# Widowed stars

and how to use them to investigate their former companion's death

**Mathieu Renzo,** E. Zapartas, S. E. de Mink, Y. Götberg, S. Justham, R. J. Farmer, R. G. Izzard, S. Toonen, D. J. Lennon, H. Sana, E. Laplace, S. N. Shore, ...

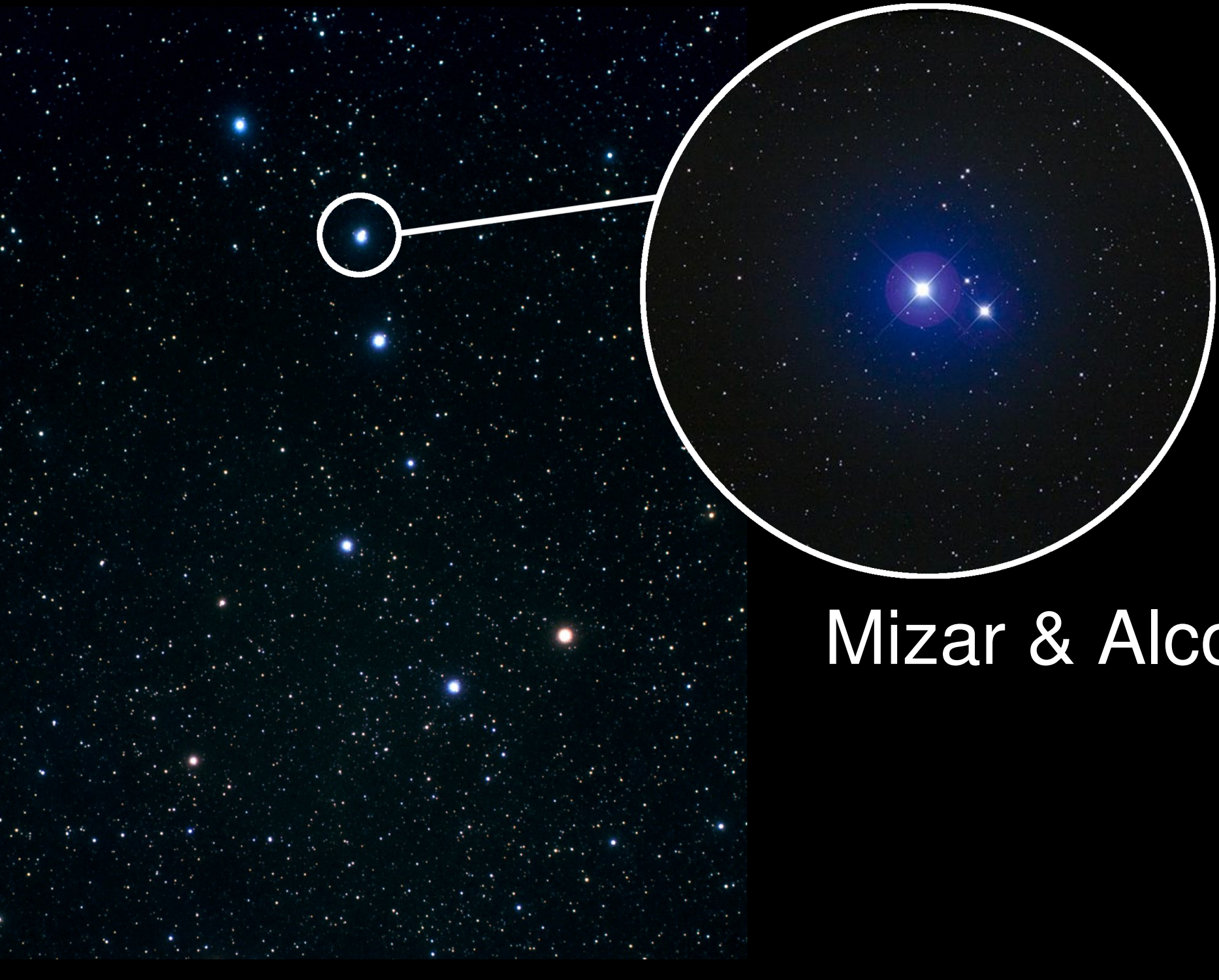
12

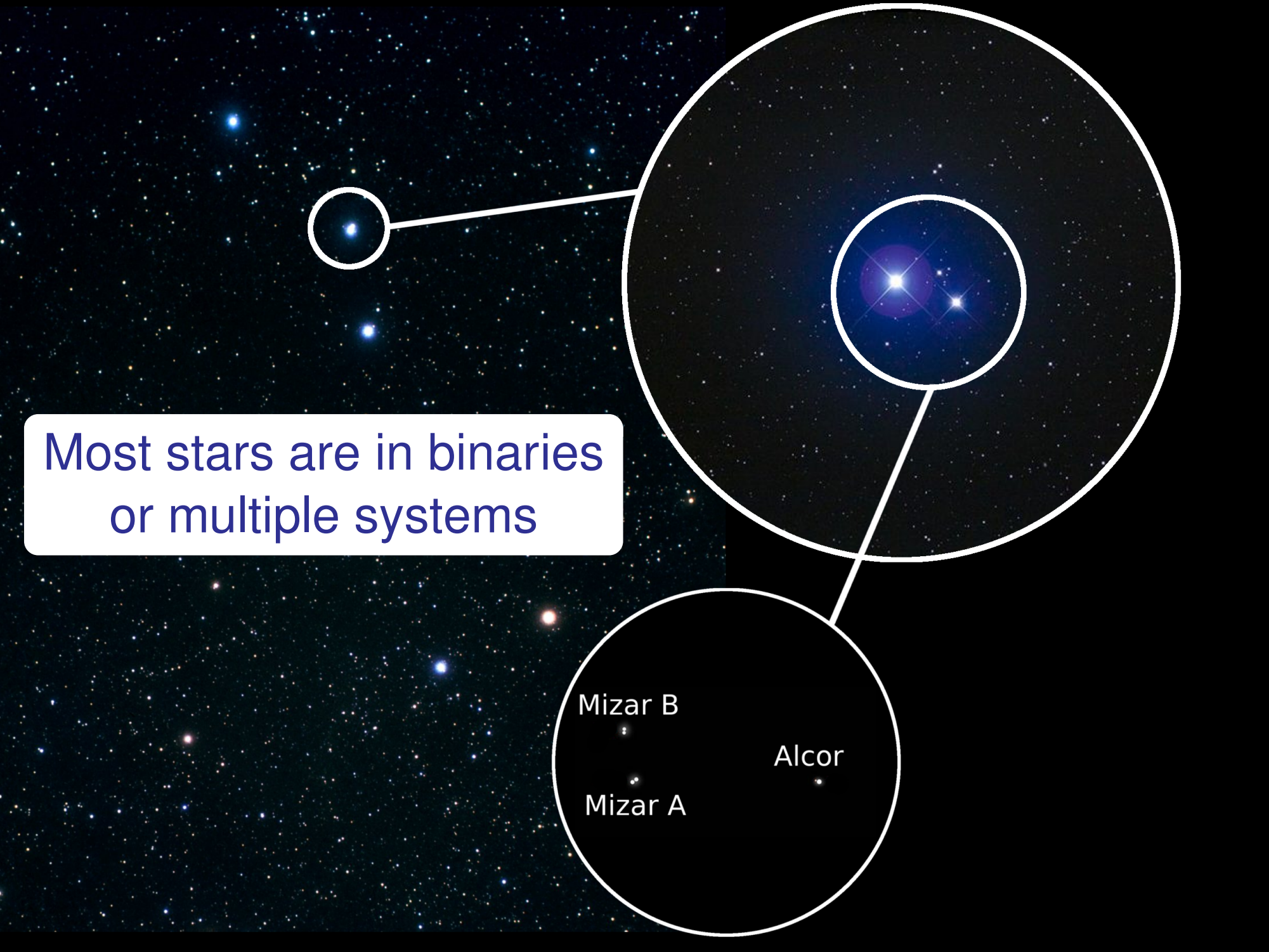
# Widowed stars

and how to use them to investigate their former companion's death

**Mathieu Renzo,** E. Zapartas, S. E. de Mink, Y. Götberg, S. Justham, R. J. Farmer, R. G. Izzard, S. Toonen, D. J. Lennon, H. Sana, E. Laplace, S. N. Shore, ...

