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ROTATION VELOCITY AND NEUTRAL HYDROGEN DISTRIBUTION DEPENDENCY ON MAGNETIC FIELD STRENGTH IN SPIRAL GALAXIES

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Abstract. The rotation velocity of a simulated plasma galaxy is compared to the rotation curves of Sc type spiral galaxies. Both show 'flat' rotation curves with velocities of the order of several hundred kilometers per second, modified by $\mathbf{E} \times \mathbf{B}$ instabilities. Maps of the strength and distribution of galactic magnetic fields and neutral hydrogen regions, as-well-as as predictions by particle-in-cell simulations run in the late 1970s, are compared to Effelsberg observations.

Agreement between simulation and observation is best when the simulation galaxy masses are identical to the observational masses of spiral galaxies. No dark matter is needed.

Key words: Plasma Cosmology, Galaxies, Dark Matter, Galactic Rotation, Galactic Magnetic Fields, Neutral Hydrogen

1 Introduction

Rotational velocities of spiral galaxies are obtained by measuring the doppler shift of the Hα line emitted by neutral hydrogen in the spiral arms. If the galaxy is canted toward earth, the emission-line in the arm moving away from earth is red-shifted while the line in the arm moving towards earth is blue-shifted. The first doppler shift measurements of the radial velocities indicated that these were flat, rather than following the Keplerian law. If galaxies were gravitationally bound systems, their outer mass should follow Kepler's laws of motion and be slower than the inner mass. The flat rotation curves of galaxies has been cited as the strongest physical evidence for the existance of dark matter. In this scenario a massivive halo of dark matter has been envoked to produce the flat rotation curves. However, the rotation curves are not really flat; they show appreciable structure representative of an instability mechanism within the arms. This instability precludes the existance on any external halo of matter around galaxies that, while making the rotation curves flat, would also dampen any instability growth.

In the late 1970s and early 1980s, fully three-dimenional, fully electromagnetic particle-in-cell simulations of plasmas of galactic dimensions became possible. As the plasma universe has always been considered filamentary in morphology (Alfvén, 1950), the simplest simulation in which an interaction

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current-conducting, plasma filaments. As noted very early on, filaments form spirals reminescent of astrophysical *nebulae* (Birkeland, 1912).

The justification for applying plasma physics to galaxies evolving out of cosmic plasma is the overwhelming strength of the electromagnetic field; of order 10^{36} times that of gravity and 10^7 times that of gravity in neutral hydrogen in the space environment.[1]

These early simulations showed ordered magnetic field and neutral hydrogen distributions that had no observational support at the time. It is interesting to compare their predictions against current observations of spiral galaxies.

2 The Association of Neutral Hydrogen with Galactic Magnetic Fields

Neutral hydrogen distributions are characteristic of spiral galaxies but not pre-spiral galaxy forms. Because the rotation velocities of spiral galaxies are determined by the motion of neutral hydrogen, it is desirable to know the process for neutral hydrogen accumulation in late–time galaxies.

In the plasma universe model, spiral galaxies form from the interaction of current-carrying filaments at regions where electric fields exist. The individual filaments are defined by the *Carlqvist Condition* that specifies the relationship between gravitational and electromagnetic constraining forces (Verschuur, 1995). In this model, whether or not neutral hydrogen and other neutral gases form from hydrogenic plasma depends of the efficiency of convection of plasma into the filament.

When an electric field is present in a plasma and has a component perpendicular to a magnetic field, inward convection of the charged particles occurs. Both electrons and ions drift with velocity

$$\mathbf{v} = (\mathbf{E} \times \mathbf{B})/\mathrm{B}^2$$

so that the plasma as a whole moves radially inwards. The material thus forms as magnetic ropes around magnetic flux tubes. Magnetic ropes thus contain material filaments that have a higher density than the surrounding plasma.

