Galaxy mass assembly

from the VLT & HST - IMAGES

&

(later) with E-ELT/MOSAIC

by François Hammer

l'Observatoire de Paris — GEPI

Galaxies Étoiles Physique et Instrumentation

Thanks to: Hector Flores, Mathieu Puech, Yanbin Yang, Sylvain Fouquet, M. Rodrigues, Philippe Amram, Catherine Cesarsky, Helmut Dannerbauer, Isaura Fuentes-Carrera & the IMAGES team

Jianling Wang, E. Athanassoula & Phil Hopkins

& The MOSAIC team

Most -72%- large galaxies have spiral structures

$M_{stellar} > 2\ 10^{10}\ M_o$

NGC 1365

NGC 2997

M100 SABbc

M 31

M83

Their progenitors are within distant galaxies

IMAGES survey

Sample selection

$M_J < -20.3$ & $0.4 < z < 0.8$

4 fields, including the CDFS

Star Forming sub-sample

$EW_0([OII]) > 15$ Å

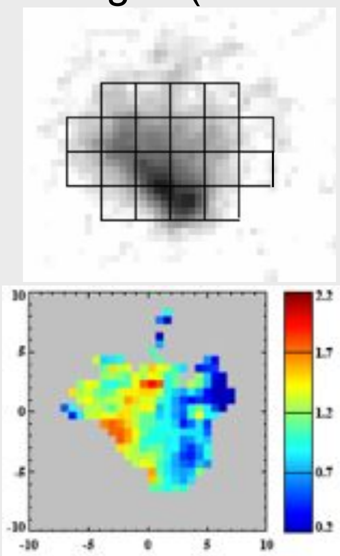
Intermediate-mass galaxies

$M_{stellar} > 1.5 \times 10^{10} M_\odot$

Likeliest progenitors of present-day ~M* spirals, six billion years ago

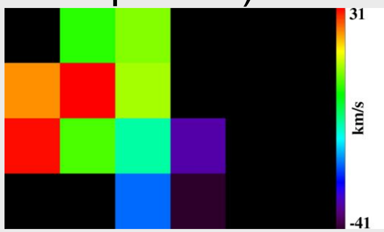
Imaging

ACS images (≥ 3 orbits)



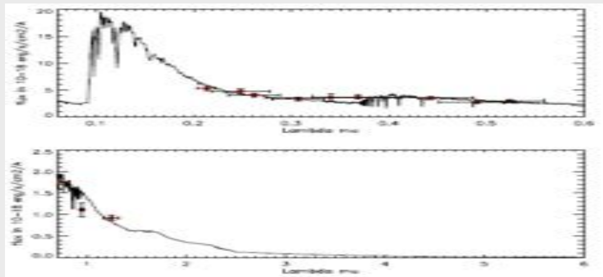
3D Spectroscopy

VLT/FLAMES-GIRAFFE (R~10 000, 8-24hrs exposure)



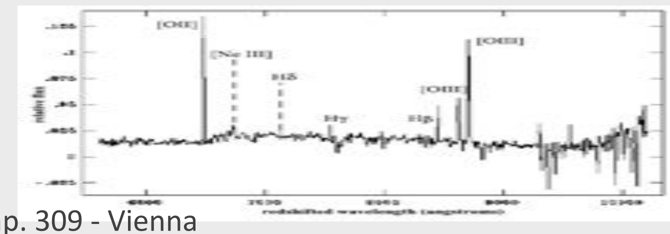
Multi-λ photometry

Spitzer, GALEX, ACS, EIS,etc.



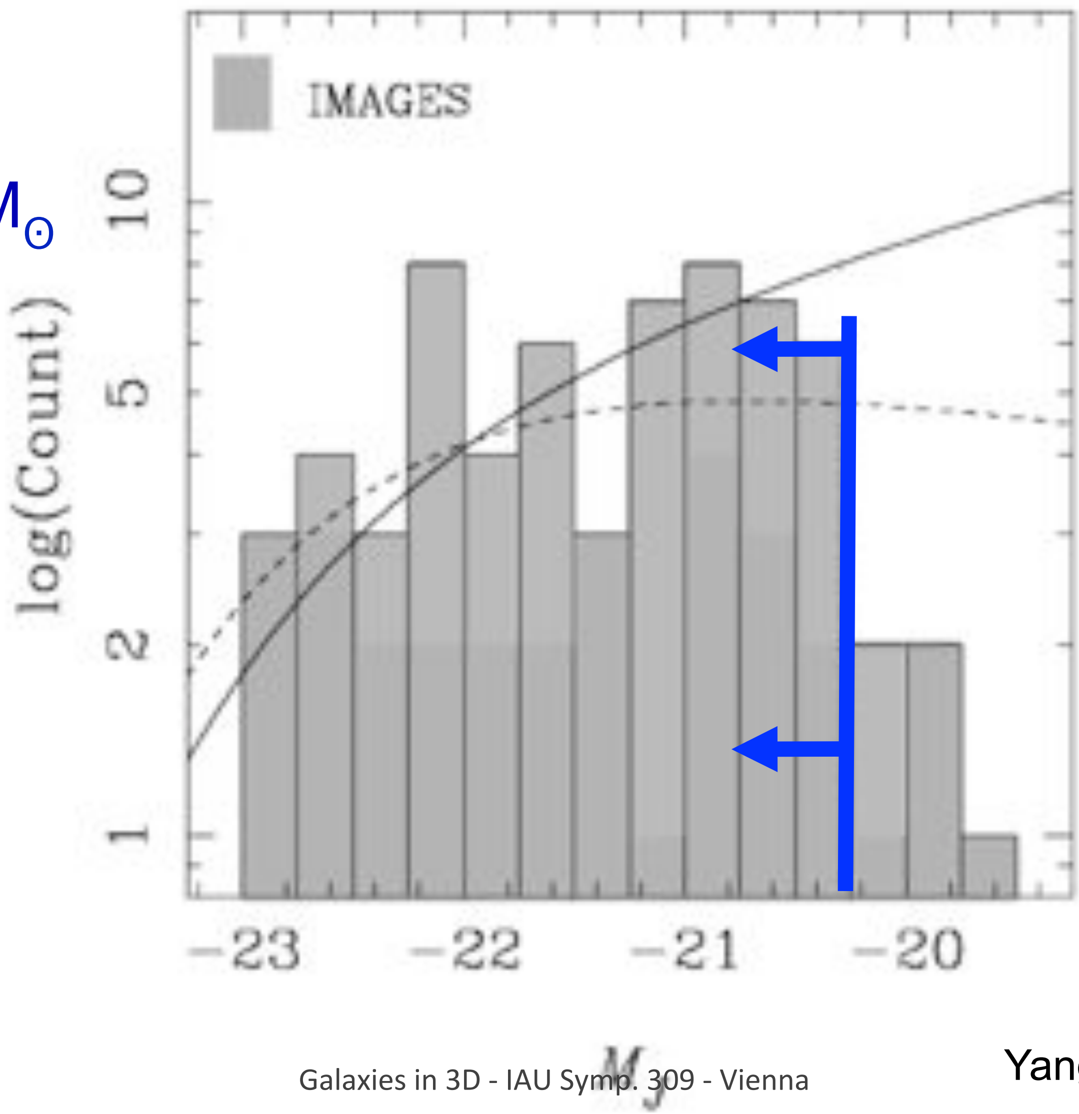
Integrated spectroscopy

VLT/FORS2 (600RI+600z) (≥ 3 hrs each)



IMAGES : a representative sample of M* galaxies, 6 billion years ago

$M_{J(AB)} < -20.3$
$M_{stellar} > 1.5\ 10^{10} M_{\odot}$
(average ~M*,
e.g. the MW)

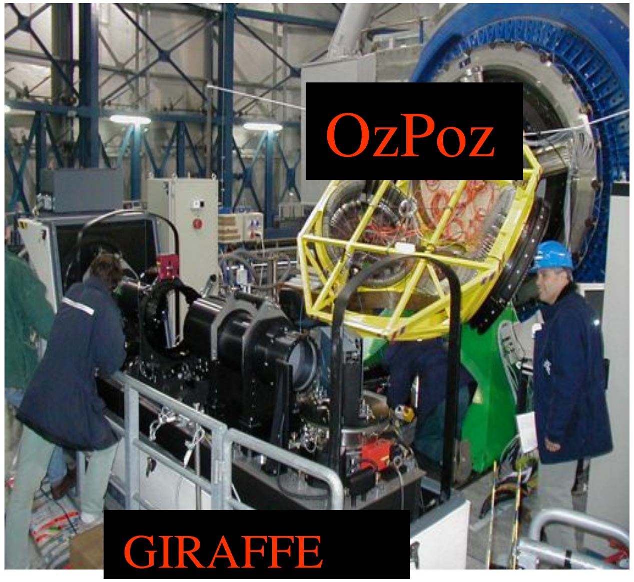


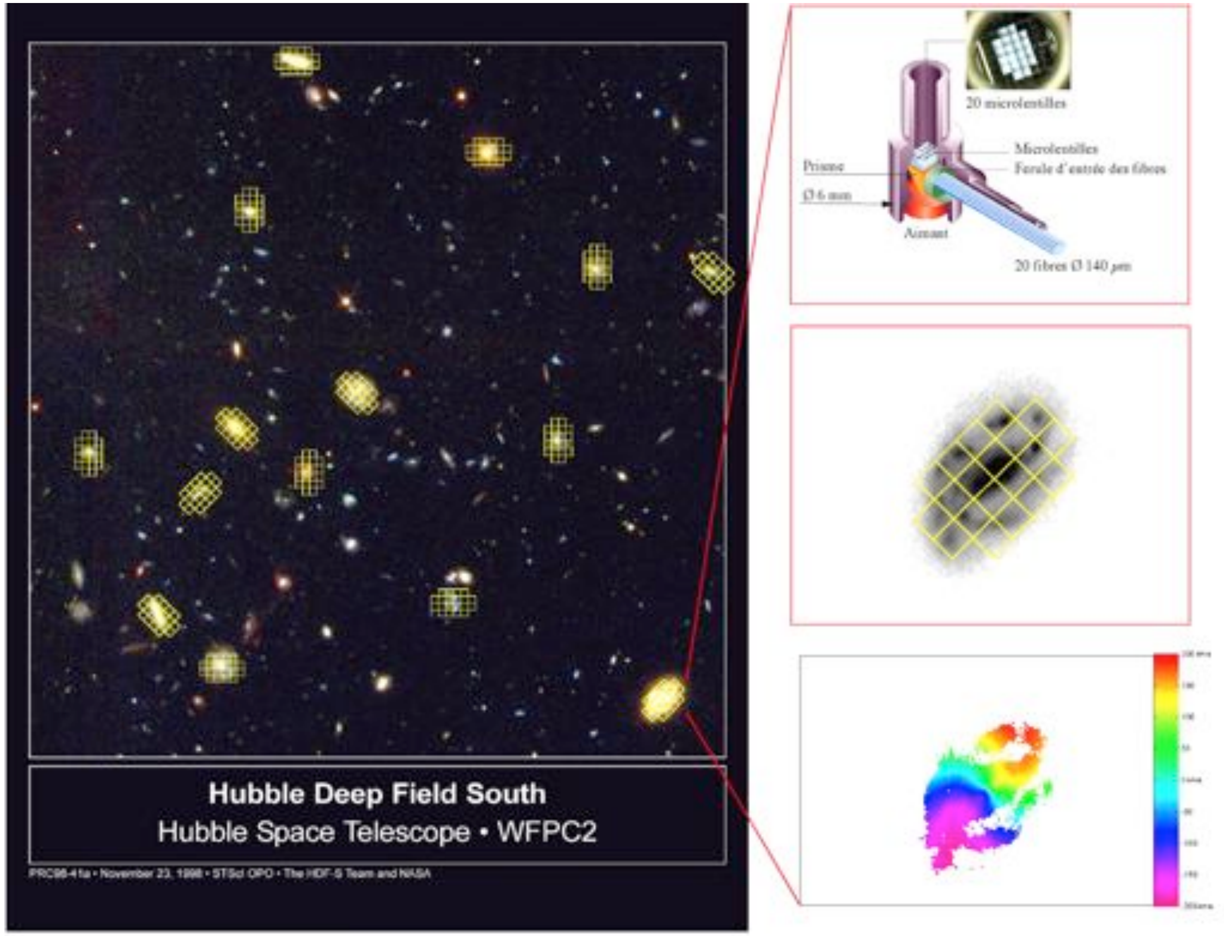
LF, z=0.5,1
Pozzetti et al 2003

Yang et al (2008)


The Very Large Telescope (VLT)

VLT/GIRAFFE

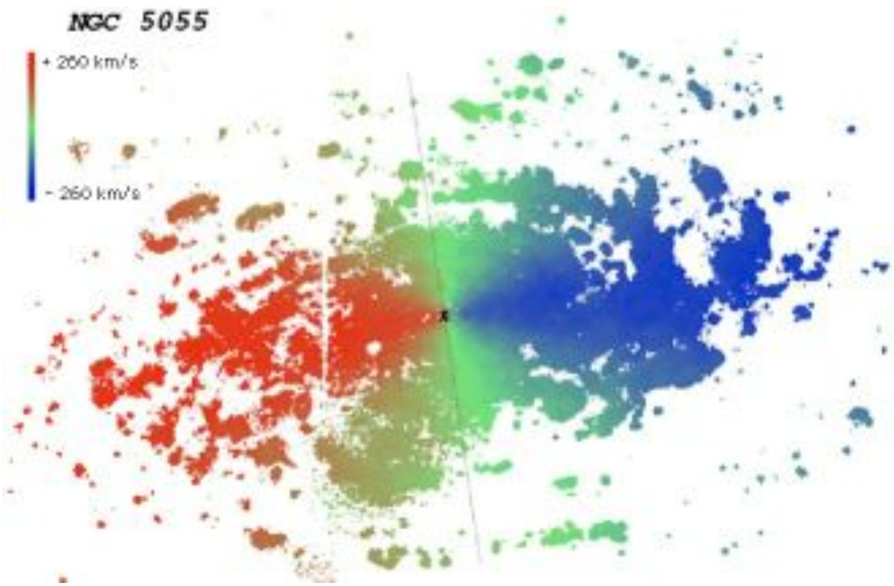

OzPoz
GIRAFFE


Hubble Deep Field South
Hubble Space Telescope • WFPC2
20 microlentilles
Microlentilles
Ferule d'entrée des fibres
Prisme
Ø 6 mm
Aimant
20 fibres Ø 140 μm

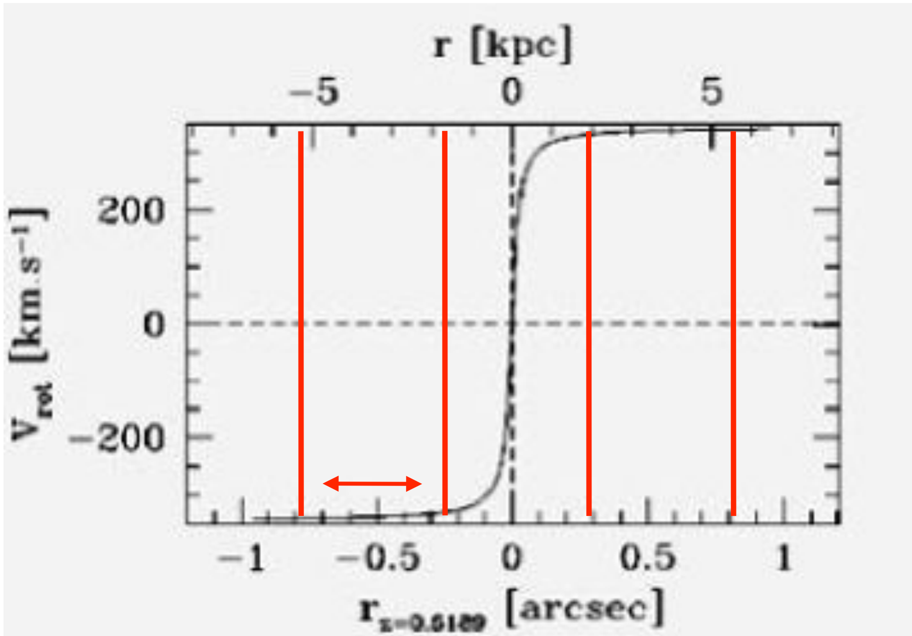
VFs but also σ-maps

<u>Provided by</u>: **the absence of cross-talk between individual spectra.**

$$\sigma_{pixel} = \sigma_{random\_motions} \otimes \Delta V_{large\_scale\_motions}$$



from Blais-Ouellete, Amram et al, 2002 (Fabry-Perot/Halpha)



