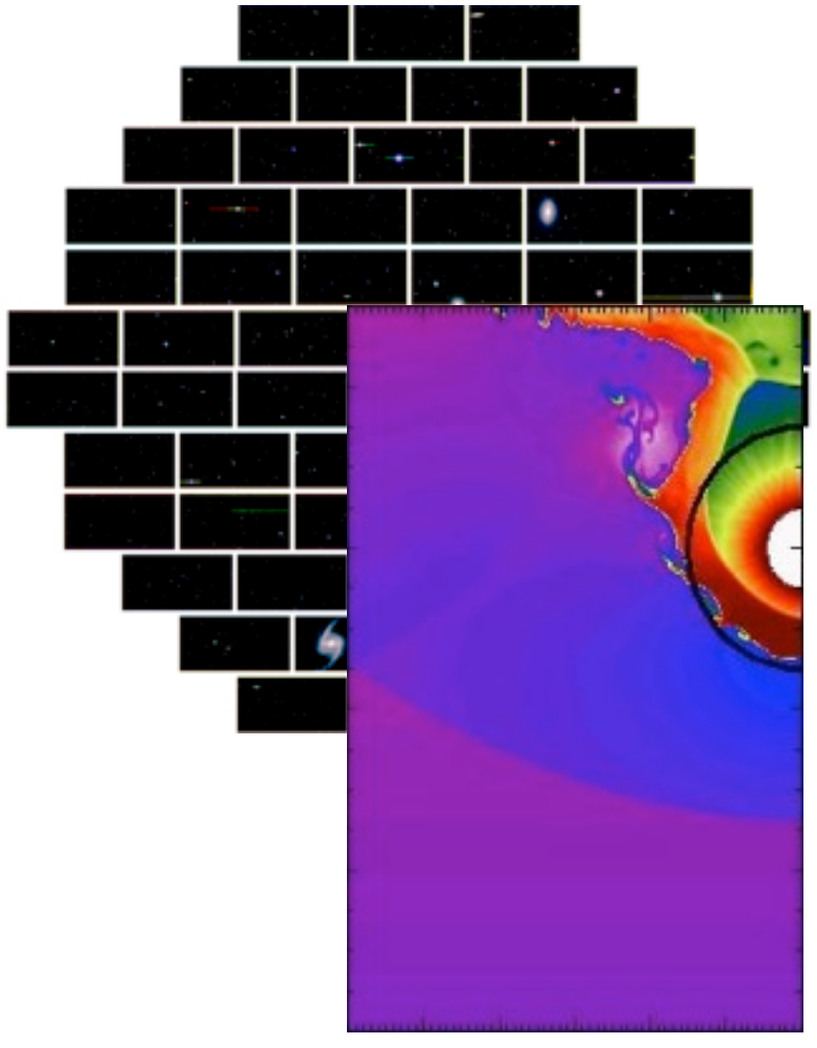
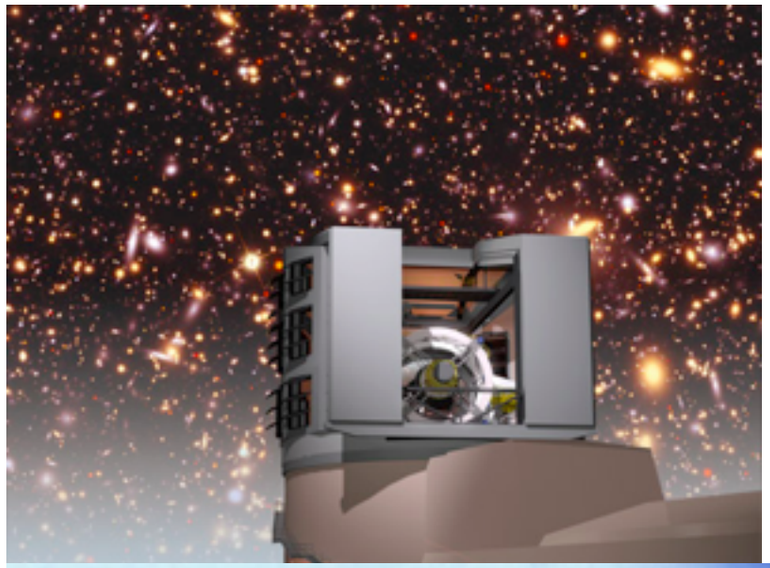
Living with Supernovae





Brian Fields

U. of Illinois

TALENT School, MSU, May 2014

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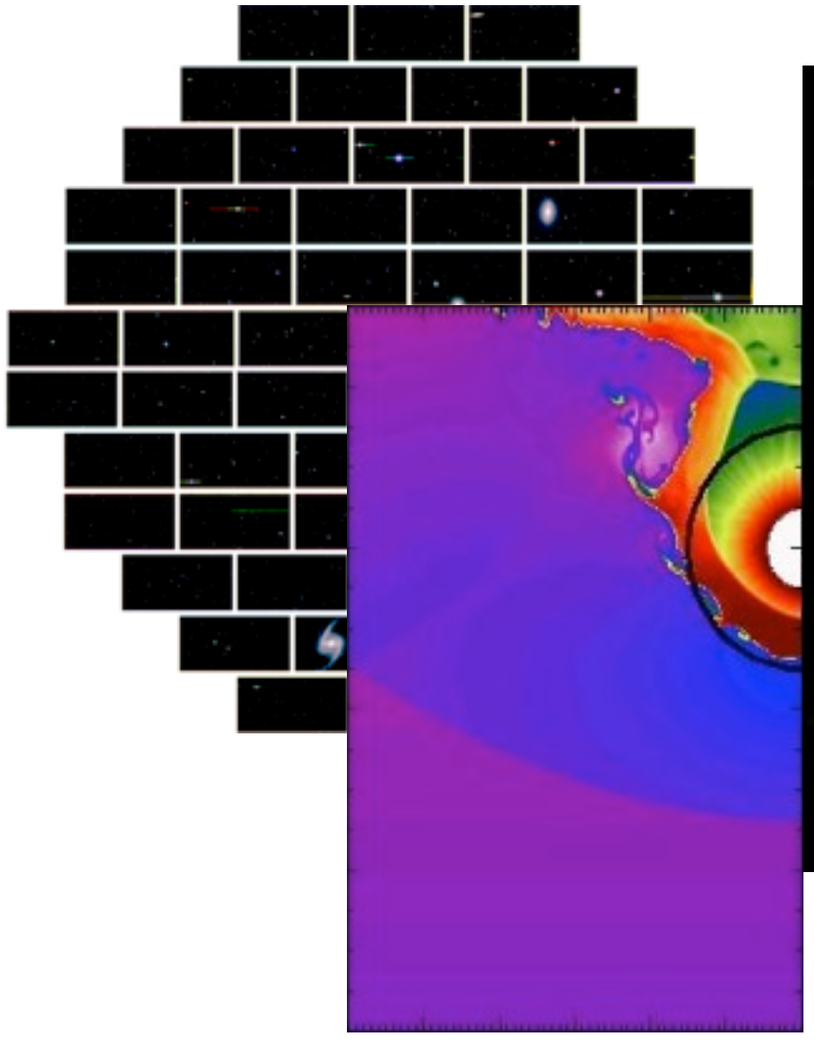

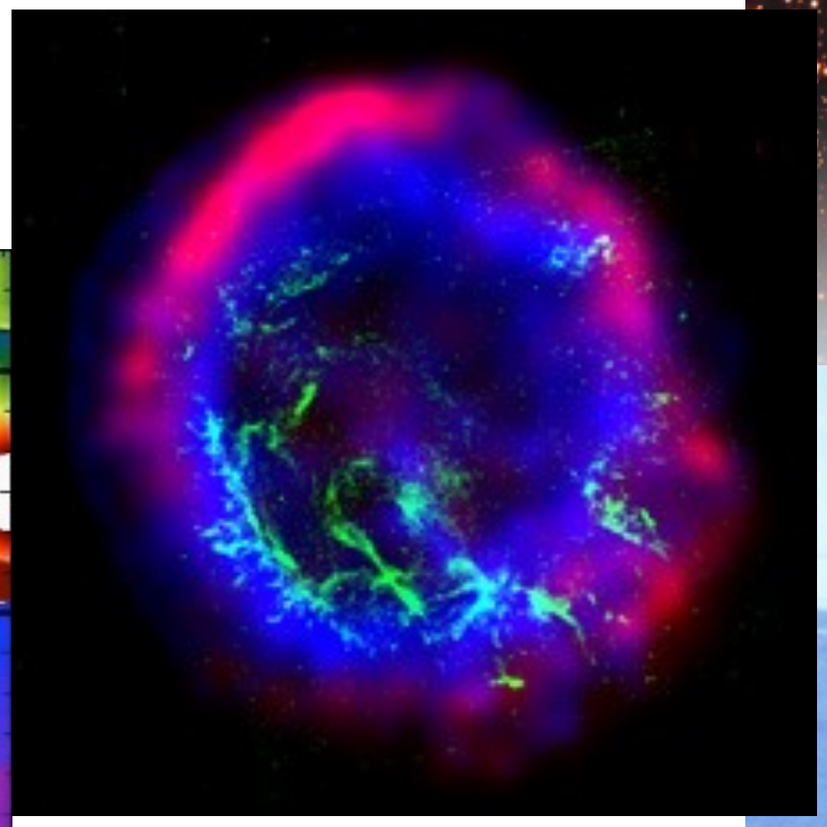

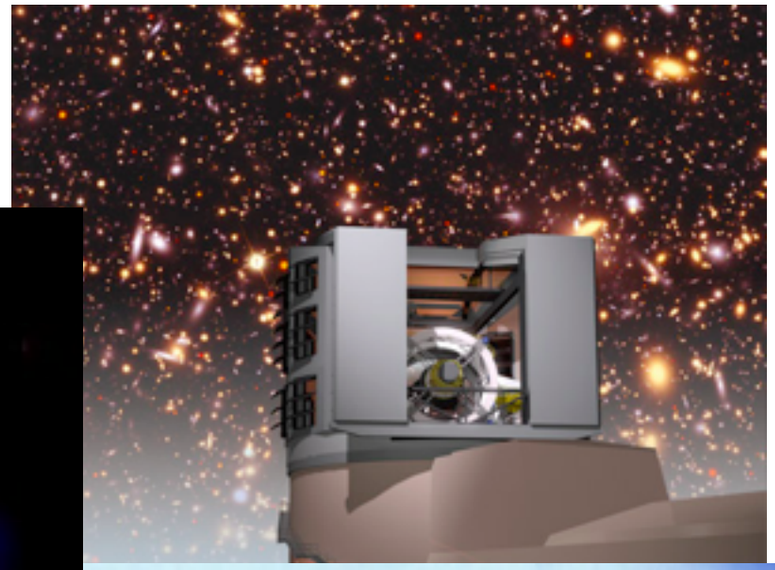

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Supernova Explosions

Core-Collapse Supernovae

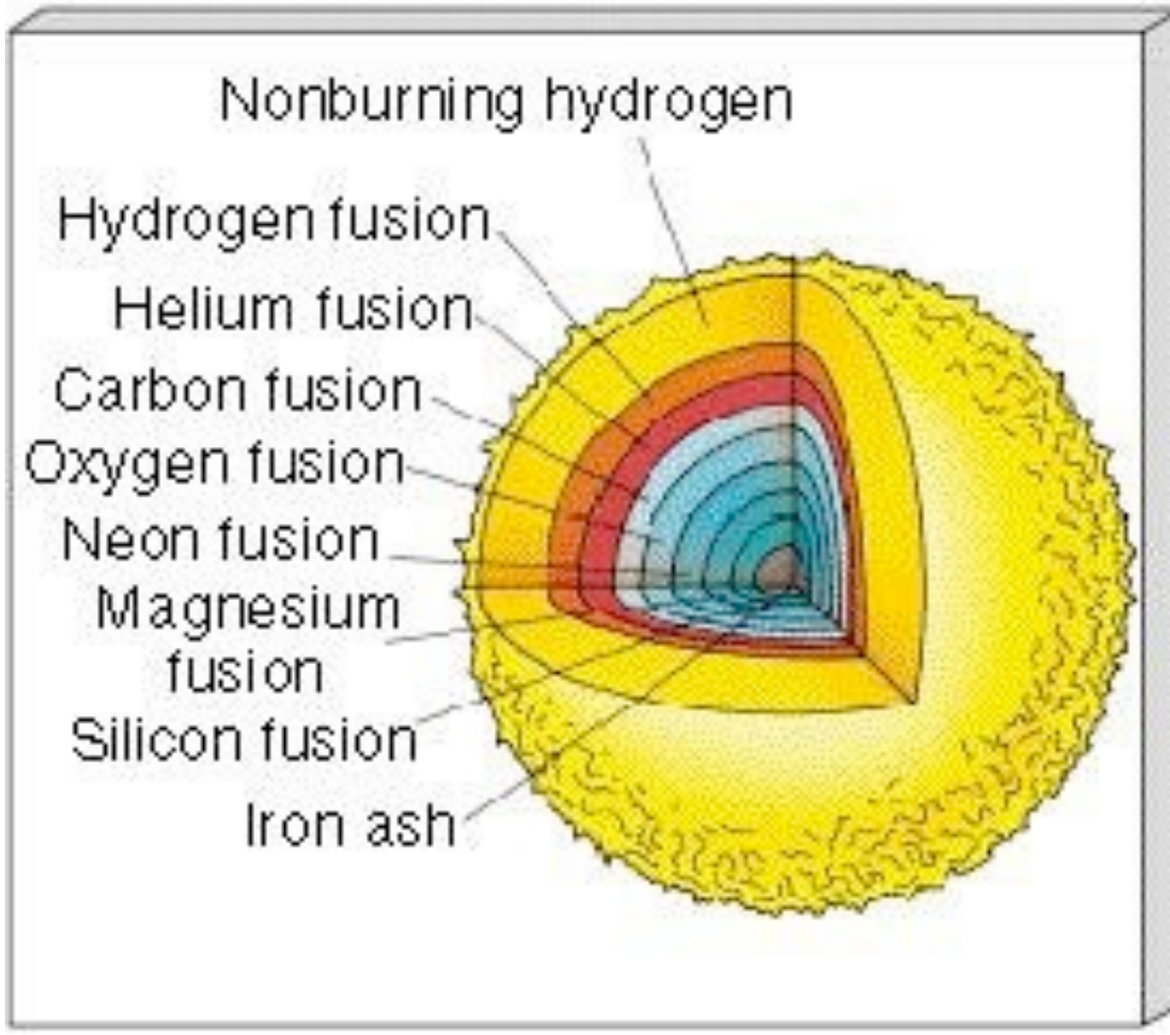
Symphonies of the Fundamental Forces

Core-Collapse Supernovae

Symphonies of the Fundamental Forces

Lives of Massive Stars (> 8-10 M_{sun})

- ★ **Begin burning** $\mathrm{H} \rightarrow \mathrm{He}$
- ★ **Then, at accelerating pace**
  - **repeated cycles of ash ⇨ fuel**
  - **ever-heavier elements in core**
- ★ **"onion skin" structure**



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When core ^{56}Fe: max binding

- ★ **core fusion stops: support by degen e$^-$**
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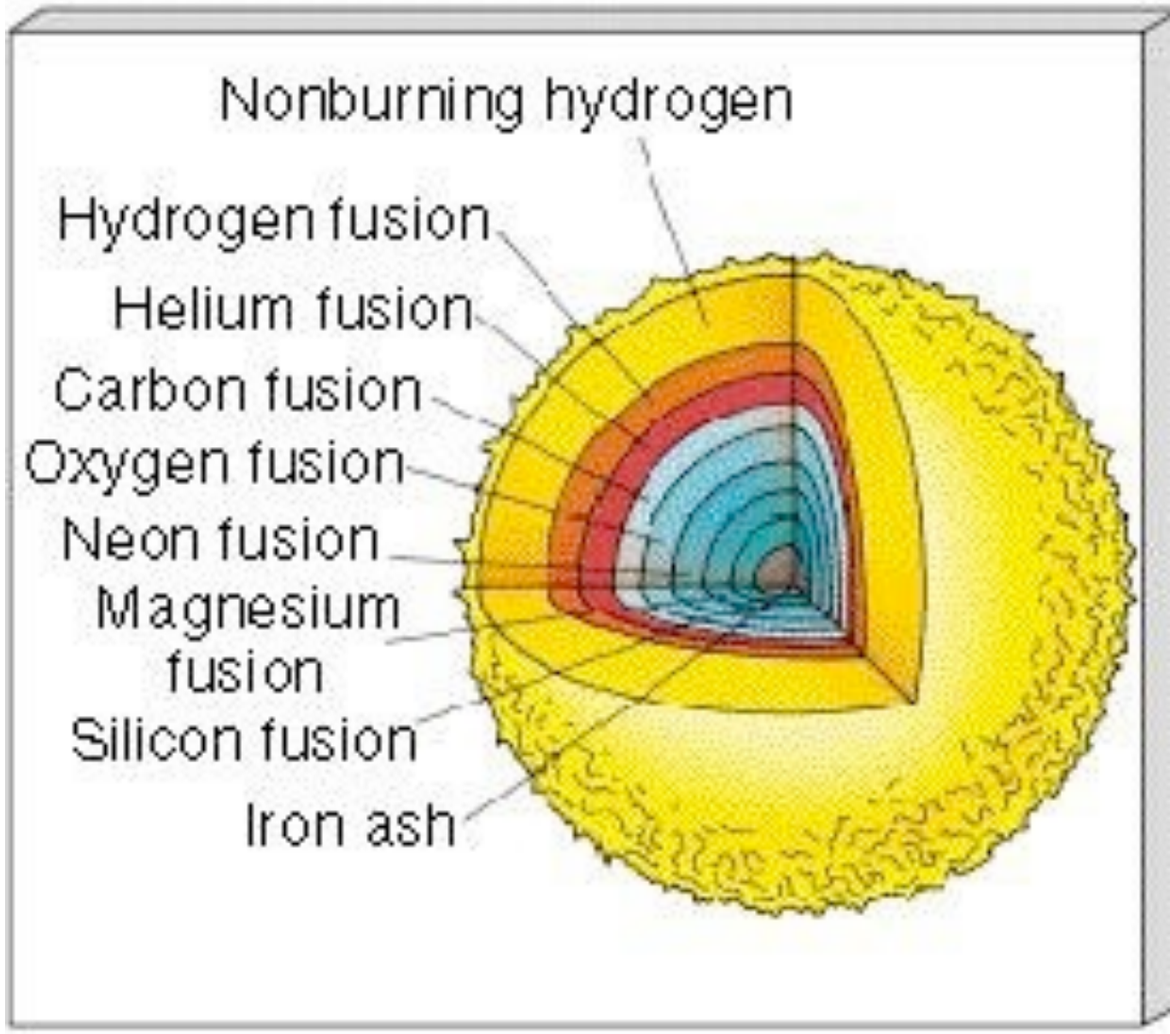

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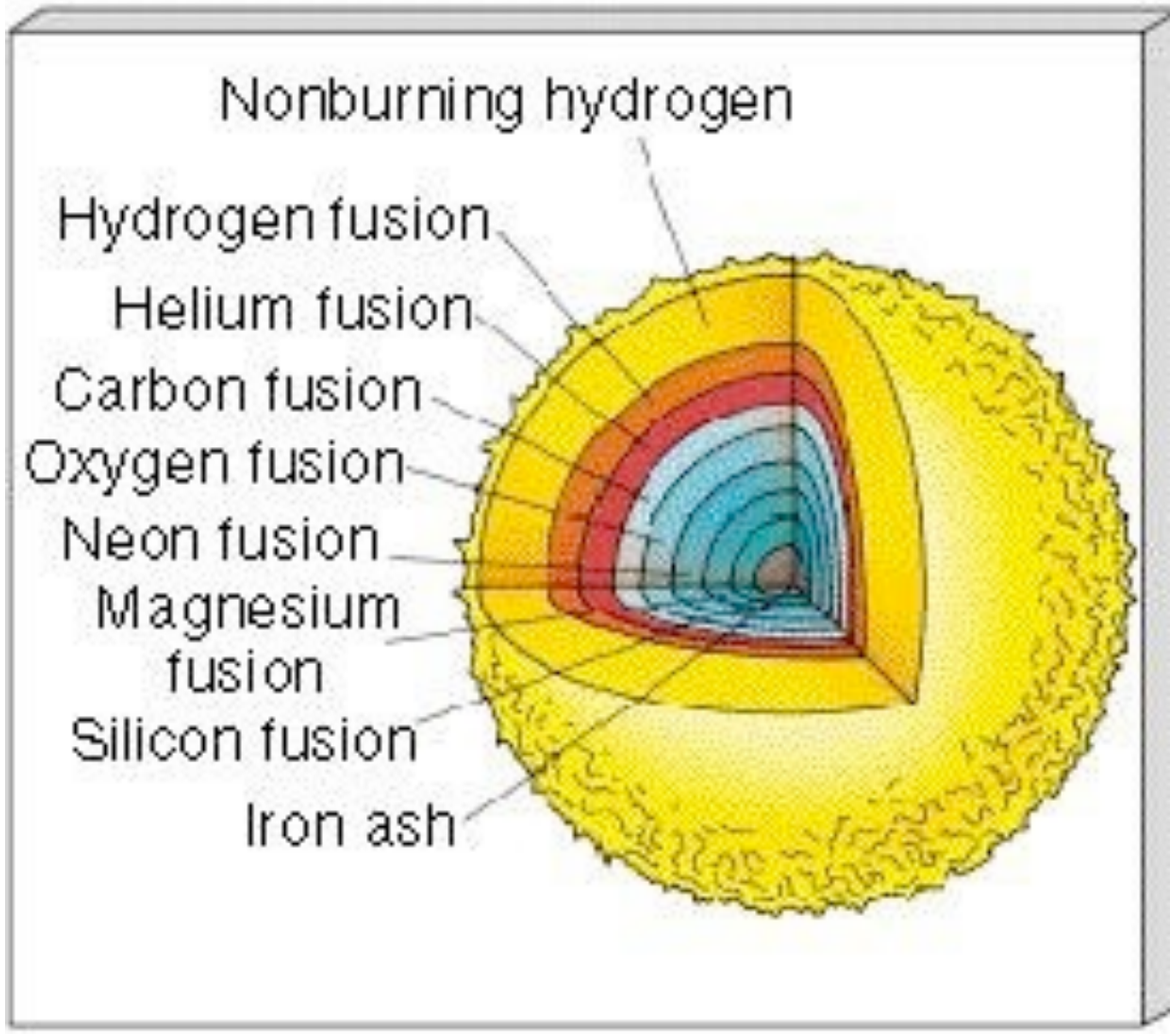

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- ★ **Core "bounce" at nuke density**
- ★ **"Neutrino bomb" ignited: ~ few 10^{53} erg**

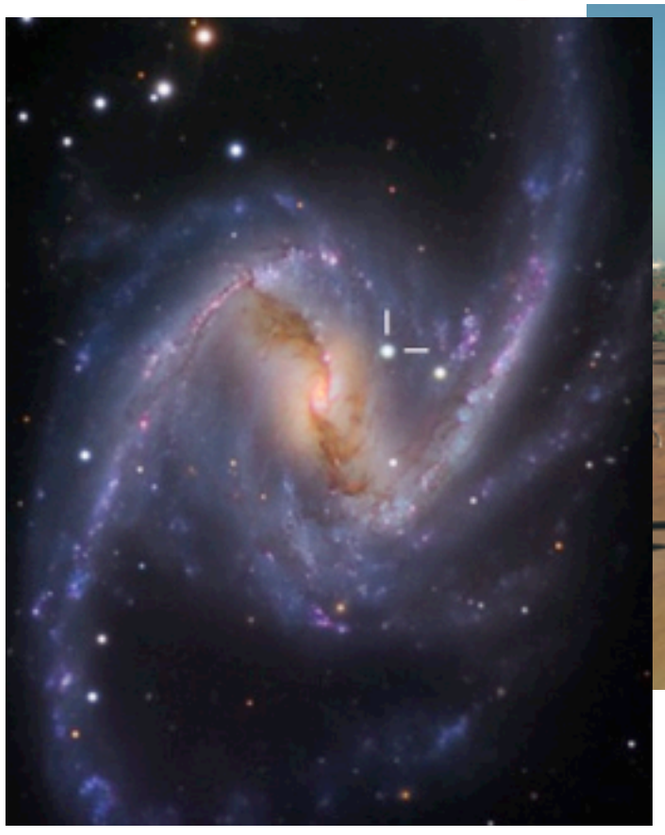
Koshiba & Kamiokande

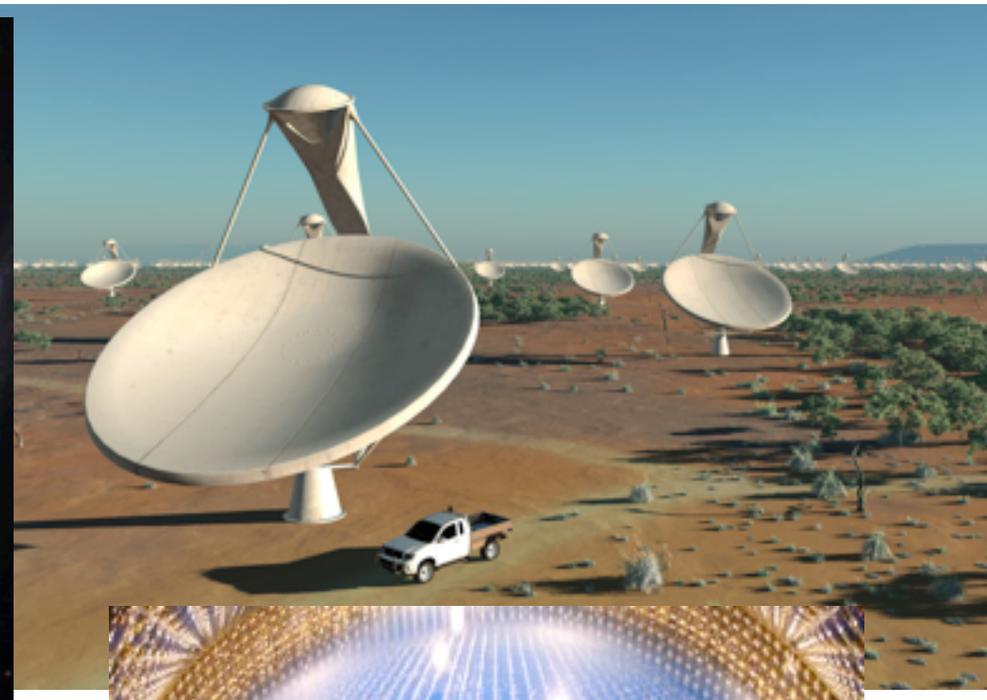
- ➡ **Shock launched: ~10^{51} erg**

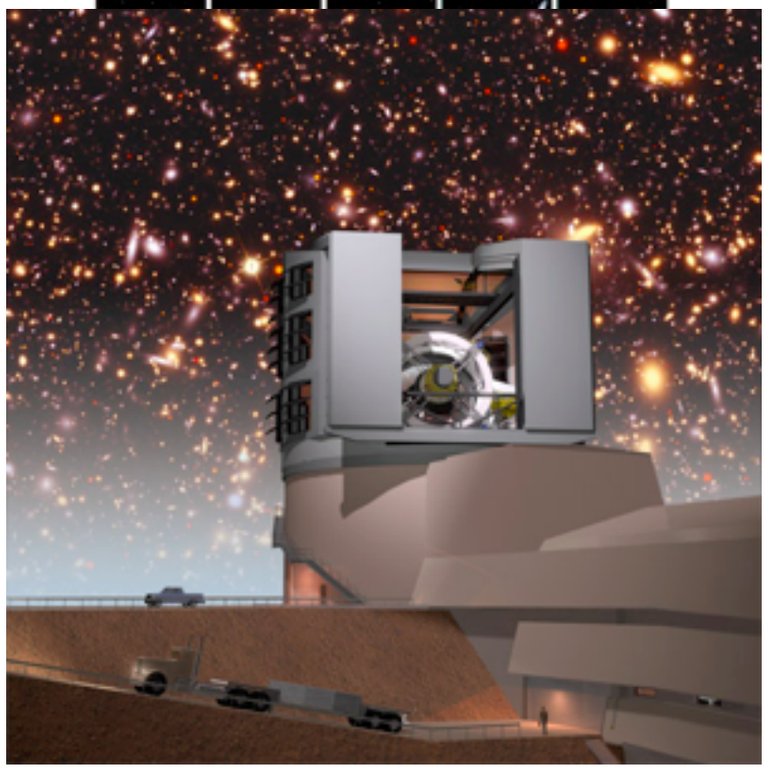
Explosion!

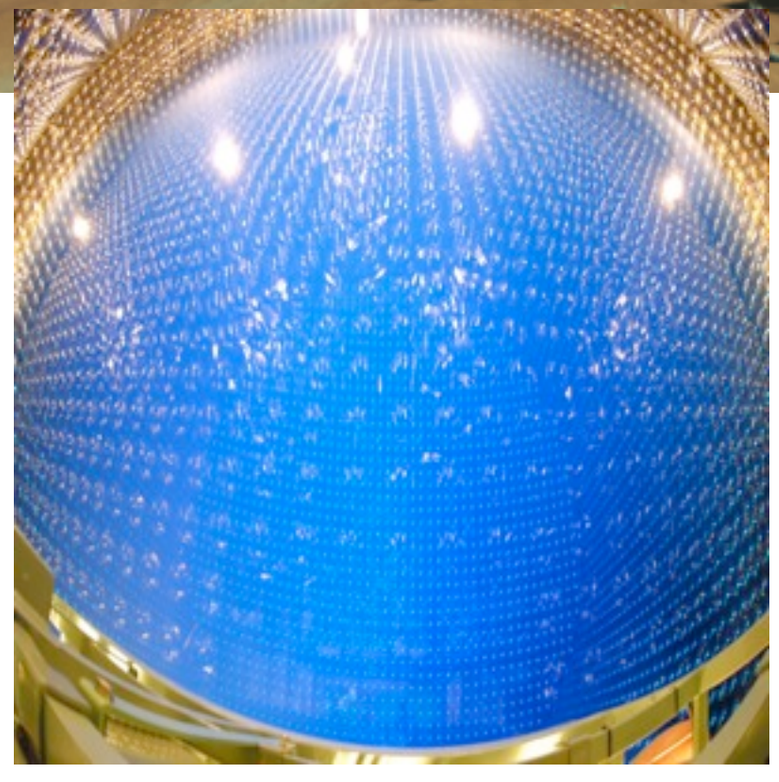
Core-Collapse Supernovae in the Great Survey Era

a Glimpse of Things to Come









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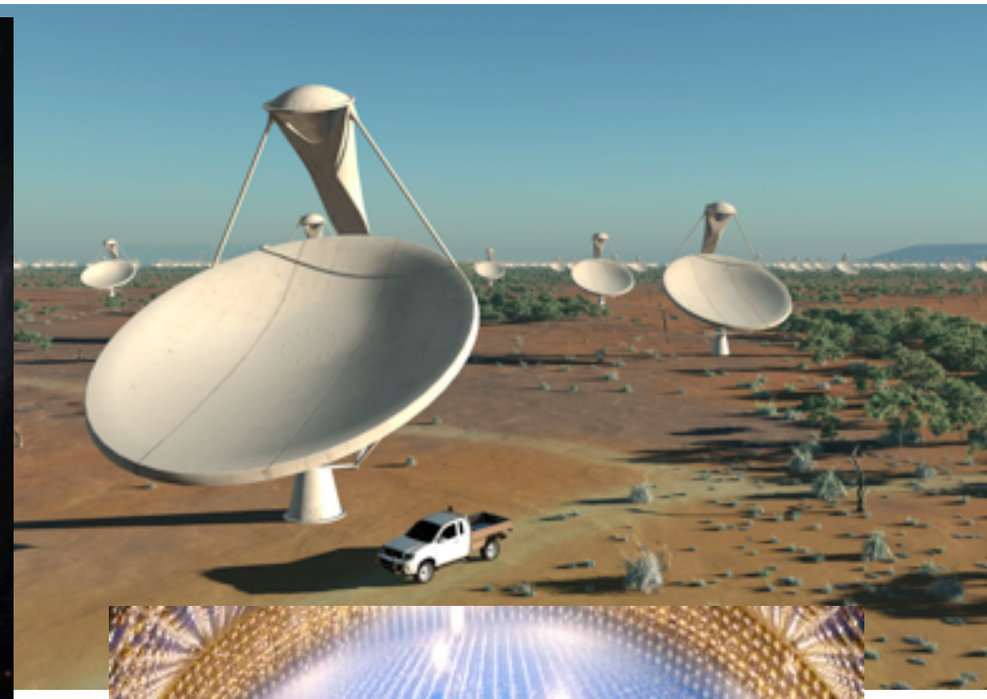

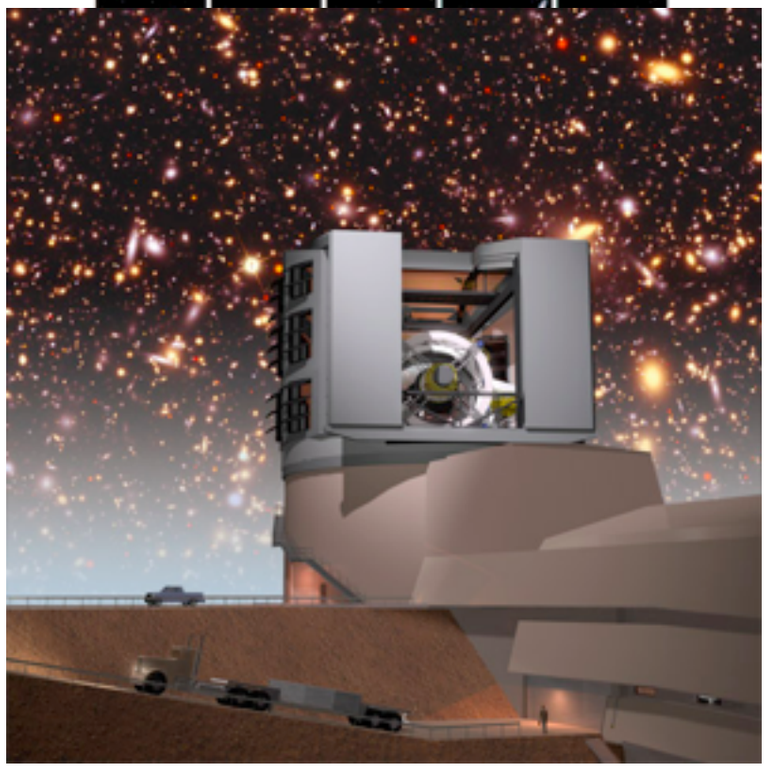

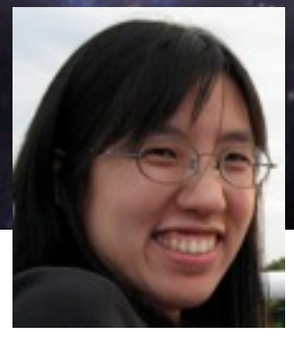

Amy Lien 連雅琳

GSFC

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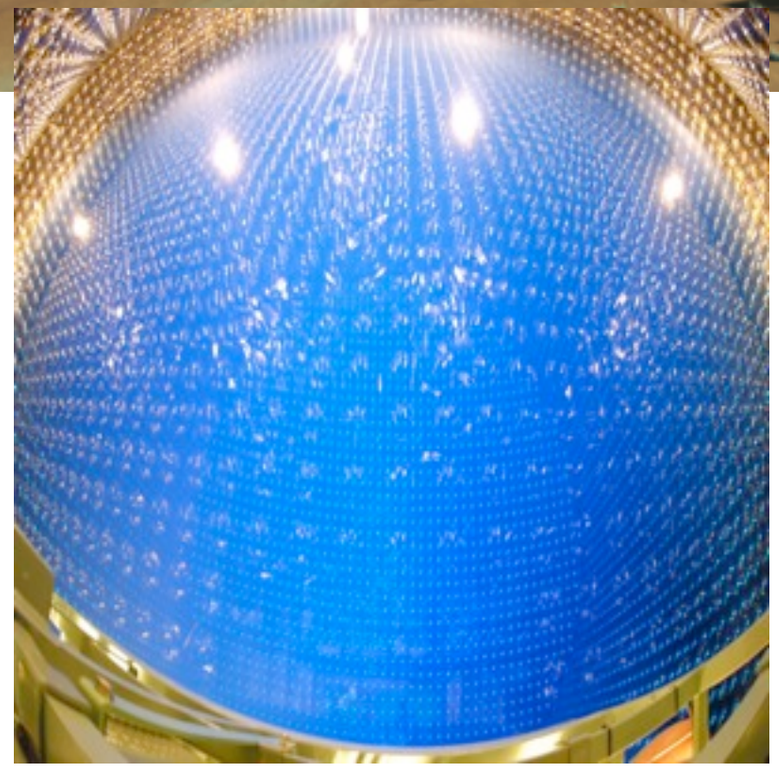

The Great Survey Era

- ★ key advance:

  large field of view & large collecting area

- ★ each exposure gives deep image of large chunk of sky

- ★ will feasibly make

  deep scans

  huge sky coverage--up to *entire* visible sky

  repeated exposures: *movies*

- ★ Optical Campaigns Lunnan talk

  prototype: SDSS

  recent/ongoing: PTF, Pan-STARRS, DES

  full-scale: LSST

- ★ Key science driver: Type Ia cosmology

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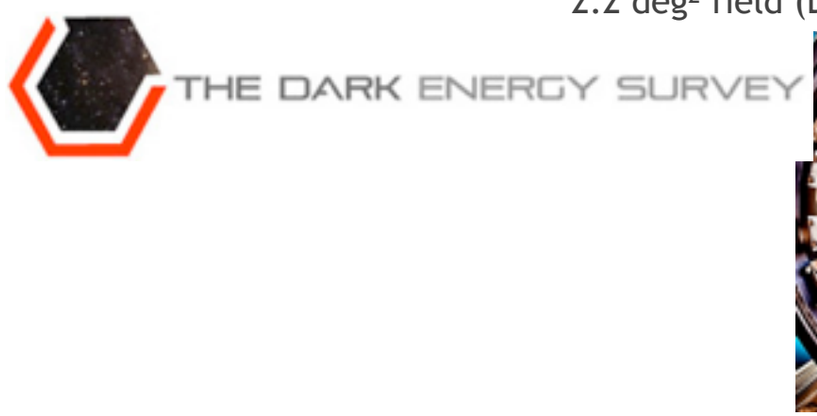

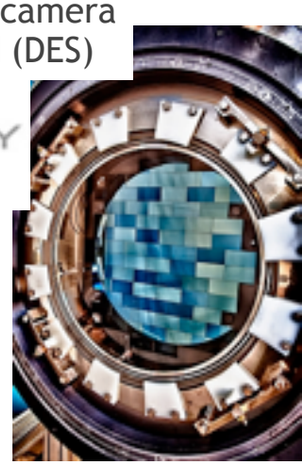

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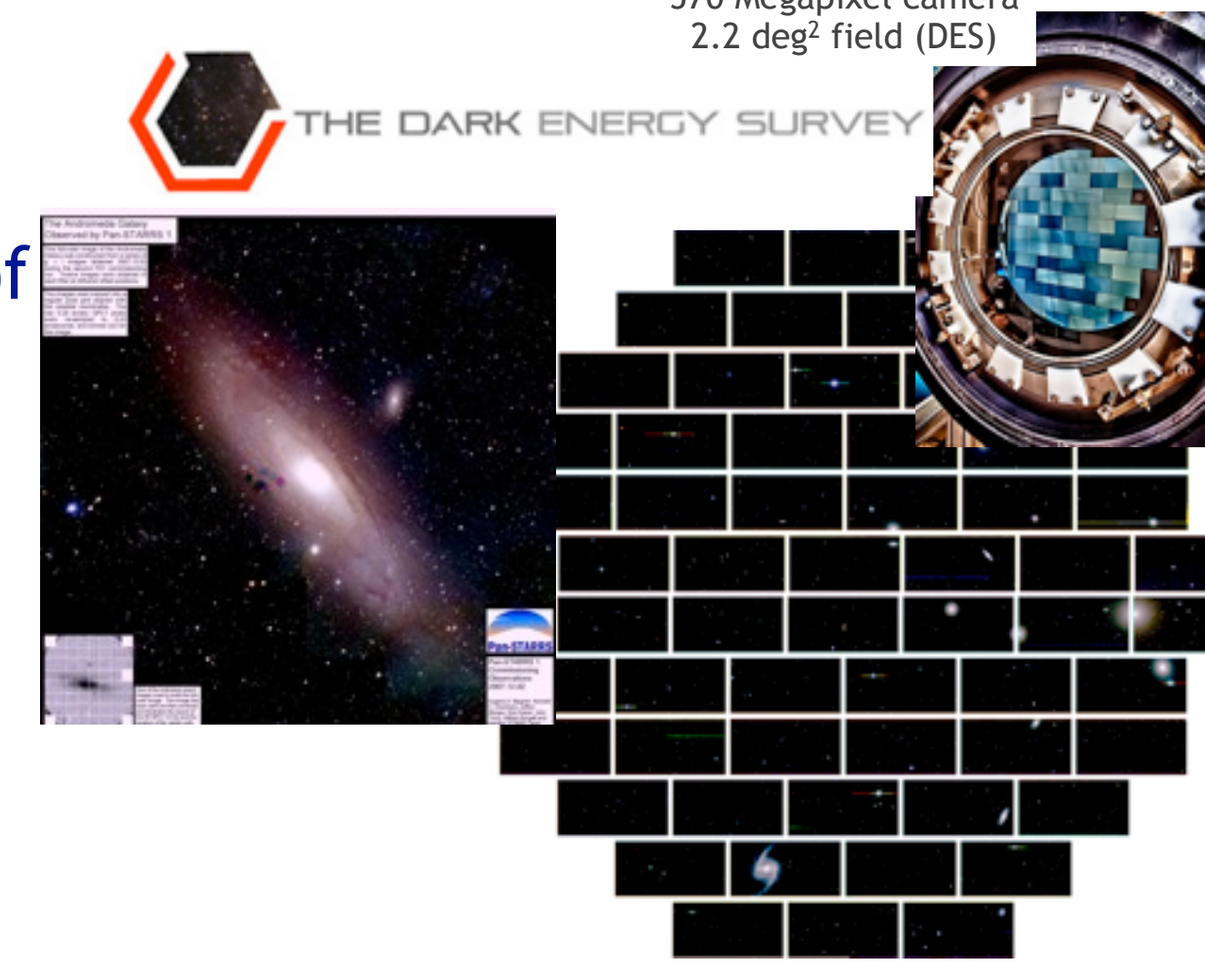

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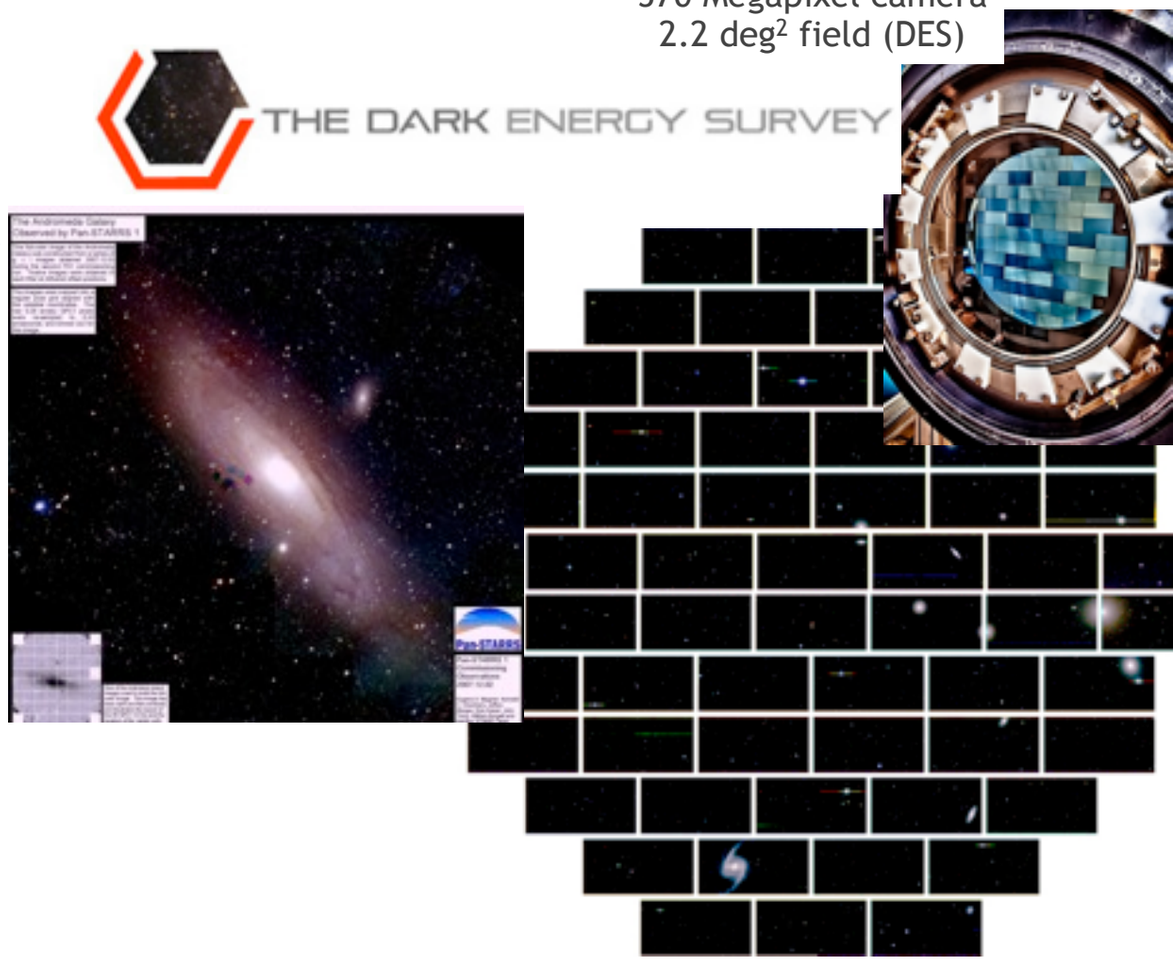

