"Galaxy Evolution & Environment" meeting, Kuala Lumpur, Mar/Apr 2009

Kinematic Deconstruction of E+A Galaxies

+ morphology & spatially resolved colours & stellar pops

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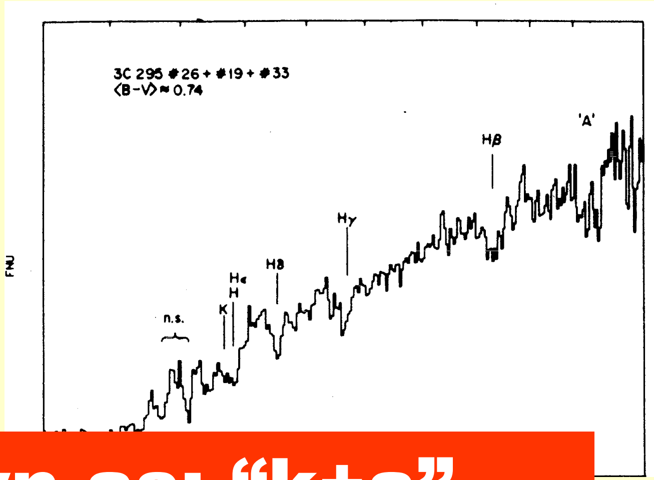
What is an E+A galaxy?

In a spectroscopic survey of galaxies in the z=0.46 3C295 cluster, Dressler & Gunn (1983) discovered a number of members with conspicuous Balmer absorption lines and no emission lines



Have also become known as: “k+a”, “a+k”, “red-HDS”, “PSG” galaxies

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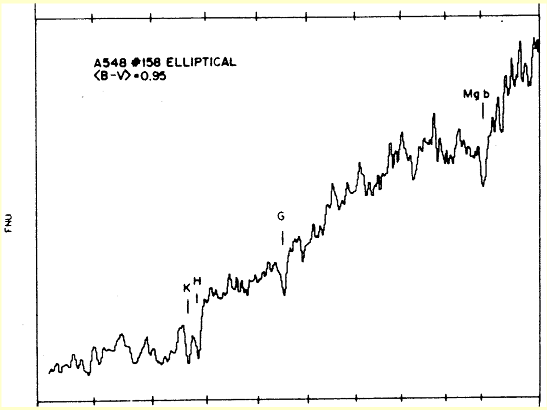
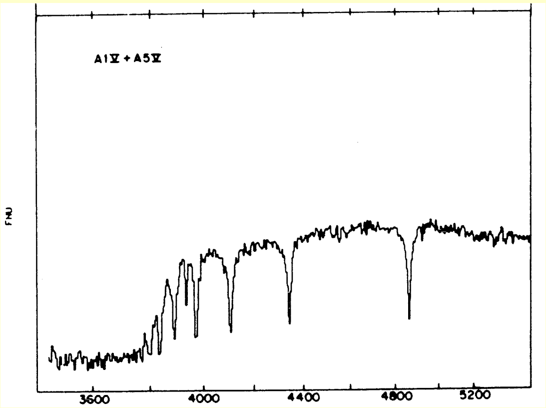


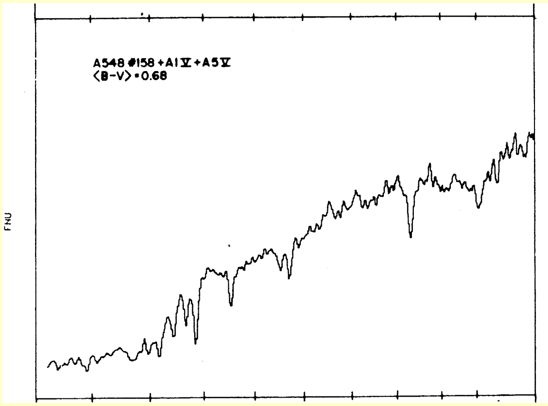
E galaxy

+



A star

=

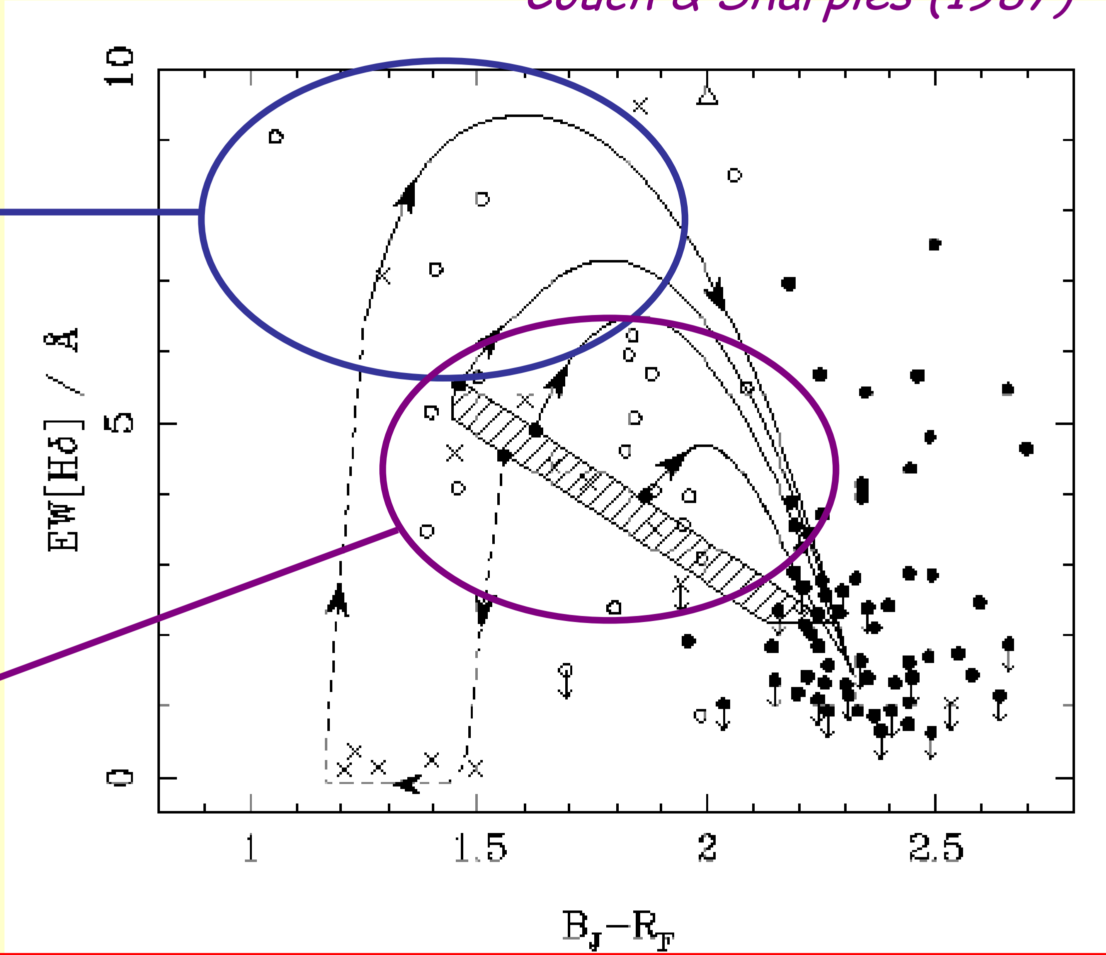


“E+A”

Interpretation of E+A spectral signature: galaxies in the process of **rapid evolution**

Couch & Sharples (1987)

Strong Balmer absorption and blue colors ⇒ galaxy underwent STARBURST which was halted less than 1 Gyr ago

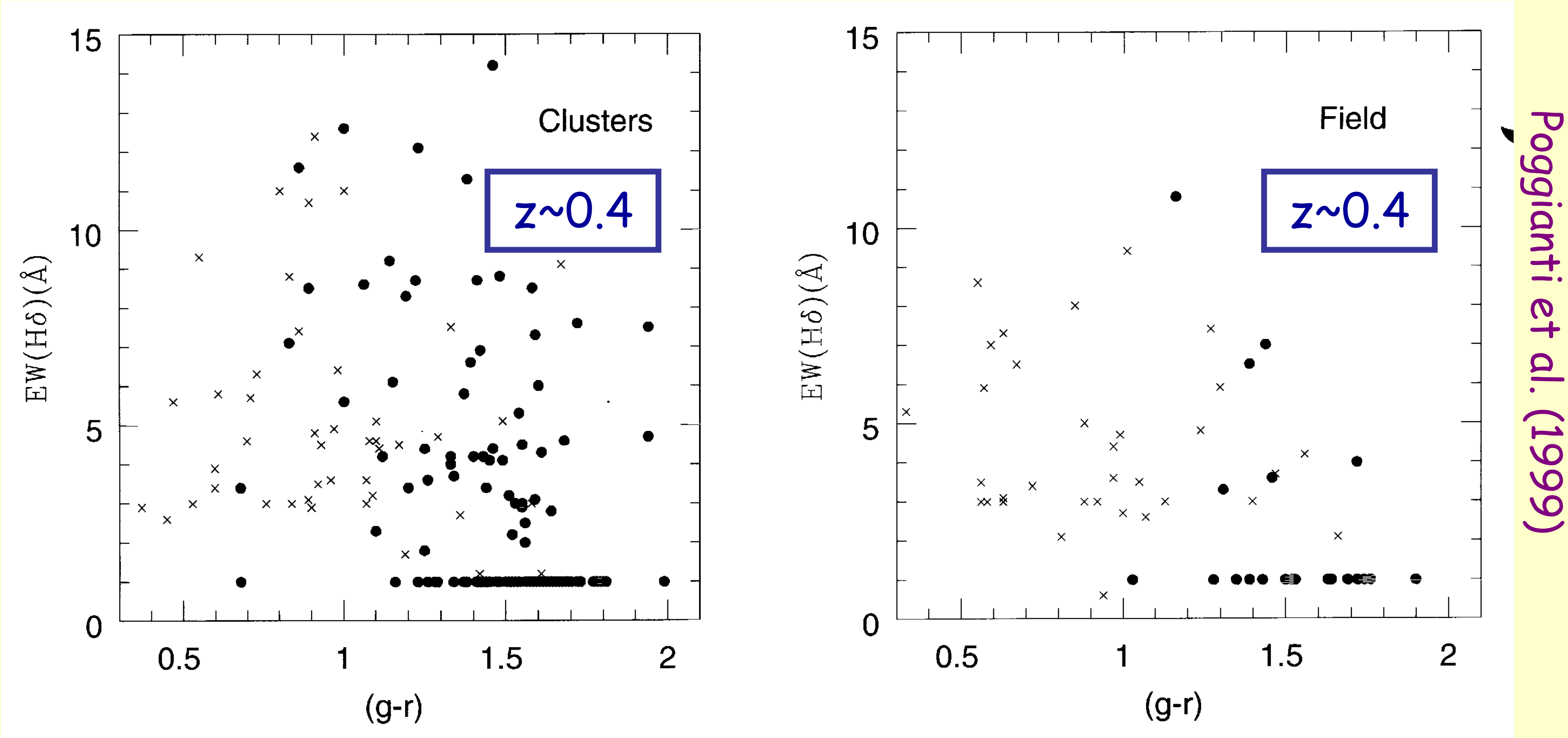


Objects with weaker Balmer absorption and redder colors could also arise from TRUNCATION of SF in normal star-forming (Sp) galaxies

Excellent examples of 'nurture' in action?

