Studying nearby disk galaxies using MEGARA

(the proposed wide-field IFU & MOS for GTC)

Armando Gil de Paz (UCM)

&

MEGARA Science Team

Science with the WHT 2010-2020
(London, March 22-23 2010)

MEGARA

Multi-Espectrógrafo en GTC de Alta Resolución para Astronomía

Outline

i) Current paradigm of galaxy-disks evolution
ii) Limitations & Challenges
iii) MEGARA @ GTC
iv) GTO plans for MEGARA
v) Synergies with future WHT instruments

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Star formation history of galaxy disks

Current paradigm

- Frequent mergers at $z>1$ led to the formation of the thick disk

- At $z<1$, stars in the thin disk started to form in the inner regions first (i.e. shorter gas infall timescale in the central regions).

- Delayed star formation occurred in the outer parts: **Inside-out growth**

- **This scenario naturally explains …**

(1) metallicity gradients & abund. patterns, (2) colors, (3) gas & SF distribution
(Matteucci et al., Prantzos et al., Boissier et al., Mollá et al.)

… first in the MW but also **recently in external galaxies** …

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Star formation history of galaxy disks

Current paradigm

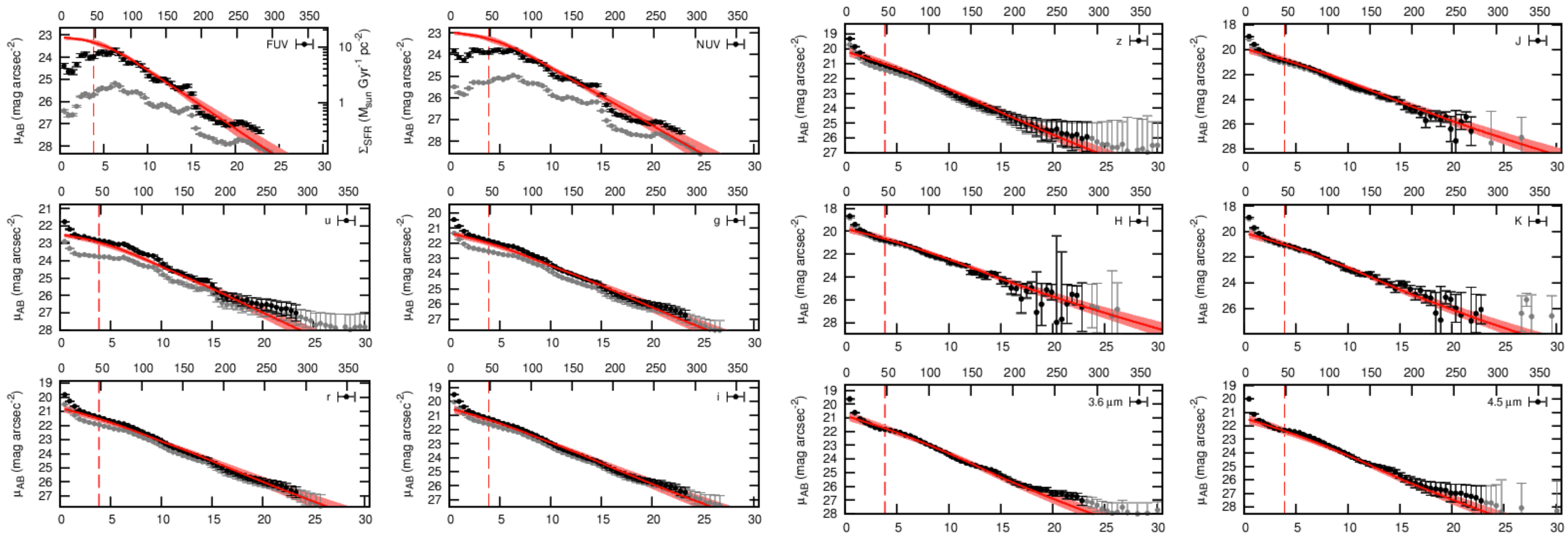
Recent multi-λ studies on spirals disks (locally and at intermediate-z) reveal an **inside-out growth of ~25% in size between z=1 and z=0** (Muñoz-Mateos et al. 2007, 2010, Trujillo & Pohlen 2005).

Multi-λ fitting of SINGS disks by Muñoz-Mateos et al. (2010)

Data: FUV+NUV,ugriz,JHK,IRAC,MIPS

Models: Boissier & Prantzos (2000)

NGC 3198 $\lambda=0.063^{+0.011}_{-0.010}$ $V_C=191^{+7}_{-5}$ km/s K01 IMF



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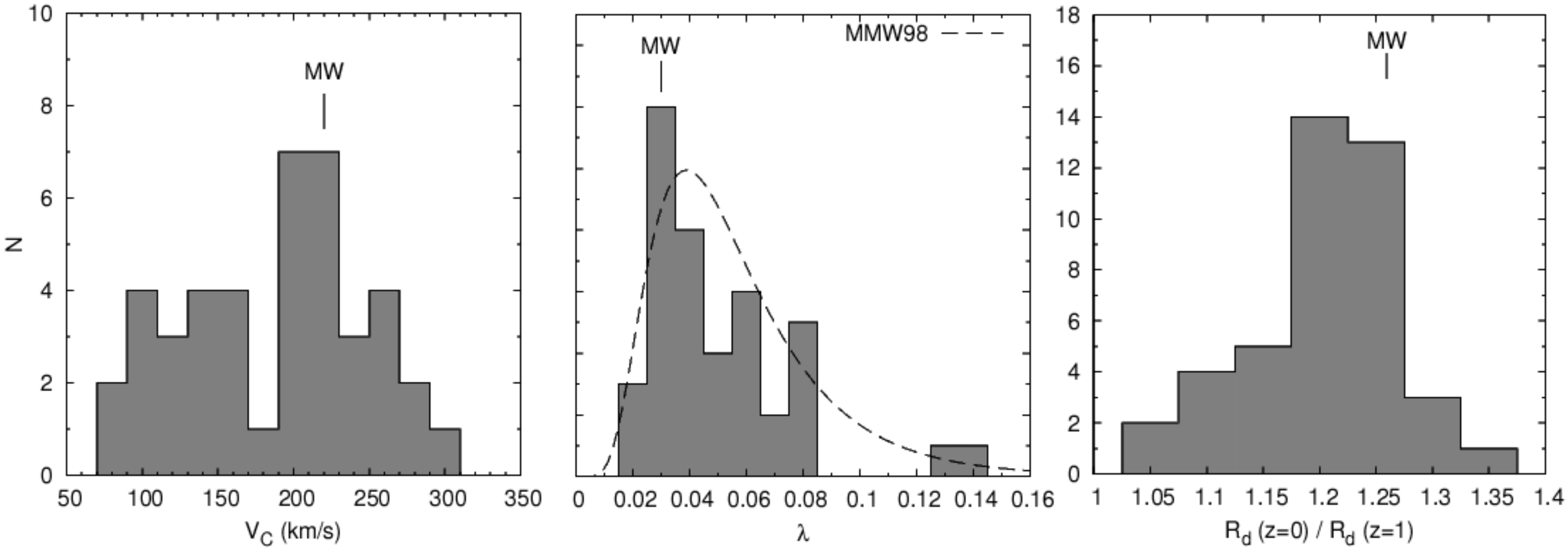
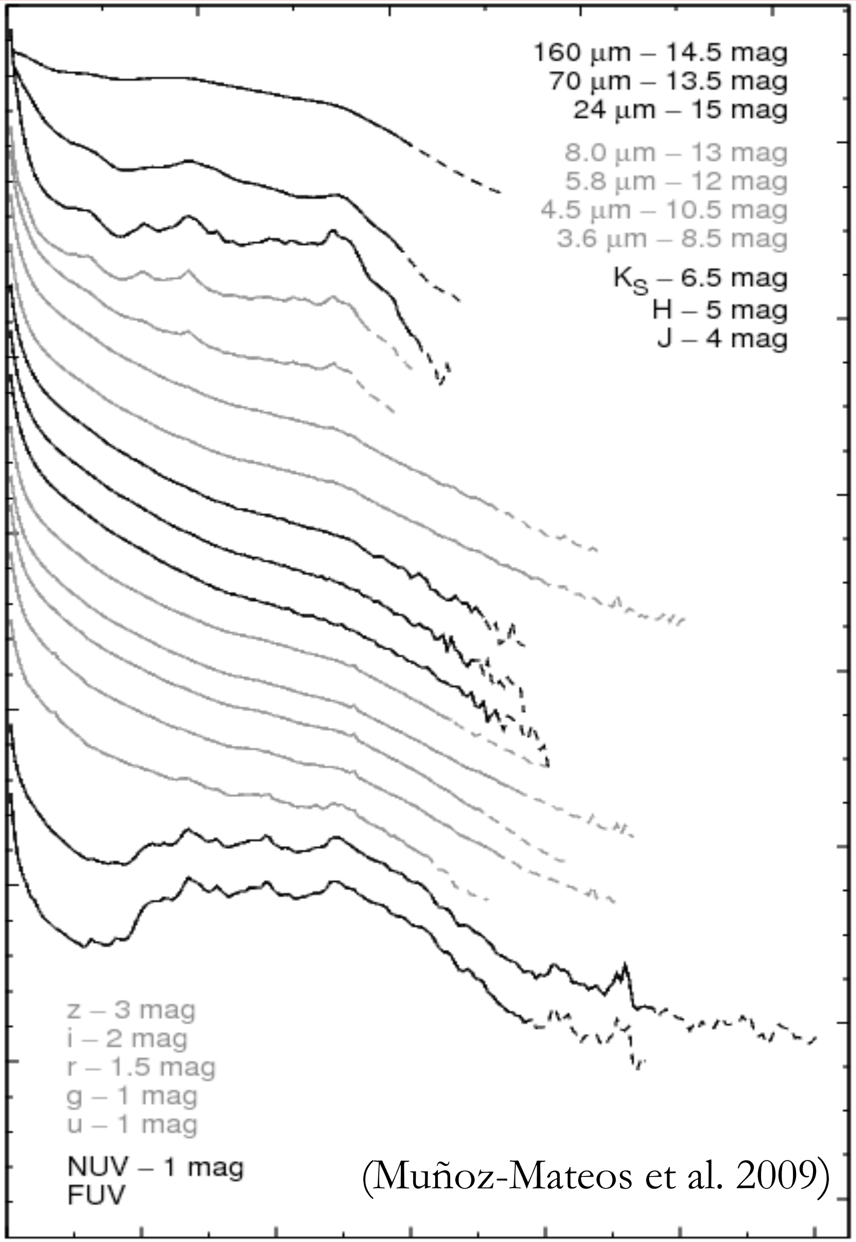


(Muñoz-Mateos et al. 2010)

Star formation history of galaxy disks

Limitations & Challenges



(Muñoz-Mateos et al. 2009)

