How a Massive Photon Retards the Universal Expansion Until Galaxies Form

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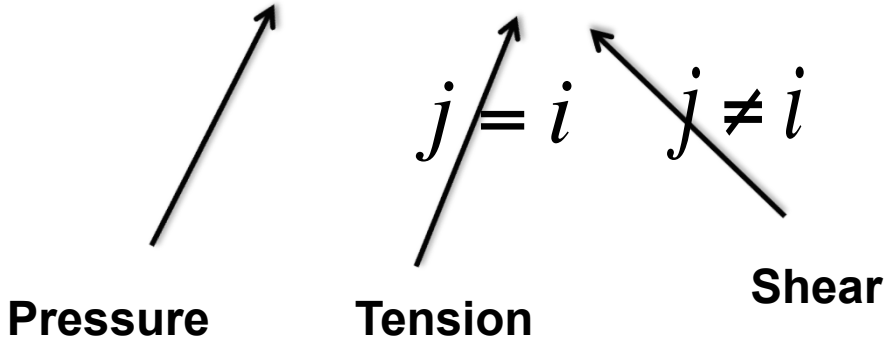
Chibisov's Stress Tensor assuming photon mass, $m_\gamma = 10^{-25}$eV ($k_0 = 2\pi/400$pc)

$$M_{ij} = (1/4\pi)(-\delta_{ij}B^2/2 + B_iB_j + \delta_{ij}k_0^2A^2 - k_0^2A_iA_j)$$



Let k be the wave number of the Fourier decomposition of the field. If $k > k_0$, the B fields dominate. If $k < k_0$, then the vector potential A dominates.

Is the Universe bound magnetically?

Coasting

$$\vec{A}(m_\gamma \neq 0)$$

$$a = const\ t \qquad a = const\ t^{1/2} \Rightarrow t^2 = a^4 / const^4$$

$$\dot{a} = const \qquad \dot{a} = \frac{1}{2} const\ t^{-1/2}$$

$$H \equiv \frac{\dot{a}}{a} = \frac{1}{t} \qquad H = \frac{1}{2t}$$

$$\ddot{a} = 0 \qquad \ddot{a} = -\frac{1}{4} const\ t^{-3/2}$$

$$q = \frac{\ddot{a}}{a} = 0 \qquad q = -\frac{1}{4t^2}$$

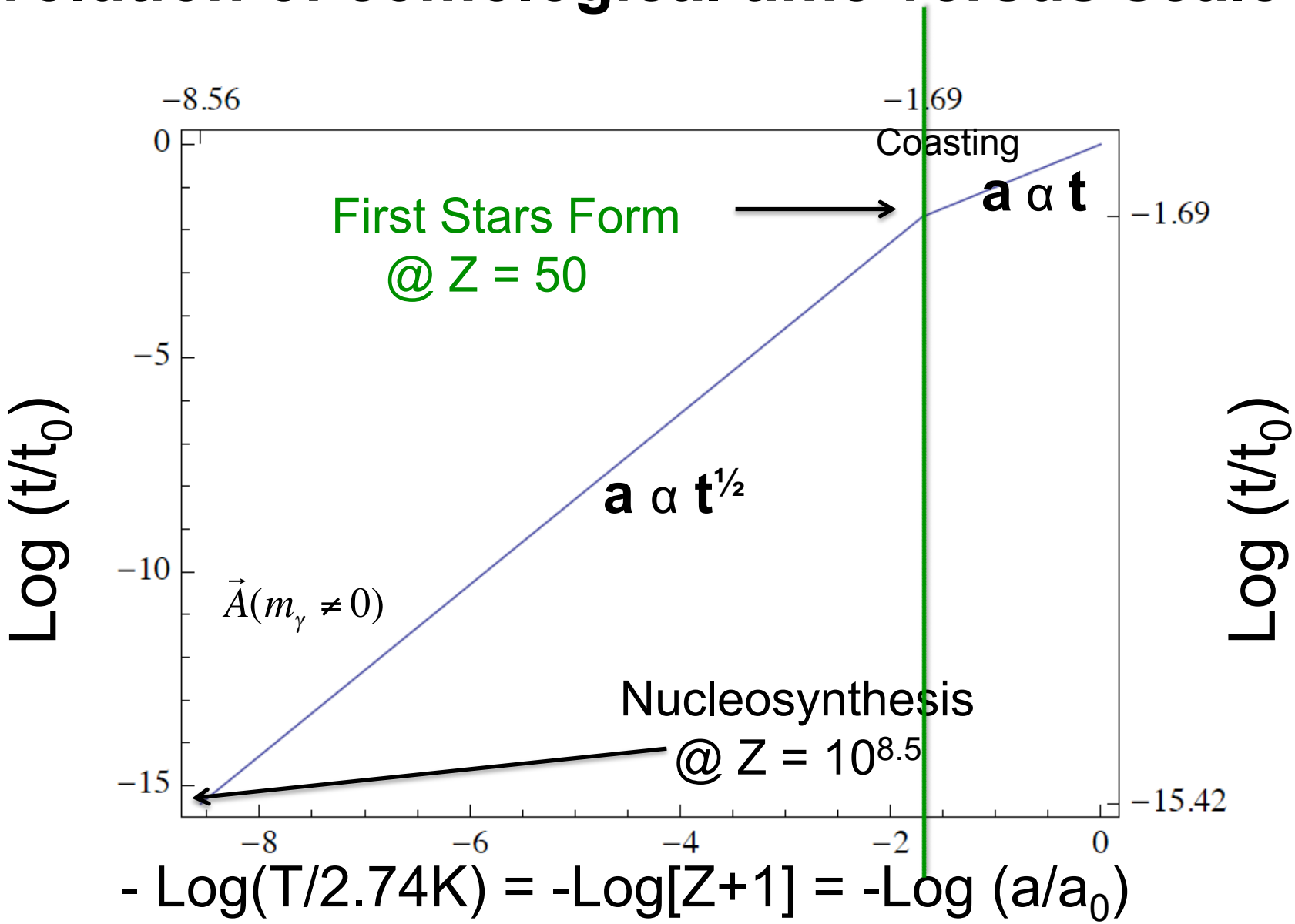
$$\ddot{a}a^3 = 0 \qquad \ddot{a}a^3 = -\frac{const^4}{4}$$