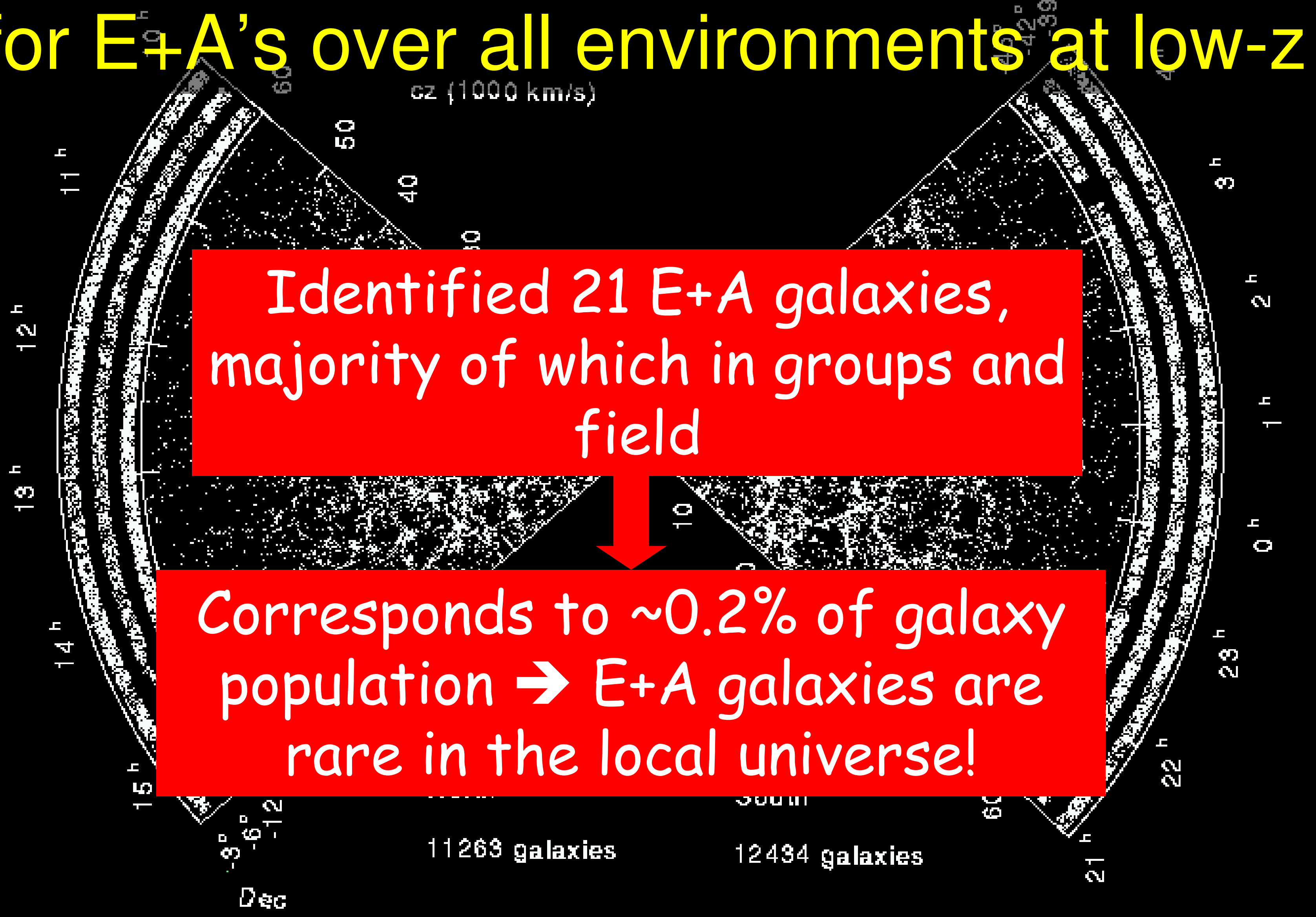
Environments of E+A galaxies:

Luminous (L>L) E+As found in significant numbers in cores of distant rich clusters:*



….but their environments at low redshift are very different!

Zabludoff et al. (1996): first major search for E+A's over all environments at low-z

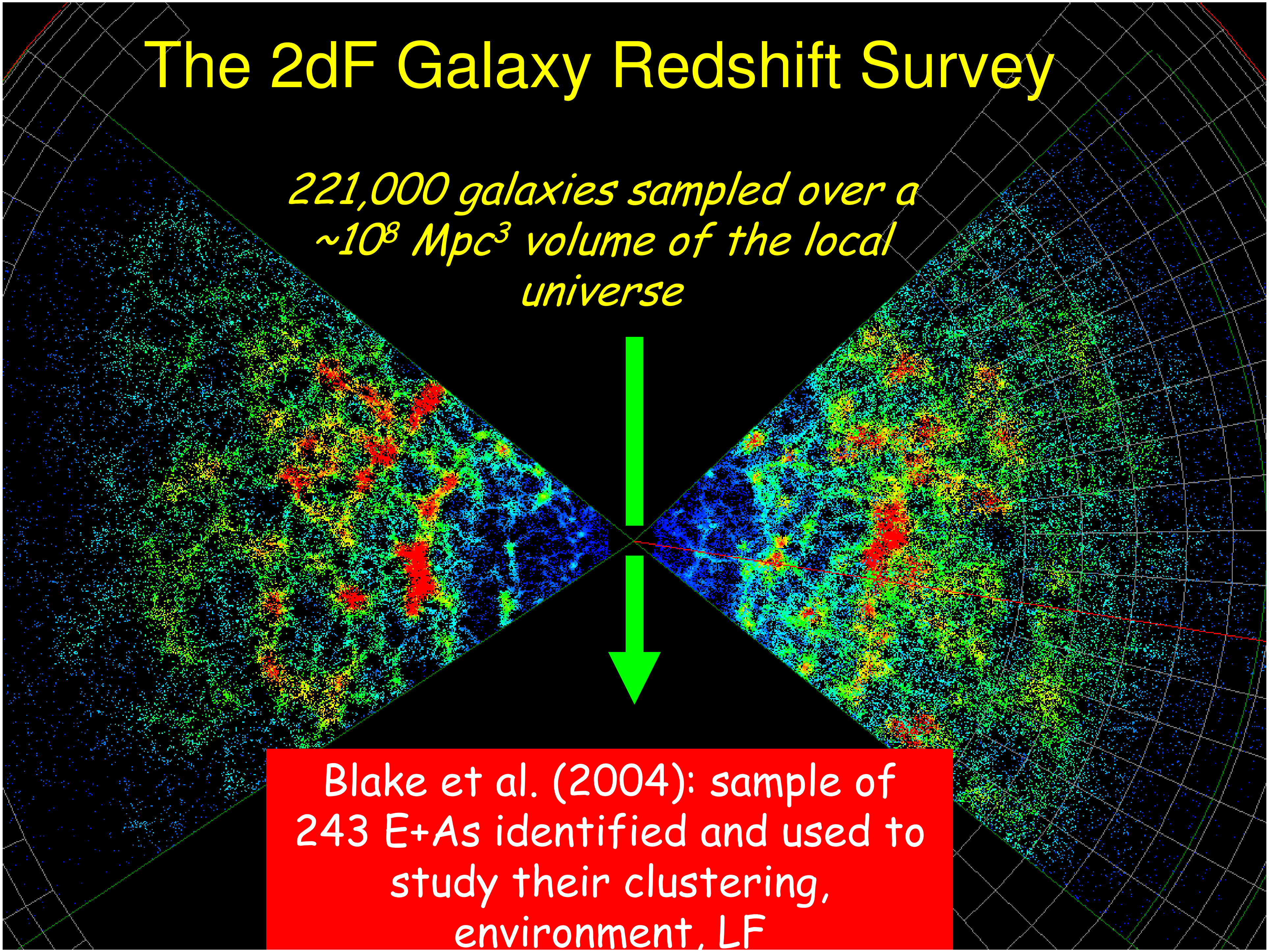


Identified 21 E+A galaxies, majority of which in groups and field

Corresponds to ~0.2% of galaxy population ➔ E+A galaxies are rare in the local universe!

Las Campanas Redshift Survey

The 2dF Galaxy Redshift Survey



221,000 galaxies sampled over a ~10^8 Mpc^3 volume of the local universe

Blake et al. (2004): sample of 243 E+As identified and used to study their clustering, environment, LF

Key outcomes from these 'local universe' E+A studies (LCRS, 2dFGRS, SDSS)

- E+A's essentially indistinguishable from the general galaxy population at these redshifts in terms of their clustering properties and their local and global clustering environments
→found mainly in **galaxy groups** and in the **field.**

Q: so what mechanism responsible for their formation?

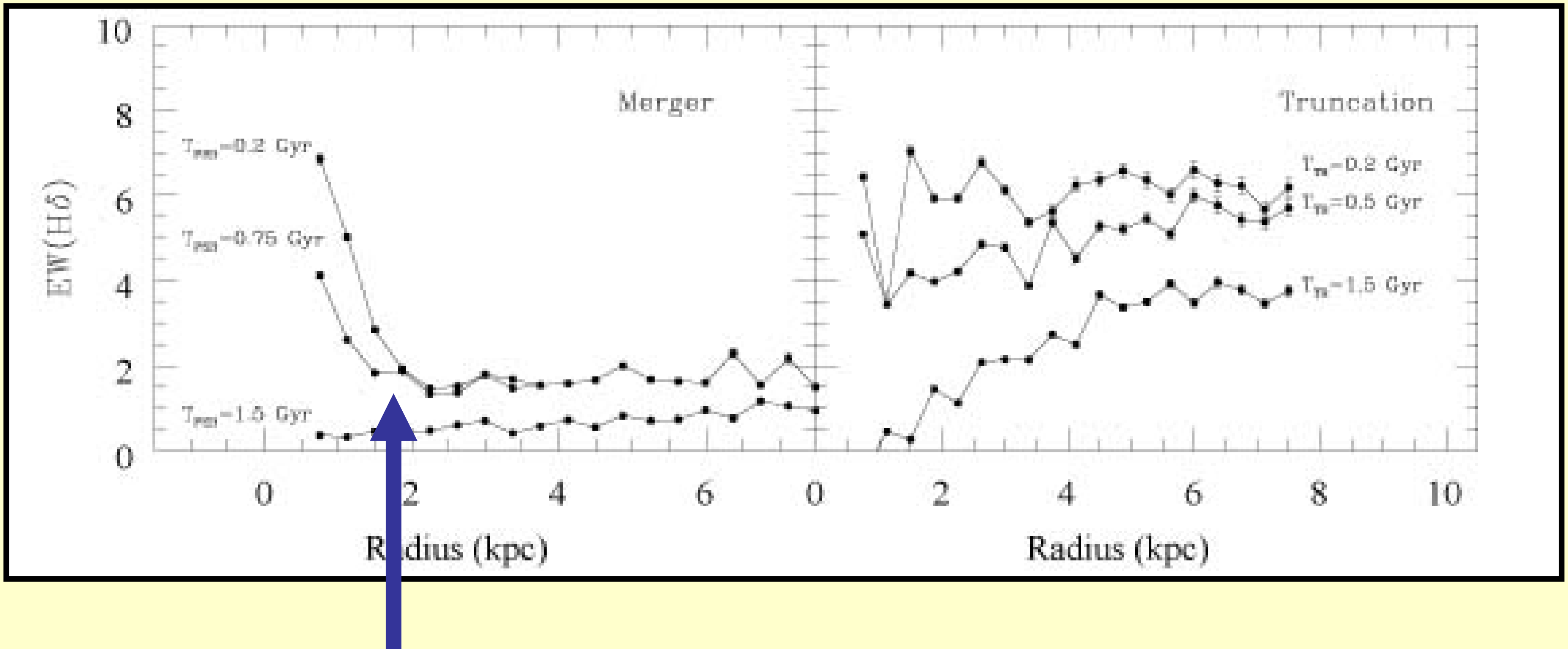
- Evidence for **mergers/interactions** being the trigger, based on 25-30% of E+A's showing **morphological** signatures associated with this process (tidal tails/bridges etc).

It is the question of E+A formation mechanisms which is the current main issue!

Prime suspects and key discriminating observables (e.g. Bekki et al 2005):

	Major merger	**Truncated spiral**
Young stars (+ *blue light, Balmer abs)*	centrally concentrated	spread across disk
Kinematics	pressure supported	rotation dominated
Morphology	spheroid dominated	faded but intact disk (⇨ Early-Sp)

Bekki et al’s (2005) predictions for radial variation in Hδ absorption strength:



Requires spatially resolved spectroscopy on scales of < 2kpc.

First attempts to obtain spatially resolved spectroscopy of low-z E+A galaxies:

Norton et al. (2001) – long-slit spectroscopy (with 2.5m Du Pont) of the Z96 E+A sample to measure the distribution and kinematics of the young and old stellar populations; majority of sample had:

young stars:	centrally concentrated
kinematics:	pressure supported and no significant rotation; consistent with Faber-Jackson relation, once brightening taken into account

Conclusion: consistent with major **merger** scenario.

BUT based on only 1D spectral information with limited spatial resolution!

Advancing these studies with Gemini/GMOS

Exploit excellent image quality and light-gathering power of the 8m Gemini telescopes to significantly progress this line of investigation via:

- **High resolution imaging** $\rightarrow$ spatially resolved color maps on ~1-2 kpc scales (@z=0.1).
- **IFU spectroscopy** $\rightarrow$ 2D spatially resolved spectral information at similar scales over a large fraction of the galaxy (IMPORTANT since kinematic center and major axis not always = photometric center).
- **Significant sample** of E+A galaxies over a range of environments (cluster, group, field).

