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Massachusetts Institute of Technology

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NuSTAR results and future plans for magnetar and rotation-powered pulsar observations

Hongjun An[1], Victoria M. Kaspi[1,⋆], Robert Archibald[1], Matteo Bachetti[2,3], Varun Bhalerao[4,5], Eric C. Bellm[4], Andrei M. Beloborodov[6], Steven E. Boggs[7], Deepto Chakrabarty[8], Finn E. Christensen[9], William W. Craig[7,10], François Dufour[1], Karl Forster[4], Eric V. Gotthelf[6], Brian W. Grefenstette[4], Charles J. Hailey[6], Fiona A. Harrison[4], Romain Hascoët[6], Takao Kitaguchi[11], Chryssa Kouveliotou[12], Kristin K. Madsen[4], Kaya Mori[6], Michael J. Pivovaroff[10], Vikram R. Rana[4], Daniel Stern[13], Shriharsh Tendulkar[4], John A. Tomsick[7], Julia K. Vogel[10], William W. Zhang[14], and the NuSTAR Team

[1]Department of Physics, McGill University, Montreal, Quebec, H3A 2T8, Canada
[2]Université de Toulouse, UPS-OMP, IRAP, Toulouse, France
[3]CNRS, Institut de Recherche en Astrophysique et Planétologie, 9 Av. colonel Roche, BP 44346, F-31028 Toulouse Cedex 4, France
[4]Cahill Center for Astronomy and Astrophysics, California Institute of Technology, Pasadena, CA 91125, USA
[5]Inter-University Center for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune 411007, India
[6]Columbia Astrophysics Laboratory, Columbia University, New York NY 10027, USA
[7]Space Sciences Laboratory, University of California, Berkeley, CA 94720, USA
[8]Kavli Institute for Astrophysics and Space Research, Massachusetts Institute of Techolology, Cambridge, MA 02139, USA
[9]DTU Space, National Space Institute, Technical University of Denmark, Elektrovej 327, DK-2800 Lyngby, Denmark
[10]Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
[11]RIKEN, 2-1 Hirosawa, Wako, Saitama, 351-0198, Japan
[12]Space Science Office, ZP12, NASA Marshall Space Flight Center, Huntsville, AL 35812, USA
[13]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA
[14]Goddard Space Flight Center, Greenbelt, MD 20771, USA

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The *Nuclear Spectroscopic Telescope Array (NuSTAR)* is the first focusing hard X-ray mission in orbit and operates in the 3–79 keV range. *NuSTAR*'s sensitivity is roughly two orders of magnitude better than previous missions in this energy band thanks to its superb angular resolution. Since its launch in 2012 June, *NuSTAR* has performed excellently and observed many interesting sources including four magnetars, two rotation-powered pulsars and the cataclysmic variable AE Aquarii. *NuSTAR* also discovered 3.76-s pulsations from the transient source SGR J1745−29 recently found by *Swift* very close to the Galactic Center, clearly identifying the source as a transient magnetar. For magnetar 1E 1841−045, we show that the spectrum is well fit by an absorbed blackbody plus broken power-law model with a hard power-law photon index of ∼1.3. This is consistent with previous results by *INTEGRAL* and *RXTE*. We also find an interesting double-peaked pulse profile in the 25–35 keV band. For AE Aquarii, we show that the spectrum can be described by a multi-temperature thermal model or a thermal plus non-thermal model; a multi-temperature thermal model without a non-thermal component cannot be ruled out. Furthermore, we do not see a spiky pulse profile in the hard X-ray band, as previously reported based on *Suzaku* observations. For other magnetars and rotation-powered pulsars observed with *NuSTAR*, data analysis results will be soon available.

