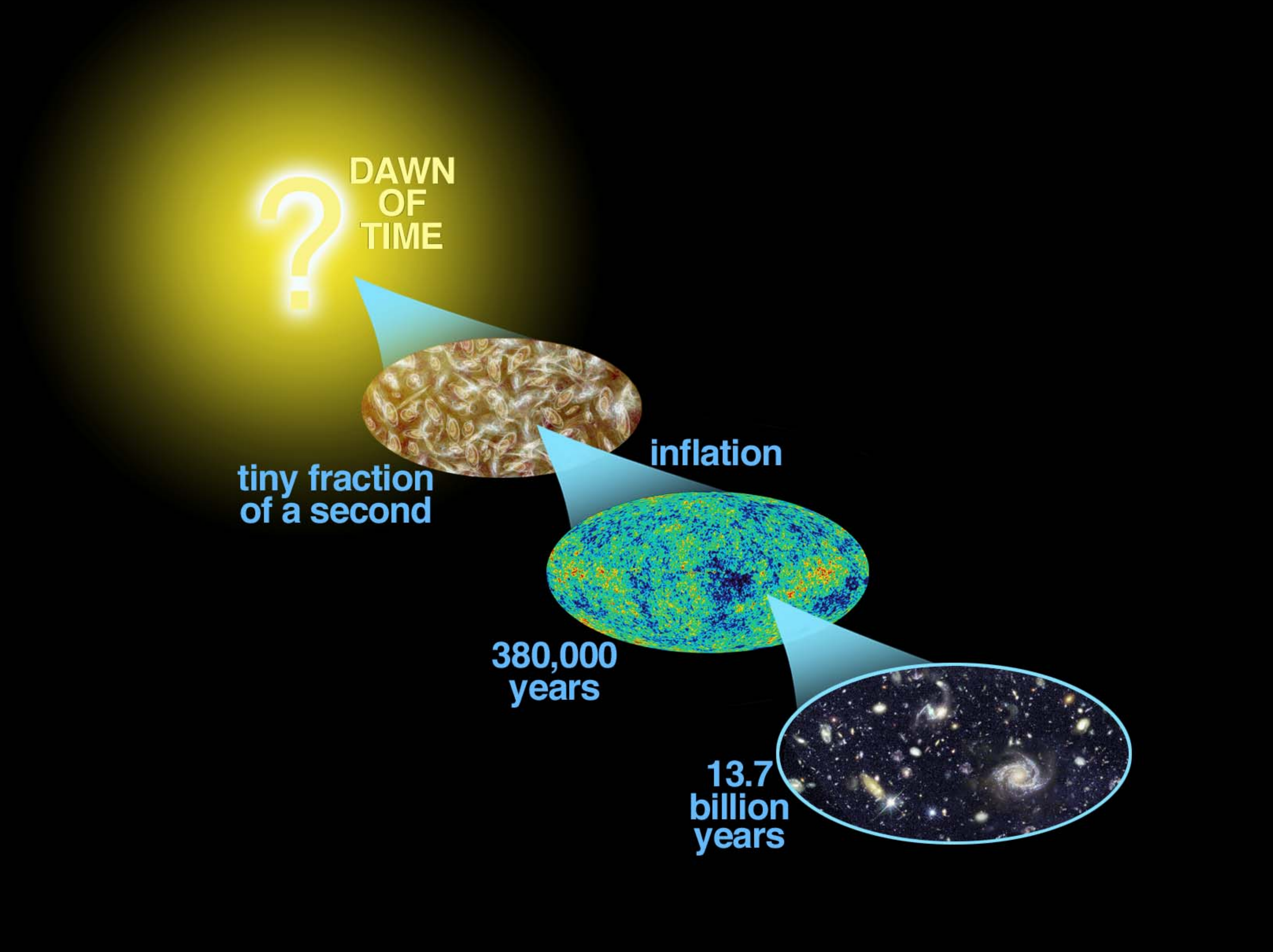
Exploring the cosmic frontier: setting the scene

Catherine Cesarsky

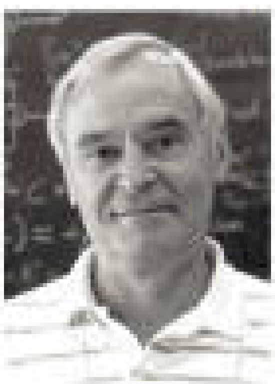
ESO

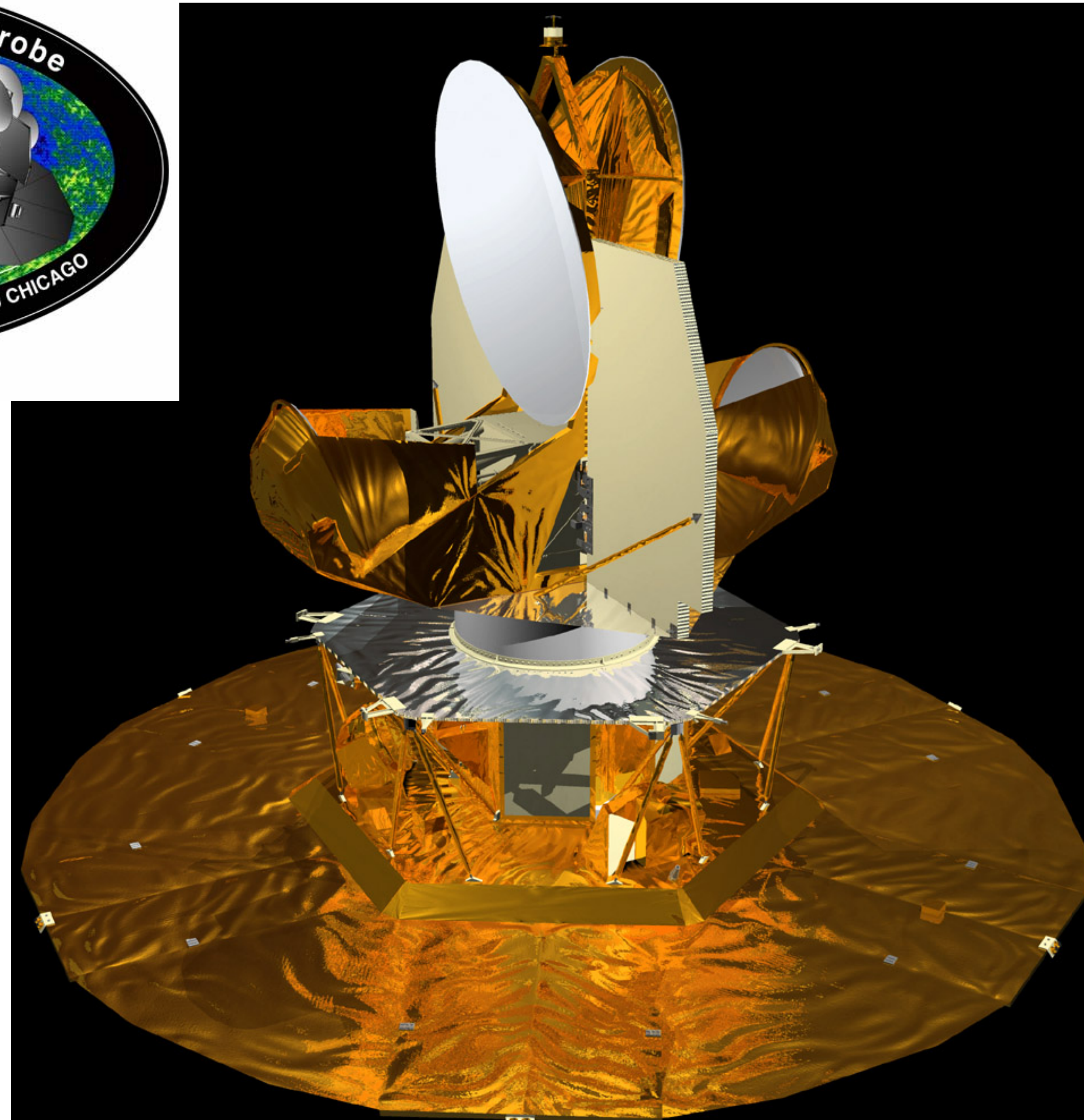

DAWN OF TIME
tiny fraction of a second
inflation
380,000 years
13.7 billion years