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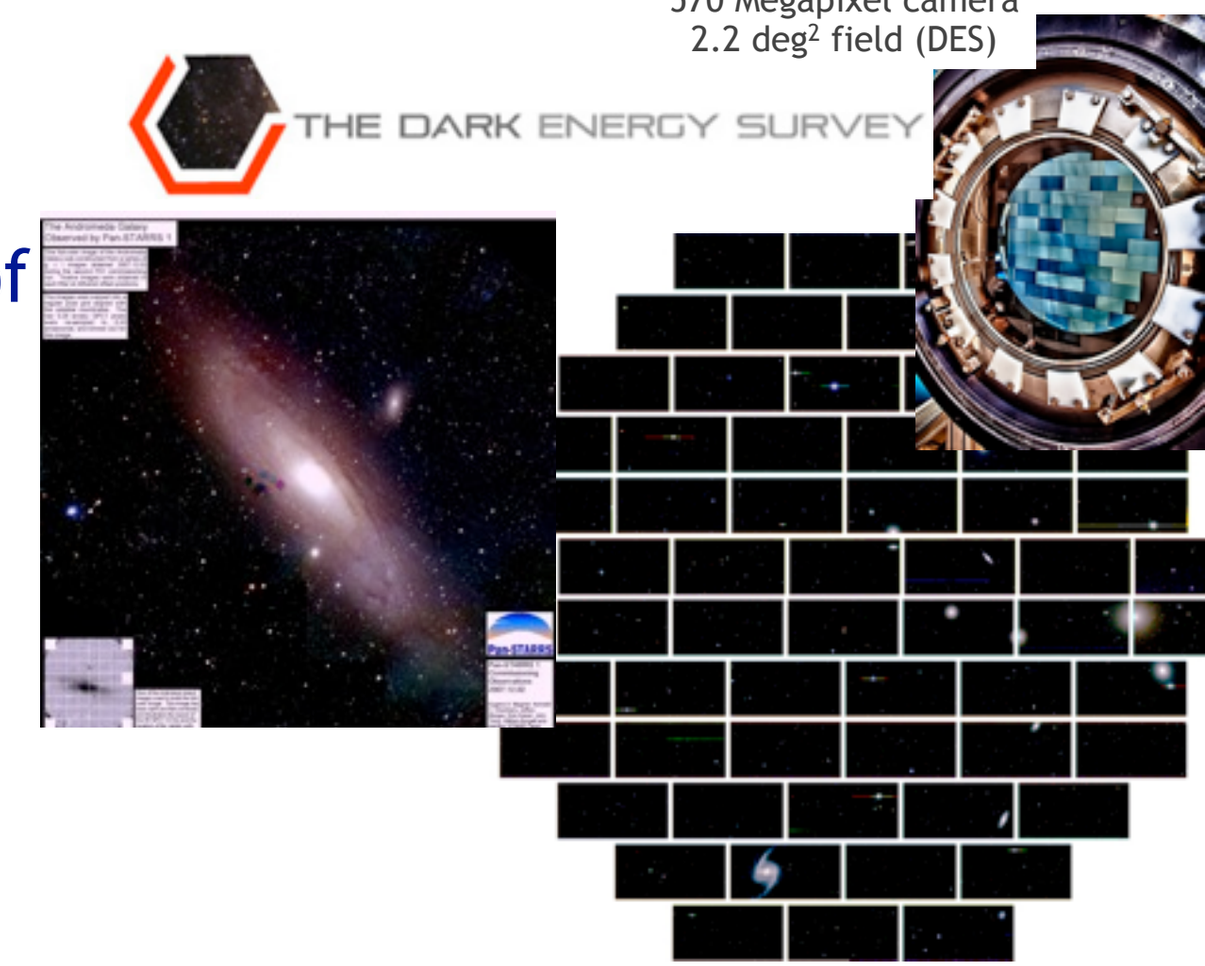

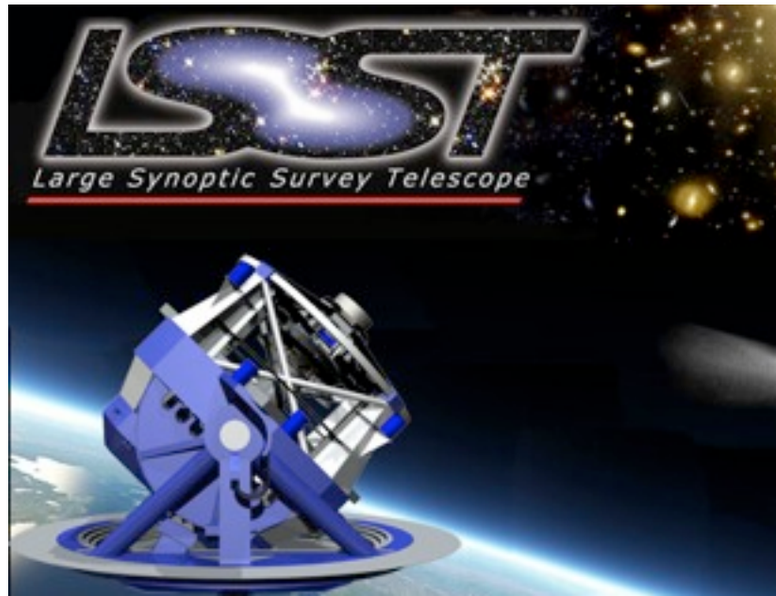

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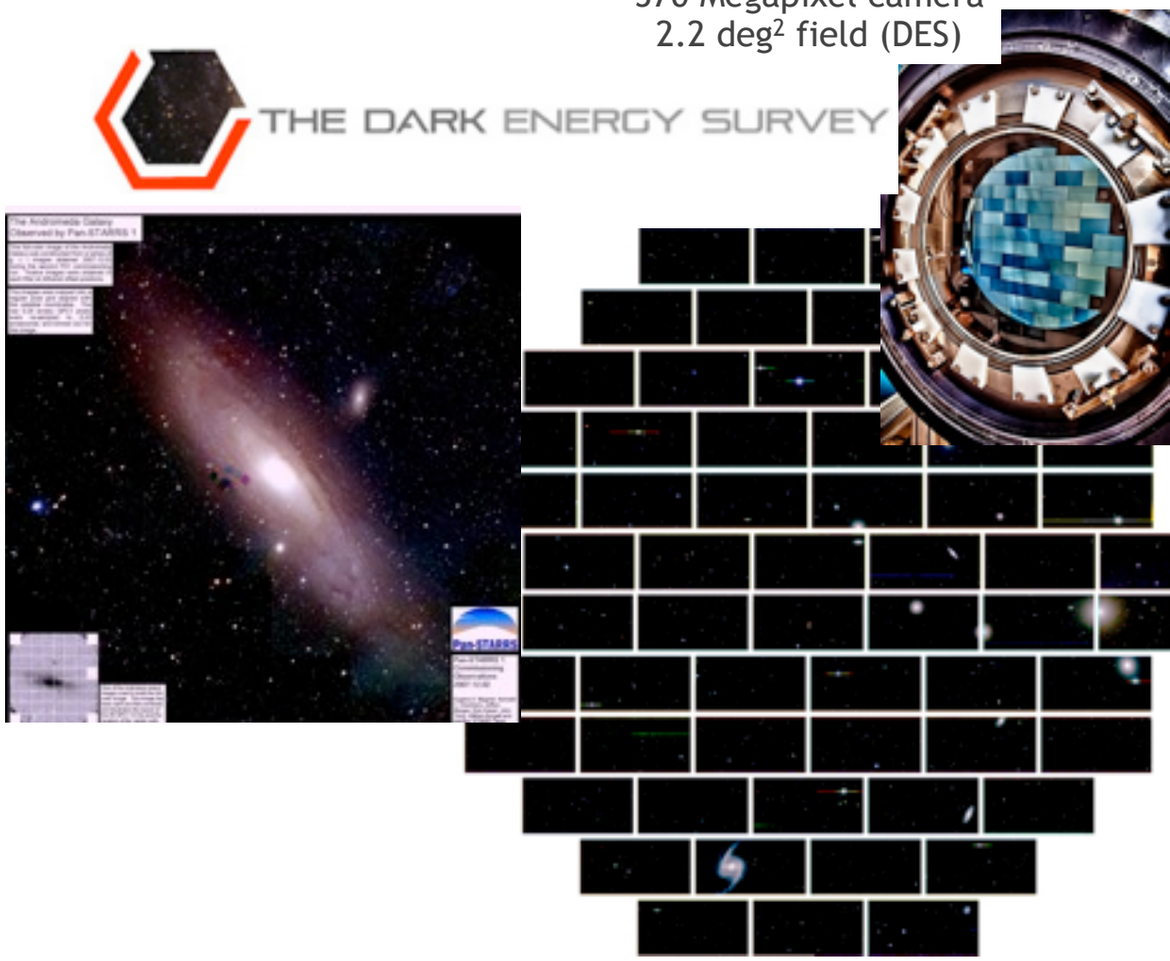

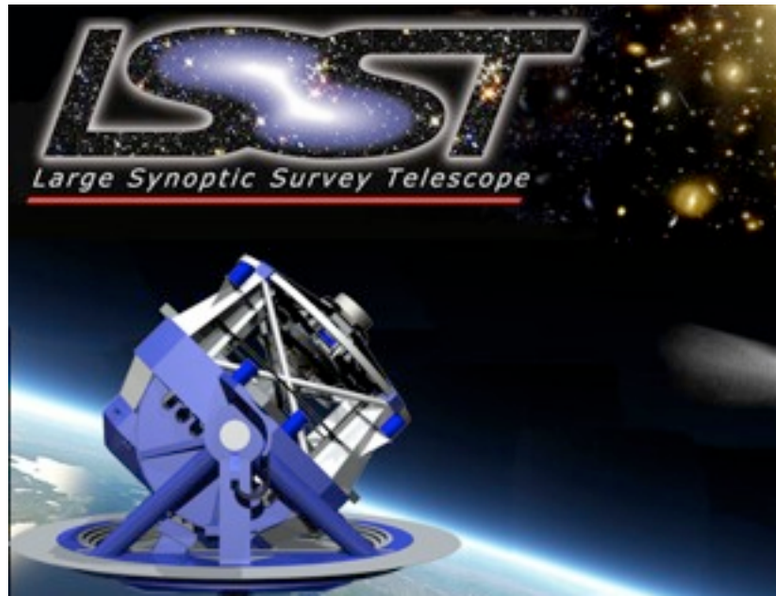

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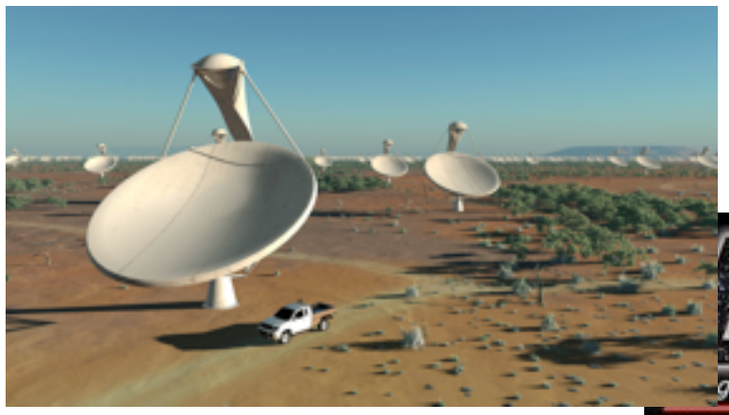

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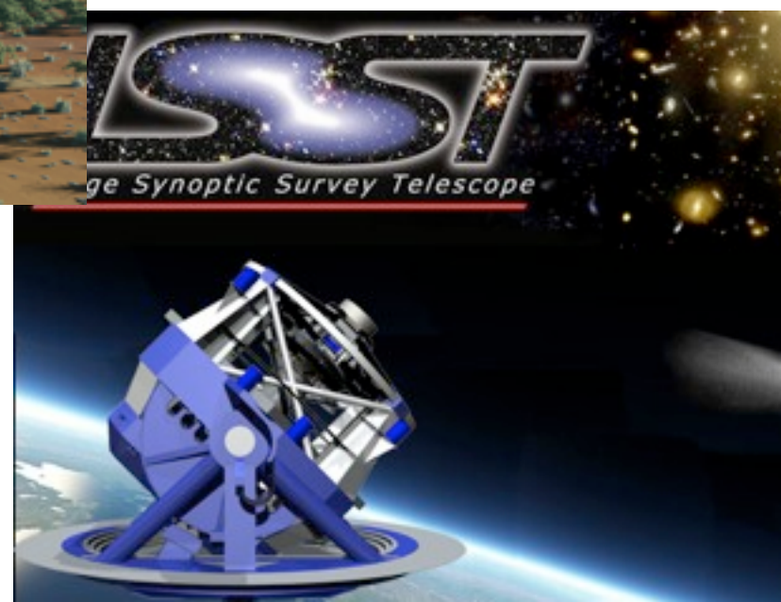

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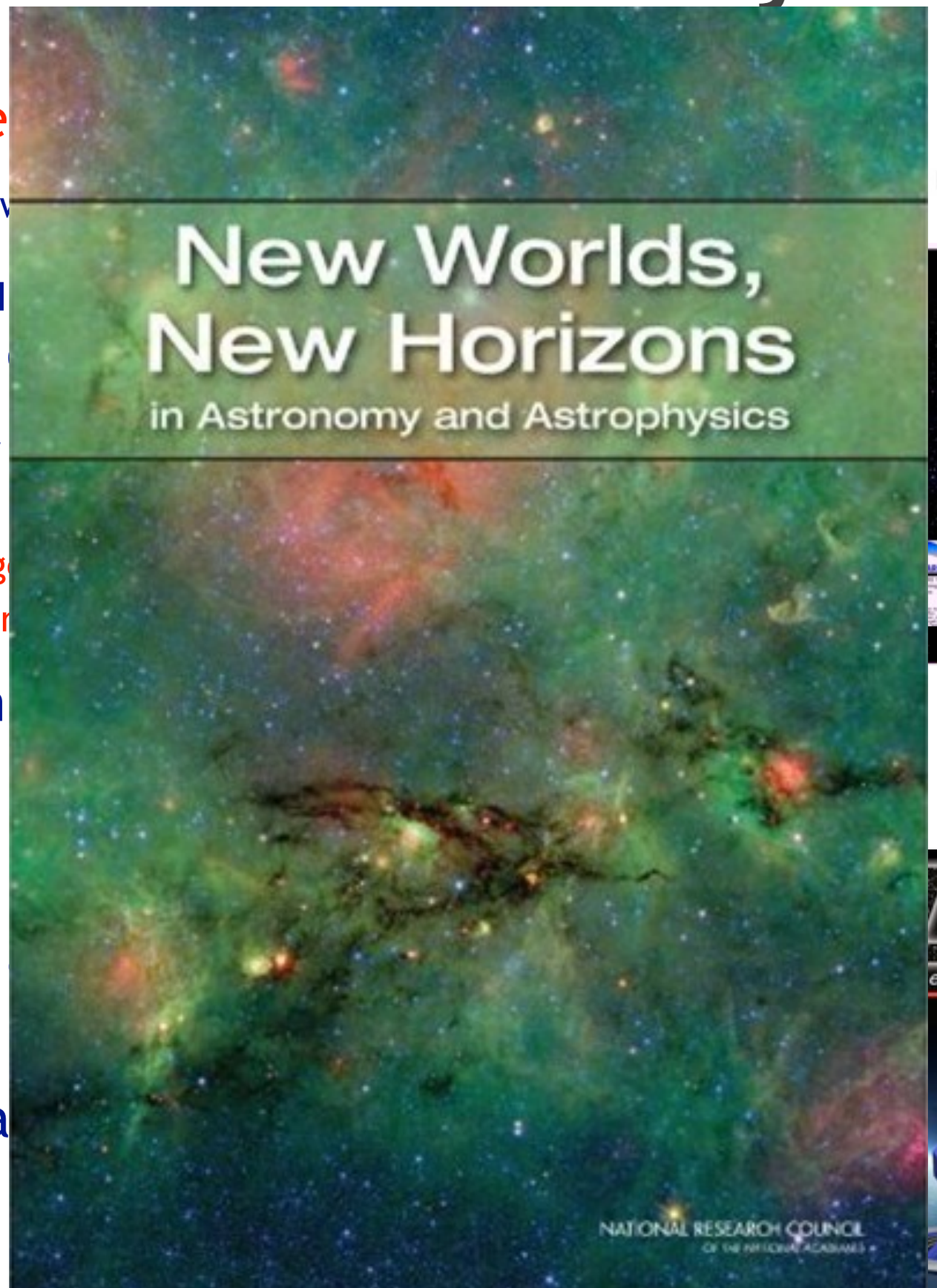

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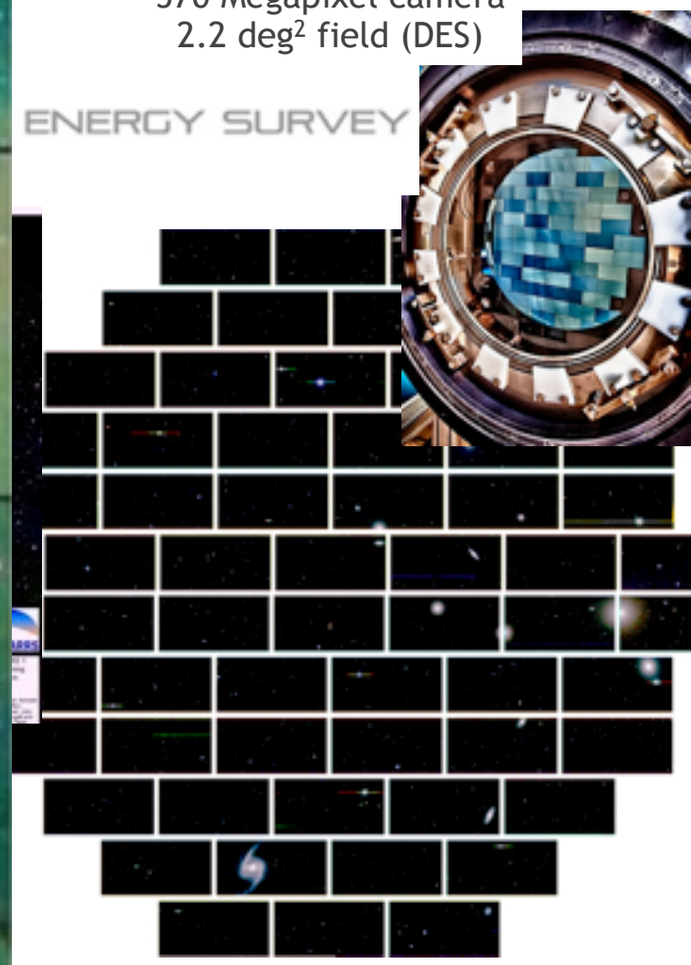

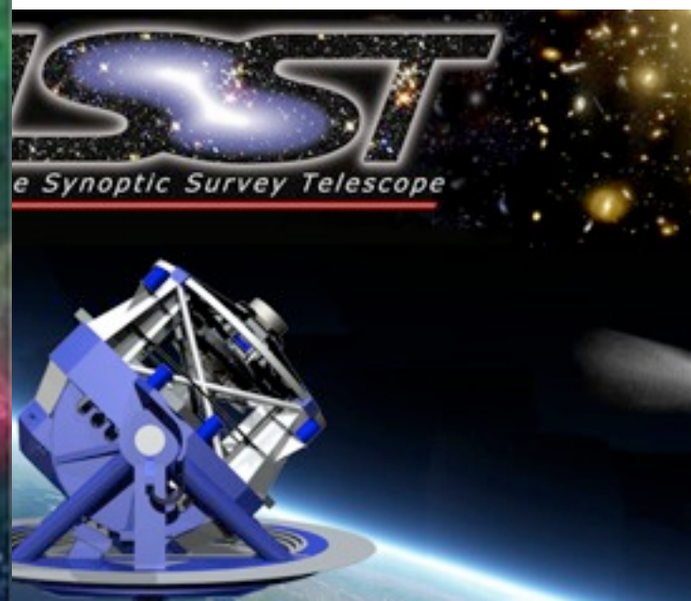

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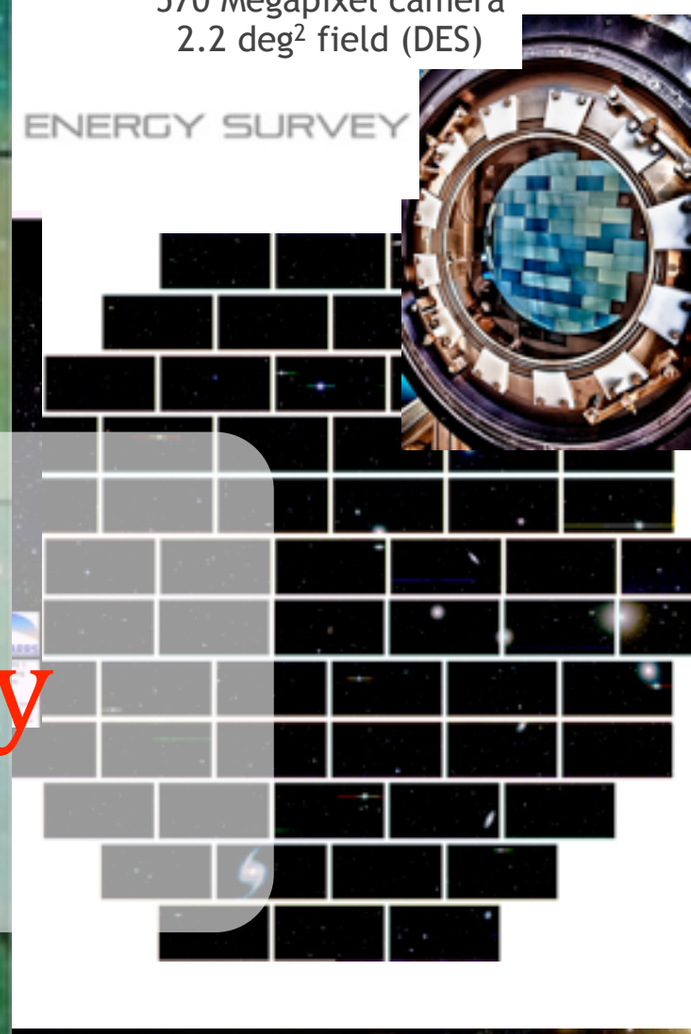

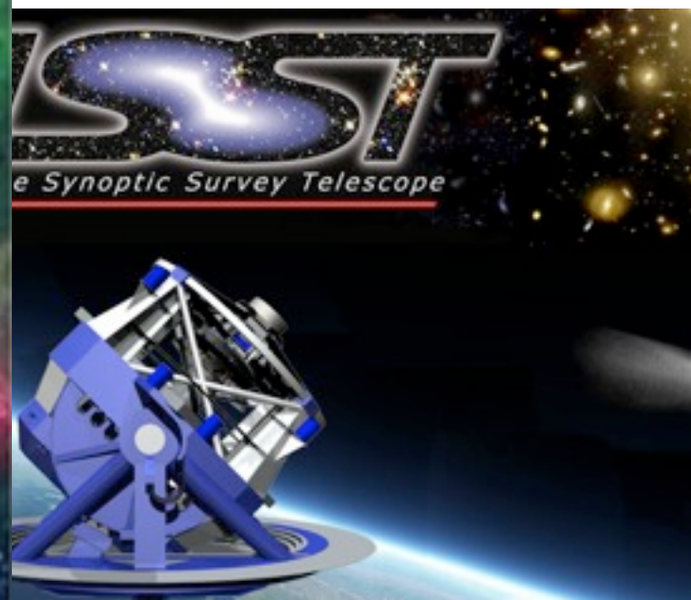

What About Core-Collapse? Forecasts

Our philosophy: future-looking

★ Assume all goes as planned

surveys come online

crucial problems will be solved

e.g., accurate photometric redshifts for host galaxies

★ Use reasonable inputs

★ Make honest forecast

★ Treat results as illustrative

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Supernovae from Optical Sky Surveys

The Transient Sky Unveiled

Opening the Time Domain

Epoch - Reference = Difference

SN Legacy Survey
~4 month scan

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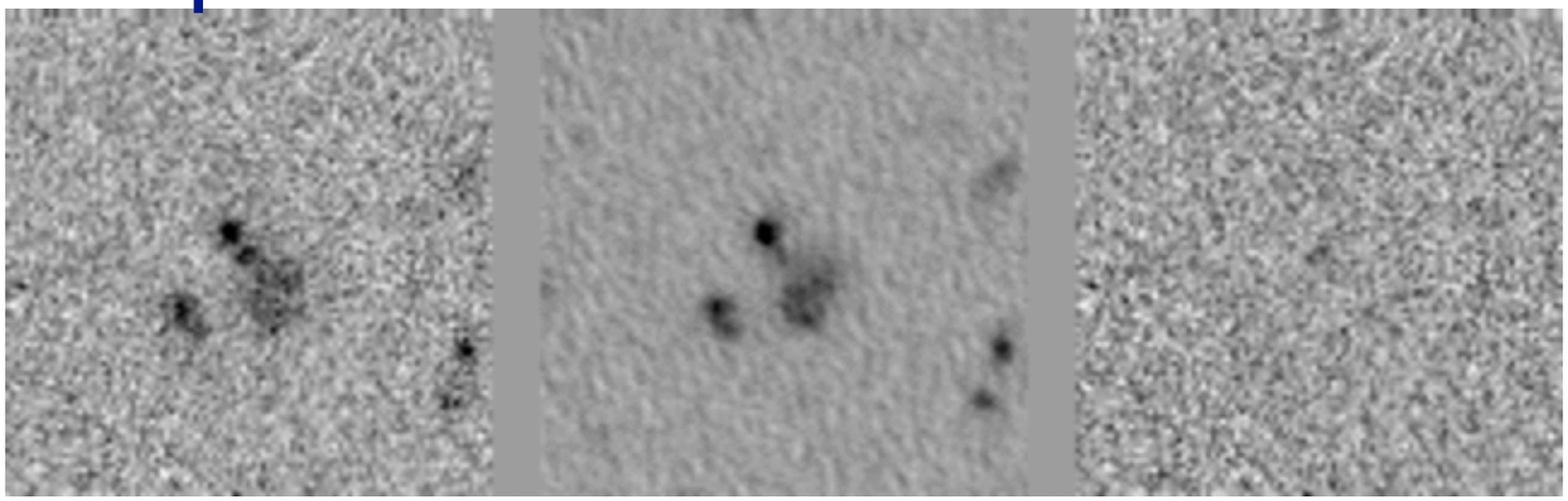

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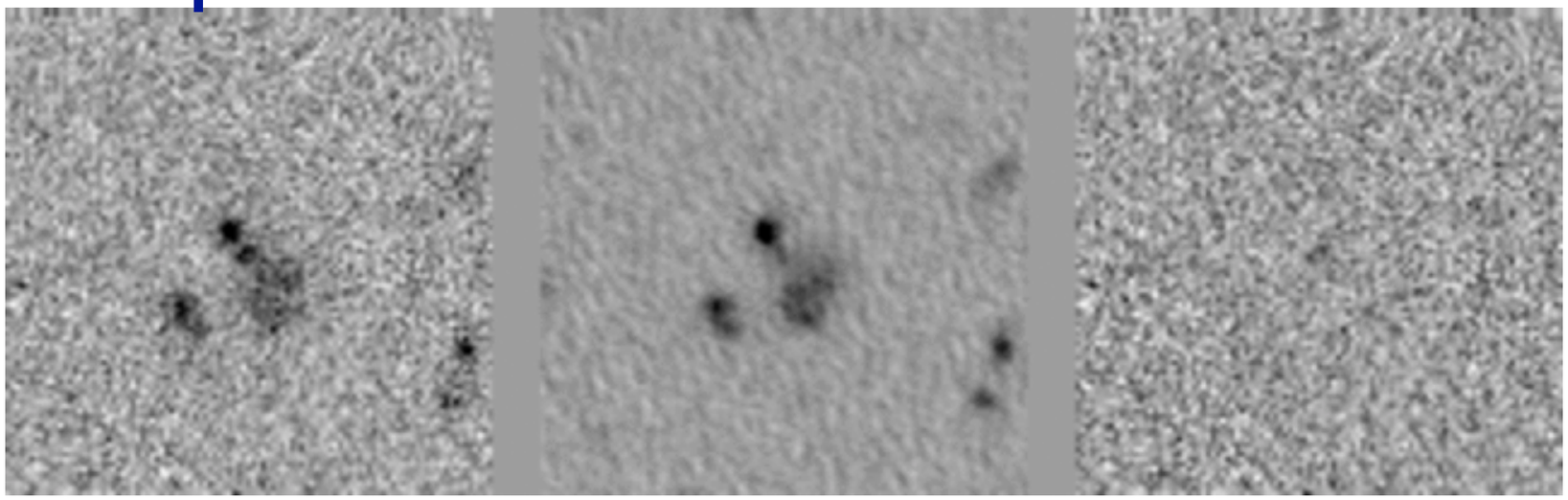

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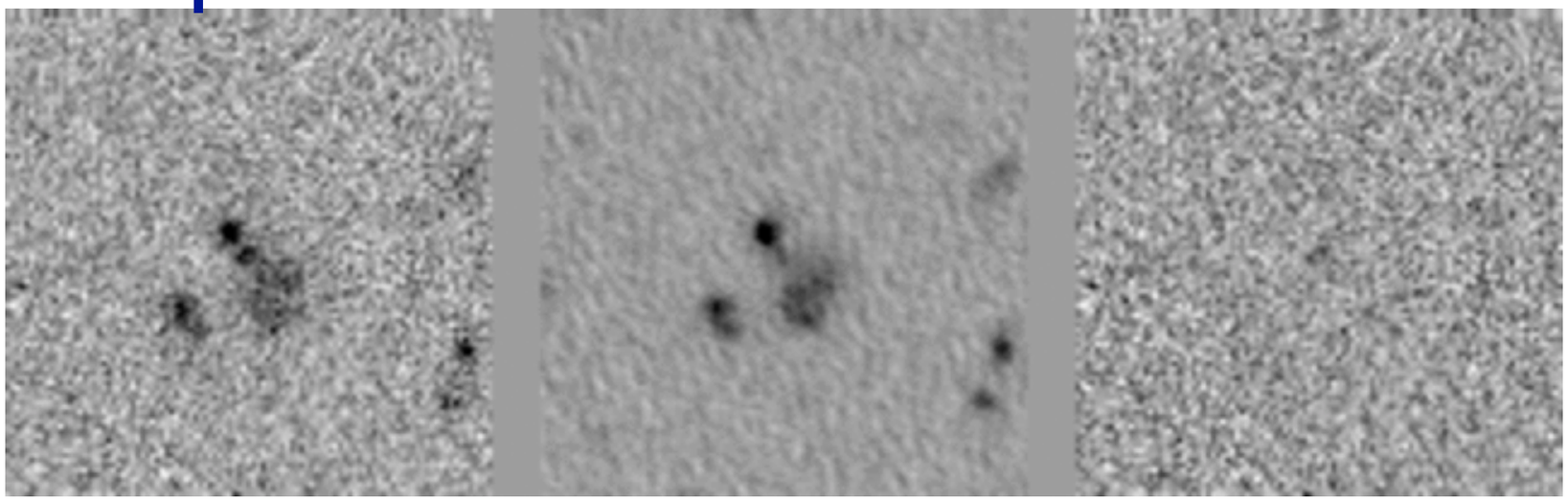

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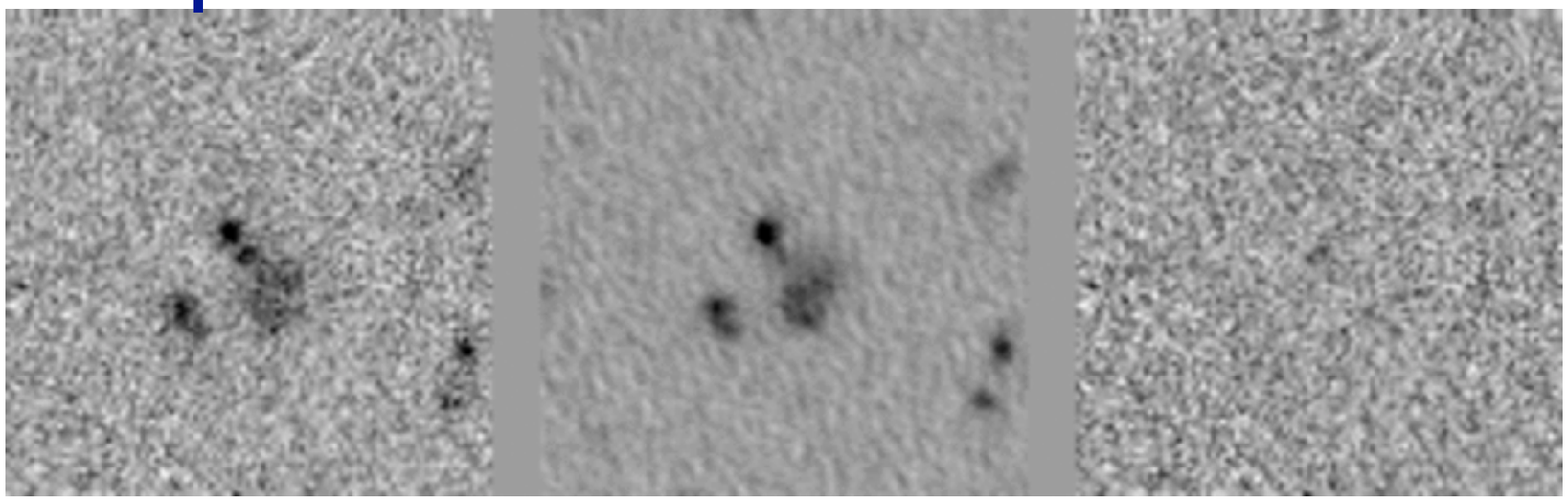

SN Legacy Survey
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Movie Stars

★ Supernovae: all types!

★ also: gamma-ray burst afterglows, active galaxy flaring, variable stars, killer asteroids, ...

Central Input:

Cosmic Supernova Rate

to date: inferred from cosmic *star formation* rate

★ massive star death "instantaneous"

star formation timescales << pre-SN lifetime

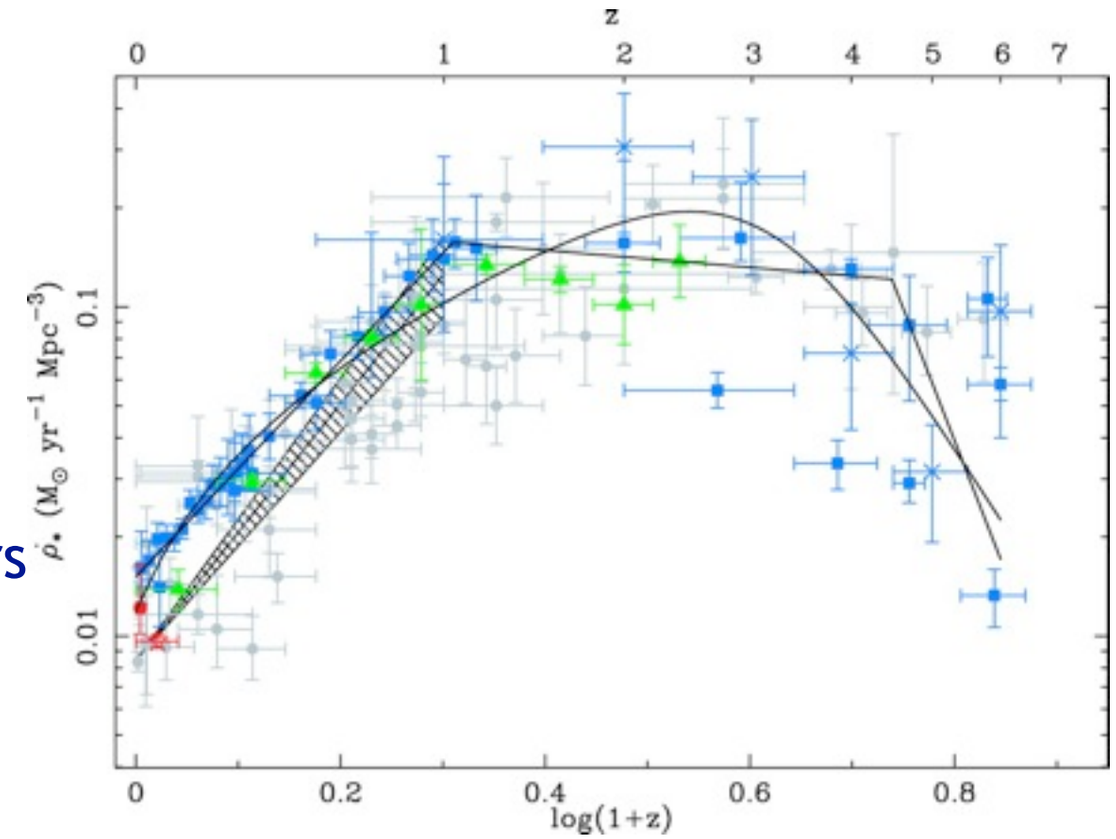
$$\mathcal{R}_{\rm SN} \propto \dot{\rho}_\star$$

★ **star formation** rate via light from massive stars

direct: UV

reprocessed: gas ⇒ lines; dust ⇒ IR

trend: factor ~10 rise to z=1, then ???



Hopkins & Beacom 2006

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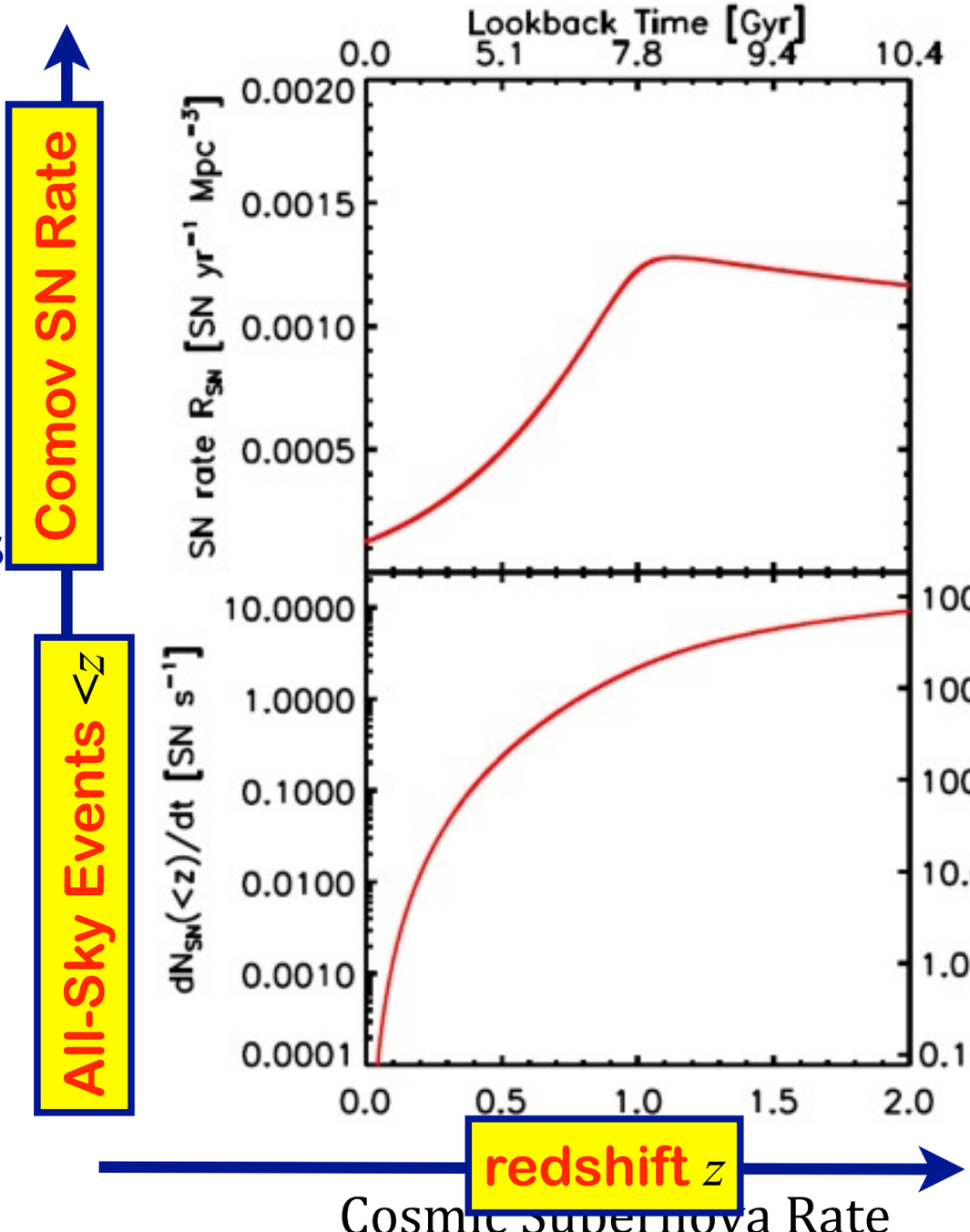

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Lien & Fields (2009)

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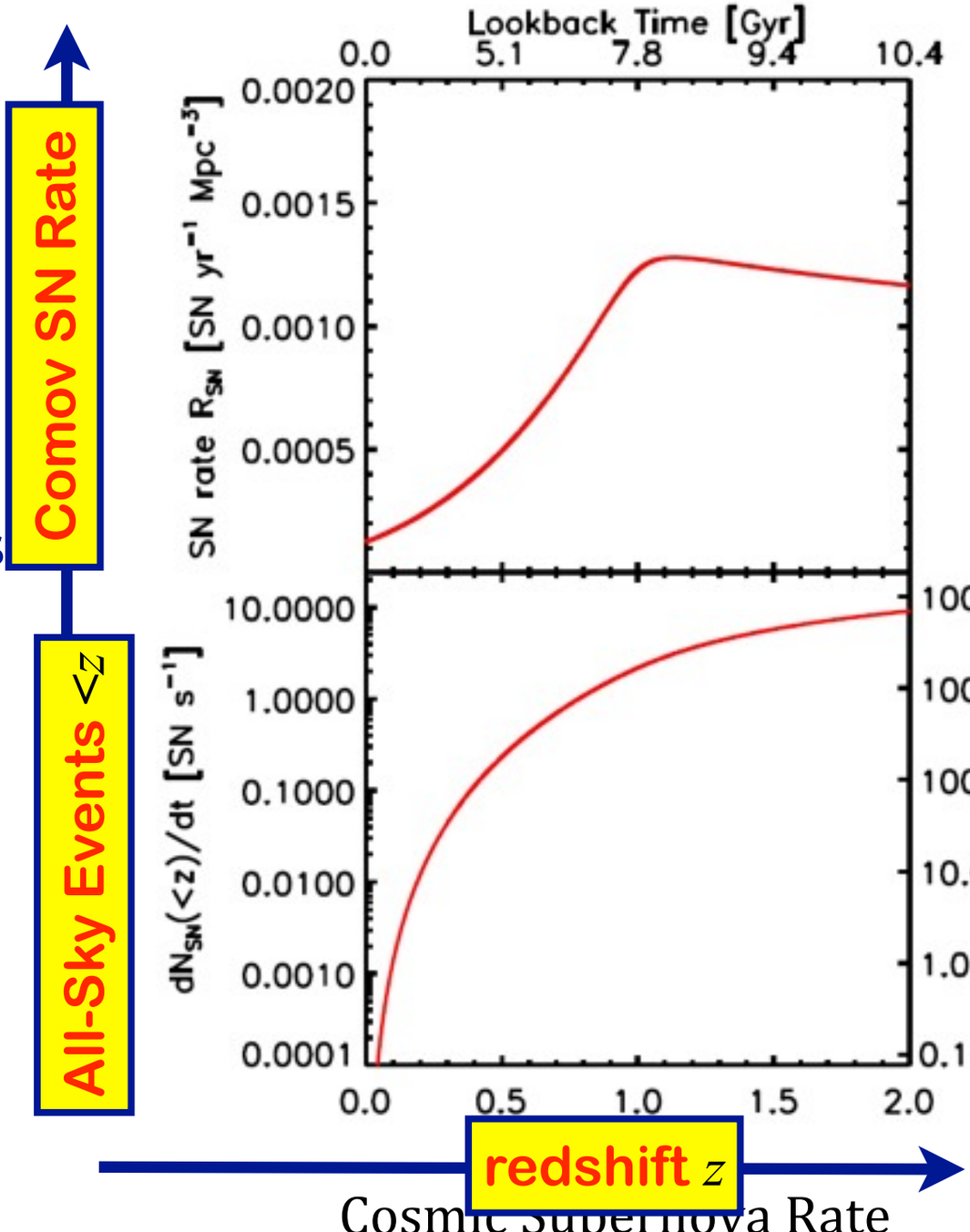
★ key uncertainty: (optically) invisible SN

failed explosions: direct collapse to black hole?

dust obscuration of star-forming regions



Cosmic Supernova Rate
Lien & Fields (2009)

The Future:

Core-Collapse Cornucopia

Lien & BDF

- ★ Unbiased, untargeted supernova search
- ★ LSST:

  ~300,000 core-collapse events *each year!*

  conservatively > 1,000,000 CC events in survey lifetime
- ★ Cosmic Supernova Rate by ***direct counting***

  rate measured to 10% out to **z~1**

  tradeoff: redshift range (scan depth) vs SN counts (sky coverage)

  looming uncertainty: dust obscuration
- ★ Deep Drilling mode complementary

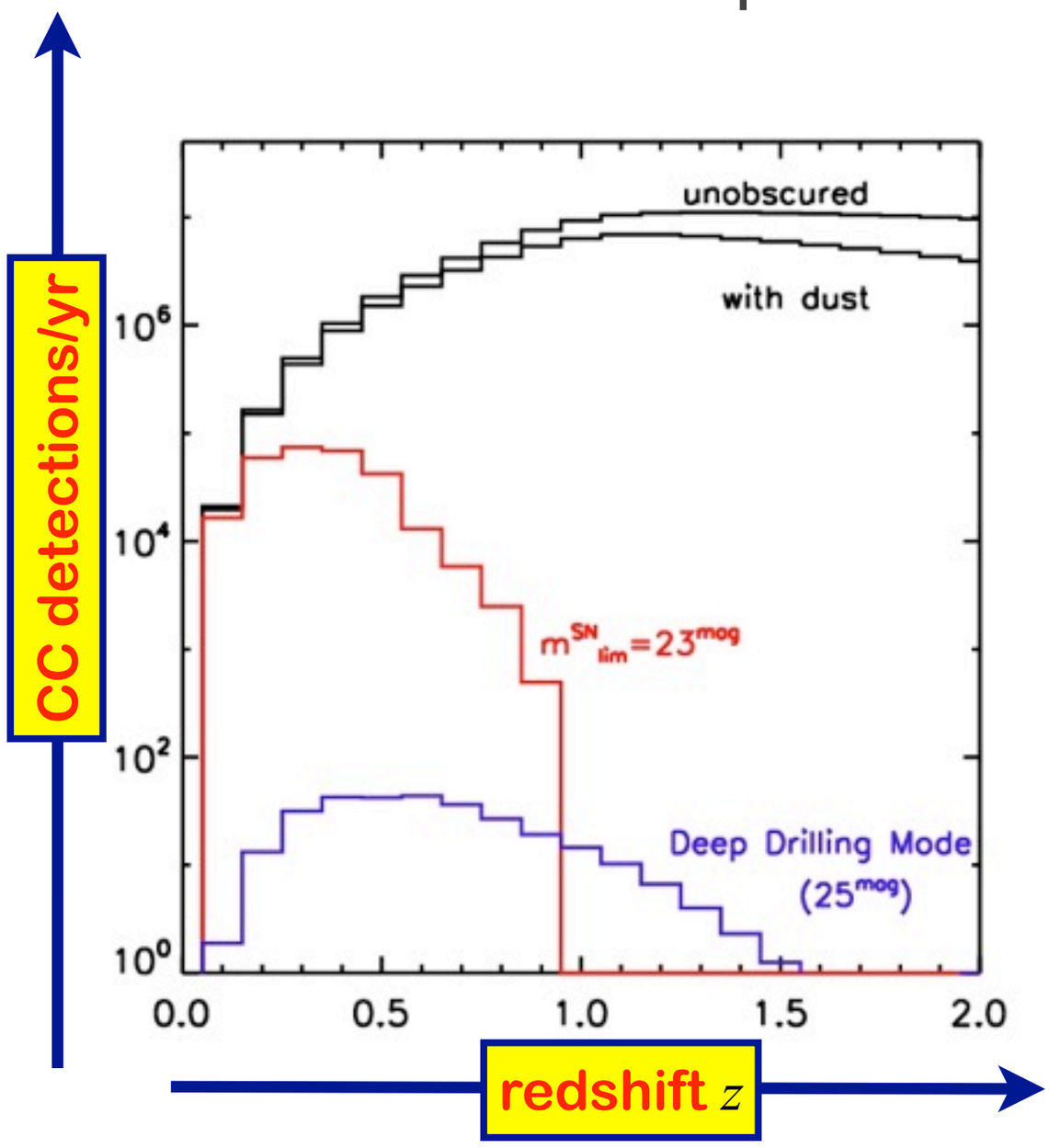
  deep exposures on 40 deg^2

  CC detections to ***z~1.5***
- ★ ***Core-collapse come for free!***

  survey characteristics tuned to SN Ia

  automatically well-suited for SN II

LSST Annual Core-Collapse Harvest



How Many is **1 Million** Supernovae?

