

Plasma Universe 2012

99.999%
of the
visible
Universe

www.plasma-universe.com

Image: Nebula M1-67 around Star W_r124.

http://hubblesite.org/gallery/album/star_collection/pr1998038a/

Credit: Yves Grosdidier (University of Montreal and Observatoire de Strasbourg), Anthony Moffat (Universit e de Montreal), Gilles Joncas (Universit e Laval), Agnes Acker (Observatoire de Strasbourg), and NASA

COVER

Plasma Universe 2012

99.999% of the Universe is Plasma

www.plasma-universe.com

Plasma Universe 2012

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JANUARY

99.999% Plasma

FEBRUARY

What is Plasma?

MARCH

Why is Plasma so?

APRIL

Electrified Plasma

The Heliospheric Current Circuit

MAY

Pinched Plasma filament

JUNE

Plasma focus?

JULY

Plasma galaxy

AUGUST

Plasma beams

Sep. 24, 1994 WFPC2	Feb. 6, 1998 WFPC2	Mar. 23, 2001 WFPC2
Jan. 5, 2001 ACS/SMC	Dec. 15, 2004 ACS/SMC	Dec. 8, 2006 ACS/SMC

SEPTEMBER

Plasma jets

Core

OCTOBER

Plasma run

NOVEMBER

Plasma rings

DECEMBER

Plasma generator

Plasma Universe pioneers

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D E C E M B E R 2 0 1 1

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1910: Georges Claude displays the first neon lamp in Paris												11							12							13							14							15							16							17						
1856: Sir J J Thomson, pioneer born												18							19							20							21							22							23							24						
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99.999% Plasma



The Universe is 99.999% plasma

Our Sun is very hot and hence nearly entirely **plasma**,...as are all the stars.

The Sun's hot solar wind filling the interplanetary medium (the space between the planets), is a **plasma**.

The interstellar medium (the space between the stars), and the intergalactic medium (space between galaxies), are nearly all **plasma**.

The Earth's ionosphere, where we see

the aurora, is a **plasma**. Dust or gas inside a plasma, behaves as a **plasma**.

Asteroids, comets and planets, are not made of plasma, but solids, liquids and gases...the exception, not the rule.

Image: COBE's Infrared View of the Universe. **Credit:** Michael Hauser (STScI), the COBE/DIRBE Science Team, and NASA. News Release Number: STcl-1998-01 <http://hubblesite.org>

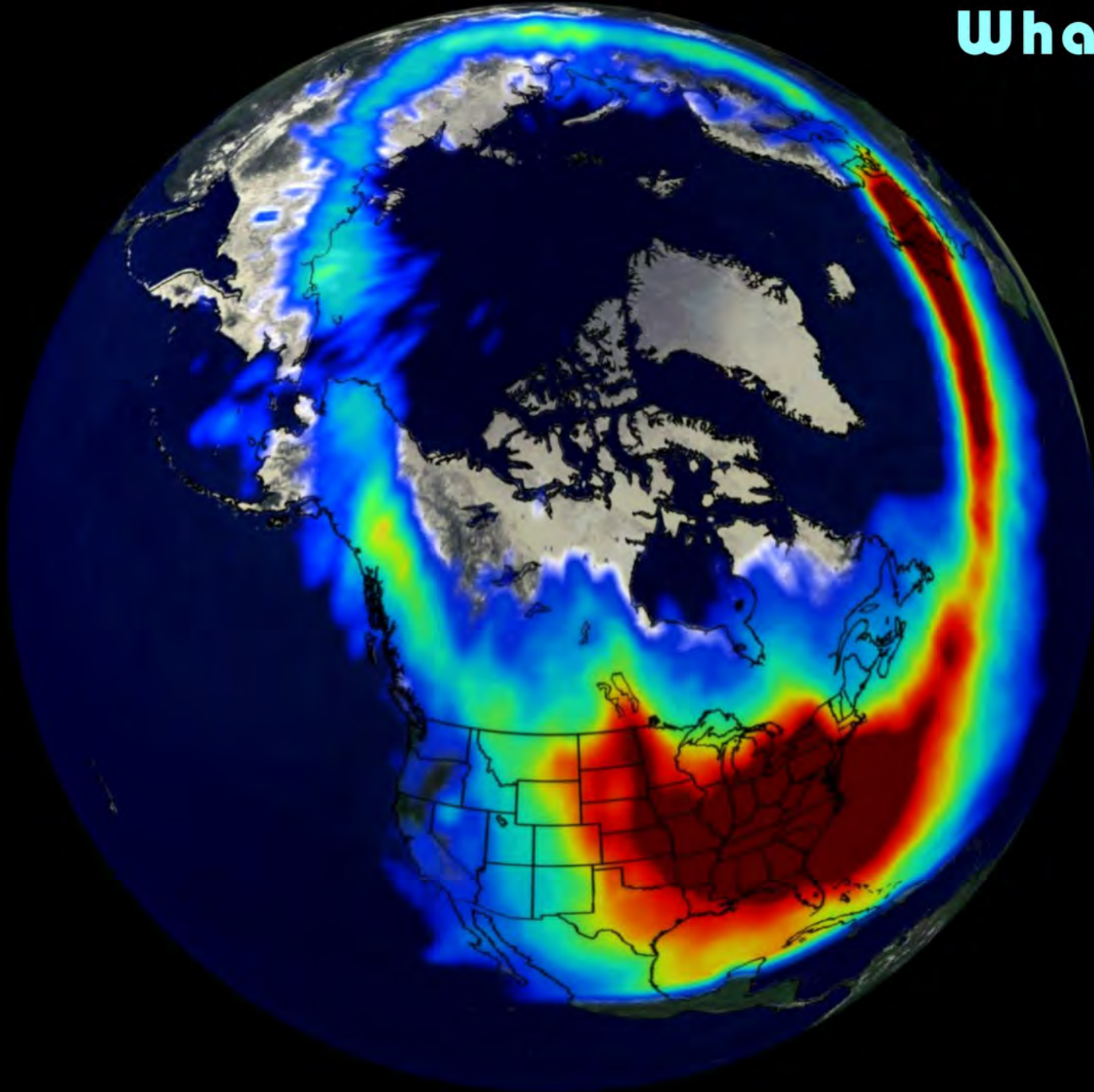
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1991: Winston H. Bostick, plasma pioneer dies

1881: Irving Langmuir, plasma pioneer born

What is Plasma?



