OBSERVING REQUEST
Telescope Access Program, China

Year: **Term:** B **Proposal type:** short-term

MMT/Hectospec Spectral Observations for the Supernova Remnant Cassiopeia A

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CoI(s): Biwei Jiang (BNU), Haining Li (NAOC)

Abstract of Scientific Justification

Supernovae are important contributors to the interstellar dust. Core-collapse supernovae originated from massive stars are suggested to be among the major production sites of cosmic dust. In the meantime, supernovae also destroy and alter the properties of the interstellar dust by strong shock wave. However, it is unclear how much supernovae may contribute to and influence the interstellar dust. **We propose to use MMT/Hectospec to perform low resolution (R=2500) spectroscopic observations on red giants located in or near the supernova remnant Cassiopeia A (Cas A). We plan to target at about 260 red giant candidates ($13 < r < 19$) and request 0.5 night for this program in total.** With the moderate resolution and wide coverage spectra from MMT/Hectospec, we can accurately identify the spectral type of these candidates by determining their stellar parameters (including effective temperature and surface gravity). Using the identified red giants as tracers, we will be able to determine the extinction law towards Cas A. Since the wavelength dependence of interstellar extinction - the interstellar extinction law (or curve) - is one of the primary sources of information about the interstellar grain population, we will model the extinction law towards Cas A with dust models to probe the dust properties, then estimate the interstellar dust mass contributed by the supernova both from the extinction law and the spectral energy distribution.

Summary of observing runs requested for this project

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling Optimal	Scheduling Acceptable	Sharing Poss.	Sharing Adv.
1	MMT		Hectospec			0.5	bright	Sep–Oct	Aug–Nov	yes	yes
or:											
1a										no	no

Scheduling constraints and unusable dates *(up to 4 lines)***:** The requested dates are due to object observability. The late of August and whole September are the most optimal time, during which our targets have extended periods of visibility with larger altitude angles from the Observatory. If the observations share nights with other project, we propose to use the half night when our targets rise highest in the sky.

no text past this line

A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a ∗ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	Cassiopeia A (bright)	23:23:24.0	+58:48:54	$13 < r < 16$, supernova remnant
2	Cassiopeia A (faint)	23:23:24.0	+58:48:54	$16 < r < 19$, supernova remnant

If this program uses a PI instrument, attach the approval email from the PI to this proposal. Please see the attachment.

Graduate students *(provide the following information for* ***each*** *student named as PI or CoI on the cover page.)*

Student's Name	Advisor's Name	Thesis
		no

Scientific Justification *Describe the overall significance to astronomy and within the proposal's discipline. Limit text to one page, with a limit of two additional pages for figures, captions, and references.*

Why do we select Cassiopeia A

It is generally believed that evolved low- and intermediate-mass stars are the main contributor to the interstellar dust. Supernovae (SNe) are also important contributors to interstellar dust, which is proved by the detection of large amount of dust in the high-redshift quasars and around supernovae (Dwek et al. 2004). However, **it is unclear how much supernovae may contribute to and influence the interstellar dust.** Theoretical studies predict that the average dust yield per SN required to explain dusty galaxies is of order 0.5-1.0 $M_{\odot}$ (Gall et al. 2014). But the infrared observations of young supernova remnants have detected only $\sim 10^3 M_{\odot}$ of hot dust.

Cas A, which is believed to be a remnant of either a Type Ib or Type IIn supernova explosion with a relatively close distance (~3.4 kpc), **is an ideal target for examining the properties of SN dust.** Dunne et al. (2003) claimed the detection of $2-5M_{\odot}$ of cold SN dust associated with Cas A from the 850 μm observation. On the contrast, the faint FIR and sub-millimeter emission from Cas A can be fitted by dust at 35 K with a total mass of $\sim 0.07\ M_{\odot}$. Very recently, using the *Herschel*'s FIR data, De Looze et al. (2017) derived a total SN dust mass between $0.4M_{\odot}$ and $0.6M_{\odot}$ for a mixture of silicate and carbonaceous grains. The mass of SN dust associated with Cas A is still unclear.

Why do we plan to observe Red Giants

The wavelength dependence of interstellar extinction, i.e., the "interstellar extinction law" (or curve) is one of the primary sources of information about the interstellar grain population (Draine 2003). Usually, the "color-excess method" is used to obtain extinction as a function of wavelength with red giants (RGs) or red clump giants (RCGs) as tracers, and widely applied to derive the extinction law from photometric data.

