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# GLAO on Subaru: A Canadian Perspective

## Subaru ULTIMATE Science Workshop
## NAOJ, Mitaka, Japan

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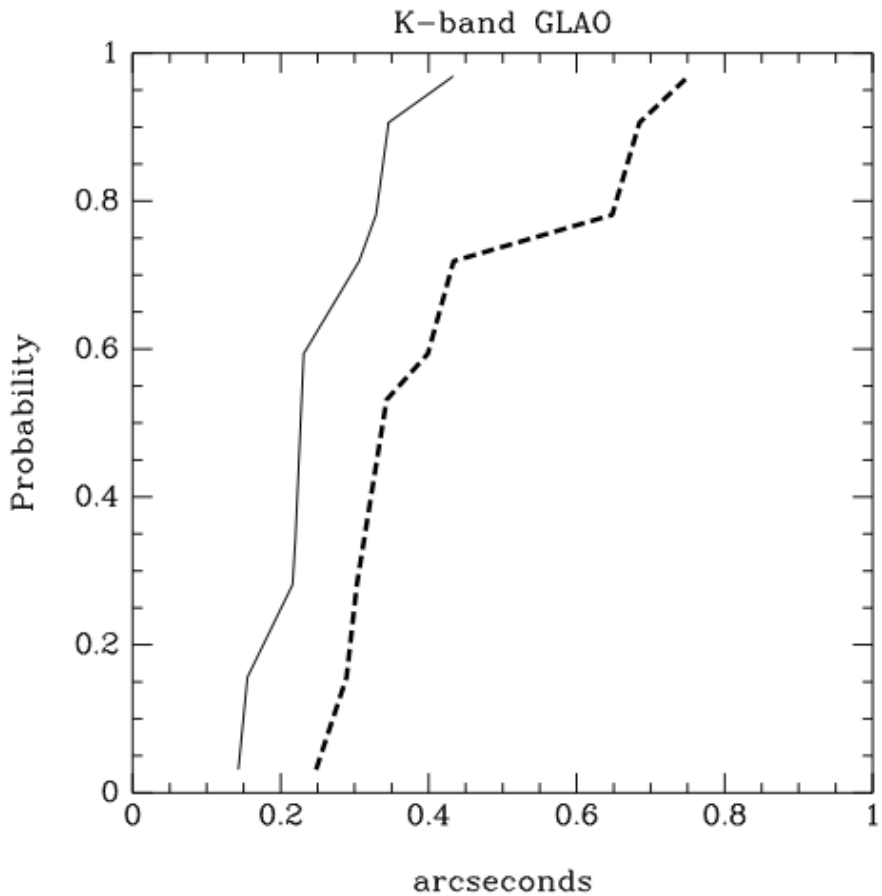
**June 16, 2016**

**Astronomy Technology Program**

# Outline

- Past, current and future Canadian Interests
- Science flowdown from 2013 Sapporo Workshop
- NRC-Herzberg Astronomy Technology Program Overview
- Thoughts on Subaru ULTIMATE

