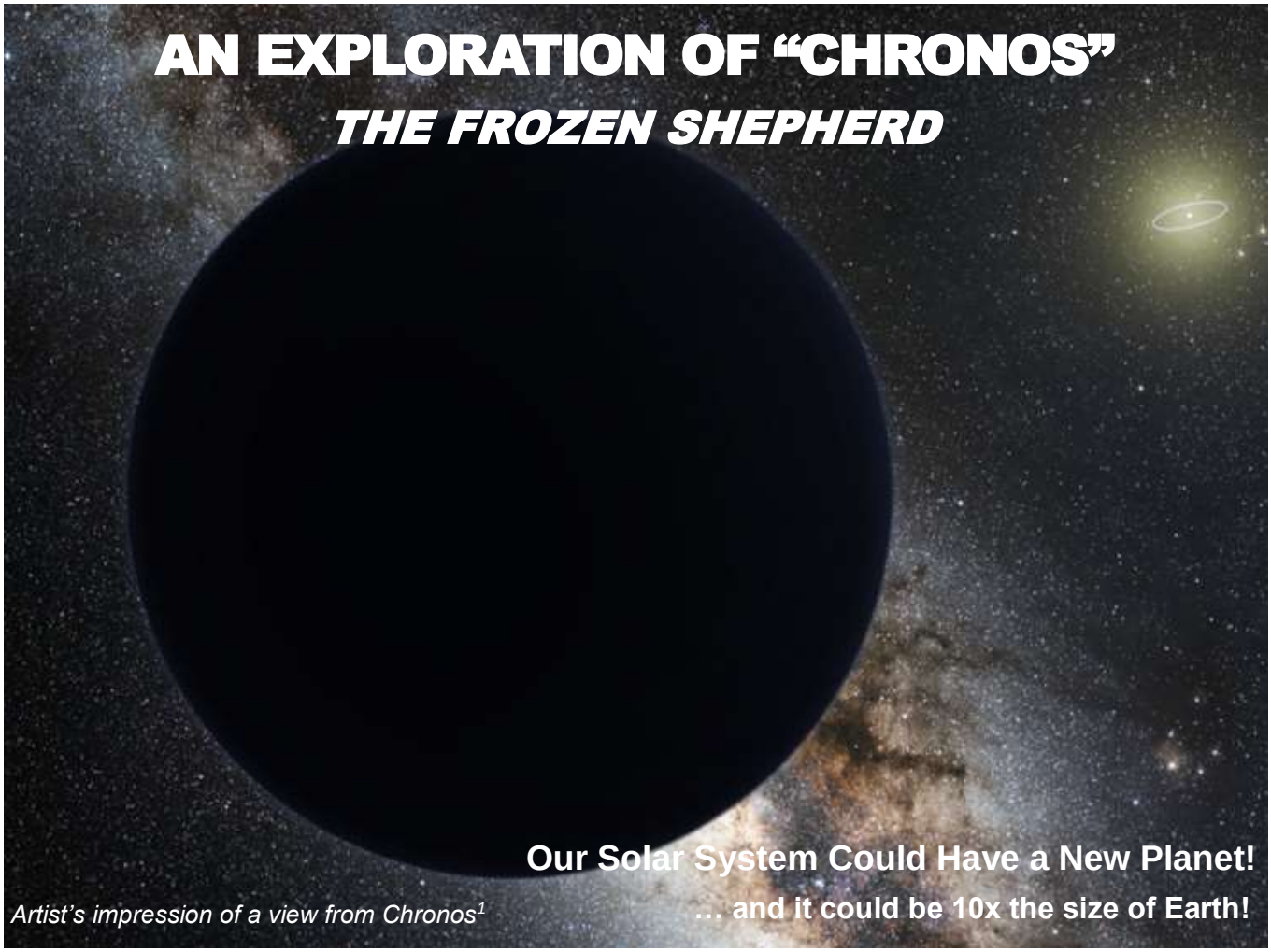
AN EXPLORATION OF "CHRONOS"
THE FROZEN SHEPHERD



Artist's impression of a view from Chronos[1]

On January 20th 2016, Astronomers suggested that a giant planet lurks at the edge of our Solar System. The founding Astronomers have code-named this discovery *"Planet Nine."* Due to the general public's strong feelings towards Pluto being demoted to a *minor planet*, I have decided to call this new discovery ***"Chronos."***

But this planet is *nothing* like Pluto. It's a behemoth. In fact, it's estimated to be 10x the mass of Earth! But it's very far away from our Sun – perhaps 1,000x the distance Earth is.[2] **It shouldn't be able to form out there.**

So where did it come from? How did it get there? Why 'The Frozen Shepherd?' What could banish Chronos to the edge of the Solar System? Why is something so big so hard to find? Did it form with the rest of the Planets? How did we find it using math? What impact will this have on Astronomy? The list goes on…

If you're looking to gain a deeper understanding of this *potential* discovery – this is for you. **This paper is built for those who are not familiar with planetary sciences.** But, it's important you already know concepts like 'planets', 'stars', 'orbits' and 'gravity.' Even if you are very familiar with outer space, I think you will still find interesting concepts and information.

Written by Christian Acosta for a Data Science Course taught by Lyna Matesi

AN EXPLORATION OF "CHRONOS"

THE FROZEN SHEPHERD

INTRODUCTION

Chronos was announced as a potential planet within our Solar System on January 20th, 2016. Astronomers believe it exists because of the movements of *minor planets* in the outer solar system (much further out than Pluto). *While Planet Nine* has not been seen directly by telescope, many astronomers view the mathematical evidence as highly-credible.[3] It has sent the astronomy world on a wild goose chase for a gigantic, cold planet.

Data suggests *Chronos* could be *ten times the mass of Earth.* It could take as long as 20,000 years to make one trip around the sun (an 'orbit'). What's astonishing is the path *Chronos* takes around the sun, which looks like a severely-stretched oval (Earth orbit is close to a circle). From the surface of *Chronos* our sun would look like a bright star in the sky.[4]

Chronos is an unexpected discovery. It shows that:

1. Our Solar System has a very complex past with 4.5+ **Billion** years of history.
2. *Chronos* is not like the other planets in our solar system. It suffered a terrible fate.
3. Our assumptions of our own cosmic *'backyard'* are biased. Many thought we've learned everything about our solar system.
4. An object with such immense size also shows us that we have a lot to learn about nature.

CHRONOS FACTS[4]

- Not yet observed through a telescope.
- Expected to be 10x the mass of Earth.
- 2x the width of Earth.
- Would be the 5th largest planet, knocking Earth to #6.
- Orbits *extremely* far from the sun.
- It's very cold in Chronos' neighborhood.
- Its history can be traced back to the beginning of our Solar System.

DISCOVERY STORY[5]

1. N*ewly discovered minor planets* in outer solar system are grouped together – something Astronomers don't expect.
2. Astronomers speculate existence of unknown planet based on orbits of other bodies in outer solar system.
3. Simulations suggest *Chronos could be* responsible.

Together, we will explore:

- **A Quick Introduction to *Chronos*.** It's very important to have the right background information. By getting a quick understanding of the new 'planet' you'll be able to apply the concepts in later chapters to the discovery.
- **Chapter I: The History of Our Solar System** will provide important context behind solar systems and planets. This will give those unfamiliar with planetary sciences information on how they form. **You may question why this is the longest chapter – the concepts you learn will make understanding *Chronos much easier*.** You will want to refer back to Chapter I as you read the later chapters.
- **Chapter II: Chronos the Frozen Shepherd** will tell you how Chronos was discovered. And from this information you'll begin to really understand the technical details. **You will leverage information from Chapter I to understand concepts presented in Chapter II.**
- **Chapter III: Explaining Chronos** will begin to explore hypotheses (ideas) to explain *Chronos'* situation – *why so far out? Where did it come from?* **You will question why this Chapter is shorter than the others. It's because Chapter I and II have laid the groundwork.** By the time you reach this chapter, you may already know what the top hypotheses are!
- **Chapter IV: Exploring Chronos** will talk about next steps in discovery. *Where will it be found? How will it be found? What will it look like? How can we get there?*
- **Closing, Sources and Appendix** will provide additional information to dig in to. It'll mention the nitty gritty details and additional resources you can use to learn about many of the concepts we've discussed.

There will be plenty of pictures and diagrams. Each page is a quick read. I try to translate every difficult concept into something that is very easy to understand.

If you're new to many of these concepts, you may want to read this document in small chunks. It can be difficult to digest all these concepts at once.

I can't stress this enough – I start with a light overview of *Chronos* so you can apply what you learn directly in Chapter I. While you're reading Chapter I you may ask *'why'* several times. Wait for the *'a-ha'* moments! I promise they'll come as you read Chapter II, III and IV.

My goal is to educate you about the fundamentals. Specifically, there is a list of questions on page 7 that will let you know *why* learning the fundamentals are important. If you only want to read about the discovery, check out the appendix.

Why did I make this document? Who is this document for?

I want to give readers who may not be familiar with planetary sciences a crash course. I feel strongly that context is important in understanding the full story of *Chronos.* By the time you are done reading this, you will be able to explain technical information about solar system formation and *Chronos* itself. Hopefully you feel compelled to send this to your friends and family. We need to continue to build excitement around Astronomy. Space **is** the final frontier. If human life is to make it past the 21st century, it'll almost certainly involve us populating space. We need to understand everything about it before we get to that point.

For our 'seasoned veterans' and amateur astronomers: I want to give you new ways to communicate information about *Chronos*. At times, you may feel the content is over-simplified. You may notice that I am very repetitive and intentional with my words – please keep in mind that **this document is geared for those with little knowledge about planetary science.** You may feel frustrated that important detail is left out. Please keep the original audience in mind. If you're not being challenged, I urge you to keep the **Appendix** section handy. It'll give you all the challenge you need to understand the gory details.

I am nothing more than a Graduate Student with a passion for outer space. I am not an Astronomer – I'm a dreamer. I've done my best to avoid making any scientific errors. I welcome everybody's feedback and criticism. My contact information is at the end of the document.

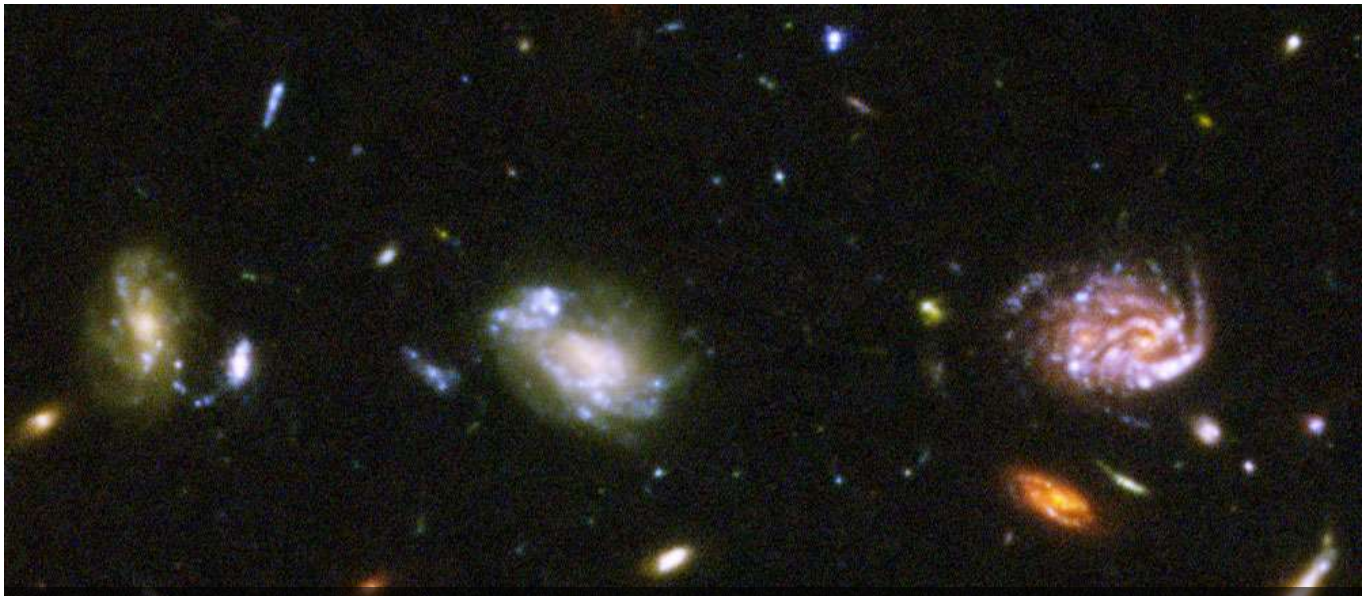
I praise all scientists that continue to explore the unknown. They put their egos and feelings aside in the hope of advancing humanity. **Scientists are the true heroes of this world.** It brings me to tears to think of humans that can't appreciate scientific discovery. Most of all, our children are being raised to believe that consumption will somehow turn in to long-term happiness. We are all caught in an endless loop of self-gratification that has no goal and has no end. Science teaches us that there is no need for a goal. It teaches us to appreciate the opportunity we've been given as humans. Magnificent.

