A PAthway Towards the Characterization of Habitable Earths (APACHE)

A. Sozzetti, M.G. Lattanzi, M. Gai, S. Ligori, R. Smart, S. Desidera, R. Gratton, H.R.A. Jones, D. Pinfield, P. Calcidese, A. Bernagozzi, M. Damasso

Rapporto nr. 110 10/11/2008

European Research Council

ERC Starting Grant
Research proposal (Part B1)[1]

A PAthway towards the Characterization of Habitable Earths

APACHE

Cover Page:

- **Principal Investigator (PI): ALESSANDRO SOZZETTI**
- **PI's Host Institution: Istituto Nazionale di Astrofisica –**
- **Osservatorio Astronomico di Torino (INAF - OATo)**
- **Proposal full title: A Pathway towards the Characterization of Habitable Earths**
- **Proposal short name: APACHE**
- **Proposal duration in months: 57**

Proposal summary (half page, possibly copy/paste of abstract from administrative part A1)

In upcoming years, the study and characterization of exoplanets will depend largely on the unique window that transiting planets offer into their properties. Transit observations reveal a planet's radius, and in combination with radial-velocity measurements, permit a determination of the planet's mass. This combination of measurements provides the only available direct constraint on the density and hence bulk composition of exoplanets. When a planet cannot be spatially resolved from its host star, transit-related observations typically offer the only means for direct measurements of planetary emission and absorption. Already, for some of the presently known short-period (~5-20 days) transiting planets transmission spectroscopy measurements have allowed to probe their atmospheric chemistries, while infrared monitoring at a variety of orbital phases including secondary eclipse has led to the detection of their broadband thermal emission and characterization of the longitudinal temperature profiles. These examples demonstrate the profound impact of the transiting class of exoplanets. It is therefore critical to extend their numbers to planets in different mass regimes, different irradiation environments, and around varied star types. In the coming years, the most consequential transit searches will be those that expand the diversity of the transiting planets, particularly to lower planetary mass regimes.

We propose to implement and conduct APACHE, a ground-based survey for habitable Earth-sized planets in transit around low-mass stars (M dwarfs) in the solar neighbourhood. We will coordinate and carry out all necessary follow-up observations to ascertain the true nature of the transiting planet candidates identified. Finally, we will develop new tools for the automated, combined analysis of large databases of photometric light-curves and stellar spectra, to very accurately determine masses and radii of the parent stars, and thus measure very precisely the masses and radii of the detected transiting planets themselves.

Upon conclusion, the data from our survey for transiting terrestrial planets around M dwarf stars will permit to determine $\eta_{\oplus}$, the rate of occurrence (or a stringent upper limit on it, in case of no detections) of planets larger than 2 Earth radii in the habitable zones of M dwarfs (and even smaller-size companions at shorter orbital distances). Thus, our data will critically contribute to test theoretical models of formation, structure, and evolution across several orders of magnitude in radius, mass, and stellar insolation, complementing observations obtained by ongoing and planned wide-field planet transit surveys, both from the ground and in space, and crucially informing future planned and proposed observatories for the detection and characterization of habitable Earths around nearby solar analogs.

[1] Instructions for completing Part B1 can be found in the Guide for Applicants on ERC Grant Schemes

ERC Starting Grant
Research proposal (Part B2)[1]

Section 2: *The Project proposal* (max 15 pages + Ethical Issues)

1) State-of-the-art and objectives

1.1) The Era of Comparative Planetology: Exoplanet Physical Structures and Atmospheres

The aim to understand the physics of planetary systems compels us to search for the underlying laws of planet formation, planetary system architecture and the diversity of planets. In that search, our Solar System is an excellent starting point. However, the limitations of a single (and often incomplete) example are well known. Thirteen years after the Doppler detection of the Jupiter-mass planet around the nearby, solar-type star 51 Peg (Mayor & Queloz 1995), the field of extrasolar planets is holding great promise in alleviating such limitations. Indeed, the observational data on extrasolar planets (over 300 of them discovered so far) show such striking properties (e.g, Udry & Santos 2007; Marcy et al. 2008) that one must infer that planet formation and evolution is a very complex process. The comparison between theory and observation has shown that several difficult problems are limiting at present our ability to elucidate in a unified manner all the various phases. Rather, one often resorts to attempt to investigate separately limited aspects of the physics of planet formation and evolution using a 'compartmentalized' approach. However, improvements are being made toward the definition of more robust theories capable of simultaneously explaining a large range of the observed properties of extrasolar planets, as well as of making new, testable predictions.

The large amount of data gathered on extrasolar planets, mostly thanks to decade-long precision radial-velocity surveys (e.g., Marcy et al. 2008, and references therein) have allowed to unveil a wide range of properties of planetary systems, such as mass and orbital elements distributions and planet frequencies, and are now beginning to provide hints on their dependence on the hosts' characteristics, such as mass and metal content (for a review, see for example Udry & Santos 2007, and references therein). However, until very recently, the information obtained concerned giant planets (those easier to spot with the Doppler method), with masses roughly as low as that of Neptune and as high as 10 times that of Jupiter. With the significant improvement of radial-velocity precision (below 1 m/s) achieved with modern spectrographs (e.g., Mayor & Udry 2008, and references therein), Doppler surveys are now uncovering a new category of massive terrestrial planets (in the mass range 3-10 $M_{\oplus}$), which have been dubbed 'super-Earths'. Super-Earths appear to be common (e.g. Gould et al 2006; Forveille et al. 2008) and they will be crucial in understanding the diversity of solid planets. Furthermore, super-Earth planets have surface conditions that are most similar to those on the early Earth (e.g., Valencia et al. 2007); their study could hold clues to understanding the origins of complex chemistry we call life. Their absence from our Solar System probably explains why super-Earths have not been the subject of detailed interior, surface and atmosphere modeling in the past. This is changing today—with work pointing out exotic bulk properties (Kuchner 2003; Selsis et al. 2008, and references therein), simple mass–radius relations (Fortney et al 2007, Seager et al 2007), and detailed models of the interiors, surfaces, and atmospheres (Valencia et al 2006; Sotin et al 2007). When combined with the significant body of models (e.g. Burrows et al. 2008; Fortney et al. 2008; Baraffe et al. 2008) describing the physical structure and the atmospheres of gas and ice exoplanets, all bearing upon proposed formation and dynamical evolution theories of planetary systems (e.g., Ida & Lin 2004, 2005; Alibert et al. 2005; Kennedy & Kenyon 2008), one then realizes how we're now witnessing the beginning of a new era of 'comparative planetology', in which our Solar System can finally be put in the broader context of the astrophysics of planetary systems.

1.2) The Power of Transits

The announcement of the first Jupiter-mass companion ever discovered transiting across the disk of its parent star is quite recent (Charbonneau e al. 2000). The class of transiting planets offers a unique window of opportunity into the properties of exoplanets, and in upcoming years the study and characterization of planetary systems will depend largely on them. Photometric transit observations reveal a planet's radius, and in combination with radial-velocity measurements, permit a determination of the planet's mass. This combination of measurements provides the only available direct constraint on the density and hence bulk composition of exoplanets. Of the over 40 transiting exoplanets known today (for an up-to-date catalog, see

[1] Instructions for completing Part B2 can be found in the Guide for Applicants on ERC Grant Schemes

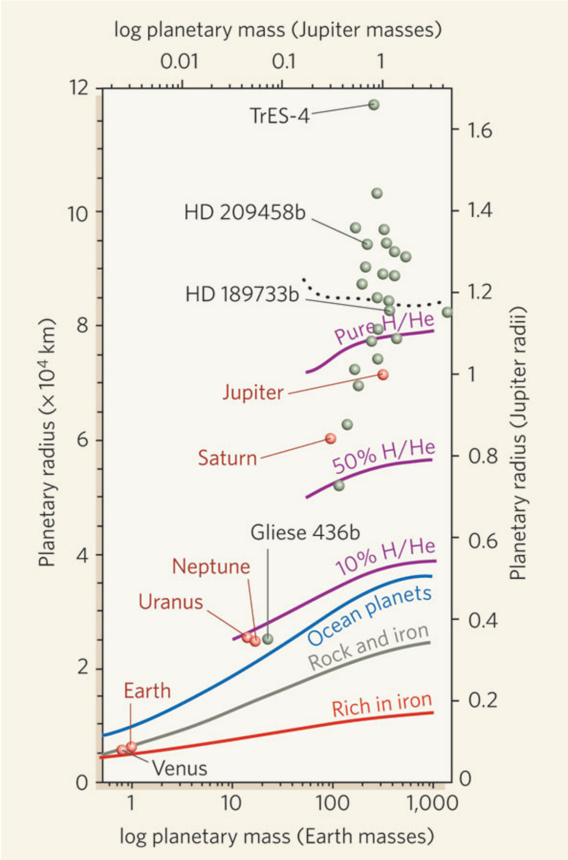

Fig. 1: **The composition of a planet determines its average density and where it will lie on a plot of radius against mass. Many giant planets have been detected that have very low densities above the upper range of pure hydrogen–helium planets (dotted line) — TrES-4 being the most extreme example— and these a serious challenge to theory.**

for example http://www.exoplanet.eu), the majority has radii and masses measured to better than 10%, but when compared to the model predictions (see Fig. 1) one realizes there is a significant discrepancy in that transiting gas giants appear to be much less dense then expected. As of today, none of the proposed solutions put forth to explain this evidence (e.g., Burrows et al. 2007, and references therein) seems entirely satisfactory.

