The Infrared Imaging Spectrograph (IRIS) for TMT Instrument Overview

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IRIS Technical Team

- James Larkin (UCLA), PI
- Kanaka Warad (TMT), PM
- Shelley Wright (UCSD), PS
- Ryuji Suzuki (NAOJ), PE
- Jenny Atwood (NRC-H), CSRO Lead
- Jennifer Dunn (NRC-H), Software Lead
- Renate Kupke (UCSC), UCSC Lead, Optical Design Lead
- Bob Weber (CIT), Lead Mechanical Engineer
- David Andersen (NRC-H), CSRO Systems Engineer
- Kai Zhang (NIAOT), Slicer Lead Optical Designer and NIAOT Lead
- Optical Designers: Dan Reiley (Caltech), Drew Phillips (UCSC), Toshihiro Tsuzuki, Mizuho Uchiyama (NAOJ), Shaojie Chen, Elliot Meyer (UofT), Victor Isbrucker (Isbrucker Cons. Inc.)
- Mechanical Designers: Alex Delacroix, Keith Matthews, Reston Nash, Ray Zarzaca, Eric Schmidt (CIT), Dean Chalmers, Brian Hoff, Ward Jensen, Vlad Reshetov, Ramunas Wierzbicki (NRC-H), John Canfield, Evan Kress, Eric Wang (UCLA), Yoshiyuki Obuchi, Bungo Ikenoue, Sakae Saito, Fumihiro Uraguchi (NAOJ)
- Software Designers: Chris Johnson, Ji Man Sohn (UCLA), Takashi Nakamoto (NAOJ), Ed Chapin (NRC-H), Reed Riddle (COO), Gregory Walth (UCSD)
- Electrical Designers: Roger Smith (Detector Lead, CIT), Tim Greffe (CIT), Kenneth Magnone (UCLA), Tim Hardy (NRC-H)
- TMT, NFIRAOS: Lianqi Wang, Corinne Boyer, Matthias Schöek (TMT), Pete Byrnes, Glen Herriot (NRC-H) and the IRIS astrometry team and many many more...

David Andersen (TMT) Instrument Group Lead
Gelys Trancho (TMT) Senior Systems Engineer
John Rogers (TMT) Senior Systems Engineer
John Miles (TMT) Instrumentation dept. Systems Engineer

10 institutions, 4 countries
| IRIS Science Team | 41 active members, 14 institutions, 6 countries |
|-------------------|------------------------------------------------|
| David Andersen, NRC-Herzberg | Matthew Hosek, Berkeley |
| Lee Armus, IPAC/Caltech | James Larkin, UCLA |
| Aaron Barth, UC Irvine | Michael Liu, U Hawaii |
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| Takahiro Uchiyama, JAXA | Andrey Vayner, Johns Hopkins |
| Gregory Walth, Carnegie | Mike Wong, Berkeley |
| Shelley Wright (PS), UCSD | |
NFIRAOS – Adaptive Optics System

- Multiconjugate Laser AO system
- Outputs 2 arcminute corrected field to three output ports
- 6 Laser WFSs with 60x60 spatial sampling at 800Hz sampling
- Two deformable mirrors
- Cooled to -30 C for thermal background
- Client instruments have their own infrared wavefront sensors:
  - 1 Tip/Tilt/Focus and 2 Tip/Tilt.
IRIS Capabilities

- First Light Imager and Spectrograph working in parallel at the
diffraction limit of the Thirty Meter Telescope.
  - Wavelength Range 0.81-2.4 microns
  - RMS Wavefront Error < 40 nm in fine scales
  - High Order Atmospheric Dispersion Correction
- On-Instrument wavefront sensors (OIWFS).
  - Three sensors to measure tip/tilt, focus and distortion
  across field.
  - Near infrared sensors to gain from NFIRAOS AO correction.
- “Wide-Field” Imager (60+ filters)
  - 34 arcsec field of view (2x2 grid of H4RG-15 Teledyne
  Detectors)
  - 4 mas plate scale (Nyquist @ 1.15 µm)
- Integral Field Spectrograph (H4RG-15 Teledyne Detector)
  - IFS with Four Plate Scales (4, 9, 25 and 50 mas per sample)
    - Up to 16,433 individual, simultaneous spectra.
  - Spectral Resolutions of 4000, 8000 and 10,000 (14 gratings)
IRIS is versatile and covers a broad range of science goals:

- Solar system
- Extrasolar planets
- Stellar structure & evolution with microlensing
- Star formation
- Galactic Center
- Nearby galaxies & stellar populations
- Supermassive black holes
- High-redshift galaxies
- First light galaxies

https://arxiv.org/pdf/1608.01696.pdf
On-instrument wavefront sensors (OIWFS)

Imager and spectrograph FoV

- Imager 16'.4x16'.4
- Deployed Slicer Pickoff and max field (4'.4x2'.25)
- Fixed Lenslet Pickoff and max field (1'.01x1'.15)

2 arcmin

34"
Sequential Design

- Imager serves as reimaging optics of spectrograph.
- Both can sit at the center of AO correction.
- AO can correct non-common path optical aberrations in both simultaneously.
- Major cost reduction with common ADC, filters, pupil stops.
- Allows dewar to be easily separated into imager and spectrograph for integration in Japan and California.
IRIS Imager – Double TMA
Ryuji Suzuki, Yutaka Hayano (NAOJ)
Spectrograph Splitters

- Slicer Pick-off Mirror (deployed)
- IMG Detector
- Slicer Pick-off Mirror (retracted)
- Lenslet Pick-off Mirror (fixed)
- Lenslet IFS Path
- Camera mirror #3
- Slicer Fold Mirror
- Slicer IFS Path
- Upper RIO
- IMG Camera Optical Bench
Lenslets vs. Slicer

- Lenslet arrays (e.g. OSIRIS, GPI) are excellent for finest plate scales
  - Easy to expand spatially to >100x100 to sample most of the PSF even at 4 mas scale.
  - Intrinsically low wavefront error since lenslets sample image plane.
    - OSIRIS has undetectable image degradation at ~25 nm rms WFE
    - GPI selected lenslets and existing camera has <25 nm of WFE.