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1 Introduction

A neutron star is the left-over dense and hot stellar core of a massive star which survived after the energetic explosion of a star. Neutron stars typically have strong surface magnetic fields (10^9–10^{15} G) inferred from their spin properties. They are typically identified with pulsations in the radio, X-ray, or gamma-ray band which are caused by the rapid rotation of the star. There are many subclasses in the neutron star population such as rotation-powered pulsars (RPPs), rotating radio transients (RRATs), high-B RPPs, X-ray dim isolated neutron stars (XDINS), central compact

⋆ Lorne Trottier Chair; Canada Research Chair

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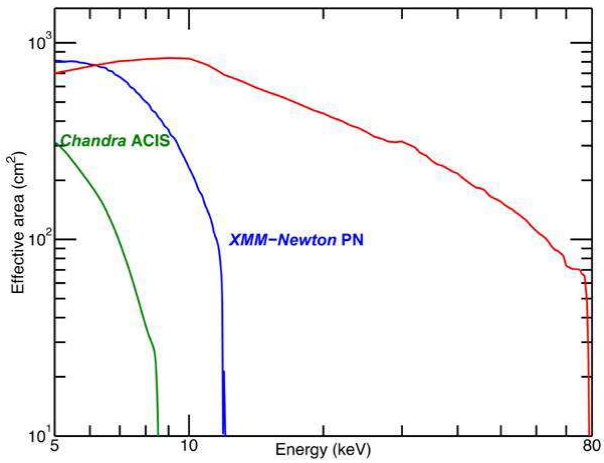

Fig. 1 Effective area of *NuSTAR* (red) together with that of *XMM-Newton*/PN (blue) and *Chandra*/ACIS (green).

objects (CCOs), and magnetars (see Kaspi 2010 for a review).

Radiation properties of neutron stars are diverse. For example, RPPs are mostly observed in the radio band, but sometimes in the X-ray to gamma-ray band as well. Magnetars typically emit thermal photons (modified in the magnetosphere) in the soft X-ray band, but several show a striking turnover and rising power-law emission (in the νF_ν representation) in the hard X-ray band. X-ray properties of X-ray emitting neutron stars have been studied with the soft X-ray observatories which operate in the $\sim$0.3–10 keV band (e.g., *XMM-Newton* and *Chandra*). However, the hard X-ray emission ($\gtrsim$10 keV) has not been very well studied because until recently hard X-ray observatories could only detect a small handful of very bright sources.

While soft-band spectra have been well measured, they are strongly affected by the hydrogen absorption, and the current results based on the soft-band observations may be inaccurate. In particular, constraining a non-thermal spectral component is difficult because it can extend down to low energy and covaries with the hydrogen column density ($N_{\rm H}$). Therefore, hard-band observations ($\gtrsim$10 keV) which are almost free from the absorption can help us accurately determine the non-thermal spectrum.

2 The Nuclear Spectroscopic Telescope Array (NuSTAR)

NuSTAR is the first focusing hard X-ray telescope in orbit, operating in the 3–79 keV band. It is composed of two hard X-ray optics and two focal plane modules (Harrison et al. 2013). The optics have an effective area of 900 cm^2 (Fig. 1), and the angular resolution in half power diameter (HPD) is 58″ at $\sim$10 keV, which makes *NuSTAR* the most sensitive observatory in the $\sim$8–79 keV band. The timing resolution of the detectors is 2 μs, but the accuracy is a little worse due to the clock drift (3 ms absolute, 100 μs relative), and the spectral resolution is 0.4 keV FWHM at 10 keV. *NuSTAR* can access 80% of sky at any time, and its Target-of-Opportunity (ToO) response is 6–8 hours typically. See Table 1 for more details.

Table 1 Performance parameters of *NuSTAR*.

Property	Performance	Comments
FoV	10′	50% response at 10 keV
Angular resolution	58″	HPD
	18″	FWHM
Timing accuracy	100 μs	Relative
	3 ms	Absolute
Spectral resolution	0.4 keV	FWHM @ 10 keV
ToO response	$\lesssim$24 hours	

NuSTAR was launched into a 600 km near-circular orbit at 6° inclination on 2012 June 13, and started its science observations two months after the launch. Extensive in-orbit calibration was performed, and its on-orbit performance is similar to what was estimated on the ground. The first public release of *NuSTAR* data, together with calibration files and pipeline tools, is scheduled for late Summer 2013.

