Galaxies Étoiles Physique et Instrumentation

The elaboration of spiral galaxies:

morpho-kinematics analyses of their progenitors with IMAGES

by François Hammer
on behalf of the IMAGES collaboration

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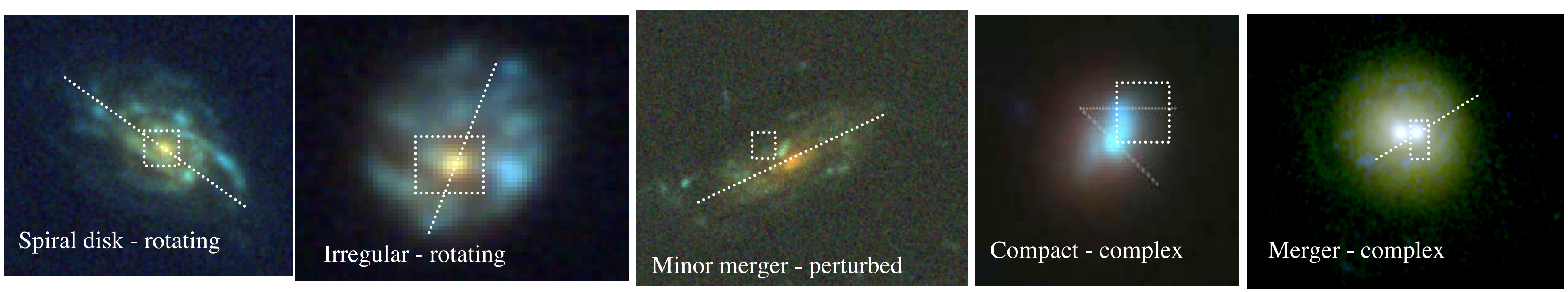
Intermediate Mass Galaxy Evolution Sequence



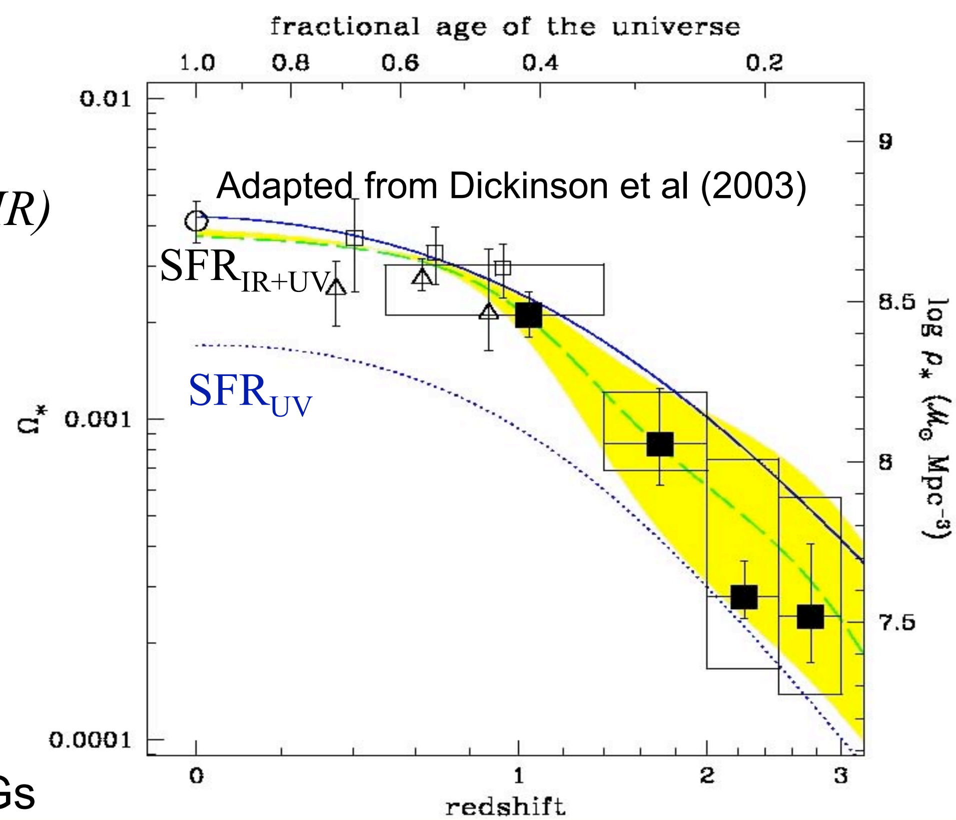
Galaxy Evolution since z=1

- 50% of the local stellar mass was formed during the last 8 Gyr, i.e., since z=1 (e.g., Dickinson+03 ; Drory+04)

From evolution of:

1. global stellar mass (photometry, near-IR)

2. integrated SFR (including IR light)



- Mostly associated to evolution of intermediate mass galaxies:
- $2\ 10^{10} < M_{stellar} < 2\ 10^{11}\ M_\odot$;
- Today, 70% of spirals;
- Most of the stellar mass formed in LIRGs (SFR > 19 $M_\odot$/yr) (Hammer+05, Bell+05)

→ *requires resolved kinematics of z~0.6 intermediate-mass galaxies*

IMAGES-GTO Survey

Which mechanism(s) is (are) driving the evolution at z<1?

Sample selection
$M_J < -20.3$ & $0.4 < z < 0.9$
4 fields including CDFS

→ **Intermediate-mass galaxies**
$M_{stellar} > 1.5\ 10^{10} M_{\odot}$
(average ~M*)

↓

Integrated properties

Spitzer
FORS2 (600RI+600z)

→ SFR
Metallicity of the gas (O/H)

Imaging
ACS imagery

→ Color-morphology
S.E.D.

3D Spectroscopy
VLT/FLAMES-GIRAFFE

→ Kinematics
Dynamics

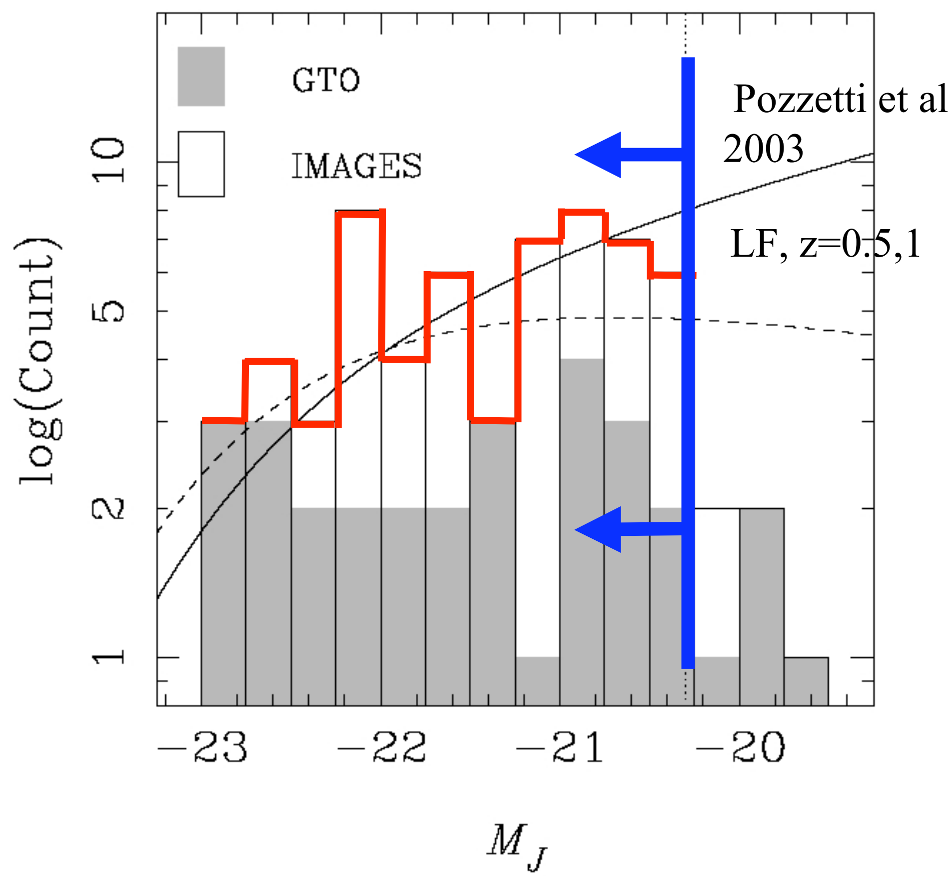
100 galaxies with spatially resolved kinematics

100 Intermediate mass galaxies :

- EW_0([OII])>15Å
- 0.4 < z < 0.9

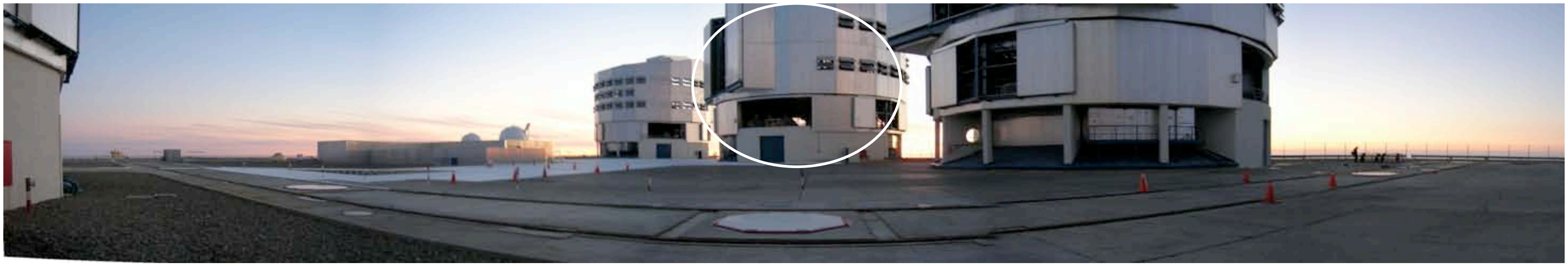
In this talk:

Representative sample of 63 M* galaxies selected in 4 different fields of view, with 0.4 < z < 0.75

