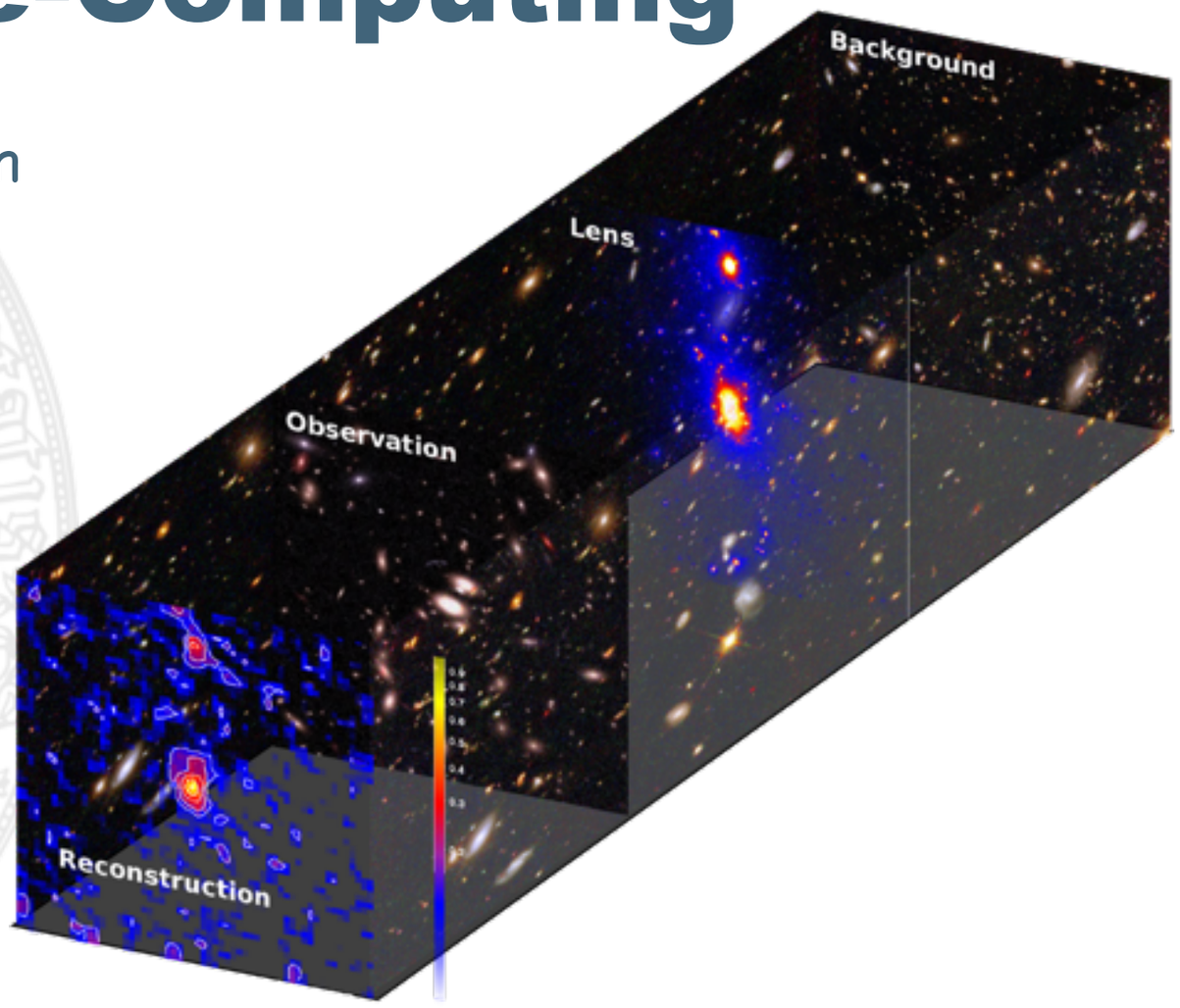
Cosmology with Galaxy Clusters: Observations meet High-Performance-Computing

Julian Merten
(ITA/ZAH)



- **Clusters of galaxies**
- **GPU lensing codes**
- **Abell 2744**
- **CLASH: A HST/MCT programme**

UNIVERSITÄT HEIDELBERG
Zukunft. Seit 1386

Clusters of galaxies

- DM dominated

  $\sim 10^{15}\ M_\odot$, Mpc scale

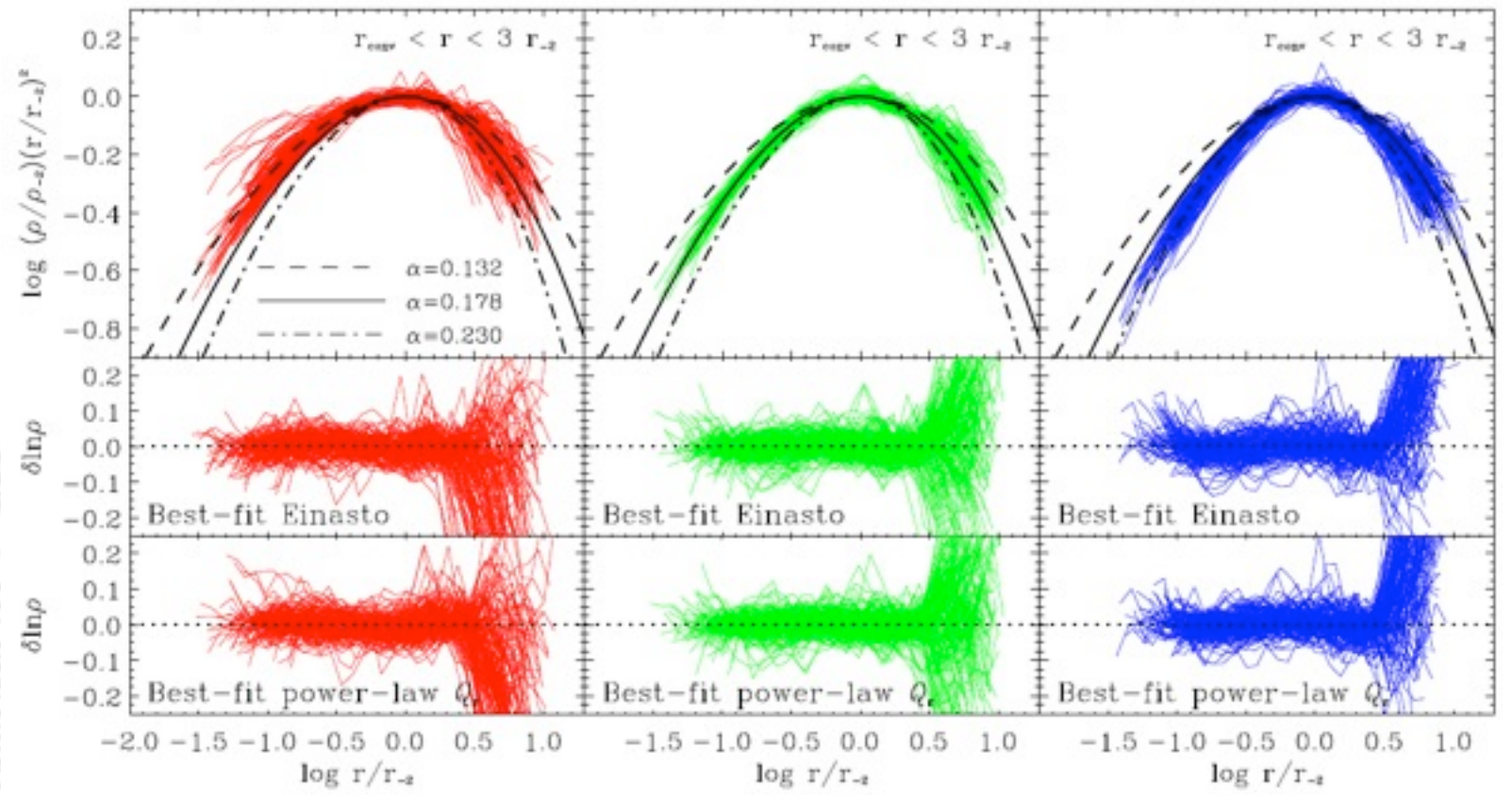
- Baryonic component not dominant, though not negligible
- Observable in 3 regimes
- Cosmic laboratories
- Strong grav. lenses
- Still pose riddles

UNIVERSITÄT HEIDELBERG
Zukunft. Seit 1386

Cluster puzzles

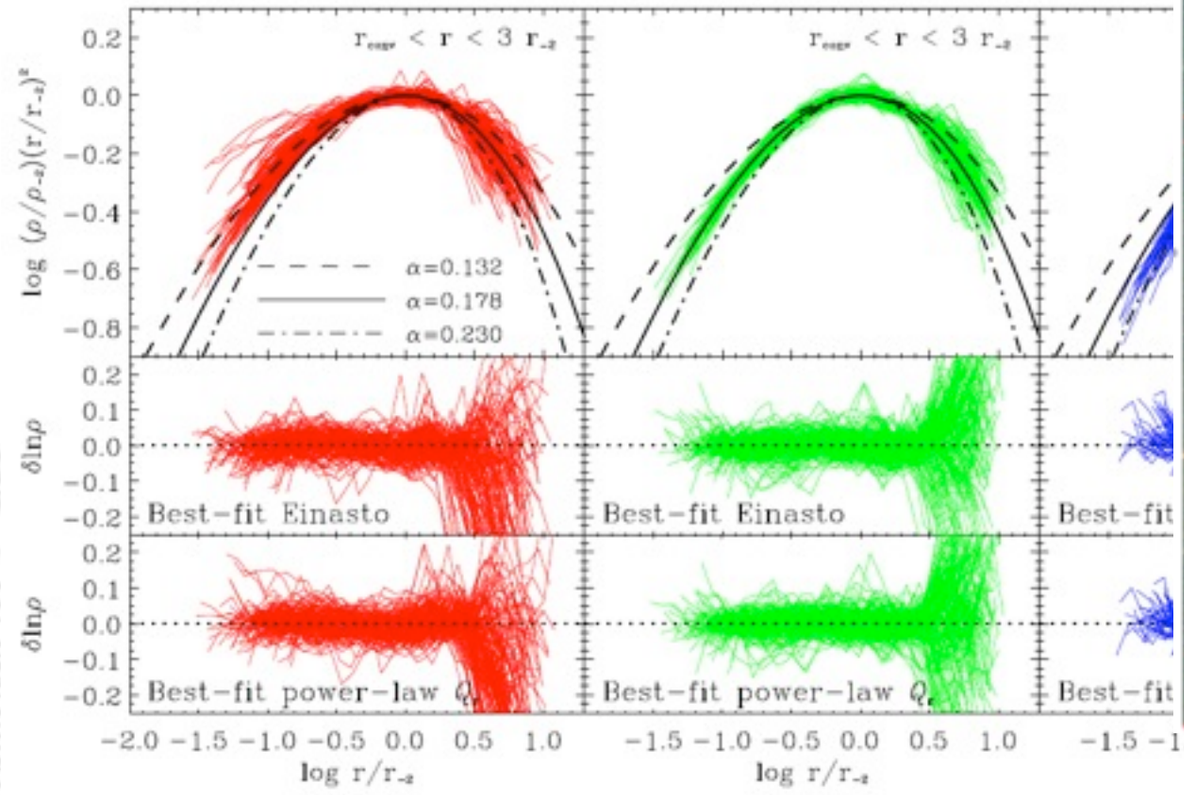
UNIVERSITÄT
HEIDELBERG
Zukunft. Seit 1386