Microwave Anisotropy Probe

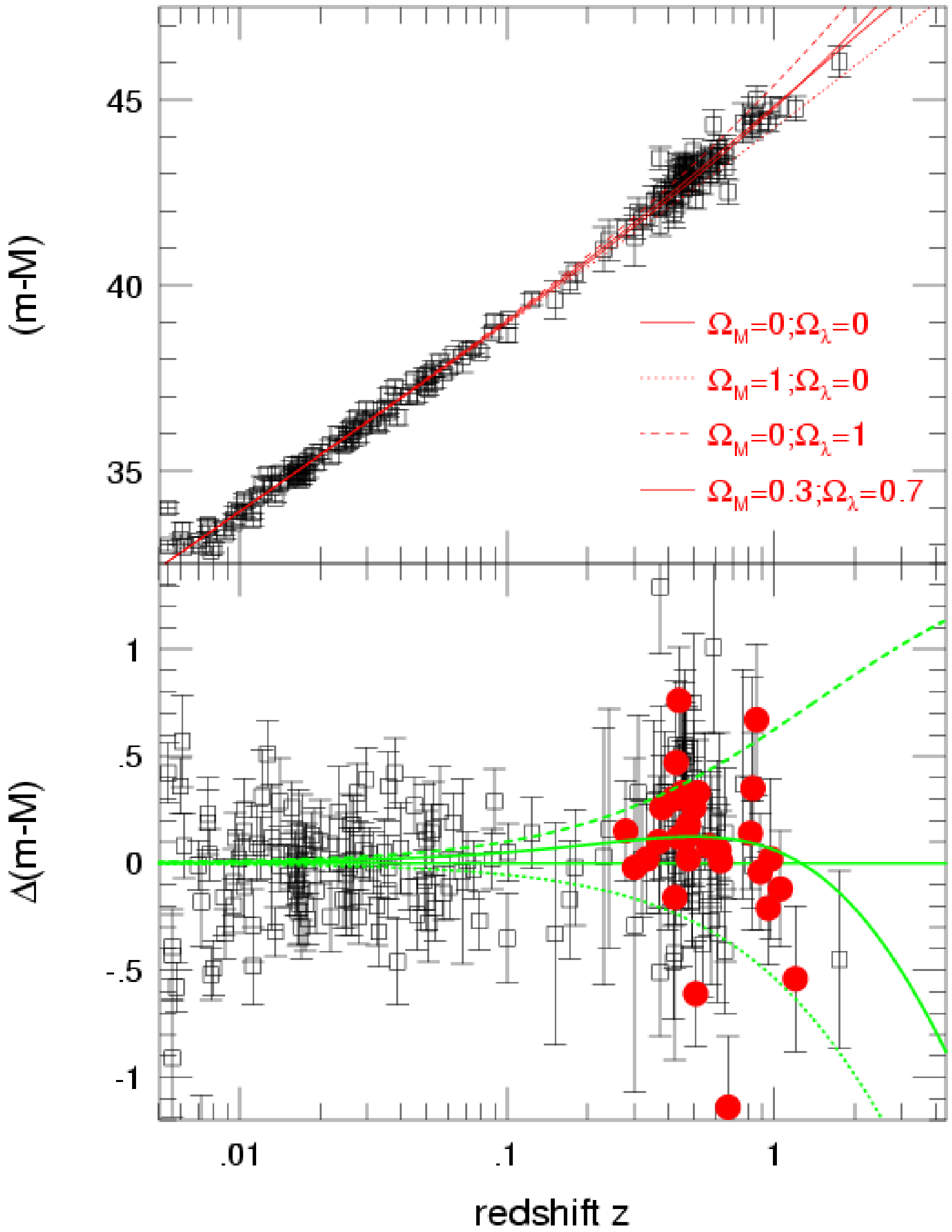
MAP

NASA GODDARD ❖ PRINCETON ❖ UCLA ❖ U CHICAGO





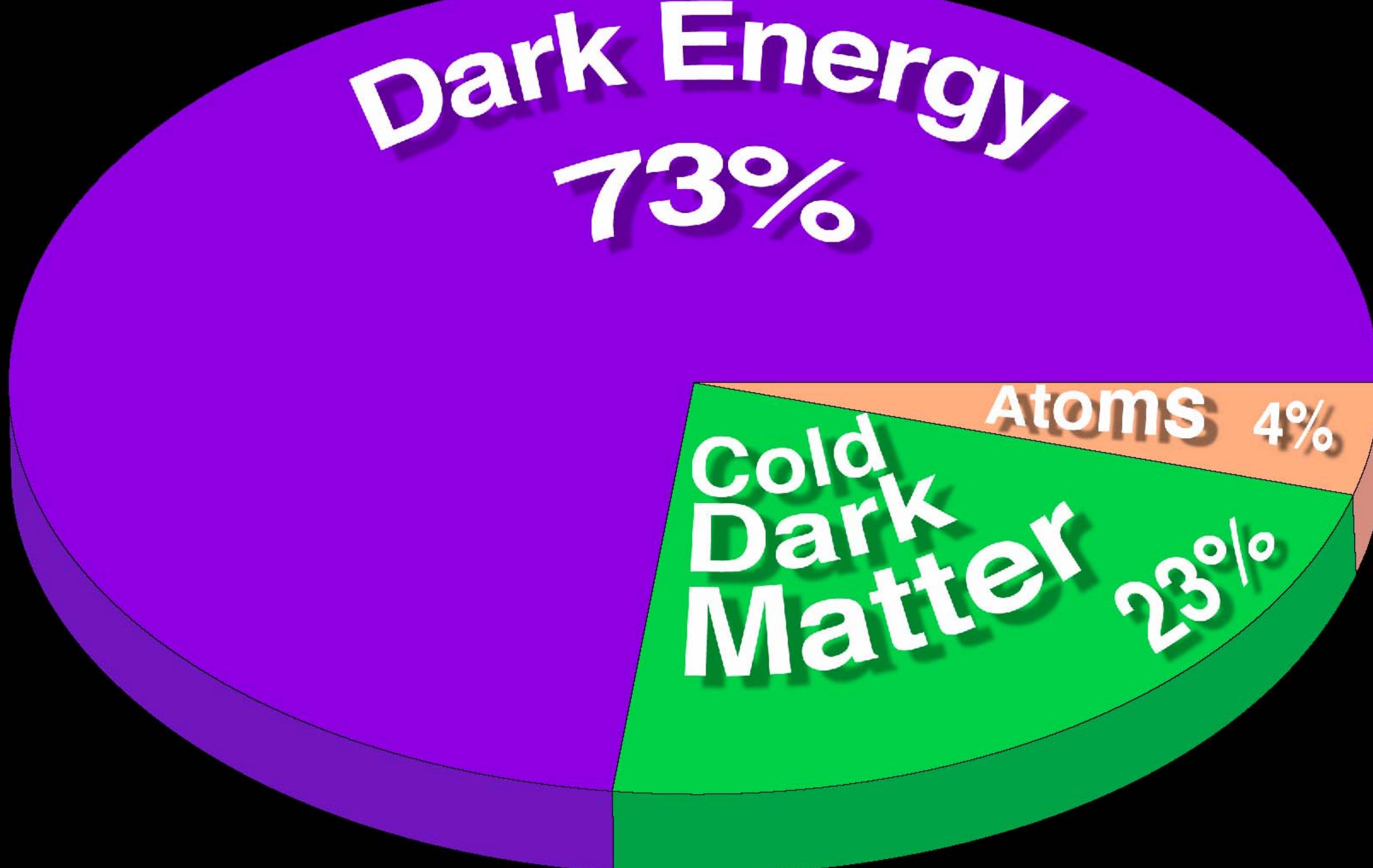
209 SNe Ia in one diagram



Tonry et al. 2003

Old Universe – *New* Numbers

$\Omega_{tot} = 1.02^{+0.02}_{-0.02}$	$n_s = 0.93^{+0.03}_{-0.03}$
$w < -0.78$ (95% CL)	$dn_s/d\ln k = -0.031^{+0.016}_{-0.018}$
$\Omega_\Lambda = 0.73^{+0.04}_{-0.04}$	$r < 0.71$ (95% CL)
$\Omega_b h^2 = 0.0224^{+0.0009}_{-0.0009}$	$z_{dec} = 1089^{+1}_{-1}$
$\Omega_b = 0.044^{+0.004}_{-0.004}$	$\Delta z_{dec} = 195^{+2}_{-2}$
$n_b = 2.5 \times 10^{-7}\,{}^{+0.1\times10^{-7}}_{-0.1\times10^{-7}}$ cm^{-3}	$h = 0.71^{+0.04}_{-0.03}$
$\Omega_m h^2 = 0.135^{+0.008}_{-0.009}$	$t_0 = 13.7^{+0.2}_{-0.2}$ Gyr
$\Omega_m = 0.27^{+0.04}_{-0.04}$	$t_{dec} = 379^{+8}_{-7}$ kyr
$\Omega_\nu h^2 < 0.0076$ (95%CL)	$t_r = 180^{+220}_{-80}$ Myr (95% CL)
$m_\nu < 0.23$ eV (95% CL)	$\Delta t_{dec} = 118^{+3}_{-2}$ kyr
$T_{cmb} = 2.725^{+0.002}_{-0.002}$ K	$z_{eq} = 3233^{+194}_{-210}$
$n_\gamma = 410.4^{+0.9}_{-0.9}$ cm^{-3}	$\tau = 0.17^{+0.04}_{-0.04}$
$\eta = 6.1 \times 10^{-10}\,{}^{+0.3\times10^{-10}}_{-0.2\times10^{-10}}$	$z_r = 20^{+10}_{-9}$ (95% CL)
$\Omega_b \Omega_m^{-1} = 0.17^{+0.01}_{-0.01}$	$\theta_A = 0^\circ.598^{+0.002}_{-0.002}$
$\sigma_8 = 0.84^{+0.04}_{-0.04}$ Mpc	$d_A = 14.0^{+0.2}_{-0.3}$ Gpc
$\sigma_8 \Omega_m^{0.5} = 0.44^{+0.04}_{-0.05}$	$l_A = 301^{+1}_{-1}$
$A = 0.833^{+0.086}_{-0.083}$	$r_s = 147^{+2}_{-2}$ Mpc


Dark Energy
73%
Atoms 4%
Cold
Dark
Matter
23%

• WMAP and Planck are determining the cosmological parameters with increasing accuracy.

WMAP results place reionization at an unexpectedly early time: importance of further careful work on CMB polarization, .of search for POP III objects and for galaxies at redshift as high as possible, for radio radiation relic from this early period

• The main cosmological problems of the future are the nature of dark matter and dark energy. Attacking these in the astrophysical context requires both detailed studies of galaxies and clusters (→ central dark matter density profiles) and large O/NIR/submm surveys (→ nature of dark energy from SNIa, clusters; dark matter distribution from weak shear).

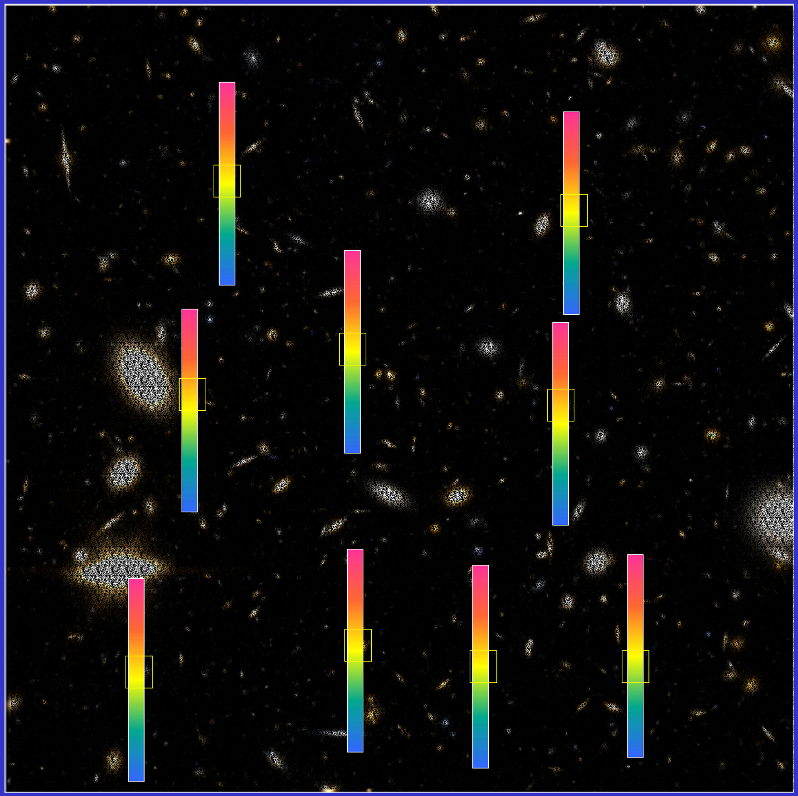
- Another important open problem is that of the formation of supermassive black holes in galaxy centers, in relation also with the formation and evolution of the galaxies themselves; requires study of non-thermal emission at high z, X rays and radio

NOW:

Imaging and spectroscopic surveys, multiwavelength, are ever expanding, e.g:
GOODS: mass assembly and morphology of galaxies to z~6
GEMS: same to z~1, but over wide area,: connection with large scale structure
COSMOS: same, to z~3
Plus various searches for galaxies of z>6, in the infrared, in particular in lensed clusters

Origin and evolution of galaxies

- Survey approach

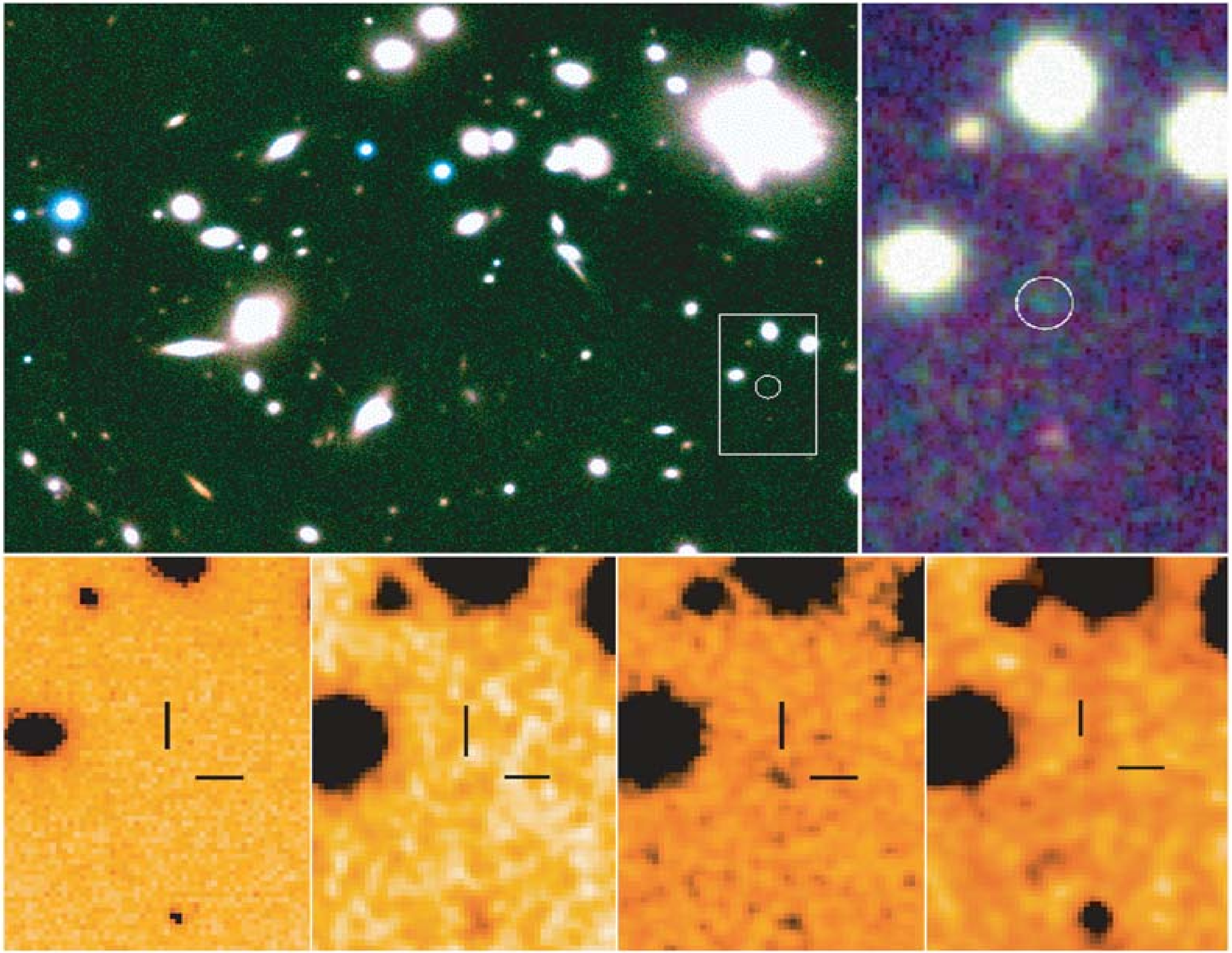


- Deep Multi-colour imaging
  - Morphologies
- Photometric redshifts
- Locate high z sample
- Multi-object Spectroscopy
  - Star formation rate
  - Abundances
  - Ages
  - Physical conditions

NOW:

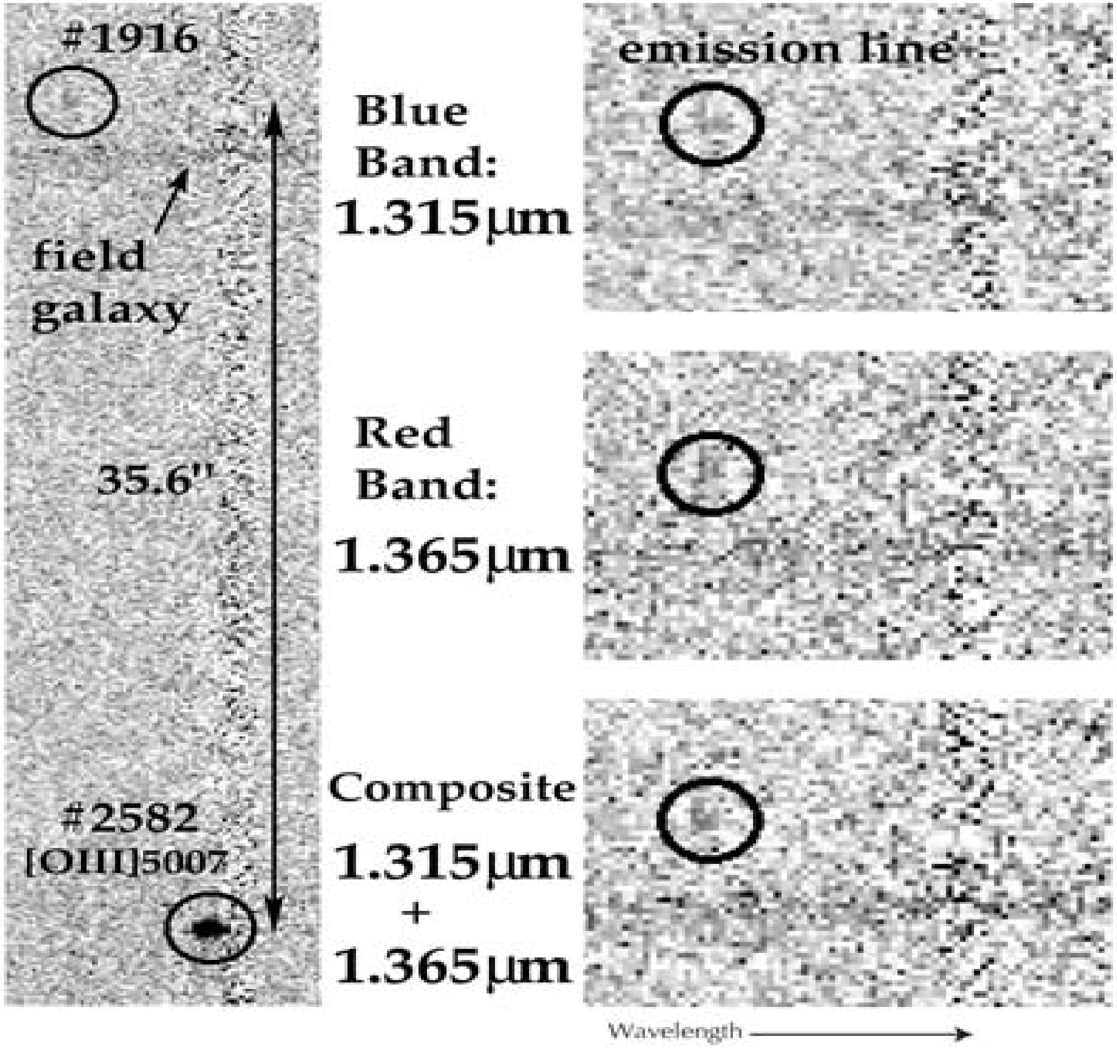
- The evolution of large scale structure, of galaxy clustering and of the galaxies themselves can be analyzed at higher and higher redshifts.

AND IN THE FUTURE?



