

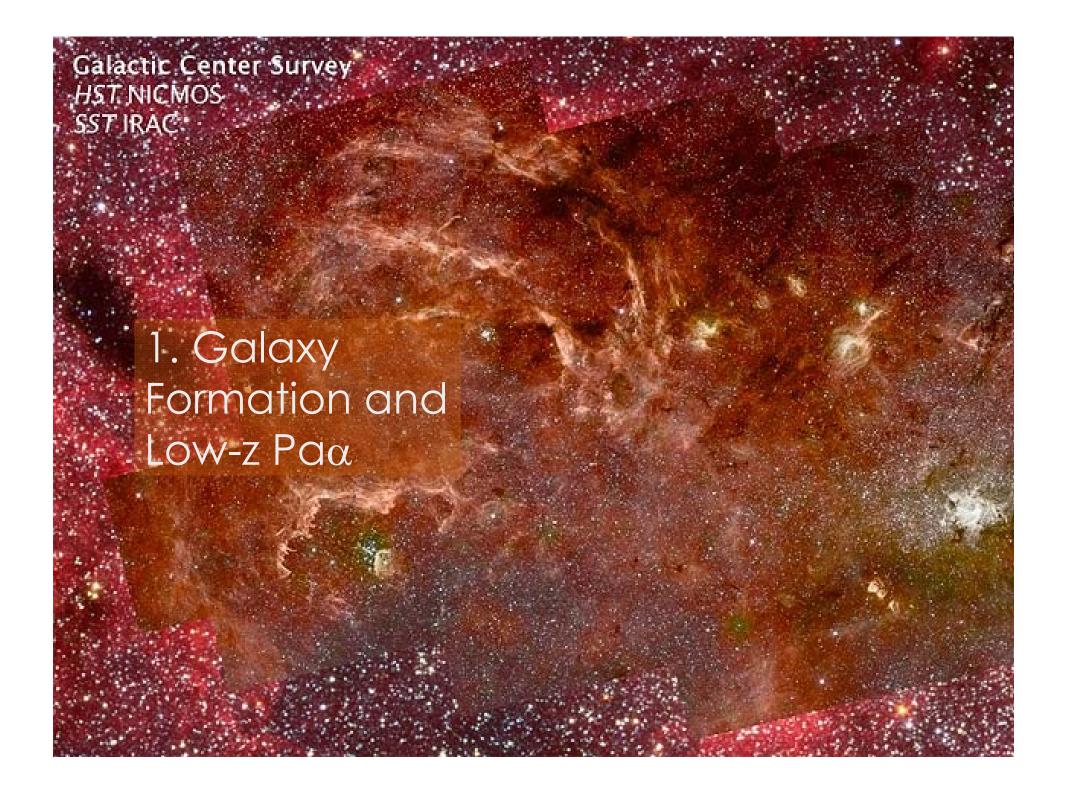




Probing Galaxy Formation with Paschen-a (ancillary science)

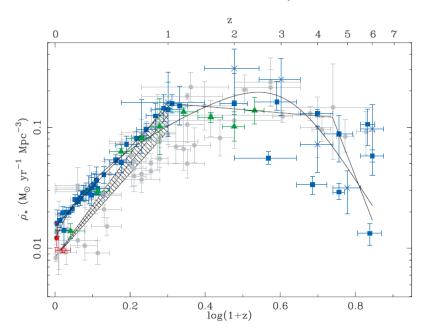
Kentaro Motohara (Univ. Tokyo),

ANIR/SWIMS/TAO Project Team, PARADISES Team



Galaxy Formation & Evolution

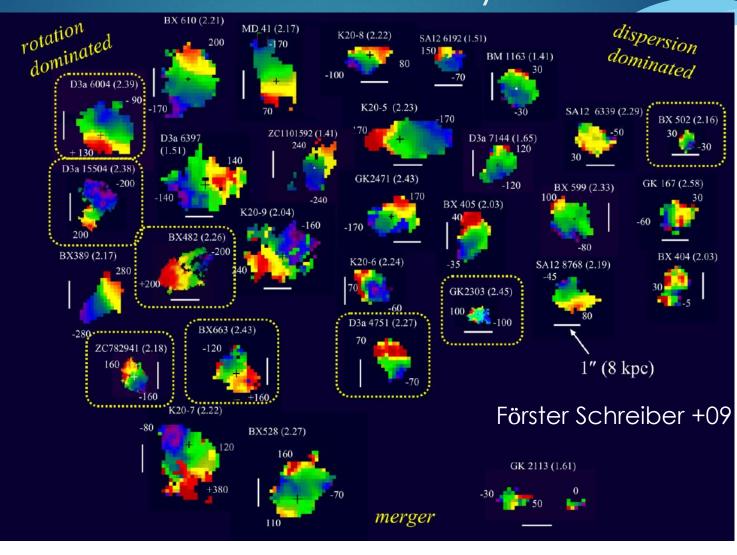
- Great progress in high-z galaxies
 - However, mostly treated as a "single point"
 - Treated statistically



