What Does NWNH Mean for Radio Astronomy?

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Chair of RMS PPP

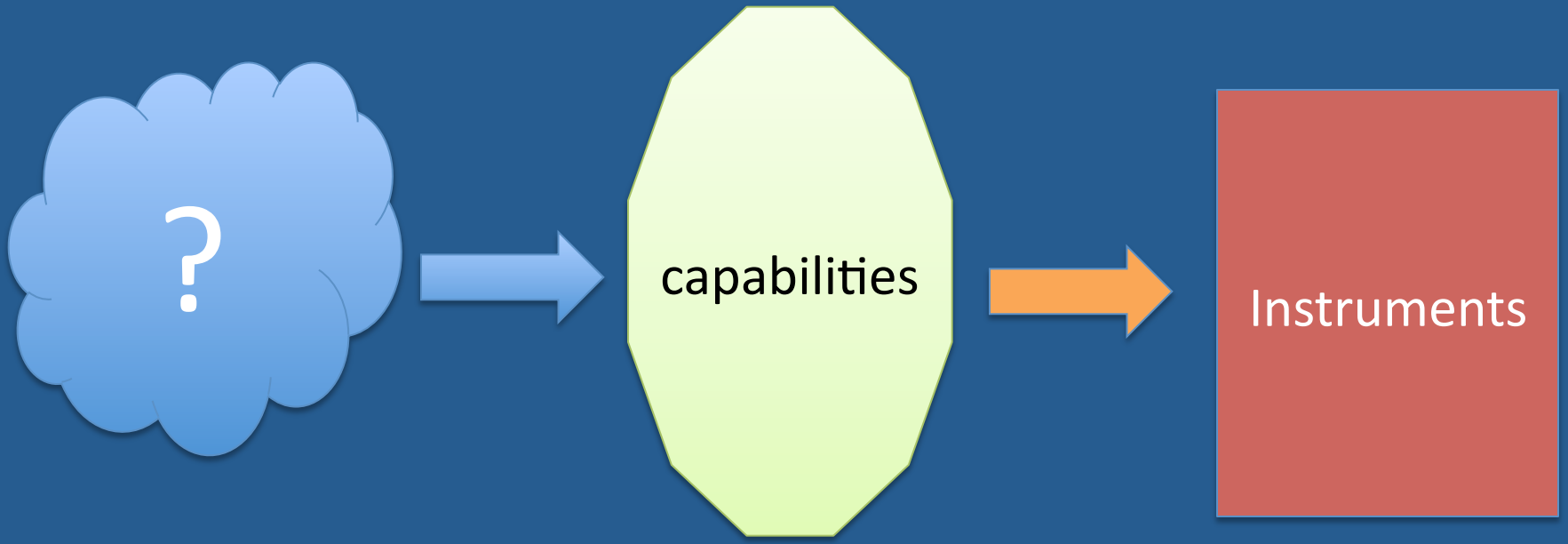
Basic Approach of RMS Panel

- We needed to “market” our program to non-radio-astronomers
- After Senior Review, clear that we needed to also play some defense
- Tried to avoid jargon whenever possible
- Translated radio terms into OIR terms when possible
- Used wavelength, not frequency, units

