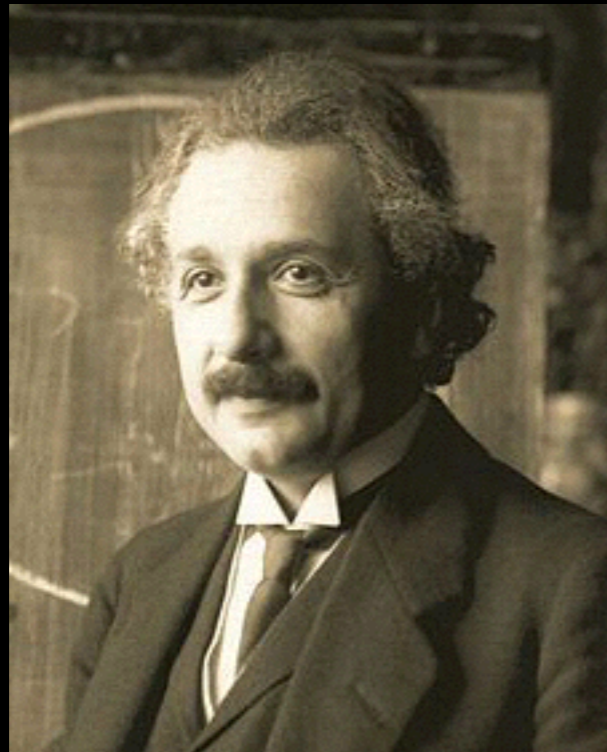


# ブラックホールはどう見える？



真貝寿明 (大阪工業大学)

しんかい ひさあき

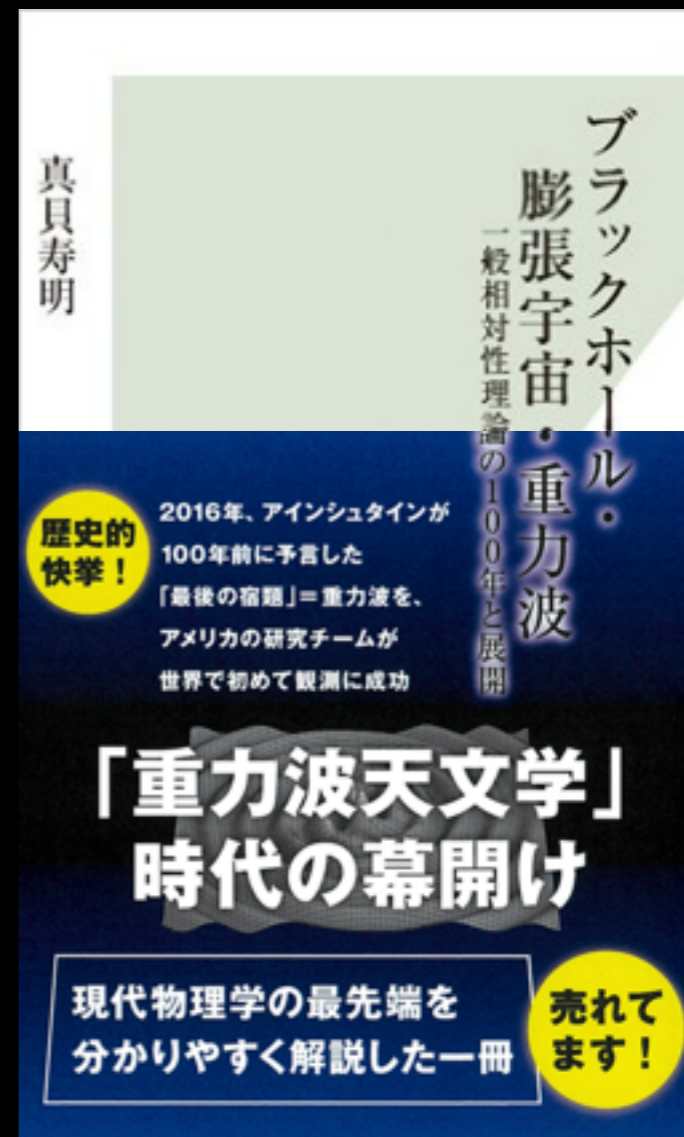




2011年2月刊



2015年10月刊



『ブラックホール・膨張宇宙・重力波  
一般相対性理論の100年と展開』

光文社新書  
2015年9月刊



2016年7月11日発売



はくちょう座



こと座



へびつかい座



わし座



土星

火星



さそり座

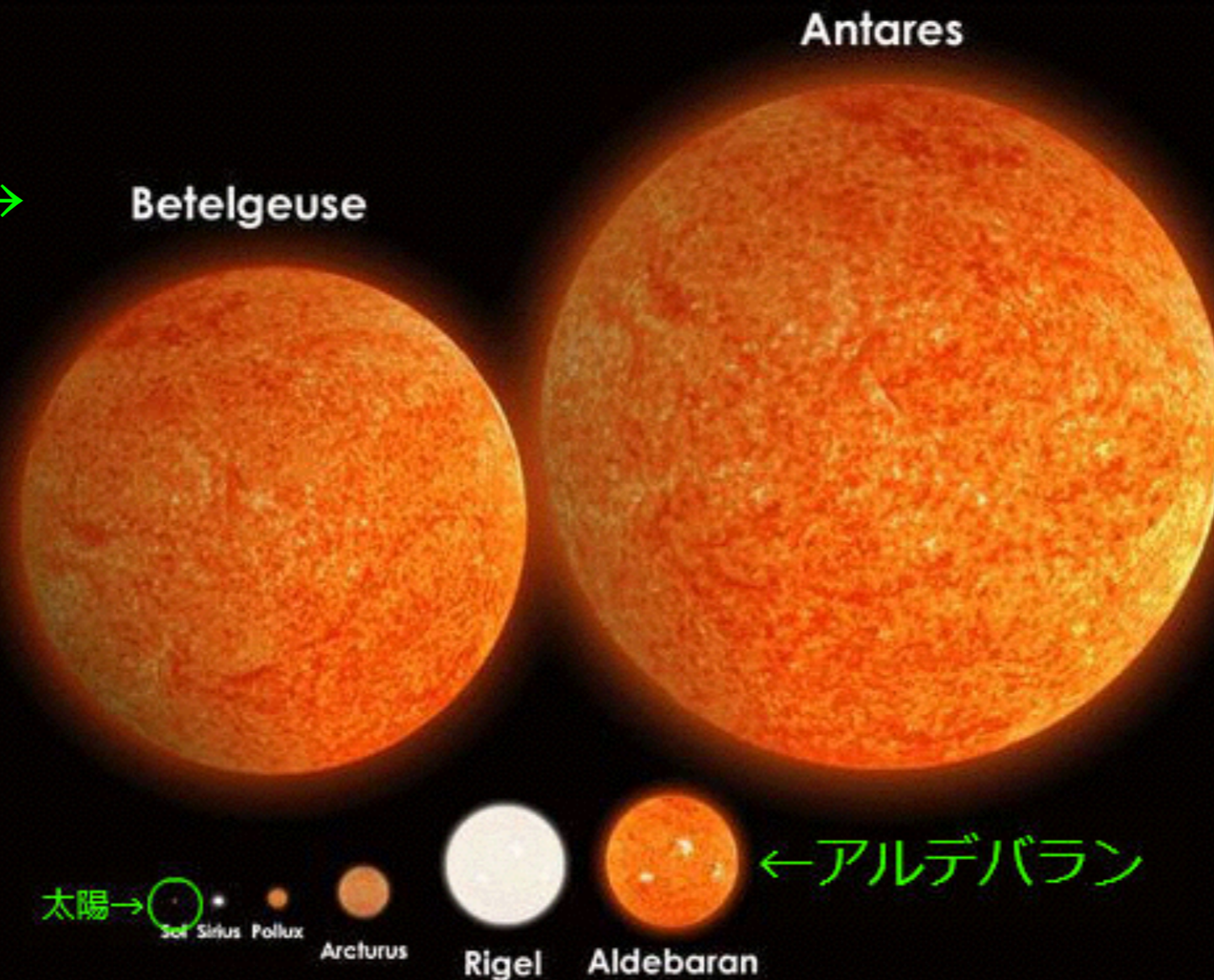


いて座

# ブラックホールとは？

= 重い星がさいごにつぶれたもの

ベテルギウス→  
(オリオン座)

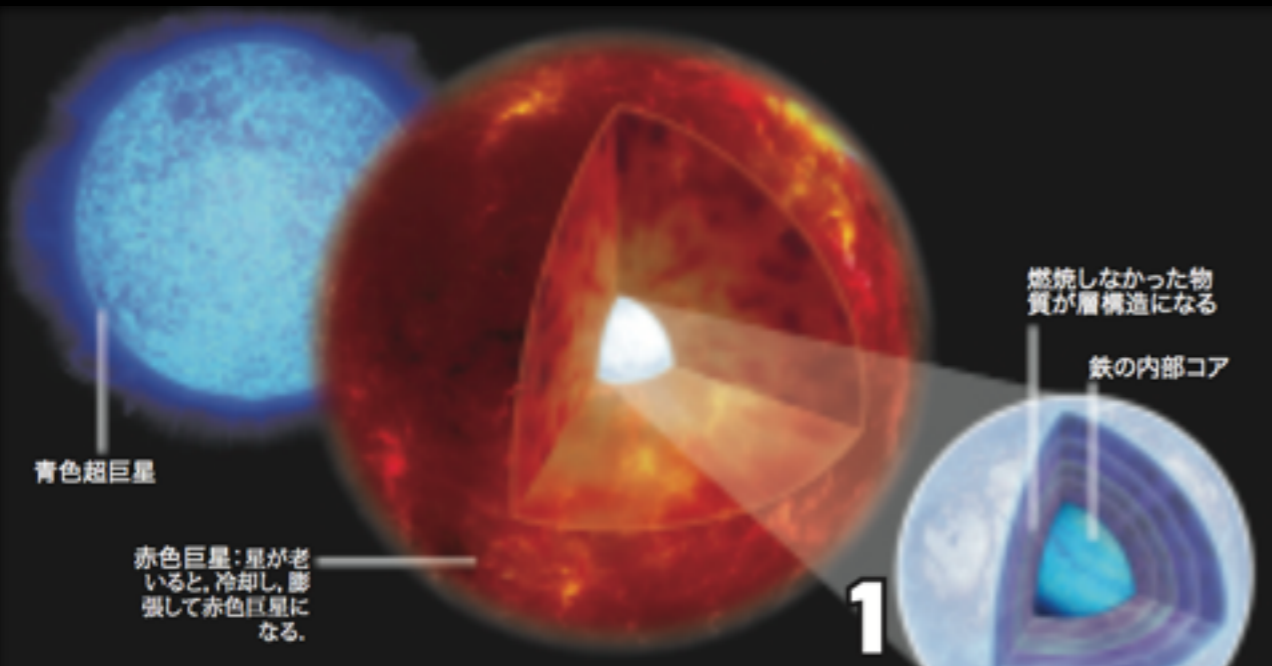


←アンタレス  
(さそり座)

太陽の700倍  
の半径  
太陽の15.5倍  
の重さ

←アルデバラン

# 星はさいごに大爆発 (超新星爆発)

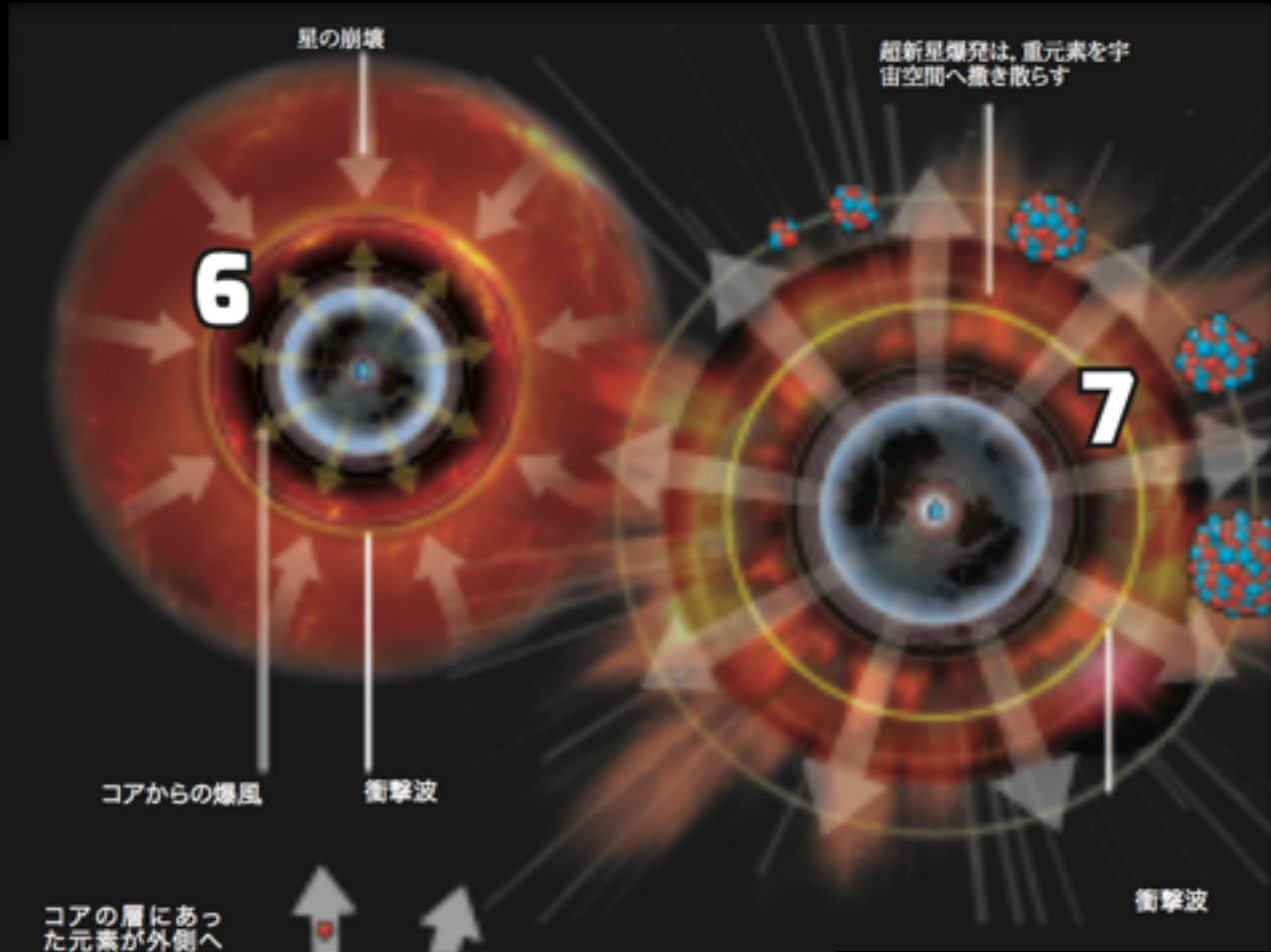
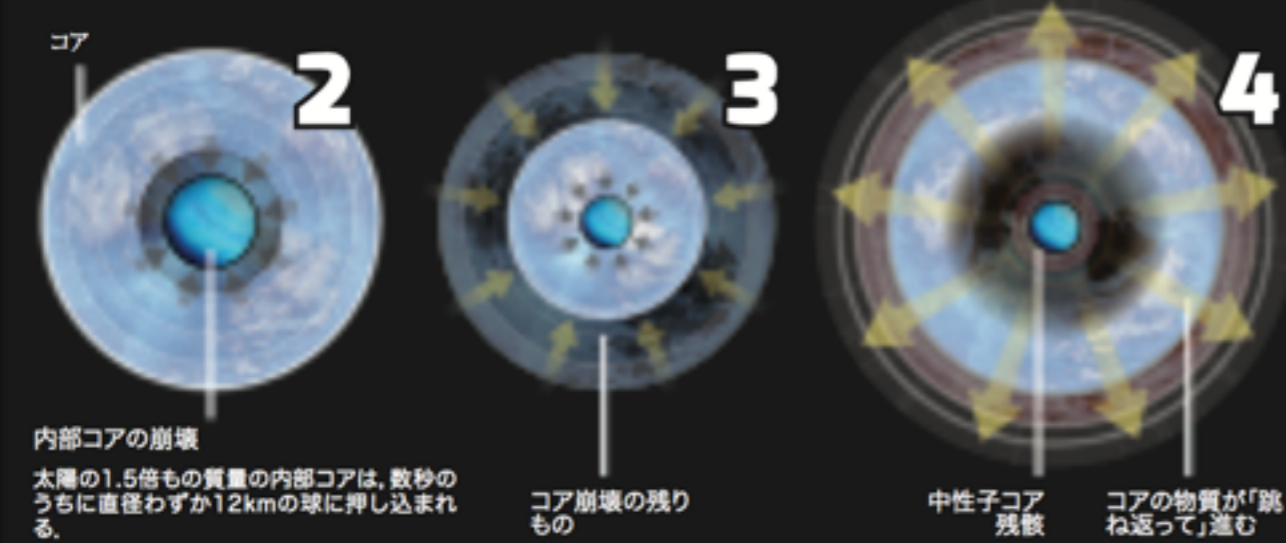


1. 鉄が合成される時点までは、星のコアは巨大なタネギ状である。燃焼していないすべての元素が層になっている。

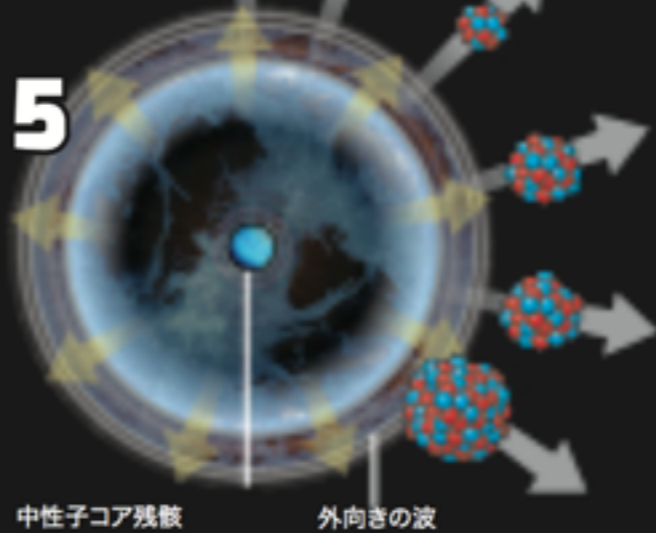
2. 鉄をさらに融合できず、核融合は終了し、鉄の内部コアは自身の重力によって激しく重力崩壊する。