My dream is that teachers use this document to bring excitement to classrooms around the world. I want to show that money is not the true source of happiness. Bringing up your fellow humans is the greatest feeling one could have. I urge you to share this document for all educational purposes – I hope you find it that valuable.

The main body of this document will be direct and to the point. But I still hope the passion from my introduction carries over into ever sentence you read.

In Summary

Chronos has yet to be directly observed. We need visual evidence of *Chronos* to verify its existence. Michael Brown and Konstantin Batygin, the astronomers who have brought the initial evidence forward, believe there is a 90% chance it exists.[6] Another astronomer at University of California puts the odds closer to 68%.[7] Astronomers around the world will work tirelessly to prove or disprove *Chronos'* existence.



The Hubble Space Telescope's "Ultra-Deep Field" survey shows us just how massive outer space is.[8] The telescope focused in on a "dark" section of the sky – Astronomers thought it was a void in space. What they found were millions of galaxies in this single shot. Each galaxy, like our Milky Way, contains **hundreds of BILLIONS of stars.** We are just one of eight (maybe nine!) planets circling our **one** star. Take a moment to let that sink in.

This picture has little to do with the focus of this document. The only thing its meant to do is to inspire you to learn more. I have found true peace after understanding my place in the Universe. I come from the same matter. I come from the same laws of the Universe that could create such beautiful objects. It is these laws that allow us to exist. It's humbling.

We ought to appreciate the opportunity humanity has been given. We must appreciate the mother Earth which has made all of this possible. For it is her that fostered our existence.

It is from the chaos in which we have arisen. A true product of chance and opportunity. Here's to science, to life and to all things unknown. It is from this cloud of possibilities that humanity will continue to grow and flourish as long as we come to fully appreciate it. Grow. Learn. Stay Humble.

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A QUICK INTRODUCTION TO *CHRONOS*

January 20th, 2016 – Research Astronomers Konstantin Batygin and Michael Brown of Caltech announce the *possible* 'discovery' of 'Planet Nine' [9] (which I have called *Chronos after the Ancient Greek God of Time*).

- The orbits (the path around the Sun) of several known *Minor Planets* (like Pluto) are interesting [Figure 1]. Many aspects of their orbits are similar.
- The odds of these orbits occurring 'randomly' would be .007% (based on models).[10]
- The Astronomers suggest that the most-likely case is an undiscovered, giant planet [Figure 2].[11]
- Astronomers doubt that a planet as large as *Chronos* could form this far from the Sun.[12]
- It could take up to 20,000 years for *Chronos* to circle the sun. *Much further out* than our 8th planet, Neptune (pictured in the center of Figure 1, and on the right of figure 2).[13]
- Batygin and Brown's model predicts this Planet to be 10x the mass of Earth – a giant.[14]

Figure 1 (15)

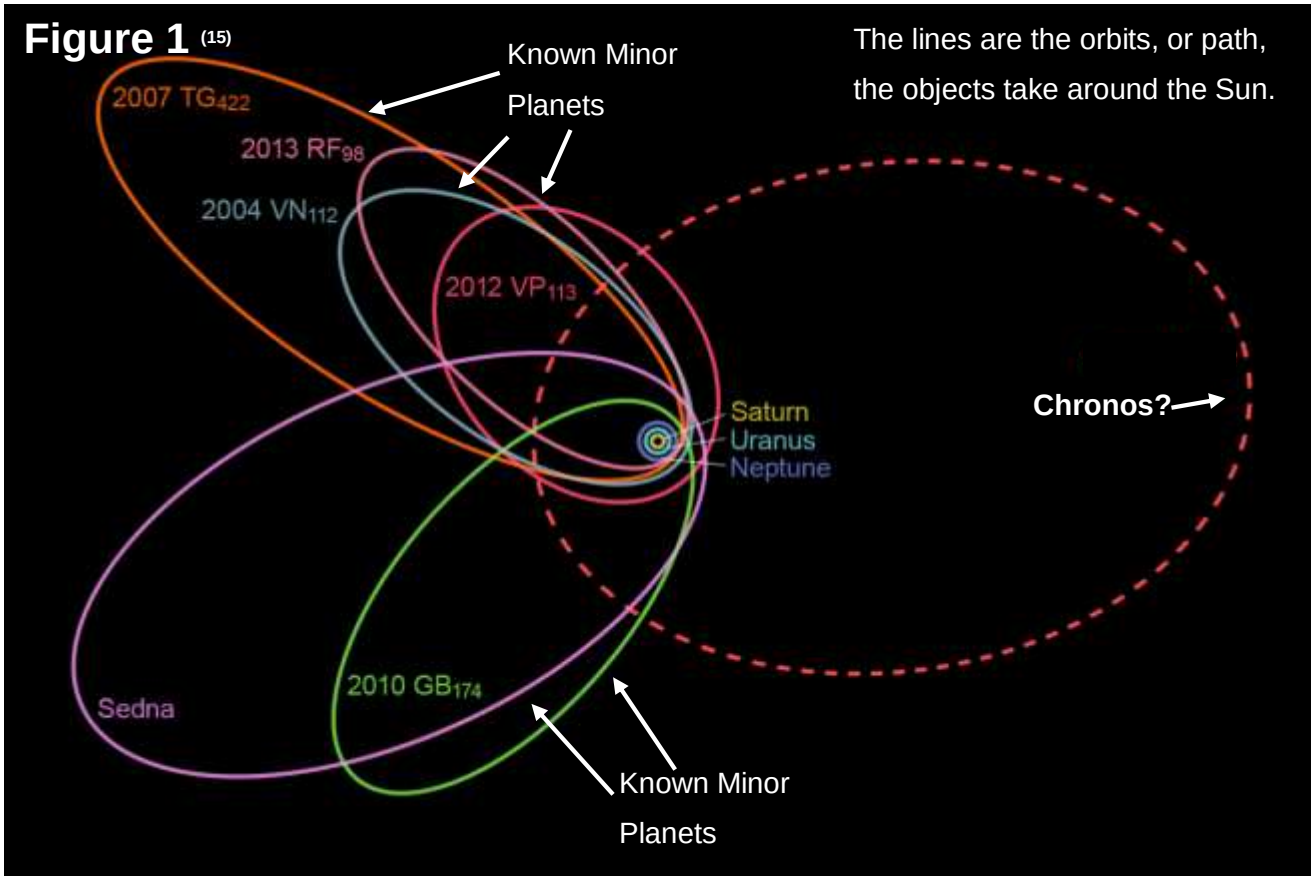
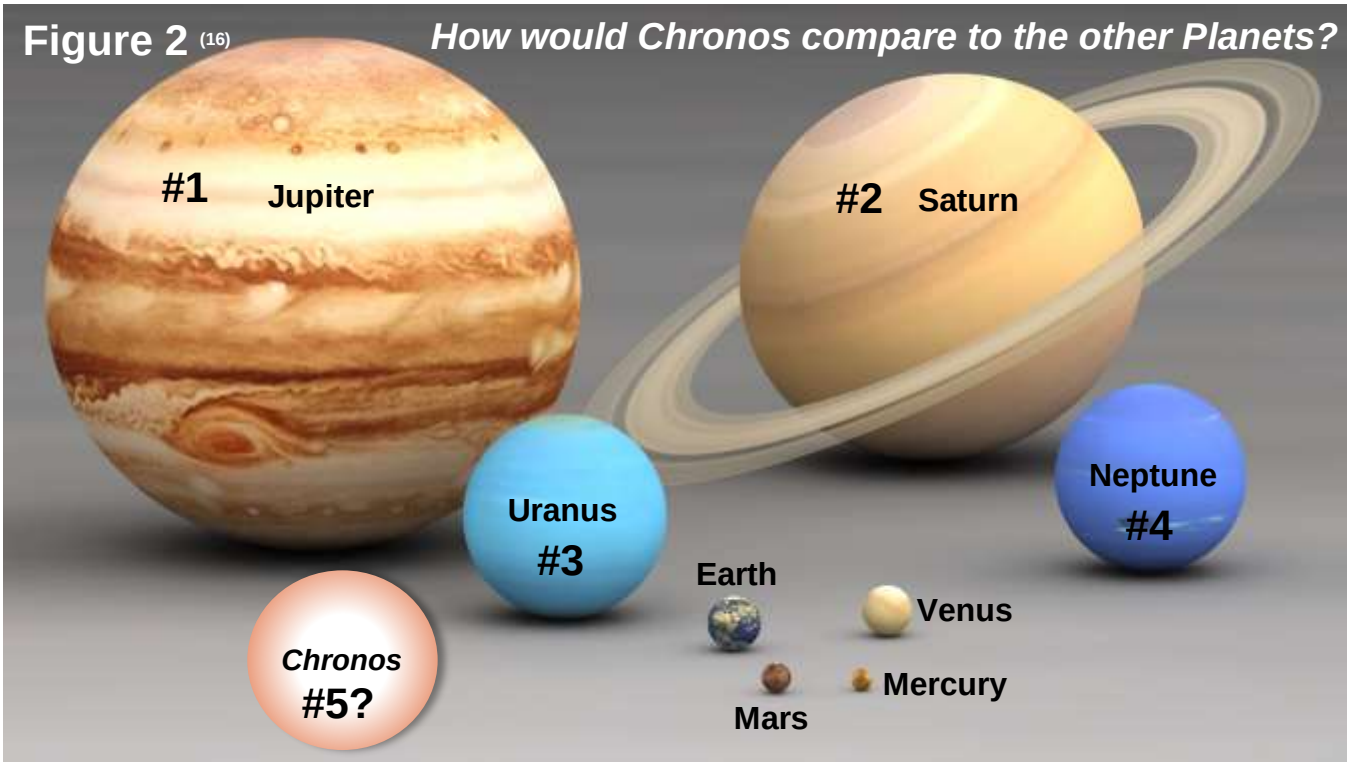


Figure 2 (16) ***How would Chronos compare to the other Planets?***



The information proposed by the Astronomers raises several interesting questions about *Chronos:*

- *If confirmed, what does Chronos tell us about how our Solar System was formed?*
- *Since it is thought to be impossible for something so large to form that far away from our Sun - how did Chronos get all the way out there?*
- *When could Chronos have possibly been sent into the outer reaches of our Solar System?*
- *Are we even sure Chronos is from our Solar System?*
- *Exactly how has Chronos **"shepherded"** these minor planets [Figure 1] into their path around the Sun?*
- *If Chronos is so large, how come it hasn't been observed yet?*
- *If it's not Chronos that has caused these unique orbits in [Figure 1] - what could it be?*
- *What will Chronos be like? Would it look like Earth?*
- *What impact, if any, has Chronos had on Earth?*
- *Will we ever be able to visit Chronos (assuming it is officially sighted)? How long would it take?*
- *Why is this discovery important to Astronomy (and all research sciences)?*

At the end of this document I want you to come back and revisit these questions. Can you answer them? The questions look daunting, but the content is organized so you can answer them confidently. If you are having trouble interpreting information, I'd be more than happy to exchange emails. My contact information is at the end.

