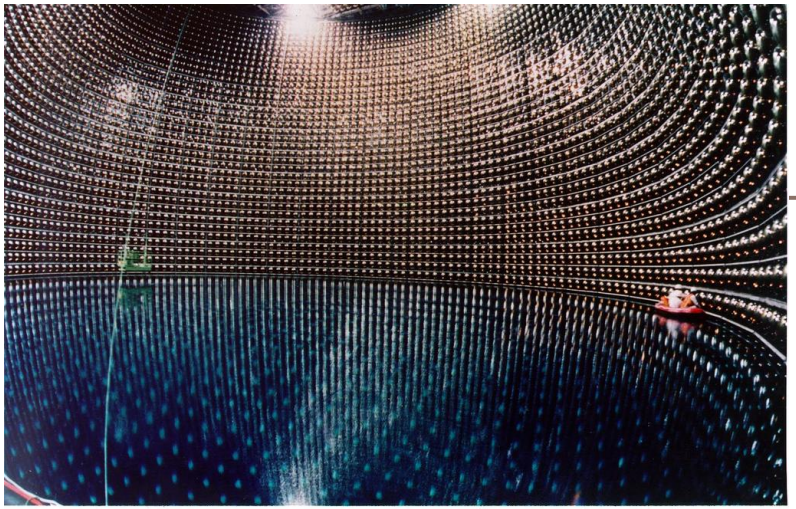
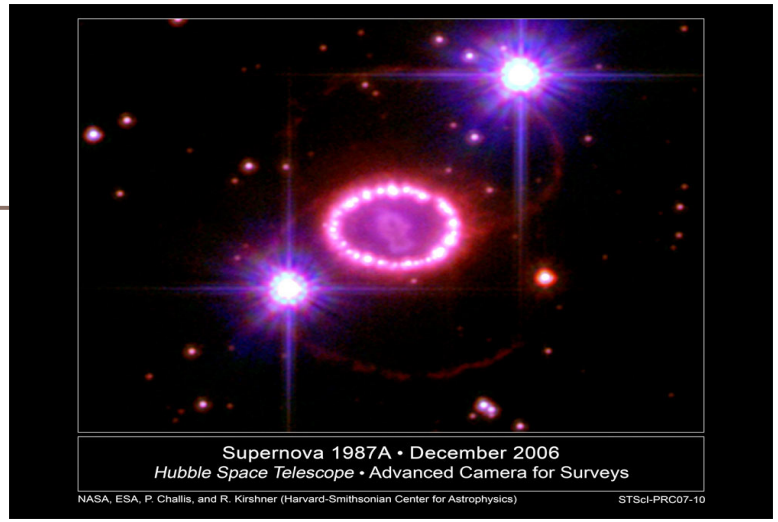
Core-Collapse Supernovae in the Great Survey Era:
Impact on Particle Astrophysics and Cosmology





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The CCAPP Symposium, Ohio State University, 2011/04/05

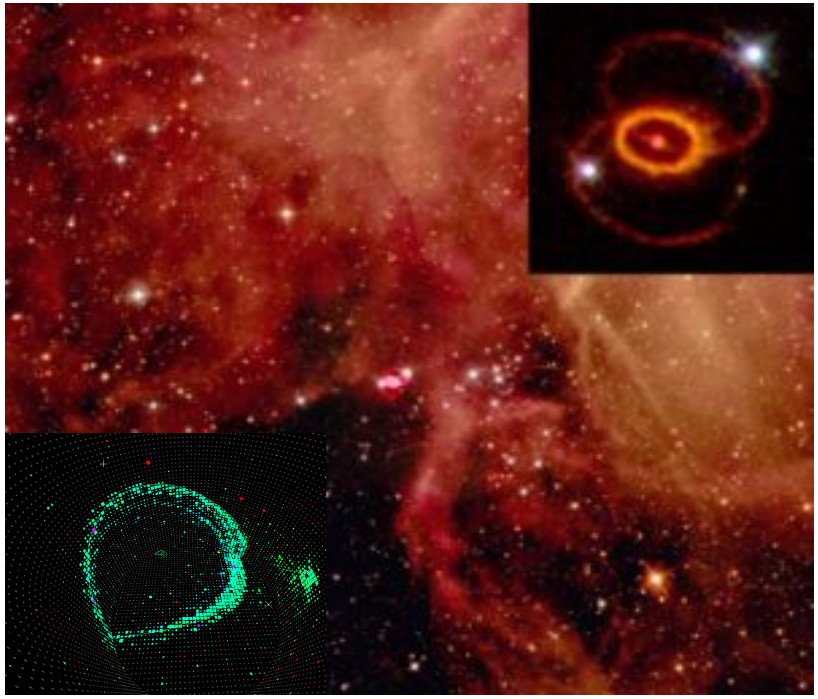
Outline

- Core-collapse supernovae (CC SNe)
- The Great Survey Era
- Particle astrophysics in the Great Survey Era
  - LSST & Neutrinos
    - Diffuse supernova neutrino background (DSNB)
    - SN neutrino physics
    - Invisible supernovae?
- Conclusions/Discussions

Core-Collapse Supernovae

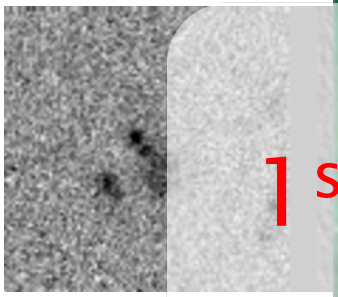
- Explosions of massive stars
  - Types Ib/c, and II
- Core-collapse rate $\propto$ star formation rate
- 99% of energy released in neutrinos
- Failed supernovae?
  - Collapse → Black hole
  - No optical explosion
  - Neutrino emission same or enhanced!

(MacFadyen & Woosley 1999, Nakazato et al. 2008)



Why Nov
– Great

- Scanning
  (e.g. SDS LS, Palomar
  Transient
  - Happenir

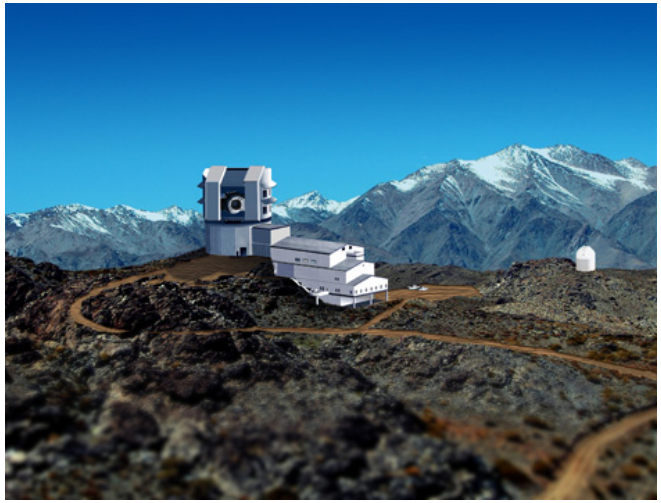


- 2010 Dec

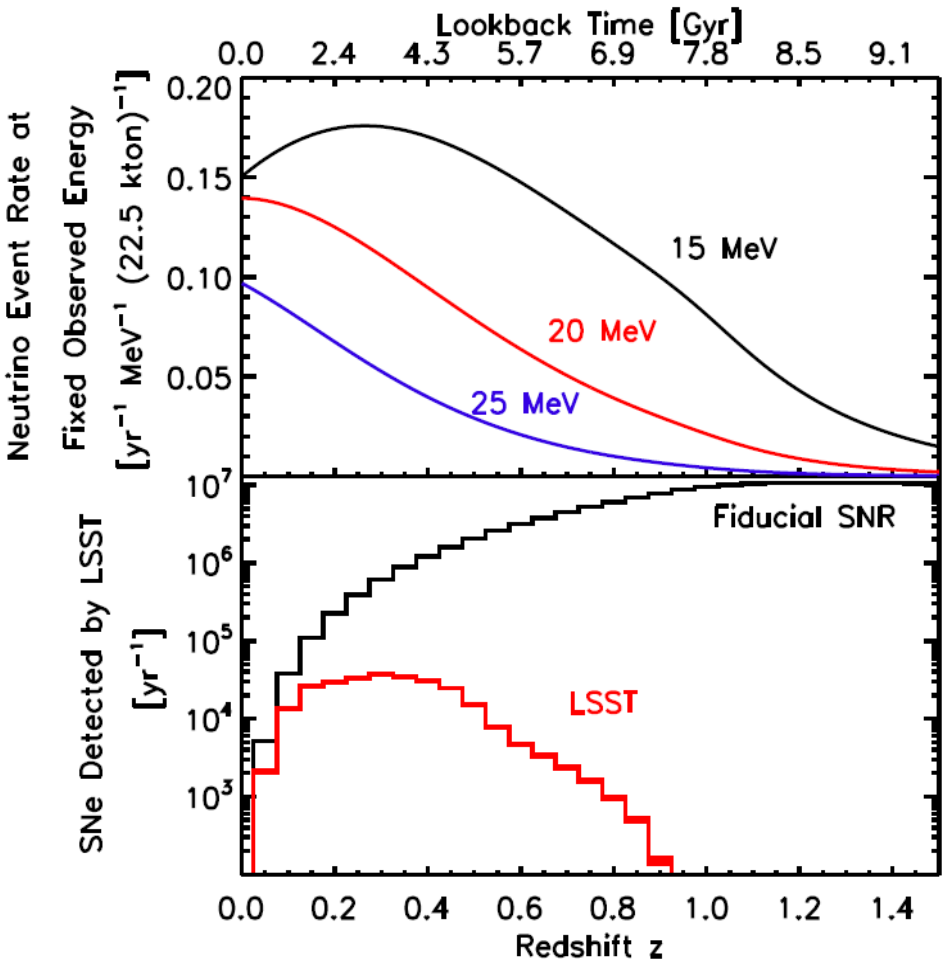
LSST
1st Ground-Based Survey
Starting in 2018!