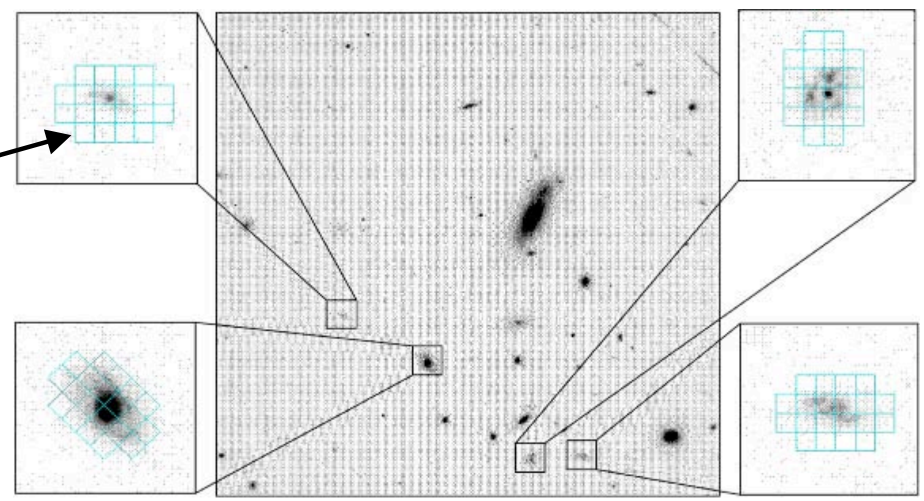


From Yang et al (2008), A&A 474, 807

FLAMES/GIRAFFE on VLT



IFU Mode: 15 x 3''x2''arrays (20 sq. mlenses, 0''.52)

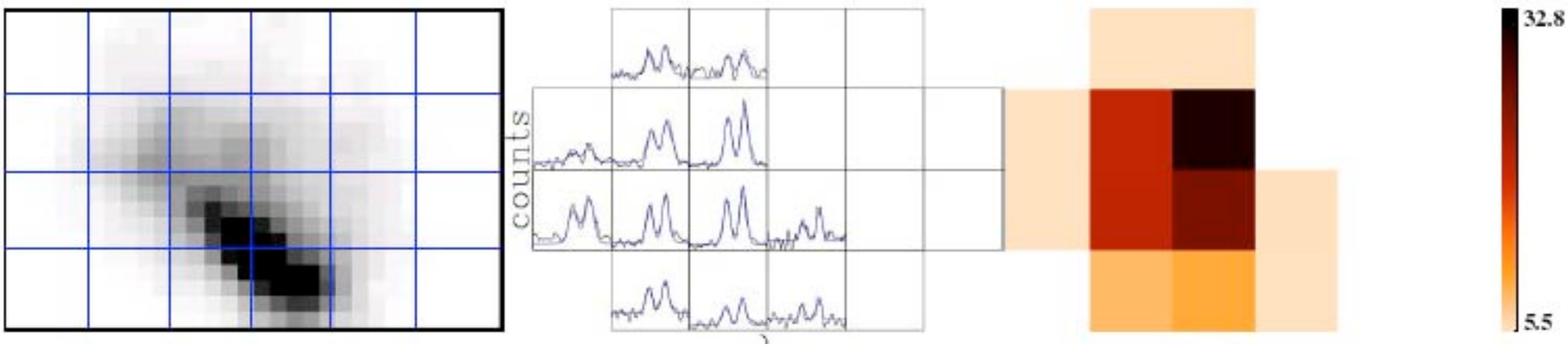


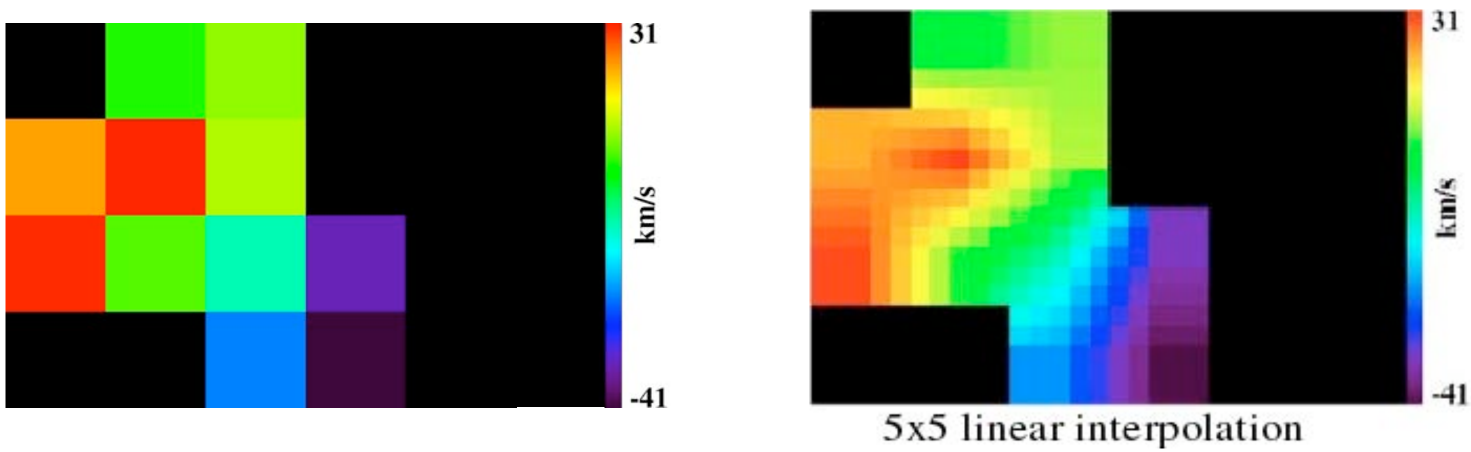
15 deployable IFUs over a 20 arcmin FoV with $R_{effective}$= 13000
➔ the [OII] doublet is well resolved

FLAMES/GIRAFFE on the VLT

8 to 24 hrs exposure on an 8 m

CFRS03.0488, z=0.46, (3''x2'')

