

# 光学近赤外線における 高エネルギーニュートリノ 対応天体の追観測

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# Collaborators

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Koji S. Kawabata, Hiroki Mori (Hiroshima Univ.) ,

on the behalf of OISTER collaboration

# Outlines

- かなた望遠鏡におけるフォローアップ戦略
- これまでのフォローアップの実際
- IceCube-170922A アラートにおける追観測：
  - TXS 0506+056の変動発見
    - 光赤外線大学連携・すばる望遠鏡による追観測
      - Light curve
      - Spectra (redshift)
      - Polarization (Current observations)
- Future prospect
  - ブレーザー・超新星
  - Tomo-e Gozen サーベイ
  - 3.8m 分光フォローアップ

# AAAS Science journal

## RESEARCH ARTICLE SUMMARY

### NEUTRINO ASTROPHYSICS

# Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A

The IceCube Collaboration, *Fermi*-LAT, MAGIC, *AGILE*, ASAS-SN, HAWC, H.E.S.S., *INTEGRAL*, Kanata, Kiso, Kapteyn, Liverpool Telescope, Subaru, *Swift*/*NuSTAR*, VERITAS, and VLA/17B-403 teams\*†

The IceCube Collaboration et al.,  
Science 361, 146 (2018) 13 July 2018

# Briefing for press in the MEXT 文科省記者会見 on Jul 20



# 9月16日付 読売新聞

## 世界の「目」で一斉観測

**1** 南極のアイスキューブが特殊な光を検知。千葉大が開発したシステムで高エネルギーのニュートリノと判断

### レーザー天体

- 中心のブラックホールをガスが取り囲み、プラズマを噴き出す
- プラズマ内で宇宙線が光とぶつかり、ニュートリノが発生

**3** 40億光年先の「レーザー天体」が放出源と特定

**2** 世界各地の望遠鏡に追加観測を呼びかける



アイスキューブや東京大、広島大、国立天文台、米航空宇宙局などの資料を基に作成

### 日本のニュートリノ研究の歴史

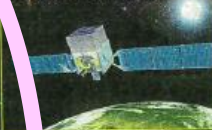
1987年	小柴昌俊・東京大特別荣誉教授が岐阜県の観測装置「カミオカンデ」で、超新星爆発によって放出されたニュートリノを観測する
1998年	梶田隆章・東京大宇宙線研究所長が「スーパーカミオカンデ」によって、ニュートリノに質量があることを証明する
2012年	千葉大などの国際チームが、アイスキューブを使って高エネルギーのニュートリノを観測する
2018年	千葉大などの国際チームが、高エネルギーのニュートリノの放出源を特定する

観測に参加した望遠鏡

すばる望遠鏡(米ハワイ島)



人工衛星「フェルミ宇宙望遠鏡」

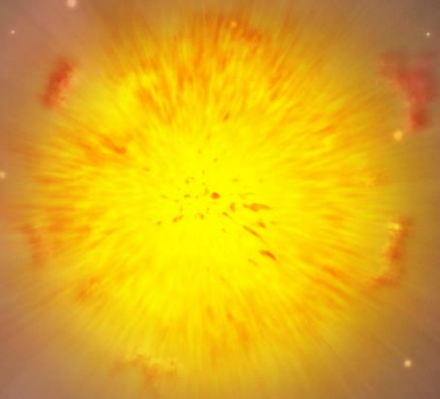


## ニュートリノ 放出源探せ



# Possible Origin of high-energy (TeV) neutrinos

©U. Tokyo

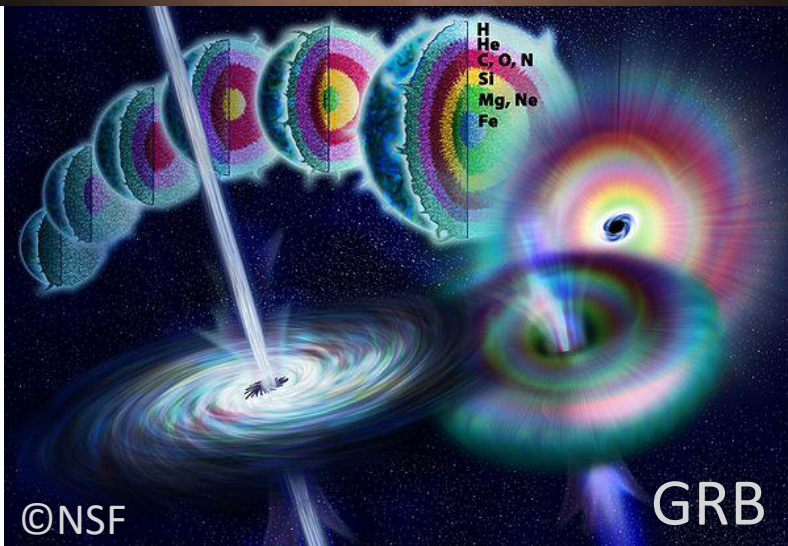


(peculiar) supernova

©NASA/Fermi



blazar: AGN relativistic jet



©NSF

GRB

日本天文学会2018春季年会

2018/03/14-17

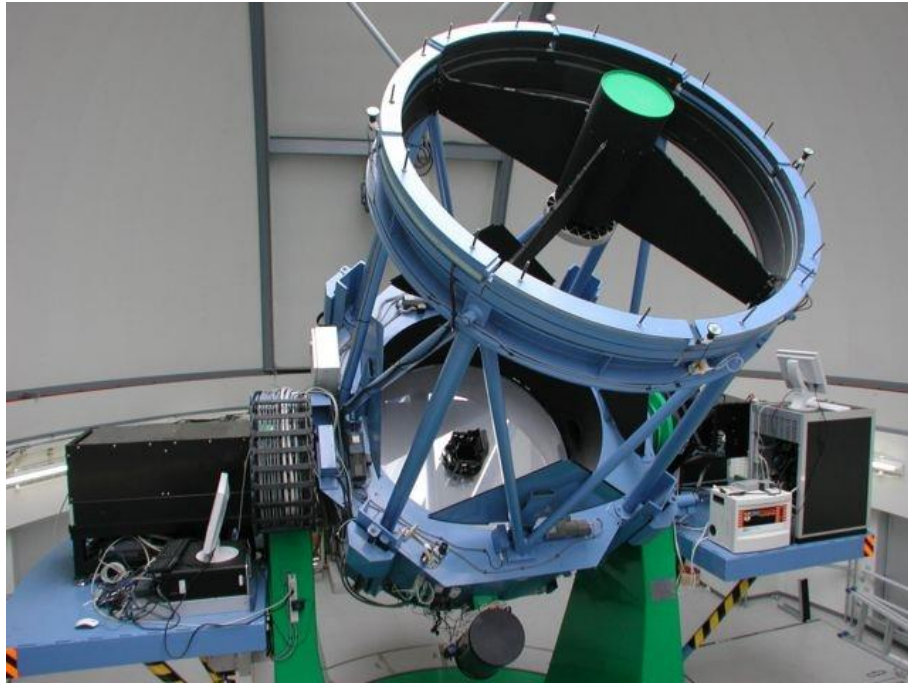
©NASA



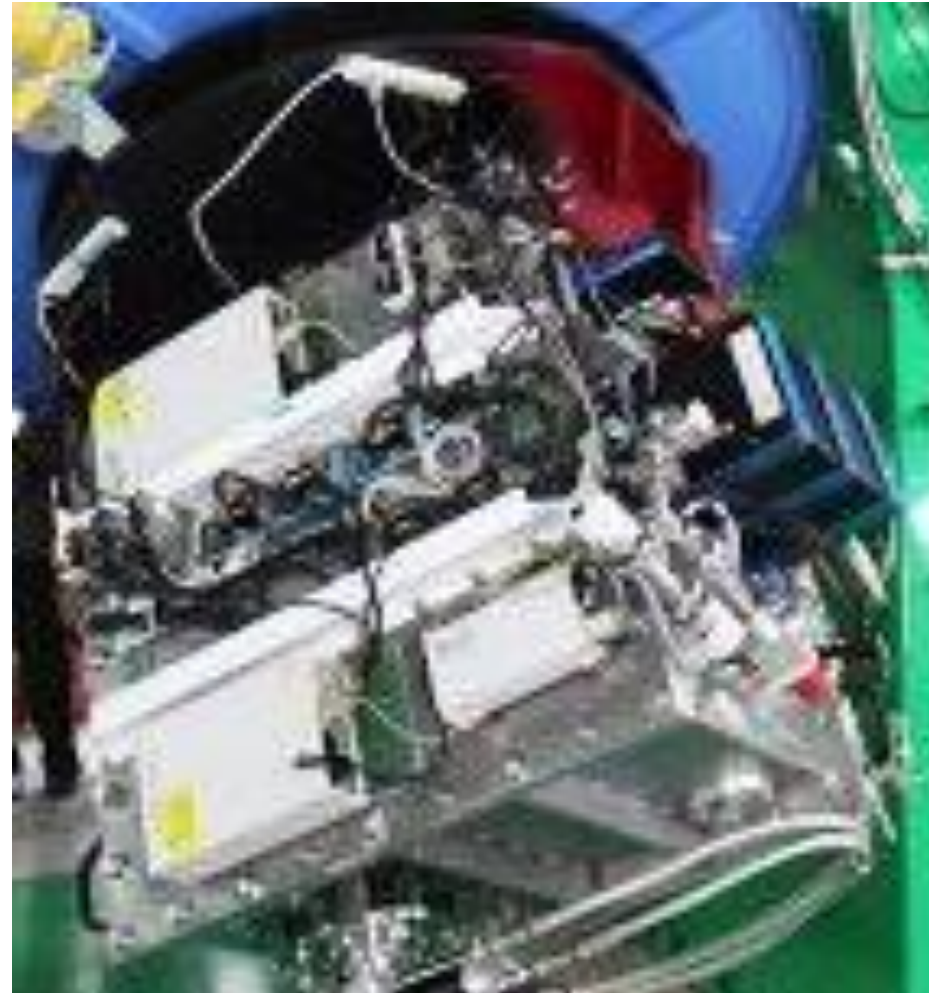
starburst galaxy

From Morokuma san's slide

# 1.5m Kanata+HONIR



HONIR (Hiroshima Optical and Near-  
InfraRed camera; Akitaya et al. 2014)  
可視近赤外線 2 バンド同時観測  
視野  $10' \times 10'$   
限界等級  $\sim 20\text{mag}$  (可視)