When a planet cannot be spatially resolved from its host star, transit-related observations typically offer the only means for direct measurements of planetary emission and absorption (Charbonneau et al. 2007, and references therein). Already, for some of the presently known short-period (P~5-20 days) transiting planets transmission spectroscopy measurements have allowed to probe their atmospheric chemistries (Charbonneau et al. 2002), including the detection of water vapor (Tinetti et al. 2007). Infrared monitoring during secondary eclipse has led to the detection of their broadband thermal emission (Deming et al. 2005; Charbonneau et al. 2005). Precise spectroscopic measurements during secondary eclipse have unveiled their infrared spectra (Richardson et al. 2007). Most recently, infrared observations gathered at a variety of orbital phases have allowed the characterization of the longitudinal temperature profiles for several Hot Jupiters (Harrington et al. 2006; Knutson et al. 2007), providing first insights on the atmospheric dynamics of exoplanets without the need to image them directly. These examples demonstrate the profound impact of the transiting class of exoplanets.

Given the importance of the transiting planets, it is critical to extend their numbers to planets in different mass regimes, different irradiation environments, and around varied star types. Until the recent discovery that the Neptune-sized GJ 436b transits its host M dwarf (Gillon et al. 2007), all known transiting planets were hot gas giants orbiting Sun-like stars. In the coming years, the most consequential transit searches will be those that expand the diversity of the transiting planets, particularly to lower planetary mass regimes. The transit method, rather than high-contrast-ratio imaging, may well be the first technique to permit pioneering studies of the compositions of habitable planets and their atmospheres.

1.3) The M-Dwarf Opportunity

The recently launched CoRoT mission (Baglin et al. 2002) and the upcoming Kepler (Borucki et al. 2003) mission are the most ambitious efforts along such lines, and are expected to revolutionize exoplanet studies. With their photometric precision and long uninterrupted time baselines, each mission will be capable of detecting rocky planets. Kepler will have the required precision to yield Earth-size planets at orbital distances out to 1 AU while CoRoT will measure the radii of closer-in super-Earths. Recent studies (Valencia et al. 2007; Adams et al. 2008) have begun the characterization of the bulk composition of super-Earths detected in transit by e.g., Kepler and with a measured mass thanks to radial-velocities obtained with ultra high-precision spectrographs such as HARPS-NEF (Li et al. 2008). On average, if the planet radius is measured to better than 5%, combined with mass measurements to better than 10% (Fig. 2), this would allow to distinguish between an icy or rocky composition. This is due to the fact that there is a maximum radius a rocky terrestrial planet may achieve for a given mass. Any value of the radius above this maximum terrestrial radius implies that the planet contains a large (>10%) amount of water (ocean planet). Given the expected performances of space-borne transit photometric surveys, one could then conclude that transit work from the ground may be coming to a close.

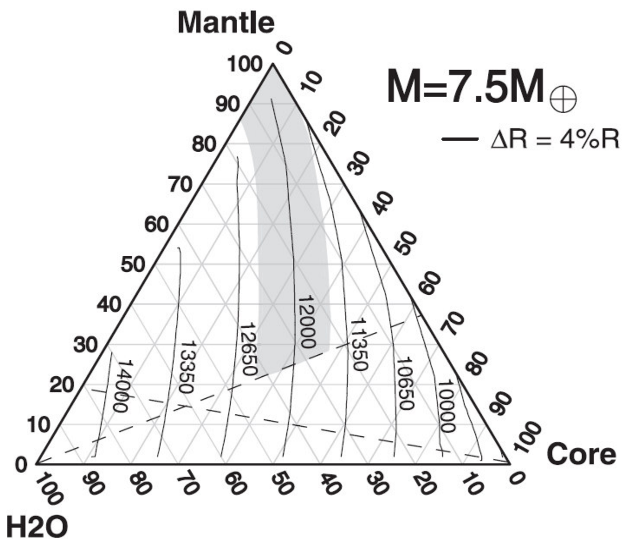

Fig. 2: **The possible compositions of a super-Earth and radius are illustrated in a ternary diagram that depicts three axis: amount of H_2O, core (Fe), and mantle (silicates). The shaded area illustrates a 4% error in radius measurement for a 7.5-$M_\oplus$ planet. An uncertainty in mass ~10% is assumed. If the planet mass were to be known only to ~30% accuracy, the same radius of 12,000 km could correspond to very different compositions, and in such a case it would not be possible to determine whether the planet is an ocean planet or a dry rocky planet.**

However, despite these unmatched capabilities, ground-based transit searches are by no means obsolete, and indeed complement the space missions. CoRoT and Kepler will in fact find planets typically orbiting solar-type stars (of spectral type F-G-K) with typical visual magnitudes V~13 and V~15, respectively. The prospects of follow-up studies, such as those mentioned above, are much less favorable for such relatively faint stars. For smaller mass planets, radial velocity follow-up will require a precision significantly better than the current state-of-the-art. For these reasons, ground-based transit surveys which discover planets around the closest stars are still vital. It is important to note that the expected yields of the space missions along with those of present wide-angle ground surveys (e.g, HAT, Super-WASP, TrES, and XO), are weighted against planets around low-mass stars (M dwarfs). This is simply because M dwarfs are strongly underrepresented in any magnitude-limited survey operating at optical wavelengths.

However, the application of the transit technique to M dwarfs presents several exciting opportunities, and the advantages are especially compelling for the detection of transiting habitable, rocky planets. See Fig. 3 for visualization. *First, the habitable zones of M dwarfs are drawn in close to the stars, improving the transit likelihood.* A planet receiving the same stellar flux as the Earth would lie only 0.074 AU from a mid-M dwarf, and would present a 1.6 % geometric probability of transiting, compared to the 0.5 % probability for the Earth-Sun system. *Second, transits from the habitable zones of M dwarfs happen much more frequently.* At 0.074 AU, a planet would transit once every 14.5 days, compared to 1 year for the Earth-Sun system. This is critical for detectability, as dramatically less observational time is required to achieve transit detection. *Third, the small radii of M dwarfs lead to much deeper transits.* Earth-sized, rocky planets eclipse up to 0.5 % of the stellar disk area, but only 1 part in 3000 of that of the Sun. *Fourth, the small masses of M dwarfs lead to up to over an order of magnitude larger induced radial velocity variations compared to the Sun*. The peak-to-peak amplitude of a 7 $M_\oplus$ planet would be 10 ms^{-1} if it orbits inside the habitable zone of an M5V star, whereas this would shrink to 1.3 ms^{-1} for a Sun-like primary. *Fifth, a number of astrophysical false alarms that plague wide-angle transit searches, such as eclipsed giant stars or stars blended with eclipsing binaries, are far less likely or at least easier to spot for nearby and relatively well characterized M dwarfs.*

Aside from these observational advantages, several developments in astrophysics point to exciting possibilities with M dwarfs. Firstly, the growing numbers of M dwarf exoplanet discoveries suggest an abundance of sub-Neptune mass planets orbiting low-mass stars. Indeed, as of October 2008, with the new detection of a super-Earth (2 $M_\oplus$ < M sin$i$ < 10 $M_\oplus$, Forveille et al. 2008) around the M dwarf Gl 176, a third of the 20 known planets with M sin$i$ < 0.1 M_J and 3 of the 7 known planets with M sin$i$ < 10 $M_\oplus$ orbit an M dwarf, in contrast to just 4 of the over 300 known Jupiter-mass planets. This could be thought initially as the by-product of an observational bias (Neptunes and super-Earths are easier to detect around low-mass stars given that the radial-velocity technique sensitivity scales inversely with stellar mass). However, early statistical analyses indicate that the higher frequency of low-mass planets around low-mass stars could be a real effect (Sousa et al. 2008), and that in general the planet population orbiting M dwarfs is probably quite different from the one orbiting G dwarfs (Bonfils et al. 2007). Indeed, this appears to be confirmed by simulations of planet population synthesis (Mordasini et al. 2007; Benz et al. 2008; Ida & Lin 2008).

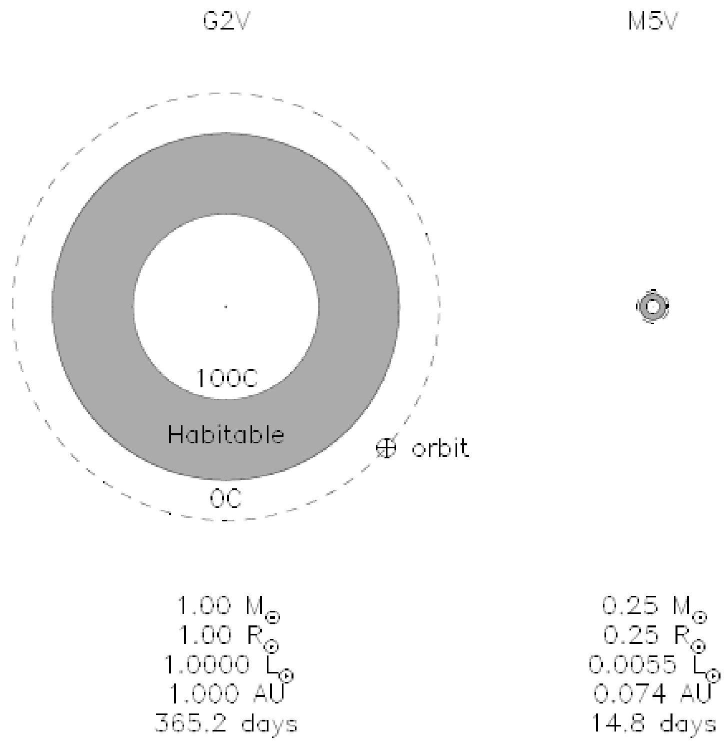

Fig. 3: **The shaded regions denote identifies the Habitable Zone around a G2V star (left) and an M5V star (right), the range of distances for which the equilibrium temperature of the planet is in the interval 0-100 °C, and hence water might be liquid at the surface (e.g., Kasting et al. 1993). The mid-M dwarf primary is a very favorable target for transit surveys, since the transits are more probable and more frequent, and both the photometric and radial-velocity signals are much larger than they would be for the Sun-like primary. The planet-to-star contrast, which depends upon the relative surface areas and brightness temperatures of the planet and star, is much larger for the M5V primary compared to the G2V system, facilitating the measurement of the planetary spectrum by occultation spectroscopy**

Second, it is an open challenge to find a transiting planet in the super-Earth mass regime; simply obtaining a radius measurement for such a planet (for which there are no Solar System analogs) would be extremely fruitful as it might allow one to distinguish between baseline rocky or ocean planet composition models (Valencia et al. 2007; Adams et al. 2008). Note for example (see Fig. 1) that the large spread in observed radii for transiting giant planets indicates that a simple division between rocky/water-dominated super Earths of ~2 Earth radii and Neptune-mass objects with ~4 Earth radii may constitute an oversimplification, and these populations of exoplanets may well be overlapping in radius.