Key elements of experimental design:

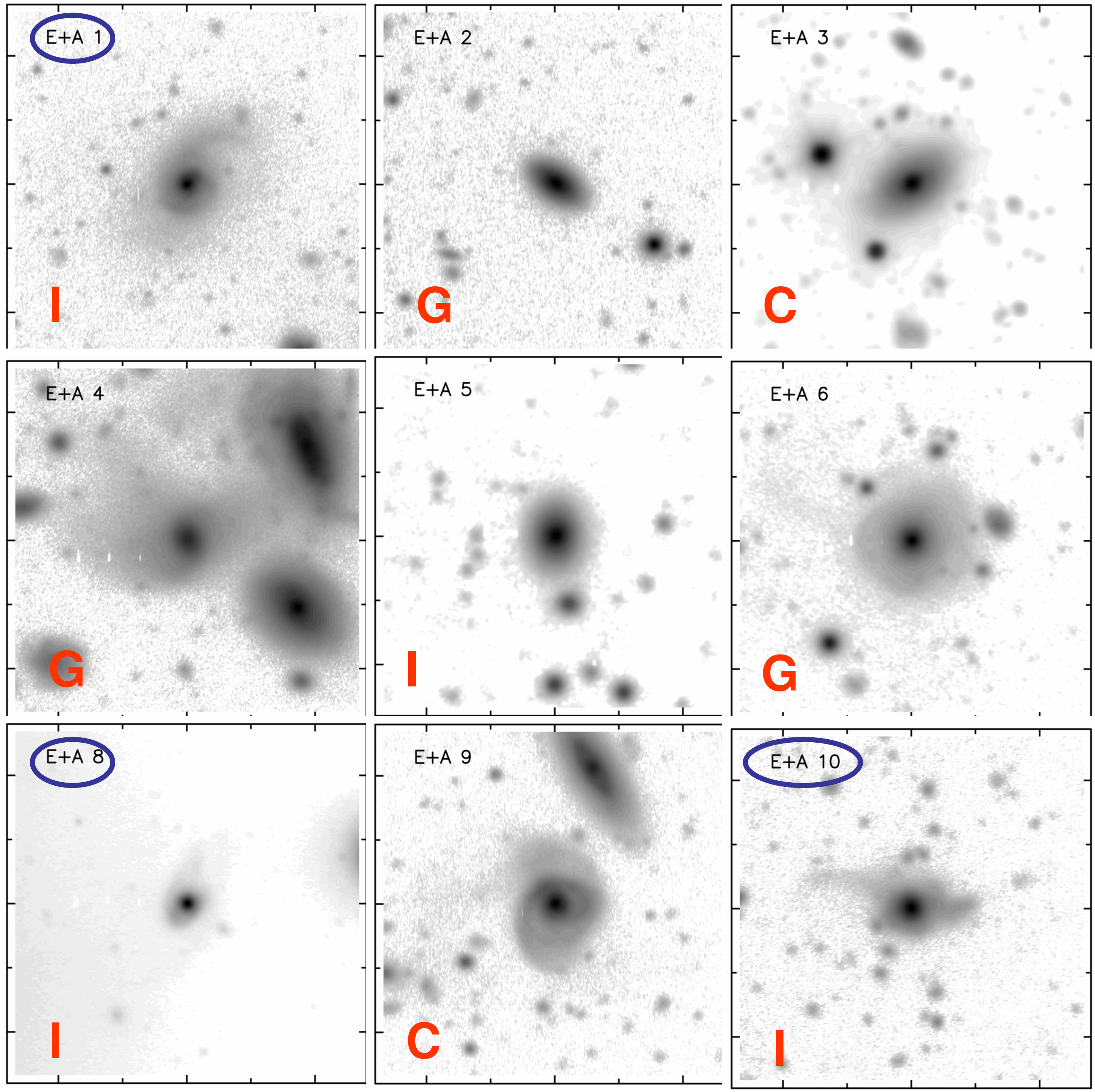
- **Sample of 10 E+A galaxies**: from Blake et al. 2dFGRS ‘gold plated’ sample [4 isolated, 4 group, 2 cluster; <z> = 0.10]
- **GMOS imaging in g & r bands @ 70% IQ (≤0.8” seeing):**
  - g′-r′ color maps (gradients/distbn of blue vs red light)
  - superior morphological information to much fainter SB limits (B~26 mag arcsec^2): further evidence for merg/int via detection of faint tidal debris?
- **GMOS IFU spec in ‘two-slit’ mode [5”x 7”/10kpc x 14 kpc] with B600 grating over range λ_{rest} = 3700 - 5100Å @ 70% IQ:**
  - trace strength of Balmer (Hδ, Hγ) and Feλ4383, $C_2$4668 lines and hence **age**, **residual star formation**, **metalicity** as well as **kinematics** across face of galaxy.

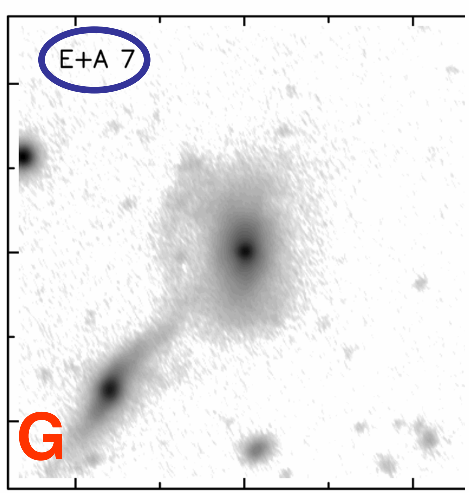
Imaging

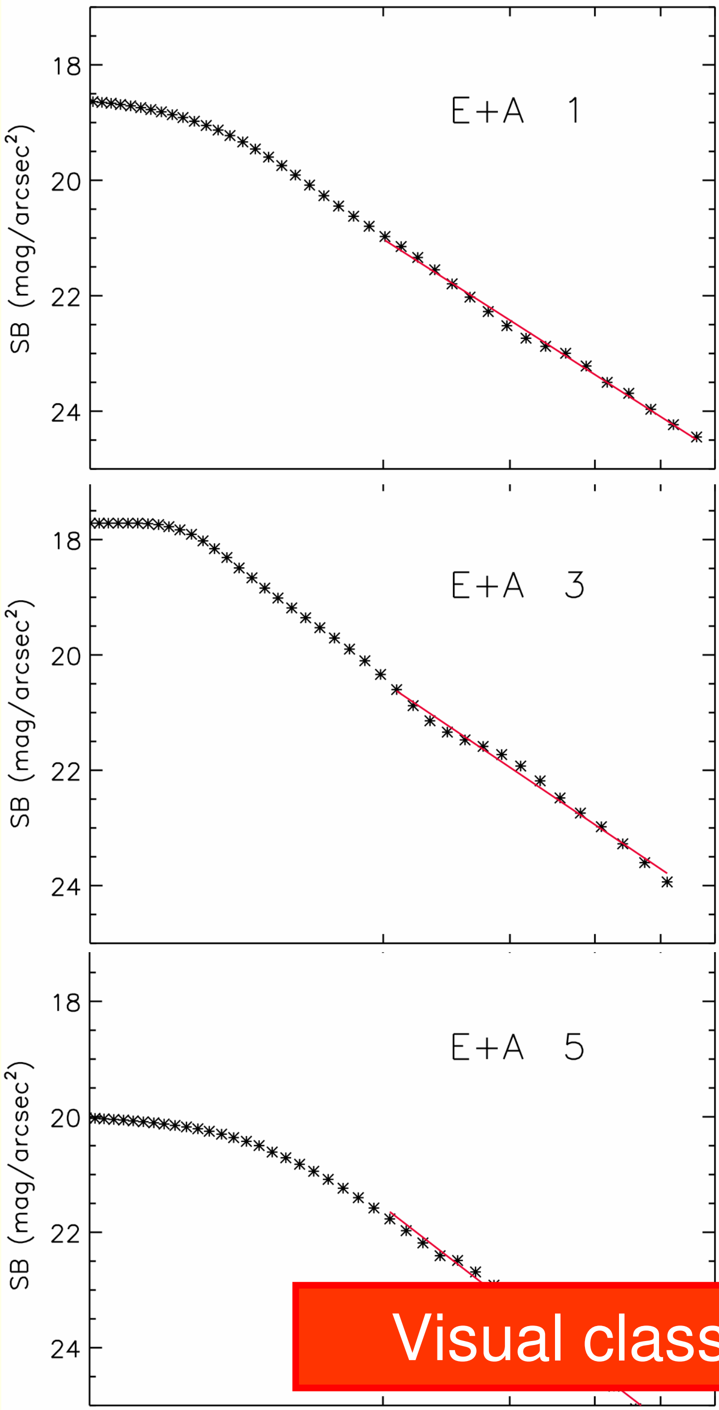
- *Surface brightness profiles*
- *Morphologies*
- *Colour maps*