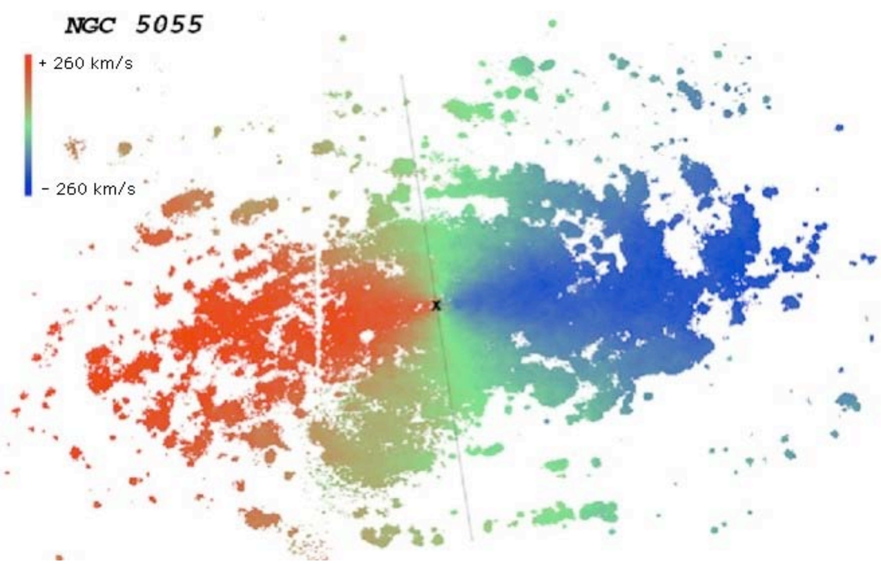




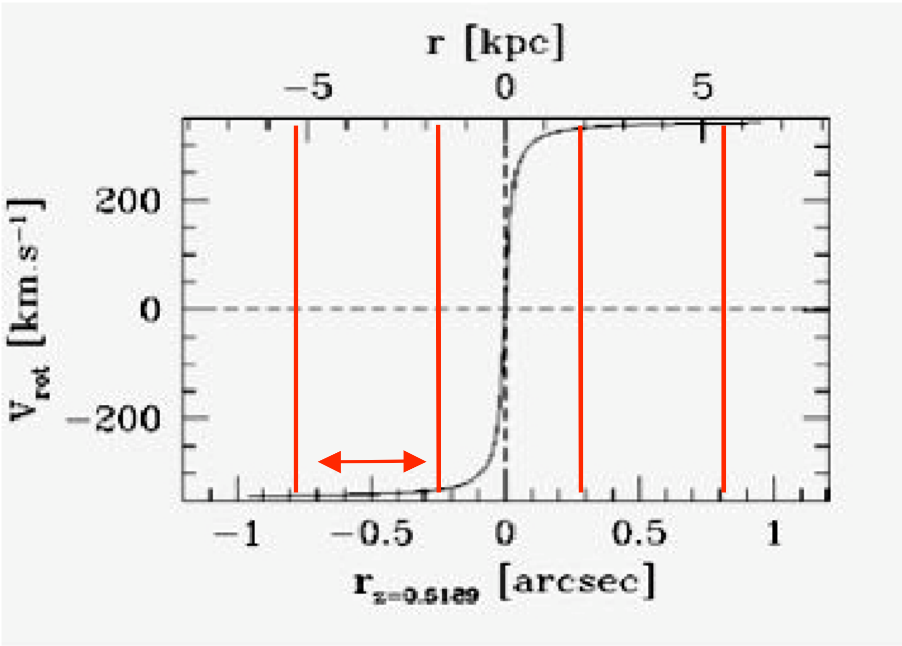
Velocity fields and also σ-maps

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

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



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

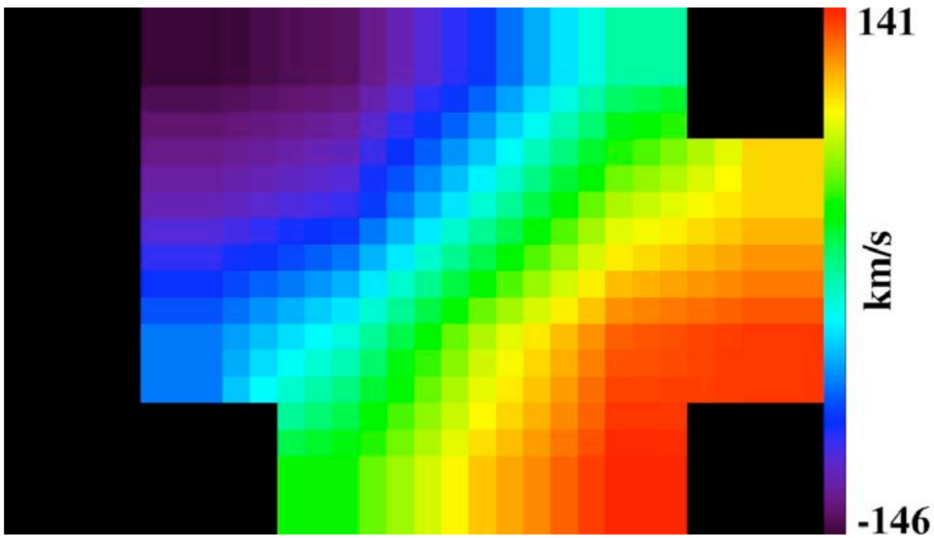


GIRAFFE pixel @ z=0.6

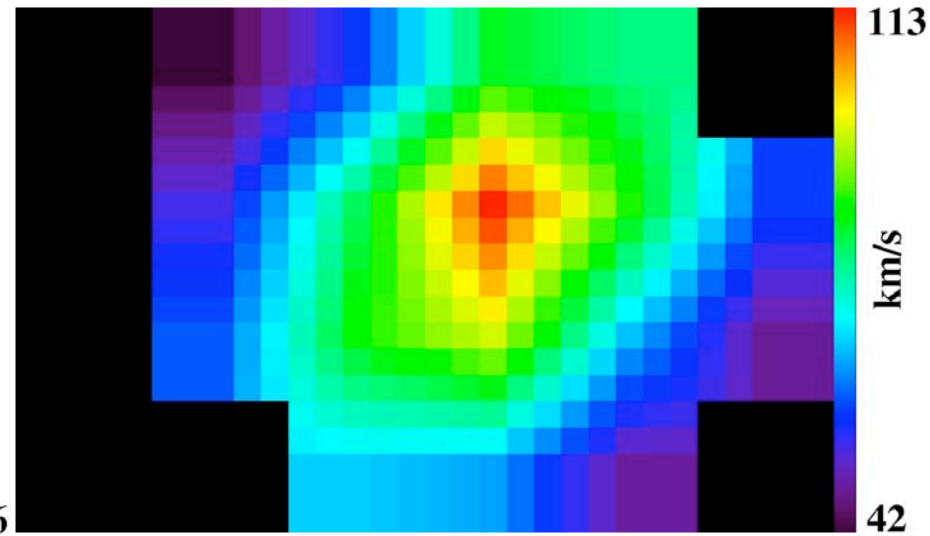
Velocity fields and also σ-maps

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

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



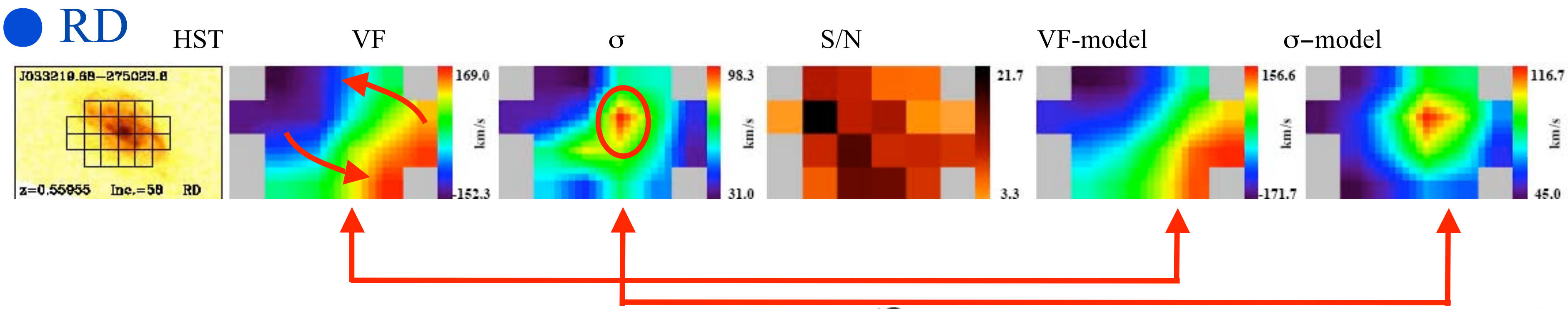
Velocity map



Dispersion or σ-map

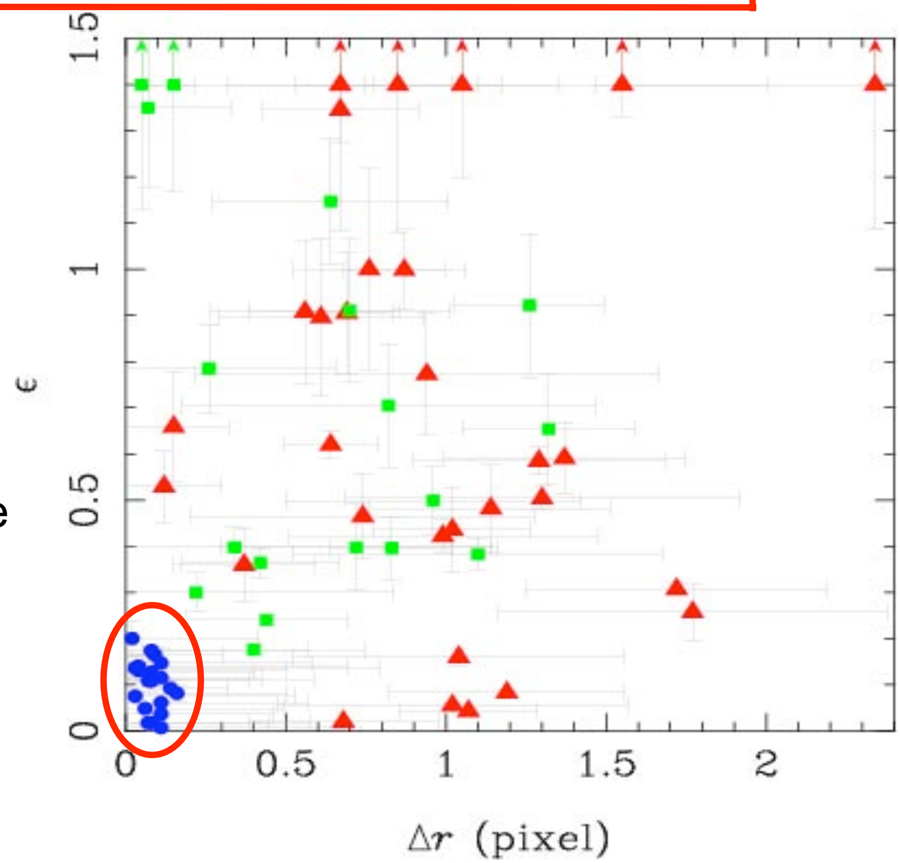
see e.g. Flores+06, Yang+08

Resolved kinematics: rotating disks (RD)

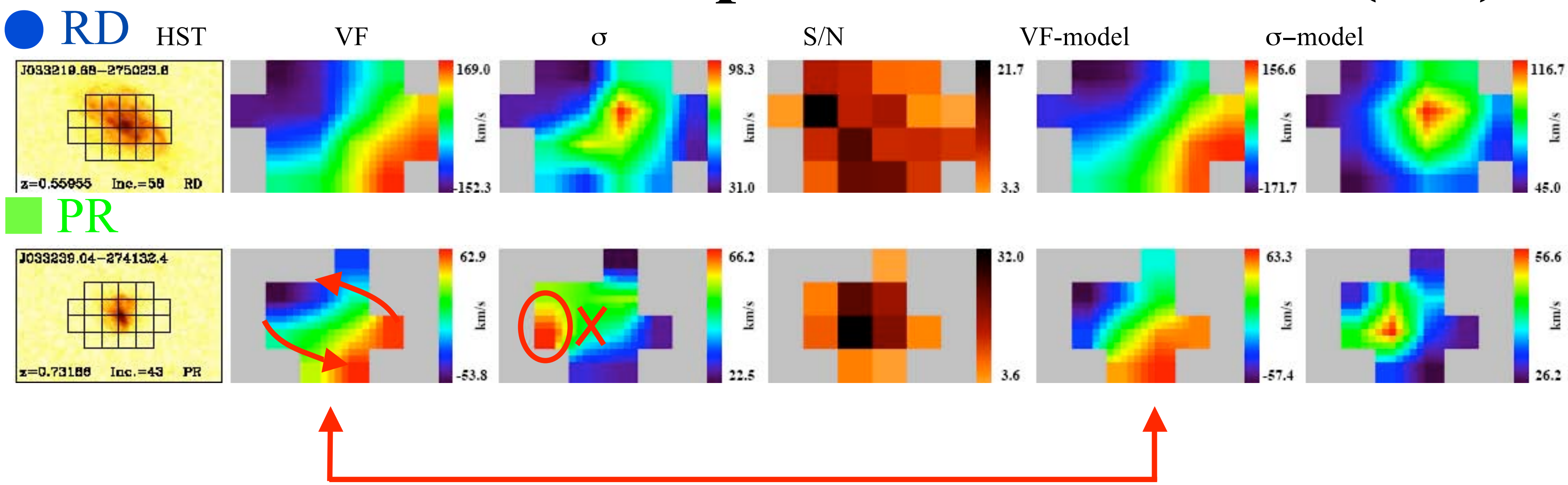


All galaxies are assumed to be rotating disks:

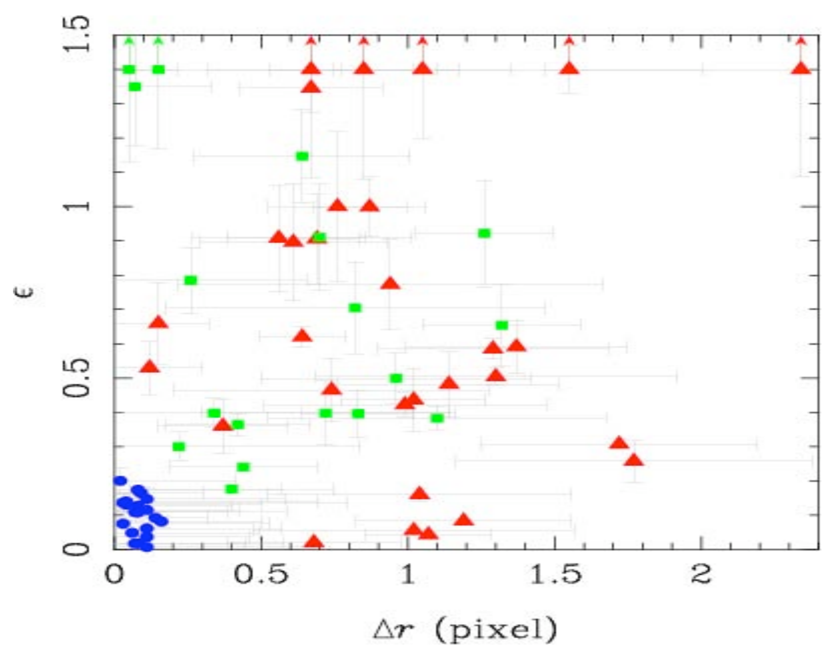
- large scale motions due to rotation
- aligned with the optical axis
- simulation of corresponding VF and σ-map
- comparison of the derived σ-maps to the observed ones (relative difference of amplitude ε vs. σ peak distance Δr)