Degeneracies from photometry alone

-- WE NEED (1) spectroscopy

Lack of depth to study outer edges

-- WE NEED (2) 10m-class telescopes

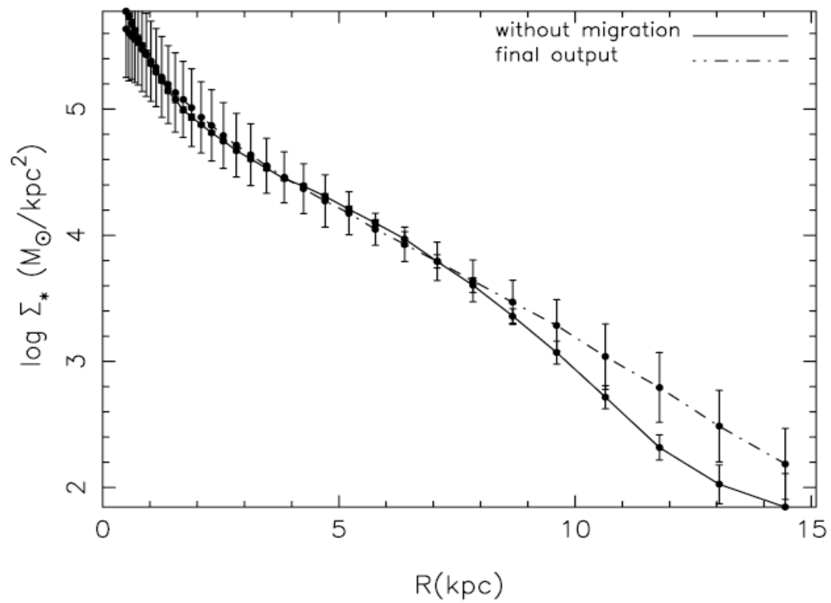
Stellar Migration

-- WE NEED (1)(2) plus …

… kinematics & resolved-stars analysis

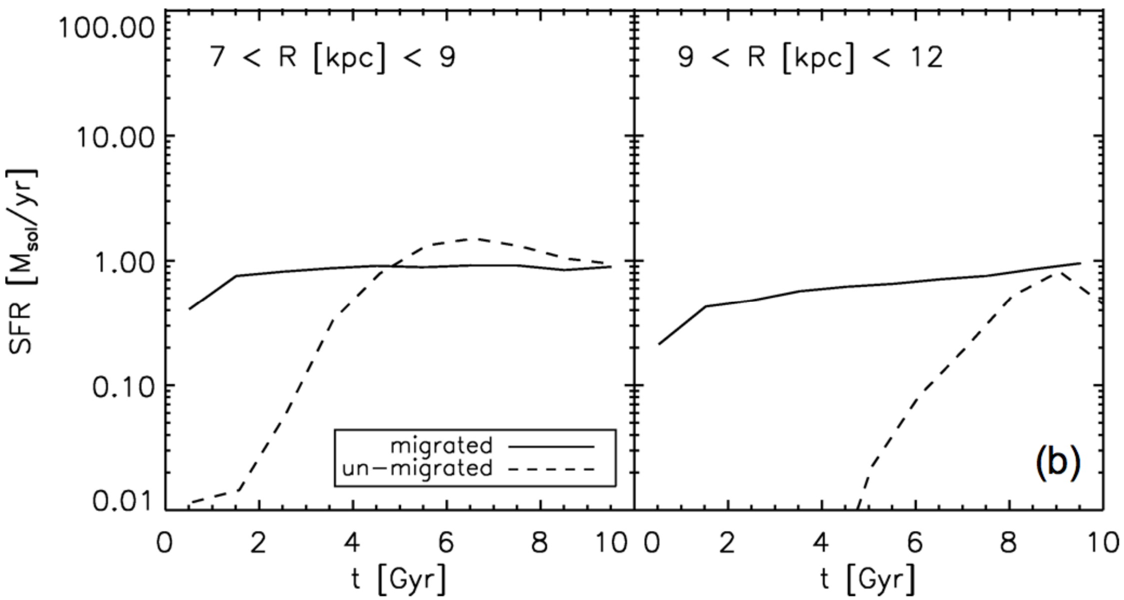
Star formation history of galaxy disks
Migration: Theoretical predictions

by heating, …



(Sánchez-Blázquez et al. 2009)

churning … (Sellwood & Binney 2002)



(Roskar et al. 2008)

… or by other mechanisms …

- **Satellite accretion** (e.g. Young et al. 2007)
- **Magnetic fields** (when gas transforms into stars the equilibrium between gravity, rotation, and B dissapears) (Battaner et al. 2002)
- **Bars** (e.g. Valenzuela & Kyplin 2003)

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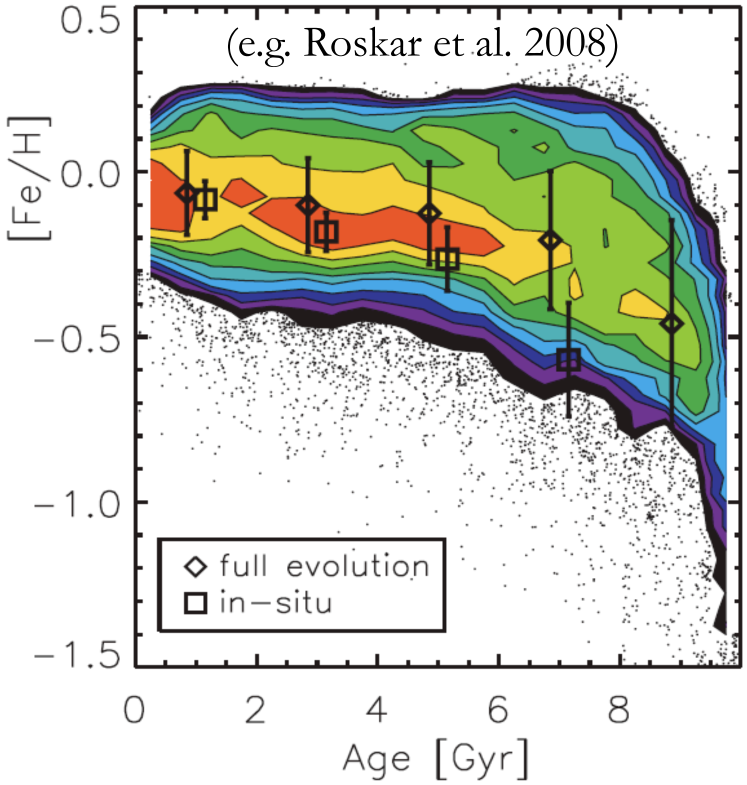
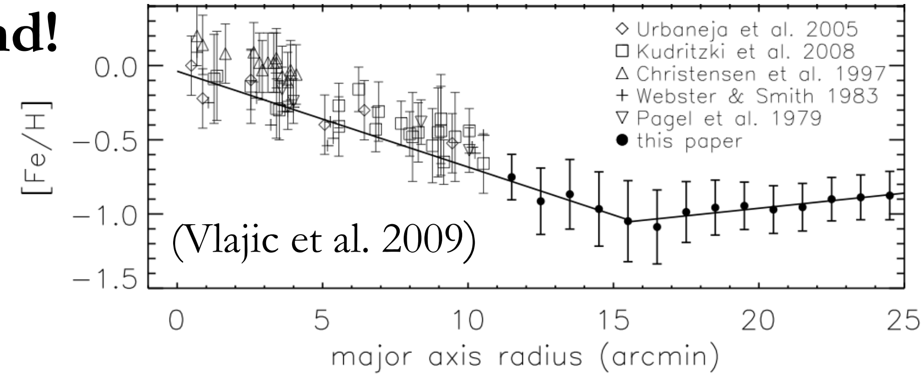
Star formation history of galaxy disks

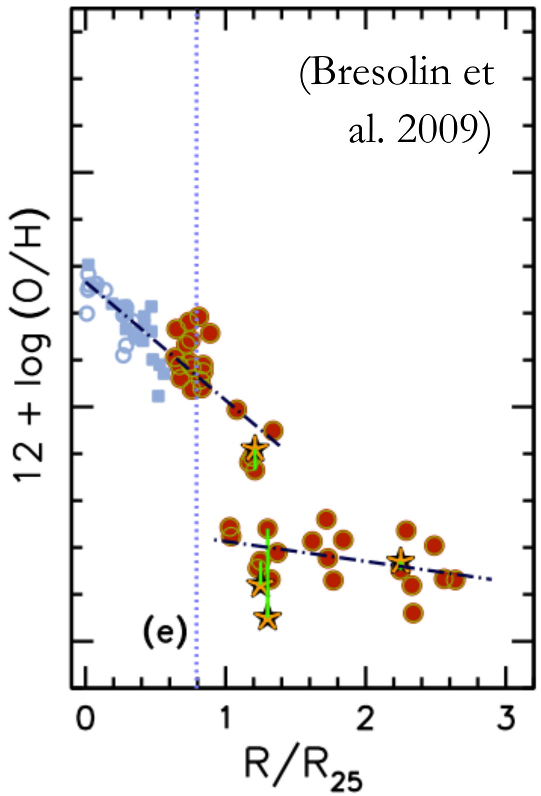
Migration: Observational evidence

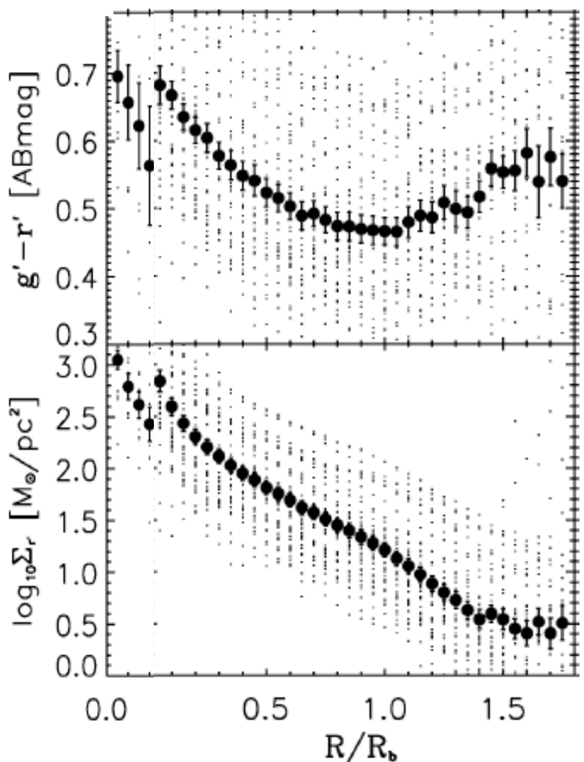
In the MW …



… and beyond!







