Electronics and Computer Aided Astronomy

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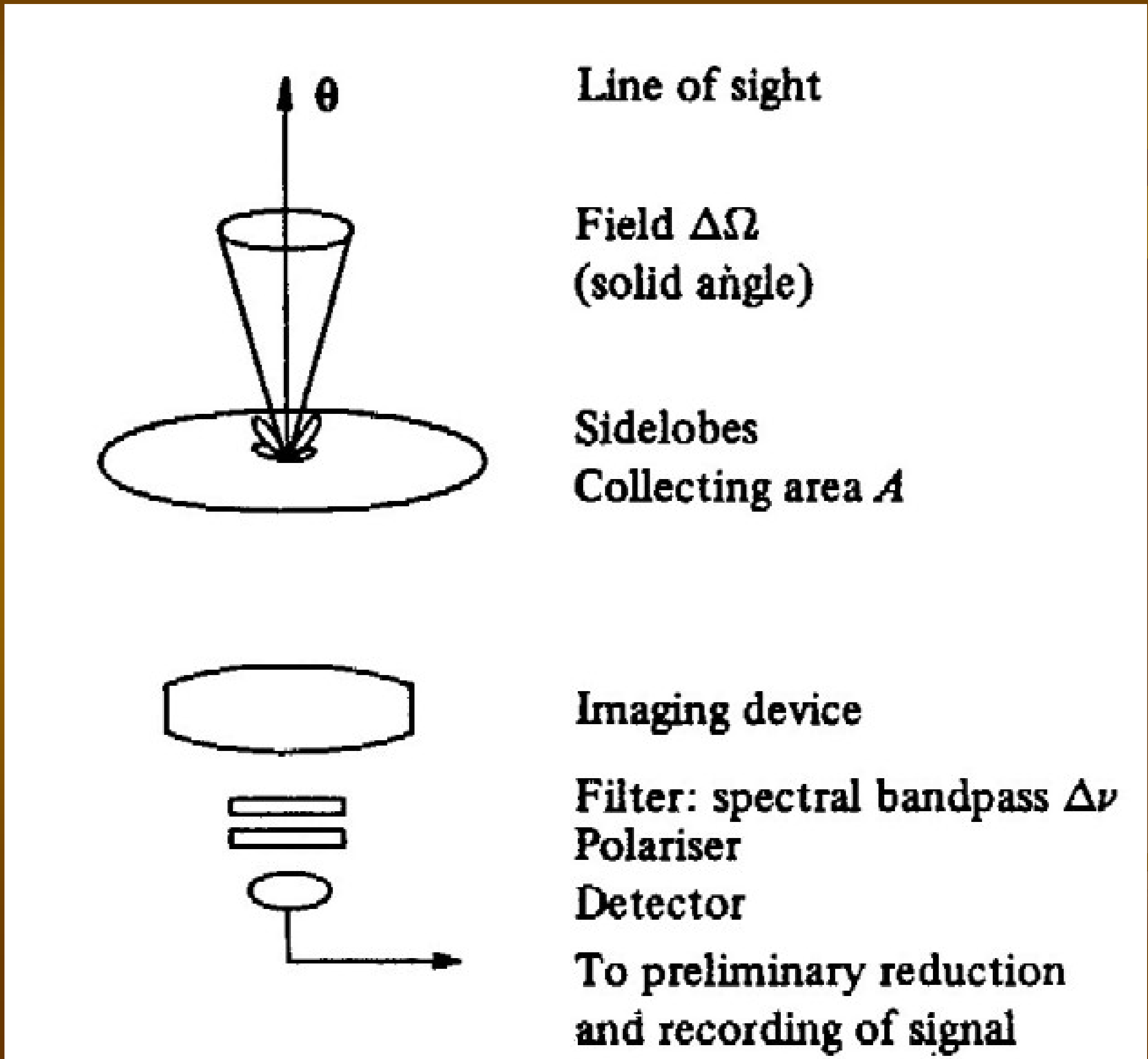
Collection and analysis of information

- Photon characteristics

Photon properties	Observing strategy
Energy, wavelength, frequency	Spectral coverage Earth atmospheric transmissivity Choice of appropriate detector
Amount of received photons (flux)	Area of collectors (telescopes)
Intensity	Detector sensitivity, photometry
Time dependent ($t \geq 1/\nu$) Temporal coherent	Spectral analysis Spectral resolution
Time dependent ($t << 1/\nu$)	Time resolution High-speed photometry
Spatial dependent (angular)	mapping, imaging, spatial resolution
Spin	Polarimetry

