Modern instrumentation and observatories

Ernst Paunzen, Petr Kabath

Masaryk University lectures, fall 2014

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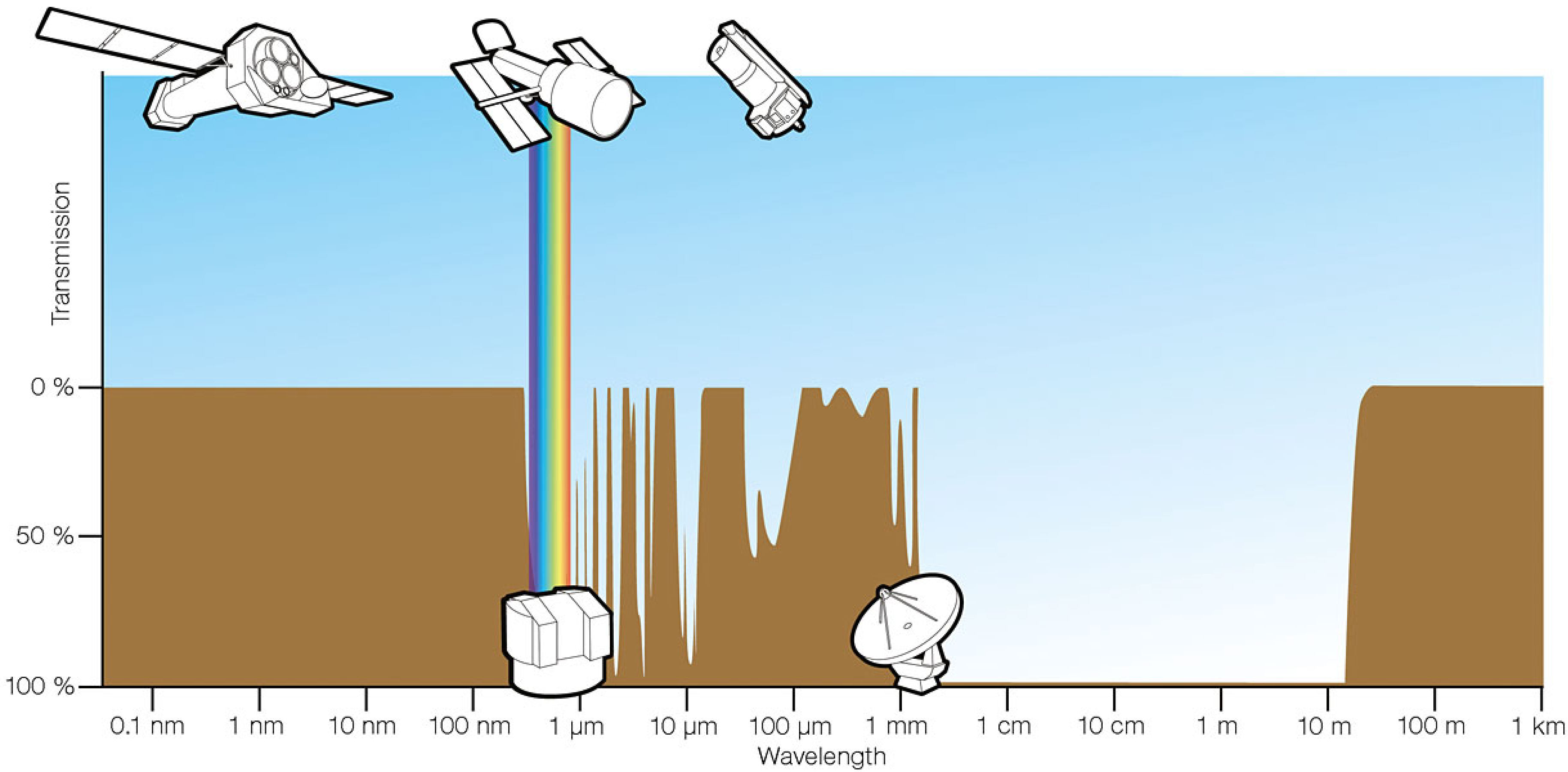
Observatories and observing techniques over centuries (08 October 2014)

www.imagesweb.org

The jungle of wavelengths



What do you expect?

- ?
- ?
- ?
- ?

What are three greatest discoveries in your opinion?

- ?
- ?
- ?

Some examples (only 20th-21st century)

- Hubble's law (1929 Hubble)
- Einstein's theory of relativity (eclipse May 29, 1919)
- The first exoplanet detection (1995 Obs. Haute Provence 51 Peg)
-
-
-
-

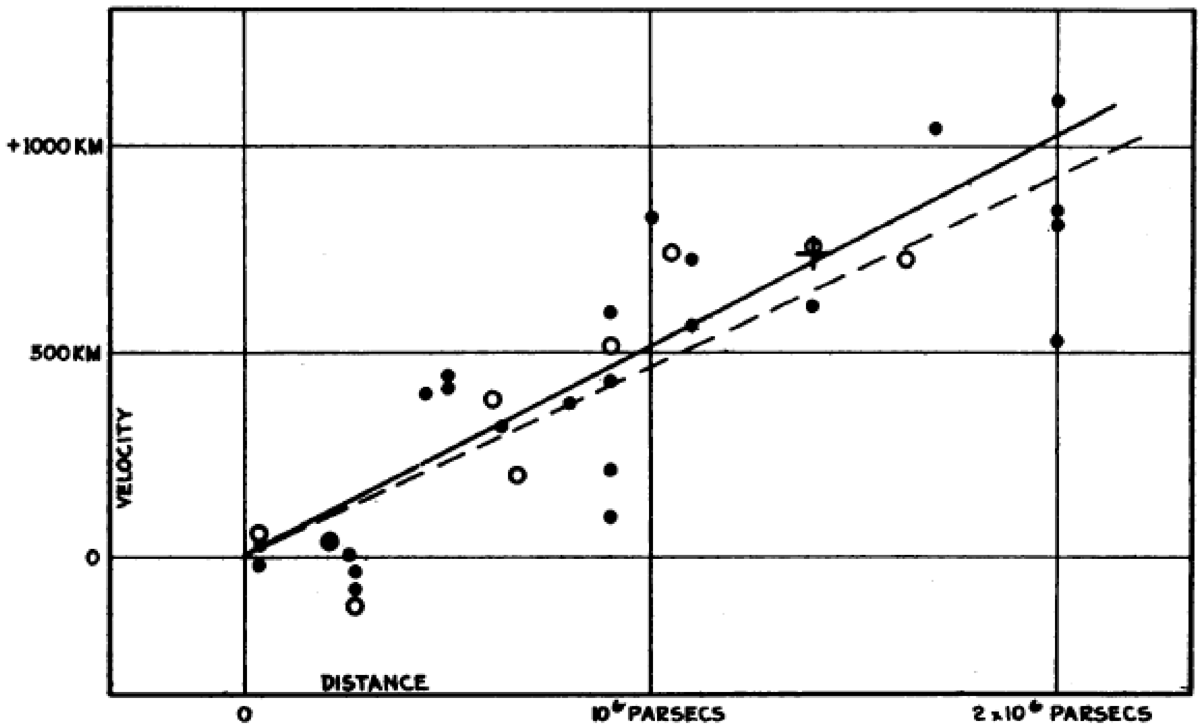


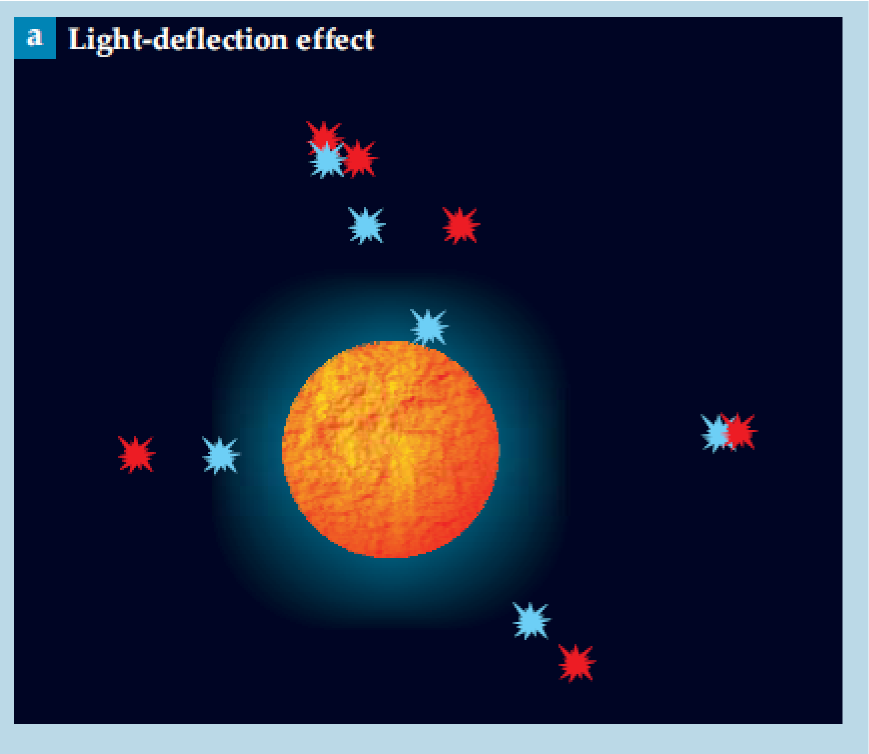
FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.

Radial velocities, corrected for solar motion, are plotted against distances estimated from involved stars and mean luminosities of nebulae in a cluster. The black discs and full line represent the solution for solar motion using the nebulae individually; the circles and broken line represent the solution combining the nebulae into groups; the cross represents the mean velocity corresponding to the mean distance of 22 nebulae whose distances could not be estimated individually.

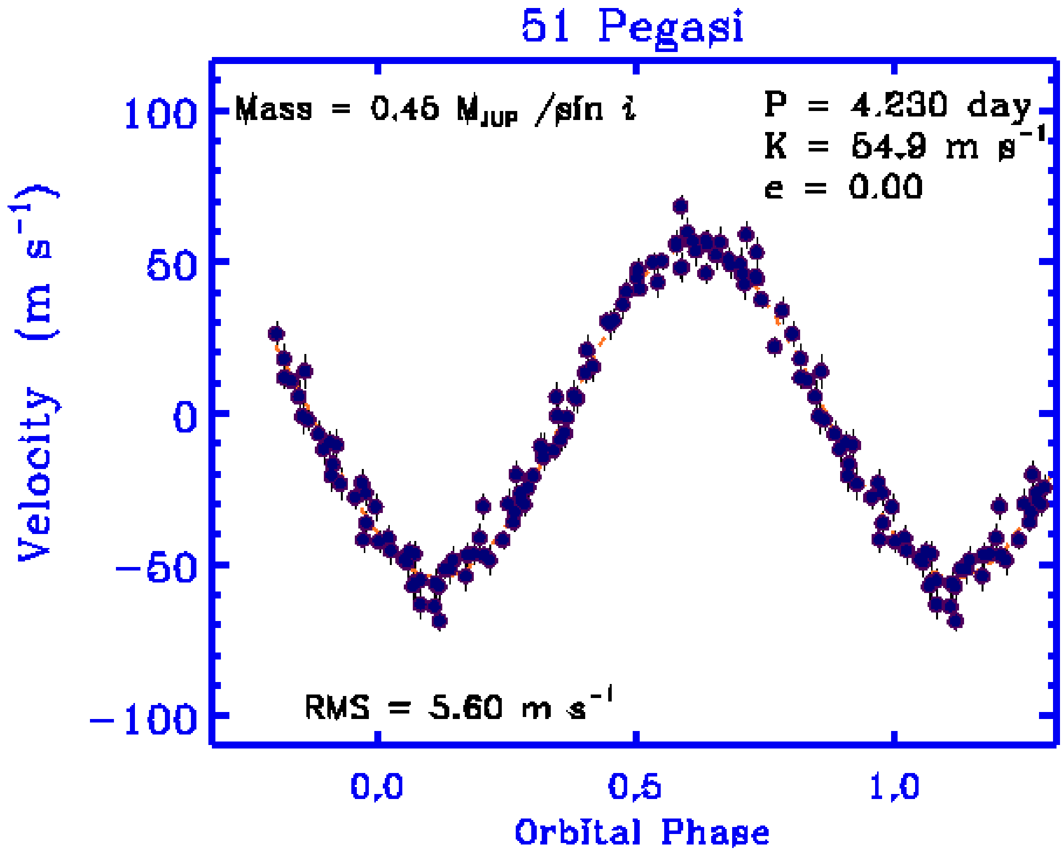
Proceedings of the National Academy of Sciences **15** (3): 168–73.

Hyades eclipsed by the Sun



D. Kennefick March 2009 Physics Today

51 Peg case



http://www.nature.com/nature/journal/v378/n6555/abs/378355a0.html

Nature **378**, 355 - 359 (23 November 1995); doi:10.1038/378355a0

Course division

- Introductory part – from the past till today astronomical observatories

  (4 sessions)
- ESO specific part – how does ESO work and how can I get involved with ESO?

  (7 sessions)
- Practical part – PROPOSAL SESSION

  (3 sessions) + home/group work

Timeline

- 08 October – Intro (Petr)
- 15 October – Intro (Petr)
- 22 October – Methods (Ernst)
- 29 October – Methods (Ernst)
- 05 November – Instrumentation & ESO
- ……..
- 10 December (closing session)
- 1 half day workshop on proposal writing

Does your expectation match ours?

- From the past to nowadays observatories
- The Challenge of site selection
- Modern observing methods (photometry, spectroscopy)
- ESO, introduction and history
- ESO instrumentation programme
- Future astronomical facilities
- How does ESO work?
- How to get observing time at ESO (not only)?

So, which main message can you take home?

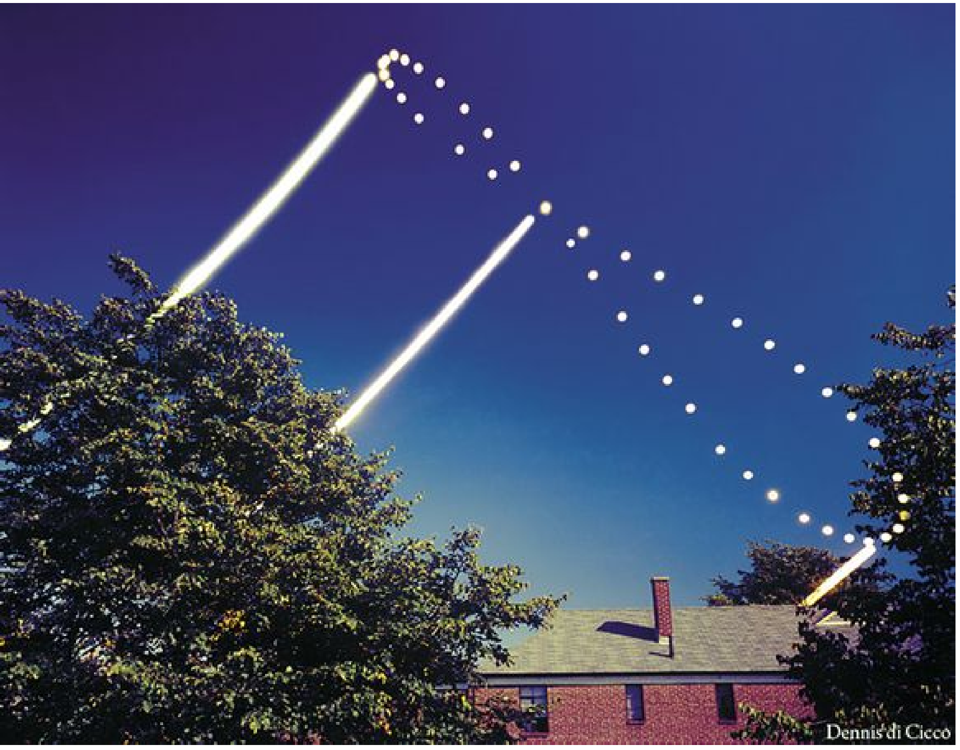
- Knowledge about modern observatories and their functionality
- Overview of modern observing methods
- Knowledge how ESO and its instrumentation works
- Overview on hot astronomy topics
- (Successful) Proposal writing skills

Astronomy from then to now

How did it start and why and how did it develop?

- First observations of the sky
- First observations of natural cycles
- Observations for religious purposes
- First discoveries of laws of nature
- Building observatories to observe the Universe
- Helping to understand where do we come from

Celestial bodies, movements



- The Sun
- Demonstration of periodic movements
- Link to cycles of the nature
- Dennis di Cicco 1978-79

"Most people say you have to be nuts to attempt a year-long exposure of the sun"

http://twanight.org/newTWAN/photos.asp?ID=3001422

http://news.nationalgeographic.com/news/2010/12/photogalleries/101228-sun-end-year-analemmas-solstice-eclipse-pictures/#/year-in-picture-analemma-sun-path-first_30693_600x450.jpg

Stars, Milky way

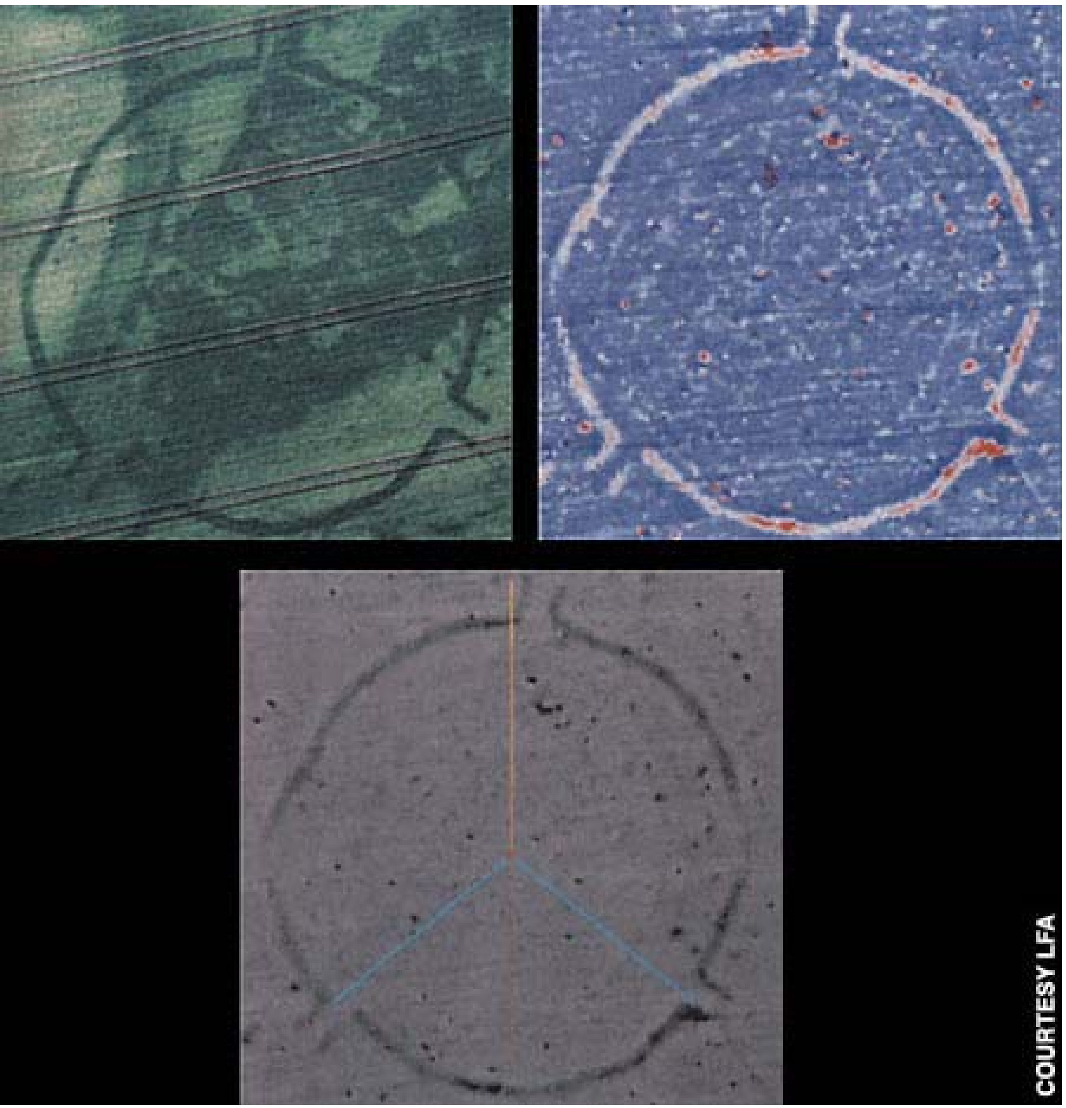
- Yolngu culture northern Australia
- EMMU on the sky
- illustrating the yearly cycles

http://www.atnf.csiro.au/people/Ray.Norris/papers/n311.pdf

http://aboriginalastronomy.blogspot.com/2014/03/the-kamilaroi-and-euahlayi-emu-in-sky.html