(Bakos et al. 2008)

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Star formation history of galaxy disks

Quantifying migration

i) Disk heating is correlated with **σz**, which can be measured with high-res. spectroscopy (R~10,000) in nearly face-on galaxies (Verheijen et al. 2004).

ii) Transient arms & heating are thought to be also responsible for the higher **velocity dispersion** found in **older stars** (Lacey 1991).

iii) The **effective Star Formation History** is driven the combined effect of *in-situ* star formation & migration. The outermost regions of disks are particularly sensible to stellar migration.

iv) These mechanisms result in different **abundance gradients** for stars (or stellar populations) of different ages and for the gas.

v) The efficiency of transient spiral arms is a function of the **disk-mass fraction** (Sellwood & Binney 2002).

vi) The **determination of the velocity ellipsoid** provides clues on whether cloud or spiral-arm scattering heat the disk.

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Star formation history of galaxy disks

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Multi Espectrógrafo en GTC de Alta Resolución para Astronomía

WE NEED

(1) intermediate-R, (2) large contiguous FOV & collecting area, (3) λ-coverage

MEGARA main characteristics

IFU FOV (in 3 dith. pointings)	~1x1 arcmin^2
MOS (simultaneous with IFU)	94 objects in 3.5x3.5 arcmin^2
Spaxel (fiber) size	0.685 arcsec
Wavelength range	3700-9800 Å
Spectral resolution	R=5900-17000
# of spectrographs	8 (7 IFU + 1 MOS)
# of spaxels / multiplexing	5300
GTC station	Folded-Cass (spectrographs @ Nasmyth)
Budget (for all 8 spectrographs)	7.5 M€
Delivery date	2014

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E spectrógrafo en
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Science Team

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PM (M. L. García Vargas**), Proj. Engineer (**A. Pérez**), Proj. Controller (**K. Hansen**)**

Consortium

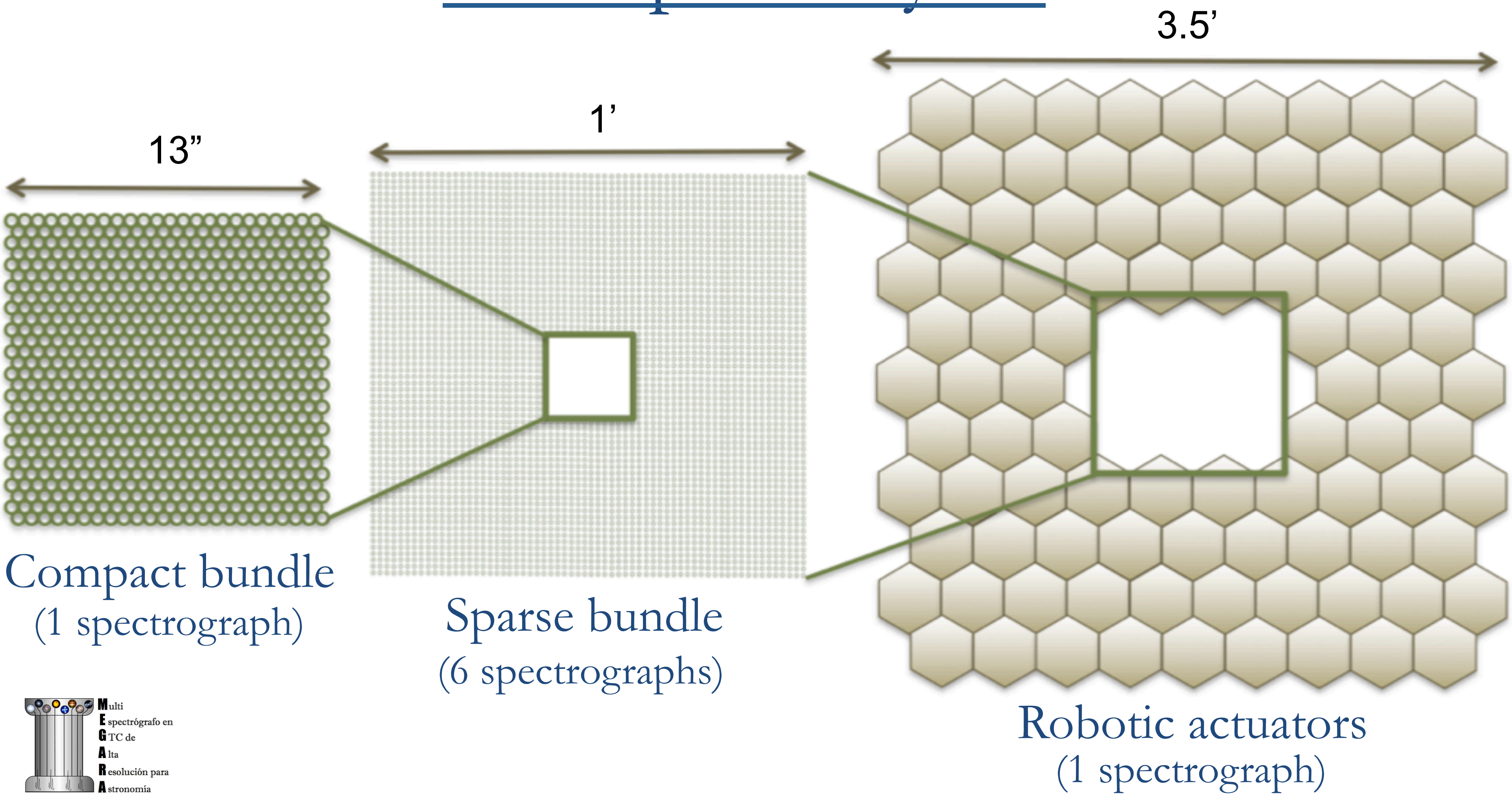
Institution	Representative	Area of expertise / interests
Universidad Complutense de Madrid	Armando Gil de Paz	Management, detectors, software
IAC	Artemio Herrero	Fiber optics, integration, verification
INTA/Centro de Astrobiología	Nuria Huélamo	Robotics, mechanics, management
INAOE	Esperanza Carrasco	Cryostats and main optics

Participating companies: **Fractal** (optical and mech. design), **AVS** (robotic positioners), **GMV** (software), **SEDI** (fiber bundles), ...

MEGARA

Multi-Espectrógrafo en GTC de Alta Resolución para Astronomía

Focal-plane layout



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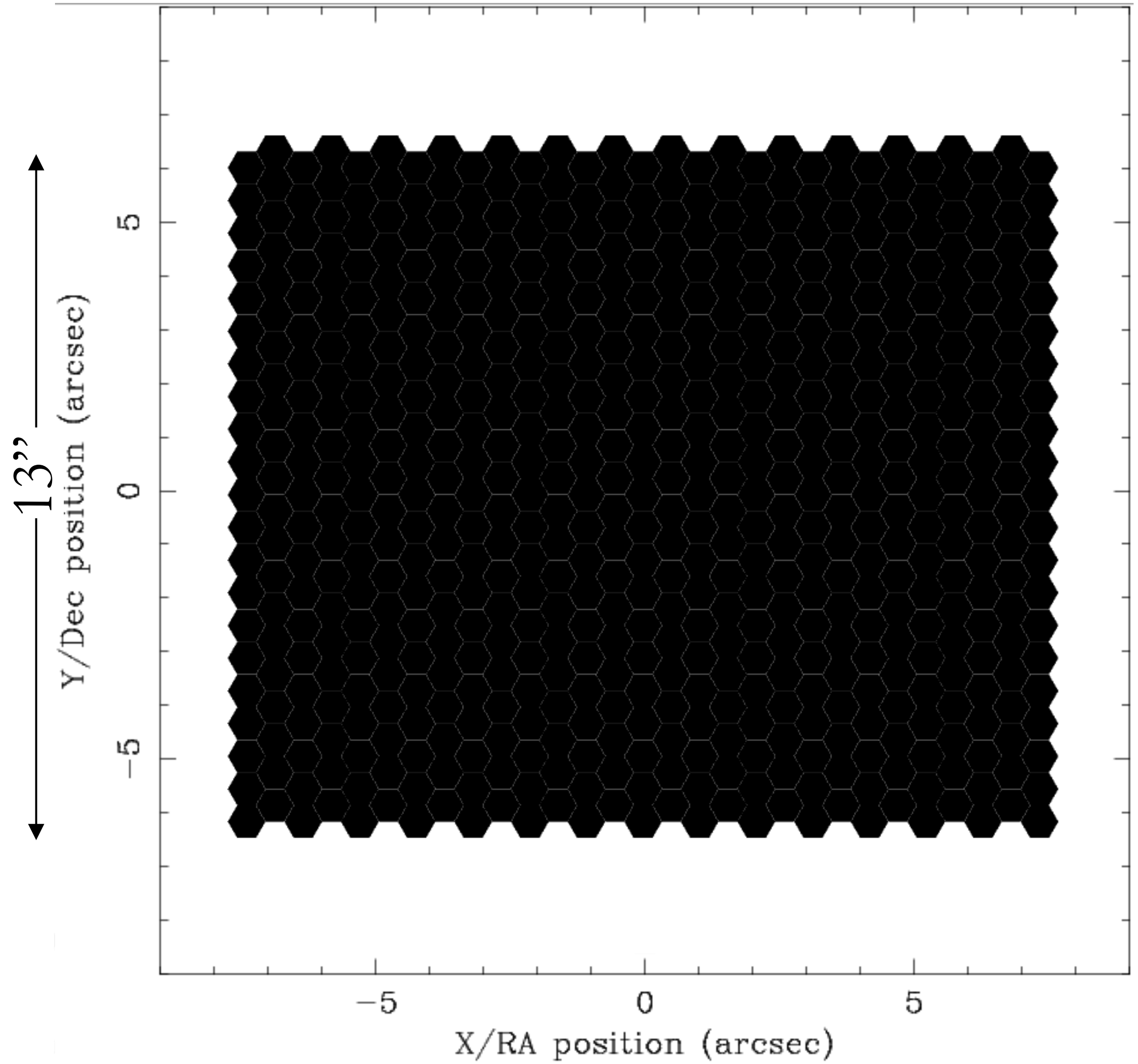

Compact bundle

~600 fibers with a lens array with 98.3% coverage

FOV ~ 12 x 14 arcsec^2

Use: Study of the central regions of
(i) extended or
(ii) clustered targets and
(iii) for calib. purposes.