g-band images of our E+A sample

0.8-1.0" seeing



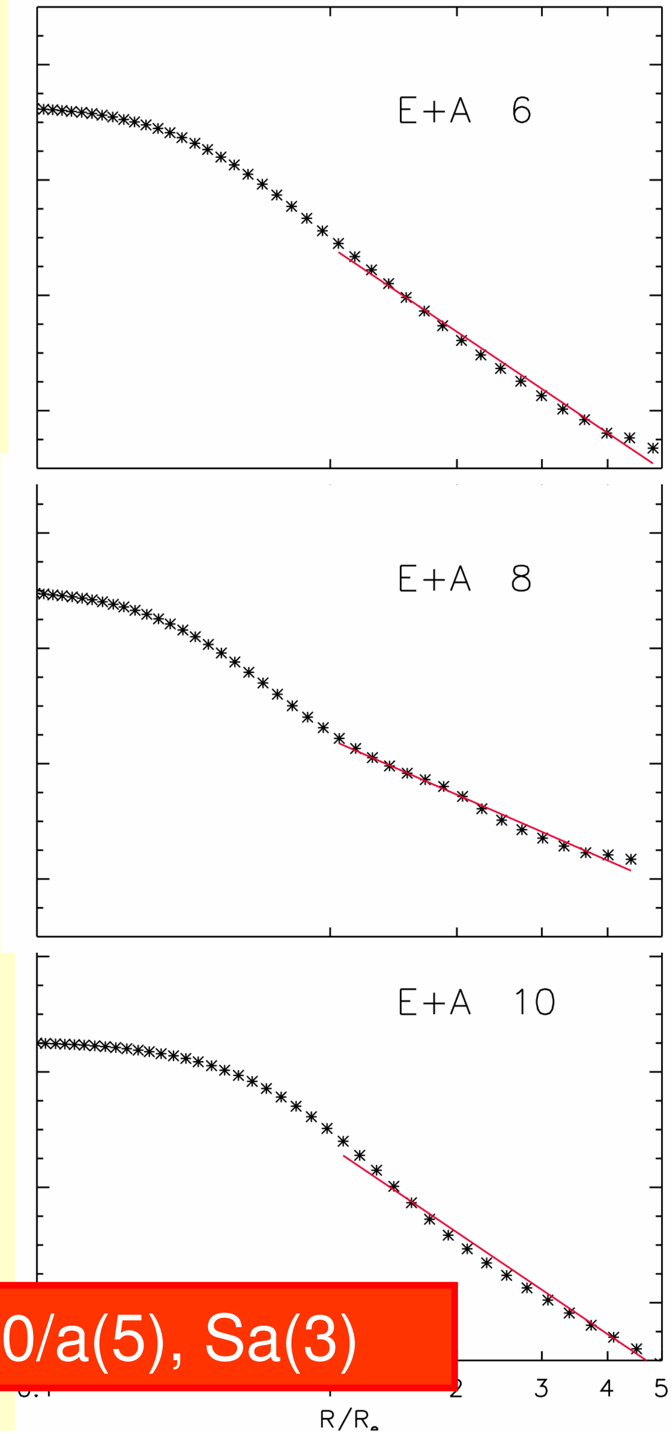




Radial surface brightness profiles

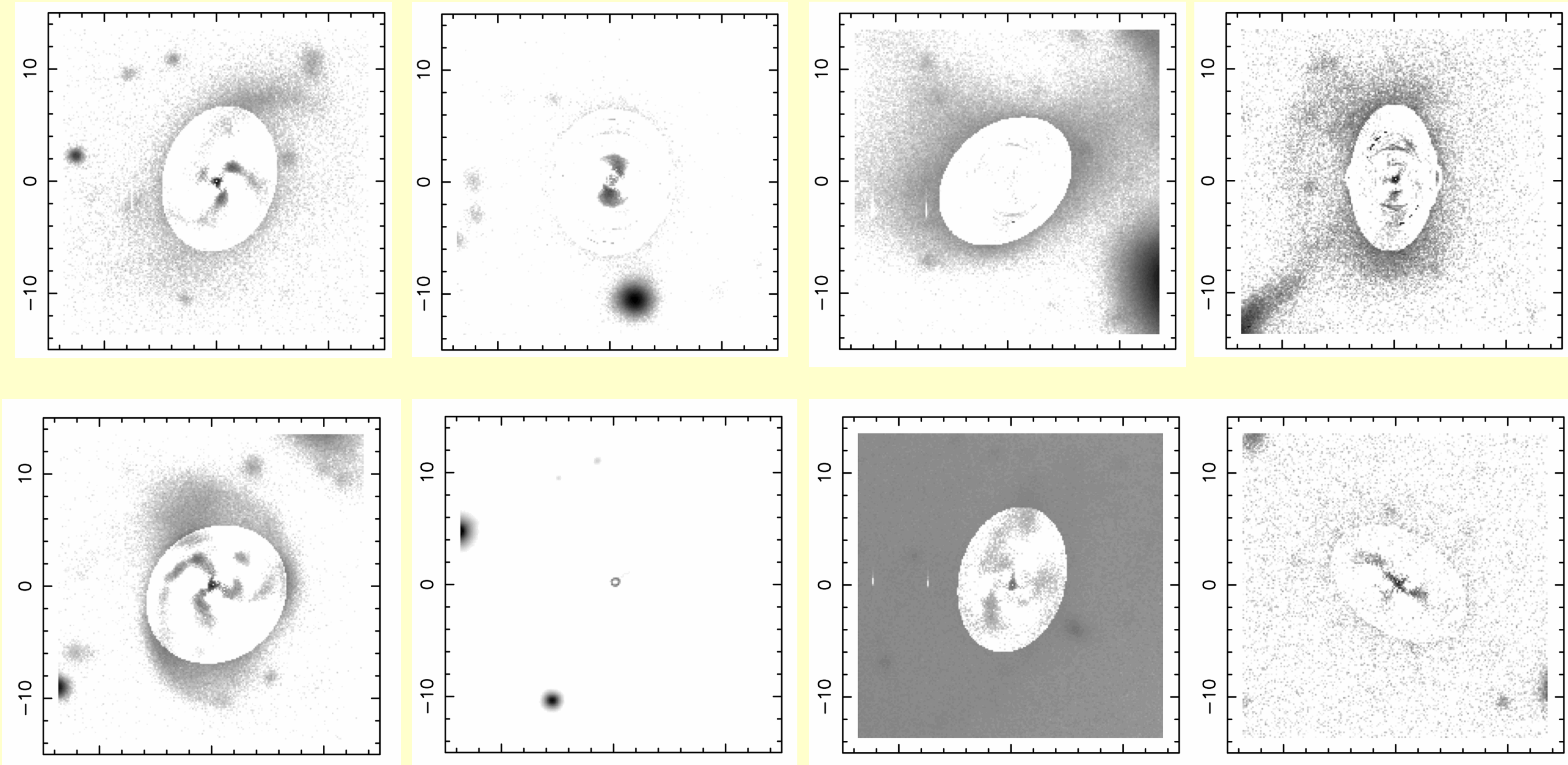
By and large show a $r^{1/4}$ behaviour at large radii

⇨early-type morphology



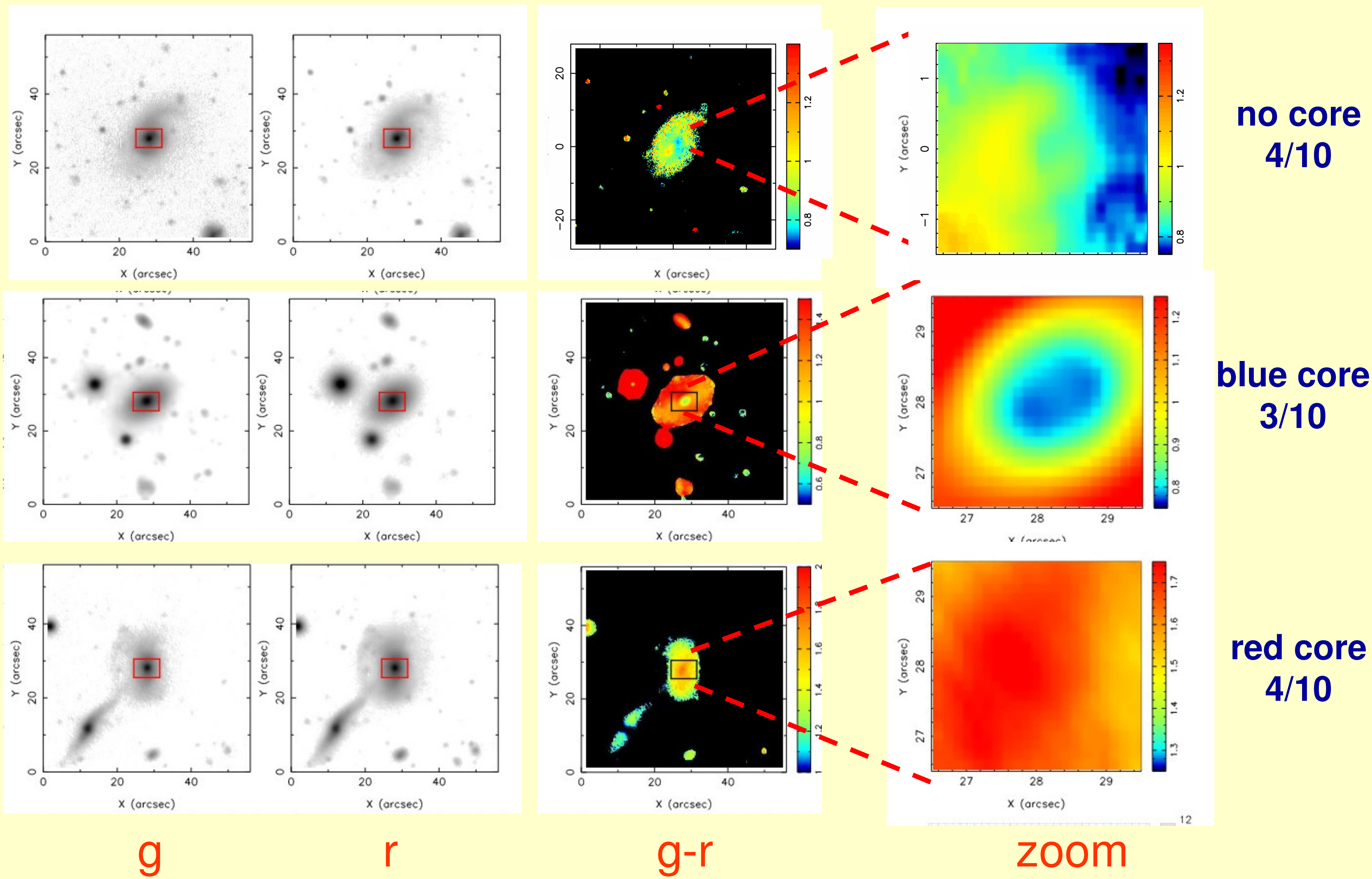
Visual classifications: S0(2), S0/a(5), Sa(3)

Subtraction of elliptical model profile:



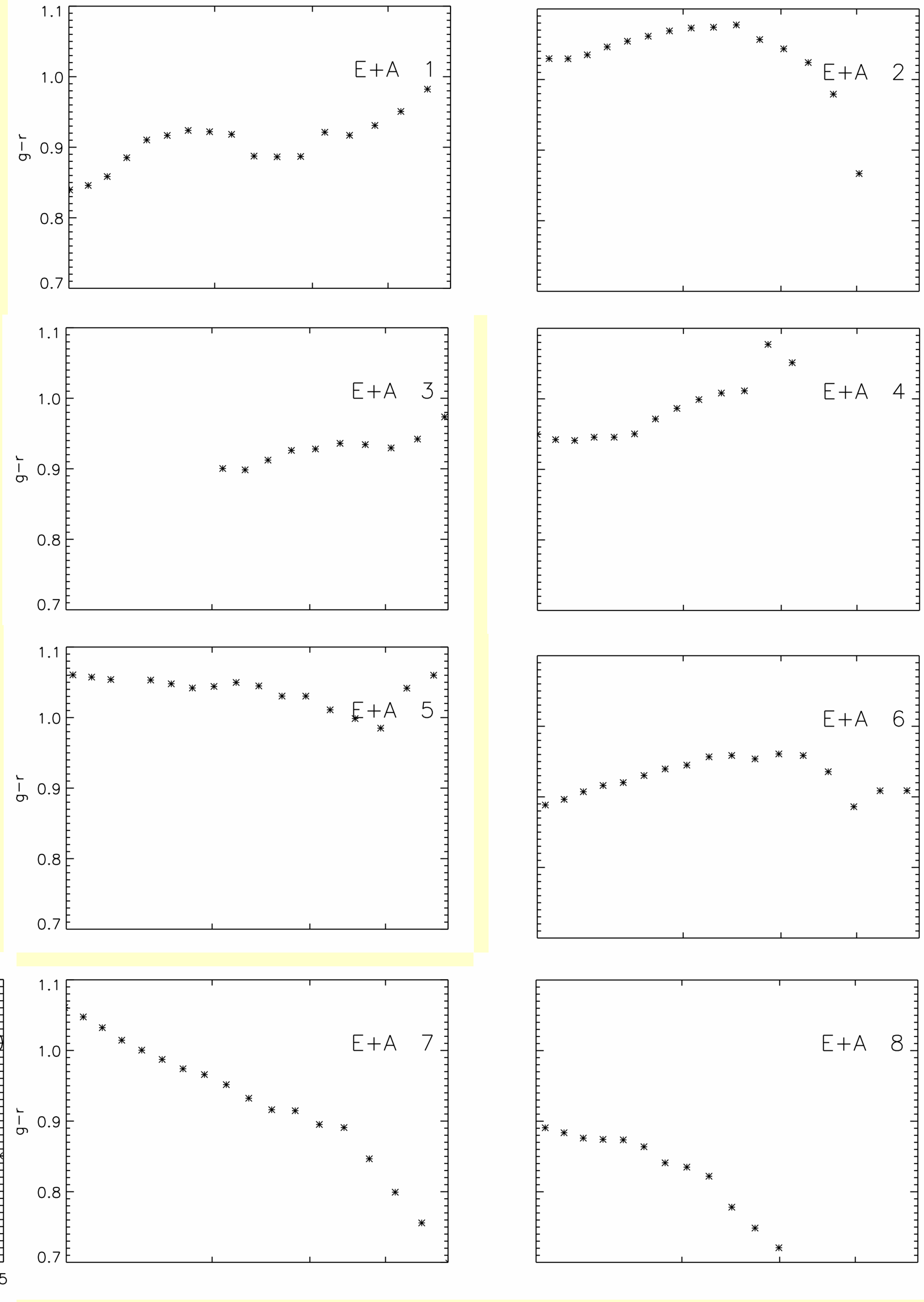
Reveals faint residual (spiral arm + dust?) structure plus tidal features in 50% of cases.

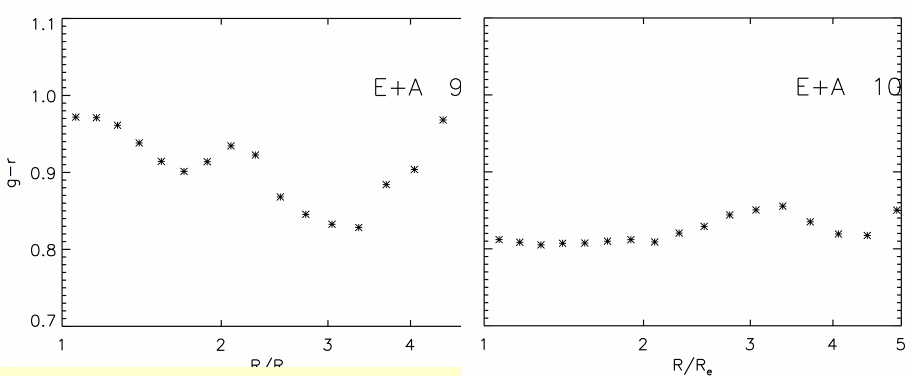
Surface colour maps: diverse core colours



Colour gradients:
(along semi-major axis)

Also a diversity of behaviour……. positive, negative and flat gradients!