Third, because they are unlikely to form in situ (Terquem & Papaloizou 2007), super-Earths necessarily require some form of migration or scattering from their formation regions (e.g., Kennedy & Kenyon 2008; Raymond et al. 2008). The emerging picture is that of planetary systems with the closest planets reduced to rocky or icy cores due to strong evaporation processes for Sun-like primaries, but significantly less so for M dwarf parent stars. Observed systems around stars of various masses can thus effectively test and inform mechanisms that form and bring planets to close-in, detectable orbits (Raymond et al. 2008).

A 'common place' which is now subject to change is the notion that life cannot survive on habitable zone planets around M dwarfs. Previously, it had been assumed that the rotational synchronization expected of close-in habitable zone planets would lead either to atmospheric collapse or to steep temperature gradients and climatic conditions not suitable for life (Huang 1960; Dole 1964). However, recently it has been argued that atmospheric heat circulation should prevent each of these barriers to habitability (Tarter et al. 2007; Scalo et al. 2007; Buccino et al. 2007; Cuntz et al. 2007). Regardless, the absence of such heat redistribution would be readily observable with precise infrared photometric monitoring as a large day-night temperature difference, while the detection of a small day-night difference would provide a strong case for the existence of a thick atmosphere. With future space-borne observatories such as the James Webb Space Telescope (JWST), atmospheric observations similar to those mentioned earlier for Hot Jupiters can be extended to habitable, Earth-sized planets orbiting M dwarfs. This possibility is brought about by the small surface areas and temperatures of M dwarfs, which lead to significantly more favorable planet-star contrast ratios.

The search for transiting low-mass planets around M dwarfs is thus a worthy and exciting pursuit, due to its many potentially observable consequences for models describing the formation, evolution, internal structure and atmospheres of rocky/icy planets. However, in the context of ground-based transit searches these planets likely require a unique mode of discovery. Whereas current ground-based surveys can stare at fixed fields containing thousands of stars, a survey targeting bright M dwarfs would need to monitor them one-by-one, since they are spread sparsely throughout the sky and are of exceedingly low density, as compared to solar-type stars, in any magnitude-limited survey.

1.4) APACHE, a new M-dwarf transiting planet survey

We propose to undertake a northern-hemisphere photometric survey for transiting low-mass planets orbiting a well-defined sample of M dwarf stars in the solar neighborhood, ***APACHE****, a key step in the pathway towards habitable Earths.* We have assembled a distributed network of scientists and institutes with great expertise in exoplanet science and transits in particular. Based on considerations of optimal band-pass, the necessary field of view, availability of calibrator stars, telescope aperture, and telescope time allocation on a star-by-star basis, as is possible for the quite well-characterized nearby M dwarfs, we estimate ~3000 M dwarfs ($R_* < 0.6\ R_\odot$) are favorable targets for transit monitoring. Based on an observational cadence and on total telescope time allocation tailored to recover 90% of transit signals from planets in habitable zone orbits, we find that a network of 5 40-cm telescopes can survey this sample of M dwarfs in about 4 years. A null result from this survey would set an upper limit (at 99% confidence) of 10% to 15% for the rate of occurrence of planets larger than 2 Earth radii and smaller than 4 Earth radii in the habitable zones of late M dwarfs, and even stronger constraints for planets lying closer than the habitable zone. If the true occurrence rate of habitable planets is 10%, the expected yield would be ~4 planets. The number of targets is selected to ensure that even a null result is astrophysically interesting, while the sensitivity goal reaches into the upper end of the radius range expected for rocky planets and extends to the realm of Neptune-sized objects.

This is not the first program engaged in a planet transit search around nearby M dwarfs. The MEarth project (Nutzman & Charbonneau 2008), is an analogous project (housed in a single enclosure in Mt. Hopkins, Arizona) which will utilize 8 identical telescopes to carry out a transit search around late M-dwarf stars ($R_* < 0.3\ R_\odot$). Furthermore, a total of 200 nights on the UKIRT telescope will soon be used to carry out a wide-field transit search around low-mass stars in the infrared. However, we strongly believe our proposed program can crucially contribute in at least three ways.

First, the experience of wide-field transit surveys teaches us that multiple sites spread in longitude are observationally favorable to a very significant extent. As shown in Fig. 4, the recovery rate of a campaign carried out by a multi-site longitudinally distributed network is critically improved with respect to both a single-site and a single-longitude network campaign. The successes of the TrES (e.g., O'Donovan et al. 2007) and HATNet (e.g., Bakos et al. 2007) transit searches owe a lot to the specific multi-site choice approach. Our program will thus optimally complement the similar US-based MEarth effort as well as the upcoming UKIRT wide-field survey. It will also be possible to establish direct connections and collaborations with these other projects, possibly reaching agreement for example on the actual coordination of the observed fields and response to alerts.

Second, our proposed program addresses not only the key astrophysical issue of the characterization of super-Earth planets, but it also wants to probe the transition regime (in radius) between super-Earths and Neptune sized planets. For this purpose, we do not limit our target choice to the late M dwarf sample as it is being done by the MEarth survey. This choice allows for the best chances, for the same photometric precision, of detecting a smaller-size planet, but late M dwarfs being intrinsically very faint, it also carries with it significant complications at the level of high-precision Doppler follow-up. We concede up to a factor of 2 in detectable planetary radius (for the same photometric precision) to encompass the ~1000 brighter M dwarfs with radii in the range $0.3_\odot < R < 0.6\ R_\odot$. The inclusion in our program of the sample of brighter M dwarfs (the most favorable targets not only for confirmation Doppler spectroscopy, but also in the perspective of e.g., further characterization of the atmospheric chemistry, detection of thermal emission and of the broadband spectrum of detected transiting planets) uniquely complements both the MEarth survey (which searches for habitable super Earths around nearby late M dwarfs) as well as the UKIRT survey (that targets many more low-mass stars, ~20,000, but is only sensitive to transiting planets with periods of 1-2 days, i.e., in the habitable zone of the lowest mass M dwarfs of typical 2MASS J~14 mag, for which high-precision Doppler follow-up is extremely difficult, and further characterization at present virtually hopeless).

Third, the team we have assembled uniquely masters a large amount of knowledge of instrumentation, and techniques for the detection and characterization of planetary systems both at visible as well as infrared wavelengths. It is in an optimal position to fully exploit not only the planet discoveries which will be the primary output of the survey, but also a host of astrophysical by-products of the APACHE observations.

Nearby M dwarfs are now being identified by many as the bearers of the lowest hanging fruit in the search for habitable rocky planets. Excitingly, these stars remain largely unexplored: Since late M dwarfs are very faint at the visible wavelengths at which iodine provides reference lines, they are not accessible in large numbers to current radial velocity planet searches. Besides the search for transiting planets, a plan to photometrically monitor this many M dwarfs represents a large step forward in the study of the intrinsic variability, and long-term activity of M dwarfs. The identification and monitoring of spotted stars, for example, will be useful to future, near-IR radial-velocity programs which would otherwise be compromised by the radial-velocity jitter and spurious signals that might result. In addition, the survey will most likely identify interesting eclipsing binary systems. These are of vital importance for constraining the mass-radius relation at the bottom of the main sequence, and hence theoretical models of low-mass stellar evolution, which are remarkably poorly-constrained even at old, main sequence ages for stars below 1 $M_\odot$. As a matter of fact, many of the observed and well-characterized systems show substantial discrepancies with the predictions of the theoretical models (e.g. Ribas 2006). These uncertainties have a direct impact on the reliability of stellar parameter estimates, and hence on planet properties inferred from analysis of transiting systems. Indeed, many of the transiting planet observations have reached sufficient quality that this uncertainty in the parameters of the host star is the limiting factor in our knowledge of the properties of the planets. For M-dwarf eclipsing binaries detected from APACHE data, it should be possible to provide very detailed system characterizations, allowing model-independent mass and radius estimates with uncertainties of only a few percent to be made (e.g. Andersen 1991). Finally, in a few years from now Gaia (e.g., Perryman et al. 2001) will begin delivering global astrometric measurements of unprecedented precision. In its all-sky survey, Gaia will observe the vast majority of our sample of nearby (d < 30-40 pc) M dwarfs with precision sufficient to a) obtain direct distance estimates of outstanding quality (0.1%-1%), and b) detect the presence of planets with mass comparable to the mass of Neptune, or larger, out to a few AU (e.g., Sozzetti et al. 2001; Casertano et al. 2008). These measurements, together with those obtained with both ground-based instrumentation, such as VLTI/PRIMA (Launhardt et al. 2008), as well as other planned or proposed space-borne observatories, such as SIM-PlanetQuest (Unwin et al. 2008) and GAME (Gai et al. 2008) will a) contribute to improve the characterization of the stellar hosts (mass, radius), and b) given their vicinity, will probe outer regions for low-mass companions, providing further observational evidence with which to test planet formation models which describe terrestrial planet formation with and without the presence of other planets in a system (e.g., Terquem & Papaloizou 2007; Raymond et al. 2008; Kennedy & Kenyon 2008, and references therein).