Cluster puzzles

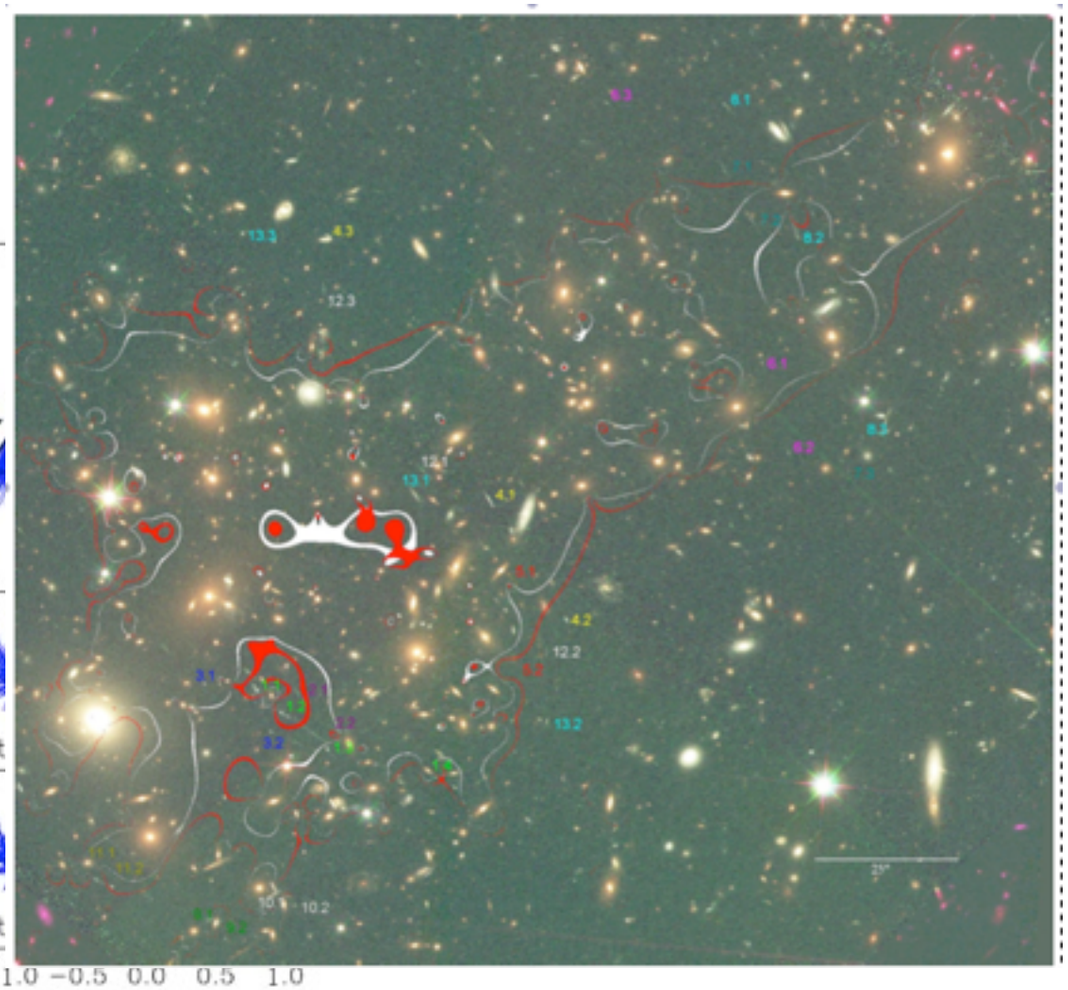


Ludlow11+

Cluster puzzles



Ludlow11+

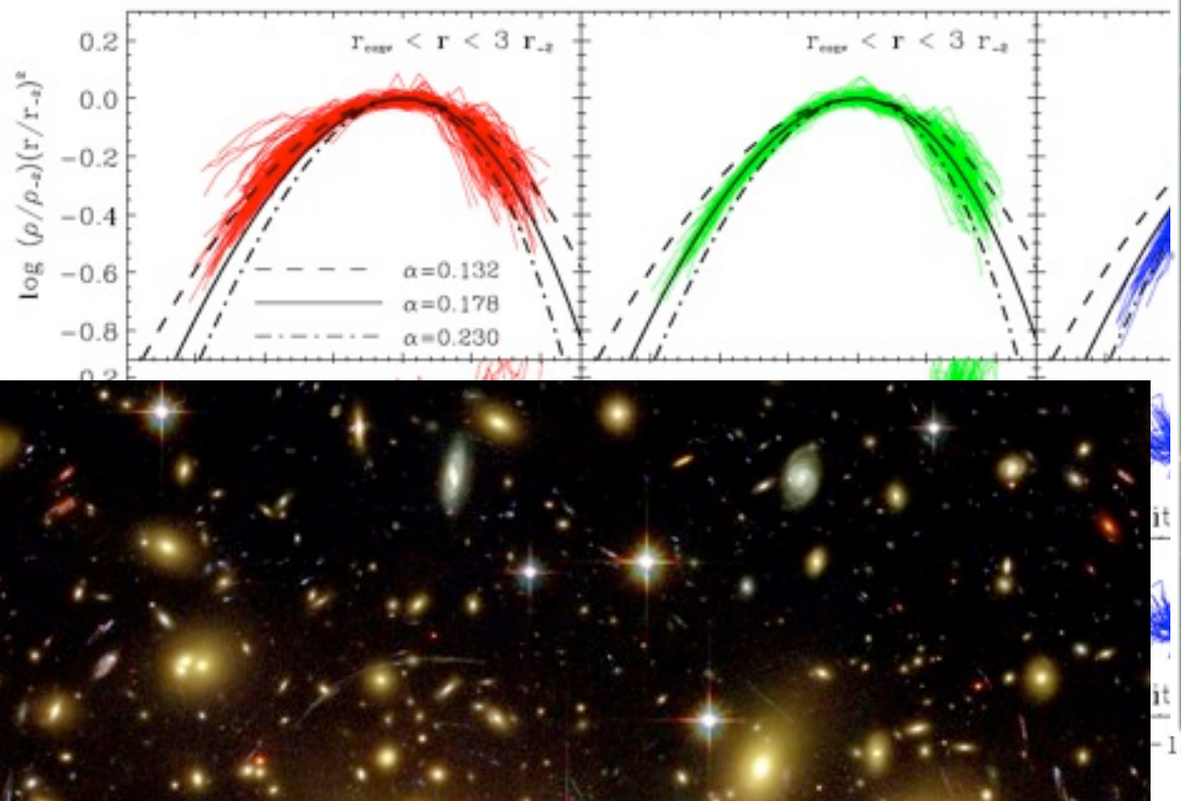


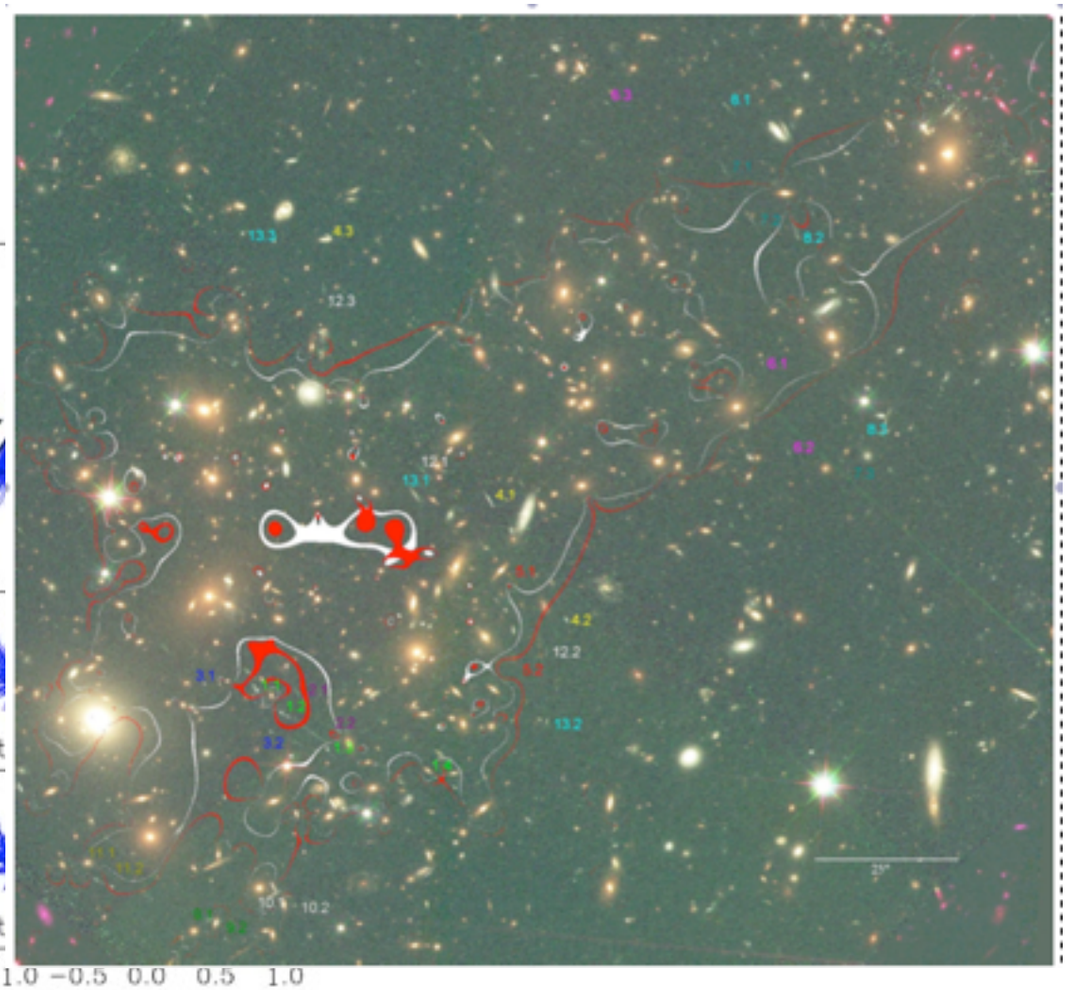
Zitrin10+

UNIVERSITÄT HEIDELBERG
Zukunft. Seit 1386

Cluster puzzles

e.g. Broadhurst08+

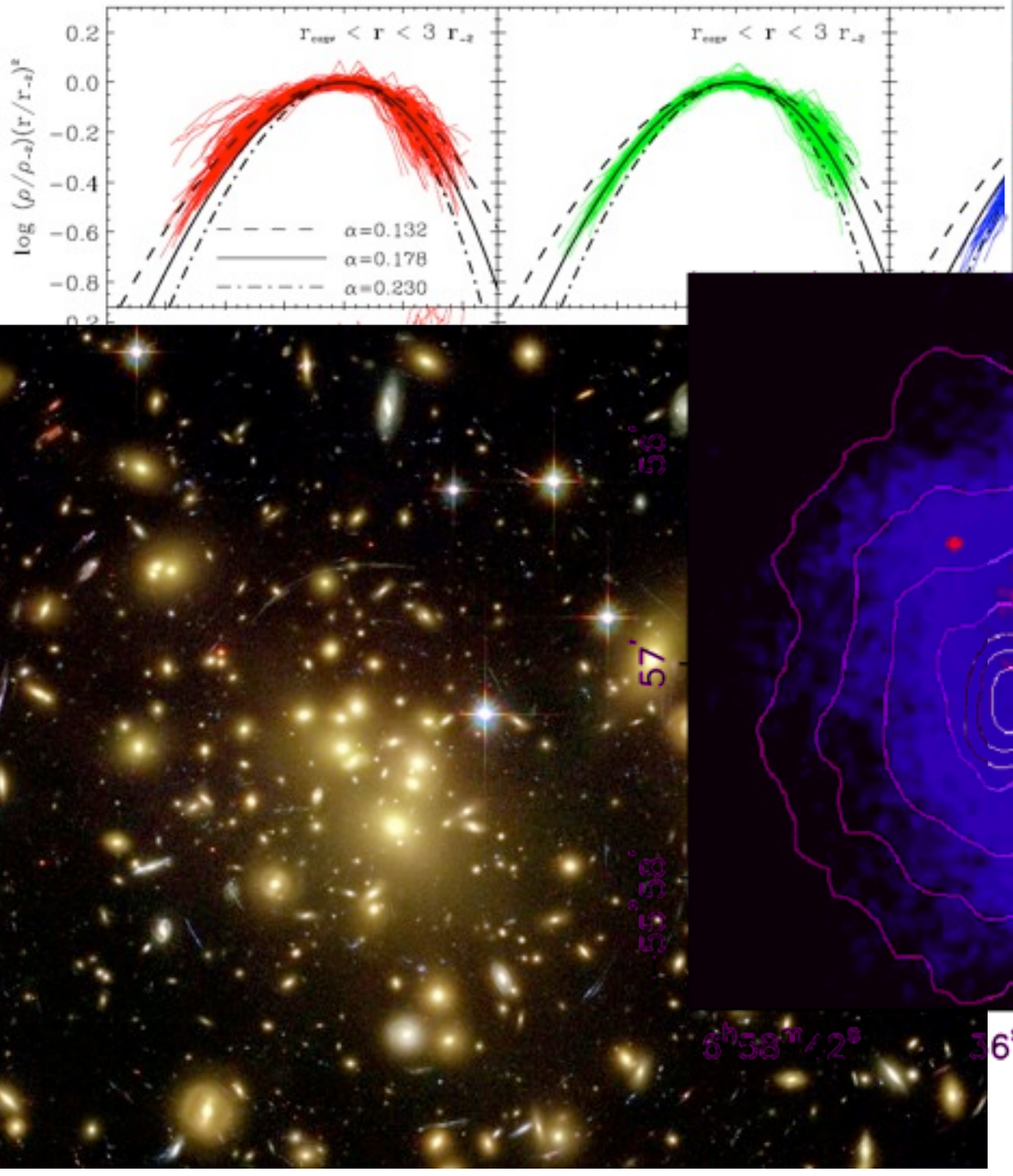




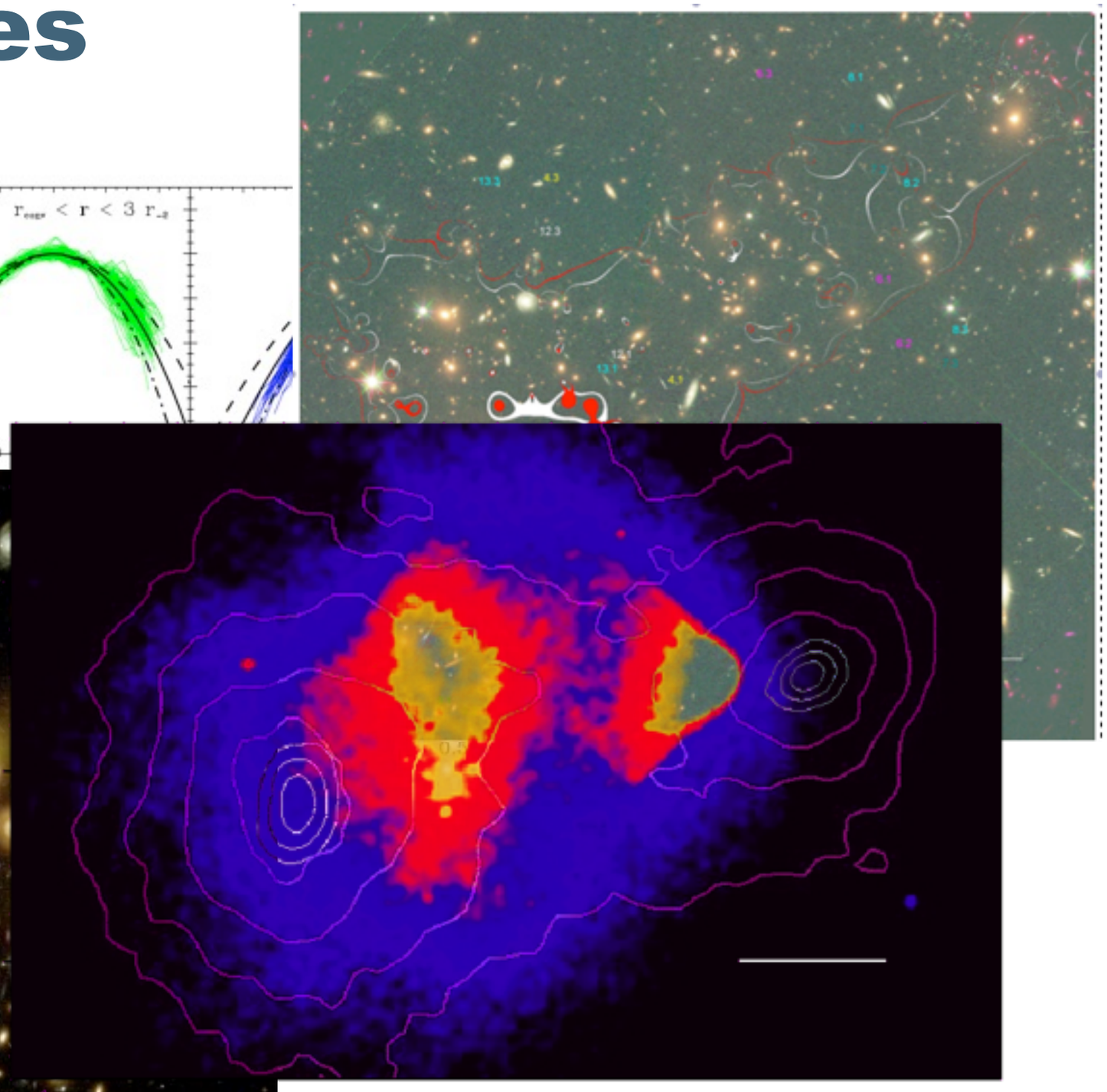
Zitrin10+

UNIVERSITÄT HEIDELBERG
Zukunft. Seit 1386

Cluster puzzles



e.g. Broadhurst08+

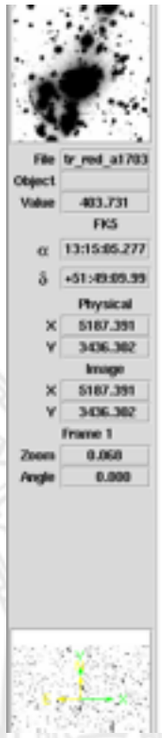


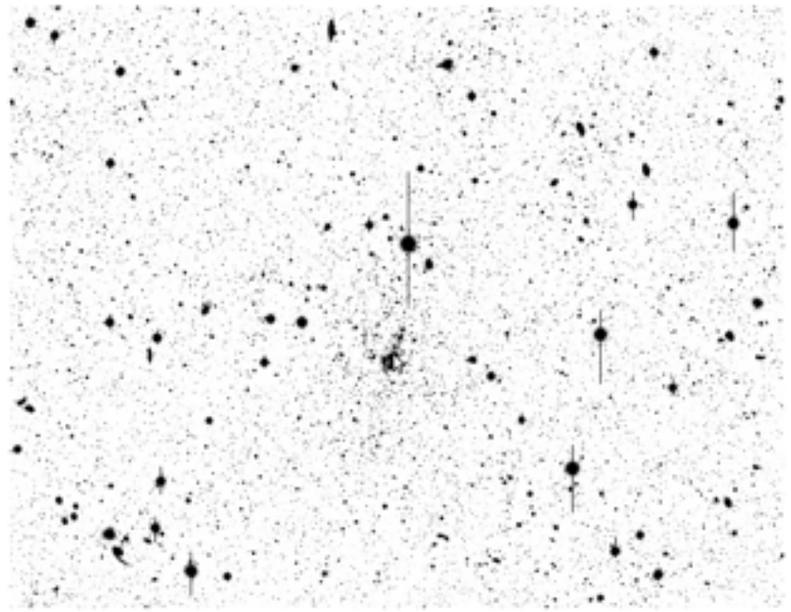
e.g. Lee10+

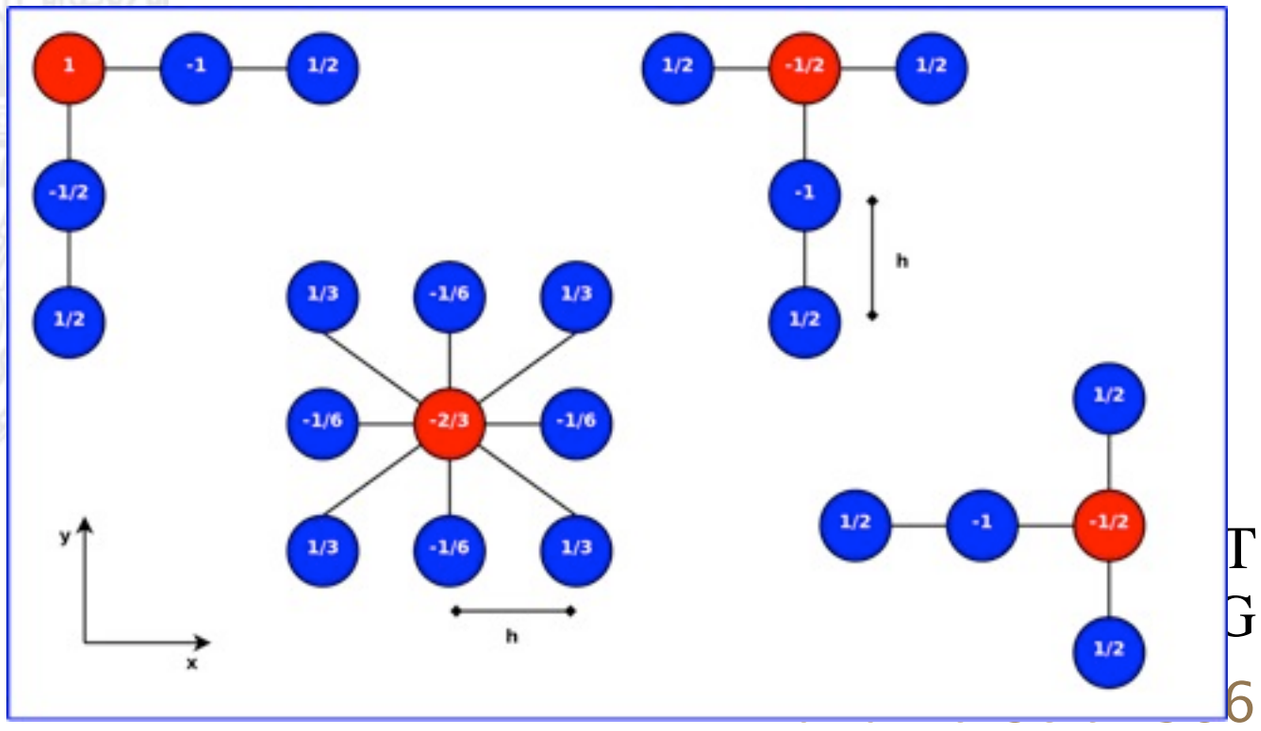
UNIVERSITÄT HEIDELBERG
Zukunft. Seit 1386

Joint lensing reconstructions

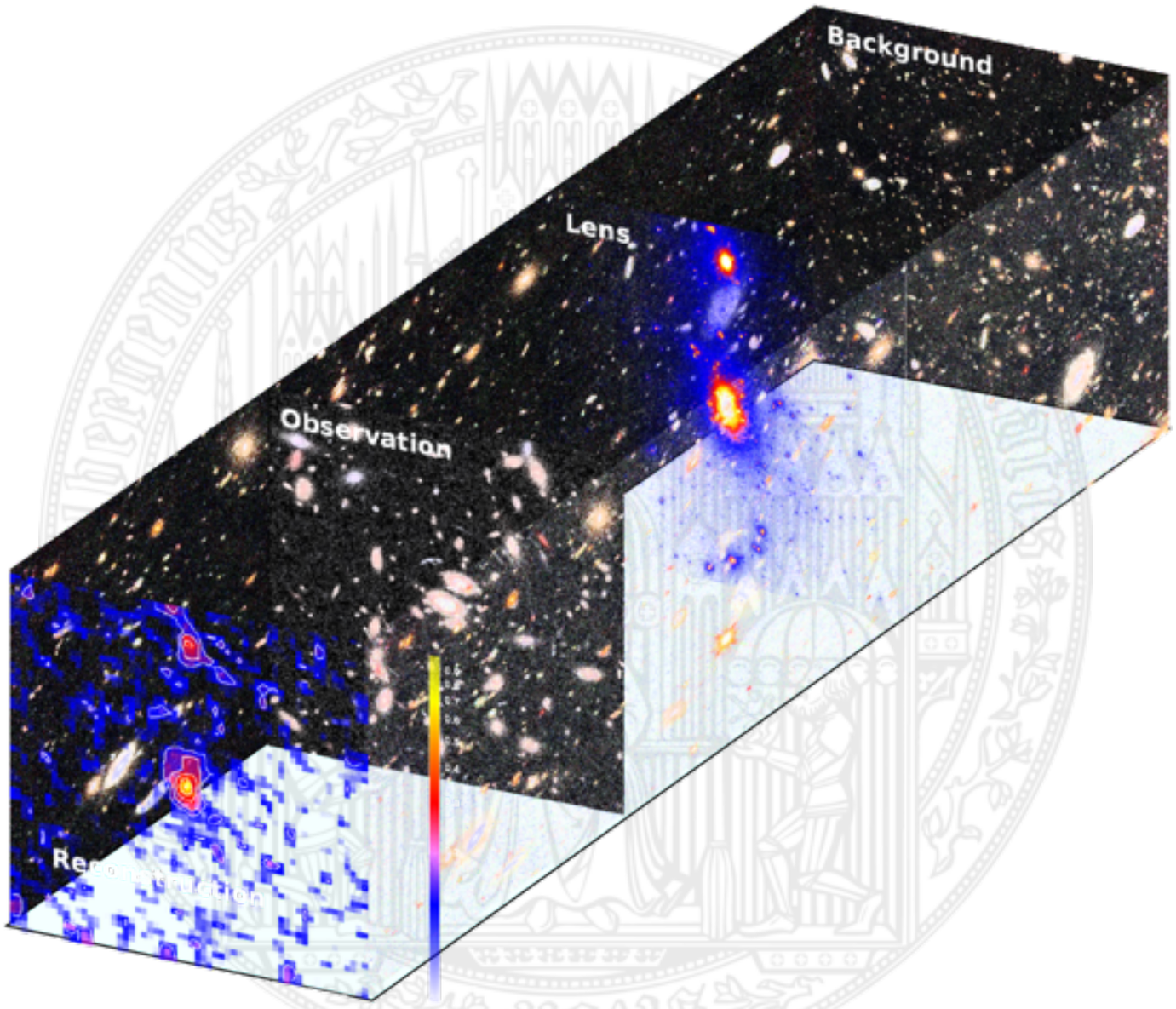
- Fully nonparametric approach
