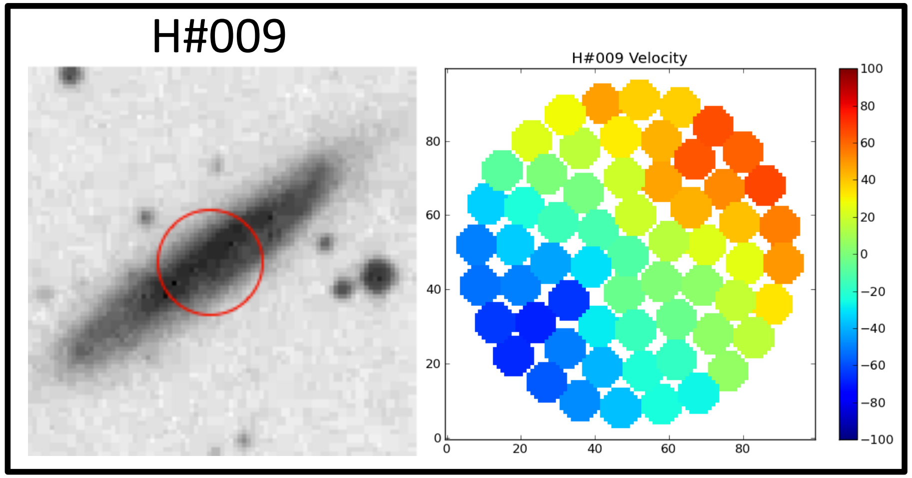
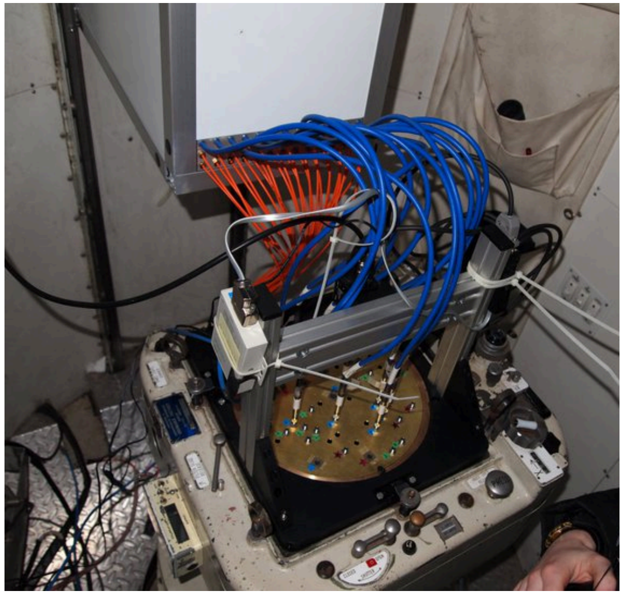
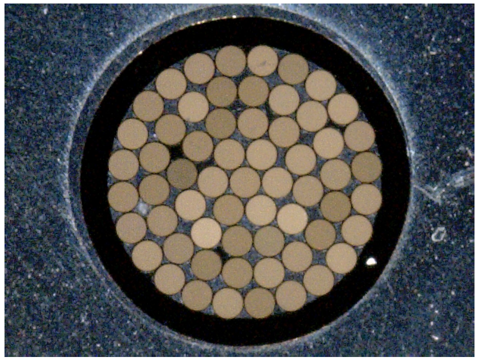
Next Generation Integral Field Surveys







The Sydney-AAO Multi-object Integral field spectrograph

Scott Croom (and the SAMI team)
With particular thanks to: Jon Lawrence, Julia Bryant, Joss Bland-Hawthorn, Sam Richards, Lisa Fogarty

Sydney Institute for Astronomy (SIfA)
CAASTRO ARC Centre of Excellence
University of Sydney

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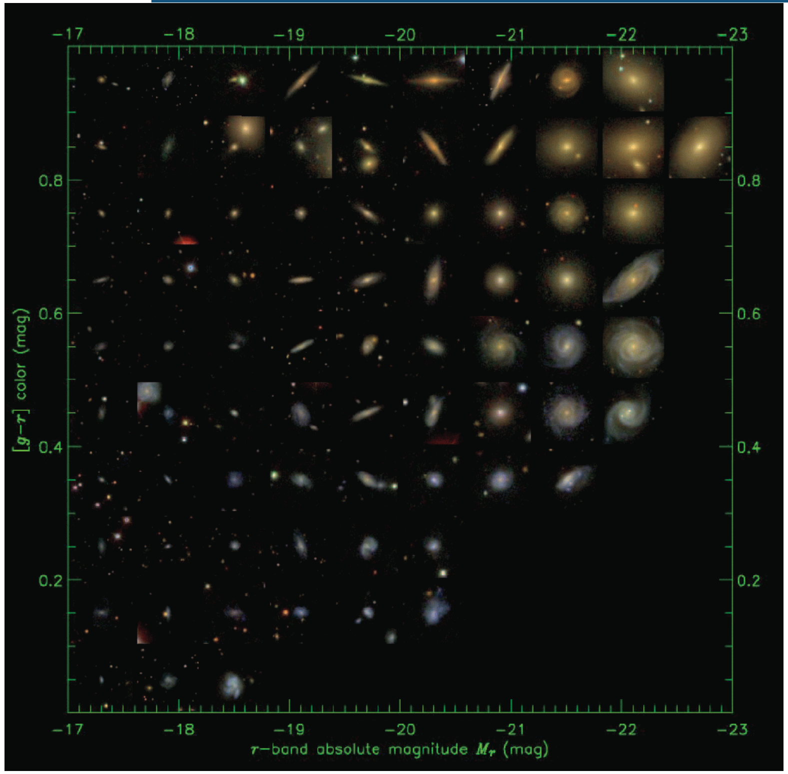
Tiantian Yuan, ANU

If you have a project, we welcome associate membership, talk to us.

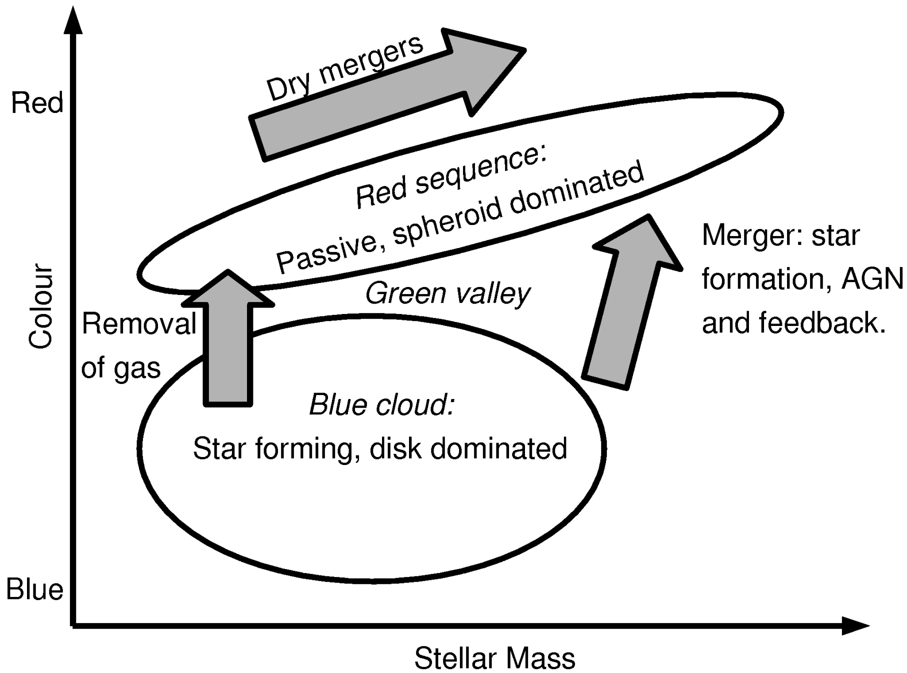
Outline

- The rationale for massive IFU surveys.
- The Sydney-AAO Multi-object Integral field spectrograph (SAMI).
- The SAMI Galaxy Survey.
- The future – bigger and better…

Science drivers



SDSS: Blanton et al. (2006)

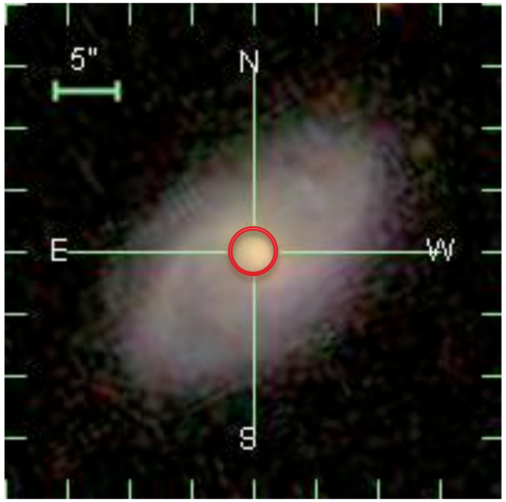


› The physics of galaxy formation.

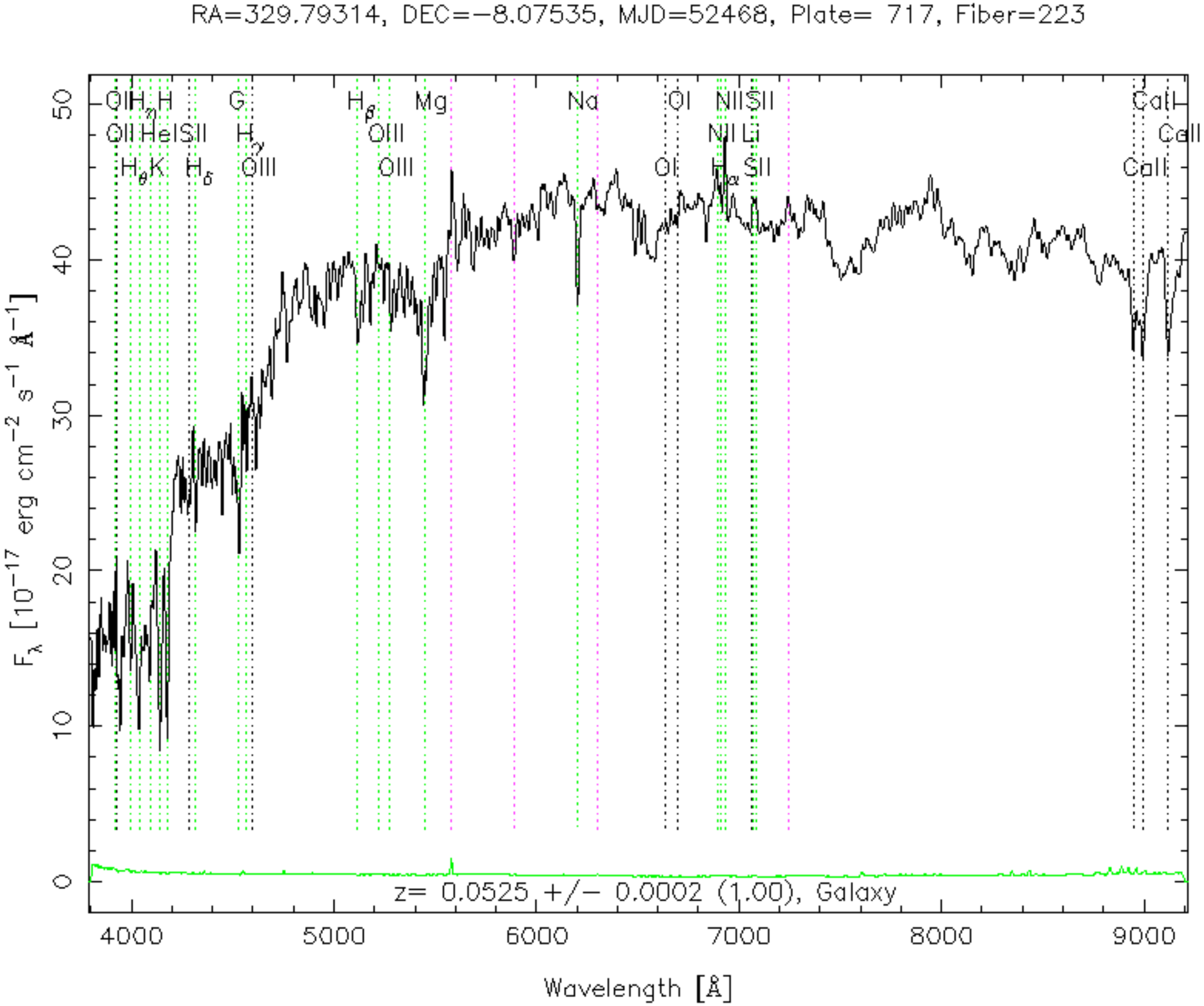
› Which processes dominate in which regimes?