# Initial Modelling Results

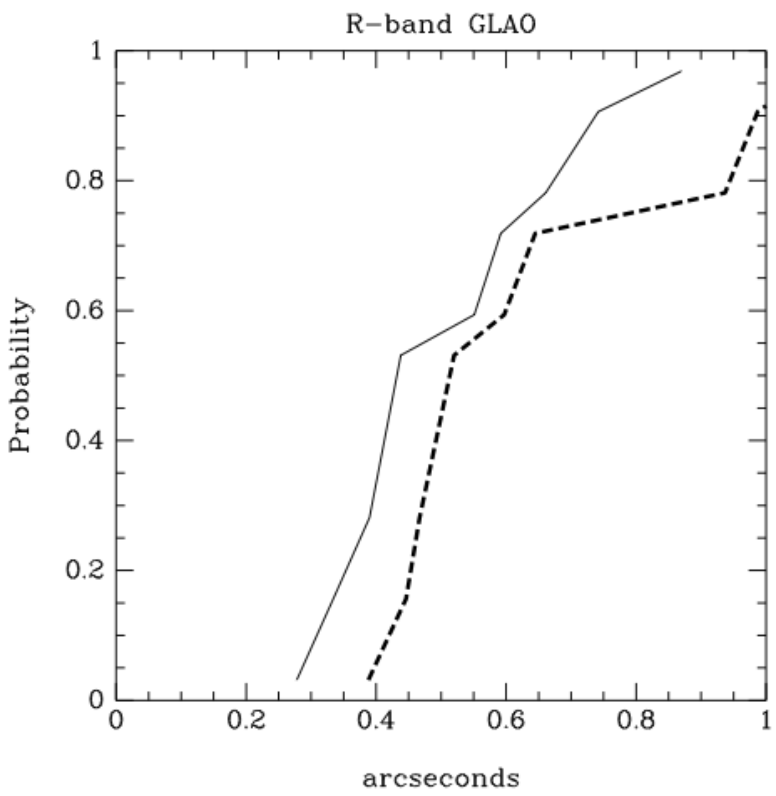


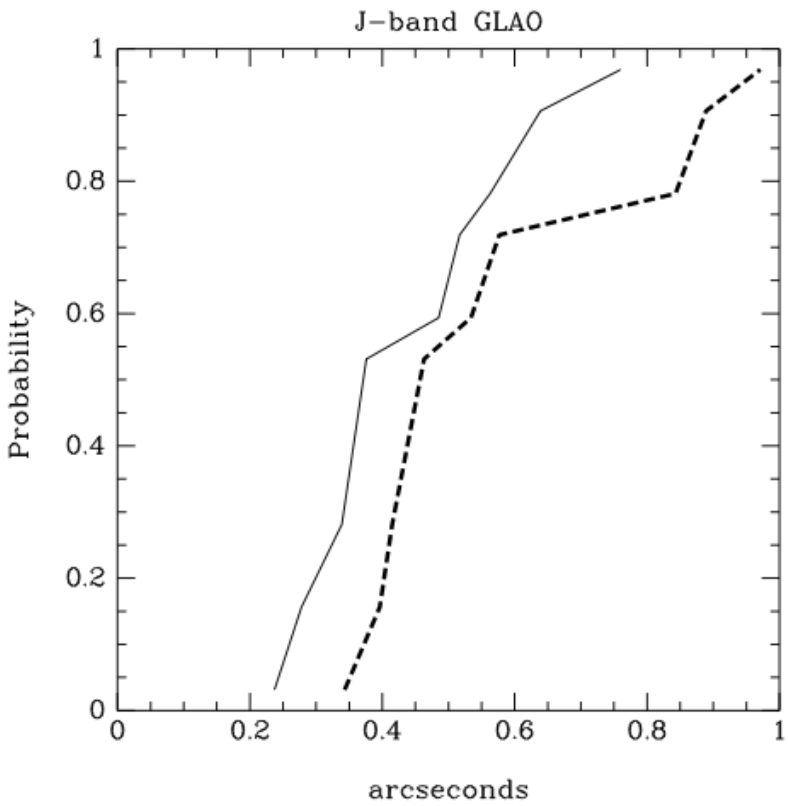

Shows FWHM of percentile seeing – i.e. if you ask for 80% seeing you get 0.35 arcsec FWHM with GLAO instead of 0.65 arcsec.

