Subaru Telescope
National Astronomical Observatory of Japan

Proposal ID	S08B-
Received	/ /

Application Form for Telescope Time (Service Programs)

1. Title of Proposal

Subaru/MMT Lensing Survey of Dark Matter in Supermassive Galaxy Clusters

2. Principal Investigator

Name: Nakajima Reiko

Institute: University of California, Berkeley

Mailing Address: Lawrence Berkeley National Lab, 1 Cyclotron Road MS 50R5005, Berkeley, CA 94720-8159, USA

E-mail Address: rnakajima@berkeley.edu

Phone: +1-510-486-7287 Fax: +1-510-486-7149

3. Scientific Category

- ☐ Solar System
- ☐ Normal Stars
- ☐ Extrasolar Planets
- ☐ Star and Planet Formation
- ☐ Compact Objects and SNe
- ☐ Milky Way
- ☐ Local Group
- ☐ ISM
- ☐ Nearby Galaxies
- ☐ Starburst Galaxies
- ☐ AGN and QSO Activity
- ☐ QSO Absorption Lines and IGM
- ☒ Clusters of Galaxies
- ☐ Gravitational Lenses
- ☐ High-z Galaxies
- ☐ Large-Scale Structure
- ☐ Cosmological Parameters
- ☐ Miscellaneous

4. Co-Investigators

Name	Institute	Name	Institute
Rachel Mandelbaum	Institute for Advanced Study	Brian McLeod	Center for Astrophysics
Gary Bernstein	University of Pennsylvania	Charles R. Keeton	Rutgers University
Satoshi Miyazaki	NAOJ	Neta Bahcall	Princeton University
Tim Schrabback	Universiteit Leiden	Nikhil Padmanabhan	LBNL
Megan Donahue	Michigan State University	Kenneth Cavagnolo	Michigan State University

5. Observing Run

Instrument	Hours	Moon	Preferred Dates	Acceptable Dates	Observing Modes
Suprime-Cam	3.0	Dark/Grey	late Dec	Aug–Jan	Imaging (r’)

Total Requested Observing Hours: 3

6. List of Targets *(Use an additional sheet if this space is not sufficient)*

Target Name	RA	Dec	Equinox	Magnitude (Band)
ABELL0068 (re-observation)	00:36:59.402	+09:08:30.05	J2000	$r'_{\rm lim} = 25.2$
ABELL0586	07:32:20.593	+31:38:14.60	J2000	$r'_{\rm lim} = 25.2$
ZwCl3146 (re-observation)	10:23:39.636	+04:11:10.65	J2000	$r'_{\rm lim} = 25.2$
ABELL1576	12:36:59.242	+63:11:11.70	J2000	$r'_{\rm lim} = 25.2$
ABELL1682	13:06:49.999	+46:33:33.38	J2000	$r'_{\rm lim} = 25.2$

Provide your program description. Do not attach any figures.

ABSTRACT: We propose a high-accuracy survey of the 20 most massive galaxy clusters in the northern hemisphere with $0.15 < z < 0.3$ to yield a uniform catalog of X-ray, galaxy and dark-matter properties (from weak lensing [WL]). There are two major scientific goals: (a) To determine the normalization and scatter in the mass-temperature relation for massive clusters, both of which are essential for using clusters to constrain cosmological parameters. This will give the first observational constraint to the *scatter* in the $M(T_x)$ relation. (b) To use the relations between WL mass, X-ray temperature, and other structural variables to validate numerical models of cluster evolution. Our survey will produce a public catalog of the most massive clusters in this redshift range. This proposal will complete the WL imaging for the remaining 5 targets that are visible this semester.

SCIENTIFIC JUSTIFICATION: The abundance of galaxy clusters is a key measure in cosmology and of dark energy (Albrecht et al. 2006), and the properties of massive clusters provide very stringent tests of theories of gravitational collapse. We have designed a survey to obtain the most precise and accurate WL measures to date of galaxy-cluster projected masses, X-ray properties, and galaxy contents, to facilitate new tests of cluster models and to evaluate the suitability of galaxy clutsers as a dark energy test.

