# *Astrophysics of Galaxies*

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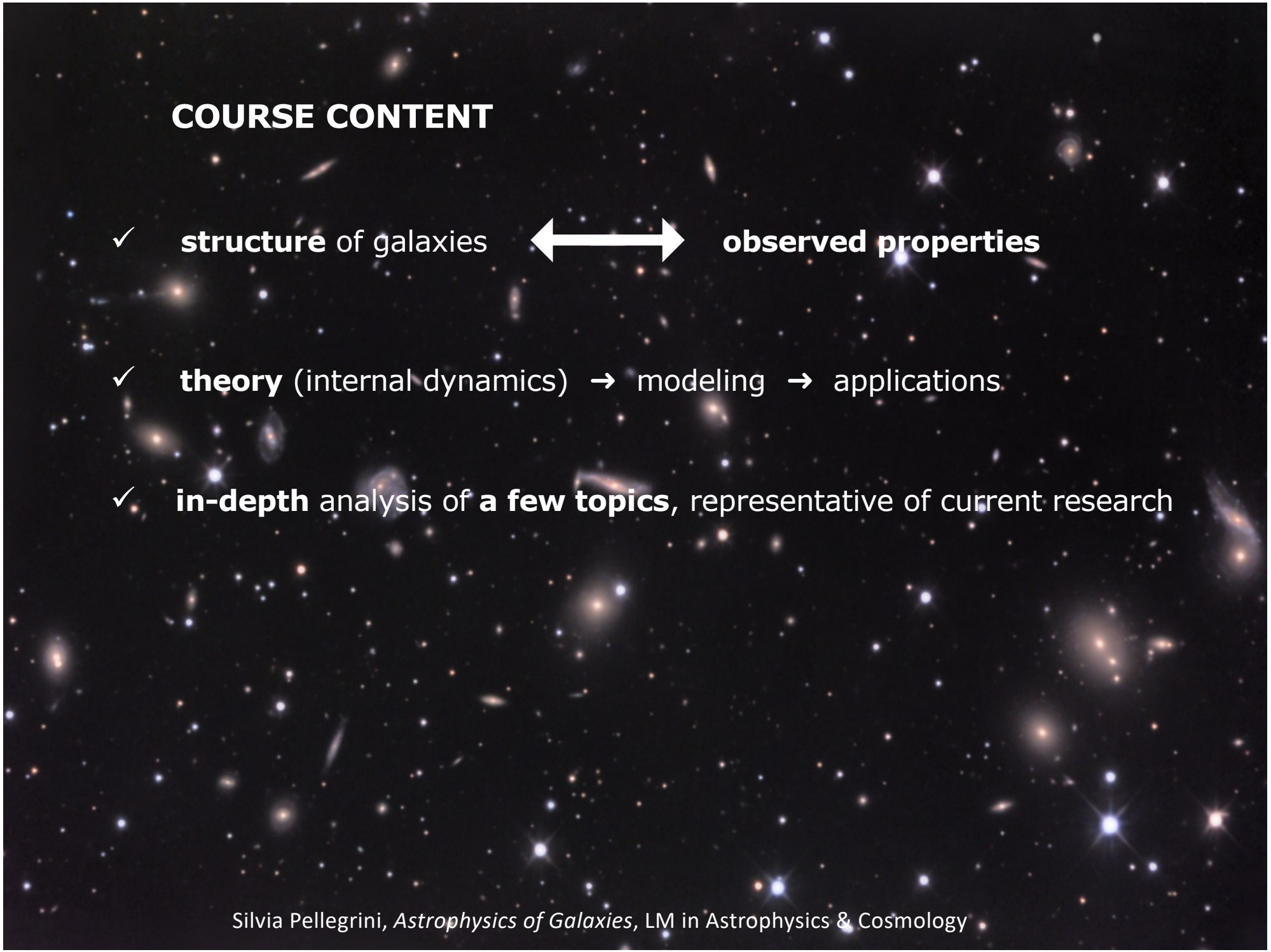