SFP-PPP Interface

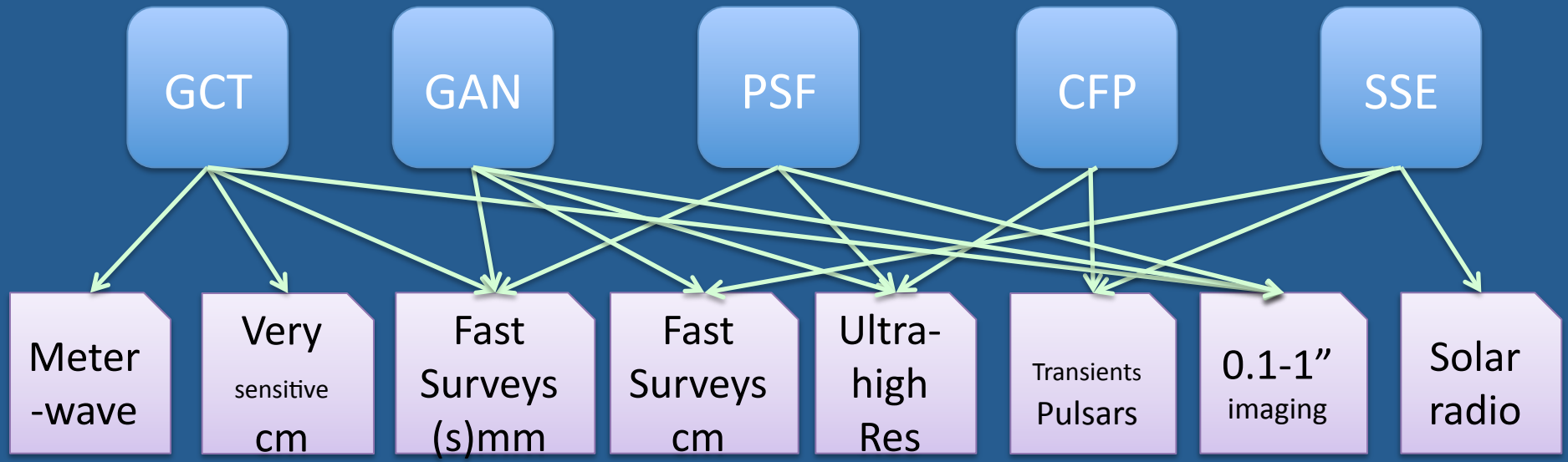
- SFPs

PPPs



RMS Panel Process

- Take the SFP questions and discovery areas
- Translate into needed capabilities
  - In some cases, the SFP had already done this
- Compare to existing capabilities
  - Consider enhancements to existing capabilities
- Compare to proposed new capabilities
- Get CATE process results
- Establish a priority for both new and enhancements
- Try to fit in budget
- Iterate…



Connecting SFP Questions to needed Capabilities

Current and Imminent Facilities

- Ongoing CMB program with many PIs
- meter-wave nascent demonstrators
- cm-wave
  - Arecibo (sensitive survey, but limited sky coverage, not fast)
  - GBT (survey, but not fast)
  - EVLA (sensitive high res, needs better PSF)
  - ATA-42 (fast survey, but lacks sensitivity)
  - VLBA (ultra-high res, not so sensitive)
- mm-smm wave
  - CSO, ARO (survey, old and small, wrong hemisphere)
  - SPT and ACT (small, currently dedicated to SZ)
  - CARMA and SMA (flexible imaging, need to be faster)
  - ALMA (sensitive high res imaging, but missing bands)
  - ad hoc mm VLBI (even higher res, but lack sensitivity)

What's Missing or Inadequate?

- Meter-wave telescope to probe EOR
- Solar radiotelescope
- Large, fast, sensitive mm/smm survey telescope
- Fast surveys for cm transients, pulsar timing
- Very sensitive cm wave imager for HI to z~2
- Sensitive, ultra-high resolution at cm-mm