8.6 (H/0) BoT + 8.4 Erb+D6 $Log (M_{star}/M_{\odot})$

Cosmic Star Formation Rate Density Evolution in Mass-Metallicity Relation

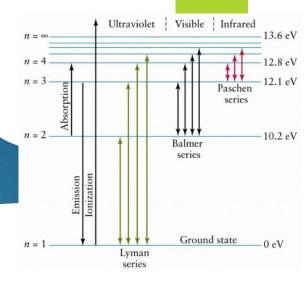
Spatially Resolved Studies of z> Galaxies Now Underway



Importance of Detailed Study at Low-z

- Spatial resolution of GMC(0.1kpc) size
 - ▶ We cannot look into detailed structures at high-z
 - ▶ 0.2arcsec~2kpc @ z=1-3
- See through Dust extinction
 - Starburst Activities produce large amount of dust
 - ► E.g.) Av>3mag in LIRGs (>10Msol/yr starburst)
 - ▶ NIR observation at z>1 only sample the rest optical

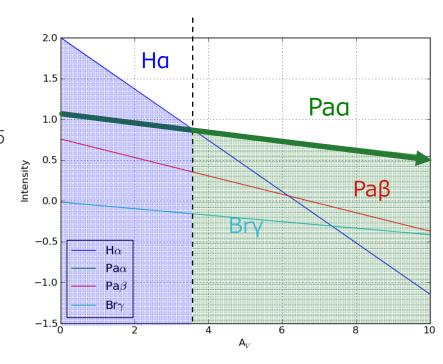
Hydrogen Paα



- ► Hydrogen recombination line @ 1.8751µm
 - Strongest emission line in the infrared wavelength (1/8 of $H\alpha$)
 - Good indicator of dusty star formation activities

$$\rightarrow \frac{A_V}{A_{\text{Pa}\alpha}} \sim 6$$

- **b** Becomes stronger than $H\alpha$ at Av>3.5
- Robust than other indicators such as MIR, FIR continuum



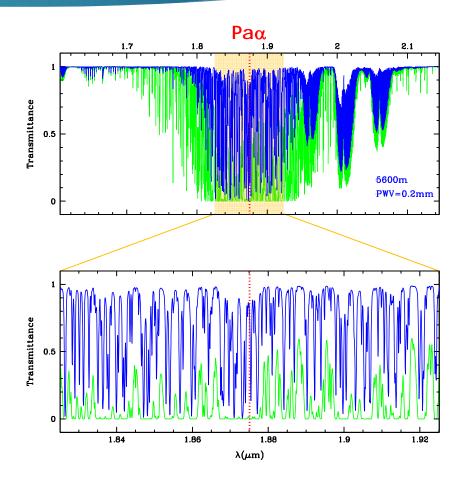
Advantages of $Pa\alpha$ to Other Indicators