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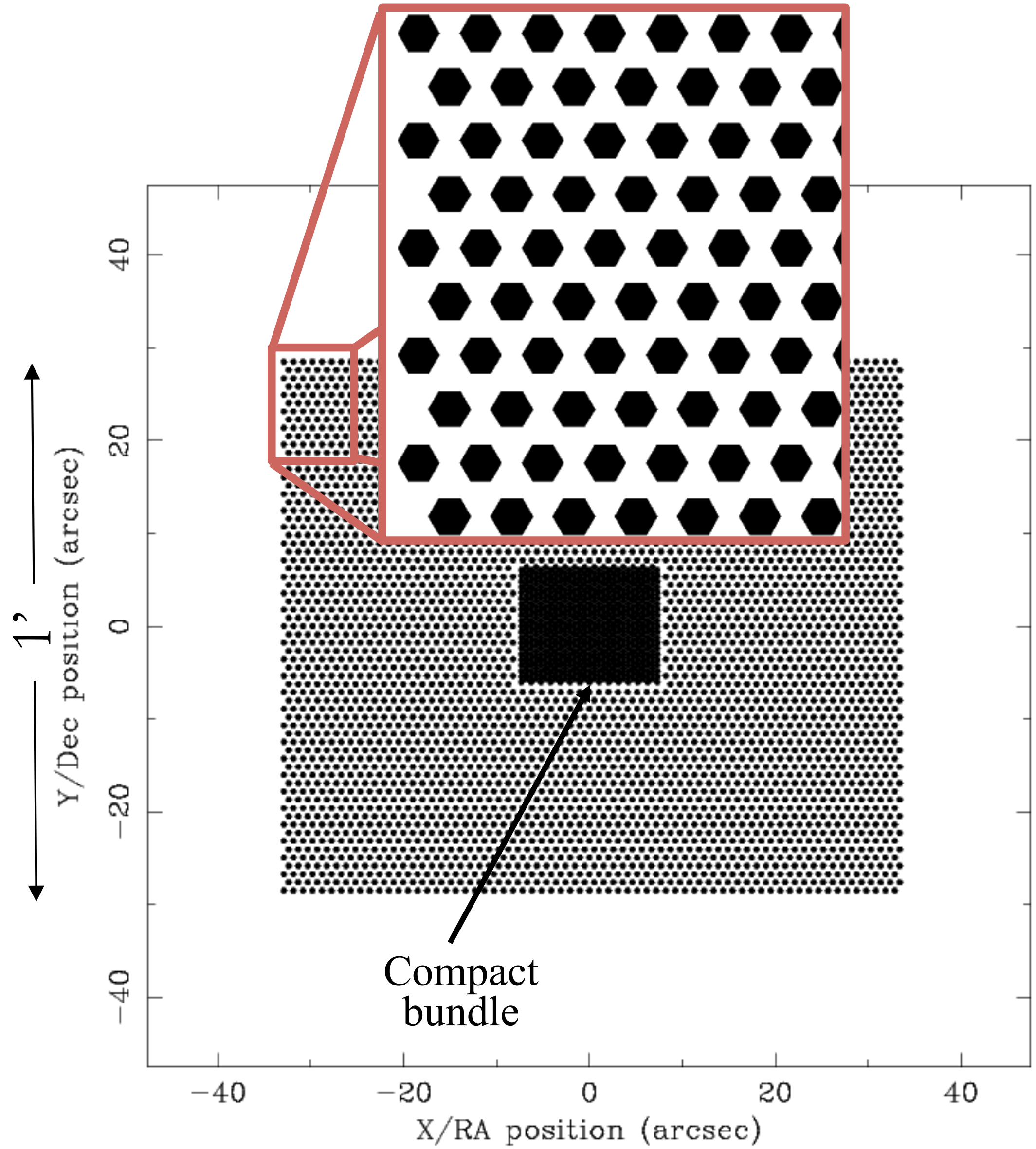


Sparse bundle

~4000 fibers in a lens array with 100% coverage in 3 pointings and no redundancy (hexagonal lenslets)

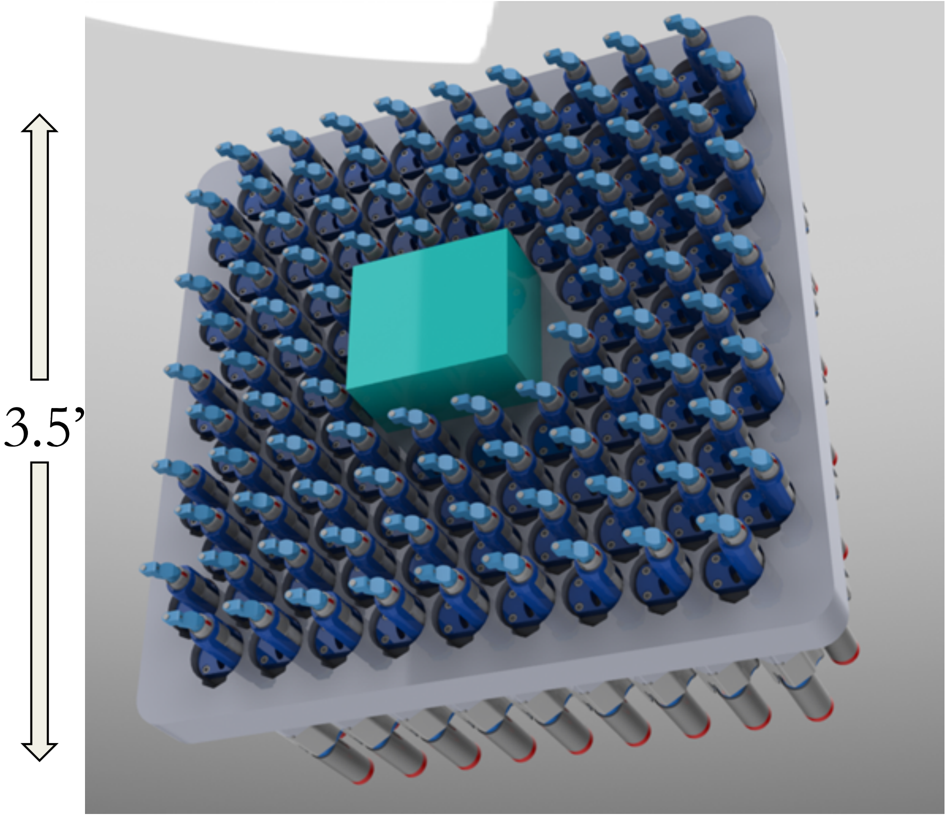
FOV~ 66 x 57 arcsec^2

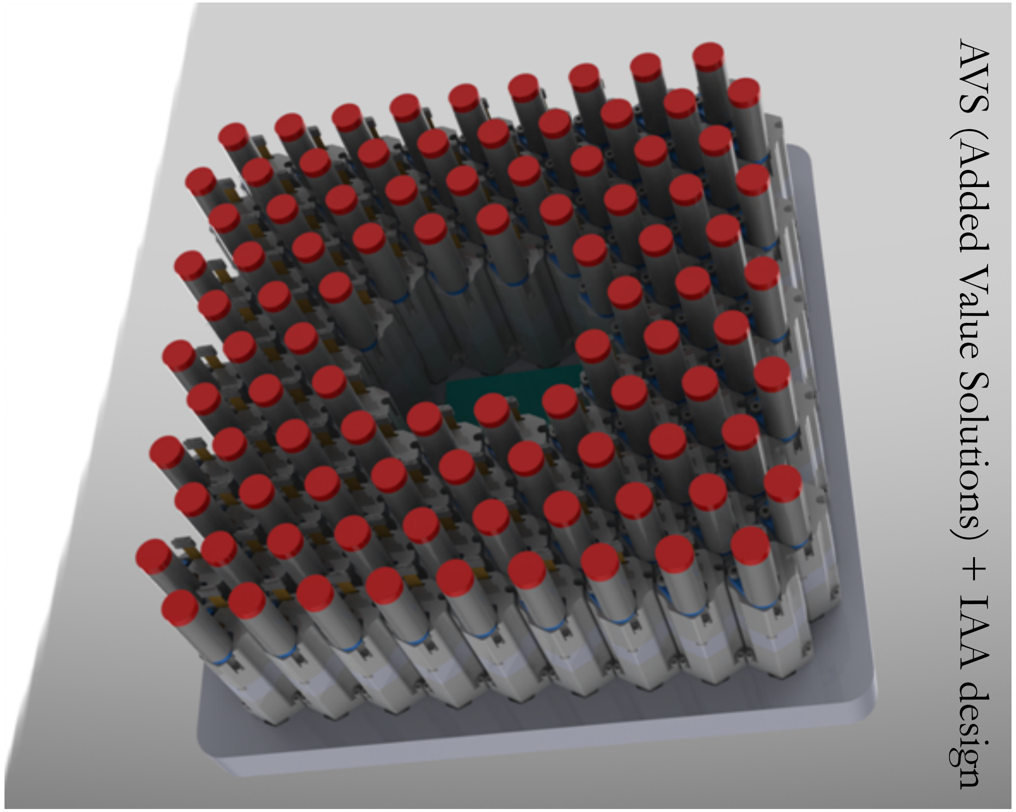
Use:

(i) Study of extended targets or

(ii) full coverage with 3 ptgs.

Robotic Actuators (MOS)