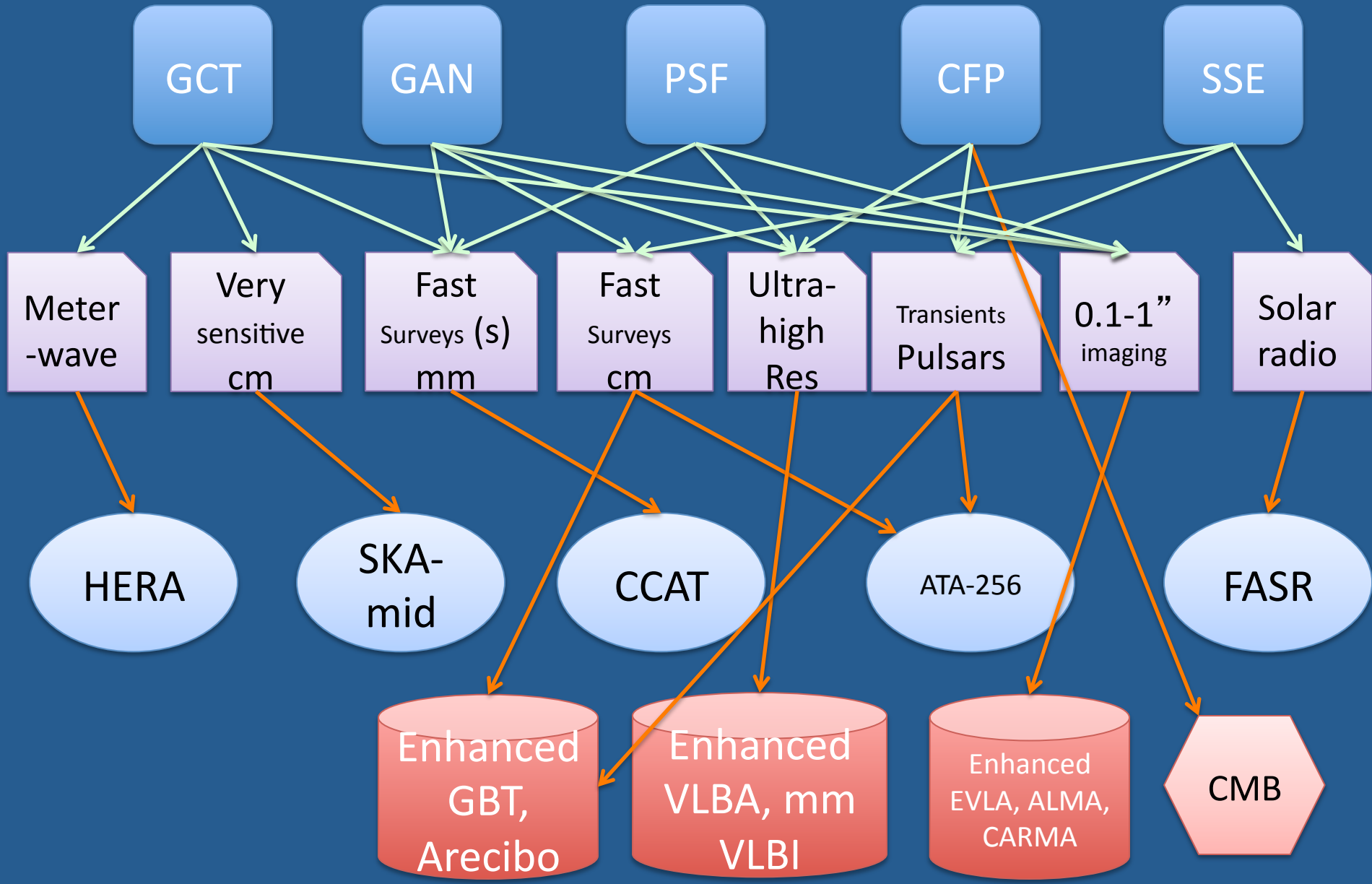
What's on Offer?

- HERA: steps toward meter-wave telescope
- FASR: dedicated solar radiotelescope
- CCAT: fast mm-smm survey telescope in south
- ATA-256: more sensitive surveyor, focus on transients, pulsar timing
- SKA-mid: very sensitive cm-wave imager
- Upgrades to existing telescopes:
  - Arecibo, GBT, CARMA multi-feed receivers
  - ALMA missing bands, VLBI capability
  - EVLA fill in baselines, add wave band, get resolution to 20 mas.
  - VLBA new wideband receivers for sensitivity
  - upgrades to mm VLBI capability (EHT)
- LWA: wavelengths > 3 m, transients, dark ages
- Other things that did not match needs or were less credible

We had to work within a budget profile that assumed a doubling of NSF AST budget over the next decade. Included in that doubling was funding for a mid-scale initiative. We assumed RMS could use all of the increase…

