W. M. KECK OBSERVATORY
On the summit of Mauna Kea, Island of Hawai'i

NASA JPL NExScI
NASA Exoplanet Science Institute

KECK Interferometer

Keck Interferometer

Rachel Akeson (on behalf of the Keck Interferometer team)

CHARA meeting, March 1, 2011

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

Current capabilities: Summary

- KI is the most sensitive IR interferometer with unique operational capabilities

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

Nulling unique to KI

Improved by over 3 mags since 2004

Unique to KI

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)

Interferometer

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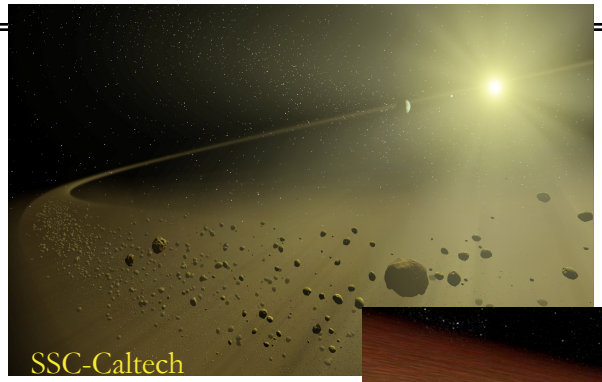
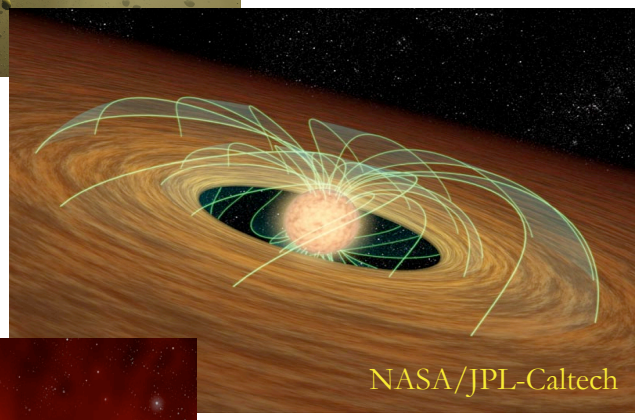
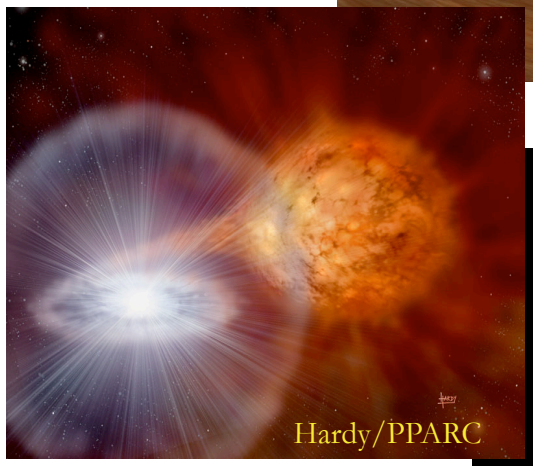
Broad range of astrophysics

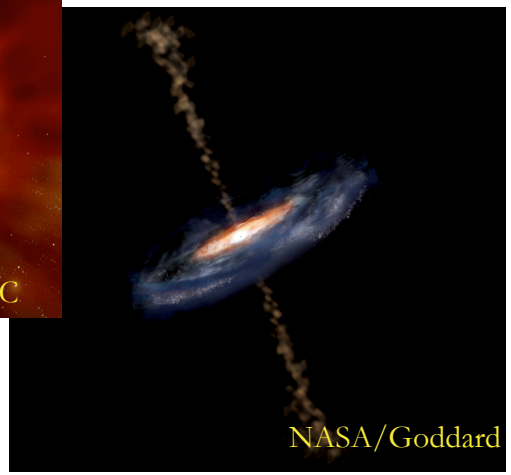
The multiple modes and high sensitivity of KI allow a wide range of astrophysical observations

- Debris disks around nearby stars
- Circumstellar disks around young stars
- Novae shells
- Centers of active galactic nuclei