› ***Moving from properties to processes….***

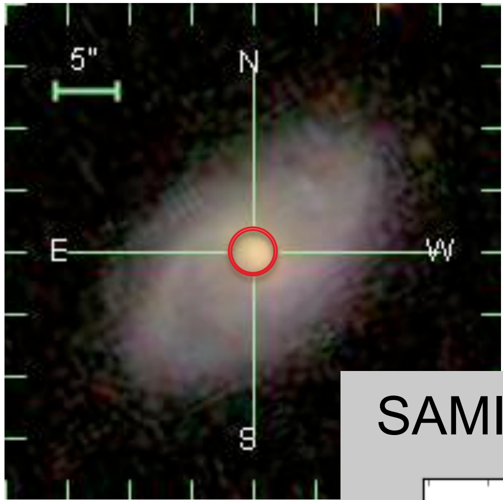
What do single fibre surveys miss?



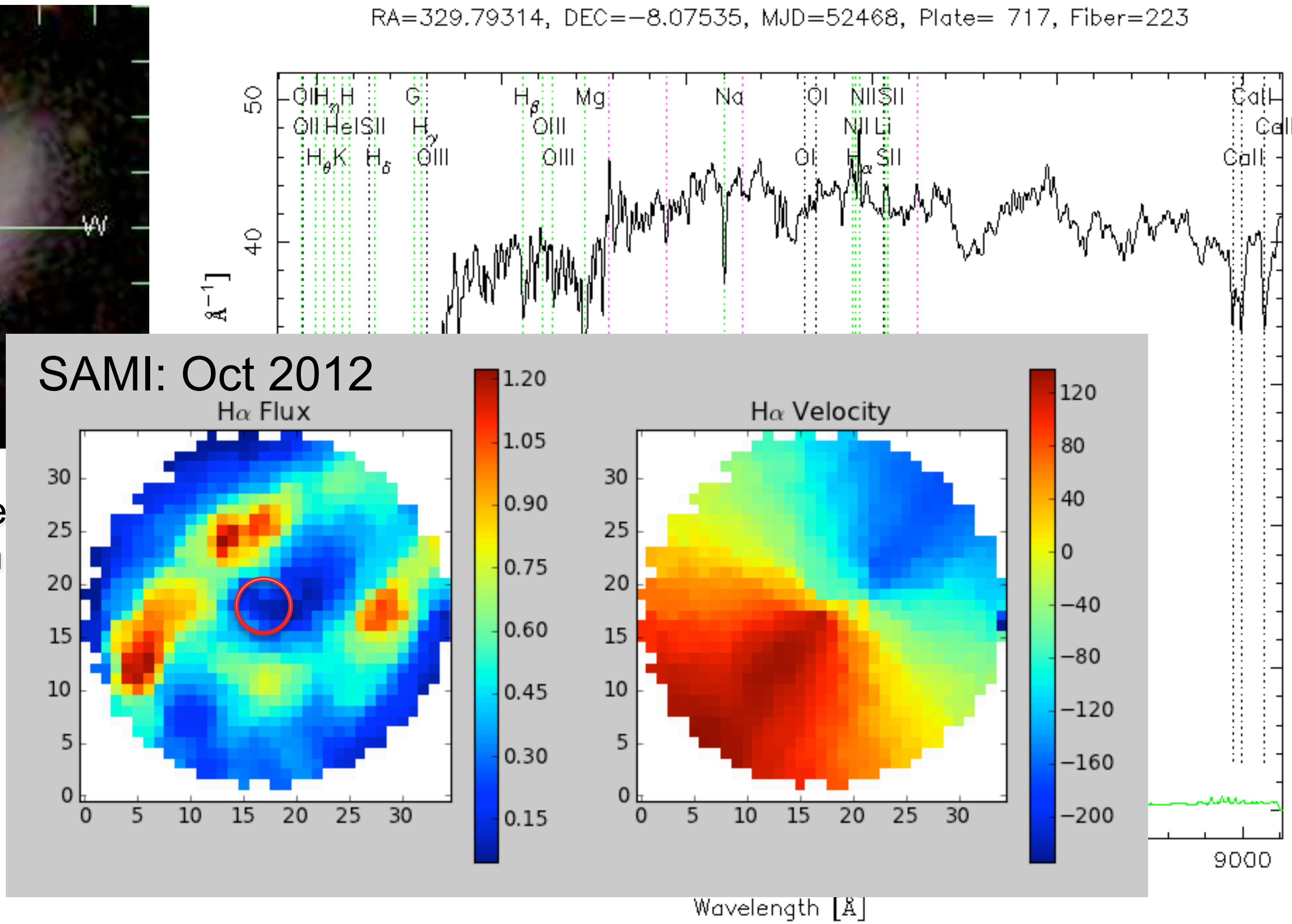
SDSS: image and spectrum



What do single fibre surveys miss?



SDSS: image
spectrum



SF morphology with SAMI: Iraklis Konstantopoulos, Andrew Hopkins++

Science drivers

› **What are the physical processes responsible for galaxy transformations?**

- Morphological and kinematic transformations; suppression of star formation; internal vs. external; secular vs. fast; ram pressure stripping; harassment, strangulation; galaxy–group/cluster tides; galaxy-galaxy mergers; galaxy-galaxy interactions…

› **How does mass and angular momentum build up?**

- The galaxy velocity function; stellar mass in dynamically hot and cold systems; galaxy merger rates; halo mass from velocity-field shear; Tully-Fisher relation…

› **Feeding and feedback: how does gas get into galaxies, and how does it leave?**

- Winds and outflows; feedback vs. mass; triggering and suppression of SF; gas inflow; metallicity gradients; the role of AGN…
- Important synergies with ASKAP HI surveys.

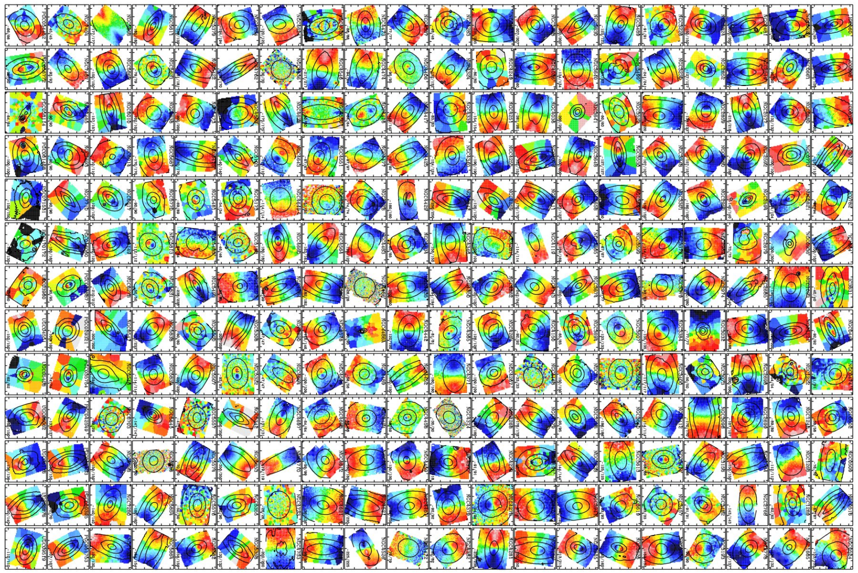
Why large samples?

- Complexity!
- Galaxy formation depends on a number of parameters:
  - Stellar mass.
  - Halo mass.
  - Environment (is this the same as halo mass?).
  - Star formation history.
  - Merger history.
  - Intrinsic stocasticity (extra parameters?).
- SDSS, 2dFGS and others have shown the power of large samples to address trends in multi-dimensional parameter spaces.

› These are arguments well understood, and have led to projects such as:

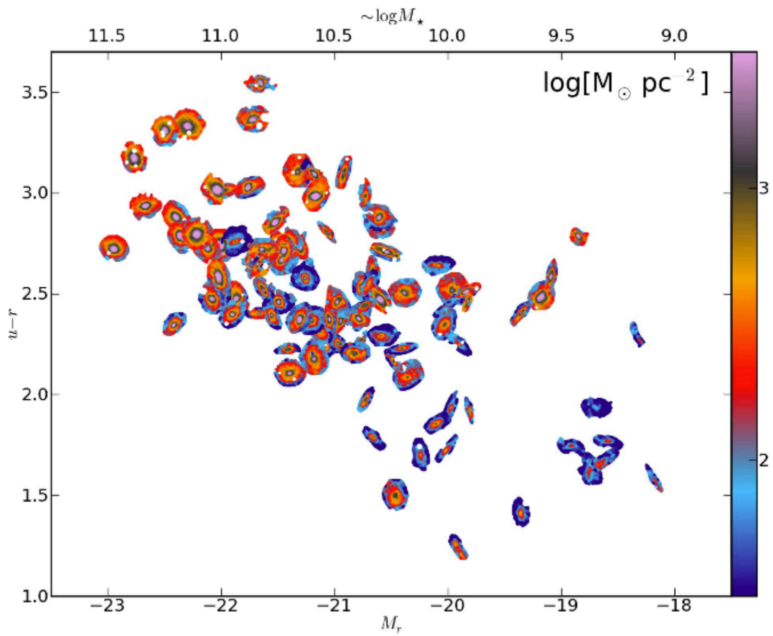
ATLAS3D (e.g. Krajnovic et al 2011):

260 local early types using SAURON.



CALIFA (Sanchez et al 2012):

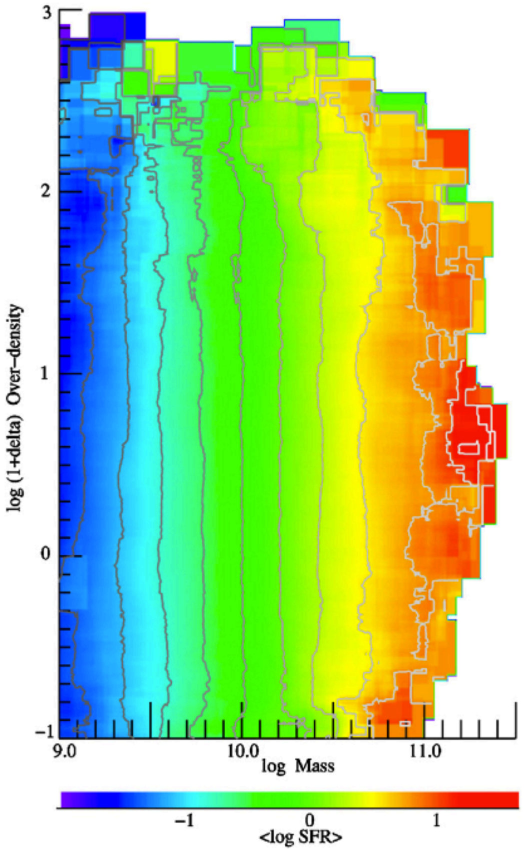
600 galaxies using PMAS.



