OFFICE OF THE DIRECTOR OF NATIONAL INTELLIGENCE

# Amon-Hen

## Proposers' Day Brief

Merrick DeWitt

11 May 2017

# Amon-Hen Proposers' Day Agenda

| Time | Topic | Speaker |
|---|---|---|
| 9:00am – 9:30am | Logistics, Program Introduction | Dr. Merrick DeWitt<br>Program Manager, IARPA |
| 9:30am – 9:45am | IARPA Overview and Remarks | Dr. Lee Knauss<br>Chief, Technology Transition, IARPA |
| 9:45am – 10:45am | Amon-Hen Program Overview | Dr. Merrick DeWitt<br>Program Manager, IARPA |
| 10:45am – 11:15am | Break | |
| 11:15am – 11:45am | Doing Business with IARPA | Mr. Tarek Abboushi<br>Chief Acquisitions Officer, IARPA |
| 11:45am – 12:15pm | Amon-Hen Program Questions & Answers | Dr. Merrick DeWitt<br>Program Manager, IARPA |
| 12:15pm – 12:30pm | Break | |
| 12:30pm – 1:00pm | Presentations, Poster Session, Networking, and Teaming Discussions | Attendees<br>(**No Government**) |

# Disclaimer

- This Proposers' Day Conference is provided solely for information and planning purposes.

- The Proposers' Day Conference does not constitute a formal solicitation for proposals or proposal abstracts.

- Nothing said at Proposers' Day changes the requirements set forth in a Broad Agency Announcement (BAA).

# Proposers' Day Goals

- Familiarize participants with IARPA's interest in research in novel interferometric approaches for imaging dim objects.
- Familiarize participants with IARPA's mission and how to do business with IARPA.
- Provide answers to participants' questions.
  - This is your chance to alter the course of events.
- Foster discussion of synergistic capabilities among potential program participants, i.e., facilitate teaming.
  - Take a chance – someone might have a missing piece of your puzzle.

# Important Points

- Proposers' Day slides will be posted on iarpa.gov
- Please save questions for the end, write on notecards
- Posters are available for browsing during break/lunch
- Government will not be present during the poster/teaming session
- Discussions with PM allowed until BAA release
  - Once BAA is published, questions can only be submitted and answered in writing via the BAA guidance.
- Name/email list of Proposers' Day participants provided to the group **with permission**

# IARPA Introduction

**Dr. Lee Knauss**

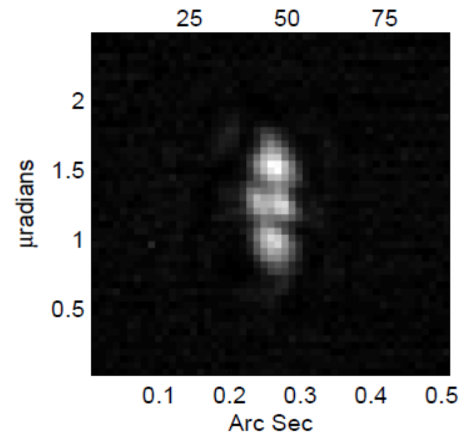
**Chief, Technology Transition, IARPA**

# Amon-Hen
# Program Introduction

# The Problem:
# Ground-based Imaging of GEO Satellites

**State of the Art**

- Low resolution imaging with large apertures (e.g., Keck II)
- Preliminary efforts at NPOI and MROI




**Factors preventing technological advancement**

- Cost!
- Low signal

**What We Need**

- Novel approaches to bend the cost curve
- Low cost approaches that collect fringe measurements rapidly to enable observation of multiple GEO objects per evening

**Rapid Acquisition of Interferometric Data for GEO Objects**

# The Solution: Amon-Hen

**Program Goal**

**Asymmetric (small/large) telescope configurations to enable a low cost, rapid acquisition interferometer**

**Technological Development needs**

- Novel approaches to large-scale interferometry
- Improved approaches to fiber collection and fiber path length compensation
- Revolutionary advances in detector design

**System Requirements**

- Rapid observation of visible GEO objects
- Hardware development must be traceable to fully resolved images with 12.5nanoradian angular resolution with an image interpretability equivalent to Space Object Rating Scale (SORS) Level 6
- Measurement thresholds must be consistent with observation and resolution requirements – *notional brightness 6 mJy/fsr*
- Develop image reconstruction techniques that enable timely image development*

