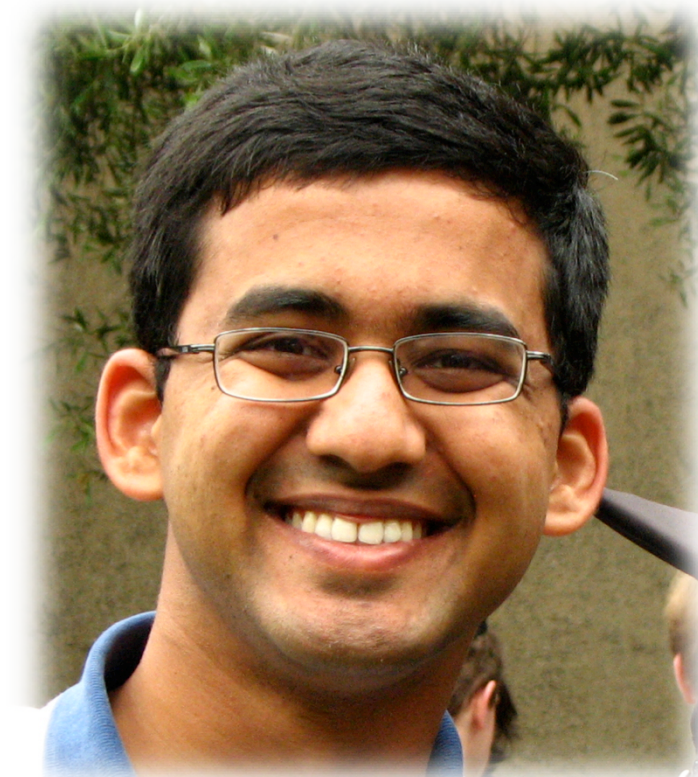




Near IR Astrometry of Magnetars

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Abstract

Over the past five years we have undertaken LGS AO observations of magnetars with the NIRC2 camera on the 10-meter Keck telescope. We have measured the proper motion of two of the youngest magnetars, SGR 1806–20 and SGR 1900+14, which have counterparts with $K \sim 21$ mag. The precision of the proper motion measurement is a few milliarcseconds per year. Our proper motion measurements now provide evidence to link these magnetars with young star clusters. At the distances of these magnetars, their proper motion corresponds to transverse space velocities of $350 \pm 100 \text{ km s}^{-1}$ and $130 \pm 30 \text{ km s}^{-1}$ respectively. We also present preliminary upper limits on the proper motion of the young AXP 1E 1841–045.

Introduction

Magnetars or highly magnetized neutron stars were proposed by Thompson & Duncan 1996 as a unified model to explain the phenomena of soft gamma repeaters (SGRs) and anomalous X-ray pulsars (AXPs). Identifying NIR counterparts for magnetars and comparing their NIR emission to X-ray emission allows us to constrain their emission mechanisms. The measurement of their proper motions allows us to identify their birth sites and estimate kinematic ages.

Using the laser guide star adaptive optics system on the NIRC2 camera, we observed the targets over multiple epochs from 2005 till 2009. After flat-fielding and dark subtracting the images, we corrected for the instrumental distortion of NIRC2 by a polynomial transformation. To reduce systematic errors caused due to residual distortion, we registered each target field at the same position on the detector in each epoch.

We calculated the proper motion of each star with respect to a grid of neighboring stars using the optimal weighting scheme developed in Cameron et al (2009). In this scheme, we chose optimal weights of each star-target vector by accounting for position jitter correlations (tip-tilt anisoplanatism). The relative astrometry was corrected for the bulk motion of the field by modeling the Galactic rotation curve.

SGR 1806–20

- The NIR counterpart of SGR 1806–20 (Star A in Figure 1) was identified by Israel et al (2005) and Kosugi et al (2005).
- We observe factor of three variability (Figure 2) in the NIR brightness of star A which strengthens the identification of the counterpart of SGR 1806–20.

