European Perspectives for ground-based Astronomy

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Astronomy

- Study of everything beyond the Earth
- Objects far away, hence small and faint
  - Limited information about their nature
  - Need for large instruments: resolution and sensitivity
- Combining different types of observations crucial
  - Images/spectra/time-series

  - Electromagnetic/neutrinos/gravitational waves
  - Visible/IR and radio regimes accessible from ground

Astronomical Research

- Exploration is integral component of this field
  - Large numbers of objects, all different
  - Searches and surveys with small telescopes and follow-up by large telescopes
  - Examples: black holes, exo-planets, dark energy
- Physical science driven by observations
  - Test models versus observations: theory and numerical simulations are crucial
  - Links with physics, chemistry, computer science, laboratory experiments, geophysics, and biology

Astronomy and Technology

- Astronomy benefits from *and* drives advances in technology
- It is now possible to
  - Study objects over 95% of the age of the Universe
  - Detect and study planets around other stars
  - Use particles to study objects in the Universe
  - Explore Solar system objecs in situ
- And also to
  - Simulate astrophysical processes
  - Analyze large data streams

Astronomy and Society

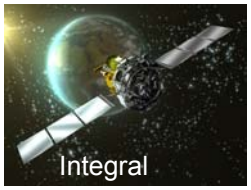
- Important for society and culture
  - Navigation, mobile phones
  - Asteroid impacts on Earth
  - Existence of other worlds, development of life
- Important for education
  - Attracts young people to physical sciences
  - Many universities opening astronomy departments
- Many exciting discoveries to come

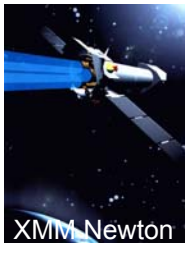
Predicting the Future

- Key questions in astronomy
  - Nature of dark matter and dark energy
  - Physics in extreme conditions (black holes, GRBs)
  - Formation & evolution of galaxies
  - Formation of stars and planets, and the origin of life
  - How do we (and the Solar System) fit in?
- Amongst most fundamental questions in science
  - Of interest to broad community and general public
- To be answered by
  - Observations with telescopes (ground and space)
  - Combined with interpretation & theory

Ground-based Telescopes

Satellites in Orbit





Also: Chandra, Spitzer, SWIFT, Akari, Spirit/Opportunity, MRO, Messenger, GLAST, …

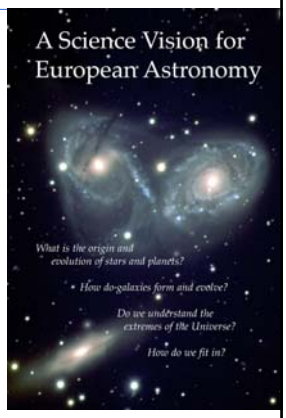
Under Development

Ambitious Plans

- European astronomy plans through 2025:
  - Will need several G€ for new investment/operations
  - EU may fund a modest fraction
  - Bulk of the support to come from funding agencies
- Funding agencies request comprehensive plan:
  - Covering all of astronomy, ground and space, including links with neighbouring fields
  - Founded ASTRONET to develop plan together with European astronomical community (EU funding)
  - Prototype for equivalent of US Decadal Surveys

Three Step Approach

- Science Vision (2007)
  - Key questions in astronomy for next two decades
  - Identifies observations, simulations, lab-experiments, interpretation and theory needed for progress
  - Use national plans, ESA's Cosmic Vision, ESA-ESO studies

