European Organisation
for Astronomical
Research in the
Southern Hemisphere

Astronomy made in Europe

Catherine Cesarsky

CERN

September 21 2006

The Making of ESO

European Organisation for Astronomical Research in the Southern Hemisphere

1964 La Silla (Chile)
1970 CERN umbrella and collaboration
1976 Completion of 3.6-m telescope at La Silla
1980 ESO located in Garching
1982 Decision to construct 3.5-m New Technology Telescope (NTT)
1987 Decision to construct 4 x 8.2-m Very Large Telescope Array (VLT)
1989 First light of NTT – the VLT Prototype and Testbench
1998 First light 1st of VLT
2003 Signature ALMA Agreement with NSF
2004 Council resolution on ELT

O. Heckmann, Sr. Marchetti, J.H.Oort, N.U.Mayall, F.K.Edmondson and A.B.Muller, 1963, guests of AURA

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La Silla

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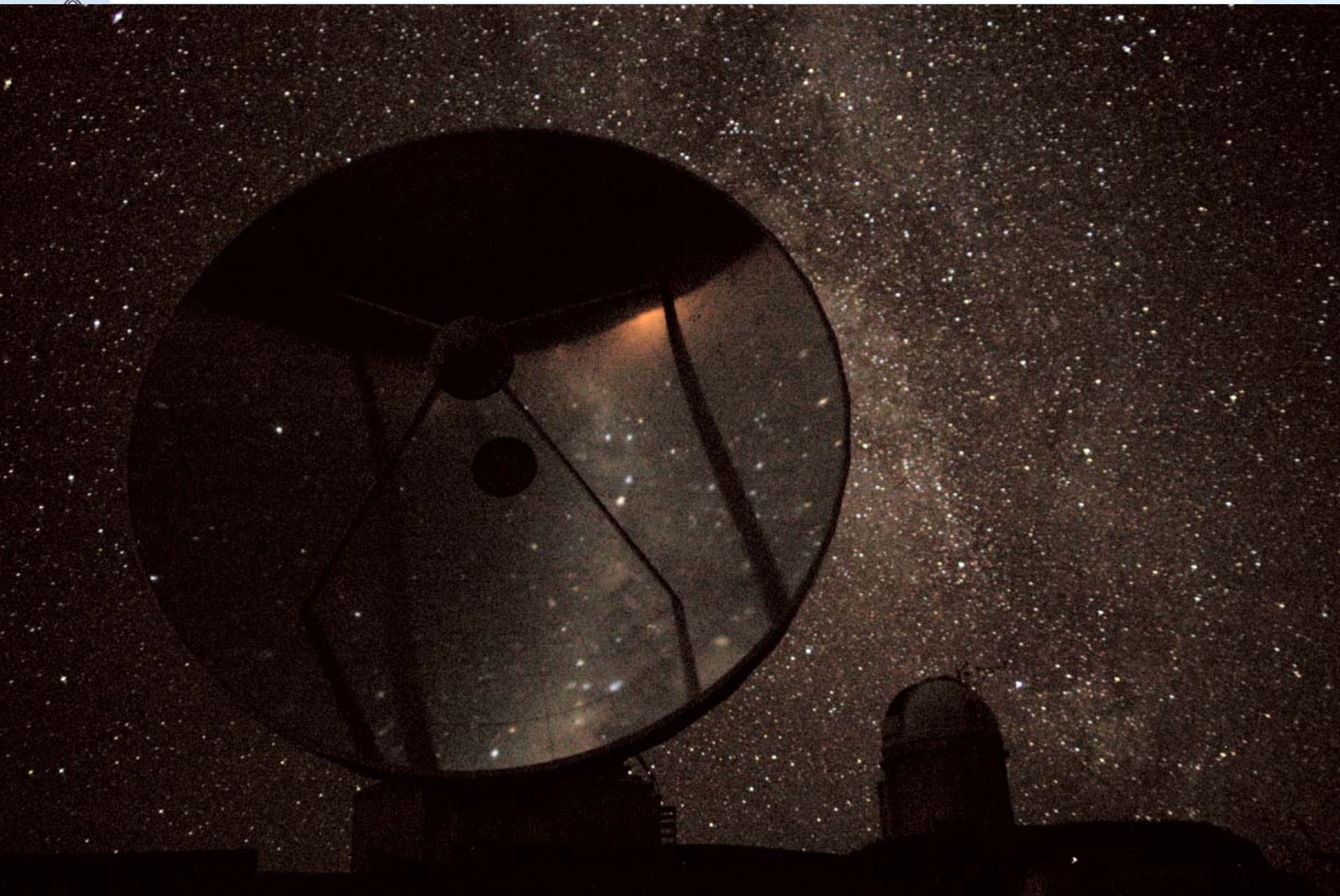
HARPS

- Assembled
- Aligned
- Detector optimized
- FIRST LIGHT
  on Feb. 12, 2003
- Commissioned
- Operation from Oct. 1, 2003
- EXOPLANETS
- ASTEROSISMOLOGY

Milky Way Above La Silla



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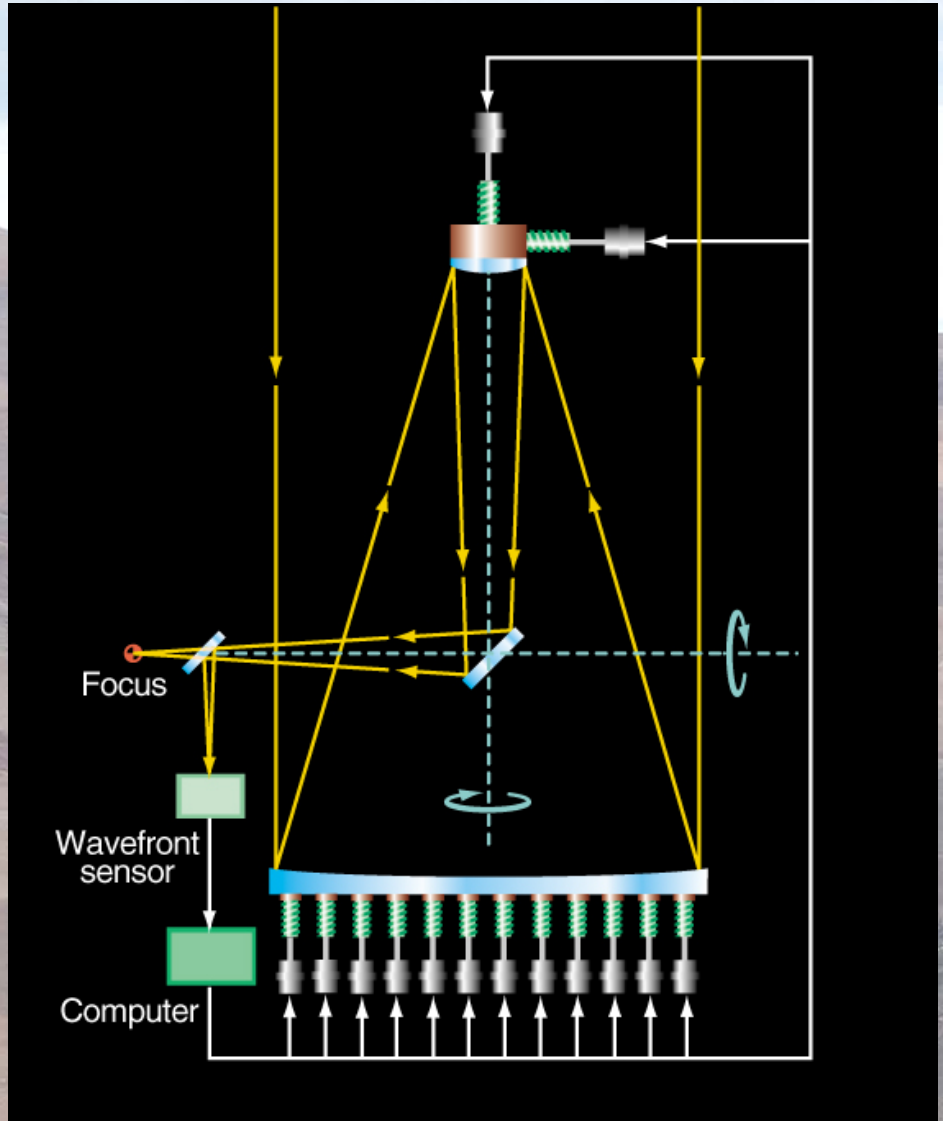
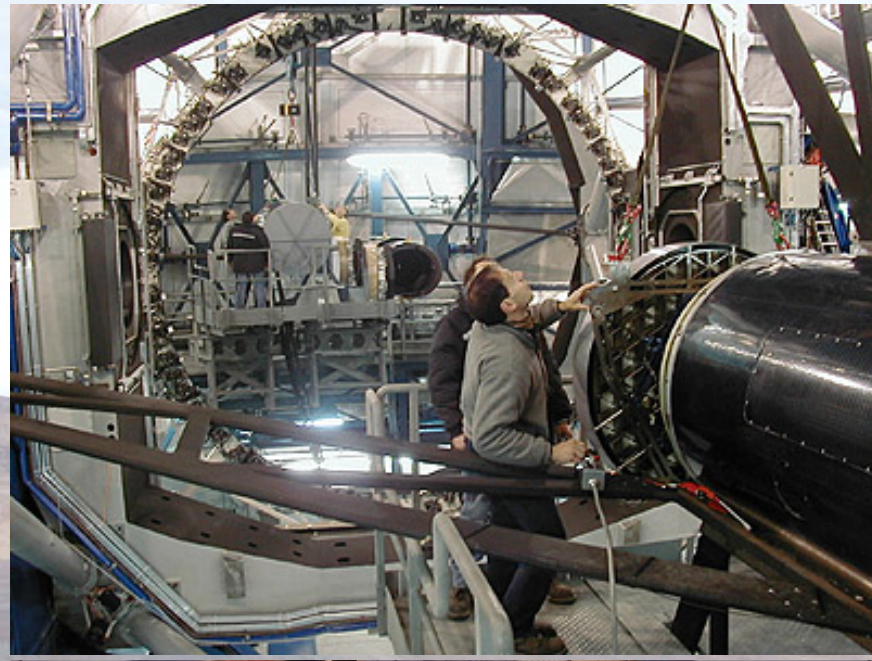
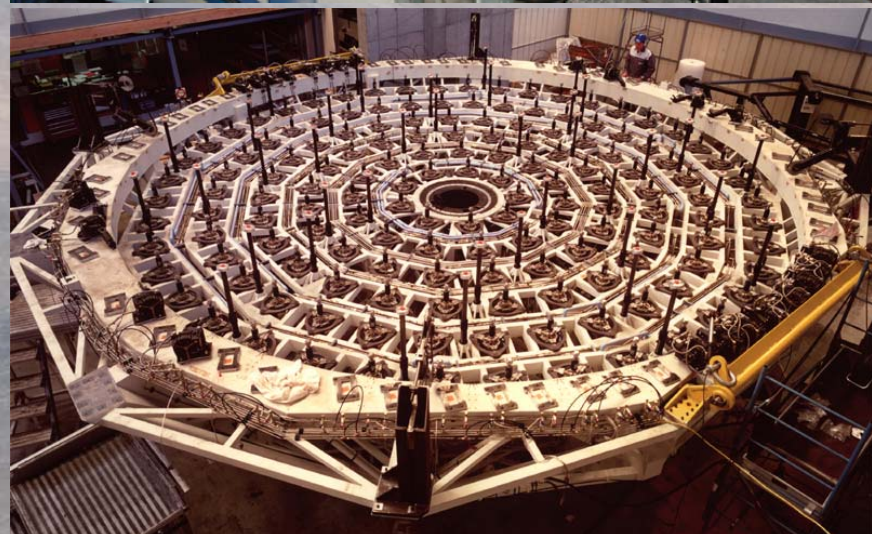
Active Optics







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Building the VLT

Transformation of the Paranal Mountain

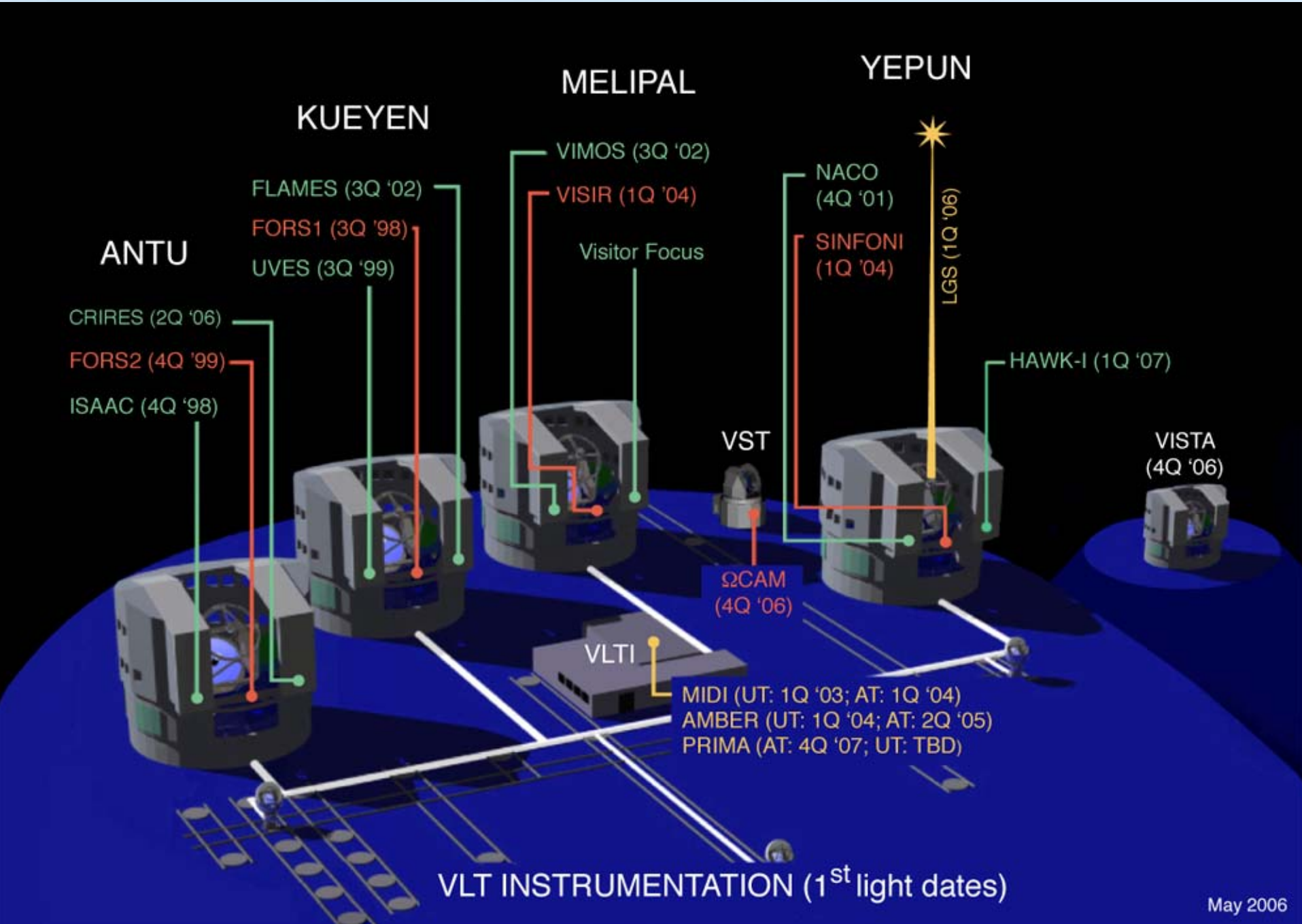
Paranal today

VISTA

VST

- UT 1 (Antu) – May 1998
- UT 2 (Kueyen) – March 1999
- UT 3 (Melipal) – January 2000
- UT 4 (Yepun) – September 2000

- AT1 – January 2004
- AT2 – December 2004
- AT3 – October 2005
- AT4 – Autumn 2006


MELIPAL
YEPUN
KUEYEN
VIMOS (3Q '02)
VISIR (1Q '04)
NACO
(4Q '01)
FLAMES (3Q '02)
FORS1 (3Q '98)
UVES (3Q '99)
Visitor Focus
SINFONI
(1Q '04)
LGS (1Q '06)
ANTU
CRIRES (2Q '06)
FORS2 (4Q '99)
ISAAC (4Q '98)
HAWK-I (1Q '07)
VST
VISTA
(4Q '06)
ΩCAM
(4Q '06)
VLTI
MIDI (UT: 1Q '03; AT: 1Q '04)
AMBER (UT: 1Q '04; AT: 2Q '05)
PRIMA (AT: 4Q '07; UT: TBD)
VLT INSTRUMENTATION (1st light dates)
May 2006

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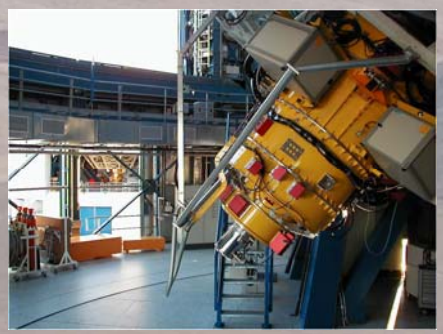
Operational VLT Instruments

ANTU

ISAAC

2x FORS



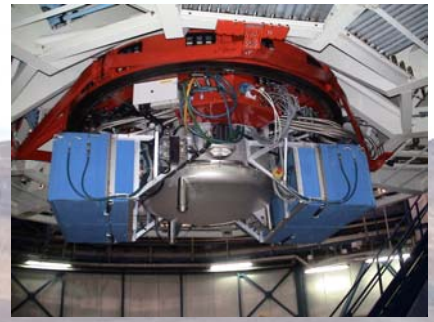
KUEYEN

FLAMES

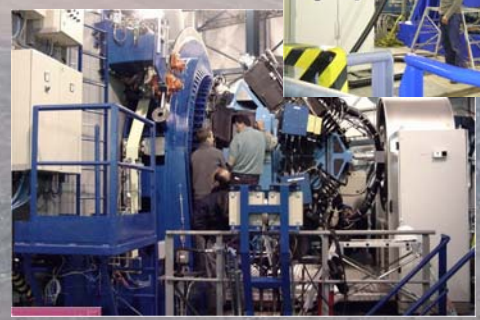
UVES

MELIPAL

VISIR



VIMOS



YEPUN

SINFONI

VISITOR (Ultracam, Dazle)

NACO

CRIRES

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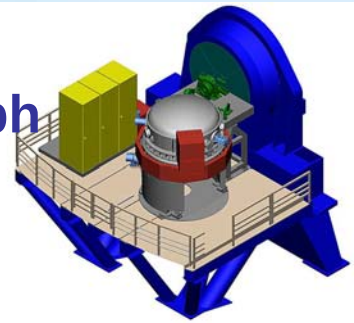
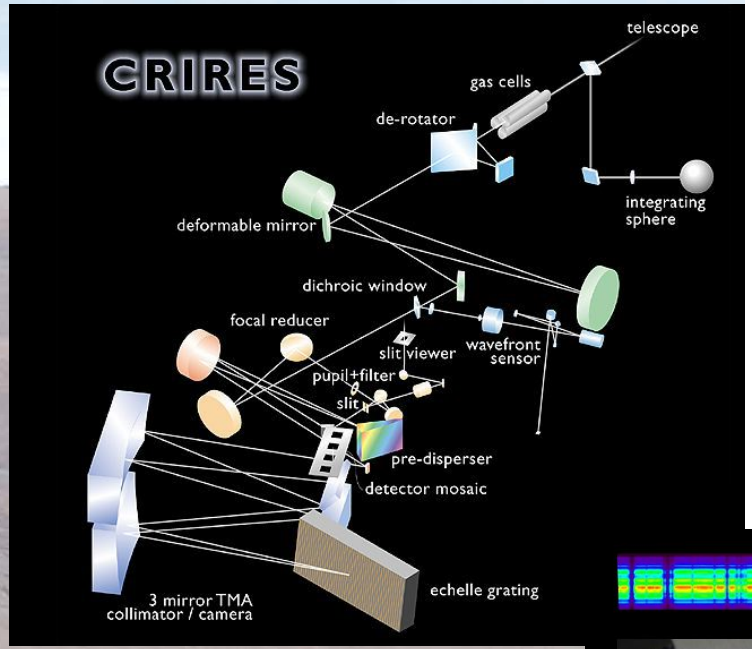
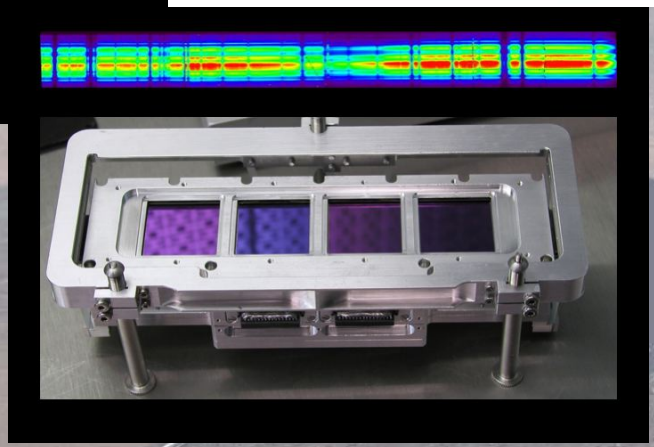
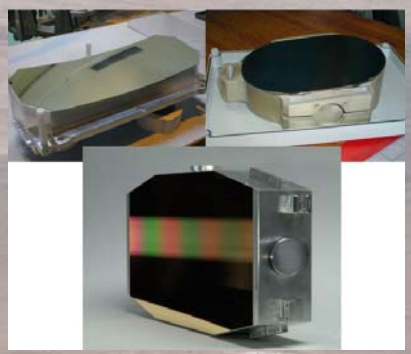
High resolution (R~10^5) (1-5µm) spectrograph

First light June 2006









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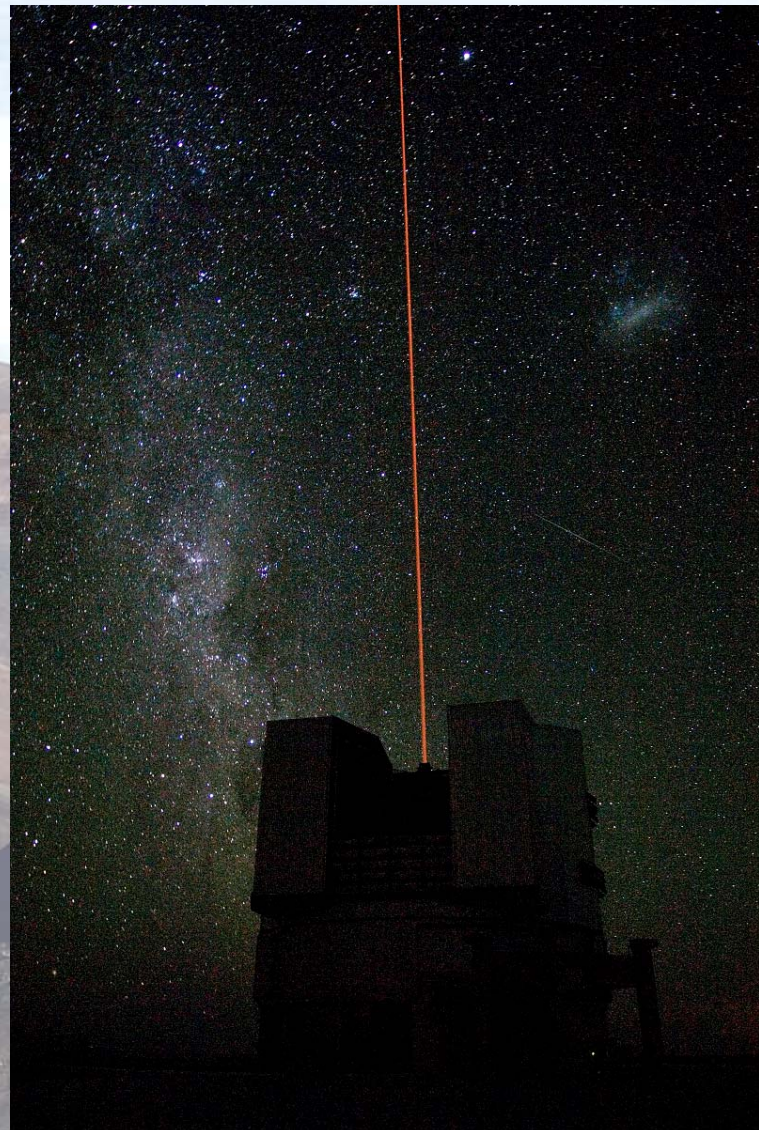
VLT Laser Guide Star

- First Light: January 2006
- AO-loop closed on NACO and SINFONI



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VLT Interferometer

- Combine light from 2 or 3 UTs or ATs

VLTI: a huge Infrastructure in place

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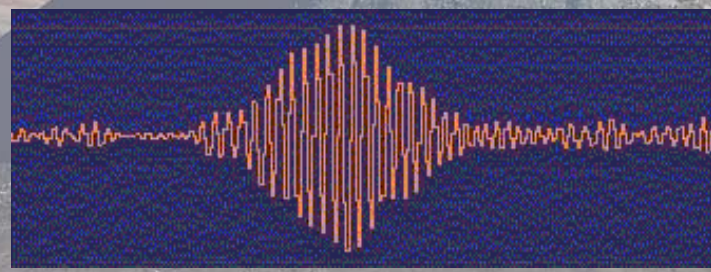
- **4 UTs with AO, 3 (soon 4) ATs, 6 Delay-Lines**
- **NIR Instrument: AMBER (3-beams)**
- **MIR Instrument: MIDI (2 beams)**

1st Fringes with two Auxiliary Telescopes (Feb '05)



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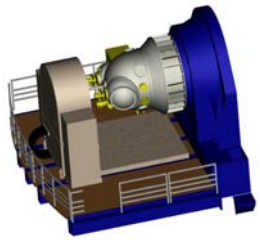
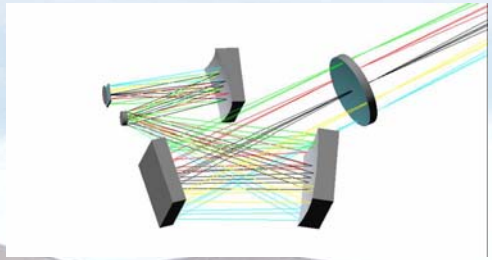
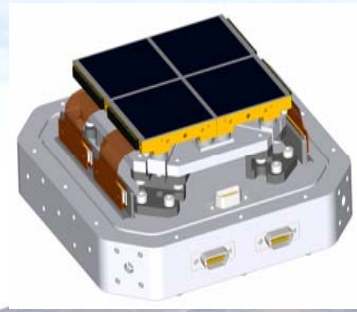
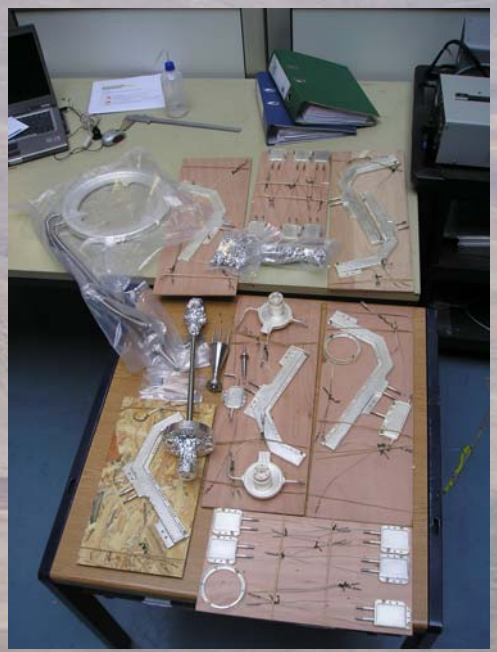
HAWK-I
Near infrared imager





- Detectors tested
- AIV phase ramping up





Pre-cooling system

- Galaxy evolution
- Survey for z>7 galaxies
- High z clusters
- Star and planetary formation
- Brown dwarf surveys

Cold structure machining

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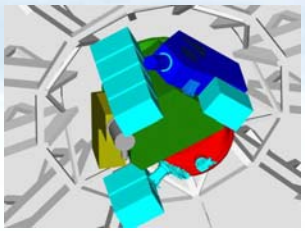
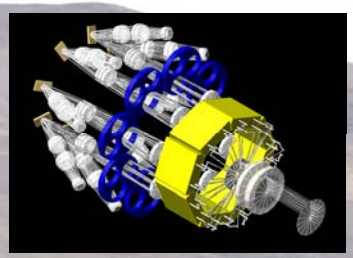
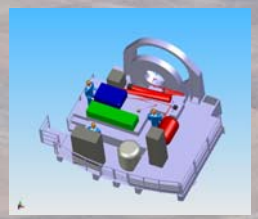
2nd Generation VLT Instruments



X-Shooter (2008)



KMOS (2011)



Sphere (2011)

MUSE (2012)

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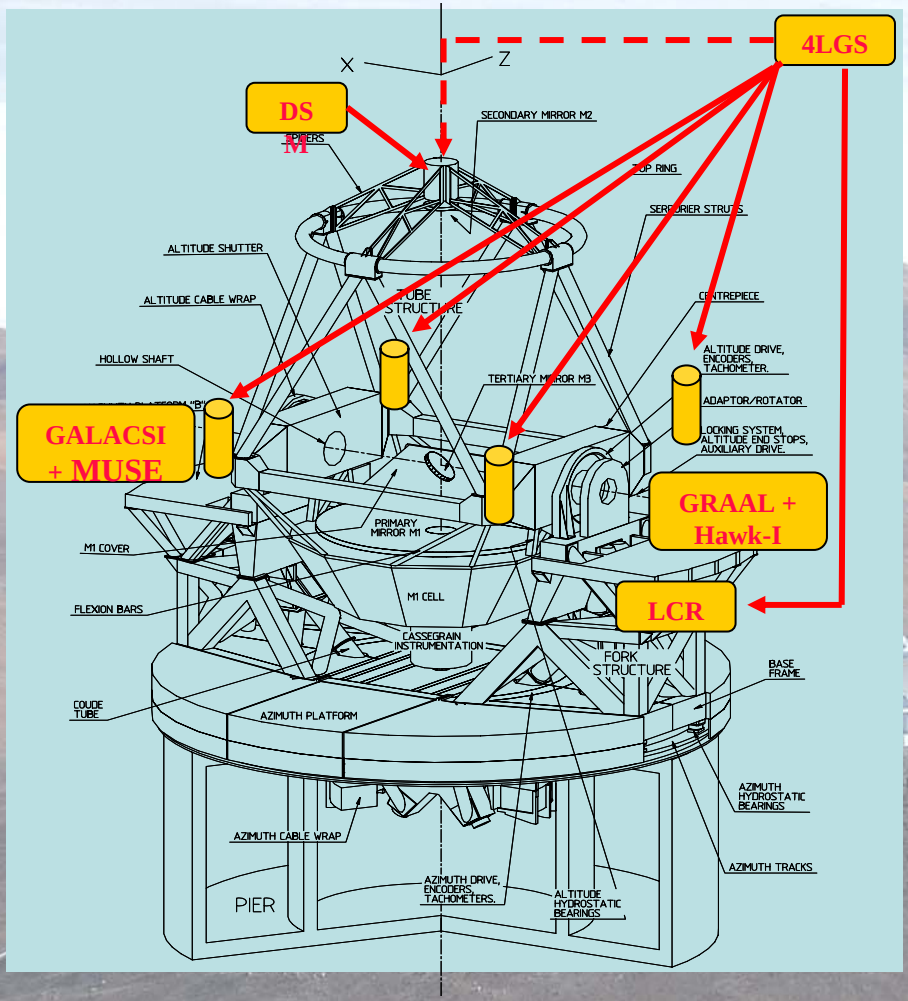
VLT AO Facility

Council Approval 12/05
Kick-off Feb 2006

- 1170 actuators DSM
- 4 Fibre lasers + 50cm launch telescopes
- GRAAL/Hawk-I 7.5' FOV near IR / GLAO correction
- GALACSI/MUSE integral field spectro. GLAO (wide field) or LTAO (narrow field)
- ELT experience



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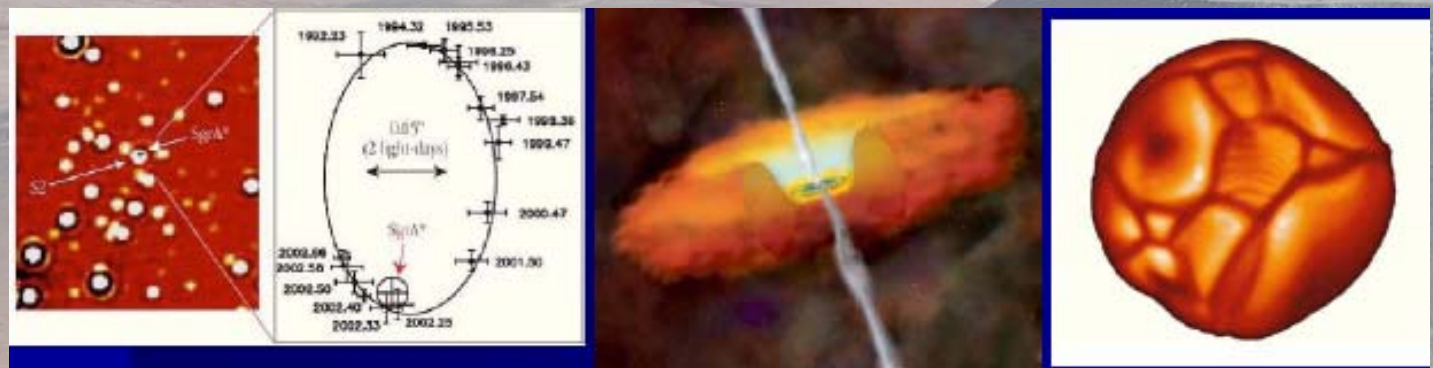
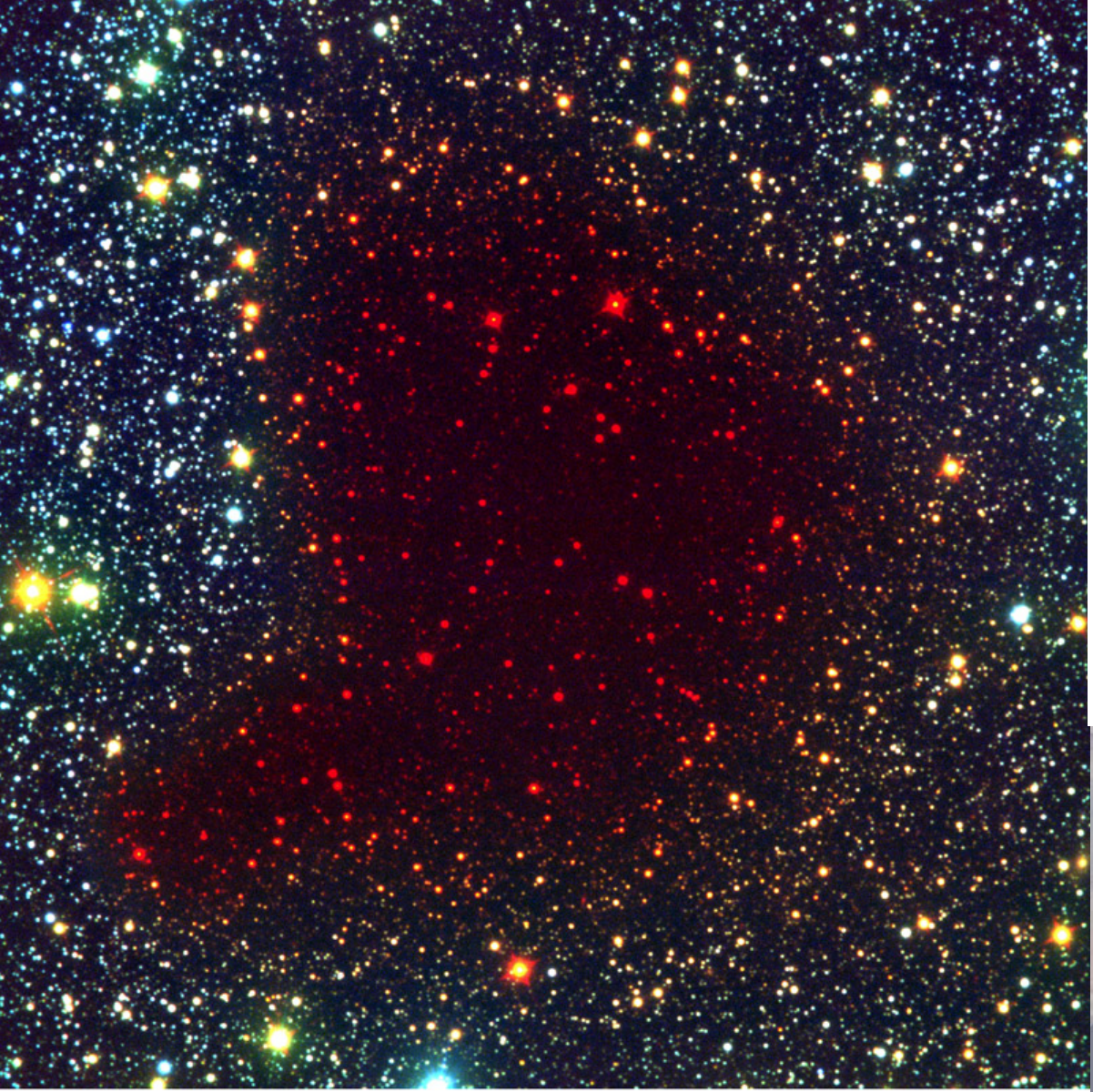
VLTI: a challenging development ahead

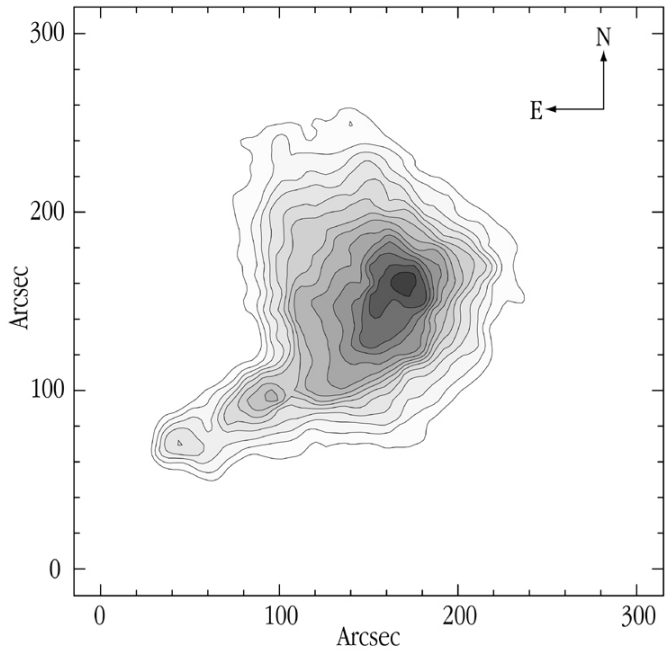
- **PRIMA: Phase-Referenced Imaging & Astrometry: Additional firmware being developed** (Fringe Sensing, Star Separators, Differential Delay Lines)
- **Infrastructure consolidation going on in Paranal**
- **Second generation instruments under study**
- **Much enlarged scientific impact ahead**





Seeing Through the Pre-Collapse Black Cloud B68
(VLT ANTU + FORS 1 - NTT + SOFI)

ESO PR Photo 02b/01 (10 January 2001)



Map of the Obscuration in the Dark Cloud B68

ESO PR Photo 29c/99 (2 July 1999)

- The structure of a Dark Cloud
- About to produce a solar-type star

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Millimeter Astronomy

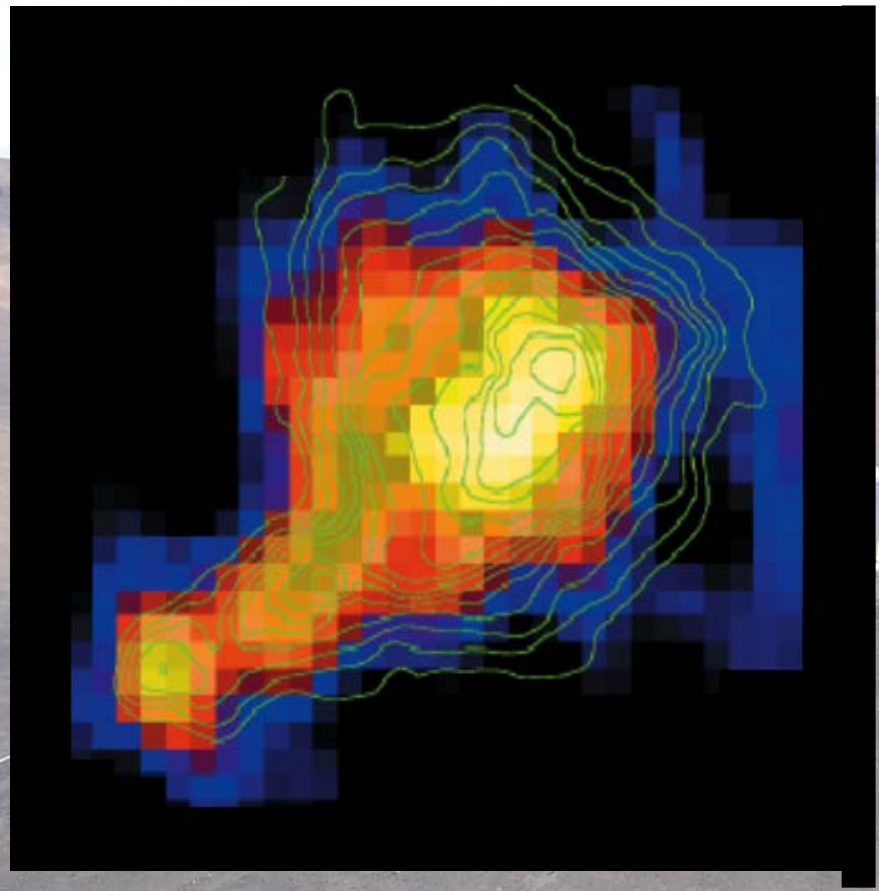
The *cold* Universe

The formation of galaxies, stars and planets

Emission from dust and molecules

A rich scientific frontier

a "dark" cloud



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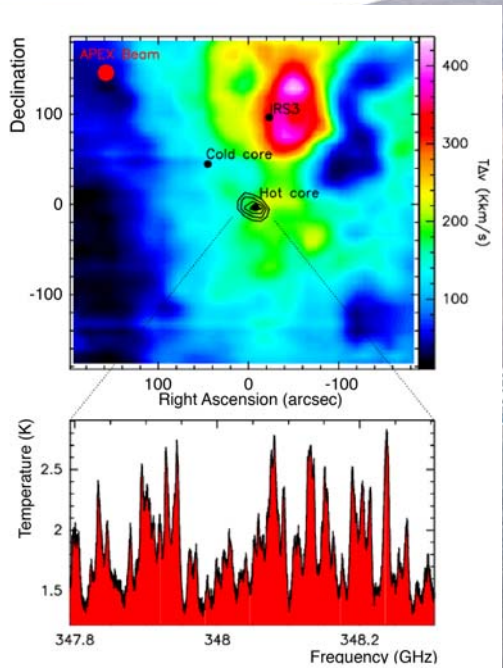
APEX - Pathfinder

- First Light - Summer 2005
- Started Regular Science Operations

The APEX Telescope at Chajnantor

ESO PR Photo 21/05 (July 14, 2005) © ESO



Sub-Millimetre Image of a Stellar Cradle (APEX)

ESO PR Photo 30/05 (September 23, 2005) © ESO

Wyrowski et al., Bisschop et al.