First human observatories

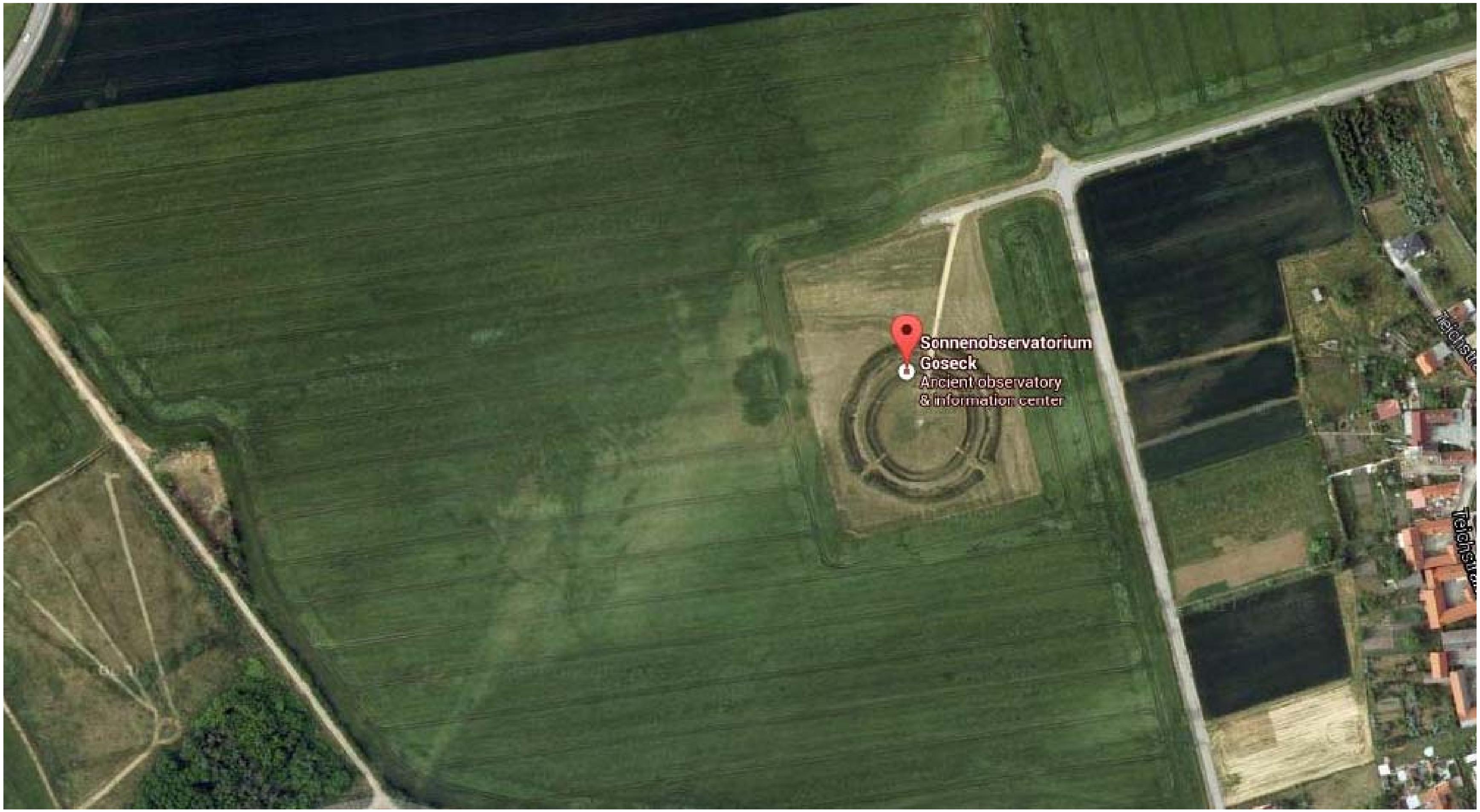
Ancient observatories (just a few)



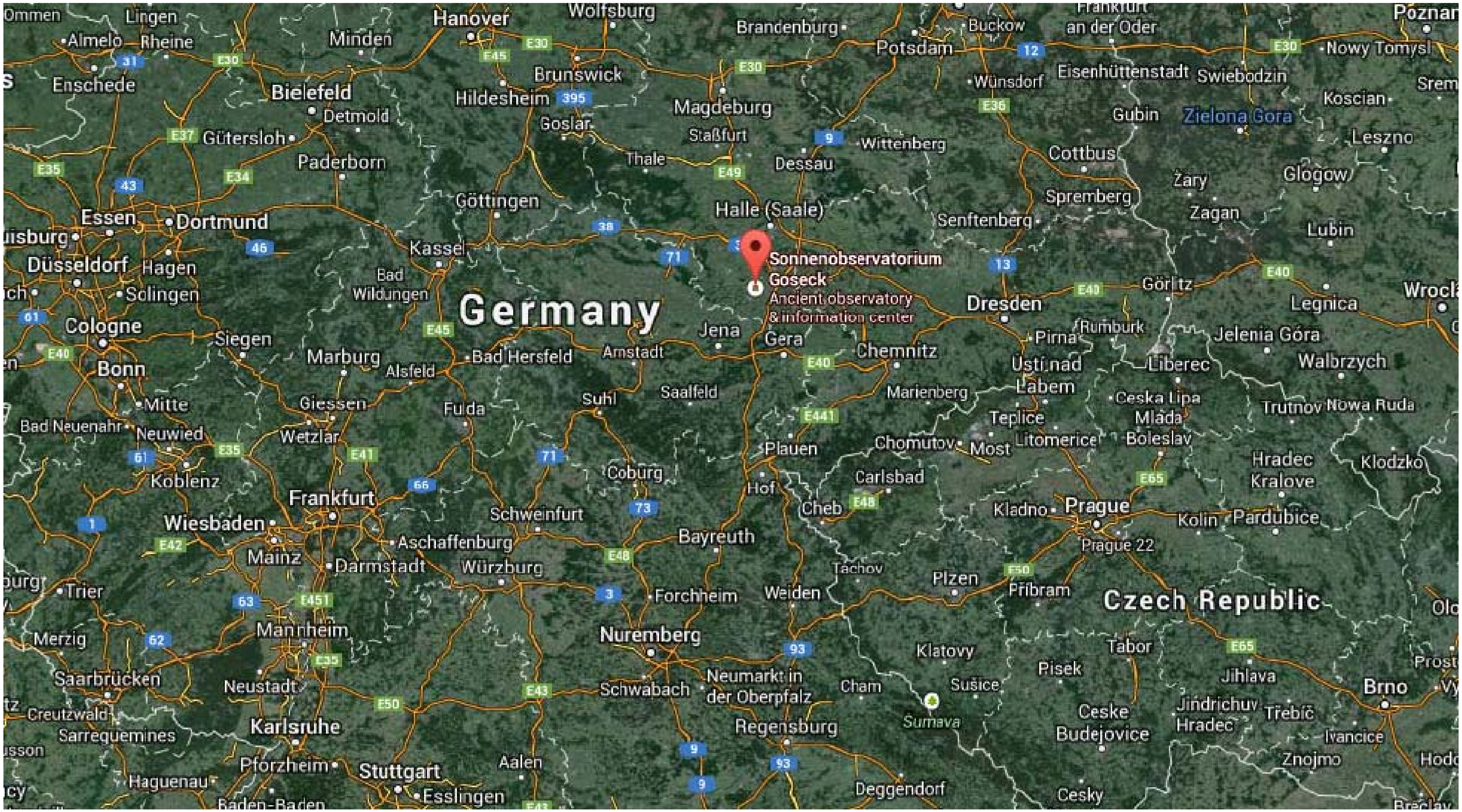
- Goseck circle in Sachsen Anhalt
- 4600 BC - first human observatory?

http://archive.archaeology.org/0607/abstracts/henge.html

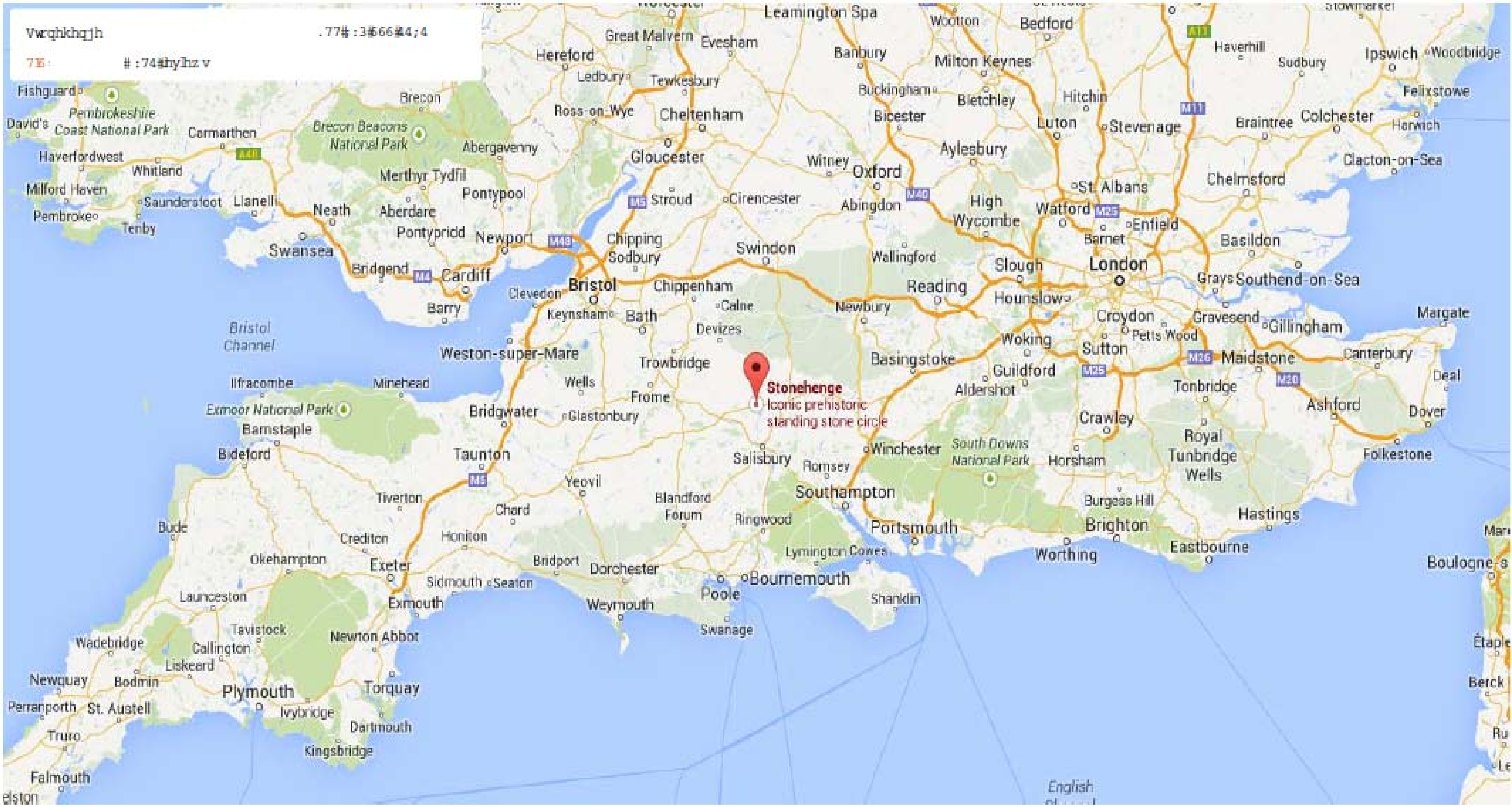
Goseck circle



Tip for a trip



Stonehenge


Vwqhkhqjh
Stonehenge
Iconic prehistoric
standing stone circle
London
Bristol
Cardiff
Swansea
Newport
Bath
Salisbury
Southampton
Portsmouth
Bournemouth
Poole
Winchester
Reading
Oxford
Swindon
Gloucester
Cheltenham
Exeter
Plymouth
Torquay
Taunton
Bridgwater
Yeovil
Dorchester
Weymouth
Brighton
Eastbourne
Hastings
Canterbury
Dover
Folkestone
Maidstone
Guildford
Basingstoke
Newbury
Chippenham
Devizes
Trowbridge
Frome
Wells
Glastonbury
Weston-super-Mare
Bristol Channel
Exmoor National Park
Brecon Beacons National Park
Pembrokeshire Coast National Park
South Downs National Park
Milton Keynes
Luton
Watford
Slough
Croydon
Chelmsford
Colchester
Ipswich
Southend-on-Sea
Basildon
Crawley
Falmouth
Truro
Newquay
Barnstaple
Bideford
Ilfracombe
English

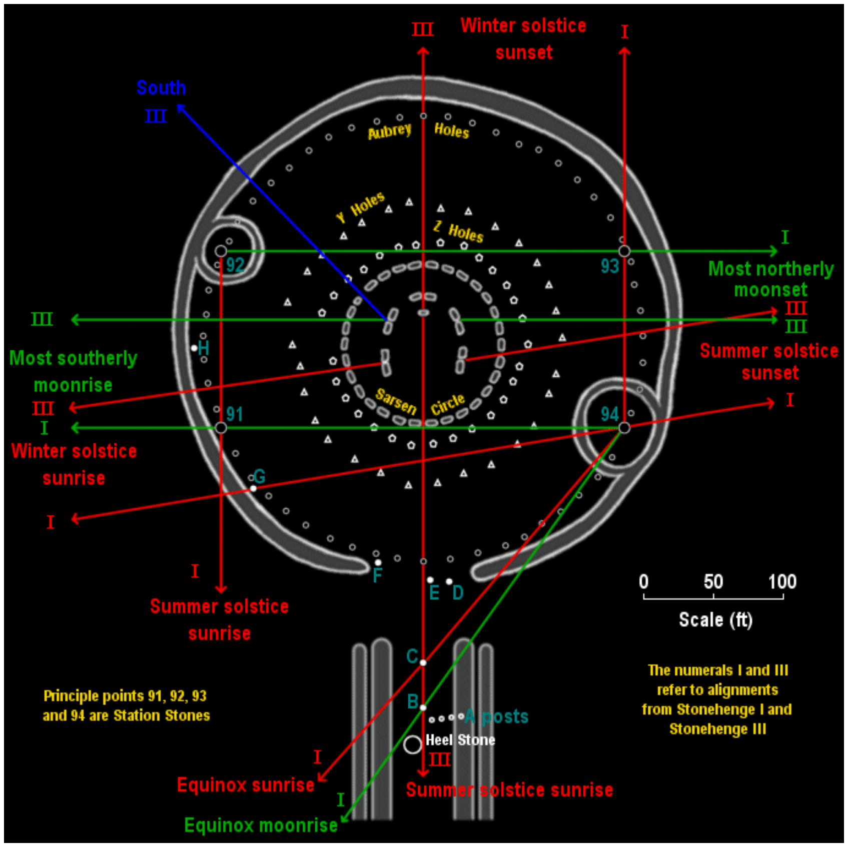
Stonehenge

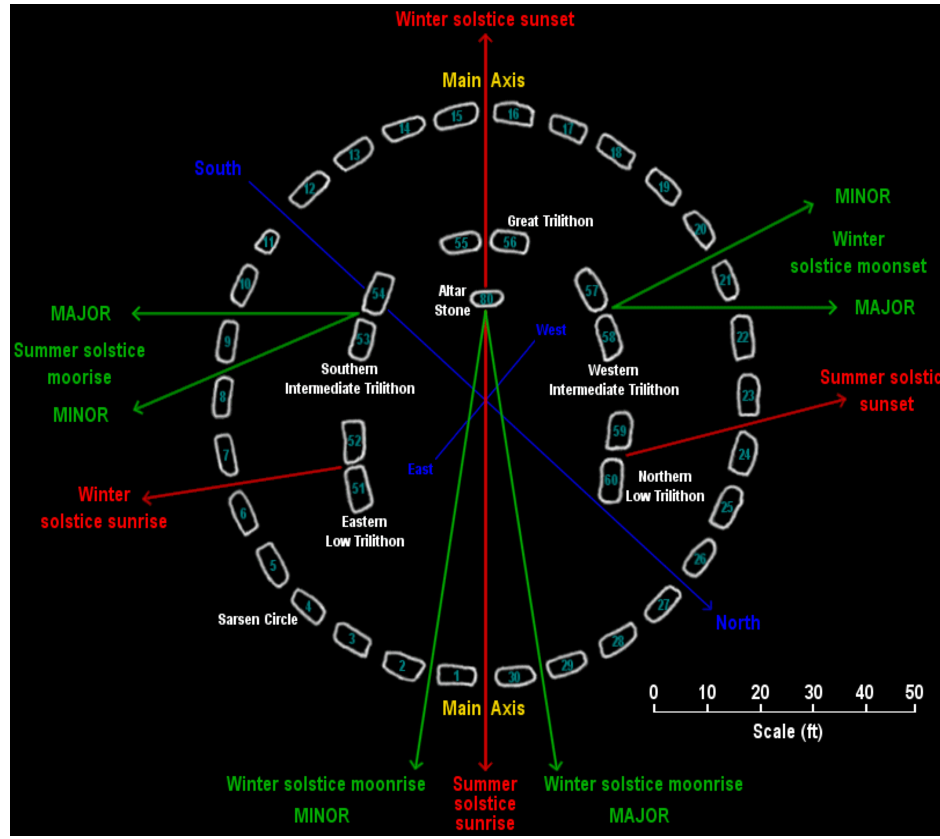
- Some evidence already from 8000 BC (postholes)
- Sacred place, burial place?
- Built in phases between 3100 – 1600 BC
- Astronomical significance – prediction of clipese

Reading:

Hawkins, Nature **200**, 306 - 308 (26 October 1963); doi:10.1038/200306a0

Astronomical significance





http://www.tivas.org.uk/stonehenge/stone_ast.html

Ancient observatories

- Pyramids in Giza
- Around 2500 BC
- N - alignment
- starry sky used for the alignment
- Precession is the key

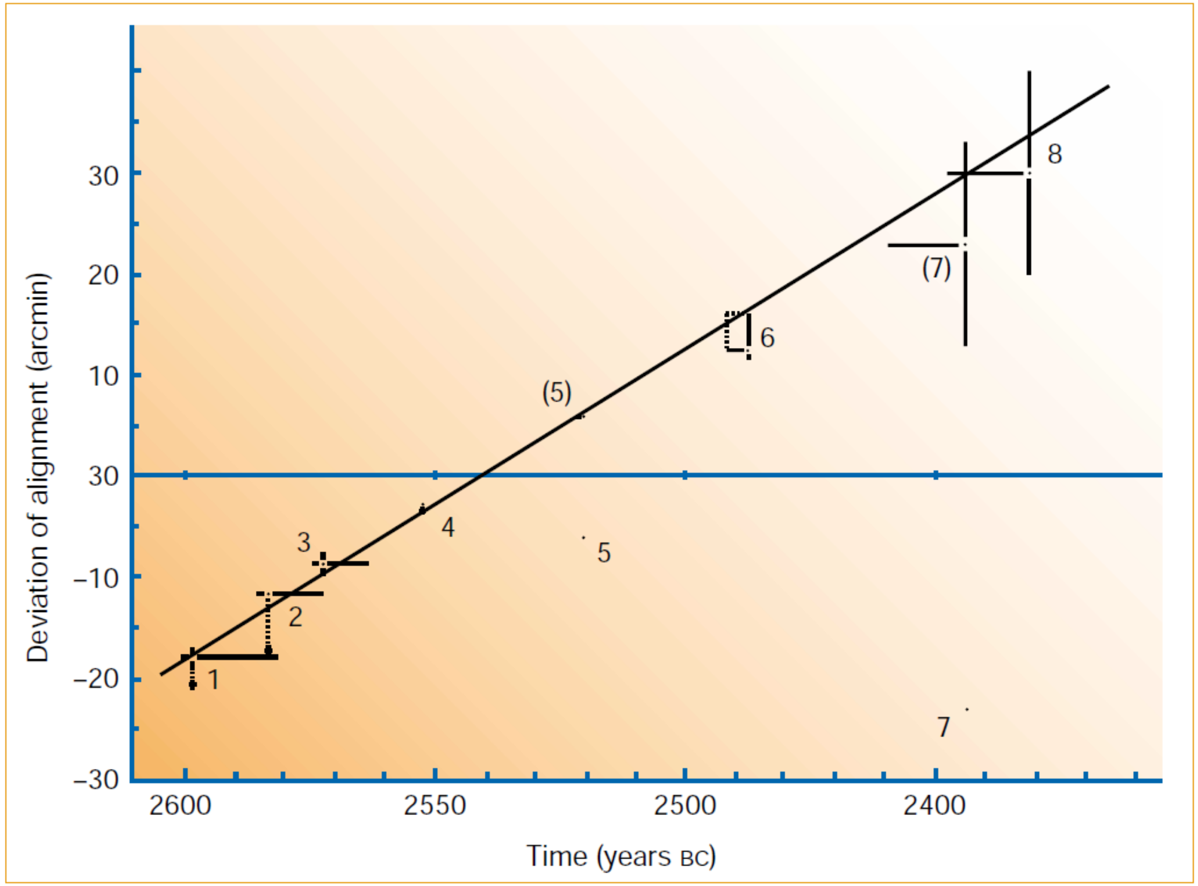


Figure 1 Astronomical modelling of the simultaneous-transit method of orientation. The points are plotted from the data given in Table 1 of ref. 1. The corrected gradient for measurements of orientation using the simultaneous transit of β Ursae Minoris and ζ Ursae Majoris is plotted over the archaeological data. The point at which this line crosses zero can be recalibrated to 2467 BC by astronomical modelling. 1, Meidum; 2, Bent Pyramid; 3, Red Pyramid; 4, Khufu; 5, Khafre; 6, Menkaure; 7, Sahure; 8, Neferirkare. Numbers in parentheses denote points replotted with positive rather than negative values to conform to the dominant trend of the alignments.