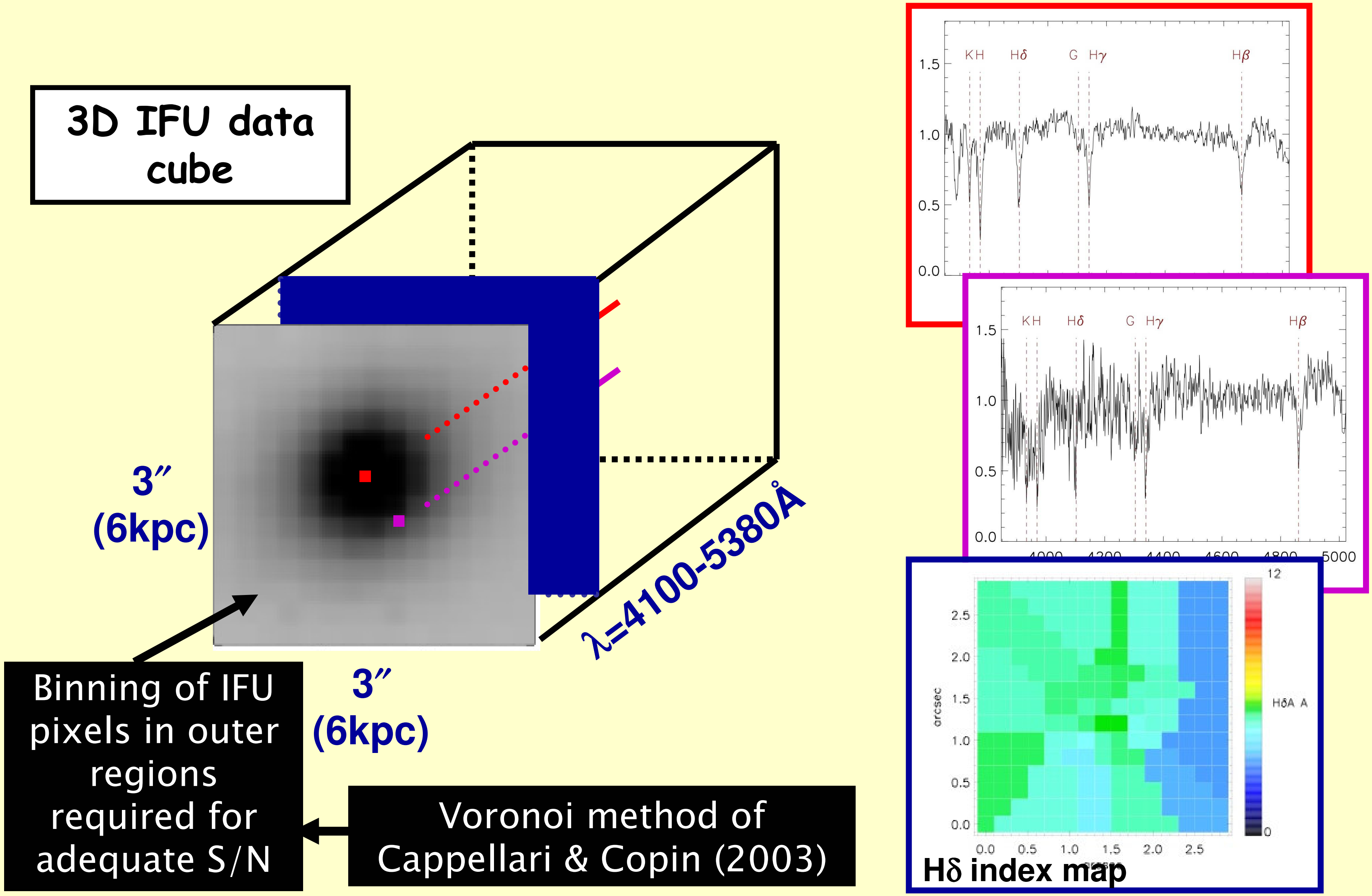


IFU Spectroscopy

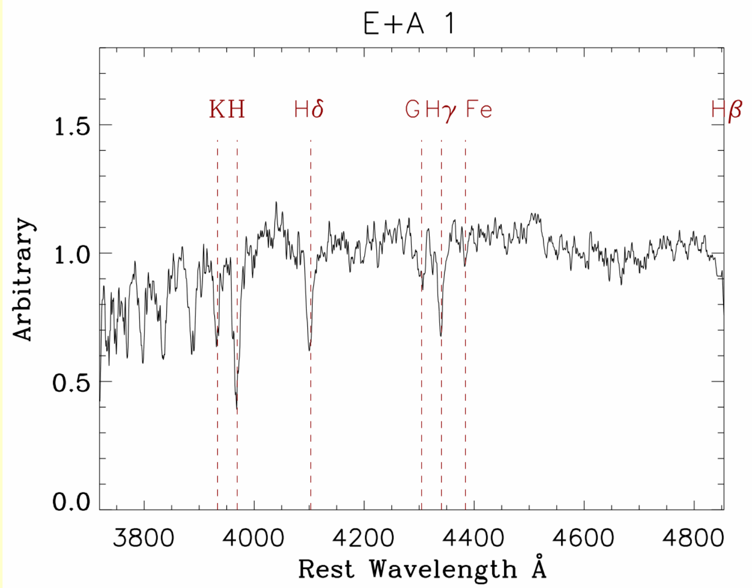
Spatially resolved:

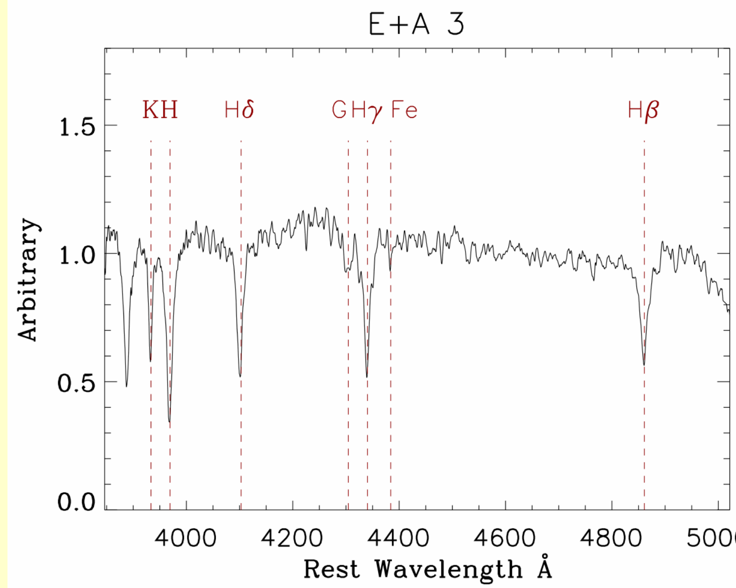
- *Kinematics*
- *Stellar pops (age, metalicity)*

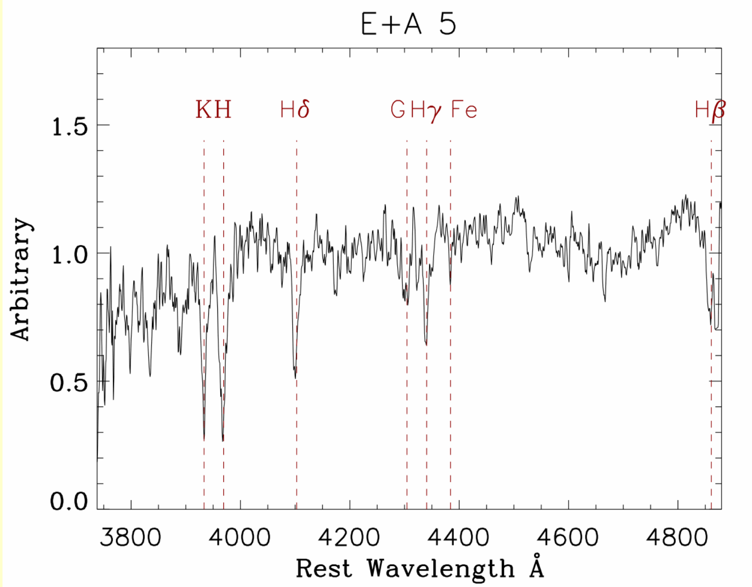
IFU Spectroscopy of our E+A sample:

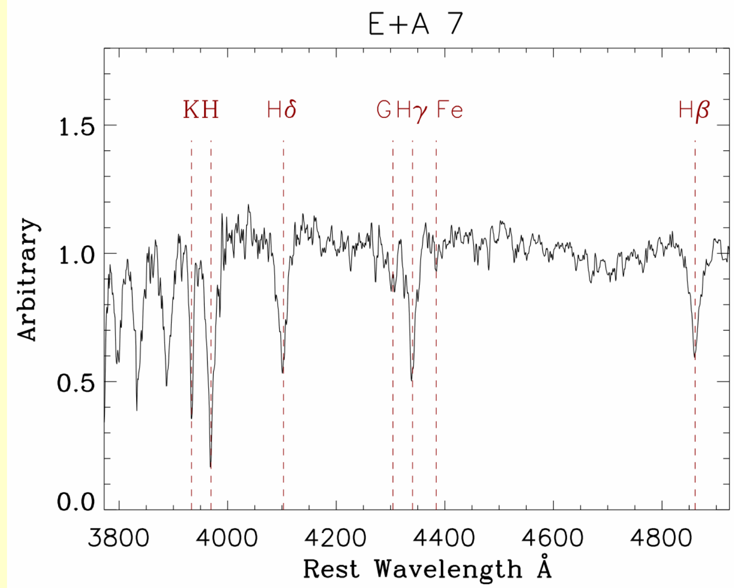


Integrated Spectra





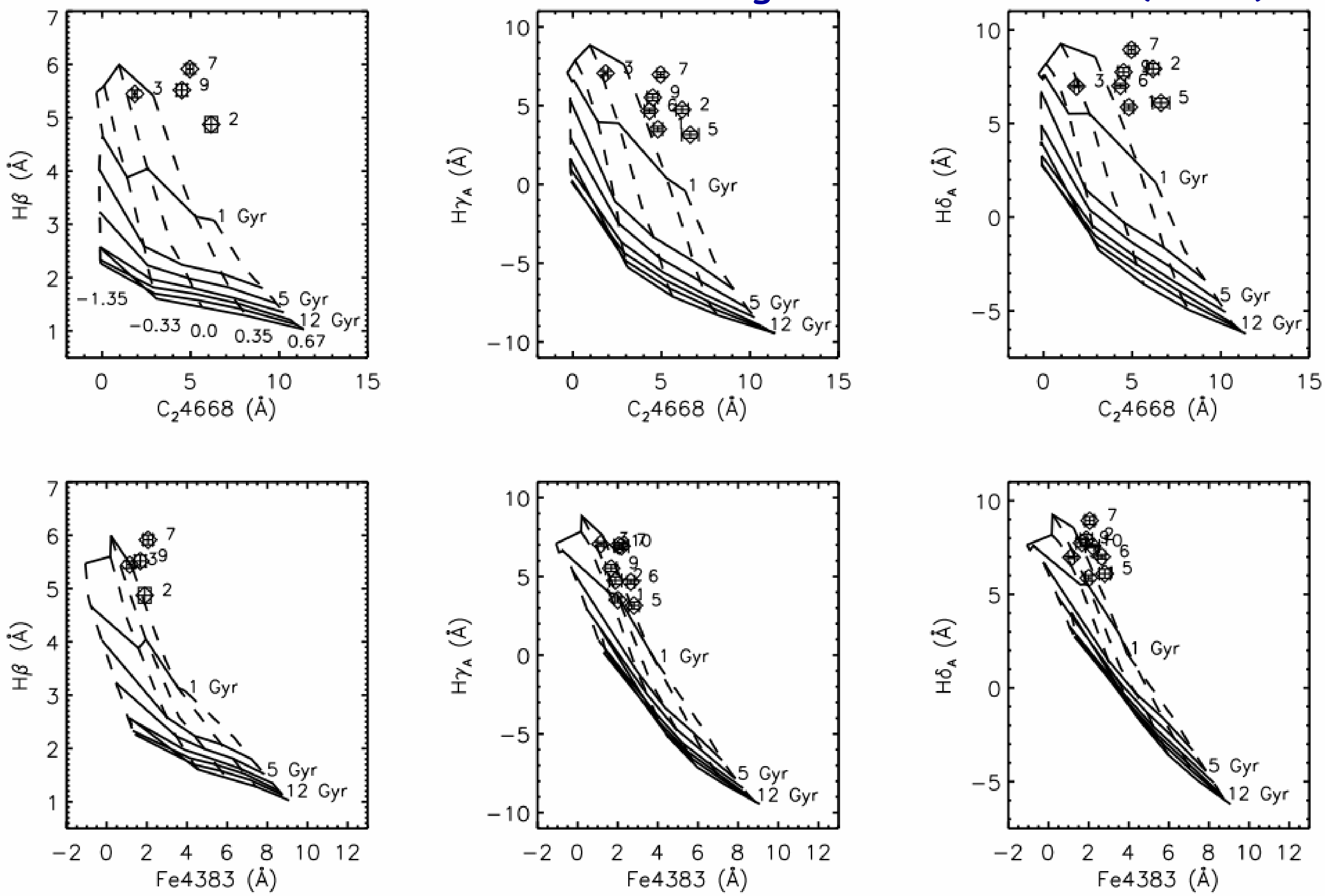




Lick indice-based measurements of age and metallicity:

All E+A galaxies have ages < 1 Gyr (mean = 0.5 Gyr)

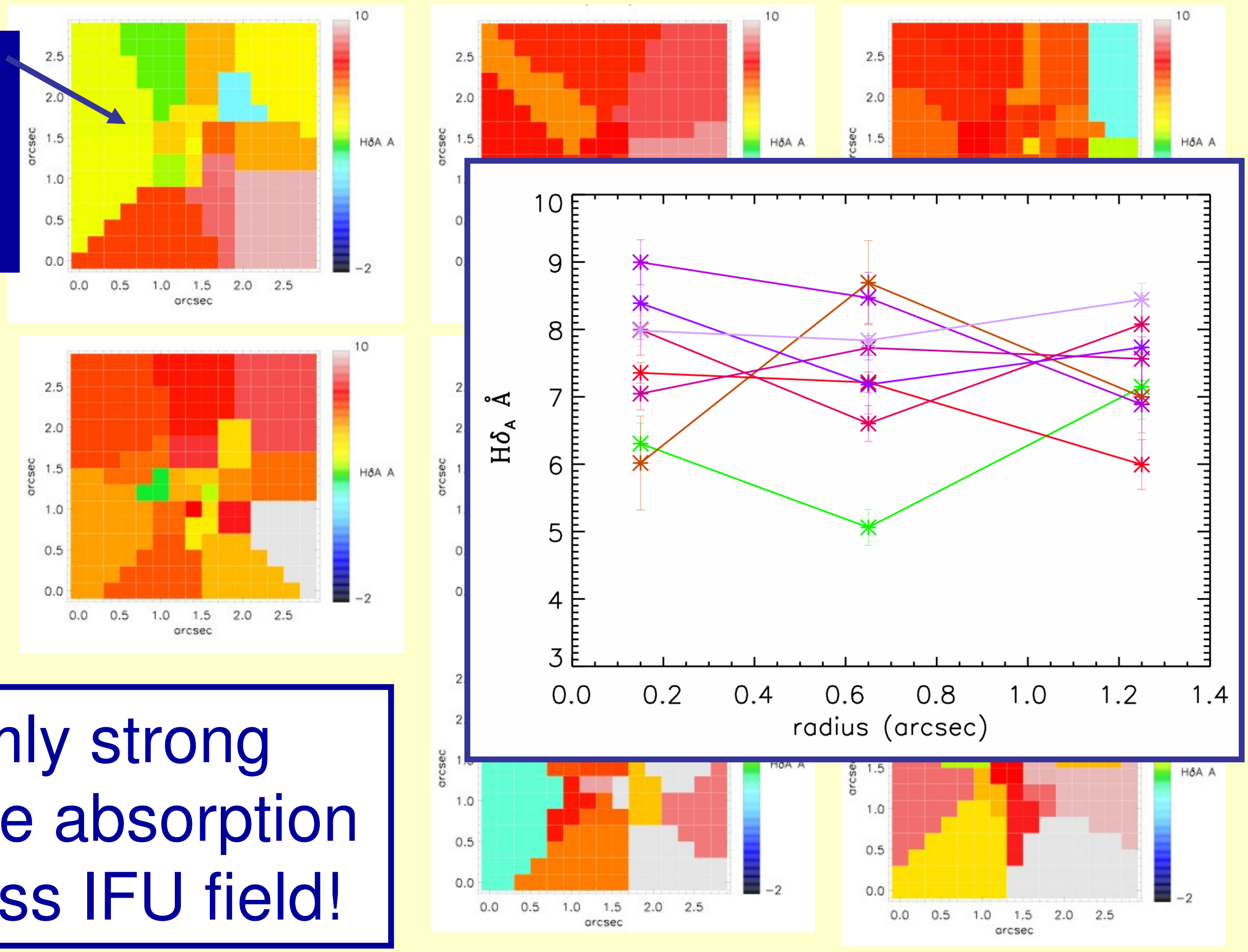
Model grids from Thomas (2003)



Geography of the ‘A-star’ emission

(via Hδ absorption maps)

Adaptively bin spatial pixels → constant S/N (=10)



Uniformly strong Balmer line absorption right across IFU field!

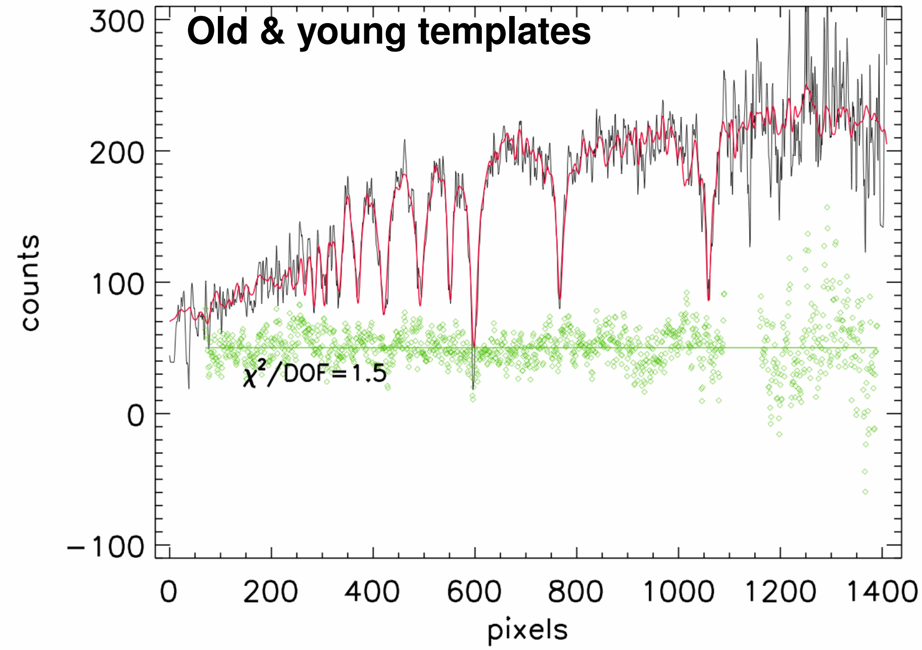
Template fitting

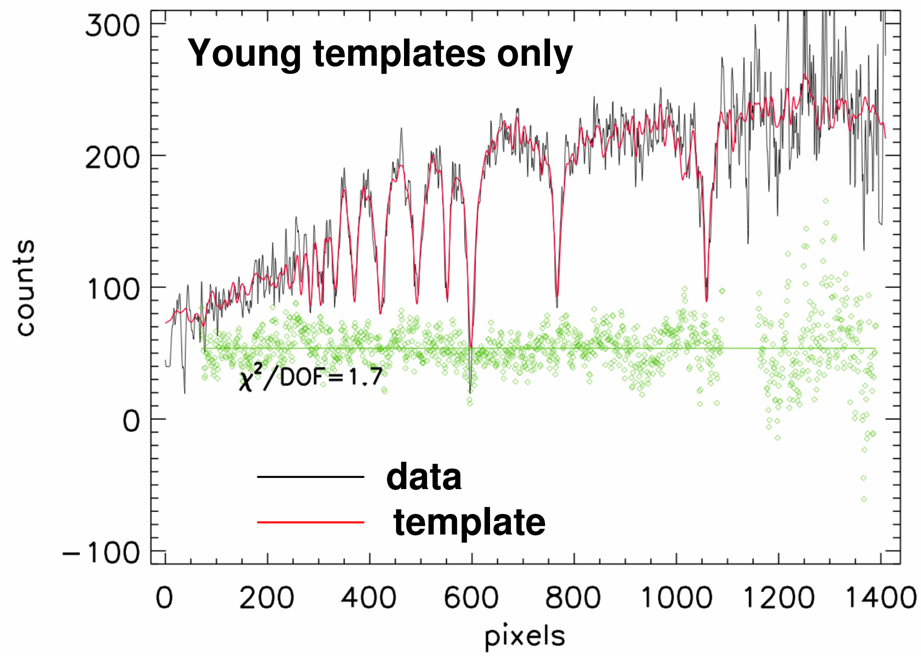
(via "penalised pixel fitting" algorithm of Cappellari & Emsellem 2004)

➔ Simultaneous measurement of:

- Stellar pops
- Streaming velocity
- Velocity dispersion

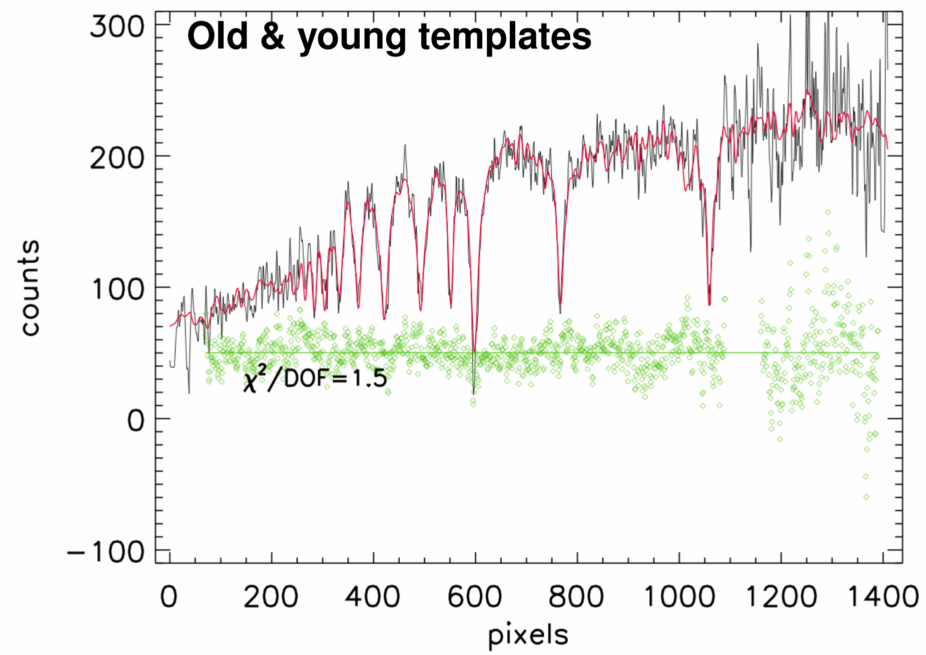
Templates = single-age, single-metallicity stellar pop synthesis models of Vazdekis et al. (2007)