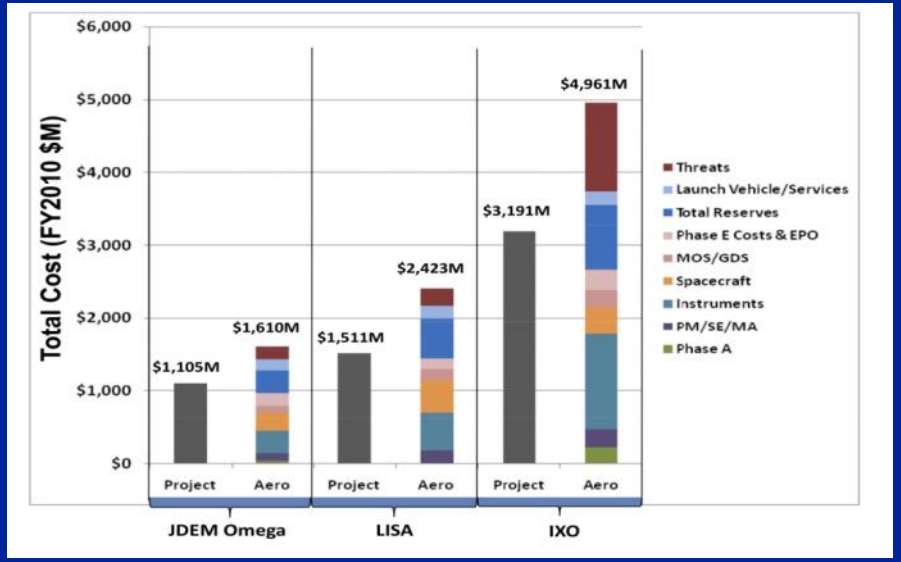
Any Large or Mid-scale project that Astro2010 would ultimately recommend had to go through the CATE process.

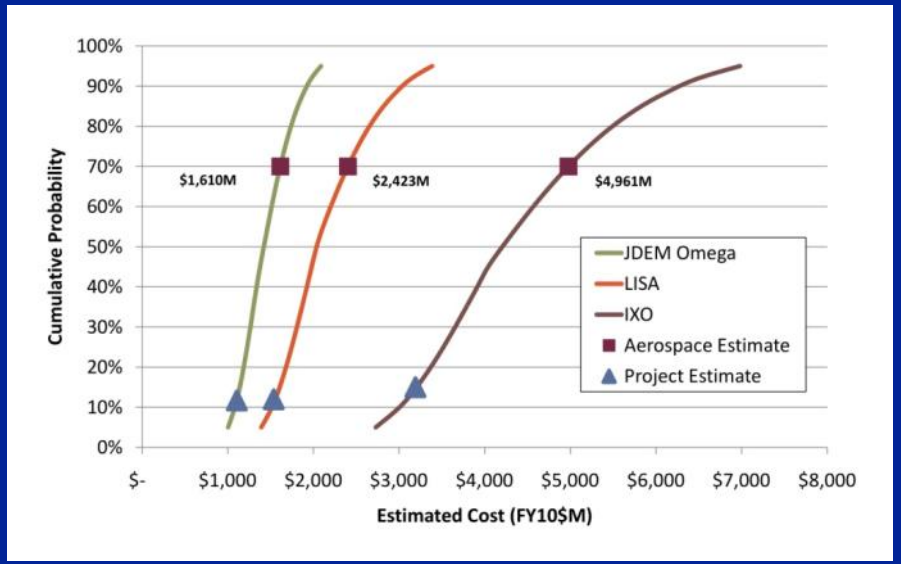
We divided our recommendations into New Initiatives (could access MREFC or mid-scale funding) and Maximizing Return on Existing or Imminent Capabilities (regular funding)


GCT
GAN
PSF
CFP
SSE
Meter -wave
Very sensitive cm
Fast Surveys (s) mm
Fast Surveys cm
Ultra-high Res
Transients Pulsars
0.1-1" imaging
Solar radio
HERA
SKA-mid
CCAT
ATA-256
FASR
Enhanced GBT, Arecibo
Enhanced VLBA, mm VLBI
Enhanced EVLA, ALMA, CARMA
CMB

