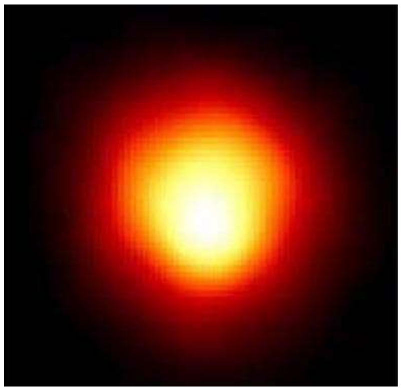
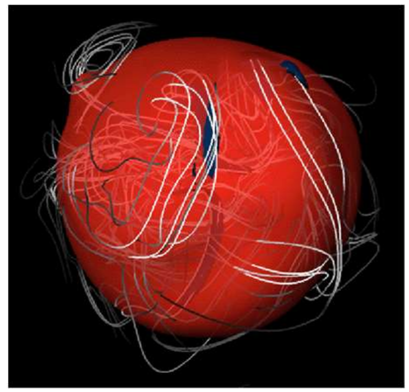
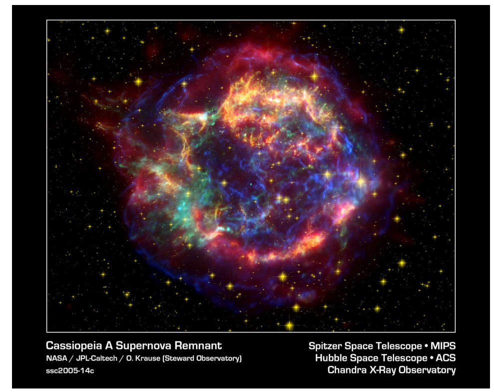
FORSKNINGENS DØGN

Betelgeuse







Gigantisk, magnetisk, eksplosiv

Astronom Bertil F. Dorch, ph.d.

Kvistgaard, Langeskov

Tirsdag den 16. april, 2019

SDU SYDDANSK UNIVERSITETSBIBLIOTEK

IAU 100 YEARS: UNDER ONE SKY

Introduktion …

Hvem, hvad, hvor?

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Bertil

Astronom

Bibliotekschef, SDU

Nørd …

FORSKNINGENS DØGN

Stjernebilledet Orion

Astronomi …

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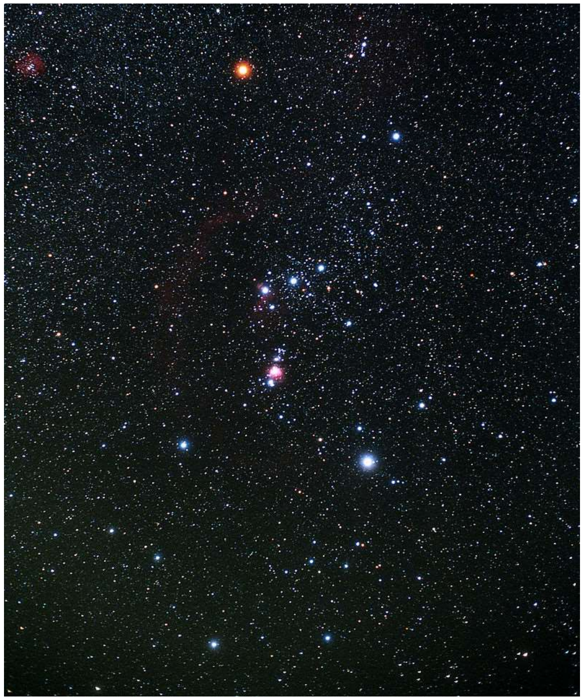
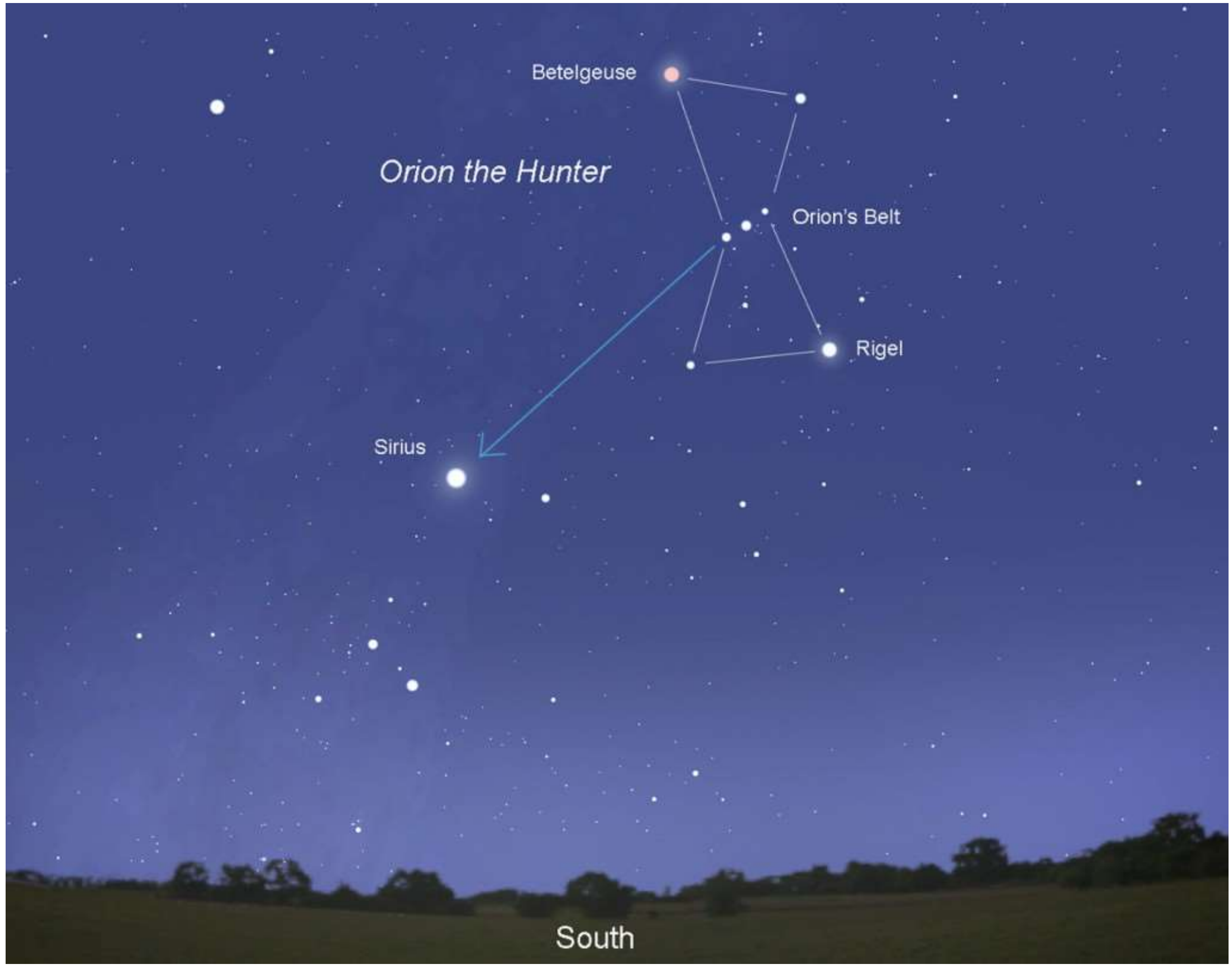
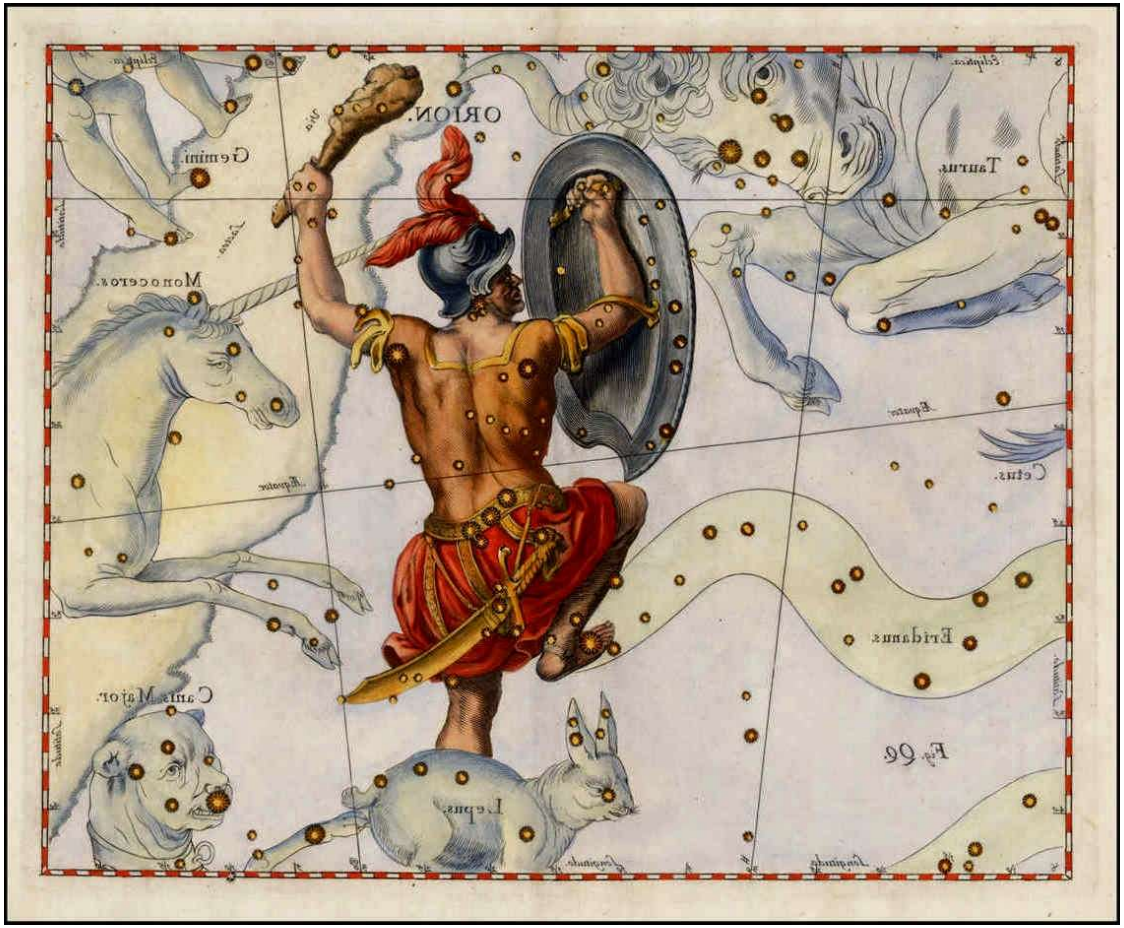
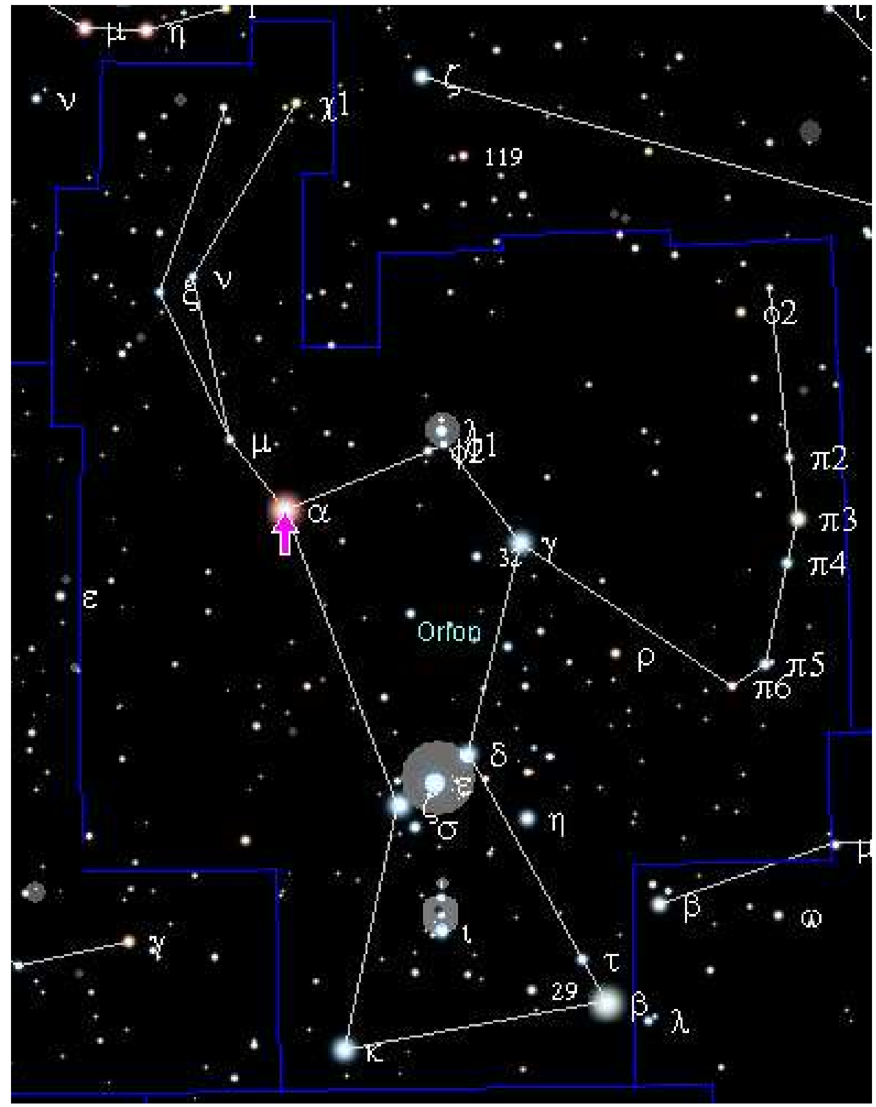
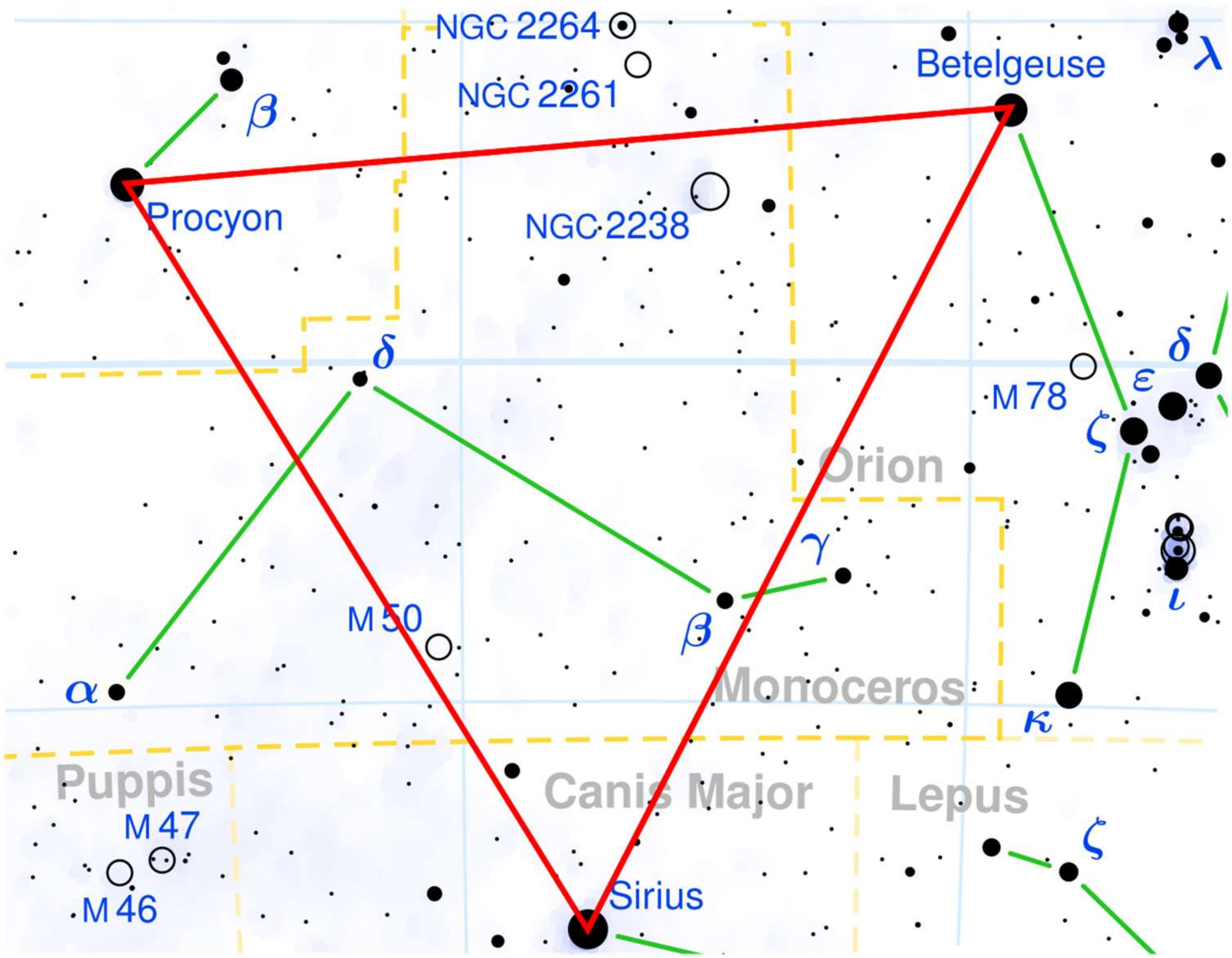
IAU 100 YEARS: UNDER ONE SKY




Betelgeuse
Orion the Hunter
Orion's Belt
Rigel
Sirius
South


ORION.
Gemini
Taurus
Monoceros
Cetus
Eridanus
Canis Major
Lepus


119
Orion
32
29



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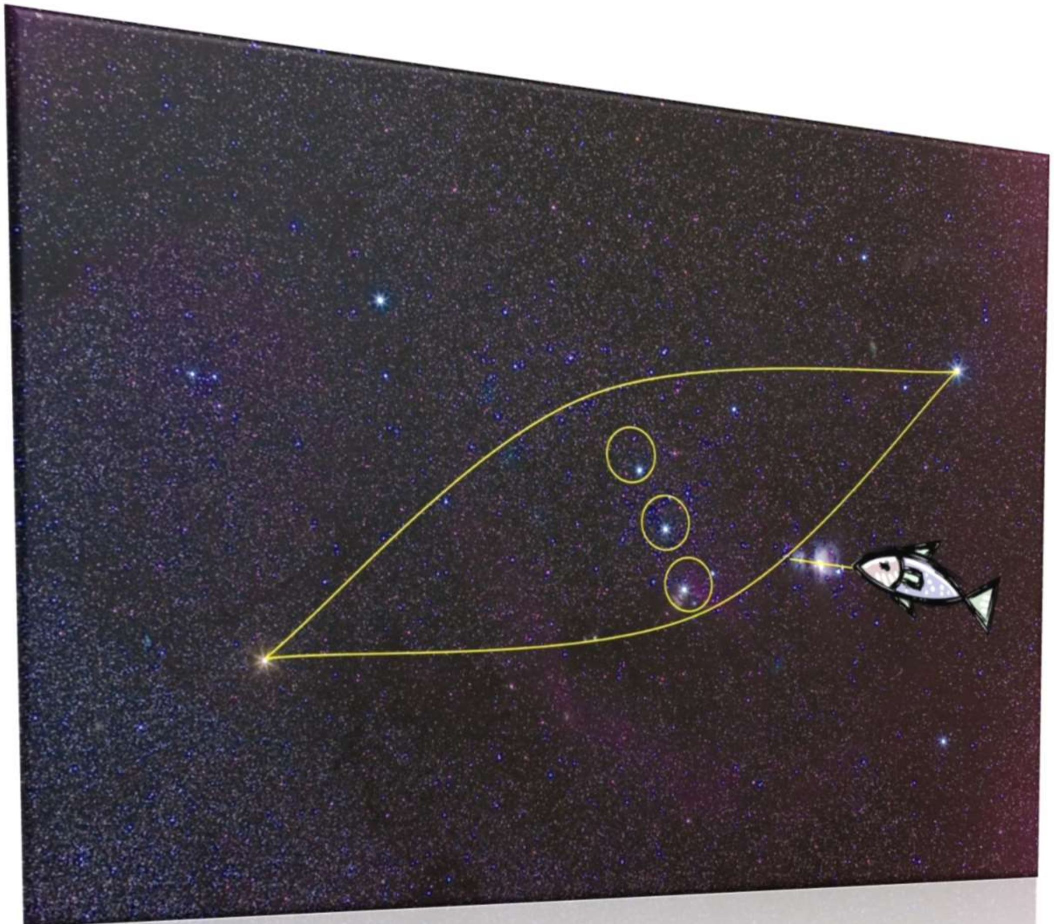
(Lithopsian CC-BY.SA 4.0)

Stjernen Betelgeuse

Kultur …

Betelgeuse



https://www.vice.com/en_us/article/gq894b/australia-has-a-night-sky-youve-never-seen

Journal of Astronomical History and Heritage, 21(1), 7–12 (2018).

