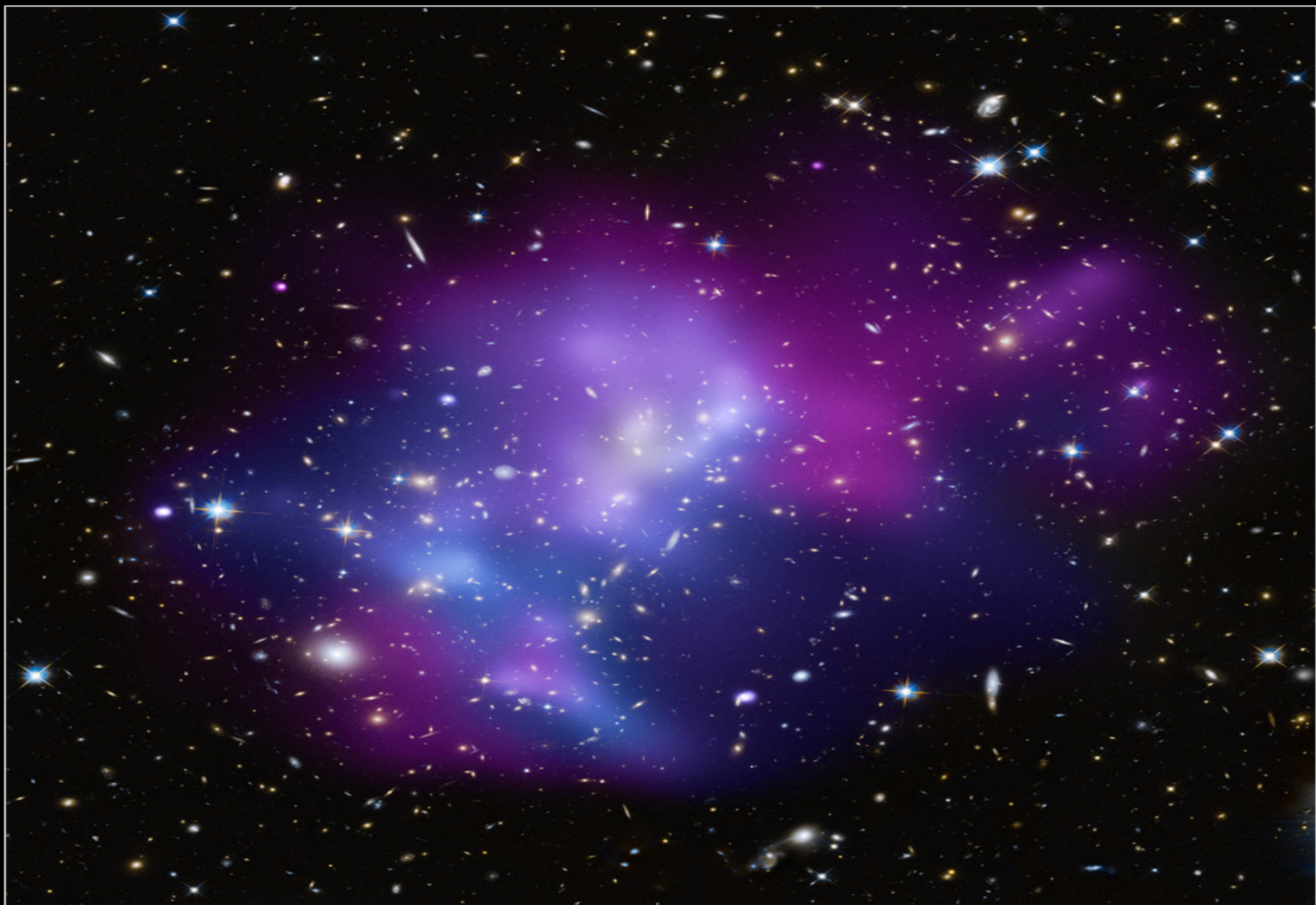


Galaxy Clusters

Michael Kunz

Galaxy Cluster
MACS J0717.5+3745

Hubble Space Telescope ■ ACS/WFC
Chandra X-ray Observatory ■ ACIS



Plan

- What is a galaxy cluster (GC)?
- Dynamics in a GC
- SZE-Effect
- Formation of a GC
- Evolution of galaxies in clusters
- GCs as probes for cosmological models
- Future questions and tasks

What is a galaxy cluster?

