Tracing the Ancestry of Galaxies (on the land of our ancestors)
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3D Spectroscopic Surveys of Late-Type Nearby Galaxies in the Optical

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Abstract. Two classes of spectro-imagers are available, the first one, usually based on grisms, allows to cover intermediate fields of view and wide spectral ranges (decreasing when the spectral resolution increases) while the second one, usually based on tunable filters (like Fabry-Perot), is generally able to cover larger fields of view but on narrow spectral ranges (also depending on the spectral resolution). Both families of instrument have access to low or high spectral resolution and are used in seeing limited conditions for observing nearby galaxies. Spectro-imagers provide data cubes consisting of a spectrum for each spatial sample on the sky. From these spectra, using both emission and absorption lines, combined with the continuum emission, the history of the stars and the interstellar medium in nearby galaxies, encoded in different physical quantities, such as chemical abundances, kinematics properties, is deciphered. Only a few surveys of galaxies using spectro-imagers have been led up to now and mainly using 4-m class or smaller telescopes. This includes the case of nearby late-type galaxies surveyed in the optical. Two large surveys of some 600 galaxies each have just been launched, one on the Magellan 6m telescope (CGS) and the other one on the William Herschel 4.2m telescope (CALIFA). Surveys containing a smaller number of galaxies have been conducted elsewhere, for instance on the WIYN and Calar Alto 3.5m telescopes (the DiskMass survey, 146 galaxies); on the ESO and CFHT 3.6m telescopes (CIGALE, 269 galaxies); on the OHP 1.92m telescope (GHASP, 203 galaxies); on the mont Mégantic 1.6m telescope (107 galaxies) and on the San Pedro Mártir 2.1m telescope (79 galaxies). Other programs surveying less then 50 galaxies have been also led, like VENGA, SAURON, PINGS or GHaFaS. The scientific drivers of these surveys are broad, they span from the study of the structural properties, star formation histories, AGN content, to mass profiles and uncertainties in rotation-curve decompositions, nature and formation of bulges and disks components.

Keywords. galaxies: general, fundamental parameters, abundances, kinematics and dynamics, ISM; instrumentation: spectrographs; surveys

1. The instrumental point of view

3D spectroscopic instruments are also called spectro-imagers or integral field spectroscopes (IFS). They allow to get data cubes consisting of 2D images for which a spectral energy distribution is available for each spatial sample of the images. Without adaptative optics correcting the atmospheric turbulence, the spatial sample is limited by the seeing. For nearby galaxies occupying a broad solid angle on the sky, in order to increase the field of view (FoV) for a given number of pixels on the detector, the spatial sampling is sometimes not limited by the seeing but by the physical size of the modules sampling the FoV (fibers, slicers, microlenses,...), that might be larger than the seeing. Data cubes constitute a large improvement with respect to 2D data for which either the spatial information along one direction (long slit spectrographs) or the spectral information (broad or narrow band images) is missing. Unfortunately, 3D detectors (energy-resolving sensors able

to detect the energy of individual photons) with acceptable performances and sizes are not yet available on the market thus, *volumic* 3D data cubes still need to be dispatched on the surface of 2D sensors. Even using the largest CCD available nowadays (including broad mosaics of large individual CCDs), only a tiny fraction of the spatial and spectral information available at the focus of telescope can fit, during one single exposure, on the sensor. This leads to define an efficient spectroscope as an instrument using, all the time, the whole surface of its receptor and to conclude that it should be chosen to collect from the sky only the needed information (P. Fellgett). Furthermore, to optimize the collect of information discontinuously dispatched throughout large FoVs available at the telescope focus, the concept of *multi*-integral field spectroscopes has been developed since the '90, usually refereed as integral field units (IFUs). Micro-lens arrays, fibre-lenslet arrays or images slicers are used to select multiple FoVs. Nevertheless, multi-object spectroscopes (MOS) which select the targets on the sky using mono fiber positioned, movable slitlets or multi-aperture plate are not 3D spectroscopes because they do not provide images at the contrary of IFS or scanning long-slit spectrographs.

