Optics Needs for Future NASA Missions

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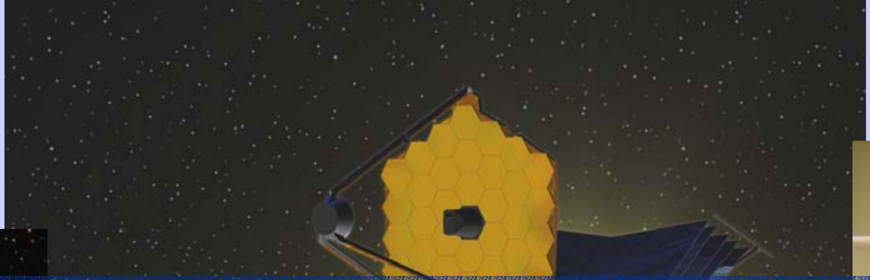
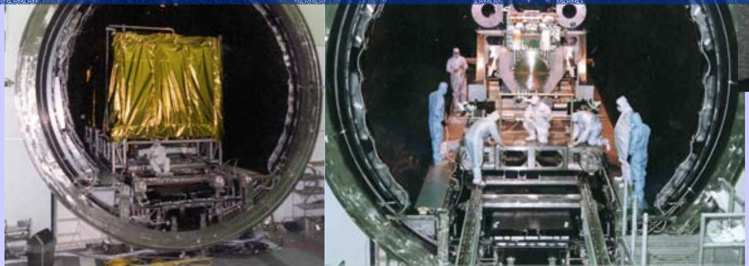




Large-aperture lightweight space optics are critical for NASA space science missions.

Telescopes need to continually double in diameter to answer each generation's next questions in Space, Earth and Planetary Science.

Industry's mirror manufacturing capabilities significantly drive programmatic cost and schedule.

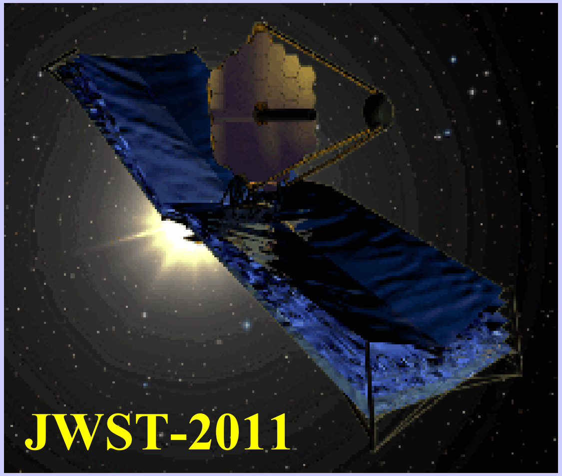
Reducing cost & schedule enables more missions from a limited budget.

Mirror mass significantly drives mission launch costs.

Reducing mirror mass enables the launch of larger telescopes.

These challenges apply equally to normal and grazing incidence systems.

Near Term Missions



Search for Origins

- James Webb Space Telescope (JWST)
- Terrestrial Planet Finder (TPF)
  - coronagraph or interferometer
- Space Interferometer Mission (SIM)

Structure and Evolution of the Universe

- Constellation-X (ConX)
  - 1.6 m Spectroscopy X-ray telescopes (4 highly nested), with 10-arcsec resolution
  - 0.4 m Hard-X-ray telescopes (12 highly nested), with 30-arcsec resolution

Space Environments (NOAA)

- Geostationary Operational Environmental Satellites
  - Solar X-ray Imager (SXI), with 10-arcsec resolution