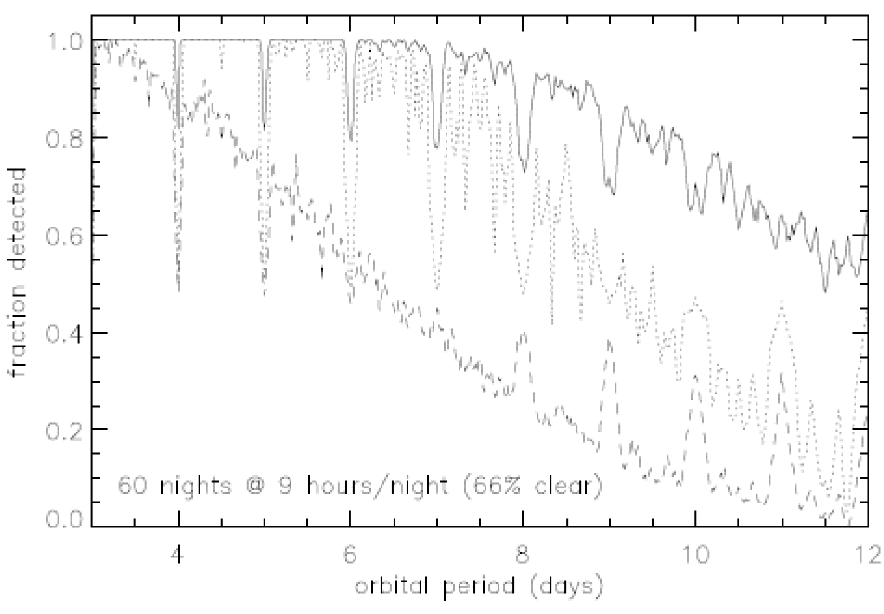

Fig. 4: **The recovery rate for a 60-day campaign to find transiting planets (assuming 9 hours per night, and 66% clear weather), as a function of orbital period. The dashed line is the result for a single telescope, the dotted line is that for three telescopes at the same longitude, and the solid line is that for a network of three elements longitudinally distributed. The enhancement in phase coverage is very significant.**

2) Methodology

2.1) Survey Design Study

In order to detect a few super-Earth planets, or to place meaningful constraints on their incidence, for a geometric transit probability of ~1% we must survey a few thousand M-dwarfs. These should be bright in order to allow follow-up studies to be performed, and given the intrinsic faintness of M-dwarfs this translates to being very nearby: for example, an M5V star has an absolute J-band magnitude of M~9. A reasonable limit for follow-up studies is J ~12, implying distances < 40 pc.

Such nearby stars are expected to have high proper motions. We therefore appeal to the recently-completed LSPM-North catalogue (Lepine & Shara 2005), a survey of the entire Northern hemisphere based on photographic plates, which should be nearly complete for stars with proper motion > 0.15″/yr, containing a total of ~62 000 sources. We further restrict this to a sub-sample of 4131 stars within 33 pc (Lepine 2005) to remove high proper motion sub-dwarf contaminants from the sample.

In order to select the M-dwarfs from the remaining population of (predominantly) main sequence dwarfs, we apply colour cuts using combinations of the V-band magnitudes from Lepine & Shara (2005), and 2MASS J, H and K_S magnitudes, which are available for every star in our sample from the 2MASS all-sky data release (Skrutskie et al. 2006). The resulting "culled" sample consists of ~3300 probable M-dwarfs. These targets are spread in a relatively uniform fashion over the entire celestial Northern hemisphere. It is therefore necessary to devise a strategy for observing them individually. This mode of operation brings a number of benefits. In particular, the requirement on the field-of-view of the detector is substantially relaxed, since it needs only be large enough to obtain sufficient comparison stars to perform differential ensemble photometry. It is also possible to tailor the parameters of each observation to the individual target M-dwarf, for example varying the exposure time to achieve the required signal to noise to detect planets of a given size, thereby saving observing time.

In a similar study, Nutzman & Charbonneau (2008) found that the most favorable targets for such a transit survey are, in fact, the smallest stars: although these are intrinsically fainter, the reduced count rates are compensated by having deeper transits, and their faintness increases the number of suitable comparison stars available for a given field-of-view. It is important to recall that for small field-of-view observations of single targets, the noise in the comparison light curve can become an important, or even dominant, contributor to the total noise budget. They therefore chose to concentrate on the smallest stars, choosing ~2000 with estimated radii $R_* < 0.33\ R_\odot$ (corresponding to a spectral type later than M4). For the purpose our program, however, we do not discard the brighter sample of M0-M3 dwarfs, which is the most easily accessible from the point of view of follow-up and characterization work. Note that the same transit depth (~0.5%) is achieved for a 2-$R_\oplus$ transiting a 0.3-$R_\odot$ primary and for a 4-$R_\oplus$ transiting a 0.6-$R_\odot$ primary. At the bright end of our target list we will still be able to investigate the radius regime at the threshold between (water-dominated) super-Earths and Netpune-sized objects.

Since the emission from M-dwarfs peaks in the near-IR, the number of detected stellar photons would be maximized by observing in this spectral region. Unfortunately, near-IR detectors remain prohibitively expensive, so APACHE (just like MEarth) will use conventional CCDs. Nutzman & Charbonneau (2008) found that the optimal pass-band for observing the (extremely red) M-dwarf target stars was a filter cutting on shortward of ~700 nm, and limited on the red end by the tail of the CCD quantum efficiency curve. The H_α line was deliberately omitted from the band-pass due to its potential variability in very active stars, which is obviously an undesirable feature for precision photometry. This pass-band approximates the sum of transmission of the Sloan i and z filters (Fukugita et al. 1996). In reality, the final band-pass using an e2v CCD42-40 is very similar to the conventional Cousins I filter, which ended up being our final choice.

Given these parameters, we can calculate the telescope aperture and field-of-view required to survey our target stars. This was done assuming a standard noise model, including contributions from Poisson noise in the stellar counts and sky background, dark current, readout noise, and atmospheric scintillation using the formulation of Young (1967). Similarly to Nutzman & Charbonneau (2008), we find that a 40 cm aperture telescope with a ~30′×30′ field-of-view is sufficient for the vast majority of the M-dwarfs with $R_* < 0.33\ R_\odot$, and approximately 50% of low-mass stars with $0.30\ R_\odot < R_* < 0.60\ R_\odot$. Our final target list then encompasses ~3000 low-mass stars. Particularly for the brighter targets, depending on the actual final prioritized target list, larger fields of view may be necessary. We will investigate possible solutions to this challenge. These include, for example, the addition of a wide angle-node to the APACHE network, or simply using a large-format camera. It may also be possible to accommodate these stars by using custom field orientations in order to grab extra calibrating stars, or to relax the conservative calibrating criteria that we assumed in our field-of-view calculations.

Given the space constraints on the observing site (see below), we have opted for five such identical telescopes. Based on simulations using an observational cadence (see below) and on total telescope time allocation (e.g., Pepper et al. 2005) tailored to recover 90% of transit signals from planets in habitable zone orbits, we find that, for an aperture of 40cm, this leads to an expected ~4 yr duration to complete the survey of the habitable zones of these ~3000 M-dwarfs. The design study indicates that a yield of ~4 habitable zone super-Earths would be predicted if the true occurrence of these planets was 10% around our targets, with larger and closer-in planets being easier to detect. Note that, as observed before, preliminary results from Doppler surveys seem to indicate that the fraction of stars with super-Earth and Neptune-class companions in relatively short-period orbits is significantly larger, as much as ~30% (e.g., Mayor & Udry 2008, and references therein). If these initial findings will hold, the final yield from our survey would be correspondingly higher. A null result would limit the occurrence of > 2 $R_\oplus$ super-Earth planets in the habitable zones of M dwarfs to be < 15% at the 99% confidence level, a result that again becomes a stronger limit for closer-in planets.

2.2) Choice of Equipment

The key advantage of choosing multiple identical telescopes is that a single pipeline for the reduction and analysis of the photometric data can be adopted.
We have converged on 5 Carbon Truss 16 inch f/8.4 Ritchey-Chrétien telescopes, with a Bisque Paramount and equipped with an Apogee U42 2K x 2K back-illuminated CCD Camera and a Johnson-Cousins I filter. Each individual system is of state-of-the-art quality performance for its class (e.g., the carbon structure guarantees negligible temperature gradients during the night, the truss improves the intrinsic seeing upon a tube telescope, the detector has QE > 90% in the whole wavelength range of interest). The chosen configuration closely resembles the one utilized by the MEarth project, and for a reason, in that it will provide the opportunity for a possible effective interaction with the US-based project in the future (note that all multi-site, longitudinally-distributed, wide-field transit searches employ networks of identical telescopes).

2.3) OAVdA Site Identification

The site of the Osservatorio Astronomico della Regione Autonoma Valle d'Aosta (OAVdA) will be the location for the realization of the survey. Inaugurated in 2003, the Observatory is located in the North-West of the Italian Alps, at 1,675 m above sea level. OAVdA has a record of collaborative efforts with INAF-OATo in a variety of scientific programs; these include the testing of the KPOL Liquid Crystal Polarimeter (Zangrilli et al. 2006) before integration on the Sounding-rocket Coronagraphic Experiment (SCORE) for the HERSCHEL program, studies of the rotational and physical properties of Near-Earth Asteriods (e.g., Carbognani & Calcidese 2007; Carbognani et al. 2008), and multi-frequency monitoring of active galactic nuclei (AGNs) in the context of the WEBT (Whole Earth Blazar Telescope) consortium (e.g., Raiteri et al. 2008; Villata et al. 2008). OAVdA also carries out significant teaching and public outreach activities throughout the year. OAVdA hosts a staff of resident scientists who can guarantee continuity in carrying out all scientific operations, from the observations to the data reduction and analysis.