# Amon-Hen
# Technical Overview

# How is it Done Now?

| Past/Current Programs | Description |
|---|---|
| DARPA Galileo | Few, 1.5m class telescopes on mobile platforms connected via fiber for systematic collection of diverse baseline measurements |
| Naval Precision Optical Interferometer (NPOI) | Multi-baseline bootstrapping to increase long baseline SNR; coherent integration of signal; null-crossing baseline phase detection for faint object detection; demonstrated 1.3m capability with current upgrades intended to reach 20cm resolution |
| Magdalena Ridge Observatory Interferometer (MROI) | Currently upgrading facility with several 1.5-2m class telescopes (with AFRL) to extend research in GEO satellite imaging |
| Telescopic Observation (e.g., Keck II, MMT) | State of the art adaptive optics with large aperture telescopes, often in multiple wavebands |

Specific technologies used in ground-based detection include:

- Adaptive optics
- Kilohertz baseline path length compensation
- Fringe acquisition/measurement
- Image reconstruction
- Object acquisition and tracking

# Current Limitations

- **Aperture size requirements:**
  - No interfering aperture can be larger than ~1.5-2m
  - Smaller apertures reduce cost, but at the expense of SNR – 1.5m/1.5m measurements already challenging!
  - However, small apertures avoid the need for adaptive optics
- **Light transport:**
  - Evacuated beam lines are complicated and expensive (NPOI, MROI)
  - Fiber beam transport challenging for long-baseline phasing (DARPA Galileo)
- **Complex object structure/fluence:**
  - Finding and locking fringes challenging for GEO light
  - Even locked fringe measurements have challenging measurement SNR
- **Data and image reconstruction challenges:**
  - Low SNR presents reconstruction challenge
  - Low baseline diversity presents reconstruction challenge

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COST!

# Component Requirements & Key Enabling Insights

- **What makes Amon-Hen possible now?**
  Achievements/advancements in component development
  - All-fiber light transport demonstrating fringe acquisition and measurement (DARPA Galileo)
  - All-on-all multiple-band fringe acquisition and measurement (MIT-LL)

  Separation of conflicting requirements
  - High SNR requirement for fringe acquisition - utilize large apertures / simple sources: *natural guide stars*
  - Avoid expense of many large apertures and associated adaptive optics for actual fringe measurement: use small apertures (15-20cm diameter) to radically reduce system costs
- **Phase 1:** Development of component technologies to provide robust system fundamentals; laboratory demonstrations of component metrics that demonstrate path to system build, development of image reconstruction algorithms and system modeling capabilities to support System Design Review (SDR)
- **Phase 2:** Maturation of component technologies to enable open sky measurements; continued development of image reconstruction algorithms and system modeling capabilities (informed by developed component capabilities) to support Critical Design Review (CDR) ; open sky experiment coordinated with large aperture owner (TBD) – full interferometry test with ~25 small apertures
- **Future:** Pending successful Phase 2 testing and supporting simulation/modeling results, a funding consideration will be made regarding a full demonstration effort

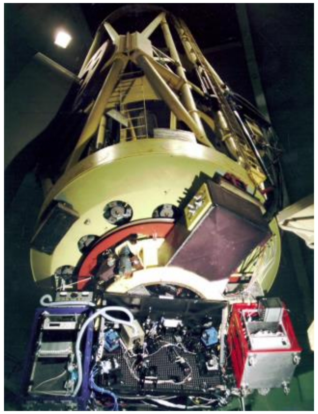
**Bench demonstrations of capabilities – mature to open sky testing**

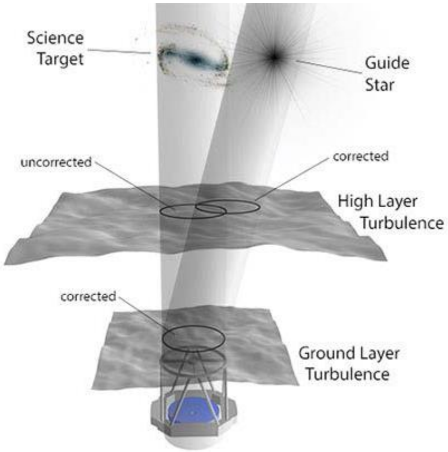
# Component Requirements & Key Enabling Insights

