Current Technology Activities

Technology Gaps

Strategic Astrophysics Technology (SAT) Grants
- Coronagraph architectures: modeling and demonstrations
- Wavefront control
- Extreme Precision Radial Velocity
- Detectors

Ultra-Stable Coronagraph Testbeds

Deformable Mirror Survey

Extreme Precision Radial Velocity

Starshade Technology Development

Segmented Coronagraph Design & Analysis Study

Public Engagement Study

Nulling Interferometry Study

Roman/CGI
10 Currently Active Strategic Astrophysics Technology (SAT) Awards

Coronagraph masks/architectures

- Vortex Coronagraph (Serabyn/NASA-JPL)
- Phase Induced Amplitude Apodization Complex Mask Coronagraph (Belikov/NASA-ARC)
- Super-Lyot Coronagraph (Trauger/NASA-JPL)
- Apodized Pupil Lyot Coronagraph (Soummer/STScI)

Wavefront-control techniques

- Single mode fiber and optimization for spectroscopy (Mawet/Caltech)
- Linear Dark Field Control (Guyon/Arizona)
- Multi-star Wavefront Control (Belikov/NASA-ARC)

Detectors

- Vis-band rad-hard photon-counting detectors (Rauscher/NASA-GSFC)
- Ultra-stable mid-IR detector array (Staguhn/JHU)

Extreme Precision Radial Velocity

- Micro-resonator optical etalon for radial velocity measurements (Vasisht/NASA-JPL)
Segmented Coronagraph Design & Analysis Study

- **Purpose:**
  - Coronagraph feasibility with segmented-mirror telescope
  - Coronagraph/segmented telescope system feasibility

- **Preliminary end-to-end modeling of telescope dynamics, wavefront control, and coronagraph -> science yield**

- **Close collaboration with Ball and Lockheed telescope modeling**
  - Reconfirmed requirement for ~10 pm WFE stability, per LUVOIR report

Next Steps:
- Understanding benefits of wavefront control techniques with both natural and laser guide stars
- Study further damping of telescope modes that most impact the science yield
- Pursuing higher fidelity Integrated Telescope-Coronagraph modeling

<table>
<thead>
<tr>
<th>RMS Amplitude [pm]</th>
<th>Yield Loss (compared to no aberration)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0%</td>
</tr>
<tr>
<td>10</td>
<td>2%</td>
</tr>
<tr>
<td>100</td>
<td>92%</td>
</tr>
</tbody>
</table>
Deformable Mirror Survey

- Goal: Survey and document viable DM technologies across the world to inform future exoplanet missions of their capabilities and technology readiness
- Completed in May 2021

- Looked at 14 candidates in 6 countries:
  - Xinetics and BMC are currently the best options – ALPAO is a backup candidate
  - New promising technology identified (Microscale, Obsidian, SLM)

- Recommended next steps:
  - Develop high actuator count devices
  - Advance DM electronics and connectorization
  - Develop backup technologies
  - Continue to revise DM survey annually

- Look for an ExEP Technology Colloquium on this topic coming soon
Starshade Technology Activity

Angelle Tanner, MSU

Starshade Data Challenge launched: all synthetic images released to two challenge teams

Brian Dunn, Quartus Engineering

Optical Modeling:
All variant subscale starshades for model validation built and measured at Princeton testbed

1 see them for yourself at https://exoplanets.nasa.gov/exep/technology/starshade-data-challenge/


Special section on starshades published in April 2021 issue of JATIS

Improved error budgeting,
Revisiting earlier results: e.g. petal optical edge bonded joint redesign

Edge before redesign

Edge after redesign
• The Past, Present, and Future of Nulling Interferometry
  Gene Serabyn (JPL)

• Ground-based Coronagraphy plus High-Resolution Spectroscopy
  Nem Jovanovic (Caltech) and Arthur Vigan (LAM)

• Recordings and slides available:
  – https://exoplanets.nasa.gov/exep/technology/tech_colloquium/
Astro2020 and ExEP Technology

- ExEP’s technology priorities flow from recommendations in the Decadal Survey and NASA’s implementation plans

- Planning underway to align ExEP (and PCOS/COR, HQ) technology activities with recommendations in the 2020 Decadal Survey
  - Astrophysics Technology Gap list update to support the SAT 2021 call for proposals
  - Analyses of the decadal survey recommendations
    - “Dot product” assessment of current investments vs. recommendations of Astro2020
    - Input to HQ on competed/directed technology

TABLE ES.4  Space: Recommended Activities—Medium-Scale (Priority Order)

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Science</th>
<th>Appraisal of Costs</th>
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</thead>
<tbody>
<tr>
<td>1. New Worlds</td>
<td>Preparation for a planet-imaging mission beyond 2020, including precursor science activities</td>
<td>$100M to $200M</td>
</tr>
<tr>
<td>2. Inflation Probe</td>
<td>Cosmic microwave background (CMB)/inflation technology development and preparation for a possible mission beyond 2020</td>
<td>$60M to $200M</td>
</tr>
</tbody>
</table>
2021 APD Technology Gap List