- $\chi^2(\psi) = \chi^2_{\rm w}(\psi) + \chi^2_{\rm s}(\psi) + ...$
- Adaptive-grid method
- Does not assume light traces mass
- Easily extendable
- Future: Kinematics, gas constraints







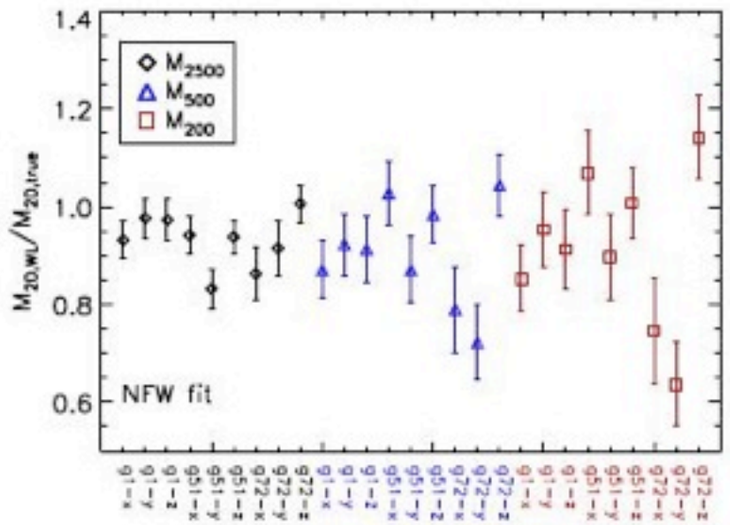
Simulating lensing

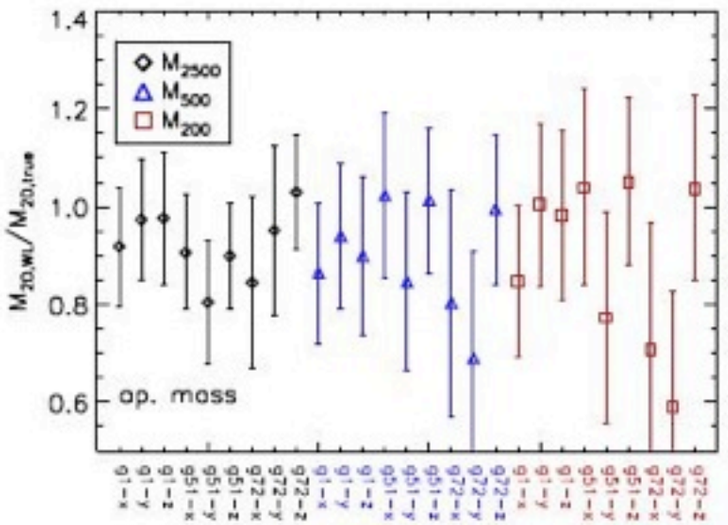


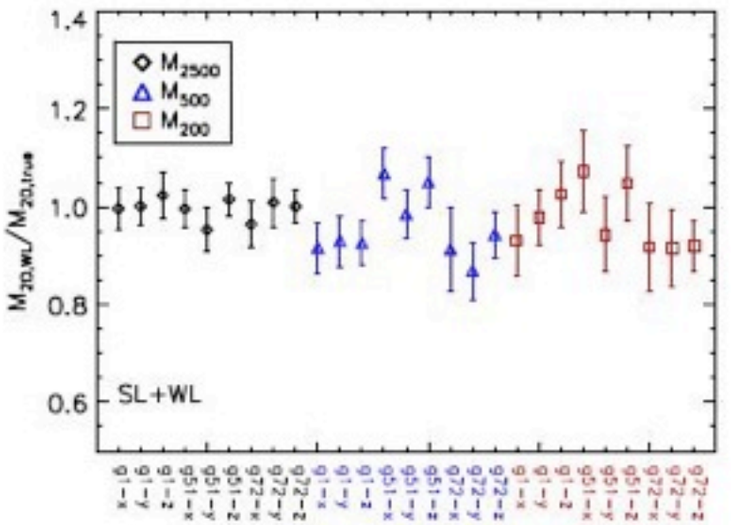
Name	Description
D	aperture diameter
g	detector gain
A_{pix}	pixel area
$F(\lambda)$	used filter
$M(\lambda)$	mirror filter curve
$O(\lambda)$	optics filter curve
$C(\lambda)$	CCD filter curve
FoV	total field-of-view
RON	detector readout-noise
f	flat-field accuracy
a	residual flat-field error
PSF	PSF model
t_{exp}	exposure time
$A(\lambda)$	atmospheric extinction
m_{a}	airmass
SED_{sky}	sky-background emission
SED_{gal}	background population
α	deflection angle map