- **What makes Amon-Hen possible now?**

Separation of conflicting requirements

- High SNR requirement for fringe acquisition - utilize large aperture / simple sources: natural guide stars
- First demonstrated at Lick Observatory - 1994
- Large aperture contributes only natural guide star light to the overall approach – high-layer turbulence problem is not relevant to approach






Extension of Natural Guide Stars to Interferometry

- Natural guide star phase referencing for faint companion interferometry - Palomar Testbed Interferometer beginning late 1990's

- Avoid expense of many large apertures and associated adaptive optics for actual fringe measurement: use piston-limited apertures (15-20cm diameter) to radically reduce system costs
- Large aperture/small aperture combinations used to phase baselines (bootstrap) in real time
- Small aperture/small aperture combinations are bootstrapped to enable GEO fringe measurements
- MANY small aperture pairs required to collect enough photons/baselines

**Separation of tasks reduces cost and increases capabilities**

# Light Collection Thrust Area

- **Light collection requirements:**
  - Must phase all small apertures to large aperture in real time – kilohertz or multikilohertz updates to compensate for atmospheric seeing
    - Rates well within existing adaptive optics capabilities
    - Many aperture approach will present a challenge
    - Large/small aperture asymmetric approach is notional – offerors can (*and are encouraged to!*) provide their own approaches that meet the overall cost and performance requirements of the program
  - Must combine light from multiple apertures via cost-effective approaches
    - The DARPA Galileo all-fiber approach might be cost effective and flexible but presents challenges, particularly for long baselines
    - The NPOI/MROI evacuated beam line approach may be cost prohibitive and lack desired system flexibility
    - A hybrid approach may be the best compromise
    - These are notional approaches – offeror approaches are likely to be among these solutions but novel approaches (*particularly efficient, low cost approaches*) not listed here are welcomed as long as the offeror can demonstrate effective performance and cost

# Light Measurement Thrust Area

- **Light measurement requirements:**
  - Must demonstrate a capability to collect and measure interferometric light that leads to resolved images of GEO satellites as detailed by the program requirements
    - Many aperture approach will require a revolutionary advance in imager design
    - Most direct path to interferometric measurement is the design of a many-on-many (or all-on-all) interferometer that simultaneously measures fringes from all interfering pairs – multiband measurement is a likely requirement to reach program goals
    - Can multiple, separate detectors be used to reduce explosion of fringe count?
    - Is there are new approach here we haven't thought of?
  - Resolved imagery of GEO objects might not require direct measurement of fringes
    - Coherent Optical Beam Forming approach reimages fiber output to reproduce image on focal plane array
    - Extremely challenging many-fiber sub-wavelength position control – but is it more challenging than the all-on-all (or many-on-many) multiband detector design?
    - Also simplifies (but does not solve) bandwidth concerns
  - Has the Amon-Hen program failed to identify any relevant technological breakthroughs here? Offerors should propose any measurement approaches they prefer that can meet program goals

# Algorithm Thrust Area

- **Algorithm requirements:**
  - There are two algorithm development requirements
    - IMAGE RECONSTRUCTION – develop algorithms for image reconstruction
      - Image reconstruction algorithms will be unique to the Amon-Hen program as a result of the fact that many apertures can potentially provide a large number of measurements relative to unknowns – fairly unique for “sparse” aperture approaches
      - Offerors adopting a Coherent Optical Beam Forming approach will have their own image processing requirements but these requirements are likely to be much less challenging
    - SYSTEM MODELING – develop robust, physics-based system models which incorporate system design philosophy and real (demonstrated, measured) component metrics to project objective system operation and capabilities

# Amon-Hen
# BAA Overview

# Program Structure

- Phase 1 (15 Months)
  - Modeling and fundamental research

| Collection | Detection | Algorithms |
| --- | --- | --- |
| • Aperture/fiber coupling<br>• real-time fiber path length compensation<br>• high volume manufacture of small apertures | • Multiband interferometer (fringe) detector<br>- or -<br>• Wide bandwidth detector employing coherent optical beam forming | • Image reconstruction algorithms<br>• Modeling/simulation of performance based on interferometer geometry and hardware performance metrics |

- Phase 2 (18 Months)
  - Applied component research, component integration tasks, and preliminary demonstrations
- Future
  - Potential for a full demonstration phase based on Phase 2