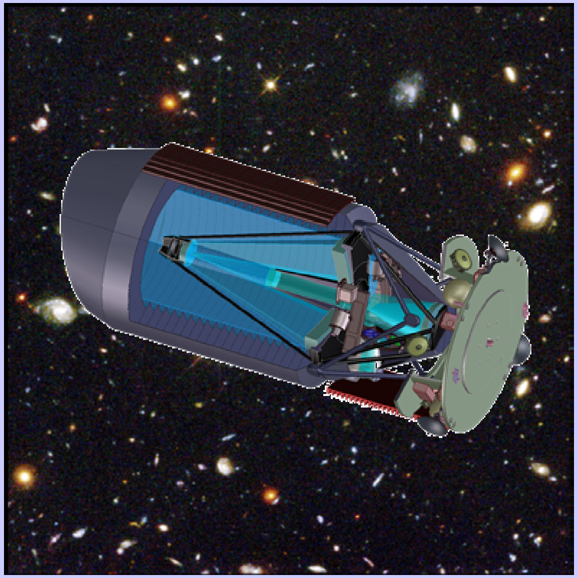
Extreme Universe Space Observatory (EUSO)

- 4 meter class 4 element segmented Fresnel Lens

Intermediate Term Opportunities

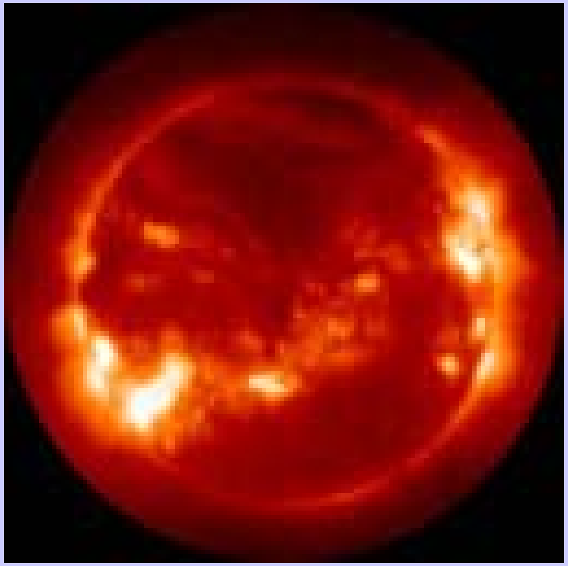
SEU Einstein Probes

- **Dark Matter Probe (DMP)**
  - **Super Nova Acceleration Probe (SNAP)**
  - **Nearly at State of Art**
- **Inflation Probe**
  - **Cosmic Microwave Background Polarization (CMB-Pol)**
  - **Requires Large Low-Cost Cold Mirrors**
- **Black Hole Finder Probe (EXIST)**
  - **Coded-aperture (non-focusing) X-ray imager**



SEC

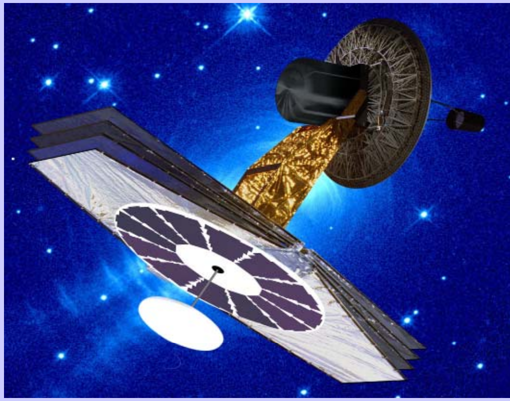
- Magnetic Transition Region Probe (MTRAP)
  - 4 meter class telescope
- Reconnection and Microscale (RAM)
  - EUV/UV Telescopes
  - X-ray telescope, with 1-arcsec resolution for imaging spectroscopy



Vision Missions

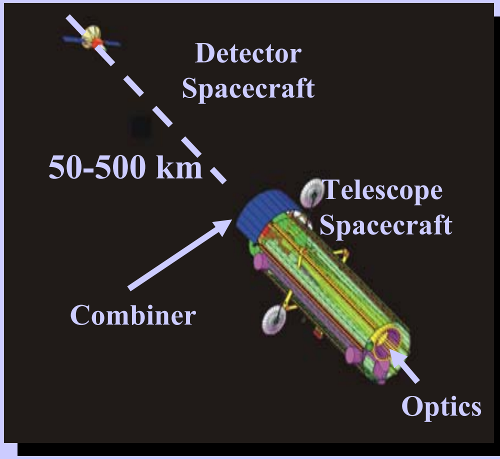
Astronomical Search for Origins (ASO)

