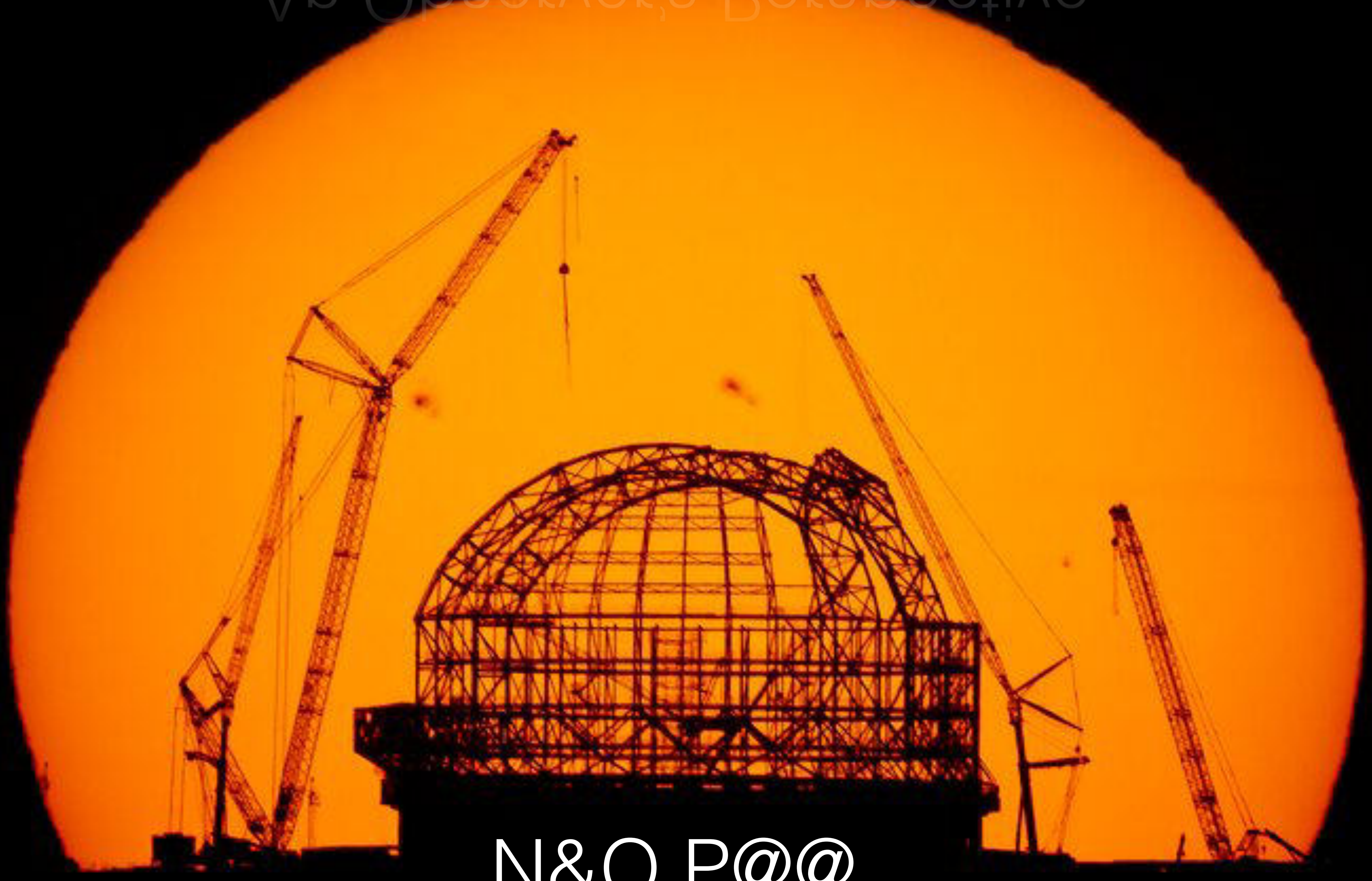
Type Ia Supernova Progenitors

An Observer's Perspective



N&O P@@

Nando Patat

European Southern Observatory - Germany

ESO Studentship Programme

Fast Track Your Career

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Deadline: Apr 15th and Oct 15th!

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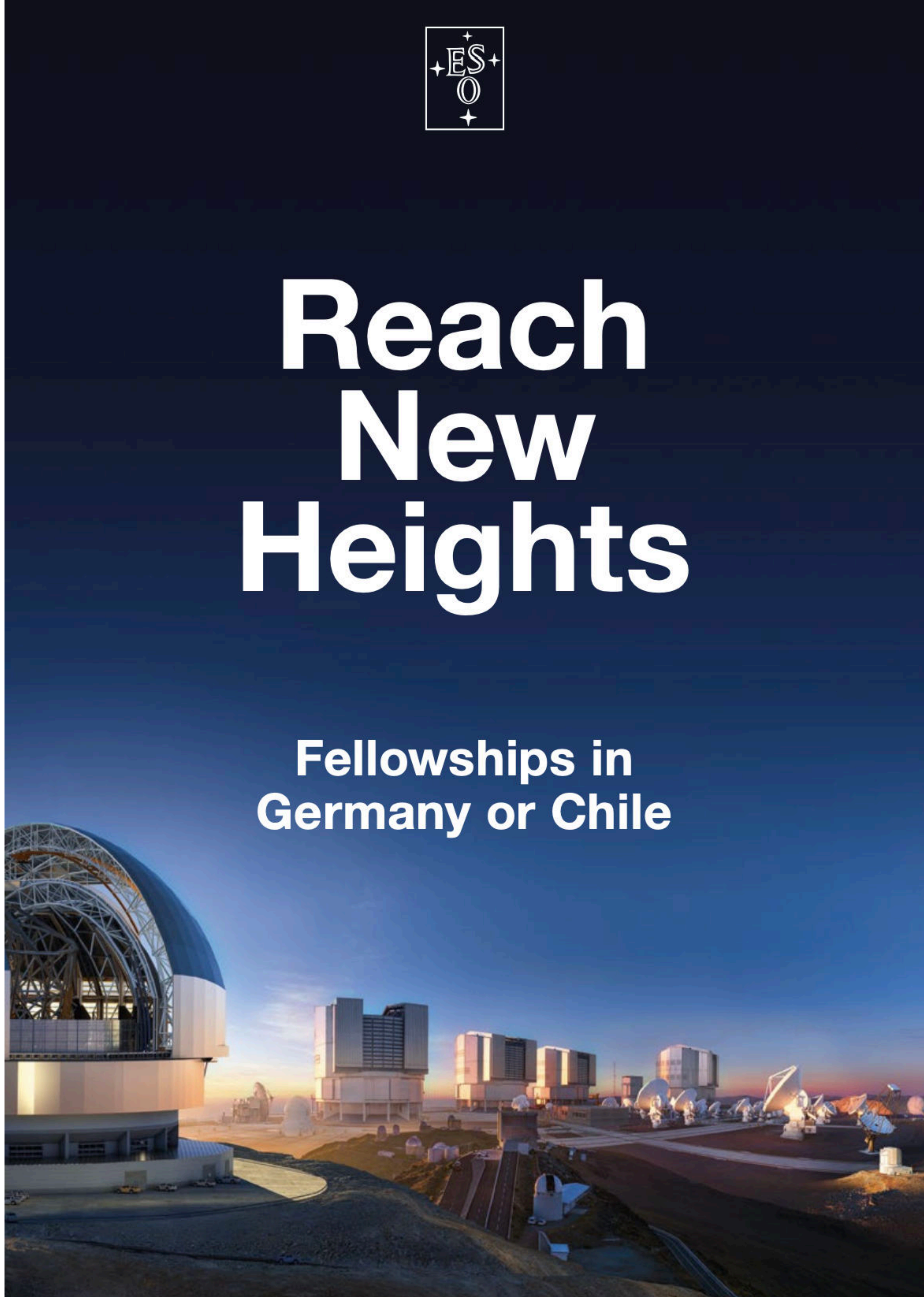

Thermonuclear SNe (aka Ia)

- Complete disruption of a C-O White Dwarf (WD) accreting from a companion
- Thermonuclear flame burning in degenerate conditions
- No compact remnant
- $\sim 0.7\ M_{sun}$ of Iron

SN1994D credit: HST)

"The fact that we do not know yet what are the progenitor systems of some of the most dramatic explosions in the universe has become a major embarrassment and one of the key unresolved problems in stellar evolution".

M. Livio (2000)

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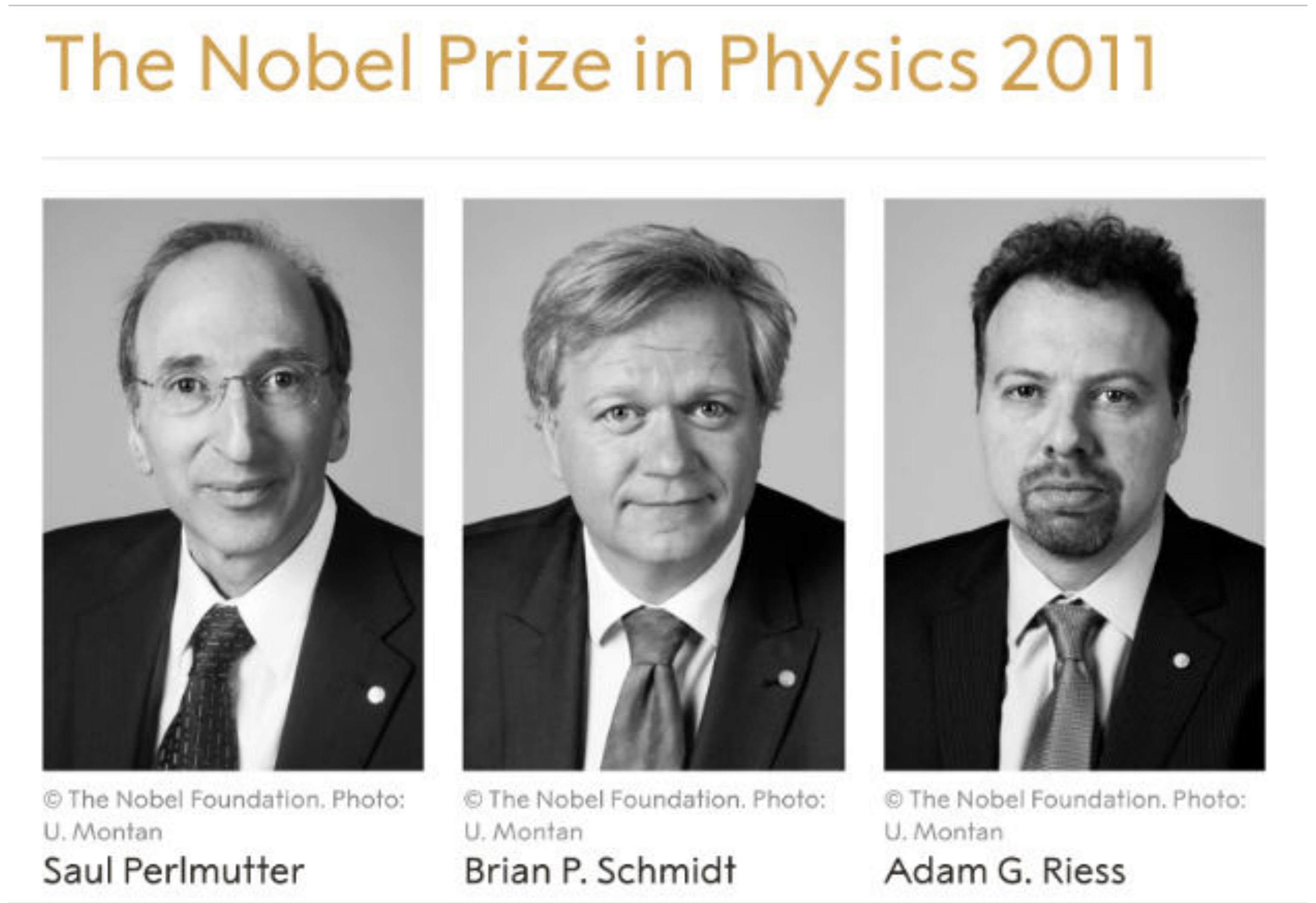

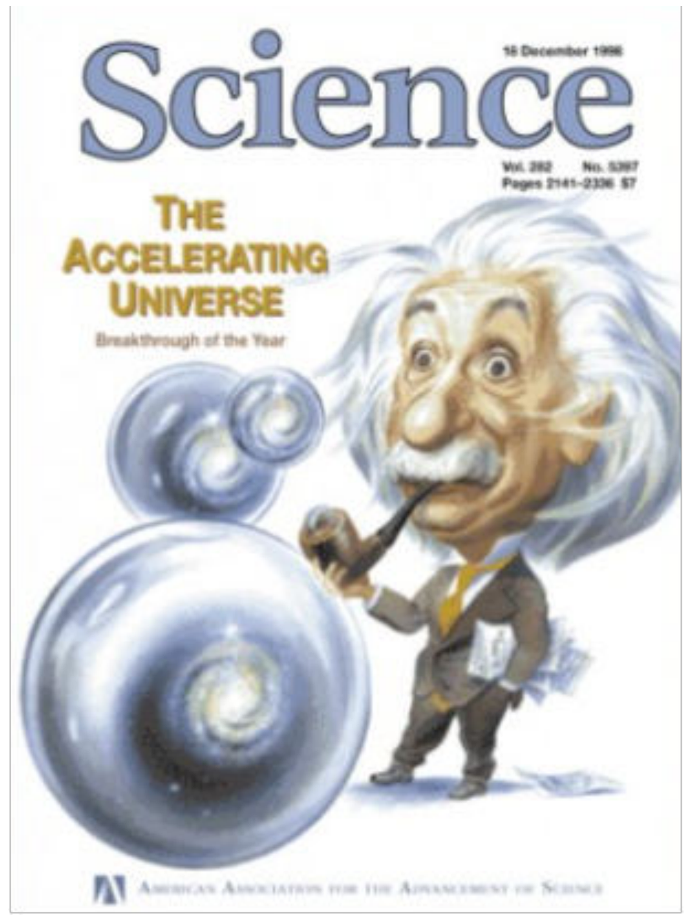

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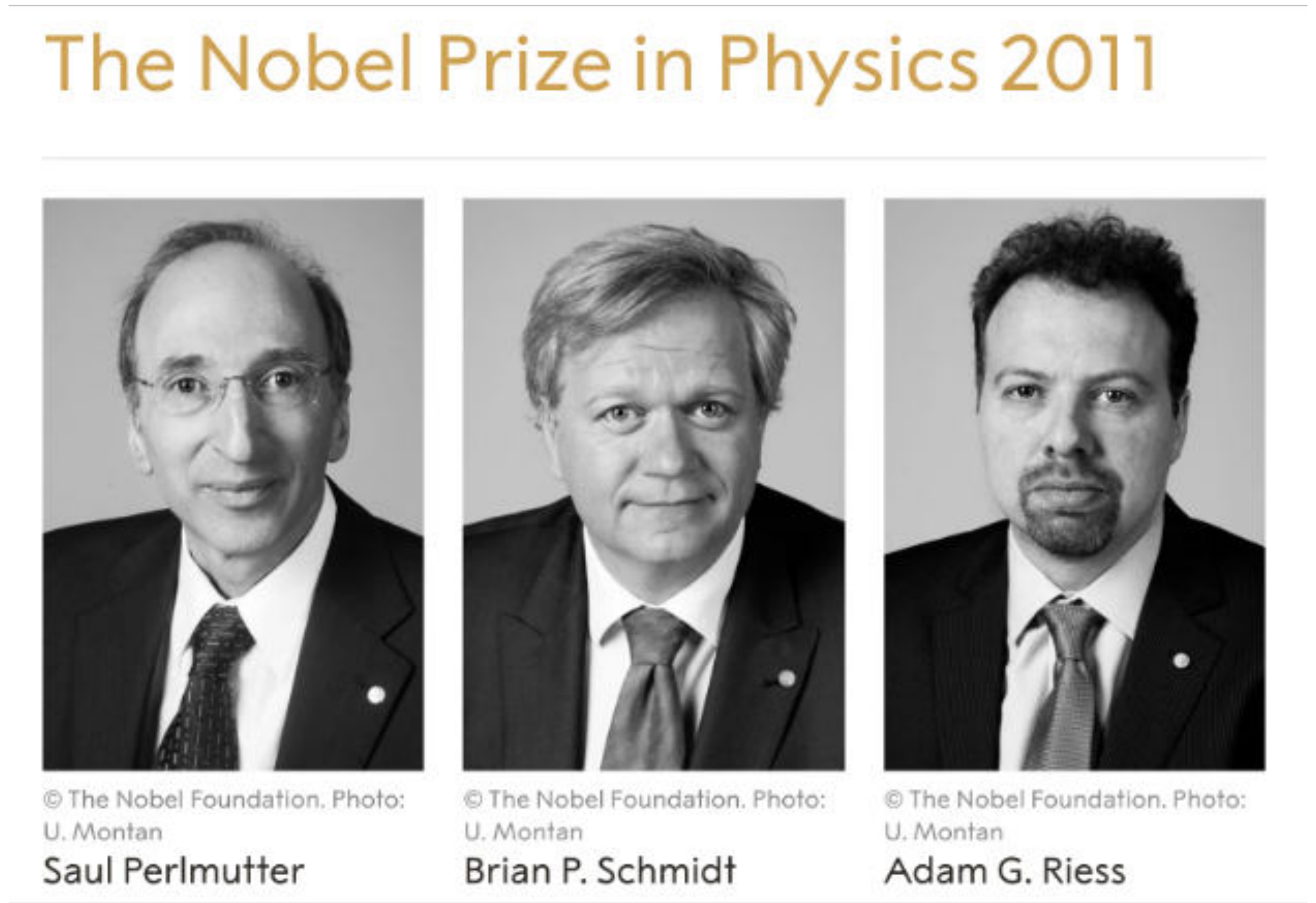

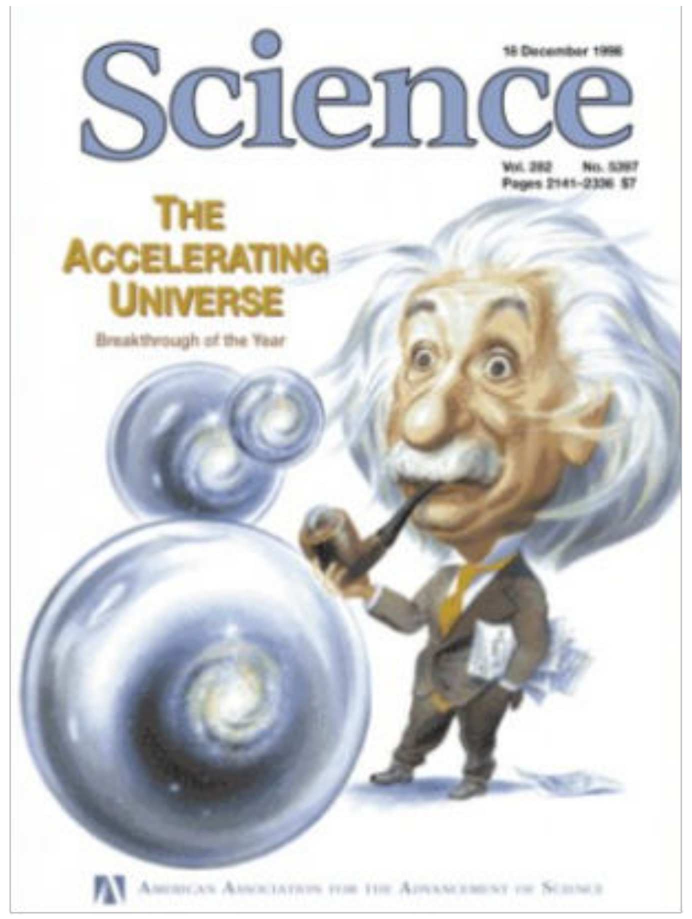

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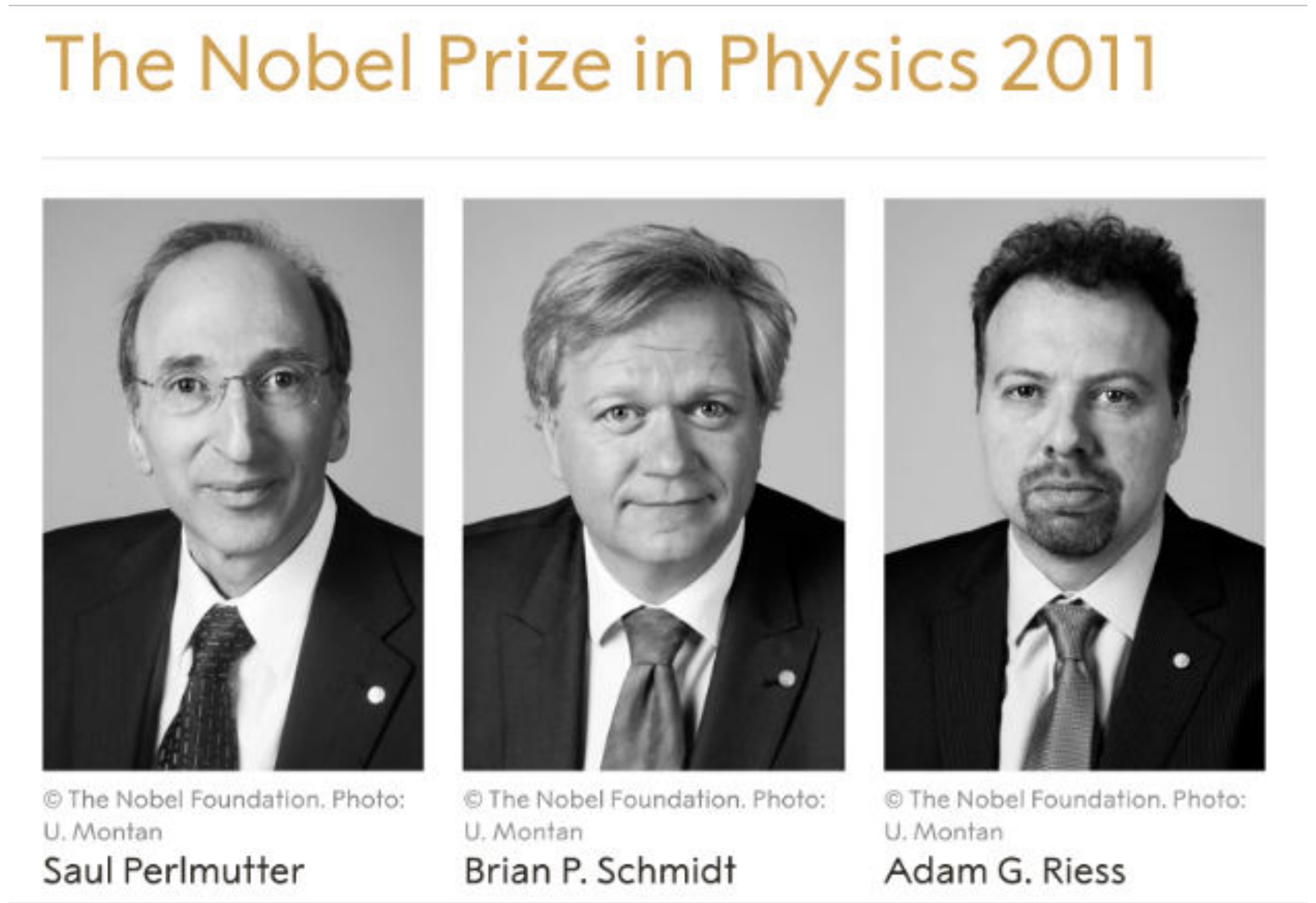

