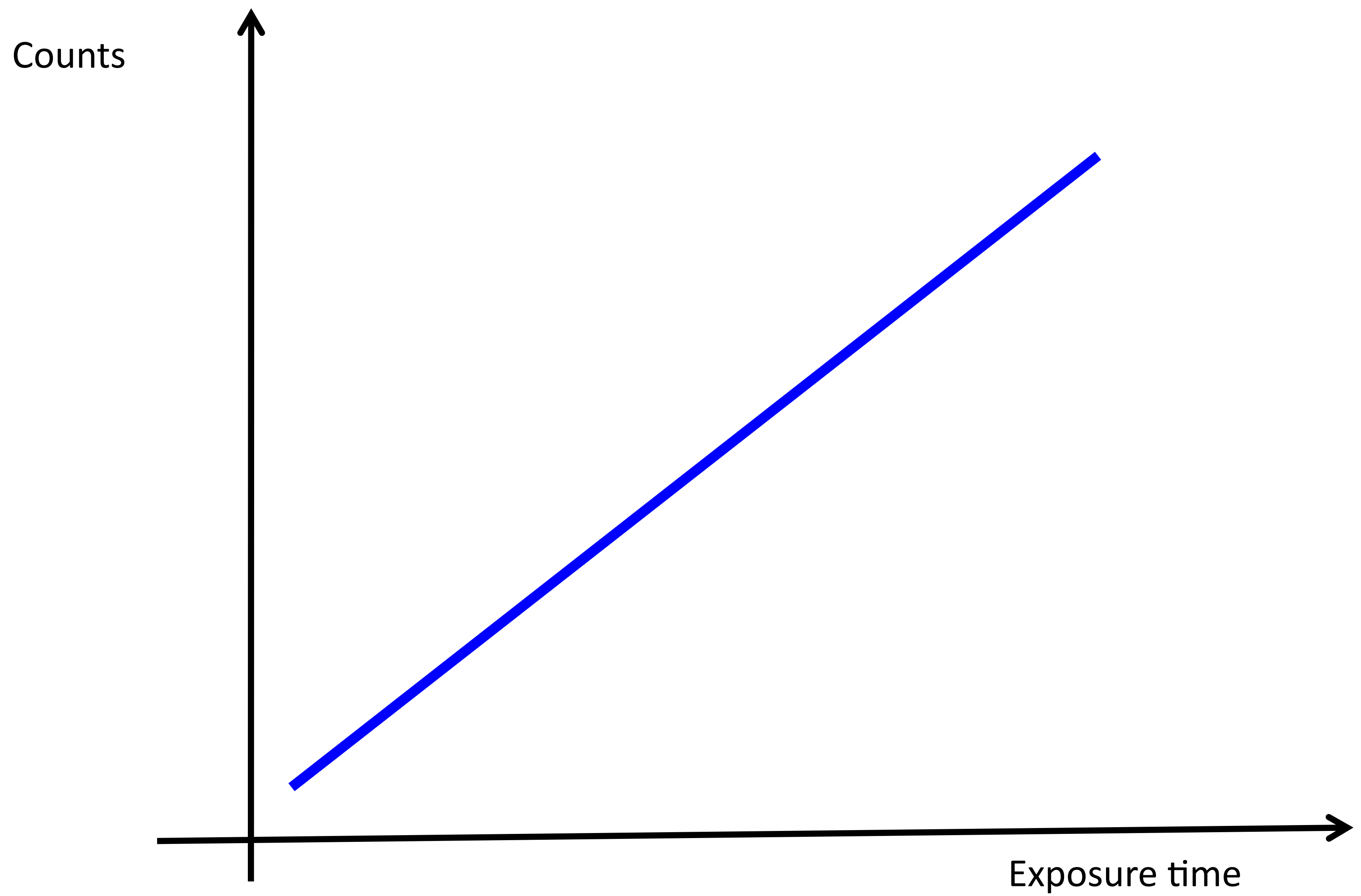
T_{exp}= 10 sec

The most striking characteristic of CCD is the fact that the digital counts LINEARLY INCREASES with the exposure CCDs are LINEAR

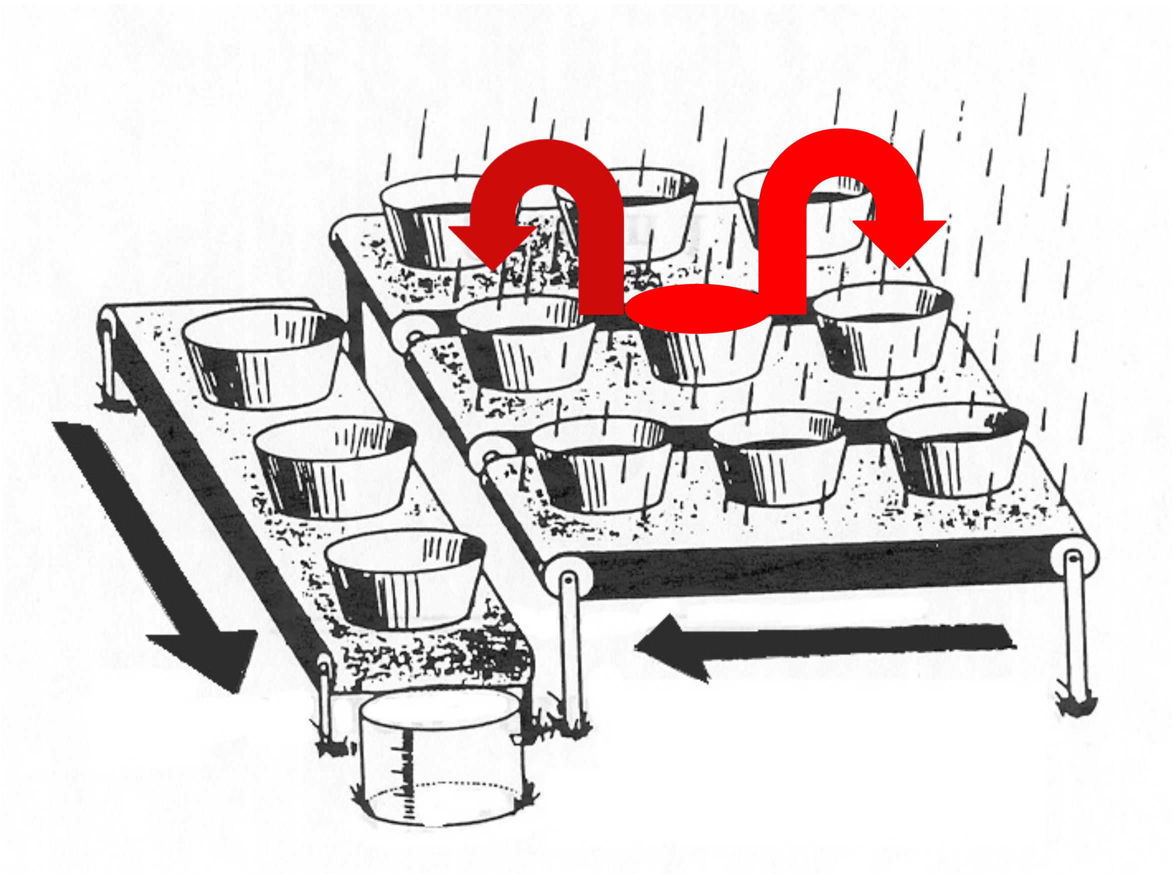
		200		
	200	500	200	
		200		

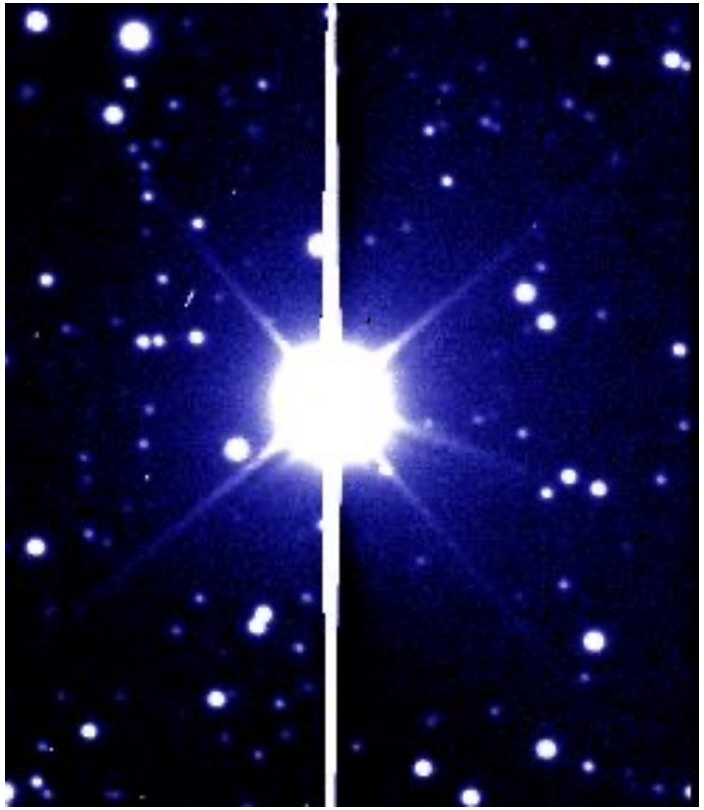
$T_{exp} = 100$ sec

CCD ARE (almost everywhere) LINEAR: digital counts increase linearly with exposure time

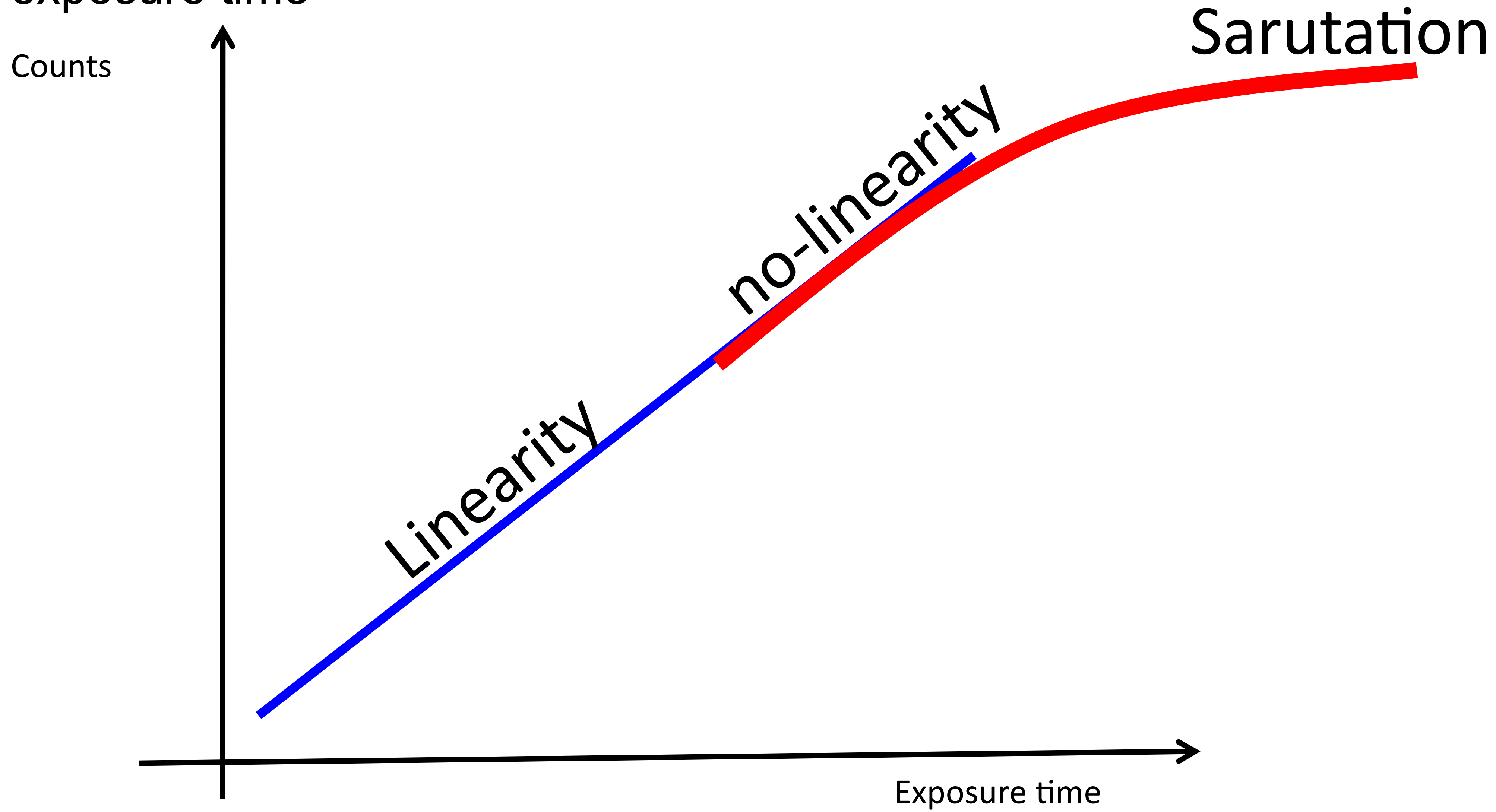


SATURATION: each pixel has a fixed capacity of accumating electric charge. When the electric well is filled the charge start to overflow into adjacent pixels producing the so-called BLOOMING effect.