Scatter in the M-T_x relation: The primary quantitative goal of our proposed survey is to carry out the first precision measurement of the normalization and *intrinsic scatter* between cluster X-ray observables (in this case, the X-ray temperature T_x). The $M(T_x)$ relation has an intrinsic scatter associated with it due to a variety of evolutionary/merger states the clusters are in. In order to constrain σ_8 within ~ 0.10 from cluster abundances, the knowledge of the size of this scatter is required (Mandelbaum & Seljak 2007). Past halo-abundance studies have had to assume a mean relation and scatter between halo mass and X-ray observable to extract comological information (e.g., Ikebe et al. 2002). This project will be the first to produce WL masses with measurement error below the intrinsic scatter, which is estimated to be ∼20% from numerical simulations (Kravtsov et al. 2006).

Cluster model validation: The mean and scatter in $M(T_x)$ are of intrinsic interest aside from their utility for cosmology. N-body + hydrodynamics models of galaxy clusters are quite advanced and make definitive, testable predictions for $M(T_x)$. Right now, there are still ∼ 20% normalization discrepancies between scaling relations in simulations and observations (Arnaud et al. 2007, Nagai et al. 2007). This could be, for example, due to the fact that ICM in real clusters has non-thermal pressure support, neglected in hydrostatic estimates of the mass. Also, models predict that the X-ray "Y_x parameter" (Kravtsov et al. 2006) has very low scatter with respect to mass even in unrelaxed clusters, but since WL is the only path to accurate mass estimates for the unrelaxed clusters, there is substantial motivation for highest-quality data on a fairly-selected sample of clusters. Our survey will enable many new tests of models by determining distributions of other observables (e.g., concentration parameters and multipole moments of the X-ray and dark matter distributions), measureable at useful S/N in these supermassive clusters.

SURVEY DESIGN: We observe and measure their mass from WL of an unbiased set of the most massive clusters based solely on X-ray temperature. This selection criteria is important if we are to quantify the scatter in the $M(T_x)$ relation. The high image quality from Subaru Suprime-Cam is crucial for precise mass measurement from this technique. The WL imaging data will be combined with 5-band photometric redshift [photo-z] for all of our targets to further improve upon the accuracy of our mass estimate. WL cluster studies (e.g., Bardeau et al. 2007, Mahdavi et al. 2007) demonstrate that our overall methodology is reasonable, but that a new survey with a larger cluster sample size is required.

Target selection: We estimate that 20 massive clusters are required to have sufficient statistics to constrain the scatter in $M(T_x)$. Our targets are the 20 most massive galaxy clusters in the northern hemisphere with $0.15 < z < 0.3$, selected by X-ray temperature to have $T_x > 6.5$keV based on Chandra/XMM data (Cavagnolo et al. 2008), corresponding to virial masses $M > 10^{15}h^{-1}M_{\odot}$ (Dahle et al. 2002, Smith et al. 2005). Our selection criteria lead to an unbiased sample of supermassive clusters, because we do not eliminate complex or merging systems. The X-ray surveys and pointed followups are complete in this mass-redshift range, so we can select a complete sample and conduct meaningful statistical studies.

Cluster mass estimate to high accuracy with WL: We use the most massive clusters to maximize S/N, with a sufficiently large sample to reduce sample variance. We also require very low *systematic* errors in WL measurement. Co-I's on this proposal have developed three of the best-performing WL pipelines (∼2% accuracy) in the WL accuracy tests (Massey et al. 2007). Many WL cluster mass estimates have large calibration uncertainties due to ignorance of the source redshift distribution. We will have photo-zs from KPNO 5-band imaging of these clusters. The multiband photo-z data will reduce the calibration uncertainty by a factor of 10, down to ∼2%. The photo-z data will also reliably identify cluster member galaxies, reducing contamination to the WL signal. We choose the redshift range $0.15 < z < 0.3$, which gives the optimal combination of high lensing efficiency and X-ray flux. An important subtlety is that, a perfect WL mass estimate still has uncertainty associated with the 3-d mass projection to 2-d, as well as any other large-scale structure projected along the line of sight. We will use numerical simulation data to estimate the uncertainty in cluster mass contributed by these effects.