The Large Synoptic Survey Telescope (LSST)

- Location: Cerro Pachón, Chile
- Synoptic: repeated-scan
- Survey depth (flux sensitivity): ~ 24^{mag}
- Large field of view: 9.6 deg^2 (~ 20 full moons)
- Large Sky Coverage:
  ~20,000 deg^2 (entire night sky) every ~3 nights
- Observe unchanging sky
  to great depth (co-add images)
- Unbiased and complete search
  for transients to great depth



Supernova Surveys and Neutrinos

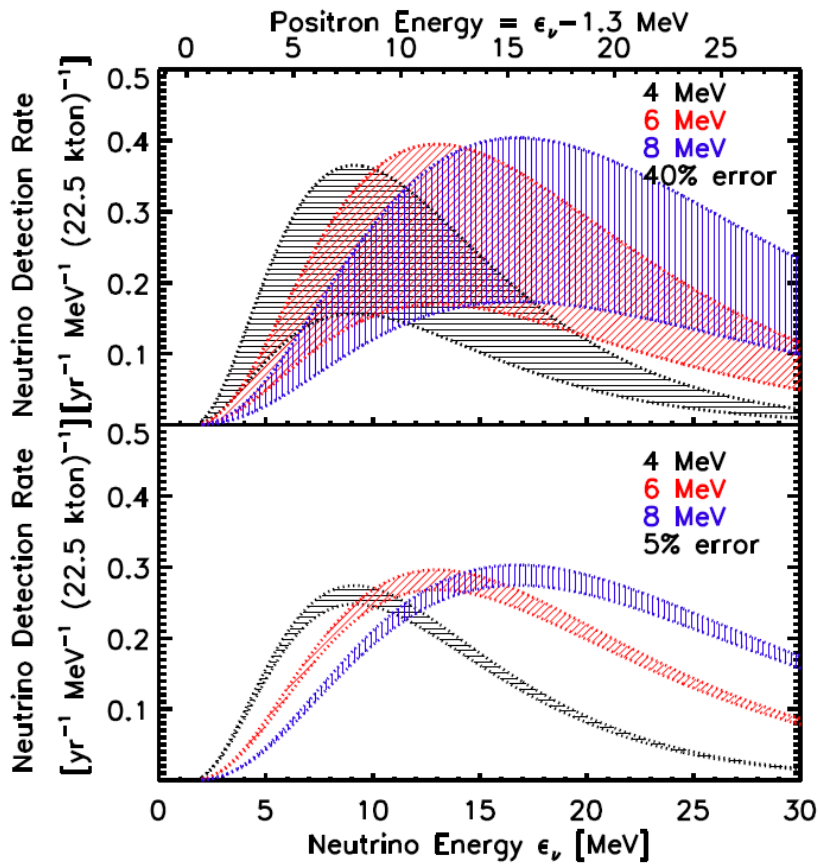


- Main upcoming CC SN survey: LSST
  - Ideal rate: 10 /sec in the whole univ.
  - Detection rate: ~ 10^5 /year to z~1
- Main neutrino detector: Super-Kamiokande (Super-K)
  - Detection energy range: 18-26 MeV
  - Possible future detection energy range: 10-26 MeV
- Neutrino detection peak at similar redshift range of SN surveys
- 76% of 10-26 MeV DSNB comes from SN with z <1

Cosmic Supernovae & The Diffuse Supernova Neutrino Background

- Neutrino flux from all cosmic supernovae
  - Energy range ~ 10 – 26 MeV
- Neutrino observatories
  - Expect first detection of background SN neutrinos in next ~ 10 yrs
- Forecast: Surveys + Neutrinos
  - Imagine: SN rate known to z~1
  - Dust effects and SN luminosity distribution understood
  - Assume 5% precision

- Example: Probing different SN neutrino models

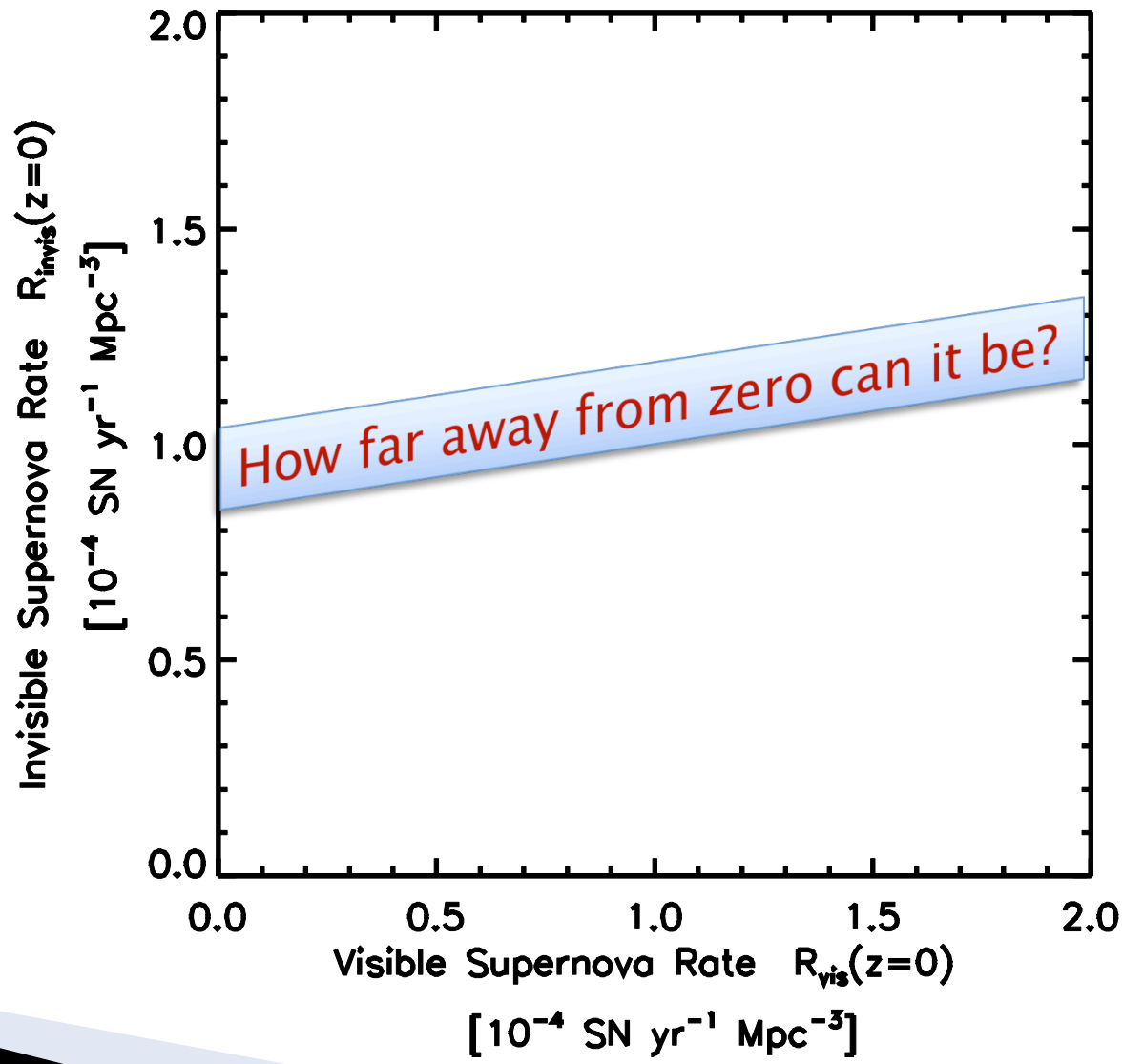


Failed Supernovae?

- Massive stars which collapse directly into black holes without optical explosions.
- Current theories suggest:
  - 8 M_{sun} < M_{star} < 25 M_{sun}: explode (81%)
  - M_{star} > 40 M_{sun}: failed (9%)
  - 25 M_{sun} < M_{star} < 40 M_{sun}: ??? (10%)
- Most of the failed supernovae create neutrinos with higher energies
- Neutrinos as a tool to probe the fraction of failed supernovae
- Horuichi et al. (2011) suggests a larger fraction of optically dim supernovae

