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SHINE, THE SPHERE INFRARED SURVEY FOR EXOPLANETS

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Abstract. The SHINE survey for SPHERE High-contrast ImagiNg survey for Exoplanets, is a large near-infrared survey of 400-600 young, nearby stars and represents a significant component of the SPHERE consortium Guaranteed Time Observations consisting in 200 observing nights. The scientific goals are: i) to characterize known planetary systems (architecture, orbit, stability, luminosity, atmosphere); ii) to search for new planetary systems using SPHERE's unprecedented performance; and finally iii) to determine the occurrence and orbital and mass function properties of the wide-orbit, giant planet population as a function of the stellar host mass and age. Combined, the results will increase our understanding of planetary atmospheric physics and the processes of planetary formation and evolution.

Keywords: Imaging and spectroscopy - Planets: physical parameters, atmospheres and formation

1 Introduction

Our understanding of the origin and evolution of extrasolar planets has drastically transformed in the last decade. Current theories favor the formation of planets within a protoplanetary disk by accretion of solids, building up a 3 to 10 $M_\oplus$ core followed by rapid accumulation of gas, or by gravitational instability of the gas (Helled et al. 2014). The planets could either migrate toward or away from the star by disk-planet interactions (Kley & Nelson 2012) or by planet-planet interactions (Dawson & Murray-Clay 2013), which will alter the original semi-major axis distribution. A wide range of potential planet masses, sizes, locations and compositions results from this diverse set of physical processes. A major goal for exoplanetary science of the next decade is a better understanding of these mechanisms. In this context, the role of observations is crucial to provide constraints that will help to understand the diversity of exoplanetary properties. The main observables are the occurrence of exoplanets, including the physical and orbital characteristics (composition, mass, radius, luminosity, distribution of mass, period and eccentricity), as well as the properties of the planet themselves (luminosity, mass, effective temperature, composition...). The main statistical constraints on exoplanets originally came from the radial velocity and transit techniques. More than 3000 exoplanets have been now confirmed, featuring a broad range of physical (mass) and orbital (P, e) characteristics around different stellar hosts (Howard et al. 2010; Mayor et al. 2011; Burke et al. 2015). Despite the success of both techniques, the time spans explored limit the studies to the close ($\leq 5-6$ AU) exoplanets. Within the coming years, direct imaging represents the only viable technique distinct from microlensing for probing the existence of exoplanets and brown dwarf companions at large ($\geq 5-10$ AU) separations. This technique is also unique for the characterization of planetary atmospheres that are not strongly irradiated by the planetary host, as well as for the connection of the exoplanets with their

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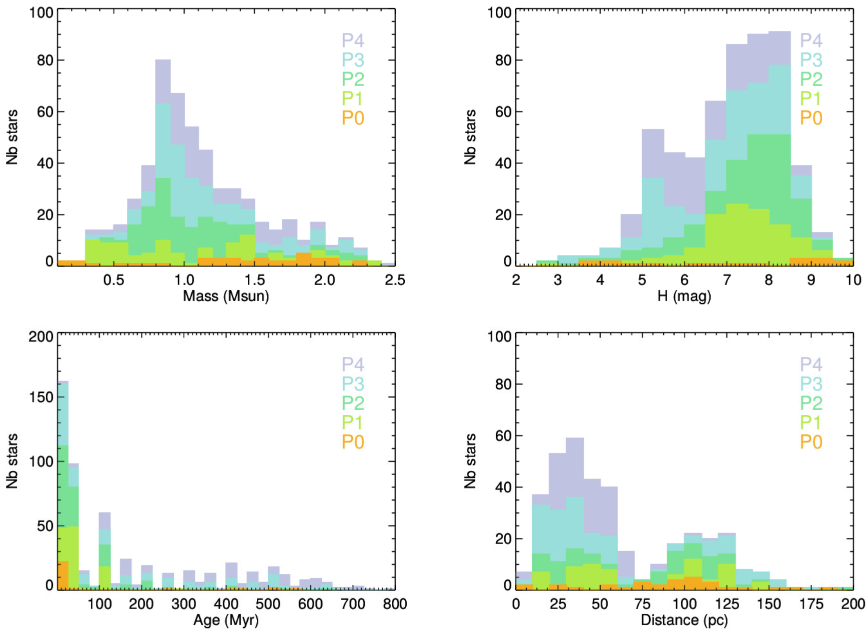