To clarify the concept of spectroscope, following Fellgett (1958), two classes should be defined: the spectrographs and the spectrometers. A spectrograph allows a *spatial* measurement of the position of maximum intensity of a line or of a fringe on the detector while a spectrometer allows its *temporal* measurement. In other words, a spectrograph is associated to an unique image obtained during an unique reading of the image sensor while a spectrometer is associated to a scanning sequence obtained during several readings of the detector. Both spectroscopes are equally efficient if, any time, the whole surface of the sensor is optimally used. Spectrographs usually use grisms to disperse the light while spectrometers request interferometers. Examples of spectrometers are tunable image filters (TF), Fabry-Perots (FP) and Fourier transform imagers systems (FTS). Their *"ecologic"* niches are different, spectrographs are used when the science drivers request large spectral ranges and small FoVs while spectrometers are preferred when larger FoVs and smaller spectral ranges are preferred. Interestingly, a wiki site lists the main IFS available through the world (http://ifs.wikidot.com/instruments).

2. Overview

Even if nowadays the new facilities allow to get exciting resolved observations of distant and primordial galaxies up to a redshift z$\sim$3 (see B. Epinat's review in this proceeding), nearby galaxies still present fundamental interests. They indeed constitute the ultimate stage of galaxy evolution and allow, due to their proximity, the detailed studies needed to tackle fundamental issues in galactic structure and dynamics. IFS observations of nearby galaxies give data cube from which 2D resolved maps could be extracted allowing the study of the different disk components such as bulges, bars, inner and outer disks or rings. IFS data cube provide for each pixel of the galaxy a spectrum from which absorption and emission lines could be extracted from the continuum emission. The stellar population, chemical abundances and kinematics properties are deduced from both emission and absorption lines and from the continuum. These properties allow to decipher the history of the stars and the interstellar medium (ISM) in galaxies encoded in different quantities. The study of the ISM is mainly done measuring fluxes, barycenters and widths of emission lines combined with emission line ratios while the stellar content is constrained using the continuum distribution and the absorption line strengths and ratios. Emission and absorption lines allow to understand *(i)* respectively the gas and stellar kinematics (radial velocities, radial velocity dispersions,...), *(ii)* the chemical abundances (metallicities of the composite stellar populations and of the ISM), *(iii)* the star formation

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rates, stellar populations and galactic feedback, *(iv)* the density and ionization states, *(v)* the dust extinction and content and *(vi)* the ages of the different populations. The surveys presented in the next section are led by different groups to address these topics.

3. Undergoing 3D spectroscopic surveys of late type nearby galaxies in the optical

3D Spectroscopic observations of galaxies have became popular these last ten years but surveys of nearby galaxies are not yet led on 8-10 meter class telescopes because they are too time consuming. Nevertheless, surveys or nearby late-type galaxies recently started on 4-6 meter class (and smaller) telescopes. This section focuses on the different undergoing optical surveys of nearby late-type galaxies. The surveys are classified through their FoVs, spectral ranges and spectral resolutions (R_λ), which is basically equivalent to a classification based on the nature of the spectroscopes used (spectrograph or spectrometer). Additional instrumental parameters of the surveys are given in the table.

3.1. *Spectrograph - intermediate FoV ∼1', large spectral range, R_λ∼1000-2000*

CGS (Carnegie-Irvine Nearby Galaxy Survey) -In the near future, the CGS (Seigar *et al.*, 2006) plan to obtain 3D data for a sample of 603 bright southern hemisphere galaxies. These galaxies have already been imaged in the BVRIK wavebands at Las Campanas Observatory, with a median seeing $\sim 0.6''$. Multi-slit spectroscopy of the sample will be realized on GISMO (Magellan Telescope). The goals of this survey is to study the structural properties, mass profiles, star formation histories, and AGN content of nearby galaxies across the entire Hubble Sequence (see Luis Ho's publication in this proceeding).