Suprime-Cam observations: Of the 20 targets, we already have 12 cluster images available, mostly from the Subaru SMOKA archive; an additional 3 more are expected to be available in July 2008 from MMT. We propose to observe the remaining 5 targets. The observability for each target is given in the "Requirements for Observation" section, item #13. We plan to observe each target in r' for 30 minutes each with the following requirements: (a) seeing $< 0''.9$, (b) airmass < 1.4, (c) lunar phase < 7, to meet the depth (and hence the WL S/N) requirements. We request re-observation of A68 and Z3146 since our preliminary reduction of the Subaru archival data of these clusters have shown that the seeing is insufficient to obtain a clear WL signal.

References:

Albrecht, A. et al., 2006, astro-ph/0609591 (Dark Energy Task Force)
Ikebe, Y. et al., 2002, A&A, 383, 773
Arnaud, M. et al., 2007, astro-ph/0709.1561
Bardeau, S. et al., 2007, A&A 470, 449
Cavagnolo, K. et al., 2008, to appear in ApJ, astro-ph/0803.3858
Dahle, H. et al., 2002, ApJS 139, 313
Mandelbaum, R. & Seljak, U., 2007, JCAP, 6, 24
Kravtsov, A. et al., 2006, ApJ 650, 128
Nagai, D. et al., 2007, astro-ph/0703661
Mahdavi, A. et al., 2007, astro-ph/0703372
Massey, R. et al., 2007, MNRAS 376, 13
Smith, G.P. et al., 2005, MNRAS 359, 417

```
1 : Object/Field name
      ABELL0068
2 : magnitude / range of magnitudes, specify band
      18 < r' < 25.2
3 : Photometric conditions necessary? (yes/no)
      no
4 : How large is the acceptable seeing size? (<0''.5, <0''.7, <1''.0, >1''.0)
      <1''.0
5 : Right Ascention (in HHMMSS.SSS)
      003659.402
6 : Declination (in +/-DDMMSS.SS)
      +090830.05
7 : Equinox (2000.0 or 1950.0)
      2000.0
8 : Position angle of the field (in degrees)
      0
9 : Filters
      r'
10: Exposure parameters for each filter
     10-1.  r'        [filter name]
     10-2.  360 sec   [individual exposure time]
     10-3.  dith      [single/dithering]
     10-4.  5         [number of dither positions (N)]
     10-5.  60        [radius of dither pattern in arcsec (R)]
     10-6.  15        [position of first dither position in degrees (T)]
     10-7.  0         [RA offset in arcsec]
     10-8.  0         [Dec offset in arcsec]

====

1 : Object/Field name
      ABELL0586
2 : magnitude / range of magnitudes, specify band
      18 < r' < 25.2
3 : Photometric conditions necessary? (yes/no)
      no
4 : How large is the acceptable seeing size? (<0''.5, <0''.7, <1''.0, >1''.0)
      <1''.0
5 : Right Ascention (in HHMMSS.SSS)
      073220.593
6 : Declination (in +/-DDMMSS.SS)
      +313814.60
7 : Equinox (2000.0 or 1950.0)
      2000.0
8 : Position angle of the field (in degrees)
      0
9 : Filters
      r'
10: Exposure parameters for each filter
     10-1.  r'        [filter name]
     10-2.  360 sec   [individual exposure time]
     10-3.  dith      [single/dithering]
     10-4.  5         [number of dither positions (N)]
     10-5.  60        [radius of dither pattern in arcsec (R)]
     10-6.  15        [position of first dither position in degrees (T)]
     10-7.  0         [RA offset in arcsec]
     10-8.  0         [Dec offset in arcsec]

=====
1 : Object/Field name
```

```
2 : magnitude / range of magnitudes, specify band
      18 < r' < 25.2
3 : Photometric conditions necessary? (yes/no)
      no
4 : How large is the acceptable seeing size? (<0''.5, <0''.7, <1''.0, >1''.0)
      <1''.0
5 : Right Ascention (in HHMMSS.SSS)
      102339.636
6 : Declination (in +/-DDMMSS.SS)
      +041110.65
7 : Equinox (2000.0 or 1950.0)
      2000.0
8 : Position angle of the field (in degrees)
      0
9 : Filters
      r'
10: Exposure parameters for each filter
     10-1.  r'        [filter name]
     10-2.  360 sec   [individual exposure time]
     10-3.  dith      [single/dithering]
     10-4.  5         [number of dither positions (N)]
     10-5.  60        [radius of dither pattern in arcsec (R)]
     10-6.  15        [position of first dither position in degrees (T)]
     10-7.  0         [RA offset in arcsec]
     10-8.  0         [Dec offset in arcsec]

====
1 : Object/Field name
      ABELL1576
2 : magnitude / range of magnitudes, specify band
      18 < r' < 25.2
3 : Photometric conditions necessary? (yes/no)
      no
4 : How large is the acceptable seeing size? (<0''.5, <0''.7, <1''.0, >1''.0)
      <1''.0
5 : Right Ascention (in HHMMSS.SSS)
      123659.242
6 : Declination (in +/-DDMMSS.SS)
      +631111.70
7 : Equinox (2000.0 or 1950.0)
      2000.0
8 : Position angle of the field (in degrees)
      0
9 : Filters
      r'
10: Exposure parameters for each filter
     10-1.  r'        [filter name]
     10-2.  360 sec   [individual exposure time]
     10-3.  dith      [single/dithering]
     10-4.  5         [number of dither positions (N)]
     10-5.  60        [radius of dither pattern in arcsec (R)]
     10-6.  15        [position of first dither position in degrees (T)]
     10-7.  0         [RA offset in arcsec]
     10-8.  0         [Dec offset in arcsec]

====
1 : Object/Field name
      ABELL1682
2 : magnitude / range of magnitudes, specify band
      18 < r' < 25.2
3 : Photometric conditions necessary? (yes/no)
```

