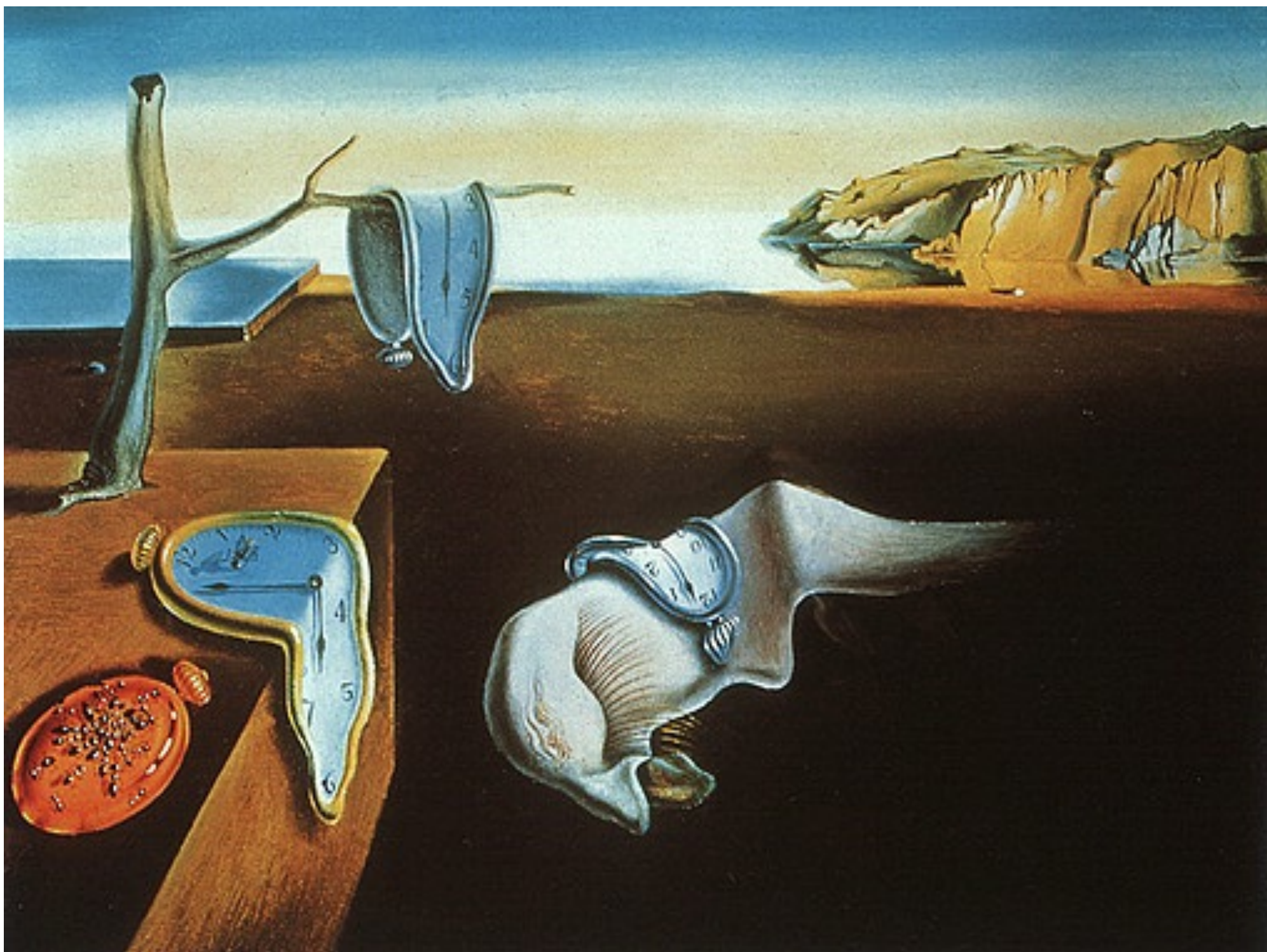


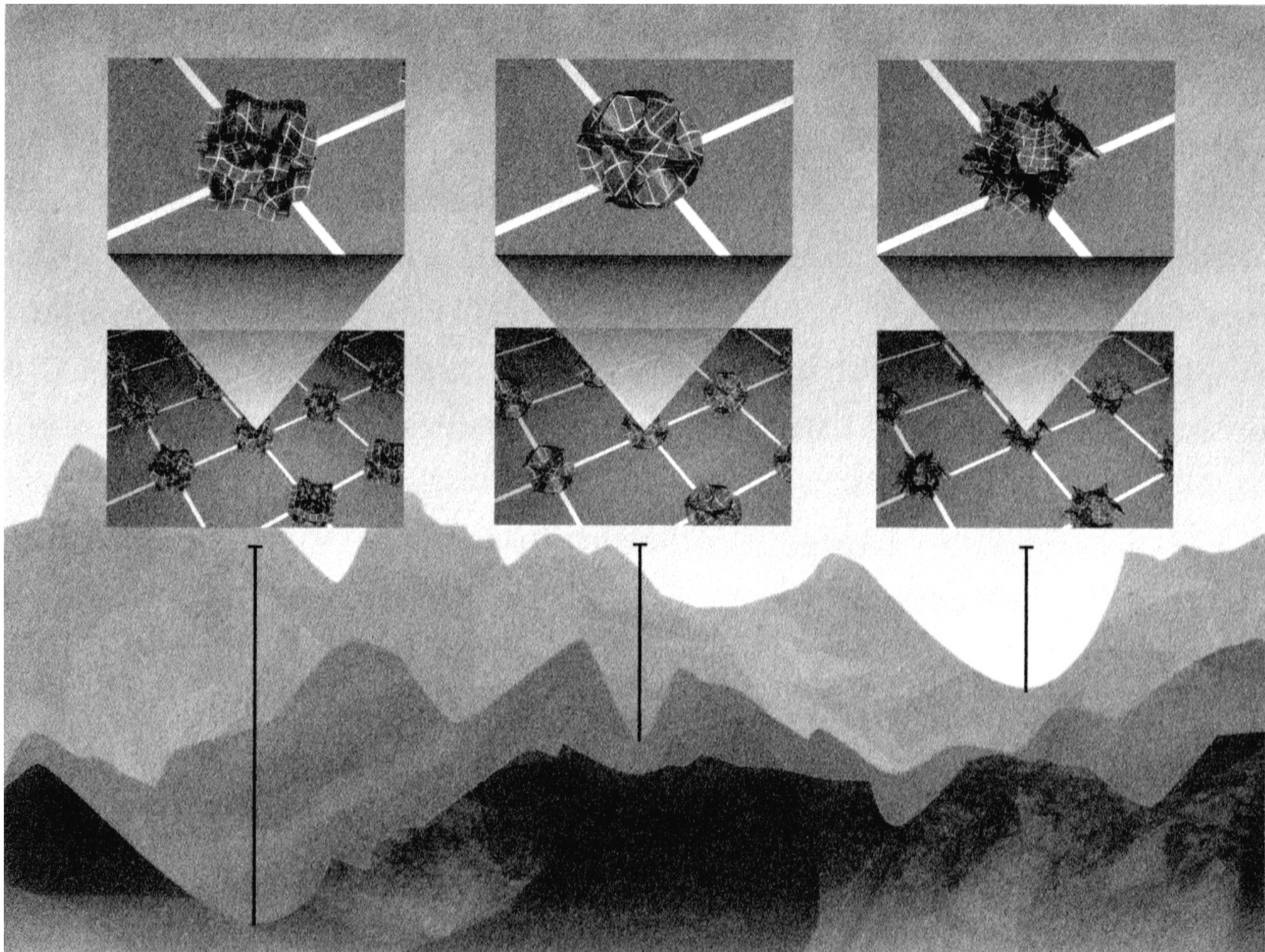
The Astronomical Landscape in 2020

Roger Blandford
KIPAC
Stanford











New Worlds, New Horizons

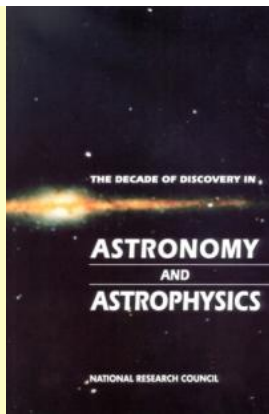
in Astronomy and Astrophysics

15 ii 2012

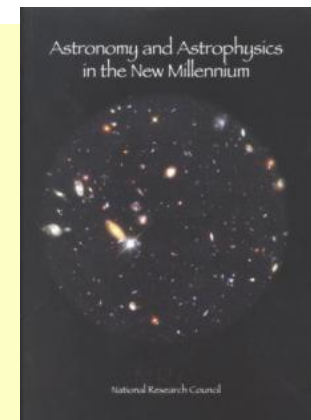
WFIRST

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

6



U.S. Decadal Surveys



Widely imitated!

- 1964: *Ground-based Astronomy: A Ten Year Program* (Whitford)
- 1972: *Astronomy and Astrophysics for the 1970s* (Greenstein)
- 1982: *Astronomy and Astrophysics for the 1980s* (Field)
- 1991: *The Decade of Discovery in Astronomy and Astrophysics* (Bahcall)
- 2001: *Astronomy and Astrophysics in the New Millennium* (McKee-Taylor)
- 2010: *New Worlds, New Horizons in Astronomy and Astrophysics*
- 2020: *Pursuing the Vision*

The Past 50 years in Astronomy

- **More channels**
 - 70 octaves x 2
 - **More countries do research at highest level**
 - All continents
 - **More collaborative**
 - 500 author papers, more agencies, countries
 - **More proposals**
 - Pressures on young astronomers
 - **More expensive and slower**
 - Telescopes, instruments, data, theory
 - **More disciplines**
 - Physics chemistry, biology, engineering, CS...
- 2020 Vision
(from someone who has always had defective eyesight)

Specific Task

Recommend a prioritized, balanced, Ground- and Space-based Program on Large, Medium and Small Scale for a range of budgetary scenarios

Astro2020 will be similar

Community Input

Community remains engaged and sophisticated

An unprecedented response

- 324 Science White Papers (a unique snapshot of the field)
- 69 State Of The Profession Position Papers
- 70 White Paper on Technology Development, Theory, Computation, and Laboratory Astrophysics
- 108 Community Responses to a Request for Information on Research Activity Proposals
- Email Inputs to the Committee
- Community-organized Town Halls



Optimizing the Recommended Program

- Prioritizing based on science objectives
- Building upon existing astronomical enterprise
- Evaluating cost risk and technical readiness
- Maximizing scientific return under highly constrained budget guidelines
- Choosing most urgently needed activities from long list of compelling ideas and concepts
- Considering international and private partnerships

Limits to Growth?