- Single Aperture Far Infrared (SAFIR)
  - 8 to 10 m class telescope, Actively Cooled to 4K
- Space Ultra-Violet Observatory (SUVO)
  - 8 meter class telescope
  - UV optics pose major fabrication and metrology challenge
- Life Finder/Planet Imager (LF/PI) – follow on to TPF
- Far-Infrared and Sub-millimeter Interferometer (SPECS)



Structure and Evolution of the Universe (SEU)

- Big Bang Observer (BBO) – requires new lasers
- Black hole Imager (BHI) – X-ray interferometer
- Advanced Compton Telescope (ACT) – detector technology
- Generation X (GenX) – 100 m^2 of X-Ray Optics
  - 4.5 m telescope (6 highly nested), with 0.1-arcsec resolution



Sun Earth Connection (SEC)

- Solar Polar Imager – solar sail
- Intersteller Probe – solar sail
- Solar Imaging Radio Array (SIRA)
- Stellar Imager (SI) – 9 formation flying meter class interferometer

Obvious gap between state-of-art & mission requirements.

Space Science Normal Incidence Mirror Requirements								
Mission	Dia [m]	Config	Seg [m]	ρ [kg/m2]	λ [μm]	Temp [K]	Launch	Current TRL
State of Art								
SIRTF	0.8	Monolith		28	6	4	2003	8
AMSD	1.2	Monolith		22	0.7	270 & 35	2003	4
EUV	0.5	Monolith		40	0.1	270	2002	4
DoD	>2.0	Monolith		<45	0.7	270	2002	8
Litho	0.5	Monolith		**200**	0.05	270	2002	4
GroundTel	8.3	Monolith		**2000**	0.7	270	1999	5
Origins								
JWST	6	Segments	1.2	< 25	2	35	2010	3-4
Eclipse	1.8	Monolith		< 60	0.5	270	2006	4
FKSI	<1	Interfere	5X + 1	30	2	35	2008	3-4
TPF-C Pre	4	Monolith		15	0.5	270	2012	2
TPF-C	4 x 10	Monolith		20	0.2	270	2020	2
TPF-I	3.5	Interfere	5X + 1	5	2	35	2020	2
SEU								
SIRCE	2	Monolith		30	100	4	2012	2
SAFIR	10	Segments	2	10	40	4	2015	2
DMP	2	Monolith		30	1	270	2008	4-5
NHST	8	Segments	1.6	15	0.5	270	2020	3
CMB-POL	2	Monolith		30	250	20	2010	3-4
SPIRIT	2	Interfere	2X + 1	10	40	4	2012	2
SPECS	4	Interfere	3X + 1	10	40	4	2020	2
SEC								
MTRAP	4	Monolith		15	0.5	270	2014	2
MTRAP	1	Monolith		30	0.15	270	2014	4
SCOPE	1	Monolith		30	0.05	270	2015	3
SCOPE	1.2	Monolith		30	0.3	270	2015	3

Sustained intermediate technology development is required …

Industry does not have capability to fabricate & test optical or x-ray mirrors required for many NASA planned missions.

Furthermore, industry is reluctant to invest their own resources in low TRL processes. (Requires Government Investment via NRA's, SBIR's, etc.)

And, since proceeding before technology is mature or down selecting a technology too early places a mission at significant risk of cost and schedule growth.

NASA requires a sustained intermediate technology development effort to:

- Develop technologies that enable missions
- Develop processes that dramatically reduce cost and schedule.
- Mature space telescope optics to TRL 6
  - mitigate programmatic cost & schedule risk.
  - mitigate technical performance risk.
- Provide a technical basis for selecting mission architectures.
- Provide a technical basis for contract insight/oversight & penetration.