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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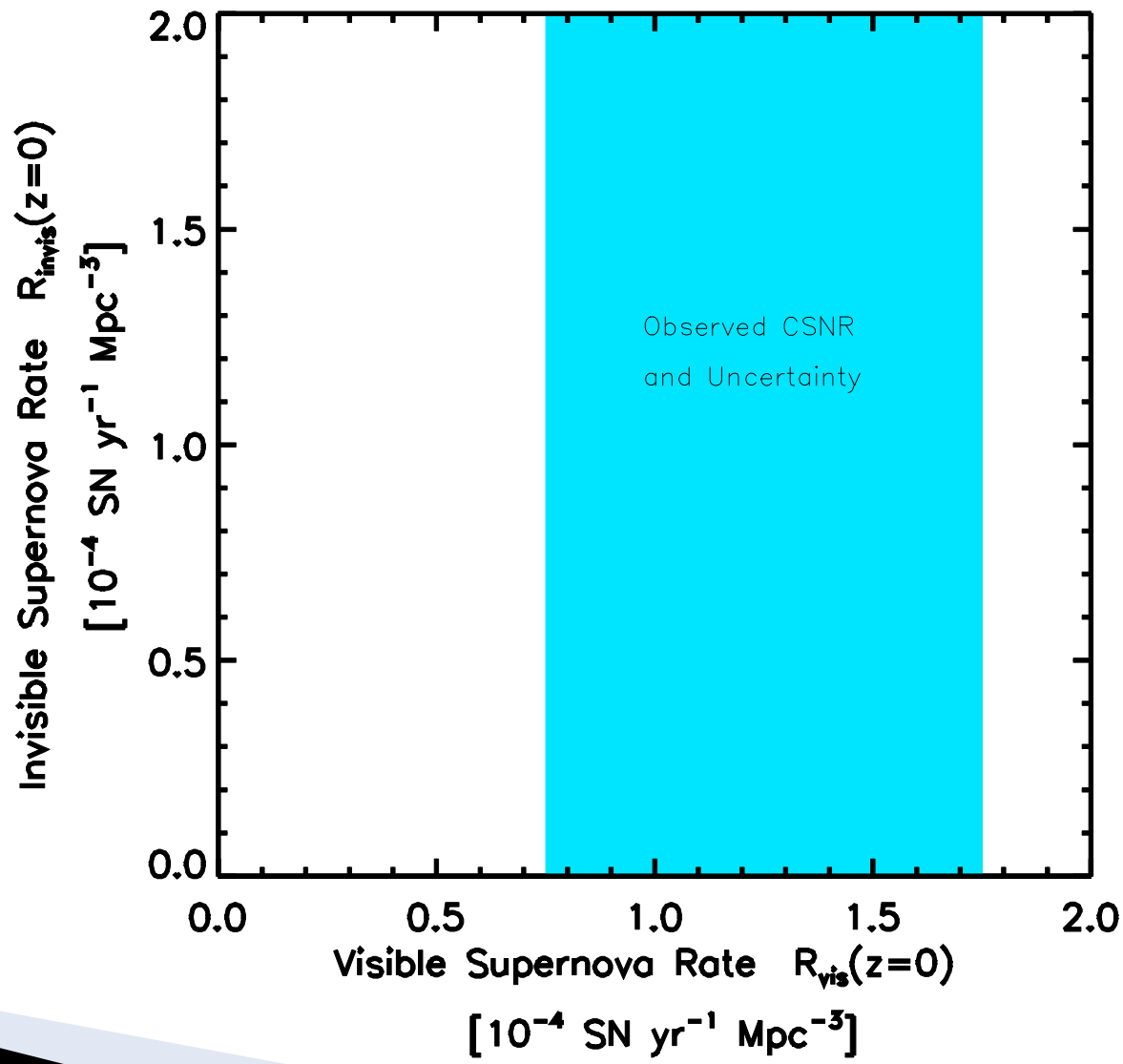

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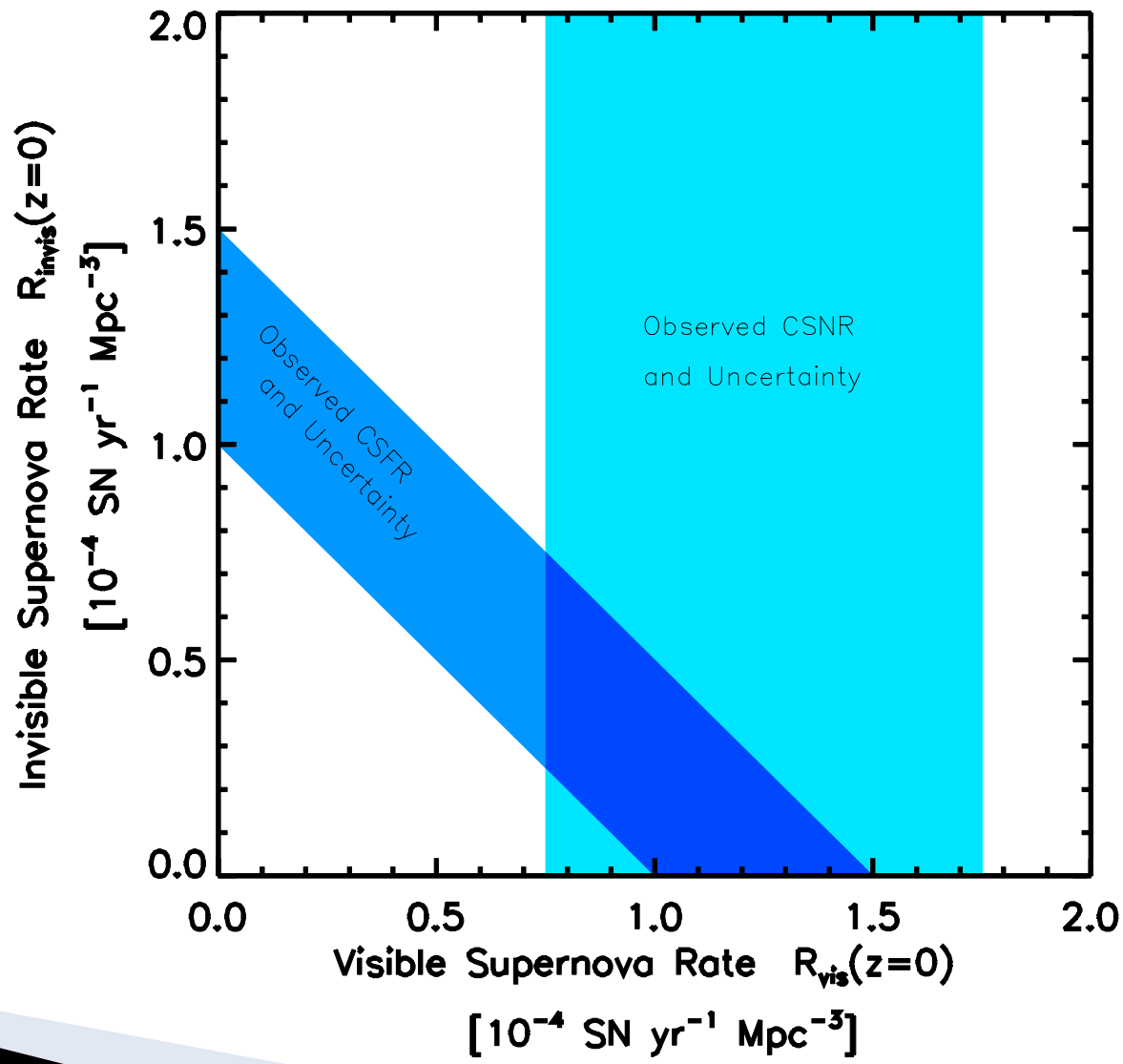

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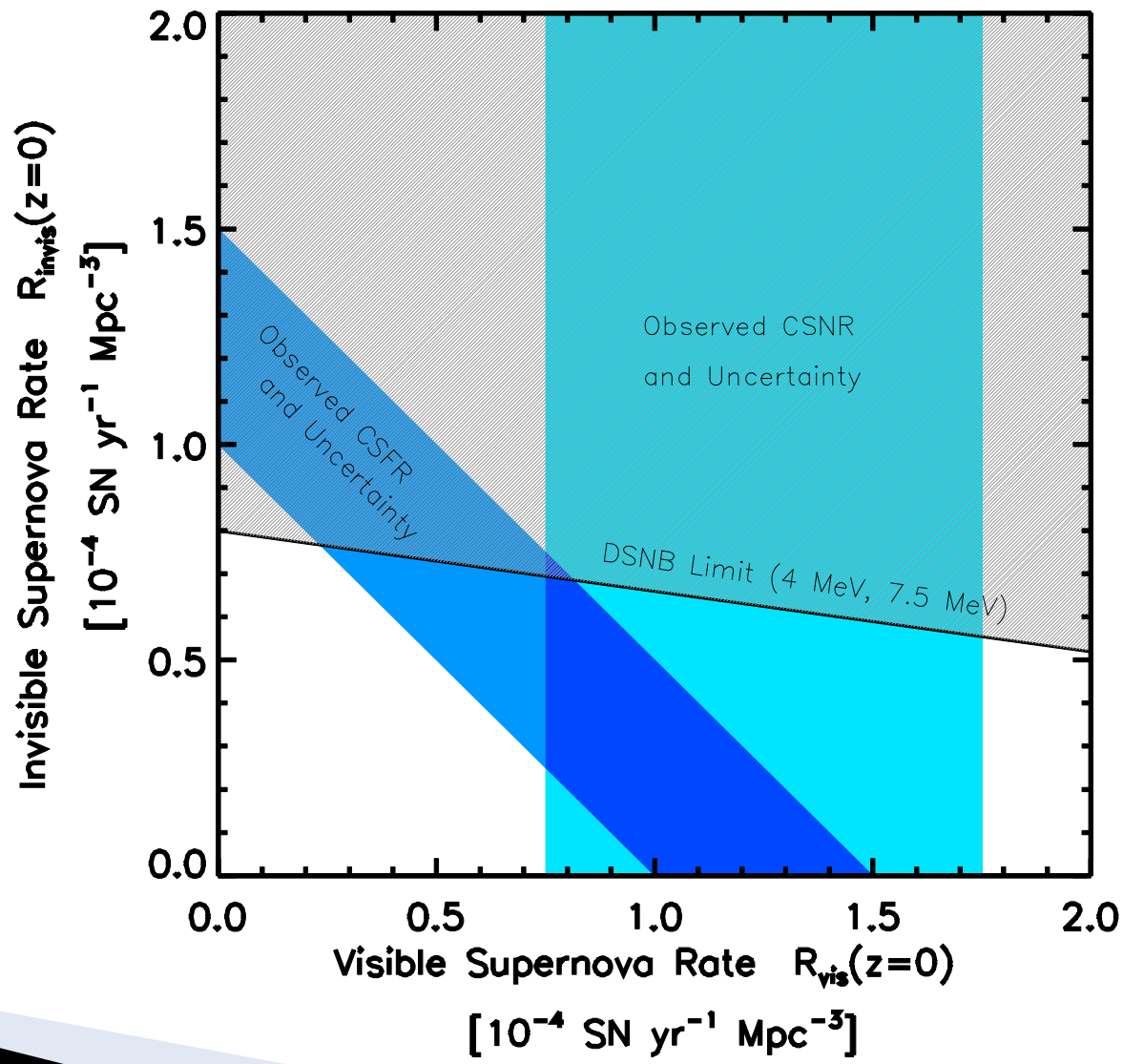