Plasma is a form of matter.

For example, we're familiar with **solids**, such as Greenland's white arctic ice, with **liquids** such as the Earth's blue oceans, and **gases**, such as the windy atmosphere.

Plasma is a mixture of free-moving negatively charged electrons and positive ions (that make up atoms and molecules in other forms of matter). Plasma may also contain neutral atoms, molecules and dust, such as the Earth's ionosphere, in which we see the aurora.

Image: Polar/VIS satellite image of the aurora over the USA, showing Greenland covered in ice, taken on July 16, 2000. Credit: NASA/Goddard Space Flight Center, Scientific Visualization Studio. <http://svs.gsfc.nasa.gov/>

F E B R U A R Y 2 0 1 2

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12	13	14	1826: George Stoney is born; proposed existence of the electron	15	16	1773: Captain James Cook 1st records & names the Aurora Australis																																																																																
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Why is Plasma so?

Electro-magnetic forces affect plasmas far more strongly than gravity. For example, solar flares (a plasma) loop, twist and spiral with the Sun's magnetic field, sometimes escaping the Sun's intense gravitational field altogether, and accelerating away as the Solar Wind.

Solar Wind charged particles approaching the Earth's gravitational field are readily deflected by its magnetic field; this magnetosphere helps protect the Earth. Plasma "leaking" into the poles appear as the aurora, but intense solar flares can knock out a city's electric power!

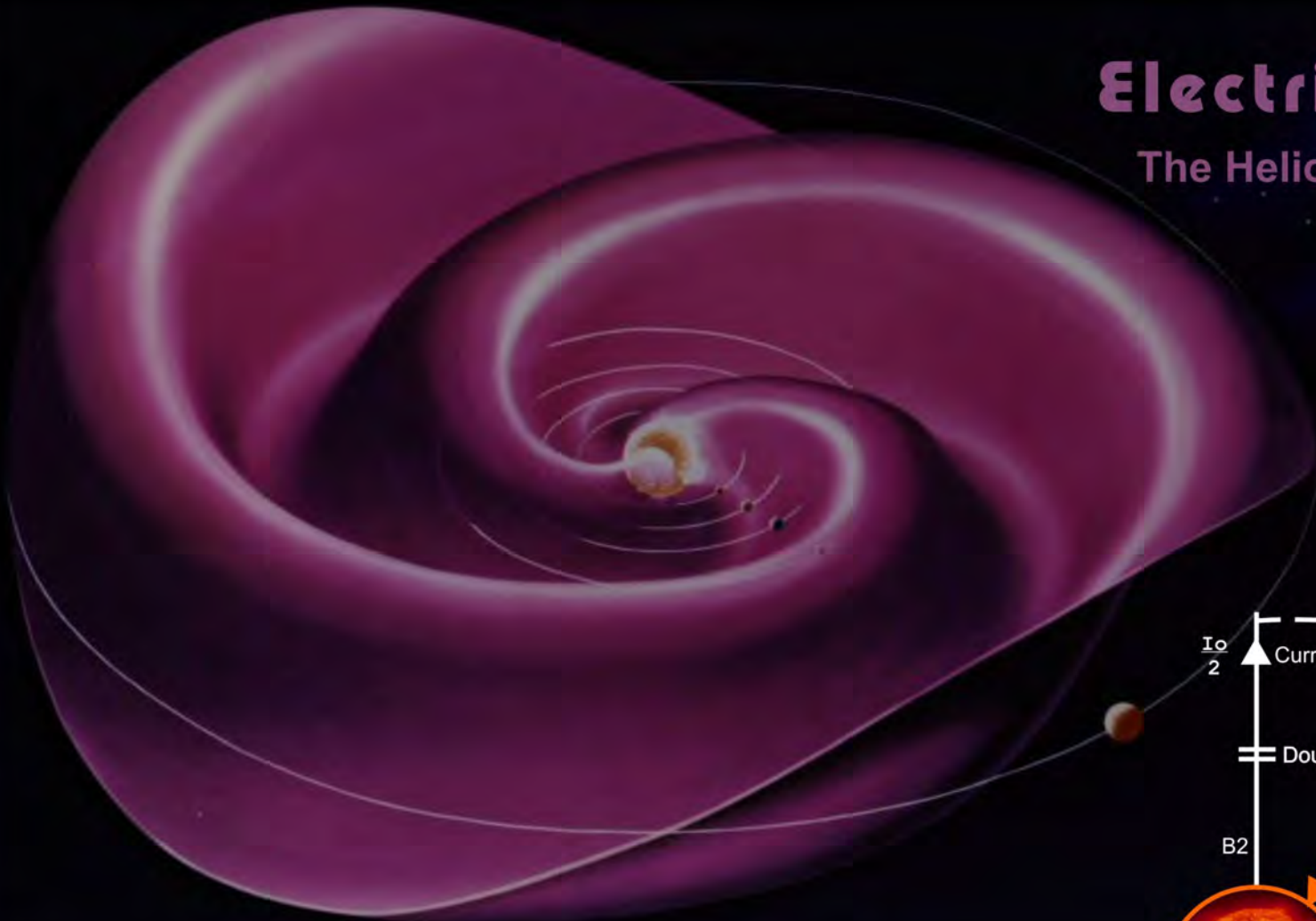
Image: Prediction of Solar Storms in Future, NIX #: MSFC-0201490. Date: 2002-06-01 **Credit:** Steele Hill, Marshall Space Flight Center, NASA
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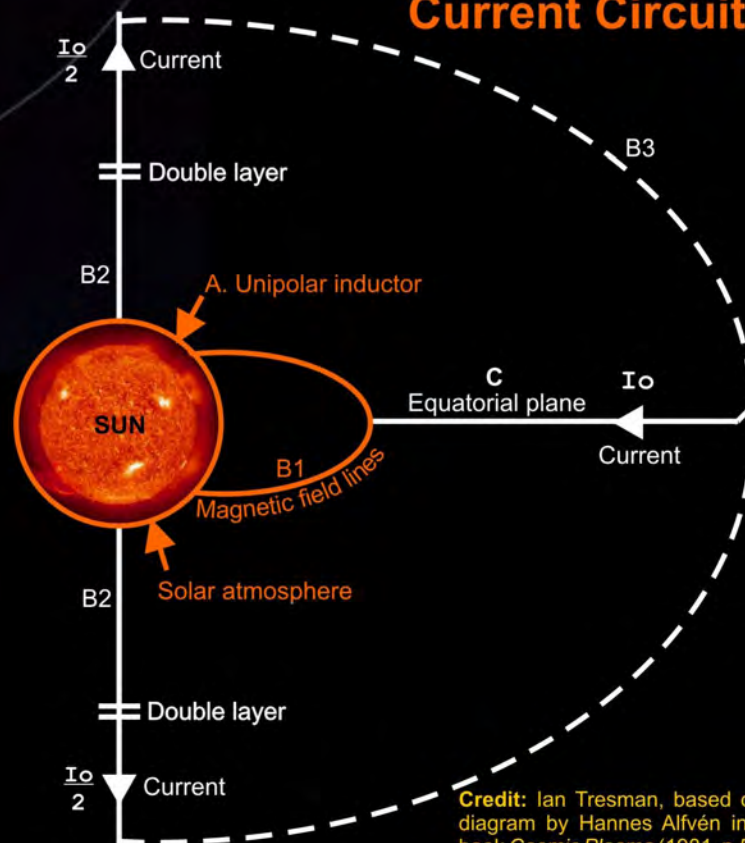
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4	1916: Winston H. Bostick, pioneer born	6	7	8	9	10
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Electrified Plasma