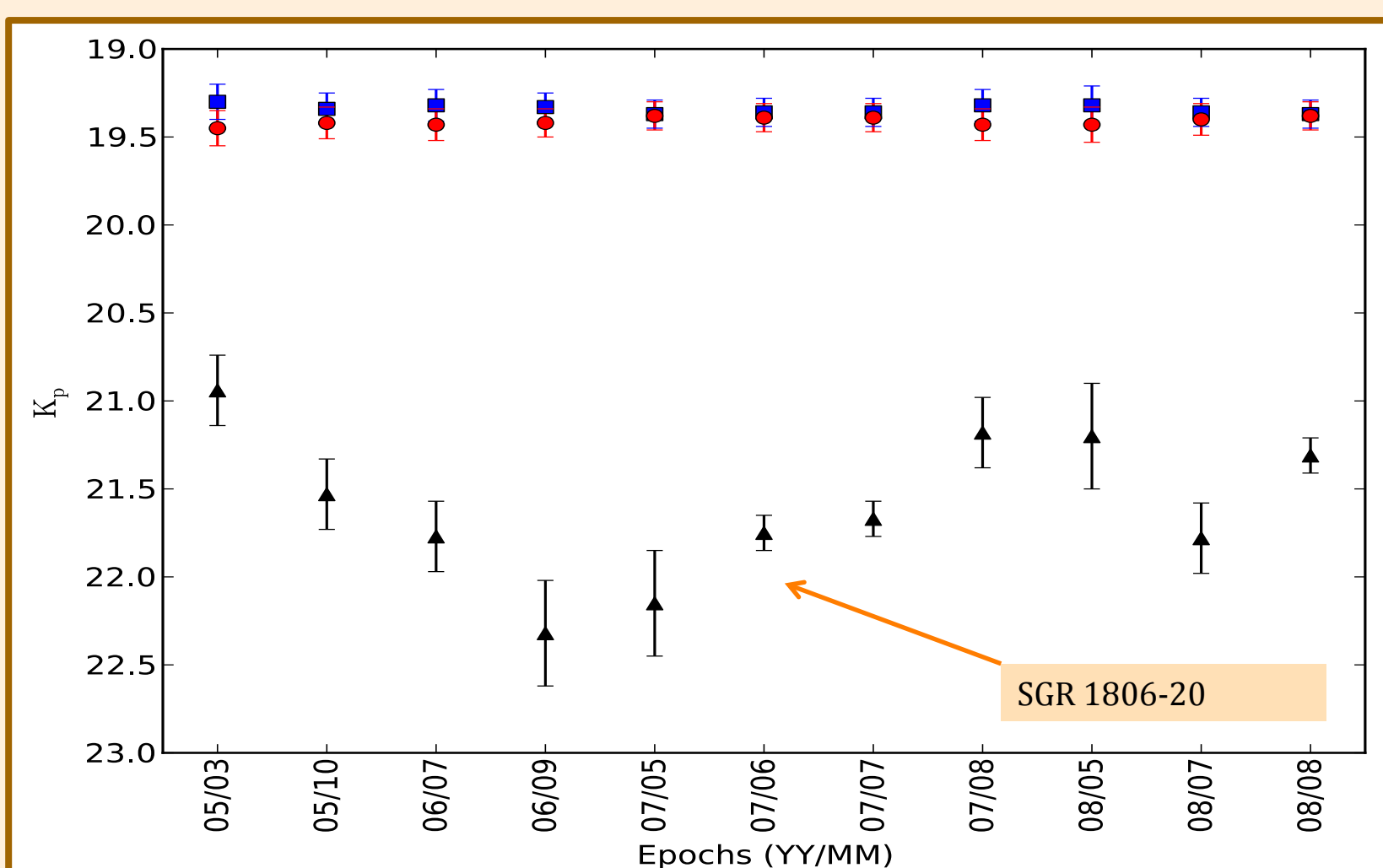


Figure 2: K_p magnitudes of stars around SGR 1806–20 measured over period of 3 years. Compared to star B (red) and star C (blue), SGR 1806–20 (black triangles) shows a clear variation over a factor of three in the brightness.

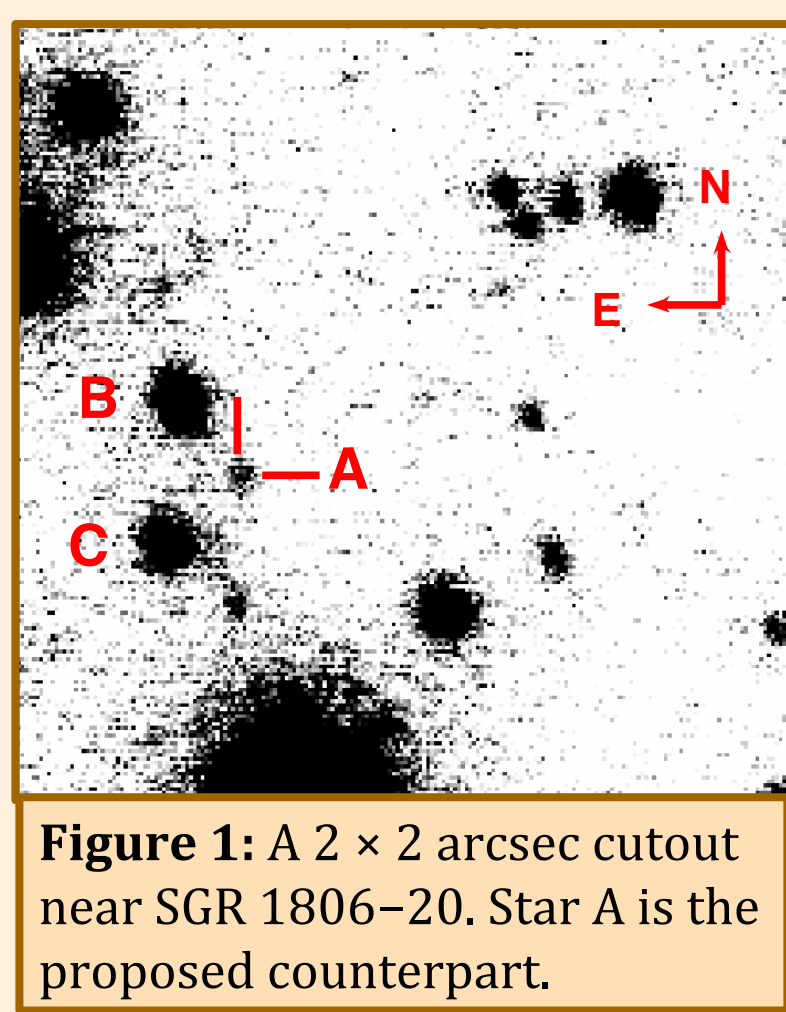


Figure 1: A 2×2 arcsec cutout near SGR 1806–20. Star A is the proposed counterpart.