# Casts related to the Kanata follow-up



Y. Tanaka

Mori

Utsumi

MY



Itoh



M. Kawabata



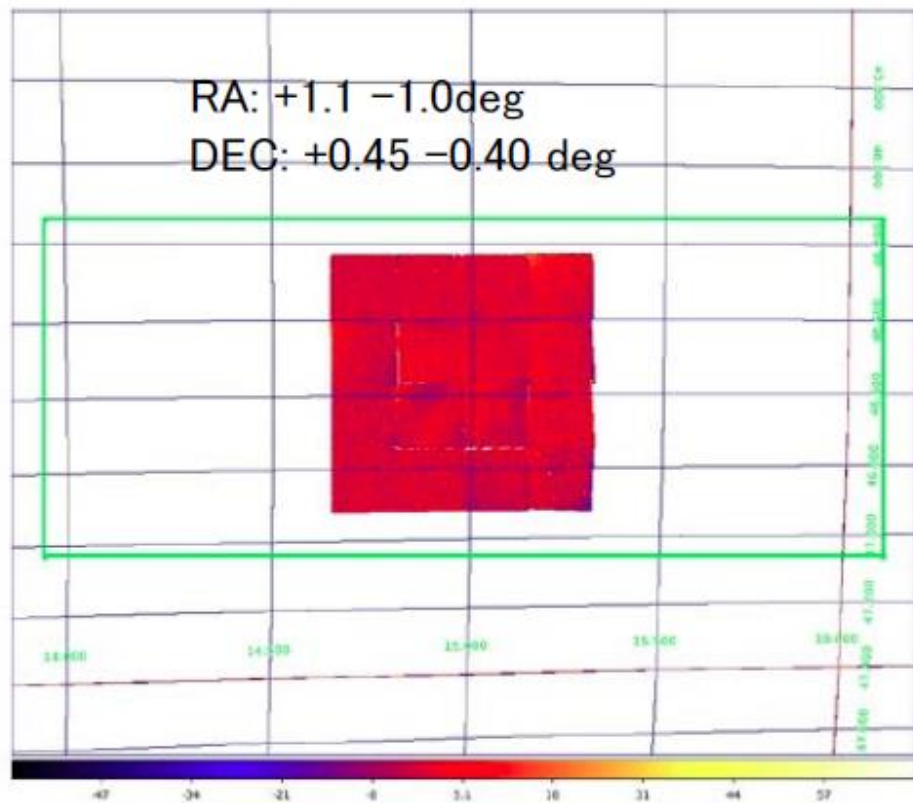
Nakaoka



K. S. Kawabata

# IceCube-161210A

Alert: 2016-12-10 20:07(UT)



2016-12-11 9:30-17:30 (UT)  
J-band imaging

## Tiling observation

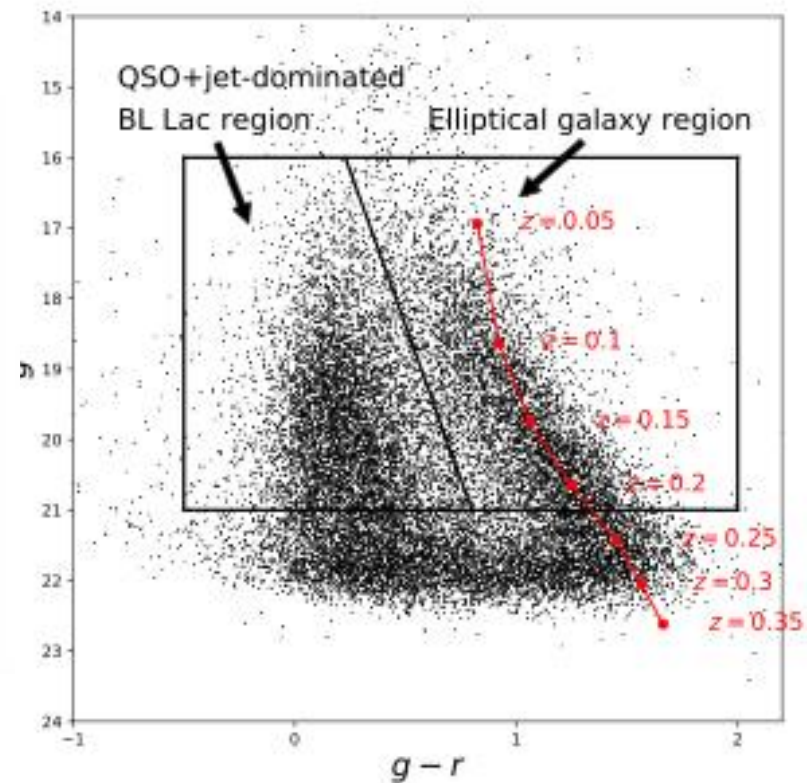
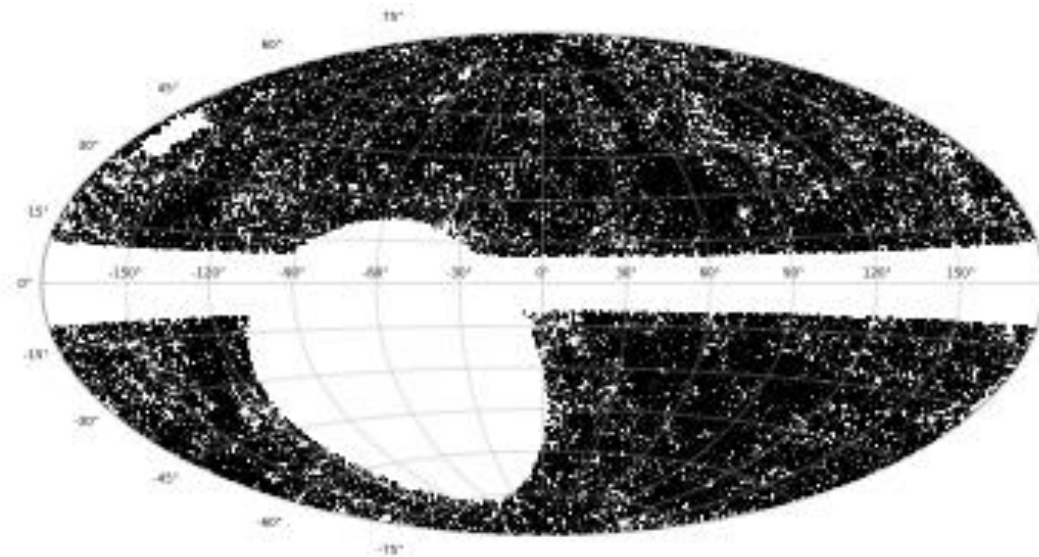
### とても大変

ID	1	2	3	4	5	6	7	8
積分時間 [sec]	300	300	300	300	300	900	1200	300
5sigma 限界等級 [AB mag]	19.29	19.39	19.27	18.64	18.58	18.07	18.50	18.32
変動天体 (目視)	なし	なし	なし	なし	なし	なし	なし	なし
ID	9	10	11	12	13	14	15	16
積分時間 [sec]	300	900	1020	300	300	300	300	300
5sigma 限界等級 [AB mag]	18.97	19.02	18.54	19.21	19.20	18.82	18.77	19.12
変動天体 (目視)	なし	なし	なし	なし	なし	なし	なし	なし

森修論(2018)

# New Blazar Catalog (BROS)

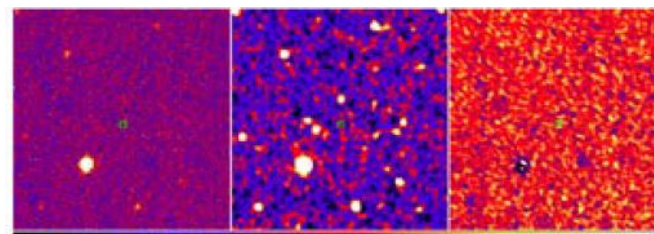
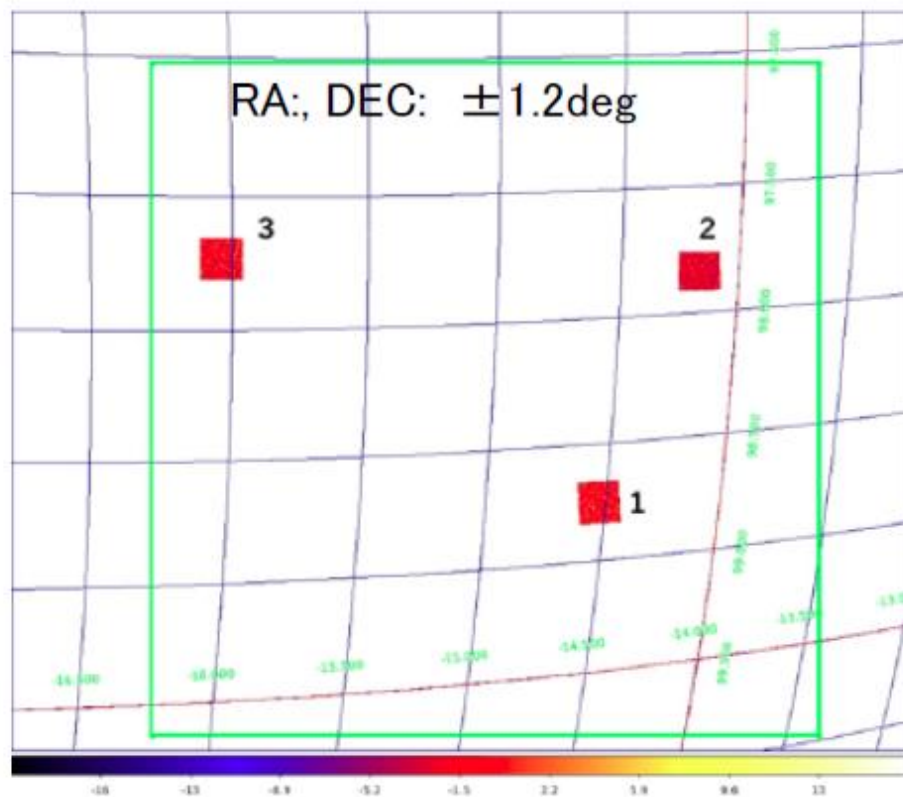
- Blazar Radio and Optical Survey (BROS; Itoh et al. in prep.)
- ~50000 sources at Dec.>-40 deg
  - BZCAT: ~4000 sources
  - flat-spectrum@radio: NVSS (1.4 GHz) + TGSS (151 MHz)
  - Pan-STARSS(PS1)@optical
    - ~40% not detected in PS1 ( $r > 23$ )



