Optical to Infrared Follow-up Facilities for GW Events at the University of Tokyo

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on behalf of Tomo-e development team
and TAO project team
Key Issues of GW Events, targeted by Opt/IR Facilities

(1) EM identifications of GW events
   ✓ Poor localization, even with 3 GW detectors (~6°)
   ✓ extremely wide field imager is necessary

(2) Opt-NIR Follow-up Observatories
   ✓ SED is expected to peak @ NIR
   ✓ NIR and spectroscopic observation is important to constrain explosion processes

Tanaka & Hotokezaka 2013
Opt/IR Facilities at IoA, Univ. Tokyo

Provide Two Types of Observations

(1) **Optical Discovery** → Identification by Kiso 1m Telescope

- Kiso Wide Field Camera (KWFC) : Tanaka-san’s talk
- Wide-Field Imager Tomo-e in Design Phase

(2) **Optical/ NIR Follow-up** → Atacama and Other Observatories

- TAO 6.5m Telescope (Atacama, Chile)
- miniTAO 1m Telescope + Atacama NIR Camera (ANIR) → Operation suspended due to the construction of the 6.5m telescope
- LISS optical spectrograph at Nishiharima 2m Telescope
(1) Tomo-e: The Next Generation WFC at Kiso Observatory

- **ZTF (1.2m), 47° (2016-)**
- **LSST (8.4m), 9.6° (2023-)**
- **iPTF (1.2m), 7.8°**
- **Pan-STARRS (1.8m), 9°**

FoV of Kiso 1m Schmidt Telescope φ 9°

KWFC/Kiso 4.8°, CCD

Fill-up 20° of φ 9° with CMOS sensors
Layout of the Focal Plane

- **φ 9° (0.44 mag vignetting)**
- **φ 4° (Vignetting-free area)**
- 480 mm x 84 chips
- 530 mm
- **Canon 35mm Full HD CMOS sensor**
  - 2000 x 1128 pix
  - Frontside-illum. + Microlens
  - QE~50% @ 550nm
  - Low noise: RON < 2e- rms
  - Large pixel: 18um/pix

- **190 Mpix: 420 MB/ exposure**
- **Driven at Room Temperature**
- → No Cryogenics
**Tomo-e Structure**

- Preliminary Design Work is now underway

- Consists of 4 unit cameras

- Each unit camera has 21 CMOS sensors

They are operated under ambient temperature/pressure
Data Acquisition System

- Data Production Rate: 420MB/one shot

Requirements:
- Typical survey observations (3sec exp / 3sec tel. slew) ⇒ 70MB/sec
- 2Hz monitoring (2Hz/frame) ⇒ 830MB/sec

Realtime Data Reduction Pipeline
- Data reduction (calibration, subtraction, source detection) should be completed within ~5sec
Tomo-e has a large advantage if the position accuracy of GW source is not so good (~100°)
Tomo-e Prototype Model

Camera Body
- 8 CMOS sensors
- Ambient Temperature
- Light-weighted

 Backend System
- 3D data process
- Maximum 3 TB/night
  - Requires large and fast disks (24 TB RAID 0)

Frontend Electronics
- Driving / Readout CMOS sensor
- AD conversion
- Installed onto the telescope

Smaller Camera to prove the element technologies, and that they work on Kiso 1m
On-Telescope Performance of Tomo-e PM

First Light: Dec 2015

M42 HDR image

2Hz, 5108 frames

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5σ Sensitivity in Magnitude
Development Schedule

Sensor development
Sensor evaluation
Data acquisition system
Camera body
Data analyzing system
Assemble
Test observations

New Innovative (GW)
Kaken A (Solar system Obj.)
Sakigake (Big Data)
Kaken A (SNe Survey)
Kaken S (GW)

CMOS Evaluation/Prototype
Prototype
Solar system Survey
Data Reduction System
Camera Develop.
SNe Survey
Camera Develop.
GW Follow-up
ToO Obs.

Long-term survey
Full Tomo-e (84 CMOSs)
(2) TAO 6.5m Telescope Project

- Install a 6.5m infrared-optimized telescope
- At the summit of Co. Chajnantor (5640m)
- PI: Prof. Yuzuru Yoshii
Advantages of TAO 6.5m for EM-follow-up

- Large Aperture: High sensitivity
  - ~24magAB in NIR broad-band filters (3600sec/5sigma)
- Excellent Weather Condition
  - Photometric > 70%
  - Observable > 80%
- Covers unobservable sky from Japan
  - Southern Hemisphere (S°23)
  - Opposite Longitude from Japan (68°W)

Atacama desert
“the driest place on the Earth”
Telescope Structure

- Preassembly underway in Harima
- By Nishimura Co., Ltd.
Mirrors

- All completed
- Borosilicate honeycomb mirror
  - M1: 6.5m primary
  - M2: 0.9m secondary
  - M3: 1.1x0.75m tertiary
- Production by Mirror Lab, University of Arizona
NIR Instrument SWIMS

Simultaneous-band Wide field Infrared MOS Spectrograph

- Simultaneous imaging/spectroscopy in 2 bands (0.9-1.4 μm & 1.4-2.5 μm)
- Wide field of view with good pixel resolution
  9.6' Φ FoV, 0.126''/pix, with 4k x 4k pixels
MIR Instrument MIMIZUKU

Mid-Infrared Multi-field Imager for gazing at the Unknown Universe

- Wide wavelength coverage with 3 detectors
  - InSb : 2-5.6μm
  - Si:As : 6-26μm
  - Si:Sb : 25-38μm

- Accurate relative photometry
  - Simultaneous observations of two discrete fields by the “Field Stacker”
Schedule

- Telescope Mount test in Japan
- Fabrication/Tests in Arizona
- Telescope Mount
- Integraton
- Enclosure Upper
  - Parts Fab.
  - Assemble #1
  - Detailed Design
  - Assemble #2
- Enclosure Lower
  - Parts Fab.
  - P&T
  - P&T
- Summit Facility
  - Redesign
- Access Road
  - Redesign
  - Exp Work
- P&T
- Obs
- ICS
- AGSH?
- Engineering first light
- In Japan
- In USA
- Shipping
- In Chile
- Summit Const.2
- Instruments Delivered
Summary

Institute of Astronomy, University of Tokyo is promoting Opt-NIR Follow-up facilities for GW-EM follow-up

- Tomo-e CMOS camera for Kiso 1m Telescope
  - Covers 20° of φ 9° of the 1m Schmidt Telescope
  - First Light in mid-2018

- TAO 6.5m telescope at 5640m altitude
  - Will open new NIR-MIR observation capability
  - Engineering first light in 2018
  - Science first light in 2019