YES, ABORIGINAL AUSTRALIANS CAN AND DID DISCOVER THE VARIABILITY OF BETELGEUSE

Bradley E. Schaefer
Department of Physics and Astronomy, Louisiana State University,
Baton Rouge, Louisiana, 70803, USA
Email: schaefer@lsu.edu

Abstract: Recently, a widely publicized claim has been made that the Aboriginal Australians discovered the variability of the red star Betelgeuse in the modern Orion, plus the variability of two other prominent red stars: Aldebaran and Antares. This result has excited the usual healthy skepticism, with questions about whether any untrained peoples *can* discover the variability and whether such a discovery is likely to be placed into lore and transmitted for long periods of time. Here, I am offering an independent evaluation, based on broad experience with naked-eye sky viewing and astro-history. I find that it is easy for inexperienced observers to detect the variability of Betelgeuse over its range in brightness from V = 0.0 to V = 1.3, for example in noticing from season-to-season that the star varies from significantly brighter than Procyon to being greatly fainter than Procyon. Further, indigenous peoples in the Southern Hemisphere inevitably kept watch on the prominent red star, so it is inevitable that the variability of Betelgeuse was discovered many times over during the last 65 millennia. The processes of placing this discovery into a cultural context (in this case, put into morality stories) and the faithful transmission for many millennia is confidently known for the Aboriginal Australians in particular. So this shows that the whole claim for a changing Betelgeuse in the Aboriginal Australian lore is both plausible and likely. Given that the discovery and transmission is easily *possible*, the real proof is that the Aboriginal lore gives an unambiguous statement that these stars do indeed vary in brightness, as collected by many ethnographers over a century ago from many Aboriginal groups. So I strongly conclude that the Aboriginal Australians *could* and *did* discover the variability of Betelgeuse, Aldebaran, and Antares.

Keywords: Aboriginal astronomy, variable stars: Betelgeuse, Antares, Aldebaran

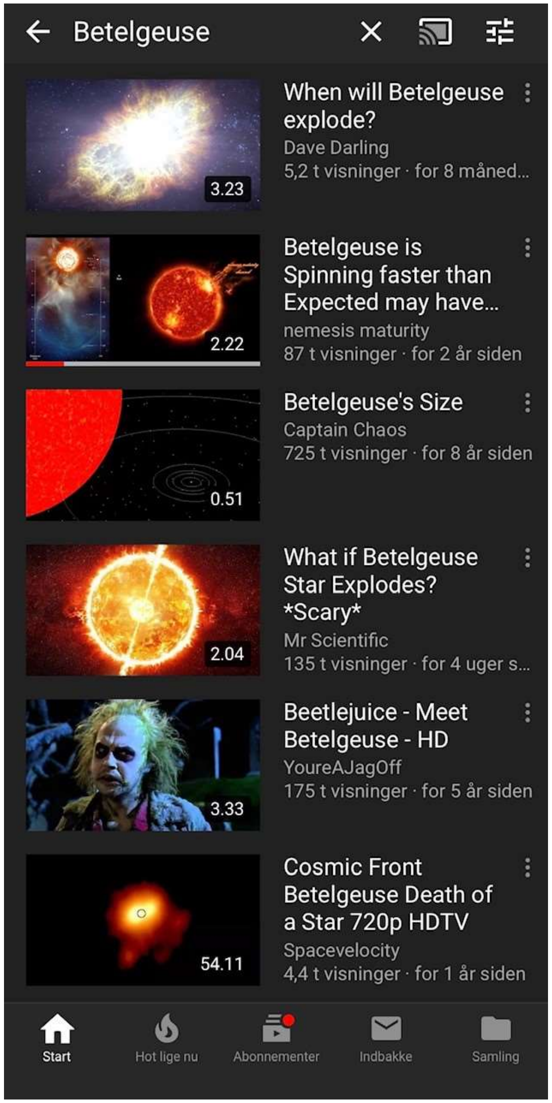
1 INTRODUCTION

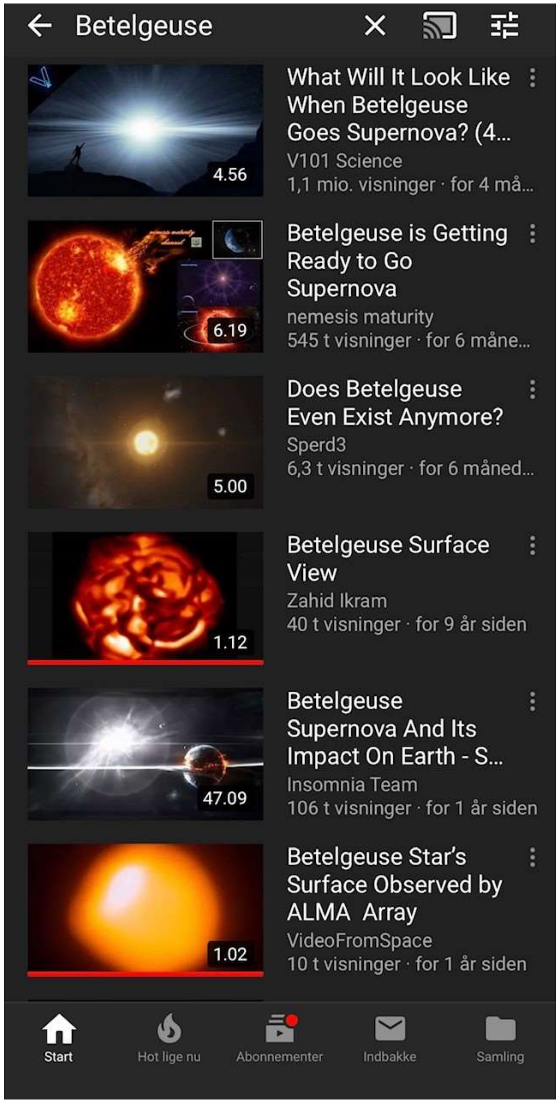
Betelgeuse (α Ori) is the bright red supergiant star in the shoulder of Orion, and it varies in brightness from visual magnitude 0.0 to 1.3 mag with a quasi-periodicity of 423 days. This variability was first 'discovered' by Sir John Herschel in 1836, or at least this was the first surviving observation to make it into Western science journals. Recently, there has been substantial excitement in the press and in the international variable star communities over a claim that the Aboriginal Australians had long ago discovered the variability of Betelgeuse (plus Aldebaran and Antares) and incorporated this discovery into lore passed down through untold generations, and being even today recognizable by ethnographers who have collected this lore.

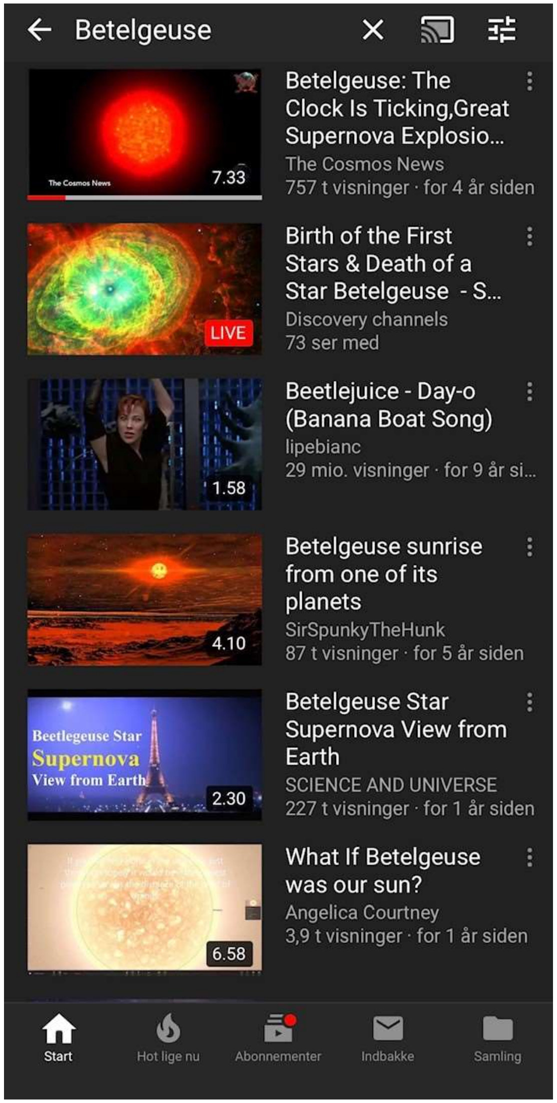
The Aboriginal Australian discovery was first noted by Fredrick (2008) then described in more depth in Leaman and Hamacher (2014) and further analyzed in Hamacher (2018). They point to lore collected a century ago from southern and central Australia for multiple groups, with two basic stories plus the usual variants. The first story is about a hunter (represented by the modern stars of Orion) chasing after some young sisters (represented by the Pleiades), with his 'fire lust' (represented in the star Betelgeuse) waxing and waning, while the older protective sister's left foot (represented by Aldebaran) also fills and empties of the 'fire magic'. The second story is also a morality tale, with a story about a young male initiate (named Waiyungari) covered in red ochre running away into the sky, where he now sits in a canoe on the Milky Way, flanked by two stars representing two women, being prominent in the September evening skies. Waiyungari is definitively identified as Antares. The lore states that when Waiyungari brightens and gets hotter, this increases the sexual desire of the people. These are clear statements from multiple communities and multiple ethnographers that the three red stars get brighter and fainter.

This basic claim (that the Aboriginal Australians discovered the variability of Betelgeuse) has excited skepticism in some quarters. The unstated root of this skepticism is the view that Aboriginal people were too 'primitive' to be able to make a discovery that is more typical of modern Western science, as well as a general frustration from having heard so many implausible claims of discoveries of lost-ancient-wisdom. This skepticism can be itemized under the question "How could the Aboriginal Australians discover the variability when so many great Western astronomical observers from before 1836 all missed it?" and under the statement "The variability of Betelgeuse is too subtle and infrequent for any casual discovery".

In this note, I will be evaluating the basic claim that the Aboriginal Australians did discover the variability of Betelgeuse. This is just an independent and critical examination of prominent claims in the field of the history and heritage of astronomy, as our field so desperately needs.


Betelgeuse
When will Betelgeuse explode?
Dave Darling
5,2 t visninger · for 8 måned...
3.23
Betelgeuse is Spinning faster than Expected may have...
nemesis maturity
87 t visninger · for 2 år siden
2.22
Betelgeuse's Size
Captain Chaos
725 t visninger · for 8 år siden
0.51
What if Betelgeuse Star Explodes? *Scary*
Mr Scientific
135 t visninger · for 4 uger s...
2.04
Beetlejuice - Meet Betelgeuse - HD
YoureAJagOff
175 t visninger · for 5 år siden
3.33
Cosmic Front Betelgeuse Death of a Star 720p HDTV
Spacevelocity
4,4 t visninger · for 1 år siden
54.11
Start
Hot lige nu
Abonnementer
Indbakke
Samling


Betelgeuse
What Will It Look Like When Betelgeuse Goes Supernova? (4...
V101 Science
1,1 mio. visninger · for 4 må...
4.56
Betelgeuse is Getting Ready to Go Supernova
nemesis maturity
545 t visninger · for 6 måne...
6.19
Does Betelgeuse Even Exist Anymore?
Sperd3
6,3 t visninger · for 6 måned...
5.00
Betelgeuse Surface View
Zahid Ikram
40 t visninger · for 9 år siden
1.12
Betelgeuse Supernova And Its Impact On Earth - S...
Insomnia Team
106 t visninger · for 1 år siden
47.09
Betelgeuse Star's Surface Observed by ALMA Array
VideoFromSpace
10 t visninger · for 1 år siden
1.02
Start
Hot lige nu
Abonnementer
Indbakke
Samling


Betelgeuse
Betelgeuse: The Clock Is Ticking,Great Supernova Explosio...
The Cosmos News
757 t visninger · for 4 år siden
7.33
Birth of the First Stars & Death of a Star Betelgeuse - S...
Discovery channels
73 ser med
LIVE
Beetlejuice - Day-o (Banana Boat Song)
lipebianc
29 mio. visninger · for 9 år si...
1.58
Betelgeuse sunrise from one of its planets
SirSpunkyTheHunk
87 t visninger · for 5 år siden
4.10
Betelgeuse Star Supernova View from Earth
SCIENCE AND UNIVERSE
227 t visninger · for 1 år siden
Beetlegeuse Star
Supernova
View from Earth
2.30
What If Betelgeuse was our sun?
Angelica Courtney
3,9 t visninger · for 1 år siden
6.58
Start
Hot lige nu
Abonnementer
Indbakke
Samling

Alpha Orionis α Ori إبط الجوزاء

Ibṭ al-Jauzā *Yad al-Jauzā'* *Bait al-Jauzā'* *Bed Elgueze*

Beit Algueze *Bet El-gueze* *al-Jabbār*

Beetlejuice *Betelgeux* *Beteigeuze*

Ulluriajjuaq *Bašn* *Klaria* 参宿四 *Shēnxiùsì*

Heike-boshi 平家星 *Kaulua-koko* *Borgil*

EDITION US

THE HUFFINGTON POST

NEWS POLITICS ENTERTAINMENT LIFESTYLE IMPACT VOICES VIDEO ALL SECTIONS

GREEN 01/20/2011 05:33 pm ET | Updated May 25, 2011

Two Suns? Twin Stars Could Be Visible From Earth By 2012

By Dean Praetorius

Earth could be getting a second sun, at least temporarily.

Dr. Brad Carter, Senior Lecturer of Physics at the University of Southern Queensland, outlined the scenario to
news.com.au. Betelgeuse, one of the night sky's brightest stars, is losing mass, indicating it is collapsing. It could run
out of fuel and go super-nova at any time.

When that happens, for at least a few weeks, we'd see a second sun, Carter says. There may also be no night during
that timeframe.

The Star Wars-esque scenario could happen by 2012, Carter says... or it could take longer. The explosion could also
cause a neutron star or result in the formation of a black hole 1300 light years from Earth, reports news.com.au.

But doomsday sayers should be careful about speculation on this one. If the star does go super-nova, Earth will be
showered with harmless particles, according to Carter. "They will flood through the Earth and bizarrely enough, even
though the supernova we see visually will light up the night sky, 99 per cent of the energy in the supernova is released
in these particles that will come through our bodies and through the Earth with absolutely no harm whatsoever," he told
news.com.au.

In fact, a neutrino shower could be beneficial to Earth. According to Carter this "star stuff" makes up the universe. "It
literally makes things like gold, silver - all the heavy elements - even things like uranium....a star like Betelgeuse is
instantly forming for us all sorts of heavy elements and atoms that our own Earth and our own bodies have from long
past supernovi," said Carter.

UPDATE: To clarify, the news.com.au article does not say a neutrino shower could be beneficial to Earth, but implies a
supernova could be beneficial, stating, "Far from being a sign of the apocalypse, according to Dr Carter the supernova
will provide Earth with elements necessary for survival and continuity."

UPDATE II: In a follow-up piece on news.com.au, Dr. Carter stressed that there is no way of knowing when the star
may go supernova. U.S. astronomer Phil Plait added, "Betelgeuse might go up tonight, or it might not be for 100,000
years. We're just not sure."

Suggest a correction

Dean Praetorius
Director of Trends and Social Media, The Huffington Post

GALAXY

The Supermassive Star Betelgeuse -- Will Its Violent Death Impact Earth? (Today's Most Popular)

June 19, 2012

Betelgeuse, one of the brightest stars in the sky, could burst into its supernova phase and become as bright as a full moon - and last for as long as a year. The massive star is visible in the winter sky over most of the world as a bright, reddish star, could explode as a supernova anytime within the next 100,000 years.

The red giant, once so large it would reach out to Jupiter's orbit if placed in our own solar system, has shrunk by 15 percent over the past decade in a half, although it's just as bright as it's ever been.
"To see this change is very striking,"

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US
NEWS POLITICS ENTERTAINMENT LIFESTYLE IMPACT VOICES

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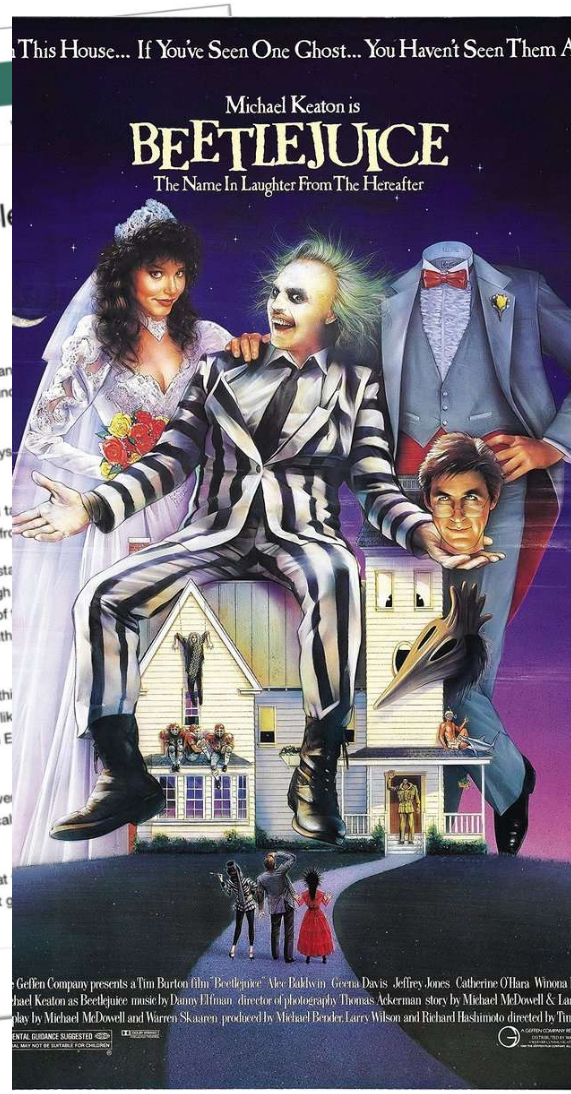

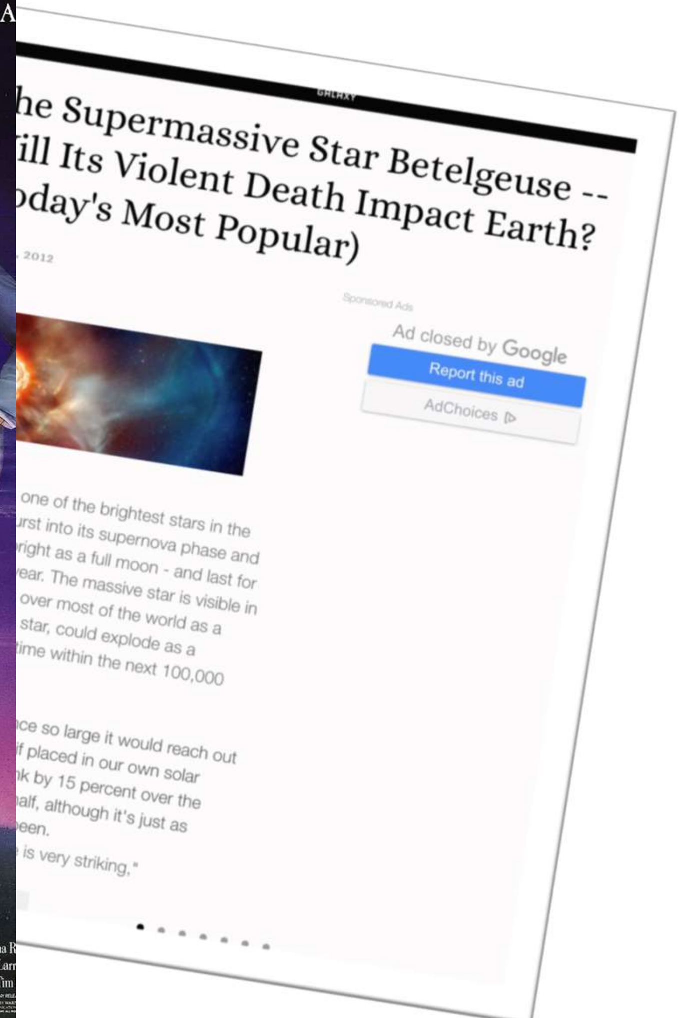

he Supermassive Star Betelgeuse --
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oday's Most Popular)

, 2012

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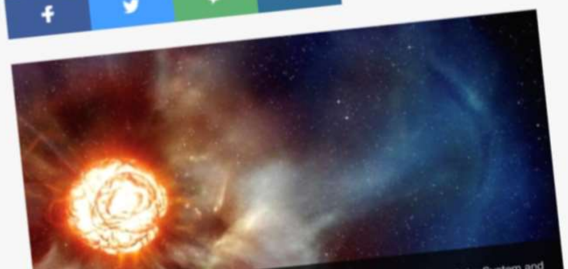
SCIENCE

Dying Star Betelgeuse Won't Explode in 2012, Experts Say

Published January 21, 2011 · FoxNews.com



The supergiant star Betelgeuse has a vast plume of gas almost as large as our Solar System and a gigantic bubble boiling on its surface, shown in this artist's impression. (ESO/L.Calcada)

The super-giant red star Betelgeuse in Orion's nebula is predicted to cataclysmically explode, and the impending supernova may even reach Earth -- someday.

Discover SCIENCE FOR THE CURIOUS

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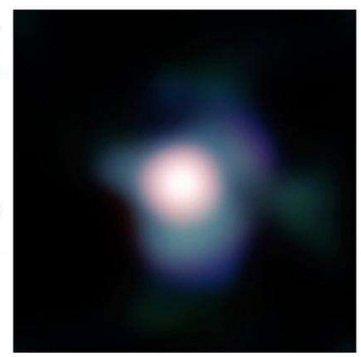
Bad Astronomy

« Mt. Etna erupts! Squishy moonrise seen from space! »

Betelgeuse and 2012

By Phil Plait | January 21, 2011 7:00 am

26



I swear, I need to trust my instincts. As soon as I saw the article on the news.com.au site desperately trying to link Betelgeuse going supernova with the nonsense about the Mayans and 2012, my gut reaction was to write about it.

But no, I figured a minute later, this story would blow over. So to speak.

I should've known: instead of going away, it gets picked up by that bastion of antiscience, The Huffington Post.

