In a shameless attempt to capitalize on the success of my earlier song "Low Flush", I have decided to title this one

Low Density

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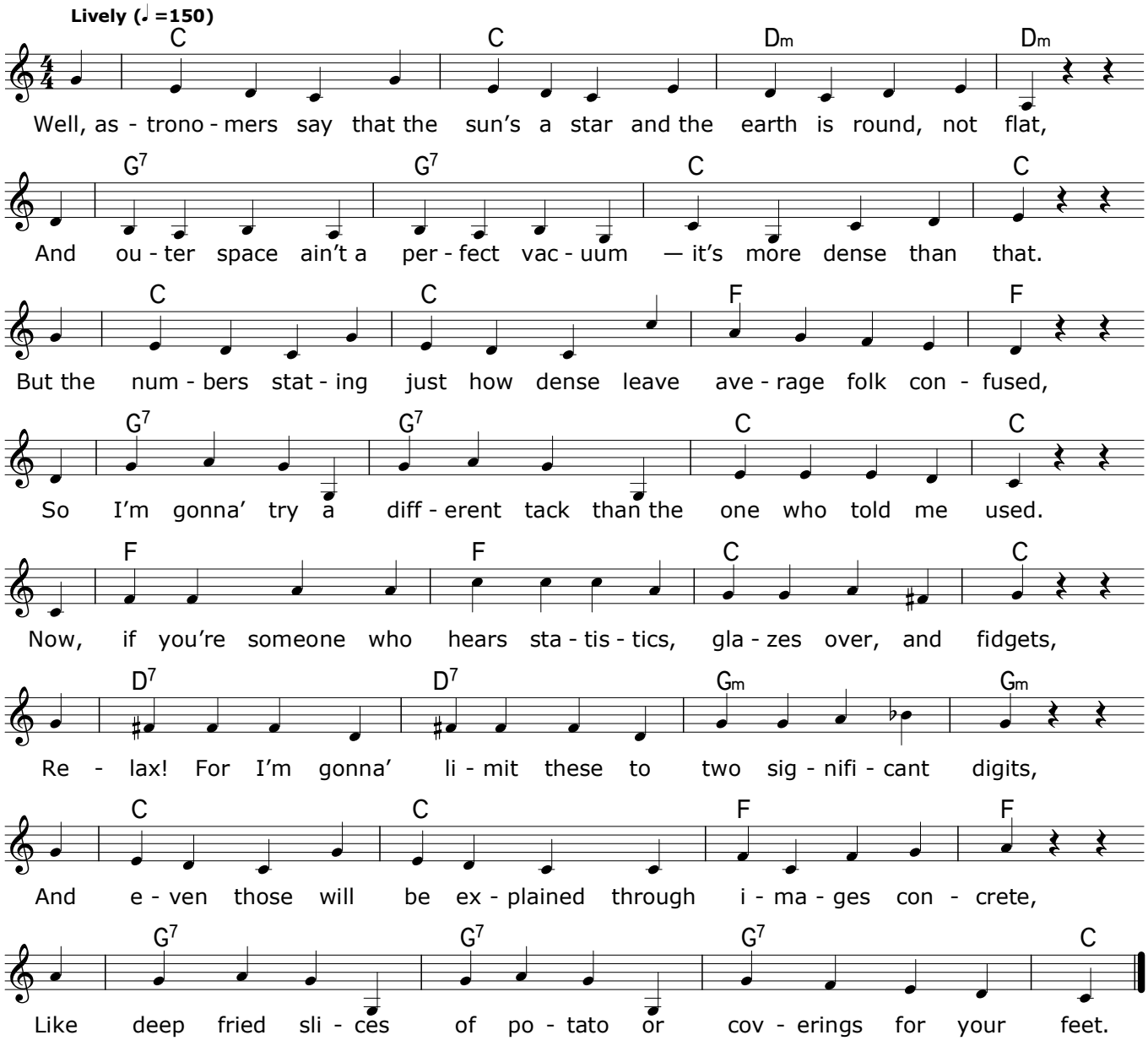
This is only an outline of the melody, which changes in detail from verse to verse to accommodate the dropped upbeats, the additional syllables, and the sentence structure. I'm not even convinced that I make the same adjustments every time I sing it, so there is no point in my trying to notate exactly what I do. If I show several syllables of the first verse attached to the same note, that doesn't mean that they're both on the same pitch, but it does mean that at least one of them is on that pitch – I'll leave it up to you to decide which one.



