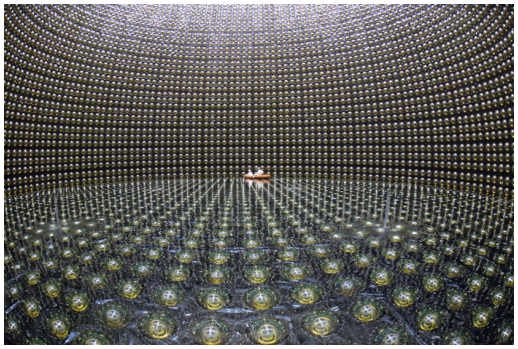
# The Cosmic Supernova Inventory from Future Sky Surveys:
## Revealing Invisible Collapse with Neutrinos

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John Beacom (Ohio State U.)

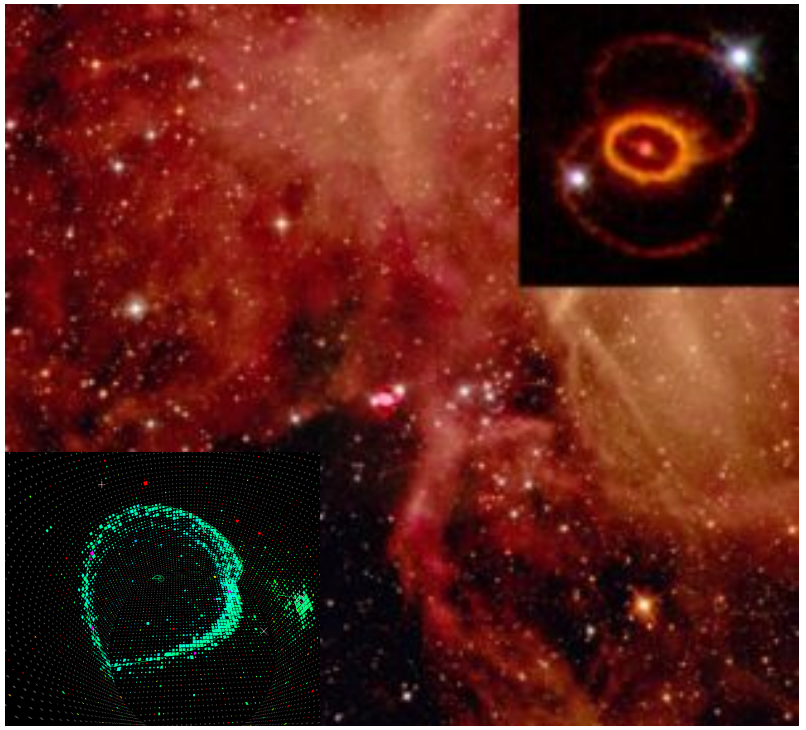


Great Lakes Cosmology Workshop 2010

# 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!

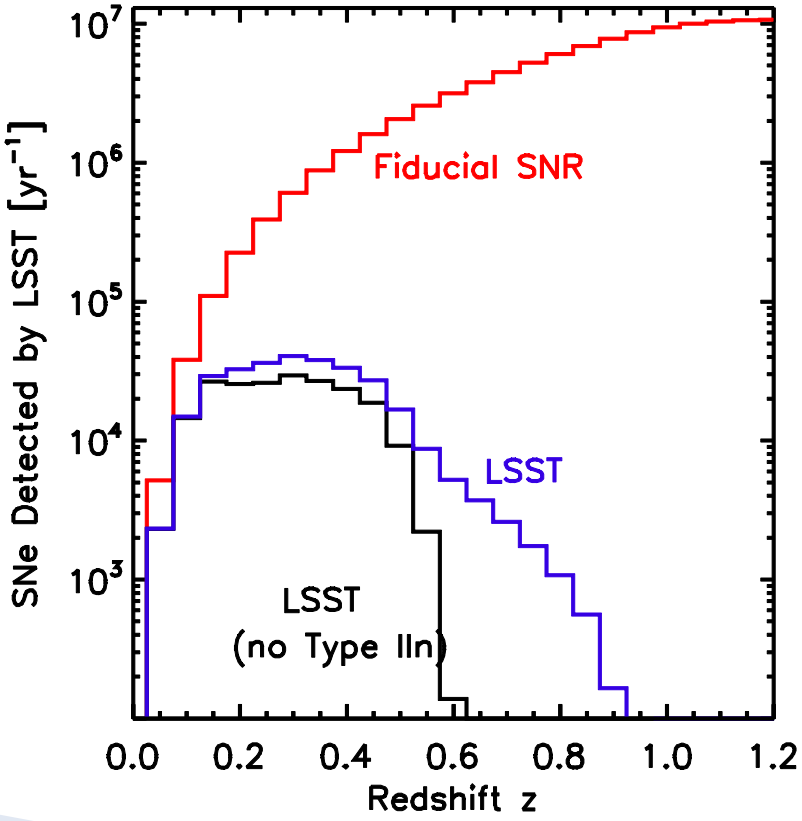
(MacFadyen & Woosley 1999, Nakazato et al. 2008)



# Why now?

## – Dr. Kuhlmann & Prof. Wood-Vasey's Talk

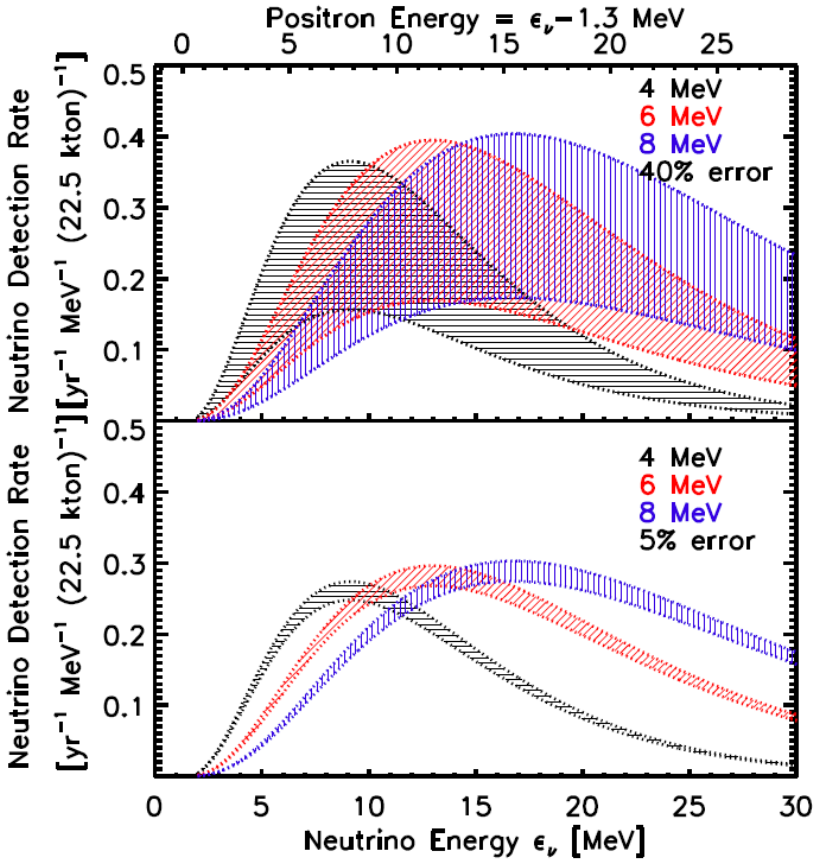
- Great survey era (e.g. SDSS, SNLS, DES, Pan-STARRS, LSST)
  - Happening now or next decade.
- $> 10^5$ CC SNe per year out to $z \sim 1$.
- SN rate by direct counting!
- CC SN rate to high precision
  - Statistical uncertainty <10% in 1 yr
  - Current uncertainty > 40%
- Particle astrophysics with cosmic SNe



