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SCIENCE WITH A WIDE-FIELD 6.5-M SPECTROSCOPIC TELESCOPE

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RESUMEN

Se describe el caso científico para un telescopio espectroscópico de campo amplio de 6.5-m. Las metas científicas principales están ligadas a dos modos diferentes de operación: (1) El estudio de la astrofísica detallada de sistemas extendidos por medio de espectroscopía de alta calidad y mediana resolución usando múltiples unidades de campo integral (IFU) y (2) El estudio de la estructura del Universo mediante espectroscopía de múltiples fibras de sistemas distantes y/o compactos.

Este telescopio de campo amplio complementará y extenderá las posibilidades disponibles con los telescopios actuales, aumentando significativamente el potencial para nuevos descubrimientos, al mismo tiempo reduciendo las posibilidades de fallas científicas. Estrategicamente intentamos atacar la mayor diversidad posible de áreas astrofísicas competitivas, minimizando el número de instrumentos.

ABSTRACT

This document describes the scientific case for a wide-field 6.5-m spectroscopic telescope. The key scientific aims are linked to two different modes of operation: 1) Study the detailed astrophysics of extended systems via high-quality, medium-resolution spectroscopy using multiple Integral Field Units (IFU) and 2) Study the structure of the Universe via multiple, single-fiber spectroscopy of distant and/or compact systems.

This wide-field spectroscopic facility will complement and extend present facilities, greatly enhancing the potential for new discoveries while at the same time minimizing the chances of scientific failure. Strategically we aim to address the widest possible range of astrophysically competitive areas while minimizing the number of instruments.

Key Words: **TELESCOPES**

1. INTRODUCTION

New telescope facilities, and their associated instrumentation, will always seek to improve along three directions: larger collecting area, better resolution in wider fields, and broader wavelength coverage. Unfortunately, for a given resolution and sampling performance, telescope aperture and covered field compete against each other. From the point of view of the relevant scientific drivers, on the other hand, both wide-field and high-spatial resolution optical-IR telescopes are the most-needed tools to address present-day and future key astronomical questions. Therefore, extremely large telescopes, with 20+ meter primaries, are better tools for reaching and resolving fainter and more distant objects, while large telescopes (6 to 10-m class), with more stable and less demanding instrumentation, are more suitable for wider field studies and broader wavelength coverage.

A group of astronomical institutions from México, Korea, UK and the USA are committed to construct and operate, on the shortest possible timescale, a highly competitive large telescope facility at the San Pedro Mártir (SPM) Observatory. The SPM site is one of the best astronomical locations in the northern hemisphere for optical and infrared observations, and is an excellent place to host either wide-field or high-spatial resolution facilities (Tapia 2003; González et al. 2007). Our objective is to tackle, with a carefully chosen pair of mid-size telescopes, some of the most important scientific niches not covered by extremely large telescopes. One telescope will be optimized for wide-field spectroscopic observations in the optical and near infrared, while the second one will be optimized for high-spatial resolution observations at mid-infrared wavelengths.

This document describes the scientific case for the wide-field telescope.

2. SCIENCE WITH THE WIDE-FIELD TELESCOPE (WFT)

When planning new facilities the simple solution of enlarging existing ones, either in size, sensitivity

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or wavelength coverage is not always the most efficient path to improvements in science. As the SDSS survey collaboration has shown (see www.sdss.org), a well planned and targeted project, run by a top quality team can make a 2.5-m telescope extremely competitive in an era dominated by 8 and 10-m telescopes.

In the strategic planing of a new facility it is important to find the areas that, while extending and complementing present facilities, also include the areas of research in which the user community excels. This aspect is fundamental to maximize the science potential of the facility and reduce the risk of scientific failure.

Our main driver is to address fundamental questions about the origin, structure and evolution of the Universe and its contents.

The technological advances in telescope and instrument design plus the incredibly fast growth in computing power and in wide-field imaging surveys, coupled with recent model developments in the evolution of stars, galaxies, and the Universe, indicate that one can look beyond the detailed study of a few objects, or the global study of many, to systematic investigation of large samples in order to understand their GLOBAL properties, their formation and evolutionary history, and their cosmological significance.