… Now

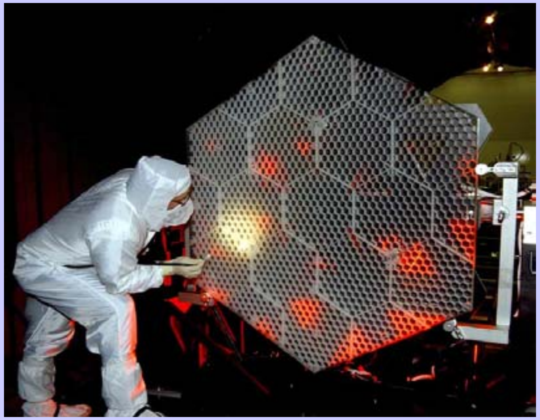
To launch planned missions (SAFIR, SUVO, NHST, MTRAP, TPF) on schedule and on budget, a moderate sustained intermediate technology development effort is required now.

- From its start in 1995, JWST will have taken 8 years to advance lightweight optics for a 30K telescope from TRL-2 to TRL-6 (2003).
- Leveraging JWST 30K optics technology, it might be possible to mature SAFIR 4K optics technology to TRL-6 in 6 years if we start today.
- Leveraging AMSD fabrication technology, it might be possible to mature 4 meter class EUV/Visible optics for SUVO & MTRAP to TRL-6 in 8 years.
- TPF Interferometer requirements are more difficult than either SAFIR or SPECS .
- TPF Coronagraph requirements are more difficult than either SUVO or MTRAP.

MSFC Optical Technology Development Mission Statement

Robust large-aperture low-mass mirrors, that can be rapidly and cost effectively fabricated, are critical to future NASA & DoD space telescopes.

The MSFC Space Optics Manufacturing Technology Center (SOMTC) and its University/Industry Partners are actively developing new enabling techniques for the design, manufacture, test, modeling and control of such mirrors.



Mirror Technology Development Program

NASA and DoD Partners have invested $40M in mirror technology development projects (via contracts, SBIR's and NRA's):

- AMSD - Advanced Mirror System Demonstrator
  - Ball — Semi-Rigid Low-Authority Be
  - Kodak — Semi-Rigid Medium-Authority ULE Glass
  - Goodrich — Iso-Grid High-Authority Fused Silica Glass
- NMSD - NGST Mirror System Demonstrator
  - Arizona — Meniscus Very-High-Authority Glass
  - COI — Rigid Hybrid-Glass-Composite
- SBMD - Small Beryllium Mirror Demonstrator
- SiC & C/SiC
  - IABG (ECM) — 0.5 meter 7.8 kg/m2 mirror has been cryo-tested
  - Xinetics — 0.5 meter 25 kg/m2 mirror has been cryo-tested
- Foam Mirrors
  - Schafer Corp Foam Si
  - MER and UltraMet Foam SiC
- JBMD - Joined Beryllium Mirror Demonstrator
- MSFC Nickel Replication

New Technology make Missions Affordable

Several key technological and manufacturing advances have been developed

Cryogenic Materials – CTE uniformity, dynamic dampening, stiffness, etc.