UNIVERSITÄT HEIDELBERG
Zukunft. Seit 1386

Simulating lensing



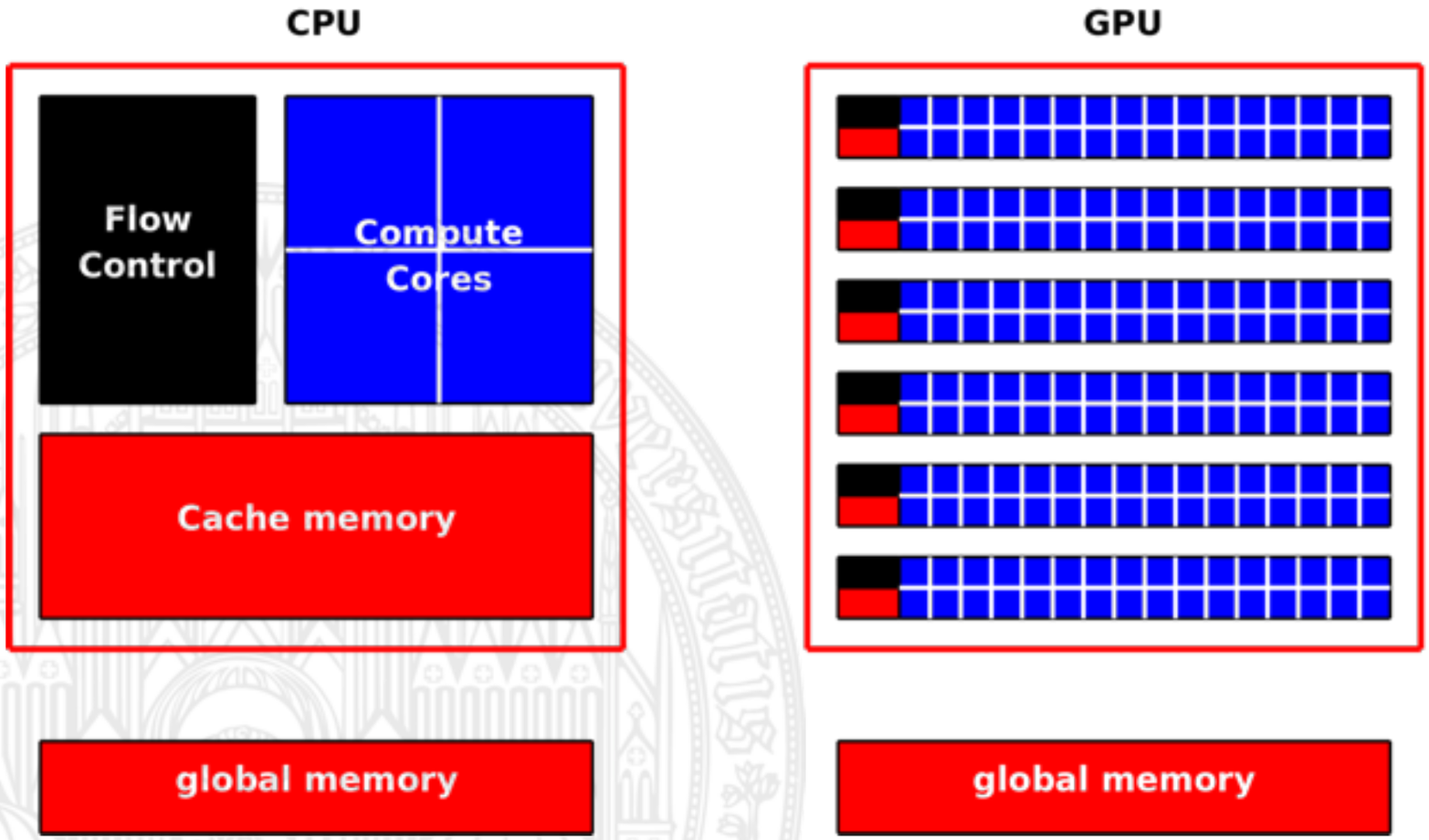




Meneghetti, Rasia, JM et al. 2010

UNIVERSITÄT
HEIDELBERG
Zukunft. Seit 1386

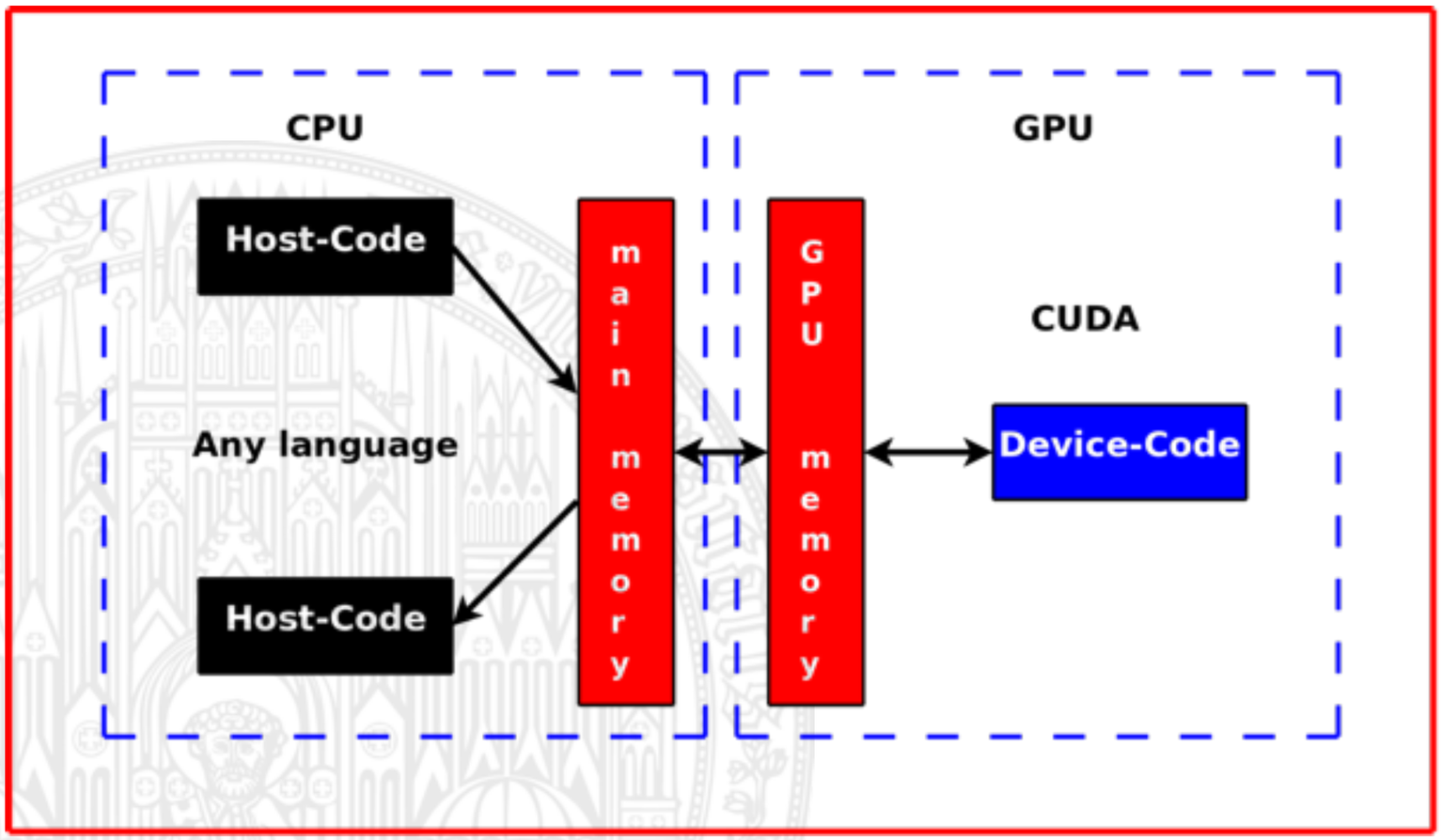
Modern implementation: GPUs



- Respect SIMT: hundreds/thousands of threads
- Respect memory hierarchy
- Almost no need for synchronisation
- Balance of parallelisation and work per thread

- Use CUDA C or OpenCL (Some alternatives upcoming)
- Available libraries: CUBLAS, CUFFT, CUSPARSE, CURAND, CULA
- Combination with MPI possible
- Some child deseases

Modern implementation: GPUs



- Respect SIMT: hundreds/thousands of threads
- Respect memory hierarchy
- Almost no need for synchronisation
- Balance of parallelisation and work per thread

- Use CUDA C or OpenCL (Some alternatives upcoming)
- Available libraries: CUBLAS, CUFFT, CUSPARSE, CURAND, CULA
- Combination with MPI possible
- Some child deseases

UNIVERSITÄT HEIDELBERG
Zukunft. Seit 1386

GPU systems and speed-up

NVIDIA TESLA C2050 (Fermi)

1 TFLOP peak (single)
500 GFLOP (double)
3 GB ECC global memory
14 (16) Multi-processors
448 (512) streaming cores

Our current workhorse: Jabba

2x quadcore XEON @ 2.4 Ghz
16 GB ECC main memory
NVIDIA TESLA C1060
NVIDIA TESLA C2050
Cluster performance for 5000 EUR

Speed-up

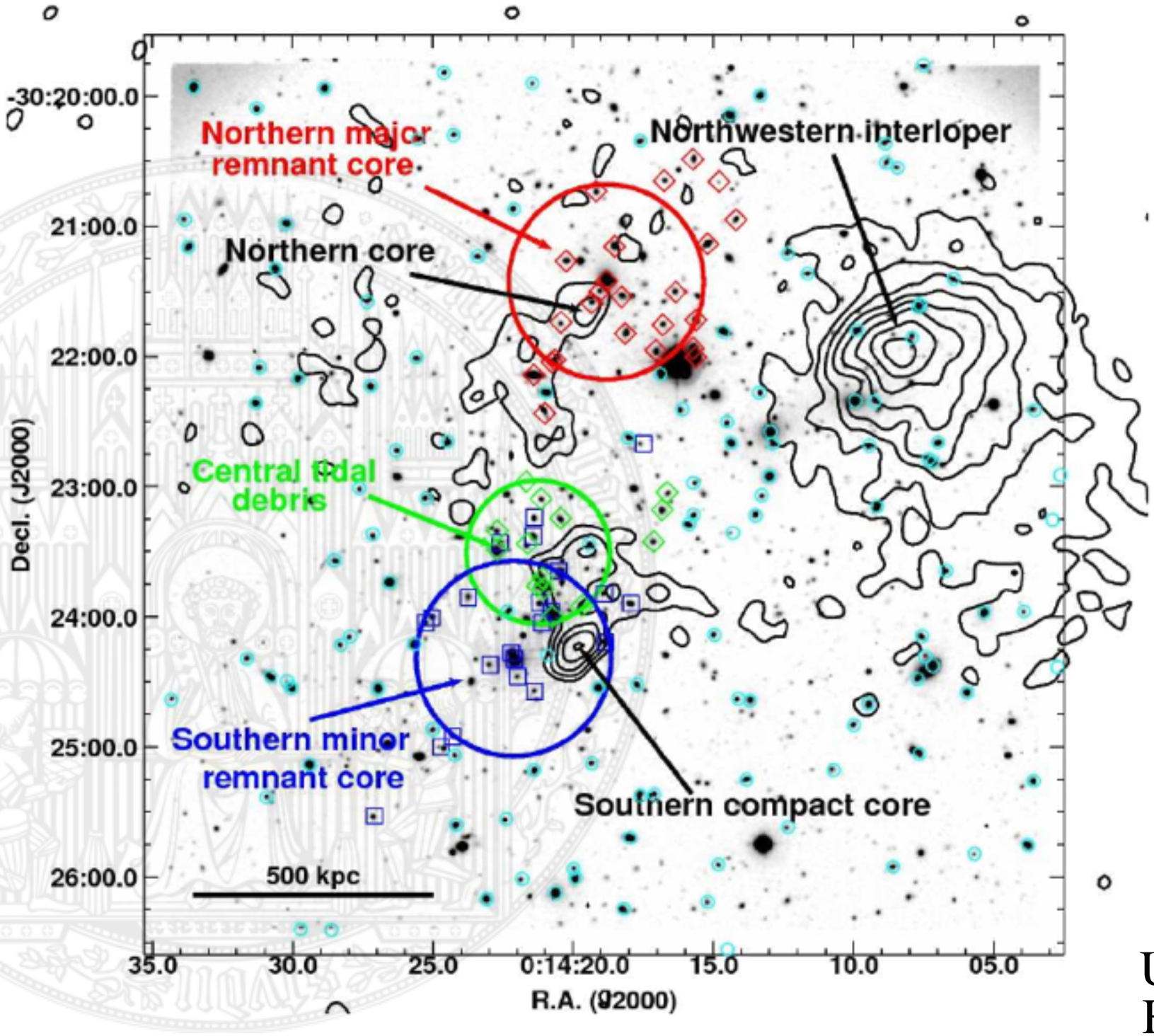
$$\mathcal{B}_{lk} = a_i b_j \mathcal{C}_{ij} \mathcal{D}_{ik} \mathcal{E}_{jl}$$