3. 少し後に、コアの残りの部分も先例にならって内側へ向かって収縮をはじめ、鉄のコアはそれ以上潰れることができず、中性子の塊に変形して崩壊が一時くいとめられる。

4. 上から降り積もる物質は中性子のボールにぶつかって跳ね返る。これが、重力のエネルギーを解放する爆風となる。



コアの層にあった元素が外側へ打ち出される。



「宇宙のつくり方」  
(丸善, 12月発売)

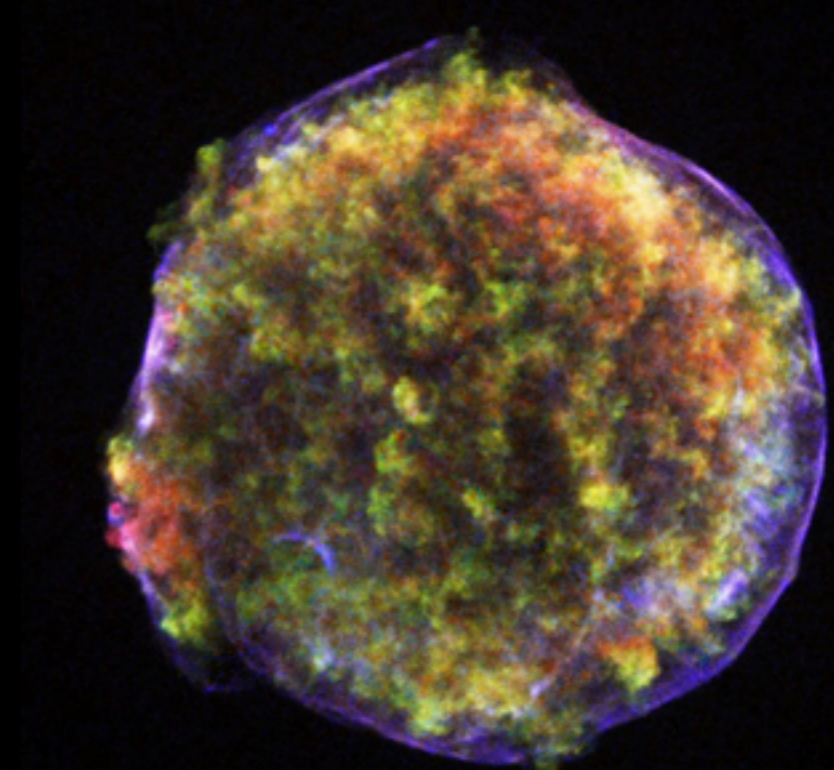
だいばくはつ

ちょうしんせい ばくはつ

# 星はさいごに大爆発 (超新星爆発)



SN1006



SN1572



SN1054

だいはくはつ

ちょうしんせい

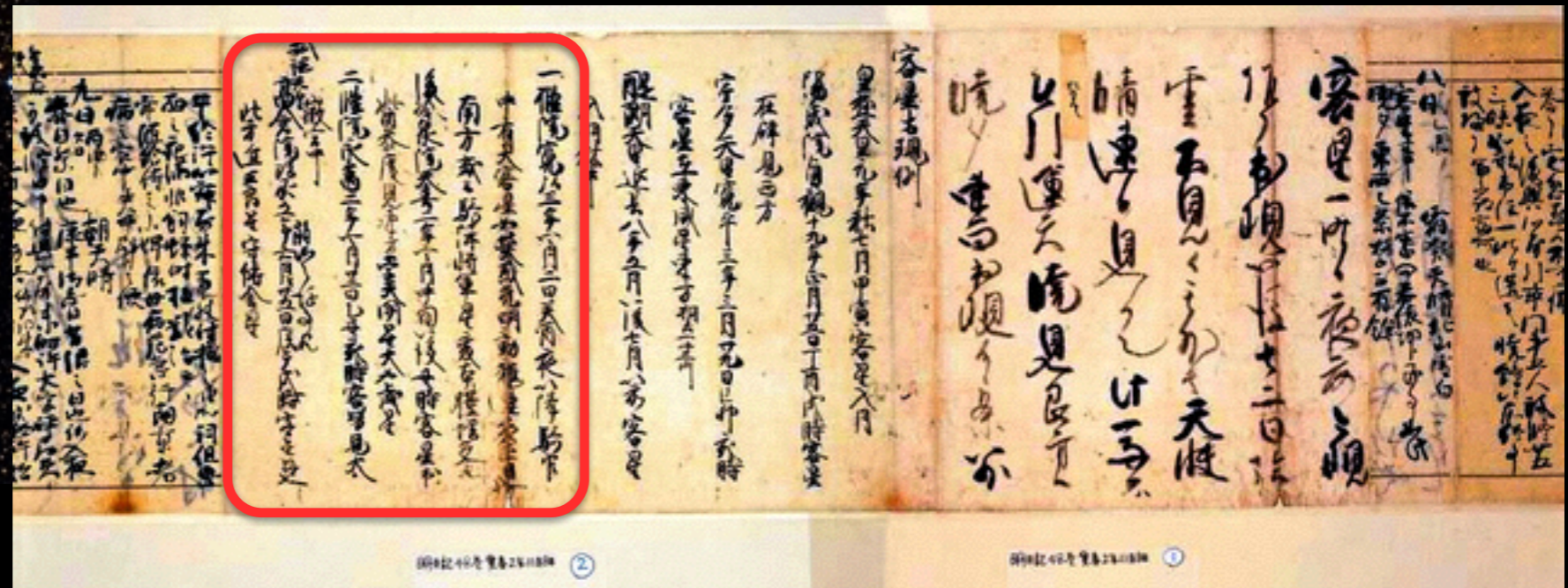
ばくはつ

# 星はさいごに大爆発 (超新星爆発)

## 「明月記」の天文現象記載



SN1006



- ① 安倍清明の息子， 安倍吉昌がSN1006を観測
  - ② 清明の子孫（詳細不明）がSN1054を観測
  - ③ 清明の子孫（詳細不明）がSN1181を観測
- 藤原定家本人も見ている可能性あり



# SN 1006 超新星残骸 Supernova Remnant

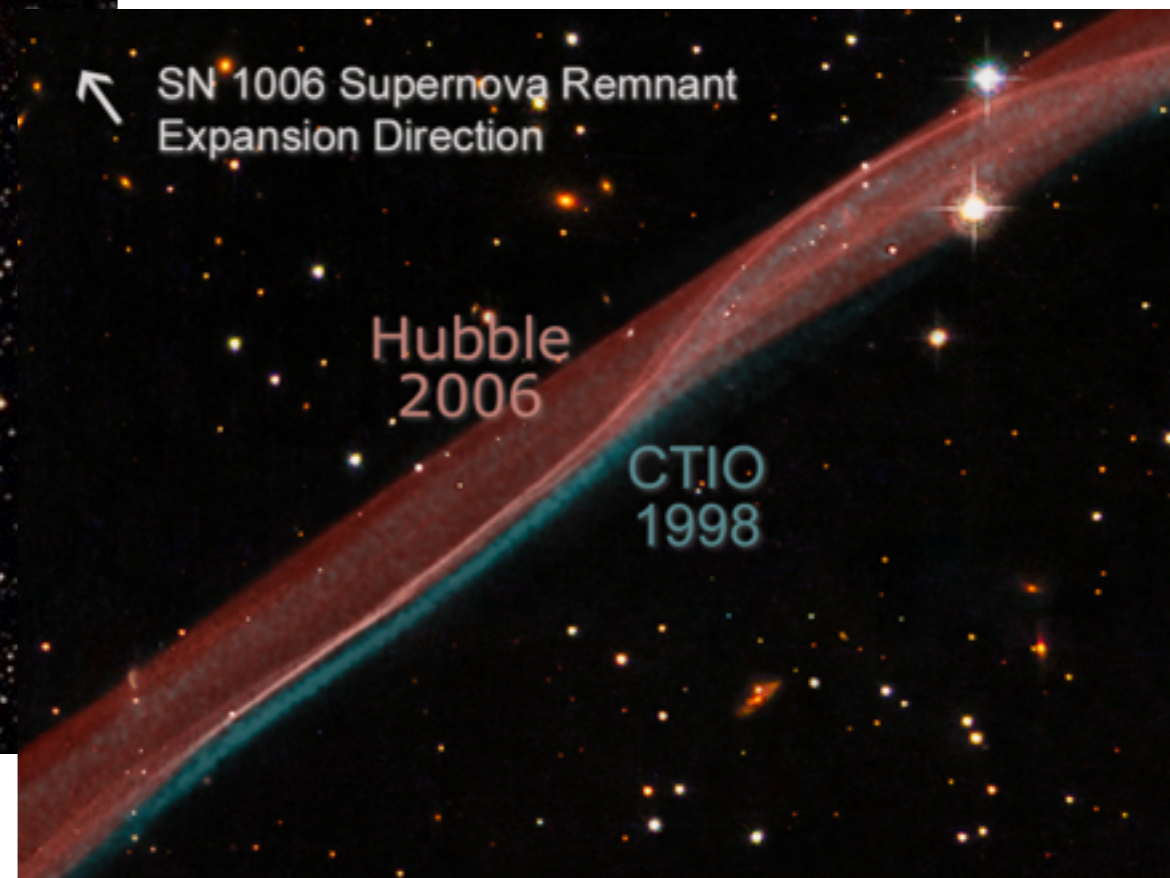
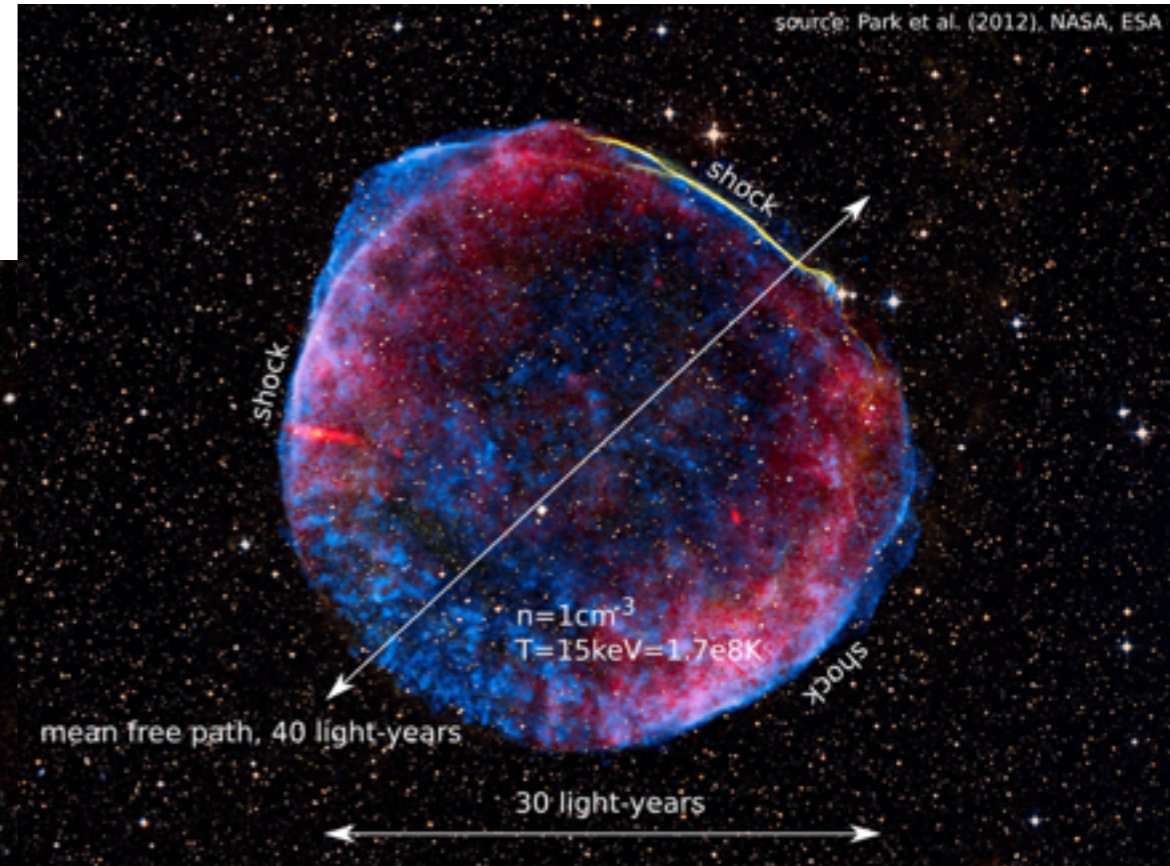
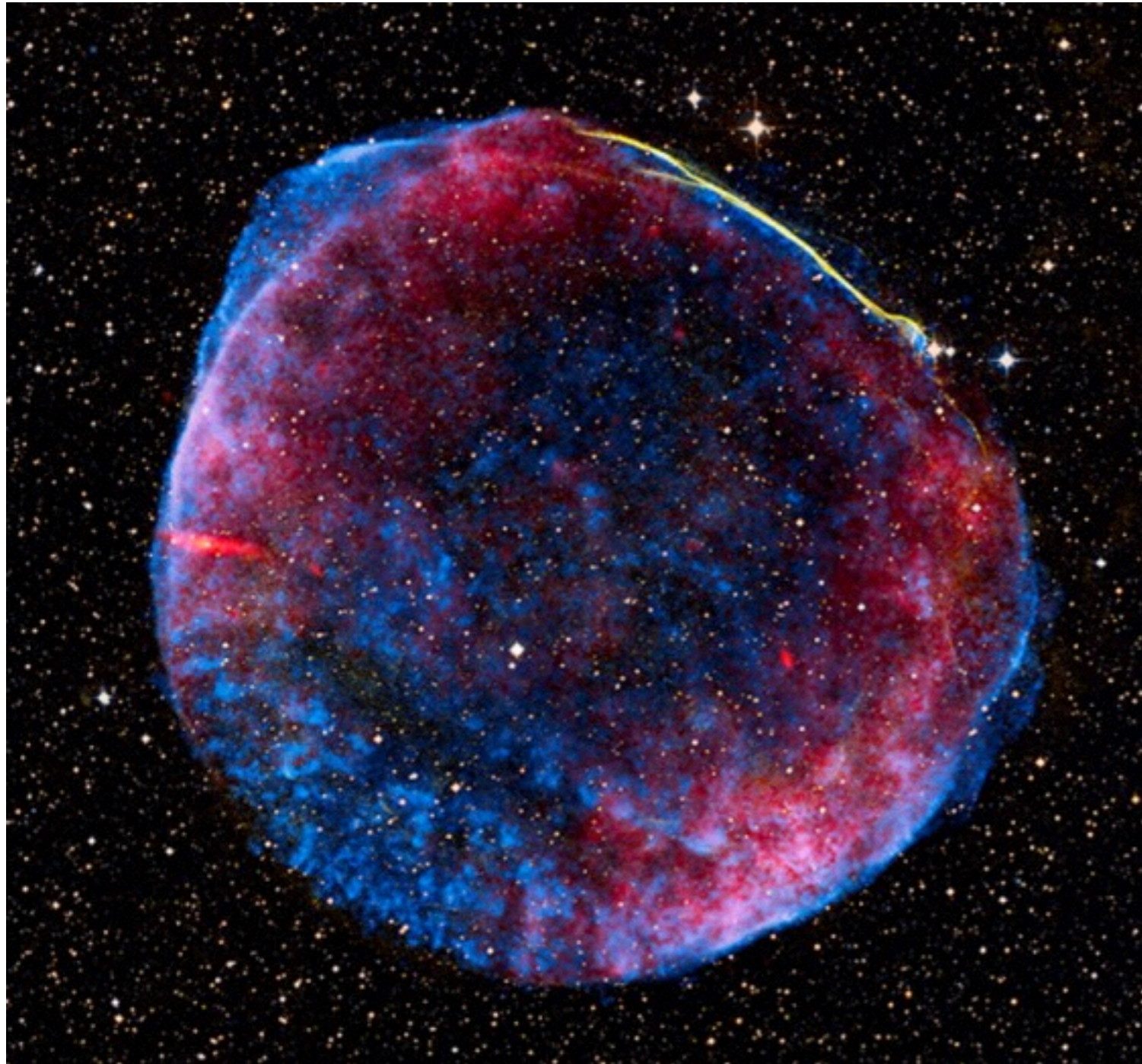
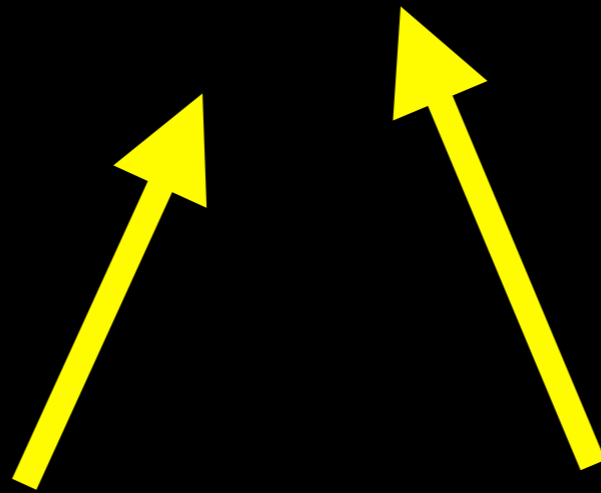


Image credit: Chandra, Hubble, and NRAO teams,  
retrieved from [heasarc.gsfc.nasa.gov](http://heasarc.gsfc.nasa.gov).