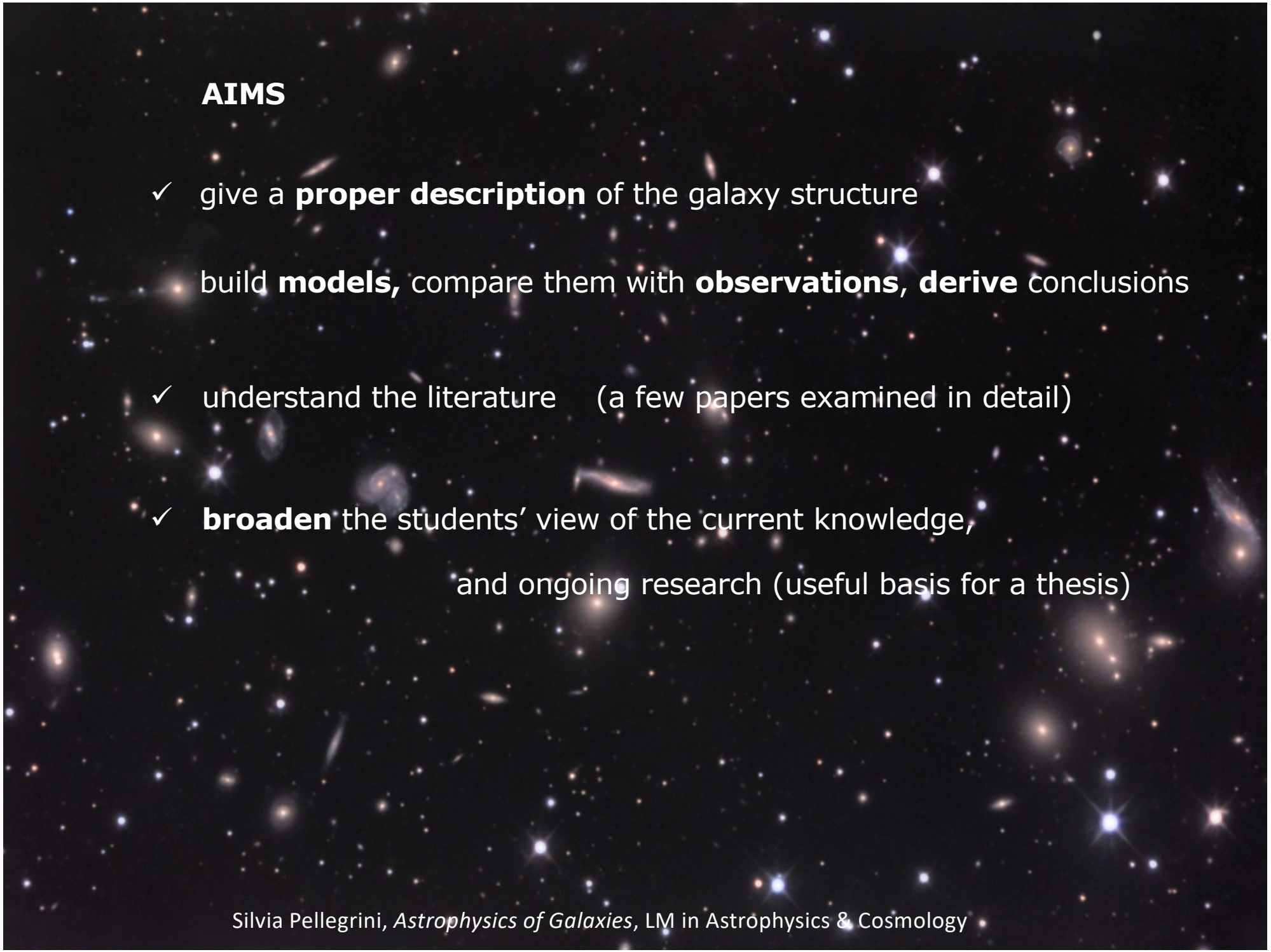
*lessons during the* **first** *period*
(from September to December)