The OAVdA site (a night-view of the Observatory is shown in Fig. 5) has been identified as an optimal location for the survey for several reasons. First, its high-altitude location and remoteness account for almost light-pollution-free night-sky conditions. Clear-sky observing conditions are realized at OAVdA ~150 nights/yr, with typical atmospheric conditions corresponding to a median seeing of ~1.5 arcsec.


Fig. 5

Second, its relative vicinity to the PI's Host Institution (less than two hours drive from INAF-OATo) minimizes travel-related time losses for the PI and other INAF-OATo team members, while optimizing work coordination and maximizing efficiency.
Third, the OAVdA site has two balconies with electronically-controlled track-mounted ceilings that can be cokmpletely opened to the sky. The plan is to keep one balcony for teaching and public outreach programs, and devote the other for hosting the group of telescopes for the APACHE project, limited to a total of five given the relative sizes of the systems and the usable area on the balcony. The availability of a single movable enclosure (the site is essentially unique in Europe) and of much of the associated support infrastructure at OAVdA will afford a very substantial cost saving for the project.

2.4) OAVdA Site Testing

OAVdA has recently been included in a ground-based program of photometric monitoring of stars known to host Doppler-detected short-period giant planets, looking for possible transits (this program has recently obtained its first success in the discovery of the transits of the massive giant planet HD 17156b, see Barbieri et al. 2007). As an example (Fig. 6), the photometric data obtained for the planet host HD 185269, in good atmospheric conditions and with a 25-cm f/3.6 telescope equipped with a low-sensitivity CCD camera HiSis 23, show an rms uncertainty of ~3 milli-mag, a typical performance achieved of bright stars. We'll reach the requested high-precision performance (~3-5 mmag) on the our M dwarf targets utilizing the proposed group of 40-cm telescopes equipped with good quality CCD detectors.

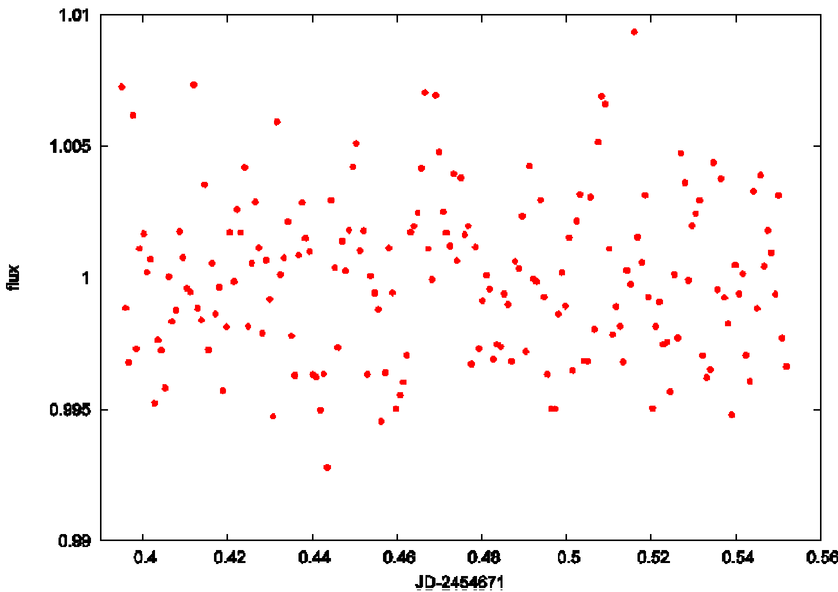

Fig. 6: **Photometric time-series of HD185269 during the predicted time of transit**

2.5) A New Mode of Operation

The network of 5 telescopes will be made entirely robotic within a short time span, as the OAVdA staff in residence has also accumulated significant experience with the automatization of the operations with the main 80-cm telescope on-site utilized for Blazar monitoring and photometry and astrometry of asteroids. However, in order to improve the survey efficiency, and in particular, to increase the number of M-dwarfs that can be monitored at once by each telescope, we will adopt a novel detection strategy. Routine observations will be carried out at extremely low cadence with ~2 visits to each target per transit timescale (we assume a mid-latitude transit, which leads to a duration 0.866 times that of an equatorial transit). The cadence is further limited to not being less than once every half-hour to assure a reasonable number of observations of each target per night, and to catch shorter period transits due to planets interior to the habitable zone. We intend to detect transits while they are still in progress via real-time analysis of the images as they are taken. This information can then be used to immediately direct follow-up resources (e.g. other APACHE telescopes) to confirm or reject the hypothesis that there is a transit in progress. In practice, this will probably proceed by immediately obtaining several more data-points, to combat the effects of noise and light curve systematics, and then following the remainder of the event, if it turns out to be real, at high-cadence to obtain a well-sampled transit egress. By continuously re-evaluating the probability of there being a transit in-progress upon obtaining additional data-points, we can quickly reject false positives without any major effect on the remainder of the targets. We can therefore cope with a relatively high false alarm rate.

2.6) New Tools for False Positives Rejection

The vast majority of transiting planet candidates in wide-field surveys proves to be false positives (Brown 2003), i.e. some configuration of binary of triple stellar systems. Some of these, in particular blends, can mimic the expected properties of a planetary system quite closely (e.g., Torres et al. 2004). In such cases, the typical telltale indicators of the stellar components are often masked and spectroscopic and even multicolor photometric follow-up is insufficient to confirm the planetary nature of a candidate. An attempt must be made to interpret the observations as those of a blended eclipsing binary and this interpretation rejected only if the observations are not in agreement. Having meticulously examined the evidence, one can then commit to obtain the radial velocity orbit of this firm candidate through high-resolution spectroscopy with a high signal-to-noise ratio (SNR).

Following e.g., Torres et al. (2004) and Hoekstra et al. (2005), we will develop a self-consistent algorithm to model light-curve under the assumption they are produced by the combination of the light from an eclipsing binary plus a brighter star. The stellar properties will be parameterized in terms of the mass, while all other stellar properties will be derived from model isochrones, which can be the same for the eclipsing binary and the third star if they form a physical triple system, or different otherwise. The mass of the brightest star in the system will be constrained by the spectroscopic and photometric information available. The blend model will be capable of accounting for all photometric and spectroscopic constraints, including the detailed morphology of the light curve (depth, duration, and shape), as well as the composite nature of the spectrum, the brightness of the eclipsing binary relative to the brightest star (amount of dilution), the orbital velocity amplitudes of the eclipsing binary, and the projected rotational velocities of its components. All predicted blend properties will be tested against the powerful combination of photometric and spectroscopic constraints obtained with follow-up observations.

2.7) New Tools for the Characterization of Transiting Systems

We plan to carry out the detailed spectro-photometric characterization of transiting planet systems discovered during the APACHE survey as follows. First, we will design, implement, and utilize an automated code for the analysis of high-resolution, high SNR stellar spectra obtained during follow-up for the determination of the atmospheric parameters. Effective temperature, the most crucial parameter to which all other derived stellar quantities are very sensitive, will be determined via 1) a classic procedure of excitation and ionization balance (Sozzetti et al. 2004, and references therein), 2) spectral synthesis of atomic and molecular features using recently revised cool-star model atmospheres and spectrum synthesis codes (Bean et al. 2006), and 3) empirical formulae derived using high accuracy optical and infrared photometry (Casagrande et al. 2008). The inferred temperature and metallicity of any given target will be then used in conjunction with the information on the stellar density coming from high-quality light-curves obtained with follow-up observations. As Sozzetti et al. (2007) have shown, the latter is a much better proxy for stellar luminosity than the spectroscopically determined surface gravity in a comparison with stellar evolution models to infer very accurate and precise values of the stellar mass and radius. These values known, it will then be possible to solve for significantly improved values of planetary mass, radius, and density.

2.8) Plans for Follow-up Observations, False-Positives Rejection, and Planet Confirmation

As with any transit survey, in order to confirm the planetary nature of any detection, or reject an impostor, a large number of follow-up observations will be required. We provide in Fig. 7 a typical follow-up decision tree representative of the one to be implemented for the APACHE program.
The team we assembled for this project has a broad experience in all critical aspects of follow-up observations, with many members of our team having routine access to state-of-the-art facilities for photometric, high-resolution imaging, and spectroscopic observations. For targets passing the initial analysis based on the APACHE light-curves themselves, we will carry out initial spectroscopic reconnaissance utilizing 2- through 4-m class telescopes (e.g., TNG), and existing spectrographs (e.g., SARG). Note, however, the target selection employed for APACHE largely eliminates the most common sources of astrophysical false positives that plague conventional wide-field transit surveys (e.g., Torres et al. 2004; Mandushev et al. 2005; O'Donovan et al. 2006). In particular, the selection by proper motion eliminates giant host stars from the sample, and hierarchical triple systems are extremely unlikely due to the very late spectral types that they must have in order to be included in the APACHE sample (the brightest star in these would be an early-M dwarf due to the color selection we apply). Triples may also be resolvable with high-resolution imaging due to their close proximity to the Earth. Finally, blends with background binaries are substantially reduced, not least because our pixel scale of 0.75″/pix is ~1/20 that of a typical wide-field transit survey, and the high proper motions of our targets mean that previous epochs of imaging can be used to resolve many of these systems, by looking for the background source at the present position of the M-dwarf. When deemed necessary, we will carry out imaging observations utilizing European facilities such as AdOpt@TNG. High-quality light-curves on 1-2m class telescopes both in the visible (e.g., the REOSC and Marcon telescopes available on the premises of INAF-OATo) and infrared (UKIRT) will then be acquired for further screening, to finalize the list of suitable targets for high-precision radial-velocity follow-up. Determining the spectroscopic orbit of the candidate will be the most critical step. In principle, this should be possible with existing instrumentation, with several groups demonstrating the required radial velocity precision on M-dwarfs using conventional instruments in relatively blue pass-bands. Ideally, in order to take advantage of the greater continuum flux of M-dwarfs in the far red and infrared, radial velocities would be derived from lines in these spectral regions.