- ‘No more bad-seeing nights’
- But not as optimistic as Rigaut result

# 2005 Gemini GLAO Study – Modelling Results

- Gains in R  and J bands more modest, but still substantial



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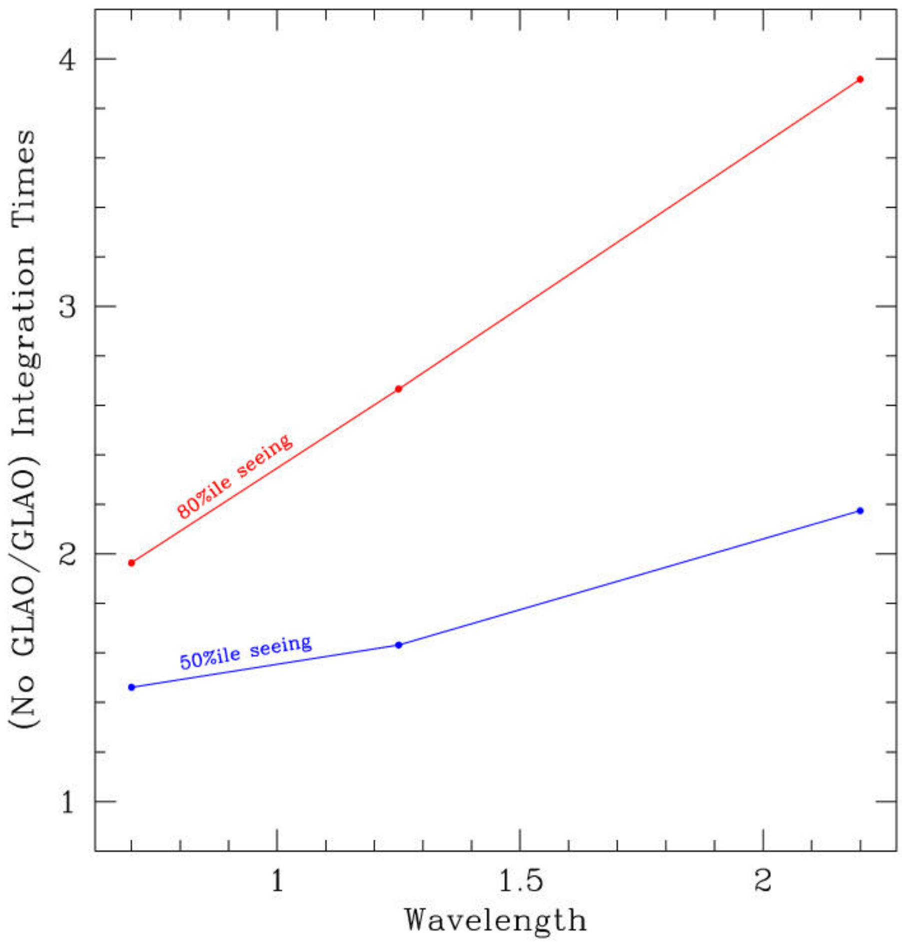
# Nevertheless, huge efficiency gains



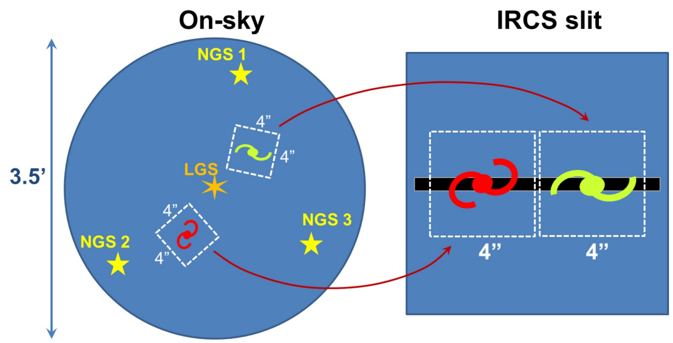

- Calculations of exposure time ratios for background limited observations
  - Used the NIRI and GMOS ITCs
- Gains are more dramatic for poor seeing => ‘A Third Gemini’

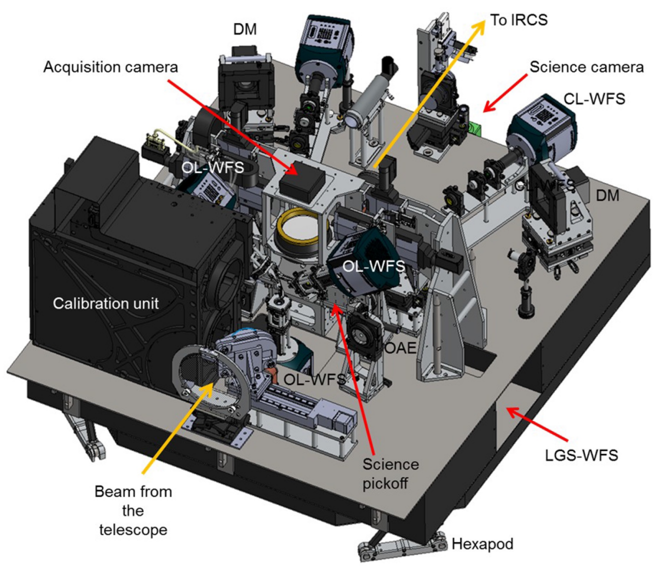
# 2005 Gemini GLAO Study – Derived Science Requirements