Abell 1835 IR1916 - the Farthest Galaxy - Seen in the Near-Infrared
(VLT ANTU + ISAAC)

ESO PR Photo 05a/04 (1 March 2004)

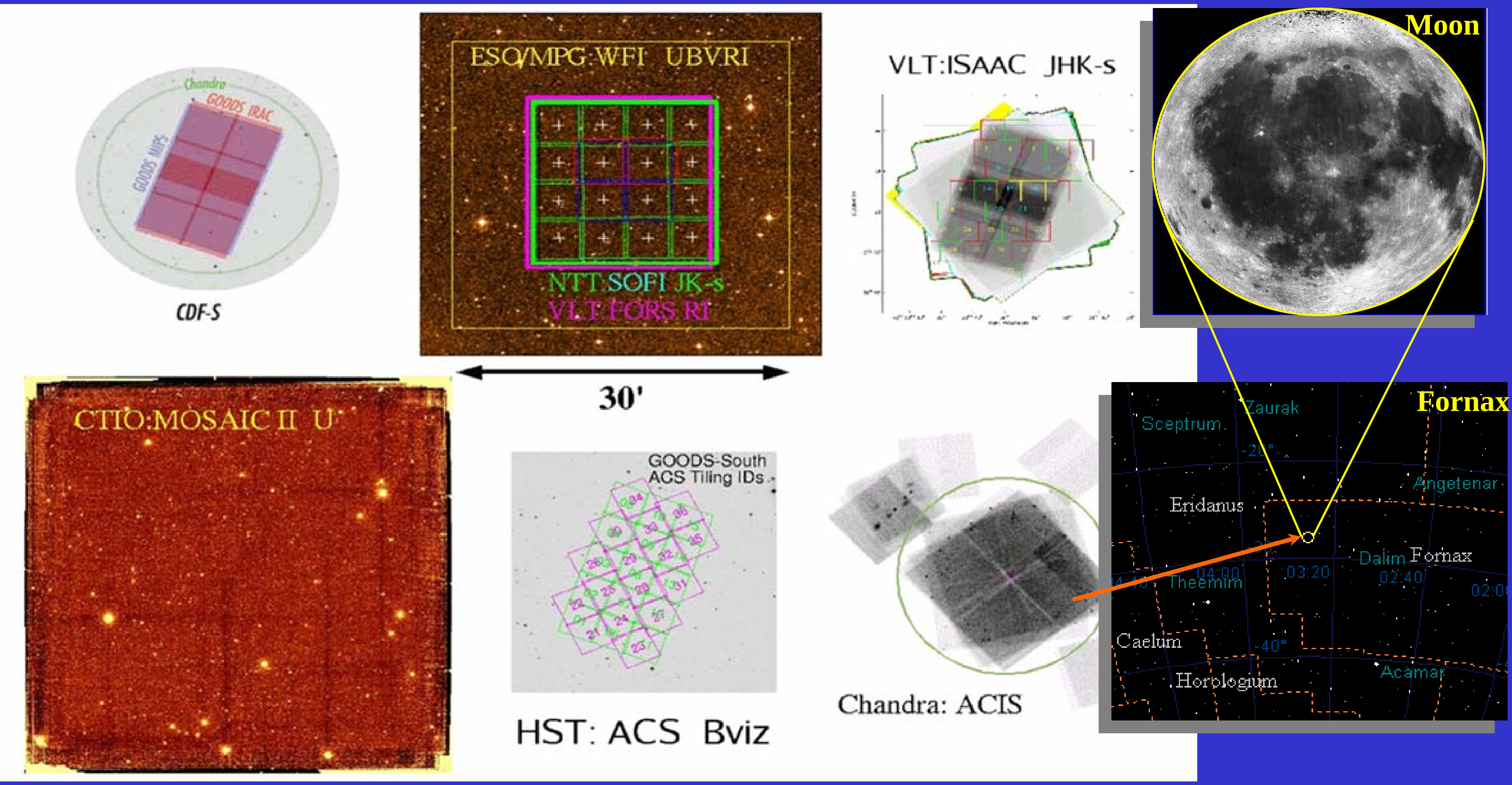


Two-dimensional Spectra of Abell 1835 IR1916
(VLT ANTU + ISAAC)

ESO PR Photo 05b/04 (1 March 2004)

- The Virtual Observatory will enhance the exploitation of these multiwavelength data bases

Astrophysical Virtual

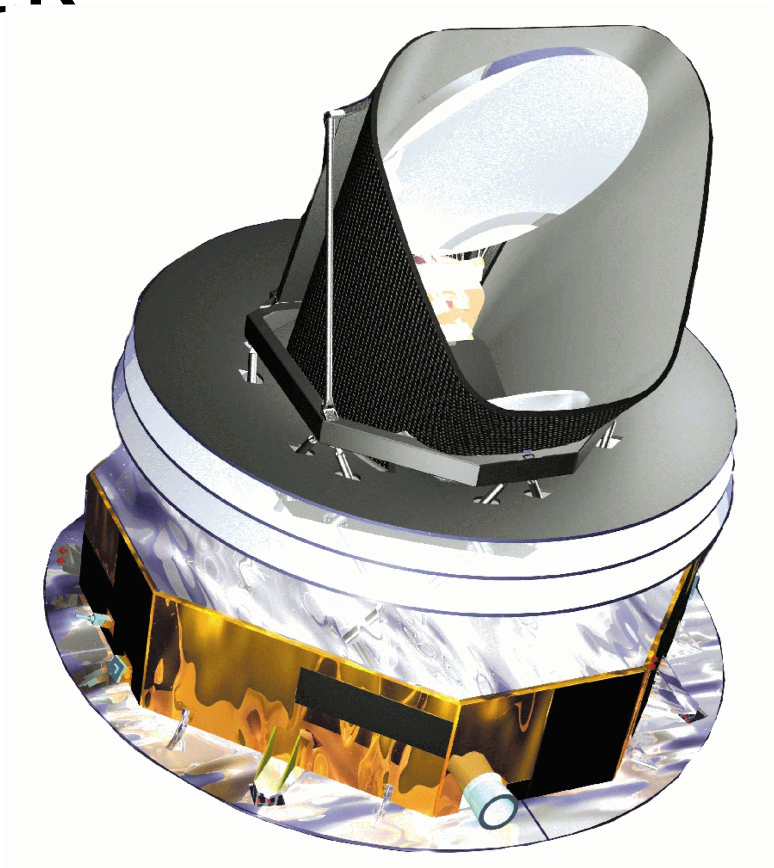


World-class facilities for extragalactic astronomy beyond 2010 (ground, space):

- 8-10m class O/IR telescopes
  - With adaptive optics & second generation instruments
  - Linked interferometrically (VLTI, KECKI,LBT)
  - Supported by survey telescopes (e.g. VST, VISTA)
- ALMA, Herschel for mm/submm regime, with Planck more specifically for cosmology
- HST: UV, O, NIR; followed by JWST: O, NIR, MIR
- Extremely Large Telescopes (GSMT or TMT, OWL)
- Radio: LOFAR, followed by SKA
- GAIA: spectroscopy and kinematics of the Milky Way
- High-energy observatories (GLAST,XEUS, CONSTELLATION X, EUSO)

Planck

The European Mission to map the Cosmic Microwave Background



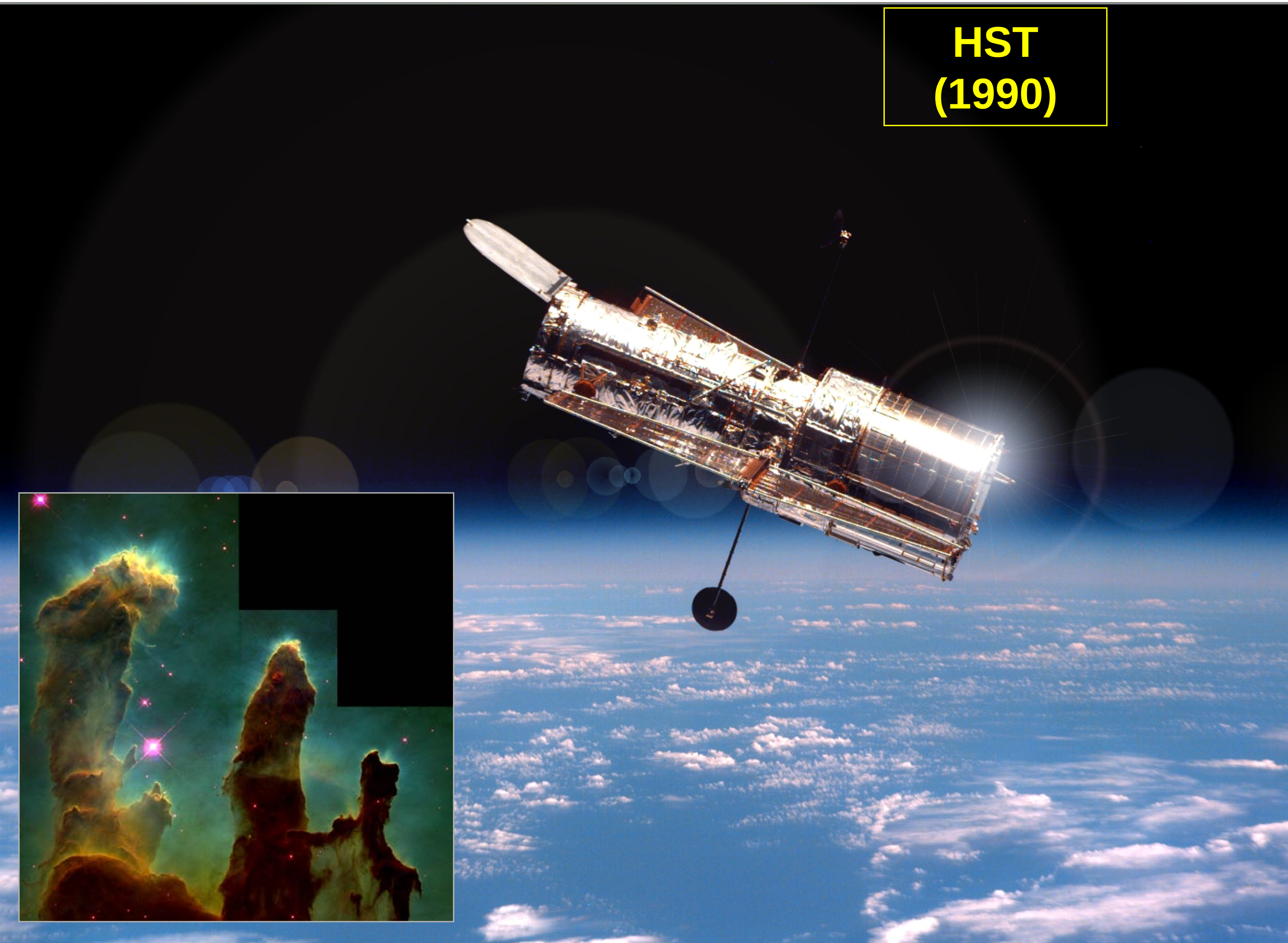
Planck Science Capabilities

Cosmology

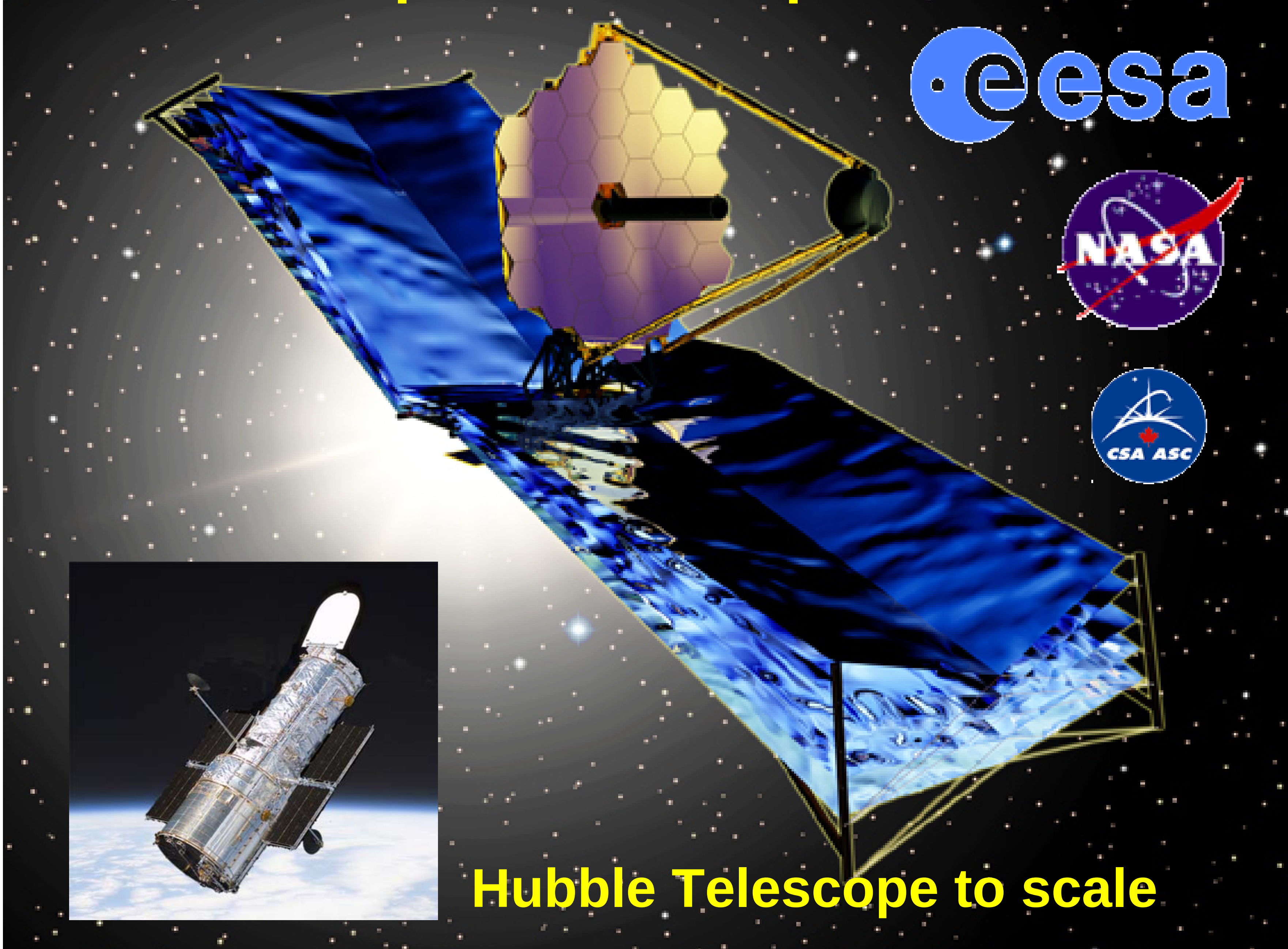
- CMB anisotropy maps to an accuracy DT/T~10^{-6}, on angular scales larger than 10 arcminutes
- Cosmological parameters, H_o, W_o, W_b, ... to a precision of a few percent
- Tests of inflationary models of the early Universe
- Search for non-gaussianity/topological defects
- Initial conditions for formation of large-scale structure
- Nature of dark matter

Astrophysics

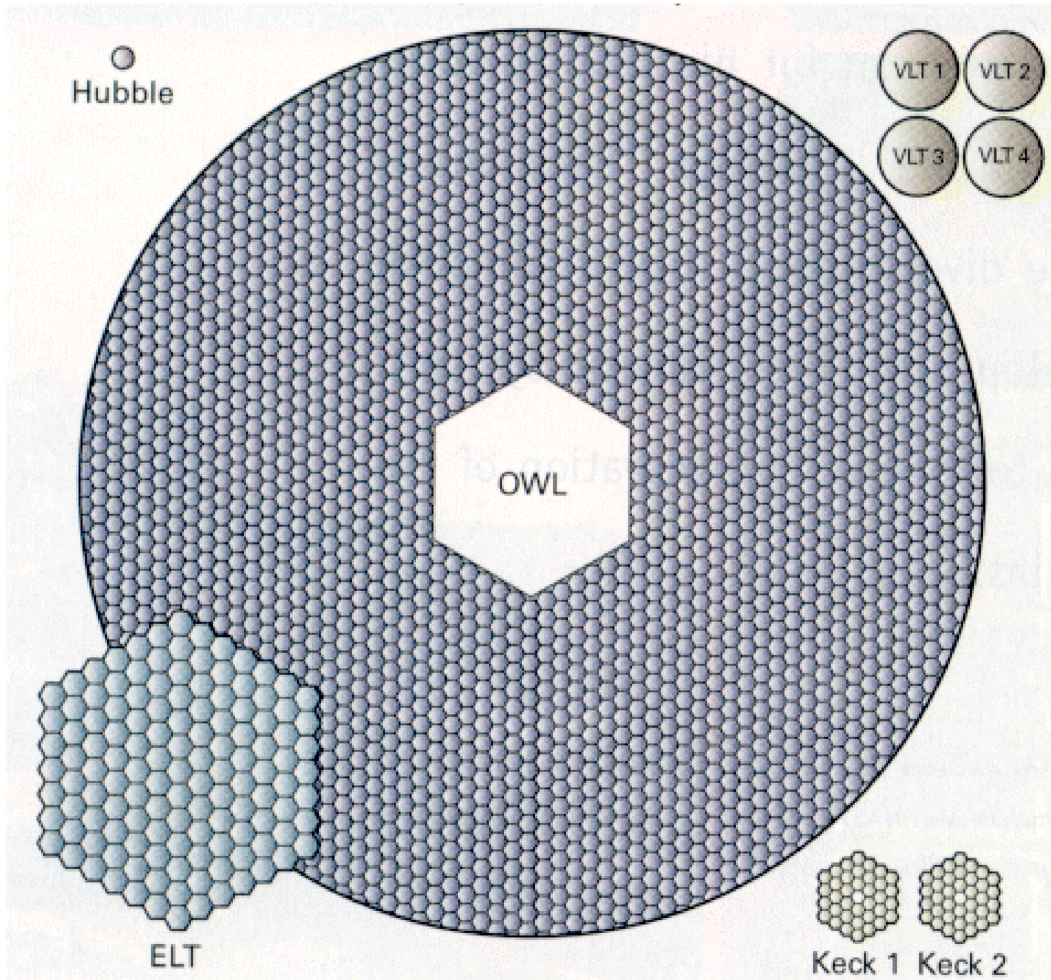
- **Detection of Sunyaev-Zeldovich effect in thousands of rich clusters of galaxies**
- **Catalogs of extragalactic sources and backgrounds**
  - **IR and radio galaxies**
  - **AGN's, QSO's, blazars**
  - **Evolution of galaxy counts to z > 1**
  - **Far-IR background fluctuations …**
- **Maps of Galaxy at frequencies 30 - 1000 GHz**
  - **Dust properties**
  - **Cloud and cirrus morphology**
  - **Star forming regions**
  - **Cosmic ray distribution**
  - **Galactic magnetic field …**