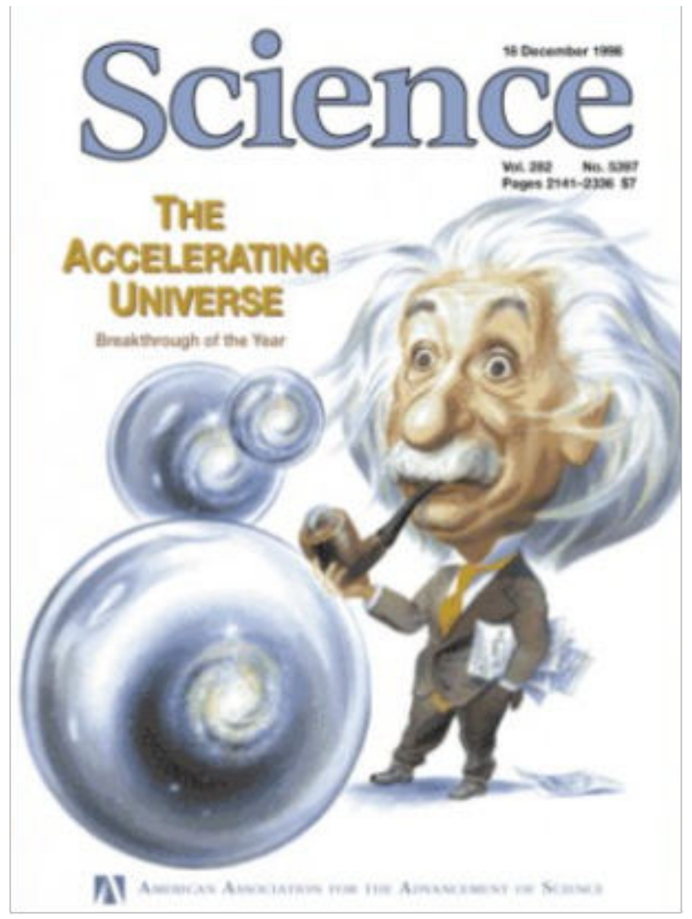

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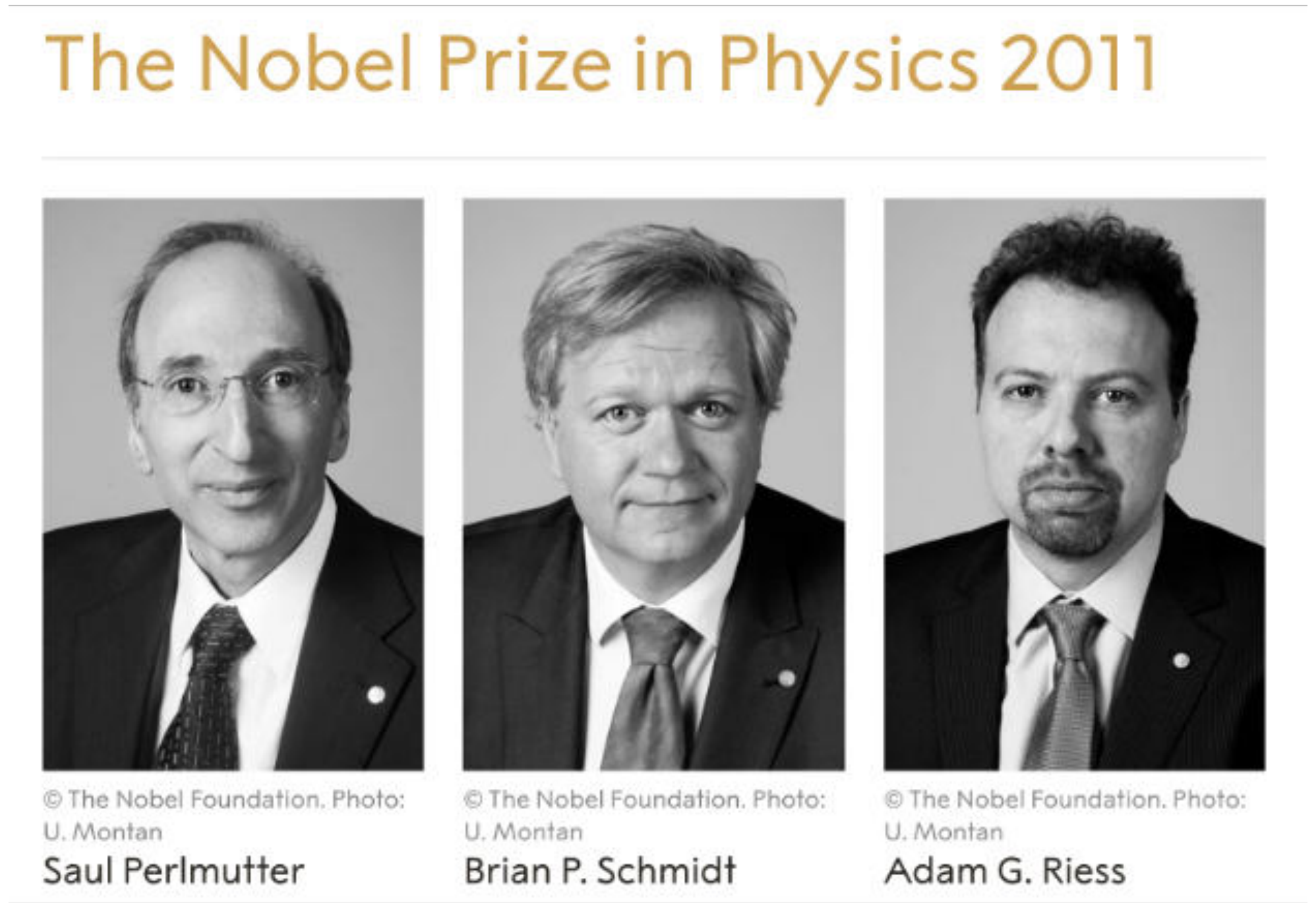

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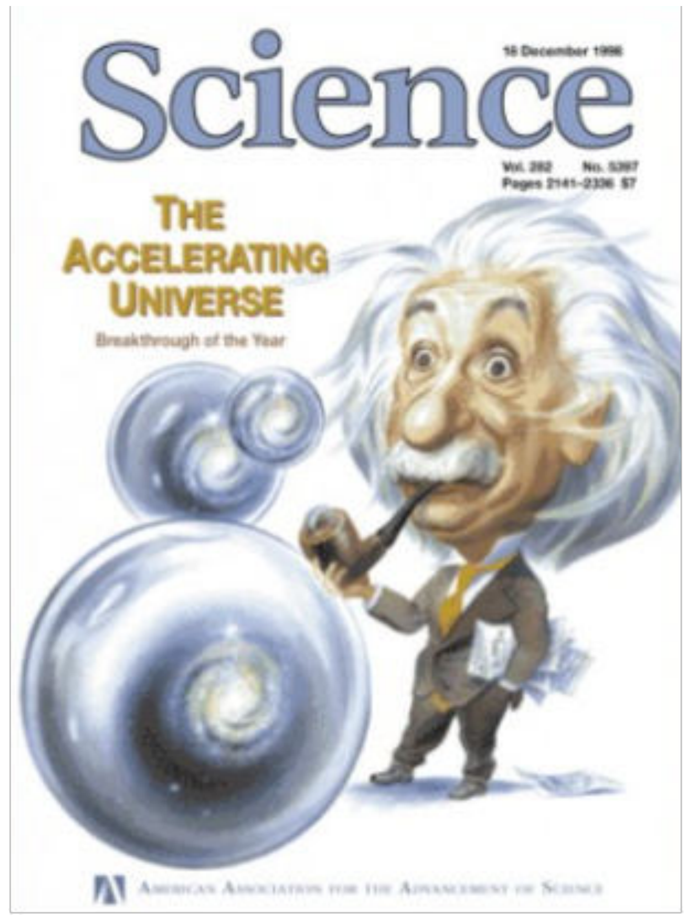

A number of techniques has been used, and people spent their careers, but the question still remains unanswered

4 reasons 4

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2. Galaxy evolution depends on the radiative, kinetic energy, and nucleosynthetic output of SNe Ia;

4 reasons 4

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3. A knowledge of the initial conditions and of the distribution of matter in the environment of the exploding star is essential for the understanding of the explosion itself;

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4. An unambiguos identification of the progenitors, coupled with observationally determined SN rates will help placing constraints on the theory of binary star evolution.

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This rules out the core-collapse of massive (M>8 M_{sun}), young stars.

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- you ought to hide the most abundant element in the universe

THE ASTROPHYSICAL JOURNAL, **186**: 1007–1014, 1973 December 15

BINARIES AND SUPERNOVAE OF TYPE I*

JOHN WHELAN† AND ICKO IBEN, JR.
University of Illinois
Received 1973 April 9

ABSTRACT

It is suggested that the immediate progenitors of Type I supernovae in elliptical galaxies are binary systems of long period (1–6 years) that have evolved from an initial configuration consisting of a light secondary of mass less than or equal to 0.8 $M_\odot$ and a primary of intermediate mass (1.8–3 $M_\odot$), with orbital period between 5 and 9 years. Beginning on the main sequence, the primary evolves rapidly and, following mass loss and/or mass transfer, becomes a carbon-oxygen white dwarf of mass close to 1.4 $M_\odot$. The secondary, now of mass 0.8 $M_\odot$, evolves for 10^{10} years before reaching the asymptotic giant branch. On swelling beyond its Roche surface, the secondary transfers mass onto the primary which then (we presume) develops rapidly into a supernova. An examination of the frequency of binary systems with appropriate orbital characteristics shows that our conjecture is not inconsistent with the available data concerning the frequency of Type I supernovae.

Subject headings: binaries — mass loss — supernovae

I. THE CONUNDRUM AND A POSSIBLE SOLUTION

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Putting two and two together, we might conclude that supernovae could not occur in elliptical galaxies. Yet we know that supernovae of Type I occur in such galaxies at a frequency of 1 per 100 years per 10^{11} stars.

A possible solution may involve mass transfer between members of a binary system (see, e.g., Wheeler and Hansen 1971; Truran and Cameron 1971; Hartwick 1972; Mazurek 1973).

We propose an initial binary system that consists of (1) a massive component (primary), that passes through its active nuclear burning life in a time short compared with a galactic lifetime, leaving an inactive white dwarf composed primarily of carbon and oxygen, and (2) a light component (secondary) whose nuclear burning lifetime is comparable to the galactic age.

I. THE CONUNDRUM AND A POSSIBLE SOLUTION

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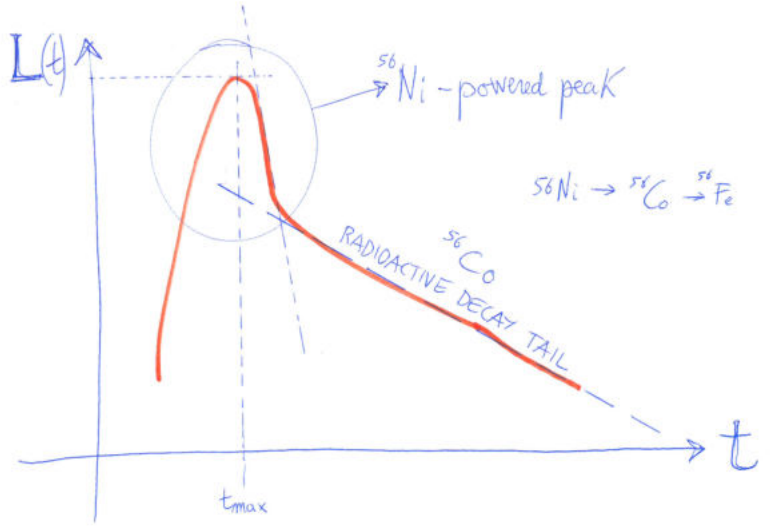

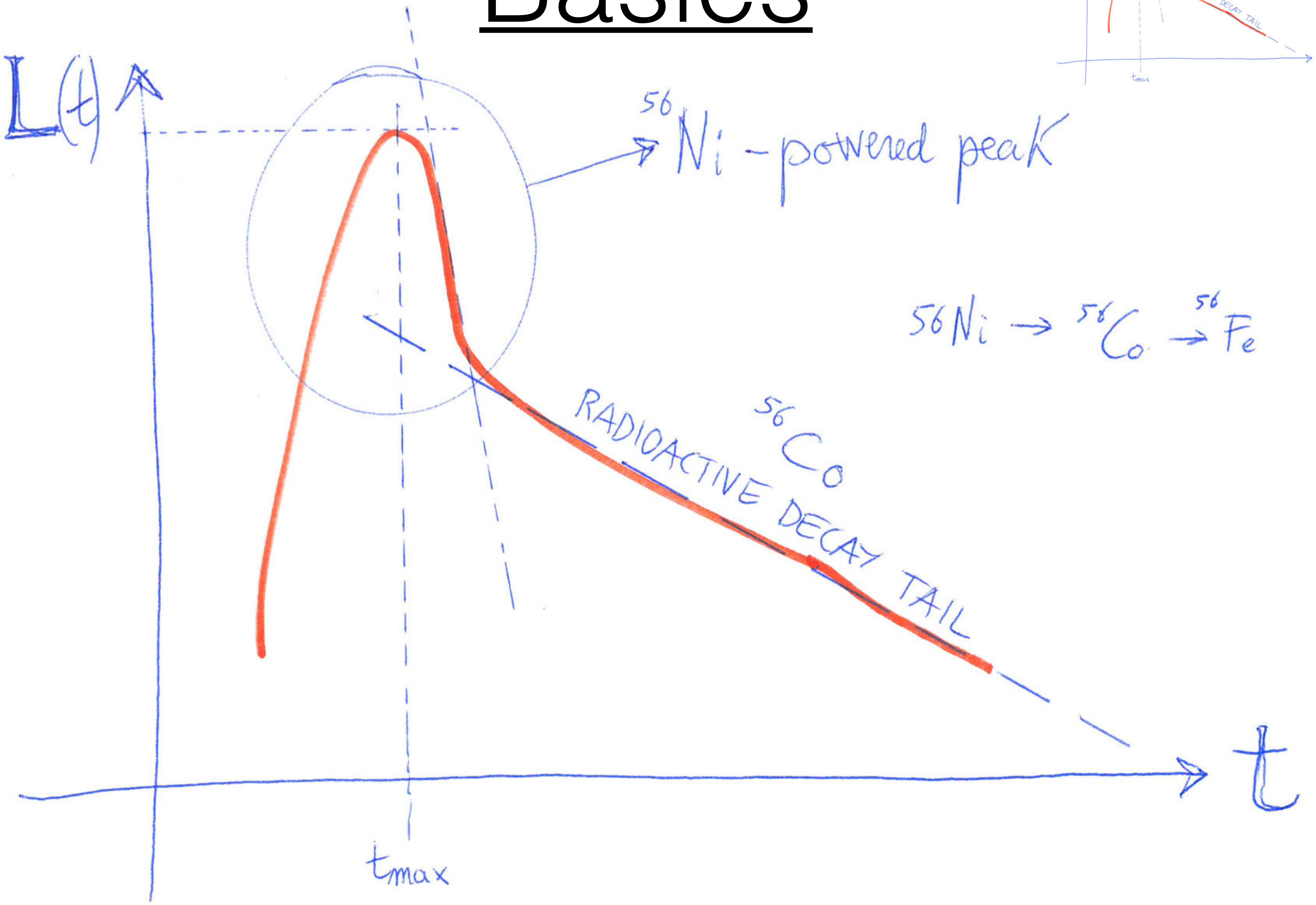
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56Ni - powered peak
56Ni → 56Co → 56Fe
56Co
RADIOACTIVE DECAY TAIL
t
tmax

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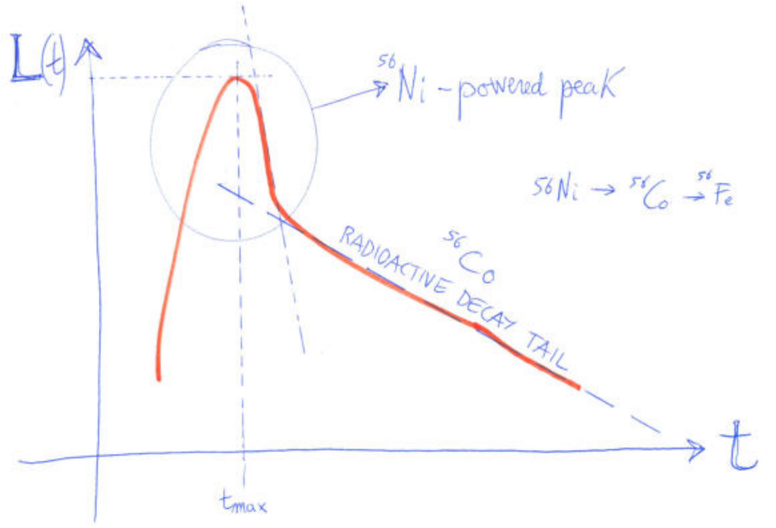

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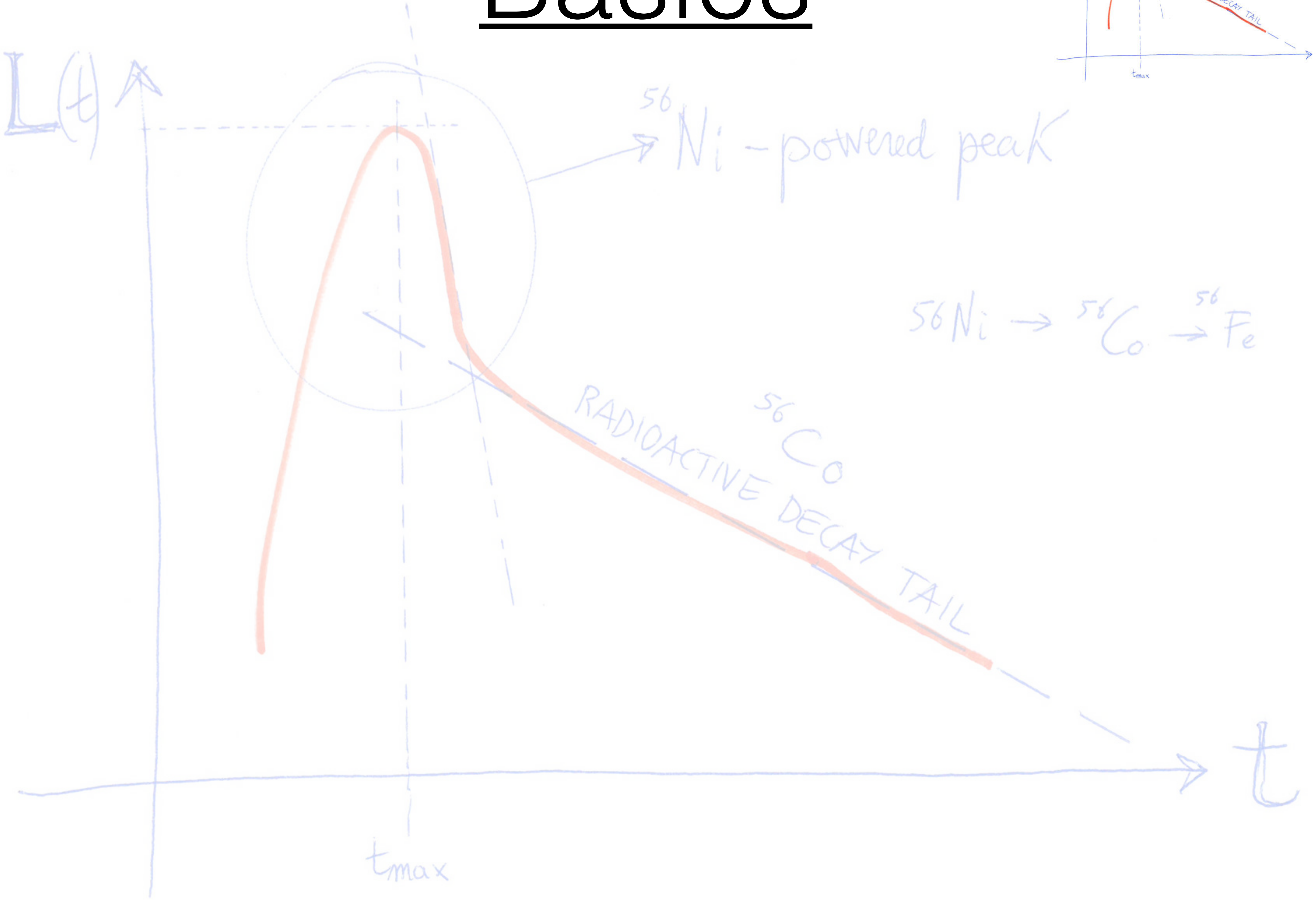

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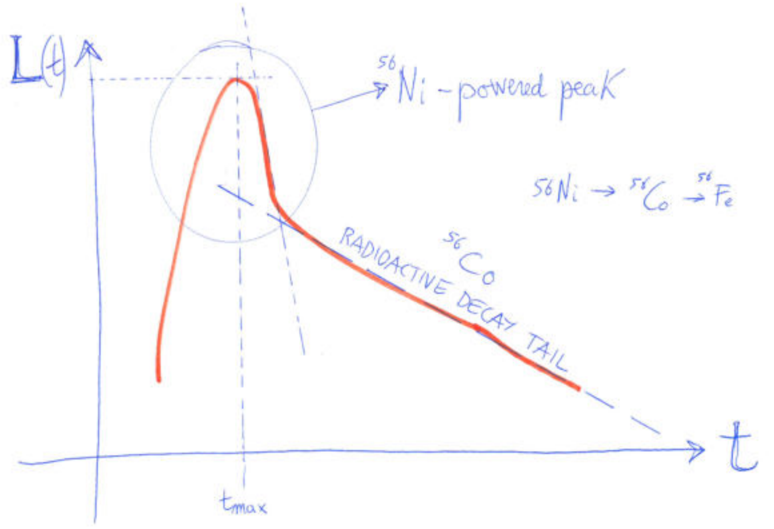

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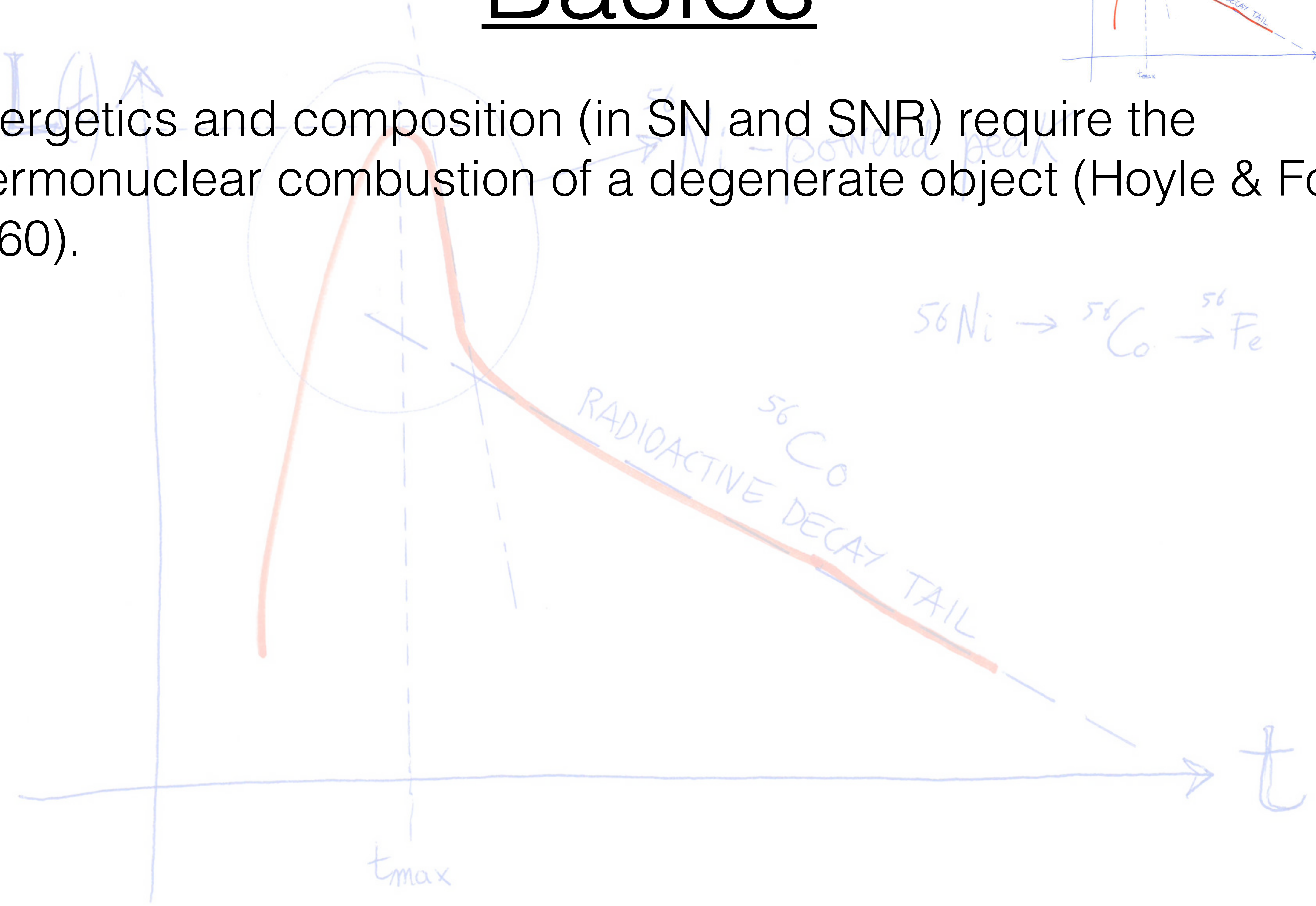
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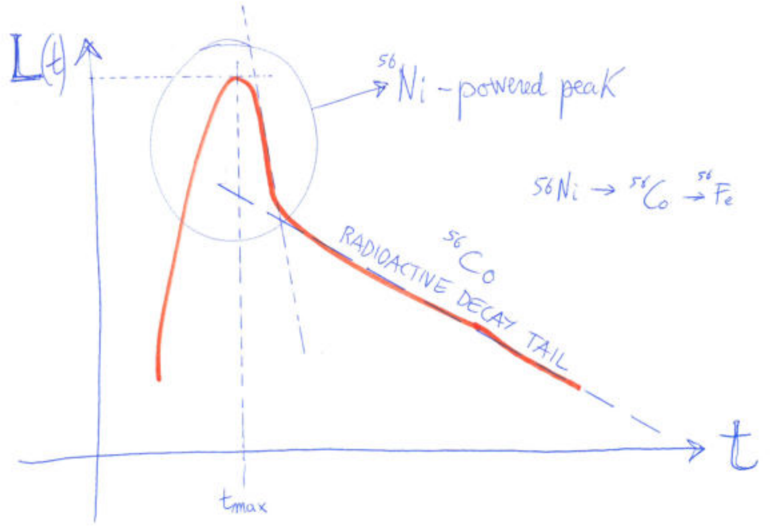

