



# Galaxies

**Formation and Evolution**

**From the Local Group to the Highest  
Redshifts**

**Observations and Modelling**

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**Postgraduate Course 2007/08**

**University of Hertfordshire**

# Large groundbased Telescopes

large mirrors & fields of view

&

# Hubble Space Telescope

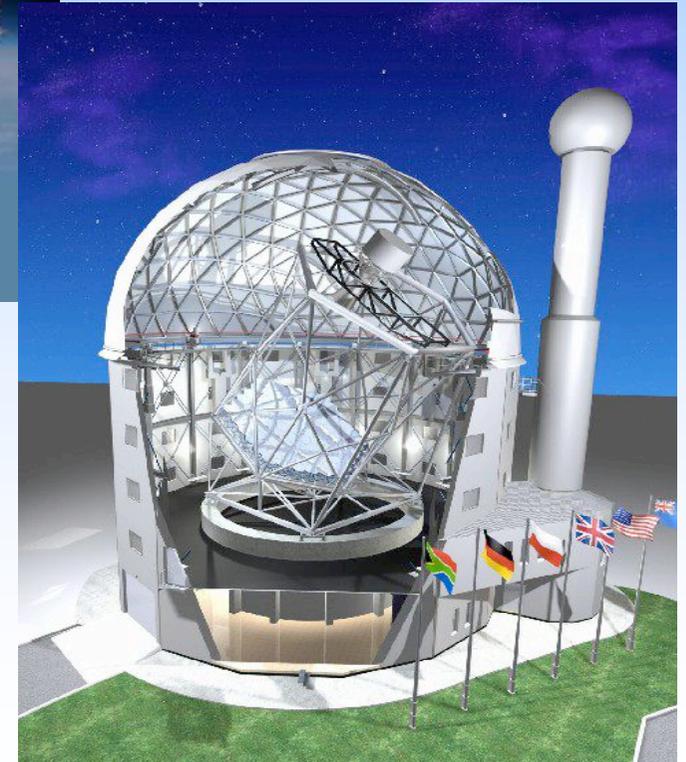
high spatial resolution

- nearby galaxies in enormous detail