The primary science goals of *NuSTAR* are to locate massive black holes in the Universe, to understand supernovae explosion mechanisms, to study the most powerful cosmic accelerators, and to survey the center of our Galaxy. In addition to these, *NuSTAR* has many other interesting science goals and constructed science working groups according to these goals.[1]

In this paper, we focus on magnetars and RPPs which were or will be studied by the magnetars and RPP working group of the *NuSTAR* team. The target list includes five magnetars, two RPPs, and a unique white dwarf binary. In Section 3, we present an overview of the target list and the observations. We then show the data analysis results for the objects already observed in Section 4. Finally, we summarize and discuss future plan in Section 5.

3 Magnetars and Neutron Stars with *NuSTAR*

NuSTAR is planning on observing magnetars and rotation-powered pulsars for a total of $\sim$ 1.2 Ms with an emphasis on magnetars. Table 2 shows the priority A targets.

The main goal of magnetar observations is to understand the hard X-ray emission. Some magnetars are clearly detected in the hard X-ray band ($\gtrsim$ 10 keV) while others are not (Kuiper et al. 2006). It is not clear if all magnetars emit hard X-rays but some of them may have not been detected due to the sensitivity limitations of previous hard X-ray observatories. Alternatively, it is possible that the hard X-ray detected sources are somehow unusual. Furthermore, the hard X-ray emission mechanism is not yet clearly understood. There

[1] see http://www.nustar.caltech.edu/for-astronomers/science-working-groups

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Table 2 *NuSTAR* target list for the magnetar and RPP working group.

Source	Exposure (ks)	Type	Obs. date
AE Aquarii	126	White Dwarf	2012 Sep.
Geminga	50	RPP	2012 Sep.
1E 1841−045	45	Magnetar	2012 Nov.
SGR J1745−29	150 (ToO)	Magnetar	2013 Apr.
1E 2259+586	170	Magnetar	2013 Apr.
PSR J1023+0038	100	RPP	2013 June
1E 1048−5937	400	Magnetar	2013 July
4U 0142+61	100	Magnetar	T.B.D

are several different models that discuss the origin of hard emission from magnetars (Heyl & Hernquist 2005; Baring & Harding 2007; Beloborodov & Thompson 2007). Recently, Beloborodov (2013) proposed a detailed model which attributes the hard X-rays to the relativistic outflow near the neutron star.

NuSTAR is well suited for studying magnetars in the hard X-ray band. Two magnetars 1E 2259+586 and 1E 1048−5937 in Table 2 have not yet been clearly detected in the hard band above ∼15 keV. *NuSTAR* was able to detect them for the first time and characterize their spectral properties. The list also includes hard X-ray bright magnetars 1E 1841−045 and 4U 0142+61 which have been relatively well studied with *RXTE* and *INTEGRAL* (Kuiper et al. 2006). With the *NuSTAR* observations, we are aiming to study the hard-band spectral properties using the physical model of Beloborodov (2013).

We will also study transient cooling of magnetars using a ToO program. Magnetars sometimes show dramatic increases of persistent emission. After such events, the flux relaxes to its quiescent level on time scales of days to months. It has been suggested that such relaxation is caused by the passive cooling of the hot crust (Lyubarsky, Eichler & Thompson 2002), or by untwisting of the external fields (Beloborodov & Thompson 2007; Beloborodov 2009). Such an event occurred near the Galactic Center in 2013 April (Degenaar et al. 2013). *NuSTAR* discovered 3.76-s pulsations as well as a spinning-down of the source and hence identified the source as a magnetar (Mori et al. 2013). *NuSTAR* is monitoring the new magnetar SGR J1745−29 in the Galactic Center to determine its spectral and temporal properties, and to study their evolution (Kaspi et al. 2014).

We are also studying two RPPs, Geminga and PSR J1023+0038. Geminga is a gamma-ray bright pulsar whose spectrum has been well measured from the IR to TeV band. The soft X-ray ($\lesssim$10 keV) spectrum was well measured with *XMM-Newton*. However, the soft X-ray spectrum does not seem to connect to the optical or to the GeV spectrum, implying there must be a spectral break (Kargaltsev et al. 2005). We are searching for a spectral break in the 3–79 keV band using *NuSTAR*. PSR J1023+0038 is a transient object between a Low Mass X-ray Binary (LMXB) and a RPP (Archibald et al. 2009). This object will give us a unique opportunity to understand the hard X-ray emission mechanism from LMXBs and its relationship to RPP emission (Burderi et al. 2003).

