Keck Interferometer

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Project Overview

Keck Interferometer

Key Features
• Two Keck 10-meter telescopes linked as an interferometer
  – 85-meter baseline
  – Wavelength bands: 1.6, 2.2, 3.8, & 10 µm
  – Modes: V^2, Nulling
  – First Light, V^2: March 2001
  – First Light, Nuller: August 2004
• Funded by NASA, operated by JPL/NExScI/WMKO

Science
– High sensitivity fringe visibility measurements
– Measurement of zodiacal dust around nearby stars via nulling interferometry

Users
– KI is open to all Keck community users including the NASA and NOAO TACs
– See http://nexsci.caltech.edu/software/KISupport for more details
KI Strengths

- **Sensitivity**: Current limits K<10.3 at low resolution and K<14 in shared-risk dual field phase referencing
- **Nulling**: Only mid-infrared nulling system in the world
- **Astrometry** (after ASTRA completion)
  - Only large aperture astrometry until GRAVITY on VLTI completed
  - Only astrometry with LGS
- **Spectral coverage**: KI covers from 2 to 10 microns and is the only interferometer to offer L-band (3.5 microns) observations
- **High time sampling and observing efficiency**: KI can be reconfigured to many of the available modes during an observing night and has the highest observing cadence
- **Development flexibility**: Existing infrastructure leveraged for projects such as L-band and ASTRA
KI is the most sensitive IR interferometer with unique operational capabilities

<table>
<thead>
<tr>
<th>Interferometer</th>
<th>KI Capabilities</th>
<th>Current performance</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Nulling mode</td>
<td>N-band flux &gt; 1.7 Jy</td>
</tr>
<tr>
<td>2</td>
<td>V^2- K5 ; R~27</td>
<td>K' &lt; 10.3</td>
</tr>
<tr>
<td>3</td>
<td>V^2- K10 ; R~54</td>
<td>K' &lt; 9.5</td>
</tr>
<tr>
<td>4</td>
<td>V^2- K42; R~230</td>
<td>K' &lt; 7.6</td>
</tr>
<tr>
<td>5</td>
<td>V^2- SPR; R~1700</td>
<td>K' &lt; 8</td>
</tr>
<tr>
<td>6</td>
<td>V^2- H4; R~22</td>
<td>H &lt; 9</td>
</tr>
<tr>
<td>7</td>
<td>V^2- L10; R~63</td>
<td>L' &lt; 6</td>
</tr>
<tr>
<td>8</td>
<td>V^2- K/L</td>
<td>K' &lt; 8.7 &amp; L' &lt; 4.8</td>
</tr>
<tr>
<td>9</td>
<td>V^2- H/L</td>
<td>H &lt; 8.0 &amp; L' &lt; 4.8</td>
</tr>
<tr>
<td>10</td>
<td>V2-DFPR</td>
<td>K &lt; 14 for 3-25” field; guide star of R &lt; 14, H &lt; 13 &amp; K &lt; 8</td>
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</table>

Modes offered for shared-risk science are highlighted in red

Adaptive optics and Angle tracking limit
- AO sensitivity: R < 12
- KAT sensitivity: J/H < 10.5 (H < 9 for SPR & H < 13 for DFPR)
Broad range of astrophysics

The multiple modes and high sensitivity of KI allow a wide range of astrophysical observations:

- Debris disks around nearby stars
- Circumstellar disks around young stars
- Novae shells
- Centers of active galactic nuclei
Young stellar objects: Directly probing the inner disk

ARAA, Dullemond and Monnier, 2010
YSOs: Herbig disks at H/K, L & N

• Herbig stars are the more massive counterpart to T Tauri stars
• Ragland et al. (2009) observed MWC 419 (young B star)
  • The L-band disk size is ~ 44% larger than the K-band size
  • The wavelength dependent size suggests an extended disk with strong radial temperature gradient.
• Ragland et al. (in prep) observed eight YSO disks in three bands (H/K, L & N bands) and sixteen additional YSO disks in two filter bands (H/K & L/N bands).
• They fit their MWC 325 (young A star) data, in conjunction with SED data, by a flared disk model with a dust sublimation radius of 0.80 AU (= 48 stellar radii) through radiative transfer modeling.
• Derived total dust mass for the disk of MWC 325 in this disk is $9.5 \times 10^{-7} M_{\text{Sun}}$. 
YSOs: High spectral resolution

- Eisner et al (2010) used the self-phase referencing (SPR) mode to resolve the Brackett gamma line in 15 young stellar objects
- Example object MWC 1080 (young B star)
  - These observations show that the Brackett gamma is more compact than the continuum and is consistent with a disk origin for the emission line
Exo–Zodiacal Dust Levels for Nearby Main–Sequence Stars

- 25 nearby stars:
  - Main sequence FGK, mean distance = 10 pc.
  - 2 previously known to have cold dust; 23 no known dust.
- Modeled the measured leaks in terms of equivalent number Solar System zodis, including dust cloud orientation effects.
- KIN sensitive to warm inner dust, located at ~0.1-4 AU.
- Both known dust objects are detected:
  - η Crv (1414 +/- 311 zodis, 4.5σ)
  - γ Oph (202 +/- 78 zodis, 2.6σ) (marginal detection)
- A new warm dust object also marginally detected:
  - α Aql (657 +/- 204, 3.2σ)
- Limits for the 22 non-detections:
  - 3-sigma limits for the individual stars are in the range 200-1500 zodis.
  - 3-sigma limit average: 500 zodis.
  - Best limits to date on exozodi levels for a sample of nearby MS stars.
Active Galactic Nuclei unification models

- General idea: All the AGN are the same but look different given the viewing angle
Kishimoto et al (2009) observed 4 targets with K=8.9-10.4, over 3 orders of mag in luminosity (including a QSO at z=0.1)

Later observations added 4 more AGN (Kishimoto et al 2011)

KI observations resolve the dust sublimation region

Approx. match with reverberation radii
Based on:
NASA investment in Keck Interferometer
K2 & K1 LGS AO capabilities
$2M NSF MRI grant

1. Self Phase Referencing
   - K<8 limit
   - R~1800

2. Dual Field Phase Referencing
   - K<8.5 reference
   - K<15 science

3. Astrometry
   - 30µ” for 10” separation

- **Young Stellar Objects**
  - Chemical Composition at R~1800
- **Active Galactic Nuclei**
  - Chemical Composition
  - Increased Sample
- **Galactic Center**
  - Stellar Population
  - BH mass and GR effects
- **Exoplanets**
  - Reflex Motion of Multiple Planet Systems
Current status: Dual Field Phase Referencing

January 2011: Demonstration on $K=11.5$!
Extrapolation to $K=14-15$
Summary

• KI is used for a wide range of astrophysical investigations utilizing high sensitivity and mode flexibility
• ASTRA is nearing completion and will provide substantial new capabilities
• The availability of KI after 2012A is not assured

• KI is open to the entire US community via the NASA and NOAO TACs
  – The NASA TAC is now open to all Solar System, Exoplanet, Cosmic Origins and Physics of the Cosmos science
    • 2011B NASA deadline is March 17, 2011
  – NOAO deadline is March 31, 2011

  – See http://nexsci.caltech.edu/software/KISupport/ for details