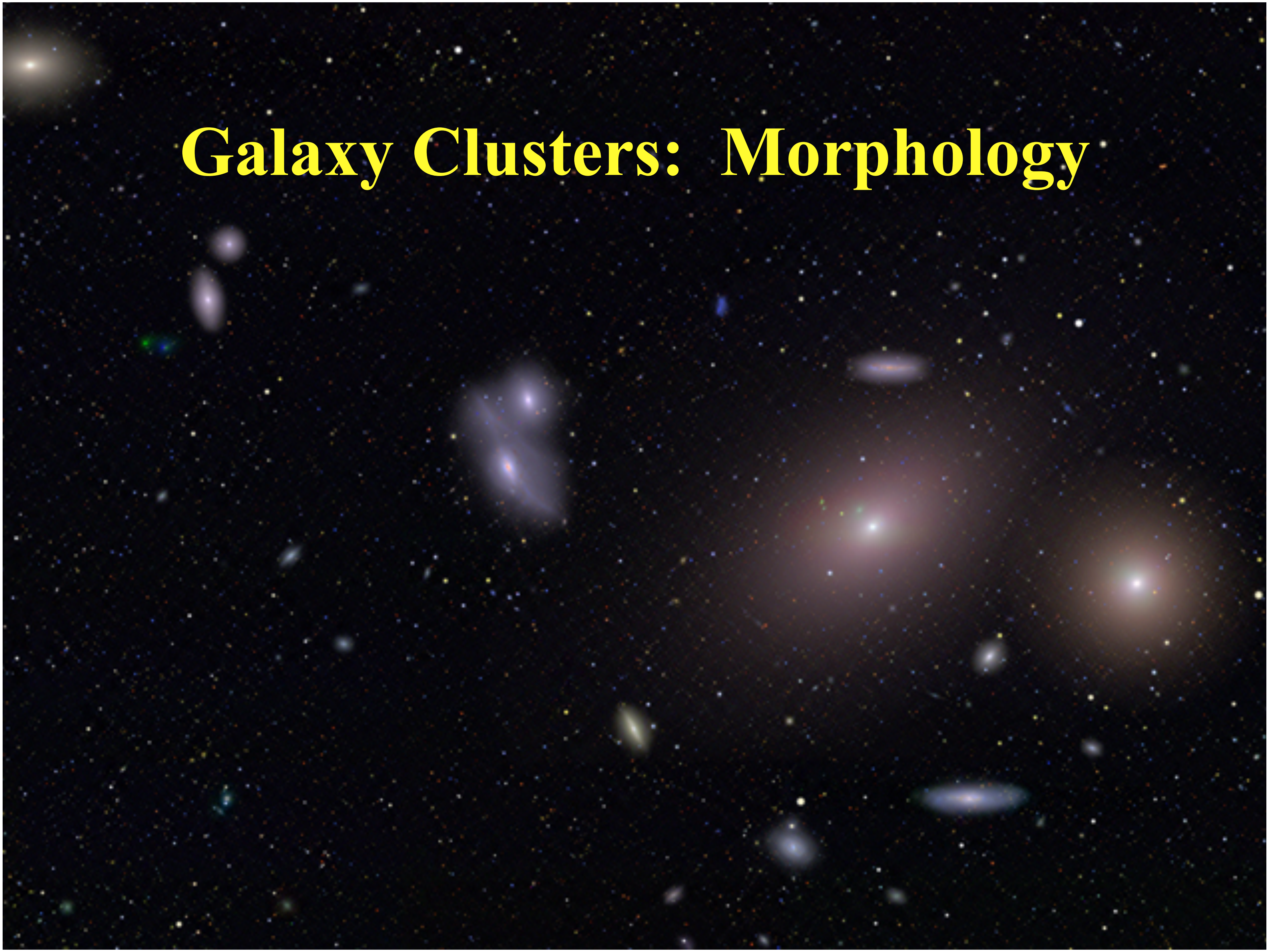
Galaxy Clusters: Morphology

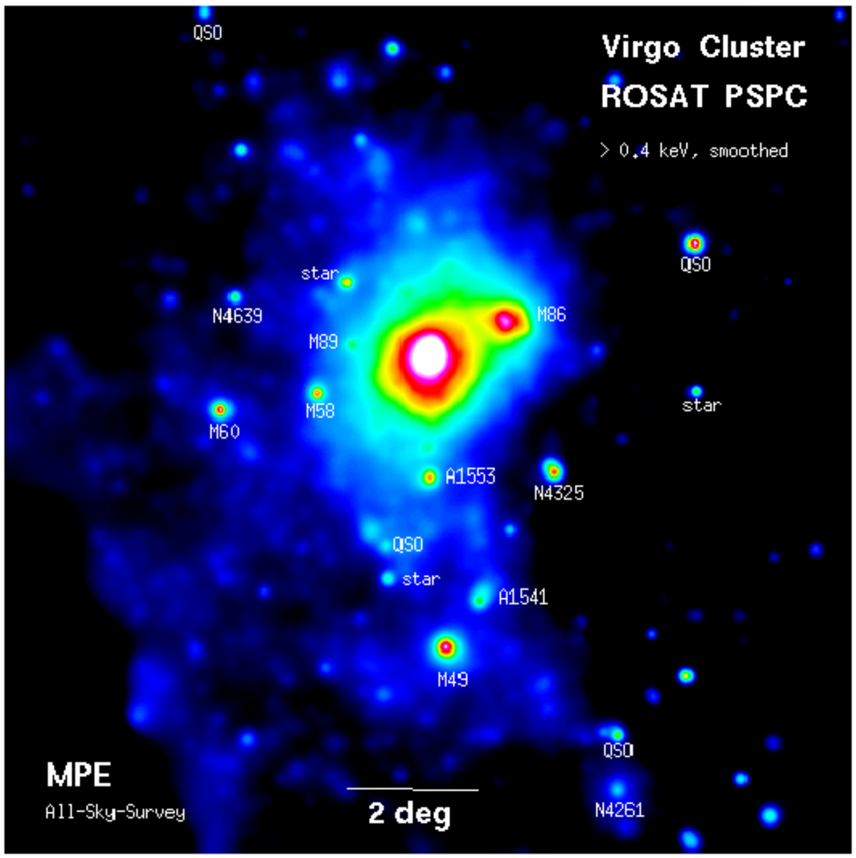


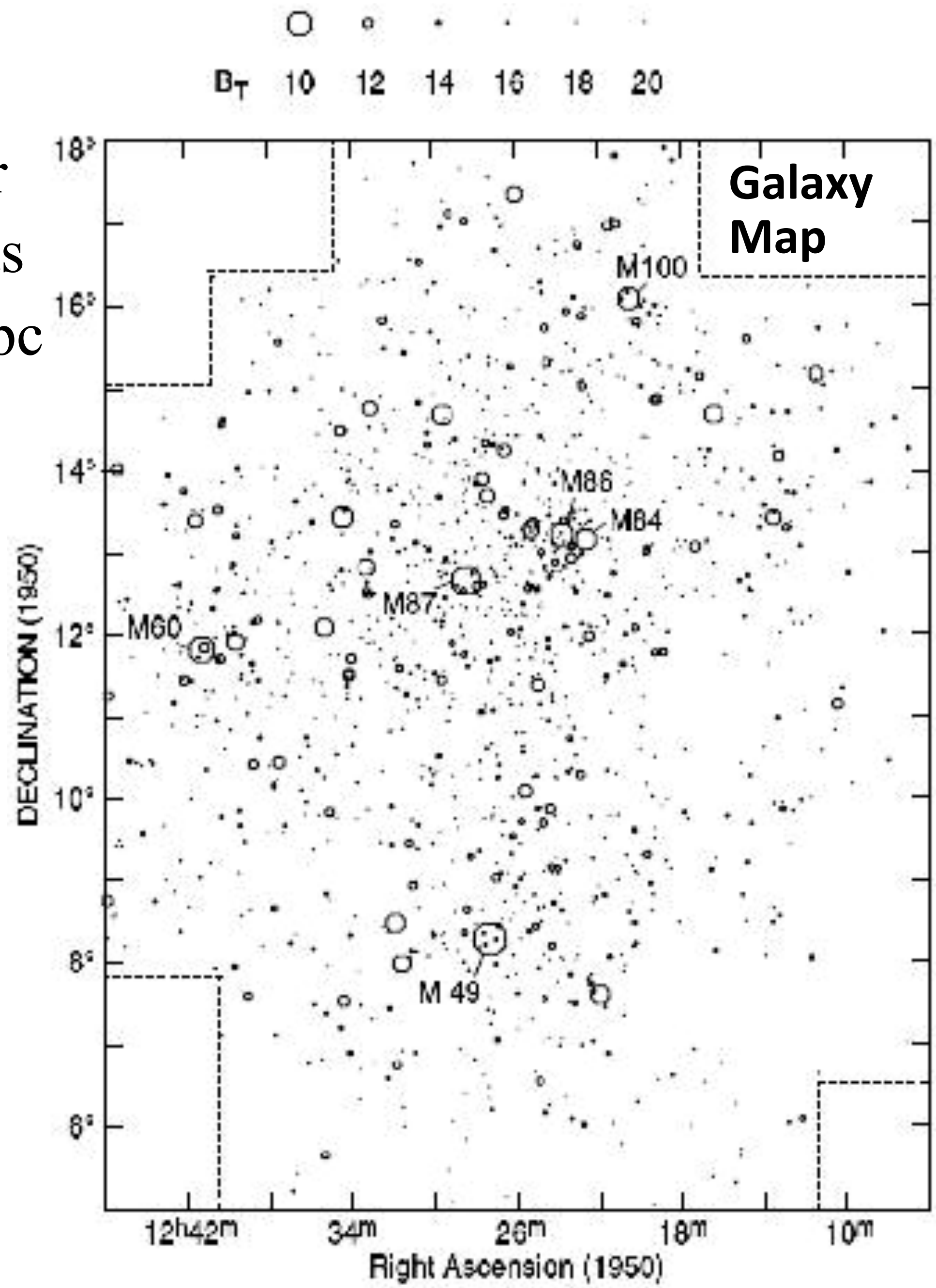
Clusters of Galaxies:

- Clusters are perhaps the most striking elements of the LSS
- Typically a few Mpc across, contain ~ 100 - 1000 luminous galaxies and many more dwarfs, masses ~ 10^{14} - 10^{15} $M_\odot$
- Gravitationally bound, but may not be fully virialized
- Filled with hot X-ray gas, mass of the gas may exceed the mass of stars in cluster galaxies
- Dark matter is the dominant mass component (~ 80 - 85%)