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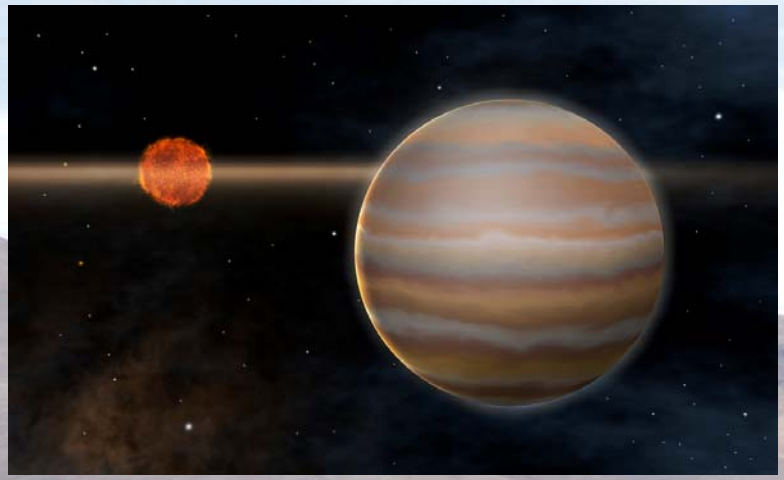
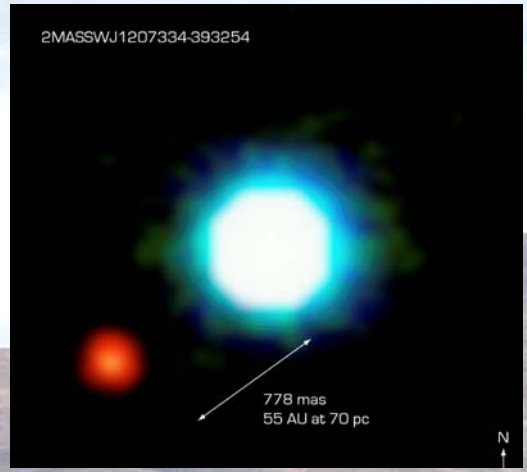
Hunt for Exoplanets

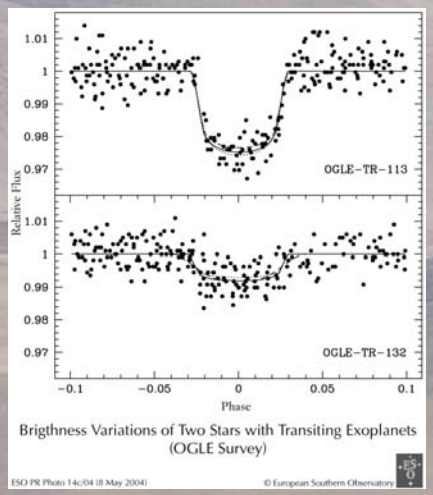
(HARPS, UVES, NACO, FLAMES, 1.54-m, 1.2-m)



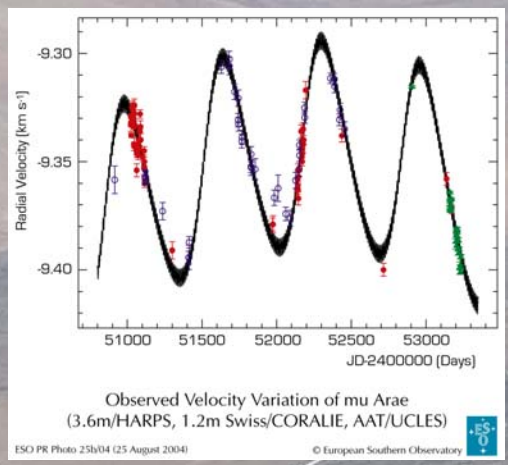
adaptive optics

$5M_J$





transits



radial velocities

$14M_\oplus$

gravitational lensing

$5M_\oplus$

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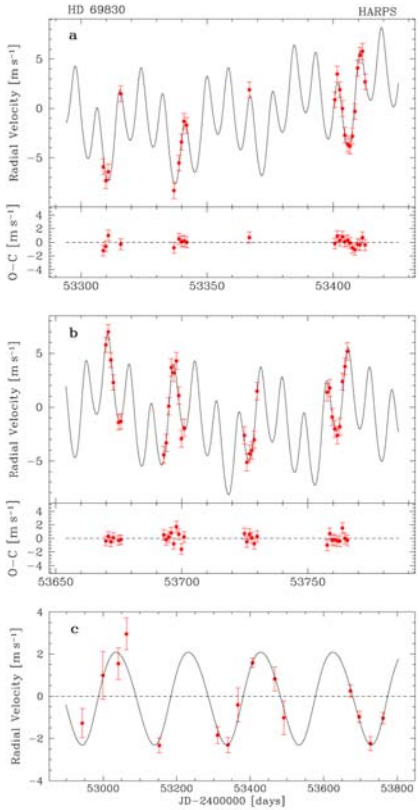
Trio of Neptunes

- Three Planets found around HD 69830:
  - Masses between 10 and 18 Earth masses
  - Periods: 8.67, 31.6, 197 days
  - Semi-major axes: 0.08, 0.19 and 0.63 AU
- HARPS measurements:

  amplitude: ~ 4 m/s; residuals: 64 cm/s!
- Spitzer: star has an asteroid belt



Radial Velocity Measurements of HD 69830 (HARPS/3.6m)

Artist View of Planetary System Around HD 69830

In habitable zone!

C. Lovis et al., 2006

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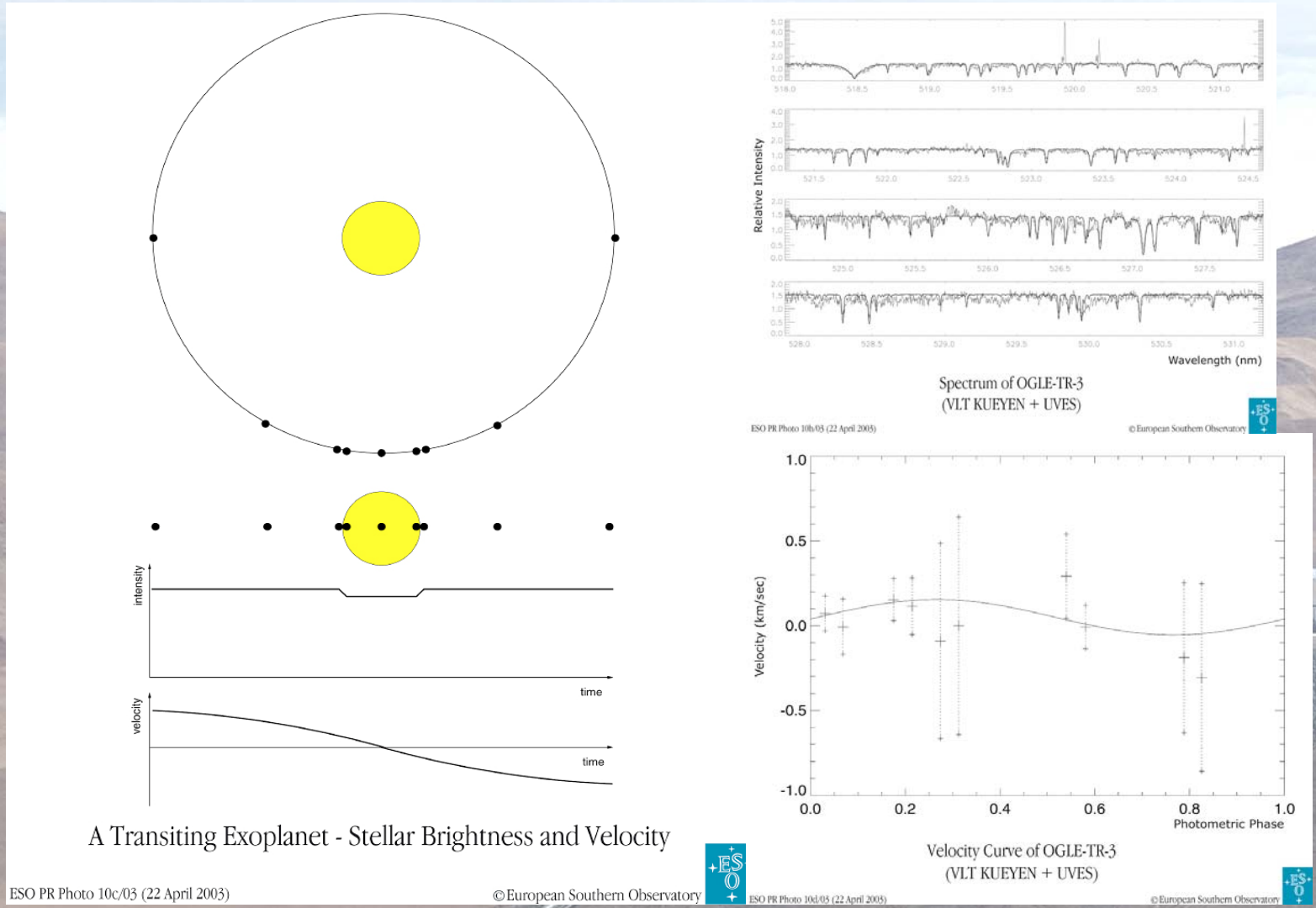
Exoplanets in Transit



Dreizler et al. 2003

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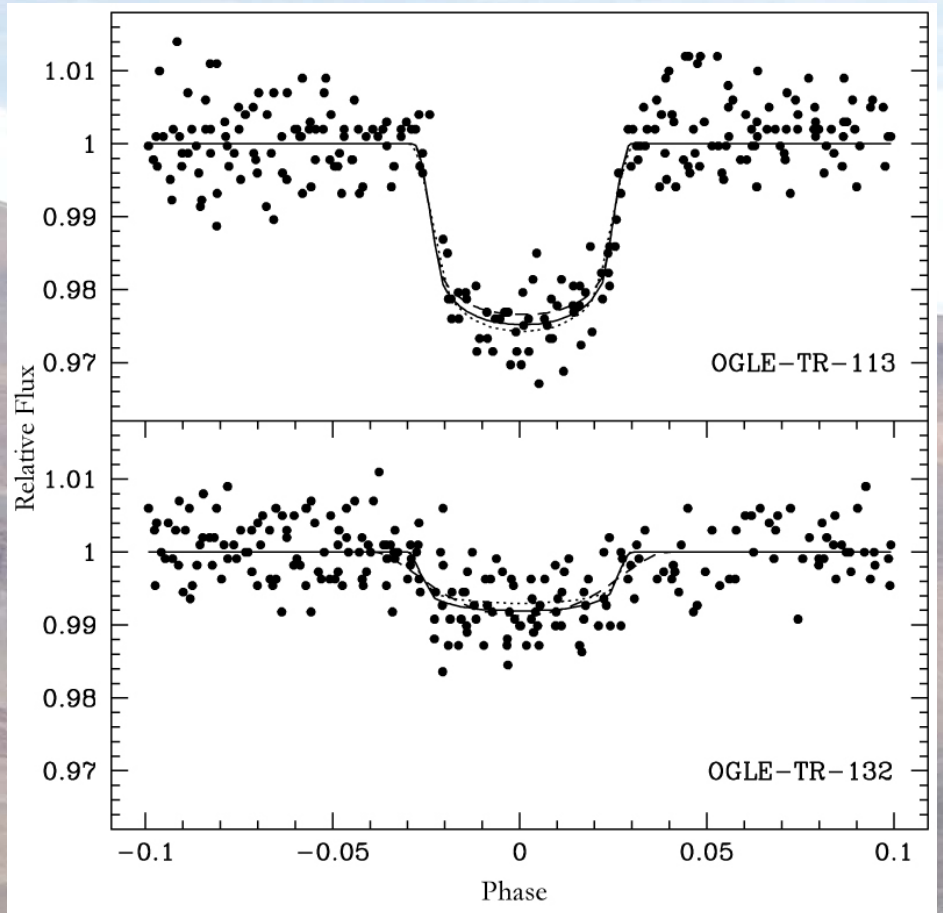
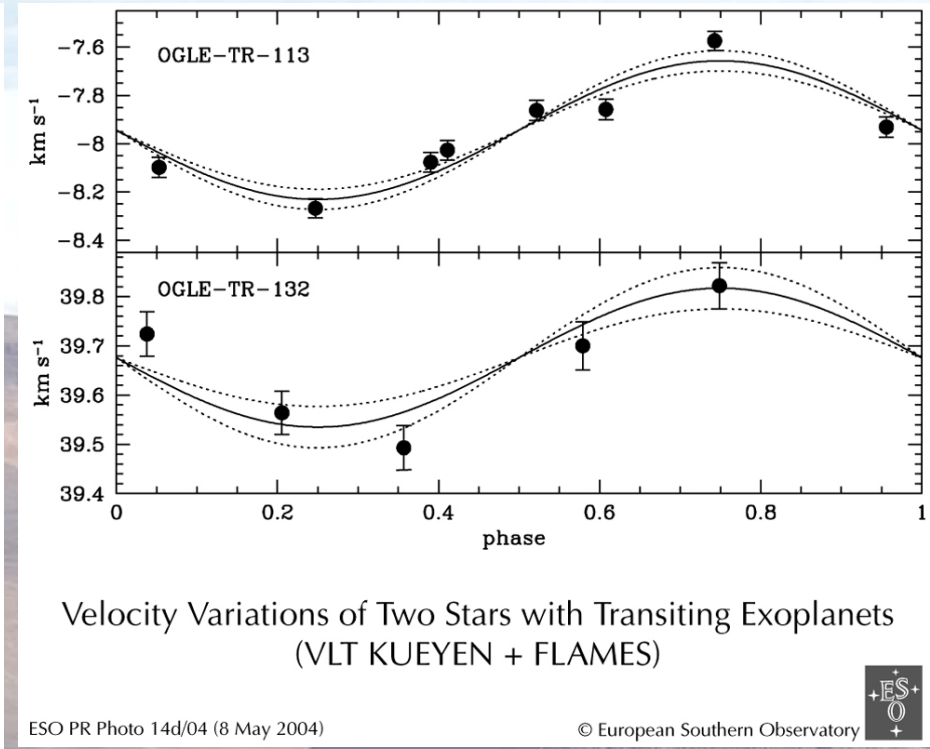
Exoplanets in Transit



Brigthness Variations of Two Stars with Transiting Exoplanets (OGLE Survey)

ESO PR Photo 14c/04 (8 May 2004) © European Southern Observatory



Velocity Variations of Two Stars with Transiting Exoplanets (VLT KUEYEN + FLAMES)

ESO PR Photo 14d/04 (8 May 2004) © European Southern Observatory

Confirmed planetary transits!

Bouchy et al. 2004

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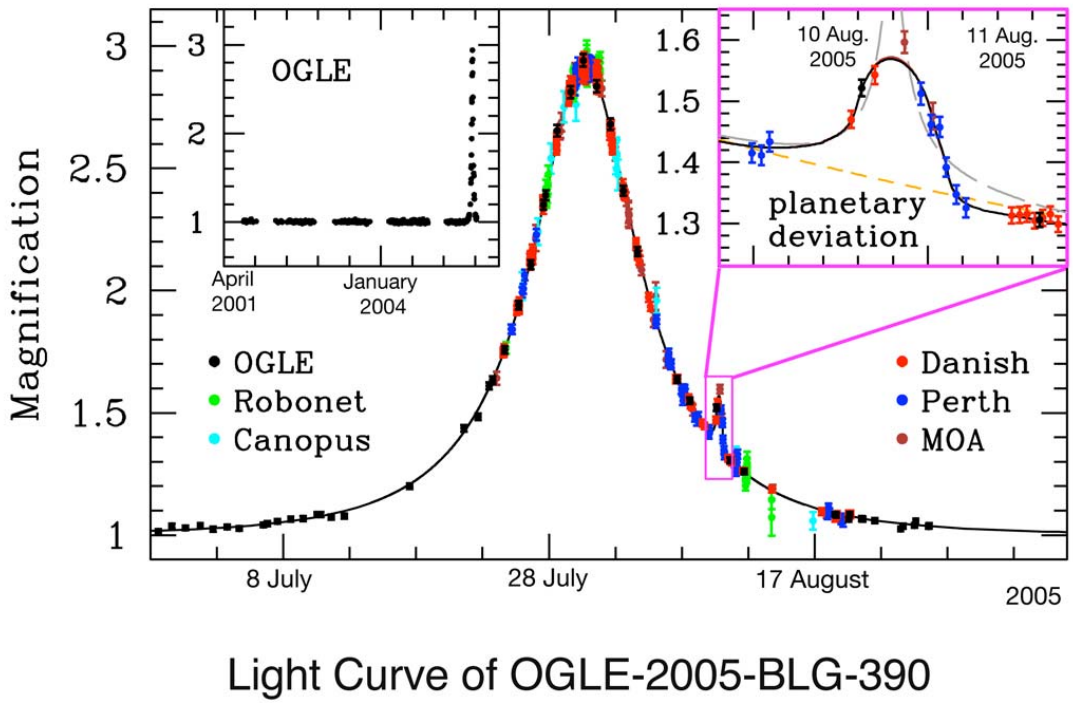
1.54-m Danish La Silla

- Five Earth mass planet with microlensing



Light Curve of OGLE-2005-BLG-390

Beaulieu et al. 2006

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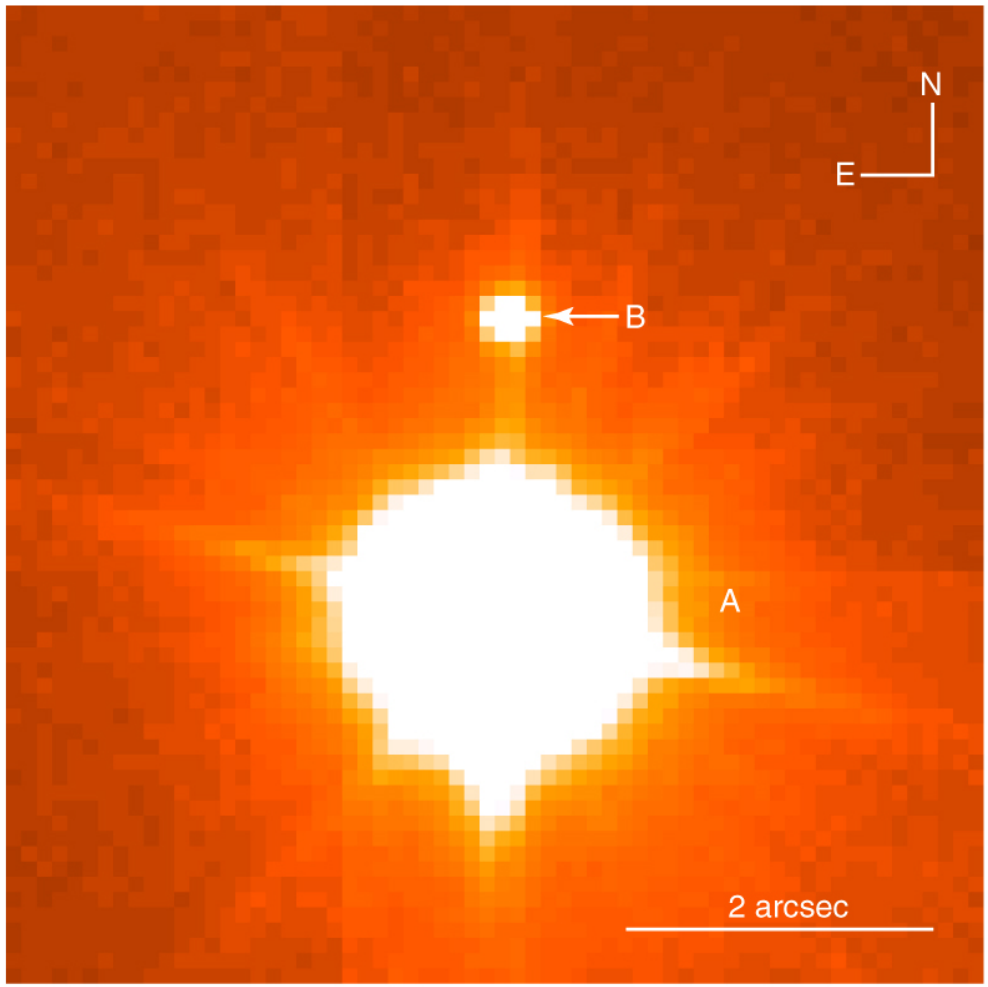
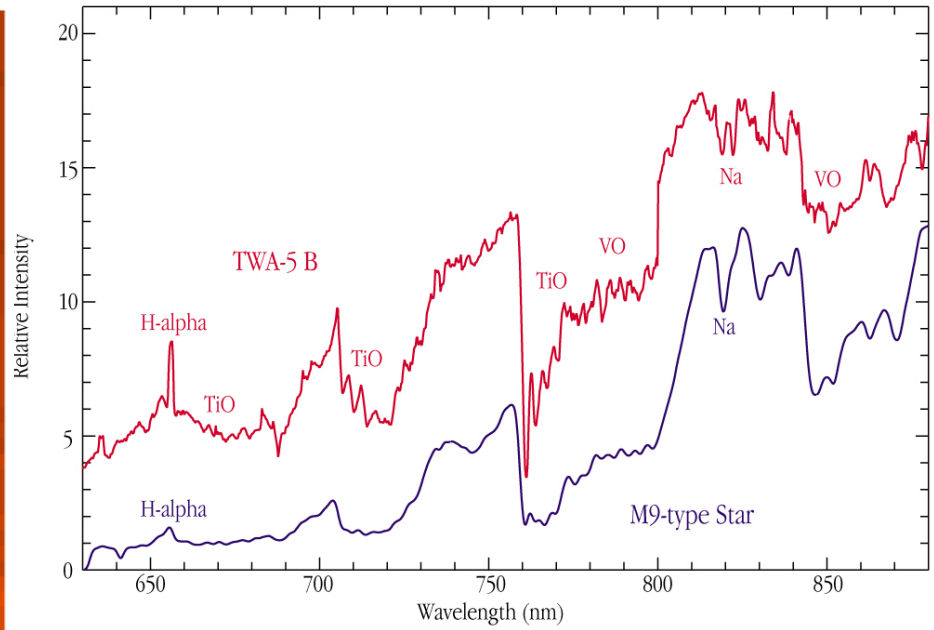
Image of Exoplanet (I)



Young Brown Dwarf in TWA-5 System
(VLT KUEYEN + FORS-2)

ESO PR Photo 17a/00 (21 July 2000) ©European Southern Observatory



Optical Spectrum of Brown Dwarf TWA-5 B
(VLT KUEYEN + FORS-2)

SO PR Photo 17b/00 (21 July 2000) ©European Southern Observatory

Neuhauser et al. 2001

This one was no planet

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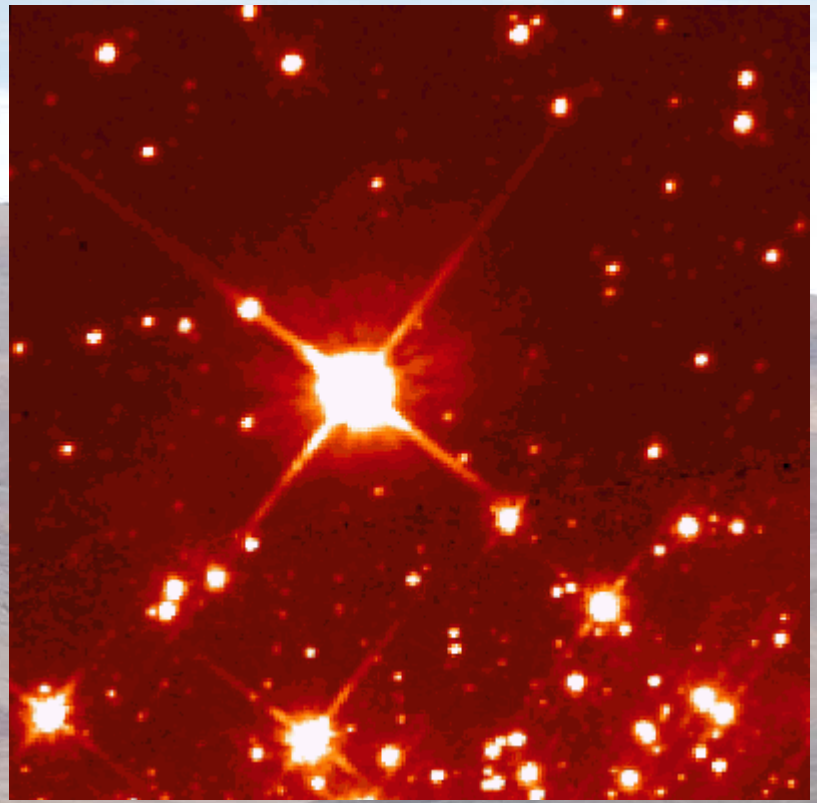
NACO



NGC 3603 stellar cluster

- Adaptive Optics
- Overcoming the atmospheric turbulence
- Ground-based (VLT)
  vs.
  Space-based (HST)

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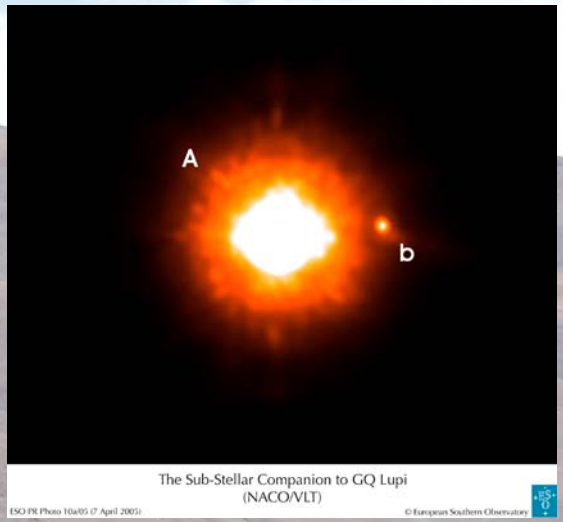
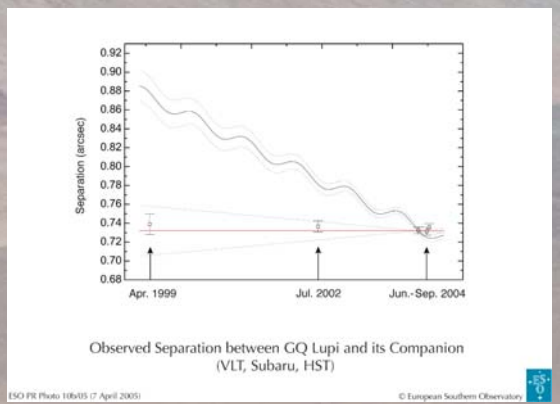
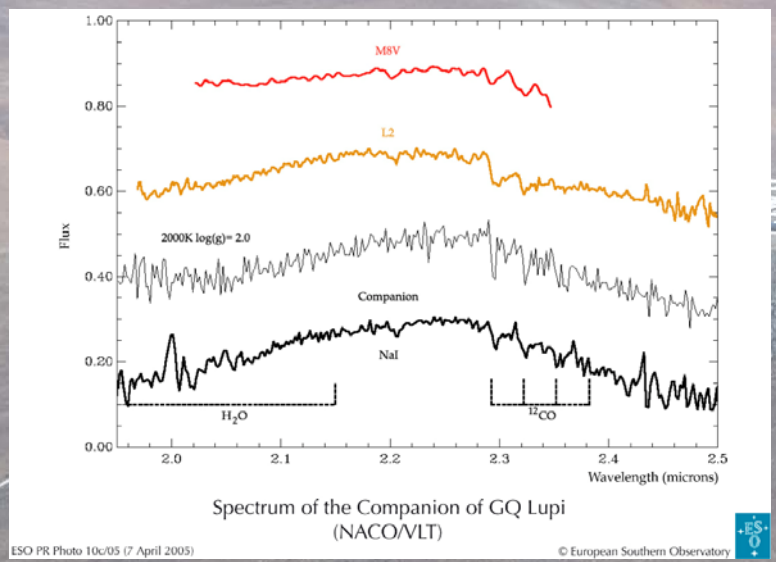
Image of Exoplanet (II)

Brown dwarf or Exoplanet?



- A cold companion to the very young T-Tauri star GQ Lupi
- Separation ~ 100 AU
- M ~ 1– 42 M_{Jup} (depends on model)





Neuhaüser et al., 2005

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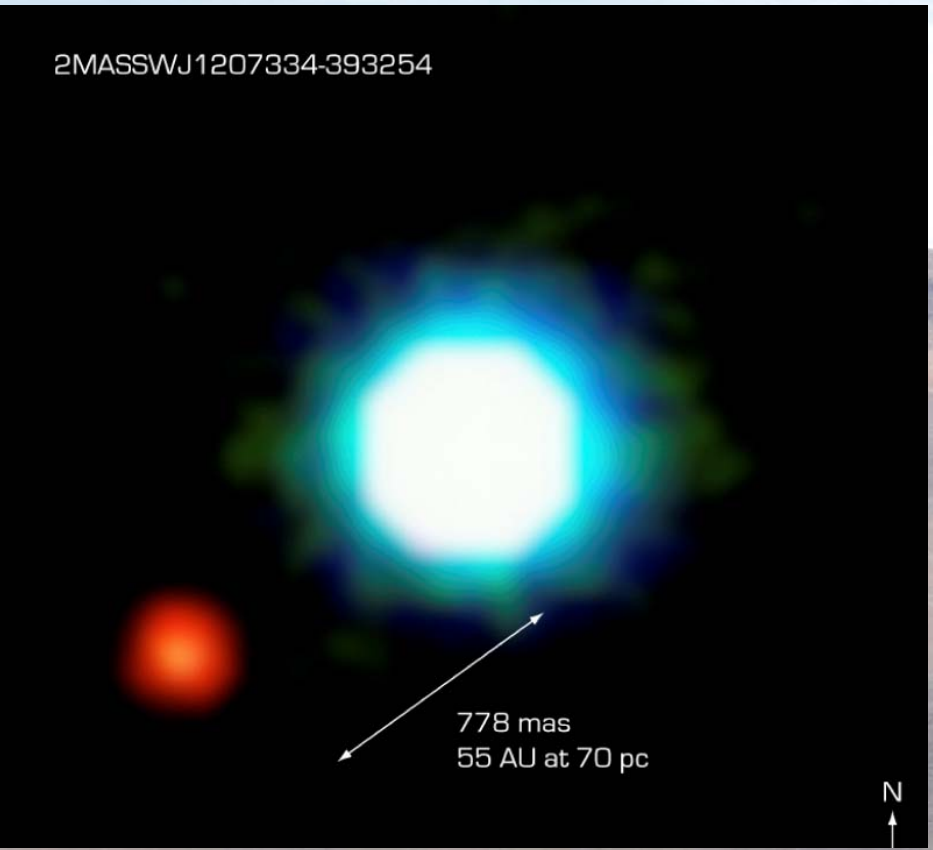
Image of Exoplanet (III)

First real image?



- Brown Dwarf “2M1207”
  - 25 Jupiter-masses
  - 8 million years old
- “Giant Planet Candidate Companion (GPCC)”
  - 100 x fainter
  - 1000 ºC
  - 55 AU distance
  - 5 Jupiter-masses
- TW Hydrae Association
  - 230 light-years
  - Water molecules

Chauvin et al., 2005

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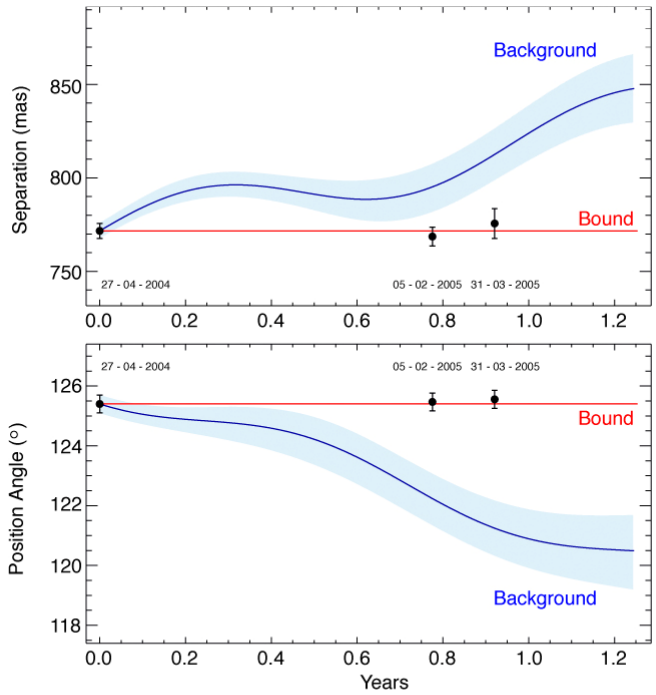
Image of Exoplanet (IV)

First real image!



Positions of 2M1207A and of its Companion (VLT/NACO)

ESO PR Photo 14b/05 (30 April 2005) ©ESO

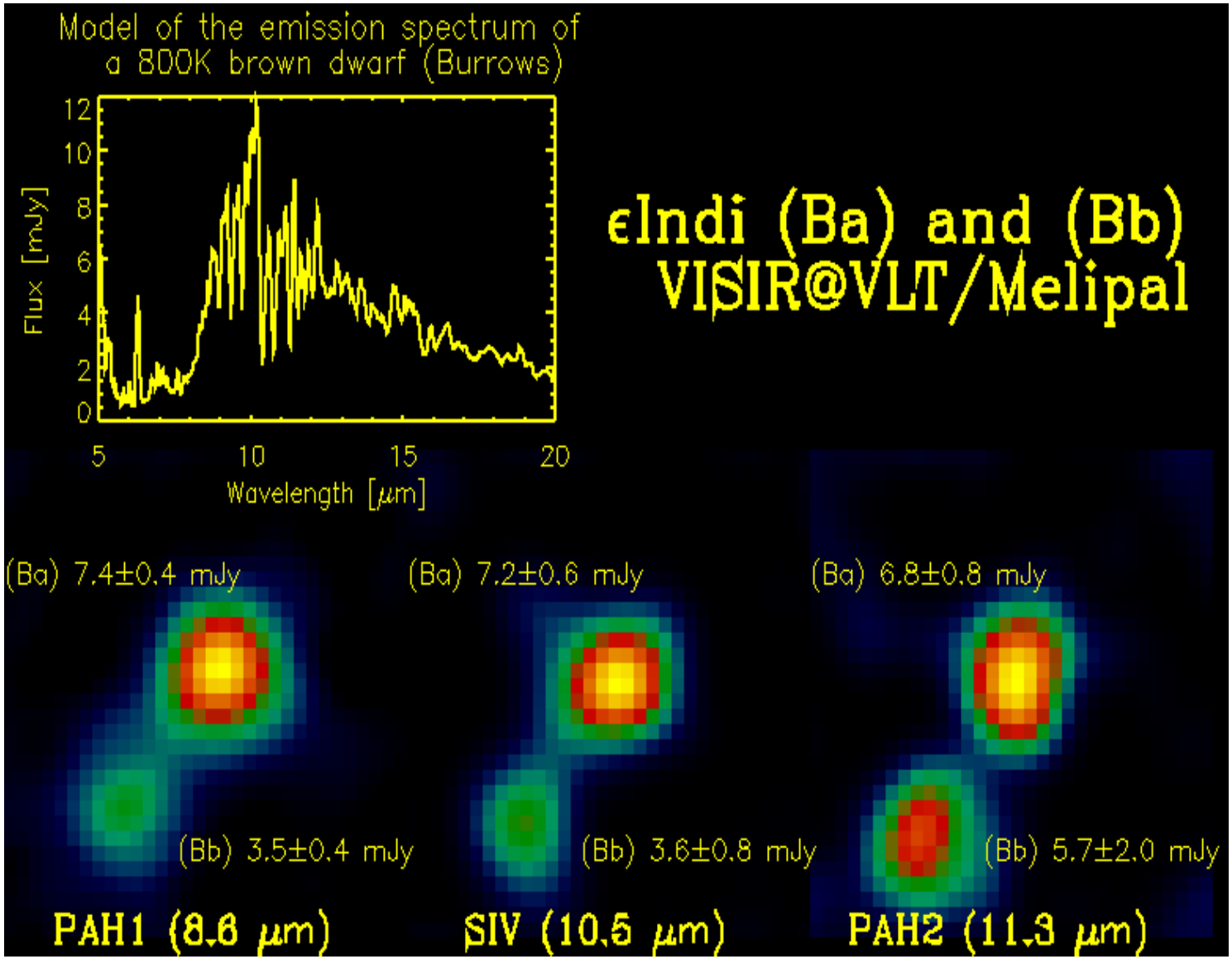
- Brown Dwarf "2M1207" and Giant Planet Candidate move together!
- Confirmed by apparent motion over a year (NACO/VLT)

Artist's rendering of the 2M1207 System

ESO PR Photo 14c/05 (30 April 2005) ©ESO

Chauvin et al., 2005

VISIR and Brown dwarfs: complementing Spitzer



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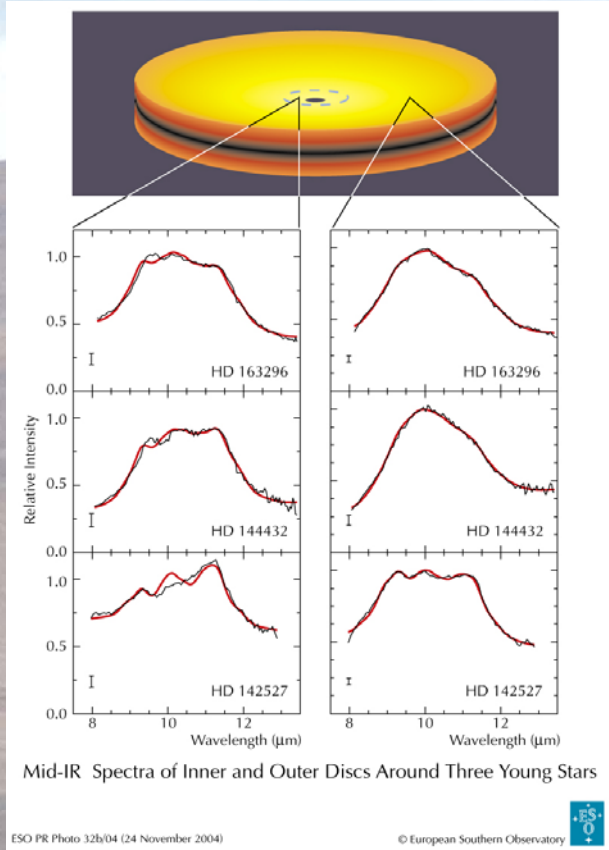
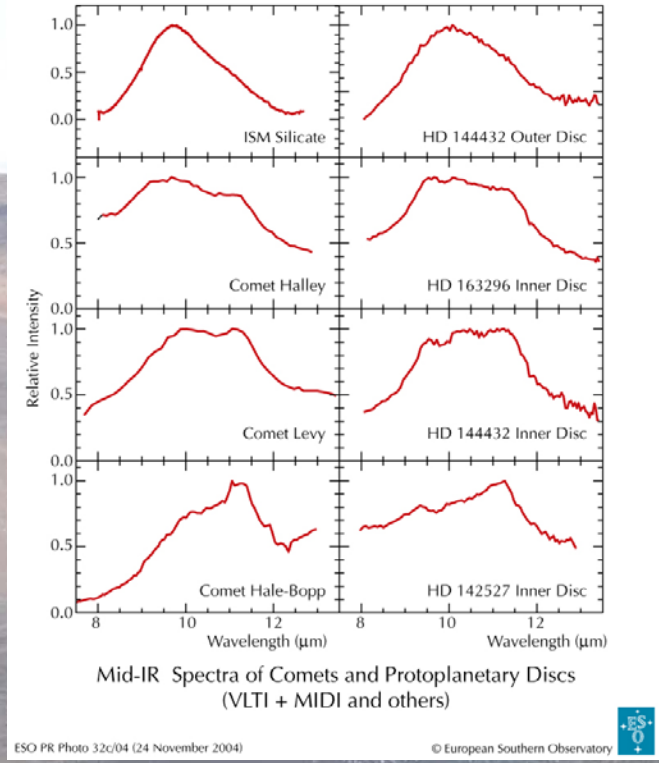
Protoplanetary discs (VLTI)



Mid-IR Spectra of Inner and Outer Discs Around Three Young Stars

ESO PR Photo 32b/04 (24 November 2004) © European Southern Observatory



Mid-IR Spectra of Comets and Protoplanetary Discs (VLTI + MIDI and others)

ESO PR Photo 32c/04 (24 November 2004) © European Southern Observatory

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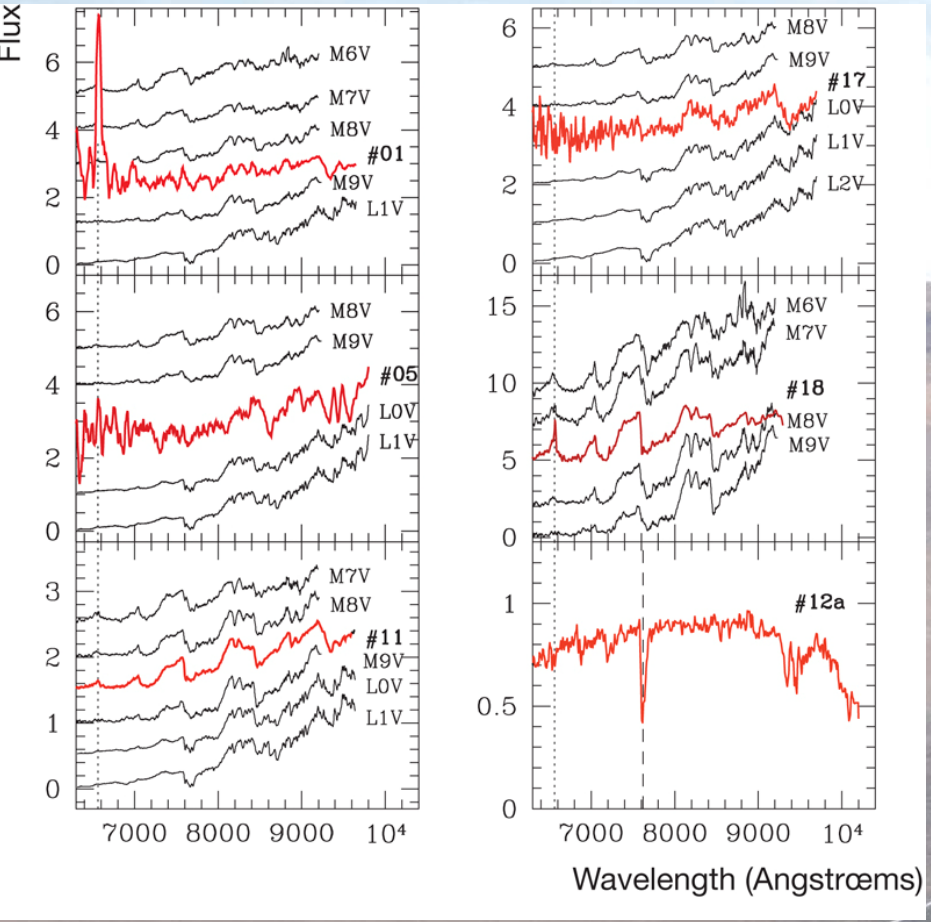
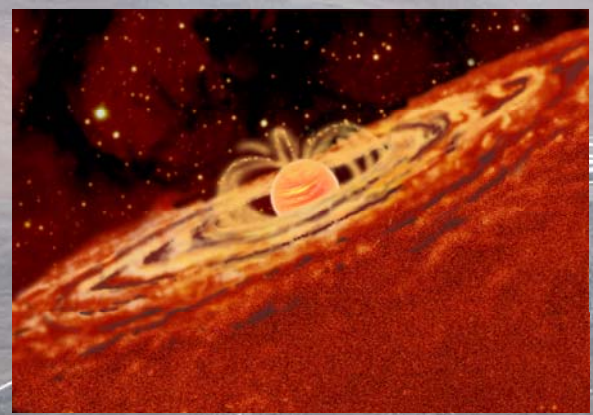
Discs around Planemos



- Planetary mass objects found to be surrounded by discs
- Form as normal stars
- Systems form as binary
- May have planetary systems
- Also around 2M1207!