Red giants are appropriate tracers of interstellar extinction because (1) they span a narrow range of effective temperatures so that the scatter of the intrinsic color indices is small, and (2) they are bright enough in the IR and remain visible even with large extinction and/or at a great distance. In general, the selection of RGs is usually based on the mid-IR colors which are barely affected by interstellar extinction. However, the chosen samples could be polluted by other types of sources with comparable colors, and the intrinsic color index dispersion may not be negligibly small even among the same type of stars.

In this project, we can **accurately identify RGs by measuring the stellar parameters** (such as effective temperature $T_{\rm eff}$, surface gravity $\log g$, metallicity [M/H]) from the spectroscopic observations of the candidates. Additionally, Wang & Jiang (2014) and Xue et al. (2016) proposed a more accurate method to determine the extinction law based on the spectroscopic data from the *APOGEE* survey. **The stellar parameters lead to a precise determination of the stellar intrinsic color indices (Figure 1).**

Why do we apply for MMT/Hectospec

We selected the supernova remnant Cas A to perform spectroscopic observations for the RG candidates. Since it has a wide field of view (1 $\rm deg^2$)and large number of fibers (300 in total) for multi-object spectroscopy, and provides wide spectral coverage with moderate spectral resolution (Fabricant et al. 2005), the MMT/Hectospec is an ideal instrument for our project. The candidates within or nearby Cas A region can be observed simultaneously with this multi-fiber spectrograph. This 6.5 meter telescope can obtain spectra with sufficient signal-to-noise ratio (S/N) in a reasonable amount of exposure time. Thus we can accurately identify the spectral class of the candidates by determining their stellar parameters.

Using the identified RGs as tracers, and considering the relationship between the intrinsic stellar color excesses and the stellar $T_{\rm eff}$ by Xue et al. (2016), we can determine the extinction curves towards different sightlines in or near Cas A. Finally, we will probe the dust properties in Cas A by modelling the extinction curves with dust models, and estimate the interstellar dust mass contributed by supernova both from the extinction and the spectral energy distribution. The proposed method, which is based on the extinction curve, avoids the uncertainty of the dust temperature and assumes a more reasonable dust absorption coefficient, **and will lead to a more precise estimation of the dust mass contribution by supernovae to interstellar dust.**

References

Alves, D. R. 2000, ApJ, 539, 732
Arendt, R., et al. 2014, ApJ, 786, 55
De Looze, I., Barlow, M. J., & Swinyard, B. M., et al. 2017, MNRAS, 465, 3309
Draine, B. T. 2003, ARA&A, 41, 241
Dunne, L., et al. 2003, Nature, 424, 285
Dwek, E. 2004, ApJ, 607, 848
Fabricant, D., Fata, R., & Roll, J., et al. 2005, PASP, 117, 1411
Flaherty, K., Pipher, J., & Megeath, S., et al. 2007, ApJ, 663, 1069
Gall, C., et al. 2014, Nature, 511, 326
Gao, J., Jiang, B. W., & Li, A. 2009, ApJ, 707, 89
Gao, J., Jiang, B. W., Li, A., & Xue, M. Y. 2013, ApJ, 776, 7
Krause, O., et al. 2004, Nature, 432, 596
Morgan, H., & Edmunds, M. 2003, ApJL, 597, L33
Schultheis, M., Zasowski, G., & Allende Prieto, C., et al. 2014, AJ, 148, 24
Wang, S., & Jiang, B. W. 2014, ApJ, 788, L12
Xue, M. S., Jiang, B. W., & Gao, J., et al. 2016, ApJs, 224, 23
Zhao, H., & Jiang, B. W. submitted to ApJ, 2017