The hunt is on to locate and confirm the existence of *The Frozen Shepherd.* It stands to be one of the largest discoveries in the history of Astronomy. To answer the questions above you must understand:

- How Solar Systems and Planets form.
- The different periods of our Solar System.
- How gravity effects the movement of objects in the sky, and how that movement is represented.
- Limitations of current technology – to view, to visit and to investigate *Chronos.*

CHAPTER I: THE HISTORY OF OUR SOLAR SYSTEM

By the end of this chapter you will have an understanding of:

- Exactly *how* was *Chronos* discovered? This will explain how *Chronos* is a shepherd.
- We will explore the facts of Chronos based on leading scientific theory.
- Lastly, we will apply the knowledge from Chapter I and discuss leading hypotheses.

Be the end of the chapter, you will be versed in the 'facts' of planets like *Chronos* form. Also, you will understand *the reasons behind Chronos' fate.* Simply – you'll be able to form your own hypotheses based on leading scientific theory!

1.1 We Are All Star Dust

Figure 1.1.1[17]

Everything in our solar system was born from mostly hydrogen, helium and leftovers of an ancient ancestor star. This ancestor was most likely *much* larger than our sun.

When a star much larger than our Sun 'dies' it creates an explosion that Astronomers call a *Supernova* [Figure 1.1.1 and Figure 1.1.3]. Humans owe their existence to these gigantic explosions. Supernovas are the only events that produce elements heavier than iron.[19]

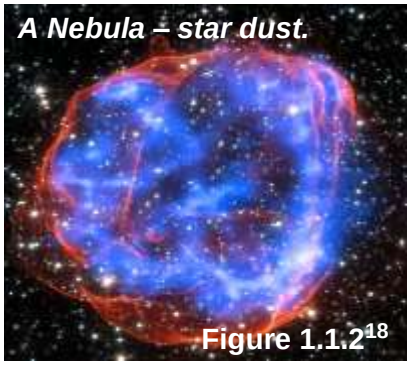
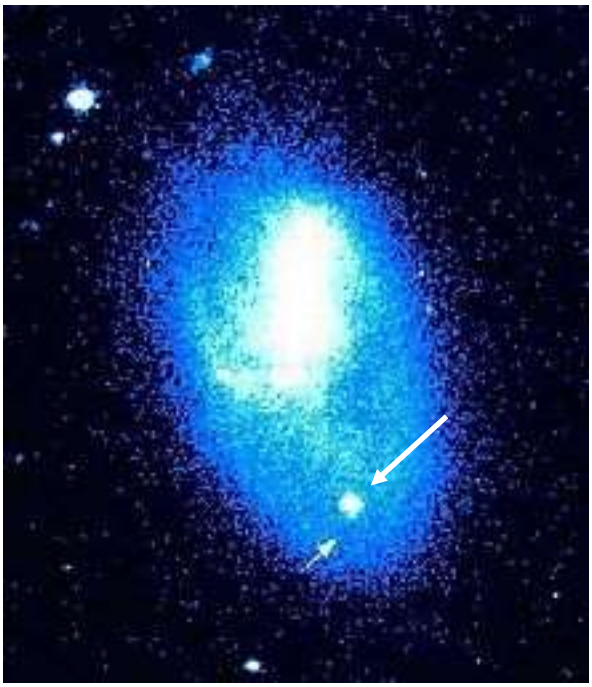


Figure 1.1.2[18]

The leftovers of this explosion leave behind a *Nebula* [Figure 1.1.2] – or *star dust*. Over the millions of years, Nebulas expand in to the beautiful structures we see around our Galaxy. The simplest definition for Nebulas is *leftover star material.*

All planets were born when this star dust mixed with Hydrogen (and small amounts of other elements). Everything in our Solar System formed from this material. It begs the question – exactly *how* does this a Solar System form from these leftovers?



[Figure 1.1.3] – A Supernova is very powerful explosion. The white dot is the Supernova and the blue is its Galaxy. If this happened in our Galaxy, we would see it in broad daylight.[20]

1.2 Star Formation – The "Protostar"

We have a good idea of how our solar system formed by looking at other young solar systems. Today's accepted model for solar system formation is known as *The Solar Nebular Hypothesis.*[21]

Stars are the dominant force in all Solar Systems [Figure 1.2.5]. When we refer to Solar System birth, we are talking about the birth of a star like our sun. The following high-level steps explain the birth of a Solar System ([Figure 1.2.6] summarizes this):

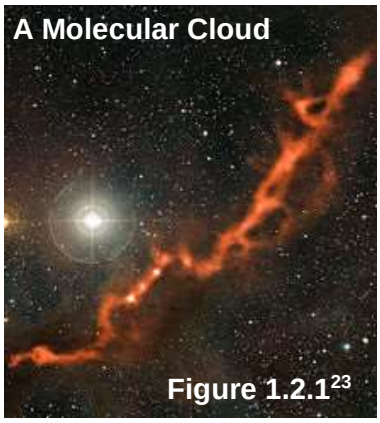
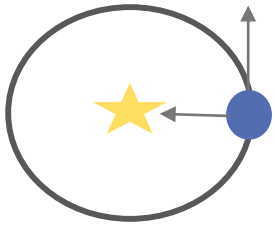


Figure 1.2.1[23]

- Stars form from gigantic clouds of matter – known as 'Molecular Clouds' [Figure 1.2.1].[22] Our Sun formed from a small pocket of a molecular cloud. A molecular cloud is mostly made of the element Hydrogen. Stars use Hydrogen to produce sunlight.
- These clouds become unstable as gravity causes small chunks of the cloud to collapse.
- A **Protostar** may form at the center of each small chunk of cloud. A Protostar does not produce sunlight. It is still gigantic - it just hasn't had enough time to heat up.[24]
- As this small chunk of cloud collapses, *Angular Momentum* causes this big pile of gas to spin faster.[25] You can imagine this like an ice skater pulling her arms in [Figure 1.2.2]. This momentum prevented the matter from collapsing into the center.[26] [Figure 1.2.3] shows how momentum prevents the Earth from falling into the Sun, today.
- As the Sun began to rotate faster, *Centripetal Force* increases.[28] This force can be thought of in terms of making a pizza from dough [Figure 1.2.4]. When you spin the ball of dough it begins to flatten out! This force created the *Protoplanetary Disc* which our planets formed from.[29] This will be discussed in the next section.
- As gravity increases pressure at the center of the Protostar, *Nuclear Fusion* begins and the star is born![30] Nuclear Fusion creates the sunlight that warms our planet.

Figure 1.2.2[27] – Angular Momentum allows a figure skater to spin faster by pulling her arms in.


[Figure 1.2.3 *left*] – Earth's momentum wants to go in a straight line. The sun wants to pull the Earth

[Figure 1.2.4 *right*] [cc] – Centripetal force causes pizza dough to flatten as it .

Because the Sun is so large, gravity pulled most of the matter into the center (an effect we don't see by tossing dough). But the 'dough-spinning' effect prevented all of the matter from falling in. It's this effect that allowed all planets to form. And it is at this point where the story of planets takes over.

[Figure 1.2.5] Our Sun Dominates Our Solar System[31] [32]

	The Sun ***Undisputed heavyweight.***	Everything Else ***Small fishes in a big pond.***
How massive?	**99.86% of mass in our Solar System.** It would take more than 333,000 Earths to match the mass.	**0.14% of the mass in the Solar System.** Jupiter is by far the most massive planet. It is still less than 0.1% the mass of the Sun.
How large?	**864,948.7 Miles Wide.** Over 1,300,000 Earths can fit inside of the sun.	Jupiter is the largest planet in our Solar System. The Sun is **still** 10x wider then Jupiter.
How hot?	**The surface is approximately 10,000°F.**	**The Earth's average temperature is 58°F.**
How did it form?	**Gravity pulled matter together towards a central point.** It got very hot and started creating sunlight.	**What the Sun didn't eat was left in the Protoplanetary Disc.** See section 1.3.

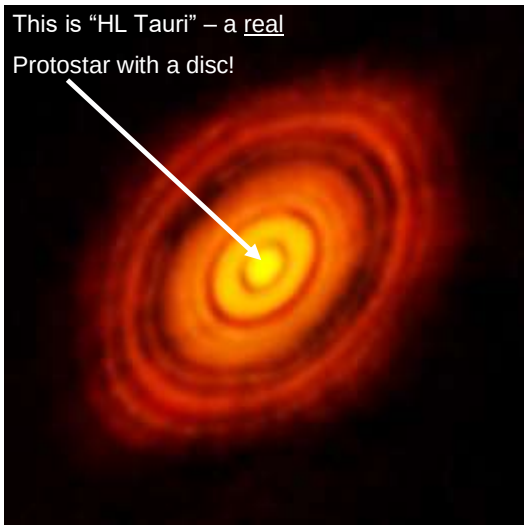
Figure 1.2.5 – The Birth of a Star Like Our Sun

A Large Molecular Cloud (black) is a big ball of matter.[33]

- It is dark because there is no sunlight. It also blocks sunlight from behind it, like fog.
- Small portions of the cloud begin to collapse – *mostly* due to gravity.

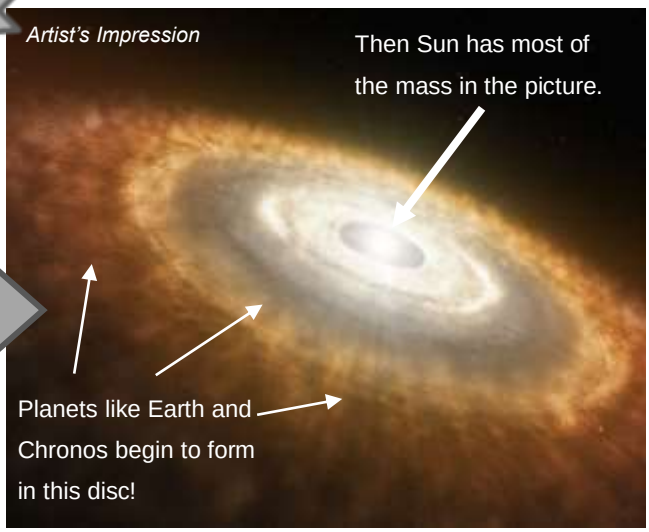
A Protostar is formed as gravity does its job.[34]

- Protostars are **not** visible to the naked eye. This image shows light that humans cannot detect.
- Our Sun was once a Protostar until it began producing sunlight.



A disc forms around the Protostar.[35]

- Most matter is in the center.
- Conservation of *Angular Momentum* causes the Protostar at the center to spin faster as it grows larger.
- *Centripetal Force,* the 'dough-spinning' effect, causes a large disc to form. This disc forms at the same angle the Protostar is spinning!