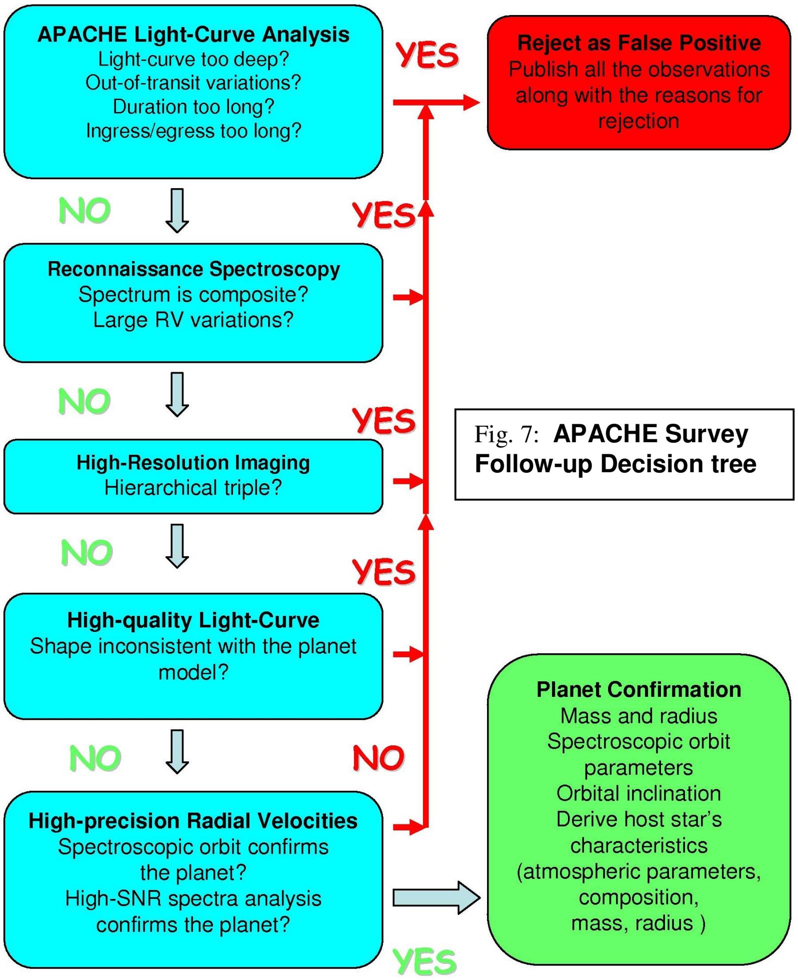

Fig. 7: **APACHE Survey Follow-up Decision tree**

Follow-up radial-velocity work to derive a high-precision spectroscopic orbit for the best candidates will be carried out with the second generation high-resolution near-infrared (0.9-2.5 μm) spectrograph GIANO equipped with a cell for high-precision IR radial-velocities, to be installed next year at the Nasmyth B focus of the TNG, with the infrared (0.8-1.8 μm) spectrometer PRVS, which should be commissioned on the Gemini-N telescope by 2011, and with the HARPS-NEF spectrograph, which will be mounted on the William Herschel Telescope (Canary Islands) within the next two years. The fact that all critically needed instruments for high-precision Doppler follow-up will be online by 2011 nicely fits with the APACHE survey operations, which we expect to begin delivering interesting candidates by summer 2010.

Then, we will run the abovementioned pipeline for bisector analysis and detailed modeling of possible blends based on the collected high-quality light-curves and high-SNR spectra. This effort will be couple to a detailed analysis of the line bisectors (LB) in the spectra collected during high-precision Doppler follow-up, searching for LB variations which would indicate that instead of a planet the radial-velocity variations are caused by stellar spots (e.g., Queloz et al. 2001). The combined application of these false positives rejection methods will provide a final word on the nature of the transit candidate. The final step prior to a discovery announcement will be to use the very high-quality spectra collected and combine them with the high-quality photometric data to very accurately determine masses and radii of the parent stars, and thus measure very precisely the masses and radii of the detected transiting planets themselves. This goal will be achieved taking advantage of the new proposed tools for the automated analysis of large databases of photometric light-curves and stellar spectra described earlier.

2.9) Activity Breakdown

The activities connected to the APACHE survey can be divided into four partially overlapping main phases.

- **Phase A:** at time T0, the equipment is bought, shipped and installed at OAVdA. We estimate the whole group of five APACHE telescopes is fully operational within nine months from T0.
- **Phase B:** APACHE telescopes commissioning observations. This phase lasts for about 1 month per system.
- **Phase C:** the APACHE survey starts, and as per estimates in the design study it lasts four years.
- **Phase D:** follow-up observations are undertaken.

All the above phases broadly overlap. In particular, by the time Phase A is concluded, Phase C has already started for some of the telescopes of the network. Phase D will begin at roughly midway through the survey duration. Based on these considerations, we estimate a total duration of the project of 4.75 years. We assume a project start date T0 = 1 June 2009, and a conclusion at T0+4.75 years = 31 March 2014.

Quite clearly, the conclusion of the survey operations will not exhaust the need for follow-up observations based on the analysis of the survey data, but additional scientific exploitation of the survey results by the various team members will not be included in the APACHE project per se.

2.10) Dissemination and Collaborations

The scientific and technological results will be presented to international conferences and published in the appropriate forms for maximum dissemination, including the preparation of a public web site containing the project related information. We will strive to interact positively with our US colleagues involved in the MEarth project for fruitful collaboration and possible establishment of an observationally preferable coordinated multi-site campaign which exploits the potential for improvement given by enhanced longitudinal coverage.

2.11) References

Adams, E.R., et al. 2008, ApJ, 673, 1160
Alibert, Y. 2005, A&A, 434, 343
Andersen, J. 1991, A&ARv, 3, 91
Baglin, A., et al. 2002, ASP Conf. Ser., 259, 626
Bakos, G.A., et al.. 2007, 670, 826
Baraffe, I., et al. 2008, A&A, 482, 315
Barbieri, M., et al. 2007, A&A, 476, L13
Bean, J.L, et al. 2006, ApJ, 653, L65
Benz, W., et al. 2008, Physica Scripta, in press (IOP Publishing)
Borucki, W.J., et al. 2003, Proc. SPIE, 4854, 129
Brown, T.M. 2003, ApJ, 593, L125
Buccino, A.P., et al. 2007, 192, 582
Burrows, A., et al. 2007, ApJ, 661, 502
Burrows, A., et al. 2008, ApJ, 682, 1277
Carbognani, A., & Calcidese, P. 2007, Minor Planet Bulletin, 34, 18
Carbognani, A., et al. 2008, Minor Planet Bulletin, 35, 61
Casagrande, L., et al. 2008, MNRAS, 389, 585
Casertano, S., et al. 2008, A&A, 482, 699
Charbonneau, D., et al. 2000, ApJ, 529, L45
Charbonneau, D., et al. 2002, ApJ, 568, 377
Charbonneau, D., et al. 2005, ApJ, 626, 523
Charbonneau, D., et al. 2007, Protostars & Planets V, University of Arizona Press, 701
Cuntz, M., et al. 2007, IAU Symposium 249, 203
Deming, D., et al. 2005, Nature, 434, 740
Dole, S.H., 1964, Habitable Planets for Man (New York, Blaisdell Publishing Company)
Fortney, J.J., et al. 2007, ApJ, 659, 1661
Fortney, J.J., et al. 2008, ApJ, 683, 1104
Forveille, T., et al. 2008, A&A, accepted (arXiv:0809.0750)
Fukugita, M., et al. 1996, AJ, 111, 1748
Gai, M., et al. 2008, 37th COSPAR Scientific Assembly, 961
Gillon, M., et al. 2007, A&A, 472, L13
Gould, A., et al. 2006, ApJ, 644, L37
Harrington, J., et al. 2006, Nature, 447, 691
Hoekstra, H., et al. 2005, ApJ, 626, 1070
Huang, S.-S., 1960, PASP, 72, 489
Ida, S., & Lin, D.N.C. 2004, ApJ, 604, 388
Ida, S., & Lin, D.N.C., 2005, ApJ, 626, 1045
Ida, S., & Lin, D.N.C. 2008, ApJ, 685, 584
Kasting, J.F., et al. 1993, Icarus, 101, 108
Kennedy, G.M., & Kenyon, S.J. 2008, ApJ, 682, 1264
Knutson, H.A., et al. 2007, Nature, 447, 183
Kuchner, M.J. 2003, ApJ, 596, L105
Launhardt, R., et al. 2008, IAU Symposium 248, 417