Art by Jon Lomberg

FORS, NACO

Jayawardhana et al., 2006, Mohanty et al. 2006

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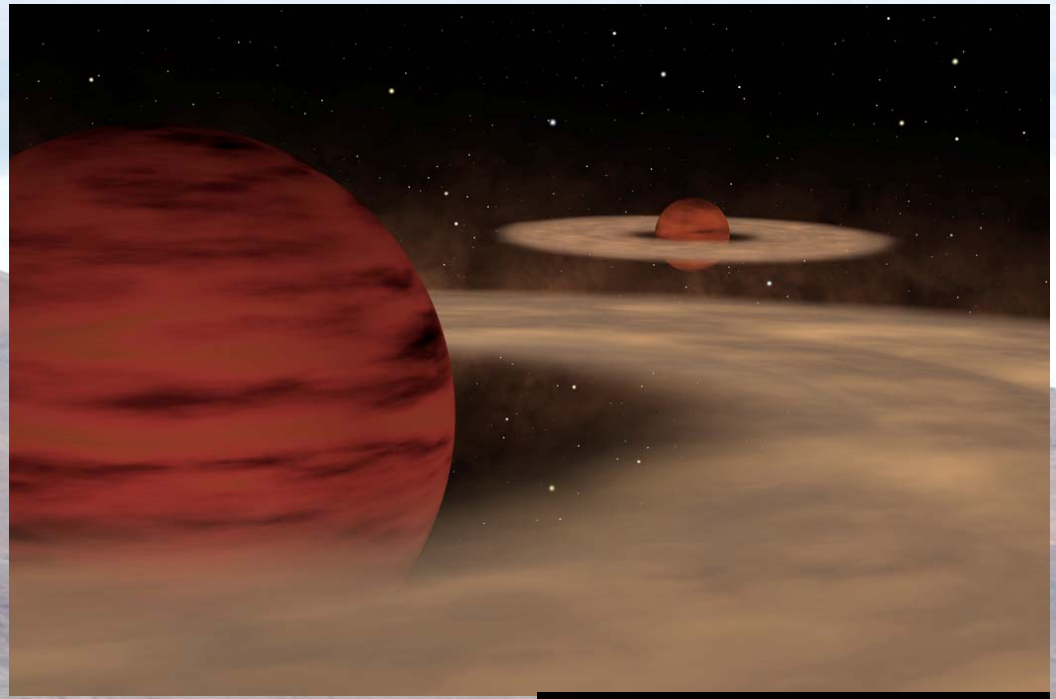
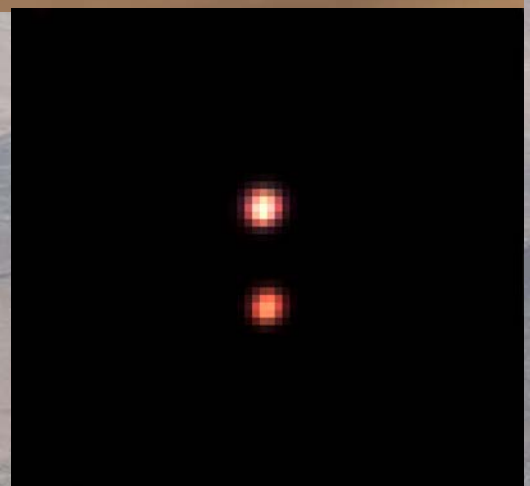
Binary Planemos





- Oph 162225-240515
- First double Planetary mass objects : 14 M_J + 7 M_J
- Separation: ~ 230 AU
- 1 million years old

- Formed as stars?

NTT, ISAAC/VLT

Jayawardhana & Ivanov 2006

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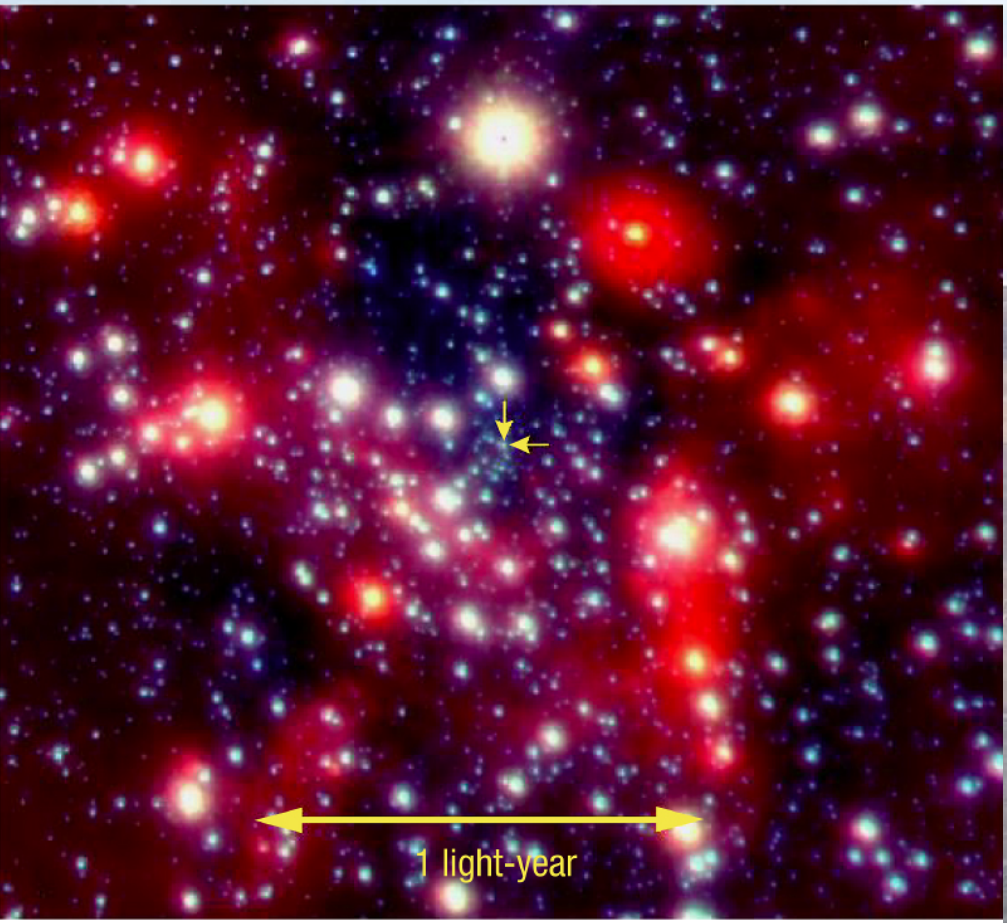
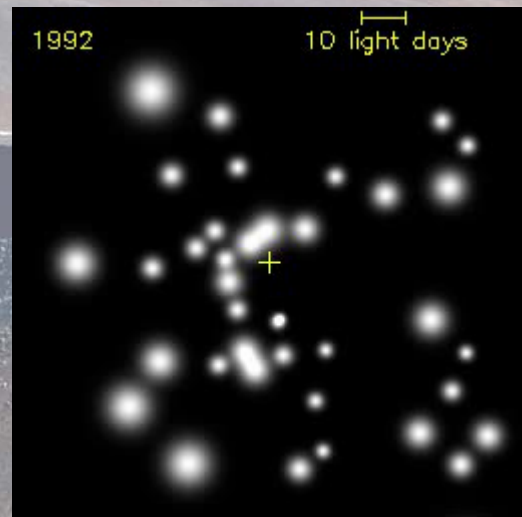
Black Hole at the Center of the Milky Way



The Centre of the Milky Way
(VLT YEPUN + NACO)

ESO PR Photo 23a/02 (9 October 2002)

- Star in orbit around Galactic Center (SgrA*)
  VLT YEPUN + NACO
  May 2002 high-res images
  Approaches to 17 light-hours
- Full orbit with 15-year period
- Central mass determined:
  2.6 ± 0.2 million solar masses
- Definitely BLACK HOLE



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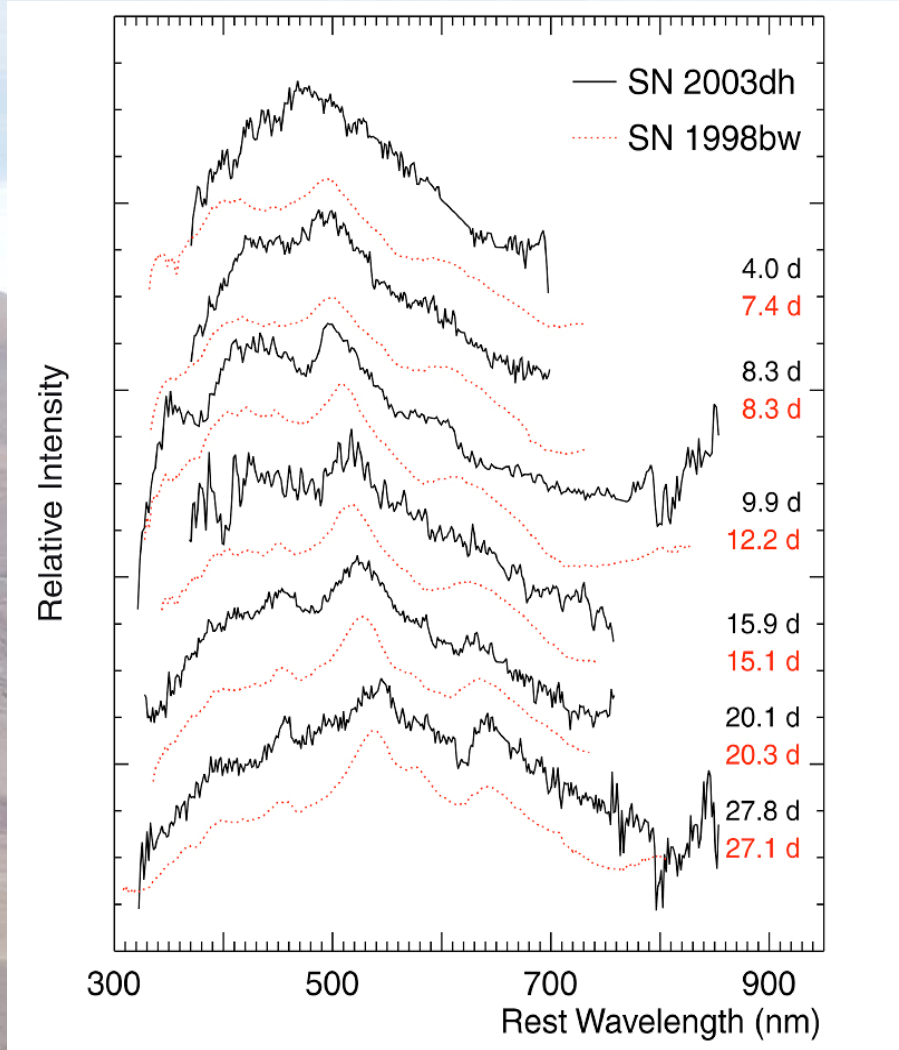
Gamma-Ray Bursts

z=0.1685



Visual Spectra of Hypernova in GRB 030329
(VLT + FORS)

ESO PR Photo 17b/03 (18 June 2003)

- Spectrum like SN 1998bw, associated with another GRB.
- Thus, long GRBs due to core collapse of massive stars.

Hjorth et al., 2003

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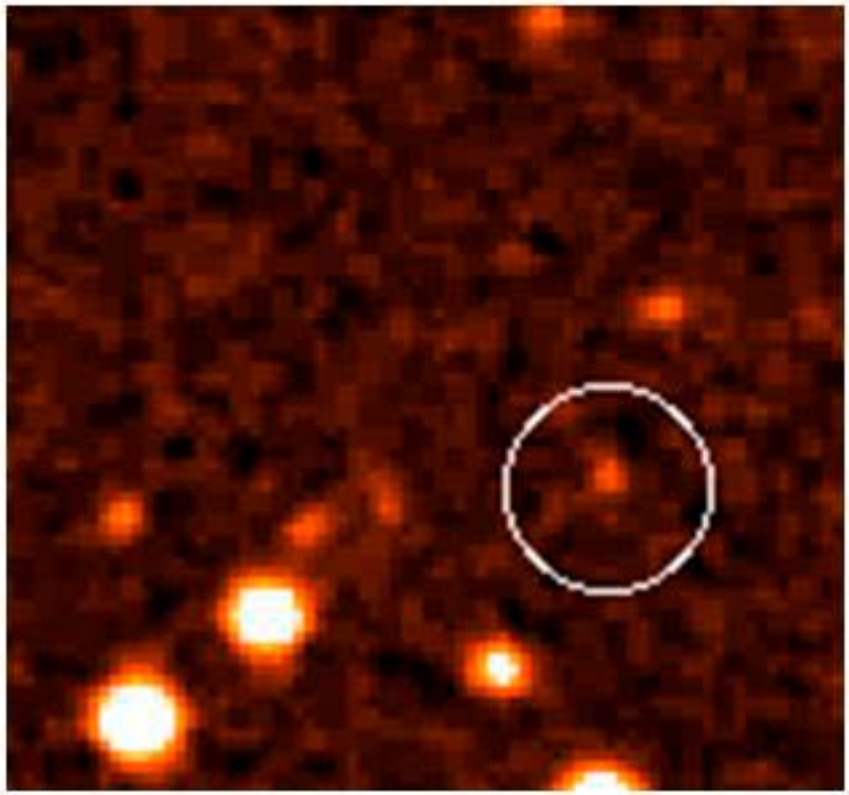
X-ray Flashes and Supernovae

- GRB 060218



DSS-2 image: Galaxy only

ISAAC/VLT image: The SN is visible

Pian et al. 2006; Mazzali et al. 2006

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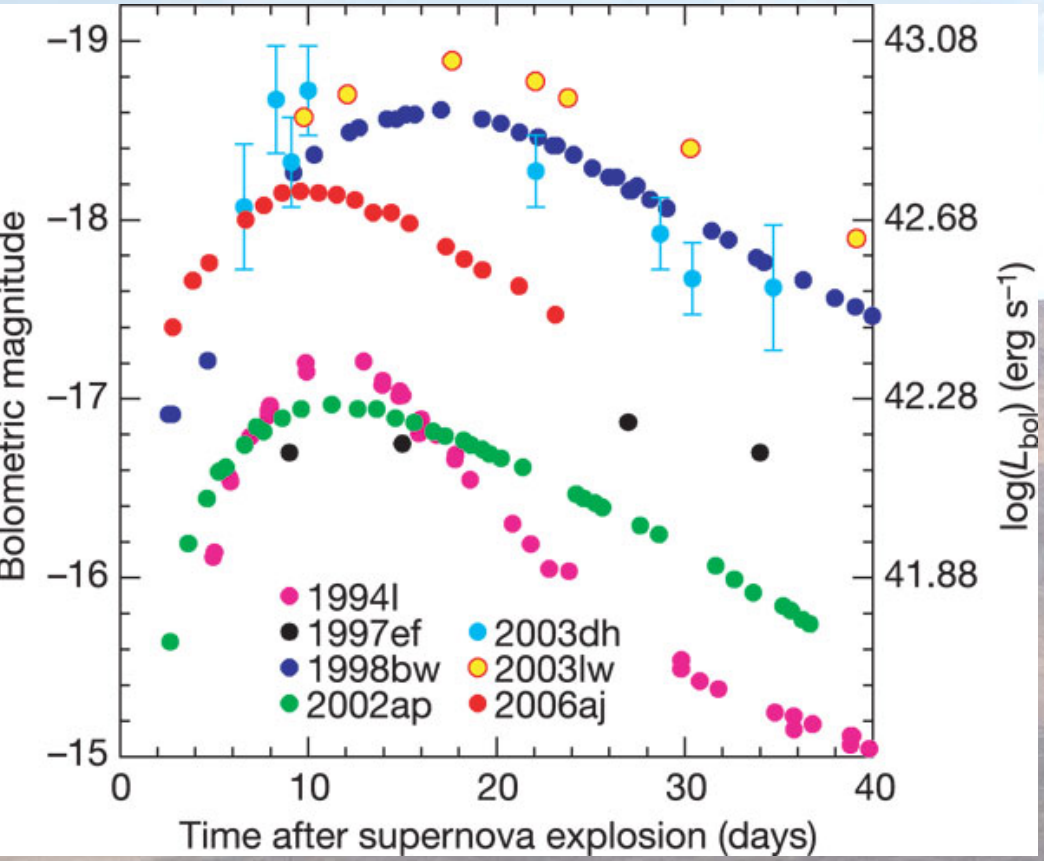
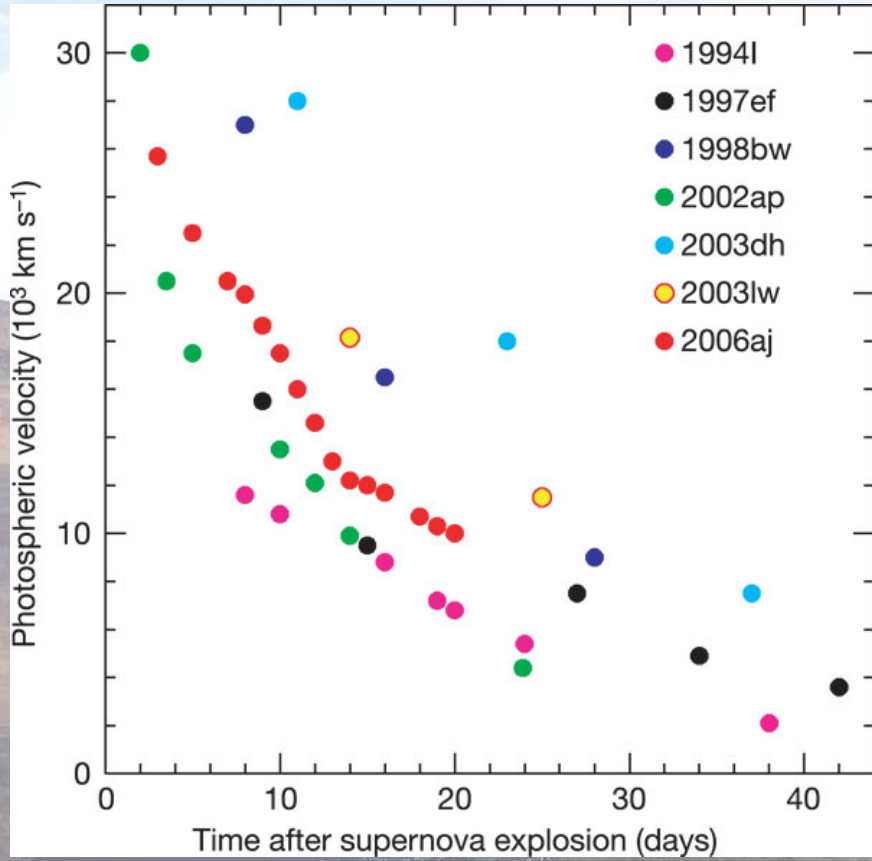
X-ray Flashes and Supernovae





Pian et al. 2006

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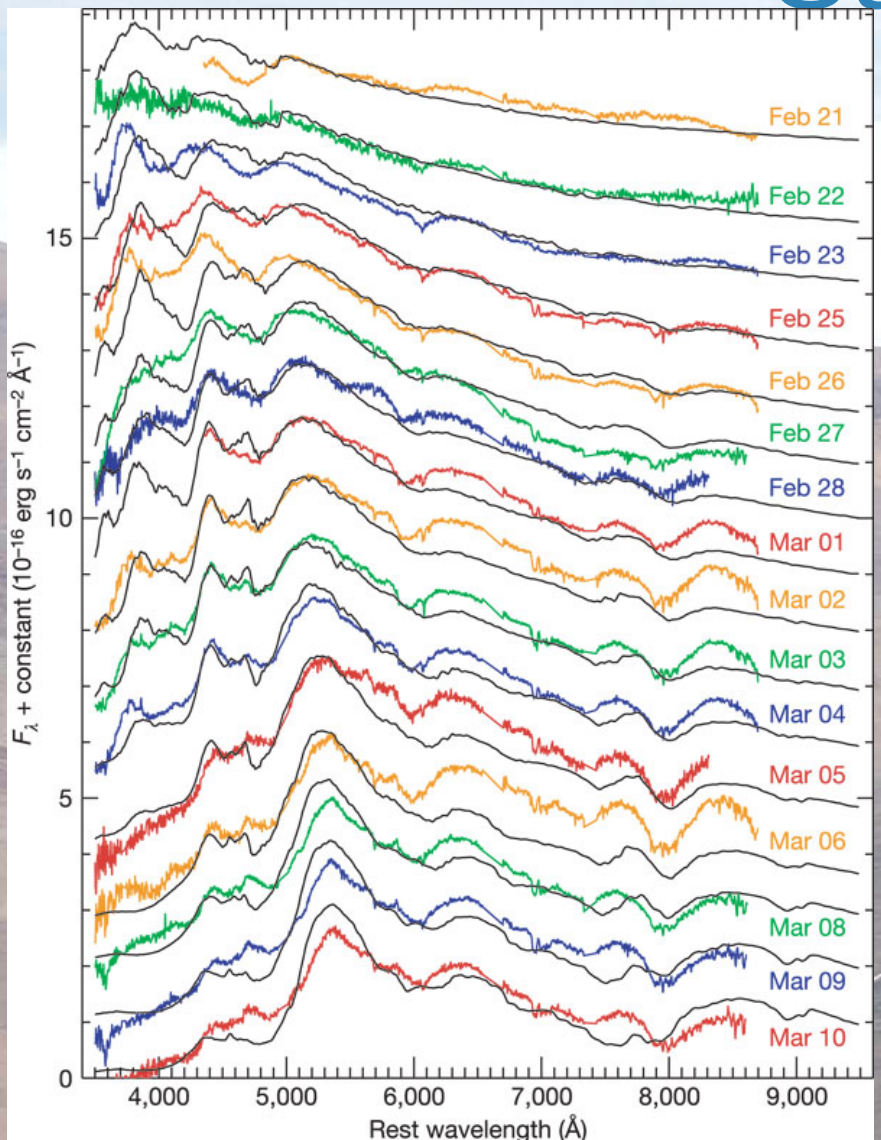
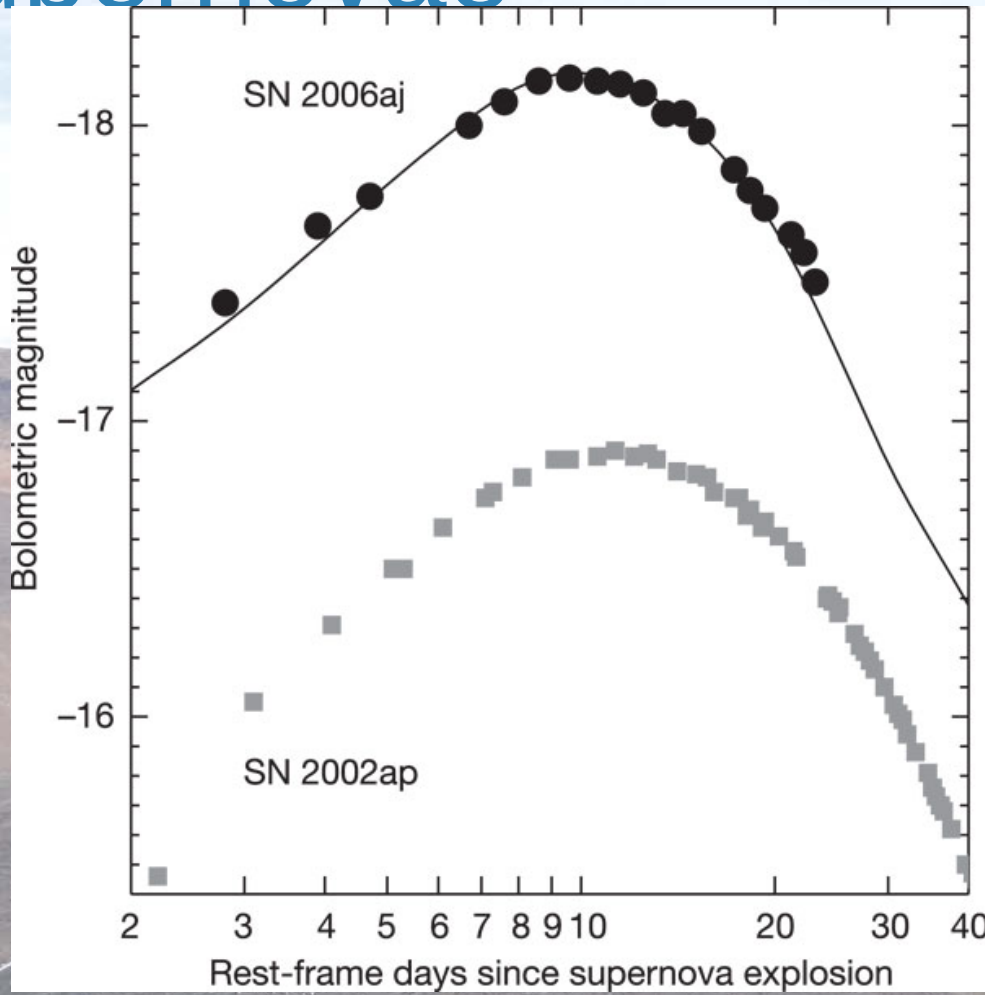
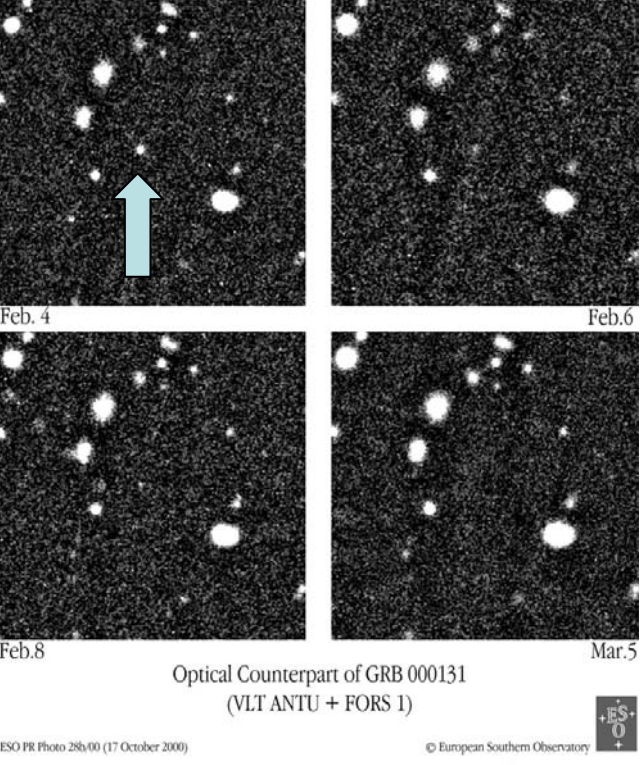
X-ray Flashes and Supernovae



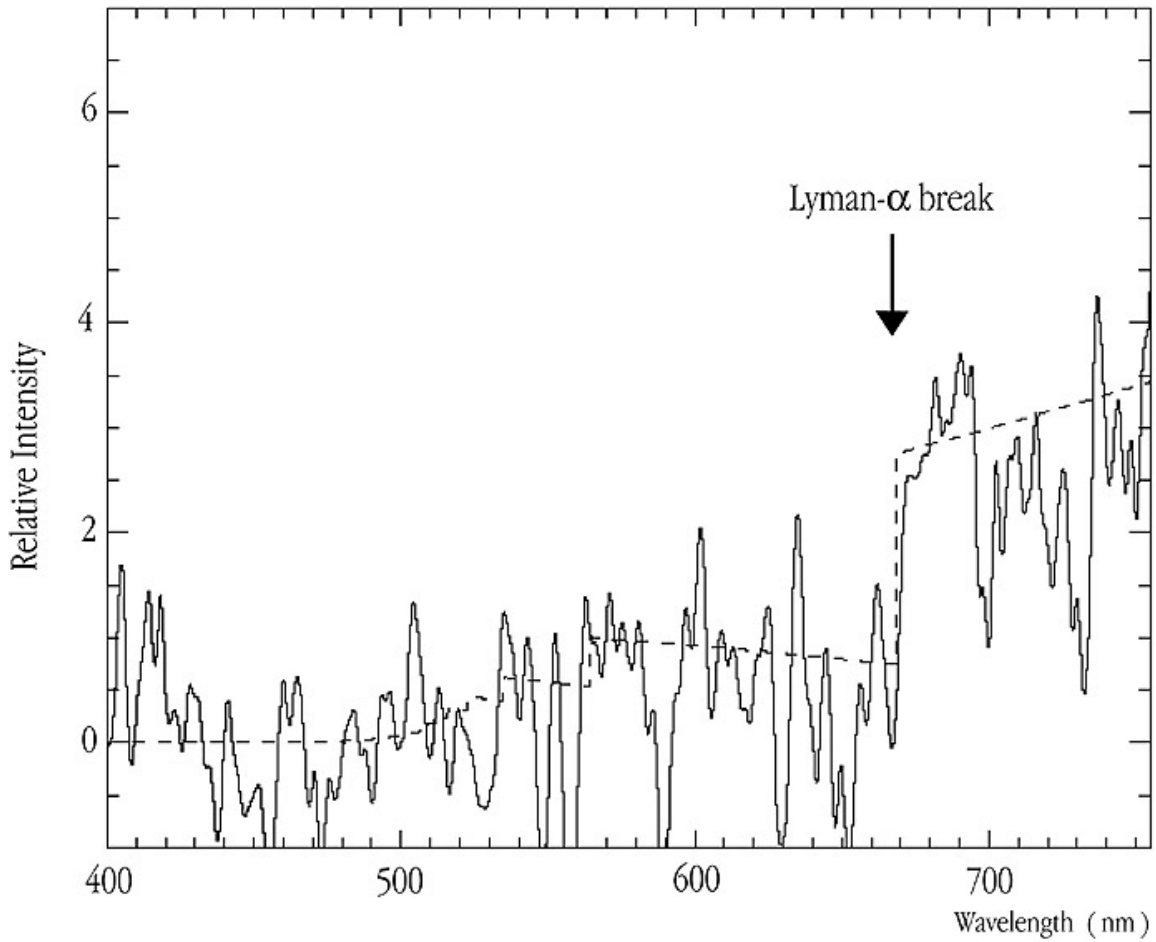


Mazzali et al. 2006



Optical Counterpart of GRB 000131
(VLT ANTU + FORS 1)

ESO PR Photo 28b/00 (17 October 2000) © European Southern Observatory



Spectrum of the Optical Counterpart of GRB 000131

ESO PR Photo 28c/00 (17 October 1999) © European Southern Observatory

Redshift z = 4.50

Most distant GRB for which the distance had been measured
(1999, VLT ANTU + FORS1)

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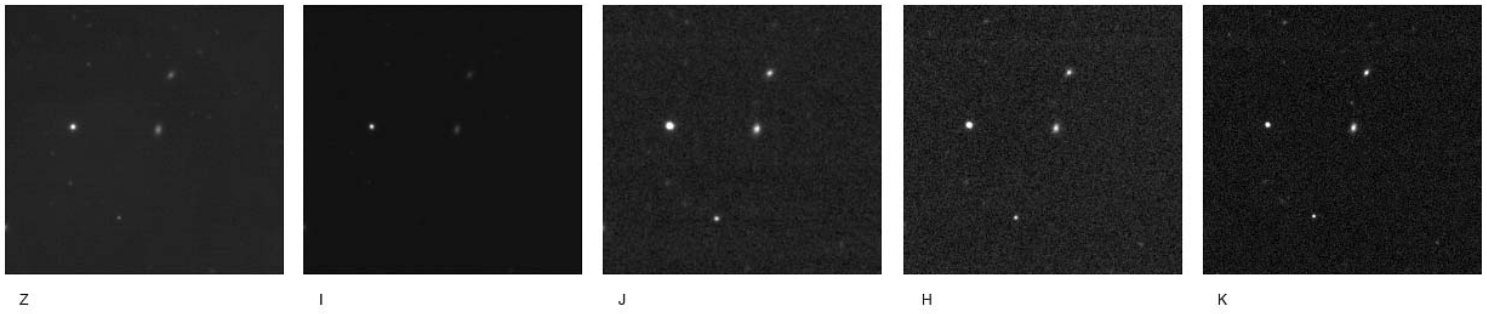
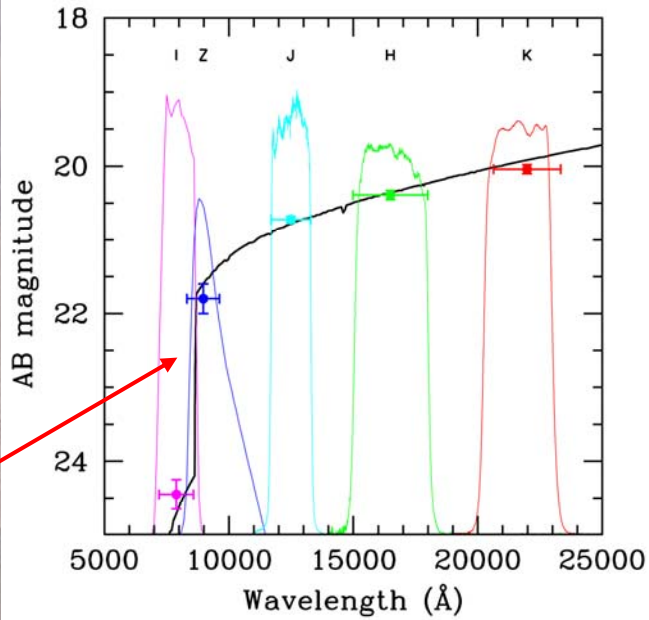
2005: even more distant GRB



Various Bands (FORS2 + ISAAC/VLT)



Spectral Energy Distribution of GRB050904

I-dropout

z=6.3

- GRB 050904
- Observations were done between 24.7 and 26 hours after the burst with ISAAC and FORS2
- Photometric redshift: 6.3 (confirmed by SUBARU)

ISAAC

Chincarini et al., 2005

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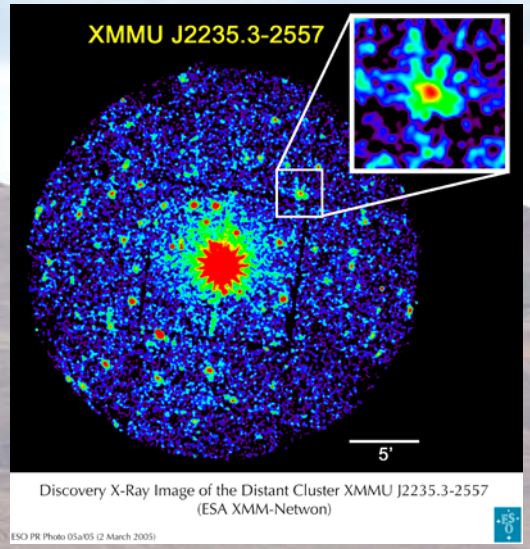
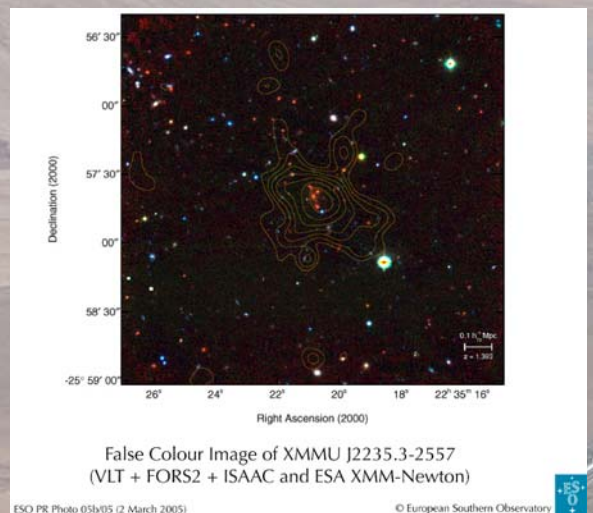
Structures in the Universe



