THE NATURE OF DARK MATTER

M31 rotation curve

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ROTATION OF THE ANDROMEDA NEBULA FROM A SPECTROSCOPIC SURVEY OF EMISSION REGIONS*

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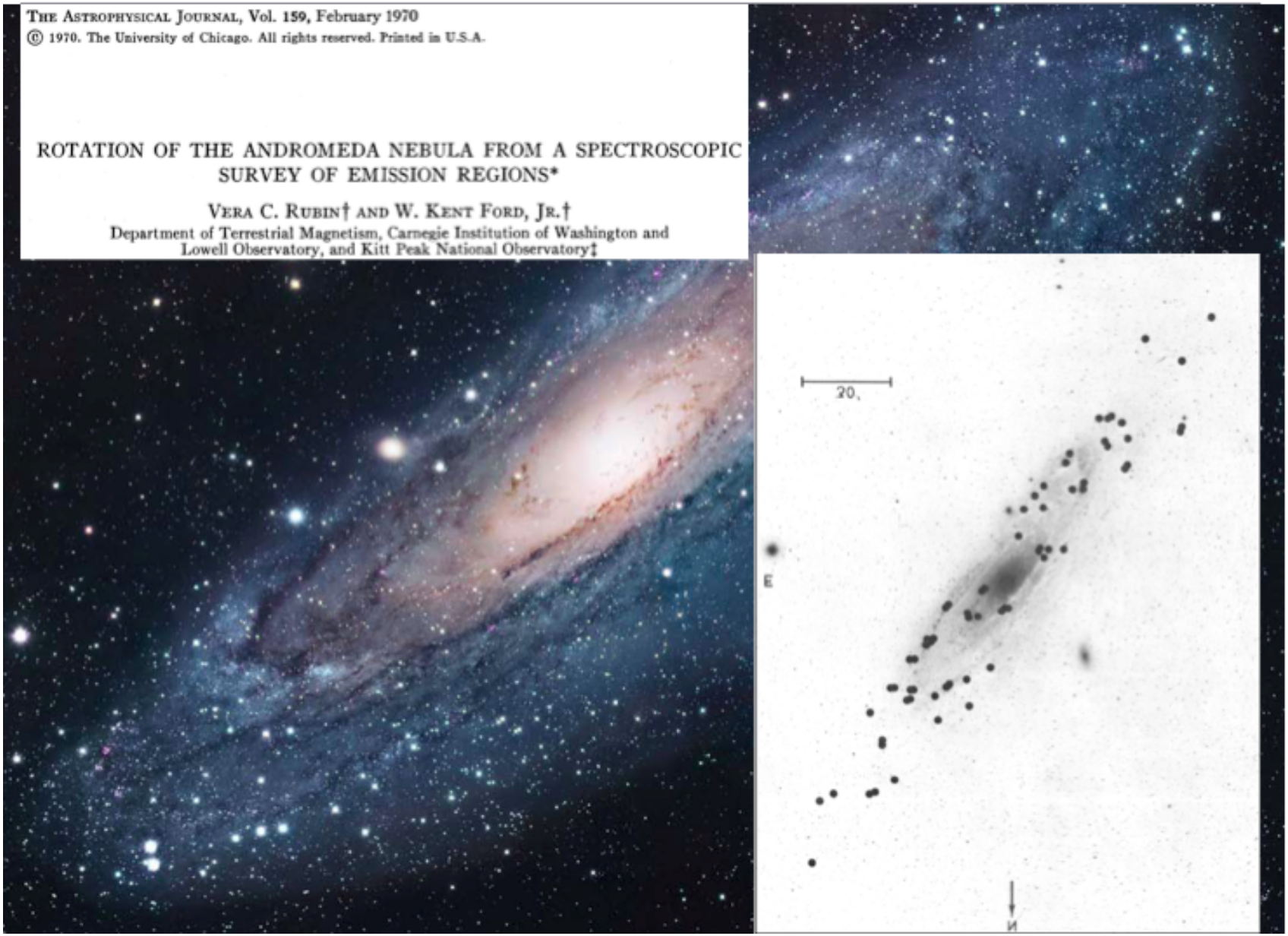
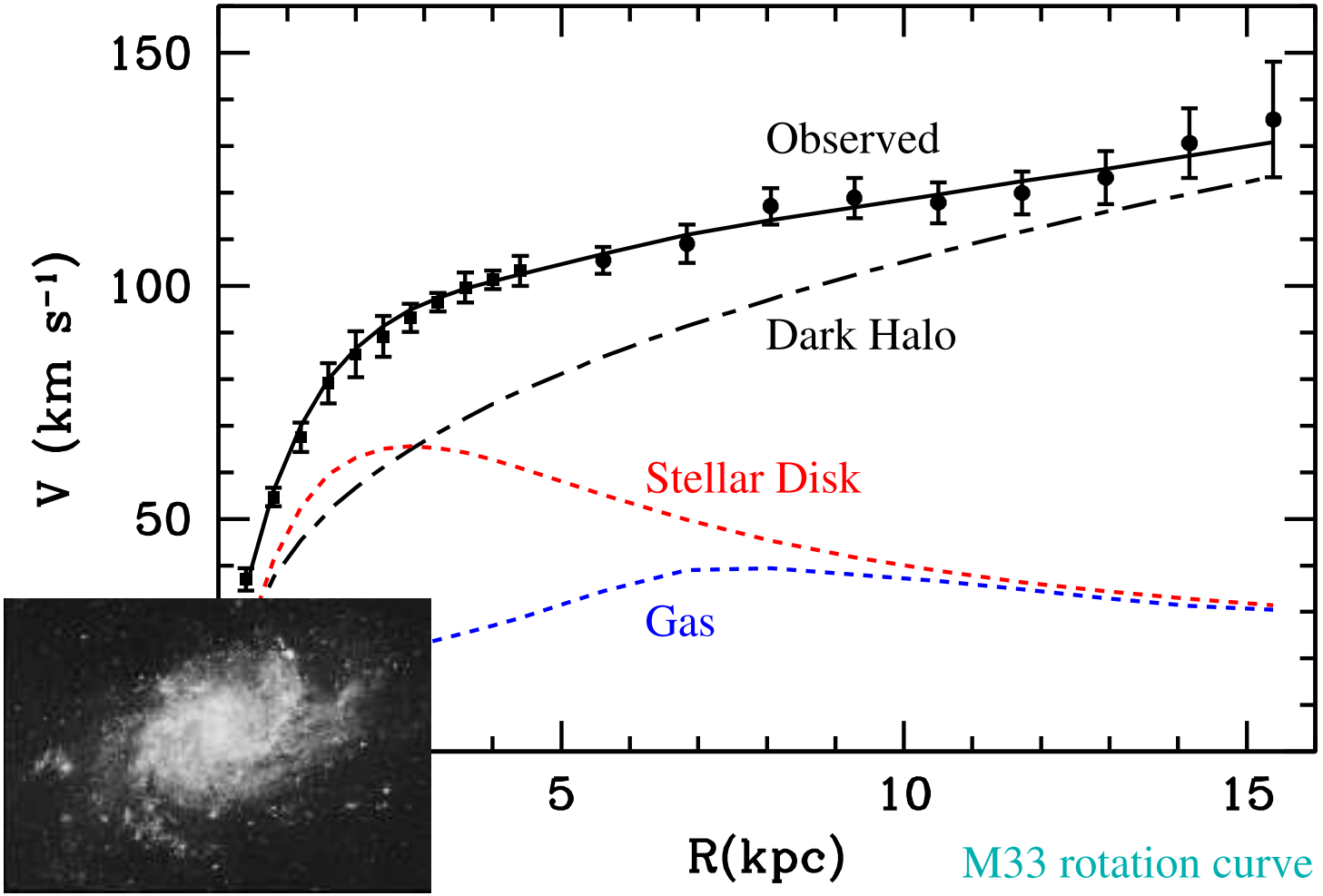