Finally, we are also planning to observe a unique white dwarf system. AE Aquarii is an Intermediate Polar (IP) which was shown to emit non-thermal X-rays and a peculiar pulsation in *Suzaku* observations (Terada et al. 2008). Based on such observed features, it was suggested that AE Aquarii may accelerate particles in its magnetosphere as RPPs do. However, the hard-band detection made with *Suzaku* was marginal, and a much better detection is required to clearly tell if the source really acts like a RPP.

4 Data Analysis Results and Current Status

As of 2013 August, *NuSTAR* observed all the priority A targets of the magnetar and RPP working group except for 4U 0142+61 (Table 2) and intensive data analyses are ongoing. In this section, we show the current analysis results and status for the observed sources.

4.1 SGR J1745−29

SGR J1745−29 is a recently discovered magnetar in the direction towards the Galactic Center. Following a magnetar-like burst detected with *Swift* (Degenaar et al. 2013), *NuSTAR* observed the source. Mori et al. (2013) discovered the 3.76-s pulsation, and measured the spectral and temporal properties of the source to identify the source. The spin-down rate was measured to be $(6.5 \pm 1.4) \times 10^{-12}$ s s^{-1}, implying a spin-inferred magnetic field $B = 1.6 \times 10^{14}$ G. The *NuSTAR*- and *Swift*-measured spectrum was well fit to an absorbed blackbody plus power-law model having $kT \sim 1$ keV, $\Gamma \sim 1.5$, and 2–79 keV luminosity of 3.5×10^{35} erg s^{-1} for an assumed distance of 8 kpc. With the measured spectral and temporal properties, the source was clearly identified as a transient magnetar.

Since the discovery, we have been monitoring the source using a ToO program to measure its spectral/temporal properties and their evolution, and to study the transient cooling (Kaspi et al. 2014). The source has been cooling very slowly, and as of today, the flux is still much higher than the quiescent value inferred from a non-detection in the *Chandra* survey (Muno et al. 2009).

4.2 1E 1841−045

1E 1841−045 was one of the brightest magnetars in the hard X-ray band reported by Kuiper et al. (2006). The hard X-ray bright magnetars typically show a turnover at ∼10 keV, which can be very well studied with *NuSTAR* because it is most sensitive at that energy. By accurately measuring the spectrum near the turnover, we can test the hard X-ray emission model of Beloborodov (2013).

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The previous measurements of the hard-band photon index made with *Suzaku* (Morii et al. 2010) and *RXTE*/*INTEGRAL* (Kuiper et al. 2006) agree only marginally in the hard band. Using our *NuSTAR* data, we find that the spectrum is consistent with the results of Kuiper et al. (2006), but not with those of Morii et al. (2010). This may be due to the imperfect Kes 73 background subtraction in the *Suzaku* data. We also found that the pulse profile in the 24–35 keV band shows an interesting double-peaked shape unlike in the other energy bands. Such deviation in a narrow energy range may suggest a possible absorption or emission feature in the spectrum although with the present data set we cannot clearly identify a statistically significant feature. Finally, we used the Beloborodov (2013) model to fit the hard-band spectrum and show that the model successfully describes the observed spectrum, and can be used to constrain the emission geometry; the angle between the rotation and magnetic axes of the neutron star is inferred to be $\sim 20^\circ$, and the angle between the rotation axis and line-of-sight is inferred to be $\sim 50^\circ$ (An et al. 2013b).

4.3 1E 2259+586

1E 2259+586 is one of the brightest known magnetars[2] (Olausen & Kaspi 2013) in the soft band ($\lesssim$10 keV) despite the fact that its magnetic-field strength is relatively low ($B = 5.9 \times 10^{13}$ G). However, in the hard band it was detected only marginally with *RXTE* (Kuiper et al. 2006). With the marginal detection, Kuiper et al. (2006) measured the hard-band photon index for the pulsed emission to be -1.02 ± 0.19, extremely hard. If so, we should be able to clearly detect the source with *NuSTAR* to first verify the previous results for the pulsed emission and to measure the total spectrum in the hard band for the first time. With a clear detection, the source will be useful for testing the hard X-ray emission model of Beloborodov (2013).