Motion of SGR 1806–20

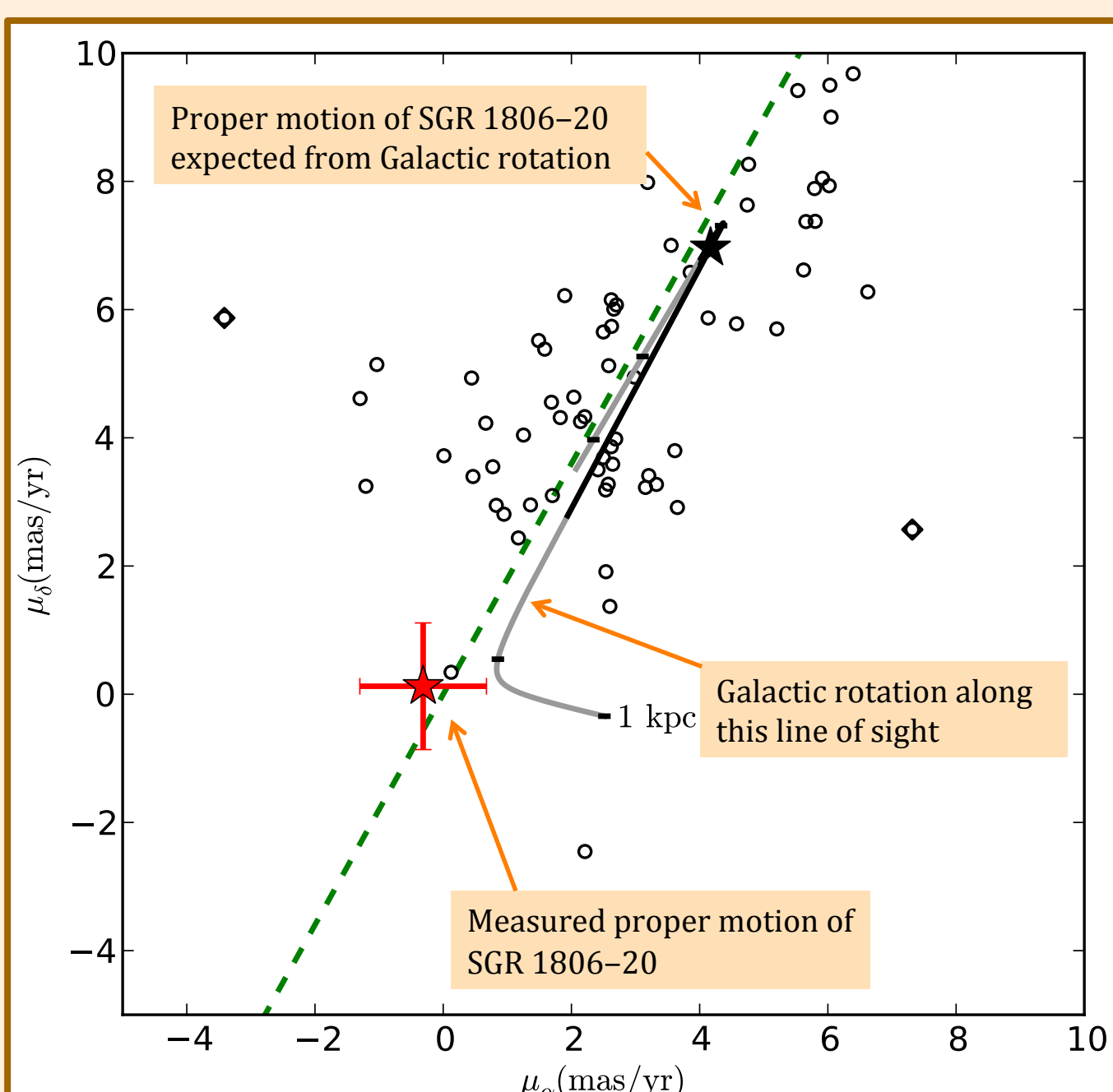


Figure 3: Proper motions of 71 stars (hollow circles) in the field of SGR 1806–20 after adding the bulk motion of the field, $(3.0, 4.8) \text{ mas yr}^{-1}$.