The Heliospheric Current Sheet



The Heliospheric Current Circuit



The heliospheric current sheet is the largest structure in the Solar System extending from the Sun and out to the heliopause, through the ecliptic in the plane of the Solar System.

Its shape results from the interaction of the Sun's rotating magnetic field with the moving Solar Wind plasma (interplanetary medium), and is sometimes likened to a ballerina's skirt.

Carrying three trillion Amps, the sheet has been described by an electric circuit (right).

Credit: From an original painting by Werner Heil, NASA, 1977. Image developed by Prof. John Wilcox to help visualize the surface that separates the Sun's two magnetic polarities. Source: Wilcox Solar Observatory, <http://wso.stanford.edu/>

Credit: Ian Tresman, based on a diagram by Hannes Alfvén in his book *Cosmic Plasma* (1981, p.55).

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Pinched Plasma filaments

Middle image: The Ant nebula (Mz3), NASA, Space Telescope Science Institute, <http://photojournal.jpl.nasa.gov/catalog/pia04216>

Lower image: Pinched aluminium can, produced from a pulsed magnetic field created by rapidly discharging 2 kilojoules from a high voltage capacitor bank into a 3-turn coil of heavy gauge wire. Credit: Bert Hickman, Stoneridge Engineering; www.teslamania.com



Filamentary structure is one of the main characteristics of electrified plasma, which is produced by constricting magnetic fields. They are seen in lightning bolts, the aurora, the Sun and nebulae (eg. the Ant Nebula above)