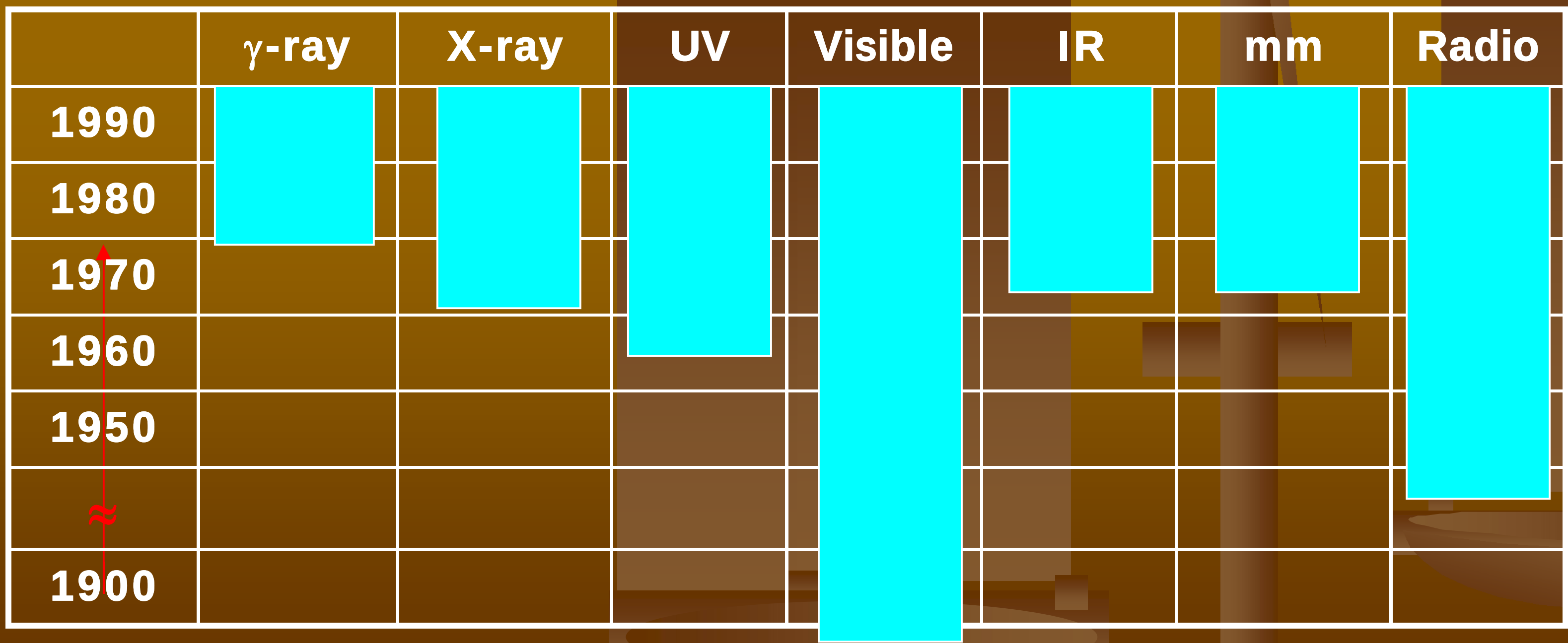
Observing system



- Photon flux collected at surface *A* ⇨ detector aperture (telescope's objective)
- Photons collected in a solid angle $\Delta\Omega$ (field of view)
- Presence of parasitic side lobes (background signals)
- Optical system: combination of mirrors and lenses ⇨ concentrates incoming energy to form image in the focal plane. $\Delta\Omega$ decomposed into picture element *(pixel)* each with solid angle element of $\delta\omega$
- Selecting device that isolate particular frequency domain $\Delta\nu$ of the arrived radiation ⇨ spectral selection determined by
  1. Physical characteristics of optical system
  2. Physical characteristics of detector
  3. The use of filters

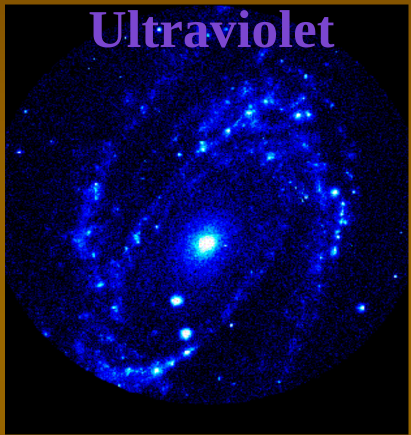
- Polarization of radiation can be observed using polarizer ⇨ split and measure linear or rotational polarization degree of incoming radiation
- Arriving electromagnetic signal ⇨ transformed by detector or *receiver* onto physical quantity that can be measured (electric current, voltage, photochemicals) and stored.
- Detector supporting system: Electronic devices that form data acquisition system to analyze and record signal