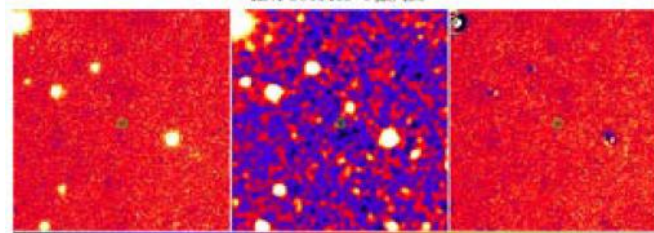
# IceCube-170321A

## BROS blazar catalog

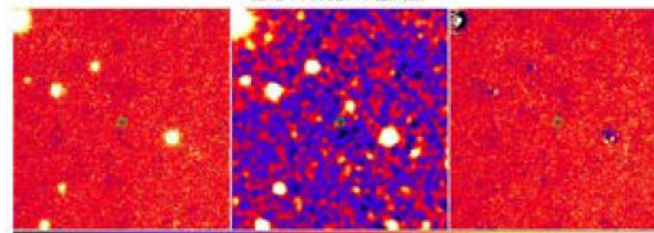
Alert: 2017-03-21 07:32(UT)



ID-1-J063450 の拡大図



ID-2-J063120 の拡大図



ID-3-J063120 の拡大図

2017-03-22 10:30-11:10 (UT)

J-band imaging

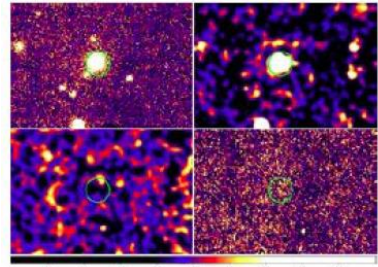
森修論(2018)



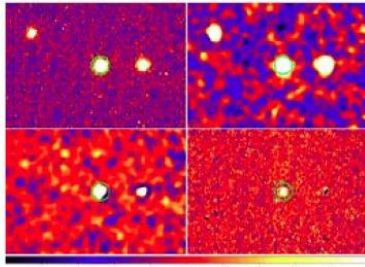
# IceCube-170922A

Follow-up observations of seven candidates within the error circle region were performed with Kanata

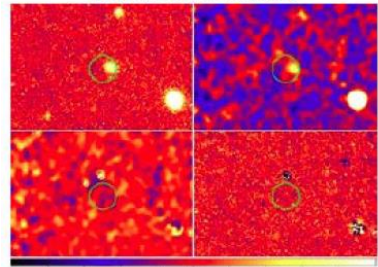
2夜の観測で7つのうち  
1天体のみ変動を検出



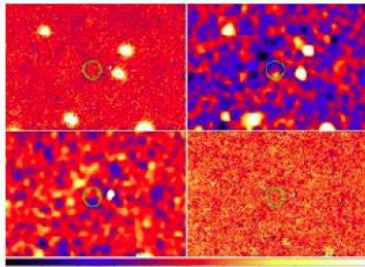
ID:1-J050912の拡大図



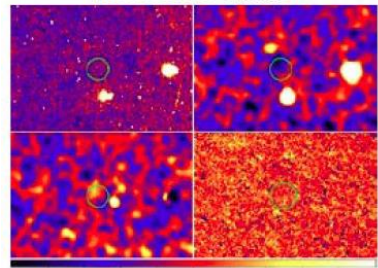
ID:2-J050926の拡大図



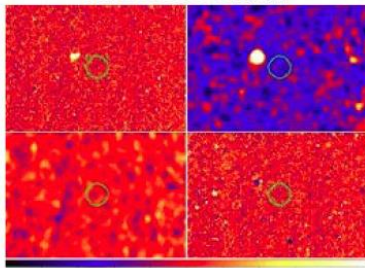
ID:3-J051205の拡大図



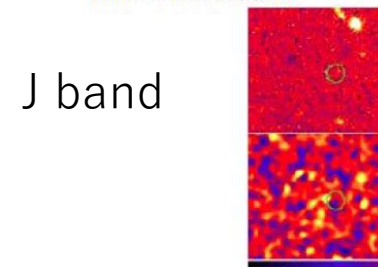
ID:4-J051211の拡大図



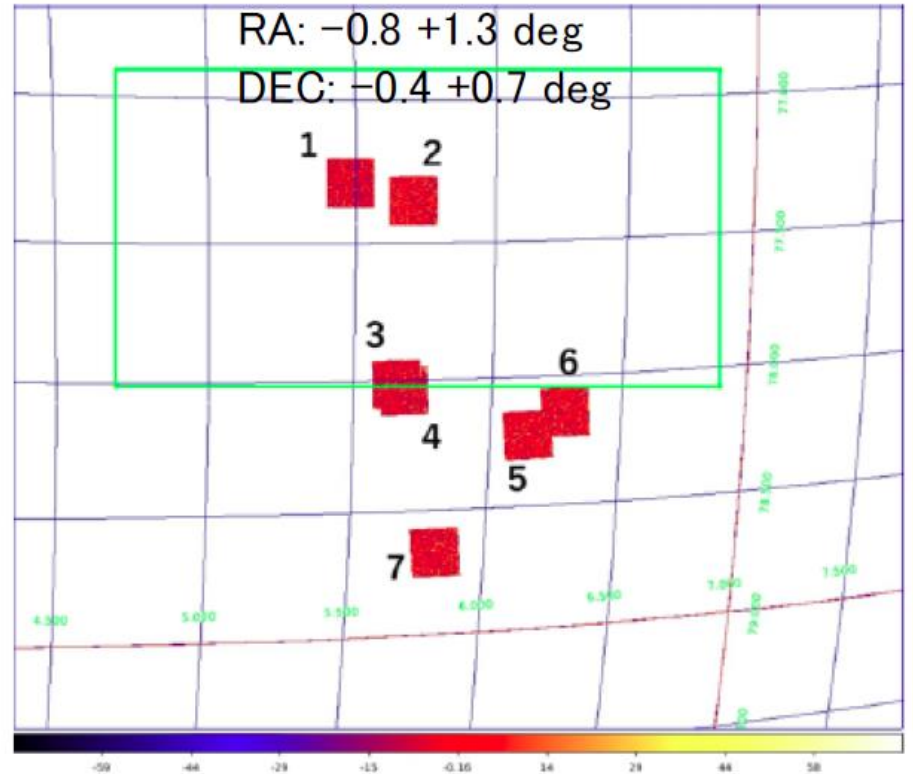
ID:5-J051256の拡大図



ID:6-J051236の拡大図



ID:7-J051440の拡大図



RA:  $-0.8 +1.3$  deg

DEC:  $-0.4 +0.7$  deg

1

2

3

4

5

6

7

森修論  
(2018)