The big dipper


Mizar & Alcor


Most stars are in binaries
or multiple systems
Mizar B
Alcor
Mizar A

# Massive stars shape the Universe

NASA, JPL-Caltech, Spitzer Space Telescope

# What happens to massive stars in binaries?

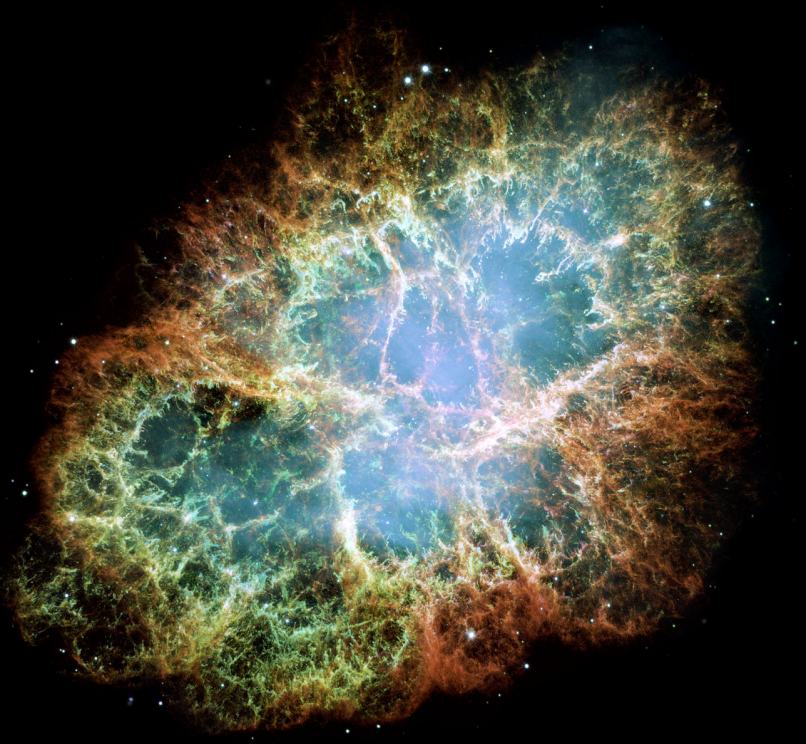
Credits: ESO, L. Calçada, M. Kornmesser, S.E. de Mink

# Mass transfer is very common!

The incoming material changes the star to-become “widow”

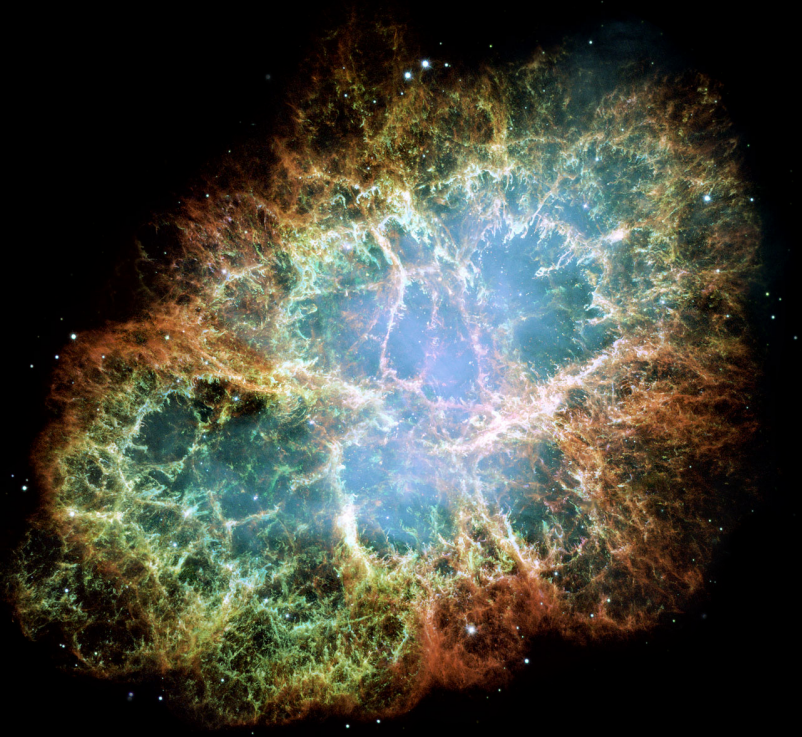
Credits: ESO, L. Calçada, M. Kornmesser, S.E. de Mink

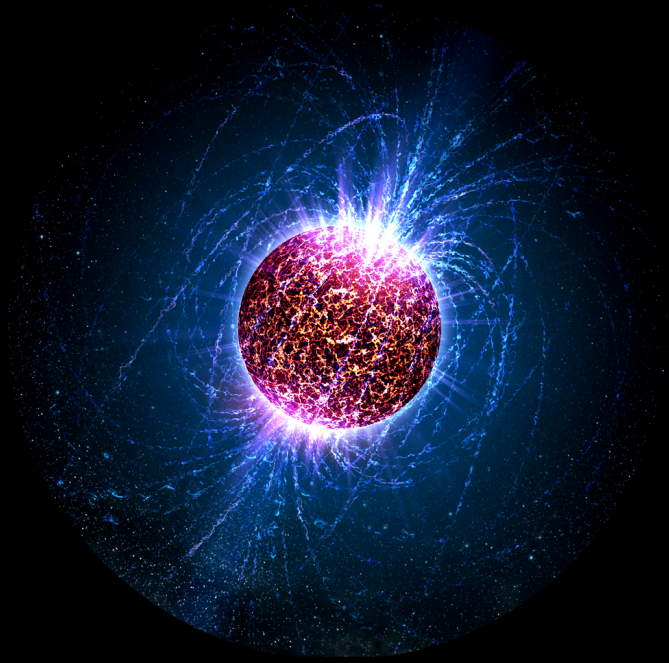
# Supernovae: explosive death of massive stars



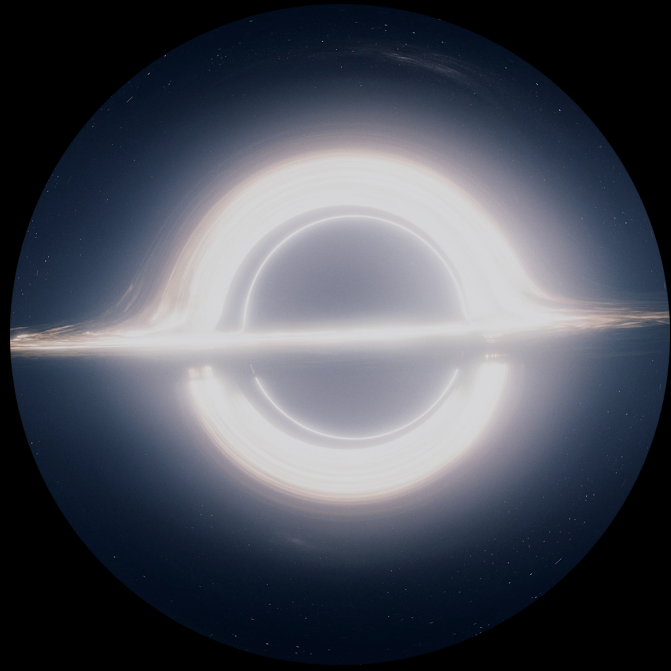
We see them, but don’t fully understand them