ブラックホール

= 光も抜け出せない重い重い重い星



# 重力の正体は？

じゅうりよく しょうたい



by Frits Ahlefeldt

<http://hikingartist.com/>



by Frits Ahlefeldt



by Frits Ahlefeldt



by Frits Ahlefeldt



# 重力の正体は？



by Fritz Ahlefeldt

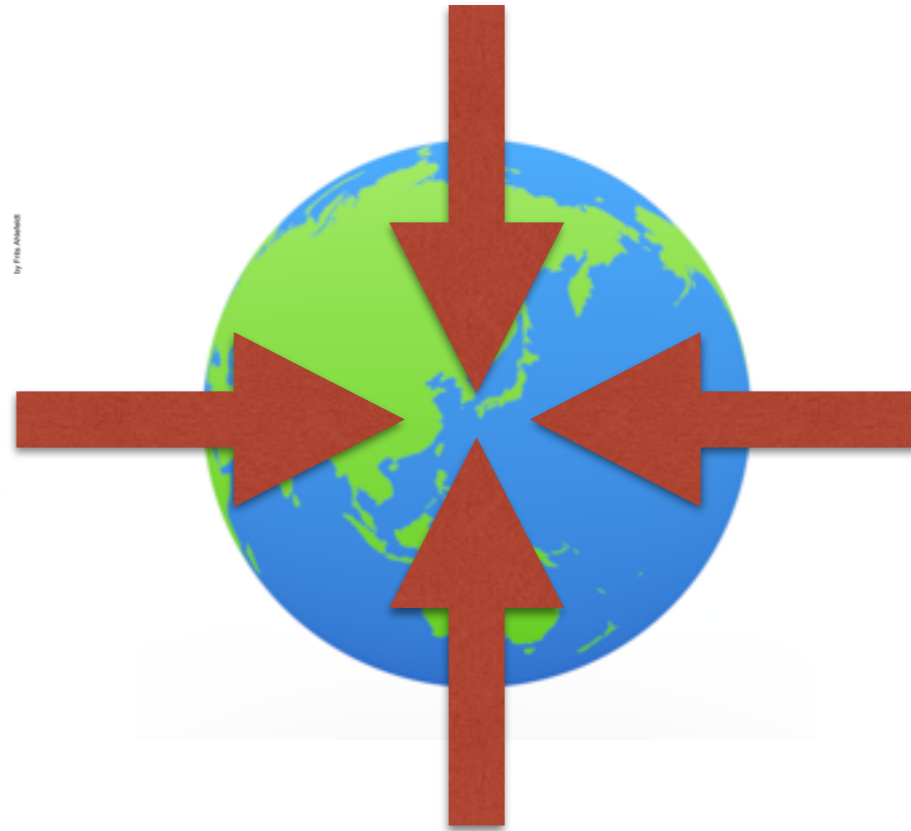
<http://hikingartist.com/>



by Fritz Ahlefeldt



by Fritz Ahlefeldt

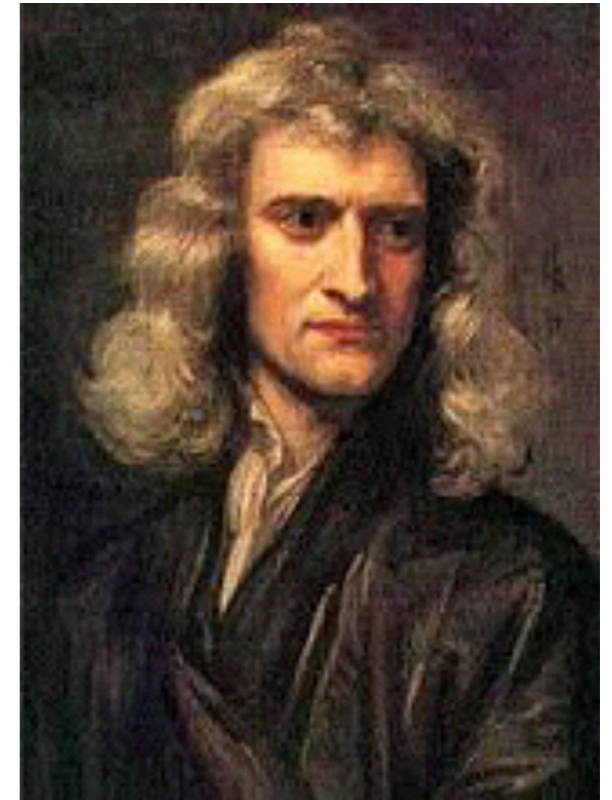
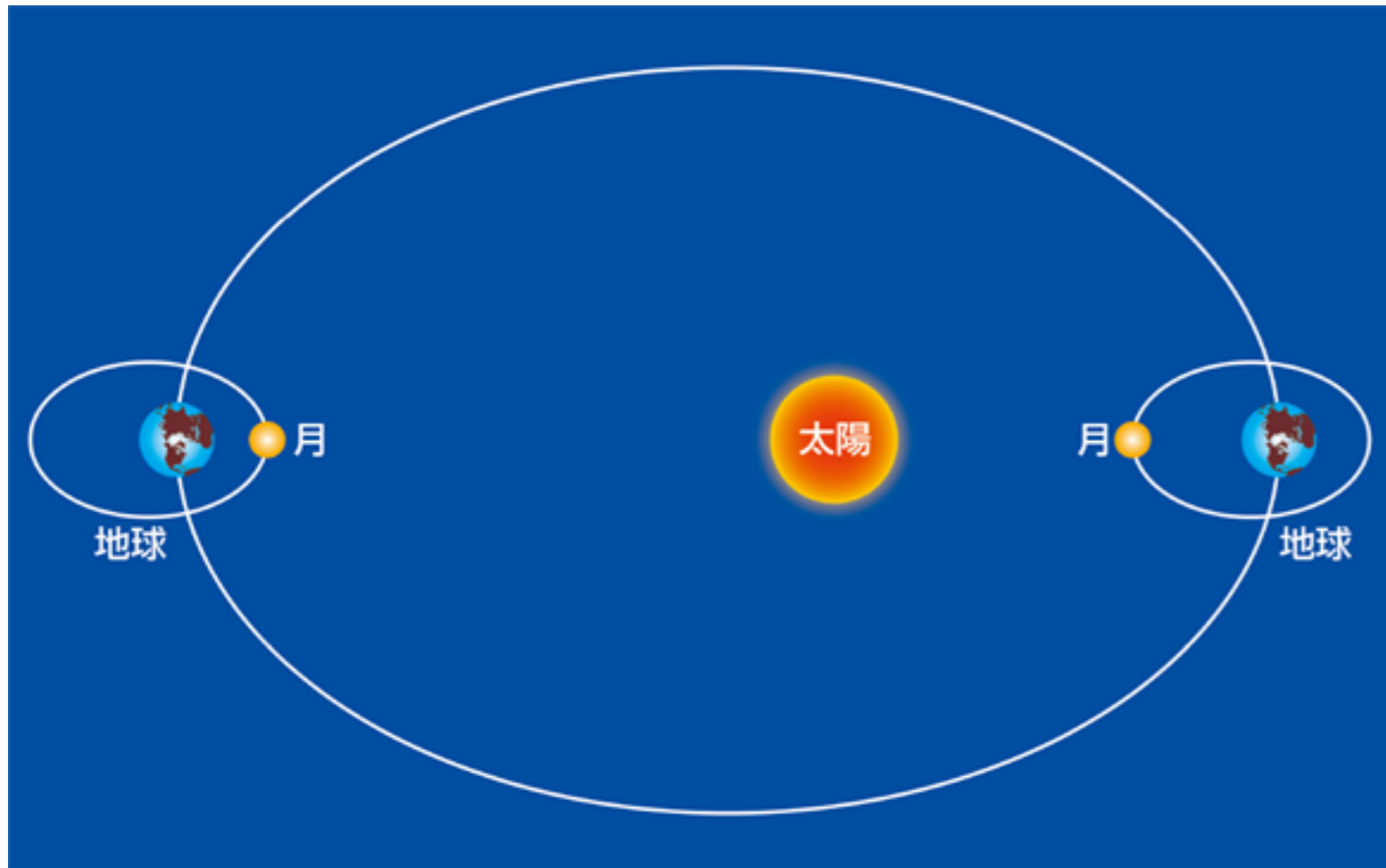


by Fritz Ahlefeldt



by Fritz Ahlefeldt

# 重力の正体は？



ニュートン

ばんゆういんりよく

**万有引力**

**＝すべてのものは引力で引き合う**

# 重力の正体は？



「万有引力があるからだ」 (ニュートン, 1687)

$$F = G \frac{Mm}{r^2}$$

$$m \frac{d^2 x}{dt^2} = F$$

じくう

「時空のゆがみだ」

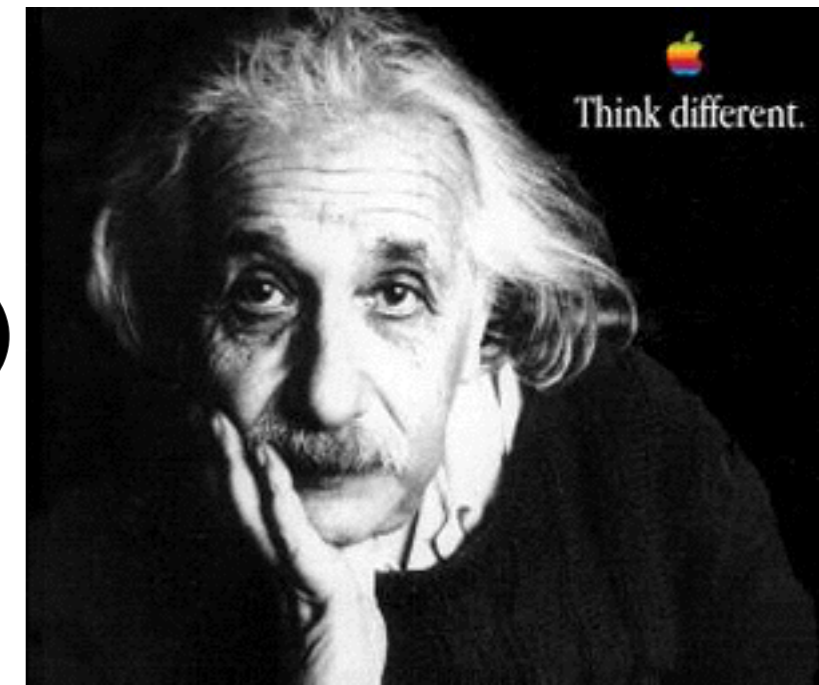
(アインシュタイン, 1915)

**一般相対性理論**

いっぱんそうたいせいりるん

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

$$\frac{d^2 \xi^\mu}{d\tau^2} = R^\mu{}_{\nu\rho\sigma} \frac{d\xi^\nu}{d\tau} \frac{d\xi^\rho}{d\tau} \xi^\sigma$$



<http://hikingartist.com/>

by Frits Ahlefeldt

IMAGINE THAT SPACE IS A GIANT SHEET OF RUBBER...

THINGS THAT HAVE MASS CAUSE THAT RUBBER SHEET TO BEND, LIKE A BOWLING BALL ON A TRAMPOLINE.

THE MORE MASS, THE MORE THAT SPACE GETS BENT AND DISTORTED BY GRAVITY.



FOR EXAMPLE, THE REASON THE EARTH GOES AROUND THE SUN IS THAT THE SUN IS VERY MASSIVE, CAUSING A BIG DISTORTION OF THE SPACE AROUND IT.



IF YOU JUST TRY TO MOVE IN A STRAIGHT LINE AROUND SUCH A BIG DISTORTION, YOU WILL FIND YOURSELF ACTUALLY MOVING IN A CIRCLE.

THAT'S HOW ORBITS WORK: THERE'S NO ACTUAL FORCE PULLING THE PLANETS AROUND, JUST A BENDING OF THE SPACE.

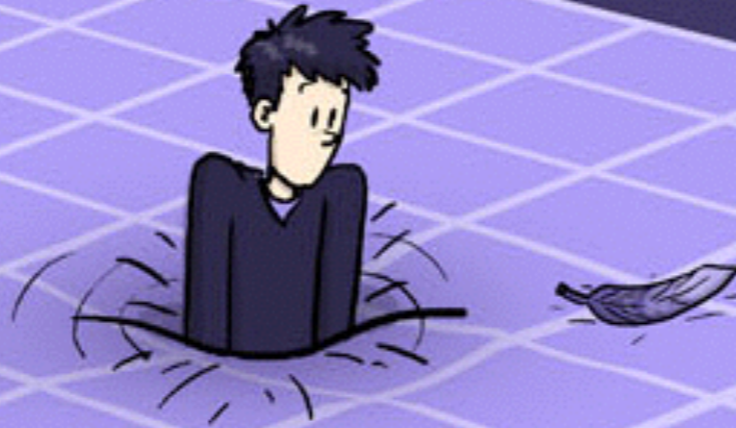


FailsShot

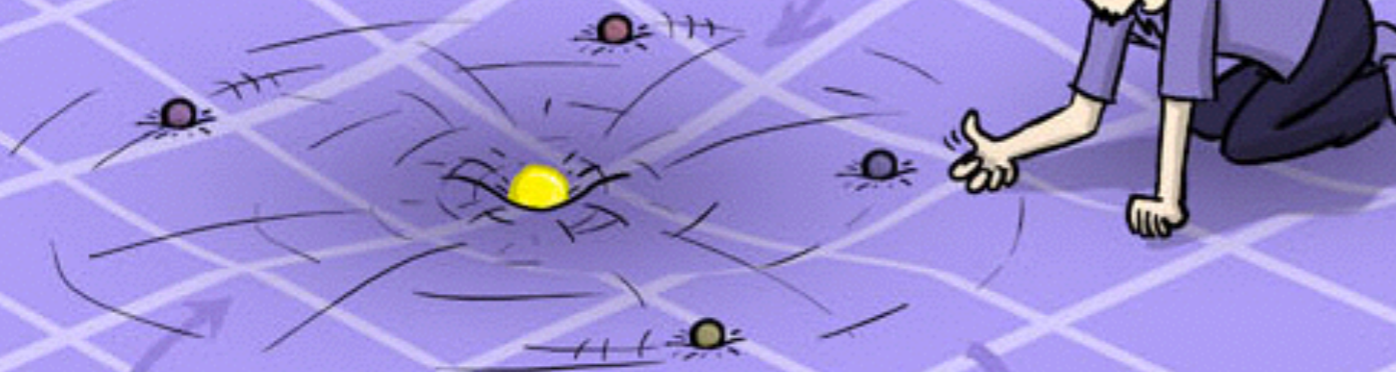
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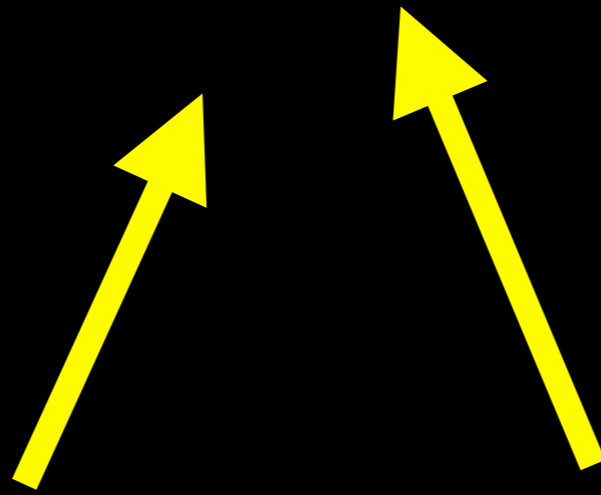
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ブラックホール