Cost, Risk, and Technical Evaluation

- 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



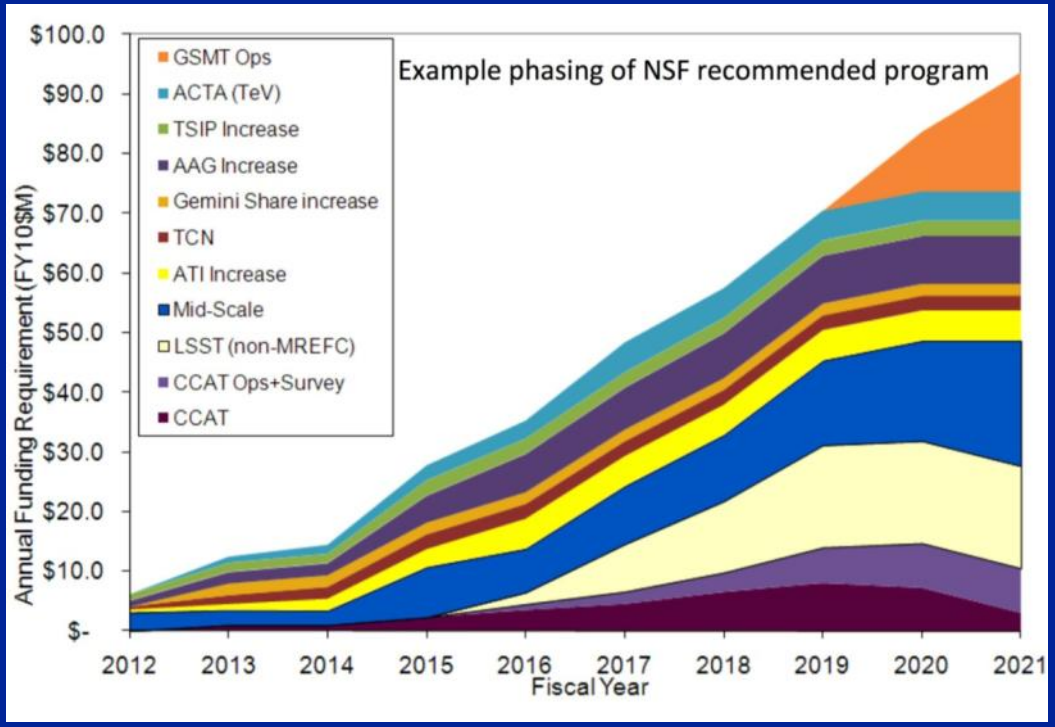


Budgetary Context

- Agency Guidelines
  - NSF and DOE – constant budgets in fixed dollars ($FY2010)
  - NASA – constant real year dollars (declining budget in $FY2010)
- Survey Budgets (the optimistic scenario)
  - NSF and DOE – "doubling" = 4% per year growth in $FY2010
  - NASA – constant in $FY2010 dollars
- Notional "sand charts"
  - Exhibit possible spending profiles consistent with committee budgets and the recommended program, i.e. phasing
  - Allowed the committee to examine possible programmatic scenarios
  - Provide advice in less optimistic budget scenarios

NSF

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



- 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

New RMS Facilities

- HERA: Epoch of Reionization
- CCAT: Galaxy Evolution, Star formation
- FASR: The Sun

From the Sun to the Epoch of Reionization

And…

- Continue a robust CMB program

From the Sun to the Big Bang!

Maximizing Returns

- We have made large investments in ALMA, EVLA, GBT, Arecibo in last two decades
- We have a unique facility in the VLBA
- We have an innovative, varied group of University Radio Observatories (UROs)
  - Student, postdoc training, testbed for instruments
  - In last decade, 160 students, 100 postdocs
- To realize the benefits of these investments:
  - Fund instrument development at ALMA, NRAO, Arecibo, UROs
  - Improve archiving of data

Development at National Observatories

- ALMA (90M$ over decade, 30M$ from US)
  - e.g., add missing receiver bands, VLBI capability
- NRAO (90M$, 0.96M$/yr additional ops)
  - EVLA (15M$, 0.36M$/yr additional ops)
    - new antenna stations, added receiver band
  - GBT (59M$, 0.6M$/yr)
    - Continuum, heterodyne arrays, data handling
  - VLBA (16M$)
    - Wideband 5 cm Rx, data handling