# Supernovae: explosive death of massive stars





Neutron stars



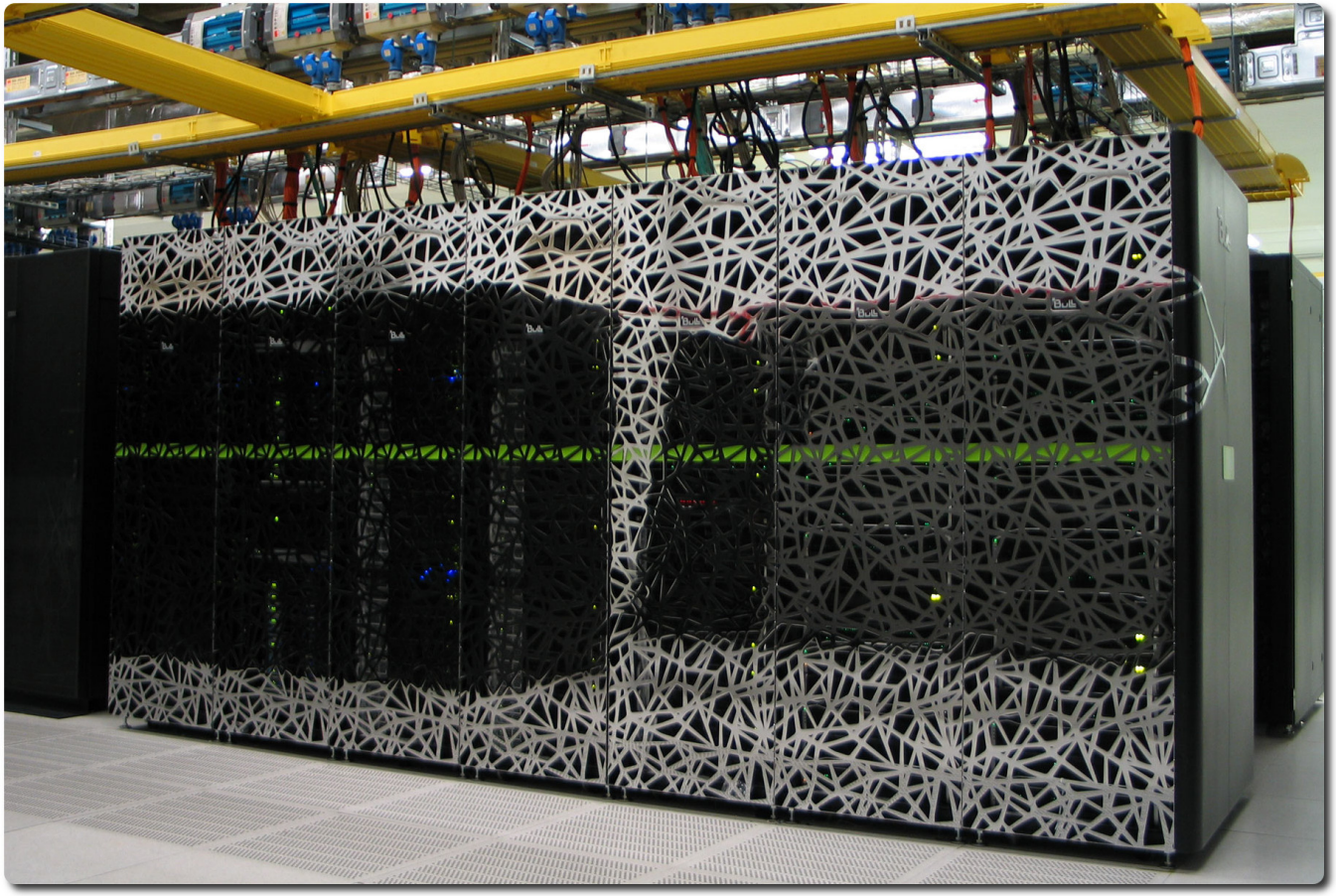
Black holes

We see them, but don't fully understand them

# How do stars explode?

Theoretical model

+



Dutch national supercomputer Cartesius

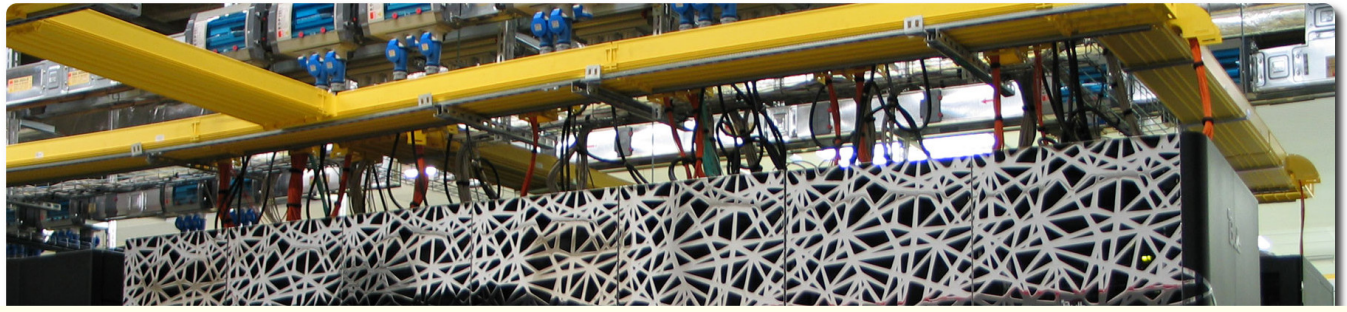
=

Numerical Simulations

# How do stars explode?

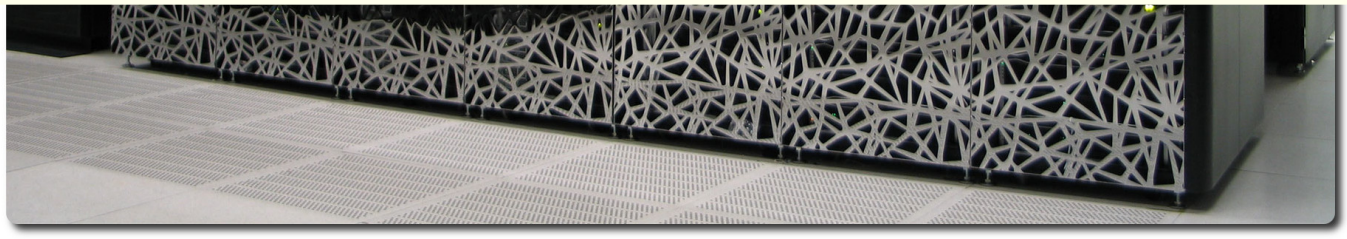
Theoretical model

+



**Nature does not need to do this**

Comparing with observations is crucial not to fool ourselves!



Dutch national supercomputer Cartesius

=

Numerical Simulations

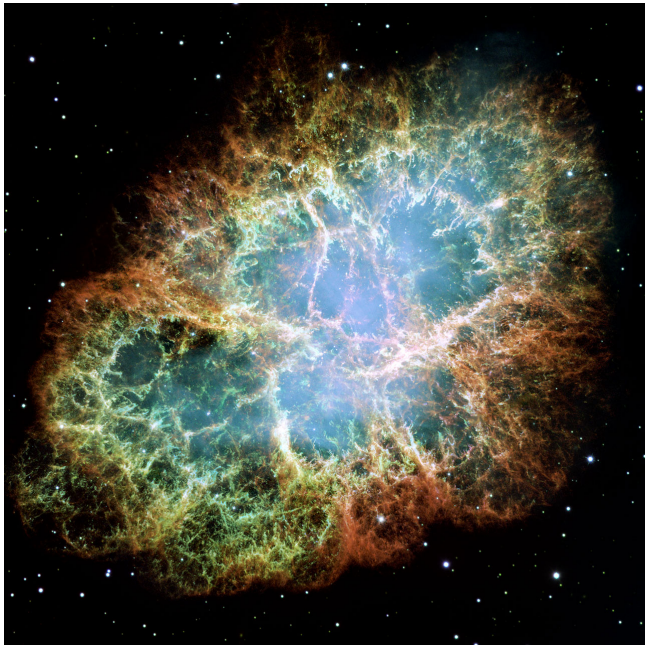
# What can we observe to understand stellar deaths?


The explosions
(typically in other galaxies)

# What can we observe to understand stellar deaths?


The explosions

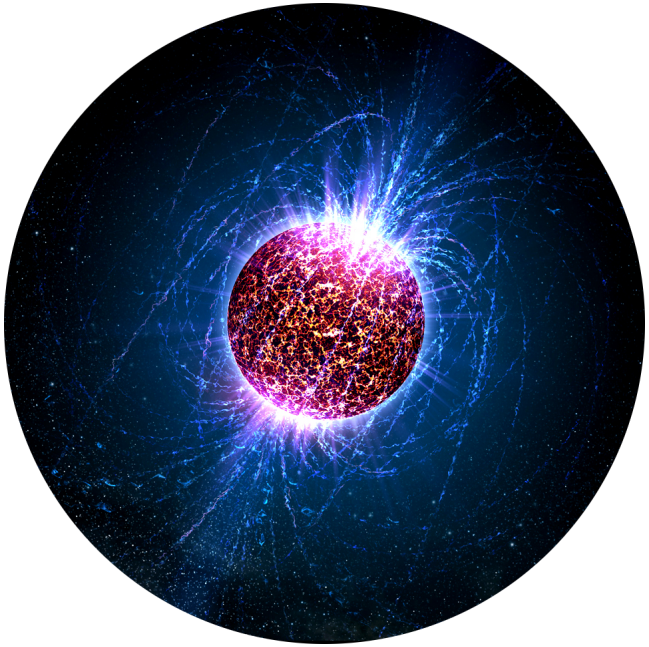
(typically in other galaxies)



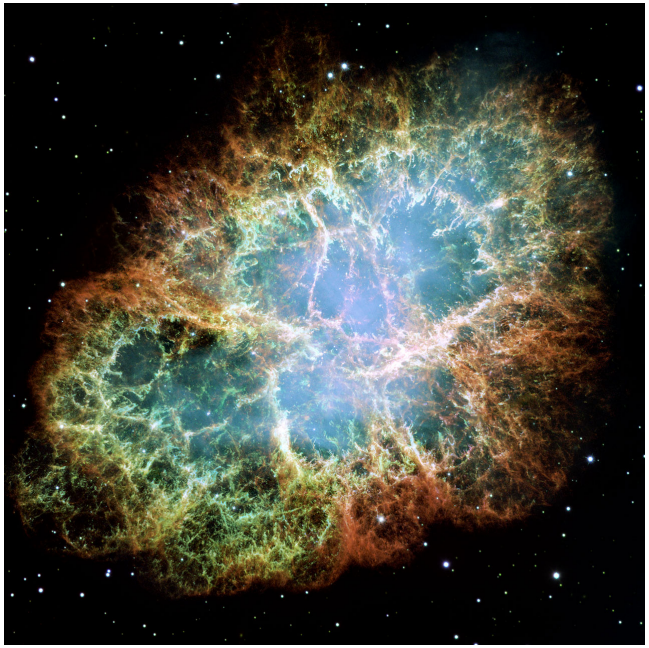
“Ashes”: supernova remnants

# What can we observe to understand stellar deaths?


The explosions
(typically in other galaxies)



Neutron stars,
both single or
with companion(s)



“Ashes”: supernova remnants

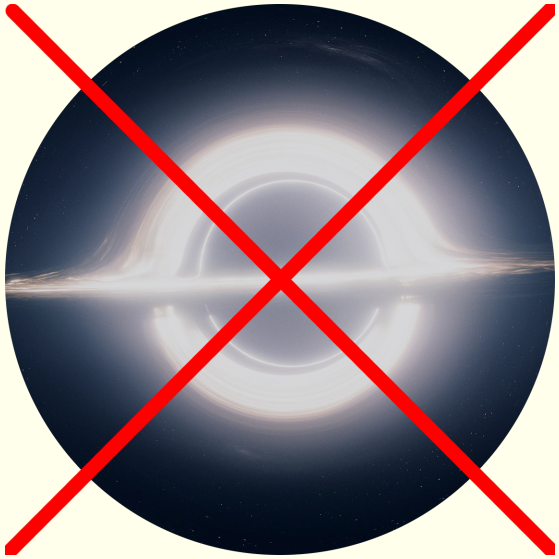
# What can we observe to understand stellar deaths?