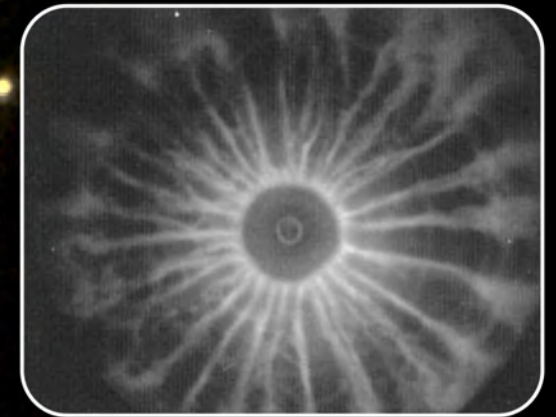
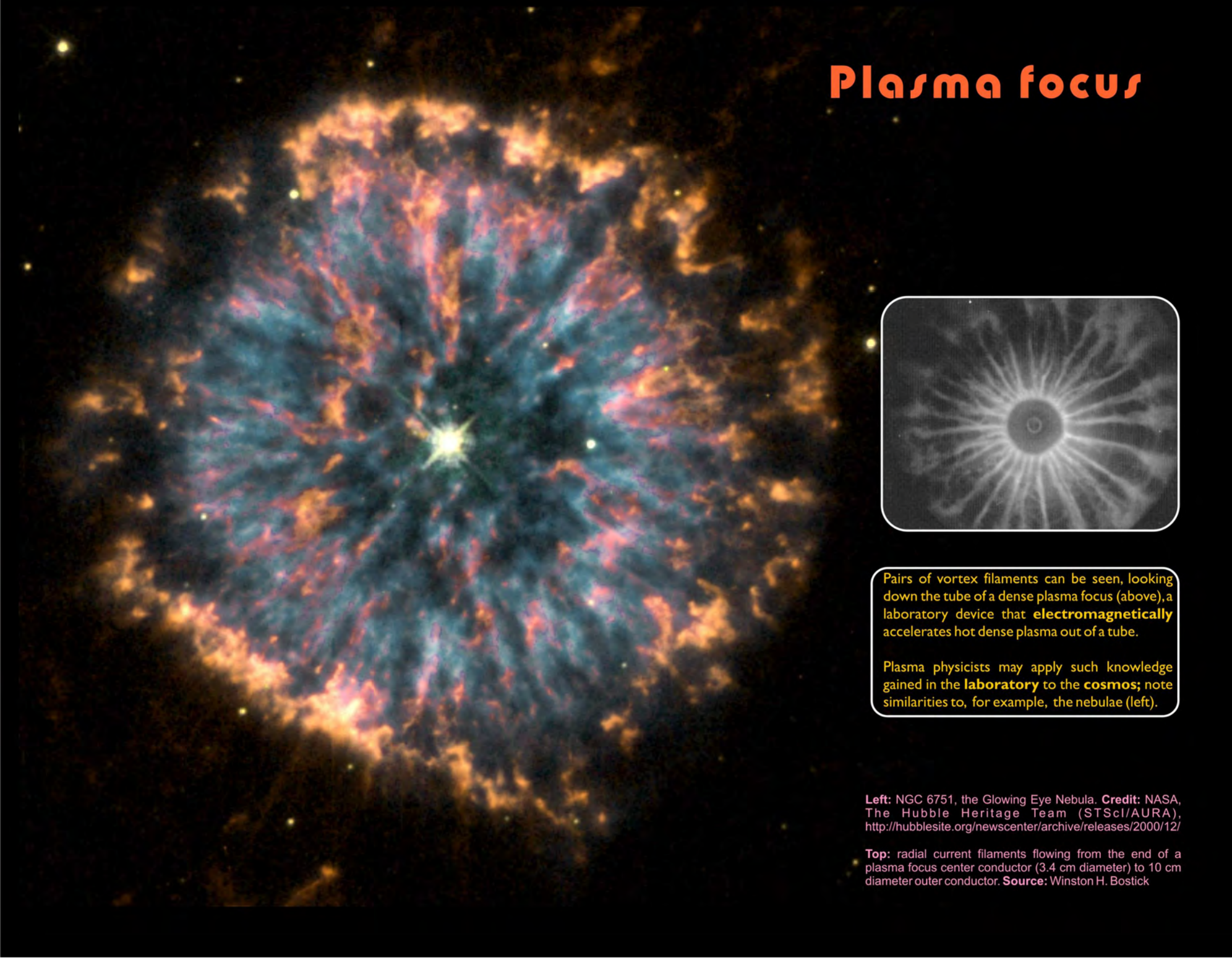
If the magnetic field becomes much stronger along one part of the filament than another, it **pinches** producing a characteristic hour-glass shape. The drinks can (left) was made this way.

Filaments often twist into helical shapes, and are sometimes called **Birkeland currents**.

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13	1937: Hannes Alfvén predicts an interstellar and intergalactic magnetic field	14	15	16	17	1850: Oliver Heaviside born. He reformulated Maxwell's equations	18																																																																																																																													
20	21	22	1960: Georges Claude dies. In 1910 he displayed the first neon lamp	23	24	25	1814: Johann Geissler born, inventor discharge tube																																																																																																																													
27	28	29	1908: Hannes Alfvén, pioneer born	30	31	1	2																																																																																																																													
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Plasma focus



Pairs of vortex filaments can be seen, looking down the tube of a dense plasma focus (above), a laboratory device that **electromagnetically** accelerates hot dense plasma out of a tube.

Plasma physicists may apply such knowledge gained in the **laboratory** to the **cosmos**; note similarities to, for example, the nebulae (left).

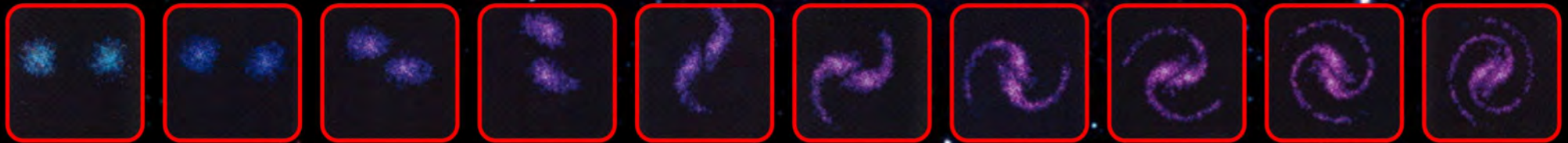
Left: NGC 6751, the Glowing Eye Nebula. **Credit:** NASA, The Hubble Heritage Team (STScI/AURA), <http://hubblesite.org/newscenter/archive/releases/2000/12/>

Top: radial current filaments flowing from the end of a plasma focus center conductor (3.4 cm diameter) to 10 cm diameter outer conductor. **Source:** Winston H. Bostick

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Plasma galaxy



A galaxy's stars are all plasma, and much of the interstellar space between them. Several theories describe their shape, such as spiral galaxy M81 above.

Plasma physicists have simulated galaxy formation as plasma clouds inside interacting parallel current-carrying magnetic filaments (bottom row).