http://www.nature.com/nature/journal/v412/n6848/pdf/412699a0.pdf

http://www.dioi.org/vols/wd1.pdf

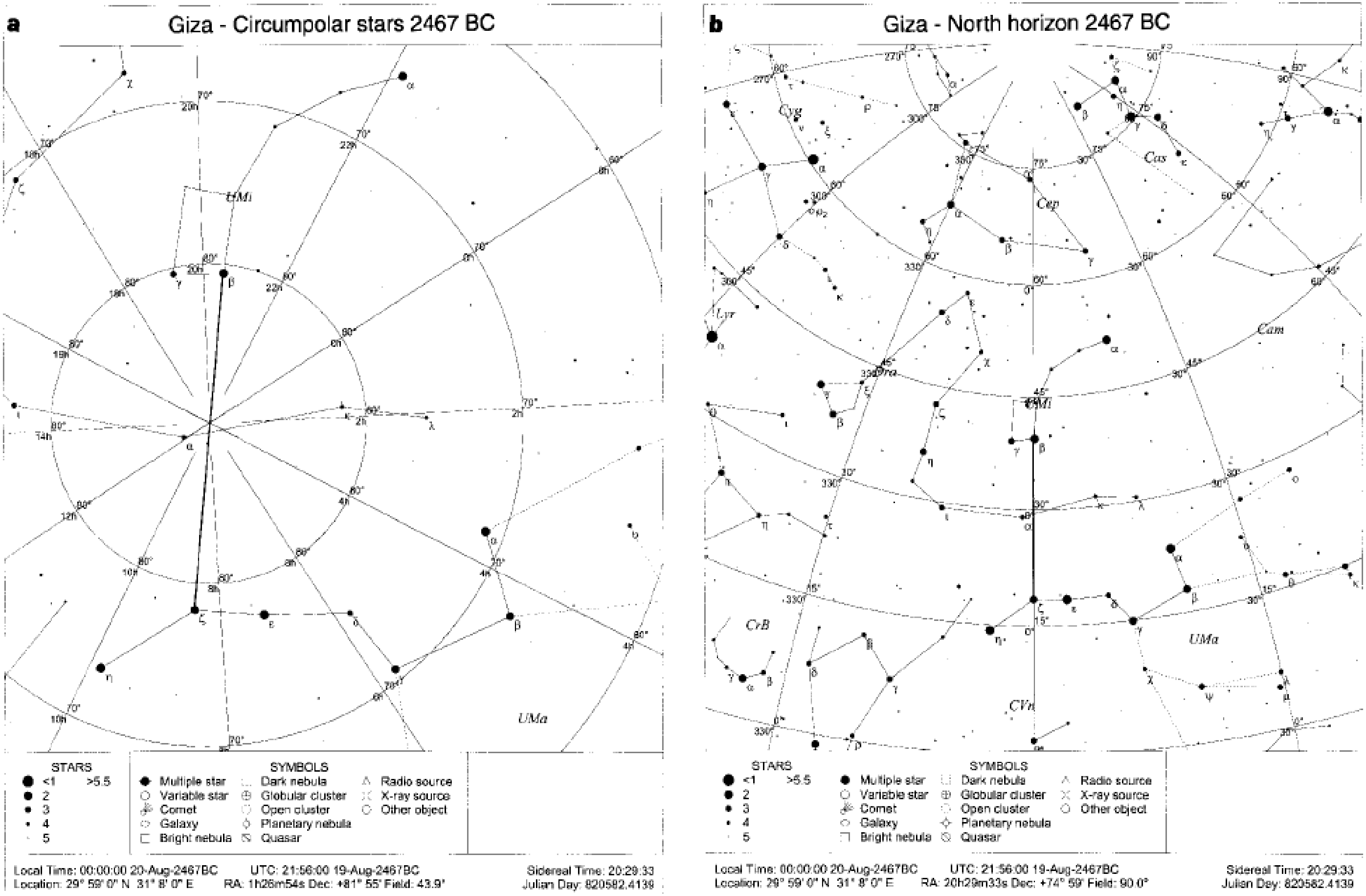


Figure 2 Modelling the simultaneous transit method for Giza, 2467 BC. **a**, A chord between stars β-UMi and ζ-UMa passes exactly through the north celestial pole. **b**, The same stars in simultaneous transit. An alignment taken toward these stars using a plumb-line would be oriented exactly to true north. Maps produced on *SkyMap Pro* 6 (ref. 17).

Kate Spence, 2000, Nature, 408, 320

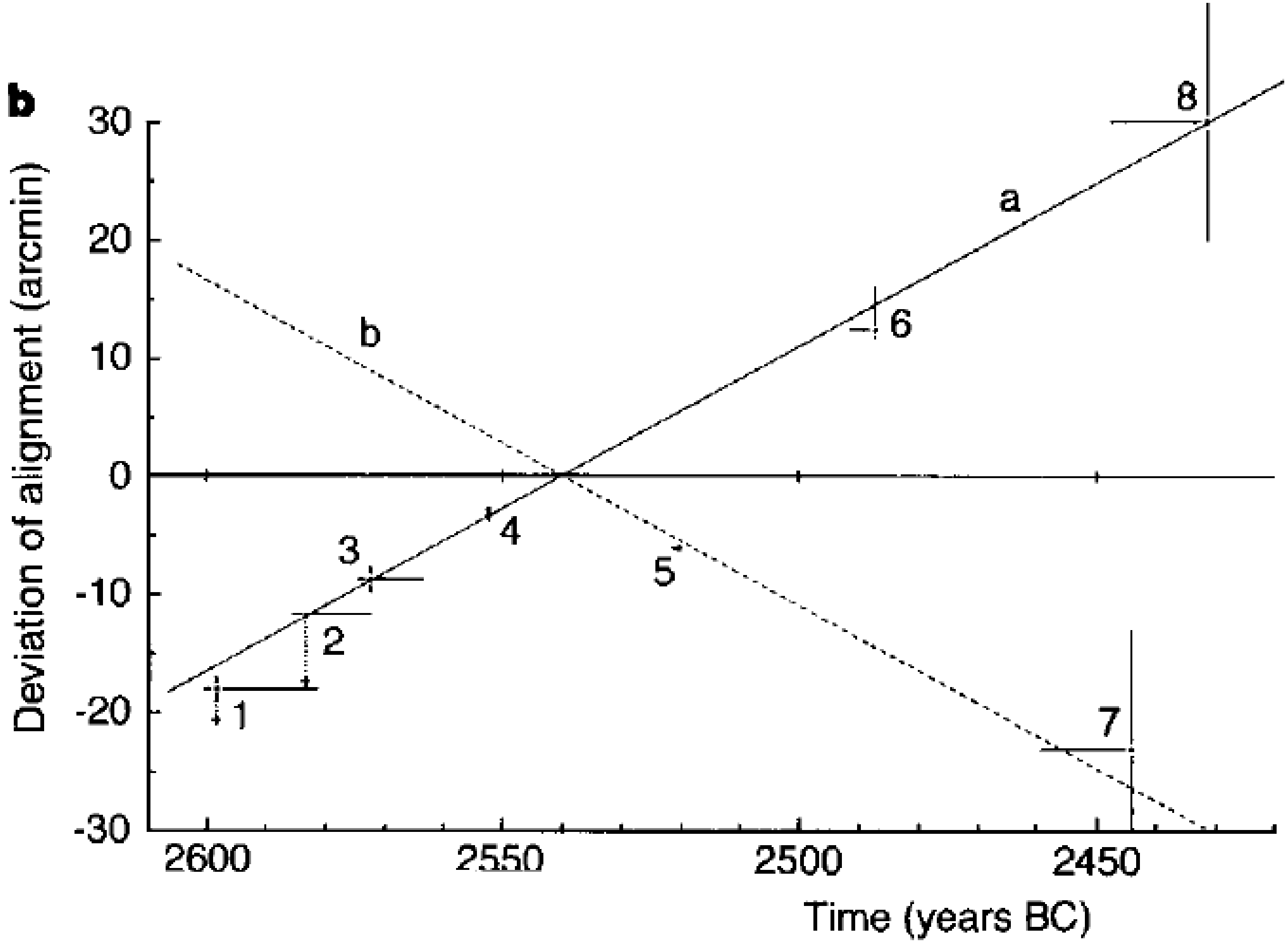


Table 1 Date and orientation of ancient Egyptian pyramids

Ruler	Currently accepted accession date	Orientation — west side of pyramid	Orientation — east side of pyramid	Recalibrated accession date
Djoser	2640 BC		~ + 180′ (ref. 3)	
Snofru–Meidum (1)	2600 BC (–2/+17)	–18.1′ (ref. 11) ±1.0	–20.6′ (ref. 11) ±1.0	2526 BC ± 7
Snofru–Bent Pyramid (2)	[2583 BC] (–2/+11)	–11.8′ (ref. 12) ± 0.2	–17.3′ (ref. 12) ± 0.2	
Snofru–Red Pyramid (3)	[2572 BC] (–2/+9)		–8.7′* ± 0.2	
Khufu (4)	2554 BC	–2.8′ (ref. 1) ± 0.2	–3. 4′ (ref. 1) ± 0.2	2480 BC ± 5
Khafre (5)	2522 BC (–1)	–6.0′ (ref. 1) ± 0.2	–6.0′ (ref. 1) ± 0.2	2448 BC ± 5
Menkaure (6)	2489 BC (–4)	Average: +14. 1′ ± 1.8′ (ref. 2)	+12.4′ (ref. 2) ± 1.0	2415 BC ± 10
Sahure (7)	2446 BC (–15)		~ –23′(ref. 3, 6) ± 10	2372 BC ± 25
Neferirkare (8)	2433 BC (–16)		~ + 30′ (ref. 3) ± 10	2359 BC ± 25
Unas	2317 BC	+ 17. 4′ (ref. 1)	+ 17.1′ (ref. 1)	
Senwosret I	1956 BC		~ –90′ (ref. 13)	
Amenemhat III	1853 BC		+ 15.7′ (ref. 14)	

Ancient observatories

- Chicen Itza – (750-1200 AD) – Mayan civilization
- Serpent appears during the equinox

National Geographic

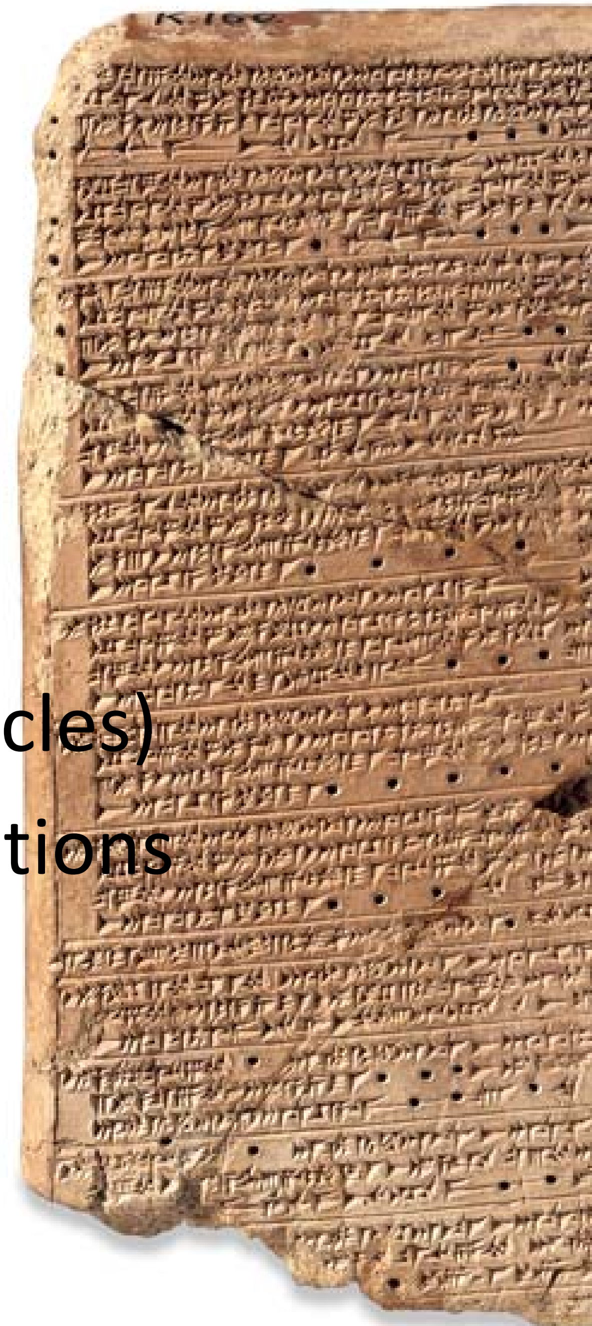
Even portable! (If not fake)

- Nebra Sky disc (Saxony-Anhalt)
- Discovered 1999
- Around 1600 BC
- Stars, Moon, Sun
- Angles between Sun setting at equinoxia
- Features added in steps
- It shows that people observed the sky and nature cycles

Observing techniques
Astronomy in use

Observations of Venus

- Babylonian observations of Venus span of more than 20 years in approx. 17th century BC
- This copy from 7 BC in cuneiform
- Recognition of periodicity (Venus cycles)
- First recorded astronomical observations
- Ammisaduqa 4th after Hammurabi



V. G. Gurzadyan - http://arxiv.org/pdf/physics/0311035v1.pdf

http://www.britishmuseum.org/explore/highlights/highlight_objects/me/c/cuneiform_venus.aspx

British Mus

Venus/Earth

	Venus	Earth	Ratio (Venus/Earth)
Semimajor axis (10^6 km)	108.21	149.60	0.723
Sidereal orbit period (days)	224.701	365.256	0.615
Tropical orbit period (days)	224.695	365.242	0.615
Synodic period (days)	583.92	-	-
Orbit inclination (deg)	3.39	0.00	–
Sidereal rotation period (hrs)	-5832.6	23.9345	243.690
Length of day (hrs)	2802.0	24.0000	116.750

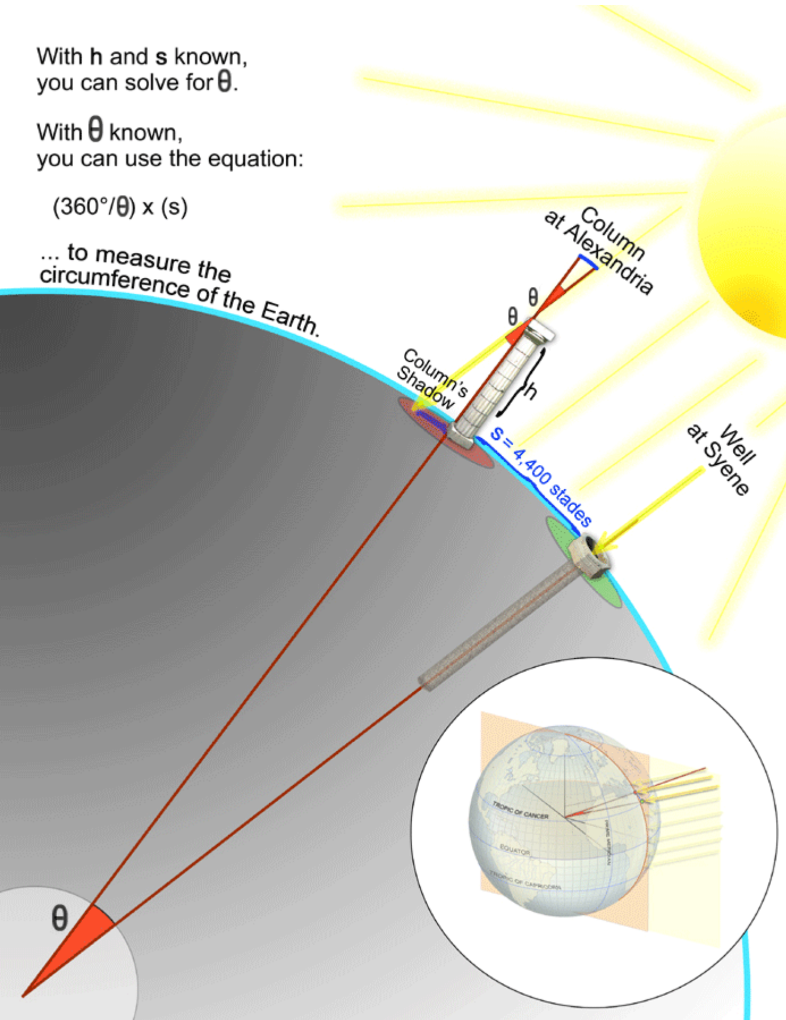
5 x Synodic year Venus = 8 x years Earth

NOTE:

BUT VENUS's & EARTH's ORBITs are eccentric and subject to precession -> we do not see transit every synodic year of Venus!

Circumference of the Earth

- Eratosthenes



Eratosthenes of Cyrene (c. 276 BC – c. 195/194 BC) was a Greek mathematician, geographer, poet, astronomer, and music theorist.

Measured the Earth size to be about 250.000 stadii -> anything between 39.000 – 46.000 km depedndent on the stadium length

Today's value for Earth circumference is: 40.075 km

Therefore, Eratosthenes measured the size of Earth only with an error less than 20%!