# BAA Highlights

- Release BAA for Phases 1 & 2 – possible second BAA release for a full demonstration effort
- Offeror team must address all program requirements within each research area
- No partial proposals, such as development of specific component technology, will be accepted
- The Government anticipates that Phase 1 & 2 proposals submitted under this BAA will be unclassified
- Multiple awards are expected
- Foreign participants and/or individuals may not participate

# Metrics for Phase 1 Thrust Areas

| Thrust Area | Metric / Performance |
|---|---|
| Collection | • Demonstrated end-to-end aperture/fiber coupling efficiency for small apertures and large apertures consistent with modeling and simulation requirements pointing to successful demonstration of program goals<br>• Laboratory demonstration of phase correction between simulated aperture inputs separated by maximum baselines consistent with modeling and simulation requirements<br>✓ *Phase correction demo must employ fluences consistent with demonstrated small and large aperture efficiencies and large aperture multiplicity*<br>• Detailed volume aperture production/acquisition approach and provide sample of aperture developed with volume production approach |
| Detection | <u>Fringe Detection Approach</u><br>• Fringe formation/detection for 100 simulated apertures with band diversity and total bandwidth consistent with modeling and simulation requirements pointing to successful demonstration of program goals<br><u>Coherent Optical Beam Forming Approach</u><br>• Image formation/detection for 100 simulated apertures with total bandwidth consistent with modeling and simulation requirements pointing to successful demonstration of program goals<br>• *This approach must account for GEO image motion on focal plane*<br>• Wide bandwidth requirement will make achromatic image formation challenging – offeror must explicitly include chromatic contributions to image blur and demonstrate how these are handled in processing/post-processing |

# Metrics for Phase 1 Thrust Areas (cont)

| Thrust Area | Metric / Performance |
| --- | --- |
| Algorithms: Image Formation | Fringe Detection Approach<br>• Image reconstruction algorithms that demonstrate rapid convergence**<br>• Simulated image reconstruction must point to demonstration metrics for brightness, resolution, image interpretability, and timely collection<br>✓ *Offeror to develop simulated data sets that reflect demonstrated collection metrics*<br>✓ *Algorithms may be advantaged by system geometry (e.g., redundant baselines)*<br>✓ ***Definition: rapid convergence means projected final image production of all collection for an evening collection campaign is fully processed before the next evening data collect commences*<br>Coherent Optical Beam Forming Approach<br>• Simulated image reconstruction must point to demonstration of program goals and metrics for brightness, resolution, image interpretability, and timely collection<br>• *This approach must account for image motion on focal plane* |
| Algorithms: Modelling/Simulation | • Offeror to develop end-to-end physics-based modelling and simulation software reflecting overall system design architecture that can flexibly ingest component design modifications and component performance metrics to provide simulated fringe detector results for image formation algorithm research<br>• *This approach enables flexible research trades to inform system development*<br>• *As an example – if an offeror finds that metric “A” is falling 6% short of an overall system design goal the simulation suite can determine if an offset improvement in another metric can still enable overall system requirements to justify continuation of effort* |

# Anticipated Metrics for Phase 2 Thrust Areas

| Thrust Area | Metric / Performance |
|---|---|
| Collection | • Mature collection approaches to sky readiness for limited end-of-phase sky measurements (e.g., 25 small apertures at large central telescope site)<br>• Large/small telescope, simultaneous multi-aperture demonstration of absolute phase correction consistent with modeling and simulation requirements (all small-large aperture pairs)<br>• Updated report on volume aperture production/acquisition approach |
| Detection | <u>Fringe Detection Approach</u><br>• Simultaneous measurement of all small-small aperture fringe pairings for all spectral bands of GEO satellite<br>• GEO fringe SNR consistent with modeling and simulations requirements pointing to demonstration consistent with program goals and metrics<br><br><u>Coherent Optical Beam Forming Approach</u><br>• Measurement of reformed (low resolution) GEO satellite image<br>• Image SNR and image chromaticity specifications must be consistent with modeling and simulation requirements pointing to demonstration consistent with program goals and metrics |