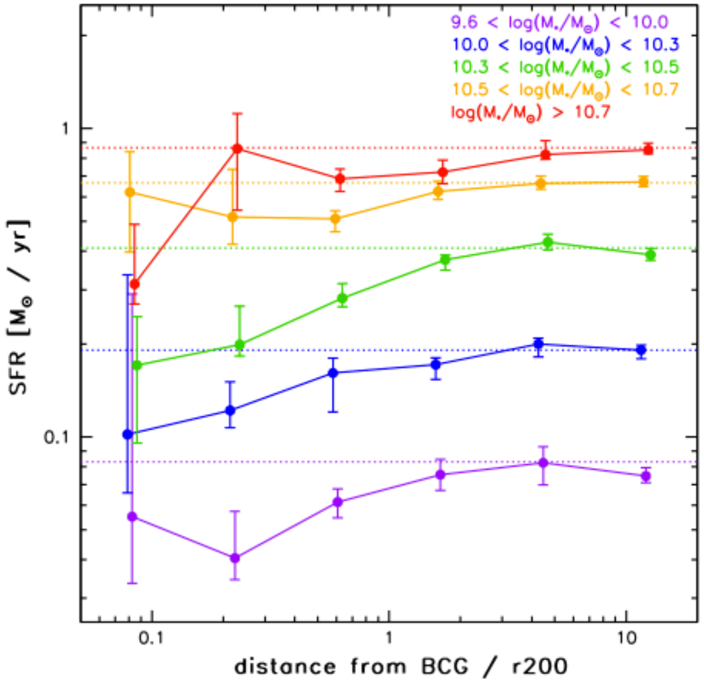
Talks by Roger Davies & Nic Scott earlier this week.

Science drivers example: Quenching

› Quenching star formation: what are the physical processes?



Peng et al. (2010, 2012)
-> **FAST**

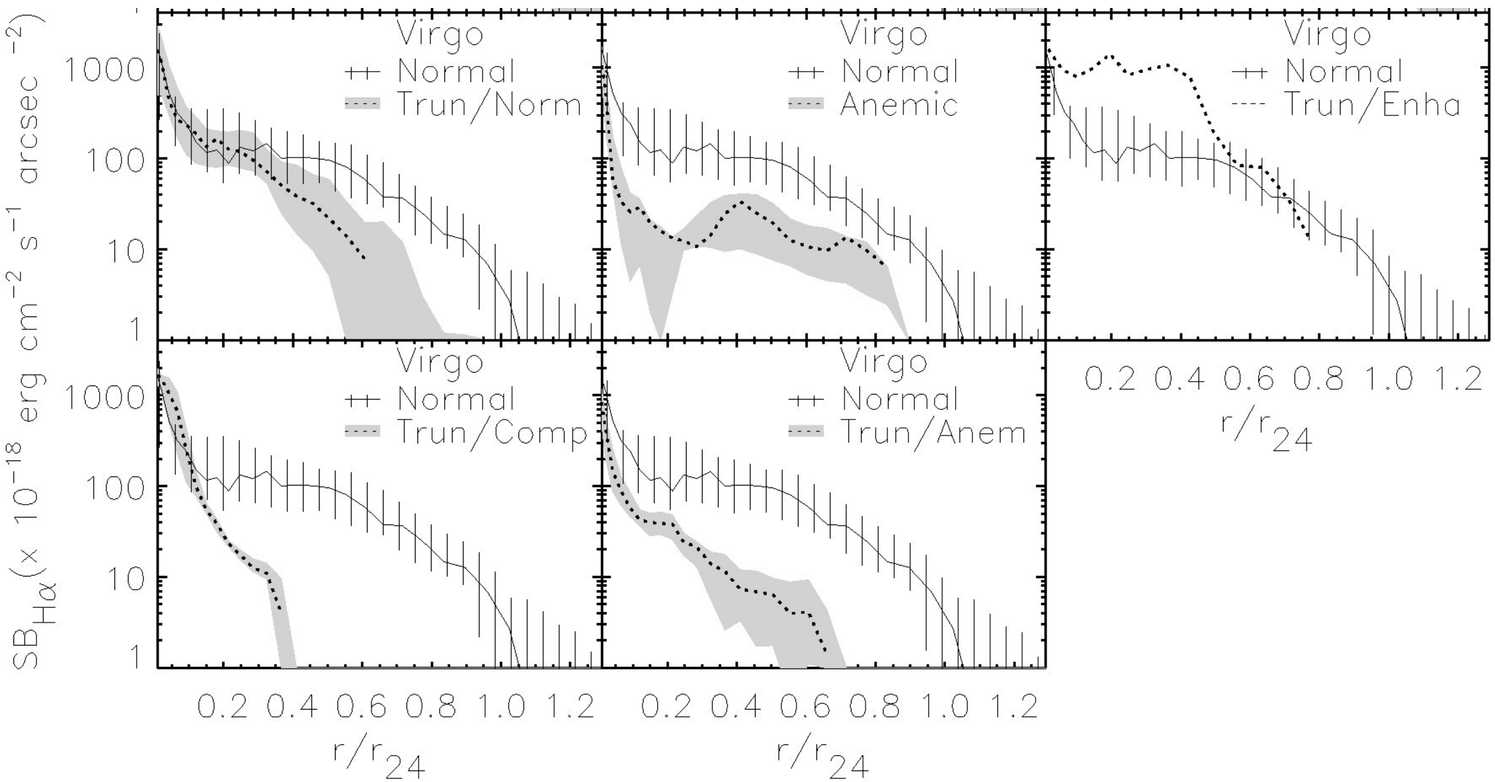


Von der Linden et al. (2010), see also Weinmann et al. (2010)

-> **SLOW**

Science drivers example: Quenching

› But… where is star formation happening?

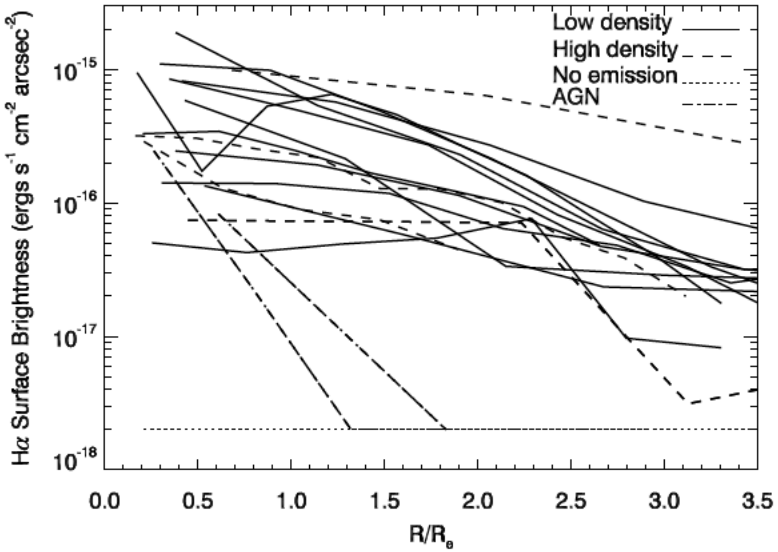


› E.g. Koopmann & Kenney (2004): Hα imaging in Virgo, ~50% of spirals truncated compared to field.

Science drivers example: Quenching

› Extend to a wide range of environments with a pilot study using the SPIRAL IFU (Brough et al. 2013):

- GAMA selected environments.
- 18 galaxies in narrow range in stellar mass $\sim 10^{10} M_{\odot}$.
- Mean SFR a factor ~2.5 lower in high density environments, but NOT significant - large scatter.



- Repeating with >300 galaxies from SAMI (USyd PhD student Adam Schaefer).

Science drivers example: Quenching

Signatures of physical processes

› Ram pressure stripping:

- Temporary enhancement of SF.
- Shock excitation of gas and one sided extra-planar gas.
- Gas disk and star formation becomes less extended.

› Strangulation (stripping of halo):

- Overall suppression of SF across the disk – less severe.

› Dynamical interactions and/or mergers:

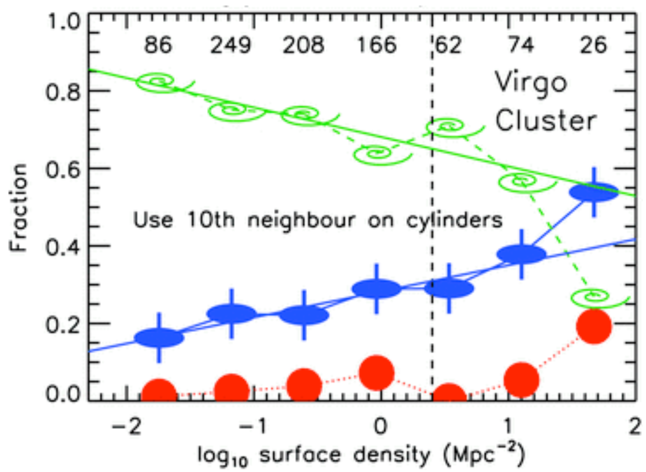
- Nuclear star formation.
- Dynamical disturbance.
- Younger central stellar populations.

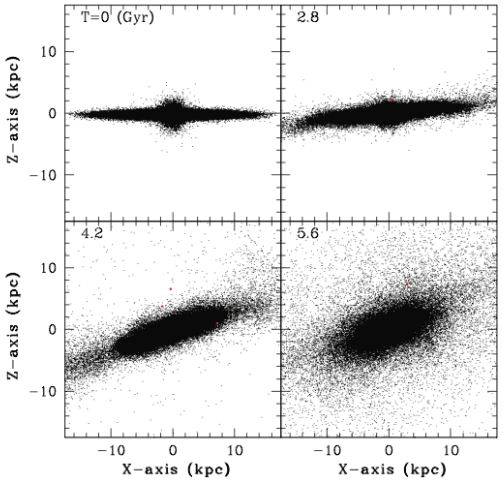
› But need to continue to simulate these signatures in detail…

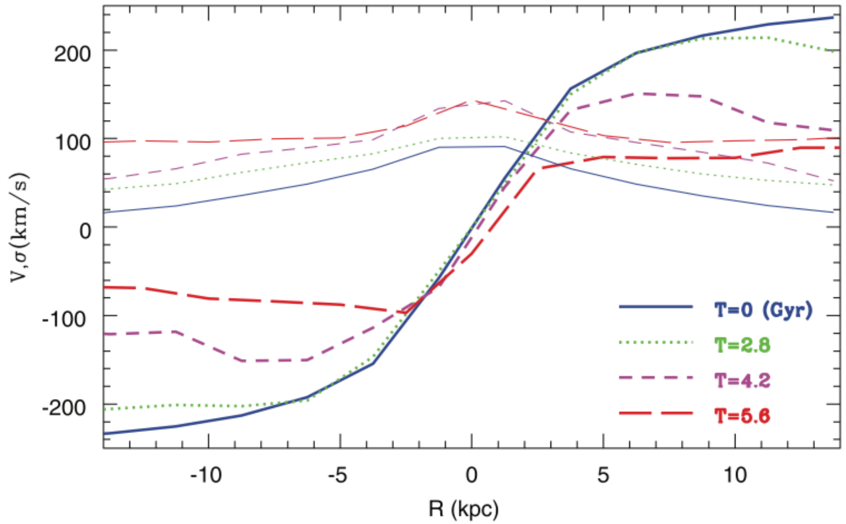
Science drivers example: Morphological transformation

› Possibly multiple paths for S0 formation.

- Fading, plausible for some S0s from TF relation (e.g. Bedregal 2006), but not all.
- Environmental dependence (e.g. Dessler 1980; Cappellari et al 2011).
- Galaxy-galaxy tidal interaction in groups a likely contender (Bekki & Couch 2011).