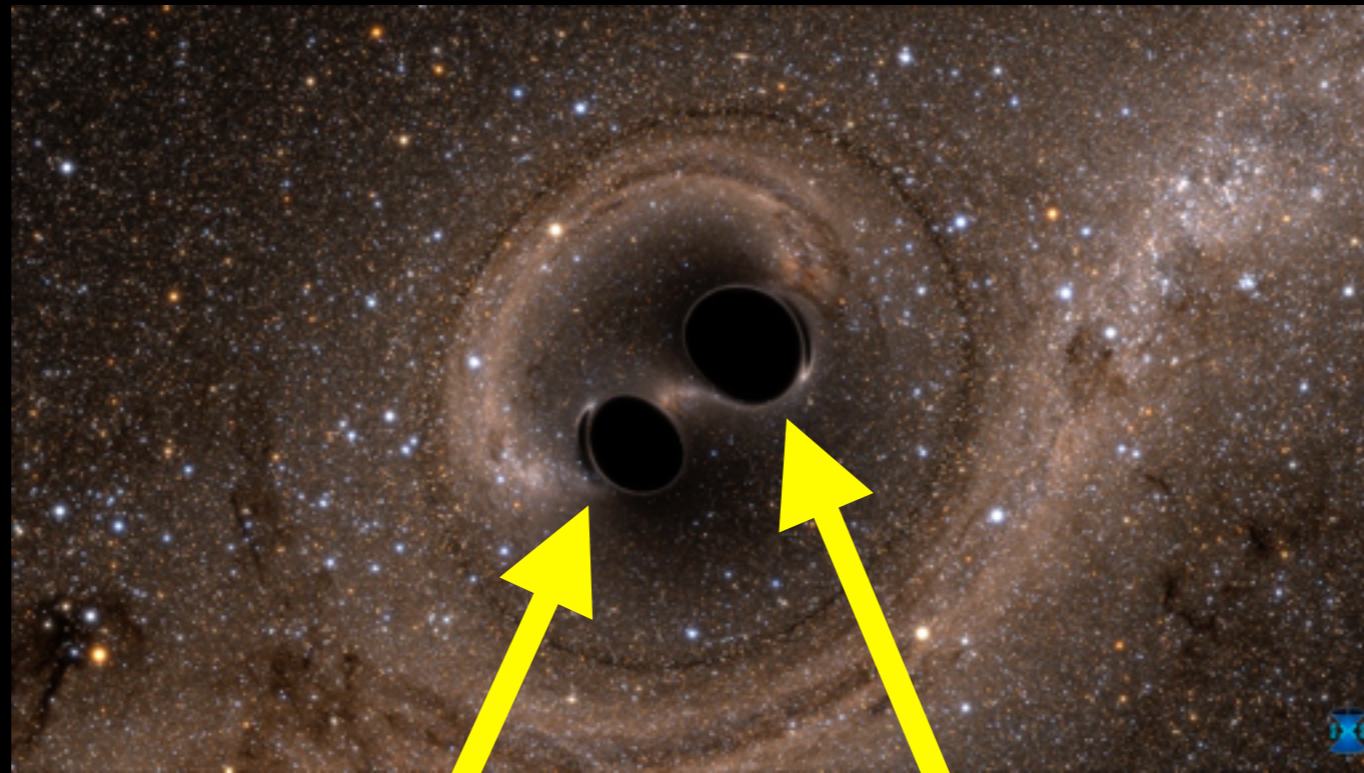
= 光も抜け出せない重い重い重い星





# ブラックホール

= 光も抜け出せない重い重い重い星



はくちょう座

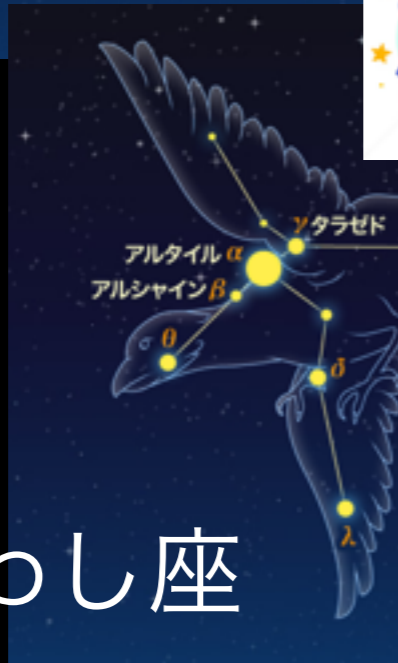


X-1

こと座



へびつかい座



わし座

いて座

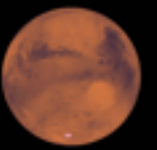


さそり座

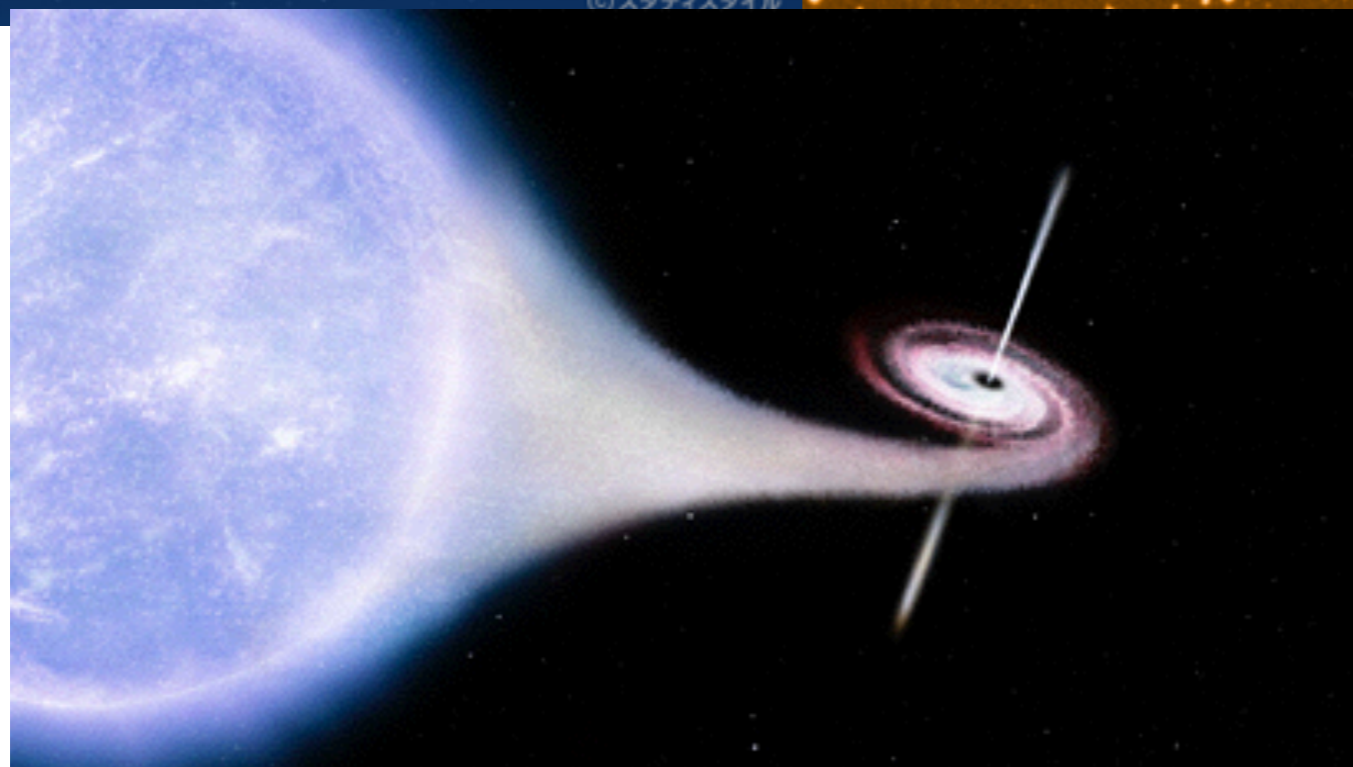
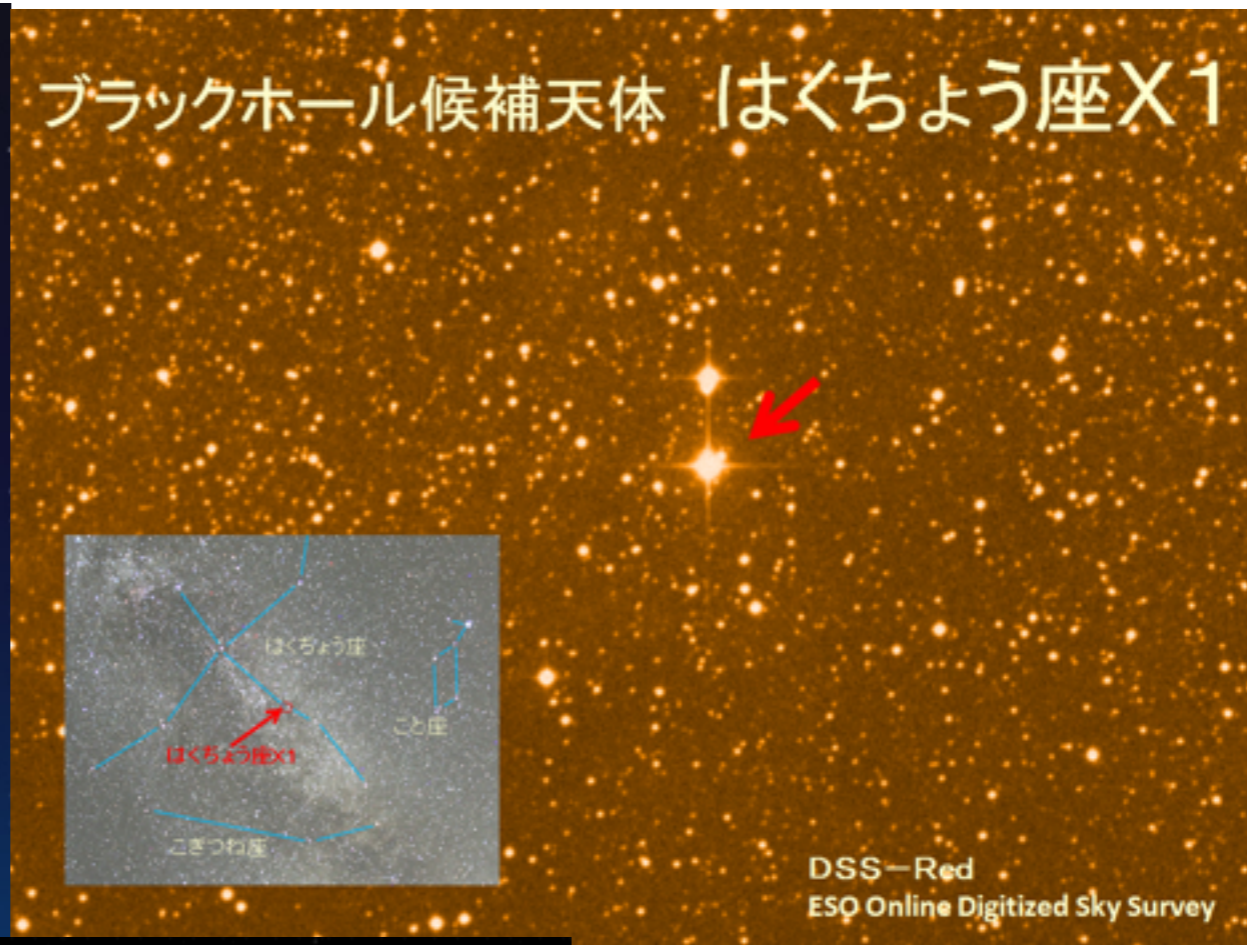
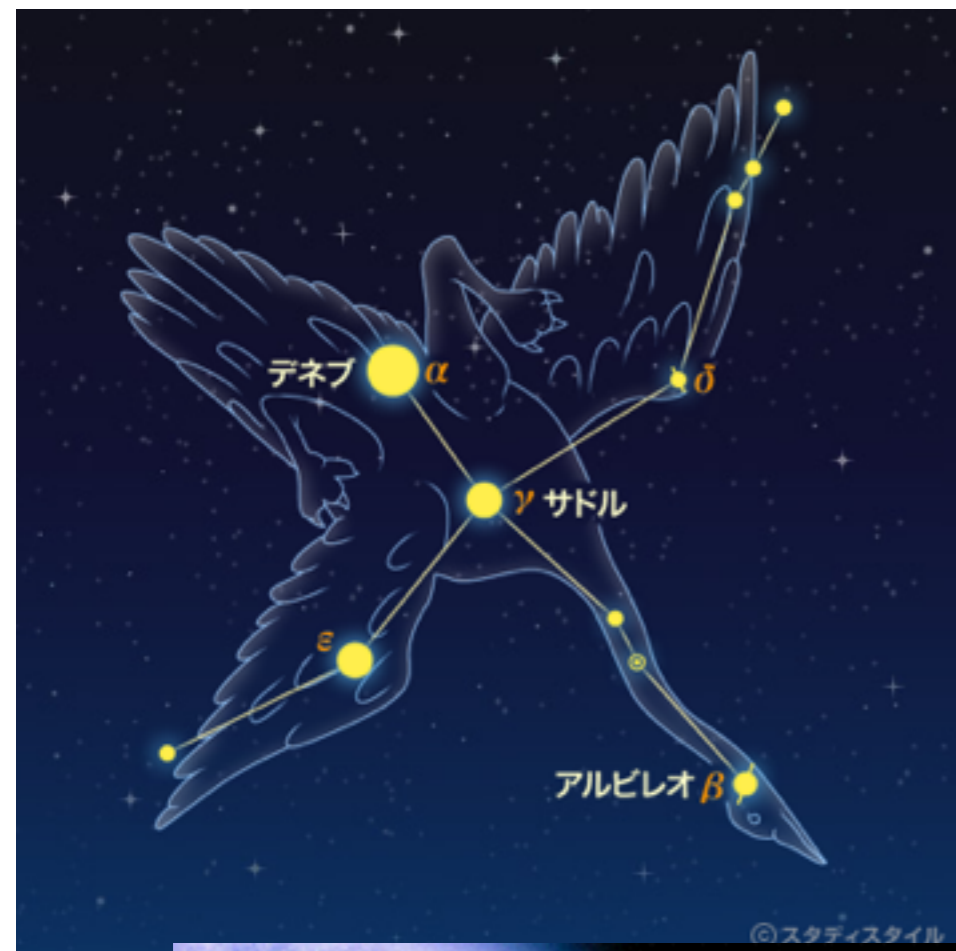


土星

火星



# はくちょう座 X-1



見えないけれど、  
ブラックホールが  
あるにちがいない！

はくちょう座



こと座



へびつかい座



X-1



わし座



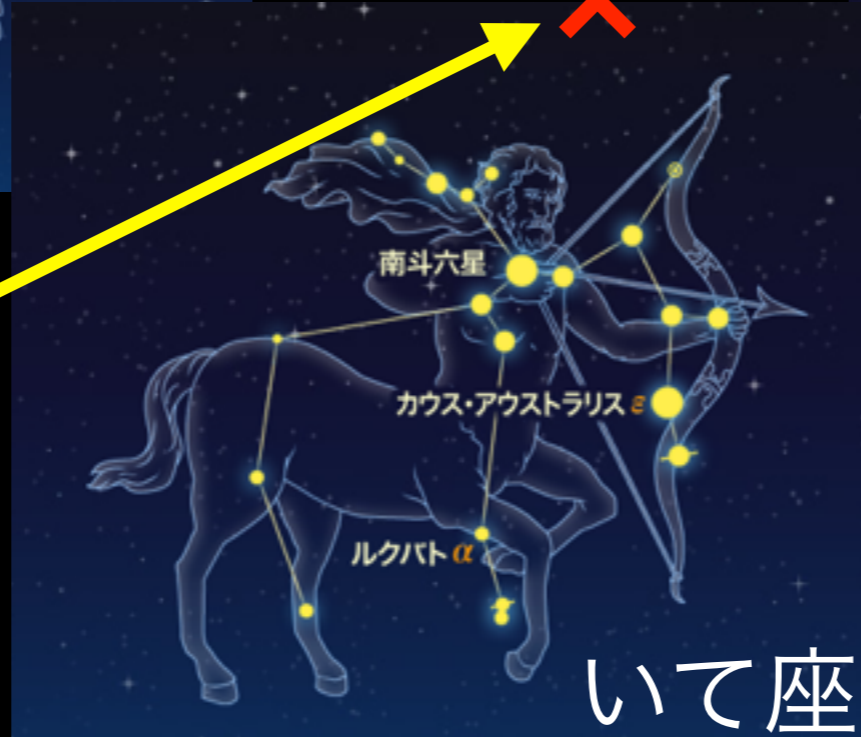
土星

火星



さそり座

Sgr A\*



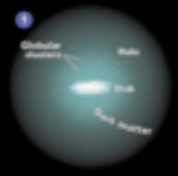
いて座

# 天の川銀河 (our Galaxy)

## THE MILKY WAY

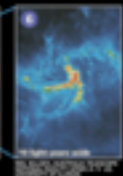
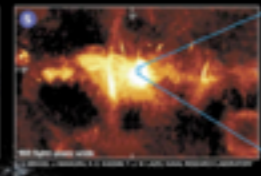
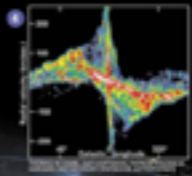
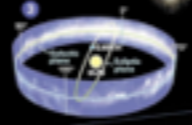


**H**ow far from Earth, the Milky Way is a spiral-shaped system of a few hundred billion stars. Bright regions of recently formed stars highlight its arms, while older stars explode or shed their outer layers as beautiful planetary nebulae, then fade away and die. A thick swarm of orange and red stars marks the galactic bulge, encapsulating the star-packed galactic center. At its core may lie a black hole, a region so dense that not even light can escape its gravitational pull. All objects in the Milky Way orbit the galactic center, much like planets in Earth's solar system revolve around the sun. But the scale is staggering: Light from a star at one edge of the galaxy takes about 100,000 years to reach the opposite side.



### GUIDE TO THE GALAXY

For beyond the galaxy disk, yet drawn by its gravity, some stars and planetary nebulae roam the galaxy halo. Regions of dark matter—regions that fall through by gravitational effects—stretch beyond that. Earth's orbit around the sun lies at a severe angle to the galactic plane.



### A TURBULENT HEART

A graph based on a radio survey reveals the retrograde motion of interstellar gas in the inner part of our galaxy, gas swirling away from Earth's galactic core and toward Earth's galactic heart. The turbulent gas appears to be a black hole some 2.6 million times as massive as the sun.

This computer-generated image of the Milky Way—our perspective of a 3-D model newly compiled for NASA's GalaxyCom—incorporates the actual positions of hundreds of thousands of stars and nebulae.

- Stellar star cluster
- Interstellar gas and dust
- Nebulae
- Star-forming region
- Galactic bulge
- Galactic disk
- Galactic halo
- Galactic center
- Galactic core

### PLANETARY NEBULA NGC 6

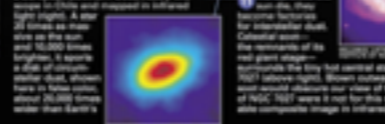


Earth's habitability in the Milky Way depends on the presence of a habitable zone around the sun. The sun's habitability zone is the region where liquid water can exist on a planet's surface. The sun's habitability zone is the region where liquid water can exist on a planet's surface. The sun's habitability zone is the region where liquid water can exist on a planet's surface.

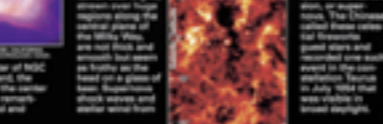
galaxy, including dark matter, is a vast, diffuse cloud of gas and dust that surrounds the sun. The sun's habitability zone is the region where liquid water can exist on a planet's surface. The sun's habitability zone is the region where liquid water can exist on a planet's surface.



stars, however, are scattered throughout the galaxy. The sun's habitability zone is the region where liquid water can exist on a planet's surface. The sun's habitability zone is the region where liquid water can exist on a planet's surface.



Light from the sun is absorbed by the interstellar dust that surrounds the sun. The sun's habitability zone is the region where liquid water can exist on a planet's surface. The sun's habitability zone is the region where liquid water can exist on a planet's surface.



stars may have shaped this surprising pattern. The sun's habitability zone is the region where liquid water can exist on a planet's surface. The sun's habitability zone is the region where liquid water can exist on a planet's surface.