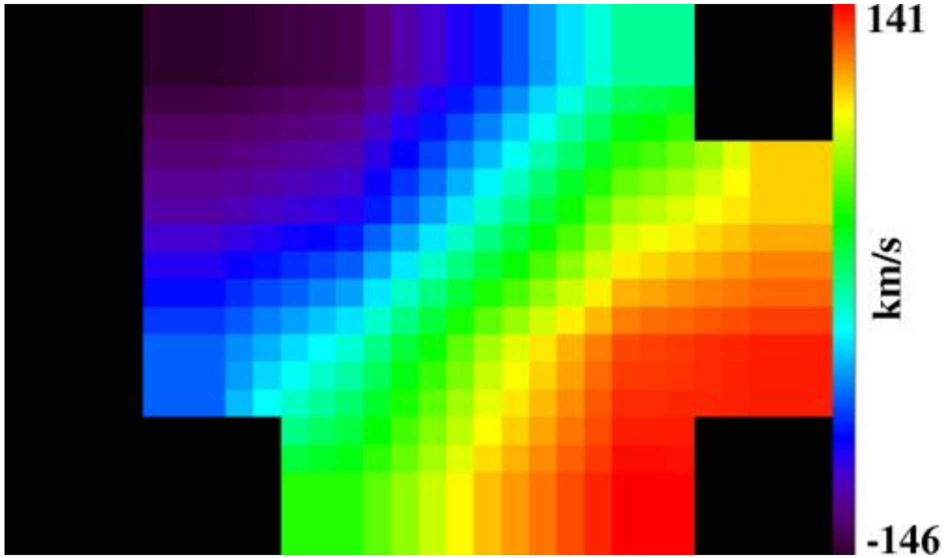
GIRAFFE IFU pixel @ z=0.6

Distant galaxies: VFs and also σ-maps

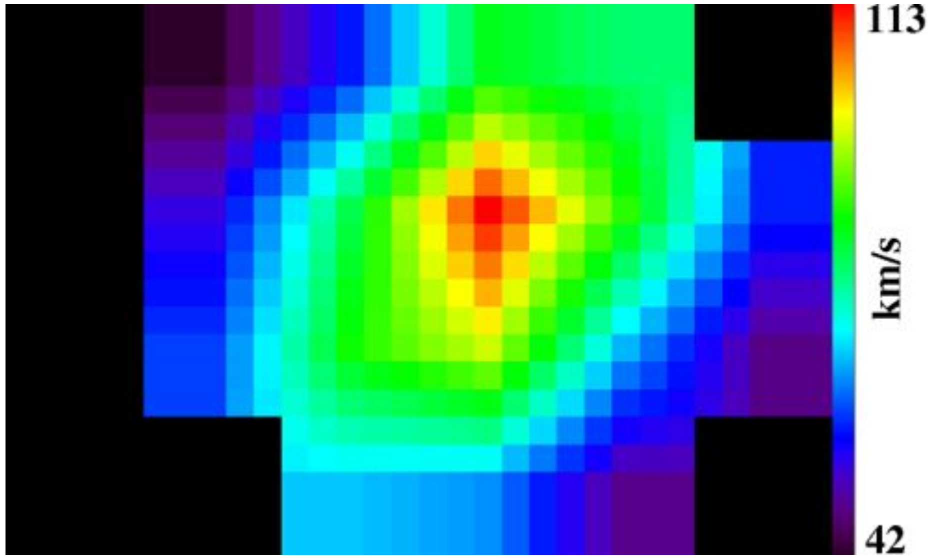
<u>Provided by</u>: the absence of cross-talk between individual spectra.

$\sigma_{pixel} = \sigma_{random\_motions} \otimes \Delta V_{large\_scale\_motions}$

At low spatial resolution, dispersion maps of rotating disks do show a peak in their dynamical center



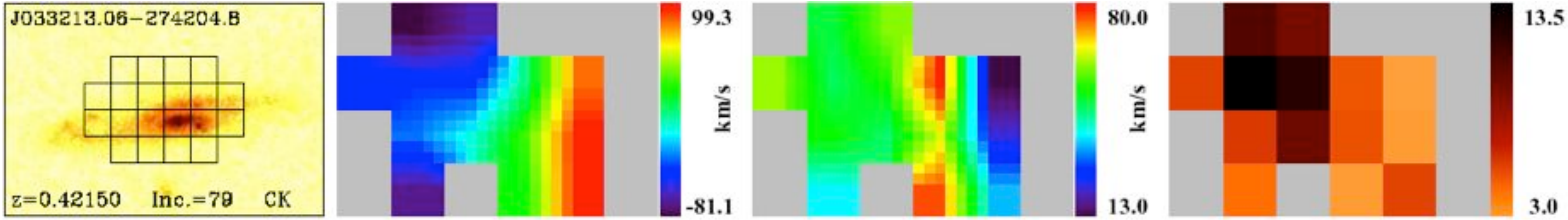
Velocity map

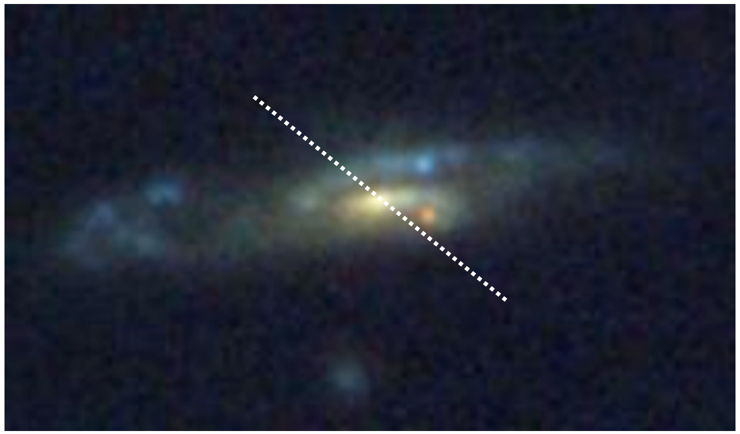


Dispersion or σ map

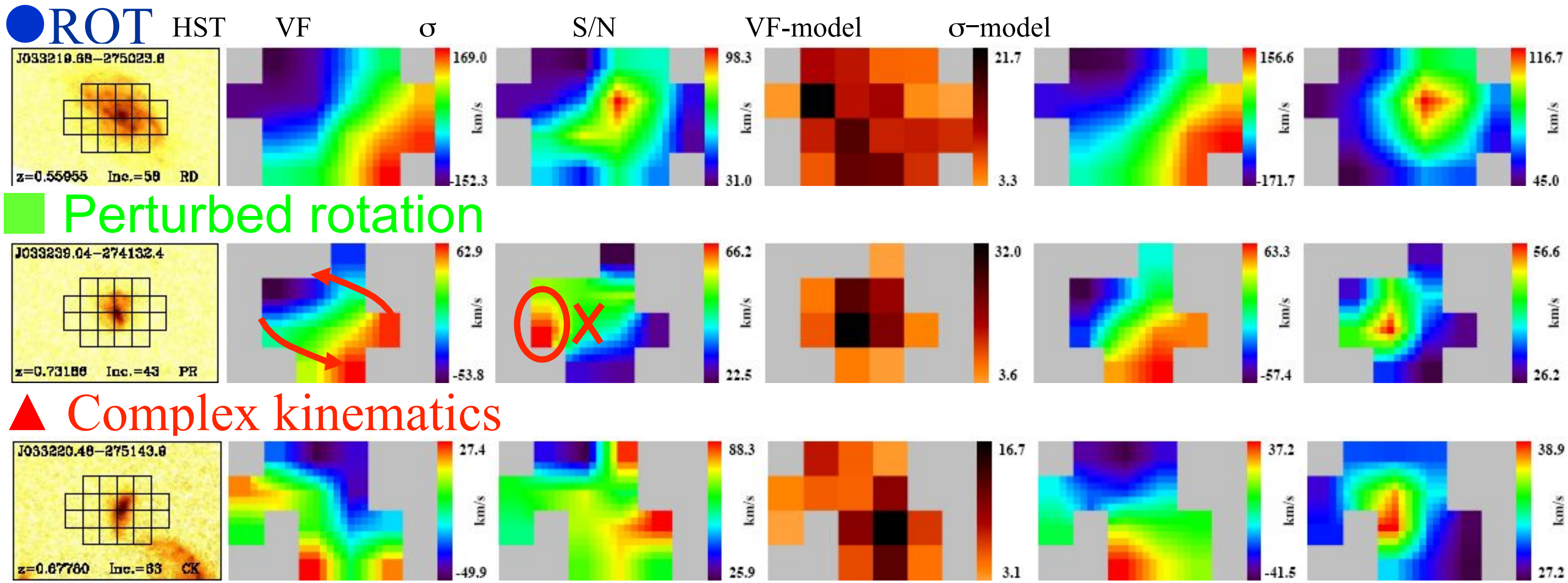
Morpho-kinematics: a rotating velocity field should be aligned with the disk major axis

HST+IFU Velocity field σ map S/N map





Spatially resolved kinematics of distant galaxies



Flores et al (2006)
Yang et al (2008)

<u>Statistics, 6 billion years ago</u>:

Rotating galaxies : 19%

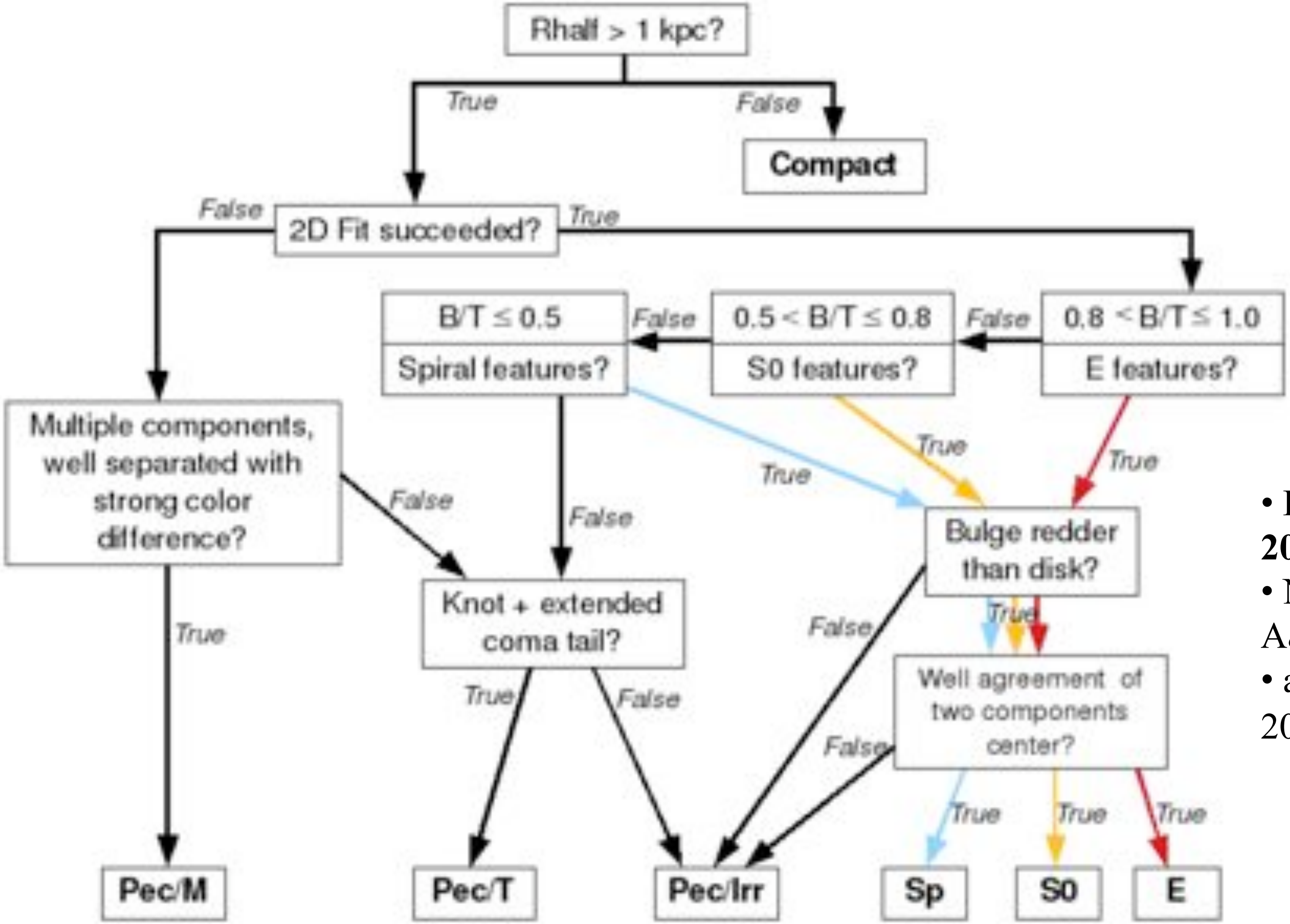
Anomalous kinematics: 41% (incl. PR: 15%, CK: 26%

& without emission (E/S0/Sa..): 40%

Morphological classification: semi-automatic decision tree

Classification based on similarities with local galaxies

Semi-automatic decision tree: GALFIT + Colour maps + Visual inspection



- **Delgado-Serrano et al, 2010, A&A, 509, 78**
- Neichel et al. 2008, A&A, 484, 159
- also Zheng et al. 2005, 2006

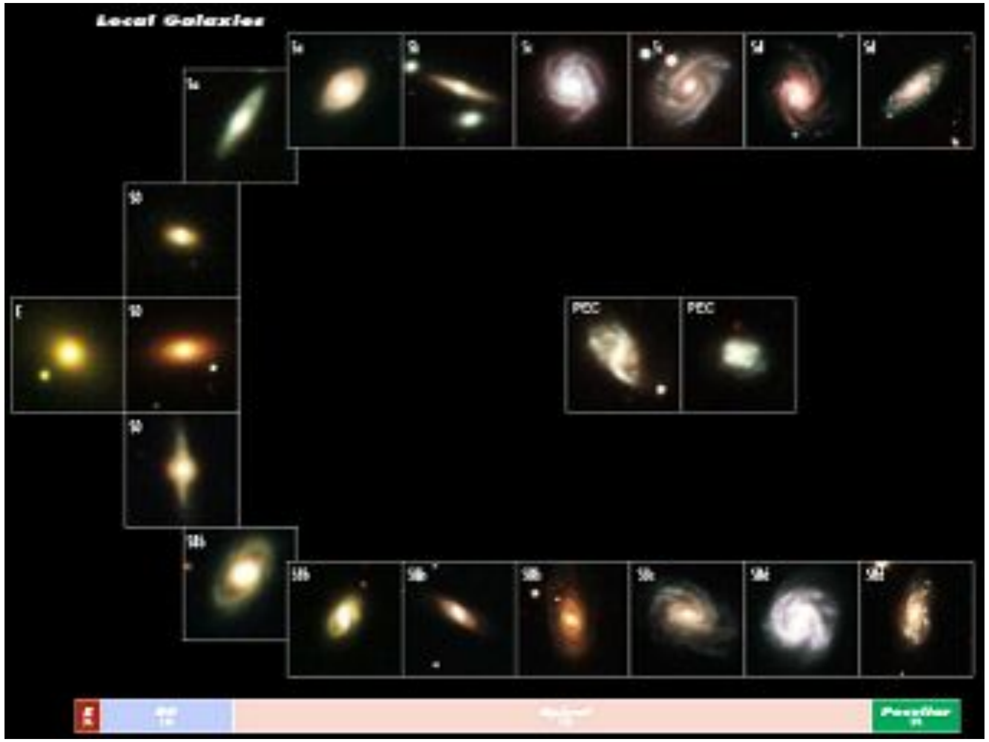
How was the Hubble sequence 6 Gyr ago?