4 : How large is the acceptable seeing size? (<0".5, <0".7, <1".0, >1".0)
<1".0
5 : Right Ascention (in HHMMSS.SSS)
130649.999
6 : Declination (in +/-DDMMSS.SS)
+463333.38
7 : Equinox (2000.0 or 1950.0)
2000.0
8 : Position angle of the field (in degrees)
0
9 : Filters
r’
10: Exposure parameters for each filter

10-1.	r’	[filter name]
10-2.	360 sec	[individual exposure time]
10-3.	dith	[single/dithering]
10-4.	5	[number of dither positions (N)]
10-5.	60	[radius of dither pattern in arcsec (R)]
10-6.	15	[position of first dither position in degrees (T)]
10-7.	0	[RA offset in arcsec]
10-8.	0	[Dec offset in arcsec]

====

11 : Total time requested
3 hours

12 : Your preferred observing schedule
The 30 minute exposure should be taken approximately between the following times for the following observation dates to meet the airmass requirements:

	A68	A586	Z3146	A1576	A1682
Aug 1-8	01:15-04:30	no	no	no	no
Aug 24-Sep 5	23:15-04:45	no	no	no	no
Sep 23-Oct 5	21:15-03:30	04:15-05:00	no	no	no
Oct 22-Nov 3	19:30-01:30	02:15-05:00	no	no	no
Nov 21-Dec 3	19:00-23:30	00:15-05:15	no	no	no
Dec 21-Jan 2	19:15-21:30	22:15-04:45	01:15-05:15	05:00-05:30	04:00-05:30
Jan 20-Jan 31	no	20:15-02:45	23:30-05:15	03:00-05:15	02:00-05:30