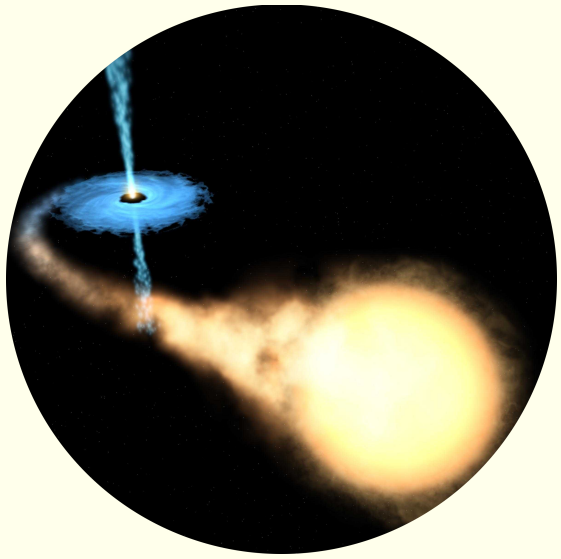
-

(typica

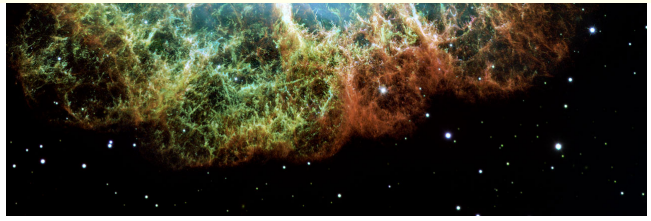
(s)

## We cannot see black holes...





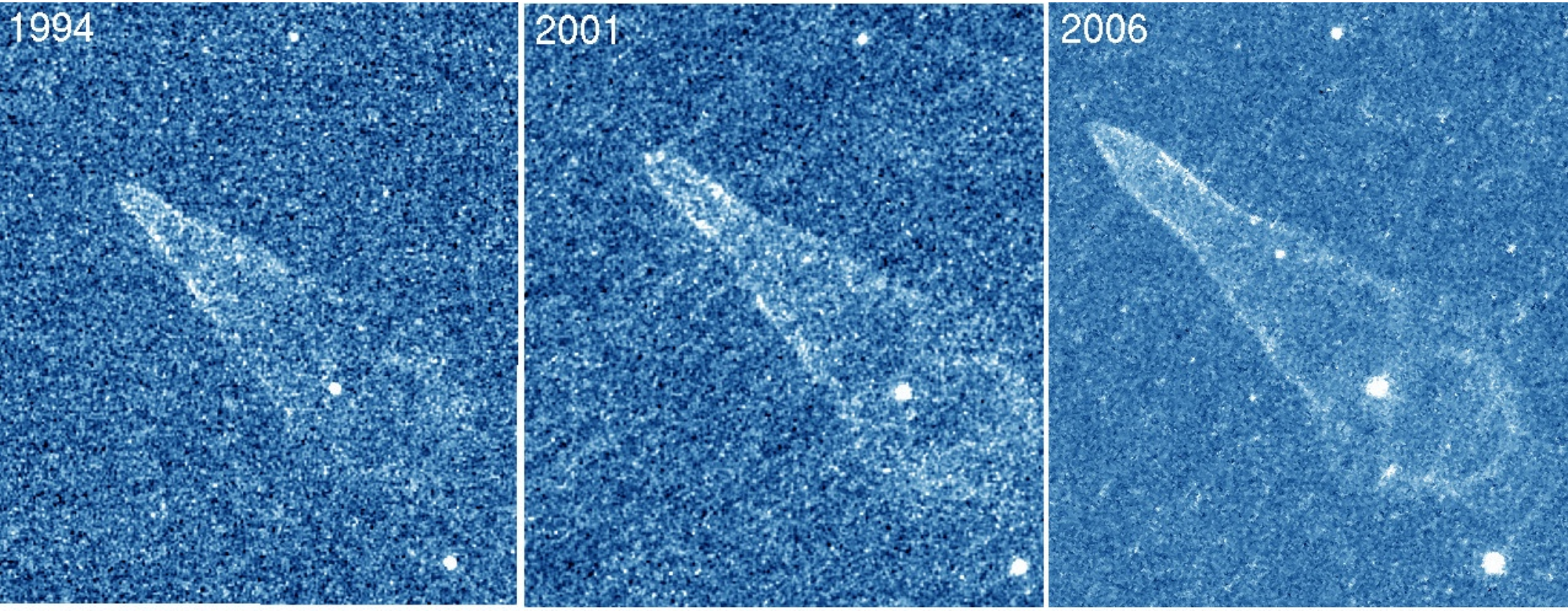
...but we can see matter falling into them!



“Ashes”: supernova remnants

# What do neutron stars teach us about supernovae?

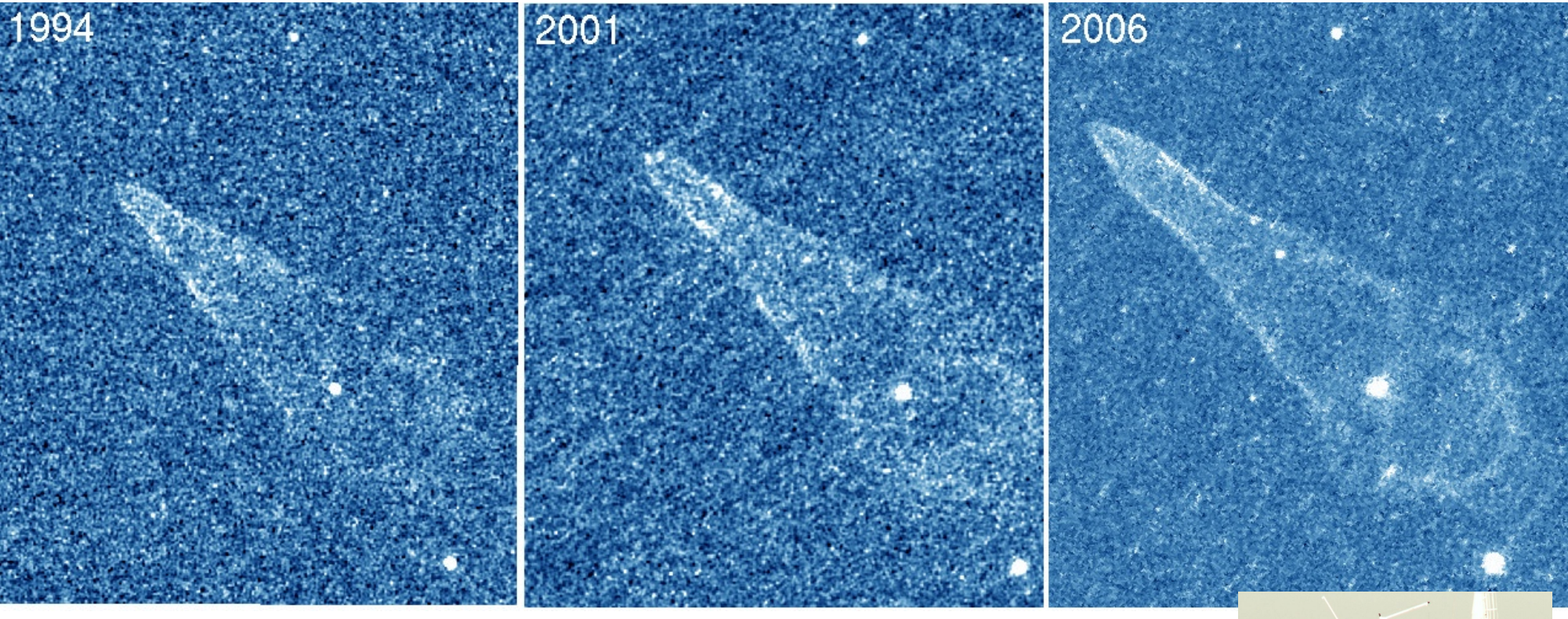
**Neutron stars that we can see are typically fast**
(especially if single)




"Guitar nebula": $v_{\rm NS} \simeq 1000\,{\rm km\ s^{-1}}$

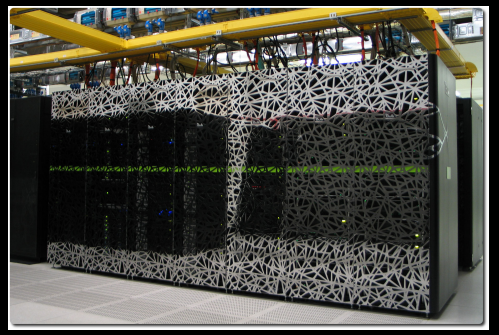
# What do neutron stars teach us about supernovae?

