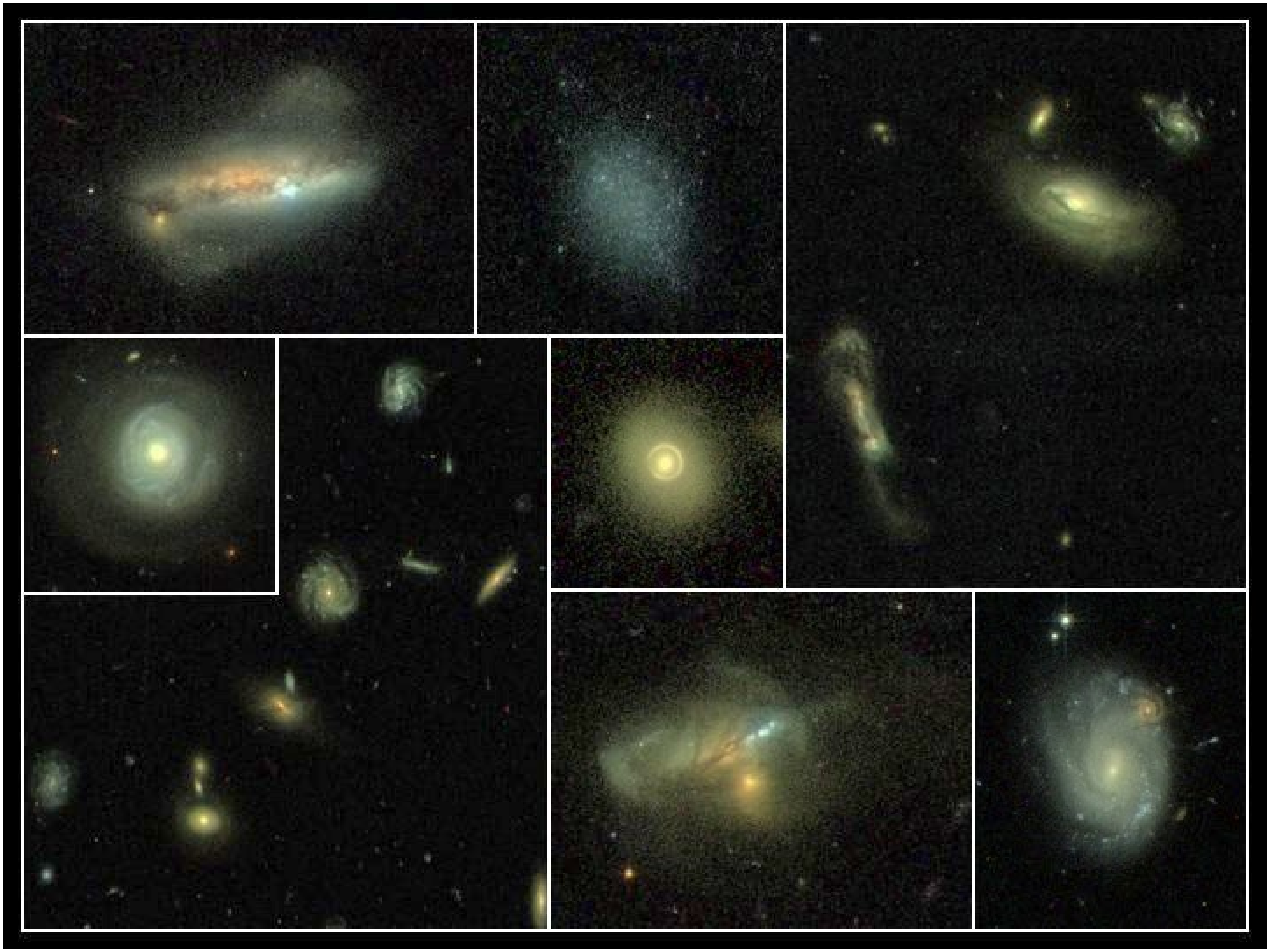
Semi-analytical models explain everything !

Eelco van Kampen
Institute for Astro- and Particle Physics,
University of Innsbruck, Austria

Well, maybe not quite explain, and maybe not quite everything ….

Morphology …



Recipes for galaxy formation …

Milky Way Galaxy recipe

Ingredients:
2 parts amaretto almond liqueur
1 cup milk
1 tsp vanilla extract
cinnamon

Recipe: Combine milk, amaretto and vanilla extract in a blender for 60 seconds. Pour over ice cubes in an old-fashioned glass, and sprinkle with cinnamon. Stir with a straw, and serve.

source: www.drinksmixer.com/drink494.html

Modelling galaxy formation

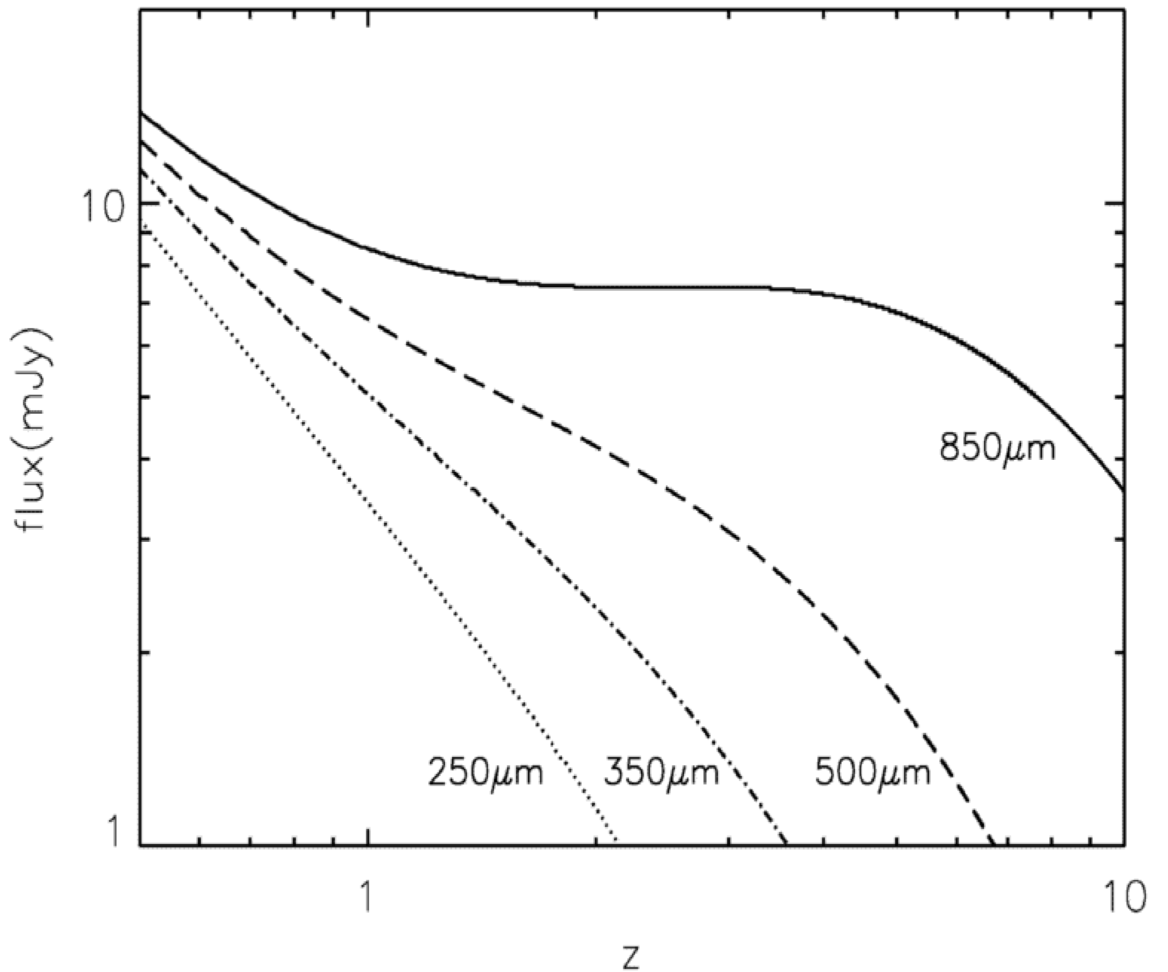
Phenomenological galaxy formation models are becoming more sophisticated and realistic as we add more and more ingredients, each with various associated parameters.

These parameters need to be constrained using observational data: but which data, and where ?

- high-redshifts, where galaxies form
- overdensities, where galaxies evolve

A clear view from z = 1 to z = 8

Exploiting negative *K* correction for dust emission in the sub-mm waveband:
at 850 micron, a galaxy has same flux density from *z* = 1 to z= 8



A clear view from the JCMT

Dust emission: far-IR & sub-mm

Dusty star-forming galaxies emit much of their light at IR to mm wavelengths

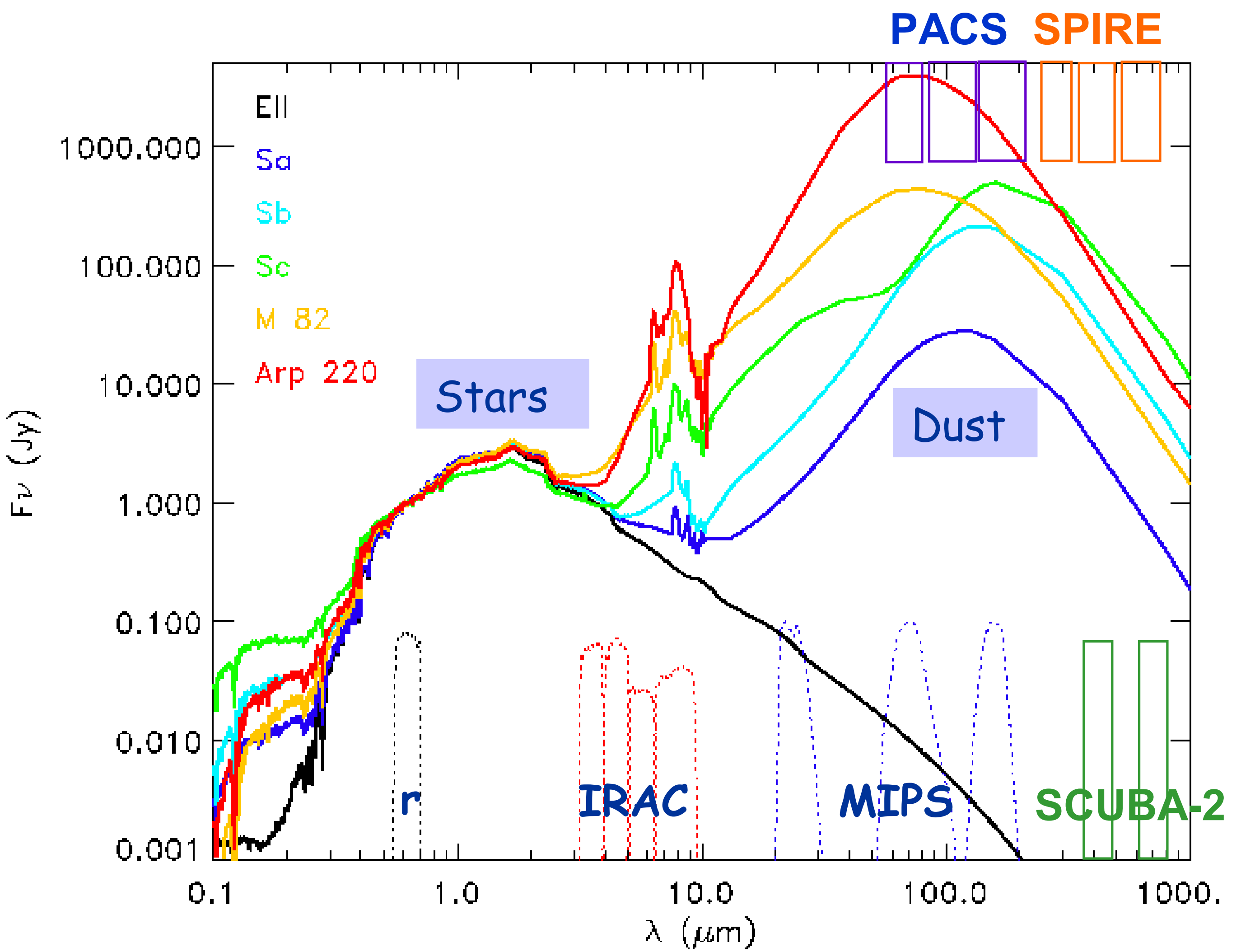
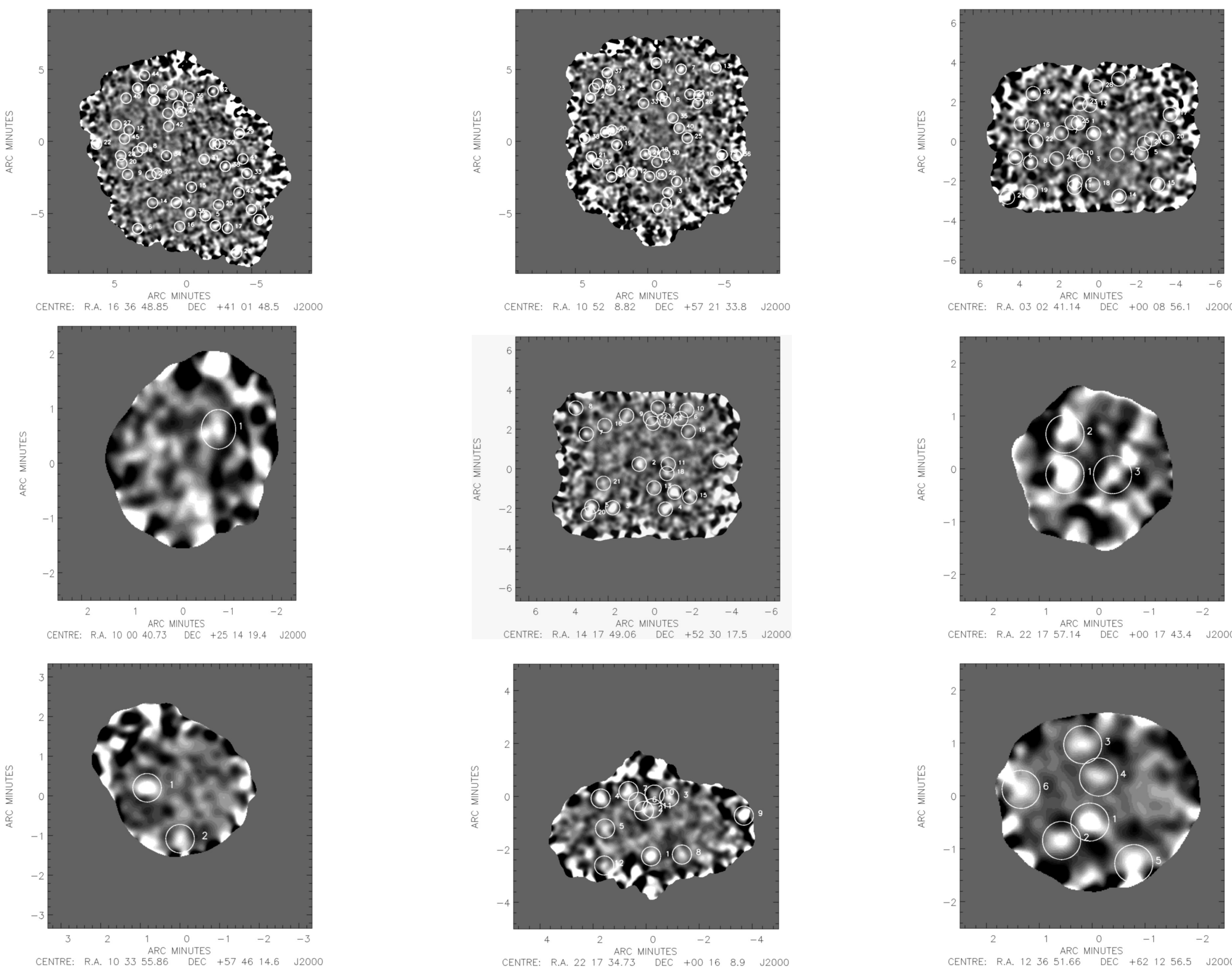