Rotation curve?

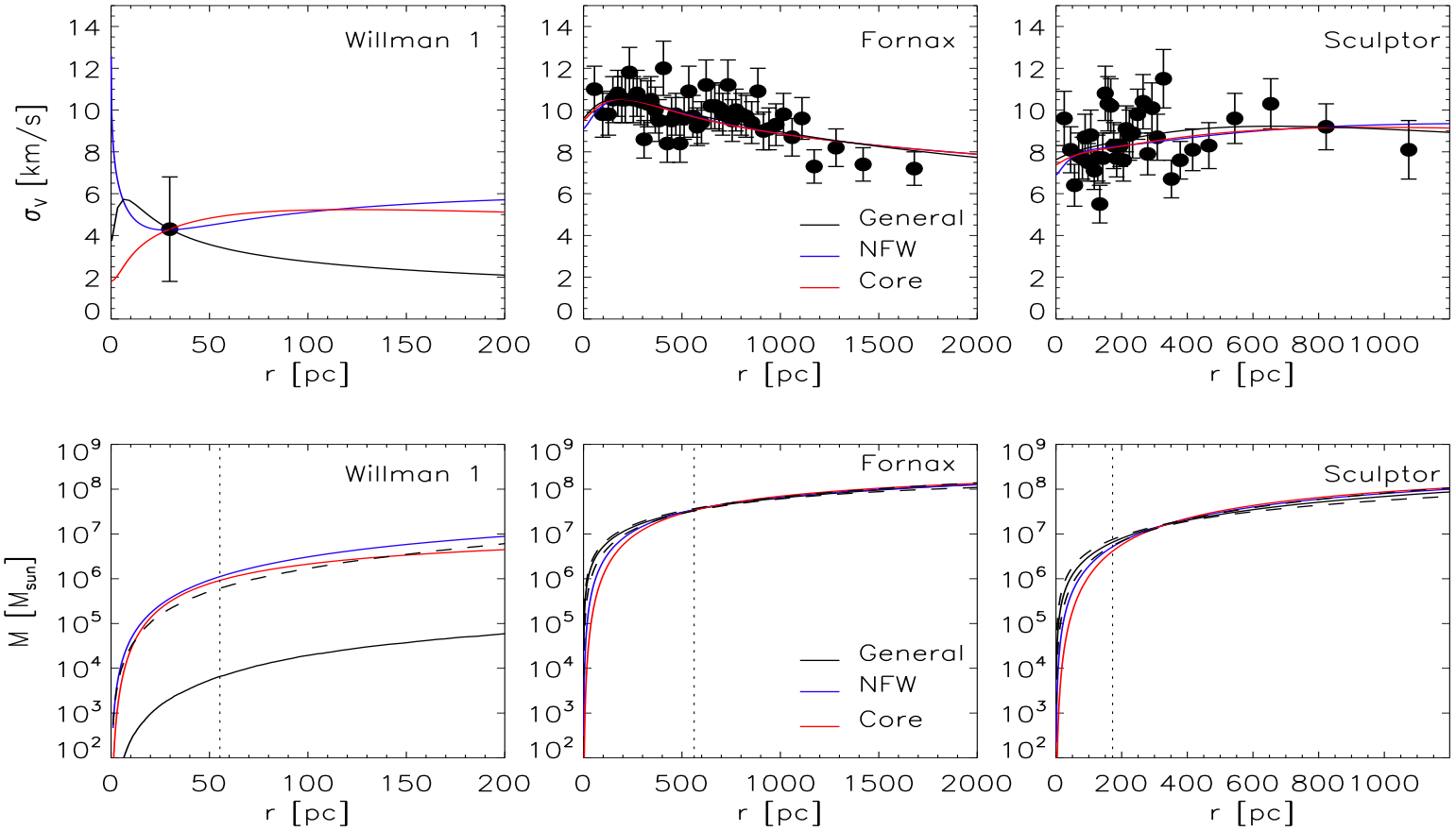


M33 rotation curve

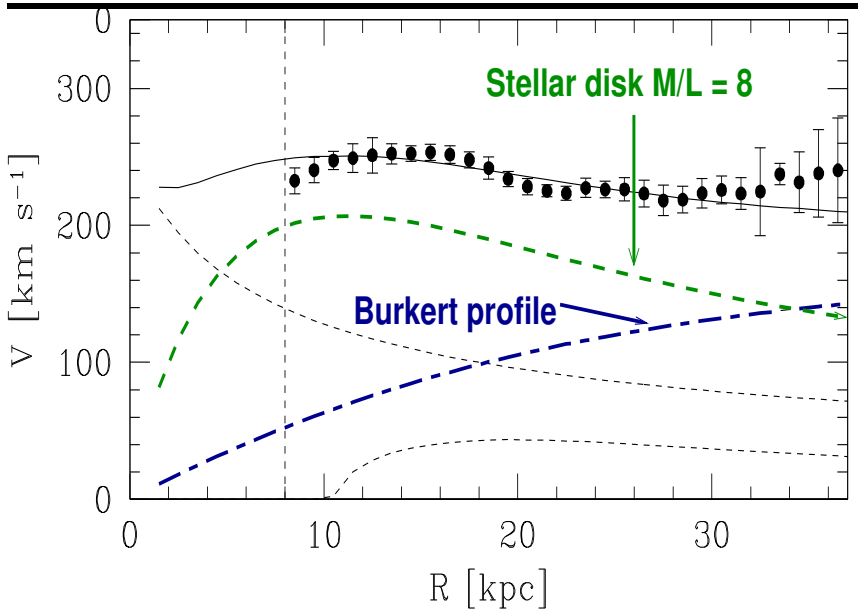
Back to DM

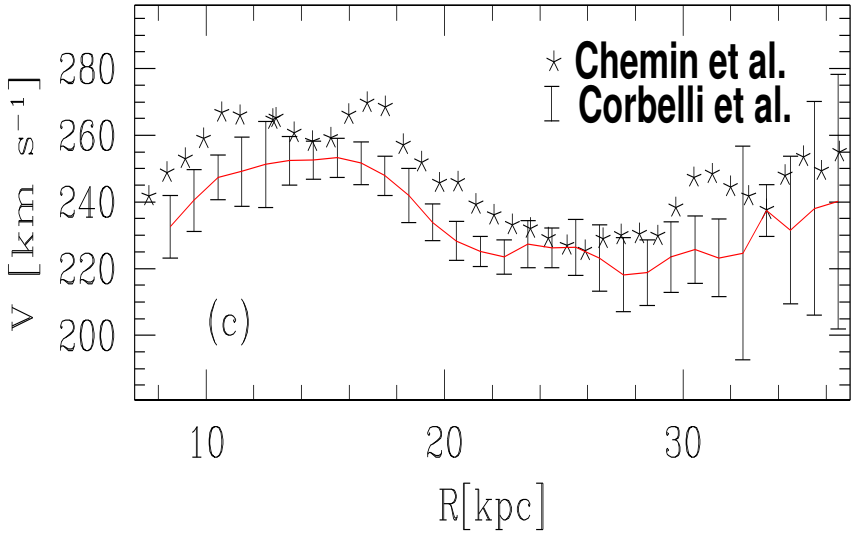
Newton dynamics: $\mathrm{V}(R) \sim \frac{1}{\sqrt{R}}$

DM in Dwarf Spherodiadals

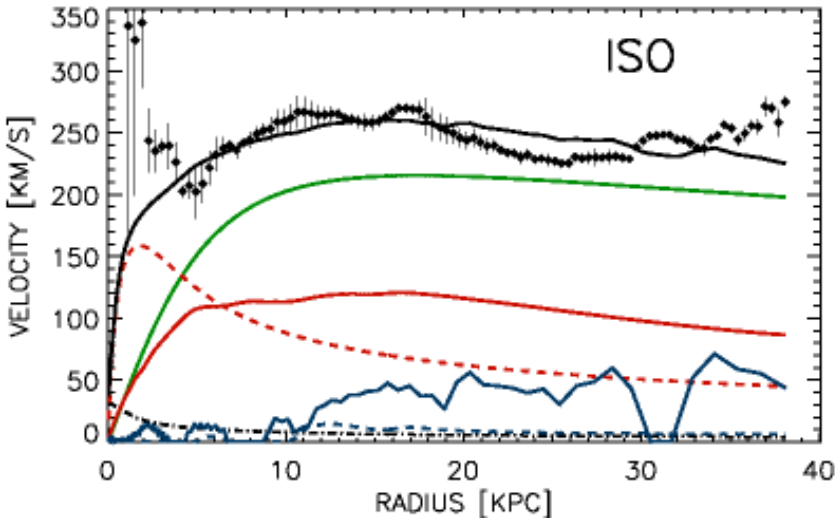