$$a^3 \propto \frac{1}{A^2(t)}$$

$$\therefore \ddot{a}(t) \propto -A^2(t)$$

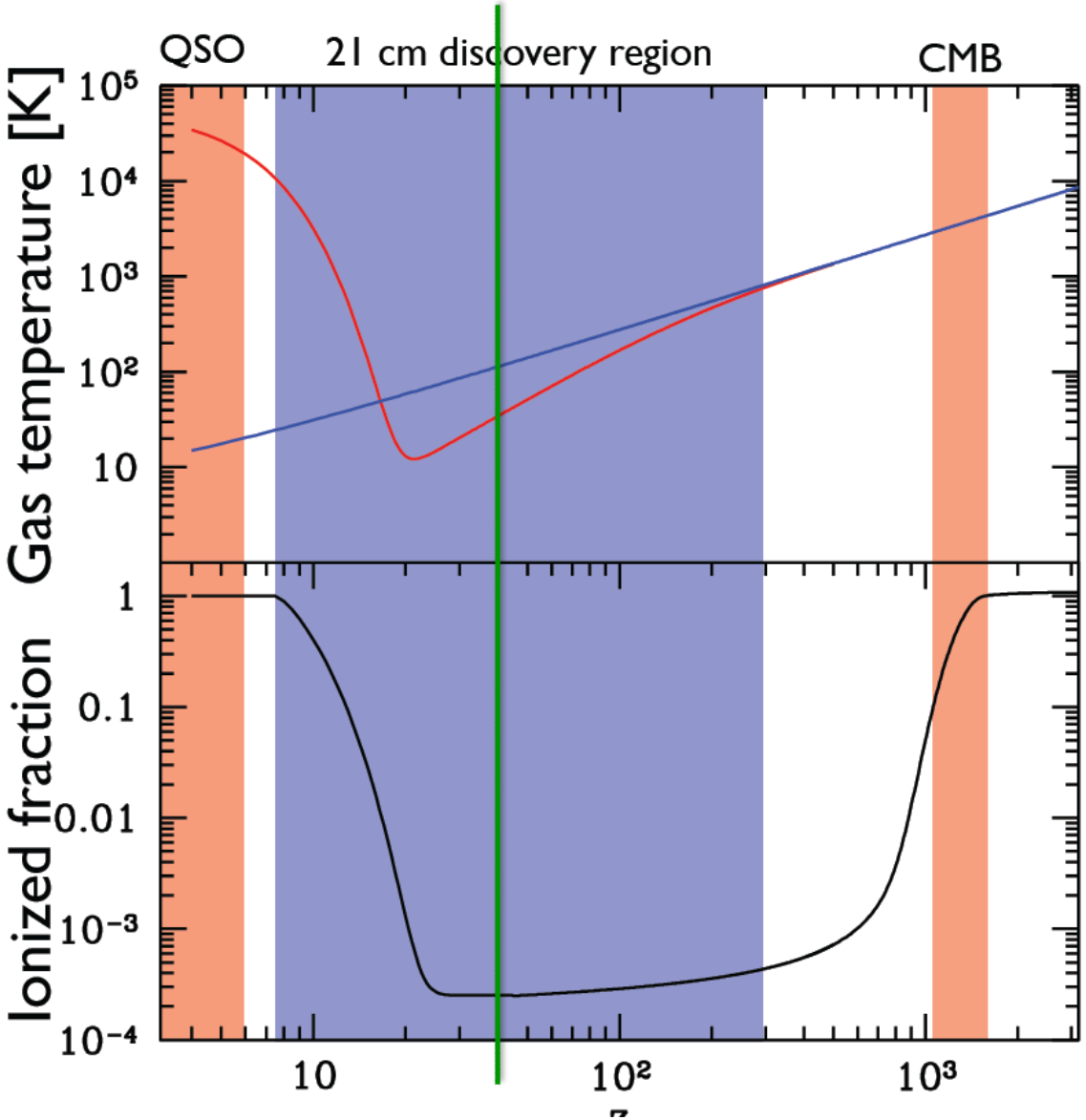
Potential Energy in an expanding sphere is conserved.