# Cosmic Supernovae & The Diffuse Supernova Neutrino Background

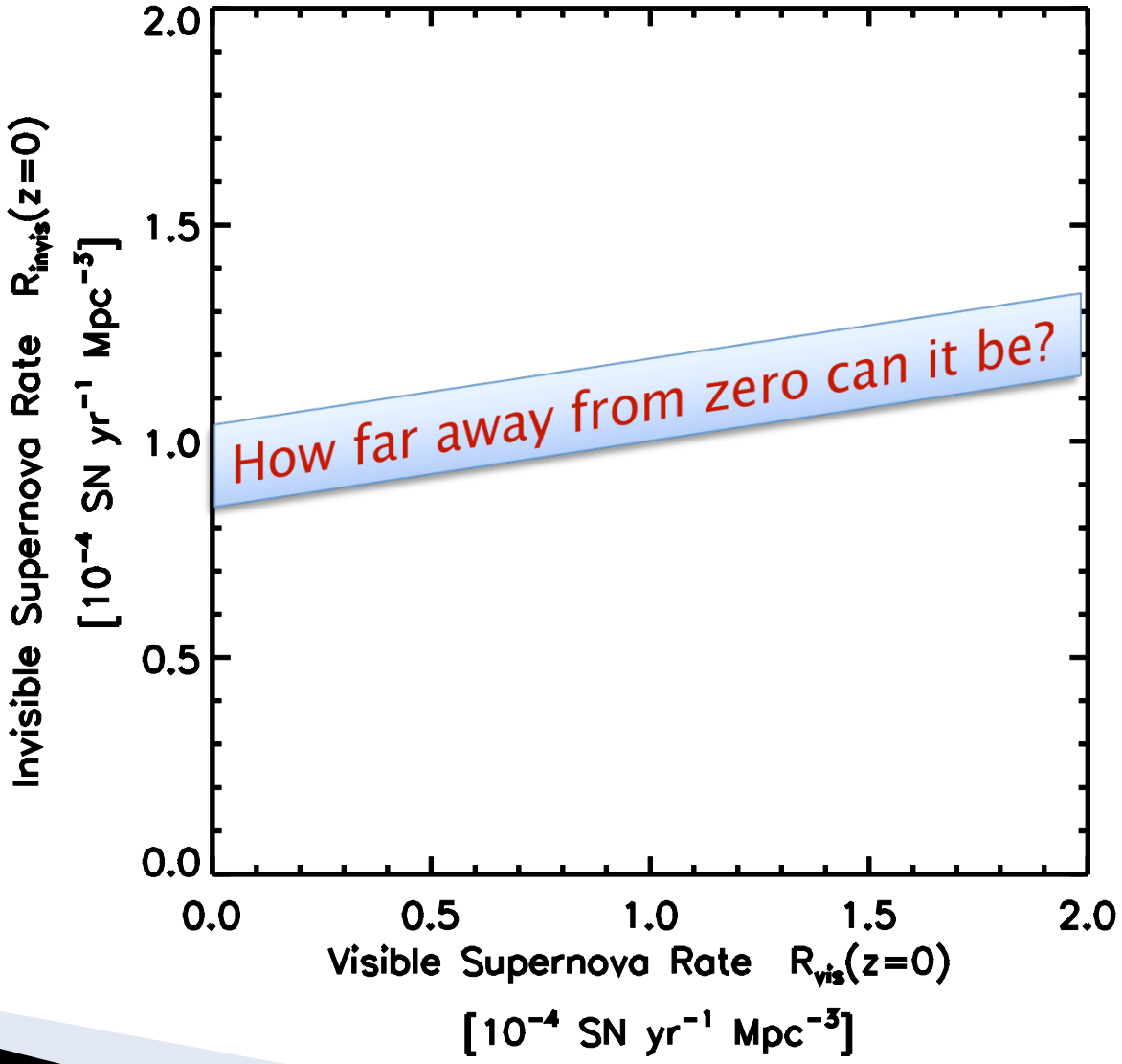
- Neutrino flux from all cosmic supernovae
  - Energy range ~ 10 – 26 MeV
- Neutrino observatories
  - Expect first detection of background SN neutrinos in next ~ 10 yrs
- Forecast: Surveys + Neutrinos
  - Imagine: SN rate known to z~1
  - Dust effects and SN luminosity distribution understood
  - Assume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

- Example: Probing different SN neutrino models



# 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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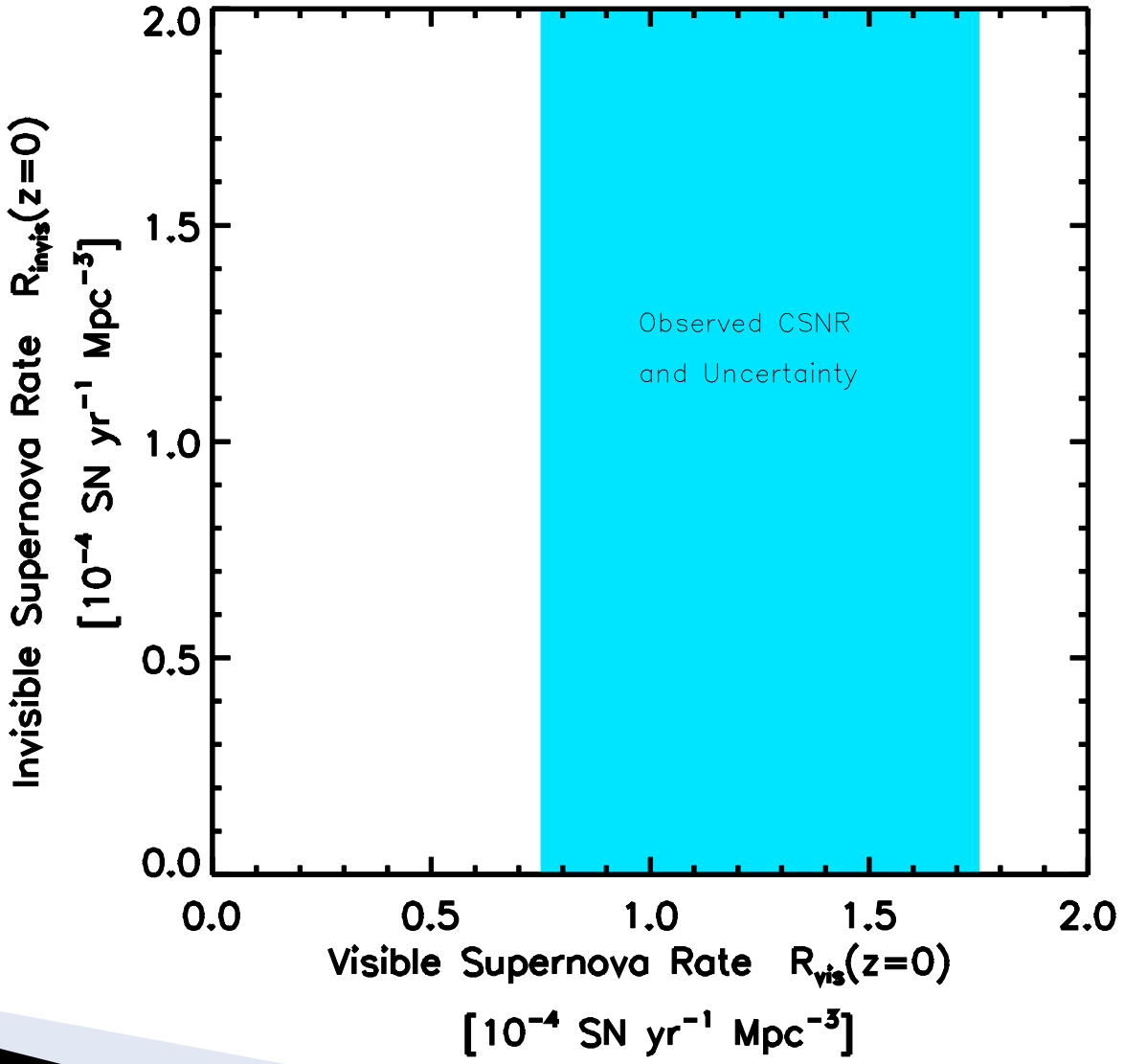