Image from: http://oceanservice.noaa.gov/education/kits/geodesy/media/supp_geo02a.html

http://www.windows2universe.org/the_universe/uts/eratosthenes_calc_earth_size.html

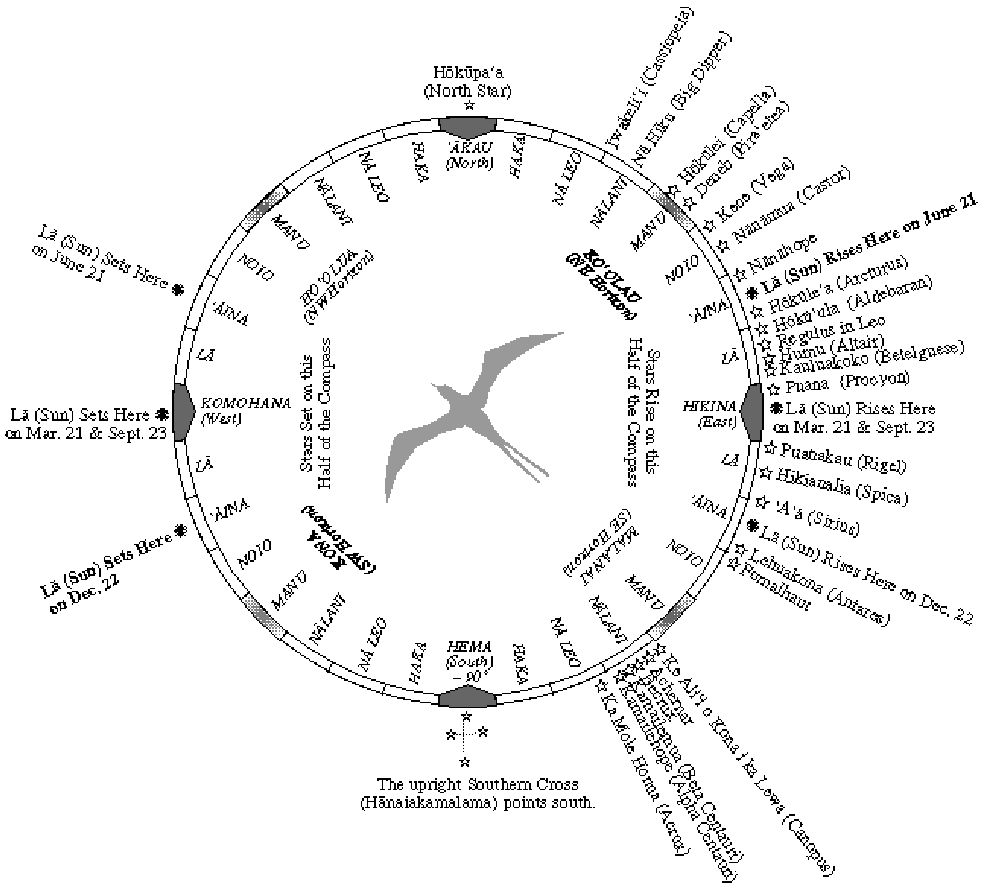
Navigation (Wayifinding)

First settlement of Easter Island:

Polynesia Marquesas-Easter Island 3820 kms – 1200 AD

But sailing centuries before in Polynesian triangle

Polynesian compass



- knowledge of the sky
- observations of the sun
- using the Southern cross

http://www.transpacificproject.com/index.php/ocean-sailing-craft/

0 na hoku no na kiu o ka lani .

"The stars are the eyes of heaven."

Polynesian Voyaging Society- http://leahi.kcc.hawaii.edu/org/pvs/

Instrumentation

First instrumentation

- Human eye

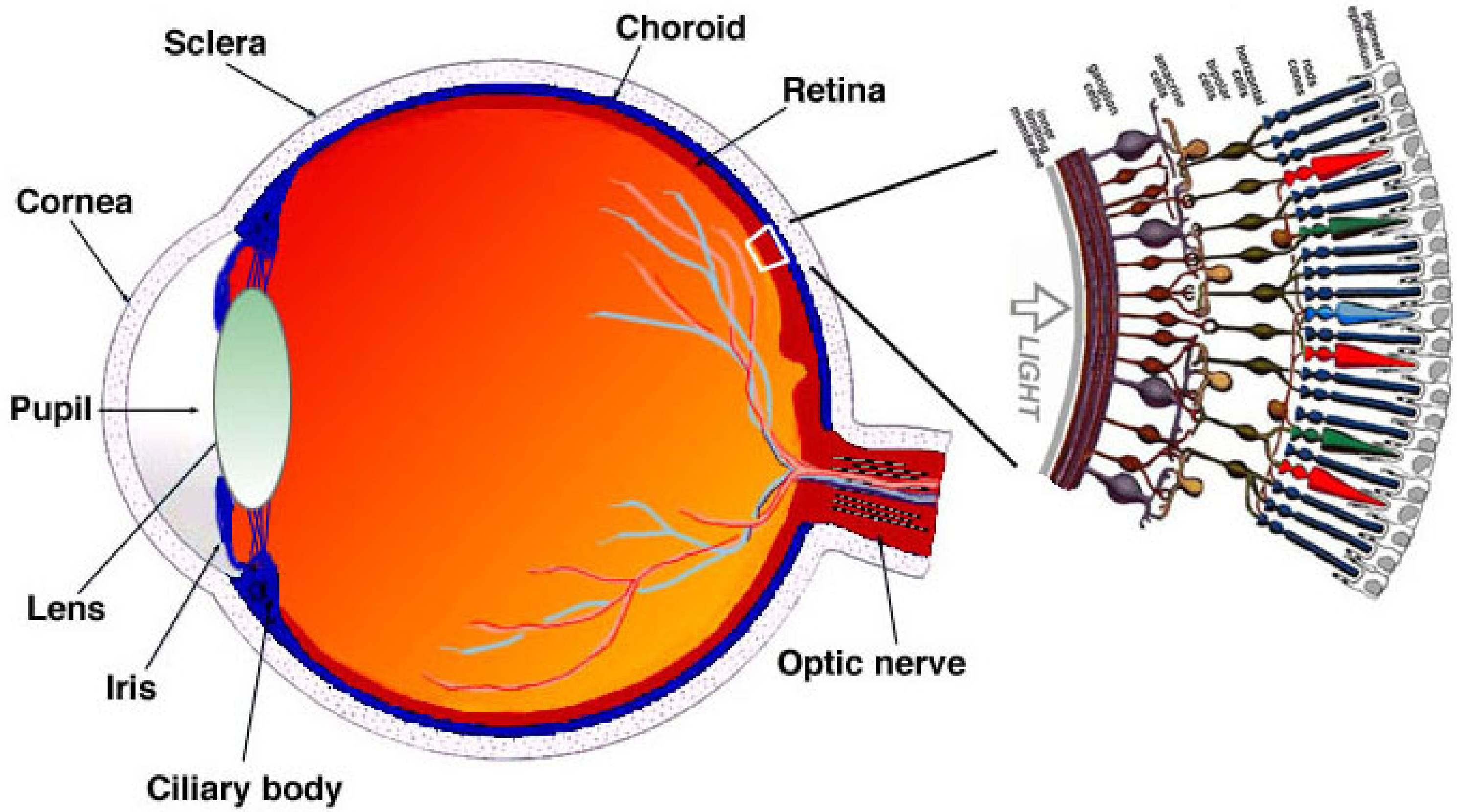


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

Is it so simple?

Photosensitive cells
- rods 100mil.
- cones 70mil.

Reading:
Feynman Lectures

http://feynmanlectures.caltech.edu/I_36.html

http://feynmanlectures.caltech.edu/I_35.html

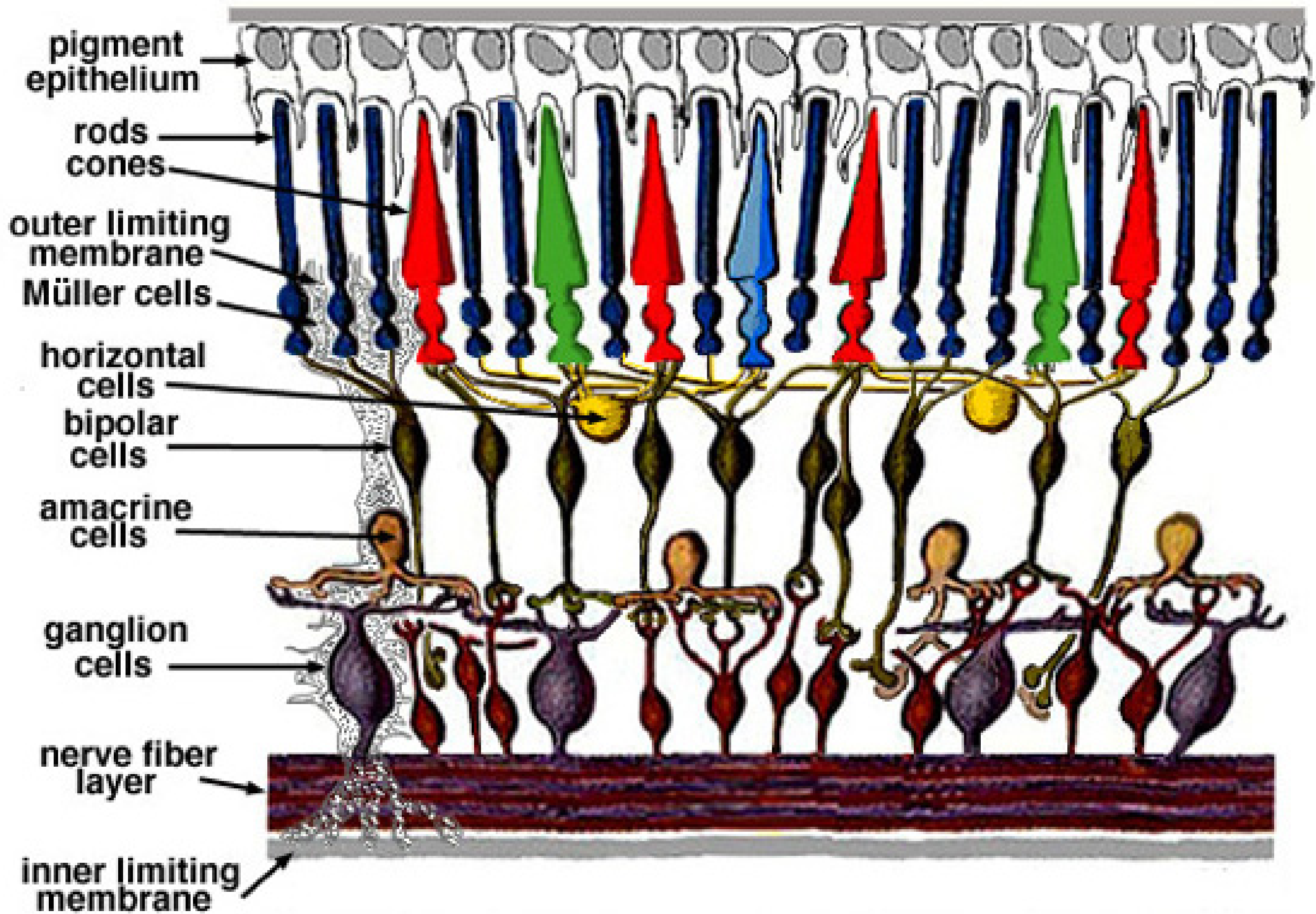


Fig. 2. Simple diagram of the organization of the retina.

http://webvision.umh.es/webvision/sretina.html

(Simple) instrumentation

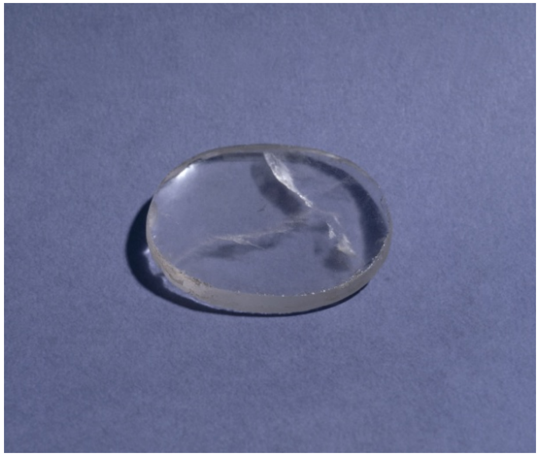
- The pinhole camera

$$D=\sqrt{(2f\lambda)}$$

http://eclipse26jan09.wordpress.com/education/

Reading:
http://idea.uwosh.edu/nick/rayleigh.pdf
Mielenz, K., J. Res. Natl. Inst. Stand. Technol. 104, 479 (1999)

From the lens to the telescope



The British Museum

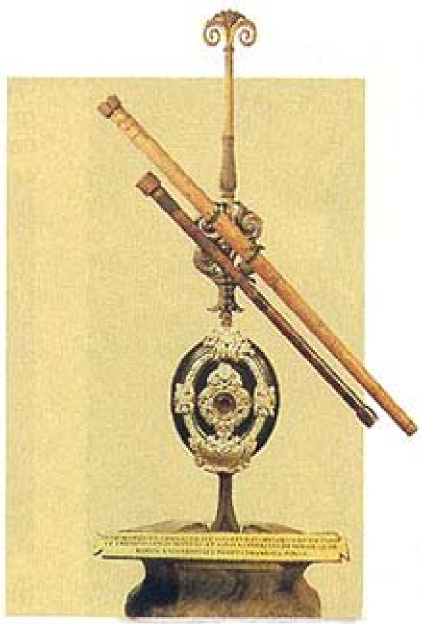
$$P = \frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right],$$

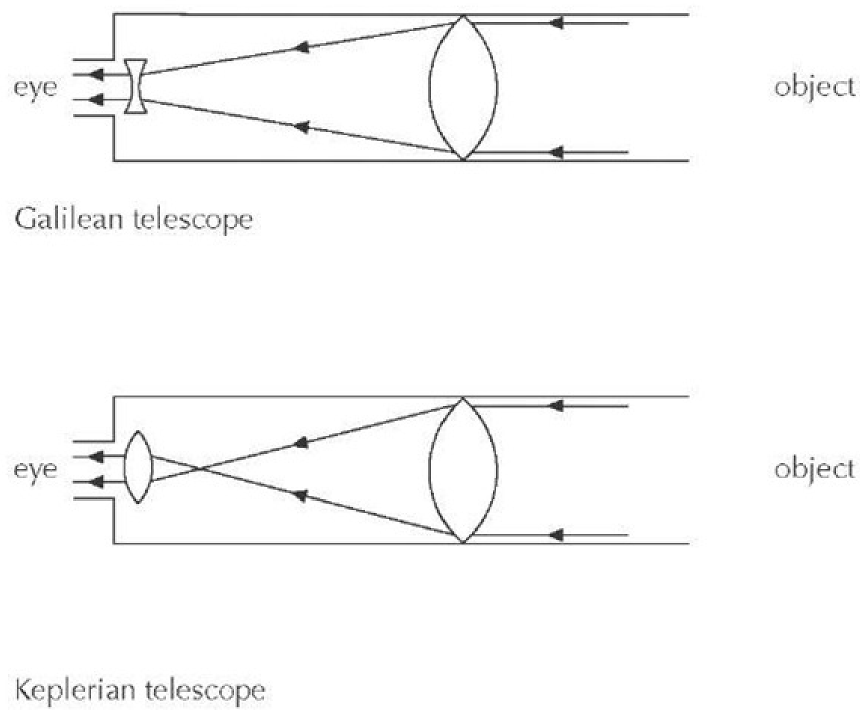
- Convex lens – Nimrud lens 750BC-710BC
  Oval rock-crystal inlay: ground and polished, with one plane and one slightly convex face. It has been regarded as an optical lens but would have been of little or no practical use.

- Eyeglass in a series of frescoes dated 1352
  by Tommaso da Modena-
  depicted Cardinal Hugo of Provence
  [Hugh de St. Cher]

A telescope

- Invented by Dutch eyeglass maker Hans Lippershey
- In 1608 but the it was also claimed by many others





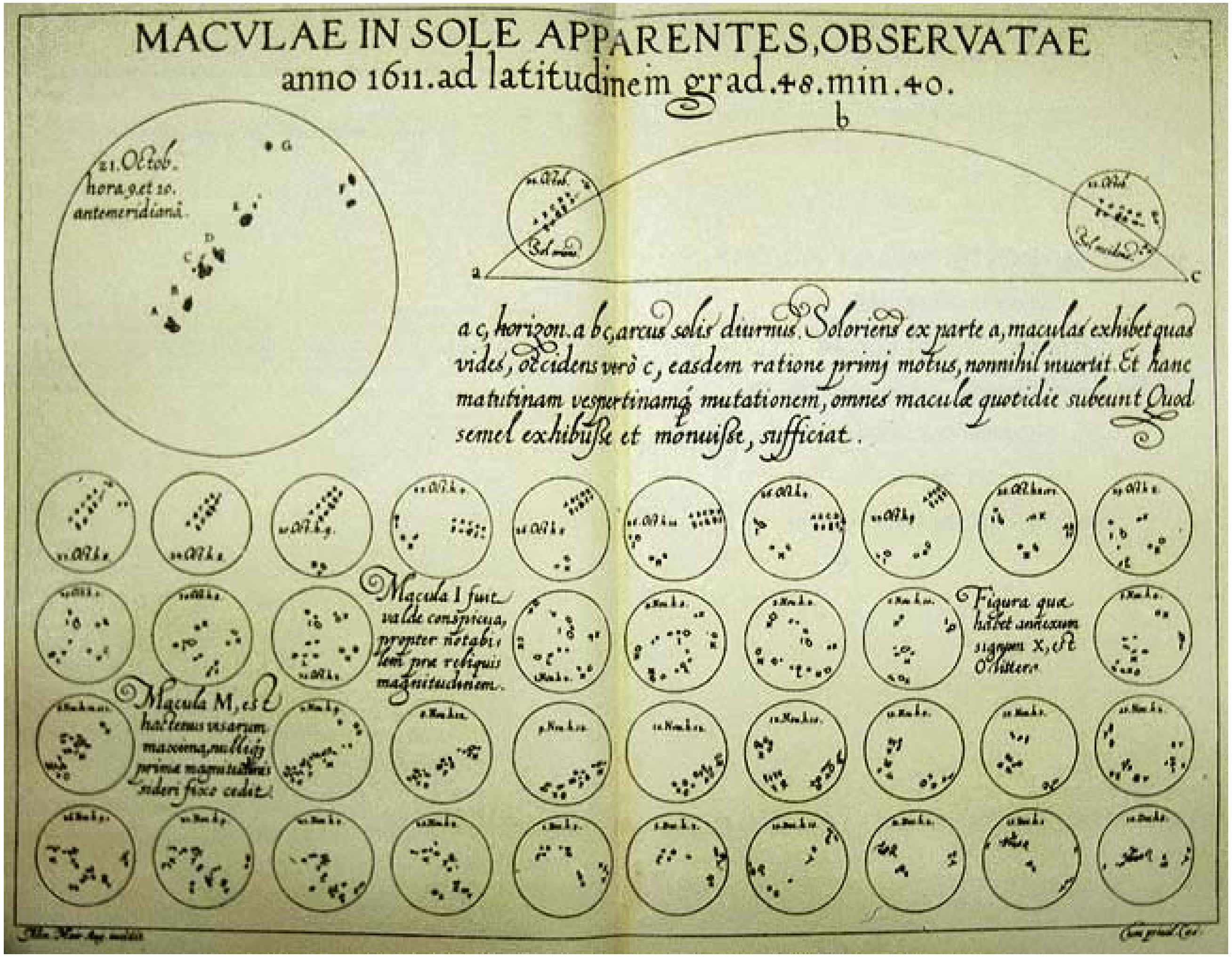
http://www.space.com/21950-who-invented-the-telescope.html

The telescope pointed at the sky

A 1754 painting by H.J. Detouche shows Galileo Galilei displaying his telescope to Leonardo Donato and the Venetian Senate

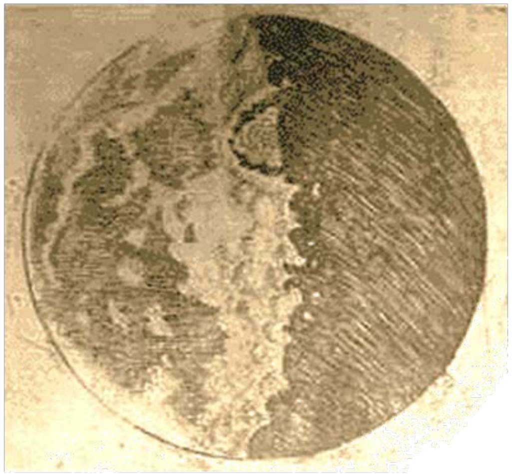
http://www.aip.org/history/cosmology/tools/tools-first-telescopes.htm

First discoveries with telescope



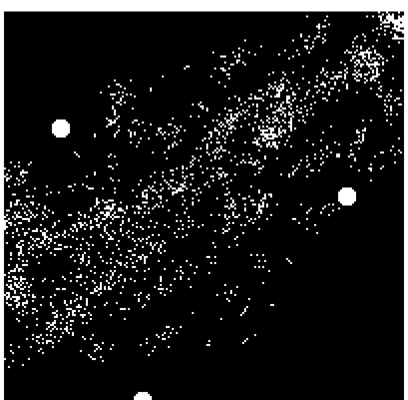
Sunspot plate from Schneiner's *Tres Epistolae*

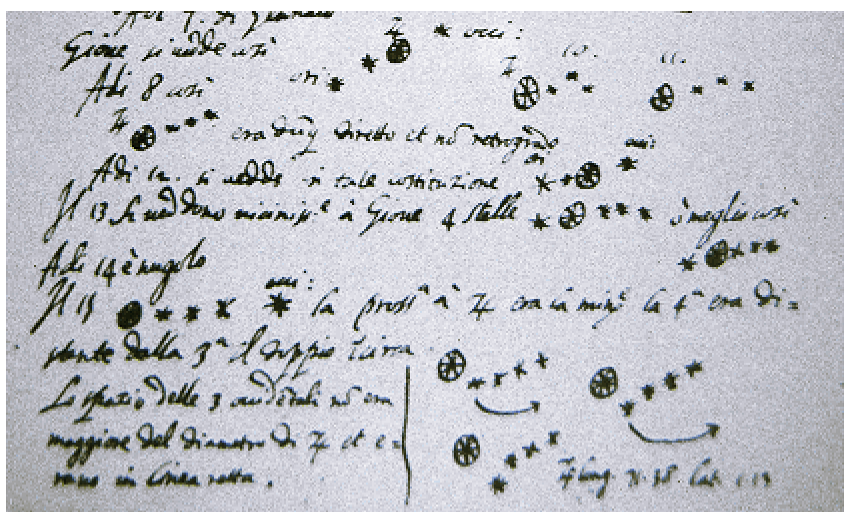
First discoveries with the telescope

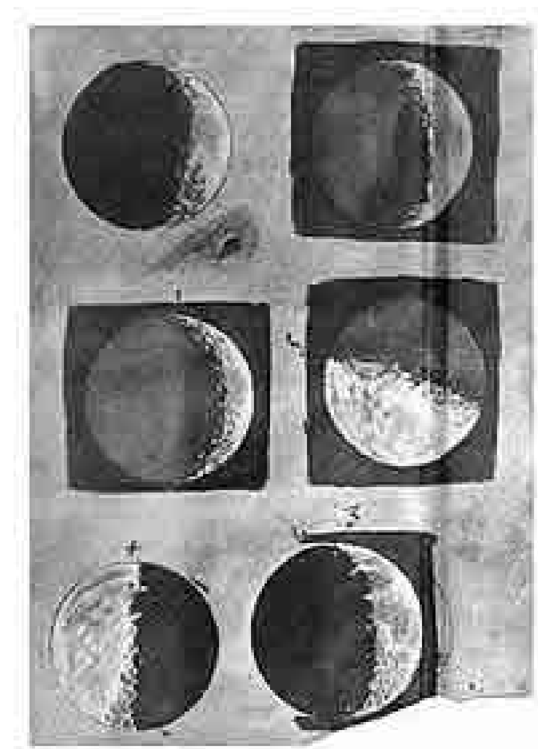


One of Galileo's drawings of the moon. 1610 A. D.