- Largest gravitationally bound objects
- Diameter: 2-10 Mpc
- Mass: 10^{14} - 10^{15} solar masses
- Formed: ~10 Gyr ago until today
- Contain:
 - 50-1000 galaxies
 - Hot gas
 - Dark matter

Dynamics in a galaxy cluster

- Detected in x-ray spectrum
- X-rays emitted by hot gas
- Absorption lines of iron
- Conclusion:
 - Intracluster Medium (ICM) is filled with hot gas
 - Velocity of the galaxies: up to ~ 1000 km/s
 - Metals from old star generations

The Sunyaev-Zeldovich Effect (SZE)

- Inverse compton scattering
- Energy boost to CMB-photons
- Energy source: electrons in the ICM
- Shadow on isotropic CMB-spectrum
- Red-shift independent effect
 - Possibility to detect high-redshift clusters ($z > 1,5$)

Formation of a galaxy cluster

- Hierarchical:
 - Dwarf galaxies form first
 - Merge to bigger galaxies (ellipticals)
 - Form (super)clusters (process still in action)
- Galaxy clusters contain oldest objects in the universe

Evolution of galaxies in clusters

- Physical effects:
 - Merging
 - Tidal forces
 - Gas stripping
 - Strangulation

Evolution of galaxies in clusters

- Evolution with red-shift (observations):
 - More spirals in distant clusters
 - In the local universe:
 - Spirals in low density areas
 - Ellipticals in high density areas
 - Fraction of spirals/ellipticals increases/decreases towards higher z

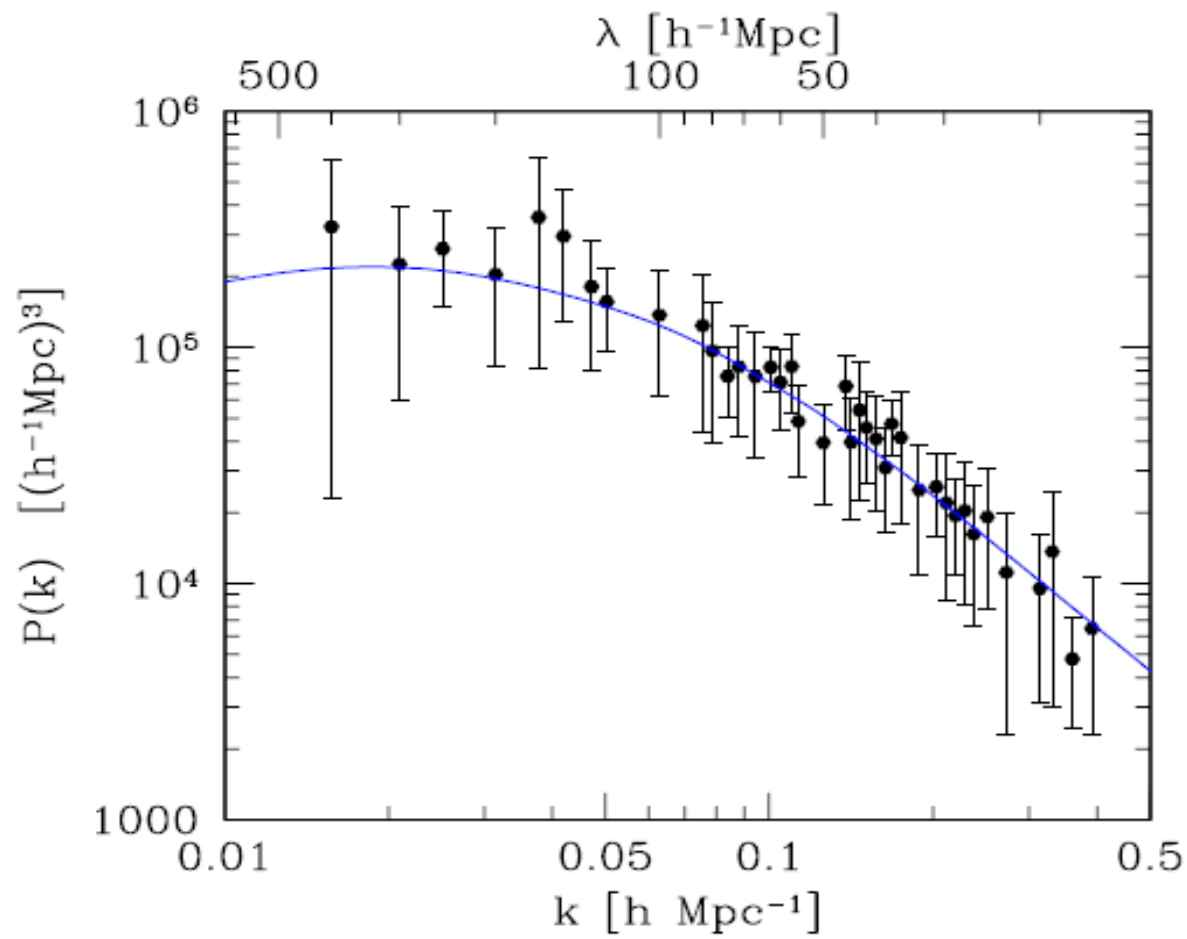
Evolution of galaxies in clusters

- $z=0,5$ same fraction of S0 galaxies as today
 - S0 have evolved from spirals
- Mass dependance:
 - Anti-hierarchical star formation
 - lower mass galaxies have more star formation
- Environmental dependance:
 - Lower density per mass leads to more star formation (transformation from spirals to S0)