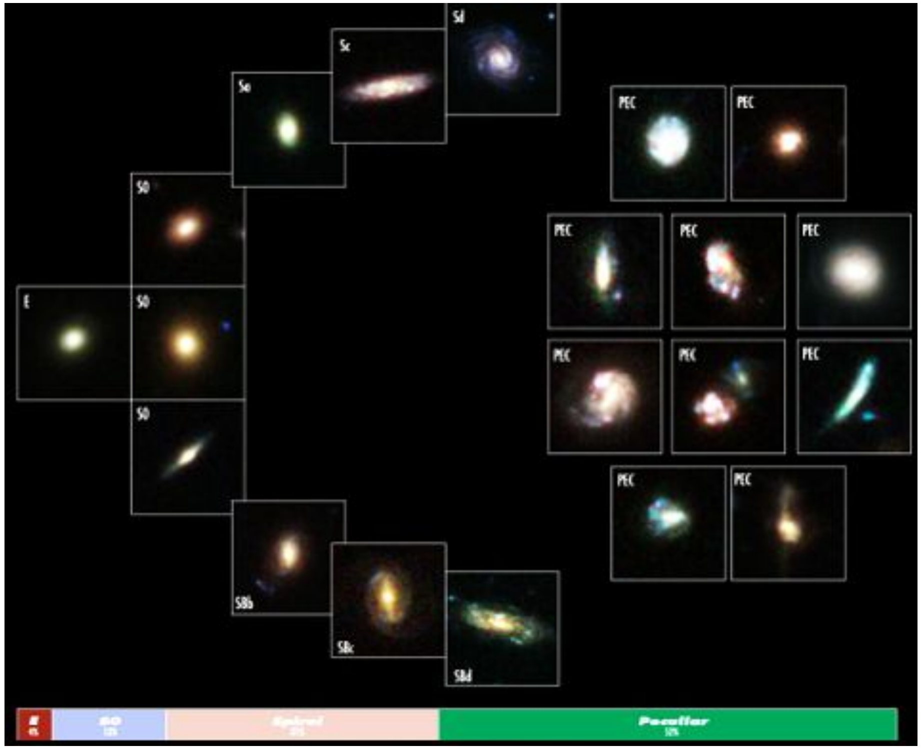
R. Delgado-Serrano[1,2], F. Hammer[1], Y. B. Yang[1,3], M. Puech[1], H. Flores[1], and M. Rodrigues[1]

A&A 509, A78 (2010)

Today

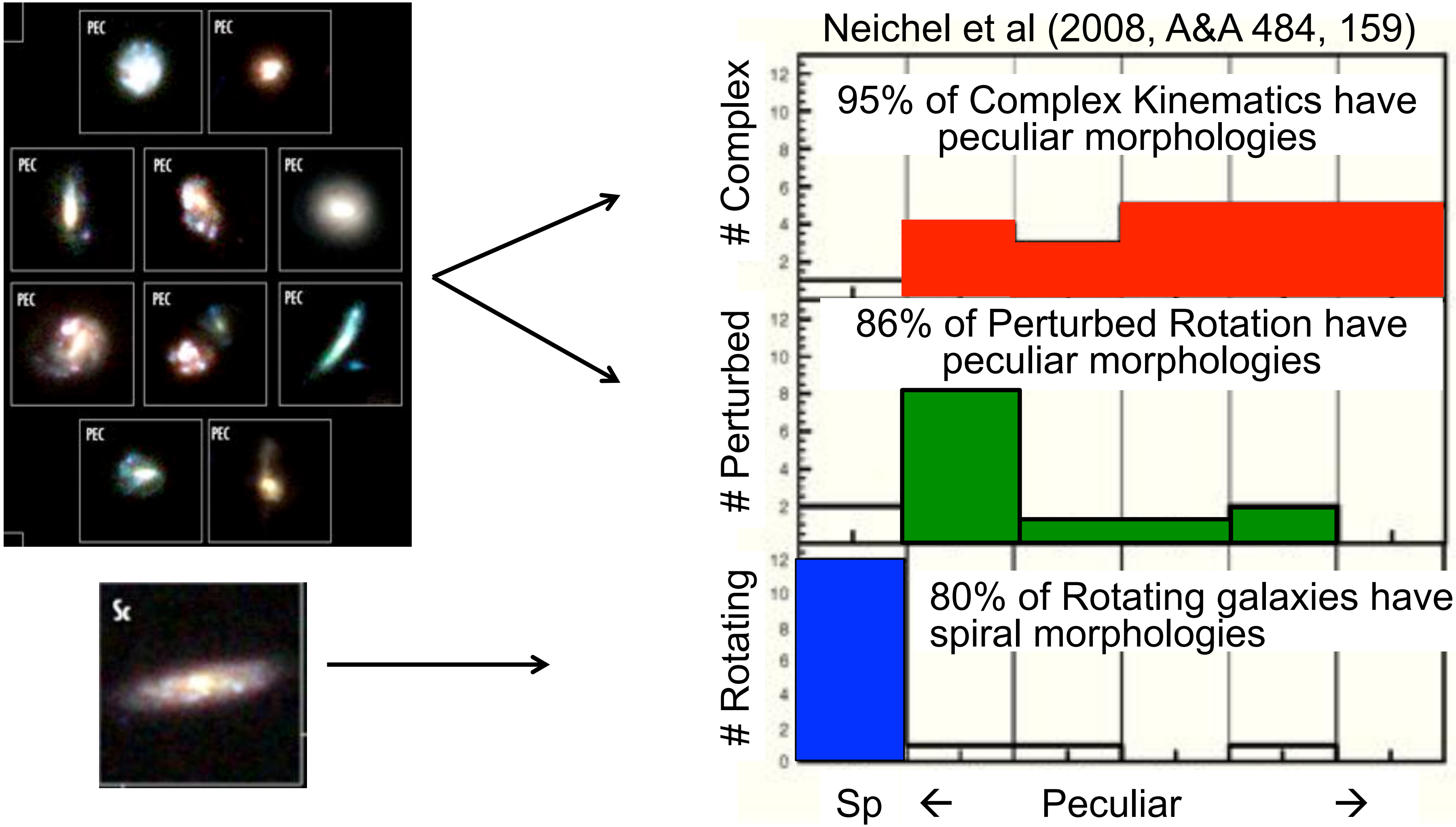
6 billion years, ago:
50% of galaxies were peculiar





@ NASA, ESA, Sloan Digital Sky Survey, R. Delgado-Serrano, F. Hammer, Y.B. Yang, M. Puech & H. Flores (Observatoire de Paris)

Agreement between spatially-resolved kinematics and morphological classifications



Anomalous kinematics of the ionised gas is linked to anomalous morphological distribution of the stars

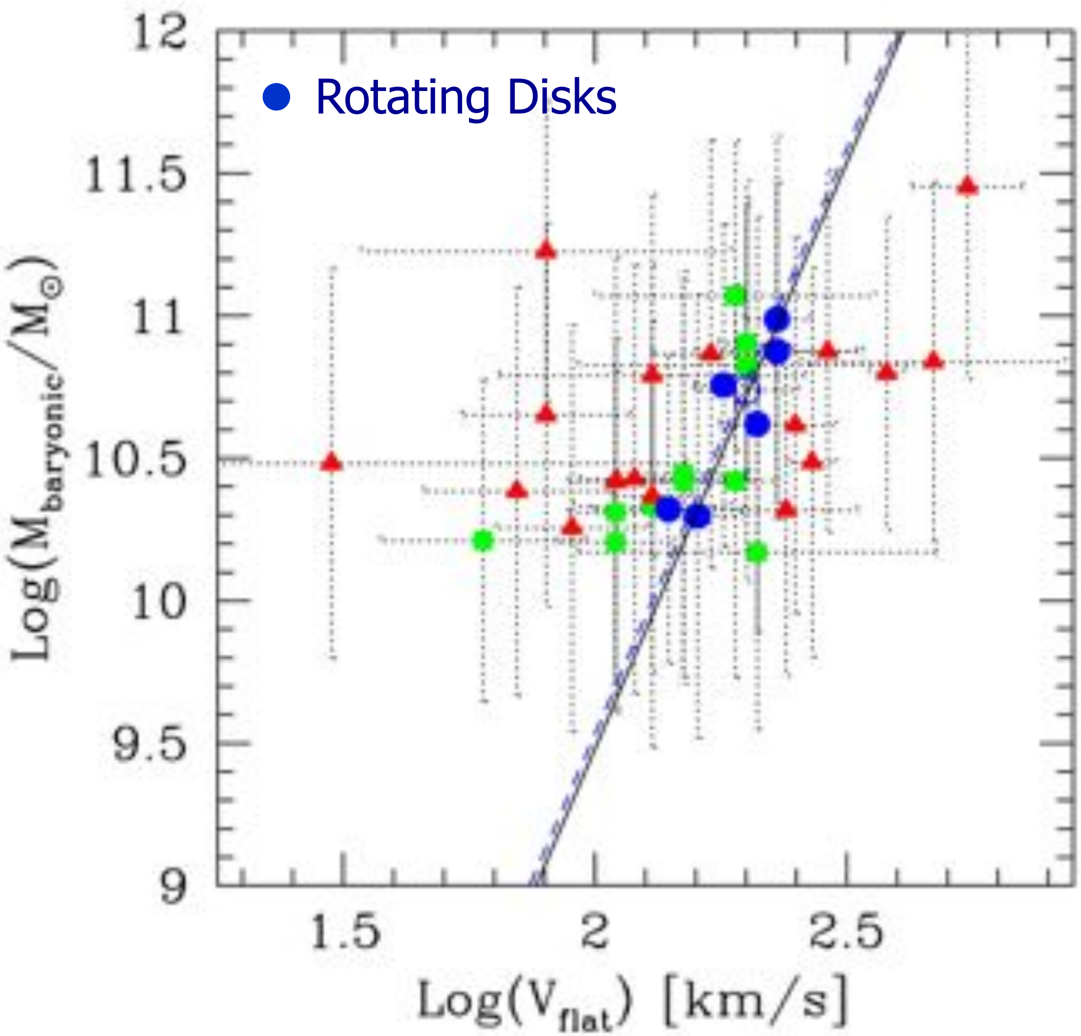
Baryonic Tully Fisher 6 Gyr ago (z=0.65)

A strong scatter of the BTF due to peculiar galaxies with perturbed or complex kinematics (green squares & red triangles)

See also Ziegler+09,Kassin +10, Vergani+10, De Rossi, Tissera & Pedrosa+13

Rotating disks:

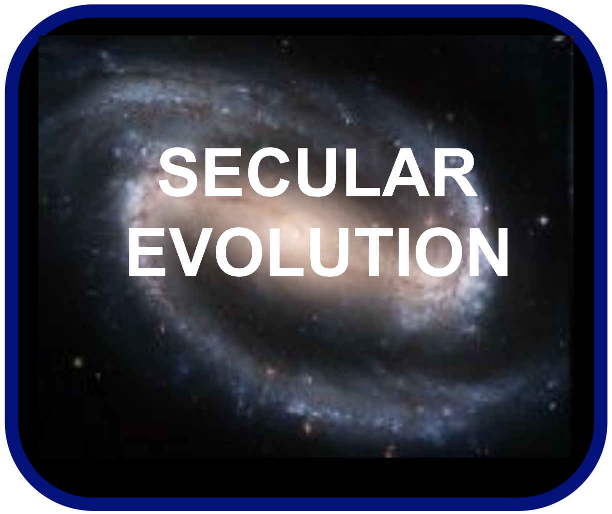
no significant evolution in slope or zero point within random and systematic uncertainties



Puech et al 2009

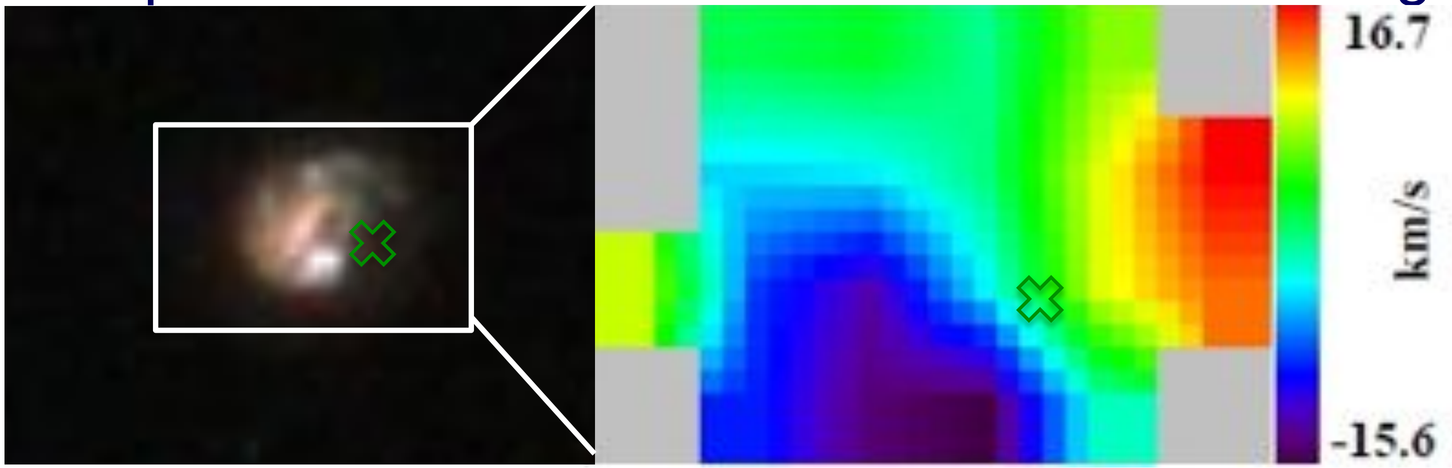
Physical processes

Associating Morpho-kinematics with physical processes



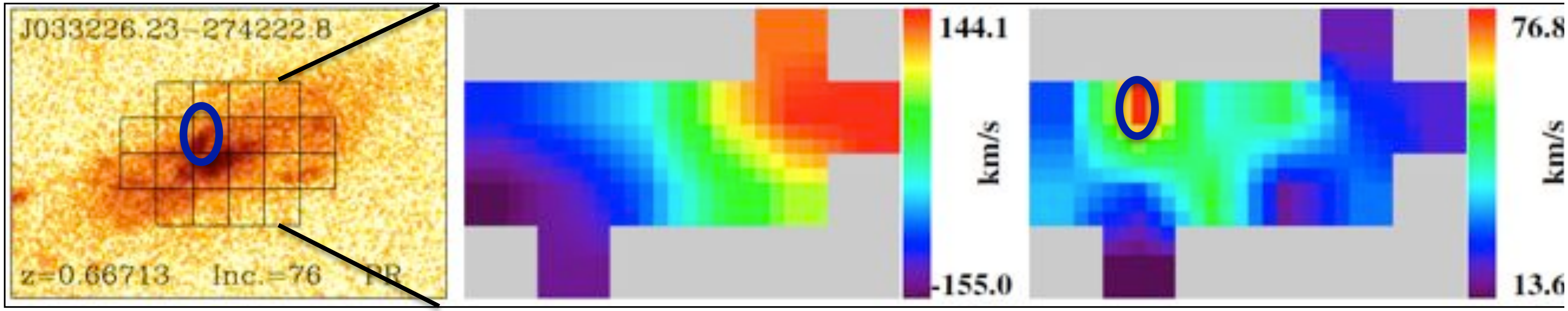
Associating Morpho-kinematics with physical processes

Complex kinematics: kinematic disturbances are global not local



GIRAFFE
IFU
resolution
~ 7 kpc @
z=0.6

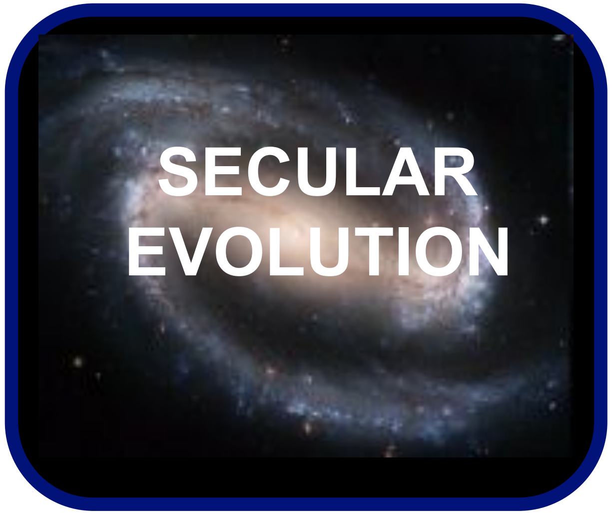
HST-ACS   Velocity field σ map



Minor merger (15:1): only tiny effect on σ map

Puech et al. (2007)

Associating Morpho-kinematics with physical processes



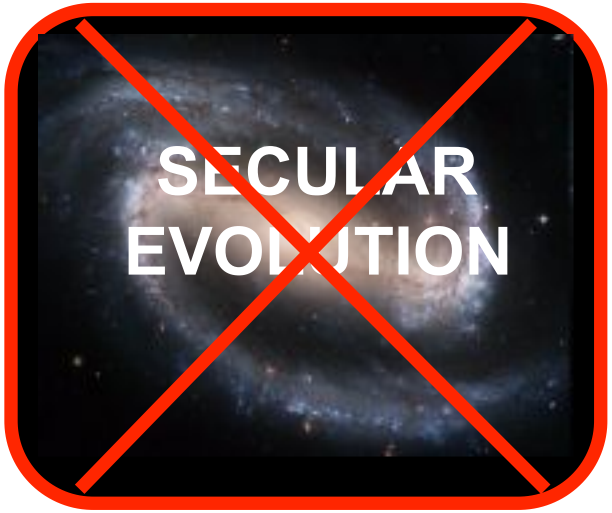
Associating Morpho-kinematics with physical processes

Outflows:
- only a handful of galaxies have significant shifts between abs. and emission lines (Hammer et al. 2009; Rodrigues et al., 2012).