Large-scale Ground-based Program - Prioritized

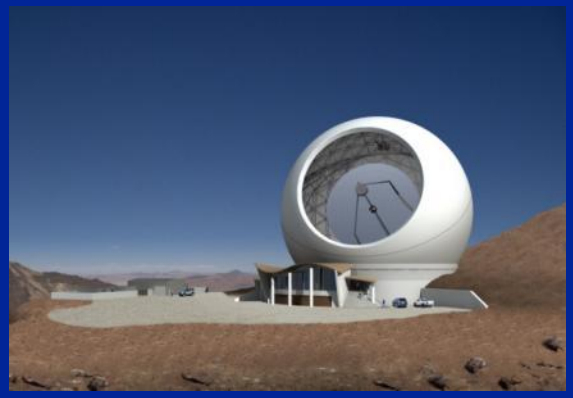
1. Large Synoptic Survey Telescope (LSST)
2. Mid-Scale Innovations Program
3. Giant Segmented Mirror Telescope (GSMT)
4. Atmospheric Cerenkov Telescope Array (ACTA)

Called out for Mid-Scale funding

- 29 White Papers in this range
- Astro2010 calls 8 “compelling” for competed line
- 4 out of 8 are RMS
- Continued robust CMB program
- FASR
- HERA(II)
- Nanograv (PAG)
- Plus…

Medium-scale Ground-based Program

1. Cerro Chajnantor Atacama Telescope (CCAT)



CCAT

- 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

Small-scale Investments

- Target work-force development
  (TSIP, Sub-orbital, AAG, ATP)
- Address changing role of computation and theory
  (TCN)
- Support current/upcoming facilities
  (Gemini, Lab Astro, TCN)
- Develop technology for future
  (NSF ATI, NASA Tech. Dev.)

Radio Astronomy & SKA

- The future opportunities, worldwide, in radio-millimeter-submillimeter astronomy are considerable, but U.S. participation in projects such as the Square Kilometer Array is possible only if there is either a significant increase in NSF-AST funding or continuing closure of additional unique and highly productive facilities.

- Square Kilometer Array (SKA) is a major international collaboration which has very strong scientific support within the U.S. However, no conceivable NSF budget will allow a significant U.S. participation this decade. Consequently, it is recommended that SKA precursors be supported and SKA be re-examined by the next decadal survey.

What did RMS Panel Say?

- See pg. 9-40 to 9-41 of Panel Reports
- "The panel believes that it is very important for the US to play a role in this international project."
- "However, based on the information received from the projects and from independent analysis, none of the parts of this project have reached maturity sufficient to recommend construction at this time."
- "Defining the way forward in this context requires a mix of technology development, demonstrator projects (…), and careful consideration of priorities."

What to do about SKA?

- SKA is now three arrays
  - SKA-low (1.0-3 meters):
    - Support HERA steps toward SKA-low
  - SKA-high (0.6 to 30 cm):
    - Support modest technology development (NAA)
  - SKA-mid (3-100 cm):
    - Continue technology development through ATI
    - Consider more modest/specialized approaches
    - Maintain role in consortium

SKA-mid

- Broad Science goals
  - Fills need for very sensitive cm-wave array
- A very large international project
  - Needs more development til 2012
  - Want to construct mid-late decade
  - Site will be in Australia or Southern Africa
  - If US does not pay, we may not play…
    - Europe, RoW funding ramps up faster than US

SKA-mid

- Project Cost this decade: 712M$ 2013 to 2020
  - To complete: Total US 964M$ + 65M$/yr (2023-)
  - 1/3 of total world cost
- Total Cost:
  - Project 2.2 B$
  - Aerospace estimates 5.9B$
  - Technical risk: Medium-high
    - 3000 antennas, correlator
  - Total cost is very high and not well known
- Technology not ready to recommend construction
  - Significant schedule issues