- PM away from putative progenitor: $(\mu_\alpha, \mu_\delta) = (-4.5 \pm 1, -6.9 \pm 2) \text{ mas yr}^{-1}$
- Space velocity: $350 \pm 100 \text{ km s}^{-1}$ (@ $9 \pm 2 \text{ kpc}$)
- Proper motion vector is pointed away from the cluster of massive stars (identified by Fuchs 1999)
- The SGR position traced back by 650 ± 300 years coincides with the cluster
- The trace-back time is larger than characteristic age ($\sim 190 \text{ yr}$) by a factor of about three

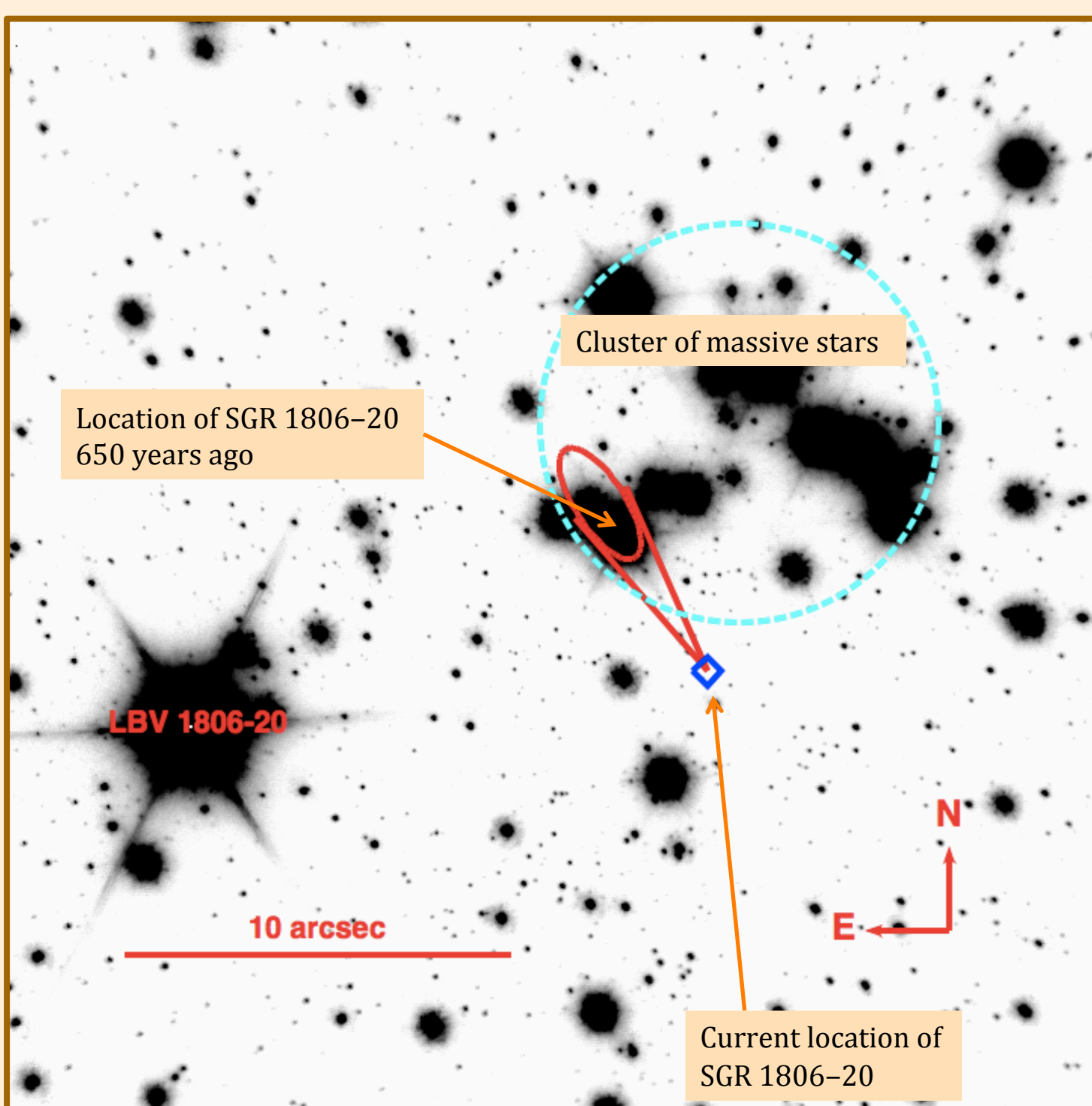


Figure 4: The position of SGR1806–20 (blue diamond) traced back by 650 yr is marked by the red ellipse. The size of the ellipse corresponds to the uncertainty in the proper motion measurement. The dashed cyan circle denotes the cluster of massive stars corresponding to the mid-IR source of Fuchs et al. (1999). The position of the luminous blue variable LBV 1806–20 is marked.

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SGR 1900+14

- NIR counterpart (Star 7 in Figure 5) was proposed by Testa et al (2008) based on 0.47 mag flux change.
- We did not observe NIR variability between 2005 and 2010. There was only one X-ray flaring episode in March – May 2006, but we have no observations in that period.
- $H - K_p$ color vs K_p magnitude diagram (Figure 6) is not distinctive.