CCD ARE (almost everywhere) LINEAR: digital counts increase linearly with exposure time



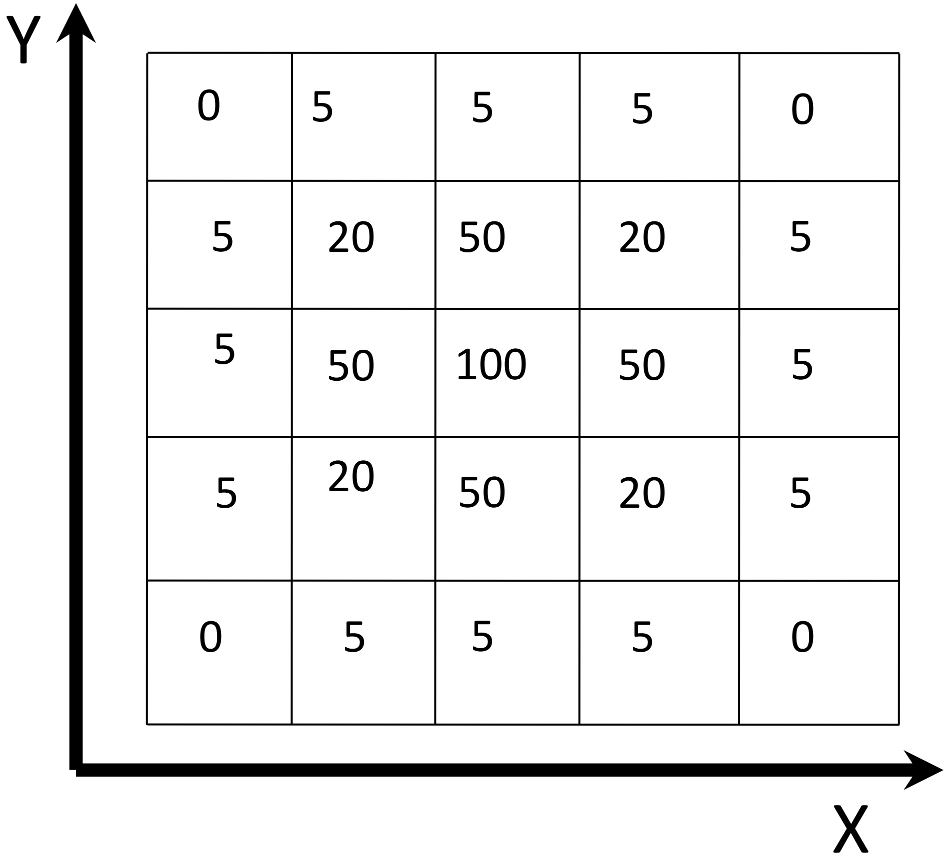
2D Image…or more?

Y

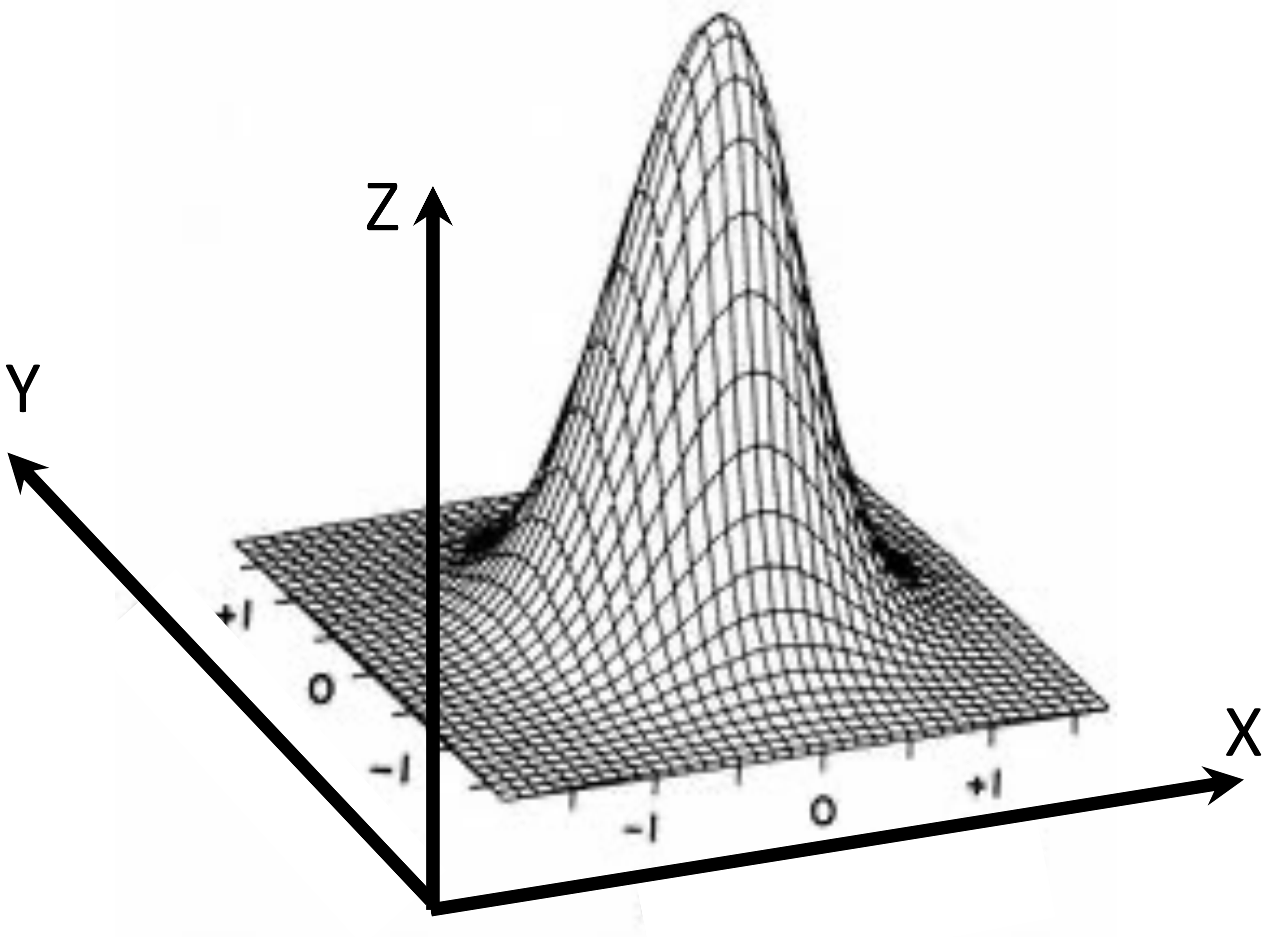
0	5	5	5	0
5	20	50	20	5
5	50	100	50	5
5	20	50	20	5
0	5	5	5	0

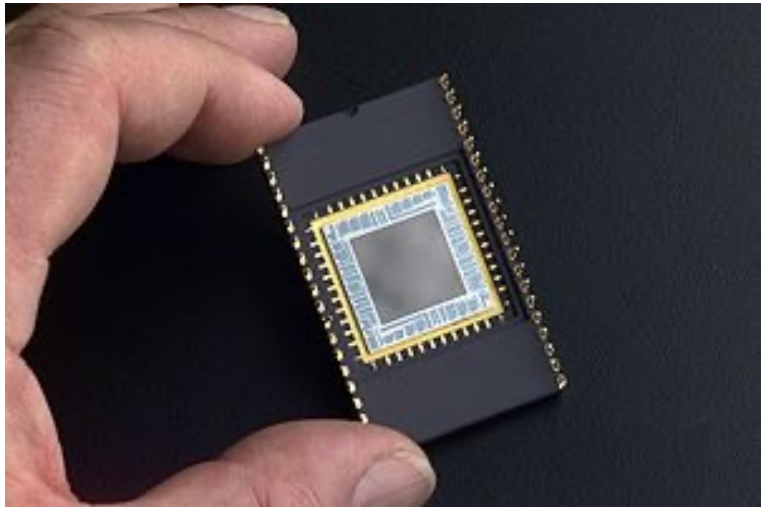
X

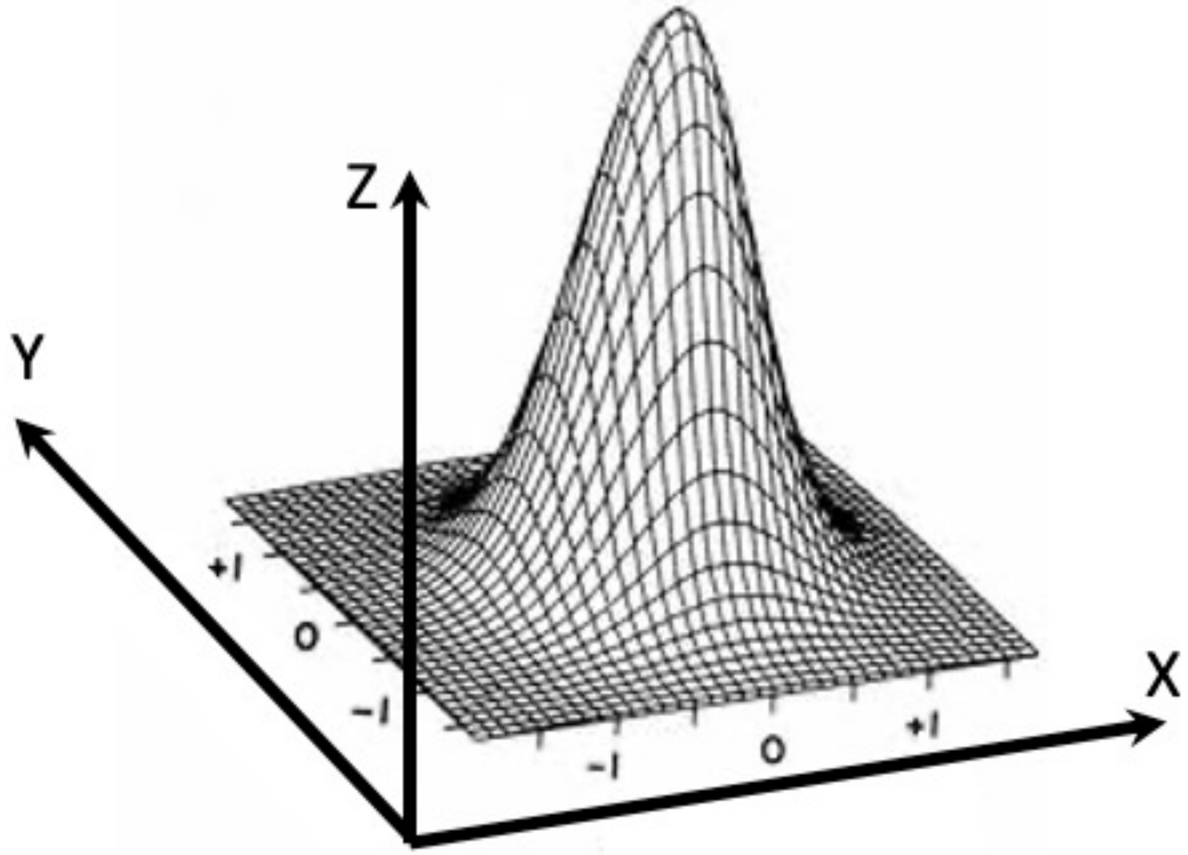
3D Image (FITS Format)



0	5	5	5	0
5	20	50	20	5
5	50	100	50	5
5	20	50	20	5
0	5	5	5	0



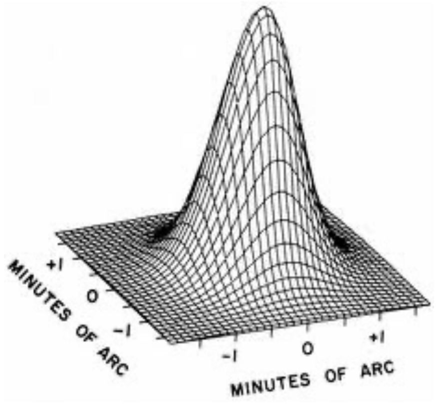




The luminosity (magnitude) of a star is obtained by simply counting all the digital counts under the PSF