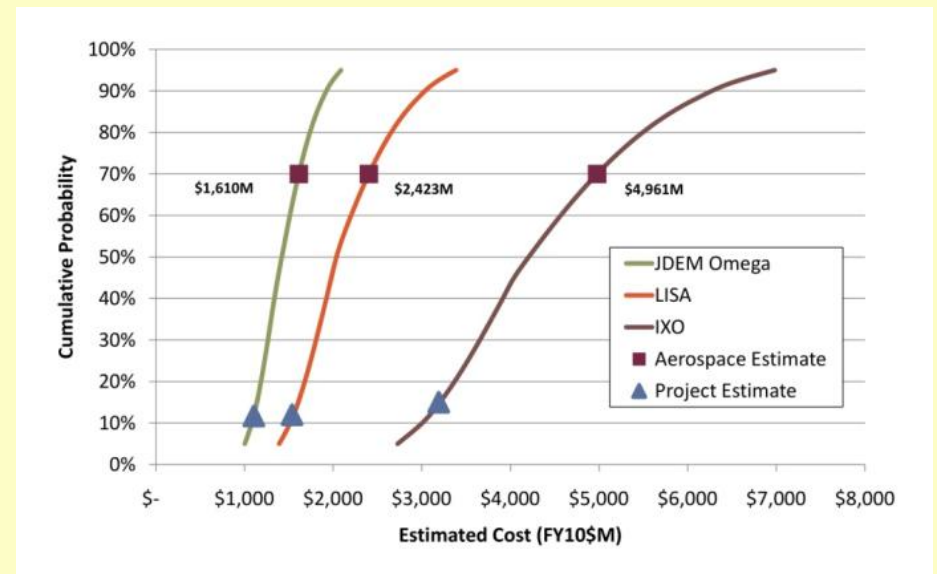
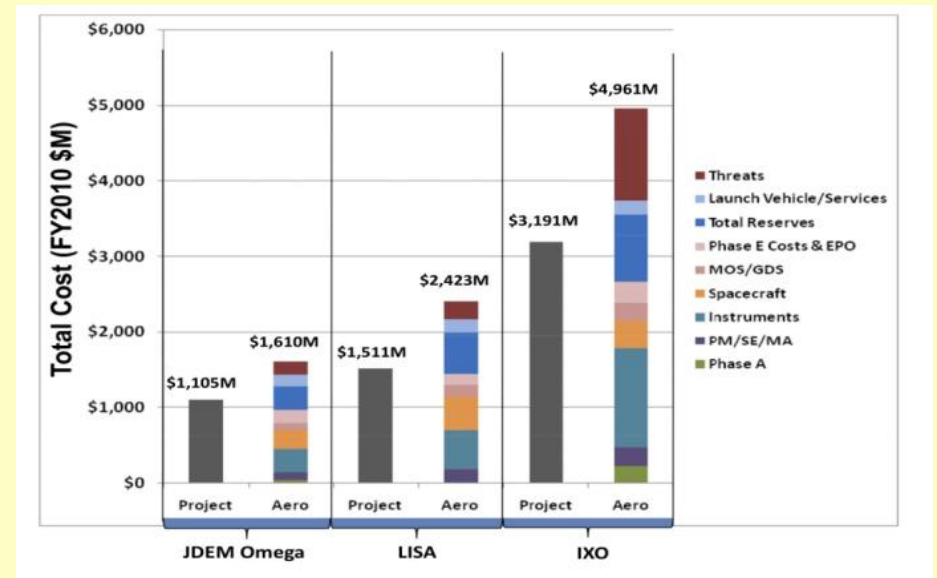
- **US/World Economic Problems**
 - Europe, Japan ... ?
- **NASA Strategic Planning**
 - Manned space, heavy lift, “commercial” space....
- **Space Science Program**
 - Declining budgets
 - JWST
 - 8.7B, 2018 launch
- **Astrophysics**
 - JDEM/Euclid/WFIRST; SDT interim report
 - Termination of IXO, LISA ->Athena, NGO
 - Support of Explorers, small program
- **NSF**
 - LSST- 2014 start. 2020 operations? DOE camera

Cost, Risk, and Technical Evaluation

Used in other reviews

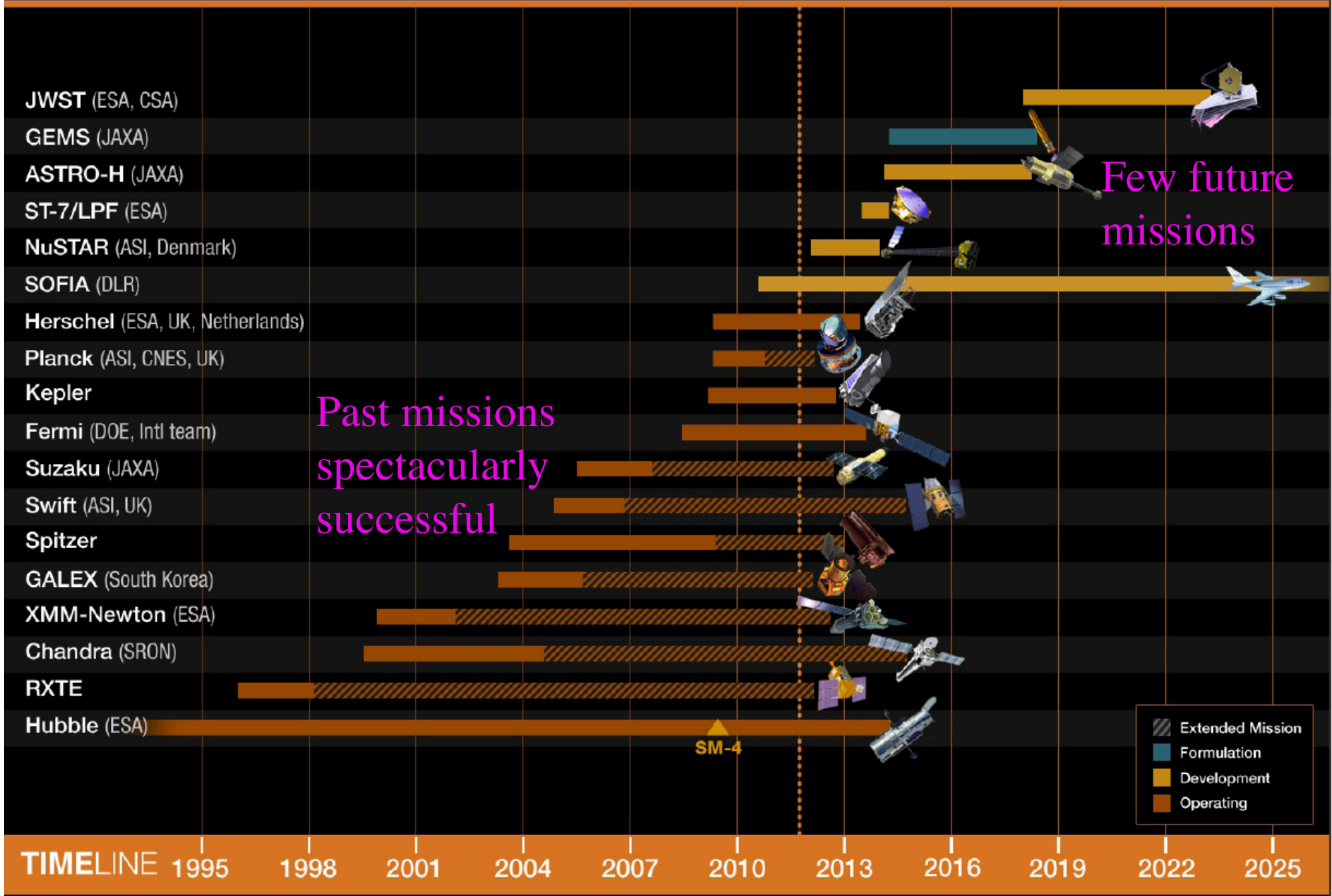
- Early call for Notices of Intent followed by open Request for Information
 - Activities selected by PPPs and committee for a 2nd Request for Information
- Subset selected by PPPs and committee for CATE review
 - Independent cost appraisals
 - Evaluations of technical readiness schedule and risk assessment

Launches and spacecraft cheaper.
Commercial space eg SPACEX.