Discovery X-Ray Image of the Distant Cluster XMMU J2235.3-2557
(ESA XMM-Netwon)

ESO PR Photo 05a/05 (2 March 2005)



False Colour Image of XMMU J2235.3-2557
(VLT + FORS2 + ISAAC and ESA XMM-Newton)

ESO PR Photo 05b/05 (2 March 2005)

Highly developed structures in the young Universe

- X-ray Cluster
- ISAAC reveals 12 galaxies
- z cluster = 1.4
- Its distance is thus 9 billion l-y
- Youngest cluster found

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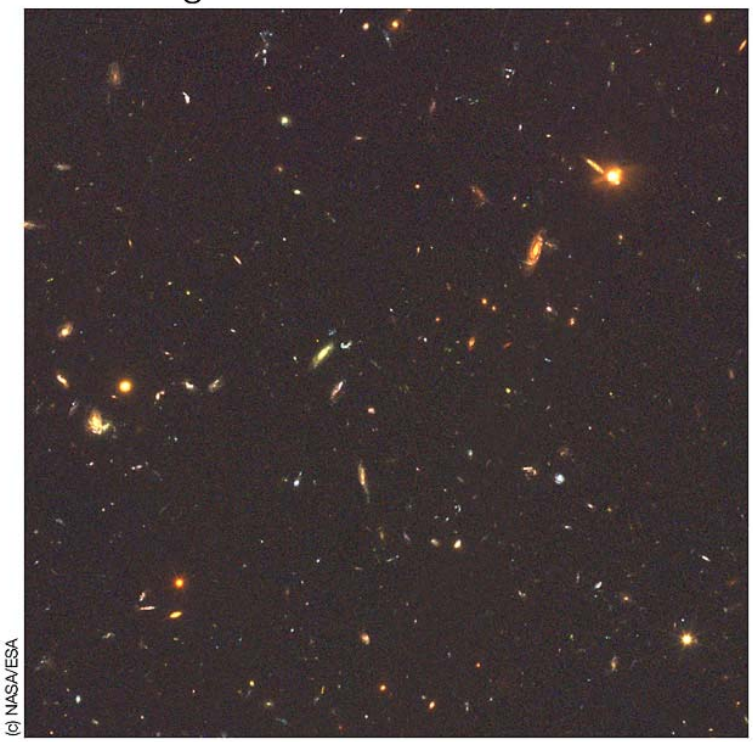
Falling onto the Dark

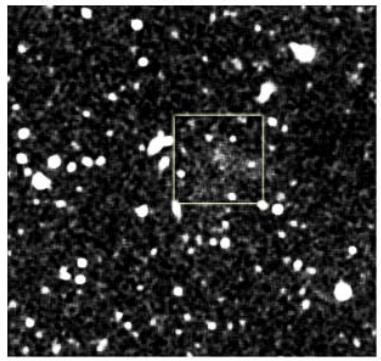
Lyman-alpha blob in the GOODS South field

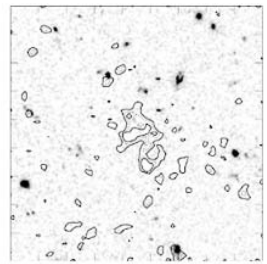
HST Image



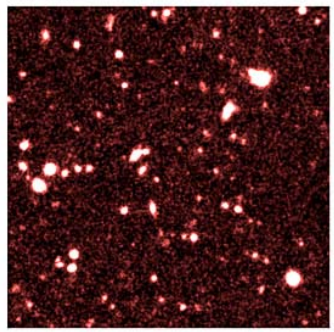
(c) NASA/ESA

Narrow-band

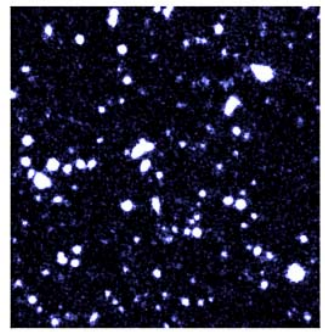




Red



Blue



WFI, FORS/VLT

Nilsson et al. 2006

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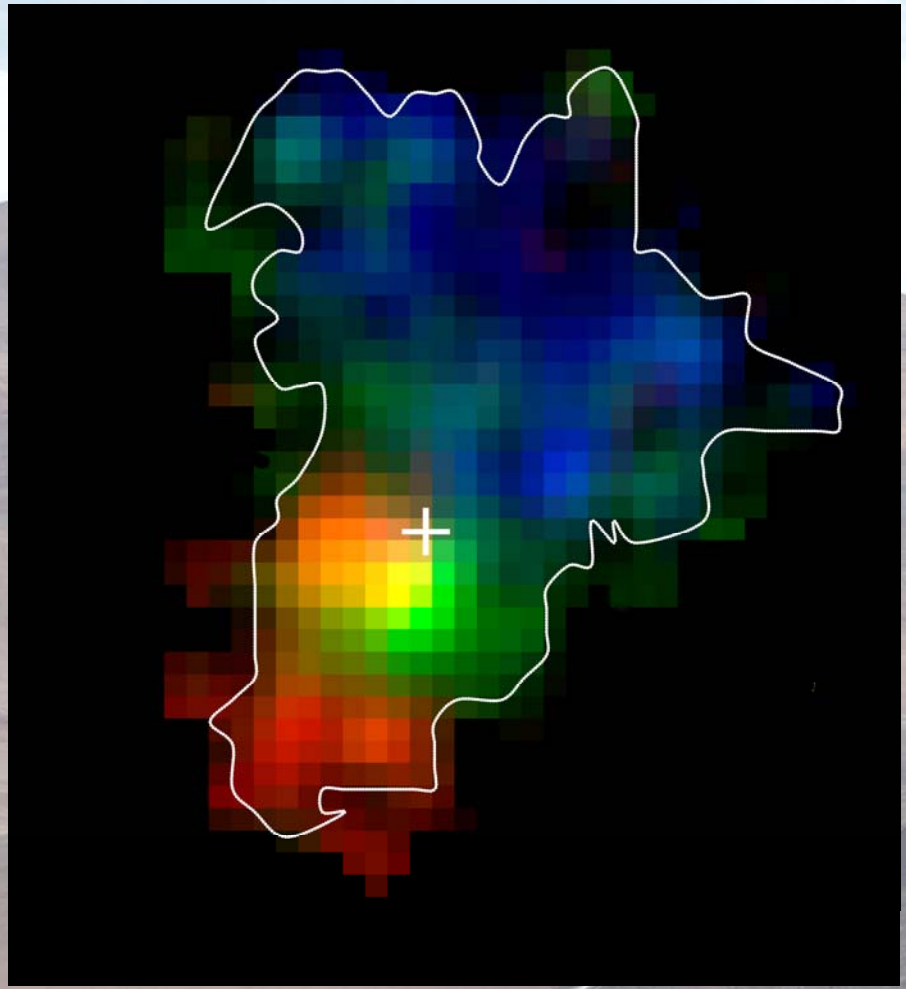
Rapid Formation of Galaxies



- Bzk -15504
- z=2.38
- AO+SINFONI: 0.15” resolution
- Galaxy as large as Milky Way already formed (stable?)
- Very intense star formation.

SINFONI/VLT

Genzel et al. 2006

SINS

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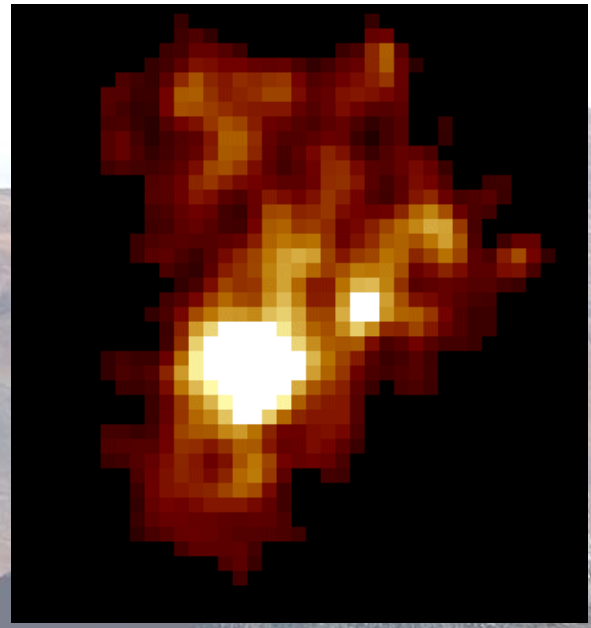
Rapid Formation of Galaxies

- SINFONI maps of H-alpha em. line separated in 65 km/s bins.
- SF occurs in luminous complexes
- Gas is funneled into nucleus



SINFONI/VLT

Genzel et al. 2006

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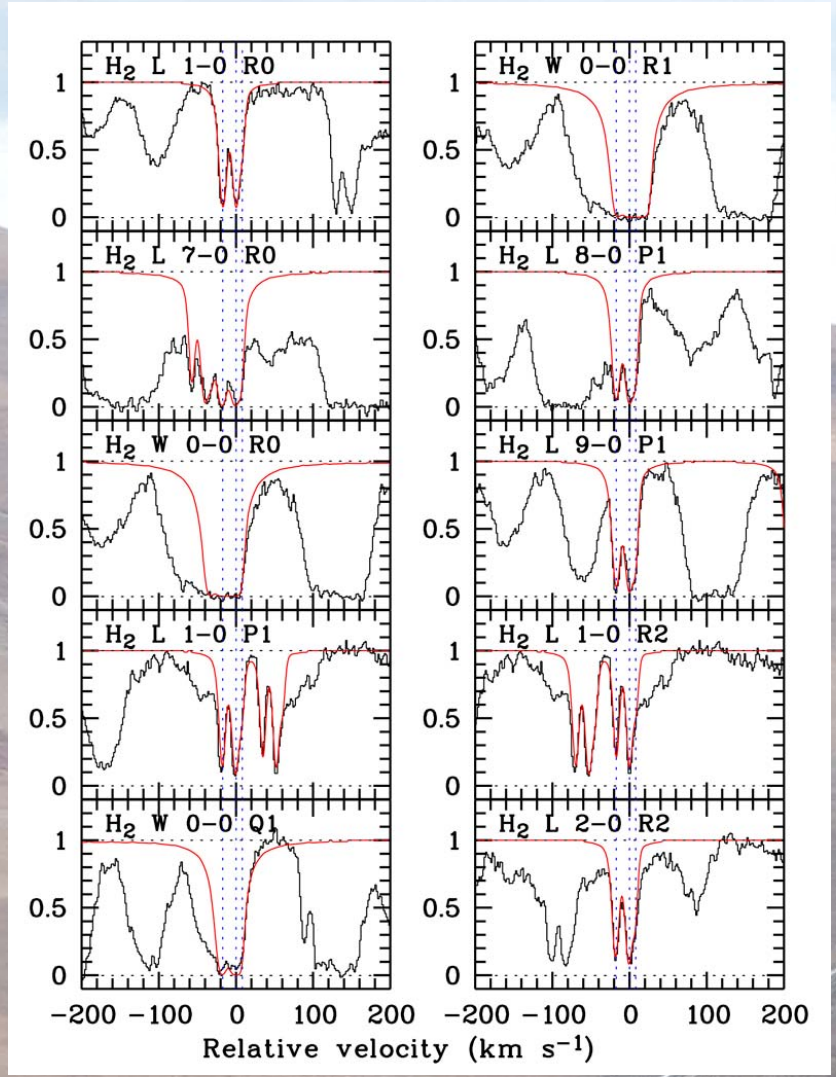
Physics in Universe's Youth



- Damped Ly-alpha system at z=4.224 towards quasar PSS J 1443+2724
- H_2 found Gas must be cold
- Metal lines seen

  SF took place when Universe was ~1 billion years old
- m_e/m_p in past: evolved?

UVES/VLT

Ledoux et al. 2006

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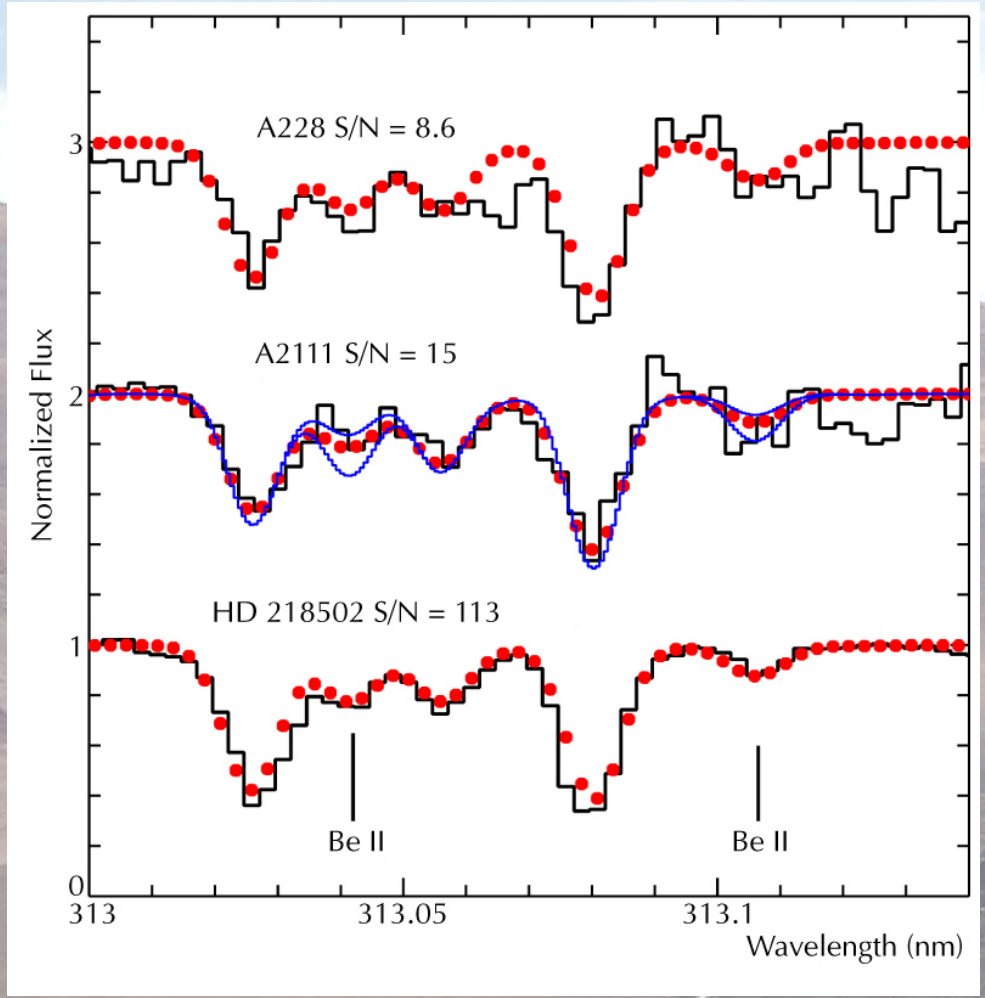
Age of Milky Way



Beryllium measurements in Globular Cluster NGC 6397

13.6 ± 0.8 Gyr

UVES

Pasquini et al. 2004

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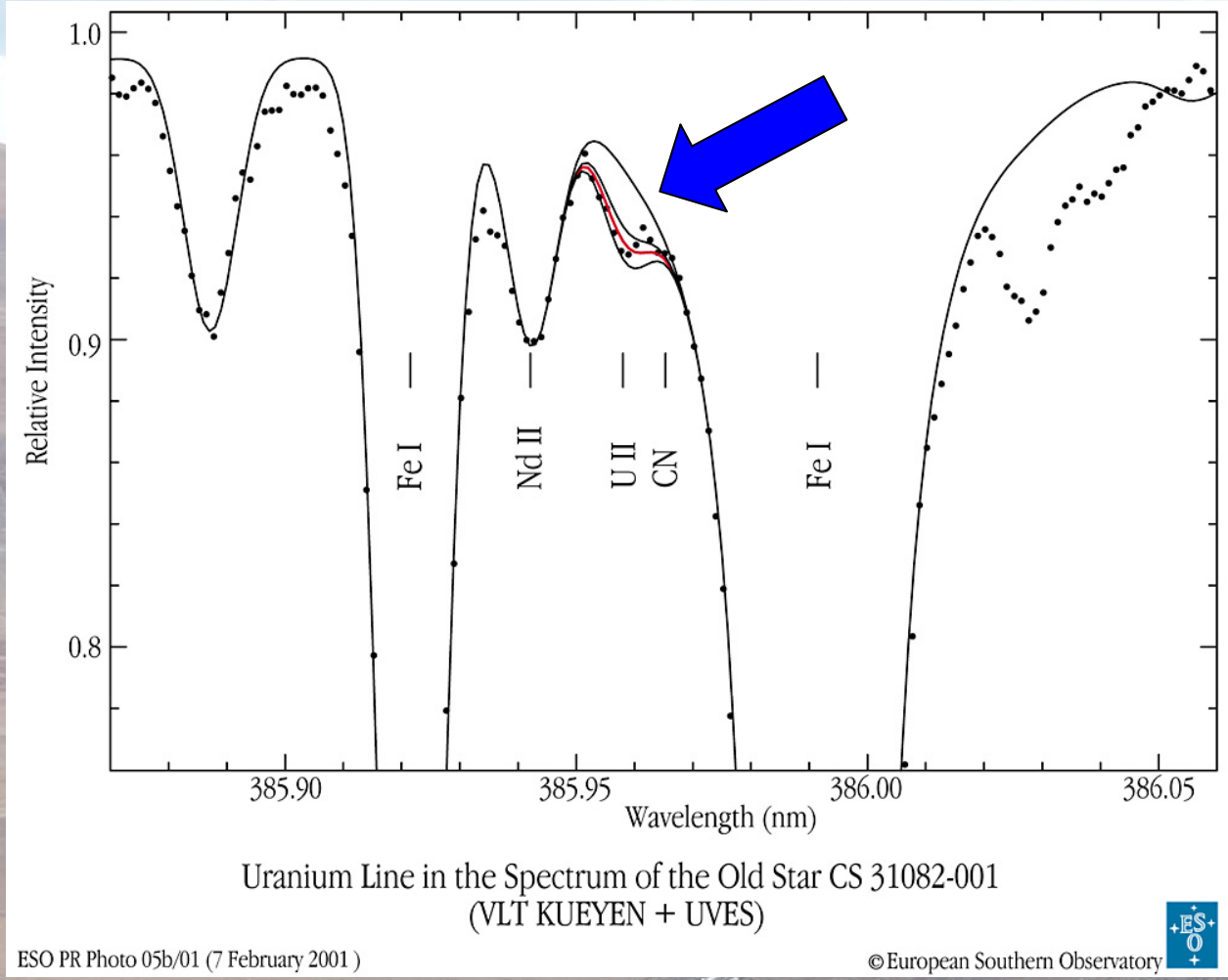
Age of Universe



14.2 ± 2.5 Gyr

UVES

Cayrel et al. 2001

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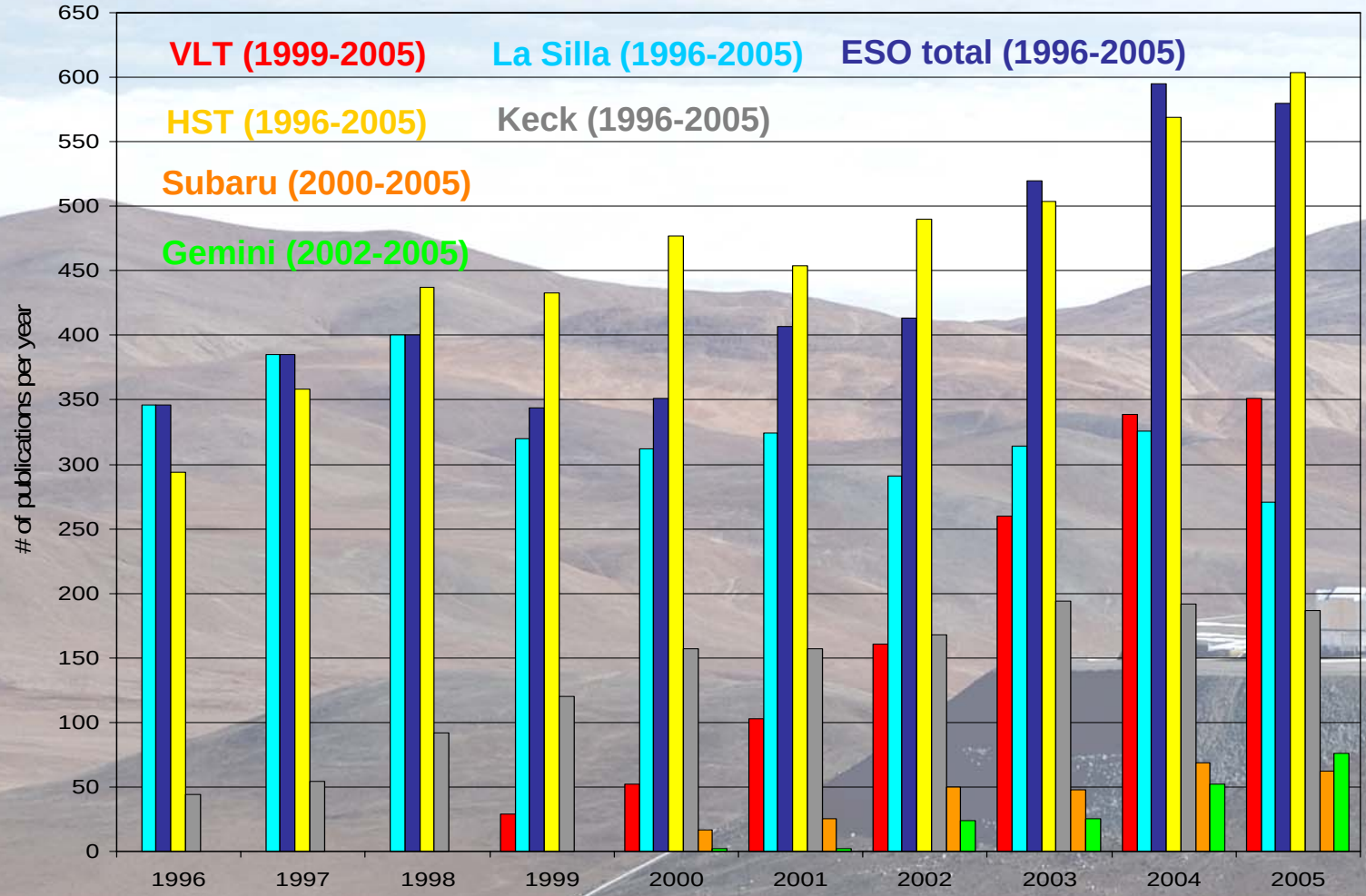
Publications per Year

VLT, La Silla, ESO total
HST, Keck, Subaru, and Gemini



Compiled by: ESO Library

VLT: ~ 8 yrs of operation; ~1500 refereed papers

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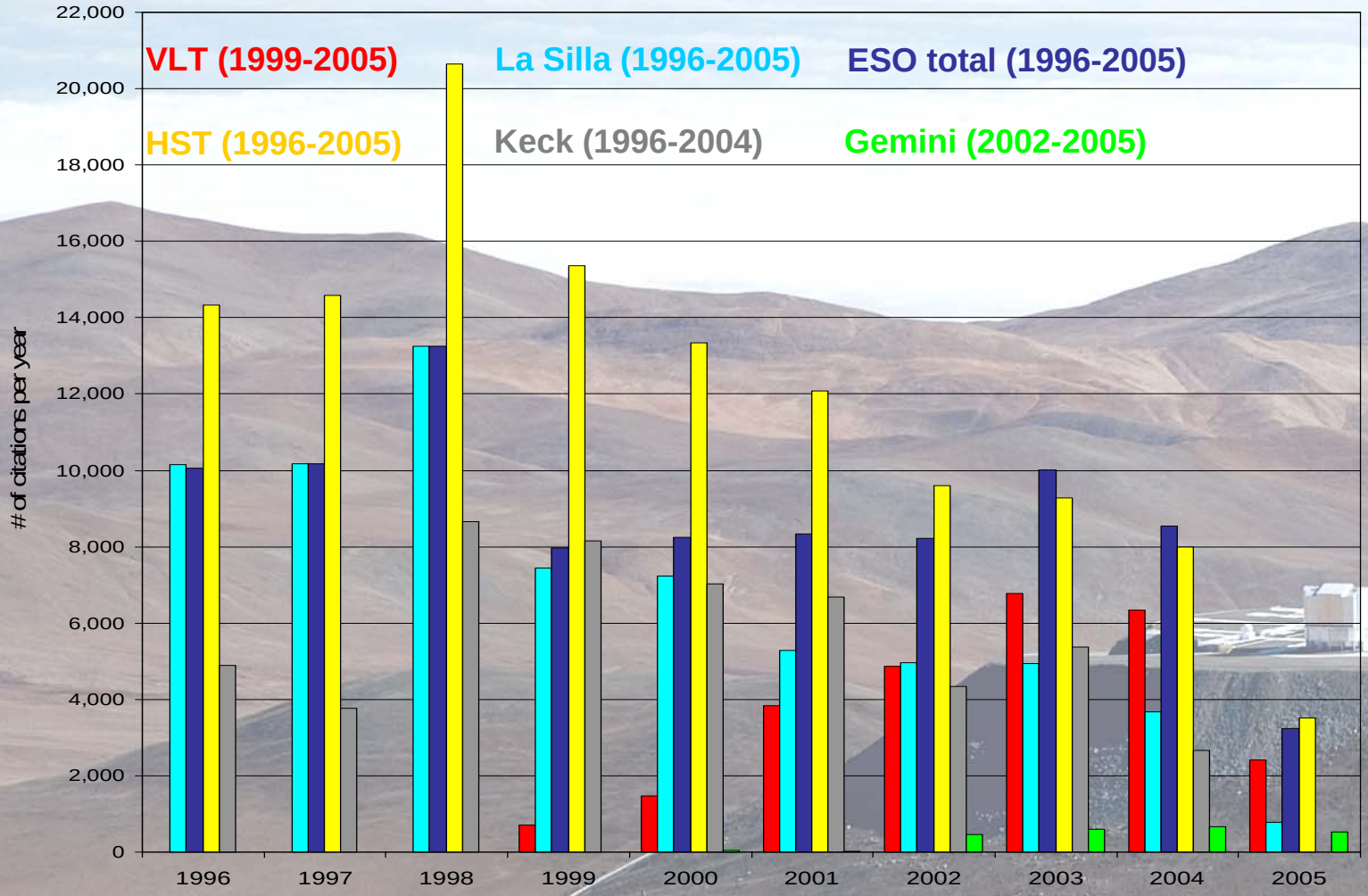
Citations per Year

VLT, La Silla, ESO total, HST, Gemini (as of 05/06), Keck (as of 12/05)



Compiled by: ESO Library

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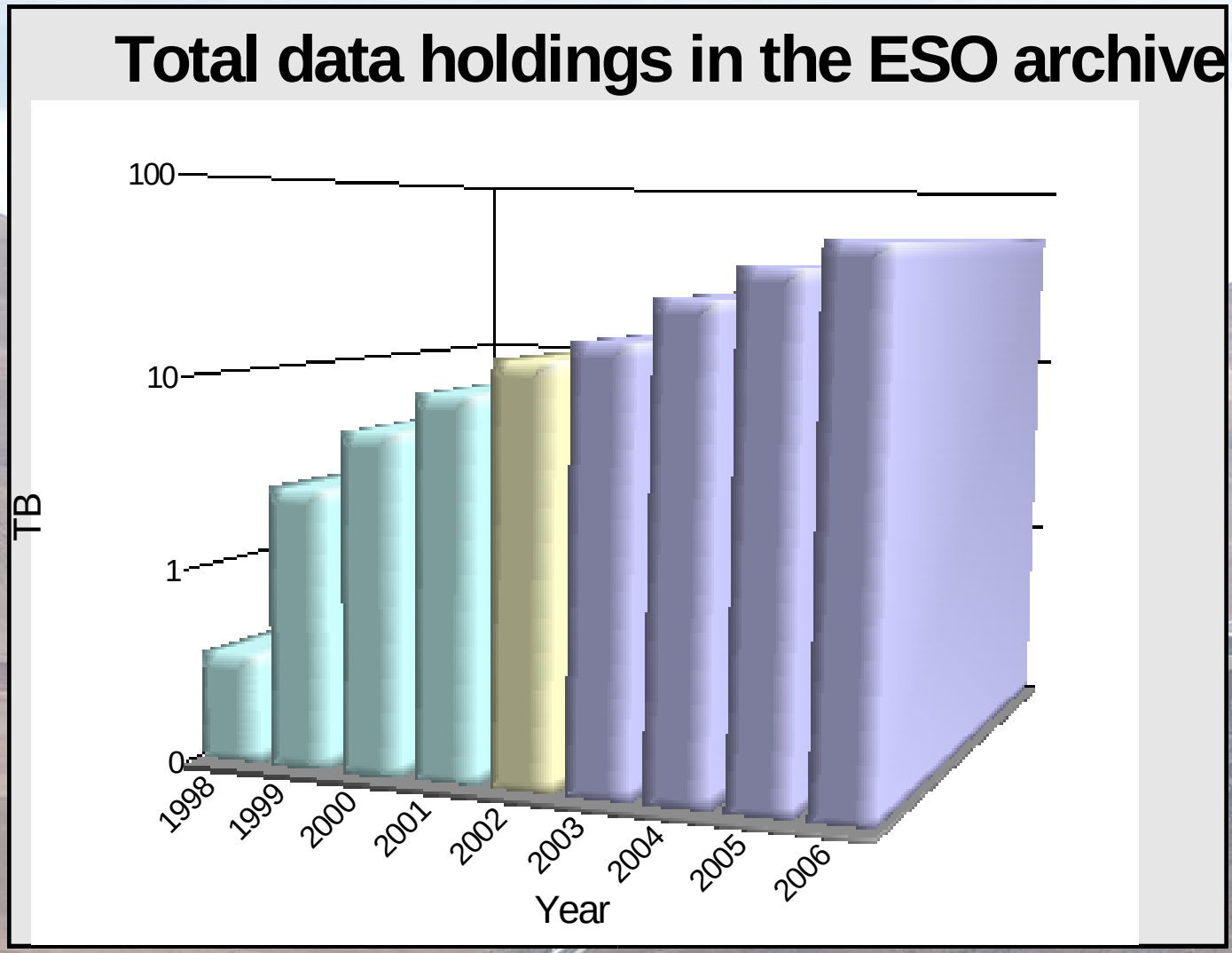
Science Data Archive Input



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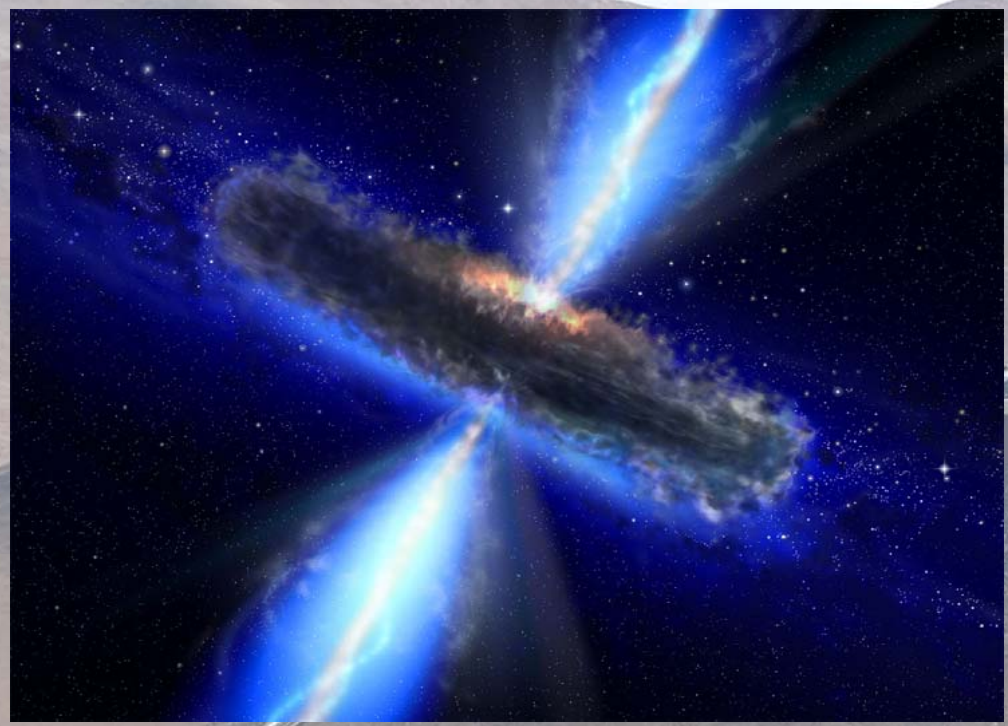
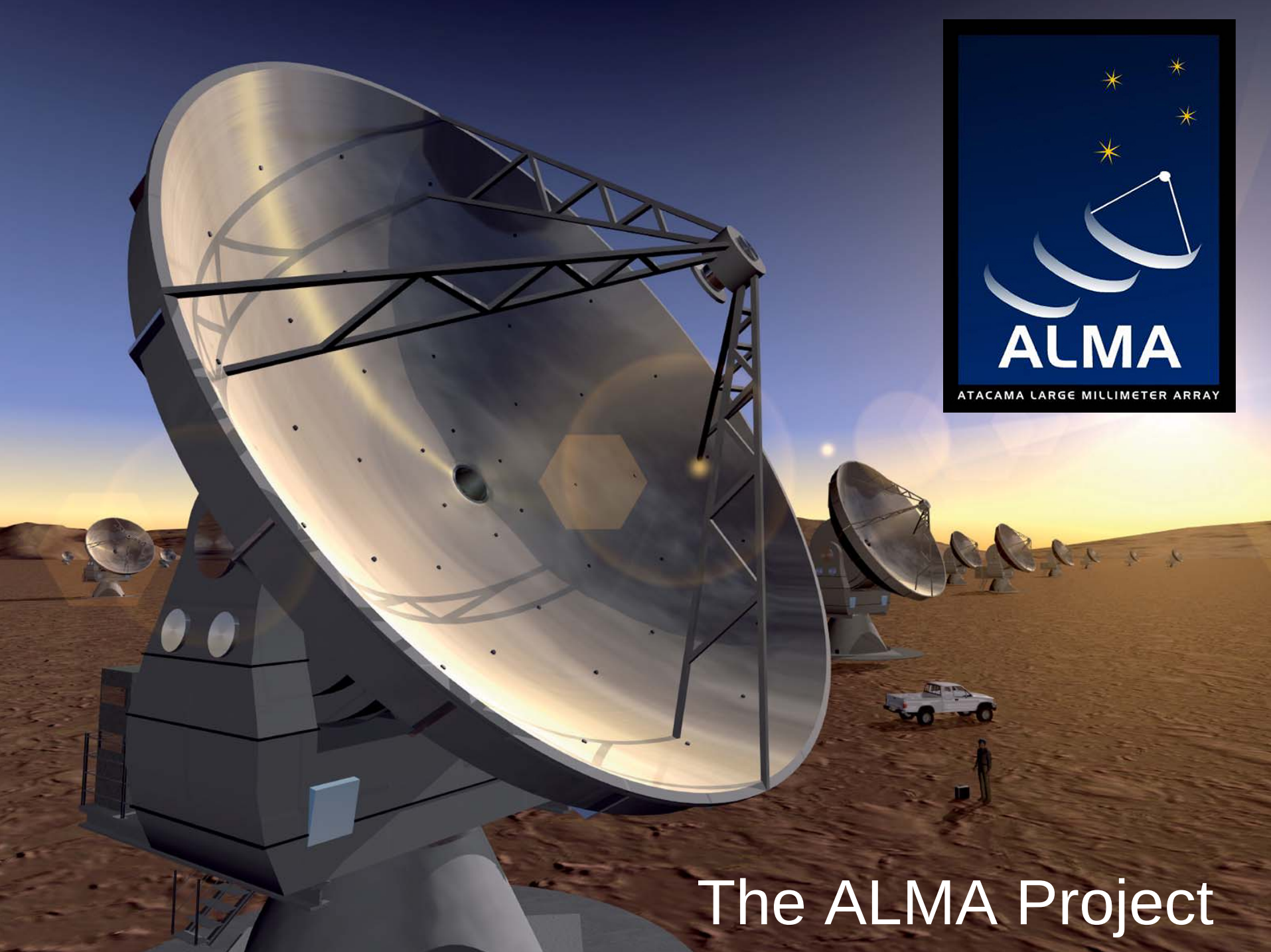
Astrophysical Virtual Observatory

- Multi-wavelength, heterogeneous, and complex data: VLA, CGPS, ISO, 2MASS, USNO, 2.2m/WFI, VLT/FORS, HST/ACS, XMM, and Chandra (images, spectra, and catalogues); GOODs survey
- AVO **First Science**
- **41 new obscured QSOs**





The ALMA Project

European Organisation for Astronomical Research in the Southern Hemisphere

Scope

- Construct and operate a large array of radio telescopes:
  - 54 antennas of 12 m diameter (initial configuration)
  - 12 antennas of 7 m diameter.
- Measure millimeter / submillimeter wavelength spectra:
  - 0.85 mm < λ < 3mm.
- Array in 5000m altitude in the Atacama desert (near St. Pedro de Atacama, Northern Chile) with
  - compact (150 m) and extended (15 km) configurations.

