INTRODUCTION TO THE ISM

1. THE COSMOGONICAL ROLE OF THE ISM

By "cosmogonical" we mean the effect of the ISM on the evolution of the Universe, from the beginning until now.

ISM is the primordial soup from which stars are made in galaxies. From the big bang it was composed of H, D, He, and some trace Li, Be, B. This gas, subject to cosmological fluctuations, formed condensations. These eventually became globular clusters, or perhaps smaller ones, within galaxies.

When ISM becomes a star it is removed from the pool except for stellar winds and supernovae. So ISM gradually decreases with time as gravitational forces pull it together to make stars and star clusters. Why is there any ISM left? The stellar winds and SN, also jets from newly forming stars, inject energy into ISM and keep it stirred up. This fights gravity. So there is a balance: the more stars form, the smaller the rate.

This balance is not stable. We see regions of high star formation, both within galaxies (large clusters and groups thereof) and also galaxies in which star formation is rampant (starburst galaxies). In the past, there were globular clusters formed; no more. And there are vast regions of space where no star formation currently occurs.

These issues are difficult to understand. If star formation is prevented by the energy input from forming stars, stellar winds, and SN, how can we ever have a starburst? Rather than a stable equilibrium, we need a positive feedback effect in which star formation begets more of the same, or some other influence that produces rampant star formation. These energetic inputs produce fast shocks behind which density increases, and this might be responsible for shock-induced star formation; if so, we have a possible positive feedback mechanism.

1.1. Madison Avenue picture

The following idealized picture of the ISM is now in vogue for spiral galaxies (and here we use MW as the canonical example):

1. We have an ocean of gas in hydrostatic equilibrium in the vertical direction. Weight = pressure. The gravity comes from stars; the weight from the interstellar gas. At the MW midplane $\frac{P}{k} \lesssim 25000$ cm^{-3} K; the pressure comes from thermal gas pressure, turbulent gas pressure, magnetic fields, cosmic rays.

2. Within this ocean, stellar winds, SN and correlated SN produce shocks that carve out spherical volumes, piling up the matter at the edges. These volumes are SN remnants, and ones

from correlated SN are called superbubbles. Inside the volumes we have the Hot Ionized Medium (HIM), $T \gtrsim 10^6$ K and $\frac{P}{k} \sim 10^4 \rightarrow 10^5$(?) K.

At the bubble edges, the swept-up gas is denser atomic and/or ionized gas, $T \sim 50 \rightarrow 10000$ K. These are three identifiable components, all with $\frac{P}{k} \sim 4000$ cm^{-3} K: WIM ($T \sim 8000$ K), WNM ($T \sim 8000$ K), CNM ($T \sim 80$ K). Gravity plays no role in any of this. These components form the three phases (I think of four) of the famous McKee/Ostriker model of the ISM.

3. Somehow the denser atomic gas coagulates into molecular clouds having $T \sim 10$ K. In these, $\frac{P}{k}$ can get very high because gravity holds them together.

4. Stars form within the molecular clouds; usually, lots of stars form.

If they are sufficiently massive ($\gtrsim$ B0; $M \gtrsim 15$ M$_\odot$) they contribute significantly to HII region development in a cluster, or have their own HII regions. These are highly overpressured and expand; also signposts for Doppler velocities in external galaxies.

If they are sufficiently massive ($\gtrsim$ B3; $M \gtrsim 8$ M$_\odot$) explode as SN. If more massive than ~ 20(??) M$_\odot$, they have significant winds as MS stars that blow big bubbles within which their SN explode (as is case for Cyg Loop and SN1987).

This energy input feeds back to stage 2, providing self-regulated star formation that, also, dictates the global fractions and physical conditions in the four ISM phases.

1.2. Reality

Things are fraught with uncertainty:

• Near the Sun, superbubbles seem to dominate the ISM volume; these require many SN to form, so required large stellar associations. According to statistics of stellar associations, the superbubble density is anomalously large.

• The aforementioned apparent observational need for a positive feedback process is not matched by any theoretical model.

• Physical conditions of the lower-temperature three interstellar phases (WIM, WNM, CNM) not in accord with theory.

• Who knows how molecular clouds form.

• Within molecular clouds, who knows how stars form. Competition among gravity, cloud surface pressure, angular momentum, magnetic forces, and dynamical jets from protostars.