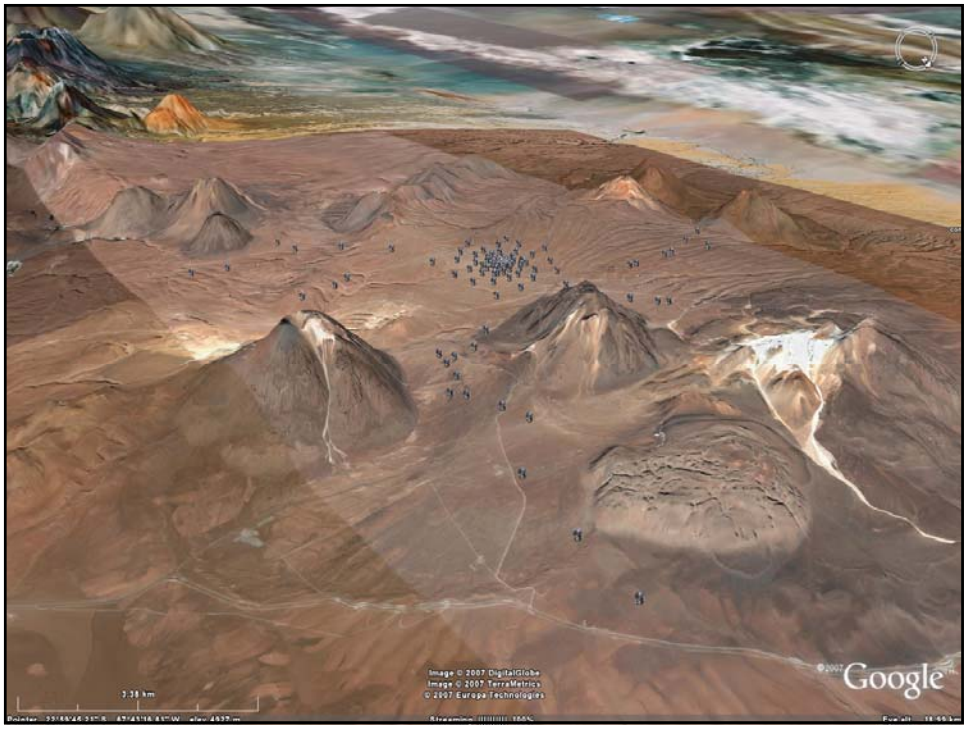


- Infrastructure Roadmap (2008)
  - Identify facilities and infrastructures needed
  - Assessment of timeline and costs
- Implementation Plan (2009-2010)

Radio Observations

- Many radio observatories world-wide
  - Powerful single dishes and interferometers
  - Linked into VLBI networks
  - Rationalization of smaller facilities needed
- Short wavelengths
  - IRAM, Nobeyama, CARMA mm observatories
  - Mauna Kea: CSO, JCMT and eSMA
  - Chajnantor: APEX, ASTE, and CMB experiments
- Transformational facility under development
  - ALMA (global partnership)


Llano Chajnantor (5000 m)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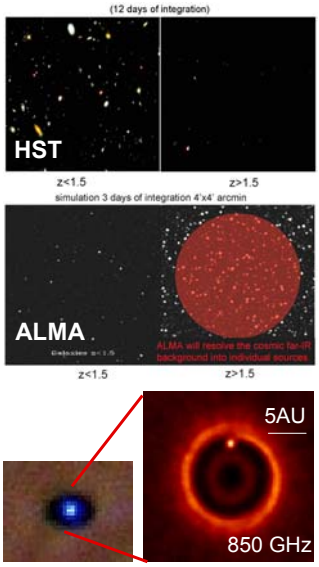
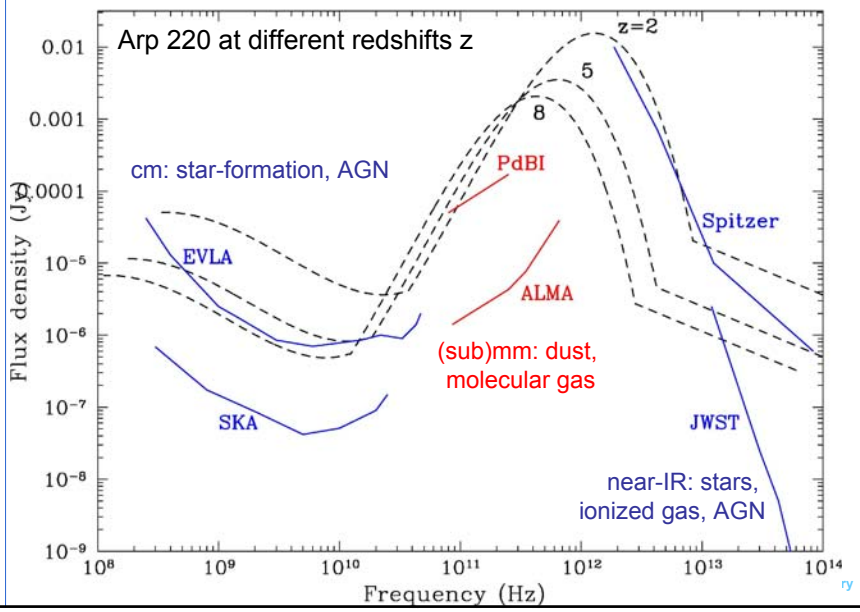
ALMA