All these problems need a large telescope with the widest field feeding the largest number of detectors or pixels. This is the most cost-effective telescope.

Two projects have had a large influence on the present proposal, the SDSS and SAURON (see www.strw.leidenuniv.nl/sauron/). SDSS has shown that projects that combine a top group of researchers with a design that optimizes all stages to obtain the best dataset can produce a deep and lasting impact in astronomy. We would like to reap the benefits of a project that combines an optimization of original science with its scope, instrumentation and human resources. SAURON, on the other hand, shows the quality of science that can be achieved by combining the use of Integral Field Units with advanced theoretical models.

3. MAIN SCIENTIFIC AIMS

The keywords for the scientific aims of the wide-field telescope (WFT) are the study of EVOLUTION and STRUCTURE by looking at the Universe at many of its scales. Among the key science problems to be tackled are:

1. The cosmic history of star-formation. This can be studied in more than one way.

• The "direct" method uses the Universe as a time-machine and obtains the "Madau-Lilly Diagram" by observation and analysis of the Universe as a function of distance or look-back time.

• The "fossil" or "local" (a.k.a. "astro-archaeological") approach. By analyzing the $z \sim 0$ Universe and comparing with stellar evolutionary models one finds the age and metallicity distributions of stars in individual galaxies. Thus it is possible to obtain locally the star formation history of the Universe.

Interestingly, these independent methods agree fairly well, making their combination a very powerful approach to test models of galaxy formation and evolution. The fossil approach includes:

• Extended systems: evolution of the stellar populations and the ISM through the study of their chemistry, structure and dynamics in nebulae and galaxies.

• Resolved systems: stellar formation and evolution in the Milky Way, the Local Group of galaxies, and nearby groups and clusters. The initial mass function and the properties of stellar clusters and systems, planetary Nebulae, Wolf-Rayet stars, etc.

2. The determination of the parameters describing the Universe, in particular the equation of state of dark energy. This project makes use of the acoustic oscillations in the baryonic component to measure the time variation in the equation of state of dark energy. This is done by measuring the linear oscillations and comparing them to the oscillations seen in the CMB at the last scattering surface. This project requires a large galaxy redshift survey at moderate to high z. This type of project becomes possible with wide field spectroscopy from a large telescope, i.e.. the WFT.

One important consideration to guarantee a wide scientific scope and minimize the chances of scientific failure, is that the data obtained for the projects or modes of operation above (this applies particularly to point 2) should be of sufficient quality to allow the performance of front-line research in topics such as:

• Detailed studies of the star-formation process in active regions in our own and nearby galaxies.

• The evolution of clustering and the growth of large scale structure in the early Universe.

• Star formation at extremely high redshift and the assembly of gas into galaxies.

• Gravitational lensing as a probe of large scale structure and the distribution of dark matter.

• Detailed studies of early and late stages of stellar evolution

• Search and research of low luminosity stars, sub-stellar objects, and extra-solar planets and other lines of research such as those presented in the next section.

We therefore believe that a wide-field facility, where telescope and instrumentation are optimized for multi-object spectroscopy, is at present the missing facility that is needed to carry out this science. Most of the instrumentation in 8-m class telescopes is oriented toward small field survey work. Our proposal is to construct a system with an integrated telescope and spectrograph design that achieves deep (28 mag), high-throughput, simultaneous (500 to 10.000 objects, 10,000 fibers) spectroscopy over a wide field (at least 1.5 degrees diameter) from the near UV to the near IR.).

This can be achieved with the use of two different front-ends to a battery of spectrographs: one front-end with multiple robotic IFU units, the other with individual fibers independently positioned.

With a collecting area seven times larger than the SDSS telescope and an image sharpness three times better on average, if the project is placed in a site like San Pedro Mártir, the WFT will provide spectrophotometry that is about two orders of magnitude deeper than that provided by surveys like the SDSS. These spectroscopic observations will map in each galaxy with a resolution better than 1 arc-sec, its kinematics, dynamics, masses, chemical composition of stars and interstellar medium, the star formation history and their chemical evolution, etc.

In the single aperture spectroscopic mode, achieved with the individual fiber front-end, the wide field of this telescope will allow the simultaneous observation of about 10,000 compact, unresolved objects. This second mode of operation is targeted to deep and wide redshift surveys needed to accurately constrain the cosmological parameters describing the Universe or to study the stellar content of Local Group galaxies.