Grrrr.

NEW ON DISCOVER

Functional Connectivity Between Surgically Disconnected Brain Regions?

The Hobbit: A Lineage More Ancient Than Once Thought?

Exploding Sea Cucumber Butt Threads Are a New Material

Naked Mole-rats Can Go 18 Minutes Without Oxygen

Giant Virus Found in Sewage Blurs the Line Between Life and Non-Life

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Røde superkæmper

Astrofysik …

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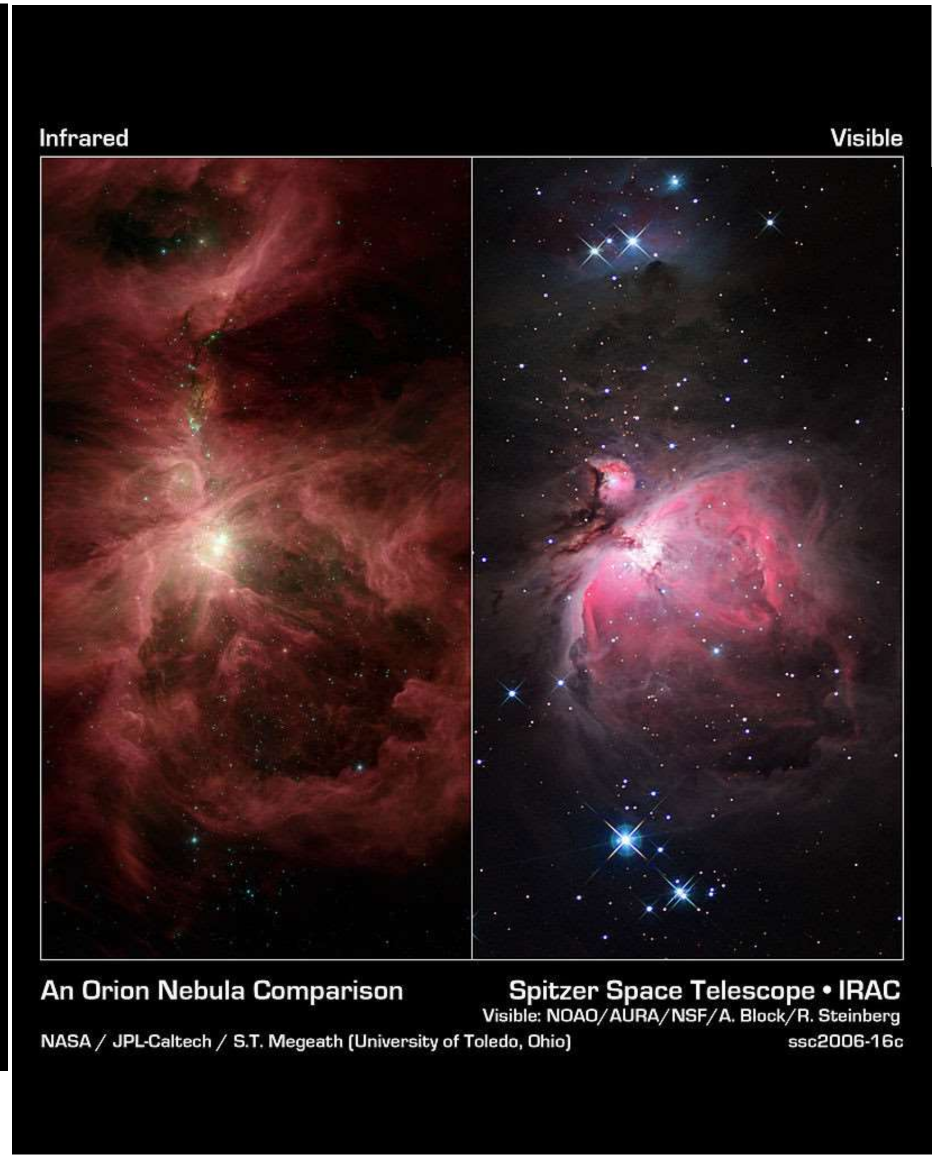

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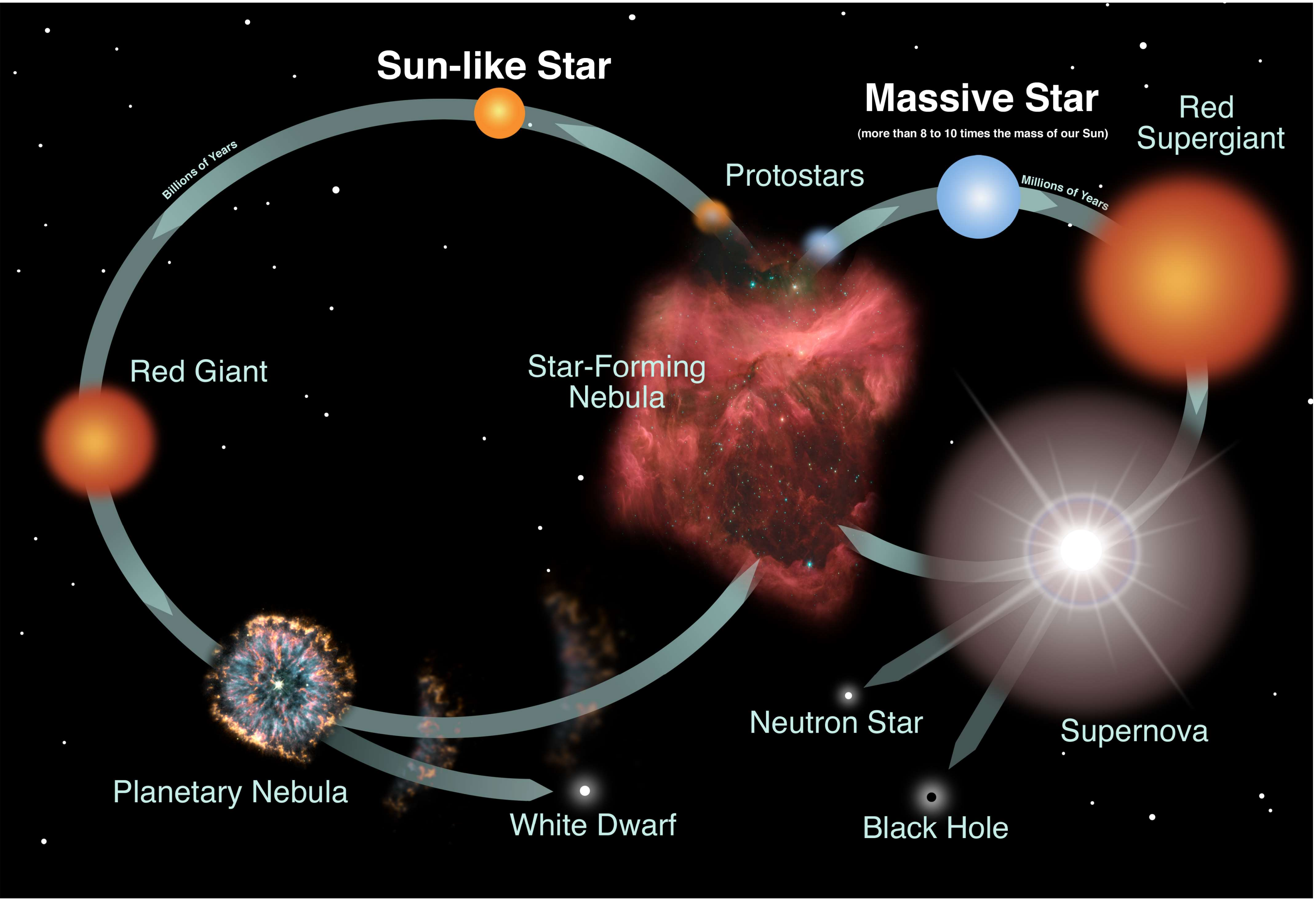
Sun-like Star
Massive Star
(more than 8 to 10 times the mass of our Sun)
Red
Supergiant
Protostars
Billions of Years
Millions of Years
Red Giant
Star-Forming
Nebula
Neutron Star
Supernova
Planetary Nebula
White Dwarf
Black Hole

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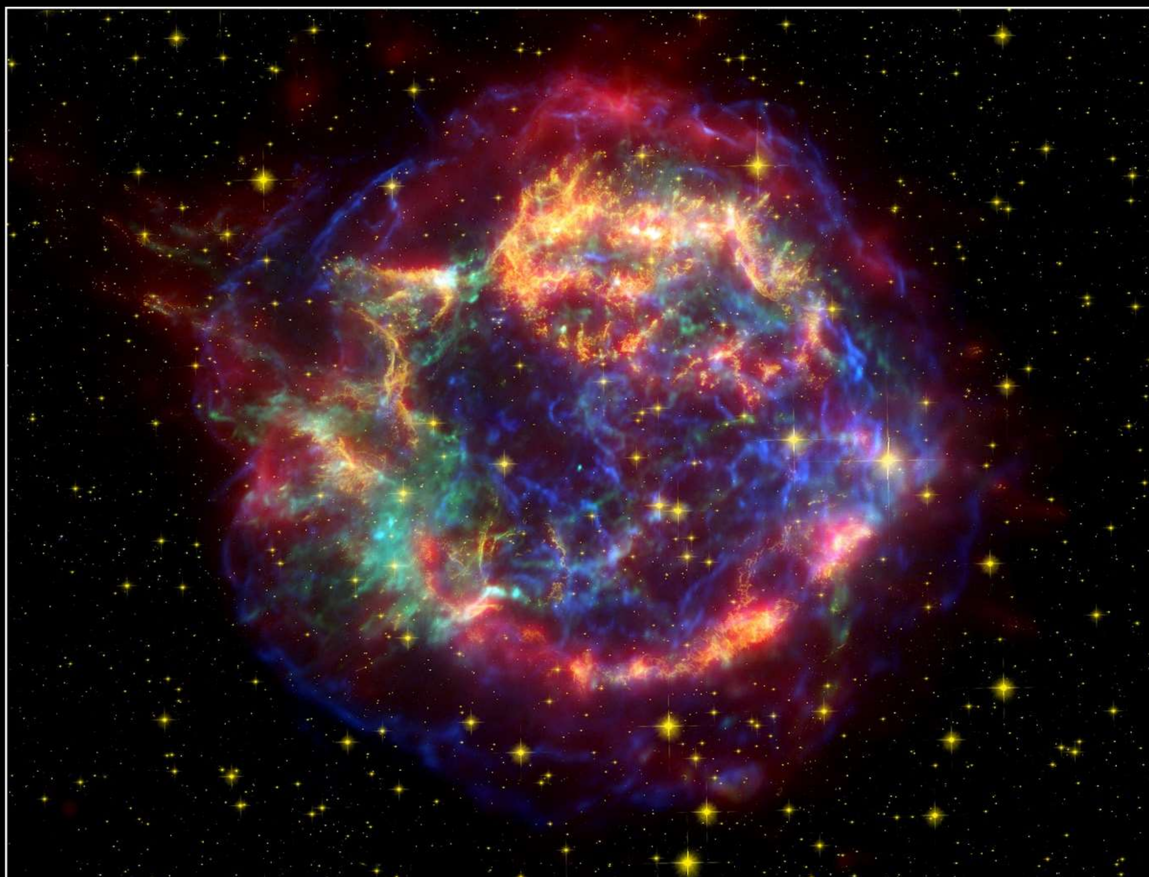

Cassiopeia A Supernova Remnant
NASA / JPL-Caltech / O. Krause (Steward Observatory)
ssc2005-14c

Spitzer Space Telescope • MIPS
Hubble Space Telescope • ACS
Chandra X-Ray Observatory

Crab Nebula Supernova Remnant
NASA / JPL-Caltech / R. Gehrz (University of Minnesota)

Spitzer Space Telescope • IRAC • MIPS
sig05-004

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FAKTA

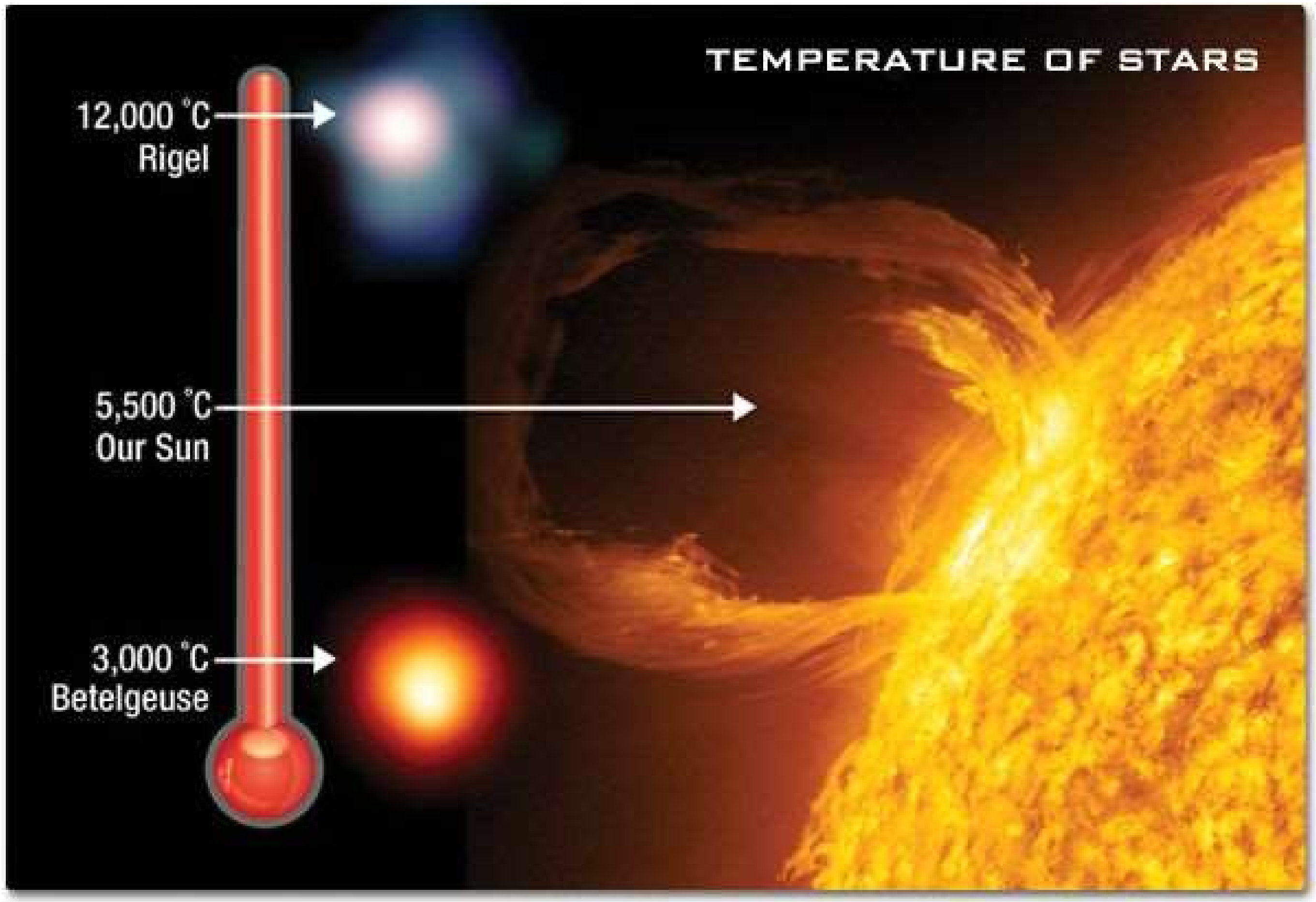
Betelgeuse vs. Solen

½ så varm

600 – 800 gange større

8 – 15+ gange tungere

10 mio. mod 5 mia. år



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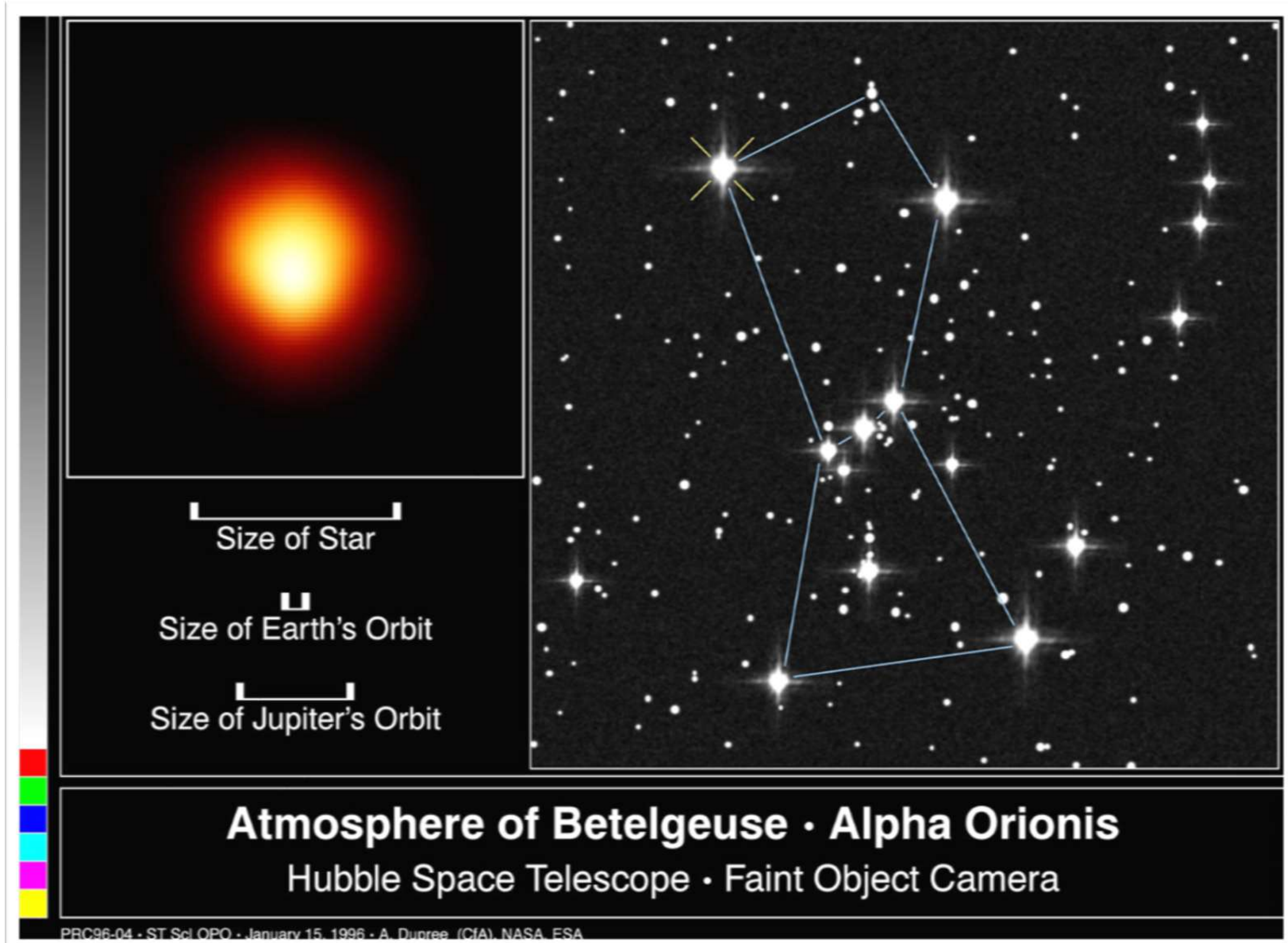

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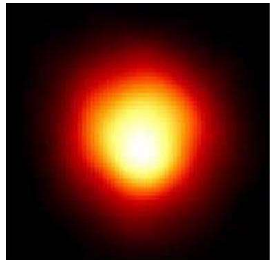