COURSE CONTENT
✓ **structure** of galaxies ⟷ **observed properties**
✓ **theory** (internal dynamics) → modeling → applications
✓ **in-depth** analysis of **a few topics**, representative of current research



**AIMS**

- ✓ give a **proper description** of the galaxy structure

  build **models,** compare them with **observations**, **derive** conclusions

- ✓ understand the literature (a few papers examined in detail)

- ✓ **broaden** the students' view of the current knowledge,

  and ongoing research (useful basis for a thesis)

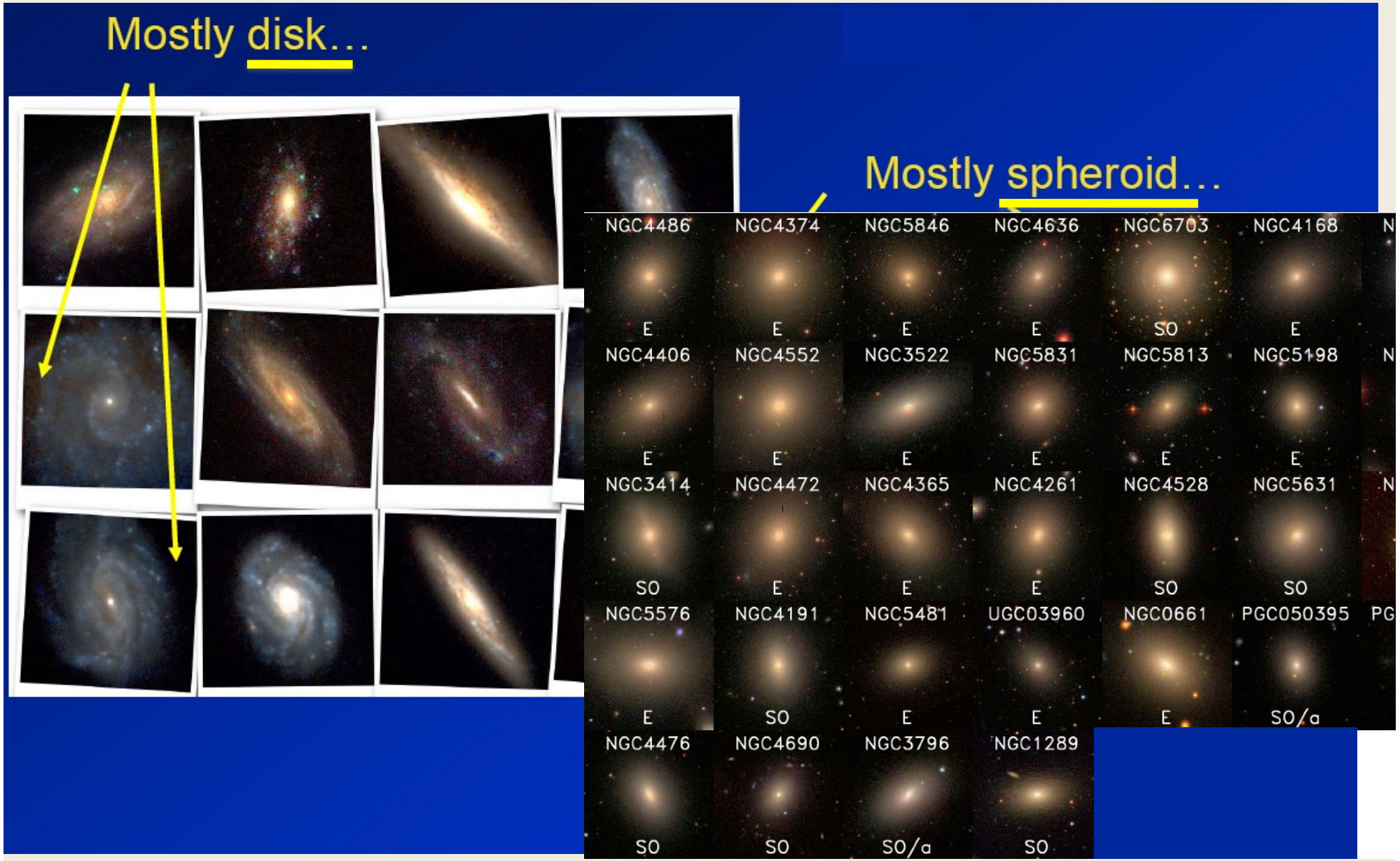
# Main topics

- **Introduction** (historical perspective)
- **Theory: structure and internal dynamics**

