REFLECTIONS / REFRACTIONS
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REFLECTIONS \ REFRACTIONS

Making Use of Your Hubble Space Telescope Tax Dollars

by Robert Wade

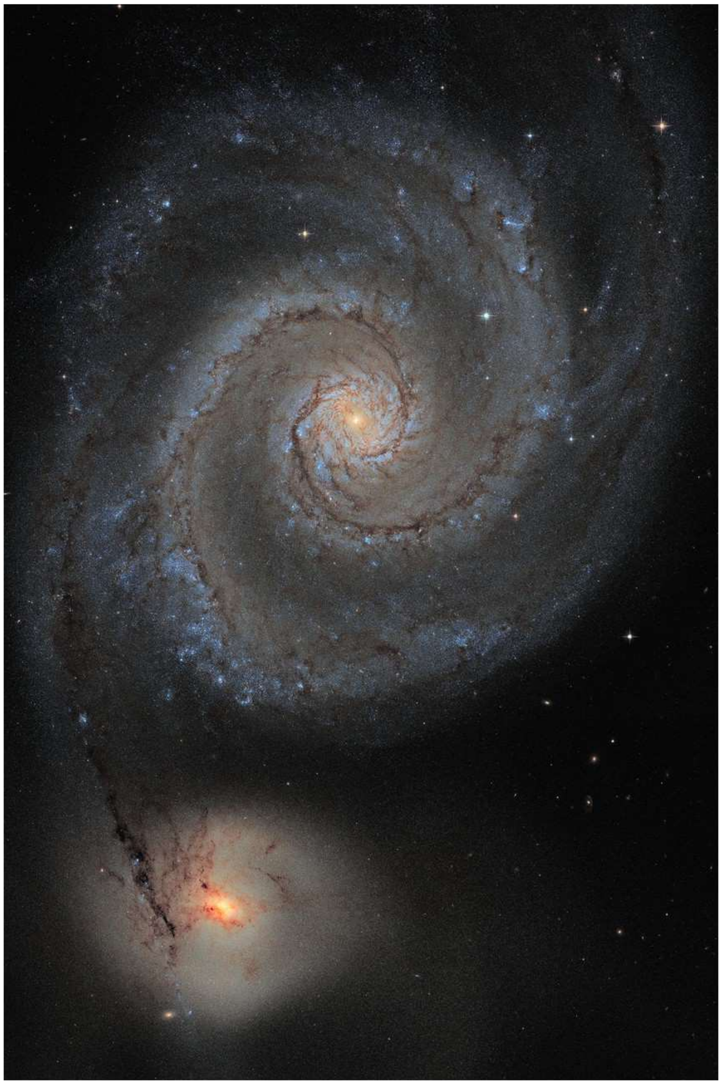


Figure 5: The Iconic M51

Clearly, there are some very talented astrophotographers in this astronomy club. Personally, I have eschewed astrophotography in my 50+ years of the hobby in favor of the visual chase. There is something special (as you all know) of putting your eyeball in front of the eyepiece to see photons emitted thousands or millions of years ago impinging on your optic nerves and causing an existential moment. However, eyeballs and muscles age, light pollution grows, and the activation barrier to getting to a dark sky seems to grow higher each year.

So, what about astrophotography? I'd like to summarize the three approaches, in increasing order of ease and decreasing cost and perhaps self-satisfaction:

Purchase equipment > take exposures > process the sub exposures

Rent equipment > take exposures > process sub exposures

Obtain exposures from someone or somewhere else > process sub exposures

There is a significant barrier to purchasing and building out your own imaging kit. Not only does Part A plug into Part B, but once everything is humming along and producing images, how do you process them? This article isn't about a tutorial on an astrophotography image processing workflow, but if you *do* know something about imaging and/or you would like to practice honing your skills further, you need to look no further than our very own public Hubble telescope images.

Disclosure: I do not own any sophisticated imaging equipment. I've taken the route of (b) and (c) above. I've been utilizing the iTelescope network (https://www.itelescope.net) for about a year and a half (another article methinks) and climbing the learning curve of PixInsight processing (https://pixinsight.com). There are many other ways to process FITS images – everyone usually finds a set of tools that works for them. I utilized many internet online tutorials as well as two Okie-Tex PixInsight classes, but the most bang for my buck came from the Adam Block online tutorials (https://www.adamblockstudios.com) - available through subscription. Adam is also available online via Zoom to help you through problematic areas.

So, how do you find FITS material to play around with? You either need a good astrophotographer friend willing to share subs or know where to obtain them. How about images taken from space? For one thing, a *lot* less worry about light pollution gradients and deconvolving to eliminate atmospheric distortion. Your skill set won't be as taxed as using your own terrestrial-obtained images and it's pleasing to come to up with some semblance of the Hubble pictures shown online.

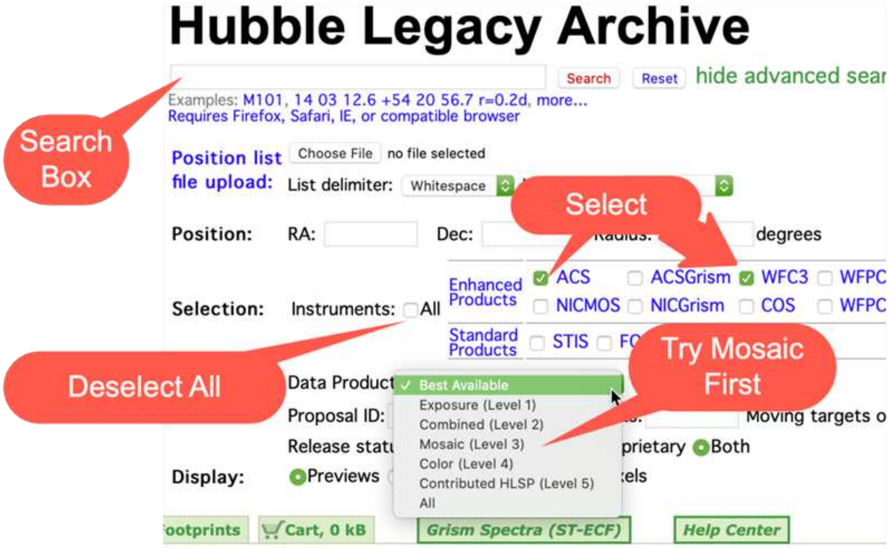
1. Go to the Hubble Legacy Archive (HLA) index page at https://hla.stsci.edu and enter the searching site at the designated link.
2. Click on the advanced search button:

2019 September 24: **Hubble Catalog of Variables released.**
Find out what's new in the Hubble Source Catalog.

Examples: M101, 14 03 12.6 +54 20 56.7 r=0.2d, more...
Requires Firefox, Safari, IE, or compatible browser

3. On the advanced search page.

a. Enter desired object (example objects and designations are illustrated)
b. Under "selection", deselect "All" and then select both "ACS" and "WFC3"
c. Finally, under "Data Product" initially select "Mosaic (level 3)." Hits here are already a stitched together mosaics and the different filters are already registered (aligned). With no acceptable hits here, I next go to "Combined (level 2)" where at least some exposures have been combined, and again, different filters are usually registered. These are the equivalent of your filter masters.