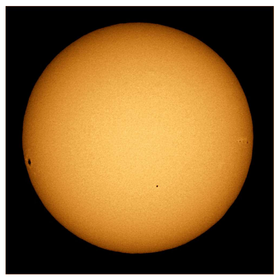

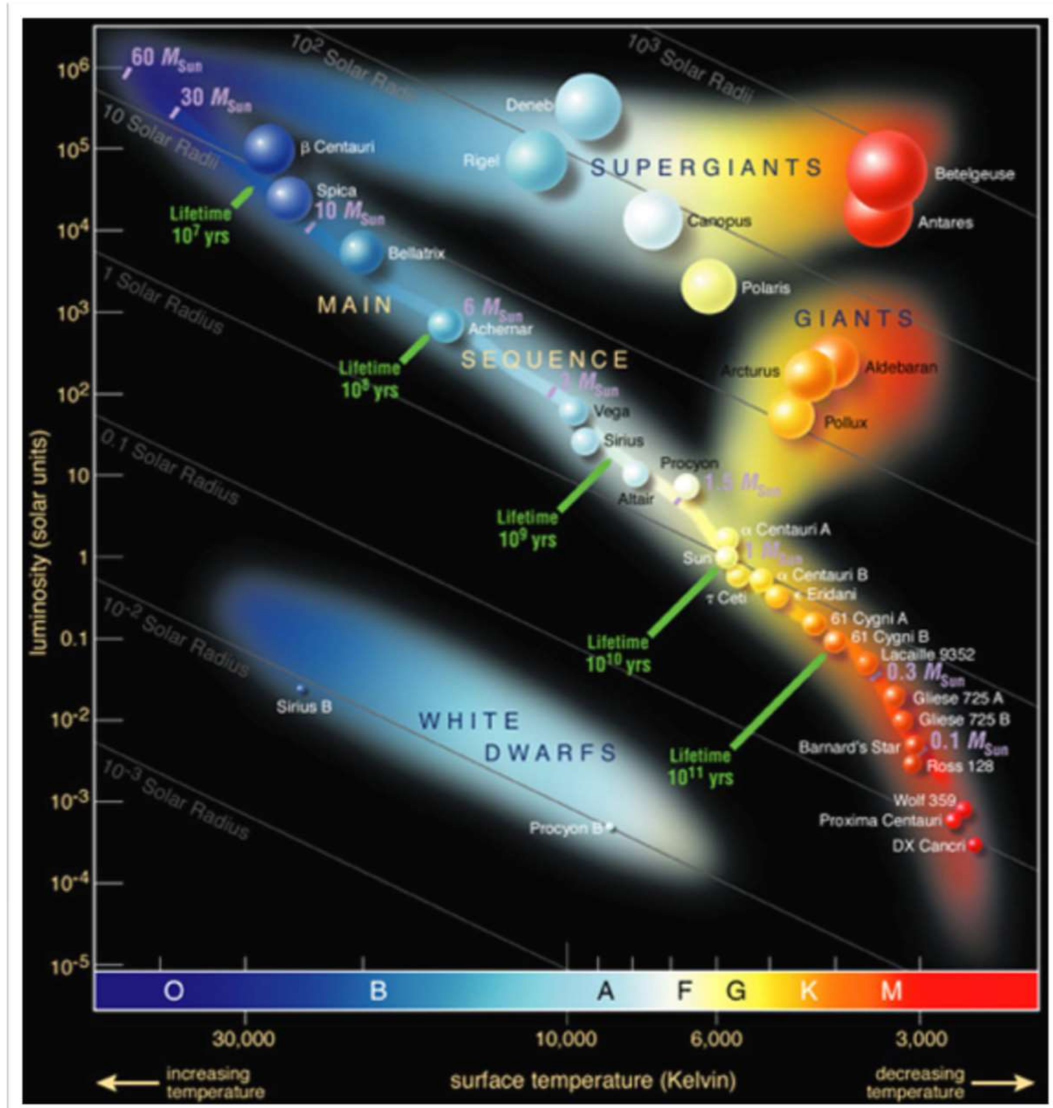

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Gådefulde α Ori

Videnskab …

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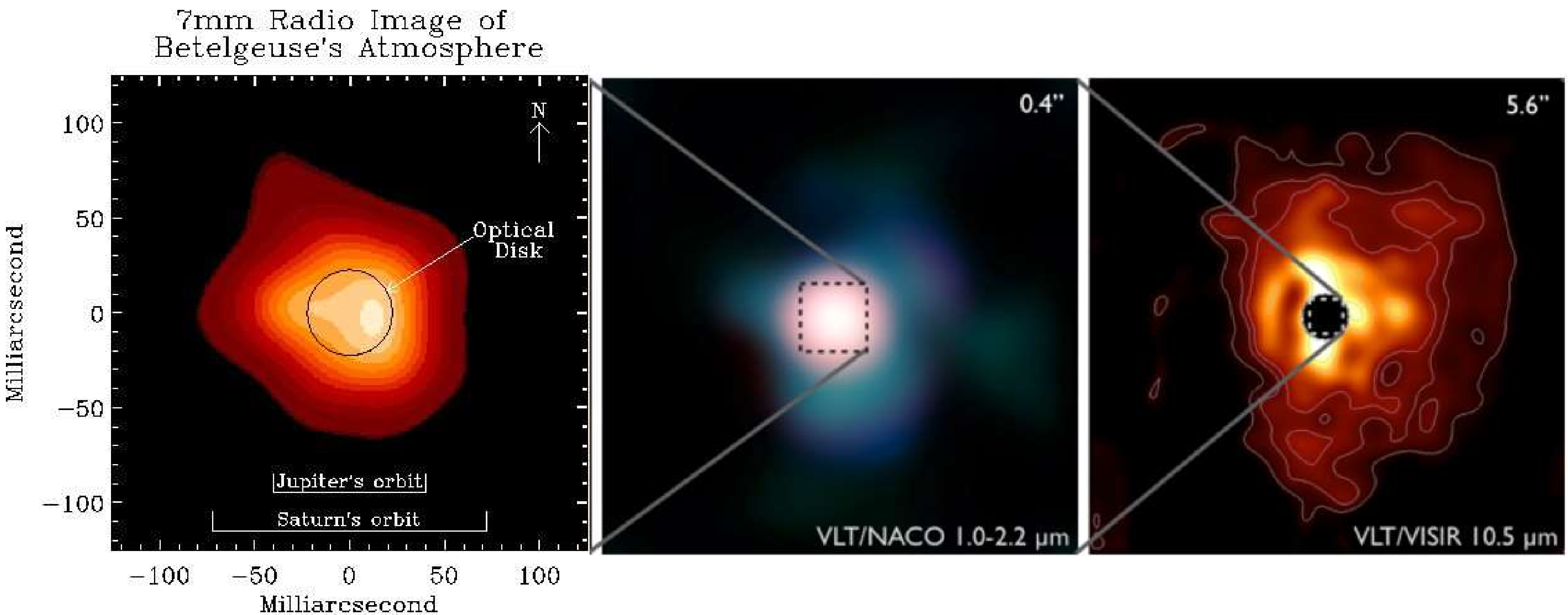
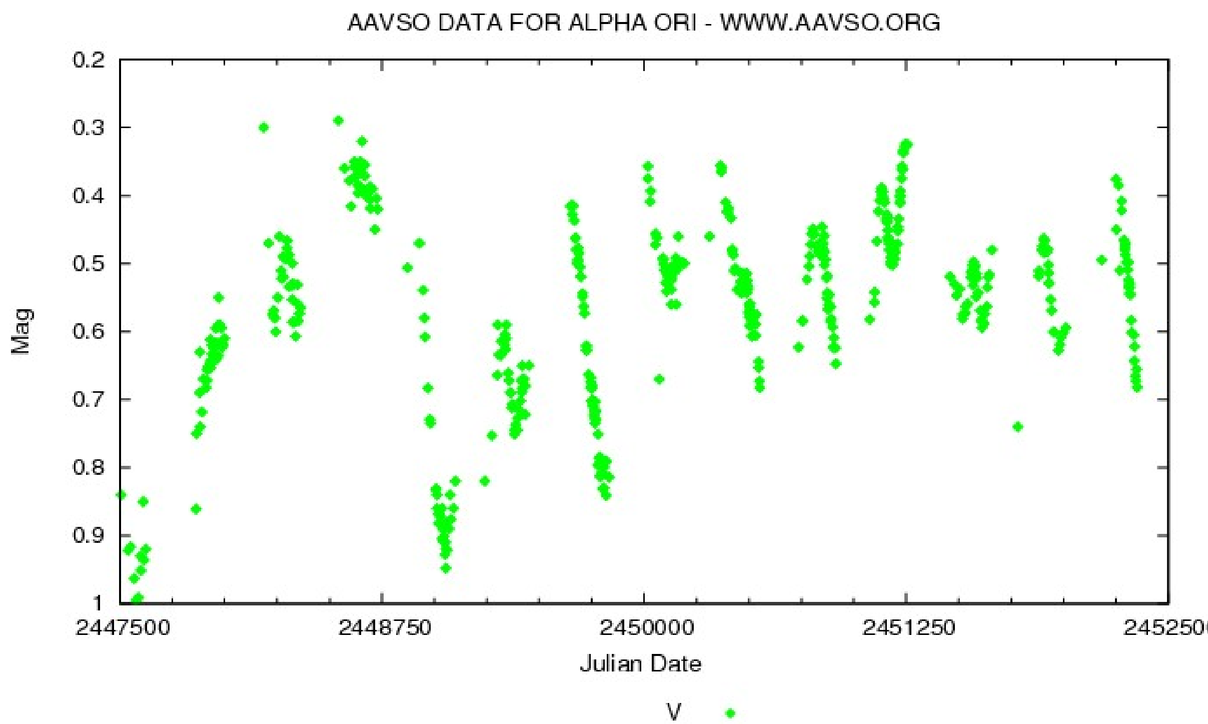
IAU 100 YEARS: UNDER ONE SKY



Courtesy of J. Lim, C Carilli, S. M. White,
A. J. Beasley, & R. G. Marson



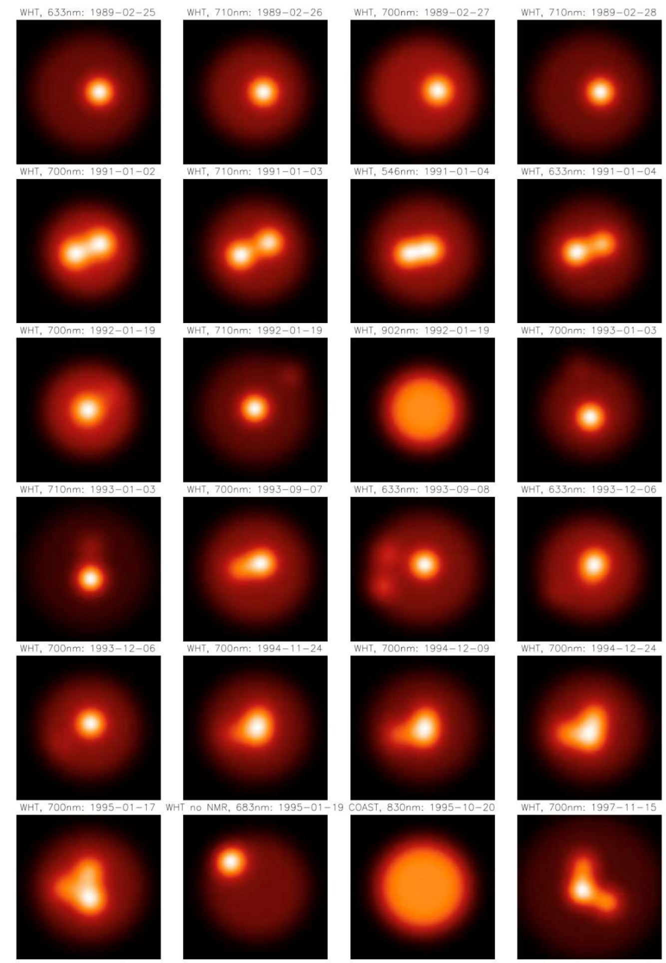
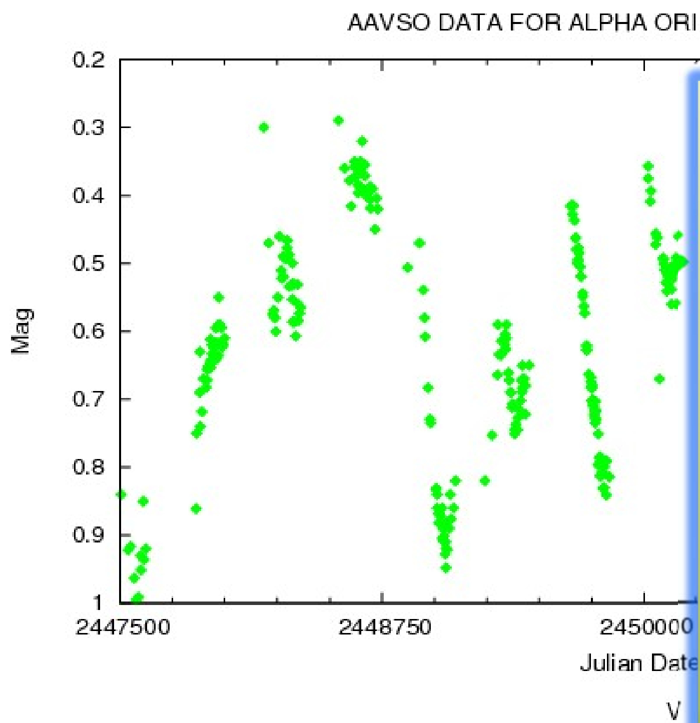


Fig. 1. WHT and COAST interferometric observations in the visible and near IR. The images were compiled from published data of spot positions and intensities, covering a time interval of almost 9 years (for references see text).



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10 celler mod 1 mio.

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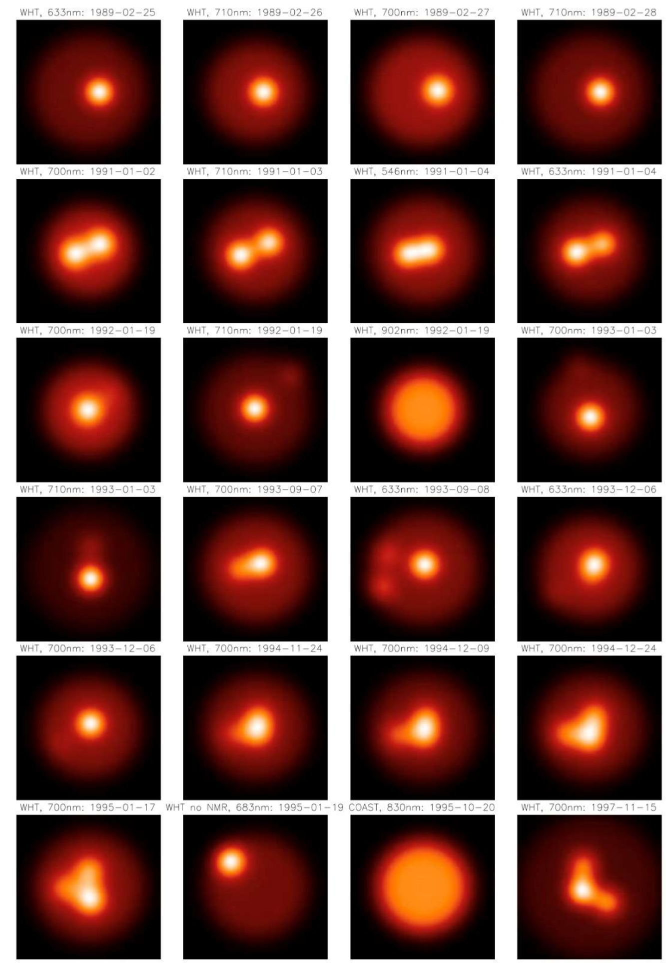
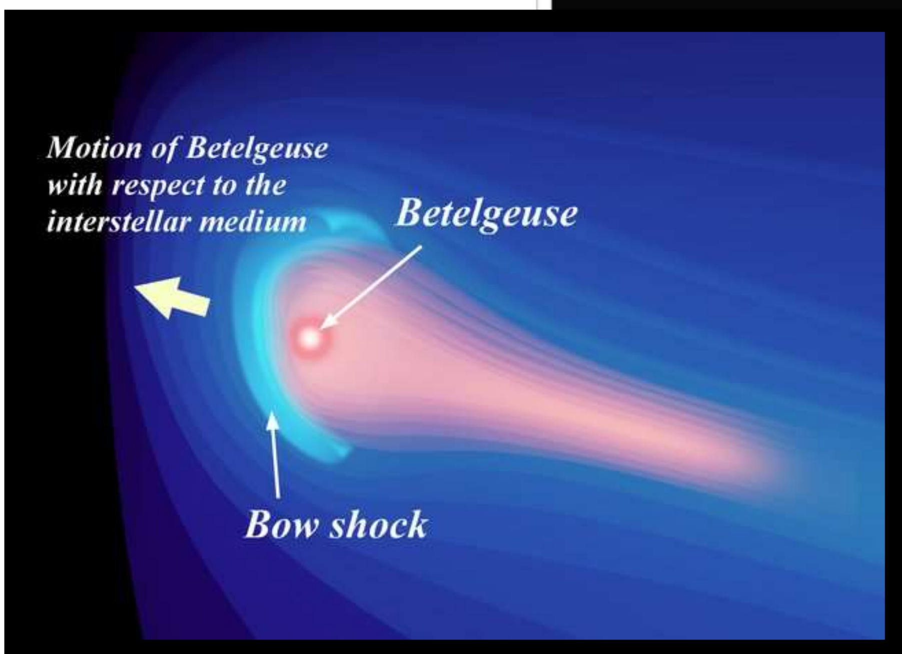
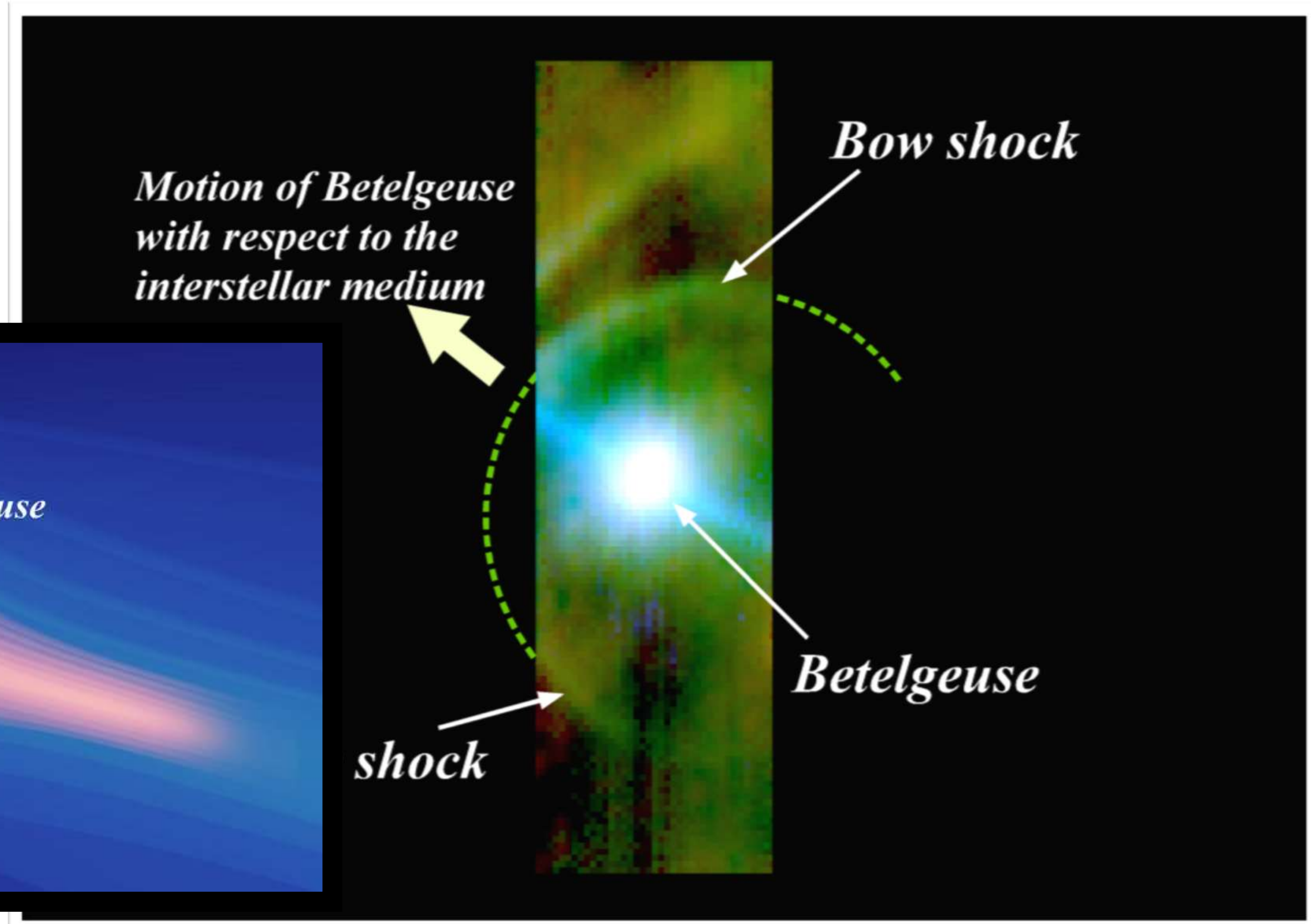


Fig. 1. WHT and COAST interferometric observations in the visible and near IR. The images were compiled from published data of spot positions and intensities, covering a time interval of almost 9 years (for references see text).

2013


Motion of Betelgeuse
with respect to the
interstellar medium
Betelgeuse
Bow shock


Bow shock
Motion of Betelgeuse
with respect to the
interstellar medium
Betelgeuse
shock

2017

Friday, Apr 21st 2017

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The giant red cannibal star that has devoured a neighbour bigger than our sun - and now Betelgeuse is ready to explode

- It is believed red supergiant Betelgeuse devoured neighbour 100,000 years ago
- The star is now rotating 150 times faster than it should be as a result of the
- Betelgeuse is thought to have expanded to 1,000 times wider than the sun

By LUKE JOHNSON
PUBLISHED: 19:17 BST, 21 December 2016 | UPDATED: 23:56 BST, 21 December 2016

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A giant red star called Betelgeuse could have devoured a neighbour bigger than our own sun.

The smaller star is believed to have been rotating faster than Betelgeuse when it was eaten, causing the larger body to speed up much.

The second brightest star in the Orion constellation, Betelgeuse sits on the hunter's shoulder and, if latest findings are correct, could have had a sister star in relatively close proximity.

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ROYAL ASTRONOMICAL SOCIETY
MNRAS 465, 2654–2661 (2017)
Advance Access publication 2016 November 10
doi:10.1093/mnras/stw2893

The Betelgeuse Project: constraints from rotation

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ABSTRACT
In order to constrain the evolutionary state of the red supergiant Betelgeuse (α Orionis), we have produced a suite of models with zero-age main sequence masses from 15 to 25 $M_\odot$ in intervals of 1 $M_\odot$ including the effects of rotation. The models were computed with the stellar evolutionary code MESA. For non-rotating models, we find results that are similar to other work. It is somewhat difficult to find models that agree within 1σ of the observed values of R, T_{eff} and L, but modestly easy within 3σ uncertainty. Incorporating the nominal observed rotational velocity, ~15 km s^{-1}, yields significantly different and challenging constraints. This velocity constraint is only matched when the models first approach the base of the red supergiant branch (RSB), having crossed the Hertzsprung gap, but not yet having ascended the RSB and most violate even generous error bars on R, T_{eff} and L. Models at the tip of the RSB typically rotate at only ~0.1 km s^{-1}, independent of any reasonable choice of initial rotation. We discuss the possible uncertainties in our modelling and the observations, including the distance to Betelgeuse, the rotation velocity and model parameters. We summarize various options to account for the rotational velocity and suggest that one possibility is that Betelgeuse merged with a companion star of about 1 $M_\odot$ as it ascended the RSB, in the process producing the ring structure observed at about 7 arcmin away. A past coalescence would complicate attempts to understand the evolutionary history and future of Betelgeuse.