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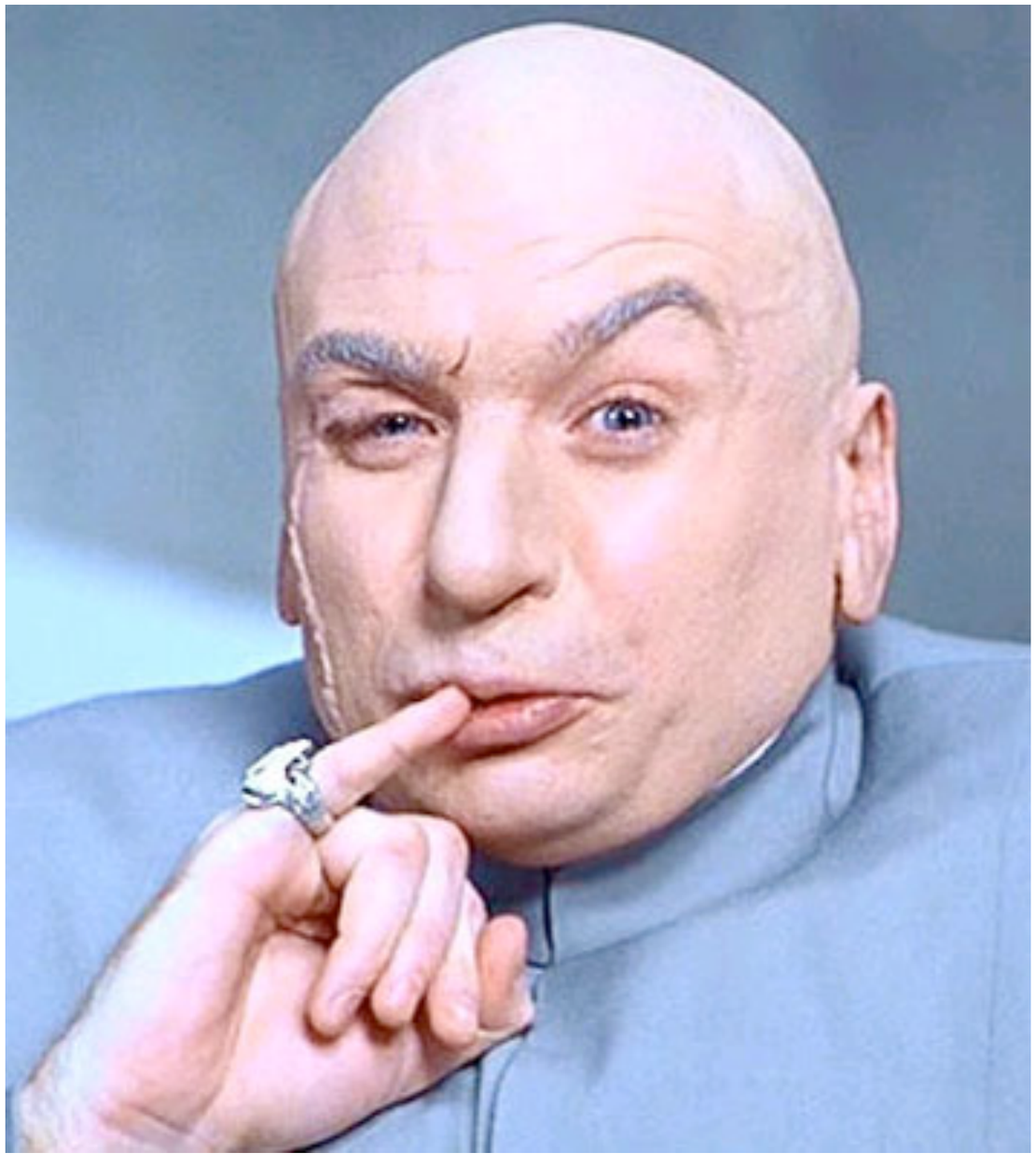

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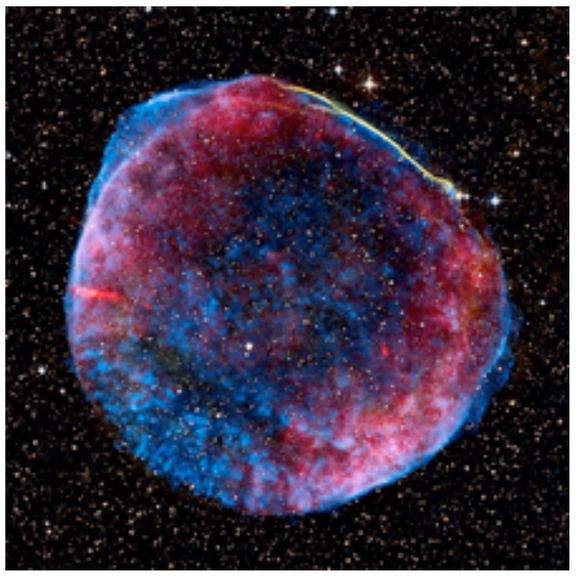
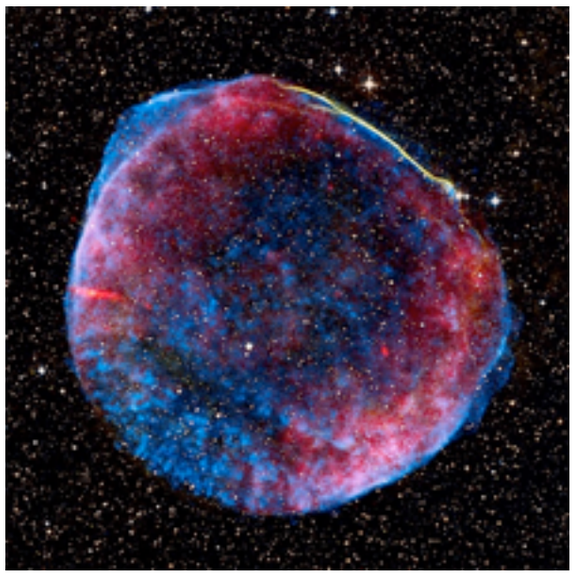


1. SN 1006

How Many is **1 Million** Supernovae?

2.
SN 1054



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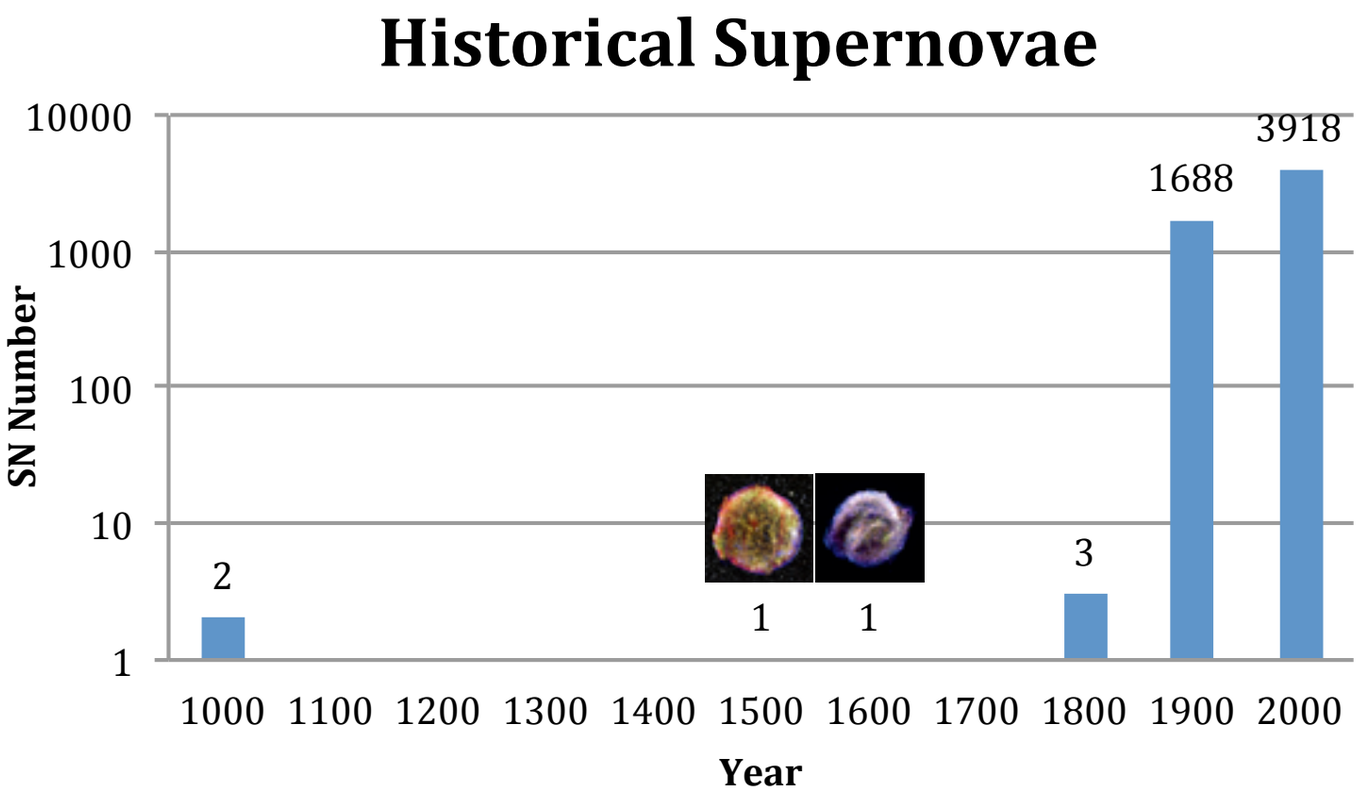
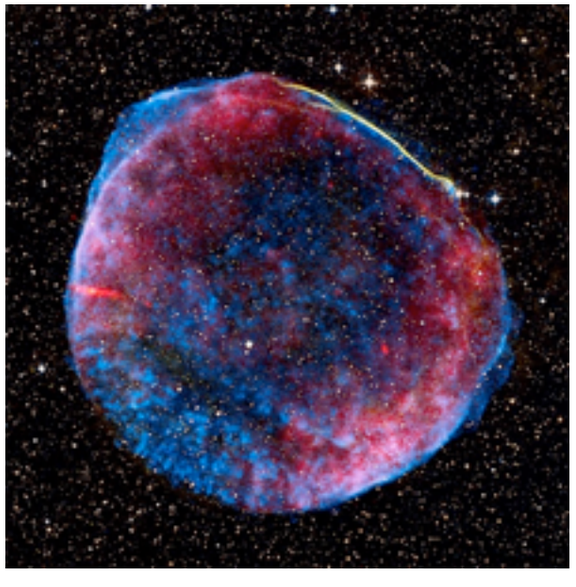


CBAT tabulation



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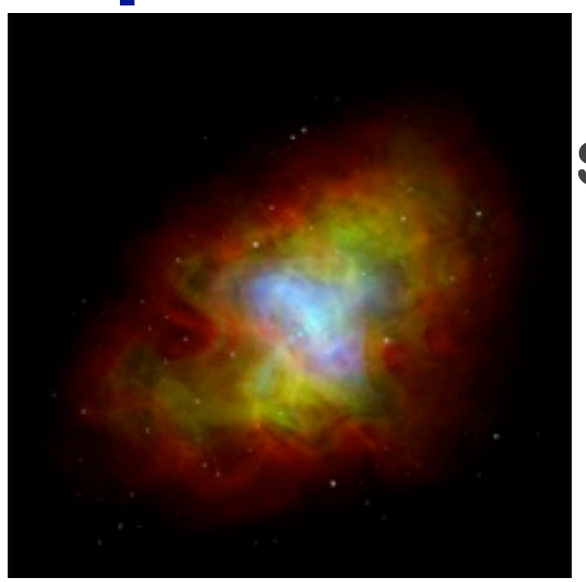

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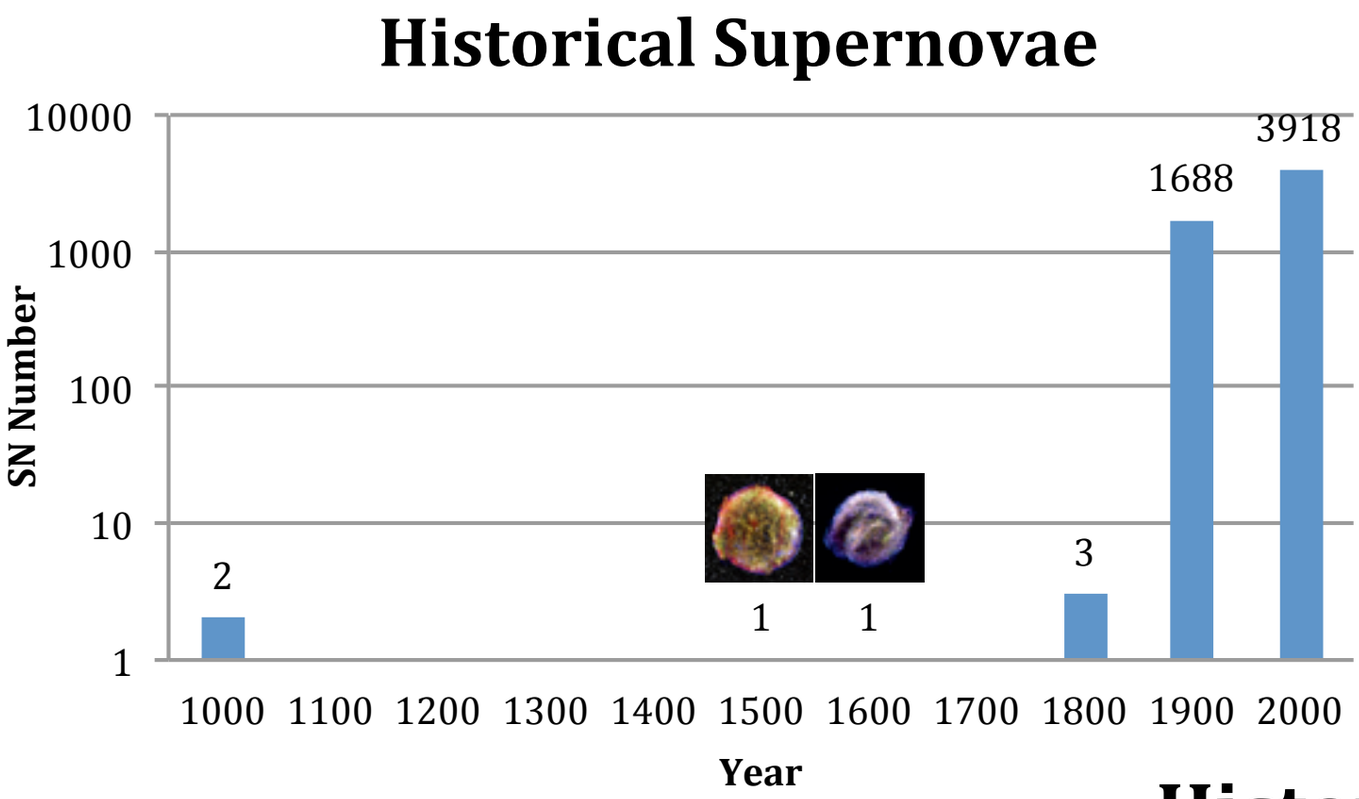

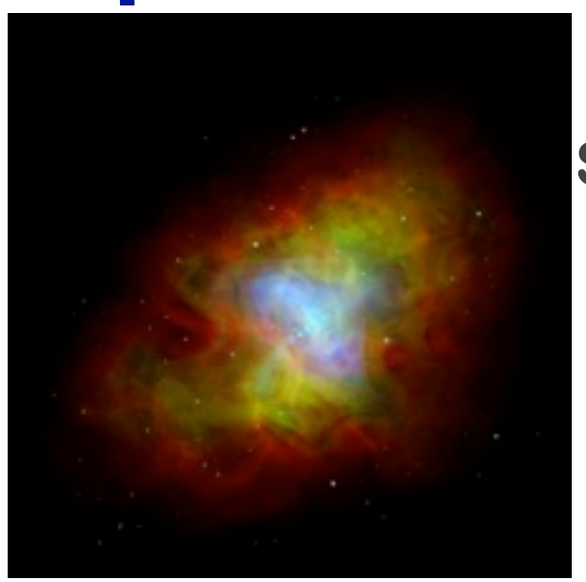

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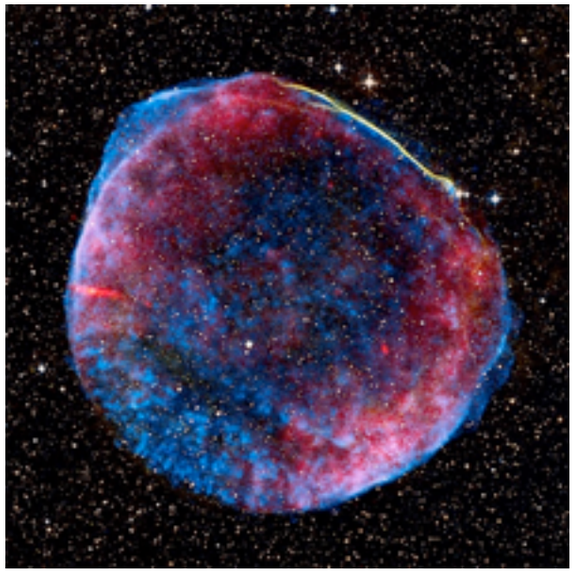

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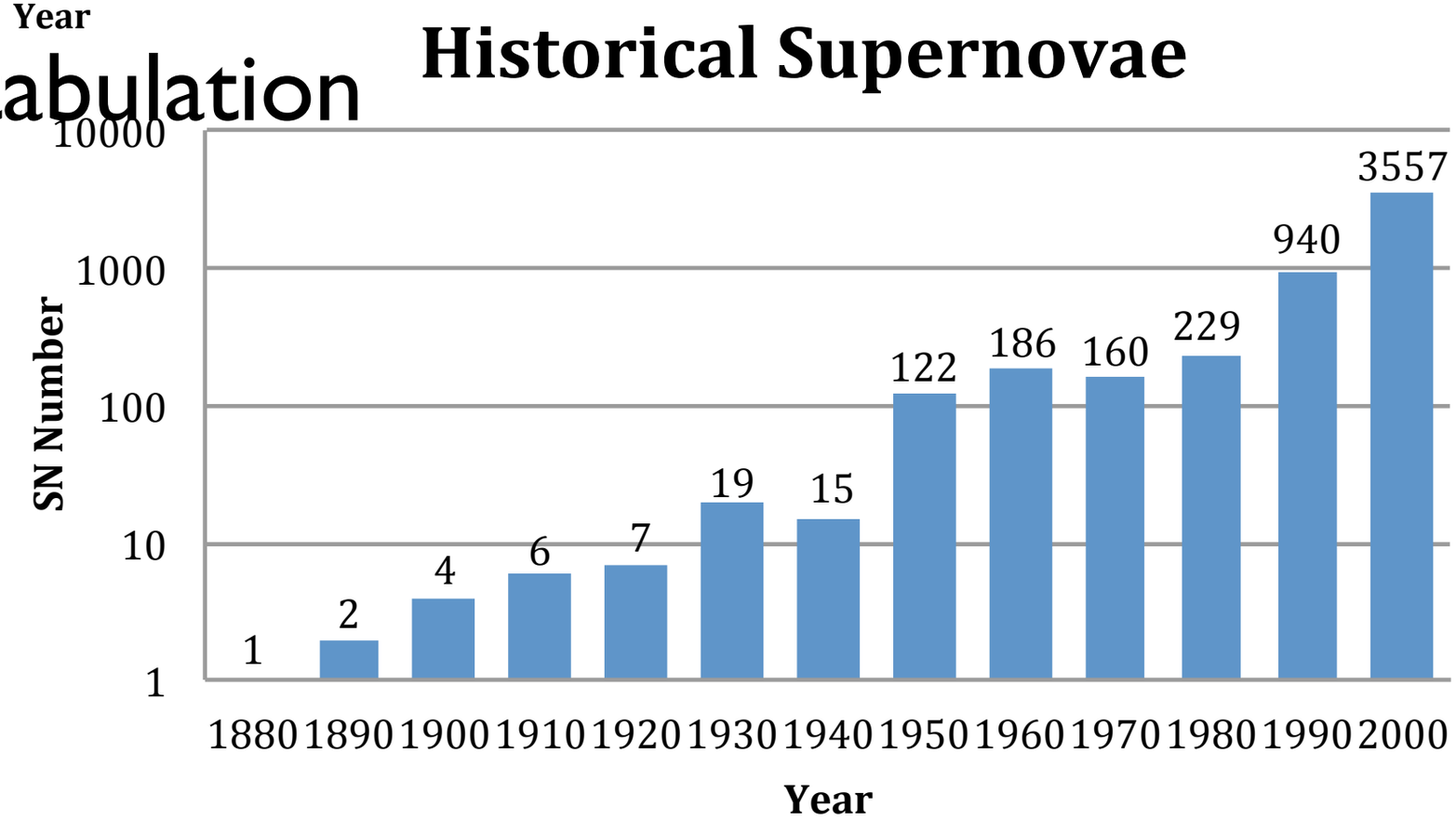

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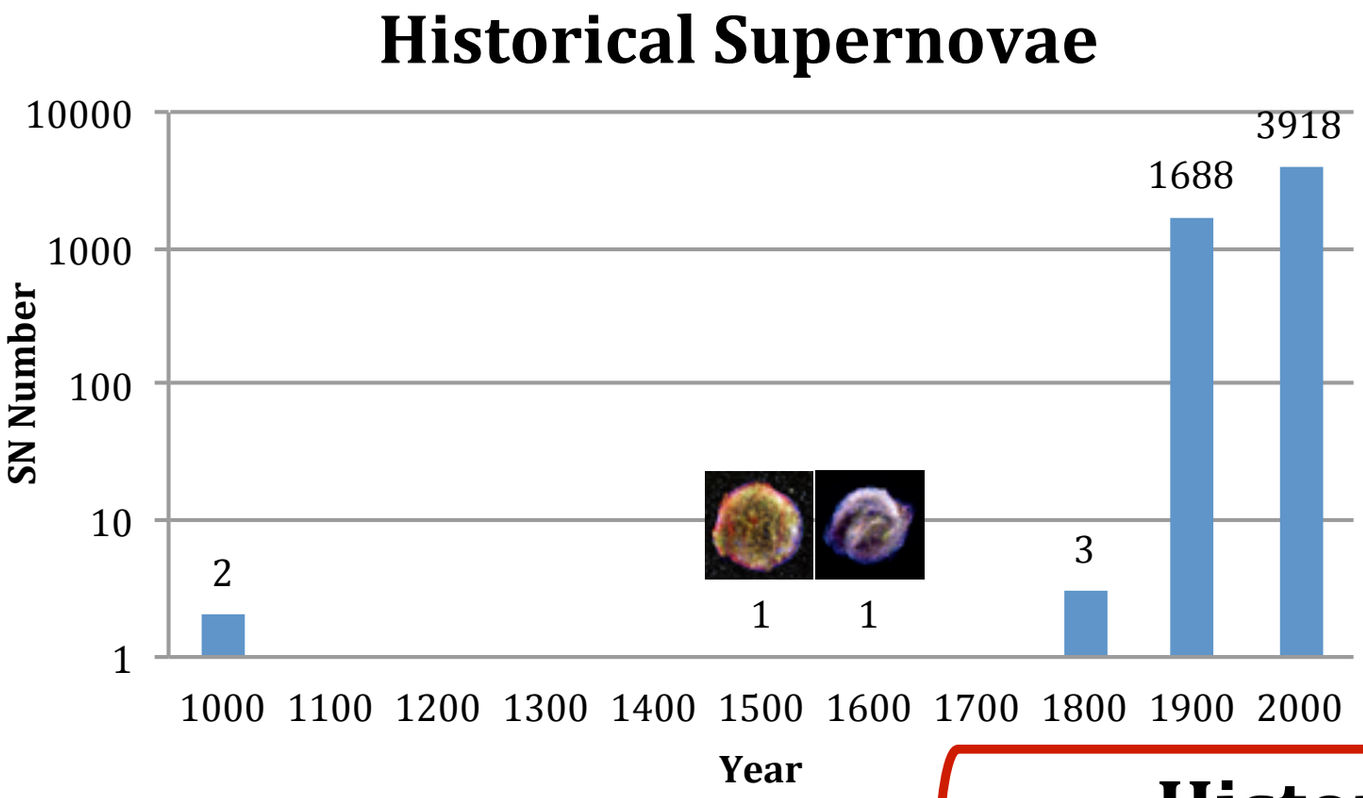

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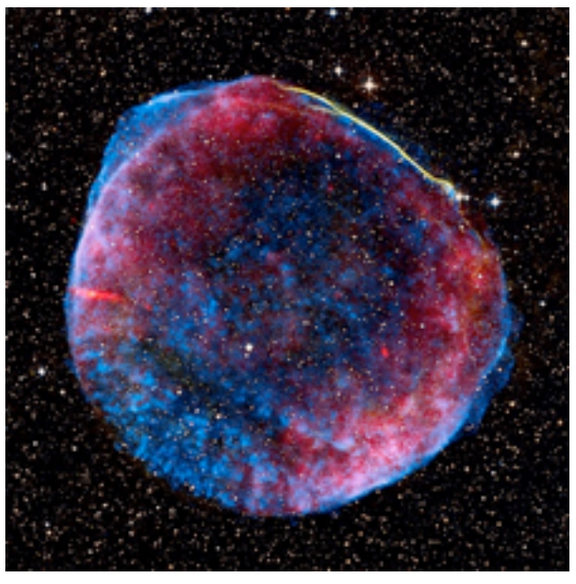

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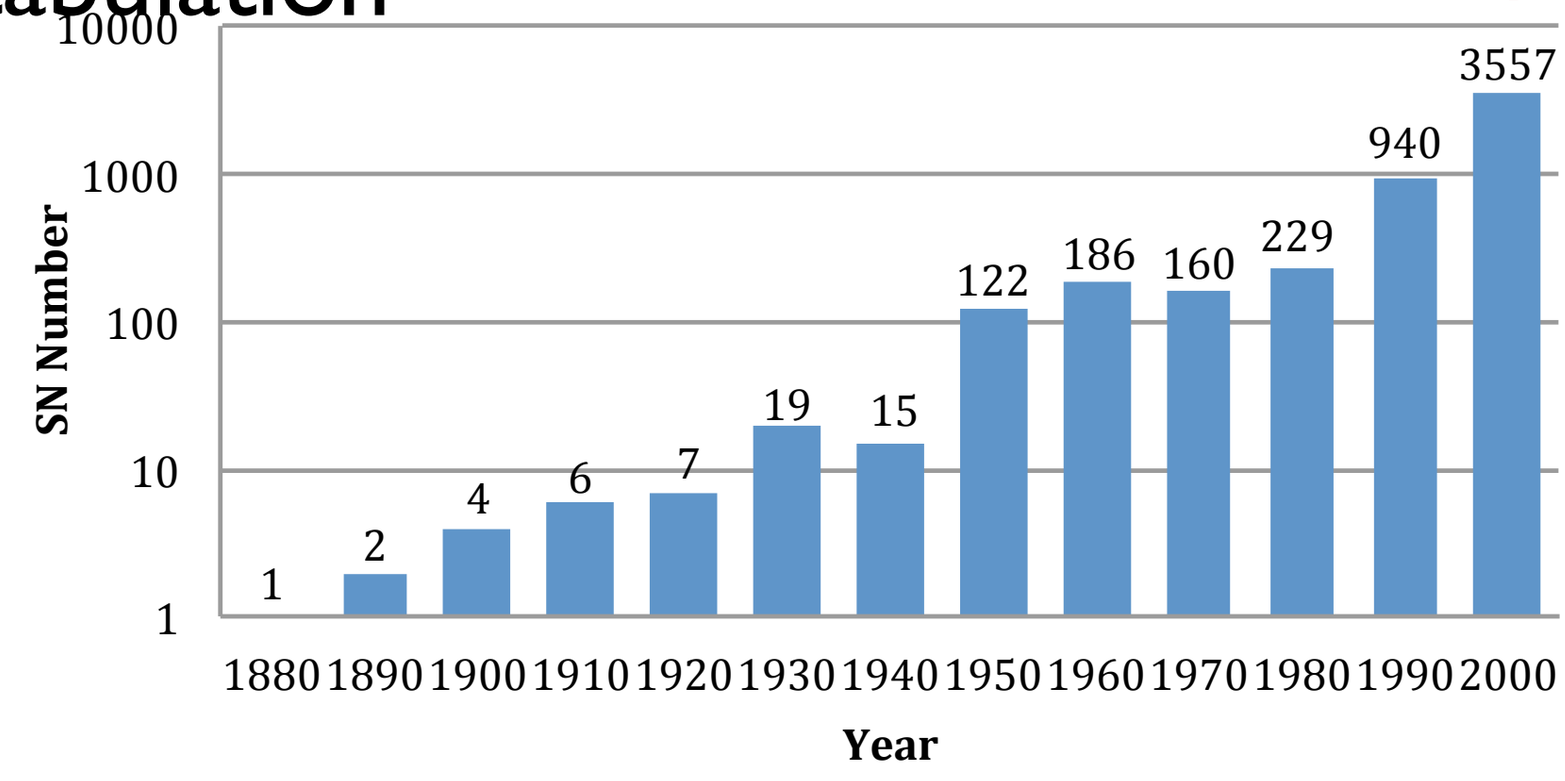
6300



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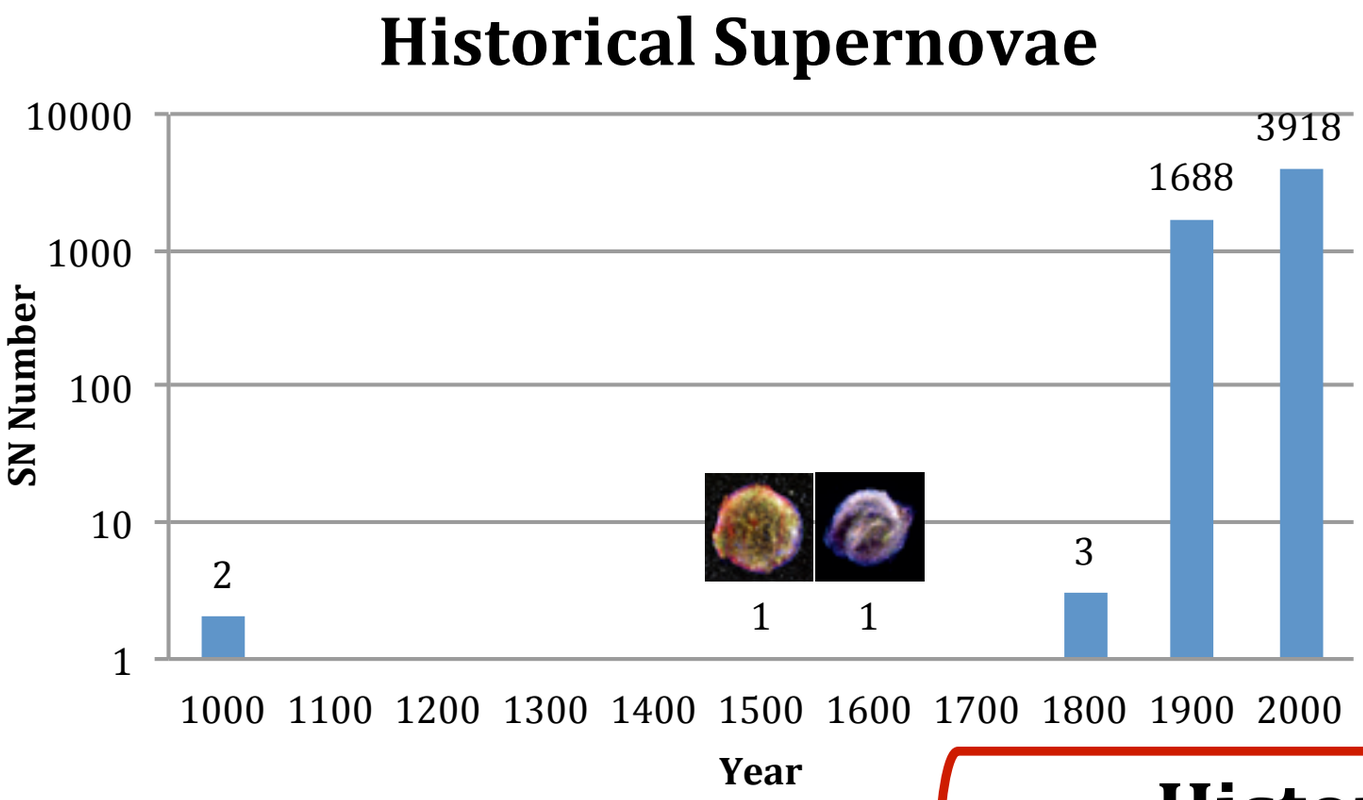

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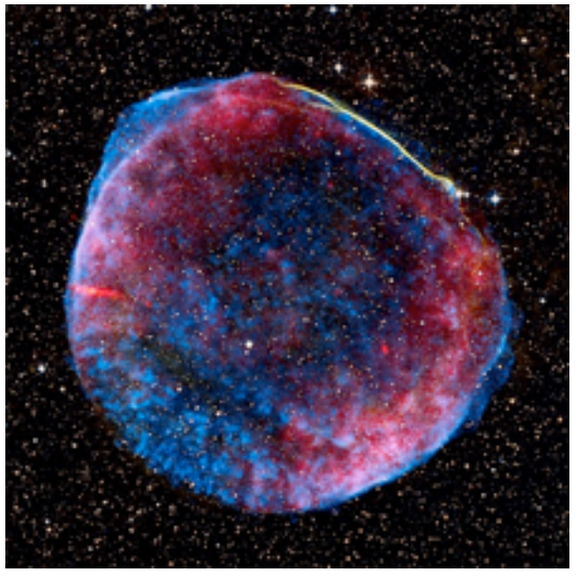

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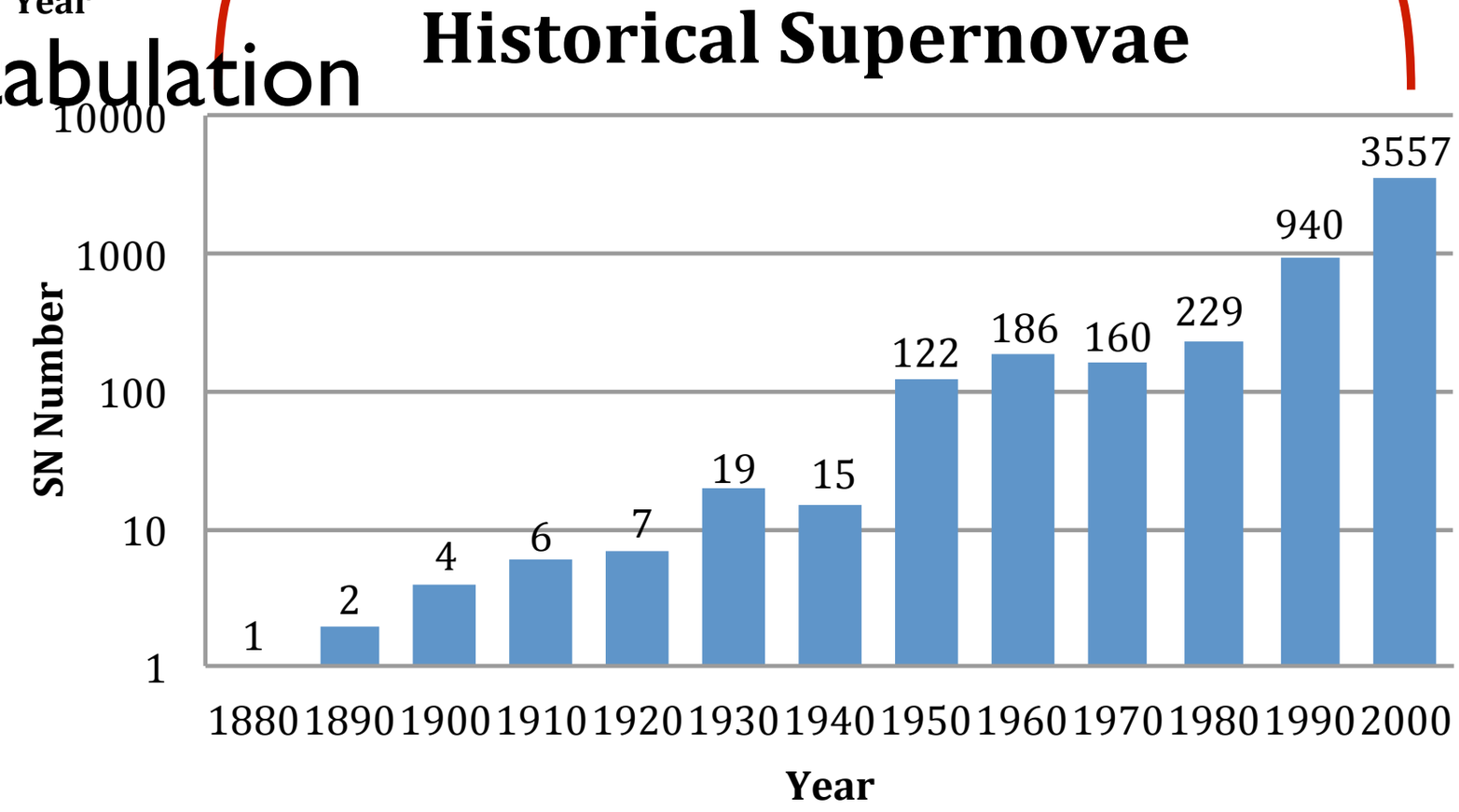


10^6

LSST

What can we do with 10^6 CC supernovae?
Demographics & Classification

★ volume limited to 200 Mpc (z=0.05):

complete, unbiased sample of supernova types

~all host galaxies visible!

progenitor stars can be seen in nearest events

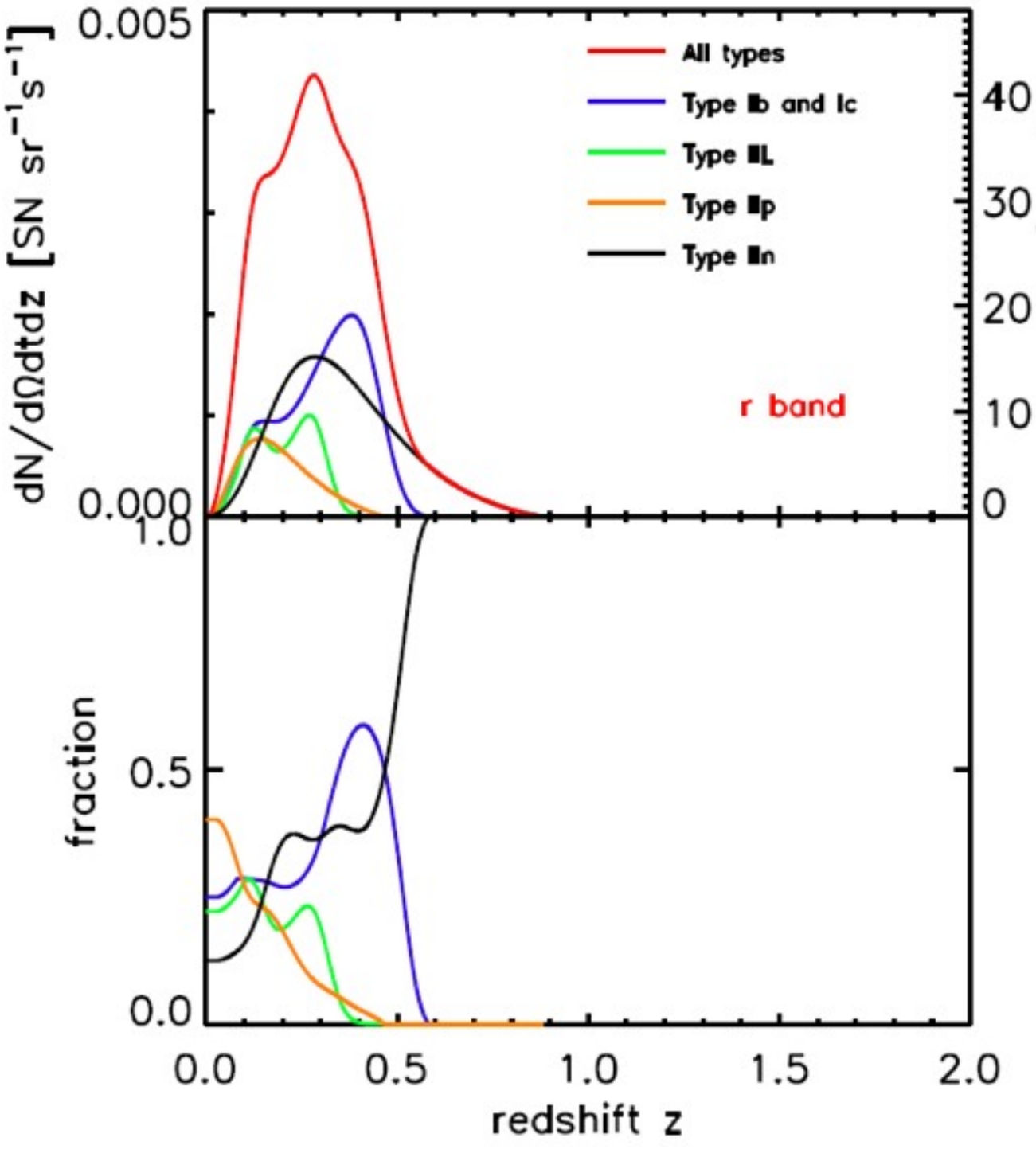
★ high statistics out to z~0.5

dependence on galactic and cosmic environment

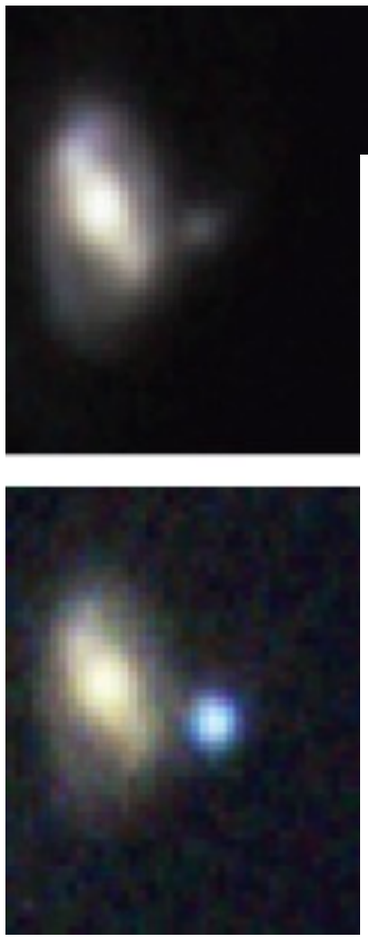
rare events become commonplace (fizzle? AIC?)