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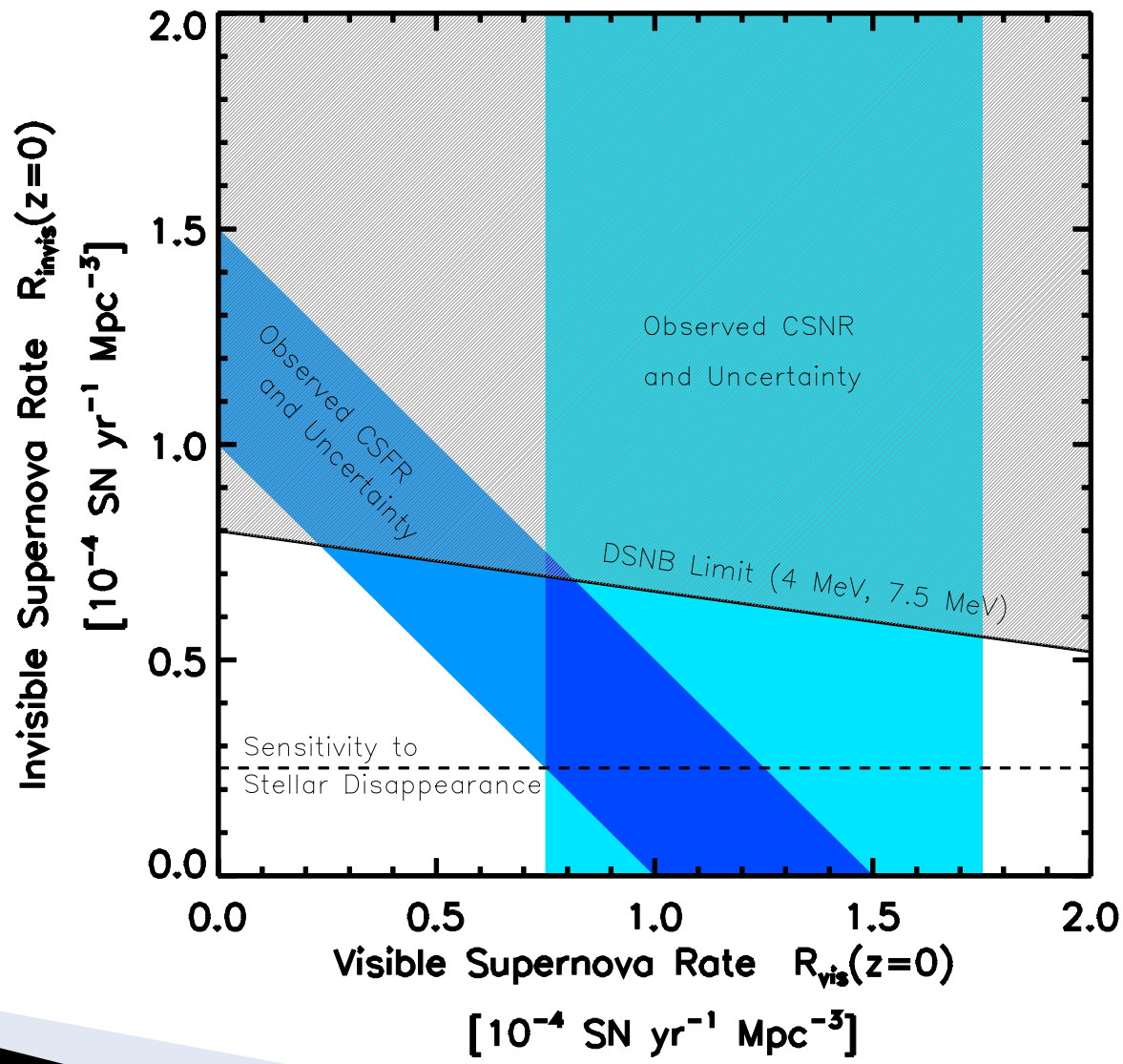

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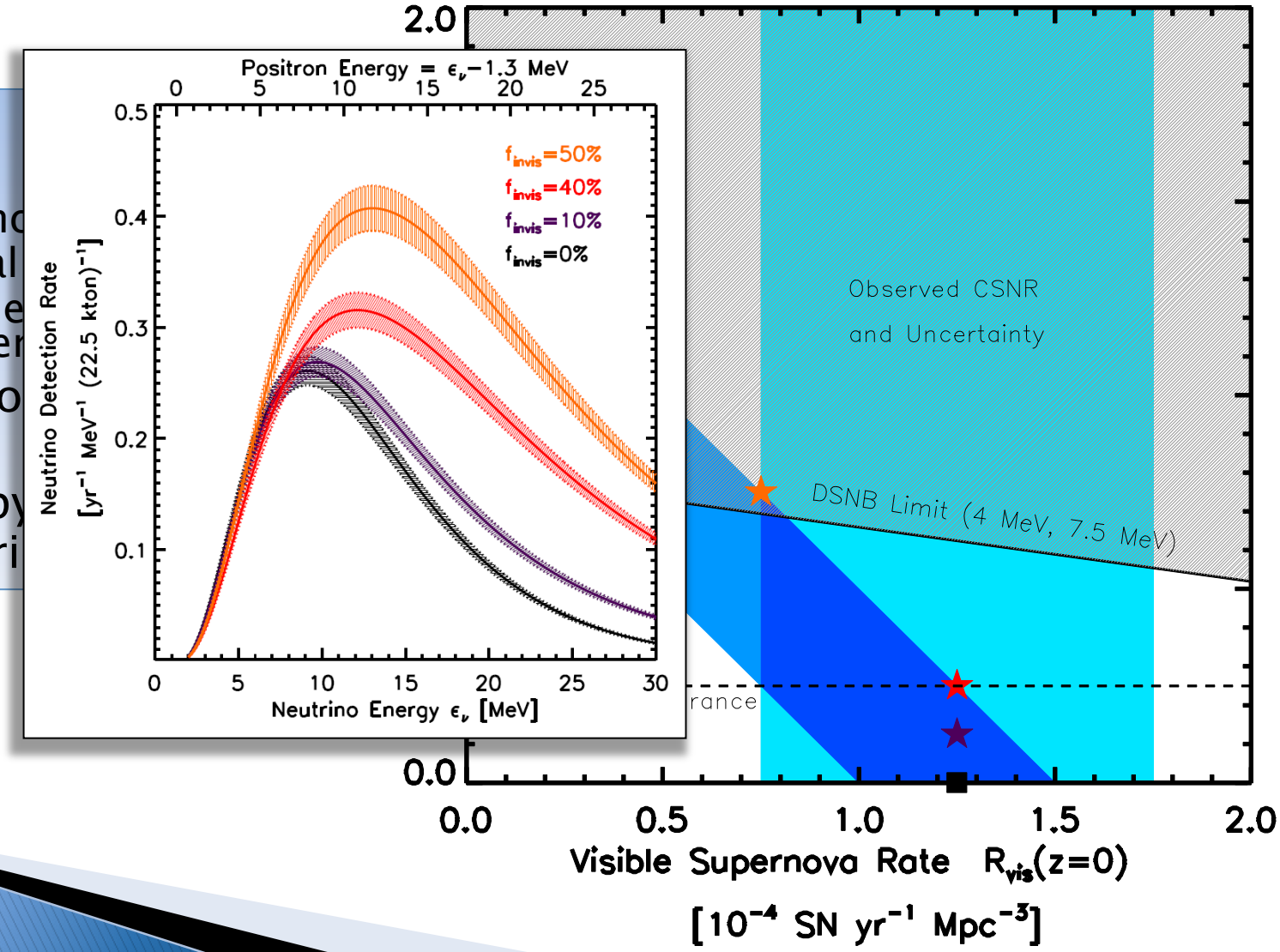


Conclusions

LSST SNe

- Measure cosmic SN rate to $z < 1$ via direct counting
- Star-formation rate to high precision out to $z < 1$
- Remove astro uncertainty in DSNB

LSST SNe + Neutrinos

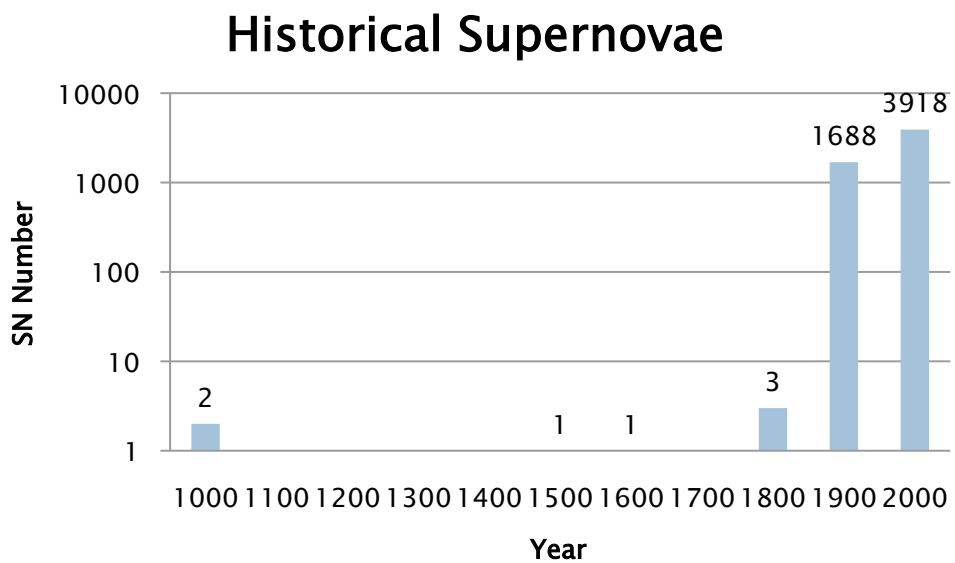
- Distinguish different supernova neutrino models.
- Probe failed supernovae.
  - DSNB flux should be at least 10% higher than flux from observed supernovae.

