(Recalling the Death of a High-Mass Star...)
Neutron stars, although they have 1–3 solar masses, are so dense that they are very small. This image shows a 1-solar-mass neutron star, about 10 km in diameter, compared to Manhattan:
Jocelyn Bell’s “LGM” Signal...

First observation of pulses from CP 1919: 28 November 1967

“I got it on a fast recording. As the chart flowed under the pen I could see that the signal was a series of pulses . . . 1½ seconds apart.” (Deflections are down.)

(Jocelyn Bell, w/Advisor Anthony Hewish)
So, what’s an “LGM” Signal?

...ok, what’s REALLY causing these Repeating Radio-Frequency Pulses...?
Pulsars

There is a pulsar at the center of the Crab Nebula; the images show it in the “off” & “on” states.

The disk and jets are also visible:
Pulsars

But why would a neutron star flash on and off?

This figure illustrates the “Lighthouse Effect” responsible:

Strong jets of matter are emitted at the magnetic poles.

If the rotation axis is not the same as the magnetic axis, the two beams will sweep out circular paths.

If the Earth lies in one of those paths, we will see the star pulse.
The Crab pulsar also pulses in the gamma-ray spectrum!
Neutron-Star Binaries

X-ray bursts are thought to come from Neutron Stars with binary partners:

(The process is similar to a Nova, but much more energy is emitted due to the extremely strong gravitational field of the neutron star.)
Most pulsars have periods between 0.03 and 0.3 seconds (i.e., between around ~3-30 pulses per second), but a new class of pulsar was discovered in the early 1980s: the “Millisecond Pulsar” (Pulsar PSR J1748-2446ad, the fastest-spinning pulsar currently known, spins 716 times a second!):

Millisecond pulsars are thought to be “spun-up” by matter falling in from a companion.
In 1992, a pulsar was discovered whose period had unexpected, but very regular, variations.

These variations were thought to be consistent with a planet...! 

**Neutron-Star Binaries**
Collide Au + Au ions for maximum volume
$\sqrt{s} = 200$ GeV/nucleon pair, p+p and d+A to compare
(What else come from the Death of a High-Mass Star...?)
Some elements heavier than Hydrogen are formed during normal stellar fusion. Here, three helium nuclei fuse to form carbon:
Carbon nuclei can fuse, either with themselves or with “alpha particles” (Helium Nuclei), to form even heavier nuclei:
The Formation of the Elements

The elements that can be formed through successive alpha-particle fusion are more abundant than those created by other fusion reactions:
The Formation of the Elements

This theory of formation of new elements in supernova explosions produces a light curve that agrees quite well with observed curves.
There are 81 stable and 10 radioactive elements that exist on our planet. This graph shows the relative abundances of different elements in the universe:

### TABLE 21.1 Cosmic Abundances of the Elements

<table>
<thead>
<tr>
<th>Elemental Group of Particles</th>
<th>Percent Abundance by Number*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen (1 nuclear particle)</td>
<td>90</td>
</tr>
<tr>
<td>Helium (4 nuclear particles)</td>
<td>9</td>
</tr>
<tr>
<td>Lithium group (7–11 nuclear particles)</td>
<td>0.0000001</td>
</tr>
<tr>
<td>Carbon group (12–20 nuclear particles)</td>
<td>0.2</td>
</tr>
<tr>
<td>Silicon group (23–48 nuclear particles)</td>
<td>0.01</td>
</tr>
<tr>
<td>Iron group (50–62 nuclear particles)</td>
<td>0.01</td>
</tr>
<tr>
<td>Middle-weight group (63–100 nuclear particles)</td>
<td>0.00000001</td>
</tr>
<tr>
<td>Heaviest-weight group (over 100 nuclear particles)</td>
<td>0.000000001</td>
</tr>
</tbody>
</table>
Gamma-Ray Bursts

“Gamma-ray bursts” also occur, and were first spotted by satellites looking for violations of nuclear test-ban treaties.

This map of where the bursts have been observed shows no “clumping” of bursts anywhere, particularly not within the Milky Way. Therefore, the bursts must originate from outside our Galaxy.

Distance measurements of some gamma bursts show them to be very far away—2 billion parsecs for the first one measured.
Two models—merging Neutron Stars or a “Hypernova”—have been proposed as the source of Gamma-Ray Bursts ("GRB’s"):
Witnessing the

“ALCHEMY OF THE UNIVERSE IN ACTION”

(Credit: Robert Hurt/IPAC/Caltech)
Supernova “Snow Plow” Effect triggers the births of New Stars & Solar Systems... *like OURS!*
Star formation is cyclical:
Stars form, evolve, & die

In dying, they send heavy elements into the interstellar medium.

These elements then become parts of new stars.

(And on & on it goes...)