- distant galaxies in large numbers

ESO - VLT Chile



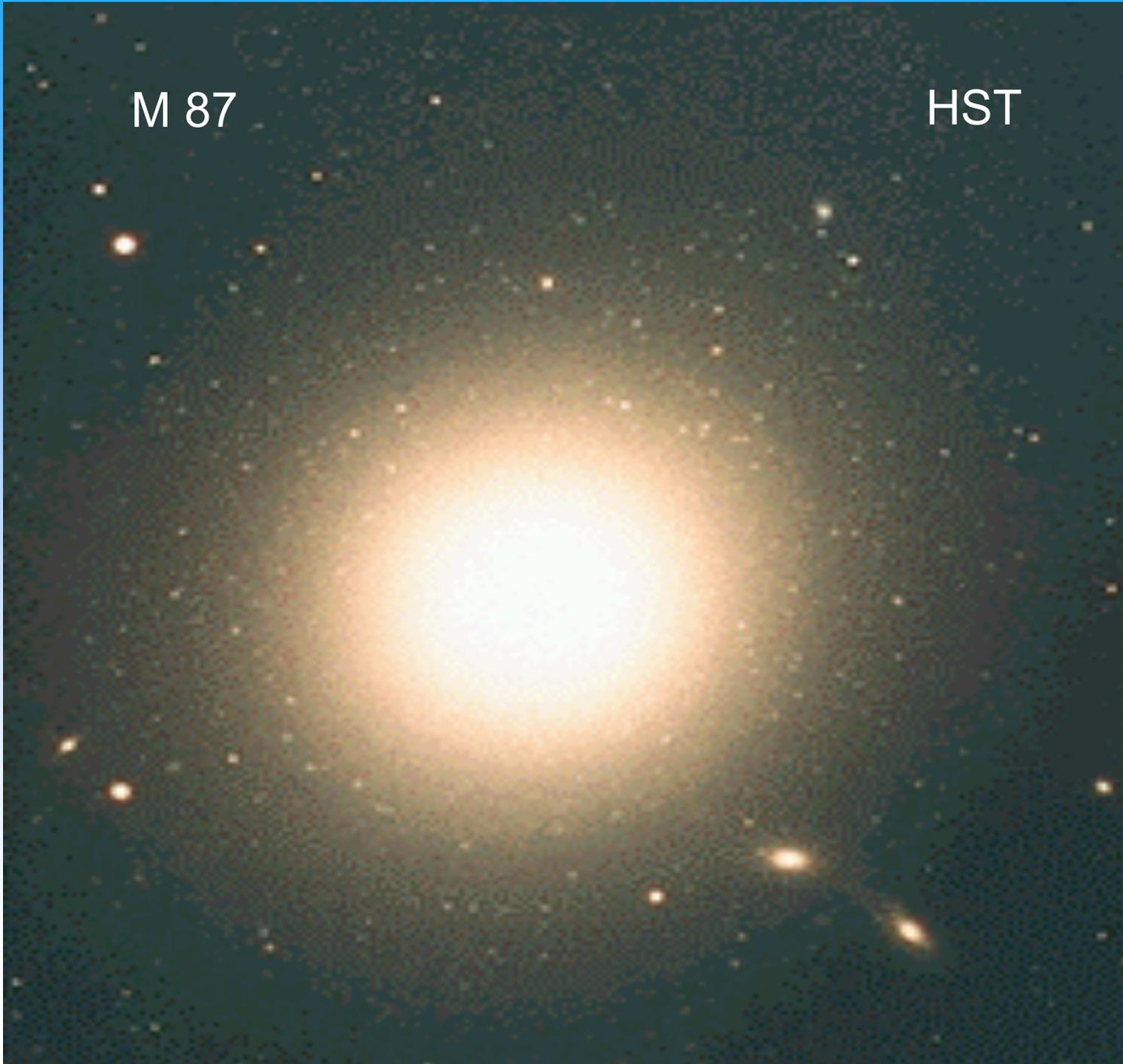
SALT



HST

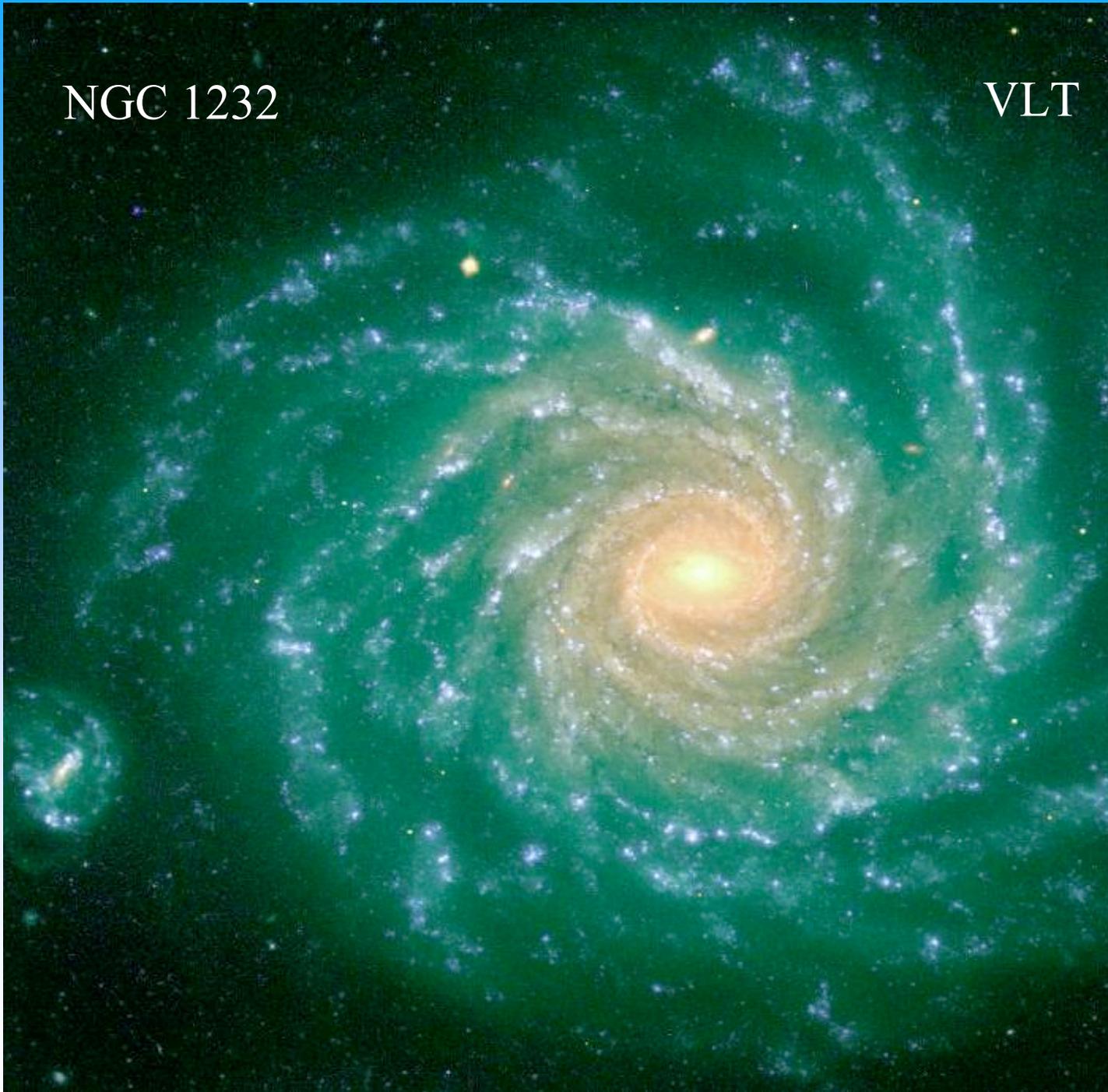
M 87

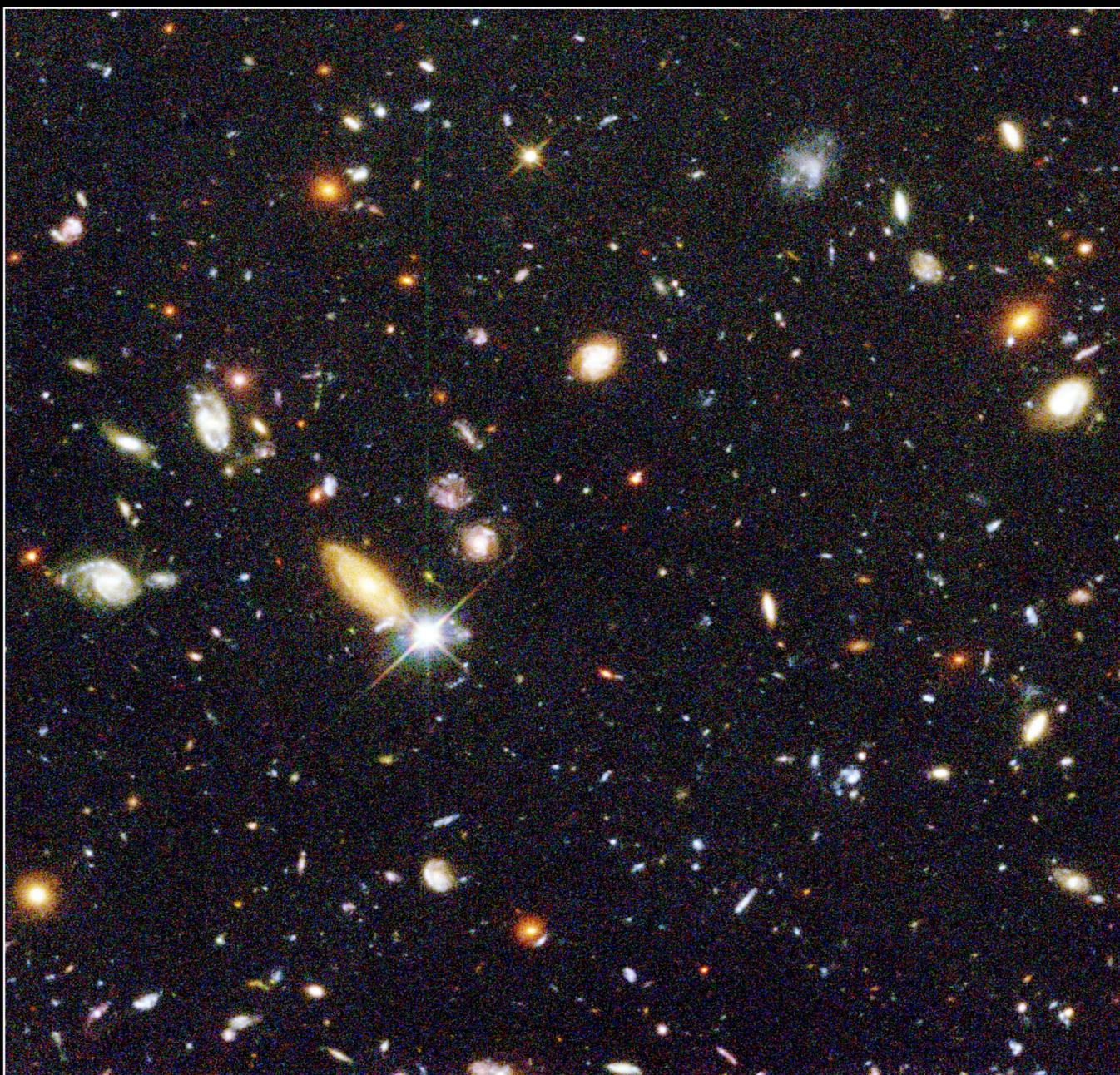
HST



NGC 1232

VLT



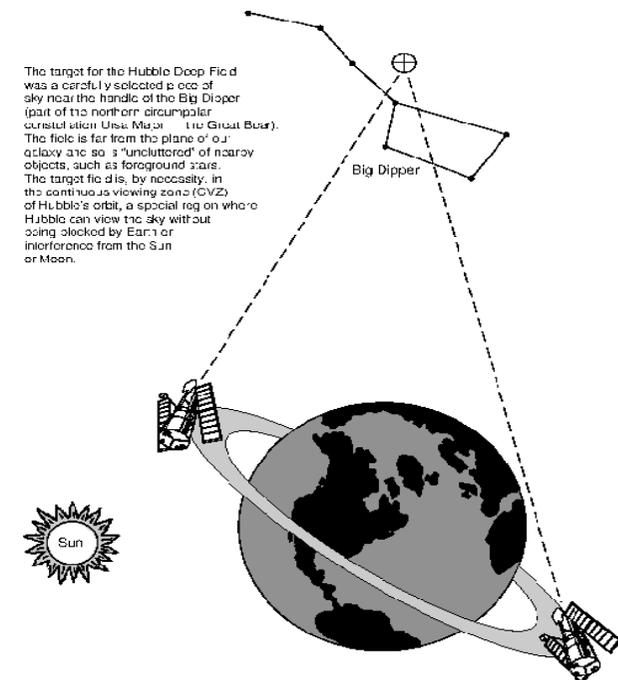


Area 1/100 Full Moon  
 ~ 3000 Galaxies  
 Faintest galaxies :  
**29 mag**

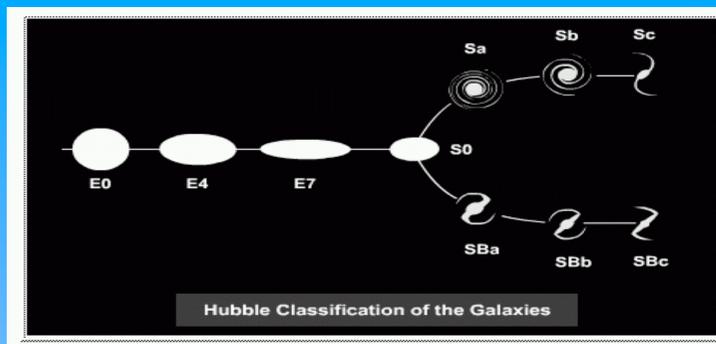
↳ candle at  $D_{\text{moon}}$   
 Multi – band imaging  
 UV – NIR  
 WFPC2 + NICMOS