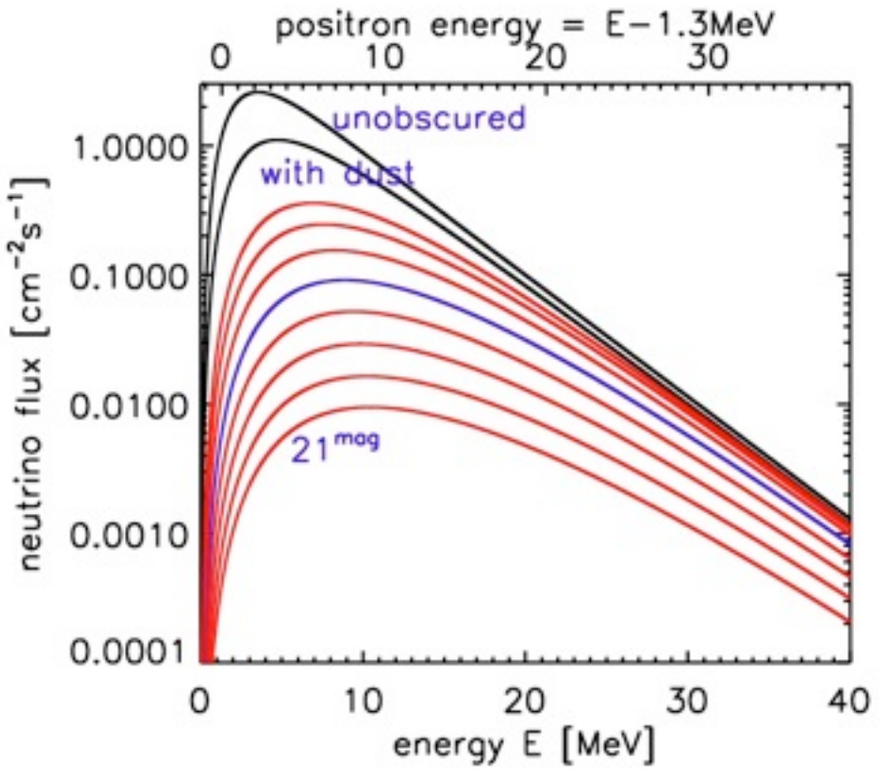
★ deep drilling events to z~1.5

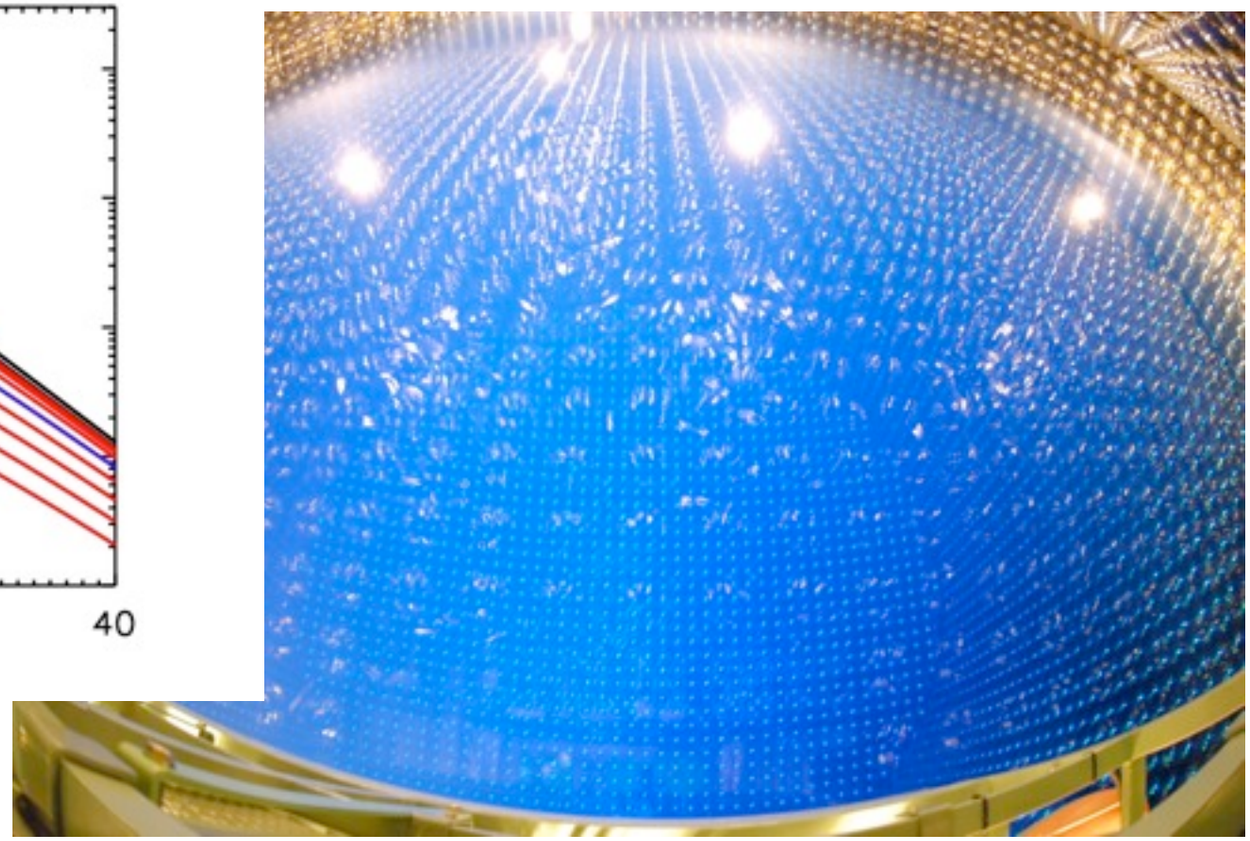
set by bright tail of luminosity function: how high does it go?



Survey Supernovae: Neutrino Impact







What can we do with 10^6 supernovae?

Diffuse Supernova Neutrino Background

Lunardini talk

- ★ Only very local SNe resolved in neutrinos
- ★ But supernovae out to cosmic horizon
  unresolved, diffuse supernova nu background

  Gusienov, Zeldovich 67; Krauss, Glashow, Schramm 84

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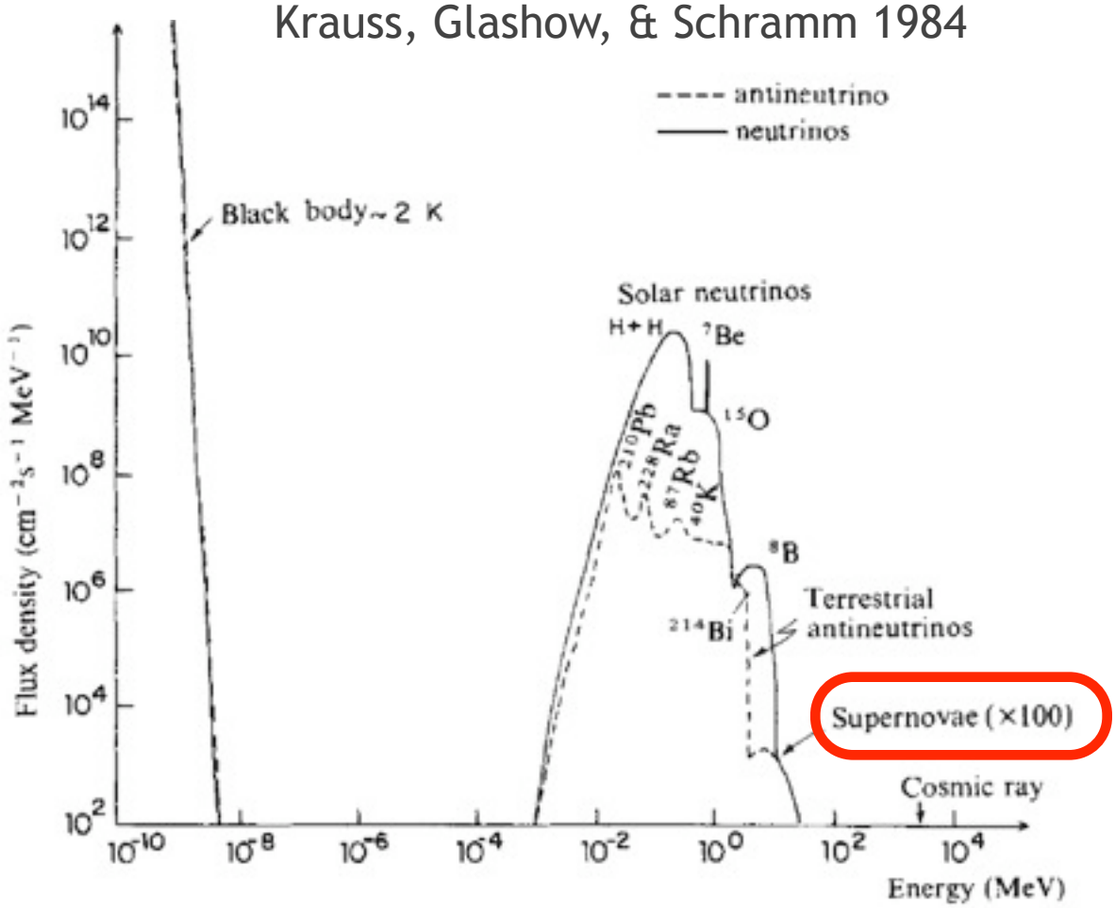

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$$\frac{d\Phi_\nu}{d\epsilon_\nu} = \int_0^\infty dz \left|\frac{dt}{dz}\right| (1+z) \frac{dq_{\rm comov}}{d\epsilon_\nu^{\rm em}}$$

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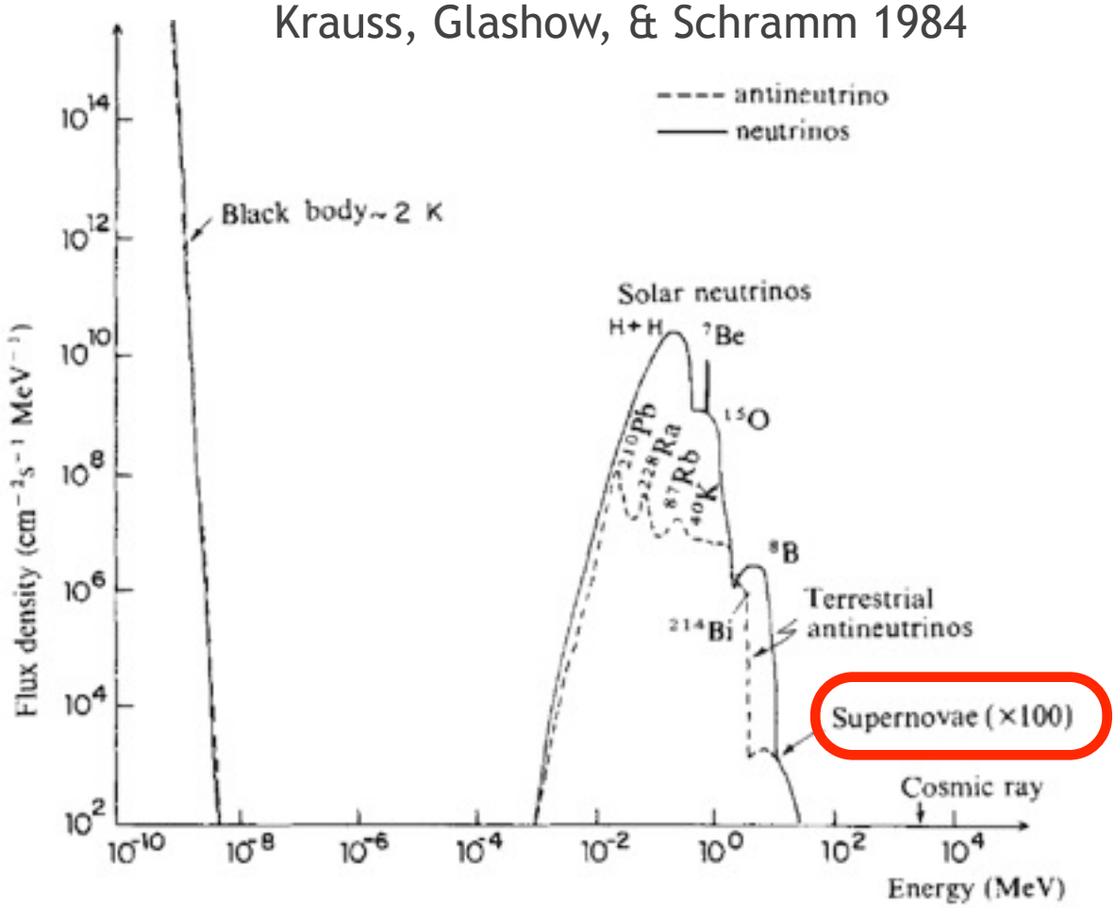

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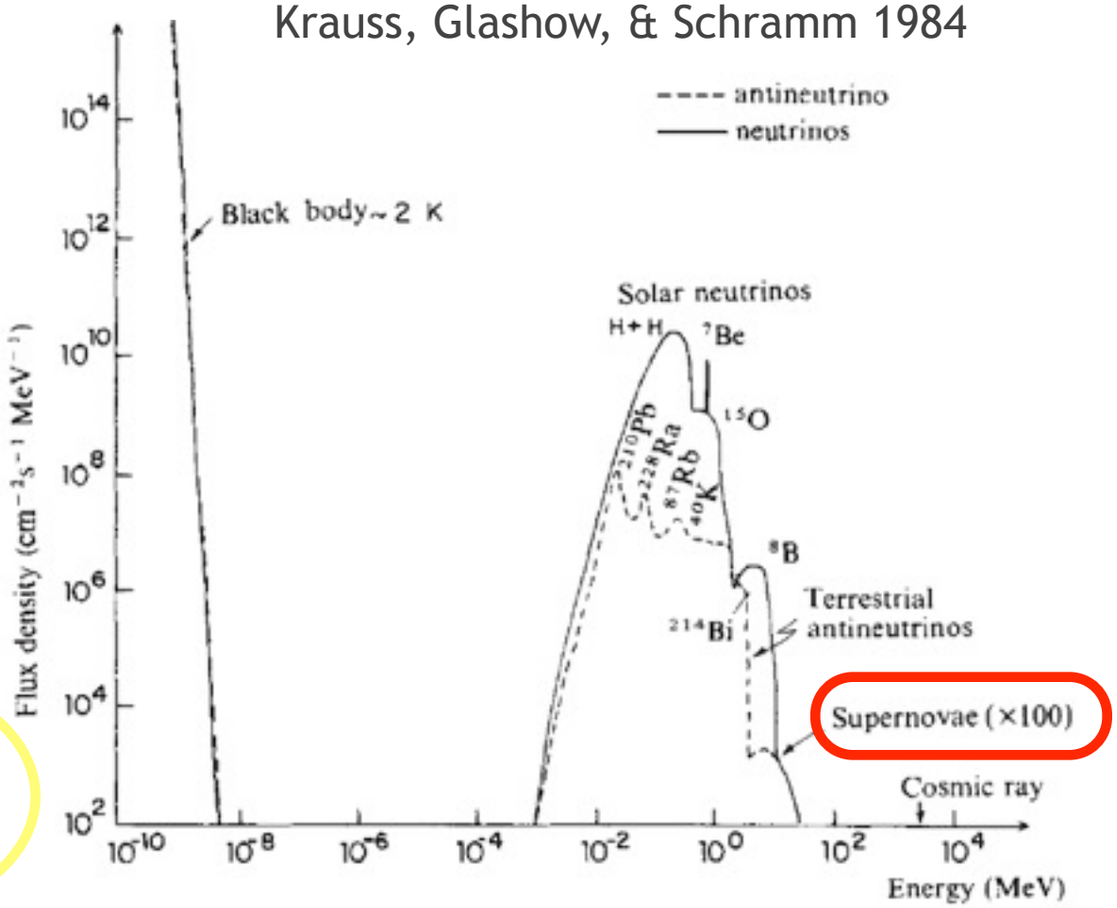

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Source function: separates

$$\frac{dq_{\rm comov}}{d\epsilon_\nu^{\rm em}} = \mathcal{R}_{\rm SN}(z) \left.\frac{dN_\nu}{d\epsilon_\nu^{\rm em}}\right|_{\epsilon_\nu^{\rm em}=(1+z)\epsilon_\nu}$$

neutrino output per SN

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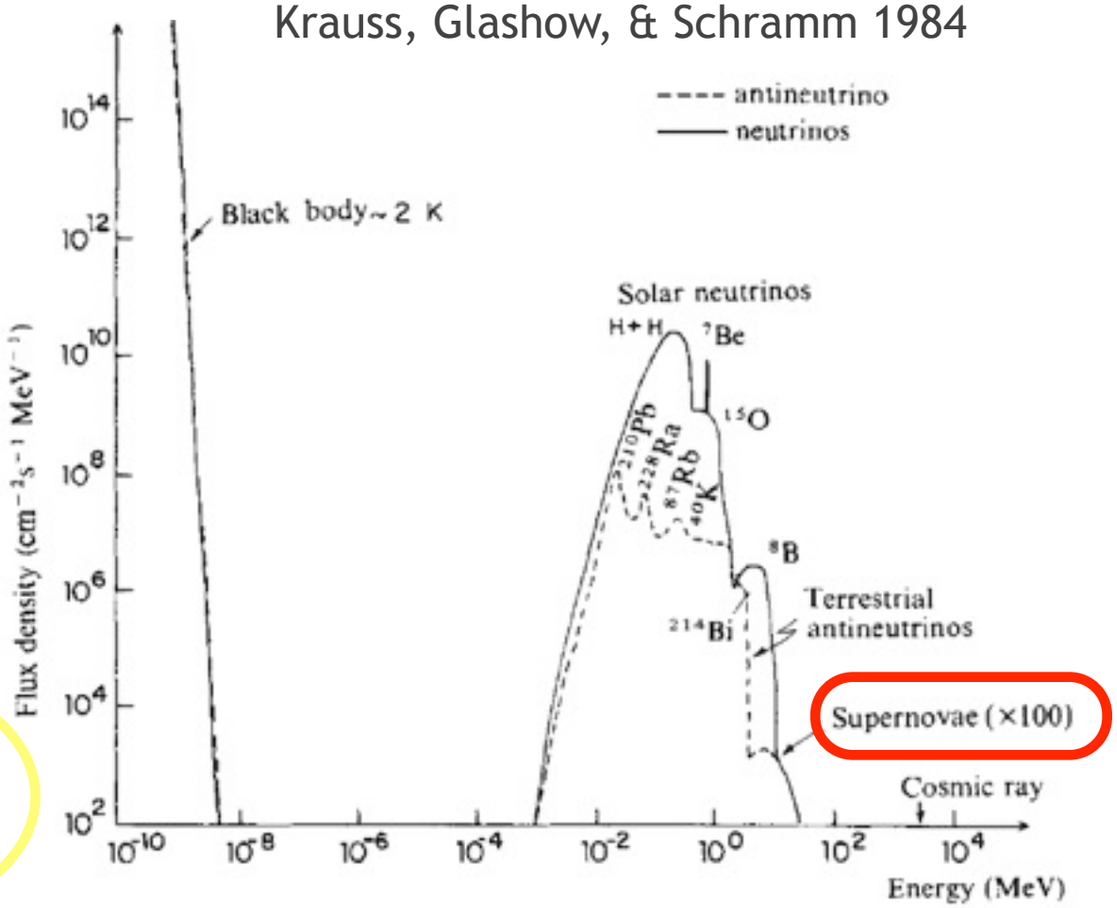

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cosmic supernova rate

$$\left.\frac{dN_\nu}{d\epsilon_\nu^{\rm em}}\right|_{\epsilon_\nu^{\rm em}=(1+z)\epsilon_\nu}$$

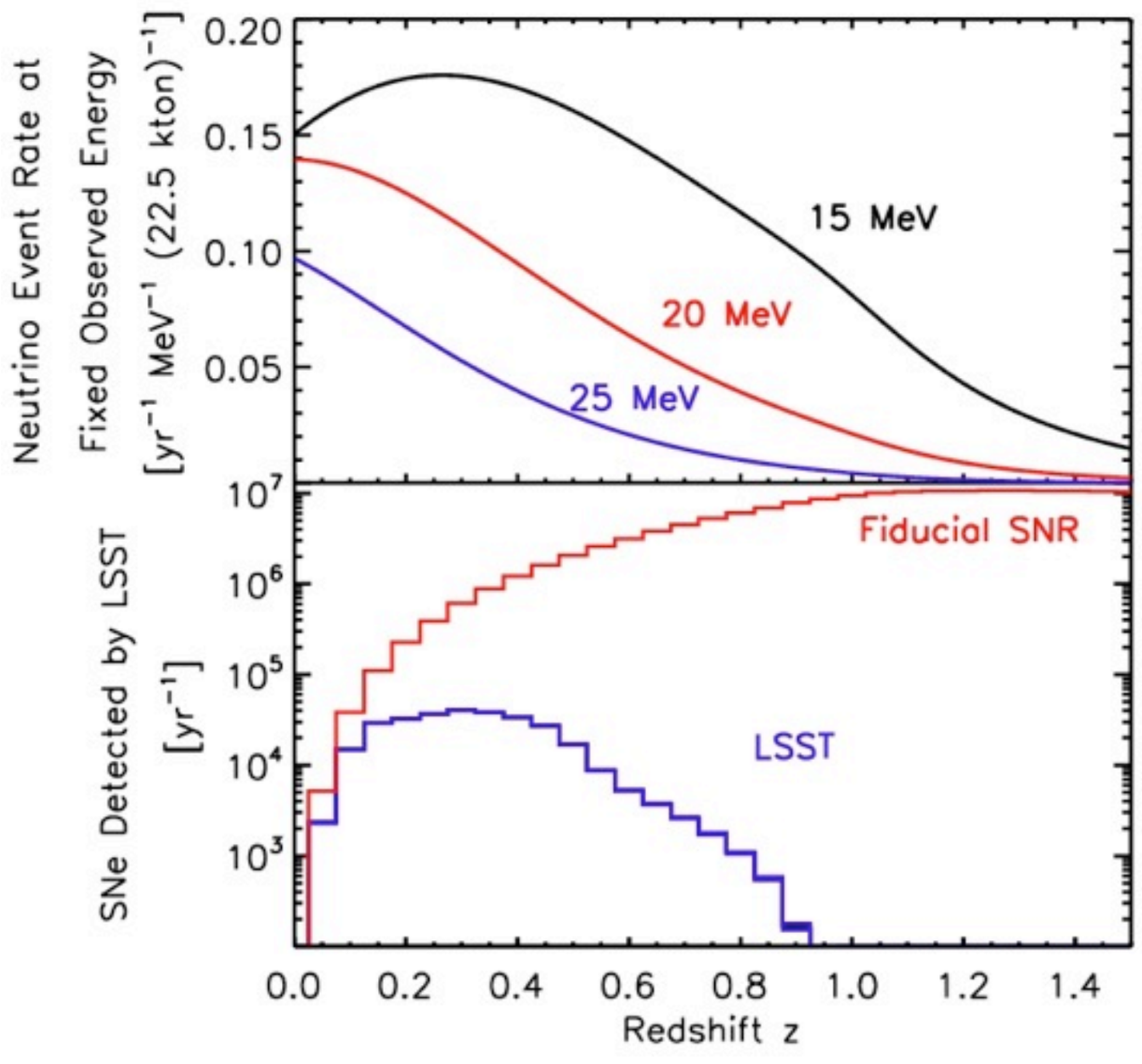
neutrino output per SN

Synoptic Surveys and the DSNB

Lien, BDF, and Beacom 2010

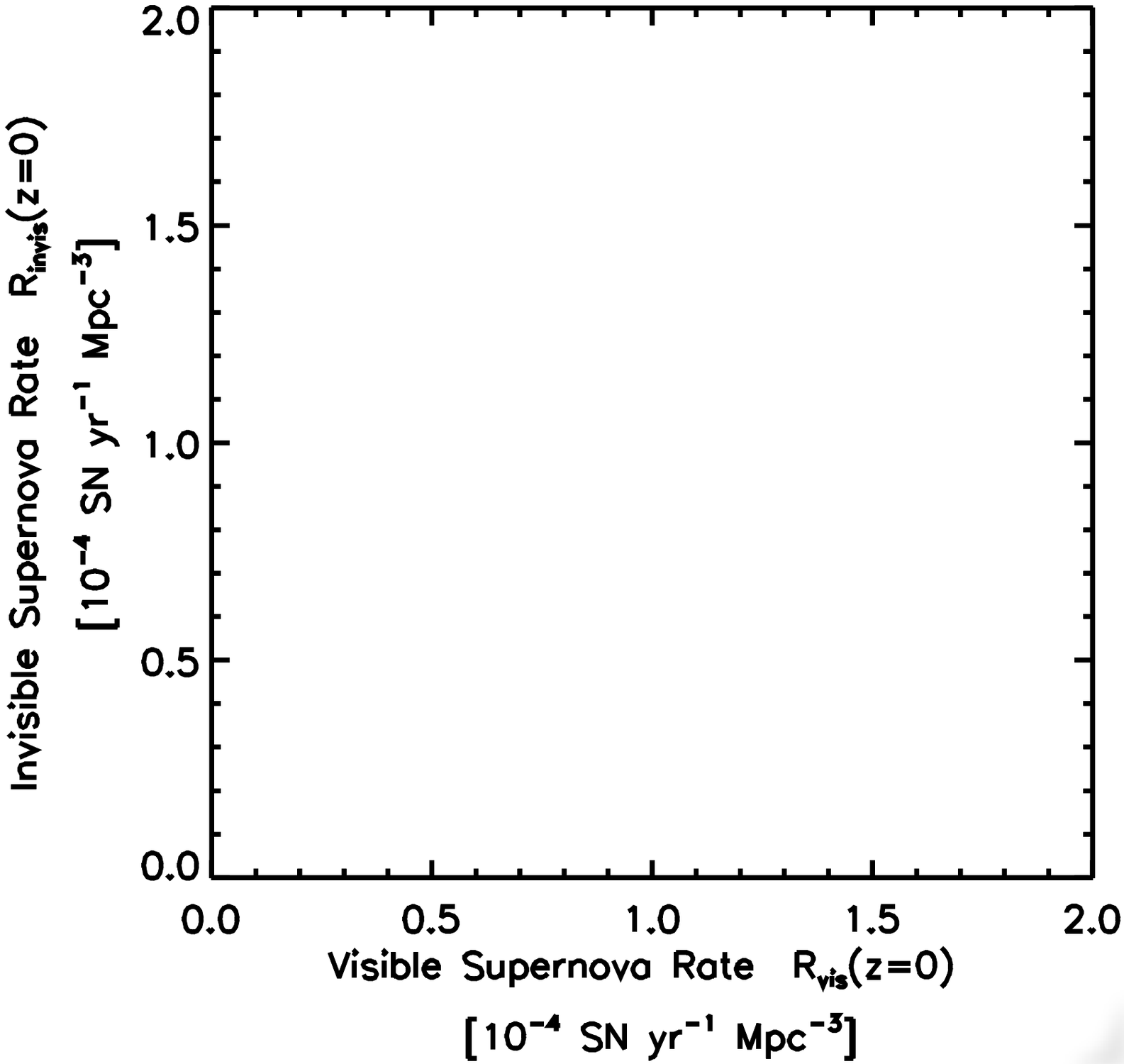
- ★ Synoptic surveys *directly observe* large fraction of nu-producing SNe out to z~1
- ★ Most of DSNB signal is from z<1
- ★ Surveys remove astrophysical rate uncertainty
- ★ Resulting DSNB flux is hard lower limit

  omits dust-obscured or failed SN
- ★ energy dependence separates low/high redshift sources



Revealing Failed Supernovae

- Failed SN
  - Collapse
    - → Black hole
  - No optical explosion
  - Neutrino emission same or enhanced!
- Missed in optical SN surveys
- Detected by neutrino observatories



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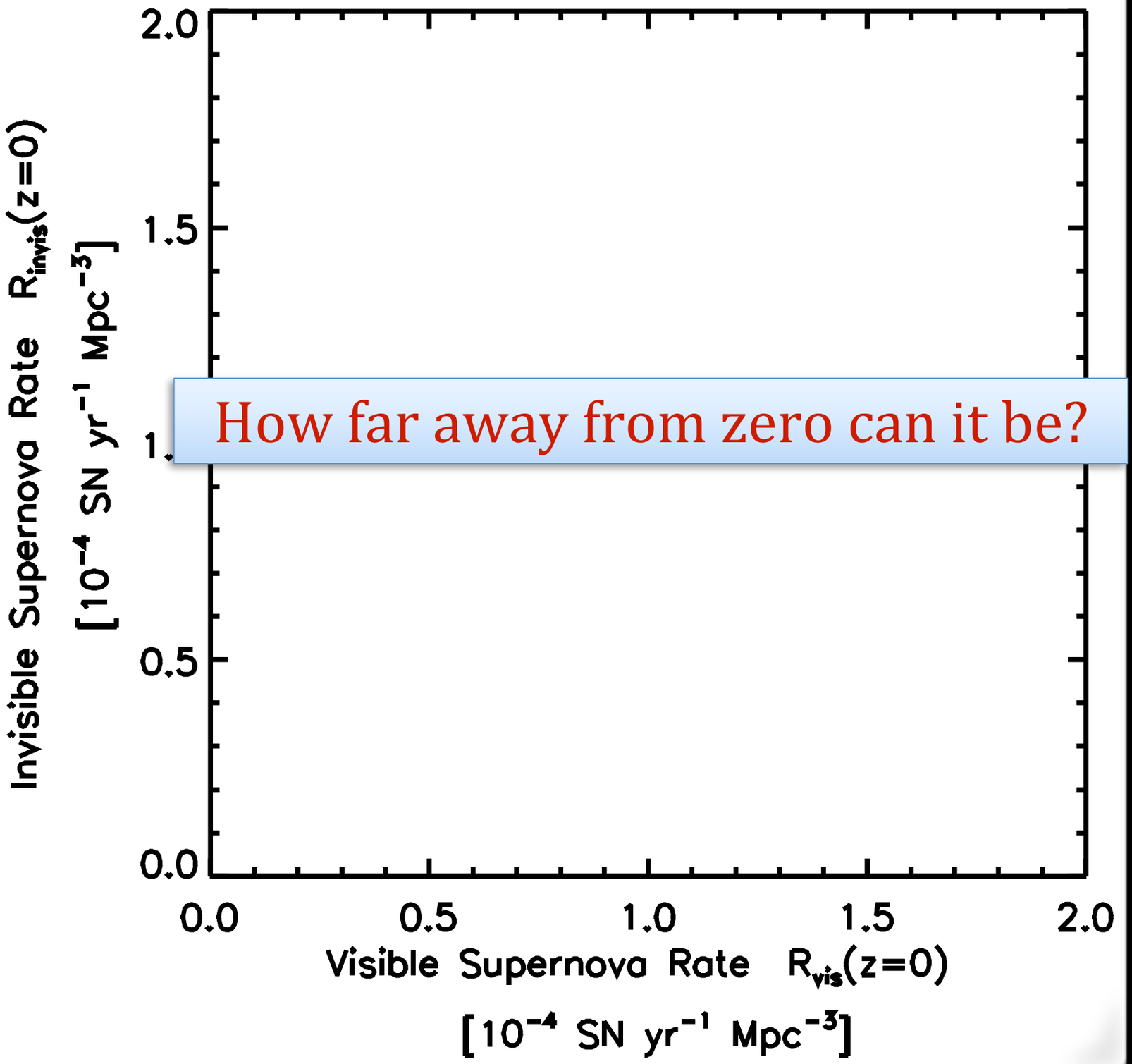

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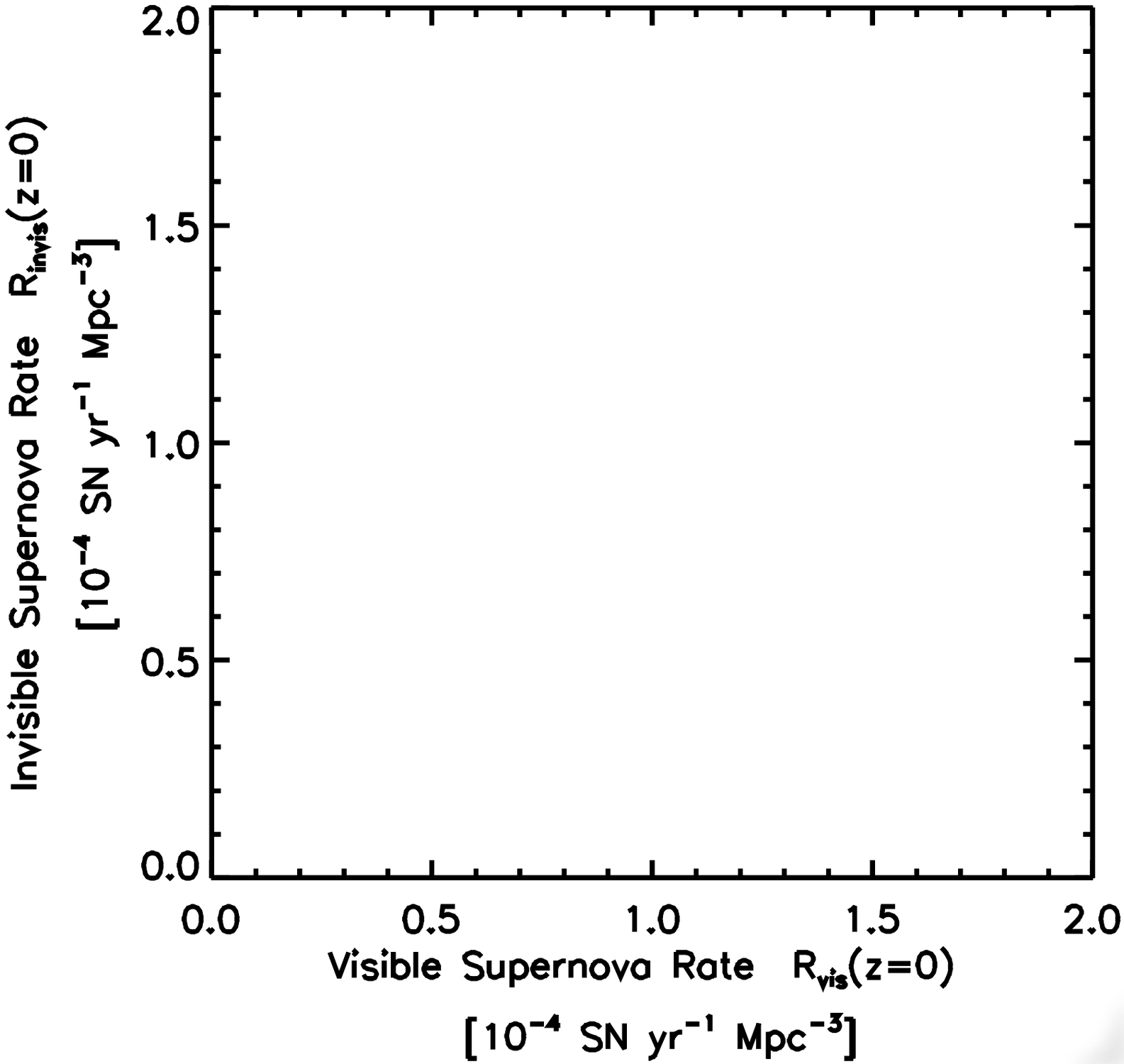

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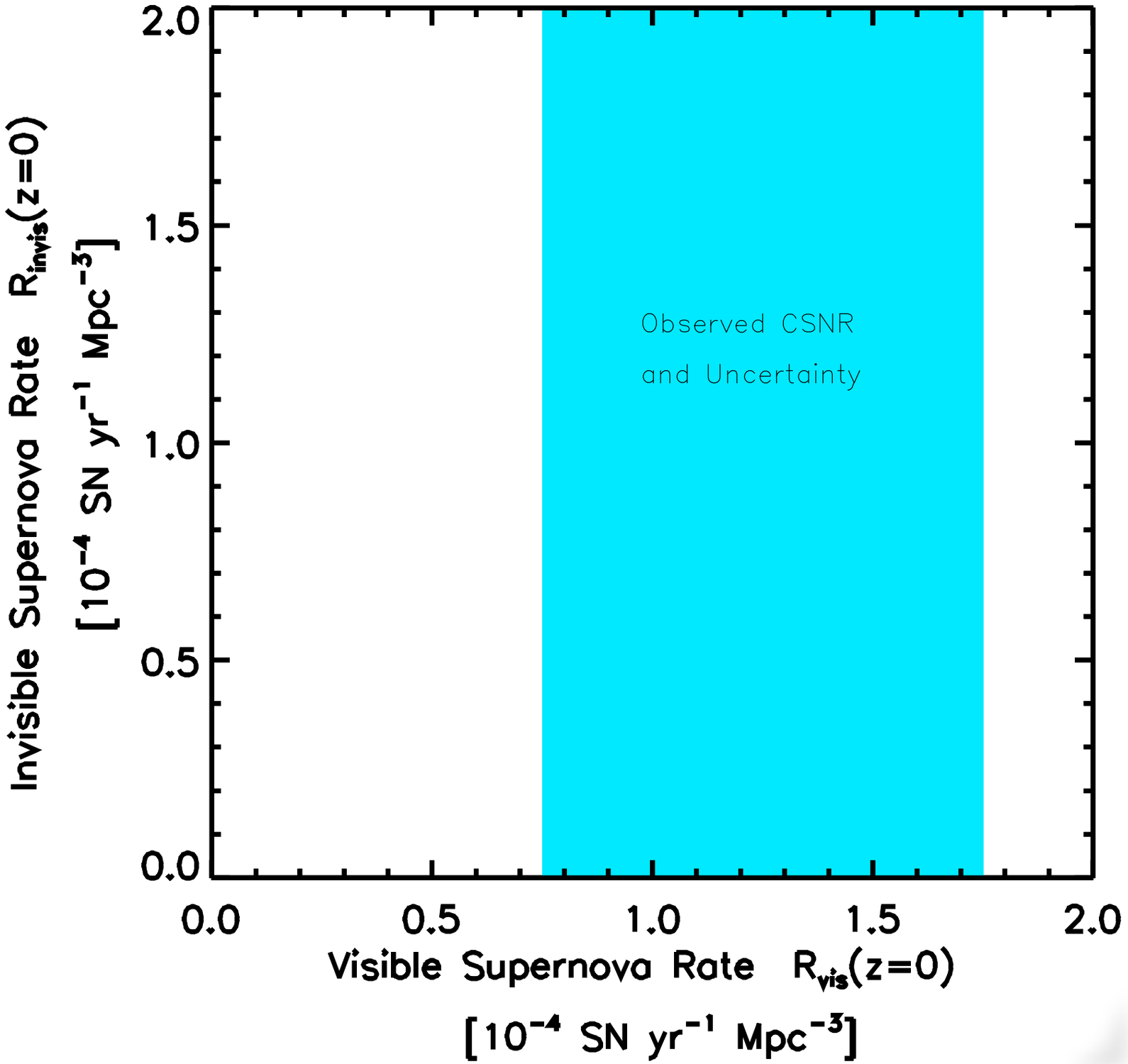

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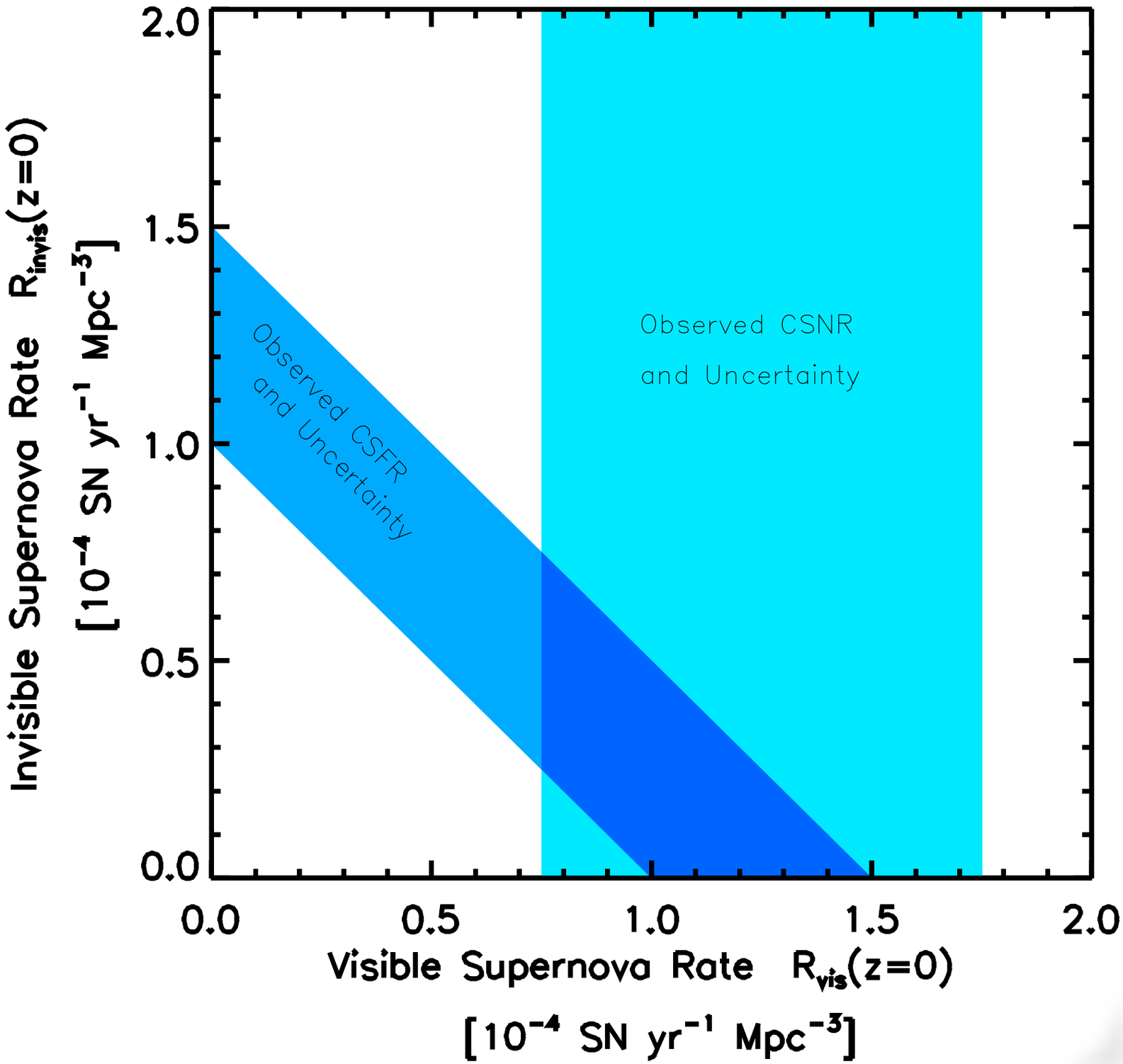

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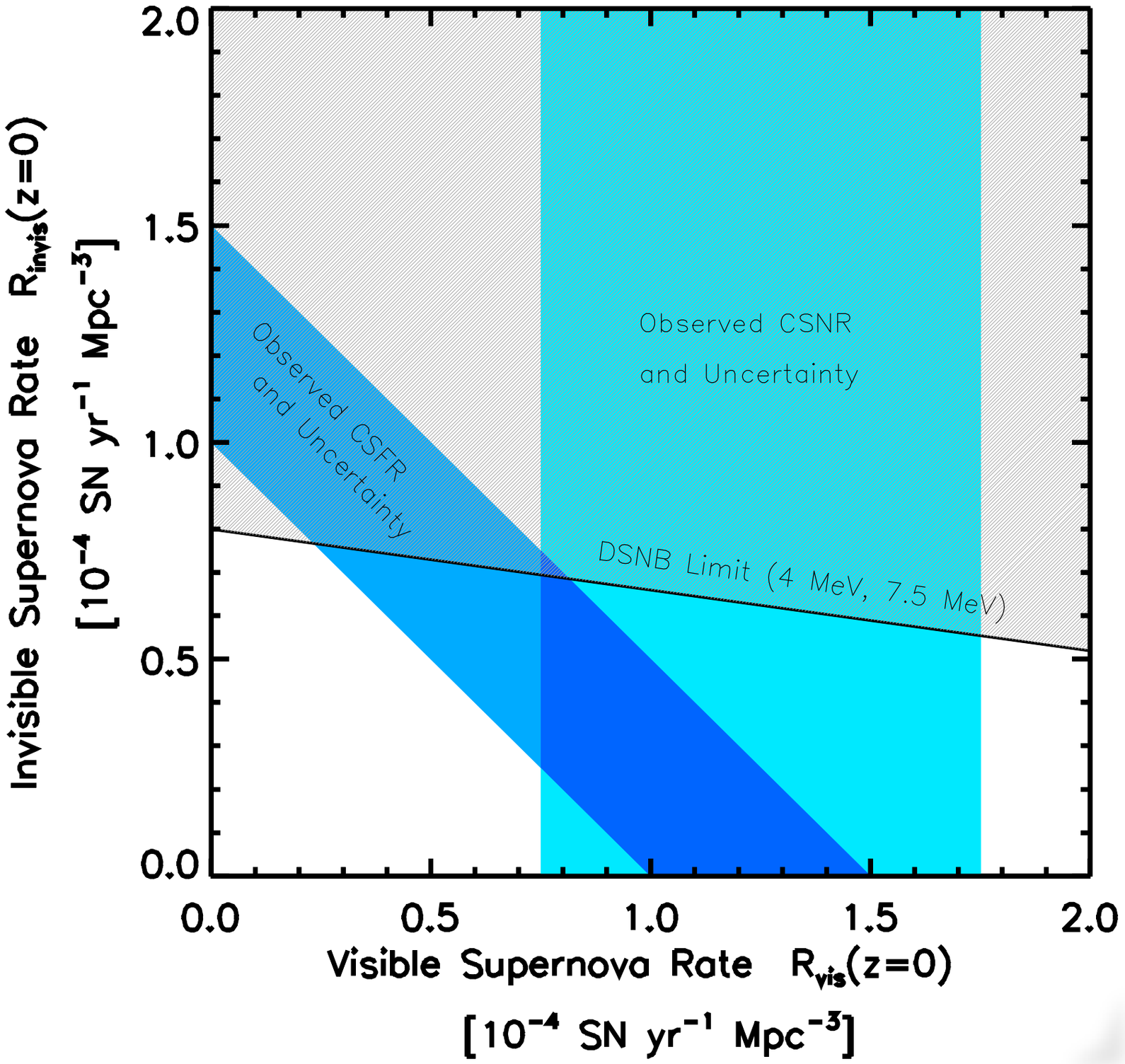

