Large-Scale Structure

Galaxy Clusters

(1) Regular Clusters:

• giant systems, spherical symmetry

• high degree of central concentration

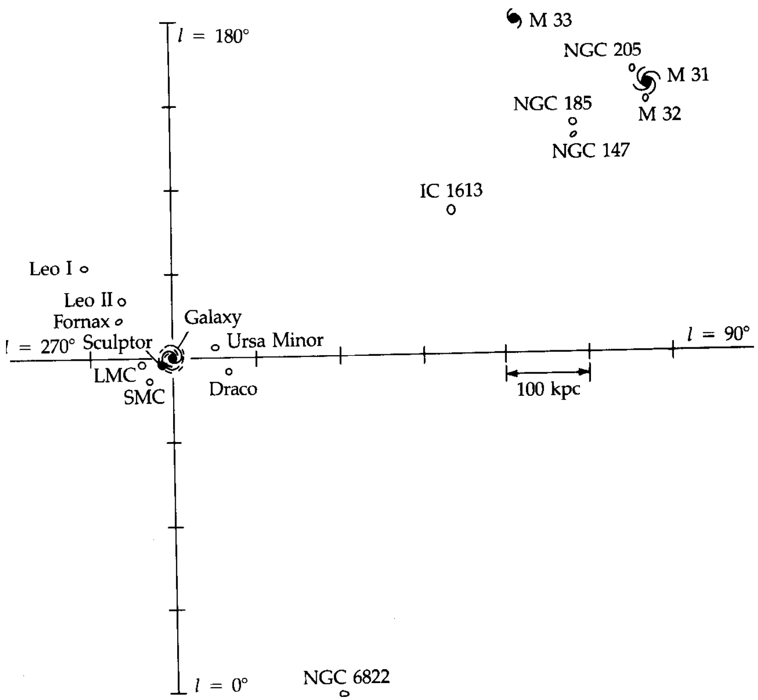
• thousands of members, almost all are elliptical or S0's

• at least one supergiant elliptical (cD galaxy) near center

Galaxy Clusters

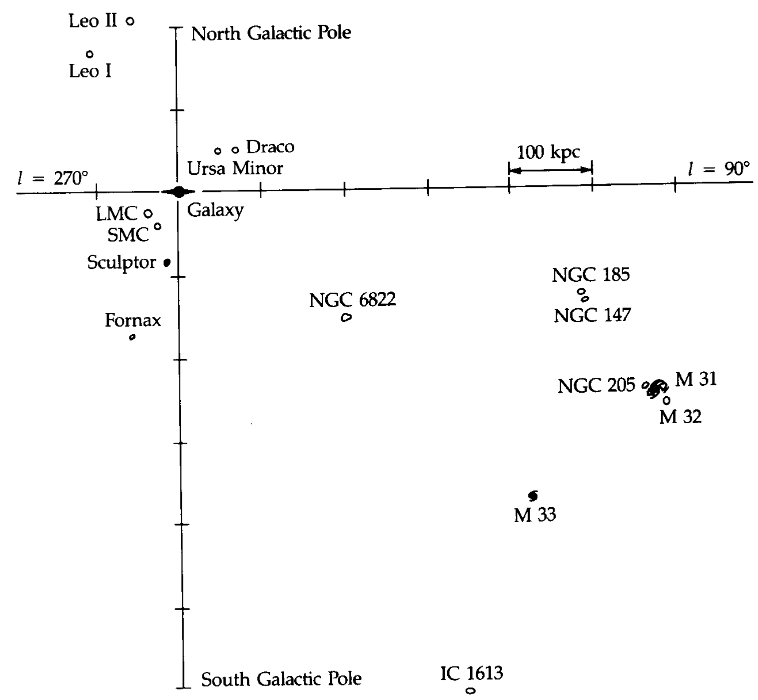
(2) Small Groups:

- loose aggregates of galaxies of all types, e.g., the Local Group



(A)