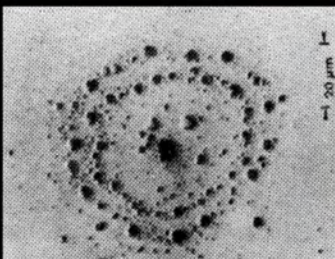
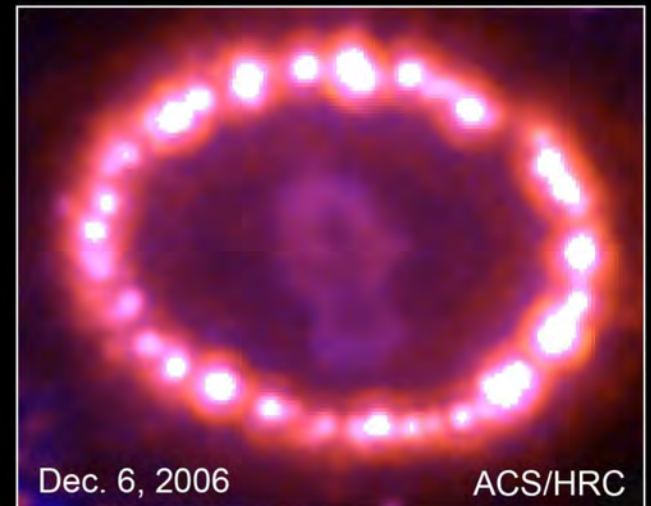
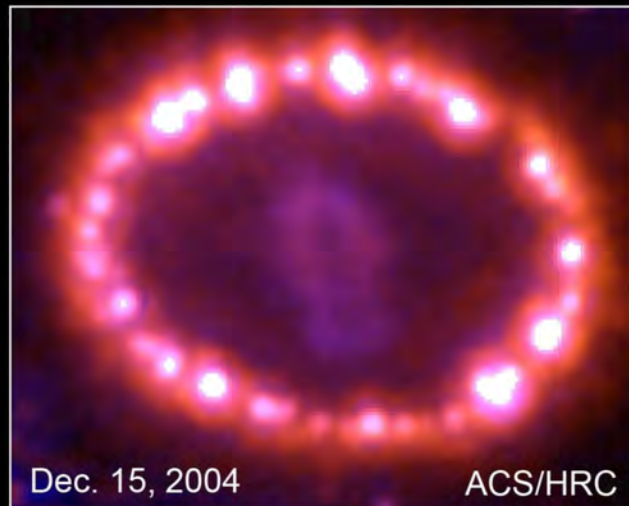
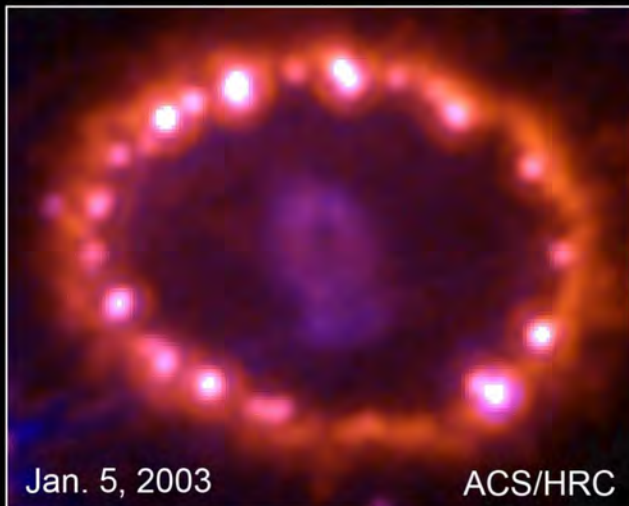
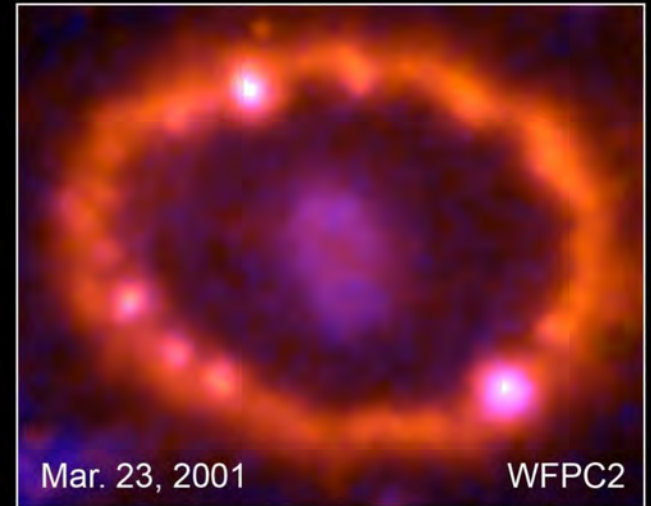
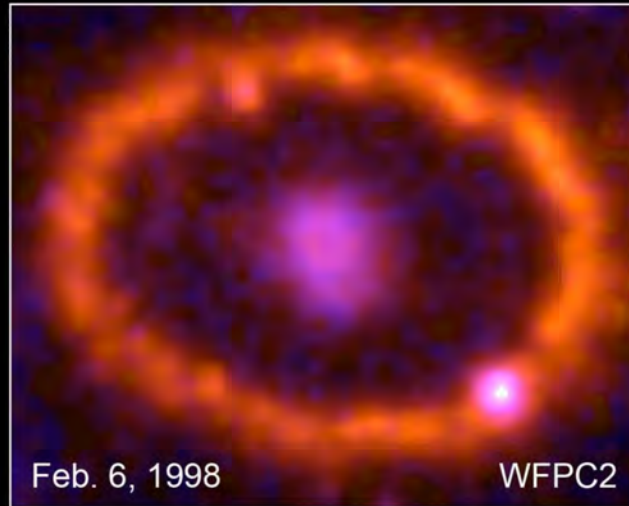
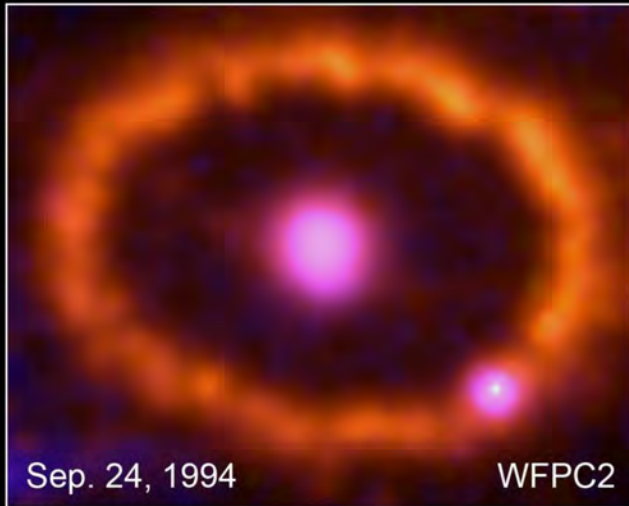
Top: M81 spiral galaxy taken with the Spitzer Space Telescope **Credit:** NASA/JPL-Caltech/S. Willner. <http://www.spitzer.caltech.edu/Media/releases/ssc2003-06/ssc2003-06c.shtml>