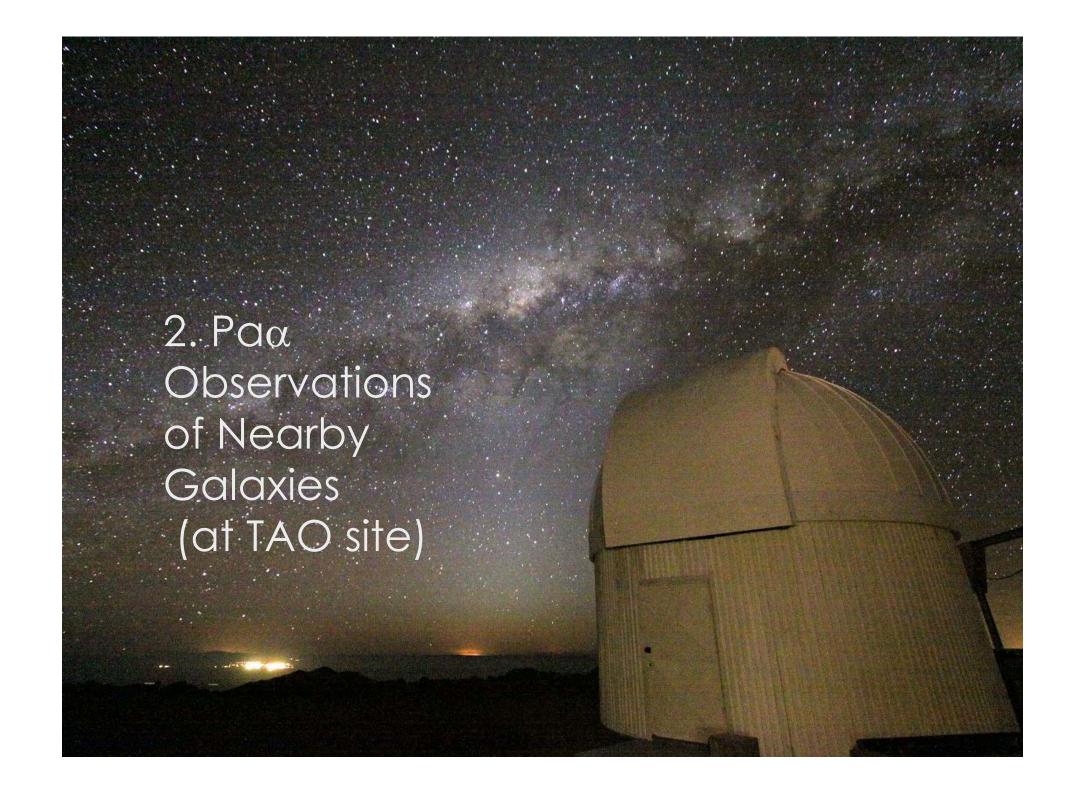
Pa α observations provide:

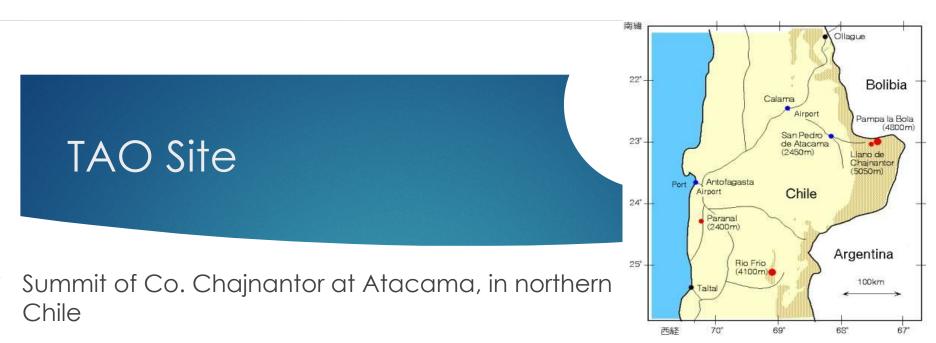
- Robust indicator of ionization photons (i.e., OB stars)
- Velocity information can be also obtained
- Compared to MIR Observations (vs. Spitzer),
 - Less metallicity dependence / less dependence on physics on PDR
- Compared to FIR Observations,
 - Far higher spatial resolution (vs. Herschel)
 - No "resolved-out" problem (vs. Interferometers)

Large Atmospheric Absorption at Paα in the Local Universe

- Absorption by Water Vapor, Carbon Dioxide, Ozone, Methane.....
- Water vapor has large contribution







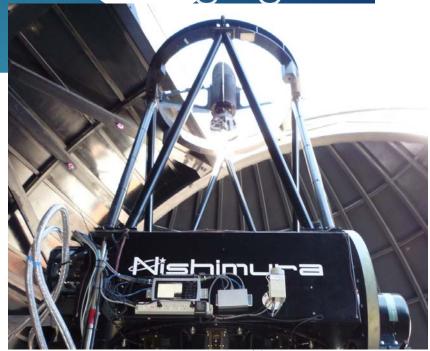
- □ 5640m altitude
- Excellent conditions
 - □ High clear fraction (82% photometric)
 - Low water vapor(PWV:0.85mm median)