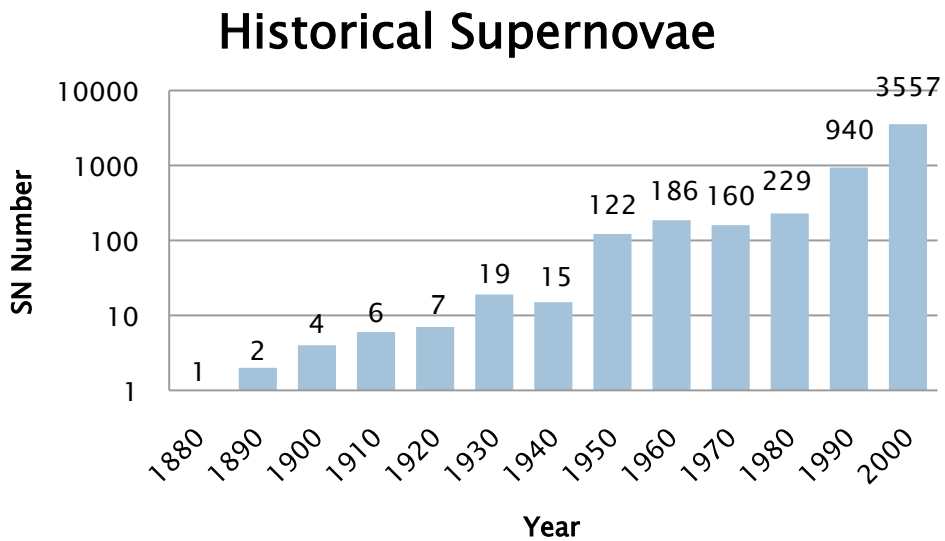
LSST SNe + Neutrinos + ?

Thank You

Back-up Slides

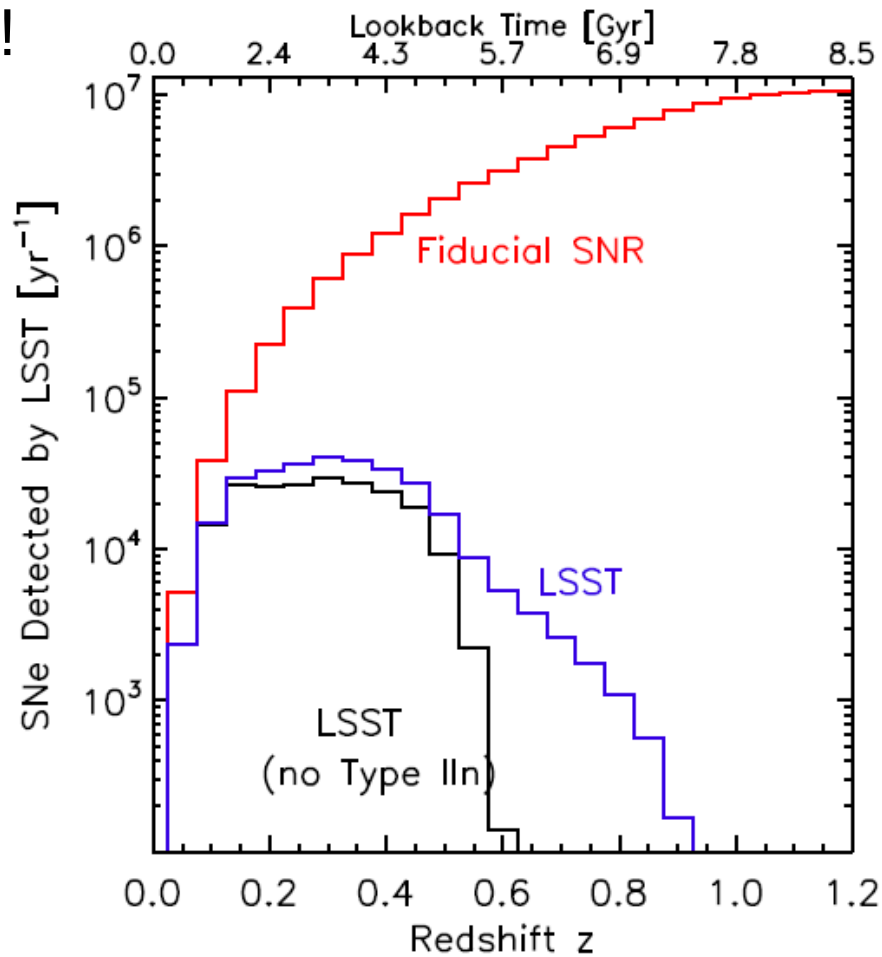
How Many is 1 Million Supernovae?





Forecasts for Synoptic Surveys

- $> 10^5$ CC SNe per year to $z \sim 1$.
- SN rate by direct counting!
- <10% statistical precision for the CC SNe rate in one year of detection (current uncertainty > 40%).
- LSST plot:
  - Scan area: 20000 deg^2
  - Proposed limiting magnitude for SNe: 23^{mag}
  - Bin size: $\Delta z=0.1$



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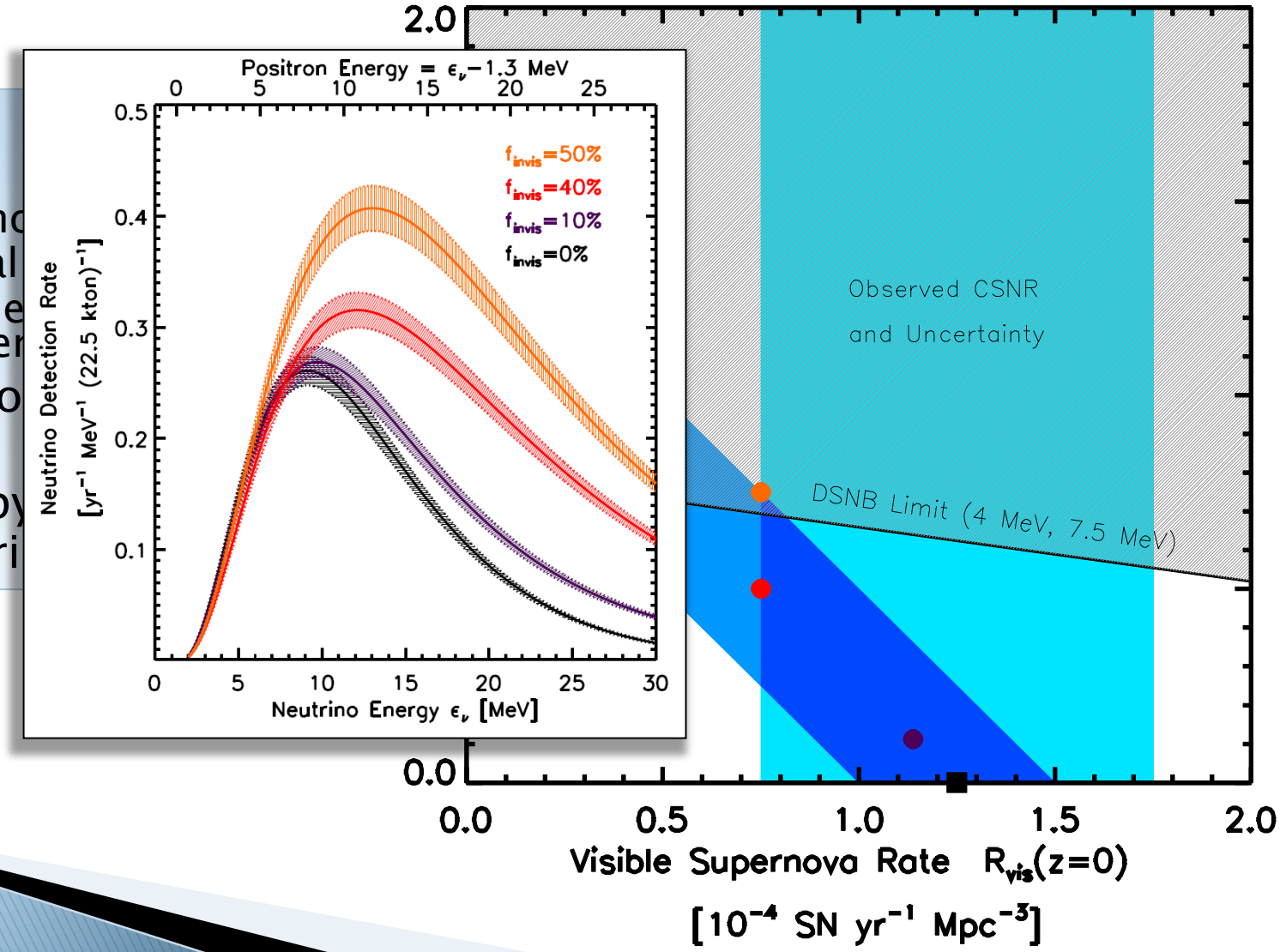
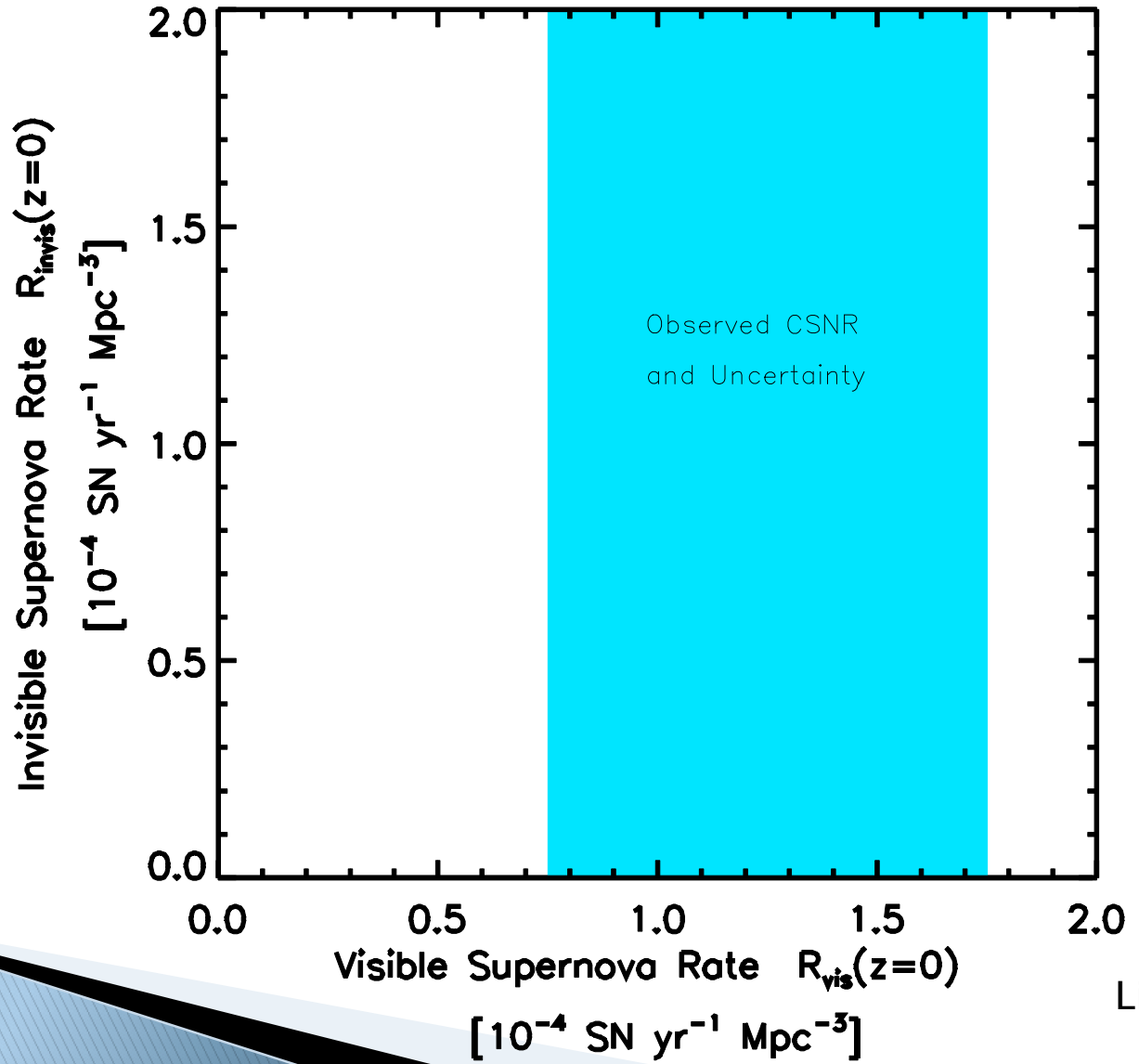


