Japanese Interest in WFIRST-2.4m project

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JAXA/ISAS Science Committee
WISH Working Group, Chair

Tohoku University: AURA international member
1. WFIRST-2.4m SDT: Japanese Interest

2. WISH: complementarity / synergy

3. Coronagraph Instruments for Extra-solar planets

4. Future prospects
Science with Wide-Field NIR Surveys

● Galaxies at z=7-15: Beyond the Epoch of Cosmic Reionization
● Cosmology: Dark Energy and Dark Matter
● Galaxy Formation and Evolution

Subaru, Akari / Subaru-HSC, PFS, TMT, WISH

● Gravitational Lensing Extrasolar Planet Search

MOA, IRSF T. Sumi contributed in WFIRST-SDT

● Galactic Bulge: astrometry, stellar population

JASMINE
Coronagraph Instruments

● Coronagraph instruments for Subaru Telescope
  CIAO + AO36
  HiCIAO + AO188: SEEDS project (Tamura et al.)

● Development for future ground-based and space-mission coronagraph instruments
  SITE for TMT (Matsuo, T. et al.)
  SCI for SPICA (Enya et al, @ mid-infrared)

● Development for various Coronagraph Architectures
  - Phase-mask coronagraphs (focal plane mask)
  - Common-path visible nulling coronagraphs
  - Binary pupil masks
  - Pupil Remapping Interferometer
  - Unbalanced nulling interferometer
1. WFIRST-2.4m SDT: Japanese Interest

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Wide-field Imaging Surveyor for High-redshift WISH space telescope project

PI: Toru Yamada
WISH

Concept developed for the next JAXA/ISAS M/L-class Mission
WISH Working Group 2008 Sept- (Chair, Yamada)

Science Goals
- Explore the universe beyond Cosmic Reionization:
  Studying the earliest galaxy formation at z=8-15
- Cosmic Expansion History with SNIa (type Ia Supernovae)
  NIR detection and light curves of SNIa at z=0-2
- Deep and Wide-field NIR Survey at 1-5μm
  Various fields in astronomy

Key Features
- Dedicated deep and wide-field imaging surveys at 1-5μm
- Survey strategy: 100deg², 28AB (5σ), 6 broad bands (main survey)
**Base Design Model**

- **1.5m** light-weighted glass primary mirror
- CFRP structure @90-100K
- Diffraction limited image at **1-5µm** over the flat focal plane
- H2RG 32x2kx2k 128Mpix
- **0.155”/pixel**(18µm-pitch), **850arcmin²/FoV**
- Light weight: **1.4t** (WET)

**Current Status**

- JAXA/ISAS WISH Working Group since 2008 (pre Phase A)
- More than 20 astronomers/engineers have been working for R&D
- JAXA/ISAS R&D budget (~1M$, without including man power cost)
- Potential international Partners: SAO (USA), LAM (France), Canada
- Proposed Schedule: 2013 Mission Definition Review,
  2015 System Definition Review, Launch by 2020
- Expected Cost (w/o launch, operation, data facility) : **250-300M$**
US-collaboration

- Proposal submitted for NASA SALMON2 MoO  
  (PI: G. Fazio, Smithsonian Astrophysical Observatory)  
- Testing and Providing Focal Plane Arrays / ASIC electronics

France-collaboration

- Proposal Submitted for CNES Missions of Opportunity Program  
- IFU Spectrograph as an optional instrument  
- French internal WISH workshop at IAP (Oct 3)

and Canada, ...
Extremely High-Redshift Galaxies: First Billion Years

\[ z=9,12,15 \quad E(B-V)=0.1 \]

WFIRST filters

WISH broad-band filters
In the observers’ frame...

Limit of AB>28 is needed

Empirical luminosity evolution

Semi-analytic Model prediction

FoV JWST NIRCam 2.2’x2.2’ x 2ch (per filter) ~ 2.8x10⁻³ deg²
For the Science Cases of the 1\textsuperscript{st} Billion Years

- 250K (2.4\textmu m cut) is very desirable, otherwise, not much gain from WFC3 results except for the survey volume.

- Additional Survey Strategy,  
  \(~100\text{ deg}^2, ~28\text{AB ZYJHK}\) is desirable

\(\Rightarrow\) \(O(10^4)\) \(z\sim8-12\) objects are detected  
\(\Rightarrow\) needs at least \(~1\) year for \(~100\text{ deg}^2\)  
\(~0.5 \quad \sim50\)

- Narrow/Intermediate-band filters?
1. WFIRST-2.4m SDT: Japanese Interest

2. WISH: complementarity and synergy

3. Coronagraph Instruments for Extrasolar planets

4. Future prospects
Subaru 8.2-m telescope has had several “Planet & Disk Finders” from its early phase to present

★ CIAO (Coronagraphic Imager with Adaptive Optics)
  ★ Operation years: 2001 - 2008
  ★ Cold Coronagraph + AO36; w/ 1024x1024 InSb array (Raytheon ALLADDIN)
  ★ Large disks (e.g., AB Aur), circumbinary disks (e.g., SR24), massive YSO disks (e.g., BN)
  ★ Very wide orbit planets (DH Tau b, GQ Lup b)