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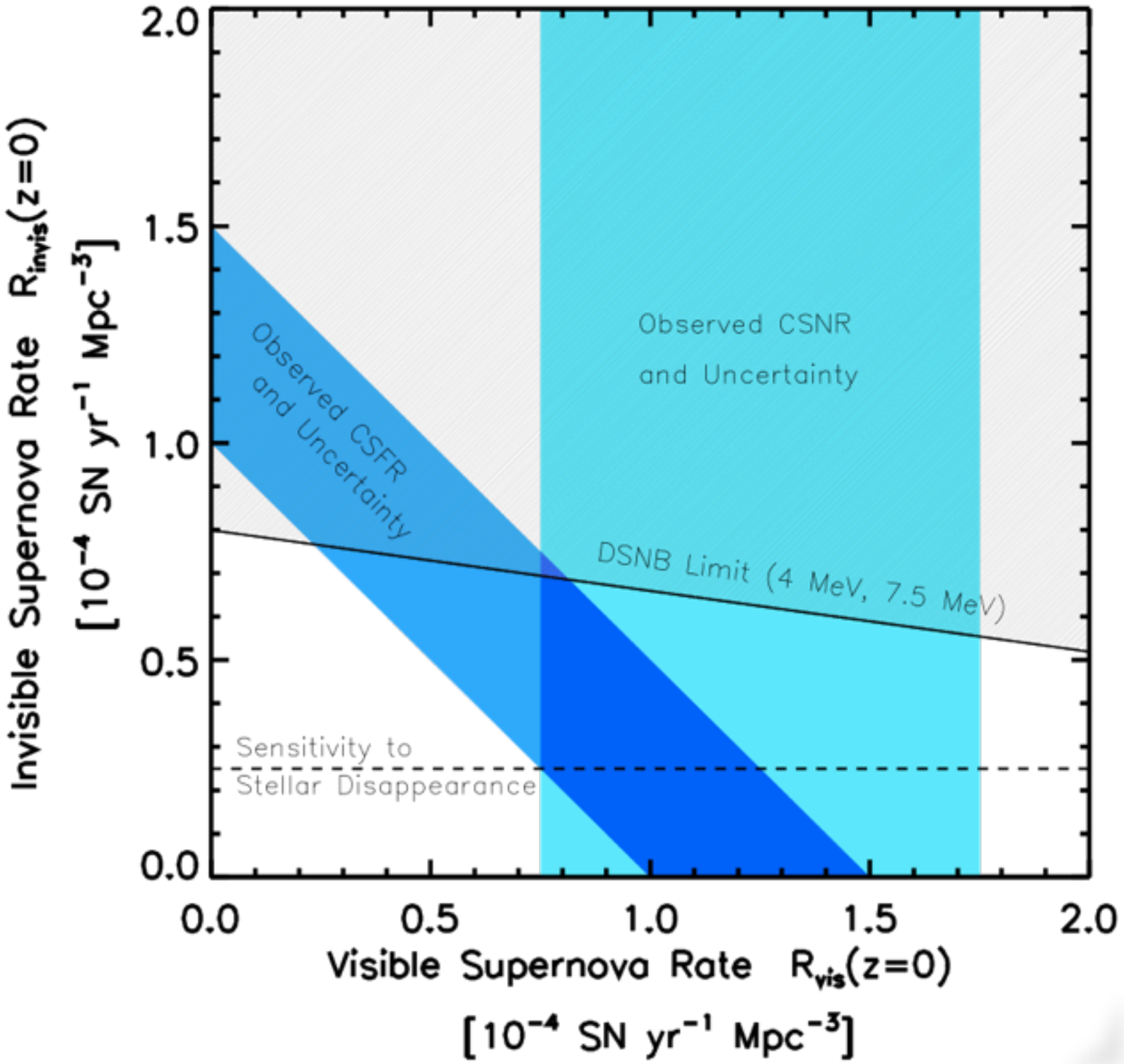

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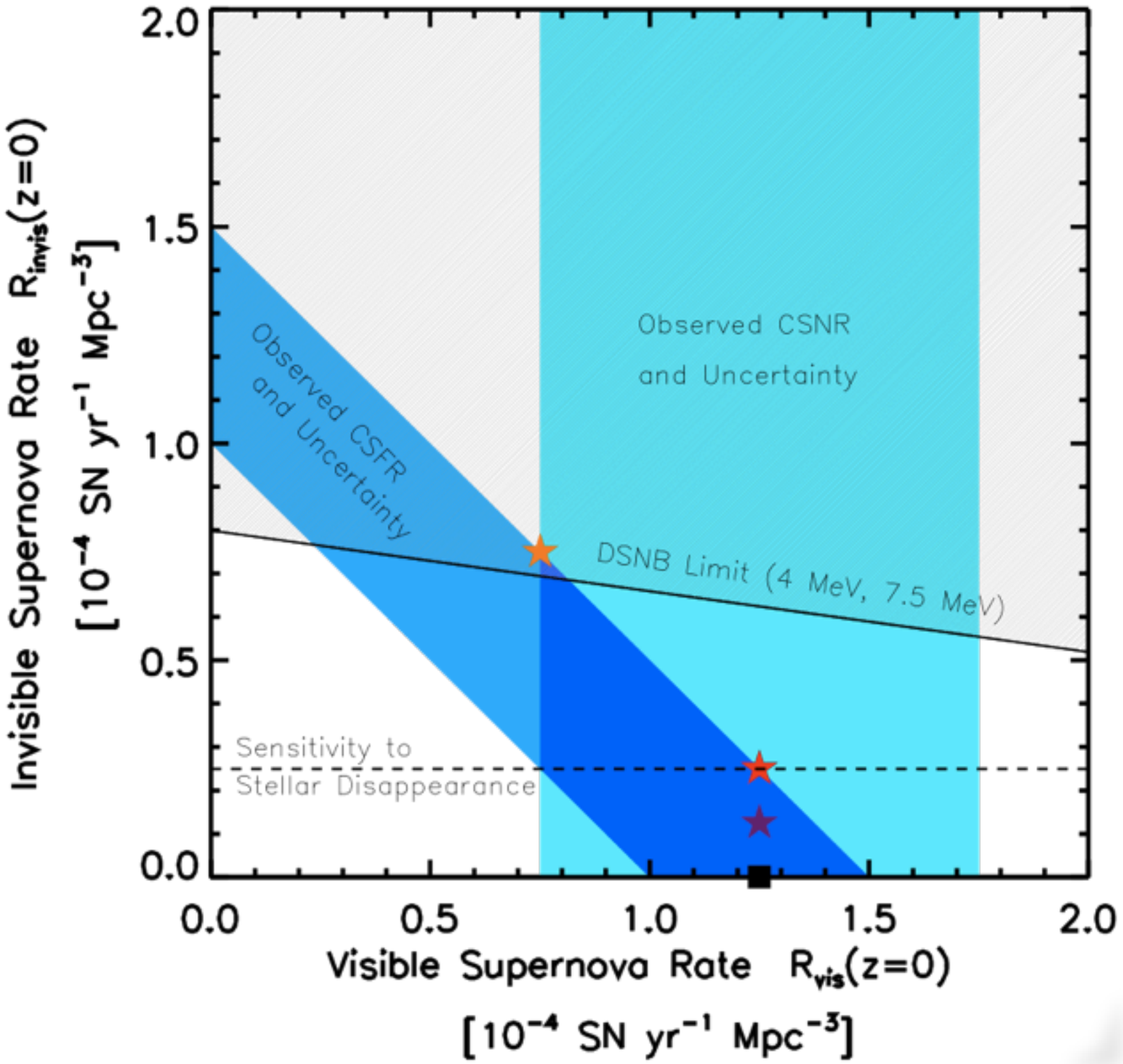

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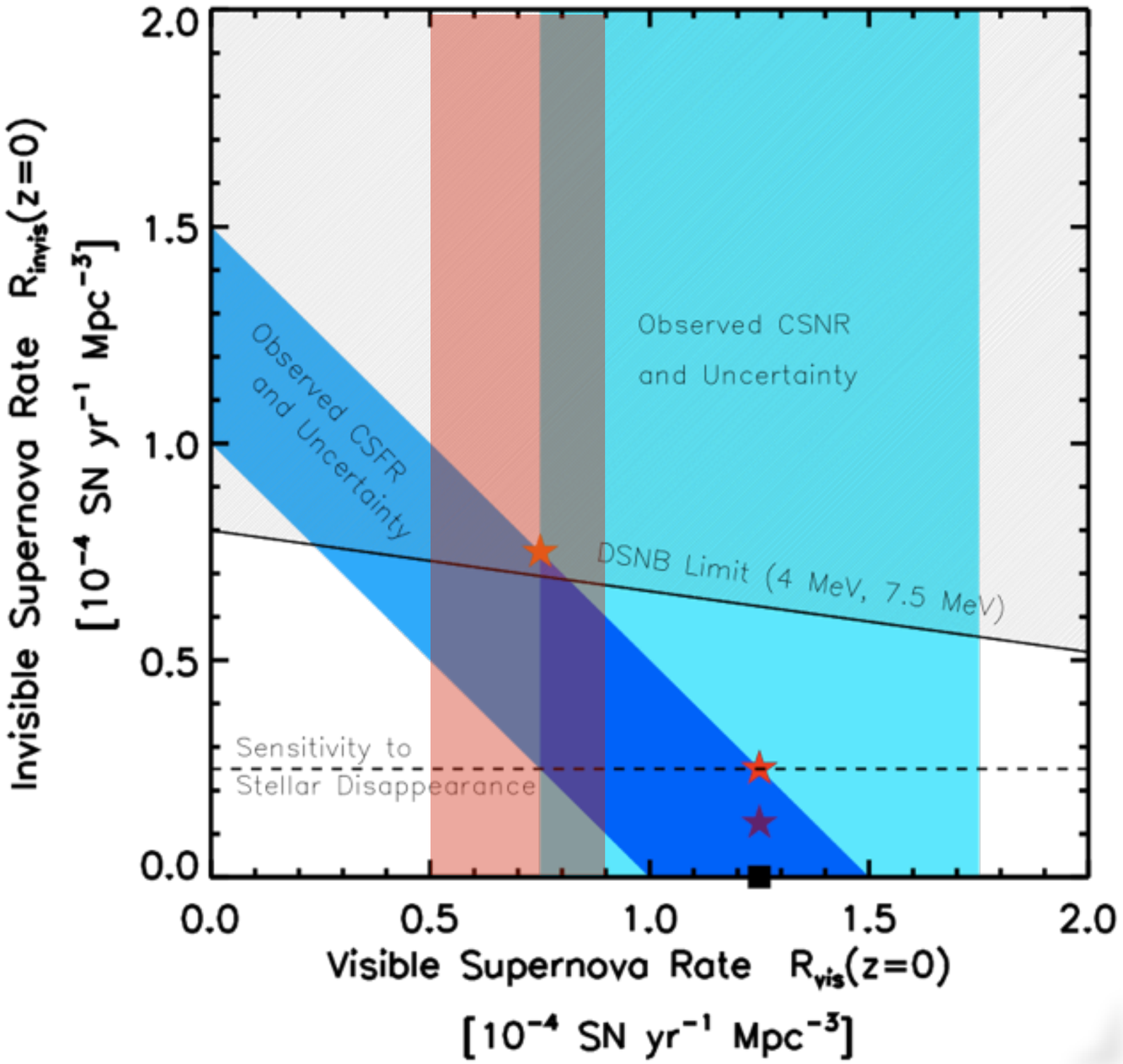
Li et al. 2010



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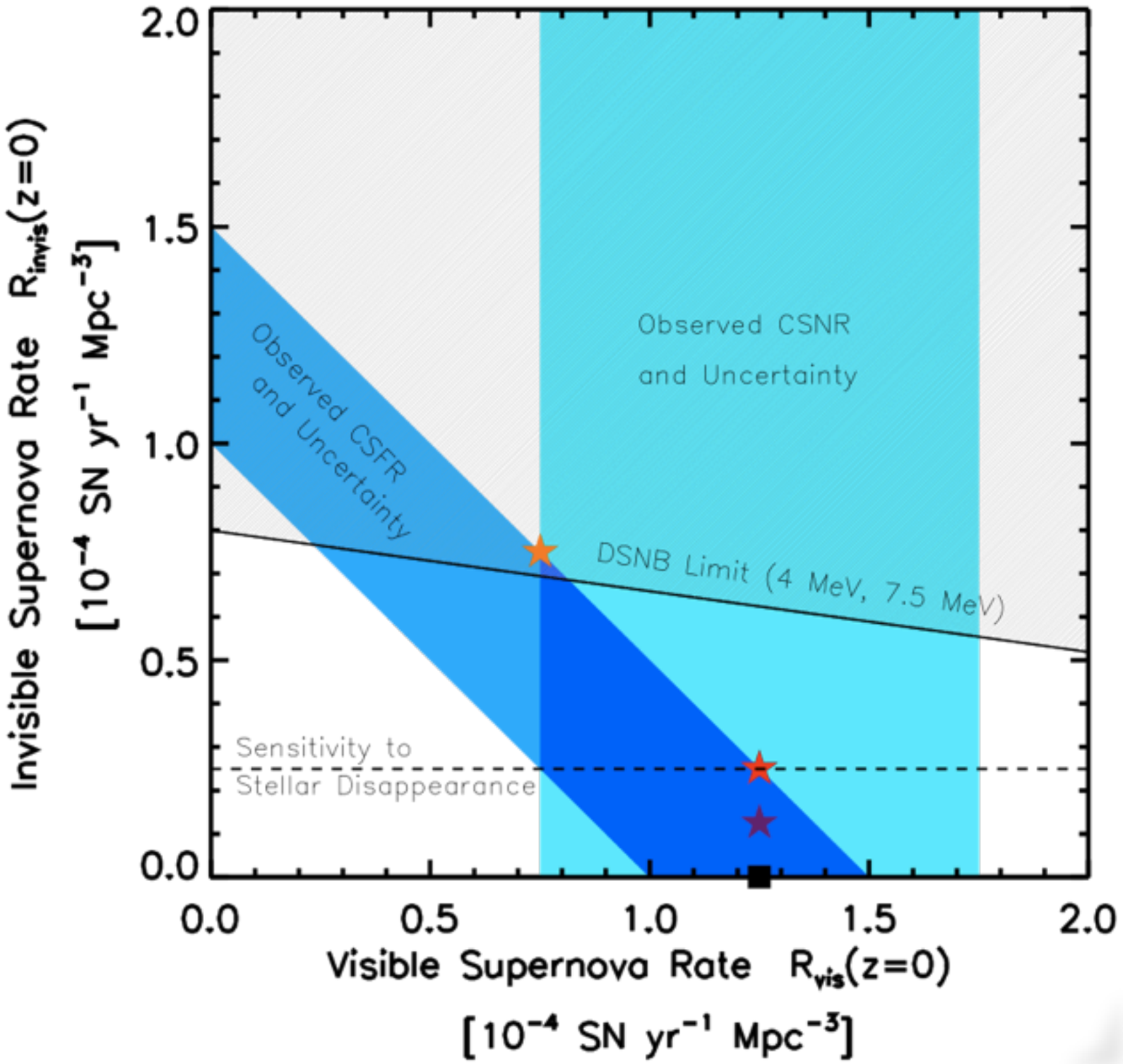

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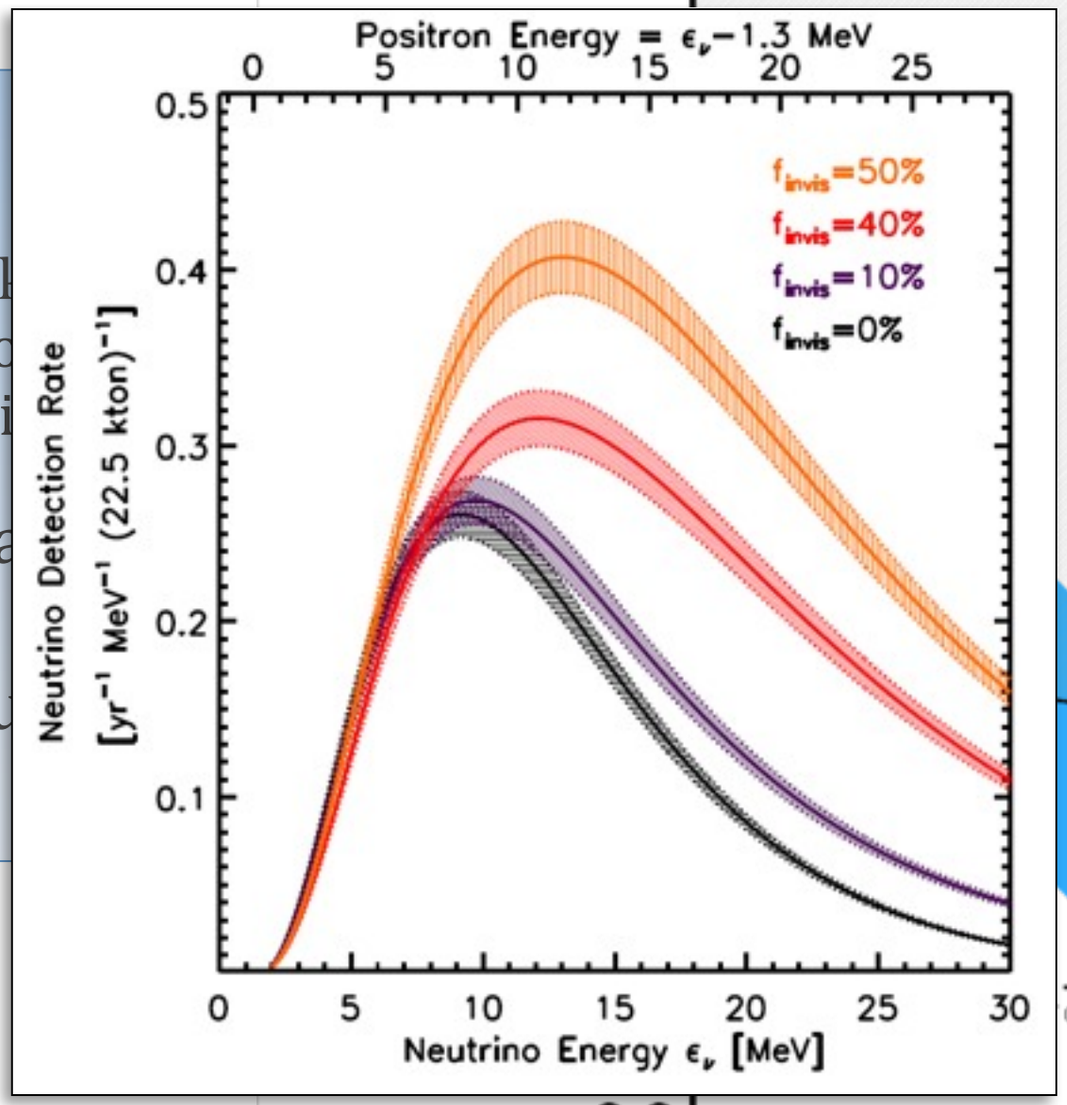

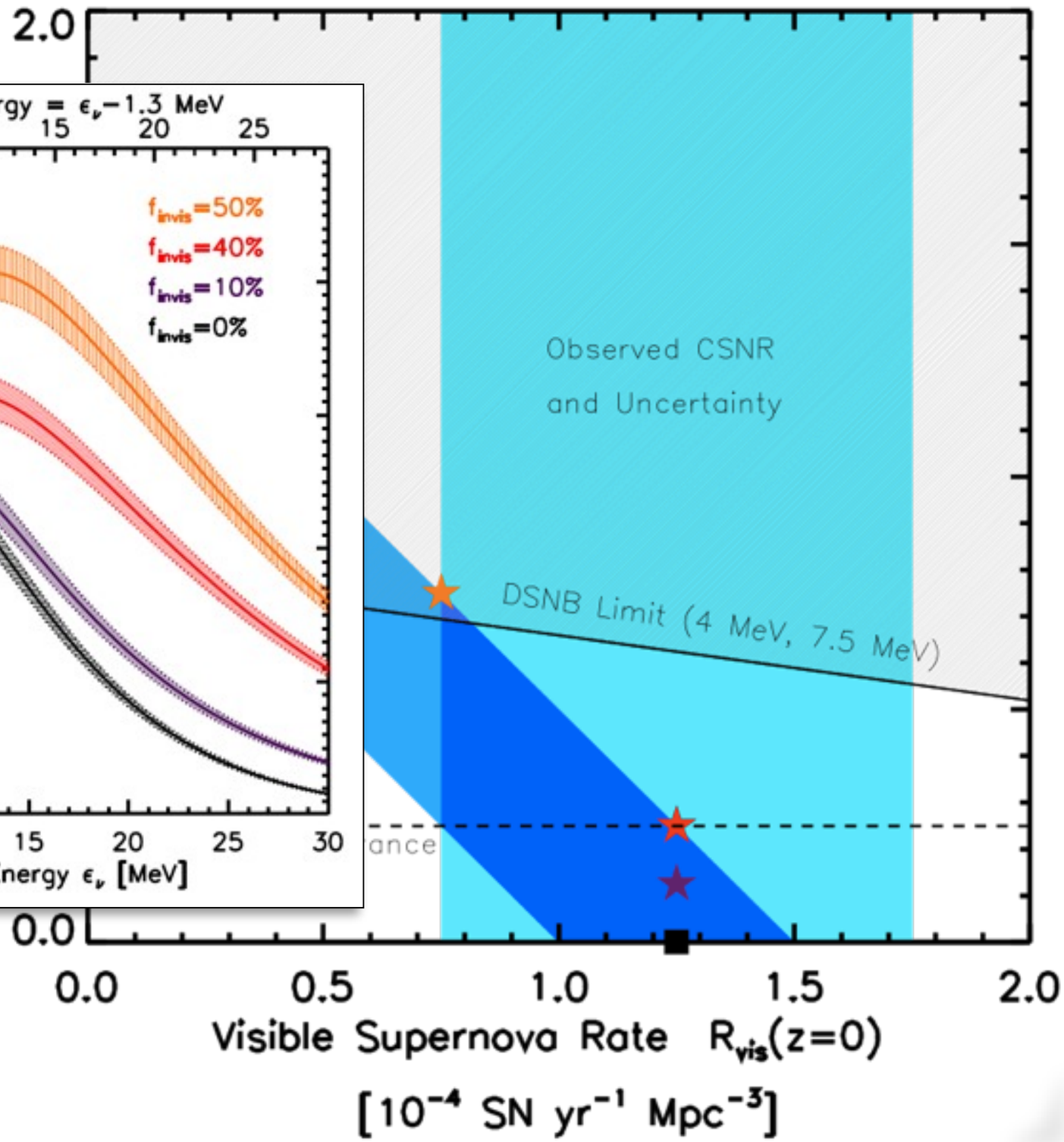

Outlook

★ Great Survey Era is dawning!

time-domain astronomy revolutionized

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★ Synoptic surveys ➡ supernova bonanza

core collapse come for free! all-sky, uniform datasets

volume limited CC sample to ~ 200 Mpc

large statistics to z~0.5

deep drilling to z~1.5

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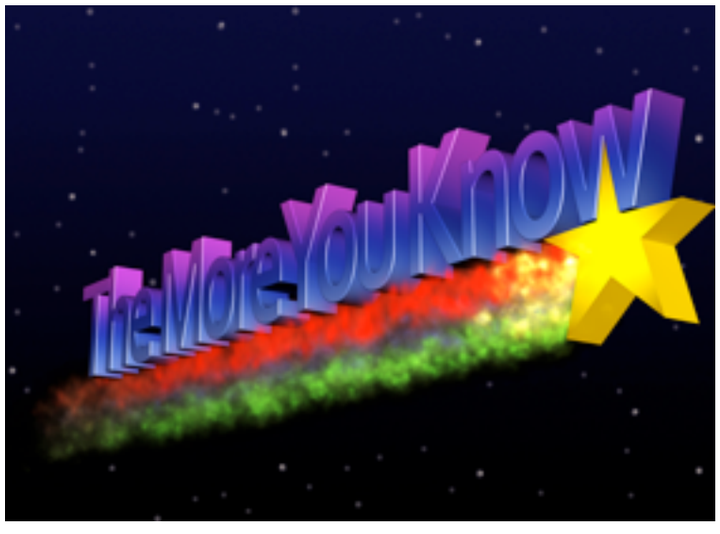
★ A great time to work on supernovae!

observers: now is the time to plan followup!

theorists: now is the time to lay your bets!

References



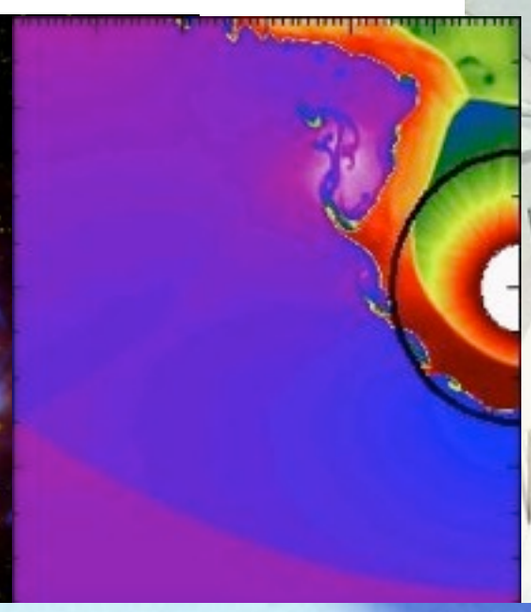
- **A. Lien and B.D. Fields 2009 JCAP 01, 047L**; arXiv:0902.979; 2009JCAP...01..047L

- **A. Lien, B.D. Fields, and J.F. Beacom; 2010 PRD 81, 083001**; arXiv:1001.3678; 2010PhRvD..81h3001L

- **A. Lien, N. Chakraborty, B.D.Fields, and A. Kemball 2011 ApJ 740, 23L**; arXiv: 1107.0775; 2011ApJ...740...23L

When Stars Attack!

Live Radioactivities as Signatures of Near-Earth Supernova Explosions



Brian Fields

Astronomy & Physics, U Illinois

Nearby Supernova Collaborators

Themis Athanassiadou — Swiss National Supercomputing Center

Scott Johnson

Kathrin Hochmuth — Technical U. Munich

John Ellis — CERN

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- both hydrostatic and explosive
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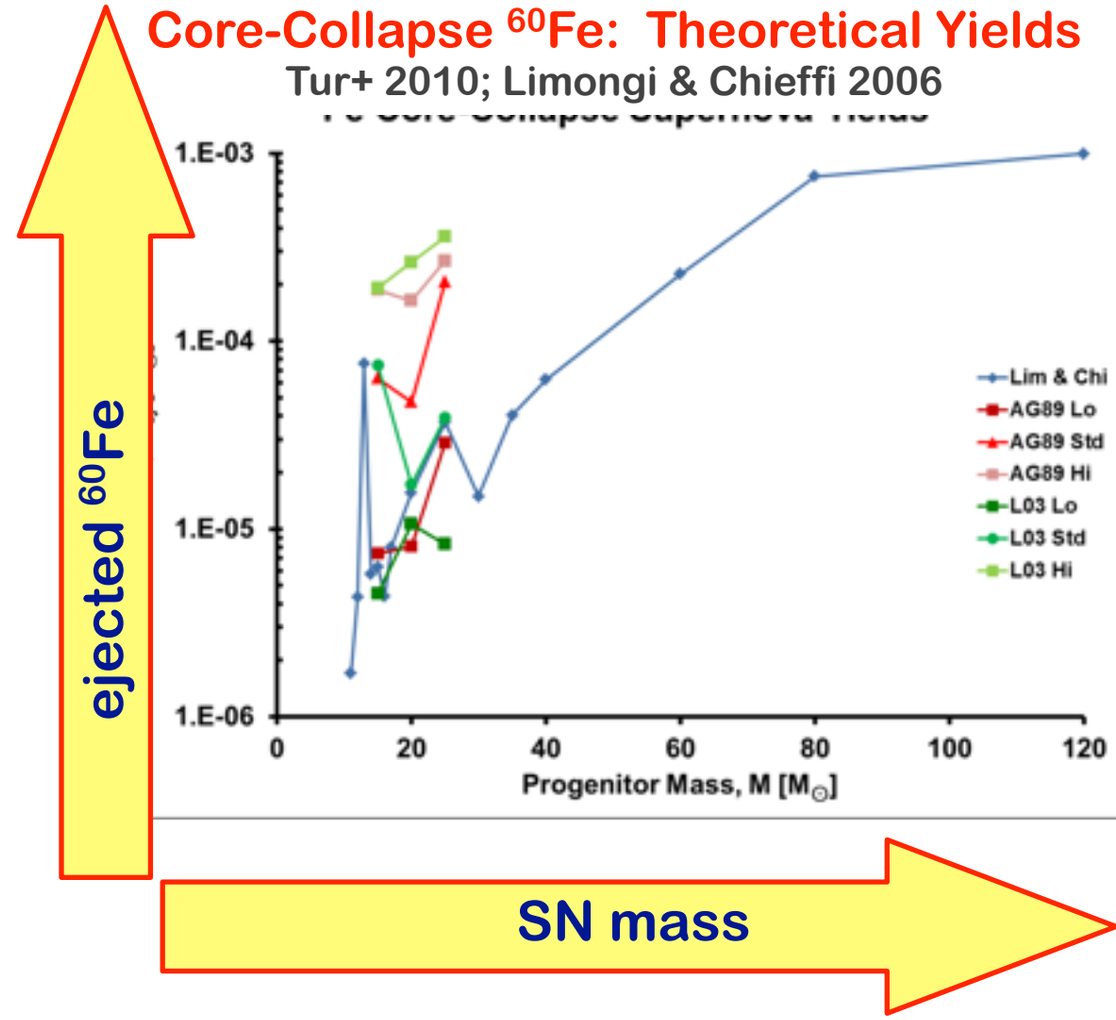

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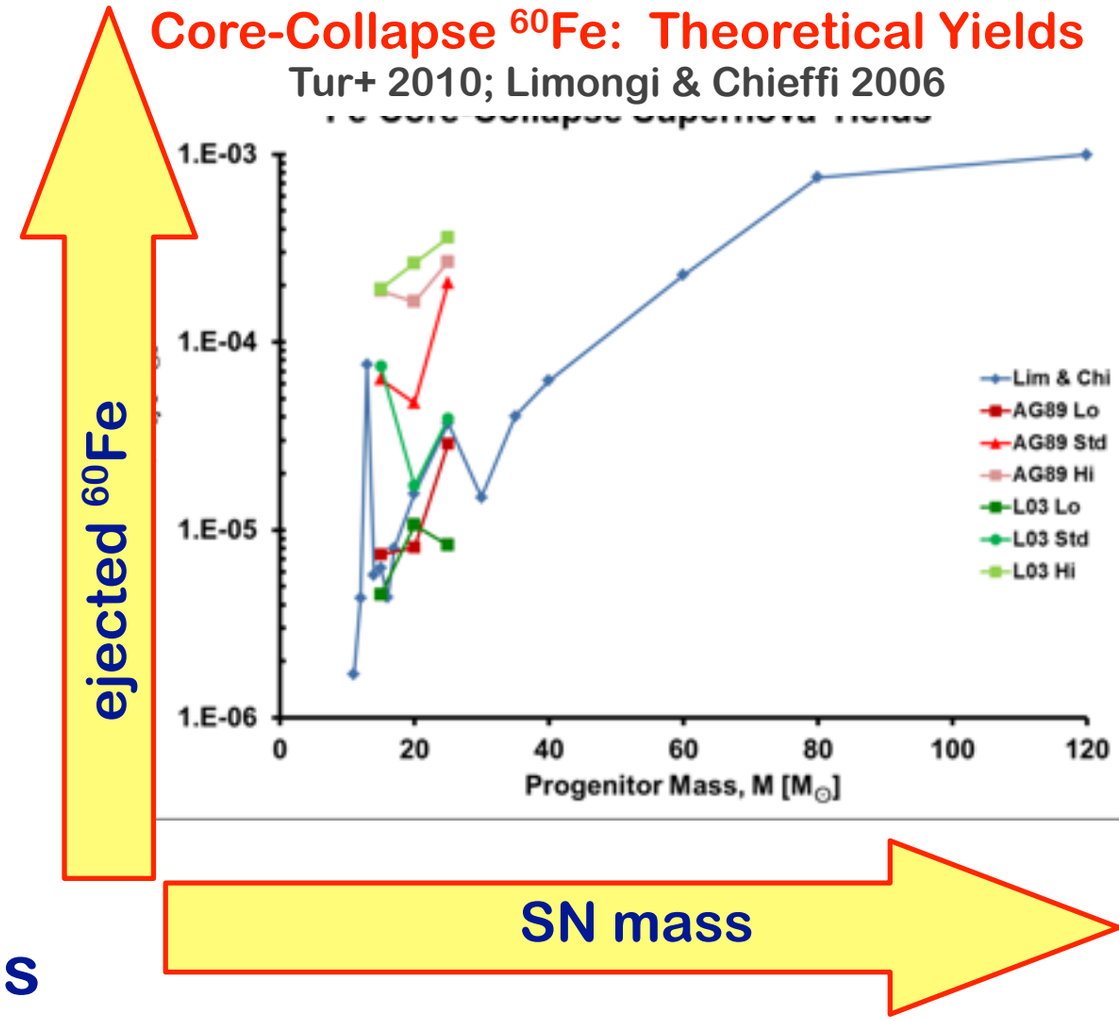

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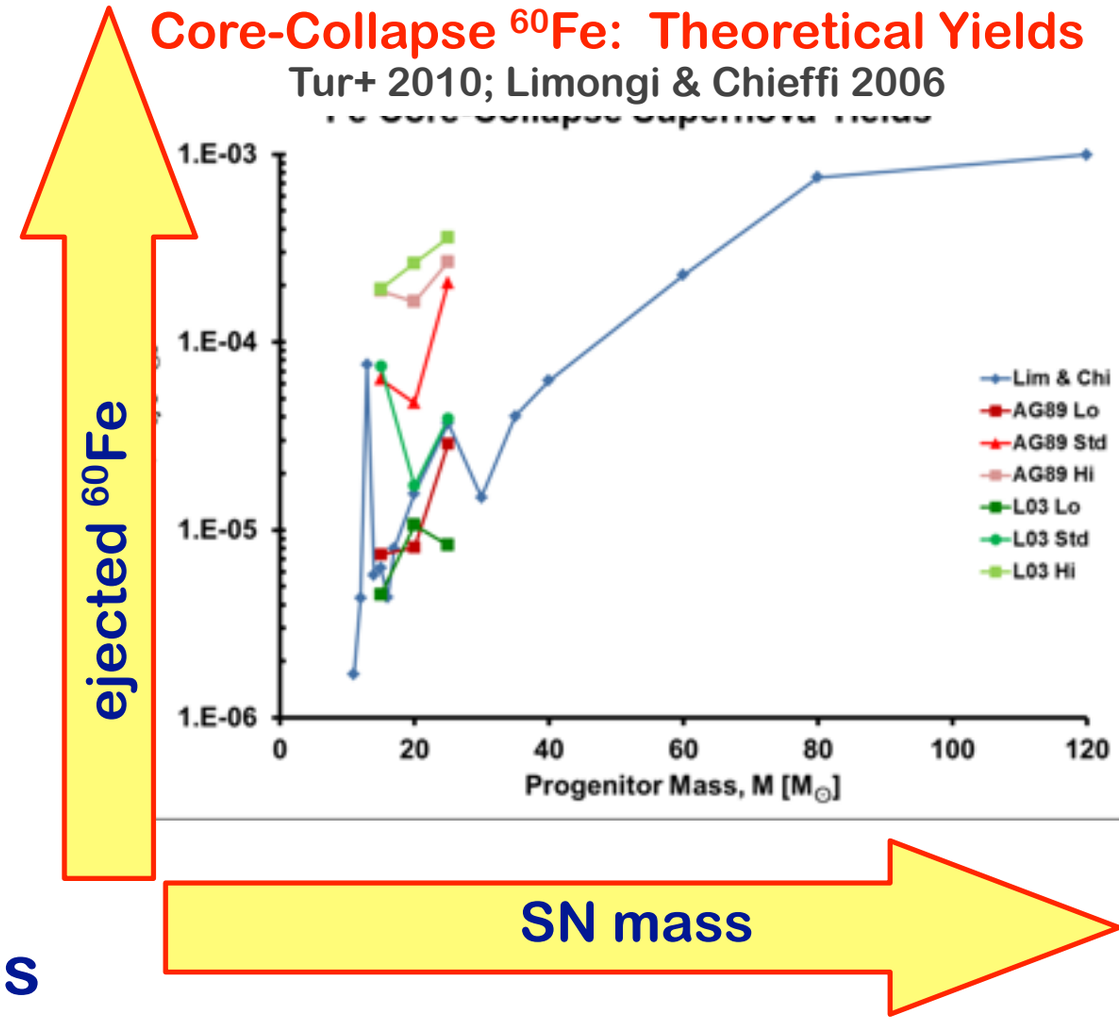

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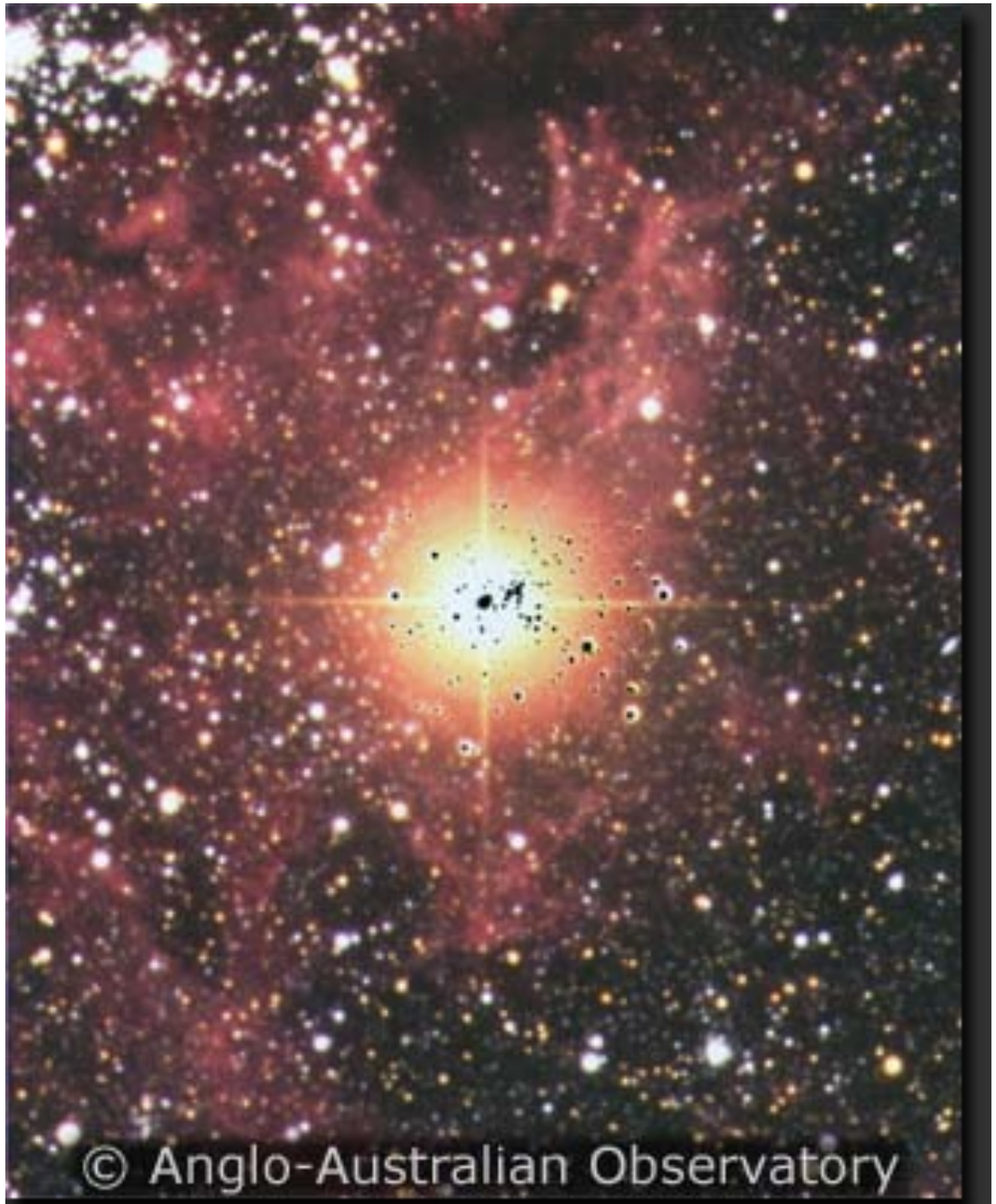

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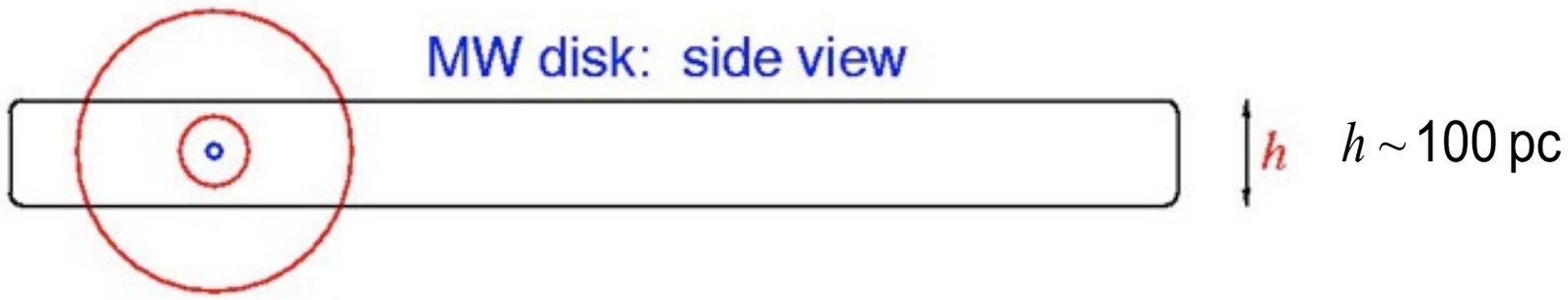

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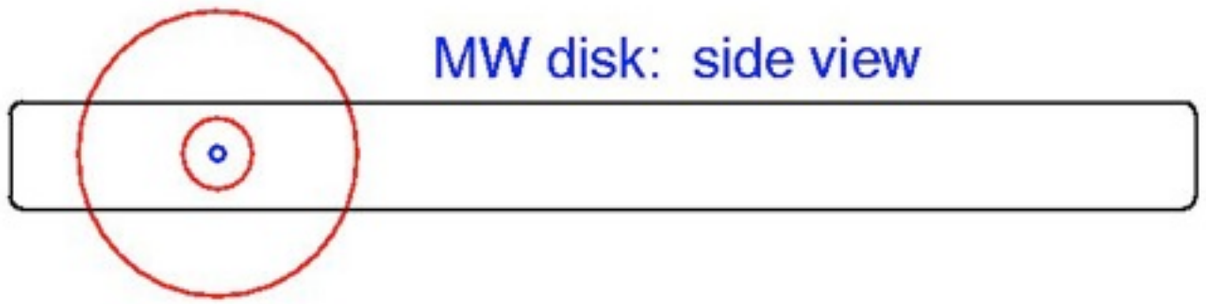

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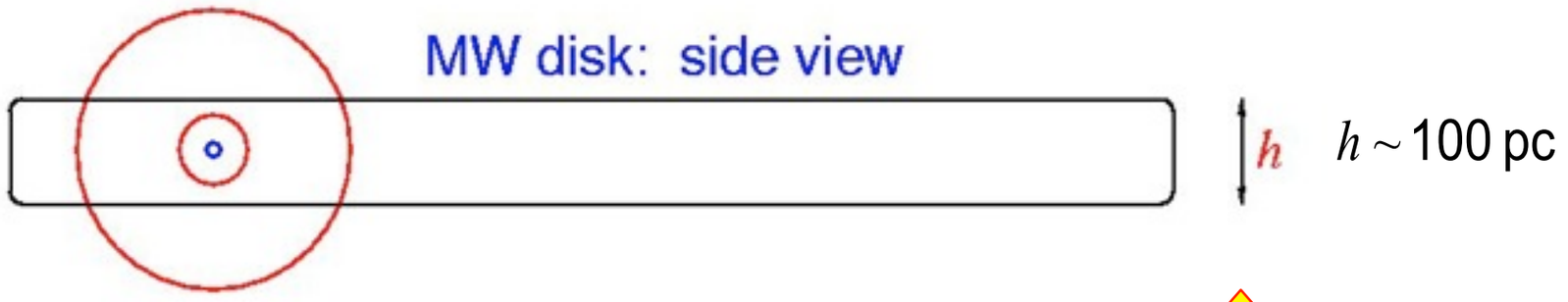

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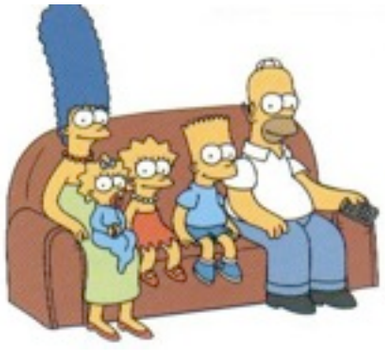