On the next three pages: the complete lyrics, notes, references, and even a spreadsheet

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This revised songsheet, to update some obsolete references, was created in September 2016

Low Density

Well, astronomers say that the sun's a star and the earth is round, not flat,
And outer space ain't a perfect vacuum — it's more dense than that.
But the numbers stating just how dense leave average folk confused,
So I'm gonna' try a different tack than the one who told me used.
Now, if you're someone who hears statistics, glazes over, and fidgets,
Relax! For I'm gonna' limit these to two significant digits,
And even those will be explained through images concrete,
Like deep fried slices of potato or coverings for your feet.

A small adult who goes in wading, stopping at the waist,
Makes roughly two and twenty litres water get displaced,
And that's a standard volume in the chemical profession:
It holds one Avogadro's worth, at sea level compression.
It must be warm like a comfortable room and in the gaseous state:
Then the mass of the gas expressed in grams is the gas's molecular weight.
A panty hose design balloon if filled from toe to hip
With H_2 gas would hold two grams: that's one potato chip.

Now, hydrogen can lift things when a large balloon's inflated,
But it oxidizes very fast, as the Hindenburg demonstrated.
So its main role is not a gas, but as a part of water,
Cellulose and cantaloupes, your dachshund and your daughter[1].
Most of mass was hydrogen the day the big bang burst,
And heavier stuff like zinc and iron wasn't there at first.
Hydrogen and helium formed stars through gravitation,
Then fusion made the heavier stuff through chains of combination.

A supernova, once collapsed from fuel exhaustion, must
Explode, dispersing atoms into space as clouds of dust.
The planet Earth was made from stuff in clouds that formed the sun,
Old star remnants blown to bits ere our sun had begun.
The stuff included copper, carbon, calcium (that's part of lime),
Nickel, and some ninety more that Tom Lehrer could make rhyme,
And hydrogen, which chemists study, measuring its particles,
And thus maintaining tenure as they publish learned articles.

The universities that we know are all found on this planet,
And outer space cannot have Yales and Heidelbergs — or can it?
There may be some on other planets through the Milky Way,
But they're far off, where even email can't reach in a day.
The planets and the stars are rare — there ain't much mass around.
Astronomers have done the math, and this is what they've found:
If you smooth out the mass in space, they used to tell their readers,
It's like one atom of hydrogen per each four cubic metres.

there are three more verses yet to come!

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[1] In those years when people know who Chelsea Clinton is, you may substitute "Cellulose and cantaloupes and Chelsea, Clinton's daughter.

Now that statistic's not just true of spaces 'twixt the stars;
It takes in heavier places, too, like Paris, Polaris, and Mars.
When you consider all the mass in bright spots in the skies,
Then most of space is emptier than that one atom implies.
A cubic metre would be quite a largish storage crate,
And four would fill an SUV maxed out to carry freight.
But atoms made of hydrogen are too small to be seen,
Even through a microscope with lenses strong and clean.

Aboard an Airbus aeroplane, 300 or 310,
With quantities of fuel sufficient not to land again
Till you had cruised for eighteen days, nonstop, both night and noon,
The miles you flew, if stretched out straight, could take you to the moon.
Pretend that pantyhose balloon discussed some time ago
Were stretched in all directions, with the same shape of the toe,
The heel, the knee, the thigh, the hip, enlarged without distortion,
Heel on the earth and thigh by the moon, all parts in proportion.

Now think what's inside that balloon: it's just two of grams of mass,
The mass of one potato chip, in the form of H_2 gas,
But now the volume occupied, enlarged past credibility,
Has got its heel by the Beaufort Sea and its thigh by the Sea of Tranquillity.
Atoms spread around so thin would tend to be quite scarce,
Though quite a few might stay H_2 and cruise about in pairs.
And so, two grams of hydrogen, spread through that leg-shaped place,
Is like the average density of mass in outer space.

Some of the science and mathematics behind **Low Density**

If we want to describe something as being equivalent to a low density of hydrogen in the universe, and we want people to understand it, then a good place to start is with the density of hydrogen in a more familiar context. We can then scale up the context, to see how much it needs to stretch to reduce the hydrogen density to its actual average value in the universe.