Evolution of comological time versus scale a



Dark Ages (Pritchard & Burns 2011)

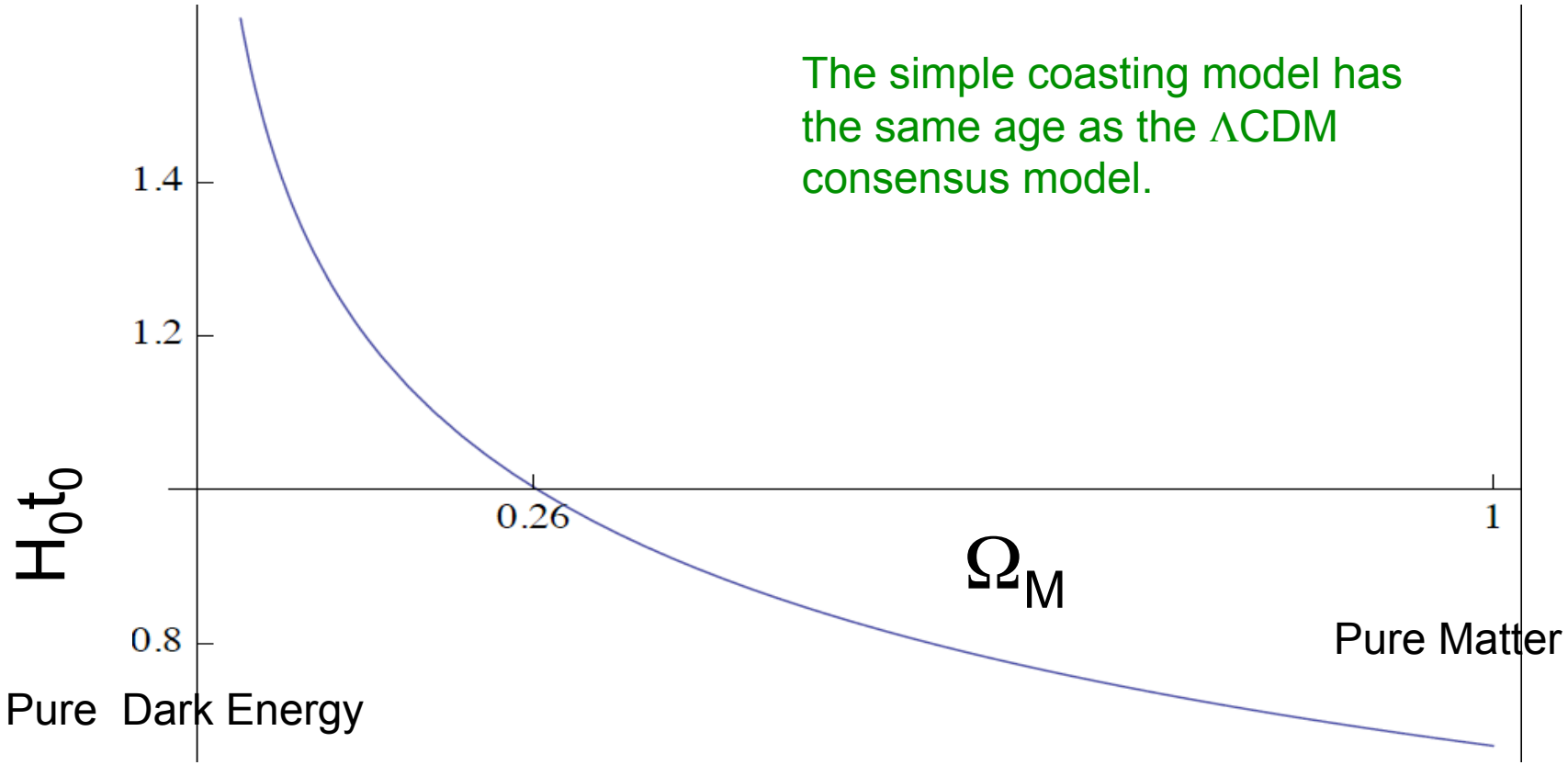
Green Line at Z=50 is end of dark ages from previous slide