**Hubble Deep Field**  
 Hubble Space Telescope • WFPC2

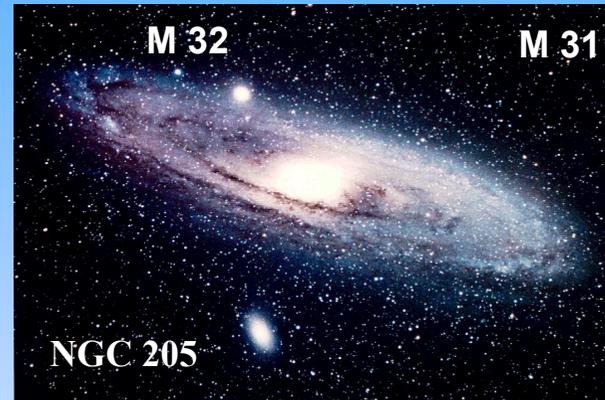
The target for the Hubble Deep Field was a carefully selected piece of sky near the handle of the Big Dipper (part of the northern circumpolar constellation Ursa Major - the Great Bear). The field is far from the plane of our galaxy and so is "uncluttered" of nearby objects, such as foreground stars. The target field is, by necessity, in the continuous viewing zone (CVZ) of Hubble's orbit, a special region where Hubble can view the sky without being blocked by Earth or interference from the Sun or Moon.



(E. Hubble



1923ff)



**Cosmic Microwave Background :**

**Universe at  $z=1000$  extremely homogeneous & isotropic**

**? Splendid manifold of local galaxies ?**

**? Relation of distant galaxies to local ones ?**

**Observations = snapshots**

**Evolution of galaxies  $\leftrightarrow$  numerical models**

# Observations at different wavelengths → complementary information

X-rays : hot gas, binary stars

UV : young, hot, high-mass stars

→ star formation (=SF)

opt. : solar-type, intermed. mass stars

NIR : old, cool, low mass stars

→ galaxy mass

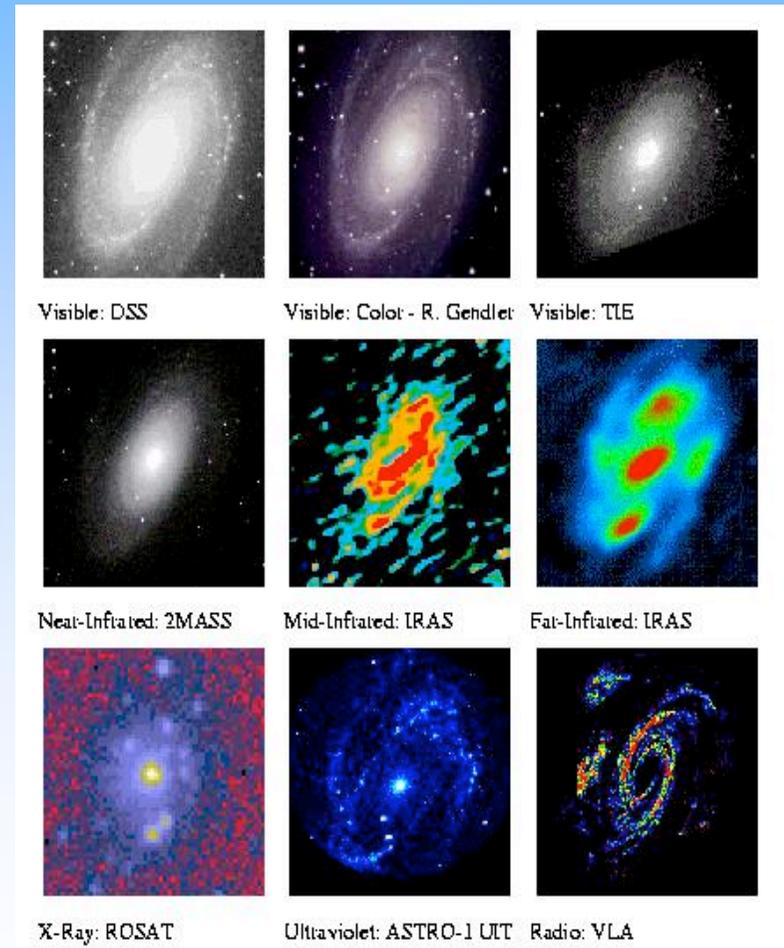
mid- & FIR : dust - therm. emission

sub-mm : cold, molecular gas

→ 1. order reservoir for SF

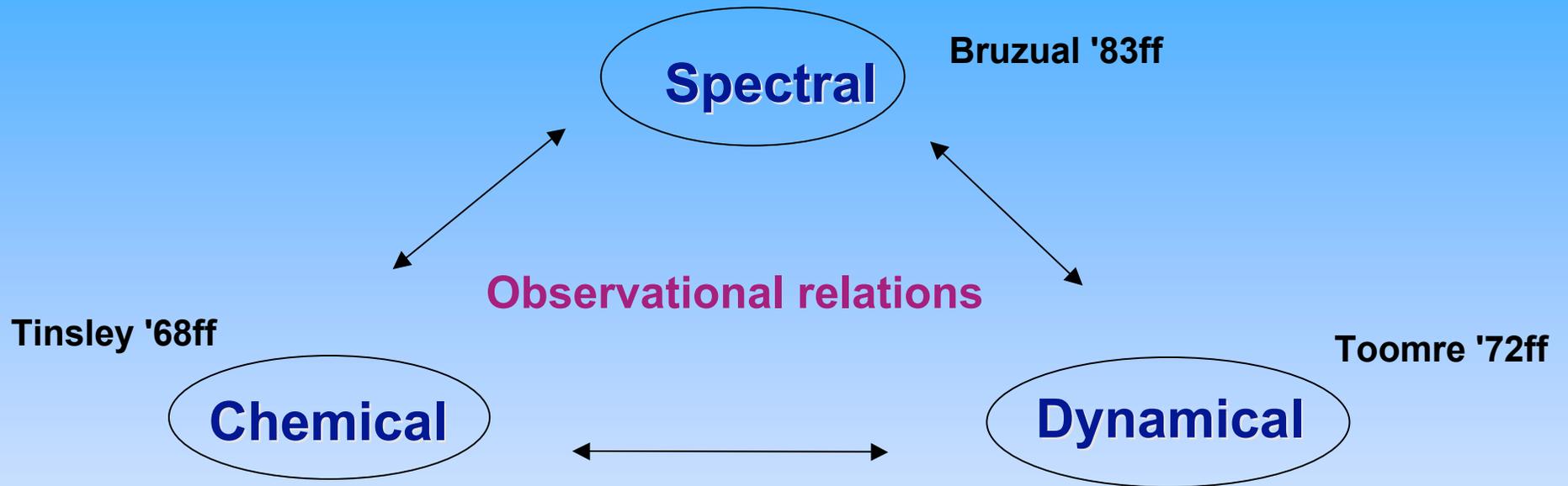
Radio : neutral hydrogen gas

→ 2. order reservoir for SF



Spiral galaxy M81

# 3 Aspects of Galaxy Evolution



Originally modelled one by one independently.