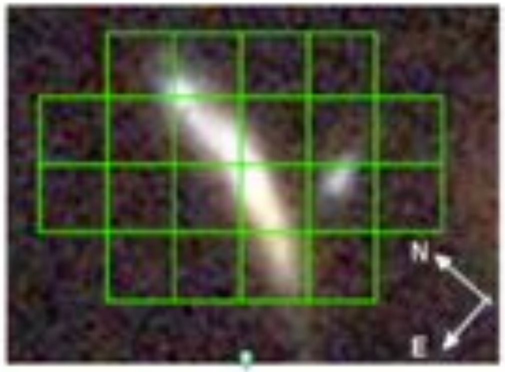
Clump fragmentation & cold flows:
- only 20% of anomalous galaxies are clumpy (Puech, 2010)
- cold gas accretion tends to vanish in massive halos at z<1 (<1.5 Mo/yr at z~0.6 see Keres et al. 2009, Brooks et al. 2009)

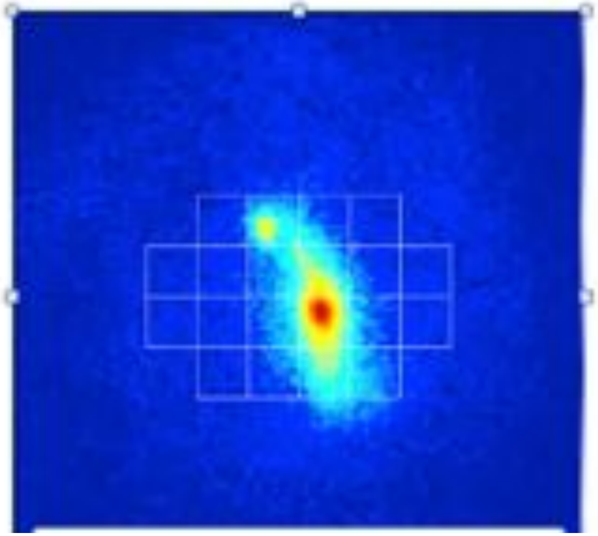
Secular evolution:
Kinematic perturbations are too strong and extended

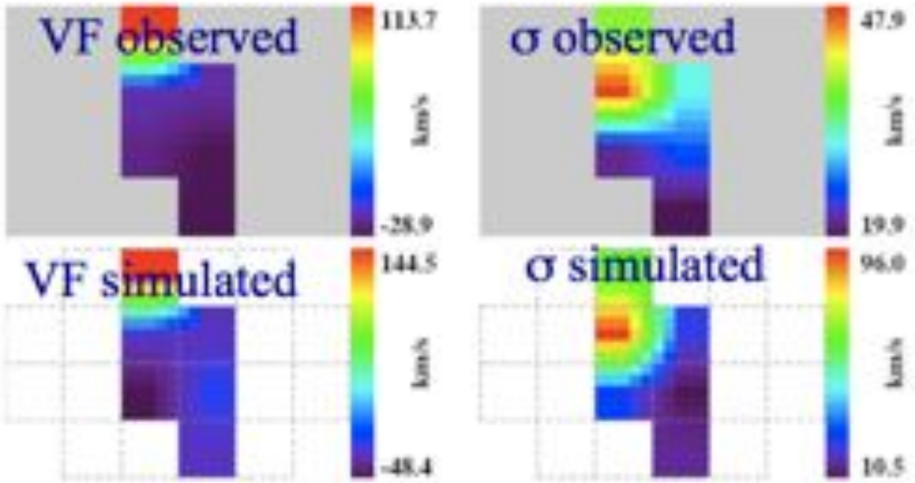
Associating Morpho-kinematics with physical processes



A giant bar induced by a merger





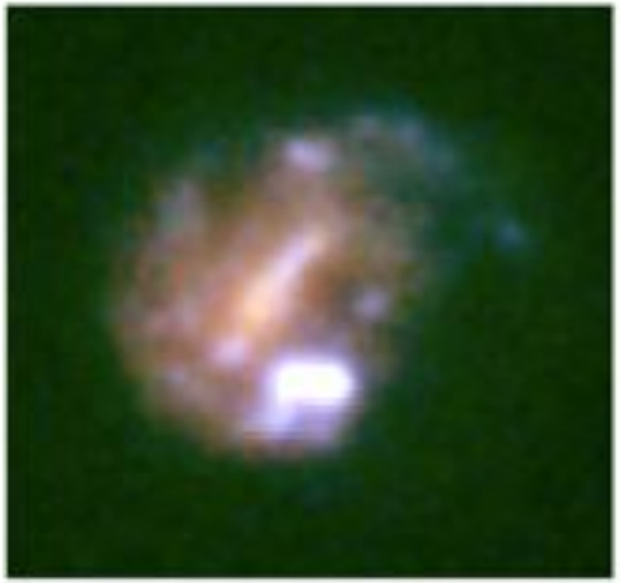


See Fuentes-Carrera et al. 2010, A&A, 513, 43
GADGET2

Anomalous galaxies: 50% of z=0.65 galaxies

All their IMAGES counterparts modelized by major mergers (Peirani+08, Yang+08, Puech+08,Fuentes-Carrera+10, Hammer+09)

HST/ACS & VLT/GIRAFFE

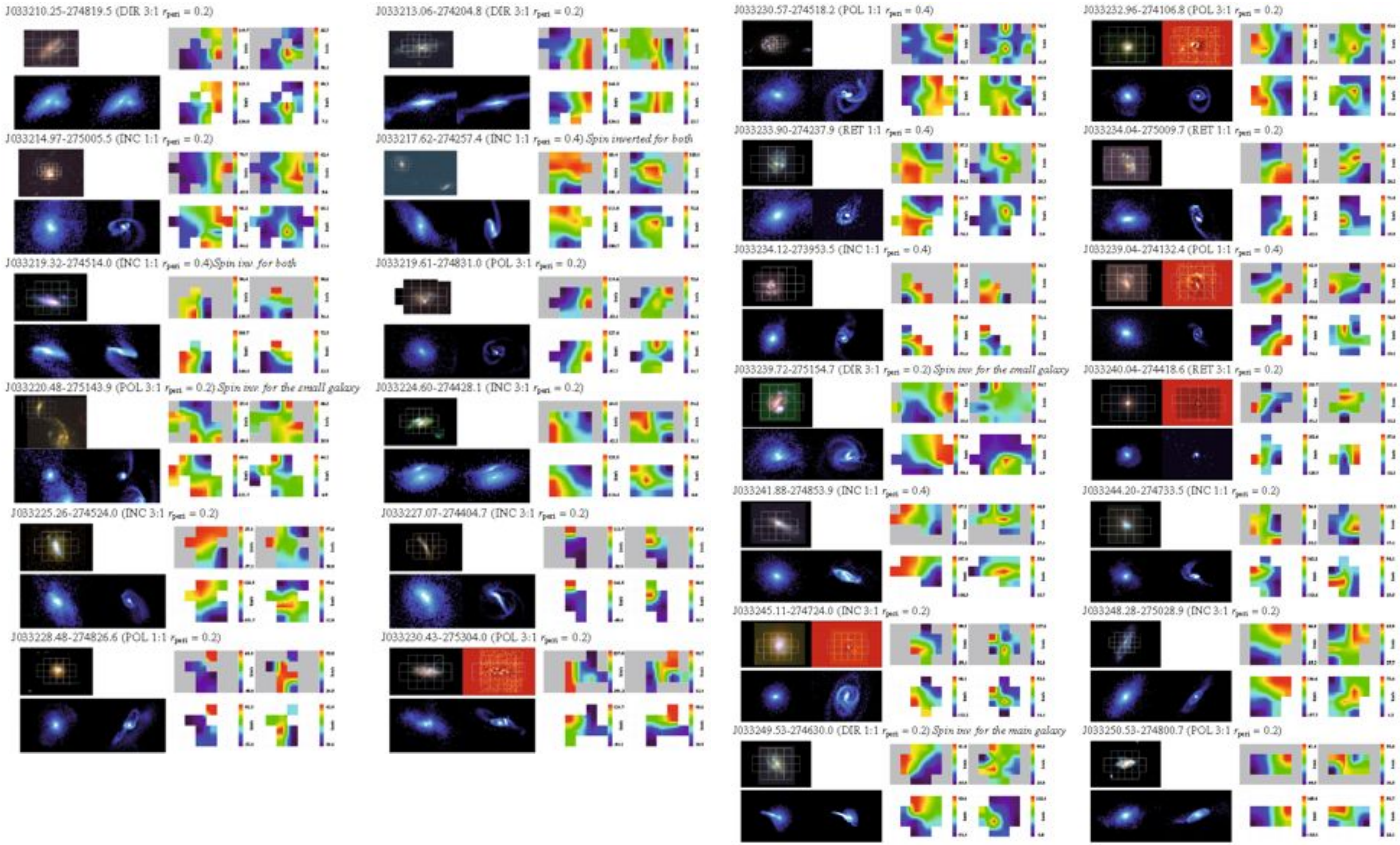


The Hubble sequence: just a vestige of merger events?★

F. Hammer[1], H. Flores[1], M. Puech[1], Y. B. Yang[1,2], E. Athanassoula[3], M. Rodrigues[1], and R. Delgado[1]

A&A 507, 1313–1326 (2009)

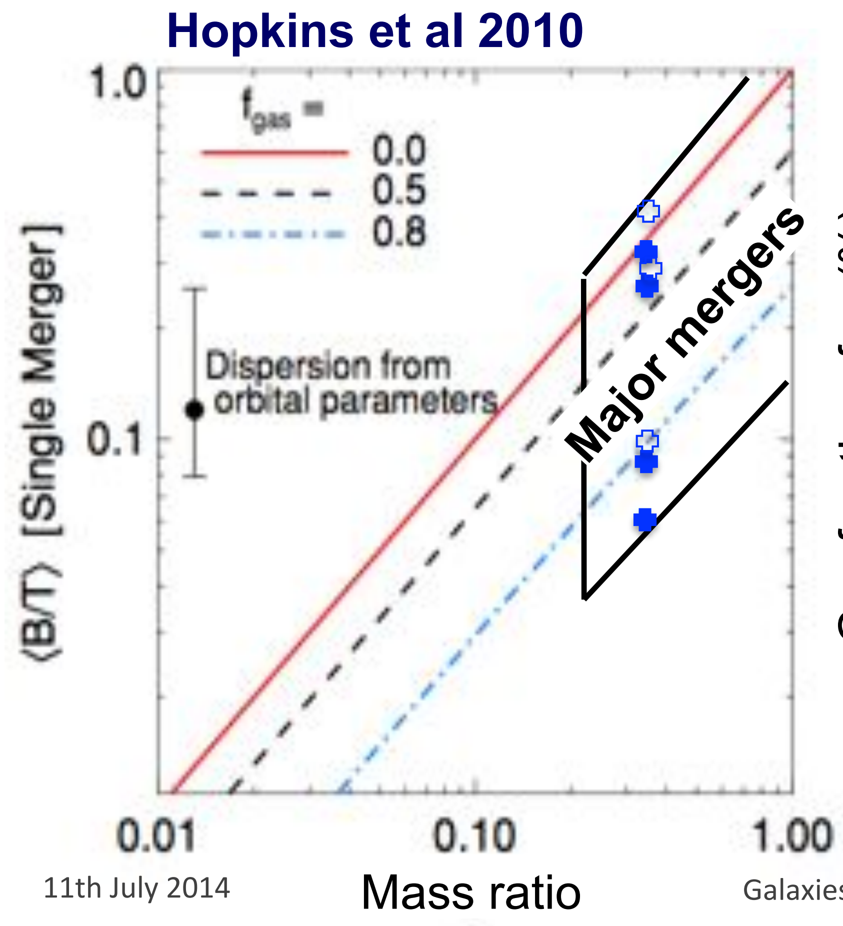
2/3 of non (or semi-)relaxed galaxies have « secured » merger models

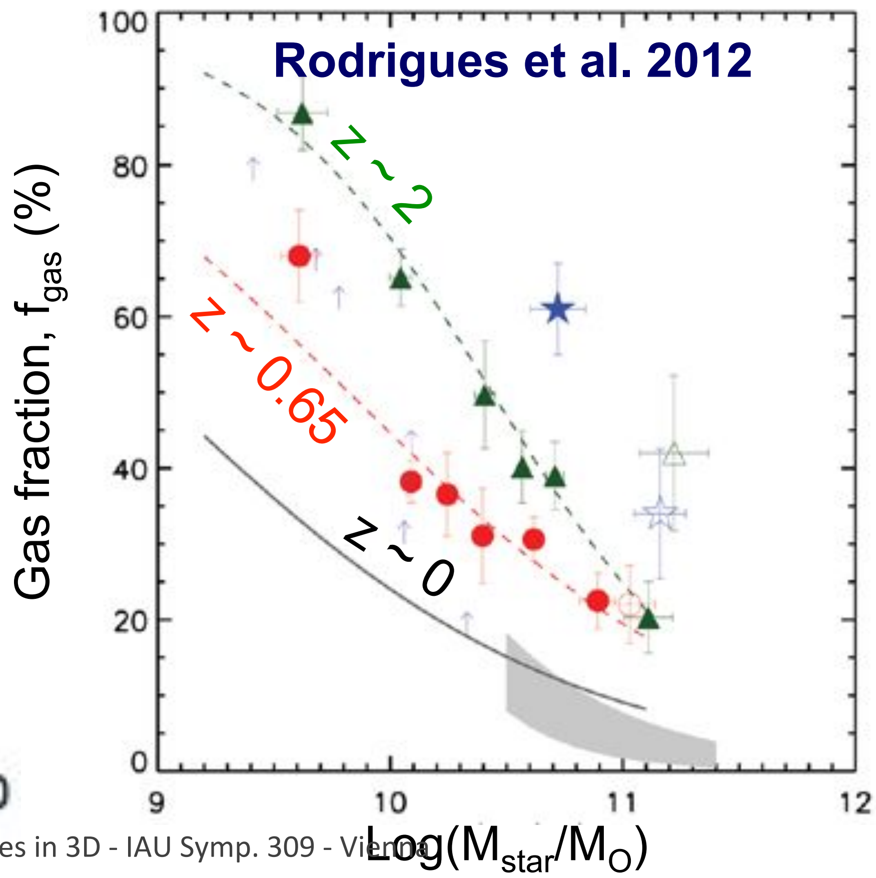


Hammer et al. 2009

A novel channel to form large disks: gas-rich mergers are rebuilding significant disks