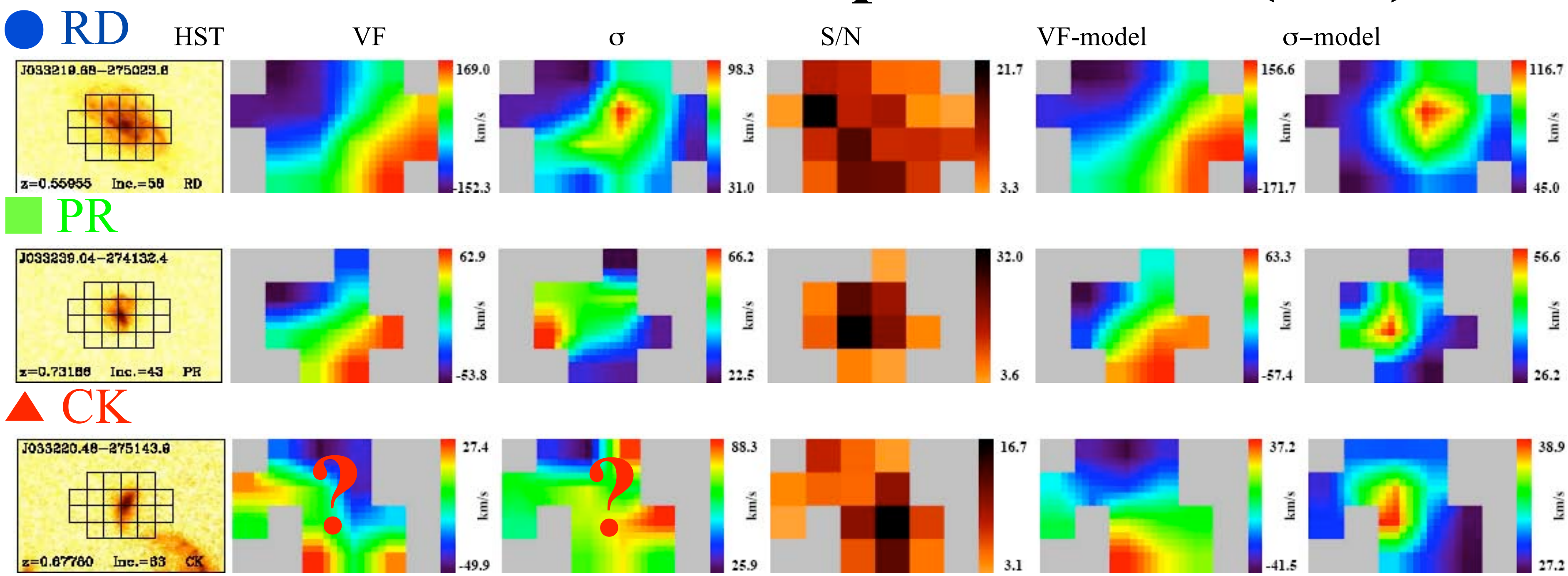
Resolved kinematics: perturbed rotation (PR)



- Rotation seen in the VF (aligned with the optical axis)
- Off-centred σ peak

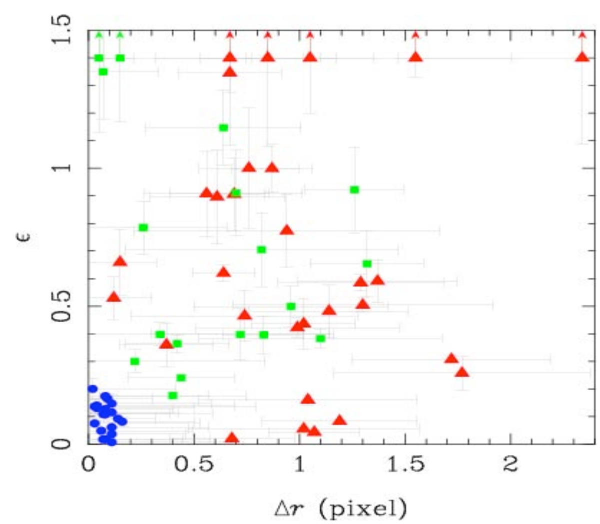


Resolved kinematics: complex kinem. (CK)

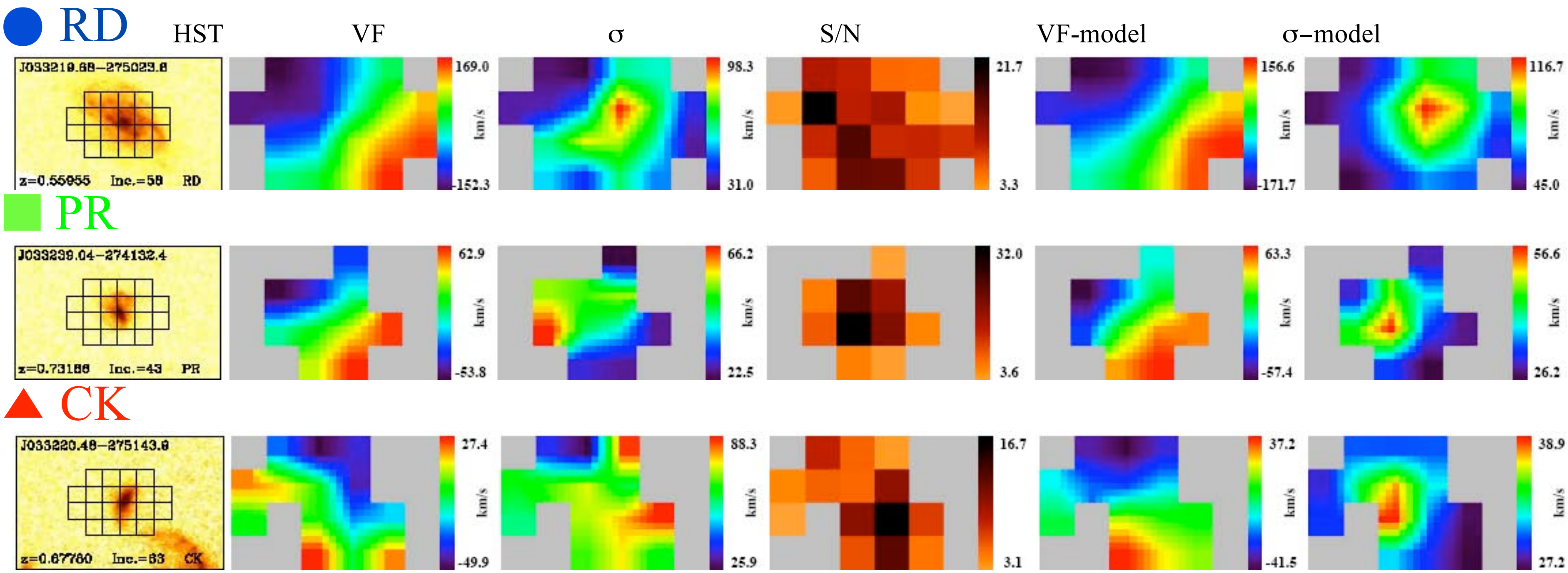


• No obvious structure in the VF/σ-map;

•dynamical axis generally misaligned vs main optical axis



Resolved Kinematics: statistics



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

Statistics in the sample

	HDFS	CFRS22h	CFRS03h	CDFS	Total (fraction)
RD	4	2	5	9	20 (32%±12%)
PR	2	2	2	10	16 (25%±12%)
CK	3	2	6	16	27 (43%±12%)
UC	3 in total			3	6 (9%)

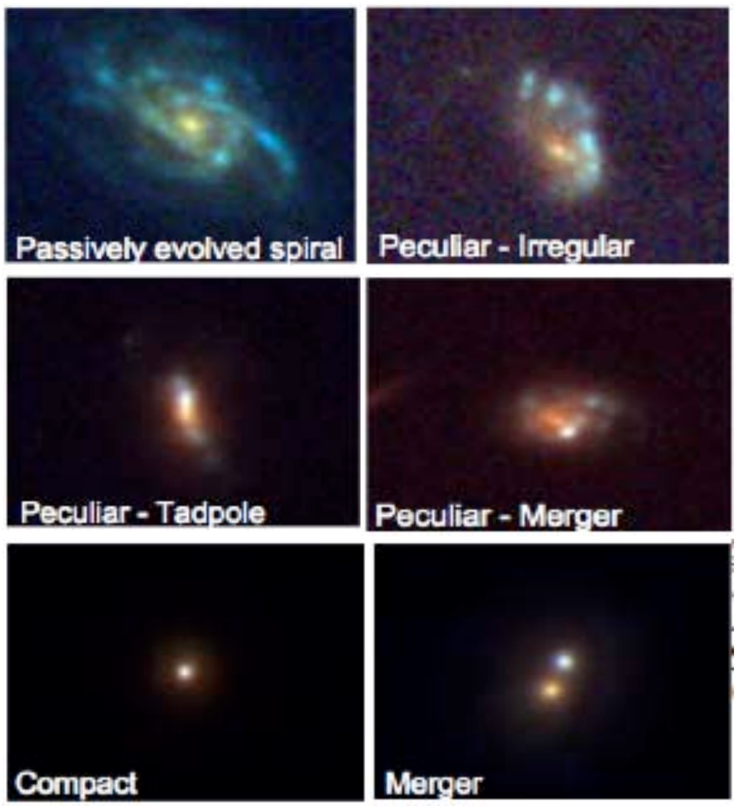
Fraction of z~0.6 intermediate-mass galaxies