Now attempting to couple consistently : **GALEV models**

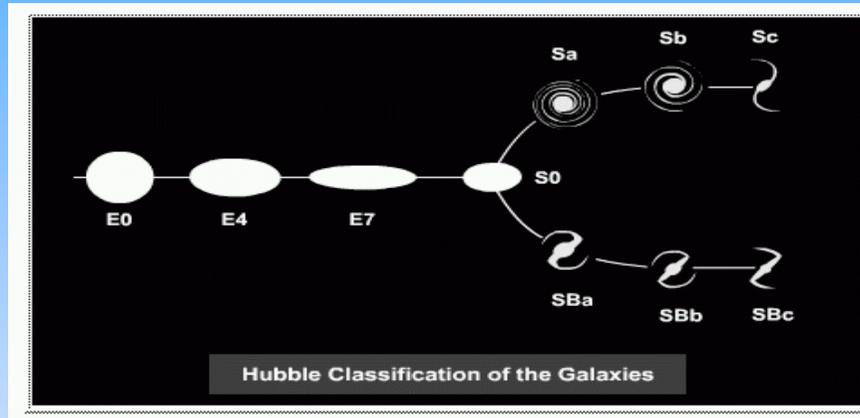
**S** : formation & evolution of stars +/- gas +/- dust

**C** : formation & nucleosynthesis of stars; infall/outflow of gas

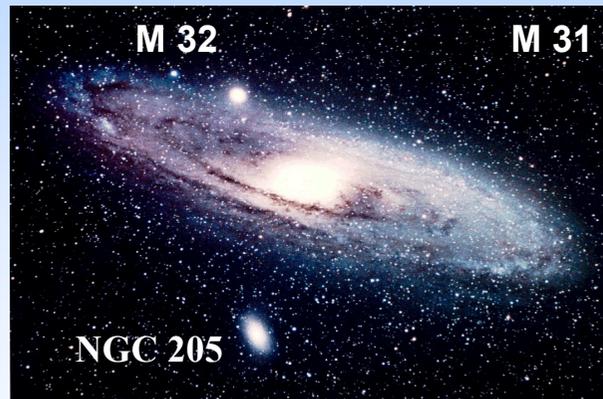
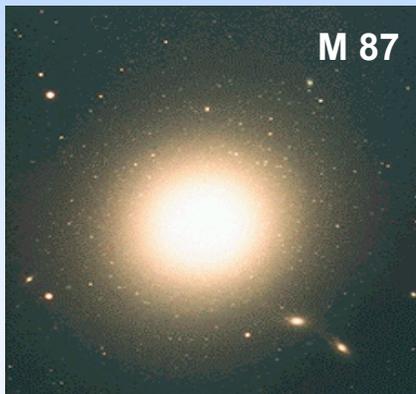
**D** : internal & external gravitation, stars + gas + DM

# Local Galaxies

Normal (= big) galaxies : Hubble sequence  
E, S0, Sa, Sb, Sc, Sd, Irr



(E. Hubble 1923ff)

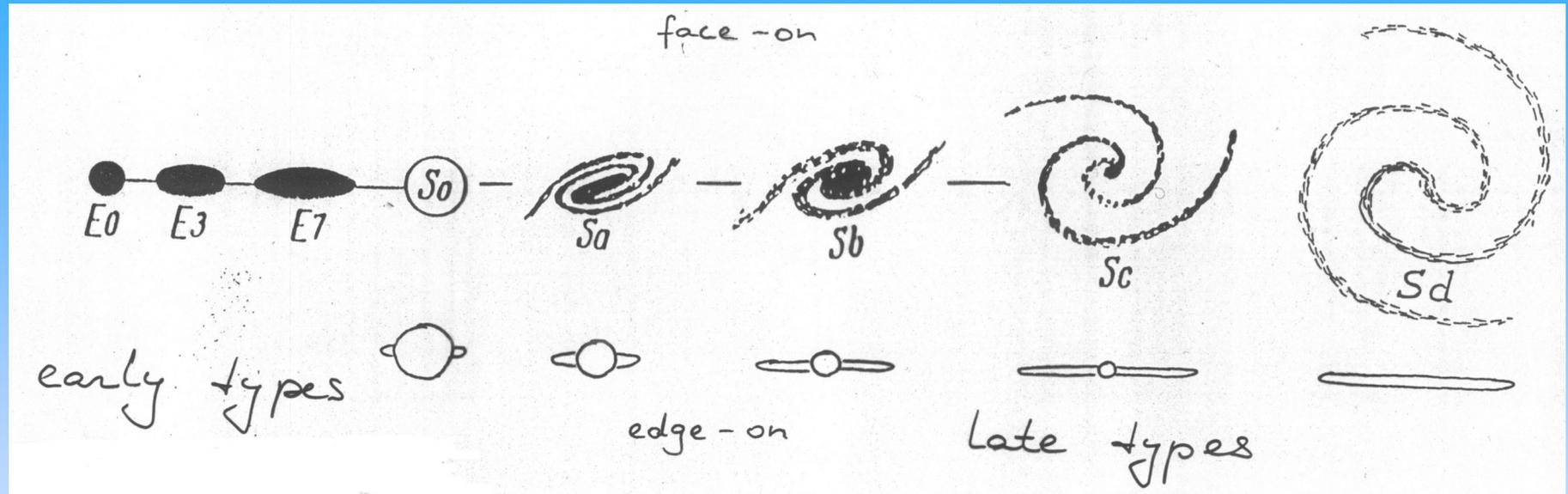


Dwarf galaxies : dE, dSph, dl

Low surface brightness galaxies : E, disk, dwarf

Starburst galaxies, interacting galaxies, radio gals,  
AGN. ULIRGs. SCUBA gals. Lyman Break Gals. . . .

# The Hubble Sequence of Normal Galaxies

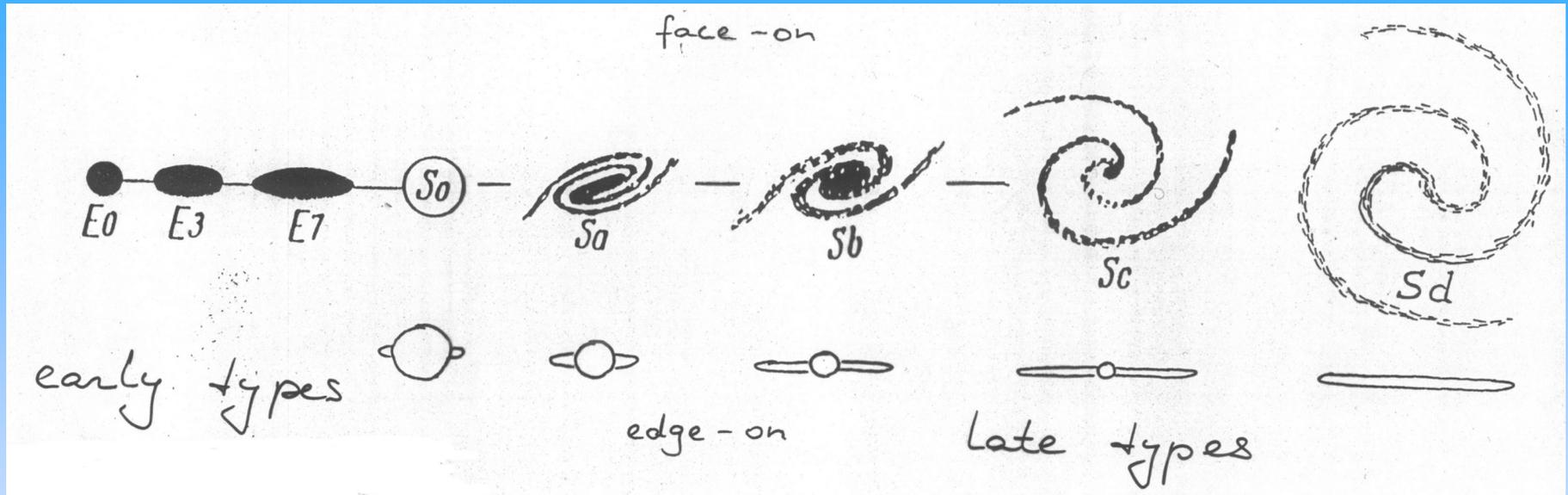


**early type**  
**old stars**  
**no/little HI, H<sub>2</sub>**  
**no SF today**  
**red colours**  
**K-star absorption line**