- Only ~ 10 - 20% of galaxies live in clusters, but it is hard to draw the line between groups and clusters, and at least ~50% of all galaxies are in clusters or groups
- Clusters have higher densities than groups, contain a majority of E's and S0's while groups are dominated by spirals
- Interesting galaxy evolution processes happen in clusters

The Virgo Cluster:

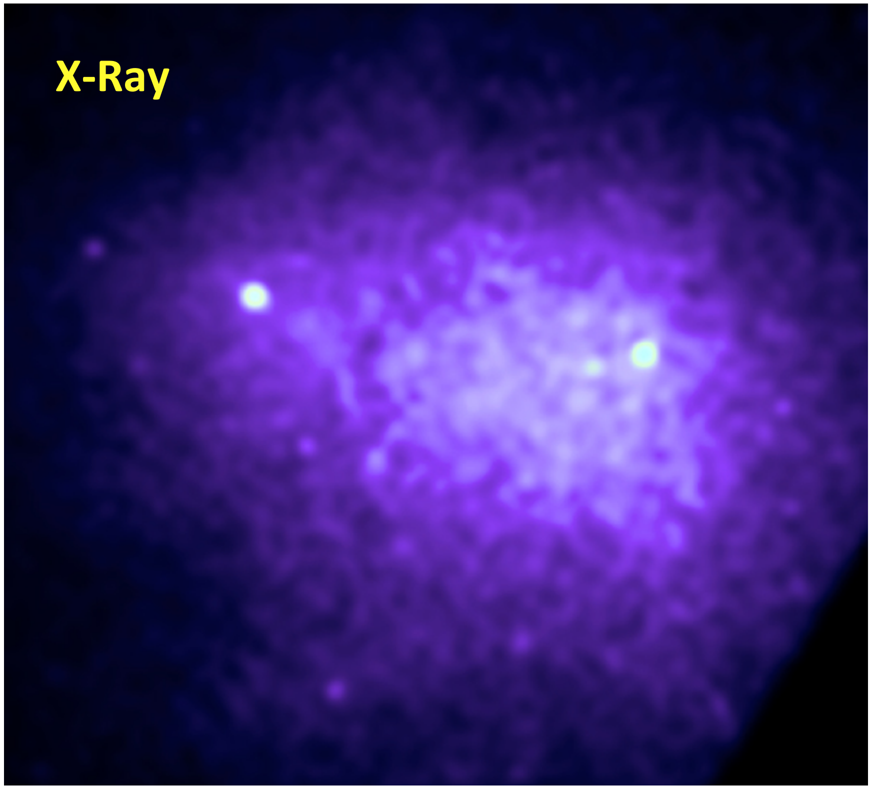
- Irregular, relatively poor cluster
- Distance ~ 16 Mpc, closest to us
- Diameter ~ 10° on the sky, 3 Mpc
- ~ 2000 galaxies, mostly dwarfs