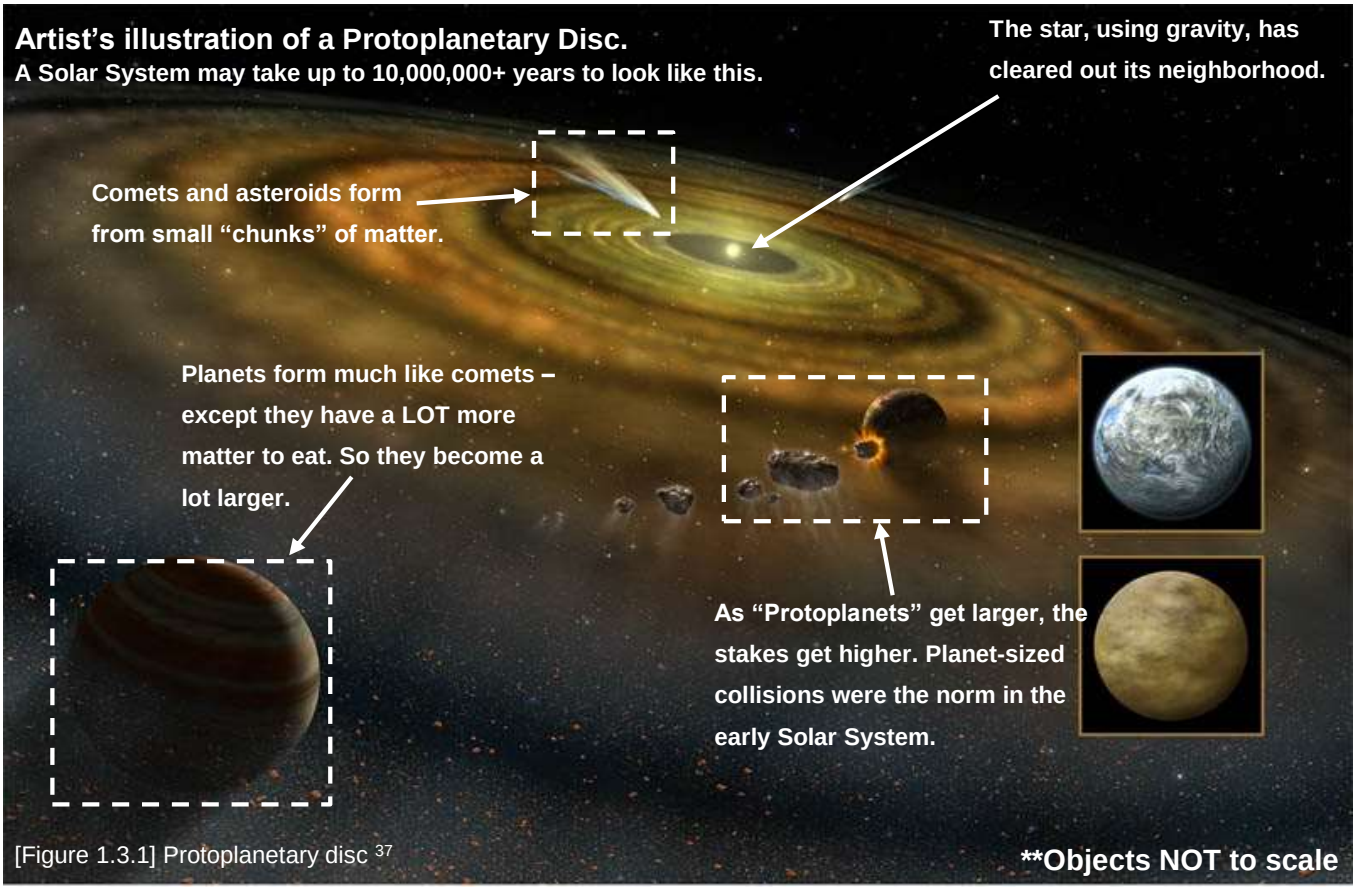
Nuclear Fusion begins – sunlight shines through the dust.[36]

- Over millions of years, gravity has done its job. The center of the star is now hot enough to produce sunlight.
- The new star is now visible to the human eye.
- Nearly all of the mass in the Solar System is inside of the star.
- Planets begin to form from leftover material in the disc.

1.3 The Protoplanetary Disc

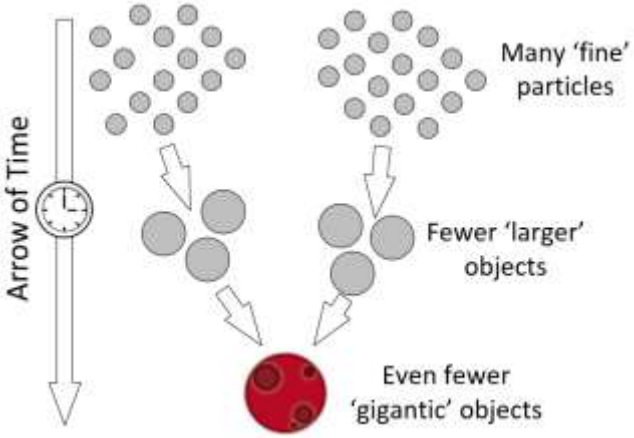
Gravity's attractive power began to clump dust and debris in the disc together to form larger objects. This is where we get the first hint of where *Chronos* came from.

This image illustrates several things about planets and how they form from the Sun's leftovers:



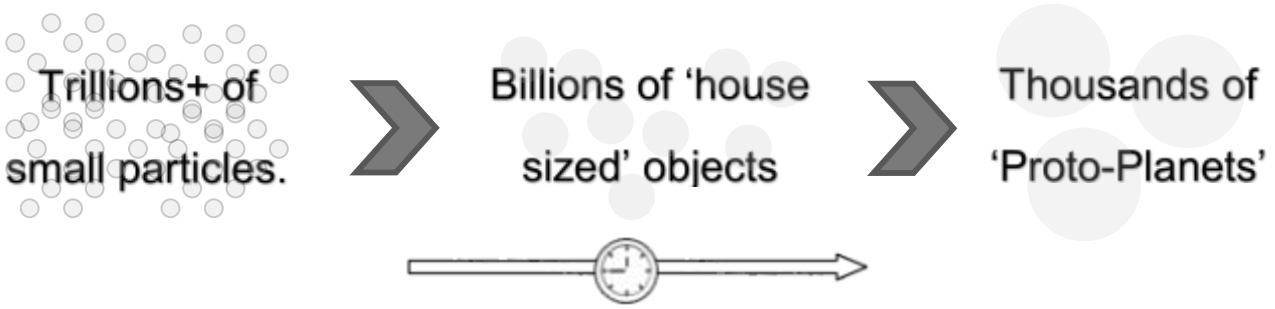
[Figure 1.3.1] Protoplanetary disc [37]

- **It was an all-you-can-eat buffet.** Anything you can pull in through gravity was yours.
- **Even though objects collided, they merged to form larger objects.** Collisions were much more frequent because there were more things.
- **There seems to be enough dust to form hundreds, or thousands of planets.** More objects mean more collisions. As the numbers of objects decreased, they increased in size [Figure 1.3.1].



[Figure 1.3.2] As the disc cools, basic particles can form. As time passes, they get larger.

1.4 How Planets Eventually Form



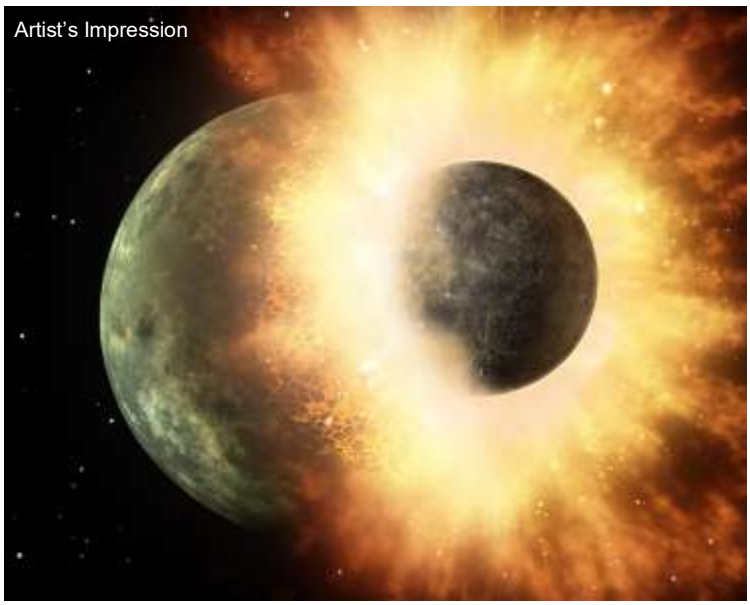
If there were potentially thousands of Protoplanets, what happened to them?

The same process that created proto-planets, most likely, formed the planets we know today. Imagine hundreds of proto-planets circling the sun – close encounters caused one of two things to happen:

How Did Protoplanets Get Larger?

- They picked up "space dust" as they circled the sun.
- Comets and asteroids hit them.
- They collided with other proto-planets.

1. Gravity caused the proto-planets to collide [Figure 1.4.1]
2. A close encounter "flung" one, or both, of the Protoplanets off course – this will be covered in further detail.



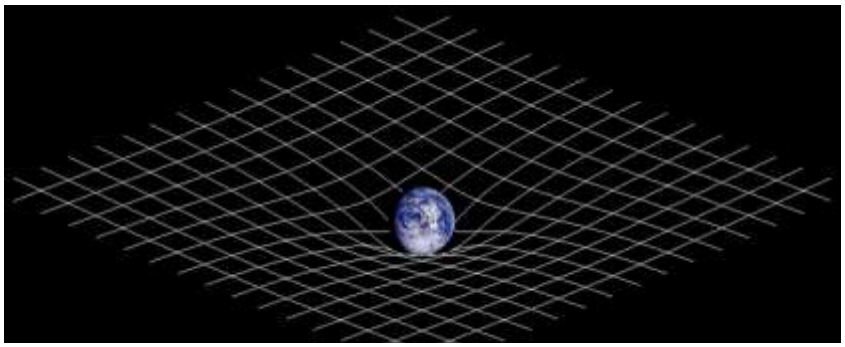
[Figure 1.4.1][38] Planet-sized objects collided. The collisions were inevitable as they occupied the same orbit around the Sun. Many Astronomers believe that Earth's moon formed after a Mars-sized planet crashed into a young Earth.[39]

As Protoplanets got larger, they became planets. A planet is an object that orbits its host star.

- Gravity is strong enough on planets to make them into a sphere.
- A planet has cleared its orbit (the path it takes around the sun) of other objects.[40]

Until Protoplanets clear their region of space, they can't become real planets. It took time for all the matter and bodies to consolidate into planets. Because it was a long time ago, definition may be a moot point. What's important is that you understand how the planets we have *eventually formed.*

1.5 A Different Side to Close Encounters – Ejection.

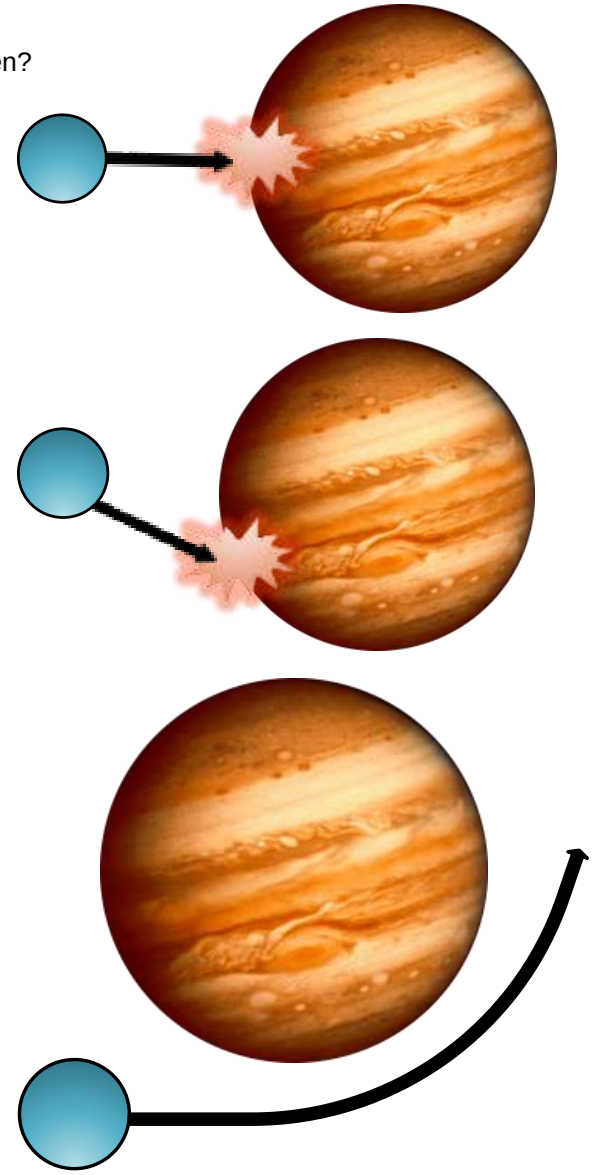


[Figure 1.5.1][41] Albert Einstein showed how large objects "warp" space. The heavier the object the larger the indent it makes. Imagine rolling a marble towards the edge – what would happen?