**late type galaxies**  
**young + old stars**  
**plenty HI, H<sub>2</sub>, HII, dust**  
**active SF today**  
**blue colours**  
**hot star + emission line**

**spectrum**

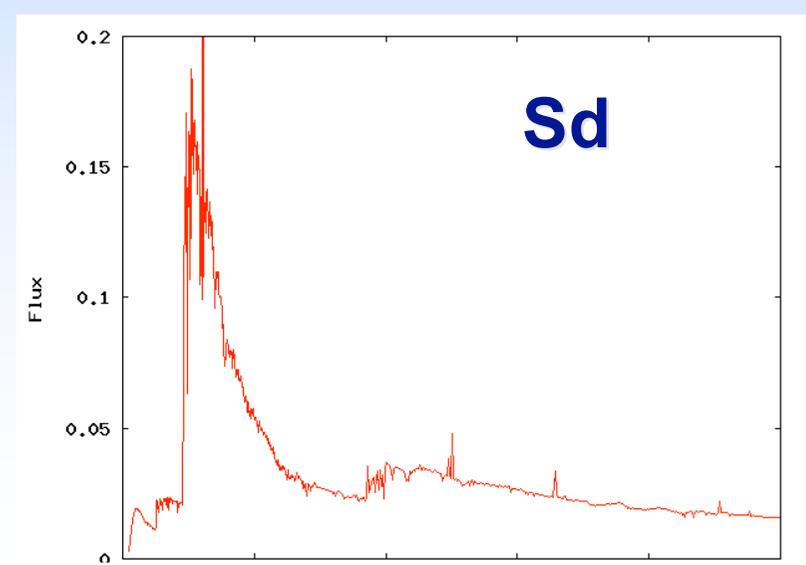
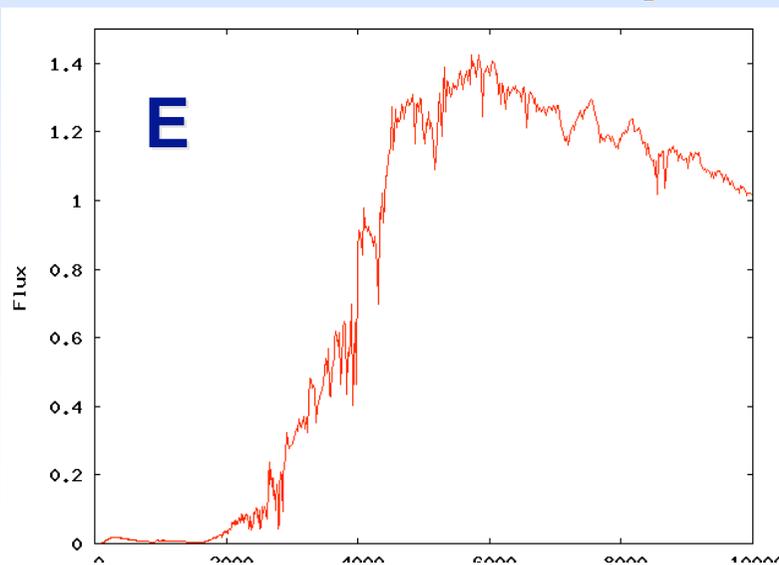
# The Hubble Sequence of Normal Galaxies



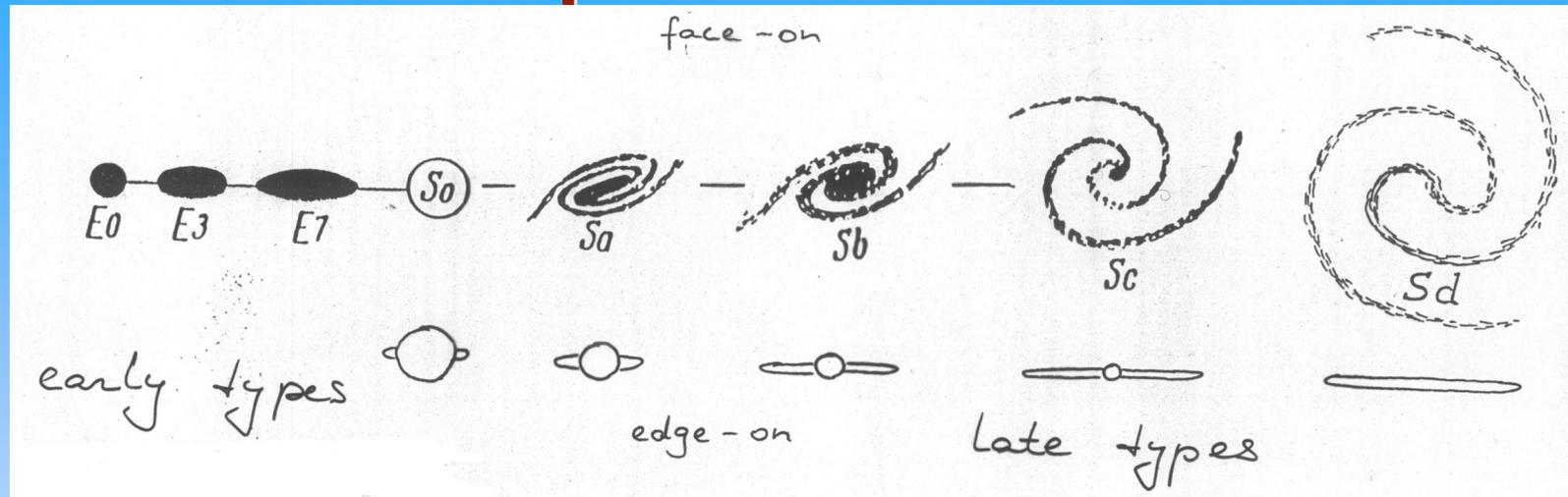
early type

late type galaxies

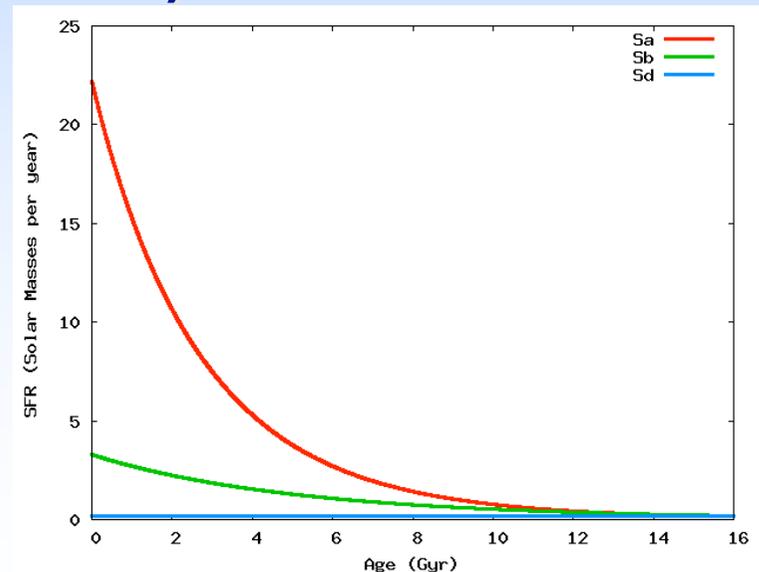
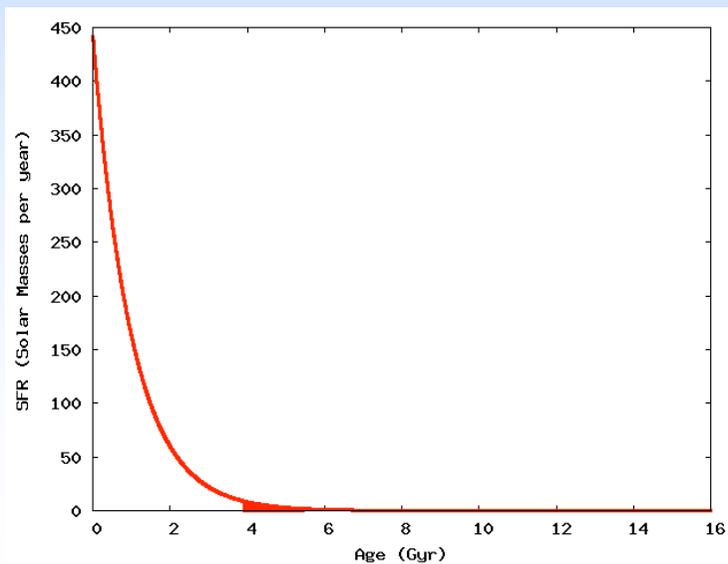
spectra