Astrophysics Missions timeline

Last updated: January 4, 2012



NASA

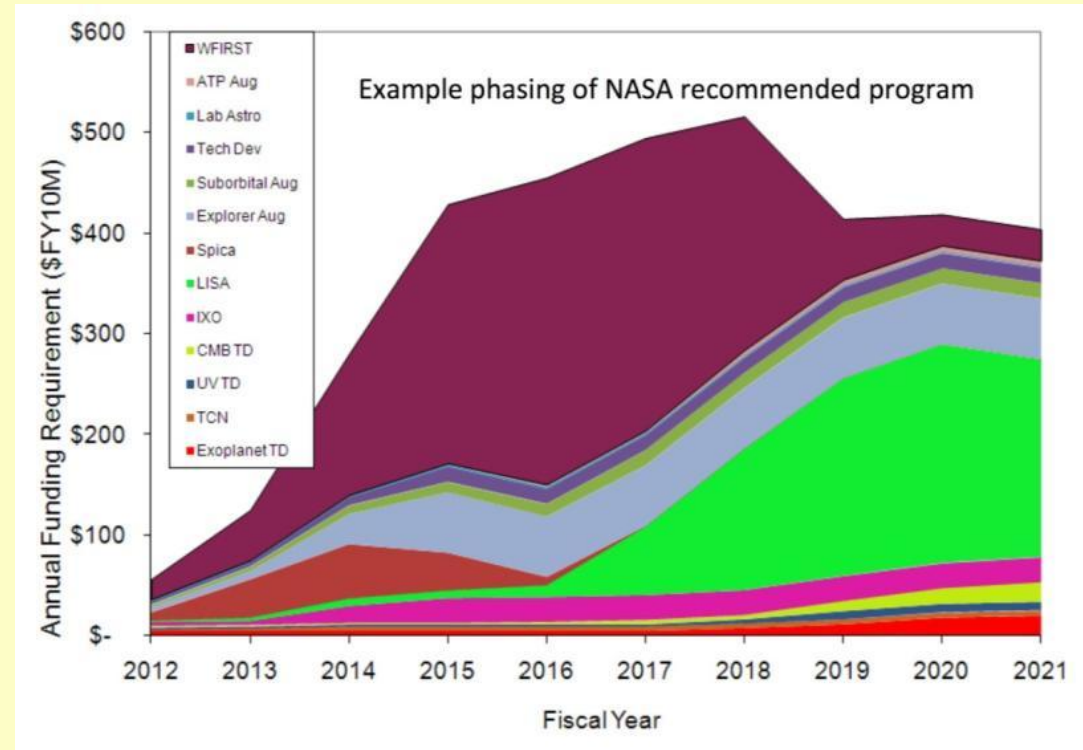
- Recommendation under survey's optimistic budget scenario:

- launch WFIRST
- augment Explorers
- start LISA
- timely contribution to SPICA
- advance
 - IXO
 - Exoplanet and Inflation technology development

- Details depend upon ESA negotiations and decisions

- If budgets are lower, SPICA contribution dropped and

- First priority: WFIRST, Explorer augmentation and small program
- Second priority: New Worlds (Exoplanet) Technology Development, LISA and IXO Technology Development
- Third priority: Inflation Technology Development



Well below pessimistic scenario

Ground-based Program

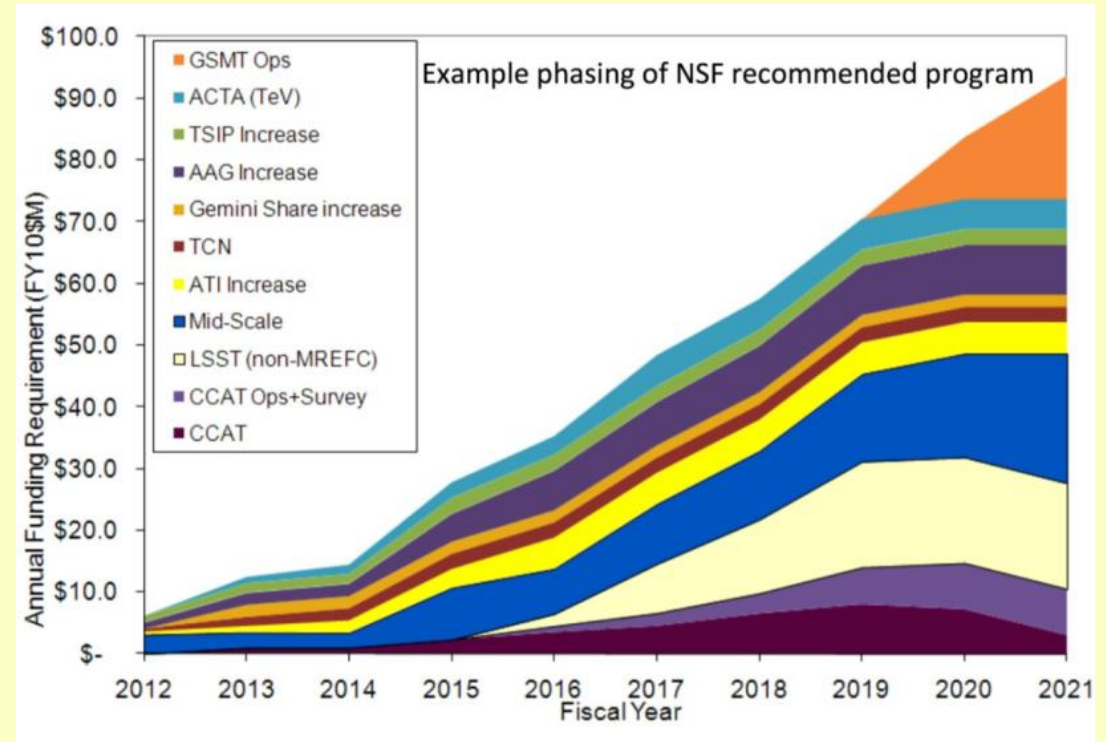
ALMA will make great discoveries in astrochemistry, cosmology...

