Planet Search Around Seven White Dwarfs in the Hyades Cluster Using Kernel Phase Interferometry

Chelsea Adelman and Stephanie Sallum
University of California, Irvine

Introduction

The majority of the 5500+ confirmed exoplanets orbit stars that will eventually become white dwarfs (WDs). Very few planets have been discovered around WDs, and none have been directly imaged, which leaves gaps in our knowledge of how planetary systems evolve as stars evolve (Fig 1). Constraining the survival rate and characteristics of post main sequence planets will address these open questions and lend insight into the inevitable fate of systems such as our own Solar System.

Direct Imaging Searches for WDs: HST can offer good image quality, but there is still a limit to detecting planets around WDs at solar system scales (≲7AU) due to their small telescope diameters. We can get around these challenges with kernel phase interferometry (KPI), which is a data processing technique that improves the achievable resolution of a telescope by a factor of several. This enables us to extract information lost in standard detection techniques (as depicted in Fig 2). We are currently applying KPI to archival HST data of seven WDs in the Hyades cluster to search for planets that have survived the death of their host star (data from Brandner et al. 2020).

Kernel Phase Interferometry: KPI treats a conventional telescope as an interferometric array. It enables us to achieve angular resolution close-to or within the diffraction limit by eliminating instrumental errors, as long as image quality is high. The procedure for KPI is shown in Figures 3 and 4.