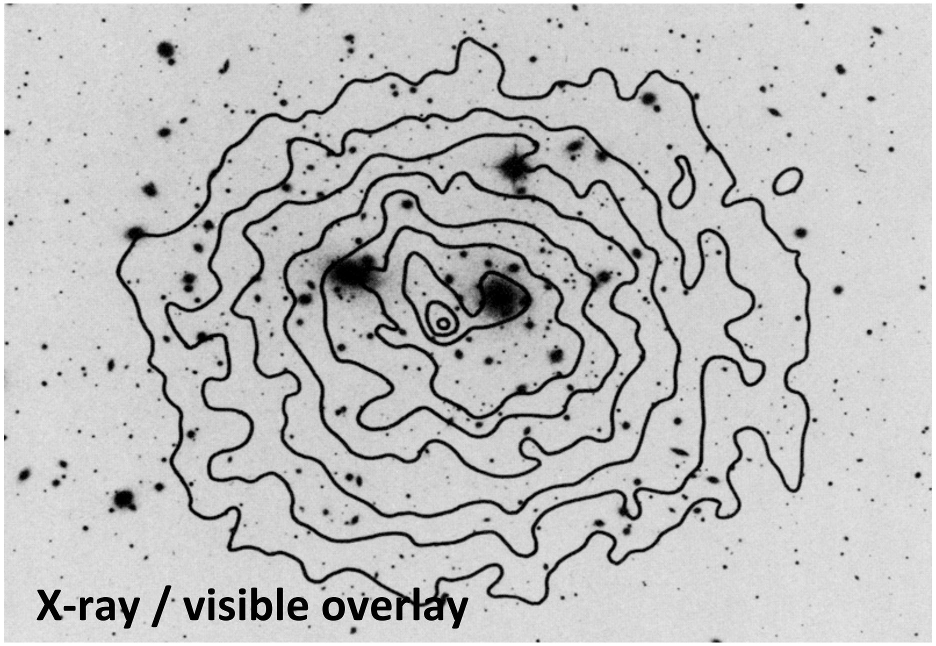


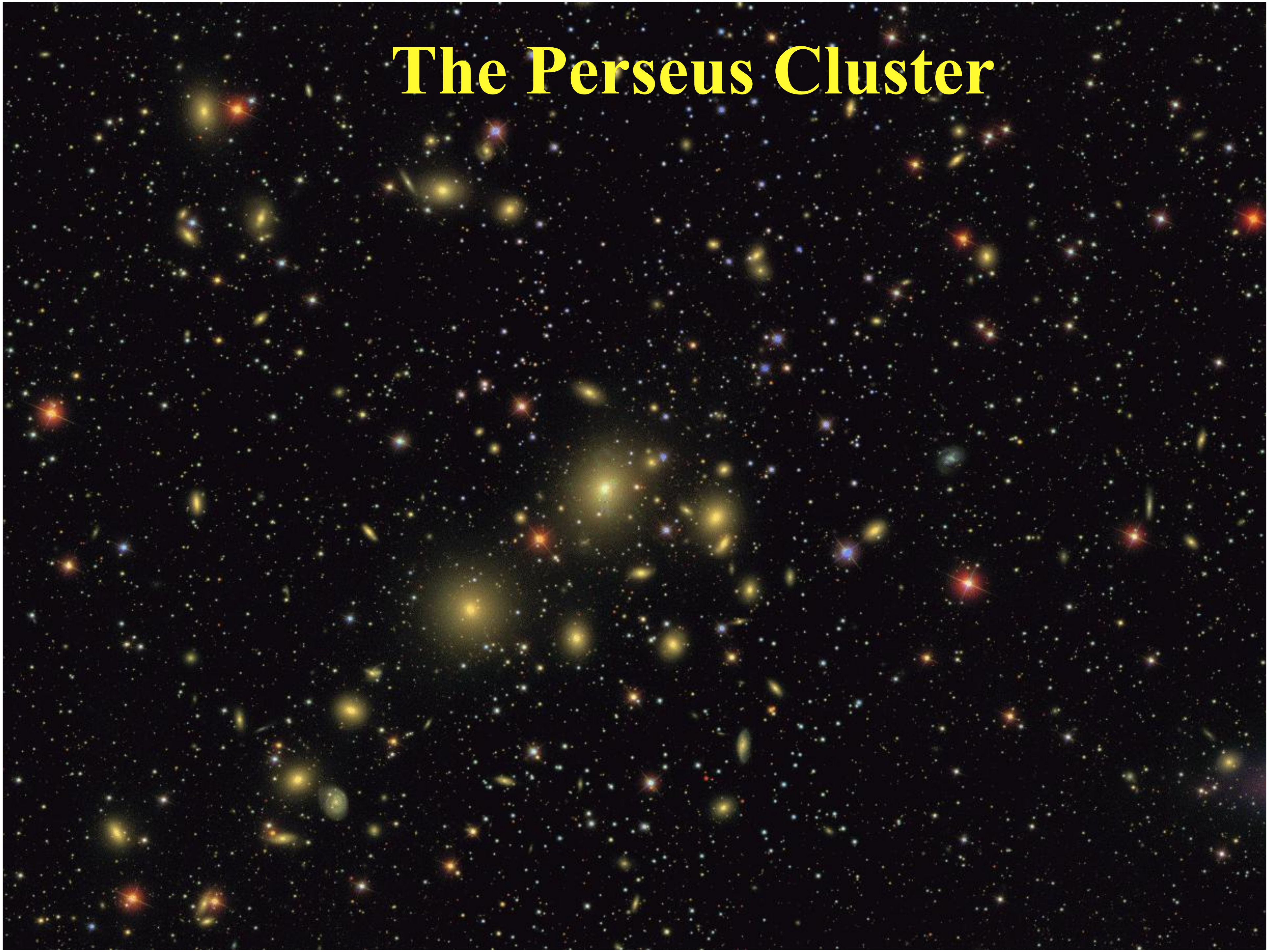


The Coma Cluster

- Nearest rich cluster, with >10,000 galaxies
- Distance ~ 90 Mpc
- Diameter ~ 4-5° on the sky, 6-8 Mpc