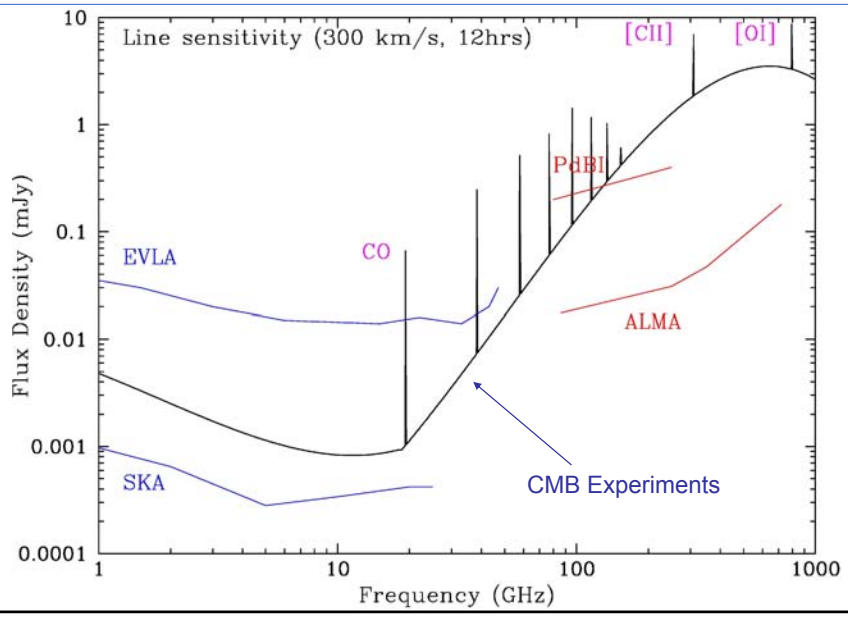
- Science requirements
  - Detect CO and [CII] in Milky Way galaxy at z=3 in < 24 hr
  - Dust emission, gas kinematics in proto-planetary disks
  - Resolution to match HST, JWST and 8-10m with AO
- Specifications
  - 66 antennas (54x12m, 12x7m)
  - 14 km max baseline (< 10mas)
  - 30-1000 GHz (0.3–10mm), up to 10 receiver bands



Panchromatic View



Line Sensitivity



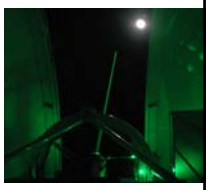
ALMA 2008

Beyond ALMA

- SKA Pathfinders being constructed
  - Focus on longer wavelengths
  - ASKAP, ATA, EVLA, LOFAR, LWA, MeerKAT, MWA
- SKA Phase 1 (0.1 km^2)
  - To build upon experience with Pathfinders
  - To be located in Southern Hemisphere
  - Organization and funding of global partnership to be defined; ALMA project provides useful lessons
- SKA Phase 2 (1 km^2)
  - To follow on longer time-scale
  - Clarify science gain/cost relative to Phase 1