In 1915, a young Albert Einstein proposed the "General Theory of Relativity" [Figure 1.5.1] which explained gravity. It is still accepted today as the best way to explain how planets move around the Sun (and all outer-space objects for that matter).[42]

He explained that objects in the sky such as stars, planets and comets "obey" larger bodies. [Figure 1.5.2] shows how a planet could get "ejected" off of its current path without colliding into a planet. It shows our largest planet Jupiter and how it would handle a close encounter with smaller planet. It explains that:

- **Angles are everything.** A head on collision would be deadly for the smaller planet. It would get swallowed by the much larger Jupiter.
- **A steeper angle that takes the planet towards the edge of Jupiter would still be destroyed.** While the planet wouldn't get immediately "swallowed" – it's as good as dead.
- **An angle that keeps the planet far enough away from Jupiter would have a different fate.** Because Jupiter 'warps' the sheet around it, like in [Figure 1.5.1], it would send this on a totally new path around the Sun. Or perhaps it could be sent out of the Sun's reach!



[Figure 1.5.2] What happens if a small planet were to get too close to Jupiter? Figure shows two options: collision or ejection.

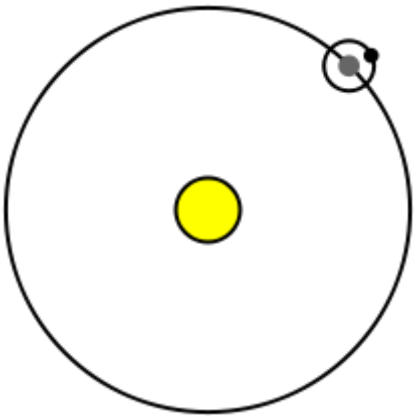
1.6 Capture

It is possible that a close encounter can have a different result. *One can become a moon of the other.* How? Let's imagine a scenario like in [Figure 1.5.2] where a planet has a close encounter with Jupiter. The angle it approaches Jupiter is very important – but let's assume it is the same for all three pictures. Equally important is the *speed* it approaches Jupiter. [Figure 1.6.1] expands on this concept. In the graphic, the angle of approach is the same for all three scenarios.

- An object moving too fast will be *ejected.*
- An object moving too slow will eventually 'fall in' or *collide* with Jupiter (keep in mind this is simplified).
- An object moving at the right speed will become a new moon of Jupiter! In Astronomy, we'd say Jupiter "captured" this planet.

It is in the realm of possibility that *Chronos* was captured by the Sun! Just like Earth could be captured by Jupiter. [Figure 1.6.2] can help explain further. [Figure 1.6.3] provides a real example! *Captures* will be revisited later.

[Figure 1.6.1] A large object, such as Jupiter, can *capture* a planet.



[Figure 1.6.2] Much like the Earth orbits the Sun, our moon orbits the Earth. This shows that objects tend to orbit the most massive object in its neighborhood!

[Figure 1.6.3][43] Our 8th planet, Neptune, captured the moon *Triton*[44] in a similar manner to [Figure 1.6.1].

Part I Recap

Solar System Formation

We learned that the entire Universe is effective at recycling material.

- Our Sun formed from a small portion of a Molecular Cloud. Heavy elements from an ancient star explosion (Supernova) littered this cloud with all elements heavier than Iron. This knowledge will play an important role in understanding what *Chronos* could be made of.
- This small portion of the cloud began to collapse due to Gravity.

We learned how Gravity pulled nearly all the matter in the Solar System into a 'Protostar' that would eventually become our Sun.

- Potentially, 99%+ of the matter ended up in the Protostar.
- As gravity pulled the matter in to the Protostar, it began to rotate faster. *The Conservation of Angular Momentum* or The 'Ice Skater effect' explains this.
- *Centripetal Force,* or the Pizza Dough effect, makes all matter along the plane of spin form a disc. This would become the Protoplanetary disc.
- As gravity was able to compress the Sun, it became hot enough to start *Nuclear Fusion* – the process that creates sunlight. Our Sun is born!

The Protoplanetary Disc

We learned that the Protoplanetary disc was made of the leftovers our Sun couldn't finish.

- Because of *Centripetal Force,* a disc of debris circled (orbited) our Sun.
- Over enough time, matter clumped together to begin forming Protoplanets.

As objects got larger the stakes got higher. Gigantic collisions and close encounters were regular.

- General Relativity (the stretched sheet) helps us explain why objects orbit each other. It explains why there were so many collisions.
- It also explains why collisions don't *always* happen, per [Figure 1.3.4] and [Figure 1.3.5]. This will be important in understanding *Chronos'* fate.

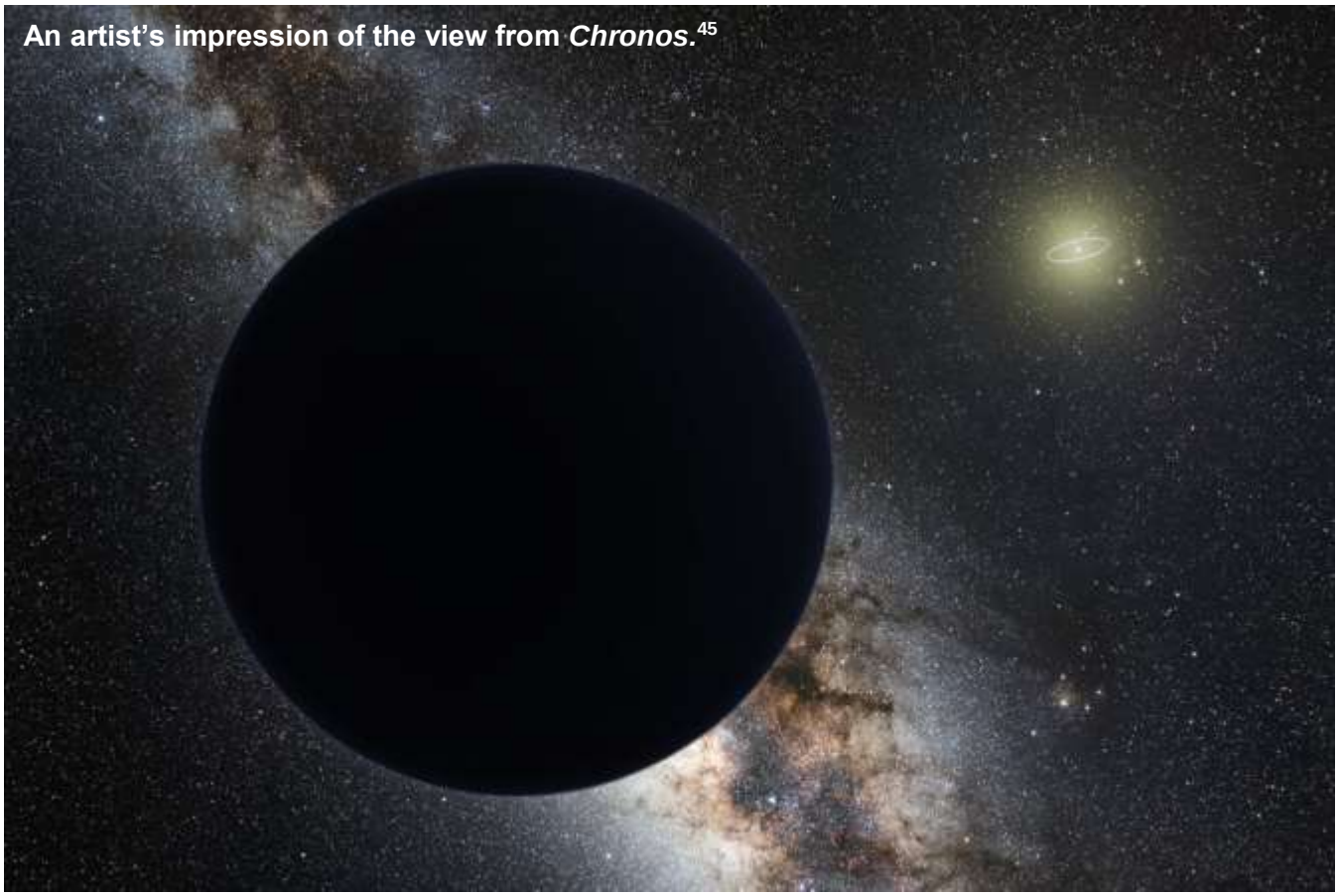
CHAPTER II: *CHRONOS* – THE FROZEN SHEPHERD

In this chapter we will cover a few key topics:

- Exactly *how* was *Chronos* discovered? This will explain how *Chronos* is a shepherd.
- Exactly *what* did *Chronos* shepherd? Hint: It's gravity.

By the end of the chapter you will be versed in the 'facts' of *Chronos.* You'll be able to explain how the founding Astronomers used math to suggest its existence.

An artist's impression of the view from *Chronos*.[45]



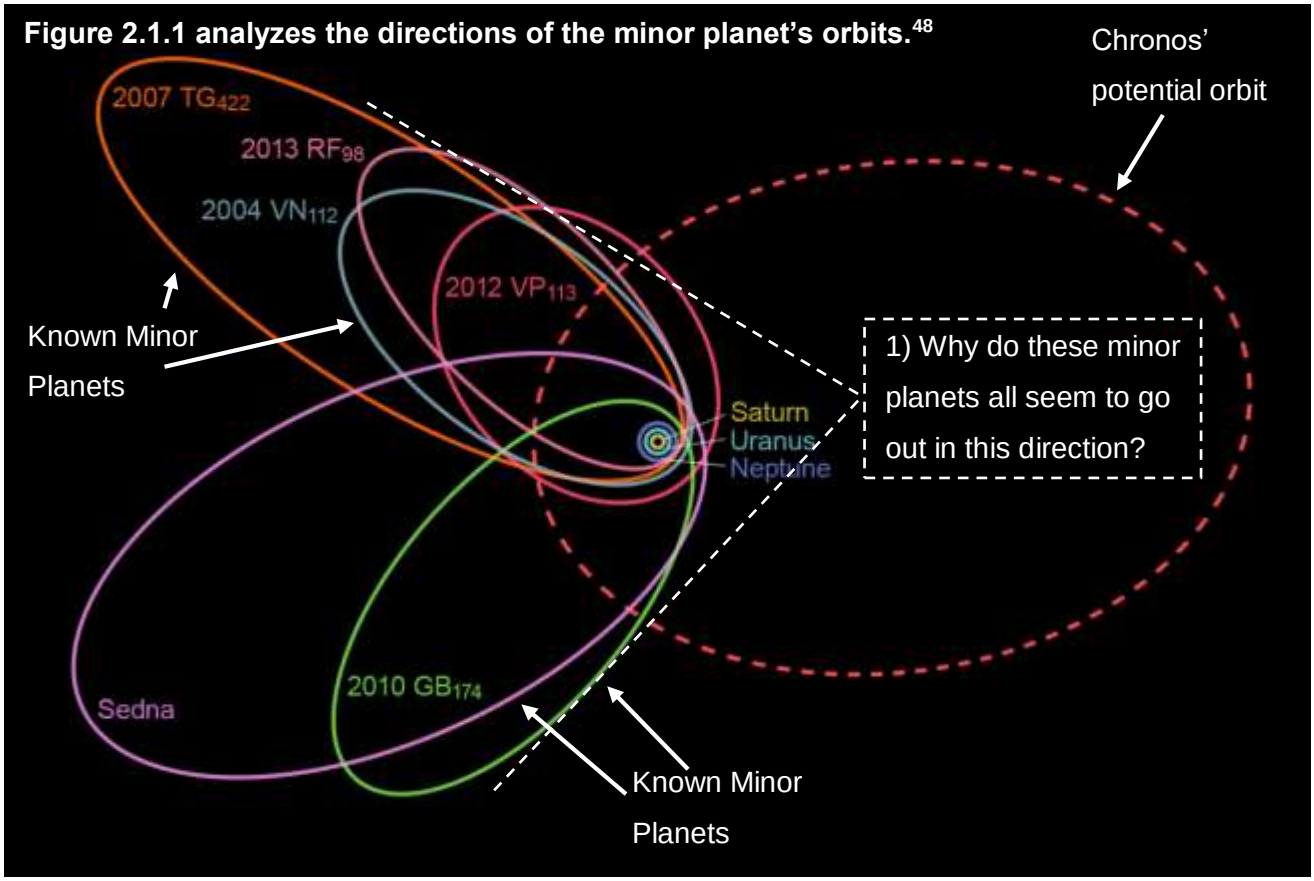
2.1 Astronomers Announce the Most Convincing Evidence for a Giant Undiscovered Planet.