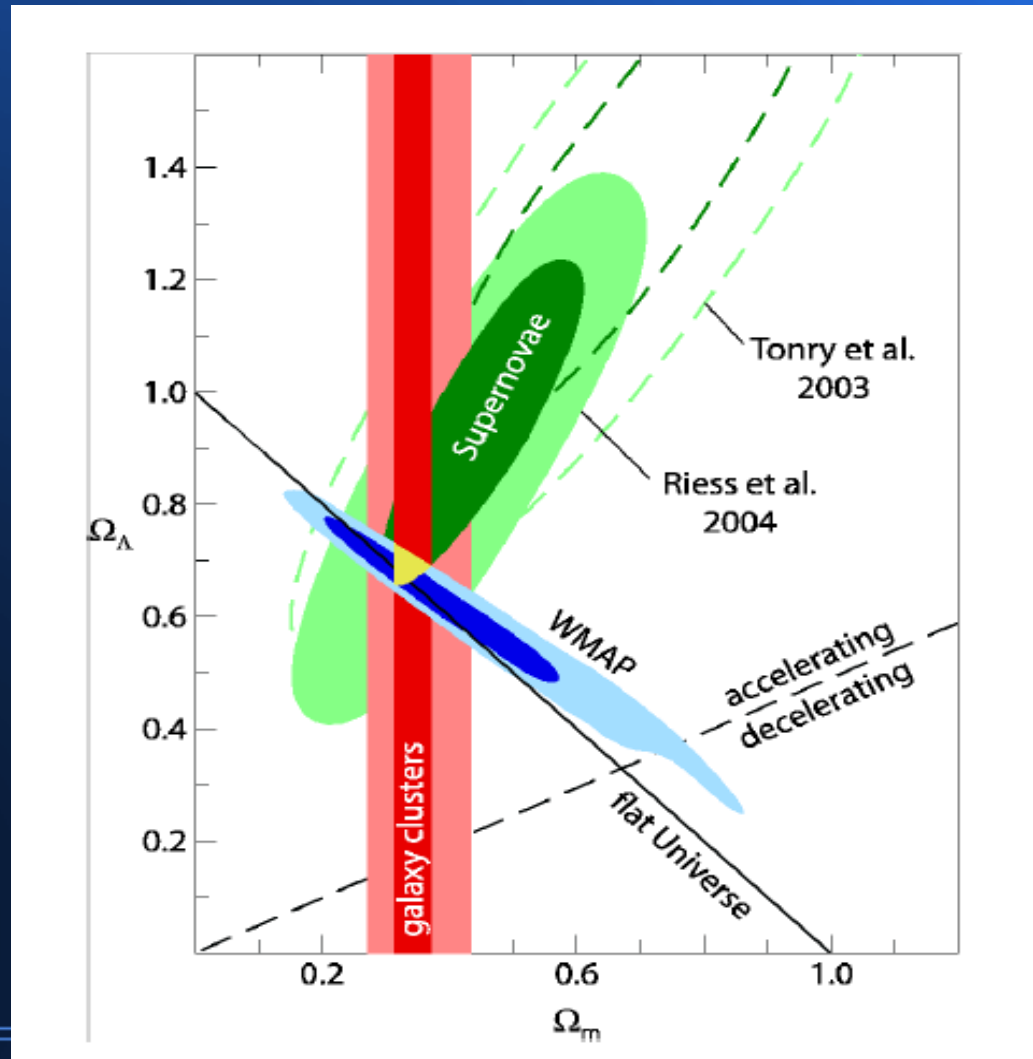
Galaxy clusters as probes for cosmological models

- REFLEX-catalogue: 447 clusters
- Redshifts: $z < 0,45$
- REFLEX power-spectrum can test cosmological models
- Friedmann-Eq:
$$\frac{H^2}{H_0^2} = \Omega_R a^{-4} + \Omega_M a^{-3} + \Omega_k a^{-2} + \Omega_\Lambda$$
- Fit: $\Omega_M = 0,34$

REFLEX-Power-Spectrum



Cosmological Model



Future questions and tasks

- Test Einstein gravity on largest scales
- Full catalogue over all $\sim 10^6$ galaxy cluster in the visible universe ($z > 2$ especially)
- Consistent theory for galaxy evolution in GCs explaining
 - Red-shift
 - Mass
 - Environment