We know nothing concrete about the thermal history of the Universe between z=1100 and z=6

We know little or nothing about galaxies at z>10

H_0t_0: Coasting = 26% Matter and 74% Dark Energy



$$H_0 t_0 = \int_1^\infty \frac{dy}{y\sqrt{\Omega_M y^3 + \Omega_R y^2 + \Omega_\Lambda}}$$

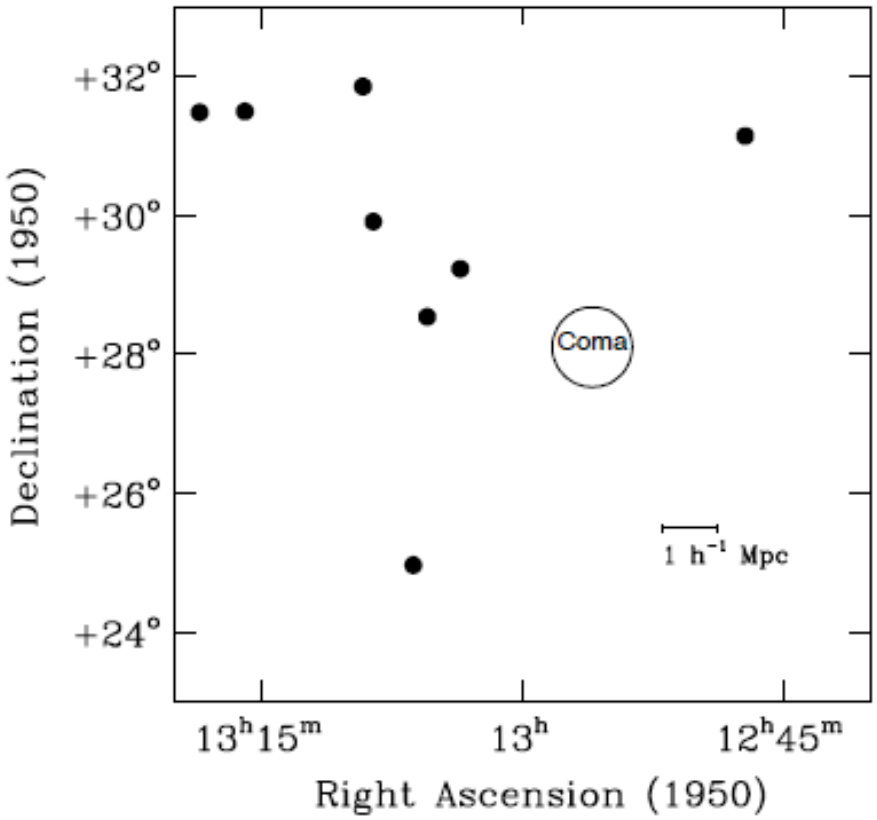
$$\Omega_R = 0$$

$$\Omega_\Lambda = 1 - \Omega_M$$

Coma Cluster & Environs

- Zwicky bound the Coma Cluster by introducing dark matter. Several alternative mechanisms persisted until Vera Rubin's flat rotation curves.
- At Zwicky's time the effects of a photon having a mass (ever so small) were not investigated.
- We will now consider this possibility.