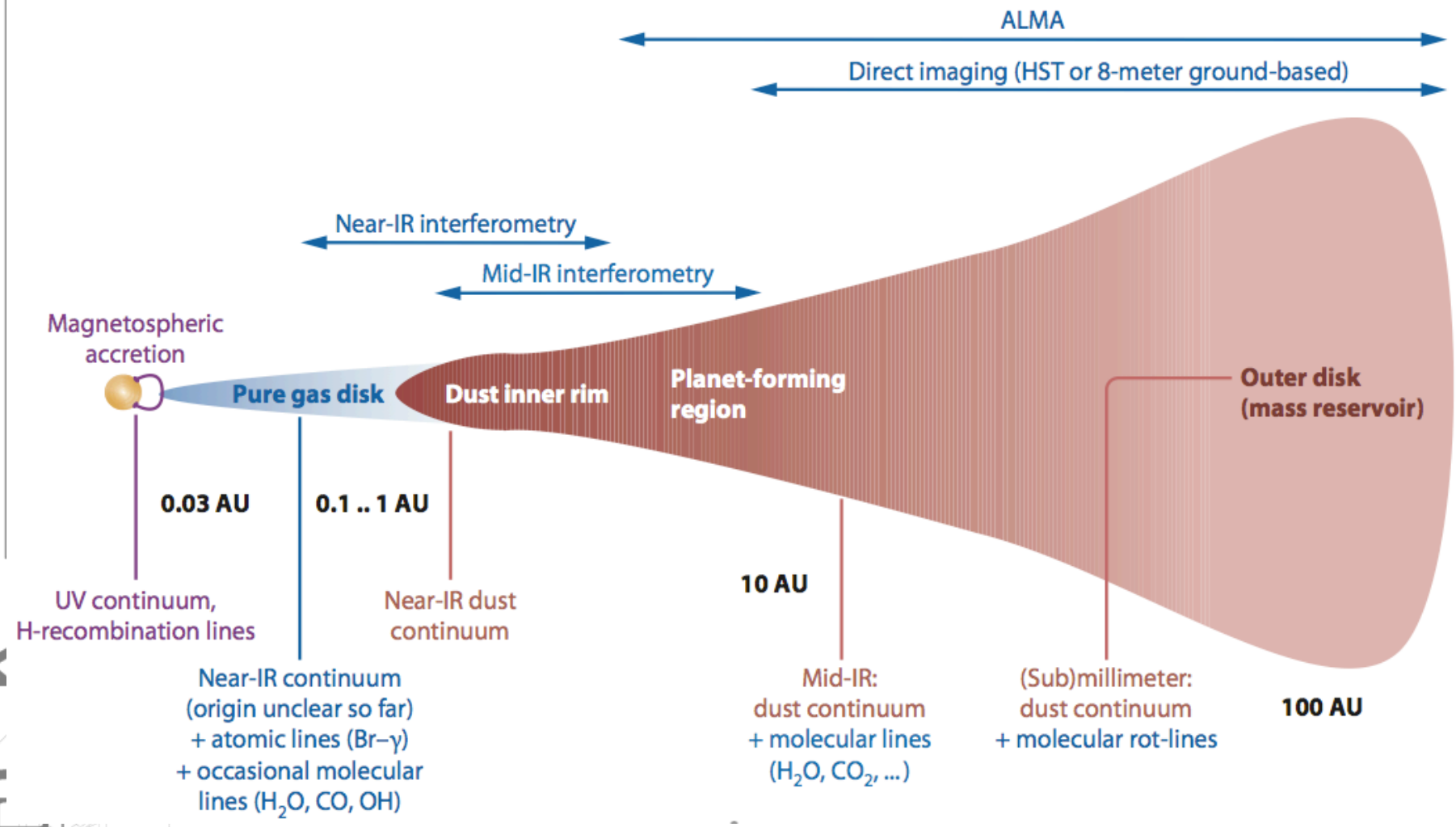

SSC-Caltech


NASA/JPL-Caltech


Hardy/PPARC


NASA/Goddard

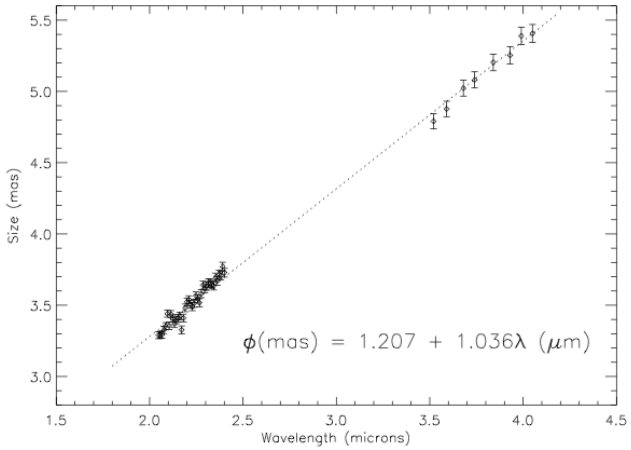
Young stellar objects: Directly probing the inner disk



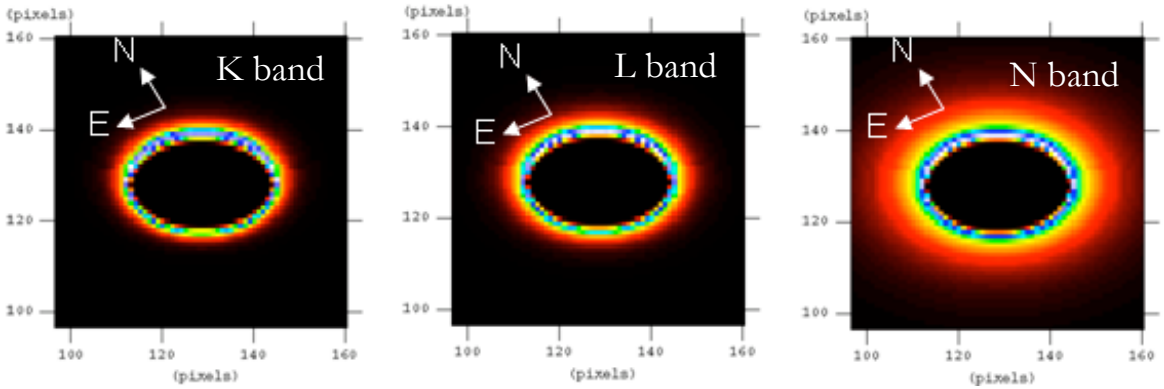
ARAA, Dullemond and Monnier, 2010