J band

# TXS 0506+056 : 活動的な時期



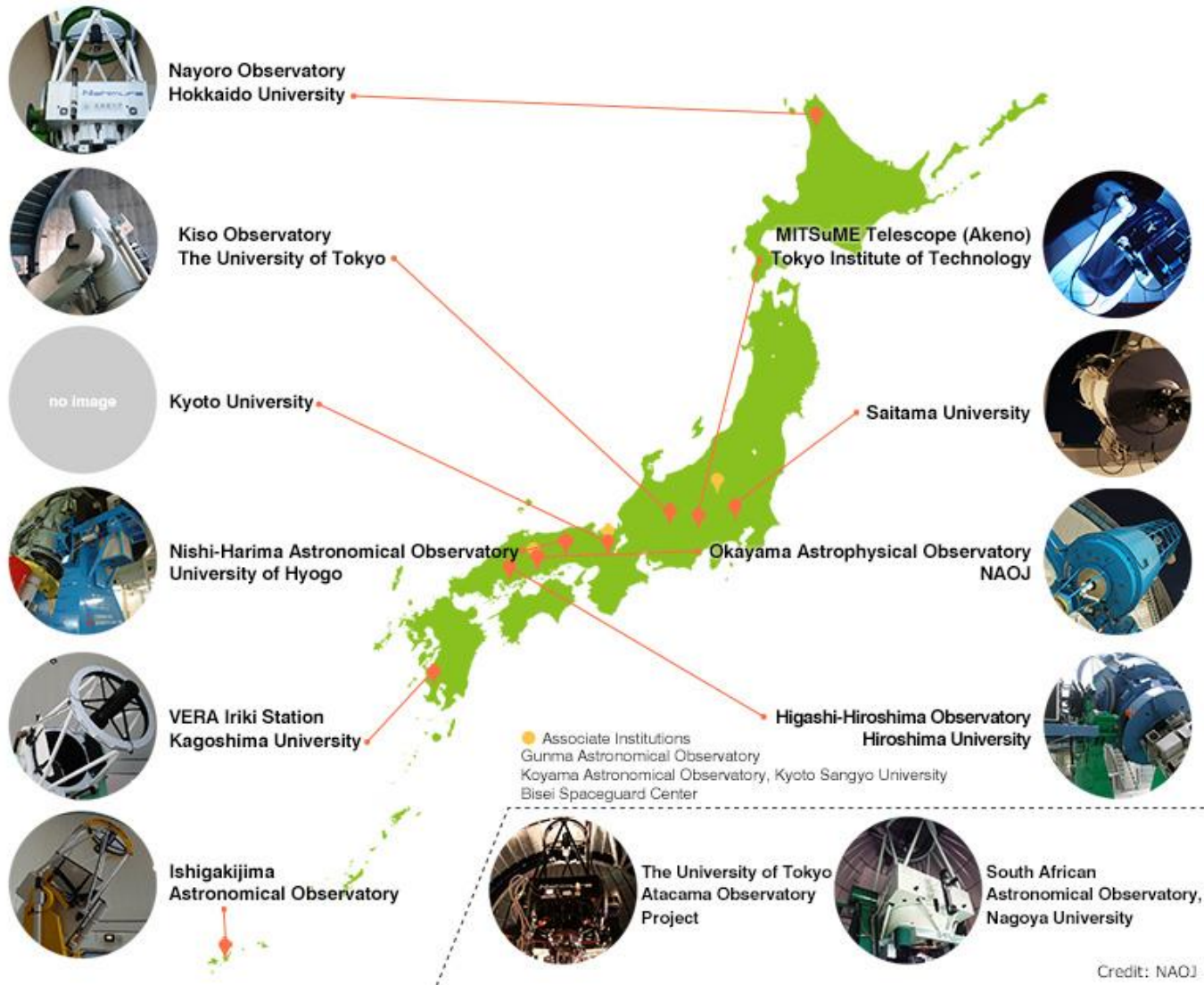
Observed in R band using Kanata/HONIR

We found that TXS 0506 was much luminous on Sep 23 comparing to the previous observations. We observed the slow decline part of the optical flux.

**The brightening the gamma-ray emission is observed, and Tanaka+ reported this observational fact. (Tanaka, Y. T. et al. ATel #10791)**

**International electromagnetic observations were promoted by this report**

# OISTER



Credit: NAOJ



# Optical and Infrared Telescopes of Synergetics for Education and Research (OISTER)

## Overalls

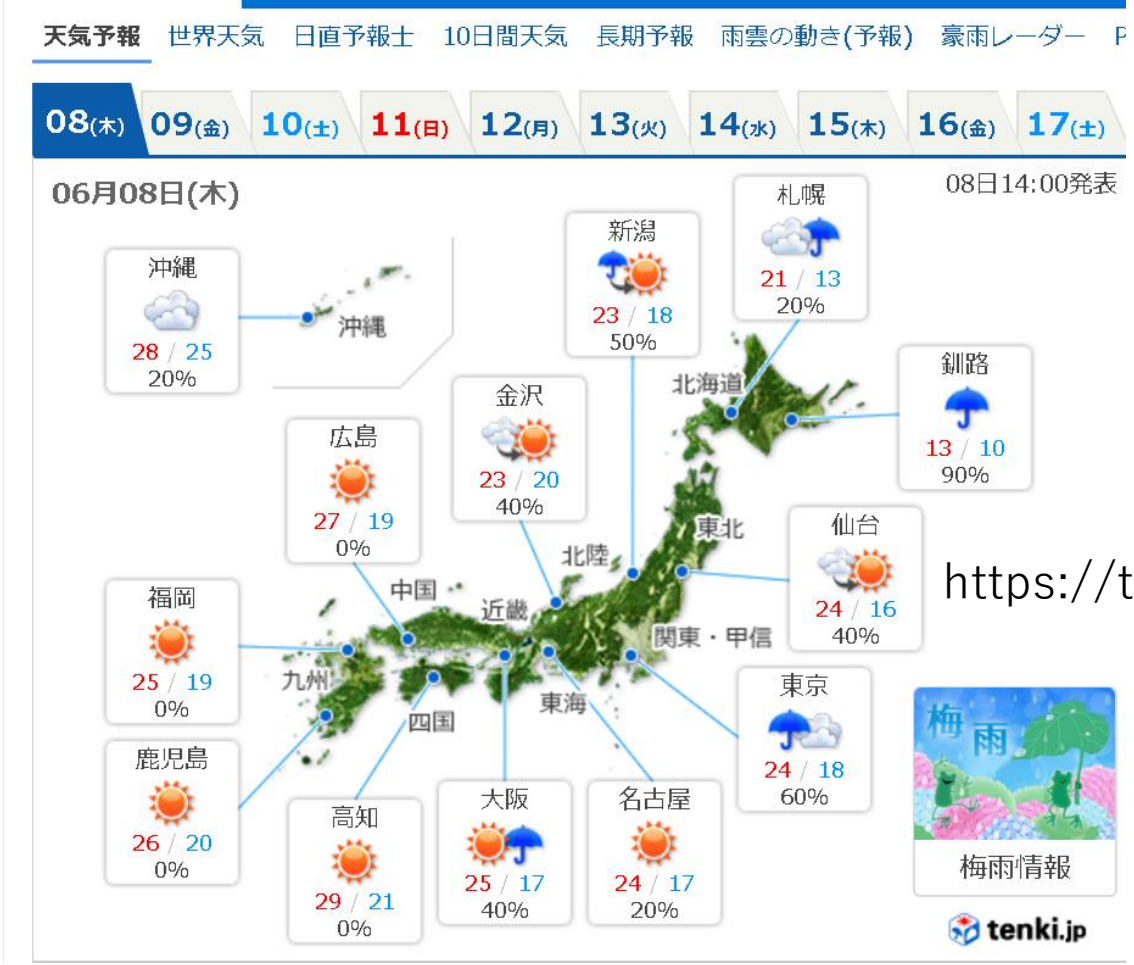
- Cooperation among Universities having optical and near-infrared small/intermediate (0.4 – 2.0m) telescopes
- Seven positions (Postdocs/Assistant prof.) were employed in each University. (MY, on May, 2017)
- An associate prof. (H. Maehara@Kyoto) was employed to summarize the overall among Universities
- First period finished and second began in 2017 (for 5 years)

## Scientific goals

- Flexible and immediate follow-ups of transients and variables including the gravitational wave and neutrino events.
- Multi –band and –mode observations using the various instruments
- Participants have right to propose observations (External researchers can join as Co-I)
- 6 ToOs were triggered in 2017-2018 (ongoing for 2 of 6)
- Flexible operation is applied to the current observations

