Astronomy at Dome Fuji in Antarctica

-background and future plan-

Tohoku University

Takashi Ichikawa
Near-infrared wide area survey

Clustering evolution of low mass galaxies (building blocks) in large scale structure is one of central issues in observational cosmology.
For the study of distant galaxies, powerful infrared camera and spectrograph are of the essence.

MOIRCS on Subaru

Ichikawa+(2006)
Widest and Deepest High-Redshift Galaxy Survey in K band

Complete samples of $10^9 M_{\text{sun}}$ at $z \sim 3$

Our Goal

- FIRES
- Subaru+MOIRCS
- MODS
- SDF
- MODS
- VLT GOODS-S
- 8m telescope
- UKIDSS
- 4m telescope
- MUSYC
To make a map of low-mass galaxies at high-z to study the evolution of large scale structure, a lot of telescope time is demanded (~hundreds nights).

However, telescope time of 8.2m Subaru is highly competitive.

Space telescopes would be best. However, they are quite expensive (>200 M US$).
Chili would not be the best site for THz astronomy to study dusty galaxies at high-z Universe.
Consortium of Astronomy at Dome-F

Infrared group: (PI) T. Ichikawa
- Nakai, N., Seta M. (Tsukuba Univ.)
- Ichikawa, T., Okano, S., Sakamoto, T. (Tohoku Univ.)
- Taguchi, M., Uraguchi, H., Iye, M. (NOAJ)
- Kurita, M. (Nagoya Univ.)
- Motoyama, H. (NIPRJ)

THz group: (PI) N. Nakai
- Nakai, N., Seta M. (Tsukuba Univ.)
- Ichikawa, T., Okano, S., Sakamoto, T. (Tohoku Univ.)
- Taguchi, M., Uraguchi, H., Iye, M. (NOAJ)
- Kurita, M. (Nagoya Univ.)
- Motoyama, H. (NIPRJ) & collaborators

~7m THz Radio Telescope

Showa station
National Institute of Polar Research

~2m Infrared Telescope
Astronomical sites at domes

Dome F (3810m)
Dome A (4040m)
Syowa
Zhongshan
Dome C (3250m)
Dome F is located at the edge of the aurora oval.

Our interest is in infrared and THz. Aurora would not be a serious obstacle.

Few data are available in infrared. However, the aurora is expected to be very weak in infrared (Phillips+1999; Espy+ 1988). (cf. strong CO, NO at 4.7, 5.4 μm)

http://ja.wikipedia.org/wiki/
Seeing strongly depends on boundary layer

Thickness of boundary layer (simulation)

Simulated height of boundary layer (model atmosphere)

Dome F  ~18m (?)
Dome A  ~20m (?)
Dome C  ~30m (measured)

Height where the residual boundary layer seeing is 0.1" or better 50% of the time (AJA 2004)

Swain & Gallee (2006)
Why astronomy in Antarctica? – the advantages

- Clear sky (photometric day > ~85%)
- Little snow (PW=2.5mm/year, 10-20cm snowfall)
- Low and stable humidity (PWV < 0.3mm)
- Low temperature (-70°C in winter)
- Very good seeing above boundary layer
- Weak wind
  - 3m/s on ground, 5.4m/s at 10m height

Japan has one of best astronomical sites in Antarctica
Low sky background & High transmittance

<table>
<thead>
<tr>
<th></th>
<th>altitude</th>
<th>temperature</th>
<th>PW</th>
</tr>
</thead>
<tbody>
<tr>
<td>blue</td>
<td>Dome Fuji</td>
<td>3810m</td>
<td>-70℃</td>
</tr>
<tr>
<td>red</td>
<td>Mounakea</td>
<td>4200m</td>
<td>0℃</td>
</tr>
</tbody>
</table>

Near-infrared

Mid-infrared

THz
Comparison with Subaru for 2.5m Antarctic Telescope

1 hour integration with S/N=5σ for point source

- Seeing (V): 0.8"
- Seeing (0.6"

- SPIZER 1.6μJy@3.6μm
8.2m Subaru+MOIRCS

2.5 m telescope in Antarctica

performance in near-infrared

1:1

Kurita et al. (2005)

Ichikawa et al. (2005)

Cost

100 : 1

Ultra light weight mount

~5M$ (?)
Ultra light weight 2.5m telescope

(Kurita+ 2009)

Light weight is highly appreciated for tower telescope installed above boundary layer (18m at Dome F)

Mount for <2.5m mirror

5t w/o mirror
1/5 of conventional
3" absolute pointing error
0.5" tracking error for 5min (w/o guider)
Cass instrument φ 900x1200 (0.5t)
• It is in very harsh environment

• No access is available in winter time

• It is long way (~1000km, 3 weeks )

• Snow mobiles with sledges are only transportation at present

• No flights are available on the dome 3810m (0.6 atm)
Sciences at Dome F

Another harsh environment:
Several scientific programs at Dome-F are proposed. Among them, the project by the astronomy group is most massive and costly. However, the astronomy is the least minority and no astronomers are in NIPR. The development of astronomy depends on the future plan of NIPR.