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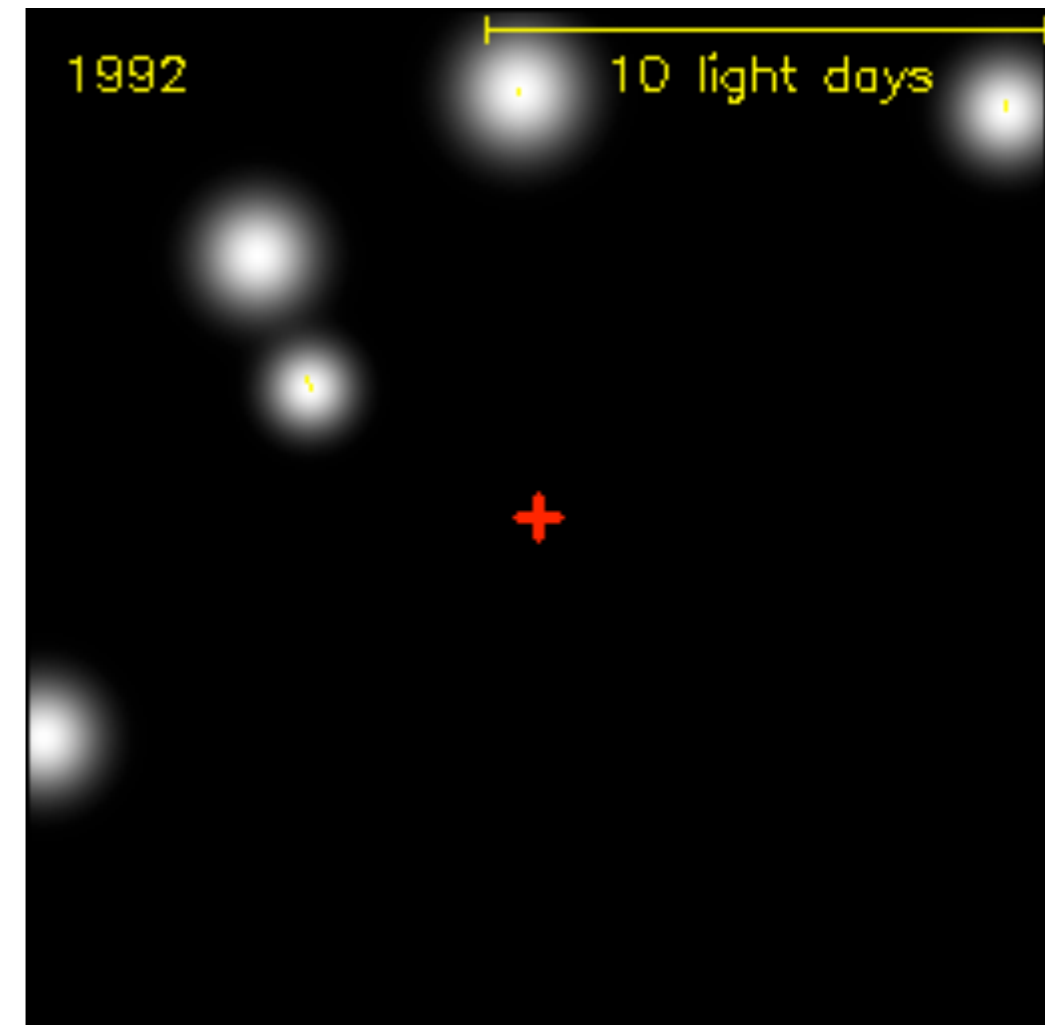
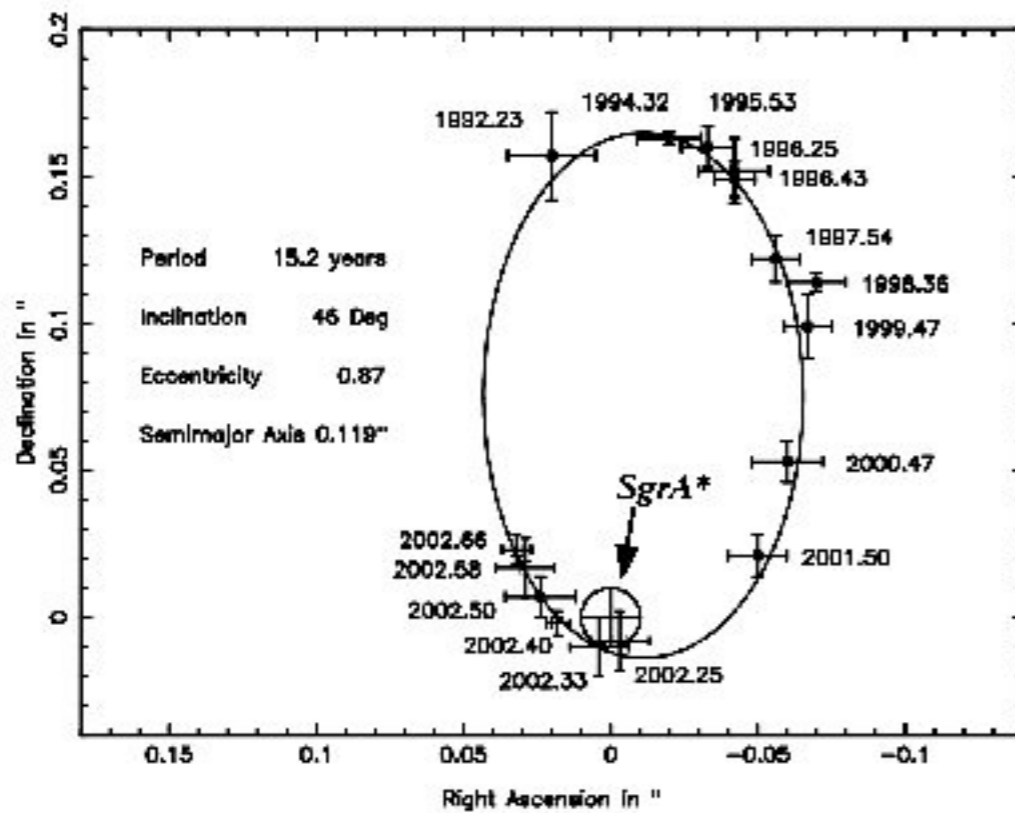
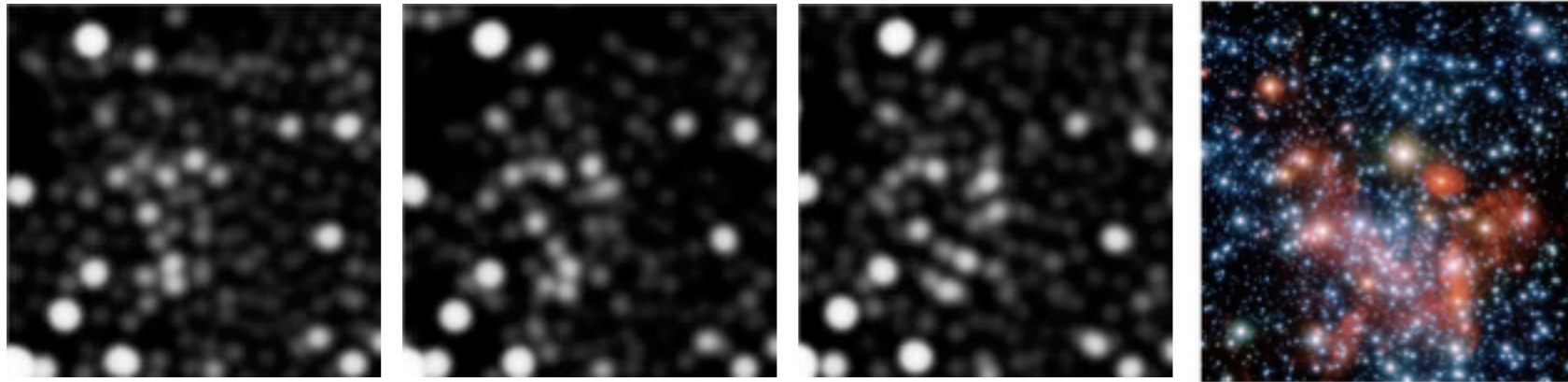
# 銀河系の中心には巨大ブラックホールがある



Zooming in on the centre of the Milky Way

<http://www.youtube.com/watch?v=XhHUNvEKUY8> (1:15)

# 銀河系の中心には巨大ブラックホールがある



<http://www.extinctionshift.com/SignificantFindings08.htm>

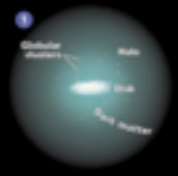
<http://www.brighthub.com/science/space/articles/13435.aspx#>

# 天の川銀河 (our Galaxy)

## THE MILKY WAY



**H**ow far from Earth, the Milky Way is a spiral-shaped system of a few hundred billion stars. Bright regions of recently formed stars highlight its arms, while older stars explode or shed their outer layers as beautiful planetary nebulae, then fade away and die. A thick swarm of orange and red stars marks the galactic bulge, encapsulating the star-packed galactic center. At its core may be a black hole, a region so dense that not even light can escape its gravitational pull. All objects in the Milky Way orbit the galactic center, much like planets in Earth's solar system revolve around the sun. But the scale is staggering: Light from a star at one edge of the galaxy takes about 100,000 years to reach the opposite side.

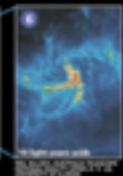
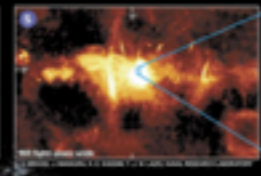
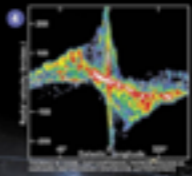
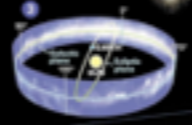


### GUIDE TO THE GALAXY

For beyond the galaxy disk, yet drawn by its gravity, some stars and planetary nebulae roam the galaxy halo. Regions of dark matter—regions that fall through by gravitational effects—stretch beyond that.

Year clouds of interstellar dust block much of our night sky view of the Milky Way, which from our position in the flat galactic disk, appears as a hazy band of light. Interstellar dust can see through the dust to reveal the galaxy's structure.

Earth's orbit around the sun lies at a severe angle to the galactic plane.



### A TURBULENT HEART

A graph based on a radio survey reveals the intergalactic structure of intergalactic gas in the inner part of our galaxy. Gas swirling away from Earth's core and toward Earth's galactic heart. The diagram gas appears white; red shows blue.

Massive amounts of energy are released near the center of the Milky Way, producing

This computer-generated image of the Milky Way—our perspective of a 3-D model—incorporates the actual positions of hundreds of thousands of stars and nebulae.

- Stellar star cluster
- Interstellar gas and dust
- Nebulae
- Star-forming region
- Stellar bulge
- Stellar bulge in center
- Galactic core

### PLANETARY NEBULA NGC 6



Earth's habitability depends on the Milky Way's stellar population and star clusters are found throughout Earth's galaxy. Stars of the red dwarf star are particularly common in a variety of surrounding nebulae. These stars form about 100 billion years from now, a dying star expanded into a red giant and was transformed into the nebula NGC 6. As its center shrinks...

galaxy, including dark matter, is rich in interstellar dust that swirls in our galaxy's spiral arms. When a star releases a dark nebula, the dust particles collect and form a protostar.

stars, however, are star in the Milky Way, the Hubble Space Telescope focused on a rare star region in the Sagittarius arm about 100,000 light years from Earth. These luminous stars formed at different times, most are older than the sun. They provide an essential part of a star's fuel.

The million-year-old stars are packed into a globular cluster such as Omega Centauri.

light are seen in the Milky Way. Unlike human

Light from the hot star is absorbed by and scatters the dust, creating a glow called a reflection nebula. Light from the hot star is absorbed by and scatters the dust, creating a glow called a reflection nebula.

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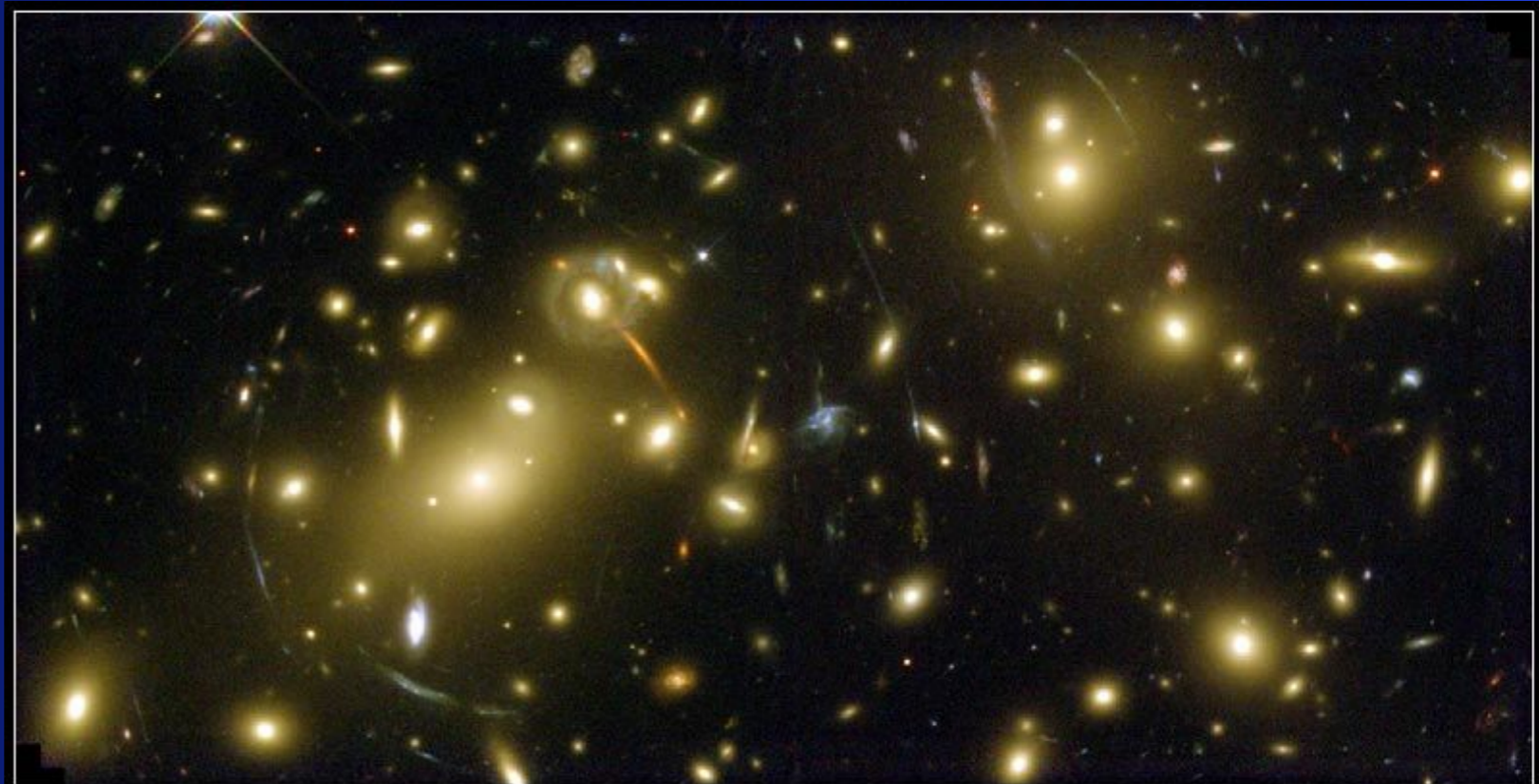
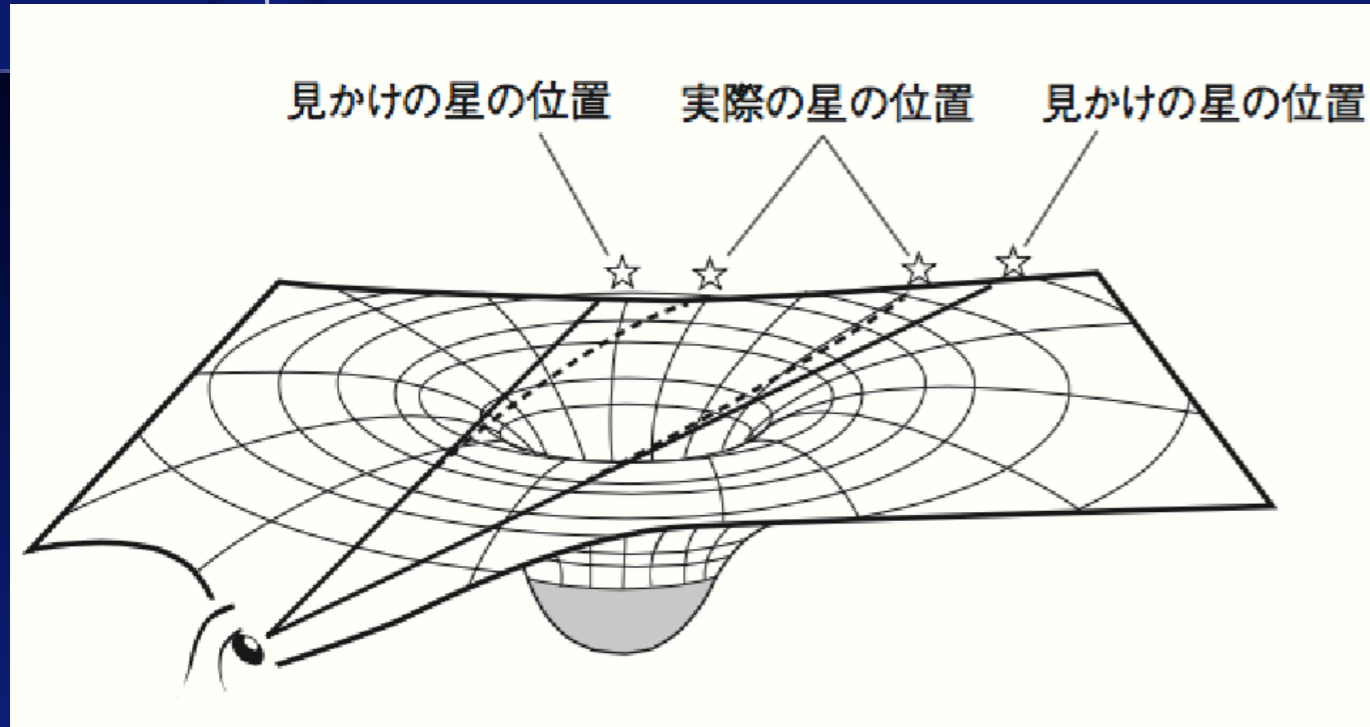
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# ブラックホールはどう見える？

1. 重力レンズで曲がって見える

# 重力レンズ効果



**Galaxy Cluster Abell 2218**

NASA, A. Fruchter and the ERO Team (STScI, ST-ECF) • STScI-PRC00-08

**HST • WFPC2**

MATTHEW  
McCONAUGHEY

ANNE  
HATHAWAY

JESSICA  
CHASTAIN

MICHAEL  
AND  
CAINE



GO FURTHER.