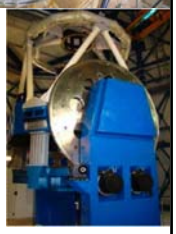
Optical Telescopes

- Many 2-4m telescopes world-wide
- Efforts to integrate/harmonize/rationalize them
  - Access program for European telescopes
  - ReStar initiative in United States (up to 6.5m)
  - Avoid duplication of instruments ⇒ system
- Focus on specific unique science
  - Sloan Digital Sky Survey
  - AO in visible (e.g. WHT, SOAR)
  - Planet searches (e.g. HARPS on 3.6m)
  - Preparation/follow-up spectroscopy for GAIA



Next Steps in Surveys

- Imaging
  - VISTA, VST coherent five-year program of public surveys; builds strong European survey capability
  - PanStarrs and upgrade
  - Giant leap forward by LSST, if funded
- Wide-field spectroscopy
  - 8m class for deep Universe/GAIA
  - Clarify trade-off between FOV and depth
  - If less than 30′, then many options; otherwise Subaru or a dedicated new 8m telescope
  - Link to space missions: JDEM, EUCLID

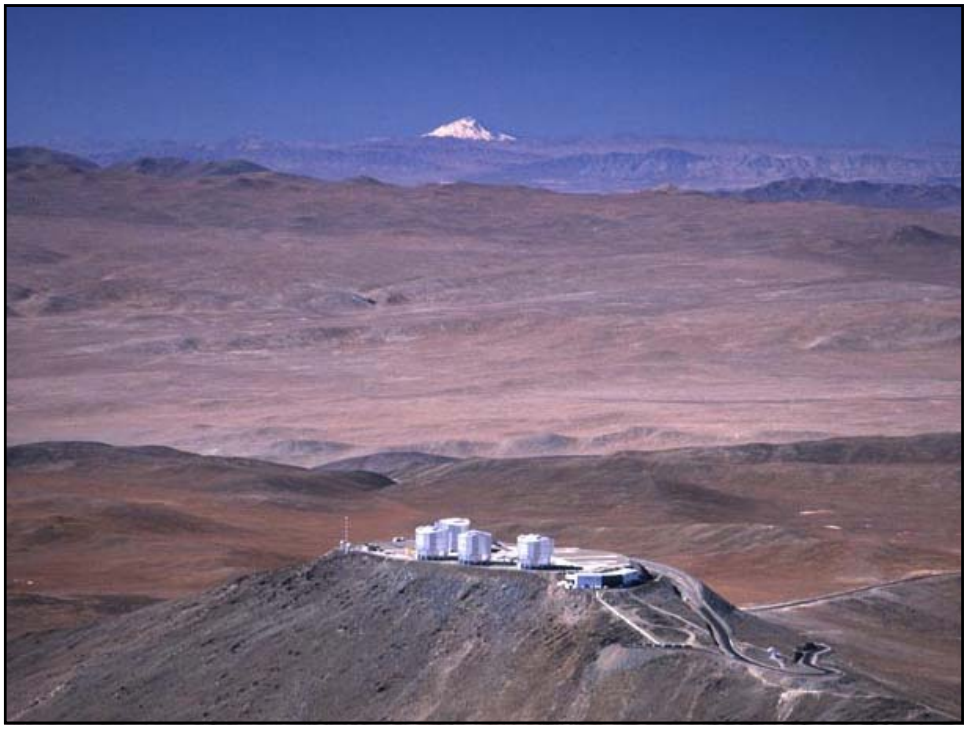


Solar Telescopes

- Many small telescopes, some with AO
- New flagship: ATST
  - 4m on Maui, to be managed by NSO (AURA/NSF)
  - Design ready, waiting for NSF funding approval
  - Will replace number of smaller US solar telescopes
- Europe
  - Plans for 4m in Canary Islands
  - Funding not identified; governance to be defined