What is the likely failed supernova rate ?



Lien et al. (2010)

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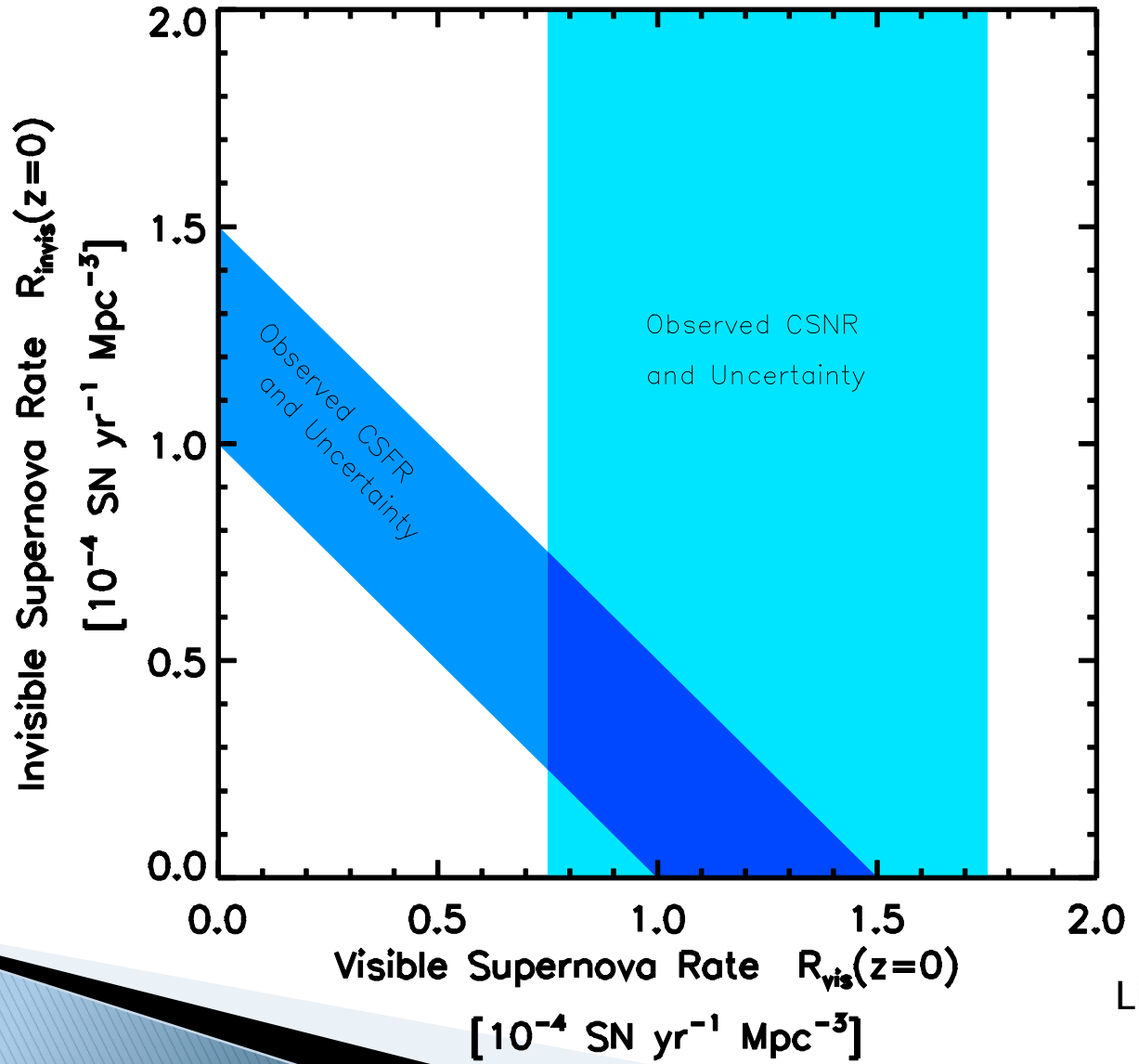

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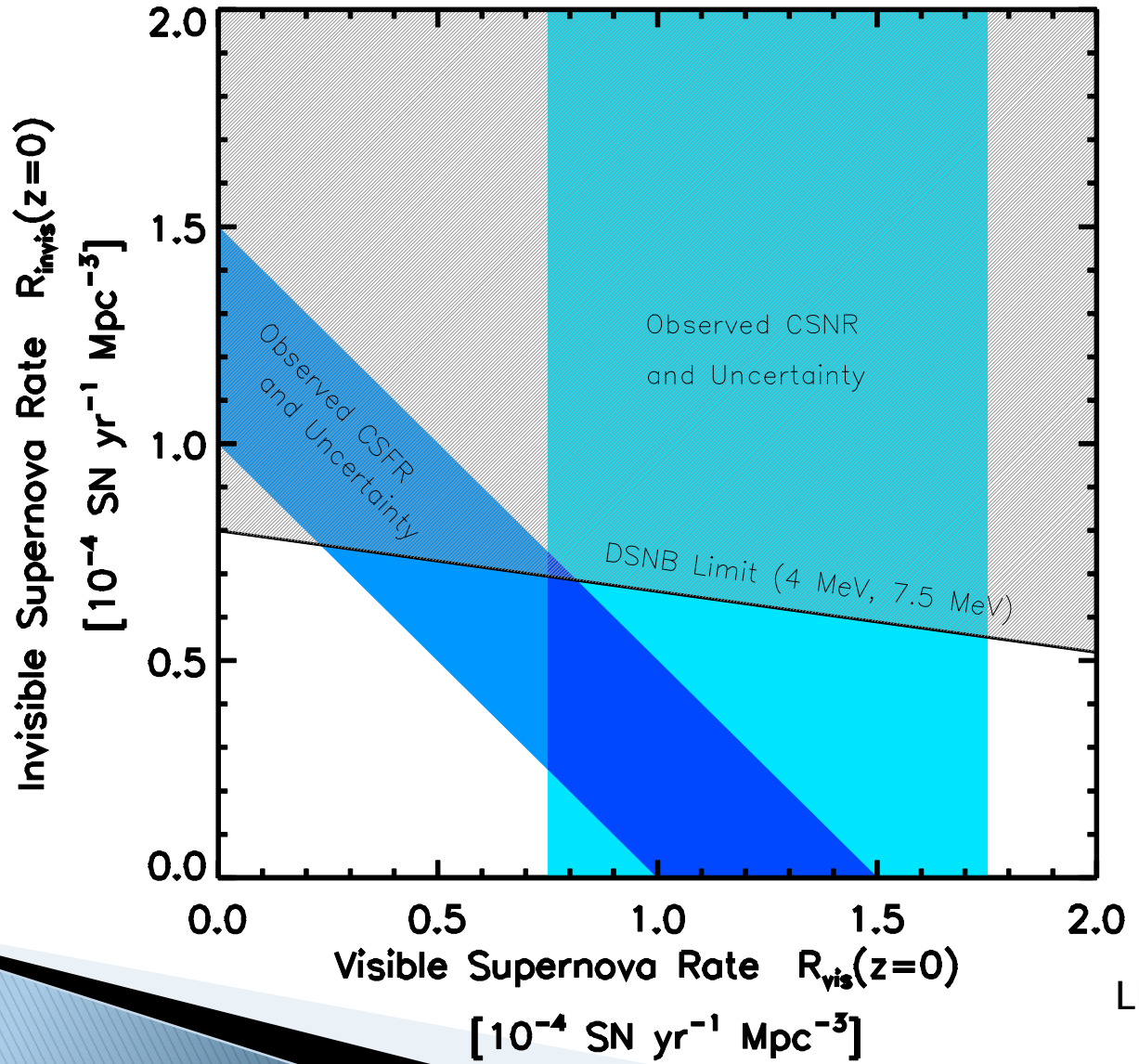