New data and mass-to-light ratio in M31





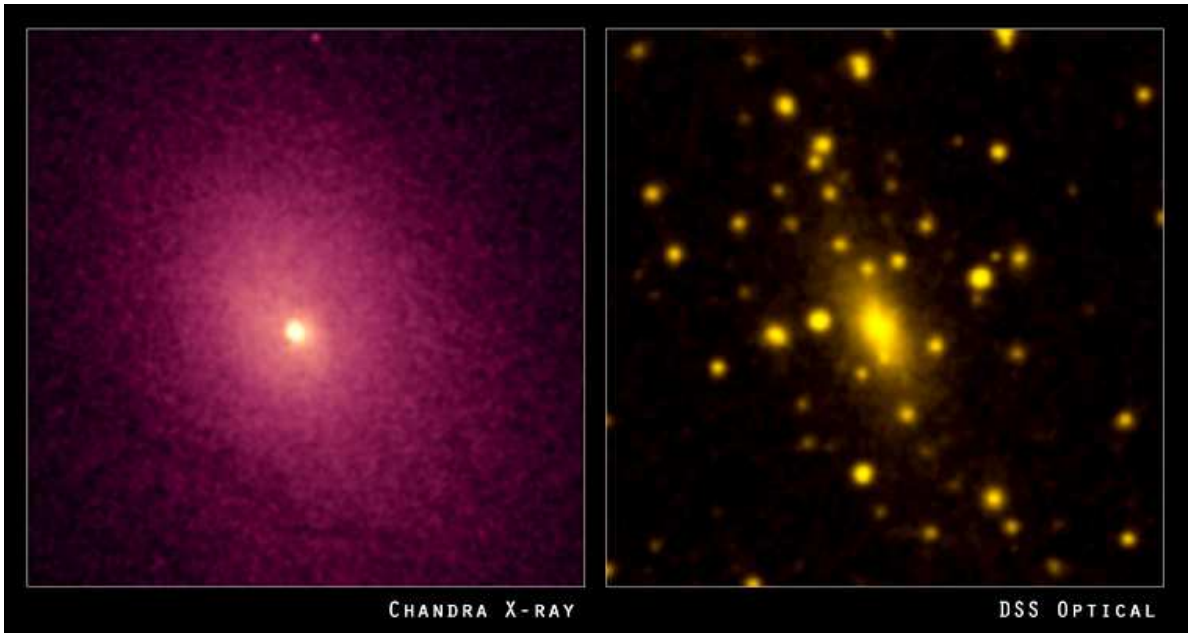
Corbelli et al. A&A 2009 [0912.4133]



Chemin et al. ApJ 2009 [0909.3846]

- New precise HI data resolve features within inner 5–8 kps
- **Chemin et al.** model this region
- **Corbelli et al.** exclude this region from the analysis