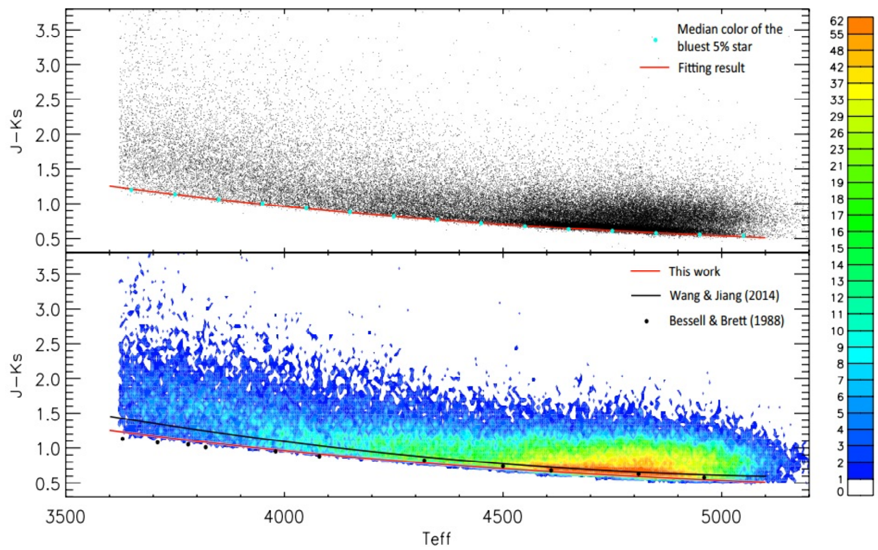

Figure 1: Distribution of the selected APOGEE stars in the observed color index $J - K_s$ vs. effective temperature $T_{\rm eff}$ diagram. The diagram is taken from Xue et al. (2016).

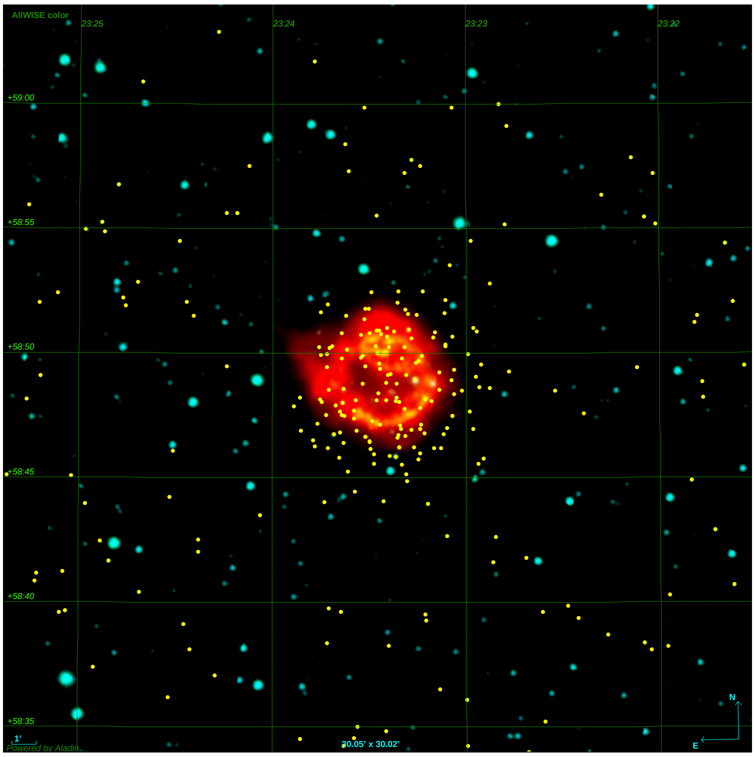

Figure 2: The selected RG candidates' (yellow dots) distribution located in or near Cas A region. The background is *ALLWISE* color image.

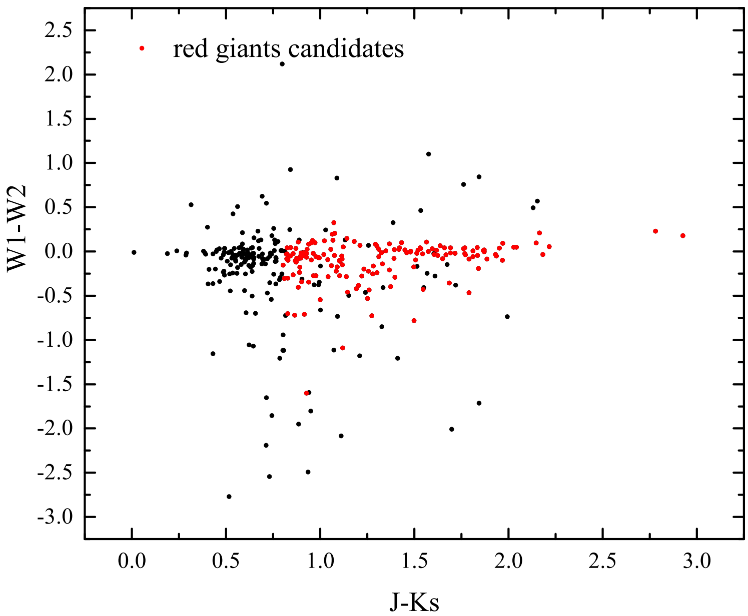

Figure 3: The $J - K_s$ vs. $W1 - W2$ color-color diagram. The RG candidates in Cas A is denoted by red dots.