Examples: M101, 14 03 12.6 +54 20 56.7 r=0.2d, more...
Requires Firefox, Safari, IE, or compatible browser

Position list file upload: Choose File no file selected
List delimiter: Whitespace

Selection: Instruments: ☐ All
Enhanced Products: ☑ ACS ☐ ACSGrism ☑ WFC3 ☐ WFPC
☐ NICMOS ☐ NICGrism ☐ COS ☐ WFPC
Standard Products: ☐ STIS ☐ FO

Data Product: ✓ Best Available, Exposure (Level 1), Combined (Level 2), Mosaic (Level 3), Color (Level 4), Contributed HLSP (Level 5), All

4. Here is an example of one of my searches:

Search: M96

Examples: M101, 14 03 12.6 +54 20 56.7 r=0.2d, more...
Requires Firefox, Safari, IE, or compatible browser

Position list file upload: Choose File no file selected
List delimiter: Whitespace List format: Degrees

Position: RA: Dec: Radius: degrees

Selection: Instruments: ☐ All
Enhanced Products: ☑ ACS ☐ ACSGrism ☑ WFC3 ☐ WFPC2
☐ NICMOS ☐ NICGrism ☐ COS ☐ WFPC2-PC
Standard Products: ☐ STIS ☐ FOS ☐ GHRS

Data Product: Combined (Level 2)
Proposal ID: Spectral elements: Moving targets only: ☐
Release status: ○ Proprietary ○ Non-Proprietary ● Both
Display: ● Previews ○ Cutouts Size: 256 pixels

5. After the search button is pushed, the results (if any) are displayed on the bottom half of the page:

M96 RA = 161.690600 Dec = 11.819939 r = 0.060333 [10:46:45.744 +11:49:11.78]

Results 1-20 of 57 Show 20 results per page

Click column heading to sort list - Click rows to select
Show selected rows:
Text boxes under columns select matching rows

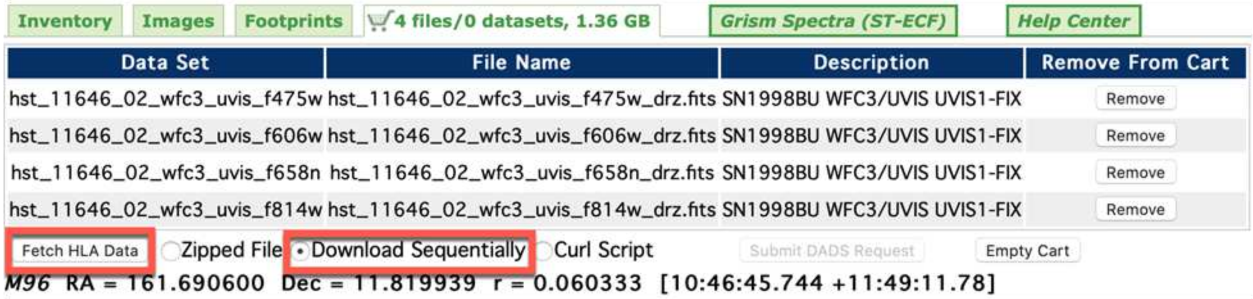
Display	PlotCat	Retrieve	RA	DEC	Level	Target	Detector	Aperture	Spectral_Elt	NExposures

6. By default, the Inventory tab is the initial display method. I usually scan down through the results to find multiple images taken through different filters that I can map to the RGB color space:

Display	PlotCat	FITS	10:46:45.06	11:50:45.3	2	SN1998BU	WFC3/UVIS	UVIS1-FIX	F475W	2
Display	PlotCat	FITS	10:46:45.06	11:50:45.3	2	SN1998BU	WFC3/UVIS	UVIS1-FIX	F606W	3
Display	PlotCat	FITS	10:46:45.06	11:50:45.3	2	SN1998BU	WFC3/UVIS	UVIS1-FIX	F658N	3
Display	PlotCat	FITS	10:46:45.06	11:50:45.3	2	SN1998BU	WFC3/UVIS	UVIS1-FIX	F814W	2
Display	PlotCat	FITS	10:46:45.06	11:50:45.3	2	SN1998BU	WFC3/UVIS	UVIS1-FIX	detection	10

   a. In this case, a whole or partial galaxy image with an embedded supernova looked intriguing, so I added these to my "shopping cart."
   b. The wavelength is listed as well as whether it is a wide-band (W) filter or a narrow-band filter (N). Thus, the three wideband combined exposures are likely ideal candidates to further process.
   c. You can get a visual preview of these by selecting the "Images" tab.

7. After selecting the shopping cart FITS icon, you can download the FITS images either as a single zipped file or sequentially download them:



Data Set	File Name	Description	Remove From Cart
hst_11646_02_wfc3_uvis_f475w	hst_11646_02_wfc3_uvis_f475w_drz.fits	SN1998BU WFC3/UVIS UVIS1-FIX	Remove
hst_11646_02_wfc3_uvis_f606w	hst_11646_02_wfc3_uvis_f606w_drz.fits	SN1998BU WFC3/UVIS UVIS1-FIX	Remove
hst_11646_02_wfc3_uvis_f658n	hst_11646_02_wfc3_uvis_f658n_drz.fits	SN1998BU WFC3/UVIS UVIS1-FIX	Remove
hst_11646_02_wfc3_uvis_f814w	hst_11646_02_wfc3_uvis_f814w_drz.fits	SN1998BU WFC3/UVIS UVIS1-FIX	Remove

M96 RA = 161.690600 Dec = 11.819939 r = 0.060333 [10:46:45.744 +11:49:11.78]

8. That's it, now you have a set of files you can bring into your workflow.

Since you are mapping individual filters to either red, green, or blue, you are effectively creating your own "Hubble Palette" and these won't be "true" color in the traditional sense. You can emphasize ultraviolet by mapping it to blue or combining 390 nm with 435 nm filter exposures. Conversely, infrared can be emphasized by combining, say 814 nm with 670 nm.

Here are some images I've come up with by searching, downloading, and processing:

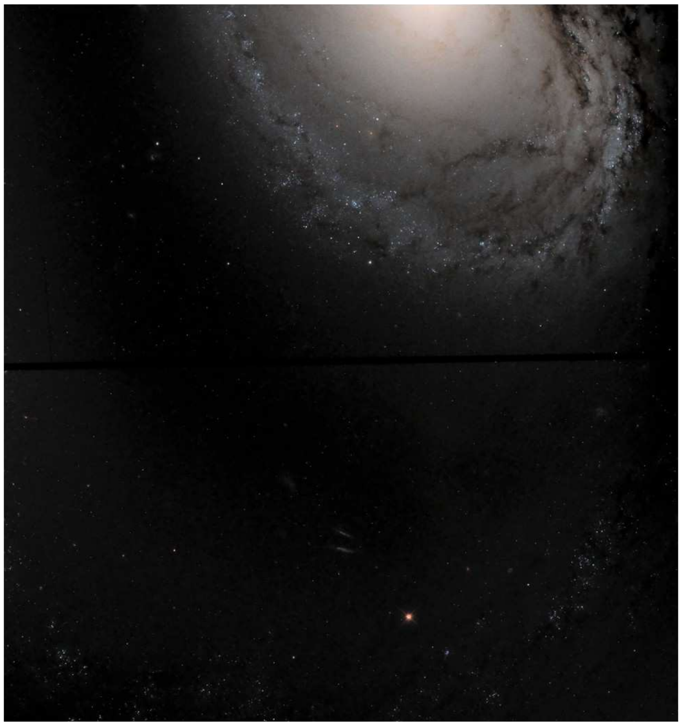


Figure 1: SN1998B in M96

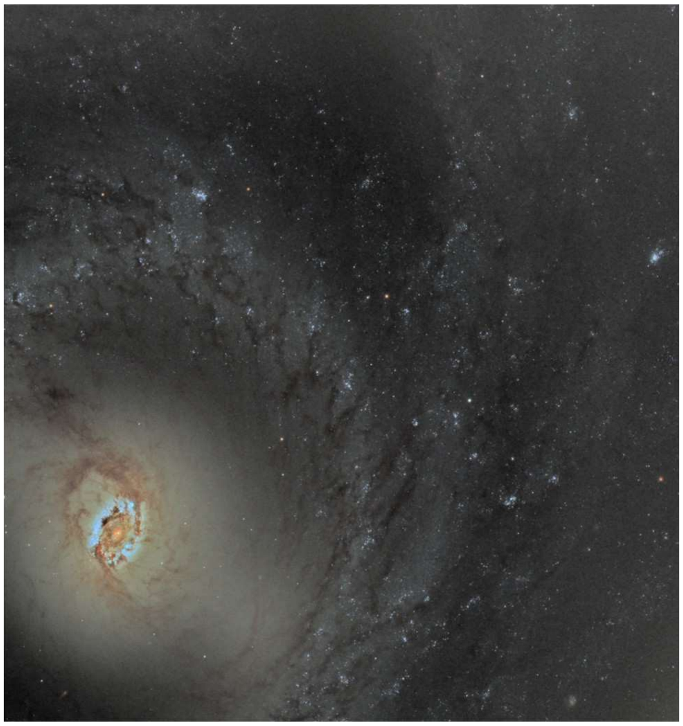


Figure 3: M95 Core – Color and Hue Due to filter RGB assignments

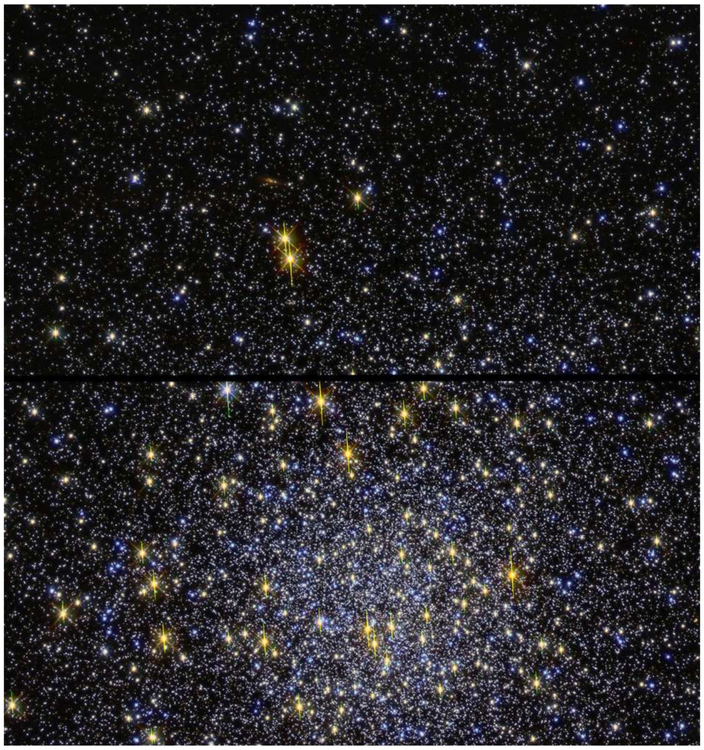


Figure 2: M5

Figure 4: In the vicinity of Dwarf galaxy Leo II (note the lensed galaxy in lower left!)

Nucleosynthesis, Part 5

by Dave Snyder

In previous articles, I discussed the nuclear processes that take place in the big bang and within stars.
This is a complicated subject. The general framework as well as many of the details were worked out by 1967, over 50 years ago. In the years since 1967 many attempts have been made to present simplified versions to the general public. In my opinion, most of these attempts were inadequate. With that in mind, a few years ago I began writing the articles in this series. My goal was to show enough of the complexity so that readers can gain an appreciation of how things work, but without showing every reaction, every step; that would be impossible within articles like these.

The first step of this process is big bang nucleosynthesis, which results in a universe with 75% hydrogen, 25% helium and a small amount of lithium. The second step, hydrogen burning, causes a slow decrease in the amount of hydrogen and a slow increase in the amount of helium. They were discussed in part 4 of this series.
In this article, I will discuss the steps that occur after the big bang and after hydrogen burning.

History

In the 1940's, George Gamov and his student, Ralph Alpher, developed a theory of nucleosynthesis. At the time, it was known that the universe was mostly hydrogen and helium, and that fusion processes in stars convert hydrogen to helium. However, there was no explanation for how elements heavier than helium are produced. Gamov and Alpher proposed that the universe was initially extremely hot and dense. It then expanded, becoming colder and less dense. A few years later this became known as the "big bang."[1] According to Gamov and Alpher, the early stages of this expansion produced all chemical elements heavier than hydrogen. These ideas were published in what is now known as the alpha, beta, gamma paper.[2]

In the 1950's, Fred Hoyle pursued a different path. Hoyle did not accept the big bang concept, preferring an alternative known as "continuous creation." Hoyle proposed hydrogen was created from the expansion of the universe, and all elements heavier than hydrogen were produced in stars. Hoyle had a hunch on how helium fused into carbon, and he asked William Fowler to do experiments to confirm his hunch. Sure enough Hoyle was right. Fowler asked Geoffrey Burbidge and his wife Margaret Burbidge to join the effort. The Burbidge's supplied data that was essential to understanding the complete process. The four continued to work on the problem, and with Margaret as first author, they jointly produced a paper known as B^{2}FH (after the initials of the authors) published in 1957.[3]

In the 60 years since the publication of B^{2}FH, there has a been a lot of additional work, filling in gaps and fixing problems with the 1957 work. This work happened gradually over the years and unfortunately never attracted the attention that either the alpha, beta, gamma or B^{2}FH papers did.

First the concepts in the alpha, beta, gamma paper had to be merged with the B^{2}FH paper. After that additional details were fleshed out. We now know the big bang produces hydrogen and helium, stars produce carbon and many other elements, and an assortment of other processes (such as neutron star mergers) produce the remaining elements. In addition, there has been clarification of the details of silicon burning (which I'll explain later), determination on how fluorine is synthesized and other details. (In this context, "burning" is used as a synonym for "fusion").

Helium Burning

After a main sequence star runs out of the hydrogen it needs for fuel, it consists of helium and unburned hydrogen, and it starts to collapse[4]. As it collapses, it gets hotter. When the star reaches about a temperature of 100 million Kelvin, fusion of helium can take place. This fusion takes place via two different processes which occur simultaneously.

1. Three helium atoms fuse to make one carbon atom. This happens through a sequence of steps[5]. Normally stars undergoing helium burning can last a long time (millions to billions of years depending on mass). However, this is not true of low mass stars. In low mass stars helium burning occurs in a brief time known as the "helium flash." This lasts a few minutes[6].
2. Some of the carbon atoms fuse with helium to form oxygen.

Thus, the result of helium burning is a mixture of carbon and oxygen. In low and medium mass stars, the result is more oxygen than carbon, but in heavier stars the result is more carbon than oxygen. The carbon/oxygen ratio has a couple of interesting consequences.

1. The stars known as "carbon stars" are not completely understood. Many of these stars are undergoing helium burning and create a supply of both carbon and oxygen. If there is more carbon than oxygen, and if the carbon/oxygen mixture is transported to the star's surface, chemical reactions take place that produce the deep red color of a carbon star. If there is more oxygen than carbon, these reactions do not take place and the star has a normal color.
2. If the carbon/oxygen mixture is released from the star and subsequently becomes part of a planet, the ratio could have important effects. In a planet with a normal carbon/oxygen ratio, carbon is relatively rare compared to oxygen. This situation is seen on the earth. Oxygen is common, and seen in oxygen gas, water and a variety of metal oxides. Carbon is less common and is seen in carbon dioxide gas, methane gas, hydrocarbons, coal and living organisms. If the ratio was reversed: carbon is common, and oxygen is rare, the planet might have enough carbon to have a diamond interior. Hydrocarbons and coal would be commonplace. Water and oxygen would be rare. The existence of such planets is speculative, so far none have been confirmed.

Note that there are three isotopes of carbon commonly seen on earth: carbon-12, carbon-13 and carbon-14. Helium burning produces carbon-12; carbon-13 and carbon-14 are produced by other mechanisms[7].

Note: I've used the word atom, but within stars it is very hot, hot enough to strip all the electrons off atoms. Two better words might be nuclei or nuclides. I will use all three words interchangeably, though a purist might object to the using the word atom in the context of reactions within a star.

Carbon, Neon and Oxygen Burning

You might have gotten the impression the entire nucleosynthesis process is a linear one, going in an orderly sequence from light elements to heavier elements. Nothing could be further from the truth. We've seen one non-linear aspect already. Helium burning skips over four elements: lithium, beryllium, boron and nitrogen. It gets worse.

I will cover three stages, carbon, neon and oxygen burning, next. There are three important reactions

1. Fusion of two carbon atoms to form magnesium.
2. Fusion of neon with helium to again form magnesium.
3. Fusion of two oxygen atoms to form sulfur.

These are not the only reactions and there are additional complexities.

Each of these fusion reactions release energy, and in some cases this energy goes into increasing the internal energy of the nucleus. Most nuclei have the lowest possible energy, they are in the "ground state." The extra energy of fusion can push a nucleus into a higher energy state, a so-called "excited state." Such excited states are almost always unstable and decay into stable atoms, in the process often creating a variety of lighter atoms. The magnesium formed in reaction 1 is an excited state and decays into stable neon, stable sodium, stable oxygen or stable magnesium. The sulfur formed in reaction 3 is an excited state and decays into stable magnesium, stable phosphorus, stable silicon or stable sulfur.