0	5	5	5	0
5	20	50	20	5
5	50	100	50	5
5	20	50	20	5
0	5	5	5	0

= 440 counts



Electromagnetic radiation

Light

Multi-Wavelength

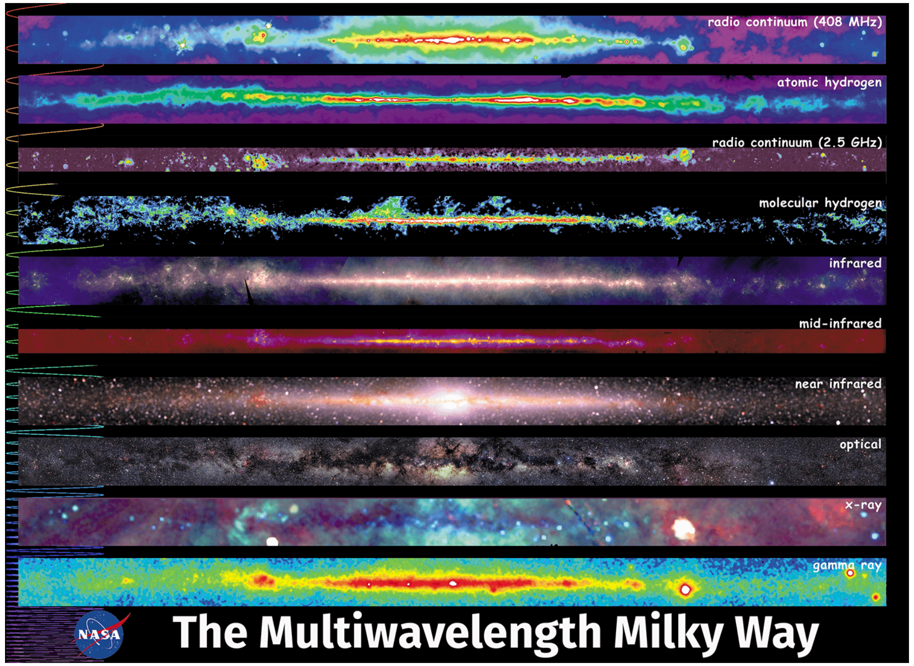
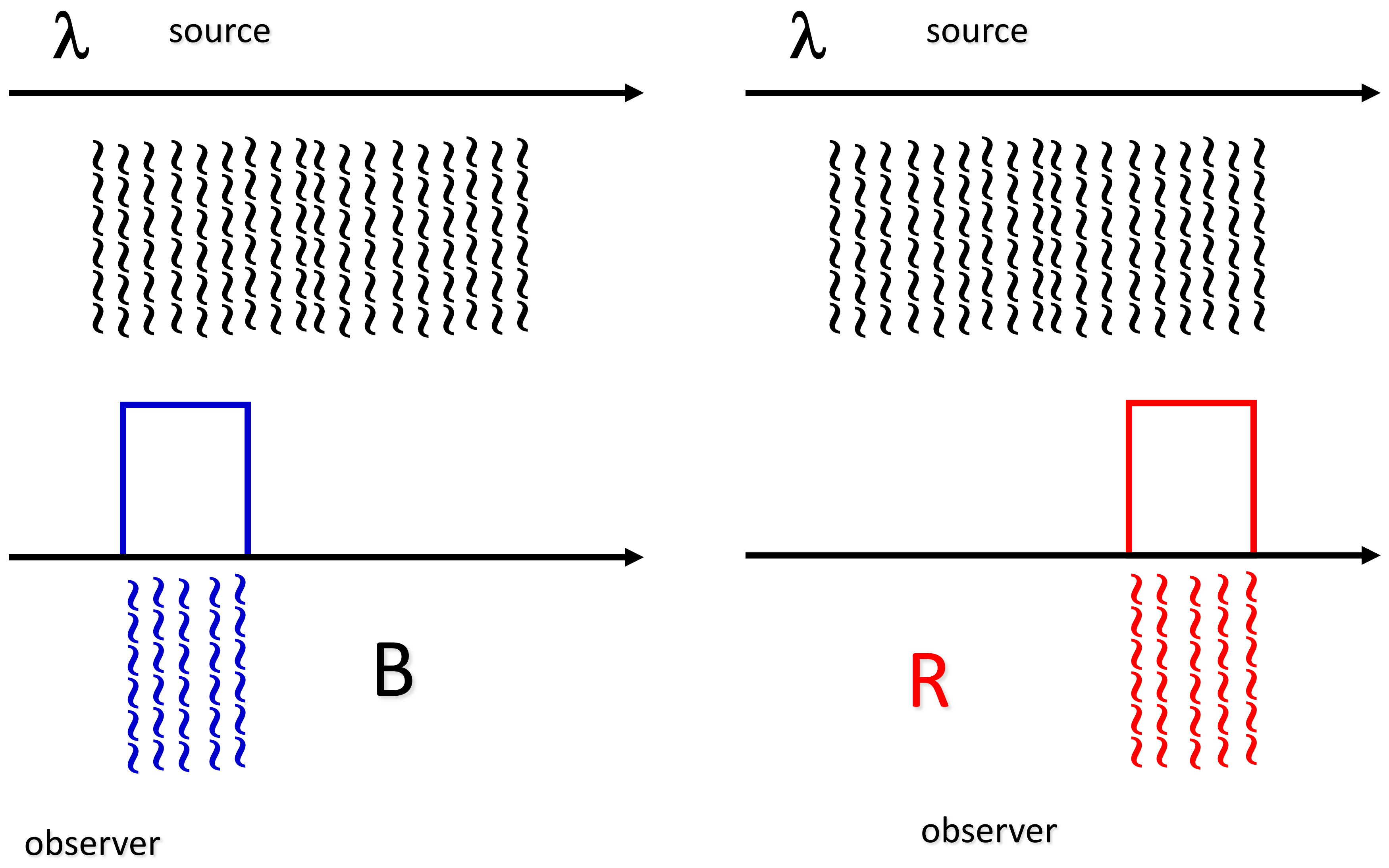


Image Credit: ESA/NASA/Felix Mirabel

FILTER: a screen, plate, or layer of a substance which <u>absorbs light</u> or other radiation or <u>selectively</u> absorbs some of its components



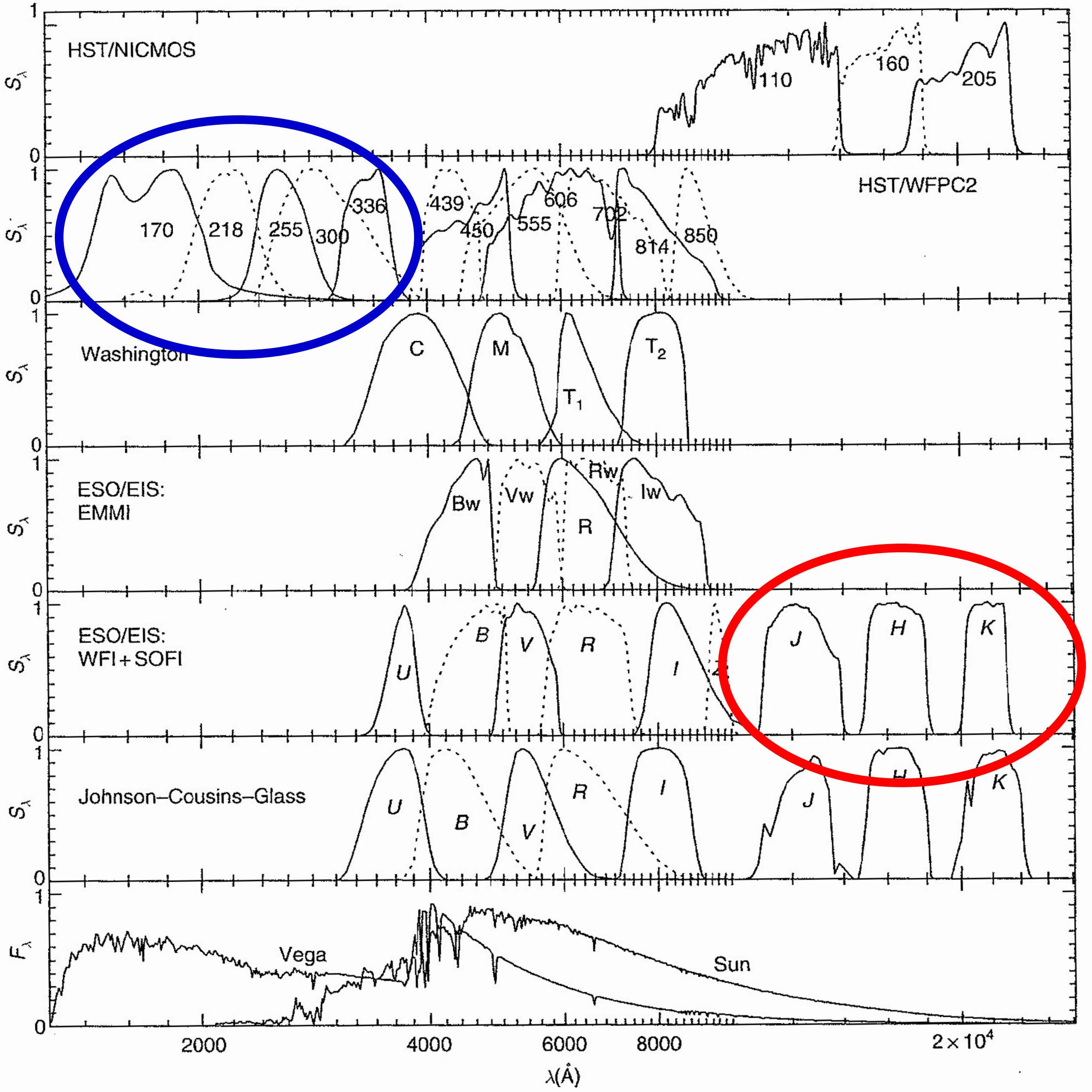
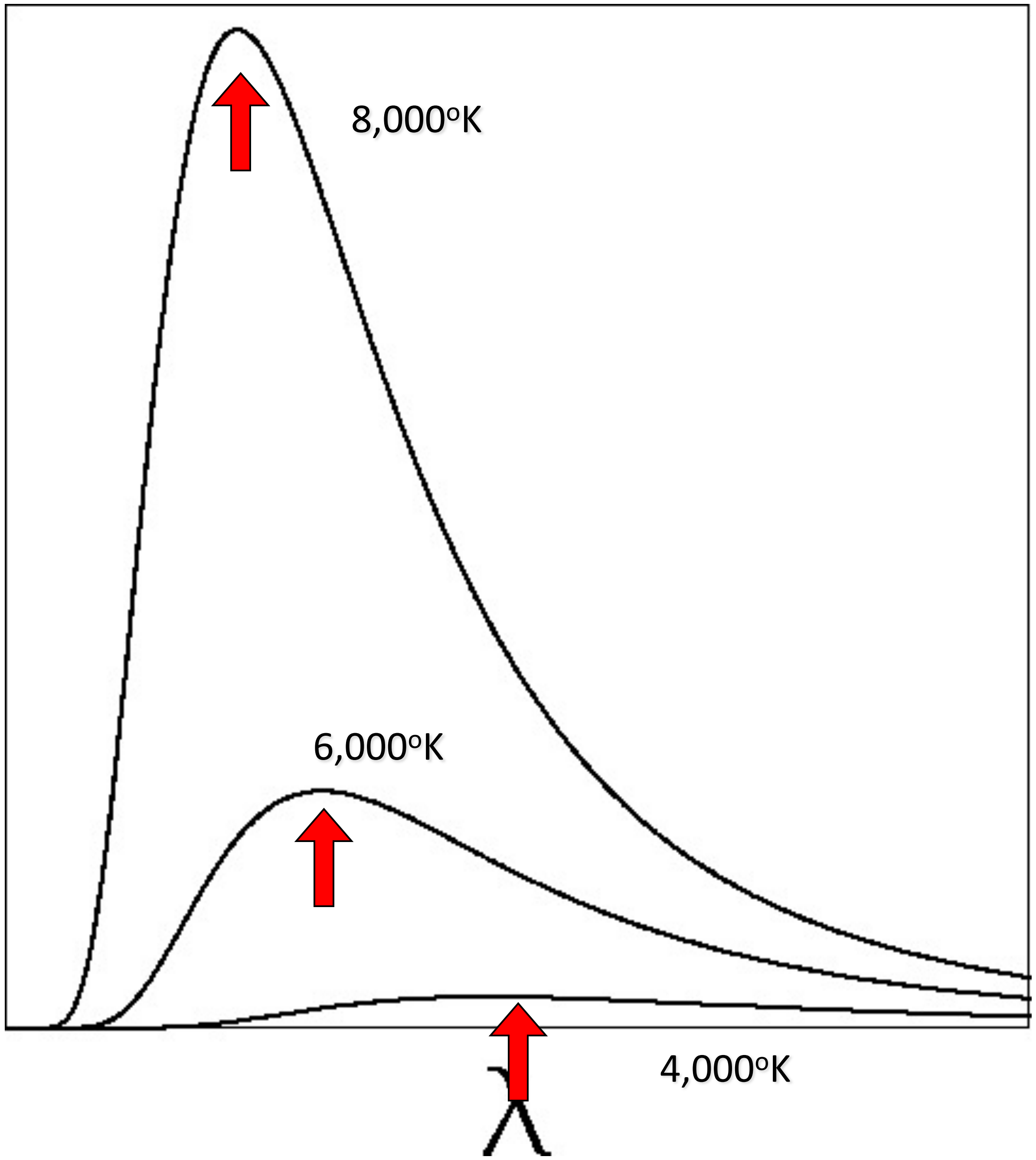


Figure 8.1 Response functions $S(\lambda)$ for filters of various photometric systems. The bottom panel shows the spectra (in arbitrary units) of Vega and the Sun (courtesy of L. Girardi)



The radiation emitted by a star is not constant at any wavelength but it follows the so-called BLACK-BODY law (emission depends on its temperature)