★ HiCIAO (High Contrast Instrument for next generation AO)
  ★ Operation years: 2009 -
  ★ Warm Coronagraph + AO188 / SCExAO1024 + various differential imaging (PDI, SDI, ADI)
  ★ w/ 2048x2048 HgCdTe (H2RG) array + ASIC SIDECAR
  ★ Giant planets/companions in wide orbits (GJ 504 b, kappa And b, GJ 758 b)
  ★ Solar-system-scale disks (gaps and spirals)
  ★ SEEDS strategic survey project ongoing
instrument & R&D Programs

- Subaru
  - SCExAO (Guyon), IRD (Tamura), CHARIS (Kasdin) [so far, HiCIAO, etc.]
- TMT
  - SEIT (Matsuo)
- J-TPF R&D
  - Coronagraphs (Hokkaido-Murakami, NAOJ-Nishikawa, TAUT-Kurokawa/Tavrov)
- SPICA
  - Coronagraph-Enya
Science Threshold for WFIRST-2.4m

Full success: characterization of nearby Jovian Planets
Extra success: characterization of superearth planets
Constraints on Formation and Compositions of Super Earths by WFIRST

Prediction from Formation Theory of Super Earths

Mass-Radius Relation of Super Earths as a function of Compositions

WFIRST Reflection flux

Contrast=10^{10}

Hydrogen-rich

Radius

Water-rich

Hydrogen 100%

Water 100%

Rock 100%

Complementary Information

With spectra

RV follow-up \( M_p \sin i \)

WFIRST inclination

Courtesy of K. Kurosaki

Y. Hori et al. in prep
Development for various Coronagraph Architectures

- Phase-mask coronagraphs (focal plane mask)  
  N. Murakami

- Common-path visible nulling coronagraphs  
  SPLINE  N. Murakami

- Pupil Remapping Interferometer  
  T. Kotani

- Unbalanced nulling interferometer J. Nishikawa

- Binary pupil masks  
  SPICA Coronagraph Instrument  K. Enya
Phase-mask coronagraphs

- Photonic-crystal masks (8OPM & Vortex)
  - $\sim 2 \times 10^{-8}$ contrast at HCIT/JPL (8OPM)
- MPIAA lenses (Secondary-mirror remover)
- Planned to be installed into SCExAO/Subaru

\((\downarrow)\) Optical setup of 8OPM/SCExAO

\((\rightarrow)\) Photonic-crystal vector vortex mask and 8OPM (Murakami et al. 2010, 2013)

\((\rightarrow)\) Manufactured MPIAA lenses, and (↑) lab. experiment of removal of a shade of a secondary mirror.

\((\rightarrow)\) Lab. experiments of 8OPM with a circular pupil at HCIT/JPL (Murakami et al. 2012).
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**SPLINE** (Savart-Plate Lateral-shearing Interferometric Nuller for Exoplanets)

- Common-path visible nulling coronagraph (VNC)
- Simple, stable, achromatic, and insensitive to pupil geometry
- Broadband lab. demonstration of 4-beam SPLINE (Bandwidth~25%)
- 2-channel design for higher throughput (in prep.)

(↑) Optical setup of a 2-beam SPLINE (Murakami & Baba 2010).

(↑) A picture and (↛) lab. experiments (contrast and stability) of a 4-beam SPLINE (Murakami et al. 2012).
Pupil Remapping Interferometer

- Pupil Remapping Interferometer (PRI) is an interferometric high-angular resolution and high-contrast imaging technique (Perrin et al. 2006, MNRAS, 272,747).
- PRI can measure wavefront errors of incoming light very precisely and PRI will act as if an extreme adaptive optics but no active mechanism is required, which is a large advantage for space instruments.

Integrated Optics Beam-combiner developed at NAOJ

Interferometric fringes obtained at Lick 3-m telescope

On-sky test of the PRI instrument at Lick 3m telescope and Subaru telescope was successfully done. It is an important step toward high-contrast imaging for the future space mission.
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  N. Murakami
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  SPLINE  N. Murakami / T. Matsuo
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**High-Contrast Techniques** (Nishikawa et al.)