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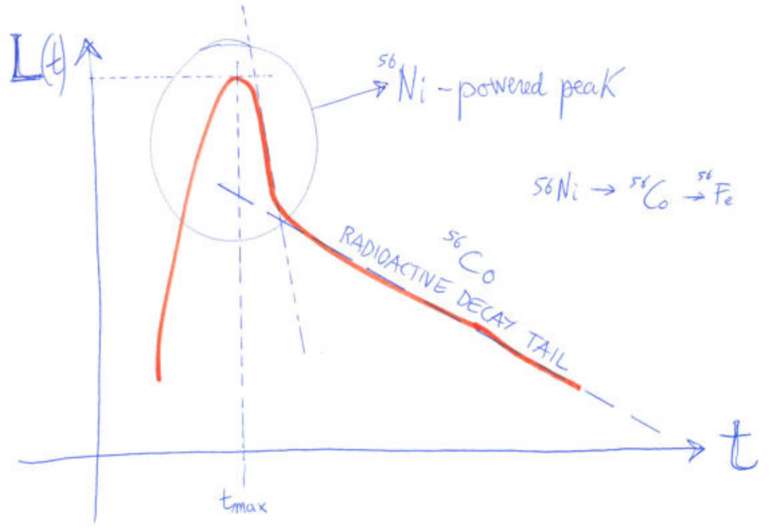

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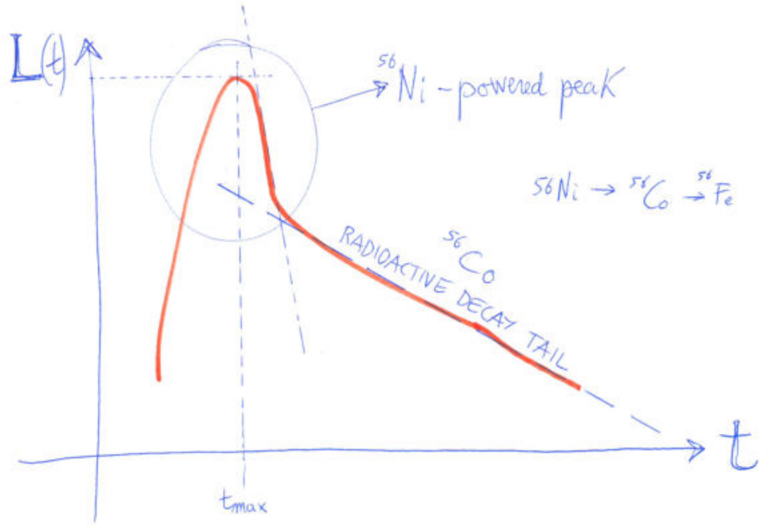

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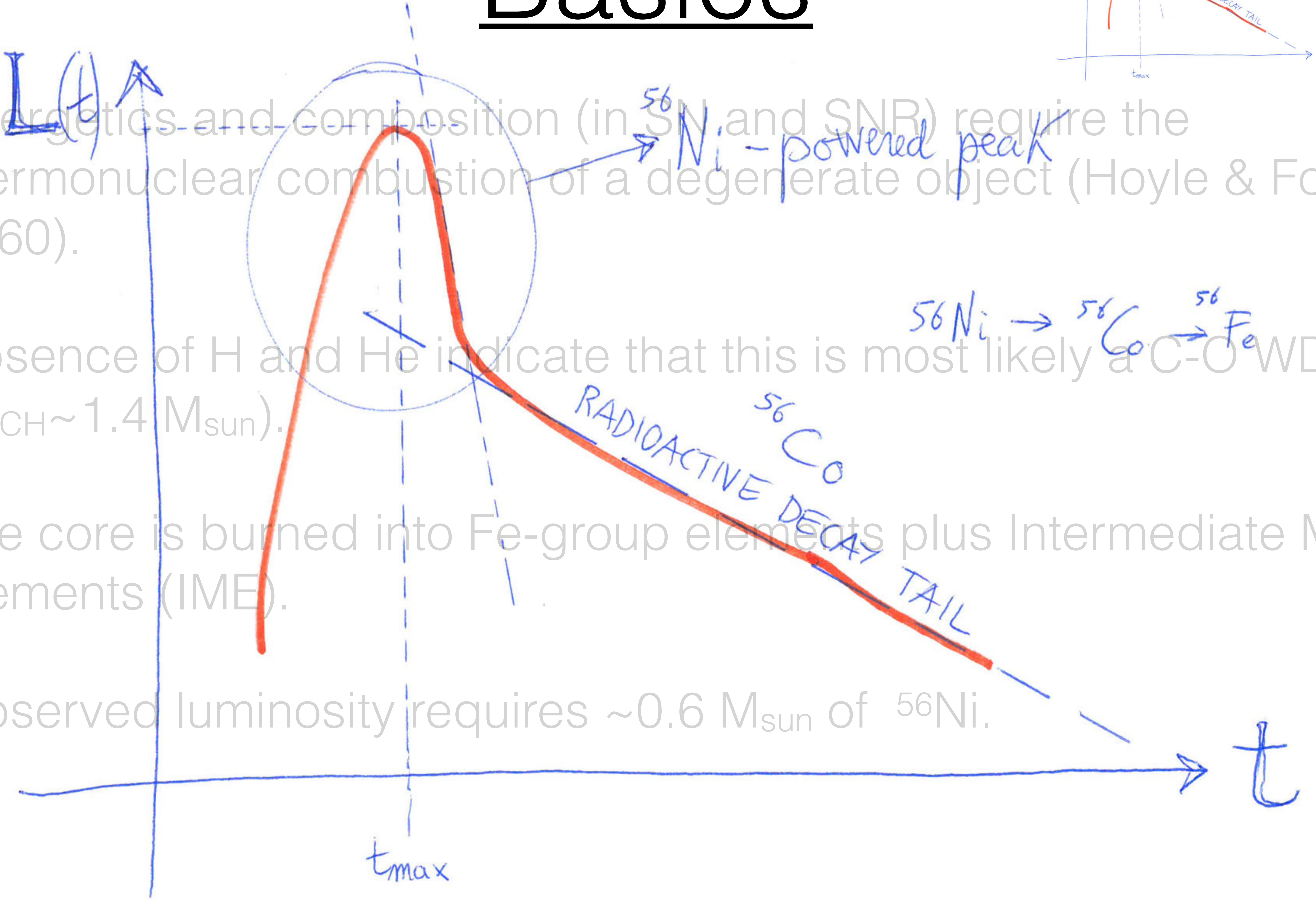

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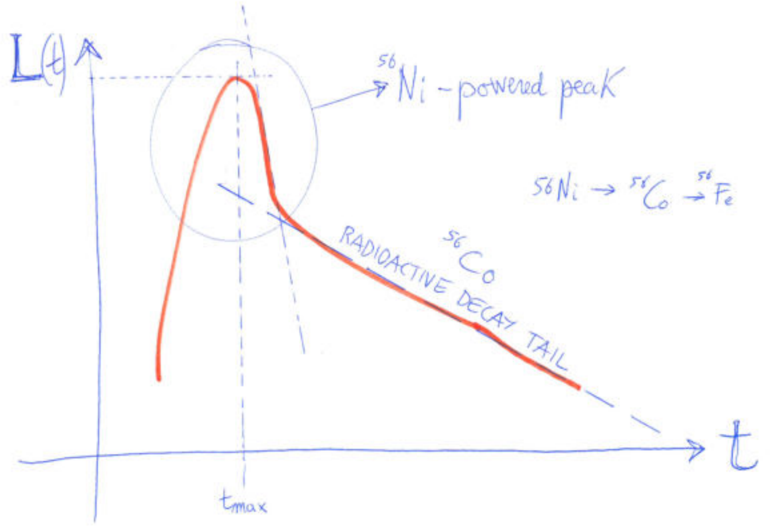

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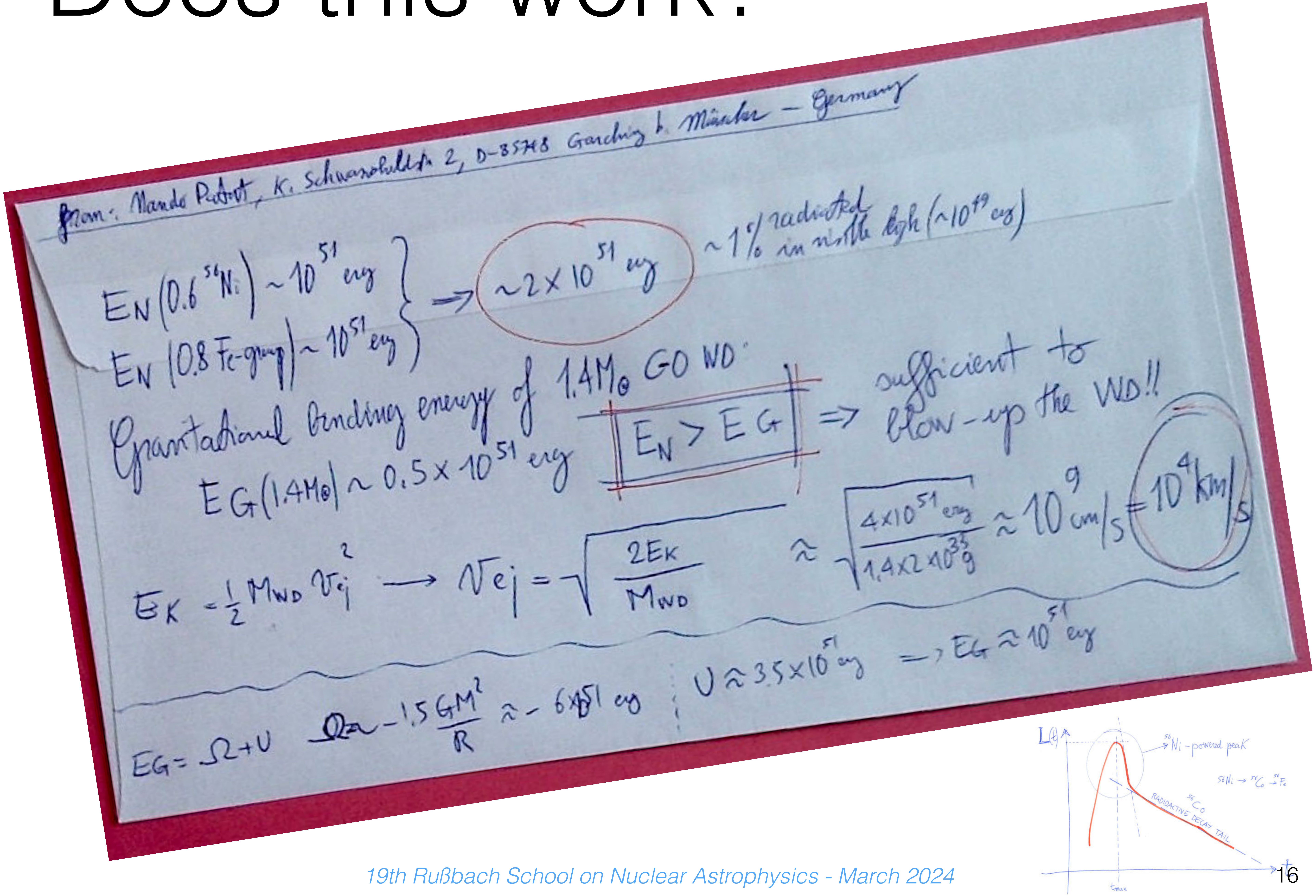

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Growing a WD to the critical limit is not that easy, though…

The Ia progenitor problem

An observational approach

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- Populations of potential progenitors

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- Pre-explosion imaging of [nearby] explosion sites

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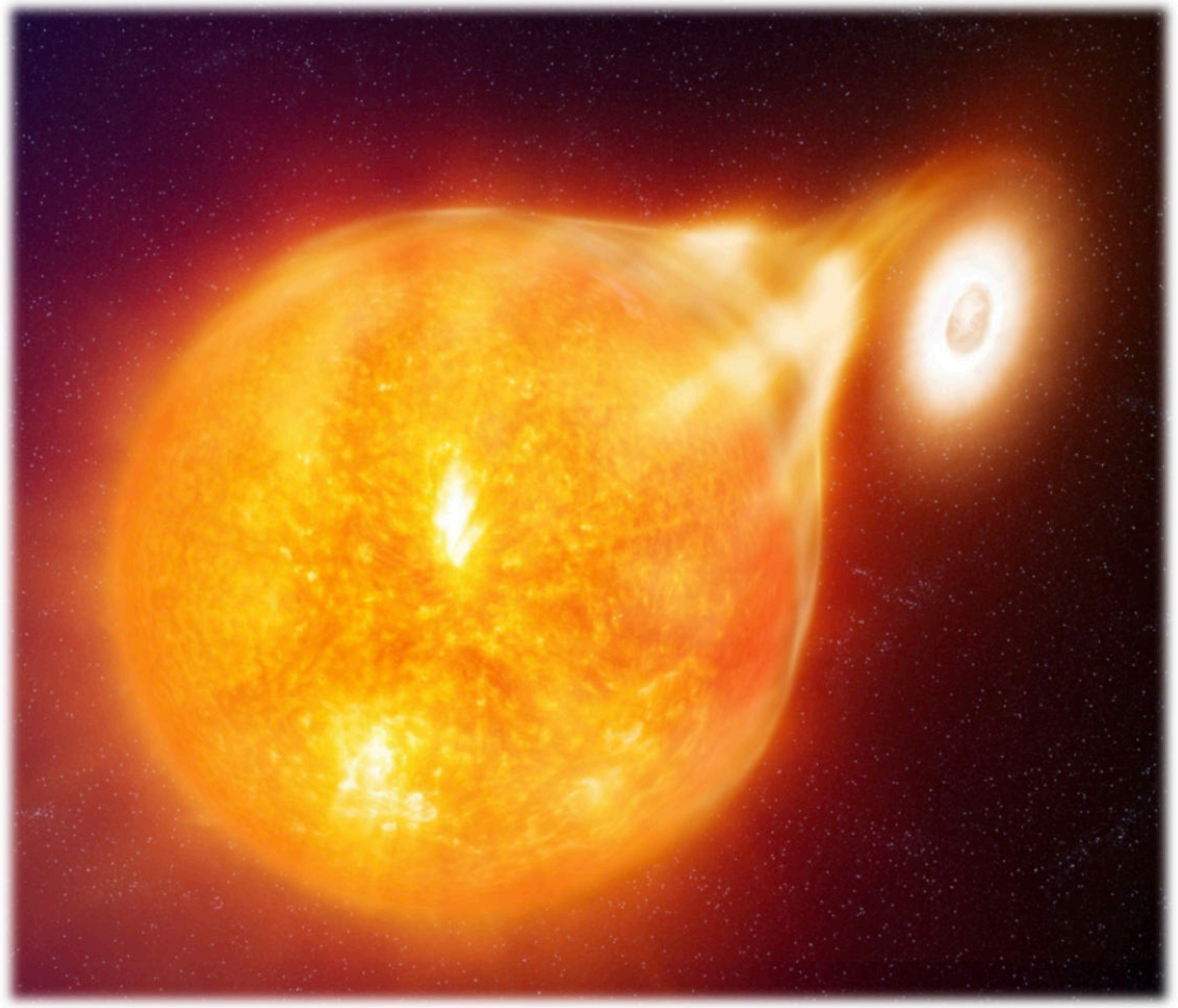
Candidate Populations

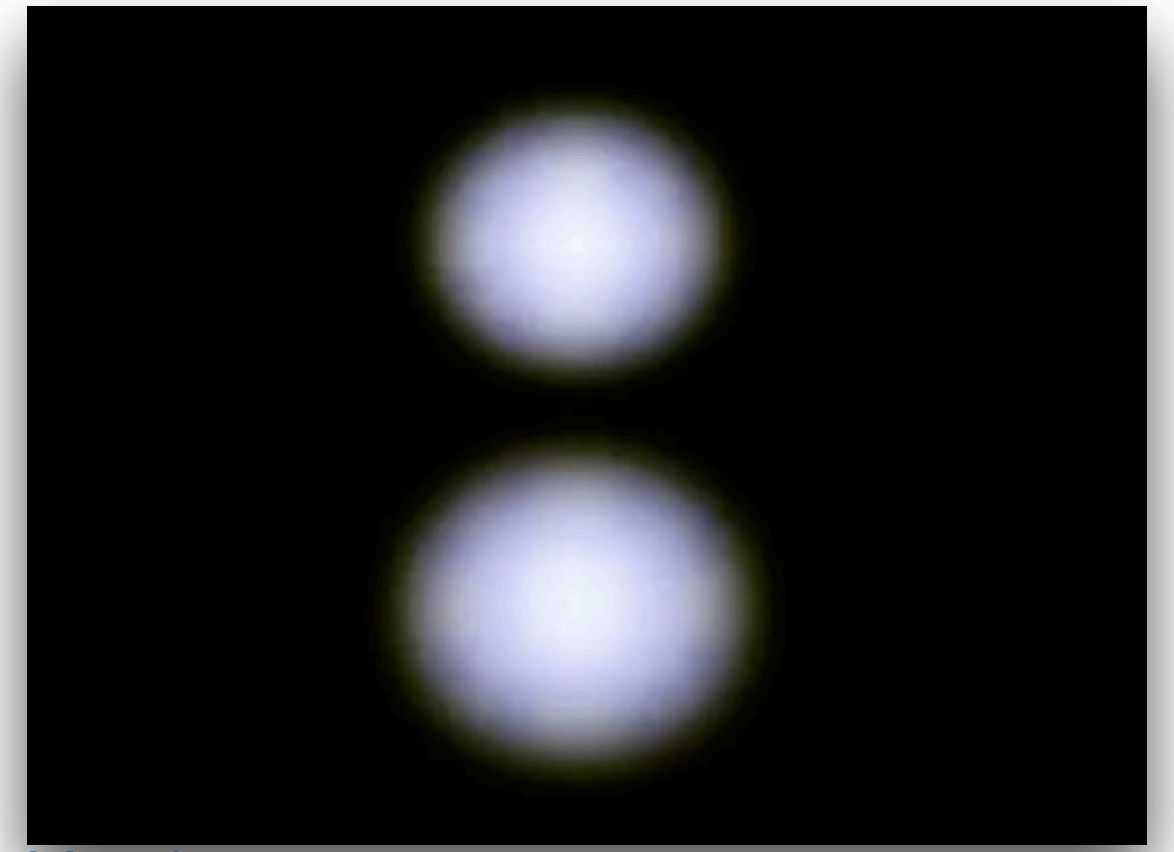
- Recurrent novae
- Supersoft X-Ray sources
- Rapidly accreting WDs
- He-rich donors

Single Degenerate



- Binary WDs

Double Degenerate



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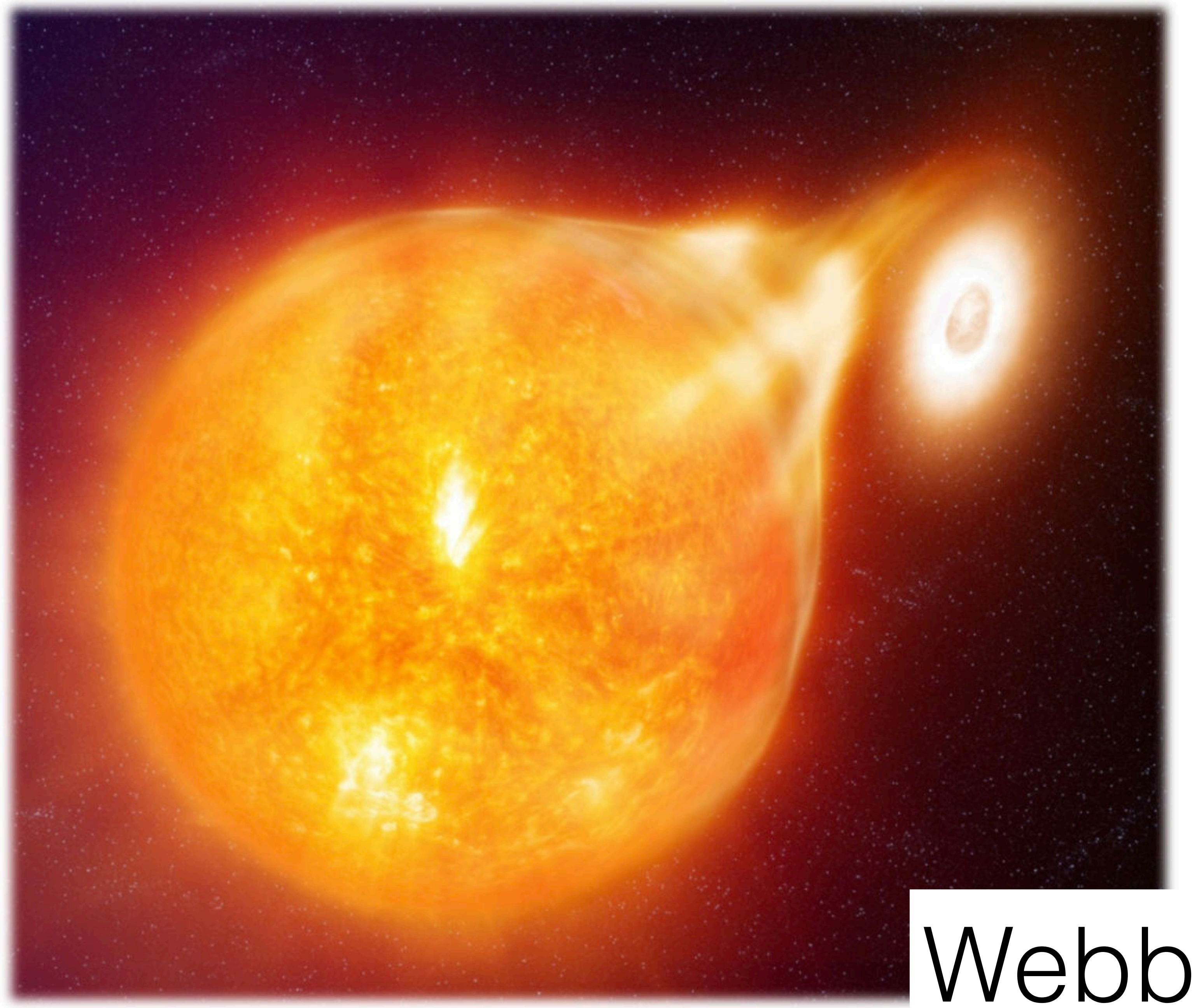

Webbink 1984

In view of the short orbital periods anticipated among newly formed CDWDs and the absence of plausible competing mechanisms, the evolution of these systems to an interacting stage is almost certainly driven by general relativistic gravitational radiation. This extracts angular momentum from the binary at a rate

$$\left(\frac{\partial \ln J}{\partial t}\right)_{GR} \equiv -\tau_{GR}^{-1} = -\frac{32}{5}\frac{G^{5/3}}{c^5}\frac{M_{1f}M_{2f}}{(M_{1f}+M_{2f})^{1/3}}\left(\frac{2\pi}{P}\right)^{8/3}$$

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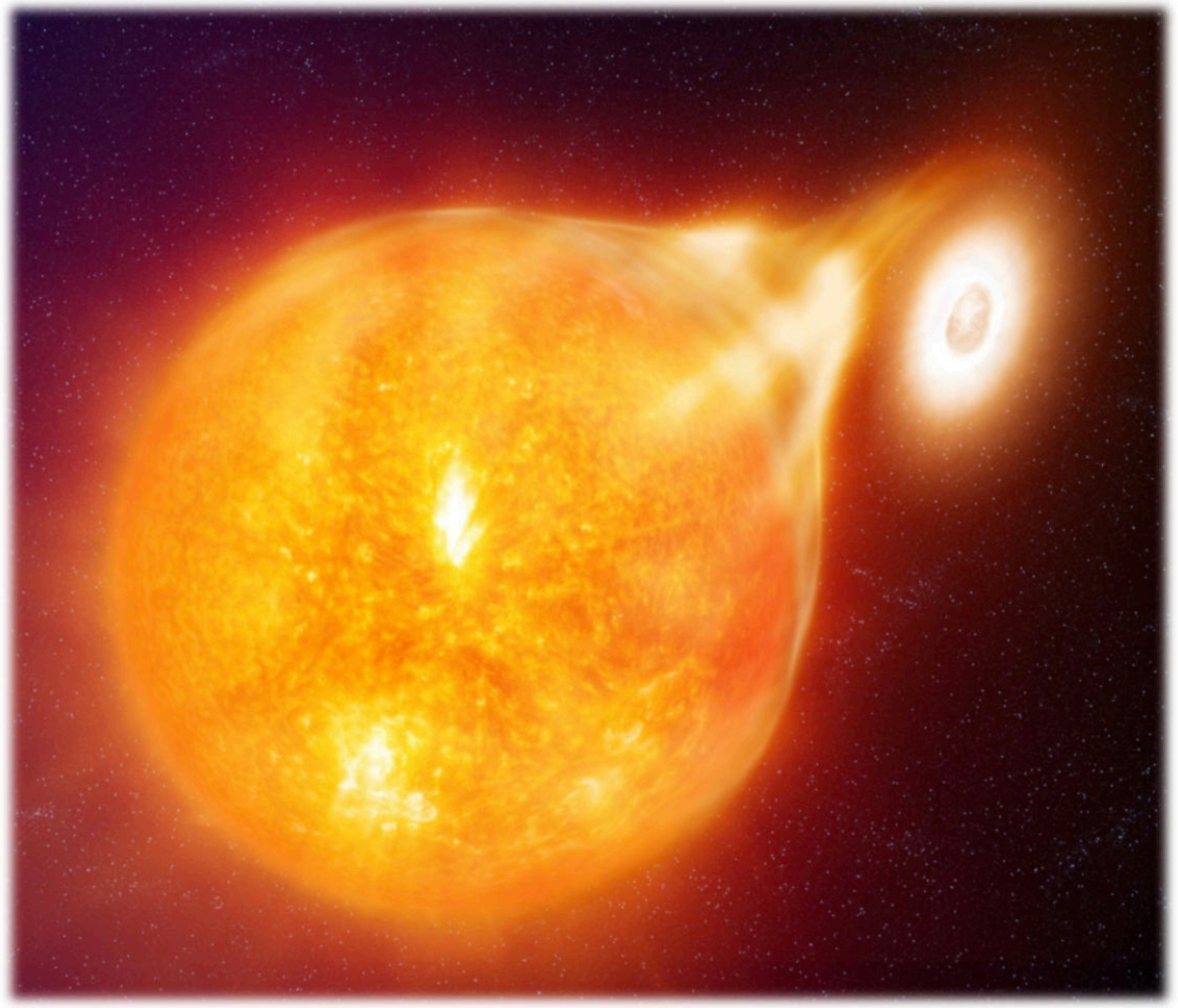