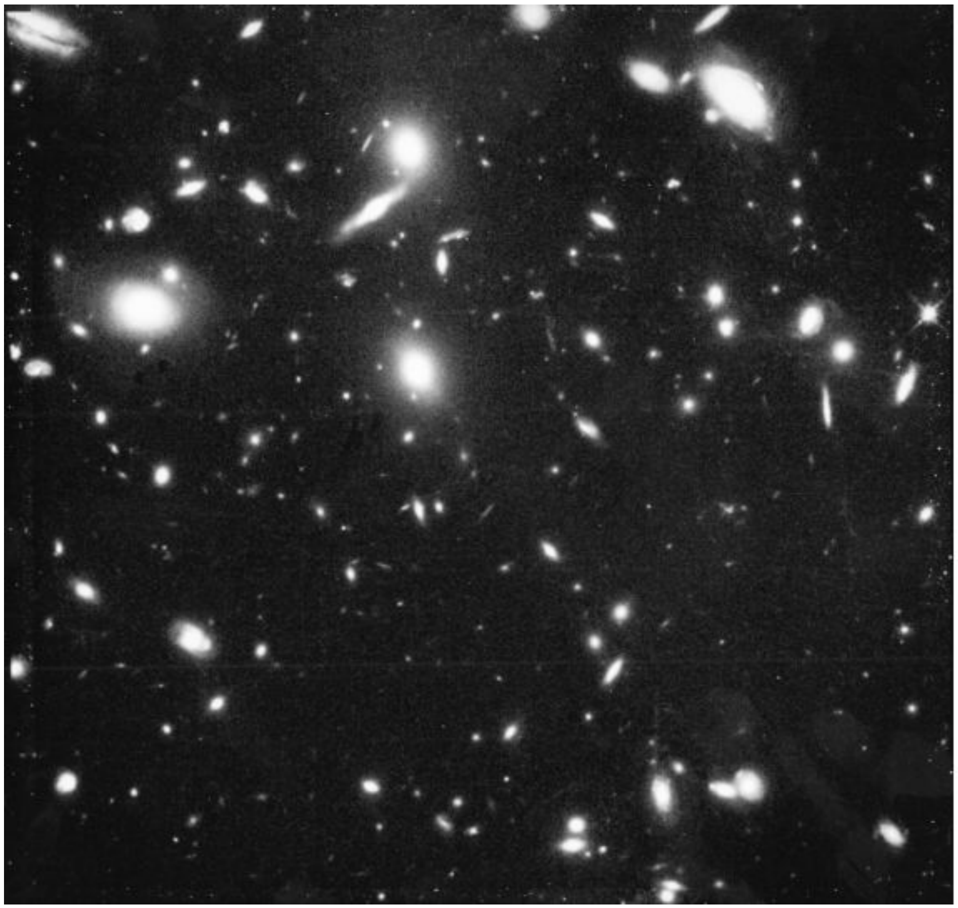




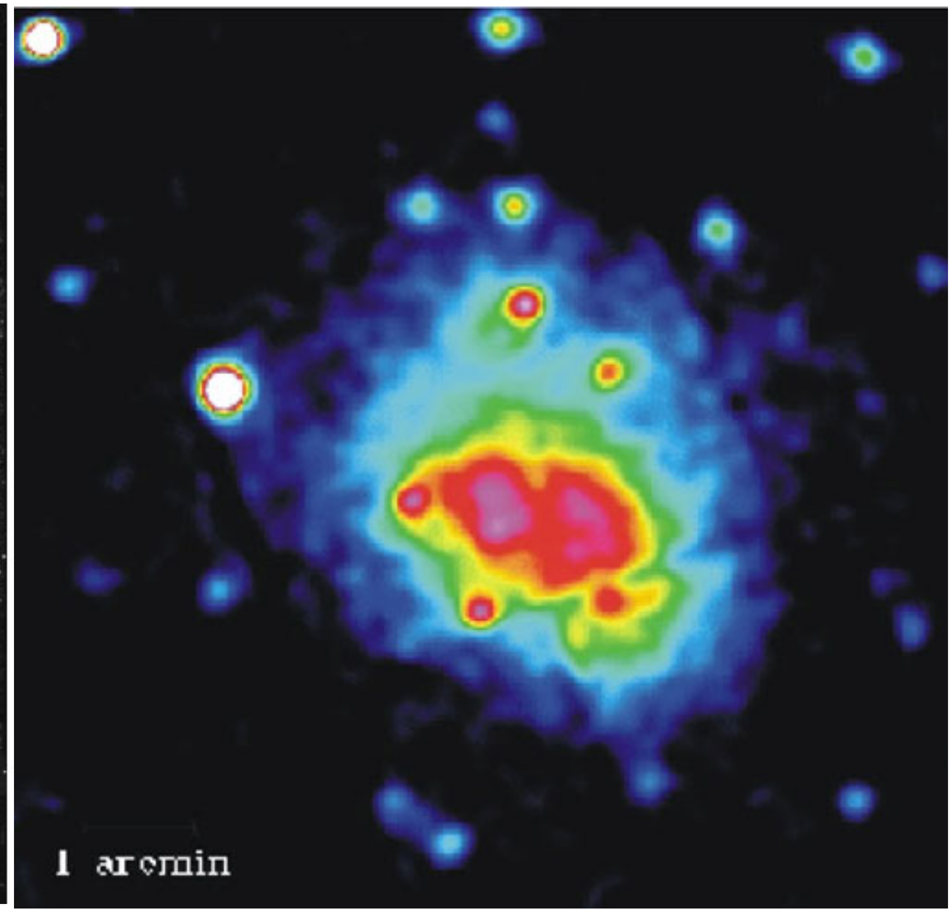

The Perseus Cluster

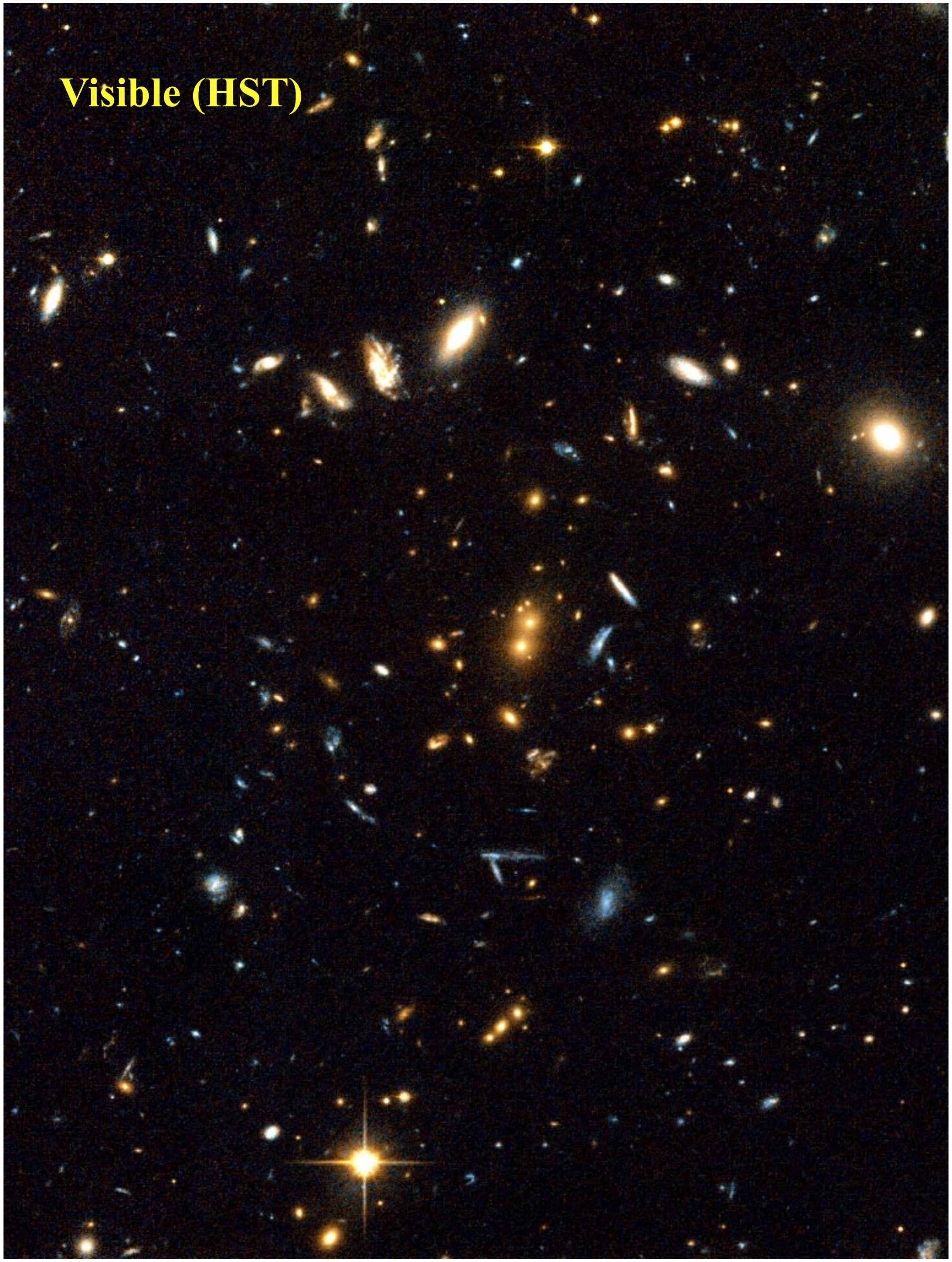