Fig. 1. Histogram of main properties (mass, age, distance and magnitude) of the SHINE target sample. Science priorities are reported with different color codes. P0 targets represent the top priority targets of the SHINE sample.

birth environment. In this context, the SpHere INfraed survey survey for Exoplanets (SHINE) is a major program of the SPHERE consortium Guaranteed Time Observations consisting in 200 observing nights spread over 5 years to conduct the largest near-infrared survey of 400-600 young, nearby stars. The science goals are to characterize known planetary systems (architecture, orbit, stability, luminosity, atmosphere), to search for new planetary ones, ultimately to determine the occurrence and orbital and mass function properties of the wide-orbit, giant planet population as a function of the stellar host mass and age. In Section 2, we describe the approach followed to build the SHINE target sample. In Section 3, are presented the observing strategy and the data reduction. In Section 4, we finally present early-scientific results illustrating the spectrophotometric and astrometric performances achieved.

2 Sample selection

The SHINE target list with flagged priorities has been selected from a target database of more than a thousand young, nearby stars catalogued with their most relevant stellar properties for the selection: coordinates, age, distance, spectral type, kinematics, activity and association membership. The final list was optimized by performing MonteCarlo simulations of planet detectability (Bonavita et al. 2012) for a variety of input planet populations, then ensuring the expectation of several detections and the potential for disentangling between different planet parameter distributions. As prerequesite, we considered stars with R-band magnitude limit set at $R \sim 12$ to ensure a good-XAO correction. Spectroscopic and close visual binaries (stellar companions within SPHERE field of view) are also excluded to have a sample suited for comparison of planet frequency as derived from RV surveys, which also typically excluded multiples. Members of nearby young groups (e.g, β Pic, Tuc-Hor, Columba etc.) represent a major source of targets. A sample of early-type stars from Sco-Cen groups is included, allowing the exploration of planet frequency on young moderately massive stars. Finally, a few individual targets which are outside the statistical sample as defined above were added to the GTO list for their special interest (signature in the disks suggesting the presence of planets, a couple of stars with RV planets potentially detectable with SPHERE if they are actually brown dwarfs companions, etc.). The main target properties (mass, age, distance, magnitude) are shown in Fig. 1.