January 20th, 2016. Research Astronomers Konstantin Batygin and Michael Brown of Caltech announce the 'discovery' of *Chronos.* But they haven't actually *seen* it. They claim it exists based on the movement of six already-discovered minor planets (similar to Pluto but *much* further out in the Solar System).[46]

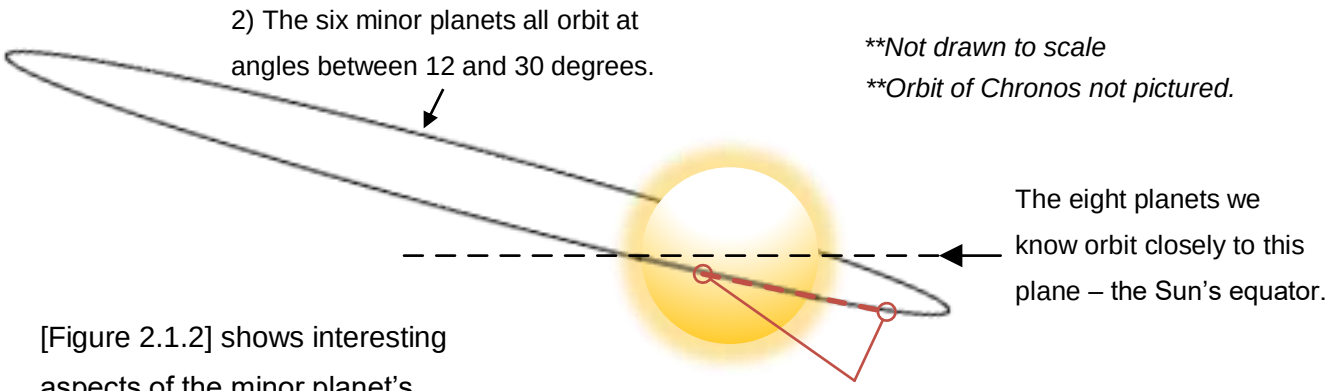
Batygin and Brown were hardly the first Astronomers to suggest the existence of a large undiscovered planet. They *were* the first to unify three observations that prevented previous Astronomers from claiming the discovery. They built a model in which *Chronos* was able to account for these *three* observations[47]:

1) The orbits of the six minor planets studied seem to shoot out in the same direction [Figure 2.1.1 - #1]. Astronomers would expect them to be random if nothing was influencing them.

Figure 2.1.1 analyzes the directions of the minor planet's orbits.[48]



2) The orbits of the six minor planets are all tilted in the same direction [Figure 2.1.2 - #2].
3) The six minor planets all come closest to the sun just before they pass the Sun's Plane [Figure 2.1.2 - #3].



[Figure 2.1.2] shows interesting aspects of the minor planet's orbits.

The Astronomers who performed these calculations claim there is only a .007% chance of this happening naturally.[49] This does ***not*** mean that there is a 99.99%+ chance of *Chronos* existing. It ***does*** means that something undiscovered is causing this formation.

The Astronomers *then* built a model with *Chronos* in it. It was able to explain the .007% chance mentioned above. Once again, this does not mean *Chronos* exists. It means that there is something unexplained in the outer Solar System. Right now, the most plausible answer is a planet 10 times the size of Earth.[50] *Chronos.*

This is why Astronomers are so excited.

2.2 The Shepherd's Sheep

Exactly *how* does a planet such as *Chronos* shepherd six minor planets into similar orbits?

Gravity.

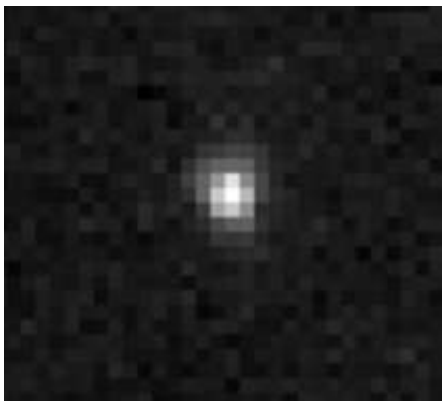
Albert Einstein's 1915 Theory of General Relativity (see sections 1.5 and 1.6 for a refresher) gave us the foundation to understand space objects using math equations. This helped Astronomers understand a few basics:

- The six minor planets were too far away from Neptune to be influenced by it (refer back to [Figure 2.1.1] to see just how far). Meaning *something* was tugging at them from deep space.[51]
- *Chronos* was able to adjust the orbits of these minor planets as they got close. Close is a relative term. As Einstein stated, the more massive the object the larger its gravitational pull.

Chronos is large enough to have this effect on the minor planets.

What do the six minor planets look like? If they are so small, and so far away, how were they discovered?[52]

- **They are near their closest pass to the sun.** Meaning they are reflecting more light from the Sun [Figure 2.2.1].
- **Objects far out in the system have a lot of ice.** They reflect a lot of sunlight.
- **They are very cold.** Chances are, everything is frozen. The Sun looks like just another star at these distances.

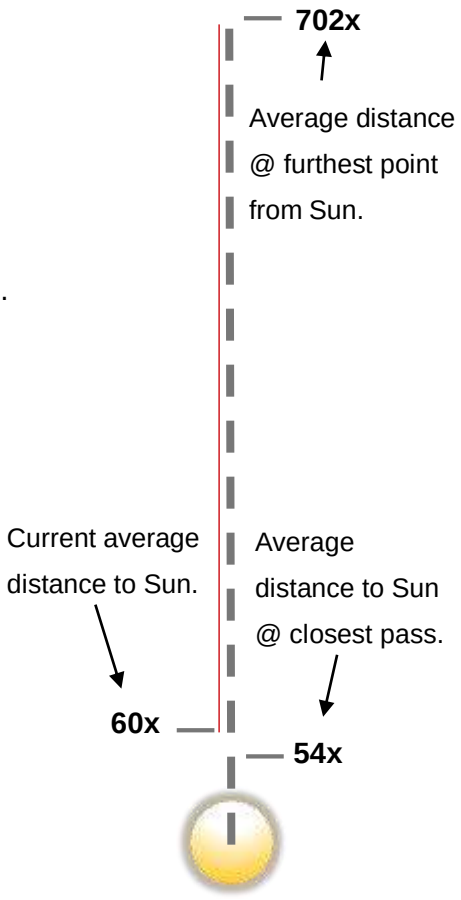


[Figure 2.2.1][53] *Sedna*, discovered in 2004, is 600 miles wide. It was discovered because it is near its closest pass to the Sun.

[Figure 2.2.2] shows us the average distance of the six minor planets. What does it tell us?

- There may be more minor planets that *Chronos* could be shepherding.[54] The average distances are shown in the image.[55]
- **BUT** we cannot assume that there are more minor planets. It could be that minor planets in other parts of the orbit collided with *Chronos.* Or, they could have been ejected (per section 1.5).

The founding Astronomers do predict several "clusters" of minor planets based on scientific theory.[56]



[Figure 2.2.2] Shows six minor planet's average distance to Sun.[57] Each unit represents 1 Earth-Sun distance.

Chronos' orbit not pictured!

2.3 Chronos' Stats

The Greek God Chronos usually looks like an old, wise man. During the Renaissance, the image of God Chronos gave rise to *Father Time.*

Chronos (the planet) embodies the characteristics of Father Time:

- The estimated time it takes to circle the sun is 15,000 years – 90x longer than Neptune.[58] It oversees the solar system as the other planets zip around the sun.
- Being so far away, it's cold in *Chronos'* neighborhood. **BUT –** this doesn't mean *Chronos* is frozen. Just like Earth, *Chronos* would most likely have a warm core and produce heat!
- Until we can learn more about it, we can't be sure how old it is.
- It's estimated that it is ten times the mass of Earth.[59] If it's verified, it'd be the 5th largest planet in our solar system.

Given this information, it's safe to assume that *Chronos* was either:

- An outcast of our Solar System. Sent away a long time ago by a close encounter with another planet (or even the Sun).
- Or, the Sun captured *Chronos* (per Section 1.6) with its immense gravity.

CHAPTER II RECAP

This history of *Chronos* goes back further than 2016.

- Many scientists have speculated its existence. More seriously in the last 10-15 years.
- The hunt intensified as minor planet *Sedna* [Figure 2.2.1] was discovered. It was obviously *shepherded* away from the inner solar system. *Sedna* is one of the six minor planets used in the investigation.

Astronomers Batygin and Brown were able to unify three observations from a set of six minor planets.

- The direction of six minor planet's orbits [Figure 2.1.1 - #1].
- The plane in which the six minor planets orbit the sun [Figure 2.1.2 - #2].
- The location where the minor planets cross the plane of the Sun [Figure 2.1.2 - #3].

The odds of the three observations occurring naturally is .007%.

- This does **not** mean *Chronos* is responsible. It means that *something* is responsible.
- Astronomers Batygin and Brown built a model which works well with a planet 10x the mass of Earth – which I've called *Chronos.*

The six minor planets are near their closest pass to the Sun.

- Astronomers believe there are more objects that *Chronos* could be shepherding.
- These six minor planets are visible because they have reflective ice on the surface. They are also near their closest to the Sun.

***Chronos* oversees our Solar System from afar.**

- *Chronos* orbits extremely far out in the solar system.
- It stands to be the 5th largest planet, if confirmed.
- The founding Astronomers believe it could be 2-4x the width of Earth.

Many details about the composition of *Chronos* were left out of the overview. As you will see, it depends on *where Chronos came from.*

CHAPTER III: EXPLAINING CHRONOS

By the end of this chapter, you will have an understanding of:

- Rogue Planets, the nomads of space.
- The Origin of *Chronos*
    - Hypothesis #1 – Born with our Solar System, but ejected early on.
    - Hypothesis #2 – Born elsewhere in the Galaxy, but captured by our Sun.

The information from Chapter I helped you understand just *how Chronos could be ejected.* But – *when?* It also showed how large bodies can be captured by even larger bodies – as I've shown in many examples.

Chapter II provided the statistics behind *Chronos.* We learned how it was discovered and from our definition in Chapter I, how it truly **is a planet –** it has dominated its region in space through gravity.

Chapter III will unite these concepts. First, it's important you understand the concept of *Rogue Planets.* They will help bring more context to the leading hypotheses.

We will then review the top hypotheses to explain *Chronos.* You will see why certain details of *Chronos* cannot be determined until we observe it.

This chapter is pretty short, but this is because you know the '*why'* already!

3.1 Rogue Planets

What if Chronos was sent speeding out of our solar system, never to return?