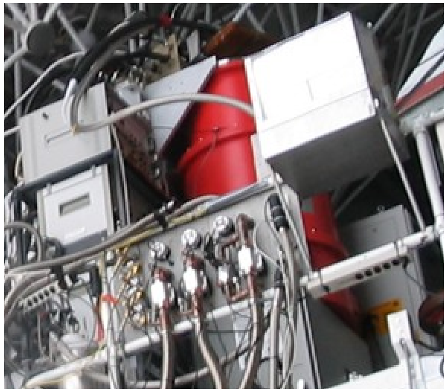
Figure compiled by Mari Polletta

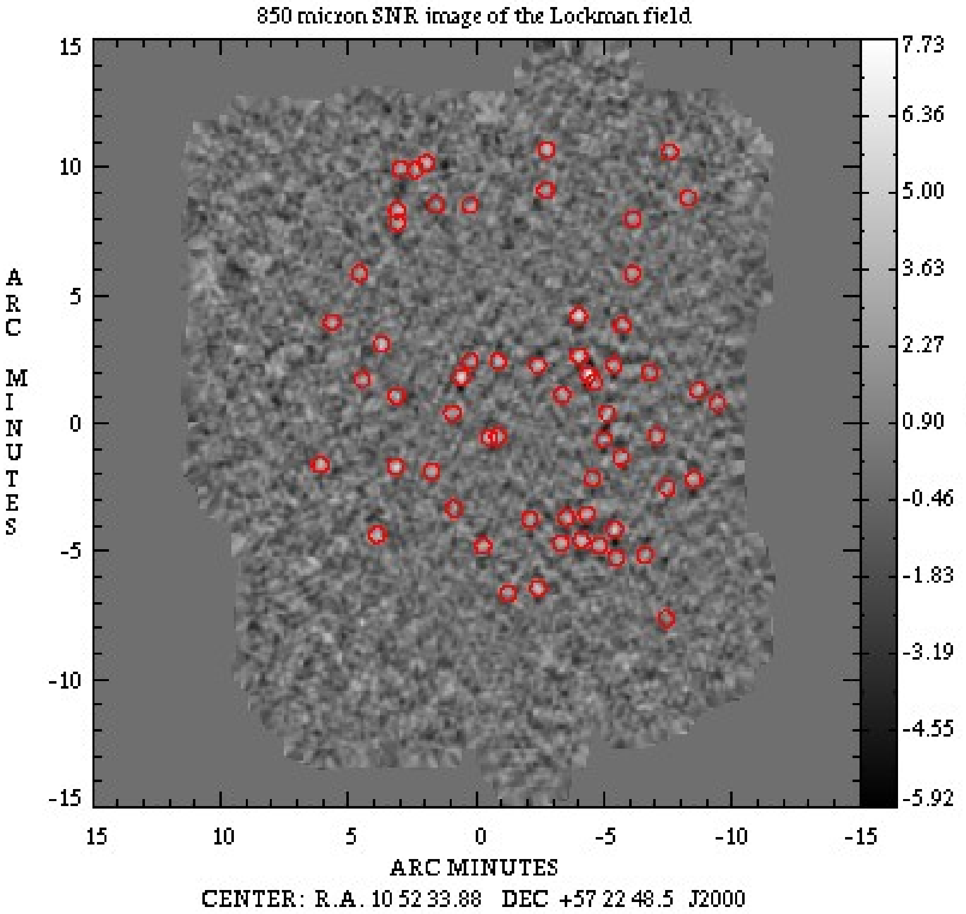

ARC MINUTES
CENTRE: R.A. 16 36 48.85 DEC +41 01 48.5 J2000
CENTRE: R.A. 10 52 8.82 DEC +57 21 33.8 J2000
CENTRE: R.A. 03 02 41.14 DEC +00 08 56.1 J2000
CENTRE: R.A. 10 00 40.73 DEC +25 14 19.4 J2000
CENTRE: R.A. 14 17 49.06 DEC +52 30 17.5 J2000
CENTRE: R.A. 22 17 57.14 DEC +00 17 43.4 J2000
CENTRE: R.A. 10 33 55.86 DEC +57 46 14.6 J2000
CENTRE: R.A. 22 17 34.73 DEC +00 16 8.9 J2000
CENTRE: R.A. 12 36 51.66 DEC +62 12 56.5 J2000

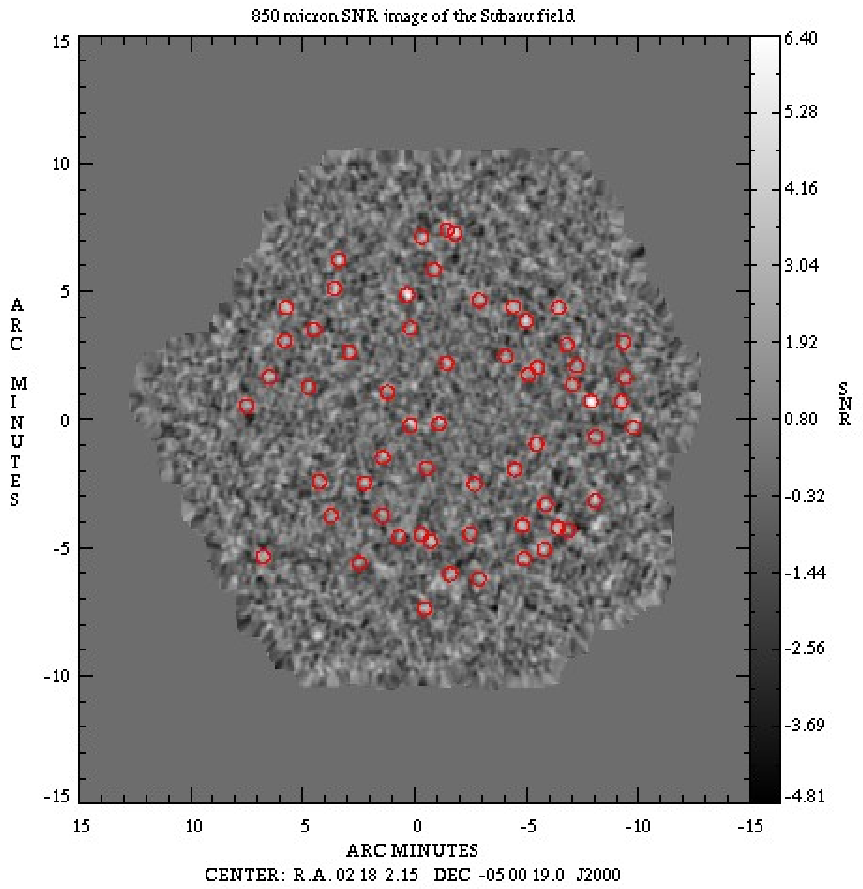
SHADES: SCUBA half-degree survey

2 fields – Lockman Hole & SXDF @ 850 micron

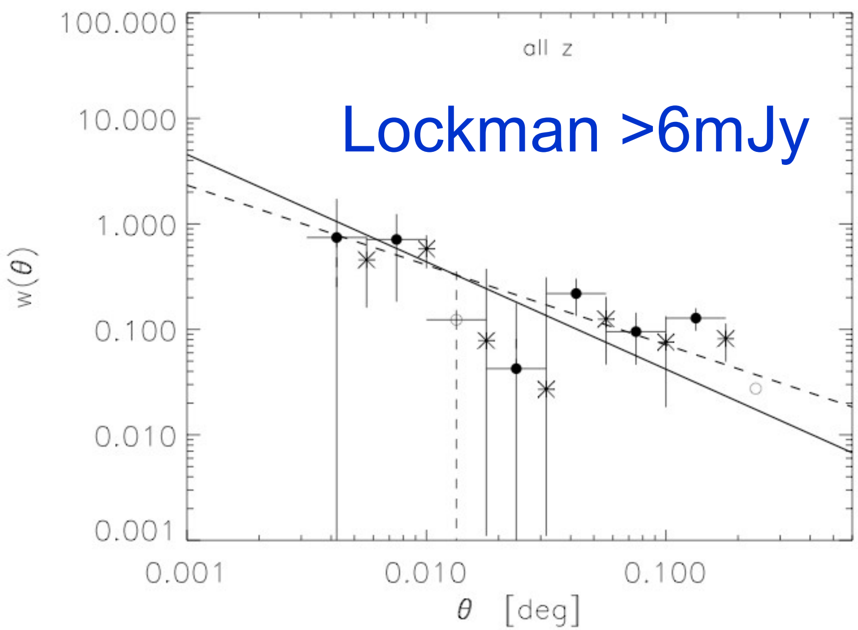
120 sources with unbiased (deboosted) flux densities

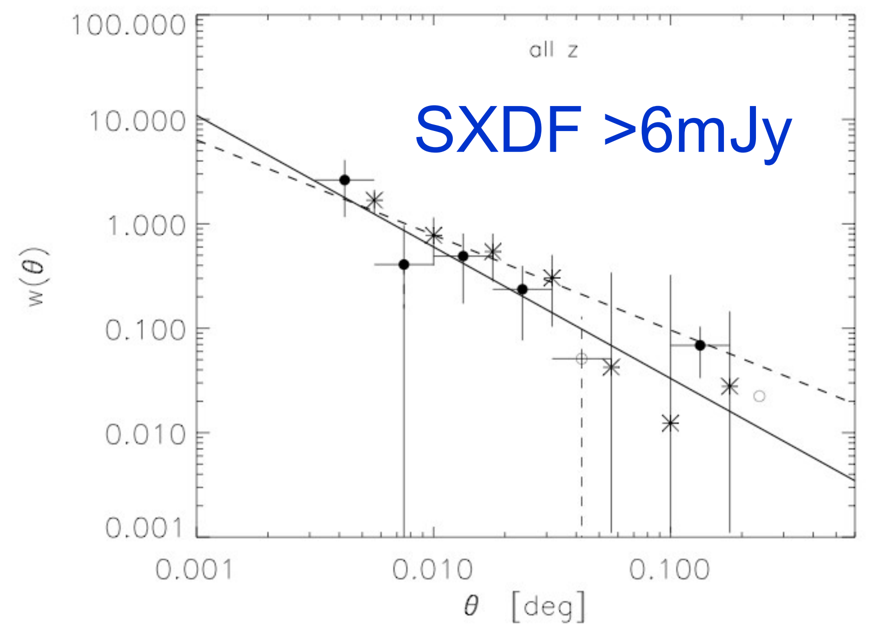






SHADES clustering measurement





Large dots and solid line (fit) for the angular correlation function $w(\theta)=(\theta/A)^{-\delta}$

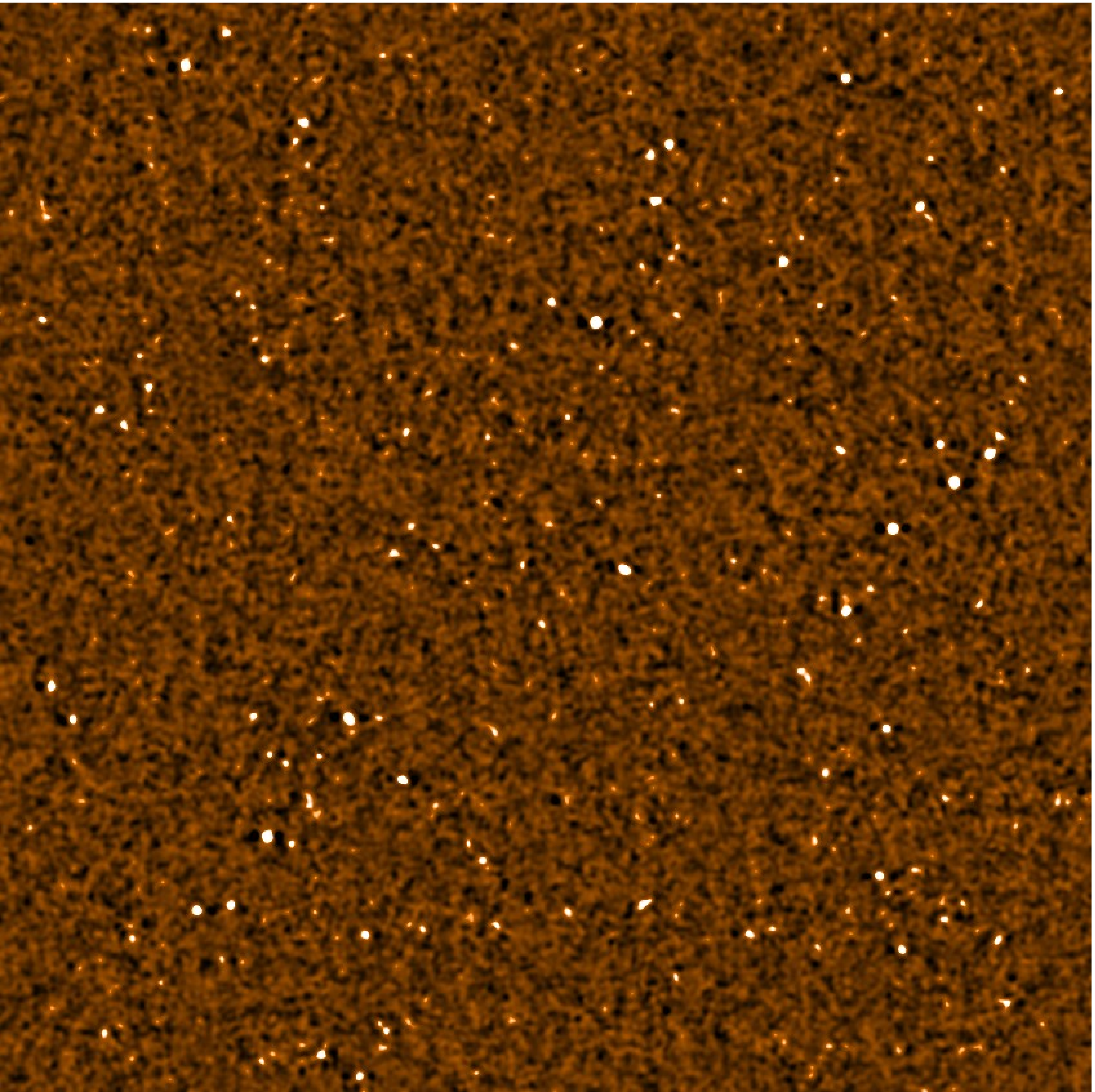
Stars and dashed line (fit) for the sky-averaged angular correlation $\langle w \rangle_{\Omega}(\theta)$

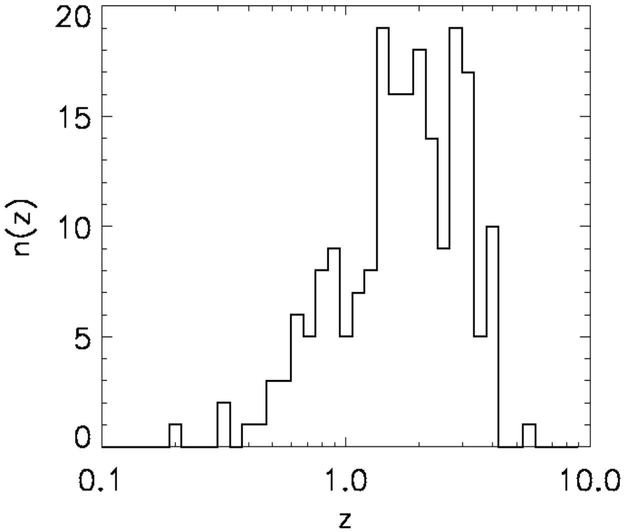
Lockman: A = 11.0" +/- 8.7"
δ= 0.76 +/- 0.31

SXDF: A = 27.4" +/- 14.7”
δ = 0.91 +/- 0.43

(both estimates from the sky-averaged angular correlation functions)