A Very Distant Cluster 0939+4713 (z = 0.41)

Visible (HST)

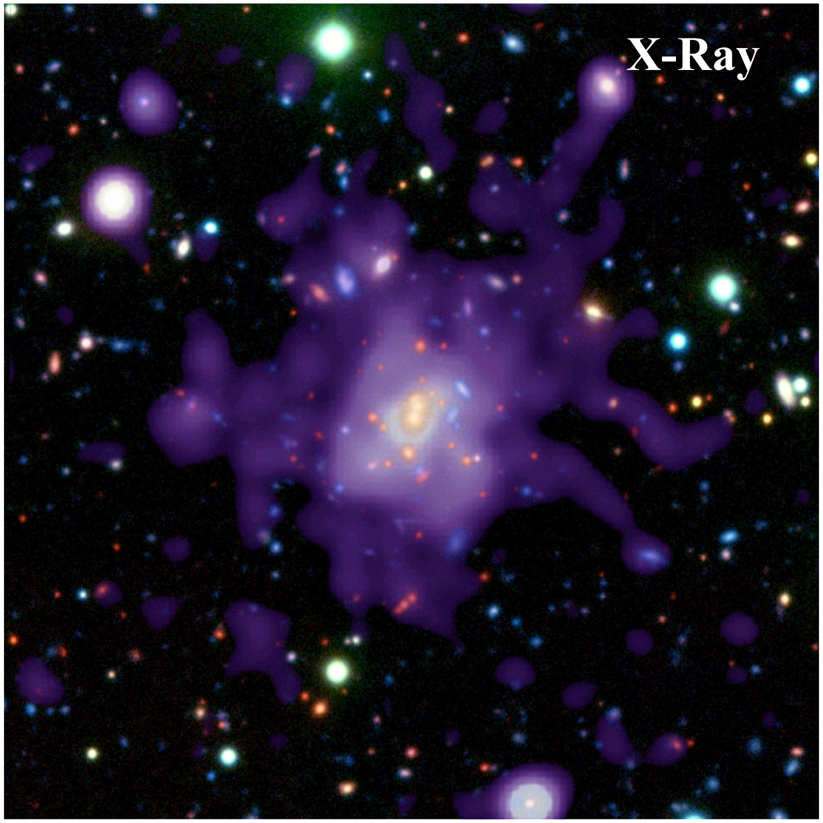


X-Ray (Rosat)