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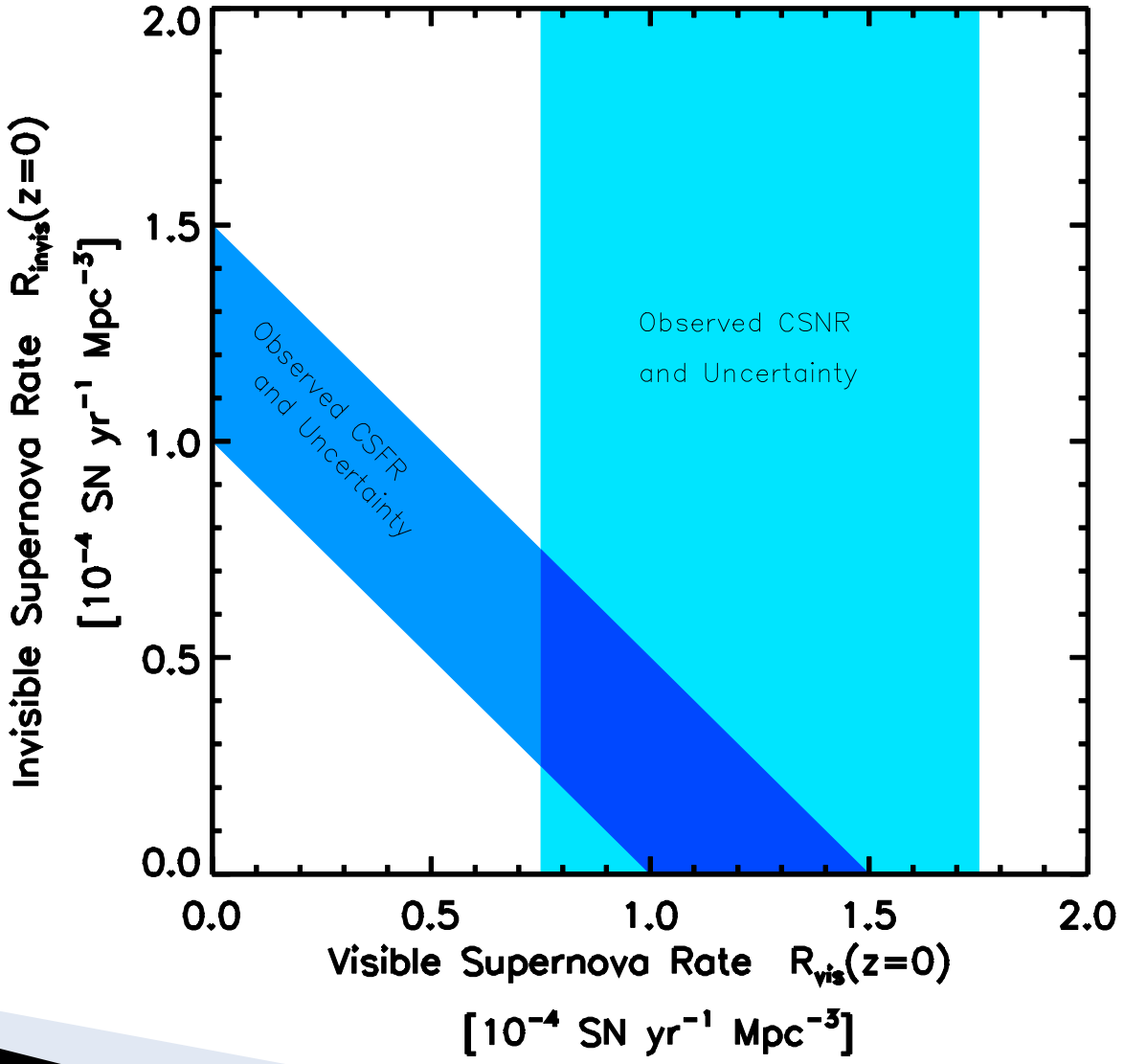