one core CPU: 82.3 s
240 core GPU: 1.03 s

+ ITA/ZITI cluster Kolob
+ Granted SFB machine

UNIVERSITÄT HEIDELBERG
Zukunft. Seit 1386

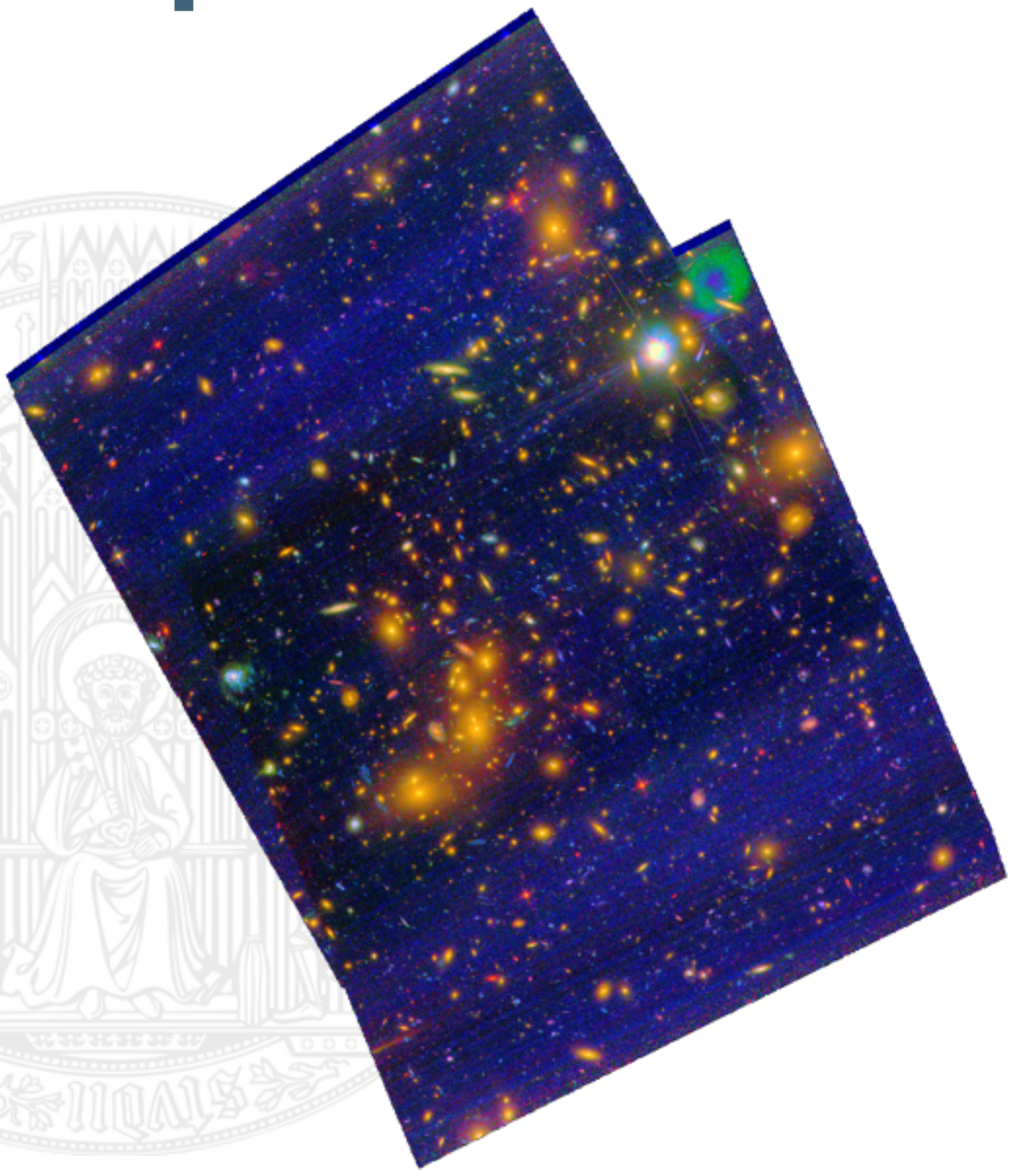
One of the pearls: Abell 2744



Owers10+

UNIVERSITÄT HEIDELBERG
Zukunft. Seit 1386

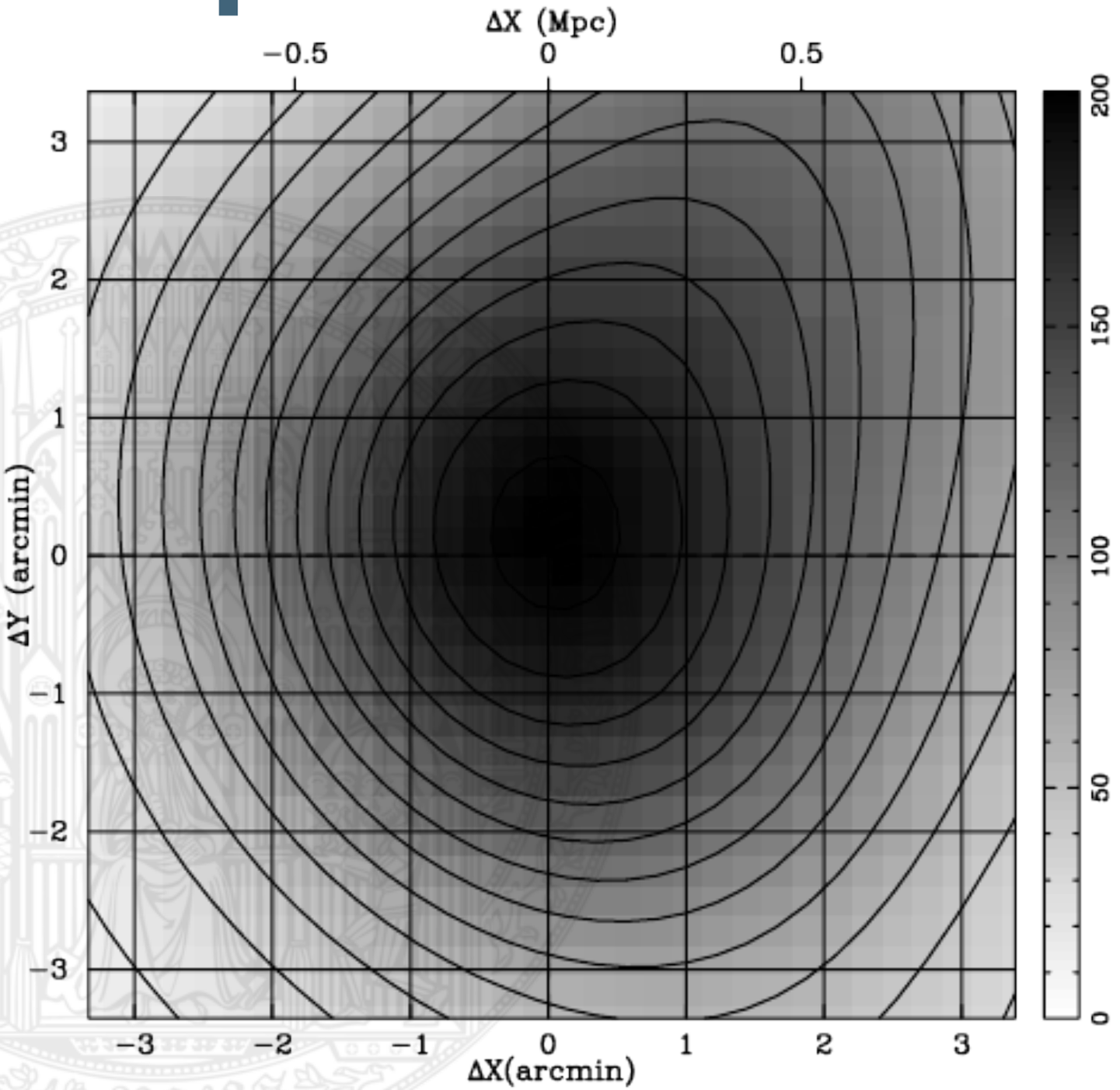
One of the pearls: Abell 2744



3band HST/ACS imaging, PI: R. Dupke

UNIVERSITÄT HEIDELBERG
Zukunft. Seit 1386

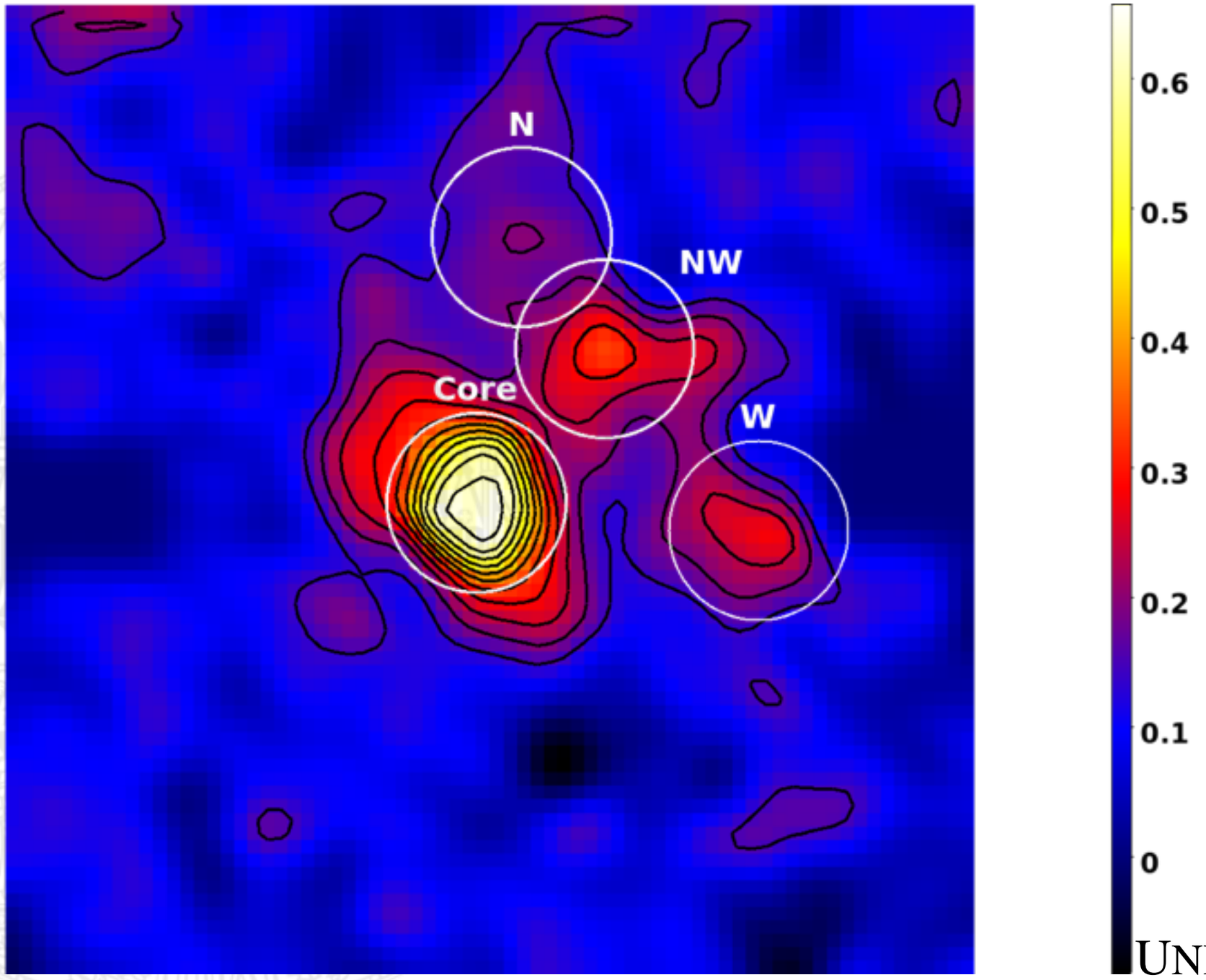
One of the pearls: Abell 2744



Cypriano 04+

UNIVERSITÄT HEIDELBERG
Zukunft. Seit 1386

One of the pearls: Abell 2744



JM11+ in prep.