Summary

- RMS priorities did well in overall priorities
- Current budget problems will make it difficult to capitalize on good outcomes
- Need to think hard about SKA, how to do international collaboration
- Need to keep communicating with, engaging non-RMS community

Backup slides

New for this Survey

- Consideration of the key science themes was done by a group separate from those considering projects. The science deliberations were done first.
- Projects recommended by earlier Surveys but not completed were assumed to be part of the process unless they were already well underway. There were no grandfathered projects.
- Medium and large recommended activities would be subjected to an independent risk assessment and cost appraisal.
- The recommended program would need to fit within a plausible budget profile.
- DOE joined NASA and NSF in providing funding for the execution of the Survey.

Science Frontier Panels

Planetary Systems and Star Formation (PSF) - Lee Hartmann

- Solar system bodies (other than the Sun) and extrasolar planets, debris disks, exobiology, formation of individual stars, protostellar and protoplanetary disks, molecular clouds and the cold ISM, dust, and astrochemistry.

Stars and Stellar Evolution (SSE) - Roger Chevalier

- The Sun as a star, stellar astrophysics, structure and evolution of single and multiple stars, compact objects, supernovae, gamma-ray bursts and solar neutrinos. Extreme physics on stellar scales.

The Galactic Neighborhood (GAN) - Mike Shull

- Structure and properties of nearby galaxies including the Milky Way and their stellar populations, interstellar media, star clusters. Evolution of stellar populations.

Galaxies across Cosmic Time (GCT) - Meg Urry

- Formation and evolution of galaxies and galaxy clusters, active galactic nuclei and QSOs, mergers, star formation rate, gas accretion, global properties of galaxies and galaxy clusters, supermassive black holes.

Cosmology and Fundamental Physics (CFP) - David Spergel

- Early universe, microwave background, reionization and galaxy formation up to virialization of protogalaxies. Large scale structure, intergalactic medium, determination of cosmological parameters, dark matter, dark energy. High energy physics using astronomical messengers, tests of gravity, physical constants as determined astronomically.

The Science Frontier
discovery areas and principal questions

Discovery areas:

- Identification and characterization of nearby habitable exoplanets
- Gravitational wave astronomy
- Time-domain astronomy
- Astrometry
- The epoch of reionization

Questions:

- How did the universe begin?
- What were the first objects to light up the universe and when did they do it?
- How do cosmic structures form and evolve?
- What are the connections between dark and luminous matter?
- What is the fossil record of galaxy assembly and evolution from the first stars to the present?
- How do stars and black holes form?
- How do circumstellar disks evolve and form planetary systems?
- How do baryons cycle in and out of galaxies and what do they do while they are there?
- What are the flows of matter and energy in the circumgalactic medium?
- What controls the mass-energy-chemical cycles within galaxies?
- How do black holes work and influence their surroundings?
- How do rotation and magnetic fields affect stars?
- How do massive stars end their lives?
- What are the progenitors of Type Ia supernovae and how do they explode?
- How diverse are planetary systems and can we identify the telltale signs of life on an exoplanet?
- Why is the universe accelerating?
- What is dark matter?
- What are the properties of the neutrinos?
- What controls the masses, spins and radii of compact stellar remnants?

Science Objectives

- Building on the science priorities identified by the survey, the recommended program is organized by three science objectives that represent its scope:
  - Cosmic Dawn
  - New Worlds
  - Physics of the Universe

- Success in attaining these science goals will enable progress on a much broader front
- Also foster unanticipated discoveries