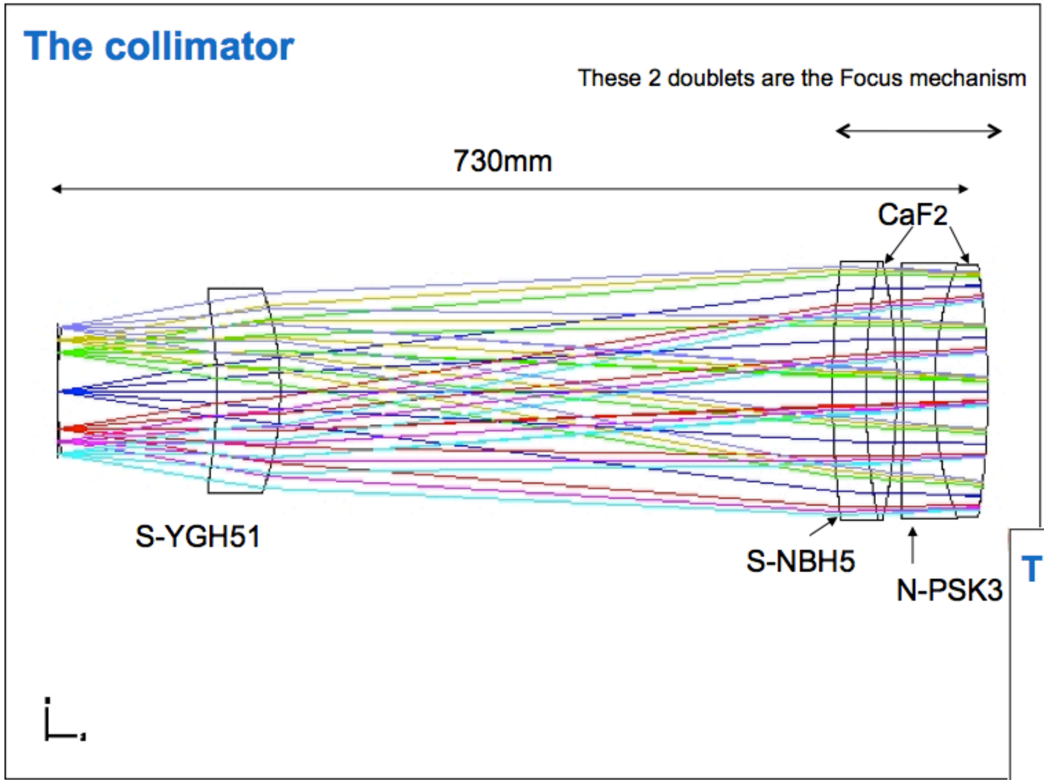


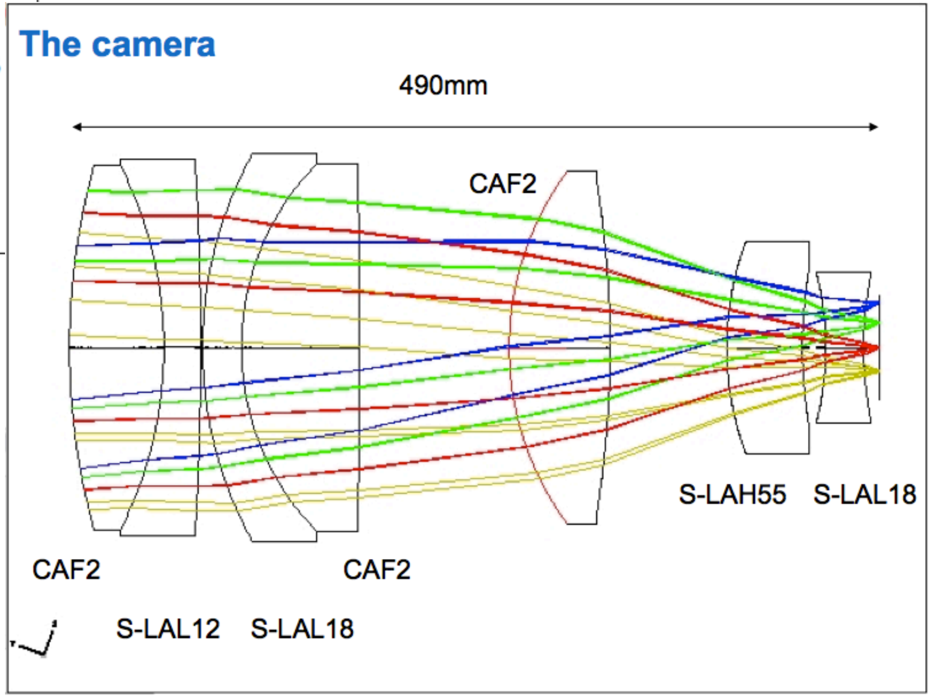


It allows observing 94 objects in the 3.5x3.5 arcmin^2 *non-curved, non-vignetted* Folded-Cass FOV (7x94 fibers to trace AD).

Use: (i) Low-density fields & **(ii)** IFU sky subtraction.

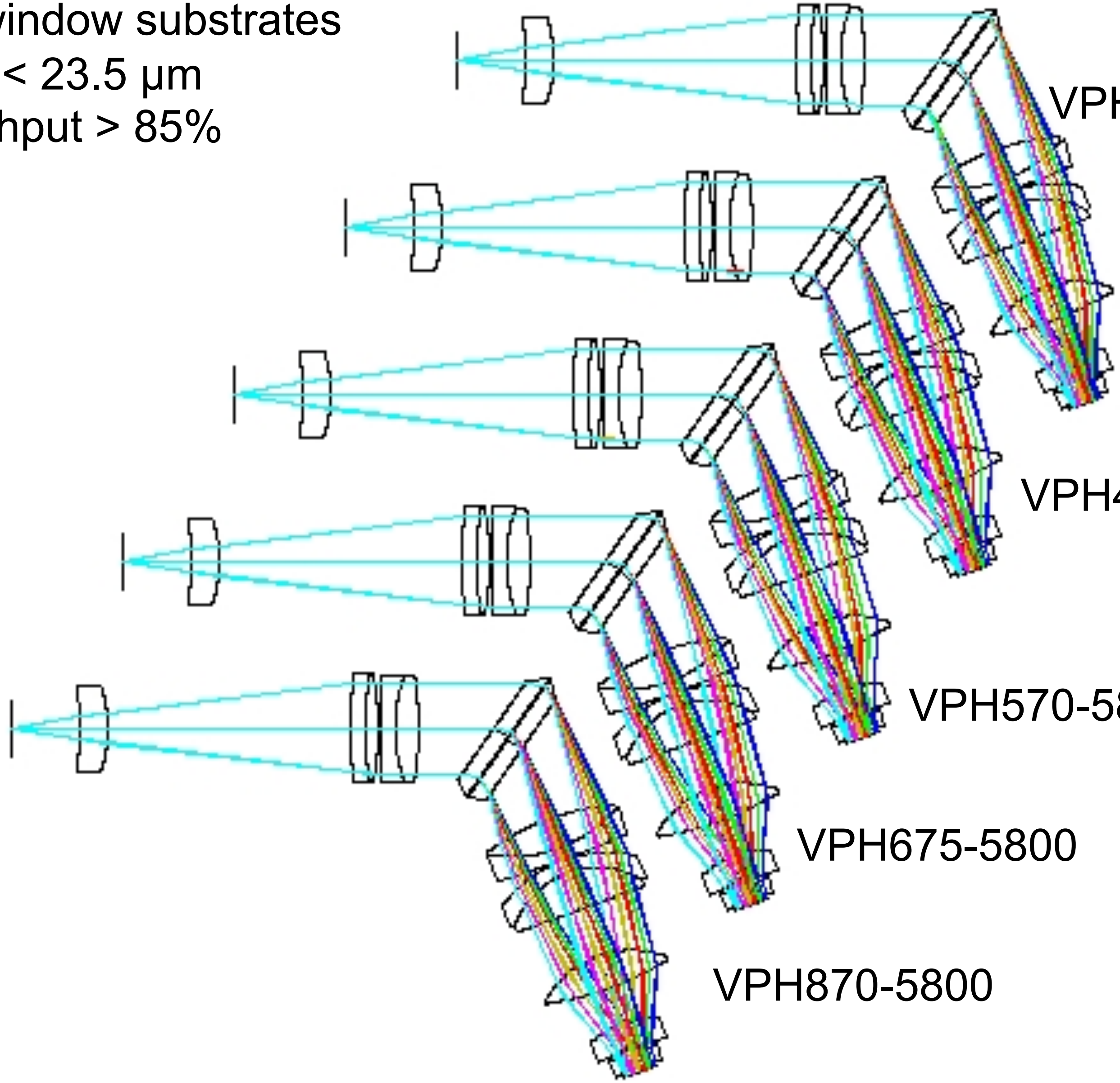
Optical design





Disperser Summary R=5800 VPHs

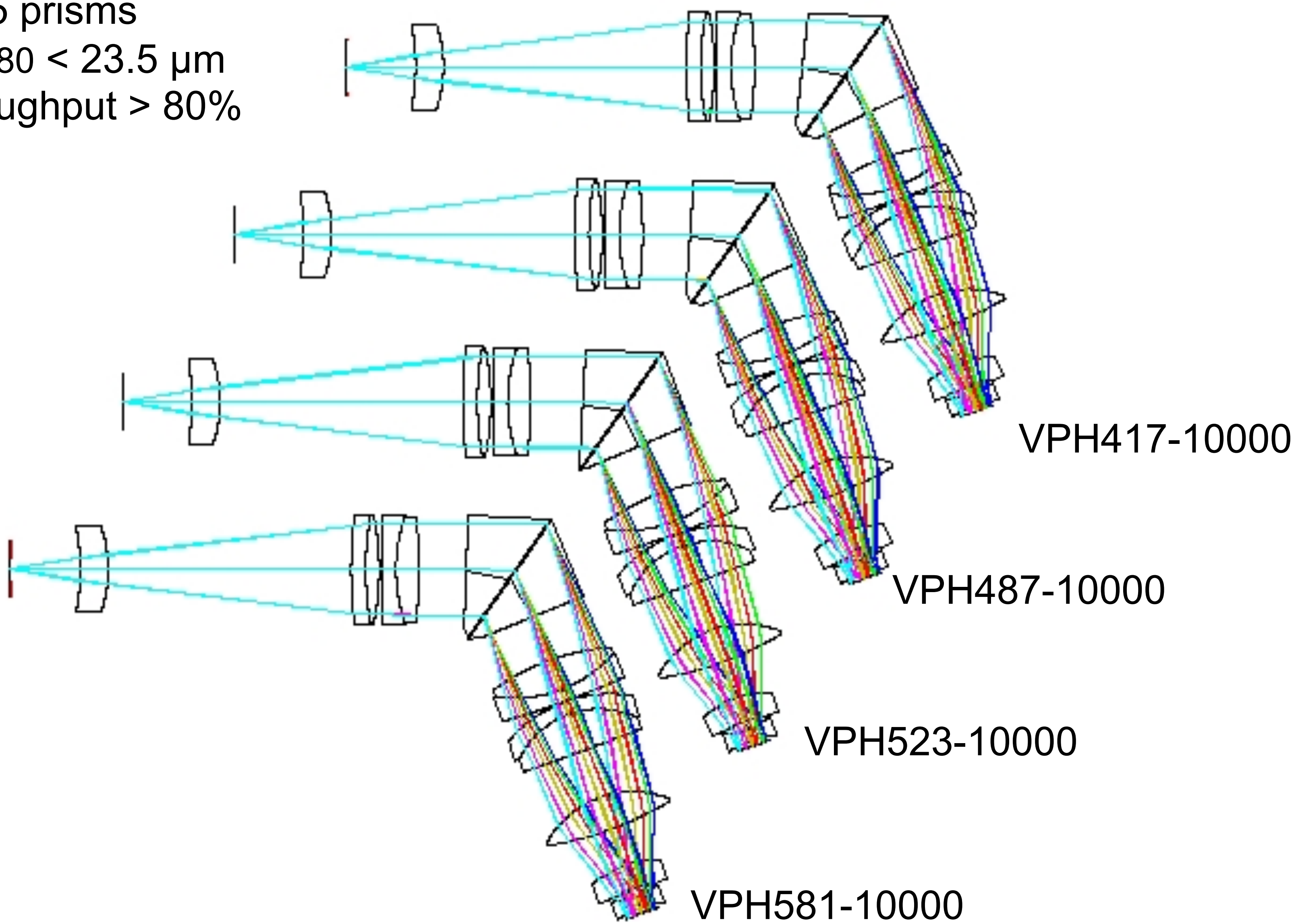
- Silica window substrates
- EER80 < 23.5 μm
- Throughput > 85%