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 x 10^{-7} M_{Sun}.



Interferometer
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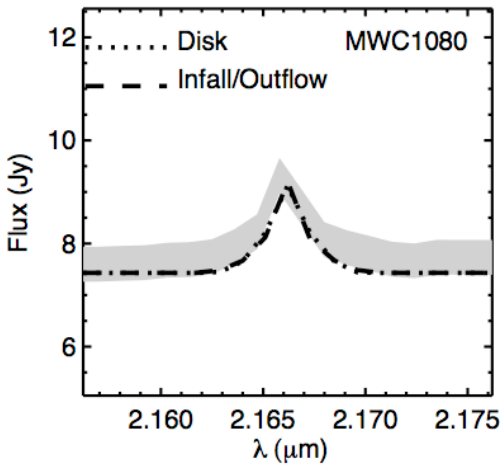
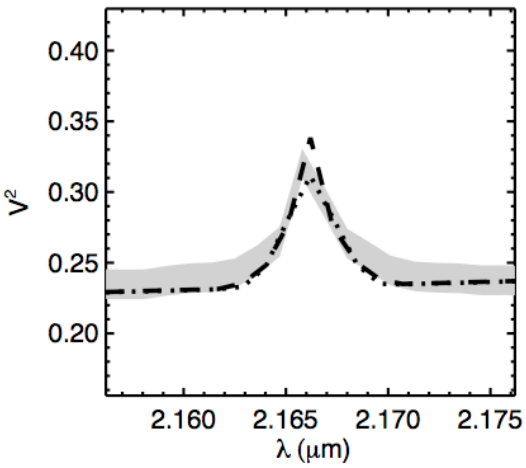
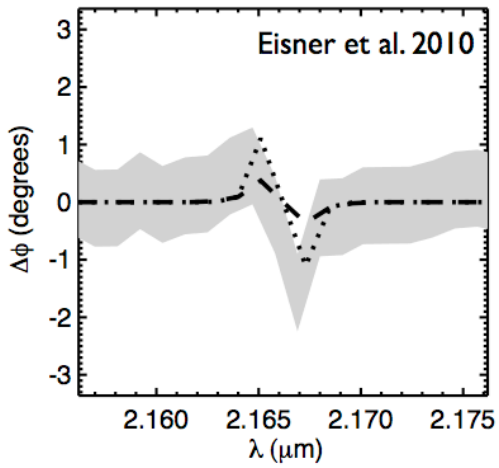
YSOs: High spectral resolution