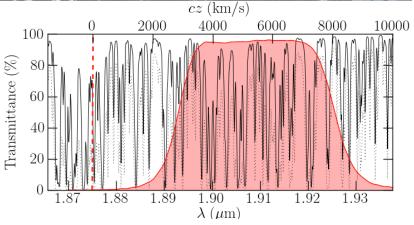


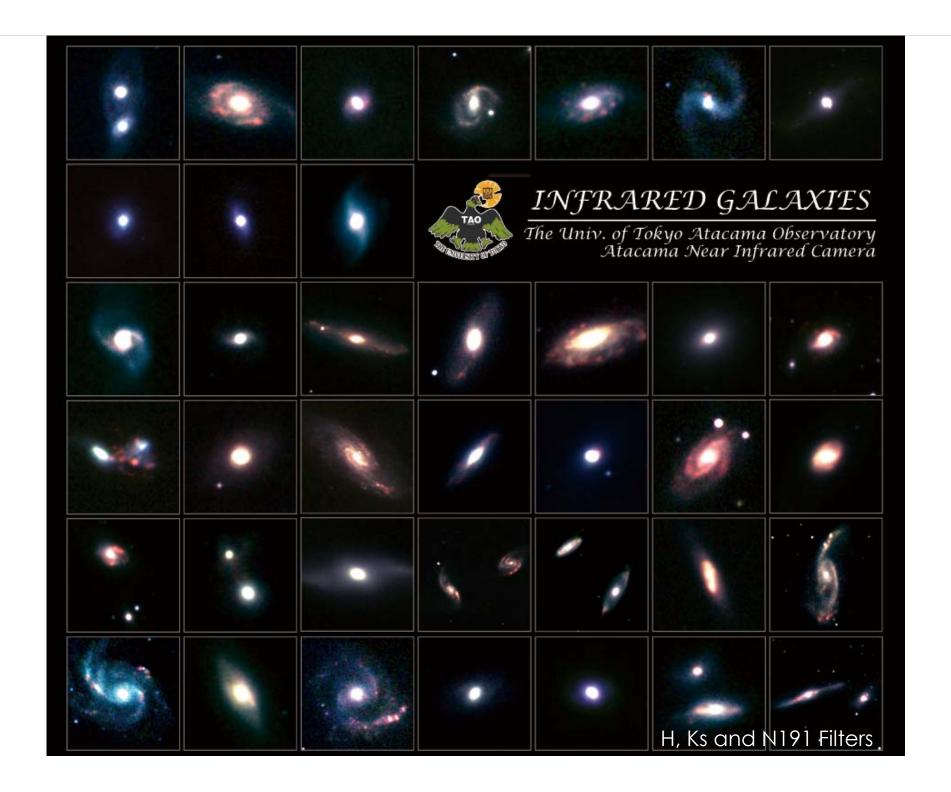


miniTAO 1.0m / ANIR imaging

- Observed 38 LIRGs from Sanders+03(IRAS Revised Bright Galaxy Catalog)
 - ▶ Dec<30deg
 - ► L>10^11Lsun
 - ► 1.91 μ m narrow band filter \Rightarrow z=0.01-0.02