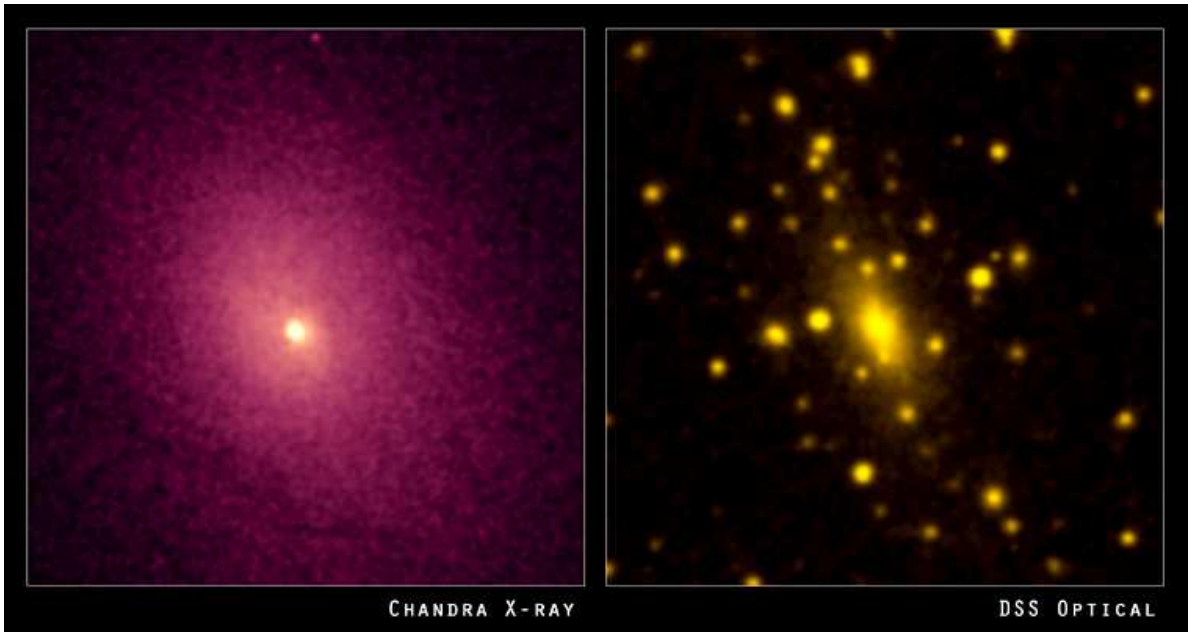
Intracluster gas



Cluster Abell 2029. **Credit: X-ray: NASA/CXC/UCI/A.Lewis et al. Optical: Pal.Obs. DSS**

$$\frac{dp}{d\boldsymbol{r}} = n_{\rm gas}(\boldsymbol{r})\frac{dT(\boldsymbol{r})}{d\boldsymbol{r}} + T(\boldsymbol{r})\frac{dn_{\rm gas}(\boldsymbol{r})}{d\boldsymbol{r}} = -\frac{GM(\boldsymbol{r})n_{\rm gas}(\boldsymbol{r})}{\boldsymbol{r}^2}\,, \tag{11}$$

Intracluster gas



Cluster Abell 2029. **Credit: X-ray: NASA/CXC/UCI/A.Lewis et al. Optical: Pal.Obs. DSS**

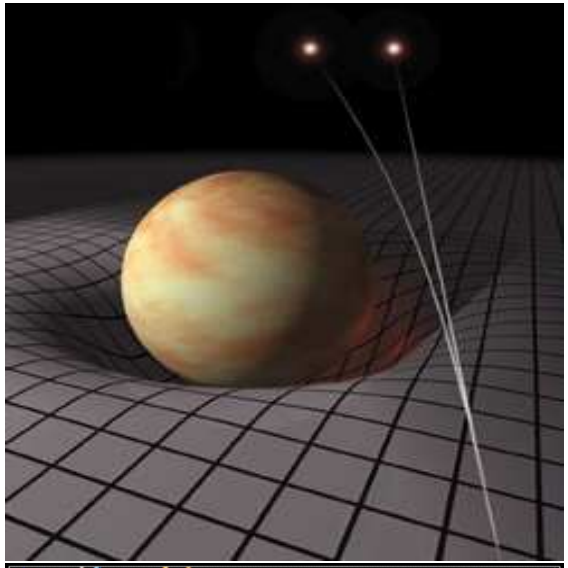
Dark Matter	$\sim 85\%$
Intracluster gas	$\sim 15\%$
Galaxies	$\sim 1\%$

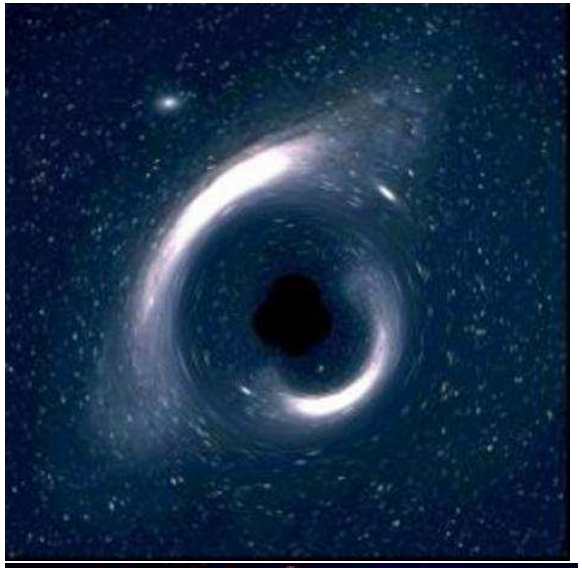
$$\frac{\text{DM in cluster}}{\text{Baryons in cluster}} \approx \frac{\Omega_{\text{DM}}}{\Omega_{\text{baryons}}}$$

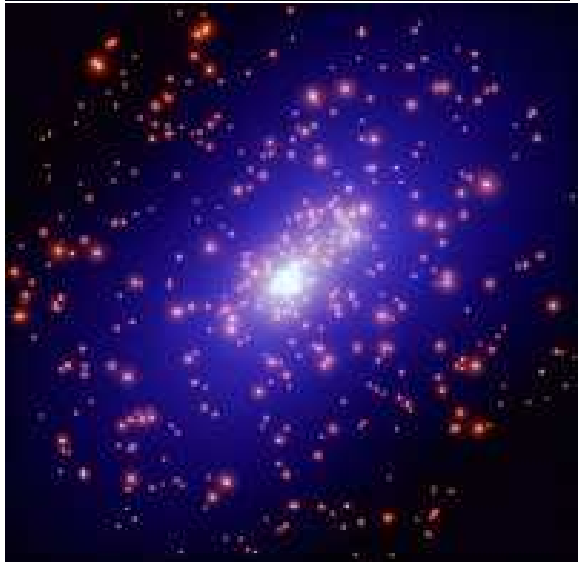
Temperature of ICM: $1 - 10$ keV $\sim 10^7 - 10^8$ K