Once the temperature gets hot enough, high energy gamma rays can hit an atom and split it into smaller atoms. This is called photodisintegration, and the most notable example of this is the splitting of neon into oxygen and helium. Fusion (which converts light atoms into heavier atoms) and photodisintegration (which converts heavier atoms into light atoms) happen at the same time. Fusion wins out, but photodisintegration slows down the process.

Once oxygen burning completes, the star collapses and the temperature rises to about 3 billion Kelvin. At this point, the star is composed mainly of silicon and sulfur, with a mixture of other elements including aluminum and phosphorus.

Silicon Burning

Next, a new a series of new reactions, known as silicon burning, occurs. This is often portrayed as a sequence that starts with silicon: an atom fuses with helium to form a heavier atom, and this continues step by step to form progressively heavier atoms. In order from lightest to heaviest: silicon, sulfur, argon, calcium, titanium, chromium, iron, nickel and zinc. While these reactions do in fact occur, it is more complicated than that.

1. The heavier atoms, those of titanium, chromium, iron, nickel and zinc, are all radioactive. This begs the question, in the universe as a whole and on earth, there are supplies of non-radioactive atoms of each of these elements, but almost no radioactive atoms of the same elements. To get the non-radioactive atoms, there must be an additional step (or steps). I'll get back to that in a moment.
2. While some zinc is produced, the quantity is small. At the end of this process, the most common atom is radioactive nickel, with smaller amounts of other elements.
3. Photodisintegration (mentioned above) is an important factor. As with neon and oxygen burning, fusion tends to win out, but photodisintegration slows down the process.
4. Unlike in the earlier stages, excited nuclear states are not much of a factor. This is because the energy released in silicon burning reactions is quite low. There isn't enough energy to create excited states.
5. Once the fusion reactions slow down, the star starts to collapse, and it heats up. The temperature reaches about 5 billion Kelvin. At this temperature, atoms break apart into protons, neutrons and helium nuclei. (This is sometimes referred to as "nuclear melting").
6. When the star cools off, the atoms recombine into various elements, primarily silicon through gallium. (This is sometimes called the "freezeout," an odd term considering how hot the star is; but after the freezeout the temperature is about 3 billion K, colder than the 5 billion K it was earlier). There are a mixture of atoms, some radioactive, some not. Again, the most common atom is radioactive nickel.

Photodisintegration and nuclear melting have the effect of spreading the atoms around the periodic table (at least within the range of silicon to gallium). It will increase some types of atoms and decrease others to form a "quasi-equilibrium."

Now the radioactive elements will over time decay into non-radioactive elements (via a process called beta decay). However, there are two different possibilities depending on the relative speed of the beta decays versus the speed of other reactions. At first it wasn't clear how fast these other reactions take place.

Possibility 1, beta decays are faster than the silicon burning process. In this case radioactive titanium has time to decay into stable non-radioactive calcium. This is a heavy isotope of calcium which can be transformed via fusion to non-radioactive titanium, chromium, iron and nickel. The authors of B^2FH guessed possibility 1 was most likely, but admitted they were uncertain.

Possibility 2, beta decays are slower than the silicon burning process. In this case at the end of silicon burning there will be radioactive titanium, chromium, iron, nickel and zinc. Only after the star explodes and time has elapsed will the radioactive titanium, chromium, iron, nickel and zinc decay into non-radioactive calcium, titanium, chromium, iron and nickel respectively.

In the decade after B^2FH was published, it was determined possibility 2 is the correct explanation. We now know that silicon burning takes about one day, faster than beta decay (and this has been accepted as correct for the past 50 years). And in 1987, observations of the supernova SN1987A confirmed this.

Depending on the mass of the star, the details of silicon burning can vary somewhat, but this is beyond the scope of this article.

Note that I've mainly talked about elements with an even number of protons (in fact I've accounted for all even elements up to nickel except for beryllium). However, silicon burning starts with some phosphorus (which is has 15 protons). From that other odd elements can be produced via fusion (stopping at scandium, which has 21 protons). In addition, the freezeout produces both even and odd elements (stopping with gallium, which has 31 protons), though the result is more even atoms than odd atoms. Note that lithium, beryllium, boron, nitrogen and fluorine are not produced efficiently in any of the processes I've discussed so far. Also, none of the elements heavier than gallium are produced efficiently in any of these processes either.

Odds and Ends

Here are some additional processes. They produce the remaining elements.

Neutron absorption: Positive charges repel, and they repel more as the charge increases. When you get to elements such as cobalt and nickel, it becomes very difficult to bring atoms together to initiate fusion. But that is not a problem in another type of reaction, neutron absorption. Since neutrons have no charge, neutron absorption does not get harder as atoms get bigger. Generally, we start at iron (though other nearby elements are possible). If an iron atom combines with a neutron, it becomes a heavier isotope of iron. If neutrons are added repeatedly, eventually the iron atom will beta decay: one of the neutrons changes to a proton, and it becomes an atom of the next element, cobalt. More neutrons are added until the next element is formed, nickel. And so on.

There are two different forms of neutron absorption: r-process and s-process. In r-process, neutrons are added rapidly (the “r” in r-process means rapid). In s-process they are added slowly (the “s” in s-process means slow). S-process stops at the element bismuth. R-process continues past bismuth to heavier elements only stopping when radioactive decays happen faster than arrival of additional neutrons. R- and s-process traverse the same elements up to bismuth, but r-process tends to reach heavier isotopes of a given element than s-process.

If we list atoms isotope by isotope, r- and s-process account for most, but not all of the isotopes heavier than iron found in nature. The missing isotopes, called p-nuclei (approximately 35) must be produced by other processes. They range from selenium to mercury and all have fewer neutrons than typical for the element in question (and thus it is impossible to create them by ***adding*** neutrons). The exact way p-nuclei are produced is not completely understood, however there are some educated guesses. I won’t go into the details here.

CNO cycle: The first stars to form after the big bang were composed of hydrogen and helium, as there were essentially no heavier atoms. But once atoms like carbon were formed, such atoms were available to form new stars (the “metallicity” of the stars increased). The affects nucleosynthesis in several ways. For one thing, some main sequence stars with higher metallicity can use the so-called CNO cycle. This is only possible if a star already contains some carbon. The CNO cycle works as follows: through a sequence of steps one carbon atom and four hydrogen atoms are converted into one carbon atom and one helium atom. The carbon atom is available to start the cycle over again, in the process forming, among other things, nitrogen and carbon-13.

Nuclear Spallation: When atoms in a cold environment (not within a star) are hit by energetic particles, they can transform into other atoms. 1) if carbon or oxygen atoms (on an asteroid, planet or moon without an atmosphere) are hit by such a particle, this can form any of the elements lithium, beryllium or boron. 2) If a nitrogen atom in a planetary atmosphere is hit by such a particle, this can create carbon-14 (that is how the carbon-14 found on earth is created). Note: other variations on these themes are possible.

Neutrinos: When a star between 10 and 29 solar masses undergoes a supernova explosion, it collapses and forms a neutron star. Before the collapse, the star is roughly one third protons, one third neutrons and one third electrons. As the neutron star forms, most of the protons and electrons are converted to neutrons via a process known as electron capture (electron capture is similar to beta decay, both involve the weak interaction). A massive number of electron capture events occurring in a short period results in a huge flux of neutrinos which interact with nearby atoms. These interactions form small amounts of a variety of light elements. In most cases there are other sources for these elements, but for lithium and fluorine (both of which are relatively rare) it is a significant (or perhaps only) source.

Lithium-7: Lithium-7 is a special case, determining the exact mechanism for production of lithium-7 has been a problem for years. There are several possible production routes, but collectively they don’t account for the observed abundance of this isotope. It is likely that this isotope is mainly produced through hydrogen burning reactions, though this is still a open question.

Conclusions

This leads to a question: if the reactions were for the most part figured out 50 years ago, why do we still see the simplified explanations? I don't know for sure, but I have some educated guesses.