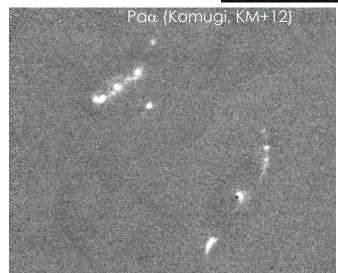


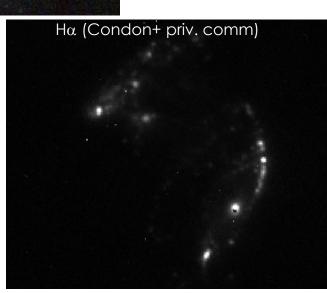




Seeing through the dust

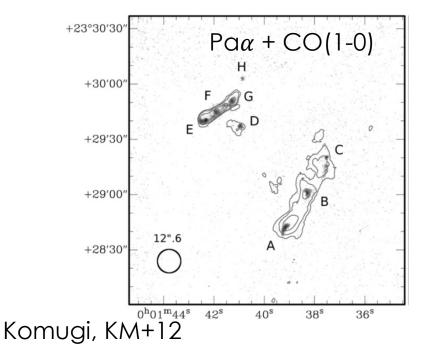


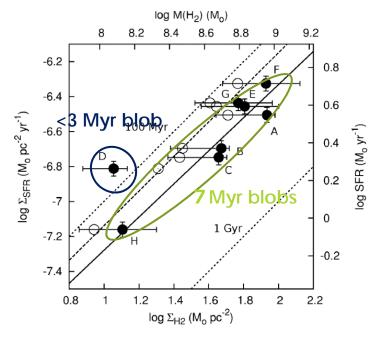




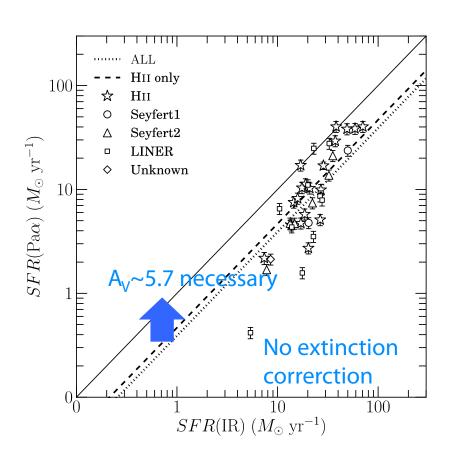
Star Formation Law in a Merger System

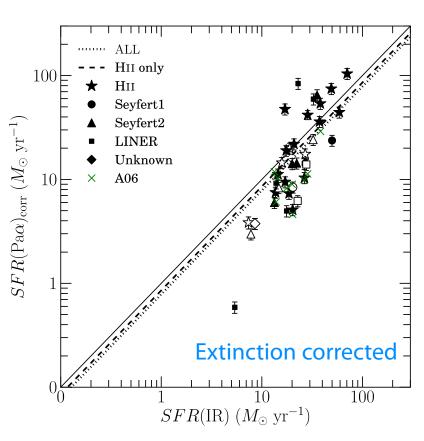
- Very tight Kennicutt-Schimidt law, with power law of 1 (linear) relation, discovered in Taffyl, an early phase interacting galaxies
- Except for "D", being a younger blob between galaxies
 - Scatter of KS law is (partly) caused by age difference?





Paα SFR compared with RR

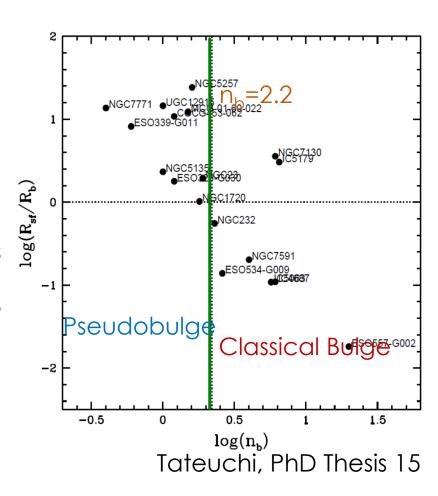




Tateuchi, KM+15

Bulge Morphology vs SFR distribution in LIRGs

- ▶ 20 non-merger LIRGs
- Measurement of
 - bulge size and Sersic index in the Ks-band
 - distribution size of star forming regions in a galaxy
- (bulge normalized) SF region size correlates with bulge Sersic indices
- Some indication to bulge formation, and SMBH coevolution?
 - Classical bulge shows better correlation of $M_{SMBH} M_{bulge}$ (Kormendy+11)

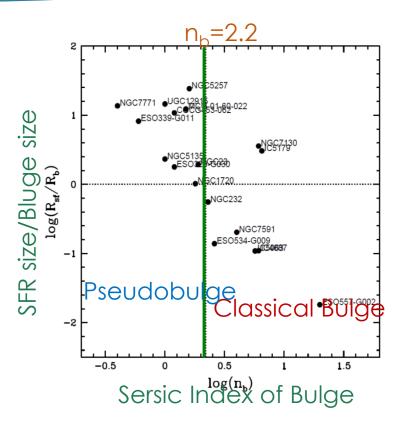


Tateuchi, PhD thesis, Tateuchi, KM+ in prep.

