

# The High-Contrast Imaging in Space Mini-Workshop

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## Abstract

Between November 14 and November 16, 2016, the Institute hosted a mini-workshop focused on high-contrast imaging techniques using space-based telescopes. Approximately 75 experts in high-contrast imaging attended the workshop and discussed a variety of topics. These included discussions of high-contrast imaging instrumentation, image post-processing techniques, and high-contrast imaging of exoplanets and circumstellar disks.

## Introduction

The nine years since the first direct images of confirmed planetary mass objects were obtained have witnessed an explosion in high-contrast imaging techniques that have been utilized for both space- and ground-based observations. The prime targets in the realm of exoplanets for these techniques have been brown dwarfs, circumstellar disks, and gas giant exoplanets, revealing a wealth of information about how planets may form in the outer regions of protoplanetary disks, the transition from stellar to substellar mass objects, and the outer architecture of exoplanet systems. The ultimate goal of these observations is to directly image Earth-like planets to search for evidence of liquid water and perhaps even life.

With the imminent launch of *Webb* and the increasing investment of efforts into the *Wide-Field Infrared Survey Telescope (WFIRST)* and its coronagraphic instrument (CGI), the scientific organizing committee for the High-Contrast in Imaging mini-workshop saw an opportunity to set the stage for the next decade of high-contrast imaging by gathering the field's foremost experts. The goal was to review the state-of-the-art in scientific results, instrumentation, and post-processing techniques to help plan for future high-contrast imaging missions in the next decade. The workshop explored the legacy of existing space-based high-contrast imaging from the *Hubble* and *Spitzer Space Telescopes* with an eye toward observations with future missions planned by NASA. Additionally, the workshop considered how these missions may open new frontiers in high-contrast imaging of Solar System, extragalactic, or other astronomical objects.

## Workshop Program

The workshop spanned two and a half days, with a total of 9 invited speakers and 25 contributed talks. The entire program of the Symposium can be found at the Institute's Webcast Archive <https://webcast.stsci.edu/webcast/searchresults.xhtml?searchtype=20&eventid=246&sortmode=2>. There were five sessions that covered high-contrast imaging techniques, imaging of circumstellar disks, the direct imaging of exoplanets, the application of high-contrast imaging techniques, and future space missions that would include high-contrast imaging.

Many topics were covered at the meeting, a selection of which we summarize here. The first session touched on the instrumentation used in space-based coronagraphy. Mark Clampin first reviewed

the legacy of high-contrast imaging on *Hubble* while looking forward to new scientific results with the many coronagraphic modes on *Webb*. Stuart Shaklan reviewed various methods and challenges of performing coronagraphy with segmented mirrors in space, the key technological challenge to using large apertures for future space telescope missions aimed at detecting and characterizing Earth-like planets.

The second and third sessions focused on scientific results made possible with high-contrast imaging, in particular for disks and exoplanets. Hannah Jang-Condell spoke about the possible observable signatures of forming exoplanets in protoplanetary disks, while Meredith Hughes discussed observations of debris disks and the discoveries of widely separated exoplanets. Both talks highlighted the remarkable complementarity of high-contrast instruments such as *Hubble*/STIS with ALMA when using dust structures to trace the formation history of nascent and adolescent exo-planetary systems. Caroline Morley then reviewed the latest techniques for inferring the atmospheric properties of gas giants and super earths as gleaned from a combination of direct imaging and transit spectroscopy. Her talk highlighted the importance of panchromatic datasets combining *Hubble*, ground-based and upcoming *Webb* information.

The fourth session focused on applying various high-contrast imaging techniques to existing and archival observations. Former Institute postdoctoral researcher Elodie Choquet presented an overview of various image post-processing techniques that have been successfully leveraged for both space- and ground-based high contrast imaging, such as the Archival Legacy Investigations of Circumstellar Environments High-Level Science Products in the Mikulski Archive (<https://archive.stsci.edu/prepds/alice/>). Daniel Rouan conducted the thought experiment of what other astronomical objects could be observed with current and future high-contrast imaging techniques, including extragalactic objects and the circumstellar matter of massive stars.

The final session looked toward future mission concepts in various stages of preparation. Jean-Luc Beuzit spoke about the synergy between high-order adaptive optics systems, coronagraphs, and future space mission designs. With missions such as *WFIRST* requiring multiple deformable mirrors in its CGI design to obtain the highest contrasts, space-based mission concepts rely more heavily on lessons learned from the ground. Nikole Lewis and Jeremy Kasdin spoke about the *WFIRST* mission, while Brad Peterson and Karl Staplefeldt spoke about the *HabEx* and *LUVVOIR* mission concepts. Anne Marie Lagrange graciously agreed to present at the Institute Colloquium on the topic of direct imaging of exoplanets to finish out the workshop.

Other mission specific activities relevant to the Institute occurred during this meeting, including a *Webb* information session with a focus on high-contrast imaging and a high-contrast imaging *Webb* early release science discussion was held by outside members of the community. Finally, the *WFIRST* mission Science Investigation Teams affiliated with the CGI met after the workshop to conduct a half-day meeting to discuss CGI design requirements and to collect the full teams together for a day of breakout sessions and collaboration.

The workshop displayed the importance of high-contrast imaging as a technique for the exploration of nearby planetary systems as well as for other astronomical objects. In a field that is mostly driven by technology and data analysis breakthroughs, this workshop provided a unique forum for a diverse section of the exoplanet and instrumentation community to come together and reflect on the success of the past decade on debris disk and young giant planet imaging, on lessons learned as we move towards more ambitious endeavors such as the search for life.



**Figure 1:** High-Contrast Imaging in Space workshop photograph. Approximately 75 people attended the workshop between November 14–16, 2016. Photo credit: Chad Smith.