CALIFA (Calar Alto Legacy Integral Field Area) - The CALIFA Survey (Sánchez *et al.* (2010)) is a large 3D survey of $\sim$ 600 nearby galaxies (selected from the SDSS). It was launched 6 months ago and the observations will start soon. This program spans over 6 semesters and will use 250 observing nights. The main scientific drivers of this survey is to study the stellar population and the star formation histories, to estimate the chemical abundances of the ISM and the kinematic properties.

SAURON (Spectrographic Areal Unit for Research on Optical Nebulae) - Using the SAURON 3D spectrograph, 24 nearby late-type galaxies have been surveyed with the aim to study the nature and the formation of nearby galactic bulges (Ganda *et al.* (2006), Ganda *et al.* (2007), Peletier *et al.* (2008)). From the 2D stellar velocity fields, it has been shown that *(i)* the (stellar) cores are kinematically decoupled from the rest of the disk in half the cases (12/24 galaxies, perhaps from cold gas being acquired during the ongoing interaction); *(ii)* the misalignments between stellar or gaseous position angle of the galaxy and the bars are the main source for non-axisymmetries in spirals; *(iii)* the central velocity dispersion drops in is due to the presence of young stars; *(iv)* higher star formation rates are observed for lowest H_β velocity dispersion (the stars being formed from cold gas accretion). These authors proposed that galactic bulges have more than one physical component: a slowly-rotating, elliptical-like, and one (or more) fast rotating in the plane of the galaxy. They concluded that the central star formation is *(i)* likely governed by short star bursts in early-type spirals; *(ii)* quiescent in late-type spirals, and *(iii)* faint in ellipticals and lenticulars.

VENGA (VIRUS-P Exploration of Nearby GAlaxies) - The VENGA project (Blanc *et al.* (2010)) is an ongoing survey targeting the central regions of galactic disks, out to a radius of $0.7D_{25}/2$, for a sample of 32 nearby Sa-Sd galaxies. The galaxies selected on the basis on available multi-wavelength data (from UV to radio emission),

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span over a wide range of Hubble type, star formation activities and inclinations. The goal of this survey is to study in star formation, structure assembly, galactic feedback and ISM in galaxies.

PINGS (PPAK IFS Nearby Galaxies Survey) - The PINGS survey (Rosales-Ortega *et al.* (2010)) is an ongoing 3D survey of 17 nearby disk galaxies leads with the aim of studying star formation, gas chemistry and their variations across late-type galaxies. Interesting illustrations have been provided in mosaicking the galaxy NGC 628 (Sánchez *et al.* (2011)).

3.2. *Spectrograph - intermediate FoV∼1', large spectral range, R_λ∼10000*

DiskMass - The aim of the "DiskMass" survey is to understand the uncertainties in rotation-curve decompositions (Bershady *et al.* (2010a,b)). Indeed, the baryon-to-total mass fraction is not a well-defined observational quantity because it is coupled to the halo mass model. This survey has been designed *(i)* to yield random and systematic errors small enough to confirm or disprove the maximum-disk hypothesis for intermediate-type disk galaxies, *(ii)* to provide an absolute calibration of the stellar mass-to-light ratio well below uncertainties in present-day stellar-population synthesis models and *(iii)* to define the shape of dark halo profiles in the inner regions of disk galaxies. Following the approach pioneered by van der Kruit & Freeman (1984) (on long slit data), they conduct a direct and absolute measurement of the dynamical mass-to-light ratio in using collisionless tracers (disk stars) to measure the disk potential. This method is optimized for low inclination disk galaxies because it minimizes *(i)* the line-of-sight velocity dispersion contamination, *(ii)* the beam smearing from velocity-field shear and *(iii)* the extinction effects on the derived surface brightness, color, and velocity dispersion of the disk. Nevertheless, the total dynamical mass of a galaxy (extracted from its rotation curve) is computable only for galaxies which are not exactly face-on ($i \neq 0^o$). A sample of 146 nearly and regular UGC galaxies with inclination disk galaxies ranging between 25 and 35^o is being observed at 515, 660, and 860 nm using a high spectral resolution spectro-imagers.