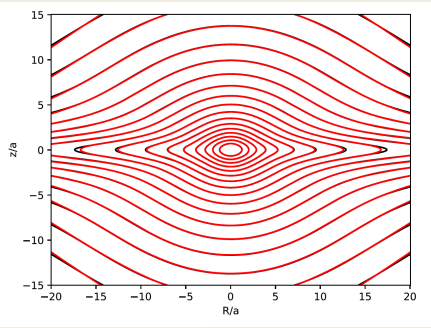
applications

- **Dark matter**
- **Supermassive (central) black holes**
- **Scaling laws** (correlations between quantities characterizing morphology/structure/stellar population)
- **Initial stellar mass function (IMF)**
- **ISM (hot)**

# Galaxies show two fundamental stellar components



# 1) Structure and internal dynamics of spheroids and discs

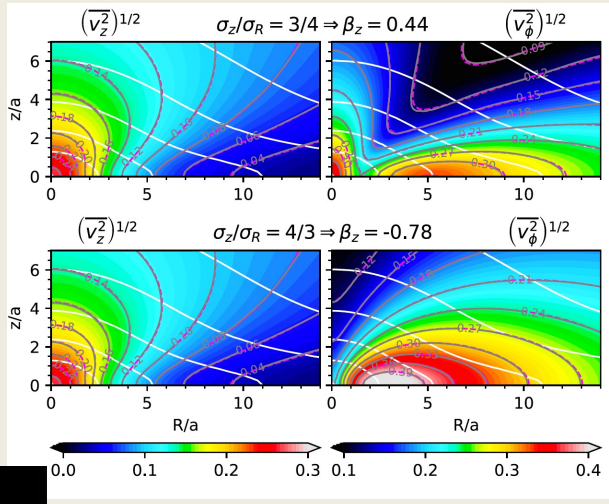



- ✓ collisionless systems (CBE)
- ✓ distribution function $f(I_1,I_2,I_3)$ ⟷ kinematic field
- ✓ **Jeans equations**:

"velocity dispersion" (σ),
"streaming velocity" (v)
orbital *anisotropy* ($\sigma_{ij}$)
multiple mass components

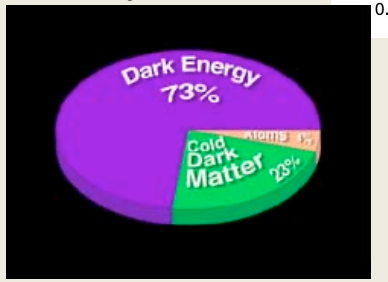
$$n\frac{\partial \bar{v}_j}{\partial t}+n\bar{v}_i\frac{\partial \bar{v}_j}{\partial x_i}=-n\frac{\partial \Phi}{\partial x_j}-\frac{\partial (n\sigma_{ij}^2)}{\partial x_i}$$

spherical and axisymmetric:
**spheroids** and **discs**




- ✓ ***"classic"* applications:**

analogy stellar system ⟷ fluid
**rotational level** ⟷ orbital **anisotropy** ⟷ **shape**
determination of the ***mass*** profiles (***stellar*** + ***dark***)
presence of ***black holes***