Simulating SHADES

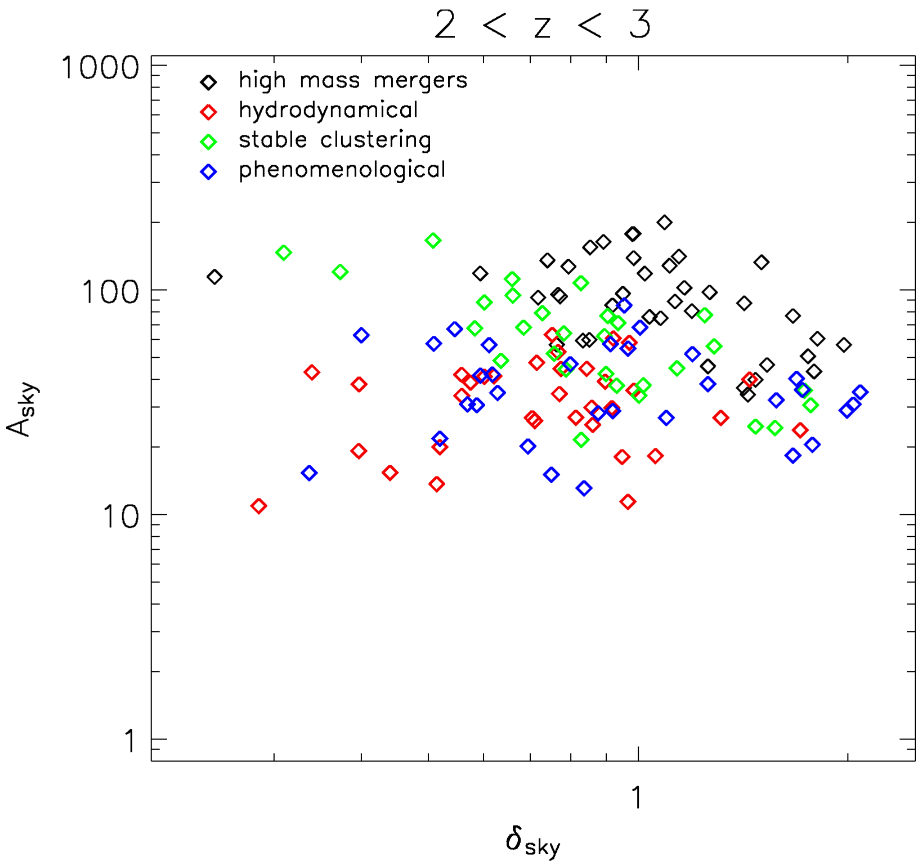




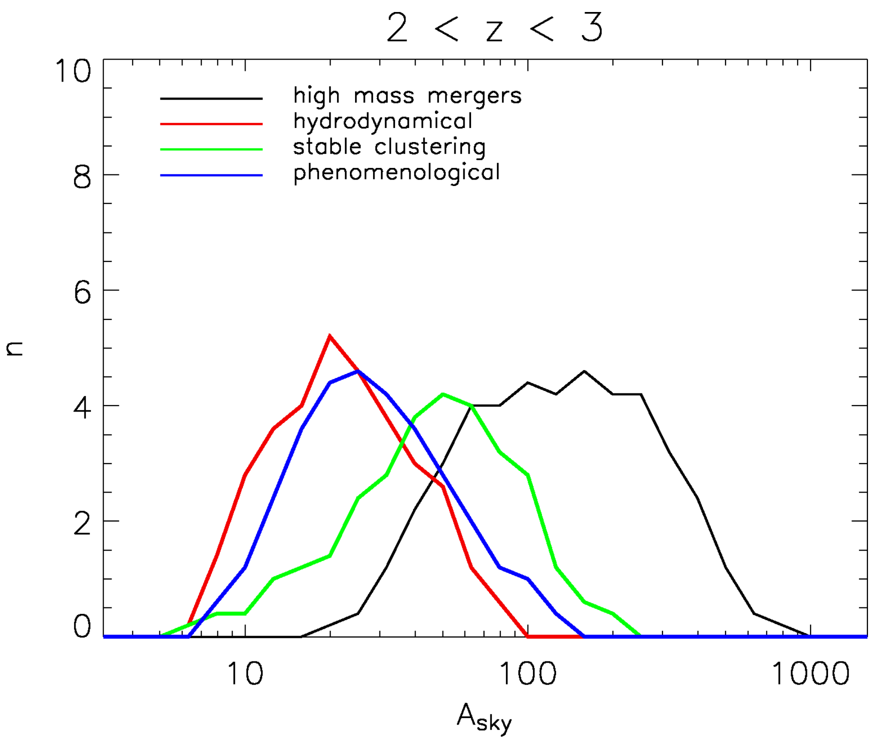
Mock SHADES map and redshift distribution

Predictions for SHADES with redshifts

Fit to slope and amplitude

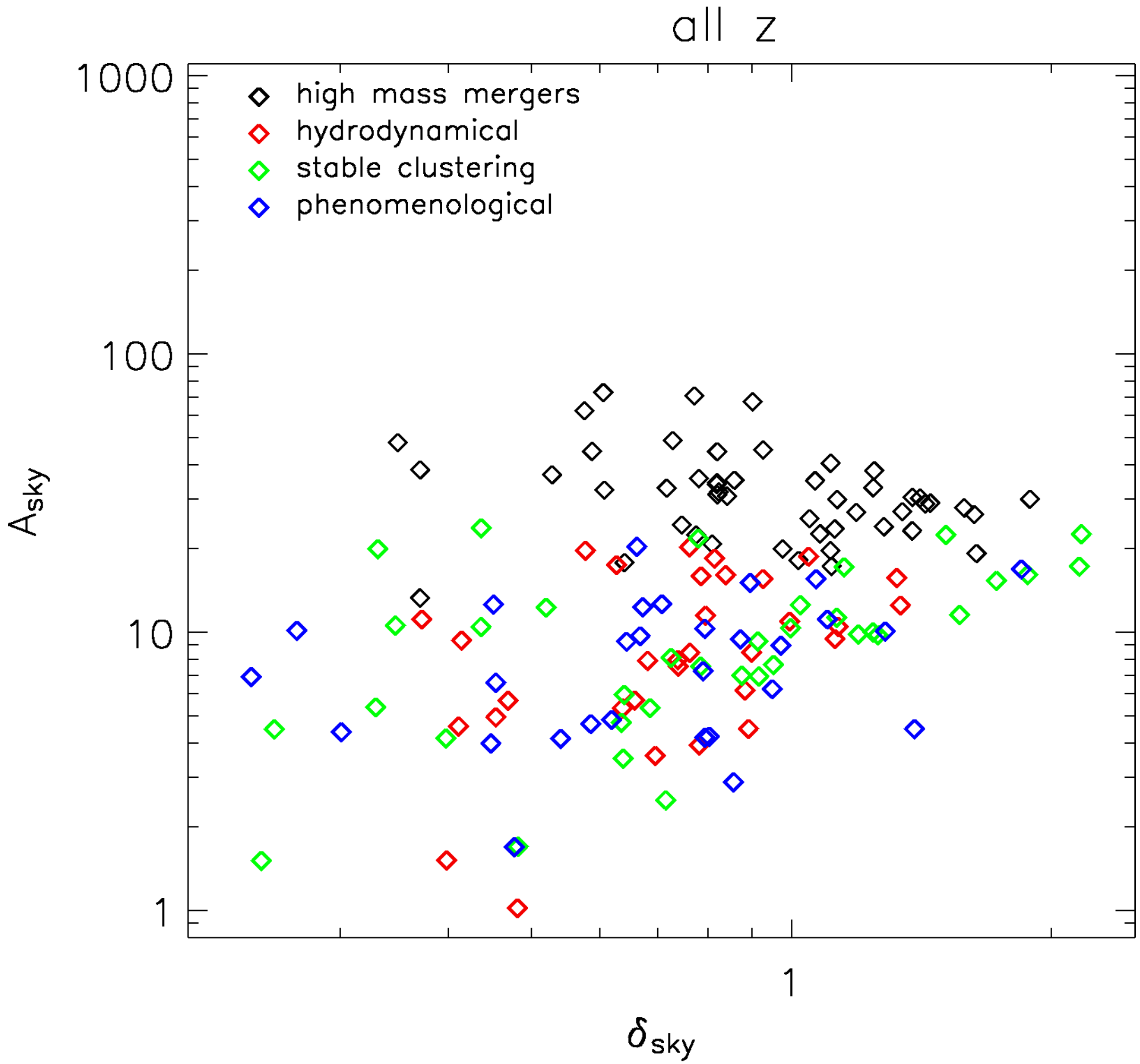


Fit to amplitude only (slope fixed to 0.8)



van Kampen et al. (2005)

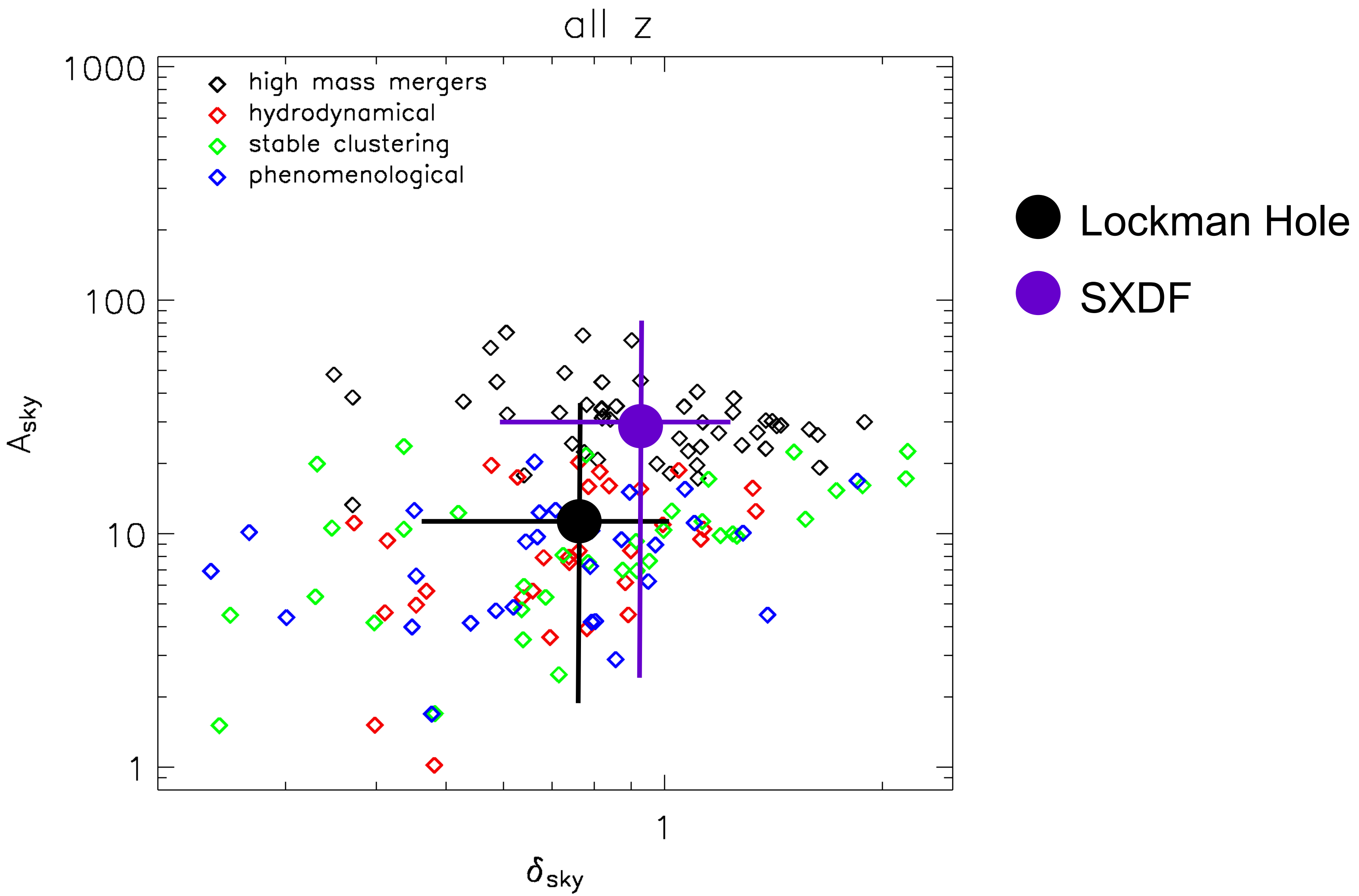
Clustering predictions for *SHADES*



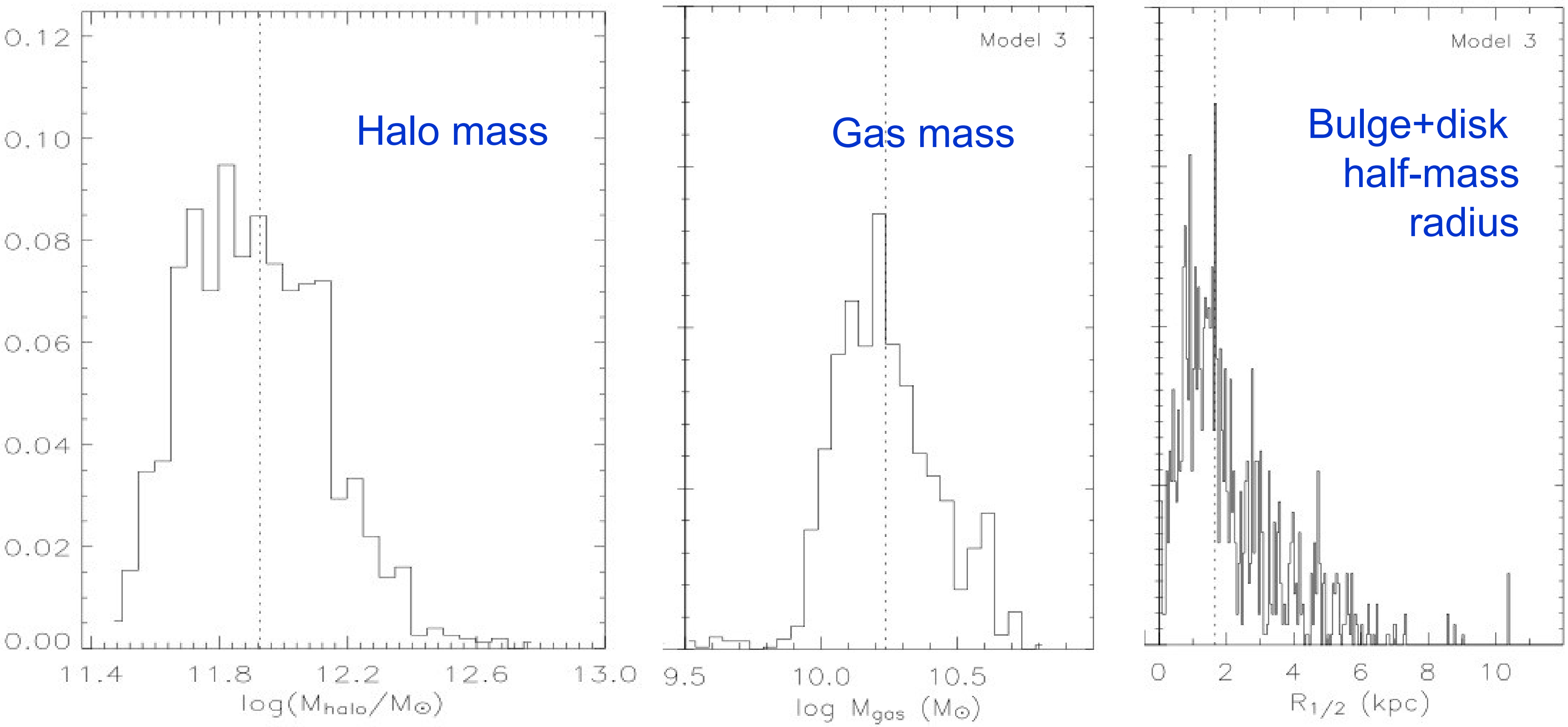
Fit to slope and amplitude for 25 mocks for four different galaxy formation models

van Kampen et al. (2005)