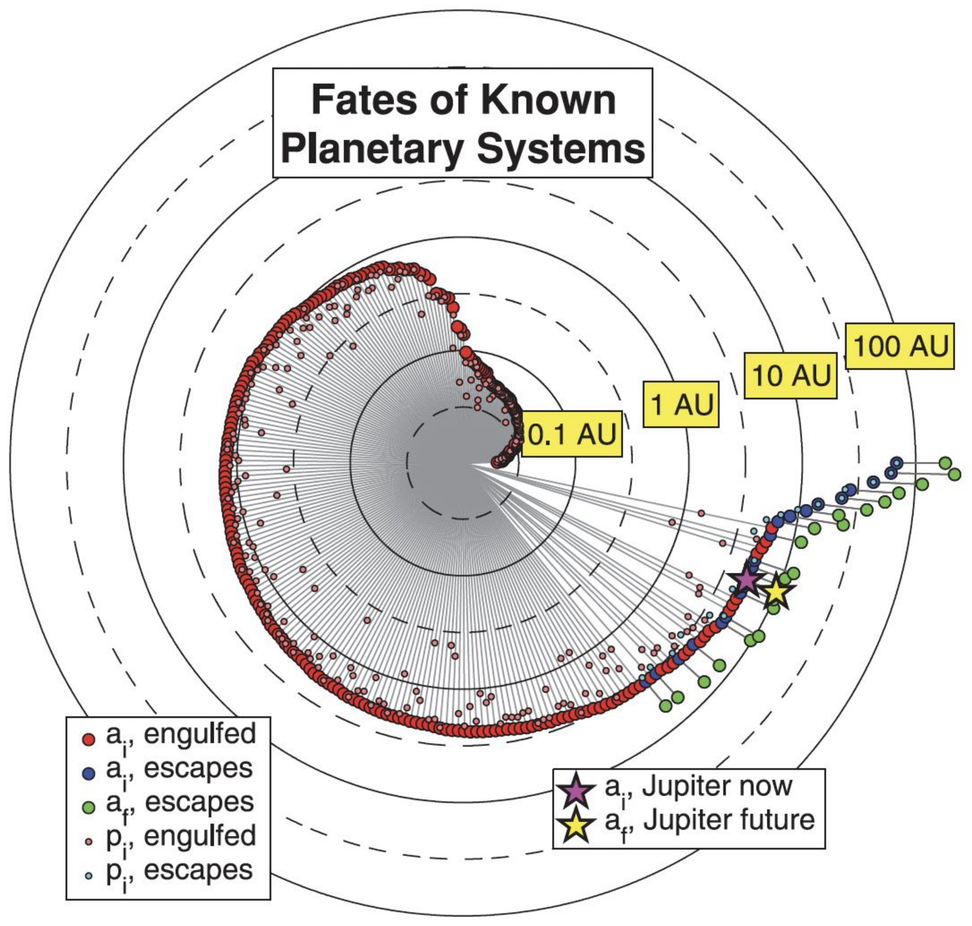

Figure 1 This plot depicts the evolution of 300 giant exoplanets ($M \geq M_J$), assuming two-body interactions with their host star. The star has $M \geq M_\odot$ and is in the center, and the *large* red and blue dots represent the current known semi-major axes of the 300 exoplanets. Red indicates the planet will be engulfed during post main sequence evolution and blue represents planets that escape engulfment. The green dots are the survived planets' new semi-major axes during the host star's WD phase. Similarly, the *small* red and blue dots are the periastron positions of the engulfed and escaped planets, respectively. Jupiter's semi-major axis is plotted as a magenta star for its current location and a yellow star for its final location (adapted from Nordhaus and Spiegel 2013).

Kernel Phase Interferometry

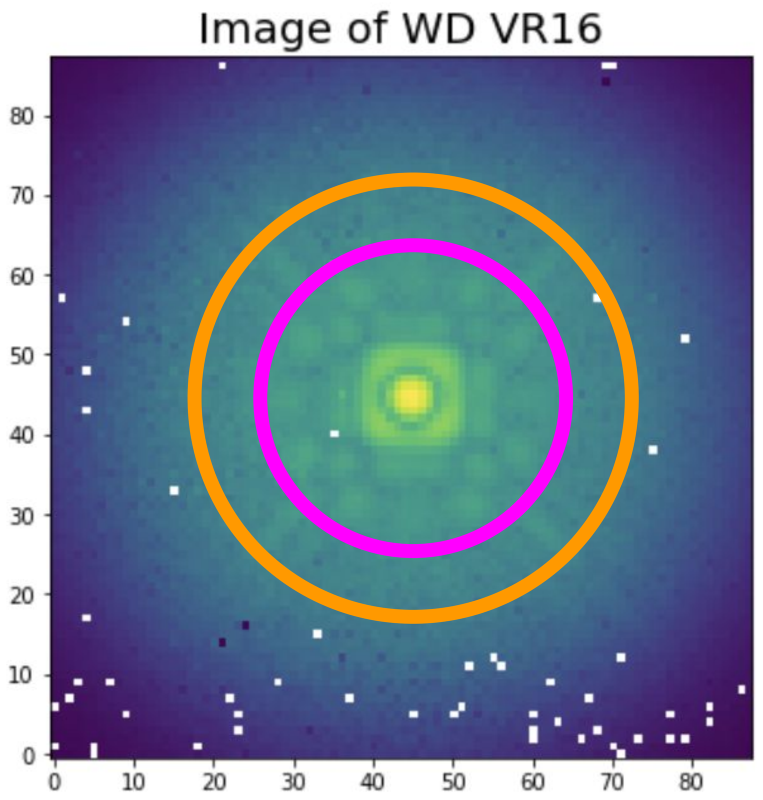

Figure 2 Kernel phase provides an angular resolution boost of a factor of several, resolving tighter orbital separations than traditional processing techniques. This image shows one WD observed with HST, VR16, with circles illustrating achievable angular resolution using a conventional telescope without KPI (orange) and with KPI (magenta). KPI can recover planet signals that are lost in standard detection techniques.