Back to DM page

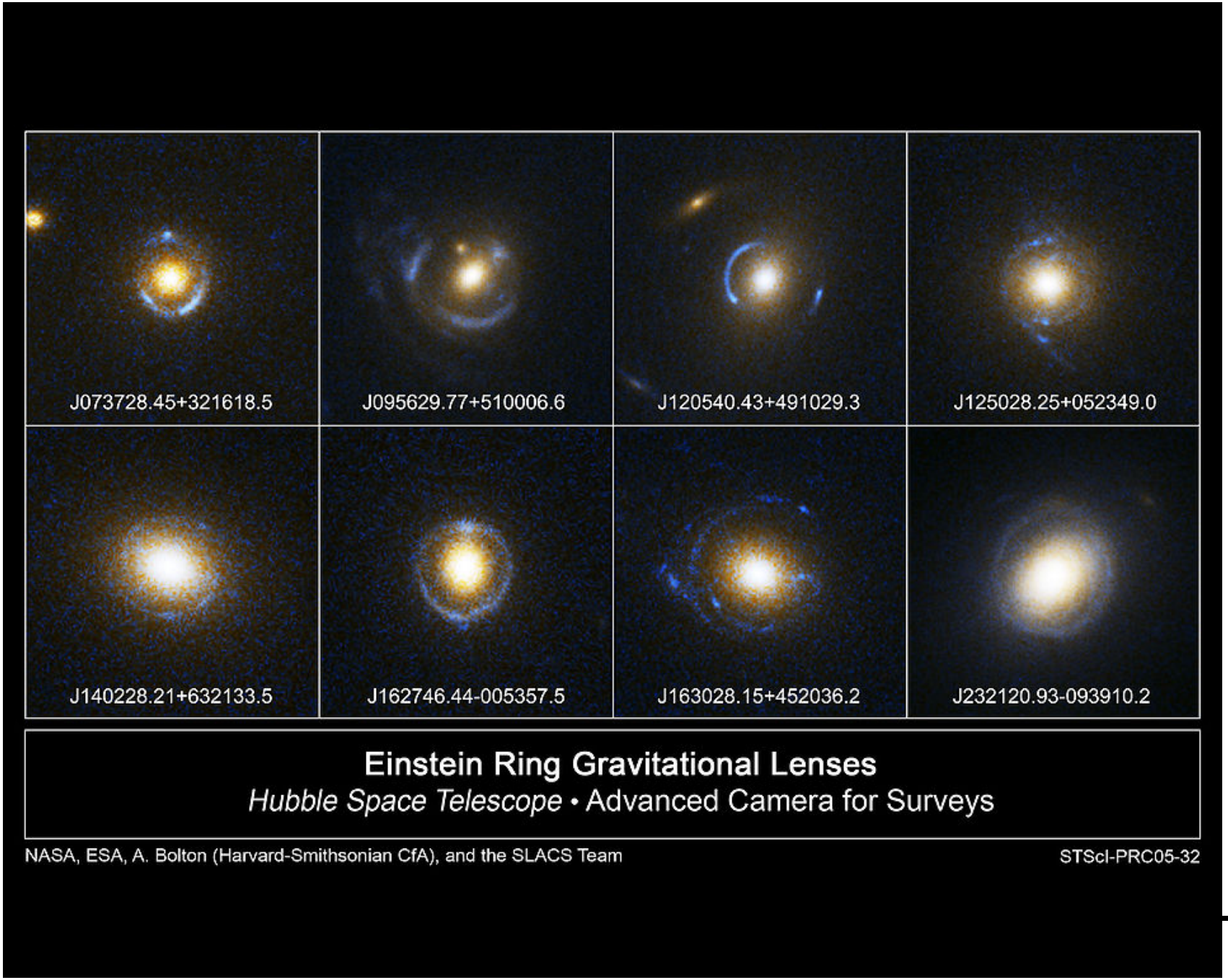
Gravitational lensing







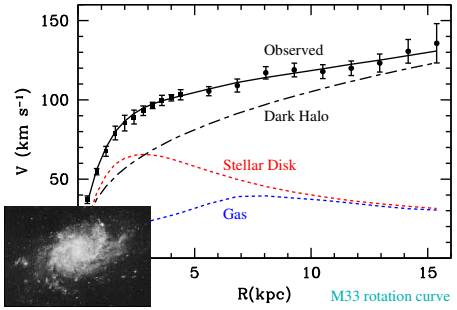
Gravitational lensing

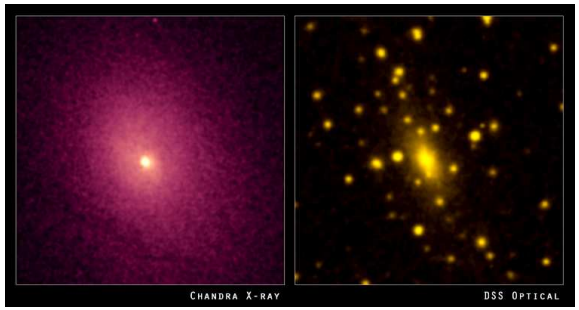


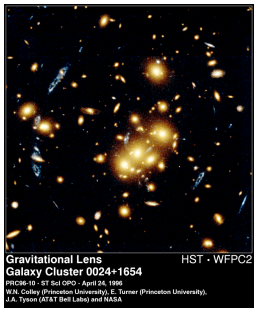
Dark Matter in the Universe

- Rotation curves of stars in galaxies and of galaxies in clusters
- Distribution of intracluster gas
- Gravitational lensing data