Sydney-AAO Multi-object IFS (SAMI)

- 1 degree diameter f-o-v.
- 13 x 61 fibre IFUs using hexabundles (Bryant, Bland-Hawthorn et al.).
- 15” diameter IFUs, 1.6” diameter fibre cores.
- Spectral resolution R~1700 (blue), R~4500 (red).

The Sydney-AAO Multi-object Integral-field spectrograph (SAMI)

Scott M. Croom[1,2*], Jon S. Lawrence[3,4], Joss Bland-Hawthorn[1], Julia J. Bryant[1], Lisa Fogarty[1], Samuel Richards[1], Michael Goodwin[3], Tony Farrell[3], Stan Miziarski[3], Ron Heald[3], D. Heath Jones[5], Steve Lee[3], Matthew Colless[3,2], Sarah Brough[3], Andrew M. Hopkins[3,2], Amanda E. Bauer[3], Michael N. Birchall[3], Simon Ellis[3], Anthony Horton[3], Sergio Leon-Saval[1], Geraint Lewis[1], Á. R. López-Sánchez[3,4], Seong-Sik Min[1], Christopher Trinh[1], Holly Trowland[1]

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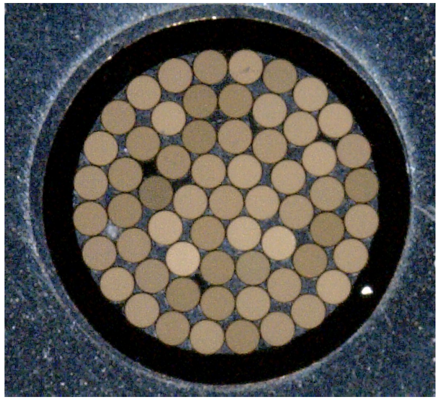
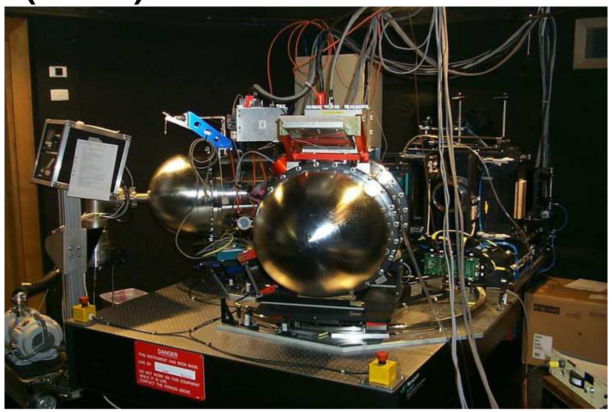
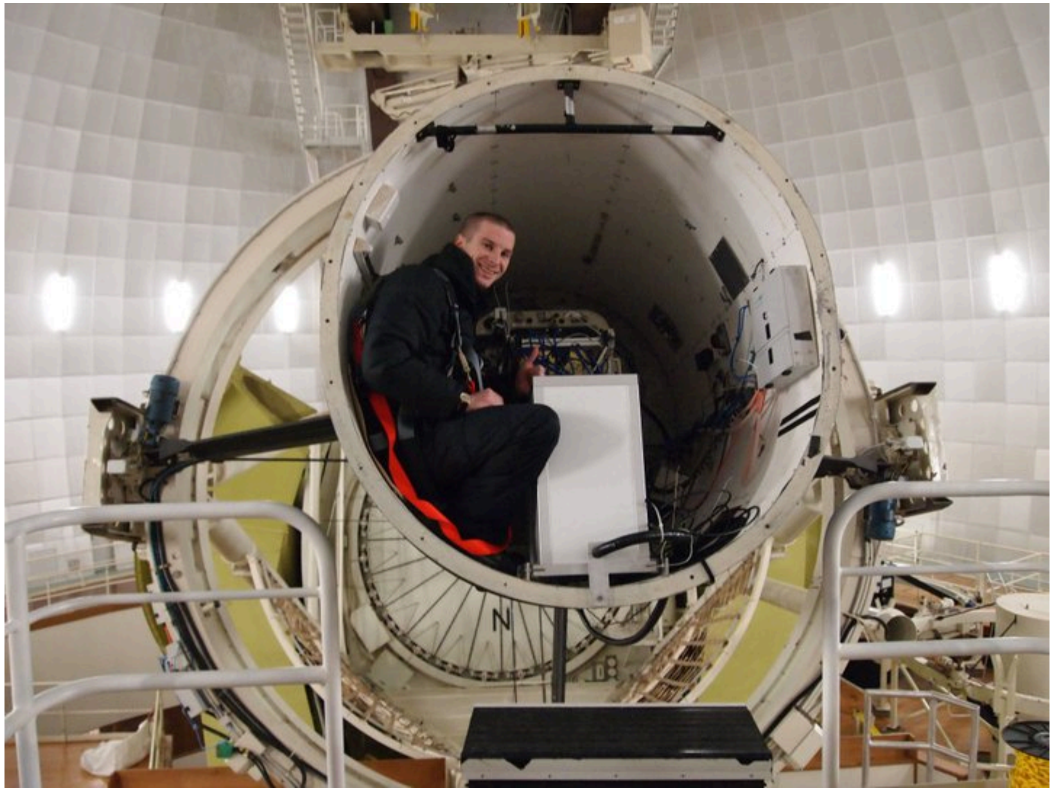
[4] *Department of Physics and Astronomy, Macquarie University, NSW 2109, Australia*
[5] *School of Physics, Monash University, Clayton, VIC 3800, Australia*

Croom et al. 2012





Commissioning



- Prototype system commissioned in 2011.
- Upgraded system commissioned Feb 2013 (Julia Bryant, Jon Lawrence, Sam Richards++).

Rising from the ashes…

› The SAMI commissioning team were the first observers on the mountain after the Siding Spring fire.

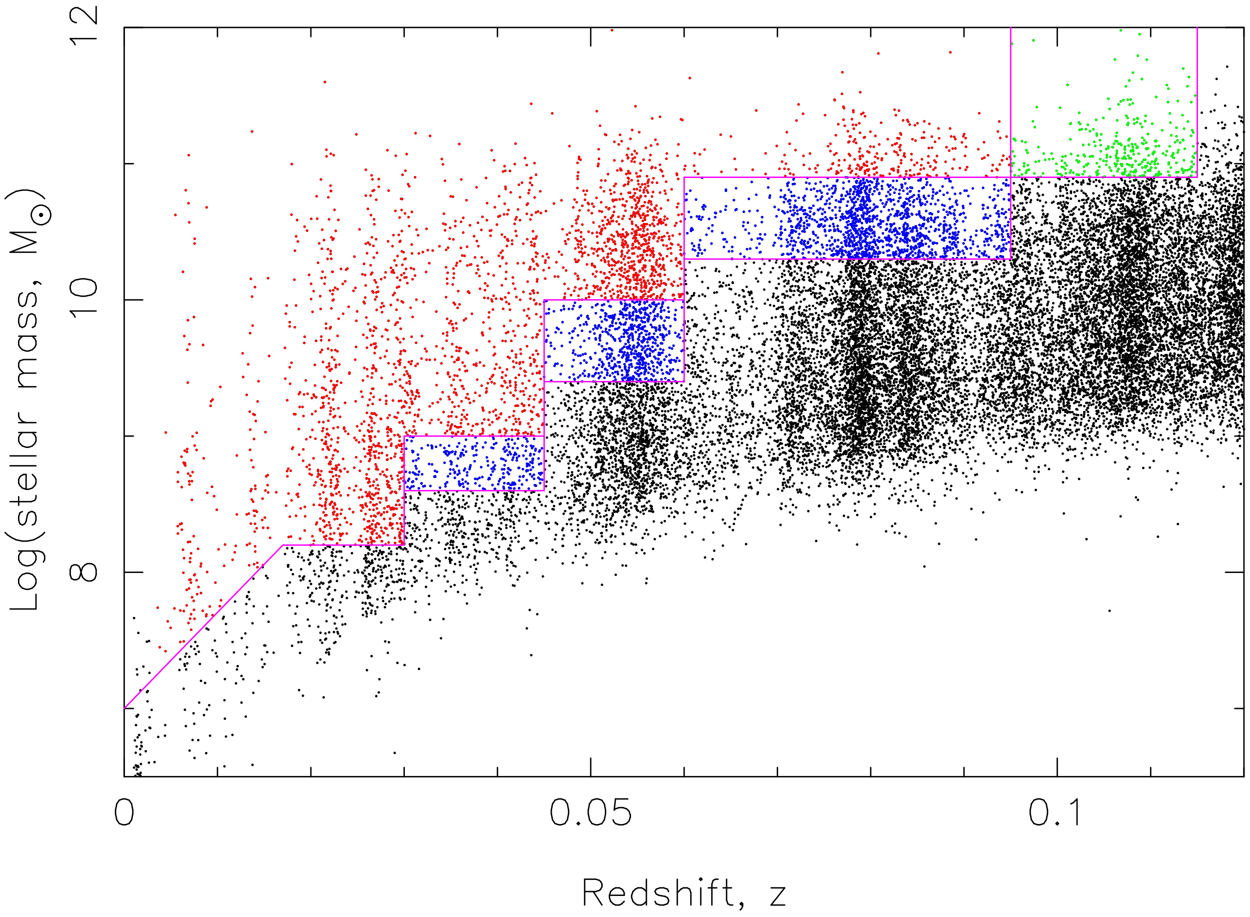
› Anglo-Australian Telescope, 13th Jan 2013:

THE UNIVERSITY OF SYDNEY

The SAMI Galaxy Survey

- Using the upgraded SAMI instrument.
- Started in March 2013.
- 3400 galaxies in ~200 nights, 4 hours exposure per field.
- Primary fields are the Galaxy And Mass Assembly (GAMA; Driver et al. 2010) regions.
  - Three 4x12 deg equatorial regions at 9hr, 12hr and 15hr RA.
  - Deep, complete, spectroscopy to r=19.8 to define environment.
  - Robust group catalogue (Robotham et al. 2011).
  - GALEX, SDSS, VST, UKIDSS, VISTA, WISE, Herschel imaging.
  - HI 21cm from ALFALFA (half the area), and in the future ASKAP.
- Specific galaxy cluster fields to be targeted in the SGP to probe the highest density environments.