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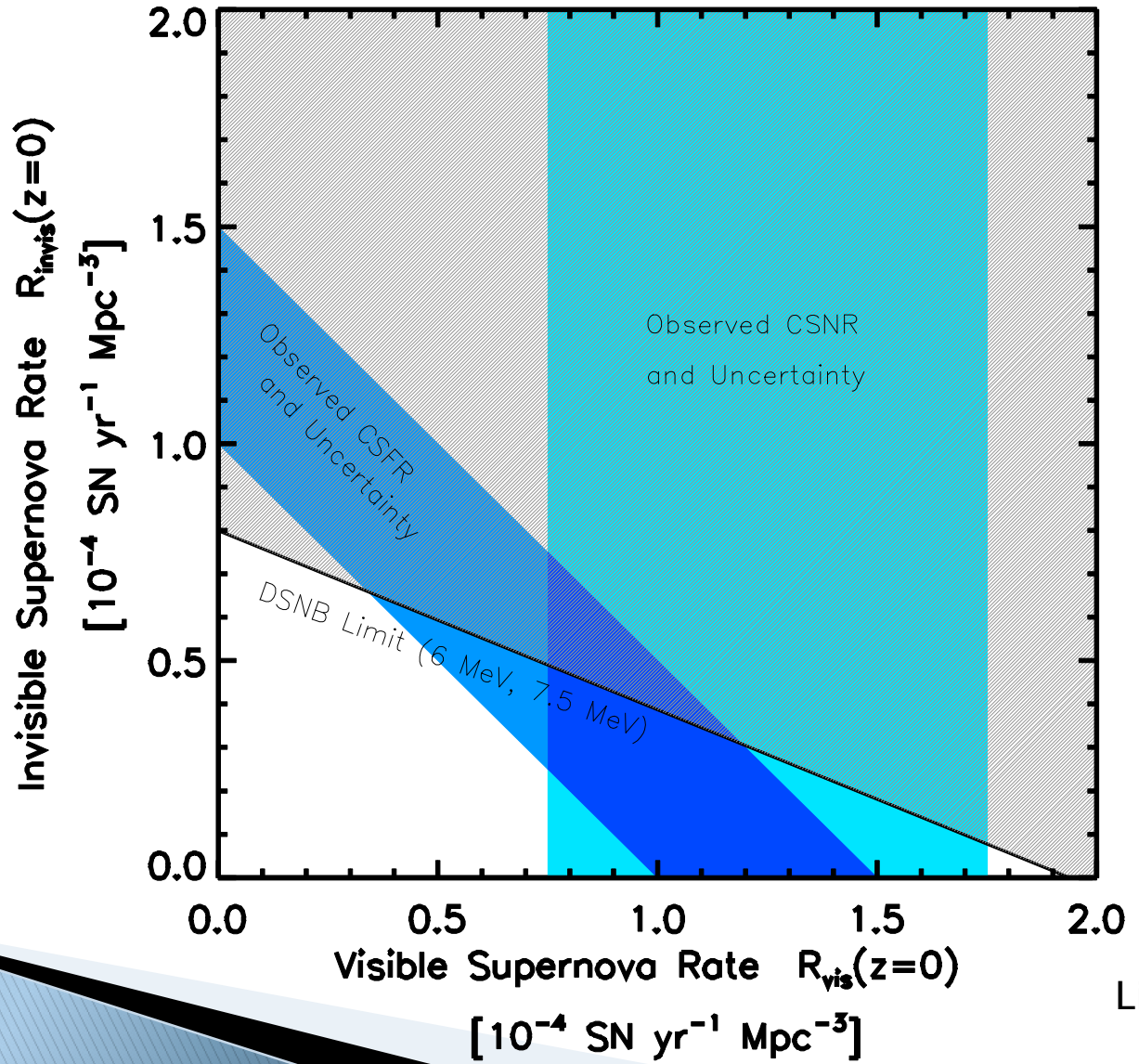

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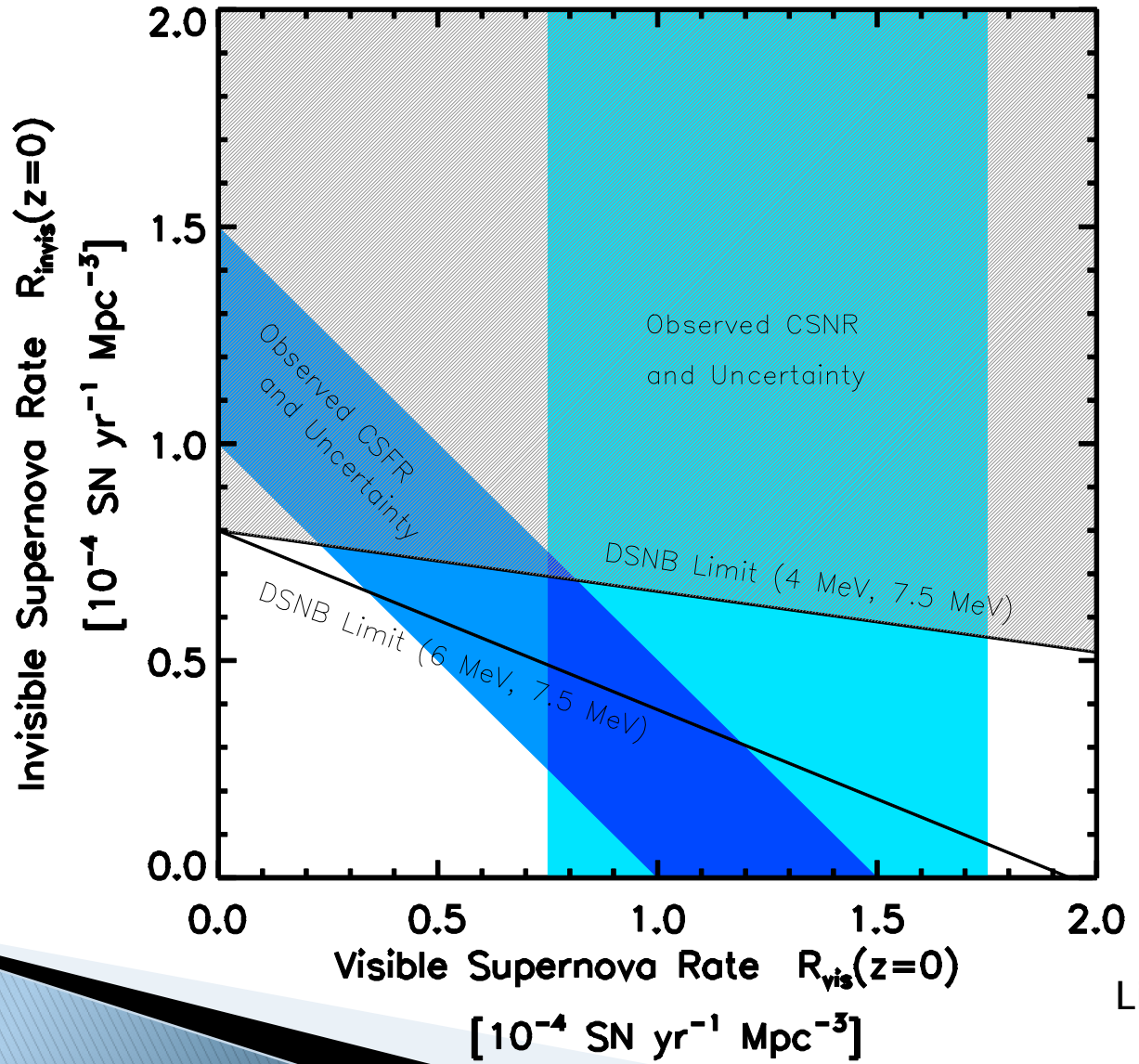