In 1980 Carl Sagan wrote a book called "Cosmos" based on the television series of the same name. In it he wrote:

> "Atoms synthesized in the interiors of stars are commonly returned to the interstellar gas. Red giants find their outer atmospheres blowing away into space; planetary nebulae are the final stages of Sunlike stars blowing their tops. Supernovae violently eject much of their stellar mass into space. The atoms returned are, naturally, those most readily made in the thermonuclear reactions in stellar interiors: Hydrogen fuses into helium, helium into carbon, carbon into oxygen and thereafter, in massive stars, by the successive addition of further helium nuclei, neon, magnesium, silicon, sulfur, and so on are built additions by stages, two protons and two neutrons per stage, all the way to iron. Direct fusion of silicon also generates iron, a pair of silicon atoms, each with twenty-eight protons and neutrons, joining, at a temperature of billions of degrees, to make an atom of iron with fifty-six protons and neutrons."

(See Sagan, 1980, p. 233).

I suspect Sagan had read both the alpha, beta, gamma and B^2FH papers, but he was a planetary scientist, and as such, it is unlikely he would have talked with any of the handful of specialists that understood the post B^2FH work on the subject.

Let's compare Sagan's account with B^2FH. The "successive addition of further helium nuclei" is an almost word for word copy of the description of the alpha process given in B^2FH (See Burbige, Burbige, Fowler and Hoyle, p. 551). However B^2FH taken as a whole depicts a convoluted, complex process. Sagan has changed it to a simple orderly process, very different. It seems Sagan took a short section of B^2FH out of context.

It is unclear to me where Sagan got the "direct fusion of silicon" bit. In our modern understanding silicon atoms do not fuse this way, they have too much positive charge for this to be possible. Even if it were possible, silicon would fuse into nickel, not iron. Sagan must have known that nickel is the result of silicon fusion; that nickel produced this way would be radioactive and would decay into stable iron-56. My guess is Sagan took "silicon fuses, which generates nickel and that in turn decays into iron" and simplified it into "silicon fuses, which generates iron."

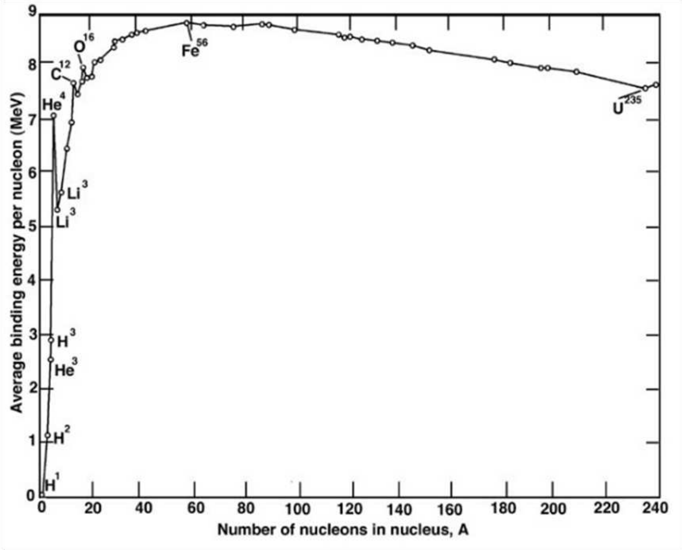
In more recent times, when nucleosynthesis is presented to the general public, instead of taking the time to adequately research the subject (which from personal experience, is very time consuming), people often merely copied or adapted previous presentations (such as Sagan's). There are many examples of this. One among many is from the "Astronomy Cast" podcast. (See Cain and Gay, 2008).

However occasionally people are more imaginative and do more than merely copy or adapt. Physicists like to take complicated situations and simplify them, often capturing the essence in a single equation. In some cases, this has been a successful strategy, but in other cases it doesn't work well. Nucleosynthesis is one of those cases where it doesn't work well.

A common simplification goes something like this:

> Each element has quantity called "binding energy." This is measured in million electron volts (MeV) and it varies from 0 MeV to 9 MeV. The lightest atom, hydrogen, has a binding energy of 0 MeV. As you work up the periodic table, binding energy increases. Helium has a binding energy of 7 MeV. Calcium has a binding energy of 8.5 MeV. Iron has a binding energy of 8.8 MeV. Iron has the highest binding energy, as we go further up the periodic table binding energy decreases. Tin has a binding energy of 8.5 MeV, lead 7.9 MeV, uranium 7.6 MeV.
>
> When atoms undergo nuclear reactions, they go from lower binding energy to higher binding energy, thus as nucleosynthesis proceeds from hydrogen to helium to carbon, etc., it must stop at iron, because iron has the highest binding energy.

Often this explanation is accompanied by a graph. Many of you have seen this and it looks like this



I have yet to track down who first used an explanation like this, but I have seen or heard them many times.

While there are elements of truth here, and it seems plausible, there are several things wrong with this explanation.

1. A minor point, the text refers to “binding energy” and the graph refers to “average binding energy per nucleon.” In this context, the later term is the correct and will be a lower number (0 to 9 MeV as stated above) than the “total binding energy.” From now on when I refer to binding energy, I really mean average binding energy.
2. It makes no sense to talk about the binding energy of an element. Binding energy can only be defined for an isotope of an element. For example, hydrogen-1 (otherwise known as ordinary hydrogen) has a binding energy of 0 MeV. Hydrogen-2 (deuterium) has a binding energy of 1.1 MeV and so on. You can see this on the graph as there is more than one isotope for both hydrogen and helium shown. The “lithium-3” shown on the graph is a typo, there are two stable isotopes of lithium, lithium-6 and lithium-7.
3. The isotope with the highest binding energy is nickel-62, not iron-56 (or any other isotope of iron)[8].
4. A series of reactions doesn’t have to end at the isotope with the highest binding energy. They do not necessarily follow the isotopes shown in the graph. They don’t in this case. If zinc is excluded, the endpoint is nickel-60, not nickel-62 (the yield of zinc is low, so it is not unreasonable to say fusion reactions stop at nickel).
5. Whether a fusion reaction takes place is not determined by binding energy, it is determined by temperature. If it’s not hot enough, a specific fusion reaction can’t take place. It is true that as you get past the peak of binding energy, fusion reactions no longer release energy, they require energy. In other words, the fusion reactions cool the star down. So fusion reactions past the peak are possible, but stars can’t exist for long if such reactions are the only source of energy.
6. Saying reactions must always increase binding energy can’t be correct, if it was, how are elements heavier than nickel produced? It is difficult to get much past nickel with fusion reactions, but neutron absorption reactions have no problem reducing binding energy.
7. The graph is somewhat misleading. In the diagram, the y axis is the average binding energy as expected, but graph only includes the binding energy for certain selected isotopes – there simply isn’t room to include all known isotopes. So, the graph as shown claims iron-56 has the highest binding energy. But nickel-62 is conveniently excluded, and if it were included it would have the highest binding energy.

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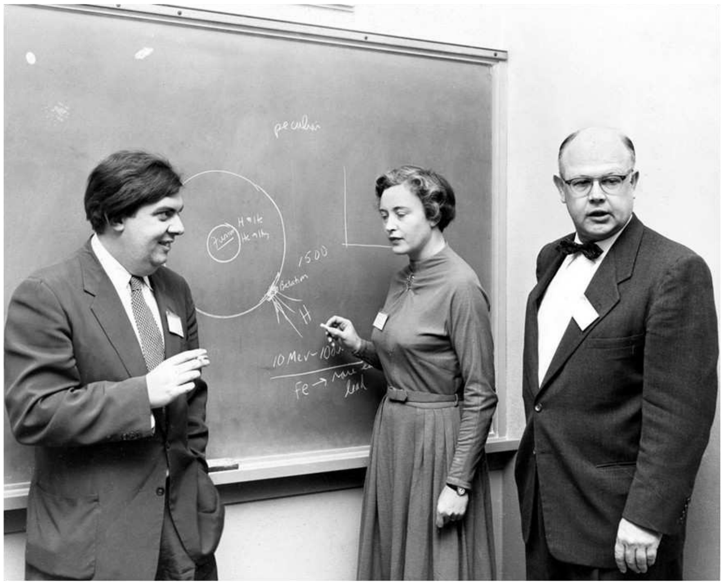
1
Fred Hoyle coined the term “big bang.” Many people assumed that this was meant as a term of derision, since Hoyle advocated a competing idea called continuous creation. However, Hoyle denied this, claiming that it was merely a colorful term to distinguish the two ideas. The truth of what Hoyle had in mind will probably never be known.