Target selection



Primary sample, high mass secondary sample,
low mass secondary sample

Survey parameters

› Wavelength coverage/resolution:

- Blue: 3700-5800A, R~1750, sigma=70km/s
- Red: 6300-7400A, R~4500, sigma=30km/s

› Galaxy sizes:

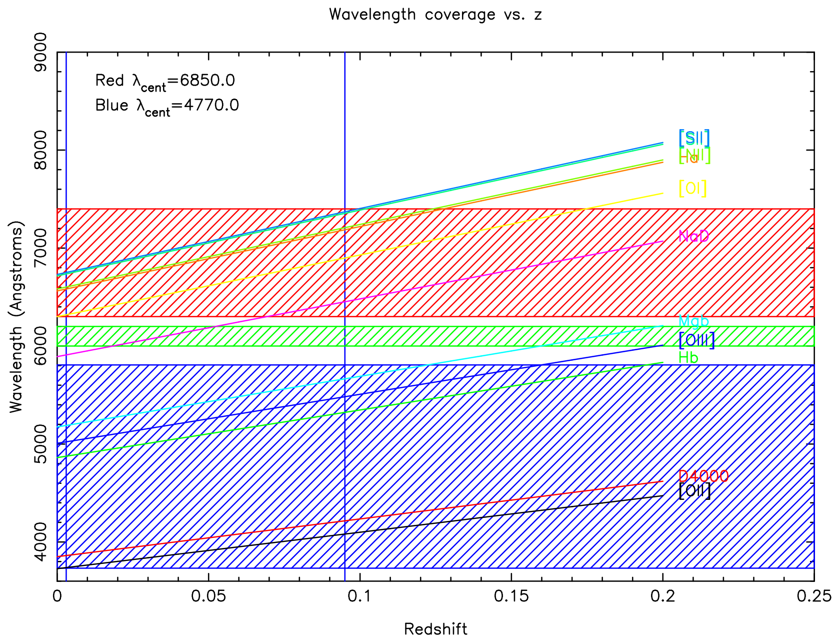
- median major axis Re=4.4”
- 10-90% range 1.8-9.4”

› S/N:

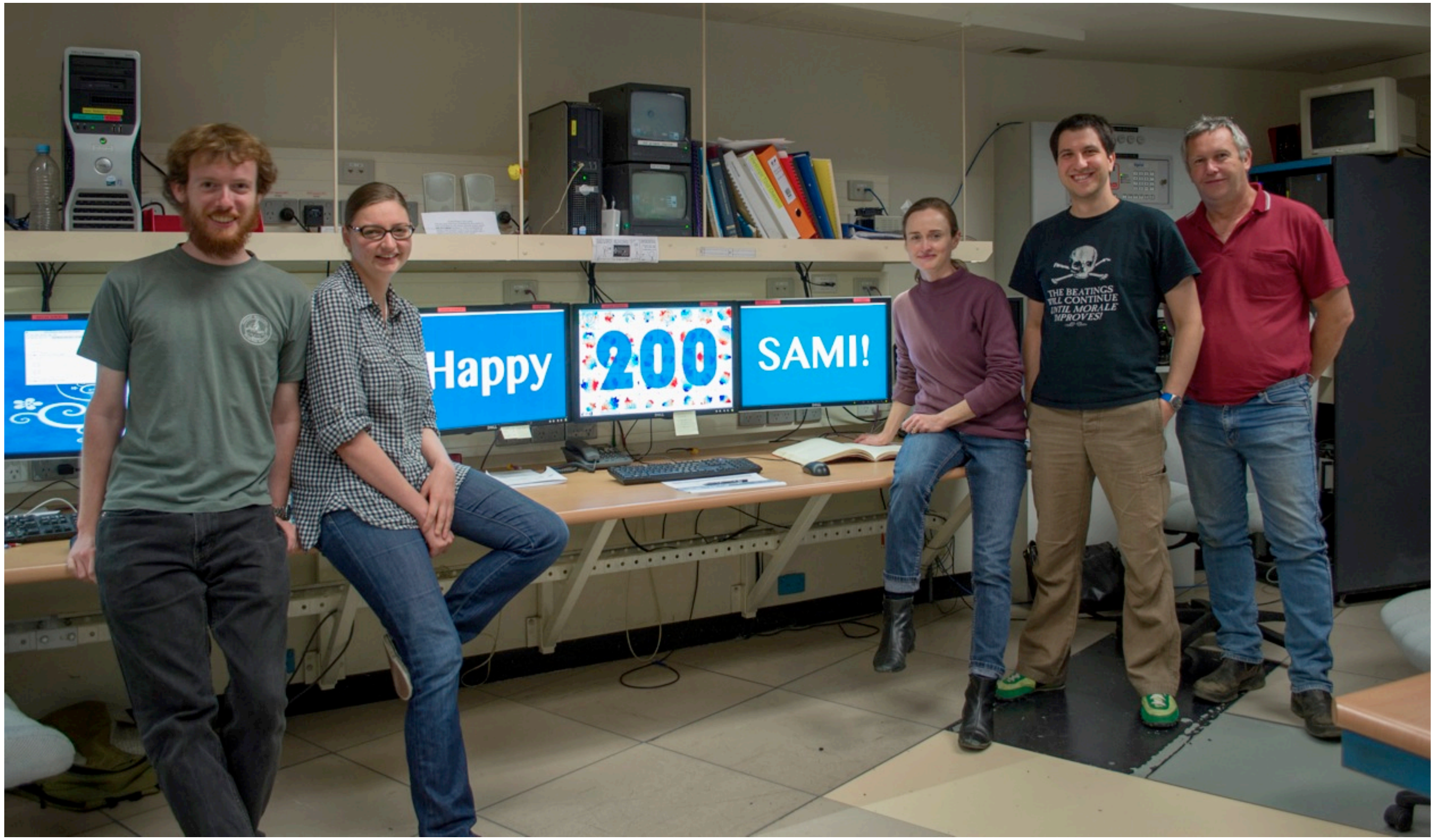
- Median at 1 Re, V-band continuum S/N=15, per spaxel, per A.
- 10-90% range S/N= 2 – 37.

› Chose to include dwarfs (to log(M*)<8.2), although lower S/N.

› Flux calibration: better than 5% over full spectral range (high fill factor, + calibration star observed with galaxies).



SAMI Galaxy Survey progress



James Allen, Lisa fogarty, Julia Bryant, Iraklis Konstantopoulos, Steve Chapman

252 galaxies in 13 nights – March 2013

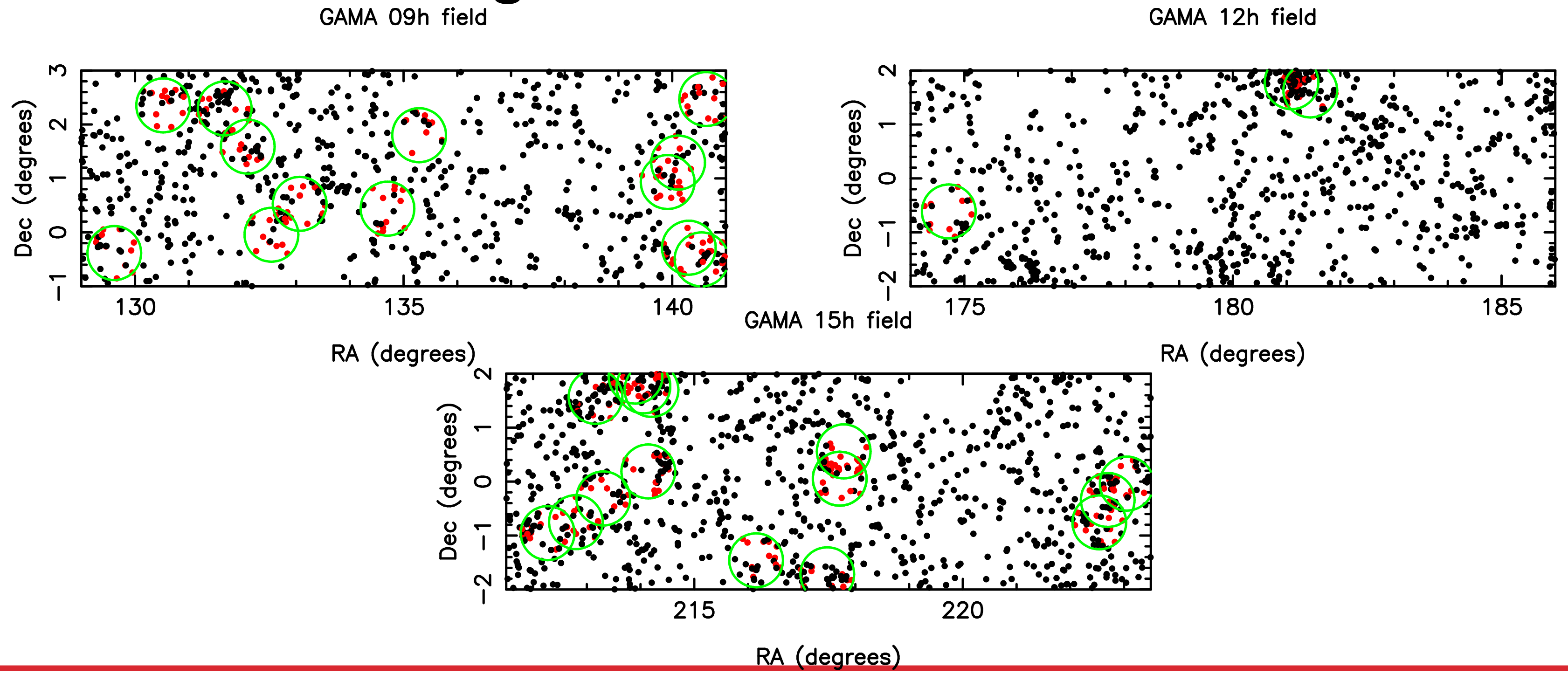
SAMI Galaxy Survey progress

› 32 fields, 384 galaxies in GAMA regions (March/April 2013).

› 11 fields, 132 galaxies in Cluster regions (Aug/Sept 2013).

› + 134 galaxies from pilot observations in 2012.

› **Total of 650 SAMI galaxies observed.**



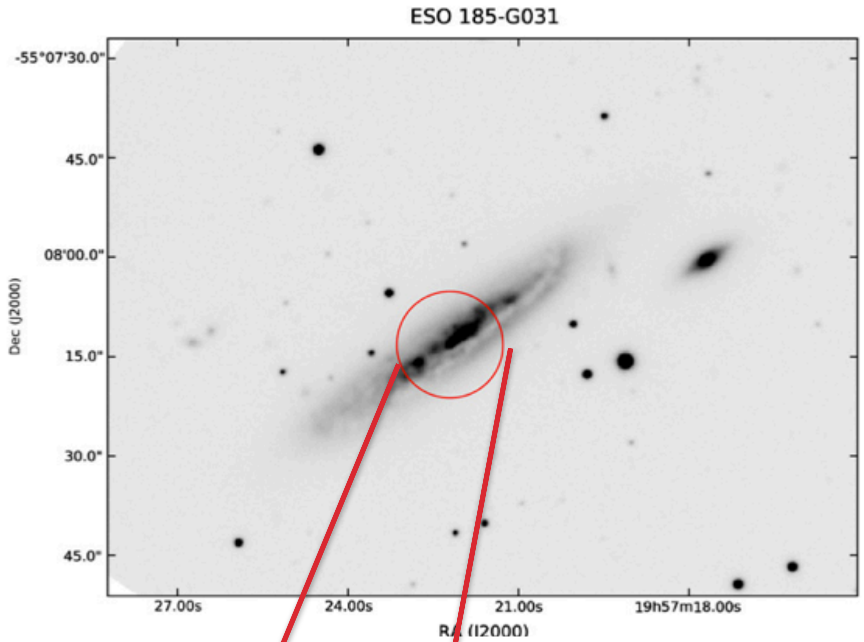
Early Science from observations so far

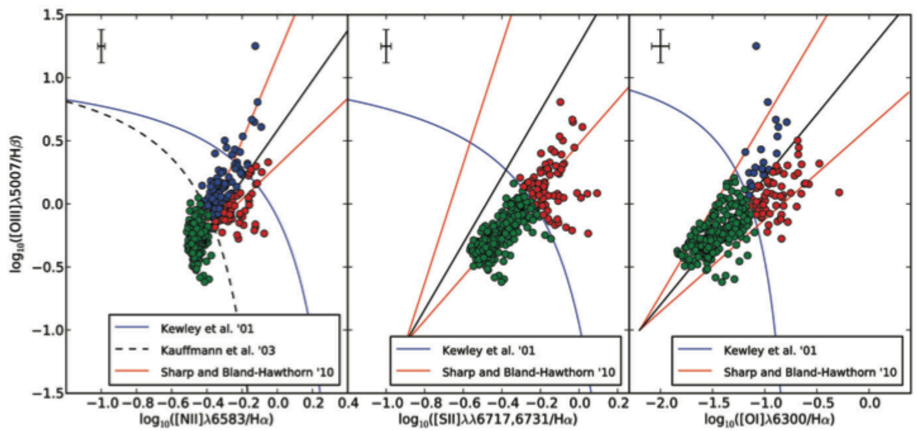
- Commissioning data from July 2011 (10 6dFGS galaxies)
  - Relatively large and bright galaxies (disks and early types).
  - Serendipitous wind galaxy discovery (Fogarty et al. 2012).