**Neutron stars that we can see are typically fast**
(especially if single)

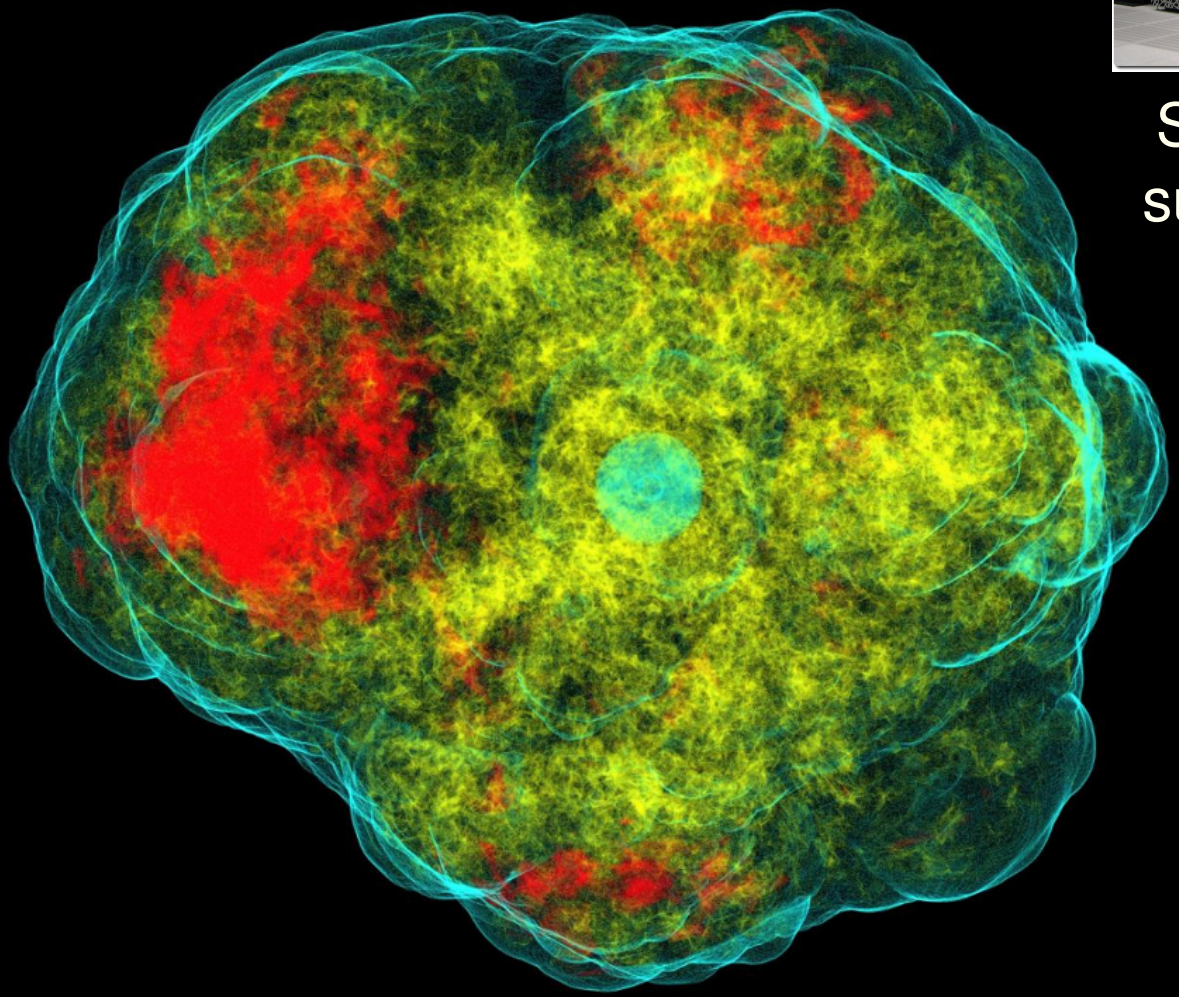



"Guitar nebula": $v_{\rm NS} \simeq 1000\,{\rm km\ s^{-1}}$

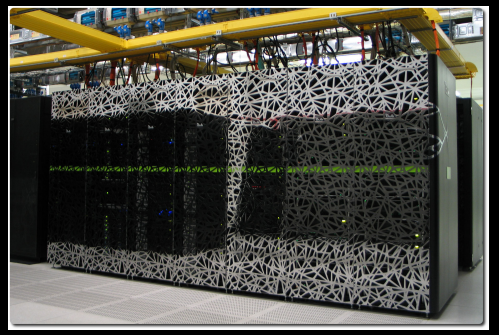
# Supernova natal kick



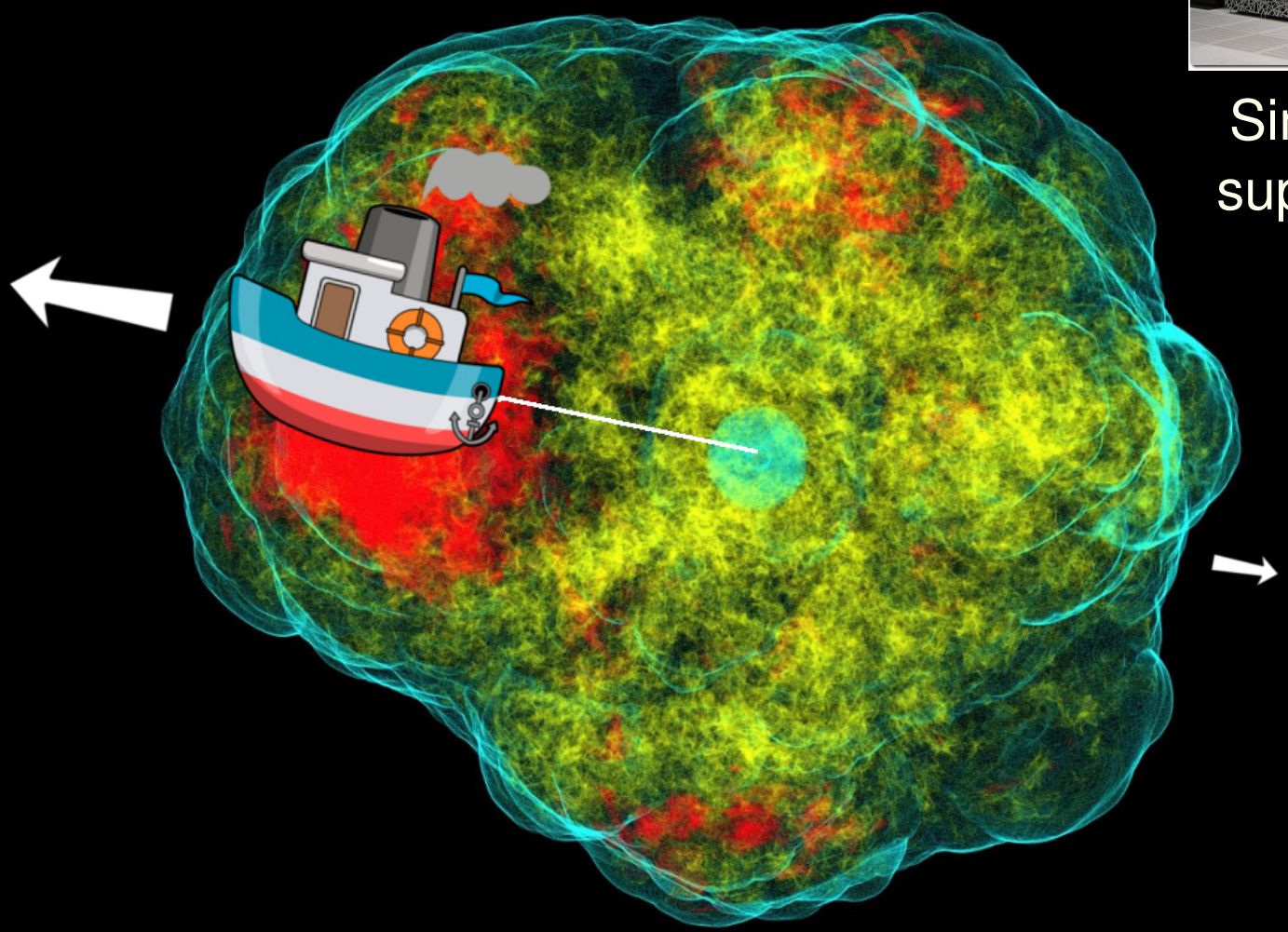
Simulations on super-computer



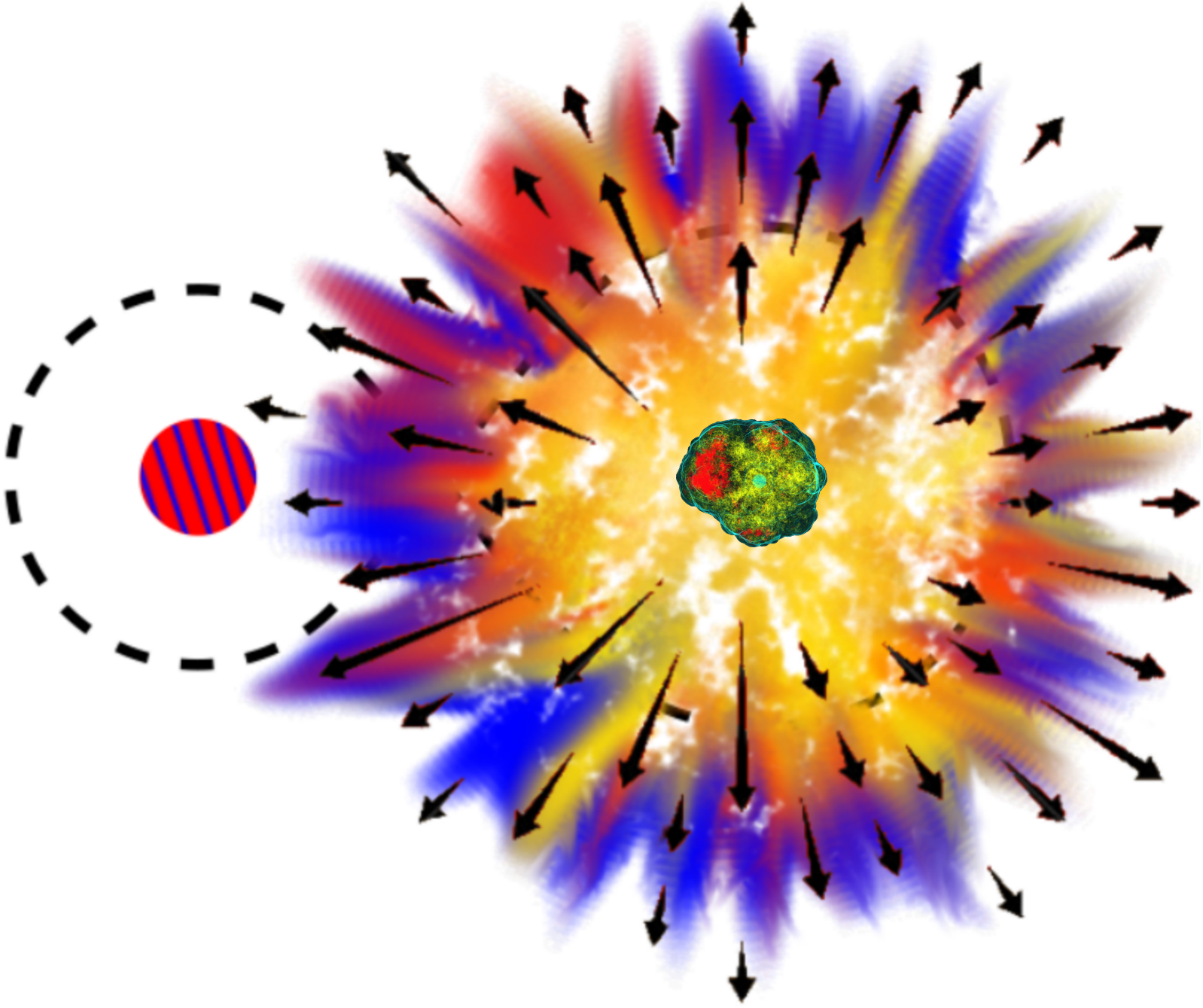
# Supernova natal kick



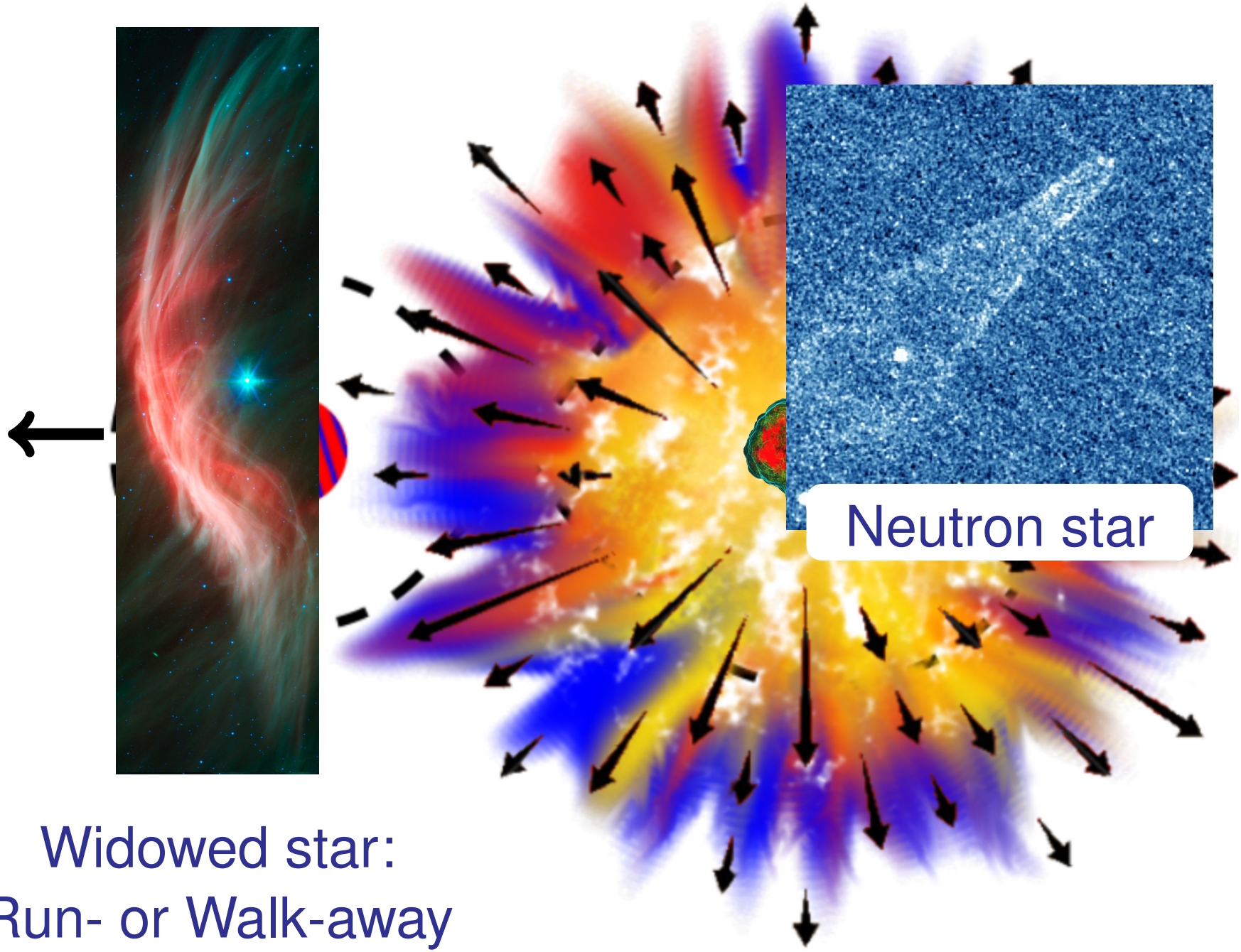