Experimental Design *Describe your overall observational program design. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? Include information such as why the specific targets were selected, the sample size, the analysis plan, instrument choice, etc. Also briefly explain what expertise or effort each team member will contribute to the project. Describe any necessary non-standard calibrations (**up to one page**).*

The Selection of Candidates

We selected the supernova remnant Cas A to perform spectroscopic observations. The angular size of remnant of Cas A is about 6 arcmin. In order to estimate the extinction contributed by the foreground interstellar medium, we enlarged the survey area to 15 arcmin (30×30 arcmin^2) centered in Cas A. The samples are made to be smoothly distributed in the field (see Figure 2), in order to be suitable for the fiber assignment of Hectospec. We also try to observe as many member stars as possible so that we can have sufficient samples to map the interstellar extinction of the Cas A.

The selection of RG candidates is based on the IR and MIR colors. Firstly, the criterion of $J - Ks > 0.8$ is used to exclude the foreground dwarf stars. Then the $W1 - W2$ colors from the *Wide-field Infrared Survey Explorer* (WISE) are constrained to be smaller than 0.4 to exclude the sources with IR excess such as YSOs and AGBs (Gao et al. 2009). These criteria are efficient to remove the contamination of other types of stars (see Figure 3 and Flaherty et al. 2007).

We finally selected ∼260 candidates with $13 < r < 19\mathrm{mag}$ and propose observations with MMT/Hectospec. By taking the average foreground extinction of 1.8 $\mathrm{mag/kpc}$, we can derive $m_V \approx 13.4$ mag for RCGs [the absolute magnitude $M_V = 0.73$ mag (Alves 2000)] at the distance of Cas A (~ 3.4 kpc). RGs are generally much brighter than those of RCGs, so that we can surely probe the extinction law produced by the SN dust in Cas A with these candidates. Meanwhile, the foreground extinction will be estimated with samples away from the regions of Cas A (see Figure 2). The wide coverage of *r* magnitude will allow us to probe the variation of extinction along with distance. Considering the stellar density and reasonable exposure times, we separate the candidates into two group: "bright" ($13 < r < 16$ mag) and "faint" ($16 < r < 19$ mag).

Observation Strategy

We propose to use MMT/Hectospec with resolution of $R = 2500$ to obtain low resolution spectroscopic data for $\sim$ 260 stars in a 30×30 arcmin^2 field. We require that the S/N of the spectra should be at least 20, in order to reach an uncertainty of 150K in the effective temperature, and the accuracy of 0.15 dex for the metallicity. Since Cas A is a bright supernova remnant, we request that both "bright" and "faint" groups will be observed more than twice to achieve sufficient S/N. After the spectra are obtained, the stellar parameters will be estimated. Using the spectra of about 260 stars in or near Cas A field, in combination with multi-wavelength data from *HST*, *Spitzer*/WISE and 2MASS, we can determine the extinction curves towards many different sightlines in or near Cas A.

Data Plan

MMT/Hectospec can obtain spectra with sufficient S/N so that we can accurately identify the spectral class of the candidates by determining their T_{eff}, $\log g$, and [M/H]. In addition, with these stellar parameters, we can estimate the luminosities of the observed stars by using Padova database (Schultheis et al. 2014; Zhao et al. 2017), and derive the distance of them. Therefore, it is possible that we can probe the extinction law towards Cas A and also find the variation of extinction along with distance. Using dust models (silicates + graphite), we will model the extinction law towards Cas A. From the best-fitted model, the dust mass produced by the core-collapse SN in Cas can be precisely estimated. In comparison with the most popular method to estimate the dust mass contribution, i.e. to fit the observed spectral energy distributions of dust emission, the proposed method will lead to a more precise estimation of the dust mass contribution by SNe.

We will use IRAF to reduce the spectral data. H.N. Li has expertise in spectroscopic data reduction and stellar parameters calculations. A similar pipeline which have been used on LAMOST spectra with similar resolution will be used to measure the stellar parameters from the MMT/Hectospec spectra. B.W. Jiang and J. Gao are experts in determining extinction laws and constructing dust models to fit the extinction curves.