Spectral coverage



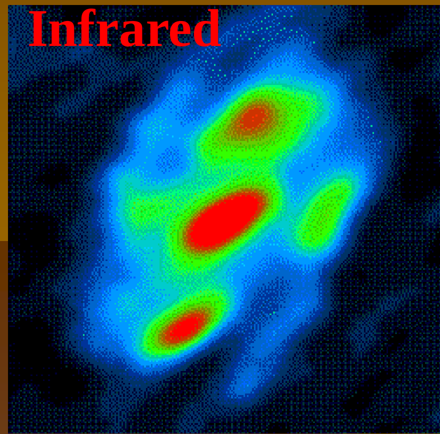
Why wide spectral coverage is important? The essence of *multiwavelength observation*:

M 81: Spyral galaxy

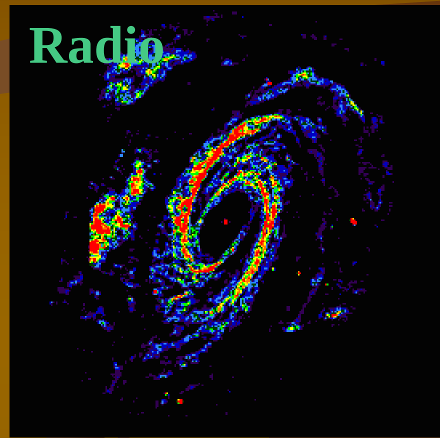


Emission from hot area

Stellar radiation



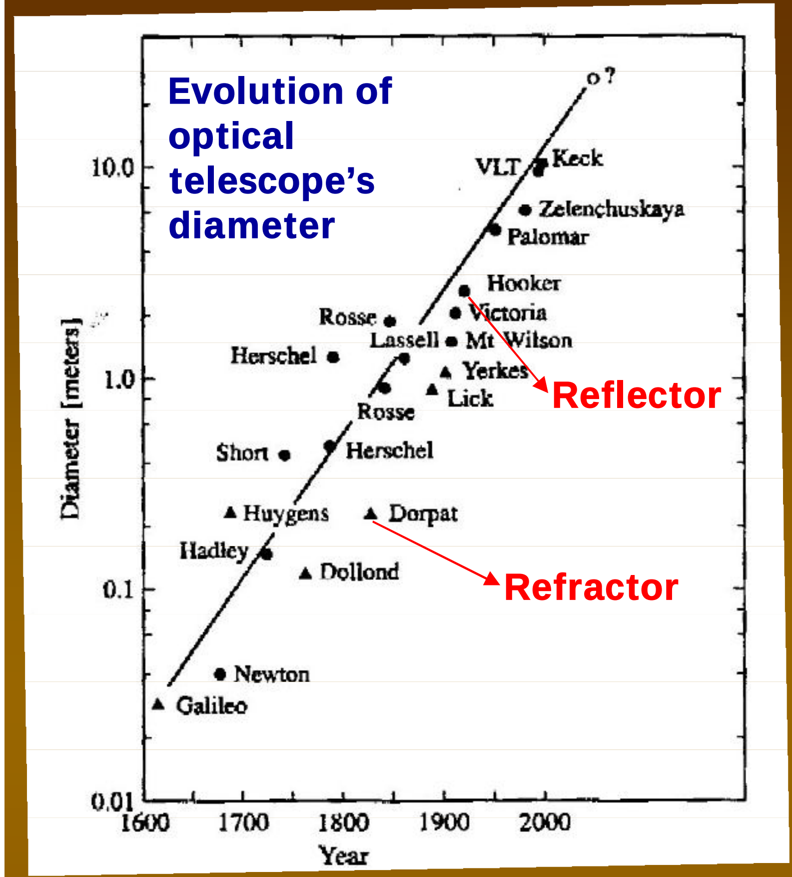