Lower image: Interacting Birkeland currents carrying 10^{18} Amps, length 80kpc width 35kpc, over 10^9 years. **Credit:** Anthony L. Peratt, <http://www.plasmauniverse.info/>

J U L Y 2 0 1 2

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday																																																																						
1 1902: Kristian Birkeland begins 2nd auroral expedition	2	3	4	5 1911: George Johnstone Stoney dies. In 1874 he proposes the existence of the electron	6	7																																																																						
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29 1922: Emil Wolf born. He discovers the Wolf "red" shift	30	31	1	2	3	4																																																																						
5	6	7	8	9	<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p>June</p> <table border="1"> <tr><td></td><td></td><td></td><td></td><td></td><td>1</td><td>2</td></tr> <tr><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td></tr> <tr><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td></tr> <tr><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td></tr> <tr><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td></tr> </table> </div> <div style="text-align: center;"> <p>August</p> <table border="1"> <tr><td></td><td></td><td></td><td>1</td><td>2</td><td>3</td><td>4</td></tr> <tr><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td></tr> <tr><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td></tr> <tr><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td></tr> <tr><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td><td></td></tr> </table> </div> </div>							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
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Plasma beams



Top: SN 1987A. Credit: NASA, ESA, P. Challis and R. Kirshner (Harvard-Smithsonian Center for Astrophysics). <http://hubblesite.org/newscenter/archive/releases/2007/10>

Left: Relativistic electron beam damage produced on polystyrene witness foil. Credit: Winston H. Bostick.

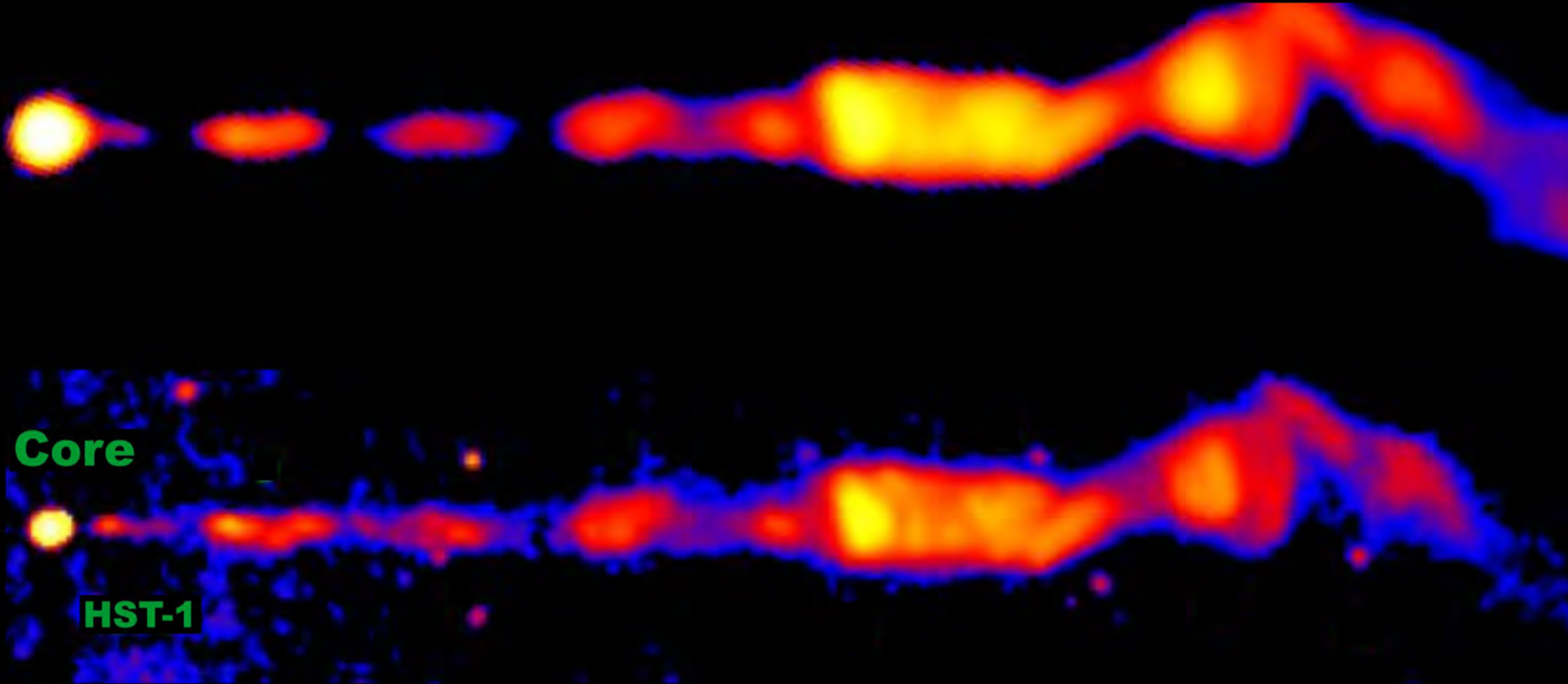
In the laboratory, a **beam** of "solid" charged particles may evolve into a hollow cylinder, the ring further subdividing into individual filamentary currents that may also pair up; see the witness foil (left) about 0.1 mm across.