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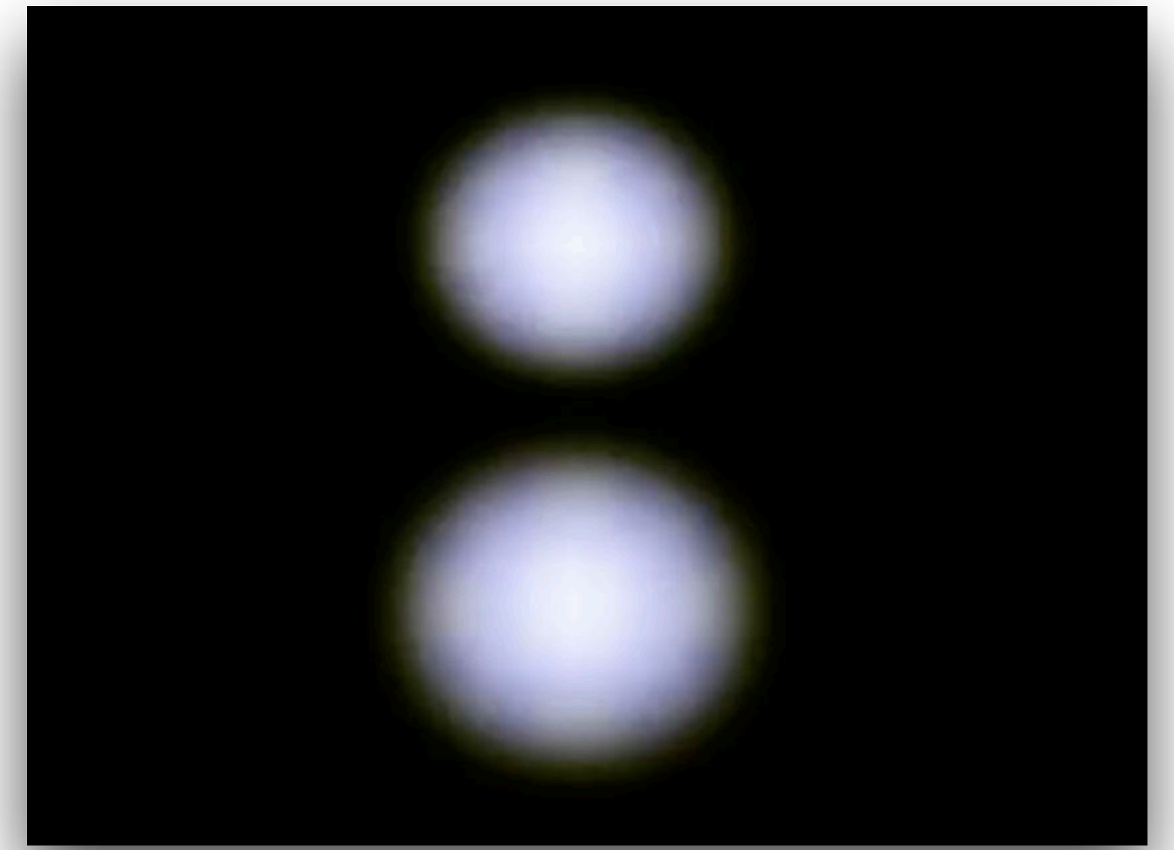

One thing is speculating about the existence of binary systems with a $M \sim M_{CH}$ accreting WD. Another is looking around for real examples. And see what they tell us…

RNe

MS companion

RG companion

RG companion

All contain WDs claimed to be close to M_{CH}

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RNe

MS companion

RG companion

RG companion

All contain WDs claimed to be close to M_{CH}

BUT:

- Is the WD really a C-O WD? If O-Ne-Mg, then …
- Is it increasing in mass? In outburst it may loose…
- And, briefly, there are not enough in the MW…

Tutukov & Yungelson 1981

Binary WDs

This was a disfavoured scenario until a few years ago, because:

Courtesy of F. Röpke

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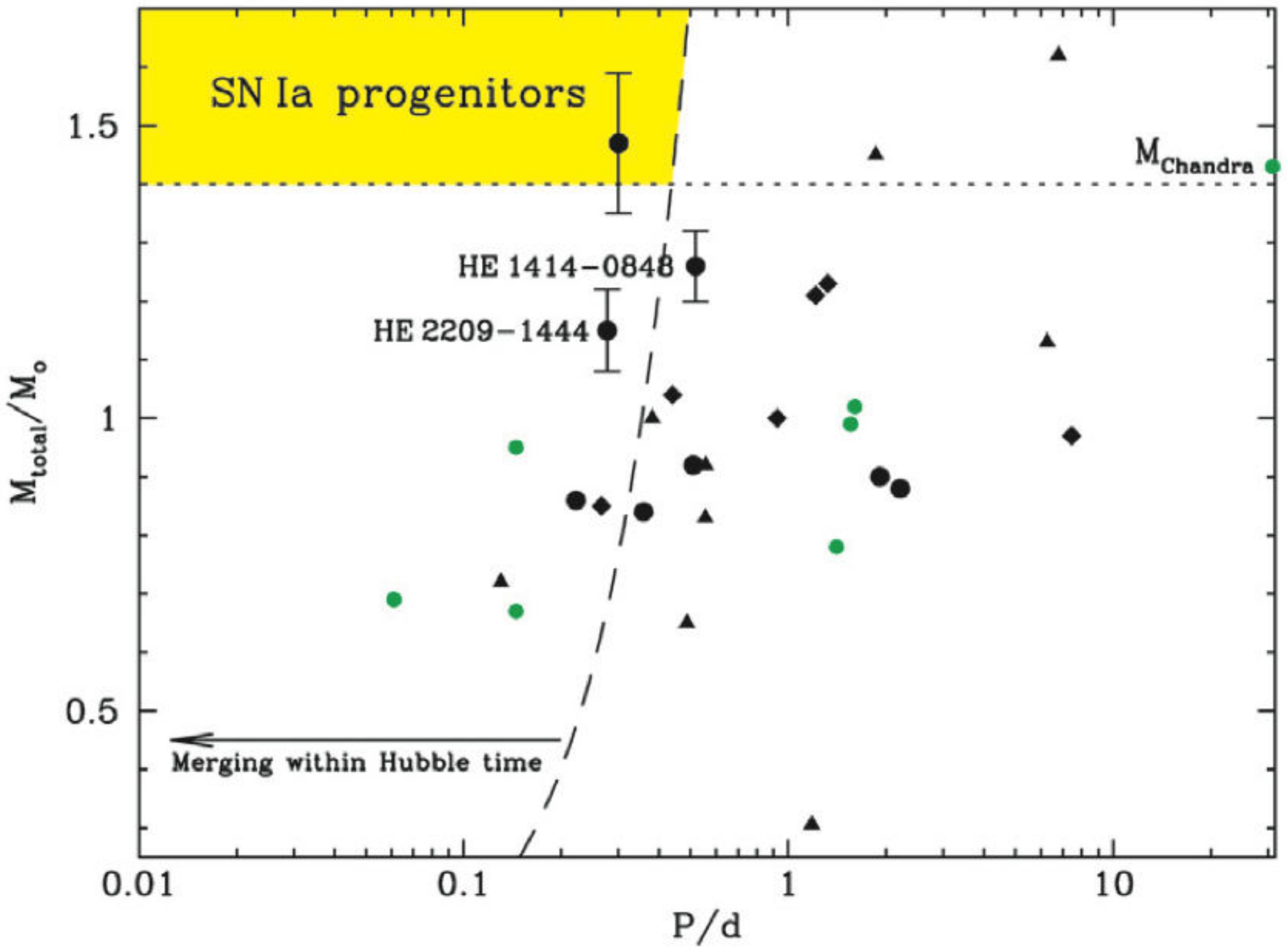

- First large-scale attempt **ESO-SPY** (Napiwotzki+04).
- ~1000 WDs and 1 candidate found.
- Now we known there are enough WD-WD systems in the Galaxy (Badenes+09, Maoz & Hallakoun 17, Maoz, Hallakoun, Badenes 18)

Final evolution of two C-O WDs (0.7+1.0 M_{sun}) with a thin He envelope (10^{-2} M_{sun} each)

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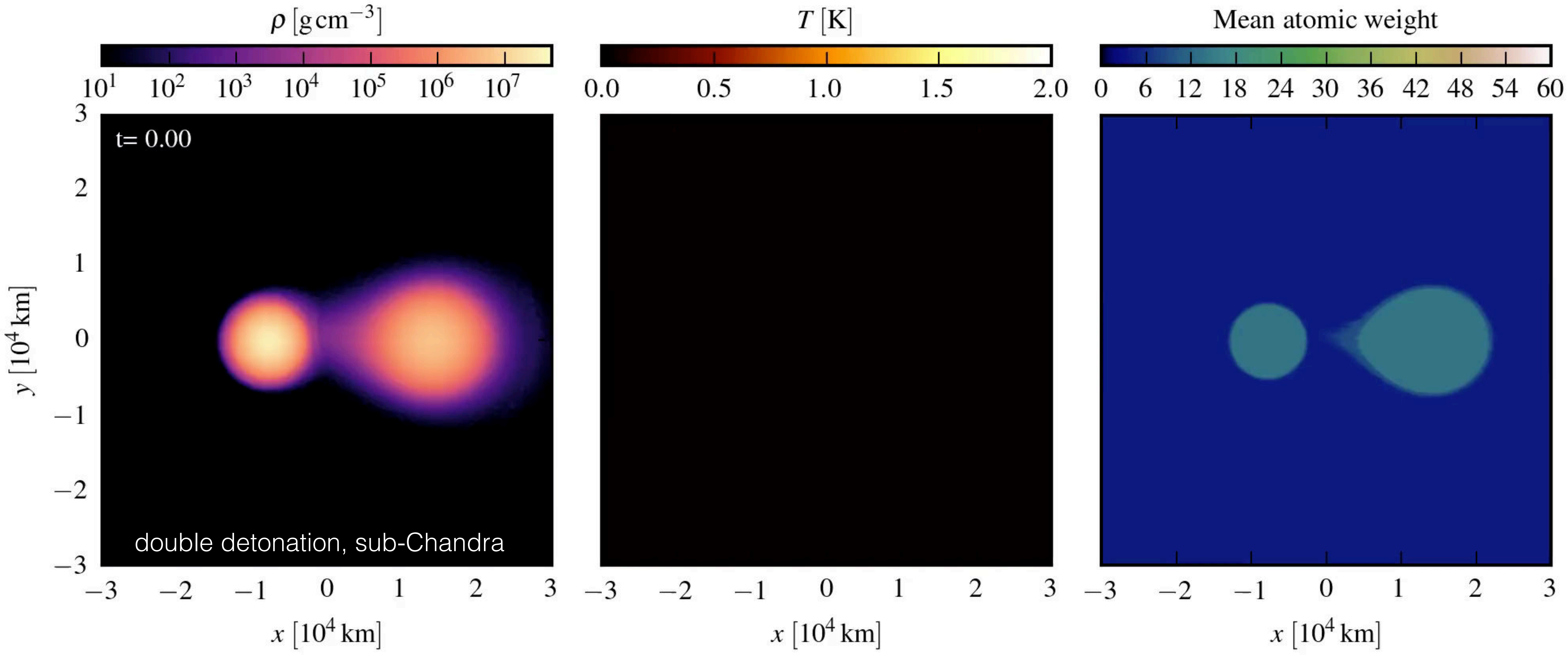

Accretion from the secondary on the primary leads to dynamical effects on the surface of the primary that ignite a He-detonation. The He-detonation wraps around the primary WD and sends a shock into its C-O core that upon converging into a single point ignites a carbon detonation in the CO core and the primary WD explodes.

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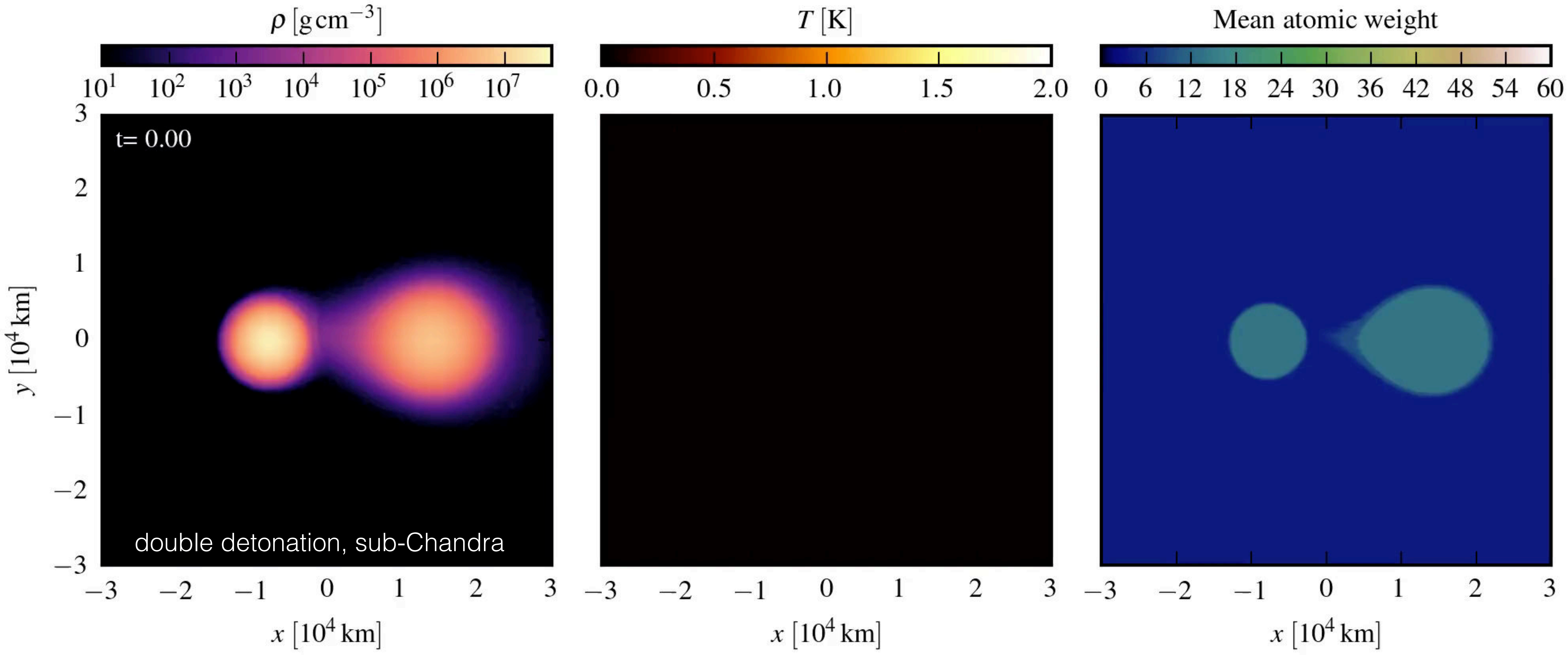

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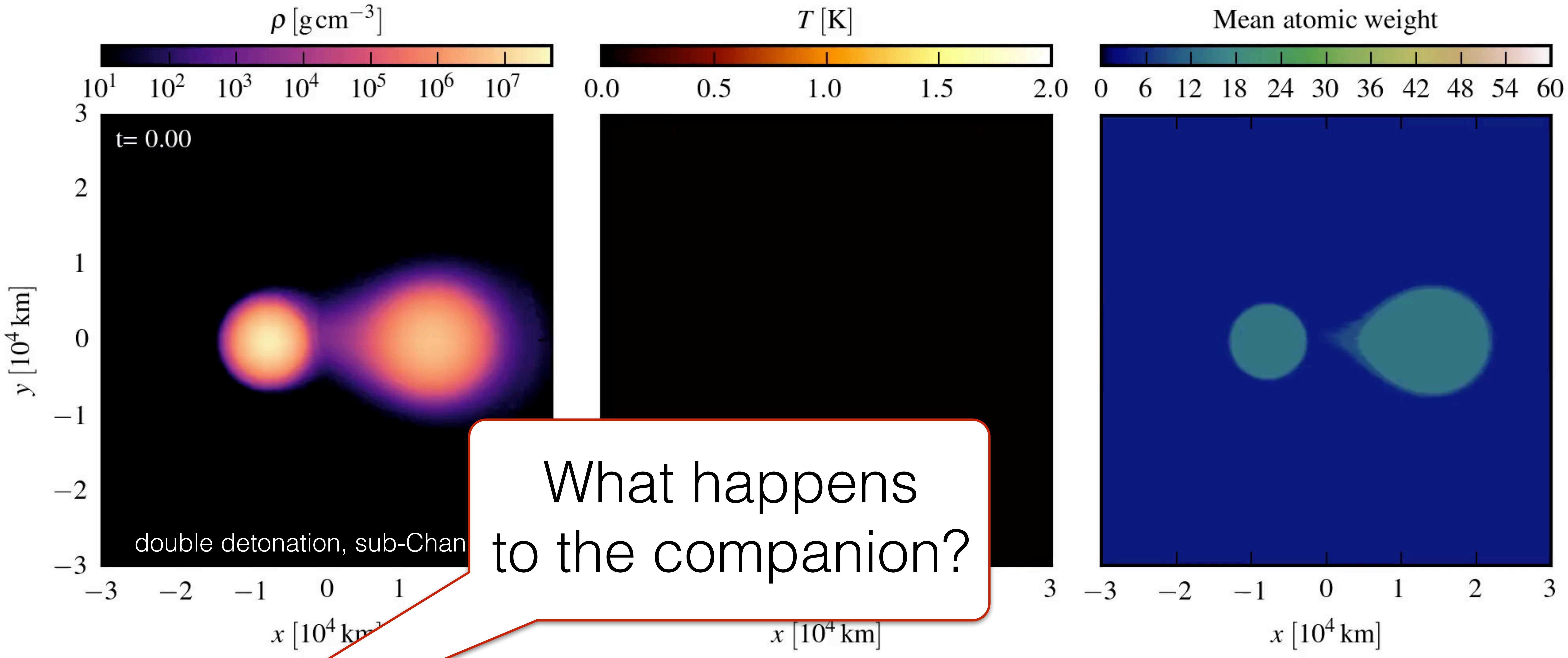

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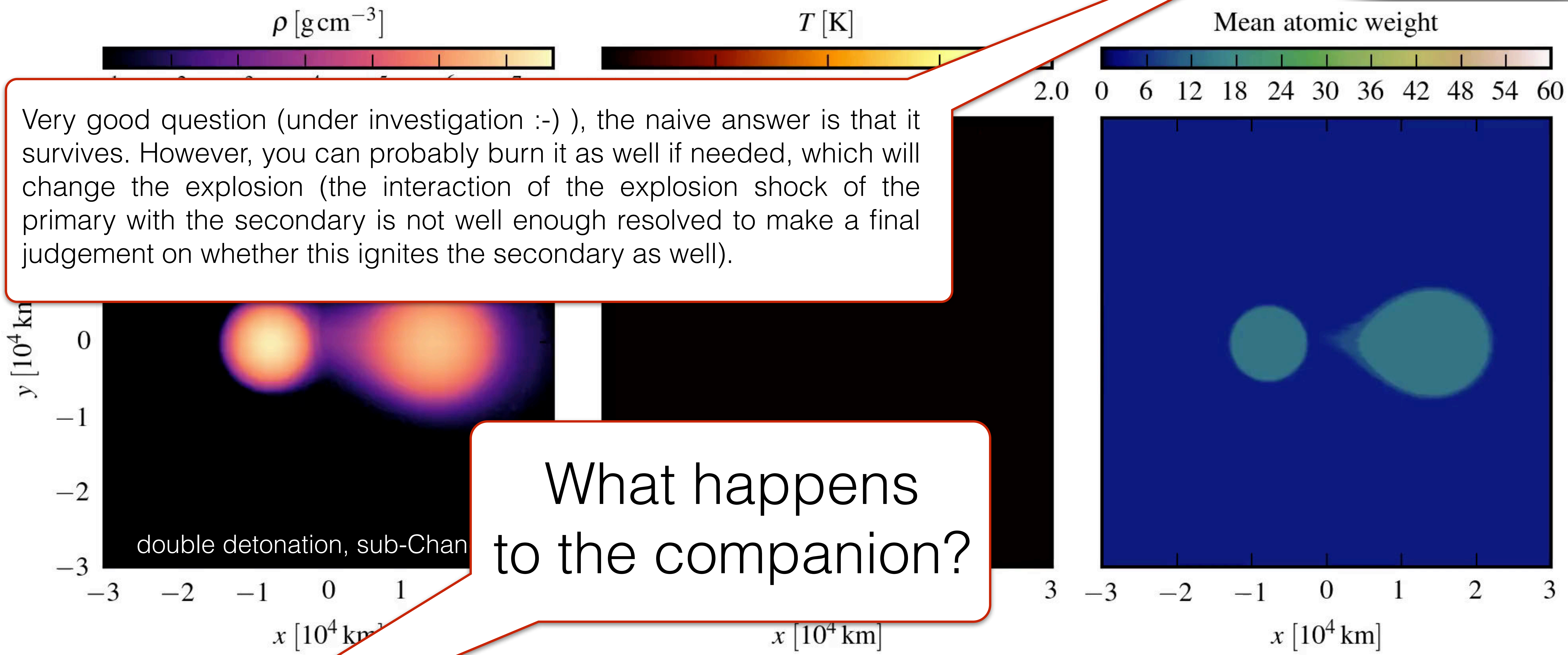

Very good question (under investigation :-)), the naive answer is that it survives. However, you can probably burn it as well if needed, which will change the explosion (the interaction of the explosion shock of the primary with the secondary is not well enough resolved to make a final judgement on whether this ignites the secondary as well).