Emission from dust

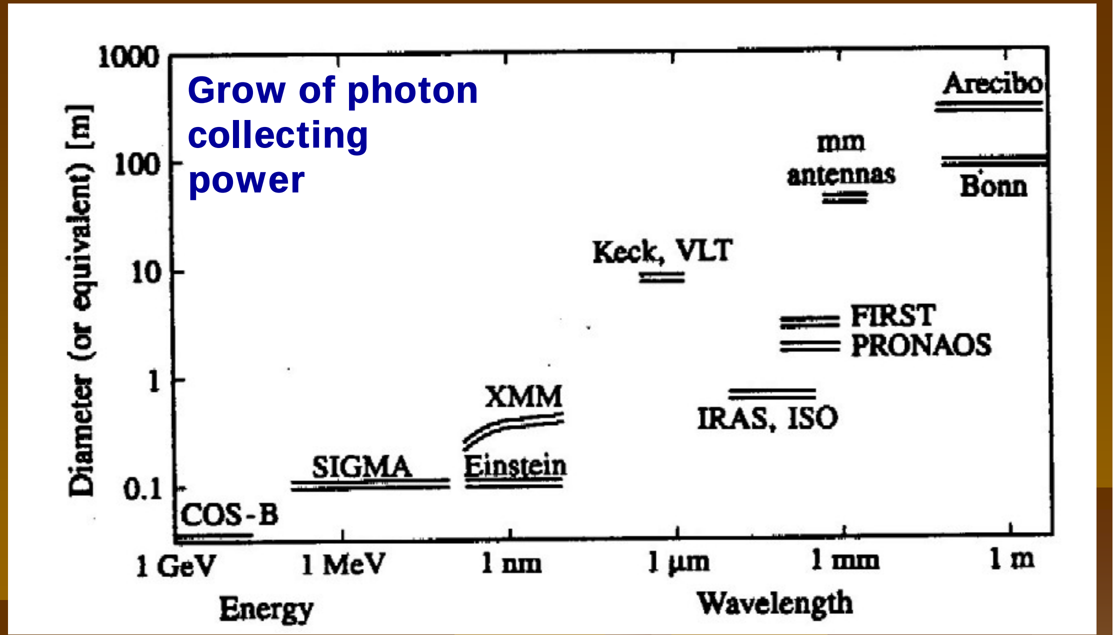


Radiation from cold dust

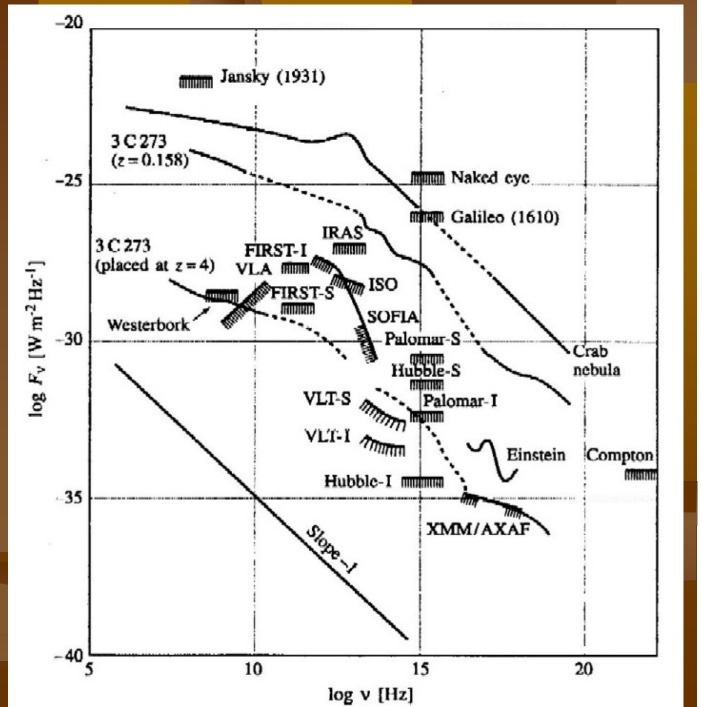
- Intensity measurements
  - Number of photons received per time unit ⇔ collector area
  - Performance of detector determine the attained precision and sensitivity