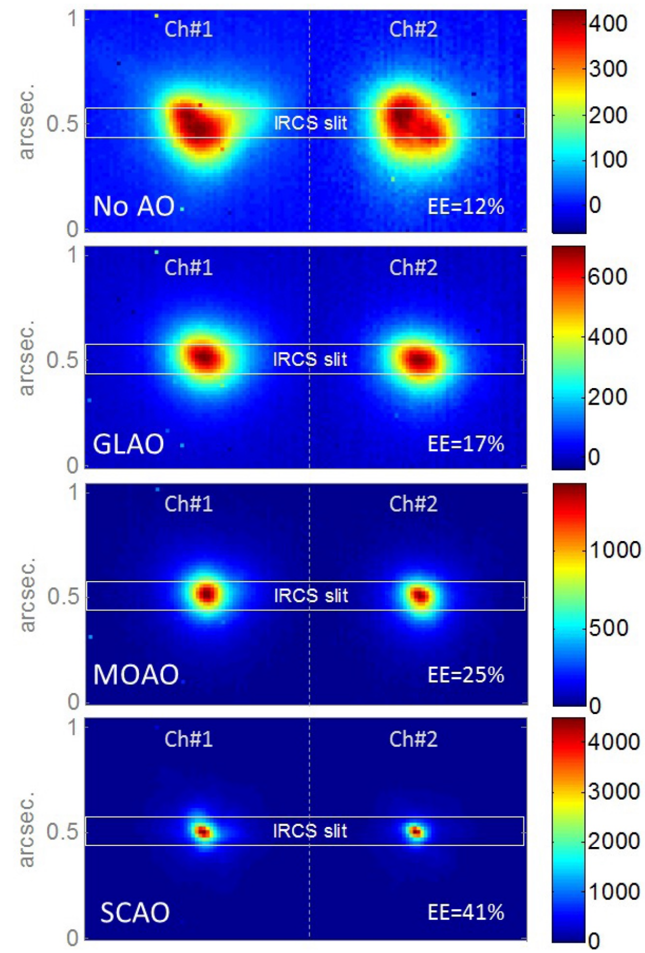
**FOV:** 50 arcmin2  requirement, 70 arcmin2  goal.
**Wavelength range**: 0.6-26μm (goal), 0.8-2.5μm (requirement).
**Delivered image quality:**
50% improvement in energy coupled to a 0.2" square IFU element in the H-band.
PSF FWHM ~0.35" in J band.
**PSF uniformity and stability:**
<10% variation in the energy coupled to a 0.1" square IFU element across a 10' FOV
'Smooth' FWHM variation <30 mas rms across the10' FOV.
**Field distortion:** <50 mas distortion across the 10'
Distortion in system should be linear, calibratable and repeatable
Uncalibratable distortion should be <1% of FWHM (requirement)
**Emissivity:** <6%.
**Throughput:** <10% decrease over the required wavelength range.
**Sky Coverage:** above 90%
**Observing Efficiency:** 75% open shutter time for imaging
**Other Instruments:** GMOS, Flamingos 2 and TRECS
**Chopping and Dithering:**
Requirement on dithering for closed loop AO NIR – 5 arcsec.
MIR needs chopping of 30 arcsec.

# Subaru RAVEN

First ever "science-grade" MOAO observations and a wonderful collaboration!



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# Gemini GIRMOS

- "Gemini InfraRed Multi-Object Field Spectrograph"
  - A TMT pathfinder instrument
  - PI: Suresh Sivanandam (Dunlap Institute/U. Toronto)
  - Collaborating institutes: U. Toronto, Dalhousie U., U. of Victoria, U. British Columbia and NRC

- Main parameters:
  - 1.0-2.4 μm (YJHK), R=3000
  - Four (or more) deployable IFUs over $1'.5$ diameter patrol field
  - 50-100 mas spaxels w/ MOAO corrections
  - >50% EE in 100 mas at 1.6μm

- Proposal to be submitted to Canadian Foundation for Innovation (CFI) in September 2016. If successful, construction start in January 2018 and first-light in 2023

# TMT GLAO

- GLAO analysis from 2006 WFOS-HIA Feasibility Study
- Basic architecture:
  - Adaptive secondary mirror w/ 43-58 actuators across 3.5-m pupil
  - 5 LGSs over an asterism diameter of 17 arcminutes
  - 4 NGS WFS