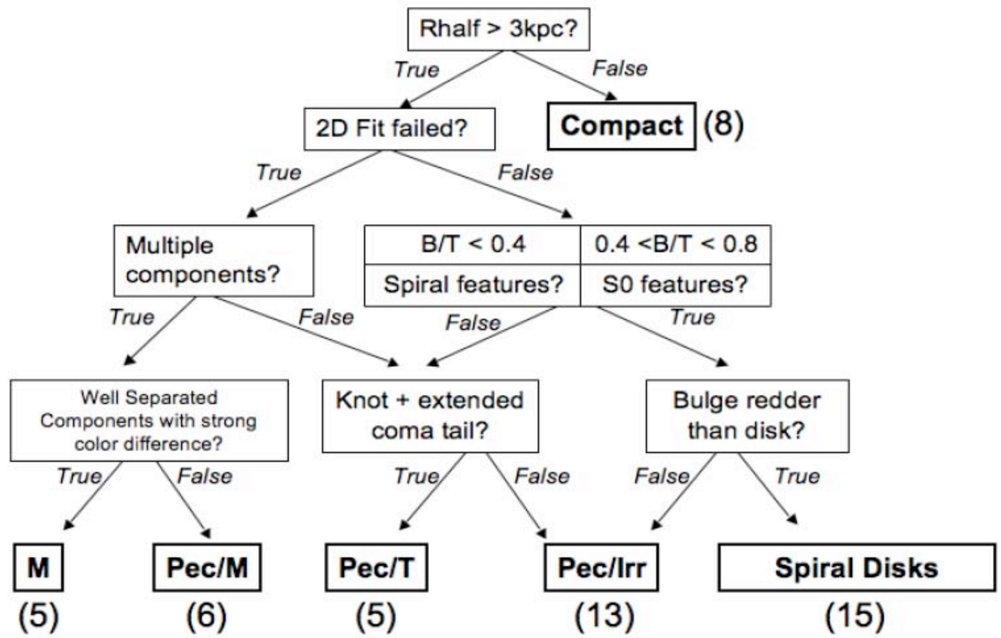
33%
15%
26%

Morphology

Neichel et al. 2008, A&A, 484, 159

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





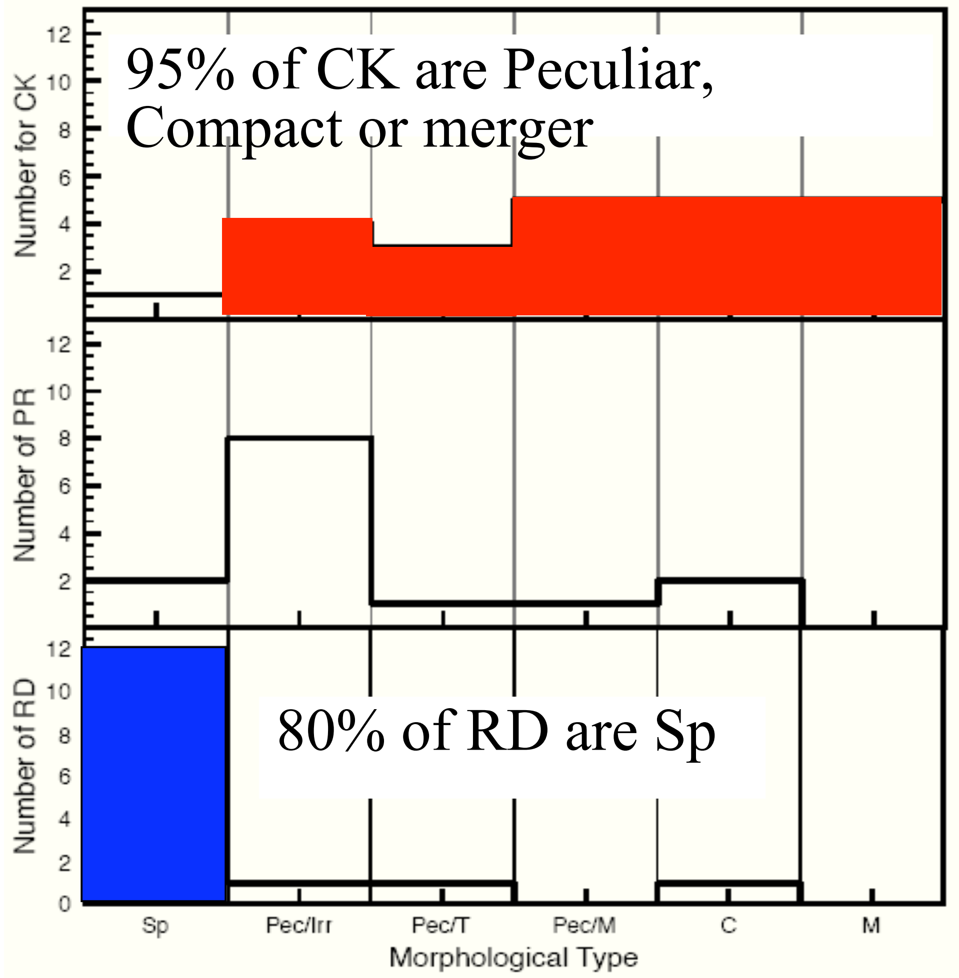
Morpho-kinematics

Neichel et al (2008)

Agreement between kinematics and morphological classifications

Automatic classification methods (C-A or Gini-M20):
- not predictive
- overestimate the number of spirals

only 16% of the sample is classified as Sp+RD



A small fraction of rotating spirals at z= 0.6

Neichel et al, 2008

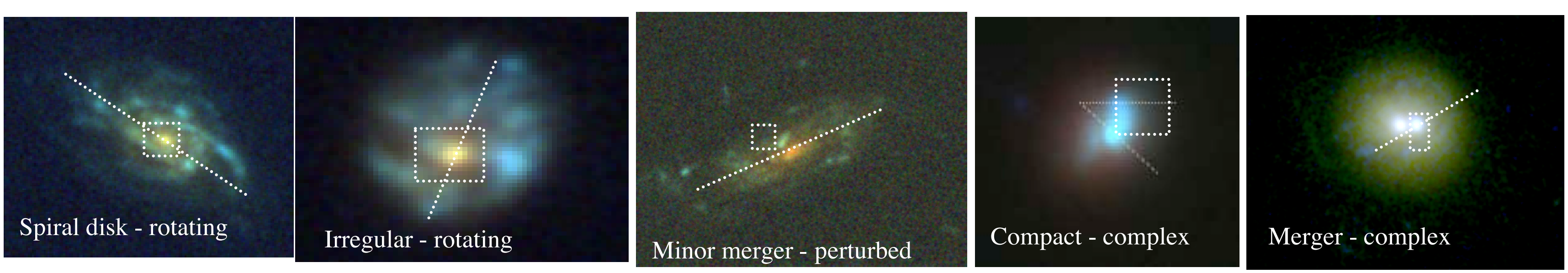
with EW([OII])<15Å		with EW([OII])>15Å			
E/S0	RSpD	RSpD	Pec	C	M
23%	17%	16%	28%	10%	6%

33% of z=0.6 galaxies are rotating spirals against **70%** today !
it supersedes earlier results from Lilly et al (1998)

Which transformation explain the numerous present-day spirals and their large angular momentum?

Based on the IMAGES sample of 63 galaxies at 0.4 < z < 0.75 :
M_J(AB)< -20.2 (M* galaxies) and W_0(OII) > 15A

Large scale kinematics (GIRAFFE) + detailed morphology HST/ACS 200pc @ z=0.6)



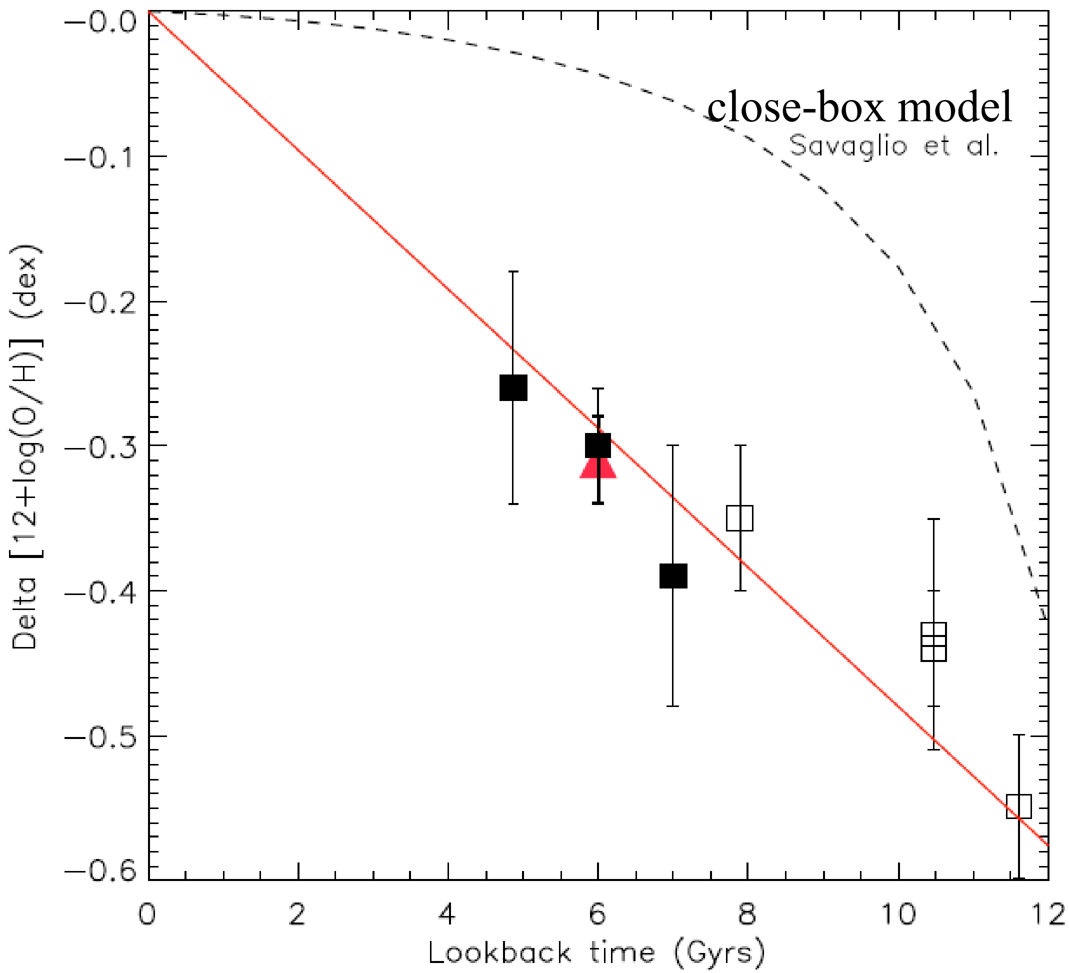
What evolve, what don't

Morphological Type	z ~ 0.6 Neichel et al, 2008		z=0 Nakamura et al (04, SDSS)
E/S0	23%		27%
Spiral	33%		70%
Peculiar/ compact/ merger	**44%**	**Anomalous kinematics** **PR & CK**	**~ 3%**
LIRGs	20%		0.5%

E/S0 mostly in place at z=0.7, half of spirals don't

Peculiar & LIRGs evolve by large factors: mostly linked with spirals

Galaxies are not isolated systems



Rodrigues et al. 2008
arXiv:0810.0272
See Rodrigues poster

Comparison with TF evolution:

It needs that ~30% of the stellar mass must be formed from external gas supply

⇩

The closed-box model is ruled out

The origin of star formation in progenitors of spirals 4-8 Gyrs ago

- Doubling their stellar masses
- Processes related to violent SF (LIRGs)
- At z~0.6 half of local spirals had anomalous kinematics & peculiar morphologies
- Gas exchanges dominate

⬇

Suggest galaxy collisions or their remnants

Galaxies with complex kinematics (CK): mostly major merger remnants?