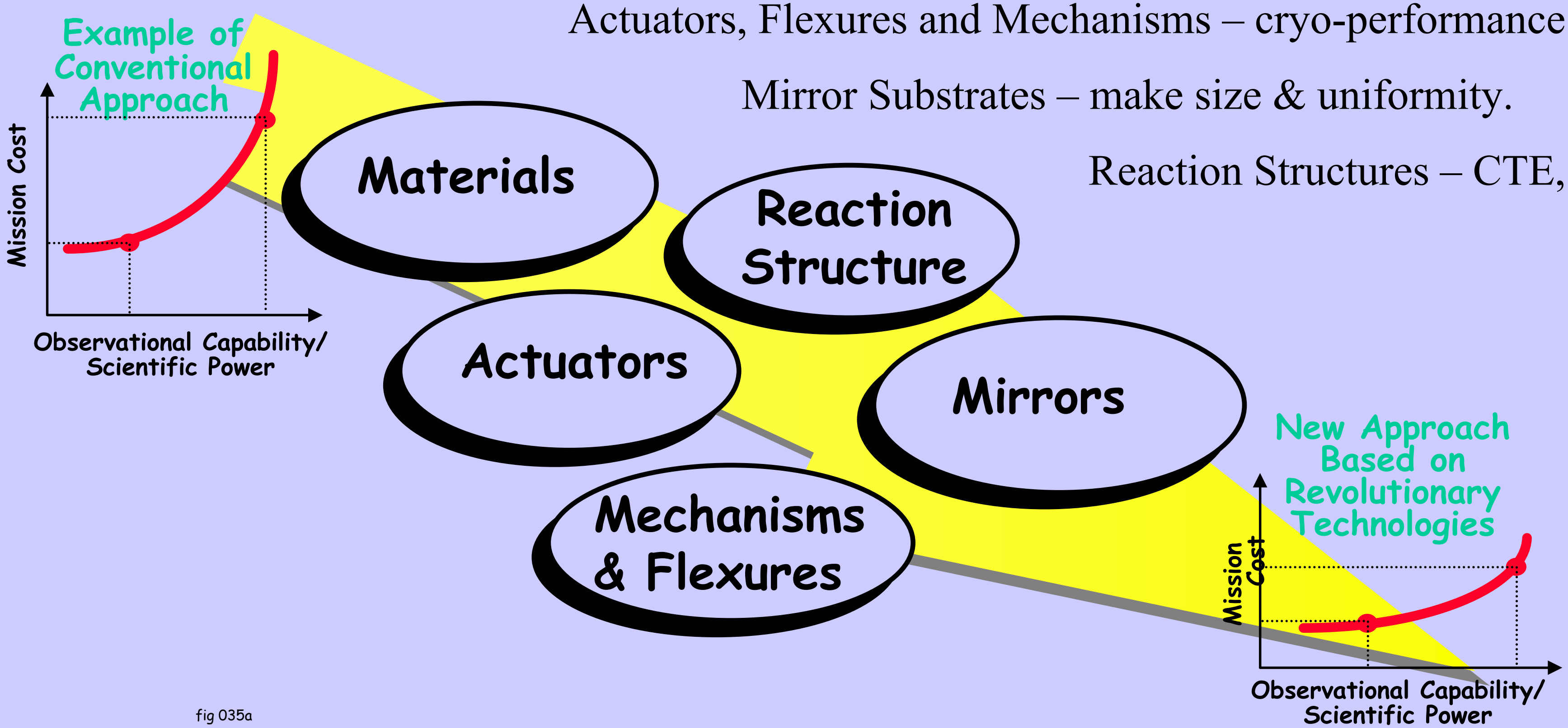
Fabrication Techniques – ability to make size & areal density to required figure.

Cryogenic Performance Characterization – optical testing, cryo-behavior.

Actuators, Flexures and Mechanisms – cryo-performance.

Mirror Substrates – make size & uniformity.

Reaction Structures – CTE, etc.