Key words: stars: AGB and post-AGB – stars: evolution – stars: individual: (Betelgeuse) – supernovae: general.

...TION

...is) is a massive red supergiant that is destined ...IIP supernova and leave behind a neutron star. ...ong been obsessed with the uncertainty in the ...Betelgeuse and has sought means to reduce ...ffort, in various guises, has been informally ...Project. An evolving team of undergradu... ...his project. Here, we report on results on ...lly the constraint of its rotational state. ...d at reproducing the observed aspects ...n by Meynet et al. (2013) and Dolan ...nd the rather surprising result that the ...was ~19 $M_\odot$, somewhat larger than

...ermining when Betelgeuse will ex... ...current evolutionary state. A typical

basic model of 20 $M_\odot$ begins core helium burning as the model crosses the Hertzsprung gap. The model is still in core helium burning when it first hits the tip of the red supergiant branch (RSB) at a luminosity of $L \approx 10^5$ $L_\odot$. The model then forms a semiconvective hydrogen-burning shell and retreats down the RSB to $L = 10^{4.83}$ $L_\odot$, still substantially brighter than the minimum luminosity at the base of the RSB, $L = 10^{4.55}$ $L_\odot$. The model ends core helium burning with a luminosity of $L = 10^{4.95}$ $L_\odot$. Core carbon burning is initiated at $L = 10^{5.1}$ $L_\odot$, only about 2000 yr before core collapse. Betelgeuse is most probably in some phase of core helium burning.

2 COMPUTATIONS

We evolved a grid of models from the zero-age main sequence (ZAMS) to near the onset of core collapse using the stellar evolution code Modules for Experiments in Stellar Astrophysics (MESA;

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2017

FAKTA

Betelgeuse vs. Solen

½ så varm

600 – 800 gange større

8 – 15+ gange tungere

10 celler mod 1 mio.

10 mio. mod 5 mia. år

17 jord-år mod 27 dage

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PAUSE...

FORSKNINGENS DØGN

IAU
100 YEARS: UNDER ONE SKY

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Magnetisk?

Ny forskning …

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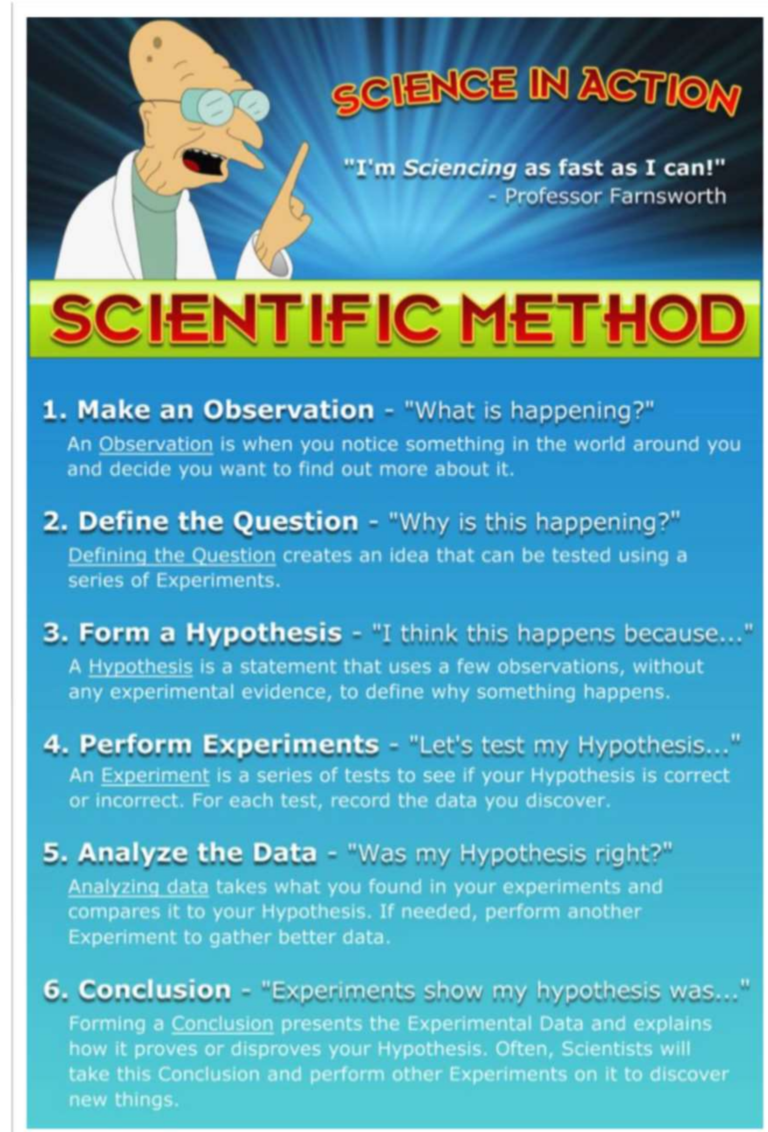
FORSKNINGENS DØGN

IAU 100 YEARS: UNDER ONE SKY

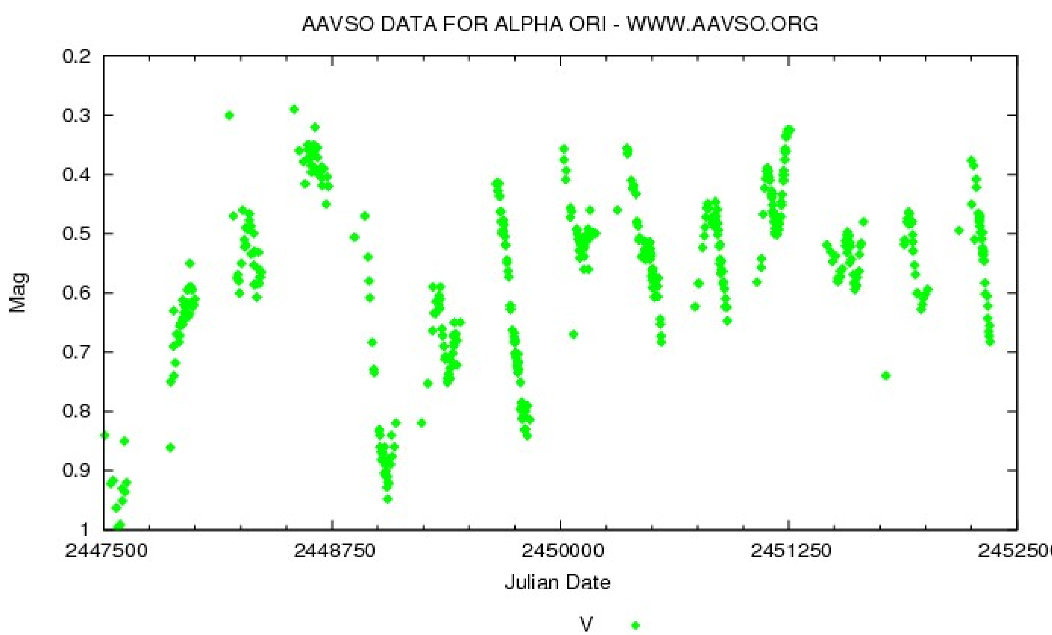
Videnskab

A. Opdagelse / spørgsmål
B. Hypotese / teori
C. Eksperiment / test
D. Analyse / observation
E. Konklusion



A. Observation / spørgsmål

Betelgeuse har gigantiske bobler / varmeceller



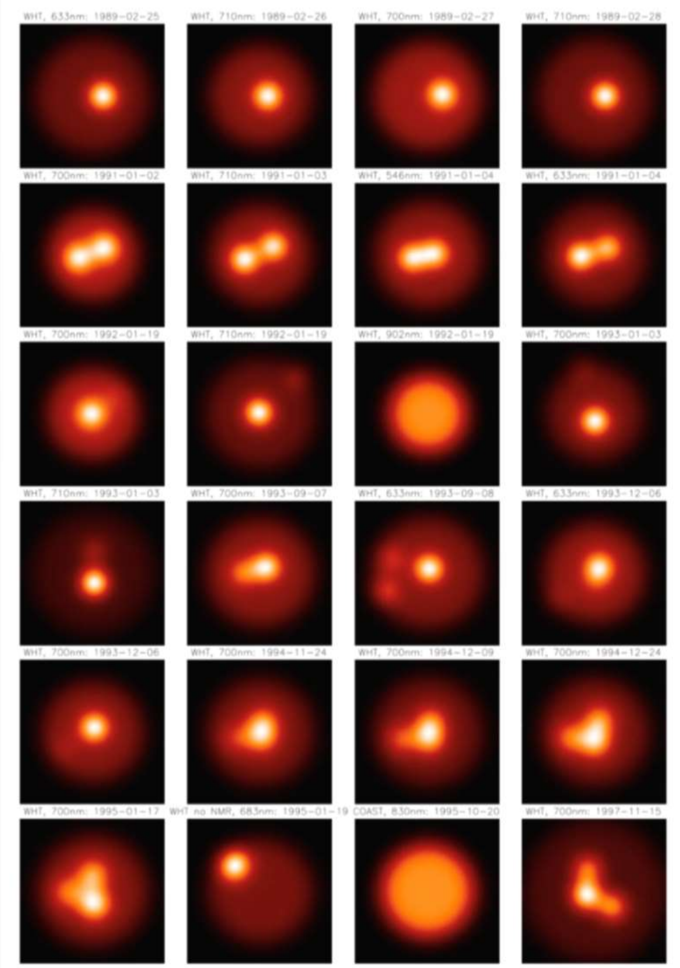
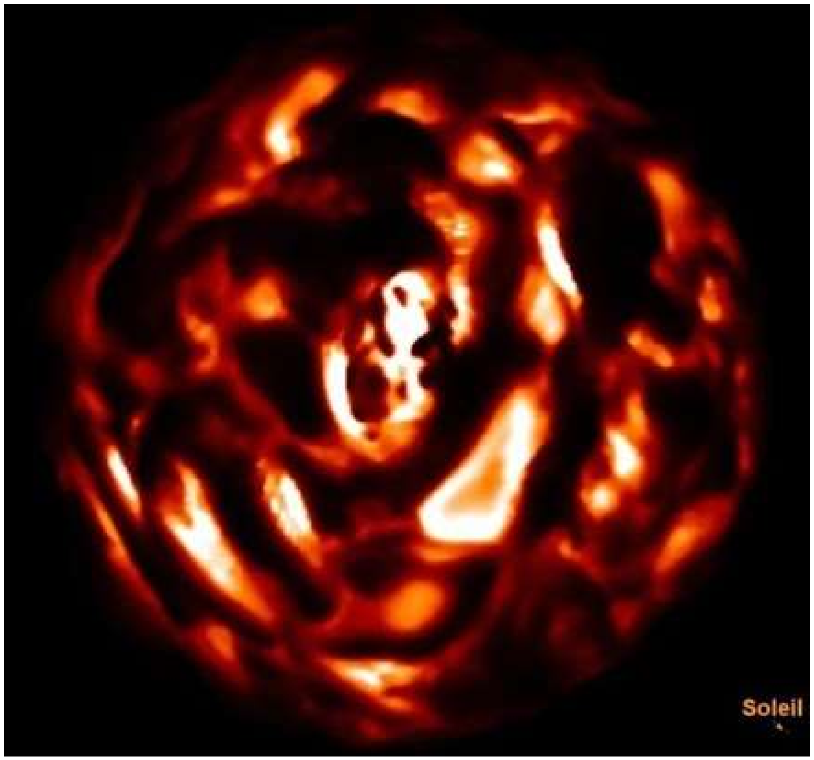


Fig. 1. WHT and COAST interferometric observations in the visible and near IR. The images were compiled from published data of spot positions and intensities, covering a time interval of almost 9 years

A. Computer-eksperiment



2002

Spots on the surface of Betelgeuse — Results from new 3D stellar convection models

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[1] Department for Astronomy and Space Physics at Uppsala University, Box 515, SE 75120 Uppsala, Sweden
[2] Astrophysikalisches Institut Potsdam, An der Sternwarte 16, D-14482 Potsdam, Germany
[3] Astronomical Observatory (NBIfAFG), Juliane Maries Vej 30, 2100 Copenhagen Ø, Denmark

Received 2002 May 10; accepted 2002 July 3

Abstract. The observed irregular brightness fluctuations of the well-known red supergiant Betelgeuse (α Ori, M2 Iab) have been attributed by M. Schwarzschild (1975) to the changing granulation pattern formed by only a few giant convection cells covering the surface of this giant star. The surface structure revealed by modern interferometric methods appears to be generally consistent with the explanation as large-scale granular intensity fluctuations. The interferometric data can be modeled equally well by assuming the presence of a few (up to 3) unresolved hot or cool spots on a limb-darkened disk. In an effort to improve our theoretical understanding of the Betelgeuse phenomena, we have applied a new radiation hydrodynamics code (CO^5BOLD) to the problem of global convection in giant stars. For this purpose, the "local box" setup usually employed for the simulation of solar-type surface convection cannot be used. Rather, we have chosen a radically different approach: the whole star is enclosed in a cube ("star-in-a-box" setup). The properties of the stellar model are defined by the prescribed gravitational central potential and by a special inner boundary condition which replaces the unresolved core, including the source of nuclear energy production. We present current results obtained from this novel generation of 3D stellar convection simulations, proceeding from a toy model ("Mini-Sun") towards the numerically more demanding supergiant regime. We discuss the basic observational properties of Betelgeuse in the light of our best model obtained so far (T_{eff} = 3300 K, $\log g = -0.4$). Finally, we describe a first attempt to investigate the interaction of the global convective flows with magnetic fields based on the kinematic approximation.

Key words: methods: numerical – stars: individual (Betelgeuse) – stars: spots – supergiants

1. Introduction

Betelgeuse (α Ori), a M2 Iab red supergiant, is among the stars with the largest apparent diameters. Its fundamental parameters are observationally not well determined: The parallax measured by Hipparcos is 7.6 ± 1.6 mas (131 pc with a considerable error). The measured angular diameter depends on wavelength, time, and assumptions about limb-darkening. With 4 m class telescopes (WHT and COAST, see references below) values between 42.6 mas and 76 mas at various wavelengths between 546 and 905 nm have been derived. Dyck et al. (1998) give a uniform disk diameter of 44.2 ± 0.2 mas at 2.2 μm. With a bolometric flux of $1.15\,10^{-11}$ W cm^{-2} μm^{-1} they derive an effective temperature of 3600 K. Radius and mass are not well known. Gray (2000) favors a radius of "some 800" solar radii and a mass between 10 and 20 solar masses. As an M2 giant, Betelgeuse lies close to the Hayashi limit in the Hertzsprung-Russell diagram, and hence is almost fully convective.

It has been possible to take direct images of Betelgeuse with HST (Gilliland & Dupree, 1996). These images, taken in the UV at 278 nm, show that the extended chromosphere deviates significantly from spherical symmetry. Spectrophotometric measurements reveal that Betelgeuse is an irregular variable. Its visual brightness changes by roughly a factor of two, and its radial velocity varies by ±3 km/s (Goldberg, 1984). The variations are clearly not harmonic but rather more stochastic, and have been attributed by M. Schwarzschild (1975) to the changing brightness of only a few giant convection cells being present at the surface of this giant star, possibly superimposed on some kind of pulsation.

Betelgeuse has been monitored by interferometric methods for about one decade. These observations reveal an irregular shape of the image of Betelgeuse, the possible imprint of giant convection cells. The observational data can be fitted

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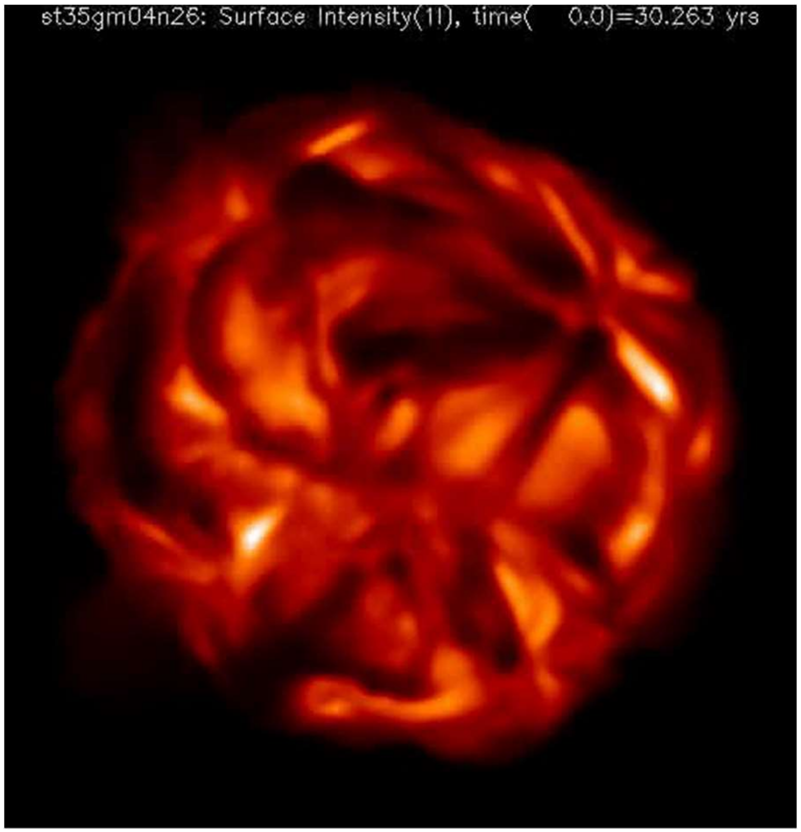
A. Computer-eksperiment



2002

Spots on the surface of Betelgeuse — Results from new 3D stellar convection models

B. Freytag[1], M. Steffen[2], and B. Dorch[3]

[1] Department for Astronomy and Space Physics at Uppsala University, Box 515, SE 75120 Uppsala, Sweden
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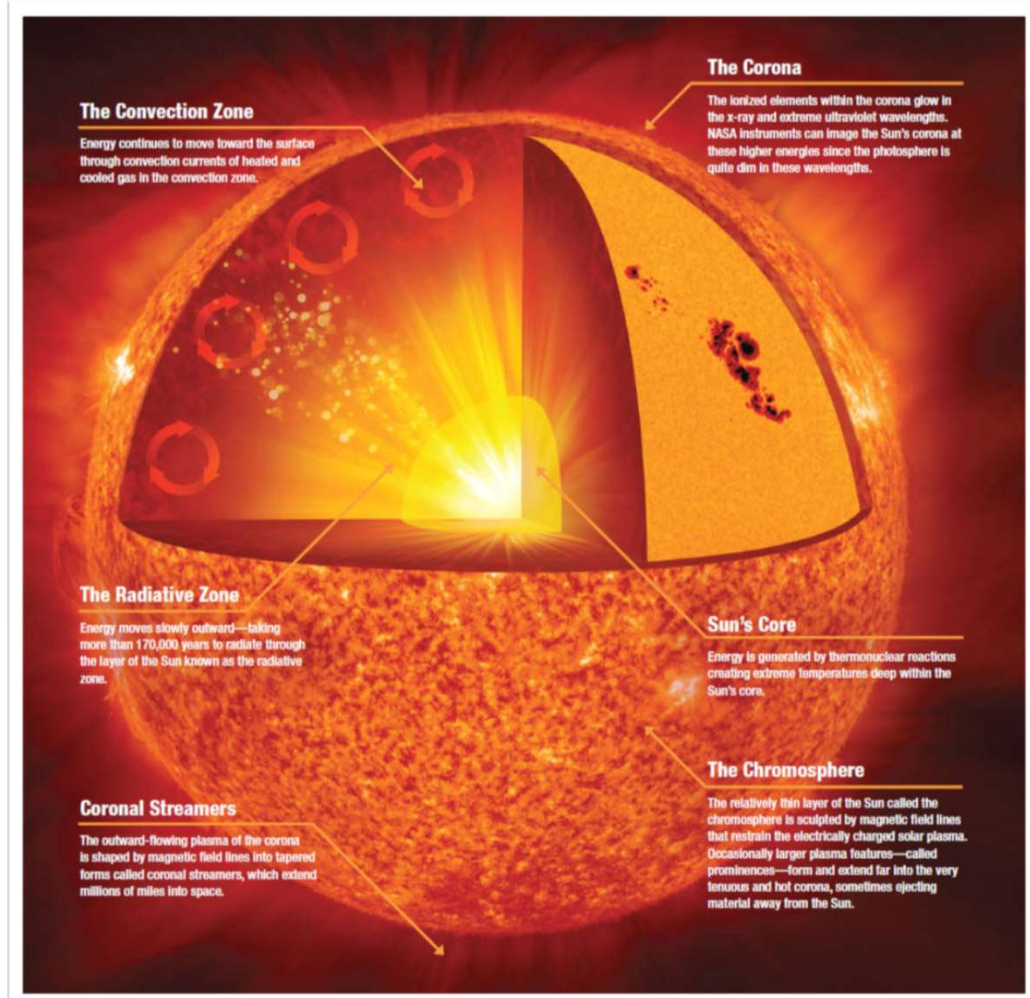
B. Hypotese / teori

Solen er magnetisk, fordi den har varmeceller.