Technical Justification *Justify the instrument configuration, the required signal-to-noise, exposure times. All requests for dark or gray time must include a detailed justification for the requested lunar phase. Specify the total time needed, and (if applicable) the minimum requested time (**up to one page**).*

Exposure times

We propose to use the 600 l/mm grating, centered at 580 nm with wavelength range from 480 to 730 nm and dispersion of $0.55\text{Å}/\text{pixel}$ for the observations. In order to achieve a minimal S/N of 20, we request 30 min $\times$ 3 = 90 min, and 15 min $\times$ 2 = 30 min exposure time for each faint and bright plate, respectively, given dark nights with the seeing better than 1 arcsec and airmass smaller than 1.2. Alternatively, grey nights is also acceptable if the moon does not rise. Since Cas A is a bright supernova remnant, we propose to use at least 100 fibers to obtain sky spectra assigned together with scientific targets in each run. Flux calibration is required in order to calculate the absolute extinction magnitude, hence we need at least 10 standard flux stars in each plates.

Total Request

Taking into account a 25-minute overheads for fiber assignment, telescope reseting, and CCD read out, etc., we expect an overhead of 0.5 hour per pointing. Hence, we estimate the program will take 0.5 night in total.

TAP Usage and Context *The TAC needs to understand the scope of this project — (1) How many total TAP nights have already been allocated for this project (if any), how many are you requesting this semester, including any CFHT time from a linked proposal, and if more time will be necessary in future semesters, how many nights will you need to complete the project (best guess)?; (2) If a observing for this project comes from, or is being requested from, resources outside TAP, tell us about that observing, and how the TAP part fits in. (3) List any time from partner institutions, going toward (or being requested for) this project from TAP partners (e.g., Arizona, UC, Caltech, CFH, etc.), and who is the lead investigator on that time; (3) If you are collaborating with people who have access to other telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how TAP time and your participation fit in. 4) Please explain any ways in which this program would help fulfill the goals of the Telescope Access Program. (**up to one page**)*

No TAP time has been assigned for this project before and we are requesting 0.5 night from TAP on the MMT in 2017B. We do not submit any other proposal for the same project to other telescope via any other program. There is currently no time from non-TAP telescopes allocated to this project. All the data reduction and analysis will mainly be done in China. If we are able to determine the extinction curves in Cas A, we may submit another proposal to TAP in future semesters to survey more supernova remnants. The studies of Cas A will be helpful to better understand the supernovae' contribution to and effects on the interstellar dust.

Previous Use of TAP Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through TAP during the past 2 years, together with the amount of time awarded (e.g. 2 nights, 6 hours), the percentage of this that was useful (e.g. 80), and text describing the current status of any data obtained. Cite publications that were based (to a significant extent) on data obtained at TAP facilities. Mark those allocations related to the present proposal (i.e, precede text with `\related` command). (**up to one page**)*

None of the PI or Co-Is has been allocated TAP times during the past 2 years.

Re: Need approval for Hectospec on MMT

Fabricant, Daniel <dfabricant@cfa.harvard.edu>

周一 2017/3/20 14:39

收件箱

收件人:GAO 高僧莫测 <halflife_gao@hotmail.com>;

Dear Dr. Gao,

You have my approval to use Hectospec for this proposal.

Best,
Daniel Fabricant

On Sun, Mar 19, 2017 at 11:33 PM, GAO 高僧莫测 <halflife_gao@hotmail.com> wrote:

> Dear Prof. Dan Fabricant,
>
> I'm Jian Gao from department of astronomy, Beijing Normal University.
> I am trying to apply MMT/Hectospec observation via Chinese Telescope Access Program.
> I'd be greatly appreciated if you approve us to MMT/Hectospec for observations in the next semester from 1 August 2017 to 31 December 2017.
>
> In 2017B, we want to apply a project " MMT/Hectospec Spectral Observations for the Supernova Remnant Cassiopeia A". We propose to use MMT/Hectospec to perform a low resolution (R=2500) spectroscopic observations for the red giants candidates in or near the supernova remnant Cassiopeia A. We will target about 260 samples, which are divided into two groups: "bright" (13<r<16) and "faint" (16<r<19). The "bright" group will be observe in grey night with exposure of 15min*2, the "faint" group will be observed in dark night with 30min*3. Thus we request 0.5 night for this program in total.
>
> With the moderate resolution and wide coverage spectra from MMT/Hectospec, the stellar parameters of our samples will be estimated. Since the wavelength dependence of interstellar extinction - the interstellar extinction law (or curve) - is one of the primary sources of information about the interstellar grain population, we will determine the extinction curves towards Cas A using real red giants as tracers, and fit the extinction curves towards Cas A with dust models to probe dust properties. The results will allow us to estimate the interstellar dust mass contributed by the supernova both from the extinction law and the spectral energy distribution.
>
> Looking forward to your reply and thank you in advance. Any comment about the telescope configuration and exposure time is very welcome.
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> Thank you very much!
>
> Best regards,
>
> Jian Gao
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