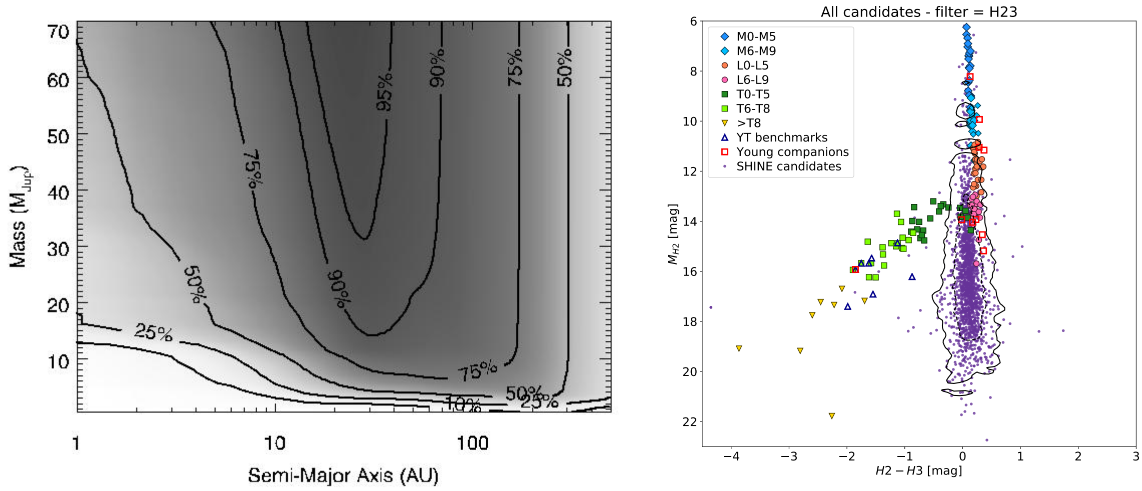

Fig. 2. *Left:* Detection probabilities given in planetary masses as a function of the semi-major axis for the first hundred stars oberved during SHINE. SHINE is sensitive in the planetary mass regime between 10 and 100 au. *Right:* Color-magnitude diagramme in H_2H_3 showing the cloud of SHINE candidates together with the predicted sequence of young late-M, L, T and Y brown dwarfs and giant planets.

3 Observations & Data reduction

The SPHERE planet-finder instrument installed at the VLT (Beuzit et al. 2008) is a highly specialized instrument, dedicated to high-contrast imaging and spectroscopy of young giant exoplanets. It is based on the SAXO extreme adaptive optics system (Fusco et al. 2006; Petit et al. 2014; Sauvage et al. 2010), which controls a 41×41 actuators deformable mirror, and 4 control loops (fast visible tip-tilt, high-orders, near-infrared differential tip-tilt and pupil stabilization). The common path optics employ several stress polished toric mirrors (Hugot et al. 2012) to transport the beam to the coronagraphs and scientific instruments. Several types of coronagraphic devices for stellar diffraction suppression are provided, including apodized pupil Lyot coronagraphs (Soummer 2005) and achromatic four-quadrants phase masks (Boccaletti et al. 2008). The instrument has three science subsystems: the infrared dual-band imager and spectrograph (IRDIS; Dohlen et al. 2008), an integral field spectrograph (IFS; Claudi et al. 2008) and the Zimpol rapid-switching imaging polarimeter (ZIMPOL; Thalmann et al. 2008).

Standard SHINE data are acquired in IRDIFS pupil-tracking mode with the 185 mas diameter apodized-Lyot coronograph (Carbillet et al. 2011; Guerri et al. 2011), using IRDIS in dual-band imaging mode with the H_2H_3 filters ($\lambda_{H_2} = 1.593\pm0.055\,\mu$m; $\lambda_{H_3} = 1.667\pm0.056\,\mu$m), and the IFS integral field spectrograph simultaneously in $Y - J$ ($0.95 - 1.35\,\mu$m, $R_\lambda = 54$) mode. This combination enables the possible use of angular differential and/or spectral imaging technics to improve the contrast perfomances at the sub-arcseconds level.

A uniform data processing of the whole dataset of the SHINE survey is already implemented within the SPHERE Data Centre (DC), hosted by IPAG, with contribution by members of the whole SPHERE Consortium, which have the possibility to remotely work on the data reduction and processing via the DC tools. During each GTO observing run, raw data are retrieved and properly archived at DC. The complete SHINE data reduction and analysis procedures are based on the combination of: i/ the SPHERE Data Reduction and Handling (DRH) automated pipeline Pavlov et al. (2008) to correct each datacube for bad pixels, dark current, flat field, sky background, frame recentering (and cross-talk and wavelength calibration in addition for IFS), and ii/ the use of dedicated post-processing procedures using the Specal pipeline (Galicher et al., in prep) ensuring the proper astrometric and photometric calibration of the reduced datacubes and the angular and spectral differential imaging processing with various algorithms, including TLOCI (Marois et al. 2014) and PCA (Soummer et al. 2012; Amara & Quanz 2012; Mesa et al. 2015), to optimally suppress the stellar right and detect and characterize the planetary signal. The final data products include reduced images of the IRDIS and IFS datacubes, positions, magnitudes and spectra of the detected point sources and circumstellar disks in the field of view, detection limits for faint companions and extended sources around each targets.