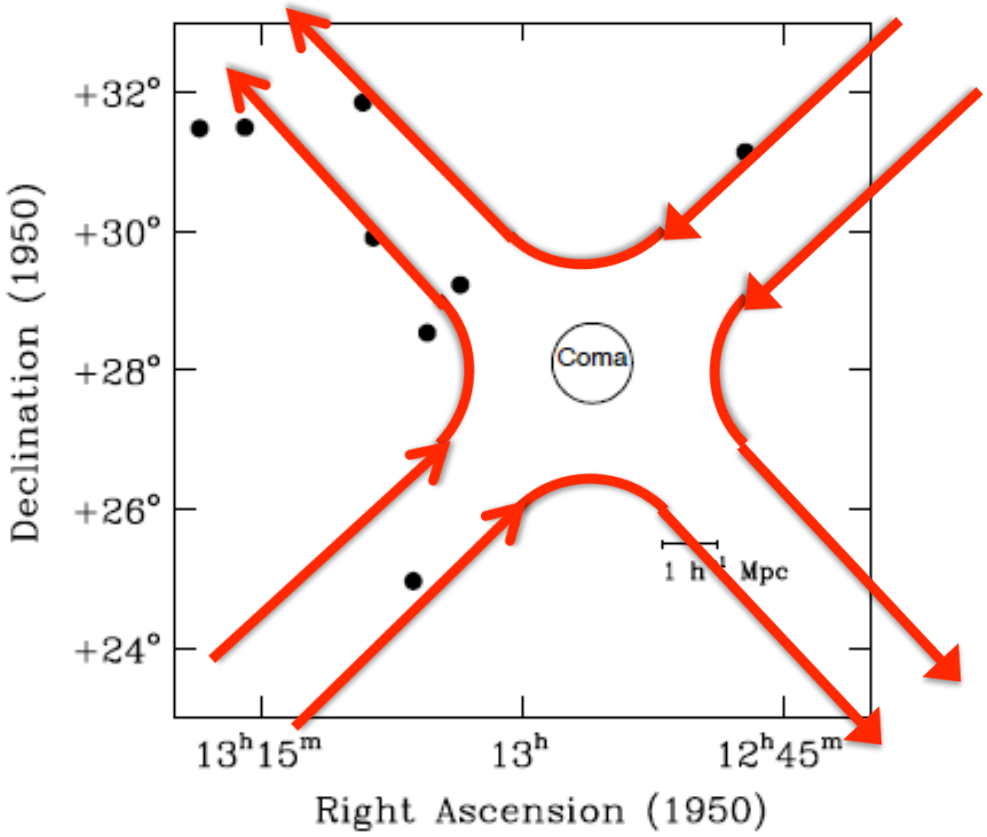
Cluster Groups Surrounding Coma



M.J. West figure (1998)

Figure 7: The distribution of groups surrounding the Coma cluster (from Ramella et al. 1997). The majority of these groups, which are the future subclusters that will fall into the cluster, lie along the filament which extends to the north-east from Coma.

Cluster Groups Surrounding Coma



Red quadrupole structure added by us to emphasize possible filament structure

M.J. West figure (1998)

Figure 7: The distribution of groups surrounding the Coma cluster (from Ramella et al. 1997). The majority of these groups, which are the future subclusters that will fall into the cluster, lie along the filament which extends to the north-east from Coma.