- (E)VLA, GBT, ALMA, VLBA, MWA....
- Keck, Magellan, Gemini, NOAO, DES...
- (A)LIGO, will discover sources of gravitational waves
- Auger, VERITAS, ICECUBE,
- Dark Matter... Supersymmetry vindicated by LHC
Direct and indirect detection results
invaluable

NSF

- Program dependent upon MREFC
 - early entry of LSST
 - followed by GSMT

Need to find operations support



- In event NSF budget is as projected by agency, there can be no new starts without closure of major facilities following senior review
- If moderate budget increase
 - First priority is small program (including time-critical Gemini augmentation), Mid-scale Innovations program, and starting LSST operations.
 - Second priority is GSMT operations, and starting ACTA

Globalization of Astronomy

- **Convergence of scientific agendas**
 - Astronet, Aspera, ESA Cosmic Vision, Canadian, Indian, Australian, Japanese, Chinese, Chilean...
 - Uncoordinated implementation
- **Collaboration and cooperation a desirable and inevitable feature of 21^c astronomy**
 - Need new mechanisms to plan, manage, observe, handle data...

Astronomy will be fully global except in funding

International Collaboration

- **Plus**

- **Better sites/orbits**
- **More expertise**
- **More money**
- **More fun**

- **Minus**

Management will improve with experience

- **Hostage to more economic problems**
- **Multiple approval processes, managements**
- **“25%” overhead**
- **Technology transfer issues** Will be seen as irrelevant

Independent Advice

- AAAC, CAA, agency committees
- Recommendation : NASA, NSF, and DOE should on a regular basis request advice from an independent standing committee constituted to monitor progress toward reaching the goals recommended in the decadal survey of astronomy and astrophysics, and to provide strategic advice to the agencies over the decade of implementation....

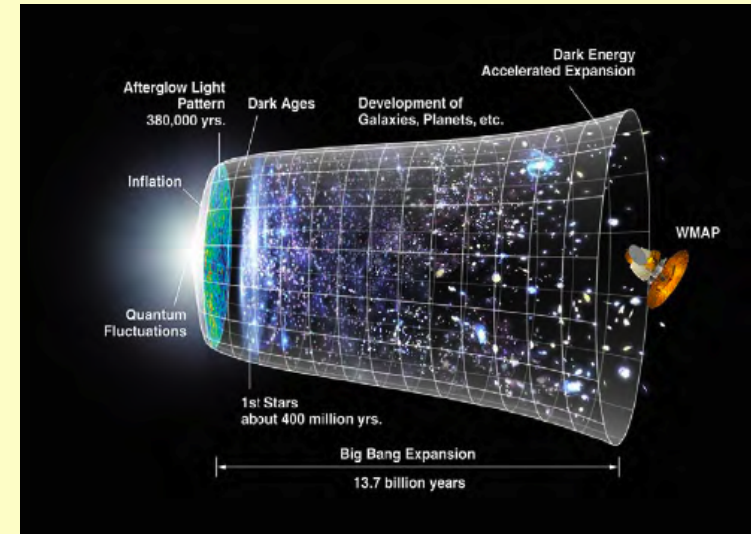
More needed than ever

Cosmic Dawn

Searching for the first stars,
galaxies, and black holes

Know EOR epoch

JWST will be fully operational and will
have delivered stunning observations
of first galaxies and stars



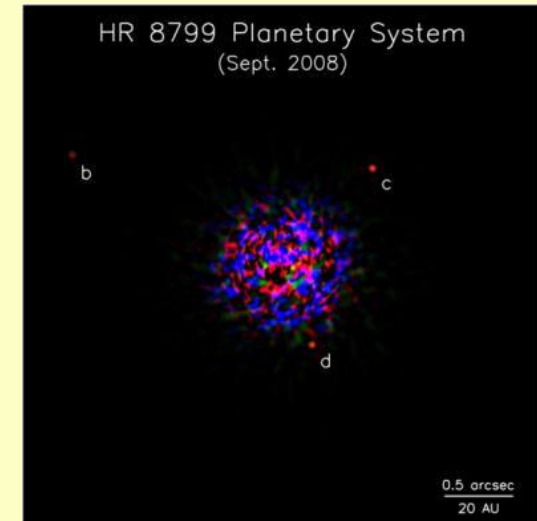
- We have learned much about the history of the universe, from the Big Bang to today
- A great mystery now confronts us: when and how the first galaxies formed and the earliest stars started to shine - our cosmic dawn
- JWST, ALMA and radio telescopes already under construction will help point the way
- Approaches:
 - Locating “reionization” – finding the epoch ~0.5 billion years, when light from the first stars split interstellar hydrogen atoms into protons and electrons
 - “Cosmic paleontology” – finding the rare stars with the lowest concentrations of heavy elements

New Worlds

Seeking nearby, habitable planets

Elementary schoolchildren will learn the names of habitable “earths”.