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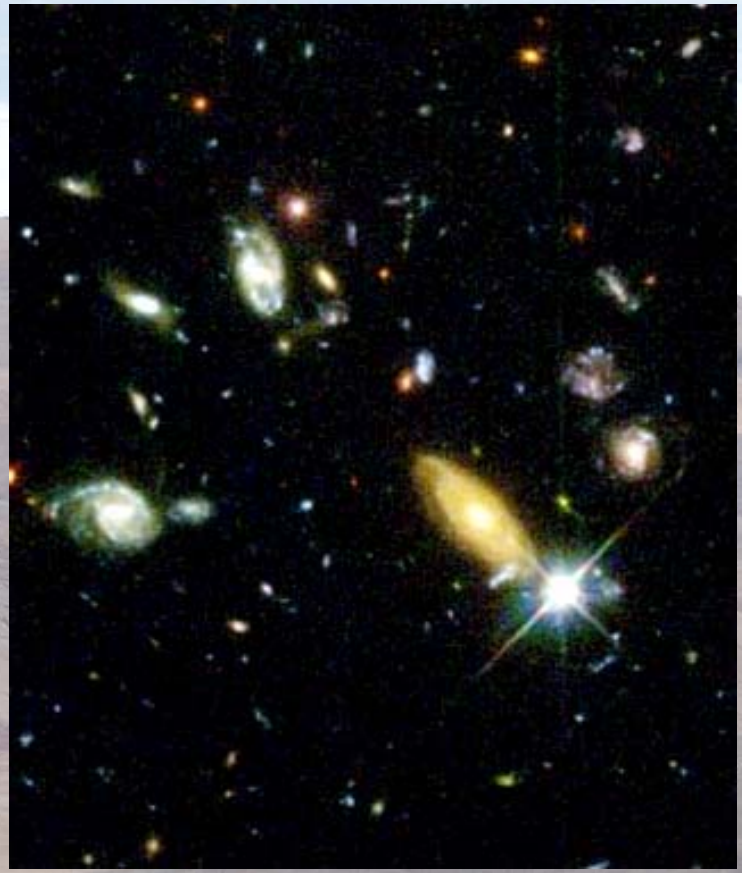
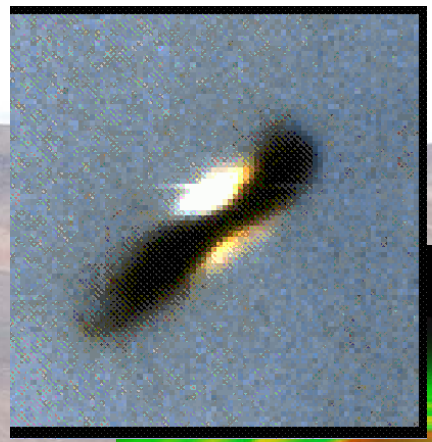
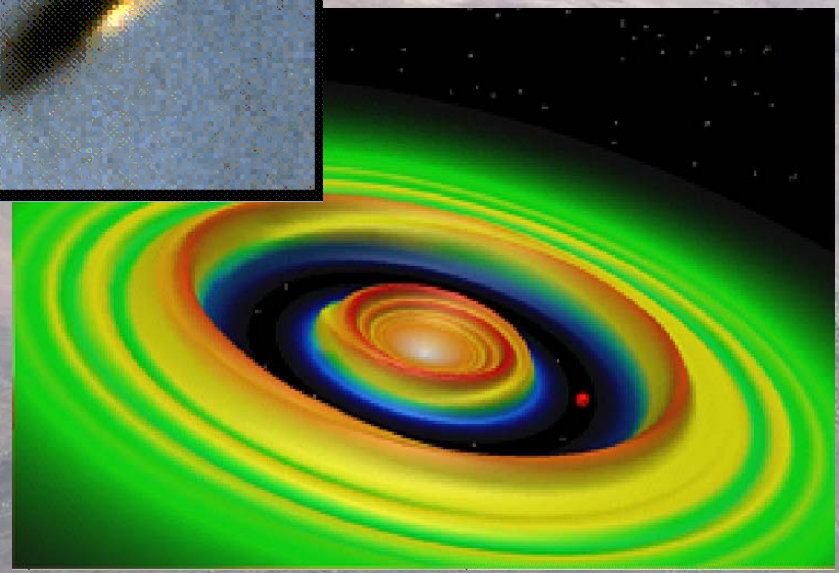
The Main Science Drivers for ALMA



Galaxy Formation in the Early Universe





Star & Planet Formation

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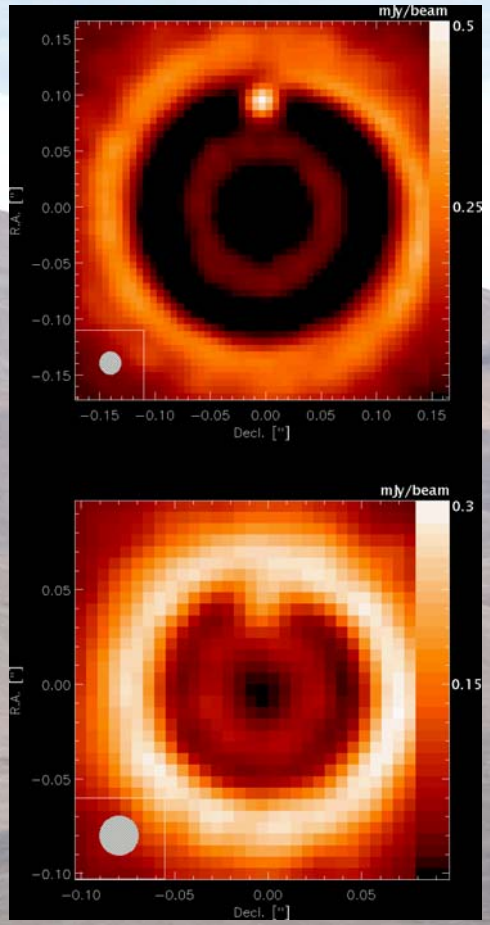
Simulation of a protostellar disc

150 light years



300 light years

Jupiter-mass protoplanet around 0.5 solar mass star

Orbital radius: 5 AU

Maximum baseline: 10 km
f = 850 GHz
8 hour integration

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History

- 2002 Project started
  - Bilateral agreement between North America (NSF) and Europe (ESO).
- 2004 Japan joined
- 2005 Project redefined / rebaselined

ALMA Ground Breaking 2003

European Organisation for Astronomical Research in the Southern Hemisphere

OSF - Contractors Camp

At present for 150 persons – at peak construction for 500 persons

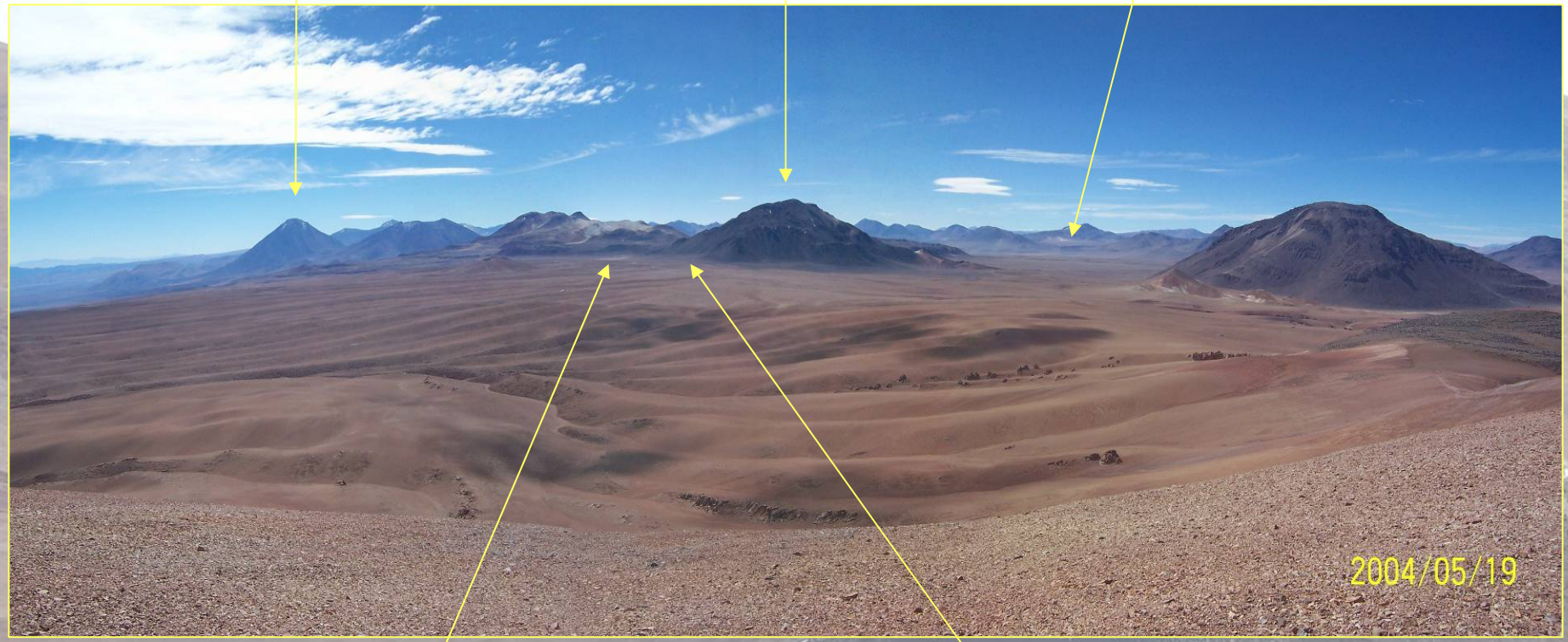
European Organisation for Astronomical Research in the Southern Hemisphere

ALMA Camp and Lascar Vulcano

Lascar Eruption – April 2006

European Organisation for Astronomical Research in the Southern Hemisphere

The Chajnantor / ALMA Plateau



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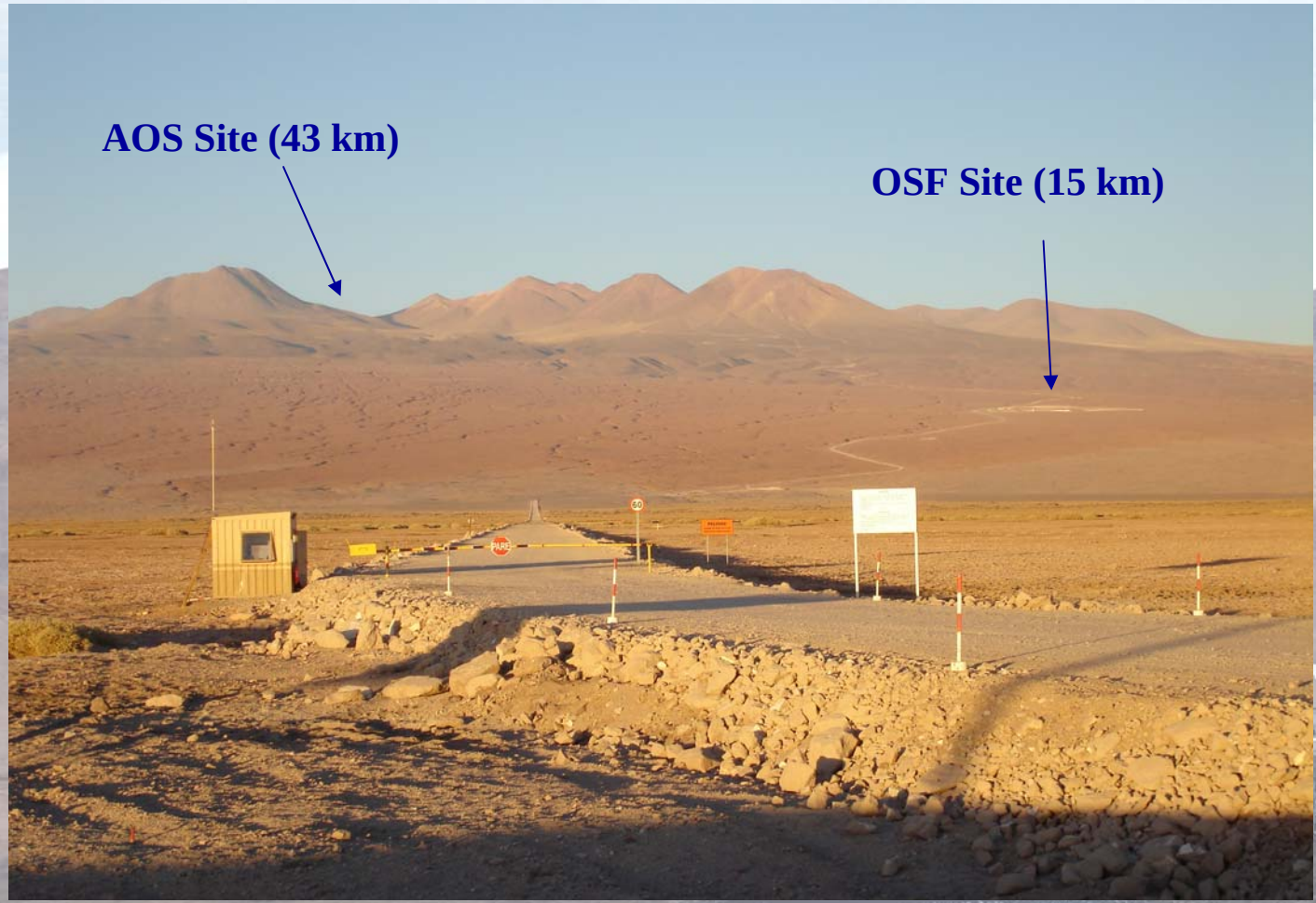
Road to AOS



Completed up to AOS – 43 km

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Array Operations Site Layout

The AOS Technical Building– July 2006

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The Three ALMA Prototype Antennas at the ATF

12 Meter Diameter, Carbon Fiber Support Structures

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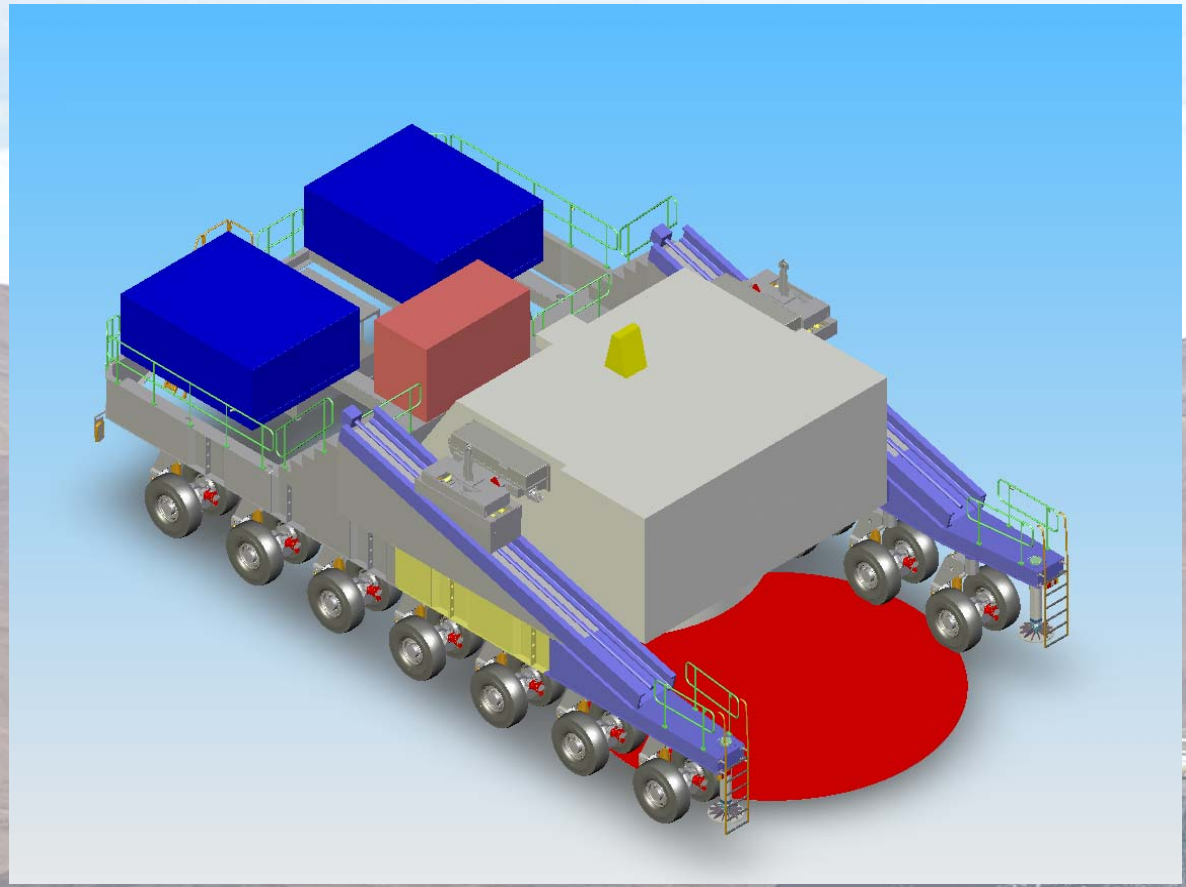
Antenna Transporters



Two transporters:
PDR held in July 2006, delivery Q3/2007 and Q1/2008

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Front End Cryostats

All cryostats will be assembled at RAL and shipped to the three Front End Integration Centres. First four cryostats accepted.

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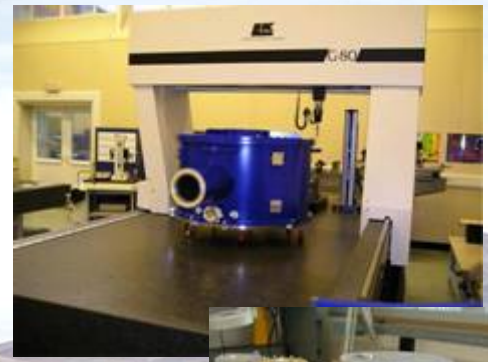
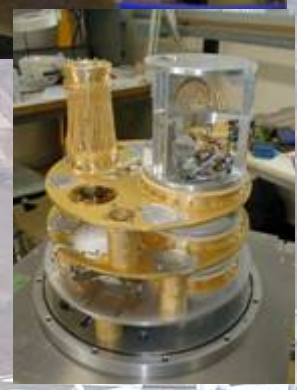
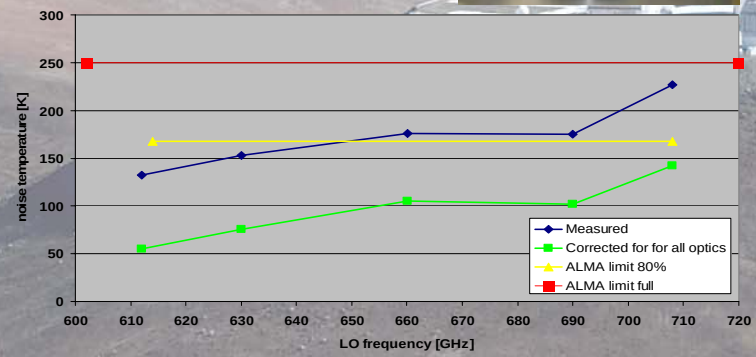
ALMA Development
Front Ends

Prototypes, fulfilling specifications, are available for all 4 ALMA frequencies (0.6, 0.9, 1.3 and 3 mm), and for the cryostat. A first series of 8 is being manufactured.

The first receivers for 2 frequency bands have been delivered







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Schedule Overview

- **First Fringes:** ATF September / October 2006
- **AOS, OSF:** construction… complete Q1/2008
- **Antennas:** #1 2007, #2 2007… #50 2011
- **Front Ends:** #1 2007, production
- **DTS:** production
- **Correlator:** Quadr. 1 complete, ... Quadr. 4 2008

- **First Interferometry at AOS:** 2009
- **Call for Proposals and Early Science:** 2010
- **Full Operations:** 2012

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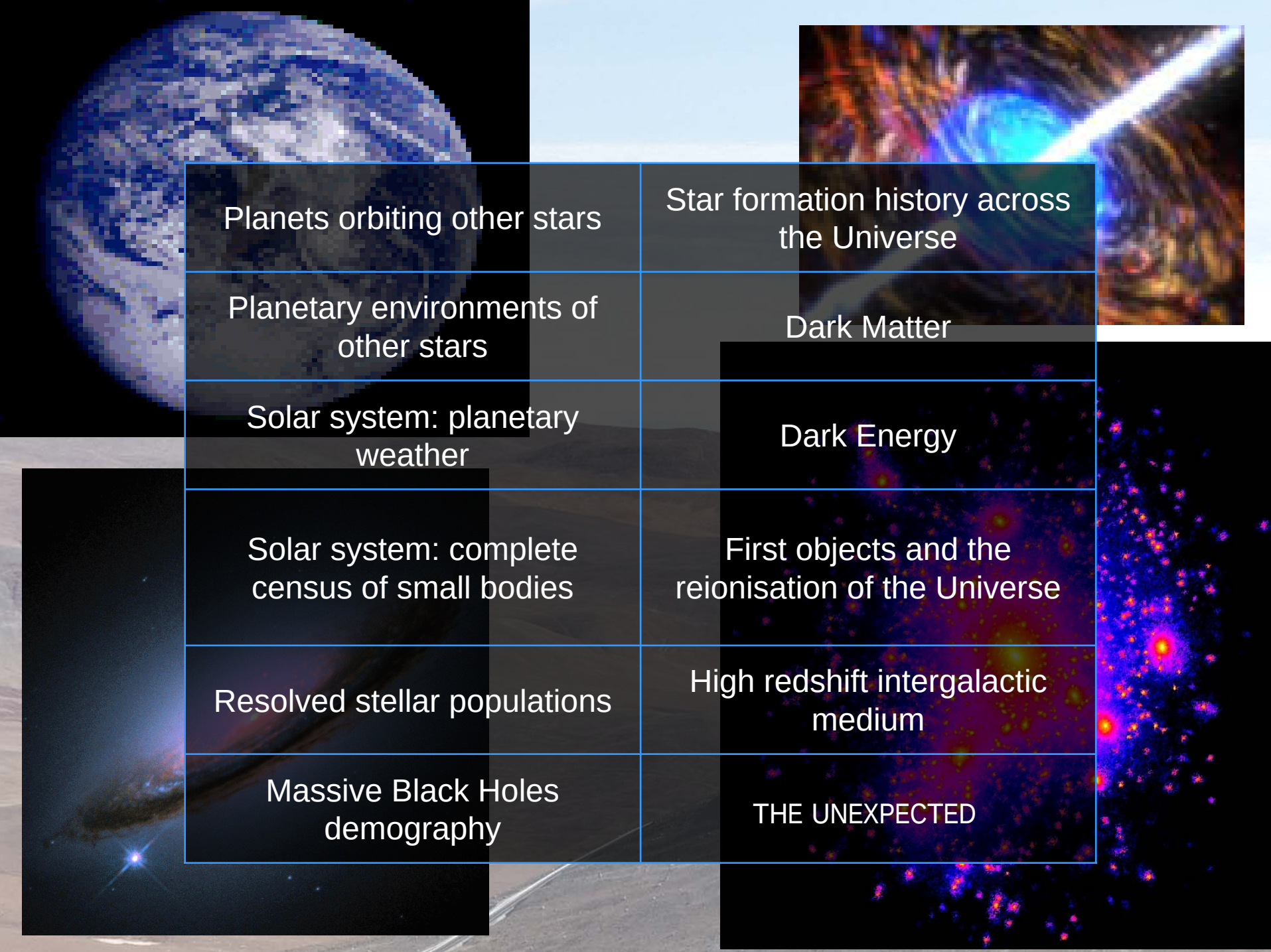
Why an ELT ?

- Increased collecting area
  - Fainter sources : brings new populations within reach
- Increased diameter
  - Increased spatial resolution : provides images with spectacular detail

- Astronomy remains a technology driven science. We are still opening parameter space.



Planets orbiting other stars	Star formation history across the Universe
Planetary environments of other stars	Dark Matter
Solar system: planetary weather	Dark Energy
Solar system: complete census of small bodies	First objects and the reionisation of the Universe
Resolved stellar populations	High redshift intergalactic medium
Massive Black Holes demography	THE UNEXPECTED

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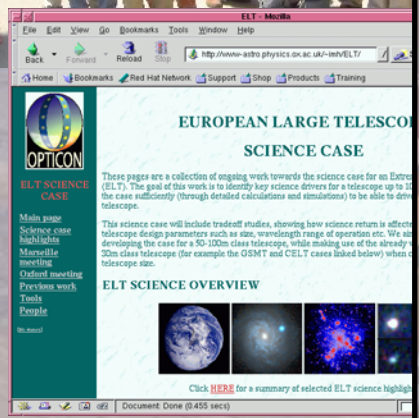
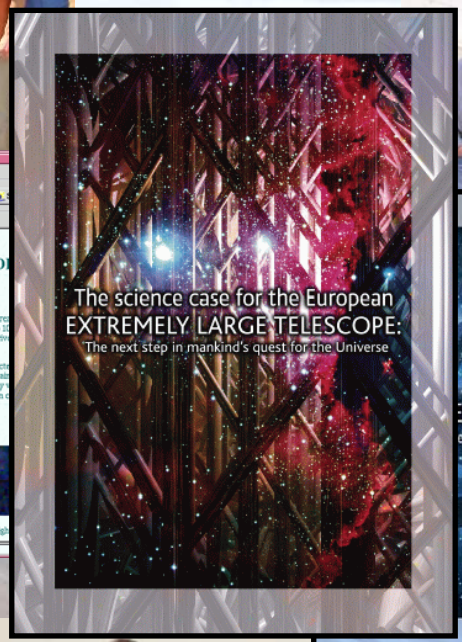
ELT science case development: a community activity

Florence 2005

Marseilles 2003



Web site



Science case documents

Florence 2004

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Science Case	λ range (microns)	Spatial Resolution	Spectral Resolution (R=λ/Δλ)	Field of View	Comments
Exo planets:					
(i) Direct detection	0.8-2.0	Diff. limited with very high Strehl	~100	10-20”	Imaging & low-resolution spectroscopy. Multiple observations needed for confirmation.
(ii) Indirect detection	visible	Seeing-limited	100 000	Small	Single sources, radial velocity measurements
Formation of planets (disks)	2 – 20	Diff. limited	10, 300, 3000, 50000	5-10”	Near and Mid-IR IFU imaging/spectroscopy. Polarimetry desirable. Strong complementarity with ALMA.
Resolved Stellar Pops					
(i) photometry	0.8 – 3 (goal 0.6)	Diff. limited	10	1-10”	High resolution imaging.
(ii) Abundances	0.8-0.9	Diff. limited	5 000 – 8 000	10” - 3’	Multi-object spectroscopy with mutiplex of 10-50
(iii) Detailed abundances & kinematics	0.45-0.75	Diff limited	> 25 000 (goal 40 000)	1- 5”	Single sources
Black Holes	~ 1.0	Diff. limited	5 000 – 50 000	5”	IFU desirable
First galaxies	0.9-2	200mas	> 3 000	> 10x10’	Rare sources: requires large FOV/high multiplex
Reionisation	1.0-2.2	See comments	1000-5000	Small	Single point sources – would benefit from AO for improved contrast
Expansion history and fundamental parameters	0.4 – 0.68	80% enclosed energy in 0.6”	50 000 - 150 000	Few arcsec	High stability spectroscopy

Science cases provide quantitative requirements on ELT performance

(work in progress!)

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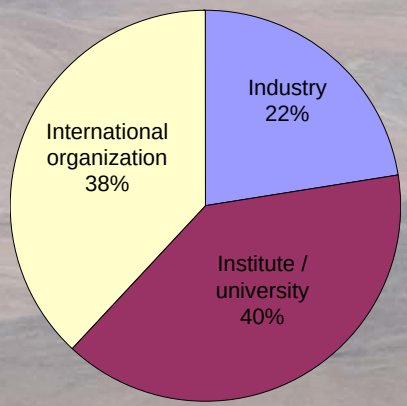
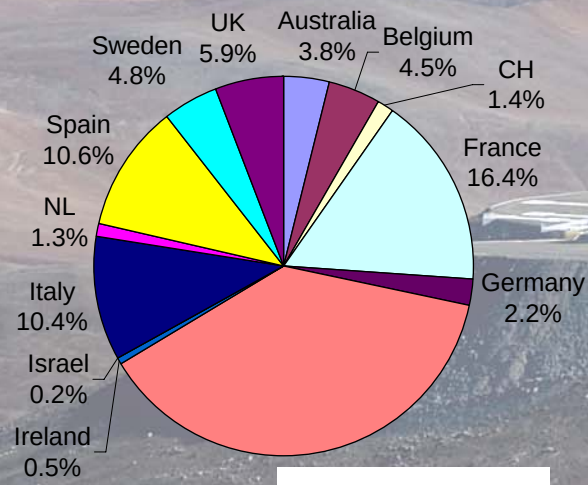
ELT Design Study

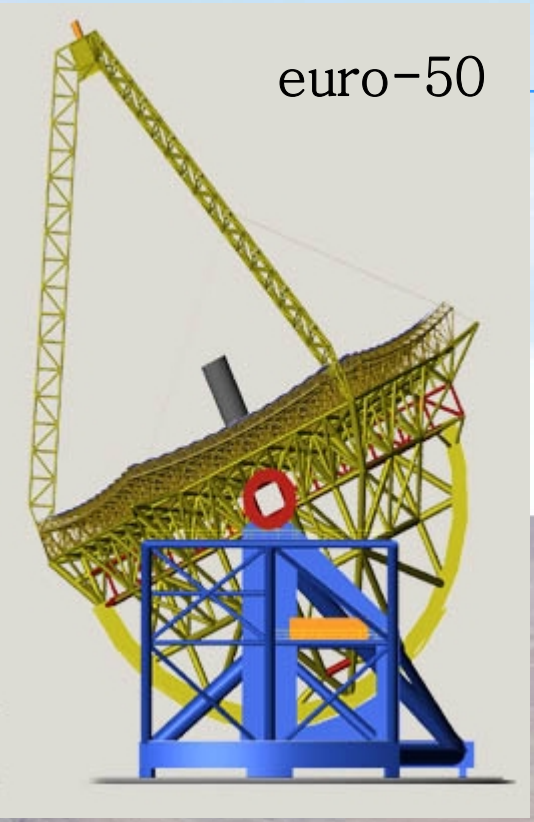
30M€ (8.4 from EU FP6)

- **Objectives**
  - **-Technology development towards a European ELT**
  - **–Preparatory work for observatory design**
  - **–Top level requirements**
  - **–Academic & industrial synergy**

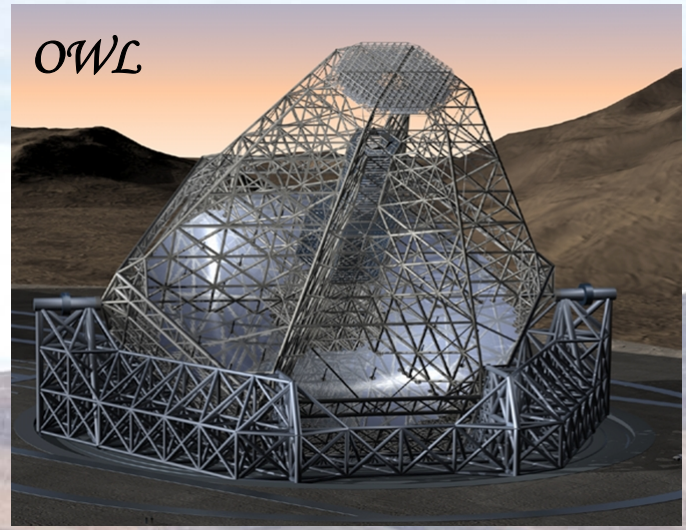




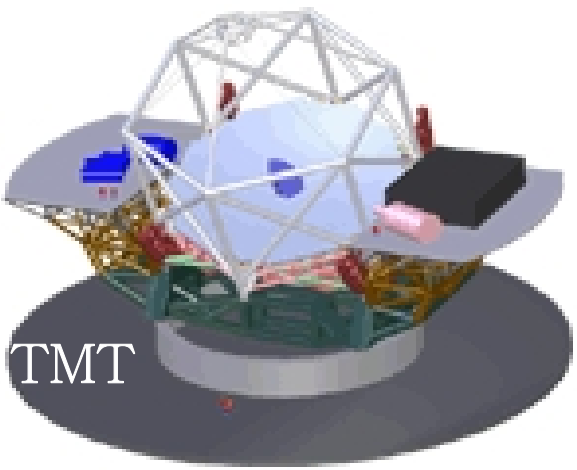
Alternative Designs

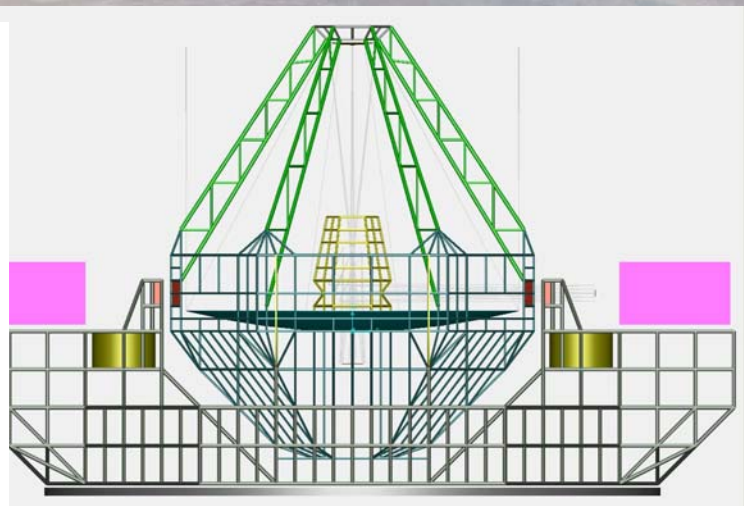


Spherical



Gregorian

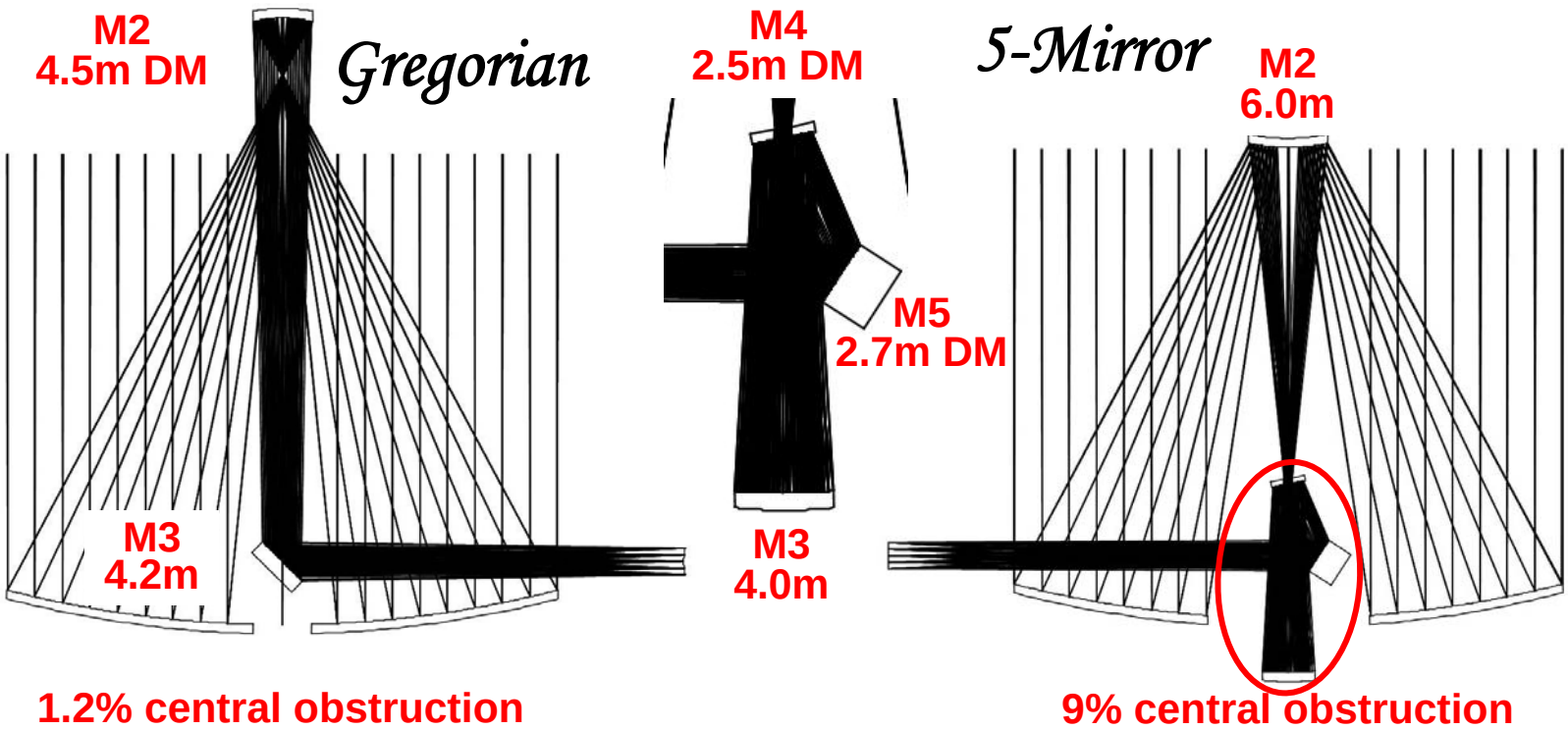




5-Mirror:

capability of multilayer AO correction using the pair of conjugate mirrors

E-ELT: Two Alternative Designs (42 m diameter)



- **3-mirror only**
  (better efficiency, lower emissivity)
- smaller concave M2
- internal F/1 prime focus

- **optimal fast wavefront control**
  (better location)
- smaller enclosure (by ~ 10 m)
- internal F/4.7 Cassegrain focus

Main Structure

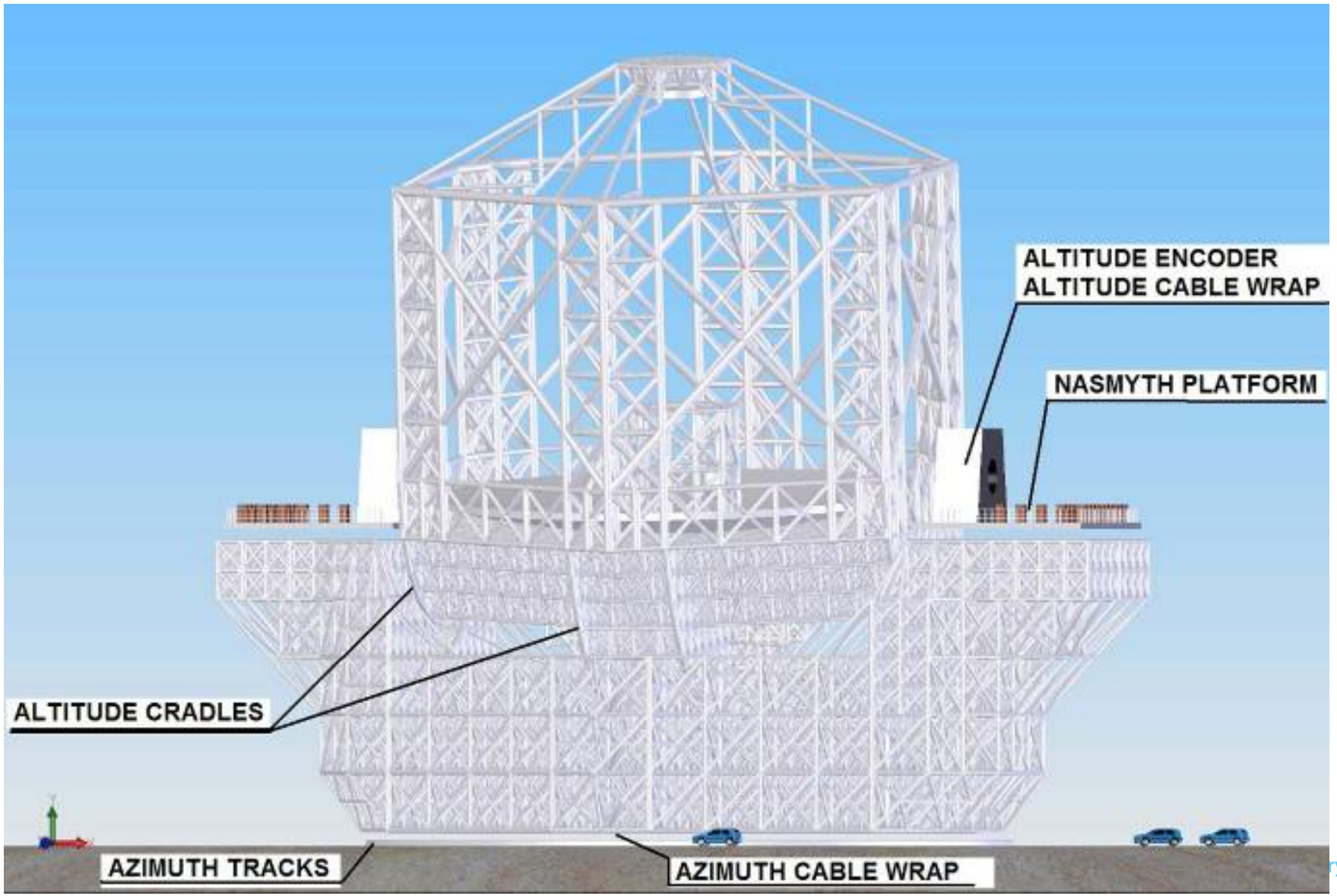


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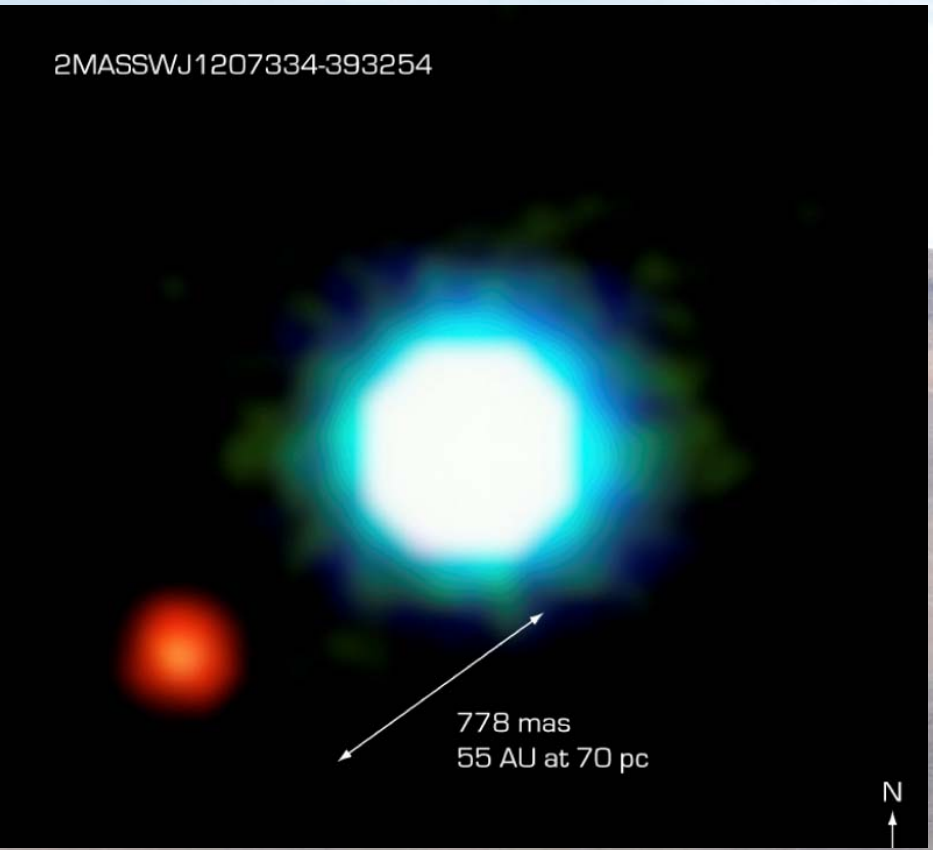
Image of Exoplanet (III)

First real image?