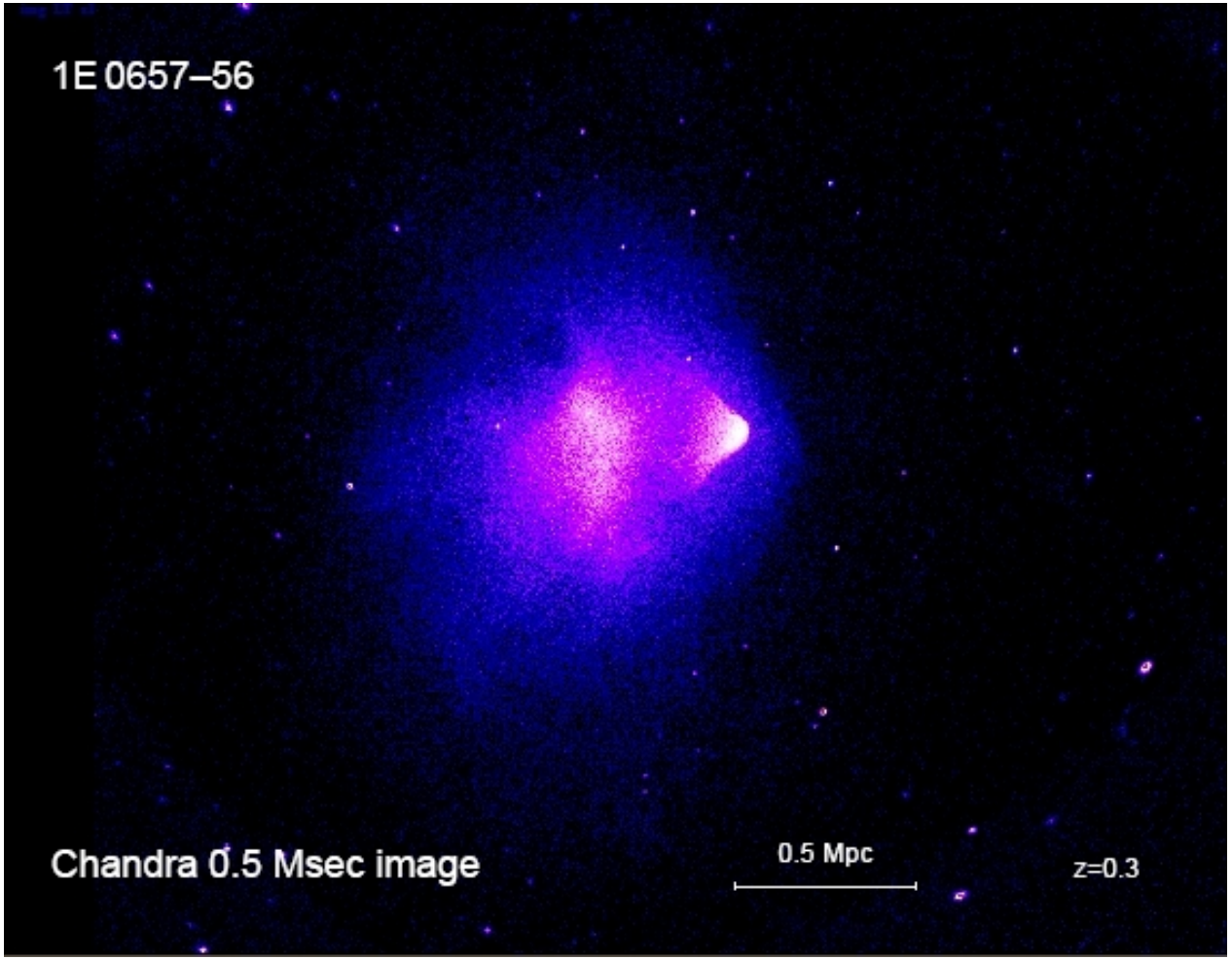
These phenomena are **independent tracers** of gravitational potentials in astrophysical systems. They all show that dynamics is dominated by a matter that is not observed in any part of electromagnetic spectrum.