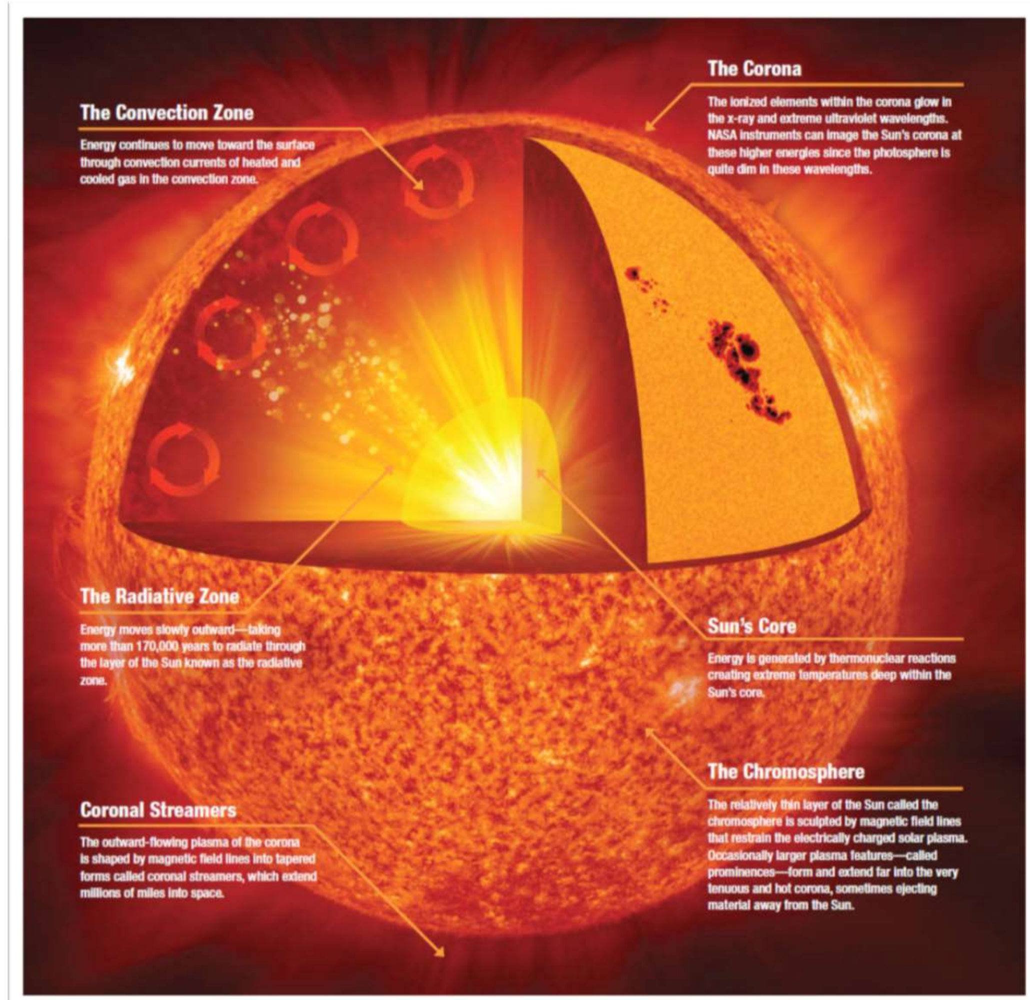


B. Hypotese / teori

Solen er magnetisk, fordi
den har varmeceller.

Varmeceller giver
bevægelsesenergi

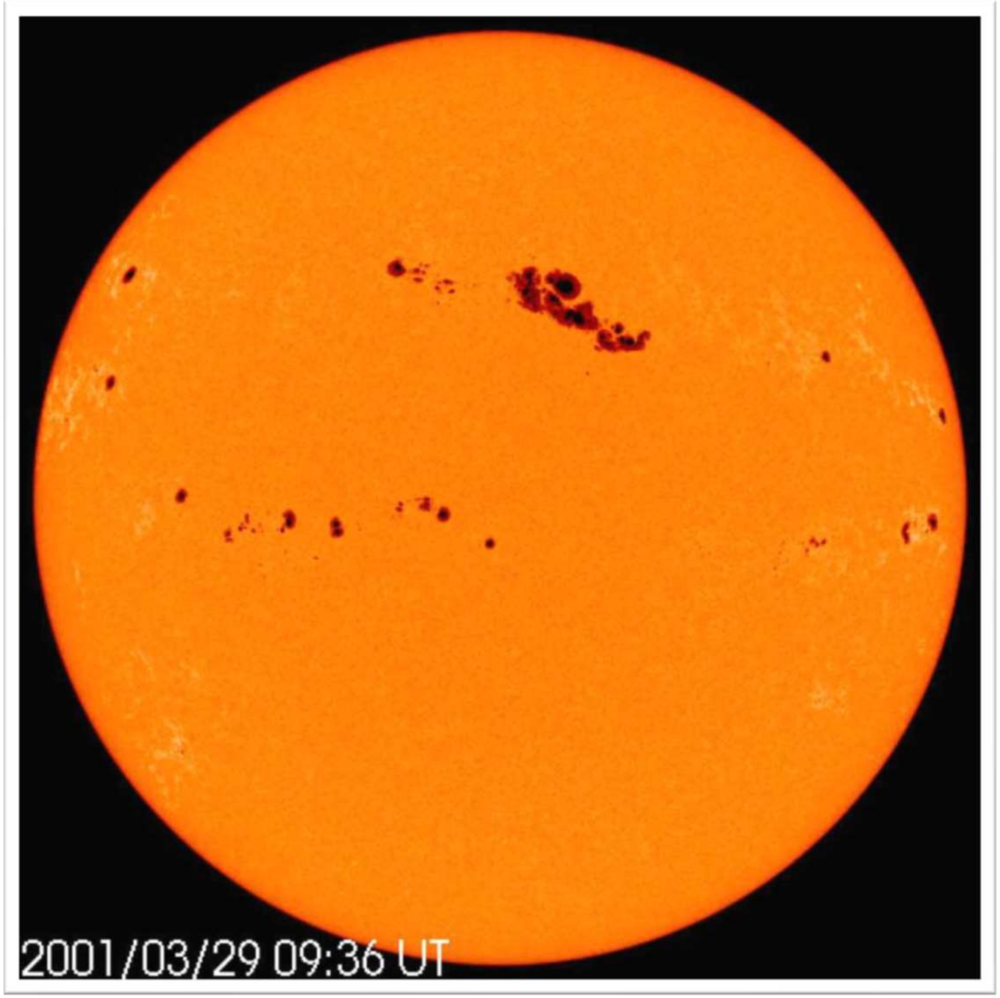
Bevægelsesenergi forstærker
magnetfelter



B. Hypotese / teori

Solen er magnetisk, fordi den har varmeceller.

Det giver den solpletter.



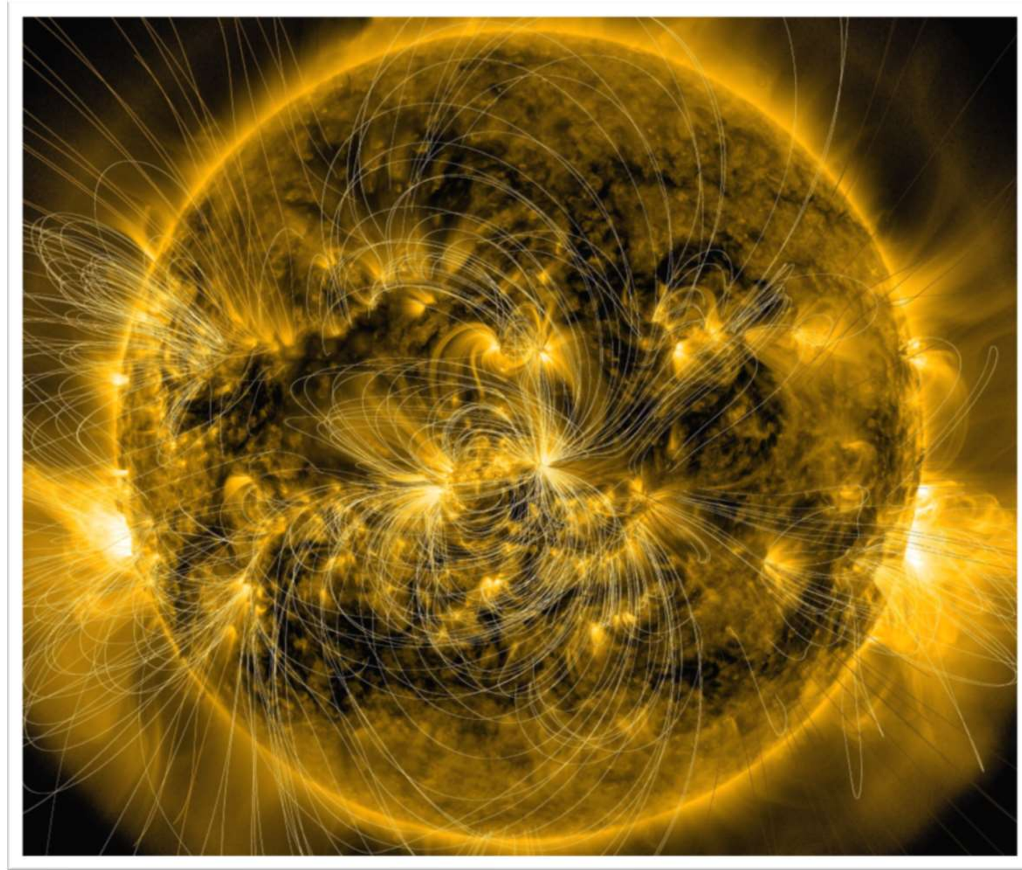
B. Hypotese / teori

Solen er magnetisk, fordi
den har varmeceller.

Det giver den solpletter.

Magnetisk energi bygges op

og frigives som stråling



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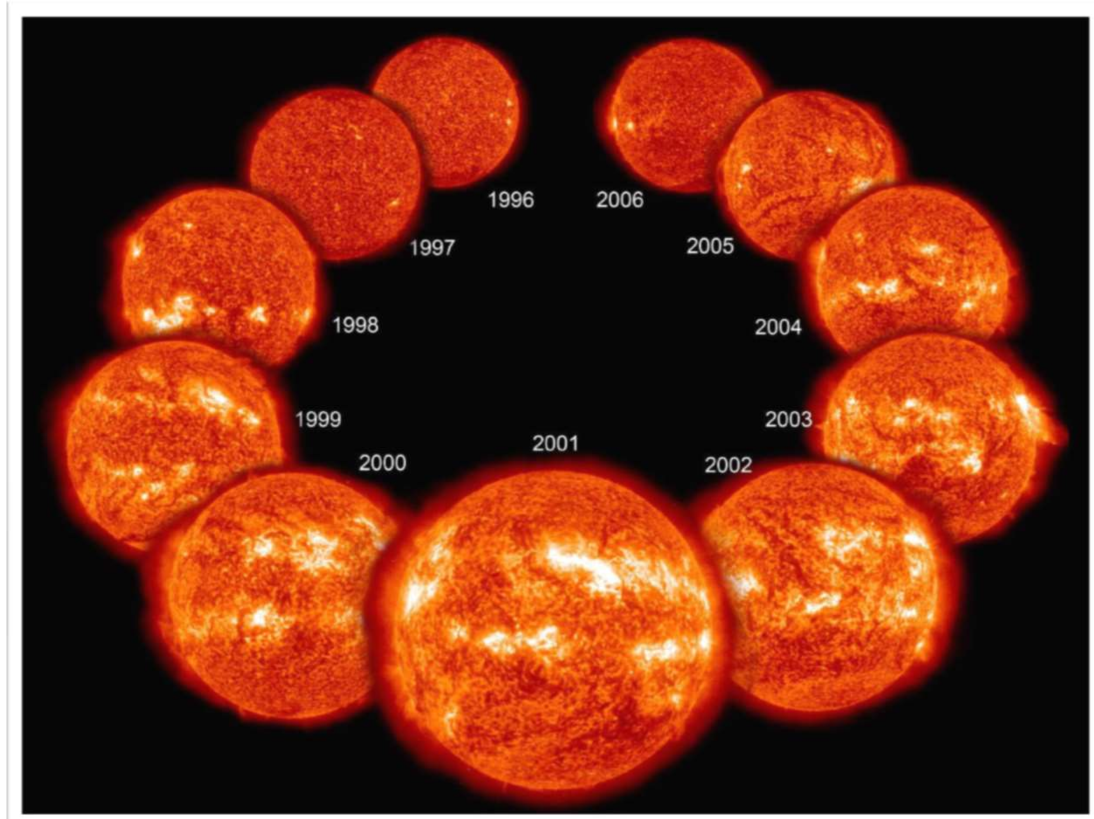
B. Hypotese / teori

Solen er magnetisk, fordi den har varmeceller.

Det giver den solpletter.

Og varierende lysstyrke.



B. Hypotese / teori

Solen er magnetisk, fordi den har varmeceller.

Det giver den solpletter.

Og varierende lysstyrke.

Hypotese:

Måske har Betelgeuse ”Stjernepletter” fordi den har gigantiske varmeceller?

Teori: Betelgeuse er magnetisk.

2004

arXiv:astro-ph/0403321v1 13 Mar 2004

Magnetic activity in late-type giant stars: Numerical MHD simulations of non-linear dynamo action in Betelgeuse

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The Niels Bohr Institute for Astronomy, Physics and Geophysics, Juliane Maries Vej 30, DK-2100 Copenhagen Ø, Denmark

Received date, accepted date

Abstract. Evidence is presented from numerical magneto-hydrodynamical simulations for the existence of magnetic activity in late-type giant stars. A red supergiant with stellar parameters similar to that of Betelgeuse (α Orionis) is modeled as a "star-in-a-box" with the high-order "Pencil Code". Both linear kinematic and non-linear saturated dynamo action are found: the non-linear magnetic field saturates at a super-equipartition value, while in the linear regime two different modes of dynamo action are found. It is speculated that magnetic activity of late-type giants may influence dust and wind formation and possibly lead to the heating of the outer atmospheres of these stars.

Key words. Stars: AGB and post-AGB — late-type — activity — individual: Betelgeuse, Physical data and processes: magnetic fields — MHD

1. Introduction

There are indications from both dynamo theory and observations that some late-type giant stars such as red supergiants and asymptotic-giant-branch stars (AGB stars) may harbor magnetic fields. On the theoretical side, it has been suggested that non-spherically symmetric planetary nebulae (PNe) may be a result of the collimating effect of a strong magnetic field: Blackman et al. (2001) studied interface dynamo models similar to the mean field theory's solar $\alpha\omega$-dynamo and found that the generated magnetic fields were strong enough to shape bipolar outflows, producing bipolar PNe, while also braking the stellar core thereby explaining the slow rotation of many white dwarf stars. Also using mean field dynamo theory Soker & Zoabi (2002) propose instead an $\alpha^2\omega$ dynamo due to the slow rotation of AGB stars rendering the ω-effect ineffective. They find that the magnetic field may reach strengths of $\sim$ 100 Gauss, significantly less than that found by Blackman et al. (2001). On the one hand, they believe that the large-scale field is strong enough for the formation of magnetic cool spots (see also Soker & Kastner 2003 on AGB star flaring). These spots in turn may regulate dust formation, and hence the mass-loss rate, but the authors argue that they cannot explain the formation of non-spherical PNe (see also Soker 2002): on the other hand, the locally strong magnetic tension could enforce a coherent flow that may favor a maser process.

On the observational side of things, maser polarization is known to exist in circumstellar envelopes of AGB stars (e.g. Gray et al. 1999, Vlemmings et al. 2003, and recently Sivagnanam 2004) and X-ray emission has been observed from some cool giant stars (e.g. Hünsch et al. 1998 and Ayres et al. 2003). These observations are generally taken as evidence for the existence of magnetic activity in late-type giant stars (cf. Soker & Kastner 2003).

The cool star Betelgeuse (a.k.a. α Orionis) is an example of an abundantly observed late-type supergiant that displays irregular brightness variations interpreted as large-scale surface structures (e.g. Lim et al. 1998 and Gray 2000). It is one of the stars with the largest apparent sizes on the sky—corresponding to a radius in the interval 600–800 $R_\odot$. Freytag et al. (2002) performed detailed numerical 3-d radiation-hydrodynamic (RHD) simulations of the convective envelope of the star under realistic physical assumptions, while trying to determine if the star's known brightness fluctuations may be understood as convective motions within the star's atmosphere: the resulting models were largely successful in explaining the observations as a consequence of giant-cell convection on the stellar surface, very dissimilar to solar convection. Dorch & Freytag (2002) performed a kinematic dynamo analysis of the convective motions (i.e. not including the back-reaction of the Lorentz force on the flow) and found that a weak seed magnetic field could indeed be exponentially amplified by the giant-cell convection on a time-scale of about 25 years.

This paper reports on full non-linear magneto-hydrodynamical (MHD) numerical simulations of dynamo

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C. Eksperiment / test

2004

$$
\begin{aligned}
\frac{\partial \boldsymbol{B}}{\partial t} &= -\nabla \times \boldsymbol{E}, \\
\boldsymbol{E} &= -(\boldsymbol{v} \times \boldsymbol{B}) + \eta \boldsymbol{J}, \\
\boldsymbol{J} &= \nabla \times \boldsymbol{B}, \\
\frac{\partial \rho}{\partial t} &= -\nabla \cdot (\rho \boldsymbol{v}), \\
\frac{\partial}{\partial t}(\rho \boldsymbol{v}) &= -\nabla \cdot \left(\rho \boldsymbol{v}\boldsymbol{v} + \underline{\underline{\tau}}\right) - \nabla P + \boldsymbol{J} \times \boldsymbol{B}, \\
\frac{\partial e}{\partial t} &= -\nabla \cdot (e \boldsymbol{v}) - P \nabla \cdot \boldsymbol{v} + Q_{\mathrm{visc}} + Q_J,
\end{aligned}
$$

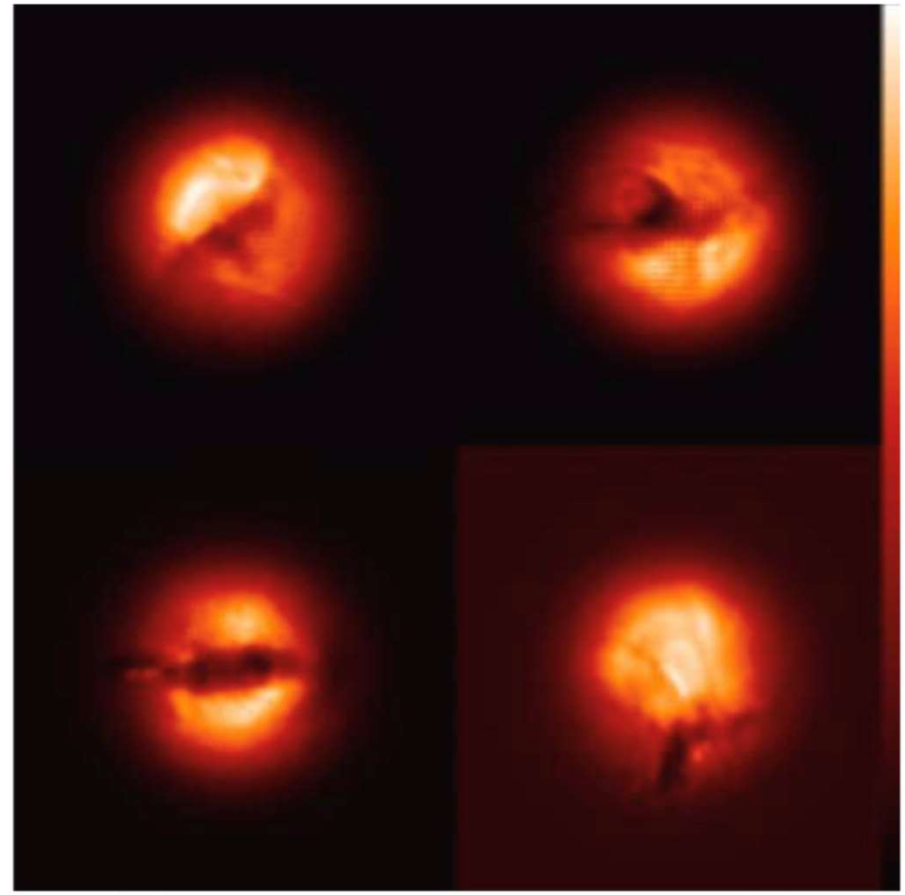

Fig. 2. Simulated surface intensity snapshots at four different instants, time = 256, 347, 457 and 494 years (from upper left to lower right).