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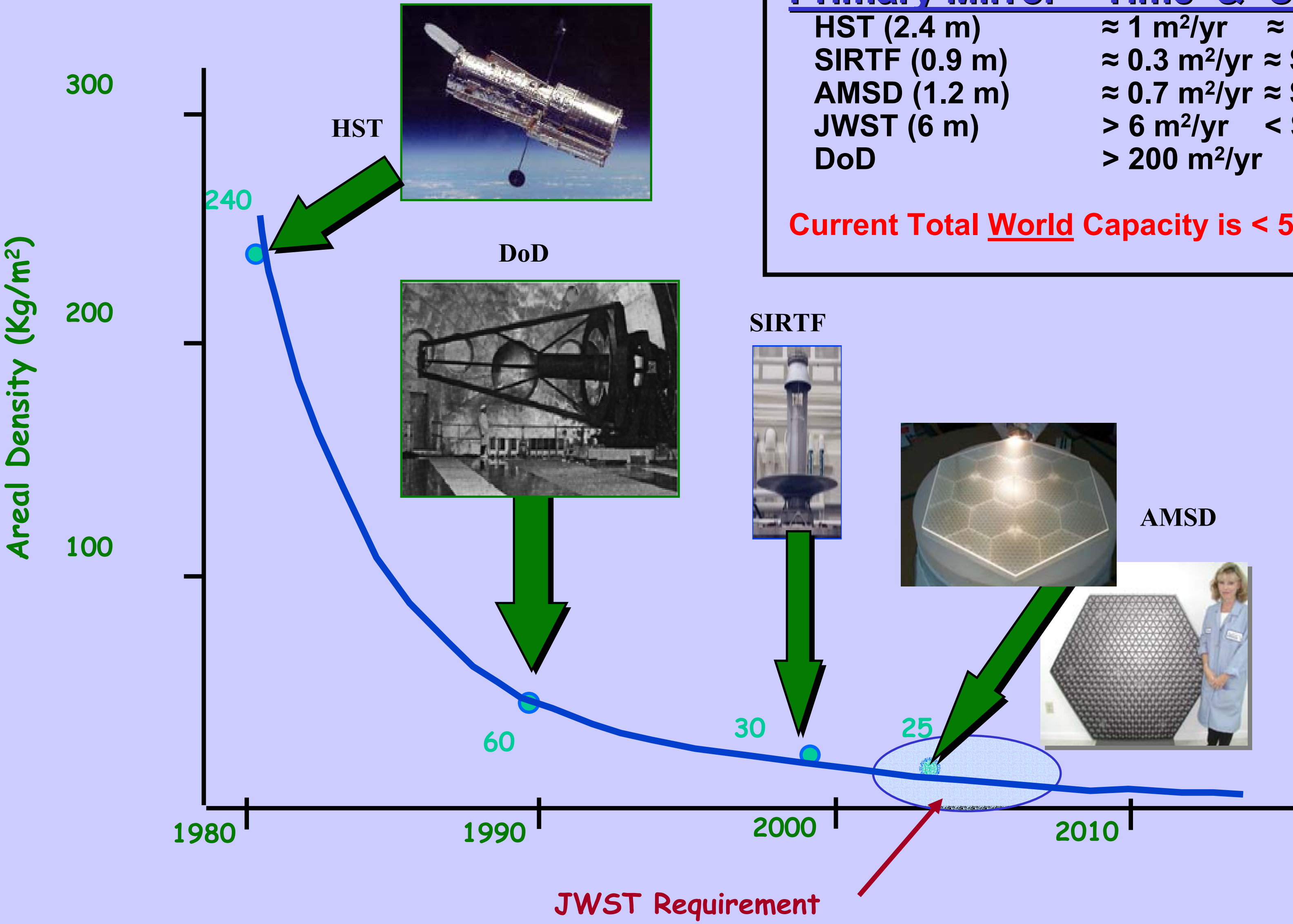
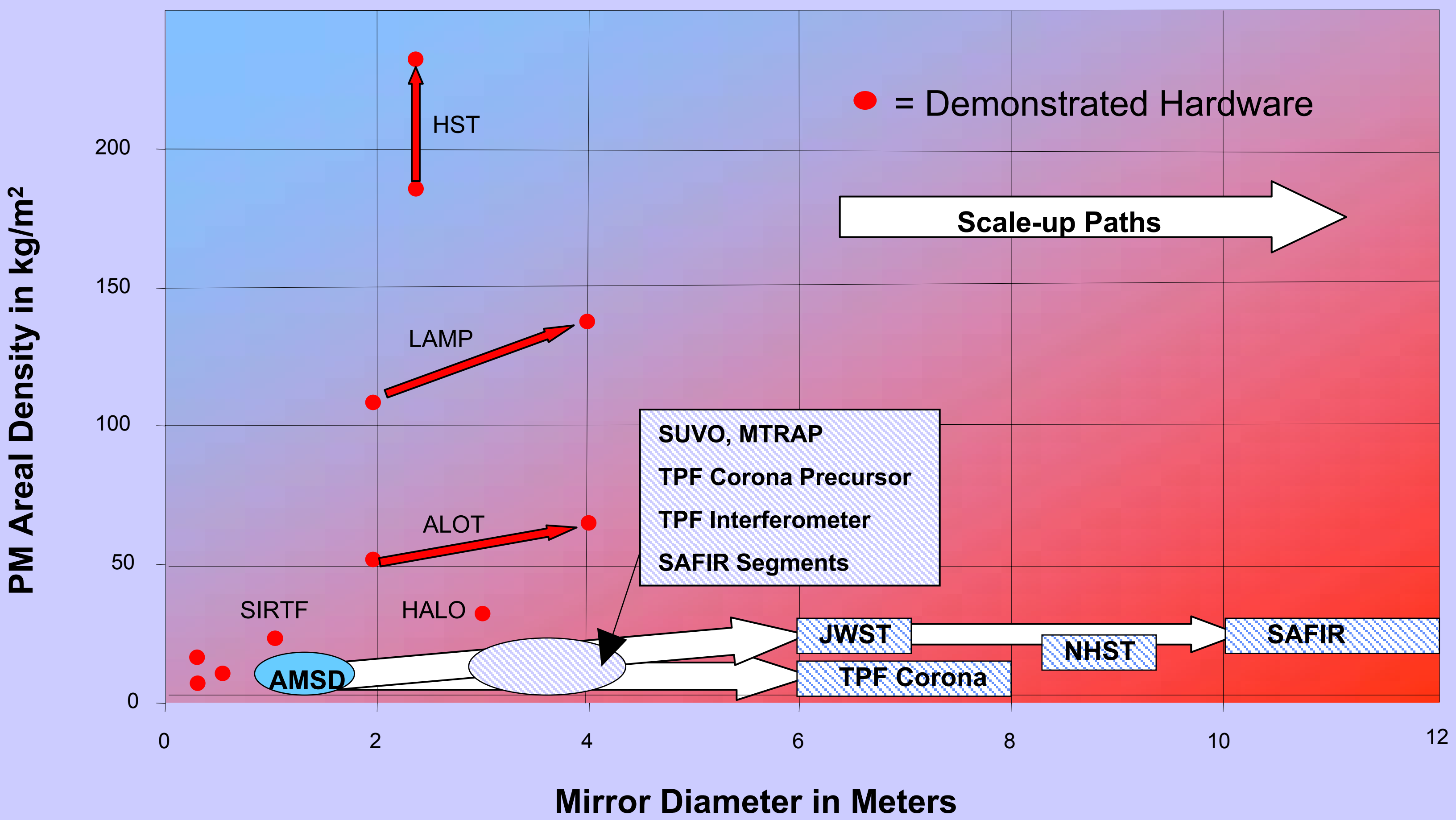
Advances have been made in Areal Density. But, Cost and Schedule are still a Concern

