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# **Long-Range FSO Research Challenges**

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**NSF FSO Networking Workshop**

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# High-Power Optical Uplinks

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- **Application:**
  - Deep-space communications
- **Status:**
  - DSN RF capacity is constrained today
  - LLCD FSO demonstration at Lunar distances
  - PYSICHE Asteroid FSO planned for 2022
- **Research Challenge:**
  - How to enable high-power optical uplinks through turbulent atmosphere?
    - Research topics: guide stars, cubesat space reference, high-power amplifiers, adaptive optics
- **Impact**
  - Critical for deep-space photon-starved FSO links with many-beamwidth point ahead
  - Enables high-rate uplink communications to spacecraft

# Deep-Space FSO Technologies

- **Application:**
  - Deep-space communications
- **Status:**
  - 1 and 1.55 um Tx and Rx efficient space-compatible technologies are available, but HPA efficiency is limited
  - Short- and long-wavelength technology maturity for space is limited
- **Research Challenge:**
  - How to improve 1 and 1.55 um high-power amplifier wallplug efficiency?
    - Research topics: Solar panel to amplifier optical output with 30-50% wallplug efficiency
  - How to enable more efficient diffraction-limited “FSO” link performance?
    - Research topics: High-Tc SNSPDs, low-SWaP cryocooler, mid-IR radiation-tolerant detector arrays, “x-ray” source/detector technology
- **Impact**
  - Reduced SWaP satellite payloads (HPA development)
  - Satellite acquisition detectors
  - Higher-efficiency uplink FSO links
  - Reduced diffraction-loss inter-planetary links (x-ray)

# Satellite Formation Flying

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- **Application:**
  - Near-Earth FSO and sensing
- **Status:**
  - Spacecraft ranging accuracy is limited today
  - Multi spacecraft launch capability exists, but is largely uncontrolled after launch
- **Research Challenge:**
  - How to enable fractionated spacecraft formation flying?
    - Research topics: FSO crosslinks with precision ranging and time transfer, improved station keeping, precision ADACS
- **Impact**
  - Coherent multi-satellite sensor processing for exo-planet surveys
  - PNT without GPS
  - Big satellite performance with lower-cost satellite coordination
  - Gravity wave sensing

# Terrestrial Gateway Infrastructure

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- **Application:**
  - Deep-space communications, Near-Earth space, Airborne
- **Status:**
  - Huge RF gateway investment has been made
  - Large scientific telescope optical gateways demonstrated
  - Prototype ‘transportable’ LLGT and ‘autonomous’ GS-2 gateway prototypes developed
- **Research Challenge:**
  - How to roll out FSO gateway terminals into existing comm architectures?
    - Research topics: Large aperture telescopes, AO turbulence mitigation, simplified maintenance, autonomous operation, multi-aperture coherent combining, multi-modal AO processing, inter-satellite crosslinks, new network protocols (end-to-end and edge-to-edge, where edge is FSO system)
- **Impact**
  - Dedicated FSO gateways for space, airborne links
  - Improved atmospheric turbulence mitigation
  - Cost-effective modular, scalable, resilient ground arrays

# Multi-User FSO Terminal

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- **Application:**
  - Deep-space communications, Near-Earth space, Airborne and Terrestrial
- **Status:**
  - TDRS has low-rate multi-access array capability
  - LCRD will fly two optical terminals in 2019
- **Research Challenge:**
  - How to accommodate multiple user FSO links simultaneously?
    - Research topics: Multi-beam optical Tx, OPA Transceiver, Multi-beam opto-electronic feeds, routing/switching
- **Impact**
  - Efficient means of supporting multiple terrestrial or airborne users
  - Military theater or hemisphere operations support
  - Resilient space-based optical networking node

# Low-Latency FSO Links

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- **Application:**
  - Near-Earth space, Airborne and Terrestrial
- **Status:**
  - Many FSO prototype systems utilize channel interleaver and terrestrial fiber networking protocols
- **Research Challenge:**
  - How to enable low latency FSO links?
    - Research topics: Multi-modal AO processing, reciprocity-enhanced turbulence mitigation, improved turbulence models, time synchronization without RF backbone, new network protocols
- **Impact**
  - Enable EW coherent processing
  - High-performance internet data center
  - Voice applications over FSO tactical links

# FSO Links for High-Performance Networks

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- **Applications:**
  - Airborne and Terrestrial
- **Status:**
  - Multiple small company products (e.g. stock trading, runway crossing)
  - NRL developing hub and spoke operational prototypes
- **Research Challenges:**
  - How to develop high-performance network using unreliable FSO links?
    - Research topics: Networking many nodes (Layer 2 through Layer 4 protocol)
    - Mobile PAT
    - Hybrid Resilient Comm (RF ISI vs. FSO Fading)
    - Self- diagnostic channel monitoring (different wavelengths and monitor change in temp, absorption)
    - Machine learning (allocating data to different media to inform network and predict changes to channel)
- **Impact:**
  - COTS building-to-building
  - Hub and Spoke FSO Networks in EW Environment
  - Mesh SoF Application (or backhaul)