Model-data comparison for *SHADES*



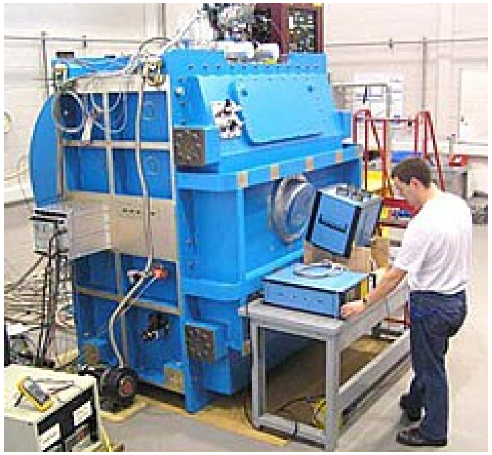
Sub-mm galaxies: parent halo properties

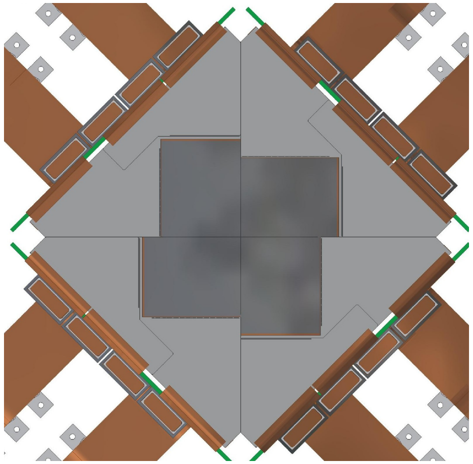


SCUBA-2

SCUBA-2 is a new generation imager for the JCMT

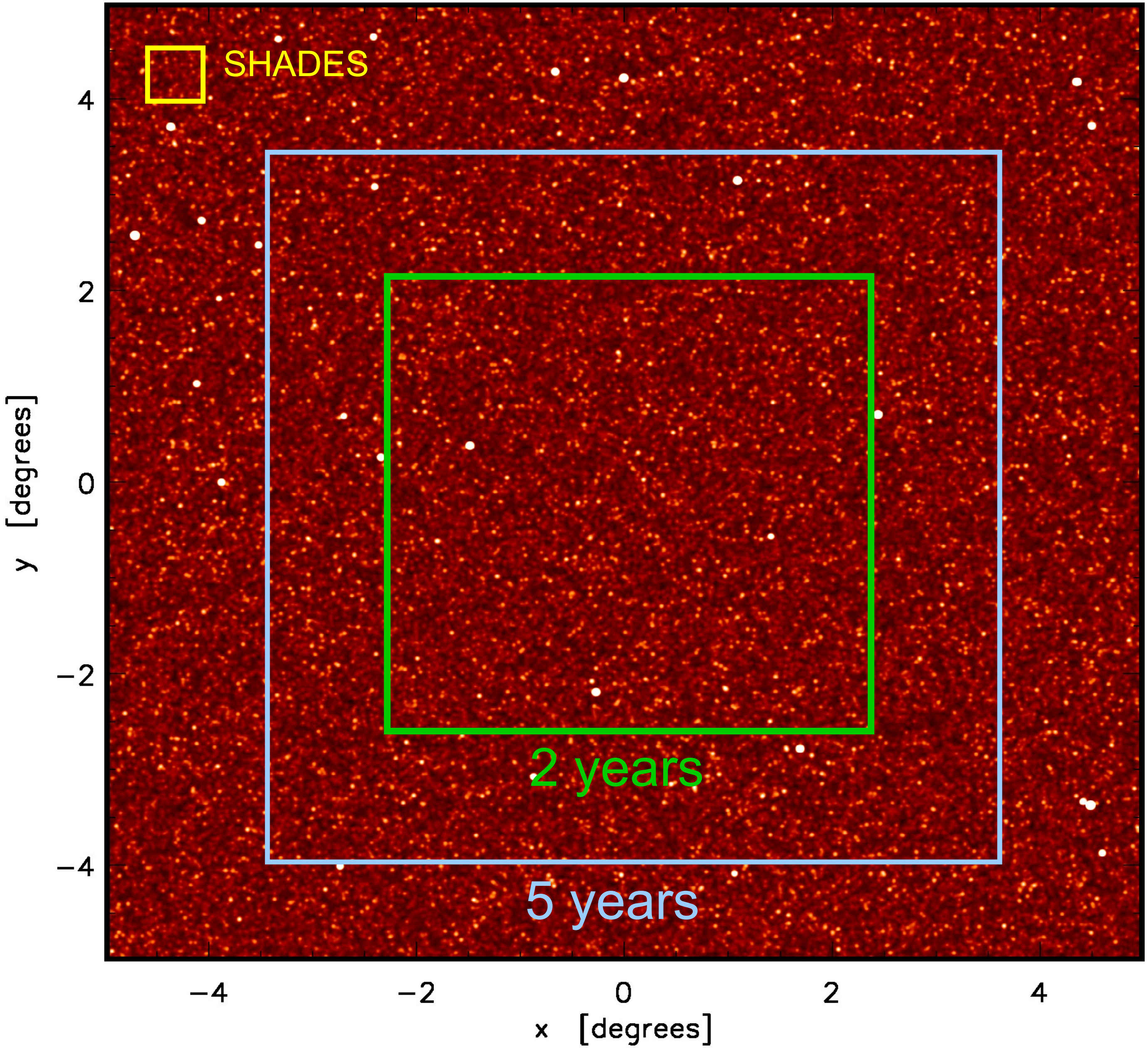
- Novel scanning mode to realise large-area surveys
- Imaging of the sky at 450 & 850 micron simultaneously
- A large (>50 arcmin^2) field-of-view
- Sensitivity governed by the sky background
- Provide fully-sampled images of the sky in ~ 4 seconds





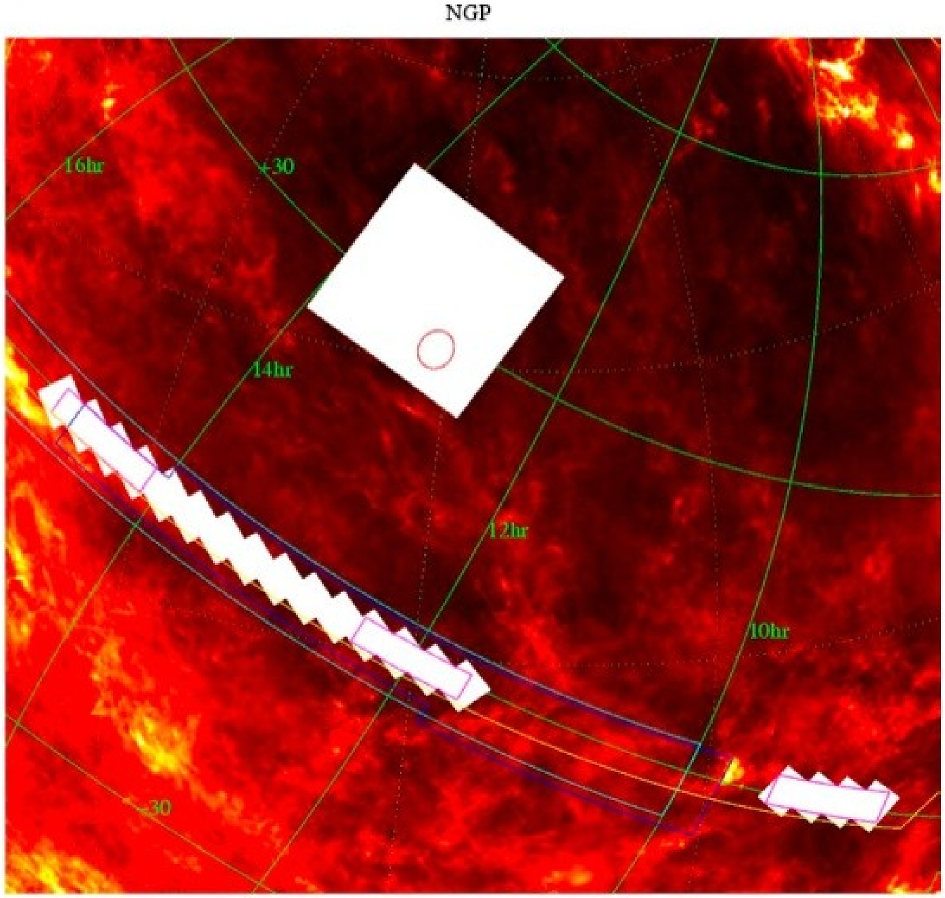
SCUBA-2 will bring “CCD-style” imaging to the JCMT for the first time

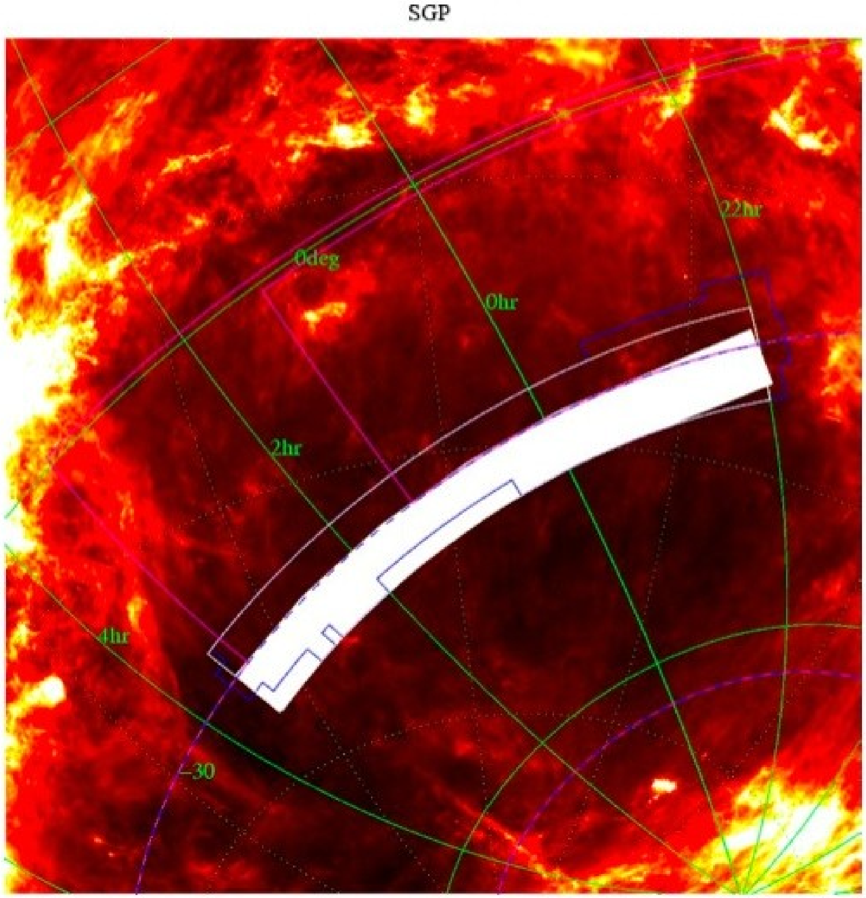
SCUBA-2 Cosmology Legacy Survey



Herschel ATLAS: 600 sq. degree survey

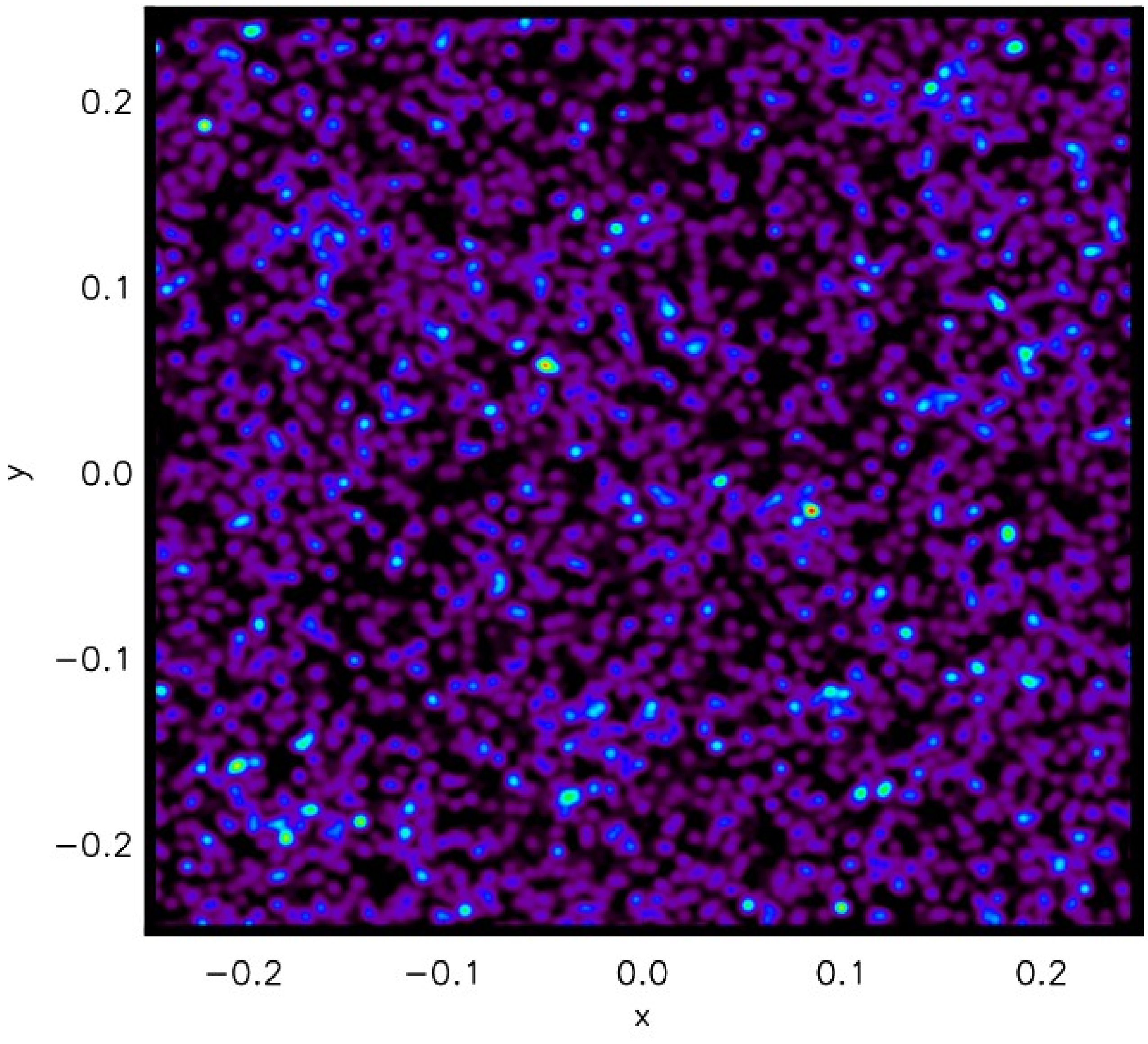
Proposed ATLAS fields (white blocks) superimposed on the IRAS 100 micron maps



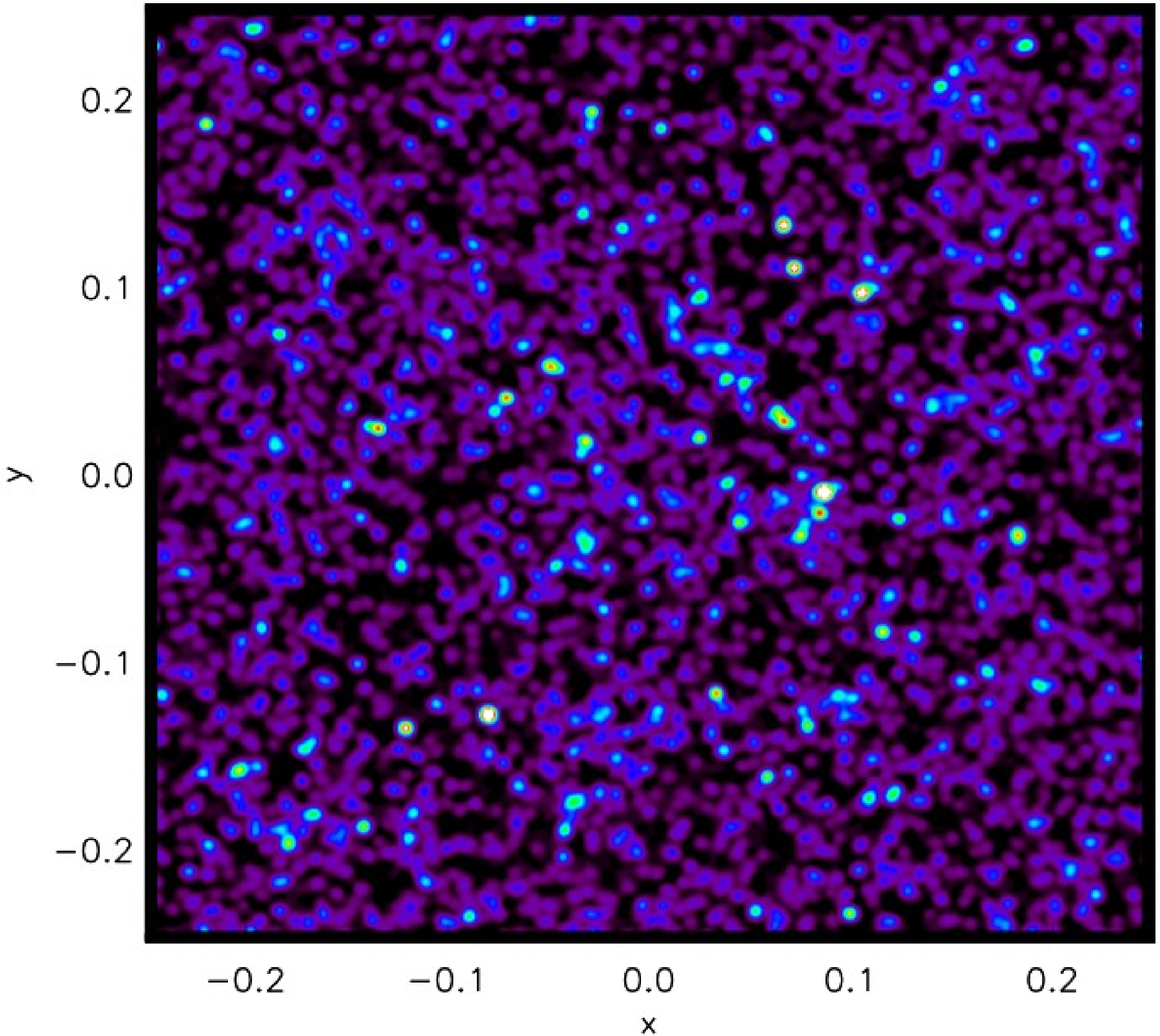


In the north the outlines of the other surveys are: 2dFGRS - continuous blue; VIKING/KIDS - cyan; GAMA - magenta ; SDSS - yellow. The red circle shows the area covered by the Coma cluster.
In the south the surveys are: 2dFGRS - continuous blue; VIKING/KIDS - cyan; Dark Energy Survey - magenta; South Pole Telescope - dashed blue.