- Brown Dwarf “2M1207”
  - 25 Jupiter-masses
  - 8 million years old
- “Giant Planet Candidate Companion (GPCC)”
  - 100 x fainter
  - 1000 ºC
  - 55 AU distance
  - 5 Jupiter-masses
- TW Hydrae Association
  - 230 light-years
  - Water molecules

Chauvin et al., 2005

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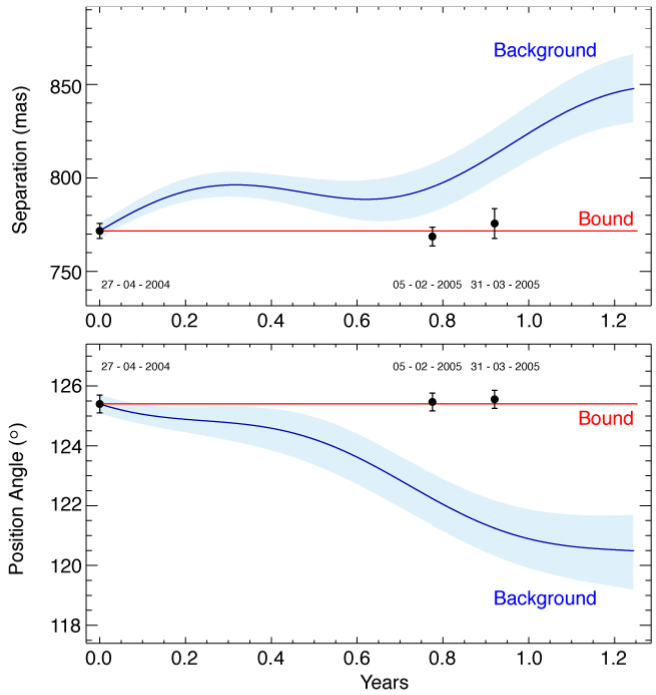
Image of Exoplanet (IV)

First real image!



Positions of 2M1207A and of its Companion (VLT/NACO)

ESO PR Photo 14b/05 (30 April 2005) ©ESO

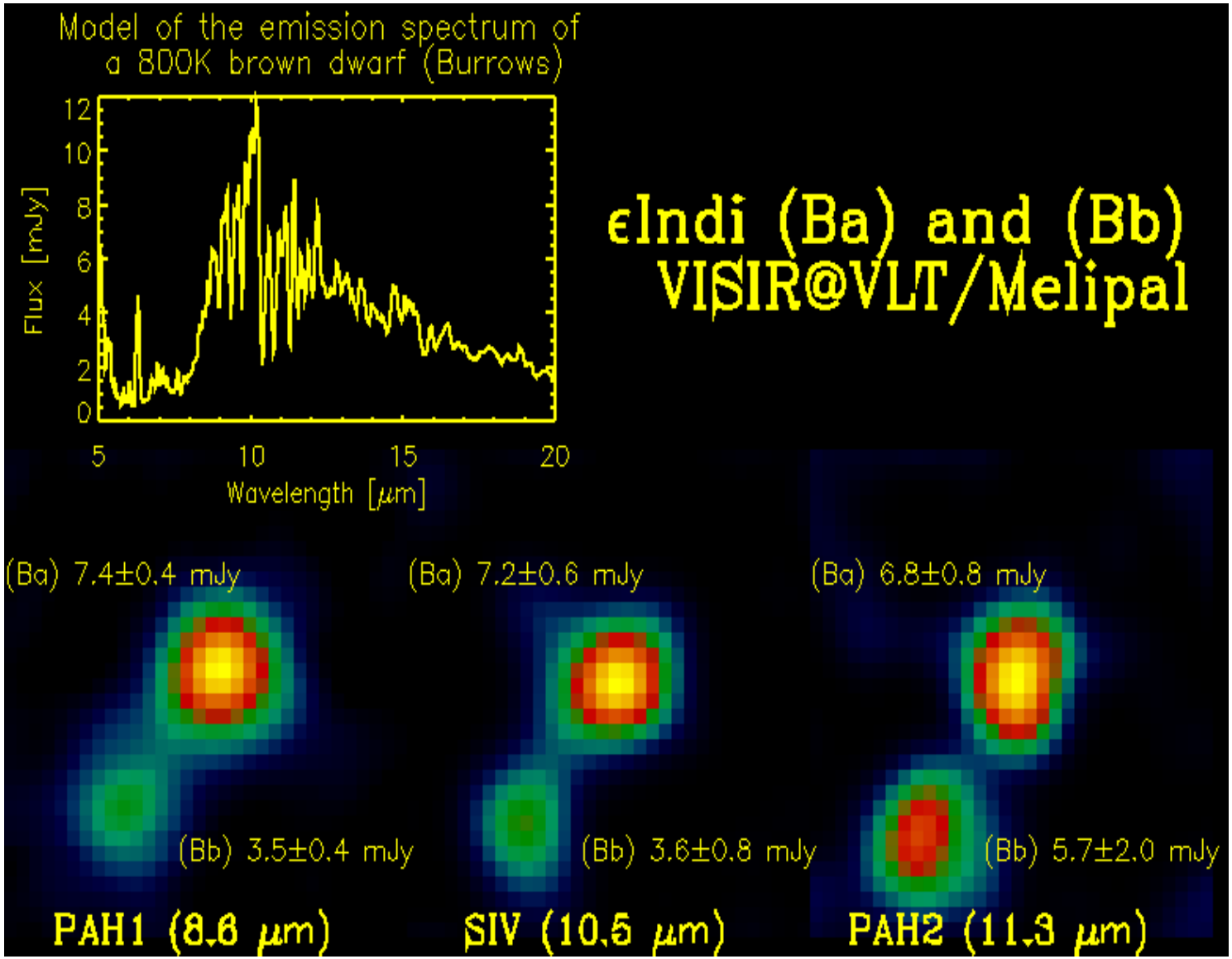
- Brown Dwarf "2M1207" and Giant Planet Candidate move together!
- Confirmed by apparent motion over a year (NACO/VLT)

Artist's rendering of the 2M1207 System

ESO PR Photo 14c/05 (30 April 2005) ©ESO

Chauvin et al., 2005

VISIR and Brown dwarfs: complementing Spitzer



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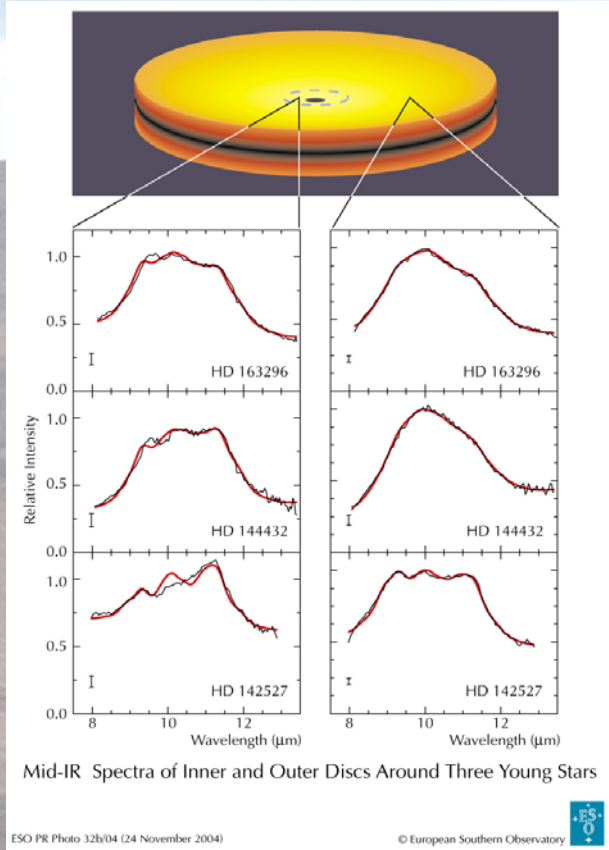
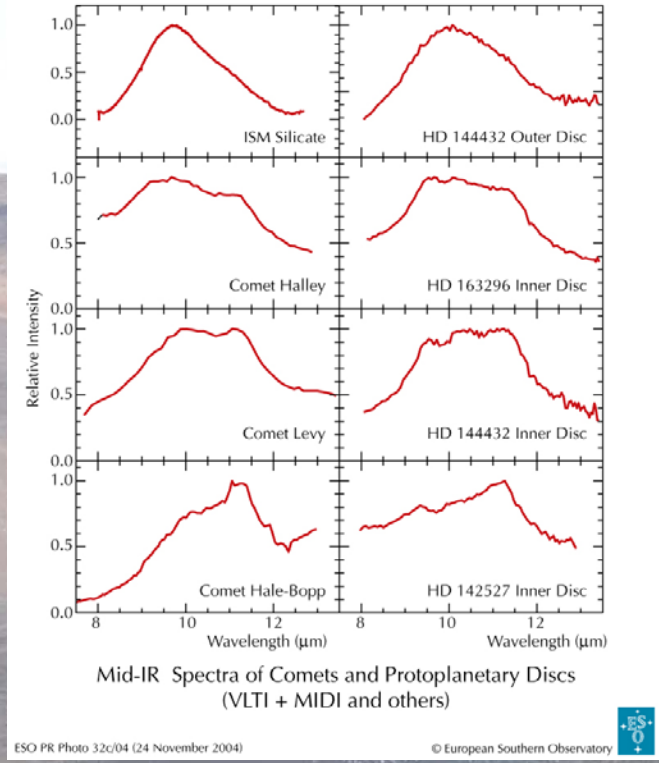
Protoplanetary discs (VLTI)



Mid-IR Spectra of Inner and Outer Discs Around Three Young Stars

ESO PR Photo 32b/04 (24 November 2004) © European Southern Observatory



Mid-IR Spectra of Comets and Protoplanetary Discs (VLTI + MIDI and others)

ESO PR Photo 32c/04 (24 November 2004) © European Southern Observatory

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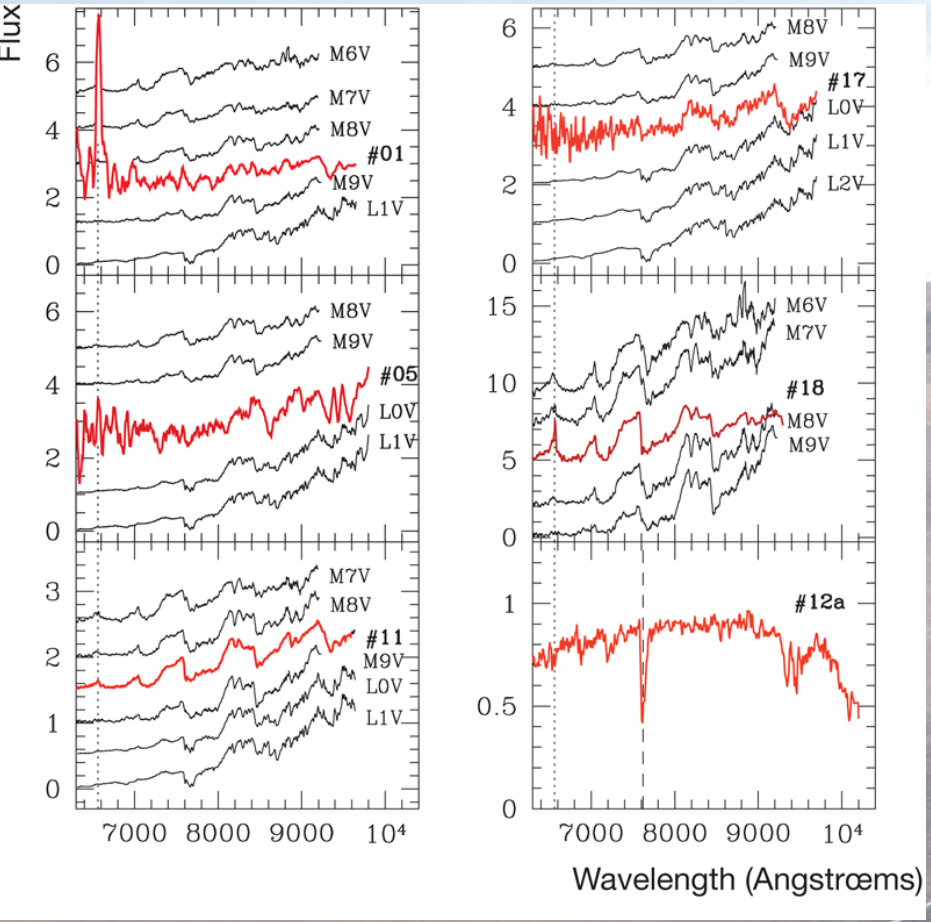
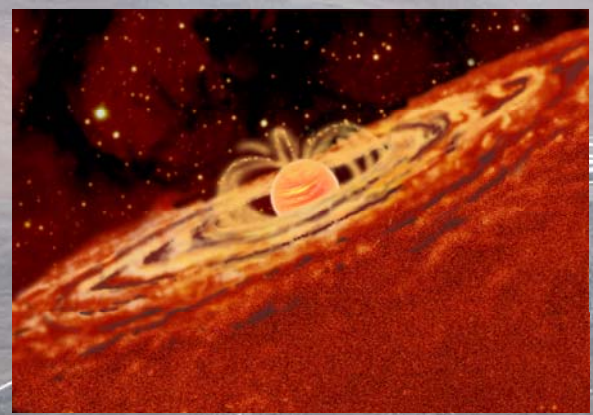
Discs around Planemos



- Planetary mass objects found to be surrounded by discs
- Form as normal stars
- Systems form as binary
- May have planetary systems
- Also around 2M1207!



Art by Jon Lomberg

FORS, NACO

Jayawardhana et al., 2006, Mohanty et al. 2006

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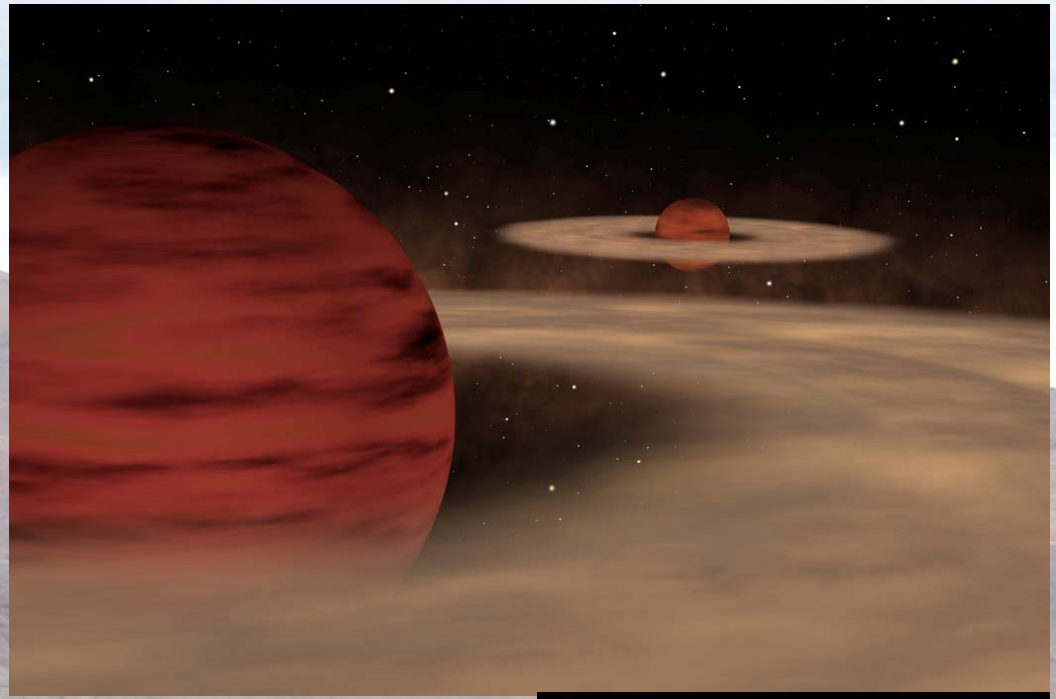
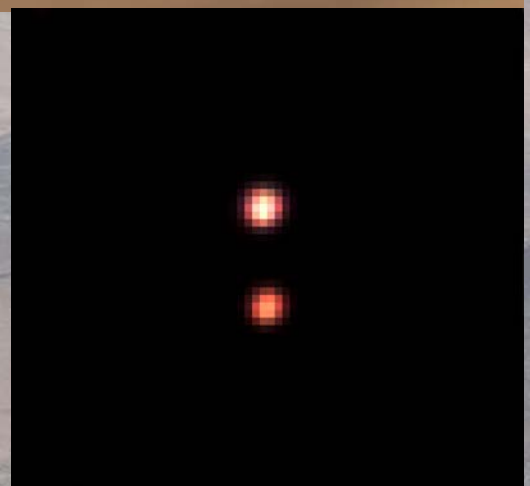
Binary Planemos





- Oph 162225-240515
- First double Planetary mass objects : 14 M_J + 7 M_J
- Separation: ~ 230 AU
- 1 million years old

- Formed as stars?

NTT, ISAAC/VLT

Jayawardhana & Ivanov 2006

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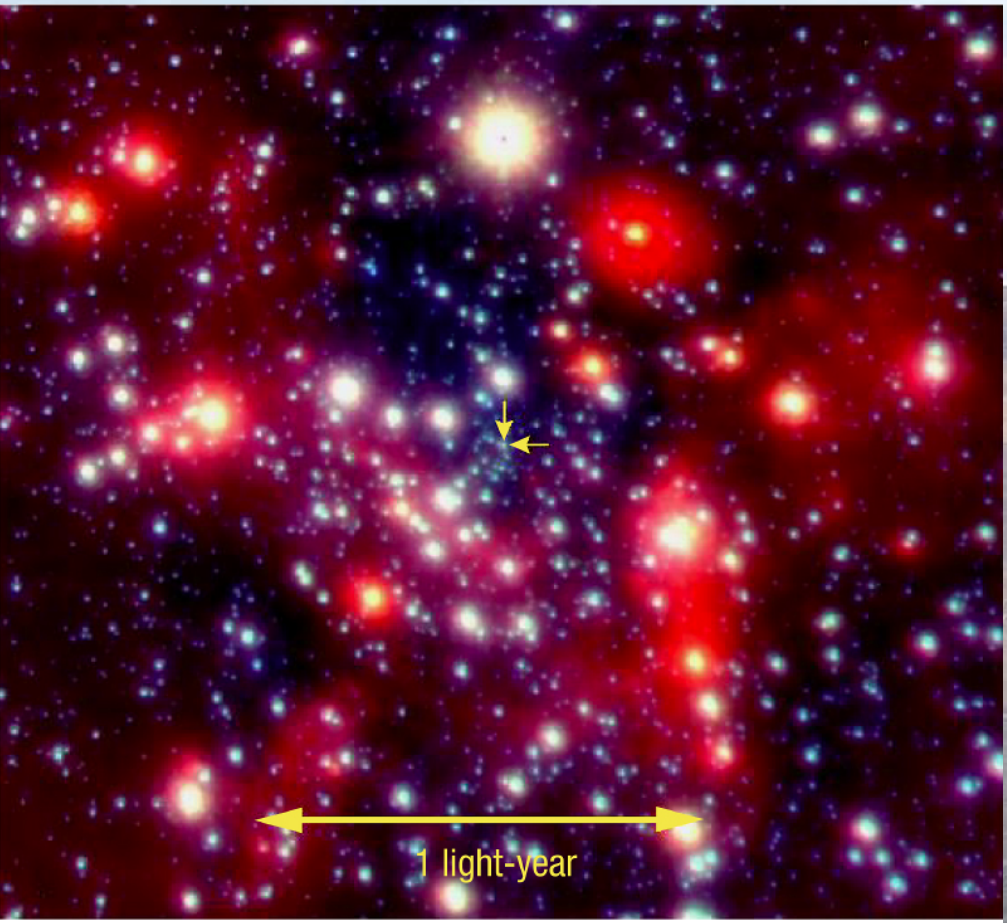
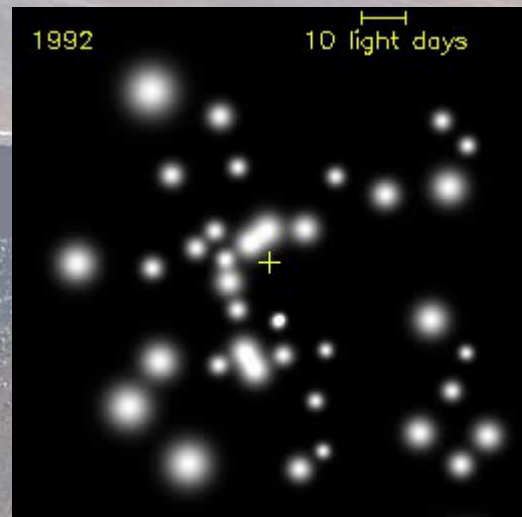
Black Hole at the Center of the Milky Way



The Centre of the Milky Way
(VLT YEPUN + NACO)

ESO PR Photo 23a/02 (9 October 2002)

- Star in orbit around Galactic Center (SgrA*)
  VLT YEPUN + NACO
  May 2002 high-res images
  Approaches to 17 light-hours
- Full orbit with 15-year period
- Central mass determined:
  2.6 ± 0.2 million solar masses
- Definitely BLACK HOLE



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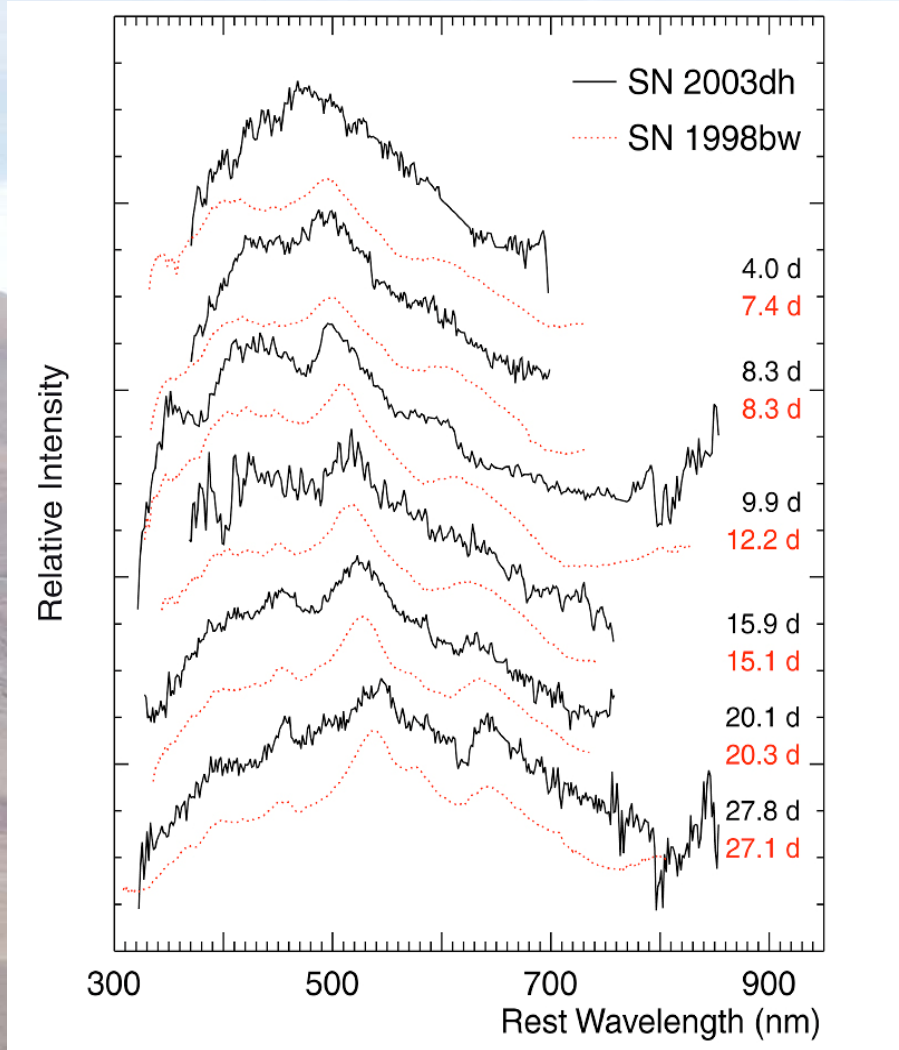
Gamma-Ray Bursts

z=0.1685



Visual Spectra of Hypernova in GRB 030329
(VLT + FORS)

ESO PR Photo 17b/03 (18 June 2003)

- Spectrum like SN 1998bw, associated with another GRB.
- Thus, long GRBs due to core collapse of massive stars.

Hjorth et al., 2003

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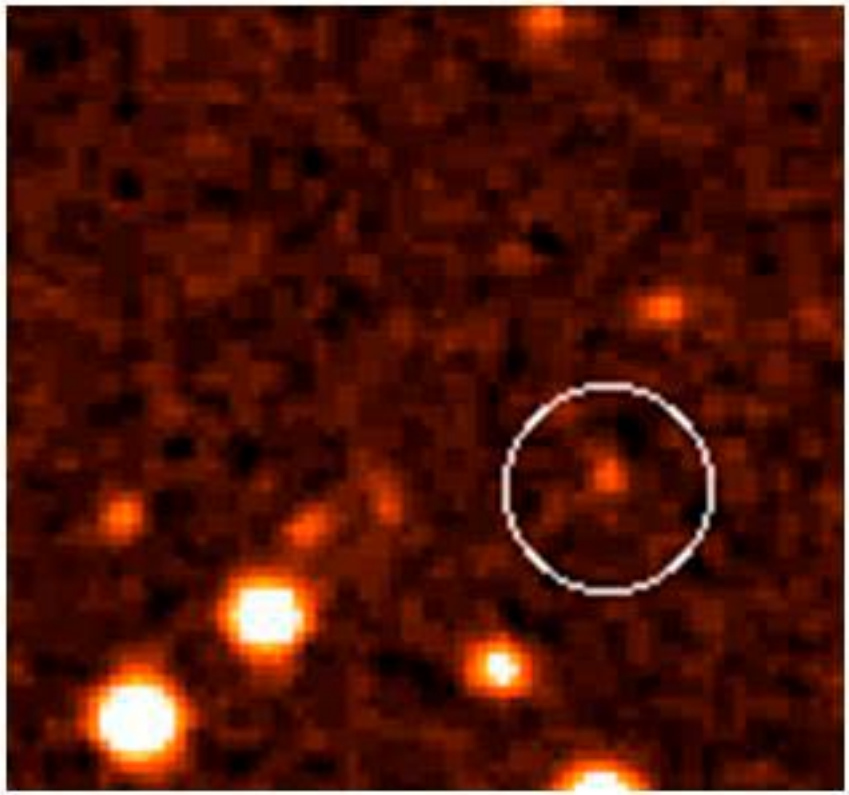
X-ray Flashes and Supernovae

- GRB 060218



DSS-2 image: Galaxy only

ISAAC/VLT image: The SN is visible

Pian et al. 2006; Mazzali et al. 2006

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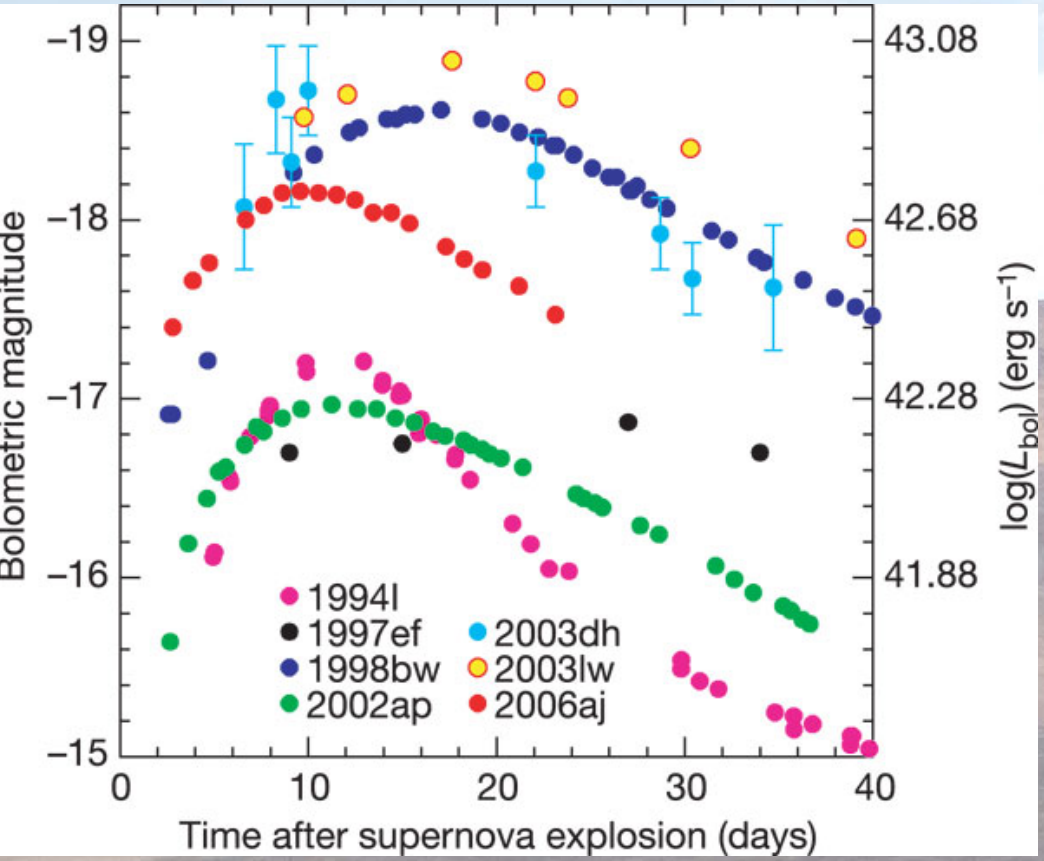
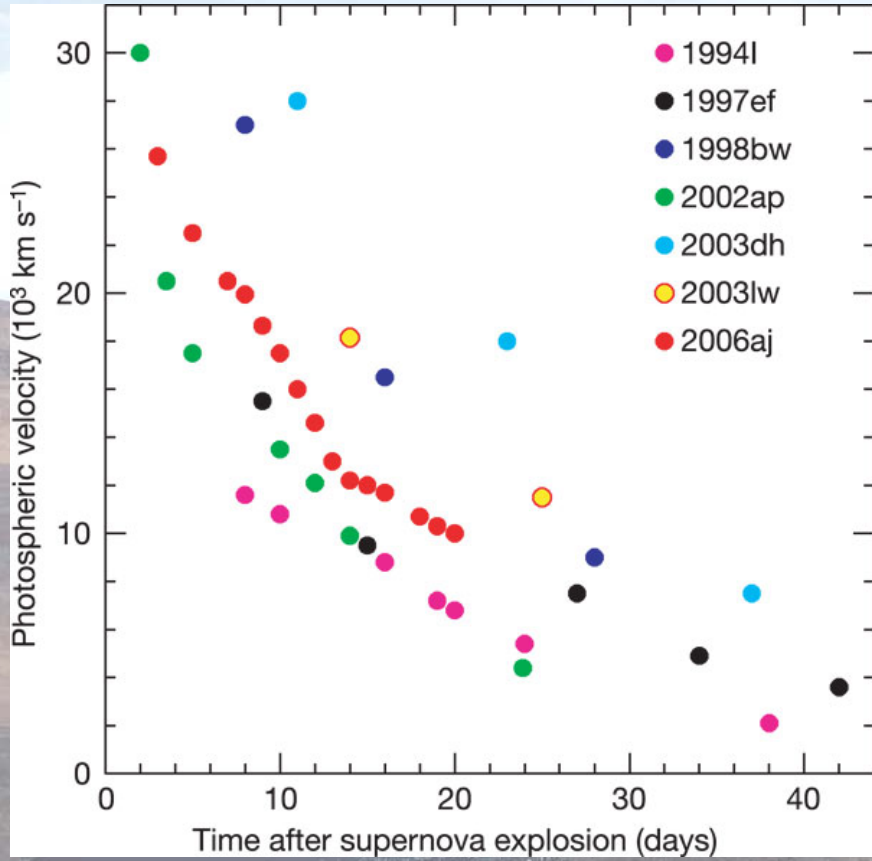
X-ray Flashes and Supernovae





Pian et al. 2006

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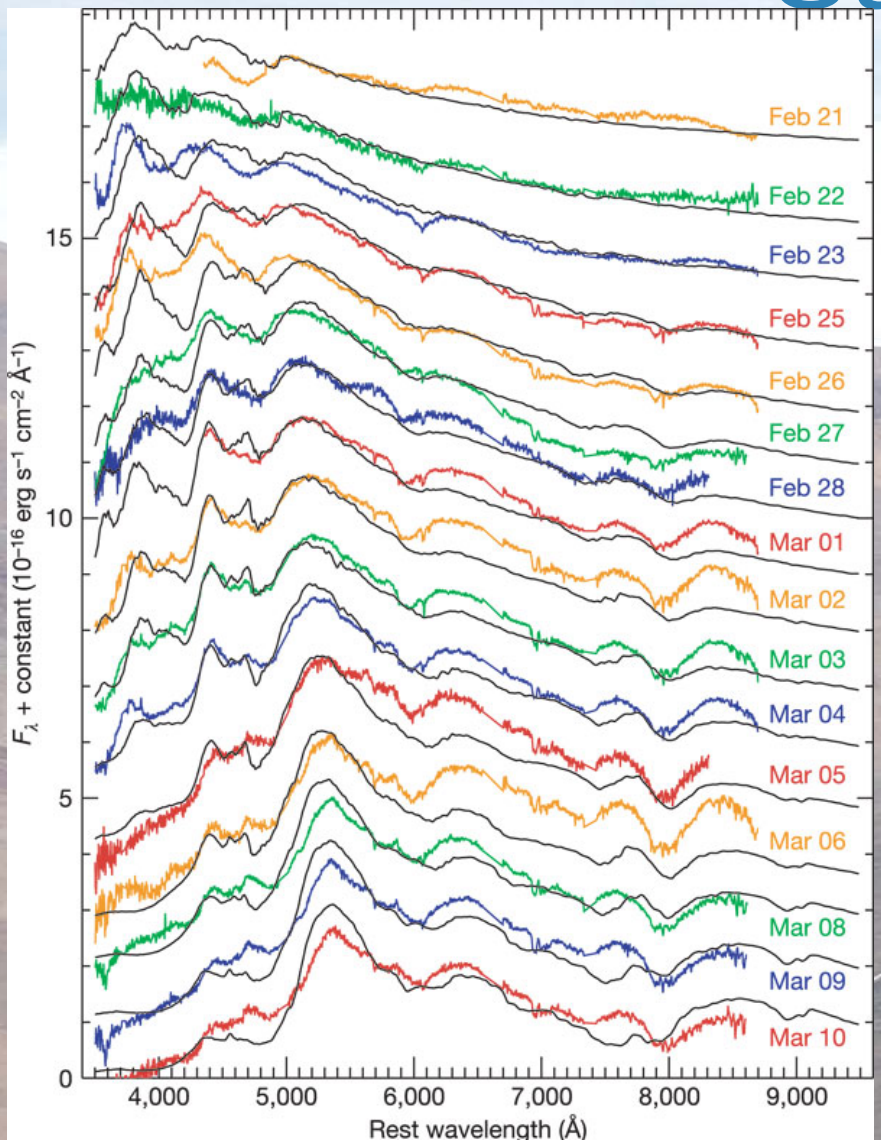
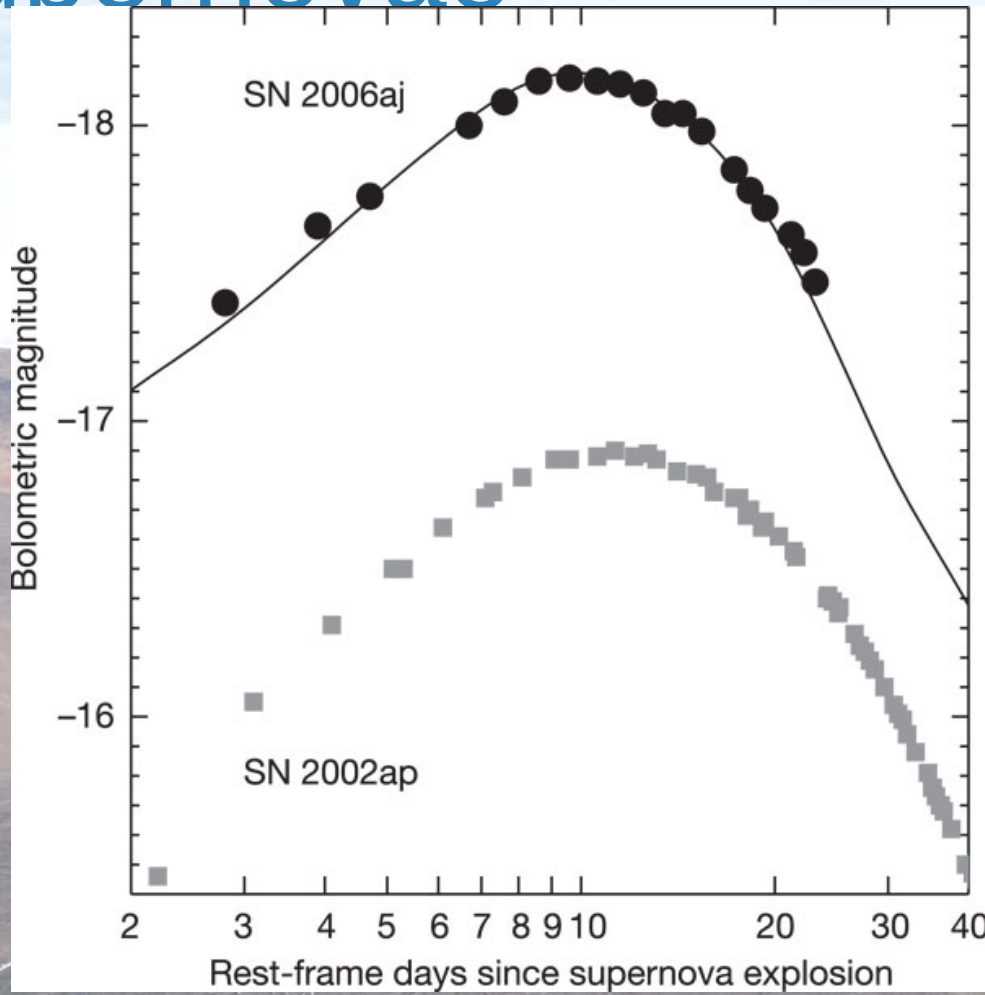
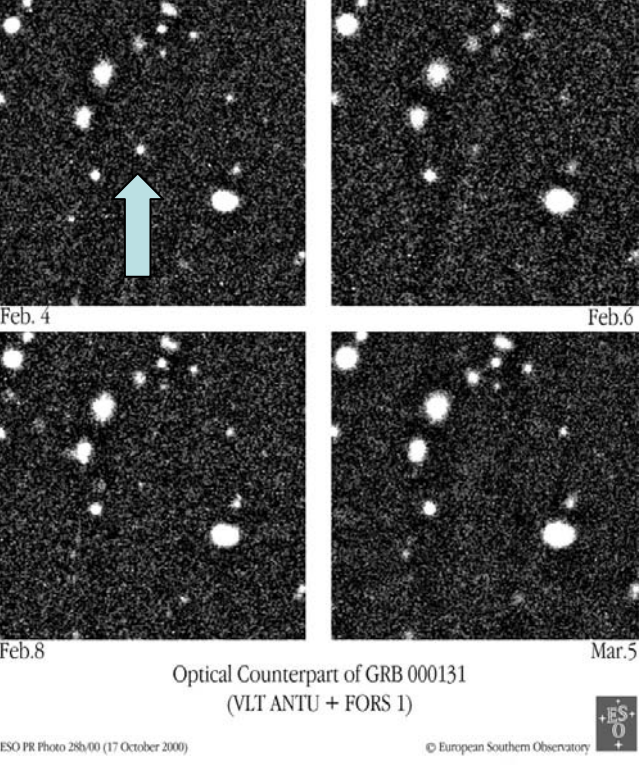
X-ray Flashes and Supernovae



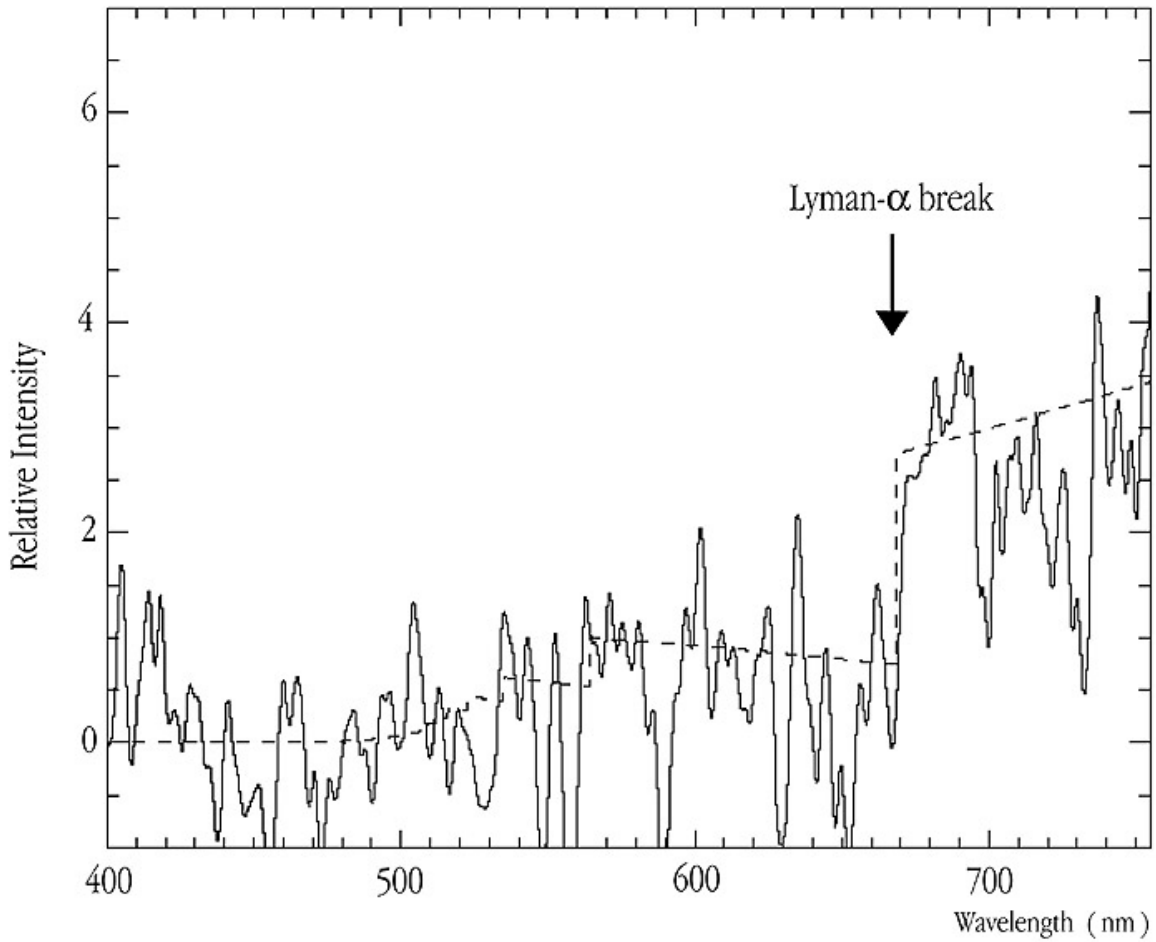


Mazzali et al. 2006



Optical Counterpart of GRB 000131
(VLT ANTU + FORS 1)