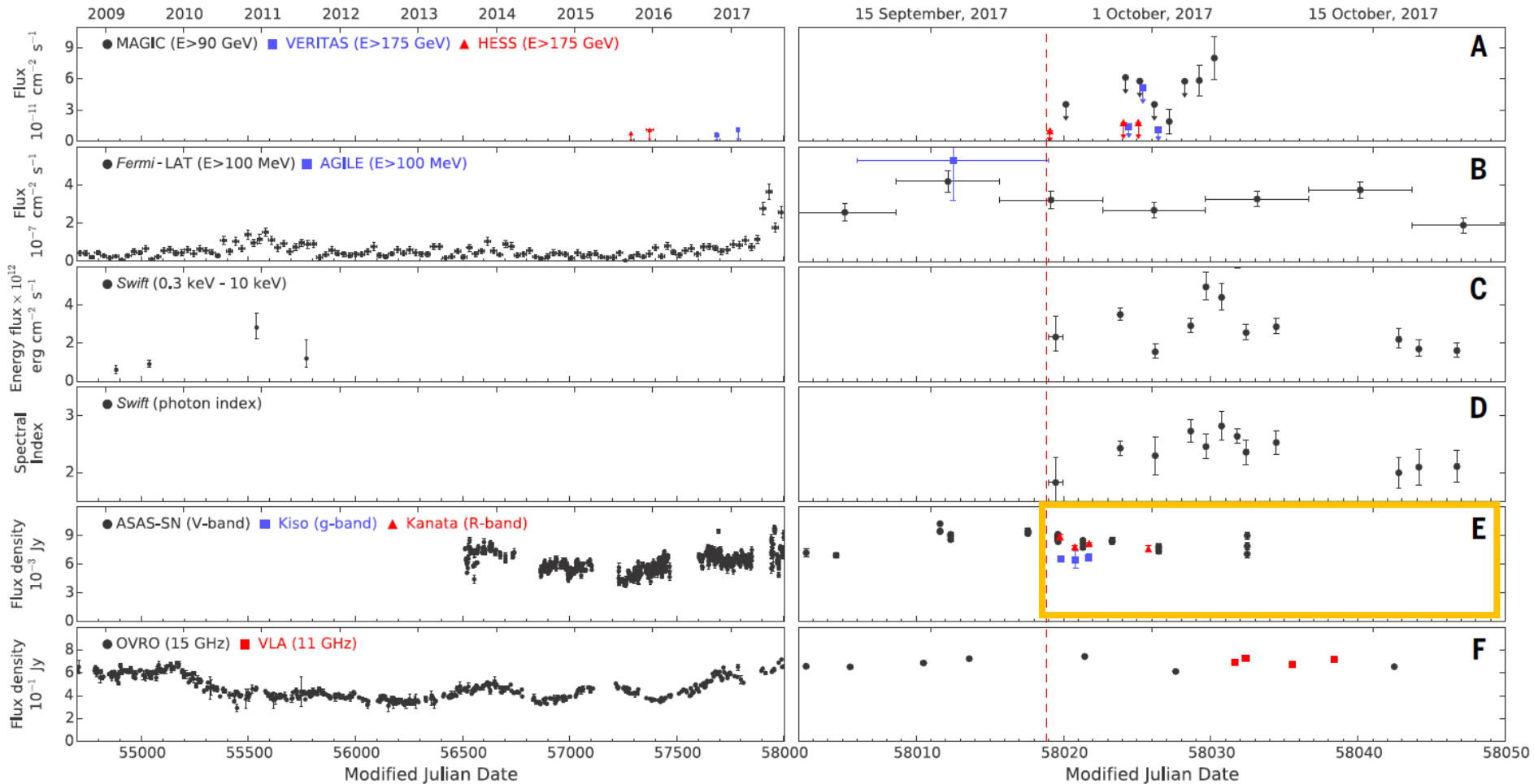


# Canceling the weather risk



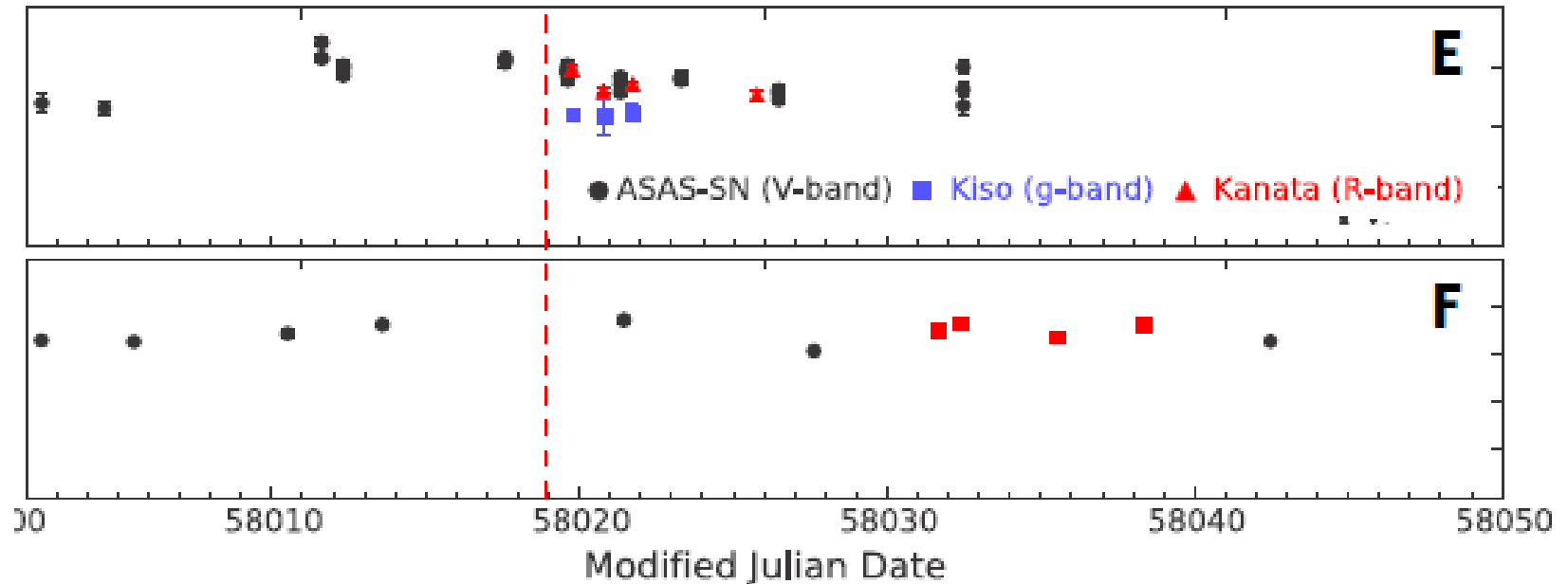
We can avoid the weather risk! (typically shows ~ 1 day delay between Hiroshima and Tokyo )

# TXS 0506+056: Multiwavelength light curves



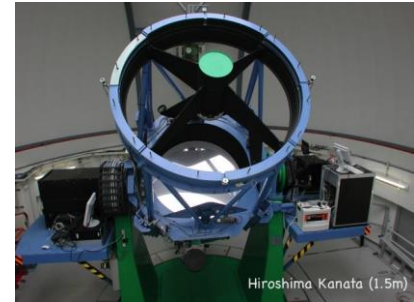
The IceCube Collaboration et al., Science 361, 146 (2018)

# Optical and NIR light curves



- We started the observations using Kanata/HONIR since 20 hours after the neutrino alert.
- We found that the luminosity is three times more luminous than the previous data, and the flux decreased by 15% on Sep 24.
- When the neutrino was emitted, this blazar would be more luminous, indicating that this object is in the active phase. The IceCube et al., 2018