UNIVERSITÄT HEIDELBERG
Zukunft. Seit 1386

Creation of cosmic structure

JM11+ in prep.
(next week)

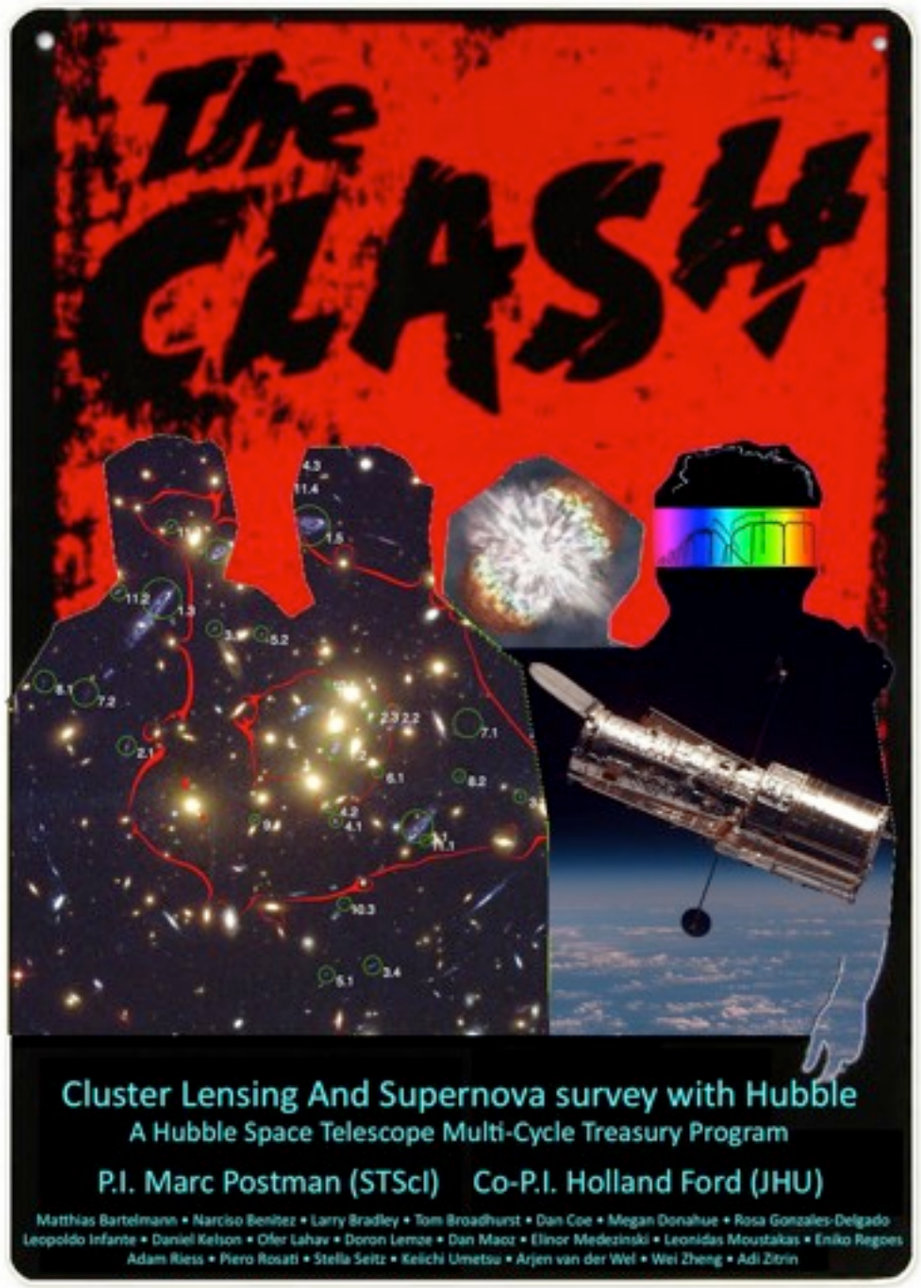
D. Coe (STScI)
R.Dupke (Michigan)
R. Massey (Edinburgh)
A. Zitrin (Tel Aviv)
T. Broadhurst (Bilbao)
E. Cypriano (S. Paolo)
N. Okabe (Taipei)
M. Meneghetti (Bologna)
J. Rhodes (JPL)
L. Moustakas (JPL)

UNIVERSITÄT
HEIDELBERG
Zukunft. Seit 1386

CLASH: A HST/MCT programme

Science Drivers

- To map dark matter in galaxy clusters
- To detect SN out to redshifts z > 1.5
- To detect and characterise z > 7 galaxies
- To study the galaxies in and behind the clusters



UNIVERSITAT HEIDELBERG

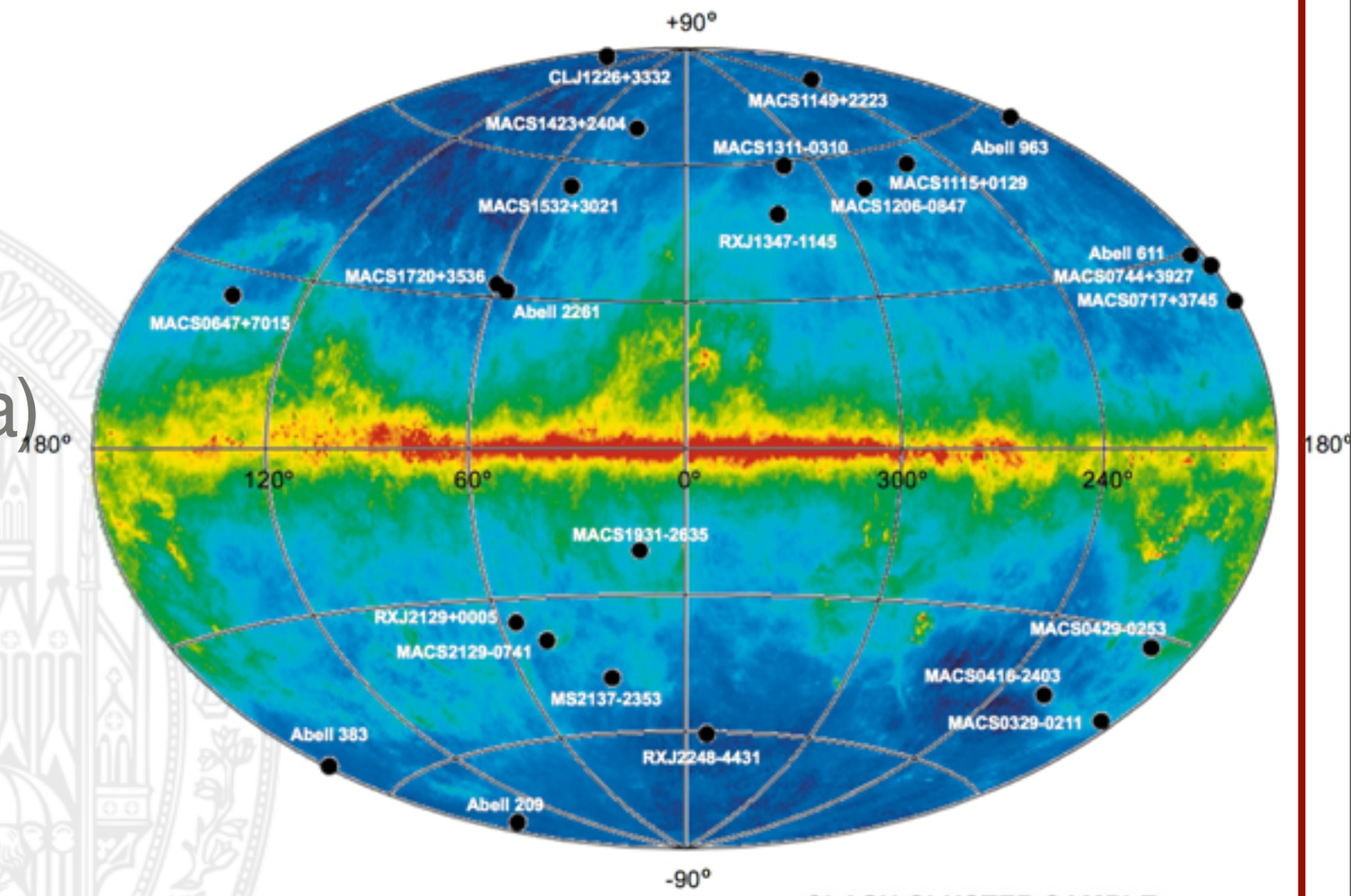
Zukunft. Seit 1386

CLASH: A HST/MCT programme

Granada, September 20, 2010

The observations: 524 HST orbits

- 25 clusters
  (0.18 < z < 0.9)
- X-ray selected
  (Chandra archival data)
- relaxed
- ACS/WFC3 in parallel
- 16 bands & 20 orbits
  per cluster (NIR - NUV)

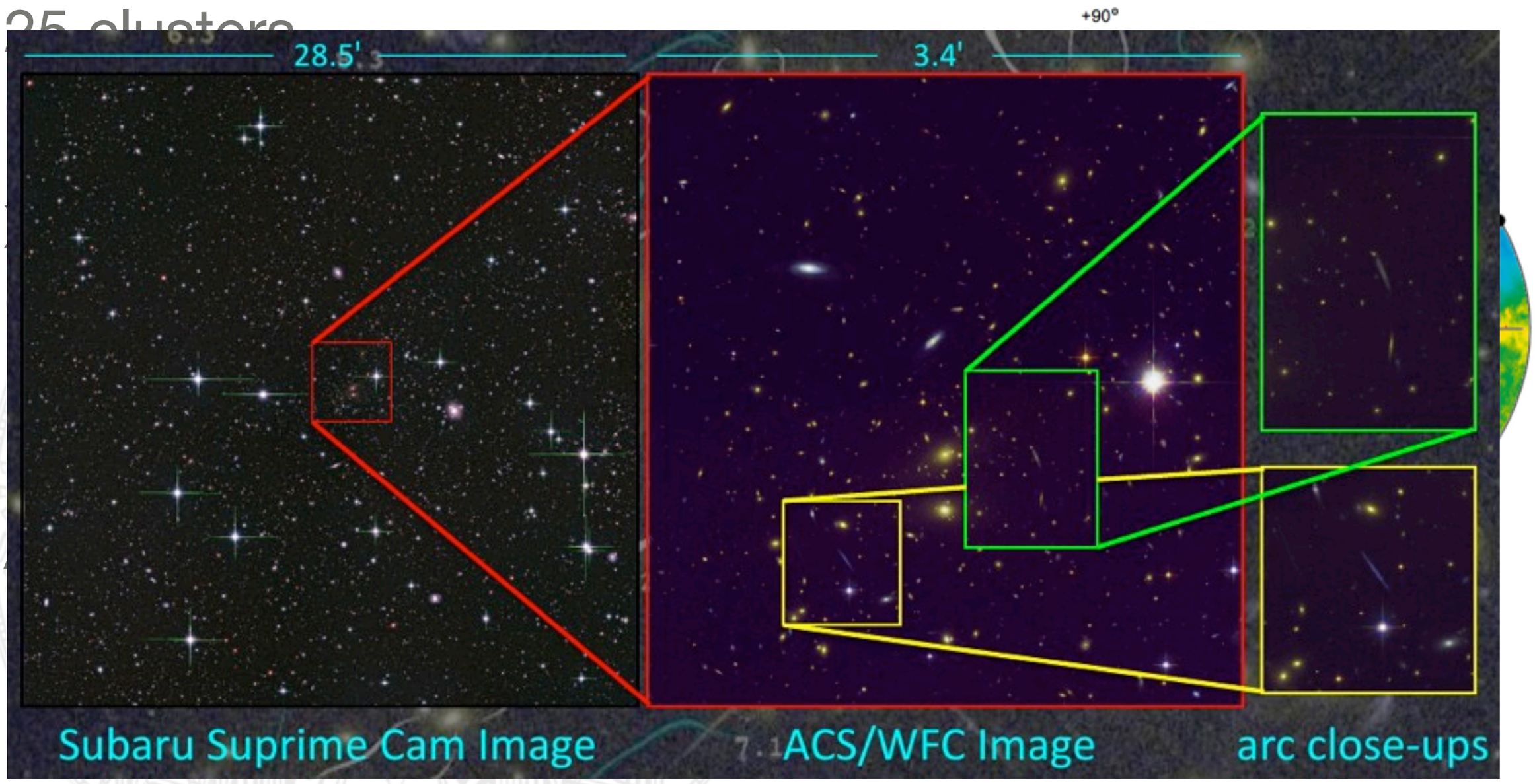


CLASH CLUSTER SAMPLE
(Galactic Coordinates)

UNIVERSITÄT
HEIDELBERG
Zukunft. Seit 1386

The observations: 524 HST orbits

- 25 clusters
-
-
-
-

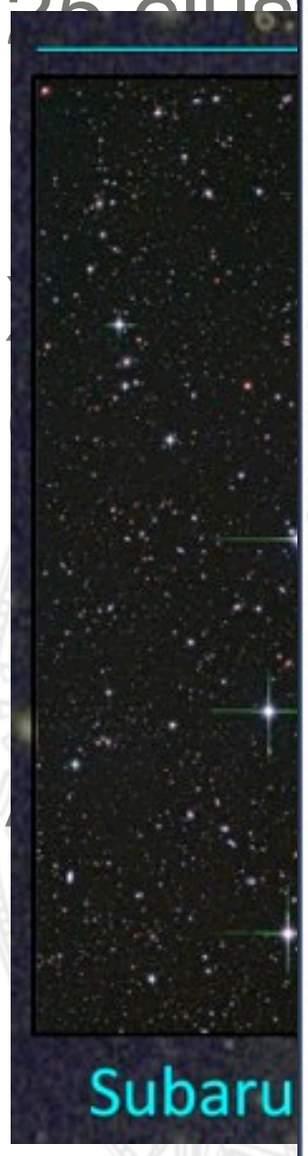


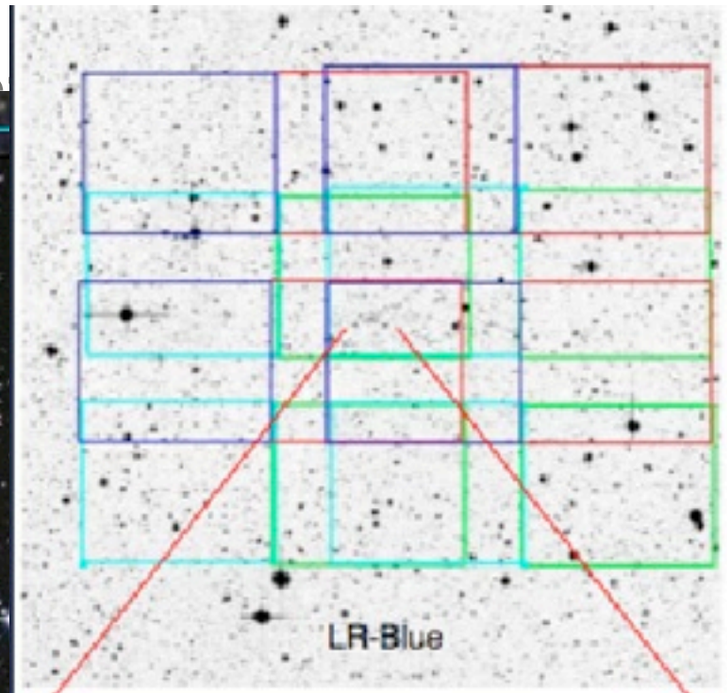
SUBARU BVRIZ weak lensing

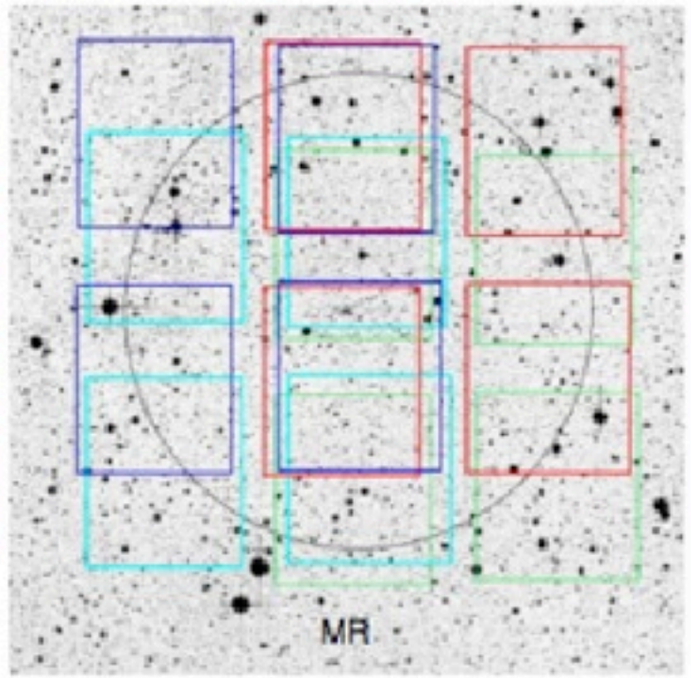
UNIVERSITÄT HEIDELBERG
Zukunft. Seit 1386