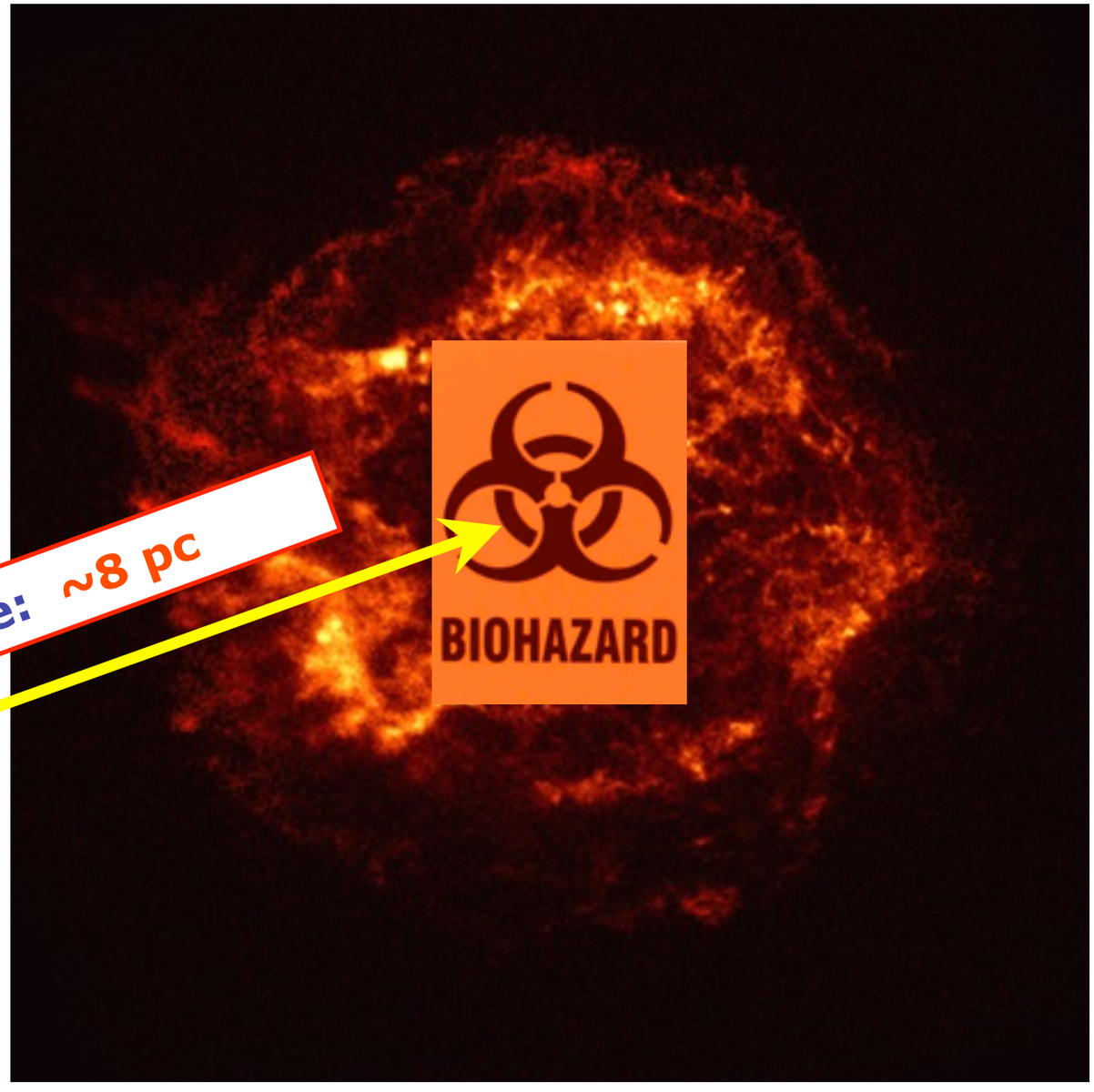

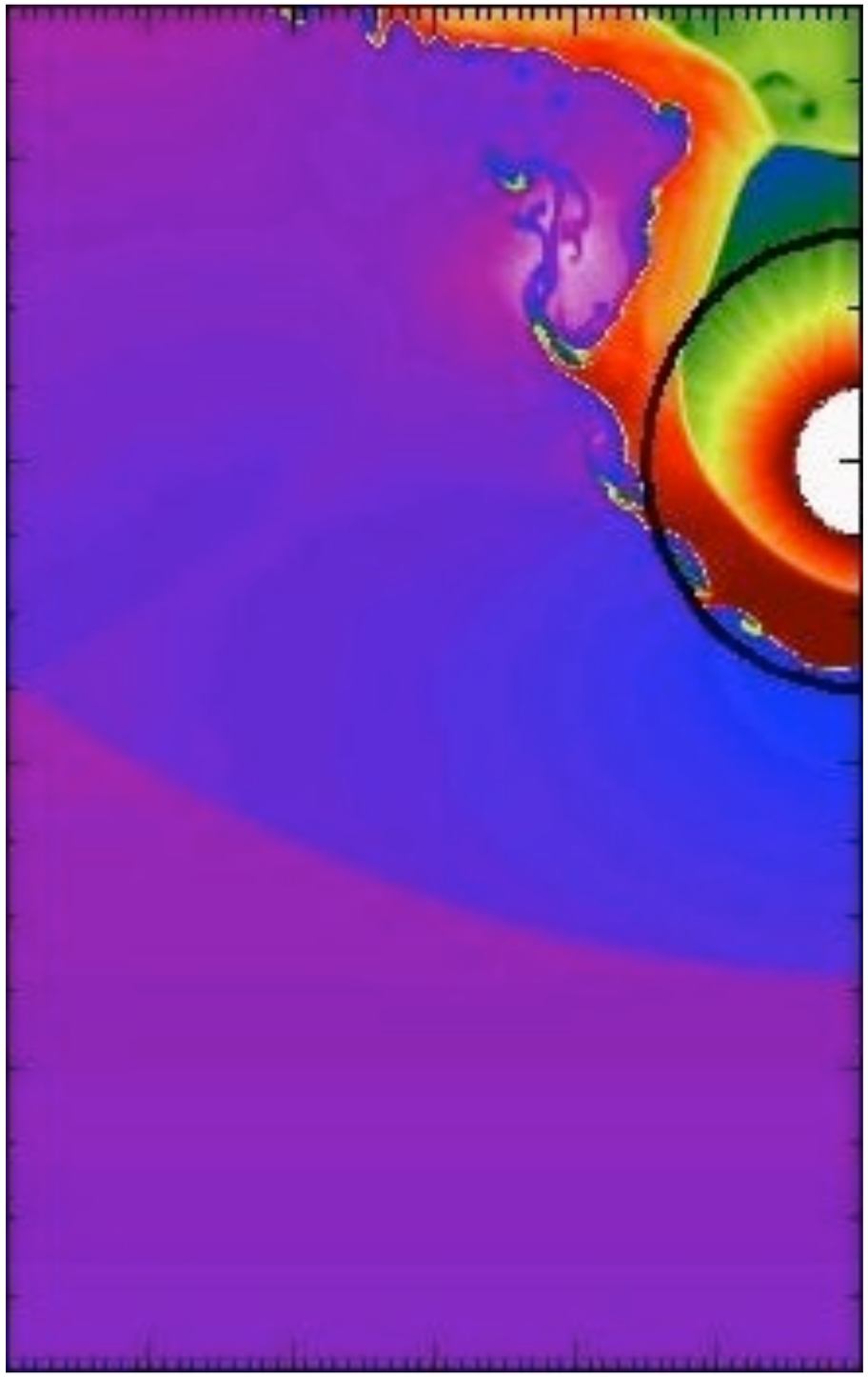

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Explosion launched at ~few% c

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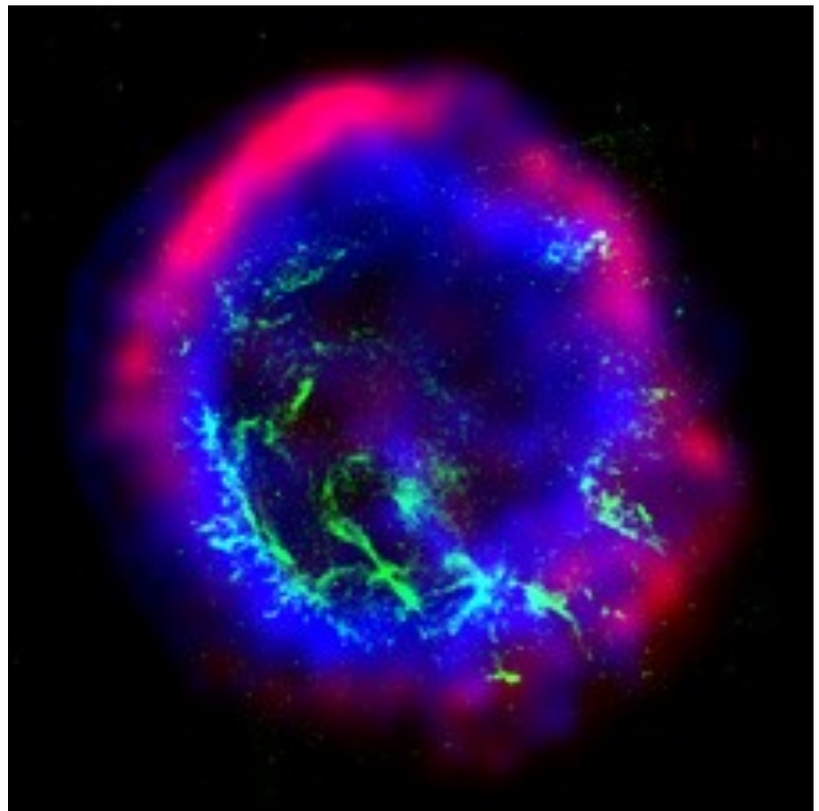

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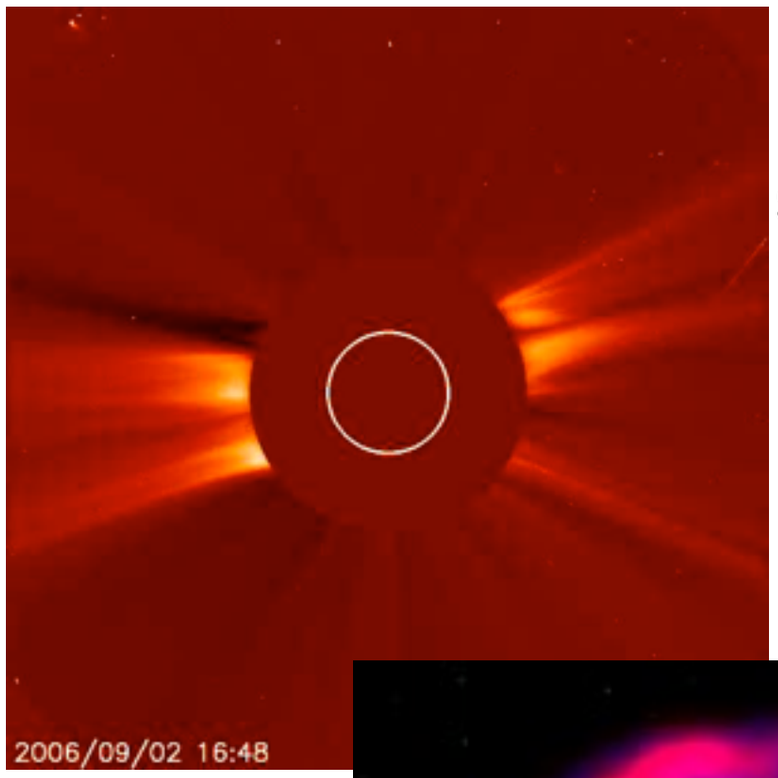

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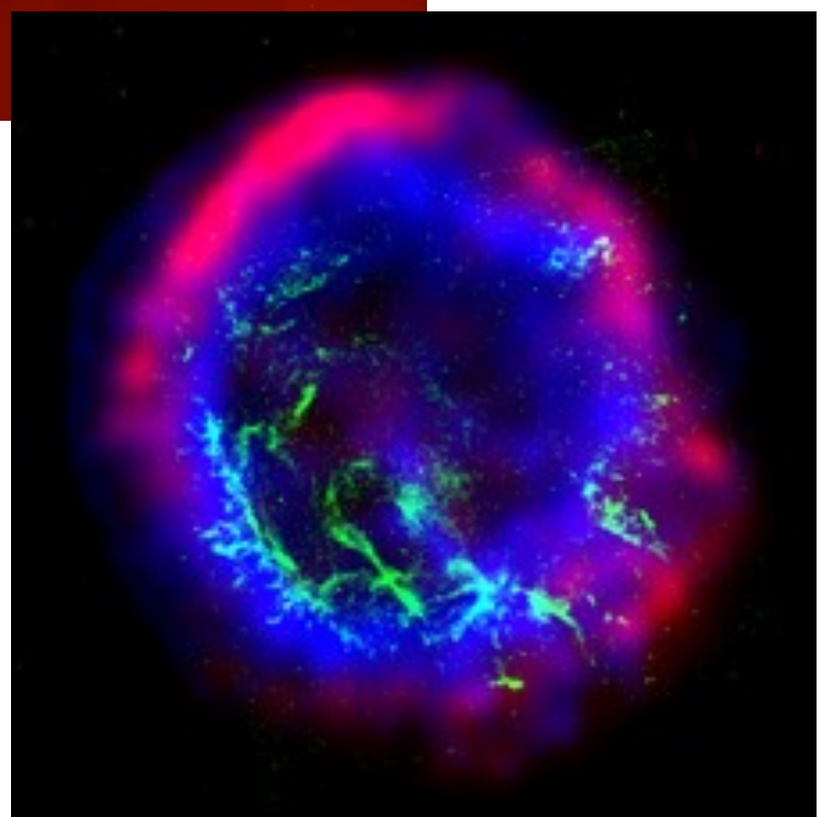

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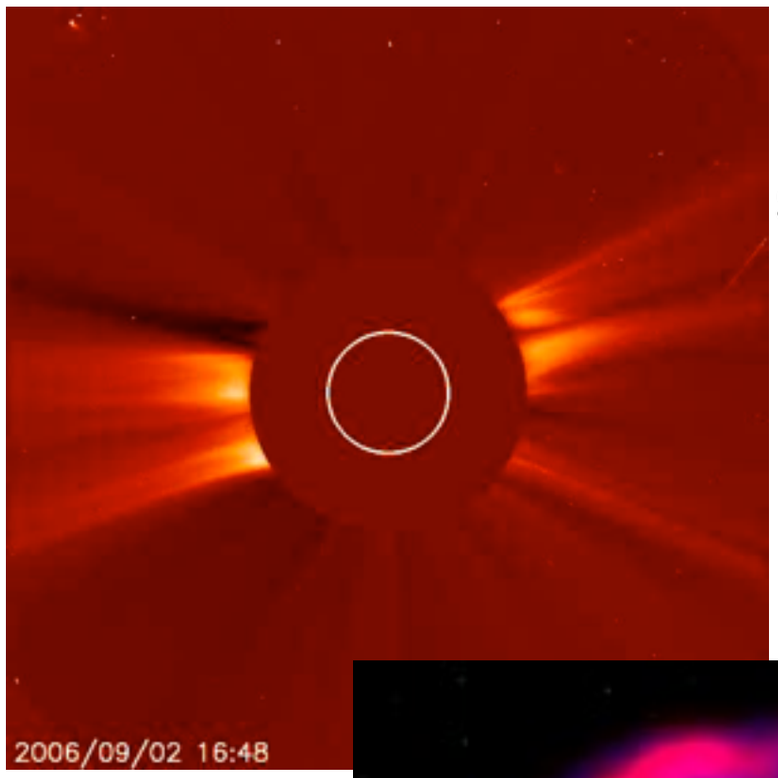

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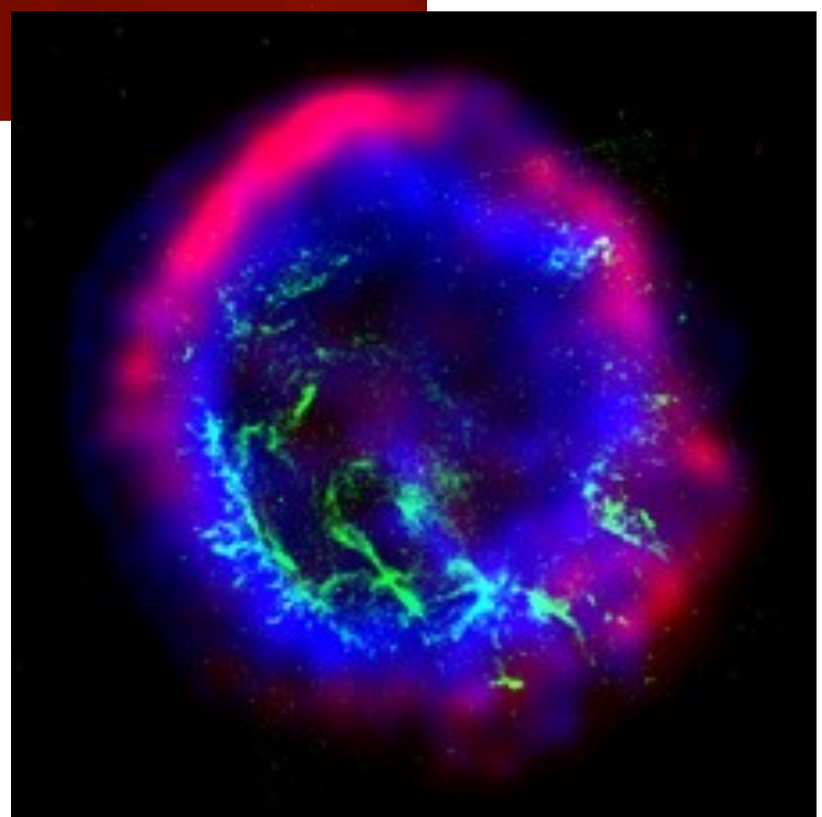

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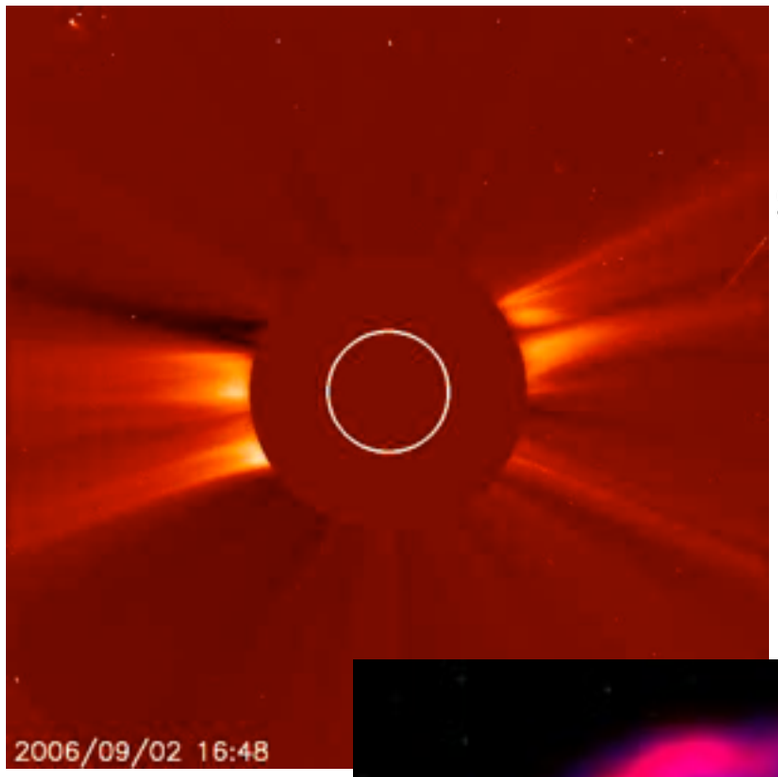

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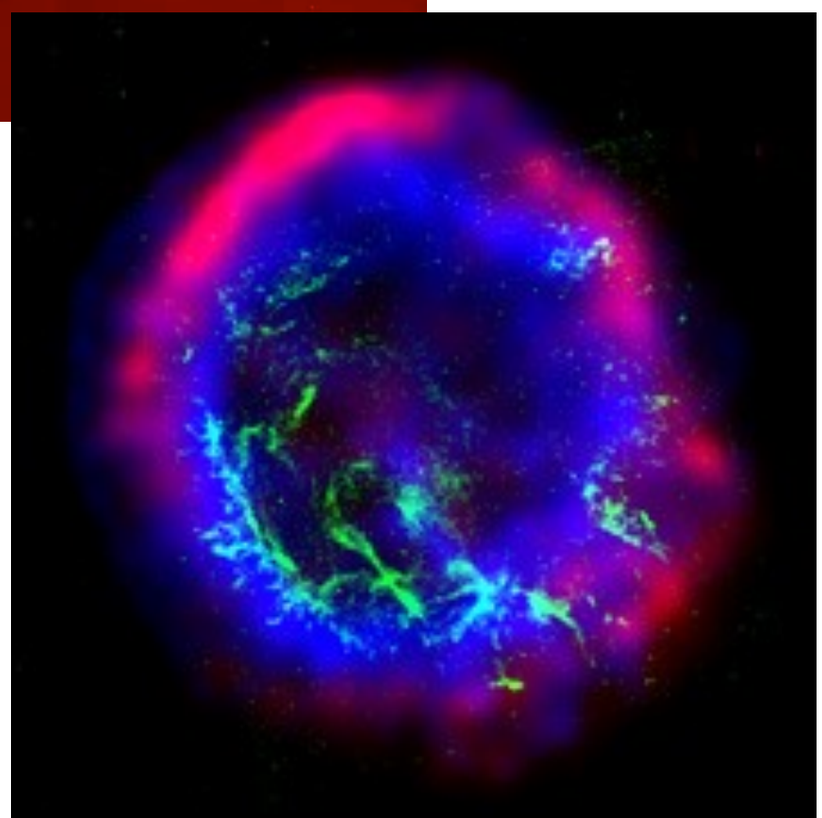

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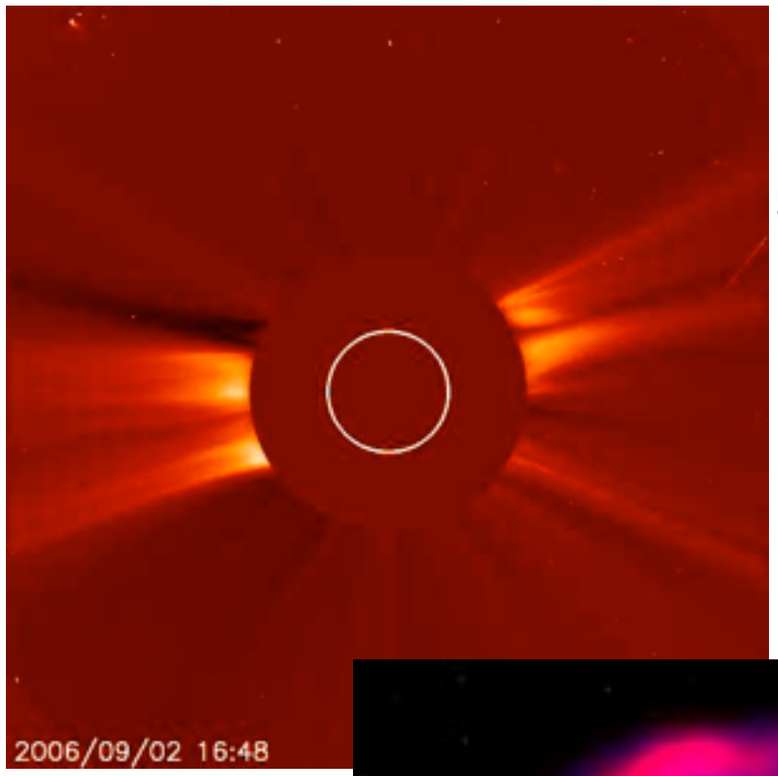

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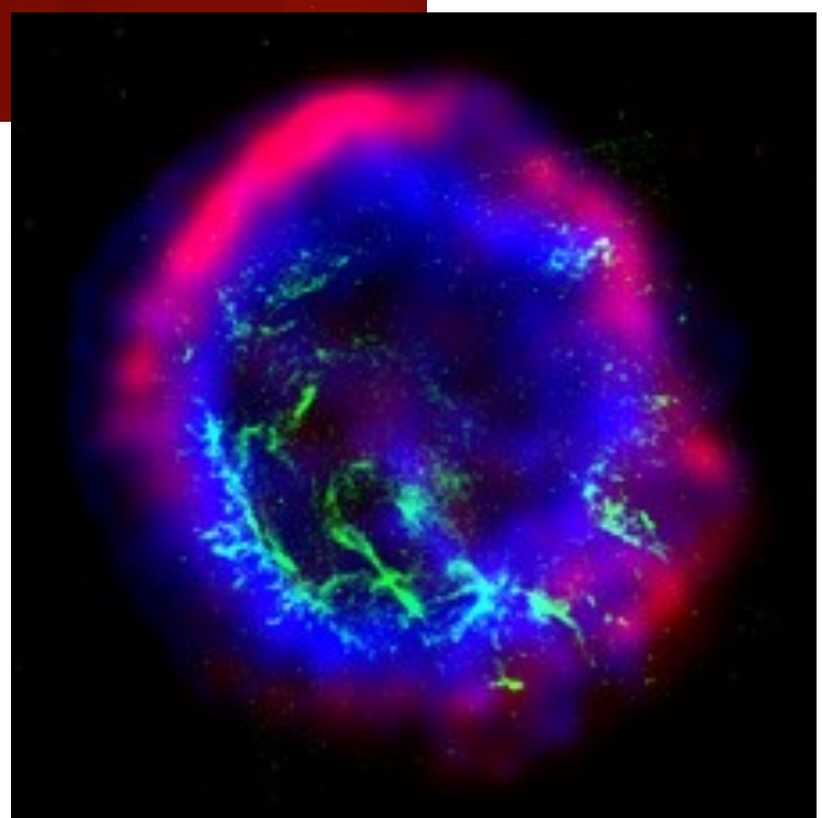

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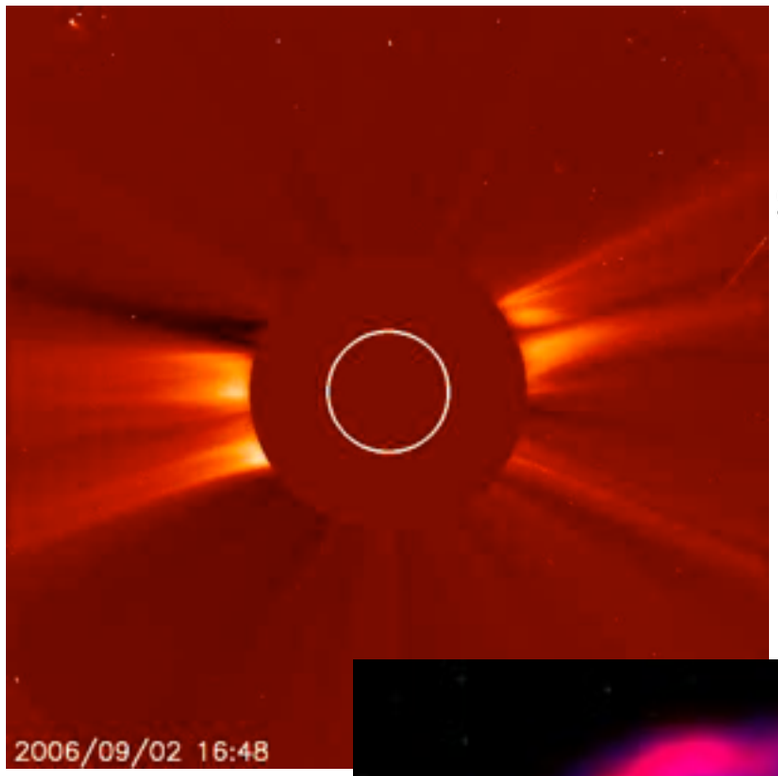

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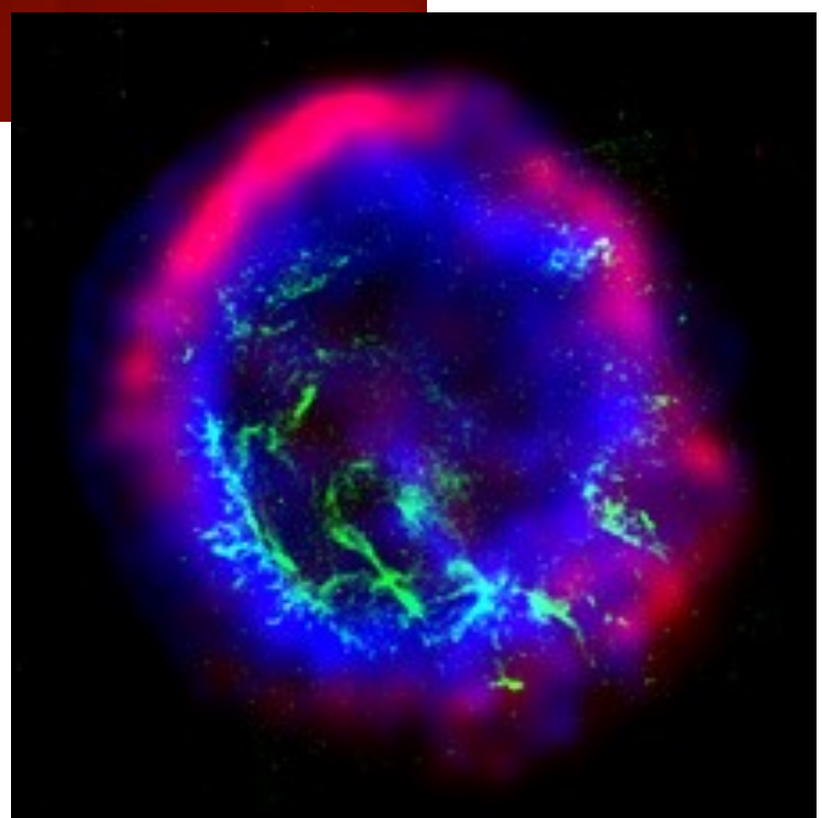

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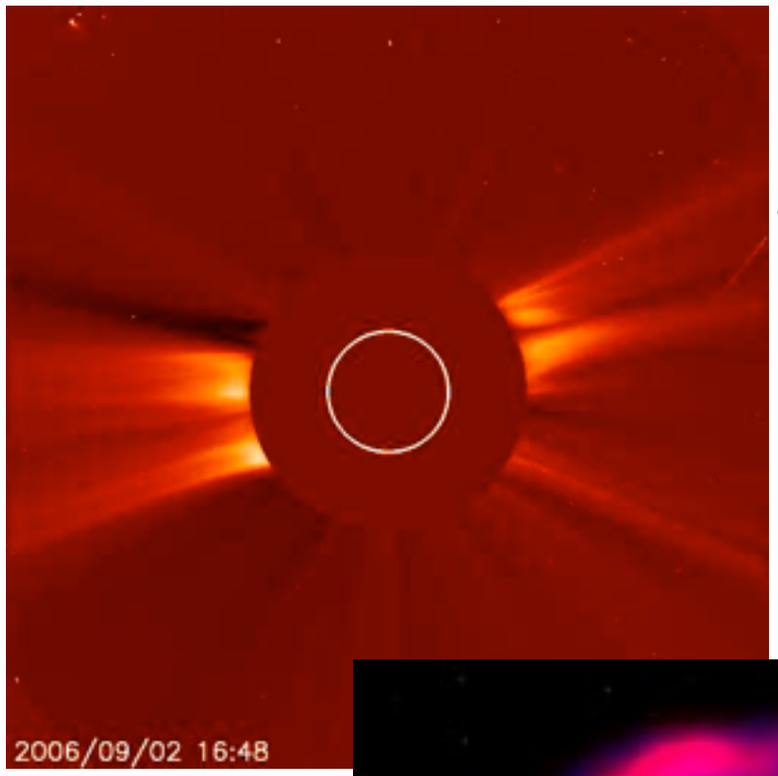

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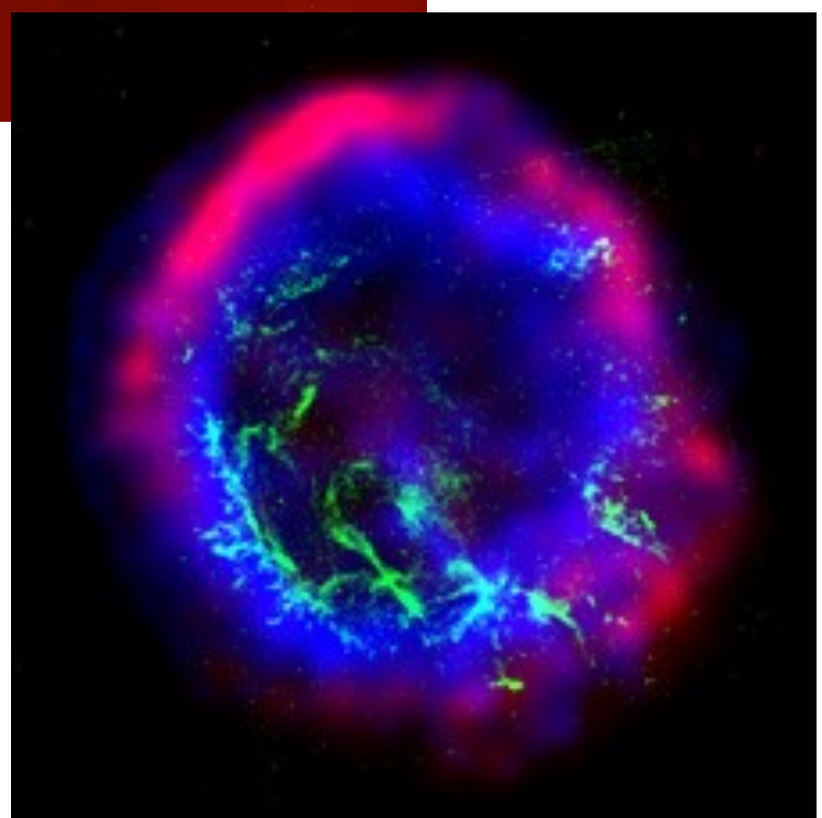

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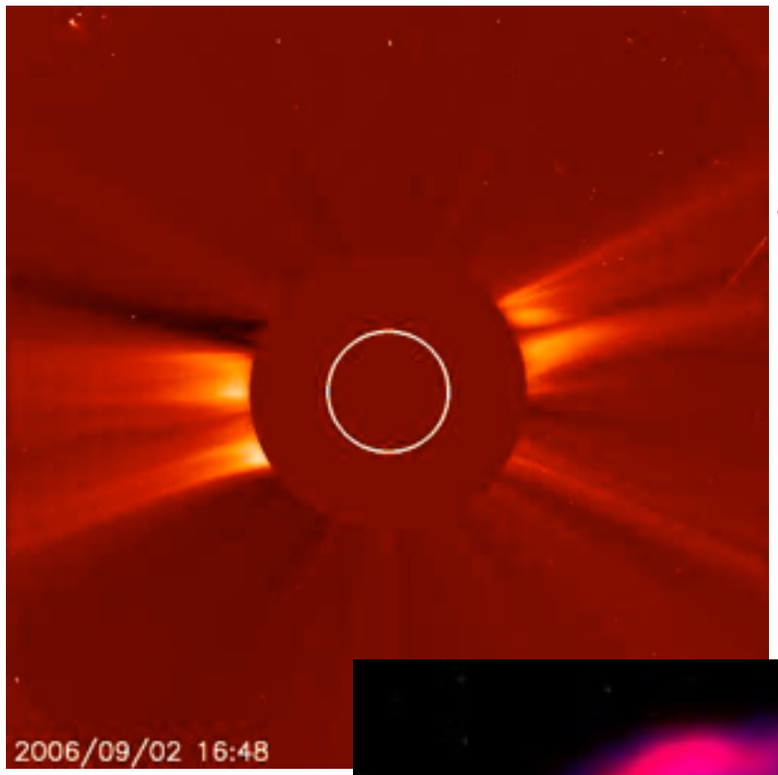

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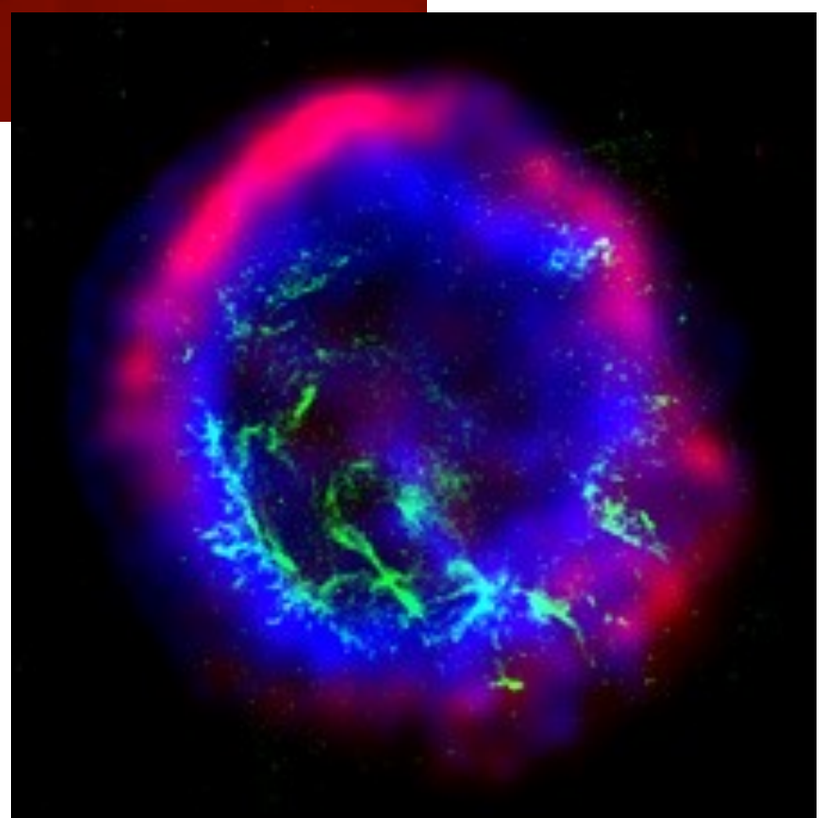

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The Fury of Aerial Bombardment:
Supernova Blast Passage--Global View

BDF, Athanassiadou, Johnson 2008

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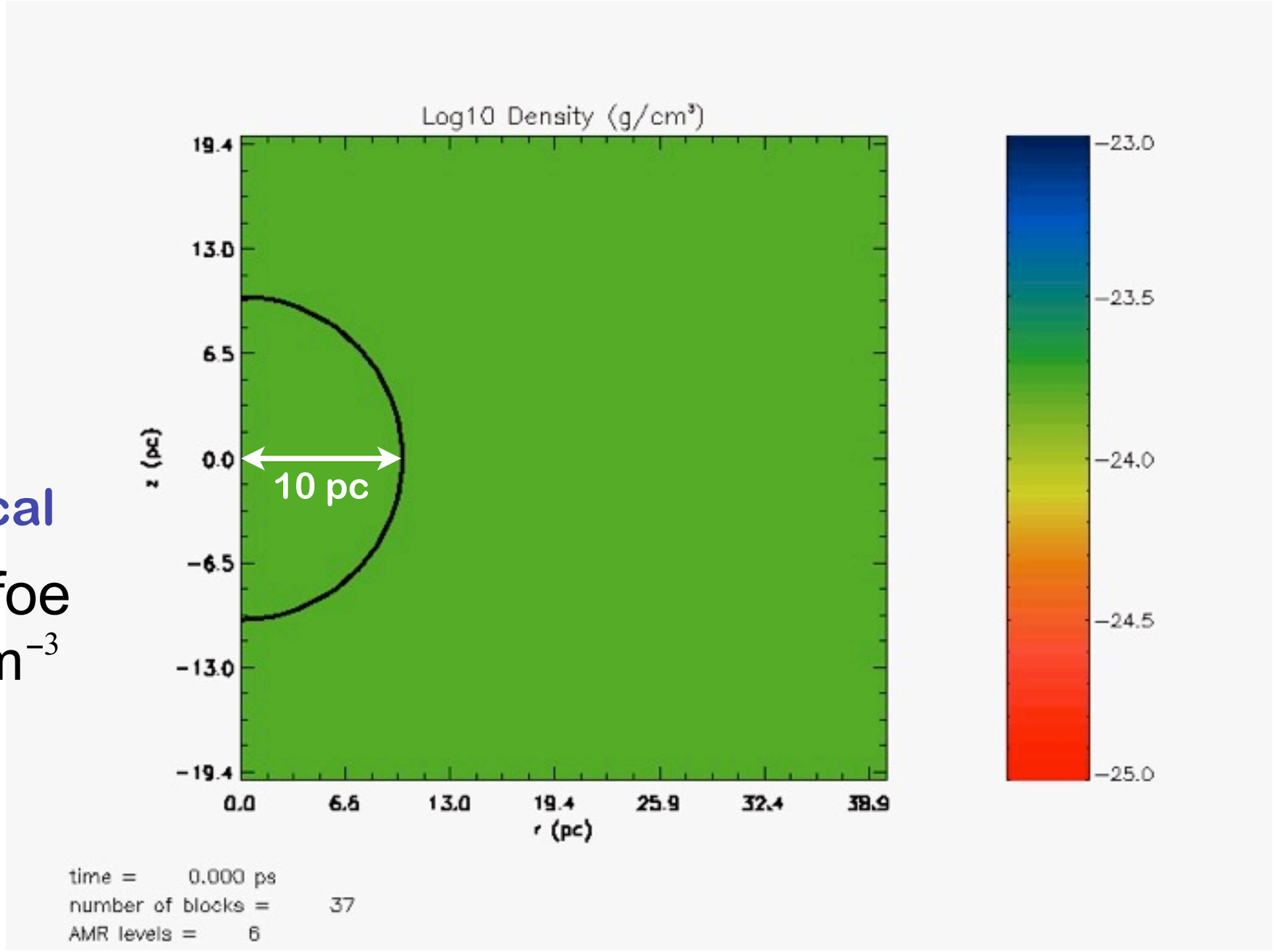

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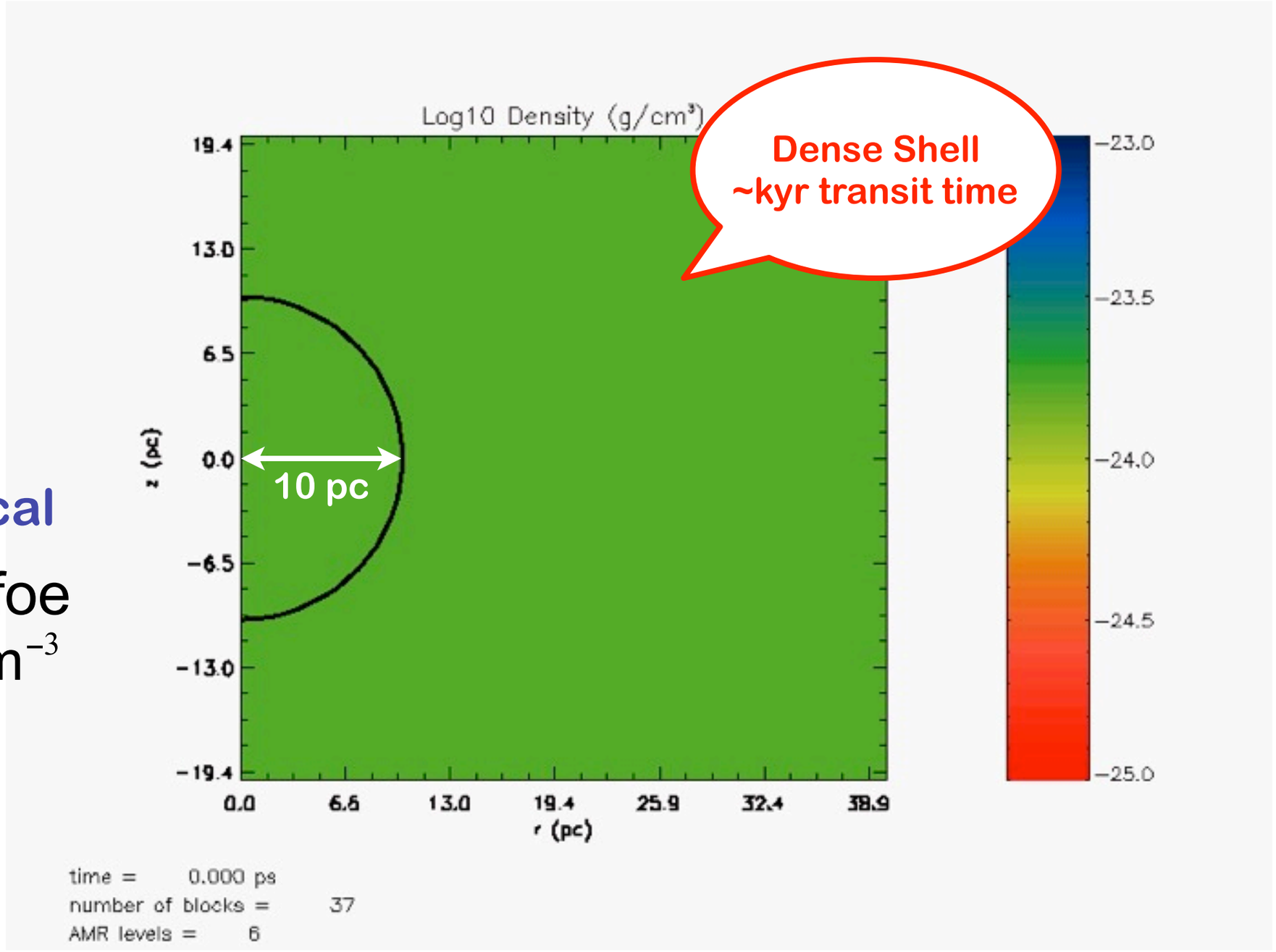