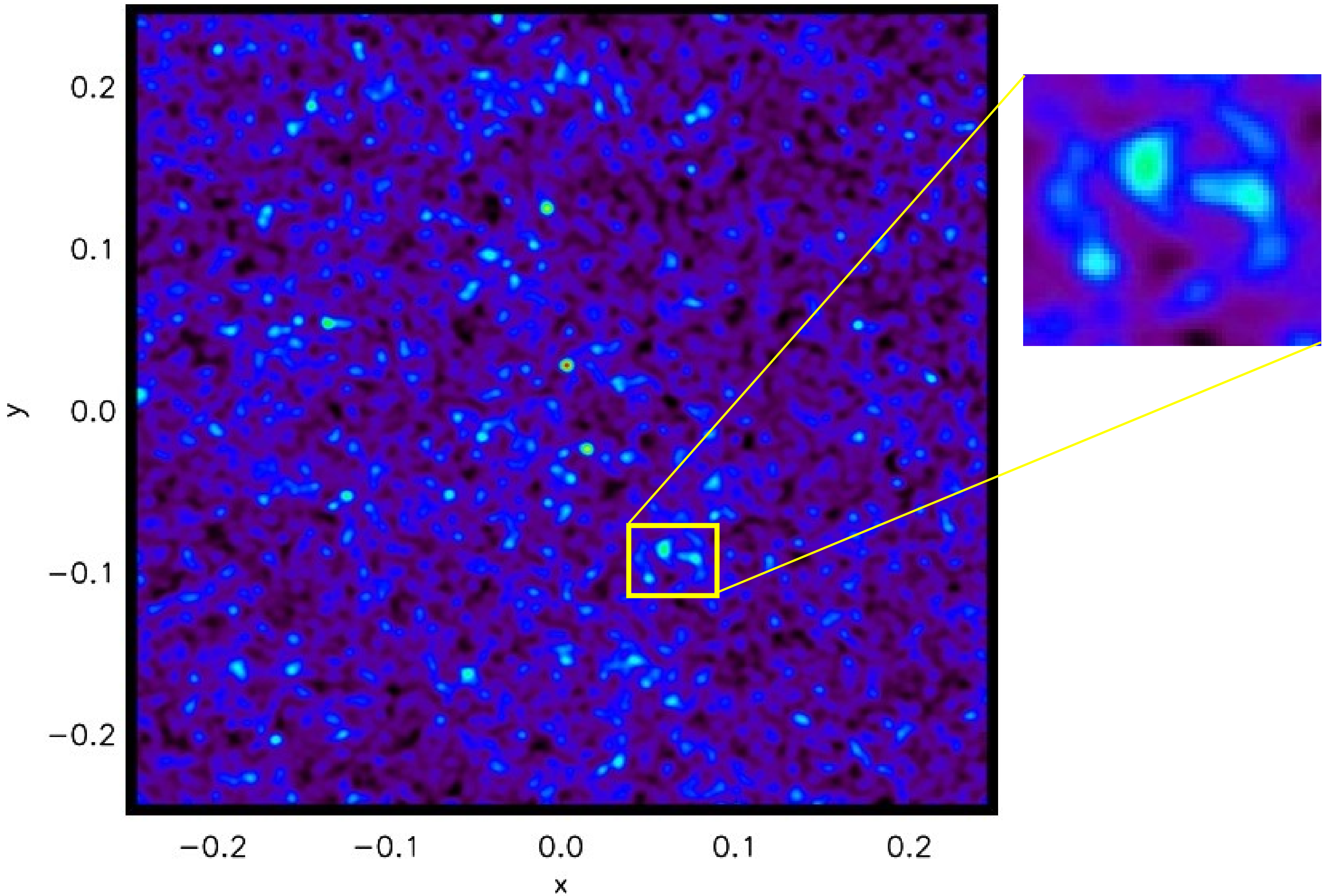
A mock blank field (850 micron @ JCMT)



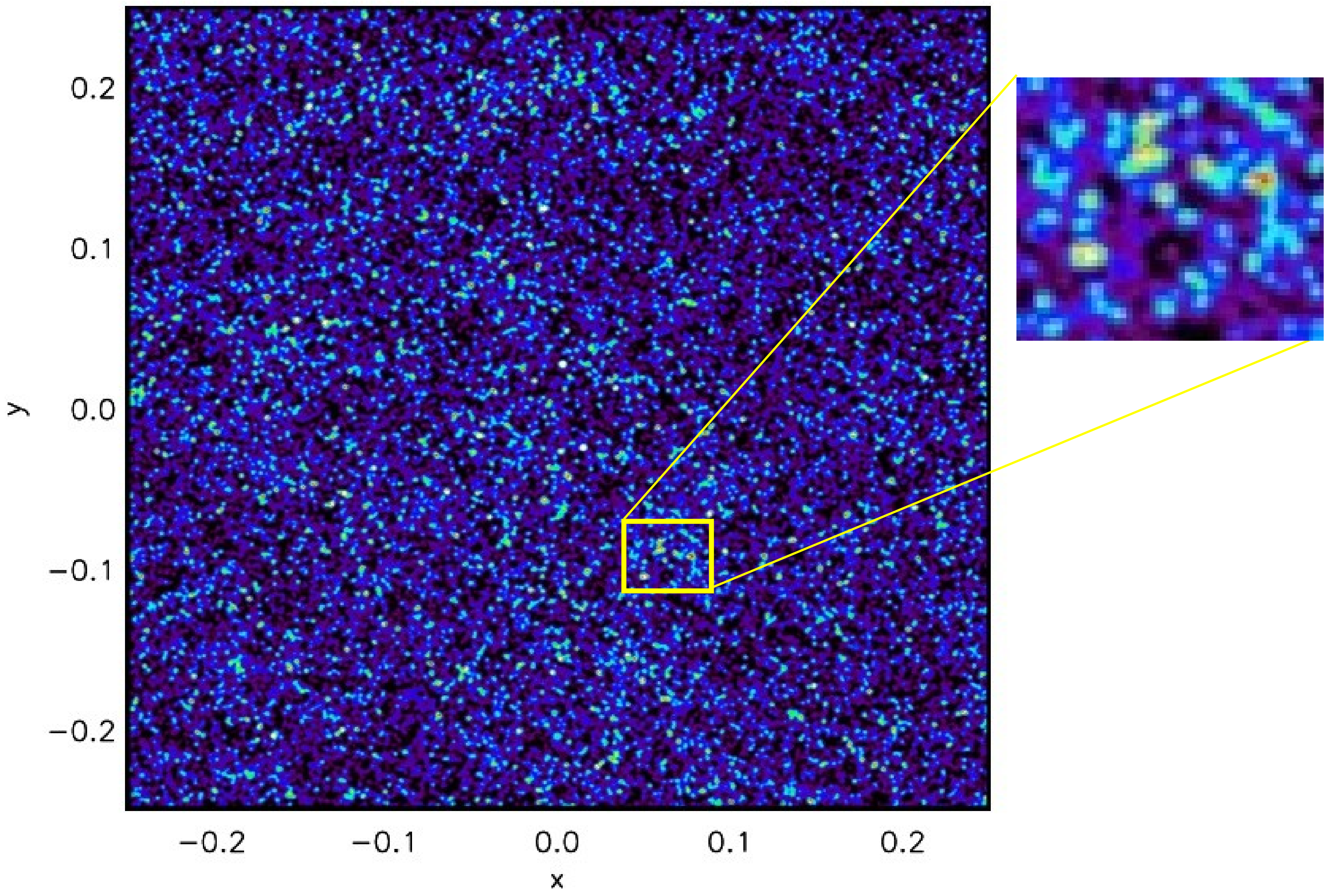
Add a mock (proto-)cluster at z=2.5



AzTEC @ JCMT (mock map)



AzTEC @ LMT 50m (mock map)



Galaxy evolution

Physical drivers for galaxy evolution, internal & external:

- Keeping the gas hot through ‘feedback’ mechanisms
  - Supernova heating
  - Reionization
  - AGN
- Turn less cold gas into stars
  - Kennicutt threshold
  - More extended disks (higher angular momentum)
- Taking away the gas supplies (hot and/or cold)
  - Stripping from the halo and/or disk

Environmental physics

Trace galaxy orbits within clusters, so that we can model:

- ram-pressure stripping
- galactic winds (limited by the ICM)
- tidal processes, incl. harassment, starbursts, etc.

These processes have an effect on:

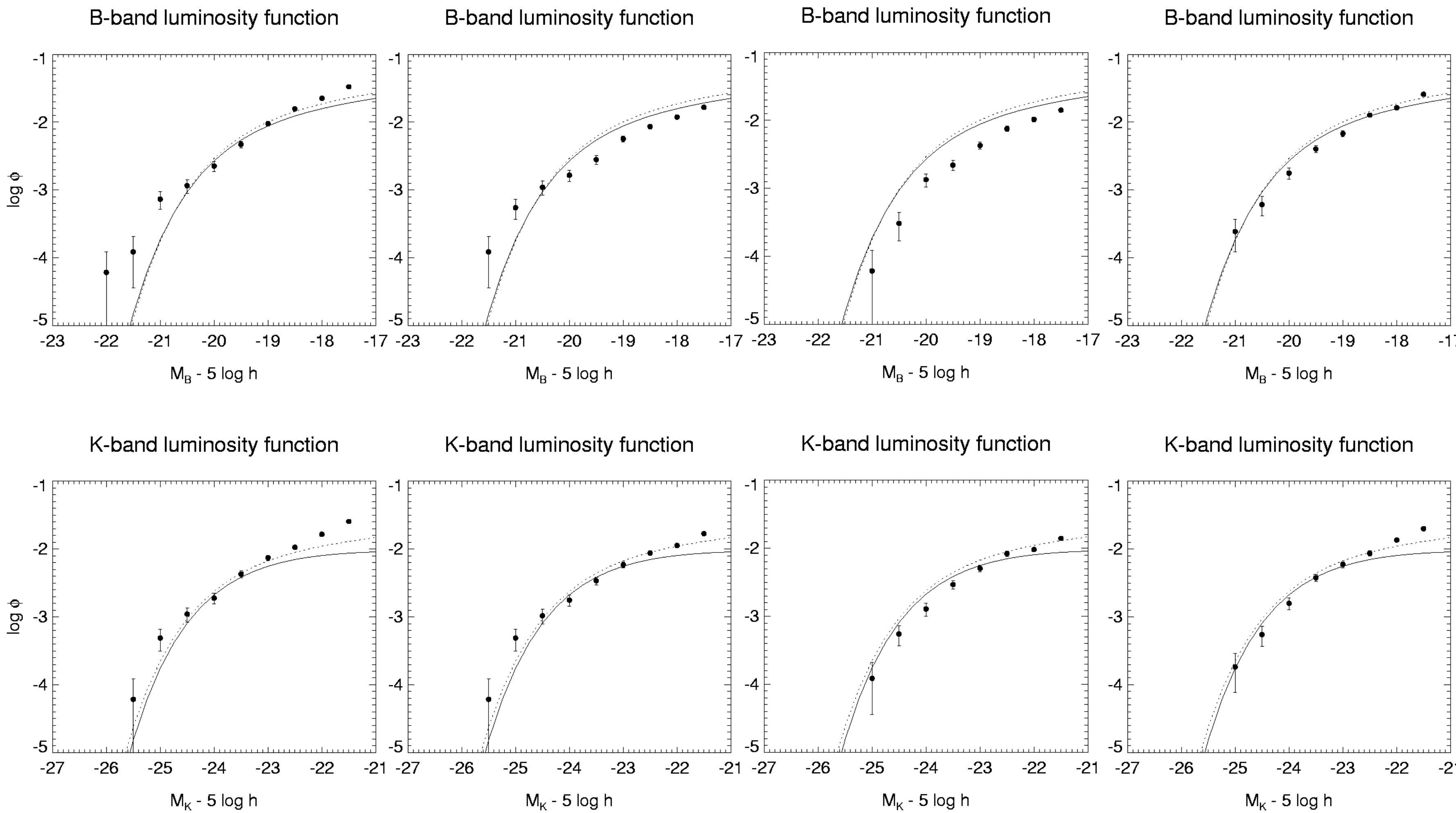
- galaxy evolution in and around (super)clusters
- properties of the ICM (metallicity)

→ combined N-body / phenomenological / hydro code

(dark matter) (galaxies) (ICM)

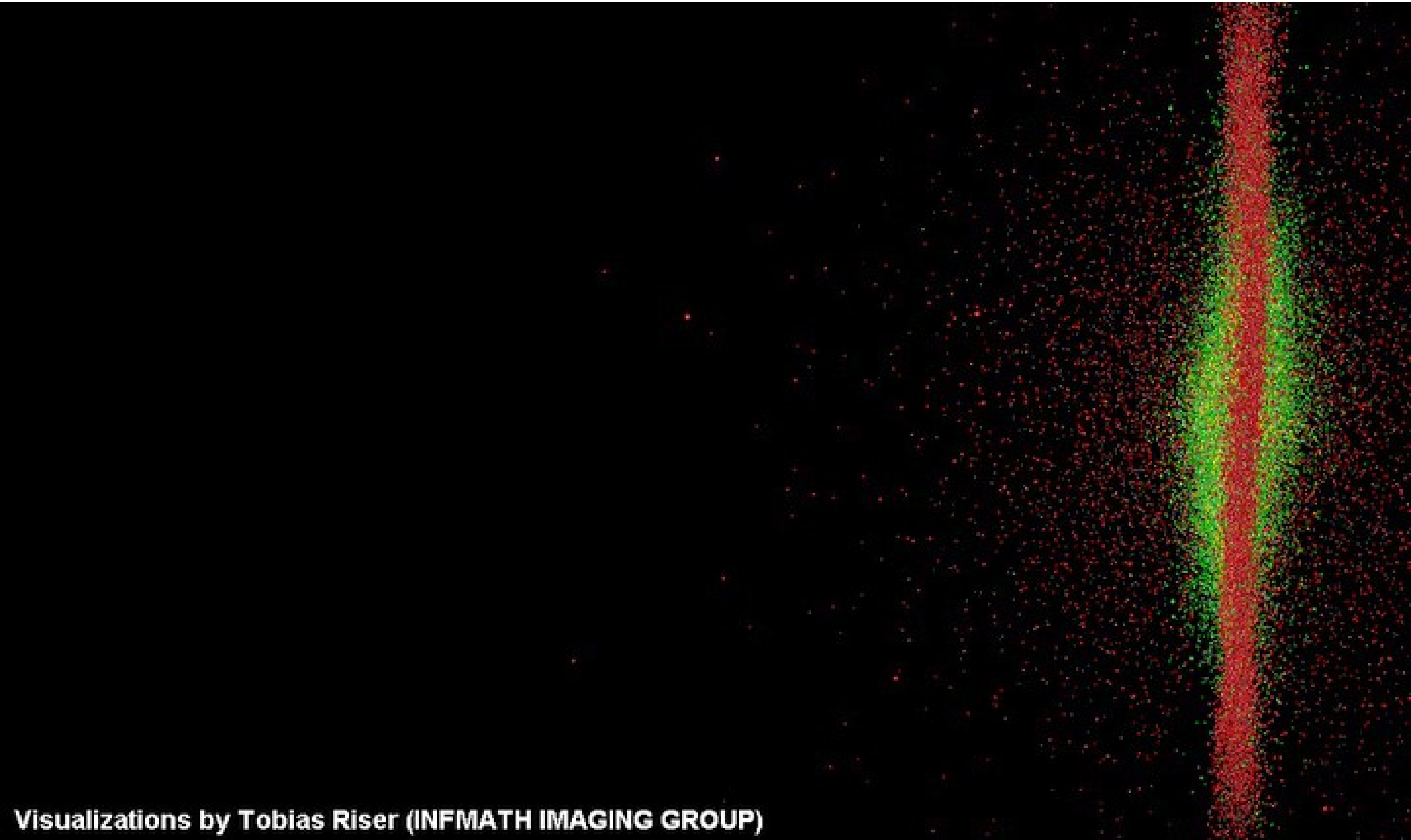
Luminosity functions (B- and K-bands)

No threshold/stripping | Kennicutt threshold | Crude stripping | Ram-pressure stripping



