European Organisation for Astronomical Research in the Southern Hemisphere

Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

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APPLICATION FOR OBSERVING TIME PERIOD: **80A**

Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of CoIs and the agreement to act according to the ESO policy and regulations, should observing time be granted

1. Title Category: **C–7**

Direct imaging of terrestrial and giant exoplanets

2. Abstract

We propose to perform a direct imaging search in the J-band (1.2 μm) for terrestrial and giant planets around 150 FGK stars within 20 pc from the Sun. Using the 42m-ELT equipped with a high-contrast coronagraph and simultaneous differential imaging we intend to achieve a contrast of 1 x 10^{-10} beyond an angular distance of $8\lambda/D$ (>50 mas) from each parent star. The observations will be conducted to ensure detection (S/N=5) of the reflected light from Earth-like planets in the habitable zone of the parent stars (i.e. at 1 AU orbital distance of the solar-type stars in the sample). This will allow a rather extensive demographic study of terrestrial and giant exoplanets over a wide range of separations leading to a better understanding of the formation mechanism of planetary systems. Second and third epoch observations will be required to determine orbital motion. Follow-up low-resolution spectroscopy (R=100) in the near IR will be pursued for the nearest detected exoplanets.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky Trans.	Obs.Mode
A	80	NACO	1.5n	mar	n	$\leq 0.8''$	THN	v

4.

Number of nights/hours	Telescope(s)	Amount of time
a) already awarded to this project:	NTT	4n in 078.B-1234
b) still required to complete this project:	2.2/NTT	2n/20h

5. Special remarks:

This is a DRM proposal

6. Principal Investigator: R. Rebolo (Inst. Astrofsica de Canarias, E, rrl@iac.es)

CoI(s): I. Name2 (Leiden, NL), I. Name3 (Geneva, CH), I. Name4 (STScI, USA), I. Name5 (ESO, ESO)

7. Is this proposal linked to a PhD thesis preparation? State role of PhD student in this project

Yes / A. Student. Data important for PhD thesis / mid-course

8. Description of the proposed programme

A) Scientific Rationale: The recent discovery that at least 7% of solar-type stars host giant planets at separations of less than 5 AU has opened a new domain for research. High precision radial velocity measurements of stars and microlensing techniques provide increasing evidence that planets with terrestrial mass and radius may also be abundant (see e.g. the recent results by Udry et al. 2007). The diversity of the properties (orbital distances, eccentricities and projected mass distributions) of known giant exoplanets has already challenged traditional theories of planet formation: do these planets form via gravitational instabilities in protoplanetary disks or via accretion of planetesimals? what are the planetary environments around other stars? how typical is our Solar System? are there other Earths? how important is evolution for habitability? Characterisation via direct imaging and low-resolution spectroscopy of exoplanets in various evolutionary stages will be key to answer these questions. Direct detection will make feasible the determination of masses, radii, composition, atmospheres and temperatures both for giant and terrestrial planets at different times of evolution. This will offer unique information to understand how planets form and evolve. Direct detection of Earth-like planets in extra-solar systems may also lead to the search for bio-markers (e.g. water in the near infrared and oxygen bands in the optical far red, ozone in the mid-infrared) via low resolution spectroscopy with a sufficiently large diameter telescope or using interferometry from space.
If the frequency of terrestrial planets around solar-type stars is similar to that of giant planets (i.e. 5-7 %), we would need to survey a minimum of one hundred solar-type stars to have a significant probability of finding an Earth-like planet. We shall note, however, that according to planet formation models the frequency of terrestrial planets may indeed be significantly higher and similarly the detection rate of such a survey. Nearby FGK stars are the primary targets for this search since for a sufficiently large diameter telescope, it may be possible to resolve terrestrial planets at physical distances where liquid water can exist on the surface, in the so-called "habitable zone". The habitable zone of a star like the Sun is approximately 0.9-1.5 AU. The habitable zone around an F star occurs farther out and around K stars occurs farther in (Kasting, 1993).
There are 71 FGK dwarf stars known within 10 pc from the Sun. Out of which 27 are F and G-type and 44 are K-type stars. Up to a distance of 20 pc we may expect 8 times more FGK stars of which a large fraction (40-50 %) are likely binaries. We will consider for our search single stars and wide binaries with angular separations larger than 10 arcsec, so unwanted reflections in the optical system caused by the companion do not limit our sensitivity. Nothing prevents that terrestrial planets form around each component in these relatively wide binaries and we may gain additional insight on the planet formation mechanism including them in the sample. Removing the unwise binaries, the total number of targets is then reduced to some 400 stars out of which one half will possibly be suitable (adequate elevation) for observations from a given hemisphere. We are left with about 200 FGK single stars or members of wide binaries as potential survey targets at a distance of less than 20 pc from the Sun. Our goal is to achieve detection of the reflected light of terrestrial planets in the habitable zone around as many of these stars as possible and also detect their giant planets up to orbital distances comparable to those of the giant planets in the Solar System.
Detection of a terrestrial planet at 1 AU of solar-type stars up to a distance of 20 pc from the Sun (angular separation of 50 mas) requires a sufficiently large diameter telescope (42m or larger) that can see such a faint planet resolved at an angular distance of at least several λ/D in the presence of the stellar glare. The limiting distances of stars where an Earth can be detected will depend among other factors: on the Strehl ratio that can be achieved by the AO system, the star cancellation technique employed and the "superspeckle" treatment. Current AO systems achieve reasonable Strehl ratios in the J-band, so we will adopt here this spectral range as suitable from the technical point of view. The diffraction limit of a 42m telescope in the J-band is 6 milli-arcsec (H-band observations may also be a valid alternative albeit with a slightly worse diffraction limit). Given the high-contrast imaging needed (Earth reflects about 5×10^{-10} L_{sun} in the optical/near-IR), coronagraphs with differential imaging cancellation will be required. At present the highest contrast images obtained at 8-10m telescopes in the near infrared are of order 10^{-6} at 10 λ/D, but extreme-AO systems are planned which may improve contrast by two orders of magnitude in the near future. We will assume here that specially dedicated instruments (coronagraphs and differential imagers) may achieve brightness contrast of 10^{-10} at 8λ/D in the near infrared at the time of operation of the 42m ELT and that the design of the telescope does not prevent this high contrast imaging work.