One of the most distant clusters now known, 1252-2927 (z = 1.24)



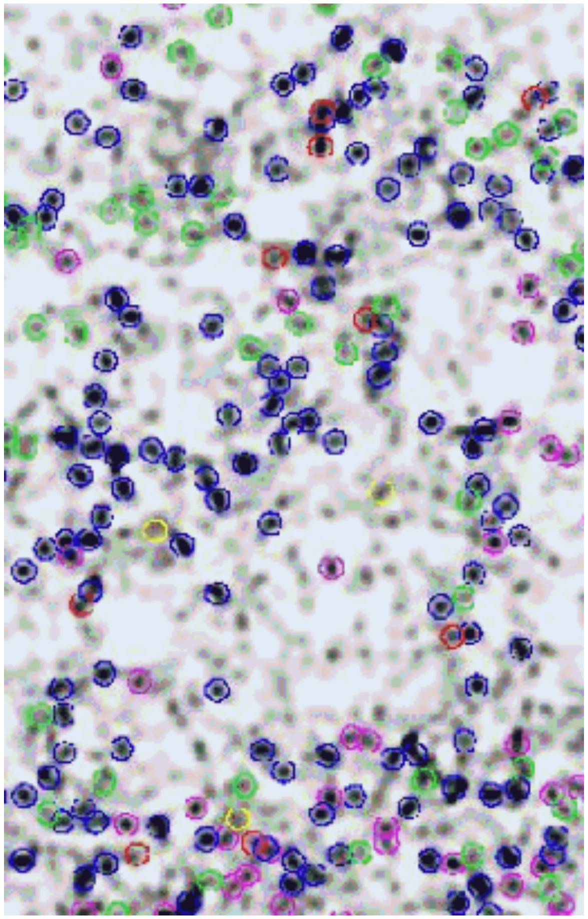
Surveys for Galaxy Clusters

Galaxy clusters contain galaxies, hot gas, and dark matter

Can survey for each of these components using observations in different wavebands:

1. Optical

- Look for an overdensity of galaxies in patches on the sky
- Can use color information (clusters contain many red elliptical galaxies)
- At higher redshifts, use redder bands (IR)
- **Disadvantages:** vulnerable to projection effects, rich cluster in the optical may not have especially high mass



Abell Cluster Catalog

- Nearby clusters cataloged by Abell (1958), extended to southern hemisphere by Abell et al. (1989)
  - By visual inspection of the POSS (& ESO) plates
  - Define region of radius $1.5h^{-1}$ (Abell radius)
  - Count galaxies within R_A between with an apparent magnitude between m_3 and $m_3 + 2$ (where m_3 is the magnitude of the 3rd brightest cluster member)
- Abell cataloged 4073 rich clusters (2712 in north)
- Richness class defined by number of galaxies with $m < m_3 + 2$ over background
  - Richness class 1-2-3-4 correspond to N = 50-80-130-200 galaxies
  - Most clusters are poor (richness class 0), catalog is incomplete here
- Extended by more modern work, e.g., ~ 20,000 clusters from DPOSS (Gal et al.)

Surveys for Galaxy Clusters

2. X-Ray

- Galaxy clusters contain hot gas, which radiates X-ray radiation due to bremsstrahlung
- Advantage: bremsstrahlung scales with density and temperature as $n^2T^{1/2}$ - i.e. *quadratically* in the density. ***Much less*** vulnerable to accidental line-of-sight projection effects
- **Disadvantage:** still not detecting clusters based on mass

3. Sunyaev-Zeldovich effect

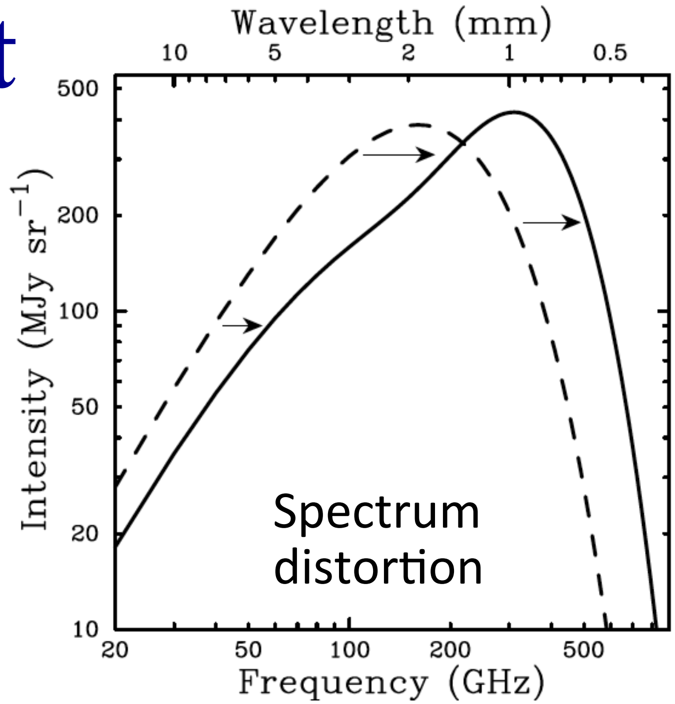
- Distortion of the CMB due to photons scattering off electrons in the cluster. Mass weighted measure, but really detects hot gas, not dark matter, and subject to messy hydrodynamics