Simulations on super-computer



# Supernova kicks cause the disruption of most binaries



# Supernova kicks cause the disruption of most binaries

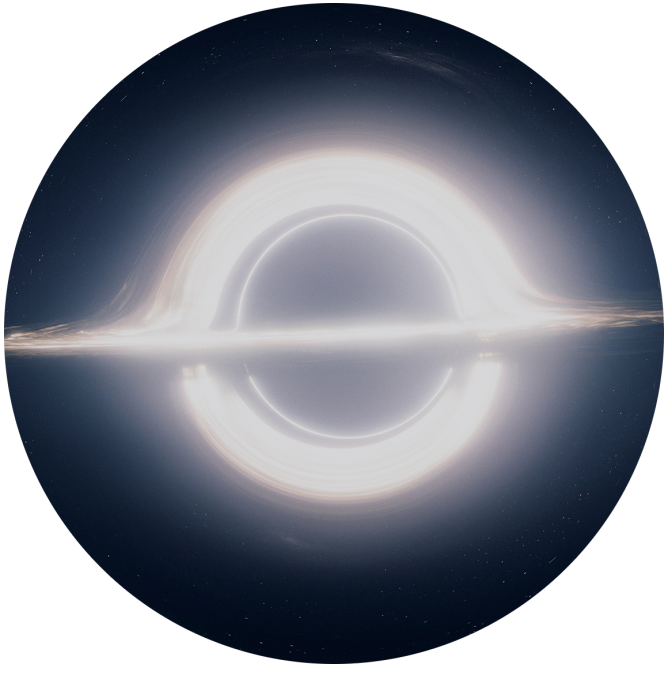



Widowed star:
Run- or Walk-away

# Do black holes receive kicks?

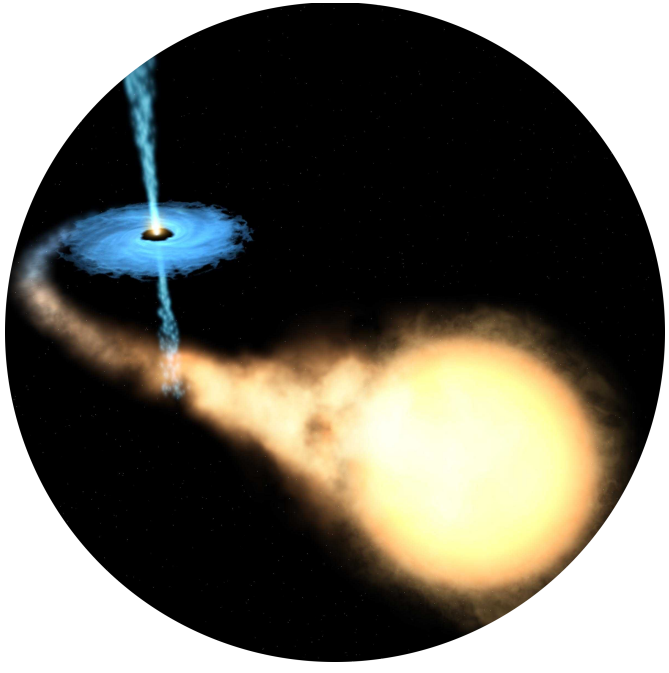
## YES

$\Rightarrow$ most are single and we can't see them...