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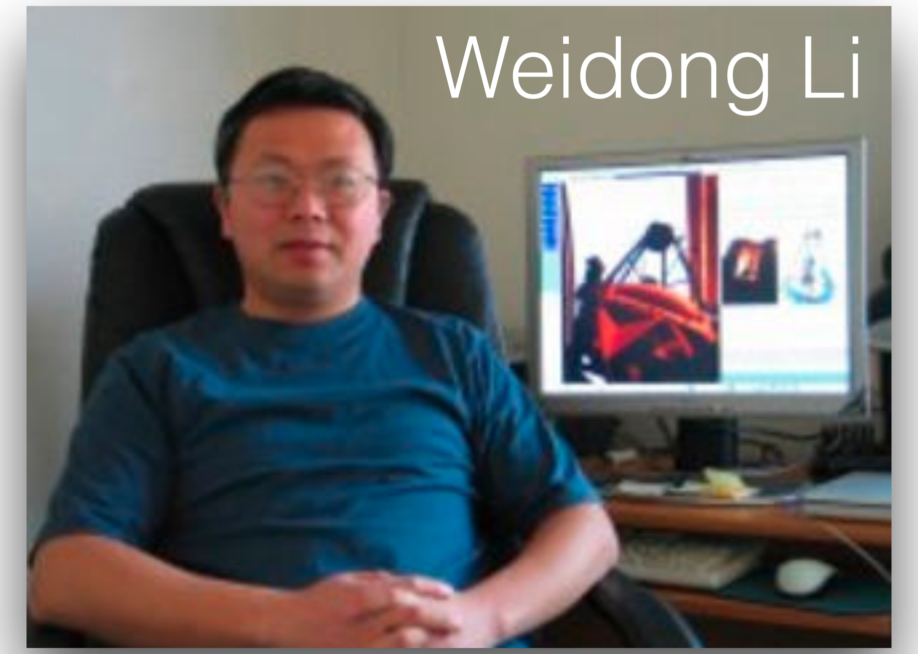
Pre-explosion sites



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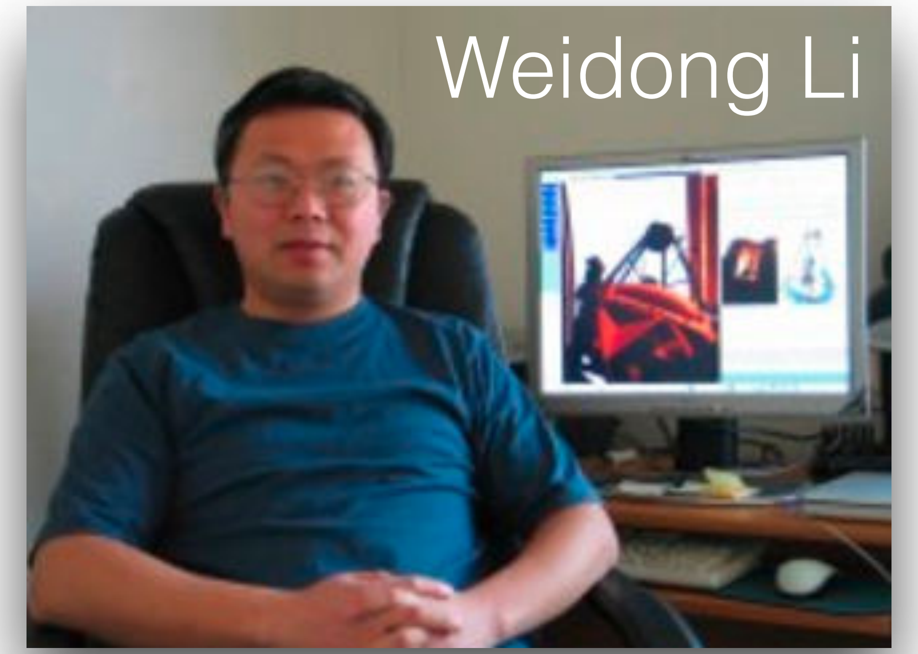

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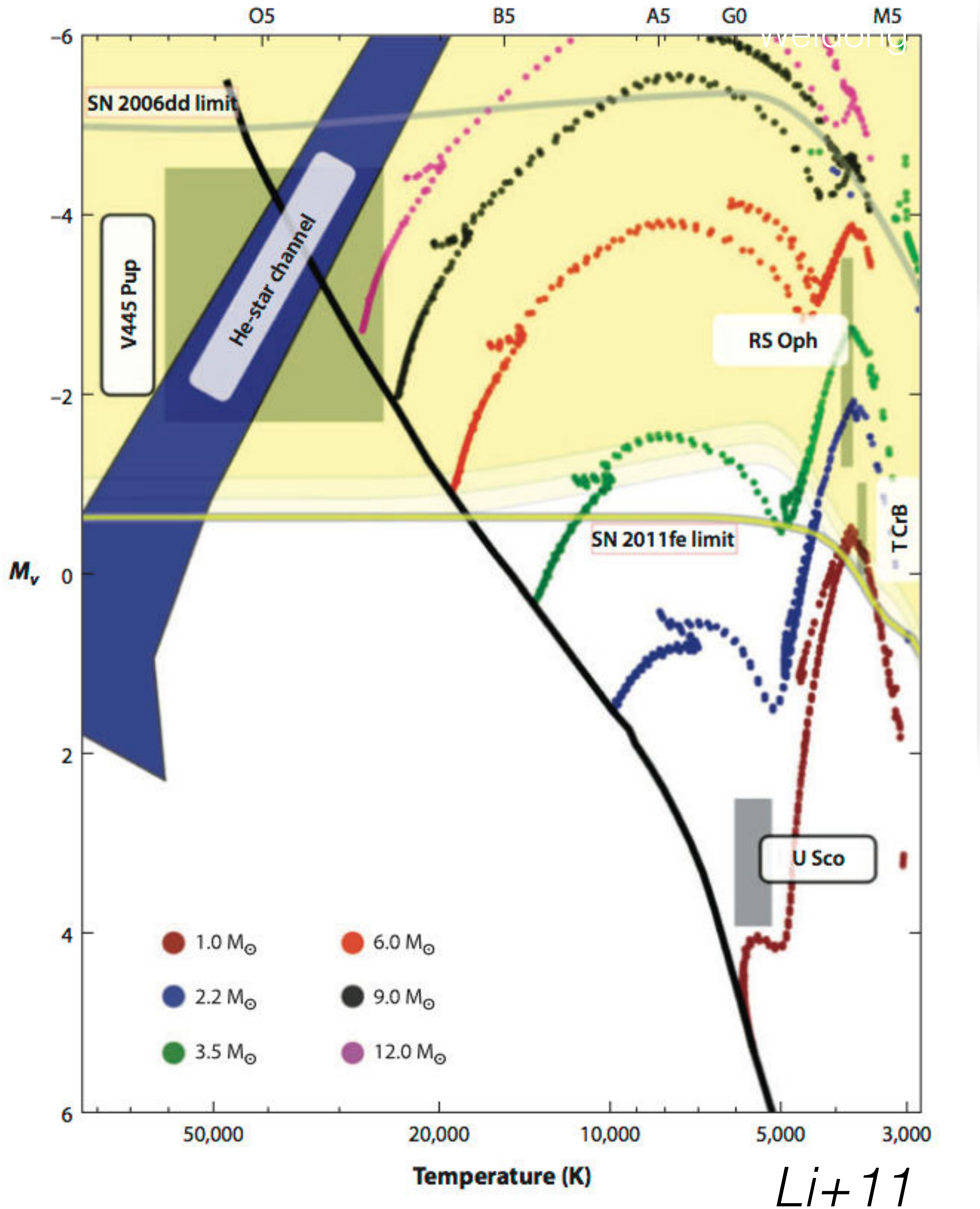

Li+11

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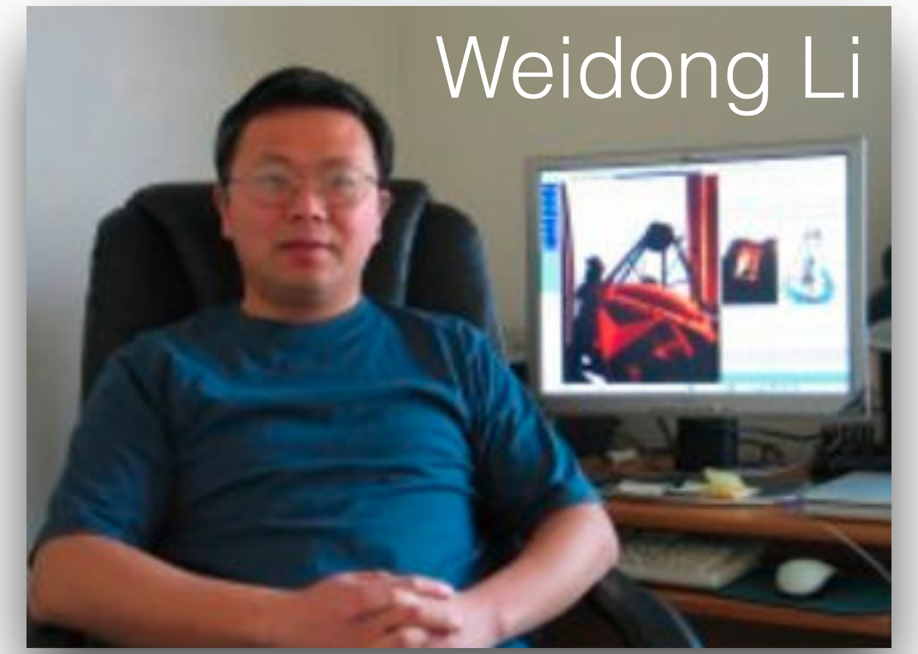

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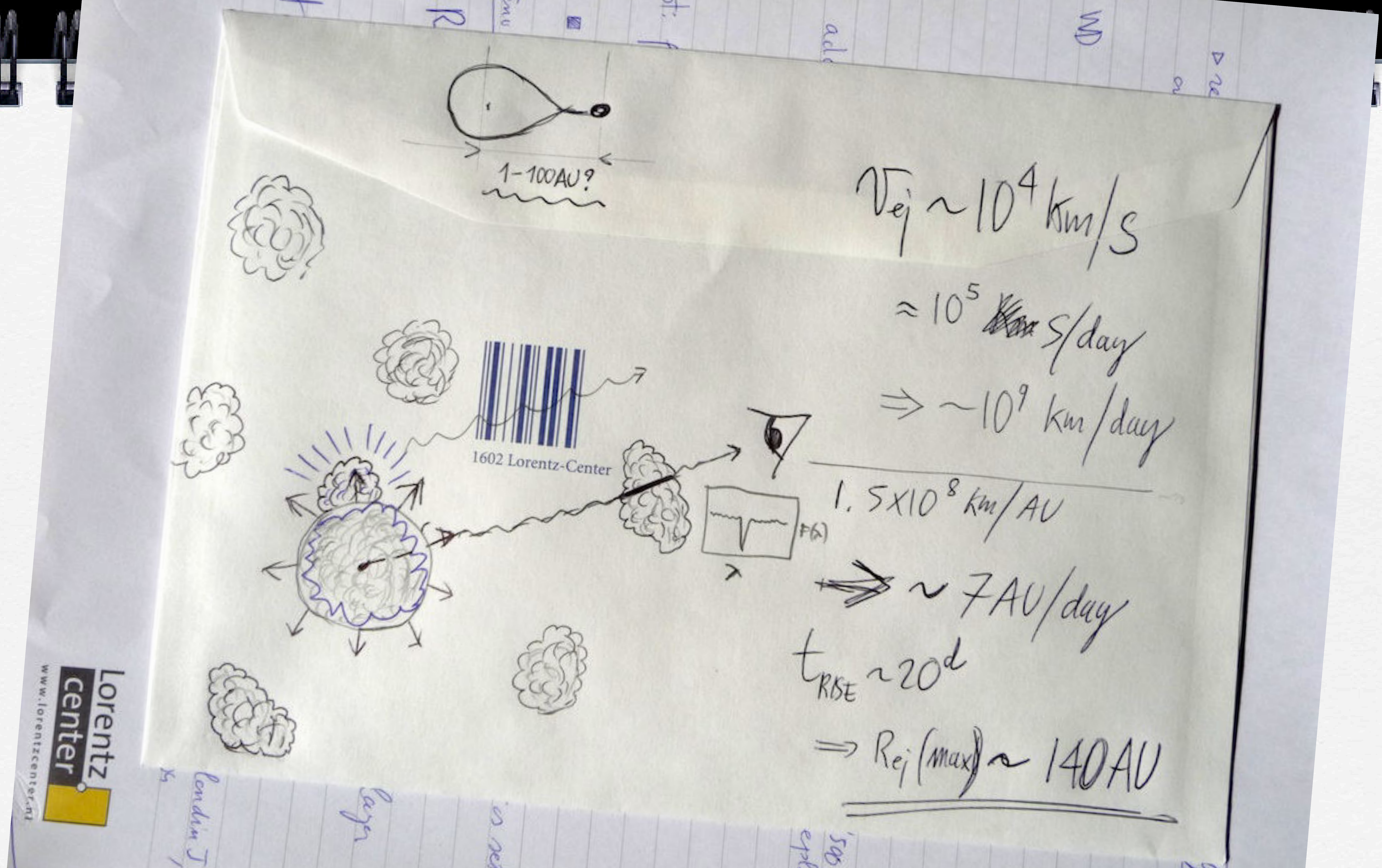
- For the first time provide a direct upper limit to the size of the exploding object, $R<0.02R_{sun}$ (either a WD or a NS).


1-100AU?
1602 Lorentz-Center
v_ej ~ 10^4 km/s
≈ 10^5 s/day
⇒ ~10^9 km/day
1.5×10^8 km/AU
~ 7AU/day
t_RISE ~ 20^d
⇒ R_ej(max) ~ 140AU
F(λ)
λ
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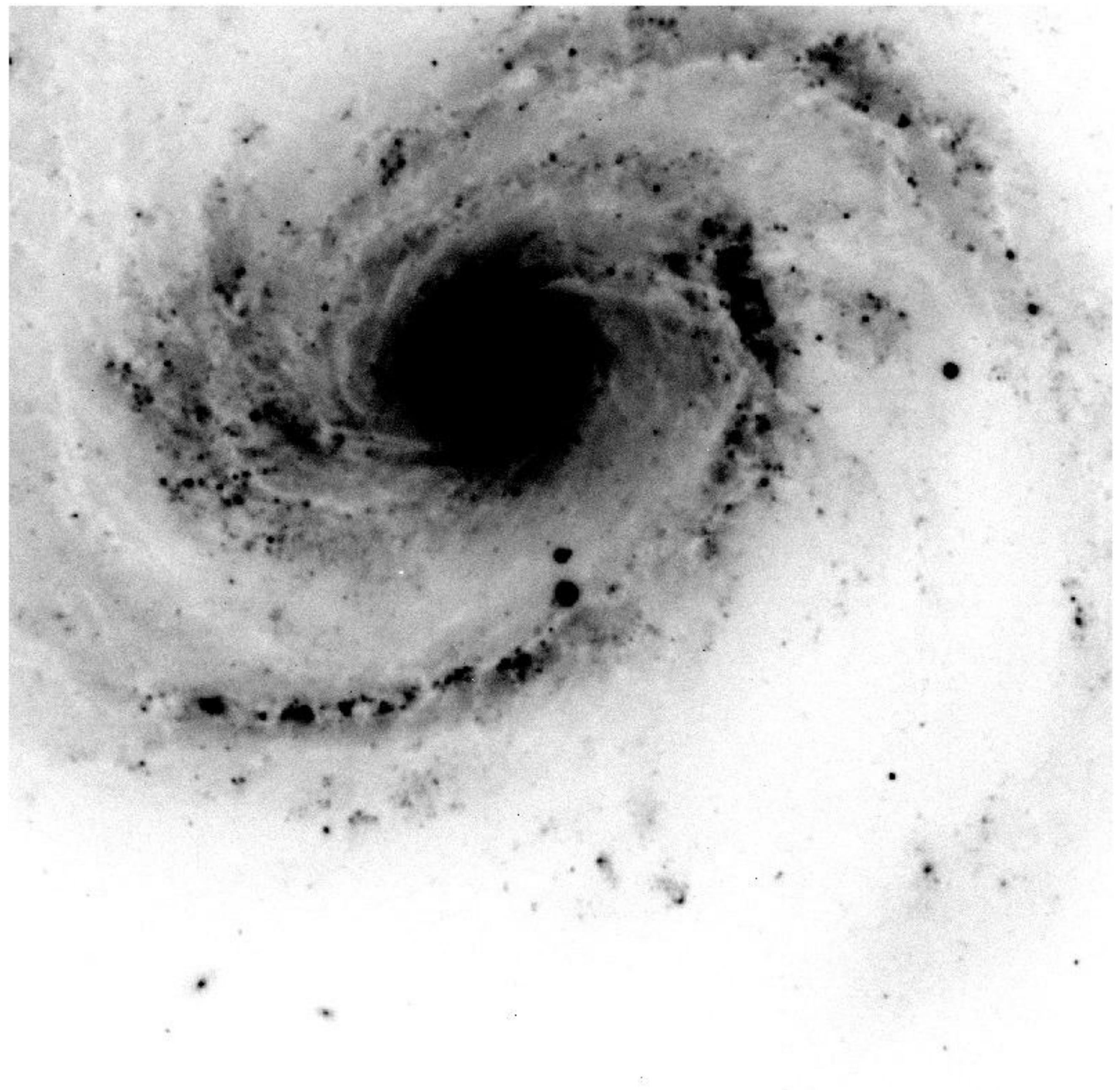

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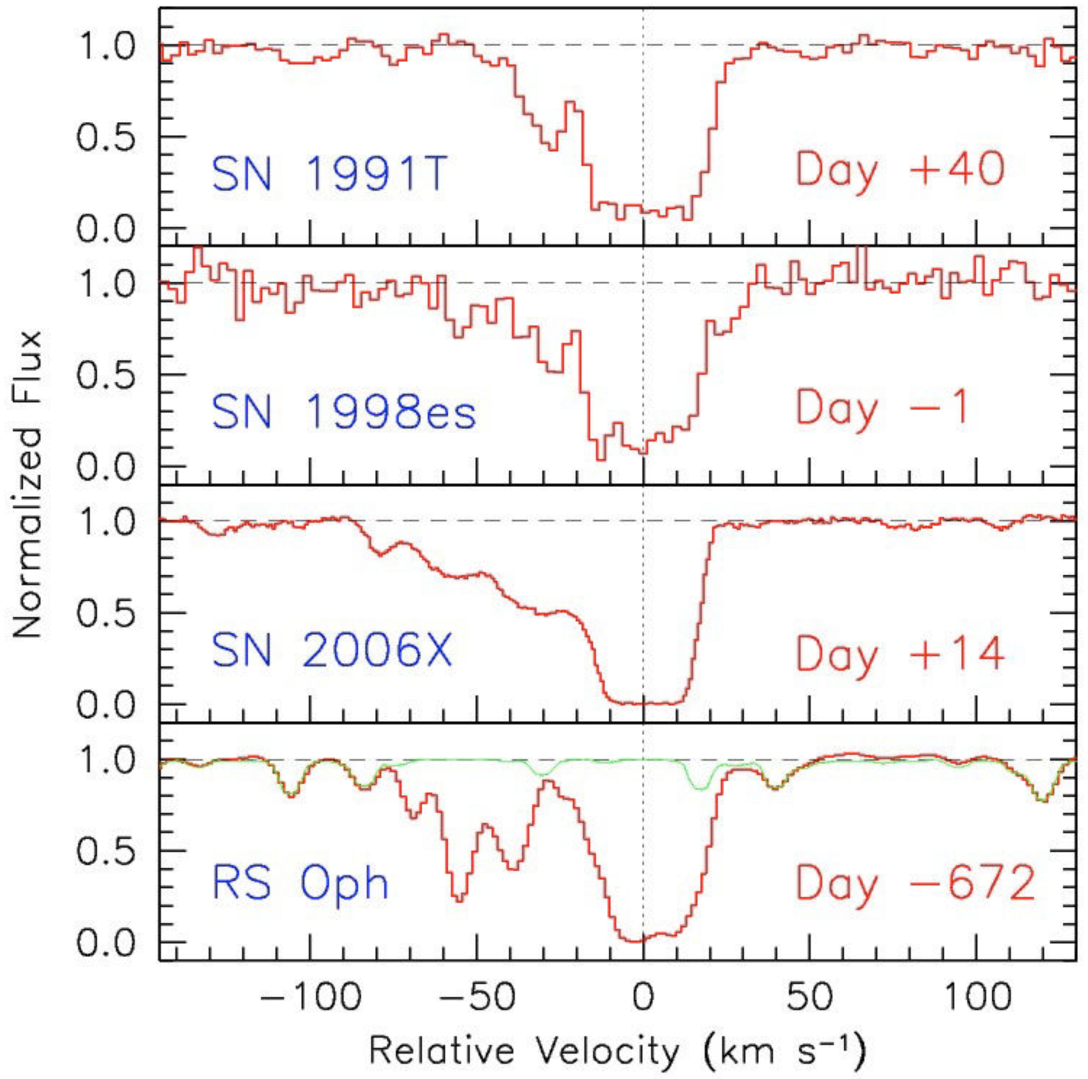
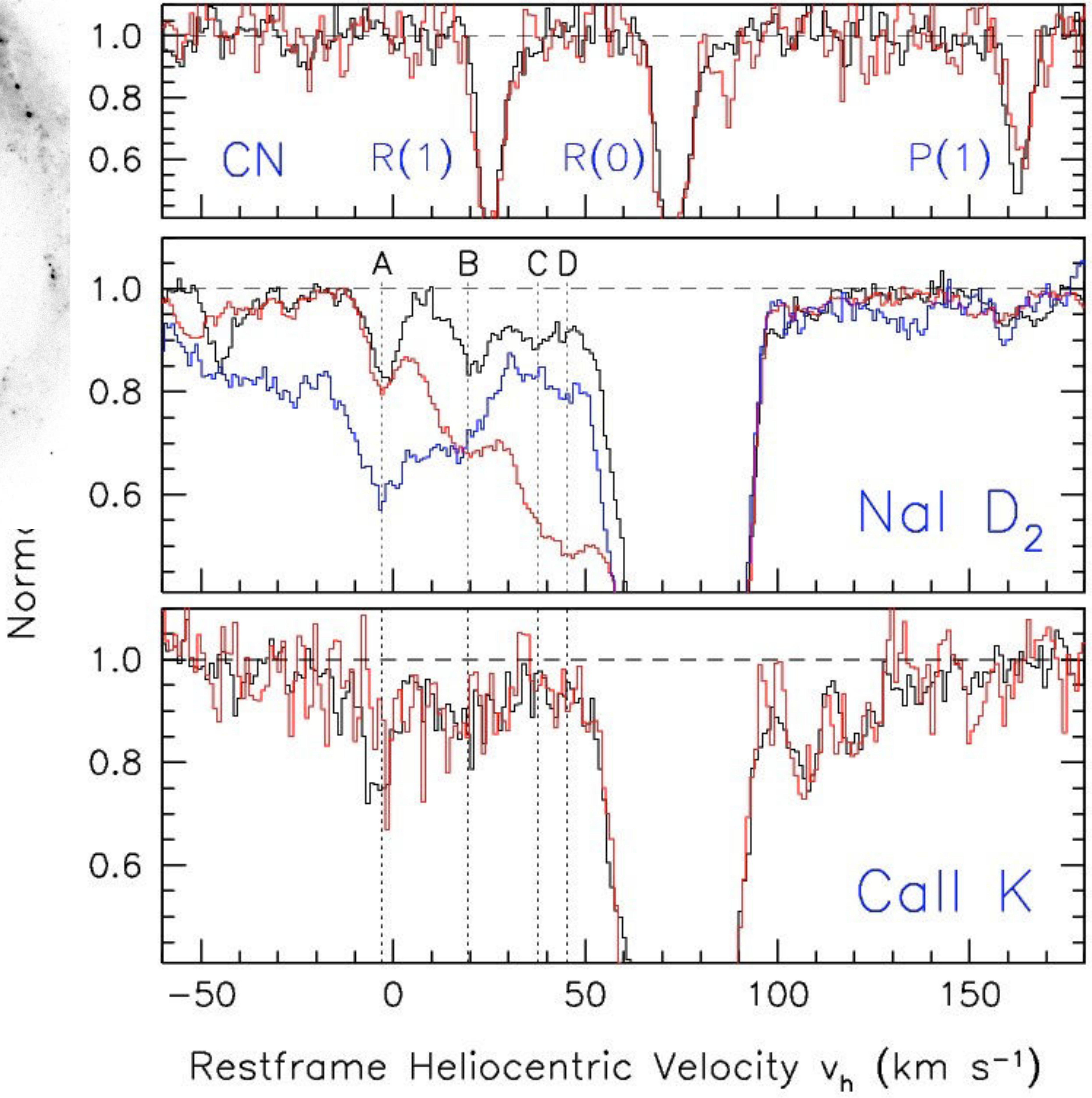
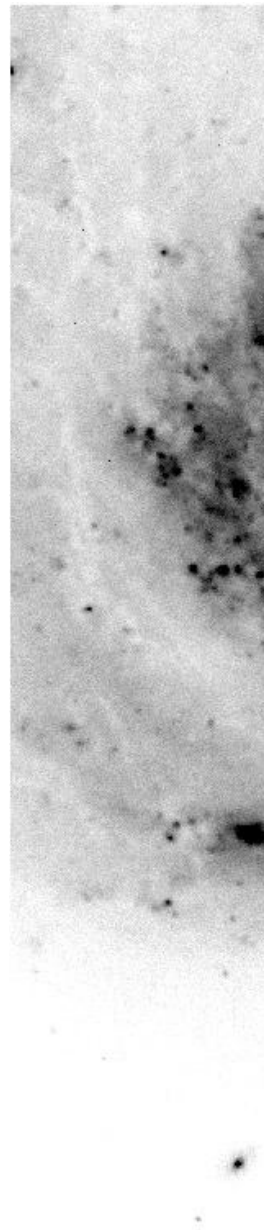
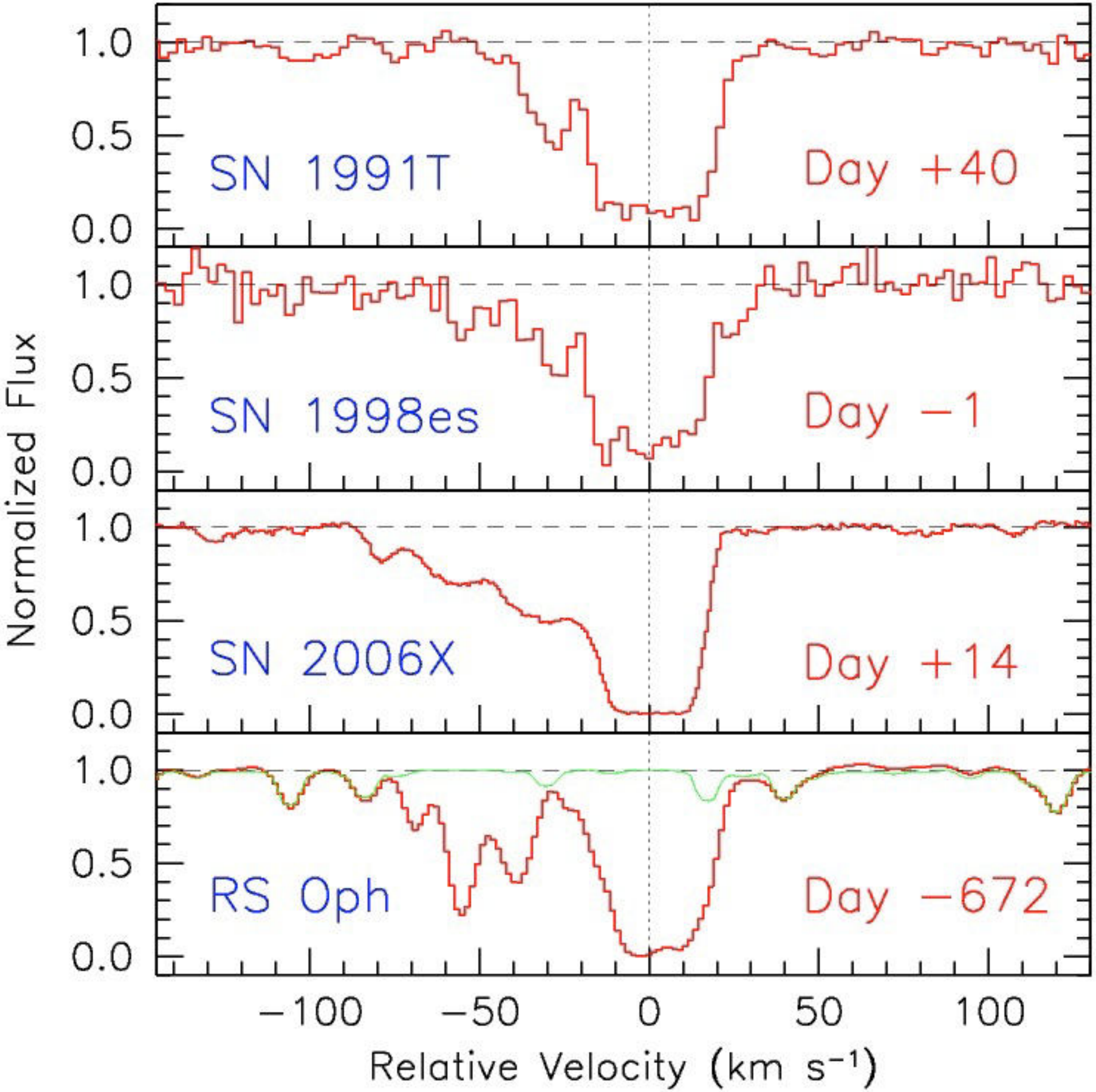