The orbital angular momentum from major mergers may solve the spin "catastrophe" *(Maller, Dekel & Somerville, 2002)*





Expectations from theory

Excerpt from Lia Athanassoula, in Granada, 2009

Disc + Disc = Elliptical

Toomre & Toomre 72; Barnes & Hernquist 92; Barnes 98; Naab & Burkhart 03; Naab, Khochfar, Bukhart 06 etc

but also

Disc + Disc = Disc

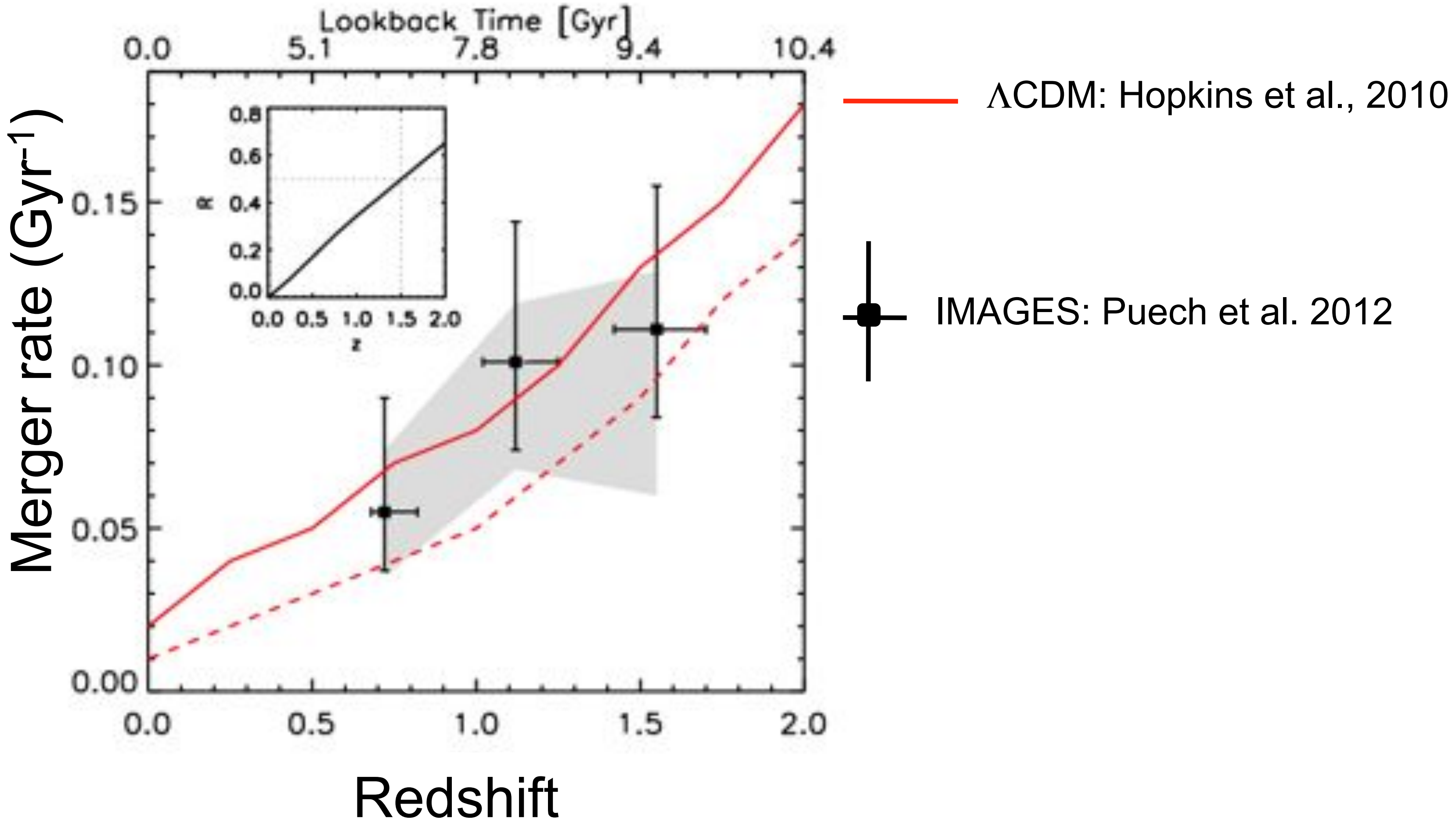
Observational starting point: Hammer et al 05, 09

Simulations: Dominguez-Tenreira et al. 98; Barnes 02; Scannapieco, Tissera 03; Brook et al 04, 07; Springel & Hernquist 05; Robertson et al 06,08, Hopkins et 08; Governato et al 07, 08; Stewart et al 09

Half of the progenitors of spirals, found at different phases of a major ($mr \leq 4:1$) merger process

➔ is it a too large fraction?

Mergers: observations vs. theory



Both ΛCDM theory and observations predict that many spirals have rebuilt their disks after a major merger

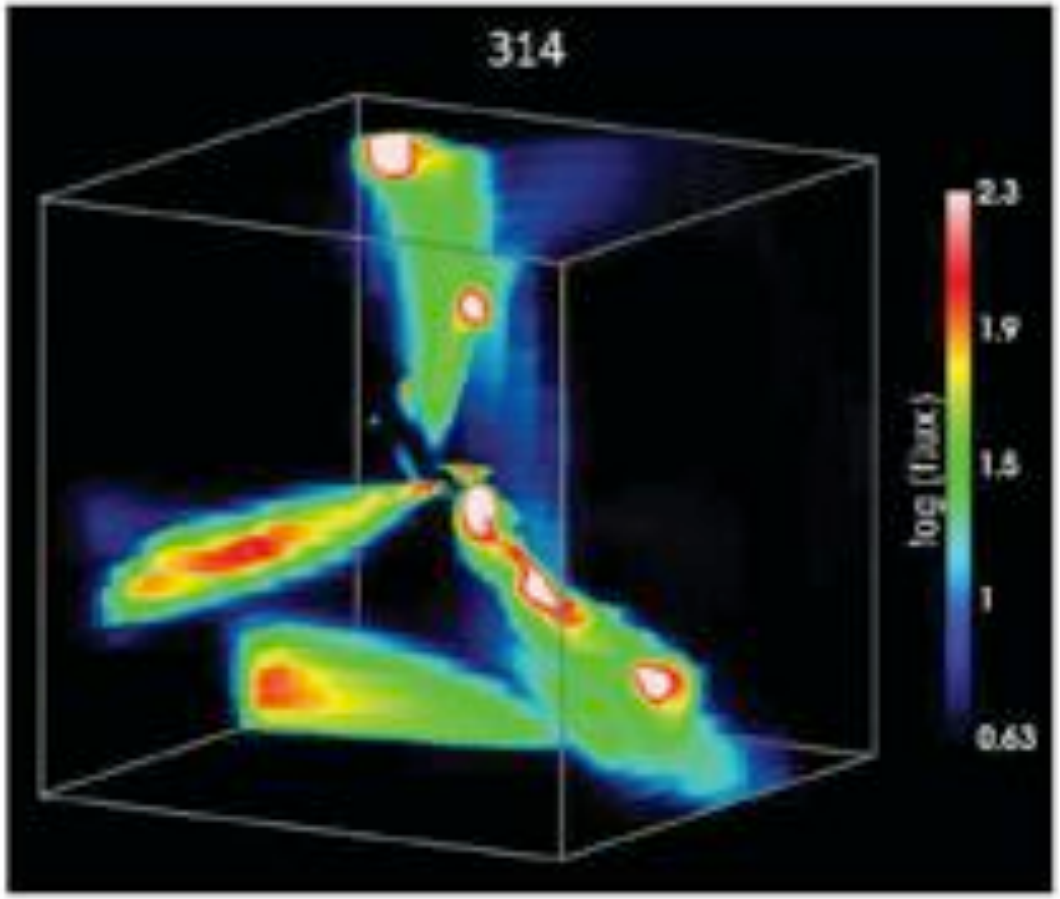
(see also Keres+2011; Guedes+11, Font+11, Brook+11)

Nowadays: many (all?) simulations report the formation of late-type disks after major mergers (Font+11, Brook+11, Keres+11, Guedes+12, Aumer & White+13, etc… codes: GADGET2, 3, AREPO)

Angular momentum:
“cold” gas accretion vs mergers

« The clumps are merging galaxies containing gas, stars and dark matter (see Dekel et al. 2009a; Ceverino, Dekel & Bournaud 2010). »

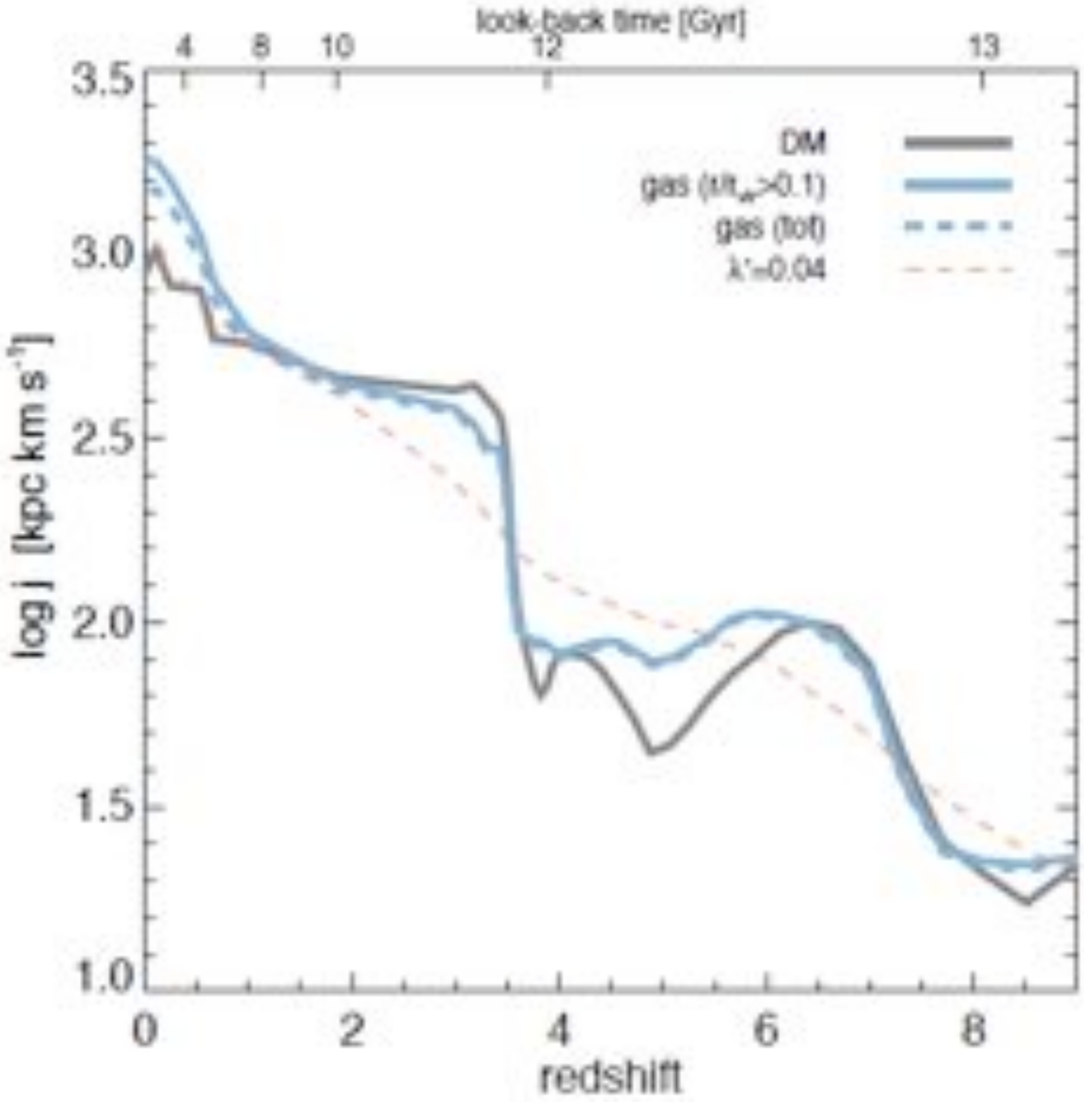
Danovich et al. 2011



One stream may dominate.

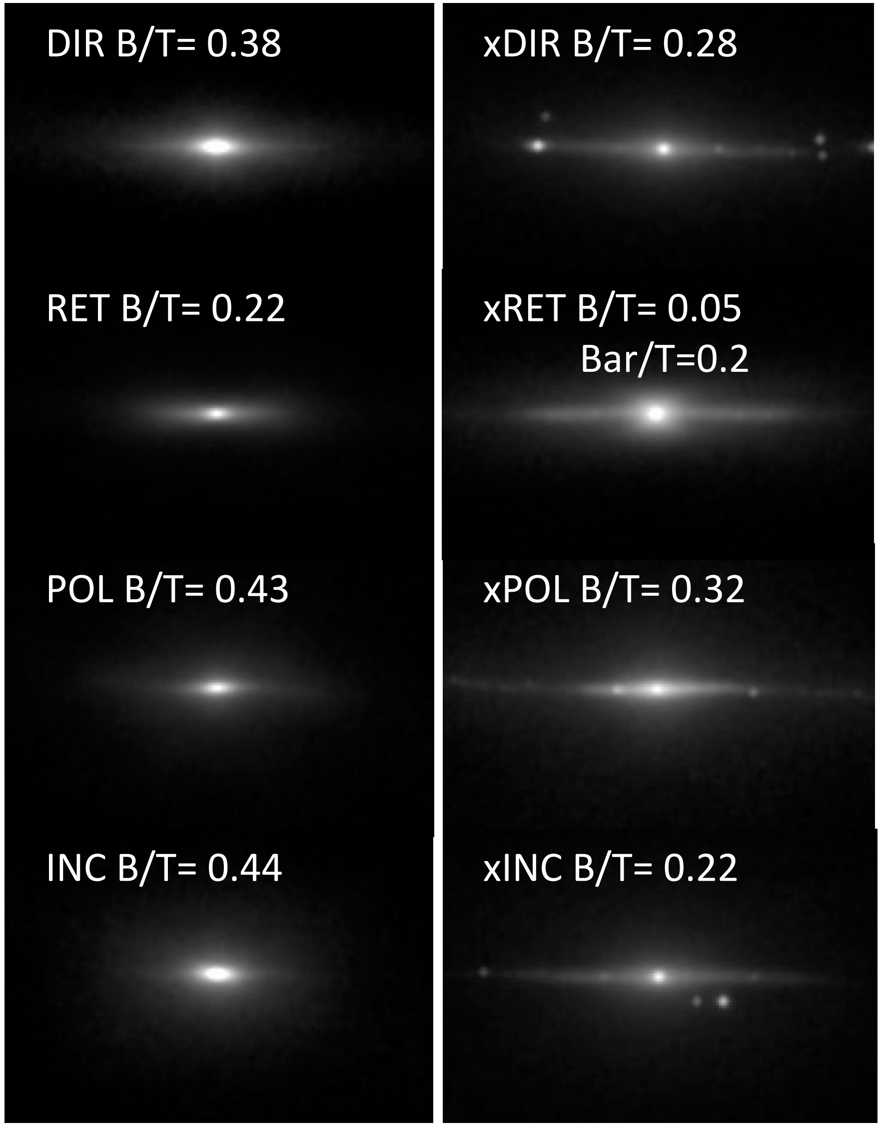
« Mergers are easily identified by large jumps in j »