ESO PR Photo 28b/00 (17 October 2000) © European Southern Observatory



Spectrum of the Optical Counterpart of GRB 000131

ESO PR Photo 28c/00 (17 October 1999) © European Southern Observatory

Redshift z = 4.50

Most distant GRB for which the distance had been measured
(1999, VLT ANTU + FORS1)

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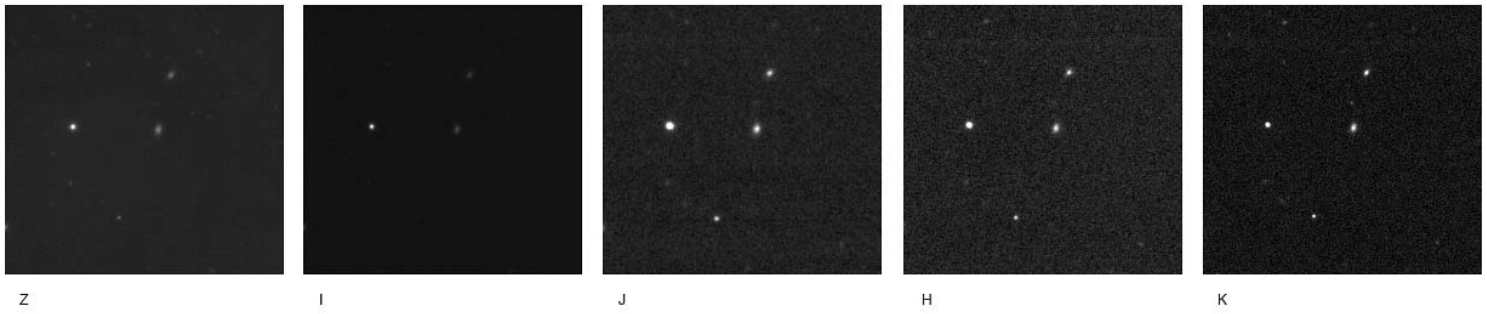
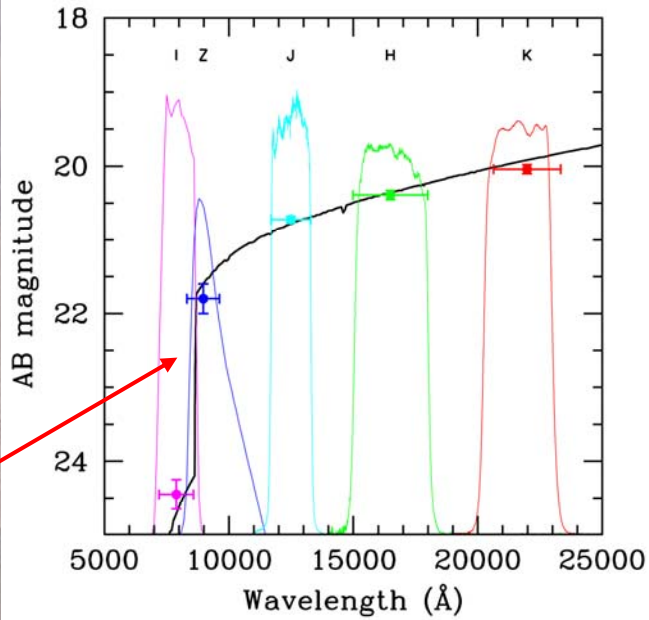
2005: even more distant GRB



Various Bands (FORS2 + ISAAC/VLT)



Spectral Energy Distribution of GRB050904

I-dropout

z=6.3

- GRB 050904
- Observations were done between 24.7 and 26 hours after the burst with ISAAC and FORS2
- Photometric redshift: 6.3 (confirmed by SUBARU)

ISAAC

Chincarini et al., 2005

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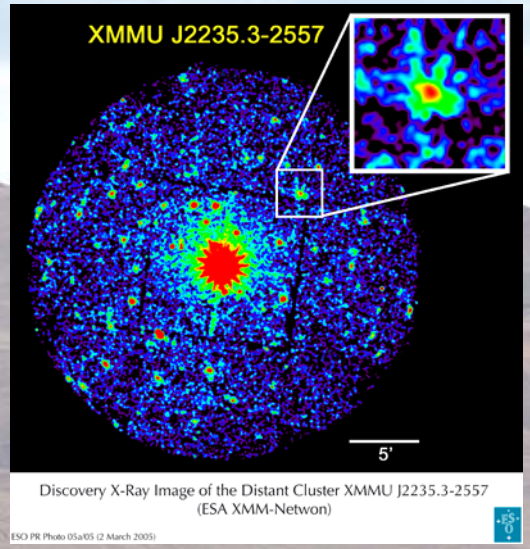
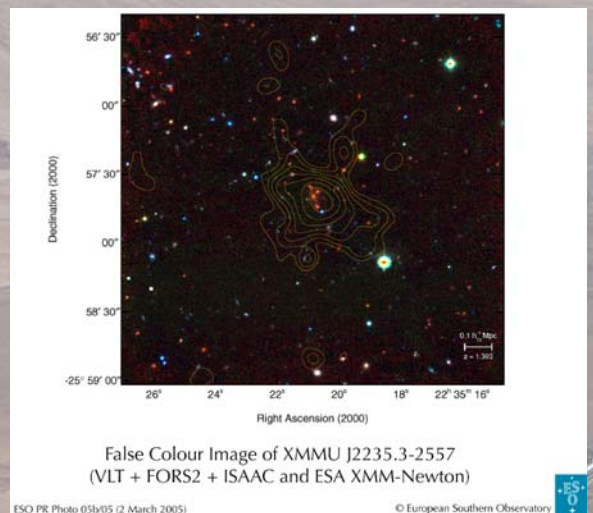
Structures in the Universe



Discovery X-Ray Image of the Distant Cluster XMMU J2235.3-2557
(ESA XMM-Netwon)

ESO PR Photo 05a/05 (2 March 2005)



False Colour Image of XMMU J2235.3-2557
(VLT + FORS2 + ISAAC and ESA XMM-Newton)

ESO PR Photo 05b/05 (2 March 2005)

Highly developed structures in the young Universe

- X-ray Cluster
- ISAAC reveals 12 galaxies
- z cluster = 1.4
- Its distance is thus 9 billion l-y
- Youngest cluster found

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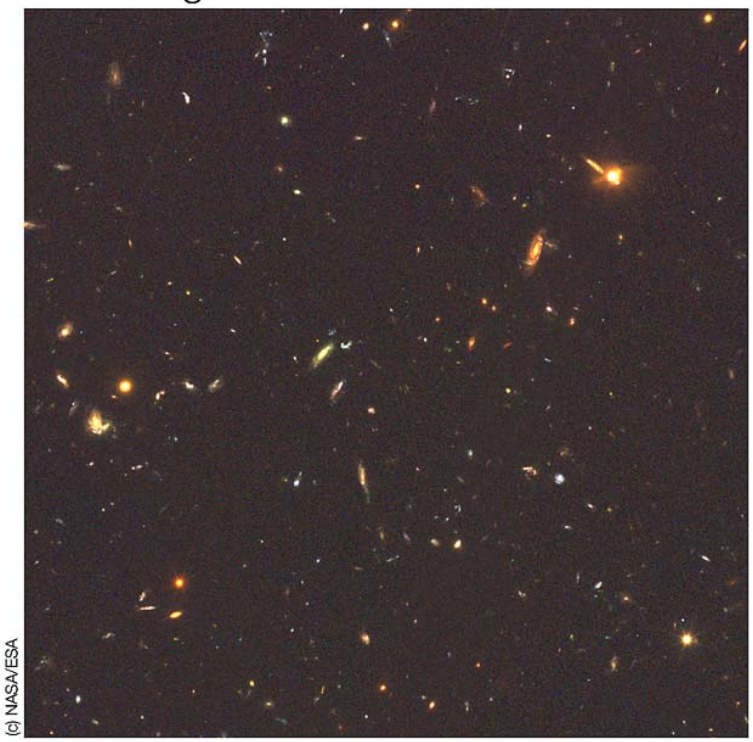
Falling onto the Dark

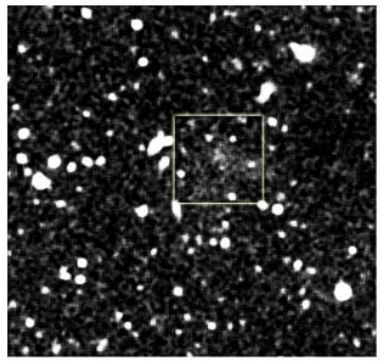
Lyman-alpha blob in the GOODS South field

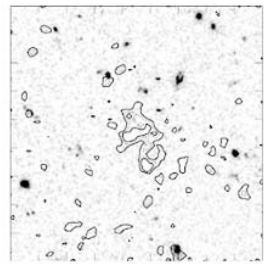
HST Image



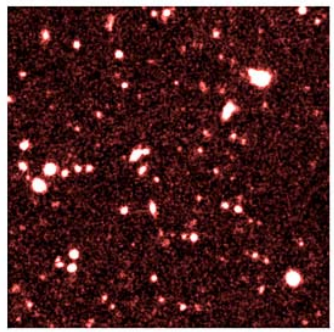
(c) NASA/ESA

Narrow-band

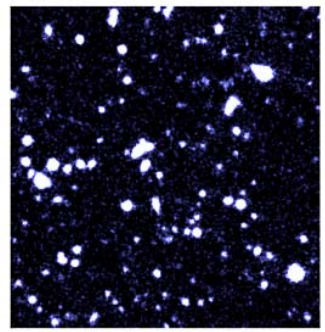




Red



Blue



WFI, FORS/VLT

Nilsson et al. 2006

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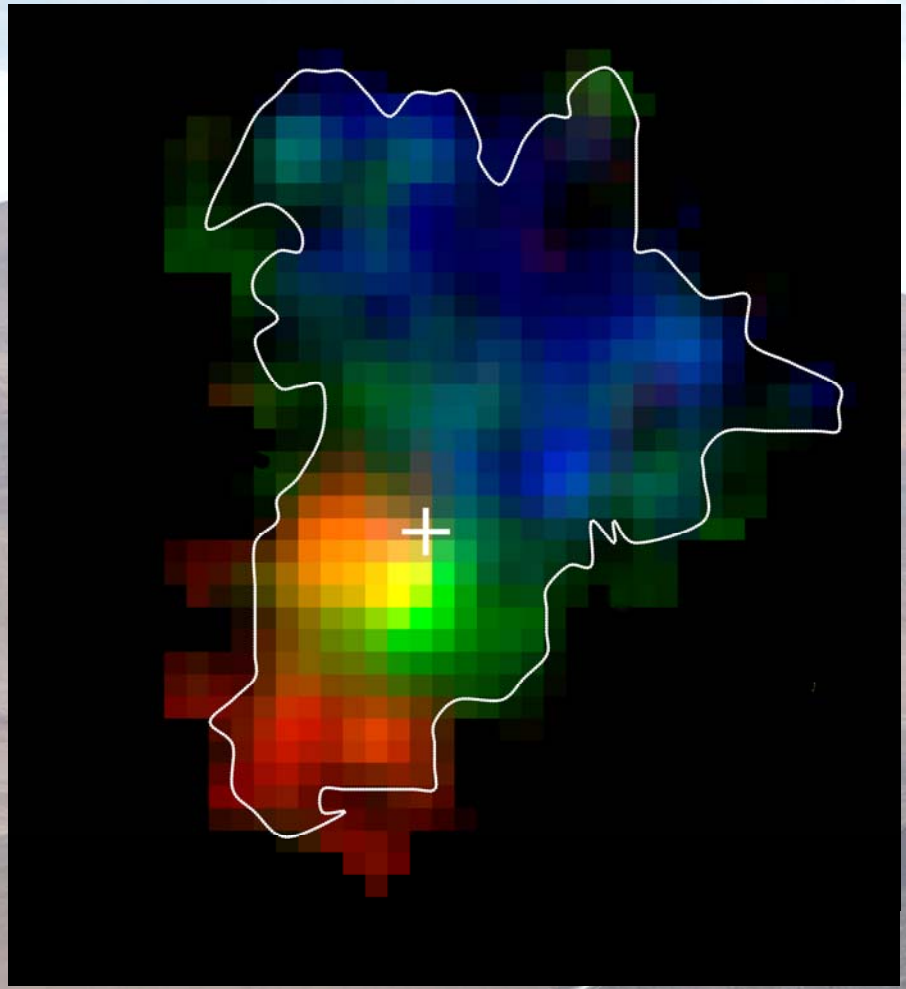
Rapid Formation of Galaxies



- Bzk -15504
- z=2.38
- AO+SINFONI: 0.15” resolution
- Galaxy as large as Milky Way already formed (stable?)
- Very intense star formation.

SINFONI/VLT

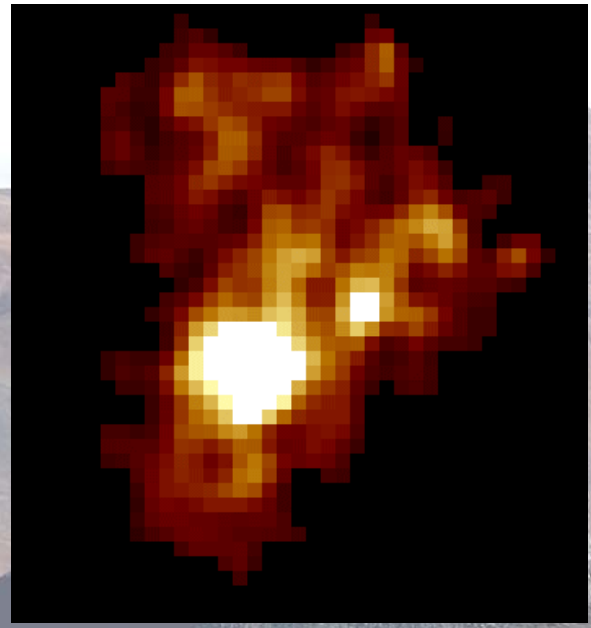
Genzel et al. 2006

SINS

European Organisation for Astronomical Research in the Southern Hemisphere

Rapid Formation of Galaxies

- SINFONI maps of H-alpha em. line separated in 65 km/s bins.
- SF occurs in luminous complexes
- Gas is funneled into nucleus



SINFONI/VLT

Genzel et al. 2006

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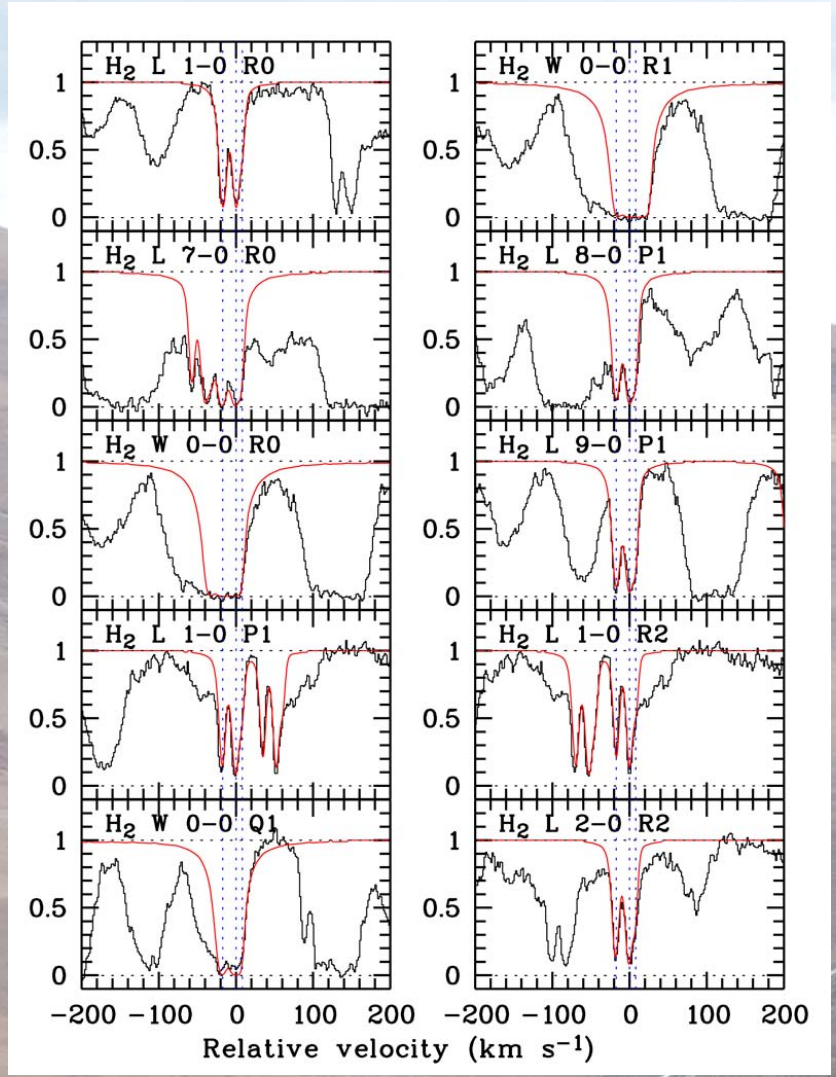
Physics in Universe's Youth



- Damped Ly-alpha system at z=4.224 towards quasar PSS J 1443+2724
- H_2 found Gas must be cold
- Metal lines seen

  SF took place when Universe was ~1 billion years old
- m_e/m_p in past: evolved?

UVES/VLT

Ledoux et al. 2006

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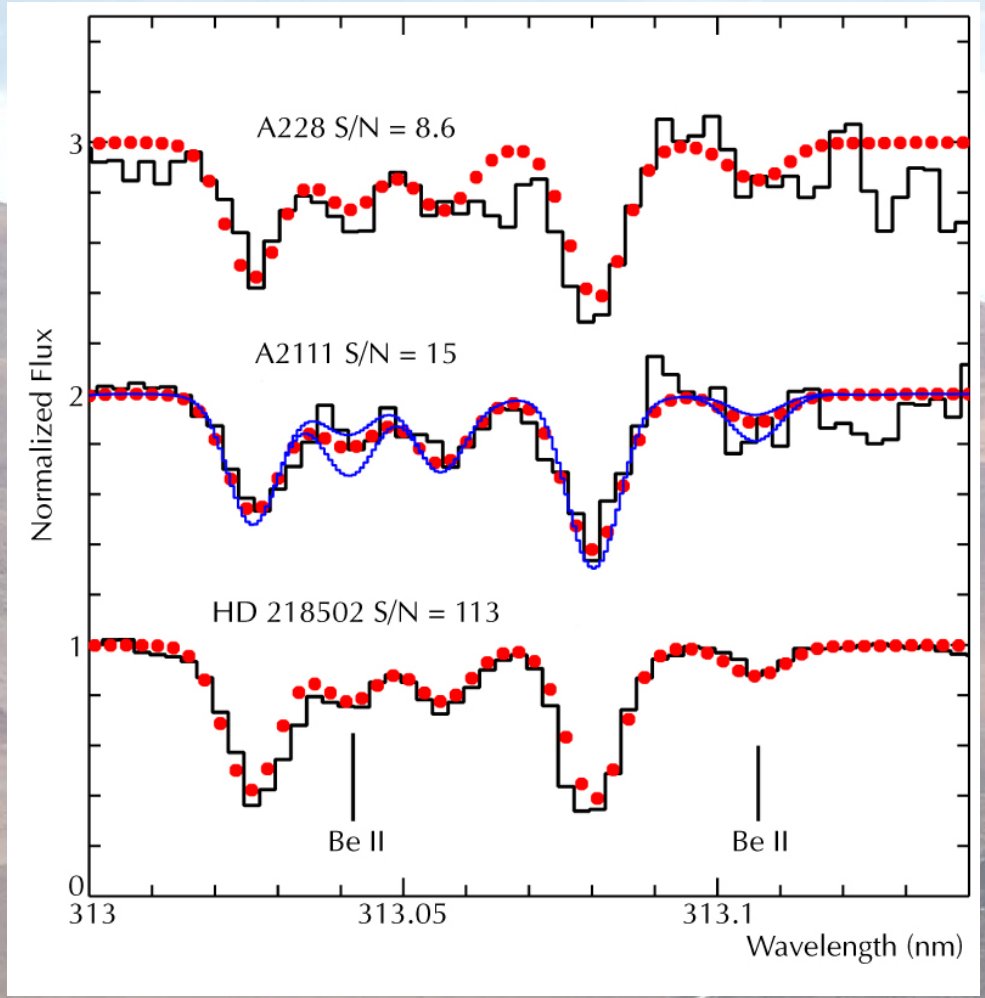
Age of Milky Way



Beryllium measurements in Globular Cluster NGC 6397

13.6 ± 0.8 Gyr

UVES

Pasquini et al. 2004

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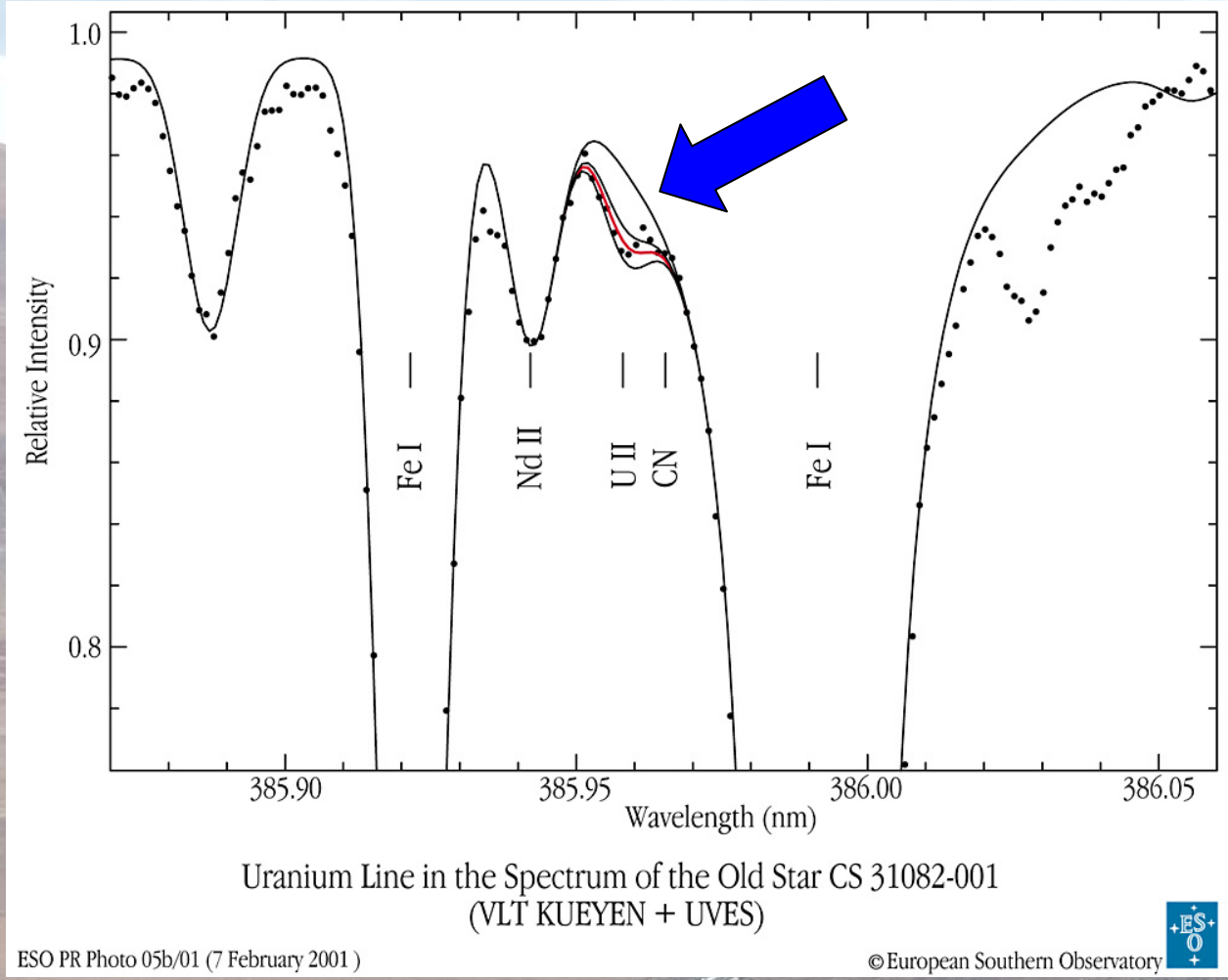
Age of Universe



14.2 ± 2.5 Gyr

UVES

Cayrel et al. 2001

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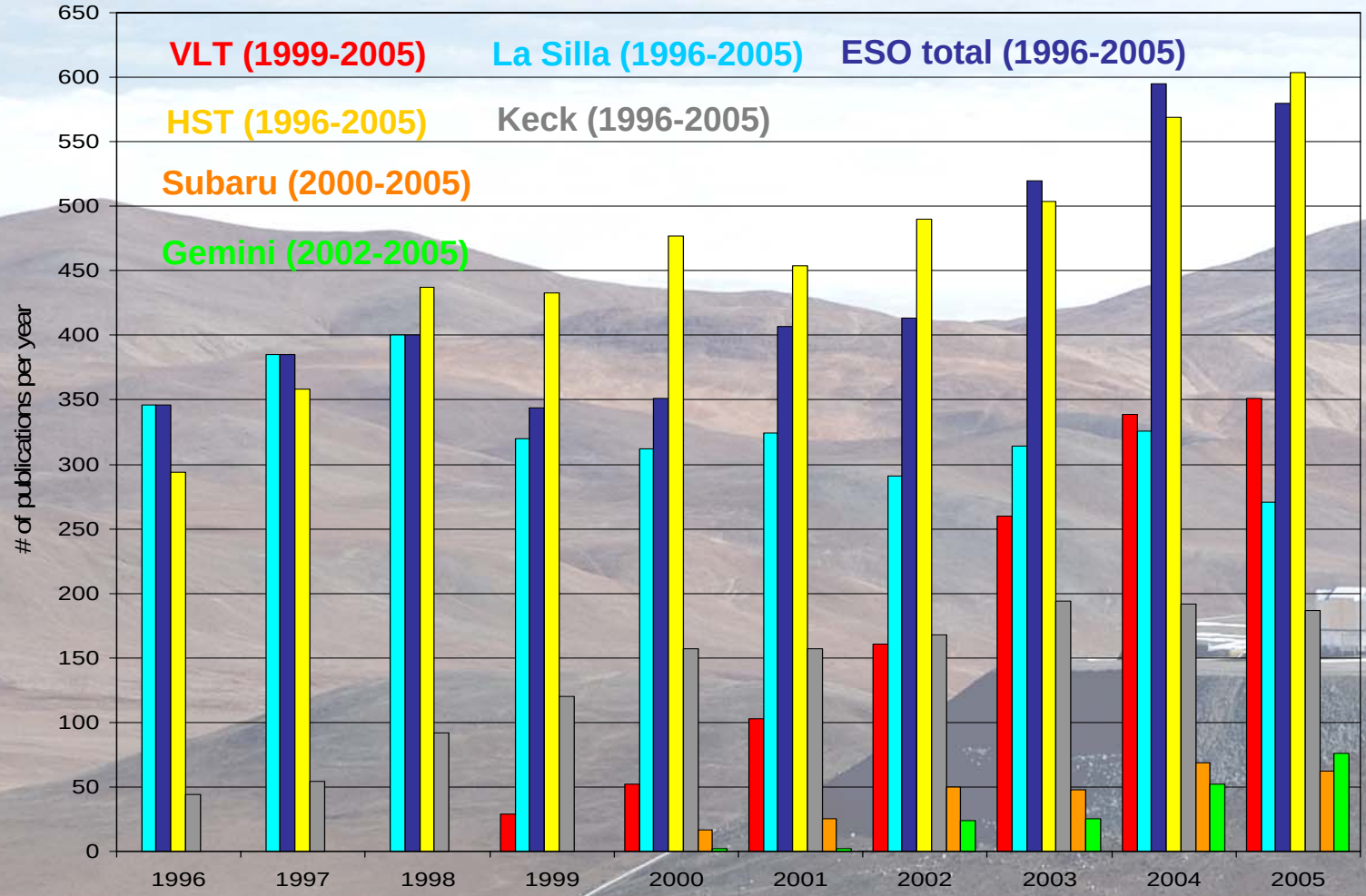
Publications per Year

VLT, La Silla, ESO total
HST, Keck, Subaru, and Gemini



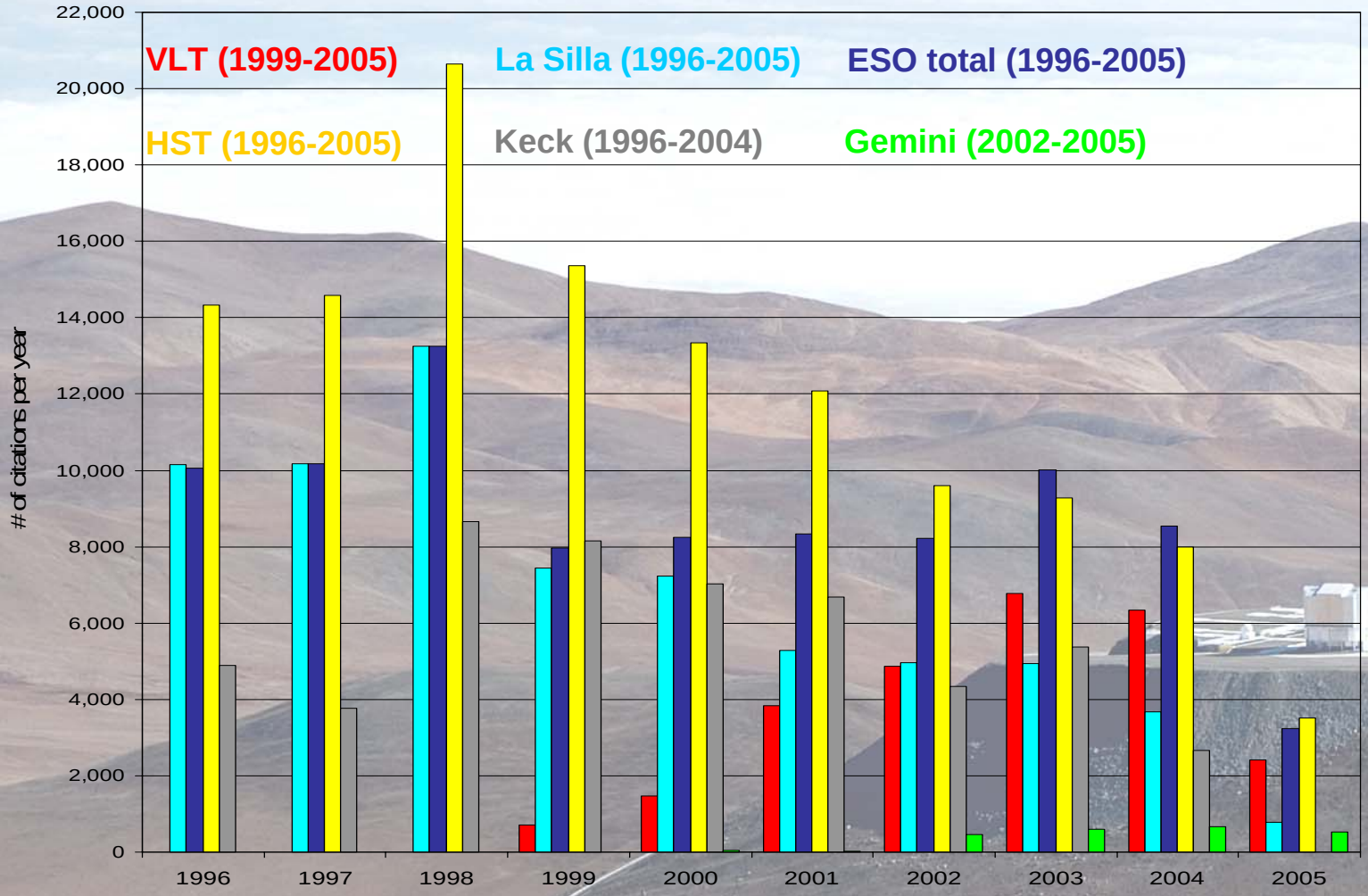
Compiled by: ESO Library

VLT: ~ 8 yrs of operation; ~1500 refereed papers

European Organisation for Astronomical Research in the Southern Hemisphere

Citations per Year

VLT, La Silla, ESO total, HST, Gemini (as of 05/06), Keck (as of 12/05)



Compiled by: ESO Library

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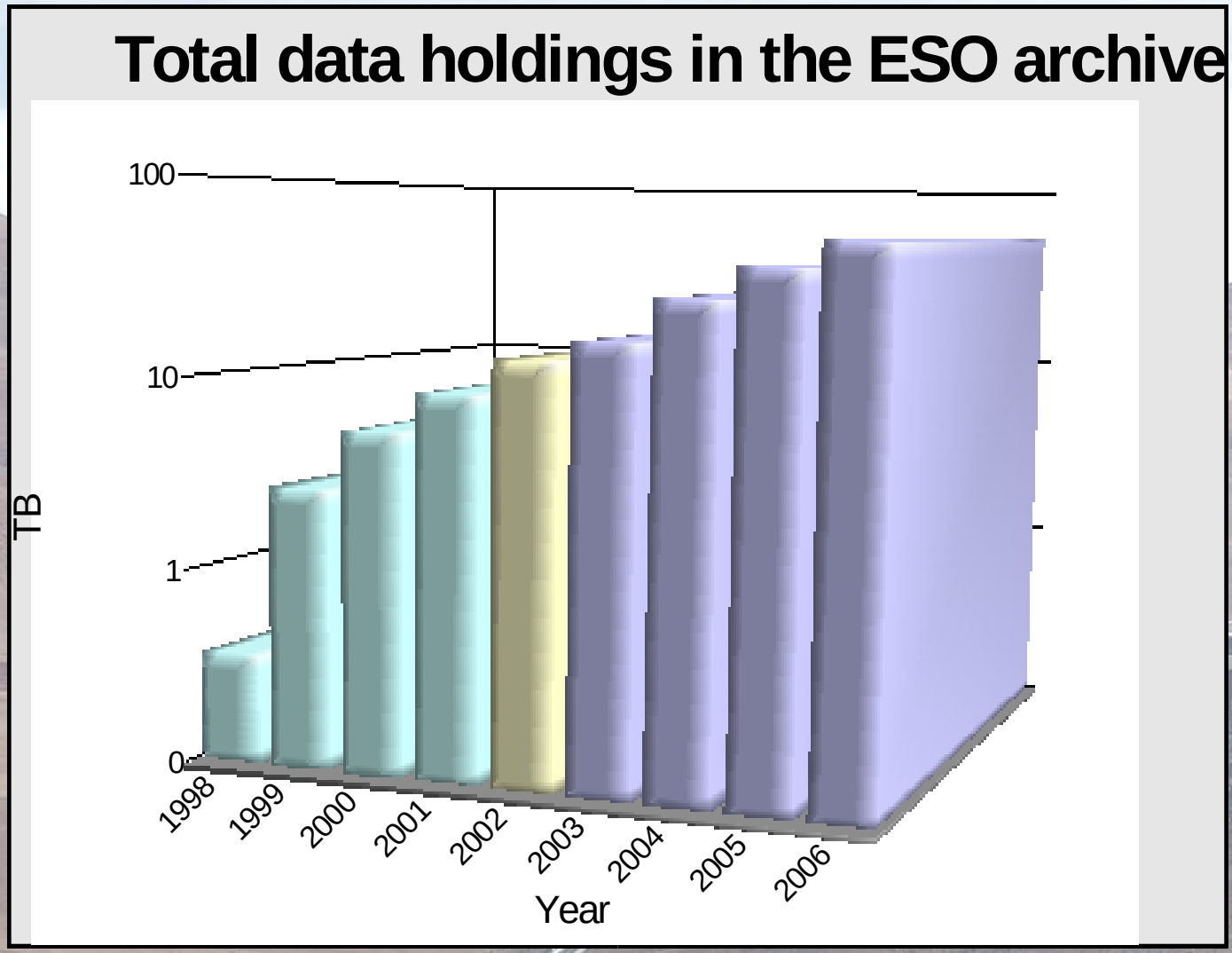
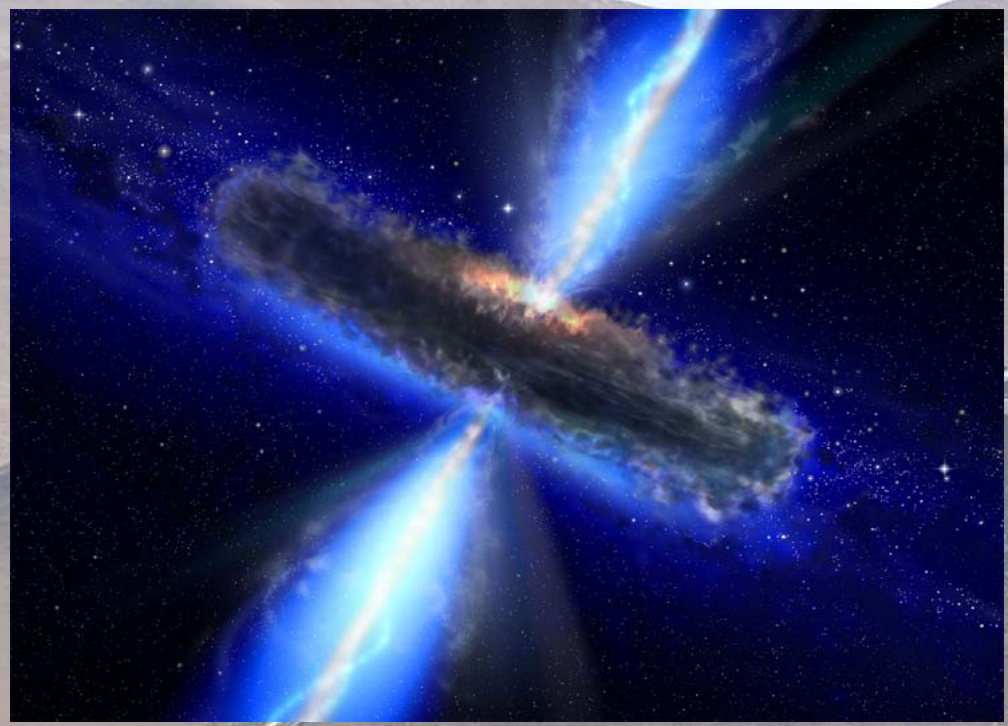
Science Data Archive Input

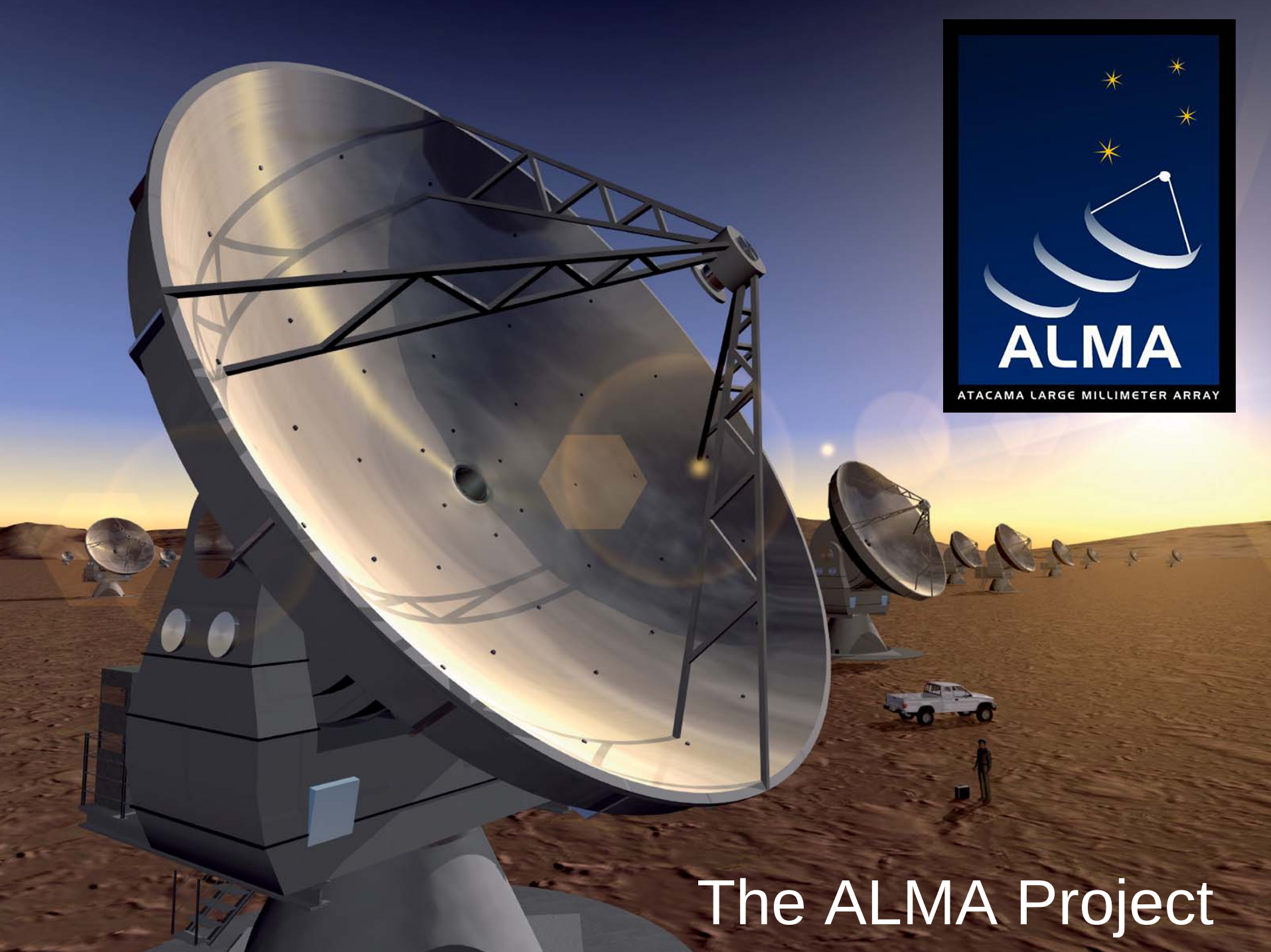


European Organisation for Astronomical Research in the Southern Hemisphere

Astrophysical Virtual Observatory

- Multi-wavelength, heterogeneous, and complex data: VLA, CGPS, ISO, 2MASS, USNO, 2.2m/WFI, VLT/FORS, HST/ACS, XMM, and Chandra (images, spectra, and catalogues); GOODs survey
- AVO **First Science**
- **41 new obscured QSOs**





The ALMA Project

European Organisation for Astronomical Research in the Southern Hemisphere

Scope

- Construct and operate a large array of radio telescopes:
  - 54 antennas of 12 m diameter (initial configuration)
  - 12 antennas of 7 m diameter.
- Measure millimeter / submillimeter wavelength spectra:
  - 0.85 mm < λ < 3mm.
- Array in 5000m altitude in the Atacama desert (near St. Pedro de Atacama, Northern Chile) with
  - compact (150 m) and extended (15 km) configurations.