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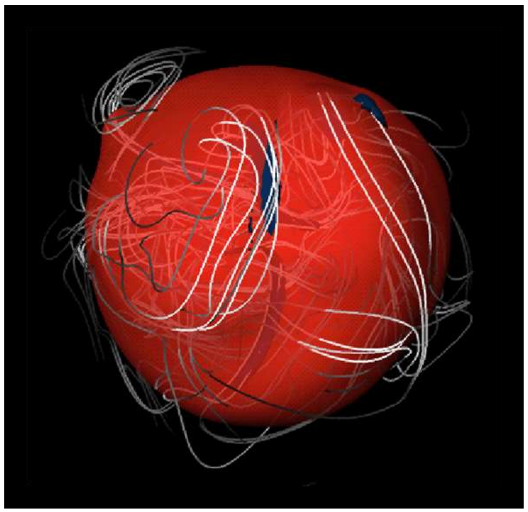
C. Eksperiment / test



2004

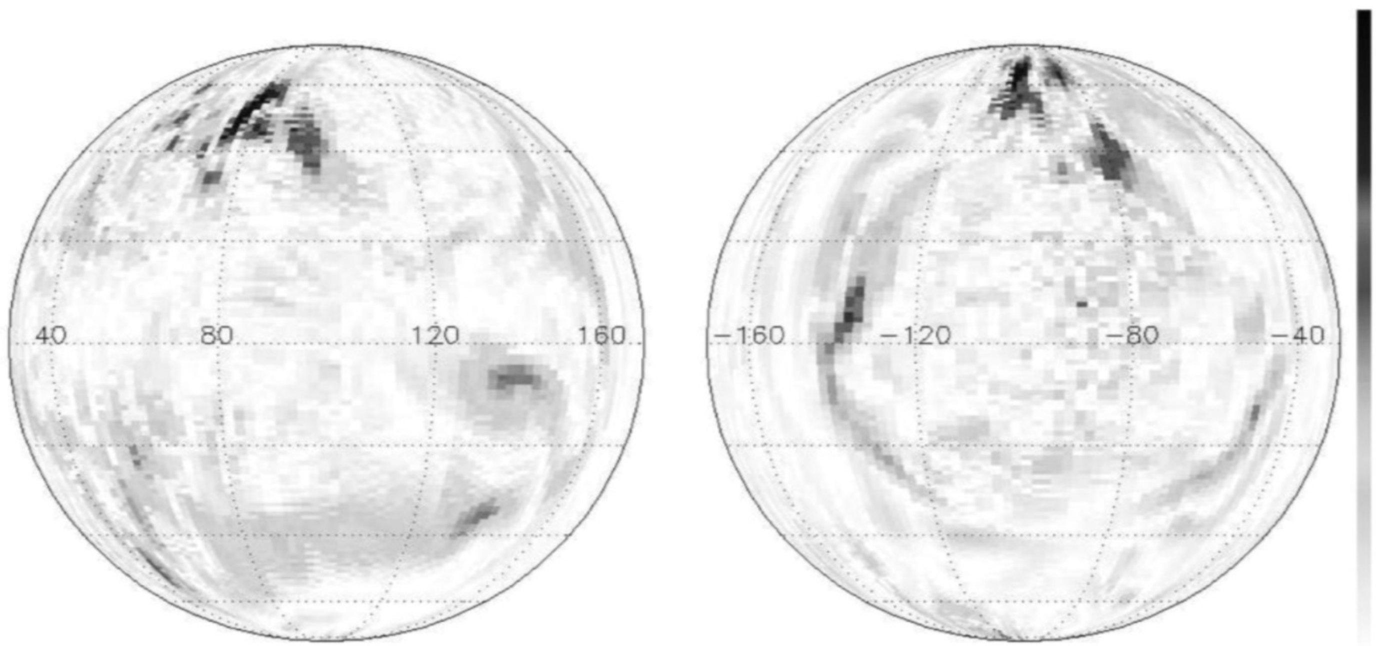
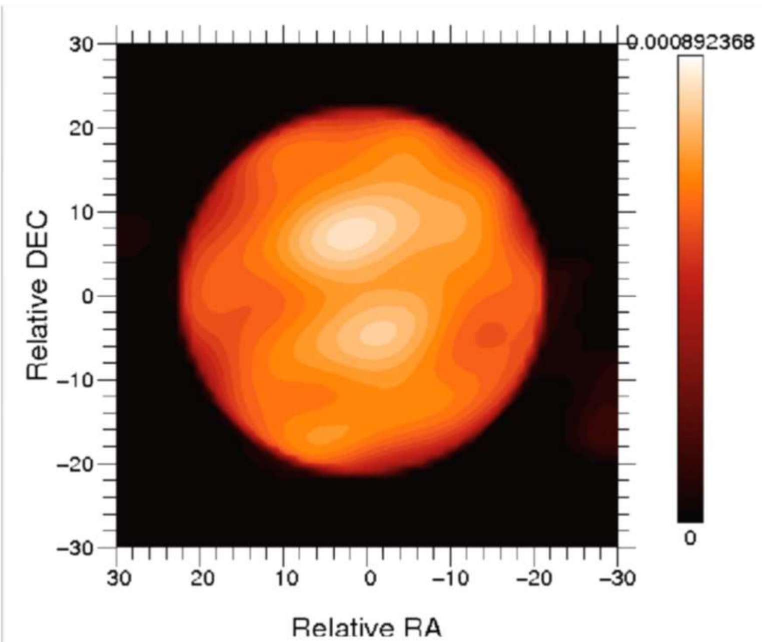


Fig. 8. An illustration of the unsigned magnetic field strength |B| at the spherical surface r = R of the model star using an orthographic map projection. The darkest patches correspond to a maximum field strength of 500 Gauss (black on the continuous scale bar). From a snapshot at time = 695 years. The views are centered on longitudes of 100° (left) and −100° (right). The grid indicated has a longitudinal spacing of 40° and a latitudinal spacing of 20°. The numerical resolution of the map is 180^2 grid points.

D. Analyse / observation



2009

arXiv:0910.4167v2 [astro-ph.SR] 9 Nov 2009

Imaging the spotty surface of Betelgeuse in the H band

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ABSTRACT

Aims. This paper reports on H-band interferometric observations of Betelgeuse made at the three-telescope interferometer IOTA. We
image Betelgeuse and its asymmetries to understand the spatial variation of the photosphere, including its diameter, limb darkening,
effective temperature, surrounding brightness, and bright (or dark) star spots.
Methods. We used different theoretical simulations of the photosphere and dusty environment to model the visibility data. We made
images with parametric modeling and two image reconstruction algorithms: MIRA and WISARD.
Results. We measure an average limb-darkened diameter of 44.28 ± 0.15 mas with linear and quadratic models and a Rosseland
diameter of 45.03 ± 0.12 mas with a MARCS model. These measurements lead us to derive an updated effective temperature of
3600 ± 66 K. We detect a fully-resolved environment to which the silicate dust shell is likely to contribute. By using two imaging
reconstruction algorithms, we unveiled two bright spots on the surface of Betelgeuse. One spot has a diameter of about 11 mas and
accounts for about 8.5% of the total flux. The second one is unresolved (diameter < 9 mas) with 4.5% of the total flux.
Conclusions. Resolved images of Betelgeuse in the H band are asymmetric at the level of a few percent. The MOLsphere is not
detected in this wavelength range. The amount of measured limb-darkening is in good agreement with model predictions. The two
spots imaged at the surface of the star are potential signatures of convective cells.

Key words. Convection-techniques: interferometric- stars: fundamental parameters- infrared: stars- stars: individual: Betelgeuse

1. Introduction

Located in the Orion constellation, Betelgeuse (α Orionis) is a red supergiant (hereafter RSG) of spectral type M2Iab. It is one of the brightest stars at optical wavelengths and has the second biggest angular diameter (~43 mas, Perrin et al., 2004) after R Doradus (Bedding et al., 1997). Classified as semi-regular, it shows periodicity in its brightness changes, accompanied or sometimes interrupted by various irregularities (Guinan, 1984). According to a recent reanalysis of a Hipparcos satellite dataset, its distance is now estimated at 197 ± 45 pc (Harper et al., 2008). The observations up to now have identified at least 7 components of the complex Betelgeuse atmosphere: two outer shells, a dust environment, a chromosphere, a gaseous envelope, a molecular shell also known as MOLsphere (Tsuji, 2000a), and finally the photosphere. Some of these components are not symmetric, and some are overlapping.

1.1. Two outer shells

Two shells (S1 and S2) have been observed in absorption in $^{12}C^{16}O$ and $^{13}C^{16}O$ at 4.6 μm by Bernat et al. (1979) but their spatial extent was not directly determined. Phoenix 4.6 μm spectra obtained by Harper et al. (2009) led to an estimation of the size for S1 and S2. An outer radius of ~4.5 and ~7 arcsec were derived, respectively, although the latter is inconsistent with other measurements made by the CARMA interferometer.

1.2. A dusty environment

A shell of dust was first detected with heterodyne interferometry at 11 μm by Sutton et al. (1977). Quite a few estimates of the inner radius of Betelgeuse's dust shell have since been made. Bester et al. (1991) used a model with an inner radius of 0.9 arcsec (~45 $R_\star$) to explain both their 11 μm heterodyne interferometry (ISI) and older speckle observations by Sutton et al. (1977) and Howell et al. (1981). In their spatially resolved mid-infrared (mid-IR) slit spectroscopy, Sloan et al. (1993) find no silicate emission within the central arcsecond around Betelgeuse[1]. Danchi et al. (1994) find from 11.15 μm ISI data that the inner radius must be 1.00 ± 0.05 arcsec, i.e. roughly 50 $R_\star$. But this result disagrees with later findings by Skinner et al. (1997), who claim an inner radius of not more than 0.5 arcsec. This environment of dust is also reported by Tatebe

[1] They also remark that this actually argues against a spherical distribution of the dust.

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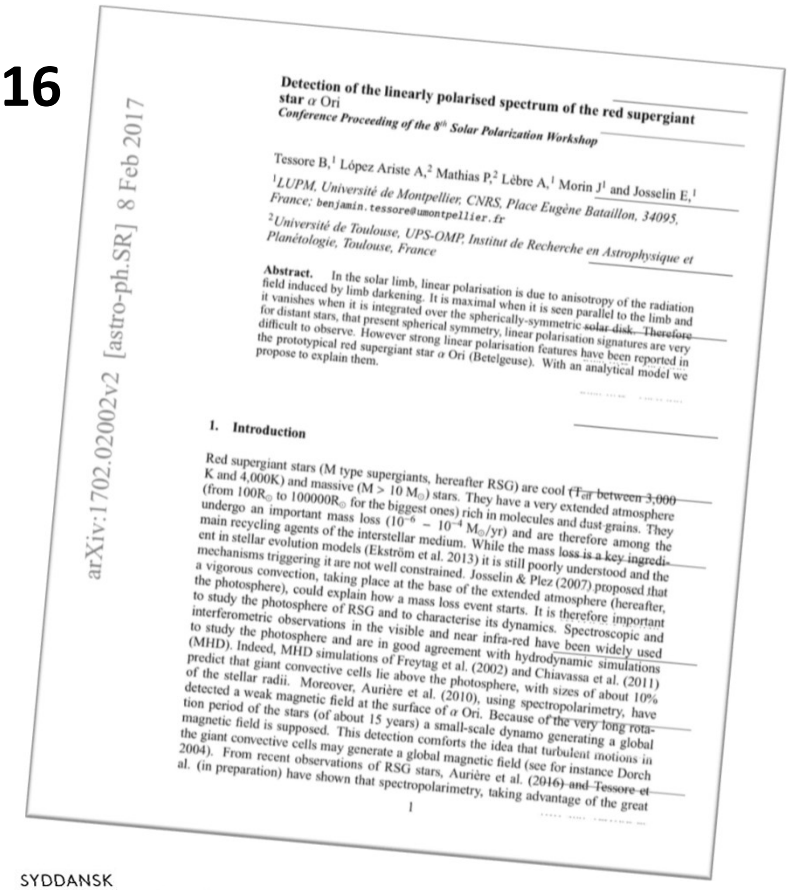
D. Analyse / observation

2016



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Detection of the linearly polarised spectrum of the red supergiant star α Ori

Conference Proceeding of the 8th Solar Polarization Workshop

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Abstract. In the solar limb, linear polarisation is due to anisotropy of the radiation field induced by limb darkening. It is maximal when it is seen parallel to the limb and it vanishes when it is integrated over the spherically-symmetric solar disk. Therefore for distant stars, that present spherical symmetry, linear polarisation signatures are very difficult to observe. However strong linear polarisation features have been reported in the prototypical red supergiant star α Ori (Betelgeuse). With an analytical model we propose to explain them.

1. Introduction

Red supergiant stars (M type supergiants, hereafter RSG) are cool (T_{eff} between 3,000 K and 4,000K) and massive ($M > 10\ M_\odot$) stars. They have a very extended atmosphere (from $100R_\odot$ to $100000R_\odot$ for the biggest ones) rich in molecules and dust grains. They undergo an important mass loss ($10^{-6} - 10^{-4}\ M_\odot$/yr) and are therefore among the main recycling agents of the interstellar medium. While the mass loss is a key ingredient in stellar evolution models (Ekström et al. 2013) it is still poorly understood and the mechanisms triggering it are not well constrained. Josselin & Plez (2007) proposed that a vigorous convection, taking place at the base of the extended atmosphere (hereafter, the photosphere), could explain how a mass loss event starts. It is therefore important to study the photosphere of RSG and to characterise its dynamics. Spectroscopic and interferometric observations in the visible and near infra-red have been widely used to study the photosphere and are in good agreement with hydrodynamic simulations (MHD). Indeed, MHD simulations of Freytag et al. (2002) and Chiavassa et al. (2011) predict that giant convective cells lie above the photosphere, with sizes of about 10% of the stellar radii. Moreover, Aurière et al. (2010), using spectropolarimetry, have detected a weak magnetic field at the surface of α Ori. Because of the very long rotation period of the stars (of about 15 years) a small-scale dynamo generating a global magnetic field is supposed. This detection comforts the idea that turbulent motions in the giant convective cells may generate a global magnetic field (see for instance Dorch 2004). From recent observations of RSG stars, Aurière et al. (2016) and Tessore et al. (in preparation) have shown that spectropolarimetry, taking advantage of the great

1

2010

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Astronomy & Astrophysics

Letter to the Editor

The magnetic field of Betelgeuse: a local dynamo from giant convection cells?*

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ABSTRACT

Context. Betelgeuse is an M supergiant with a complex and extended atmosphere, which also harbors spots and giant granules at its surface. A possible magnetic field could contribute to the mass loss and to the heating of the outer atmosphere.
Aims. We observed Betelgeuse, to directly study and infer the nature of its magnetic field.
Methods. We used the new-generation spectropolarimeter NARVAL and the least square deconvolution (LSD) method to detect circular polarization within the photospheric absorption lines of Betelgeuse.
Results. We have unambiguously detected a weak Stokes V signal in the spectral lines of Betelgeuse, and measured the related surface-averaged longitudinal magnetic field B_l at 6 different epochs over one month. The detected longitudinal field is about one Gauss and is apparently increasing on the time scale of our observations.
Conclusions. This work presents the first direct detection of the magnetic field of Betelgeuse. This magnetic field may be associated to the giant convection cells that could enable a "local dynamo".

Key words. stars: individual: Betelgeuse – stars: magnetic field – stars: late-type – supergiants

1. Introduction

Betelgeuse (α Ori, HD 39801) is a nearby M2Iab supergiant, and a star with the largest apparent diameter. It has naturally deserved direct imaging and interferometric studies of its surface, which was found to deviate from circular symmetry and to present variable behavior (Wilson et al. 1997; Haubois et al. 2009). The presence of a few spots and giant granules appeared as a natural explanation for the imaging and interferometric observations and their variability. A magnetic field at the surface of this star has also been suggested by Dorch & Freytag (2003). Numerical simulations of convection now match interferometric observations and enable determination of the convection pattern on Betelgeuse (Chiavassa et al. 2010).

In this context, we have undertaken a very sensitive magnetic study of Betelgeuse, using the new generation spectropolarimeter NARVAL in operation at Télescope Bernard Lyot (TBL, Observatoire du Pic du Midi). We present here the result of a short campaign in March-April 2010. We report the definite detection of a weak magnetic field at the surface of Betelgeuse. Section 2 describes our observations and Sect. 3 our results. We discuss the nature of the magnetic field in Sect. 4 and give our conclusions in Sect. 5.

2. Observations with NARVAL

Observations of Betelgeuse were obtained at the TBL using the spectropolarimeter NARVAL, which is a twin of ESPaDOnS (Donati et al. 2006).

We observed Betelgeuse on 6 dates in March-April 2010. A standard circular polarization observation consists of a series of 4 sub exposures.

To avoid saturation, we performed short exposures (3–5 s, sky-quality depending) for each sub exposure. We got 16 to 20 Stokes V / Stokes I series each night, which were averaged. Also included in the output are "diagnostic null" spectra N, which are in principle featureless, and therefore serve to diagnose the presence of spurious contributions to the Stokes V spectrum. Each single spectrum used in this work has a peak signal-to-noise ratio (S/N) in Stokes I per 2.6 km s^{-1} spectral bin between 1700 and 2100. Details on the used procedure can be found in Donati et al. (1997) and Aurière et al. (2009). Table 1 gives the log of observations with the dates, the mean Heliocentric Julian Date (HJD) of the binned measurement of each night, and the total exposure time. To obtain a high-precision diagnosis of the spectral line circular polarization, the least-square deconvolution (LSD, Donati et al. 1997) was applied to each reduced Stokes I and V spectrum. We used a solar abundance line mask calculated from data provided by VALD (Kupka et al. 1999) for an effective temperature of 3750 K, $\log g = 0.0$, and a microturbulence of 4.0 km s^{-1}, consistent with

* Based on observations obtained at the Télescope Bernard Lyot (TBL) at Observatoire du Pic du Midi, CNRS/INSU and Université de Toulouse, France.

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E. Konklusion

A. Opdagelse / spørgsmål 2002
B. Hypotese / teori 2003
C. Eksperiment / test 2004
D. Analyse / observation 2009, 2010, 2016
E. Konklusion / spørgsmål 2017

F. Ny opdagelse / nyt spørgsmål ? ☺

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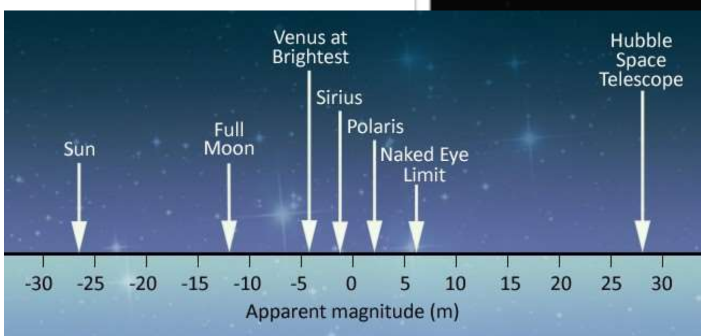

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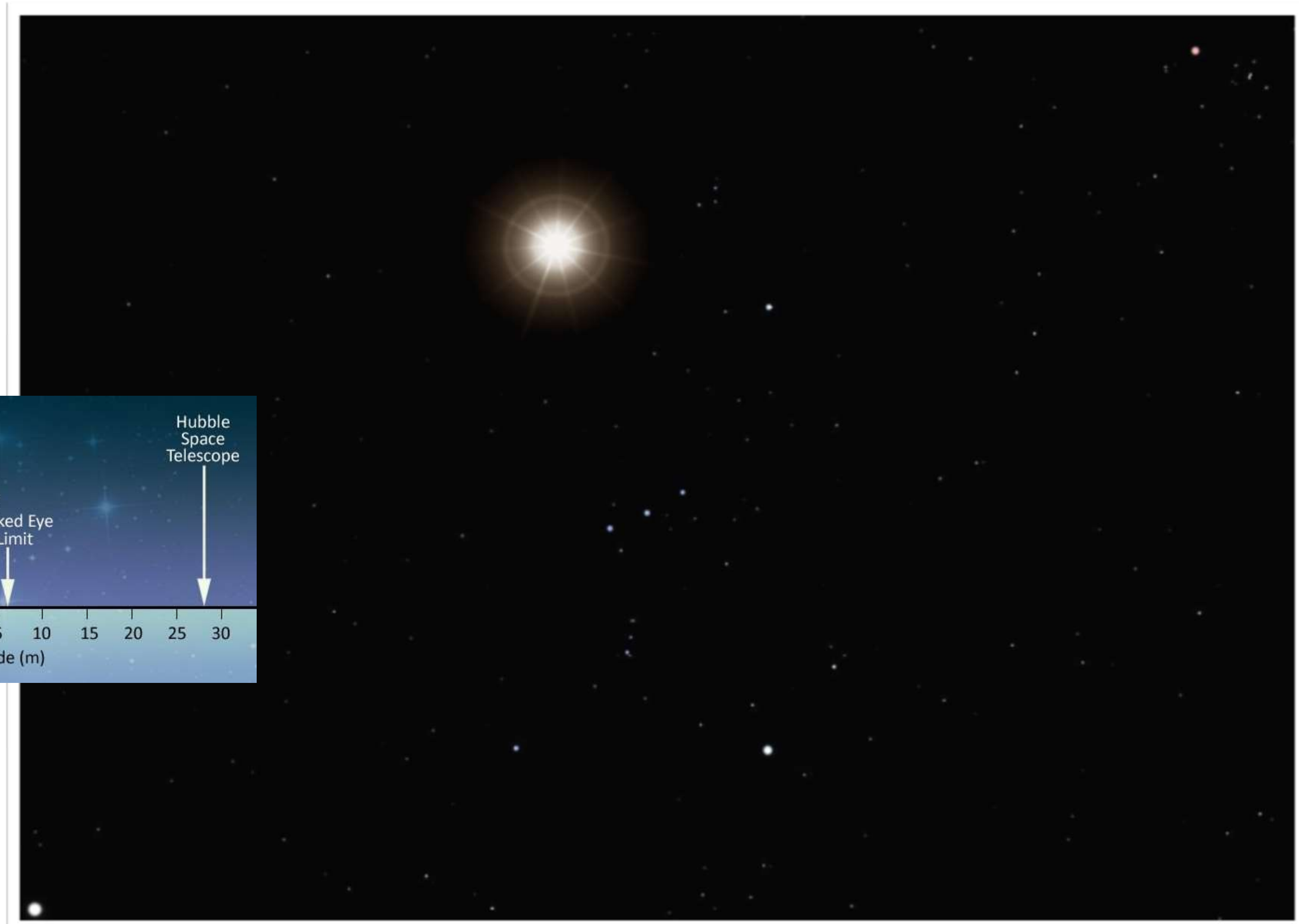