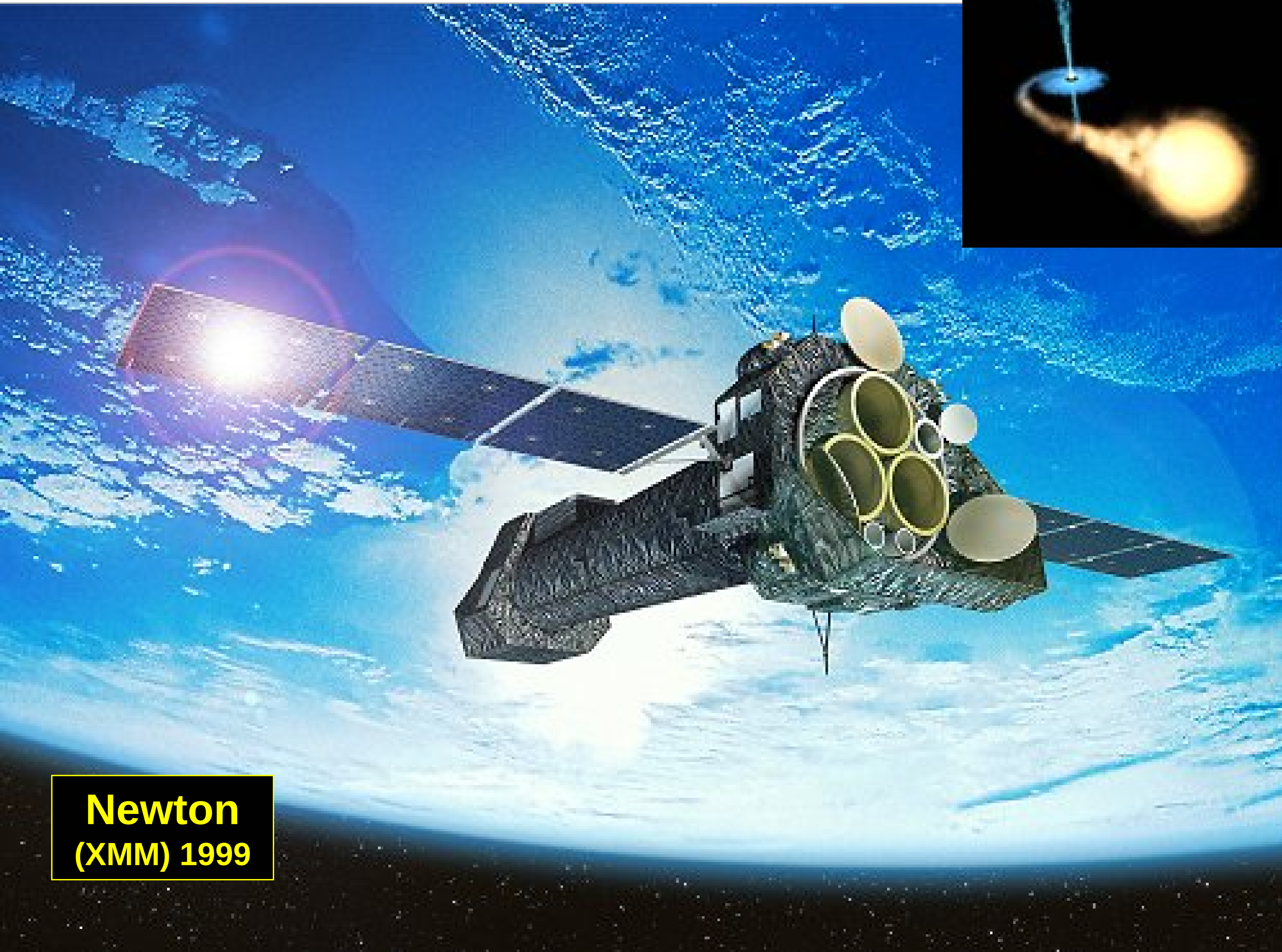

HST
(1990)

James Webb Space Telescope – launch 2011

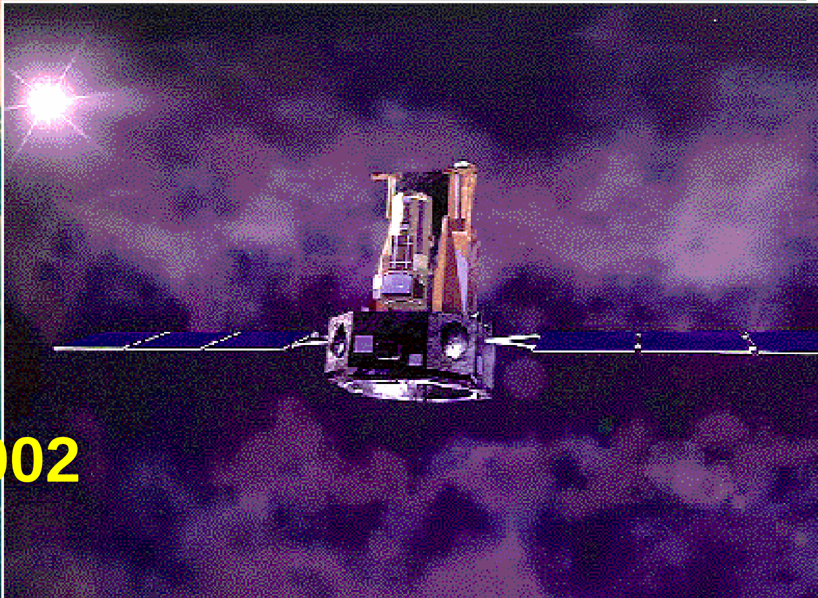


Hubble Telescope to scale

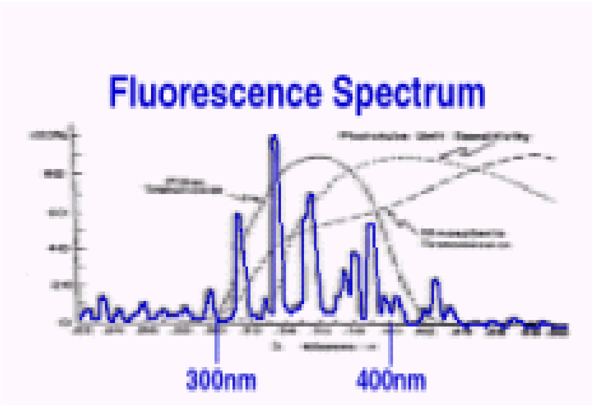

Hubble
VLT 1
VLT 2
VLT 3
VLT 4
OWL
ELT
Keck 1
Keck 2

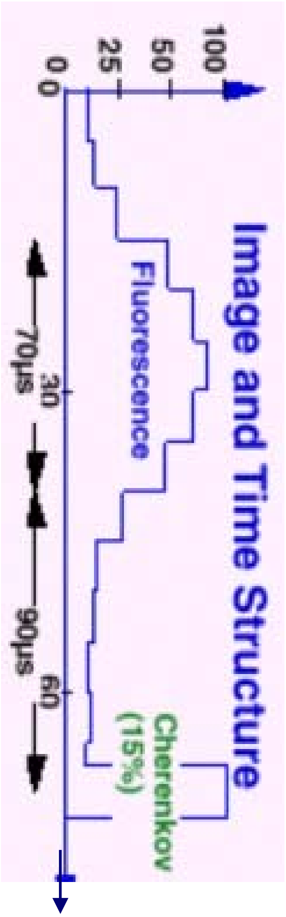

Newton
(XMM) 1999

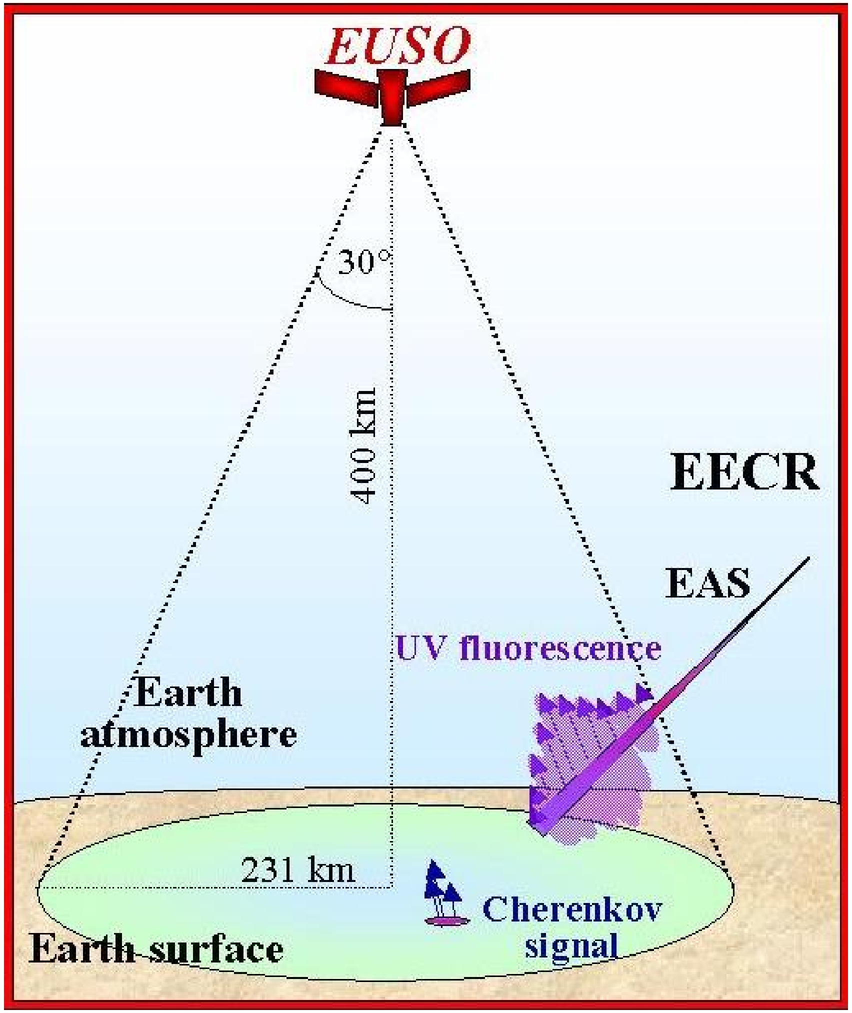
INTEGRAL



EUSO – concept & method of Operation

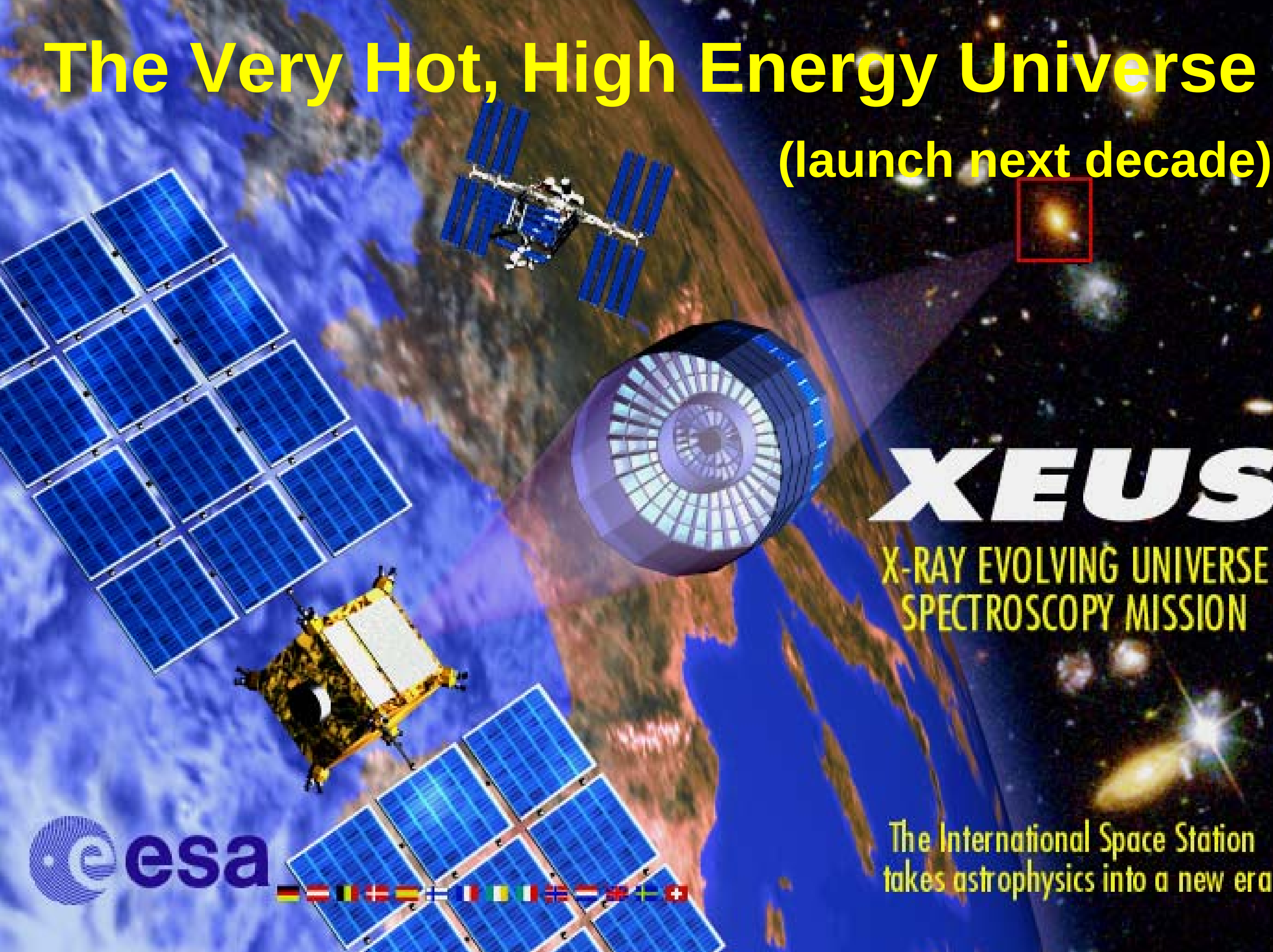




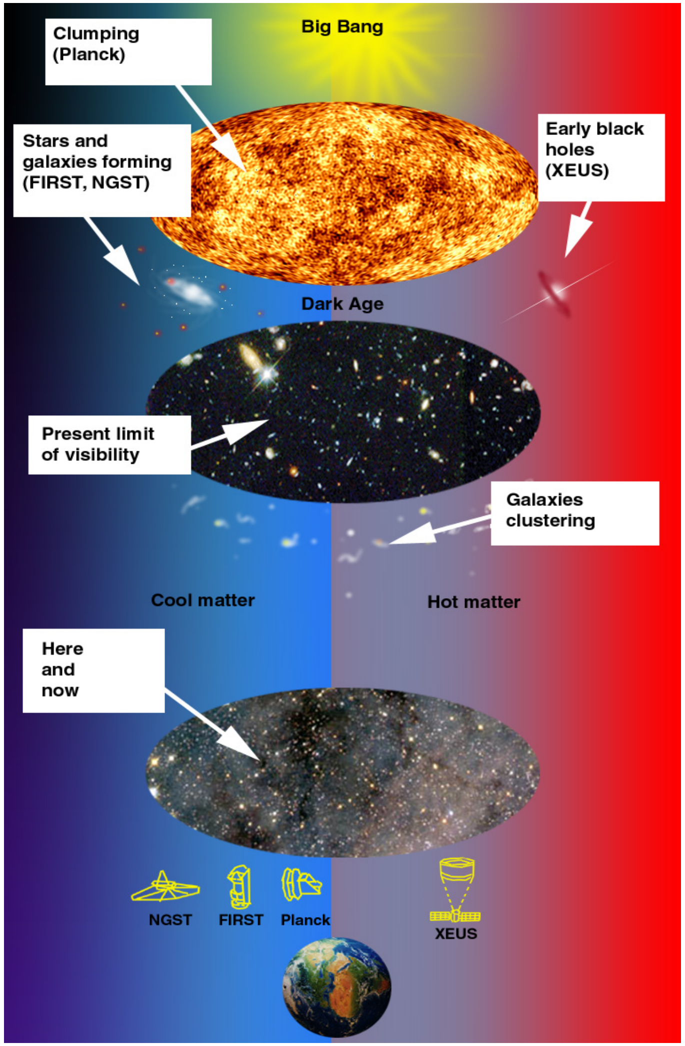


The Very Hot, High Energy Universe

(launch next decade)