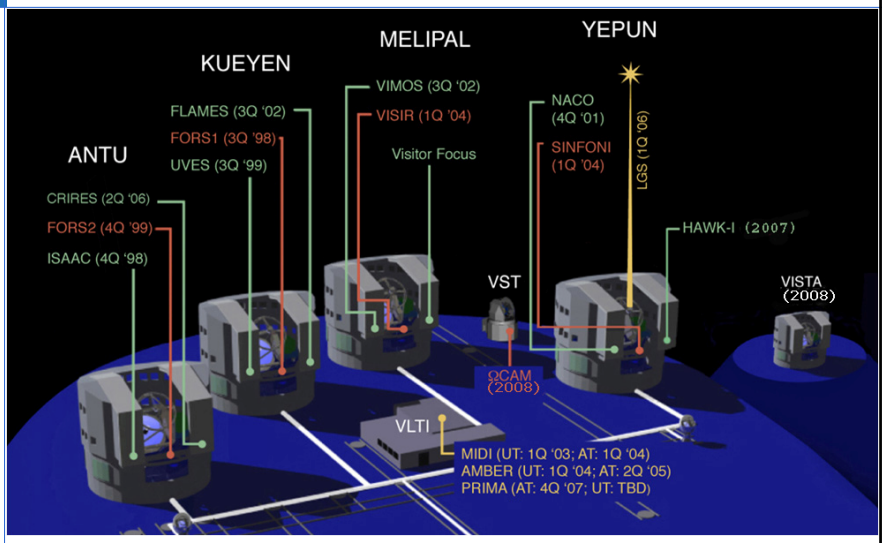
8-10m Telescopes

- Mauna Kea
  - Twin Keck telescopes, Subaru, Gemini-North
  - Opportunity to develop this into powerful *system*
- Chile
  - Gemini-South, optimized for IR
  - VLT plus Interferometer: *fully-integrated system*
- Other
  - LBT, including interferometric mode
  - GranTeCan, nearly operational
  - HET (with HETDEX) and SALT

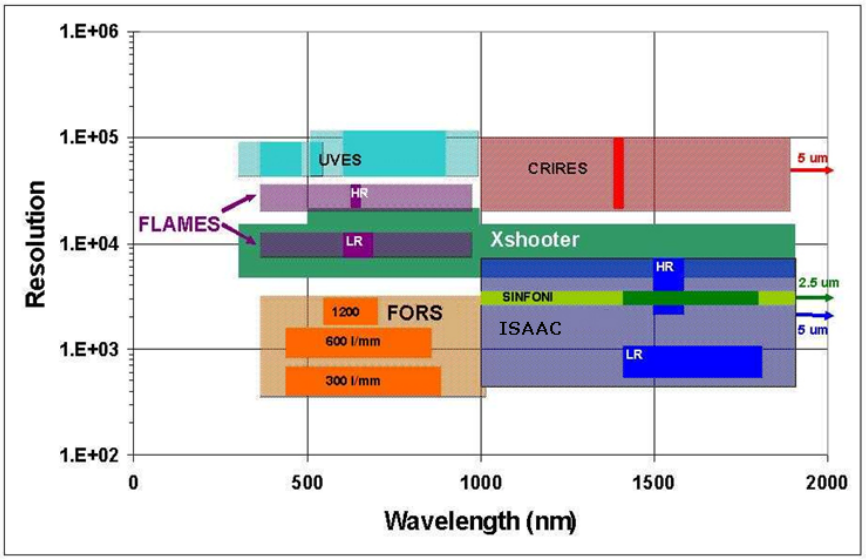


Paranal

The Arsenal



Coverage in λ and $\mathcal{R}$

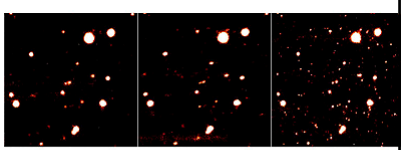


2nd Generation Instrumentation

- Approved VLT instruments in development
  - X-Shooter – Single object UV-IR spectrograph
  - KMOS – Near IR MOS, deployable IFUs
  - SPHERE – XAO + Near IR/Vis planet finder
  - MUSE – Visible IFU spectrograph (24 modules)
- New VLTI instruments
  - GRAVITY – K Band, 4 telescope, astrometry near GC
  - MATISSE – L, M, N band, 4 telescope image/spec
  - VSI – 4-6 telescope near IR imager/spectrometer
- Additional VLT instruments planned
  - Including ultra-stable high-resolution spectrograph