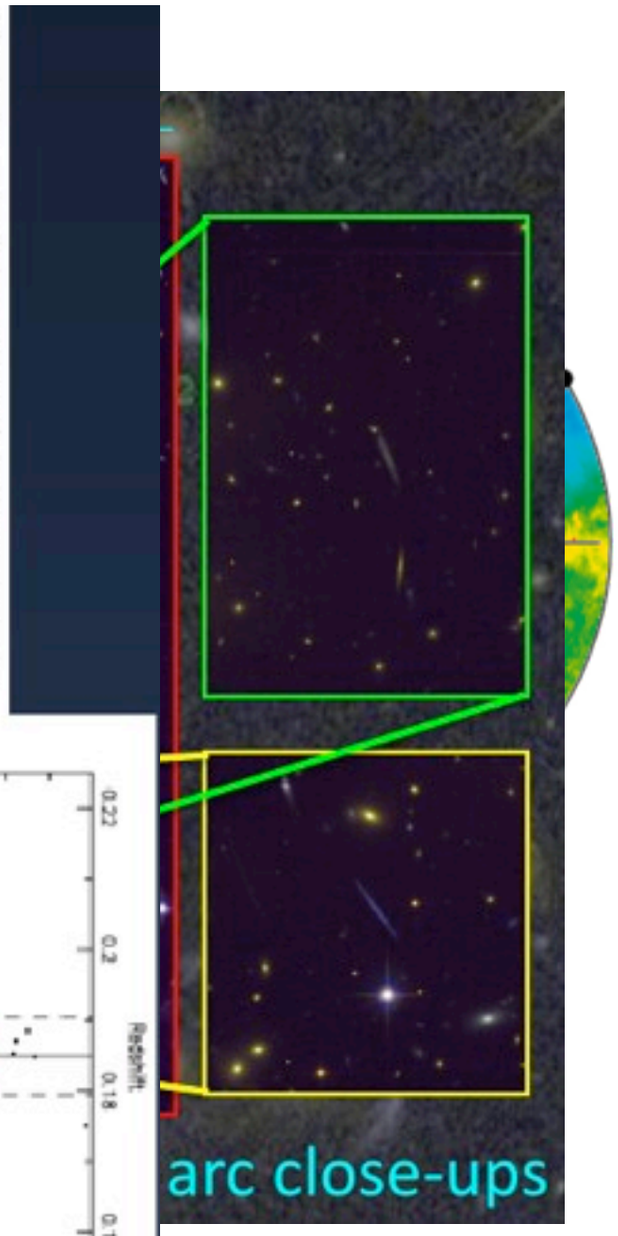
The observations: 524 HST orbits

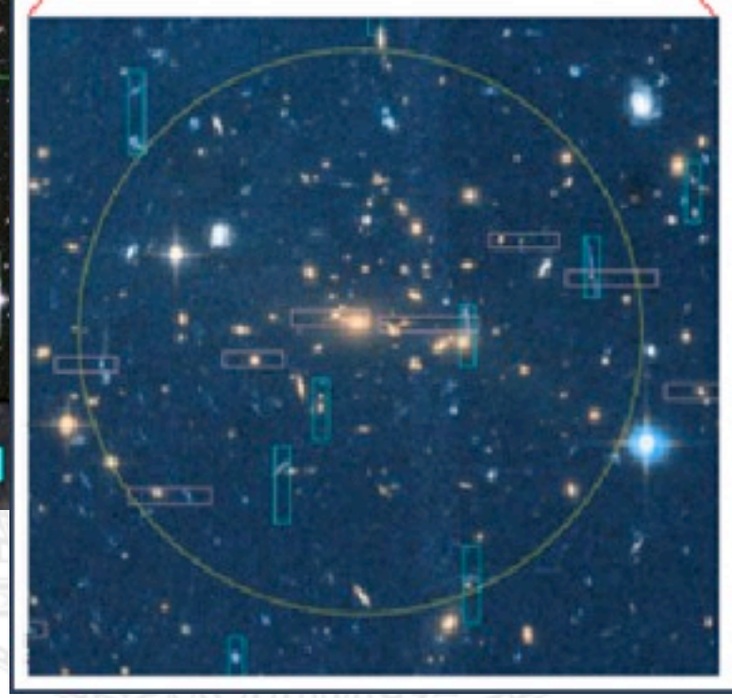
- 25 clus
-
-
-
-

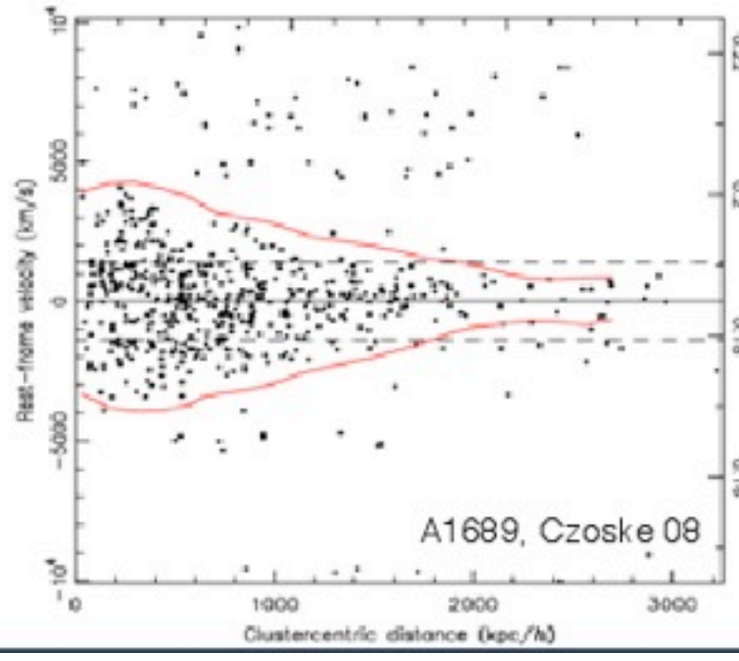










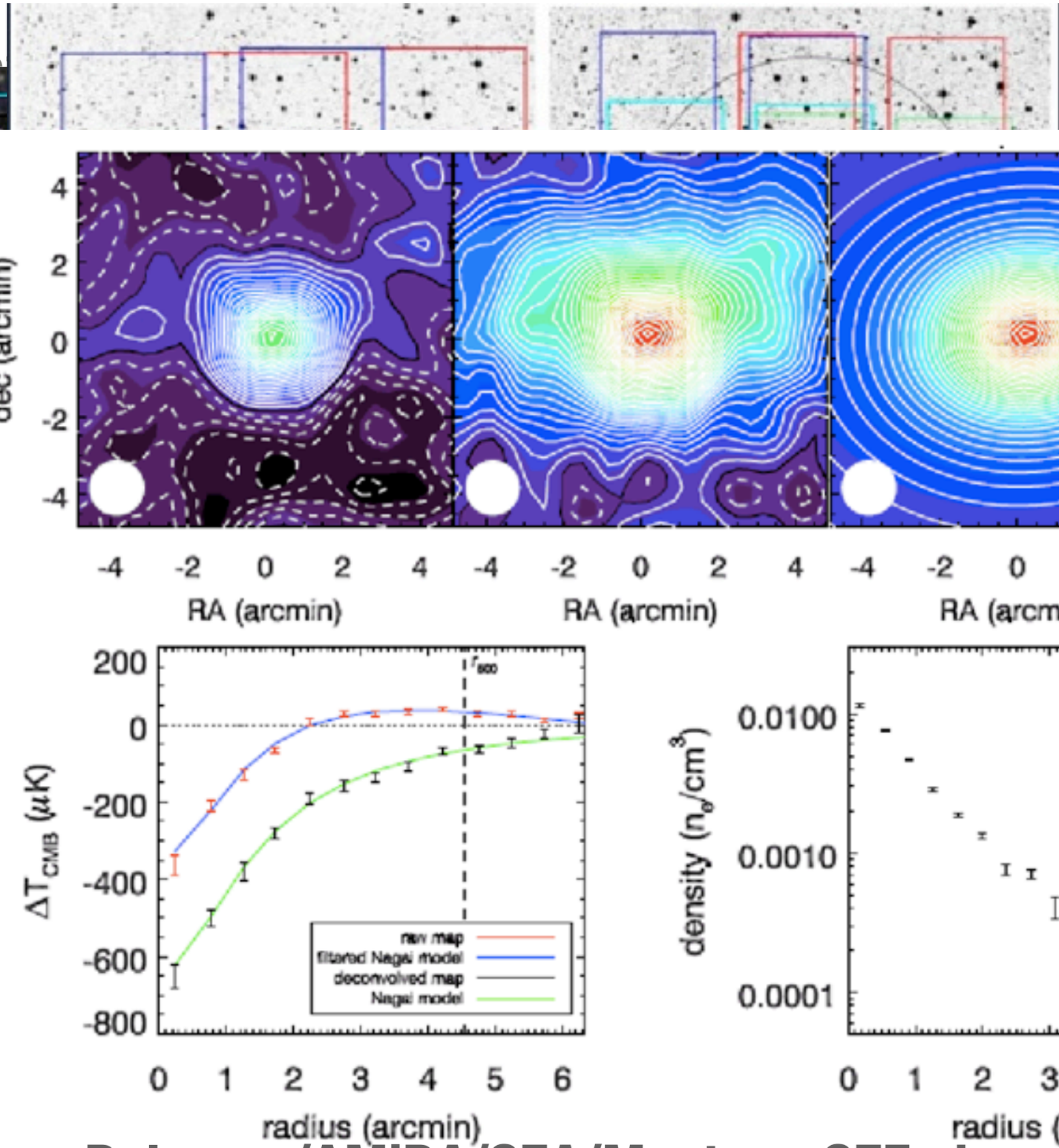


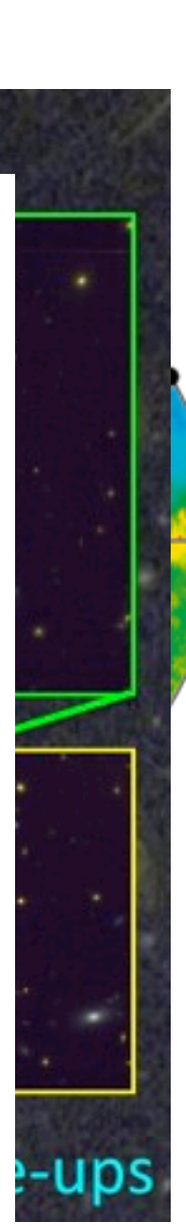
GTC/VLT/Magellan spectroscopy

UNIVERSITÄT HEIDELBERG
Zukunft. Seit 1386

The observations: 524 HST orbits

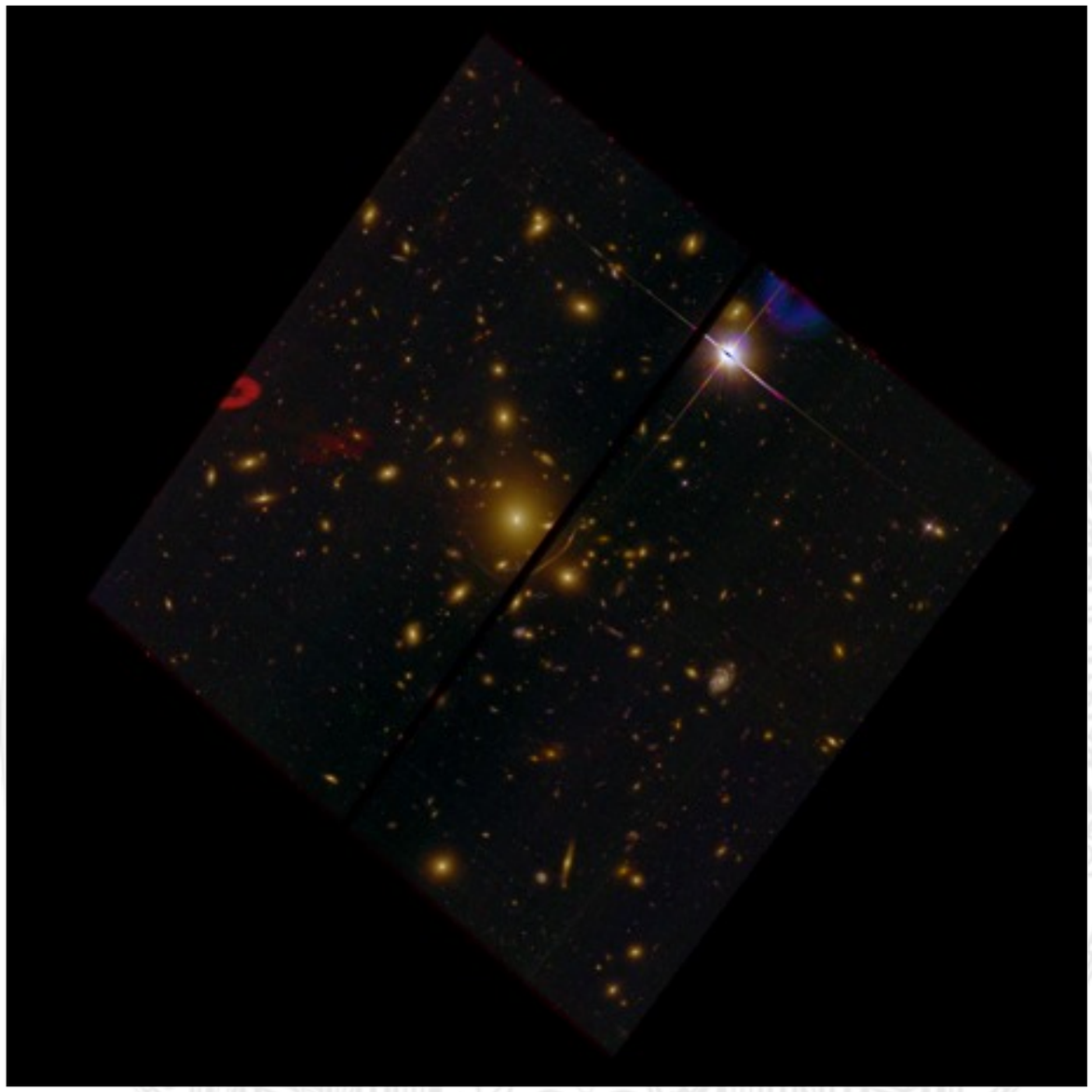
- 25 clus
-
-
-



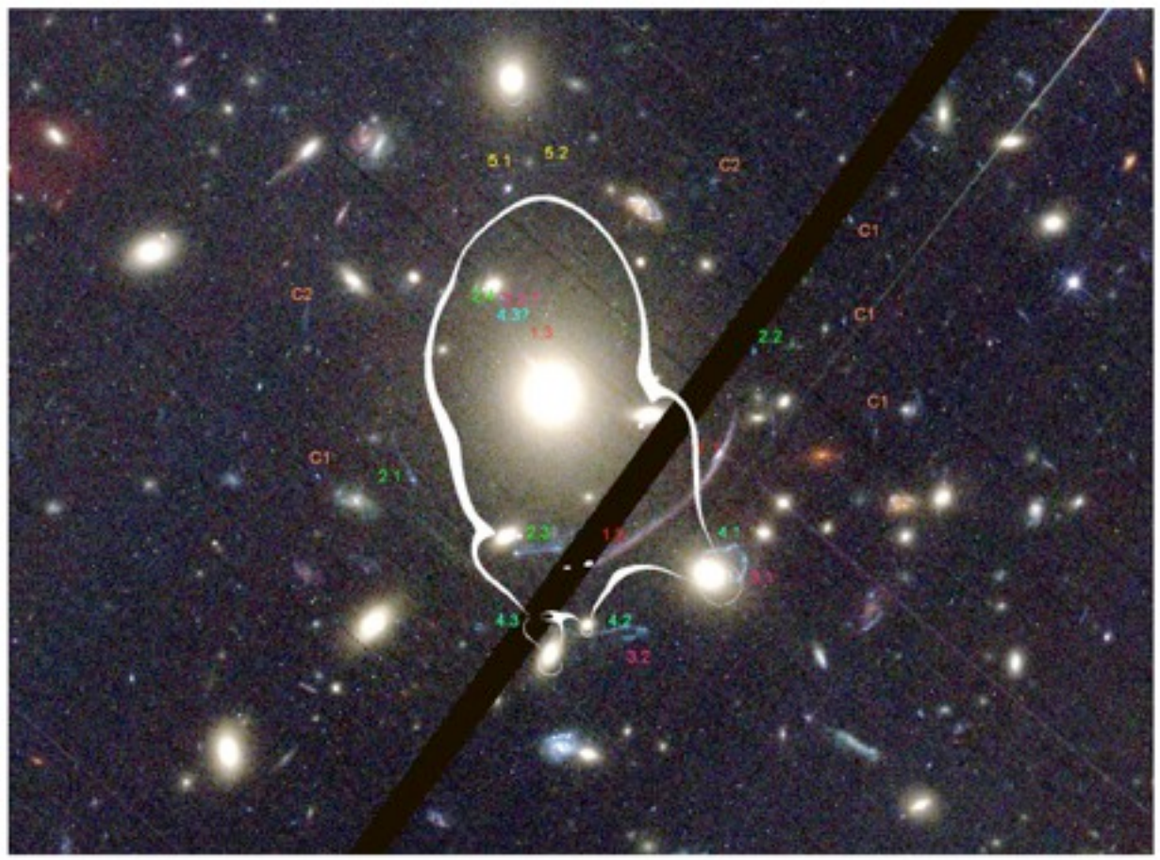


Bolocam/AMiBA/SZA/Mustang SZE observations

First results: Abell 383

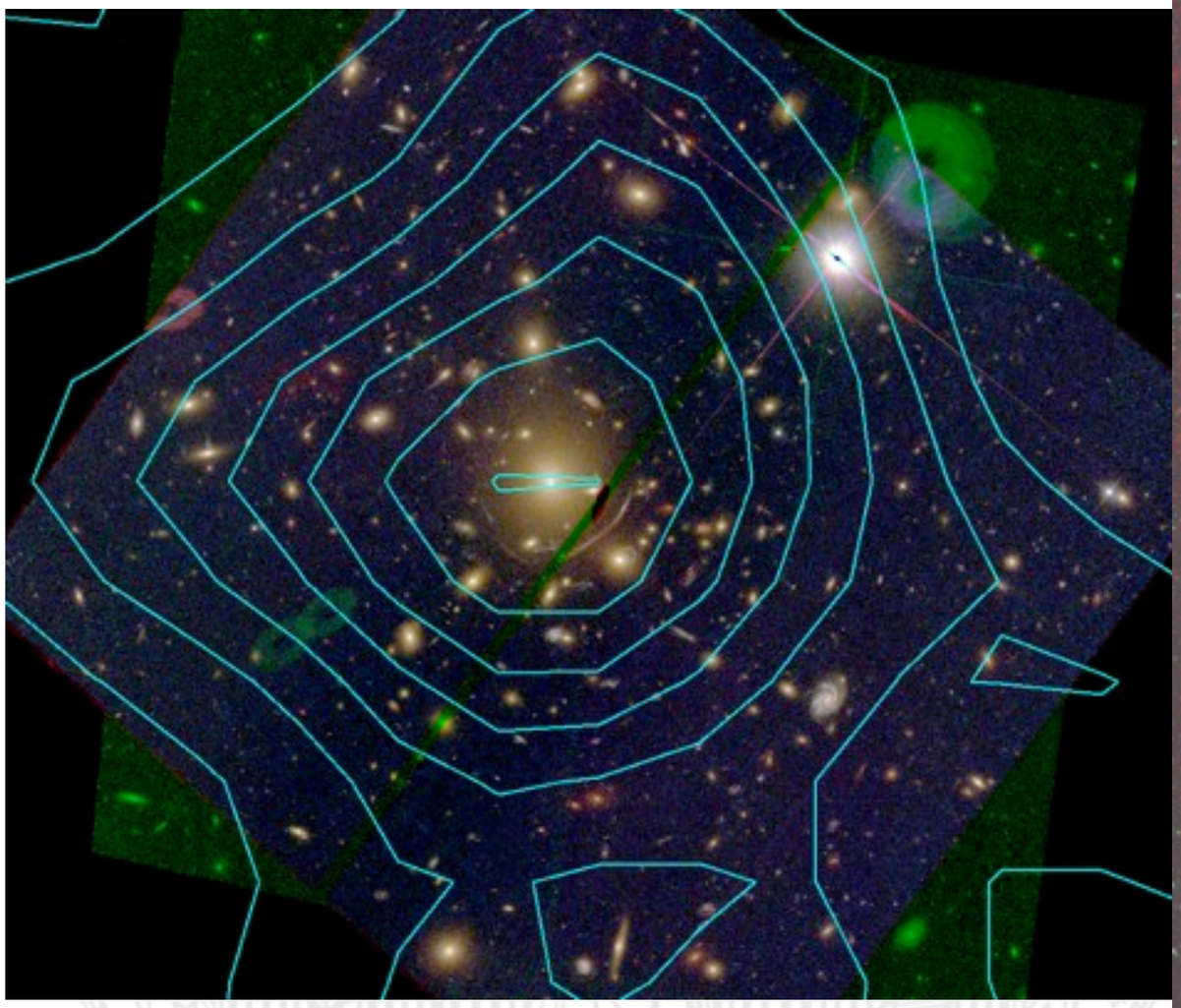


Colour composite using Trilogy, credit Dan Coe