Designated after the year it was detected, Supernova 1987a has been described as a "ring of pearls". Synchrotron radiation and X-rays have also been observed, that are consistent with a **relativistic particle beam**.

A U G U S T 2 0 1 2

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Plasma jets



M87's jet was first observed by Heber Curtis in 1918 who described it as "a curious straight ray", seen here in both radio (top) and optical wavelengths. Non-thermal polarized synchrotron radiation is also a characteristic.

Jets such as M87 are radio-luminous **pinched plasmas** whose magnetic fields may be derived from an electric current analogous to auroral Birkeland currents in planetary atmospheres. M87's jet is 5400 light years long.

Laboratory jet simulations produce shared characteristics such as power magnitude, isophotal morphology, spectra, and polarized synchrotron radiation as electrons are accelerated through a magnetic field.

Image: M87 jet in radio (top) & optical. Credit: H. L. Marshall/MIT/NASA/NRAO. **Radio:** NRAO/AUI/NSF. **Optical:** NASA/STScI/UMBC/E. Perلمان *et al.*, <http://hea-www.harvard.edu/XJET/source-d.cgi?M87>

S E P T E M B E R 2 0 1 2

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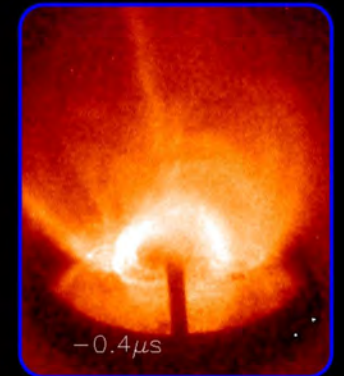
1870: Georges Claude born. In 1910 he displays the first neon lamp

1987: Willard Harrison Bennett, pioneer dies

Plasma sun

The Sun is a plasma producing the solar wind, as well as solar flares and prominences: arch-shaped, sometimes twisting structures in the corona.

Plasma physicists at Caltech have made a plasma gun which produces arched, erupting, twisted flux tubes (see photo below) that are similar to solar prominences.



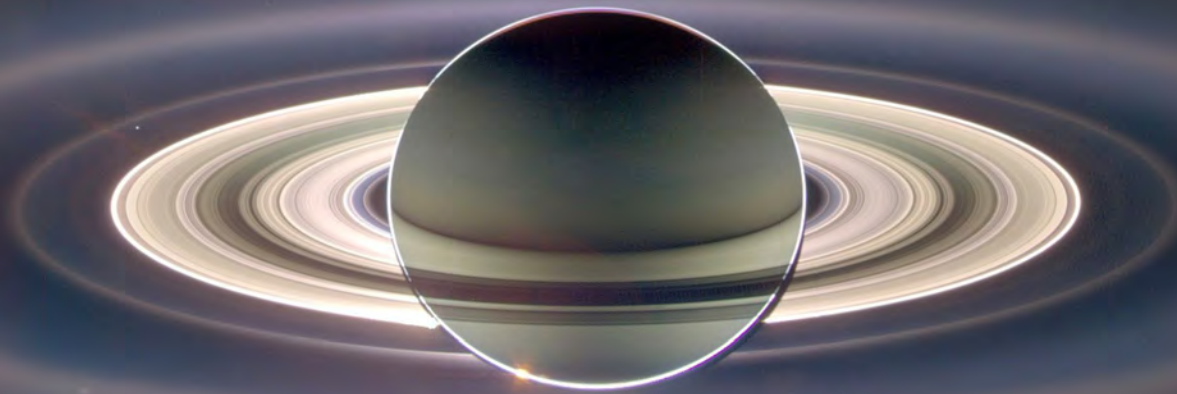
Top: Simulated prominences. Credit: J. F. Hansen and P. M. Bellan, Caltech, Bellan Plasma Group, http://ve4xm.caltech.edu/Bellan_plasma_page/

Left: Sun false color X-ray image. Credit: ISAS, Yohkoh Project.

O C T O B E R 2 0 1 2

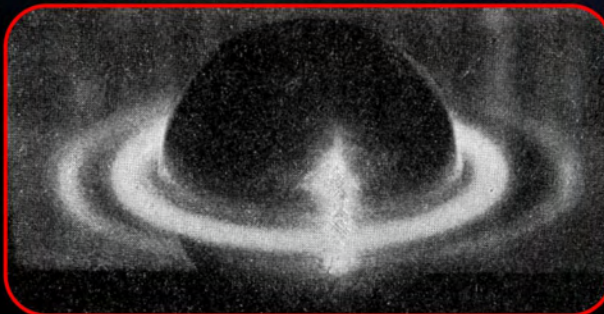
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30	1956: Winston H. Bostick coins the word "plasmoid"	1	2	1942: Hannes Alfvén predicts Solar plasma waves	3	4																																																																																		
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Plasma rings



Top: Cassini's view of Saturn's rings in exaggerated color contrast. **Credit:** NASA/JPL/Space Science Institute. PIA08329. <http://photojournal.jpl.nasa.gov/catalog/PIA08329>

Right: Kristian Birkeland's small cathode-globe terrella, with about 0.1 milliampere current. Source: Sec.2, Ch VI, *The Norwegian Aurora Polaris Expedition 1902-1903*, publ. 1908.



Backlit by the Sun, Saturn's rings are composed of small particles.

In the interplanetary plasma, dust is charged negatively by electrons, and positively by sunlight, resulting in a "dusty plasma". Electromagnetic forces dominate.