Long-term Program

- Long range plan
  - Continuous upgrades through at least 2020
- Most instruments built by consortia
  - ESO pays hardware costs (~1/3rd of total)
  - Consortia provide fte's; paid in Guaranteed Time
  - Typically 250 nights for 2nd generation instruments
  - Used for coherent science programs
- Development program
  - MCAO Demonstrator
  - Laser Guide Star Facility
  - Fully adaptive M2 for UT4

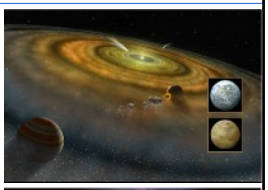


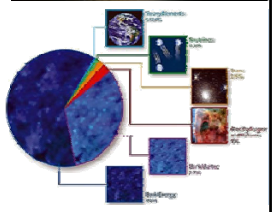
Comparing AO Techniques

ESO Press Photo 19e/07 (30 March 2007)

The Next Step: Giant Telescopes

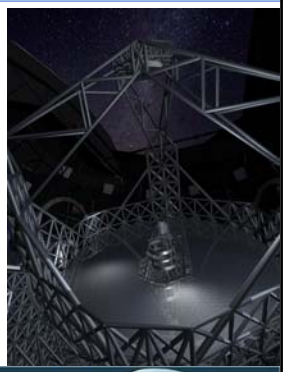
- Exo-planets
  - Imaging and spectroscopy
  - Earth-like planets accessible
- Stellar populations
  - Resolved out to Virgo cluster
  - To high redshift in integrated light
- Cosmology
  - The first stars and galaxies
  - Direct measure of deceleration
  - Evolution of cosmic parameters
  - Dark matter, dark energy





Extremely Large Telescope

- Detailed design study
  - Baseline 42m primary mirror
  - Adaptive optics built-in
  - Fully funded (~62⁺ M€)
  - Site selection ongoing
  - Concludes early 2010
- Project
  - Builds on *entire* expertise at ESO *and* in member states
  - Construction 2010-2017
  - Synergy: JWST/ALMA



Global Situation

- ELT
  - Highest priority ground-based project in Europe
  - Coherent European effort, led by ESO
  - *Transformational extension of VLT/I system,* which currently already has 4000⁺ registered users
- United States: two competing projects
  - TMT: 30m, many 1.45m segments
  - GMT: 22m, seven 8.4m mirrors on Las Campanas
  - Private initiatives with international partners
  - Part of construction funding identified; NSF to be asked for operations funding (after Decadal Survey)
  - TMT would be ideal addition to *Mauna Kea system*

Curious Symmetries

- North America
  - World-leading space science program through NASA
  - Radio astronomy nationally led by NRAO
  - O/IR effort: free market structure, except Solar
- Europe
  - High-quality space science program through ESA
  - Radio astronomy: network of institutions
  - World-leading O/IR program through ESO
- ALMA
  - Bridges traditional divide between O/IR and radio
  - Best of three worlds: NAOJ, NRAO, ESO

Conclusions

- Answering key science questions requires
  - Best use of existing facilities, including rationalization or specialization of medium-size telescopes
  - Full science harvest of facilities under construction
  - Next generation ground-based telescopes, providing synergy with armada of space missions
  - Supported by theory, simulations and laboratory experiments, and development of enabling technology
- Tremendous scientific & technical opportunities
  - Infrastructure roadmap to be followed by a coherent implementation plan supported by funding agencies
  - Key ESO role in construction of world-class facilities