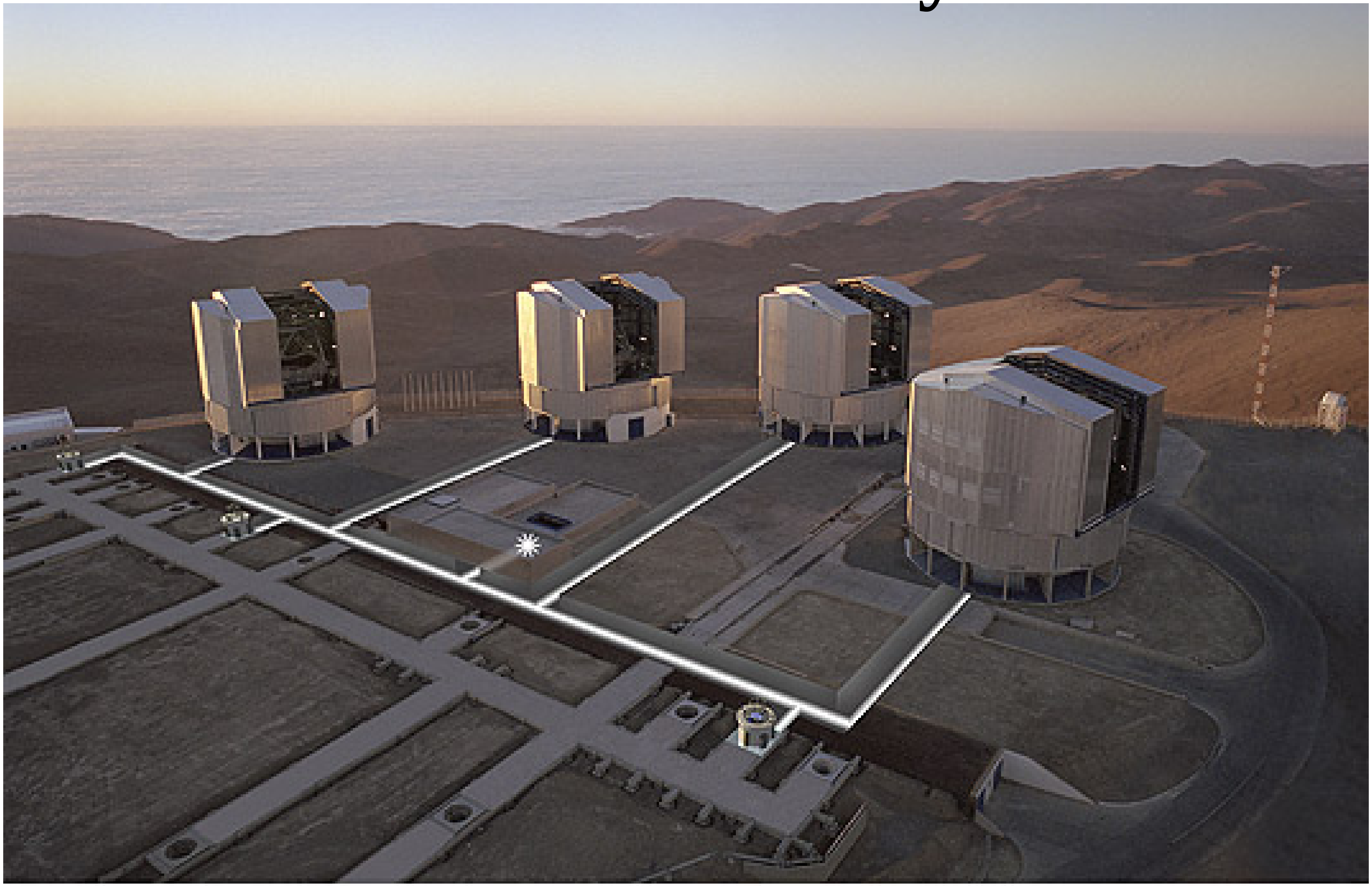
XEUS Science Topics



Observations of the hot Universe at high redshifts will provide crucial complimentary information to NGST, ALMA, Herschel etc on:

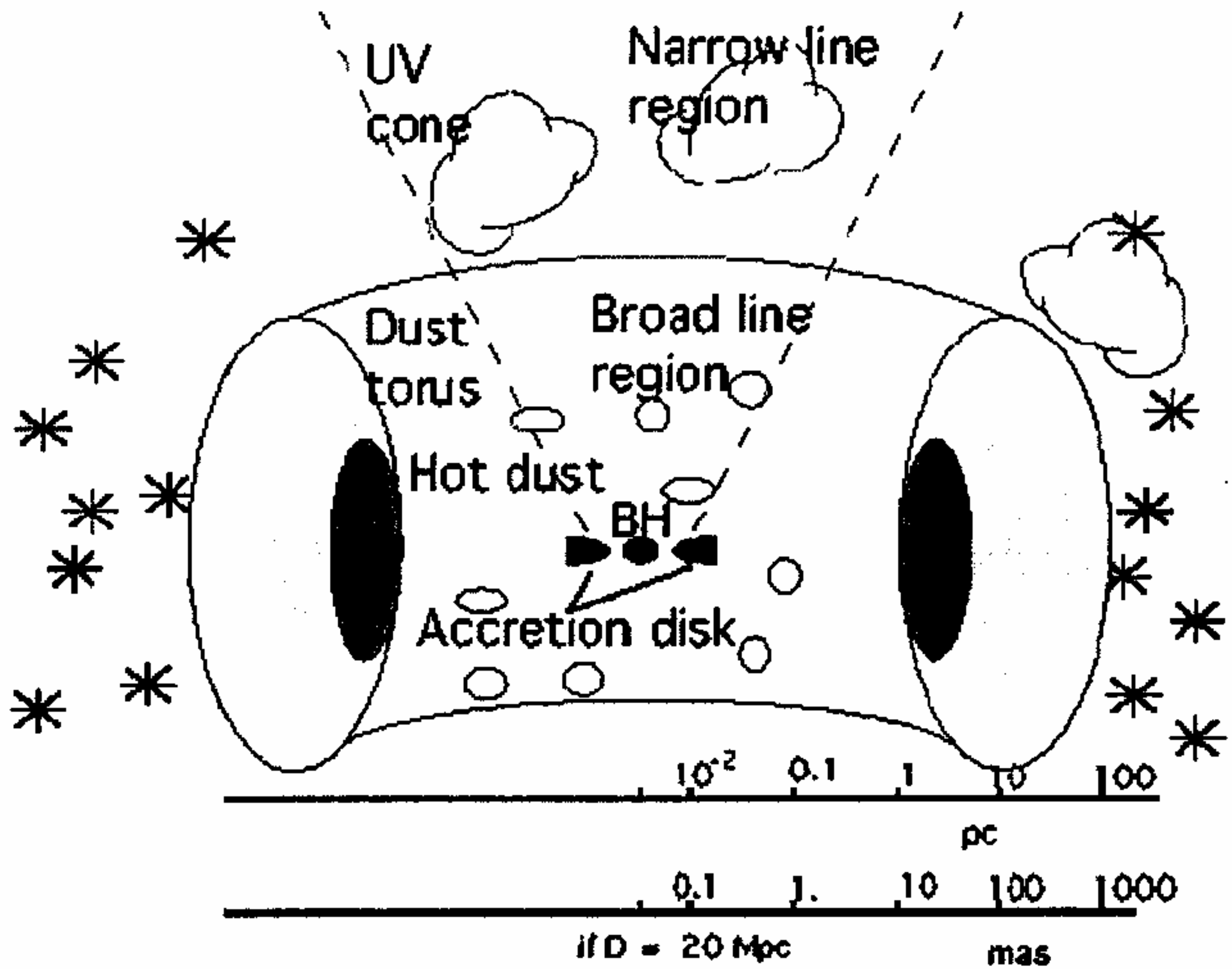
- The formation and evolution of the first massive blackholes
- The large scale structure of the Universe and hot filamentary components at high redshift
- Study of the first small groups of galaxies and their evolution to today's massive clusters
- Study of the formation of the first metals, in the hot inter-galactic medium

The VLTI array



Aerial View of Paranal Observing Platform with VLTI Light Paths

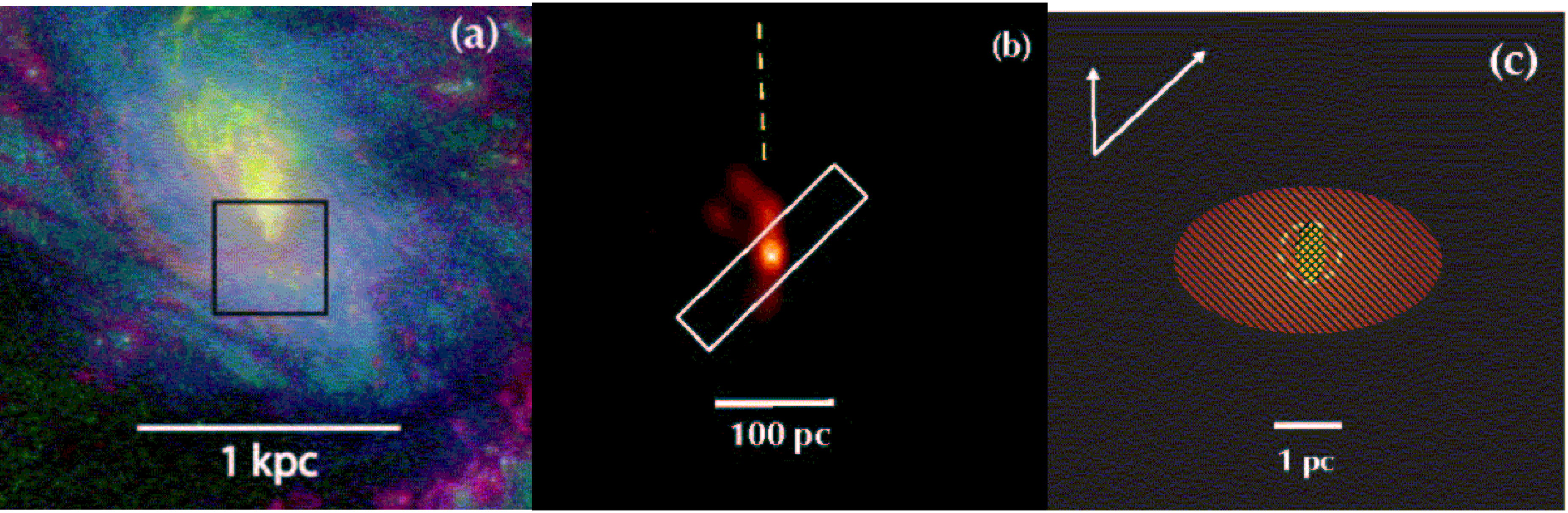
ESO PR Photo 10f/01 (18 March 2001)



UV cone
Narrow line region
Dust torus
Broad line region
Hot dust
BH
Accretion disk
10^{-2} 0.1 1 10 100
pc
0.1 1. 10 100 1000
if D = 20 Mpc
mas

NGC 1068: MIDI in N

Jaffe et al., Nature, 2004, 429, 47



Optical:
HST (Bruhweiler,2001)

Image at 8.7μ
MIDI acq. and
slit position
beam width=0.4”

Simplest model :

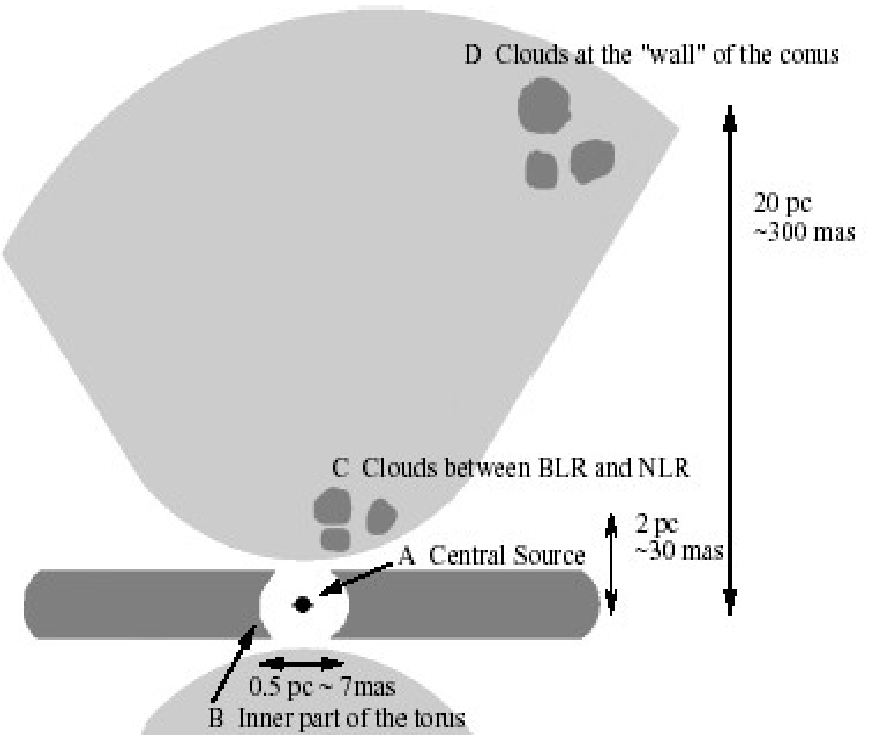
1. hot partially resolved component:
   yellow, h=0.7pc, w<1pc, T>800K
2. warm resolved component:
   red, d=3.4pc, T=320K