Photometry: Measurement of the received radiation intensity

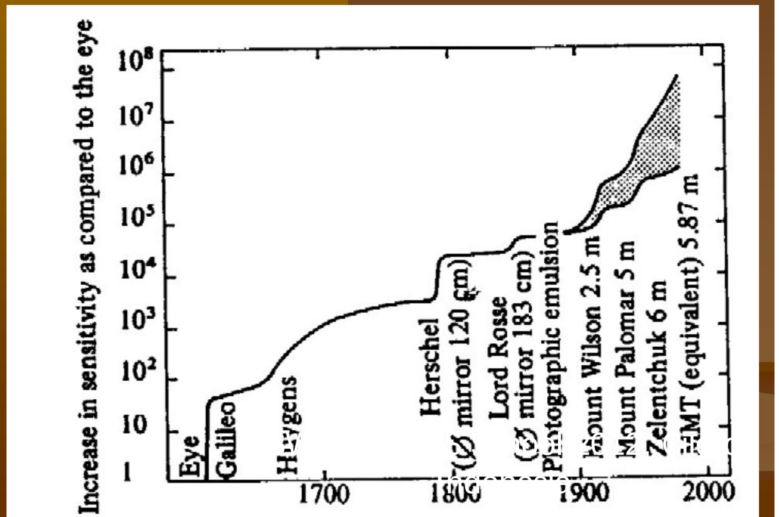




Sensitivity of astronomical instruments

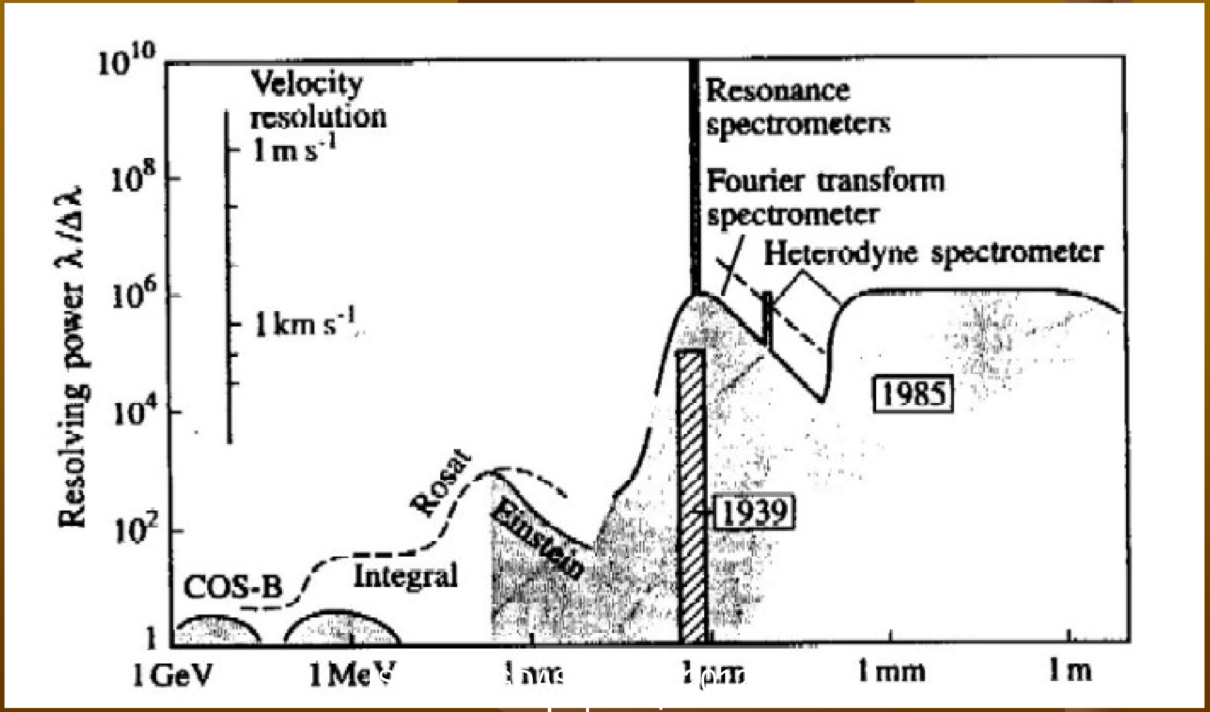


Sensitivity development of visible detectors



Spectral analysis

- Spectral analysis ⇨ Composition of chemistry & isotopes, velocity field, turbulence, temperature, pressure, magnetic field, gravitation, etc ⇔ astrophysics
- Spectral resolving power of instrument ($R=\lambda/\Delta\lambda$): Ability to measure 2 close spectral lines at each frequency ⇔ spectrograph, area of collector, integrating time & detector sensitivity