2
In 1948, Alpher and Gamov described these ideas in a paper slightly over a page in length. Gamov, in a moment of whimsy, decided to add Hans Bethe’s name to the paper. Bethe worked on hydrogen fusion reactions but contributed nothing to this paper. Gamov did this as a play on words; “Alpher, Bethe and Gamov” sounds like “alpha, beta, gamma.” Bethe didn’t care, but Alpher was annoyed that an extra author was added to the paper (see Alpher, Bethe, and Gamow, 1948).

3
While not perfect, this paper is amazingly close to our current understanding. Unlike the alpha, beta, gamma paper, it is long, over a hundred pages in length. This paper was frequently cited and led to half of the 1983 Nobel Prize in physics (see Burbidge, Burbidge, Fowler and Hoyle, 1957).

Fowler received the prize, the other three never did. (The Nobel Committee never comments on those people who were ***not*** awarded a prize). While we’ll never will know for sure, there are a number of theories that might explain Hoyle’s exclusion (see for example: Wikipedia Contributors. “Fred Hoyle” and Wikipedia Contributors. “B^2FH Paper.”)

Margaret survived her husband, Fowler and Hoyle. She died in April 2020.



From left to right, Geoffrey, Margaret and William Fowler.

From left to right, Margaret, Geoffrey, William Fowler and Fred Hoyle.

4
At the end of hydrogen burning all the hydrogen in the core has been converted to helium, however there will be hydrogen in the outer part of the star that does not participate in helium burning. It is not hot enough, and there is no mechanism to move the hydrogen to the core where it is hot enough.

Stars less than 0.4 solar masses should in theory end up as an inert ball of helium; they never get hot enough to burn that helium. However, this will take 100’s of billions of years. The universe is not old enough for such inert balls of helium to form.

5
Regardless of the mass of the star and the speed of the process, the reactions are the same. The first step is:

$He^4 + He^4 \rightarrow Be^8$

Be^8 is unstable. The half-life is extremely short, too short to be directly measured. However, by measuring the mass/energy of beryllium atoms and then using quantum mechanics it is possible to estimate the half-life. This gives a half-life of approximately $7\ 10^{-17}$ seconds. The decay is unusual, it is a "strong interaction" decay of this form:

$Be^8 \rightarrow He^4 + He^4$

In spite of the short half-life, at any given moment in time, a small amount of Be^8 can be found in the star, and fuses with helium thus:

$Be^8 + He^4 \rightarrow C^{12*}$

The asterisk (*) indicates an excited state. C^{12*} breaks down in two main modes:

$C^{12*} \rightarrow Be^8 + He^4$
$C^{12*} \rightarrow C^{12}$ + photon

The first is much more likely (by a factor of approximately one million). So, the formation of stable C^{12} is possible, but is an unlikely result of a convoluted sequence. While it is unlikely a specific group of three helium atoms will fuse to form carbon, there are many atoms in a star, and some helium will fuse over time. The low probability means that helium burning is slow.

6
In high mass stars, there is a feedback process that keeps the temperature hot enough for fusion, but no higher. In low mass stars there is no such feedback process and the temperature increases well above what is needed for fusion. This dramatically increases the speed of the process. When helium burning is fast, the entire process is known as the "helium flash."

7
Carbon-13 is formed by the CNO cycle, carbon-14 is formed when high energy particles hit nitrogen atoms in the earth's atmosphere.

8
Iron-56 has been frequently and incorrectly stated to be the isotope with the highest binding energy, in spite of measurements to the contrary. For a history of how this happened, see Fewell 1995.

Parts 1 thru 4 of ***Nucleosynthesis,*** were printed in Reflections/Refractions

Part 1 March 2012
Part 2 August 2012
Part 3 October 2013
Part 4 July 2014

The June 19th meeting was recorded and can be viewed on you tube

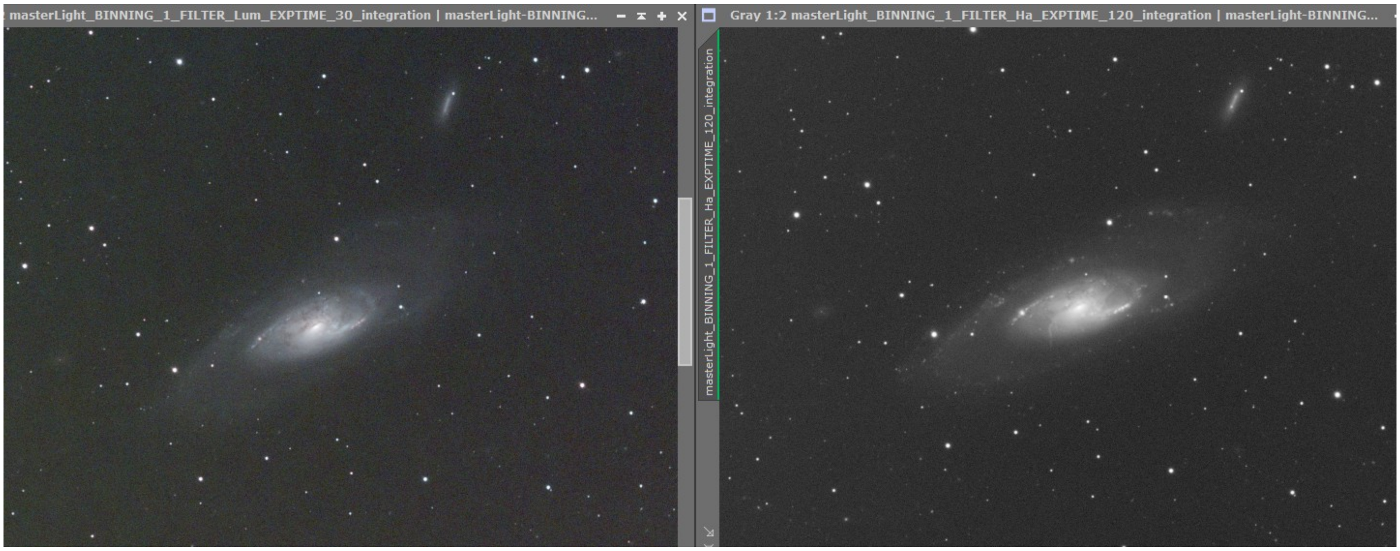
https://youtu.be/RdCUvgtHYIY

Member Images of M106

(Left) Brian Ottum wrote in an email to members on May 22nd. “I took this a couple weeks ago, but did not process it until today. This inspires me to take a look through the telescope. It’s about mag 9 and located near the Big Dipper.