Zoom into Coma Cluster & 5C4.81=NGC 4869

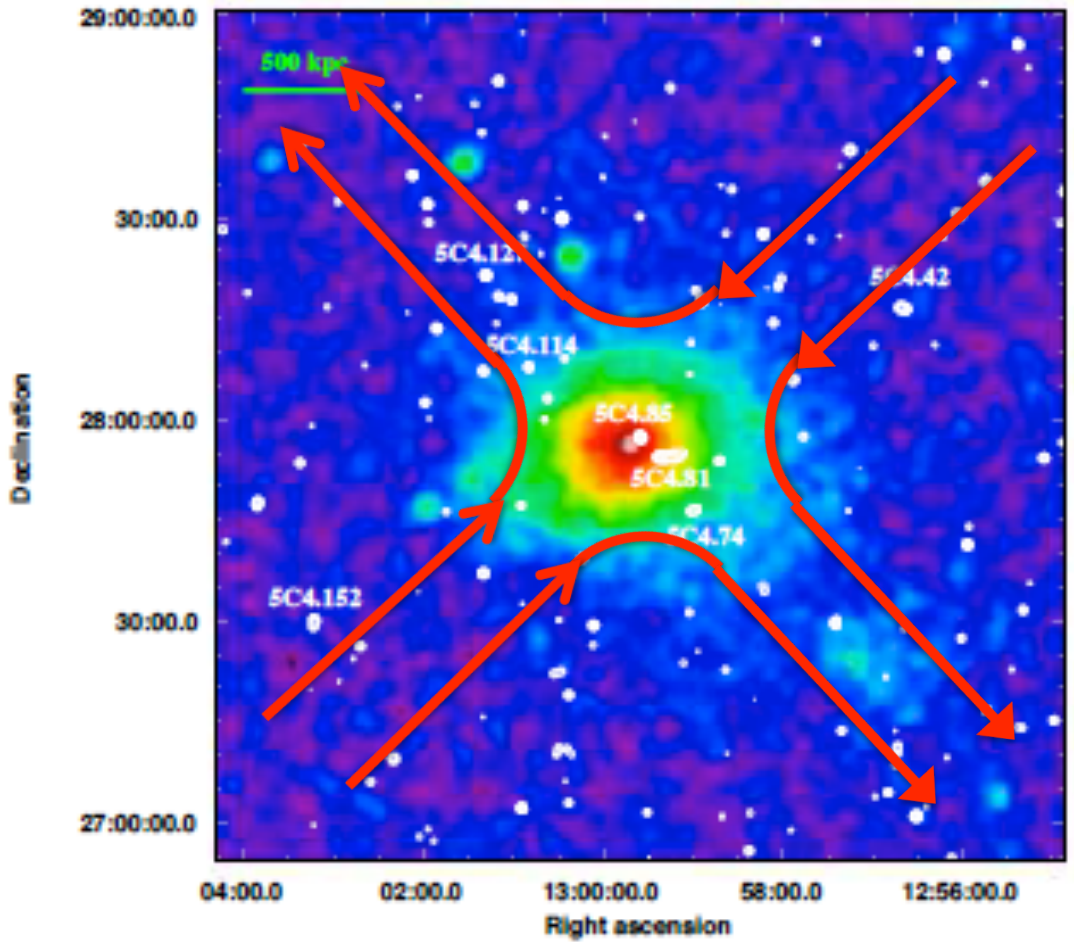
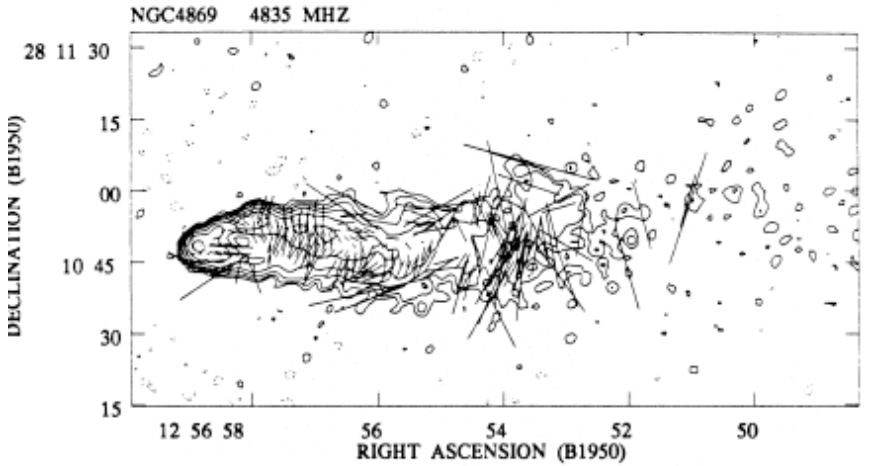


Fig. 1. Colors: Coma X-ray emission from the ROSAT All Sky Survey in the energy band [0.1, 2.4] kev. Contours: Coma radio emission at 1.4 GHz from the NVSS. The beam FWHM is 45″×45″, contours start from 1.5 mJy/beam and are spaced by a factor of 2. The observed sources are labelled.

Radio Structure Data for NGC 4869 – shows tangled magnetic fields ~1kpc

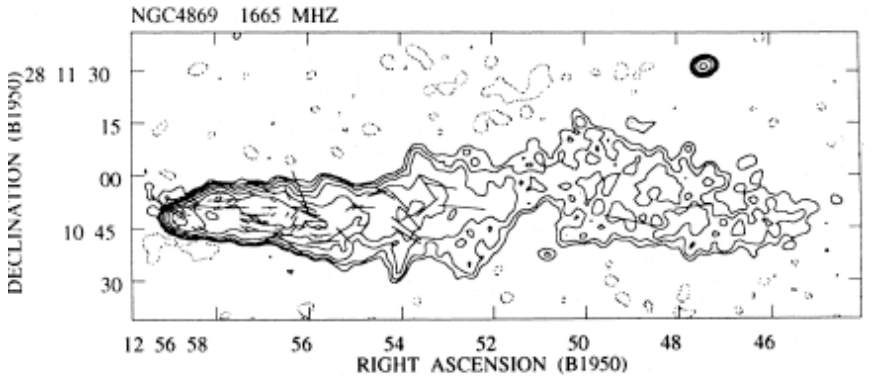
N
G
C
4
8
6
9



6 cm

λ^2 Law?