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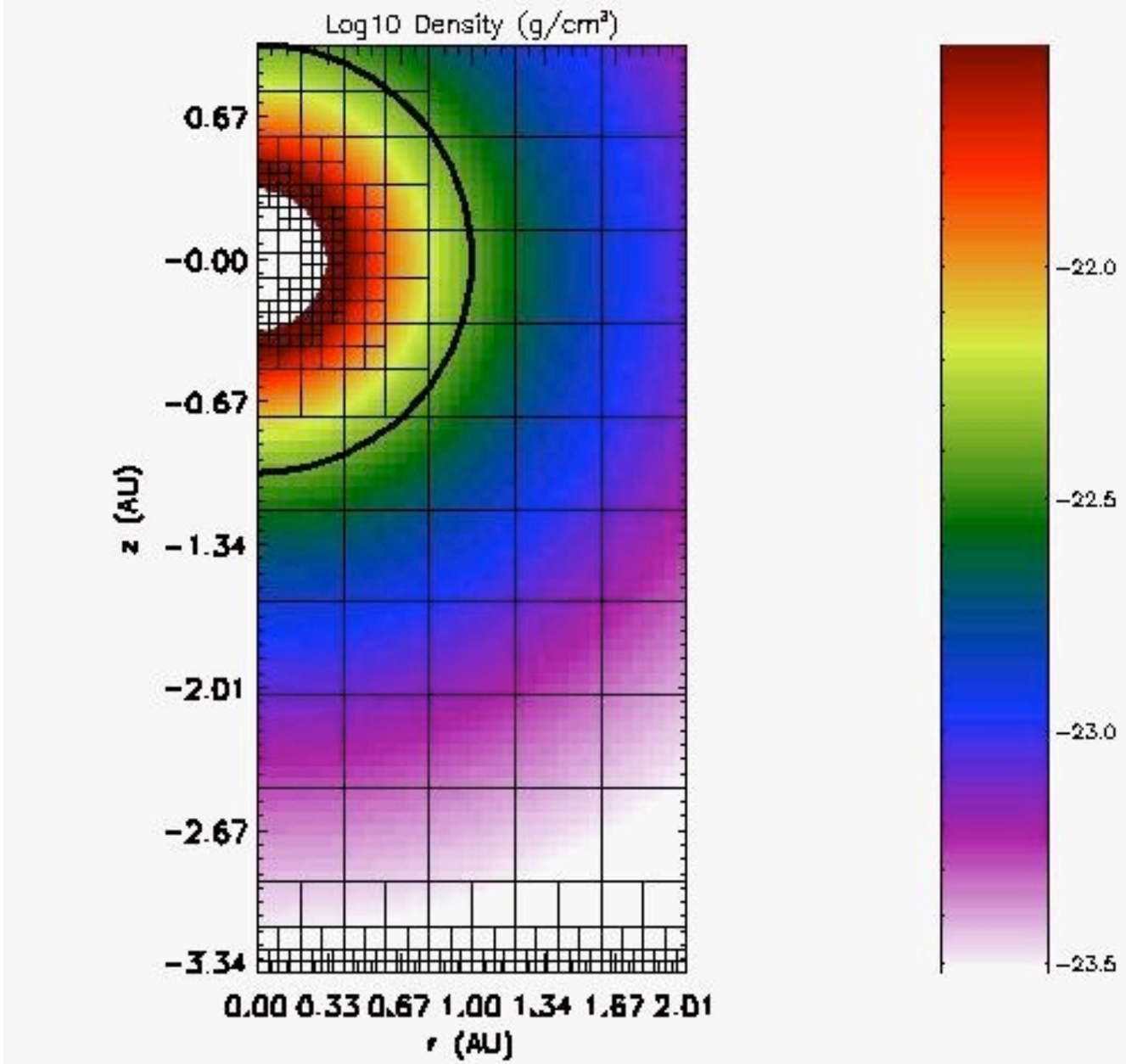

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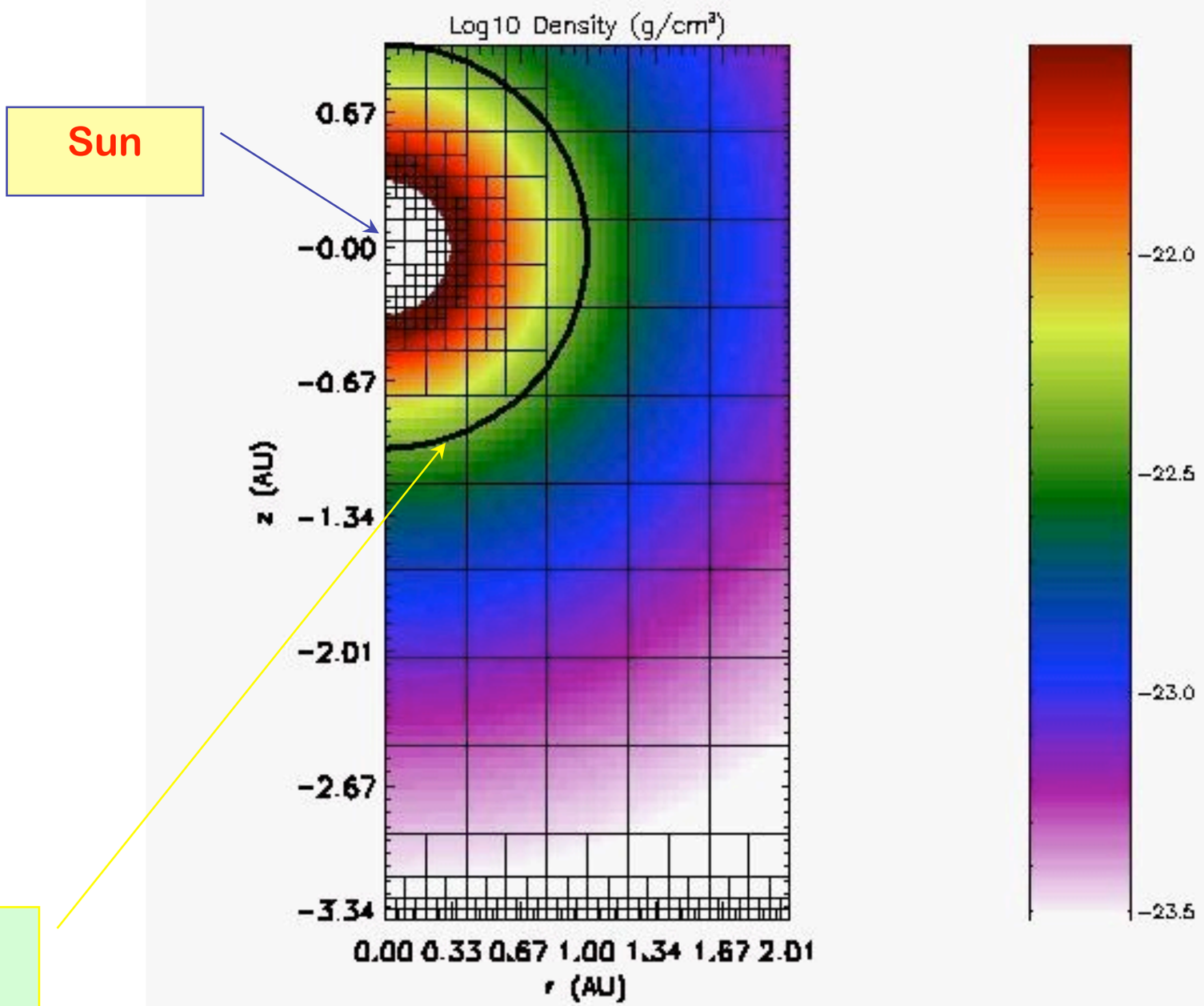

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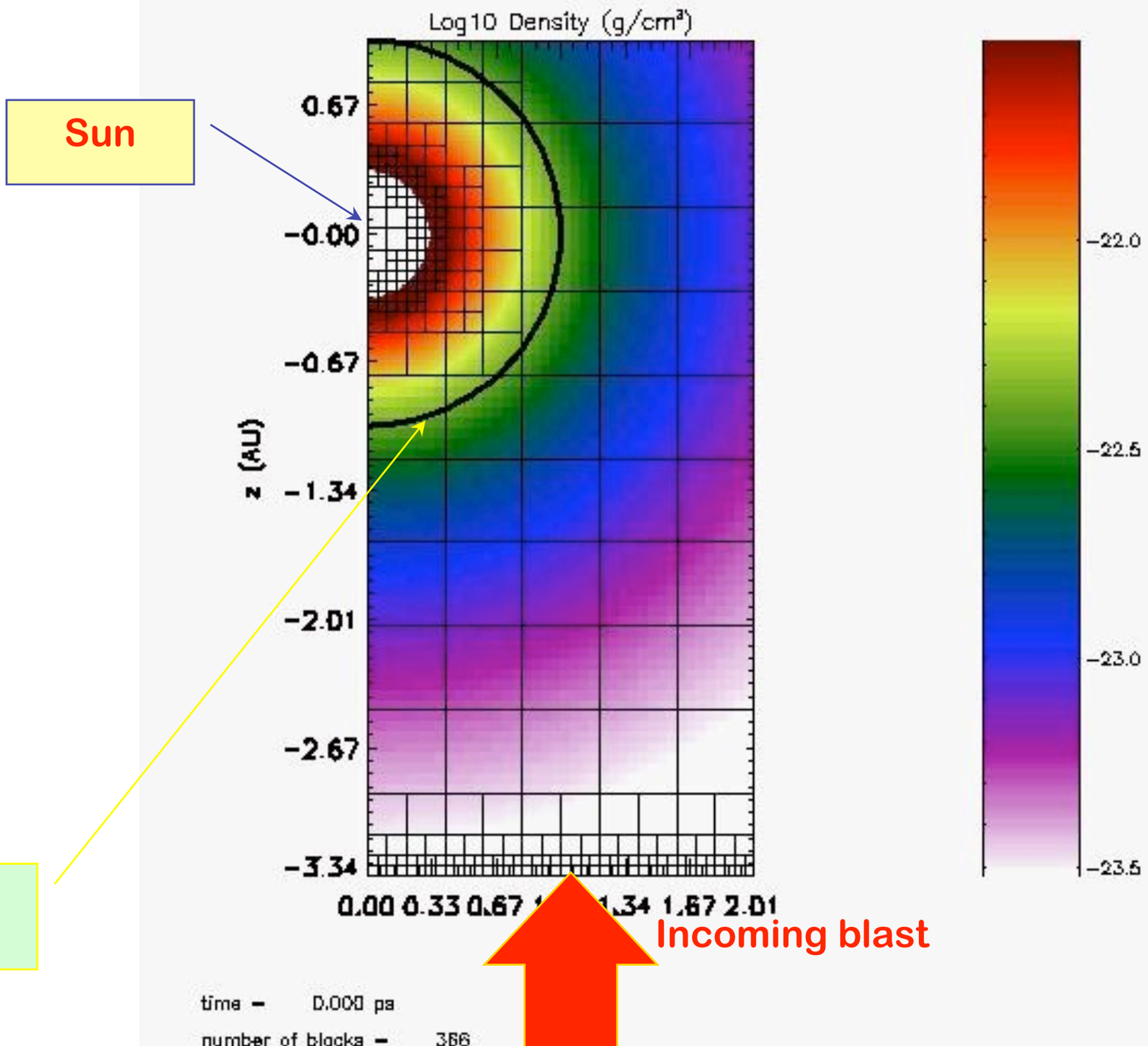

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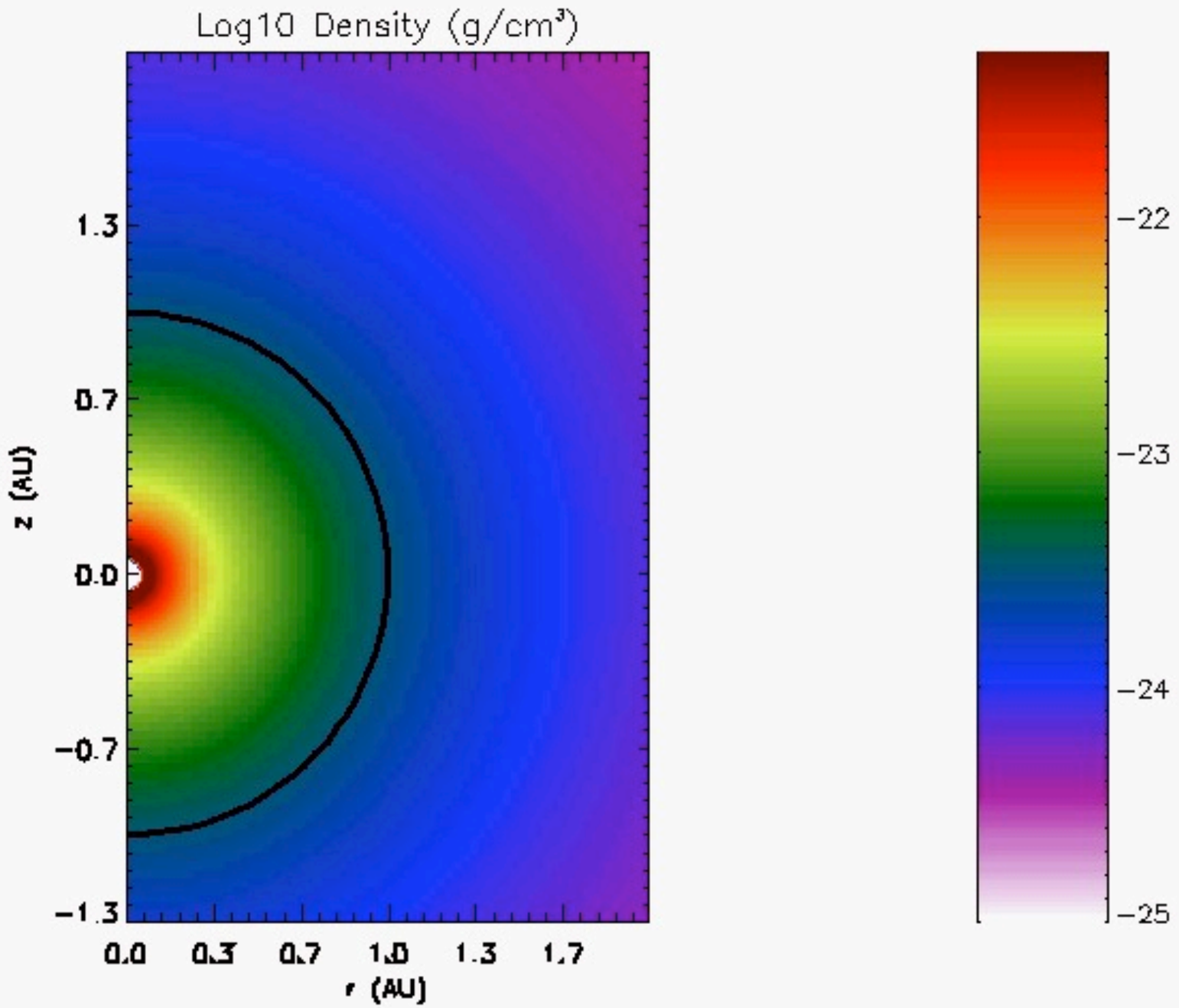

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AMR levels = 3

Now in 3-D!

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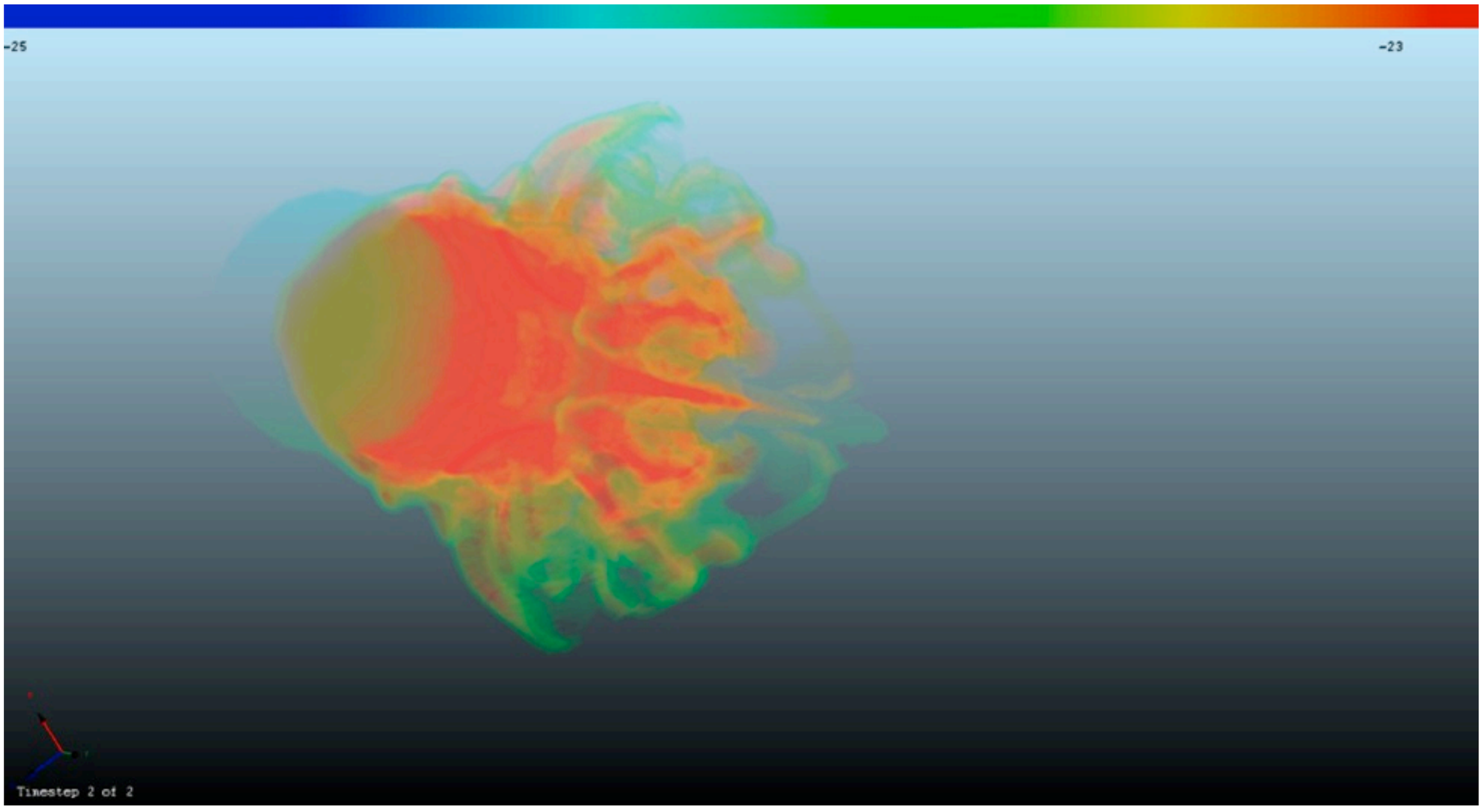

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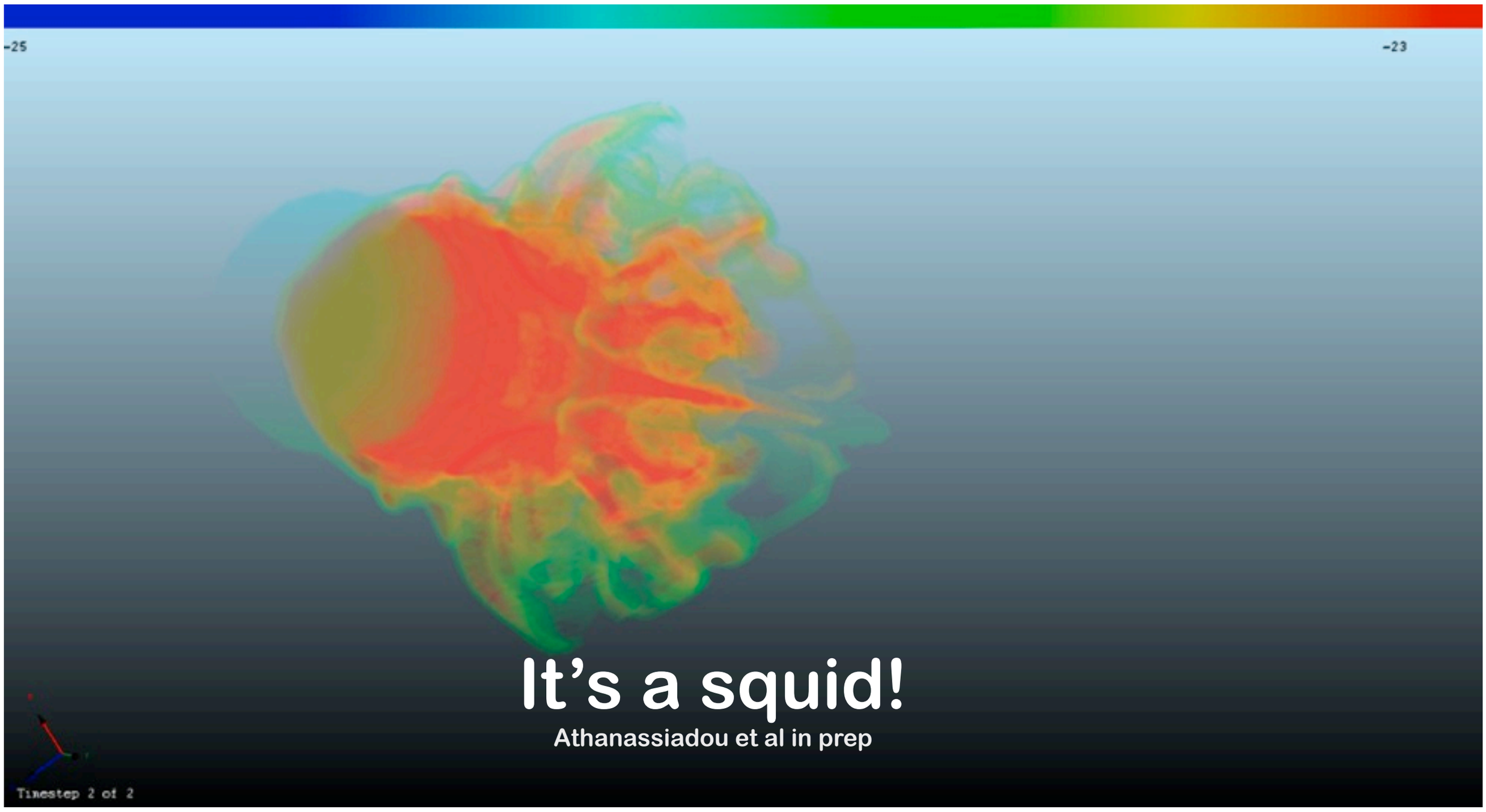

It’s a squid!

Athanassiadou et al in prep

Assault on the Heliosphere: Lessons

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For today:

- **Take seriously possibility of SN ejecta → Earth**
- **Look for observable consequence**

Debris Delivery via Dust

Athanassiadou & BDF 11; Fry & BDF in prep

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- **gas-phase** SN debris excluded from Earth

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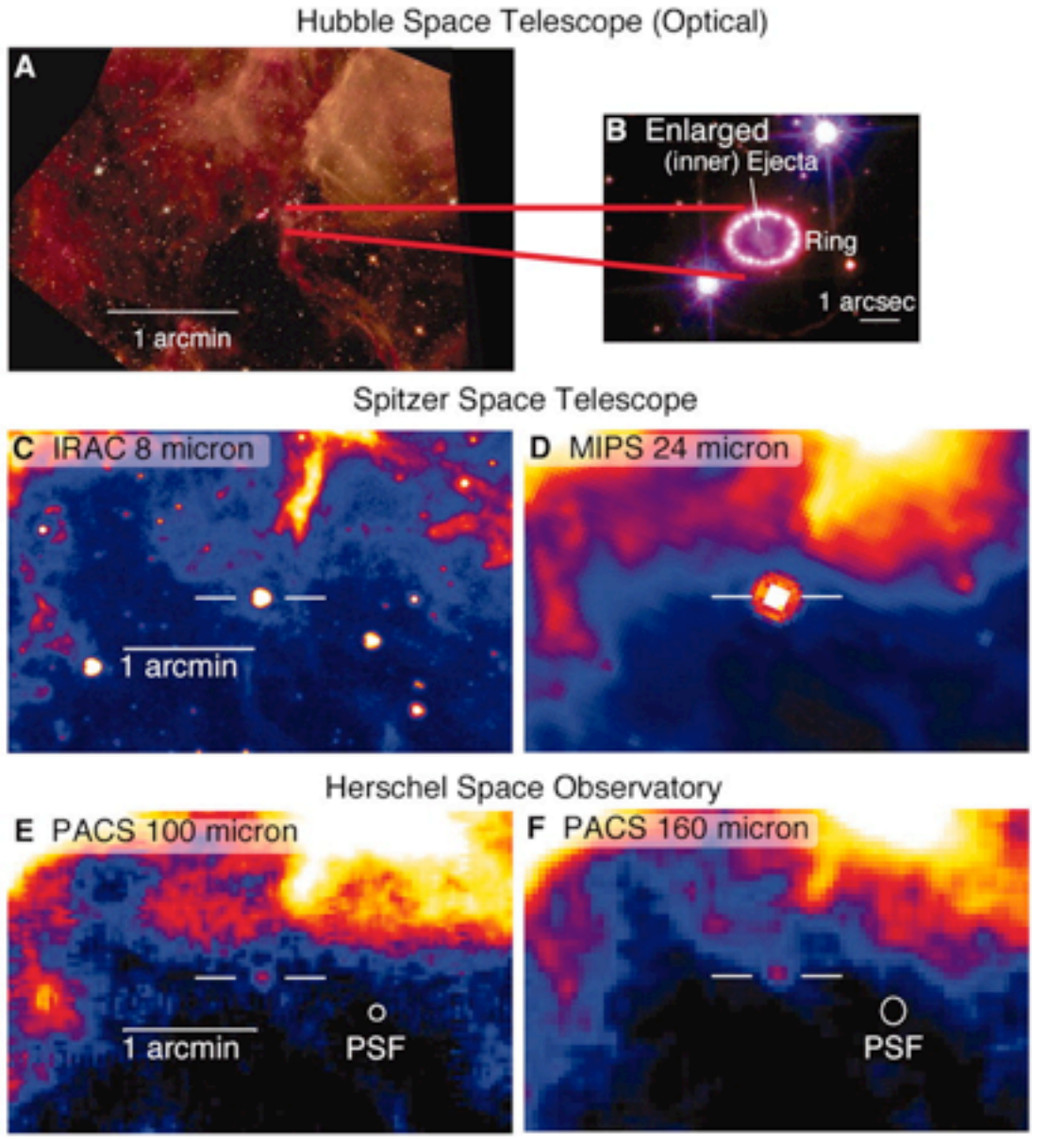

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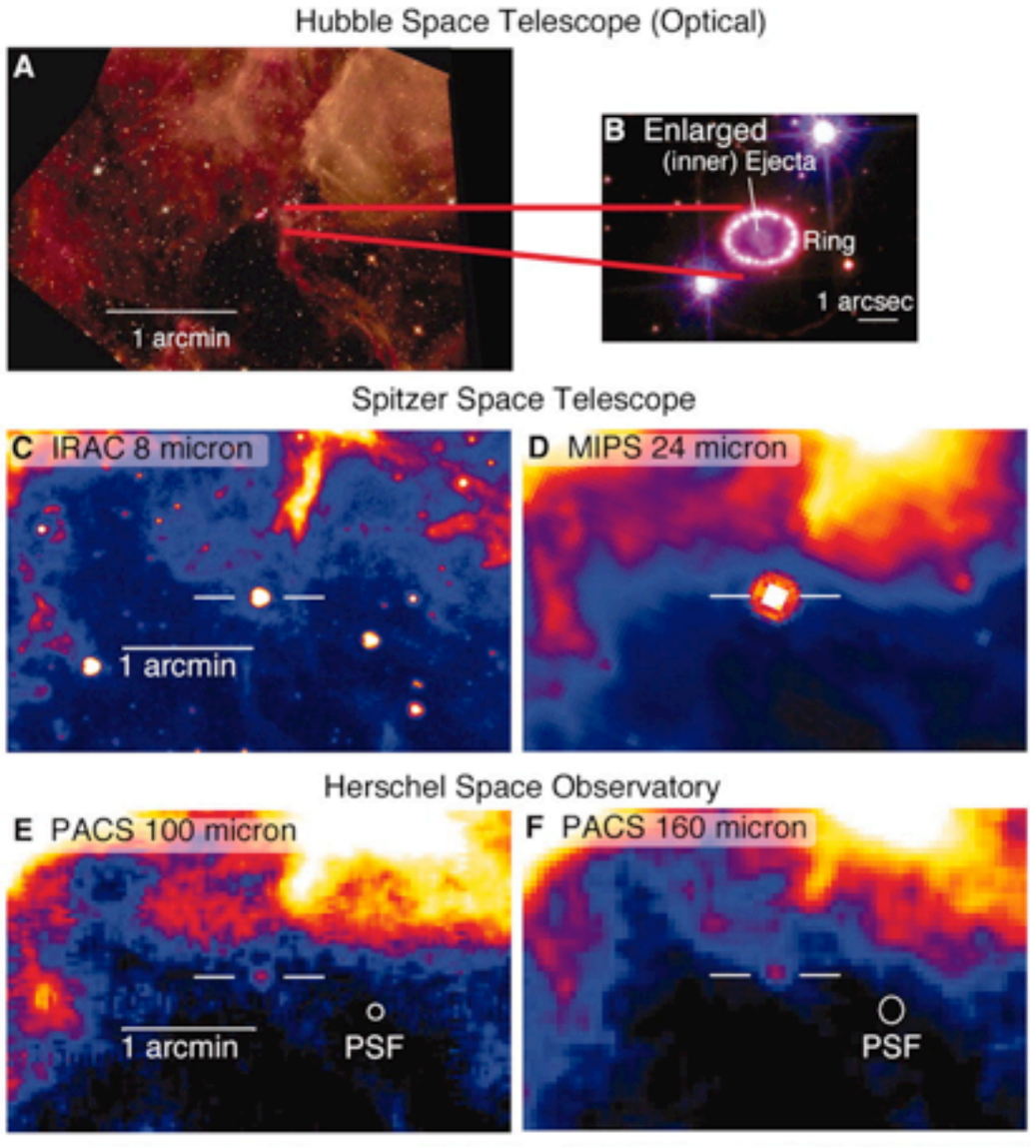

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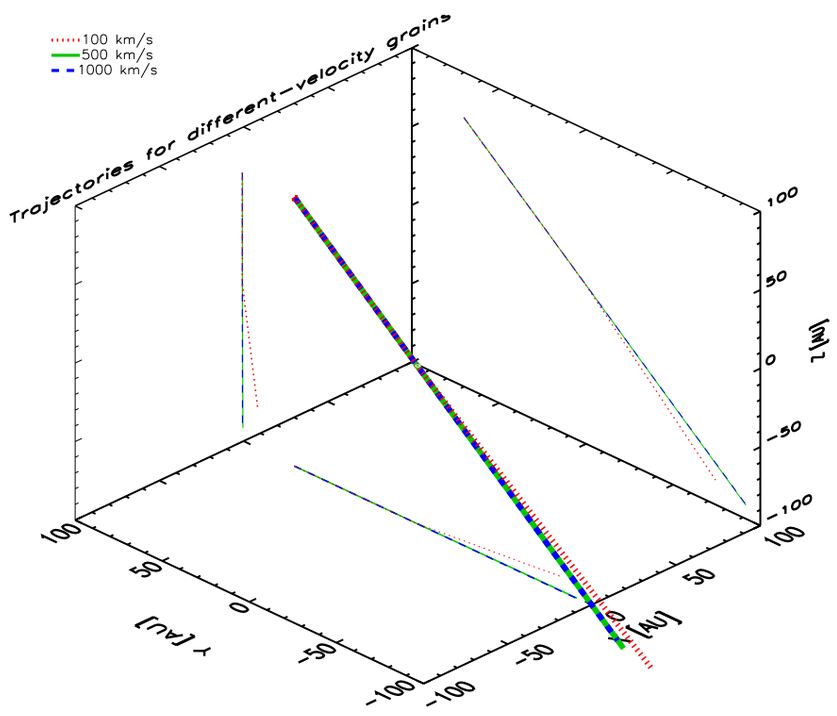

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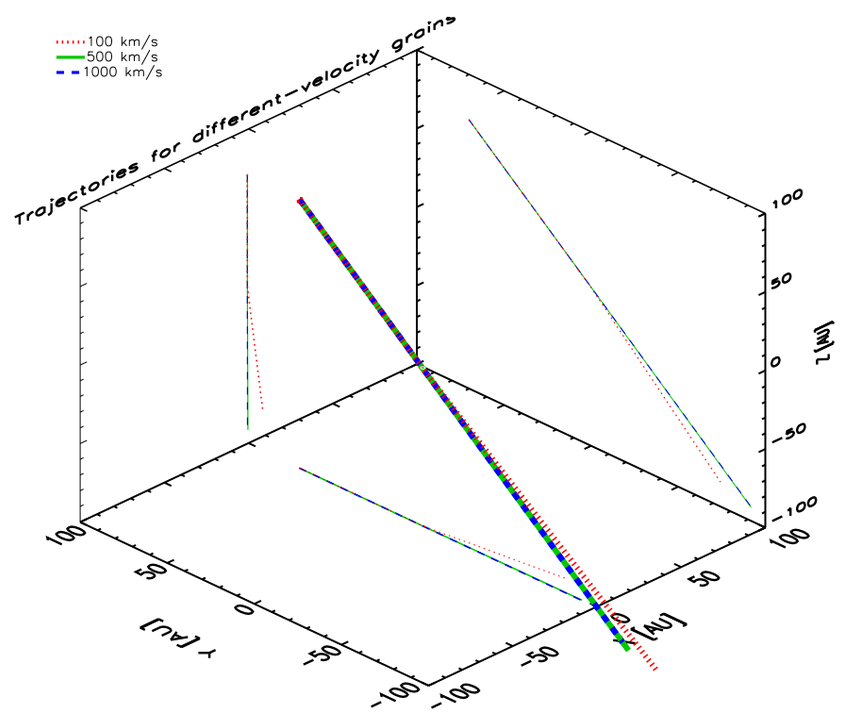

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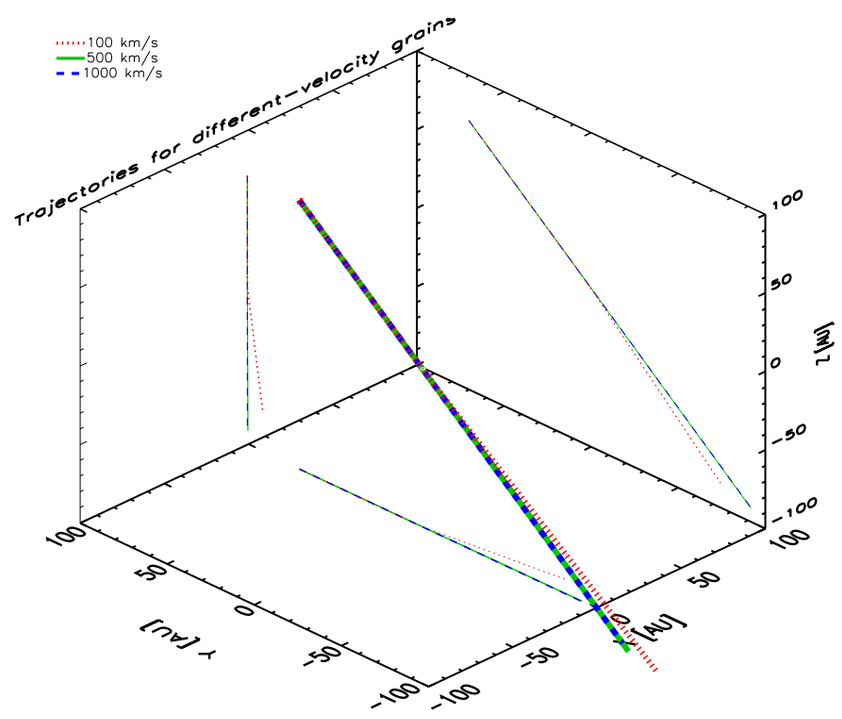

Geological Signatures

Deep Ocean Crust

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Knie et al. (1999) ferromanganese (FeMn) crust

Pacific Ocean

growth: ~ 1 mm/Myr

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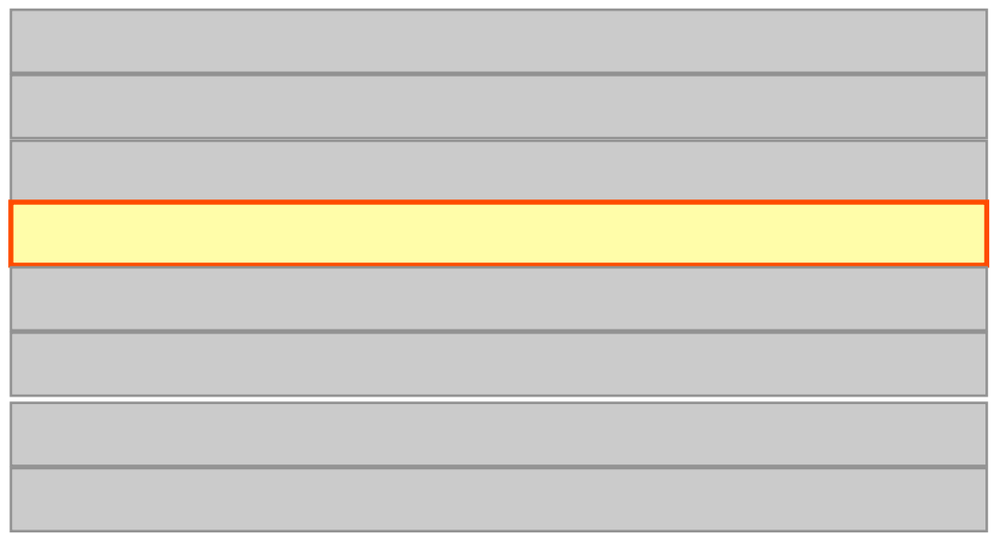

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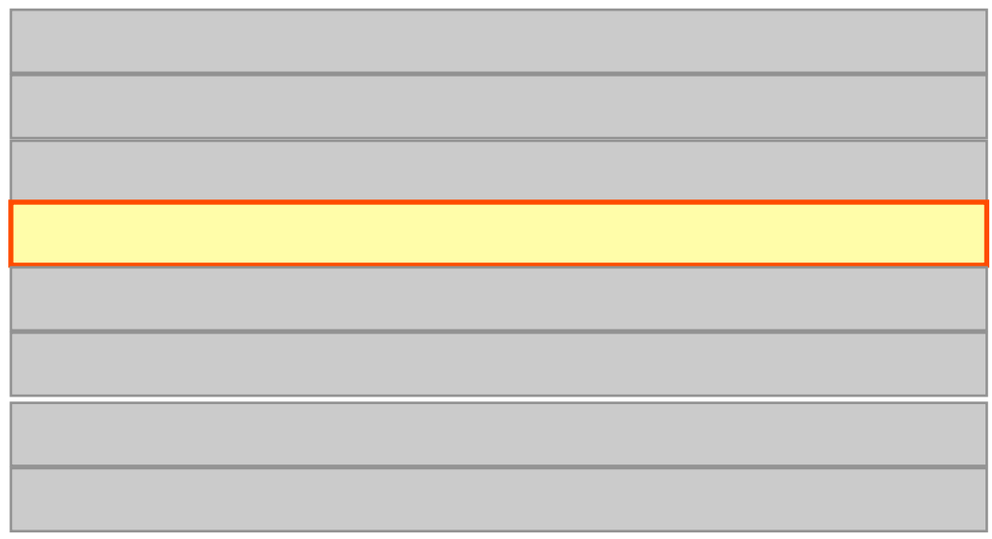

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- detectable signal exists
- but not time-resolved

^{60}Fe Confirmation

Knie et al (2004)

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Advances

New crust from new site

- ✓ Better geometry (planar)
- ✓ better time resolution
- ✓ ^{10}Be ⇒ radioactive timescale

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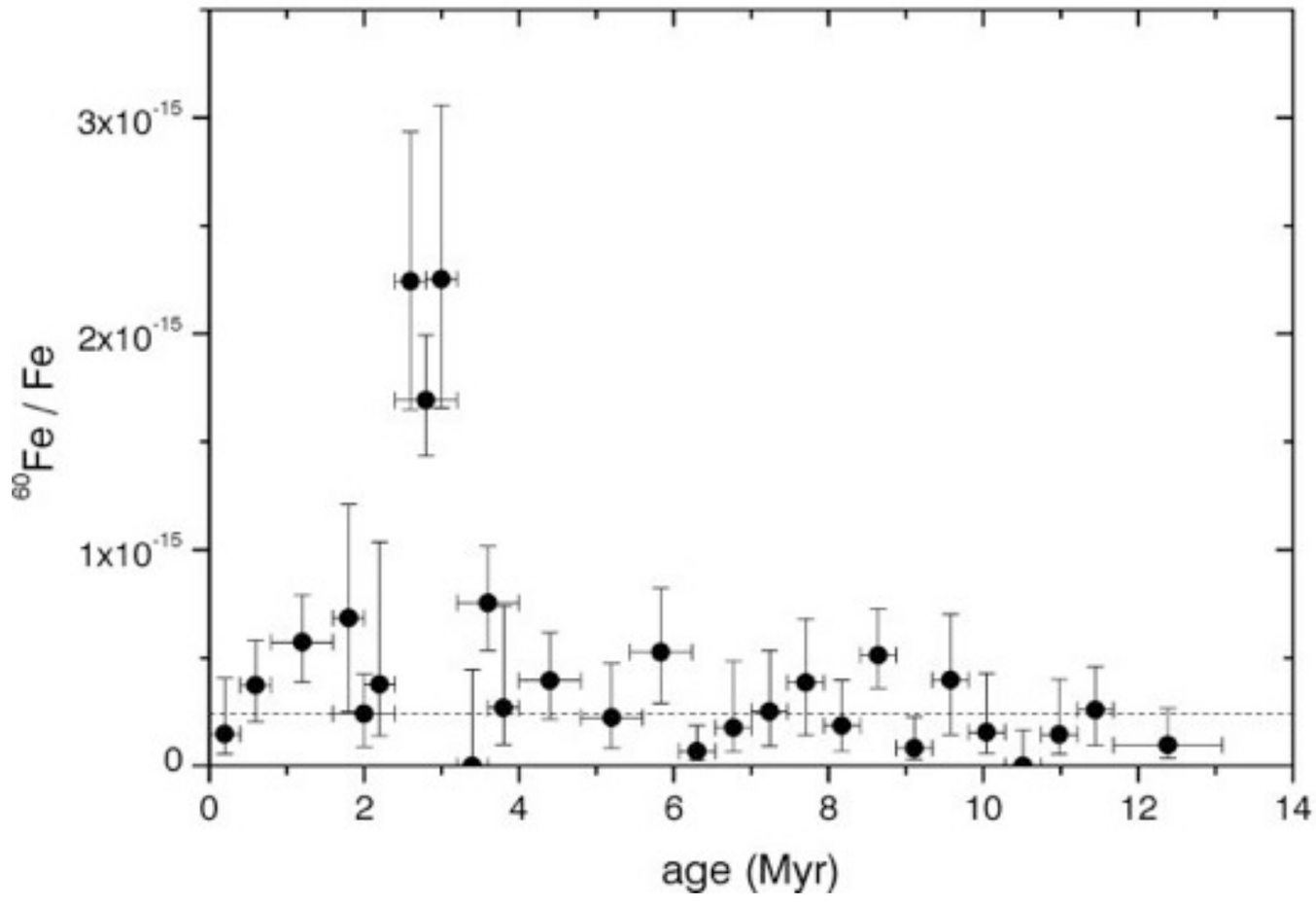

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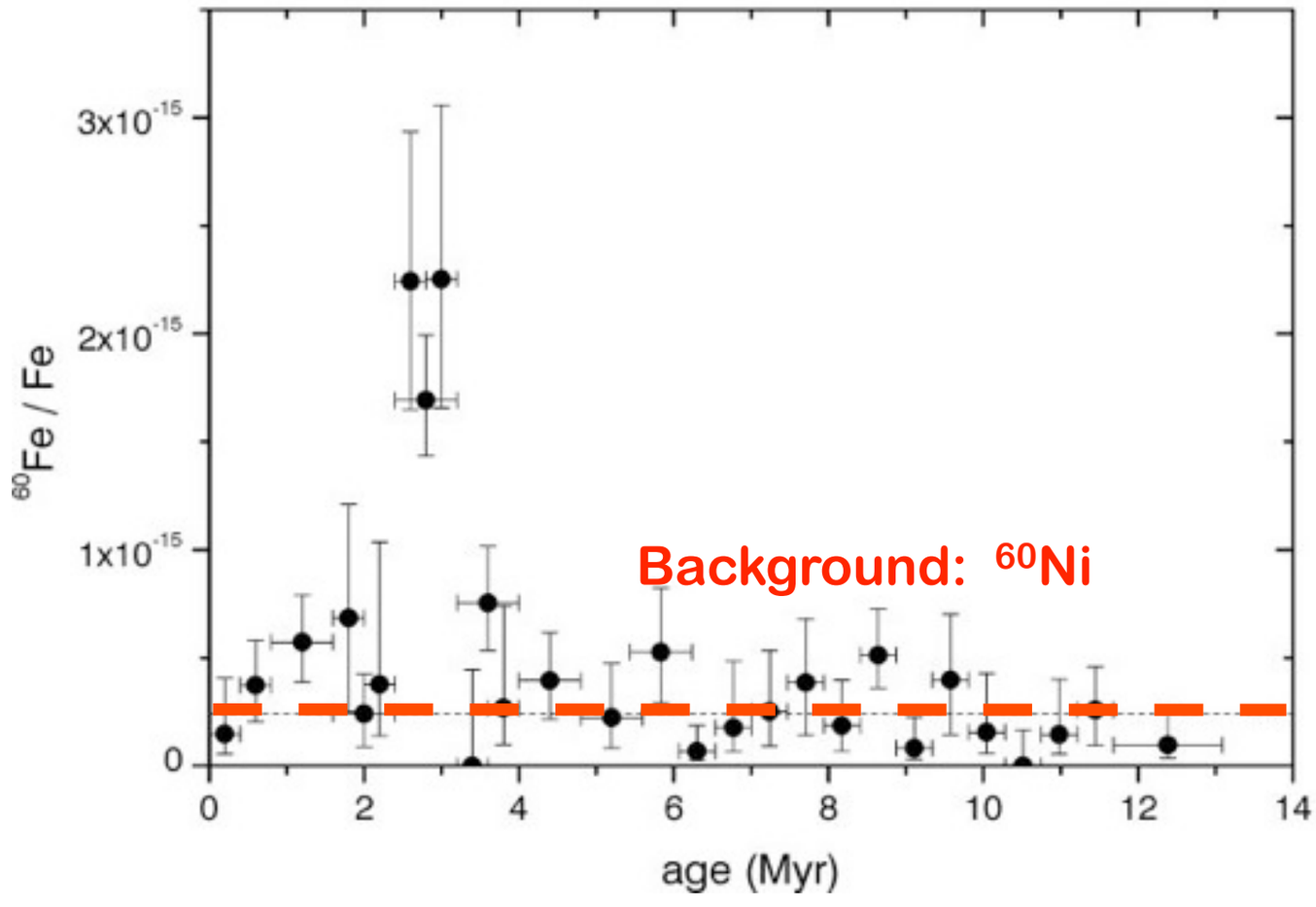