Because hydrogen in the form of H_2 is a gas, we can use a well-known relationship in chemistry between the density and molecular weight of any gas. Chemists often use molecular weight units, where each proton or neutron contributes a weight of approximately 1 (the electrons barely affect the total). In this scale, hydrogen gas, H_2, has a molecular weight of 2, while carbon dioxide, CO_2, has a weight of 44. Thus, the same mass of CO_2 contains only 2/44, or about 5%, as many individual molecules as the same weight of H_2, because each molecule is so much more massive.

When chemists need to specify the same number of molecules of different substances, they weigh them in moles rather than grams: one mole of H_2 weighs 2 grams, one mole of CO_2 weighs 44 grams, etc., and one mole of any substance contains the same number of molecules, 6.023×10^{23}, or Avogadro's number. If gases (not solids or liquids) are measured at standard temperature and pressure (STP, or, roughly speaking, room temperature and sea-level pressure), then one mole of any gas occupies the same volume, 22.4 litres.

continued on the next page

A typical 70 kg adult is about the same density as water and therefore displaces about 70 litres. The legs and hips occupy a bit more than half the total height, but the upper part is thicker (especially when the arms are taken into account), so only in a small adult would the the legs and hips occupy only 22 litres.

When I originally wrote this song in 1977, I was using a figure of 1 hydrogen atom per 17 m^3, taken from a photocopied page dated 80.01.30 and prepared by the astronomer Charles Seeger. The page was given to me by his brother, Pete, who had heard me sing another science song in June 1996 and told me that his astronomer brother was interested in finding ways to explain the density statistic to people who had no idea about the size of the hydrogen atom. To me, that suggested need for a very graphic analogy. Many of the current estimates for the density of matter in space are much higher, close to 1 atom per cc^3, but those estimates may be based on a different definition of "outer space". The estimate used in the current revision is 1 hydrogen atom per 4 m^3, taken from the 2015 NASA reference cited below. Despite 35 years of remarkable astronomy discoveries between 1980 and 2015, the NASA estimate was only a factor of 4 different from the one which Charles Seeger quoted.

Here are the key steps in the computation:

	A	B	C
1		22	Capacity of small adult's pantyhose, litres
2		2	Mass of hydrogen gas to fill pantyhose at STP, g
3		6.02E+23	Molecules of H_2 gas to fill pantyhose at STP
4	(b3*2)	1.20E+24	Atoms of H_2 gas to fill pantyhose at STP
5	(b4/(22/1000))	5.48E+25	Atoms per cubic metre filling pantyhose at STP
6	(b5/(1/4))	2.19E+26	Ratio of pantyhose density to mean outer space density
7	(exp(ln(b6)/3))	6.03E+08	Cube root of density ratio
8		1.1	Waist to heel length, real pantyhose, m
9	(b7*b8)/1000	6.63E+05	Waist-to-heel length, expanded pantyhose, converted to km
10		362600	Smallest (perigee) distance of earth-to-moon, km
11	(b10/b9)	0.55	Earth-to-moon as a fraction of expanded pantyhose waist-to-heel length
12	(b11/b8)*100	60	Conversion of that fraction to cm on real pantyhose (note: 67 cm is roughly the distance from Howard's heel to his lower thigh, so it would reach mid-thigh on a smaller adult)
13	(b10/833)	435	Flight time to moon to moon at 833 km/h A310 cruising speed, hours
14	(b13/24)	18.1	Time required, converted to days

Key references, as of September 2016:

Avogadro's law: https://en.wikipedia.org/wiki/Avogadro%27s_Law

Density of space, NASA estimate: http://map.gsfc.nasa.gov/universe/uni_matter.html

Density of space, other estimates: http://hypertextbook.com/facts/2000/DaWeiCai.shtml

Distance to moon: http://en.wikipedia.org/wiki/Moon

Other astronomical facts: Michael Seeds, Foundations of Astronomy, 1990

Toyota Sienna SUV cargo space:
http://blog.toyota-town.com/the-new-toyota-sienna-in-ontario-makes-your-summer-road-trip-great/

Airbus 310 speed: https://en.wikipedia.org/wiki/Airbus_A300