Pair fraction at z~0.6 : *remarkable agreement* on **5 ± 1 %**

(Le Fevre+00; Conselice+03; Bell+06; Lotz+08; Rawat+08, Jogee+08)

$\oplus$

Fraction of CKs at z~0.6:

26%

(Yang+08; see also Kutdemir+08)

If CKs are major merger remnants, then: $$\frac{\tau_{remnant}}{\tau_{pair}} = \frac{f_{remnants}}{f_{pairs}} \sim 5$$

Assuming τ_{pair} = 0.3-0.5 Gyr $\Rightarrow$ $\tau_{remnant}$ = 1.5-2.5 Gyr

➡ Predicted by simulations of major mergers

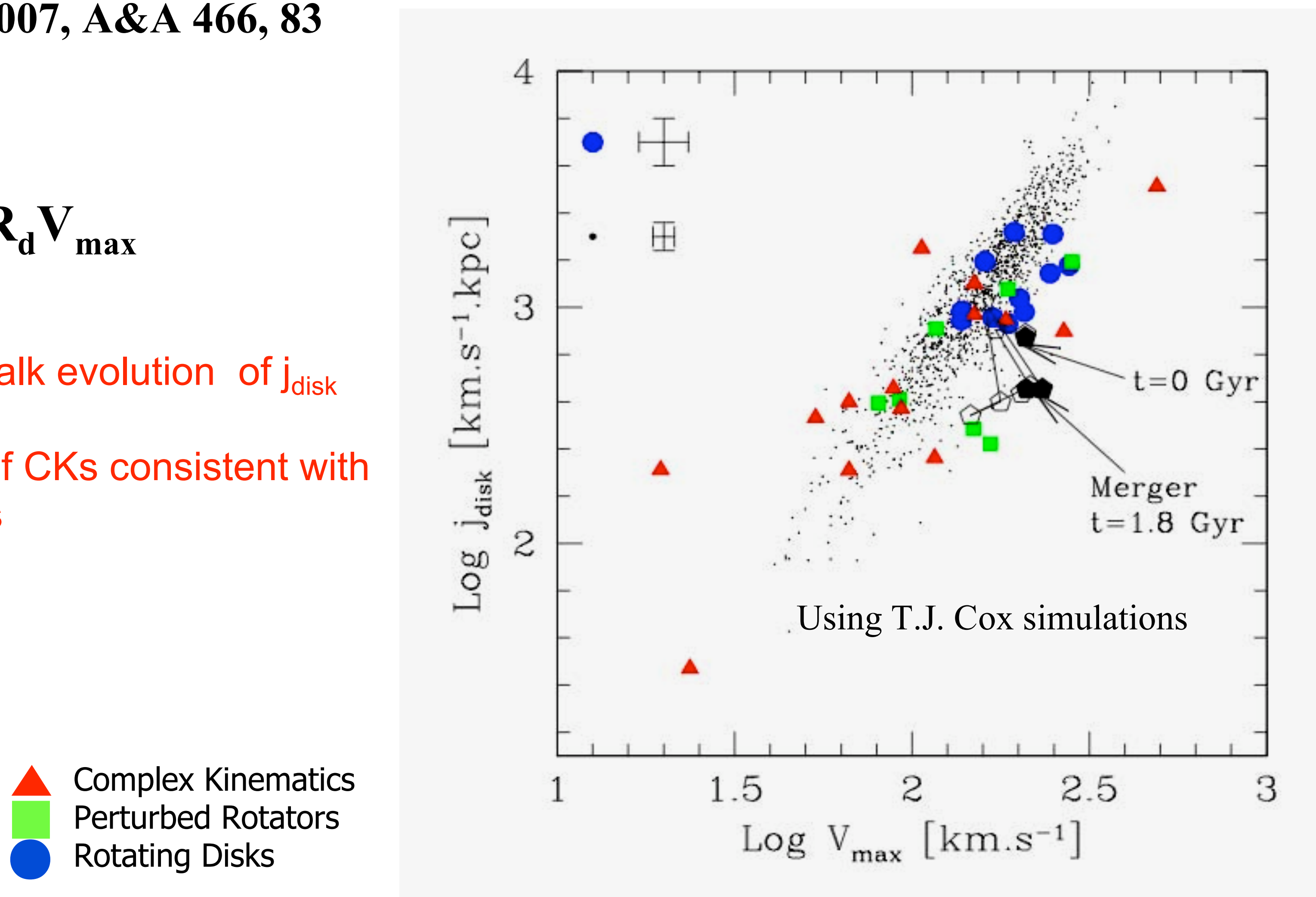
(e.g., Robertson+06; Cox+07, Governato+07)

Specific Angular Momentum

Puech et al. 2007, A&A 466, 83

$$j_{disk}=2R_dV_{max}$$

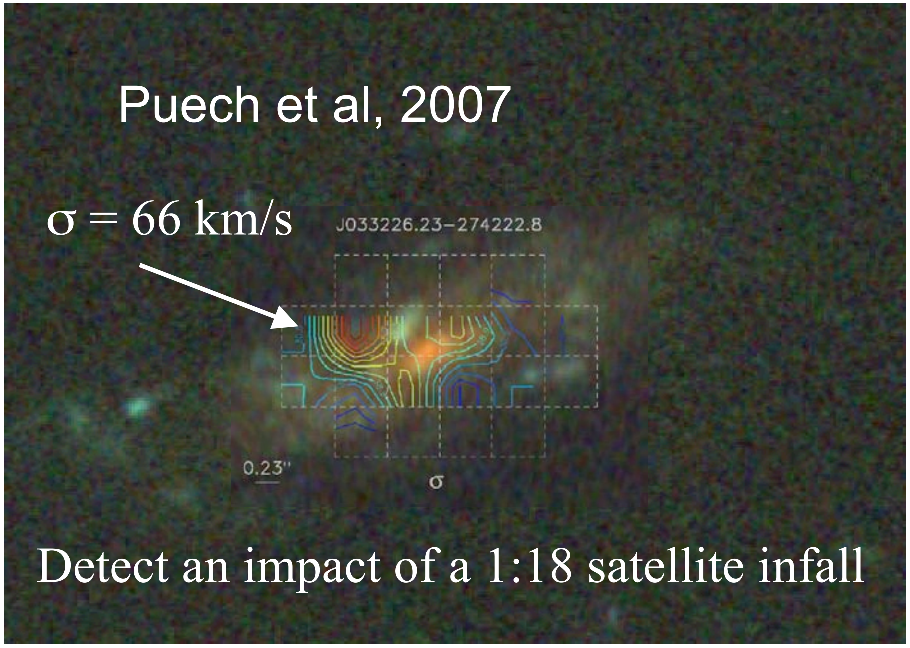
- A random-walk evolution of j_{disk}
- Dispersion of CKs consistent with major mergers



Detailed studies

" Examine the objects as they are and you will see their true nature; look at them from your own ego and you will see only your feelings; because nature is neutral, while your feelings are only prejudice and obscurity."