13 : Special request (if any)

For all targets, we require the following to acheive our intended goal:
(1) Seeing < 0".9
(2) Airmass < 1.4 (< 1.5 for A1576)
(3) Lunar phase < 7

Re-observation request:
The following two clusters have SMOKA archival data avaliable.
However, we request re-observation for the following reason:

- A68: Preliminary weak-lensing analysis of this cluster does not show sufficient S/N in the lensing signal; our analysis show the seeing size is too large for both V and I+ bands.
  *** The archive has good seeing (<=0".8) for 15 minutes in V, so it is also acceptable to get an additional 15 minutes in the V band, with appropriate dithering, instead of 30 minutes in the r’ band. ***
- Z3146: The archival data indicate that the seeing size is too large for a high-accuracy WL measurement (seeing > 1".38).

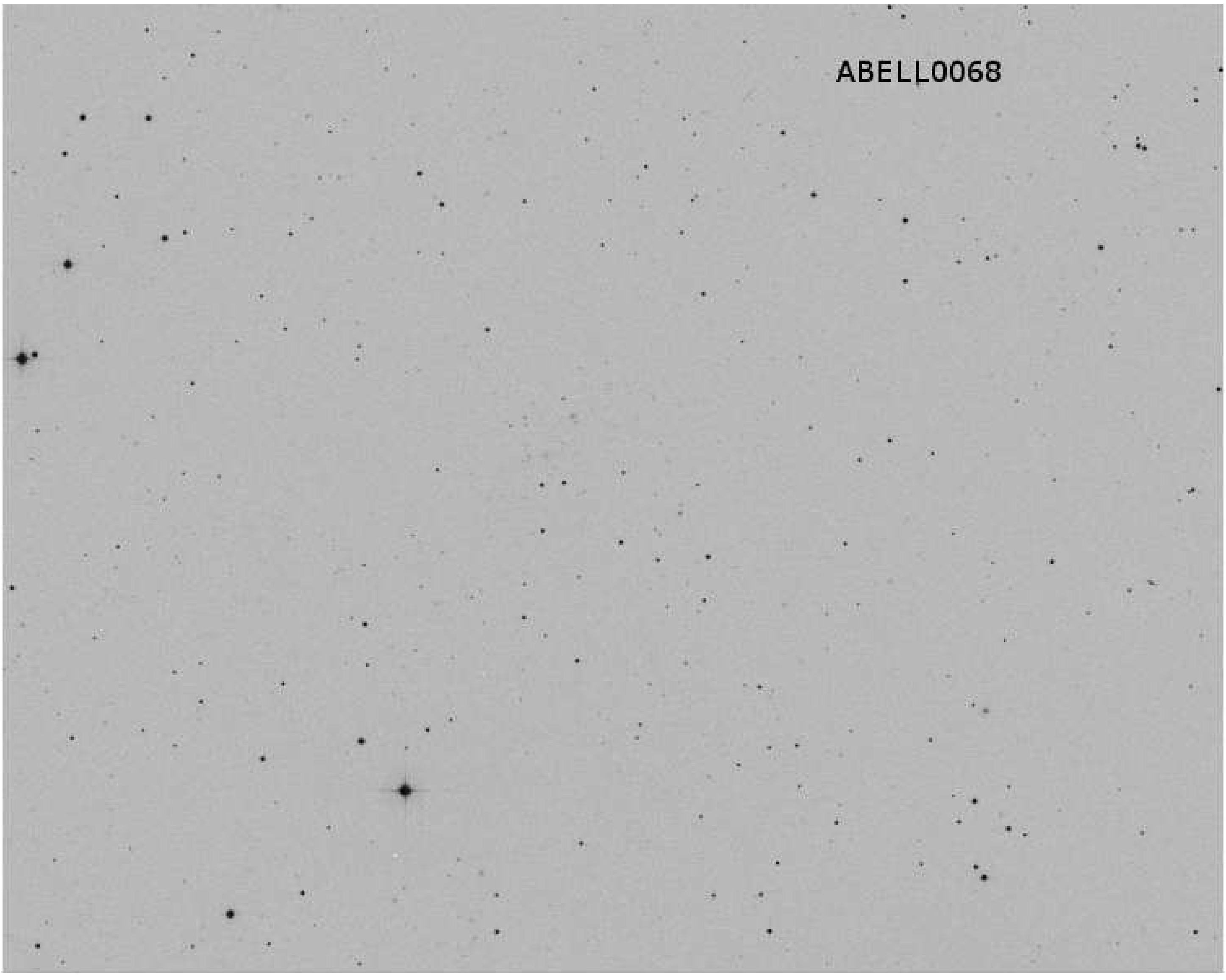
A : Finding charts

A-1. Finding charts attached?
Yes

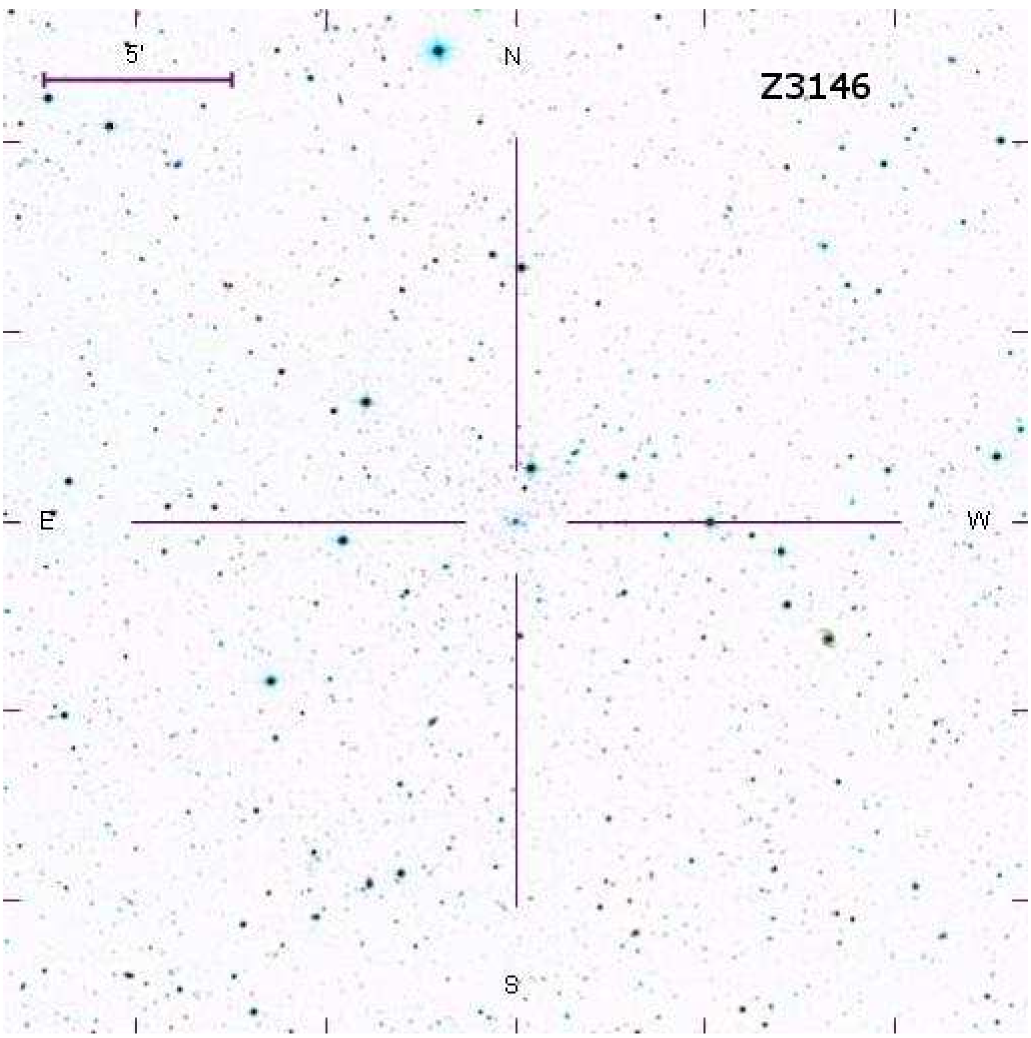
A-2. Number of finding charts
5

A-3. Information

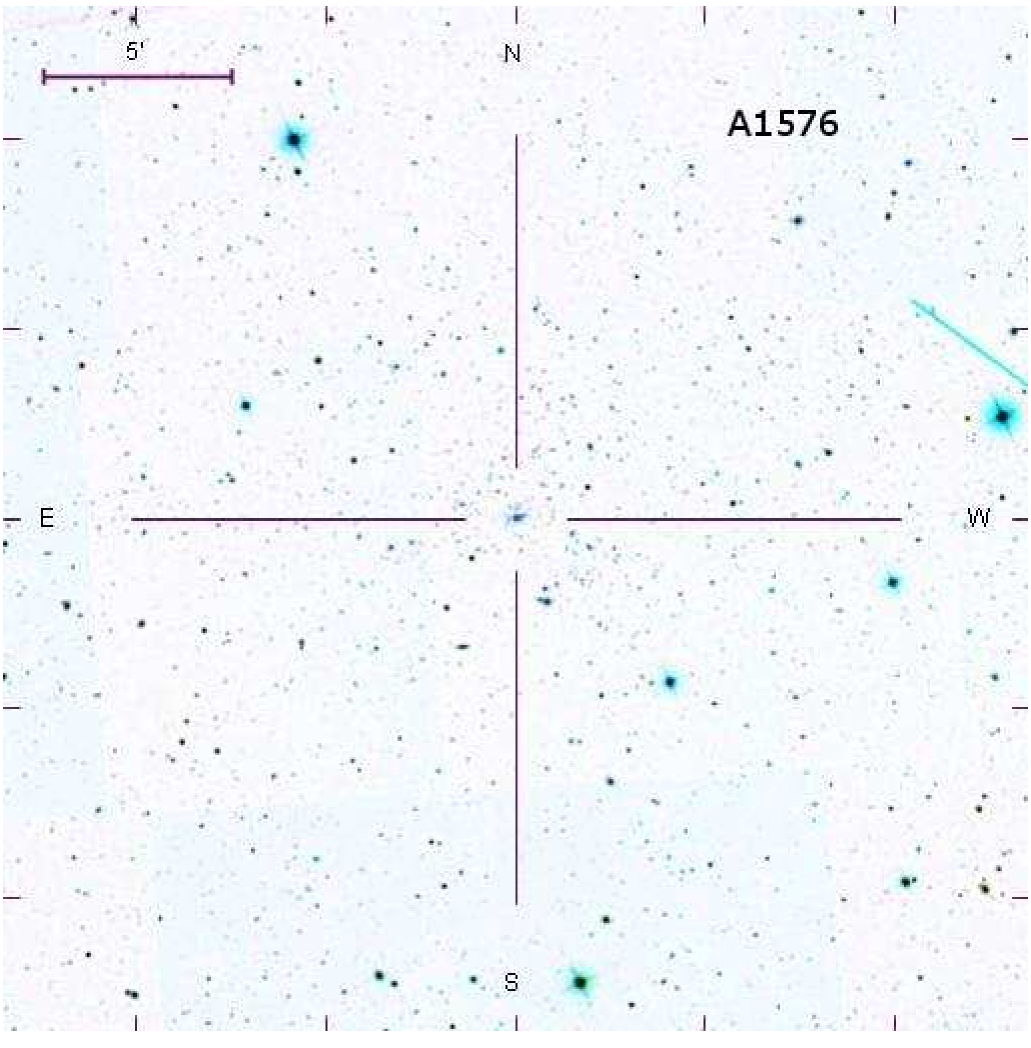
1.	ABELL0068	34'x27'	north is up	none
2.	ABELL0586	34'x27'	north is up	none
3.	ZWCL3146	30'x30'	north is up	none
4.	ABELL1576	30'x30'	north is up	none
5.	ABELL1682	30'x30'	north is up	none