- 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





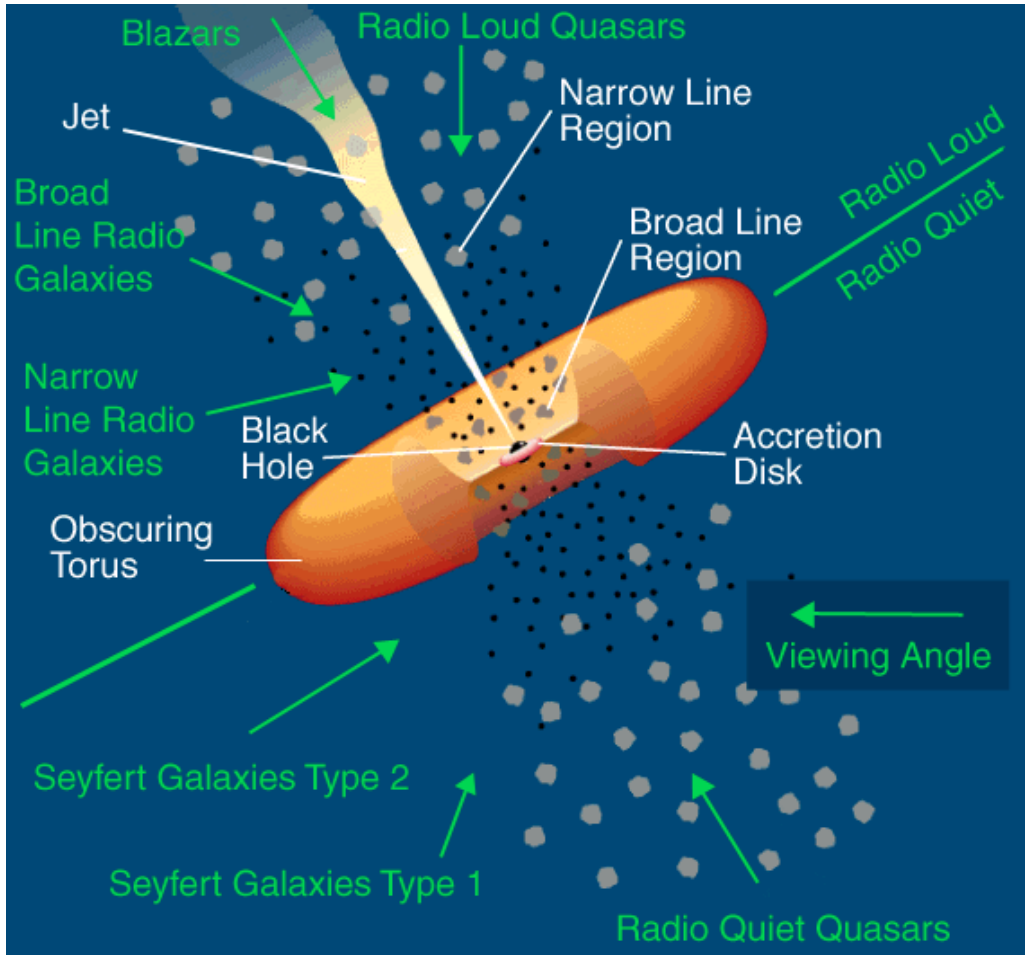


Exo–Zodiacal Dust Levels for Nearby Main–Sequence Stars

- Results of NASA Key Science project with the KIN (PI: G. Serabyn, JPL). *Millan-Gabet et al. submitted to ApJ (Jan 28 2011).*
- 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