When a plasma is only partly ionized, the electromagnetic forces act on the non–ionized components only indirectly through the viscosity between the ionized and non–ionized constituents. For a filament, the inward radial velocity drift is

$$v_r = E_z/B_\phi$$

for the case of an axial electric field and azimuthal magnetic field (induced by the axial current I_z). Hence, at a large radial distance r, the rate of

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[1] 'Neutral' hydrogen in space has a degree of ionization of the order of 10^{-4}.

accumulation of matter into a filament is

$$\frac{dM}{dt} = 2\pi r v_r \rho_m = (2\pi r)^2 \rho_m \frac{E_z}{\mu_0 I_z} \tag{1}$$

Marklund (1979) found a stationary state when the inward convections of ions and electrons toward the axis of a filament was matched by recombination and outward diffusion of the neutralized plasma (Figure 1). The equilibrium density of the ionized component normally has a maximum at the axis. However, because of the radiated loss of energy, the filament cools and a temperature gradient is associated with the plasma. Because of this hollow cylinders, or modifications of hollow cylinders of matter, will form aout the flux tubes.

Because the radial transport depends on the ionization potential of the element, elements with the lowest ionization potentials are brought closest to axis. The most abundant elements of cosmical plasma can be divided into groups of roughly equal ionization potentials: He(24 eV); H, O, N(13 eV); C, S(11 eV); and Fe, Si, Mg(8 eV). These elements can be expected to form hollow cylinders whose radii increase with ionization potential. Helium will make up the most widely distributed outer layer; hydrogen, oxygen, and nitrogen should form the middle layers, while iron, silicon, and magnesium will make up the inner layers. Interlap between the layers can be expected and, for the case of galaxies, the metal–to–hydrogen ratio should be maxium near the center and decrease outwardly. Both the convection process and luminosity increase with the field E_z.

For the case of a fully ionized hydrogenic plasma, the ions drift inwards until they reach a radius where the temperature is well below the ionization potential and the rate of recombination of the hydrogen plasma is considerable. Becouse of this "ion pump" action, hydrogenic plasma will be evacuated from the surroundings and neutral hydrogen will be most heavily deposited in regions of strong magnetic field.

When this process was discovered in the laboratory, there existed some debate as to whether galaxies possessed magnetic fields at all. Today, it is known that large-scale magnetic fields do exist in spiral galaxies. For example, the Effelsberg radio telescope has collected polarization data from about a dozen spiral galaxies at 6 to 49 cm wavelengths (Beck, 1986, 1990). Rotation measures show two different large-scale structures of the interstellar fields: Axisymmetric-spiral and bisymmetric-spiral patterns (Krause et al, 1989).

The orientation of the field lines is mostly along the optical spiral arms. However, the uniform field is often strongest outside the optical spiral arms. For example, in the case of galaxy IC 342, two filamentary structures were found in the map of polarized intensity (Peratt, 1992, Chap. 3). Their degree of polarization of ≈ 30 percent indicates a high degree of uniformity of the