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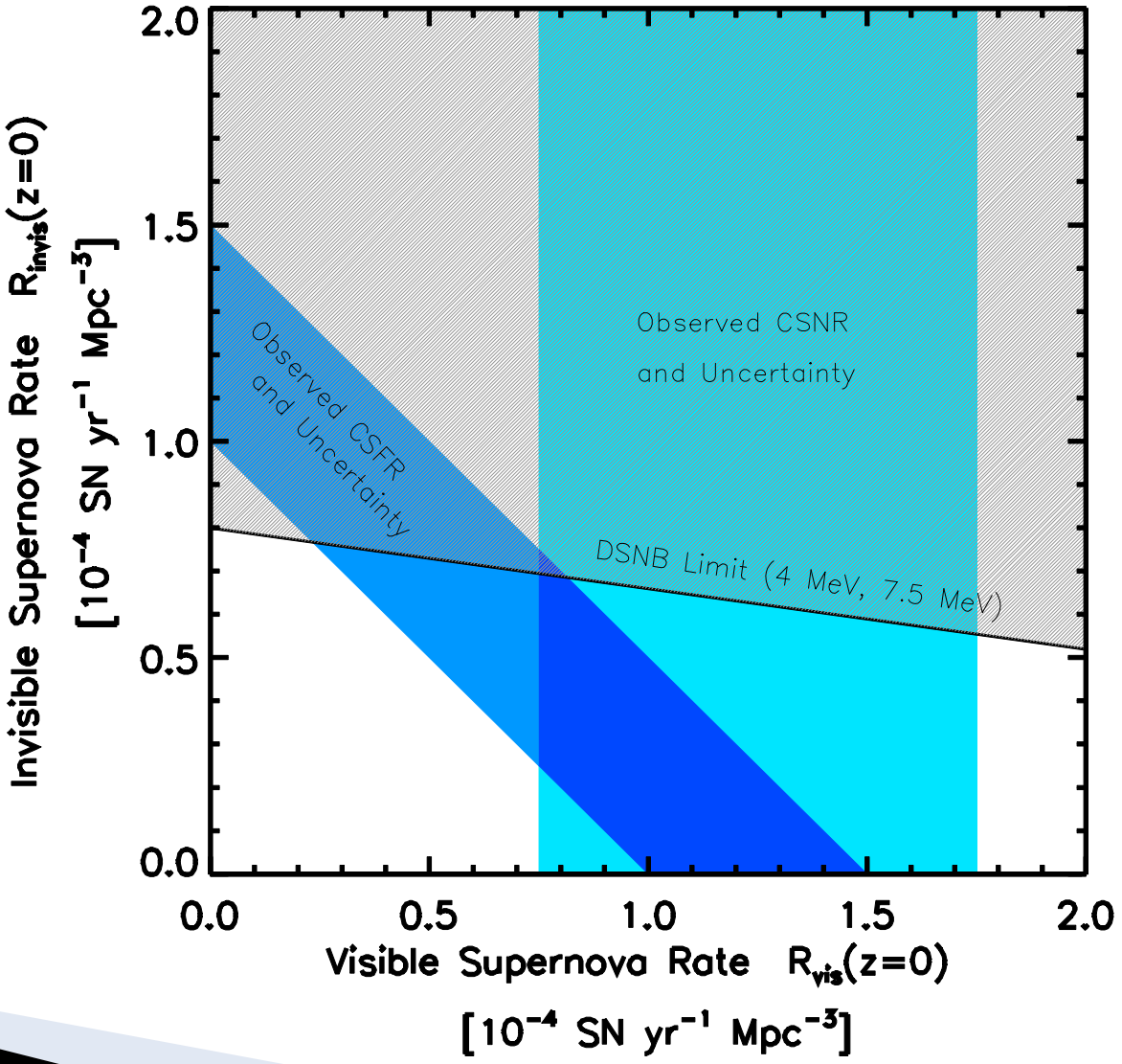

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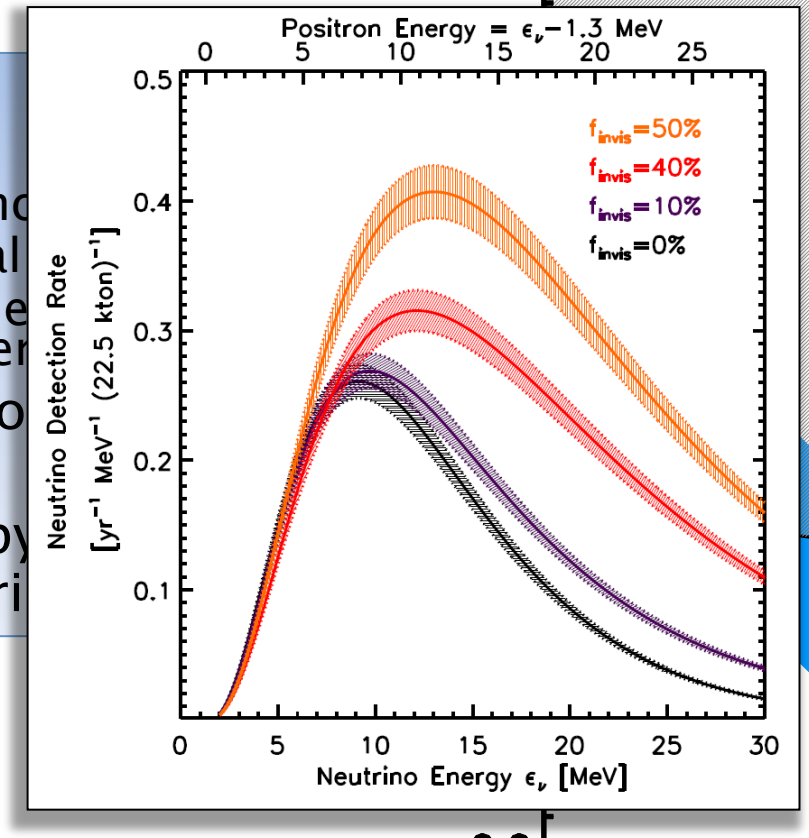
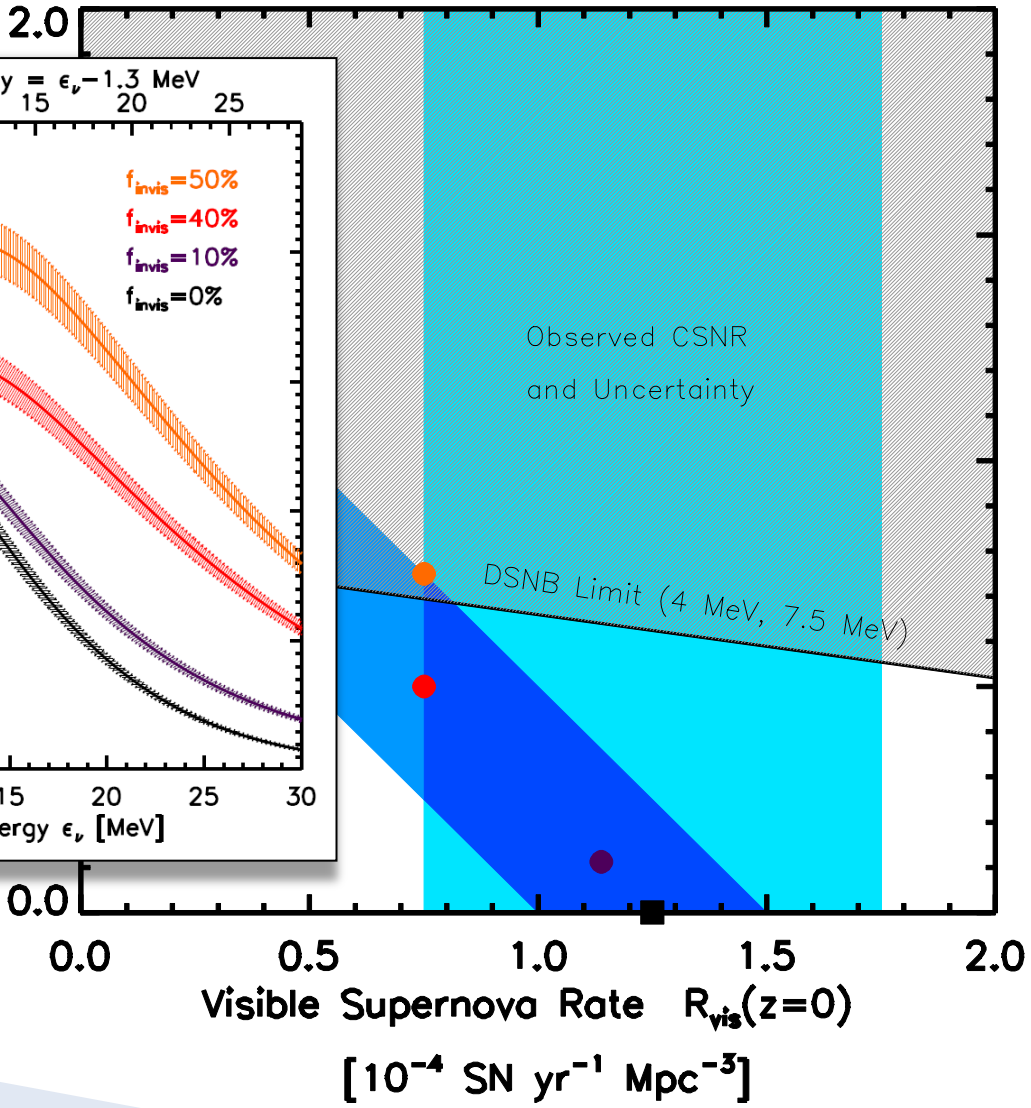
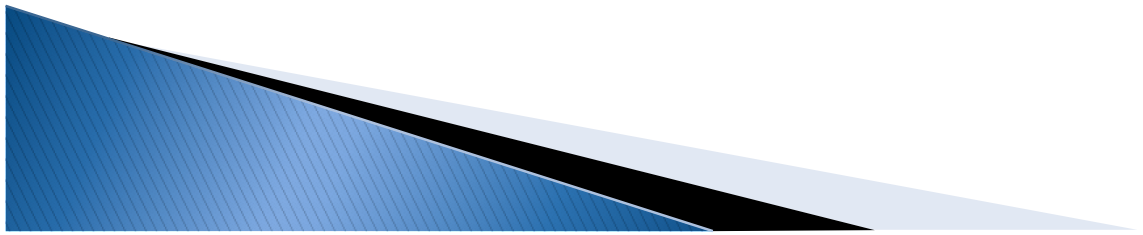