Wien Law

$\lambda_{max} = 0.290\ (cm\ K) / T\ (K)$

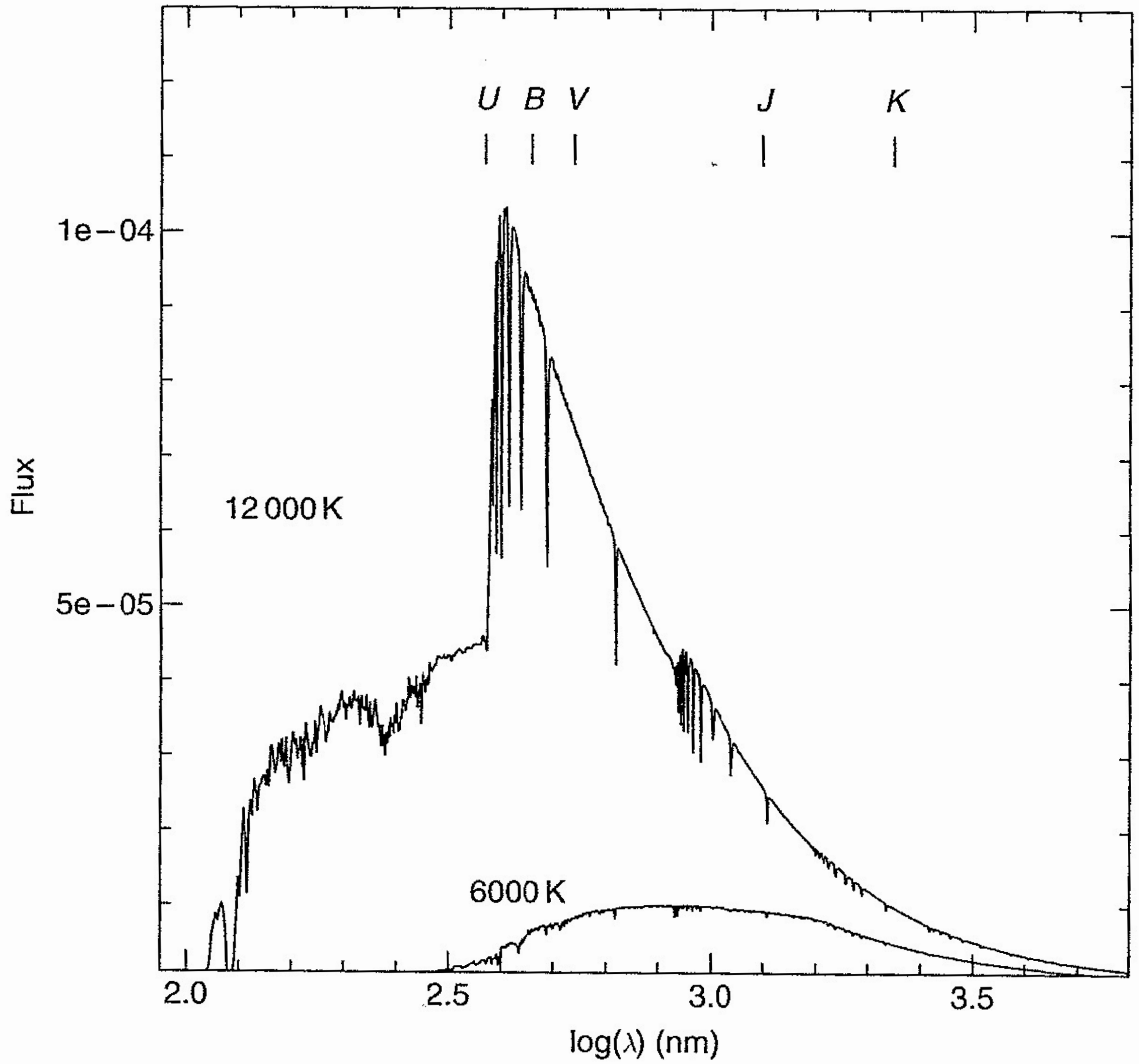
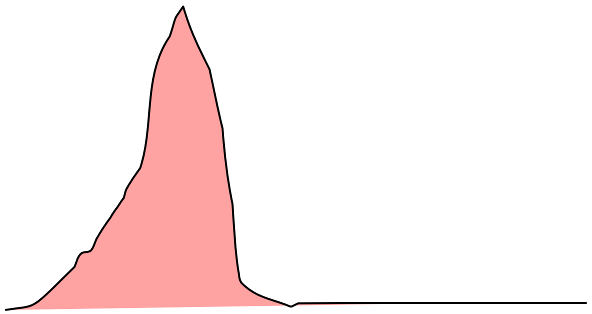
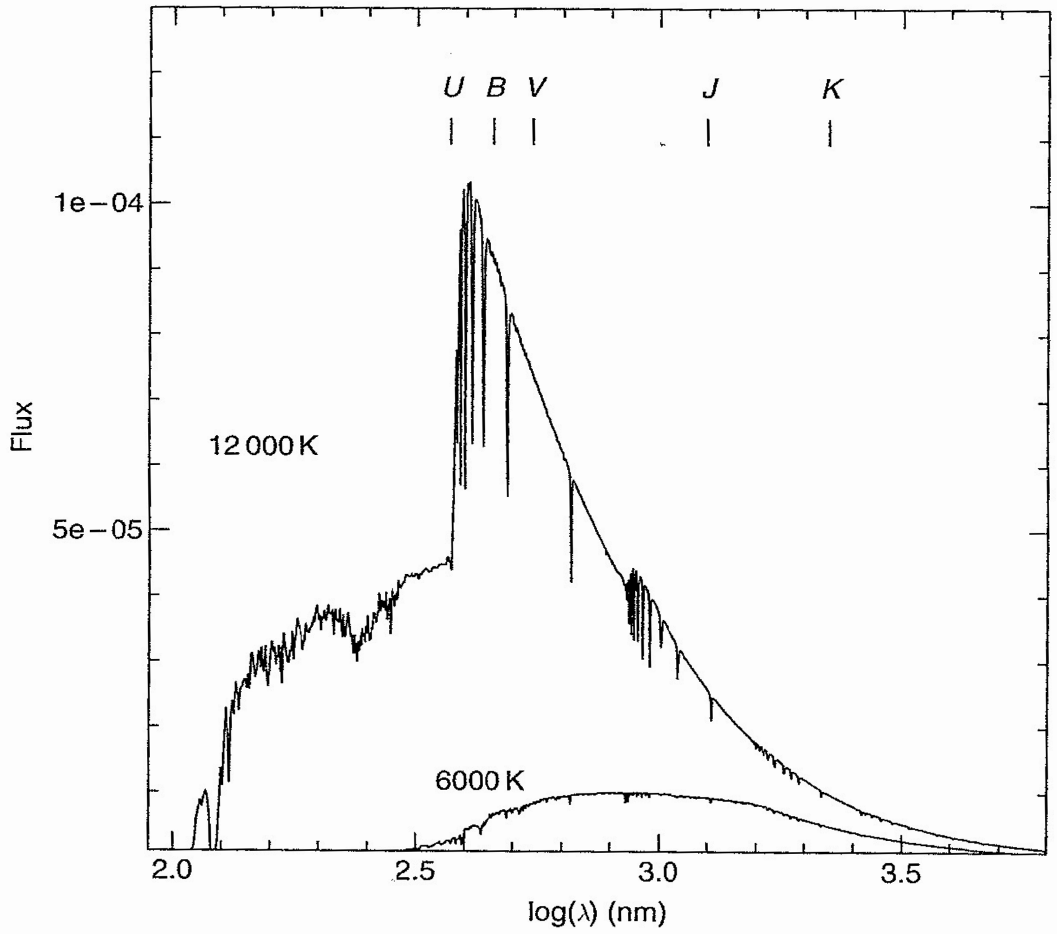


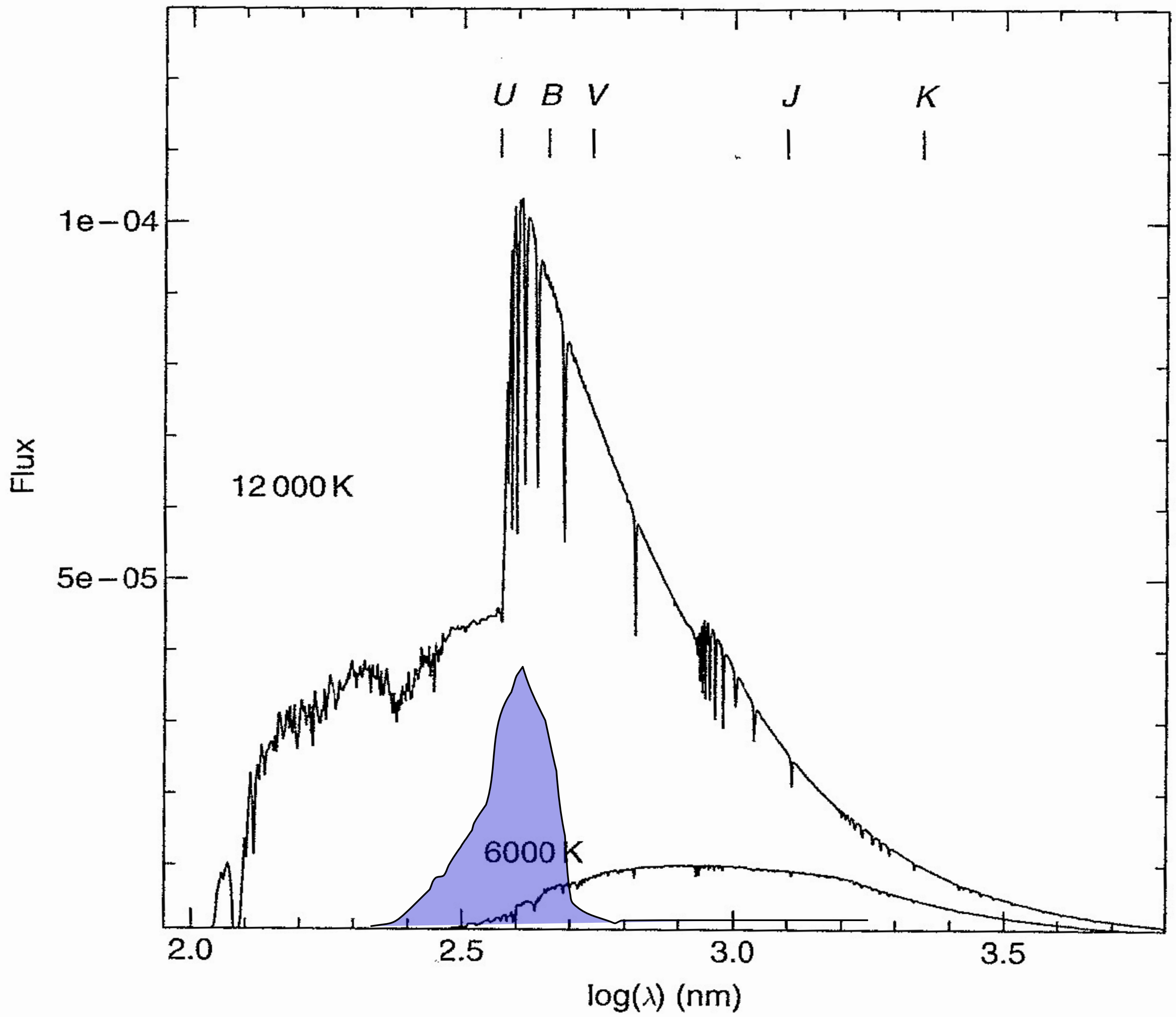
Figure 8.2 Comparison of the energy fluxes (units of erg cm^{-2} s^{-1} hz^{-1} ster^{-1}) emitted by two stars with the same solar chemical composition and solar gravity, and two different values of $T_{\rm eff}$. The effective wavelength of some photometric filters is also marked

What we call MAGNITUDE is the convolution between the FILTER BANDPASS PROFILE and THE ENERGY DISTRIBUTION of a given object