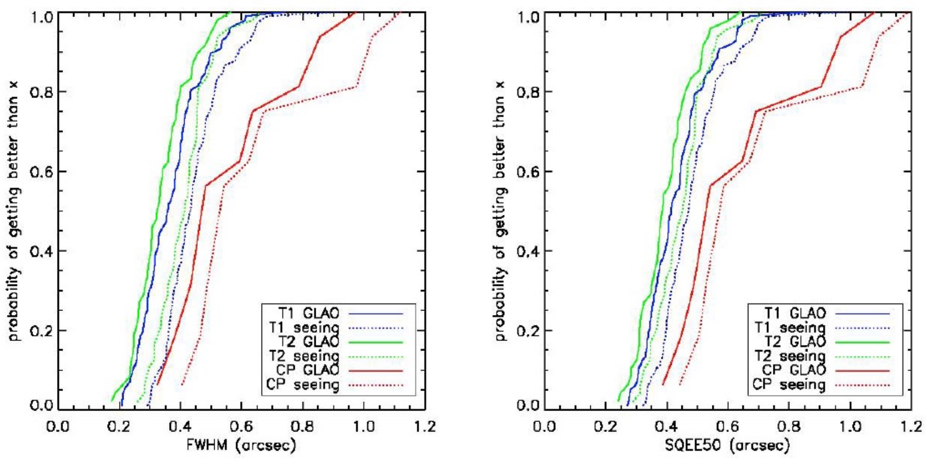



**Figure 95 - The cumulative histograms of FWHM (left panel) and full width of 50% ensquared energy (EE50, right panel) for the baseline design at 0.6µm and zenith. The no-GLAO case is also plotted as the (dotted lines).**

No "killer app" BUT:
- 25% shorter exposure times
- ASM provided common woofer to other TMT instruments

# Sapporo 2013 Workshop - Science Flowdown

**Subaru GLAO Science Flowdown**

**Version: DRF01** — **Last Update: 13 June 2013**

| Observing Program | Key Observables | Principal Investigator | Spectral Parameters: Wavelength Range (filter/μm) | Spectral Parameters: Spectral Resolution | Spatial Parameters: Resolution (mas) | Spatial Parameters: Pixel Sampling (mas) | Spatial Parameters: PSF uniformity (%) | Depth: Flux Limit (mag or ergs /s /cm2 | Depth: S/N |
|---|---|---|---|---|---|---|---|---|---|
| High-z bulges and disks | | Okamoto | | | 200 | 100 | | | |
| Galaxy Evolution- NIR Imaging | | Balogh | | NB | 200 | | | | |
| Galaxy Evolution - NIR Spec | | Balogh | | 3000 | 200 | | | 2x10^-18 | 10 |
| "Ultimate-MAHALO" | • Halpha geometry survey across environments<br>• Galaxy stellar profiles | Koyama | ZYJHK | NB, BB | 200 | 100 | | | |
| High-z AGN host galaxies | Structural parameters | Schramm | | | 200 | | | | |
| Galactic Center | • Narrow-band photometry<br>• Astrometry | Nishiyama | K | NB | 200 | < 100 | | K~16 | 20 |
| Diversity of Star/Planet Formation | | Oasa | JHK | BB | 200 | 100 | | | |
| Exoplanetary science with MOS/GLAO | Transmission spectroscopy | Narita | | | 200 | | | | |
| Enrichment History of Elements | Abundances and star formation rates | Yamada | | 20000 | 200 | | | | |
| Wide field view of nearby dwarfs | •CMDs<br>•Faint substructures | McConnachie | JHK | BB | 200 | 100<br>50 | | 30 mag / sq" | |
| Probing GCs in the GC region with GLAO | CMDs | Chiba | JK | BB | 200 | 100? | | K~20 & J~22.5 | |
| Globular clusters | •CMDs<br>•IMBHs<br>•IR excesses around WDs in GCs | Richer/Venn | | | 200 | | | | |
| First Star Relics in Galactic Center | 3D kinematics (RV w/ proper motion) | Venn | | BB<br>5000 | 200 | < 100 | | | |