3.3. *Spectrometer - large FoV ∼5', narrow spectral range, R_λ >15000*

Fabry-Perot data are being available on the data base http://fabryperot.oamp.fr/.

GHαSP (Gassendi Hα survey of SPirals) - The GHASP survey, now completed, consists of 3D Hα data cubes for 203 spiral and irregular galaxies for kinematics analysis. It is the largest homogeneous sample of Fabry-Perot data published to date. It demonstrates *(i)* the increased accuracy of position angles measurements using kinematical data, *(ii)* the difficulty to reach robust determinations of both morphological and kinematical inclinations in particular for low inclination galaxies and *(iii)* a good agreement between the Tully- Fisher relationship derived from these data and previous determinations found in the literature (e.g. Epinat *et al.* (2008)). As already shown using a preliminary Fabry-Perot survey of 12 late type galaxies by Blais-Ouellette *et al.* (2004), mass models favor dark matter halos with a constant density core in the center of the galaxies rather than a cuspy core as predicted by the canonical cosmological ΛCDM model. This had been confirmed using a subsample of the GHASP survey in showing that *(i)* halo surface density is constant over a wide range of magnitudes and morphological types; *(ii)* small core radius have higher central surface density and *(iii)* dwarf galaxies have more concentrated dark matter halos than earlier types (Spano *et al.* (2008)). The GHASP data have also been used to simulate high redshift galaxies and pointed out strong evidence for dynamical evolution in disk galaxies through the last 11 Gyr (see B. Epinat's review in this proceeding).

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CIGALE (CInematics of GALaxiEs) - The acronym CIGALE covers several kinematical studies of galaxies in clusters and in Hickson compact groups (HCGs) as well as low surface brightness (LSBs), blue compact (BCGs), elliptical and tidal dwarfs (TDGs) galaxies. The galaxies have mainly been observed using the ESO 3.6m telescope but also the CFHT 3.6m telescope (MOSFP).
(Clusters)- A set of 45 galaxies belonging to different nearby clusters of galaxies was used to demonstrate that the dark halo have not been stripped in cluster galaxies, at least up to the optical radius (Amram *et al.* (1993)).
(HCGs)- A set of 105 late type galaxies has been observed. The velocity fields extracted from the data cubes allowed to derive a rotation curves (RCs) only for two thirds of the sample. Among them, half displays a "normal" shape and the other half shows a peculiar behavior (e.g. Torres-Flores *et al.* (2010)).
(LSBs and late type Spirals)- Early 3D observations of late type spirals by Blais-Ouellette *et al.* (1999) have shown that the central dark halo profiles are more likely core-like than cuspy. One step forward was to study LSB galaxies that allow, due their negligible disk component with respect to their halo, to address directly the inner halo shape. The analysis of a sample 36 nearby faint dwarves and LSB galaxies is in progress (Chemin *et al.* (2008); Chemin *et al.*, in preparation).
(BCGs) - In extension of a previous study by Ostlin *et al.* (2001), 50 BCGs and emission-line galaxies have been targeting. Their complex Hα kinematics suggest that strong starbursts deeply modify the kinematics and the dynamics of these galaxies.
(Ellipticals) - Early 3D observations of 15 elliptical galaxies, selected from their Hα content, have shown the existence of extended rotating Hα disks (Plana *et al.* (1998)). Five additional elliptical have been observed in 2000 (Rampazzo *et al.* (2003)).
(TDGs)- Recycled galaxies can form in the collisional debris of massive galaxies, the so-called TDGs. Contrary to theoretical models predicting that TDG should be free of dark matter, they do contain a massive dark component, perhaps located in large amounts of unseen, presumably cold, molecular gas. This additional mass should be present in the disks of their progenitor spiral galaxies, accounting for a significant part of the so-called missing baryons (Bournaud *et al.* (2007)).