MEGARA Resolución para Astronomía

Disperser Summary R = 10000 VPHs

- SF15 prisms
- EER80 < 23.5 μm
- Throughput > 80%



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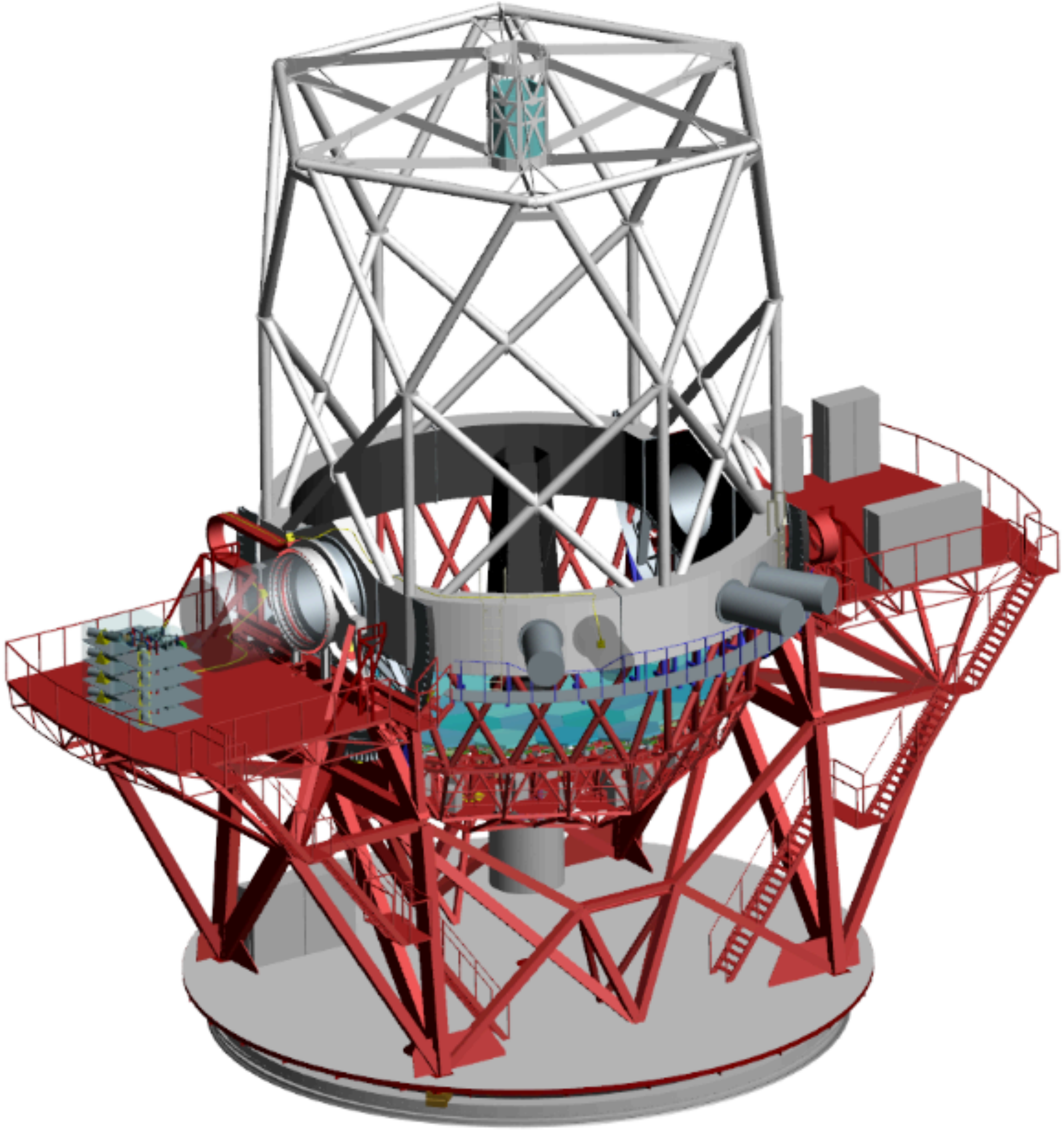
Multi-Espectrógrafo en GTC de Alta Resolución para Astronomía

GTC station

i) **IFU+ MOS actuators:**
Folded-Cass

ii) **Spectrographs:**
Nasmyth (preferred) or
rotating floor



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Spectral setups

#	Name	Setup	R	FWHM (Å)	FWHM (km/s)	Rec.Disp. (Å/pixel)	$\Delta\lambda_T$ (Å)	Range (Å)	# of spec.
1	VP665-17000	HR-R	17000	0.39@6650Å	18	0.0978	401	6520 - 6921	8
2	VP863-17000	HR-I	17000	0.51@8630Å	18	0.1269	520	8540 - 9060	2
3	VP417-10000	MR-U	10000	0.42@4175Å	30	0.1044	427	3962 - 4389	8
4	VP487-10000	MR-B	10000	0.49@4870Å	30	0.1217	498	4621 - 5119	8
5	VP523-10000	MR-V	10000	0.52@5230Å	30	0.1307	535	4963 - 5498	2
6	VP581-10000	MR-O	10000	0.58@5810Å	30	0.1452	595	5512 - 6107	2
7	VP405-5900	LR-U	5900	0.69@4050Å	51	0.1716	702	3699 - 4401	8
8	VP480-5900	LR-B	5900	0.81@4800Å	51	0.2034	833	4384 - 5217	8
9	VP570-5900	LR-G	5900	0.97@5700Å	51	0.2415	989	5206 - 6195	8
10	VP675-5900	LR-R	5900	1.14@6750Å	51	0.2860	1171	6164 - 7335	8
11	VP850-7000	LR-I	7000	1.21@8475Å	43	0.3027	1240	8000 - 9240	8

(1) CaT at both R=17000 (2 spec) and R=7000 (8 spec)

(2) Hα at R=17000 (8 spec)

(3) Full optical coverage (3700-7300 Å) at R=5900

(4) R=10000 in the entire blue optical range (~3900-6100 Å)

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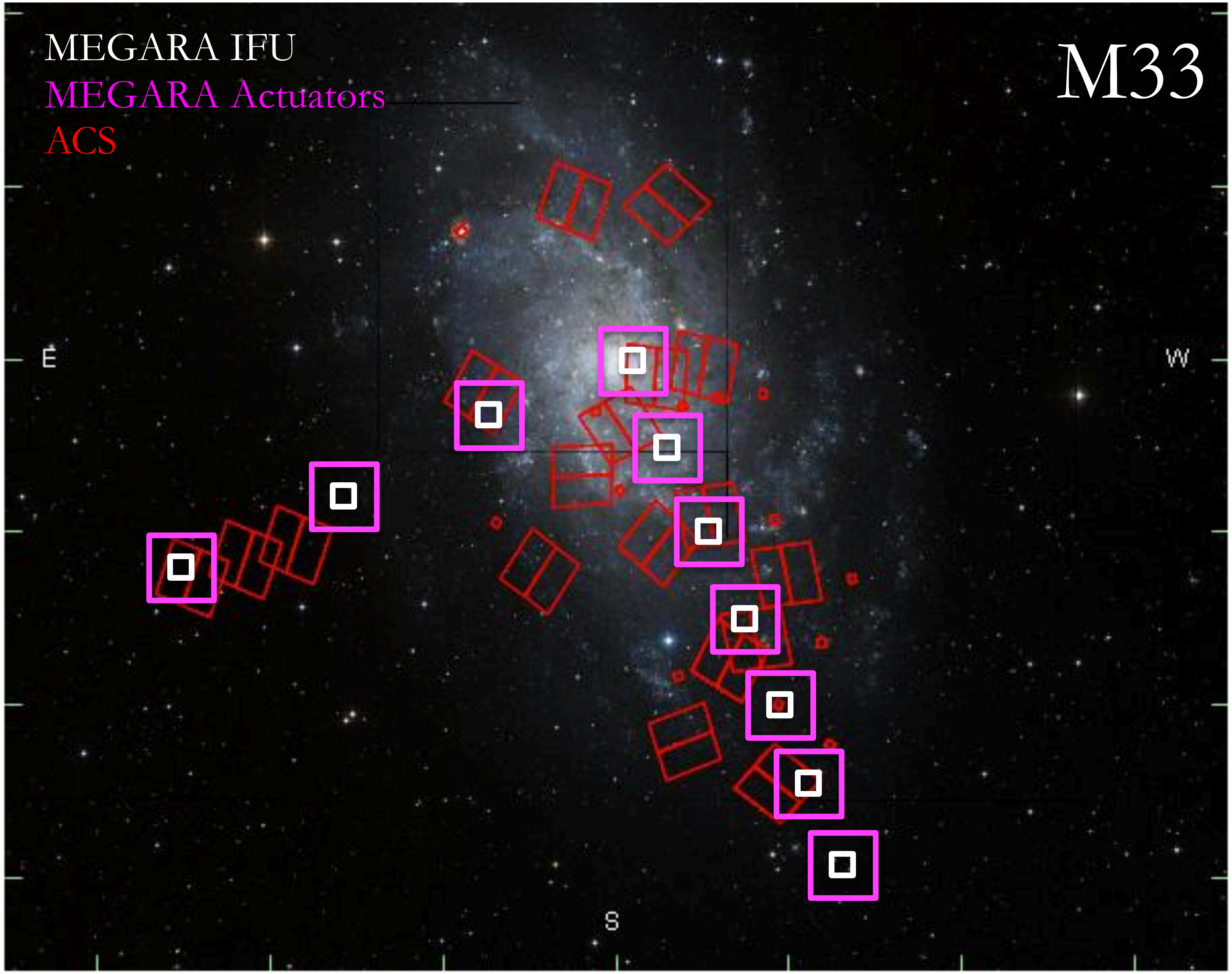
GTO plans for MEGARA

