GALILEO
And
The Physics of the Heliosphere

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Galileo's road map

a. Direct observation and experiment with Nature.

b. "The Book of Nature is written in mathematical characters"

Galileo wrote persuasively on (a) and (b)

and pointed out the Copernican implications

of the Jovian satellite system.

- Galileo's writings and scientific success posed a threat to the traditional verbal logic analogies of the Aristotelian professors.
- The professors persuaded the Church that Galileo's ideas were Copernican, heretical, and must be suppressed.
- Galileo's trial, conviction and life-term house arrest followed.

- Unfortunately, human nature is the basic invariant in human history, and the modern parallels of the Galileo affair press close around the periphery of the physics of the heliosphere.

- Consider the parallels to avoid repeating them in the discussion of the heliosphere.

Modern Parallels

- A. The spirit of Aristotelian professors and the Inquisition lives on in some of the anonymous referee's of scientific papers, protecting their intellectual turf by unjustified rejection of scientific papers submitted for publication.
- B. The Aristotelian verbal logic of analogies has led some to the view that the magnetic field **B** in space is created by the electric current **j,** which in turn is driven by the electric field **E.** The (**E, j**) paradigm.
- Further analogy has led to the idea that the dynamical behavior of **j** is described by a suitable laboratory electric circuit analog.
- It is imagined that the plasma velocity **v** can be driven by the electric field **E**=- **v**x **B**/*c* in the moving plasma.

- Unfortunately these notions are contradicted by the basic laws of physics.

Magnetohydrodynamics

- Newton's and Maxwell's equations are readily expressed in terms of **B** and **v** -the (**B**,**v**) paradigm.
- This is magnetohydrodynamics (MHD) representing the direct mechanical interaction between the magnetic field and the co-moving plasma.
- The plasma motion **v** works against the stresses in the infinitely elastic magnetic field.

- MHD is the basis for understanding the dynamics of the Sun and the heliosphere.

- Sadly, magnetospheric physics and ionosperic physics (aeronomy) are encumbered with the (**E**,**j**) paradigm.

The Heliosphere

- The heliosphere is created by the continual expansion of the million degree solar corona, providing the supersonic solar wind,. The coronal expansion stretches out magnetic fields from the surface of the Sun all the way to the terminal shock in the solar wind at 10^2 AU.
- The energy from the thermonuclear core of the Sun drives convection in the outer 2/7of the solar radius.

- The turbulent convection twists and stretches the magnetic field to generate more magnetic flux, the άω dynamo.
- Magnetic fields are buoyant, so magnetic fields appear in profusion at the surface of the Sun, continually swirled and deformed by the convection.
- Magnetic fields, driven by the convection, are the architects of solar activity.
- Magnetic stresses in complex field topologies produce concentrated current sheets and rapid, sometimes explosive, dissipation of magnetic energy. Such flaring extends from ~ 10^{32} ergs down to microflares and nanoflares.

- Plasma waves from the incessant microflares are believed to be the major heat source creating the 10^6 K corona – the essential step in creating the solar wind and heliosphere.
- The solar wind agitates the magnetic fields of the planets in complicated and interesting ways.
- The solar wind pushes back the interstellar gas and magnetic field to ~10^2 AU, defining the limits of the heliosphere.

- Note that Neptune lies at 30 AU.
- Voyager I travelled for 26 years to reach the termination shock (TS) at 94 AU.
- Light travel time is ~13 hours.
- The solar wind travels out to 94 AU in about a year.
- Note that the Sun revolves about 14 times in one year, winding up the magnetic fields in the solar wind into a tight spiral.

- The nearest star, Alpha Centauri, is at 3000 x 94 AU. Voyager I would take 75,000 years to reach that distance.
- Stellar wind spheres occupy ~ 3×10^{-11} of interstellar space.

- Note that the distance to the TS has varied enormously over the life of the solar system.
- TS at 1AU in a cold dense H cloud?
- Infalling interstellar neutral H becomes ionized by UV and charge exchange.
- The resulting pick up ions seriously burden the solar wind beyond about 20 AU.
- Pick up ions have a KeV or more of energy and are selectively accelerated in the TS, some reaching energies of several MeV.
- Penetrating back into the heliosphere at solar minimum, they are observed as the “anomalous cosmic rays”, differing in nuclear abundances from the cosmic rays of solar or galactic origin.

The Shape of the Heliosphere