Kimm et al. 2011



Gas-rich mergers are efficient in producing disk and disky structures

Hammer et al. 2012, Modern Physics Letters A, 27, 33



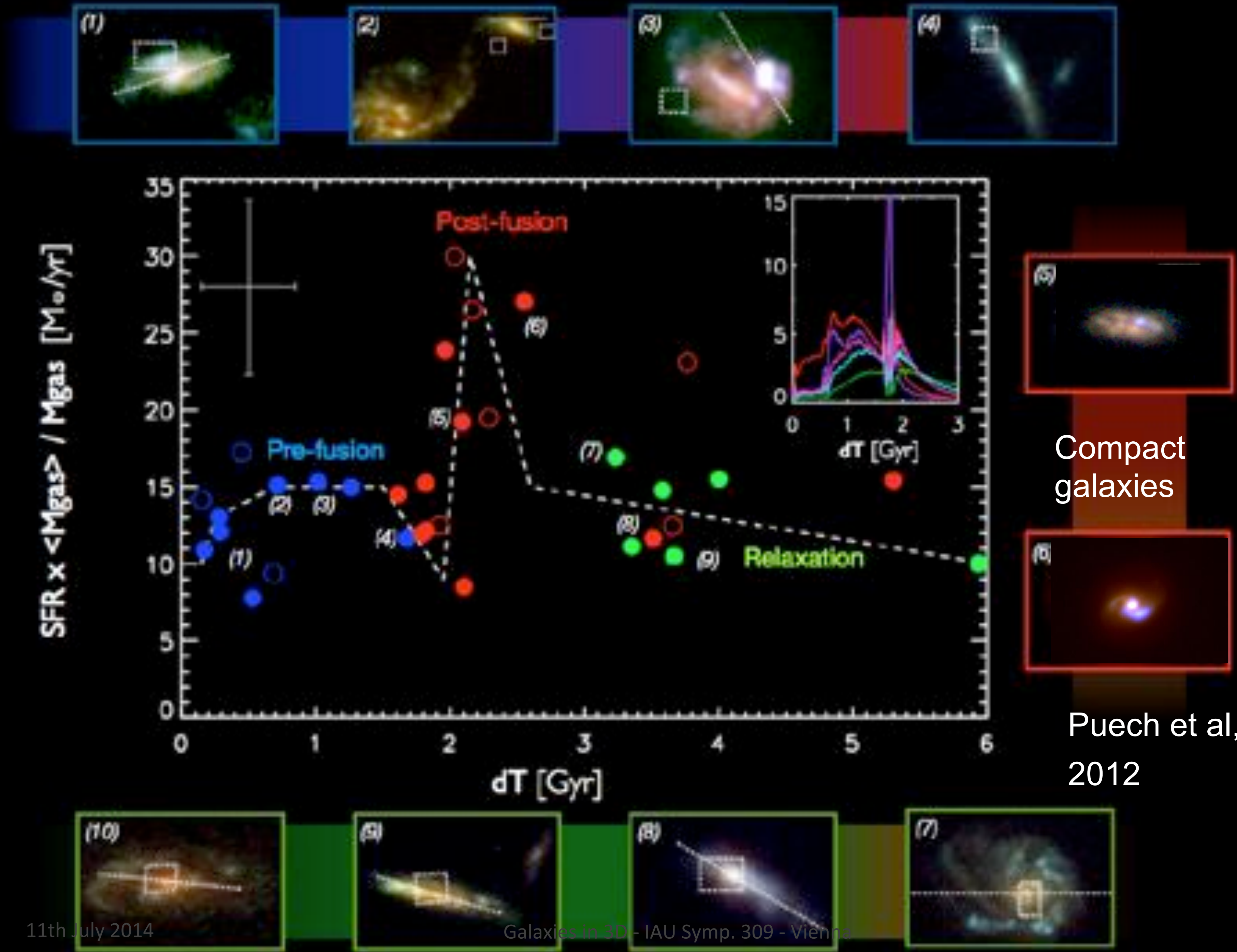
3:1 merger remnants, f_{gas}= 60% at z=2,
Stars, 8 Gyr after fusion
GADGET2, 2M particles

Feedback is half the high value of Cox +06, or alternatively decreasing with time (but see Phil Hopkins's talk)

For all orbits, bulge N Sersic indices below 1.5 (pseudo-bulges)

See also Kelseman & Nusser (2012)

Star formation & mass assembly

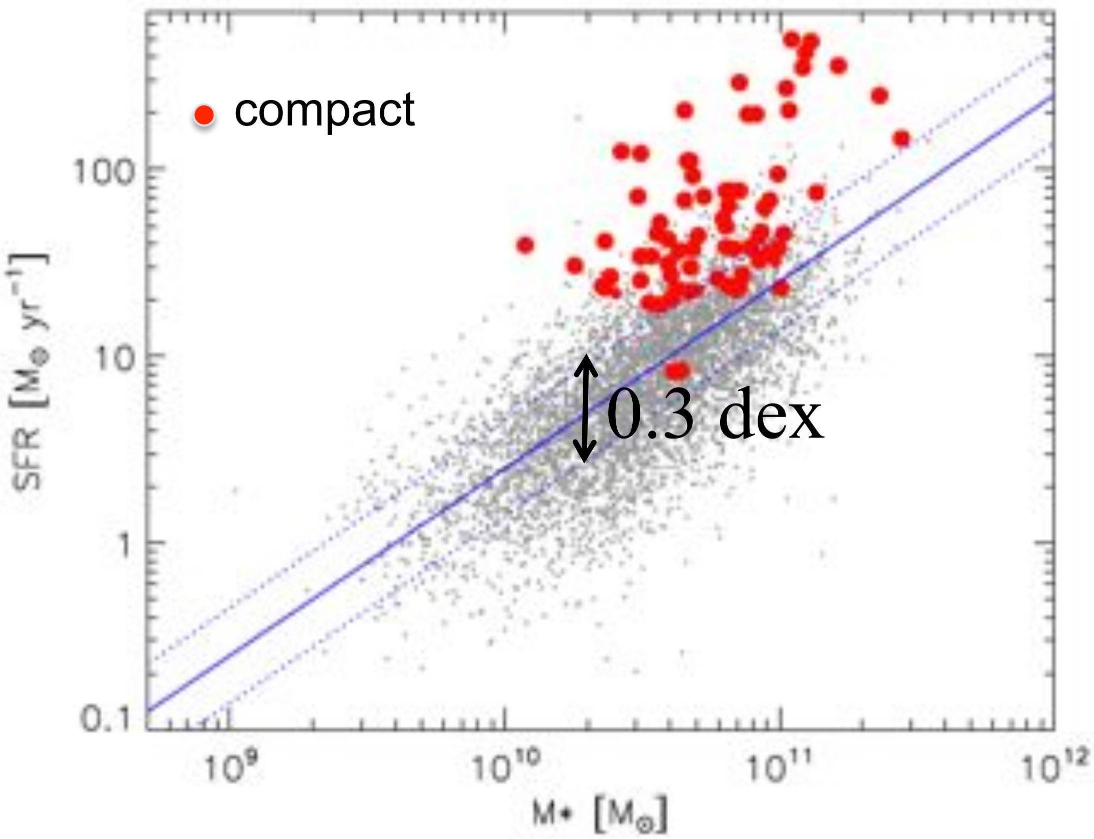


Compact galaxies

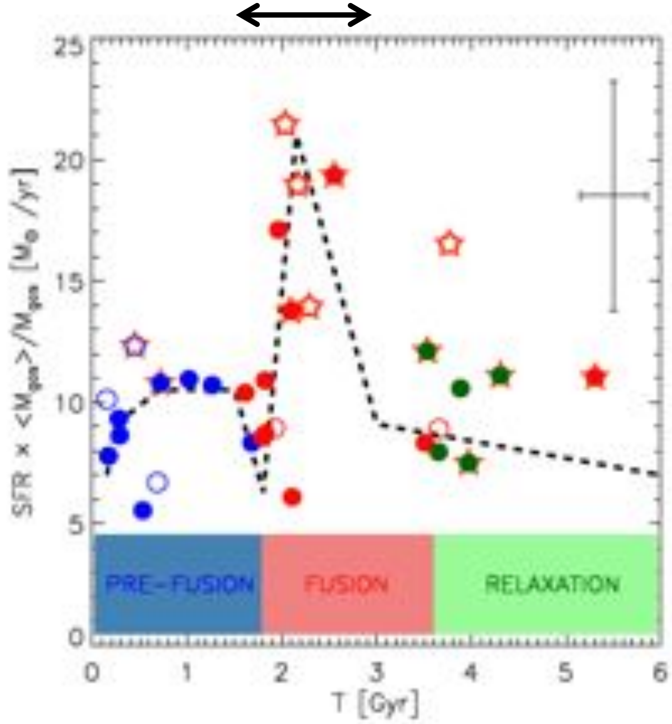
Puech et al, 2012

SFR-M_{star} relation is well consistent with mergers (Puech et al. 2014, MNRAS 443, 49)

Elbaz et al. 2011



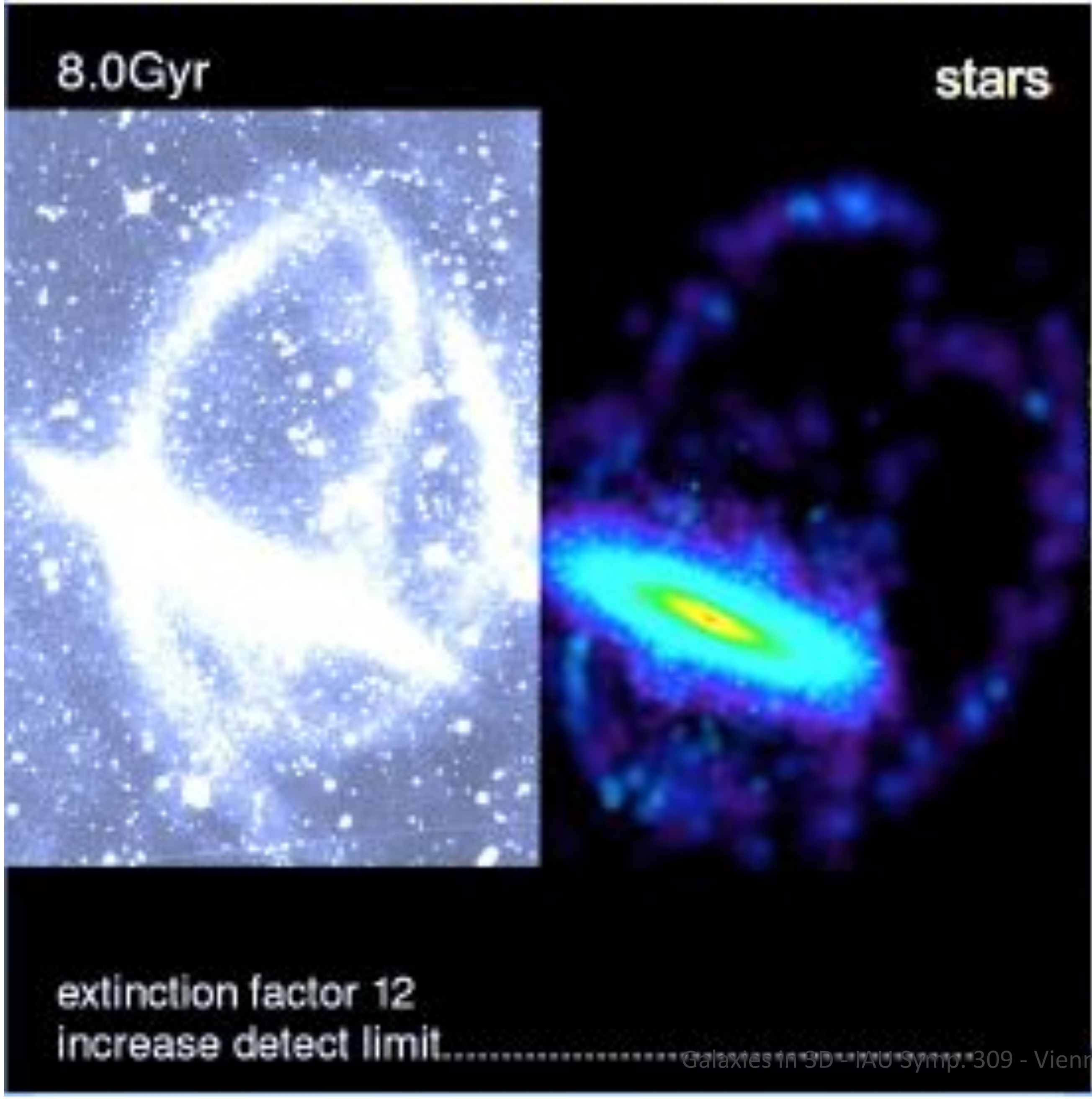
1.8 Gyr



Nearby Universe*: search for imprints

*Already similarities with age studies from CALIFA (Perez+12) & 3D studies by Arribas (this conf.)

Formation of disk & tidal features in nearby spirals



NGC 5907

Observations from
Martinez-Delgado+08

GADGET2, 2M particles
f_baryons=17%

Wang et al, 2012
A&A, 538, 121

No dynamical friction for infalling stars : stellar loops have a specific signature for major mergers

On average each massive galaxy has experienced a major merger since the last 10 billion years

M31:

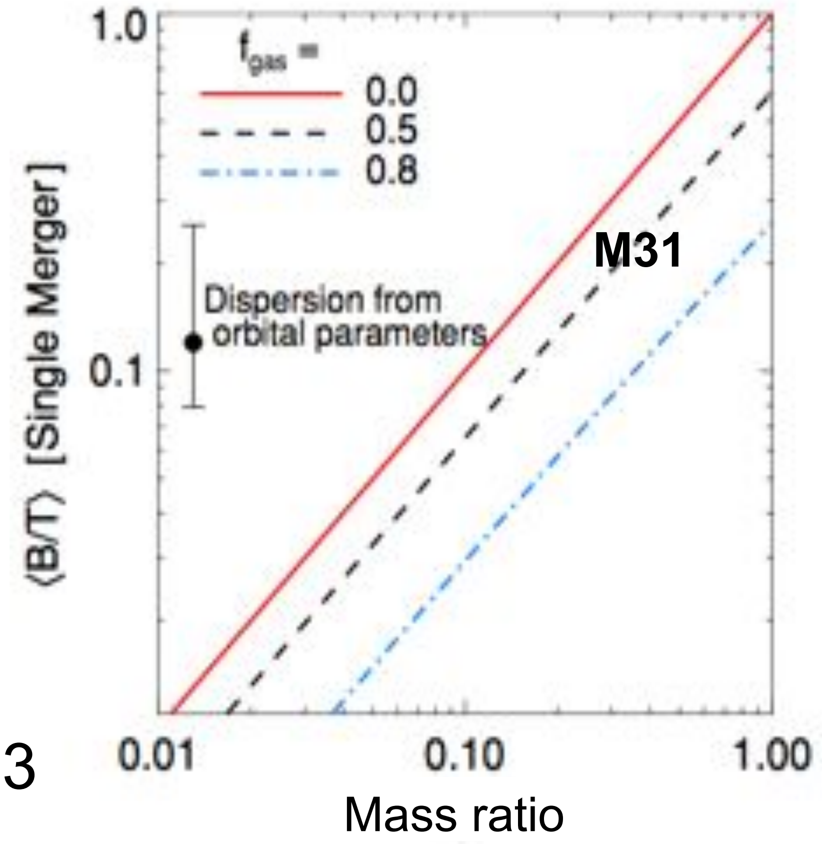
- bulge (B/T=0.23), Sersic n=2.2

(e.g.,Courteau+11)

- enriched halo with intermediate metallicity streams

- 10 kpc ring

➔ A polar orbit and f_{gas}~60% for mr=3



Van den Bergh (2003): «It is suggested that M31 was created by the early merger of two massive galaxies »

DOES M31 RESULT FROM AN ANCIENT MAJOR MERGER?