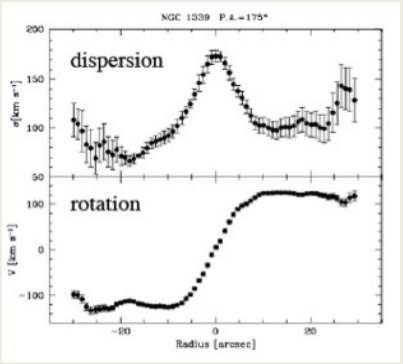


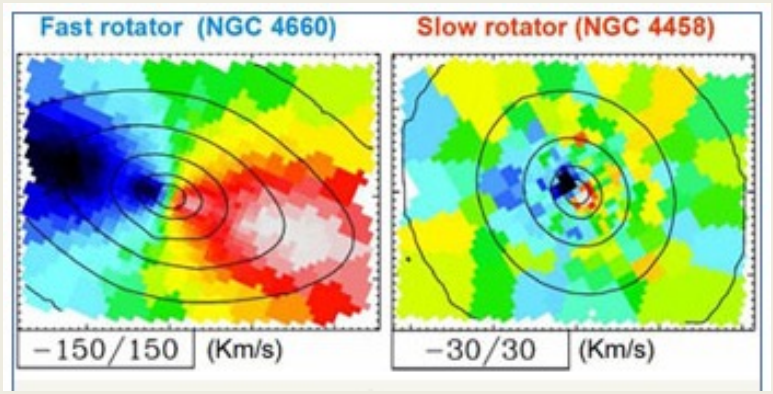

- ✓ **more "operative" applications**

(examples from current research) →

✓ **more "operative" applications** (examples from current research):

❖ Epoch of IFS & large surveys




Emsellem et al. 2011, Cappellari et al. 2011,

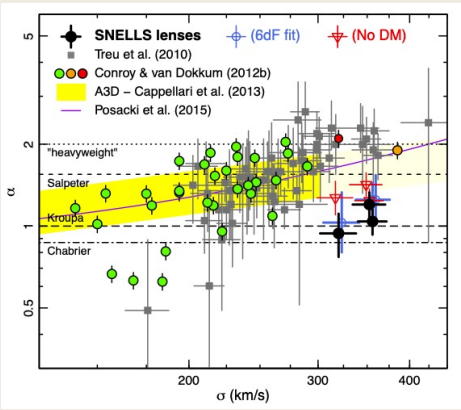
→ kinematical classification (vs. morphological)
→ improved correlations/scaling laws

**ATLAS$^{3D}$**
CALIFA
MaNGA
SAMI
…

❖ Compare observed and theoretical/model quantities

Derive clues/constraints on the galaxy properties:

→ what is the total mass profile? is it "universal" ?
→ what is the stellar initial mass function (IMF)? "universal"?
→ implications for the formation



# 2) Supermassive central black holes

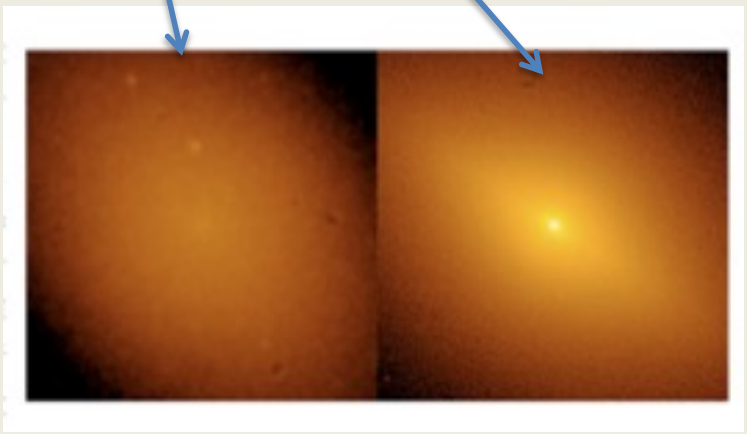
✓ discovery, mass measurement (HST)