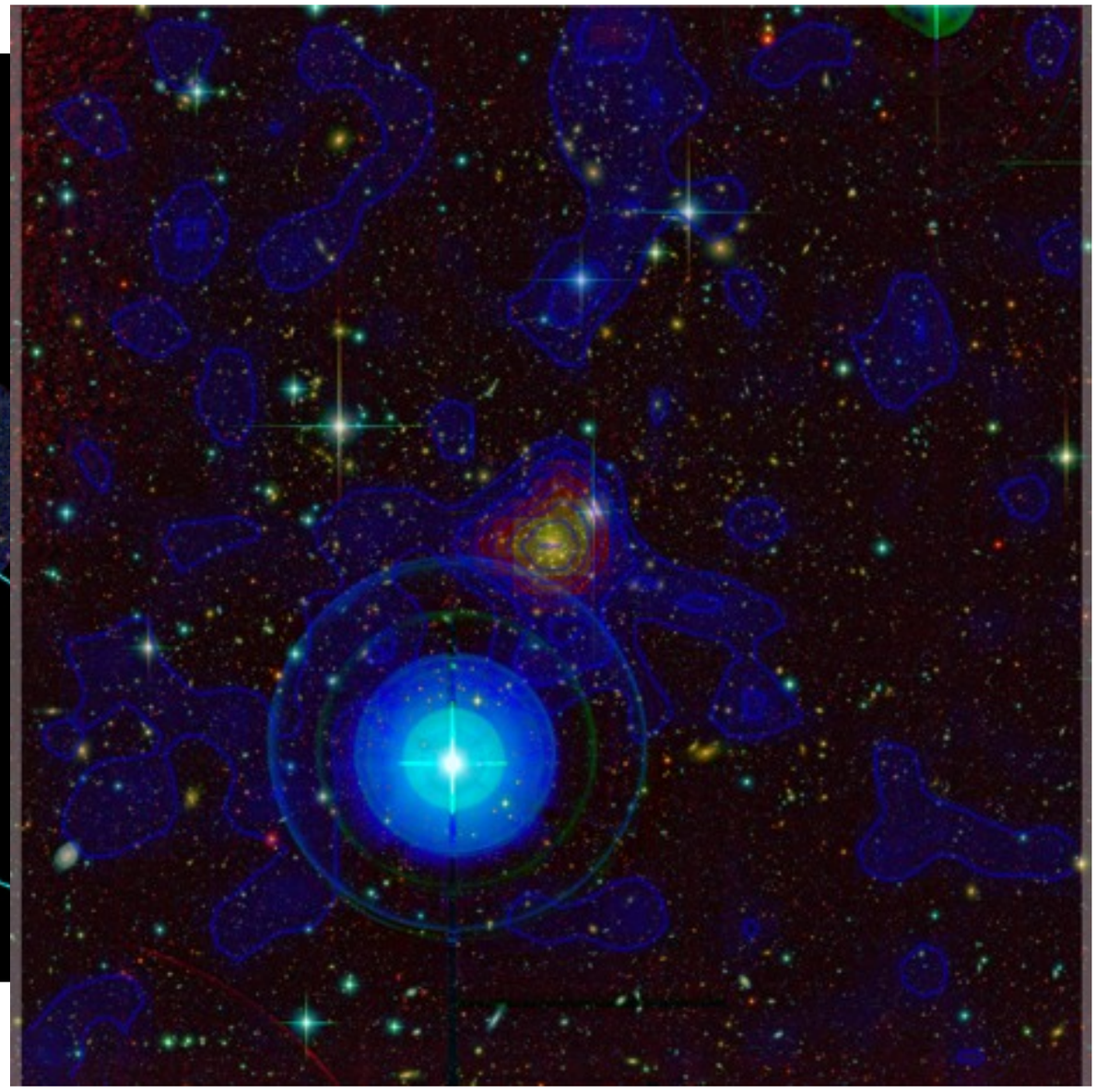


First SL mass models, Zitrin11+ in prep.

First results: Abell 383



WL contours on ACS (JM)



WL contours on SUBARU (JM)

Conclusions

- Galaxy clusters are an exciting topic for cosmology
- Combined lensing codes are able to reconstruct their mass distribution to a few percent
- For testing and comparing to simulations, the full pipeline has to be simulated
- GPUs are an energy -and price-efficient way to implement time-consuming codes
- Abell 2744: cosmic structure formation at work
- CLASH will help answering some open questions, at least we hope so