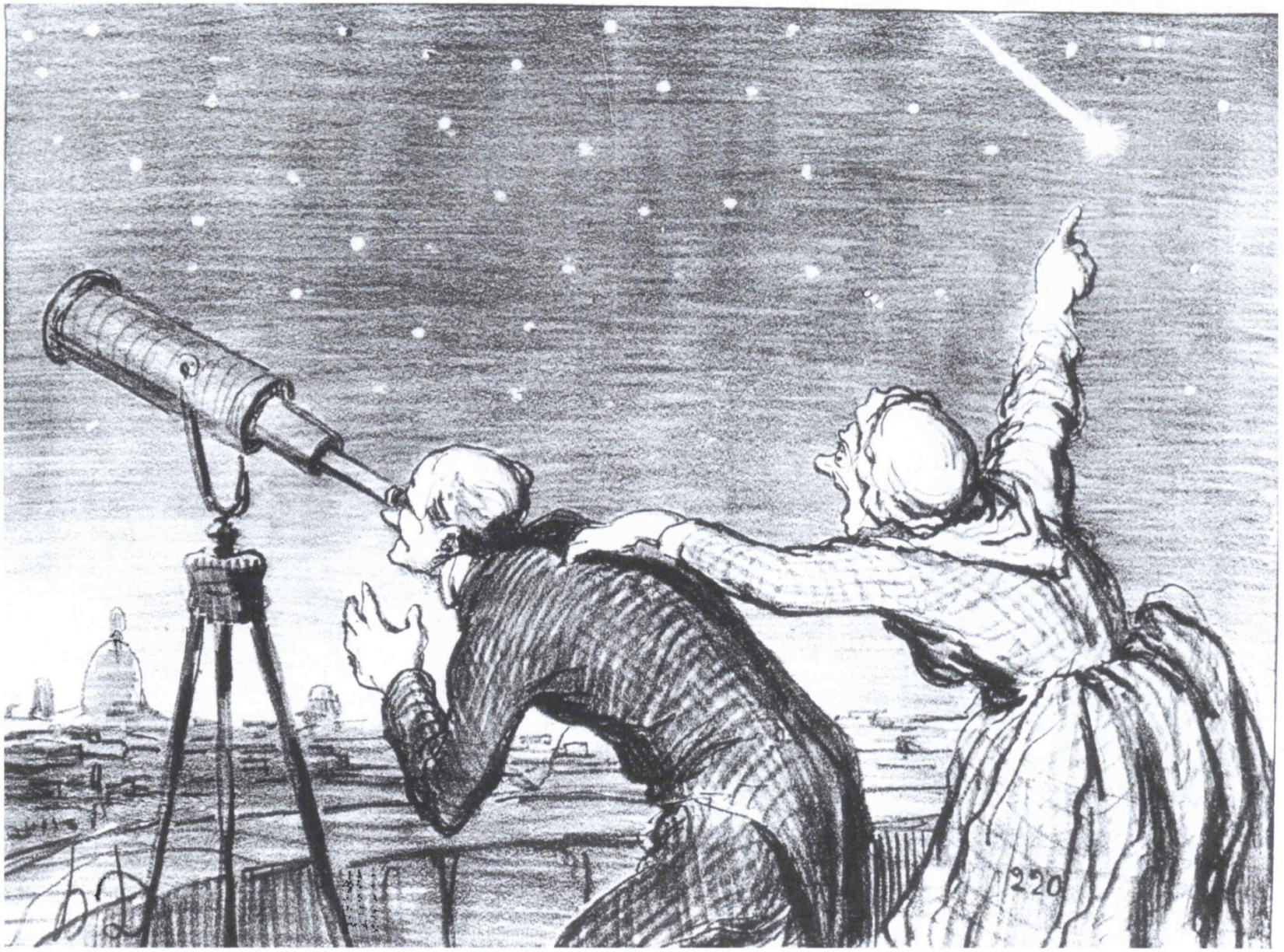
Fig. 2. Polarization image of NGC 4869 at 4.84 GHz. The restoring beam is a circular Gaussian of HPBW = 2.5". Contour levels of the total intensity image are –0.04,0.04,0.08,0.15,0.3,0.6,1,2 mJy/beam. The E-vector length is proportional to the polarization percentage: 1 arcsec corresponds to 6.25%



