Subaru Telescope
National Astronomical Observatory of Japan

Semester	S18B
Proposal ID	PROPIDTMP
Received	RECEIVETMP

Application Form for Telescope Time (Service Programs)

1. Title of Proposal

Measuring H_0 Through Detailed Modeling of 2 Quadruply Lensed Quasars

2. Principal Investigator

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3. Scientific Category: Gravitational Lenses

4. Co-Investigators

Name	Institute	Name	Institute
Anupreeta More	IPMU		
Ciprian Berghea	Naval Observatory		
John Lucey	Univ. of Durham		
Smith Russel	Univ. of Durham		

5. Observing Run

Instrument	#Hours	Moon	Preferred Dates	Acceptable Dates	Observing Modes
IRCS+LGS-AO	1	any	Jan. 15 - Jan. 31	Jan. 1 - Jan. 31	Imaging (20 mas)
IRCS+LGS-AO	3	any	Jan. 15 - Ja. 31	Jan. 1 - Jan. 31	Imaging (52 mas)

Both targets are visible during the same 4 hour period.

Total Requested Observing Hours: 4 Minimum Acceptable Observing Hours: 4

6. List of Targets

Target Name	RA	Dec	Magnitude (Band)
2M1134-2103	113440.52	-210322.5	$I = 16.94(A), 16.96(B), 17.00(C), 18.53(D)$
2M1310-1714	131020.07	-171457.4	$i = 19.81(A), 19.89(B), 20.94(C), 19.93(D)$

The coordinates refer to the centers of the extended targets. Magnitudes are those of the quasar images.

7. Public Data Archive of Subaru

☒ *Yes, I have checked SMOKA.*

If your targets have already been observed by Subaru in the past, please describe why you need to observe them again.

The targets have not been observed with Subaru AO in the past.

8. Duplications with Normal/Intensive Programs ☐ Proposal ID:

9. Technical Justification

Please describe in detail about instrument configuration, exposure time, required sensitivity, and so on.

We will use IRCS+LGSAO in order to achieve the resolution and depth necessary to measure the morphology of the lensing galaxy in 2M1134-2103, to resolve the lensing galaxies and the predicted 5th quasar image in 2M1310-1714, and to measure the extended arcs from the quasar host galaxies in each system. We will observe both systems in Kp-band, where the AO system achieves superior correction, and where the contrast between the host galaxies and the quasar point sources are higher at $z \sim 2$.
Both targets have tip-tilt guide stars bright enough to be observed in bright or gray sky conditions. For 2M1134-2103 there are two potential guide stars: R=16.2 at 33 arcsec, and R=13.5 at 65 arcseconds. We prefer the first one due to its proximity to the target, but the second one can be used if the sky is very bright. For 2M1310-1714 the guide star is R=13.6 at 43 arcsec.
In order to avoid saturating the detector due to the bright point sources, and also to increase the contrast between the lensing galaxy and the close-by quasar point source, we will observe 2M1134-2103 with the 20 mas pixel scale. Conversely, we will observe the large separation, fainter system 2M1310-1714 with the 52 mas pixel scale. We will use the following observational setup:
2M1134-2103: 20 mas, coadd=1, NDR=16, readout mode=normal, exp1time=150sec
2M1310-1714: 52 mas, coadd=1, NDR=16, readout mode=normal, exp1time=60sec
We will take short exposures of the standard star FS 129 with both pixel scales, in order to measure the intrinsic magnitude of the quasar host galaxies. We therefore require photometric conditions. In order to avoid the region of bad pixels close to the center of the detector, we request that the center of the detector be offset 1.5 arcsec to the W for 2M1134-2103, and 4 arcsec to the W for 2M1310-1714. we request the same offsets for the standard star observations.
We used the online IRCS Imaging Overhead and Total Observing Time Calculator, as well as the Subaru Imaging Exposure Time Calculator to estimate the S/N we will achieve, and the total observing time including overheads:
2M1134-2103: 8 min [initial slew and target acquisition] + 15 min [TTGS+LGS acquisition and AO parameter optimization] + 2 [number of dither sequences] x 5 [number of positions in dither] x 150 sec [exposure] + 2 [number of dither sequences] x 76.8 [telescope moving in dithering, readout, FITS writing per dither sequence] + 5 min [slew to nearby std star and acquisition] + 2 [both pixel scales] x (3 [positions in dither] x 1 sec [exposure for std star] + 29 sec [telescope moving in dithering, readout, FITS writing per sequence]) = 23m+25m+2m34s+5m+2x(3s+29s) = 56m38s (achieving S/N/pixel=7.6 for extended host galaxy 2.5 mag fainter than the 3rd quasar image, when binning 2x2; larger S/N will be achieved for the lensing galaxy)
2M1310-1714: 7 min [slew to nearby target and target acquisition] + 15 min [TTGS+LGS acquisition and AO parameter optimization] + 25 [number of sequences] x 5 [positions in dither] x 60 sec [exposure] + 25 [number of sequences] x 76.8 [telescope moving in dithering, readout, FITS writing per sequence] = 20m+125m+32m = 179min (achieving S/N/pixel=5.0 for extended host galaxy 2.5 mag fainter than the 3rd image, S/N=6.2 for 5th image, if 6 mag fainter than the 4th image)
Finally, we do not require other calibration data, as we will use the science data to produce flat fields and perform sky subtraction.