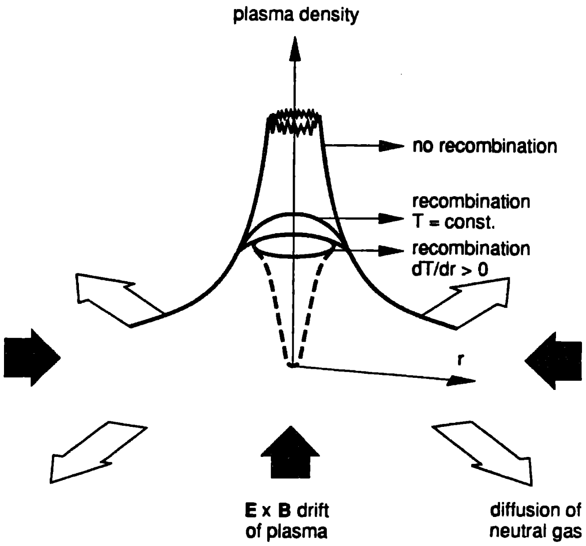


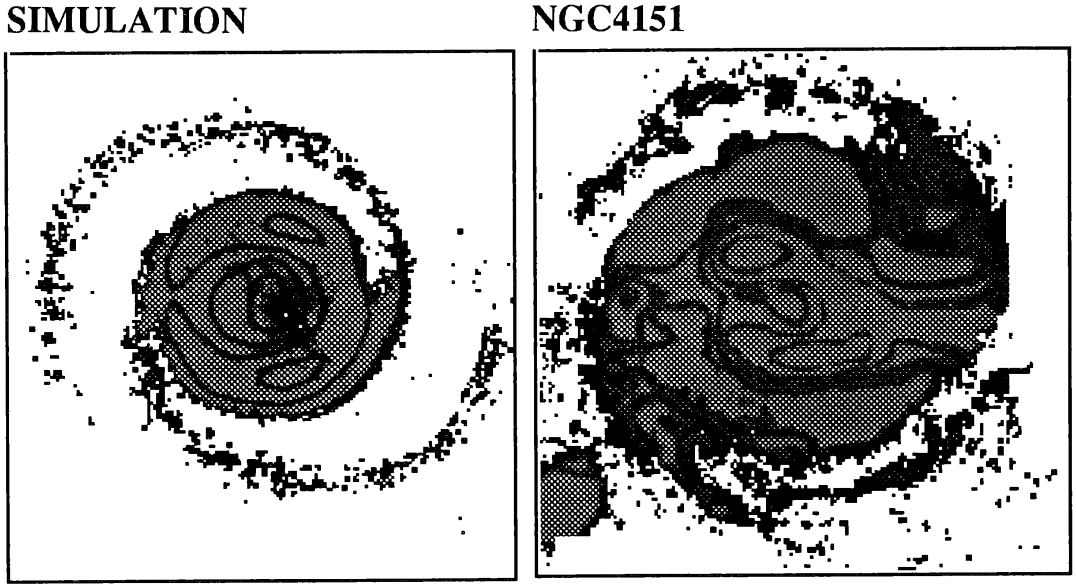
Fig. 1. Plasma density profile as a function of radius shown qualitatively for three cases: No recombination, recombination with temperature T = constant, and recombination with a lower central temperature.

magnetic field on the scale of the resolution ($\approx$ 700 pc). These filaments extend over a length of $\approx$ 30 kpc and hence are the most prominent magnetic-field features detected in normal spiral galaxies so far.

A detailed analysis of the rotation measure distribution in a spiral arm southwest of the center of the Andromeda galaxy M31 (Beck et al, 1990) shows that the magnetic field and a huge HI cloud complex are anchored together. The magnetic field then inflates out of the plane outside the cloud. The tendency for the magnetic field to follow the HI distribution has been noted in several recent observations. Circumstantial evidence has accumulated which suggests that there is a close connection between rings of CO and Hα seen rotating in some galaxies and the magnetic fields in the nuclear regions. This is particularly apparent in observations of spiral galaxies viewed edge-on. This scenario has also been invoked for our Galaxy (Wielebinski, 1989).

Neutral hydrogen is detected from galaxies via the van de Hulst radio-emission line at 21.11 cm (1.420 GHz). High-resolution observation of neutral hydrogen in irregular and spiral galaxies usually reveal extended HI distributions. Contour maps of the HI typically show a relative lack of HI in the cores of spiral galaxies but high HI content in the surrounding region, usually in the shape of a horseshoe. This region is not uniform but may have two or more peaks in neutral hydrogen content. Figure 2 (right–side) shows an

1995Ap&SS.227..167S



SIMULATION

NGC4151

Fig. 2. (right) HI distribution superimposed on an optical photograph of NGC 4151. (left) Simulation magnetic energy density superimposed on simulation galaxy. In both cases a 'horse–shoe' shaped cusp, opening towards a spiral arm, surrounds a magnetic field/HI minima core. Within the cusp, two magnetic field/HI peaks are observed.

example of the HI distribution in a spiral galaxy.

3 Simulation Results

Figure 2 (left–side) shows the plasma spiral formed in this simulation overlayed on its magnetic field line (squared) isobars. The diameter of the spiral is about 50 kpc with a mass of 10^{41} kg, i.e., a size and mass of that observed from spiral galaxies. A direct comparison to observations is made by superimposing the HI distribution in NGC 4151 on its optical photograph. The observation shows two peaks in neutral hydrogen surrounding a void. The void is orientated towards one of the arms. The simulation allows the two peaks to be traced back to their origin. Both are found to be the remnants of the originally extended components, i.e., cross-sections of the original Birkeland filaments. The hydrogen deficient center is the remnant of an elliptical galaxy formed midway between the filaments, in the magnetic null.