Lépine, S., & Shara, M.M. 2005, AJ, 129, 1483
Lépine, S. 2005, AJ, 130, 1680
Li, C.-H., et al. 2008, Nature, 452, 610
Mandushev, G., et al. 2005, ApJ, 621, 1061
Marcy, G.W., et al. 2008, Physica Scripta, in press (IOP Publishing)
Mayor, M., & Queloz, D. 1995, Nature, 378, 355
Mayor, M. & Udry, S. 2008, Physica Scripta, in press (IOP Publishing)
Mordasini, C., et al. 2007, ASP Conf. Ser., in press (arXiv:0710.5667)
Nutzman, P., & Charbonneau, D. 2008, PASP, 120, 317
O'Donovan, F.T., et al. 2006, ApJ, 644, 1237
O'Donovan, F.T., et al.. 2007, ApJ, 663, L37
Pepper, J., & Gaudi, B. S. 2005, ApJ, 631, 581
Perryman, M. A. C., et al. 2001, A&A, 369, 339
Queloz, D., et al. 2001, A&A, 379, 279
Raiteri, C.M., et al. 2008, A&A, 480, 339
Ribas, I. 2006, Ap&SS, 304, 89
Raymond, S.N., et al. 2008, MNRAS, 384, 663
Richardson, L.J., et al. 2007, Nature, 445, 892
Scalo, J., et al. 2007, Astrobiology, 7, 85
Seager, S., et al. 2007, ApJ, 669, 1279
Selsis, F., et al. 2008, Physica Scripta, in press (IOP Publishing)
Skrutskie, M. F., et al. 2006, AJ, 131, 1163
Sotin, C., et al. 2007, Icarus, 191, 337
Sozzetti, A., et al. 2001, A&A, 373, L21
Sozzetti, A., et al. 2004, ApJ, 616, L167
Sozzetti, A., et al. 2007, ApJ, 664, 1190
Tarter, J., et al. 2007, Astrobiology, 7, 30
Terquem, C., & Papaloizou, J.C.B. 2007, ApJ, 654, 1110
Tinetti, G., et al. 2007, Nature, 448, 169
Torres, G., et al. 2004, ApJ, 614, 979
Udry, S., & Santos, N.C. 2007, ARA&A, 45, 397
Unwin, S.C., et al. 2008, PASP, 120, 38
Valencia, D., et al. 2006, Icarus, 181, 545
Valencia, D., et al. 2007, ApJ, 665, 1413
Villata, M., et al. 2008, A&A, 481, L89
Young, A.T. 1967, AJ, 72, 747
Zangrilli, L., et al. 2006, Proc. International Symposium on Solar Physics and Solar Eclipses (SPSE 2006)

3) Resources (incl. project costs)

3.1) Team Description, Manpower Allocation and Functions

The INAF-Osservatorio Astronomico di Torino (INAF-OATo) team has a pivotal role in the APACHE M dwarf transiting planet survey. The OATo team coordinates the selection of the prioritized list of M dwarfs targets. The team at the PI's host institution maintains the large database of stellar light-curves and stellar spectra obtained during the survey and the follow-up observations. The PI coordinates the entire team activities. The INAF-OATo team helps in the implementation of the pipeline for data analysis, develops tools for the analysis of light-curves and spectra to identify blends, and develops tools for the automated combined analysis of large numbers of light-curves and stellar spectra of confirmed transiting planets to refine stellar and planetary parameters. The INAF-OATo carries out part of the follow-up observations, and led by the PI, it spear-heads the astrophysical interpretation of the results. The INAF-OATo team (as per FTE summary table) contributes with M.G. Lattanzi (0.15 FTE), M. Gai (0.15 FTE), S. Ligori (0.30 FTE), and R. Smart (0.30 FTE).

The Osservatorio Astronomico della Regione Autonoma Valle d'Aosta (OAVdA) team helps crucially in several aspects of the APACHE survey. The team helps in the execution of all the observations with the group of telescopes, and all day-to-day duties. It helps in the implementation of the pipeline for the real-time photometric data reduction and analysis, and in the optimization of the global survey strategies. The OAVdA team contributes with Mario Damasso (1 FTE), Andrea Bernagozzi (1 FTE), and Paolo Calcidese (0.1 FTE).

The INAF-Osservatorio Astronomico di Padova (INAF-OAPd) team has broad experience in the observational field of exoplanets, as testified by the important contributions of the team in terms of e.g., radial velocity searches for giant planets in binary stellar systems, and its significant contribution to the building of the SPHERE instrument for the VLT. The INAF-OAPd team carries out crucial follow-up observations with AdOpt@TNG, with the SARG spectrograph at visible wavelengths and with the upcoming GIANO infrared spectrometer. The INAF-OAPd team contributes with S. Desidera (0.10 FTE) and R. Gratton (0.10 FTE).

The University of Hertfordshire (UoH) team brings a decade-long strong involvement in a wide variety of programmes to detect and characterise extrasolar planets and brown dwarfs**.** Of particular overlapping interest are two main projects closely related to our proposed study: the infrared extrasolar planet transit survey recently awarded 200 UKIRT nights, and the new infrared radial velocity spectrograph for the Gemini Observatory (PRVS). The UoH team helps in the prioritization of the list of M dwarf targets and conducts follow-up observations with the new wide-field infrared camera on the UKIRT telescope, with the PRVS spectrometer and the HARPS-NEF spectrograph, both soon to be operational on Gemini-North and the William Herschel Telescope, respectively. The UoH team contributes with H.R.A. Jones (0.10 FTE) and D. Pinfield (0.10 FTE)

The costs charged to the project are those for the PI salary, the salaries of two scientists in residence at OAVdA, one postdoc in residence at INAF-OATo, one PhD student and the FTE fractions of the INAF-OATo, INAF-OAPd, OAVdA, and UoH staff. The FTE summary table is provided below.

NAME	Institution	FUNCTION	FTE	FTE	FTE	FTE	FTE
			YR 1	YR 2	YR 3	YR 4	YR 5
Alessandro Sozzetti	INAF-OATo	Principal Investigator	0.9	0.9	0.9	0.9	0.67
Mario G. Lattanzi	INAF-OATo	Data reduction, science	0.15	0.15	0.15	0.15	0.11
Mario Gai	INAF-OATo	Instrumentation support	0.15	0.15	0.15	0.15	0.11
Sebastiano Ligori	INAF-OATo	Follow-up, data reduction, science	0.1	0.3	0.3	0.3	0.23
Richard Smart	INAF-OATo	Target selection, data reduction and analysis	0.3	0.3	0.3	0.3	0.23
Postdoc	INAF-OATo	Data reduction, analysis survey observations	1.0	1.0	1.0	2.0	1.5
PhD Student	INAF-OATo	Data reduction, analysis, survey observations	1.0	1.0	1.0	0.0	0.0
Andrea Bernagozzi	OAVdA	Survey observations, real-time data reduction	1.0	1.0	1.0	1.0	0.75
Mario Damasso	OAVdA	Survey observations, real-time data reduction	1.0	1.0	1.0	1.0	0.75
Paolo Calcidese	OAVdA	Scientific support to survey observations	0.1	0.1	0.1	0.1	0.075
Silvano Desidera	INAF-OAPd	Follow-up, science	0.1	0.1	0.1	0.1	0.075
Raffaele Gratton	INAF-OAPd	Follow-up, science	0.1	0.1	0.1	0.1	0.075
Hugh Jones	UoH	Follow-up, science	0.1	0.1	0.1	0.1	0.075
David Pinfield	UoH	Follow-up, science	0.1	0.1	0.1	0.1	0.075

3.2) Infrastructure and Equipment

The infrastructures and equipment on the premises of INAF-OATo, OAVdA, INAF-OAPd, and UoH will be available for all APACHE-related activities at no cost for the project. Access to all INAF-coordinated as well as UK observational facilities identified above as necessary for follow-up observations will also be guaranteed at no cost for the project. The relevant costs include the five telescope systems. We assume at least one year of full warranty on the equipment (thus the beginning of expenditure on consumable is expected to start during the third year of the project). The restructuring of the APACHE survey balcony at

OAVdA for accommodating the group of five telescopes, a total estimated effort of ~245,000 €, will also come at no cost to the project.

3.3) Project Costs

The total project costs do not include a 20% VAT.

(Note: To facilitate the assessment of resources by the panels the following costing table is suggested.)

	Cost Category	**Year 1**[2]	**Year 2**[2]	**Year 3**[2]	**Year 4**[2]	**Year 5**[2]	**Total (Y1-5)**[2]
Direct Costs:	*Personnel:*						
	PI	€ 55,000	€ 55,000	€ 55,000	€ 55,000	€ 41,250	€ 261,250
	Senior Staff	€ 66,600	€ 74,300	€ 74,300	€ 74,300	€ 55,700	€ 345,200
	Post docs	€ 30,000	€ 30,000	€ 30,000	€ 60,000	€ 45,000	€ 195,000
	PhD Students	€ 16,000	€ 16,000	€ 16,000			€ 48,000
	Scientists	€ 60,000	€ 60,000	€ 60,000	€ 60,000	€ 45,000	€ 285,000
	Total Personnel:	€ 227,600	€ 235,300	€ 235,300	€ 249,300	€186,950	€1,134,450
	Other Direct Costs:						
	Equipment	€ 300,000					€ 300,000
	Consumables			€ 20,000	€ 20,000	€ 20,000	€ 60,000
	Travel	€ 15,000	€ 20,000	€ 20,000	€ 20,000	€ 25,000	€ 100,000
	Publications, etc		€ 5,000	€ 5,000	€ 10,000	€ 10,000	€ 30,000
	Other						
	Total Other Direct Costs:	€ 315,000	€ 25,000	€ 45,000	€ 50,000	€ 55,000	€ 490,000
	Total Direct Costs:	€ 542,600	€ 260,300	€ 280,300	€ 299,300	€241,950	€1,624,450
Indirect Costs (overheads):	Max 20% of Direct Costs	€ 108,520	€ 52,060	€ 56,060	€ 59,860	€ 48,390	€ 324,890
Subcontracting Costs:	(No overheads)						
Total Costs of project:	(by year and total)	€ 651,120	€ 312,360	€ 336,360	€ 359,160	€290,340	€1,949,940
Requested Grant:	(by year and total)	€ 651,120	€ 312,360	€ 336,360	€ 359,160	€290,340	€1,949,940

4) Ethical issues

(Note: Research involving activities marked with an asterisk * in the left column in the table below will be referred automatically to Ethical Review)

	Research on Human Embryo/ Foetus	**YES**	**Page**

[2] Adapt to actual project duration.