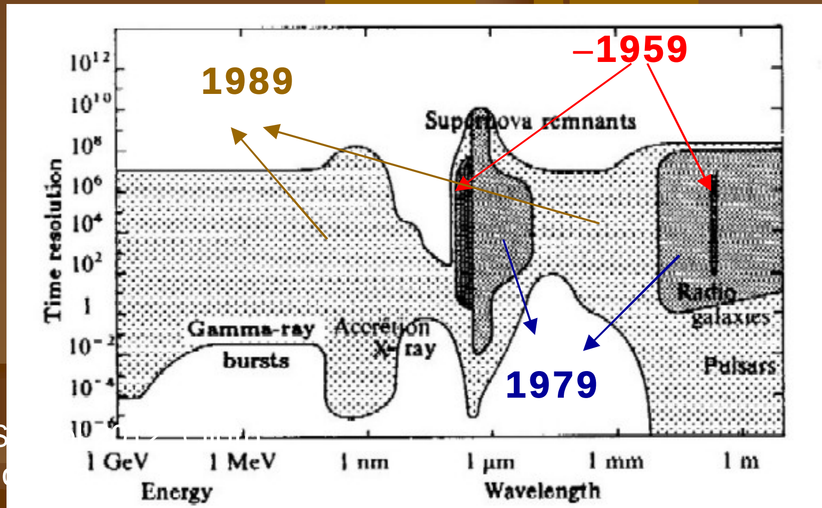
■ Time variation

- Variabel stars with slow time variation → Mira Ceti
- Pulsar with period of 1.377 milliseconds founded in 1968

⇨ Sensitivity & time response of detector

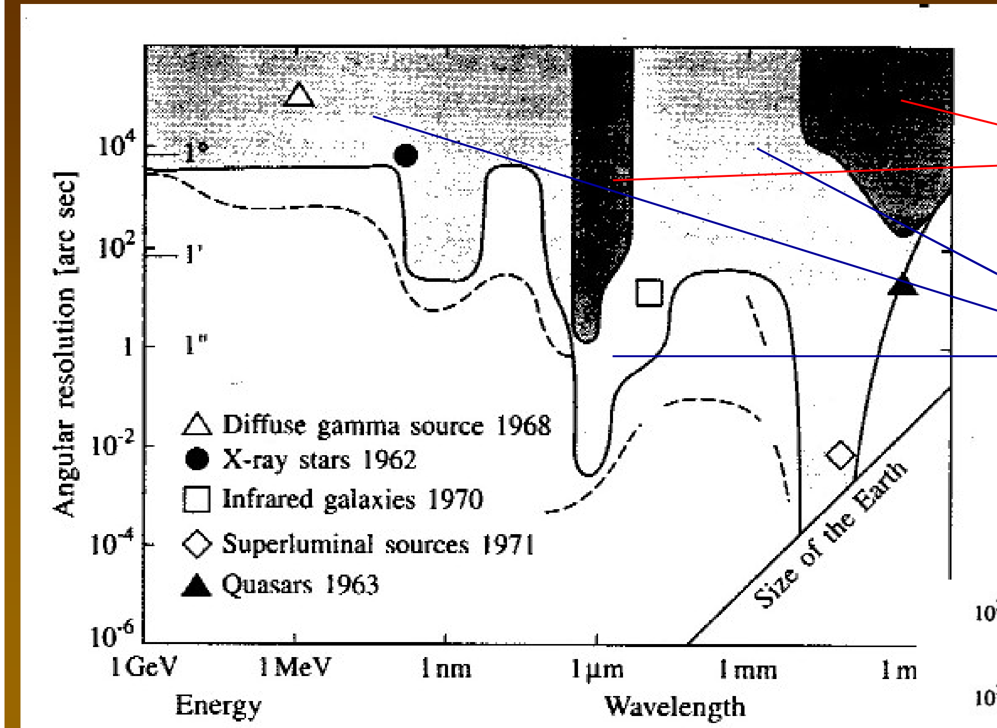
Table 1.4. Time variability of astronomical sources

Phenomenon	Wavelength region	Characteristic time scale or range [s]
Accretion in binary systems	All	$>10^{-1}$
Black holes	X-ray, visible	$>10^{-3}$
Gamma bursts (thermonuclear explosions at the surface of a neutron star)	γ-ray, radio	10^{-4}–10^{1} $>10^{-4}$
Interstellar scintillation	Radio, X-ray	$>10^{-3}$
Solar flares	Visible, IR, radio	10^{-6}–10^{3}
Variable stars	All	10^{1}–10^{7}
Supernovæ	Visible	10^{2}–10^{6}
Solar and stellar oscillations (gravity)	Visible, UV	10^{2}–10^{4}
Stellar variability (convection, magnetic fields)	Radio, IR, UV, visible	10^{5}–10^{10}
Variability of galactic nuclei, quasars	All	$>10^{6}$



