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DETECTION OF GIANT PLANETS WITH THE GTC

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RESUMEN

Con los instrumentos de primera luz del GTC será factible la detección de objetos de masas similares a la de Júpiter en diversos contextos astrofísicos. La cámara para el infrarrojo medio, CANARICAM, puede contribuir a detectar y caracterizar estos objetos alrededor de estrellas con tipos espectrales F–M y alrededor de enanas marrones. Permitirá explorar un dominio de radios orbitales complementario al de las actuales búsquedas basadas en medidas precisas de velocidad radial. Los modos de imagen y espectroscopía de OSIRIS permitirán el estudio de proto-Júpiters en regiones de formación estelar con baja extinción. Ambos tipos de investigaciones son cruciales para nuestra comprensión de los procesos que dan lugar a los planetas gigantes.

ABSTRACT

Detection of objects with masses close to that of Jupiter in various astrophysical contexts will be feasible with GTC first light instruments. The mid-infrared camera, CANARICAM, will contribute to the detection and characterization of these objects orbiting around F–M stars and brown dwarfs. It will allow us to explore a domain of orbital radii complementary to that of current radial velocity searches. The imaging and spectroscopic capabilities of OSIRIS are very well suited to the study of free-floating protojupiters in low extinction young star forming regions. Both types of studies are crucial to our understanding of the processes that originate giant planets.

Key Words: **PLANETARY SYSTEMS: BROWN DWARFS — PLANETS**

1. INTRODUCTION

Jovian-mass substellar objects are known to be orbiting stars in the solar neighborhood (Mayor & Queloz 1995; Marcy & Butler 1996). High precision radial velocity measurements have shown the existence of giant planets with masses similar to that of Jupiter around more than 80 nearby stars. About five per cent of solar-type stars appear to have such planets. The Doppler technique has favored detection of planets in a range of orbital semimajor axis from 0.04 to 4 AU. The generally small angular separation and large luminosity contrast with the parent stars have precluded direct imaging and spectroscopy of these objects. Except for the eclipsing planet around the star HD 209458 (Charbonneau et al. 2000), there is a lack of direct measurements of the planetary atmospheres and our knowledge of their physical conditions is rather limited. Direct imaging of giant planets should bring a wealth of information on these planets and is thus an important goal for the new generation of very large diameter telescopes like the GTC.

Recent deep surveys in very young stellar clusters have shown that the fragmentation of clouds extends well below the frontier between stars and brown dwarfs, reaching the planetary-mass domain (Zapatero-Osorio et al. 2000; Lucas & Roche 2000). Very recently the detection of a 3–5 M_{Jup} object has been reported free-floating in the σ Orionis star cluster (Zapatero Osorio et al. 2002). This is the lowest-mass object directly imaged outside the Solar System. It seems that Jupiter-like objects also exist isolated from stars. Their origins are not yet well understood. Large diameter telescopes like the GTC are crucial to both extending the searches for these free-floating objects to lower masses and to detecting cool giant planets at large separations ($\geq$ 6–10 AU) from their parent stars. Both types of studies are essential to the building of a complete picture of the mechanisms of formation of Jupiter-like objects. This paper outlines some of the contributions that the GTC may achieve in this field.

2. SEARCH FOR GIANT PLANETS AROUND STARS AND BROWN DWARFS

Direct imaging of cool giant planets is an enormous challenge. The large luminosity contrast of a Jupiter analogue with respect a solar-type parent star (larger than 10^9 in the visible) makes direct imaging of these bodies extremely difficult. However, the contrast is much smaller in the mid-infrared ($\cong 10^6$) and a 10 m telescope equipped with a mid-infrared camera like CANARICAM should be able to image them. The expected sensitivity of CANARI-

CAM at 10 μ is $\sim 40 \mu$Jy for a 1hr exposure time. This is sufficient, according to the Arizona models (Burrows et al. 1998), to detect a 1 Gyr jupiter around a star located at 10 pc from the Sun. At earlier ages, it would be possible to detect giant planets at much larger distances since they are expected to be intrinsically much more luminous. Within 30 pc of the Sun there are a large number of very young stars (age less than 100 Myr) which are suitable targets for these searches. At the age of the Solar System, Jupiter analogues are at least 5–10 times fainter in the mid-infrared, much more difficult to detect, but not impossible for very nearby stars.

CANARICAM should routinely provide a FWHM $\sim$ 0.2 arcsec diffraction limited images at 10 μ. A systematic search of all northern hemisphere stars and brown dwarfs within 10 pc (about 200) for objects of masses of a few $M_{\rm Jup}$ orbiting at separations larger than 1 arcsec will result in a major contribution to planet searches, of comparable importance to that of current radial velocity programmes. It is therefore important that CANARICAM achieves the best possible optical quality, particularly with its coronagraphic mode. The detectability of giant planets around most of the nearby F and G stars will possibly require coronography and it will probably be limited to separations larger than 10 AU, complementary to the domain explored by Doppler searches. Detection around the intrinsically fainter very low mass stars and brown dwarfs in the solar neighborhood will not require coronography. Orbits as close as 2–3 AU will be easily explored around targets which are currently not accessible to the radial velocity programmes. At such small physical separations, the orbit of any detected giant planet can be directly measured in a few months or years, providing a complete characterization of the systems. There is an enormous potential for this research which will undoubtedly bring crucial information to our understanding of the formation and evolution of giant planets.