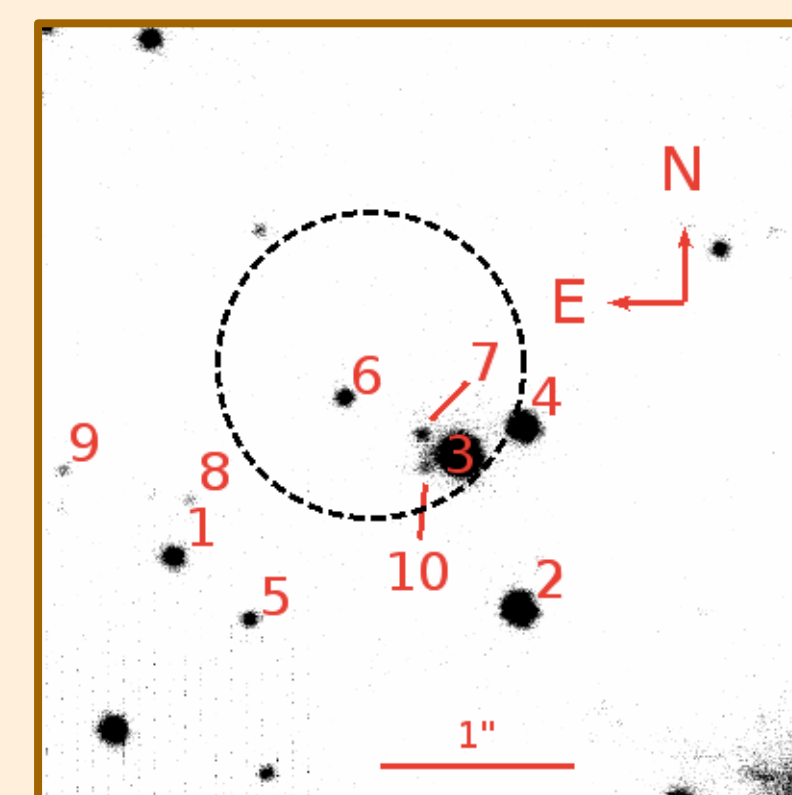


Figure 5: A 4×4 arcsec cutout near SGR 1900+14. Star 7 is the proposed counterpart.