NGC 1068: Conclusions

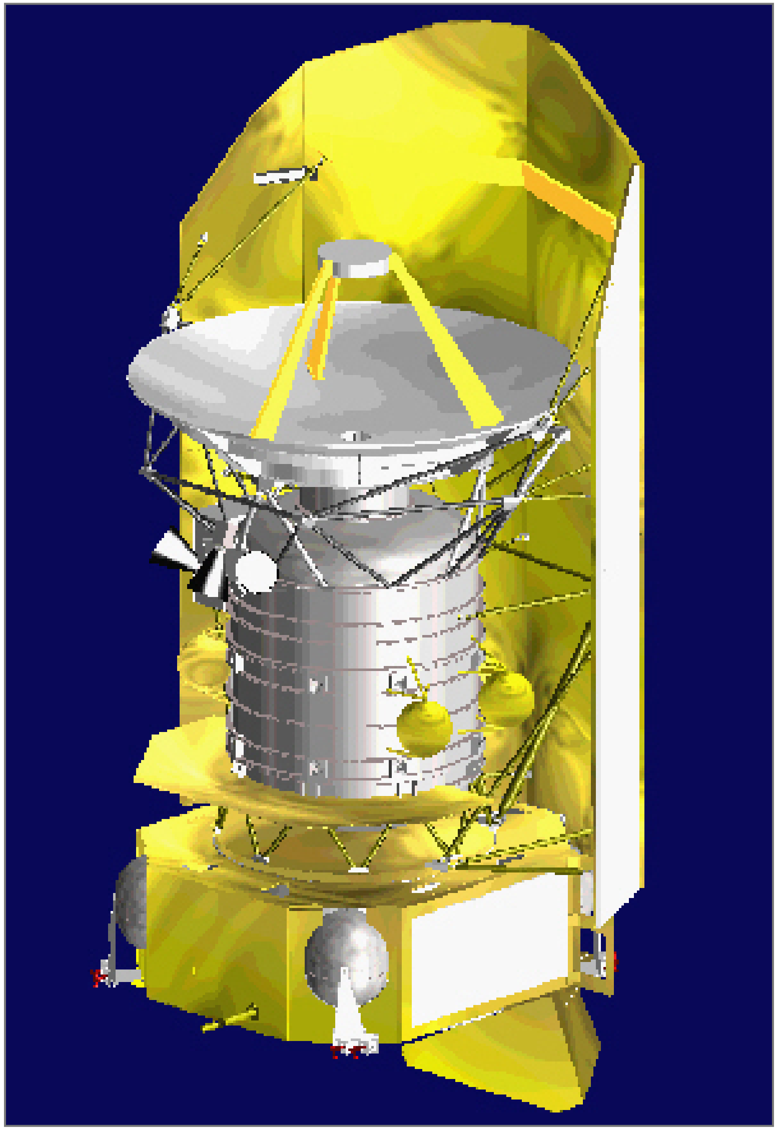
- The simple hueristic model agrees astonishingly well with basic predictions of a Sey2 AGN:

1. Emission from the innermost regions close to the BH should be very compact (d<1pc) and be heavily obscured by dust along the LOS
2. The warm component size d = 2.8pc is the size expected from the Sey1 and 2 galaxy unification hypothesis
3. A chemical differentiation exists between the hotter inner and warmer outer dust components

- Phase info still to be mined!



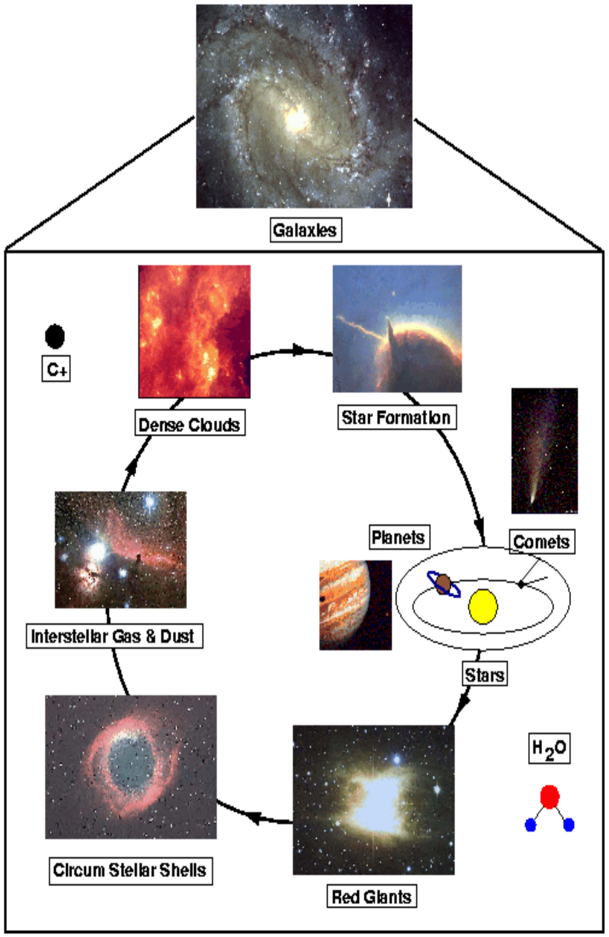
Sensitivity versus Spatial Resolution



HERSCHEL: 3.5m

ALMA: baseline ??km

Herschel: Science Objectives



- **Galaxy Formation and Evolution**
  How & when did galaxies form, universal star formation history, relation to near-IR and sub-mm galaxies

- **Interstellar Medium in the Milky Way and Nearby Galaxies**
  properties of star forming ISM, structure, dynamics, and composition, templates for understanding high-z galaxies

- **Dense Cores and Star Formation**
  dynamics, role of water, disks

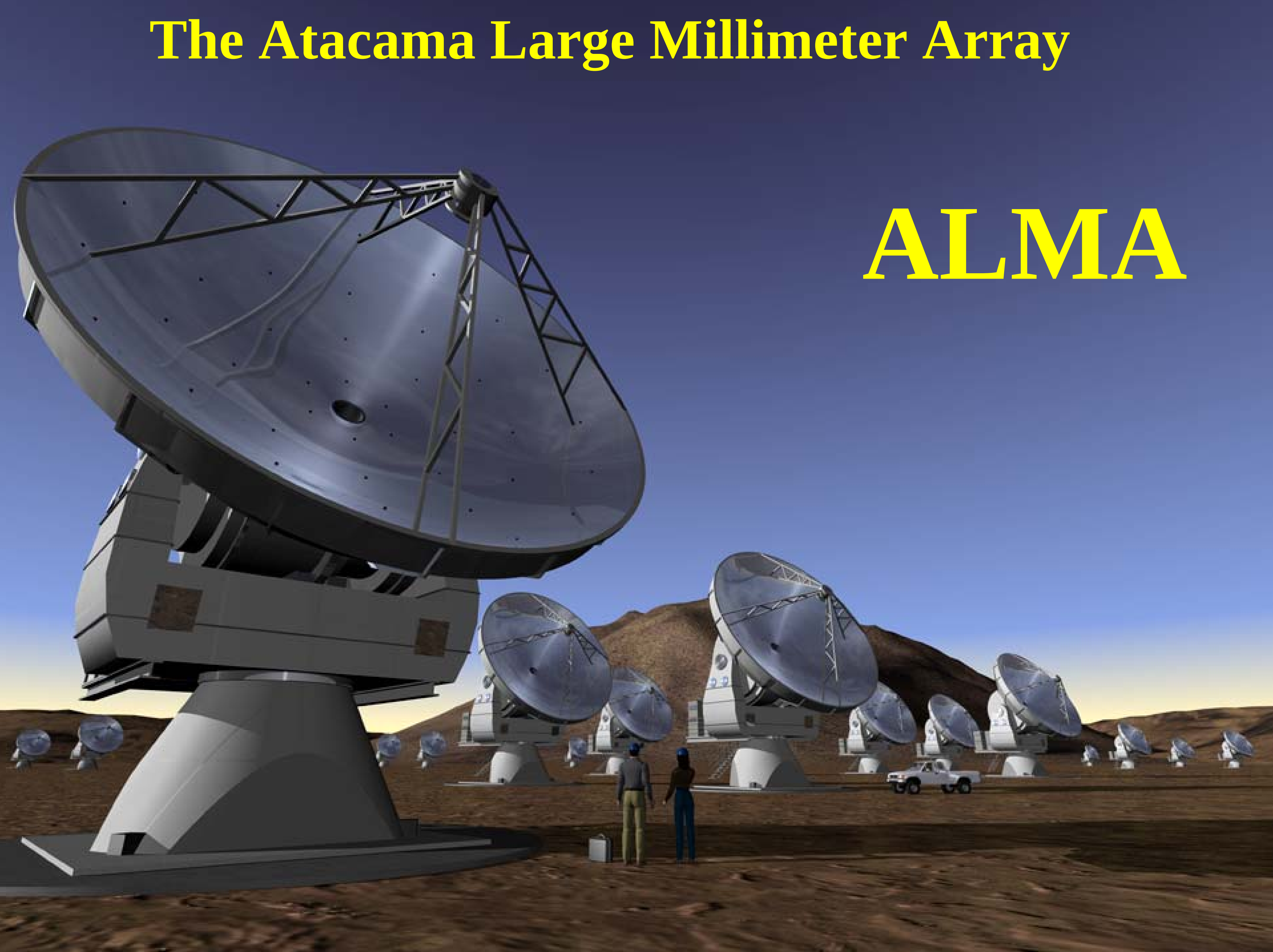
- **Late Stages of Stellar Evolution**
  winds, mass loss, asymmetries, composition

- **Solar System Bodies**
  comets, water in giant planets, chemistry of atmospheres

- **Observatory Mission**
  community's inputs and proposals

The Atacama Large Millimeter Array

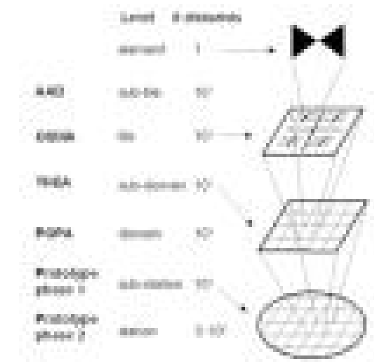
ALMA

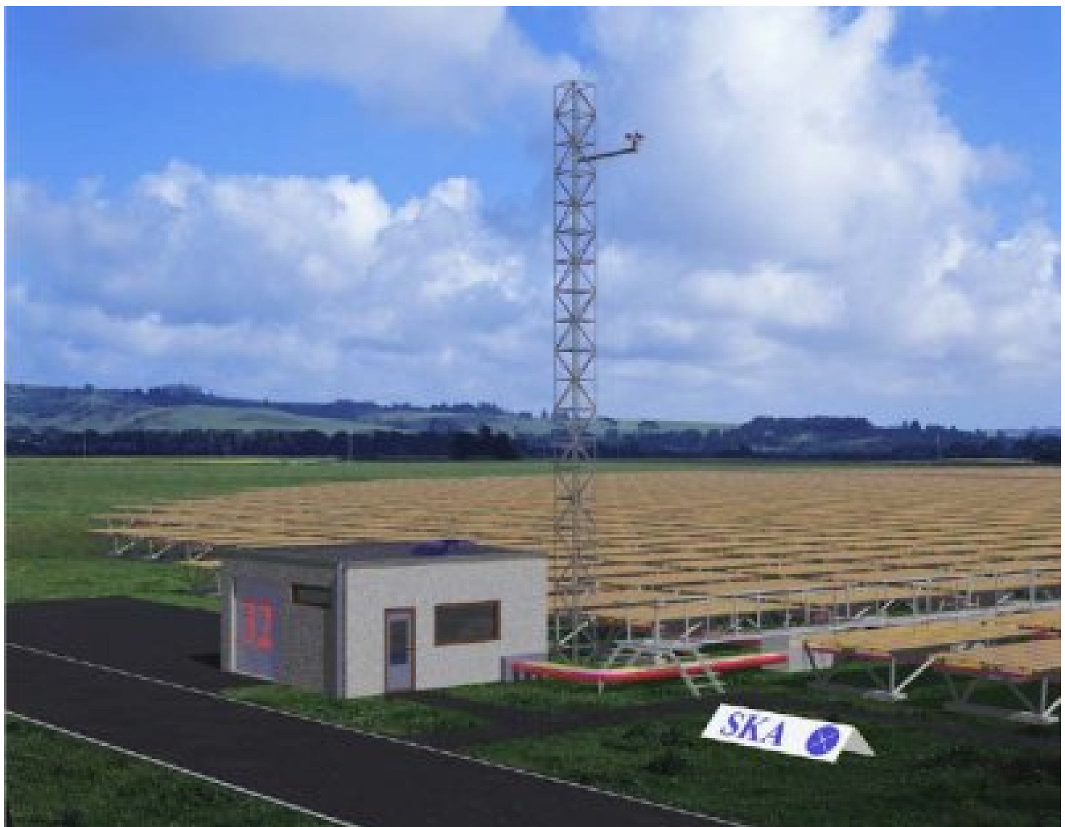


A Global Collaboration

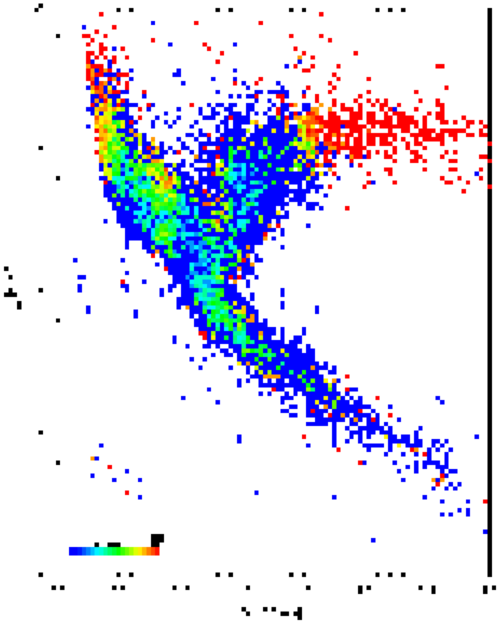
- A large mm/submm array has been the top priority in many countries - the major ground-based astronomical project after VLT/VLTI
- ALMA is an equal partnership between Europe and North America (with a probable participation from Japan)

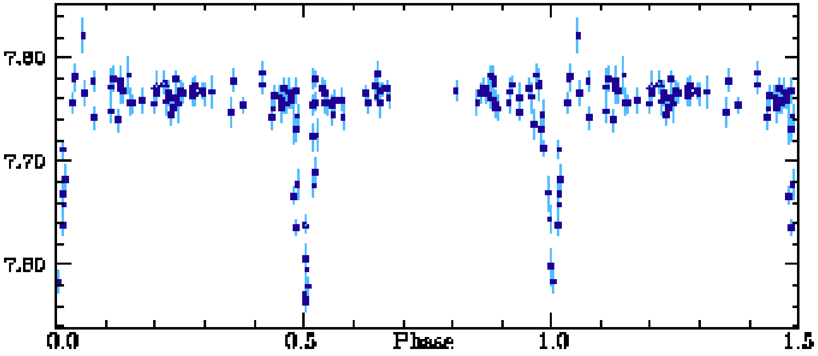

SKA

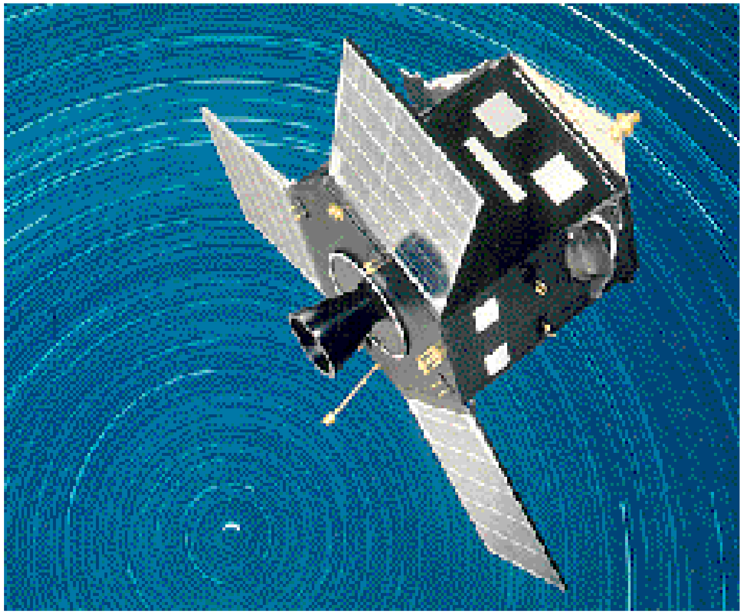



SKA

HIPPARCOS: collected the positions and movements of a million stars (as well as a photometric survey)