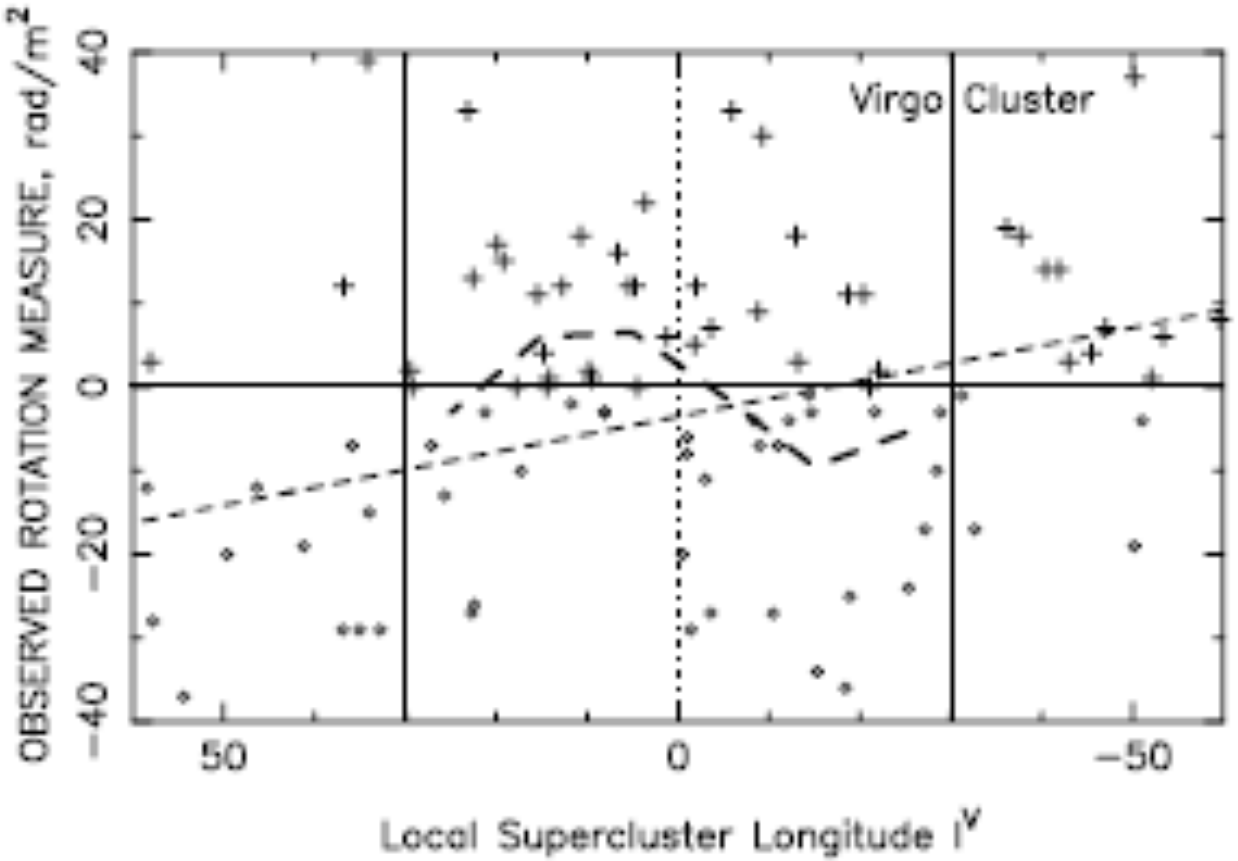
18 cm

Fig. 3. Polarization image of NGC 4869 at 1665 MHz. The restoring beam is a circular Gaussian of HPBW = 3". Contour levels of the total intensity image are –0.12,0.12,0.2,0.35,0.7,1.5,3,6,10 mJy/beam. The E-vector length is proportional to the polarization percentage: 1 arcsec corresponds to 2%

L. Feretti et al (1995)


220

Faraday Rotation Measure of Quasars as seen thru Virgo



Vallee (2002)

Energy Density (Matter & Gravitational)