# Polarization



サイエンスにて報告  
された偏光度:7-8%  
IceCube collaboration et al. 2018

4月あたりの  
観測

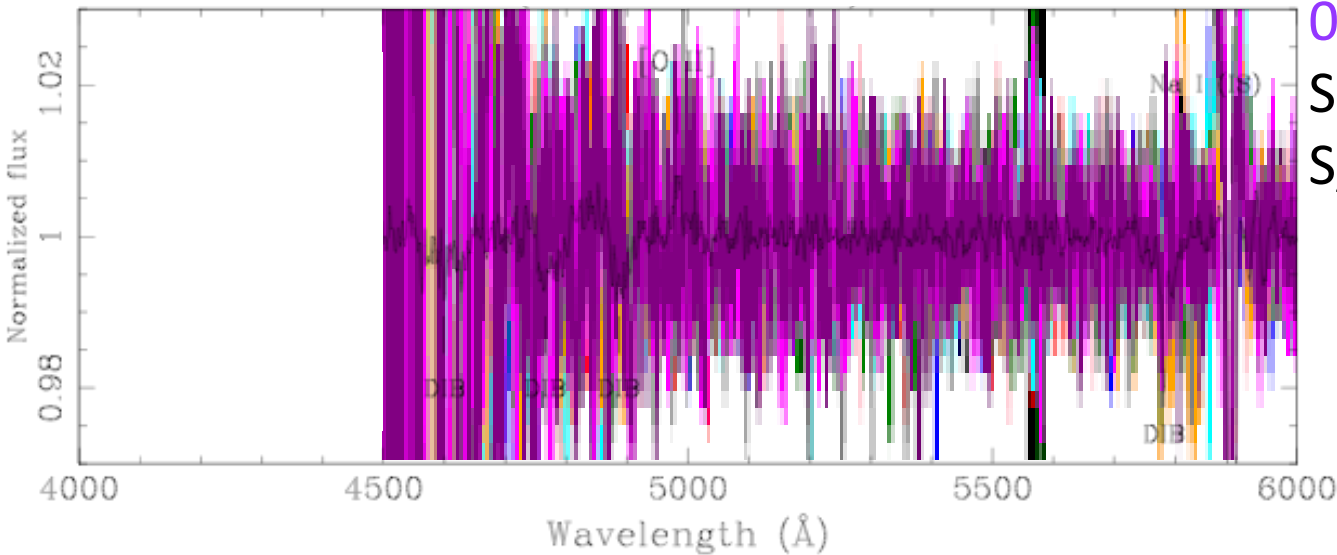


激しい偏光度の変化

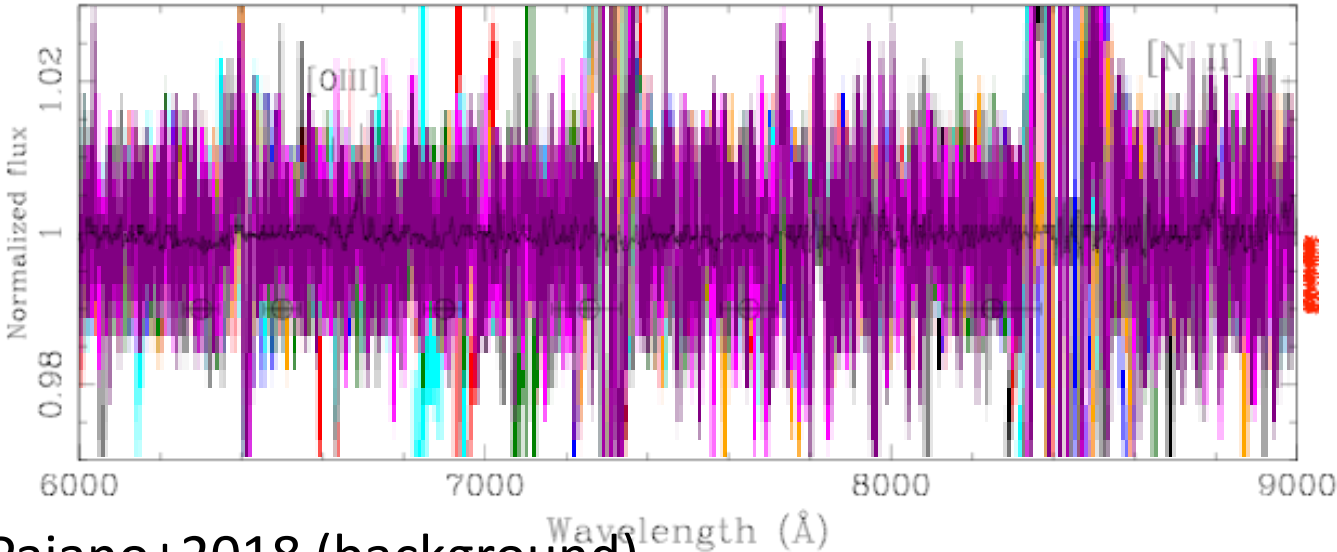


# Optical Spectroscopy: redshift determination

TXS 0506+056



0.5-hour integration  
Subaru(8.2m)/FOCAS  
S/N~100

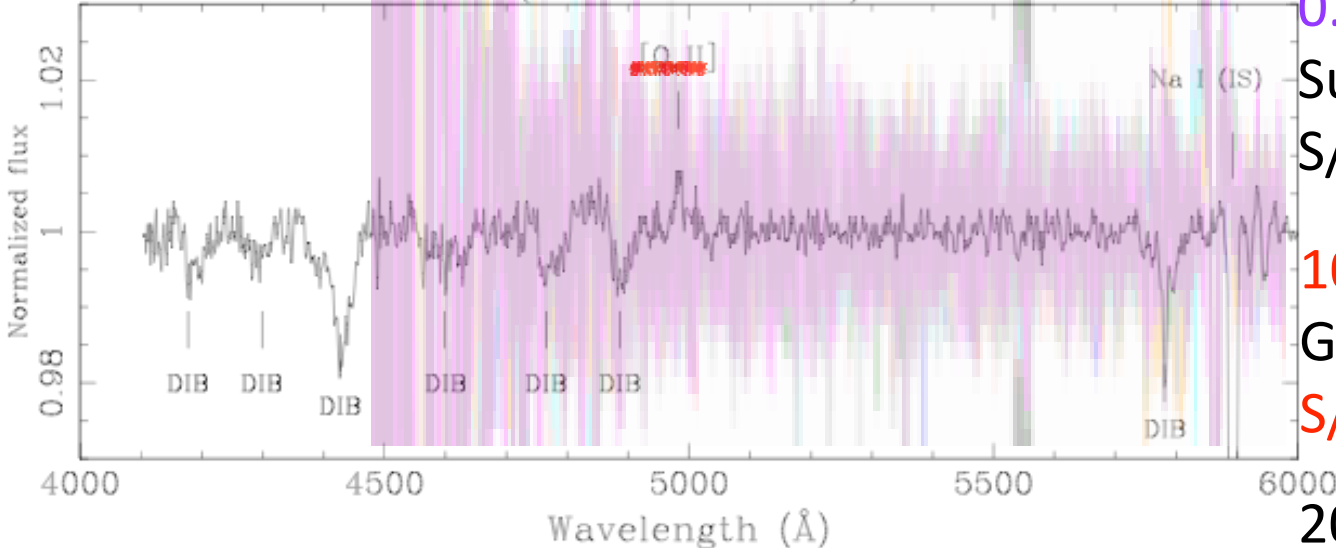


1% (S/N=100)

Paiano+2018 (background)

# Optical Spectroscopy: redshift determination

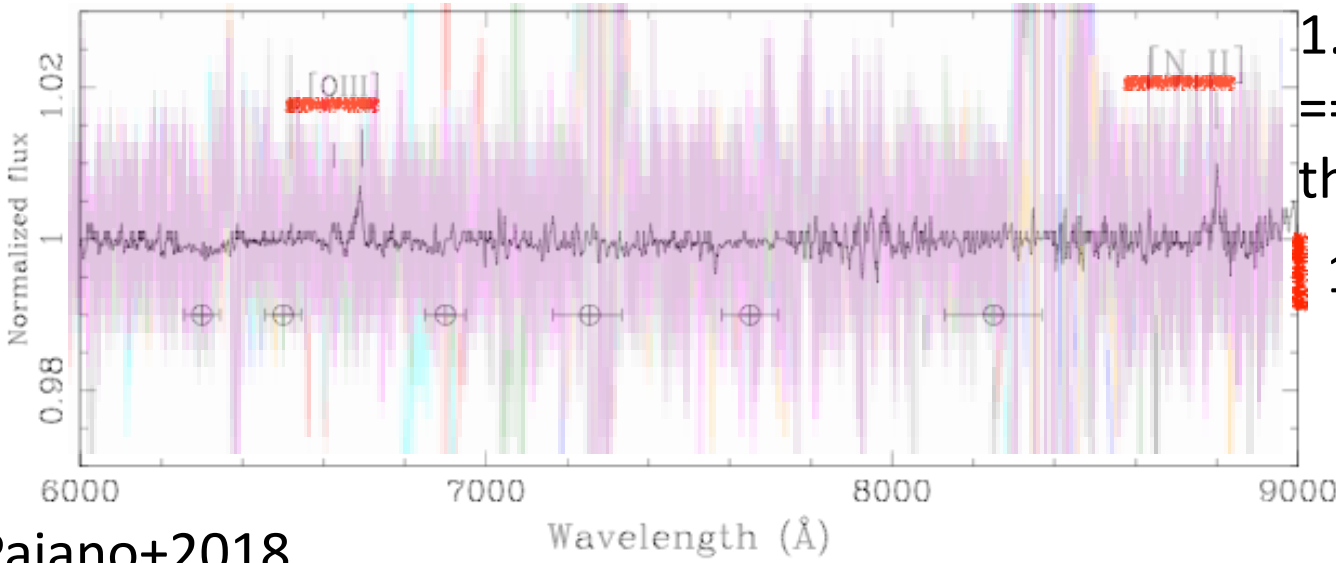
TXS 0506+056 ( $z = 0.3365$ )



0.5-hour integration  
Subaru(8.2m)/FOCAS  
S/N~100

10-hour integration  
GTC(10m)/OSIRIS  
S/N~500

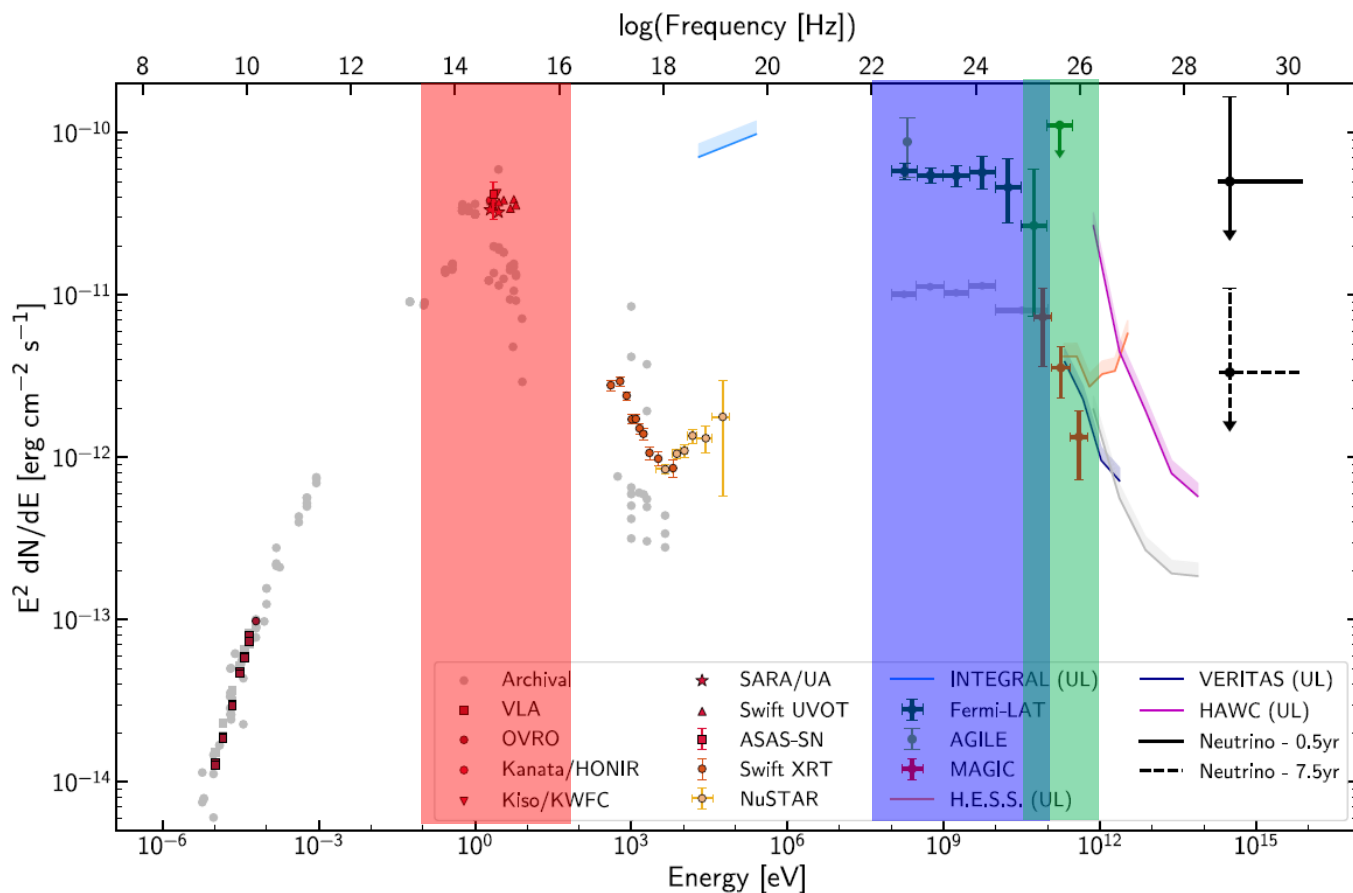
20 times longer  
1.5 times larger  
==> ~5 times better  
than Subaru/FOCAS



1% (S/N=100)

**z=0.336**

# Spectral Energy Distribution



かなた・木曾

Fermi MAGIC

# Future prospect

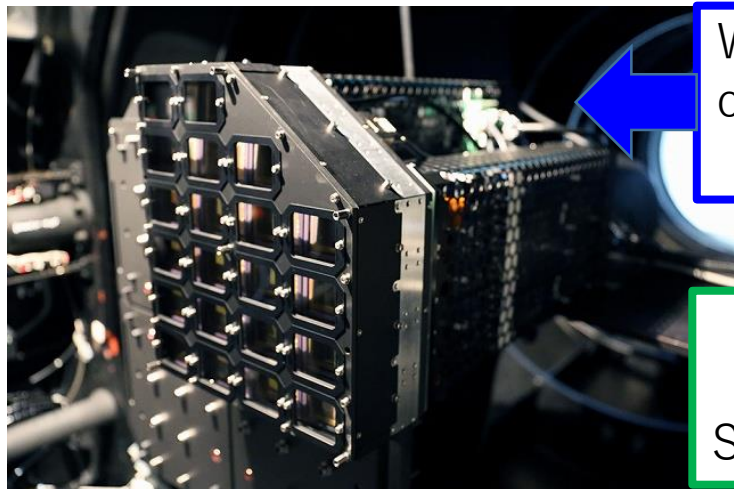
## ➤ blazar (AGN) ?