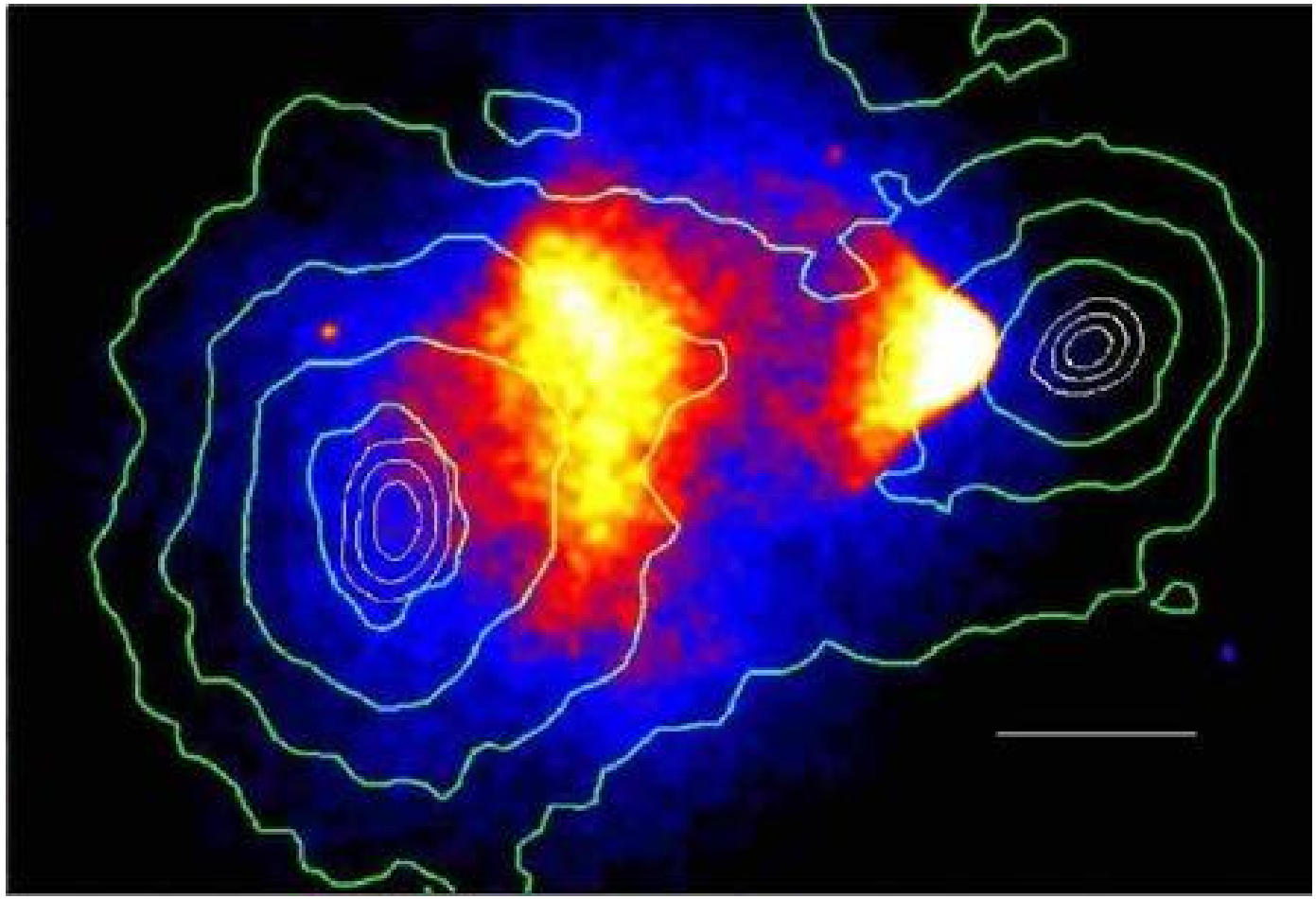


"Bullet" cluster



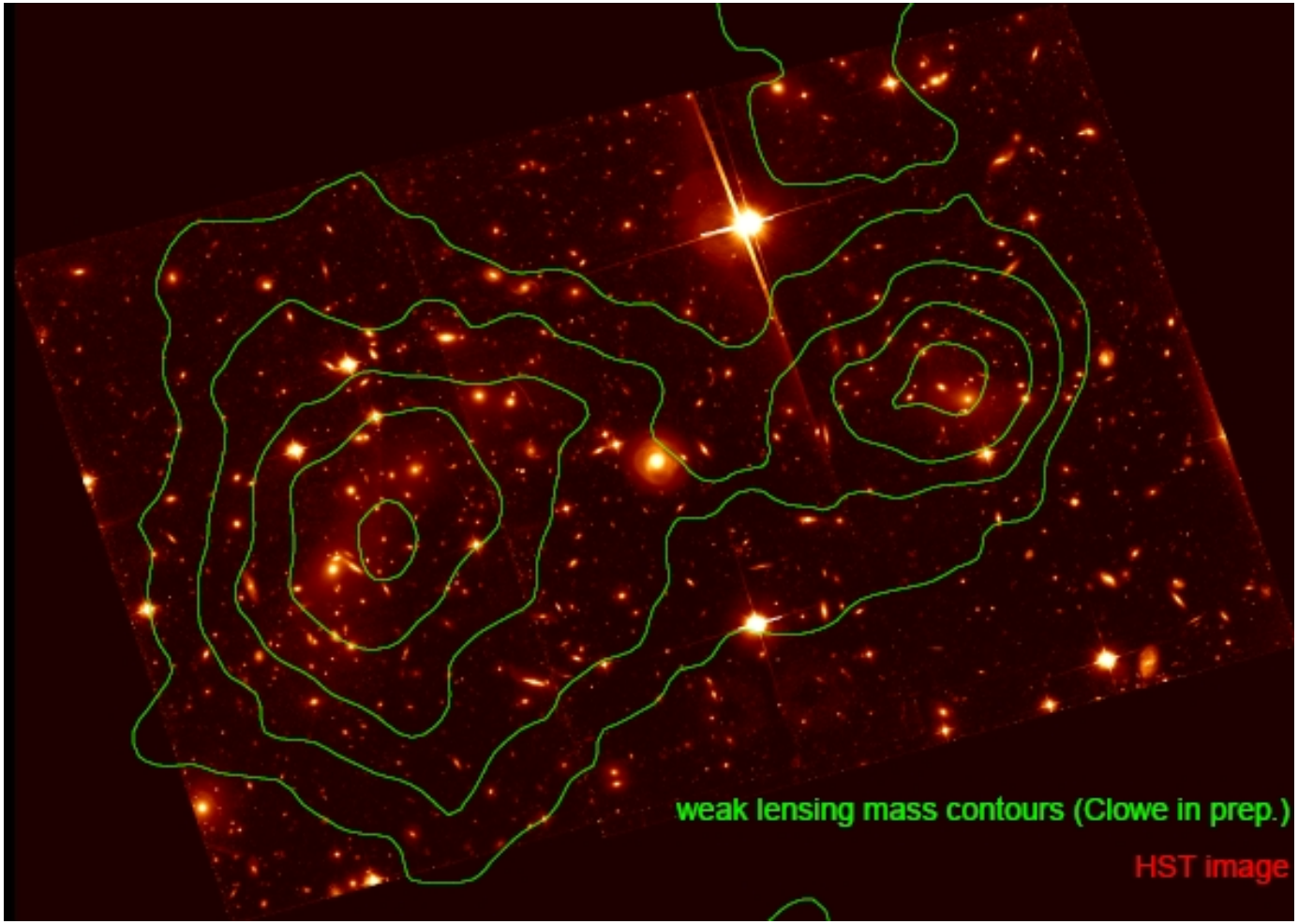
Cluster 1E 0657-56
Red shift $z = 0.296$
Distance $D_L = 1.5$ Gpc

Merging system in the plane of the sky



- Subcluster passed through the center of the main cluster.
- DM and galaxies are collisionless.
- Gas has been stripped away (shock wave, Mach number $M = 3.2$ and $T_{\rm shock} \sim 30$ keV)

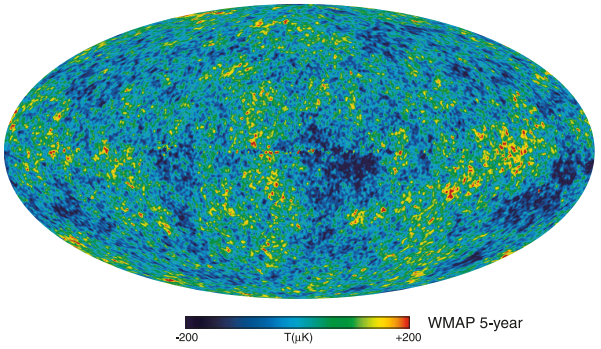
Mass determined via gravitational lensing



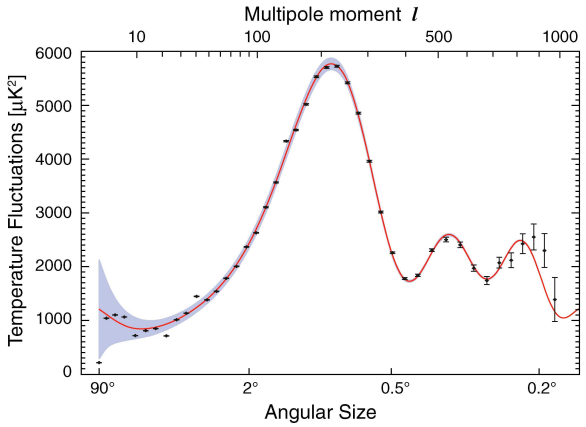
⋆ Comparing the weak gravitational lensing data with velocity distribution for galaxies