B) Immediate Objective: We propose to perform a direct imaging search for planets around 150 FGK dwarf stars in the solar neighbourhood (d< 20 pc) with sufficient sensitivity for J-band detection (S/N=5) of Earth-size planets in the habitable zone of the parent stars. At a distance of 10 pc, an Earth-like planet orbiting at 1 AU of a solar-like star of absolute magnitude $M_J = 3.70$ will display a J-band magnitude of 28.5 (assuming albedo of 0.35). The search will be conducted around the nearest 80 F and G-type stars and the nearest 70 early/mid K-type stars accessible to the telescope. While F and G-type stars (absolute magnitudes M_J=2.3-3.2 and M_J=3.3-4.4, respectively) will be surveyed up to a distance of 20 pc, the intrinsic lower luminosity of K-type dwarfs and the subsequent smaller orbital distances associated to the habitable zone (0.5-0.7 AU) will restrict the search up to a distance of 15 pc and 10 pc for early K-types (M_J=4.5-5.0) and mid K-types (M_J=5-5.5), respectively. This survey will also be able to detect giant planets in a much wider range of orbital distances

8. Description of the proposed programme (continued)

from the parent stars. For instance, Jupiter-mass planets would be detected up to separations of 10-15 AU of a G-type star at a distance of 20 pc from the Sun. It will then be possible to identify planetary systems similar to ours.

We expect to detect by direct imaging more than 10 terrestrial planets and a comparable number of giants (possibly many more of each class if several terrestrial and giant planets orbit the same star as it is the case of the Solar System and also for many giant planets found in radial velocity searches). We also expect that a large fraction of the terrestrial planets will show physical conditions very close to those of Earth. The candidate planets will require second and third epoch observations for confirmation. In the long-term, follow-up of the orbital motion should allow precise determination of the orbital parameters and characterisation of the planet main physical parameters. Photometric monitoring of the giant planets as they orbit their parent stars may also show evidence for rings (the radius of the rings are expected to scale with the third power of the planet mass), and the light curve may yield the size, optical depth, the albedo and colour of these rings.

Low-resolution spectroscopy in the far red and near infrared (R=100) shall be performed in the J-H (and K-band if suitable separation from the primary) for preliminary characterisation of the atmosphere of any confirmed terrestrial planet. We remark that complementary observations in the more demanding I-band may be critical to prove the oxygen content in the atmosphere of any terrestrial planet. Any Earth-like planets detected in this survey will be crucial targets for mid-infrared spectroscopy of bio-markers (e.g., ozone) with future space interferometry missions.