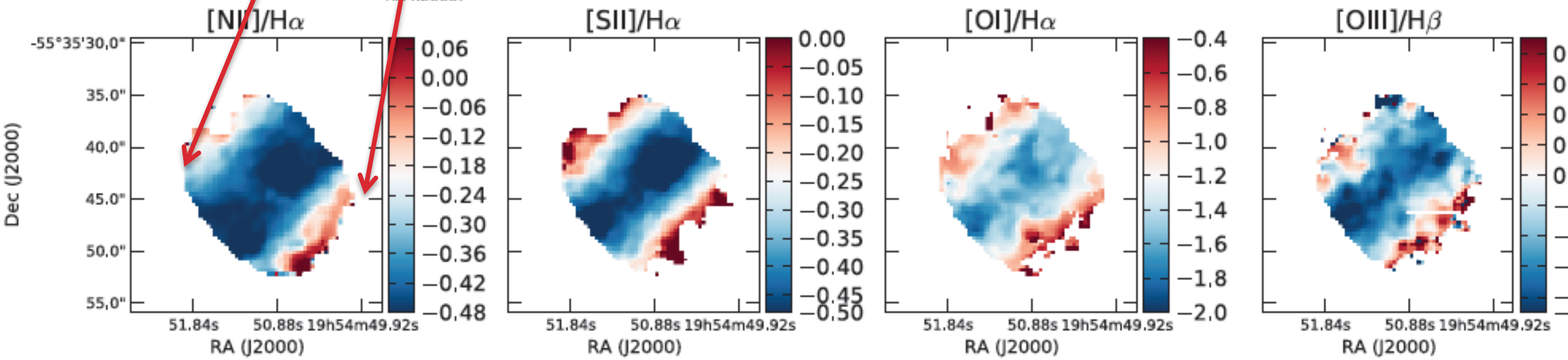
- 10 nights on AAT for pilot observations in Sept/Oct 2012, just completed:
  - Targeting galaxy clusters at z~0.05.
  - Studying the environmental dependence of fast and slow rotators.
  - First look at spatially resolved star formation vs. environment.
  - Sample of 134 galaxies (including a few targets from commissioning in May 2012).

First science: serendipitous wind discovery

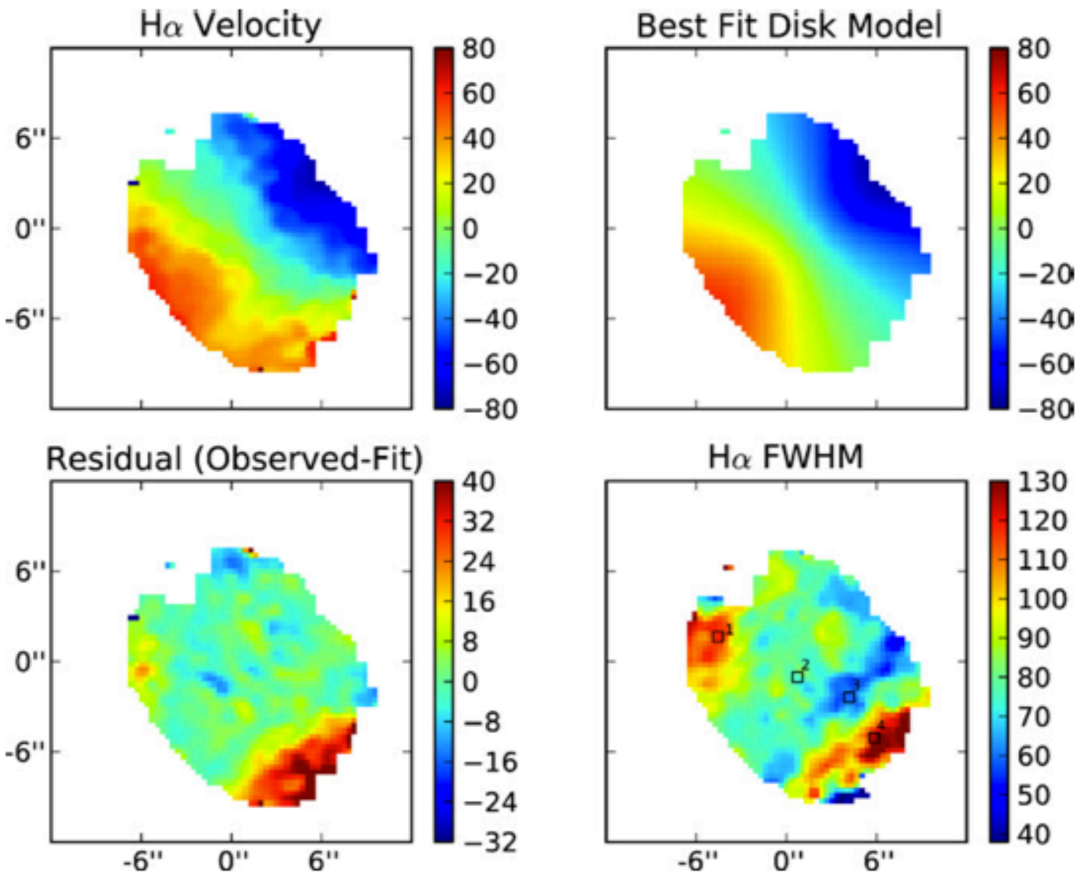
Lisa Fogarty et al. (2012)







First science: serendipitous wind discovery

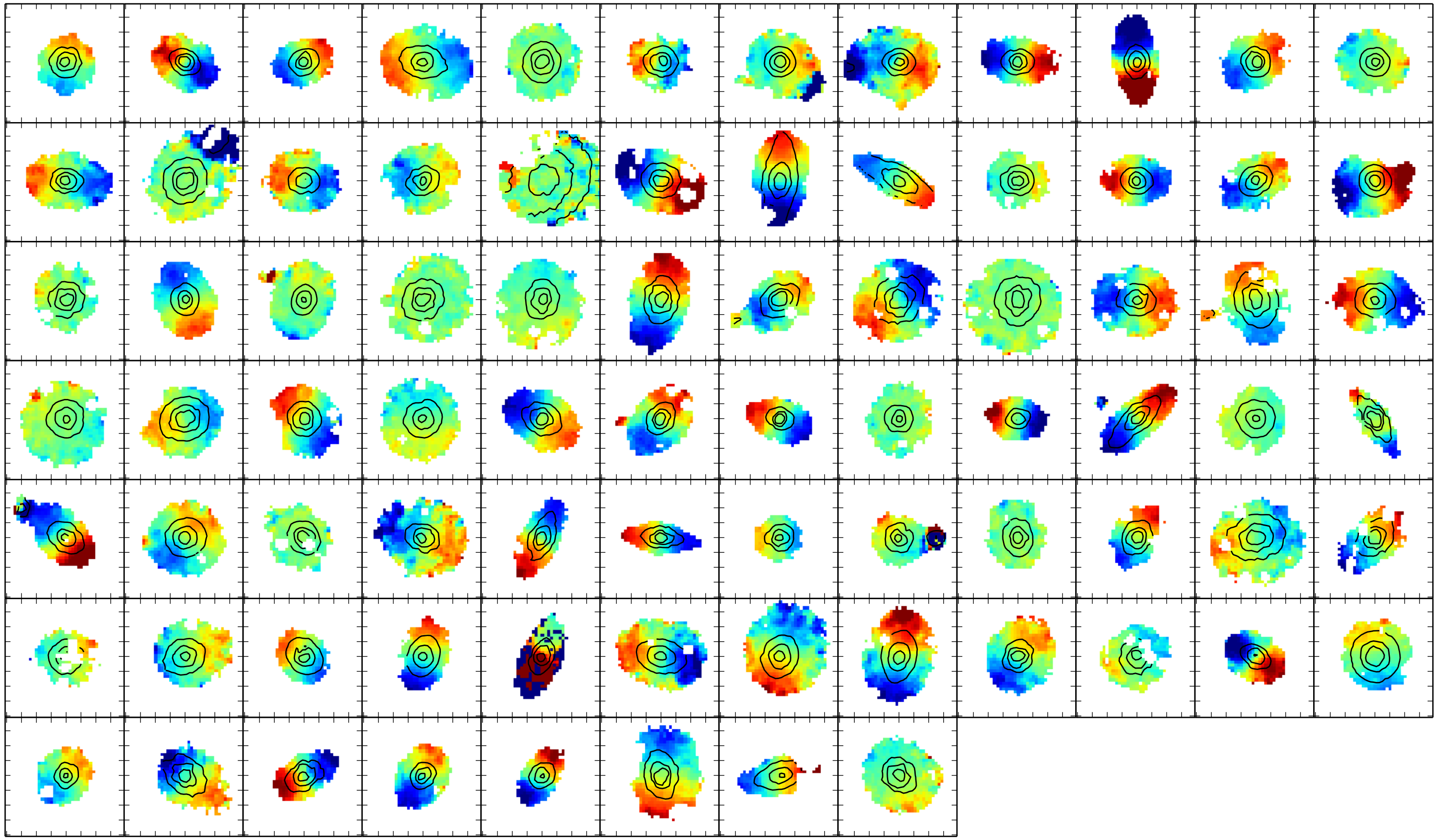


Lisa Fogarty et al. (2012)

Q: how rare are low-z outflows?

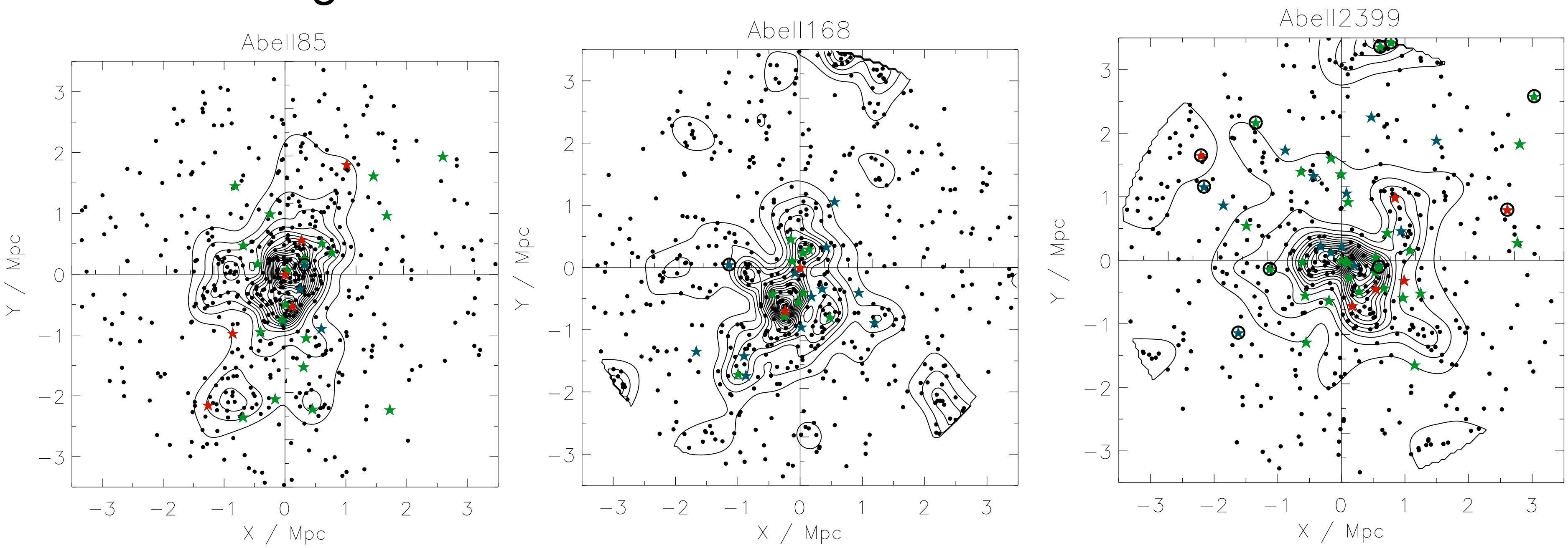
First science: fast/slow rotators in clusters

› 134 galaxies in Abell85, Abell168, Abell2399, with 80 ~~early types~~ (***non-spirals***) (Lisa Fogarty, Nic Scott, Matt Owers et al.):



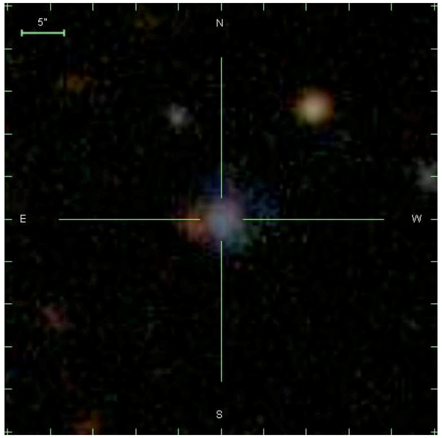
First science: fast/slow rotators in clusters

- Slow rotators not just in the centres of clusters. Also associated with infalling substructure.