F. HAMMER[1], Y. B. YANG[2], J. L. WANG[1,2], M. PUECH[1], H. FLORES[1], AND S. FOUQUET[1]

THE ASTROPHYSICAL JOURNAL, 725:542–555, 2010 December 10

First passage ~ 8.5 Gyr ago, fusion ~ 5.5 Gyr ago

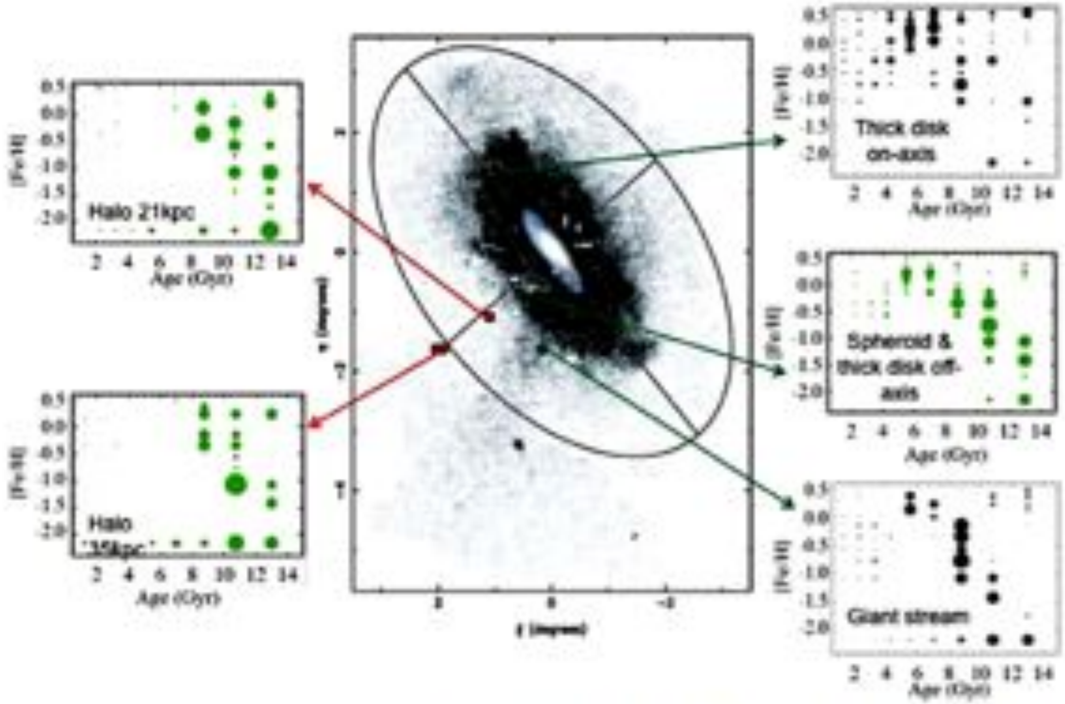
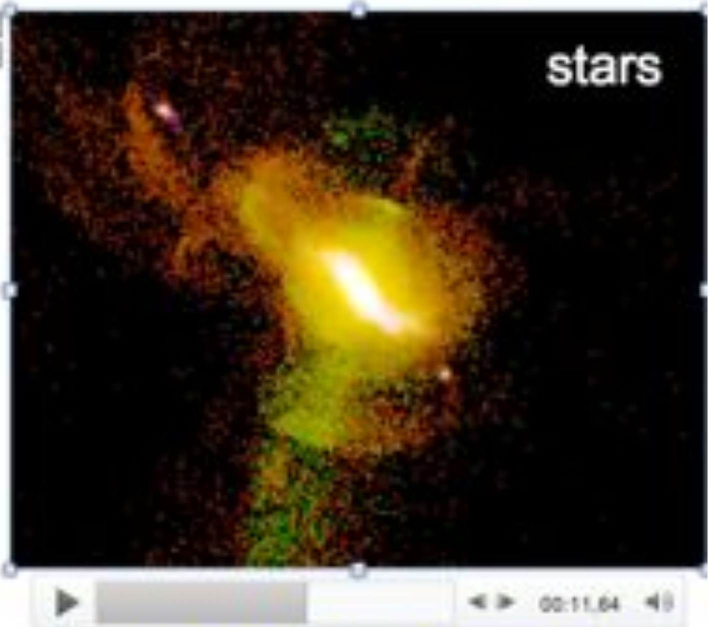


Fig. 1.— Chronological sketch of the structures surrounding M31. In the central panel (reproduced from Ibata et al. 2005), the large and thick rotating disk is a vast flattened structure with a major axis of about 4 degrees. Squares represent fields observed by Brown et al. (2006, 2007, 2008), and are linked to their measurements by arrows.

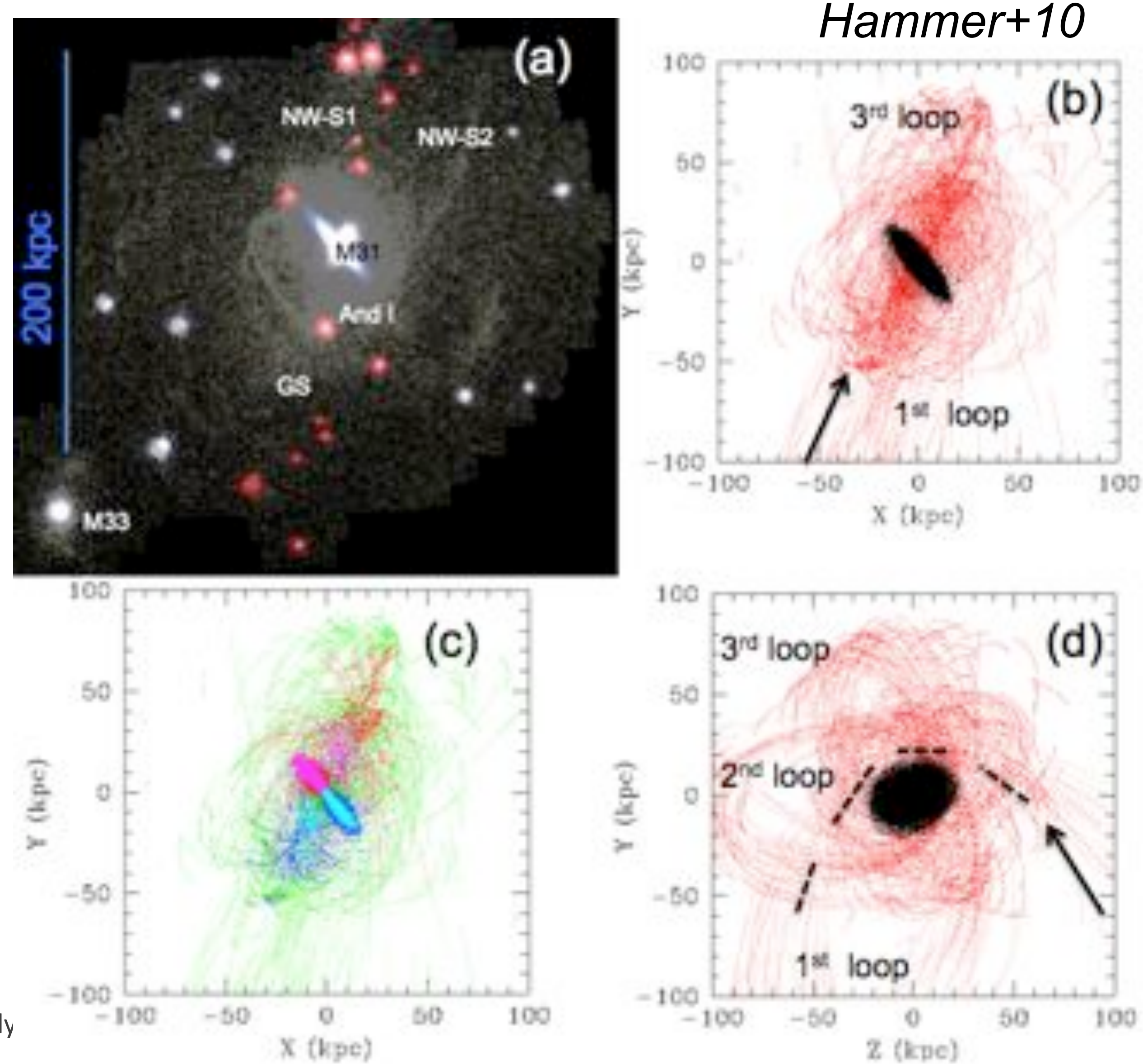


GADGET2, 8M particles
Initial gas fraction: 55%
Feedback from Cox+06

“Ibata ‘s plane” somewhat predicted in 2010!

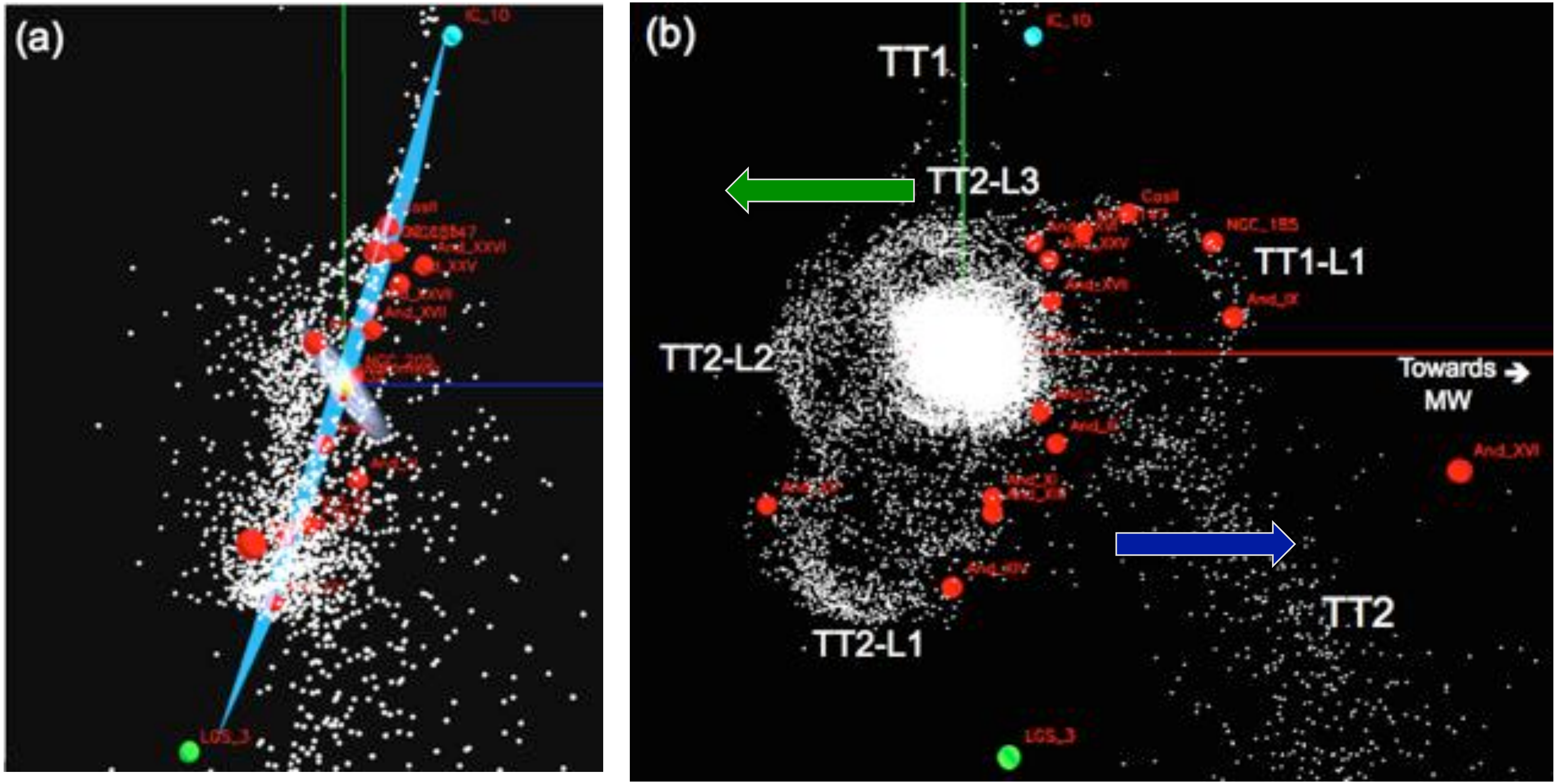
0.998 significance, Ibata+13

Hammer+10



Most dSphs of the plane lie in the loops

Hammer et al., 2013, MNRAS, 431, 3343

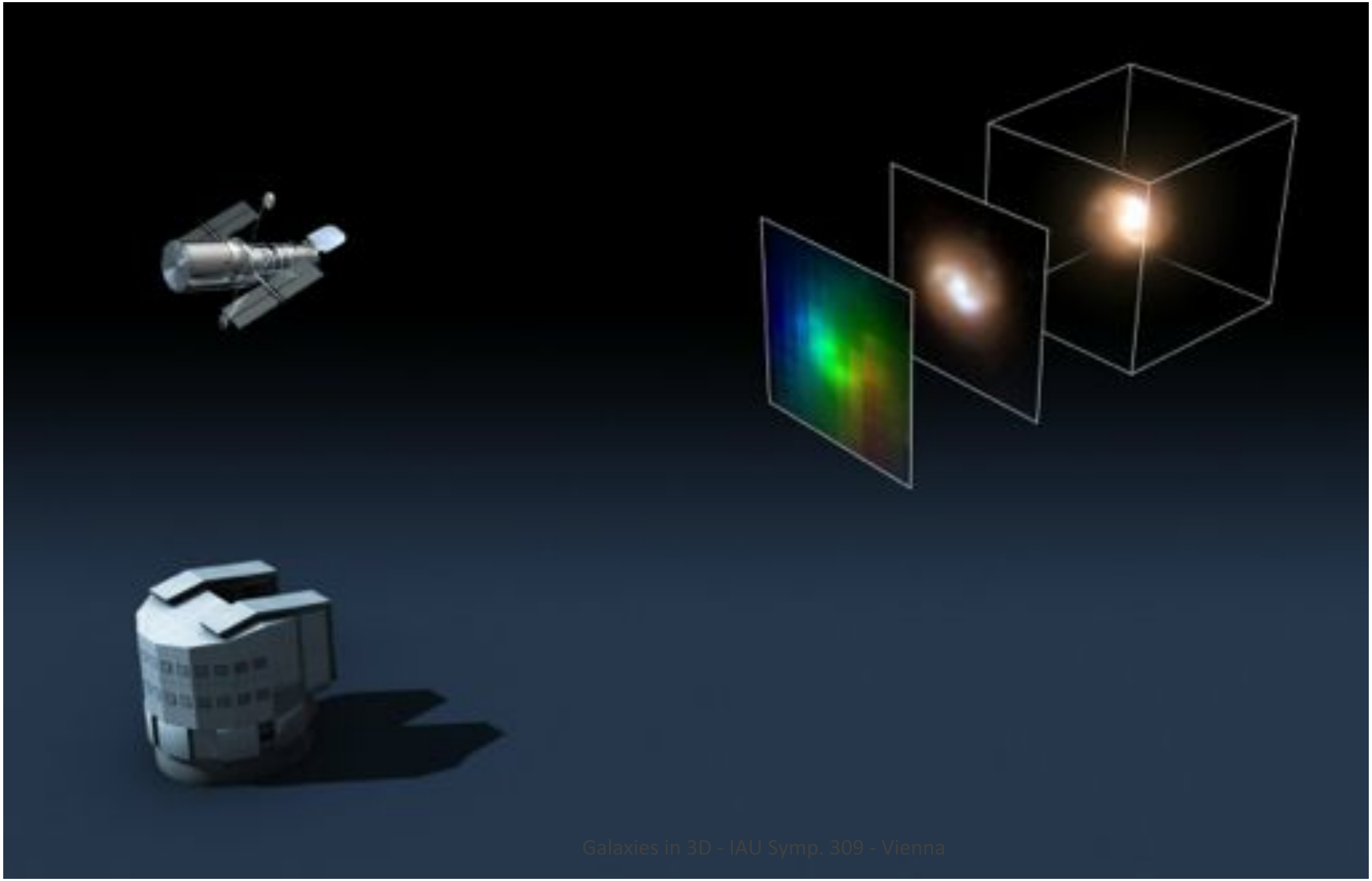


Conclusions

- VLT + HST (IMAGES): representative sample & robust methodology to characterize z≤ 1, MW-mass galaxies
- 2/3 of MW-mass galaxies have likely experienced one major merger during the last 9-10 Gyr
- ΛCDM & IMAGES observations: many galactic disks have been re-built after **gas-rich** mergers
- Just after fusion the gas settles into a gigantic disk, strong SF, then relaxation phase, to generate today spirals
- Solve the angular momentum crisis & fairly consistent with SFR-M_{star} relationship
- Later on: how an ancient merger may have impacted the Local Group and its content!