*	Does the proposed research involve human Embryos?		
*	Does the proposed research involve human Foetal Tissues/ Cells?		
*	Does the proposed research involve human Embryonic Stem Cells (hESCs)?		
*	Does the proposed research on human Embryonic Stem Cells involve cells in culture?		
*	Does the proposed research on Human Embryonic Stem Cells involve the derivation of cells from Embryos?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	X	

	Research on Humans	YES	Page
*	Does the proposed research involve children?		
*	Does the proposed research involve patients?		
*	Does the proposed research involve persons not able to give consent?		
*	Does the proposed research involve adult healthy volunteers?		
	Does the proposed research involve Human genetic material?		
	Does the proposed research involve Human biological samples?		
	Does the proposed research involve Human data collection?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	X	

	Privacy	YES	Page
	Does the proposed research involve processing of genetic information or personal data (e.g. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?		
	Does the proposed research involve tracking the location or observation of people?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	X	

	Research on Animals	YES	Page
	Does the proposed research involve research on animals?		
	Are those animals transgenic small laboratory animals?		
	Are those animals transgenic farm animals?		
*	Are those animals non-human primates?		
	Are those animals cloned farm animals?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	X	

	Research Involving Developing Countries	YES	Page
	Does the proposed research involve the use of local resources (genetic, animal, plant, etc)?		
	Is the proposed research of benefit to local communities (e.g. capacity building, access to healthcare, education, etc)?		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	X	

	Dual Use	YES	Page
	Research having direct military use		
	Research having the potential for terrorist abuse		
	I CONFIRM THAT NONE OF THE ABOVE ISSUES APPLY TO MY PROPOSAL	X	

Section 3: *Research Environment* (max 2 pages)

i. PI's Host institution (INAF)

The Istituto Nazionale di Astrofisica (INAF) promotes, coordinates, and carries out, within the context of programs of the European Union and other International Entities, research activities in the fields of Astronomy, Radioastronomy, Space Astrophysics, and Cosmic Physics, in collaboration with Italian Universities as well as other private and public, national and international research organizations.

In particular, INAF coordinates research activities carried out at national facilities (the Telescopio Nazionale Galileo, TNG, in the Canary Islands, and the Large Binocular Telescope, LBT, on Mt. Graham, Arizona) and at 18 between research institutes and astronomical observatories on Italian soil. The proposed project will be undertaken with the participation of two of the INAF-coordinated astronomical observatories, i.e. the Osservatorio Astronomico di Torino (INAF - OATo), which has been authorized by the legal representative and president of the INAF to formally serve as the PI's host institution, and the Osservatorio Astronomico di Padova (INAF-OAPd).

INAF-OATo: the institute is involved in many research areas, ranging from theoretical astrophysics and data processing to observational astronomy and instrumentation development. Several past and current activities are carried out in collaboration with national and international astronomical institutions, including the European Southern Observatory, the European Space Agency, and the Space Telescope Science Institute. The studies, experiments and observations are based on both ground based instruments (VLBI, TNG, TIRGO, VLT/VLTI, LBT), and on satellites (Hipparcos, HST, IUE, ROSAT, IRAS, Gaia, NGST).

INAF-OATo was involved, in recent years, in the development and use of astronomical instrumentation in the visible, near- and mid-infrared bands (including the integration of three near- and mid-IR cameras), for conventional telescopes and interferometers, as well as in data processing programs. In particular, OATo had a significant participation in the Hipparcos Mission data processing and reduction, operation and calibration of the Hubble Space Telescope Fine Guidance Sensors, and the production of the Guide Star Catalog II for STScI and ESO. OATo contributed to the design study for the interferometric option of the ESA mission Gaia (1996-1998), under ESTEC contract, and to the initial proposal for the NIRVANA interferometric camera for LBT (1998-1999). OATo developed FINITO (1999-2003), the first Fringe Sensor Unit (FSU) for VLTI, in collaboration with ESO, and contributed as sub-contractor to the development of the two units of the PRIMA FSU (currently delivered to ESO-Garching). OATo participates to the JRA 4 of the EU FP6, under Opticon, with activity focused on Co-phasing and Fringe Tracking, and is fostering the development of astronomical interferometry in Italy on both scientific and technological aspects.

INAF-OATo also hosts the PI-ship of the nation-wide INAF activity for the data reduction of Gaia, funded by the Italian Space Agency (ASI), with critical contributions to the astrometric reduction on modelling of the instrument and its operations at the micro-arcsec level, within the context of the pan-European Data Processing and Analysis Consortium (DPAC), which has been awarded by the European Space Agency (ESA) the responsibility for the overall astrometric, photometric and spectroscopic data reduction of Gaia. OATo is also one of the leading institutes in the European Leadership in Space Astrometry (ELSA) initiative, a Marie Curie Research Training Network supported by the European Community's Sixth Framework Programme (FP6).

INAF-OATo confirms its intention to support all activities related to the APACHE survey for transiting low-mass planets orbiting nearby M dwarf stars, in case this application is successful, with the staff manpower involved, according to the program proposed, and with its infrastructures and laboratories (including the telescopes for tests on sky). In particular, it commits itself to ensure that the proposed activity will be fully implemented following the prescriptions set forth in this proposal, under the responsibility and scientific guidance of the principal investigator. It will support the principal investigator in the management of the team and provide reasonable administrative assistance to the principal investigator, in particular as regards the timeliness and clarity of financial information, the general management and reporting of finances, the organization of project meetings as well as the general logistics of the project. It will also provide research support to the principal investigator and his/her team members throughout the duration of the project, in particular as regards infrastructure, equipment, products and services necessary for the conduct of the research. It will ensure the necessary scientific autonomy of the principal investigator, in particular as regards (a) the selection of other team members, hosted and engaged by INAF-OATo, in line with the profiles needed to conduct the research, including the appropriate advertisement; (b) the control over the budget in terms of its use to achieve the scientific objectives; (c) the authority to deliver scientific reports to the Commission. The signed statement on acceptance by INAF-OATo of the general ERC Grant rules, and the intention of signing a supplementary agreement, in which the obligations will be listed in detail, in case of success of the application, will be uploaded as a separate PDF document.

INAF-OAPd: The research activities of the institute cover several key areas of astrophysics, such as galaxies and active galactic nuclei, stars, stellar populations and the inter-stellar medium, high-energy and relativistic astrophysics, and cosmology. INAF-OAPd is also widely actively in the field of exoplanets. Several observational and technological projects are on-going at INAF-OAPd. A major effort is being dedicated to the study of the effects of the dynamical environment (binary systems, star clusters) on the frequency and properties of planetary systems. Additional searches for transiting planets are on-going or planned, and a dedicated radial velocity survey for planets orbiting red giants is in progress. In the next years, the most relevant area of work will concentrate on technological projects aimed at direct detection of exoplanets (SPHERE and EPICS), with significant involvement both on the scientific definition and preparation and on the instrument design and development.

ii. Additional institutions (additional participants)

1) Osservatorio Astronomico della Regione Autonoma Valle d'Aosta (OAVdA)

Saint-Barthelemy Observatory (OAVdA, http://www.oavda.it) is located near a very small alpine village North-West of Italy, at 1,675 m above sea level. In this site the sky is dark and free from light pollution. The observatory belongs to the "Regione Autonoma della Valle d'Aosta" (Italy), and was inaugurated in 2003. The Observatory, from November 2006, has a formal partnership with INAF. A similar agreement has recently been reached with the University of Savoie, France. OAVdA hosts a staff of resident physicists who can guarantee continuity to the carrying out of the scientific operations, from the observations to the data reduction and analysis. The main activities of OAVdA focus on teaching and public outreach, and research in astrophysics.

The primary research activities at OAVdA cover at the moment two areas: 1) astrometric and photometric observations of near-Earth asteroids and studies of the rotational properties of Trojans in collaboration with the Planetology group at INAF-OATo and 2) multi-frequency monitoring of active galactic nuclei (AGNs) in collaboration with the extra-galactic group at INAF-OATo in the context of the international consortium Whole Earth Blazar Telescope (WEBT).

2) University of Hertfordshire (UoH)

The Centre for Astrophysics Research (CAR) at the University of Hertfordshire carries out research on a range of key science questions in astronomy. Research programmes include observations covering wavelengths from X-ray to the radio, extensive computer modelling, theoretical studies and instrument development. In particular, UoH is involved in a wide variety of programmes to detect and characterise extrasolar planets and brown dwarfs. They are one of only a few groups worldwide to discover nearby extrasolar planets and over the last decade have found around 40 extrasolar planets from the radial velocities of nearby stars (the AAT Doppler survey) and from imaging and spectroscopy in Orion. They have also made substantial contributions to the related and similarly flourishing area of brown dwarfs by discovering, characterising and modelling nearby and cluster brown dwarfs by a variety of techniques. They are pioneering a number of new extrasolar planet and brown dwarf projects: (1) using polarimetry to observe the reflected light from extrasolar planets, (2) an infrared extrasolar planet transit survey recently awarded 200 UKIRT nights, (3) a new infrared radial velocity spectrograph for the Gemini Observatory (PRVS), (4) the detection and follow-up of brown dwarfs from the UKIDSS LAS survey, (5) the UKIDSS and VISTA galactic plane surveys. The variety of scientific objectives naturally converges into the long-term ones of the discovery and characterisation of other Solar Systems relative to our own and in particular the detection of extrasolar 'Earths' within the habitable zones of their parent stars as well as the determination of the low-mass mass function and its environmental dependence.