Direct Imaging Exoplanet Searching of the Nearby Solar-type Star ϵ Eridani

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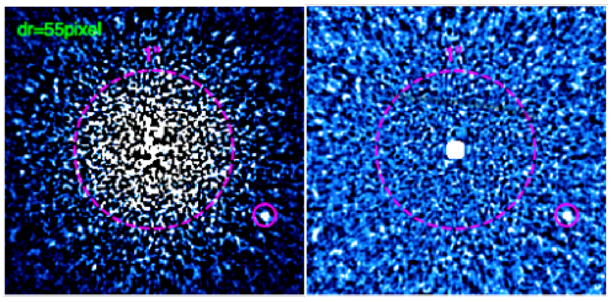
Abstract

ϵ Eridani is one of the nearest stars to the Sun. Previous observation for H-band and CH_4R12-band direct imaging with Subaru HiCIAO+AO188 in SDI mode which have been analyze with LOCI subtraction algorithm by Fuji et al. (2012) found a suspicious feature. The S/N ratio was ˜ 2-3 and it has been done with several statistical methods to reject the possible feature from the image. However it is not so strong enough to reject or to accept the possible result. The most recent direct imaging data was obtained for H-band with Subaru HiCIAO+AO188 in ADI mode. We analyzed it with LOCI pipeline. The current observation is deeper than Fuji et al. (2012) but still there is no such possible feature in the final frame nor the S/N map. We calculated the detection limit with assumption of age is 1 Gyr (Baines Armstrong 2012). The limit for positive detection is about 5 M_J.The possible feature that detected by Fujii et al. (2012) at 5.4 AU possibly was a noise signal because if it is not it should have been detected with current observation. According to the COND model (Baraffe et al. 2003) for 1 Gyr exoplanet with the expected mass by Baines & Armstrong (2012) observation in L-band will be the best option to detect such companion.

1 Introduction

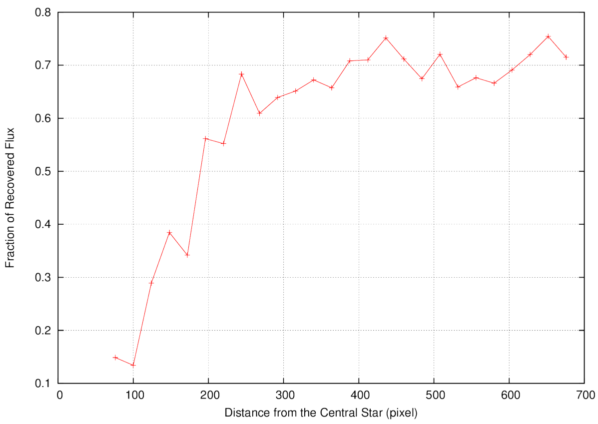
ϵ Eridani is one of the closest Sun-like stars (K2V, 3.22 pc). It has been known with a strong IR excess (Aumann et al. 1984) which lead to the discovery of the debris disk around it by Greaves et al. (1998). From indirect method it has been reported for the existence of its giant planet companion (Hatzes et al. 2000; Deller Madison 2005). Recent observations were with Hubble Space Telescope Fine Guidance Sensor observation and ground-based astrometry and radial velocity data, Bennedict et al. (2006) calculated the exoplanet mass was 1.55 $\pm$ 0.24 M_J. Baines et al. (2012) conducted an observation with Navy Optical Interferometer to confirm the fundamental properties of the host star ϵ Eridani and resulting consistent exoplanet mass 1.53 $\pm$ 0.22 M_J which orbiting the host star with semi major axis 3.39 $\pm$ 0.36 AU. Several direct imaging observations have been conducted (Macintosh et al. 2003; Marengo et al. 2006; Janson et al. 2007; Heinze et al. 2008; Morengo et al, 2009) but none of them detected imaging confirmation of its existence. Only H-band and CH_4R12-band direct imaging with Subaru Telescope and HiCIAO+AO188 in 2 channel SDI+ADI mode and LOCI subtraction algorithm (Lafreniere et al. 2007) performed by Fujii et al. (2012) detected such a possible feature located 1."7 (5.4 AU) from the host star with S/N ratio ˜2-3 (see figure 1). Such a possible feature has been tried to be rejected with several statistical methods but it always exists at the same location at mostly every possible final image. In order to confirm what Fujii et al. (2012) had found, Strategic Exploration of Exoplanets and Disk with Subaru (SEEDS) survey (Tamura 2009) team conducted the same observation but with only H-band filter in ADI mode in order to go deeper than the previous one.



1: left: final image, right: S/N Map. Fuji et al. (2013, Master Thesis) changed the radial size of the differential area in the LOCI subtraction from 25 pix to 70 pix, and this is the case in which the feature appears most conspicuous (dr= 55 pix)