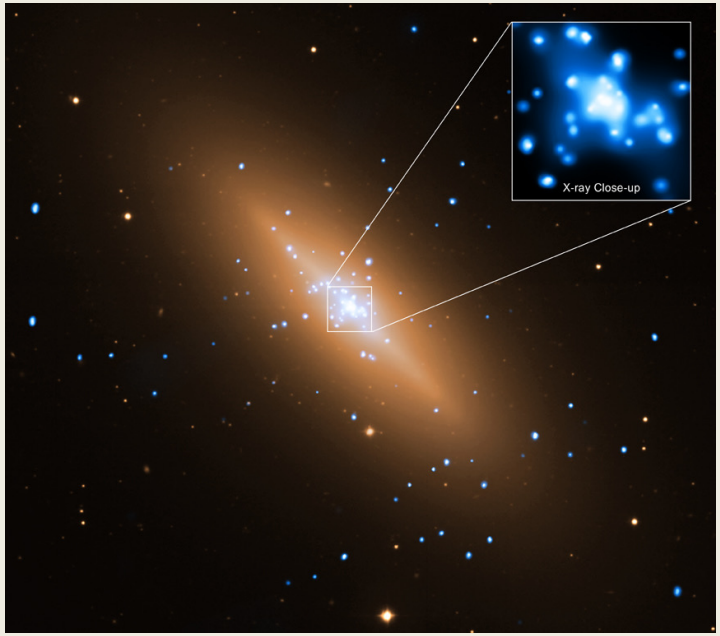
$M_{BH} - \sigma$

✓ relationship with the host galaxy

example: brightness profiles in the central galactic regions:

**core** and **cusp**






NGC3115,
*VLT & Chandra*

## 3) Scaling laws

→ $j - M_\star$ ,

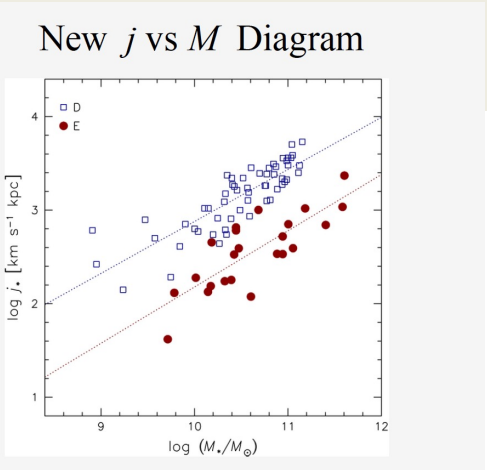
Faber-Jackson ($L - \sigma^4$),

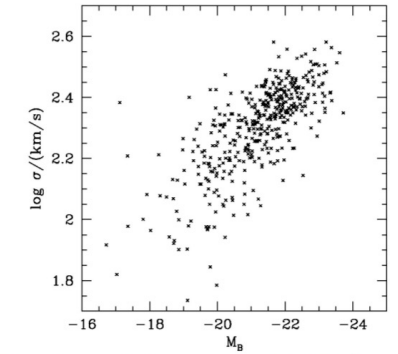
$Mg - \sigma$,

$M_{BH} - \sigma$,

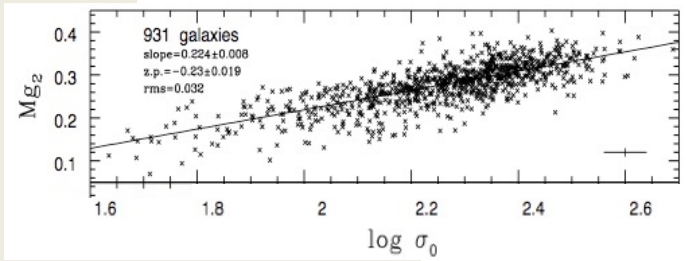
→ fundamental plane,

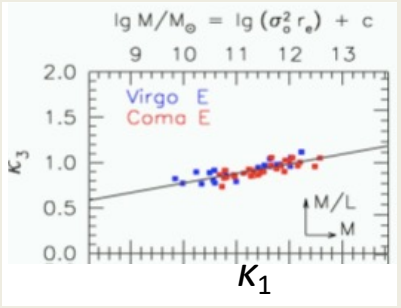
…

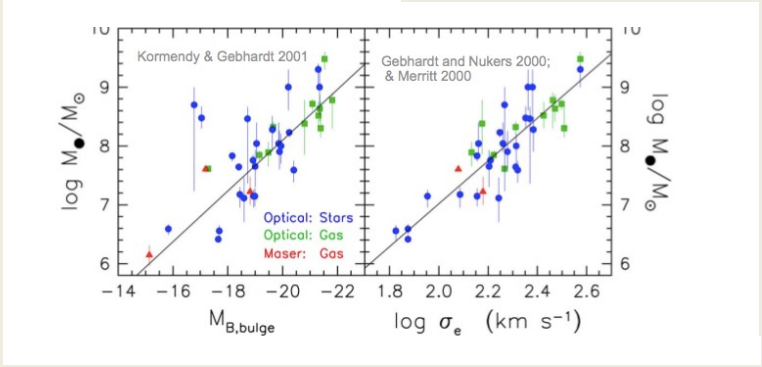



Faber-Jackson relation between central velocity dispersion and total magnitude of elliptical galaxies ($L_B \sim \sigma^4$).



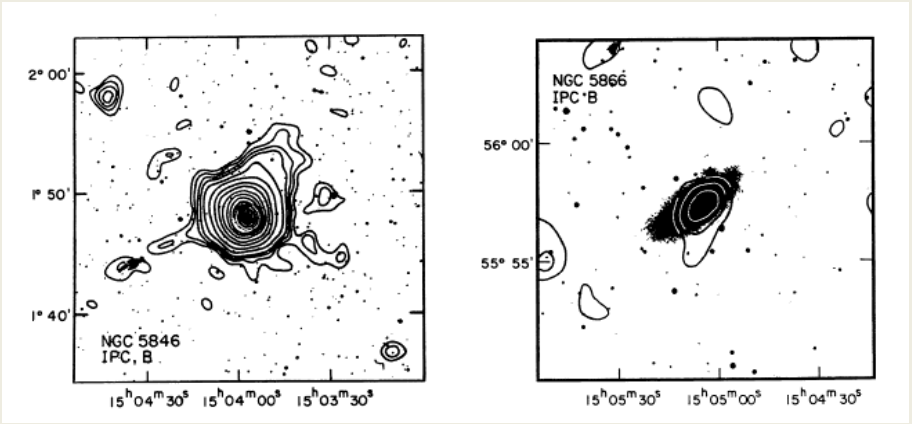

**What physical interpretation ?**

**What constraints on the structure and evolution of galaxies?**

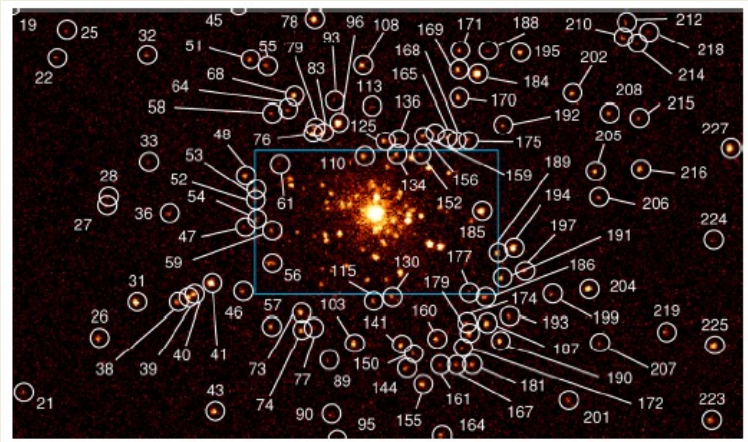
# 4) ISM in ETGs: properties, origin, evolution

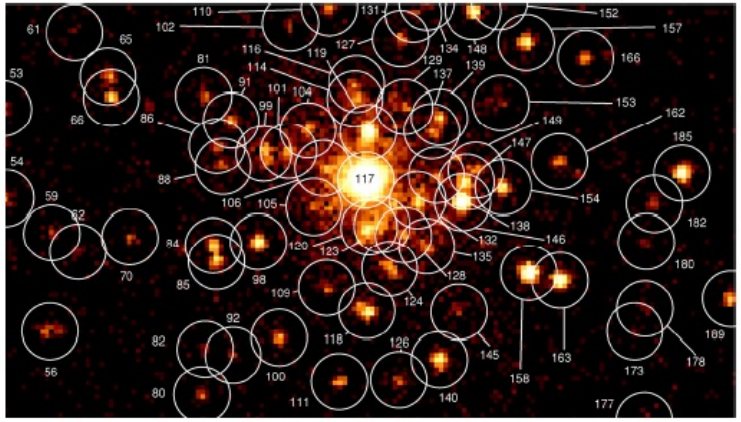
**hot** phase (T~few X$10^6$ K)