# The Hubble Sequence of Normal Galaxies



All properties (chemical abundances, gas content, spectra) **can** be explained by differences in the **Star Formation Histories (= SFHs)**



**SFR =  $\sigma_1 \cdot E^{-1.1} \cdot D^{-1.8} \cdot \text{SFR}(\sigma_1)$**

# Trends along the Hubble Sequence

- ☞ Morphology : Bulge/disk light ratio ✓
- ☞ Colours
- ☞ Spectra
- ☞  $SFR_0$
- ☞ Luminosities
- ☞ Composition: stars, gas, dust ✓
- ☞ Metallicity: chemical composition

metallicity  $Z :=$  mass fraction of everything  $> {}^4\text{He}$

→  $\langle SFR \rangle_{HT}(t)$



# Trends along the Hubble Sequence

- ☞ Colours : RC2 (de Vaucouleurs et al. 1977), RC3 (Buta et al. 1995)

<elliptical>

$T = -5$

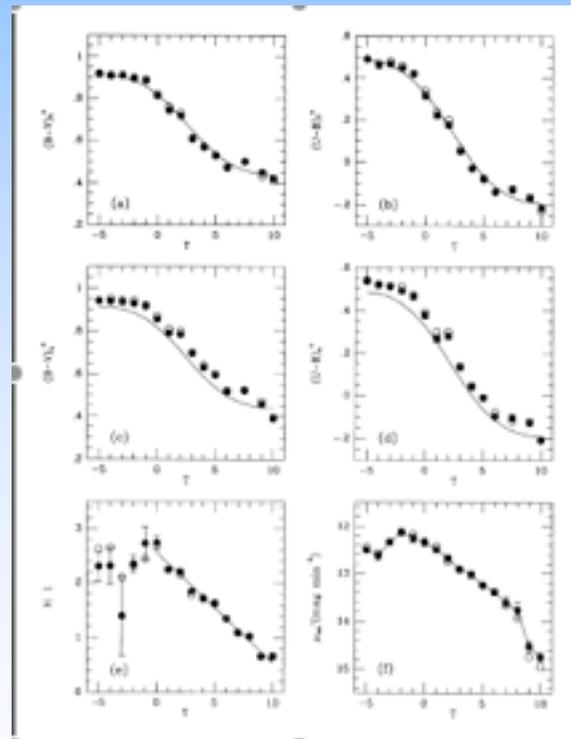
red

.....

<Sd/Irr>

$T = 8, 10$

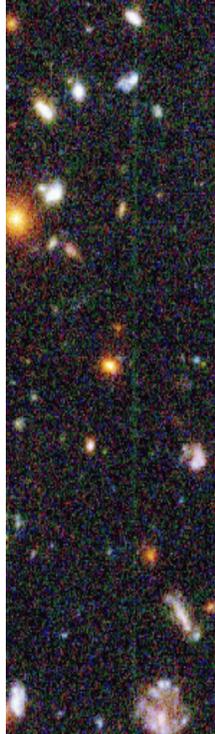
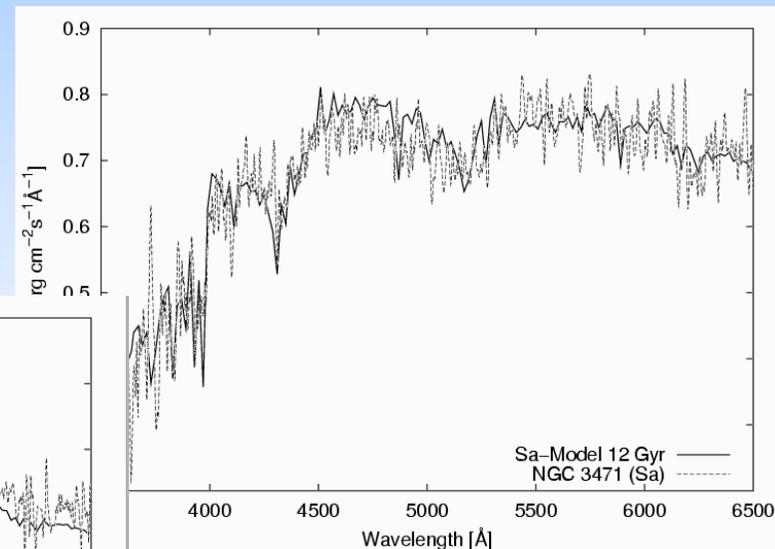
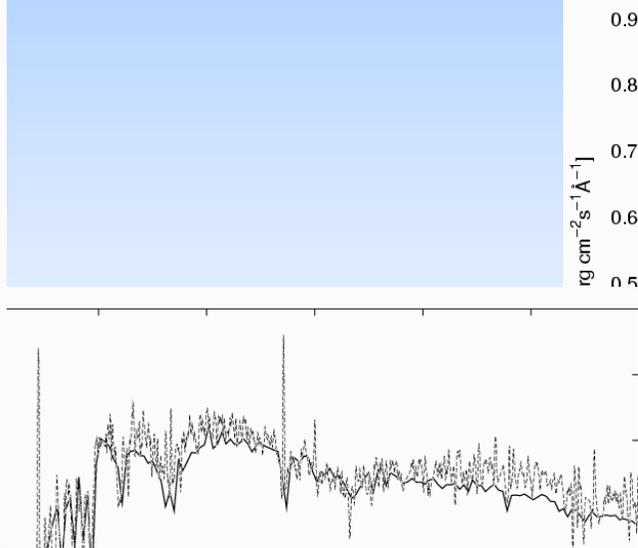
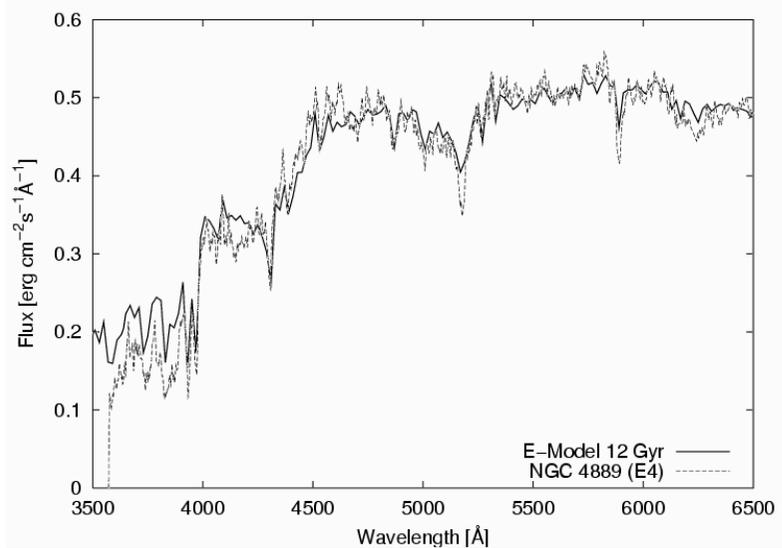
blue