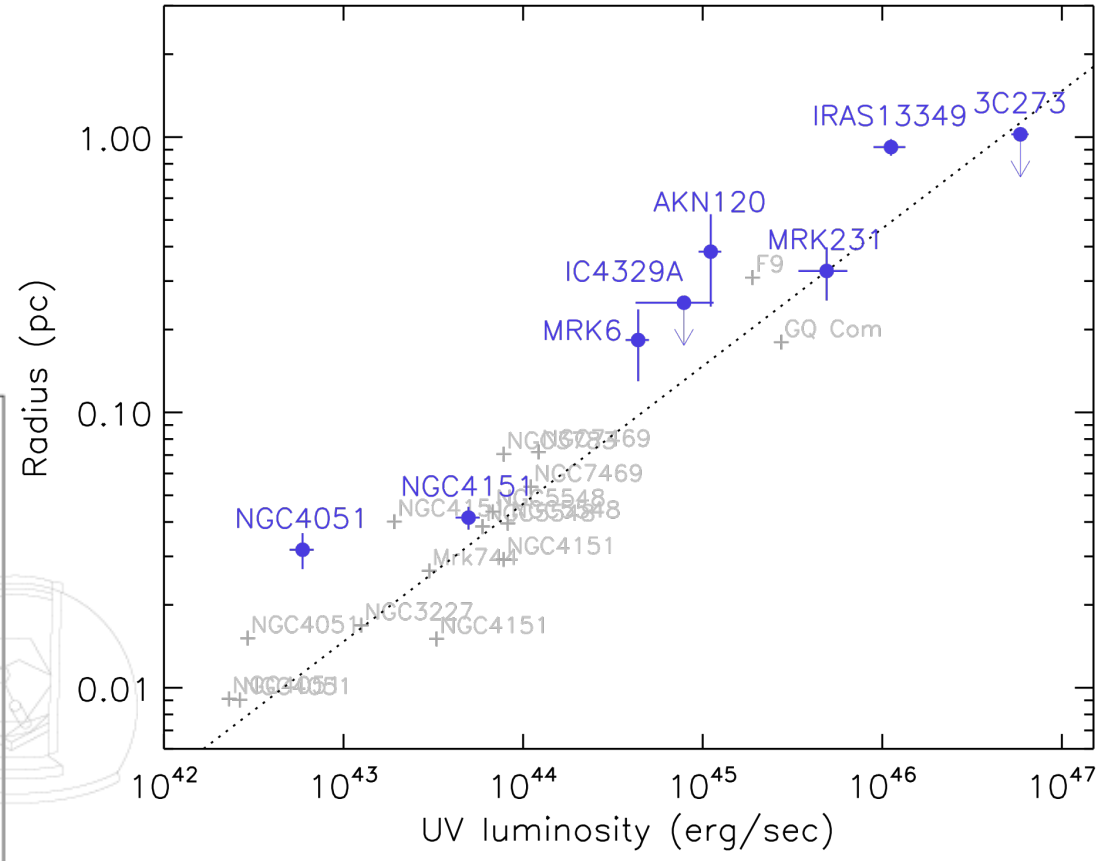
- General idea: All the AGN are the same but look different given the viewing angle



NASA

AGN: Expanding the sample at 2 microns

- 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

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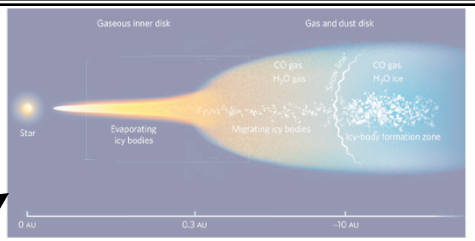
ASTRA overview

Based on:
NASA investment in Keck Interferometer
K2 & K1 LGS AO capabilities
$2M NSF MRI grant



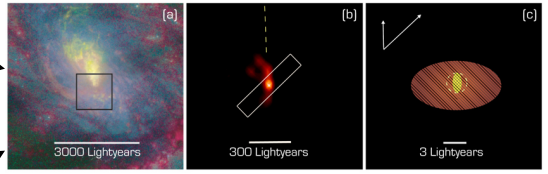
Young Stellar Objects
Chemical Composition at R~1800