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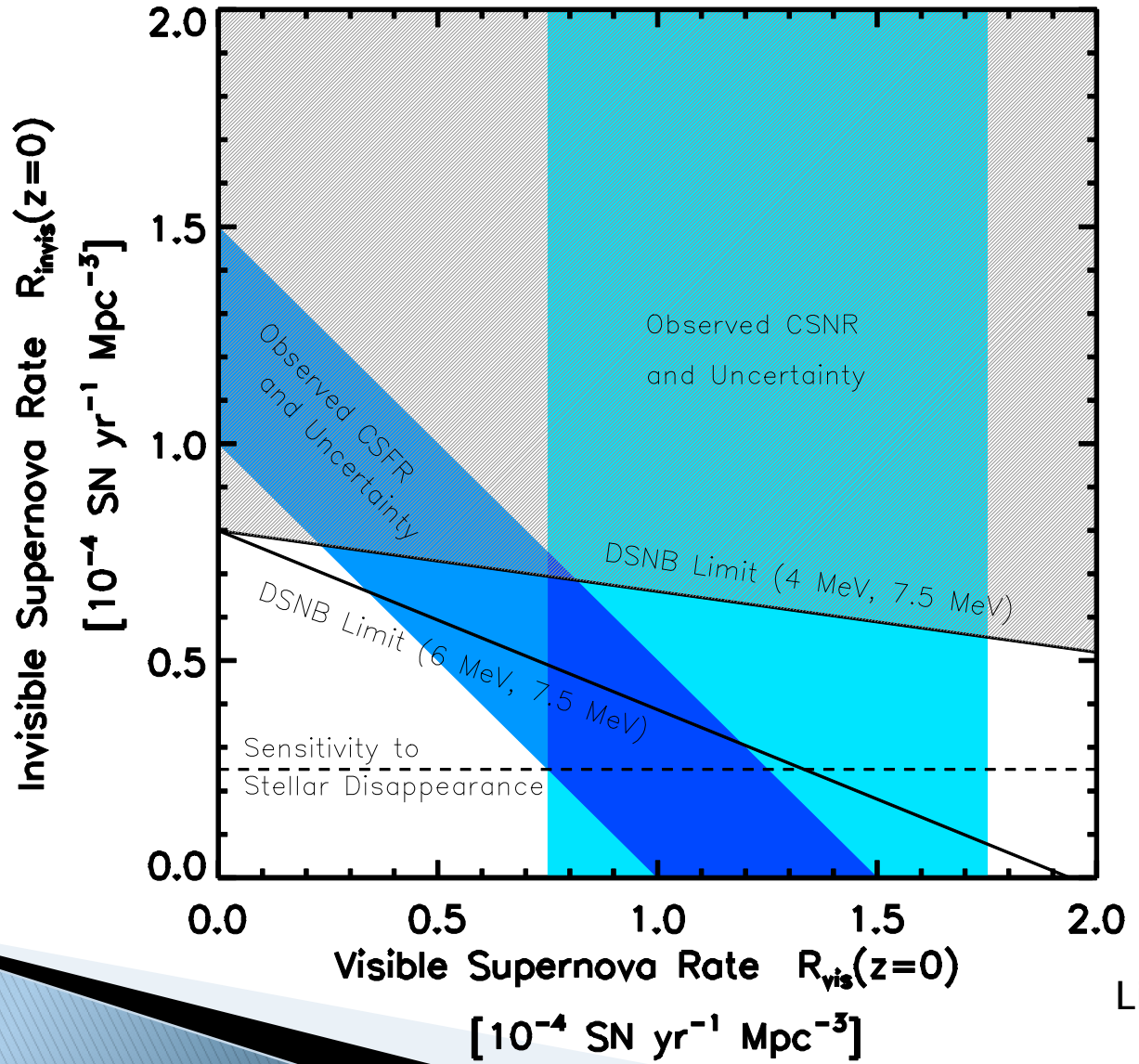

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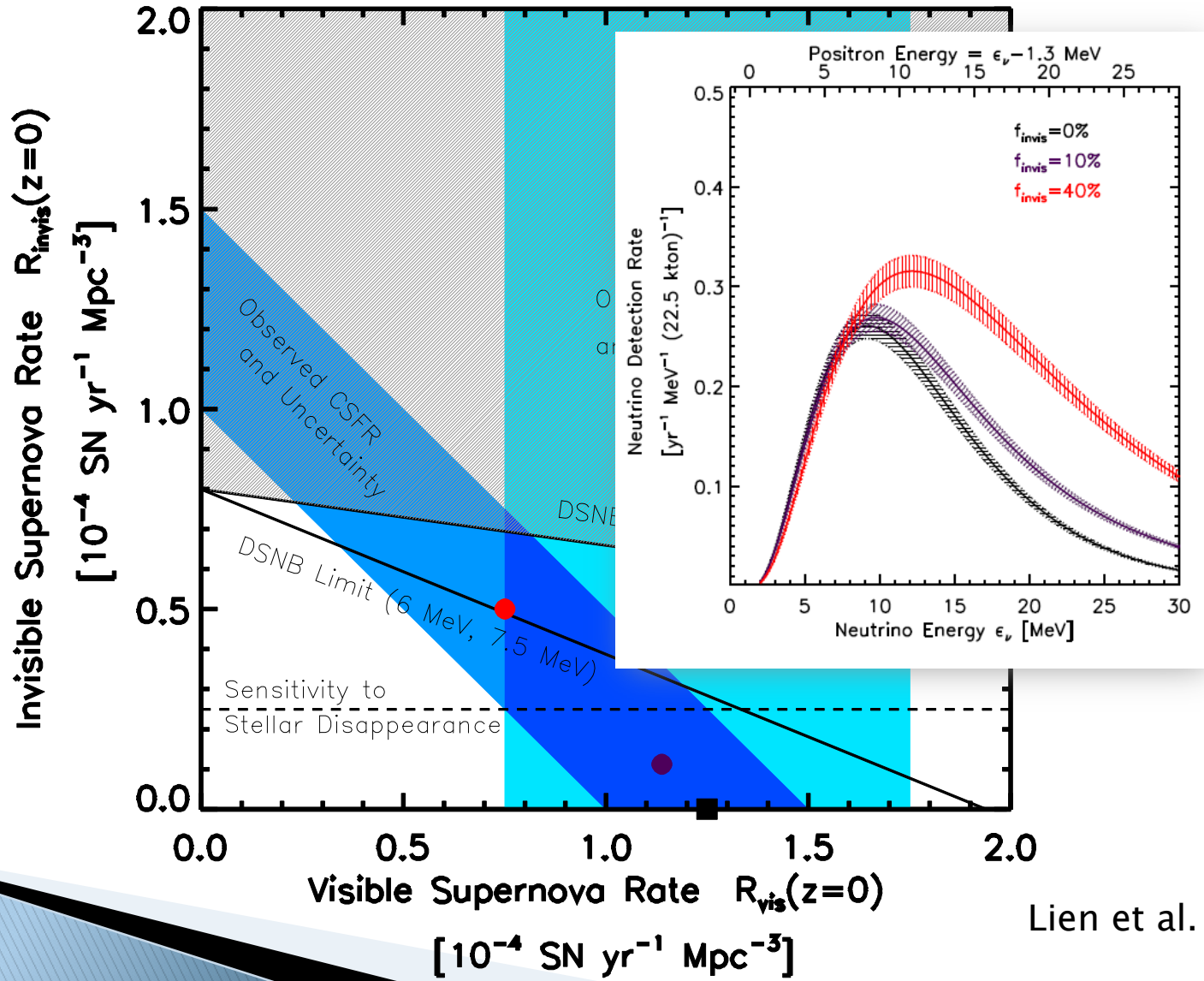

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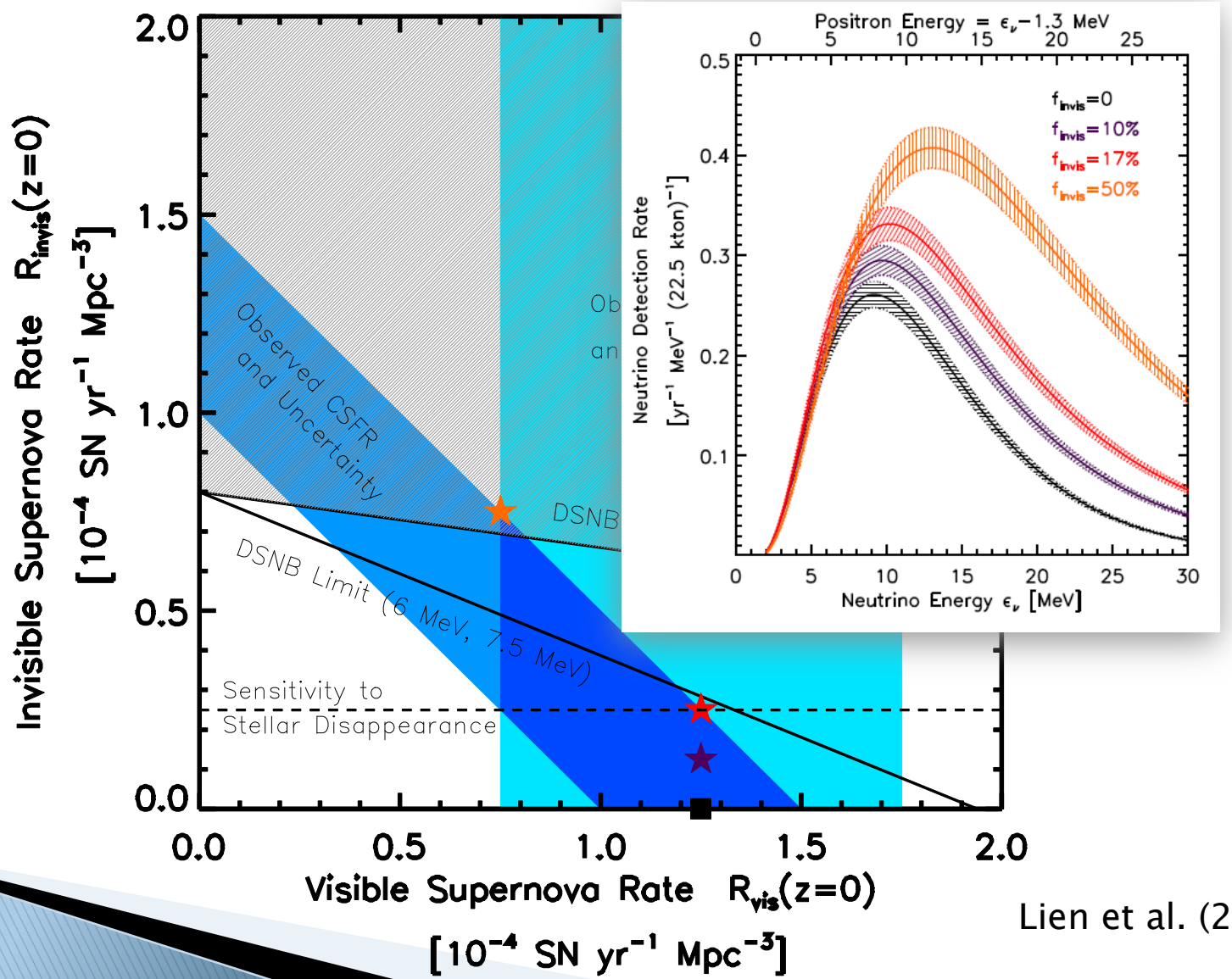

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