Primary Mirror	Time & Cost	
HST (2.4 m)	≈ 1 m^2/yr	≈ \$10M/m^2
SIRTF (0.9 m)	≈ 0.3 m^2/yr	≈ \$25M/m^2
AMSD (1.2 m)	≈ 0.7 m^2/yr	≈ \$4M/m^2
JWST (6 m)	> 6 m^2/yr	< \$3M/m^2
DoD	> 200 m^2/yr	

Current Total World Capacity is < 50 m^2/yr



Mirror Technology scale-up paths from AMSD/JWST to SUVO, MTRAP, TPF & SAFIR



Normal Incidence Space Optics Technology Roadmap

Two roadmaps are clearly identifiable to leverage an orderly development of achievable technology that maximizes science at a minimum risk.

Cryogenic Optics to enable <10K temeperature optics for SAFIR, SPIRIT, SPECS & TPF Interferometer:

- rapid fabrication and lower cost,
- materials for lighter & stiffer mirror substrates,
- larger aperture & lower mass,
- colder operating temperature.

Goal: Fabricate SAFIR OTE for 1/3 JWST cost & schedule ($200M Savings)

EUV/Visible Ambient Optics to enable 4 meter class (and larger) optics for DMP, SCOPE, MTRAP, SUVO, NHST and TPF Coronagraph:

- rapid fabrication and lower cost,
- full aperture measuring techniques for mid-spatial frequency errors,
- materials for lighter & stiffer mirror substrates,
- larger aperture & lower mass,
- shorter diffraction limited wavelength.