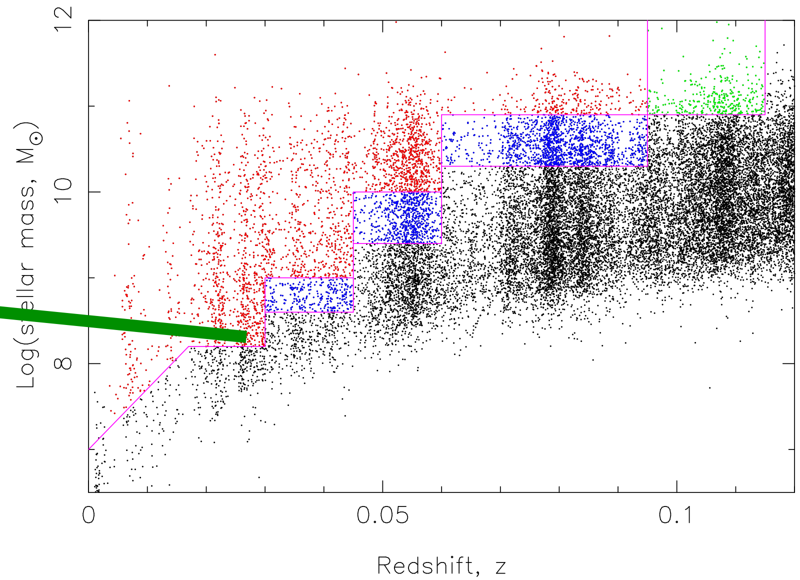


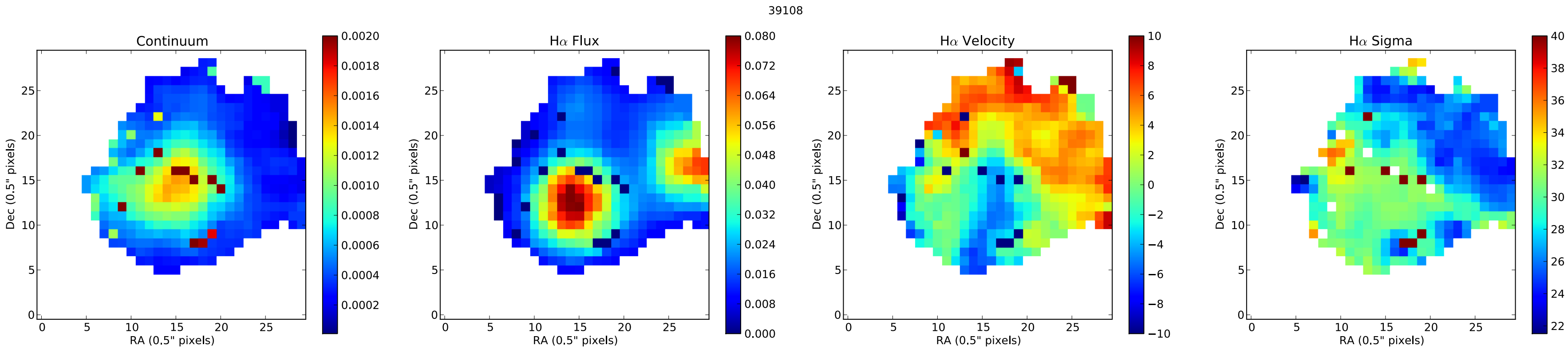
- Are SRs fundamentally linked to centrals or galaxy mass or something else?
- SAMI will look at groups as well, (GAMA; Robotham et al. 2011)

Low mass galaxies…



z=0.029, log(M*)=8.35, R_e=2.7"





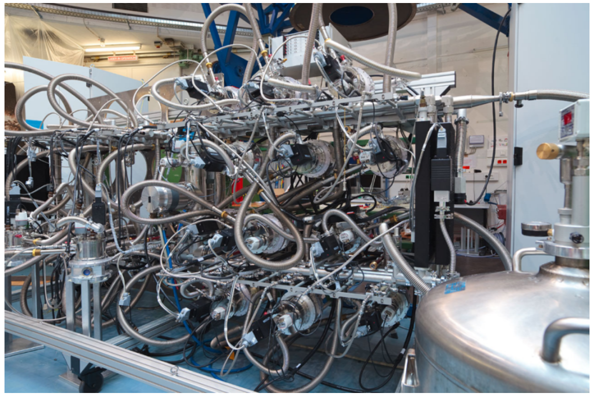
Probe dynamical disturbance over full range of mass (PhD student Jess Bloom).

HECTOR

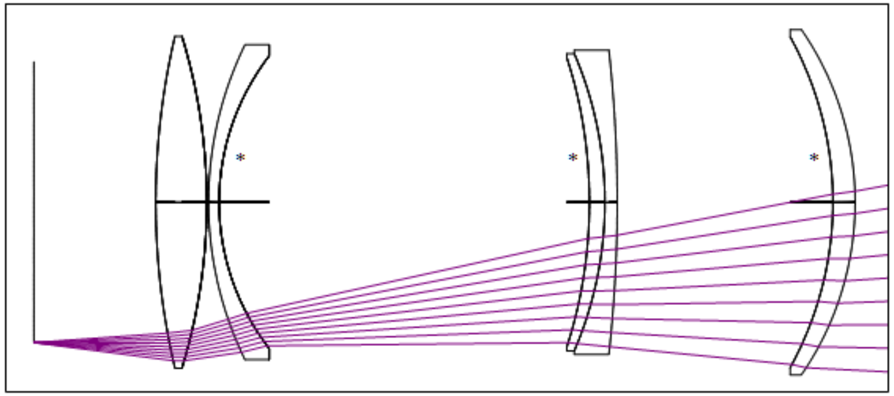
› Concept for a next generation AAT instrument with:

- 50-100 IFUs.
- 2-3 deg diameter field-of-view (new wide field corrector for the AAT?).
- Resolution R~4000 over the entire optical window using fixed format replicated spectrographs.

› Potential to carry out a survey of ~100,000 spatially resolved galaxies.



MUSE

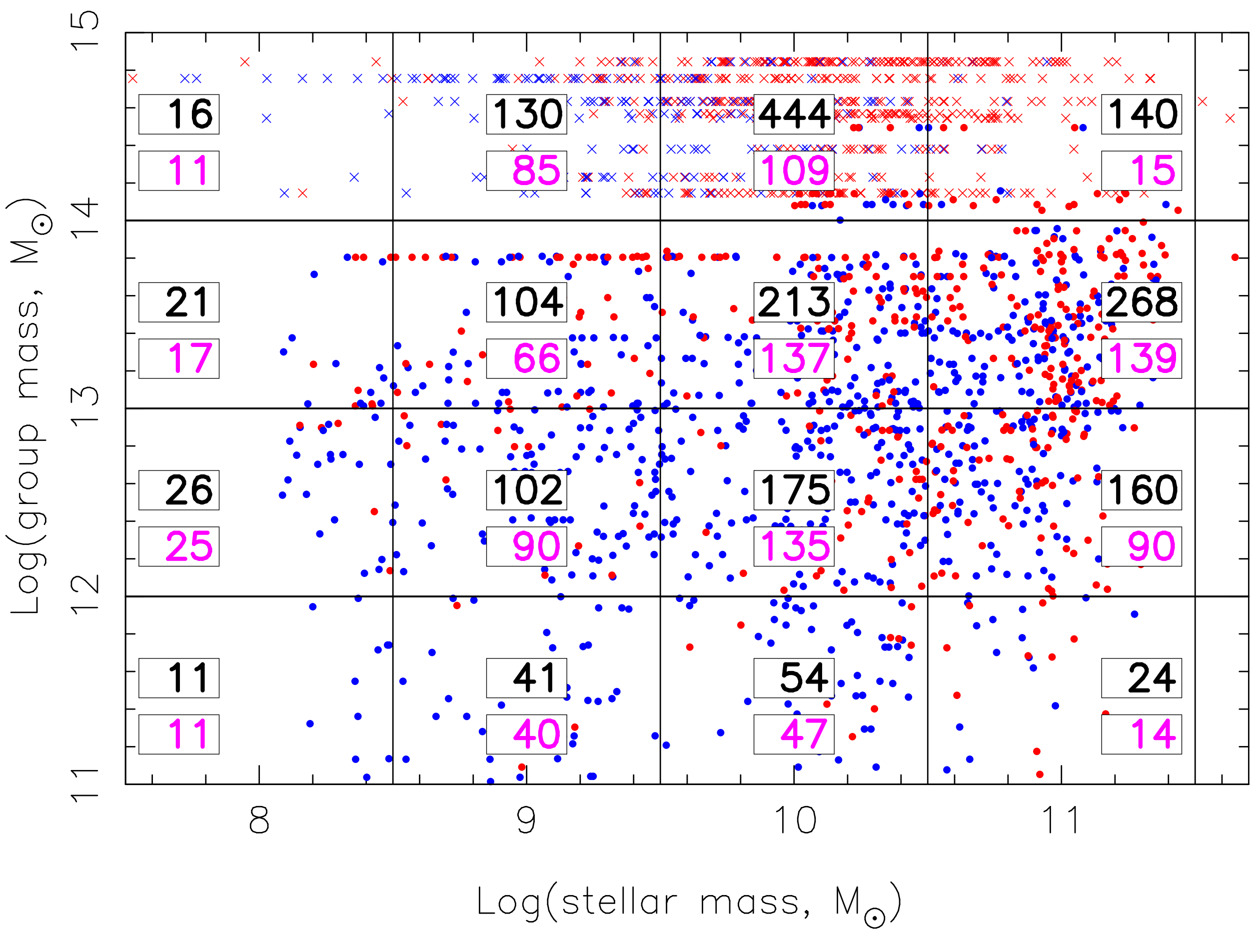


Design for 3-degree field of view AAT corrector

Summary

- Multi-object IFU surveys will provide the next revolution in galaxy evolution studies – **the natural next step.**
- This is already happening with SAMI: 600+ galaxies observed to date.
- Early days, but SAMI already generating first science: wind galaxies, SR/FR vs. environment… much more very soon!
- ***VISION:*** Single fibre galaxy evolution surveys a thing of the past! We can re-define how we observe galaxies in the local Universe and our understanding of galaxy evolution.