Local Group from above MW

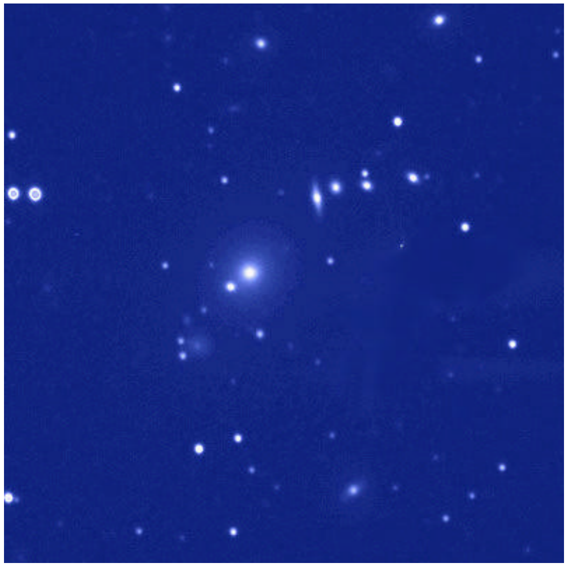


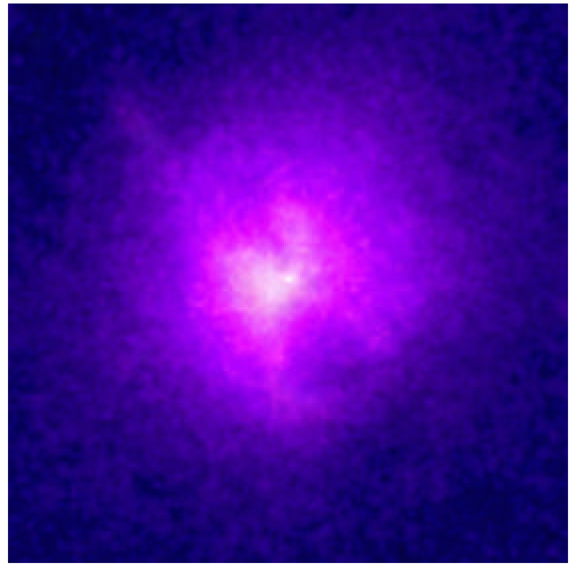
(B)

Side view of Local Group

Hot Gas

Space between galaxies in a cluster not empty.





The cluster Hydra A in optical and x-ray emission.

- x-ray observations => hot gas, $T \sim 10^6$ - 10^7 K
- mass of hot gas ~ mass of visible galaxies!
- gas contains Fe - from supernovae in galaxies?
- no hot gas seen between clusters

Missing Mass

Equilibrium relation for a cluster is $2E_{\text{int}} + U = 0.$

$$U \approx -\frac{GM^2}{R}, \quad E_{\text{int}} = \frac{1}{2} M v^2,$$

where $v = \langle v^2 \rangle^{1/2}$ = rms speed of galaxies,

$M = Nm$, where N = # of galaxies, m = mean galaxy mass.

Leads to $M \approx \frac{Rv^2}{G}.$ (note: similar to estimate for a rotating disk)

Observed v, R, imply $\frac{M}{L} \approx (300 - 500) \frac{M_{Sun}}{L_{Sun}},$

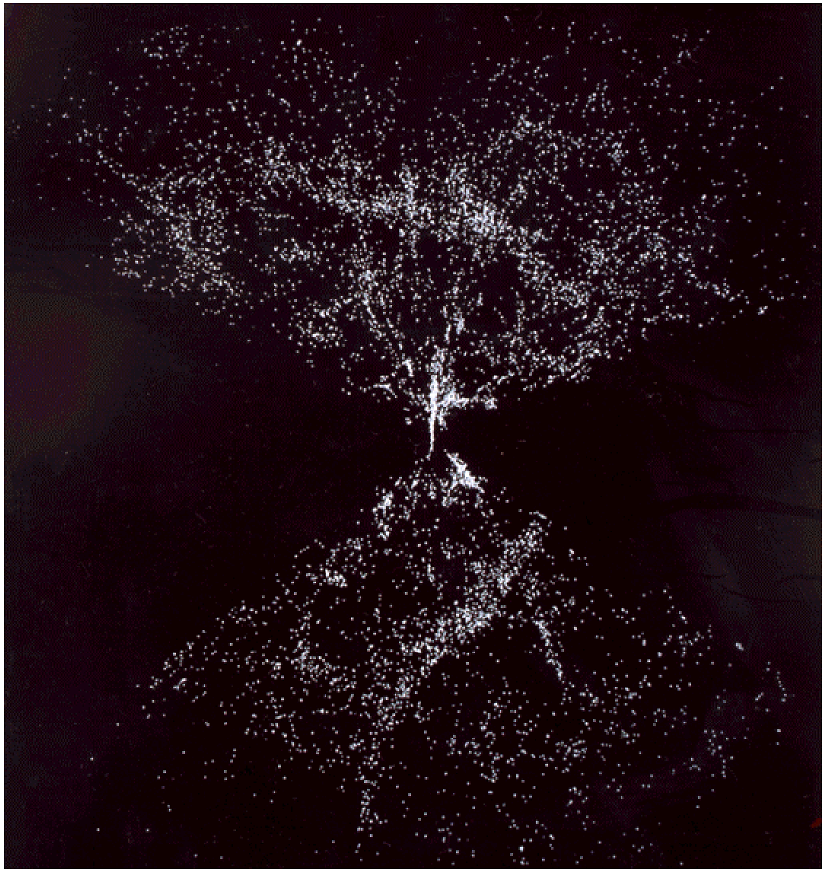
versus factors of up to 50 for individual galaxies.

$\therefore$ Relative importance of dark matter increases with the characteristic scale of a system.

Hierarchichal Clustering

• clusters of clusters => superclusters and beyond

• no spherical symmetry this time! See filaments and voids.



Clustering properties of 11,000 galaxies, up to d = 140 Mpc.

• mostly filamentary structure

• voids *are* predominantly spherical

• voids empty of at least bright galaxies

• how is the dark matter distributed?