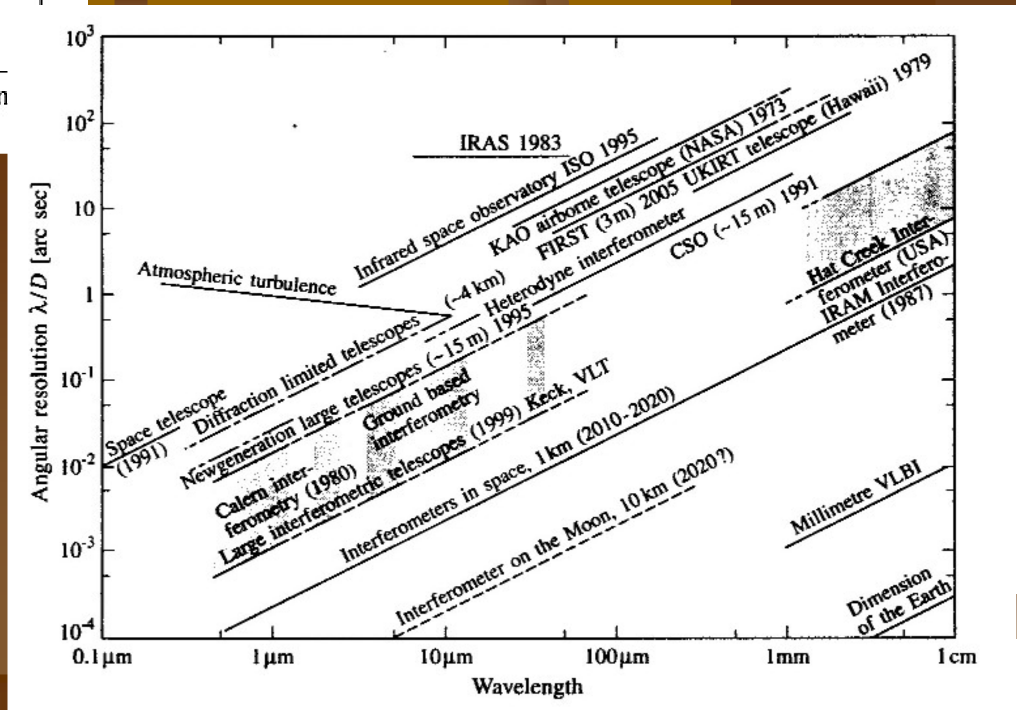
- Imaging
  - Objective: to measure electromagnetic beam coming from different direction in space
  - Capacity of observing device in doing this: Spatial resolving power ↔ Size of instrument, wavelength, atmospheric turbulence effect

Resolution	Number of pixels to cover 4π sr	Obtained information	Spectral area
1°	4×10^{4}	Background radiation Sky survey	milimeter sinar-γ
1′	1.5×10^{8}	Sky survey	IR (10-100 μm)
1″	5.4×10^{11}	Sky survey Specific object	Visible mm, IR, UV, sinar-X
0.01″	5.4×10^{15}	Specific object	IR, visible
1 milliarcseconds	5.4×10^{17}	Specific object	Radio [cm]
1 microarcseconds	5.4×10^{21}	Specific object	Radio [cm,mm]


Angular resolution [arc sec]
10^4
10^2
1
10^{-2}
10^{-4}
10^{-6}
1°
1'
1"
Diffuse gamma source 1968
X-ray stars 1962
Infrared galaxies 1970
Superluminal sources 1971
Quasars 1963
Size of the Earth
1 GeV
1 MeV
1 nm
1 µm
1 mm
1 m
Energy
Wavelength