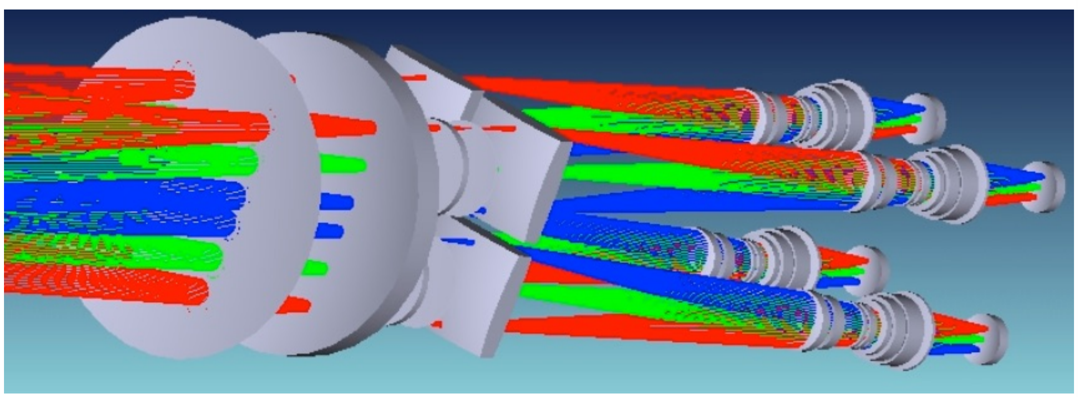
# Sapporo 2013 Workshop - Science Flowdown

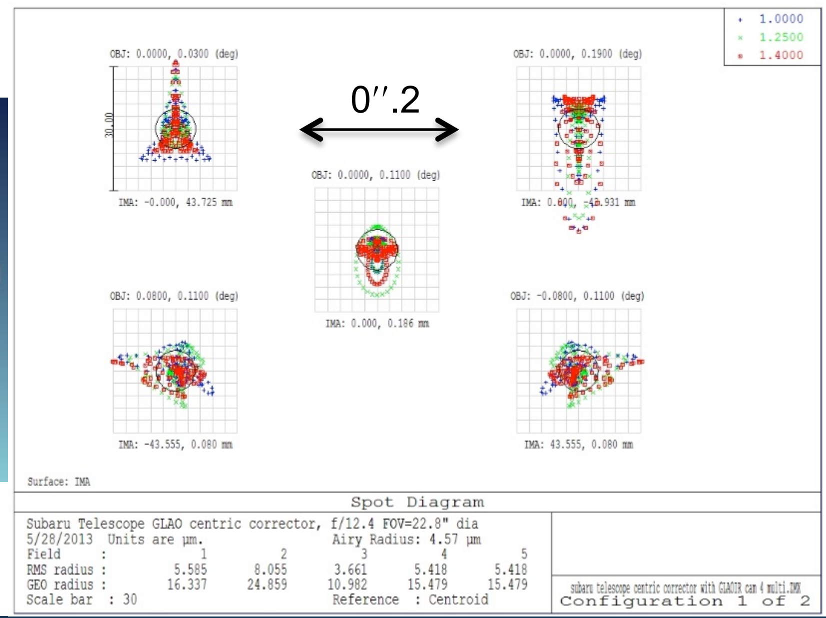
**Subaru GLAO Science Flowdown**
**Version: DRF01**