• Spiral arms, density waves, differential Galactic rotation feed energy into ISM in unknown ways that have unknown effects.

• The interstellar medium has a turbulence spectrum that is more like the Earth's gaseous atmosphere than the ocean.

• Magnetic fields have typical energy densities exceeding the gas thermal pressure and comparable to the turbulent pressure. Everything can be regarded as a superconductor, so magnetic lines tie everything together. Magnetic pressure is anisotropic: pressure across lines, tension along them; a complicated business. Wave motion induced by turbulence probably important for kinetic energy transfer among phases. Magnetic fields ignored in global ISM models.

• Cosmic rays have energy densities comparable to the above; a direct dynamical interaction with the magnetic field, gets transferred to the gas. CR's ignored in global ISM models.

2. ASTRONOMICAL ROLE OF THE ISM

By "astronomical", we mean the effect of the ISM on non-ISM astronomical observations. For some wavelengths, it's as bad as the Earth's atmosphere for optical/UV light.

2.1. Those Dust Grains

Dust grains wreak havoc with optical observations because of extinction. Extinction not only makes everything look dimmer but also changes the colors. Also, regions of star formation are dense, with lots of dust; it's hard to see what's going on, even in the IR; you need mm-wavelength radio astronomy.

Extinction doesn't mean absorption. Much of the light gets scattered. That's a significant source of light on dark moonless nights, more than the stars themselves (I think); when you're out camping and it's really dark, trees stand out as black against a non-black sky.

Grains scatter X-rays, so distant X-ray stars have halos.

Dust grains are solids and emit blackbody radiation. Their emission limits the accuracy of measurement of angular fluctuations of the CBR at many wavelengths. Moreover, dust grains are asymmetric and aligned by the magnetic field, making their emission polarized. Measurements of the polarized CBR make many cosmologists excited, but they will have to deal with the foreground.

These comments apply to interstellar dust. There's also interplanetary dust—the Zodiacal light and related matters.

2.2. Atomic Hydrogen (HI)

Prevents us from seeing far UV (> 13.6 ev) photons because of absorption by photoionization. Fortunately, this eases with increasing energy, so X-ray sources and gamma-ray sources are not rendered invisible.

2.3. The WIM

This very diffuse ionized Hydrogen phase causes pulsar dispersion, makes it hard for pulsar observers to see pulsars at low frequency. But even more serious is the scintillation caused by turbulent scattering. And are there are dense lenses, with truly bizarre conditions, that produce Extreme Scattering Events for extragalactic radio sources.

In conjunction with the interstellar magnetic field, the WIM produces Faraday rotation of linearly polarized radio waves.

3. THE ISM FOR ITS OWN SAKE

Working in the ISM, there's one thing you generally don't have to worry about: talking to reporters. Current research topics in the ISM are too esoteric for public consumption. But you can make a big hit at public lectures because the ISM offers lots of photogenic opportunities and plays a central role in "origins".

3.1. Observers

The ISM offers the most diverse observing opportunities of any astronomical topic. Observers get to play with line emission over the widest range of wavelengths, from the 21-cm line in the CNM/WNM to kilovolt energies in the HIM (and maybe even the electron/positron line at γ ray energies); blackbody emission from dust from a few microns up to about 2 mm wavelength; continuum emission from 300 meter (yes, that's *meters*: a few MHz) to γ-rays (that's γ, not X!); polarization, often very small but highly important, from radio to UV and in both lines and continuum.

• If you like travel long distances on coach class on airplanes, the ISM lets you travel to just about anywhere (the frozen South Pole to the tropics in Puerto Rico).

• Into computing? you can justify the largest computers and fancy image processing for analyzing huge data cubes.

• Love fiddling with instrumentation? Spectroscopy, really weak continuum, really weak po-

larization and spectropolarimetry, absolute measurements—you name it, the ISM lets you indulge your desires for developing sophisticated instrumentation of any type.

- Like to schmooze? Lots of ISM-oriented meetings!

3.2. Theorists

You theorists have the same opportunities for computers and schmoozing that the observers do. Moreover, if you love physics, the ISM needs people who can combining physics from an infinitely large pool of subdisciplines to show off your physical intuition and prowess. And if you love complicated tensor stuff, PDE's, you've got it: quantum, solid state (!), dynamics, relativity, electromagnetism, magnetogasdynamics... and some people even make up their own physics (massive neutrinos for heating the intransigent ISM).