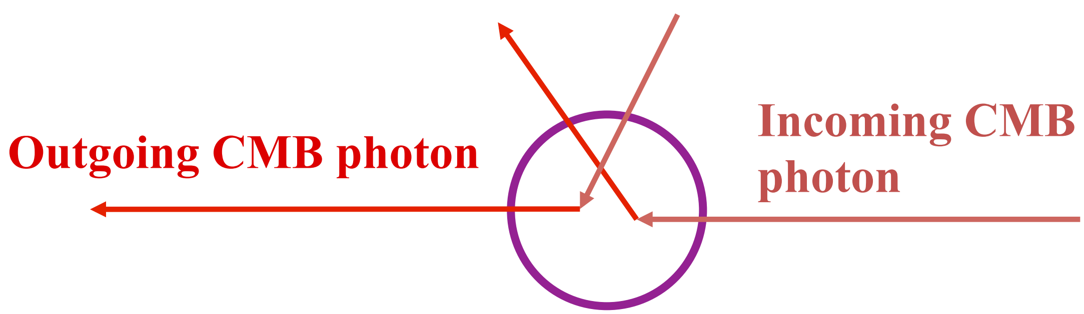
4. Weak Gravitational Lensing

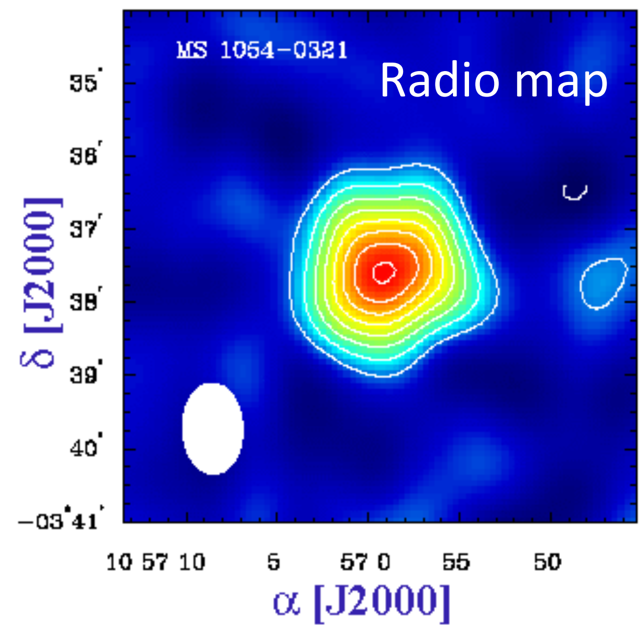
- Selection based on mass. Difficult observationally

Synyaev-Zeldovich Effect

- Clusters of galaxies are filled with hot X-ray gas
- The electrons in the intracluster gas will scatter the background photons from the CMBR to higher energies and distort the blackbody spectrum
- This is detectable as a slight temperature dip or bump in the radio map of the cluster, against the uniform CMBR background







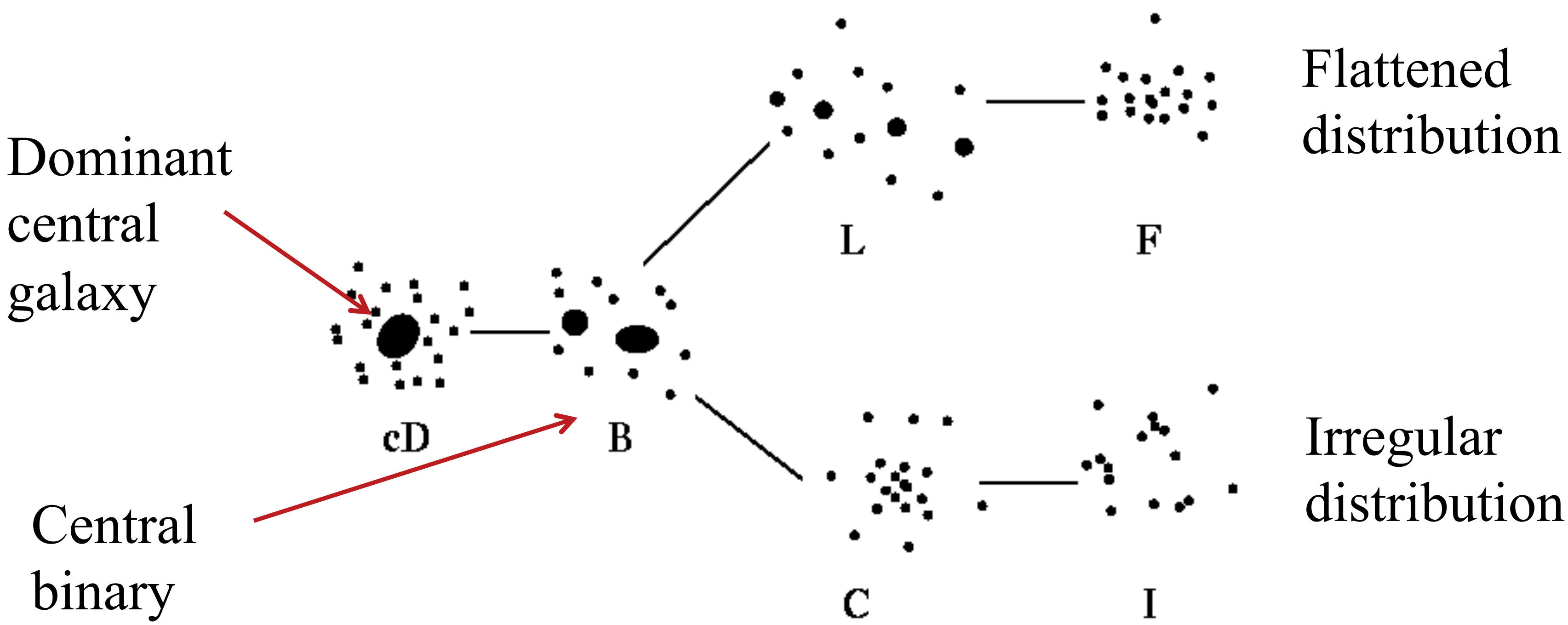
Cluster Classifications

- Abell classified clusters as:
  - Regular: ~ circularly symmetrical w/ a central concentration, members are predominantly E/S0's (e.g., Coma)
  - Irregular: ~ less well defined structure, more spirals (e.g., Hercules, Virgo)
- Bautz-Morgan classification scheme (1970), based on brightest galaxy in cluster:
  - I: Cluster has centrally located cD galaxy
  - II: central galaxy is somewhere between a cD and a giant elliptical galaxy (e.g., Coma)
  - III: cluster has no dominant central galaxy
- Oemler (1974) classified clusters by galaxy content:
  - cD clusters: 1 or two dominant cD galaixes, E:S0:S ~3:4:2
  - Spiral rich: E:SO:S~1:2:3 (similar to the field)
  - Spiral poor: no dominant cD, E:S0:S~1:2:1