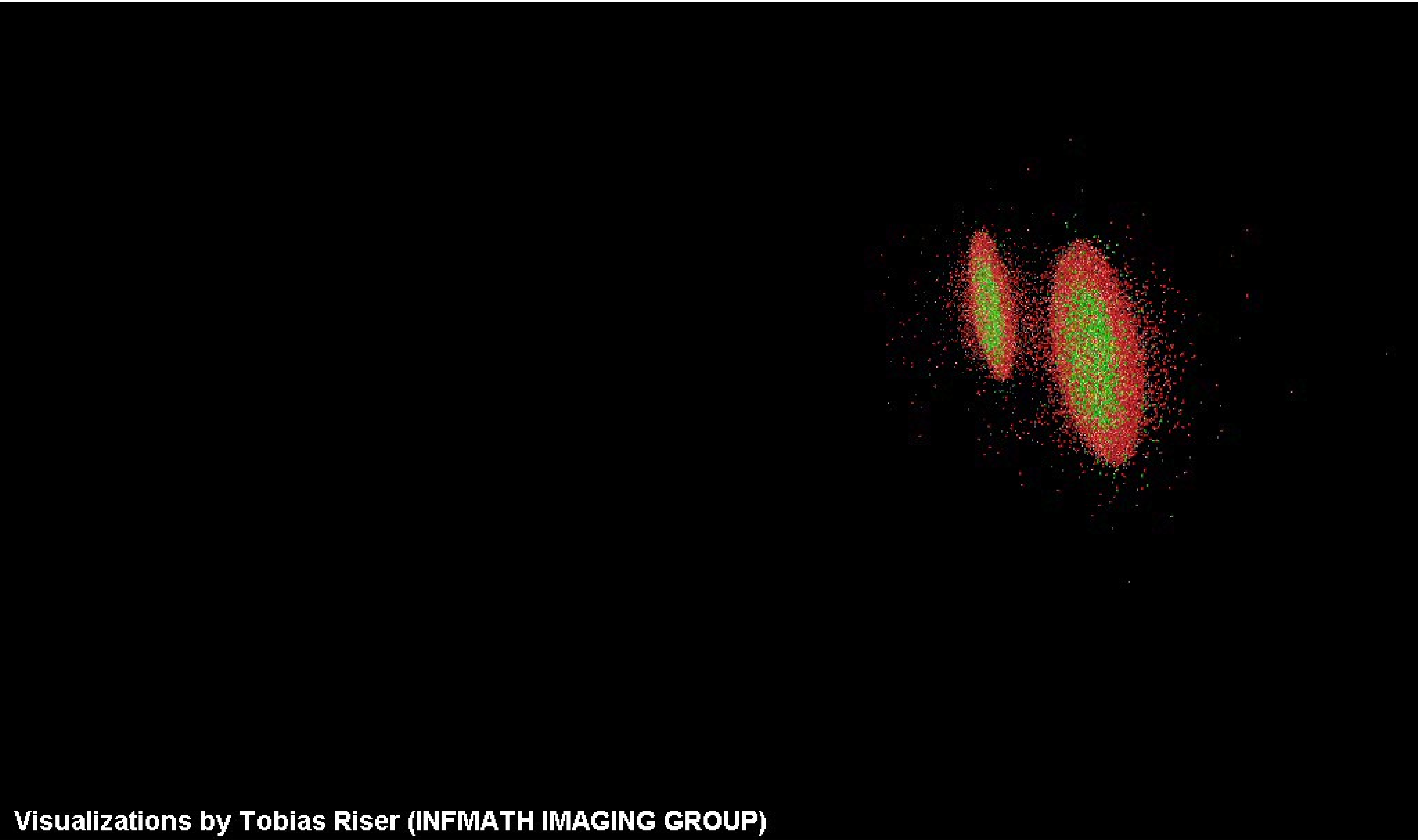
Environmental effects on the evolution of galaxies

The effects of ram-pressure stripping a single galaxy



Environmental effects on the evolution of galaxies

The effects of ram-pressure stripping a pair of interacting galaxies



But SIMs are also SAMs …

➔ **sub-grid physics** !

(in this case the hybrid method for star formation and feedback introduced by Springel & Hernquist (2003) was used)

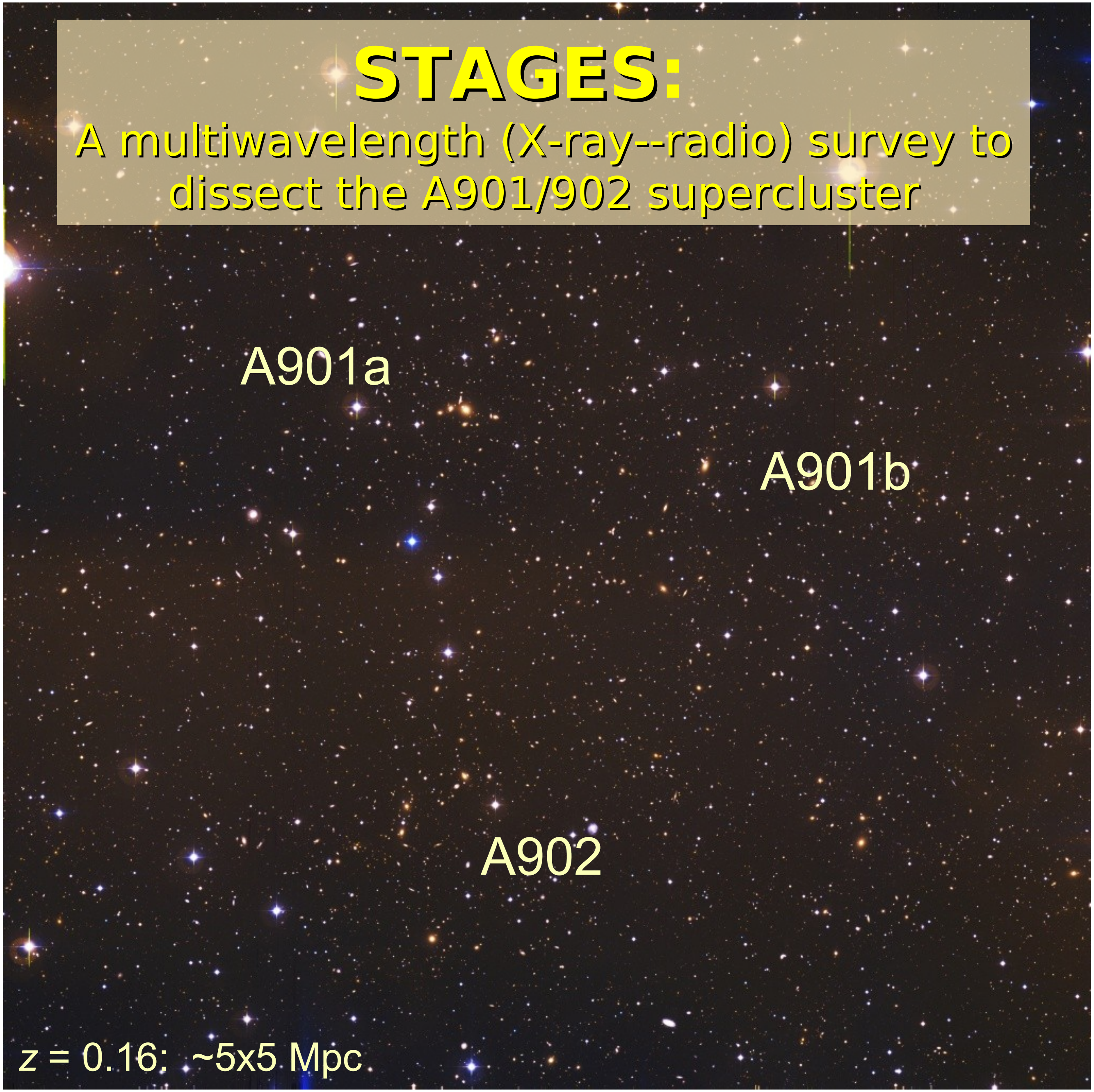
Modelling specific clusters and superclusters

Using *constrained* initial conditions to model:

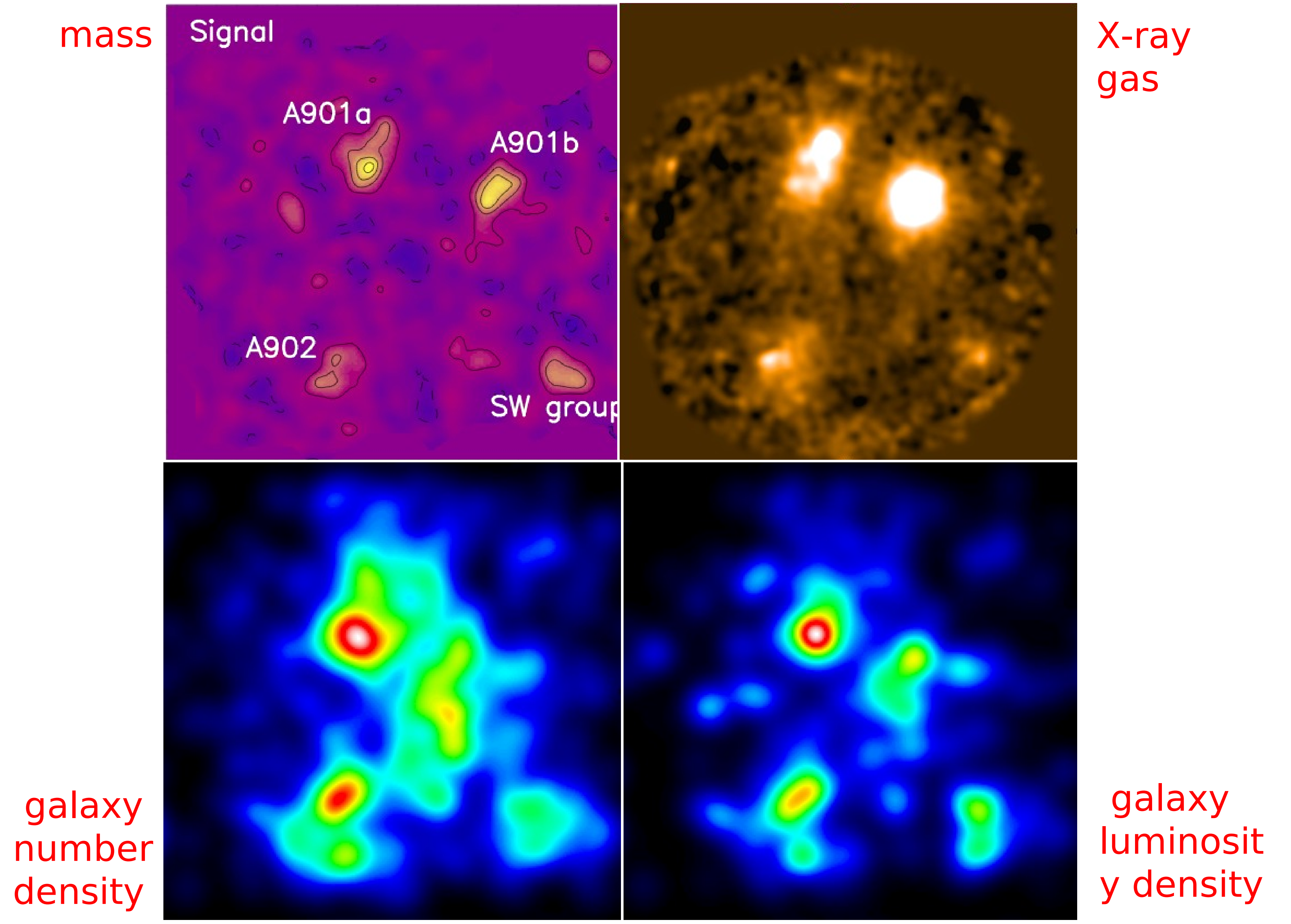
- the A901/A902 supercluster (the STAGES project)
- Shapley supercluster (with Haines, Napoli, Catania)
- CL0152 (with Ricardo Demarco, Piero Rosati)
- and various others …

STAGES:

A multiwavelength (X-ray--radio) survey to dissect the A901/902 supercluster



COMBO-17 image

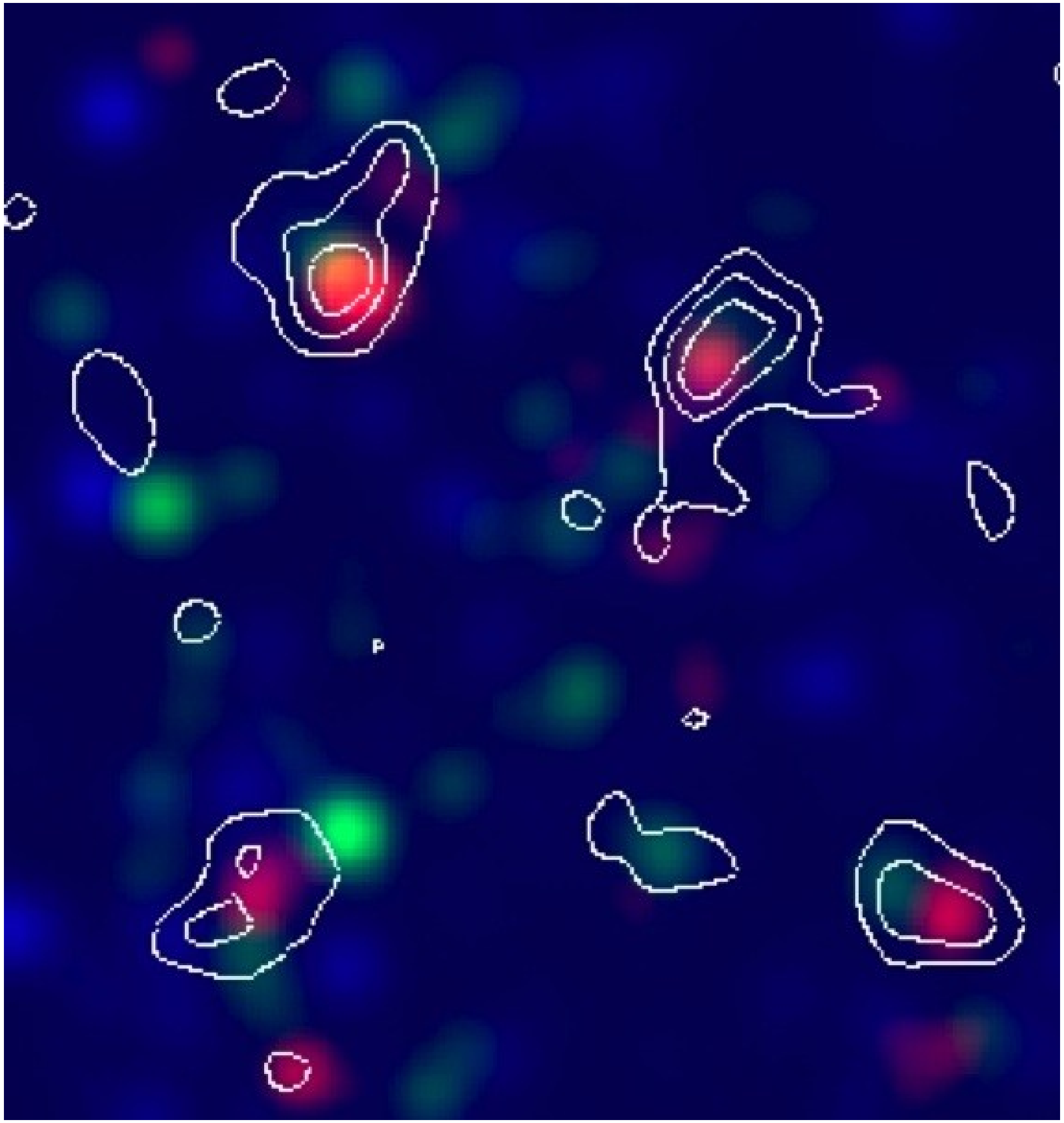

mass
Signal
A901a
A901b
A902
SW group
X-ray
gas
galaxy
number
density
galaxy
luminosit
y density