- The Moon
- Galilean moons (Shephard moons)
- Sun spots
- Planets drawings
- The Milky way







That’s it for today!

- NEXT LECTURE 15 October
- Moving towards the modern era!
- Have a great week

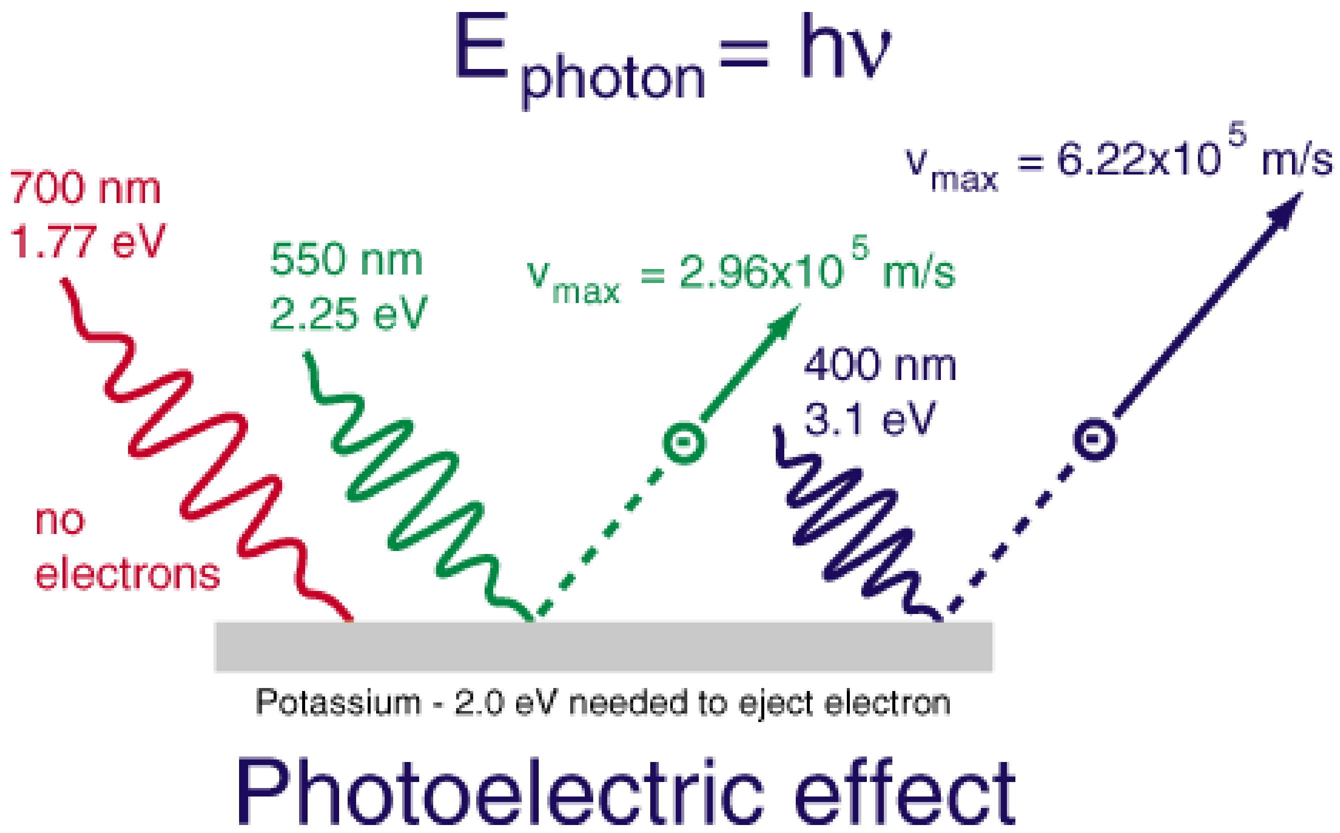
Introduction to modern observing (15 October 2014)

Outline

- The effect which moves the astronomy
- From a photo-plate to a CCD
- Modern observatories
- Example of astronomy done with ESO telescopes

Photoelectric effect

- Driving effect of the modern detectors



From a photo-plate to a CCD

The photographic plate in astronomy

- Invented by: Joseph Nicéphore Niépce and Louis J. M. Daguerre (19th century)
- The first daguerrotype of the moon - John William Draper (at left; 1811-1882) in 1840, in full 20 minute exposure.
- Photography of the first star (Vega) – mid 19th century

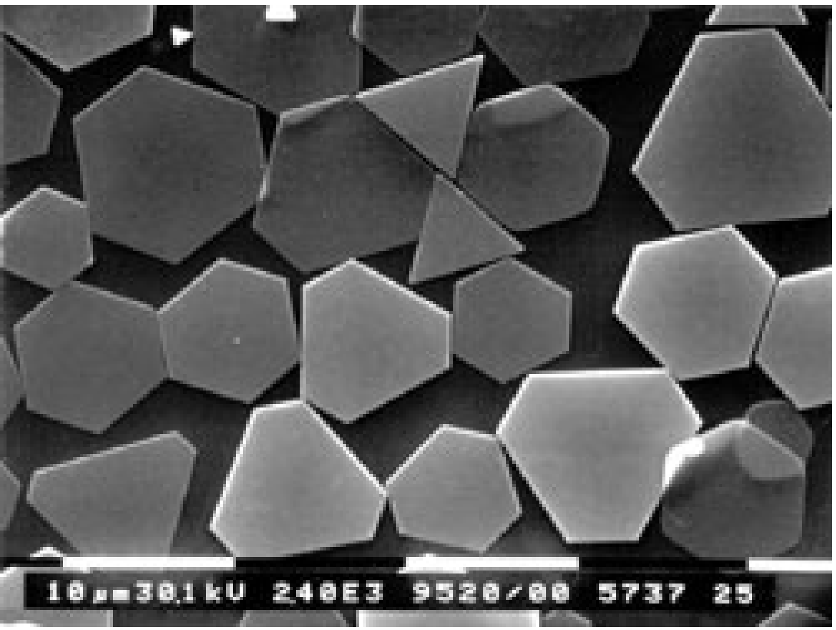
http://www.astro.virginia.edu/~rjp0i/museum/photography.html

Harvard University – photoplate

How does it work?

- Emulsion of silver halide crystals - AgBr sensitive to light (halide salts – halogenidy in CZ)
- Ag atoms created by interaction with light
- Grouping of Ag atoms create latent image (only a few atoms beyond being visible)
- Interaction with developer (electron donor) – Ag ions around the Ag atoms accept the electrons and build-up around the crystals -> IMAGE

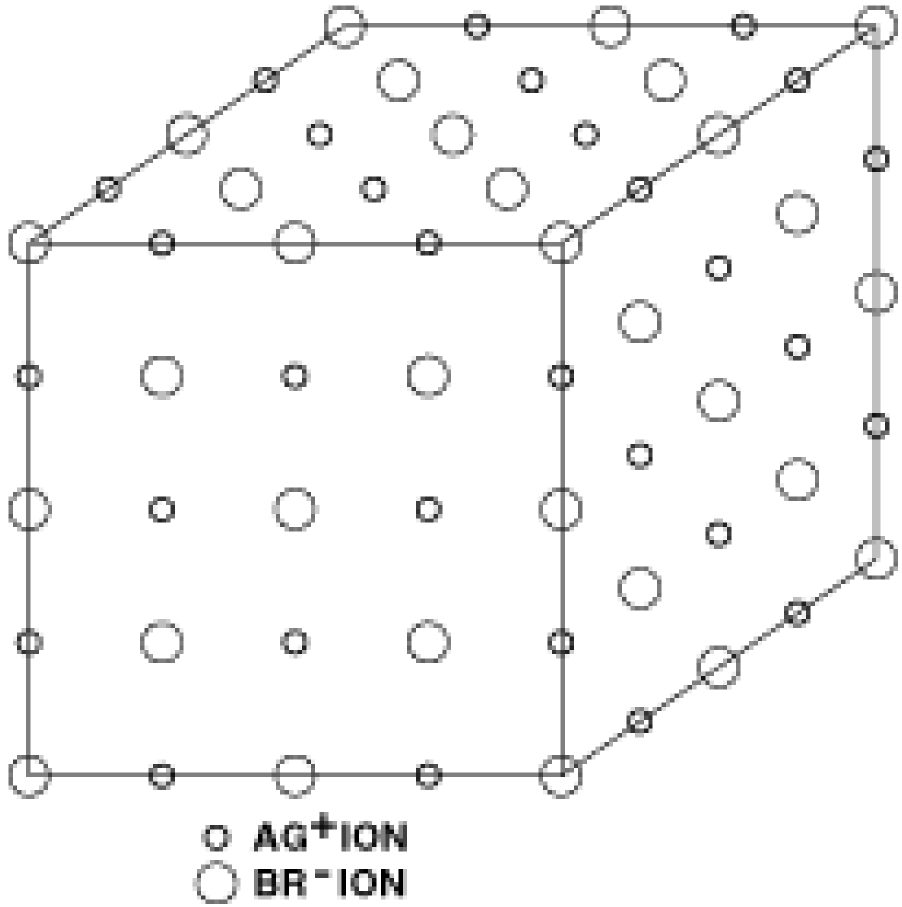
How does it work?



Electron micrograph of tabular grain emulsion

Kodak

- small photosensitve crystals in gelatine
- AgBr or similar
- (Emulsion) deployed on the plate/film
- crystal size 0.1-few micron
- Ag atoms (from 10+) form on the sensitivity spots – latent image
  - displacement in the lattice
  - edge
  - dopant – Au, Silver sulfide…



Kodak

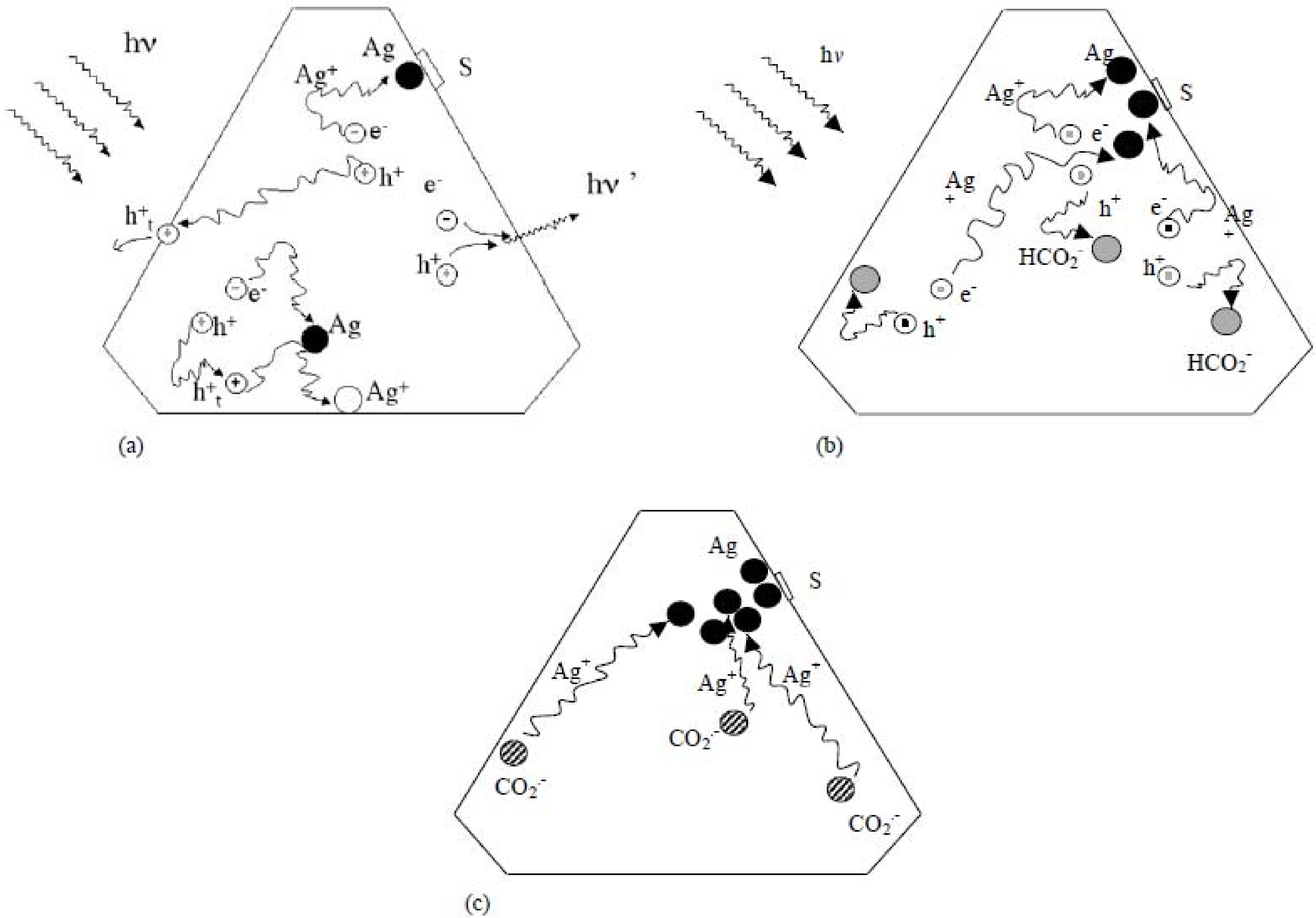


Fig. 2. Latent image formation: (a) undoped AgBr crystal; (b) formate doped crystal: hole scavenging step; and (c) formate doped crystal: silver ion reduction by formyl radical.

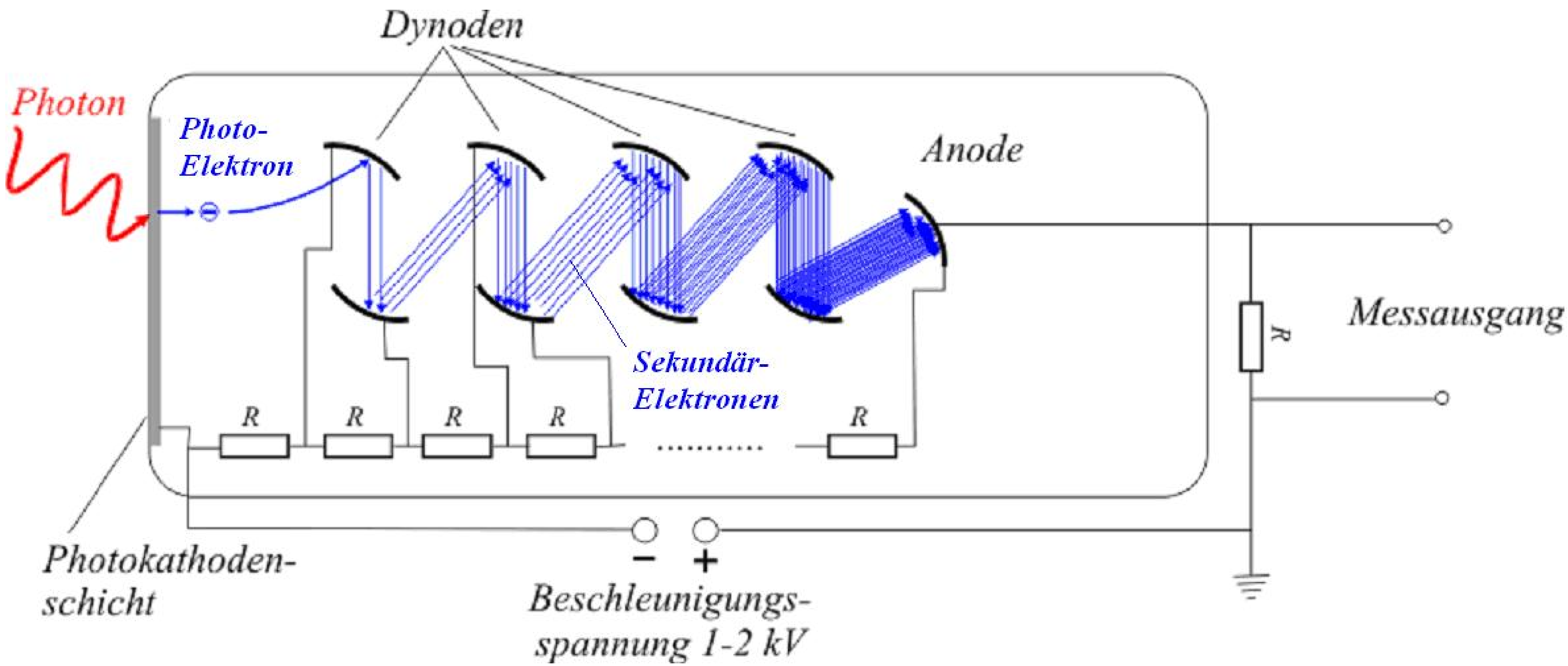
Radiation Physics and Chemistry 67 (2003) 291–296 Belloni J.