Classification of Clusters

Can classify clusters of galaxies according to (i) **richness**, or (ii) **morphology**. No morphological scheme enjoys same support as Hubble's tuning fork diagram for galaxies. Example:

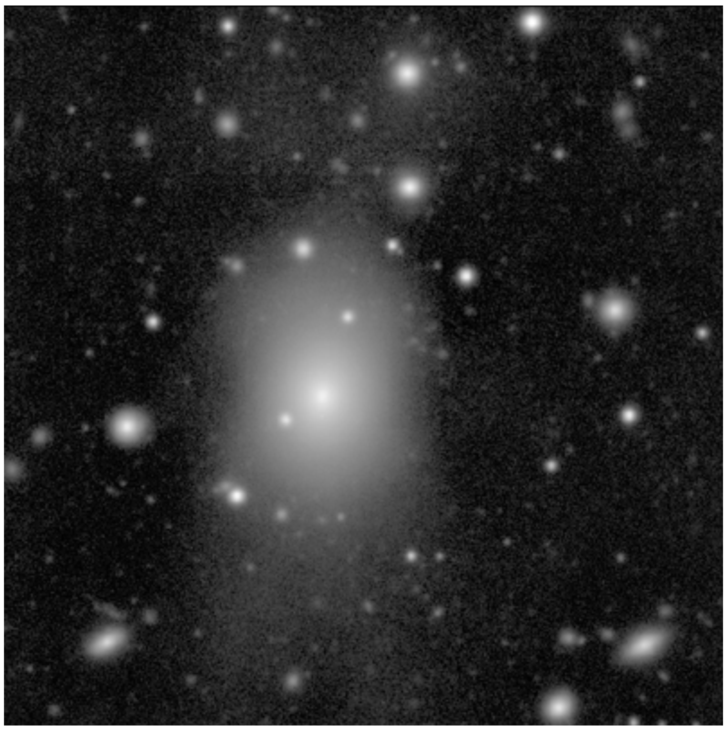
<u>Rood and Sastry scheme</u>

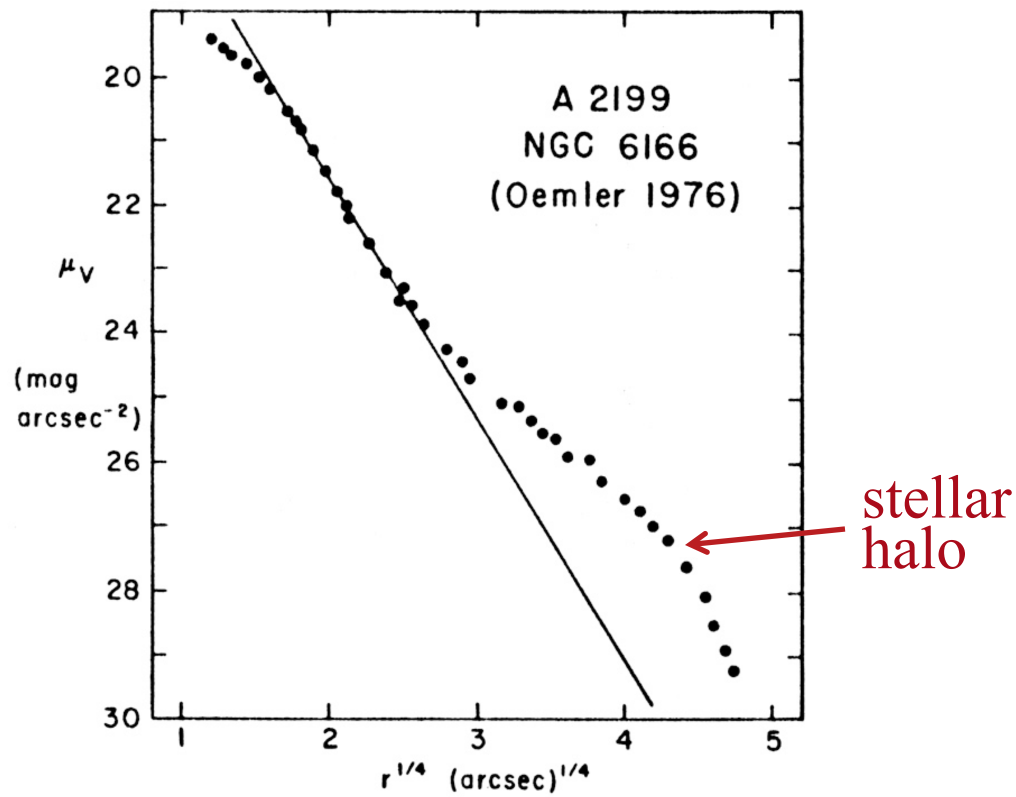


Importance: some clusters have cD galaxies. Expect a range of morphologies because clusters are young, merging systems…

Central Dominant (cD) Galaxies in Clusters

Many clusters have a single, dominant central galaxy. These are always giant ellipticals (gE), but some have extra-large, diffuse envelopes - these are called cD galaxies





These envelopes are probably just “star piles”, a remainder of many tidal interactions of cluster galaxies, sharing the bottom of the potential well with the gE galaxy

Some important trends:

- Spatial distribution of galaxies:
  - cD and regular clusters: spatial distribution is smooth and circularly symmetric, space density increases rapidly towards cluster center
  - Spiral-rich and irregular clusters are not symmetric, little central concentration. Spatial density is ~ uniform
- Morphological segregation:
  - In spiral-rich clusters, radial distribution of E, SO, Sp galaxies is about the same
  - In cD and spiral-poor clusters, relataive space density of spirals decreases rapidly to cluster core (morphology-density relation)

What does it all mean?

- Regular, cD clusters have had time to "relax" and reach dynamic equilibrium
- Intermediate and Irregular clusters are still in the process of coming together, have not yet reached dynamic equilibrium
- cD galaxies probably formed by merging in the central regions
  - Many show multiple nuclei, and have extended outer envelopes compared to luminous ellipticals, accrete additional material due to tidal stripping of other galaxies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