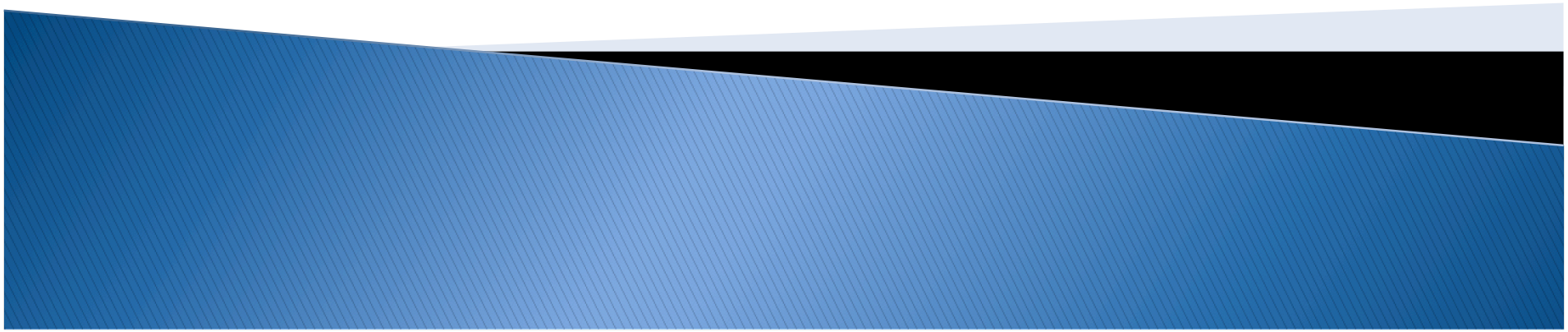



# Conclusions

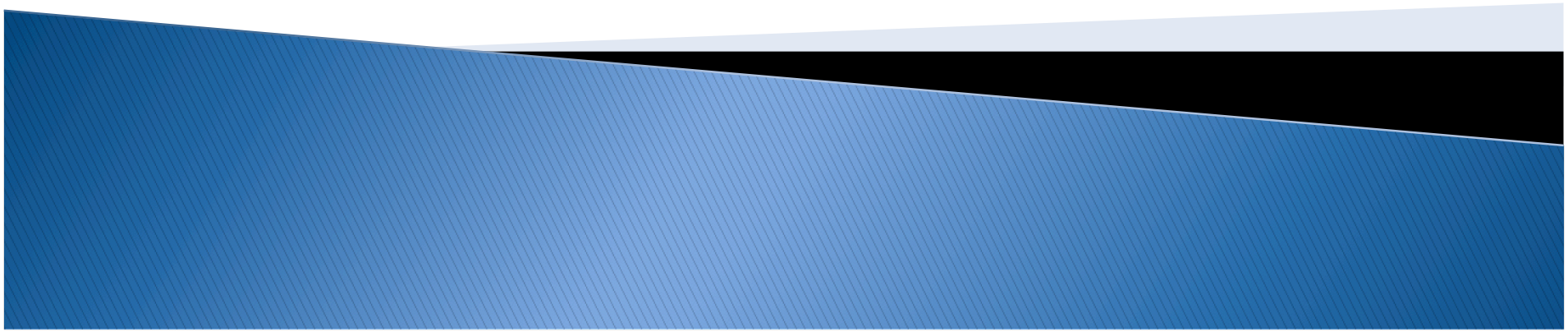
- Synoptic surveys: SN rate to $z \sim 1$
  - Star-formation rate to high precision out to $z < 1$
- Surveys + neutrinos can distinguish different supernova neutrino models.
- Surveys + neutrinos probe failed supernovae.
- Lessons for surveys:
  - Core-collapse come for free!
  - Not just “Type Ia noise” but important signal!
  - Report your core-collapse events proudly!