- *Catalogues published 1997*

GAIA: science objectives

GAIA will map a billion stars in 3-d…

…and thus provide:

- our Galaxy's spatial and dynamic structure + formation history
- distance and velocity distributions of all stellar populations
- a rigorous framework for stellar structure and evolution theories
- details of a template galaxy for cosmological studies
- definitive distance standards out to the LMC
- fundamental physical quantities to unprecedented accuracies
- support to developments such as VLT, JWST, etc
- a large-scale survey of extra-solar planets
- a large-scale survey of Solar System bodies
- rapid reaction alerts for supernovae and burst sources

A topic of ever increasing importance in contemporary astrophysics:

- Extrasolar planets, from hot Jupiters (well started) to terrestrial planets (very difficult)

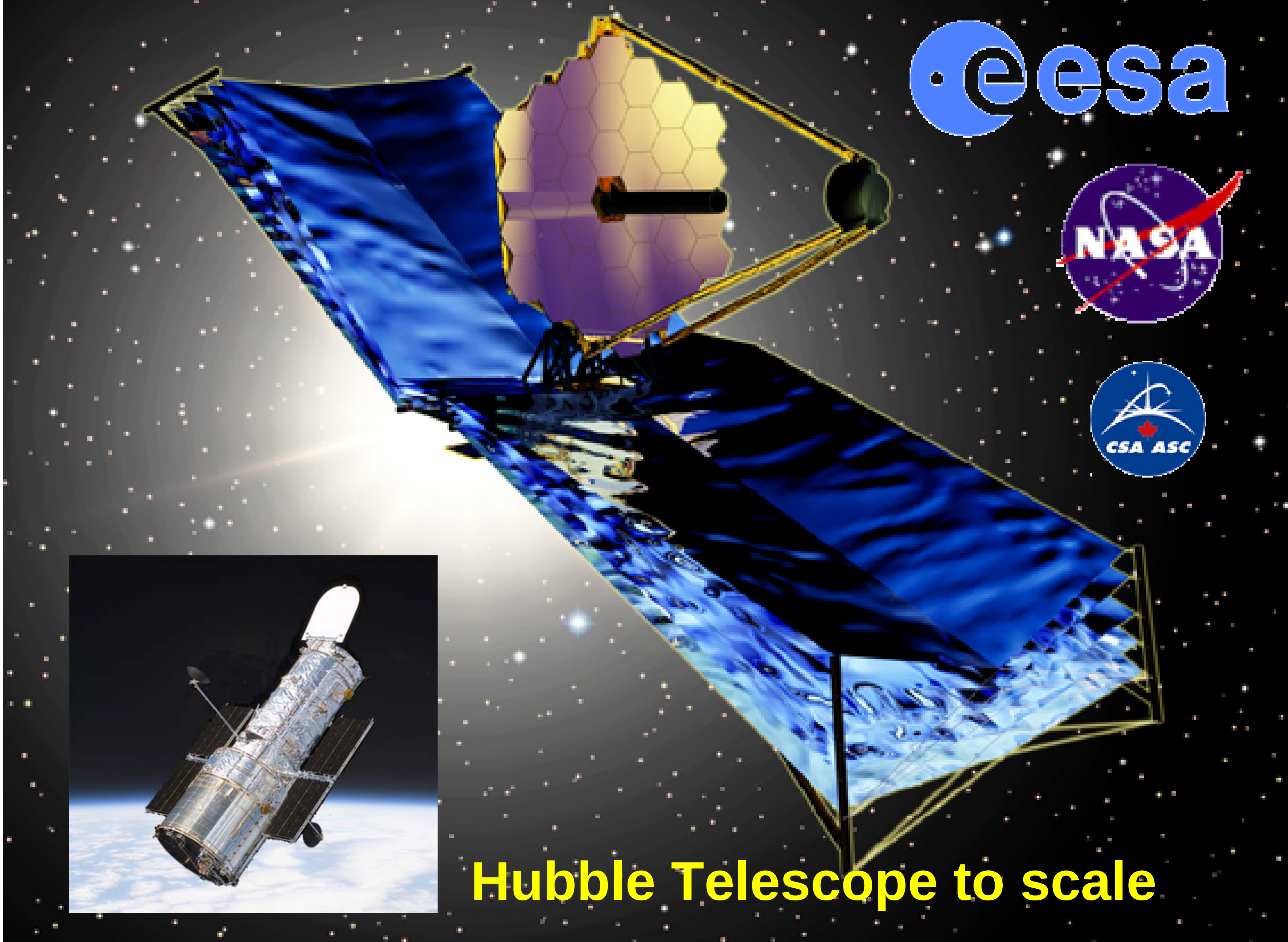
- Circumstellar disks and planet formation

Synergy between ground and space: circumstellar disks

- Spitzer/Herschel/submm bolometer arrays will detect (largely unresolved) mid- and far-infrared excesses around hundreds of stars of different age, luminosity, evolution stage, …
- ALMA and JWST-MIRI will have the sensitivity to detect and image dust in disks down to lunar masses at subarcsec resolution (down to 1 AU) out to distances of 300 pc
- VLTI-MIDI will be able to image the hot dust within few AU in brightest systems
- Herschel will provide peak luminosity and spectral energy distribution
- Complete spectroscopy 1 μm to 3 mm of both gas and dust by combined VLT/JWST/Herschel/ALMA data in brighter systems
- GAIA essential to obtain accurate distances for analysis and statistics

- (E. van Dishoeck)

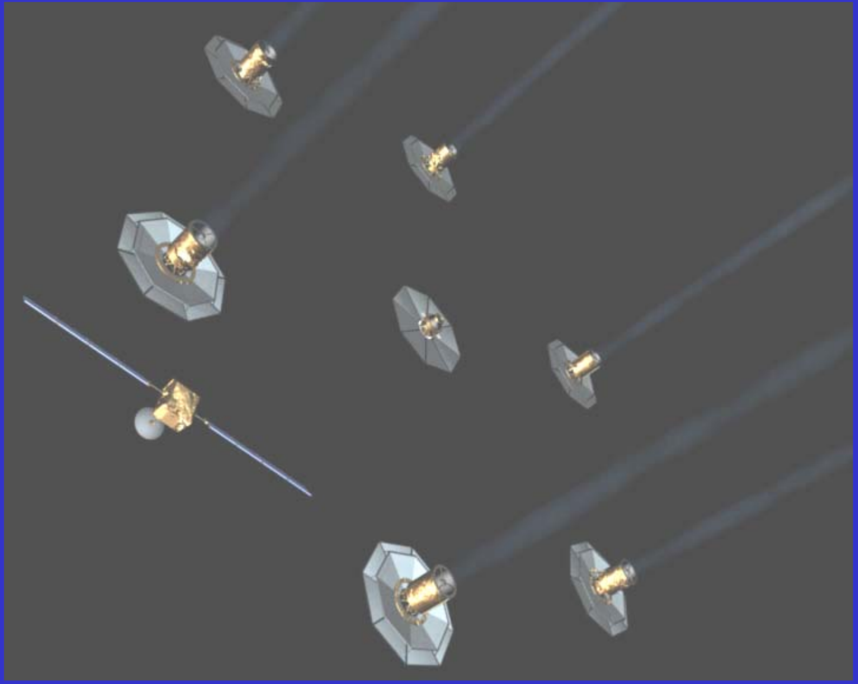
James Webb Space Telescope – launch 2011

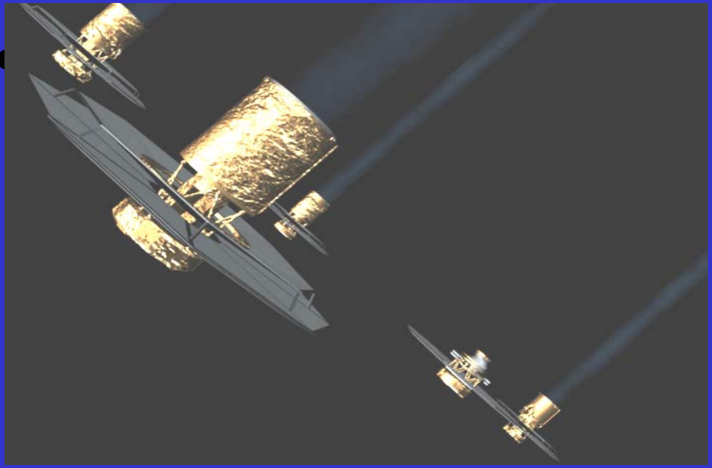


Hubble Telescope to scale

Darwin: baseline design

- Array of 6 telescopes, + 1 beam combiner + 1 command satellite
- 5 µm – 18 µm wavelength range

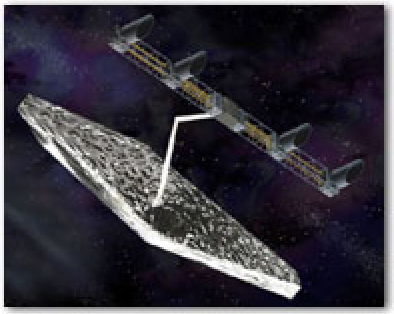




Technology Challenges – Space based hunt for exo-planets in the habitable zone

Interferometers

Formation flying or large structures (10-100 m)



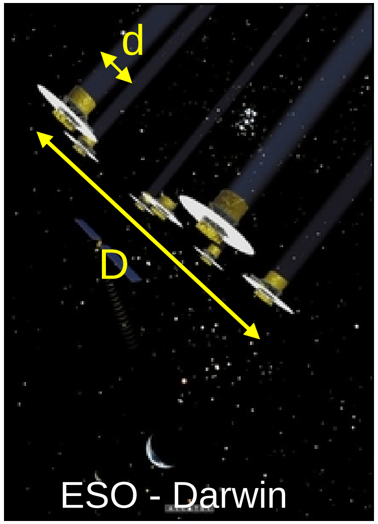
Lockheed - TPF

Exceptional parent star rejection though interferometry

Loss of planet flux through interferometric dilution (Angel, 1994)

Planet flux reduction

$\sim nd^2/D^2$

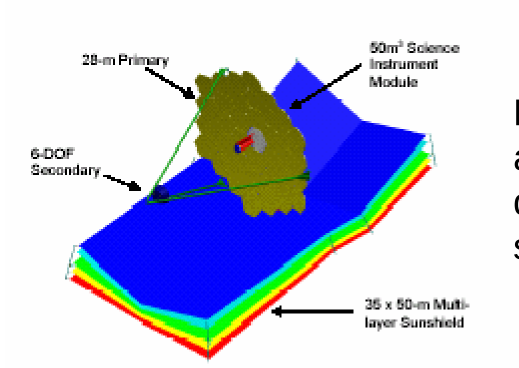


ESO - Darwin

Forming an image or spectra will require long integrations – hence high interferomtetric stability

Large Aperture Telescopes

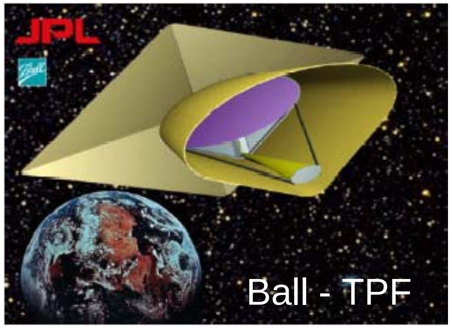
Extremely high precision (e.g., λ/5000) wavefront control of large (deployable) mirrors (4-20 m)



TRW - TPF

Exceptional collecting area for faint planet detection and spectroscopy

Deployable/lightweight mirrors require precise wavefront control at all spatial scales, and low scattering properties

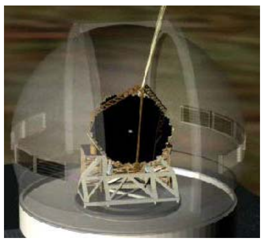


Ball - TPF

- JWST is first "prototype"

Technology challenges and trades will have to be resolved by JWST, TPF (NASA) and Darwin (ESA) Teams

Technology Challenges – Groundbased hunt for exo-planets



30m concept

100m concept

It is still cost effective to build extremely large telescopes on the ground.

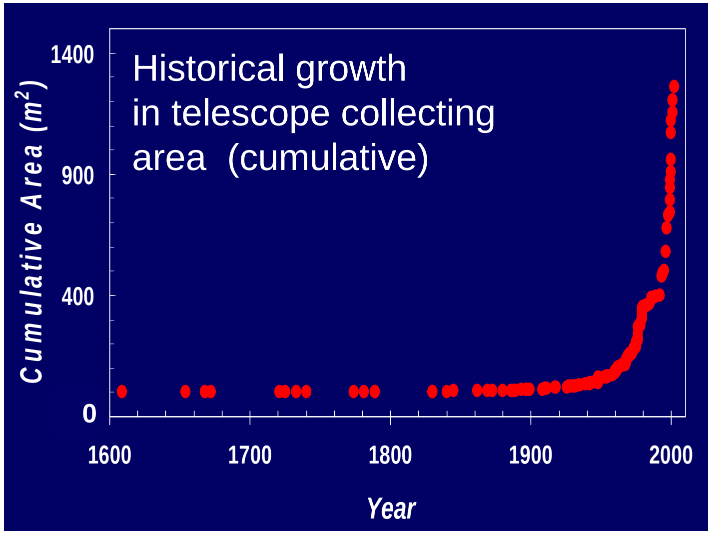
However the hunt and study of planets and their environments requires adaptive optics (AO)

AO implementation complexity scales with telescope diameter (D)

$\sim D^3 - D^4$

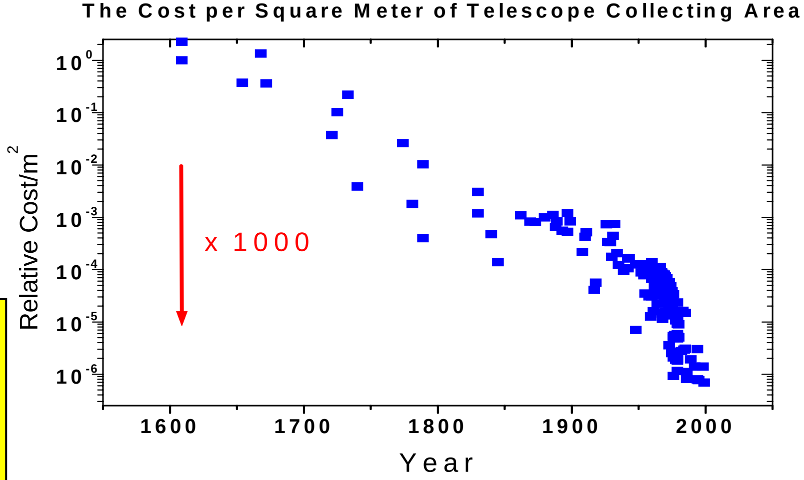
Scaling current AO technologies from the current state-of-the-art presents the greatest technical challenge since several technologies must be developed concurrently.

Consequently cost scaling laws for AO remain uncertain.