Galaxy Mass Assembly with **E-ELT/MOSAIC**

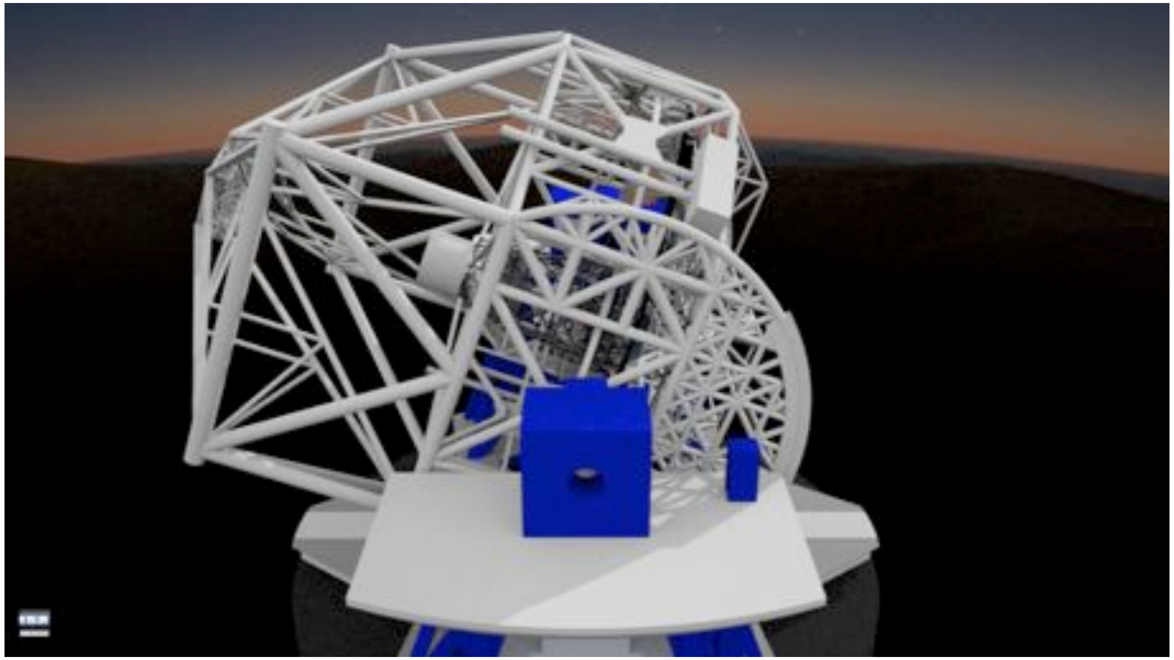
TODAY: $z < 1$ galaxies

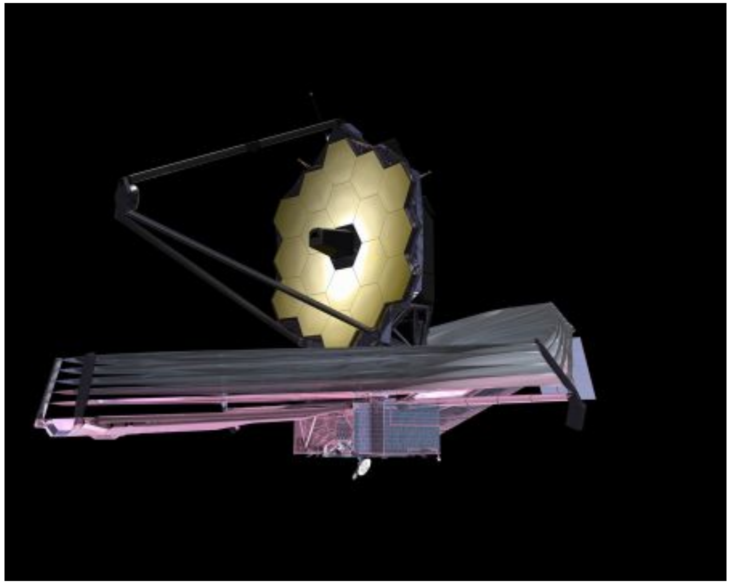


TOMORROW: z >> 1 galaxies with E-ELT + JWST

MOSAIC

Multiplex is the key is for studies of galaxy evolution & formation:
E-ELT-MOS white paper by Evans, Puech et al. (ArXiv:1303.0029)

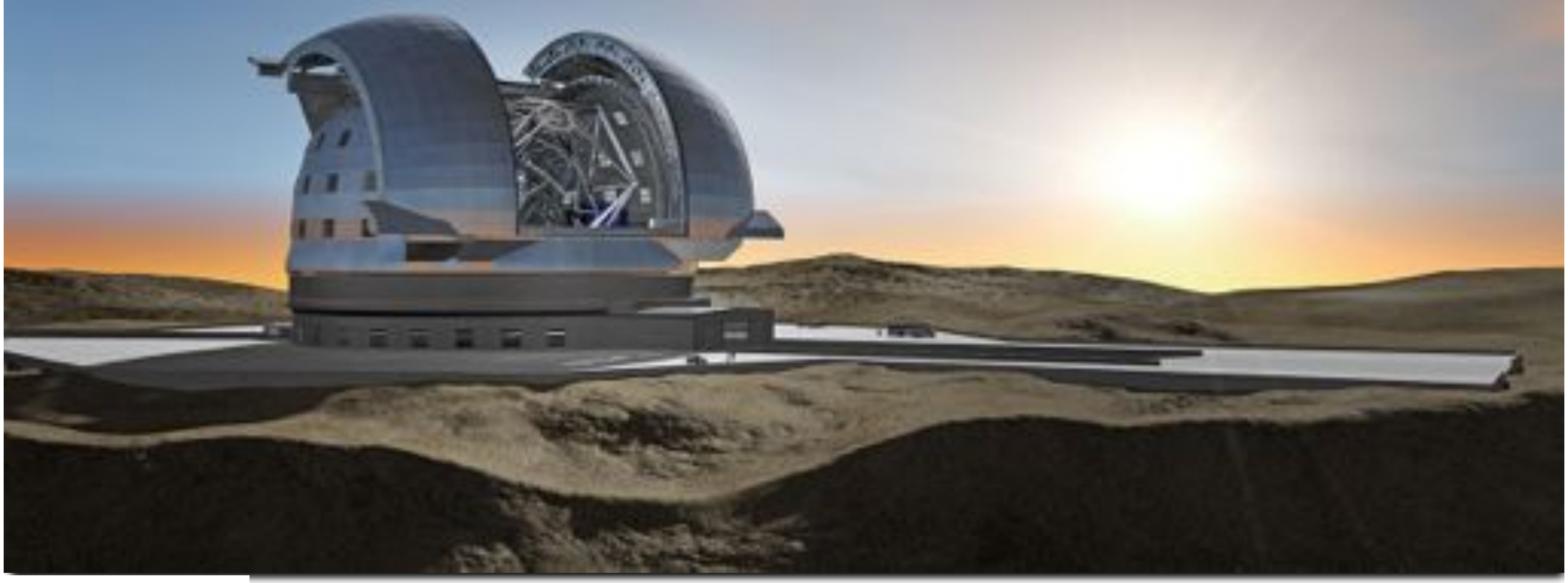




MOSAIC

MOSAIC preliminary study

MOSAIC team have developed, then implemented:
GIRAFFE/FLAMES - NACO - X-SHOOTER - KMOS



l'Observatoire de Paris

Science & Technology Facilities Council
UK Astronomy Technology Centre

LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

UNIVERSITEIT VAN AMSTERDAM

Durham University

NOVA

UNIVERSITY OF OXFORD

Includes also: AIP Potsdam, Nice, Toulouse, Vienna, Stockholm, Roma, Arcetri, Madrid & Geneva

MOSAIC with 2 main different observing modes

- High definition (HDM, 80 mas/pix) with ≥10 MOAO IFUs

EAGLE science cases

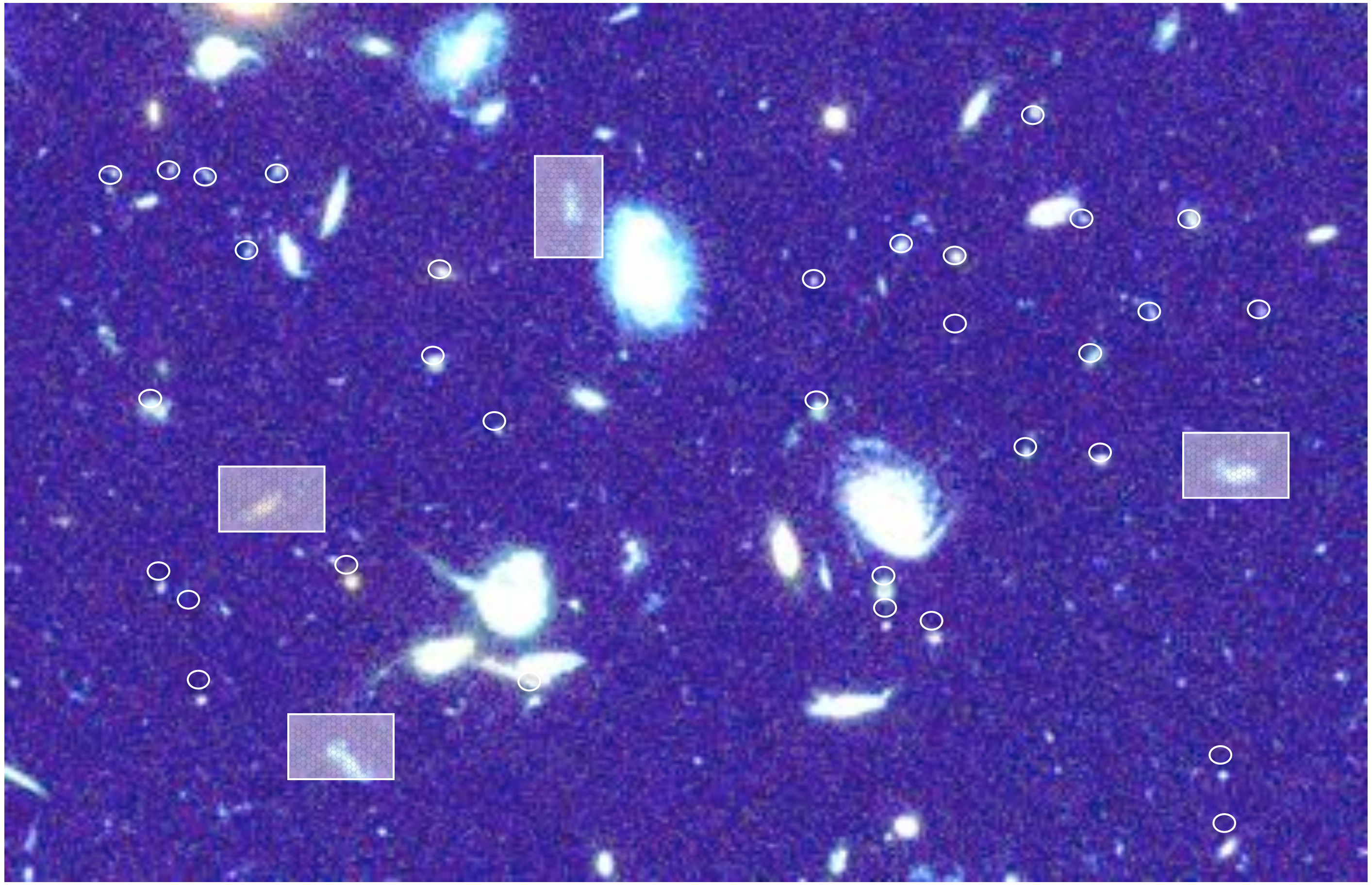
e.g., first objects & detailed kinematics of galaxies up to z=5, R=5000

- High multiplex (HMM, 100-250), GLAO/seeing resolution

OPTIMOS-EVE science cases

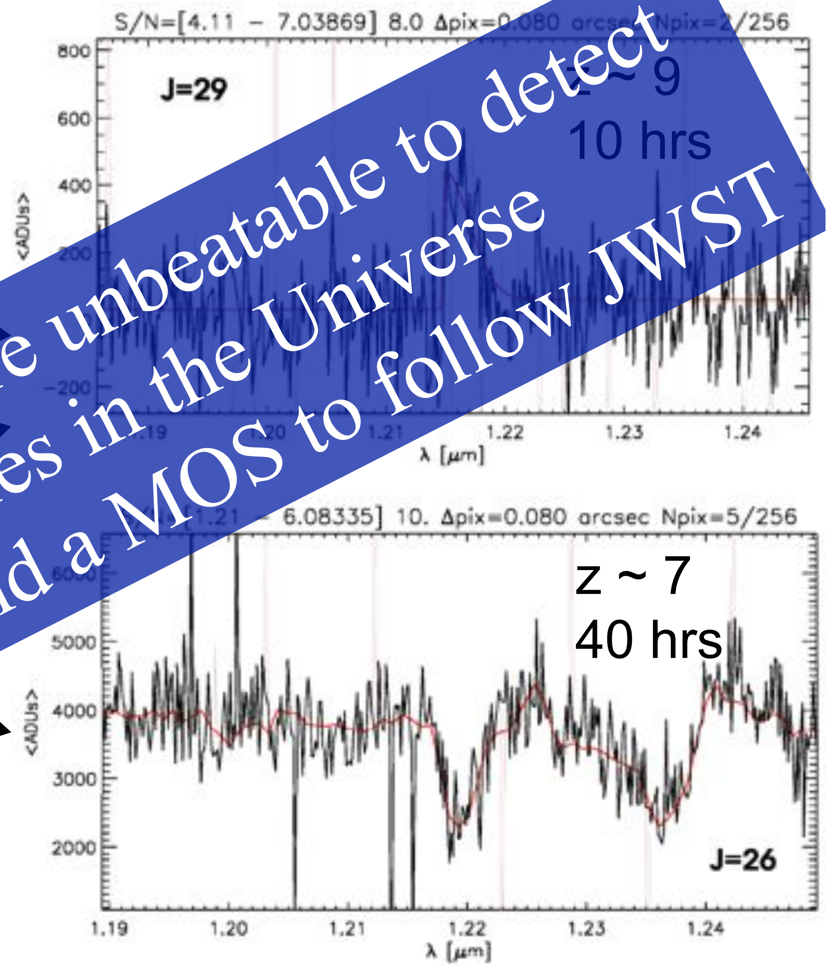
e.g., stars & 1600 z > 1.5 galaxies in an E-ELT FoV, R=5000-20000

High definition & high multiplex modes



≥ 10 IFUs with MOAO
≥ 200 fibers with natural seeing or GLAO

End-to-end simulations, see Disseau et al., 2014, SPIE
MOAO simulations based on CANARY (Gendron et al. 2014, SPIE



Multi-IFUs on a 39m E-ELT are unbeatable to detect and study the first galaxies in the Universe

We just need the E-ELT (!) and a MOS to follow JWST

IFUs: essential for the best sky subtraction
(Rodrigues et al., 2014, SPIE)