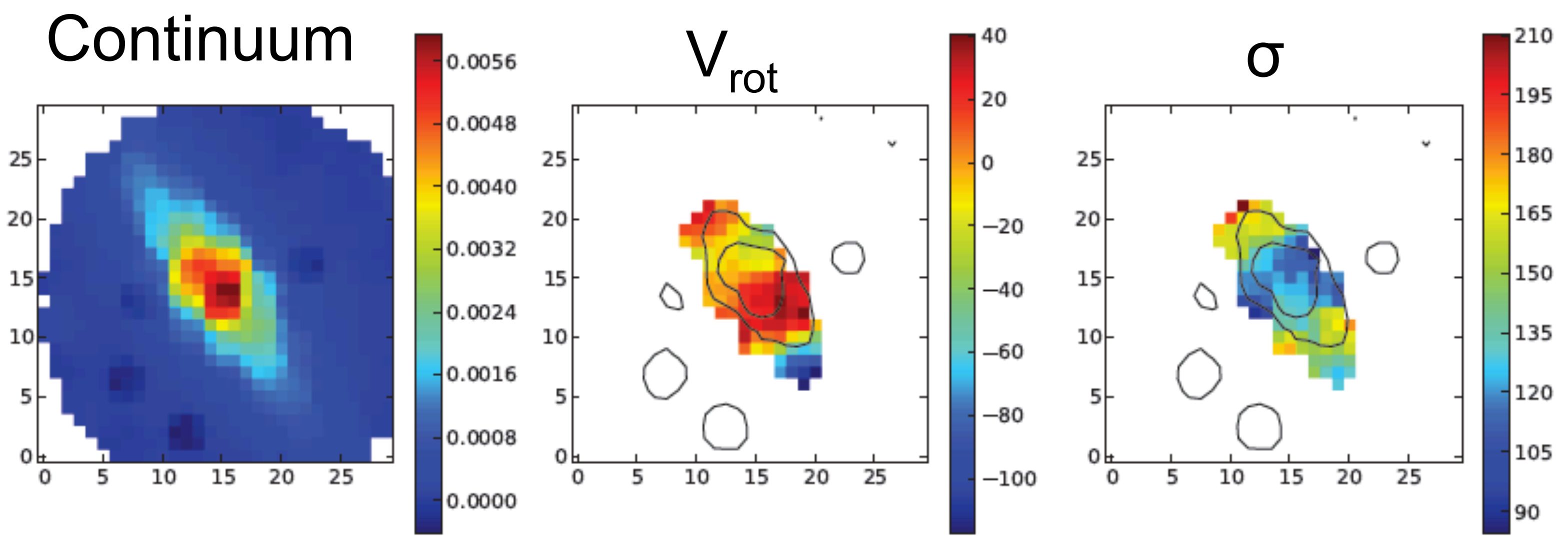
Target selection



Group masses from GAMA (Robotham et al., 2011).
Emission line and passive galaxies from GAMA/SDSS.

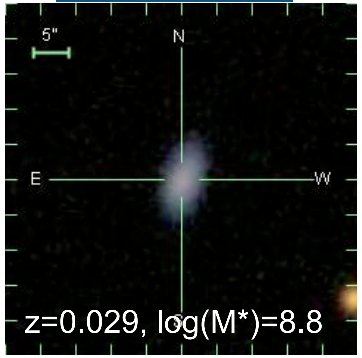
First science: fast/slow rotators in clusters

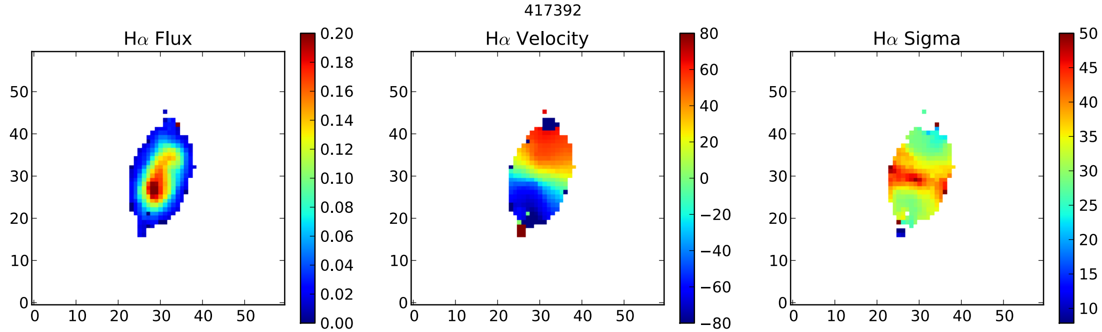
› Rare objects, counter-rotating disks:

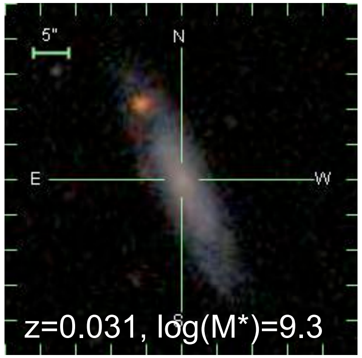


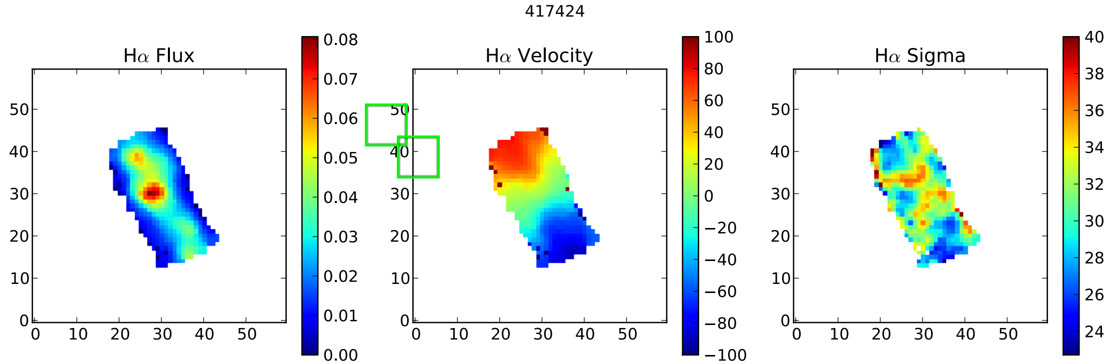
› Will eventually know how common these are as a function of environment, mass etc.

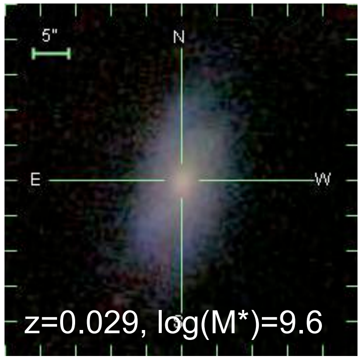
Examples…

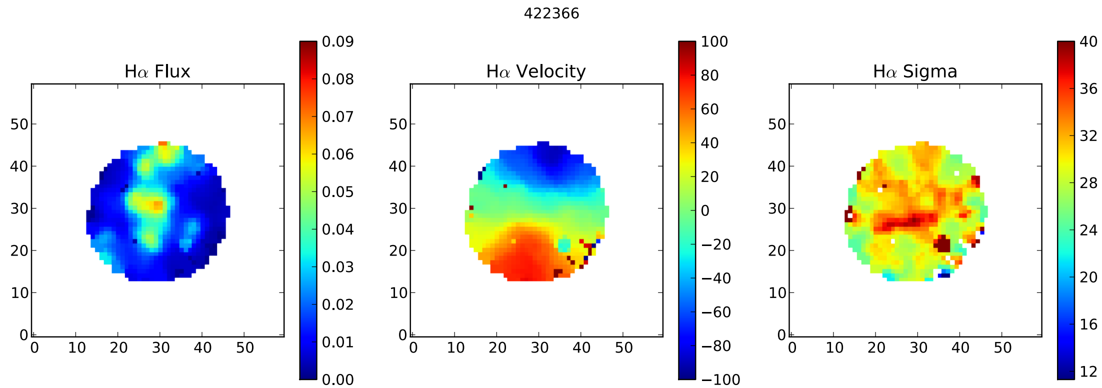

5"
N
E
W
z=0.029, log(M*)=8.8


417392
Hα Flux
Hα Velocity
Hα Sigma


5"
N
E
W
z=0.031, log(M*)=9.3

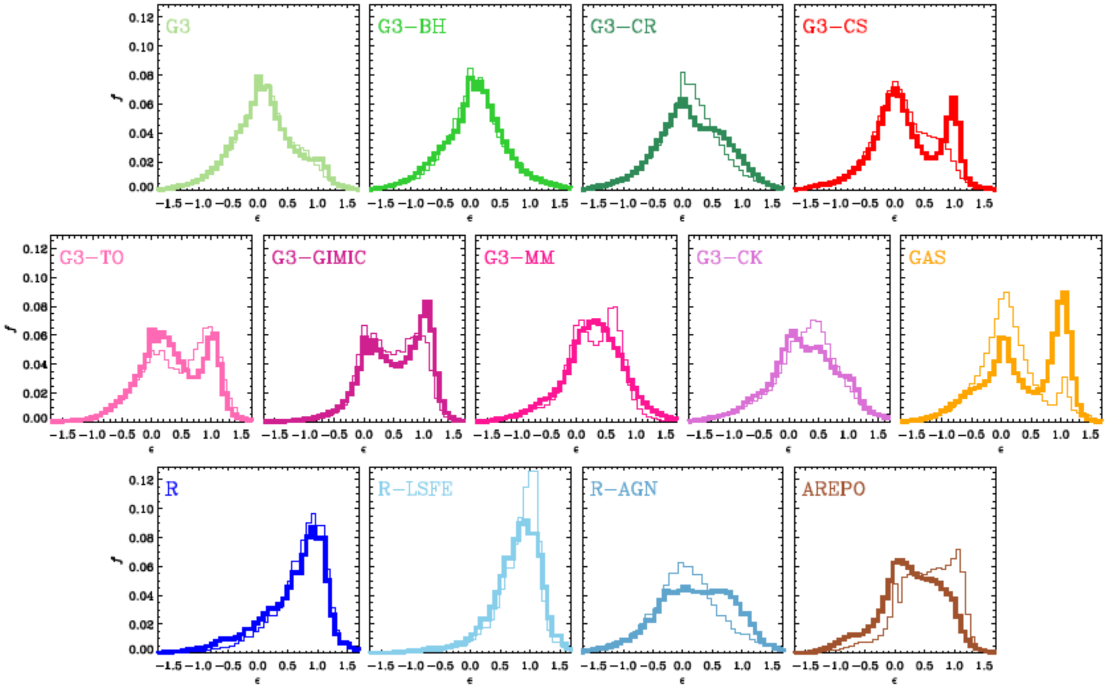

417424
Hα Flux
Hα Velocity
Hα Sigma


5"
N
E
W
z=0.029, log(M*)=9.6


422366
Hα Flux
Hα Velocity
Hα Sigma

Resolved kinematics: simulations…

› Still gross disagreement between different gas physics implementations (Aquila project; Scannapieco et al. 2012) – mostly due to feedback and sub-grid physics.



Same initial conditions.

Distribution of $\varepsilon = j_z/j_c$.

$\varepsilon \sim 1$ is due to a rotationally supported disk

Figure 3. Distribution of stellar circularities, $\epsilon = j_z/j_c$, for the different models. The circularity parameter is the z-component of the specific angular momentum of a star particle, j_z, expressed in units of the circular orbit value, j_c, *at that radius*. Stars with $\epsilon \approx 1$ typically belong to a rotationally-supported disk component. Thick and thin lines correspond to level-5 and level-6 resolution runs, respectively.

Hexabundles

- Fibres IFUs without lenslet arrays that have high fill factor and can be handled similarly to single fibre (MOS) systems.
- Over short distances (few cm), cladding only needs to be 2λ, not the assumed 10λ (Bland-Hawthorn et al. 2009, 2011).
- Better FRD properties for bundles that are not fully fused (Bryant et al., 2011). SAMI bundles have 75% fill factor.