| Observing Program | Survey Field Geometry | | | Astrometry | | Multiplexing | | Synoptic Signature | | | Tracking Rate (Sidereal = 1.00) | Comments (Synergy, competitiveness, instrument type, etc.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total Areal Coverage (sq. arcmin) | FoV / observation (sq. arcmin.) | Contiguous FoV required? | Precision (mas) | Stability Timescale (years) | Total Sample Size | # objects / observation | Baseline (years) | Cadence (# observations / baseline) | Duration / observation (hours) | | |
| High-z bulges and disks | | | | | | | | | | | 1.00 | Multi-IFU |
| Galaxy Evolution- NIR Imaging | | | | | | | | | | | 1.00 | |
| Galaxy Evolution - NIR Spec | | 13.6 x 13.6 | | | | 5500 | >> 150 | | | 4 | 1.00 | Multi-slit |
| "Ultimate-MAHALO" | | 30'x30' | | | | 2000 | 100-200 | | | 18 | 1.00 | MOS follow-up for cluster membership<br>multi-IFU follow-up for internal kinematics |
| High-z AGN host galaxies | 1100 | | | | | | | | | | 1.00 | |
| Galactic Center | 40'x40' | | yes | 40 | 4 | | | 4 | 100 | 0.017 | 1.00 | |
| Diversity of Star/Planet Formation | | 10'x10' | | | | | | | | | 1.00 | Multi-slit<br>IFU for jets |
| Exoplanetary science with MOS/GLAO | | | | | | | | | | | 1.00 | Not a GLAO science case! |
| Enrichment History of Elements | | | | | | | | | | | 1.00 | |
| Wide field view of nearby dwarfs | | >= 10'x10' | | | | | | | | | 1.00 | Spectroscopy not required |
| Probing GCs in the GC region with GLAO | | | | | | | | 15 years? | | | 1.00 | |
| Globular clusters | | | | | | | | | | | 1.00 | Proper motion cleaning: 5 mas/yr especially important for open clusters |
| First Star Relics in Galactic Center | | | | | | | | | | | 1.00 | Proper motion cleaning: 2 mas / yr<br>Overcoming confusion is key |

# Subaru ULTIMATE Imager Concept (J. Pazder, 2013)

- Adaptive Secondary Mirror + Concentric corrector providing a universal 22′.8 diameter field of view with residual aberrations less than 66 mas
- 4-barrel imaging system feed :
  - Each barrel has 4K×4K H4RG detector covering 6′.8×6′.8 FoV w/ 0′′.1/pixel
  - Total imager FoV of 185 square arcminutes







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# NRC-H ATP Overview – Program Resources

Critical mass of human, infrastructure, and financial resources:

- 2 sites - Victoria and Penticton, with well established special purpose laboratories
- ~60 staff - engineers, scientists, technicians, and support staff – matrix organization
- Stable operations budget baseline, plus project funding
- Healthy collaborative framework, domestic and international, institutional and industry

# ATP Overview – Projects and Collaborations

- Canada-France-Hawaii Telescope (Canada, France, Hawaii + new partners):
  - MegaPrime new broadband and narrowband filters
  - SPIRou high-resolution IR spectropolarimeter
  - NIRPS high-resolution IR spectrograph
  - Maunakea Spectroscopic Explorer (MSE)

- Gemini (US, Canada, Chile, Brazil, Argentina):
  - GRACES remote CFHT/Espadons fiber feed
  - GHOST high-resolution optical spectrograph (w/ AAO)
  - Gen4#3 new instrument
  - ALTAIR upgrades

- ALMA (US, Europe, Japan, Chile, Canada, Taiwan):
  - Band 3 upgrades and Band 1 components
  - Mm-Camera studies
  - Wideband correlator studies

# ATP Overview – Projects and Collaborations (cont.)

- JWST (NASA, ESA, CSA):
  - FGS/NIRISS detectors, optics, mechanics support
- TMT (CIT, UC, ACURA, Japan, China, India):
  - NFIRAOS AO system + AO components
  - IRIS science instrument
- SKA (10+ countries):
  - Dish correlator
  - Feed digitizers
  - Cryogenic low noise amplifiers
- Next-generation VLA:
  - Composite dish antennas, feeds, correlator studies

# ATP Overview – Precursors

Engaged in a range of exploratory projects on promising technologies for future projects

- Phased array feeds; room temp & cryogenic
- Low voltage deformable mirrors
- Zero read noise IR detectors
- Advanced wavefront sensors & reconstruction algorithms
- Dynamic mechanical modal analysis
- Integrated opto-mechanical modeling
- Segmented mirror control
- Fiber optics/photonics
- Monolithic microwave integrated circuits (MMICs)

# Thoughts on Subaru ULTIMATE

- There are "infrastructure" investments that make sense no matter what path is taken:
  - New laser(s)
  - Adaptive secondary that would act as a "woofer" for <u>any</u> AO architecture

- Main conclusion from Sapporo 2013 workshop: Narrow-band, "wide-field" imaging is the best justification for GLAO on Subaru
  - Imager was preferred science instrument back then
  - Imager? d-IFUs? Answer should come from updated science case flowdown at this workshop

- Canada has a long-standing interest in a next-generation AO system on a 8-m class telescope
  - NRC ATP can make contributions to ULTIMATE – to be discussed!

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# Thank you!

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