The source was observed with *NuSTAR* in 2013 Apr–May for an exposure of 110 ks. We detected the source above the background level up to $\sim$25 keV, and used an absorbed blackbody plus broken power-law model to fit the spectrum. Interestingly, the hard-band spectrum for the total emission ($\Gamma \sim 1$) is not as hard as the pulsed one. Further analysis is on-going to measure other source properties including the pulsed spectrum (Vogel et al. 2014).

4.4 Geminga

Geminga is one of the brightest RPPs in the gamma-ray band. In the soft X-ray band, it is faint and shows a blackbody plus power-law spectrum. This source can serve as an archetype for many other X-ray faint/gamma-ray bright RPPs (see Kaspi, Roberts, & Harding 2006, for a review). The power-law spectral component is not very well constrained, and does not seem to connect to the gamma-ray band, suggesting a possible spectral break between the hard X-ray and gamma-ray band (Kargaltsev et al. 2005). With *NuSTAR*, we can measure the hard X-ray spectrum very well, and constrain the non-thermal spectral component. Furthermore, we will be able to detect the spectral break if it is in the *NuSTAR* band.

The source was observed in 2012 Sep with *NuSTAR* for $\sim$50 ks. Archival *XMM-Newton* and *Chandra* data were combined with the *NuSTAR* data for the spectral analysis. From the spectral analysis, we find that the non-thermal X-ray spectrum seems to extend up to the *Fermi* band, implying no spectral break in the hard X-ray band. However, combining the soft-band data together was not trivial for an unabsorbed source like this; cross-calibration issues in the soft-band seem to be severe. As the soft-band spectra affect the hard-band results in the analysis, we are currently conducting careful sensitivity studies (Mori et al. 2014).

4.5 AE Aquarii

AE Aquarii is a very interesting IP which was suggested to accelerate particles in its magnetosphere as RPPs do based on a *Suzaku* detection of a non-thermal spectral component and a spiky pulsation in the hard band (Terada et al. 2008). However, the hard-band detection was marginal and required confirmation.

The source was observed by *NuSTAR* in 2012 Sep, and was clearly detected up to $\gtrsim$20 keV. We find that the spectrum of the source can be described with a multi-temperature thermal model or a thermal plus non-thermal model; we cannot clearly rule out the thermal model in the hard X-ray band ($\gtrsim$10 keV). Furthermore, we find no evidence of the spiky structure in the hard-band pulse profile seen in the *Suzaku* observation (Terada et al. 2008). Therefore, we conclude that AE Aquarii is more likely an accretion-powered IP than a pulsar-like accelerator (Kitaguchi et al. 2014). However, we find that the highest temperature of the thermal model is significantly lower than those of other IPs; conventional accretion shock emission models seem not to work for this source. Therefore, a new model will be applied to interpret the spectrum we measured (Kitaguchi et al. 2014).

4.6 PSR J1023+0038 and 1E 1048−5937

PSR J1023+0038 is a millisecond radio pulsar in an LMXB which has shown a hard power-law tail ($\Gamma \sim 1.3$) in the previous *XMM-Newton* and *Chandra* observations (Archibald et al. 2010; Bogdanov et al. 2011). It can serve as a template for understanding non-thermal emission from quiescent LMXBs which are suggested to have unseen millisecond radio pulsars.

If the non-thermal spectrum measured in the soft band extends to the *NuSTAR* band, we will accurately measure

[2] See the online magnetar catalog for a compilation of known magnetar properties, http://www.physics.mcgill.ca/∼pulsar/magnetar/main.html

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the spectrum with *NuSTAR* and compare it with those of other similar quiescent LMXB systems. We observed the source with *NuSTAR* in 2013 June for 100 ks, and detected the orbital modulation up to $\sim$50 keV with *NuSTAR*, and are presently conducting detailed spectral/temporal analyses (Tendulkar et al. 2014).