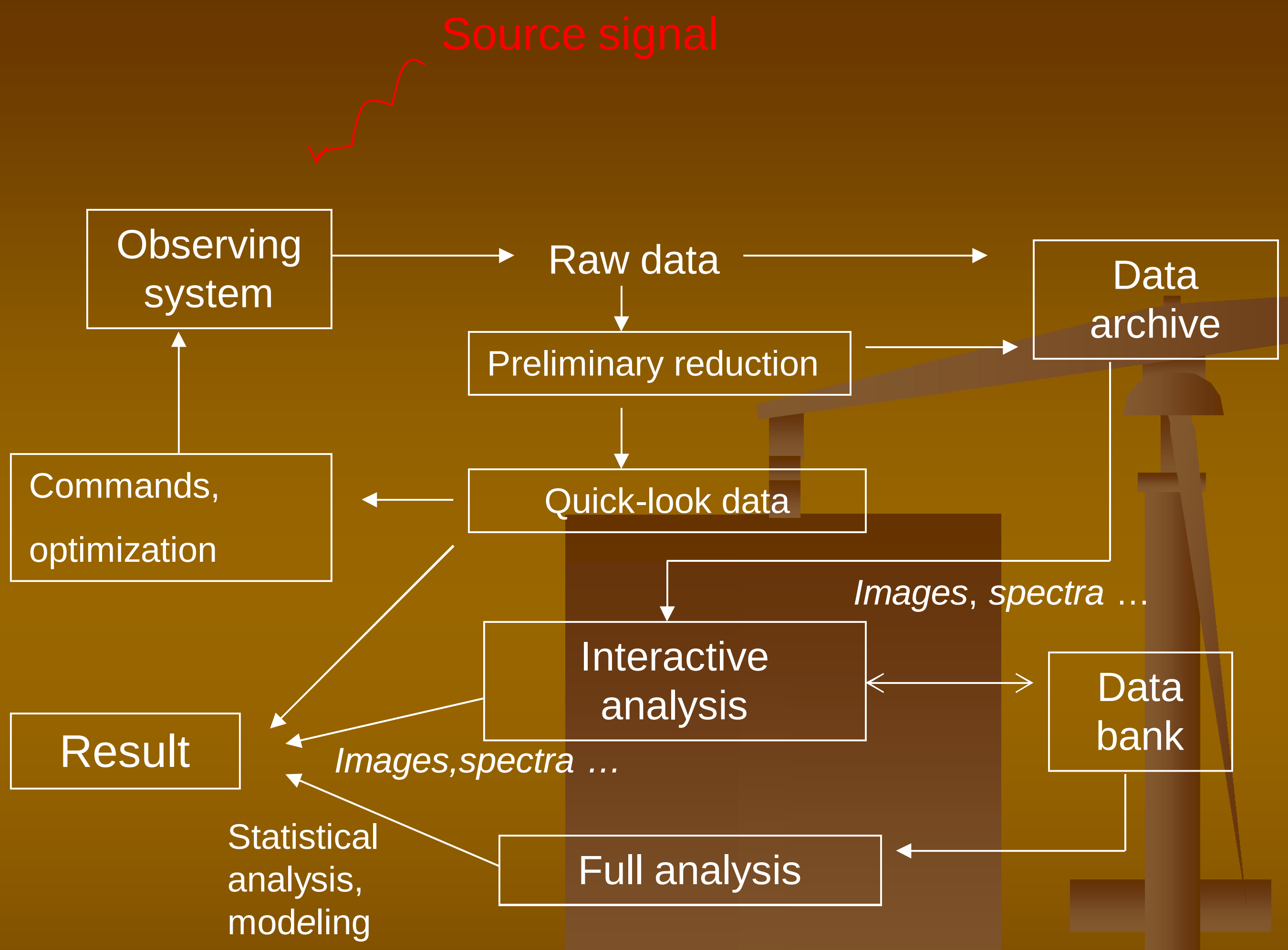
1959

1990


Angular resolution λ/D [arc sec]
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
IRAS 1983
Infrared space observatory ISO 1995
KAO airborne telescope (NASA) 1973
FIRST (3 m) 2005 UKIRT telescope (Hawaii) 1979
Heterodyne interferometer
CSO (~15 m) 1991
Atmospheric turbulence
(~4 km)
Space telescope (1991)
Diffraction limited telescopes
Newgeneration large telescopes (~15 m) 1995
Ground based interferometry
Calern interferometry (1980)
Large interferometric telescopes (1999) Keck, VLT
Interferometers in space, 1 km (2010-2020)
Interferometer on the Moon, 10 km (2020?)
Hat Creek Interferometer (USA)
IRAM Interferometer (1987)
Millimetre VLBI
Dimension of the Earth
0.1 µm
1 µm
10 µm
100 µm
1 mm
1 cm
Wavelength

Processing and storage of information

- Astrophysical information ⇨ data collected from all range of source.
  - Continuously improve the accuracy
  - Very high historical values
- Volume of collected data very is sharply increasing:
  - 10^7 stars have been catalogued (position, magnitudes and colours)
  - Information rate in radio astronomy : 10^8 bits peryear (1972) $\rightarrow$ 10^{10} bits peryear (1982), HST (1989) : 10^{13} bits peryear!



Acquisition and analysis of Astronomical Data

Stages in Astronomical data processing & the role of computer system

- Real-time acquisition system
  - Quick-look facility : Optimization of observation
- Acquisition rate: Individual photon detection from faint source (*t* ~ hours, days) until fast detection (10^8–10^9 bits per second)
- Real-time data handling: Reducing raw data volume & facilitating permanent storage system (compression & filtering)
- Interactive analysis: astronomer-data-computer
  - Extraction & Analysis of information
  - Programs to calibrate
  - Programs for viewing & manipulation

- Processed data including error assessement ⇨ Signal-to-noise ratio
- Presented to scientific community through
  - Publication
  - Contribution to data bank equipped with standardization process & format homogenization
- Detailed analysis:
  - Extraction of big volume of data from data bank to model or describe statistically