邵雍, *Shao Yong,* 1011–1077



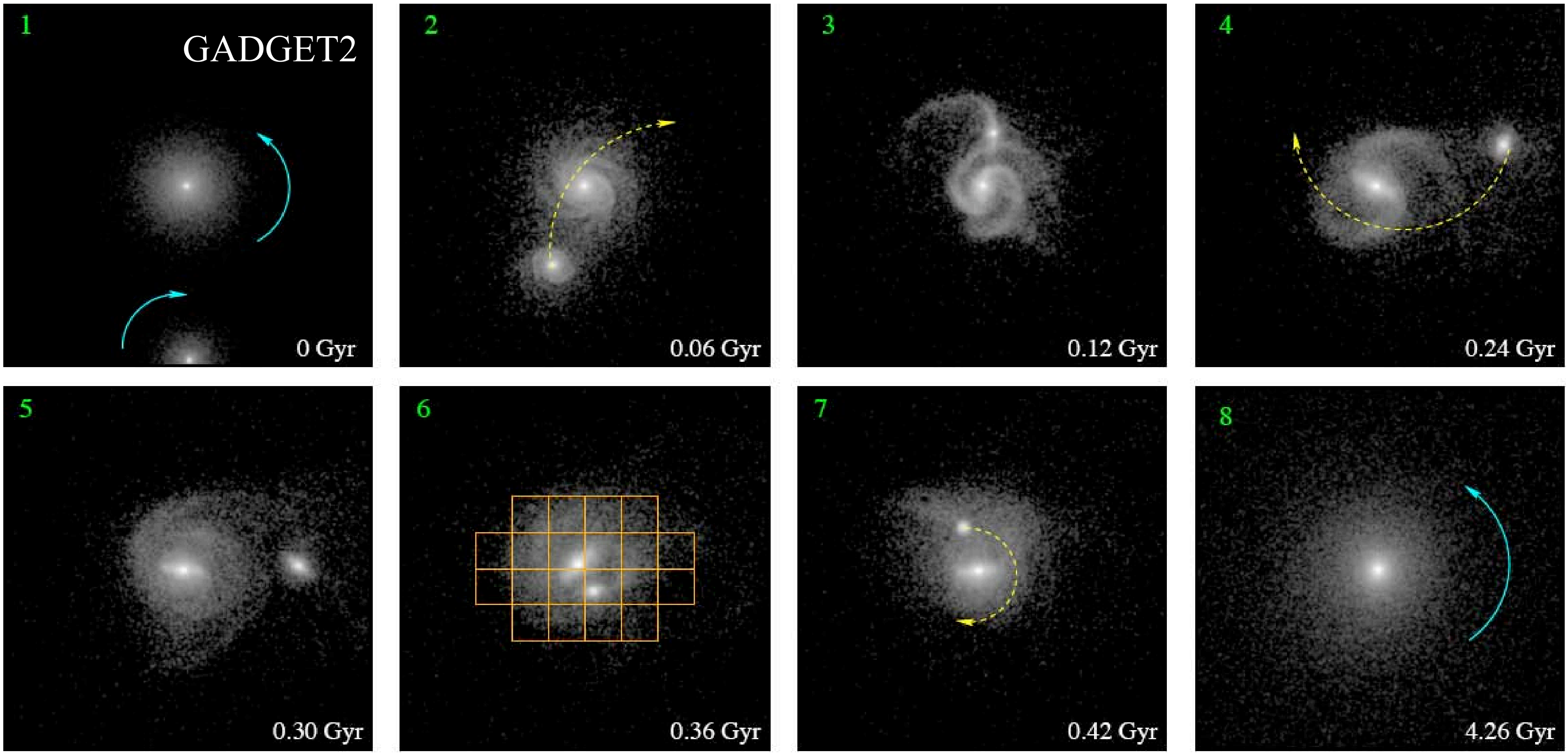
modelling z~ 0.6 galaxies

with a similar accuracy than

for local galaxies

A giant bar induced by a merger at z=0.4

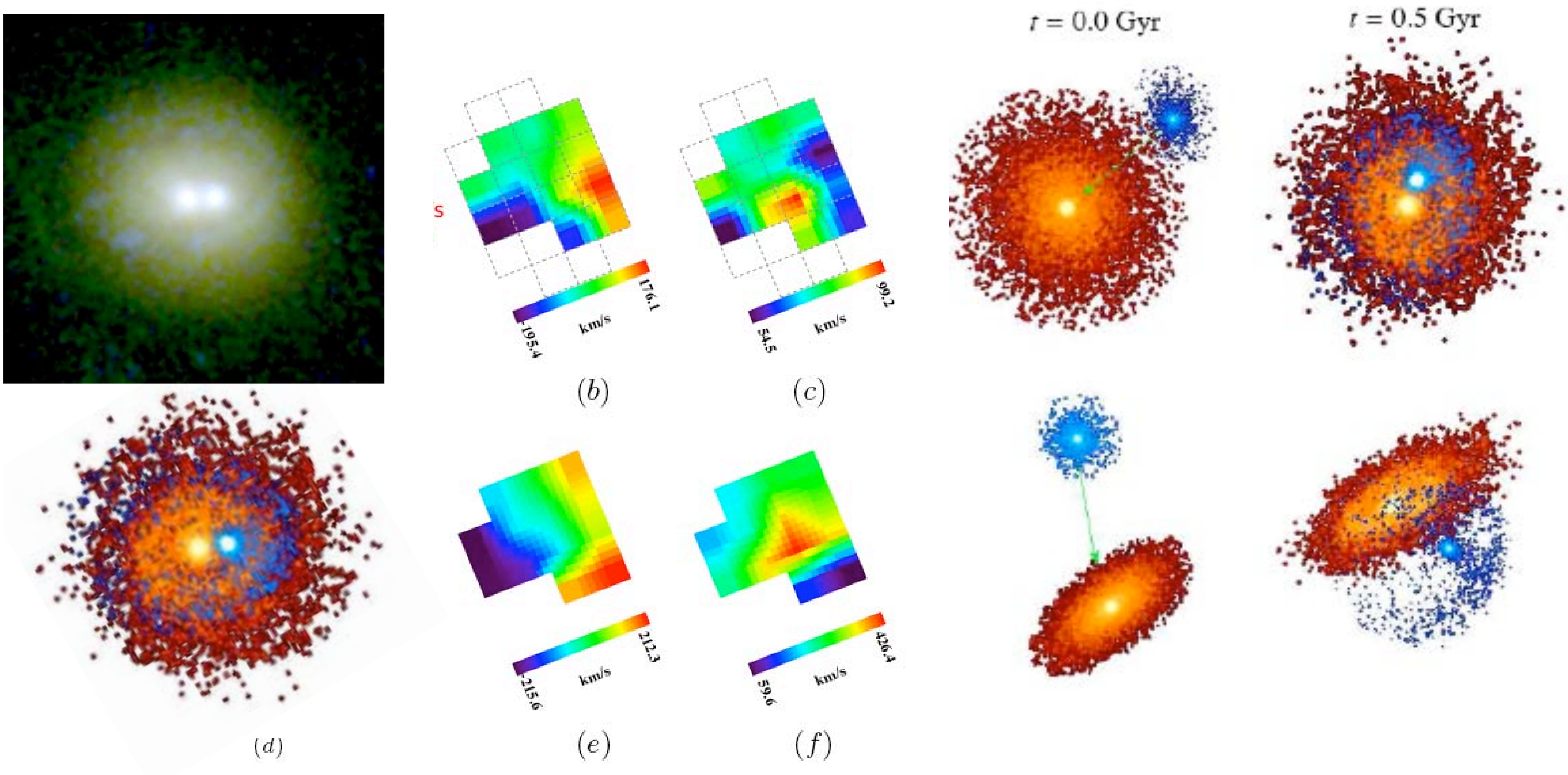
Peirani et al, 2008, A&A submitted



Galaxy morphology & angular momentum are driven by the last major merger (here 1:3 mass ratio, S0_a)

A surviving disk from a 6:1 mass ratio central collision

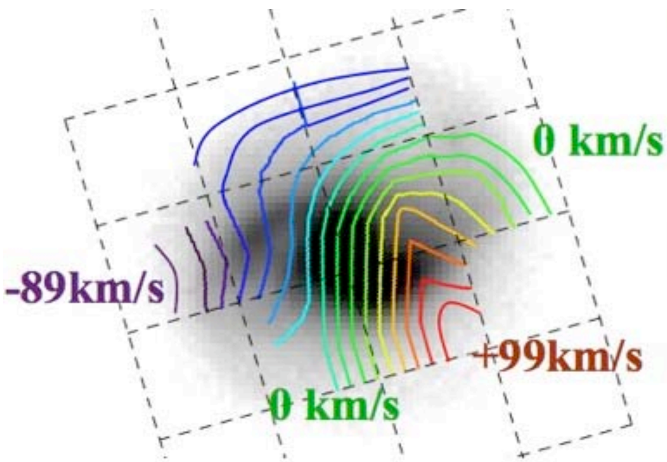
Yang et al, 2008b, A&A submitted

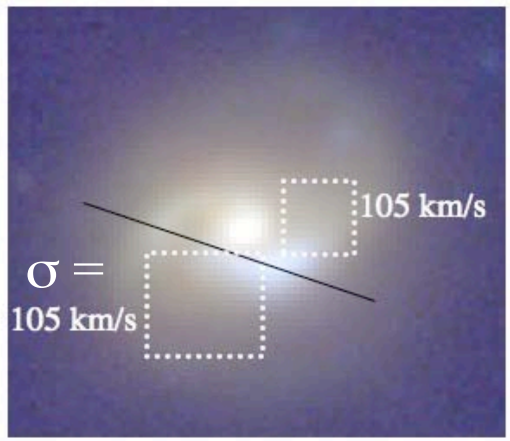


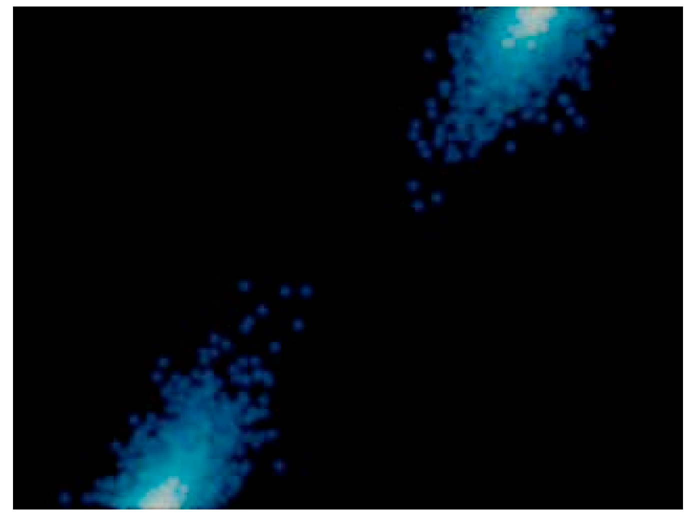
Spiral morphology & angular momentum are driven by the last major merger parameters (here 1:6 mass ratio, Sa)

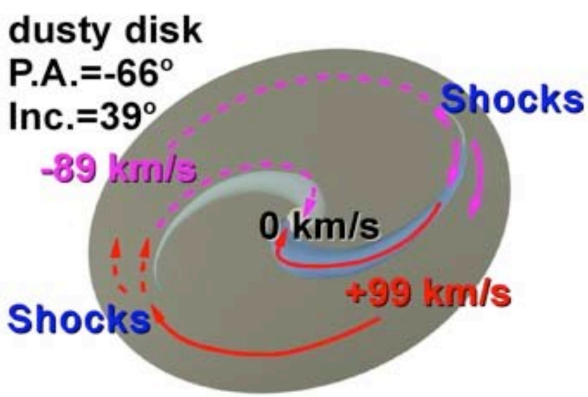
A disk rebuilt 500 Myrs after a gas rich merger at z~0.4