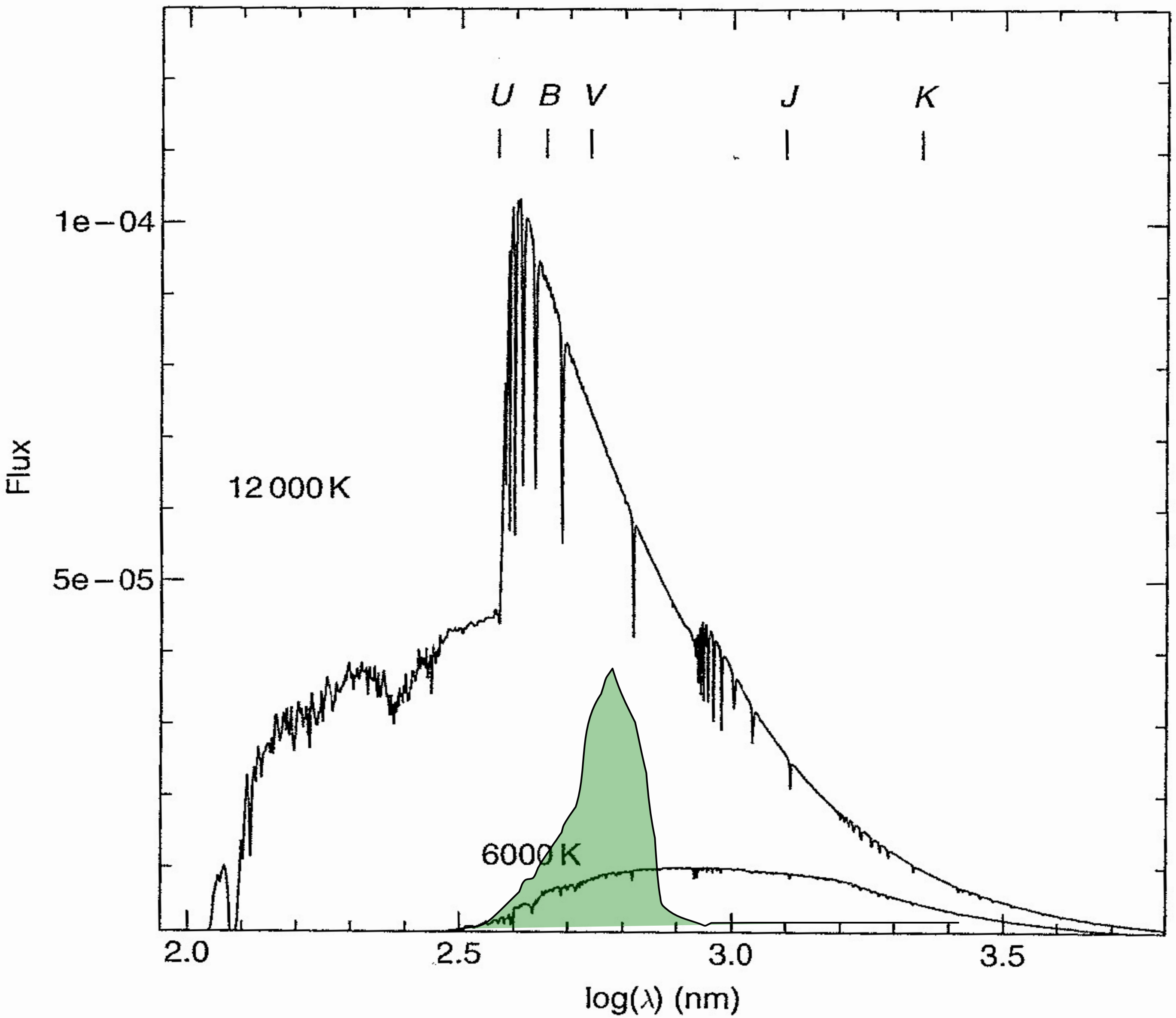


X

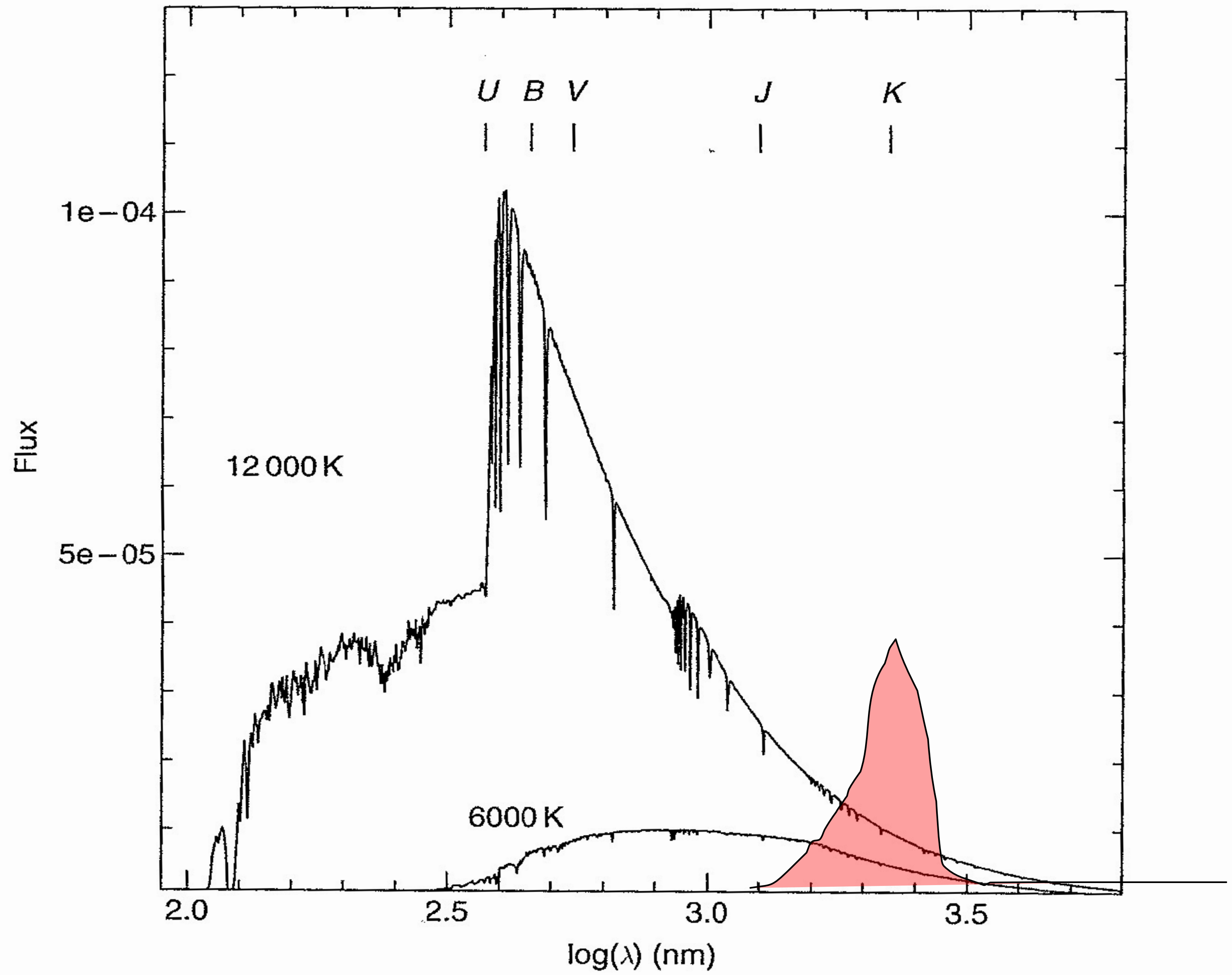




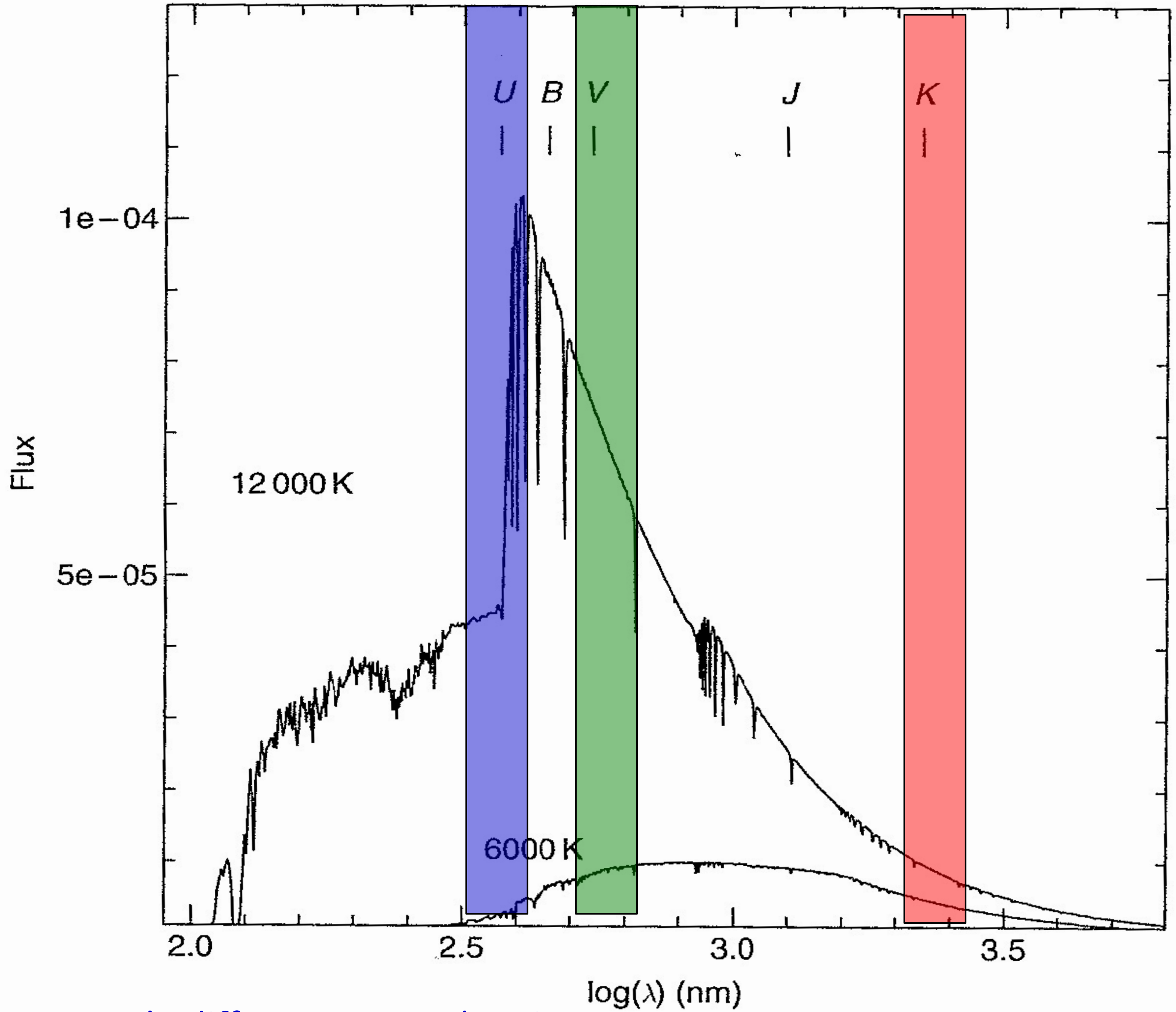
U



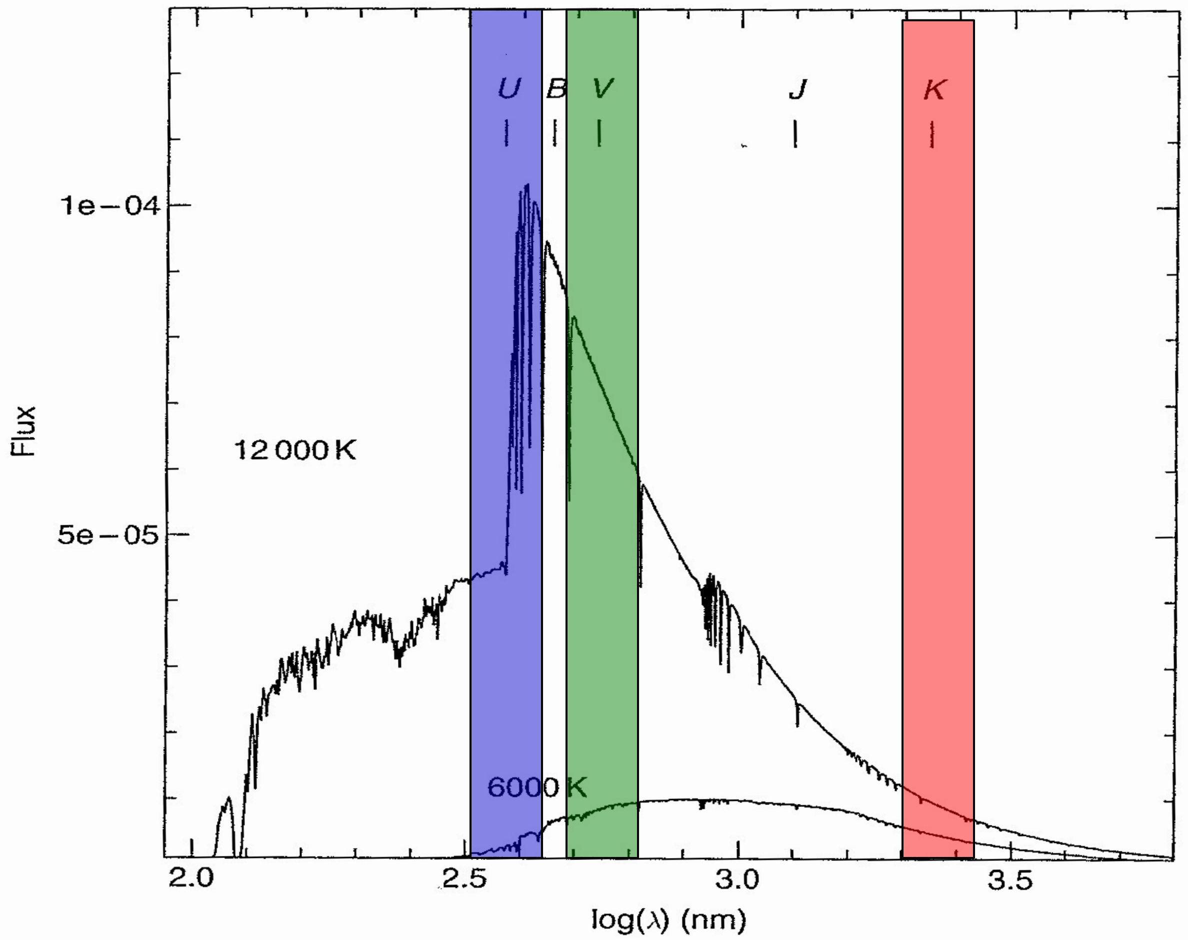
V



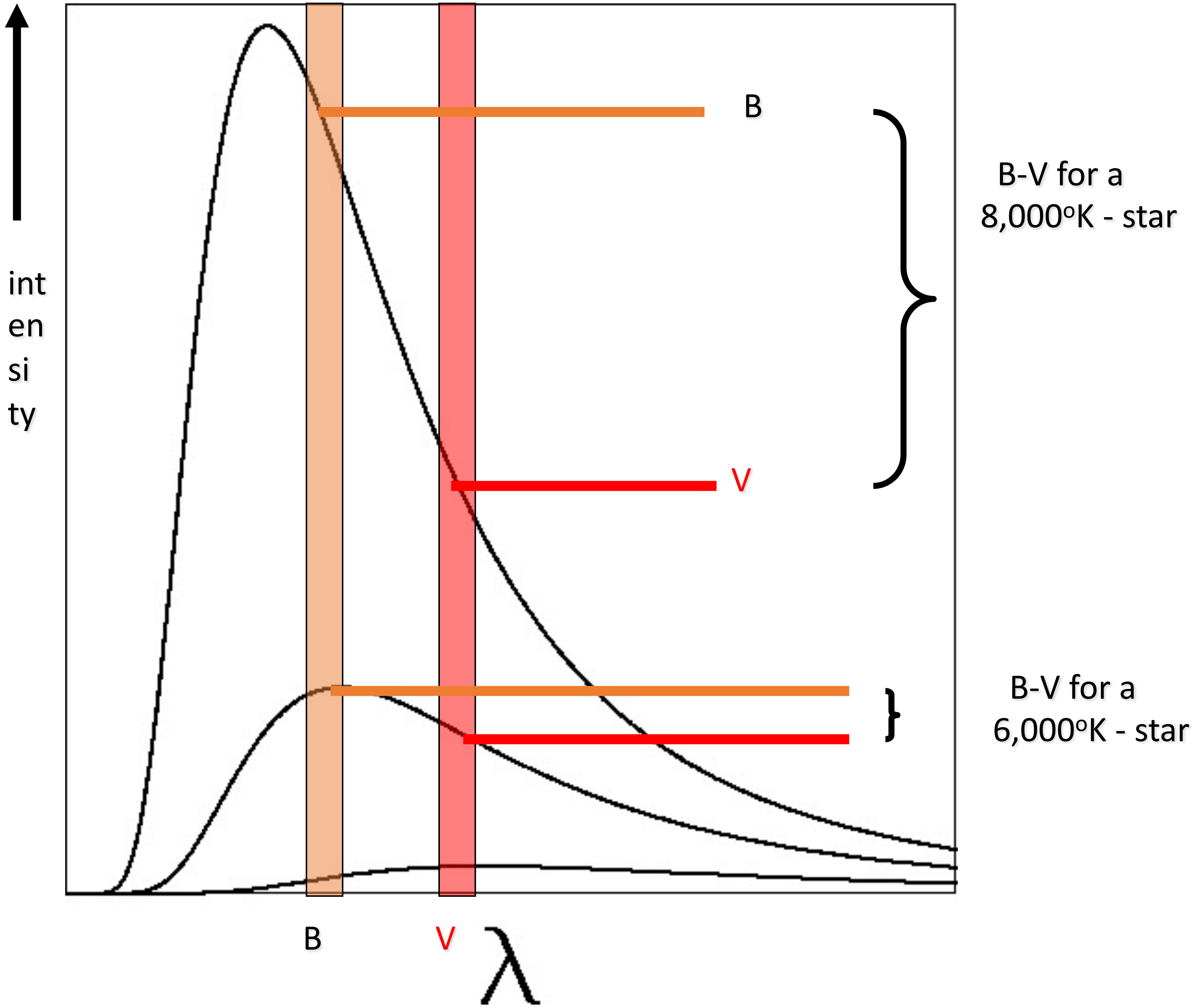
K



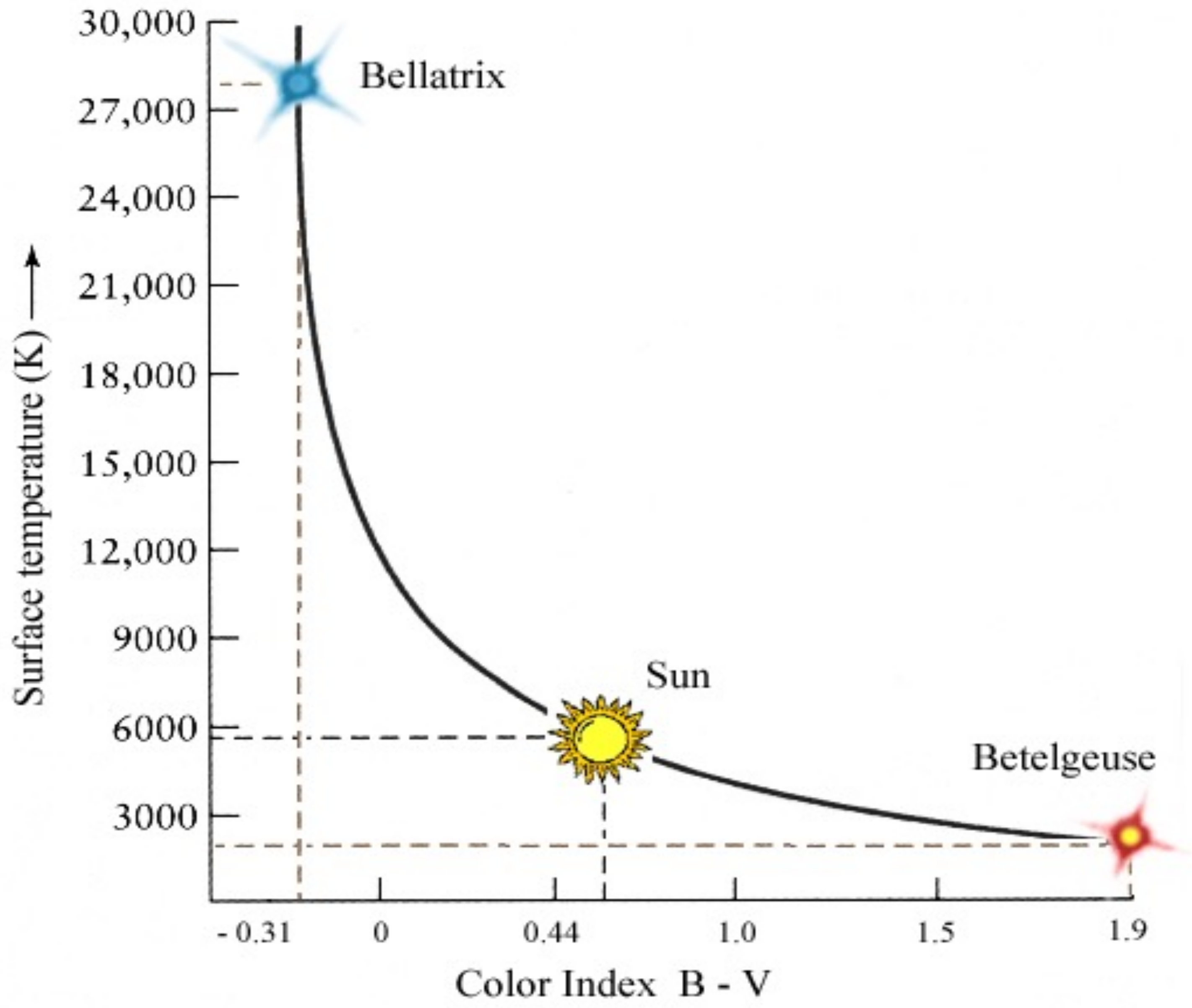
different filters sample different spectral regions
hence we expect very different magnitudes



The differences are expected to depend on the spectrum shape (hence on temperature)..