Local Group galaxies



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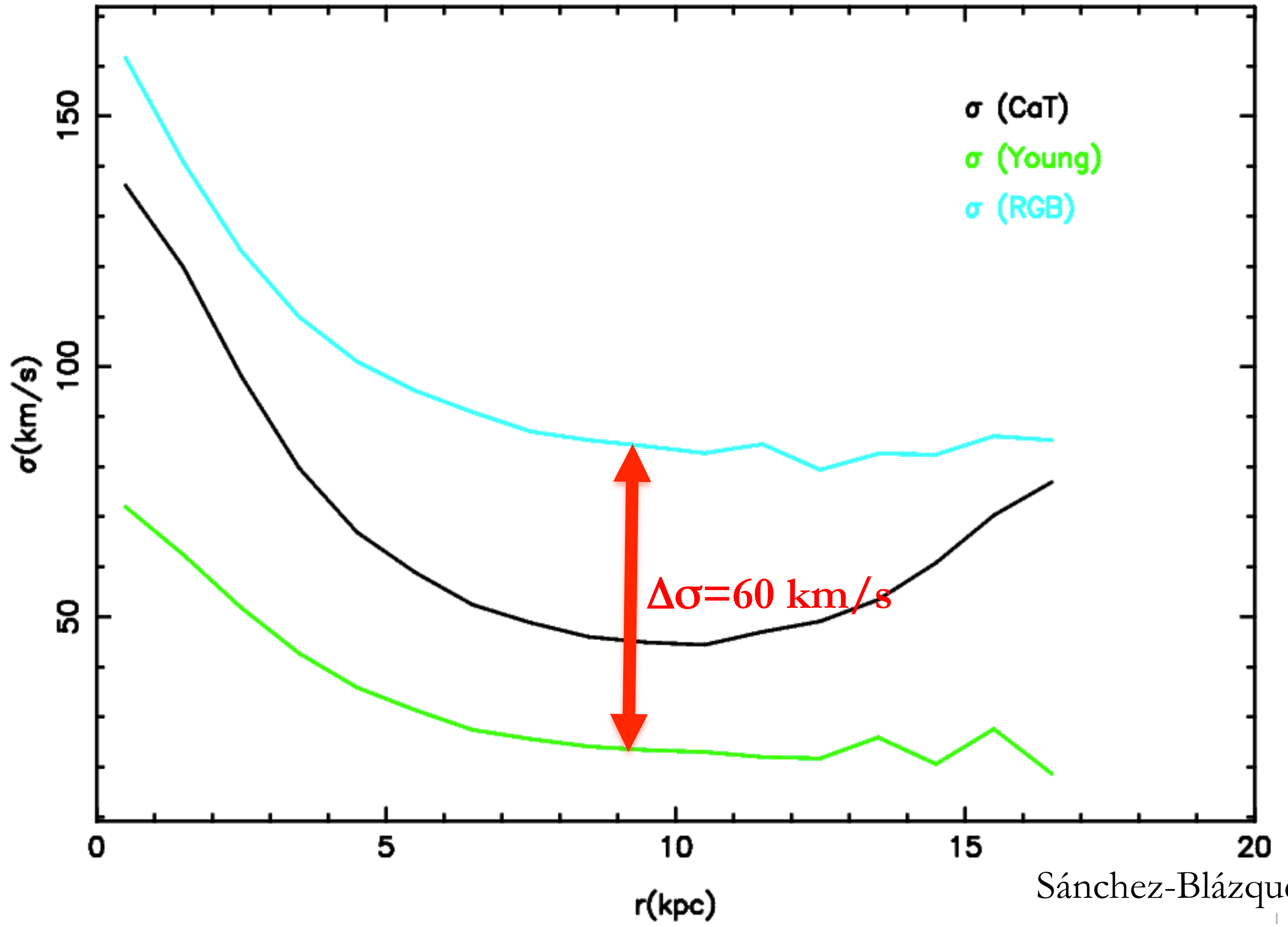
Local Group galaxies

Observables: **(1)** σ_z profiles from individual massive stars and RGBs
(2) Spectral indices profiles



Sánchez-Blázquez et al. (2009)

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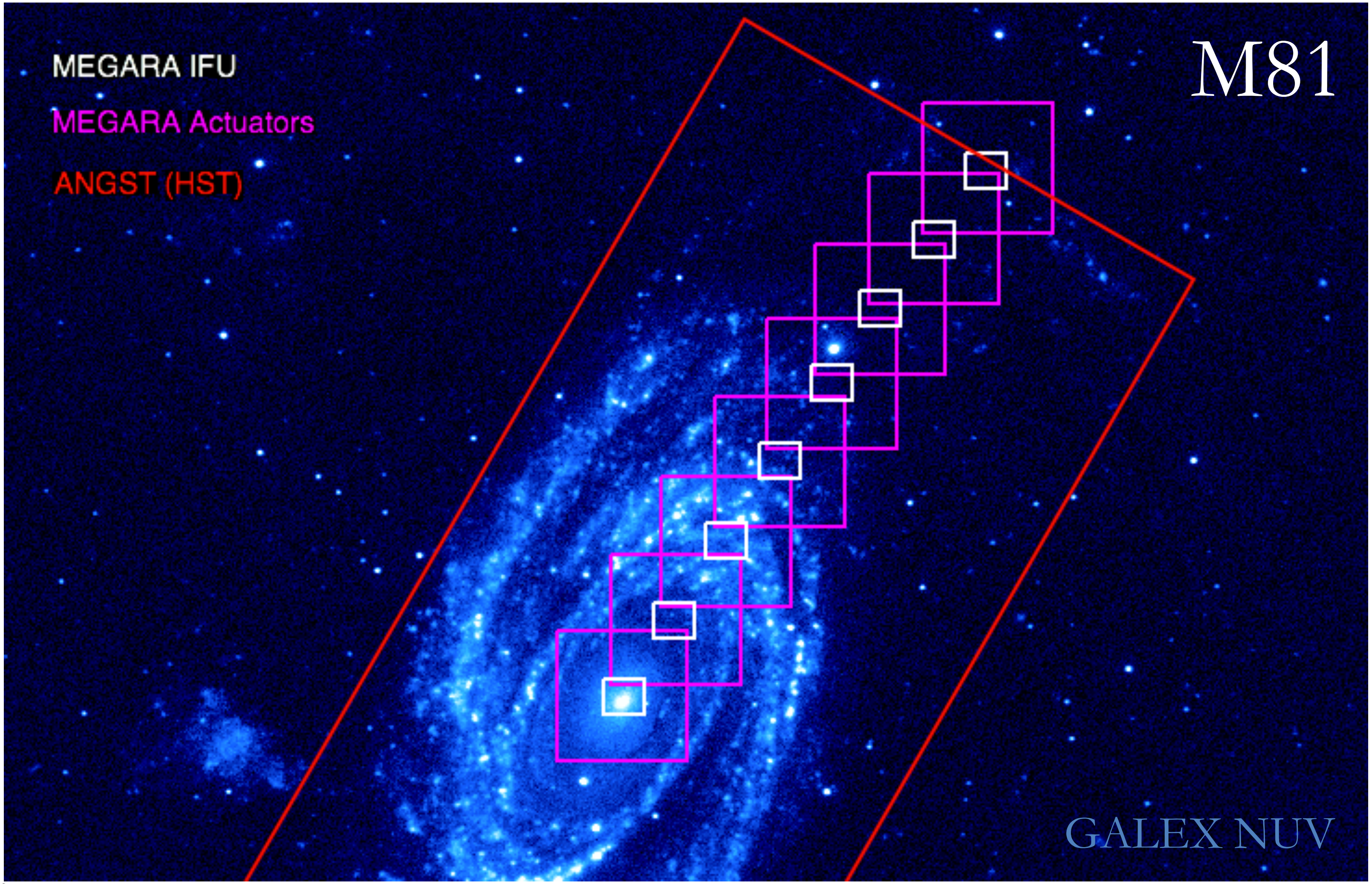
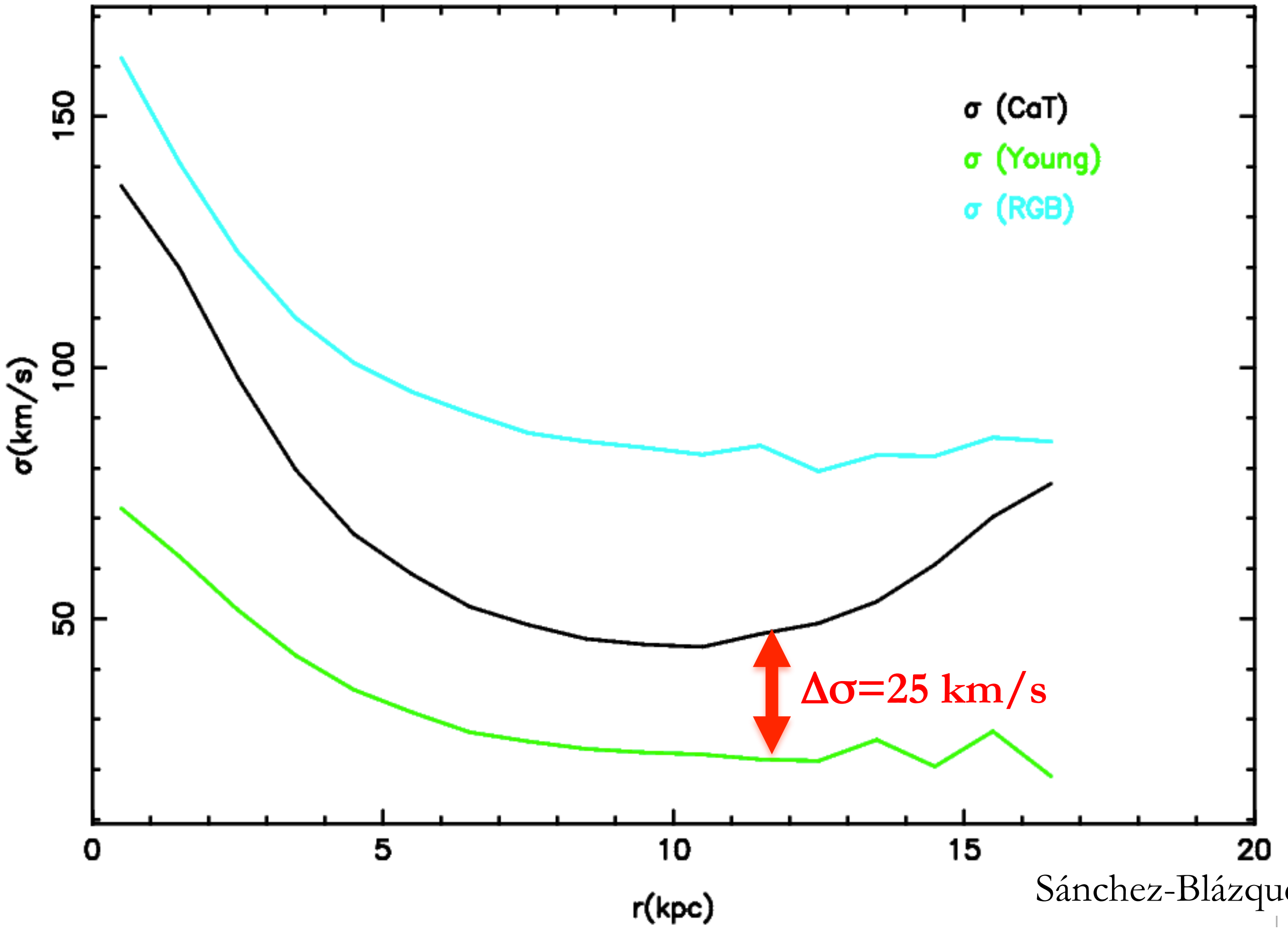
Local Volume galaxies



Multi Espectrógrafo en GTC de Alta Resolución para Astronomía

GTO plans for MEGARA
Local Volume galaxies

Observables: **(1)** σ_z profiles from massive stars and integrated light
(2) Spectral indices profiles