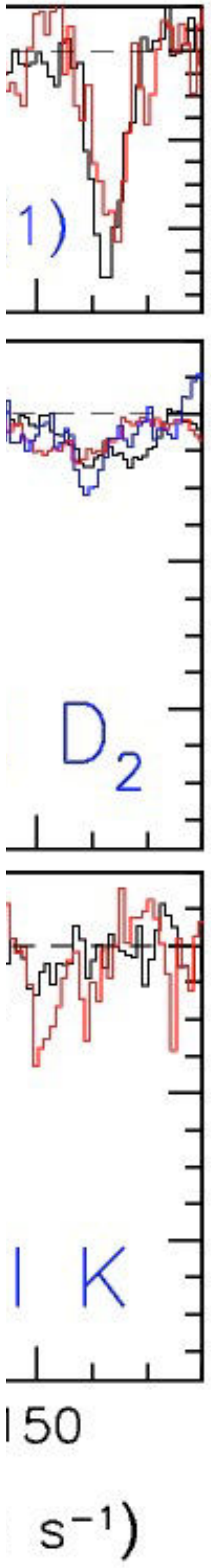


Patat+07





Normalized Flux
SN 1991T
Day +40
SN 1998es
Day −1
SN 2006X
Day +14
RS Oph
Day −672
Relative Velocity (km s⁻¹)



D2

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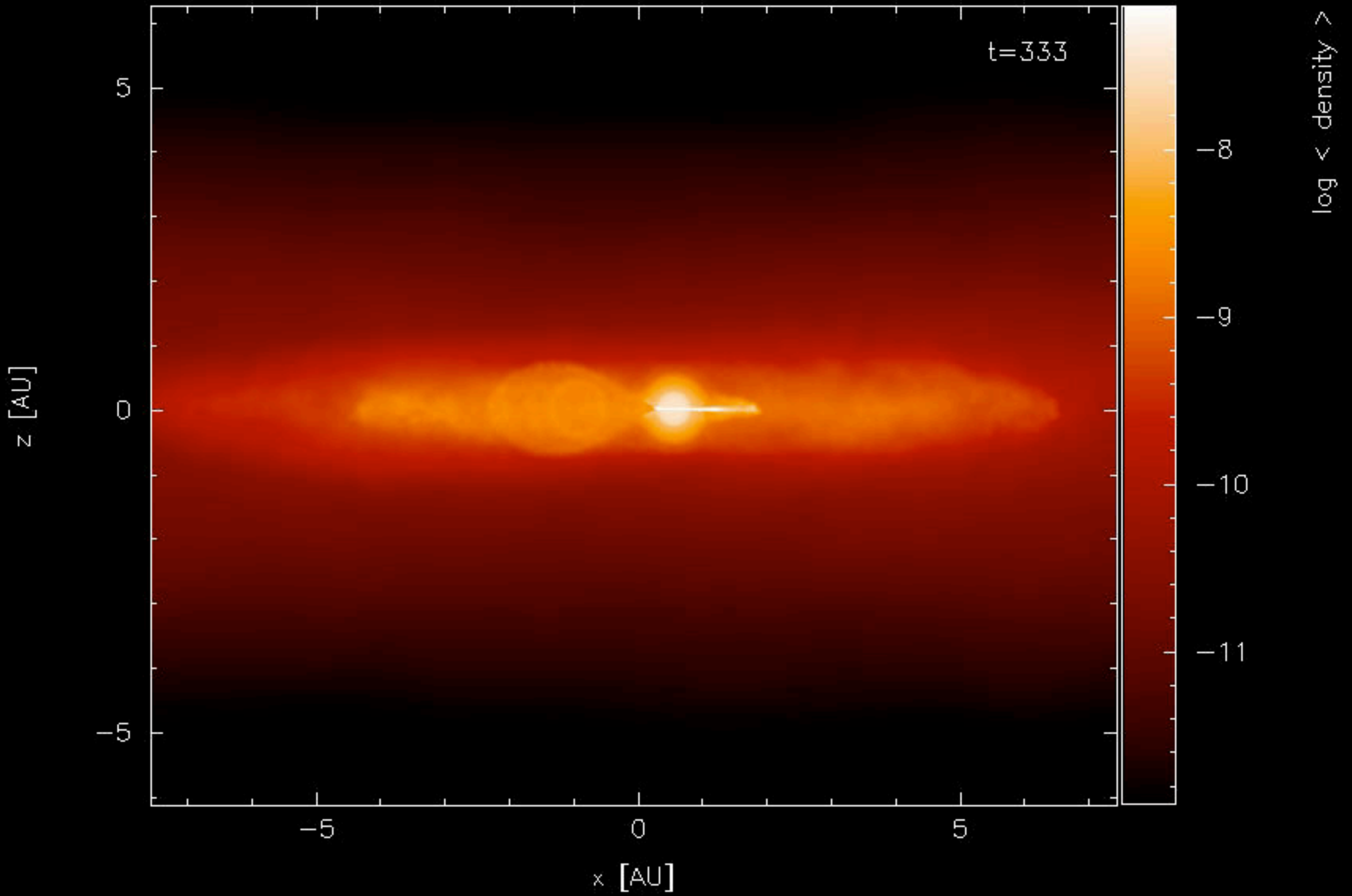
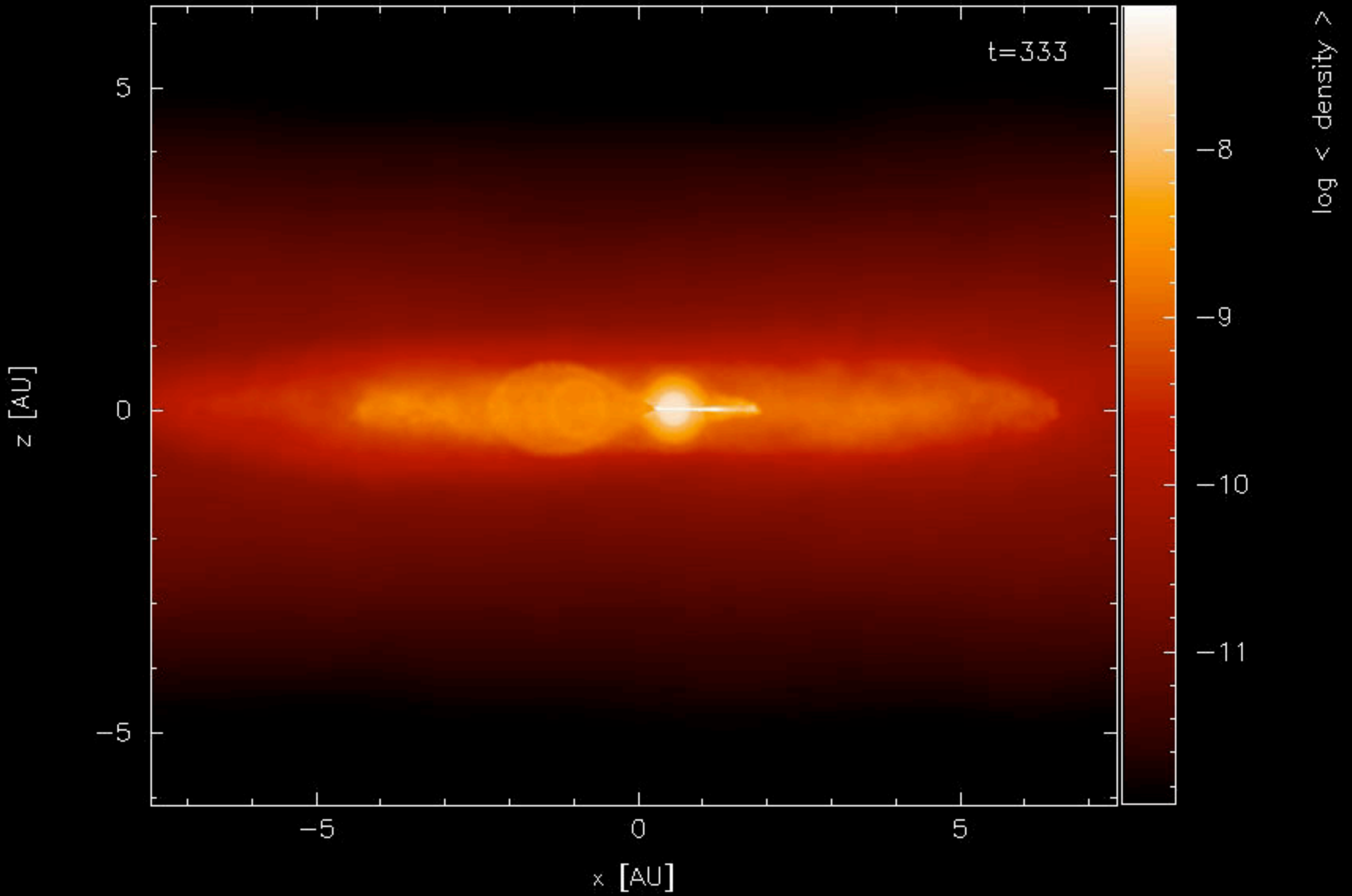


S. Mohamed, 2010



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- It has the advantage of “clearing” the immediate surroundings, and still leave material to be seen in absorption.

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Kerzendorf+
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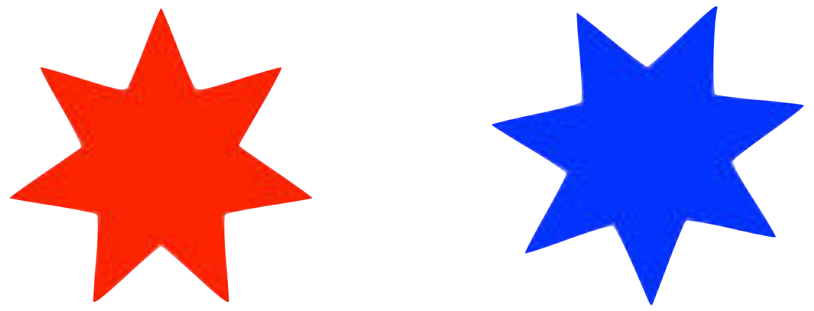

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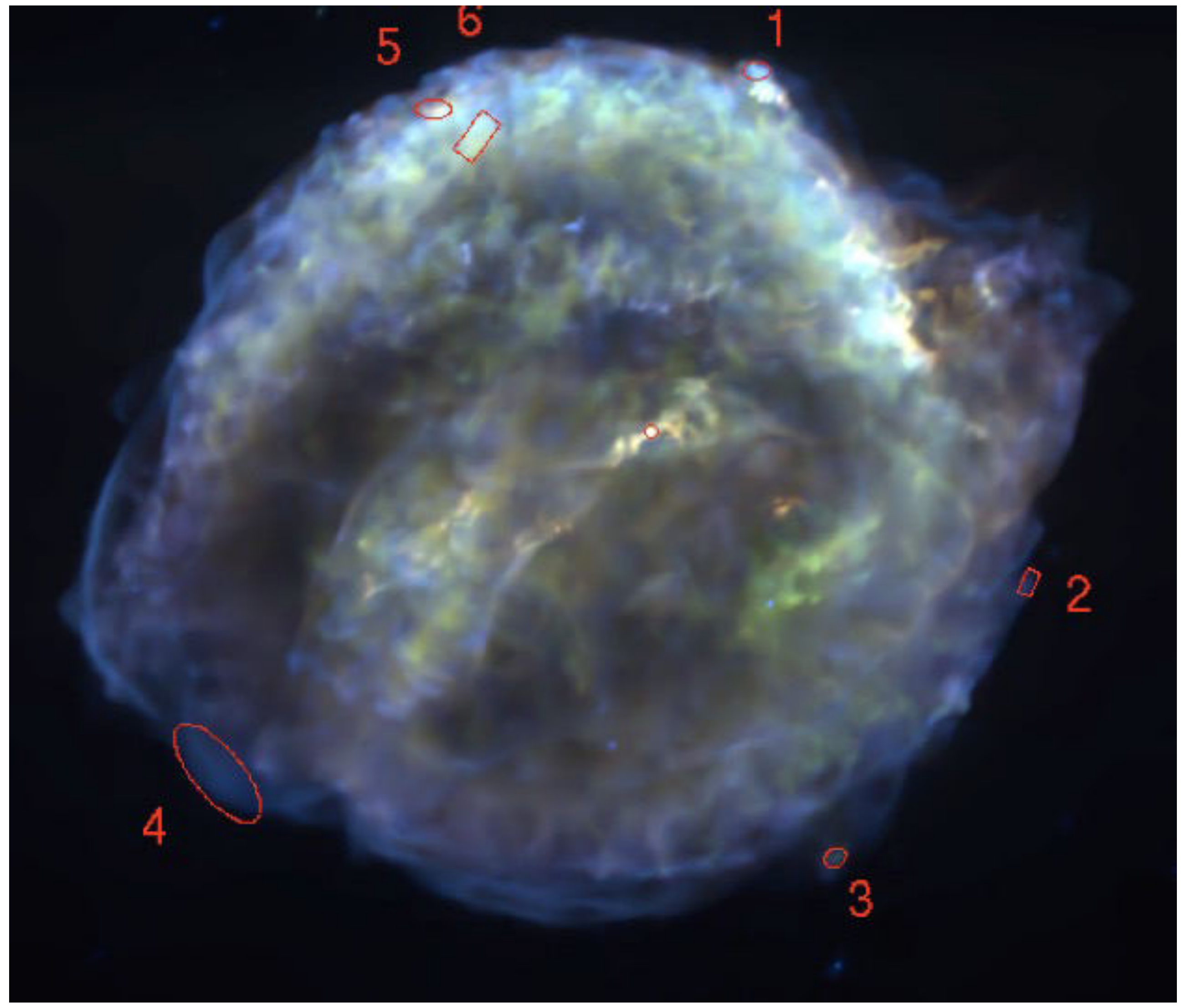

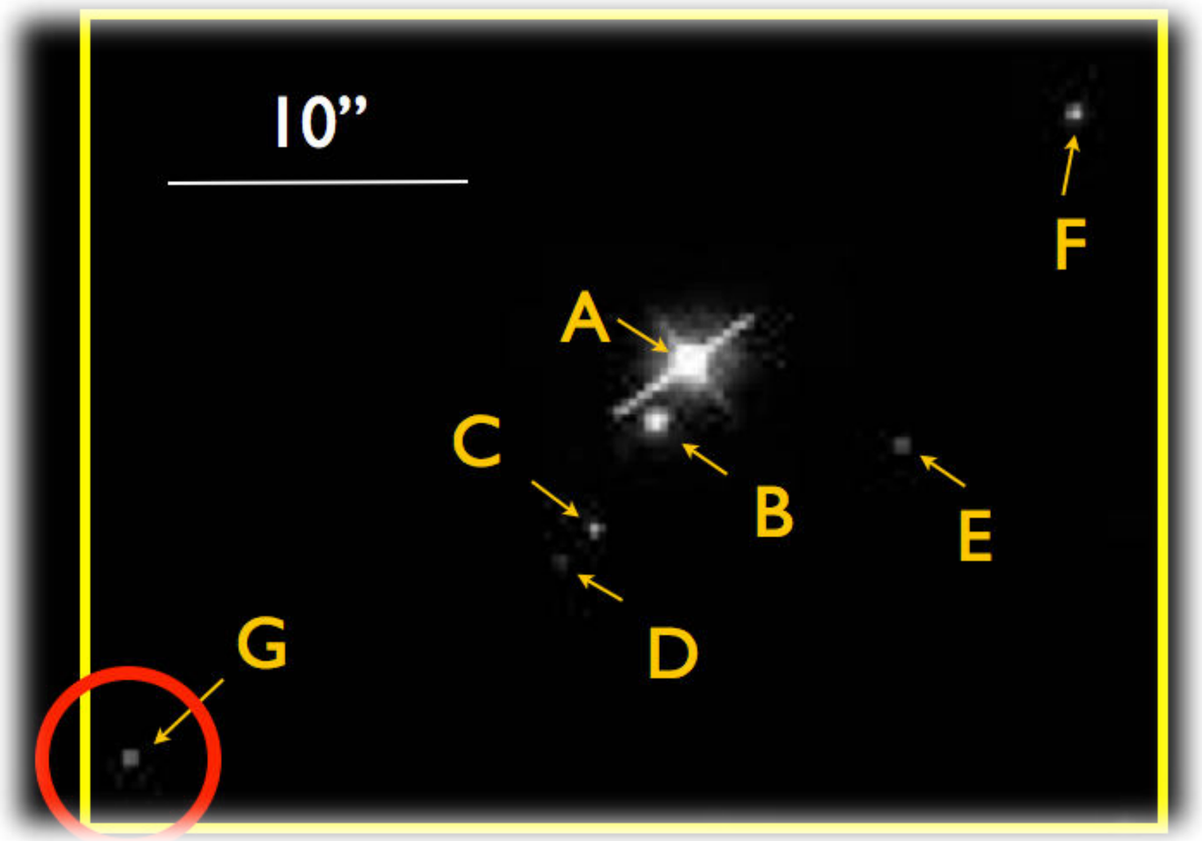

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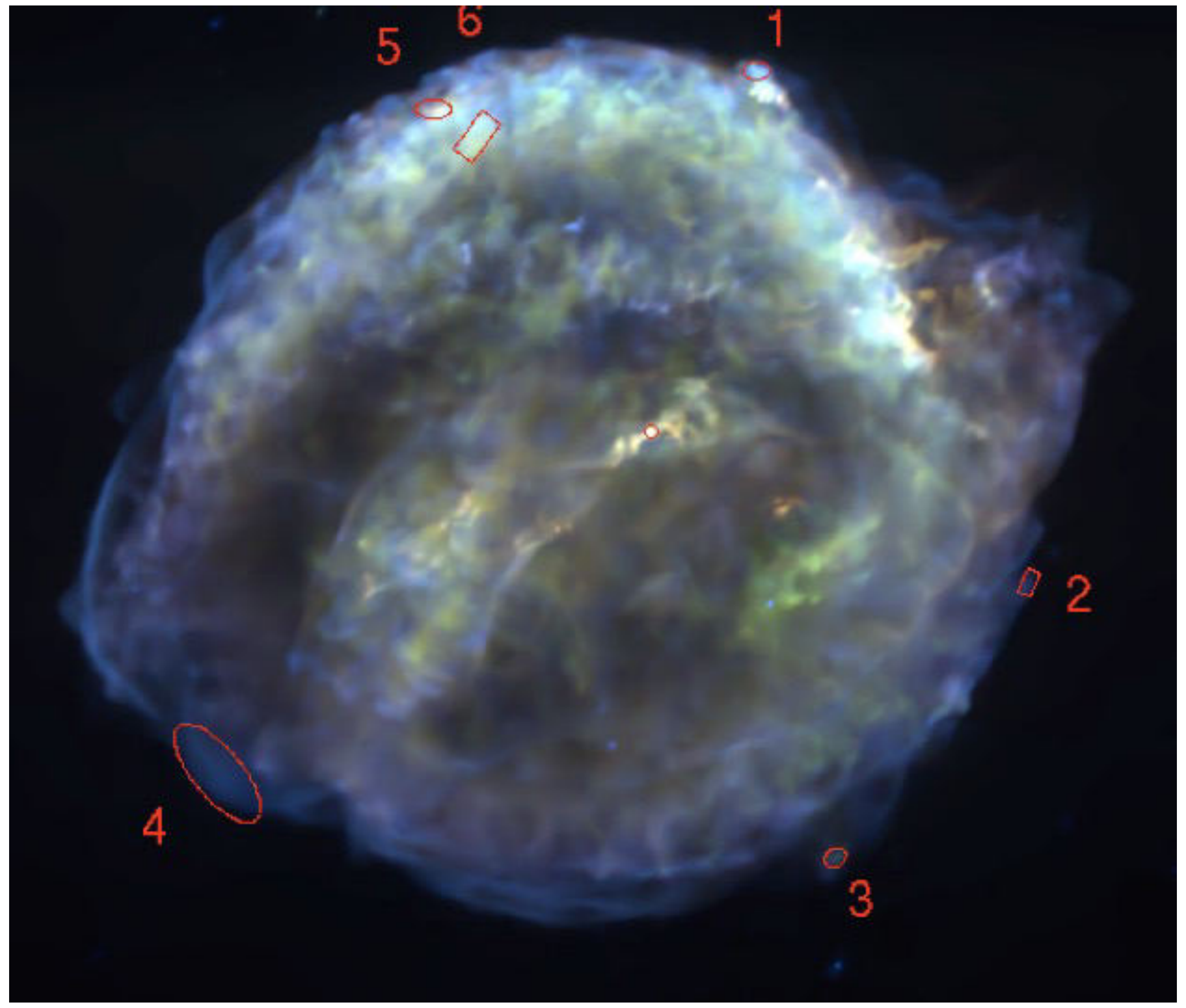

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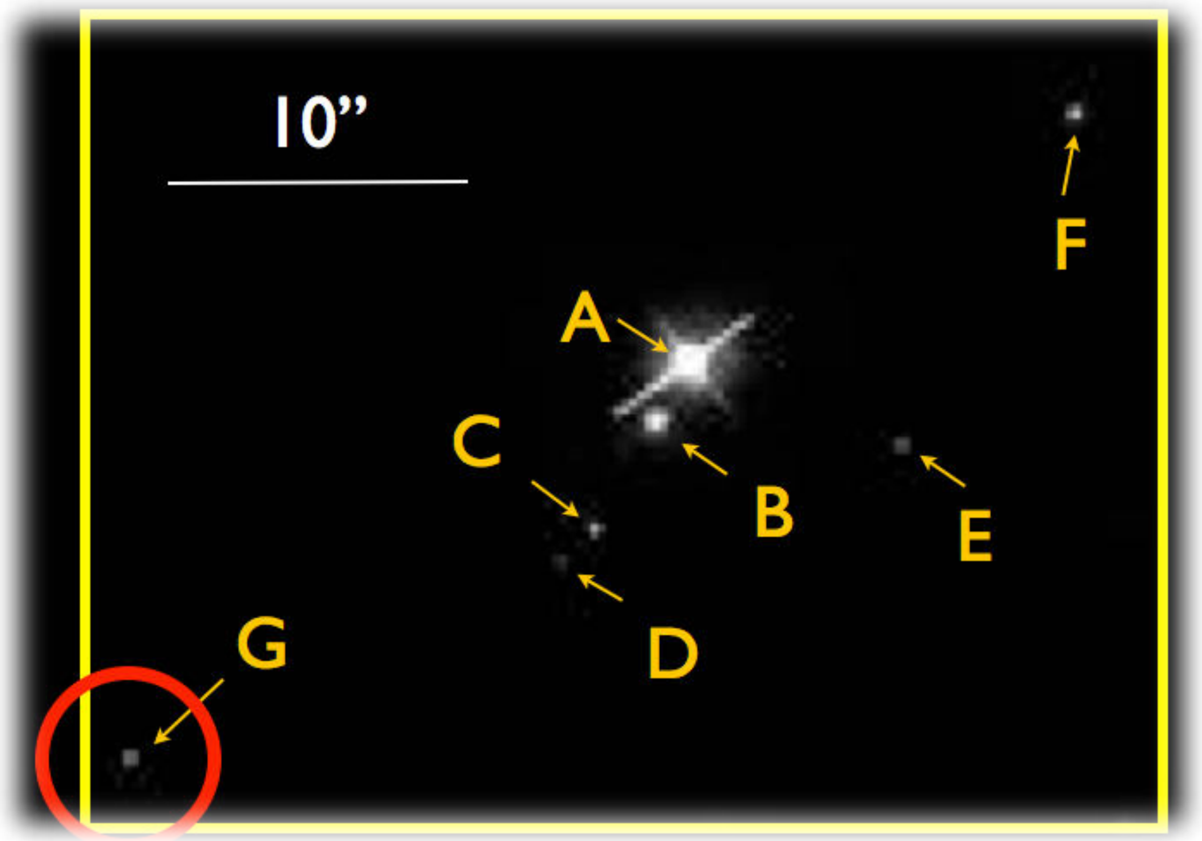