- **UNI** (unbalanced nulling interferometer)  (Yokochi et al. 2011 Opt Exp, Nishikawa et al. 2008 A&A)
  
  Pre-nuller for Dynamic Range Enhancement
  
  Principle was confirmed by experiments

- **Dual-feedback control method** (Ohya et al. 2012 SPIE)
  
  Under development

  Pupil-plane WFS (fast feedback) + focal-plane wavefront sensing (slow feedback)

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**Graphical Representation**

- **UNI** (unbalanced nulling interferometer)
- **AO** (active optics)
- **Coronagraph**
- **WFS** (wavefront sensor)

**Diagram Description**

- **Star**
- **Partial Nulling of star**
- **Wave front Re-Correction**
- **Residual halo/planet Contrast** \( \approx 1 \times 10^5 \)
- **Speckle**
- **Planet**

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**Yokochi et al. 2011.**

Extra-reduction of wavefront-error energy after UNI and AO (PAC) having the same amount of phase error.
Coronagraph Technique

- Common-Path AIC (3D Sagnac Interferometer)
- Pupil-rotation Nulling Coronagraph

(Tavrov et al. 2008, Yokochi et al. 2009)

**Coronagraph Technique**

- **Common-Path AIC (3D Sagnac Interferometer)**
- **Pupil-rotation Nulling Coronagraph**

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**Output (Bright)**

**Output (Nulled)**

**Input**

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![Graph](image)

- Normalized intensity
- Separation \[\frac{\lambda}{D}\]
- CP-AIC
- 8OPM

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Clear aperture at 180 deg rotation
Development for various Coronagraph Architectures

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  N. Murakami

- **Common-path visible nulling coronagraphs**  
  SPLINE N. Murakami / T. Matsuo

- **Pupil Remapping Interferometer**  
  T. Kotani

- **Unbalanced nulling interferometer** J. Nishikawa

- **Binary pupil masks**  
  SPICA Coronagraph Instrument K. Enya
SPICA Coronagraph

Burrows et al. 2003

The SPICA coronagraph team
(Document preparation: K. Enya)

- SPICA: astronomical space observatory mission with 3m class cryogenic (6K) telescope (e.g., Nakagawa et al. 2013)

- The SCI: the SPICA Coronagraph Instrument. Coronagraphic spectroscopy in MIR is unique (e.g., Enya, Kaneda, Kotani et al. 2013)
Developments for coronagraph (1/2)

• Design
  – Binary pupil masks for obscured pupil
  – Advantages: wide IR coverage, less sensitive on telescope pointing error, simple optics

• Laboratory experiment
  (a) Precise masks on glass substrate by electron beam lithography
  (b) Free-standing masks (i.e., no substrate)
  (c)-(e) High contrast is demonstrated at visible wavelength (e.g., Haze et al. 2011, Enya et al. 2007)

* Based on LOQO: Vandervei 1999
Organizations in Japan 
(on exoplanets)

ISAS & NAOJ are National Agencies for Big Projects Joined by University Researchers

Steering Participating to Projects Using Science Data Exchange of People
Potential Japanese Contribution/Initiative in wfirst-2.4m Project

- **Science**
  “first billion yeas” (WISH, Subaru)
  extrasolar planets (microlensing, superearth models, SEEDS)
  survey design (e.g., optimization for microlensing)

- **Development (hardware)**
  Telescope or Spacecraft module /
  Instrument / Detector on-sky testing /
  Coronagraph development

- **Data Management**

Coordination with Subaru HSC/PFS optical observations for northern sky
People involved in the early discussion:

Gouda, N. (NAOJ), Iwata, I. (NAOJ/Subaru),
Kawai, N. (TiTech), Kodama, T. (NAOJ),
Miyazaki, S. (NAOJ), Morokuma, T. (Tokyo)
Nakagawa, T. (ISAS)
Shibai, H. (Osaka), Sumi, T. (Osaka),
Takada, M. (IPMU), Tamura, M. (Tokyo/NAOJ),
Yamada, Y. (Kyoto), Yamada, T. (Tohoku), Yano, T. (NAOJ)
(WISH, JTPF, JASMINE, Subaru-Euclid ,,,)

Coronagraph:
Enya, K., Kotani, T., Kawahara, H., Murakami, N., Nishikawa, J.

.. and more...
Optimize observation fields by mapping the microlensing event rate.

Peak at $l=1^\circ$

1.6X higher rate than SDT report.
IR survey with existing four H4RGs

- Four H4RGs, Dewar, electronics are ready
  - New 1.8m IR telescope in Namibia
  - WiFCOS camera for IRSF *(with R. Barry at GSFS)*
    - Need focal reducer optics
      - Focal Length: 13.8m → 6.61m
      - Pixel scale: 0.45”/pixel → 0.312”/pixel
      - FOV: 7.7’ → 45’
    - Filter systems (J, H, K, narrow-band, polarization filter? )
Possible contribution to WFIRST from Japan

Hardware:
- Flight calibration system
- Integral field spectrograph
- Fine guidance sensor
- Coronagraph
- H4RG development by ground base IR telescope
  \( \rightarrow \) long-term characterization

Non-Hardware
- Data from a wide-area sky survey by Subaru HSC, designed to complement the WFIRST observing program
- Data processing and archiving
- Optimize the WFIRST fields by ground base IR telescope