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## Imaging observation with AO for the first target ##
1. Object/field name :
    2M1134-2103
2. Right ascension of the target field in format HHMMSS.SSS
    113440.520
3. Declination of the target field in format (+/-)DDMMSS.SS
    -210322.5
4. Equinox of position in format YYYY.Y
    2000.0
5. Are photometric conditions necessary? (Yes/No)
    Yes
6. Observation mode (Imaging/Grism/Echelle) imaging
  i. For imaging, do you need AO188? (Yes/No) Yes
  ii. NGS, or LGS? LGS
7. Magnitude/range of magnitudes in a specified NIR band.
    VEGA K=15.3 (A), 15.1 (B), 15.2 (C), 16.8 (D), 17.3 (G)
8. What is the maximum acceptable seeing size (in arcseconds) in the specified NIR band? In case of
using AO188, please provide the maximum acceptable FWHM of the point-spread function after the AO
correction.
  0.2 arcseconds
9. Please describe the AO guide stars as follows.
  i. R (or, V if not available) magnitude of your AO guide star.
     R=16.2 (second choice, in case of bright sky, is R=13.5)
  ii. Separation between the target and the AO guide star
     33 arcseconds (second chose is 65 arcseconds; see the finding chart)
  iii. Whether the AO guide star is a point source or not.
     point source
10. Filter(s)/Band configuration for observation. If more than one filter is to be used, separate
them with commas.
     Kp
11. Pixel scale of camera detector array for imaging, or Grism spectroscopy (20MAS/52MAS).
     20MAS
12. Slit width for Grism/Echelle spectroscopy. A value must be given for each band configuration
specified in item 10, separated by commas.
     N/A
13. Field position angle (PA) for imaging, or slit PA for Grism/Echelle spectroscopy.
    90 degree
14. Single frame exposure time in seconds.
     150
15. Number of coadds at each dithering position.
     1
16. Dither patterns.
     S5*2
17. Dithering size in arcseconds ("DITH" in the above figures).
    5.5 in both RA and DEC
18. Type of target. Use "OBJ" for objects, "STD" for standards.
    OBJ
19. Name of the target, to be written in the OBJECT field of the image FITS header.
    2M1134-2103
# LGS Target List
#   HH:MM:SS.SSS [+/-]DD:MM:SS.SS Target name and additional
11:34:38.163 -21:03:20.61 2M1134-2103 TT Guide star (first choice)
11:34:42.694 -21:02:25.30 2M1134-2103 TT Guide star (second choice)