Obviously, spectroscopic observations shall also be conducted with as much spectral coverage as possible for a full characterisation of any detected giant planet. Very likely, giant planets will be found at sufficiently large separations of their parent stars for AO systems to allow observations in the red part of the optical spectrum.

Specific cases: As a reference we discuss details of this search for several FGK type stars within 20 pc from the Sun where radial velocity studies have already shown the presence of giant planets. We list these cases in order of increasing distance to the Sun, i.e. from less to more demanding observations (an albedo of 0.35 is alwasy assumed):

Case 1.

a) JHK-band imaging of the giant planet in ϵ Eri. This is a K2 V star (V=3.73, J=2.3) at a distance of 3.2 pc from the Sun. Radial velocity studies (e.g. Hatzes et al. 2000, ApJ 544, L145) give evidence for a giant planet (m sin i > 1.55 M_{Jup}) orbiting at 3.4 AU of the star, angular separation of 1.06 arcsec. We estimate the planet reflected light from the parent star to be $\sim$4.5 x 10^{-9} L_{sun} assuming the size of Jupiter. Contrast imaging at the level 1-2 x 10^{-9} at 175 λ/D is required to detect this giant planet with an estimated magnitude of J=23.2.

b) A super-Earth with 1.5 times the radius of the Earth (approx. 5 times the mass), in the habitable zone of this star ($\sim$0.5 AU) would display a magnitude J=23.3 but at angular separation of 26 λ/D.

Case 2.

a) JHK-band imaging of planets Upsilon Andromeda c and d. This is a F8V star (V=4.1, J=3.17) located at a distance of 13.5 pc from the Sun. The star hosts a planetary system where planet "c" has a mass of $\sim$ 2 M_{Jup} and semimajor orbital axis of 0.83 AU (angular separation of 0.06 arcsec) and planet "d" with a mass of $\sim$ 4 M_{Jup} orbits at 2.5 AU (angular separation of 0.186 arcsec). The expected J-band magnitudes of planets "c" and "d" are 21.1 and 23.5,respectively. We intend to obtain direct imaging of both planets.

Case 3.

a) JHK-band imaging of planet HD 39091b. This is a 10 M_{Jup} orbiting a solar-type star G1 IV star at a distance of 20.6 pc from the Sun (V=5.7, J=4.8). The semimajor axis of the planet's orbit is estimated at 3.3 AU, angular separation of 0.16 arcsec. Because of reflected light from the primary, we expect a J-band magnitude of J=25.8 for this rather massive planet.

b) Imaging of a super-Earth with 1.5 times the Earth radius in the habitable zone of the same star (i.e. at 1 AU) would require detection of an object with J=28.1 at 0.05 arcsec, or 8 λ/D for this band.

C) Telescope Justification: This is the only telescope able to perform the requested observations

D) Observing Mode Justification (visitor or service): visitor

E) Strategy for Data Reduction and Analysis: We will use available reduction packages.

9. Justification of requested observing time and lunar phase

Lunar Phase Justification: Provide here a careful justification of the requested lunar phase.

Time Justification: (including seeing overhead) Provide here a careful justification of the requested number of nights or hours. ESO Exposure Time Calculators exist for all Paranal and for most La Silla instruments and are available at the following web address: http://www.eso.org/observing/etc.

Calibration Request: Special Calibration - Adopt a special calibration

10. Report on the use of ESO facilities during the last 2 years

Report on the use of the ESO facilities during the last 2 years (4 observing periods). Describe the status of the data obtained and the scientific output generated.

11. Applicant's publications related to the subject of this application during the last 2 years

Name1 A., Name2 B., 2001, ApJ, 518, 567: Title of article1

Name3 A., Name4 B., 2002, A&A, 388, 17: Title of article2

Name5 A. et al., 2002, AJ, 118, 1567: Title of article3

12. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	eps Eri	03 32 55	-09 27 29	5.0	3.7		K2V	
A	HD39091	05 37 09	-80 28 08	5.0	5.7		G1IV	
A	Ups And	01 36 48	+41 24 38	5.0	4.1		F8V	

Target Notes: The planned grid of pointings around the targets listed above will be defined during the first observing night.

12b. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If yes, explain why the need for new data.

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13. Scheduling requirements

2. Specific date(s) for time critical observations:

Run	from	to	reason
A	12-nov-07	14-nov-07	parallel observation with HST

3. Unsuitable period(s) of time

Run	from	to	reason
A	15-jan-08	18-jan-08	International Conference

14. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
80	NACO	A	IMG 54 mas/px IR-WFS	provide HERE list of filters