FROM THE DIRECTOR OF THE DARK KNIGHT TRILOGY AND INCEPTION

# INTERSTELLAR

IN THEATRES AND IMAX  
EVERYWHERE  
NOVEMBER 7

WARNER BROS. PICTURES PRESENTS A LEGENDARY PICTURES PRODUCTION AN INTERSTELLAR FILM BY CHRISTOPHER NOLAN CASTING BY JAMES NEWTON HOWARD COSTUME DESIGNER JAMES HENNINGSON EXECUTIVE PRODUCERS JONATHAN HOLMES AND JONATHAN WOLFF PRODUCED BY KATHLEEN KENNEDY AND JONATHAN WOLFF WRITTEN BY JONATHAN HOLMES AND JONATHAN WOLFF DIRECTED BY CHRISTOPHER NOLAN



**Interstellar (2014)**



**Executive Producer: Kip Thorne**

<https://www.youtube.com/watch?v=qZZ9jRan9eo>



## Interstellar (2014)

映画『インターステラー』スペシャル映像【HD】2014年11月22日公開

part 5'00

<https://www.youtube.com/watch?v=qZZ9jRan9eo>



**Interstellar (2014)**

**Executive Producer: Kip Thorne**

<https://www.youtube.com/watch?v=qZZ9jRan9eo>

# ブラックホールはどう見える？

1. 重力レンズで曲がって見える

2. 重力波で見える



ブラックホールも同じだ

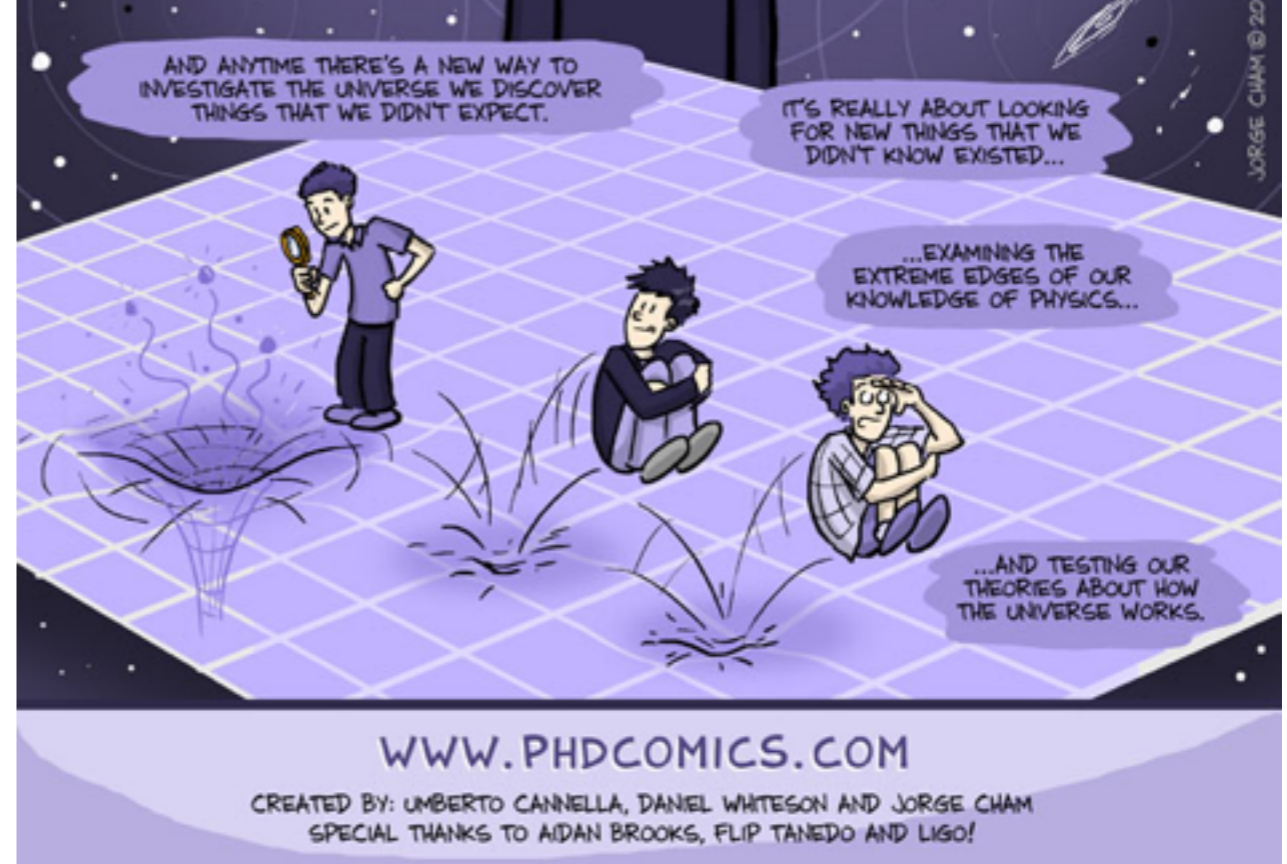
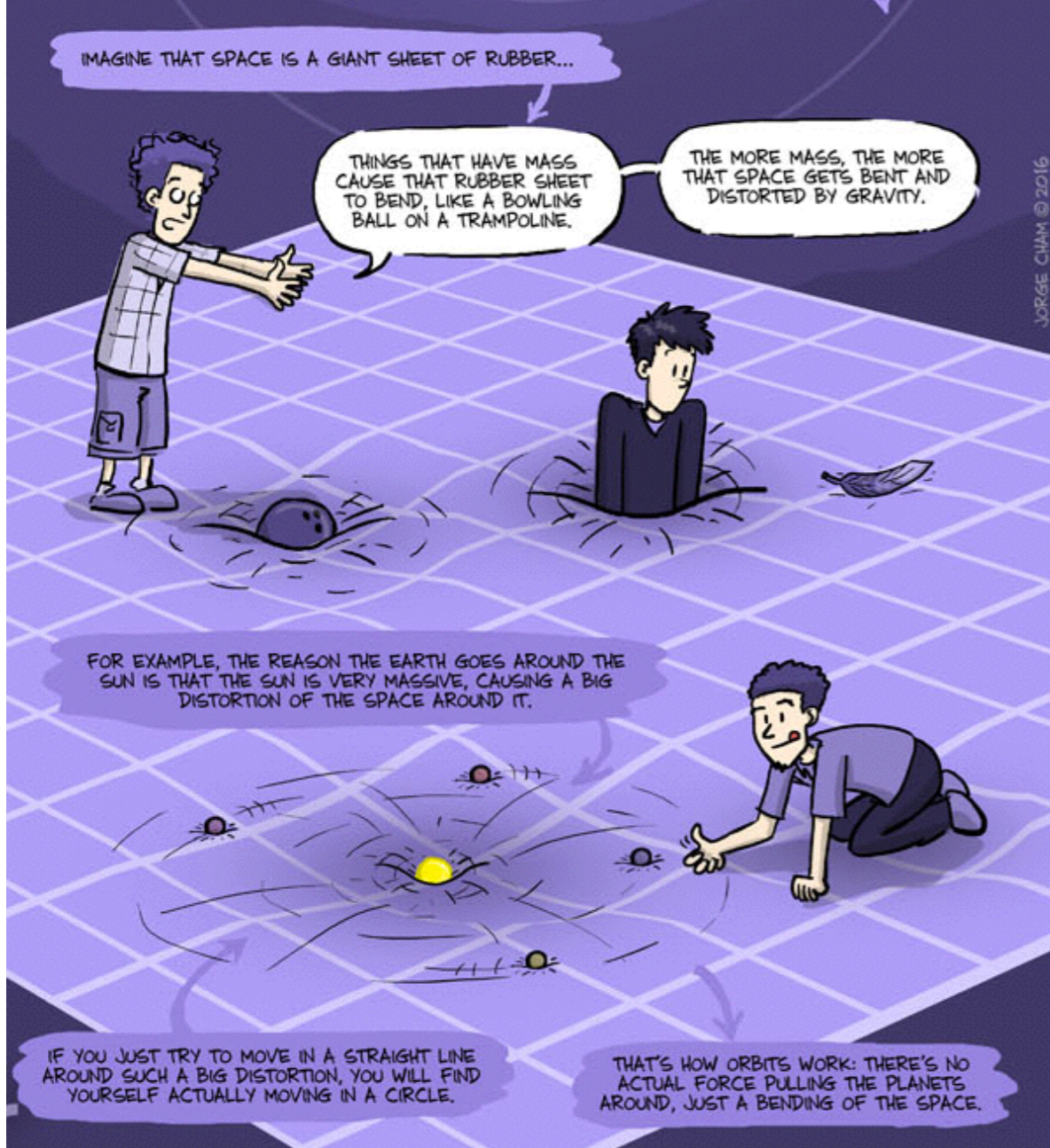
# 重力波とブラックホール

2016年2月, LIGOが重力波を初めて検出した, と発表した



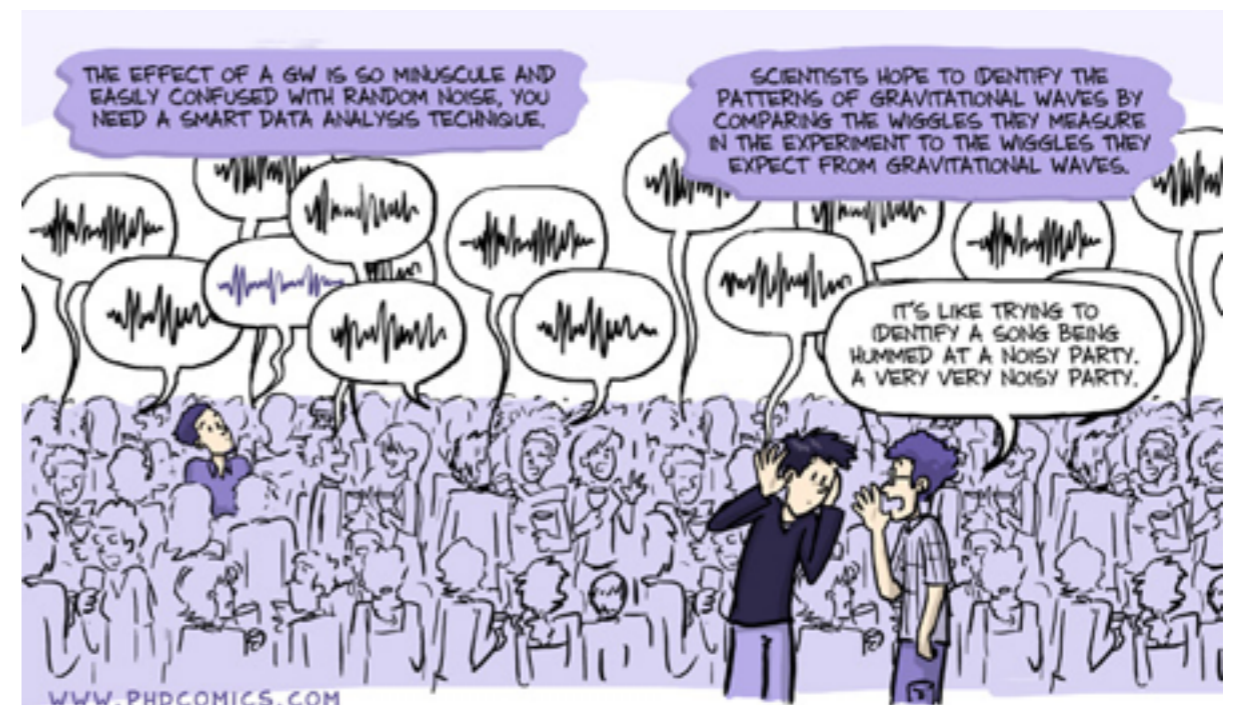
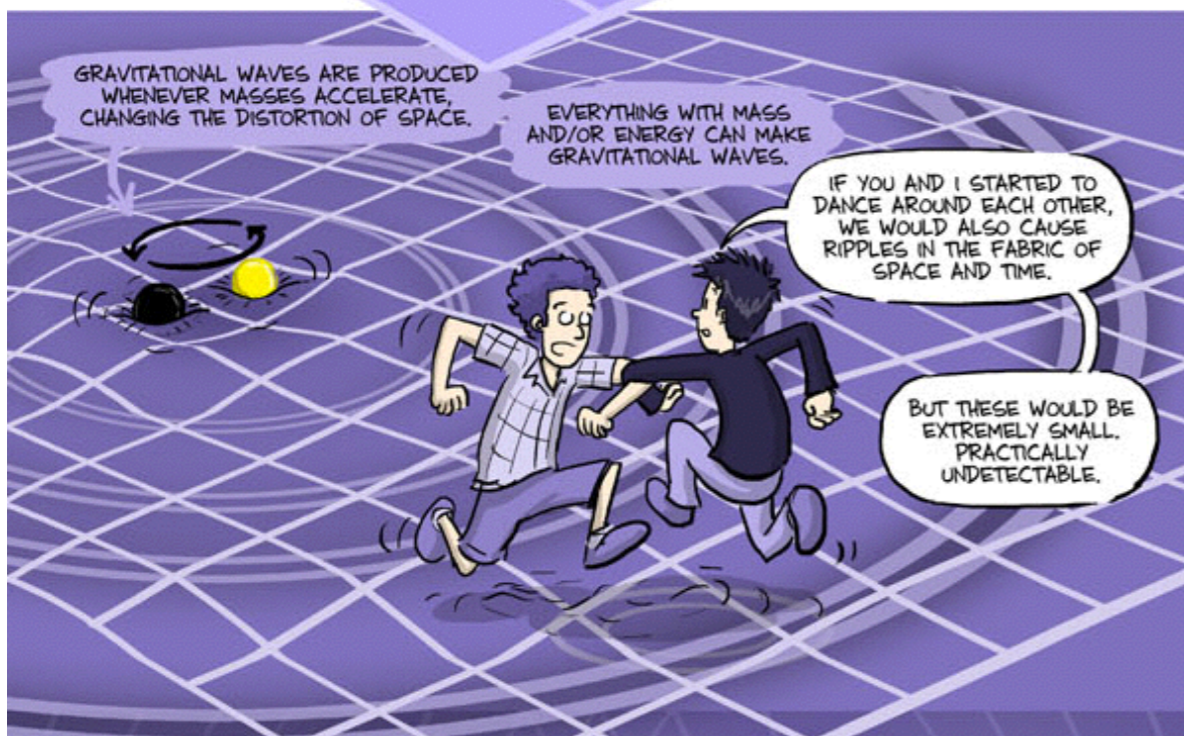
四国新聞だけ  
ちがった... 残念 (笑)



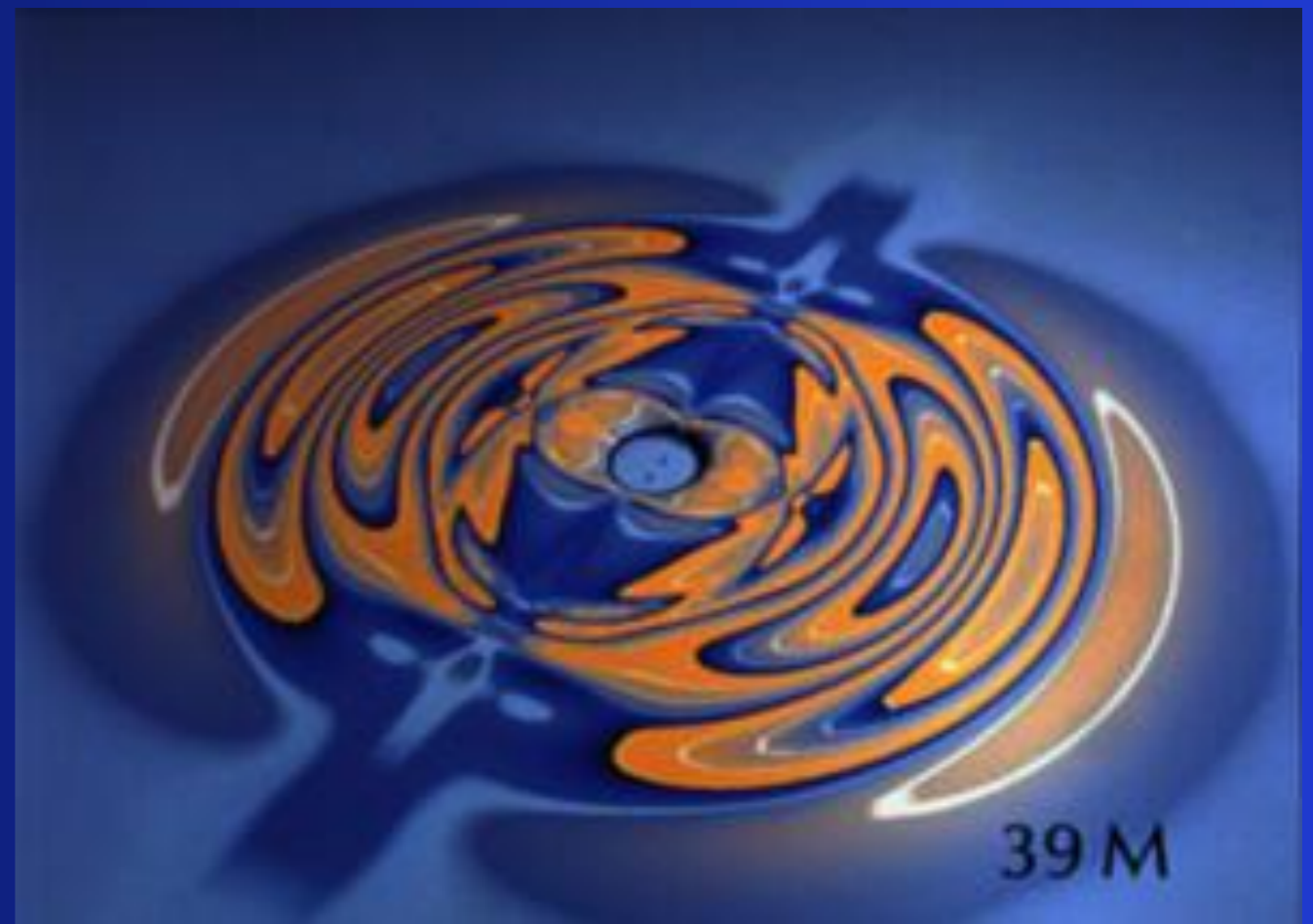
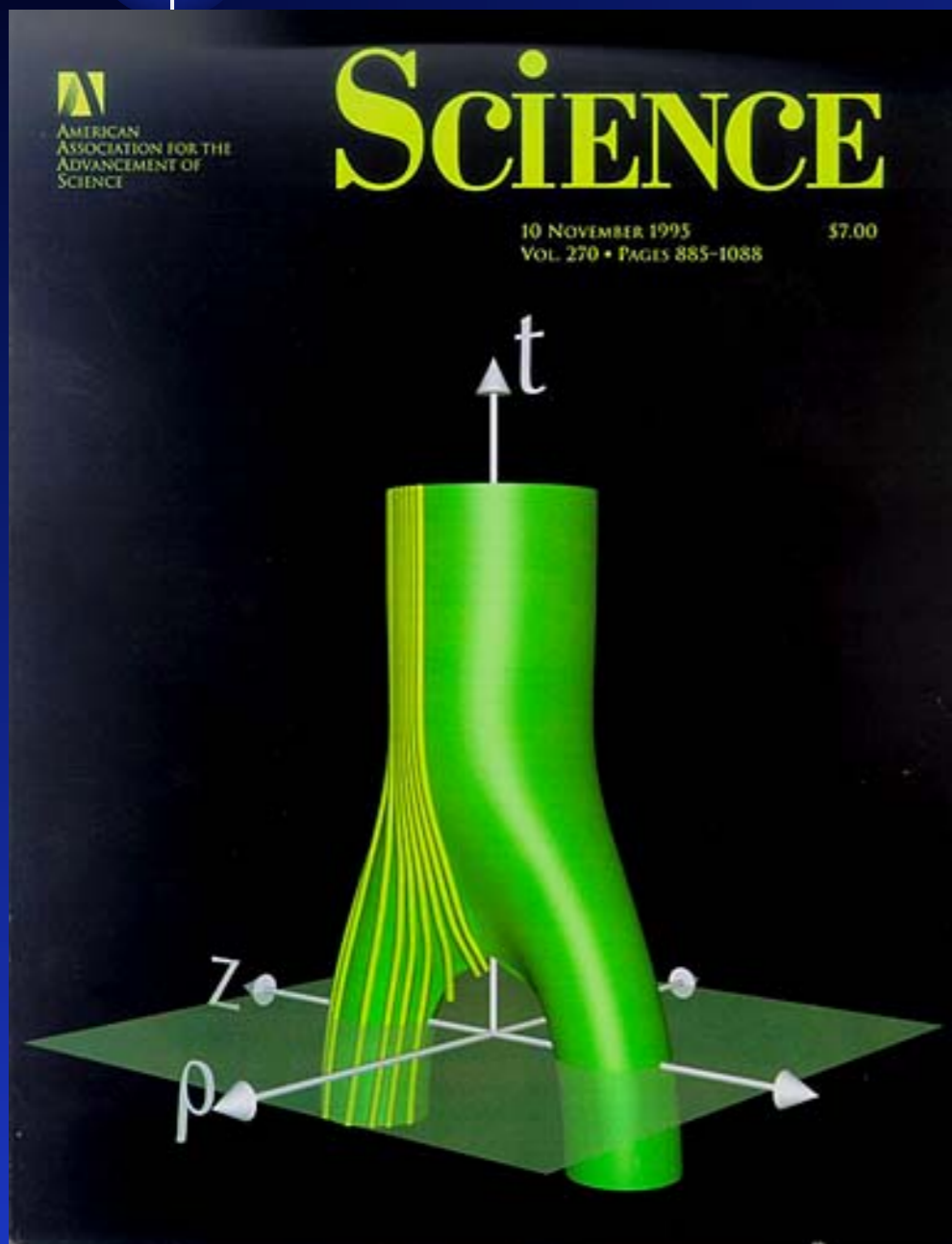


