Recycling in the Universe

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NGC 3603

HST • WFPC2

PRC99-20 • STScI OPO • June 1, 1999
Wolfgang Brandner (JPL/IPAC), Eva K. Grebel (Univ. Washington),
You-Hua Chu (Univ. Illinois, Urbana-Champaign) and NASA
## Recycling on Earth & In Galaxies

<table>
<thead>
<tr>
<th></th>
<th>On Earth</th>
<th>In Galaxies</th>
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<tbody>
<tr>
<td><strong>Storage</strong></td>
<td>Neatly, in a ‘Recycling’ Bin</td>
<td>Not as neatly, in the Interstellar Medium</td>
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<tr>
<td><strong>Collection</strong></td>
<td>Big Trucks</td>
<td>Gravity &amp; Supernova ‘Snowplows’</td>
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<tr>
<td><strong>Processing</strong></td>
<td>Recycling Plant</td>
<td>Molecular Clouds</td>
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<td><strong>Production</strong></td>
<td>Factories</td>
<td>Star-forming Cores in Molecular Clouds</td>
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<td><strong>Consumption</strong></td>
<td>Humans</td>
<td>Stars</td>
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<td><strong>Discarding</strong></td>
<td>Human Tosses</td>
<td>Stellar Winds</td>
</tr>
<tr>
<td><strong>Efficiency of One Cycle</strong></td>
<td>Pretty Low, Maybe 10%</td>
<td>Pretty High, Maybe 90%</td>
</tr>
<tr>
<td><strong>Timescale for One Cycle</strong></td>
<td>Weeks to Years</td>
<td>Millions to Billions of Years</td>
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Recycling in the Universe
Making the First Recyclables...

Fluctuations about 300,000 years after the Big Bang lead to “Structure Formation.”

Gravitational collapse of some of these “structures” produces the first stars and galaxies.
Pretty young galaxies

Hubble Deep Field
HST · WFPC2
PRC96-01a · ST ScI OPO · January 15, 1996 · R. Williams (ST ScI), NASA
"Star Formation 101"

- Molecular Cloud
- Protostellar Core
- Young Star with Outflow + Protoplanetary Disk
- "Main Sequence" Star (with Planets)

Time:
- Stage 1: $2 \times 10^6$ yr
- Stage 2: $3 \times 10^4$ yr
- Stage 3: $10^5$ yr
- Stage 4/5: $10^7$ yr
Molecular Clouds: The Stuff of New Stars

The Oschin telescope, 48-inch aperture wide-field Schmidt camera at Palomar

Red Plate, Digitized Palomar Observatory Sky Survey
How much stuff is there?

“Star-counting”

Counts of stars per unit area measure how much material must be producing obscuration.

Observations by Alves, Lada & Lada 1999
Radio Spectral-line Observations of Molecular Clouds
How do Optical & Radio Views Compare?

Region of Radio Spectral-Line Survey

Observations by Alves, Lada & Lada 1999
Gas and Dust are Very Cold in Molecular Clouds, $T \sim 10^2 = 100$ Kelvin

Dust at 10 K “Glow” in the Far-Infrared
Consumption of Recyclables

The Hertzsprung-Russell Diagram

The 'Initial Mass Function' (IMF)

e.g. for every "Sun" there are 22 stars with mass 10x smaller than the Sun's
Stellar Recyclables

The Hertzsprung-Russell Diagram

Supernova, then neutron star/pulsar or black hole

Spectacular contribution, and collection. Explosion injects, and "sweeps up" interstellar material.

Red giant then white dwarf

Good recyclables. Red-giant wind main dust injection in ISM.

Long-lived brown dwarfs

"Styrofoam"
Stellar Winds: Discarding the Recyclables

Mass = 100 x Sun

Eta Carinae

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PRC96-23a • ST ScI OPO • June 10, 1996
J. Morse (U. CO), K. Davidson, (U. MN), NASA
"Excess Gas?"

(Post-red-giant planetary nebula)
Stellar Recyclables

The Hertzsprung-Russell Diagram

- Supernova, then neutron star/pulsar or black hole
- Spectacular contribution, and collection. Explosion injects, and "sweeps up" interstellar material.
- Red giant then white dwarf
- Good recyclables. Red-giant wind main dust injection in ISM.
- Long-lived brown dwarfs
- "Styrofoam"
Massive Stars & Supernovae

- **Winds** from O stars account for 30% of recyclable input to ISM
- **Supernovae** from O stars throw out much of the remaining mass
- Biggest contribution of (correlated) supernovae is to “collection”
Swept-up Gas: The Next Generation

Far-infrared dust emission map of North Celestial Pole Loop,

Pound & Goodman 1997

Spectral-line Emission from Gas In Cassiopeia

Tóth et al. 1995
(At least) How much Gas is Swept-Up?

Radius $R = 20$ pc

Volume $V = \frac{4\pi}{3} R^3$

Density $\rho = \frac{\text{Mass}}{\text{Volume}} = \rho$

$\rho_{\text{ISM}} \approx 1$ atom/cc $= 1.67 \times 10^{-24}$ g/cc

Mass$_{\text{swept-up}} = \frac{4\pi}{3} R^3 \rho = 1.5 \times 10^{36}$ g = 800 Solar Masses
Recycling in the Universe

Storage & Collection in Interstellar Medium

Processing, Production

Discarding

Consumption
Young Stars do Their Share Too

Giant Molecular Clouds

"Cores" and Outflows

Jets and Disks

Solar System Formation
One Picture with the Whole Story

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Recycling in the Universe(?)
For more information...

cfa-www.harvard.edu/~agoodman

and

Alyssa Goodman's upcoming article in Sky & Telescope Magazine
(Unusual?) Stellar Nursery in the Eagle Nebula

Gaseous Pillars • M16

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PRC95-44a • ST ScI OPO • November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA
Star Formation Caused by A Galaxy Collision (a.k.a. igniting the trash)