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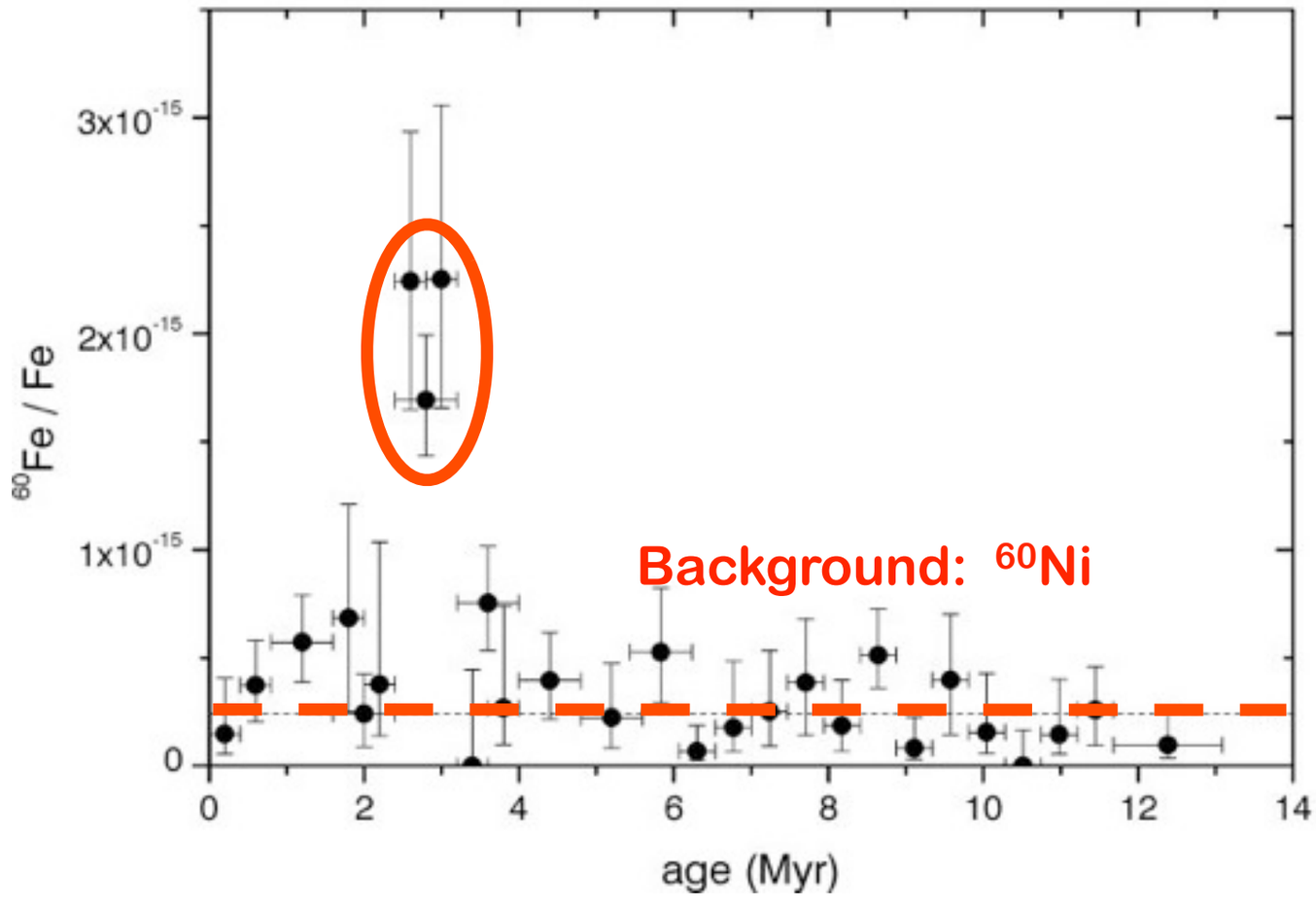

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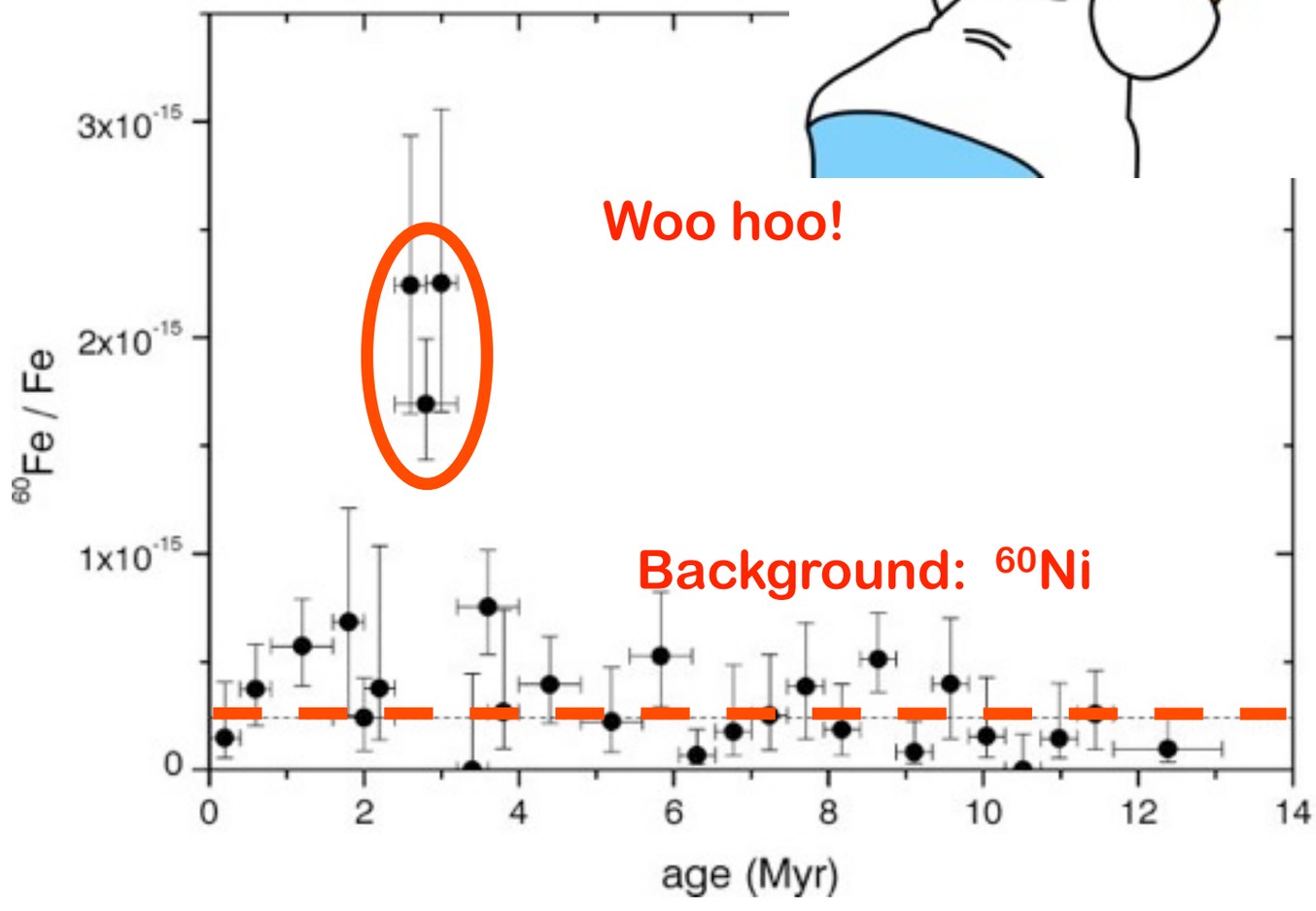

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$$t = 2.8 \pm 0.4 \text{ Myr}$$

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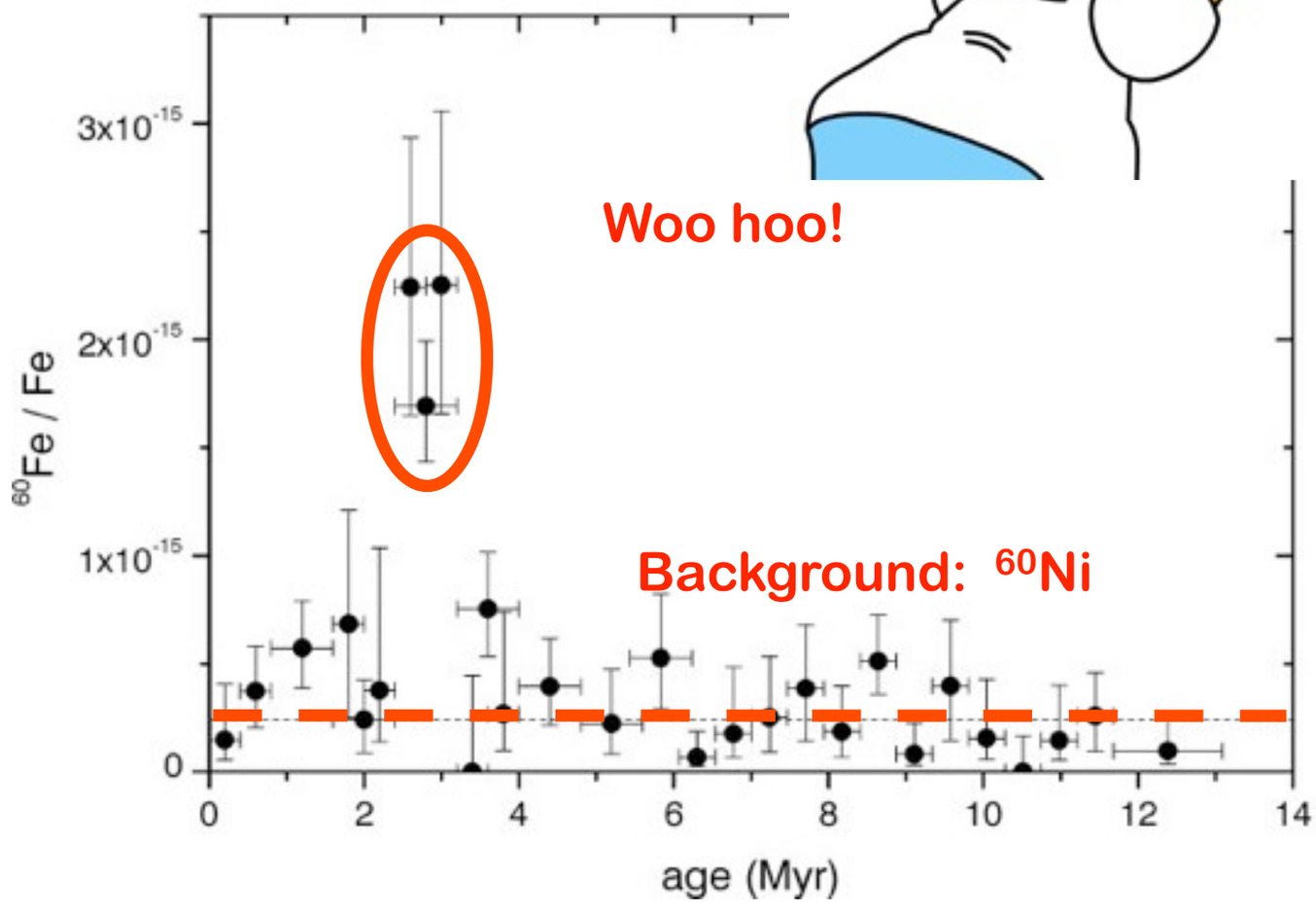

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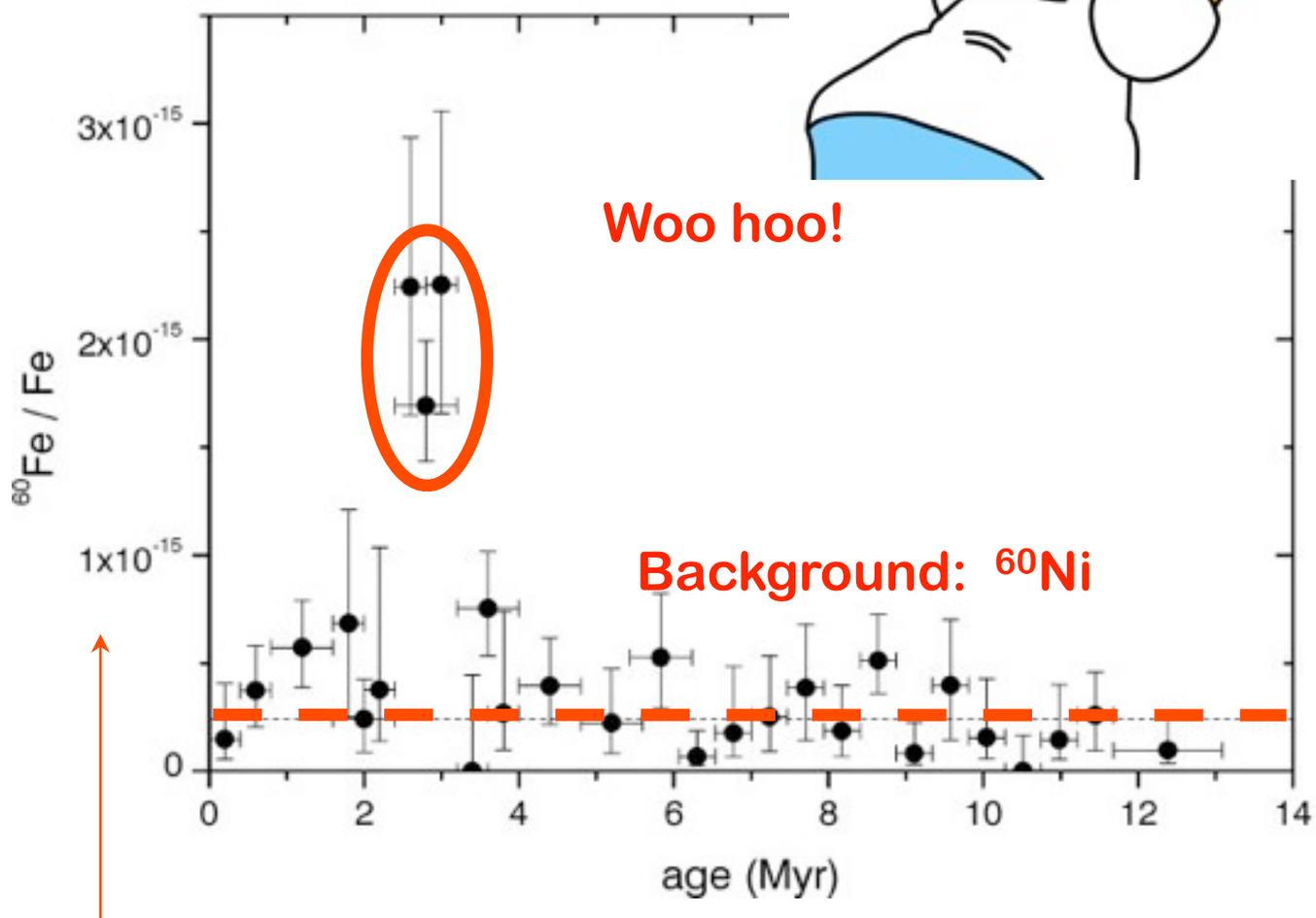

Note fantastic AMS sensitivity!

Implications: SN Distance

Turn the problem around:

$$N_{60,\mathrm{obs}} \sim M_{\mathrm{ej},60} e^{-t/\tau} / d^2$$

$$d \sim \sqrt{\frac{N_{\mathrm{obs}}}{M_{60}(M_{\mathrm{SN}})}}$$

In principle:

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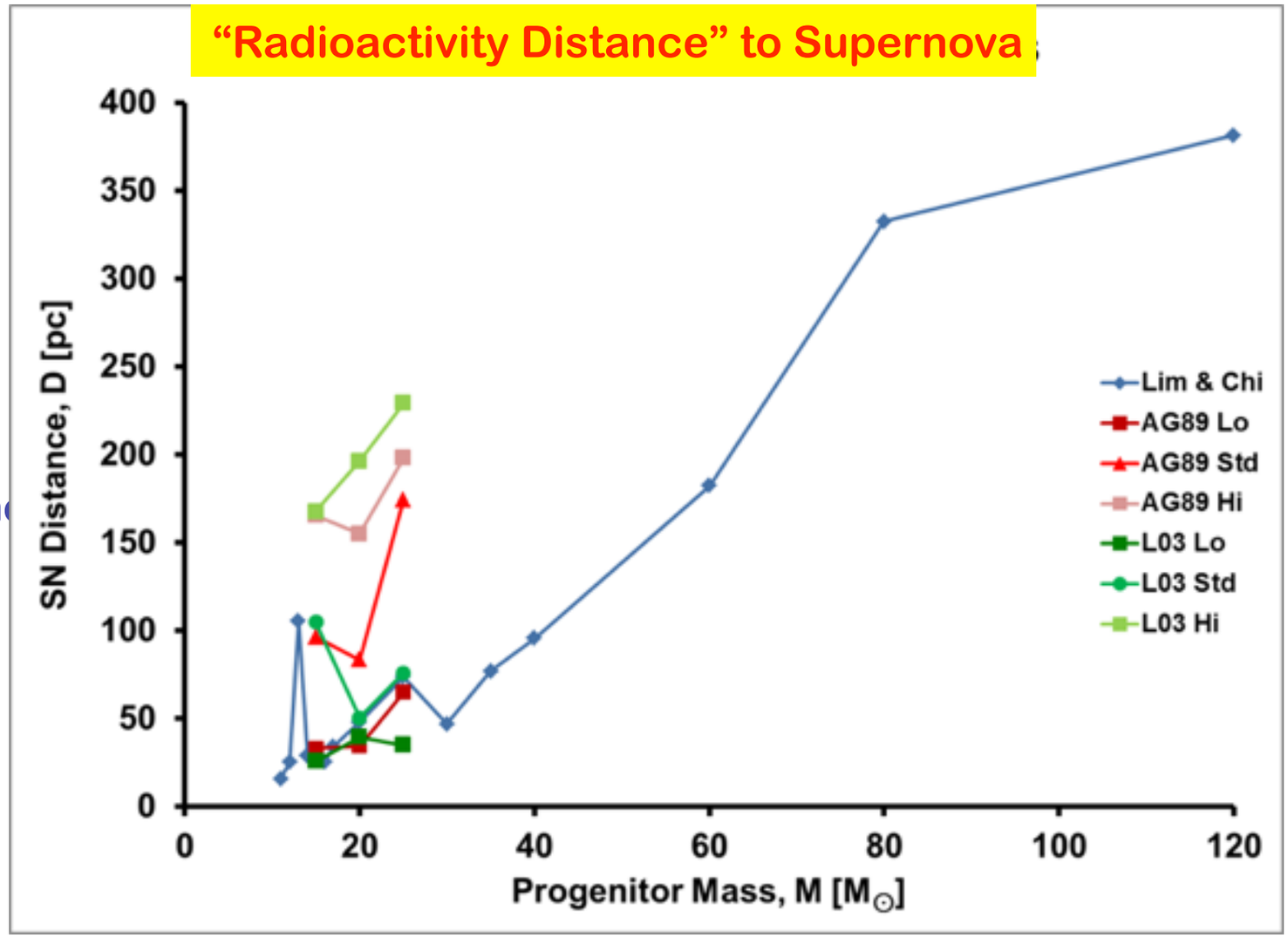
For now

$$d(\mathrm{SN}) \sim 20 - 100 \ \mathrm{pc}$$



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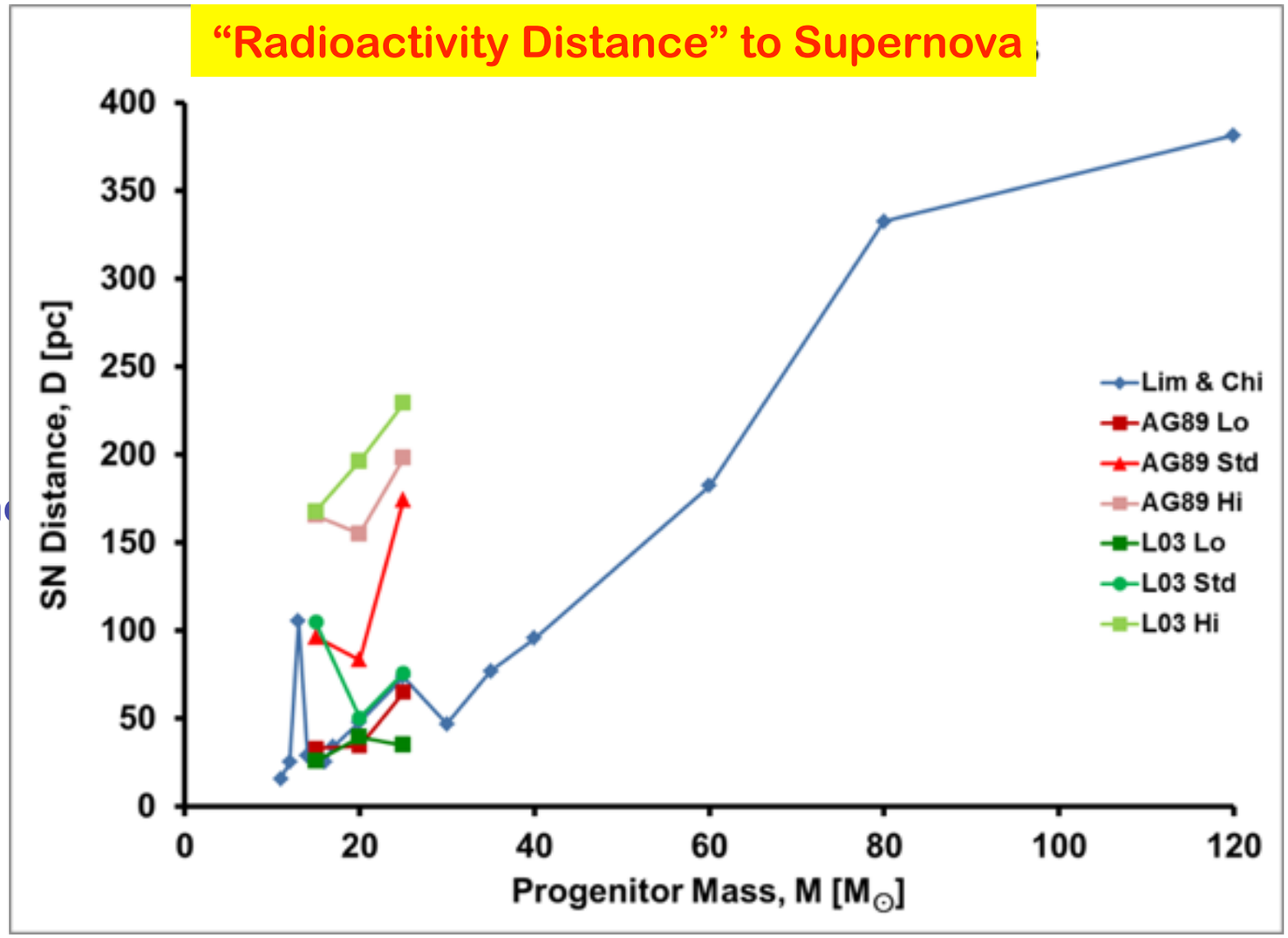

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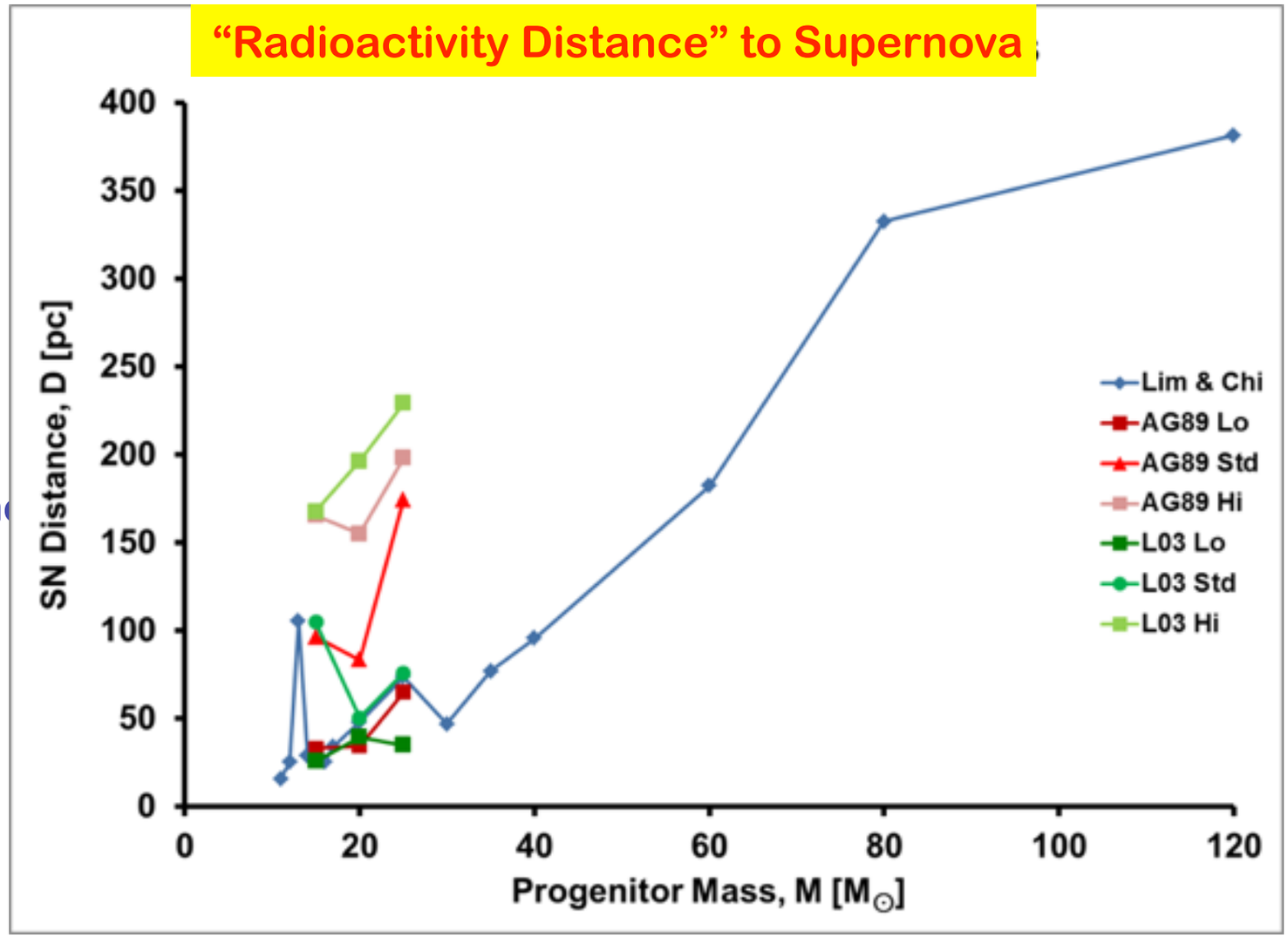

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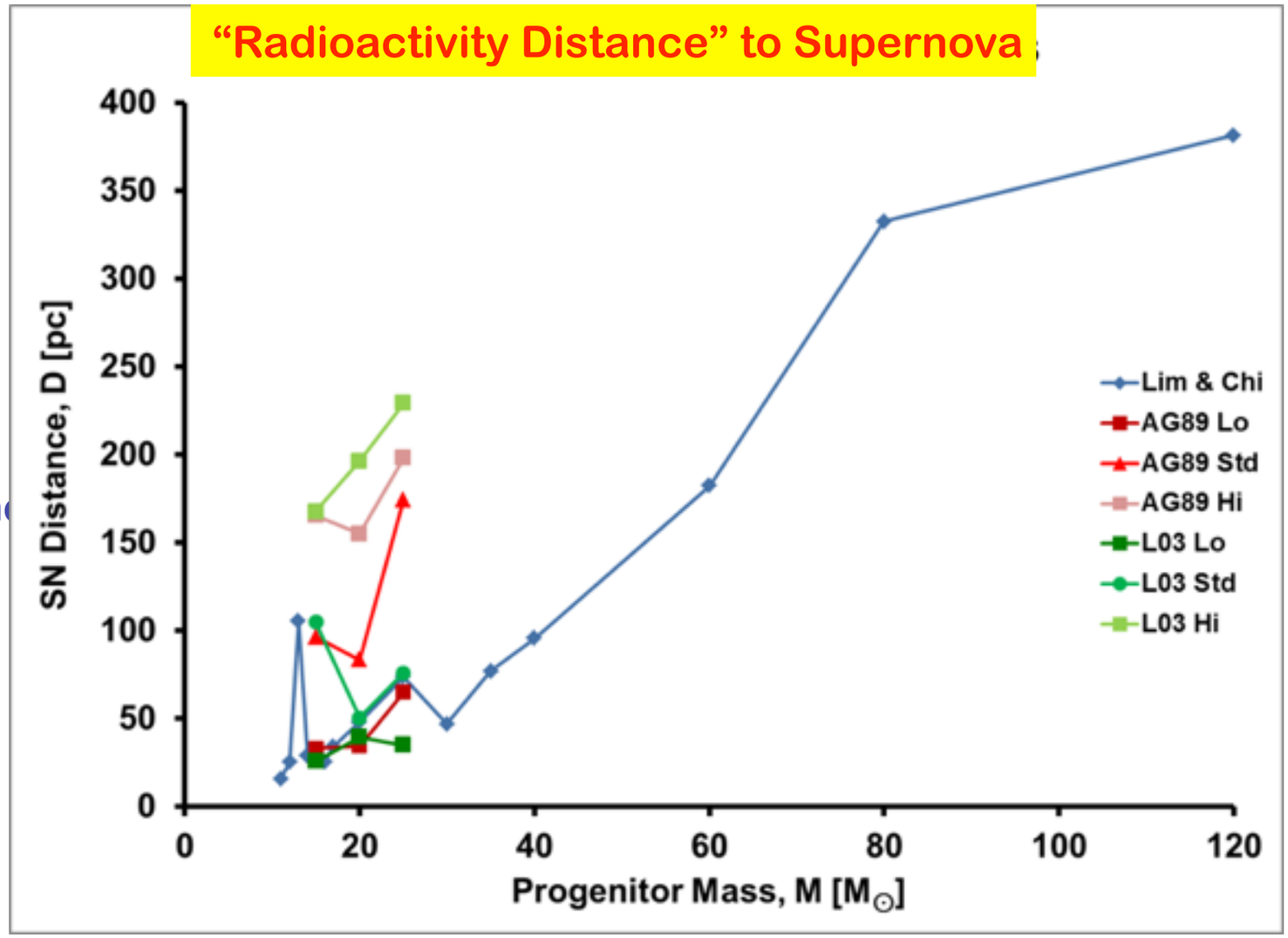
★ $d(^{60}\mathrm{Fe}) \approx d(\mathrm{SN} \rightarrow \mathrm{Earth}) \approx d_{\mathrm{SN}}(3\ \mathrm{Myr})$

⇒ ontrivial consistency!



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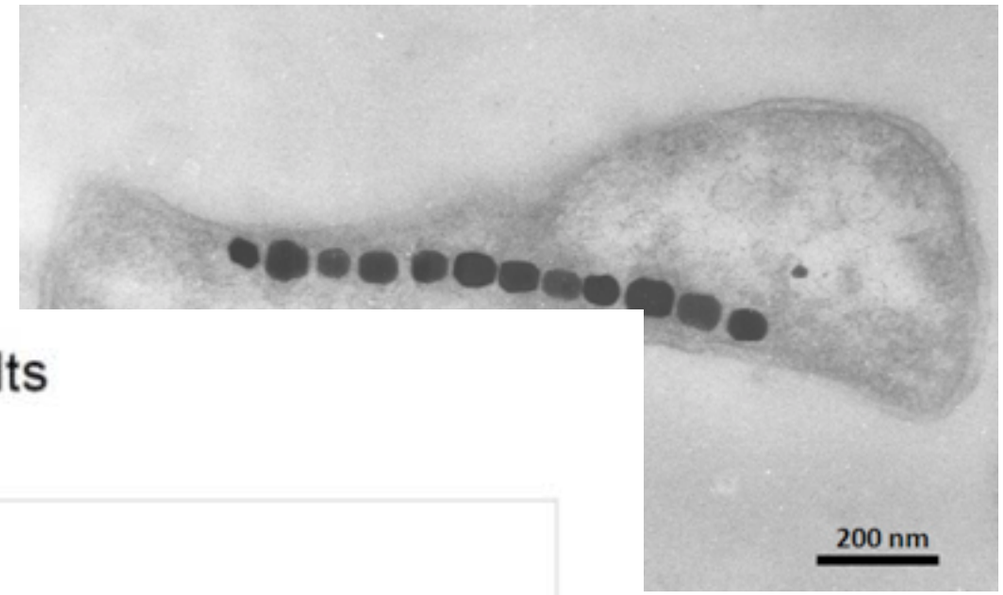

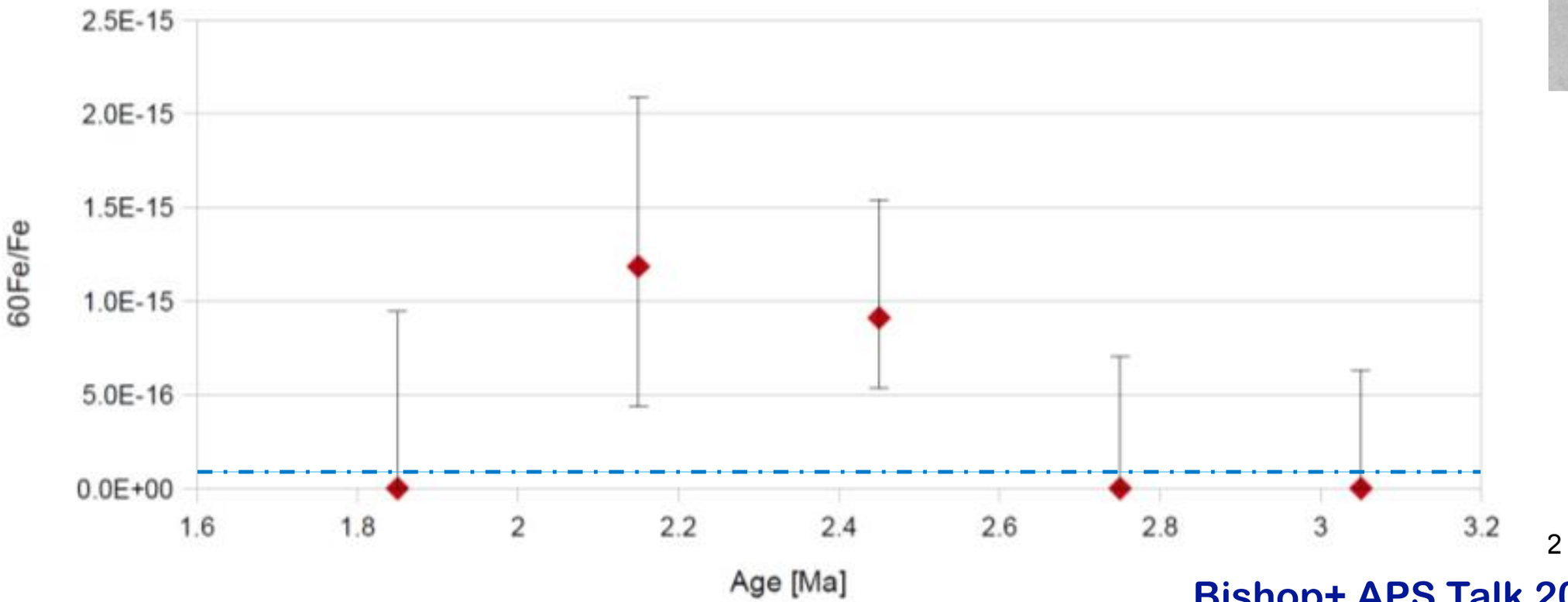

Bishop+ APS Talk 2013

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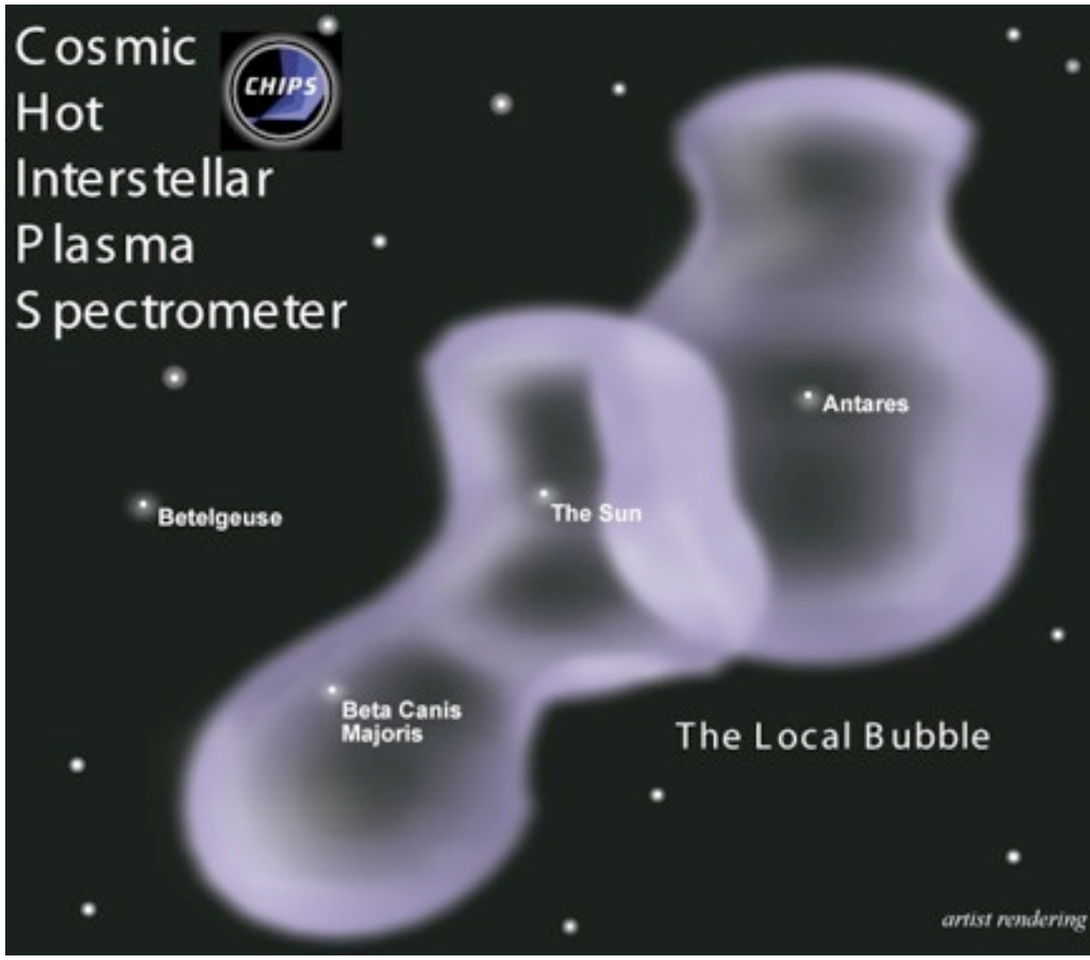
Aftermath: The Local Bubble?

★The Sun lives in region of hot, rarefied gas



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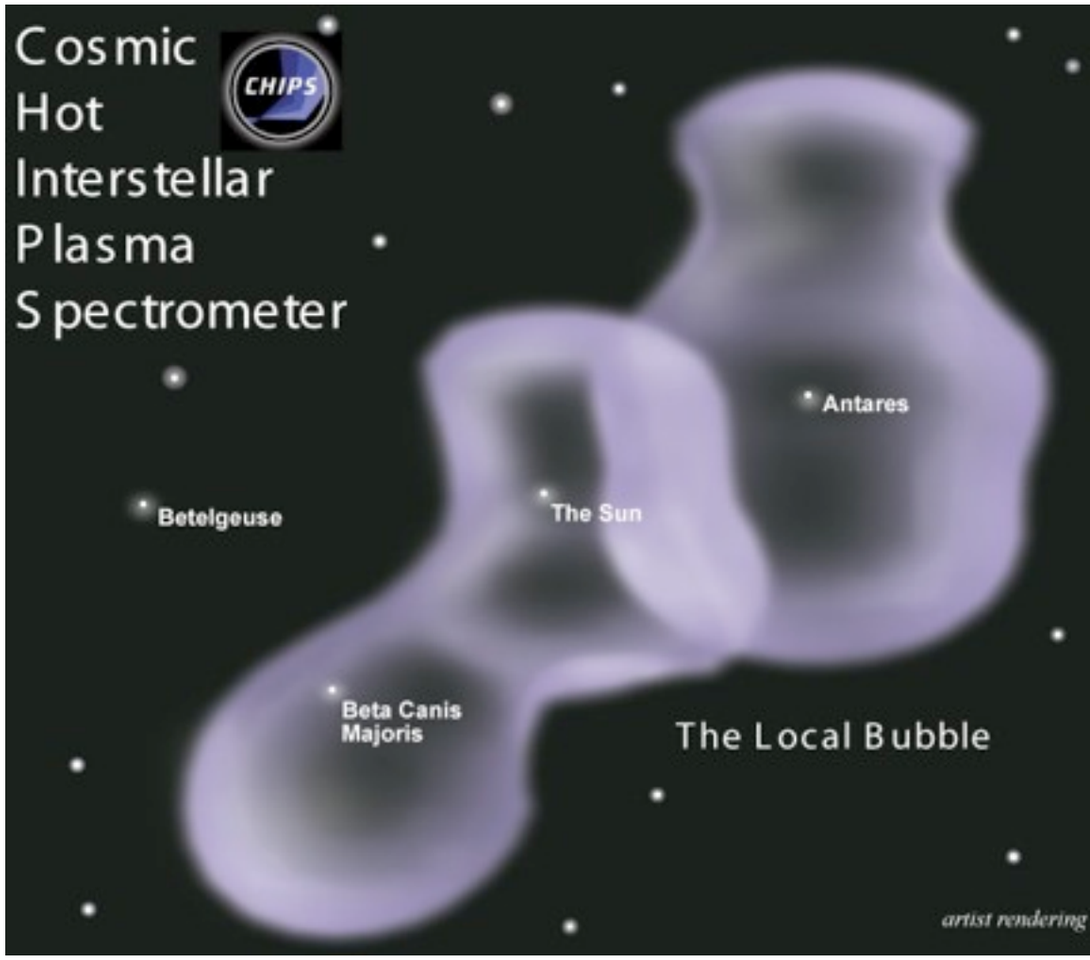
- seen via foreground absorption in nearby starlight



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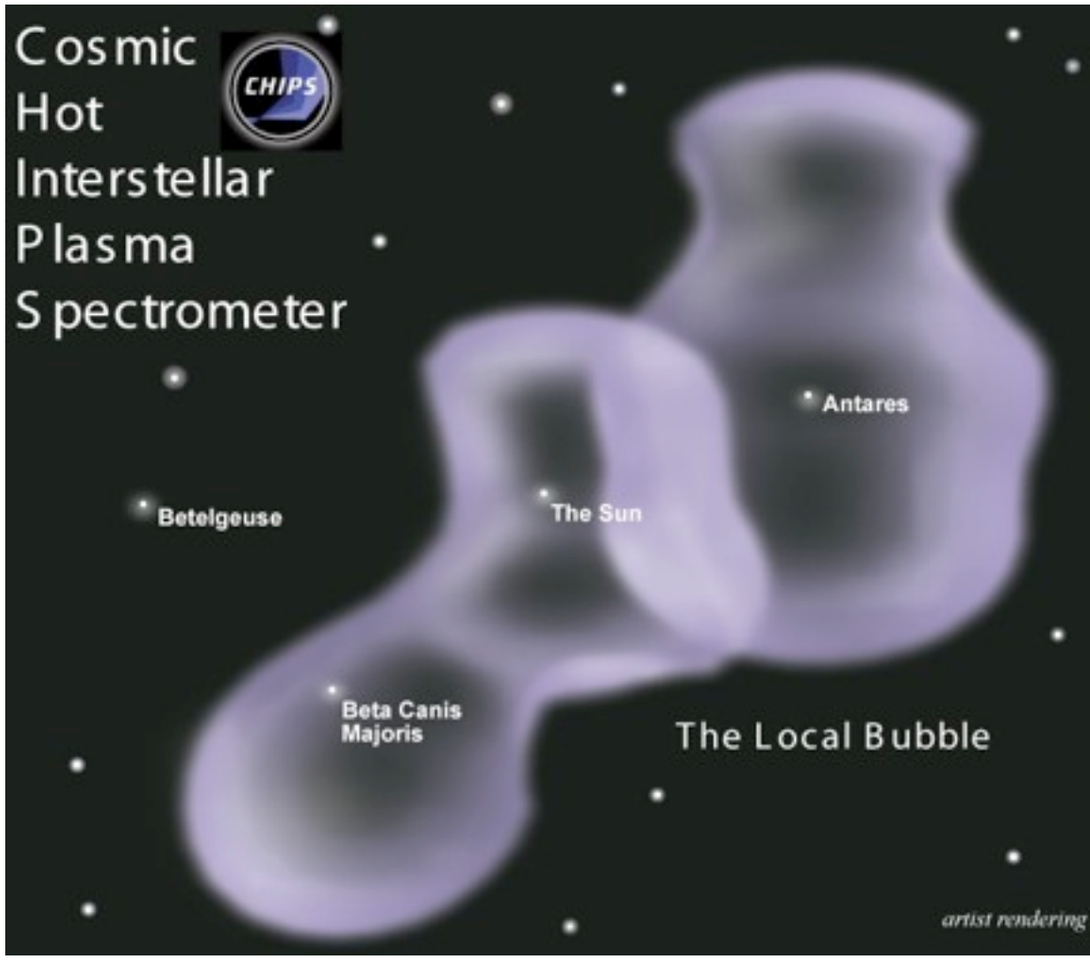
★ **Nearby SN needed**

- we live inside SN remains
- bubble models require >> 1 SN in past 10 Myr Smith & Cox 01
- ^{60}Fe event from nearest massive star cluster? Benitez et al 00



A Near Miss?

$d > d_{\text{kill}} \sim 10$ pc **...but barely: "miss"**

¿ cosmic ray winter?

¿ bump in extinctions?

If true:

implications for astrobiology

tightens Galactic habitable zone

Image: Mark Garlick
www.markgarlick.com

Outlook

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Summary and Conclusions

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Future Research

- better model of SN penetration of heliosphere
- improved SN nucleosynthesis
- more, different samples:
  - ✓ other isotopes
  - ✓ other media (fossil bacteria)
  - ✓ other sites (lunar cores?)
- other epochs? Mass extinction correlations?
- stay tuned…