## NO

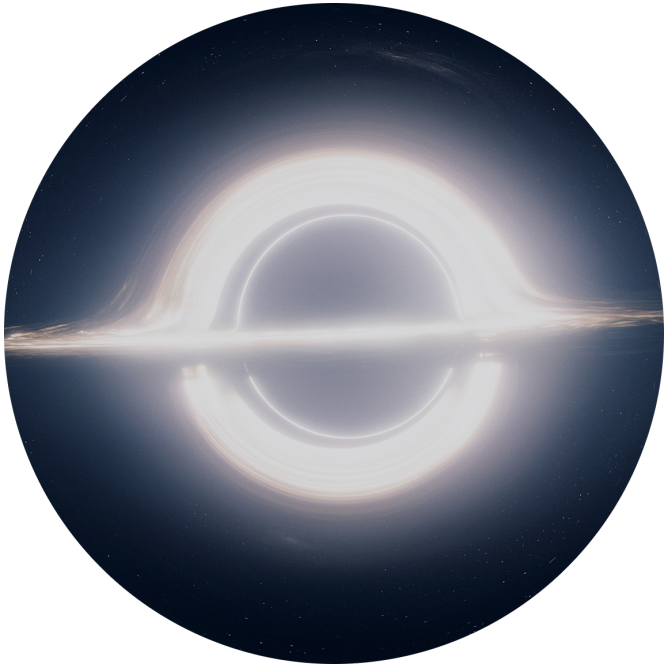
$\Rightarrow$ most remain together with their widowed companion



# Do black holes receive kicks?

## YES

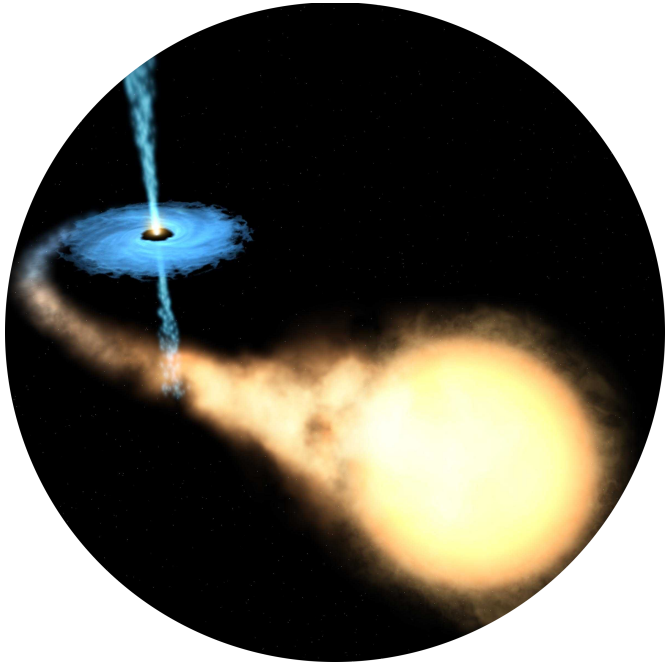
$\Rightarrow$ most are single and we can't see them...



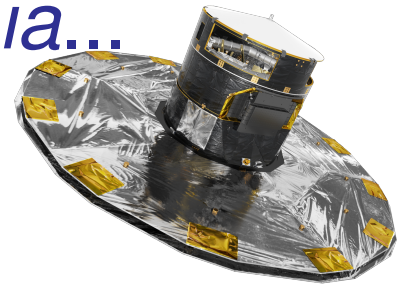
...but we can see their widow!

## NO

$\Rightarrow$ most remain together with their widowed companion



# We can measure stellar velocities with *Gaia*...



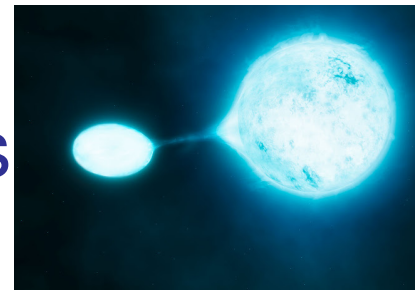
gaia

If many very **massive** widowed stars

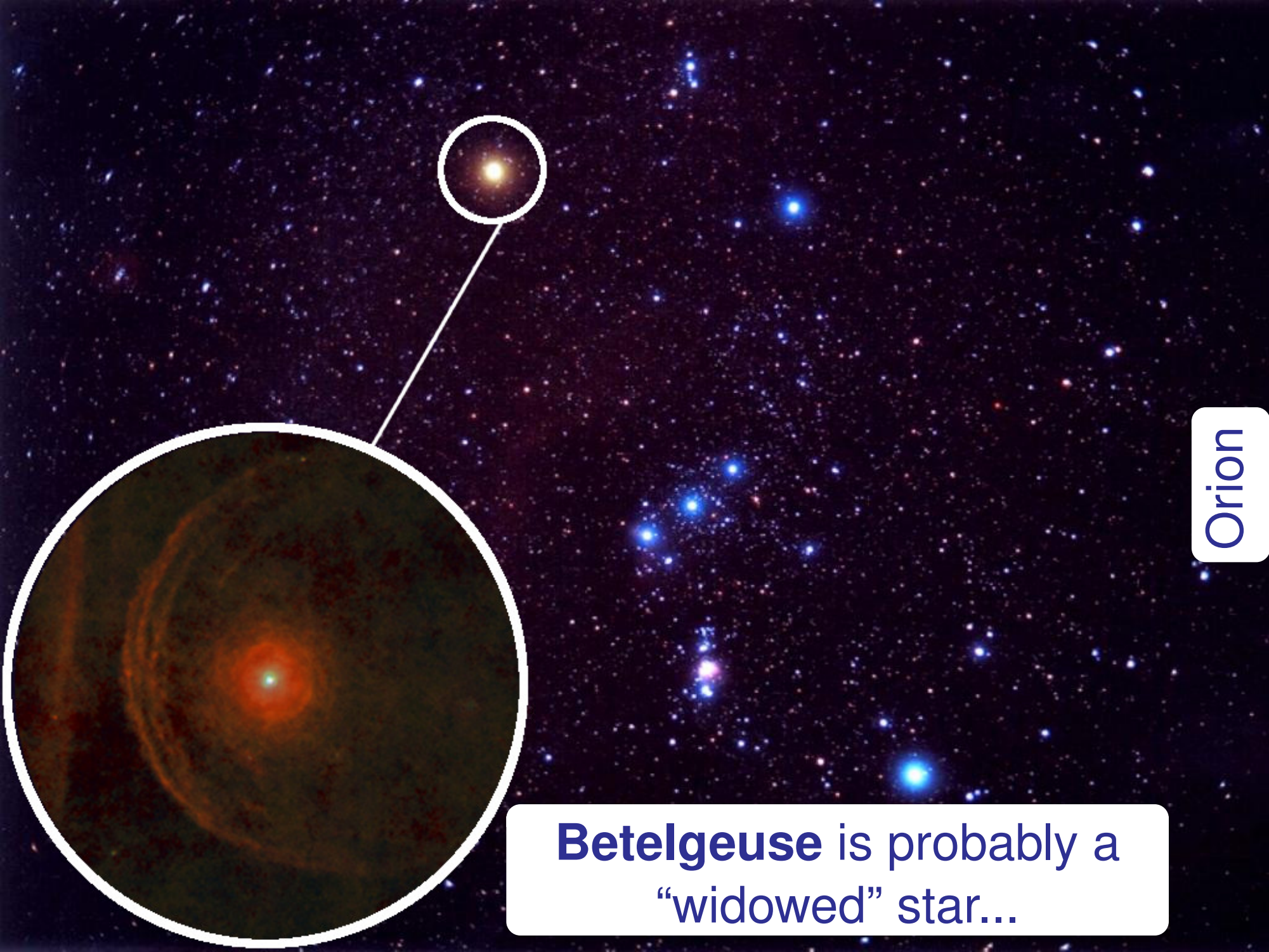
⇓

Black holes do receive kicks!

...and use other telescopes to find signatures of mass transfer!




Orion


Orion
**Betelgeuse** is probably a "widowed" star...

# Outline

## Backup slides

# Not all fast stars are widows!

## Dynamical Interactions

- Happen early on, before SNe
- Can produce faster stars
- (Typically) least massive thrown out