Cosmological evidence for dark matter

- We see the structures today and 13.7 billions years ago, when the Universe was 380 000 years old (encoded in anisotropies of the temperature of cosmic microwave background)

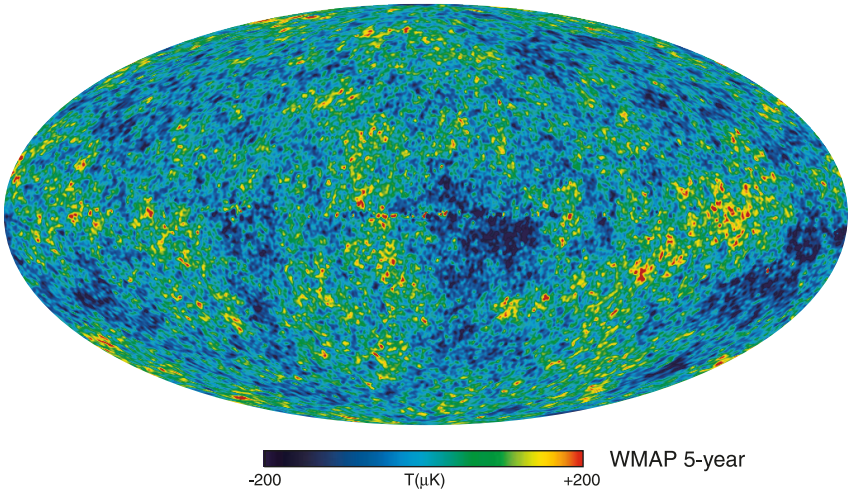


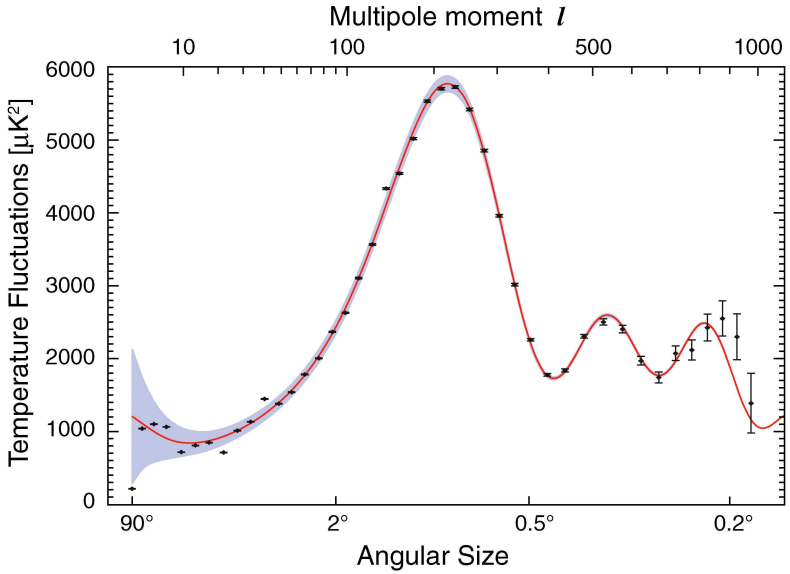
- All the structure is produced from tiny density fluctuations due to gravitational Jeans instability

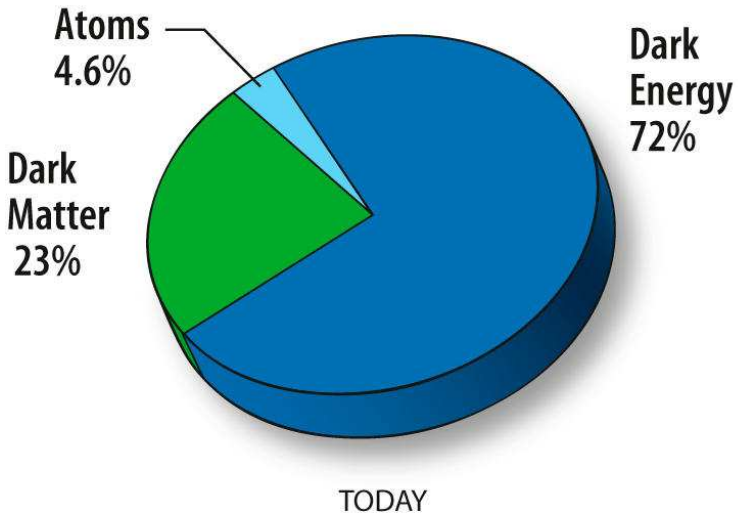


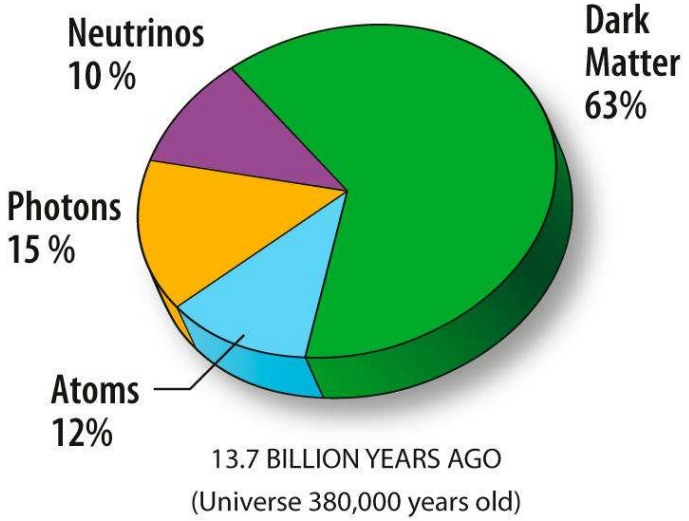
- In the hot early Universe before recombination photons smeared out all the fluctuations
- The structure has formed already, $\delta\rho/\rho \sim 1$ has to be long ago.i
- At CMB $\delta\rho/\rho \sim 10^{-5}$, then grow $\delta\rho/\rho \sim a$ (matter domination)
- $\frac{a_{today}}{a_{dec}} = 1 + z_{dec} \sim 10^3$ **Not enough!**

What (how) can we learn from CMB?









Cosmological parameters and CMB