1 Self Phase Referencing

K<8 limit
R~1800

2 Dual Field Phase Referencing

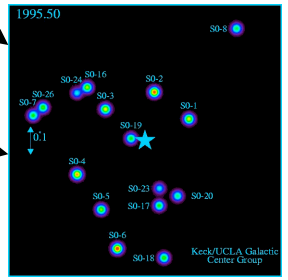
K<8.5 reference
K<15 science



Active Galactic Nuclei
Chemical Composition
Increased Sample

3 Astrometry

30μ˝ for
10˝ separation



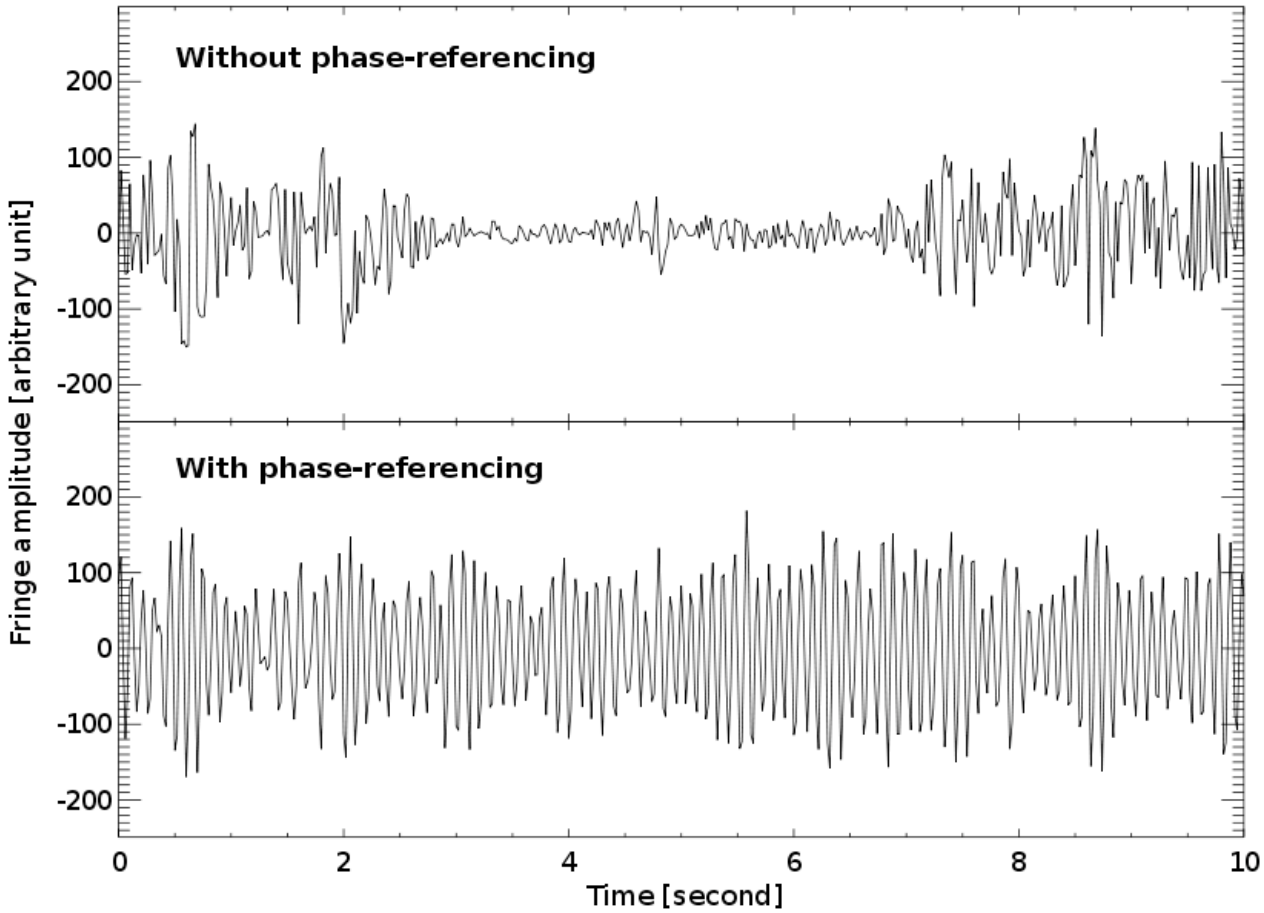
Galactic Center
Stellar Population
BH mass
and GR effects

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