Reading

- http://webstag.kodak.cz/US/en/business/aim/industrial/ndt/literature/radiography/18.shtml
- Gurney-Mott theory
- Electron trapping – Shluger et al. Modelling Simul. Mater. Sci. Eng., 17, (2009) 084004
- http://www.astro.virginia.edu/~rjp0i/museum/photography.html

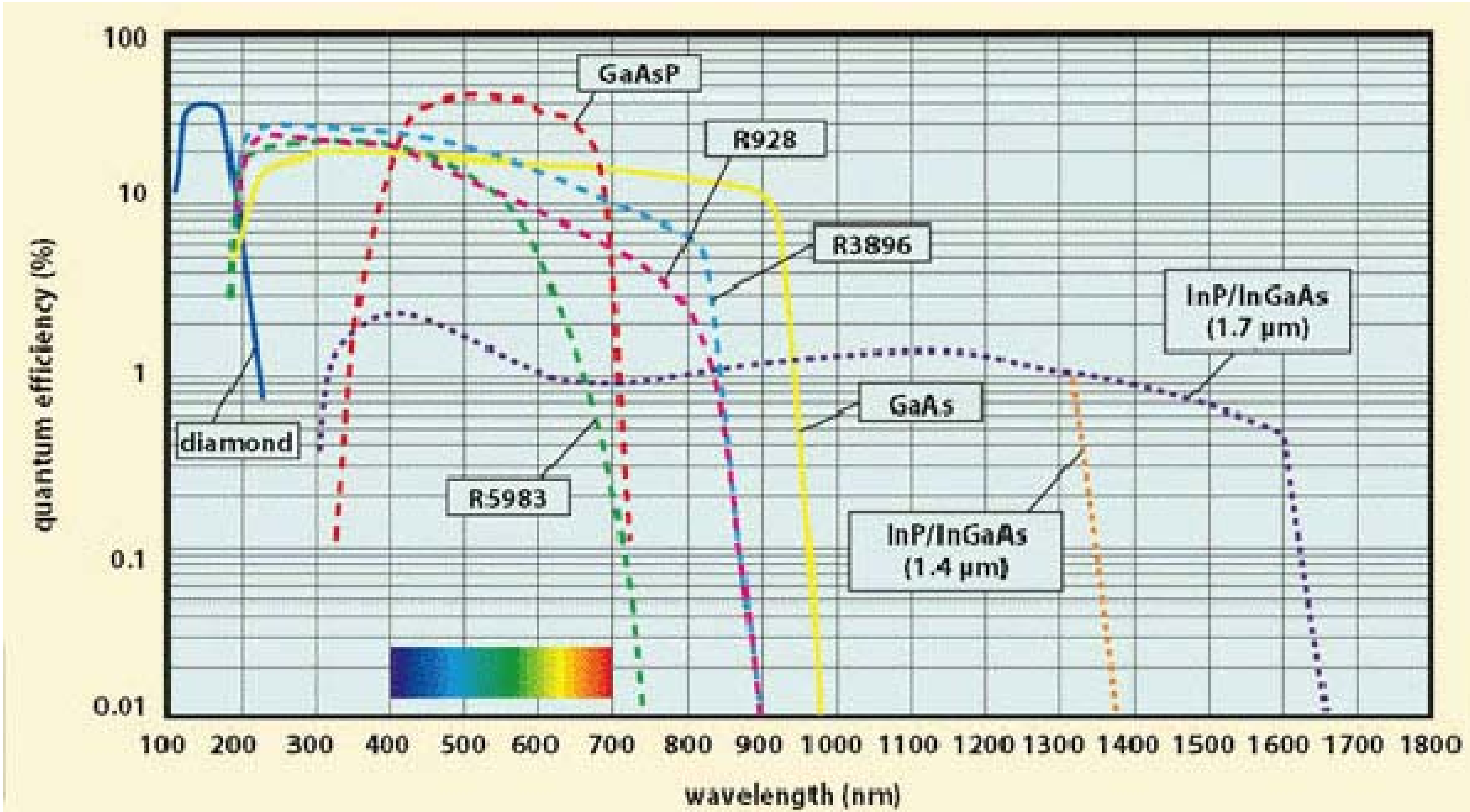
The photomultiplier in astronomy

Computer History Museum
Mountain View, Calif., U.S.



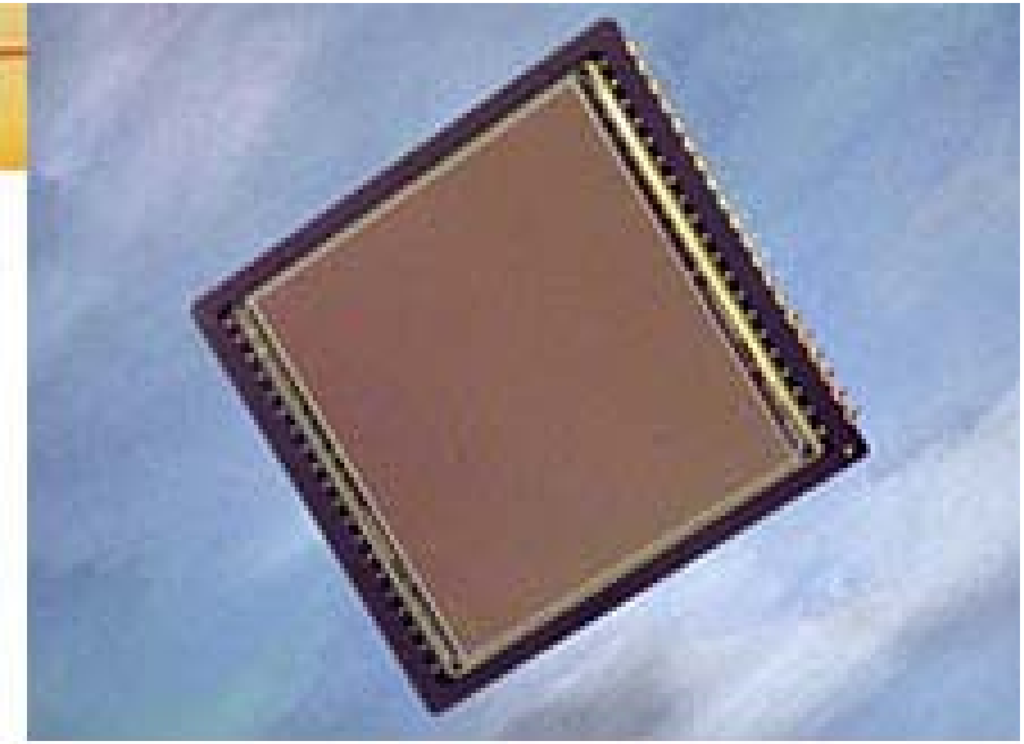
DESY Zeuthen

Spectral response



Olympus

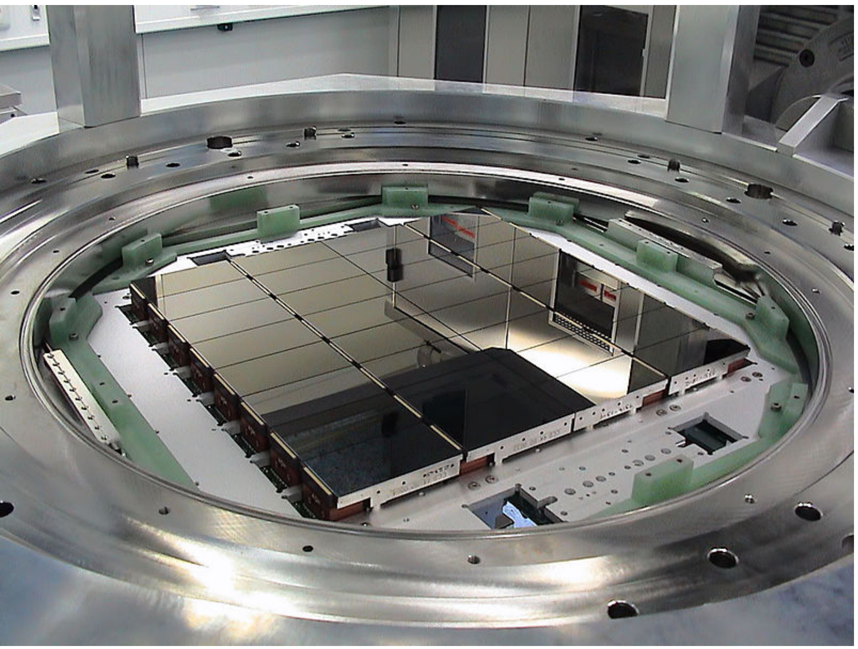
The CCD



Kodak

- Developed in 1969 by AT & T's Bell
- silicon substrate
- large chip arrays
- large FoV
- high QE
- linear
- sensitivities in optical till 1.1 micron
- mostly linear in dynamic range

The principle



Omegacam at Paranal - ESO

- Detector consists of pixels of microns size
- Photodiodes sit in p-Silicon substrate
- A gate is an electrode controlling the charge transfer in the Si substrate
- Photon creates a pair hole + electron in Silicon substrate
- Electron moved to the surface, hole to the deeper substrate – electrons kept in the potential well
- Voltage applied on the gates to move the charge to the register = readout
- Why is CCD good in optical?
- Si – bandgap about 1.1eV energy < 1.1 micron = OPTICAL
- To release electron in a Si semiconductor an incident photon needs to carry at least 1.1eV energy or higher!

Nice reading:
http://www.physics.udel.edu/~jlp/classweb/ccd.pdf

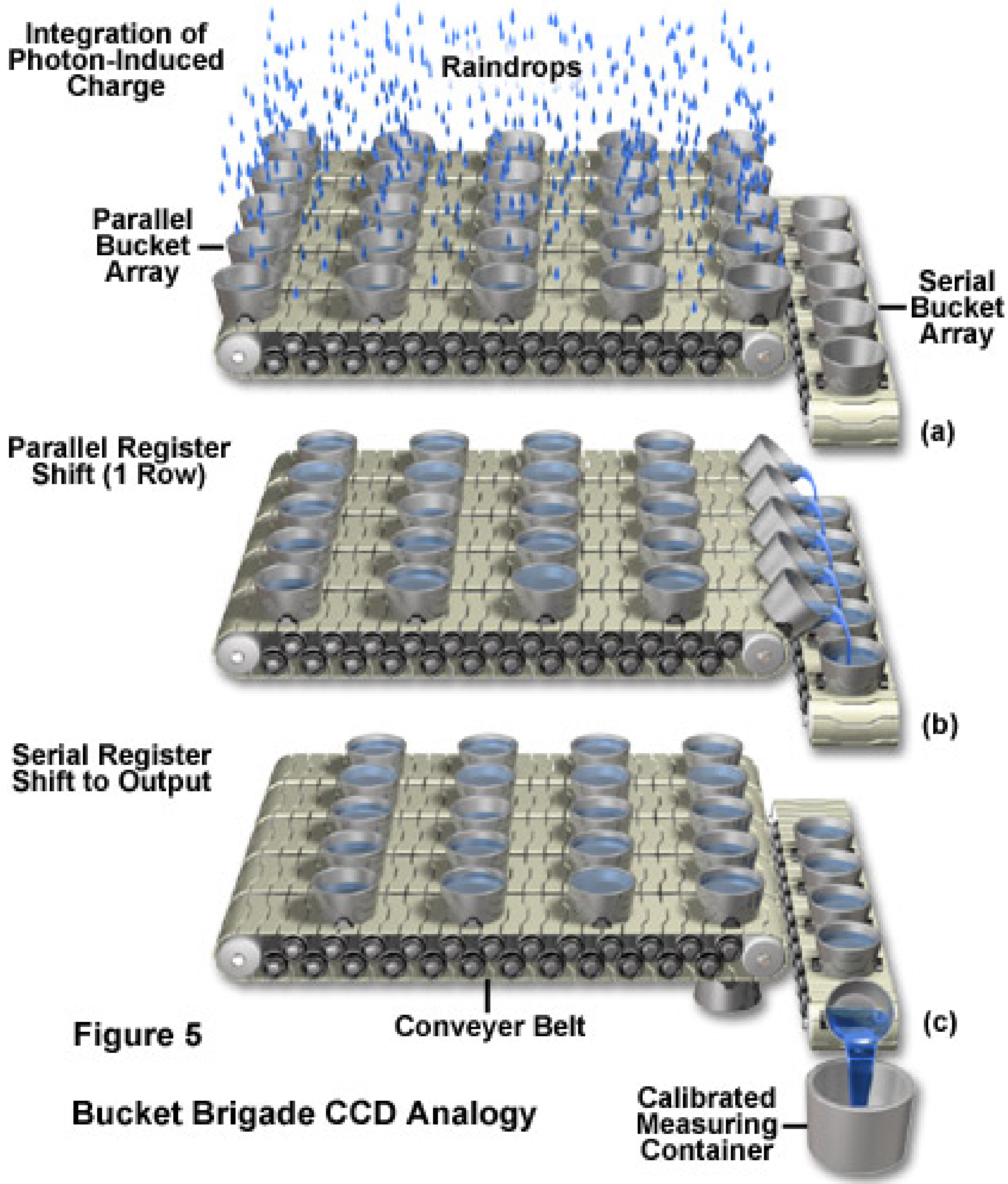


Image by NIKON

Examples

Lagoon Nebula - Berlin Eoplanet Search Telescope, Cerro Armazones, Chile
Image by Th. Fruth (DLR)

Modern observatories

Where and why to build an observatory?

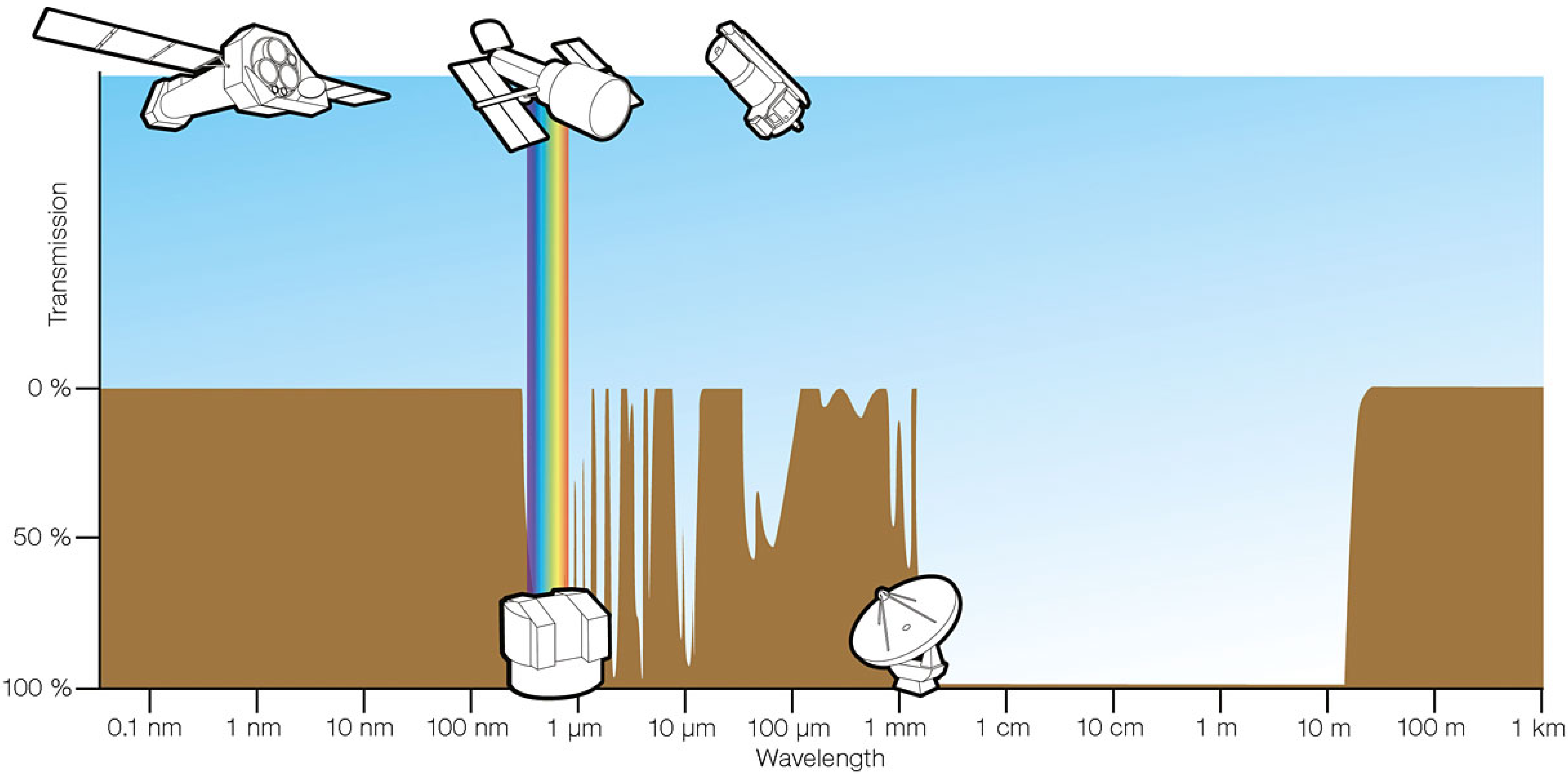
Key factors for decision:

- Science drivers
- Which wavelength?
- Weather statistics
- Site testing

Modern observatories (just a few)

European Southern Observatory

Wavelength coverage



How a good site is selected? Paranal example

The "Discovery" of Paranal

L. WOLTJER[1], *Observatoire de Haute-Provence, France*

Introduction

Early morning on April 10, 1983 an expedition consisting of Mr. Bachmann, Ms. Demierre, Dr. Muller, Mr. Schuster, Mr. Torres and myself left La Silla to explore some northern sites in Chile. The next day we visited the Paranal area for a first inspection. After subsequent discussions with the *Intendente* in Antofagasta and a visit to the areas of S. Pedro de Atacama, we returned by plane to have another look at Paranal and its surroundings. Soon thereafter, under the leadership of Dr. Ardeberg, an observing station was set up at Paranal that provided the data based on which some seven years later the decision could be taken to locate the VLT there. It may be of some interest to describe the reasons why Paranal could be considered a promising site so early on.

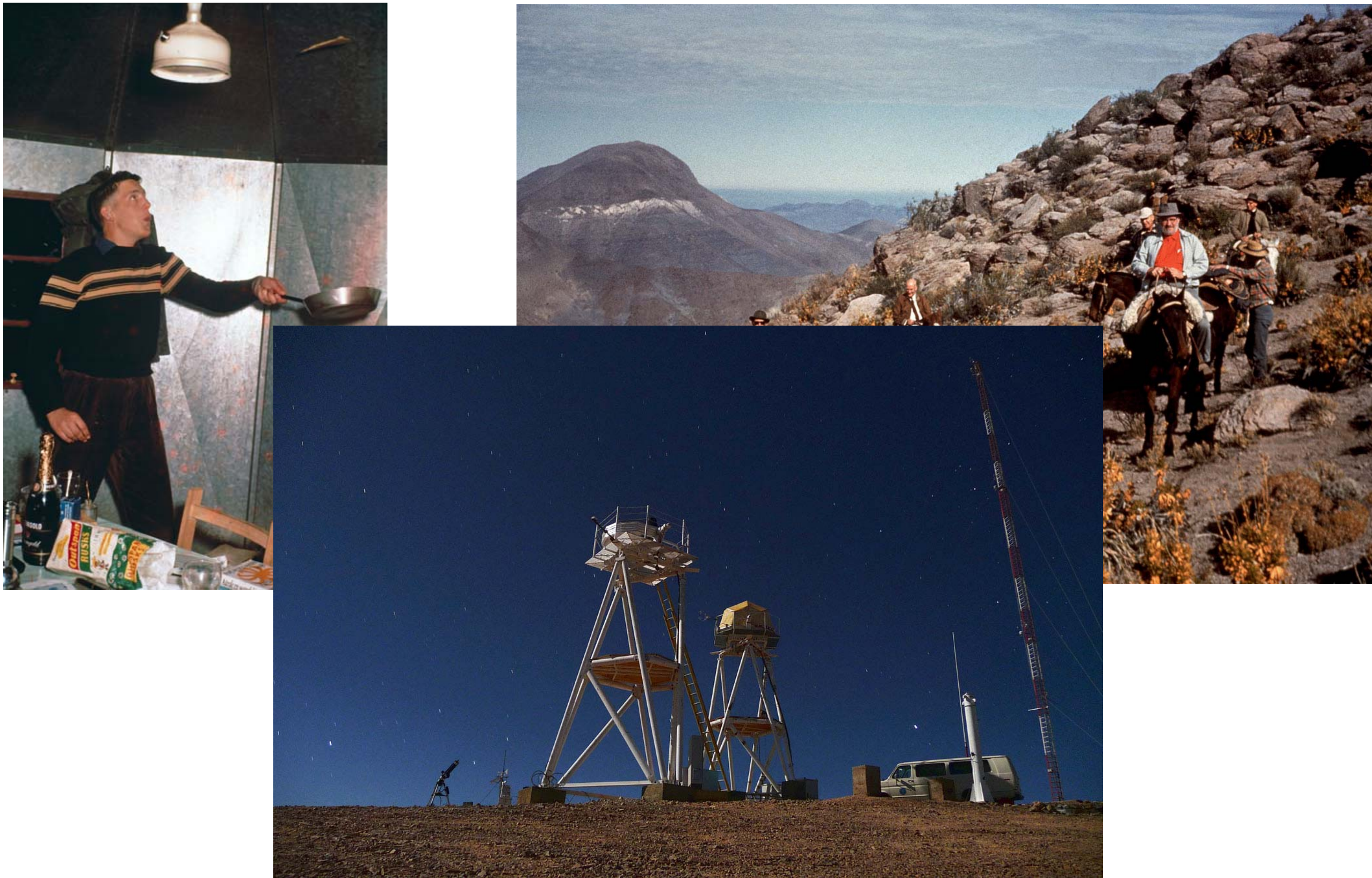
At the beginning of the eighties plans for the VLT were still in a preliminary stage. It was clear, however, that infrared observations would constitute an important part of the raison d'être of the VLT; the choice of 8-m unit telescopes was, in part, dictated by the wish not to be diffraction limited at 20 microns wavelength. Since infrared observations from the ground are hindered mainly by water vapour in the earth's atmosphere, a very dry site was needed. Water vapour will absorb wherever it is located, and what matters is therefore not the local humidity but the integrated amount of water vapour in the atmosphere above the site. It is usually expressed in mm of precipitable water – the amount of rain that would fall if all the water vapour rained out. Sites with less than 1 mm of H_2O are comparatively very good sites for IR observations, sites with more than 3 mm rather poor. The local humidity has only a limited relation to the integrated amount of water vapour. If it is locally very humid, the integrated