[www.phdcomics.com](http://www.phdcomics.com)

“gravitational waves explained”

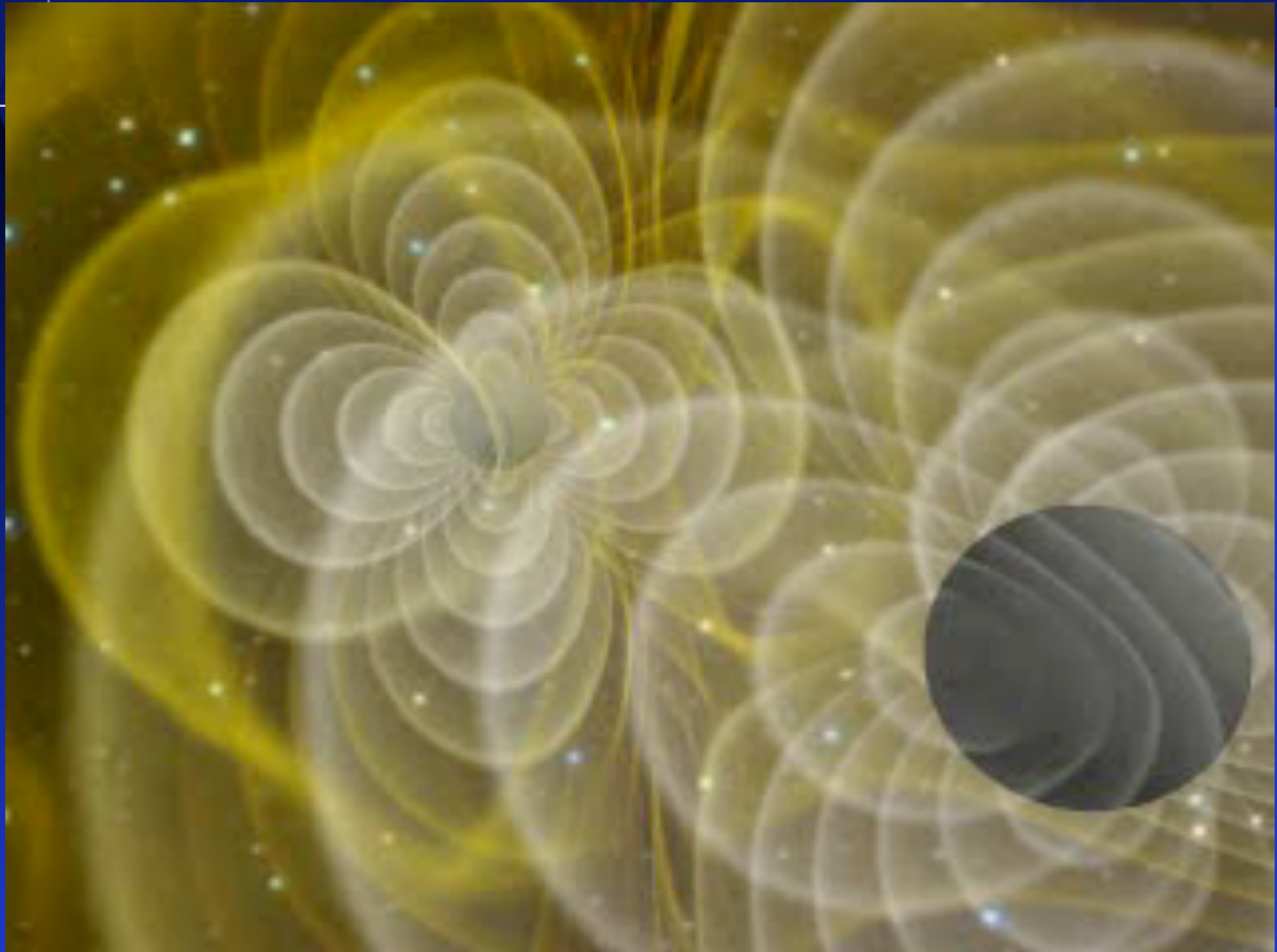


# ブラックホールの合体シミュレーション

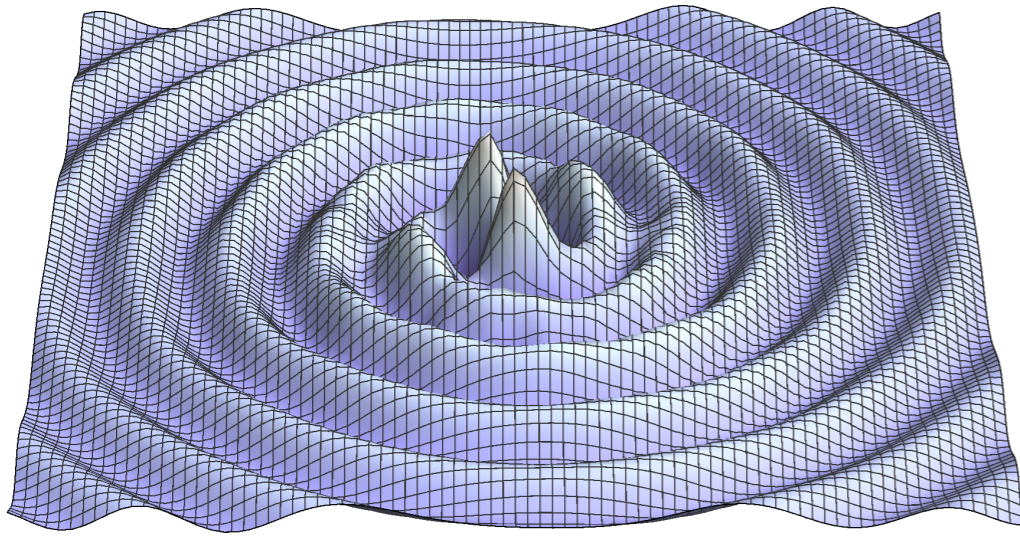


2つのブラックホールの合体と重力波放出  
(90年代, NCSAグループ)

# ブラックホールの合体シミュレーション

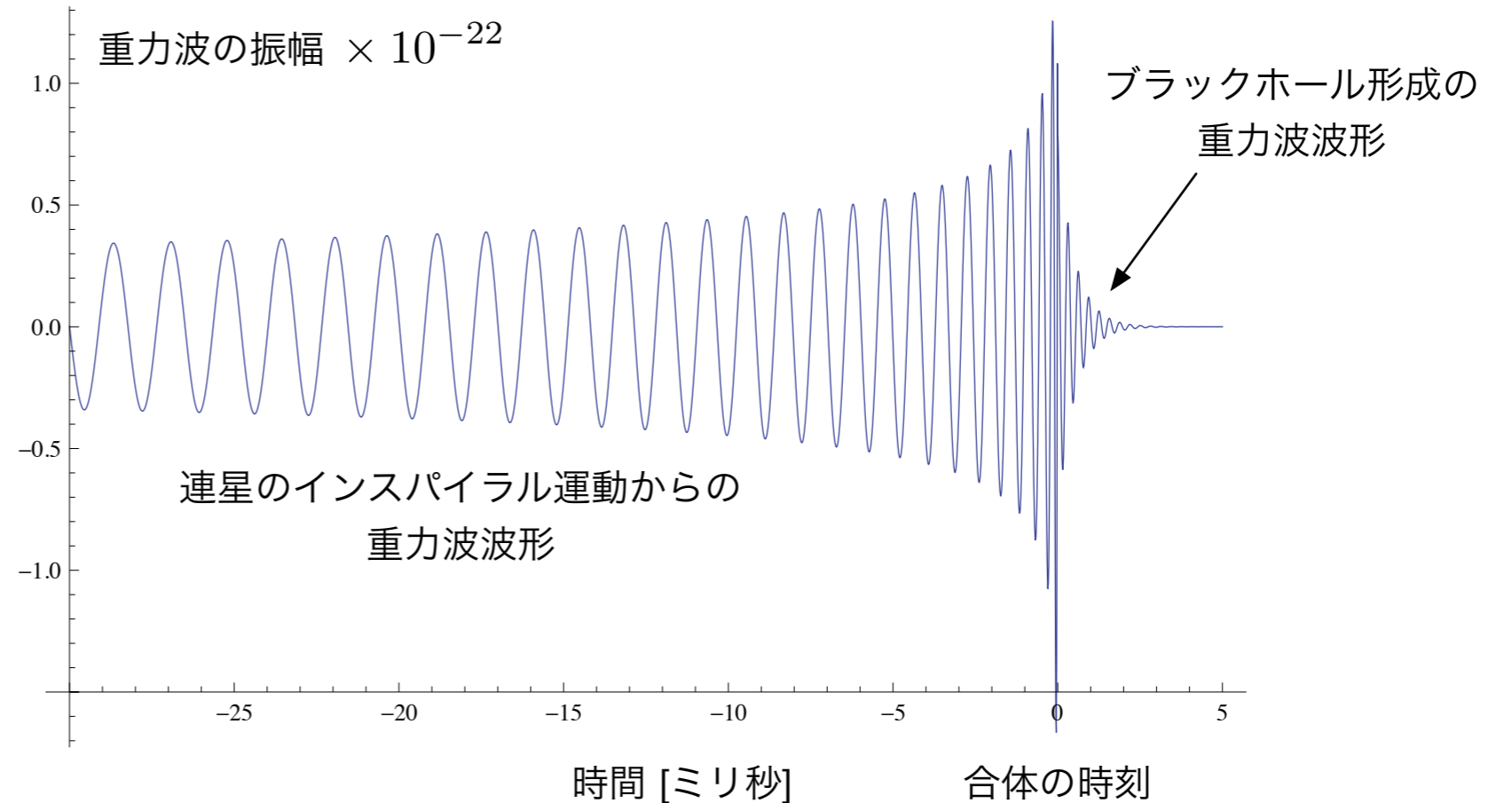


NCSA-AEI group (1998)



重力波の直接観測をしたい！

連星中性子星  
連星ブラックホール



# 重力波初検出を発表するライツィLIGO所長

2016年2月11日

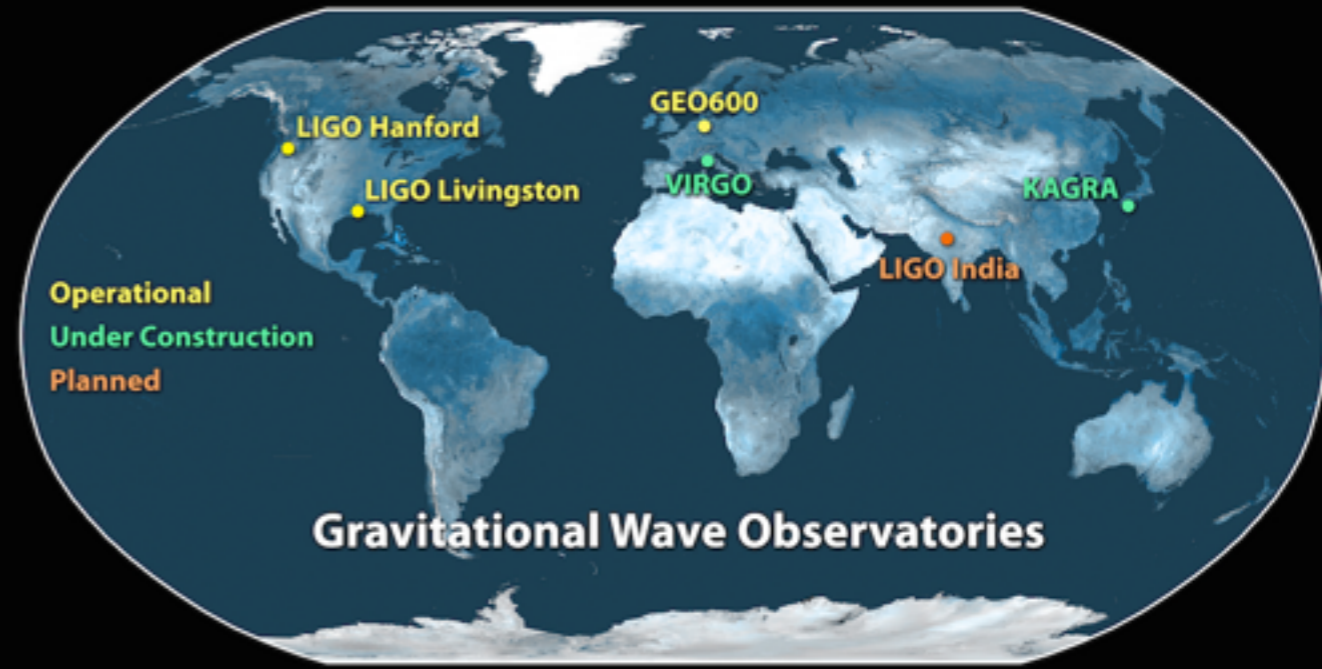
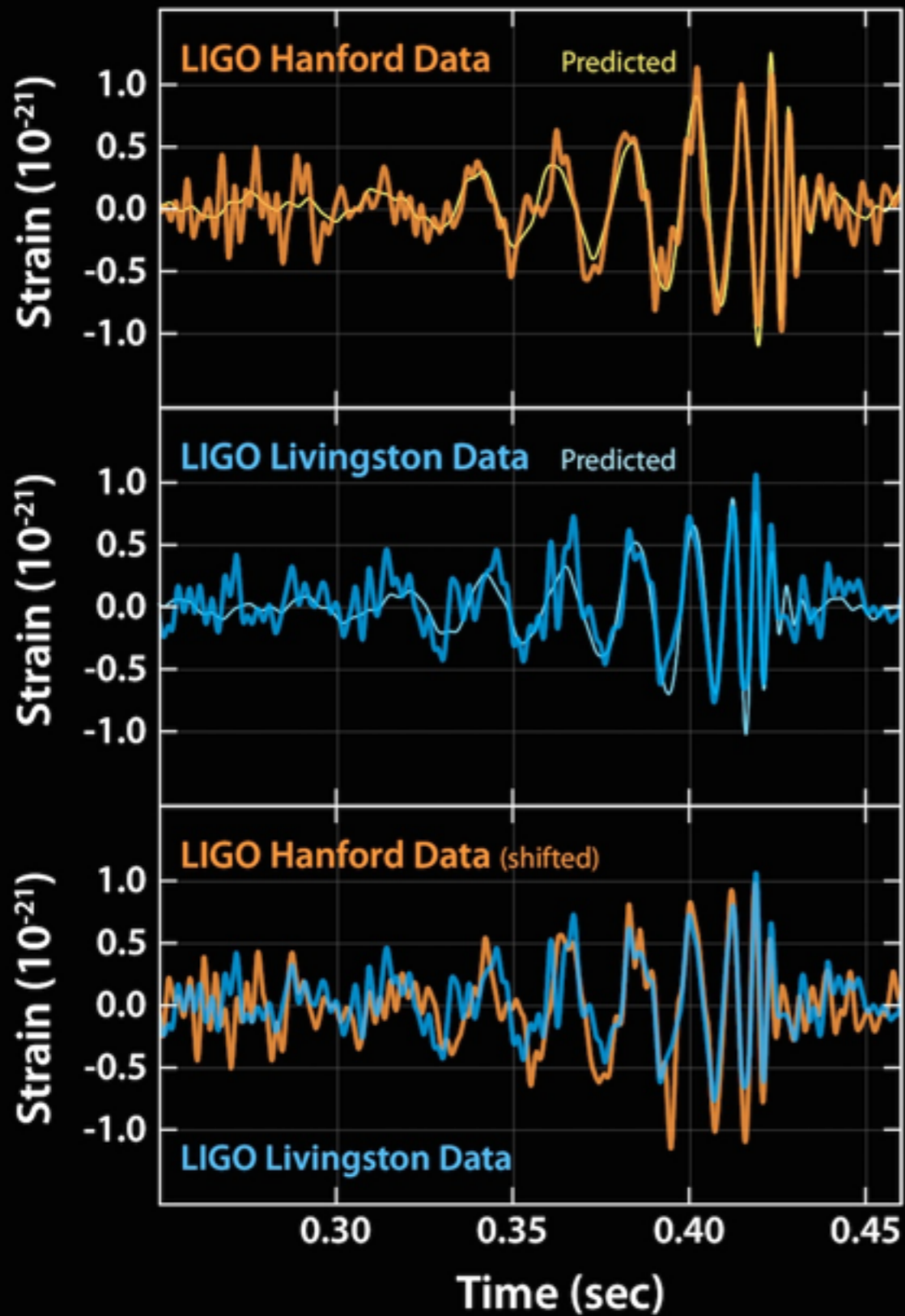