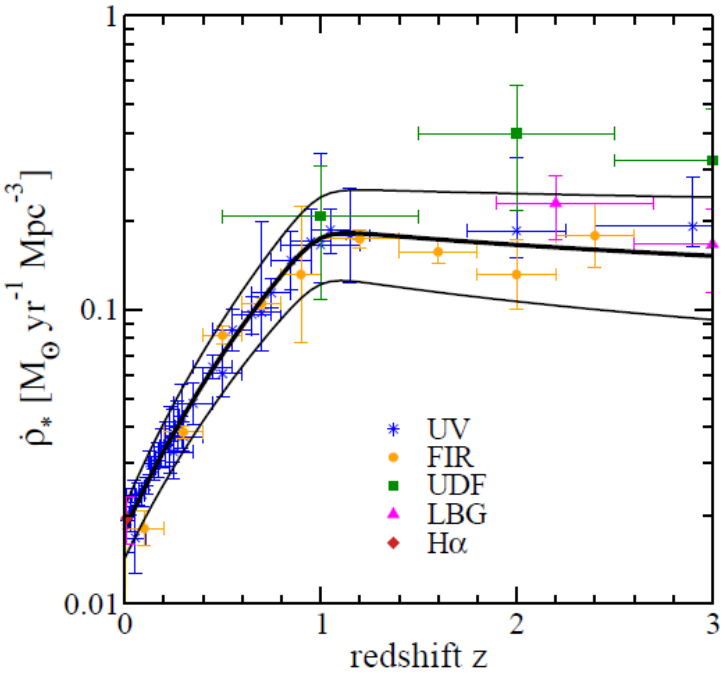
# Thank you



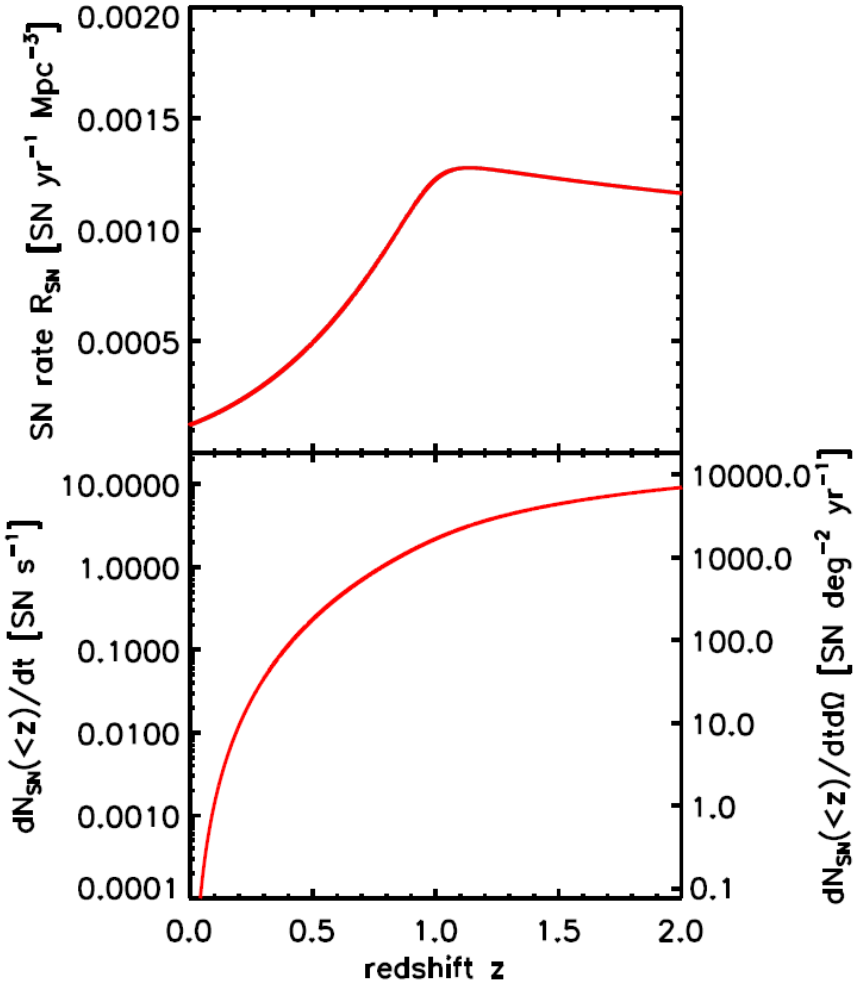
# Back-Up Slides



# Cosmic Star-Formation Rate and Supernova Rate



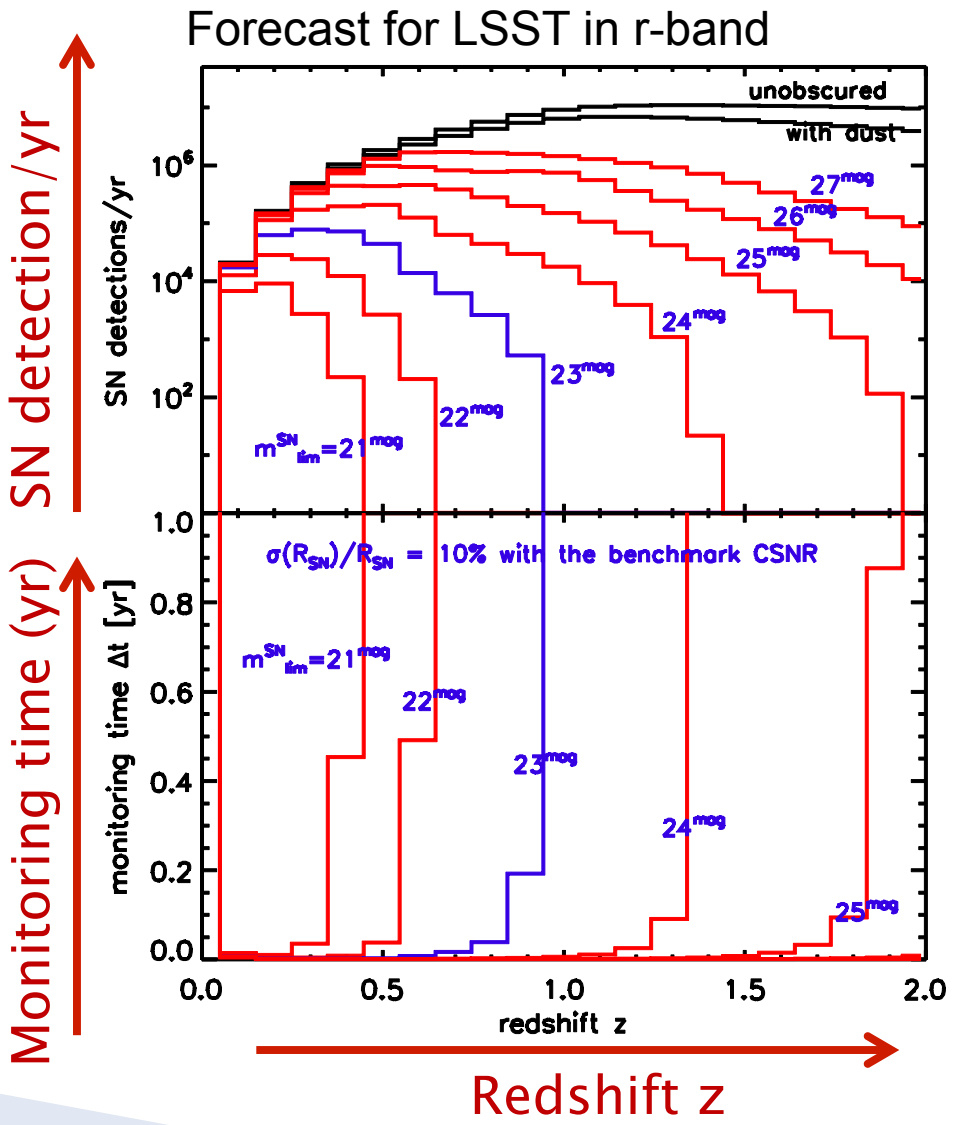

Star-Formation Rate
Credit: Horiuchi et al. (2009)