Figure 1: *The first ESO expedition to Paranal (from left to right: H.-E. Schuster, A. Muller, G. Bachmann, and the author; photograph Ms. U. Demierre).*

[1]Professor Lodewijk Woltjer was Director General of ESO from 1975 to 1987.

https://www.eso.org/sci/publications/messenger/archive/no.64-jun91/messenger-no64-5-8.pdf

Site testing



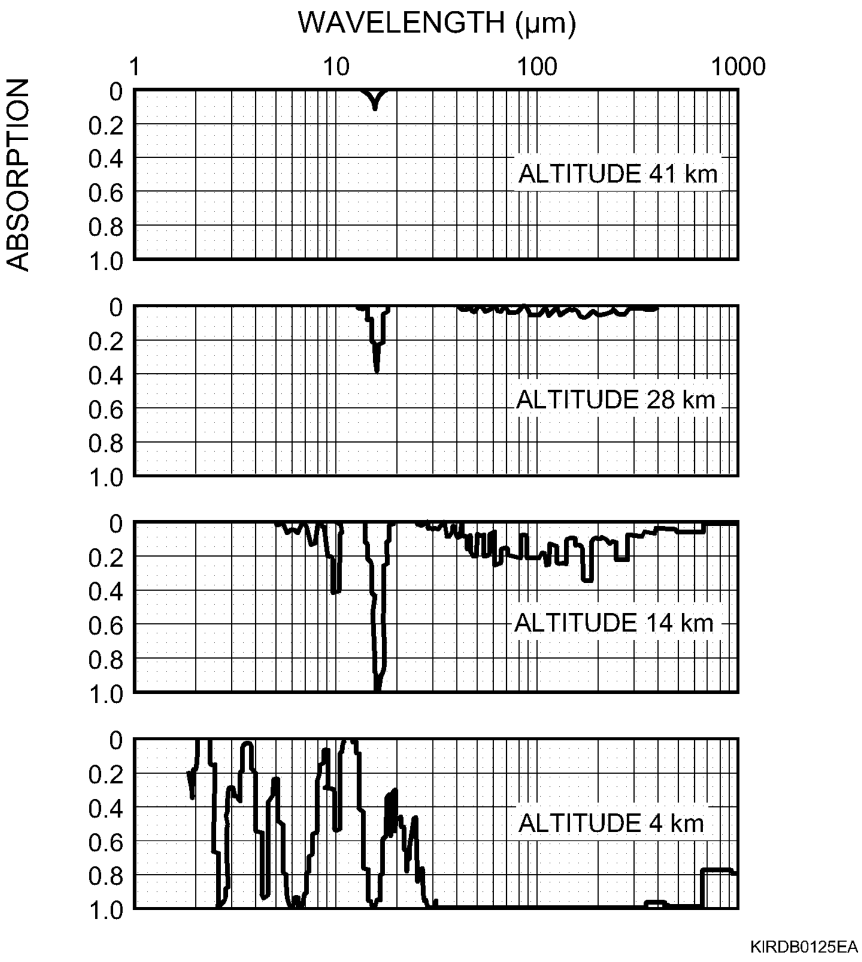
- Interestingly, in terms of atmospheric stability La Silla was found to be better than previously thought, with a measured median "seeing" [2] of 0.76 arcsec. Paranal is better with a mean of 0.66 arcseconds, but of even greater importance is the fact that the number of clear nights of exceptional quality (seeing better than 0.5 arcsecond) is about 2.4 times higher on Paranal (16% of all nights) than on La Silla (7 %). Indeed, during one night in September 1990, the mean seeing at Paranal (over 10 hours) was measured with a "seeing monitor" as only 0.32 arcsecond, reaching the incredibly good value of 0.25 arcseconds during three consecutive hours.
- The atmospheric conditions on Paranal will allow the VLT to take full advantage of its unique imaging and spectroscopic capabilities so that fainter and more distant objects can be observed than with any other telescope in the world. Moreover, when the VLT is supported by "adaptive optics", it will produce images that are almost as sharp as if it were in space. In the "interferometric" mode, when the light from the four 8.2-m telescopes is combined coherently (in the same phase), the resolving power of the VLT is further increased, so that even finer details can be seen. Under optimal circumstances, it should be possible to achieve a resolution of 0.0005 arcseconds. This would correspond to imaging 1 metre objects on the surface of the Moon.
- Because of the extremely low atmospheric water vapour content in the Paranal region, probably the driest area on the surface of the Earth, this site is also highly suited for astronomical observations in the infrared and submillimetre wavelength regions.

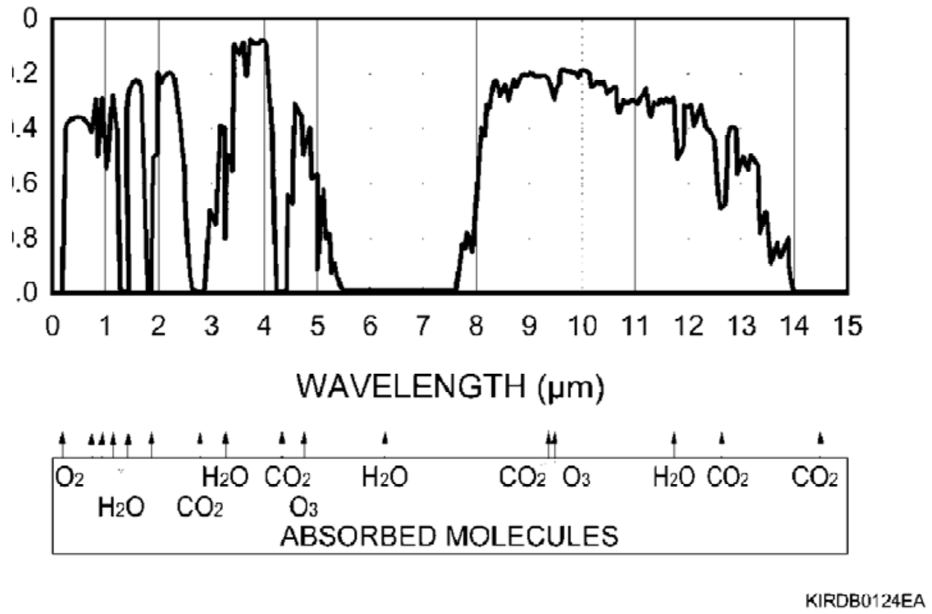
From:

https://www.eso.org/sci/publications/messenger/archive/no.64-jun91/messenger-no64-5-8.pdf

Cerro Paranal observatory

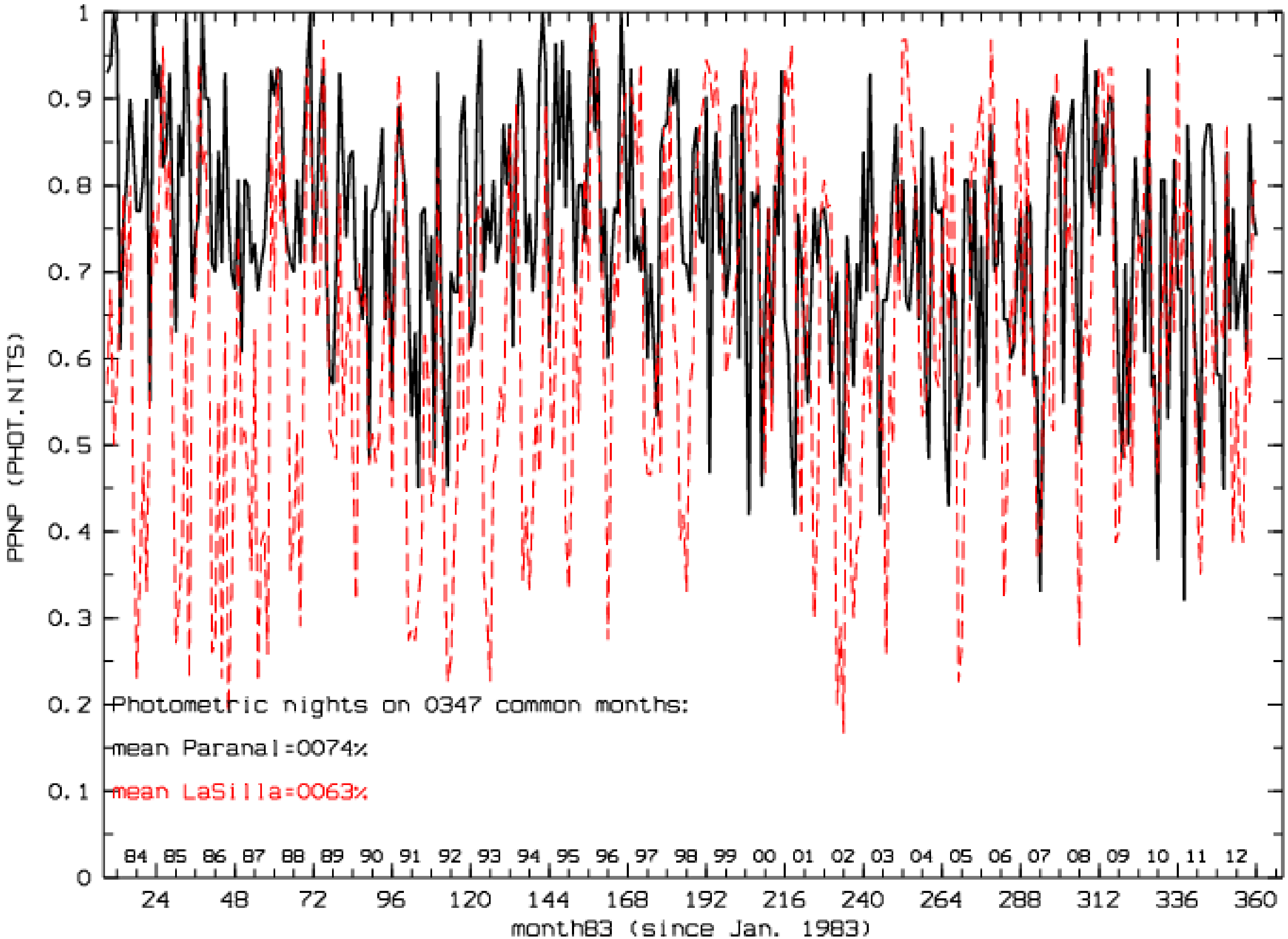
Why Paranal (Chile)?





Material from HAMATSU

Why Paranal?



Data in slides: ESO Astroclimatology web - http://www.eso.org/gen-fac/pubs/astclim/paranal/

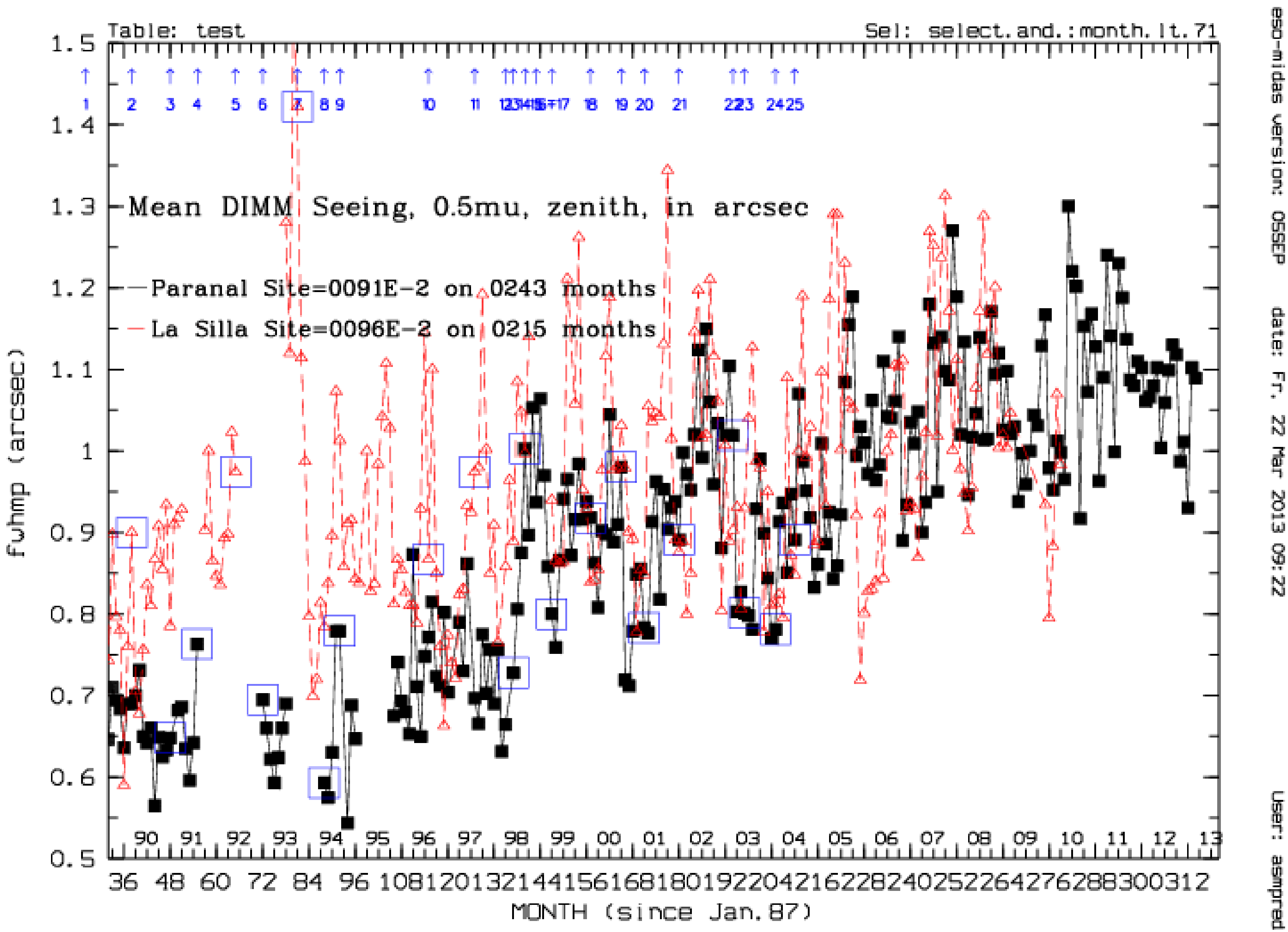
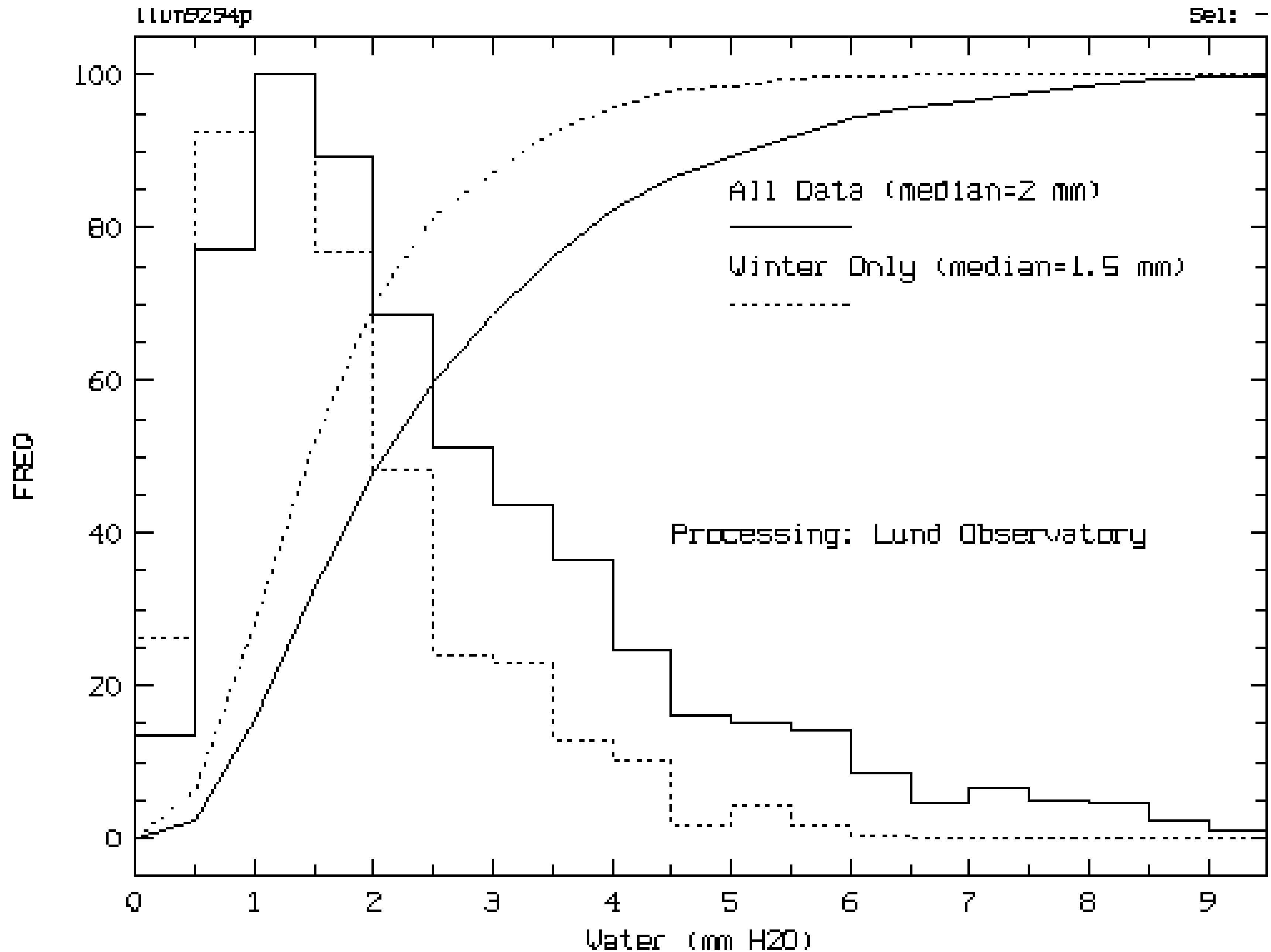


Table: test
Sel: select.and.:month.lt.71
Mean DIMM Seeing, 0.5mu, zenith, in arcsec
Paranal Site=0091E-2 on 0243 months
La Silla Site=0096E-2 on 0215 months
fwhmp (arcsec)
MONTH (since Jan.87)
90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13
36 48 60 72 84 96 108 120 132 144 156 168 180 192 204 216 228 240 252 264 276 288 300 312
0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5
eso-midas version: 05SEP
date: Fr, 22 Mar 2013 09:22
User: asmpredi


llun8294p
Sel: -
100
80
60
40
20
0
FREQ
0
1
2
3
4
5
6
7
8
9
Water (mm H2O)
All Data (median=2 mm)
Winter Only (median=1.5 mm)
Processing: Lund Observatory