From the beginning (*Einstein* ) …



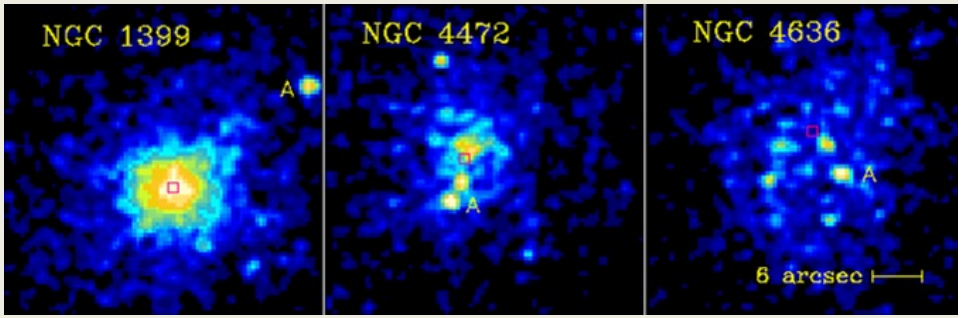

to *Chandra*:





NGC3379

- ✓ relation with host galaxy
- ✓ hydrodynamical modeling
- ✓ total galaxy mass measurements



# Bibliography


1) **Binney & Tremaine 1987, 2008 Galactic Dynamics**,
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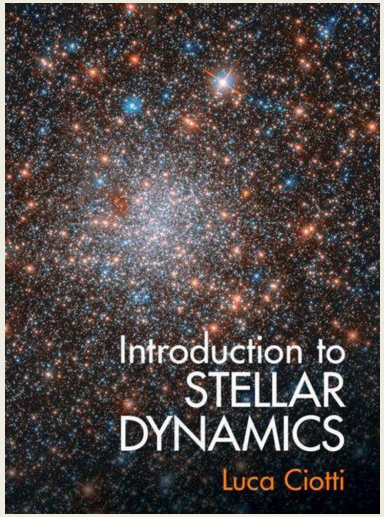
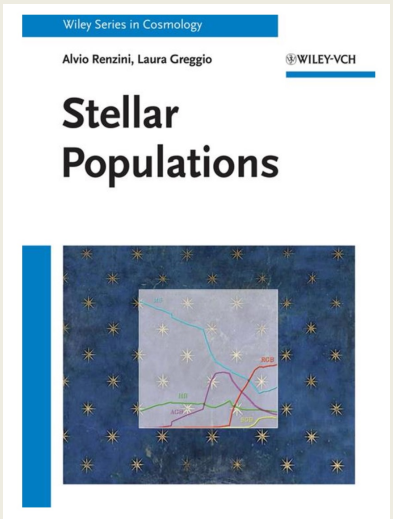
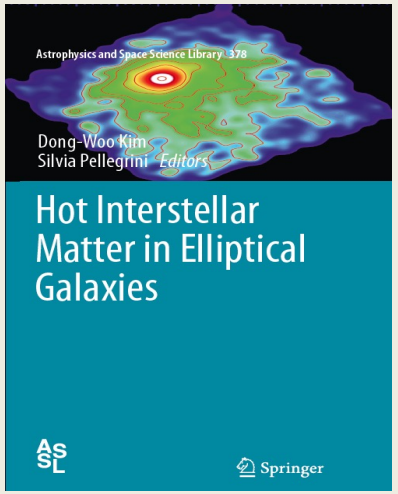
2) **Ciotti 2021, Introduction to Stellar Dynamics**, Cambridge Univ. Press




3) **Greggio & Renzini 2011, Stellar Populations**. A user guide from low to high redshift, Wiley




4) **Kim & Pellegrini** 2012




Springer (2012)

5) **Papers**

6) **teaching material on** virtuale.unibo.it

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