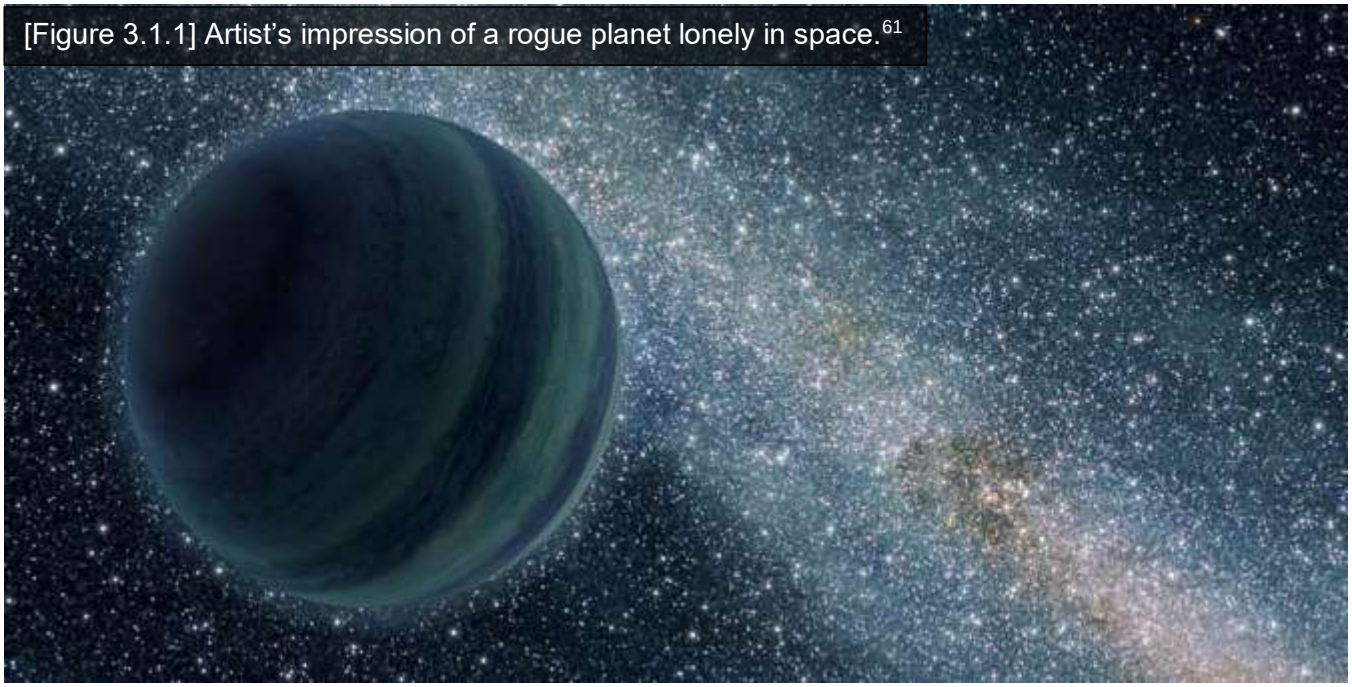
A reminder on planetary formation

- The protoplanetary disc 'consolidated' over millions of years to form Planets. Most of the time this involved Protoplanets picking up dust and debris as they circled the Earth. Sometimes this involved planets smashing into each other.
- As Protoplanets became larger they turned into Planets. Planets are round due to gravity. They also 'dominate' their path around the Sun.
- Planets don't always smash into each other when they get close. Sometimes the smaller of the two can get flung in a different direction.

If that still sounds hard to believe – it's because it is. Especially when you consider how *large Chronos is* at 10 times the mass of Earth.

Planets much larger than *Chronos* have been found floating around in space. Many Astronomers believe this scenario is very common! They call these *Rogue Planets.*[60]

[Figure 3.1.1] Artist's impression of a rogue planet lonely in space.[61]



The Outcasts of Outer Space

Rogue Planets are the outcasts of the Universe. Like their name suggests, they belong to no star. Imagine a scenario where *Chronos* was flung out at such a speed that the Sun couldn't hold on. This probably came close to happening!

It'd be free to roam the Universe. Cold. Dark. Lonely.

In fact, our own solar system has almost certainly ejected planets that we'll never see again.

Rogue planets are extremely hard to find. They don't make any of their own sunlight. They are floating aimlessly in space.

Why are Rogue Planets so hard to find?

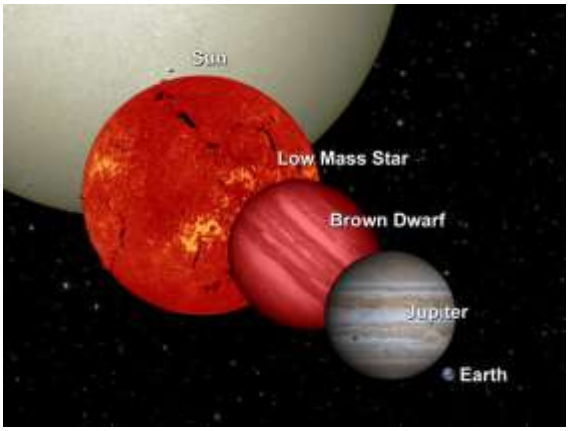
- They don't produce any of their own sunlight.
- There are no stars nearby, so they don't reflect much sunlight.
- Our technology is not good enough.
- Our methods for detecting them are new.

A quick reminder on solar system formation

- [Figure 1.2.5] showed how Stars form from big clouds of gas. Aren't stars just a really large object that was able to 'suck in' a lot of matter? And then gravity became strong enough to heat up the star so it produced sunlight?
- [Figure 1.3.1] showed how comets, planets and stars are relative based on their size. This is a very simplified comparison – but isn't mass the main difference between these objects?
- What if I combined the equivalent of 1.3 Million Earth masses from [Figure 1.2.4] – would it become a star? You bet!

Rogue Planets can form on their own, much like our Sun did. They just weren't heavy enough to produce sunlight.[62]

- We lightly touched on nuclear fusion in sections 1.2 and 1.3. Our Sun was able to compress its core to a high enough temperature to begin making sunlight.
- What if a chunk of a molecular cloud formed on its own but didn't get hot enough to produce sunlight? **A rogue planet is born.** [Figure 3.1.2] can help you visualize this.



[Figure 3.1.2][63] Illustrates why size matters. The 'Low Mass Star' still produces sunlight, however the 'Brown Dwarf' doesn't! If we expanded this to things smaller than Earth, you'd see Planets like Mars, then comets and asteroids!

Rogue Planets could have been ejected from their solar system.

In section 1.5 we discussed ejection. [Figure 1.5.2] showed how a planet could be flung in a random direction by a much larger Jupiter. Refer to sections 1.5 and 1.6 for a refresher.

Most Astronomers believe Rogue Planets are very common.

Much more investigation needs to be done about *how many*. However – I can confidently state that they do exist.

- Astronomers used a visual method to take a survey of the sky. They estimated that there could be two Rogue Planets for every star in our Galaxy.[64] That could be 400 billion rogue planets in our galaxy alone!
- A study by Stanford suggest that **100,000 rogue planets per star may be likely.**[65] That's 200 billion stars in our Milky Way multiplied by 100,000. That's a lot of Rogue Planets!

This range in possibilities is exciting. It also has us asking, how can we even be sure that *Chronos* (or any of the other six minor planets) came from our Sun in the first place?

Can we ever be positive that our eight confirmed planets formed with our solar system? That's a resounding **NO** (although we are pretty certain they all did)**.**

3.2 Hypothesis One: Chronos was Ejected

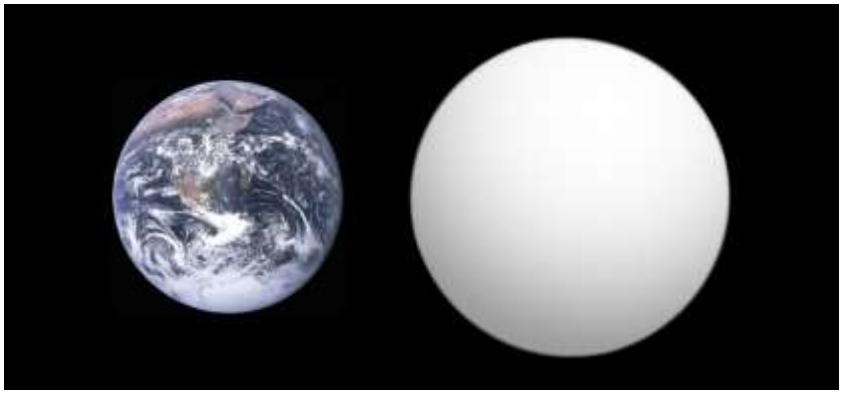
By this point you probably already are able to explain how this is a plausible scenario. Gravity is not always destructive in the early solar system. *So what leading scenarios exist to explain Chronos' ejection?* What are the best guesses we can make about how it got ejected?

It was most likely cast out by Jupiter.

Jupiter is *massive*. Jupiter has 2.5x more mass *than the other 7 planets combined.*[66] It is most likely Jupiter's fault from odds alone. If we assume *Chronos* was ejected, what could it be like?

An ejected "Super-Earth."

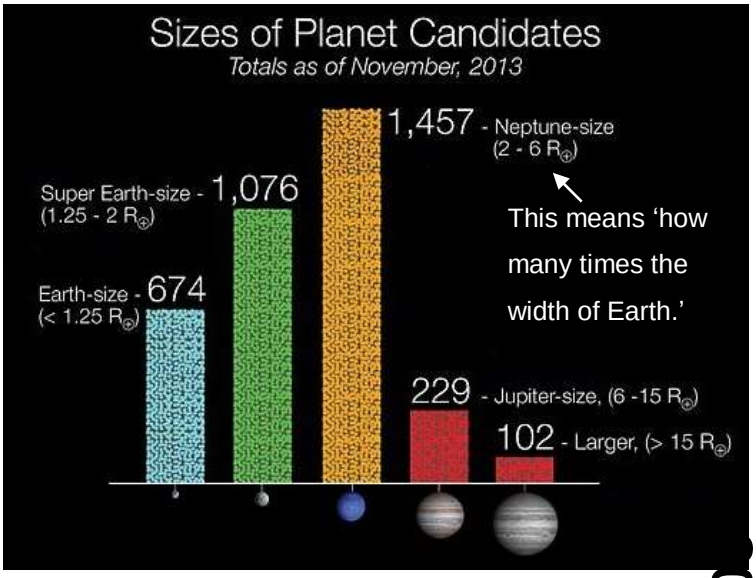
Without knowing what *Chronos* looks like or what it's made of makes this difficult to confirm. But, it would *most likely be very different from the planets we know today.* If it does have a mass of 10 Earths, it *could* fall into a category astronomers call a *Super-Earth* [Figure 3.2.1 and 3.2.2].[67]



[Figure 3.2.1 *left*][68] Shows Earth next to a "Super-Earth." There are no Super-Earths in our Solar System today, but *Chronos* is a prime candidate. Super-Earths may be rocky, but they may also have a very thick atmosphere.

[Figure 3.2.2 *right*][69] Shows the results of the Kepler mission. The Kepler mission looks for planets circling *other stars* in our galaxy. *What's interesting is that most of the planets that have been 'discovered' are between Earth and Neptune's size.*

So why doesn't our solar system have any planets that fit this description? Check the Appendix if you want to learn more!



It was ejected and is an "Ice Giant" like Uranus and Neptune.

It's cold out there. That's why Uranus and Neptune are called "ice giants." It's very possible that *Chronos* is a lost ice giant that was banished by Jupiter.

For those looking to learn more, the **Nice Model** helps explain some scenarios where this is possible.

Optional Section for those wanting to learn about "The Nice Model."