4. OTHER SCIENTIFIC AIMS

The WFT will also enable a variety of research projects with a much wider scope than the main drivers above. Bearing in mind that several 8-m class wide-field telescopes are or will be producing in the next few years enormous data sets of deep, broad-band imaging, a wide-field spectroscopic telescope will benefit from the availability of this data and in turn will open a completely new type of science, reaching to the edges of the local group in the study of individual stars and to the edge of the observable Universe in the study of galaxies and QSOs.

Since all kinds of images can be reconstructed from the IFU spectra, among many other research possibilities offered by the WFT are:

- Emission line intensity maps of the local and extragalactic ISM and nebulae, leading to 2D maps for their temperature, density, chemical composition, ionization state, reddening and dust content, as well as the distribution and total content of the ionized gas mass. This information can be correlated with other parameters such as redshift and galaxy morphology.
- Research on the diffuse ionized gas in the local Universe in order to determine its prevalence, ionization state, morphology, distribution and luminosity, as well as variations with galaxy morphology.
- Emission line rotation and linewidth maps leading to galaxy surface density distribution and accurate total mass determinations.
- Imaging and kinematics of barred spirals in the local Universe to understand their effects on nuclear activity and disk development, among others.
- Absorption line maps leading to maps of stellar population age and abundances.
- Exploration of the evolution of the fundamental plane of ellipticals.

Bearing in mind that the single aperture mode in the WFT will be used only in compact/unresolved or distant galaxies, it will be relatively free of the main weakness of spectroscopic surveys of galaxies like the SDSS. I.e., the strong bias introduced by the fact that all galaxies are observed through a similar aperture independent of its distance or size.

In the single aperture mode the WFT will be able to extend to a larger distance the type of spectroscopic survey pioneered by the SDSS collaboration and obtain for each distant or compact galaxy accurate

- Redshifts
- Stellar population ages
- Elemental composition of the stellar component (Fe, α elements, O, etc.).
- Composition of the ISM (H, He, D, C, N, O, Ne, S, Ar, Fe, etc.).
- Several modes of reddening determination (stellar methods, nebular methods).
- Kinematics and dynamics of their component stars.
- Kinematics and dynamics of their ISM.
- Composition and kinematics of nebulae, such as HII regions, PN and SNR (includes their discovery).

All this and more with a telescope field that nicely matches the sizes of clusters of galaxies, meaning that the galaxies of a complete cluster can be studied simultaneously providing additional advantages for the studies of intrinsic properties of these systems.

Projects like the LSST (see www.lsst.org) and the KAOS/WFMOS (Basset et al. 2005) are the scientifically most ambitious, technically feasible wide-field implementations, but the specifics of their designs are of little use for the goals of WFT. The LSST is a telescope optimized for wide-field direct imaging which may not easily accommodate integral field spectroscopy. The present KAOS/WFMOS design, aimed in principle at the same goals as WFT, is driven by the need to modify the front-end at the prime focus of existing 8-m telescopes. This operation is financially difficult, mechanically compromising, and incompatible with a compact Magellan-type telescope design.

No existing modern large telescope has been designed to reach a field-of-view in excess of 1° for integral-field spectroscopy as sought by the WFT. The Magellan consortium has built, and is successfully operating, two twin 6.5-m telescopes at the Las Campanas Observatory in Chile. The mirrors were made and polished by the Mirror Lab of the University of Arizona, who is also a partner in the present project. The telescopes are Gregorian reflectors, and one of them also has a Cassegrain f/5 secondary to match the requirements of wide-field instruments. The existing Magellan telescopes have a much smaller field-of-view but they represent a very efficient, compact, and affordable solution to start the design of the WFT. Details of possible implementations can be found elsewhere in this volume (see González 2007; González & Orlov 2007).

5. GENERAL LINES REGARDING THE WFT INSTRUMENTATION

The basic strategy driving the design of the instrumentation is that it should amply satisfy the scientific requirements, maximize the output, have the highest performance and stability even under the most extreme weather conditions, be easy to use and operate with minimum costs.