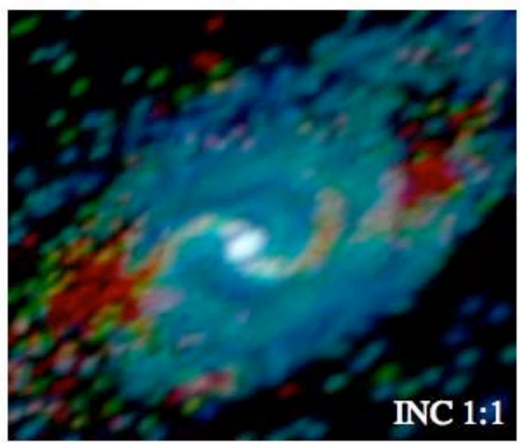
Hammer et al. 2008, A&A submitted











Barnes, 2002
Gas, INCLINED, 1:1

A disk rebuilt 500 Myrs after a gas rich merger at z~0.4

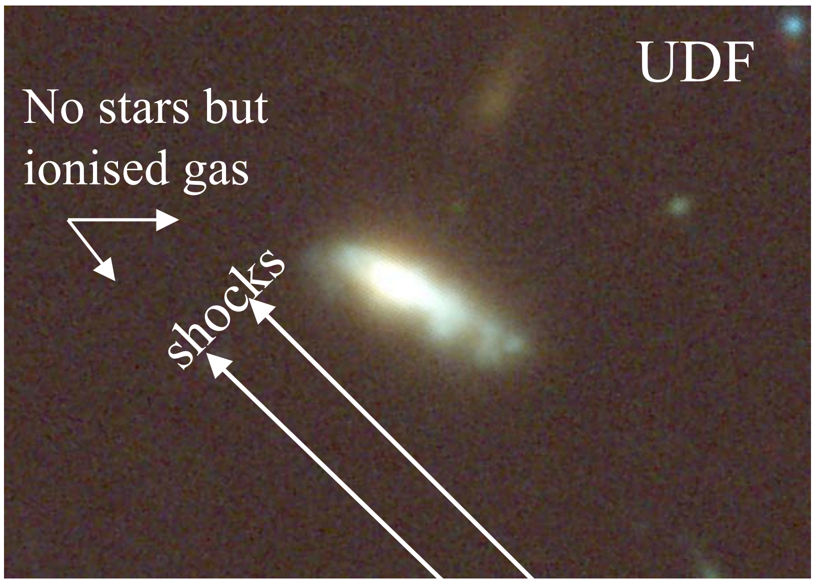
Hammer et al. 2008, A&A submitted

- The kinematical axis is misaligned by 45° from the optical axis
- No outflows from spectroscopy (z_{abs}~ z_{emi} & NaD dominated by stars)
- The velocity dispersion peaks coincide with the end of the « two arms » system
- Half of stars have ages lower than 800Myrs
- Gas fraction is 37% (from Kennicutt-Schmidt) and was 67% 800Myrs ago
- All properties favour a merging scenario rather than a perturbed disk

Spiral morphology & angular momentum are driven by the last major merger parameters (here 1:1 mass ratio, Sc)

Gas ionisation induced by shocks in a z~0.6 forming galaxy

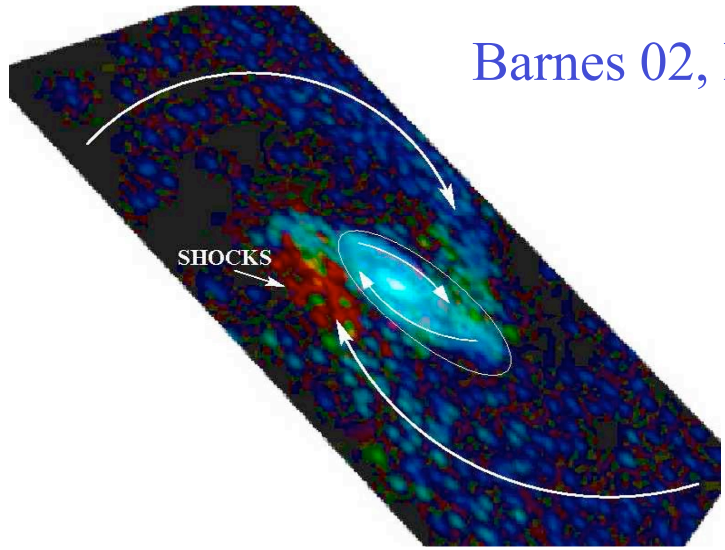
Puech et al. 2008, A&A submitted



f_gas=73-82%

(SED fitting+TF & Kennicutt-Schmidt)

Barnes 02, DIR 1:1



Property	Starbursting Rotating Disk	Major Merger Remnant
Extention of the peak of dispersion in the Southern part	Cause unknown	Heating due to shocks between the gas in tidal tails and the central regions
Decoupling between the distribution of the ionized gas & stars	Photo-ionization can account for only 10% of $EW_0([OII])$	Shocks can ionize the gas and account for 100% of $EW_0([OII])$, while preventing star formation

Preliminar conclusions from IMAGES

Based on a representative sample of intermediate mass galaxies at z~0.6

➡ Half of local spirals had anomalous kinematics at z~0.6

Detailed analyses reveal merger processes (more in progress)

Local disks rebuilt after a major merger ?

Consistent with the spiral rebuilding scenario for which 50 to 75% of local disks might have been rebuilt following a major merger since z=1

(Hammer et al. 05; see also Hopkins et al. 08)

How disks form ?

Angular momentum

tidal torque theory « *acquisition from early galaxy interactions* »
(Eggen et al, 1962; Peebles, 1976; White, 1984)

⇨ **Apply well to the Milky Way: no significant interactions since z~ 3**

However:

- **kinematics & morphology of distant galaxies**
- **angular momentum catastrophe**
- **Milky Way representativeness?**

Learning from local spirals (including MW & M31)

Intermediate mass galaxies at z=0.6 are their progenitors, and many show anomalous kinematics due to merging

- MW past history **without** major interaction since z=3
- M31 **with** much more interactions

(Ibata et al, 2001; 2004; Beasley et al, 2004; Brown et al, 2006, 2008)

Is MW a typical spiral or alternatively M31 ?

THE MILKY WAY, AN EXCEPTIONALLY QUIET GALAXY: IMPLICATIONS FOR THE FORMATION OF SPIRAL GALAXIES

F. HAMMER, M. PUECH, L. CHEMIN, H. FLORES, AND M. D. LEHNERT

THE ASTROPHYSICAL JOURNAL, 662:322–334, 2007 June 10

The Milky Way versus M31 and other spirals

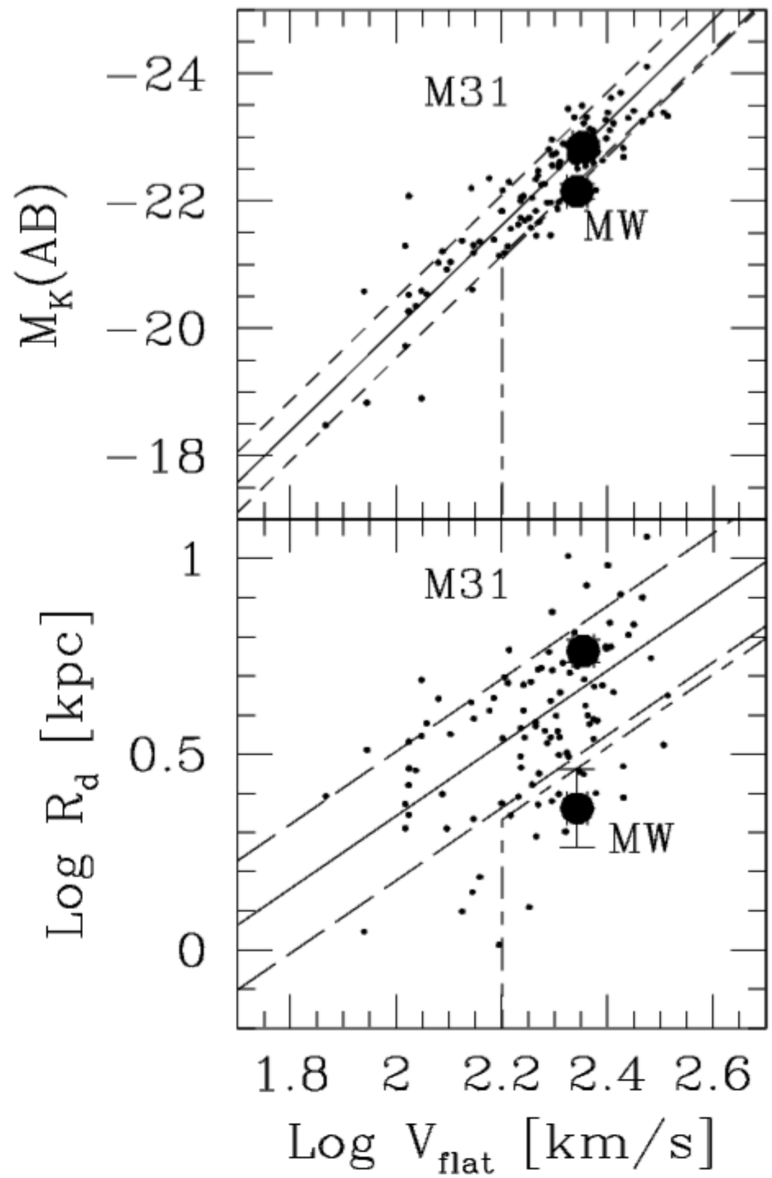
More accurate measurements of M_K, R_{disk} (COBE, Spitzer) and V_{flat} for the MW and M31

Compared to other spirals (SDSS):

- the MW has a too small stellar mass, radius & angular momentum;
- M31 is rather typical.

In the (MK, Rdisk, Vflat) volume, there are only 7+/-1% of MW-like galaxies.

Star abundances in galactic outskirts (Fe/H, inner halo 5-30 kpc):
Most spirals (incl. M31) have stars in outskirts far more enriched than MW's
(see also Mouhcine et al, 2006)



Conclusions

- the MW has an exceptionally quiet history since z=3: most other spirals (e.g. M31) may have had a much richer merger history;
- 6 Gyr ago half of the spiral progenitors were out of equilibrium, mostly showing merger remnant properties;

⇨ **Disk survival is a key issue !** **(Hammer 07; Stewart 08; Purcell 08)**

Disk rebuilding scenario consistent with:

- distant galaxy properties (stellar mass assembly mainly through episodic IR phases driven by mergers);
- evolution of the gas content;
- the relics in haloes of local spirals.

⇨ In excellent agreement with hierarchical prediction: both E & Sp are hierarchically formed

⇨ Potentially could solve the angular momentum catastrophe and explain the elaboration of the Hubble sequence