Since E_z is out of the plane of the page, the column electrons spiral downward in counter-clockwise rotation while the column ions spiral upward in clockwise rotation. A polarization induced charge separation also occurs in each arm, which, as it thins out, produces a radial electric field across the arm. Because of this field, the arm is susceptable to the diocotron instability

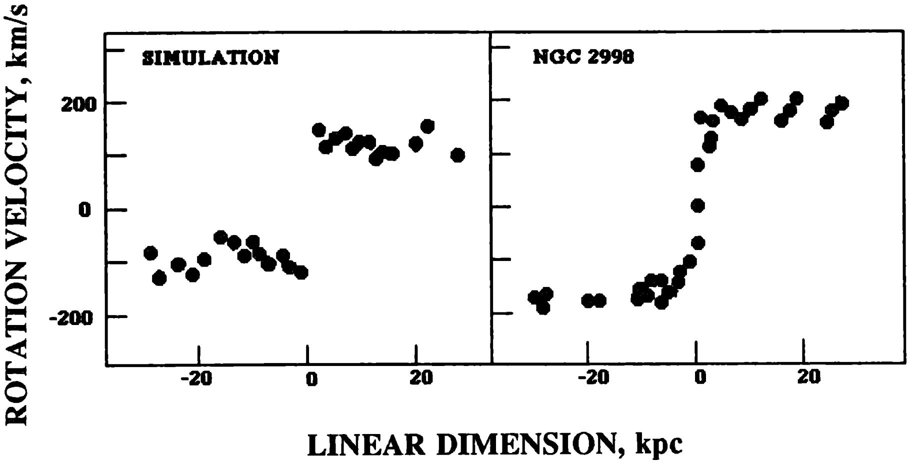


Fig. 3. Spiral galaxy rotational velocity curves. Note the well–defined structure on the 'flat' portions of the curves.

(Peratt, 1992). This instability appears as a wave motion in each arm and is barely discernable in the single frame photographs in Figure 1 of Peratt (1995) at late times. However, the instability is readily apparent in the simulation spiral rotational velocity curve (Figure 3).

The velocity consists essentially of a linearly increasing component due to a central body undergoing rigid rotation, with two flat components on either side of $r = 0$ due to the trailing arms. The diocotron instability modulates the flat components at the strong-magnetic-field, low-density instability wavelength $\lambda \approx 2.5\Delta r$, where Δr is the width of an arm.

4 Conclusions

In the late 1970s, plasma simulations of galaxies suggested that highly-ordered magnetic fields existed in galaxies, stretching for tens of thousand of light years. The strengths of the magnetic fields appearing in the simulations also suggested that appreciable amounts of nearly neutral hydrogen, known as HI regions, should collect around the field lines.

Simulation plots of the magnetic fields compared nicely with maps of observed HI regions, both showing a horse-shoe shaped distribution of gas with a bi-polar characteristic.

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At about the same time, radio astronomers at the Max-Planck-Institute for Radio Astronomy in Bonn, started to measure ordered magnetic fields in galaxies. This work had by 1988 shown unequivocally that large scale magnetic fields do exist in galaxies and do trace the distribution of neutral hydrogen.

With respect to the rotation velocities of spiral galaxies measured from the rotation of the neutral hydrogen: If galaxies were gravitationally bound systems, their outer mass should follow Kepler's laws of motion and be slower than the inner mass. The flat rotation curves of galaxies has been cited as the strongest physical evidence for the existance of dark matter. In this scenario a massivive halo of dark matter has been envoked to produce the flat rotation curves. However, the rotation curves are not really flat; they show appreciable structure representative of an instability mechanism within the arms. This instability precludes the existance of any external halo of matter around galaxies that, while making the rotation curves flat, would also dampen any instability growth.

The best agreement between the particle–in–cell maps, both magnetic field and neutral hydrogen, to the radio telescope data, and the replication of the optical features of spiral galaxies by the simulation, occurs when the observable galaxy mass is used. No dark matter is needed to explain the detailed features of a galaxy if electromagnetic forces are present.

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