The change in inflation corrected cost/unit area

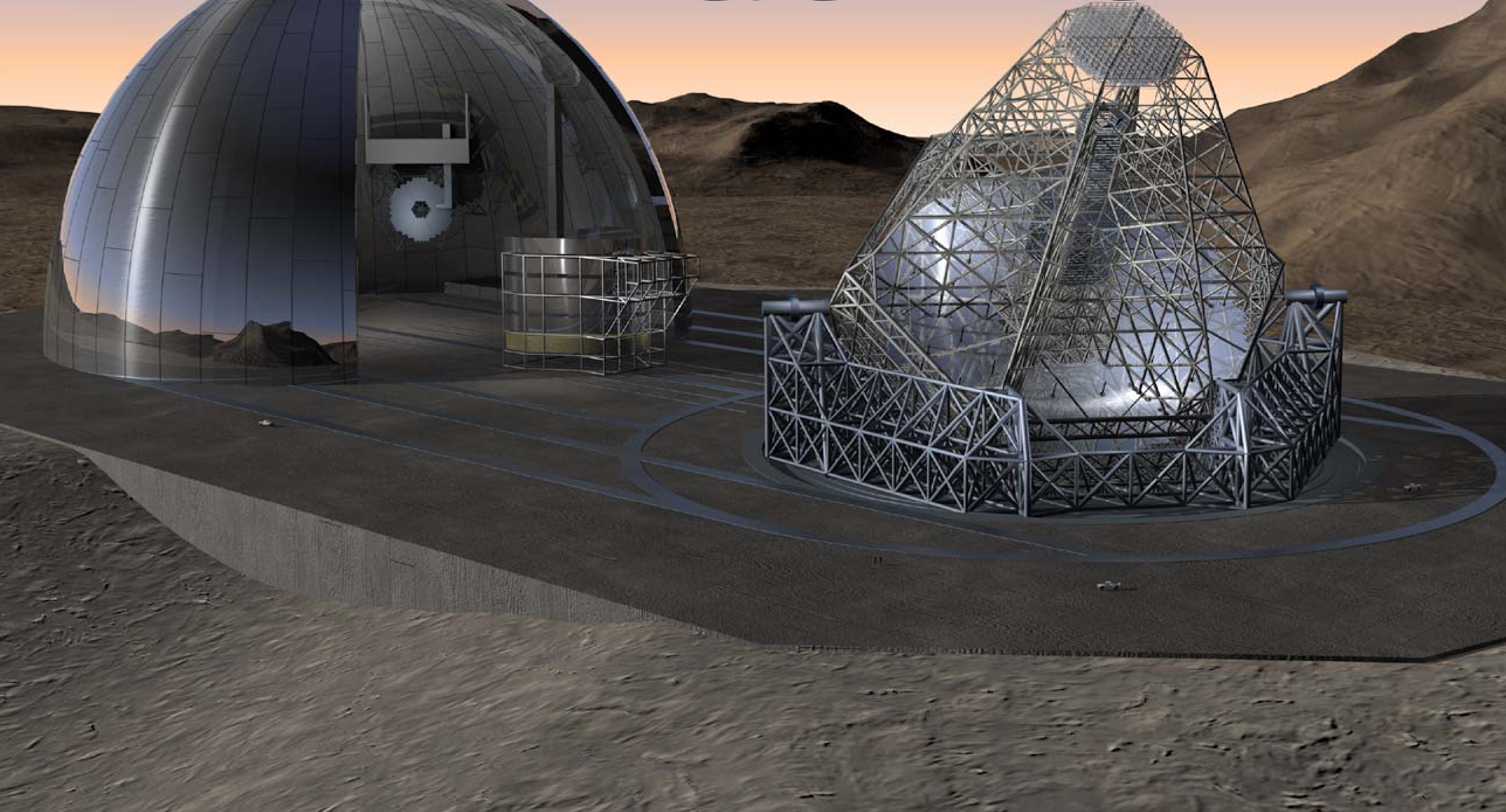
(normalized to 1600)



Recent studies of 30m – 100m end-to-end concepts have suggested science effectiveness compared to technical risk and cost may still scale with diameter (D) between $D \sim D^4$

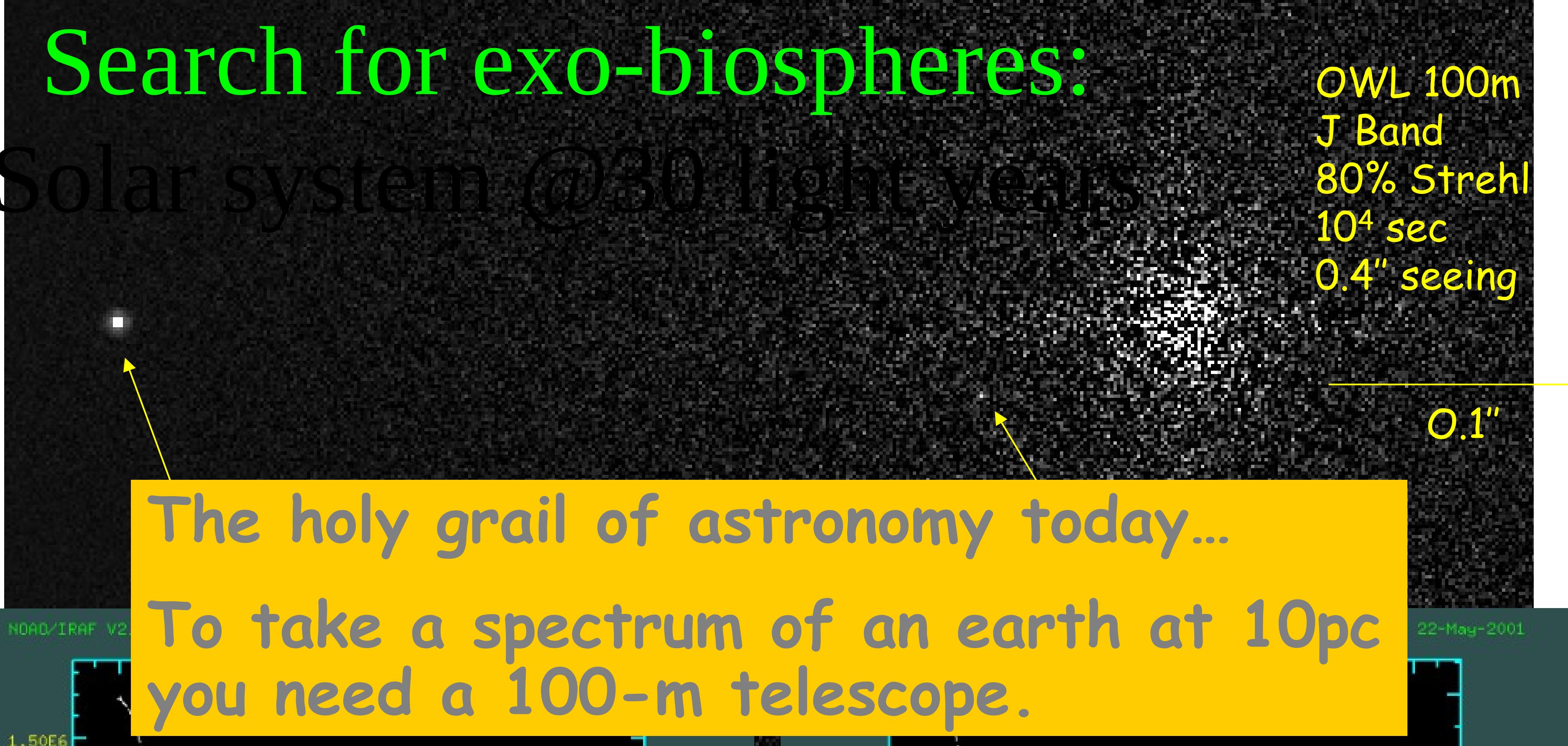
- ➢ science value/$ still increases with D

THE OWL 100-M TELESCOPE



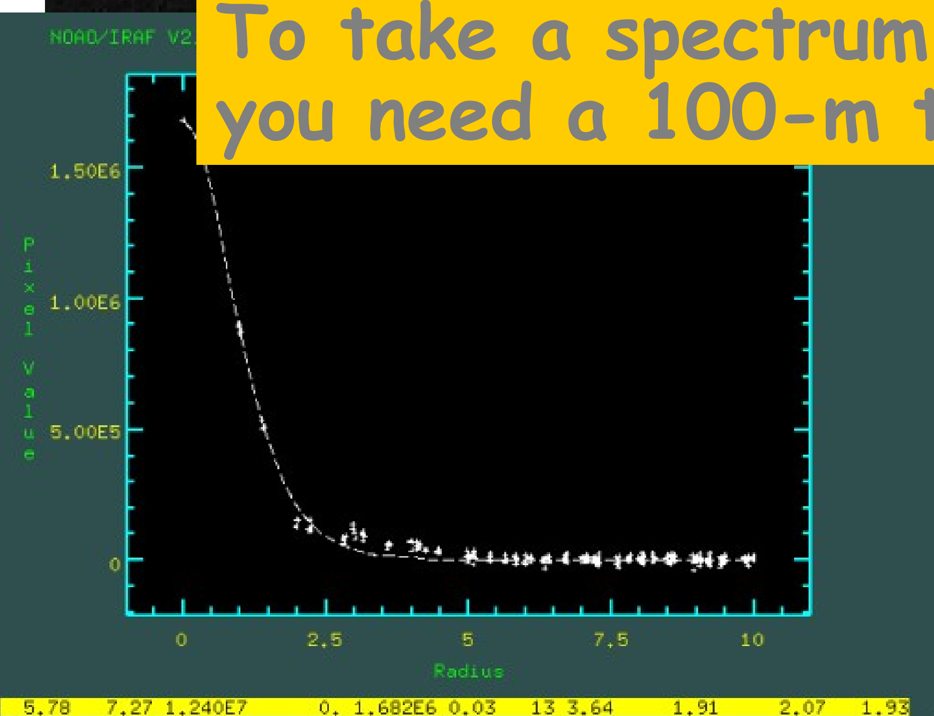
Search for exo-biospheres:

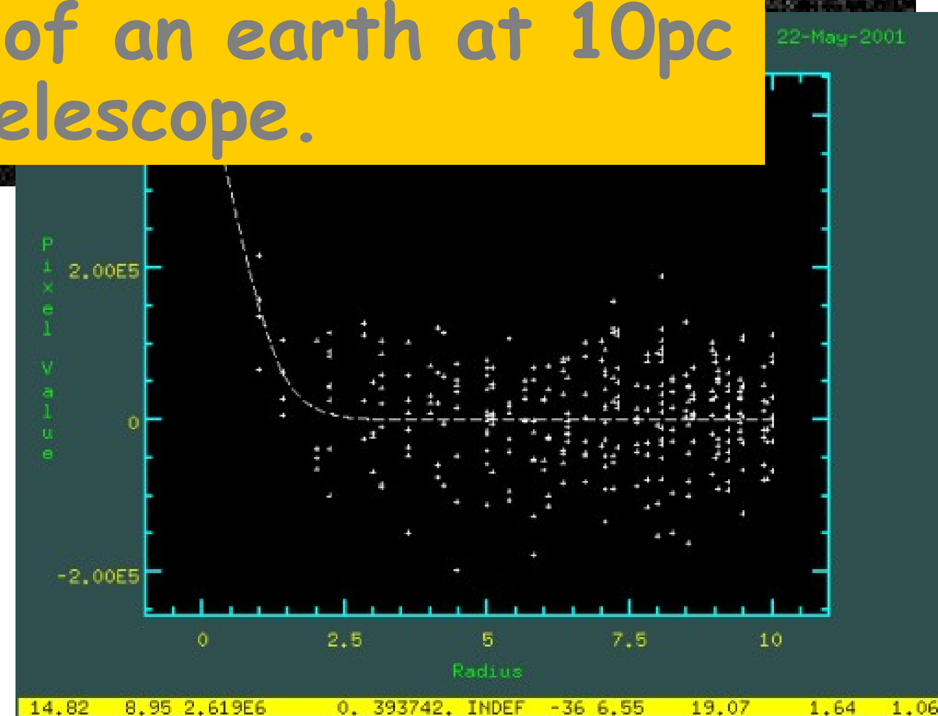
Solar system @30 light years



The holy grail of astronomy today…

To take a spectrum of an earth at 10pc you need a 100-m telescope.

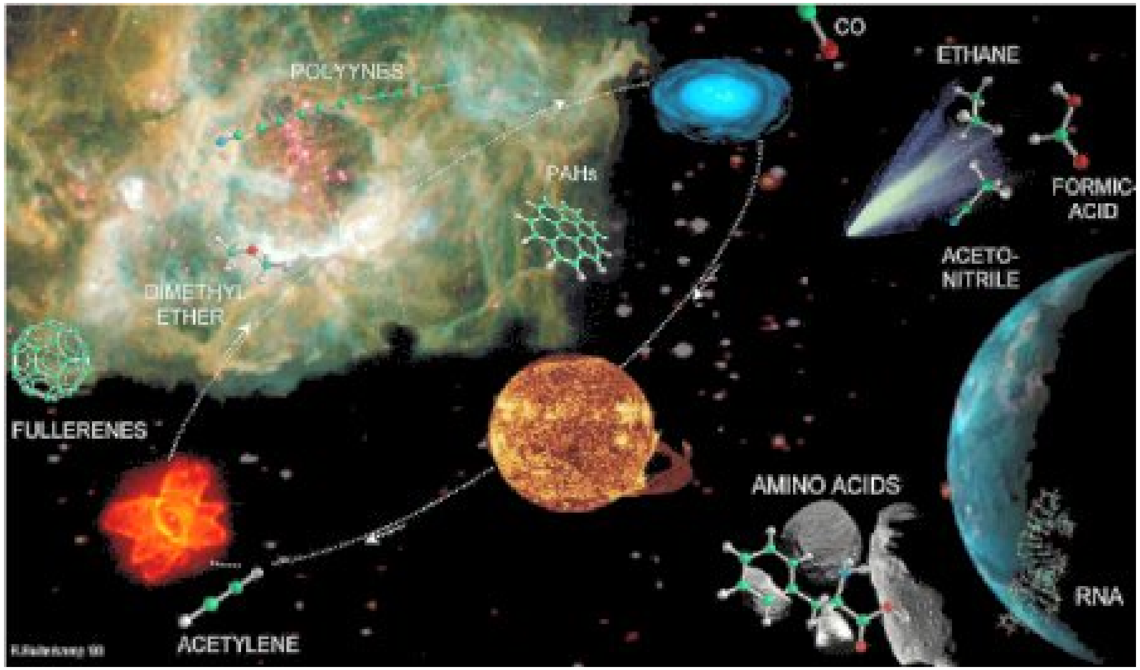




"Complementarities of OWL"

- **NGST**
  - Unmatched in the thermal IR
  - OWL would
    - be a better imager for $\lambda < 2.5\ \mu m$
    - be a better spectrograph ($\Re \geq 5000$) for $\lambda < 5 \mu m$
    - have better resolution at *any* λ (but needs bright objects for $\lambda > 2.5 \mu m$)
- **ALMA**
  - Synergetic role (*e.g.* in finding/studying protoplanets)
- **VLTI**
  - Bright object precursor with better resolution (but mainly a separate ecological niche)
- **VLBI**
  - "They" have been waiting for us optical people to catch up in resolution for decades…

LIFE IN OUTER SPACE



ISO and SPITZER, ROSETTA, MARS missions, 8 to 10m, VLTI, ALMA, JWST, ELT, SKA, DARWIN/TPS

This meeting:

- Opportunity for the various wavelengths communities to confront, compare and complement their science goals, and for all of us to get excited about the forthcoming discoveries of THE FIRST GALAXY, or AN HABITABLE, EARTH LIKE PLANET, or…