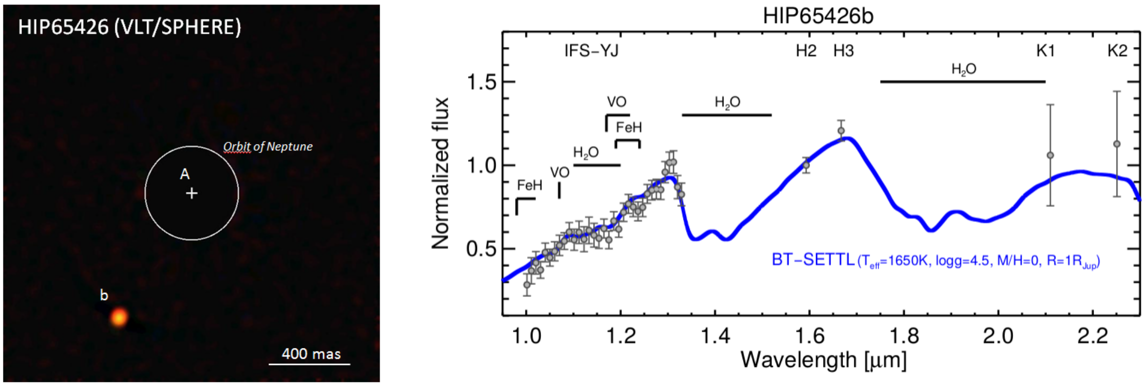

Fig. 3. *Left:* First planet discovery with SPHERE around the young star HIP 65426 (Chauvin et al. 2017). *Right:* SPHERE near-infrared spectrum of HIP 65426 b compared to BT-Settl atmospheric models for $T_{eff} = 1650\,K$, $log(g) = 4.5$ and solar-metallicity.

4 Scientific results

The performance of the instrument in terms of detectability of exoplanets, brown dwarfs and disks at very small separation fully agrees with expectations achieving 5σ detection limits of 15 mag at 300 mas. SHINE is particularly sensitive to giant planets between 10 and 100 au as shown with the survey mean detection probabilities in Fig 2 (*Left*). A specific focus has been dedicated to the characterization of several known systems at the beginning of the survey to highlight the SPHERE detection, astrometric and spectrophotmetric performances and its versatility. Among the systems characterized, we can list: the brown dwarf companions around GJ 758 (Vigan et al. 2016), PZ Tel (Maire et al. 2016), HD206893 (Delorme et al. 2017), GJ 504 (Bonnefoy et al., submitted), the giant planet 51 Eri b (Samland et al. 2017) or the multiple-planet system HR8799 (Zurlo et al. 2016; Bonnefoy et al. 2016) and the young Solar-Analogue HD 95086 (Chauvin et al., submitted). The first discovery of a warm, dusty Jovian planet with SPHERE at VLT in the course of SHINE has been in addition rcently announced (Chauvin et al. 2017) (see Fig. 3). To date, more than 1900 planetary candidates have been detected as illustrated by the color-magnitude diagramme of Fig. 2 (*Right*). Second-epoch observations are required to confirm the physical association of the most promising candidates to their central stars. While focused on detection of giant planets, SHINE program is also contributing significantly to the detection and characterization of circumstellar disks. Several disks were spatially resolved for the first time. They include the new disk discoveries around HD 106906 (Lagrange et al. 2016), RXJ1615.3-3255 (de Boer et al. 2016) or HIP 73145 (Feldt et al. 2017). Since the beginning of the SPHERE GTO operation in February 2015, 25 papers exploiting SHINE data have been accepted for publications in journals (Science, ApJ, MNRAS and A&A). A serie of three papers presenting the early-statistical analysis of the first 200 SHINE targets is foreseen for 2018, before the final analysis that will be carried out at the horizon 2020 when the survey will be completed.

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