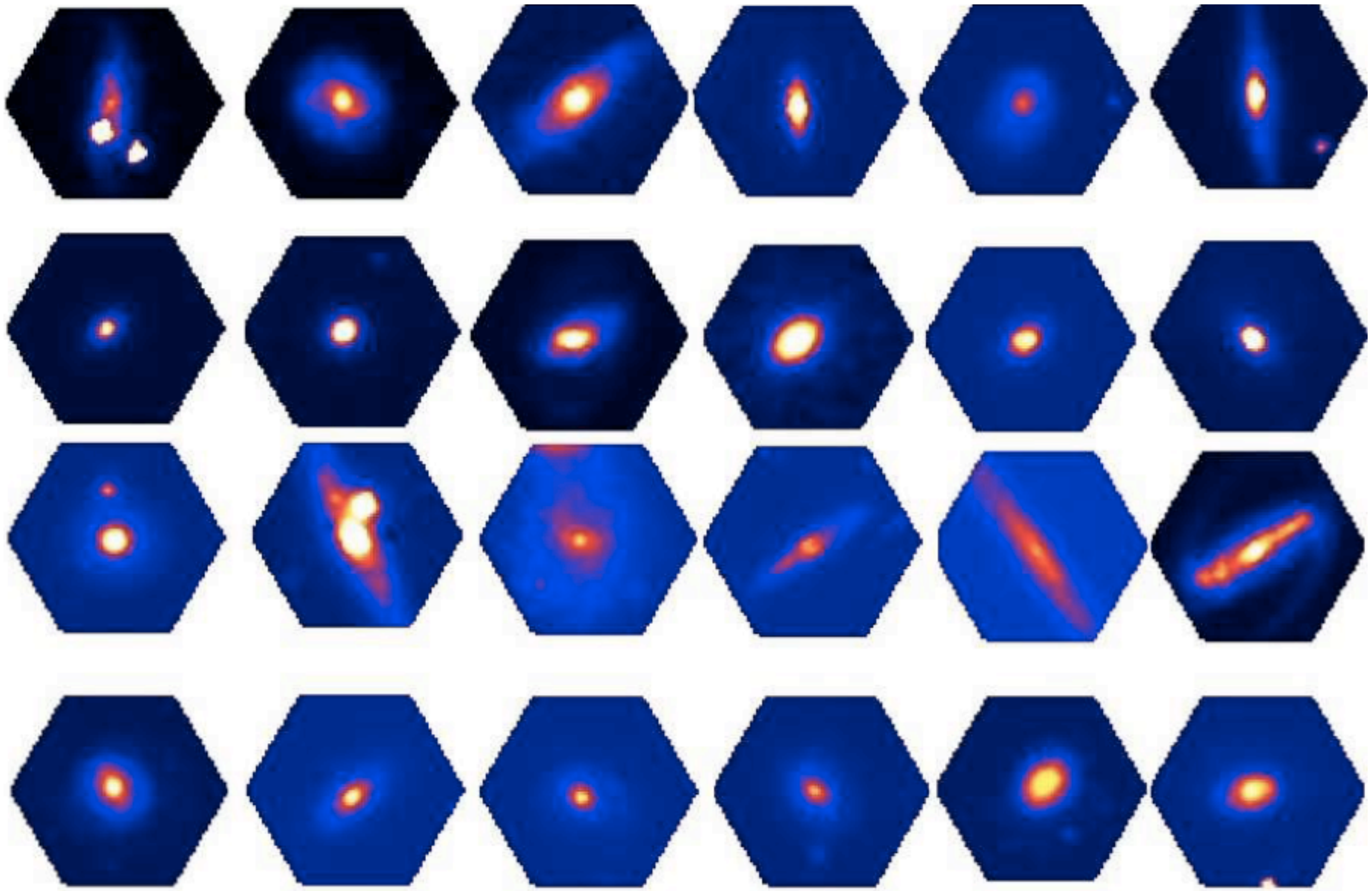


Sánchez-Blázquez et al. (2009)

GTO plans for MEGARA

Unresolved nearby disk galaxies

Analysis of a diameter-limited sample of nearby galaxies



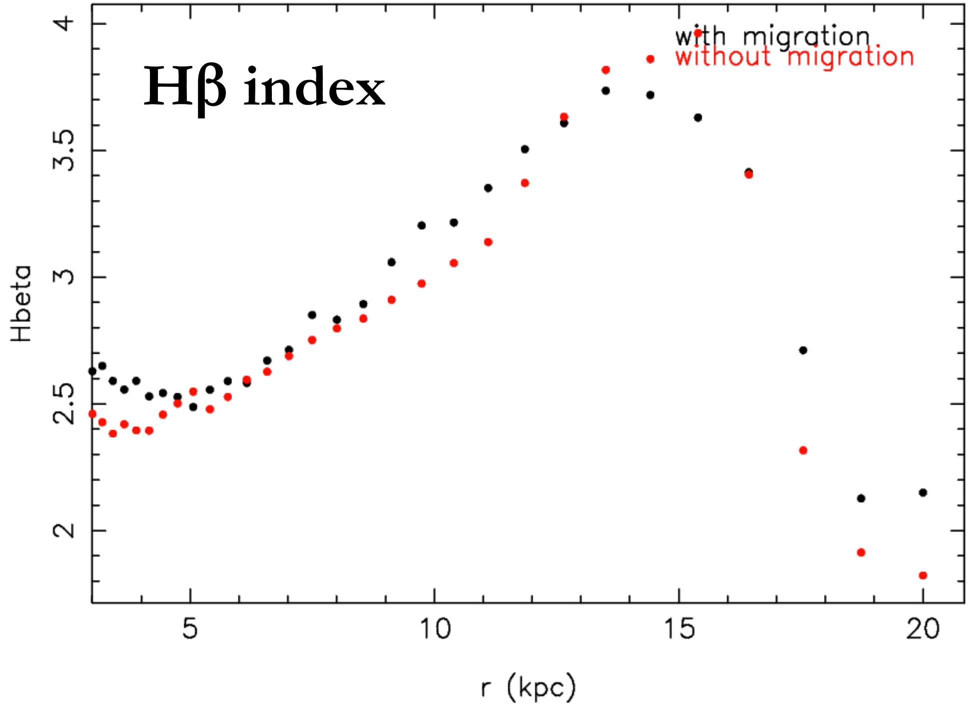
Sanchez et al. (2010, in prep.)

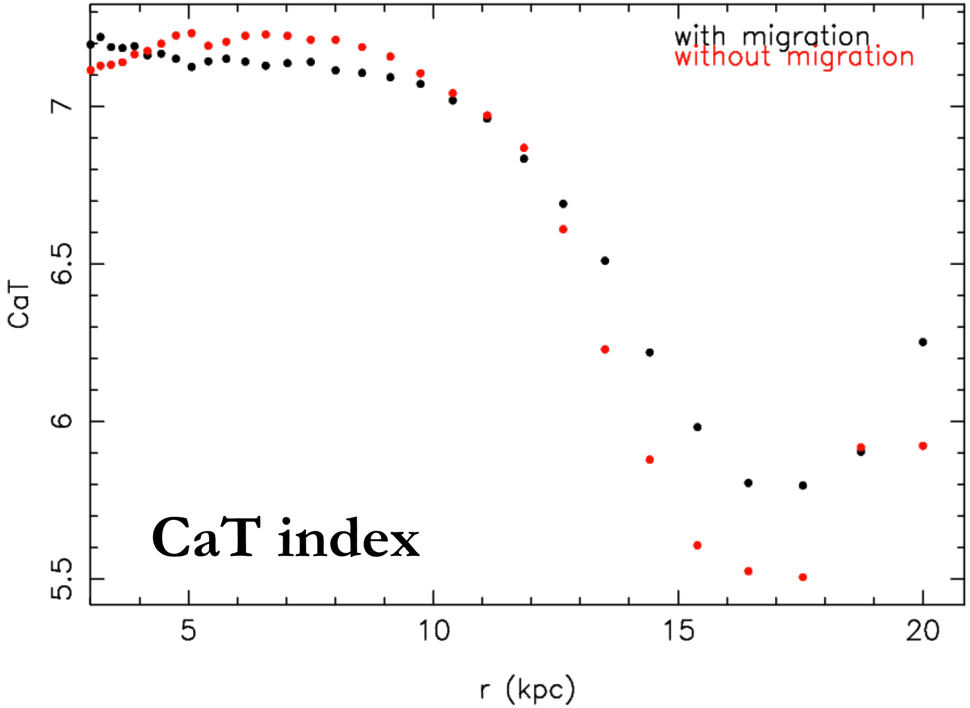
We will select ~30 objects from the CALIFA sample (PPAK@CAHA3.5 legacy) covering a range of luminosities, colors, environments

GTO plans for MEGARA

Unresolved nearby disk galaxies

Observables: **(1)** σ_z profile from the integrated light
(2) Spectral indices profiles





Sánchez-Blázquez et al. (2009)

Multi Espectrógrafo en GTC de Alta Resolución para Astronomía

Synergies with future WHT instruments

Current or planned IFUs on 4m-class telescopes:
- VIRUS-P: Large FOV, low R, very coarse spaxels
- SparsePak: Large FOV (low filling factor), intermediate-high R, very coarse spaxels
- PPAK: Large FOV, low-intermediate R, coarse spaxels, λ>3700Å
- SAURON: Intermediate-large FOV, low-intermediate R, small spaxels, narrow λ-range
- OASIS: Intermediate FOV, intermediate R, small spaxels.

Current or planned IFUs on 10m-class telescopes:
- VIMOS: Large FOV, very low R, small spaxels, λ>4000Å
- GMOS: Small FOV, low-intermediate R, small spaxels
- VIRUS: Large FOV, low R, coarse spaxels
- MUSE: Large FOV, intermediate R, small spaxels, λ>4500Å
- MEGARA: Large FOV, intermediate-high R, small spaxels, λ>3700Å

One possible niche for a IFU at WHT:

Large FOV with relatively coarse spaxels (~1-2”), R~4000-10000 in two arms covering the full-optical range at low resolution. Such an instrument would be highly competitive for **stellar populations studies in nearby (unresolved) galaxies** and could share (or duplicate) a **MOS** with the same specifications.

Multi Espectrógrafo en GTC de Alta Resolución para Astronomía

From the

Report by the ETSRC on Europe's 2-4m OIR telescopes over the next decade

In strong contrast, IFU spectroscopy provides spatial information that is relatively unbiased. IFU observations of nearby galaxies can offer a wealth of information on their stellar populations, star formation and ionized gas properties, as well as kinematics, structure and possible imprints of environmetal effects.

In order to perform an efficient 2D spectroscopic study of galaxies in the local Universe a larger field of view is a must. For a galaxy at, for example, the distance of the Coma cluster (i.e. $z \sim 0.023$), 1 arcsec on the sky represents $\sim$0.5 kpc within the galaxy (assuming standard cosmology); therefore, it is clear that an IFU field of view ≥ 1 arcmin in diameter is necessary to carry out an efficient mapping of the full spatial extent of such objects out as far as Coma.

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