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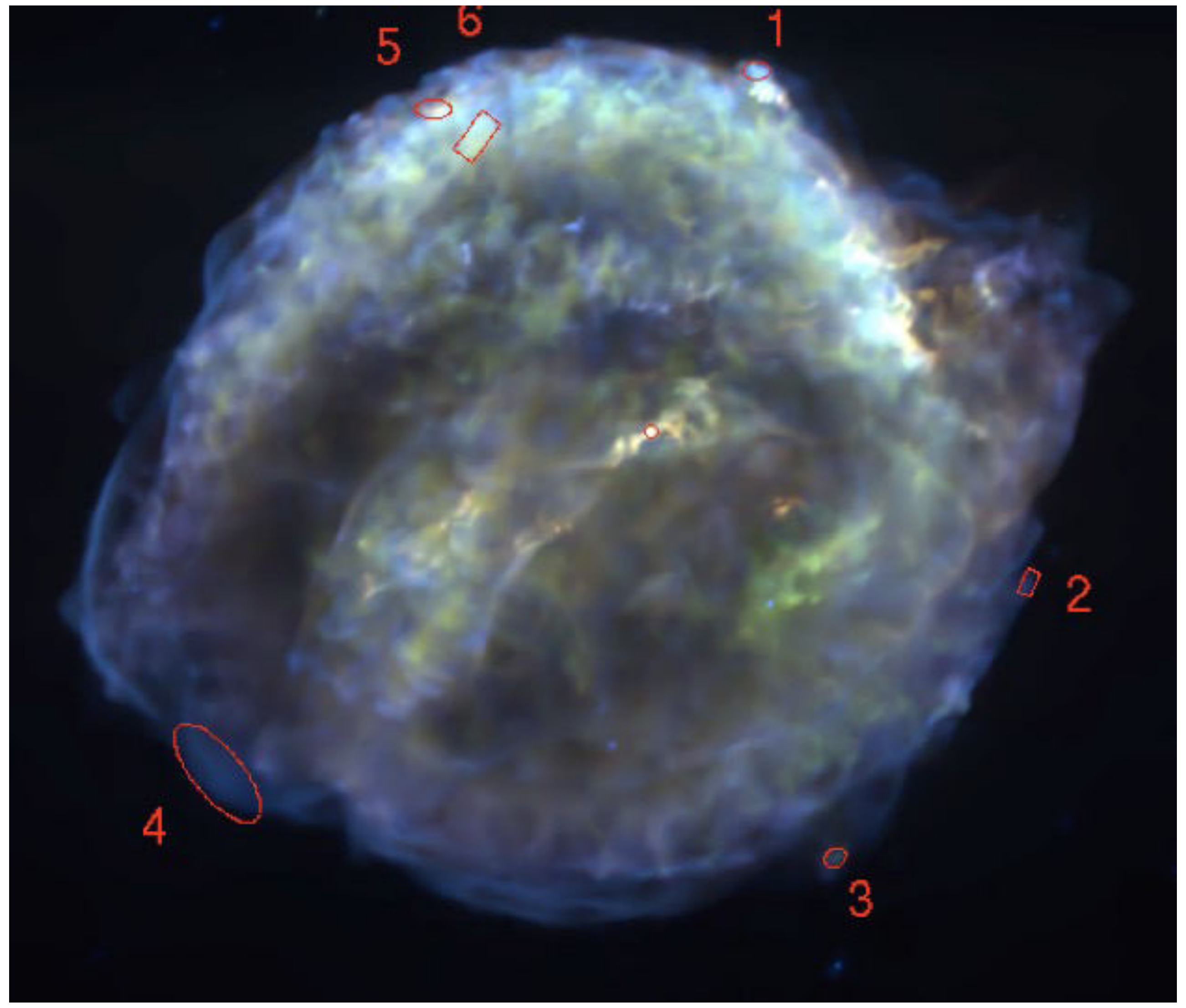

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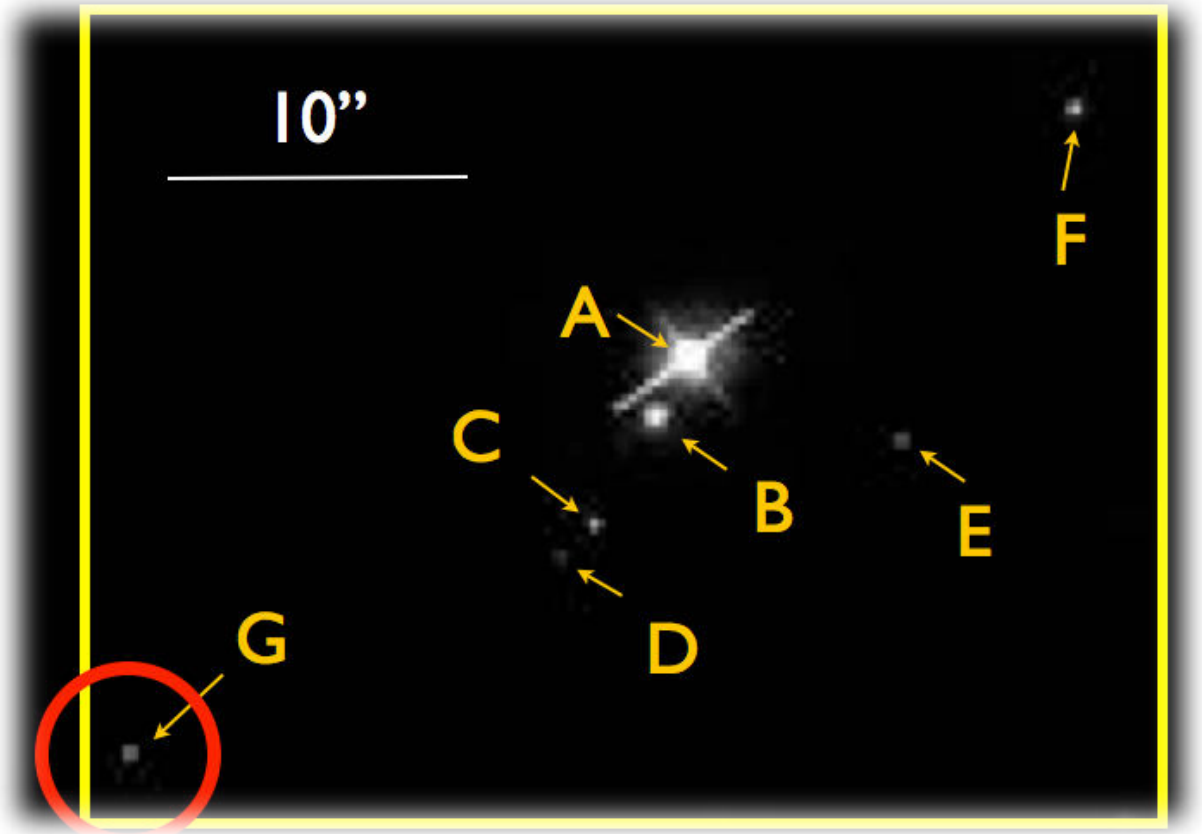

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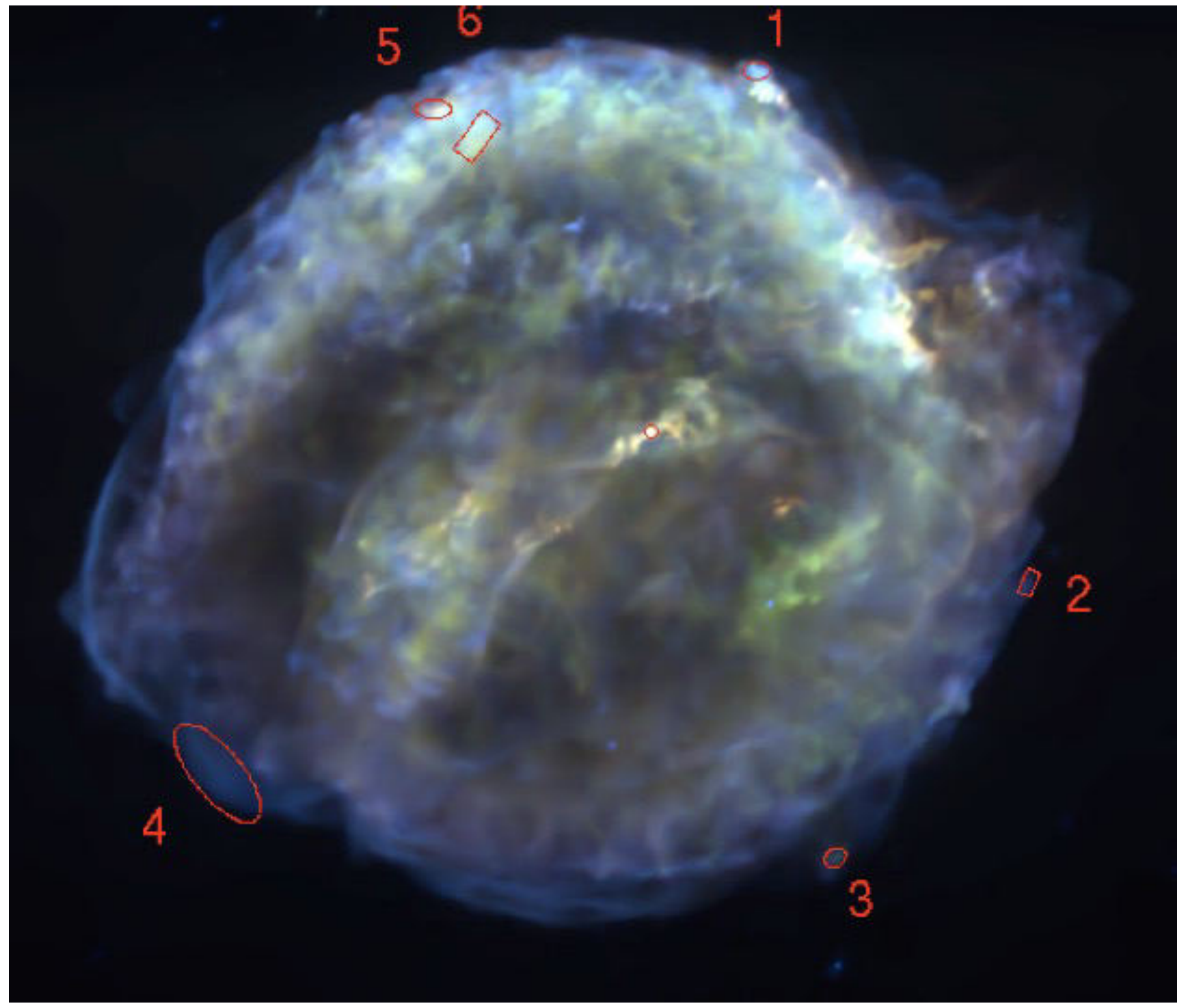

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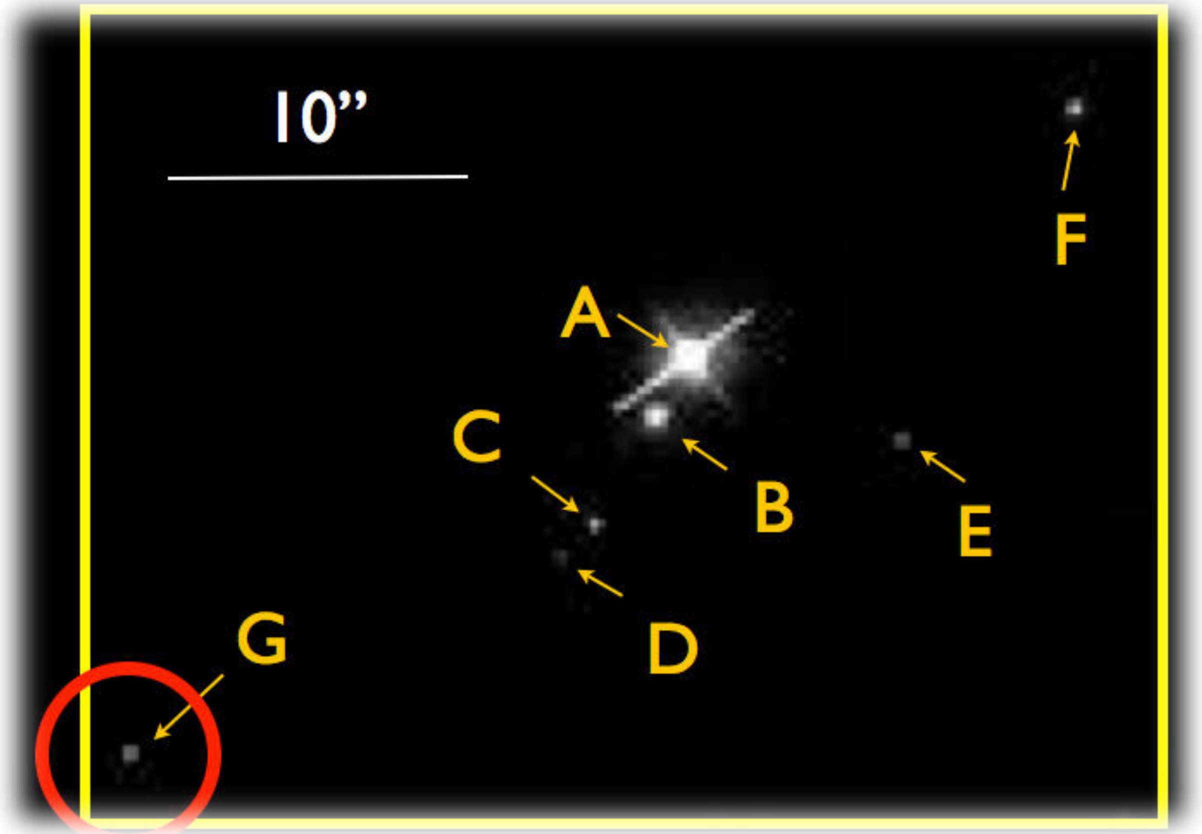

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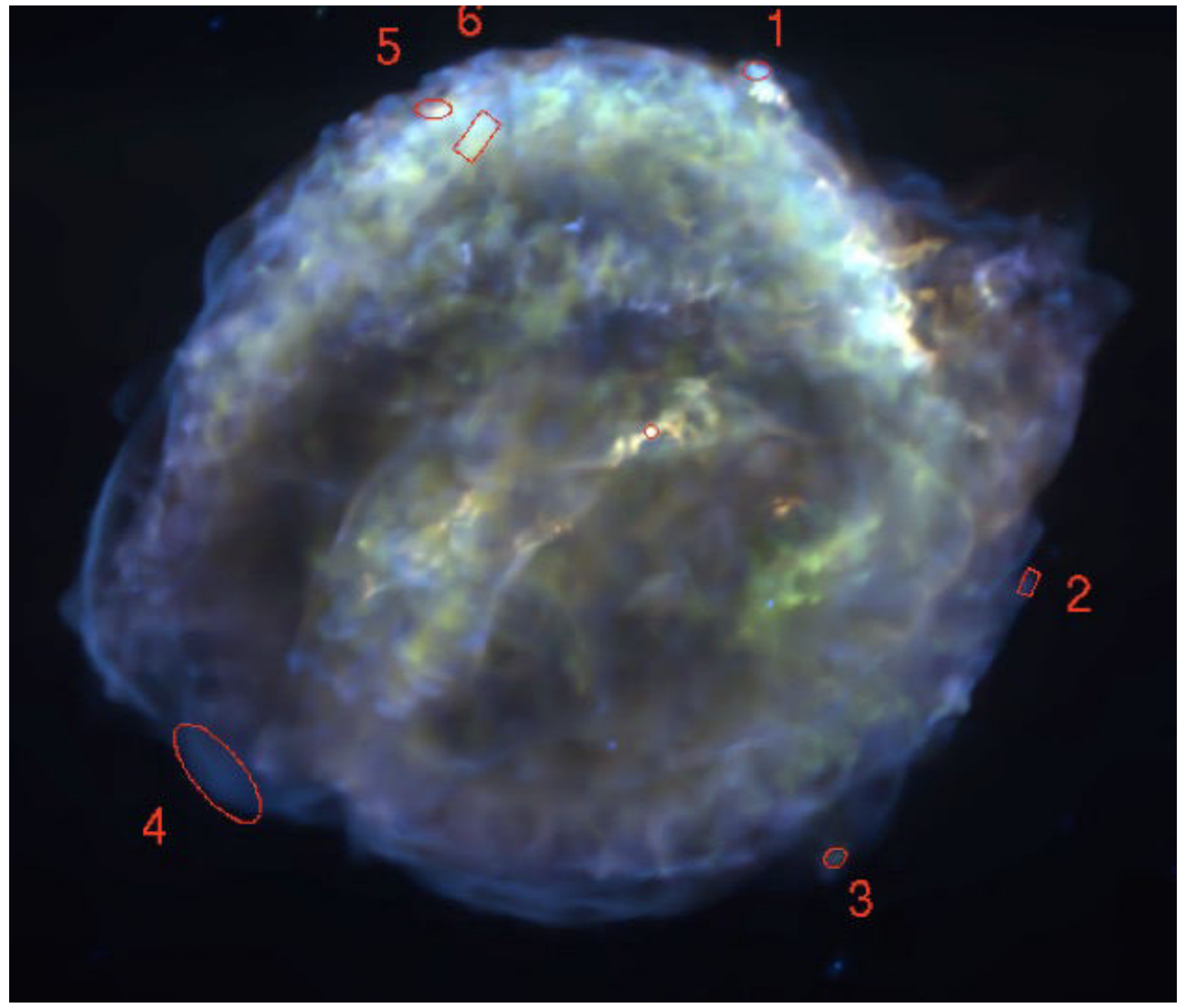

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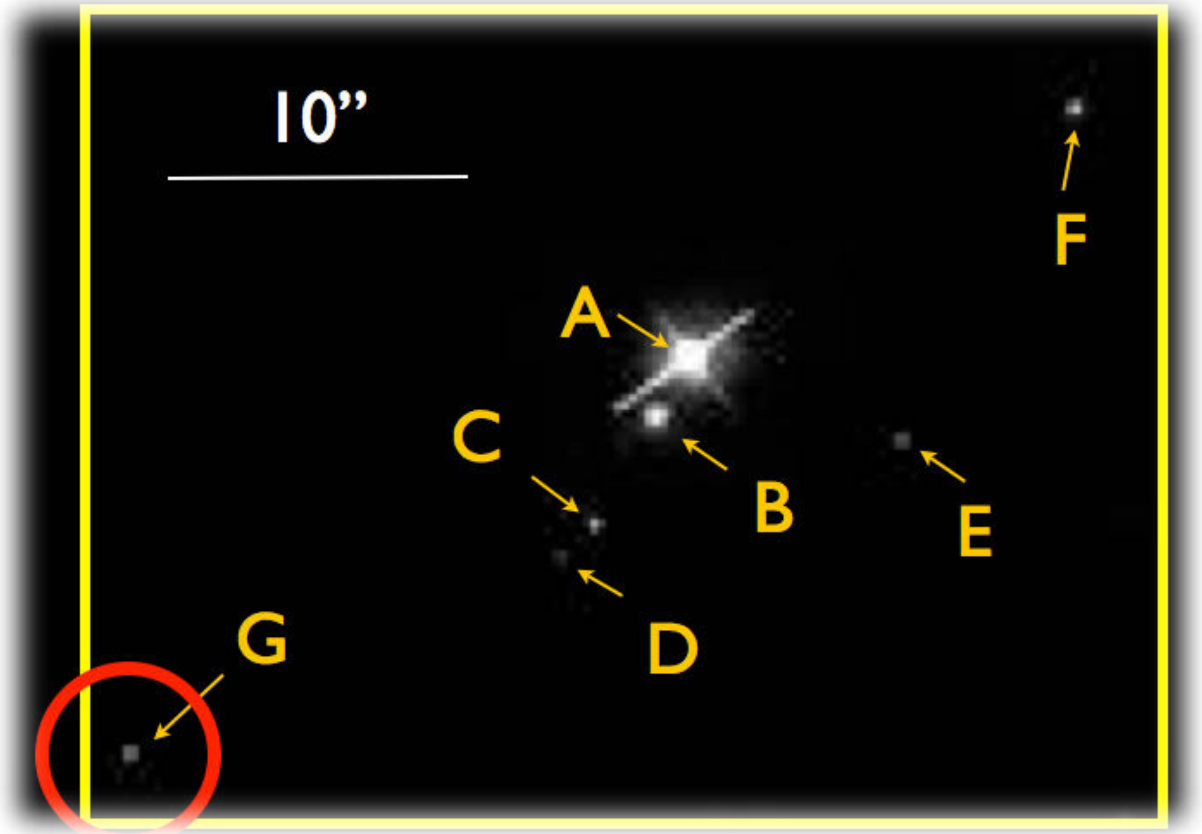

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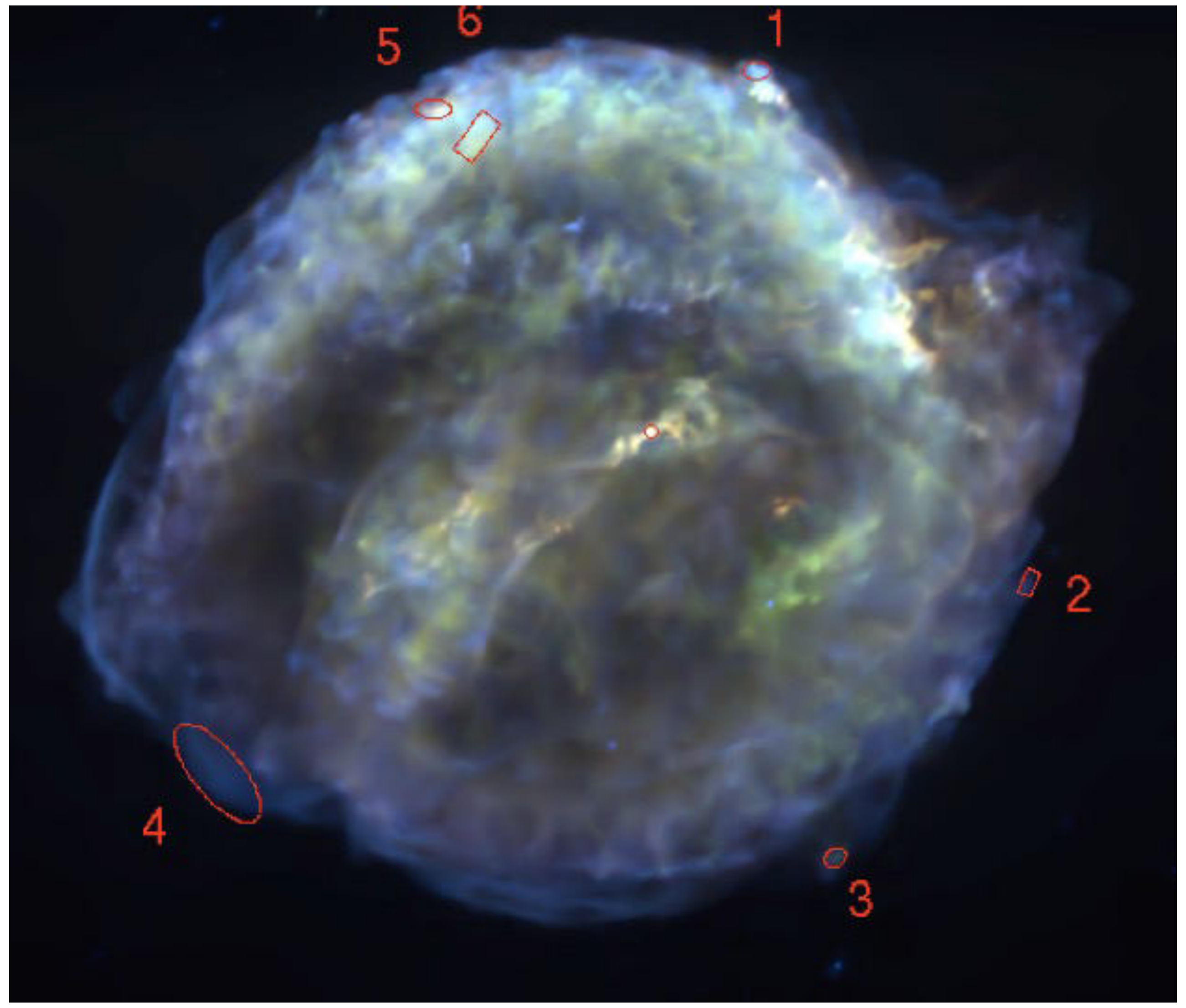