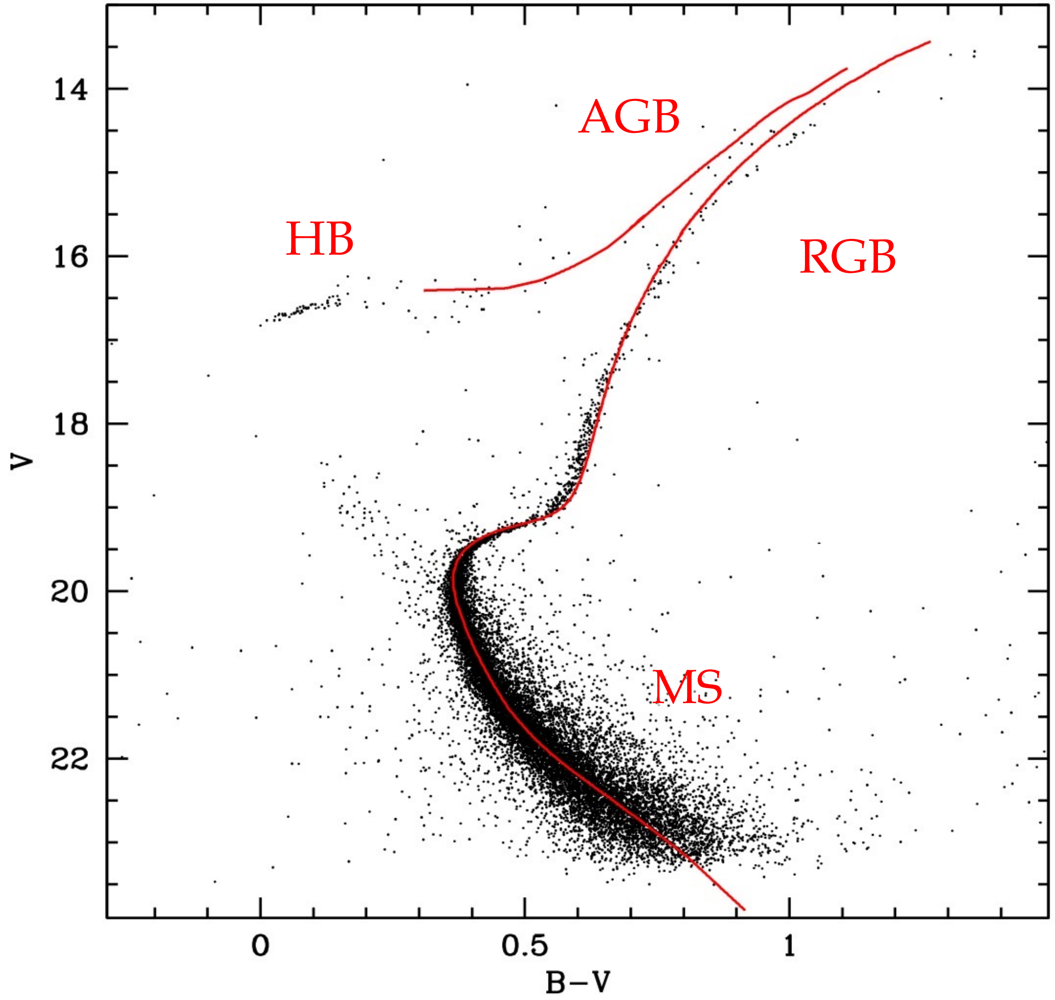


B
V
B-V for a
8,000ºK - star
int
en
si
ty
B-V for a
6,000ºK - star
B
V
λ


30,000
27,000
24,000
21,000
18,000
15,000
12,000
9000
6000
3000
Surface temperature (K)
Bellatrix
Sun
Betelgeuse
- 0.31
0
0.44
1.0
1.5
1.9
Color Index B - V

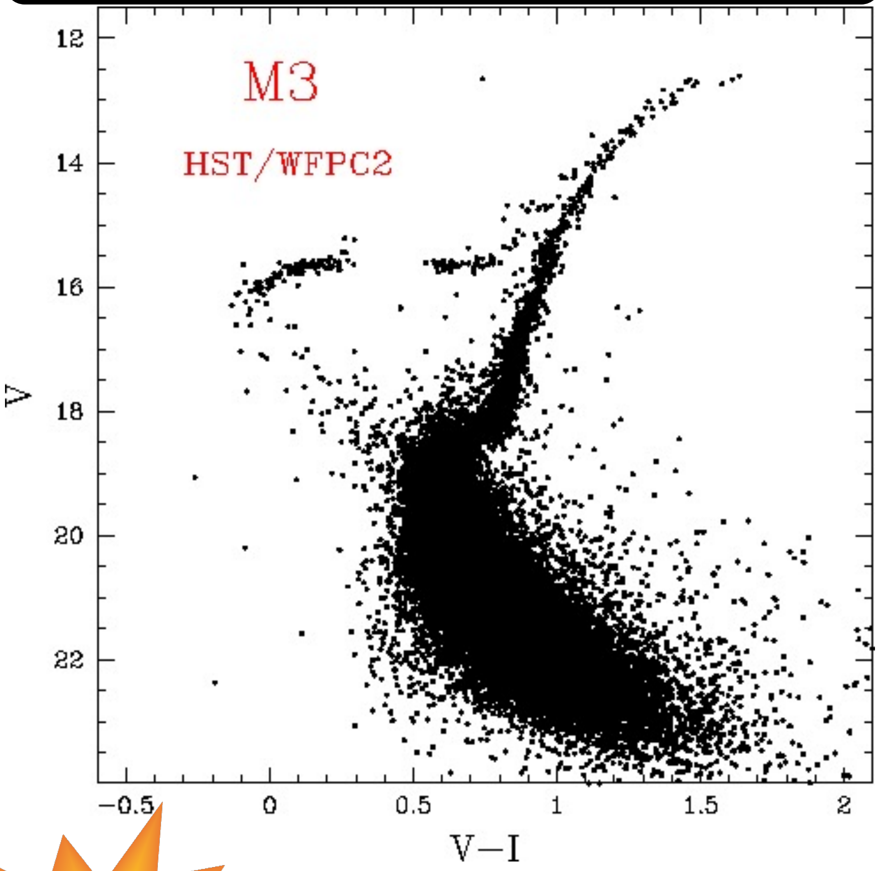
Observational Strategies: Multi-band

Scientific Goal • Tune your filter to the science!!!