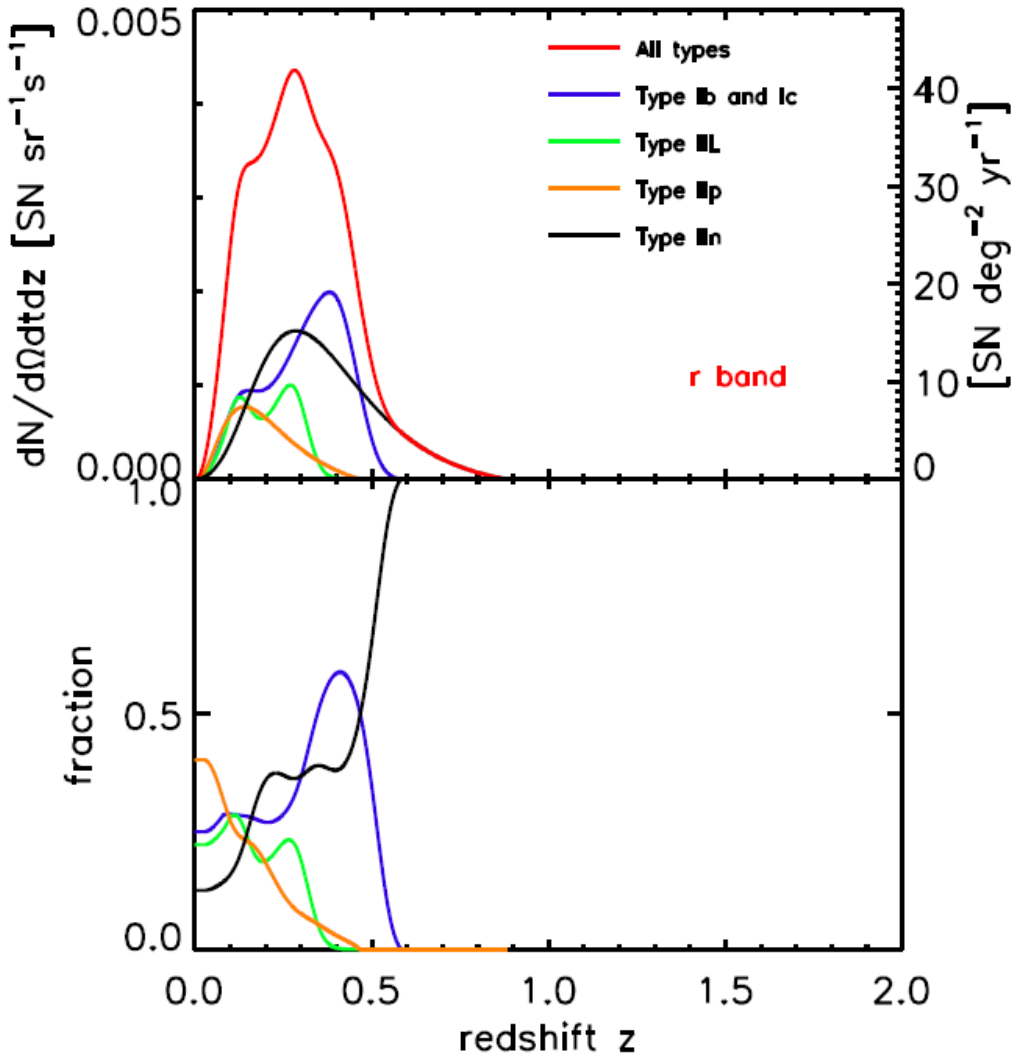

Supernova Rate

# Forecasts for Synoptic Surveys

- $> 10^5$ CC SNe per year out to $z \sim 1$.
- SN rate by direct counting!
- <10% statistic 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: $\Delta z = 0.1$



# Forecast of SN detection in Types

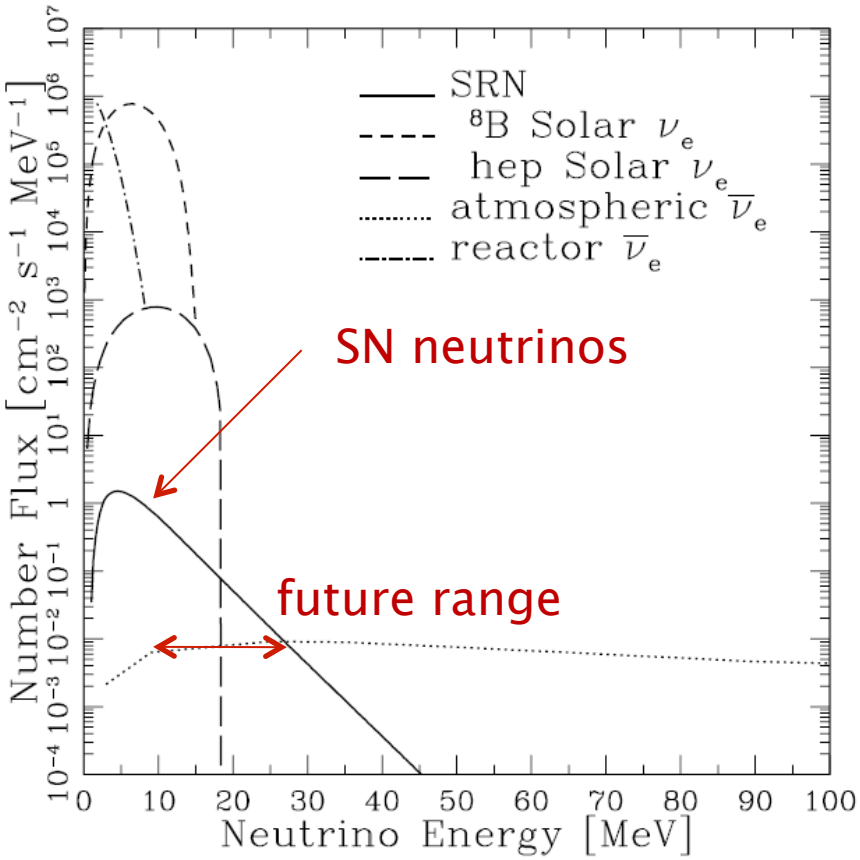


# Neutrino Sources from Earth & Sky

Main neutrino background sources:

- Supernovae (10-30 MeV)
- Sun (create νe, not anti νe)
- Atmospheric (from interaction with cosmic ray particles)
- Artificial (nuclear reactors)
- Earth (similar to reactors)
- High energy cosmic neutrinos ($10^{12}$ eV)
- Cosmic background radiation neutrino ($1.7*10^{-4}$ eV)

Ando et al. 2002



# Diffuse Supernova Neutrino Background (DSNB)

- Neutrinos from supernovae
  - ν & anti-ν of all species
  - 10-30 MeV
- Cosmic SNe ~ 10 events/sec
- ~ $10^{59}$ neutrinos per SN
- Add them up

$$\phi_\nu(\epsilon) = c \int_0^\infty (1+z) \left|\frac{dt}{dz}\right| \mathcal{R}_{\rm SN}(z) N_\nu[(1+z)\epsilon] dz$$