In general terms the desired instrumentation is considered as an integral part of the telescope design and includes:

1. An instrumental set for Wide-Integral field spectroscopy, consisting of four main parts:

a) A wide-field and atmospheric-dispersion corrector (WFC) capable of producing polychromatic $0.5''$ images at distances 0.75° from the center.

b) Two different front-ends will connect spatial probes on the sky to a set of spectrographs:

b1- a robotic system positioning the IFU for extended objects,and

b2- an individually moving fiber system (WFMOS-like) for unresolved objects. The size and shape of each IFU is designed according to scientific and experimental requirements. The field-of-view of a square compact IFU with 800 140 μm fibers is approximately 30×30 arcseconds.

c) About 12 monolithic fiber-fed spectroscopic units, all of them with a spectral coverage from the UV cutoff at 0.32 μm up to 2.2 μm. This implies that each unit will have three spectroscopic arms or units designed for maximum efficiency in the following wavelength ranges (with some wavelength overlap):

0.32 μm to 0.55 μm (BLUE arm),
0.55 μm to 1.00 μm (RED arm) and
1.00 μm to 2.20 μm (NIR arm).

The incoming light will be dichroically split. The motivation driving the BLUE and RED arms is the CCD detector efficiency, which can be maximized for either wavelength range but not for both simultaneously.

Each spectroscopic unit will be fed by some 800 fibers, each with a $\sim$ 140 μm core. The targeted instrumental resolution is 15 μm. Notice that the resolution can improve if the fibers are "thinned" at the entrance slit, which would also reduce the slit length and the spectrograph size and complexity.

A spectral resolution of R = 5000, or 25 km s^{-1} (1σ) is achievable in both optical arms (smaller resolutions and higher S/N can be achieved by binning). This resolution is equal to the typical minimum line width of all kinds of galaxies, but twice as much as objects such as HII regions, PN and globular clusters. Since the spectroscopic units would be replicated, design, development, cost and time issues would benefit. Furthermore, maintenance and repairs could be done without sacrificing telescope time.

2. A wide-field unit for narrow and intermediate band imaging (FWHM starting from $\sim$ 10 Å) with a spatial sampling of roughly $0.50''$/pixel or better, preferably using a pair of tunable filters optimized for the blue and red parts of the visible range. A third CVF for NIR imaging in the J, H and K bands as well as narrow band filters in interesting lines, such as HII, would also be desirable even after the limitations of NIR efficiency, given that the field corrector and collimator will not be cryogenic.

There are about 27 million square-arcseconds in a 1.5 degree field-of-view, making it impossible to cover at the same time all spatial and wavelength resolution elements.

With these instruments the WFT provides on the one hand, full spectral coverage for the largest affordable number of spatial probes over the field-of-view and, on the other hand, full spatial coverage and resolution of the wide-field over a continuum of narrow-band wavelength intervals.

6. CONCLUSIONS

We find that there is a large and important scientific niche to be covered by large, wide-field spectroscopic telescopes. A facility that can provide high S/N 3D spectra of few hundred thousand galaxies simultaneously covering 3600Åto 1.8 microns with R = 5000, and also high S/N 2D spectra of a few million galaxies, again covering 3600Åto 1.8 microns with R = 5000, all during its first few years of operation, would have a profound impact on modern astrophysics.

It would allow us to tackle some of the most interesting problems in astrophysics such as:

1. The determination of cosmological parameters, in particular the equation of state of dark energy, and perhaps more importantly,
2. The study of the formation and evolution of galaxies over a wide range of look-back time,
3. The detailed mapping of the structural parameters of nearby galaxies leading to, among many other projects, the local reconstruction of the history of star formation and chemical evolution of galaxies.

All this no doubt will go a long way to answer fundamental questions such as:

- What is the geometry of the Universe?
- What is dark energy?
- How does the evolution of the stellar population and ISM of galaxies in the nearby Universe compare with that of distant galaxies?
- How do the star formation histories of the Universe as determined by the “direct” and “fossil” methods compare and what constraints do they impose on the theory of formation and evolution of galaxies?
- What formation mechanisms determine the structure of galaxies?
- How does galaxy formation and evolution depend on the formation and evolution of large scale structure?
- What mechanisms determine the yields, dispersal and mixing of metals in the Universe?

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