3. ISOLATED PLANETARY-MASS OBJECTS IN STELLAR CLUSTERS (IPMOS)

The classical picture of formation of jupiters in protoplanetary disks has been recently challenged by the detection of a rather numerous population of objects with masses below 10 $M_{\rm Jup}$ in very young stellar clusters and star forming regions. In the young (age 3–7 Myr) σ Orionis star cluster, the correlation of deep optical and infrared images obtained by our group allowed identification of 18 objects with

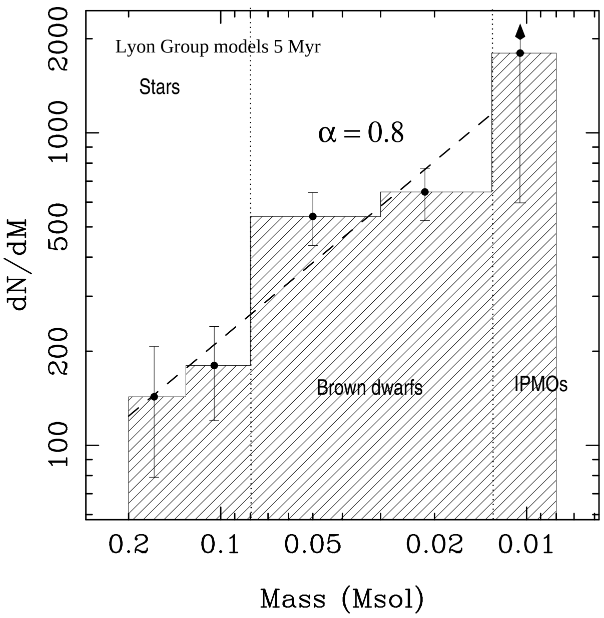

Fig. 1. Substellar mass function in the young star cluster σ Orionis, adapted from Béjar et al. (2001).

masses within the planetary-mass regime, i.e., below the deuterium-burning mass limit ($M < 0.013\ M_\odot$). Spectroscopy of these objects resulted in classification as types L0–L4 ($T_{\rm eff}$ $\sim$2000–1500 K), extending significantly the substellar spectral sequence in the cluster (Zapatero Osorio et al. 2000; Barrado y Navascúes et al. 2001; Martín et al. 2001). As shown in Figure 1, these findings suggest a smooth extrapolation of the brown dwarf mass function $dN/dm \sim m^{-0.8}$ (Béjar et al. 2001) to the domain of planetary masses. The contribution of isolated planetary-mass objects (IPMOs) to the last bin in Figure 1 is actually a lower limit owing to the incompleteness of the survey at their faint magnitudes.

The behavior of the mass function in the 10–1 $M_{\rm Jup}$ is crucial to delineating the formation mechanism that gives rise to IPMOs. Are they formed in protoplanetary disks around stars and then ejected? Or are they formed in the same fragmentation process as low mass stars and brown dwarfs? What is the minimum mass of objects produced in such process? How sensitive is the substellar mass function to the physical conditions of the original cloud and in particular to the presence of very massive stars? How frequent are jupiters orbiting stars compared to free-floating ones? OSIRIS is a powerful instrument to address these questions. The imaging mode is well suited to extending the search for IPMOs to lower masses and to exploring star forming regions of

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different characteristics. At the typical distances of star forming regions in Orion, a few Myr-old protojupiters will probably show magnitudes $I \sim 26$ and colors $I - Z \geq 2$. Their spectral characteristics will be similar to those of methane brown dwarfs with a very steep spectrum between the I and J bands. I vs. $I - Z$ color–magnitude diagrams are very efficient discriminators for these objects. Exposure times of less than 1 hour per filter and field should be sufficient for an effective search programme. The relatively high density of IPMOs in the σ Orionis cluster (about 0.25 objects per arcmin^2) suppports the probable discovery of several such objects per OSIRIS field. Follow-up spectroscopy with the multiobject mode will be an efficient way to confirm their nature. Second-epoch imaging with a baseline of several years will provide proper-motion measurements and further insight into the process of formation.

If the recent findings in σ Orionis were representative of other star forming regions and, in general, of the Galactic disk, free-floating Jupiter-like objects would be as numerous as solar-type stars. Some very efficient mechanism for formation of this kind of object may be present in nature. It could possibly be more efficient than the much more intensively studied formation processes in protoplanetary disks. Prospects to disentangle this new mechanism with the GTC are very exciting.

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