**“We had detected gravitational waves. We did it.”**

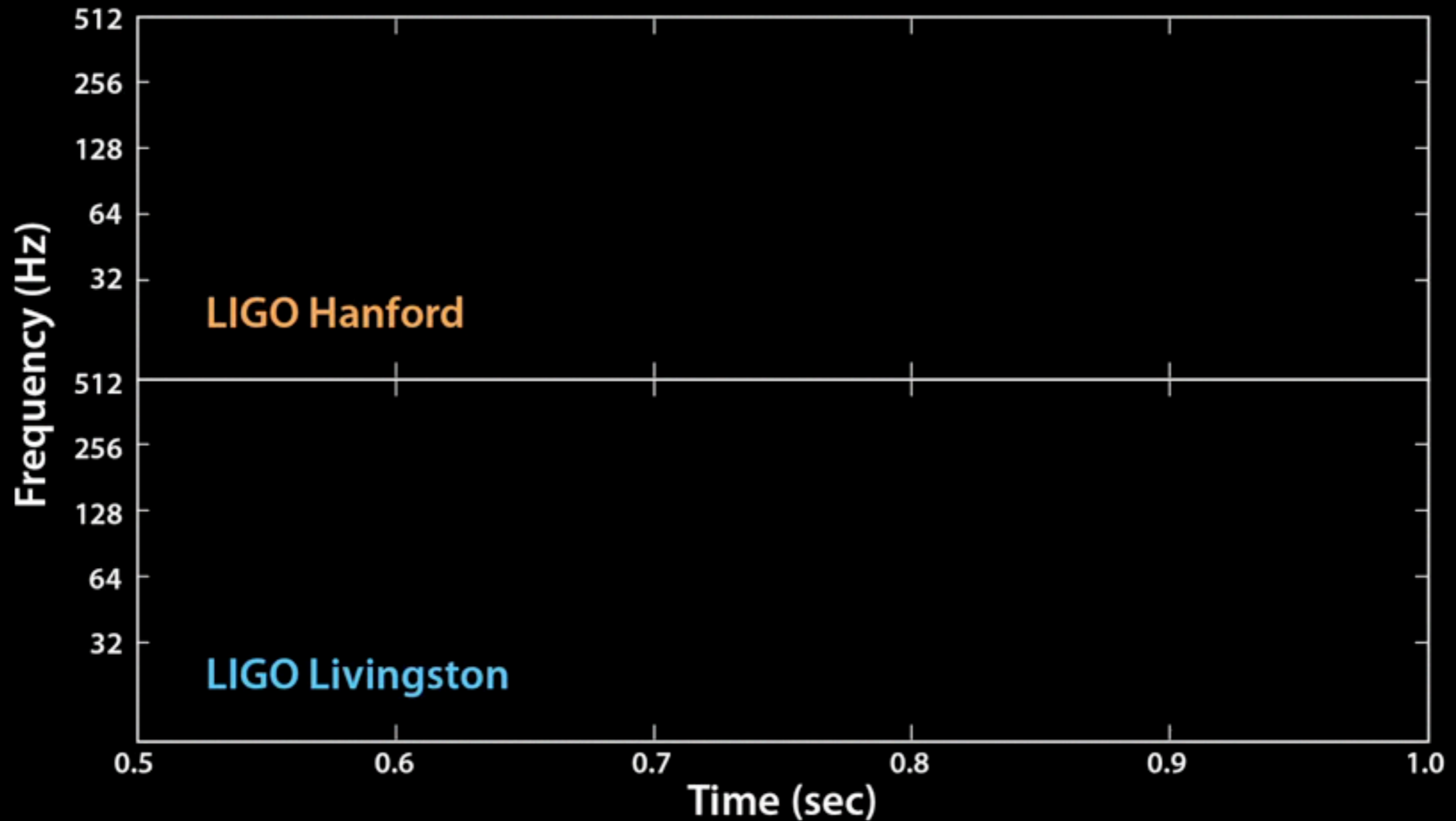
**“我々は、重力波を検出した。やり遂げたのだ。”**

<https://www.youtube.com/watch?v=aEPlwEJmZyE>

2015年9月14日



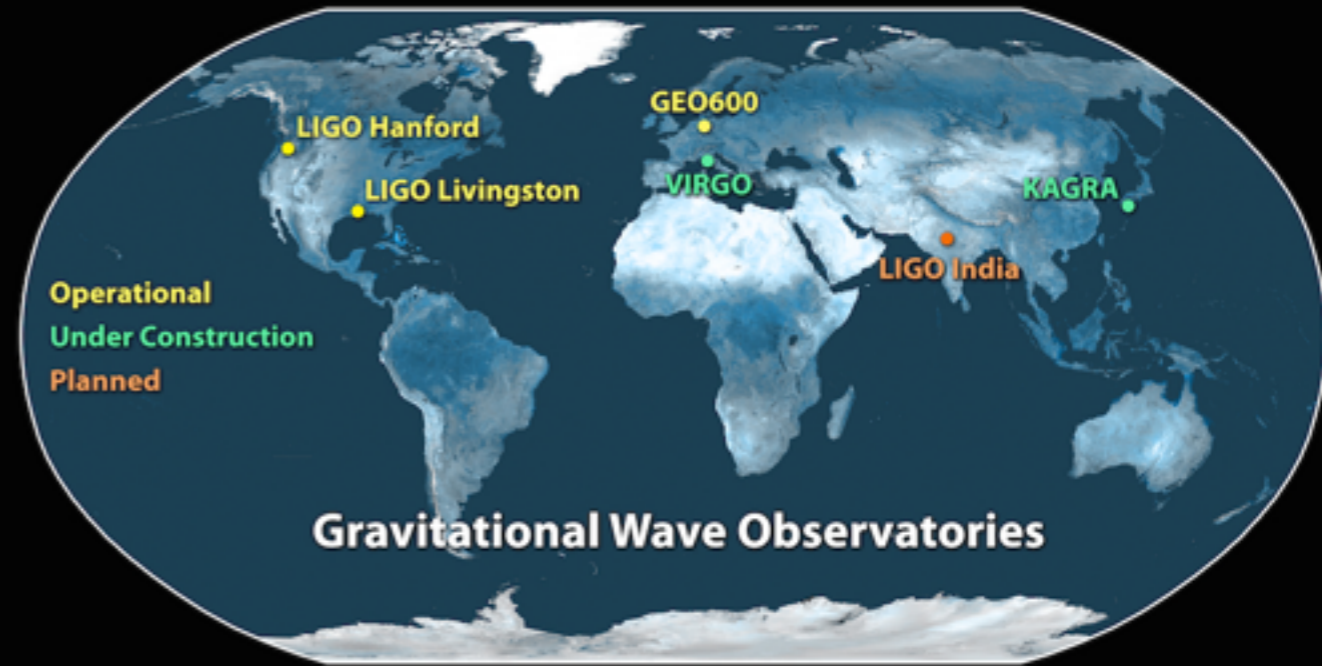
# 重力波波形を音にすると. . .



始め2回は実周波数, 後の2回は聞きやすいように+400Hz

<https://mediaassets.caltech.edu/gwave>

2015年9月14日

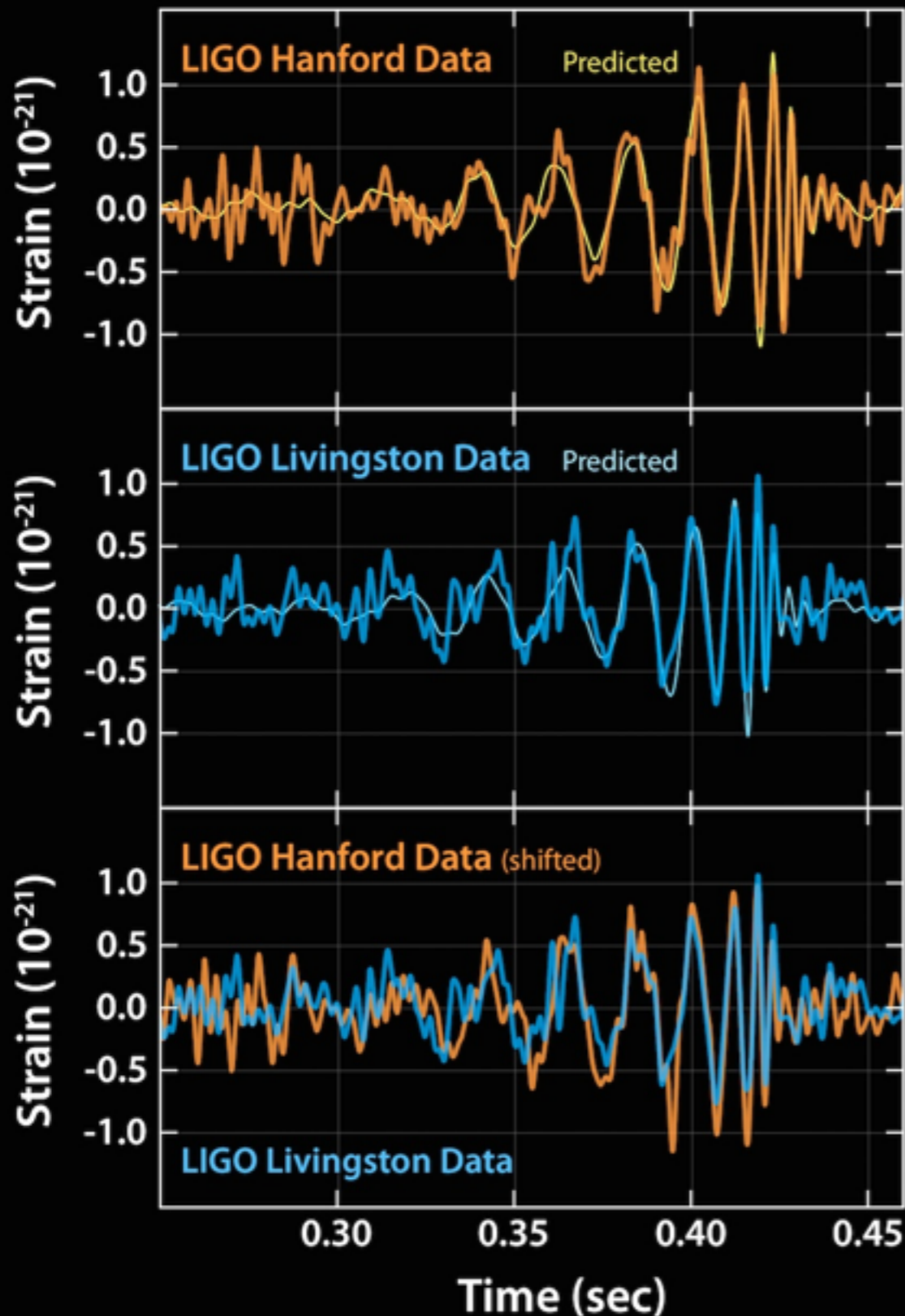


太陽の36倍と29倍のブラックホールが合体して、  
太陽の62倍のブラックホールになった。

3倍の質量が消失

$$E = mc^2$$

13億光年先





# 重力波 初の直接観測

## 「研究者勇気づけた」

### 大阪市大院・神田教授 学生らに解説

米国を中心とした国際研究チームが「重力波」を初めて直接観測したとの発表を受け、重力波の研究が専門の神田展行・大阪市立大学院教授(51)は12日、発表内容についての説明会を大阪市住吉区の同大杉本キャンパスで開いた。成果を詳しく理解してもらう狙い。学生ら約1000人が参加し、真剣な表情で聴き入った。

【畠山哲郎】



重力波観測について解説する大阪市立大学大学院理学研究科の神田展行教授—大阪市住吉区で、川平愛撮影

神田教授は、岐阜県飛騨市の大型低温重力波望遠鏡「KAGRA」のプロジェクトでもデータ管理グループのリーダーを務める。説明会では観測されたデータの見方などを解説し、「我々にとっても勇気づけられるものだった」と語った。発表を受けて、研究室の学生

同大学院理学研究科2年の和知慎吾さん(23)は「重力波だけでなく、ブラックホールも直接観測したことになる」と分かったため、「期待が膨らんだ」と話していた。重力波は、質量を持った物体が動いた時に周囲の時空にゆがみが生じ、そのゆがみが光速でさざ波のように宇宙空間に伝わる現象。物理学者のアインシュタインが「一般相対性理論」で存在を予言し、世界中の研究者が観測に挑戦していた。

# ブラックホール 解明に期待

重力波の大きな特徴はブラックホールからも放出されること。連星が合体してブラックホールが生まれる瞬間を観測できると期待される。時間と空間をねじ曲げてすべてをのみ込むブラックホールは、光も電波も出さないため直接には観測



る精度を目指す。実現すれば七億光年の範囲にある連星からの重力波を捉えられる。一年で十回ほどキヤッチできる計算だという。また、弱まらずに遠くまで届くので、遠い星の観測や誕生直後の宇宙の姿を知るのにも役立つと期待されている。

大阪工業大の真貝寿明教授(理論物理学)は「重力波を天文学に使うには、発生した場所を割り出す必要がある。それには望遠鏡が四力所必要だ。KAGRAを含めた世界的なネットワークが重要」と話す。

東京新聞 2016/2/12

重力波が検出された！  
重力波が検出できた！  
ブラックホールが存在した！  
ブラックホール連星が存在した！  
相対性理論、正しかった！

大阪工大「予想通りで驚いた」  
真貝教授  
大阪工業大情報科学部の真貝寿明教授(一般相対性理論)は「祝・重力波の直接検出」と題して、研究室のウェブページに

100年と展開」を出版している。「こんなにも予想通りのものが見つかるのかと驚いた。素晴らしい発見だ」と感想を語った。今後の研究については「日本でもKAGRAを使い、改めて重力波を確認したり、海外のチームと協力して重力波がどこから来たものなのかを調べたりしていくことが重要だ」と話した。  
【畠山哲郎】

毎日新聞 2016/2/13

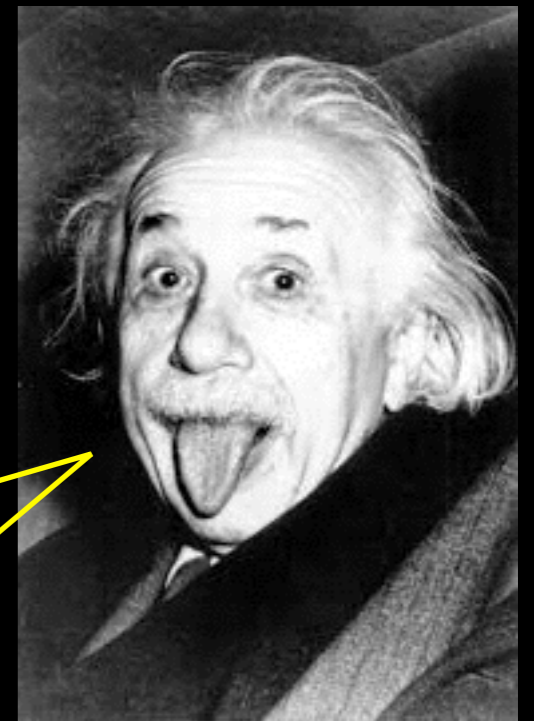
# 2016年 重力波天文学の幕開け

重力波が検出された！  
重力波が検出できた！  
ブラックホールが存在した！  
ブラックホール連星が存在した！  
相対性理論、正しかった！



光学天文学の幕開け  
ガリレイ 1609年

100年もかかったのか。

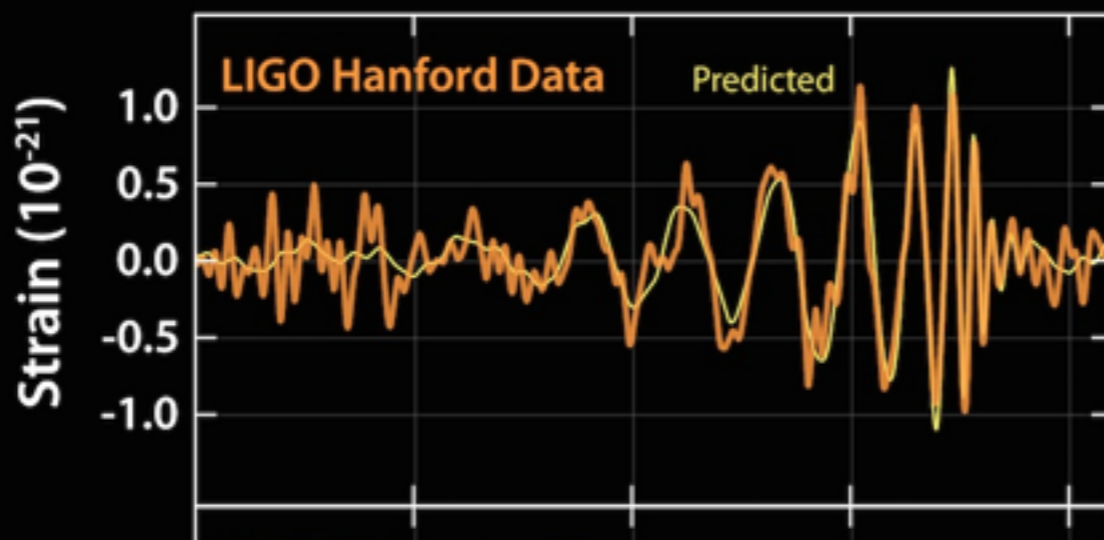


# ブラックホールはどう見える？

1. 重力レンズで曲がって見える



2. 重力波で見える



はくちょう座



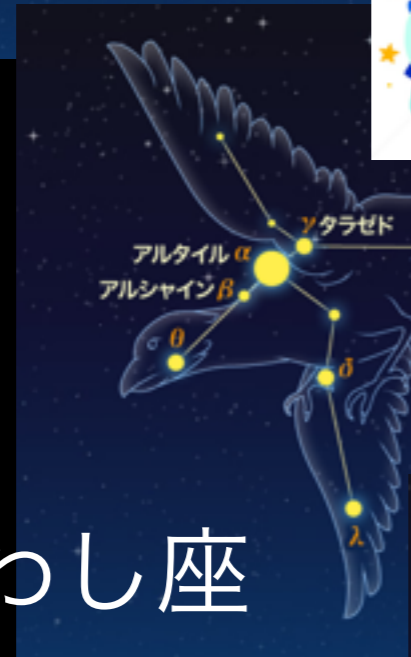
こと座



へびつかい座



X-1



わし座



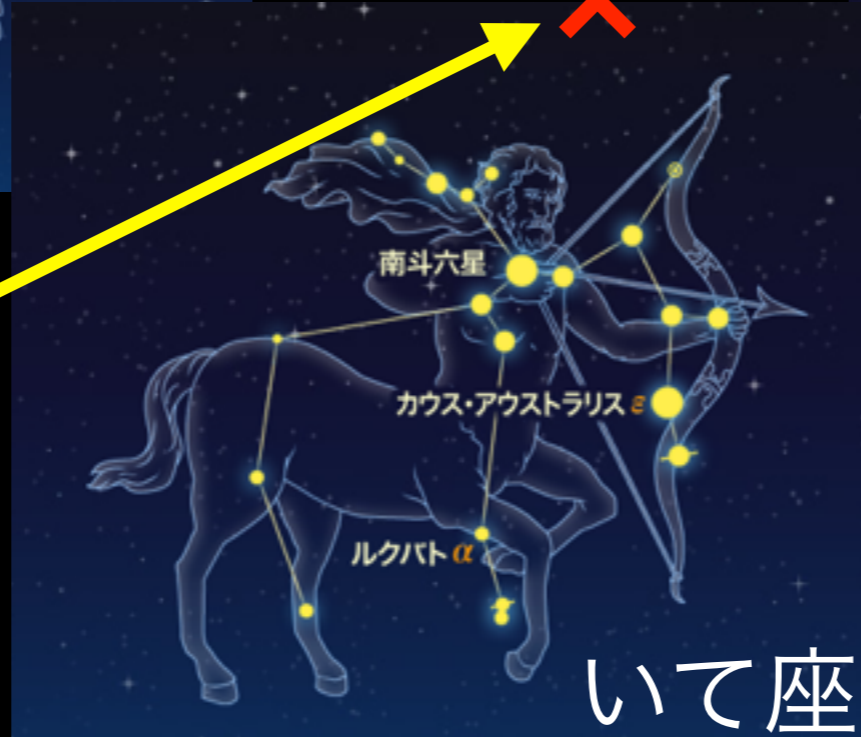
土星

火星



さそり座

Sgr A\*



いて座