SF versus environment

Blue galaxies

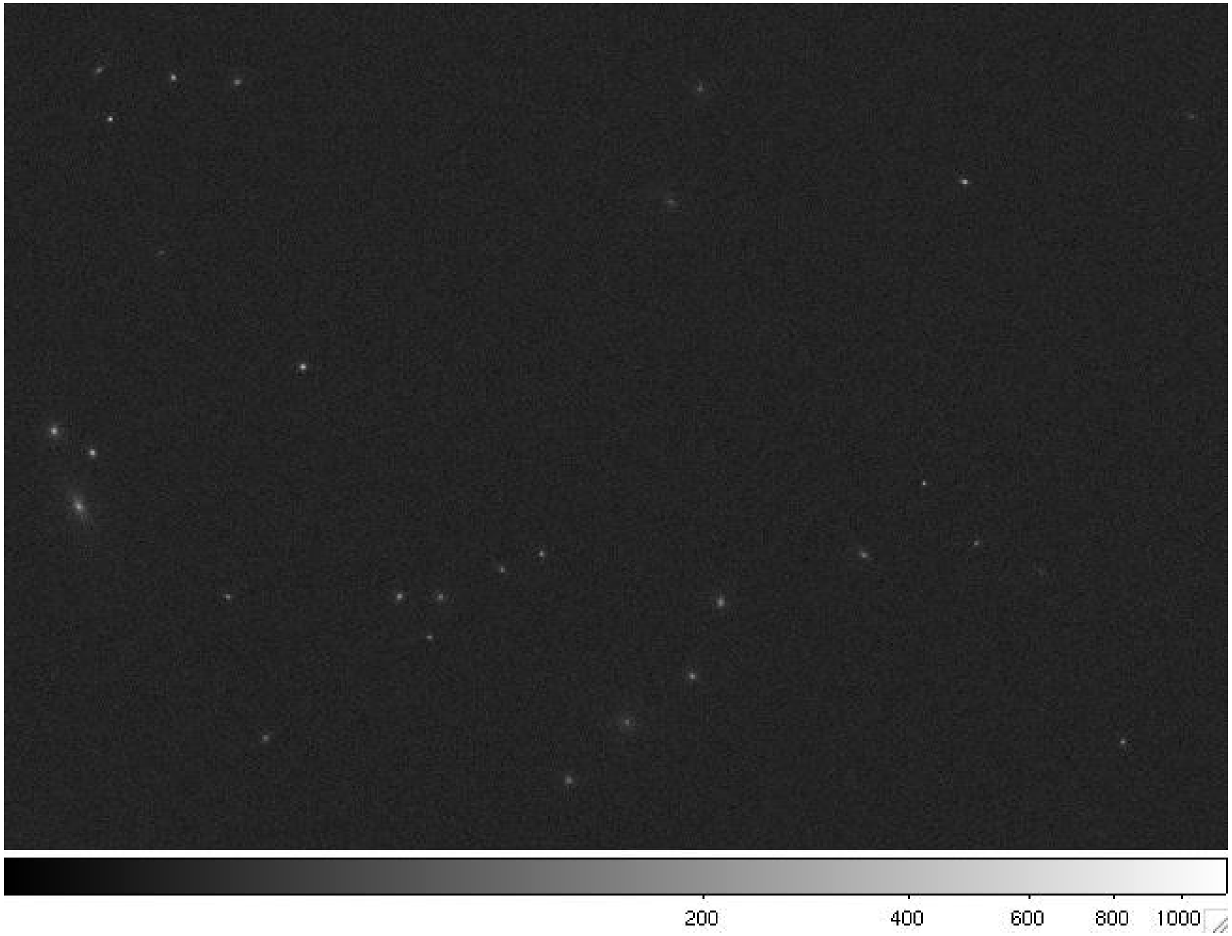
Dusty red galaxies

Old red galaxies

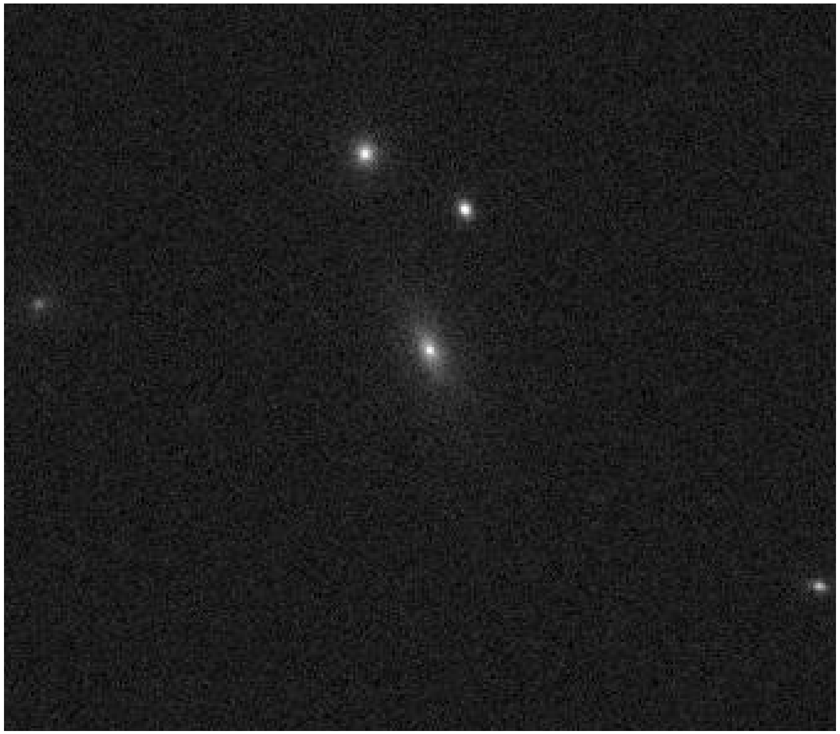


Mock HST tiles for *STAGES*

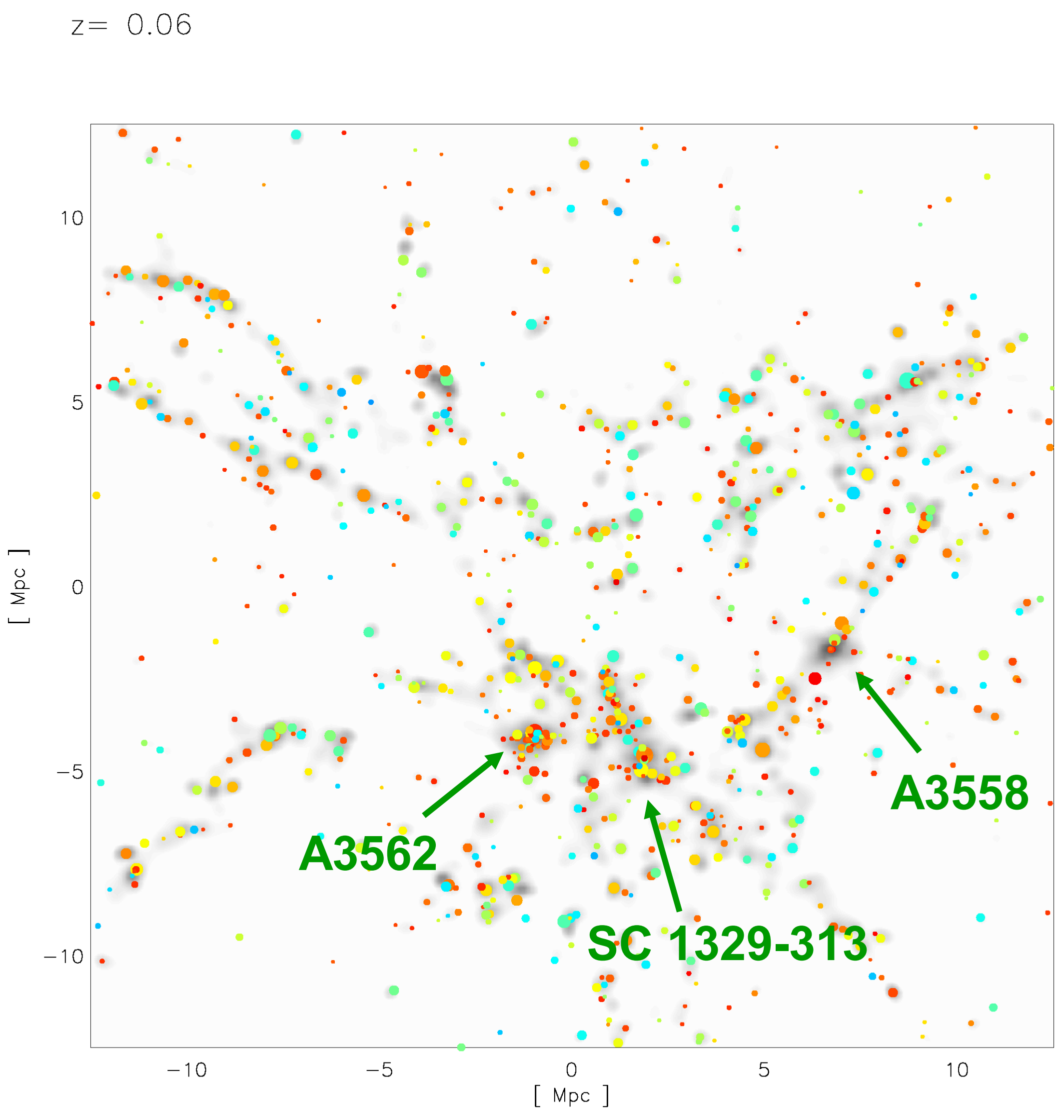
Using a code written by Boris Haeussler (Nottingham)
(no local stars included)



Examples of mock galaxies



Shapley supercluster mock



Dots:

$M_B < -21$

B-R colour

GAMA

- PI: Simon Driver (St Andrews) + 7 Co-PIs + 18 Co-Is
- Associated groups: UKIDSS LAS, VST KIDS, VISTA VIKING, ICC
- Building on success of the 2dFGRS, SDSS and MGC
- 200 sq degrees (2x100 sq deg. in various large chunks), 250k galaxies
- General science:
  - A study of structure on 1kpc-1Mpc scales, where baryon physics is critical
  - Tracing how mass (stars and cold gas) follows light
  - Provide a definitive zero redshift benchmark for the JWST and the SKA
- Specific goals:
  - the CDM Halo mass function from group velocity dispersions
  - the stellar mass function into the dwarf regime
  - the HI mass function and associate gas/stellar mass ratios
  - the baryonic mass function and baryon to dark matter ratios
  - determine the galaxy merger rates as a function of mass ratio
- Provision of a SDSS/2MASS like public database incorporating:
  - Optical: ugri (VST), spectra (AAT)
  - Near-IR: ZYJHK (VISTA)
  - Radio: 21cm (xNTD, SKADS)
  - Far-IR/sub-mm: multi-band imaging (Herschel Space Observatory)

Summary

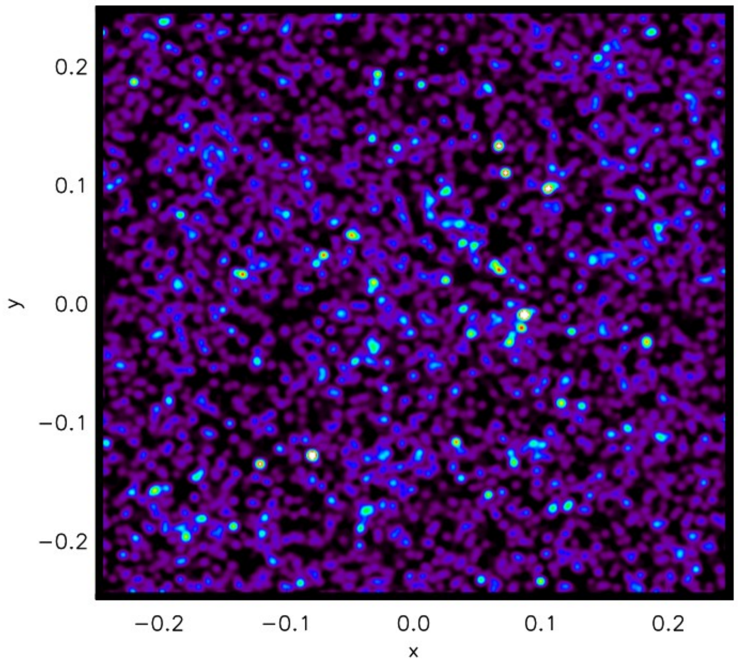
- constrain semi-analytical galaxy formation models:
  - at high redshifts, where galaxies form,
  - in overdense regions, where galaxies evolve
- large observational programmes planned or in progress to improve sample size, especially in the sub-mm (any z) and the optical at intermediate z

Discussion

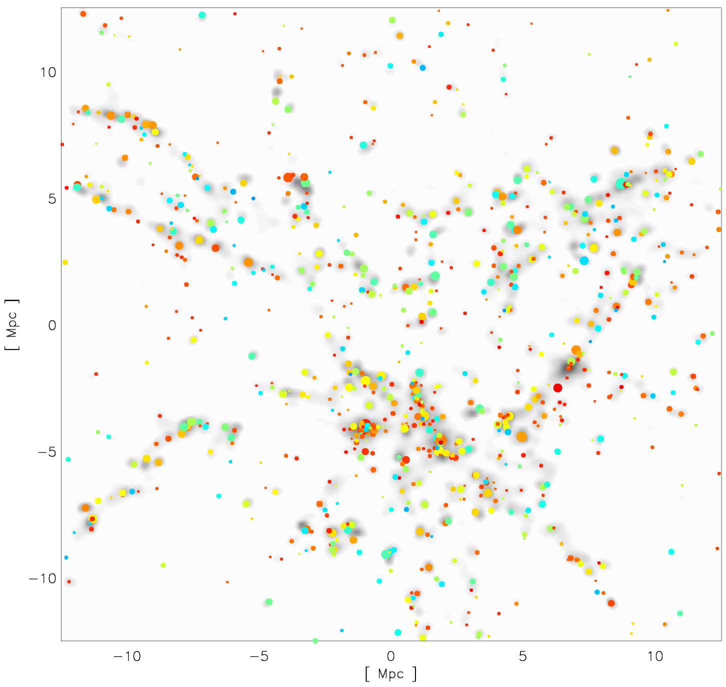
- can we ever stop using semi-analytical models ?
- how much more should we improve such models ?
- gradual progress to fully self-consistent models ?
- do these exist anyway ? Just shout “sub-grid physics” !
- so are SIMs actually SAMs anyway ?

- data constraints: multi-wavelength or large redshift range ?
- data from large samples or detailed test cases ?
- comparison of the various semi-analytical models ?

Semi-analytical models can *describe* everything ...



High-z sub-mm galaxies

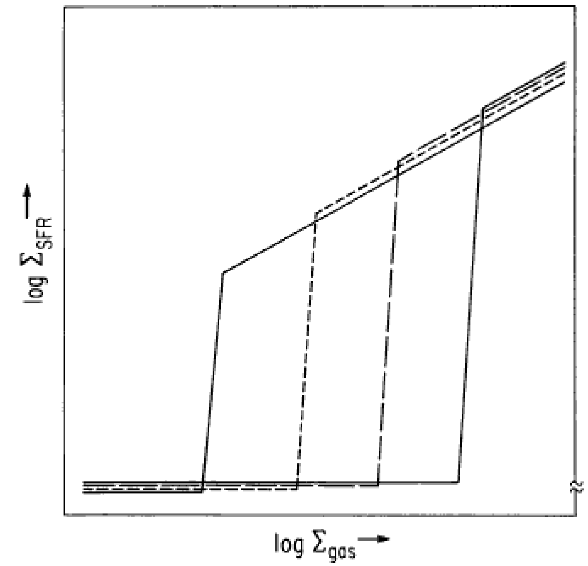


Local overdense regions

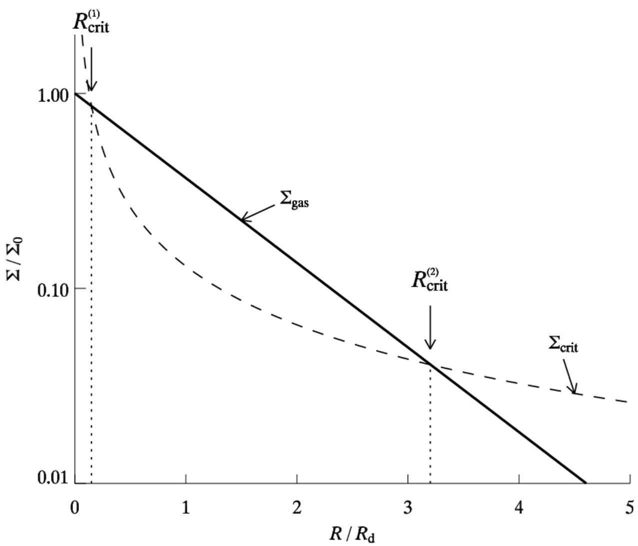
Star formation in discs

- At high surface densities: $\Sigma_* \sim \Sigma^n$ or $\Sigma_* \sim \frac{\text{avaliable gas}}{\text{dynamical time}}$
- Kennicutt (1989) threshold - based on Toomre criterion for local gravitational stability:

$$\Sigma_{\text{critical}} \quad \alpha \frac{\kappa c}{33.6\text{G}}$$

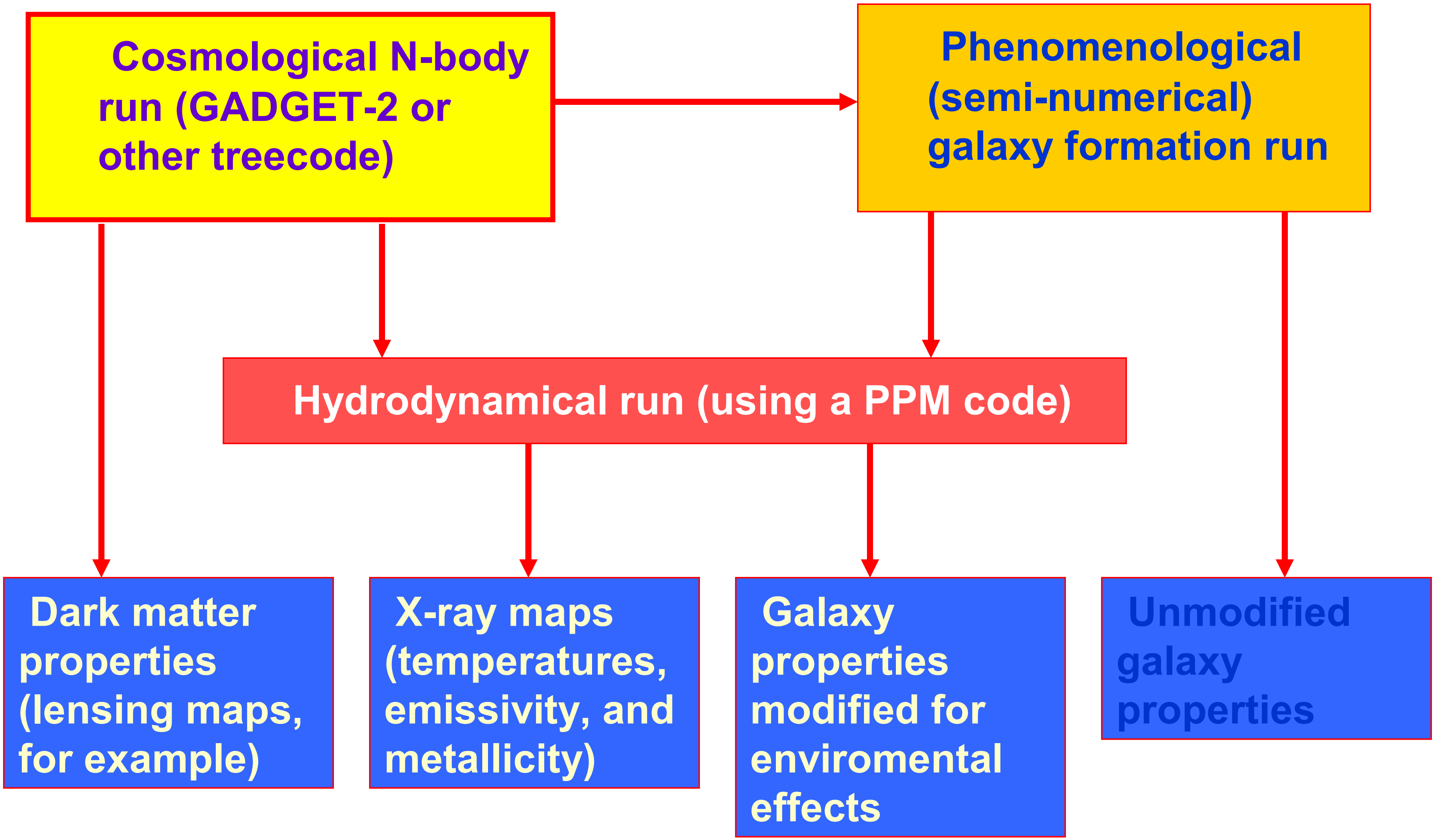


- Below threshold disc is stable – no stars form



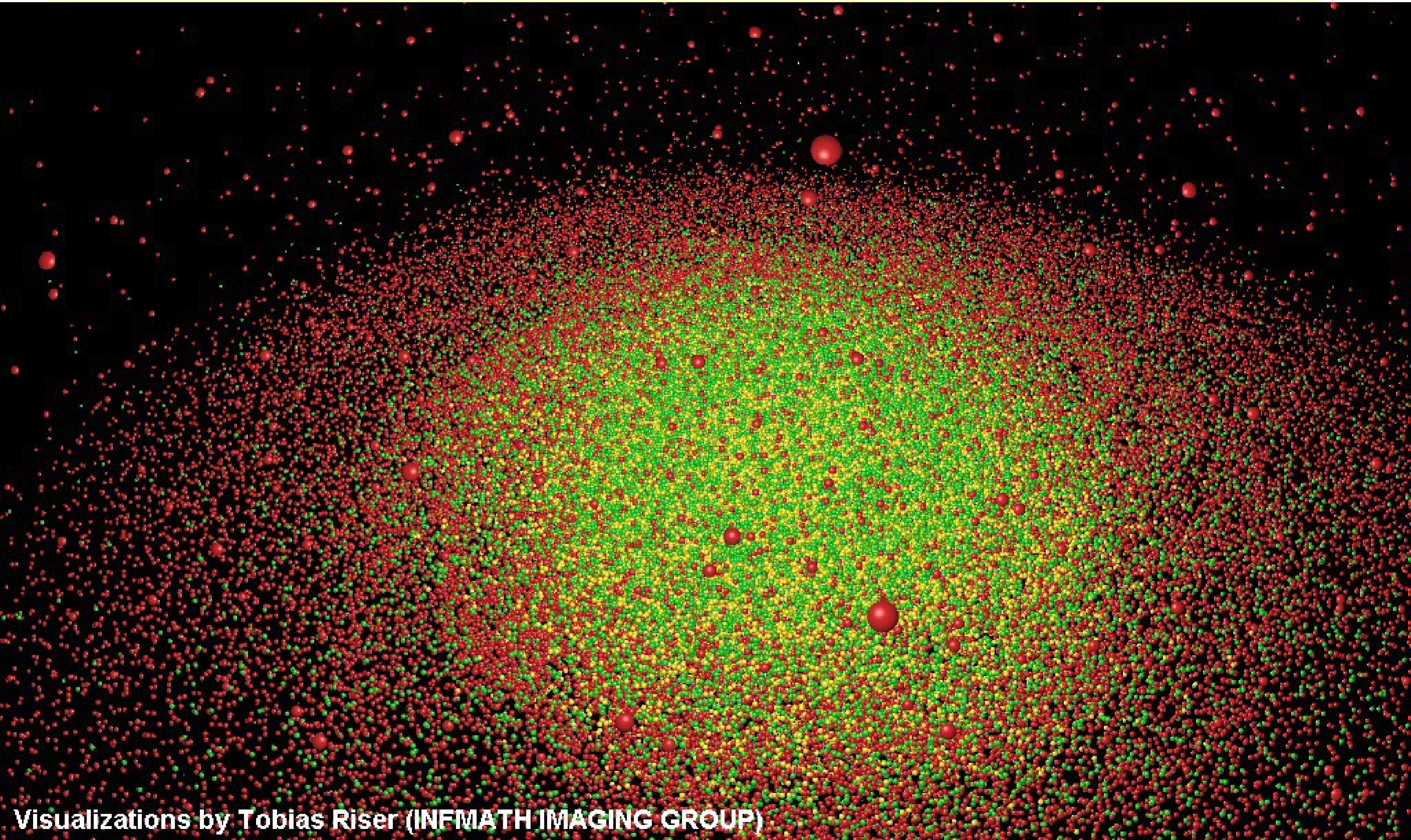
- Two critical radii where density = critical density
- Stars only form between critical radii – identified with optical disc

A combined N-body / hydro / phenomenological approach

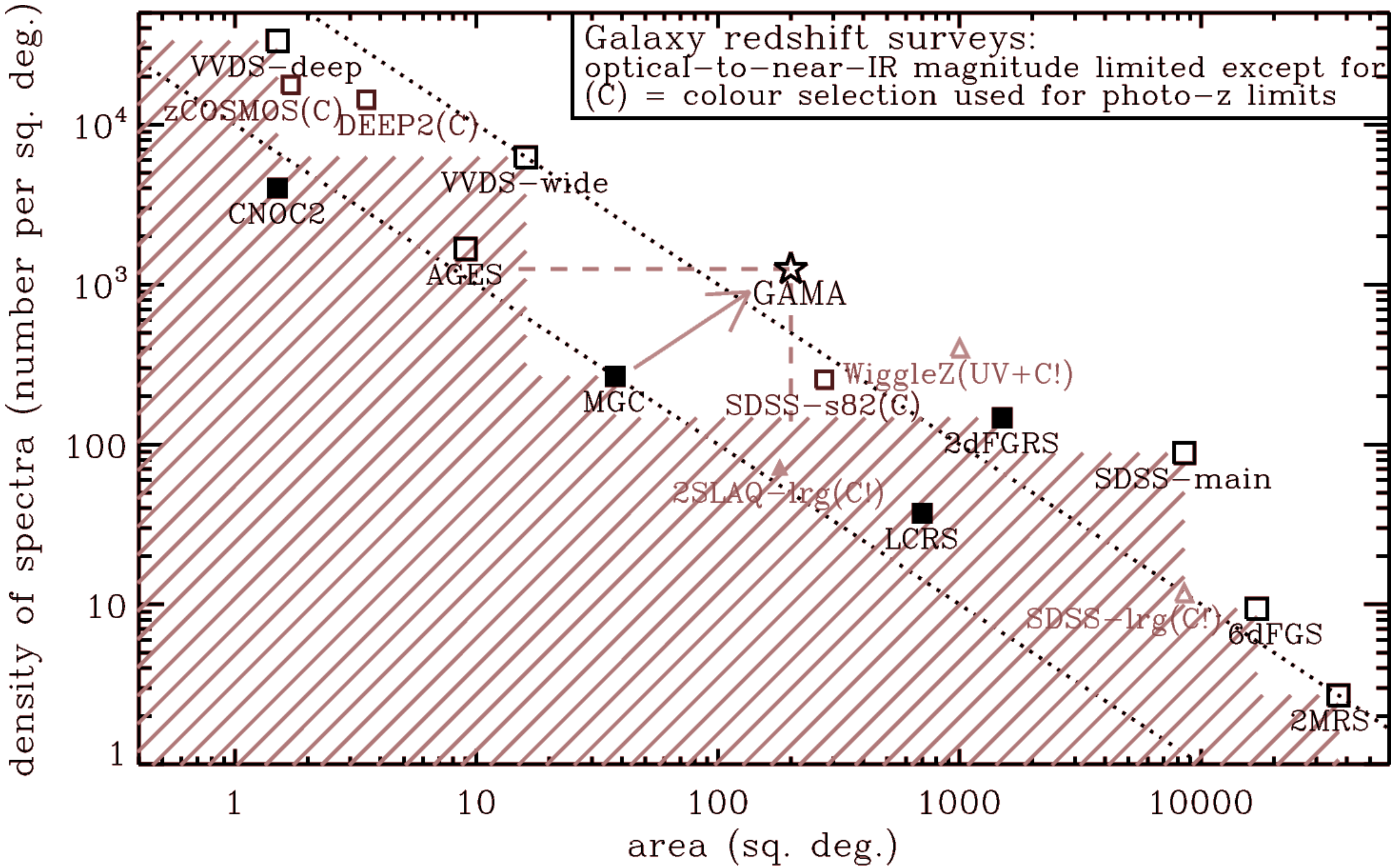


Environmental effects on the evolution of galaxies

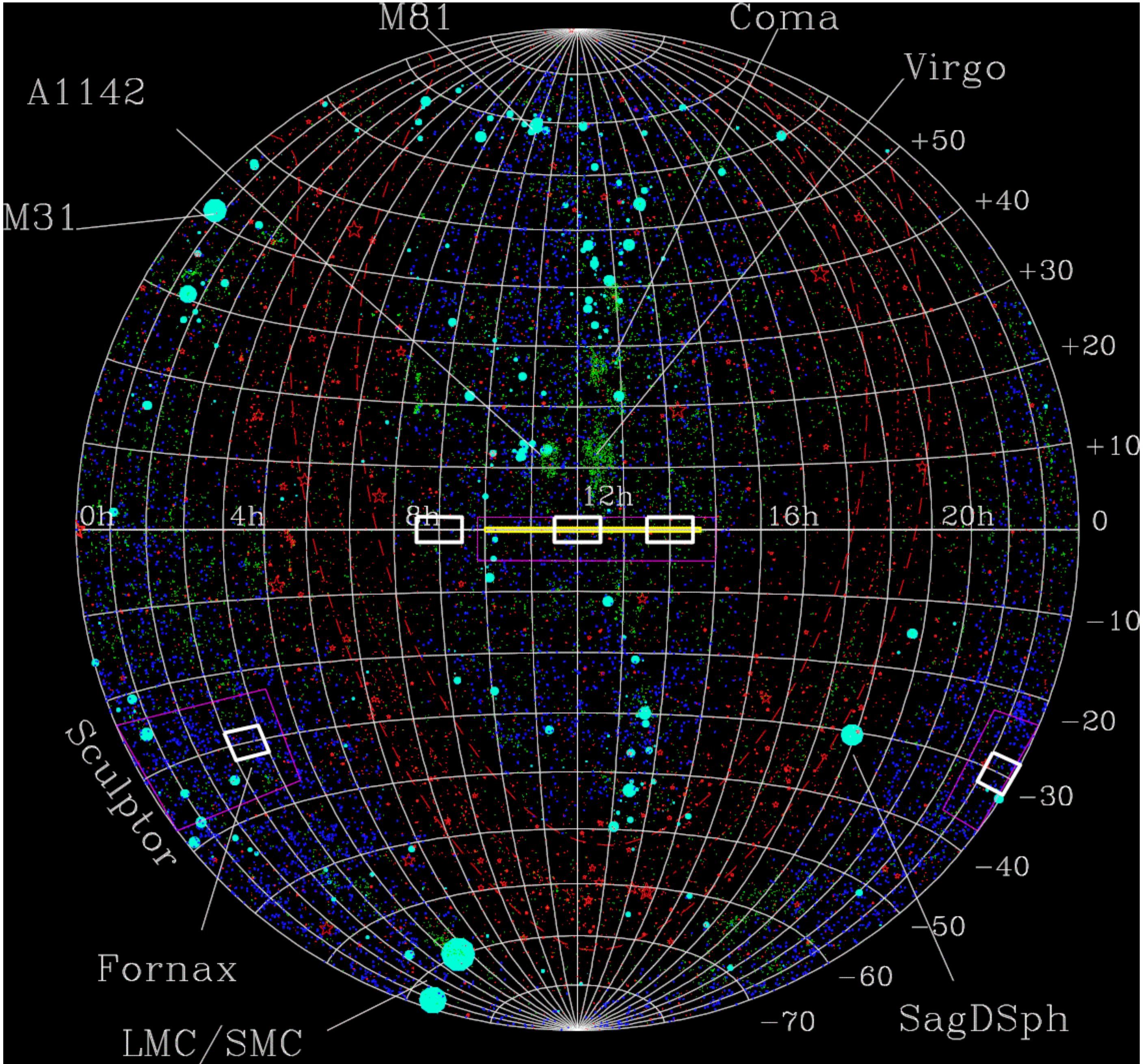
The effects of ram-pressure stripping the different components of galaxies including the velocity field.

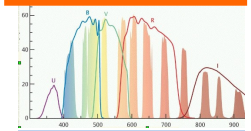
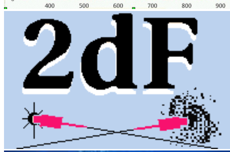
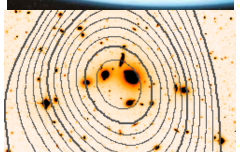
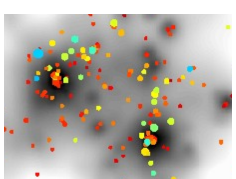


GAMA: Survey comparison



GAMA fields


M81
Coma
Virgo
A1142
M31
+50
+40
+30
+20
+10
0
−10
−20
−30
−40
−50
−60
−70
0h
4h
8h
12h
16h
20h
Sculptor
Fornax
LMC/SMC
SagDSph

	**Hubble Space Telescope**	**80-orbit mosaic with 3 cameras:** morphologies, precision lensing
	COMBO-17 survey	17-band optical imaging: ‘fuzzy spectroscopy’ for 15000 objects
	2dF spectrograph	spectroscopy of ~300 cluster galaxies: dynamics, star-formation histories
	XMM-Newton	deep X-ray imaging/spectroscopy: hot cluster gas, AGN
	Gravitational lensing	dark matter mass maps
	Omega2000 camera	near-infrared extension: stellar mass estimates, photo-z’s
	GALEX	ultraviolet imaging: unobscured star formation
SPITZER SPACE TELESCOPE	Spitzer	infrared imaging (8 and 24 μιχρον): obscured star formation, AGN
	constrained simulations	dark matter, gas, galaxies

Survey fields

850 micron survey:

field	RA	area [deg²]
XMM-LSS	2	5
ECDFS	3	3
Cosmos	10	2
Lockman	10	4
Bootes	14	2
EGS	14	1
ELAIS-N1	16	2
Akari-NEP	18	1

450 micron survey:

field	RA	area [deg²]
UDS	2	<0.25
ECDFS	3	<0.25
Cosmos	10	<0.25
GOODS-N	12	0.05
Akari-NEP	18	0.02
SA22	22	0.02

Field selection (partly) driven by complementary data of the required depth; e.g., K_{AB}=25

Distribution of dust …