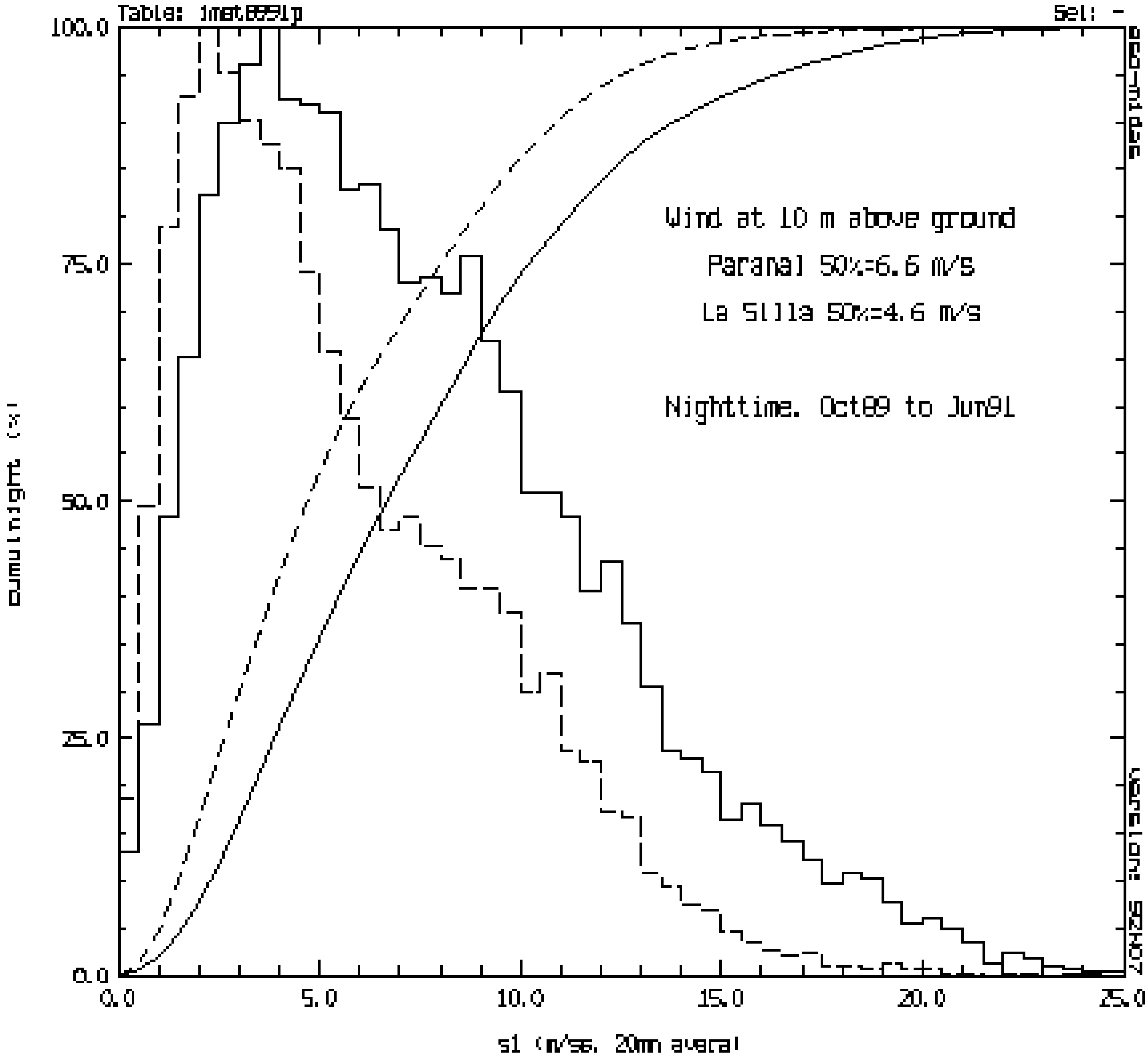
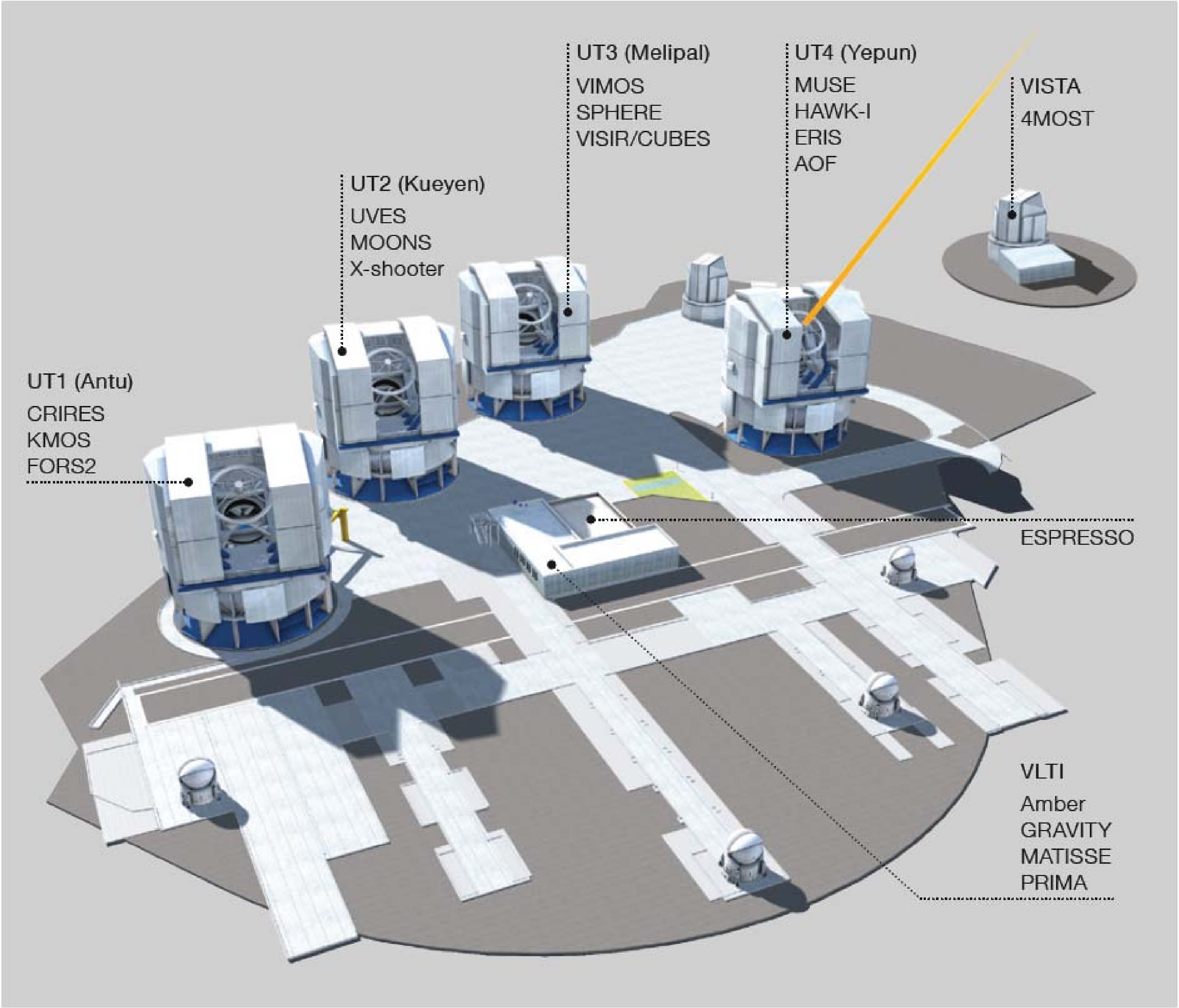


Table: imet8991p
Sel: -
Wind at 10 m above ground
Paranal 50%=6.6 m/s
La Silla 50%=4.6 m/s
Nighttime. Oct89 to Jun91
cumulnight (%)
s1 (m/ss. 20mn avera)
0.0
25.0
50.0
75.0
100.0
5.0
10.0
15.0
20.0

Image from ESO press releases


UT1 (Antu)
CRIRES
KMOS
FORS2
UT2 (Kueyen)
UVES
MOONS
X-shooter
UT3 (Melipal)
VIMOS
SPHERE
VISIR/CUBES
UT4 (Yepun)
MUSE
HAWK-I
ERIS
AOF
VISTA
4MOST
ESPRESSO
VLTI
Amber
GRAVITY
MATISSE
PRIMA

Examples of astronomy done with ESO telescopes

ESO Top 10 Astronomical Discoveries

Top 10 ESO science discoveries

1. **Stars orbiting the Milky Way black hole**

   Several of ESO's flagship telescopes were used in a 16-year long study to obtain the most detailed view ever of the surroundings of the monster lurking at the heart of our galaxy — a supermassive black hole.

   Science papers:

   Schödel et al. 2003 (Telbib),

   Gillessen et al. 2009 (Telbib)

   Read more in the ESO Press Release eso0226, eso0846 and eso1151. The Crafoord Prize in Astronomy 2012 was awarded for this result.

2. **Accelerating Universe**

   Two independent research teams, based on observations of exploding stars, including those from ESO's telescopes at La Silla and Paranal, have shown that the expansion of the Universe is accelerating. The 2011 Nobel Prize in Physics was awarded for this result.

   Science papers:

   Perlmutter et al., 1999ApJ...517..565P (Telbib),

   Riess,A. et.al., 1998, AJ116 1009 (Telbib),

   Schmidt, B. et.al., 1998, ApJ 507 46 (Telbib),

   Perlmutter, S. et al, 1998, Nature, vol. 391, 51 (Telbib),

   Tonry, J.L. et al, 2003, ApJ (Telbib),

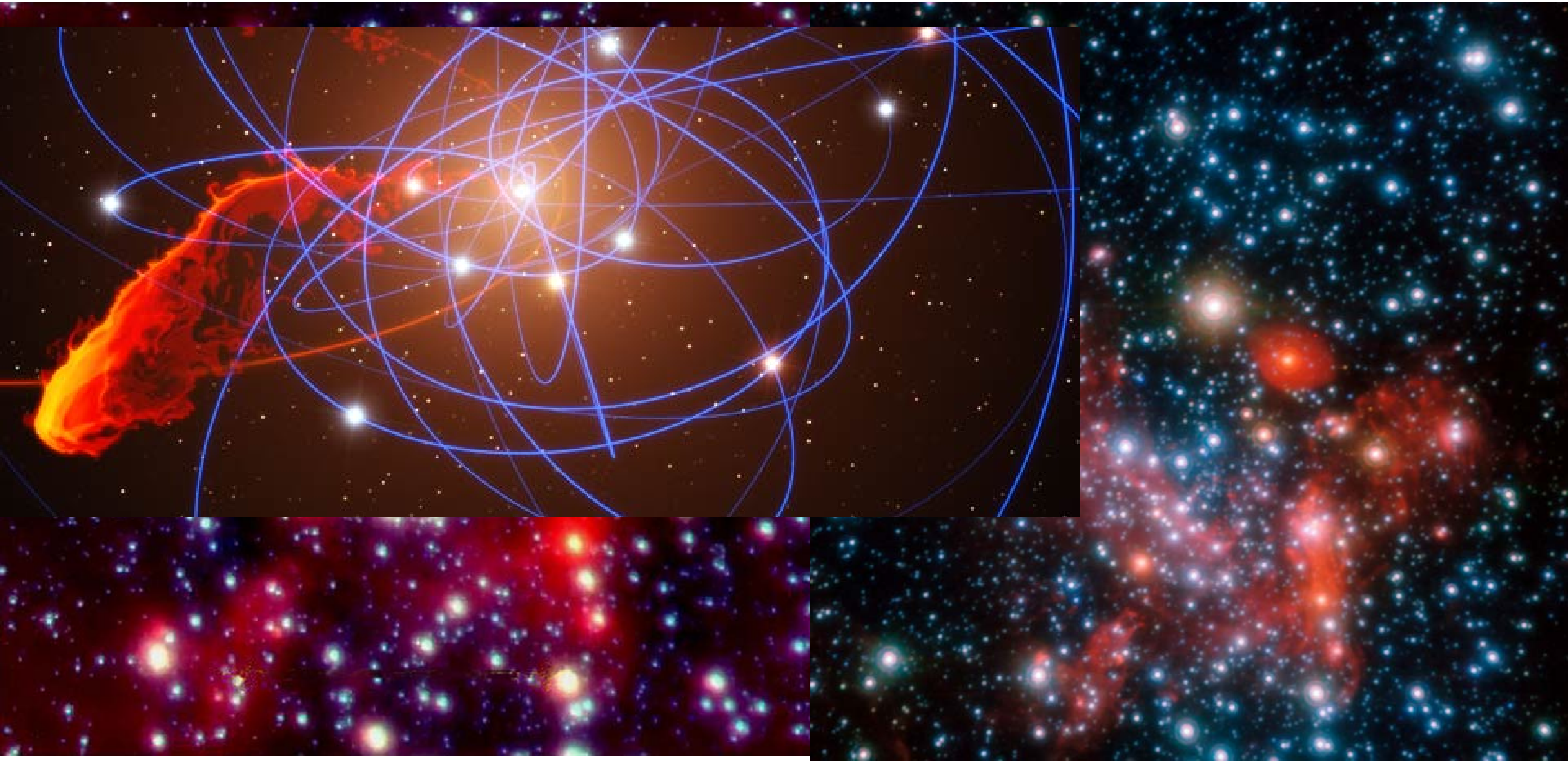
   Knop, R.A. et al, 2003, ApJ (Telbib),

   Riess, A. et al, 2004, ApJ (Telbib),

   Astier, P. et al, 2006, A&A (Telbib)

   Read more in the ESO Press Release eso9861

S - stars



ESO/S. Gillessen et al.; Genzel et al.

3. **First image of an exoplanet**

The VLT has obtained the first-ever image of a planet outside our Solar System. The 5-Jupiter-mass planet orbits a failed star — a brown dwarf — at a distance of 55 times the mean Earth-Sun distance.

Science paper:

Chauvin et al. 2004 (Telbib)

Read more in the ESO Press Release eso0428

4. **Gamma-ray bursts – the connections with supernovae and merging neutron stars**

ESO telescopes have provided definitive proof that long gamma-ray bursts are linked with the ultimate explosion of massive stars, solving a long-time puzzle. In addition a telescope at La Silla was able for the first time to observe the visible light from a short gamma-ray burst, showing that this family of objects most likely originate from the violent collision of two merging neutron stars.

Science papers:

Galama T.J., et al., 1998, Nature

Hjort et al., 2003 (Telbib)

Hjorth, J., et al., 2005, Nature

Pian, E., et al., 2006, Nature

Read more in the ESO Press Release eso0318 and in the ESO Press Release eso0533

5. **Cosmic temperature independently measured**

The VLT has detected carbon monoxide molecules in a galaxy located almost 11 billion light-years away for the first time, a feat that had remained elusive for 25 years. This has allowed astronomers to obtain the most precise measurement of the cosmic temperature at such a remote epoch.

Science paper:

Srianand, R. et al, 2008, A&A (Telbib)

Noterdaeme et al., A&A (Telbib)

Read more in the ESO Press Release eso0813

6. **Oldest star known in the Milky Way**

   Using ESO's VLT, astronomers have measured the age of the oldest star known in our galaxy, the Milky Way. At 13.2 billion years old, the star was born in the earliest era of star formation in the Universe. Uranium has also been detected in a Milky Way star and used as an independent estimate of the age of the galaxy.

   Science paper:

   Pasquini et al. 2004 (Telbib)

   Cayrel, R et al, 2001, Nature

   Read more in the ESO Press Release eso0425 and in the ESO Press Release eso0106

7. **Flares from the supermassive black hole at the centre of the Milky Way**

   The VLT and APEX team up to study the violent flares from the supermassive black hole at the centre of the Milky Way, revealing material being stretched out as it orbits in the intense gravity close to the central black hole. In addition exquisite VLT observations revealed powerful infrared flares coming from the black hole, strongly suggesting that it rotates very rapidly.

   Science papers:

   Eckart, A. et al, 2008, A&A

   Eisenhauer, F. et al, 2005, ApJ

   Read more in the ESO Press Release eso0841

8. **Direct measurements of the spectra of exoplanets and their atmospheres**

   The atmosphere around a super-Earth exoplanet has been analysed for the first time using the VLT. The planet, which is known as GJ 1214b, was studied as it passed in front of its parent star and some of the starlight passed through the planet's atmosphere. The atmosphere is either mostly water in the form of steam or is dominated by thick clouds or hazes. This follows from the earlier first direct spectrum of an exoplanet.

   Science papers:

   Bean, J. et al, 2010, Nature

   Janson, M. et al, 2010, ApJ

   Read more in the ESO Press Release eso1047 and in the ESO Press Release eso1002

9. **Richest planetary system**

   Astronomers using ESO's HARPS have discovered a planetary system containing at least five planets, orbiting the Sun-like star HD 10180. Also evidence that two other planets may be present, one of which would have the lowest mass ever found. Furthermore, the team also found evidence that the distances of the planets from their star follow a regular pattern, as also seen in our Solar System.

   Science paper:

   Lovis, C. et al, 2010, A&A

   Read more in the ESO Press Release eso1035

10. **Milky Way stellar motions**

    After more than 1,000 nights of observations at La Silla spread over 15 years, astronomers have determined the motions of more than 14,000 solar-like stars residing in the neighbourhood of the Sun, showing that our home galaxy has led a much more turbulent and chaotic life than previously assumed.

    Science paper:

    Nordström, B. et al, 2004, A&A

    Read more in the ESO Press Release eso0411

Summary

- Importance of astronomical observation for the society
- New technologies and new discoveries with astronomical observations
- Observatories were built since the dawn of humanity
- Observing techniques developed over centuries

Summary

- New instrumentation – lens, telescope, photo plate, photomultiplier, CCD, IR detectors
- New scientific topics
- Currently, we observe objects in the solar system, stars, exoplanets, galaxies and the very high redshift quasars
- Large and very sensitive telescopes with modern instrumentation needed

What comes next?

- Let’s go to have a look at modern observing methods and then at modern observatories like ESO
- Let’s be part of the frontiers of astronomical research! It is not easy but is doable!

- NEXT LECTURE: Ernst, 22 October 16:00 (CONFIRMED)
  Observing methods – photometry, spectroscopy, interferometry, etc…
- SPECIAL SESSION: South Africa 29 October
- SPECIAL SESSION: Paranal Obs. 05 November

Please check the last minute changes! Sometimes, the schedule needs to be changed due to operational reasons! We will confirm the exact dates always on Monday before the lecture! Please check the lecture web!

We will also prepare a summary of the literature used for the slides and post it also on lecture web.

Can you see an Emu?

Photo Yuri Beletsky – ESO press releases

READING:

- *Proceedings of the National Academy of Sciences* **15** (3): 168–73. - Hubble's law
- http://www.nature.com/nature/journal/v378/n6555/abs/378355a0.html - The first exoplanet 51 Peg
- http://astro.berkeley.edu/~kalas/labs/documents/kennefick_phystoday_09.pdf - General Theory of Relativty proof
- http://news.nationalgeographic.com/news/2010/12/photogalleries/101228-sun-end-year-analemmas-solstice-eclipse-pictures - Analema National Geographic
- http://aboriginalastronomy.blogspot.com/2014/03/the-kamilaroi-and-euahlayi-emu-in-sky.html - Aboriginal astronomy
- http://www.atnf.csiro.au/people/Ray.Norris/papers/n311.pdf - Aboriginal astronomy
- http://archive.archaeology.org/0607/abstracts/henge.html - Goseck circle
- *Hawkins, Nature* **200**, 306 - 308 (26 October 1963); doi:10.1038/200306a0 - Nature Stonehenge
- http://www.nature.com/nature/journal/v412/n6848/pdf/412699a0.pdf - Nature pyramids
- http://arxiv.org/pdf/physics/0311035v1.pdf - V. G. Gurzadyan - Venus cycles
- http://www.transpacificproject.com/index.php/ocean-sailing-craft/ - Ancient wayfinding in modern era
- http://feynmanlectures.caltech.edu/I_36.html - Feynman lectures – Human eye
- http://feynmanlectures.caltech.edu/I_35.html - Feynman lectures – Human eye
- http://idea.uwosh.edu/nick/rayleigh.pdf - Lord Rayleigh – original paper on Pinhole camera
- Mielenz, K., J. Res. Natl. Inst. Stand. Technol. 104, 479 (1999) - Pinhole camera revised
- http://webstag.kodak.cz/US/en/business/aim/industrial/ndt/literature/radiography/18.shtml - Gourney Mott theory
- Electron trapping – Shluger et al. Modelling Simul. Mater. Sci. Eng., 17, (2009) 084004 - how the electrons get trapped in lattice defects
- http://www.astro.virginia.edu/~rjp0i/museum/photography.html - history of photography
- http://www.physics.udel.edu/~jlp/classweb/ccd.pdf - very nice reading about CCDs
- https://www.eso.org/sci/publications/messenger/archive/no.64-jun91/messenger-no64-5-8.pdf - Site testing made by ESO, very nice description of Paranal site testing and selection
- http://www.eso.org/gen-fac/pubs/astclim/paranal/ - Paranal astroclimatology page, access might be restricted

Feel free to contact me: pkabath@eso.org, kabath@asu.cas.cz (from 1.1.2015) or Ernst Paunzen