Morphology of Star Formation : Bulge Type vs. Extension of SFR

- Sersic indices of bulge shows good correlation with normalized sizes of SF distribution.
 - Classical bulges (dispersion supported) have SFRs within them
 - Pseudo-bulges (with advanced rotation) have SFRs extended beyond their extent



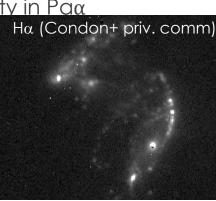


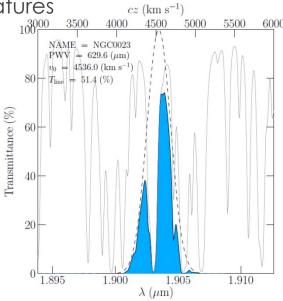
Indication to bulge formation, and SMBH coevolution? : Classical bulge shows better correlation of $M_{SMBH}-M_{bulge}$ (Kormendy+11)

Problem with the Narrow-band Imaging with a 1m telescope

- Low sensitivity
 - Want to see lower surface brightness
 - Cannot go beyond z>0.05 (only several ULIRGs observable)
- No spectral information
 - No dynamical information
 - Uncertainty due to residual atmospheric absorption features
- Dust Extinction
 - Typical Av~5mag for LIRGS,
 still factor of 2 uncertainty in Paα







Tateuchi 15

Dynamics in Local Clumpy Galaxies (Obreschkow+15)

- Low-z Clumpy Starbursts
 - > Z=0.07-0.14
- Paα: Keck/OSIRIS IFS
 - 0.24" resolution (w. AO)=> ~0.3-0.6kpc
- Hβ: Gemini /GMOS
- Dynamical modelling
 Shows smaller specific angular
 momentum than normal disk galaxies
 Results in Toomre Q=1
- Paα information is essential to understand the full kinematic information

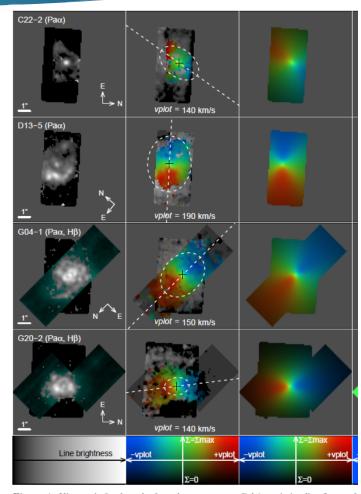


Figure 1. Kinematic fits four the four clumpy targets. Col 1: emission line fluxes of

What we want to do by ULTIMATE?

- Tunable Filter imaging assisted by GLAO
 - Wide FoV (~10arcsec) IFU is best, however, may not match current ULTIMATE concept
- z>0.05 dusty galaxies
 - ▶ 0.2"=200pc @z=0.05
 - Typical sizes of galaxies are <10arcsec</p>
 - Targeted multiple hydrogen lines in the NIR (Paα, Paβ, Bry)
 - Dynamics can be obtained simultaneously, if the tunable filter has enough high spectral resolution (R=1000?)
 - ▶ The problem is we don't need large FoV
 - Target at high density region?
 - ▶ High density region has low SFR in the local universe
- Detailed study of z~0.02 galaxies on low PWV(<1mm) days</p>
 - ▶ 0.2" = 80pc
 - Typical size of z~0.02 galaxies are 10-60arcsec
 - Merger systems have size of few arcmin

Answers to Questions

- Q1: What do you think is the "KEY" science/observations for ULTIMATE in your research field? We hope to establish the very best science cases which are unique enough even in mid-late 2020s (i.e. post-JWST or WFIRST era!).
 : Paa velocity field in local galaxies must be important to understand dynamics of dusty star forming galaxies. This may require an IFU with large FoV, or a tunable filter.
- Q2: Which instrument (WFC/MOS/IFU) do you think is 1st priority for ULTIMATE?
 : Wide Field Imager with a tunable fliter is most attractive, which can cover not only Paa but other hydrogen lines as Pa-b, and Br-g, to solve the dust extinction, and cover other higher ionization lines like Hell at 2.2um, CIV at 2.09um etc., which is a indicator of Wolf-Rayet Stars and AGNs
- ▶ Q3: Our current plan is to (1) build GLAO first, and then to (2) build new NIR instrument(s). This means that we will start our ULTIMATE science with GLAO +MOIRCS at the first stage. Do you have good science cases to be done with GLAO+MOIRCS during the period of ~2020-2023?
 : nuMOIRCS NBF or IFU must be a good instrument
- Q4: Which survey design sounds best for you (see survey_design.pdf)? Your comments/suggestions on the ULTIMATE survey design are very welcome.
 : No survey matches, however, there may be a slight chance that foreground Paa galaxy is detected in narrow-band imaging survey? (We may check with currently existing survey data)