GHαFaS (Galaxy Hα Fabry-perot System for WHT) - GHaFaS is available (since 2007 July) at the 4.2 m William Herschel Telescope. GHaFaS provides a facility over a 7' seeing limited circular field. GHaFaS is mainly used for studying the internal dynamics of star-forming HII regions and their efficiency in interacting with the ISM (Blasco-Herrera *et al.* (2010)) but one of its key program is the dynamics of nearby spiral galaxies (Fathi *et al.* (2009)), specially in the Virgo Cluster.

FaNTOmM (Fabry-Perot de Nouvelle Technologie pour l'Observatoire dumont Mégantic) - The Instrument FaNTOmM was devoted to several programs:
(SINGS 3D Hα)- A subsample of 61 galaxies extracted from the SINGS (Spitzer Infrared Nearby Galaxies Survey) sample has been observed using the FaNTomM and CIGALE instruments (see table and Dicaire *et al.* (2008)). Kinematics of galaxies in common from this 3D Hα and from the THINGS surveys (The HI Nearby Galaxy Survey, Walter *et al.* (2008)) have been compared. Intrinsic dissimilarities between the kinematical tracers used are responsible of some of the observed disagreements (Daigle (2010)).
(BHαbar) - A sample of 21 nearby barred galaxies has been observed for the BHαbar survey (Hernandez *et al.* (2005)). The Tremaine-Weinberg method, which is generally used to determine the pattern speed of the stellar components, was successfully applied to the gaseous one (Chemin & Hernandez (2009)).
(VIRGO) - Almost all the Virgo sample of 30 galaxies observed to date is mildly or strongly perturbed. Rare are the galaxies having regular morphology and velocity field.

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Table 1. Instrumental Parameters of the Surveys.

Survey[1]	N[2]	Status[3]	Telescope[4]	IFS[5]	Wv Range[Å][6]	R_λ@λ[Å][7]	FoV["][8]	S["][9]
DiskMass	146/46	Started	Wiyn(3.5m)[a]	SparsePak	5000-5262/4000	11770@5130	1.17	4.7
			Calar Alto(3.5m)[b]	Ppak	4980-5380	8000@5180		2.7
			Wiyn(3.5m)[a]	DensePak	6500-6900	13150@6700		2.8
				SparsePak	6482-6687	10050@6690		2.8
					8389-8961	9700@8675		2.8
VENGA	32	Started	McDonald(2.7m)[c]	VIRUS-P	3600-5800/4000	720@3600	1.7	4.3
				VIRUS-W	4600-6800/4000	1360@6800		4.3
SAURON	18	Achieved	WHT(4.2m)[d]	SAURON	4800-5380	1800@5320	0.42	1
						1800@5320		
PINGS	17	Started	Calar Alto(3.5m)[b]	PMASS	3700-7100	850@3700	1.21	2.7
						1650@7100		
CALIFA	600	Started	Calar Alto(3.5m)[b]	PMASS	3700-5000	1650@4350	1	2.7
					4300-7000	850@5650		
CGS	603	Started	Magellan(6.5m)[e]	GISMO	3600-7000	17000	3.5	
GHASP	203	Achieved	OHP(1.92m)[f]	GHASP	6563/6782($\pm$5-10)[α]	15000	5.8	0.68
CIGALE	269	Achieved	ESO(3.60m)[g]	CIGALE	6563/6782($\pm$5-10)[α]	15000	5.0	0.45
		Achieved	CFHT(3.60m)[h]	FPMOS	6563/6782($\pm$5-10)[α]	15000	5.8	0.34
GHaFaS	$\sim$40	Started	WHT(4.2m)[d]	GHaFaS	6563/6782($\pm$5-10)[α]	10000-20000	4.0	0.45
FaNTOmM	107	Started	Mégantic(1.6m)[i]	FaNTOmM	6563/6782($\pm$5-10)[α]	10000-20000	19.4	1.61
PUMA	79	Started	S. Pedro(2.1m)[j]	PUMA	6563/6782($\pm$5-10)[α]	10000-20000	10	0.60