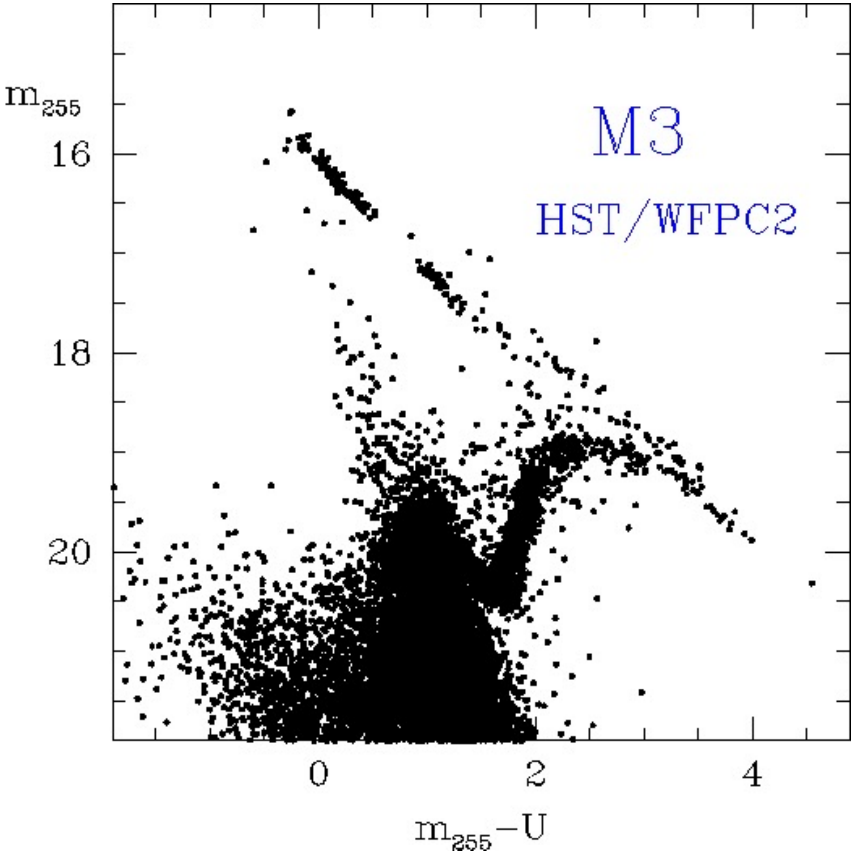


Observational Strategies: Multi-band

The "classical" plane



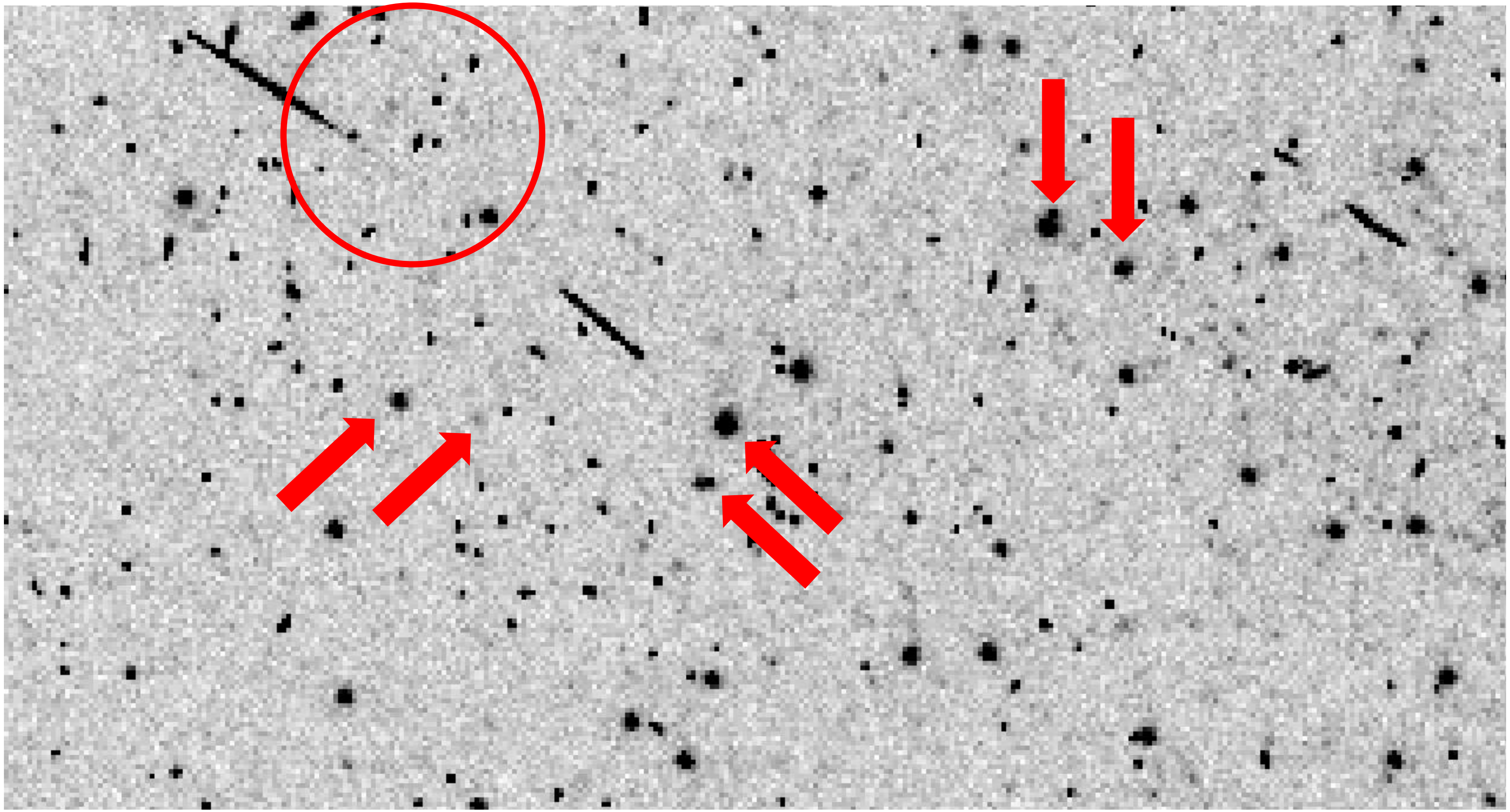
The UV plane



HST

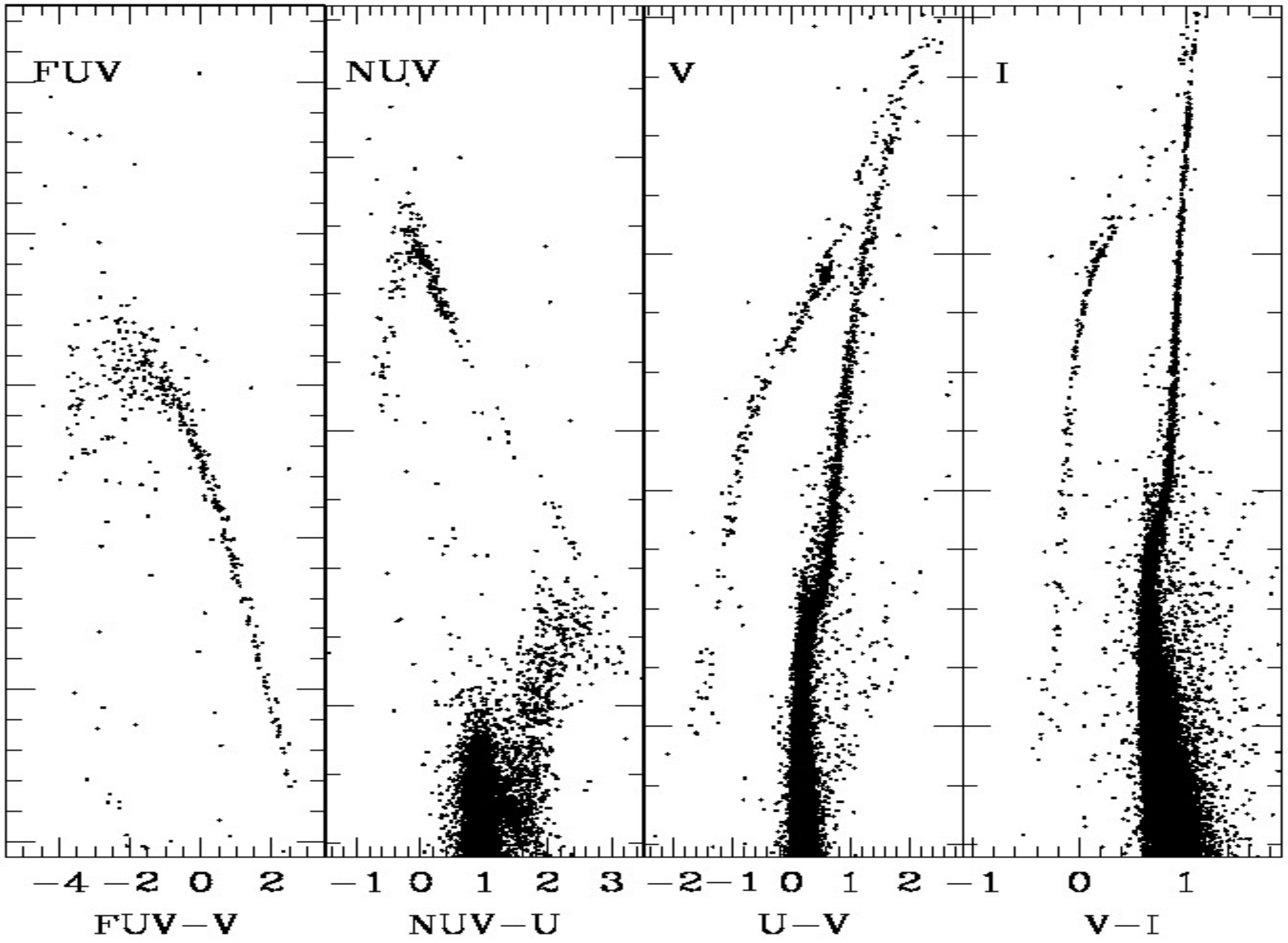
UV sensitivity and high angular resolution

F555W (V) ⟷ **F255W (UV)**



Far-UltraViolet (FUV)

Optical-Near InfraRed (NIR)



M2, Dalessandro et al. 09

2. Instruments

2.1 **Scientific Goal**

2.2 Choose the right instrument

2.3 Read the….Manual!!!

- gain
- read-out noise
- saturation
- pixel scale
- Field of View (FOV)
- geometric distortion
- Flat Fielding
- Illumination Correction ….

2. Instruments

2.1 **Scientific Goal**

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2.3 Read the….Manual!!!

gain
read-out noise
saturation
pixel scale
Field of View (FOV)
geometric distortion
Flat Fielding
Illumination Correction ….

Capabilities
Limits
Known Problems

2.2 Choose the right instrument: The Exposure Time Calculator (ETC)

Input Parameters		Output Parameters
Input Flux Distribution		…
Spatial Distribution	→	Exposure Time
Sky Conditions		Sky background value
Instrument Setup		Detector saturation
Requested S/N		…

2.3 The Manuals!!!

http://www.eso.org/sci/facilities/paranal/instruments.html

Paranal Instrumentation

The currently offered Paranal telescopes and instruments and their location are listed in the following table

valid for Period 96, October 1, 2015 - March 31, 2016.

The links to the different instruments provide an overview of the respective instrument capabilites and the offered instrument modes. For details please refer to the Call for Proposals for Period 96.

Information on Paranal decommissioned instruments is available on a separate page.

Please refer to the Call for Proposals for Period 97 for Paranal telescopes and instruments offered in Period 97.

Telescope	Focus			
	Nasmyth A	Cassegrain	Nasmyth B	Interferometric
UT1 (Antu)	NACO	FORS2	KMOS	AMBER PIONIER
UT2 (Kueyen)	FLAMES	XSHOOTER	UVES	
UT3 (Melipal)	SPHERE	VISIR	VIMOS	
UT4 (Yepun)	HAWK-I	SINFONI	MUSE	
AT1				AMBER PIONIER
AT2				
AT3				
AT4				
VISTA		VIRCAM		
VST		OmegaCAM		

http://www.eso.org/sci/facilities/paranal/instruments.html

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    - UVES
    - VIMOS
    - VISIR
    - X-SHOOTER
    - Visitor Focus
    - VLTI AMBER
    - VLTI PIONIER
    - VLTI Visitor Instrument
    - VIRCAM @ VISTA
    - OmegaCAM @ VST

Paranal Instrumentation

The currently offered Paranal telescopes and instruments and their location are listed in the following table

valid for Period 96, October 1, 2015 - March 31, 2016.

The links to the different instruments provide an overview of the respective instrument capabilites and the offered instrument modes. For details please refer to the Call for Proposals for Period 96.

Information on Paranal decommissioned instruments is available on a separate page.

Please refer to the Call for Proposals for Period 97 for Paranal telescopes and instruments offered in Period 97.