The original Nice (named after Nice, France) Model was proposed in 2005 to explain several beliefs of our early solar system:

- There was not enough *stuff* for the Planets Uranus and Neptune to form in their current locations. *Something* must have caused these two gigantic planets (which are both thought to be slightly larger than *Chronos)* to shift into their current orbit.[70]
- *The Late Heavy Bombardment* [Figure 3.2.1 *on the next page*] – a period of "hell on Earth" conditions around 500 Million years after the formation of our solar system.[71]
- Astronomers believe that the four gas giants in our Solar System formed *much* closer to the Sun. It would have been twice as compact.[72]

The Nice Model is seen as one of the most realistic models of our solar system's formation. This is because it predicts many things we've observed in our Solar System. At a high-level, the Nice model suggests:

> Jupiter and Saturn, the two largest planets, enter into a *gravity dance (*called an Orbital Re*sonance).* For every one time Jupiter goes around the Sun, Saturn goes around twice. Over Jupiter *pushes* Saturn outwards [Figure 3.2.2 *on the next page*]. In the simplest form – this causes Uranus and Neptune to *also* migrate outwards! As these two planets migrated outwards, they sent a ton of debris into the inner-solar system. This may have caused the *Late Heavy Bombardment!*[73]

So, what does this have to do with Chronos? Continue reading…

The Nice Model (continued)

[Figure 3.2.1 *left*][74] Illustrates what the moon may have looked like during a period known as *The Late Heavy Bombardment.* It occurred approximately 10% into the solar system's life. This period is thought to be caused by Uranus and Neptune migrating out from the inner solar system.[75]

The Apollo moon mission brought back a lot of rocks. They found evidence that turned into *The Late Heavy Bombardment Theory.* It helps explain a lot of other observations.

The common thought is Uranus and Neptune disturbed a lot of space rocks that were untouched. These rocks of different sizes (some perhaps the size of Pluto) were sent flying into the inner solar system.

It's important to note that there are many theories to explain this evidence.

[Figure 3.2.2 *right*] A swing is a good way to think of the *gravity dance* between *Jupiter and Saturn.* Since Jupiter is much larger, it is the one pushing Saturn.

- If Jupiter were to *push Saturn* at random times while it was on the swing nothing would really happen.
- If Jupiter were to *push Saturn at regular periods* – like at the back of the swing – Saturn could fly away after a few pushes!

The Five-Planet Nice Model

This variation to the original model suggests there were *five giant planets instead of four.* Sound familiar?

This variation, which still has its own flaws, suggests:

> The original Nice Model tended to make the inner planets (Mercury, Venus, Earth, Mars) become unstable. *Remember the swing analogy from [3.2.2]?* When Jupiter and Saturn, the two largest planets, enter this situation they begin to boss around *all* of the planets. Especially the puny inner solar system planets. When the original model was run over-and-over, it usually ended up with Mars being thrown out of the solar system (or sent colliding with another planet).[76]
>
> In addition, the original Nice model would usually end up with only 3 gas giants instead of the 4 we see. As explained previously, Jupiter usually ejected one of the 4 from the solar system.

A potential solution for this problem was to introduce a *fifth giant planet into the model.*[77]

> During many of the simulations, the fifth gas giant would be ejected after a close encounter with Jupiter.
>
> The model suggests that this planet would have started between Saturn and Uranus, making it the 3rd of 5 gas giants. As Jupiter and Saturn entered into their *2:1 gravity dance* it made *all the giant planets unstable.* This planet would pass Saturn before encountering Jupiter. This usually resulted in the extra planet being ejected from the solar system![78]

While this model predicts a fifth gas giant – *it unfortunately does not fit the description of Chronos.*[79]

It does give you further ideas on how it could happen.

3.3 Hypothesis Two: The Sun Captures Chronos

We've discussed how it'd be possible for a planet to become a moon of Jupiter in section 1.6. If the Sun is a lot more massive than our largest planet, Jupiter (more than 1,000x more massive) – couldn't it capture a lot more? **Absolutely.**

***Chronos* is a Rogue Planet which formed on its own but was captured by our Sun.**

It's possible that *Chronos* formed on its own. Section 3.1 covered the concept of Rogue Planets and how they can form from gas just like a Star.

Chronos is a Rogue Planet which formed around *another Star but was captured by our Sun.*

What if *Chronos* formed around another star altogether? And it was ejected from its solar system? Section 3.1 touched on how a planet can become rogue. It's possible that *Chronos* has swapped stars!

Where do <u>you</u> think Chronos came from now that you know the options? What seems most plausible to you?

CHAPTER III RECAP

Rogue Planets can be very common in the Universe.

- The concept of banished planets is a near certainty in Astronomy.
- Planets could be sent flying out of their solar system. This could have happened to *Chronos,* but maybe it wasn't moving fast enough to fully escape.

Hypothesis One states that Chronos was ejected from our Solar System.

- Until we can observe it, everything is a guess.
- It could be a very massive Earth – many of the solar systems we see around the universe have a lot of "Super-Earths." This is a large gap in our solar system that Astronomers can't explain. *Neptune's almost 4 times as wide and 17 times as heavy* (Uranus is slightly lighter than Neptune).
- It could be an "ice giant" that was banished (most likely by Jupiter). The Five-Planet Nice Model predicted this, but *Chronos* does not fit the description.

Hypothesis Two states that Chronos was captured by our Sun.

- *Chronos* could have been born a rogue planet and eventually captured.
- *Chronos* could have been born to another star, but was stolen! Or, it was ejected by its original solar system.

It's evident that we need to locate *Chronos* to learn more. It holds the key to a lot of questions about solar system formation.

CHAPTER IV: EXPLORING CHRONOS

By the end of this chapter, you will have an understanding of:

- How we would *observe* Chronos and what it'd look like. Also, what can we learn once we observe it?
- Will we be able to explore *Chronos* with a lander or satellite? If so, how long will it take us?

Now that we've understood leading ideas it's time to put the rubber to the road. Exploring *Chronos* will unlock answers about the birth of our solar system. It will also help us build better models around how solar systems form.

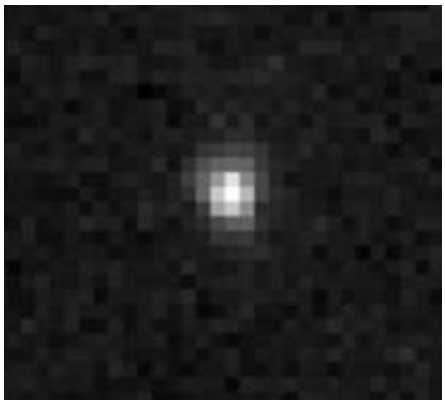
4.1 Locating and Observing Chronos

Locating *Chronos* won't be easy. It's expected to be close to the furthest point it gets from the Sun. This translates to at *1,000 times the distance from the Earth to the Sun.*[80]

90,000,000,000 miles. Give or take a few **billion.**

So what do you need to know?

- **There have been many surveys of our solar system.**[81] The discovering Astronomers have searched through existing data. They expect that it is towards the edge of its orbit if it exists.[82]
- **The furthest point *Chronos* gets from the Sun happens to be towards the center of our Milky Way Galaxy.** This means there will be a lot of 'background noise' when looking for *Chronos.*
- **It is going to be *very dim.*** This also explains why we haven't found it. Remember Sedna from section 2.2? If we catch a photo it'll be pretty underwhelming [Figure 4.1.1]. It is expected to be at least 600 times *dimmer than Pluto.*[83]
- **It's so far away that it doesn't reflect much sunlight.** Per previous sections, something of *Chronos* size is not large enough to produce its own sunlight.
- **It <u>is</u> expected to be 'hot' enough to produce enough infrared light.** Like Earth, *Chronos* most likely produces heat in its core. It will give off a heat signal which could make it easier to find.



[Figure 4.1.1] *Sedna*, discovered in 2004 is 600 miles wide. It was discovered because it is near its closest pass to the Sun. If *Chronos* is spotted it may not look any clearer that this picture.

There is strong reason to believe it'll be spotted in the next 5-10 years.[84]

- **Many large observatories already have the power to spot it.** But it's like searching for a needle in a haystack.
- **The James Webb Telescope will be launched in 2018.** This telescope will replace the Hubble Space Telescope (which produced the large photo in the introduction) and is expected to be strong enough to find it.[85]
- **The Large Synoptic Survey Telescope is expected to be completed in 2023.** This telescope will be able to survey the entire night sky, very quickly. This should help find other objects *like the six minor planets we have been talking about.*[86]

If we spot it, what can we learn?

Don’t let the poor pictures of Sedna discourage you. *Spectroscopy*, the study of interaction between light and matter, will help analyze *Chronos*.

- **It will help understand what *Chronos’ atmosphere is made of.*** Maybe this can give us an idea of what the planet looks like! Chances are, there will be a lot of ice in the atmosphere.
- **It can tell us how warm it is.**

In summary, we may be able to learn enough to form some more reliable theories about *Chronos.* This could help us understand how our solar system formed.

4.2 Can we visit *Chronos*?

Yes, but not anytime soon.

Given the distance we expect *Chronos* to be at, it's safe to say any mission would take more than 30 years.

- **Missions take a long time to prepare.** You have to devise the right method. Most importantly you have to get funding.
- **We can't travel that fast.** One of the best methods we know of could still take 20-30 years at best guess.

Studying a long-last planet up close could be very interesting. I'll be the first to admit that it is not the most pressing thing in a long list of priorities. The first step is to locate *Chronos then* decide if it is worth the funds, time and energy to study it up close.

I will leave that up to the heroes at NASA and other space agencies around the world.

IN CLOSING

I hope you enjoyed reading this document. I had a **blast** writing it. My hope is that it inspires you to be passionate about *any* type of scientific research. The potential discovery of *Chronos* is a small chunk of the potential that humans have. I'm a firm believer in *the scientific method.* It has led humanity to new heights and new discoveries. It has given us the wonderful, unique lives we are privileged to live.

But in all, science is underfunded.

Research sciences such as Astronomy don't have a direct path to profit, and this doesn't jive with our society where profits are key. It takes humble people and humble leaders to plant the seeds for further scientific discovery – discovery these people may not be alive to see.

Thank you for taking your time to read this. By showing interest you are directly supporting science. If you were inspired by this document, please let me know about it. It would make my day to hear from *anyone* who has benefited from it.

If you have any questions, concerns or suggestions do not hesitate to contact me. I will make this document better if you want me to. You can reach me at christiananthonyacosta@gmail.com.

A society grows great when old men plant trees whose shade they know they shall never sit in.

I'm unsure of who the author is of this great image, but thank you for the inspiration.

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Appendix

List of great articles about Planet Nine:

http://www.popsci.com/could-there-really-be-9th-planet-that-we-didnt-know-about

https://www.washingtonpost.com/news/speaking-of-science/wp/2016/01/20/new-evidence-suggests-a-ninth-planet-lurking-at-the-edge-of-the-solar-system/

http://www.nature.com/news/evidence-grows-for-giant-planet-on-fringes-of-solar-system-1.19182

http://www.newyorker.com/tech/elements/discovering-planet-nine

http://www.thestar.com/news/world/2016/01/20/is-a-real-ninth-planet-out-there-beyond-pluto.html

Wikipedia is one of the greatest products of the Internet Revolution. This paper would not have been possible without it. I strongly believe that it is a great starting point to launch your continued discovery.

Planet Nine: https://en.wikipedia.org/wiki/Planet_Nine

Giant Impact Theory: https://en.wikipedia.org/wiki/Giant_impact_hypothesis

The Nebular Hypothesis: https://en.wikipedia.org/wiki/Nebular_hypothesis

Five Planet Nice Model: https://en.wikipedia.org/wiki/Five-planet_Nice_model

The Theory of General Relativity: https://en.wikipedia.org/wiki/General_relativity

The Late Heavy Bombardment: https://en.wikipedia.org/wiki/Late_Heavy_Bombardment

Stanford article on Rogue Planets: http://news.stanford.edu/news/2012/february/slac-nomad-planets-022312.html

Super-Earths: https://en.wikipedia.org/wiki/Super-Earth

How weird is our solar system (mentions of lack of Super-Earth)?
http://www.bbc.com/earth/story/20150515-how-weird-is-our-solar-system