Create a Pupil

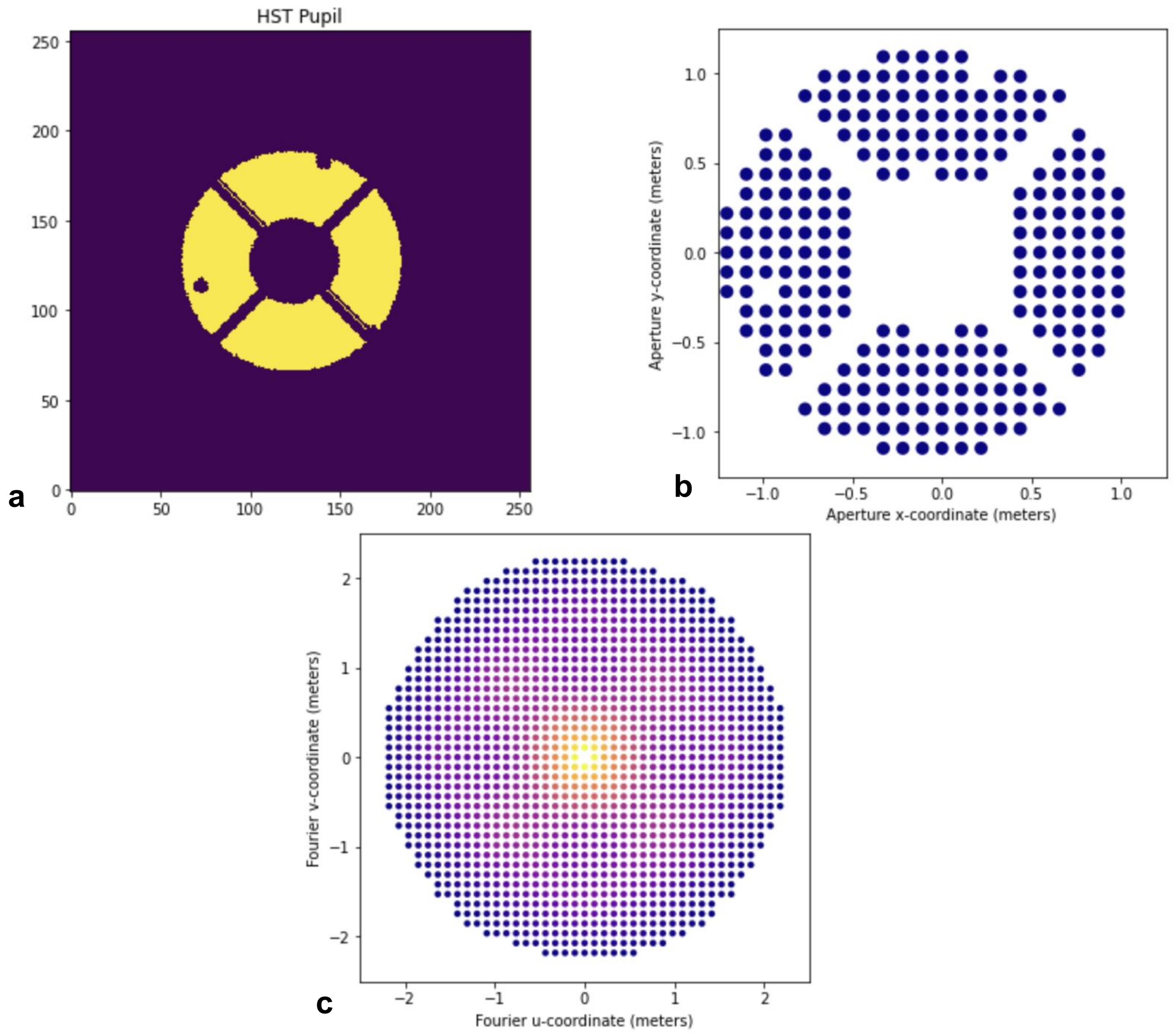

Figure 3 Kernel Phase Model Generation: **(a)** A model image of the HST pupil is created. **(b)** That image is used to create a model interferometric array to represent the HST pupil. Each virtual subaperture in the array forms a baseline with every other subaperture, with a range of regularly-spaced spatial frequencies sampled. **(c)** The Fourier transforms of the images (Fig 4.) are then sampled at those spatial frequencies. Self calibrating Fourier phase observables called kernel phases can then be calculated.