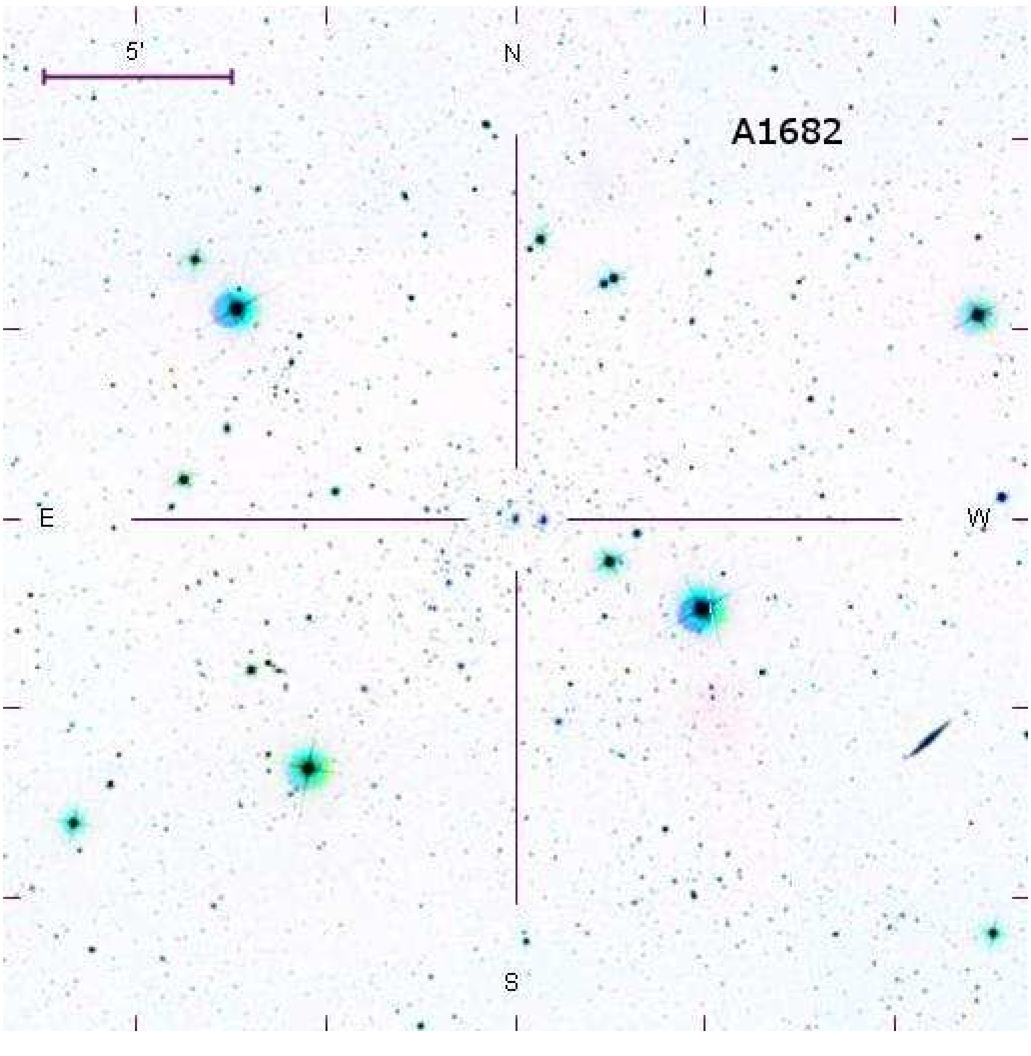

ABELL0068


ABELL0586



5'
N
Z3146
E
W
S


5'
N
A1576
E
W
S



5'
N
A1682
E
W
S