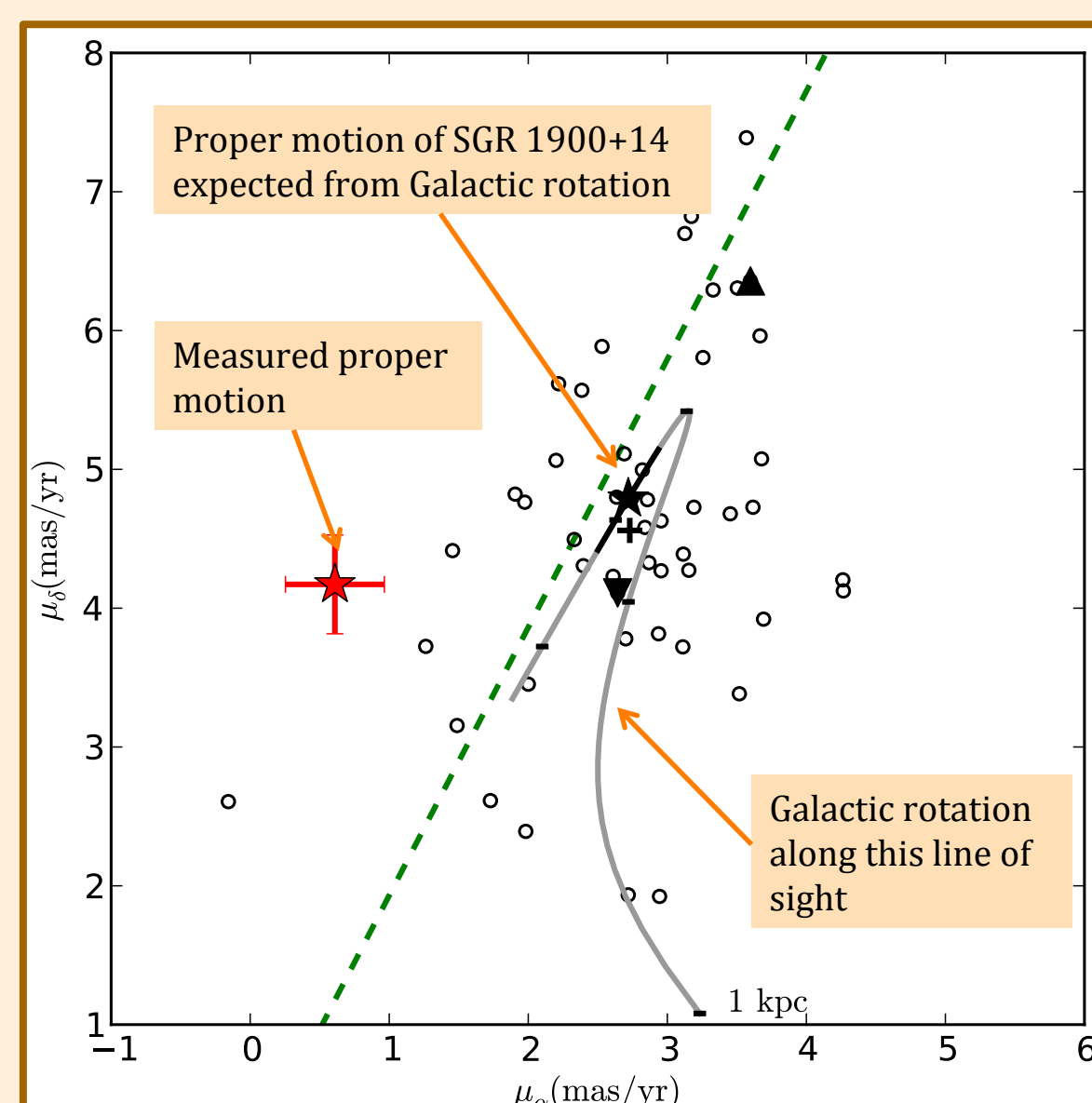


Figure 7: The proper motion of 50 stars in the SGR 1900+14 field after correcting for bulk motion of the field, $(2.7, 4.6) \text{ mas yr}^{-1}$.

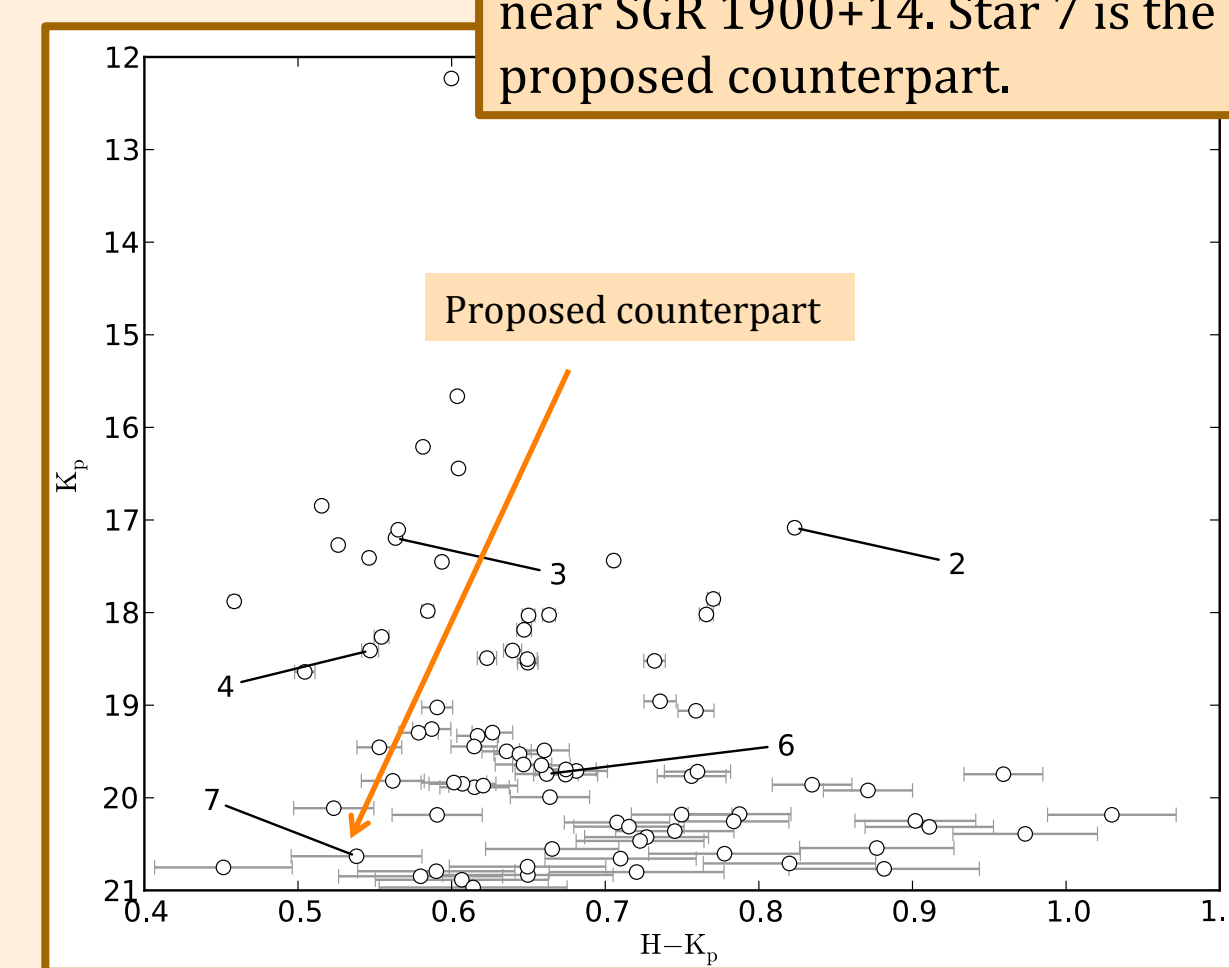


Figure 6: $H - K_p$ color vs K_p magnitude diagram for 50 stars in the SGR1900+14 field. Stars 2–7 (except 5) are marked.