During the 1900s, Norwegian scientist Kristian Birkeland experimented with a magnetized metal globe called a **terrella** in a vacuum chamber (see photo left).

Different currents could produce aurora... and Saturn-like rings.

N O V E M B E R 2 0 1 2

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October 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31							December 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31							30							31							1							2							3													
4							1879: James Clerk Maxwell, pioneer dies							5							6							7							8							9							10						
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Plasma generator

Michael Faraday discovered that an electrically conductive disk rotating in a magnetic field generated an electric current between the central axis and the disk's circumference.

It is sometimes called a Faraday disk, or homopolar generator or **unipolar inductor**.

As electrically conducting plasma rotates through its own magnetic field, electric currents are created along its axes.

Unipolar inductors have been associated with the Sun, stars, galaxies, sunspots, and nebulae (left)... almost everywhere we see a rotating plasma!

Image: Crab Nebula showing the X-ray (blue), and optical (red) images superimposed. **Credit:** NASA/CXC/ASU/J. Hester et al.

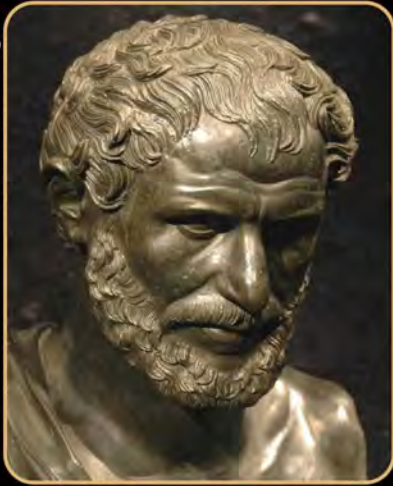
<http://hubblesite.org/newscenter/archive/releases/2002/24/image/a/>

D E C E M B E R 2 0 1 2

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2	3	1931: Carl-Gunne Fälthammar, plasma pioneer, born	4	5	6	7	8	
9	10	1910: Georges Claude displays the first neon lamp in Paris	11	12	1867: Kristian Birkeland, plasma pioneer born	13	14	15
16	17	1856: Sir J J Thomson, pioneer born	18	19	20	21	22	
23	24	25	26	27	28	29	30	
1979: Charles Bruce, electrical engineer, dies	31	1	2	3	4	5	6	

Plasma Universe pioneers

Source: Livius.Org



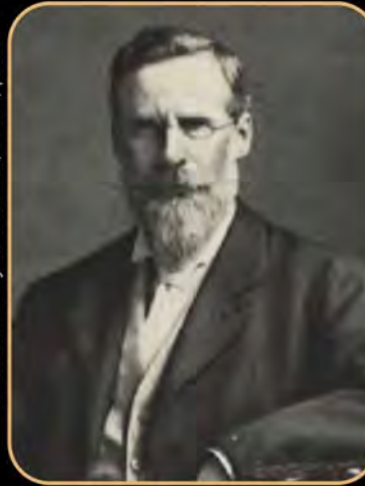
Heraclitus of Ephesus (540–475 BC) noted that: “.. the thunderbolt steers the course of all things”

Source: Cavendish Lab., Univ. of Cambridge



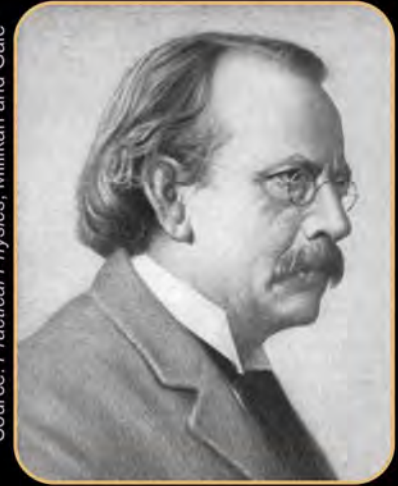
James Clerk Maxwell (1831-1879) devised a unified model of electricity, magnetism and inductance.

Source: *History of Science*, vol. 5, p.106



Sir William Crookes (1832-1919) discovers in 1879 “radiant matter”, he also calls the “Fourth State of Matter”.

Source: *Practical Physics*, Millikan and Gale



Sir J. J. Thomson (1856-1940) in 1897 identifies “plasma” as consisting of charged particles.

Source: Wikipedia



Kristian Birkeland (1867-1917) models the aurora in a terrella, and predicts “space is filled with electrons and flying electric ions of all kinds”

Source: *GE Review*, Dec. 1932



Irving Langmuir (1881-1957) investigates the properties of ionized gases, and coins the term “plasma”. 1932 Nobel Prize, Chemistry

Source: Royal Institute of Technology, Sweden



Hannes Alfvén (1908-1995) stresses the importance of electrified magnetic space plasmas. Awarded the 1970 Nobel Prize in physics.

2012
Plasma Universe
Calendar

www.plasma-universe.com

With special thanks to Prof. Paul Bellan (California Institute of Technology), Hanna Dahlgren (Royal Institute of Technology, Sweden), Dr. Timothy E. Eastman (www.plasmas.org), Bert Hickman (teslamania.com), Dr. Todd Hoeksema (Stanford University), Dr Herman L. Marshall (Massachusetts Institute of Technology), Dr Anthony L. Peratt (Los Alamos National Laboratory), Caroline Tresman.

Web sites

www.plasma-universe.com • plasmauniverse.info
www.plasmas.org • www.plasmacoalition.org

Books

Cosmic Plasma by Hannes Alfvén, 1981
Physics of the Plasma Universe
by Anthony L. Peratt, 1992
The Electric Sky by Donald E. Scott, 2007

Text & compilation © 2011 Ian Tresman

J A N U A R Y 2 0 1 3

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
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					30 31	

1881: Irving Langmuir, plasma pioneer born

1991: Winston H. Bostick, plasma pioneer dies

December								February								
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