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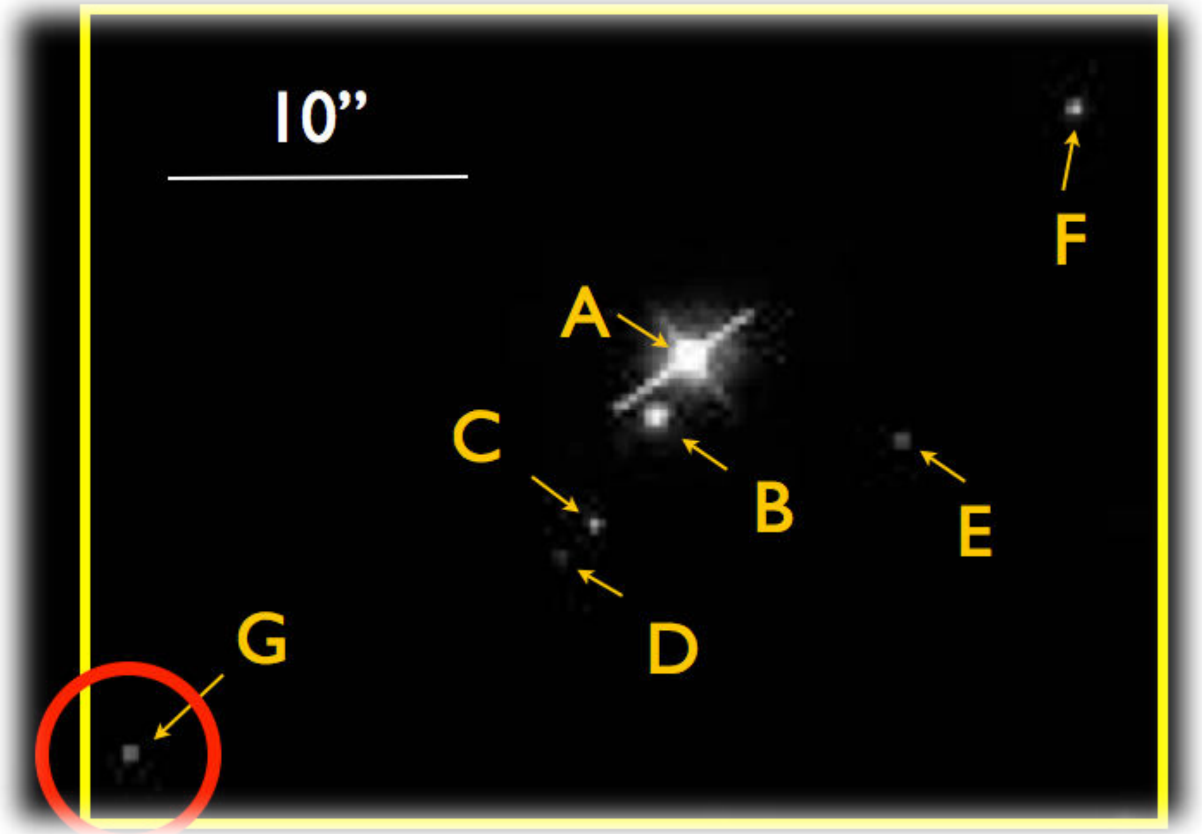

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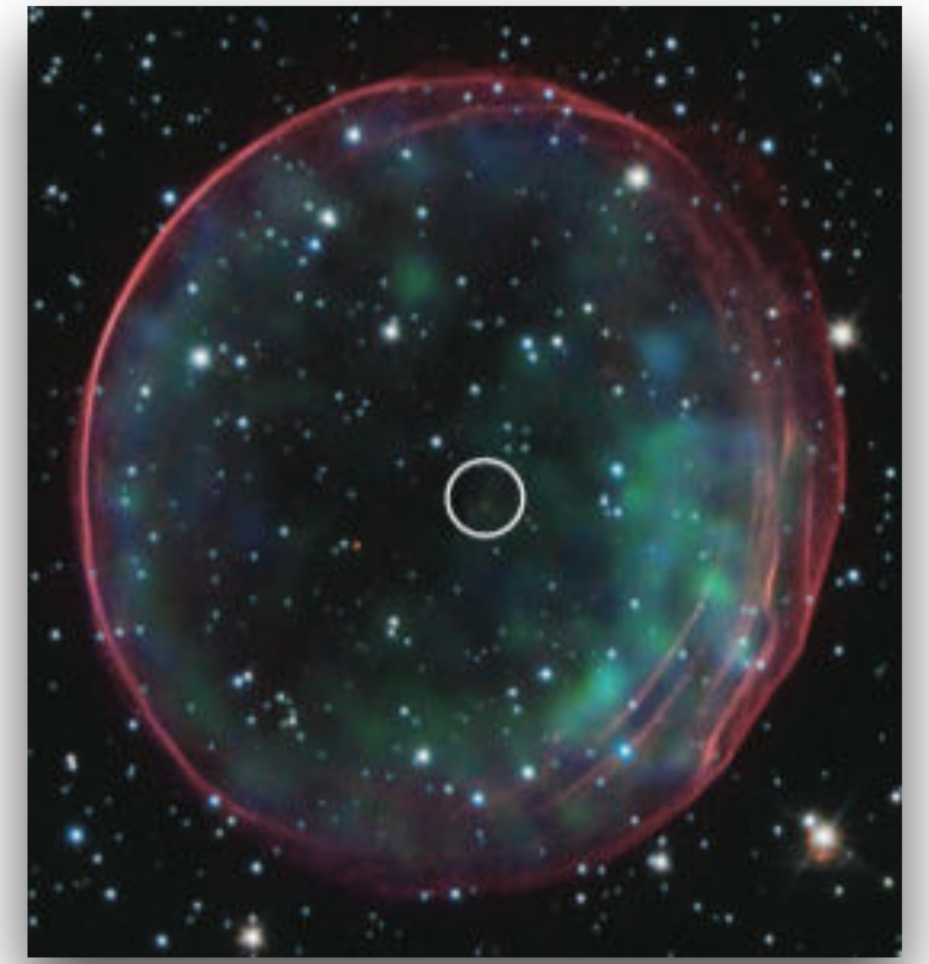

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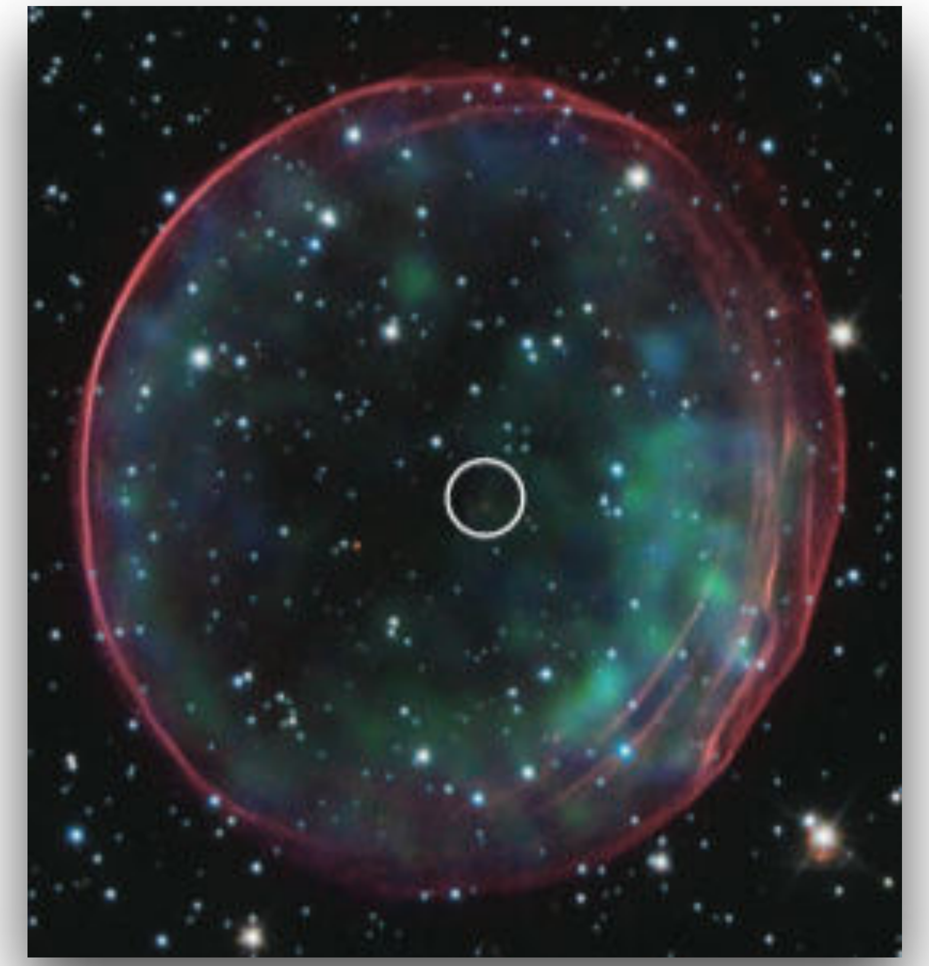

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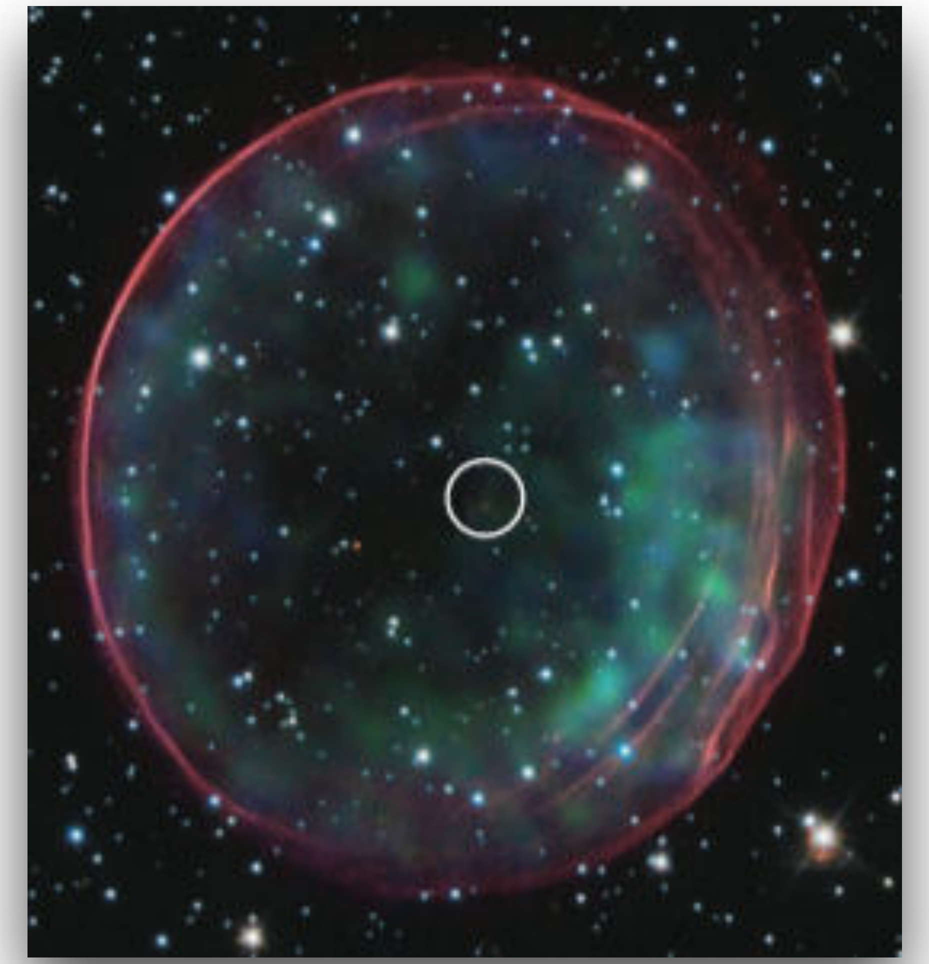

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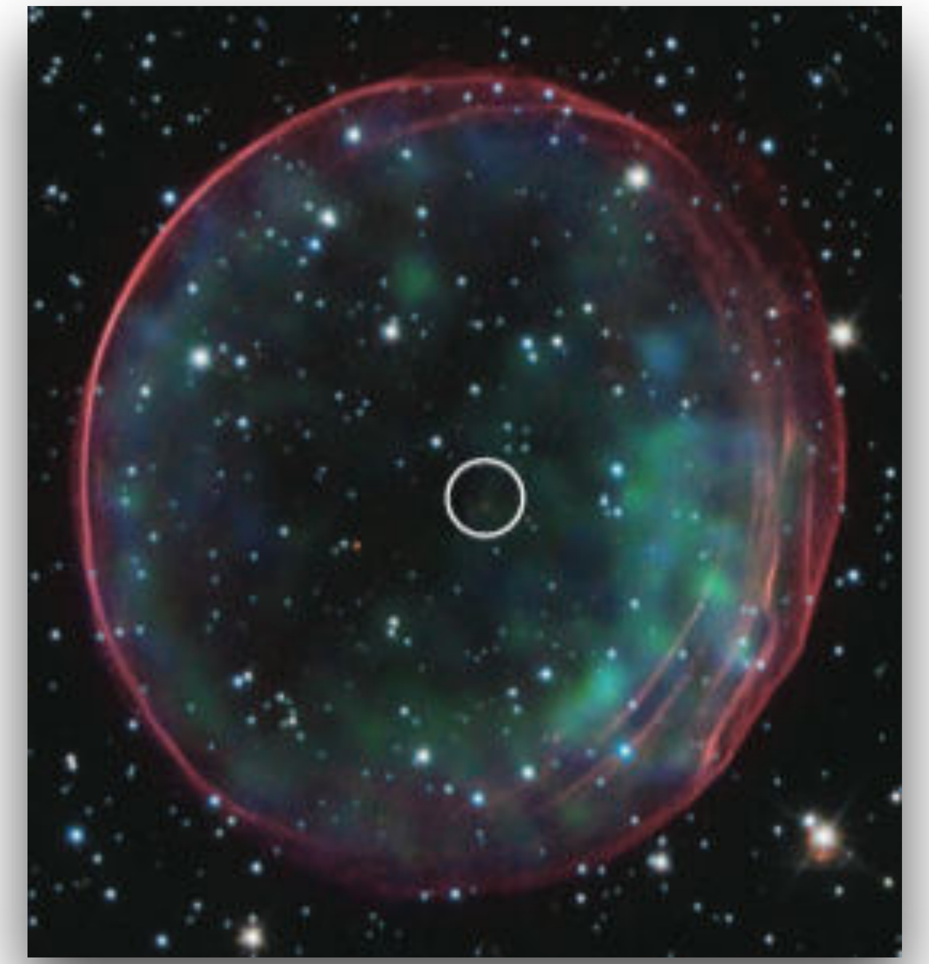

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$$r(t) = \int_0^t SFR(t - t')DTD(t')\,dt'$$

so that different DTDs produced by BPS (or parameterised models) can be compared to the observed rates.

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- It remains to be seen whether this explains the bulk of normal Type Ia in terms of observed properties.

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On the Progenitors of Type Ia Supernovae☆

Mario Livio[1,2], Paolo Mazzali[2,3]

2018

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We review all the models proposed for the progenitor systems of Type Ia supernovae and discuss the strengths and weaknesses of each scenario when confronted with observations. We show that all scenarios encounter at least a few serious difficulties, if taken to represent a comprehensive model for the progenitors of all Type Ia supernovae (SNe Ia). Consequently, we tentatively conclude that there is probably more than one channel leading SNe Ia. While the single-degenerate

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- We gained quite some insights, though, and we managed to change our minds quite a bit

A clear-cut case?

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Single Degenerate

- Systems like RS Oph (WD+RG) have periods of 100s of days, separations of 100s of R_{sun}
- Very weak GW signal (?) during accretion
- ~No GW signal at explosion time (it's a sphere!)

Double Degenerate

- The WDs have to get very close (~0.01 R_{sun})
- P of 100s to ~10s at merger time
- The GW signal falls in the <~ 0.1Hz region
- If we do not see this signal, well, then the DD scenario is ruled out.

SNIa and GWs

$(WD)^4$ = **W**hat **D**o **W**e **D**o **W**ith **D**ouble **W**hite **D**warfs

$(WD)^4$ = What Do We Do With Double White Dwarfs

The comparison between the known rate of SNIa and the rate of GW sources with the properties expected for the merging of DD systems is probably one of the most promising tools to solve this key question.

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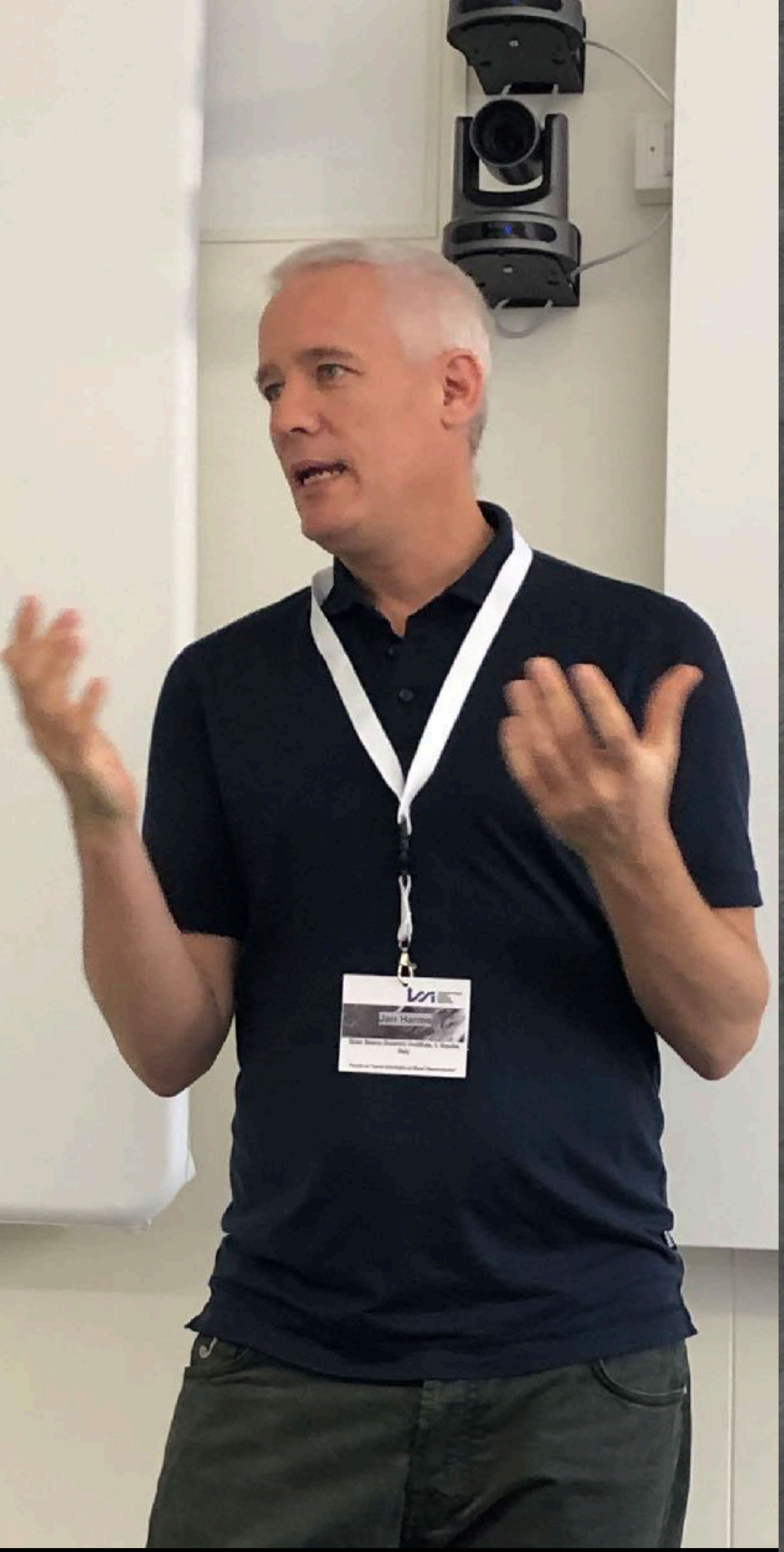
P_h (s)	$f_{GW,l}$ (Hz)	$t_{m,h}$ (yr)	N_*
40000	5.0×10^{-5}	1.3×10^{10}	$(7.1\pm1.6)\times10^{7}$
3600	5.6×10^{-4}	2.2×10^{7}	$(1.2\pm0.3)\times10^{5}$
2000	10^{-3}	4.6×10^{6}	$(2.4\pm0.6)\times10^{4}$
200	10^{-2}	9.9×10^{3}	52 ± 12
47	4.3×10^{-2}	200	1.0 ± 0.2



Jan Harms

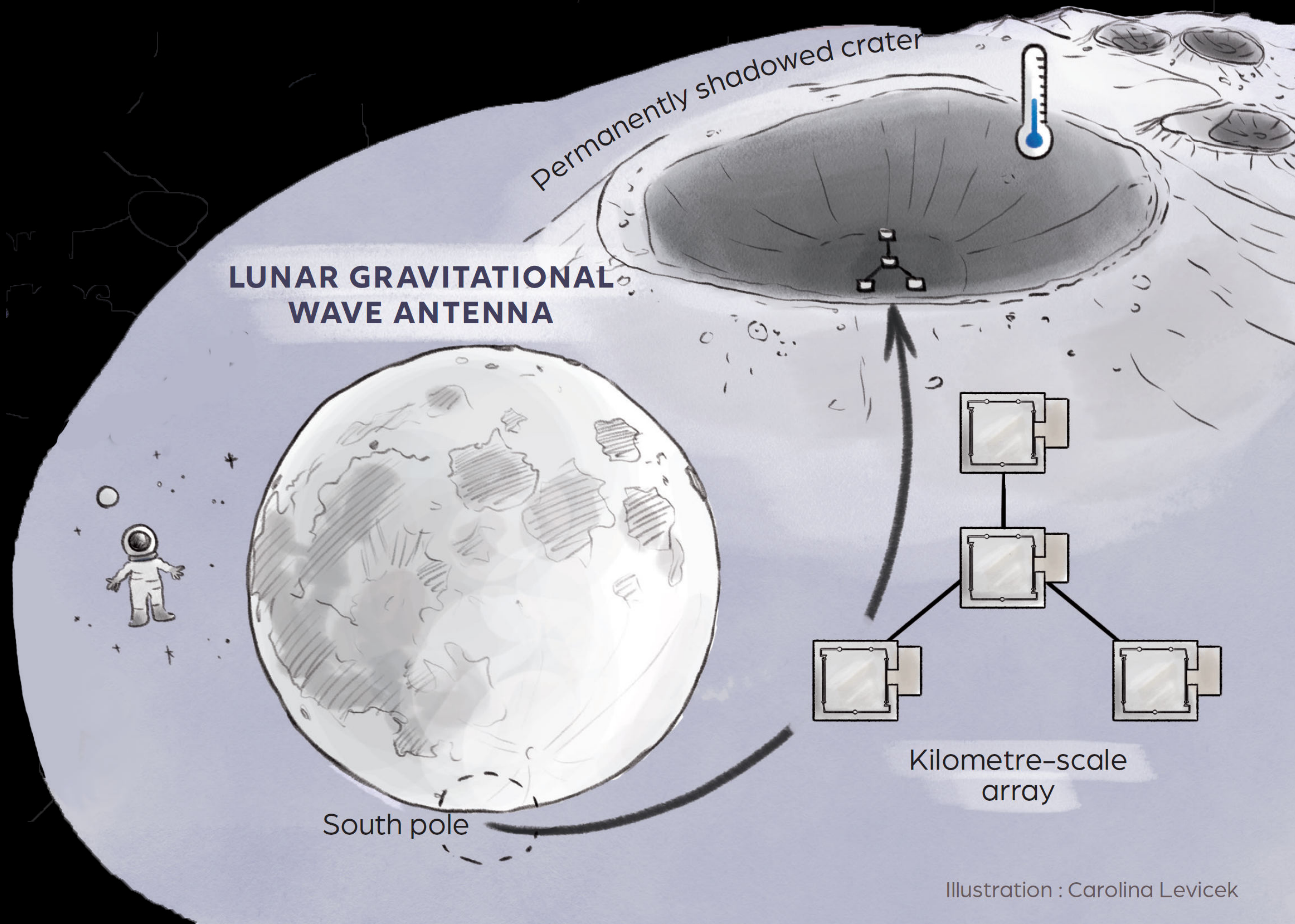


Illustration : Carolina Levicek


0.0° E 0.0° N
1000 km


0.0° E 0.0° N
1000 km

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