# Trends along the Hubble Sequence

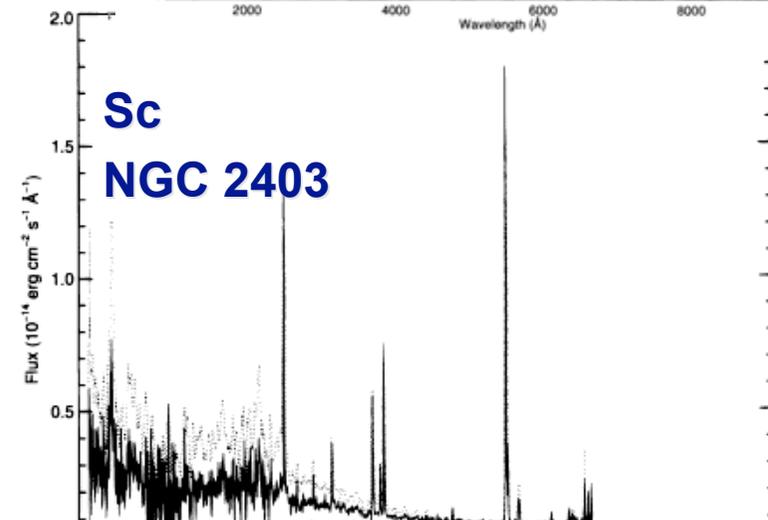
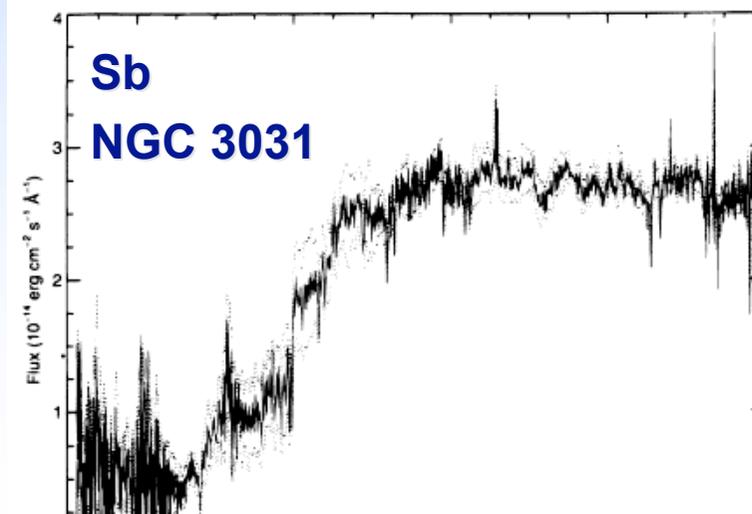
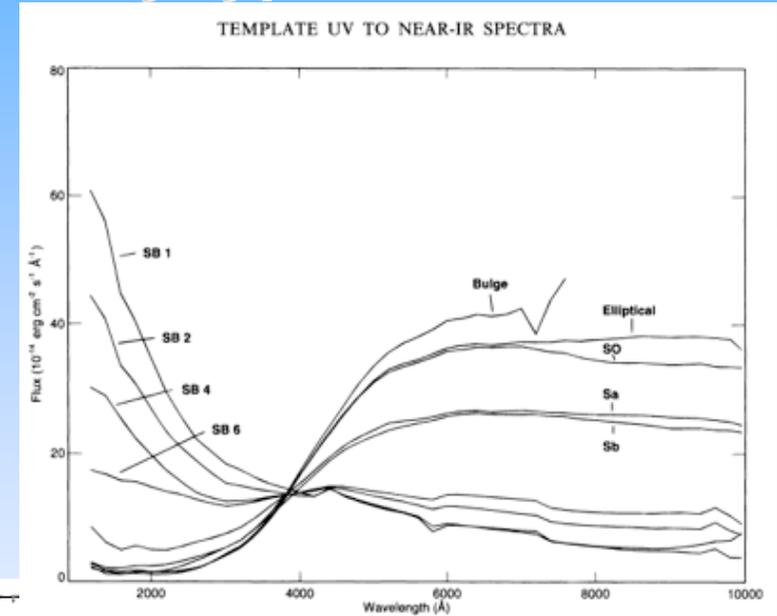
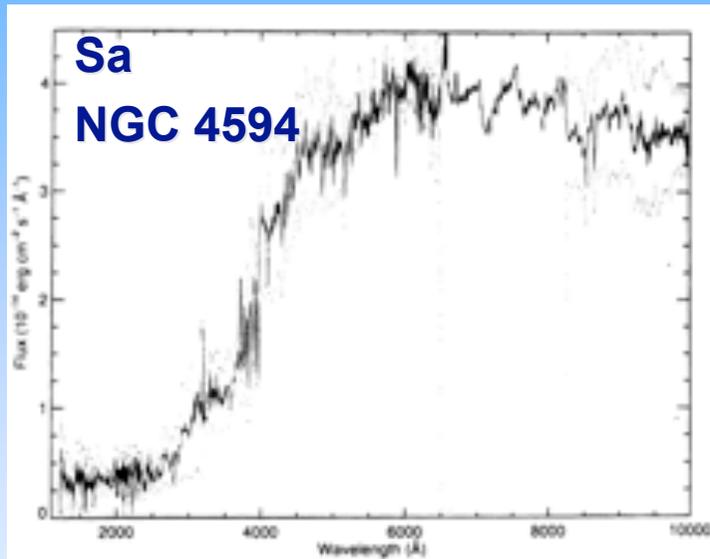
☞ Spectra : Kennicutt 1992, Kinney et al. 1996  
Template spectra of different galaxy types

Spectral type  $\leftrightarrow$  morphological type  
in the local universe ✓  
NOT at high redshift !