## Imaging observation with AO for the second target ##
1. Object/field name :
    2M1310-1714
2. Right ascension of the target field in format HHMMSS.SSS
    131020.070
3. Declination of the target field in format (+/-)DDMMSS.SS
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-171457.4
4. Equinox of position in format YYYY.Y
2000.0
5. Are photometric conditions necessary? (Yes/No)
Yes
6. Observation mode (Imaging/Grism/Echelle) imaging
i. For imaging, do you need AO188? (Yes/No) Yes
ii. NGS, or LGS? LGS
7. Magnitude/range of magnitudes in a specified NIR band.
AB K=18.8 (A), 18.9 (B), 19.9 (C), 18.9 (D), 18.5 (G1), 18.75 (G2)
8. What is the maximum acceptable seeing size (in arcseconds) in the specified NIR band? In case of using AO188, please provide the maximum acceptable FWHM of the point-spread function after the AO correction.
0.3 arcseconds
9. Please describe the AO guide stars as follows.
i. R (or, V if not available) magnitude of your AO guide star.
R=13.6
ii. Separation between the target and the AO guide star
43 arcseconds (see the finding chart)
iii. Whether the AO guide star is a point source or not.
point source
10. Filter(s)/Band configuration for observation. If more than one filter is to be used, separate them with commas.
Kp
11. Pixel scale of camera detector array for imaging, or Grism spectroscopy (20MAS/52MAS).
52MAS
12. Slit width for Grism/Echelle spectroscopy. A value must be given for each band configuration specified in item 10, separated by commas.
N/A
13. Field position angle (PA) for imaging, or slit PA for Grism/Echelle spectroscopy.
90 degree
14. Single frame exposure time in seconds.
60
15. Number of coadds at each dithering position.
1
16. Dither patterns.
S5*25
17. Dithering size in arcseconds ("DITH" in the above figures).
10 in both RA and DEC
18. Type of target. Use "OBJ" for objects, "STD" for standards.
OBJ
19. Name of the target, to be written in the OBJECT field of the image FITS header.
2M1310-1714
LGS Target List
HH:MM:SS.SSS [+/-]DD:MM:SS.SS Target name and additional
13:10:19.863 -17:14:14.44 2M1310-1714 TT Guide star

Standard star observations without AO
1. Object/field name :
FS 129
2. Right ascension of the target field in format HHMMSS.SSS
112148.95
3. Declination of the target field in format (+/-)DDMMSS.SS
-131307.9
4. Equinox of position in format YYYY.Y
2000.0
5. Are photometric conditions necessary? (Yes/No)
Yes
6. Observation mode (Imaging/Grism/Echelle) imaging
i. For imaging, do you need AO188? (Yes/No) No
7. Magnitude/range of magnitudes in a specified NIR band.
J=11.8, H=11.2, K=10.7

8. What is the maximum acceptable seeing size (in arcseconds) in the specified NIR band?
    0.7 arcsecond
9. Please describe the AO guide stars as follows. N/A
10. Filter(s) for observation.
     Kp
11. Pixel scale of camera detector array for imaging, or Grism spectroscopy (20MAS/52MAS).
     20MAS,52MAS
12. Slit width for Grism/Echelle spectroscopy. A value must be given for each band configuration specified in item 10, separated by commas.
     N/A
13. Field position angle (PA) for imaging, or slit PA for Grism/Echelle spectroscopy.
    90 degree
14. Single frame exposure time in seconds.
     1
15. Number of coadds at each dithering position.
     1
16. Dither pattern.
     S5*3/5 (the first three positions are sufficient)
17. Dithering size in arcseconds ("DITH" in the above figures).
    10
18. Type of target. Use "OBJ" for objects, "STD" for standards.
    STD
19. Name of the target, to be written in the OBJECT field of the image FITS header.
    FS 129