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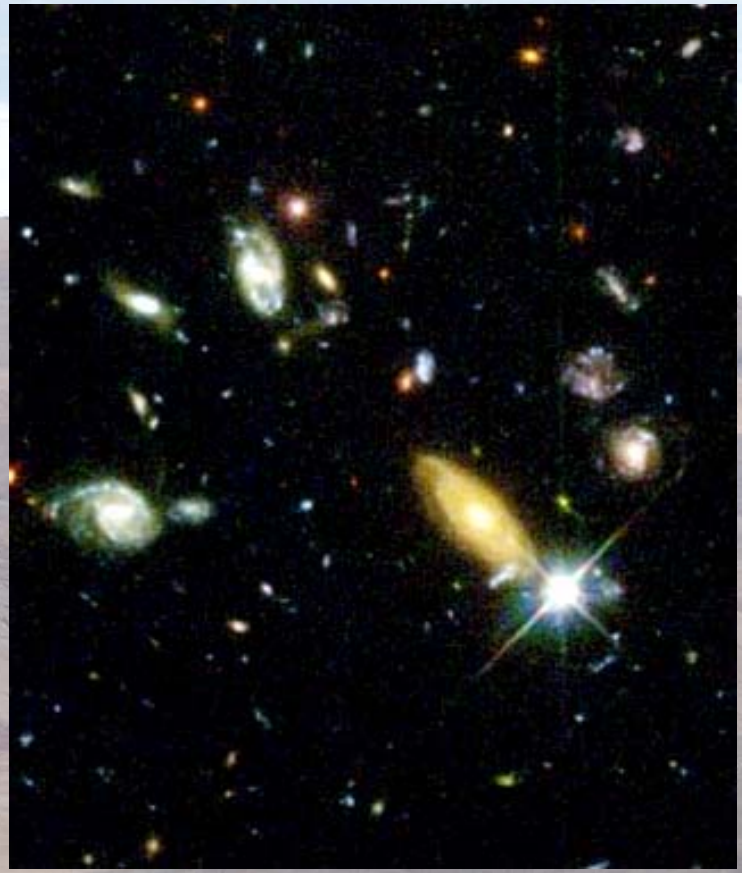
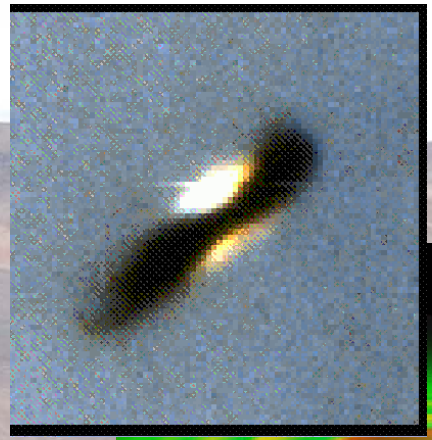
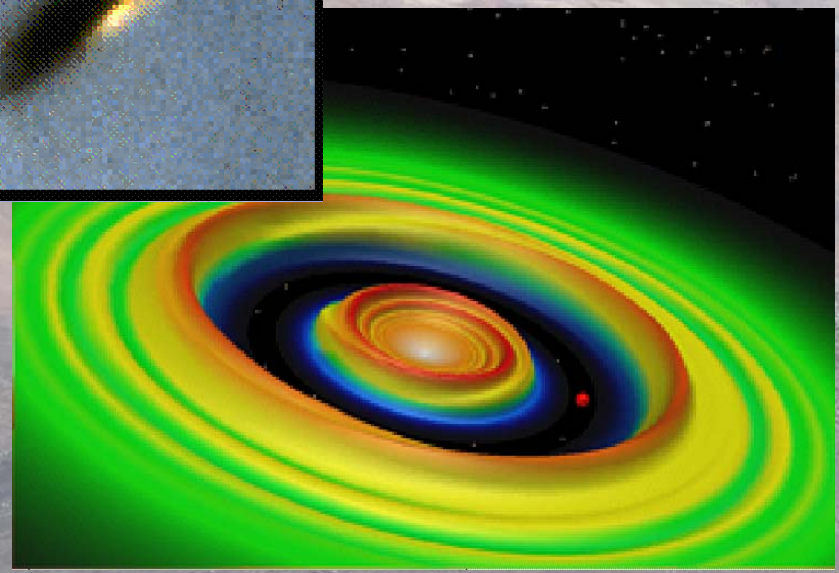
The Main Science Drivers for ALMA



Galaxy Formation in the Early Universe





Star & Planet Formation

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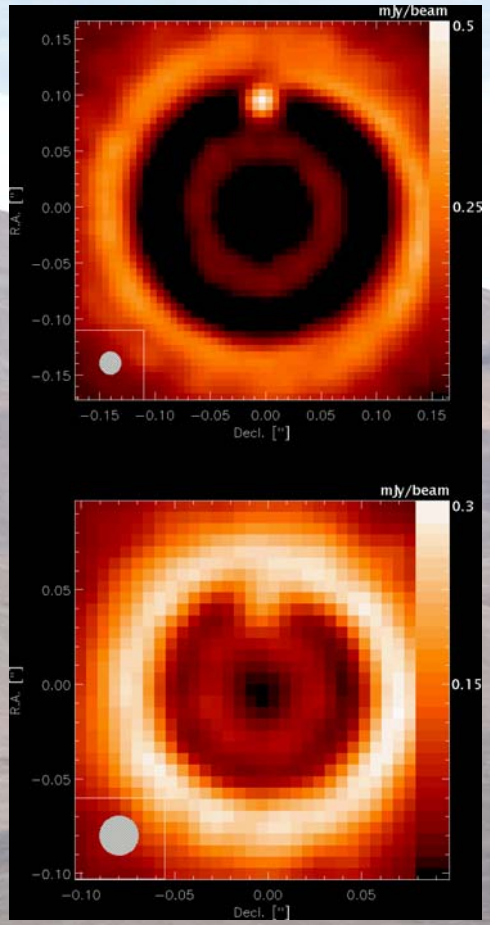
Simulation of a protostellar disc

150 light years



300 light years

Jupiter-mass protoplanet around 0.5 solar mass star

Orbital radius: 5 AU

Maximum baseline: 10 km
f = 850 GHz
8 hour integration

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History

- 2002 Project started
  - Bilateral agreement between North America (NSF) and Europe (ESO).
- 2004 Japan joined
- 2005 Project redefined / rebaselined

ALMA Ground Breaking 2003

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OSF - Contractors Camp

At present for 150 persons – at peak construction for 500 persons

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ALMA Camp and Lascar Vulcano

Lascar Eruption – April 2006

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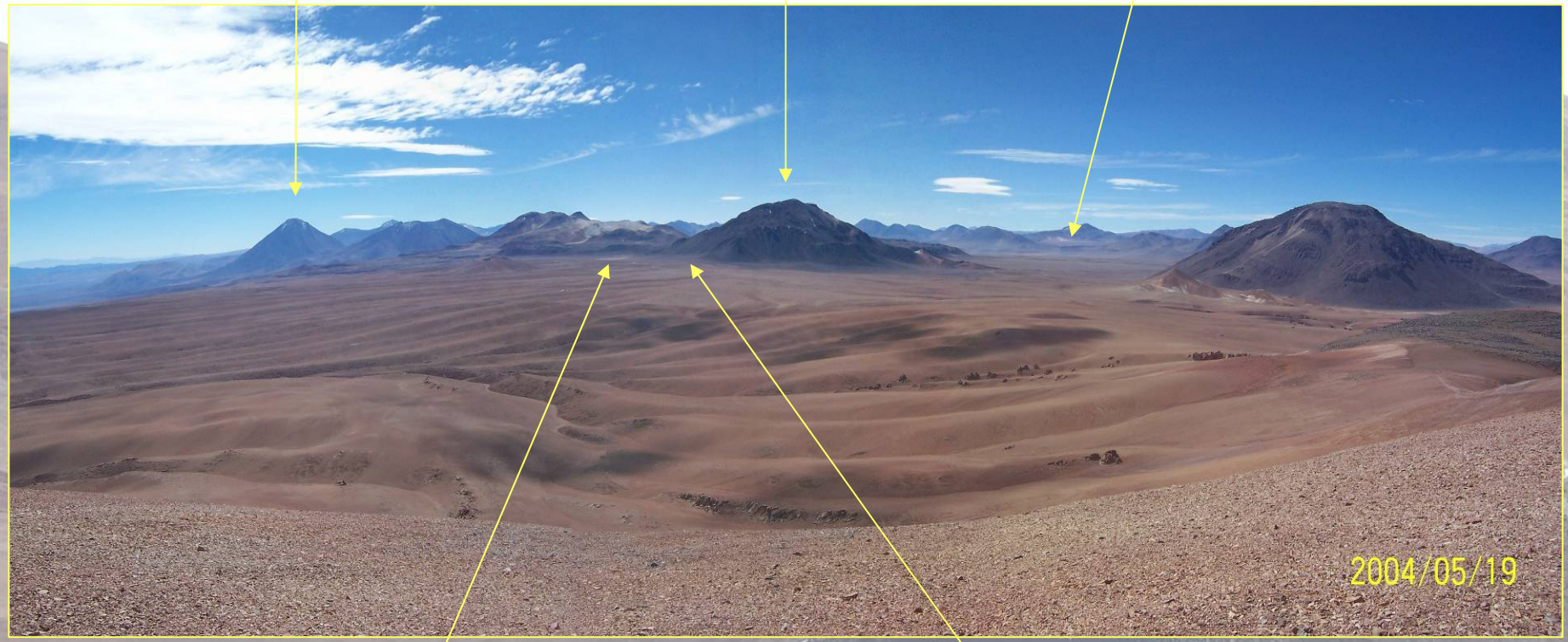
The Chajnantor / ALMA Plateau



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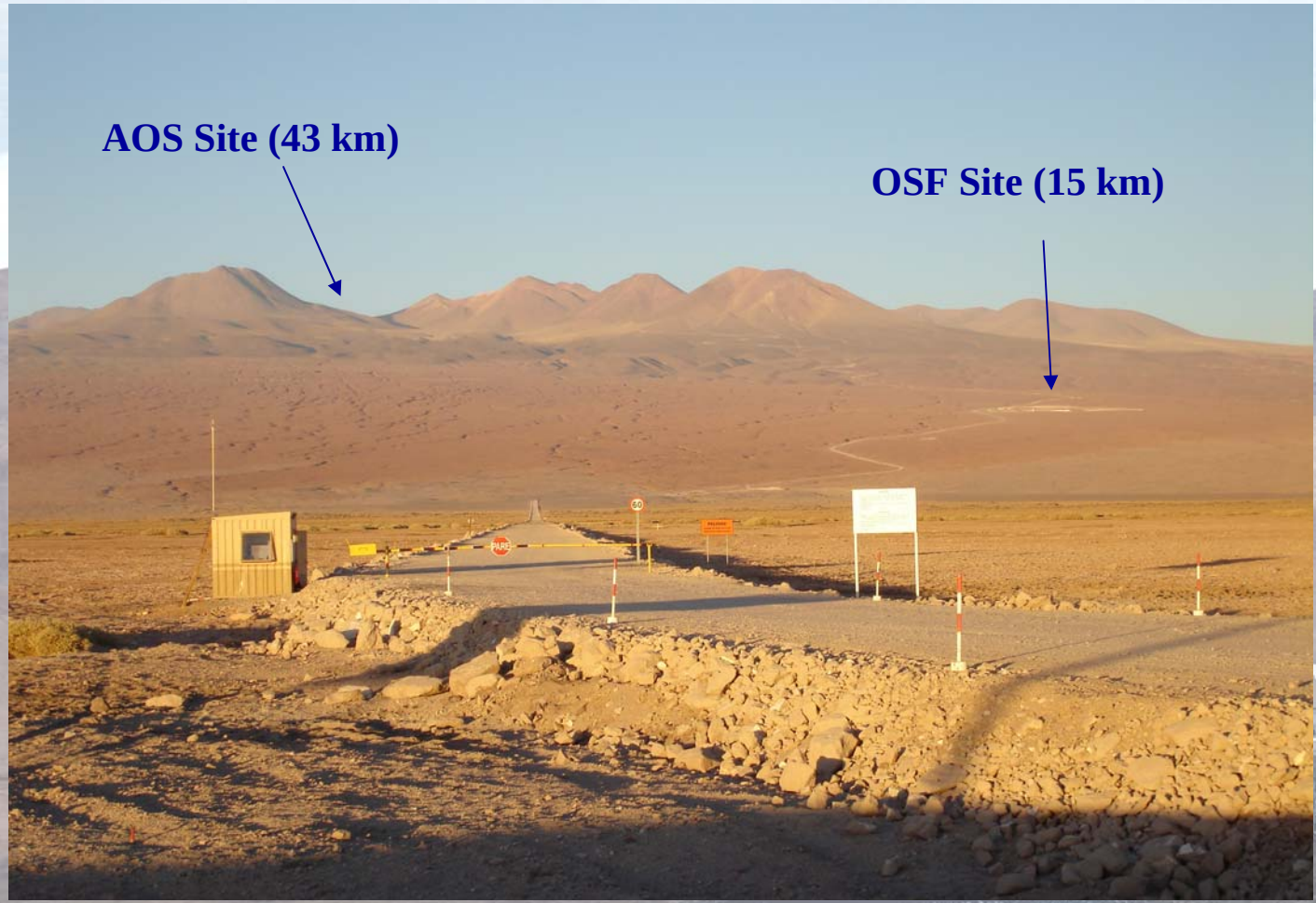
Road to AOS



Completed up to AOS – 43 km

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Array Operations Site Layout

The AOS Technical Building– July 2006

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The Three ALMA Prototype Antennas at the ATF

12 Meter Diameter, Carbon Fiber Support Structures

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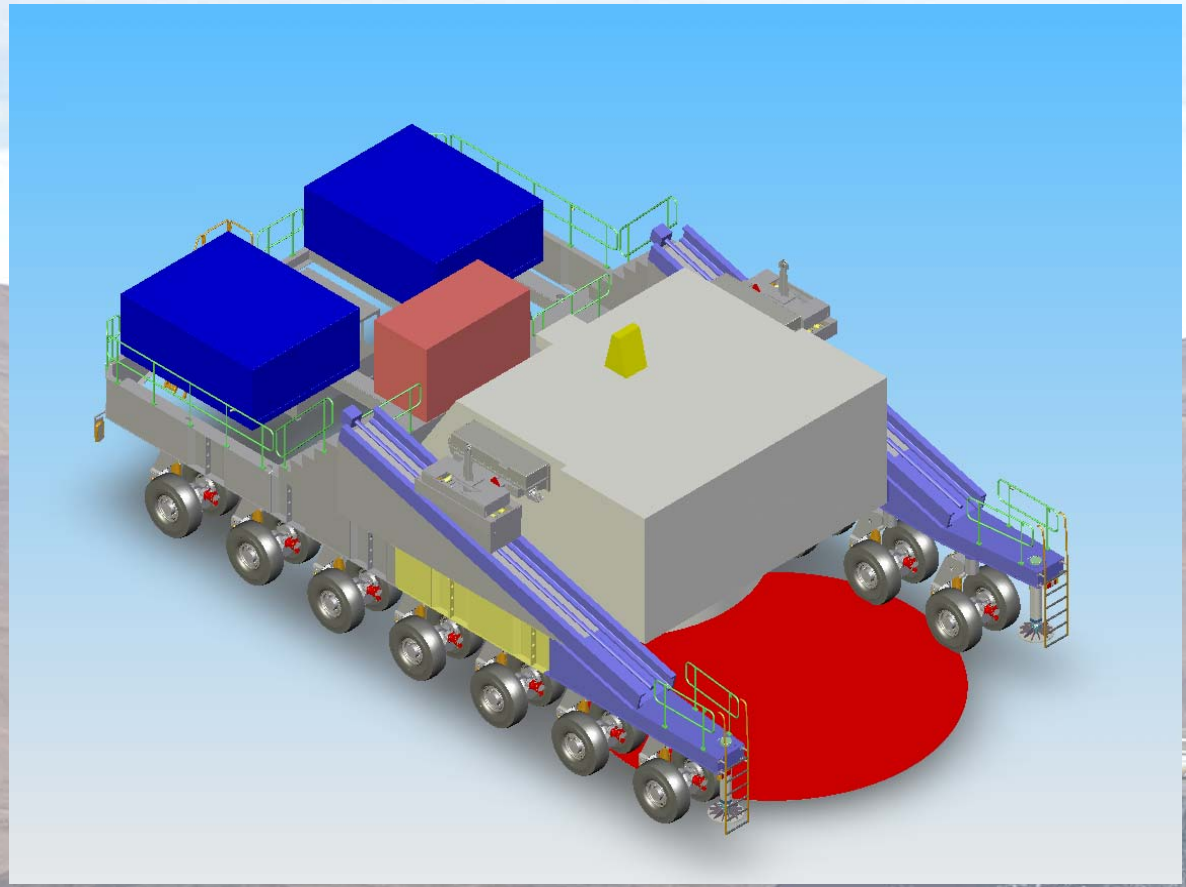
Antenna Transporters



Two transporters:
PDR held in July 2006, delivery Q3/2007 and Q1/2008

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Front End Cryostats

All cryostats will be assembled at RAL and shipped to the three Front End Integration Centres. First four cryostats accepted.

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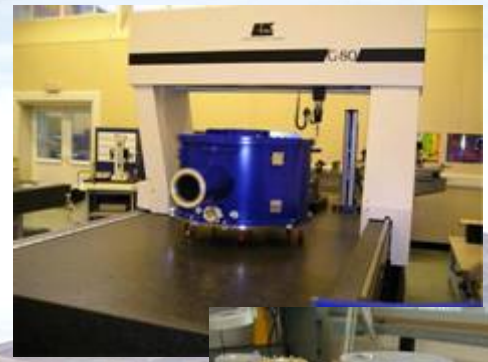
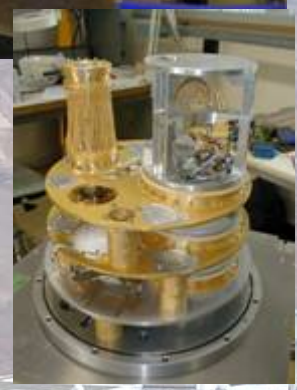
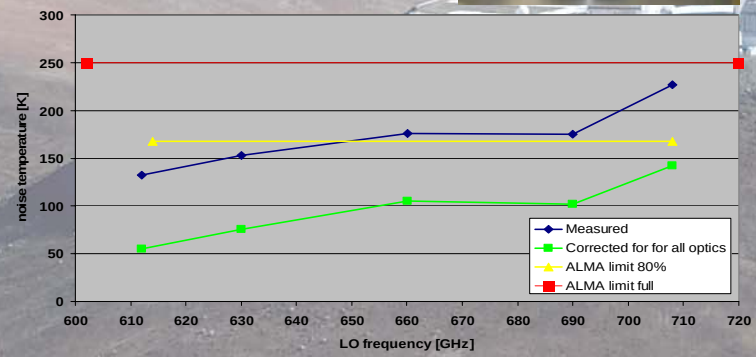
ALMA Development
Front Ends

Prototypes, fulfilling specifications, are available for all 4 ALMA frequencies (0.6, 0.9, 1.3 and 3 mm), and for the cryostat. A first series of 8 is being manufactured.

The first receivers for 2 frequency bands have been delivered







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Schedule Overview

- **First Fringes:** ATF September / October 2006
- **AOS, OSF:** construction… complete Q1/2008
- **Antennas:** #1 2007, #2 2007… #50 2011
- **Front Ends:** #1 2007, production
- **DTS:** production
- **Correlator:** Quadr. 1 complete, ... Quadr. 4 2008

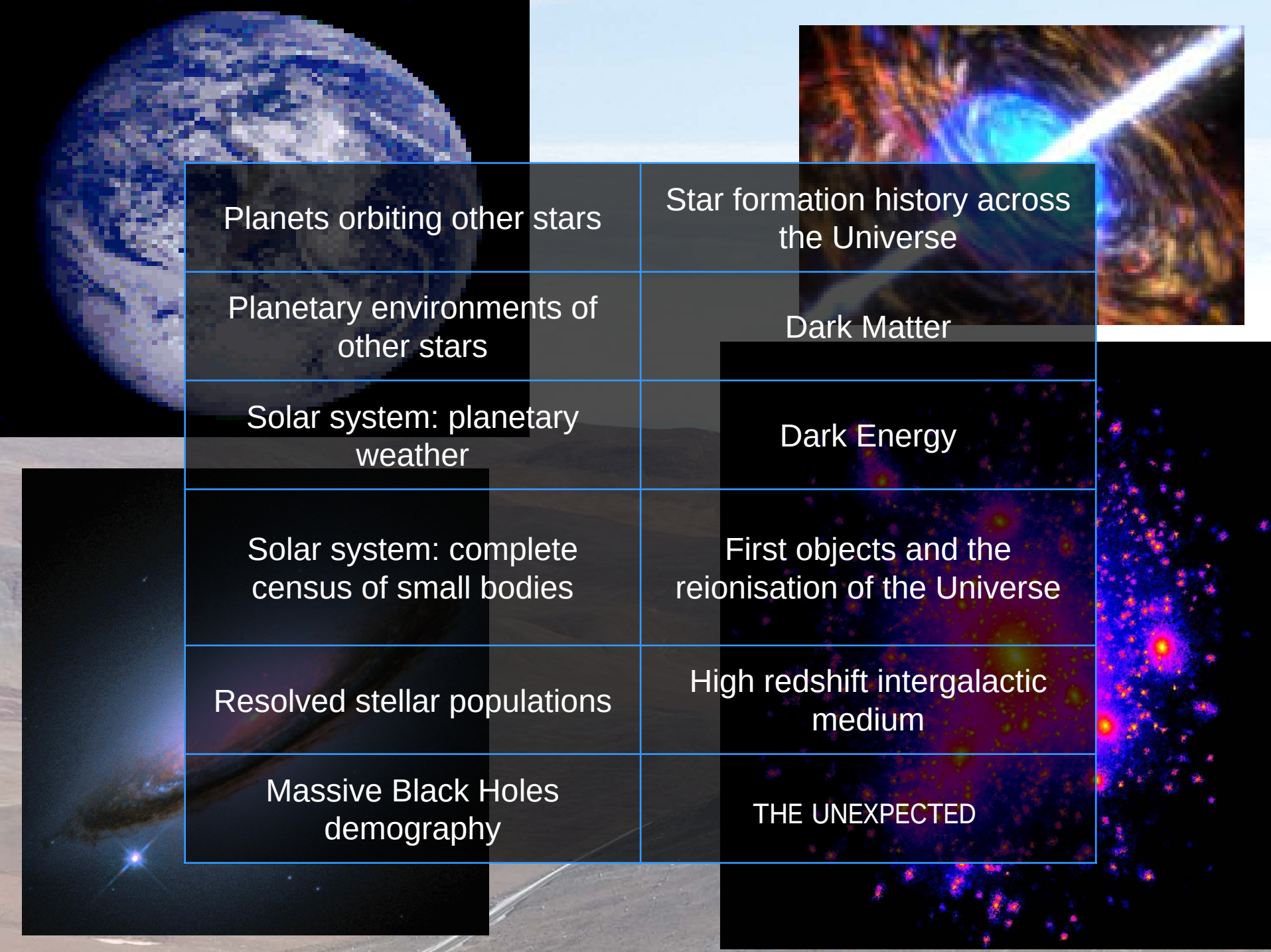
- **First Interferometry at AOS:** 2009
- **Call for Proposals and Early Science:** 2010
- **Full Operations:** 2012

European Organisation for Astronomical Research in the Southern Hemisphere

Why an ELT ?

- Increased collecting area
  - Fainter sources : brings new populations within reach
- Increased diameter
  - Increased spatial resolution : provides images with spectacular detail

- Astronomy remains a technology driven science. We are still opening parameter space.



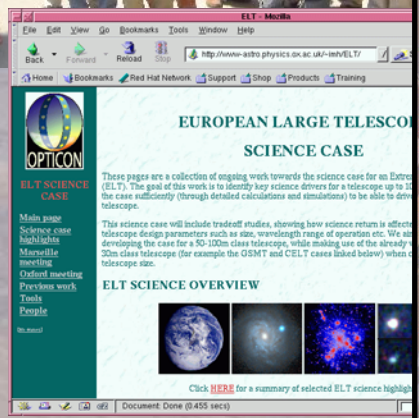
Planets orbiting other stars	Star formation history across the Universe
Planetary environments of other stars	Dark Matter
Solar system: planetary weather	Dark Energy
Solar system: complete census of small bodies	First objects and the reionisation of the Universe
Resolved stellar populations	High redshift intergalactic medium
Massive Black Holes demography	THE UNEXPECTED

European Organisation for Astronomical Research in the Southern Hemisphere

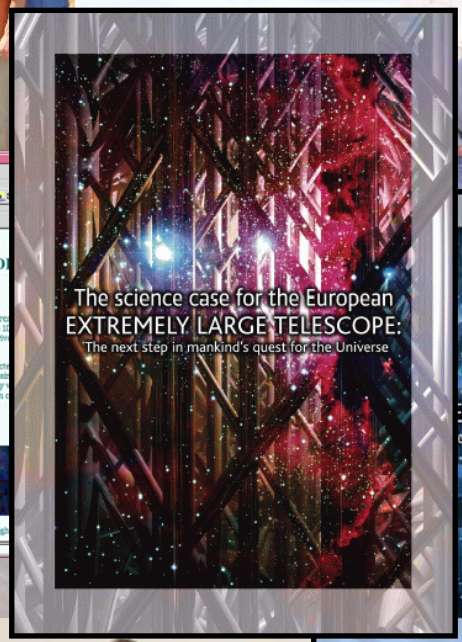
ELT science case development: a community activity

Florence 2005

Marseilles 2003



Web site



Science case documents

Florence 2004

European Organisation for Astronomical Research in the Southern Hemisphere

Science Case	λ range (microns)	Spatial Resolution	Spectral Resolution (R=λ/Δλ)	Field of View	Comments
Exo planets:					
(i) Direct detection	0.8-2.0	Diff. limited with very high Strehl	~100	10-20”	Imaging & low-resolution spectroscopy. Multiple observations needed for confirmation.
(ii) Indirect detection	visible	Seeing-limited	100 000	Small	Single sources, radial velocity measurements
Formation of planets (disks)	2 – 20	Diff. limited	10, 300, 3000, 50000	5-10”	Near and Mid-IR IFU imaging/spectroscopy. Polarimetry desirable. Strong complementarity with ALMA.
Resolved Stellar Pops					
(i) photometry	0.8 – 3 (goal 0.6)	Diff. limited	10	1-10”	High resolution imaging.
(ii) Abundances	0.8-0.9	Diff. limited	5 000 – 8 000	10” - 3’	Multi-object spectroscopy with mutiplex of 10-50
(iii) Detailed abundances & kinematics	0.45-0.75	Diff limited	> 25 000 (goal 40 000)	1- 5”	Single sources
Black Holes	~ 1.0	Diff. limited	5 000 – 50 000	5”	IFU desirable
First galaxies	0.9-2	200mas	> 3 000	> 10x10’	Rare sources: requires large FOV/high multiplex
Reionisation	1.0-2.2	See comments	1000-5000	Small	Single point sources – would benefit from AO for improved contrast
Expansion history and fundamental parameters	0.4 – 0.68	80% enclosed energy in 0.6”	50 000 - 150 000	Few arcsec	High stability spectroscopy

Science cases provide quantitative requirements on ELT performance

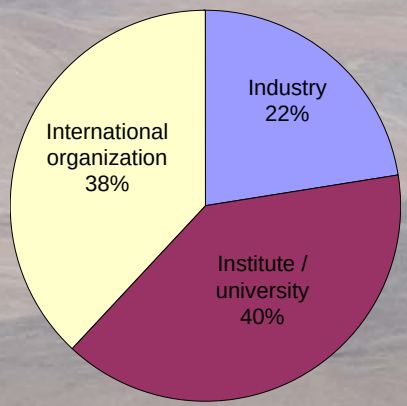
(work in progress!)

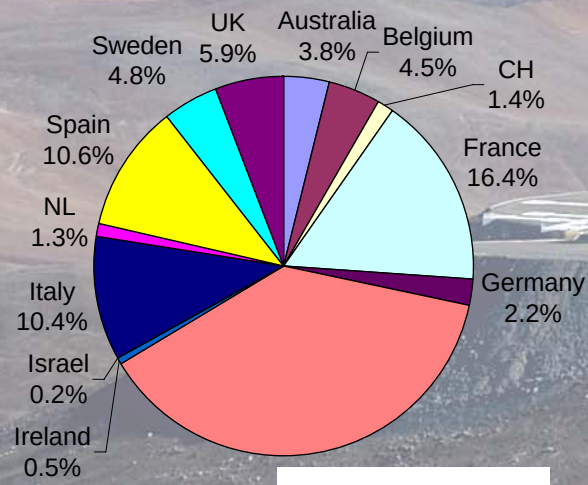
European Organisation for Astronomical Research in the Southern Hemisphere

ELT Design Study

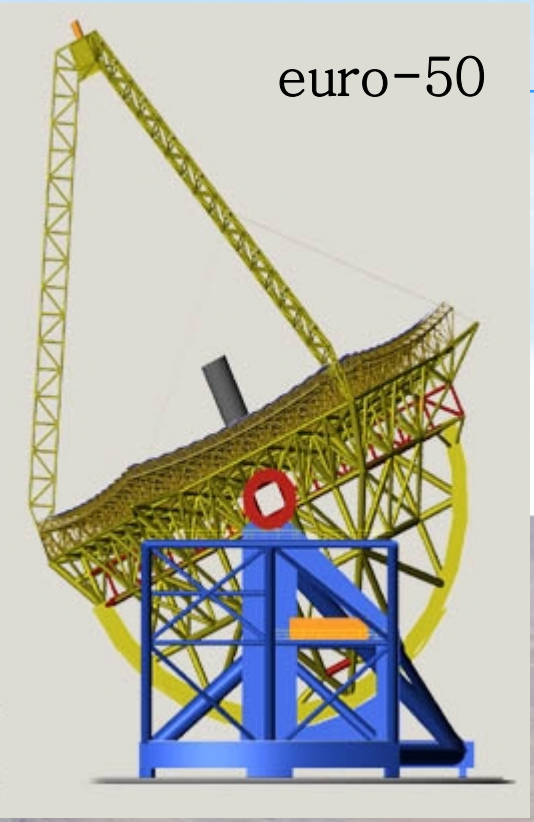
30M€ (8.4 from EU FP6)

- **Objectives**
  - **-Technology development towards a European ELT**
  - **–Preparatory work for observatory design**
  - **–Top level requirements**
  - **–Academic & industrial synergy**

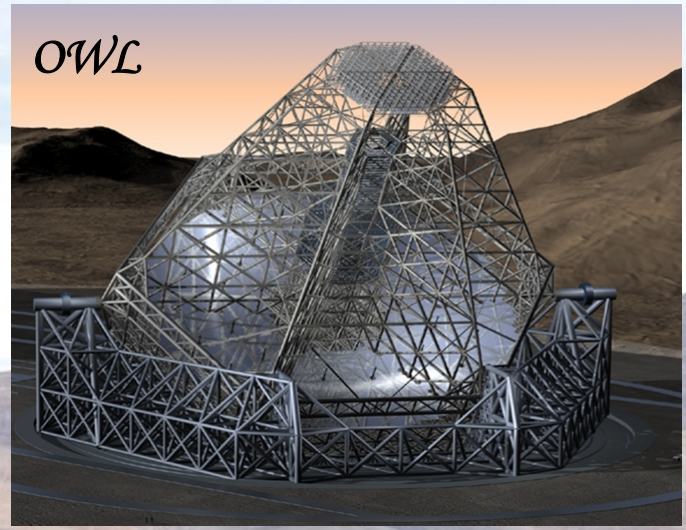




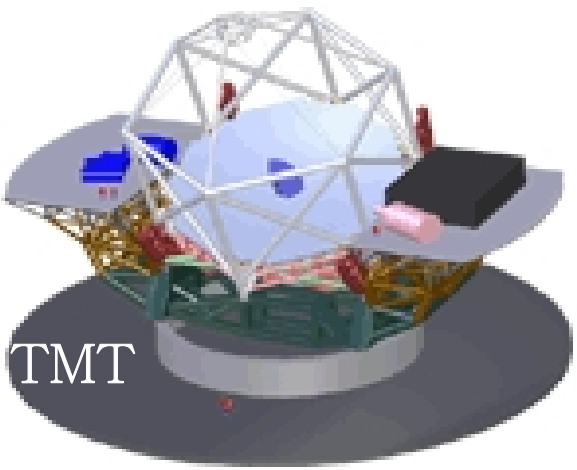
Alternative Designs

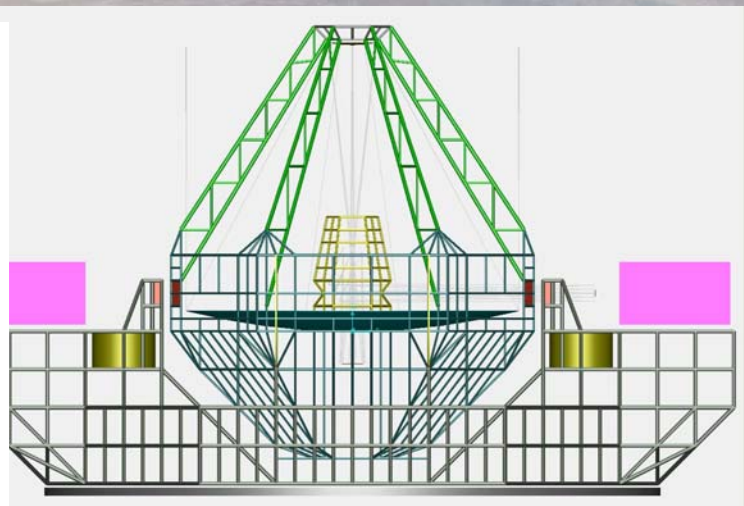


Spherical



Gregorian

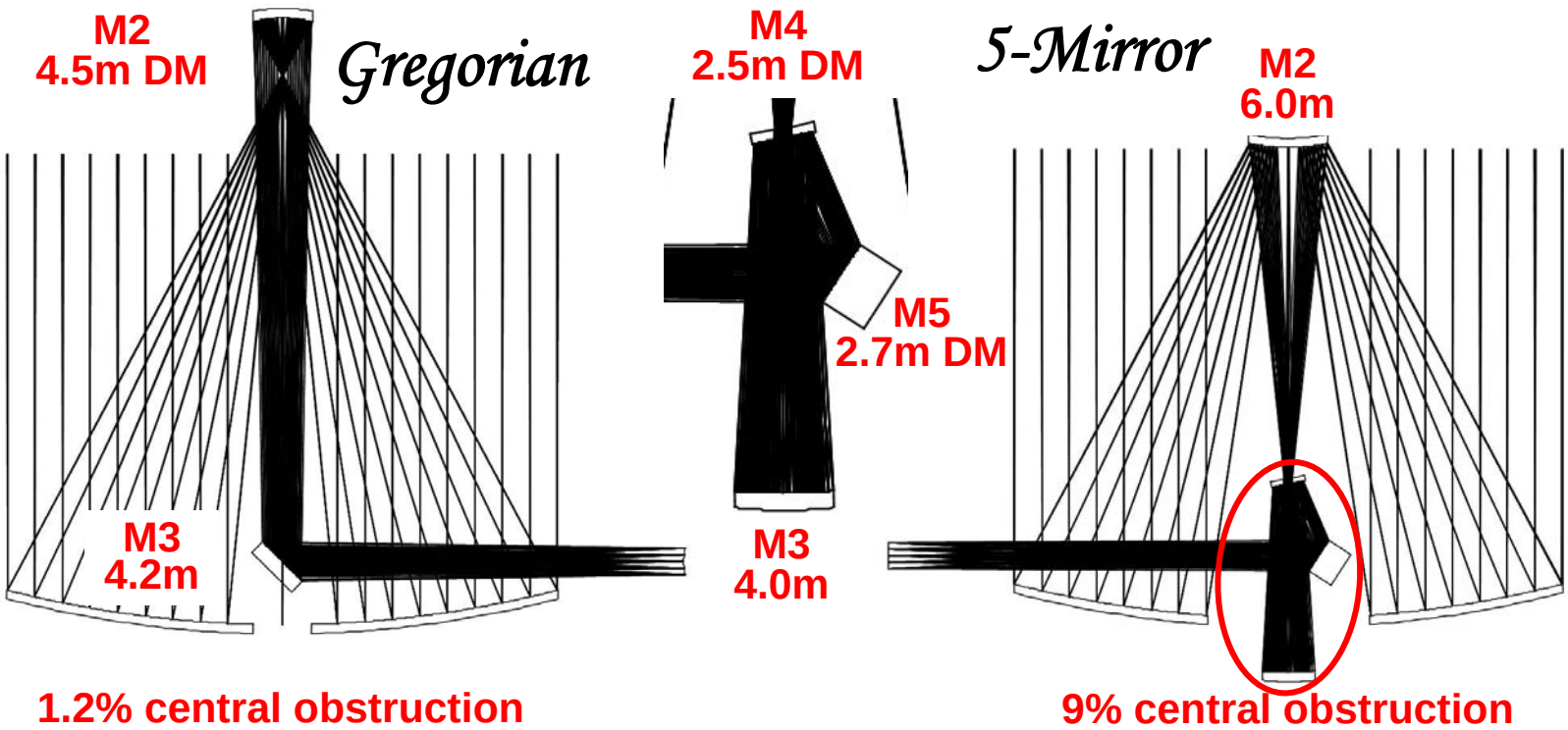




5-Mirror:

capability of multilayer AO correction using the pair of conjugate mirrors

E-ELT: Two Alternative Designs (42 m diameter)



- **3-mirror only**
  (better efficiency, lower emissivity)
- smaller concave M2
- internal F/1 prime focus

- **optimal fast wavefront control**
  (better location)
- smaller enclosure (by ~ 10 m)
- internal F/4.7 Cassegrain focus

Main Structure