1E 1048−5937 is a magnetar with spin-inferred magnetic-field strength of $\sim 4\times10^{14}$ G. However, hard-band emission from the magnetar 1E 1048−5937 has not yet been clearly detected. Our goal for observing this source is to first detect the hard-band emission, and test the putative correlation between the degree of spectral turnover ($\Gamma_{\rm s} - \Gamma_{\rm h}$) and the spin-inferred B reported by Kaspi & Boydstun (2010). The correlation suggests that *NuSTAR* should be able to clearly detect the source in the hard band with a $\sim$400-ks exposure.

We detected the hard-band emission up to $\gtrsim$20 keV with *NuSTAR*. More interestingly, there were several bursts detected during the observations. We are currently analyzing the data to study the bursts and the persistent properties of the source (An et al. 2014; Archibald et al. 2014).

5 Conclusions

Since its launch in 2012 June, *NuSTAR* has performed excellently. As a part of *NuSTAR*'s science program, we have observed carefully selected magnetars, RPPs and a white dwarf. Many interesting results are ready to be published for some sources, and detailed data analyses are on-going for others.

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References

An, H., et al.: 2014, in preparation
An, H., Hascoët, R., Kaspi, V. M., et al.: 2013, ApJ, 779, 163
Archibald, A. M., Stairs, I. H., Ransom, S. M., et al. 2009, Sci 324, 1411
Archibald, A. M., Kaspi, V. M., Bogdanov, S., Hessels, J. W. T., Stairs, I. H., Ransom, S. M., McLaughlin, M. A.: 2010, ApJ 722, 88
Archibald, R. F., et al.: 2014, in preparation
Baring, M. G., Harding, A. K.: 2007, Ap&SS 308, 109
Beloborodov A. M.: 2009, ApJ 703, 1044
Beloborodov A. M.: 2013, ApJ 762, 13
Beloborodov A. M., Thompson, C.: 2007, ApJ 657, 967
Bogdanov, S., Archibald, A. M., Hessels, J. W. T., Kaspi, V. M., Lorimer, D., McLaughlin, M. A., Ransom, S. M., Stairs, I. H.: 2011, ApJ 742, 97
Burderi, L., Di Salvo, T., D'Antona, F., Robba, N. R., Testa, V. 2003, A&A 404, L43
Degenaar, N., Reynolds, M., Miller, J., Kennea, J., Wijnands, R.: 2013, ATel, 5006
Harrison, F. A., Craig, W. W., Christensen, F. E., et al.: 2013, ApJ 770, 103
Heyl, J., Hernquist, L.: 2005, ApJ 618, 463
Kaspi, V. M.: 2010, PNAS 107, 7147
Kaspi, V. M., et al.: 2014, submitted
Kaspi, V. M, Boydstun, K.: 2010, ApJ 710, L115
Kaspi, V. M, Roberts, M. S. E., Harding, A. K.: 2006, in Compact Stellar X-Ray Sources, ed. W. H. G. Lewin & M. van der Klis (Cambridge: CambridgeUniv. Press) 279
Kargaltsev, O. Y., Pavlov, G. G., Zavlin, V. E., Romani, R. W.: 2005, ApJ 625, 307
Kitaguchi, T., An, H., Beloborodov, A. M., et al.: 2014, 782, 3
Kuiper, L., Hermsen, W., den Hartog, P. R., Collmar, W.: 2006, ApJ 645, 556
Lyubarsky, Y., Eichler, D., Thompson, C.: 2002, ApJ 580, 69L
Mori, K., et al.: 2014, in preparation
Mori, K., Gotthelf, E. V., Zhang, S., et al.: 2013, ApJ 770, L23
Morii, M., Kitamoto, S., Shibazaki, N., et al.: 2010, PASJ 62, 1249
Muno, M. P., Bauer, F. E., Baganoff, F. K., et al.: 2009, ApJS 181, 110
Olausen, S., Kaspi, V. M.: 2013, submitted, (arXiv:1309.4167)
Tendulkar, S., et al.: 2014, submitted
Terada, Y., Hayashi, T., Ishida, M., et al.: 2008, PASJ 60, 387
Vogel, J. K., et al.: 2014, in preparation

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