Motion of SGR 1900+14

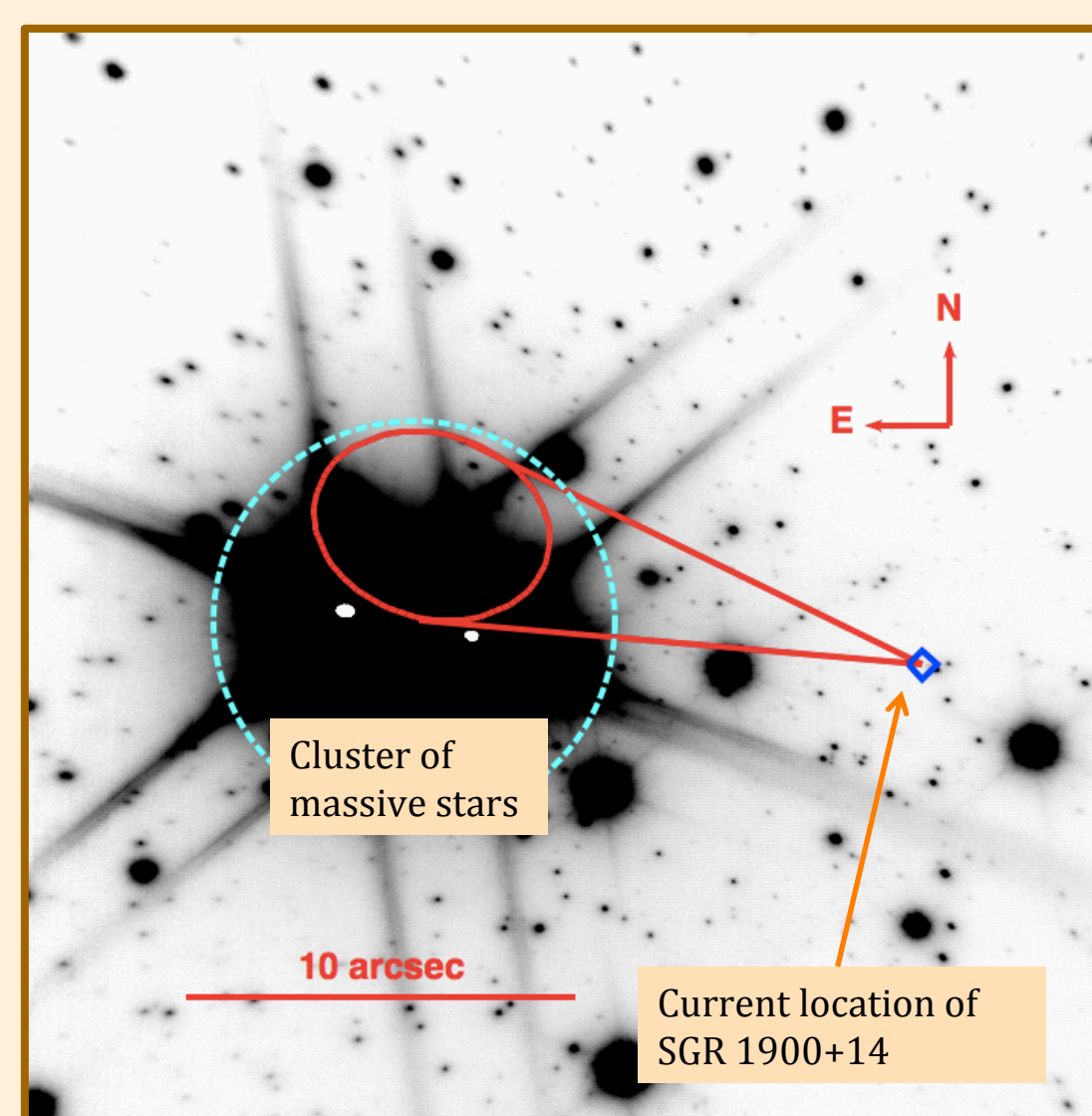


Figure 8: The position of SGR 1900+14 (blue diamond) traced back by 6 kyr is marked by the red ellipse. The size of the ellipse corresponds to the uncertainty in the proper motion measurement. The cyan circle denotes the cluster of massive stars.

- PM away from putative progenitor: $(\mu_\alpha, \mu_\delta) = (-2.1 \pm 0.4, 0.6 \pm 0.5) \text{ mas yr}^{-1}$
- Space velocity: $130 \pm 30 \text{ km s}^{-1}$ (@ $12.5 \pm 1.7 \text{ kpc}$)
- Proper motion vector is pointed away from the cluster of massive stars (identified by Vrba 2000)
- The SGR position traced back by $6 \pm 1.8 \text{ kyr}$ coincides with the cluster
- The trace-back time is larger than characteristic age ($\sim 900 \text{ yr}$) by a factor of about six!