• Technology Gap List update this year will be responsive to Decadal
  – Prioritization will be adjusted to reflect mission priorities from Decadal
  – We are prepared to add new technology gaps

• We are now accepting new technology gaps from the community
  – Will be considered for prioritization
  – Due date is 3 weeks after release of Decadal Survey report
  – Astrophysics Technology Gap List update schedule is driven by plans for SAT 2021

• Stay tuned for the SAT 2021 call..
Exoplanet Missions

NASA Missions

CoRoT

Hubble

Spitzer

W. M. Keck Observatory

KEPLER

TESS

JWST

CHEOPS

PLATO

ARIEL

Gaia

Roman

ESA Partner Missions

1 NASA/ESA Partnership
2 NASA/ESA/CSA Partnership
3 CNES/ESA
4 ESA/SSO
5 NASA/ESA/ESO/STScI Partnership
6 NASA
7 ESA
8 NASA
Technology Gap List

• **Astrophysics Technology Gap List**
  - Technology gaps for all three NASA Astrophysics Division (APD)’s programs
  - Database of technology activities:
    - [http://astrostrategictech.us/](http://astrostrategictech.us/)
  - Update coming in 2021, post-decadal

• **Exoplanet Technology Gap List**
  - Subset of APD gap list corresponding to exoplanet science:
    - [https://exoplanets.nasa.gov/exep/technology/gap-lists/](https://exoplanets.nasa.gov/exep/technology/gap-lists/)
Starshade Technology Activity

- Starshade Data Challenge launched, all synthetic images released to two challenge teams.¹
- Special section on starshades published in April 2021 issue of JATIS²
- All variant masks for contrast optical model validation built and measured at Princeton testbed
- Milestone 6A report on petal thermal deformation revised for final submission to ExoTAC
- Debris disk scattering phase functions added to starshade noise budget
- Secondary solar reflection analysis underway to set requirements on starshade out-of-plane deformations
- Petal optical edge bonded joint re-designed, and shown to survive environmental testing.

¹ see them for yourself at https://exoplanets.nasa.gov/exep/technology/starshade-data-challenge/
MEMS Deformable Mirrors

- 2000-actuator Deformable Mirror demonstrations in vacuum
  - MEMS DM narrowband demo in Decadal Survey Testbed contrast $8 \times 10^{-10}$ from 3.5 to 13.5 $\lambda/D$ narrowband at 516 nm; $2 \times 10^{-9}$ 10% band

- Two 2000-actuator MEMS DM’s to undergo launch-level vibrations
  - one not coated (to allow IR microscopy)
  - one coated

- Pre-test performance characterization underway

- Next step: expose devices to random vibe
S5: Closing Starshade Technology Gaps

https://exoplanets.nasa.gov/exep/technology/starshade/

Milestone Completed
Report under Review
In Progress
Not Started

Gap 1
Starlight Suppression
- Complete by CY21
  - Contrast NB 1A
  - Contrast BB 1B
  - Modeling Validation 2

Gap 2
Scattered Sunlight
- Complete by CY21
  - Edges 3
- Sensing 4

Formation Flying
- Complete by CY25

Gap 3
Shape Accuracy
- Critical Features
  - Petal 5A
  - Truss Bay 7A
  - Inner Disk Deployment 7C

Shape Stability
- Petal 6A
- Inner Disk (thermal) 8A

Optical Model Validation Milestone 2:
- Five of six ‘variant shape’ masks made and tested
- Enormous progress on understanding vector diffraction effects in small-scale starshade masks
- Delay primarily due to COVID-19 restrictions on mask production

Milestones completed in FY20
V-NIR Coronagraph/Telescope Technology Gaps

Contrast
- CG-2: Coronagraph Architecture
- CG-3: Deformable Mirrors
- CG-4: Data Post-Processing

Angular Resolution
- CG-1: Large Monolith Mirrors
- CG-1: Segmented Mirrors

Contrast Stability
- CG-5: Wavefront Sensing and Control
- CG-6: Mirror Segment Phasing
- CG-7: Telescope Vibration Sensing and Control or Reduction

Detection Sensitivity
- Ultra-low Noise Visible (CG-8) and Infrared (CG-9) Detectors
Other Technology Gaps

UV Contrast
CG-10 UV/V/NIR Mirror Coatings

Stellar Reflex Motion Sensitivity
M-1: Ground-based Ultra-high Precision Radial Velocity
M-2: Laser Frequency Combs for Space-based EPRV
M-3: Astrometry

UV Detection Sensitivity
CG-12: Ultra-low Noise UV Detectors

Transit Spectroscopy Sensitivity
M-4: Ultra-stable Mid-IR Detectors for Transit Spectroscopy
Mid-IR Technology Gaps

Mid-IR Coronagraph Contrast

CG-10 UV/V/NIR Mirror Coatings

Transit Spectroscopy Sensitivity

M-4: Ultra-stable Mid-IR Detectors for Transit Spectroscopy