However, NIPR is strongly supporting astronomy program.
Astronomy proposals by Japanese groups

optical, Infrared

• Wide and deep imaging survey at high redshift -- stellar assembly in large scale structure
• Exoplanet atmosphere by transit observations of the second eclipse
• Microlensing observations
• 3-D velocity field information on the full-disk Sun by continuous monitoring in five wavelengths around H-alpha
• Coronal Magnetic field in Sun

THz, submm

• Survey of proto-galaxies at high-z
• Molecular clouds and star forming region in the Galaxy
Dome Fuji (2006/2007)

Radiometer
Transmittance of atmosphere

Doppler Sodar
Turbulence of upper atmosphere
Transmittance in 220GHz band

Very stable than Atakama in summer
However, higher transmittance than Atakama in the best days
Turbulence strength

Dome Fuji
Diurnal variation of turbulence strength

See in Aristidi + 2005

Seeing at Dome C

Aristidi + 2005
Pilot studies with small telescopes

- **40cm Infrared telescope**
  - Stellar halo in clusters of galaxies at 2.4 μm
  - Exoplanet atmosphere by second transit
  - Site test

- **30cm THz telescope**
  - Survey in galactic plane
  - Site test
Light weight
AIR-T-40
40 cm Antarctic Infra-Red Telescope
+ remote control
(under developing)

Full specs for the environment at $-80^\circ C$

at Rikubetsu (Hokkaido)
$-23^\circ C$
All parts are tested in refrigerator at \(-80^\circ\text{C}\)
Jungflau in Swiss

30cm THz telescope

for Galactic plane survey

3580m
-28°C

Seta et al.
Near-infrared three-color camera

\[
\begin{align*}
K_{\text{dark}} &\ (2.4\mu\text{m}) &\ 2\text{Kx2K} &\ \text{MCT} &\ 15'\times15' \\
\text{CH}_4 &\ (3.4\ \mu\text{m}) &\ 256\times256 &\ \text{InSb} &\ 6'\times6' \\
L' &\ (3.8\ \mu\text{m}) &\ 256\times256 &\ \text{InSb} &\ 6'\times6'
\end{align*}
\]

Lundock+ (2008)
Science Program for 40cm Infrared telescope (1)

Stellar halo in clusters of galaxies at 2.4 μm

Katsuno (2005)

Dark halo model (Okamoto 1999)

Abell 1795

I (0.8 μm) 28.2 mag/arcsec

No detection

Dwarf density < 200 galaxies/Mpc³

K band window
Science Program for 40cm Infrared telescope (2)

Atmosphere of Extrasolar planets

Transit of planets in front of star or behind star

Sato+ (2005)

Second eclipse hides the atmosphere of planet
Planet atmosphere is characterized by molecules like CO$_2$, H$_2$O or CH$_4$.

By transit observations with broad infrared at the second eclipse, we can classify the planets into Rock, Ice, and Gas planets. CO$_2$, H$_2$O, or CH$_4$ are also observable with median-width bands.
Collaboration with Australia group at Dome Fuji

Engine module
long-term continuous automatic operation with remote control

Engine module for Dome A

1kW for 400 days

Storey+
Future plans

2009/12-2010/2
• A first step on Dome Fuji by a Japanese astronomer
• Transmittance measurement by handy infrared spectrograph
• Transmittance measurement by 220GHz radiometer

2010-2015 New 6-year Projects by National Institute of Polar Research
• Construction of winter-over facilities at Dome F
  • our proposal for astronomy with small telescopes has been accepted for the first 3-year program (2010-2012)

2010/12-2011/2
• Deployment of 40cm-infrared and 30cm-THz telescopes at Dome Fuji
• Deployment of PLATO-Fuji by collaboration with UNSW
• Observations with small telescope over winter (remote operation)

2014? - Construction of large telescope(?)