6 hours of exposures really helps bring out the faint outer arms. At f/5. “

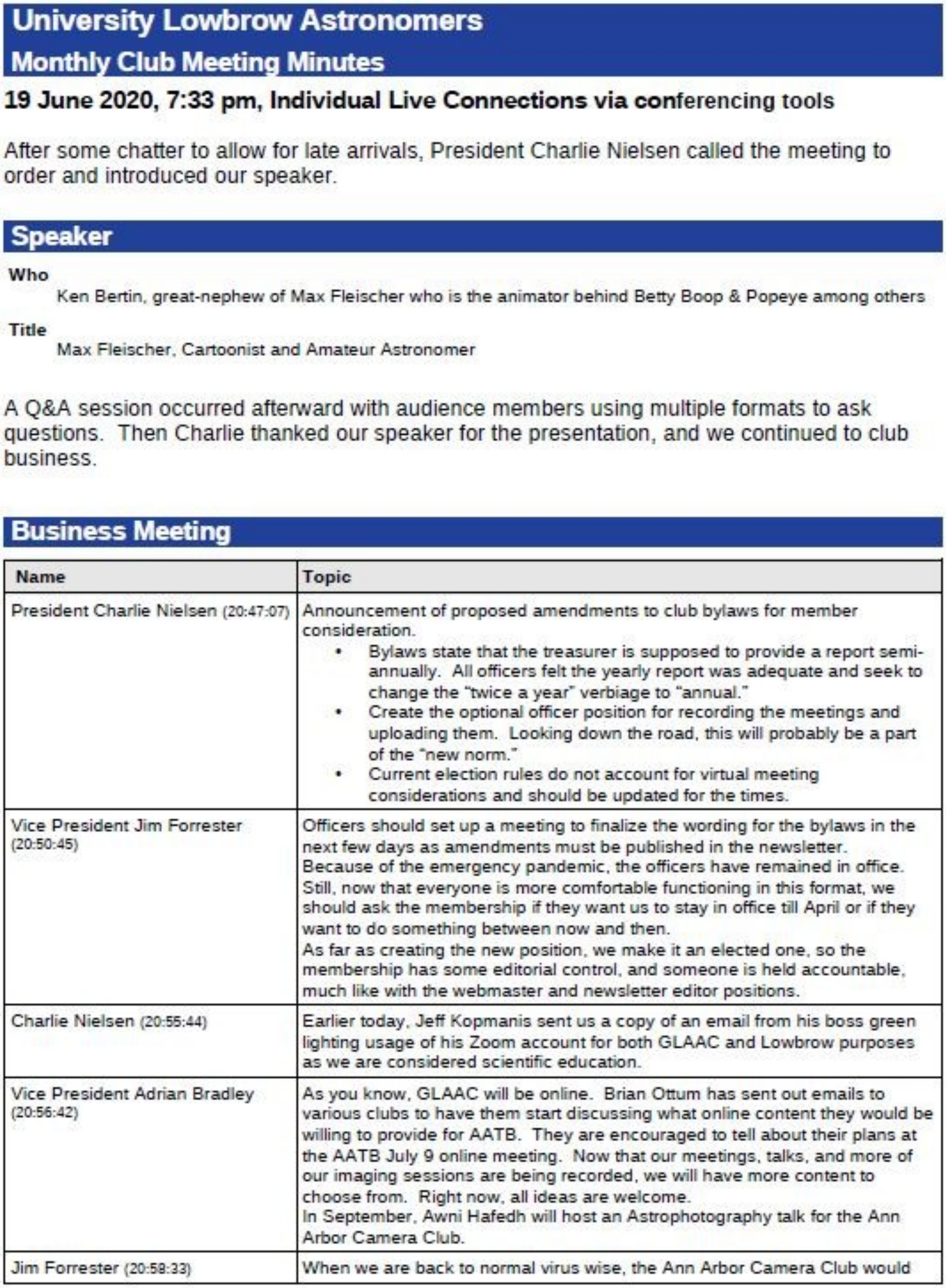
(Below) Awni Hafedh wrote in an email to members on May 23rd. “I got the exact same object with the hyperstar, this is only the stacked results not processed, the RGB is 1 hour total exposure and H-Alpha is 412min total exposure. One day I'll get the chance to process it.”



Upcoming Events

Note June thru September Open House and other events have been canceled.

DATE	EVENT	LOCATION	
Friday July 17th. 7:30 pm	Monthly Meeting	By Video Conference. Instructions will be emailed to members,	Guest Speaker: Jim Shedlowski



University Lowbrow Astronomers
Monthly Club Meeting Minutes

19 June 2020, 7:33 pm, Individual Live Connections via conferencing tools

After some chatter to allow for late arrivals, President Charlie Nielsen called the meeting to order and introduced our speaker.

Speaker

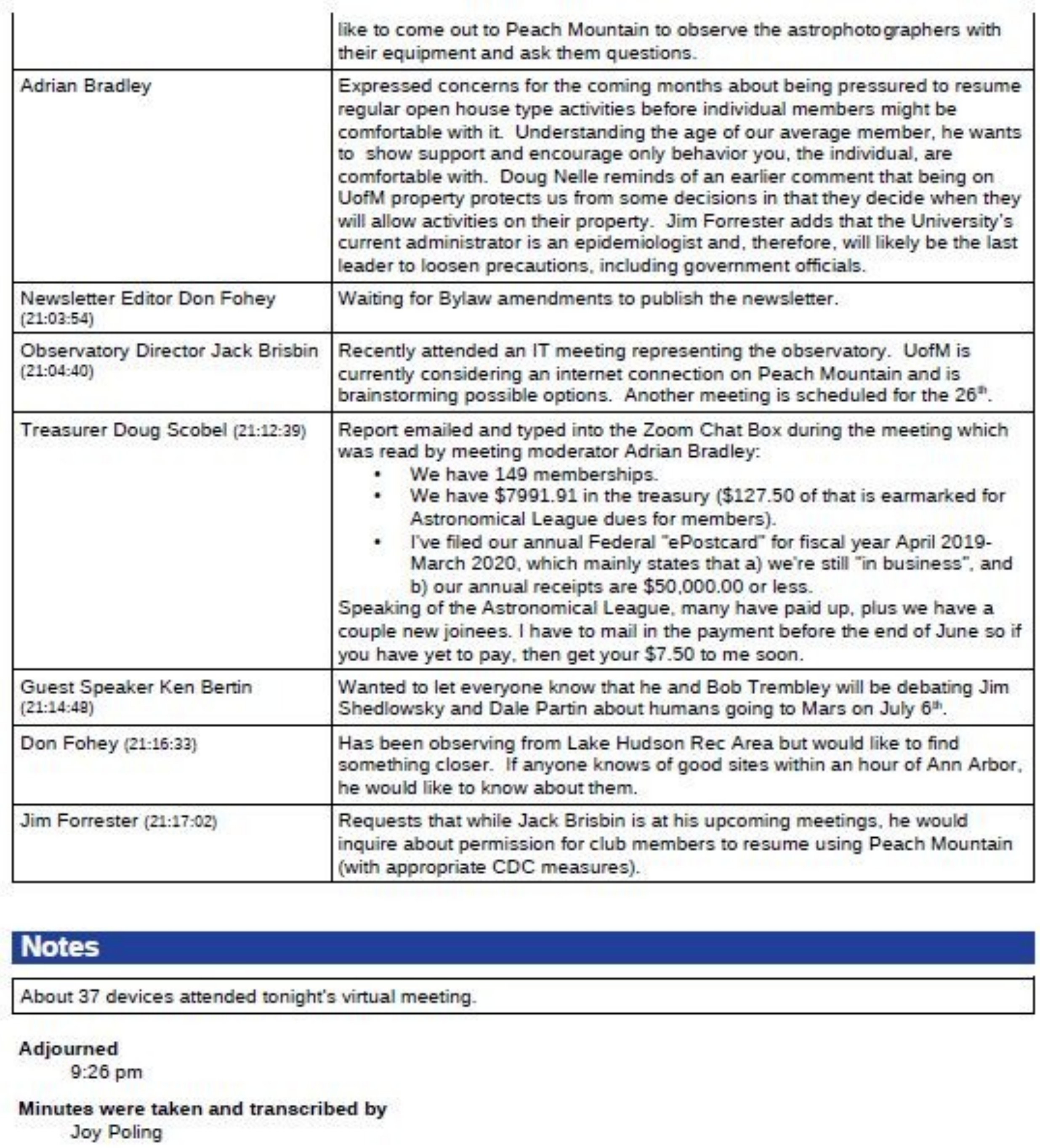
Who
Ken Bertin, great-nephew of Max Fleischer who is the animator behind Betty Boop & Popeye among others

Title
Max Fleischer, Cartoonist and Amateur Astronomer

A Q&A session occurred afterward with audience members using multiple formats to ask questions. Then Charlie thanked our speaker for the presentation, and we continued to club business.