Perform KPI

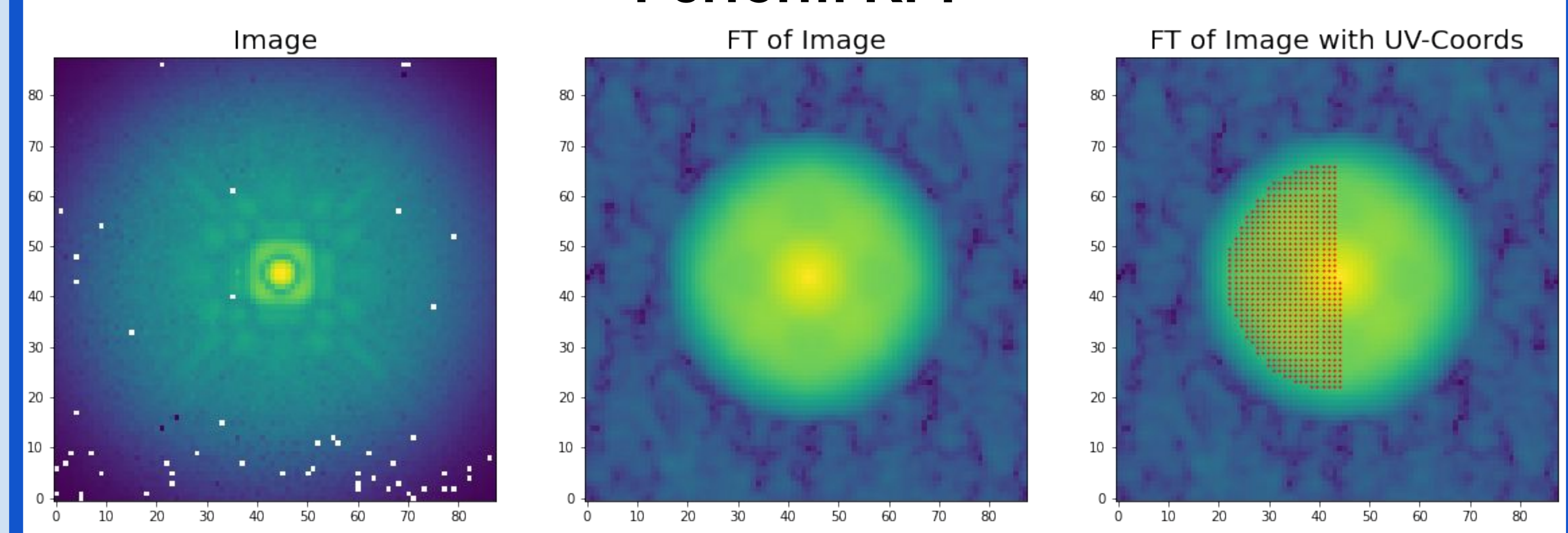

Figure 4 The image of the WD is cropped, bad pixel corrected, and windowed via multiplication with a Gaussian to suppress pixels far from the PSF (left). The Fourier transform is taken of the image (middle) and then it is sampled at uv coordinates (right), where phase and amplitude information are extracted. A specific combination of the Fourier phases, called kernel phases, can eliminate instrumental errors. This results in angular resolution close-to or within the diffraction limit.

Achievable Contrast

With the Hyades cluster ~47pc away, those angular resolution boosts provided by KPI access orbital separations much tighter than what HST standard imaging can provide (Fig 5). As shown in Figure 5, if a planet with a contrast relative to its host star of ~6.5 mag was present, the standard technique of angular differential imaging (ADI) would detect it in the NICMOS data at ~8 AU, but KPI would detect it at ~4 AU.