Program Prioritization Panels

Radio, Millimeter and Submillimeter from the Ground (RMS) - Neal Evans

- Observatories and telescopes that observe primarily in these wavebands

Optical and Infrared Astronomy from the Ground (OIR) - Pat Osmer

- Observatories and telescopes that observe primarily in these wavebands

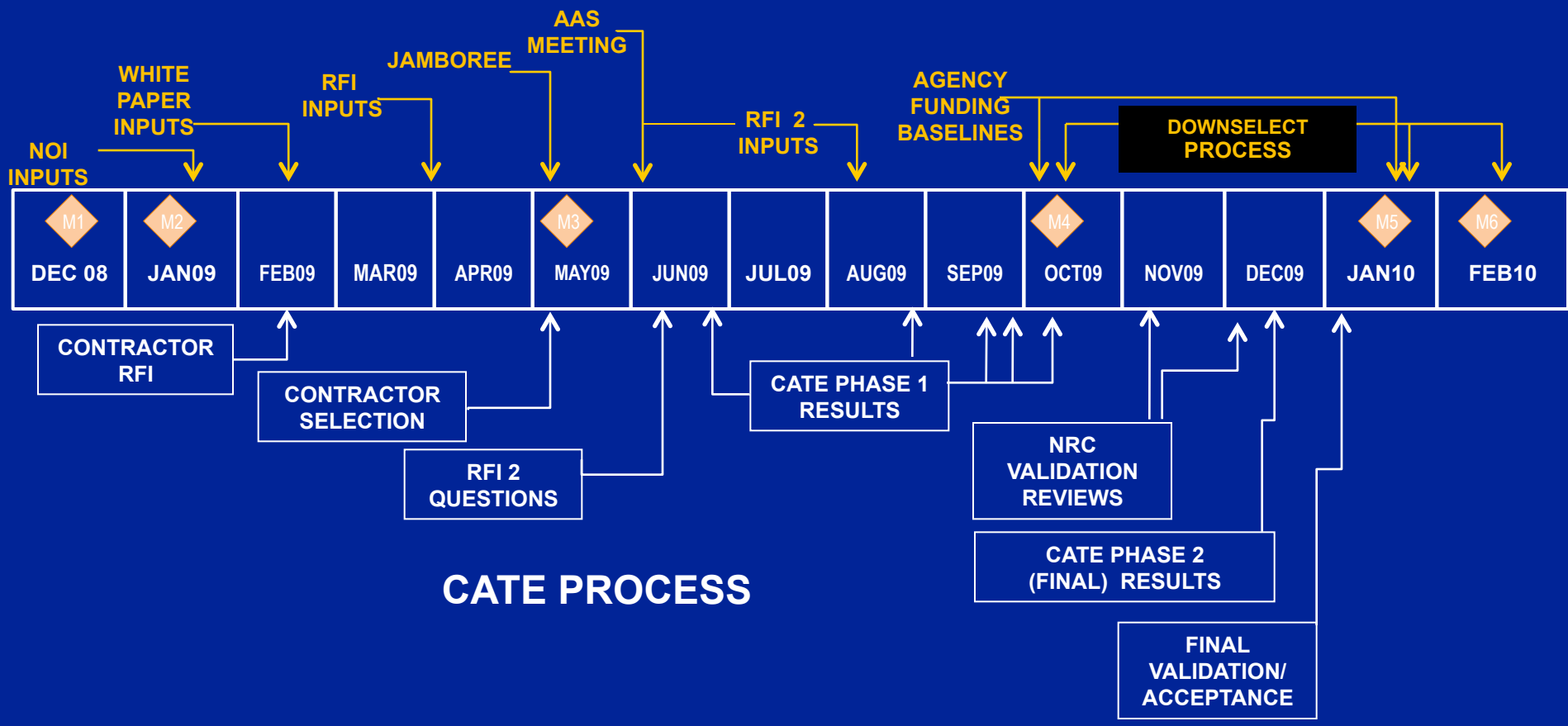
Electromagnetic Observations from Space (EOS) - Alan Dressler

- All space-based astronomical projects observing the electromagnetic spectrum.

Particle Astrophysics and Gravitation (PAG) - Jackie Hewitt

- All projects exploring areas at the interface of physics and astronomy such as gravitational radiation, TeV gamma-ray astronomy, and free-flying space missions testing fundamental gravitational physics.

COMMITTEE PROCESS



CATE PROCESS

DATA GATHERING AND EVALUATION PROCESS FLOW

SKA-mid Recommendations

- We do not recommend proceeding to construction at this point
- Leaves key requirement unmet:
  - Very sensitive cm wave imager
  - Sensitive HI surveys to z ~ 1 cannot be done