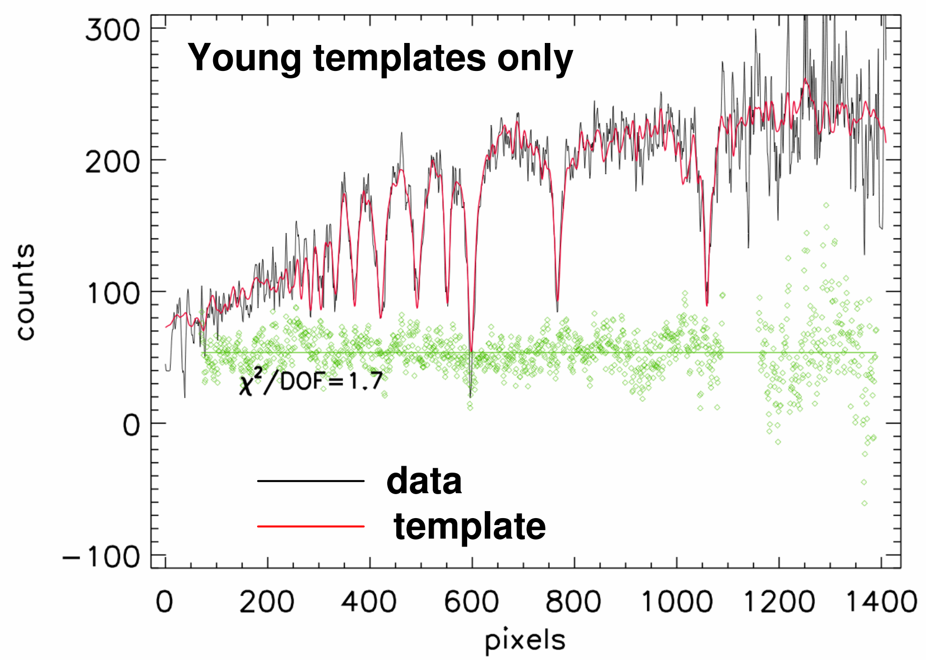




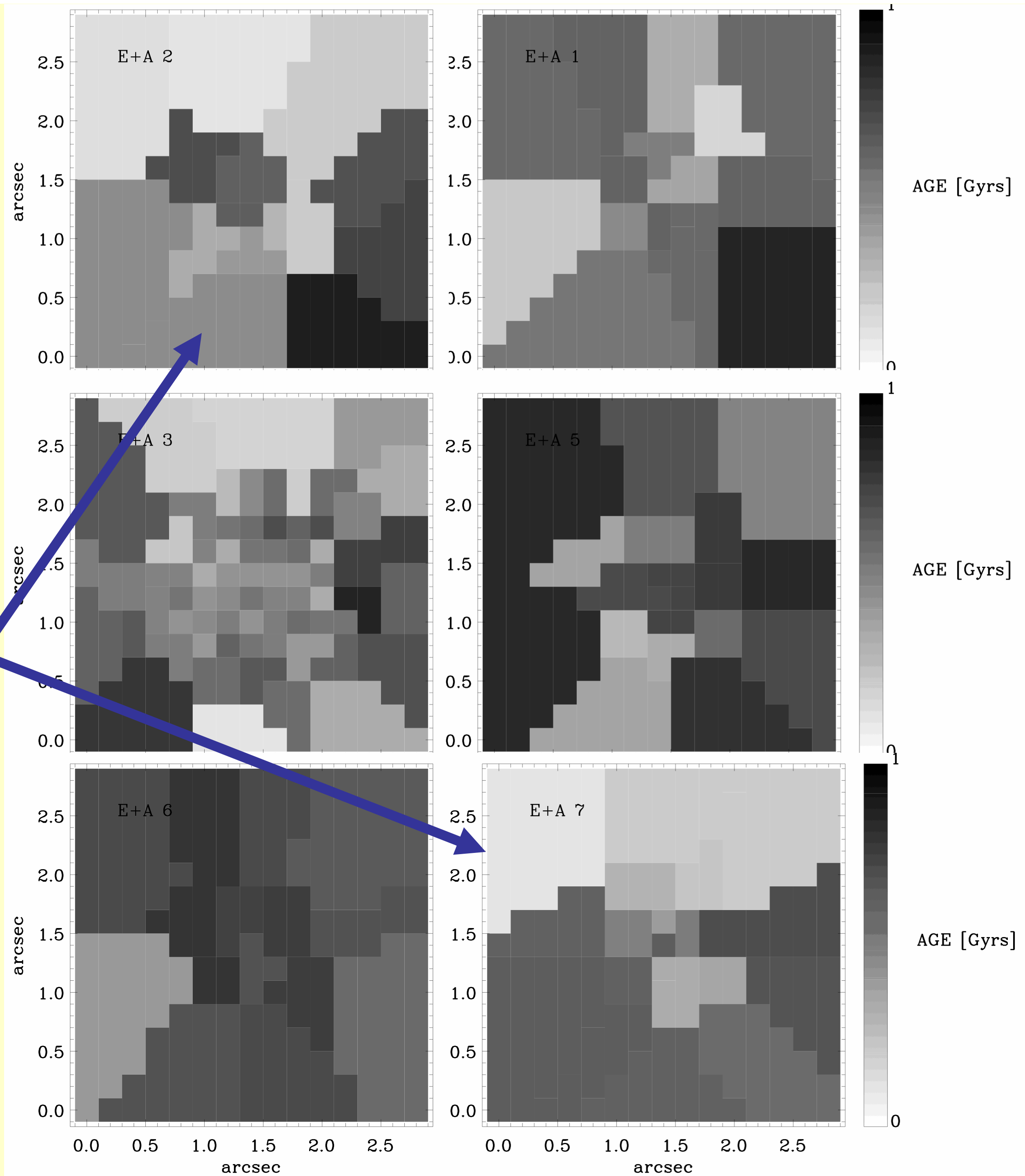
Template fitting:

Fits dominated by young (<1Gyr) stellar population templates; at S/N of data, unable to detect any old population contribution!





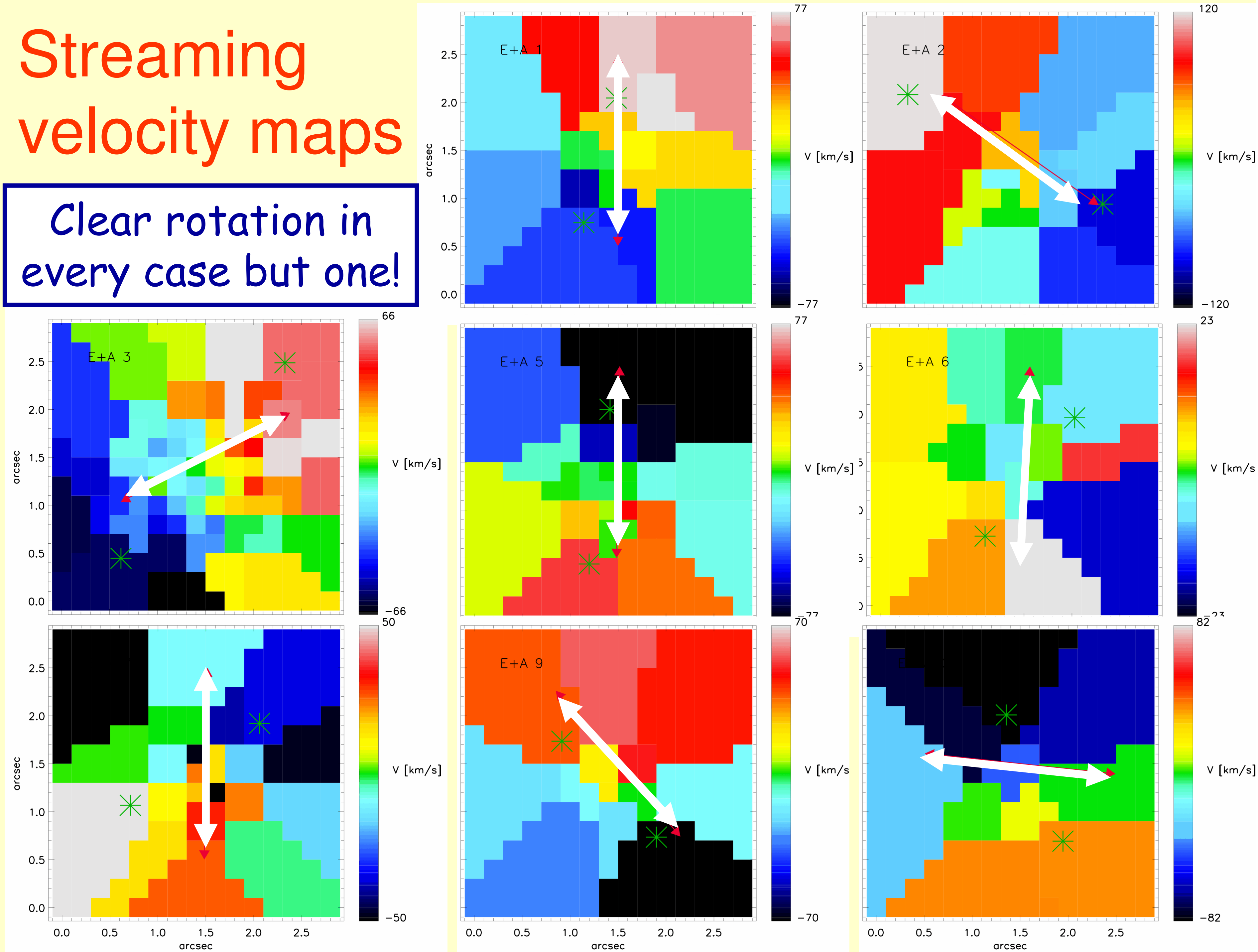
Age maps – based on weighted age of the best fitting SSP template at each spaxel



Possible age gradients across face of galaxy in 2 cases

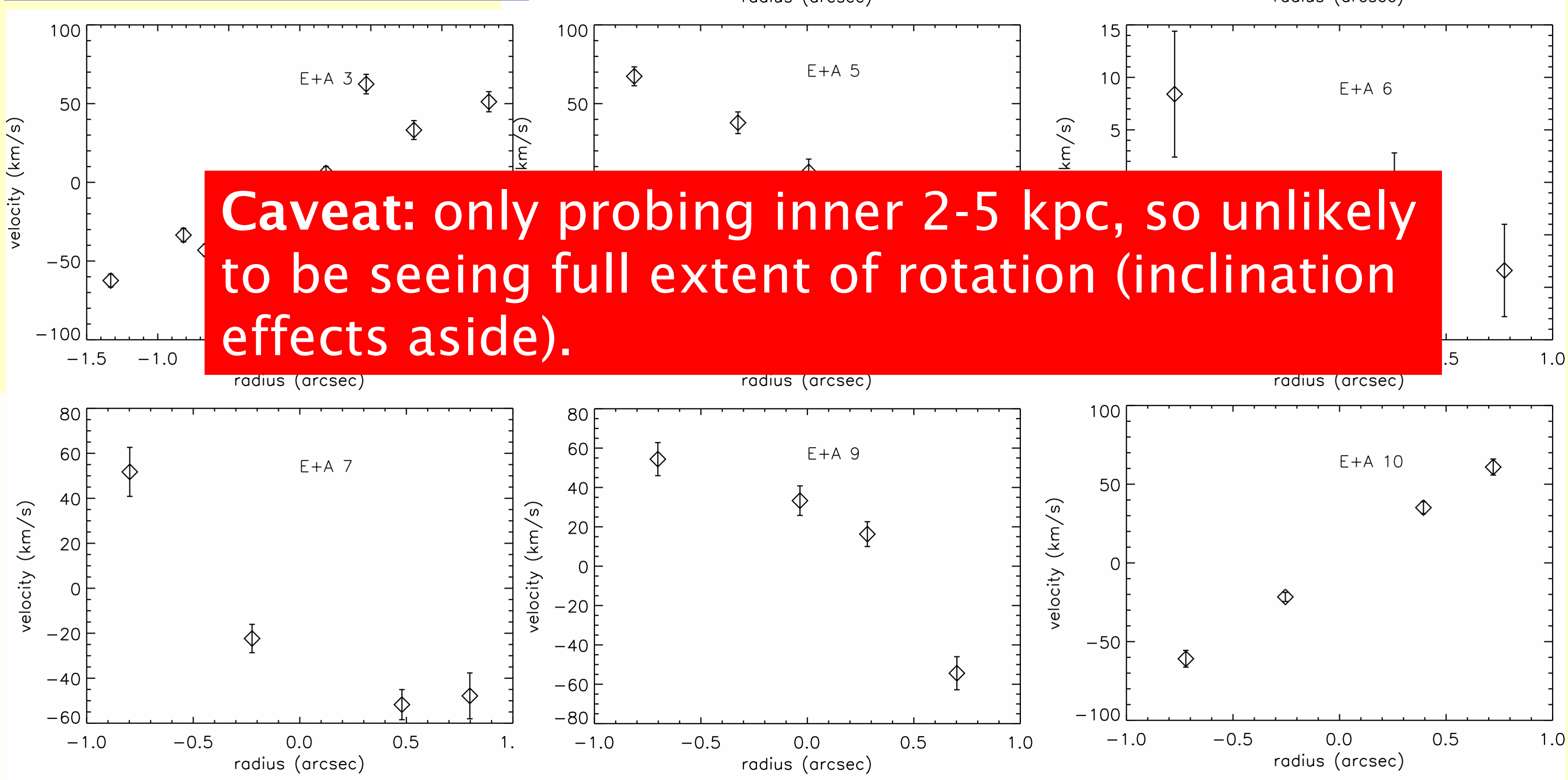
Streaming velocity maps

Clear rotation in every case but one!