Business Meeting

Name	Topic
President Charlie Nielsen (20:47:07)	Announcement of proposed amendments to club bylaws for member consideration. • Bylaws state that the treasurer is supposed to provide a report semi-annually. All officers felt the yearly report was adequate and seek to change the "twice a year" verbiage to "annual." • Create the optional officer position for recording the meetings and uploading them. Looking down the road, this will probably be a part of the "new norm." • Current election rules do not account for virtual meeting considerations and should be updated for the times.
Vice President Jim Forrester (20:50:45)	Officers should set up a meeting to finalize the wording for the bylaws in the next few days as amendments must be published in the newsletter. Because of the emergency pandemic, the officers have remained in office. Still, now that everyone is more comfortable functioning in this format, we should ask the membership if they want us to stay in office till April or if they want to do something between now and then. As far as creating the new position, we make it an elected one, so the membership has some editorial control, and someone is held accountable, much like with the webmaster and newsletter editor positions.
Charlie Nielsen (20:55:44)	Earlier today, Jeff Kopmanis sent us a copy of an email from his boss green lighting usage of his Zoom account for both GLAAC and Lowbrow purposes as we are considered scientific education.
Vice President Adrian Bradley (20:56:42)	As you know, GLAAC will be online. Brian Ottum has sent out emails to various clubs to have them start discussing what online content they would be willing to provide for AATB. They are encouraged to tell about their plans at the AATB July 9 online meeting. Now that our meetings, talks, and more of our imaging sessions are being recorded, we will have more content to choose from. Right now, all ideas are welcome. In September, Awni Hafedh will host an Astrophotography talk for the Ann Arbor Camera Club.
Jim Forrester (20:58:33)	When we are back to normal virus wise, the Ann Arbor Camera Club would



	like to come out to Peach Mountain to observe the astrophotographers with their equipment and ask them questions.
Adrian Bradley	Expressed concerns for the coming months about being pressured to resume regular open house type activities before individual members might be comfortable with it. Understanding the age of our average member, he wants to show support and encourage only behavior you, the individual, are comfortable with. Doug Nelle reminds of an earlier comment that being on UofM property protects us from some decisions in that they decide when they will allow activities on their property. Jim Forrester adds that the University's current administrator is an epidemiologist and, therefore, will likely be the last leader to loosen precautions, including government officials.
Newsletter Editor Don Fohey (21:03:54)	Waiting for Bylaw amendments to publish the newsletter.
Observatory Director Jack Brisbin (21:04:40)	Recently attended an IT meeting representing the observatory. UofM is currently considering an internet connection on Peach Mountain and is brainstorming possible options. Another meeting is scheduled for the 26th.
Treasurer Doug Scobel (21:12:39)	Report emailed and typed into the Zoom Chat Box during the meeting which was read by meeting moderator Adrian Bradley: • We have 149 memberships. • We have $7991.91 in the treasury ($127.50 of that is earmarked for Astronomical League dues for members). • I've filed our annual Federal "ePostcard" for fiscal year April 2019-March 2020, which mainly states that a) we're still "in business", and b) our annual receipts are $50,000.00 or less. Speaking of the Astronomical League, many have paid up, plus we have a couple new joinees. I have to mail in the payment before the end of June so if you have yet to pay, then get your $7.50 to me soon.
Guest Speaker Ken Bertin (21:14:48)	Wanted to let everyone know that he and Bob Trembley will be debating Jim Shedlowsky and Dale Partin about humans going to Mars on July 6th.
Don Fohey (21:16:33)	Has been observing from Lake Hudson Rec Area but would like to find something closer. If anyone knows of good sites within an hour of Ann Arbor, he would like to know about them.
Jim Forrester (21:17:02)	Requests that while Jack Brisbin is at his upcoming meetings, he would inquire about permission for club members to resume using Peach Mountain (with appropriate CDC measures).

Notes

About 37 devices attended tonight's virtual meeting.

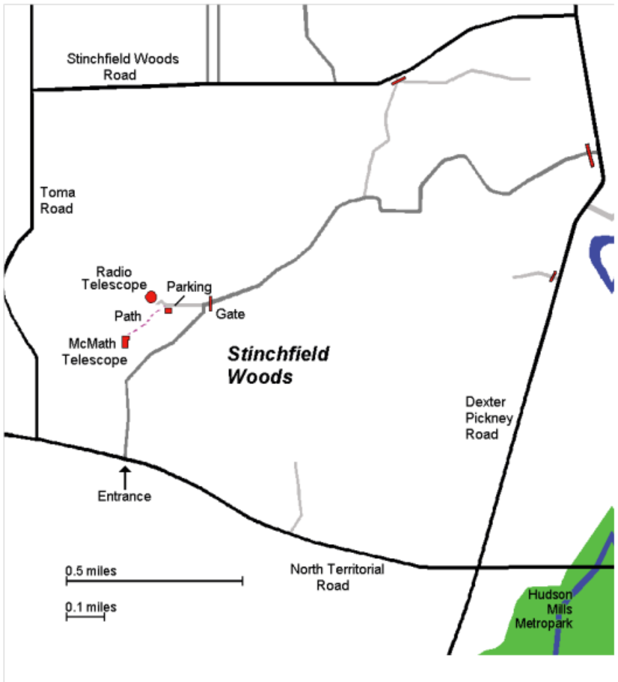
Adjourned
9:26 pm

Minutes were taken and transcribed by
Joy Poling

Places & Times

Monthly meetings of the University Lowbrow Astronomers are held the third Friday of each month at 7:30 PM. The location is usually Angel Hall, ground floor, Room G115. Angell Hall is located on State Street on the University of Michigan Central Campus between North University and South University Streets. The building entrance nearest Room G115 is the east facing door at the south end of Angell Hall.

Peach Mountain Observatory is the home of the University of Michigan's 25 meter radio telescope and McMath 24" telescope which is maintained and operated by the Lowbrows. The entrance is addressed at 10280 North Territorial Road, Dexter MI which is 1.1 miles west of Dexter-Pinckney Rd. A maize and blue sign marks the gate. Follow the gravel road to the top of the hill to a parking area south of the radio telescope, then walk about 100 yards along the path west of the fence to reach the McMath Observatory.



Public Open House / Star Parties

Public Open Houses / Star Parties are generally held on the Saturdays before and after the New Moon at the Peach Mt. Observatory, but are usually cancelled if the forecast is for clouds or temperature below 10° F. For the most up to date info on the Open House / Star Party status call: (734) 975-3248 after 4pm. Many members bring their telescope to share with the public and visitors are welcome to do the same. Mosquitoes can be numerous, so be prepared with bug repellent. Evening can be cold so dress accordingly

Lowbrow's Home Page

http://www.umich.edu/~lowbrows/

Membership

Annual dues are $30 for individuals and families, $20 per year for students and seniors (age 55+) and $5 if you live outside of the Lower Peninsula. Membership entitles you online access to our monthly Newsletters and use of the 24" McMath telescope (after some training). A mailed copy of the newsletter can be obtained with an additional $18 annual fee to cover printing and postage. Dues can be paid by PayPal (contact the treasurer to find out how) or by check made out to "University Lowbrow Astronomers" and mailed to:

The University Lowbrow Astronomers
P.O. Box 131446
Ann Arbor, MI 48113-1446

Lowbrow members can obtain a discount on these magazine subscriptions:
Sky & Telescope -$32.95/year or $65.90/2 years
Astronomy -$34.00/year, $60.00/2 years of $83.00/3 years
For more information about dues or magazines contact the club treasurer at: lowbrowdoug@gmail.com

Newsletter Contributions

Members and non-members are encouraged to write about any astronomy related topic. Contact the Newsletter Editor: Don Fohey donfohey@gmail.com to discuss format. Announcements, articles and images are due by the 1st day of the month as publication is the 7th.

Telephone Numbers

President:	Charlie Nielsen	(734) 747-6585
Vice President:	Adrian Bradley	(313) 354 5346
	Jim Forrester	(734) 663-1638
	Joy Poling	
	Dave Jorgensen	
Treasurer:	Doug Scobel	(734) 277-7908
Observatory Director:	Jack Brisbin	
Newsletter Editor:	Don Fohey	(734) 812-3611
Key-holders:	Jim Forrester	
	Jack Brisbin	
	Charlie Nielsen	
Webmaster	Krishna Rao	

A NOTE ON KEYS: The club currently has three keys each to the Observatory and the North Territorial Road gate to Peach Mountain. University policy limits possession of keys to those who they are issued. If you desire access to the property at an unscheduled time, contact one of the key-holders. Lowbrow policy is to provide as much member access as possible.

Email to all members

Lowbrow-members@umich.edu

University Lowbrow Astronomers

Member Club

Astronomical League Member Society
#201601, Great Lakes Region

University Lowbrow Astronomers
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