Goal: Scale AMSD technology 4X for MTRAP, TPF, NHST

Collaborate with DoD

Cryogenic Optics Roadmap to SAFIR and Beyond

SAFIR is a direct extension of JWST technology

- JWST – 6 m deployable, 1 m segments, <50K passive, 2 μm wavelength
  - Validates segmented mirror architecture.
  - Validates 1-meter class <50K component fabrication and test.
- CMBPOL – 2 m monolithic, <20K temperature, 250 μm wavelength
  - While no new technology is required, standard Al mirror is of limited reuse value.
  - Examine new substrate materials for lower cost and better performance.
  - Verify using technique developed to cryo-test AMSD structure.
  - Characterize cryogenic material properties – CTE, stability, survival.
- SIRCE & SPIRIT – ~2 m monolithic, 4K temperature, 100 μm wavelength
  - Continue material and fabrication development started for CMBPOL
  - Improve surface figure and lower operating temperature
  - SAFIR Segment Pathfinders
- SAFIR – 10 m deployable, 2 m segments, 4K active, 40 μm wavelength
  - Reduce cost & schedule at least 3X from JWST.

SPECS & TPF Interferometer

- Both need 4-meter class monolithic cryogenic optics.
- This requires a significant advance in the state-of-art beyond SAFIR.
- SPECS is easier because of its longer operating wavelength.

EUV/Visible Optics Roadmap to NHST and Beyond

AMSD – 1.2 m, 0.7 µm

- Validates fabrication and test of 1-meter class lightweight mirrors.
- Validates actuator figure control for 1 micrometer performance.

DMP – 2 m, 0.5 µm

- While no new technology is required, standard mirrors have limited scale-up value.
- Extend AMSD technology to higher areal density, larger aperture & improve figure
- Improve cost & schedule – rapid fabrication

SCOPE – 1 m, 0.05 µm

- Dramatically improve diffraction limited surface figure – mid-spatial errors
- Improve cost & schedule – rapid fabrication
- Metrology Instrumentation

MTRAP, SUVO and Pre-TPF Coronagraph – 4 m, 0.5 µm

- Extend DMP to larger aperture
- Technology includes surface figure, roughness & correctability

NHST – 1.6 m segments, 8 meter full aperture, 0.5 µm

- SCOPE mirrors scale to segments for NHST

TPF Coronagraph – 4 x 10 m, 0.2 µm

- Extend MTRAP/SUVO to larger aperture – very difficult.

Polish AMSD mirrors to SUVO & TPF Specification

Team with DoD

Funding Opportunities

There are currently two opportunities for companies to participate in NASA's Mirror Technology Development Efforts.

SBIR Proposal Solicitation.

Large-Aperture Lightweight Cryogenic Telescope Mirrors

Soliciting proposals that will advance the state Of the art in manufacturing actively cooled large-aperture lightweight cryogenic optics. The goal for this effort is to mature technologies that can fabricate 50 to 100 square meters of flight qualified mirrors at a cost of less than $300K per square meter. These mirrors must be diffraction limited at 5 to 20 micrometers and operate at temperatures from 4 to 10K. It is anticipated that these mirrors will need active cooling. The desired areal density is 3 to 8 kg/m2. High stiffness is also important.

UV Telescope Mirrors

Code R NASA Research Announcement (NRA):

Large Optical Systems

Large, lightweight scalable optical systems for imaging and monitoring celestial objects throughout the electromagnetic spectrum, but with an emphasis on visible through far-infrared. Also, moderate-sized optical systems for far-ultraviolet mirrors and lidar receiver applications.

Conclusion

Large-aperture lightweight space optics are critical for NASA space science (and DoD) missions.

But, an obvious technology gap exists between current state-of-art and future mission requirements.

To enable planned missions (SAFIR, SUVO, MTRAP, TPF), requires:

- Unified moderate sustained intermediate technology development effort.
- Coordinated engineering based technology development team that is accountable to missions.

Goal is to return a 10X cost savings on each dollar invested.