Similar procedure through the Kanata/OISTER will unveil another possible transient (2匹目のドジョウ) .

Basical properties can be unveiled through multi-mode and -band observations

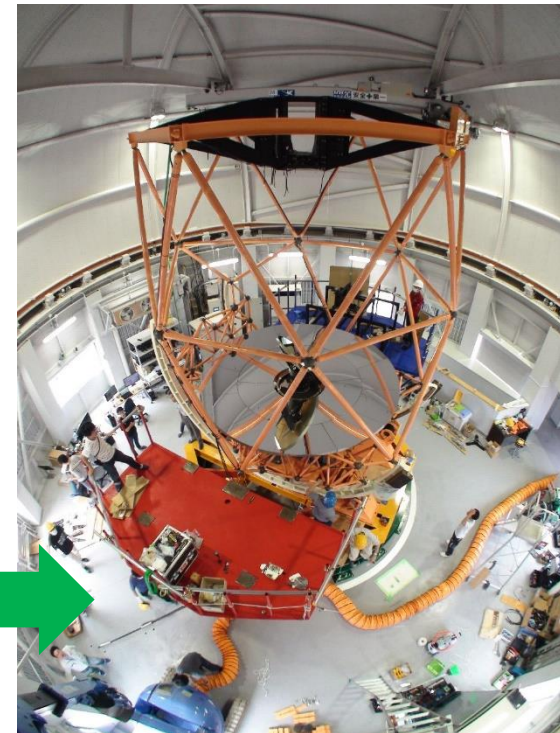
## ➤ (IIn/Ibc) supernova? **-still strong candidate**

Prompt exploring the new transient in the galaxies using wide-field camera. Prompt follow-up would be performed by spectrograph.



Wide-field camera: Tomo-e Gozen (Kiso, U of Tokyo)

「Seimei」 3.8m telescope (Okayama, Kyoto U.) Spectroscopy





# Follow-up of transients discovered by “Tomo-e Gozen”

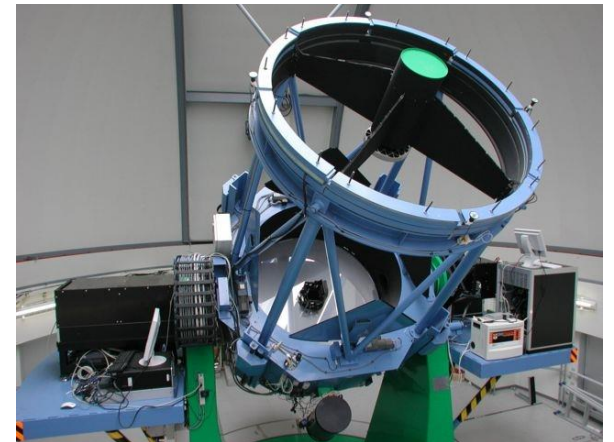
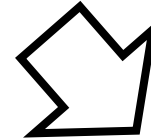
Discovery



spectroscopy

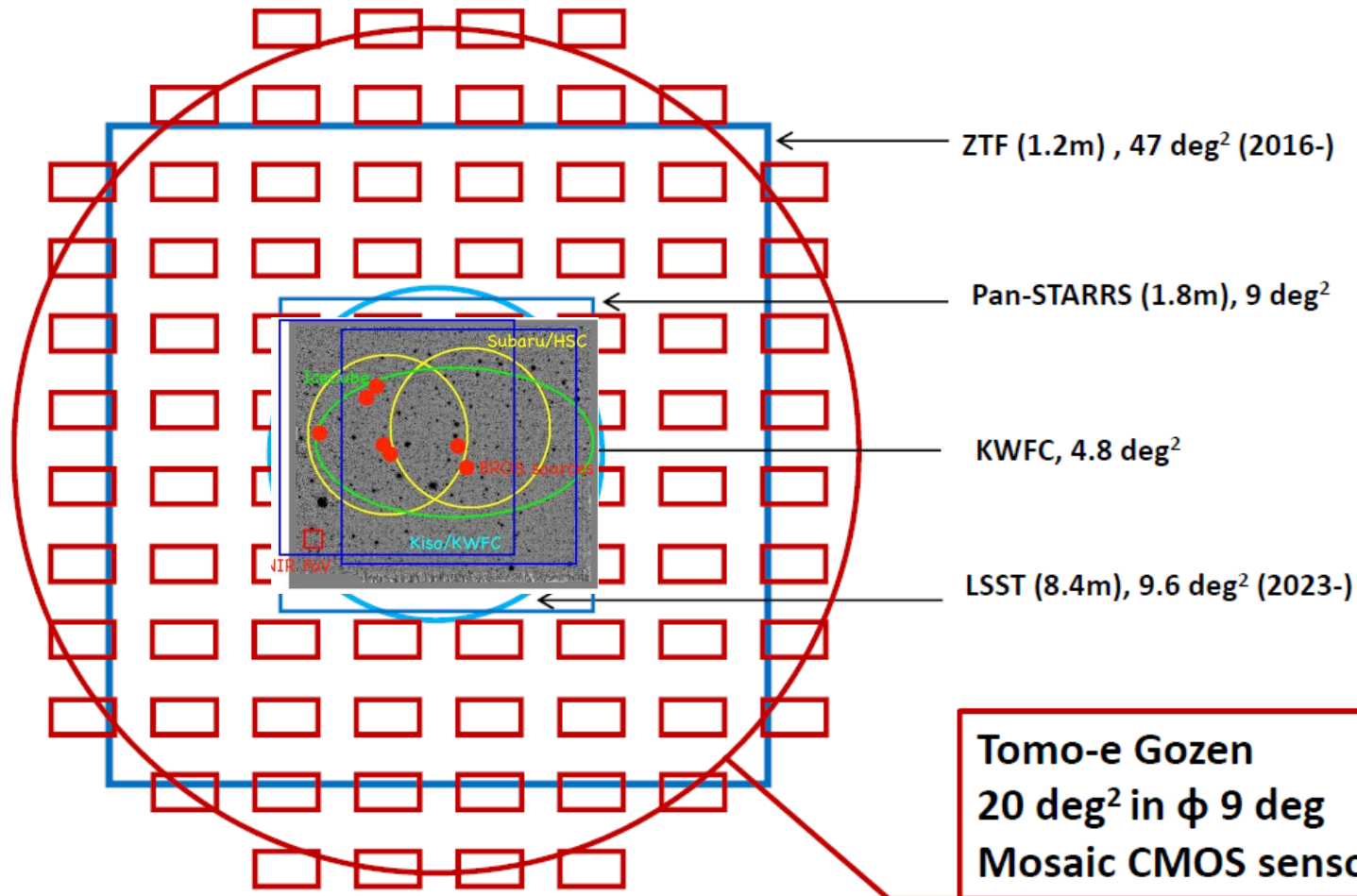


Photometry  
(polarization)