# Anticipated Metrics for Phase 2 Thrust Areas (cont)

| Thrust Area | Metric / Performance |
|---|---|
| Algorithms: Image Formation | Fringe Detection Approach<br>• Image reconstruction algorithms that demonstrate rapid convergence**<br>• Simulated image reconstruction must incorporate demonstrated hardware performance and point to demonstration consistent with program goals and metrics for brightness, resolution, image interpretability, and timely collection<br><br>Coherent Optical Beam Forming Approach<br>• Simulated full resolution image reconstruction must point to demonstration consistent with program goals and metrics for brightness, resolution, image interpretability, and timely collection<br>• Demonstrated ability to handle image motion on detector and recover resolved imagery from moving object image |
| Algorithms: Modelling/Simulation | • Offeror to further enhance end-to-end physics-based modelling and simulation software based on overall system design architecture that can flexibly ingest component design modifications, component performance metrics, and system architecture modifications to provide simulated fringe detector results for image formation algorithm research<br>• System trades that support system design approach or inform any design modifications to maintain or exceed ability to reach end-of-program metrics/goals |

# Overall Program Traceability Goals/Metrics

| Thrust Area | Metric / Performance |
|---|---|
| Collection | • Rapid data collection (must point to future capability to collect multiple data sets per evening)<br>• Maximum baselines and baseline diversity must support resolution (12.5nanoradian) and image interpretability (SORS Level 6) program requirements |
| Detection | <u>Fringe Detection Approach</u><br>• Natural guide star fringe SNR must support phase correction accuracy to enable imaging requirements<br>• GEO fringe SNR must be consistent with modeling and simulations requirements pointing to successful demonstration consistent with program goals and metrics<br><u>Coherent Optical Beam Forming Approach</u><br>• Satellite data from open sky experiment must show beam forming accuracy to enable imaging requirements<br>• Satellite data SNR and chromaticity specifications must be consistent with modeling and simulation requirements pointing to successful demonstration consistent with program goals and metrics |
| Image Formation | <u>Fringe Detection Approach</u><br>• Data reconstruction must point to program resolution and interpretability requirements<br>• All image reconstruction must be complete prior to subsequent evening observations<br><u>Coherent Optical Beam Forming Approach</u><br>• Corrected satellite data consistent with program resolution and interpretability requirements<br>• Data SNR and chromaticity specifications must be consistent with modeling and simulation requirements pointing to successful end-of-program demonstration |

# Milestones and Waypoints

- **Milestones** are Government-defined progress metrics that must be met by the end of each phase
- **Waypoints** are offeror-defined, task-driven intermediate steps towards a milestone
  - Depending on an offeror's specific approach, progress towards a milestone is not assumed to be linear in all areas
  - Waypoints are how the offeror clearly explains to the Government the quantitative and timely progress that must be made for their overall concept to meet the end-of-phase Milestones – performance against these waypoints is reviewed throughout program
- **Technical reviews** held at months **3, 5, 8, 11,** and **14** will quantify progress against the waypoints & assess whether course corrections are needed for success

# GFI/GFE – Phase 1

- **At Contract Award:**
  - TDB – suggested needs?
- **During program execution:**
  - Phase 2 demonstration can be performed at offeror chosen site – government site preferred
  - Government site location information will be provide by Month 6 to enable planning and negotiations for Phase 2 proposal

# T&E/Deliverables – Phase 1

- **Months 3, 5, 8, 11 & 14** – Progress review against offeror-defined waypoints (emphasis on months 5 and 11)
- **Month 14** – Report on component performance, traceability of system design to Phase 2 metrics and overall program goals
- **Month 14** – On-site demonstrations of component and algorithm performance
- **Month 15** – Final report & hardware/software deliverable.

# Notional Program Schedule

CY18 | CY19 | CY20 | CY21 | CY22

**Phase 1: 4 Teams**

**System and software/algorithm requirements, modeling and preliminary lab experiments**

End of Phase 2

New BAA???

**Phase 2: 2 Teams**

**Algorithm and fiber compensation testing**

**Interferometer demonstration with ~25 small apertures**

**Source Selection Schedule**

| | |
|---|---|
| Proposers' Day: | 11 May |
| *BAA Release:* | *02 June* |
| *Proposals Due:* | *31 July* |
| *Source Selection:* | *15 September* |
| *Program Kickoff:* | *02 January 2018* |

**Potential Demonstration: 1 Team**

***NOT part of Amon-Hen Opportunity***

**System build out and demonstration**

***Successful demonstration burns down all key risks***

| Phase 1 | Phase 2 | Potential Future Effort |
|---|---|---|
| Design Phase | Testing Phase | Full Demonstration |

# Notional Program Schedule

FY17 | FY18 | FY19 | FY20 | FY21 | FY22

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Proposers' Day

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