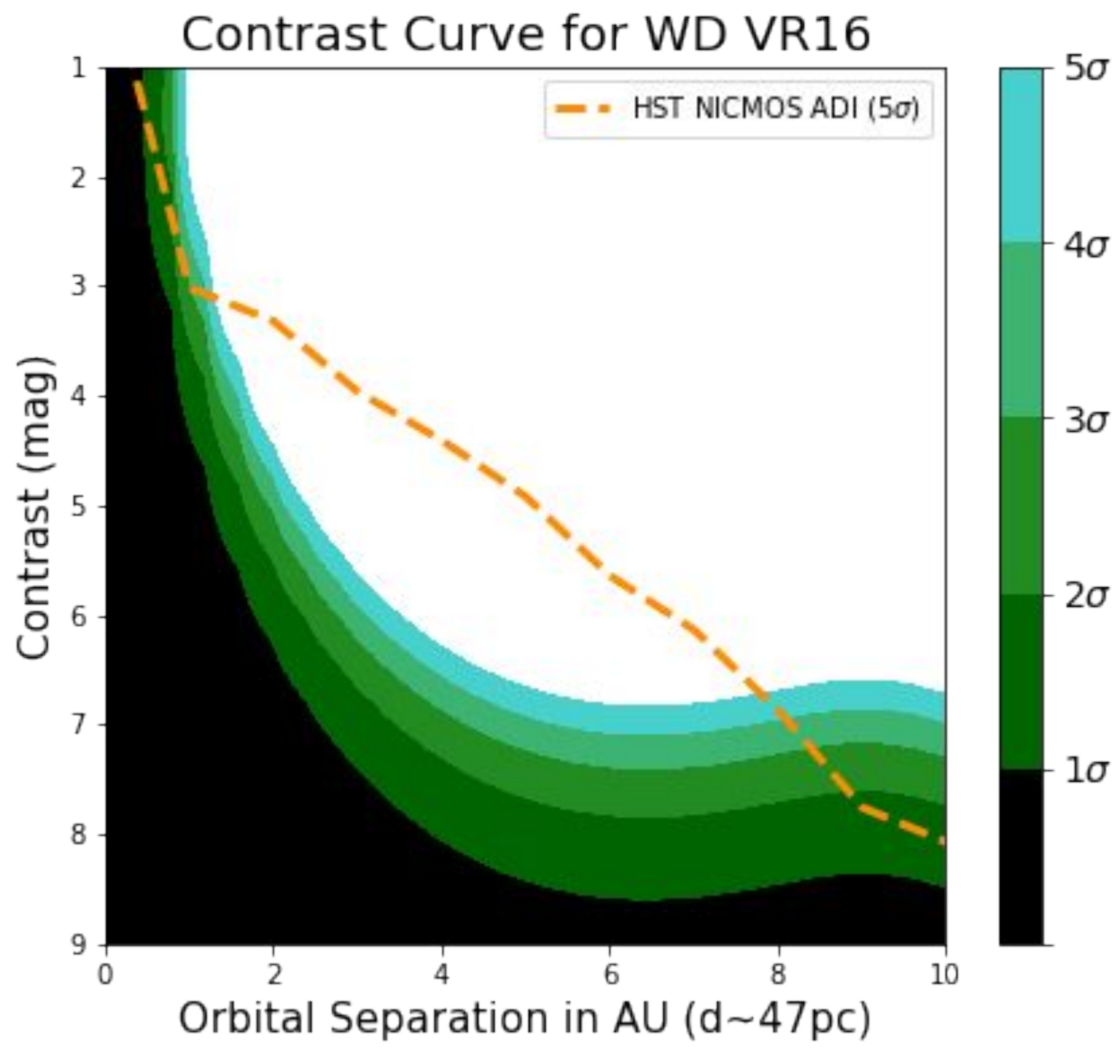

Figure 5 Achievable contrast in magnitudes at orbital separations in AU of WD VR16, 47pc away. KPI (green filled contours) reaches high contrast at tighter orbital separations than standard techniques such as angular differential imaging (ADI; dashed orange line).

Next Steps

We are in the final stages of determining if any planets are present around these seven WDs. Planets radiate in thermal emission, and the contrast sensitivity can be converted to mass sensitivity. We will be converting contrast limits (as seen in Fig 5) into mass limits by using the WD's flux and age and planetary atmosphere models. We expect to reach planets with $M \sim 5\text{-}10 M_J$ for this sample. Applying KPI to this dataset will result in the highest resolution planet search around WDs to date, and it will provide new constraints on post main sequence planetary evolution.

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