Many “nomads” discovered



- Nearly 500 extrasolar planets now detected - extraordinarily rapid progress
 - Huge range of properties exhibited, surprisingly different from those in our own solar system
 - Many ongoing approaches seek new “Earths” – potentially habitable rocky planets with liquid water and oxygen
 - New techniques being developed
- Kepler data adds over 300 "candidates" to the list, including many less than twice the size of Earth
- Next great step forward: understand frequency of different types of planets and lay scientific and technical groundwork to inform future strategies for detailed study of nearby Earth-like planets

Physics of the Universe

Understanding Scientific Principles

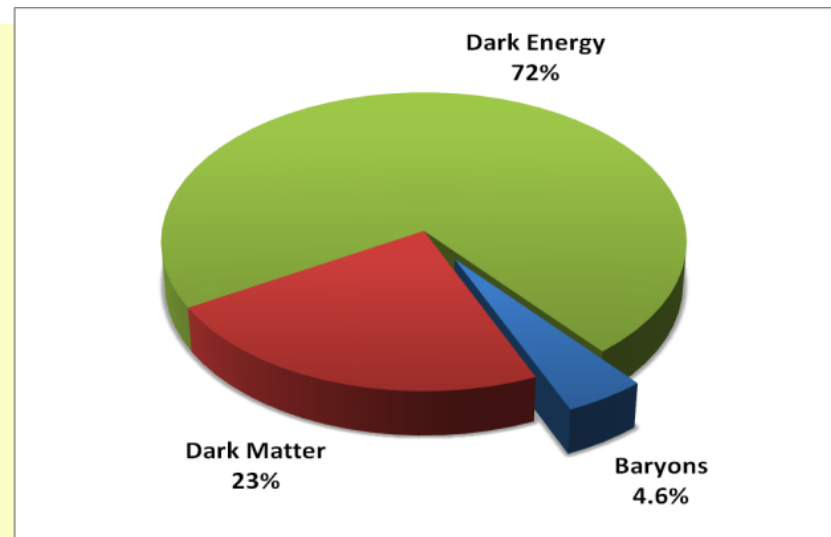
Increasingly accurate measurements affirm Λ CDM

Supersymmetry detected at LHC, probed by direct, indirect searches
Neutrino number, masses, mixing measured by CMB etc, experiment

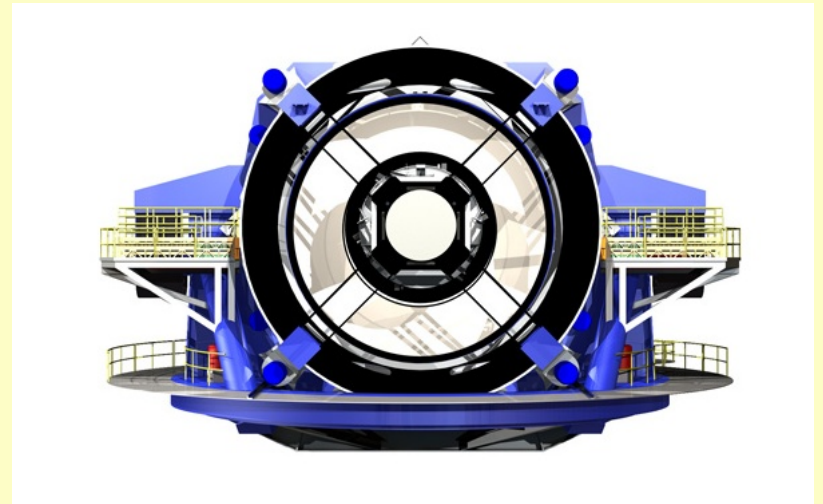
Particle physics has a future

- Determine properties of dark energy, responsible for perplexing acceleration of present-day universe
- Reveal nature of mysterious dark matter, likely composed of new types of elementary particles
- Explore epoch of inflation, earliest instants when seeds of structure in the universe were sown **B modes detected on ground**
- Test Einstein's general theory of relativity in new important ways by observing black hole systems and detecting mergers

Strong field GR vindicated



My 2020 predictions for
LSST- Science



First light, survey begun
Most initial science unanticipated

- **Efficient, deep optical survey telescope**
- **Will transform observation of the variable universe and address broad questions:**
 - **Dark energy using gravitational lensing and supernovae**
 - **Dark matter**
 - **Near-Earth, Kuiper-belt objects**
 - **Solar neighborhood**
 - **Transient phenomena**
 - Gamma-ray bursts, Variable stars, Supernovae...
- **Publicly accessible archive - >100 Pbyte**

Novel approaches to data archiving, curation, mining transform astronomy

Mid-Scale Innovations Program - Overview

- Large number of exciting and viable projects addressing survey goals are in ~ \$10-\$100M range

Program thriving and value recognized



GSMT - Overview



- Will transform a broad range of science including stellar astronomy, exoplanets, black holes:
 - Complements JWST, ALMA, LSST, GAIA, eROSITA....
 - High spatial resolution; high sensitivity spectroscopy
 - Top ground-based recommendation in AANM
 - Now two U.S. projects for 30m class optical-infrared telescopes under development:
 - Giant Magellan Telescope in Chile
 - Thirty Meter Telescope in Hawaii
 - Also ESO's E-ELT in Chile
- All three well into construction
NSF partners on instrumentation, operations



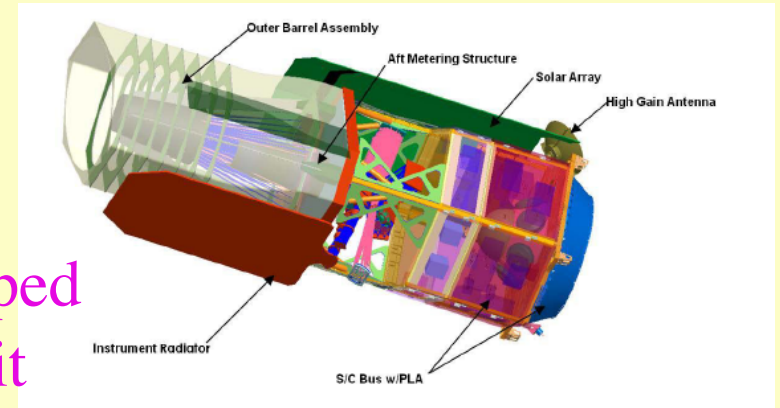
CCAT

Nearing completion

- Kick-off example of Mid Scale Innovations Program
- 25m wide-field submillimeter telescope in Chile
- Work as survey facility in conjunction with ALMA
- RECOMMEND NSF to be one-third partner
- Total appraised cost \$140M; annual operations \$11M
- Needs immediate start to be ready for ALMA
- Estimated completion date 2020; Medium risk