2 Methods/Instruments and Observations

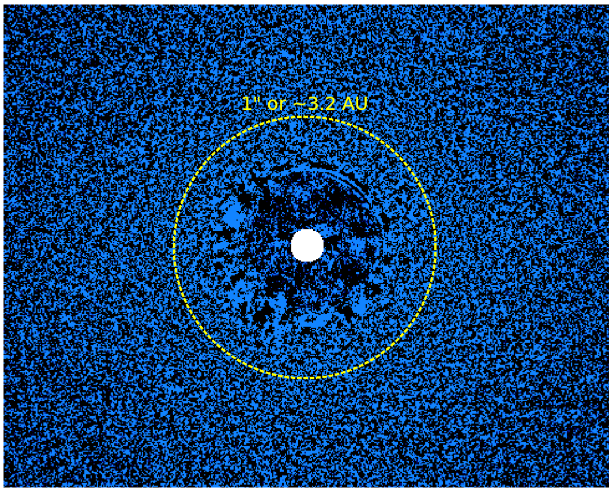
Direct imaging observation was obtained in H-band using Subaru Telescope with HiCIAO+AO188 in ADI mode on November 24, 2013. The central star, ϵ Eridani, was used as Natural Guide Star (NGS). 450 x 4.2 s science frames (with occulting mask 0.4") and 8 x 1.5 s frames (without occulting mask but neutral density filter (ND) 0.1, the transmission is 0.00063) were obtained. The science frames then reduced with LOCI subtraction algorithm (Lafreniere et al. 2007) and the same dr value with Fujii et al. (2012) work that is 55 pixel. Only 428 frames were reduced until the final because other frames were suffered from AO bad performance. Because LOCI subtraction algorithm basically reduces the flux of the speckle around the central star so it could also reduce the flux from any point source, an exoplanet for example. Then we injected artificial companion and performed LOCI from the beginning to measure the flux degradation. The result can be seen in figure 2. We also made S/N map in order to see whether there is suspicious feature or not. Frames without occulting mask were also reduced and used as photo-metric calibration.



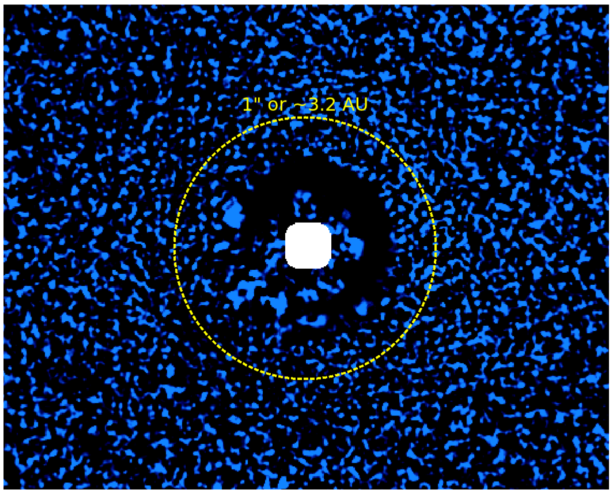
2: Distribution of the recovered flux after LOCI was performed in a function of distance from the central star. It was used to scaled the r.m.s to calculate the detection limit

3 Results

Figure 3 and 4 show that we do not detect any suspicious feature around the ϵ Eridani as indicated



3: Final reduced image by LOCI pipeline

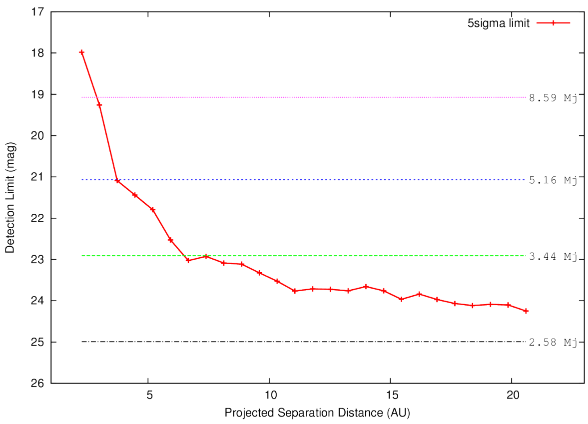


4: S/N map of the final reduced image

by Fujii et al. (2012). However we calculate the limiting magnitude that can be detected by this observation. We make circular annuli centered at the central star with width is 2FWHM and the radius is growing by 6FWHM. We measure the rms by doing aperture photometry inside the width of each annuli with isotropic distribution respect to the central star.

4 Discussion and Conclusion

Figure 5 show the 5 detection limit for our observation. The figure also show the expected magnitude of 2.58 M_J, 3.44 M_J, 5.16 M_J, and 8.59 M_J for 1



5: Detection Limit in H-band as a function of projected separation distance in AU

Gyr age. The detection limit is deeper than Fujii et al. (2012) detection limit by 2 magnitude. Near the central star (<5 AU), the observation was not deep enough to detect any companion with mass <5 MJ. Referred to Baines & Armstrong (2012) and Benedict et al. (2007) with distance about 3 AU and ˜1.5 MJ it is certainly resulting non detection with current performance in H-band given the signal from the companion is much weaker than the speckled pattern near the central star. If we referred to the age that had been estimated by Baines Armstrong (2012), which is 1 Gyr, the possible feature that detected by Fujii et al. (2012) at 5.4 AU possibly was a noise signal because if it is not it should have been detected with current observation.Given the current result and facility, it is hard to detect any companion with low mass near the host star in H-band observation. In figure 5 based on the COND model (Baraffe et al. 2003) for 1 Gyr age we can expect absolute magnitude of various mass of exoplanet in various photo-metric band passes.And as we see in figure 6 for the spectral energy distribution of HR 8799b that it will be brightest in L band and the host star brightness will decrease so that the contrast is much smaller. With the estimated properties of the companion by Baines Armstrong (2012), the observation in L-band will be the best option to detect such companion.

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