[1] Name. [2] Total number of galaxies. [3] Present status. [4] Telescope(s) and size. [5] Integral Field Spectroscope(s). [6] Wavelength range. [7] Spectral resolution @ wavelength. [8] Field of view. [9] Spatial sampling. [a] Wiyn, Kitt Peak (US). [b] Calar Alto (Spain). [c] Smith McDonald, Austin (US). [d] William Herschel, Canaries (Spain). [e] Magellan, Las Campanas (Chile). [f] Observatoire de Haute Provence (France). [g] European Southern Observatory (Chili). [h] Canada-France-Hawaii (US). [i] Mont-Mégantic (Québec). [j] San Pedro Mártir (Mexico). [α] The spectral range depends on the width of the interference filter ($\pm$ 5-10 Å corresponds to their mean FWHM). In changing of interference filter, the spectral domain ranges from Hα at rest (6563Å) to 6782Å for a radial systemic velocity of 10000 km.s^{-1}.

About 30-40% of the sample exhibits strong morphological and dynamical disturbances like off-plane filaments, nuclear spiral, rings, lopsidedness,... Detection of extended ($\sim$10 kpc) diffuse off-plane $H\alpha$ filaments caused by ram pressure stripping and tidal interaction are detected (Chemin *et al.* (2005), Chemin *et al.* (2006)). This survey is presently extended towards fainter late type and irregular galaxies (Kam *et al.*, in progress).

PUMA (The UNAM Scanning Fabry-Perot Interferometer) - The instrument PUMA is mainly devoted to the study of binary interacting galaxies and the perturbations induced by the encounter on each member of the pairs, including the bridge connecting the two galaxies and the tidal tails. Special attention is given to the galaxy mass distribution to test dark halo profiles and to the non-circular motions. A sample of 79 galaxies, essentially selected from the Karachentsevs catalog of isolated pair of galaxies, has been observed to date (Repetto *et al.* (2010), Rampazzo *et al.* (2005)).

The Galaxy, the Magellanic Clouds, M31 & M33 - The Hα kinematics of the Milky Way and the Magellanic Clouds have been surveyed using CIGALE on a 0.4 m telescope at La Silla(ESO, Chili, Russeil *et al.* (1998)), and the galaxies M31 & M33 are being surveyed with FaNTomM (Djabo *et al.* in progress).

4. Perspectives

Hitherto, most spectroscopic surveys of galaxies were made with single-aperture (a few HII regions per galaxy), long-slit spectrographs (single spectra of large samples e.g. SDSS). New generation of emission-line surveys with full 3D coverage of the disks are now possible. Surveys of first generation are modest in size (several tens galaxies). Surveys of second generation are coming (several hundreds galaxies). IFU observations of galaxies is becoming common on large telescopes, but observing nearby galaxies in 3D is actually time consuming, furthermore optical/NIR 8-10 m class telescopes are not suitable for surveying them, and it will be even worse with the ELTs (E-ELT, TMT, GMT). On the

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other hand, next generation of radio telescopes (ALMA, SKA precursors and pathfinders, SKA) that will produce massive amount of data cube, will be intensively used in survey mode, even for nearby galaxies. Thus, the need of surveying nearby galaxies in 3D in the optical and in the IR will dramatically increase and will probably be led on 4-m class telescopes. The forthcoming GLAO on large FoVs, associated with 3D spectroscopy, will still increase the ability to understand fine structure in galaxies and to address fundamental issues in galactic structure and evolution.

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