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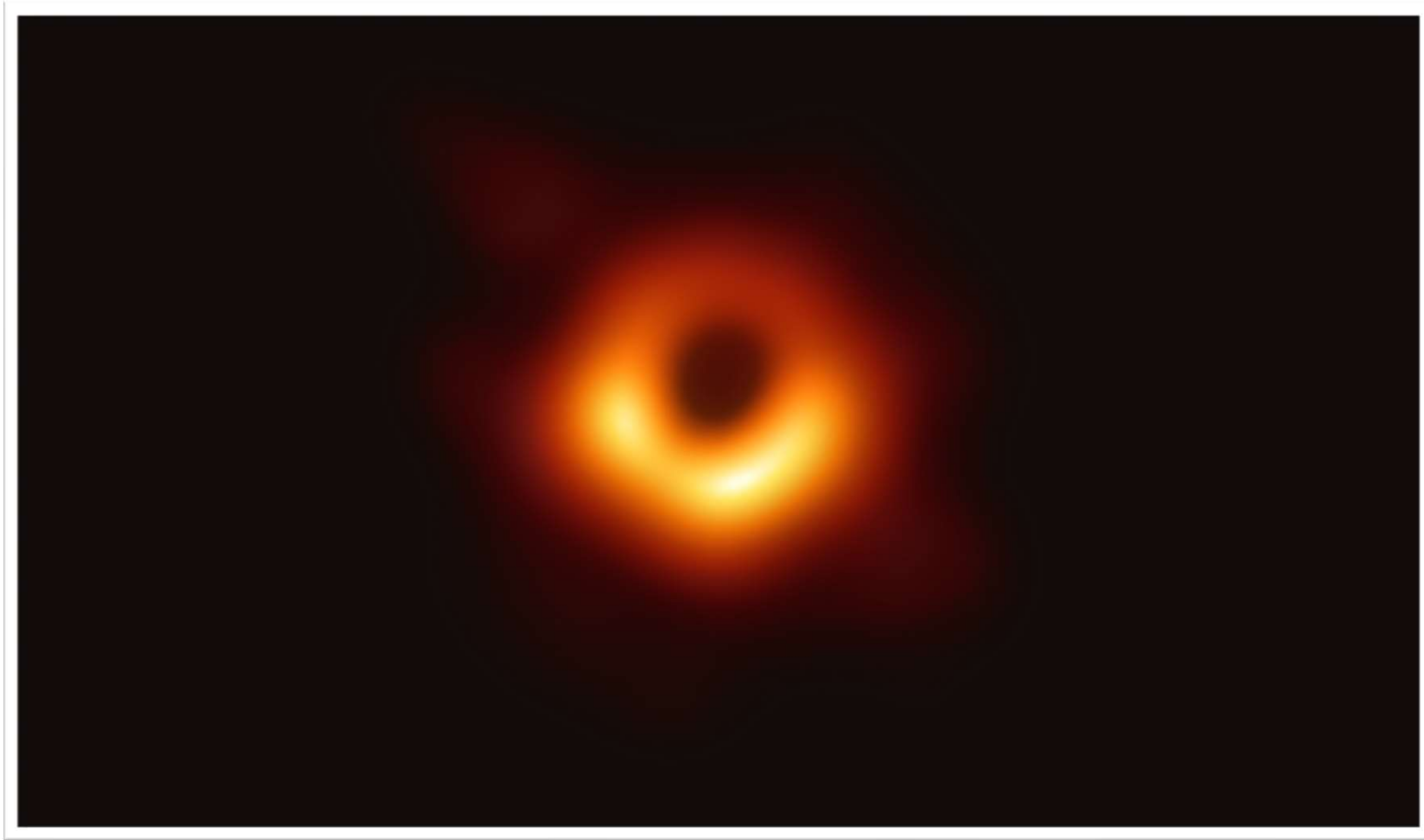

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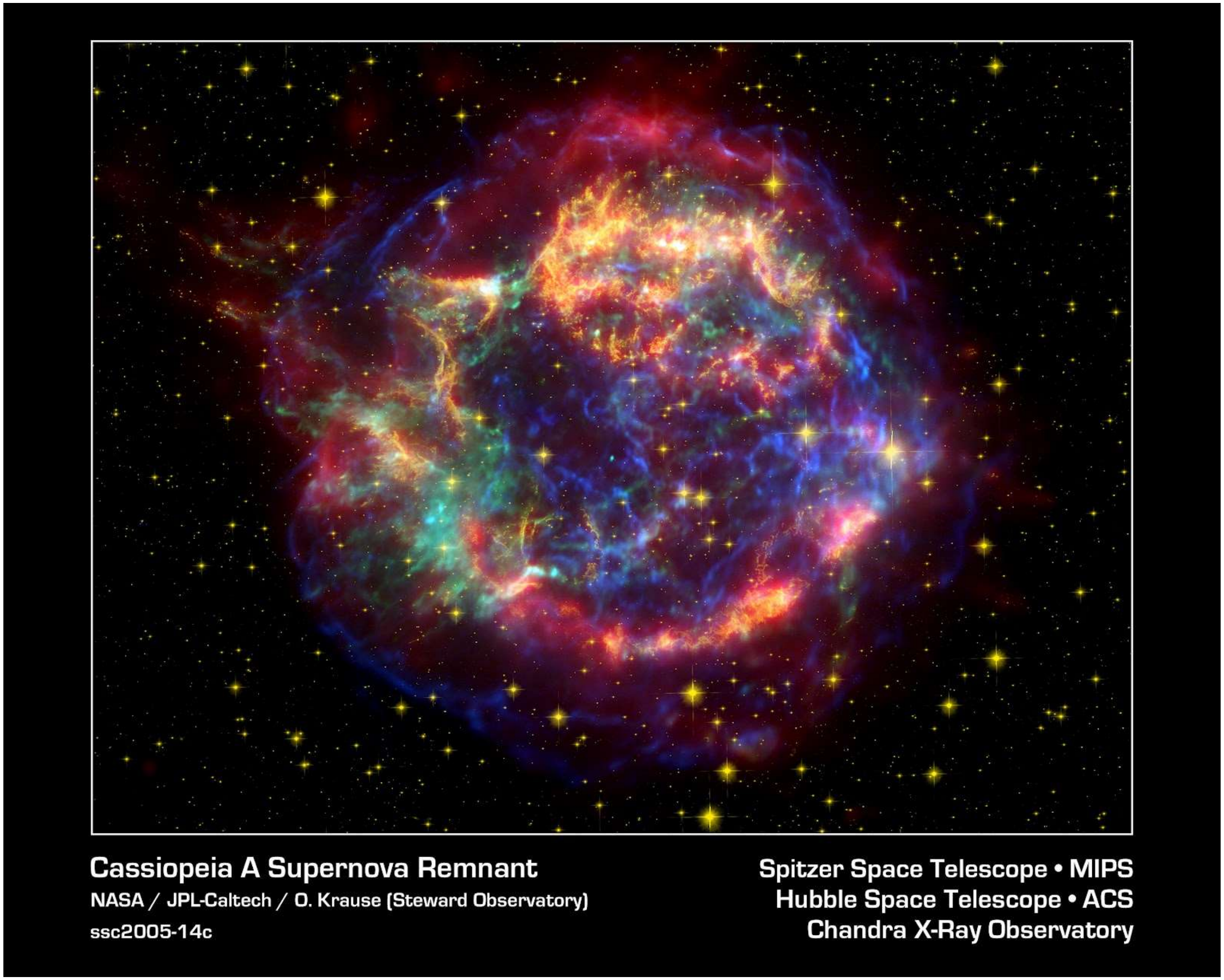

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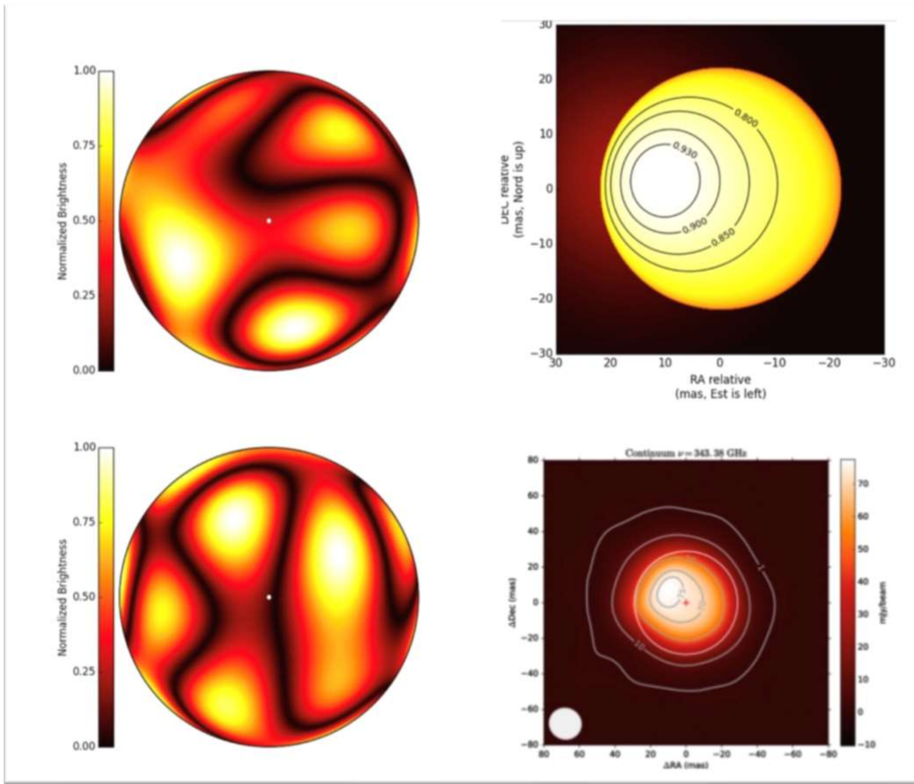

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Astronomy & Astrophysics

Convective cells in Betelgeuse: imaging through spectropolarimetry*

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ABSTRACT

Aims. We assess the ability to image the photosphere of red supergiants and, in particular Betelgeuse, through the modelling of the observed linear polarization in atomic spectral lines. We also aim to analyse the resulting images over time, to measure the size and dynamics of the convective structures in these stars.
Methods. Rayleigh scattering polarizes the continuum and spectral lines depolarize it. This depolarization is seen as a linear polarization signal parallel to the radial direction on the stellar disk. Integrated over the disk, it would result in a null signal, except if brightness asymmetries/inhomogeneities are present. This is the basic concept behind our imaging technique. Through several tests and comparisons, we have tried to assess and extend its validity, and to determine what can be learnt unambiguously through it.
Results. The several tests and comparisons performed prove that our technique reliably retrieves the salient brightness structures in the photosphere of Betelgeuse, and should be relevant to other red supergiants. For Betelgeuse, we demonstrate that these structures we infer are convective cells, with a characteristic size of more than 60% of the stellar radius. We also derive the characteristic upflow and downflow speeds, 22 and 10 km s^{-1}, respectively. We find weak magnetic fields concentrated in the downflow lanes in between granules, similar to the quiet sun magnetism. We follow those convective structures in time. Changes happen on timescales of 1 week, but individual structures can be tracked over 4 yr of observations.
Conclusions. The measured characteristics of the convection in Betelgeuse confirm the predictions of numerical simulations in both the strong, supersonic upflows and the size of the convective cells. They also concur in the presence of weak magnetic fields that are completely dominated by the convective flows and constrained to the dark lanes of down-flowing plasma.

Key words. stars: imaging – supergiants – techniques: imaging spectroscopy – techniques: polarimetric

1. Introduction

The chemical enrichment of the interstellar medium is mostly due to the late stages of stellar evolution; this is particularly true for red supergiants (RSG) because of their mass loss. However, the mechanisms that drive mass loss from these stars are not well understood. Mechanisms that are often invoked include thermal gas and radiation pressure, acoustic and shock waves, Alfvén waves, magnetism, and most probably other additional phenomena. The strong wind of these stars is probably triggered by dust, formed at a great distance from the photosphere, and so has no direct connection with the atmosphere dynamics. It is thus essential to characterize the phenomena that take place close to the stellar surface. Josselin & Plez (2007) suggested that high velocities and steep velocity gradients, possibly caused by convective motion, generate line asymmetries, that turbulent pressure decreases the effective gravity, and that this decrease combined with radiative pressure on lines initiates the mass loss. Convection seems indeed to be a key component to understand the evolution of massive, cool evolved stars. Schwarzschild (1975) suggested that the outer envelope of RSG could host a small number of large convective cells. These gigantic convection cells have also been predicted in simulations (e.g., Freytag et al. 2002; Chiavassa et al. 2011) and suggested in observations of Betelgeuse as bright photospheric spots observed with direct UV imaging (Gilliland & Dupree 1996) or with interferometric techniques (e.g., Haubois et al. 2009).

Indeed, because of its relative proximity (about 200 pc), and as an MIab supergiant, Betelgeuse offers the largest angular diameter of any star (except for the Sun), and has been extensively studied in interferometry (e.g., Haubois et al. 2009; Montargès et al. 2016). Because interferometry may suffer from modelling hypothesis (limb-darkening, spot(s) shape, etc.) and cannot resolve velocity fields, it is interesting to develop alternative approaches that complement and reinforce these results.

Since 2013 the instrument Narval on the Télescope *Bernard Lyot* (TBL) has been monitoring linear polarization on Betelgeuse with roughly one observation per month during the visibility period of the year, leading up to 43 observations in total through April 2018. Aurière et al. (2016) first interpreted linear polarization in terms of Rayleigh scattering in the continuum and depolarization during the formation of spectral lines. Those authors also proposed a first modelling of linear polarization through bright spots that would result in the net linear polarization we observe. A tentative confirmation of such

* Based on observations obtained at the Télescope *Bernard Lyot* (TBL) at Observatoire du Pic du Midi, CNRS/INSU and Université de Toulouse, France.

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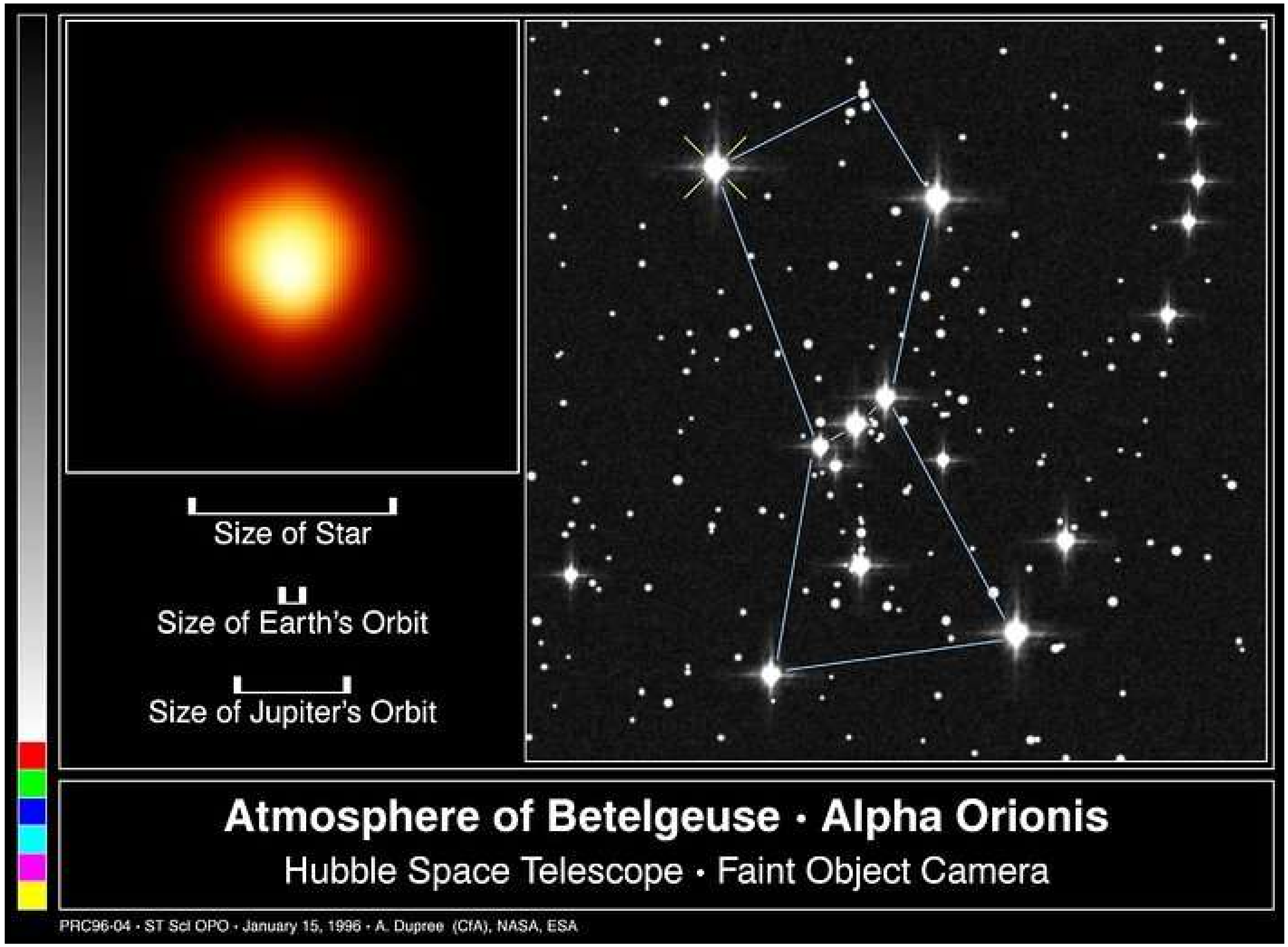

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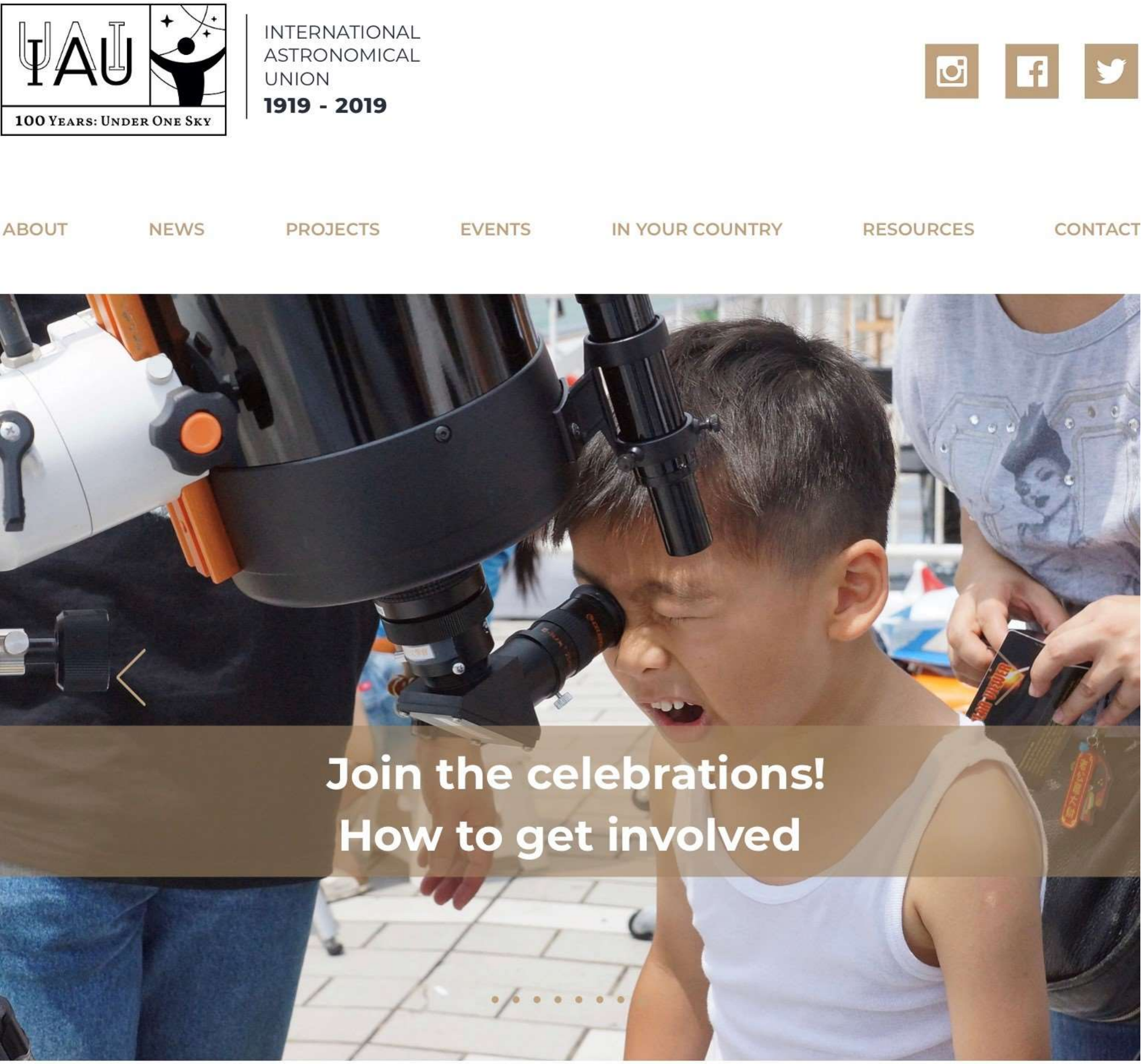

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