# Wide-field transient survey w/ Tomo-e Gozen

*From Sako-san's slide*



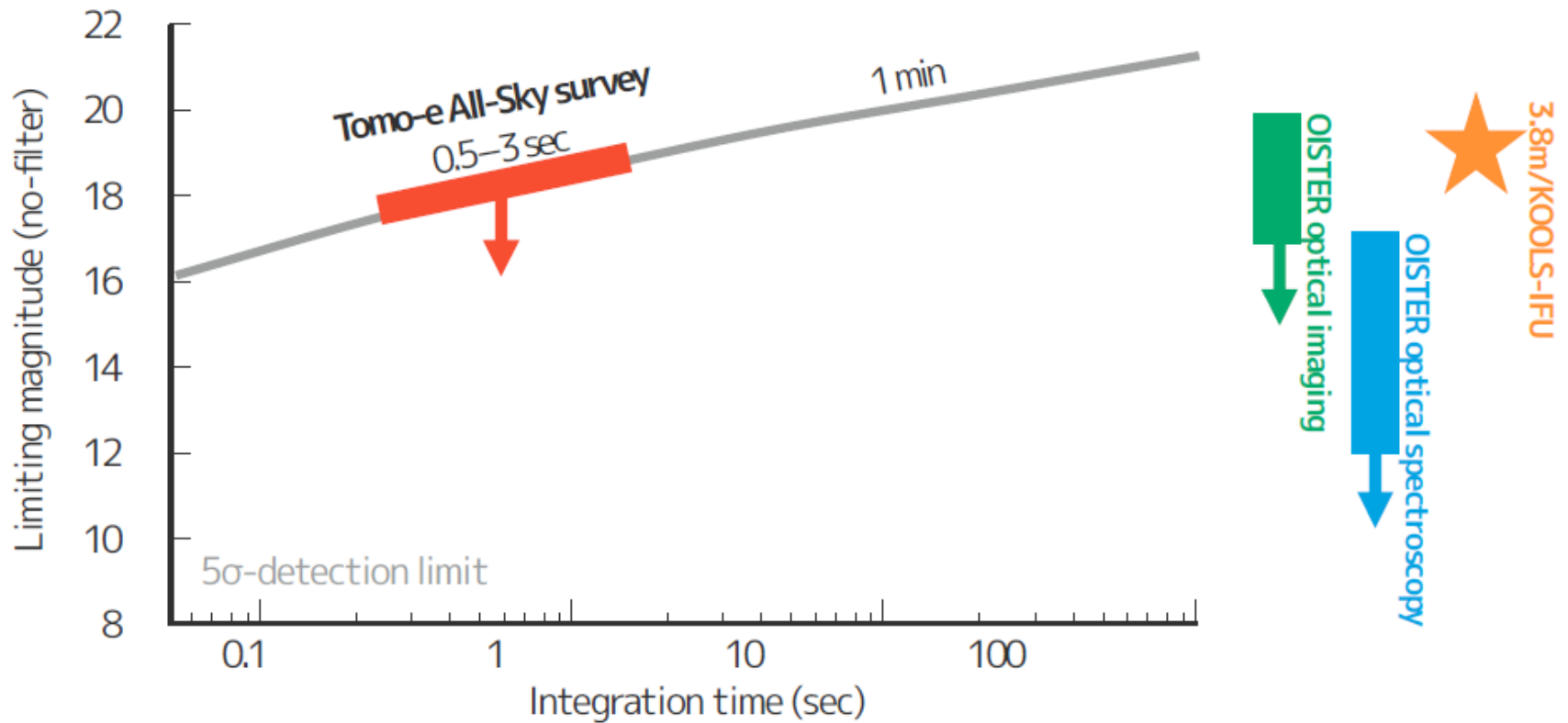
# Wide-field transient survey w/ Tomo-e Gozen

All-sky survey ( $\sim 10000 \text{ deg}^2$ ) will be performed @  $<1$  day cadence

-> We can research all light curves of BROS catalog blazars...

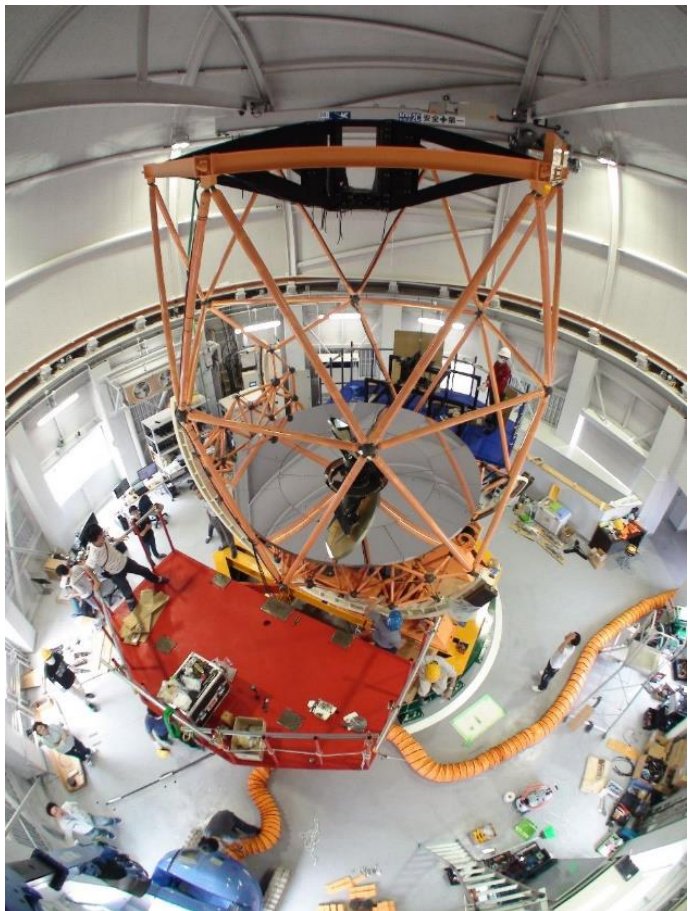
# Detection limit

*from Osawa-san's slide*



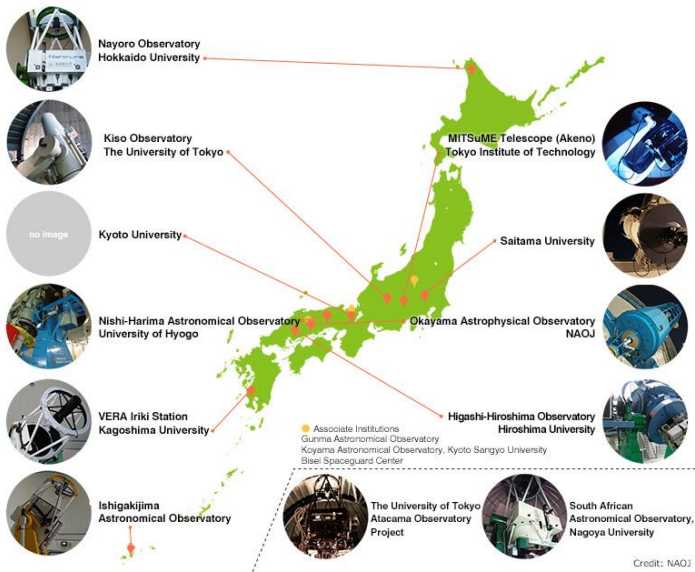


# 3.8m + KOOLS/IFU



KOOLS-IFU (PI:松林)  
ファイバー分光器  
限界等級 **~20mag**

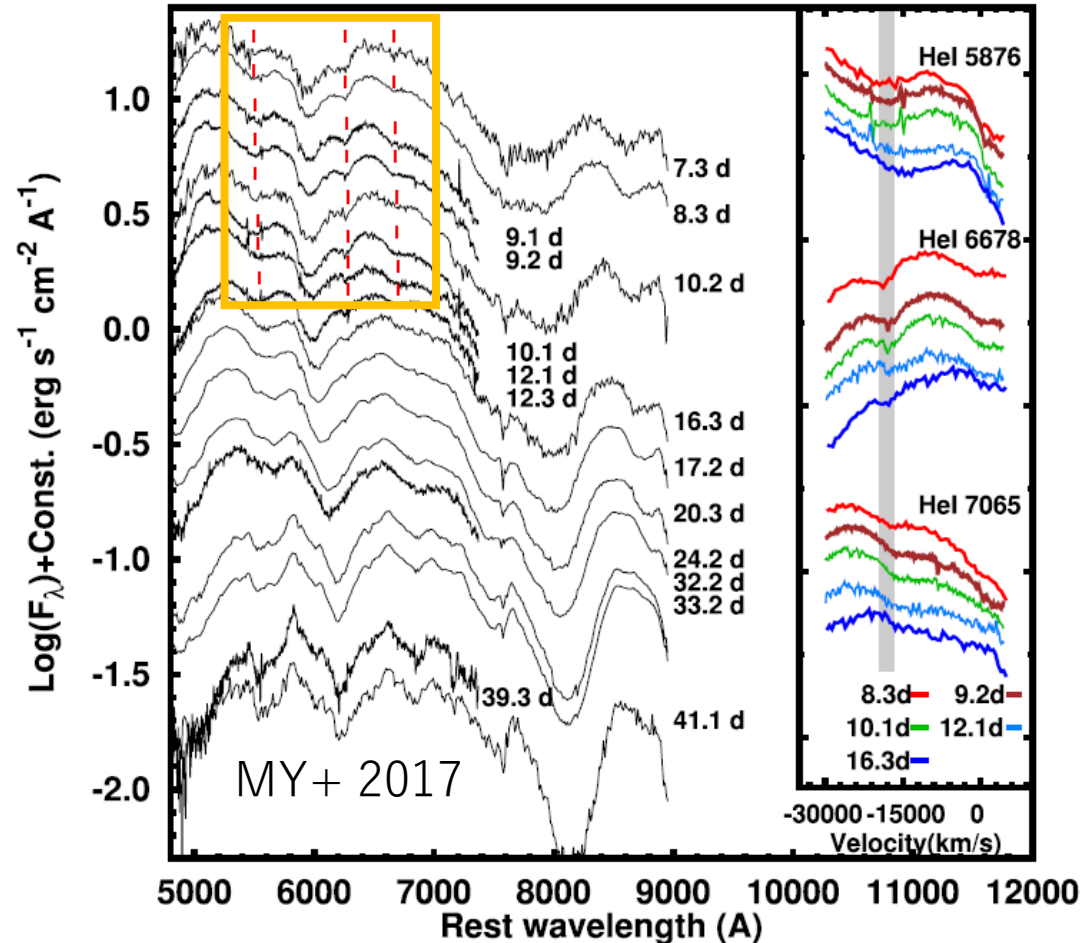
# Early-phase spectroscopy



• **近傍であれば**超新星の性質を詳細に研究可能

• KOOLS-IFU  **$z \sim 0.07$** 程度までのBL SNe分光可能?

Broad-lined `Type Ib' SN 2016coi



# Summary

- 我々は、これまでIceCubeアラートに対して3度の即応的追観測を実施してきた。その結果、IceCube 170922Aにおいて、TXS 0506+056が明るい時期にあり、アラート後1日で減光過程にあることを見出した。
- Fermiの解析につながり(Tanaka 2017, ATEL)、国際的なマルチメッセンジャー追観測につながった
- TXS 0506+056はアラート直後 ~7%程度の偏光度、featurelessなスペクトル、BL Lacに一致
- 超新星シナリオを含めた制限を与えるべく、Tomo-e Gozen+3.8mのサーベイ・フォローアップ体制を構築中