- Slicer IFUs (e.g. SINFONI, NIFS) are excellent for coarser plate scales
  - Easy to expand wavelength coverage once sufficiently large field is achieved in coarse scales.
  - Generally easier data reduction and calibration.
LENSLET ARRAY

- 128 x 128 elements each with 500 spectral elements
  - 0.45”x0.51” @ 0.004” scale
  - 1.01”x1.15” @ 0.009” scale
- Or 16 x 128 elements each with almost 4000 spectral elements
- Spot sizes set primarily by diffraction
- 98% Fill factor

AO Reimaged Focus
@F/272 or F/603

Micropupil Plane
IRIS Lenslet Simulation
16,433 individual spectra
88 slicer mirrors reformat field of view into pseudoslit for spectrograph.

- Slices are 25 or 50 mas wide for 2.2” or 4.4” widths.
- Lengths are 1.125” or 2.25” long.

At pseudoslit Spectrograph input

~2000 spectral channels
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At pseudoslit Spectrograph input

Result of Slicer mirror set

Slicer Stack

1,2,3,...88

~4000 spectral channels
Final Slicer IFU was designed by Winlight System

- They will fabricate and align.
Slicer Raw Spectra

Field (4.400"x 2.250")

Raw Spectra

Layout

Zemax Model
Slit Trace for all modes
Filters + Grating + Scale
Instrument PSFs

88 Slices
Monitoring Io’s volcanism with IRIS

- IRIS simulation
  - Imaging of Io using IRIS 0.004” scale in 2 seconds!

Rundquist et al., in prep
Monitoring Enceladus cryo-volcanism
IRIS and Adaptive Optics tracking solar system targets

• Observing moons of Saturn (e.g. Enceladus)
Larger Imaging Field Significantly Improves Astrometric Accuracy

IRIS can observe 8 maser sources (VLA astrometry) simultaneously with central stars orbiting GC black hole. Dramatic improvement to astrometric accuracy in this field.
Observing individual stars in nearby galaxies

Nearby Virgo Cluster – 53 million light years away
Individual Stars in Virgo Cluster Galaxies

Only very bright AGB stars are detectable. AGB plus upper stars on the RGB allow for age and chemical composition directly.

Simulated image from region of 22 mag/sq arcsec
IRIS will resolve high-z individual star forming regions

IRIS is 2\textsuperscript{nd} generation and learns from past IFUs like OSIRIS and SINFONI. Coarse scales are optimized for low surface brightness work.

- IRIS is 2\textsuperscript{nd} generation and learns from past IFUs like OSIRIS and SINFONI. Coarse scales are optimized for low surface brightness work.
- Simulation is coarsest 0.050” scale with slicer.

H\textsubscript{\alpha} at z=1.02 in J-band
H\textsubscript{\alpha} at z=2.30 in K-band
[OII]3727 at z=4.8 in K-band
Studying quiescent galaxies in distant universe

- Resolved spectroscopy of a 900 Myr stellar population in a z=2.6 galaxy. The thumbnail is 2"x2" region of a simulated galaxy using the IFS 50mas scale at H-band.

- Compared to stacked Keck spectrum from MOSFIRE of 30 z~2 galaxies.
Observational planning on gravitationally-lensed galaxies
NFIRAOS and OIWFS
field of view
IRIS imager and IFS field of view
Studying Gravitationally lensed galaxies

With combination of gravitational lensing and IRIS resolution, we get 10 pc source plane sampling of this $z=3.04$ galaxy. Image is extrapolation of stellar light including $A_V$ of 3.

Wright et al. 2016
IRIS needs to be ready well before TMT first light in order to integrate with NFIRAOS.

Officially in final design phase (Started Oct, 2017).

Four formal final design reviews (Level C):

- Science Cryostat 28, 29 May 2021
- Data Reduction Software 5 May 2021
- Support Structure, Rotator, On-Instrument WFS 19 May 2021
- Imager and IFS – 21, 22 June 2021
Very mature Mechanical Design
Bob Weber (Lead ME, Caltech)
We’ve already completed large amounts of prototyping and lifetime testing.

Periscope Mirror Tests

Mirror prototype with mount

2/3rd scale prototype of grating turret

270 mm
Mirror deformation measurement and modeling - NAOJ at cryogenic temperature
Large amounts of prototyping and lifetime testing.

Grating Piston Stage

Prototype TMA Mirror from AOS

Cryogenic Assembly Station
NRC Integration Facility
Summary

- IRIS will be a revolutionary diffraction limited instrument for TMT.
- Sequential, hybrid design yields high performance and efficiency.
- Dedicated and very active science team. Advanced simulator and data reduction pipeline.
  - https://oirlab.ucsd.edu/IRIS_sims.html
- We are at end of final design phase.
- For more read our past papers (SPIE), the OCDD and thousands of pages of documents!
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