WFIRST - Science

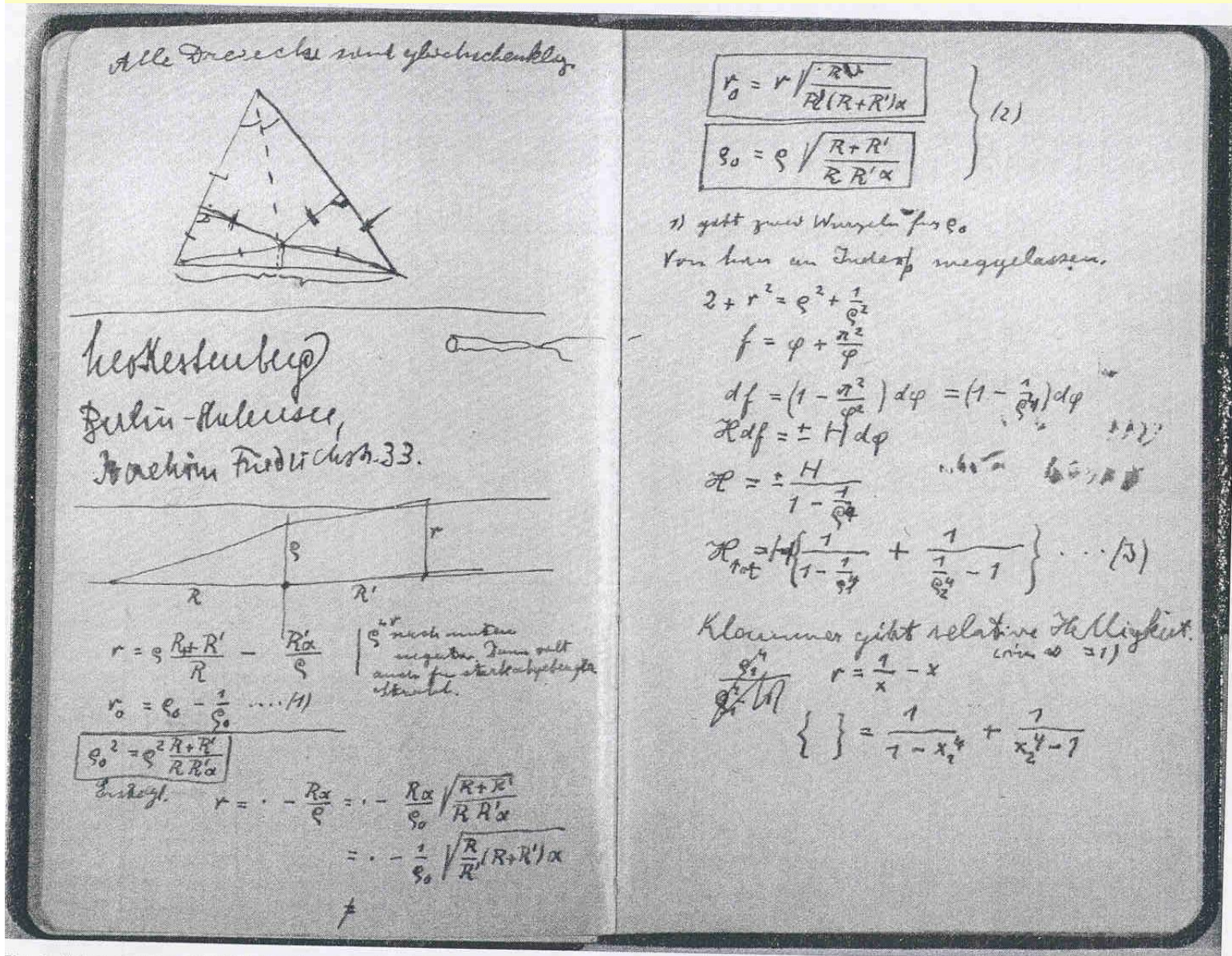
Higher resolution, lower noise arrays developed
Designed to complement Euclid with which it
will overlap. Approaching launch



Near infrared wide-field telescope with a *set* of key science objectives:

- **Dark energy (part of a coherent ground-space strategy):**
 - Baryon acoustic oscillations
 - Distant supernovae
 - Weak lensing
- **Exoplanet statistics**
 - Gravitational microlensing
- **Guest investigator mode enabling survey investigations**

Microlensing Centenary!



Einstein's
First
Wonder?

Guide to the Hitchhikers' Galaxy

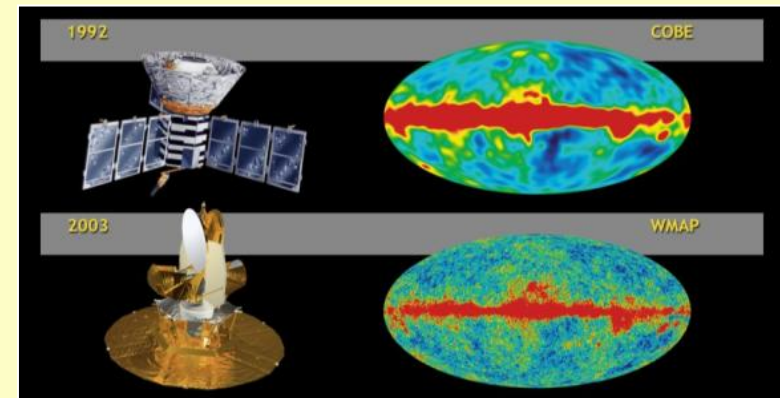
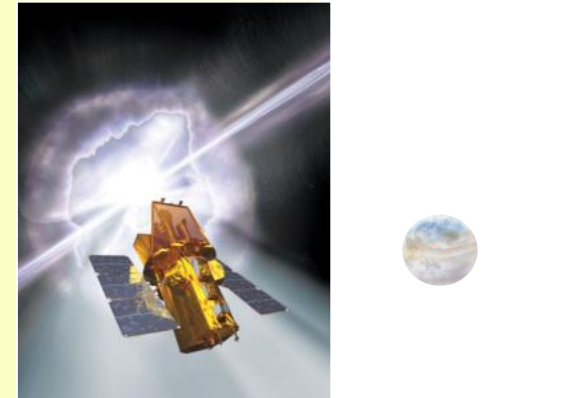
(Strigari, Barnabe, Marshall, RB)

- How many "Nomads"?
 - Up to 100,000/star \gtrsim Pluto?
- \gtrsim km size moons/
 - Room at the bottom
- Bacteria/archaea propagation through IPM, ISM, IGM
 - Occasional collisions create mobile fragments which may impact protostellar disks
- GAIA, LSST, WFIRST... will find?
 - As part of regular observing program
- Eclipsing and shorter cadence events
 - New ways to use existing or new cheap telescopes
- Much discovery space!