	Focus			
	Nasmyth A	Cassegrain	Nasmyth B	Interferometric
	CO	FORS2	KMOS	AMBER PIONIER
	MES	XSHOOTER	UVES	
	HERE	VISIR	VIMOS	
UT4 (Yepun)	HAWK-I	SINFONI	MUSE	
AT1				AMBER PIONIER
AT2				
AT3				
AT4				
VISTA		VIRCAM		
VST		OmegaCAM		

EUROPEAN SOUTHERN OBSERVATORY

Organisation Européene pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

ESO - European Southern Observatory
Karl-Schwarzschild Str. 2, D-85748 Garching bei München

Very Large Telescope

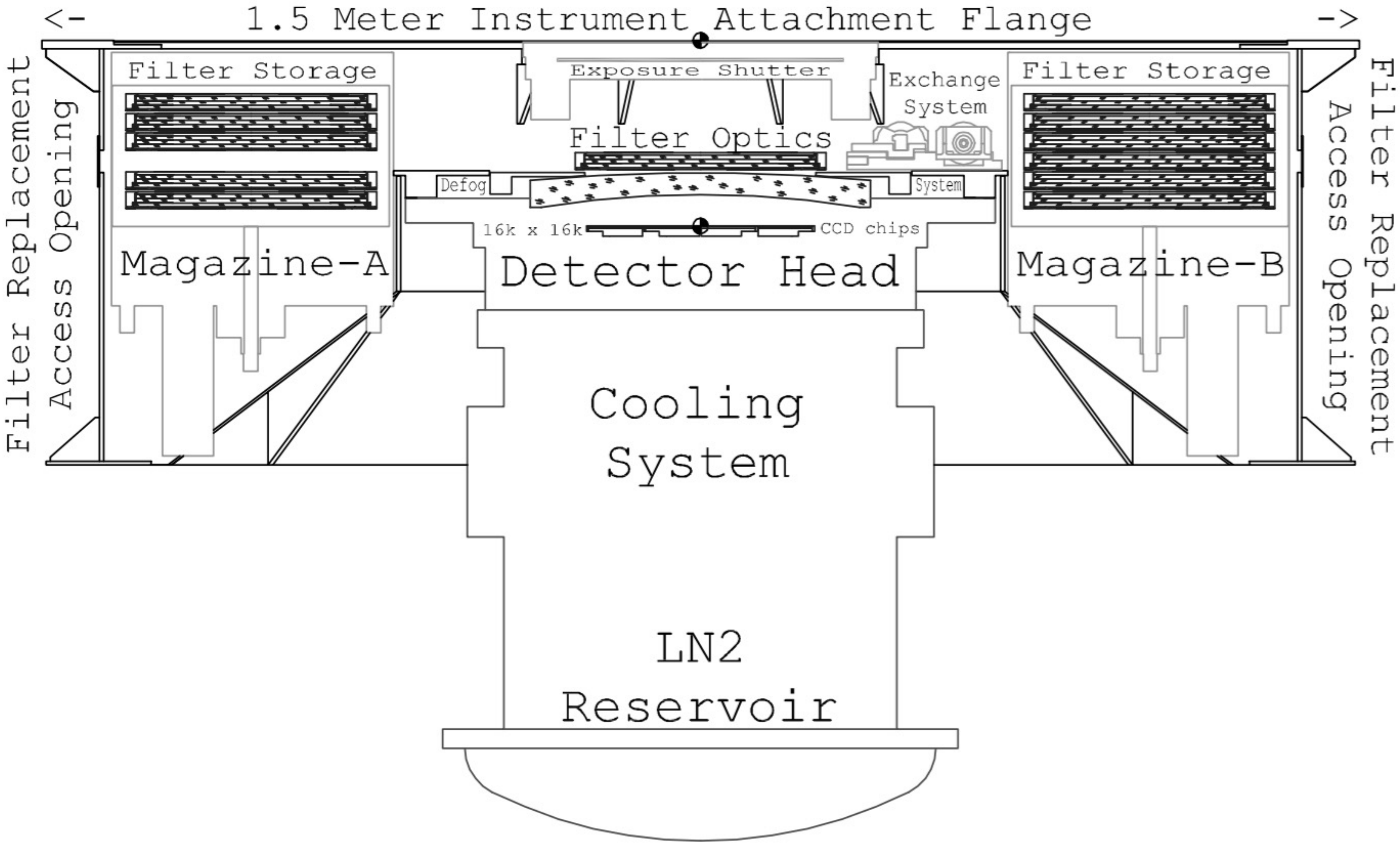
Paranal Science Operations

OmegaCAM User Manual

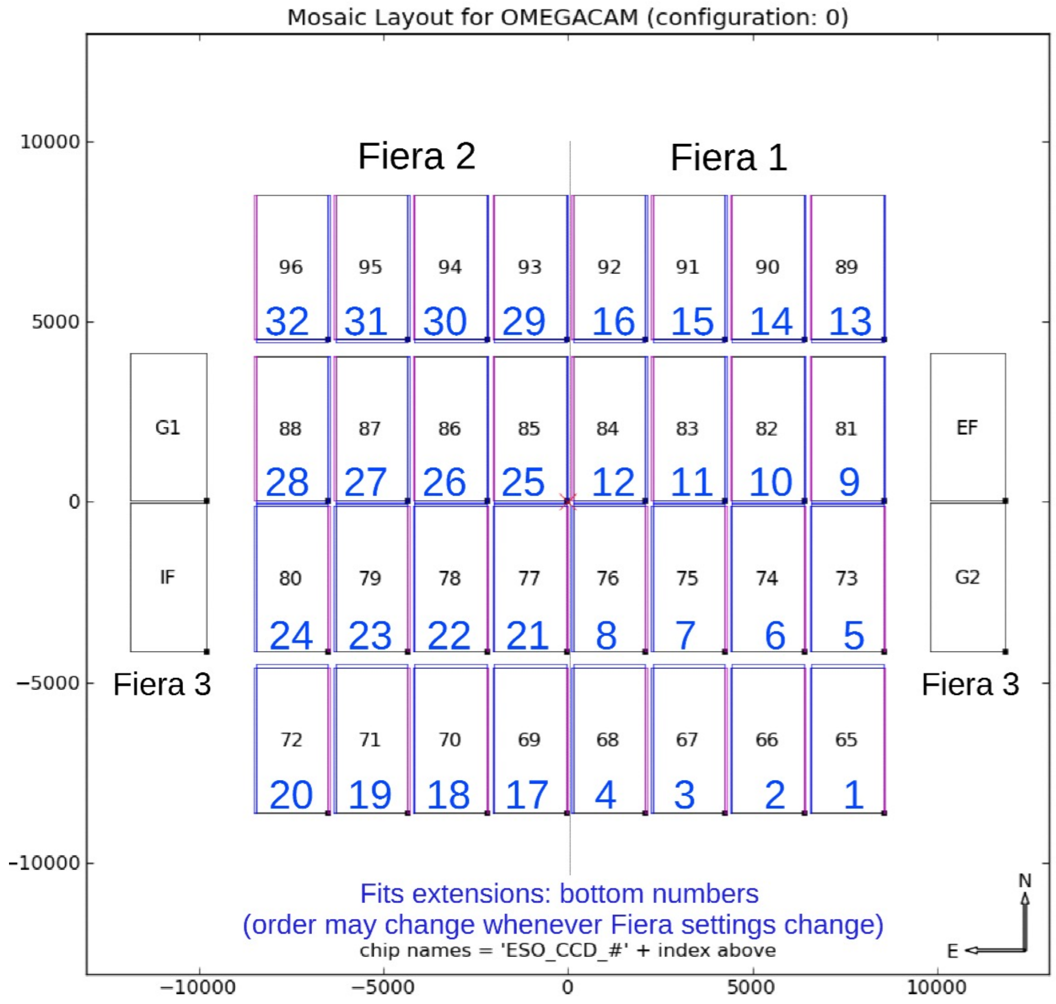
Doc. No. VST-MAN-OCM-23110-3110

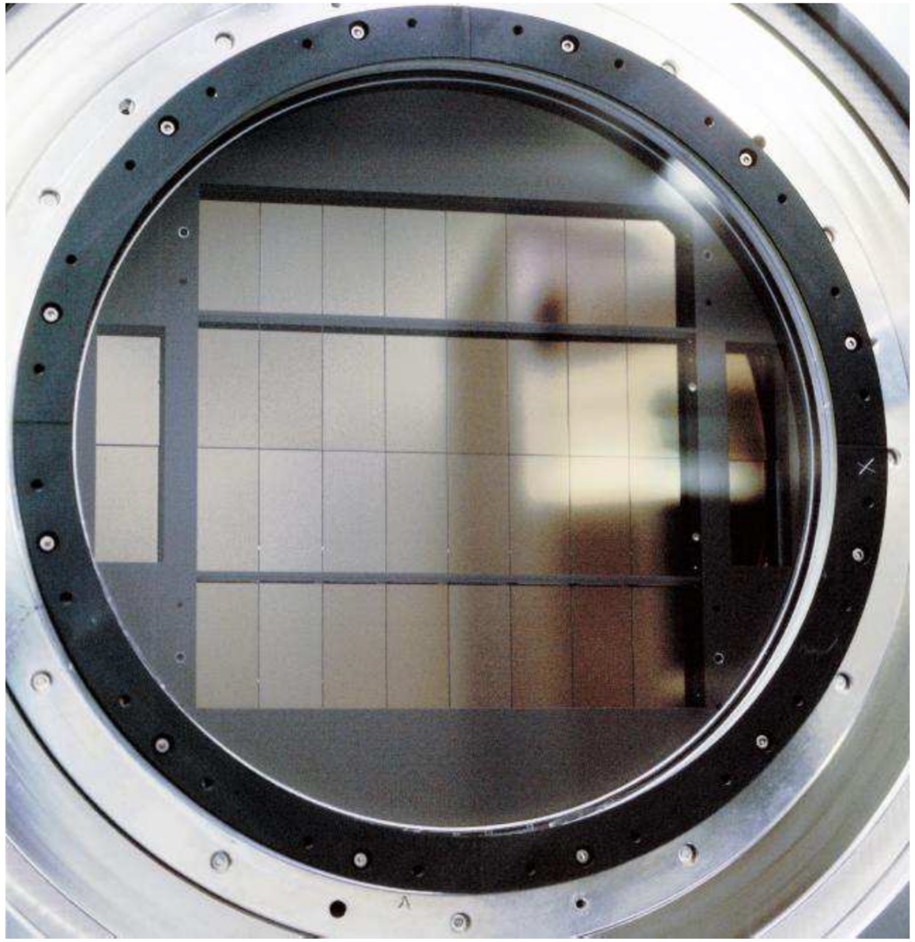
Issue 96.0, Date 22/01/2015

Meet your instrument



Meet your instrument





Meet your instrument

CCD Parameter	Value
CCD type	Marconi / e2v / CCD 44 - 82 - 1 - A57 thin devices (20μm)
Pixel size	15 μm
Format	Active Pixel Area 2048 x 4102 pixels (2048x4100 used) 50 horizontal pre- and 50 overscan pixels
Default Read Speed	280 kpix/sec
Flatness	< 20μm peak to valley
R.O.N. (not including system noise)	2 e- at 50 kpix/sec 4 e- at 500 kpix/sec 6 e- at 1000 kpix/sec
Full R.O.N. (including system noise) at default read speed	5-7 e-
Gain [e-/ADU]	~2.6 with 10% chip-to-chip RMS
Output Amplifiers	2 identical output amplifiers with integrated post chip amplifiers. Charge can in principle be read through either one completely or through both of them simultaneously. In practise, only the respective "left" one is used.
Device Layout	No frame transfer option, 3 phase parallel register (non split), 3 phase serial register (split)
Dump Drain	A dump drain exists parallel to the serial readout register, so that lines can be discarded as a whole
Cosmetics	A global defect budget exists, specifying the overall defects for all of the 40 science devices (Cosmetically the final device cosmetics are much better than devices used for the WFI)
CTE	> 0.999995 per parallel or serial shift
Horizontal Transfer Frequency	2 Mpixels/sec
Vertical Transfer Frequency	15-20 klines/sec
Full Well / Linearity	>200 000 e-. Serial full well is at least 2 times the pixel full well and the summing full well is at least 4 times the pixel full well. These full well values correspond to the maximum charge that can be handled while attaining the CTE specified. Amplifier full well is around 200 000 e-. Amplifier full well refers to the limit of linearity, i.e. the maximum amount of charge that can be amplified while producing output that matches a linear response to within 1 %.
Dark Current	< 2 e- / pixel / hour (at operating temperature of −120 °C)
Cross talk	There is cross talk at the level of < 0.4% between CCDs 93-96.
Gain variations	CCDs # 87 and 88 shows day-to-day gain variations of 1-2% RMS.
Cosmic Ray Sensitivity	< 3 events / square cm and minute
Optical Coating	Single layer anti reflection coating astro BB (with thickness 42nm instead of 46nm)
Package design	Four side buttable (fourth side with larger gap), Invar package with integrated PT100 temperature sensor

Meet your instrument

Table 3: Filters available in OmegaCAM

Filter name	System	λ (nm)[a]	$\Delta\lambda$ (nm)[b]	P2PP name	comment[c]
u'	SDSS	354	56	u_SDSS	IF, M
g'	SDSS	475	134	g_SDSS	IF, M
r'	SDSS	625	135	r_SDSS	IF, M
i'	SDSS	756	155	i_SDSS	IF, M
z'	SDSS	880	80	z_SDSS	IF, M
B	Johnson	439	103	B_JOHN	IF, S
V	Johnson	551	98	V_JOHN	IF, S
v	Strömgren	412	21	v_STRM	IF, M
$H\alpha$[d] VPHAS+	—	658.6, 659.3	10.5	NB_659	IF, S
$H\alpha$[e]	—	659.0, 666.0, 672.6, 679.1	11	H_ALPHA	IF, 4Q
$H\alpha(z = 0.3)$[f]	—	851.9, 861.4, 869.0, 877.7	12.5	NB_852_861_869_878	IF, CG, 4Q
NB3[f]	—	453.6, 494.3, 533.5, 575.6	15–20	NB_454_494_533_575	IF, CG, 4Q
NB4[f]	—	616.1, 710.2, 755.1, 816.4	13–20	NB_617_710_755_817	IF, CG, 4Q
Calib[g]	SDSS	u',g',r',i'		u_g_r_i_SDSS	IF, CG, 4Q

Meet your instrument

Gosts

Fringes