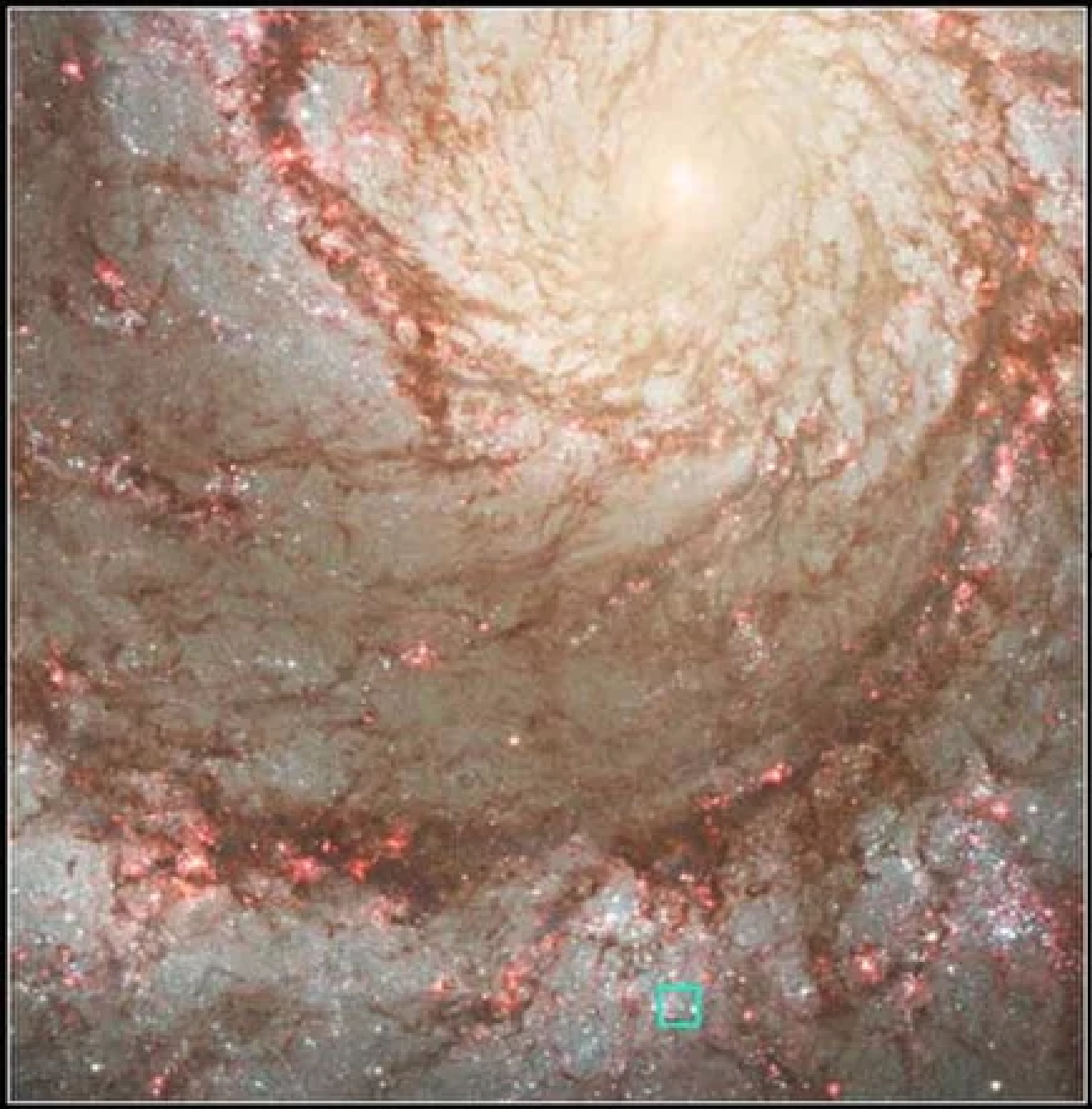
...Binaries are still important! but might not leave signature

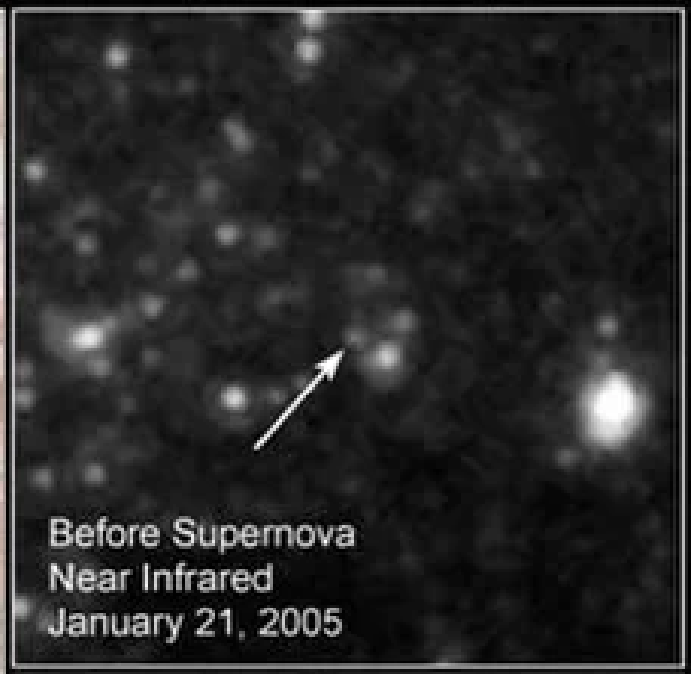
## Binary SN disruption

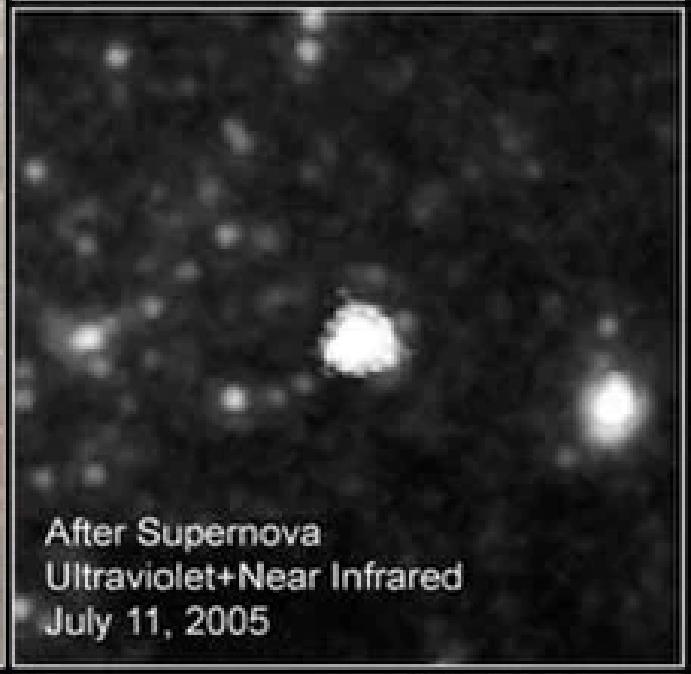
- Ejects initially less massive star
- Requires SN kick
- Final $v \simeq v_2^{\rm orb}$
- Leaves binary signature (fast rotation, He/N enhancement, lower apparent age)

# Supernova 2005cs in M51

*Hubble Space Telescope • ACS*






NASA, ESA, W. Li and A. Filippenko (University of California, Berkeley),
S. Beckwith (STScI), and The Hubble Heritage Team (STScI/AURA)

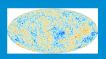
STScI-PRC05-21

# Elements in the Universe...

## ...without stars

1 H

4 Be

big bang fusion 

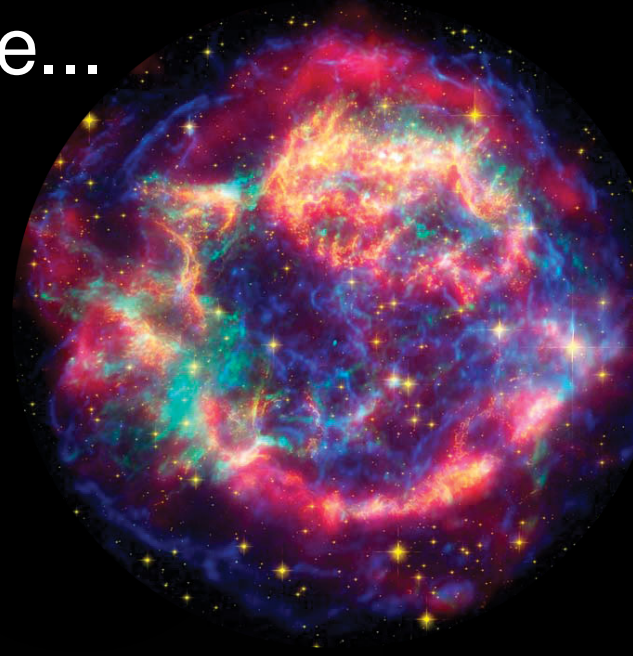
cosmic ray fission 

5 B

2 He

# Elements in the Universe...

...with stars



| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H | | big bang fusion | | | cosmic ray fission | | | | | | | | | | | | 2 He |
| 3 Li | 4 Be | merging neutron stars | | | exploding massive stars | | | | | | | 5 B | 6 C | 7 N | 8 O | 9 F | 10 Ne |
| 11 Na | 12 Mg | dying low mass stars | | | exploding white dwarfs | | | | | | | 13 Al | 14 Si | 15 P | 16 S | 17 Cl | 18 Ar |
| 19 K | 20 Ca | 21 Sc | 22 Ti | 23 V | 24 Cr | 25 Mn | 26 Fe | 27 Co | 28 Ni | 29 Cu | 30 Zn | 31 Ga | 32 Ge | 33 As | 34 Se | 35 Br | 36 Kr |
| 37 Rb | 38 Sr | 39 Y | 40 Zr | 41 Nb | 42 Mo | 43 Tc | 44 Ru | 45 Rh | 46 Pd | 47 Ag | 48 Cd | 49 In | 50 Sn | 51 Sb | 52 Te | 53 I | 54 Xe |
| 55 Cs | 56 Ba | | 72 Hf | 73 Ta | 74 W | 75 Re | 76 Os | 77 Ir | 78 Pt | 79 Au | 80 Hg | 81 Tl | 82 Pb | 83 Bi | 84 Po | 85 At | 86 Rn |
| 87 Fr | 88 Ra | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 57 La | 58 Ce | 59 Pr | 60 Nd | 61 Pm | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy | 67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu |
| 89 Ac | 90 Th | 91 Pa | 92 U | | | | | | | | | | | |