Explorer Program - Science

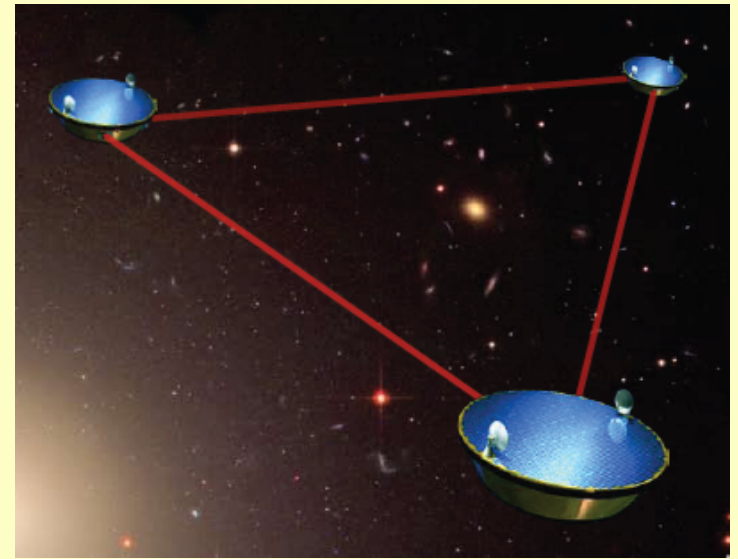
NuSTAR GEMS ASTRO-H follow up ongoing

- Rapid, targeted, completed investigations
- Versatile program delivers high scientific return
- WMAP, Swift, GALEX, WISE... are extraordinarily successful past examples
- NuSTAR, GEMS, Astro-H very promising Other explorers launched



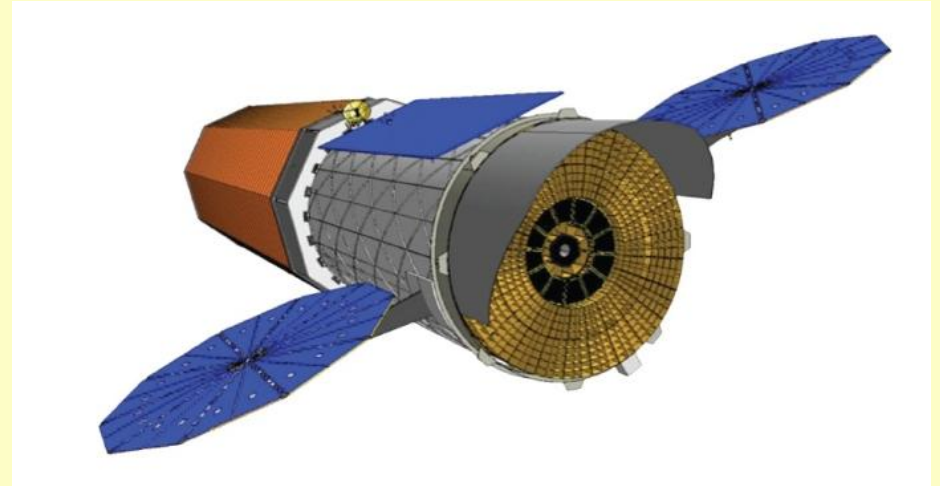
LISA - Science

US joins NGO following
successful LPF



- Exploiting a new field of astronomy using long wavelength gravitational radiation - ripples in spacetime - to observe:
 - Inspirals and mergers of binary black holes to cosmological distances, back to Cosmic Dawn; measure black hole masses, spins
 - Large numbers of ultra-compact binary stars in our galaxy
- Precision tests of general relativity
- Possible detection of spacetime ripples from the very early universe
- The unexpected

IXO - Science



- Large area, high spectral resolution x-ray observatory to explore hottest regions in the universe
- Clusters of galaxies, intergalactic medium, black hole accretion disks
- IXO would revolutionize X-ray astronomy and address many high priority science objectives in the spirit of Chandra and XMM-Newton

US joins international high resolution X-ray spectroscopy mission

Medium-Scale Space Program - Prioritized

1. New Worlds Technology Development Program

Focused on follow up of specific targets and early results
from JWST

2. Inflation Technology Development Program

B-modes and non-Gaussianity targeted

Astronomers

- There is a widely-acknowledged urgency for increasing “STEM” education, and astronomy has a role to play
- Astronomy research provides technological “spin-offs” of benefit to the nation.
- Astronomy research and astronomers’ skills are well matched to many scientific and technical issues of strong current national importance.

Astronomy becomes increasingly “environmental”
and accessible to the public

Techniques developed by astronomers find widespread application

Astronomers

- There is much concern among early career astronomers as to their long term professional career opportunities

Always has been; always will be. However, today it is a major issue.

- Minorities and women are under-represented in astronomy compared with the general population, and efforts to increase their numbers percentages must be continued.

Globalization will ameliorate this problem.

- There is corresponding uncertainty in the number and range of opportunities over the coming decade.

Leaving and returning to astronomy will be quite common

- An astronomical education is demonstrably a gateway to success in many other careers Big data, energy, remote sensing...

Young scientific talent, like capital and jobs will be highly mobile.

The world of astronomy will be quite “flat”

in the Friedman as well as the Friedmann sense.

Summary

- **Scientifically Astrophysics has never been stronger**
 - Age of discovery, will continue through 2020
- **Existing missions performing and delivering**
 - Credit to all who worked on them
- **Exciting recommended program**
 - New Worlds, New Horizons, international plans
- **Perfect storm has set back execution in US**
 - Economy, NSF operations, NASA, JWST, DOE Domestic HEP...
- **Have to work with agencies**
 - Independent community advice on major choices
- **International cooperation and collaboration**
 - Never more important than now; take the long view
- **Exploit existing facilities to the maximum**
 - Be ready to move with consensual missions/projects as soon as possible