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AXP 1E 1841–45

- No NIR counterpart identified. Star 9 (in Figure 9) was proposed by Testa et al (2008) but is outside the 99% confidence circle.

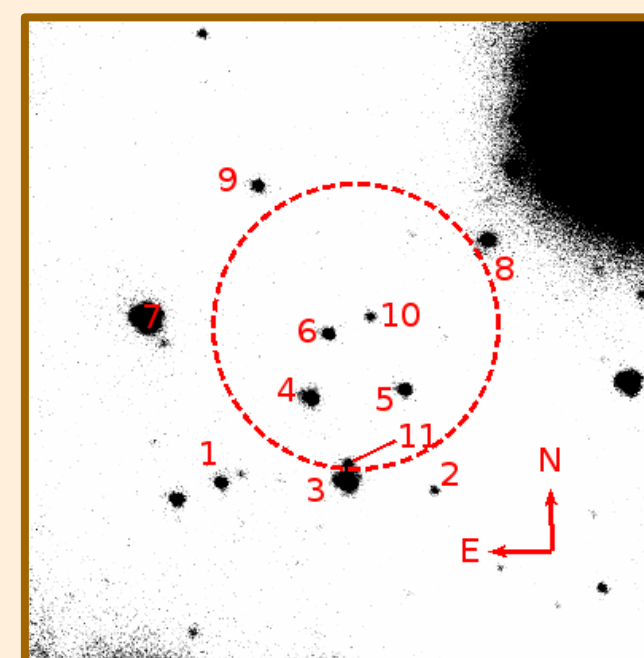


Figure 9: The *Chandra* position of 1E 1841–045 has many NIR sources. The red circle is the 99% confidence position (with a $0.9''$ radius). The image is 4×4 arcsec wide.

- Preliminary photometry shows no variability from 2005 – 2009
- Upper limit of proper motion is $\sim 4 \text{ mas yr}^{-1}$
- Corresponds to 160 km s^{-1} (@ 8.5 kpc)

Preliminary Results

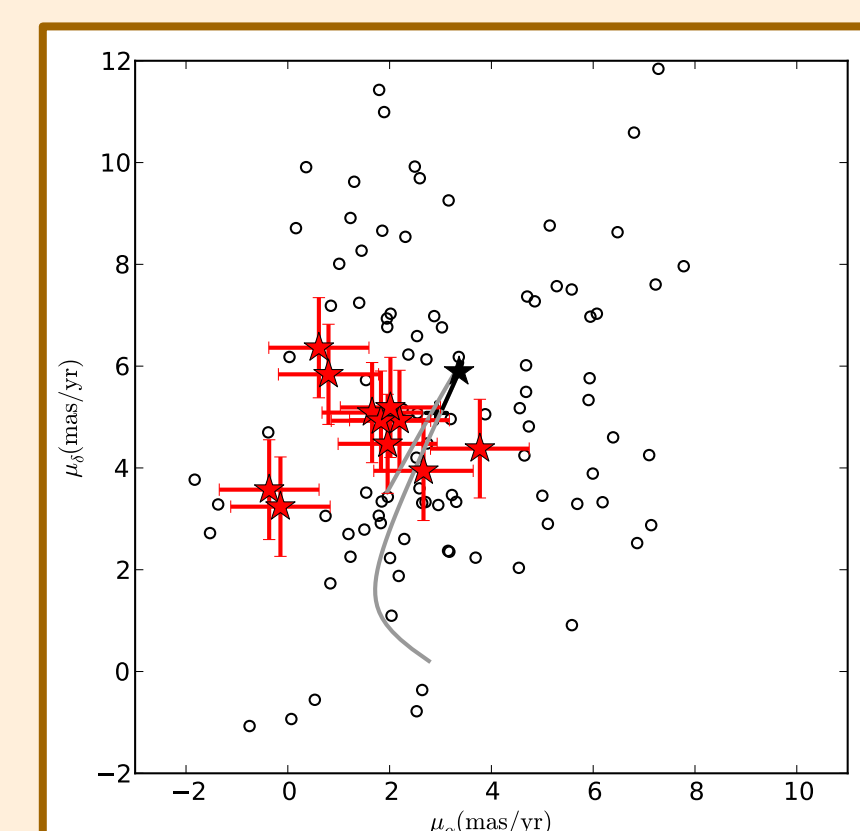


Figure 10: The maximum proper motion compared to putative birthsite (black star) is $\sim 4 \text{ mas yr}^{-1}$. Stars 1–11 are marked in red.

Conclusions

- The space velocities of magnetars are similar to the $\sim 200 - 300 \text{ km s}^{-1}$ velocities of pulsars. This is consistent with the results of Helfand (2007) and Deller (2012).
- There is strong evidence for associating SGR 1806–20 and SGR 1900+14 with neighboring clusters.
- The trace-back time to the clusters is few times greater than the characteristic time of these magnetars.
- This may indicate a low braking index, but period derivative (and hence characteristic time) can vary by factor of 3 – 4.