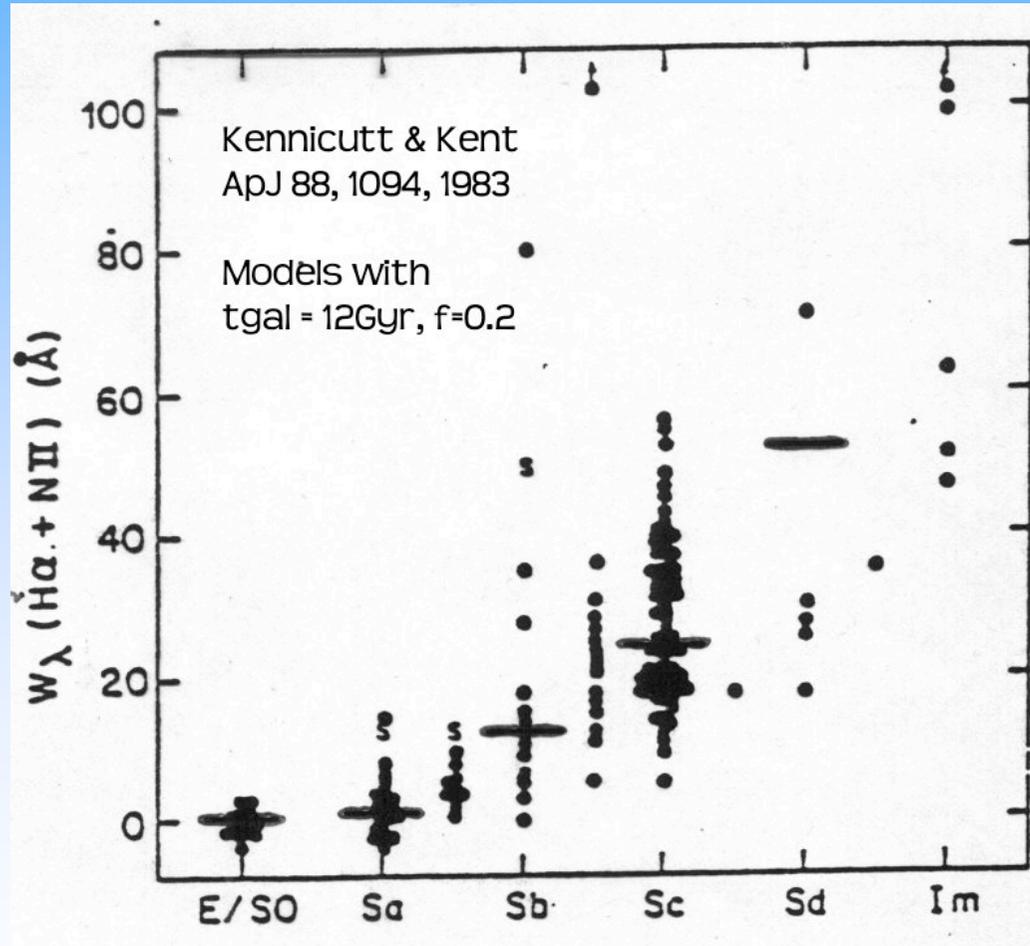
# Trends along the Hubble Sequence

☞ Spectra : UV(IUE) + optical(KPNO) : Kinney et al. 96  
Template spectra of different galaxy types



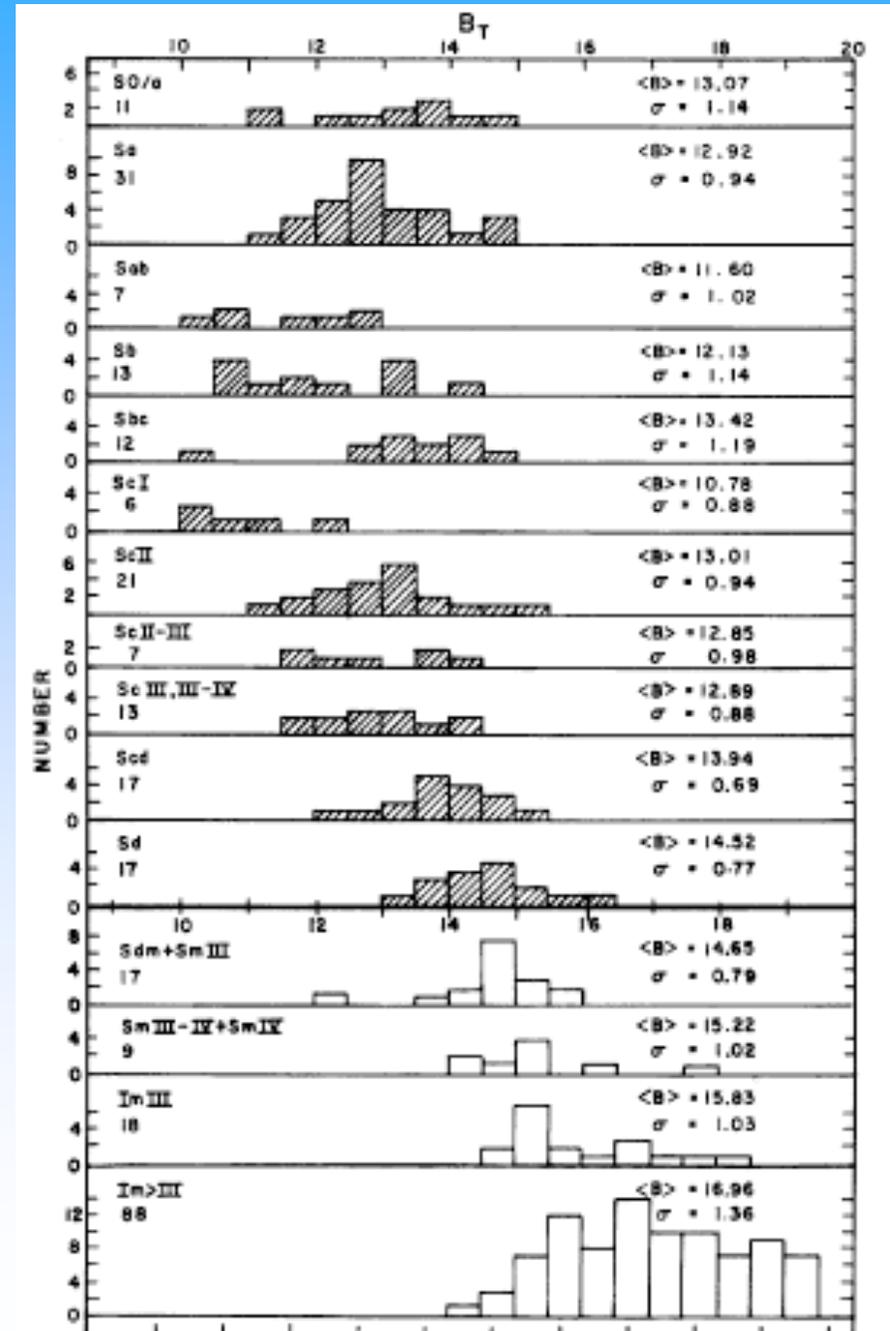
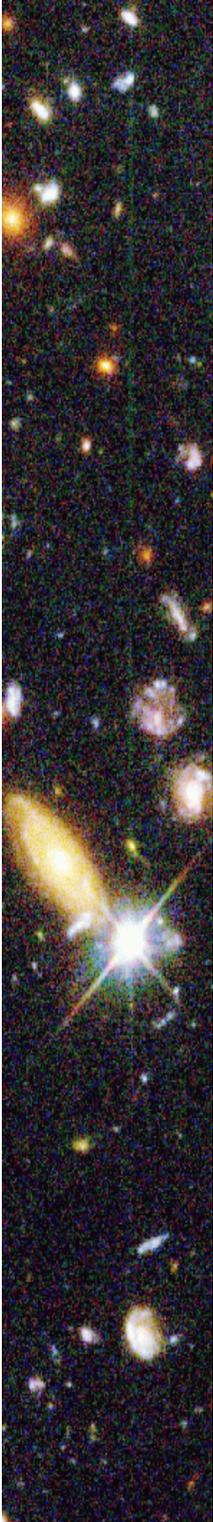
# Trends along the Hubble Sequence

☞  $SFR_0$  : Kennicutt & Kent 1983



# Trends along the Hubble Sequence

- ☞ Luminosities :  
Sandage et al. 1985a, b



# Trends along the Hubble Sequence

- ☞ Luminosities : Sandage et al. 1985a, b



Typ	Parameter der LF		$M_B$
E + dE	$B^* = 10.2$	$\alpha = -1.45$	-21.5
S0	$\langle B_T \rangle = 12.60$	$\sigma = 1.5$	-19.1
Sa	$\langle B_T \rangle = 11.95$	$\sigma = 1.15$	-19.7
Sb	$\langle B_T \rangle = 12.90$	$\sigma = 1.43$	-18.8
Sc	$\langle B_T \rangle = 12.83$	$\sigma = 0.84$	-18.9
Sd	$\langle B_T \rangle = 13.95$	$\sigma = 1.5$	-17.7
Im	$B^* = 15.6$	$\alpha = -0.25$	-16.1

Tabelle 3.3: Parameter der Leuchtkraftfunktionen der Galaxien im Virgo - Haufen nach Sandage *et al.* (1985a,b).  $B^*$  und  $\alpha$  beziehen sich auf eine Schechter'sche,  $\langle B \rangle$  und  $\sigma$  auf eine Gauss'sche Leuchtkraftfunktion (LF).  $M_B$  sind die aus  $B^*$  bzw.  $\langle B \rangle$  über den bolometrischen Entfernungsmodul (Sandage & Tammann 1976) errechneten scheinbaren  $B$ - Helligkeiten.