1-D rotation curves

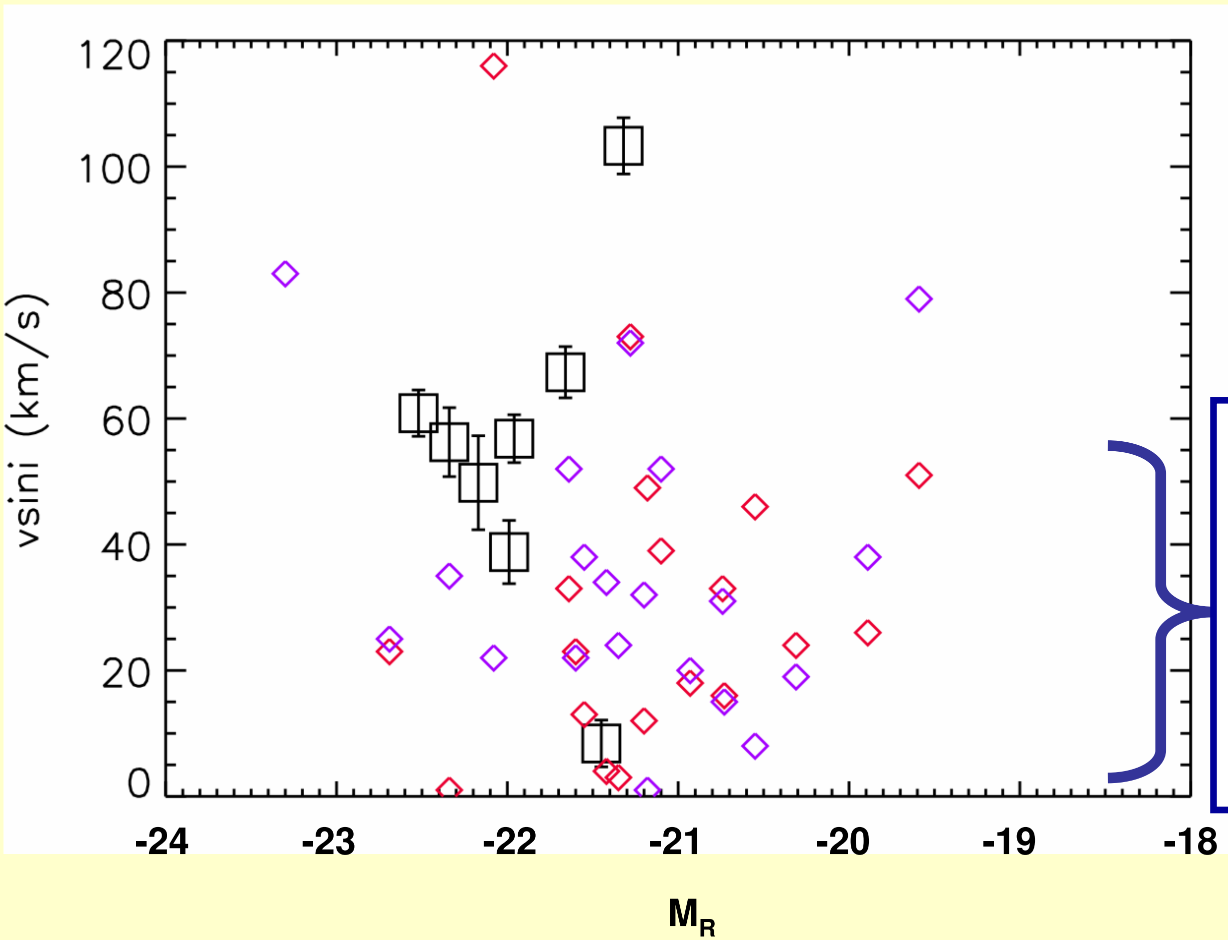
Generally monotonic variations ⇨ rotation!



Caveat: only probing inner 2-5 kpc, so unlikely to be seeing full extent of rotation (inclination effects aside).

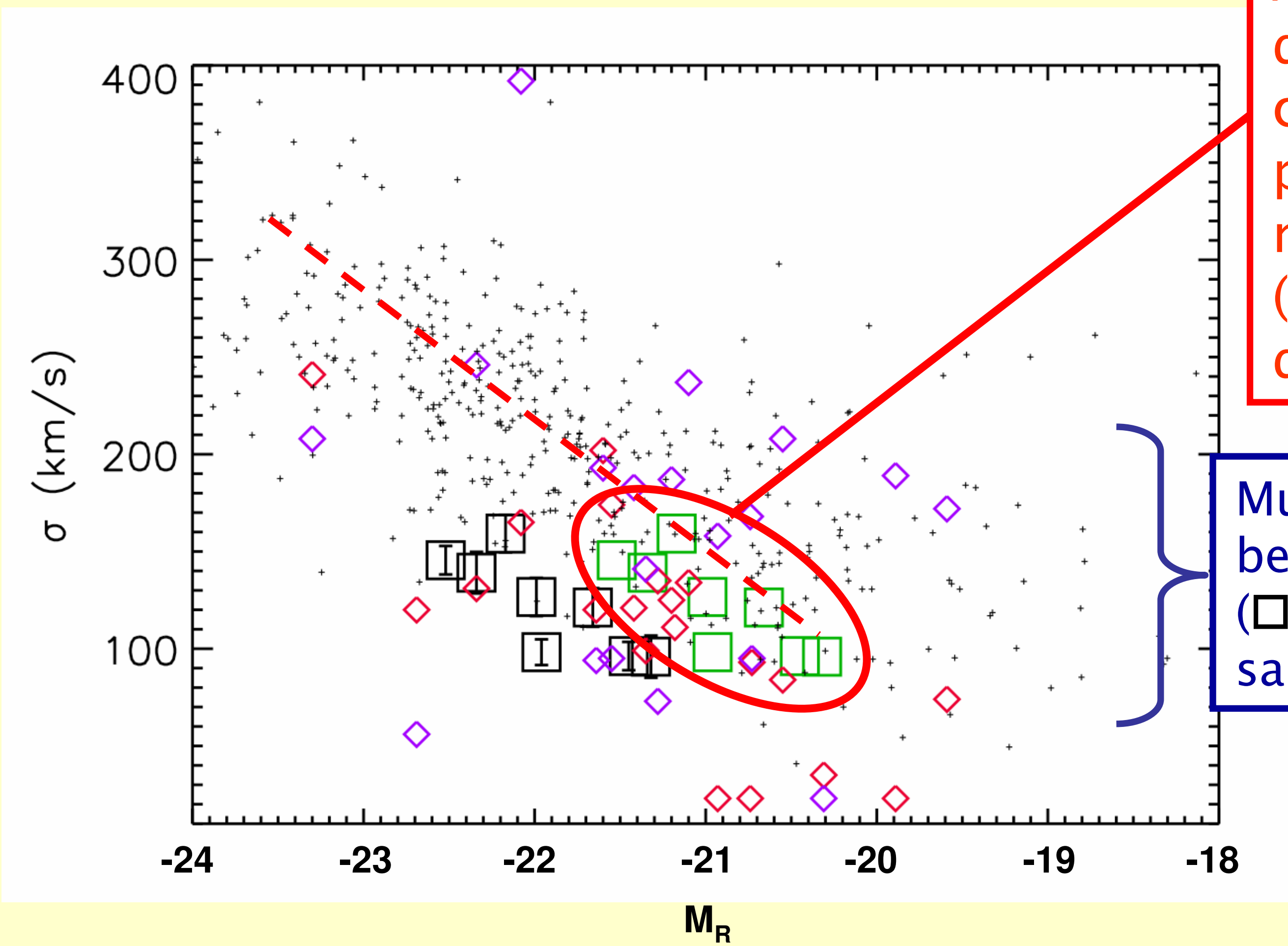
Comparison with other work – Norton et al.

[Norton et al's long-slit spectroscopy of Zabludoff etal LCRS sample, only extends to radii of 1-3 kpc!]



Bulk of Norton etal's E+A sample which they concluded "show little evidence for significant rotation"

Central velocity dispersions:

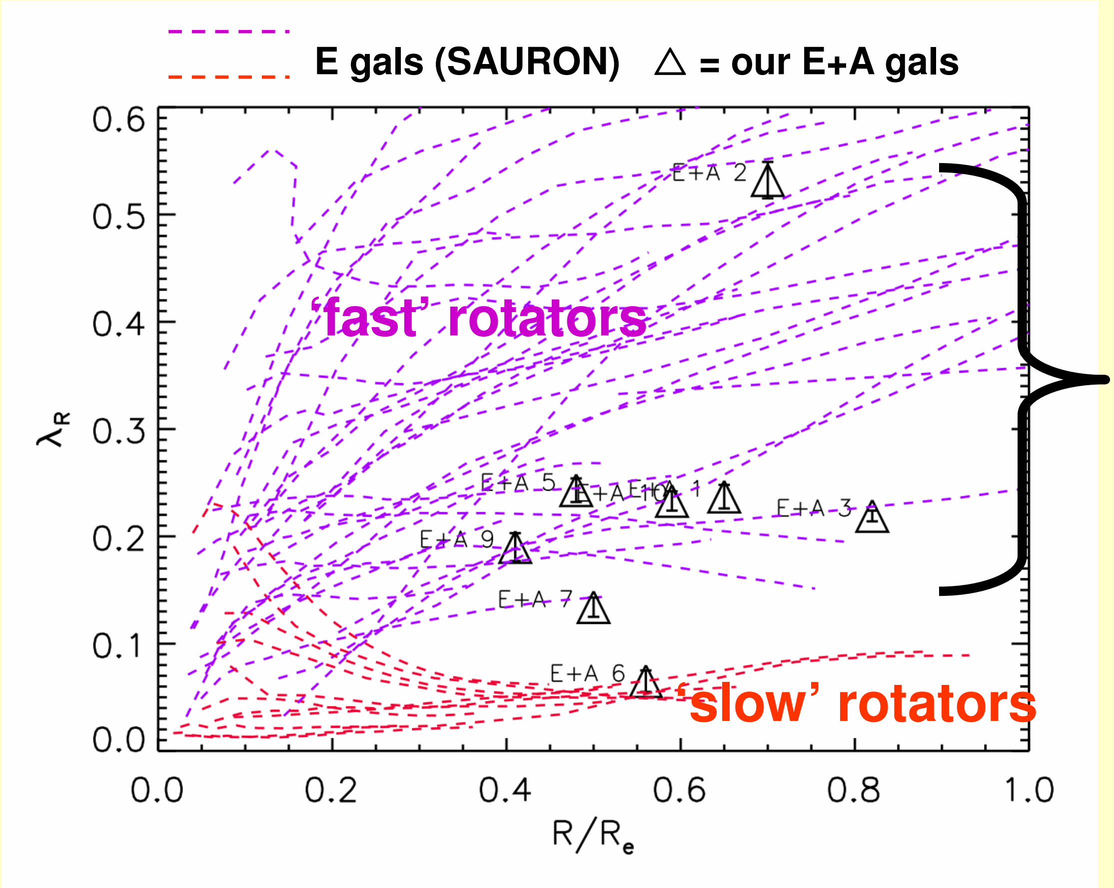


At their predicted quiescent M_R (□), consistent with population of normal early-types (Faber et al; small dots)

Much greater overlap between our sample (□) and Norton et al's sample (◇◇)

Further quantification of rotation: λ_R

λ_R parameter developed for use with 2-D IFU data and is a proxy measure for the projected stellar angular momentum per unit mass, derived by averaging over the 2-D kinematic field – Emsellem et al. (2007), SAURON sample.



7 out of 8 of our E+A galaxies are consistent with being 'FAST ROTATORS'

Young A-star population is a transient one whose rotation may not dominate observed kinematics in future.

Summary of key results:

• **Structural Morphology** – our E+A's are early-type spheroid-dominated **disk** galaxies, half of which show tidal signatures indicative of recent **merger**:

- ♦ *Hubble types in narrow range S0-Sa;*
- ♦ *$r^{1/4}$-like surface brightness profiles;*
- ♦ *consistent with Faber –Jackson relation (having accounted for transient brightening).*

• **Colour Morphology** – our E+A's are **diverse** in their radial colour properties:

- ♦ *mixture of red, blue or no cores;*
- ♦ *negative, positive, or flat radial gradients.*

Summary of key results continued….

• **Spatial distribution of young stellar popln** – generally uniformly distributed over the central 6kpc x 6kpc region with no evidence of any radial gradient:

⇨ *`Red core' E+A's: cases where **dust** associated with starburst + possible obscured ongoing SF – our model-subtracted images are inconclusive on this.*

• **Kinematics** – the young stellar populations in all the E+A's in our sample show **strong rotation.** Moreover, their project angular momentum per unit mass (as measure by λ_R) shows them to be consistent with **"fast rotator"** population of early-type galaxies.

• **Environment** – no sign of any dependency on global environment (isolated, group, cluster), but numbers small!!

Physical mechanism(s) responsible for E+A formation:

• The presence of tidal features in many cases, the strong and centralized Balmer absorption/young population, and the 'fast rotator' kinematical behaviour points to **mergers** being favoured (with neither *major* or *minor* being ruled out in terms of producing the fast rotation; Bournard et al. 2009):

BUT – the red cores and negative radial colour gradients remain a difficulty!!

• The **flavour** of merger (major, minor, gas-rich, gas-poor) remains an issue, and where there is a lot more parameter space for the simulations to explore:

- *Bekki currently extending simulations to gas-poor/gas-rich minor mergers – preliminary results show some promise reproducing red cores and negative colour gradients.*