- Cosmic
- Known
- Line of Sight

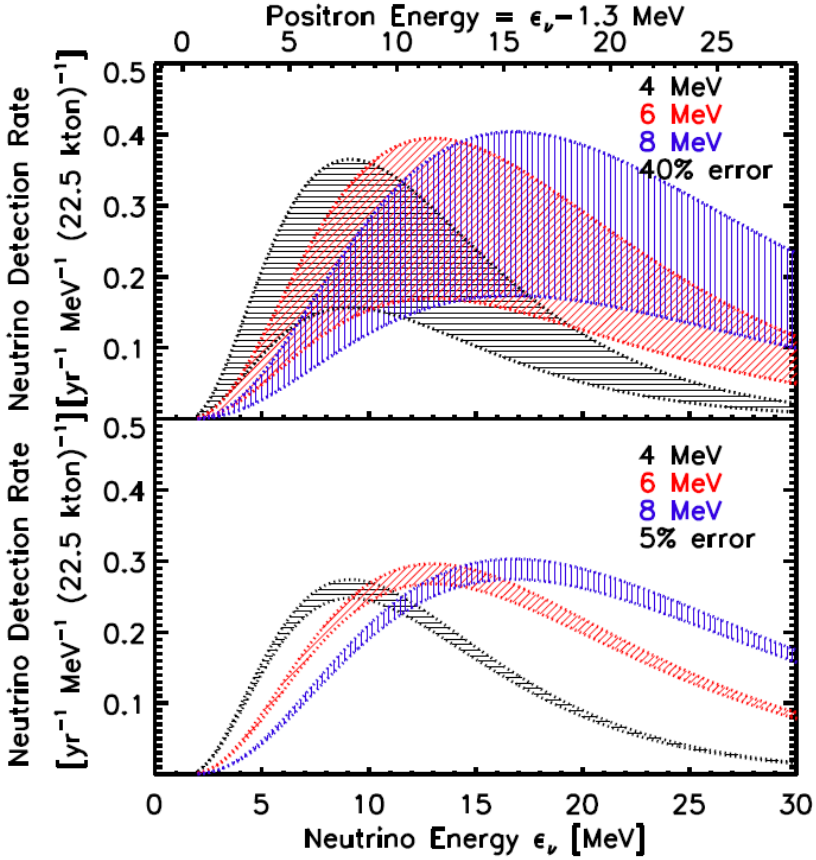
- SN rate
- Astro
- Will know (from survey)

- Neutrino energy spectrum
- SN theory
- Want to know

# Supernovae & Neutrinos – What Can We Learn?

- Neutrino detectors: Expect to have first detection of supernova neutrinos in the next ten years
- Strategy/Attitude
  - Imaging that we will be able to measure SN rate out to z~1
  - Dust effects and SN luminosity distribution understood
  - Expecting a 5% precision
- We hope to learn
  - Supernova and neutrino physics
  - Failed supernovae

- Example: Probing different supernova neutrino models

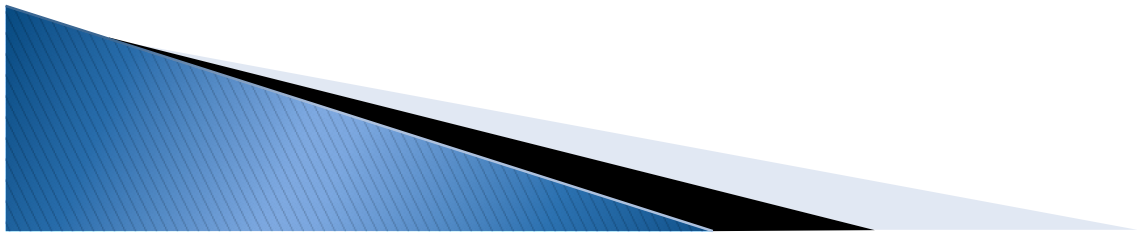


# Connecting Supernovae & Neutrinos

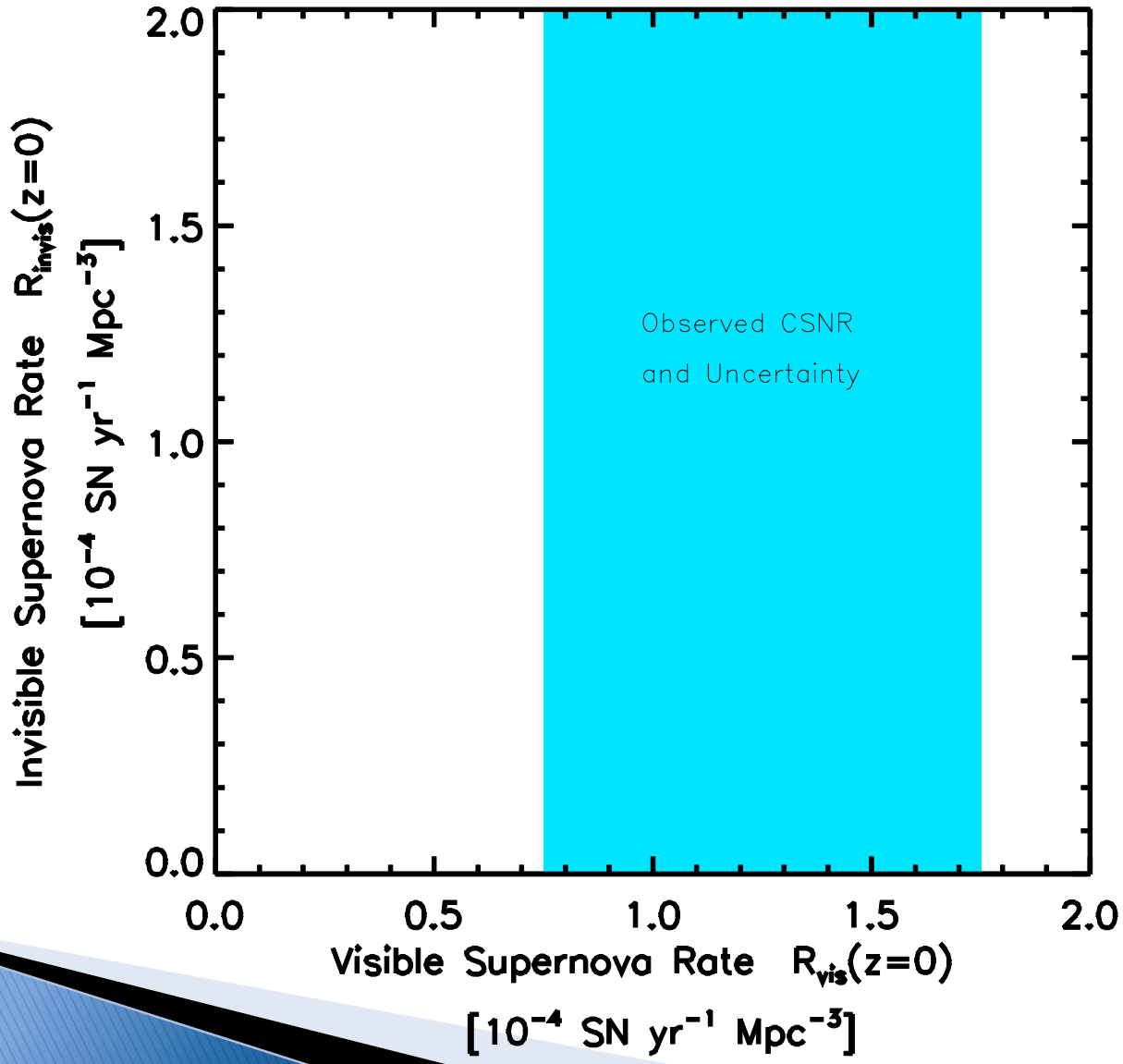
- Predict neutrino flux from supernova surveys $\phi_\nu^{\text{survey}}$ : Add neutrinos from all observed supernovae
- Measure neutrino flux from neutrino detectors $\phi_\nu^{detect}$
- Compare $\phi_\nu^{\text{survey}}$ and $\phi_\nu^{detect}$
- We hope to learn
  - Supernova and neutrino physics
  - Failed supernovae
    - Massive stars which collapse directly into black holes without optical explosions.
  - Dust? Weak constraint

# 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



# What is the likely failed supernova rate ?



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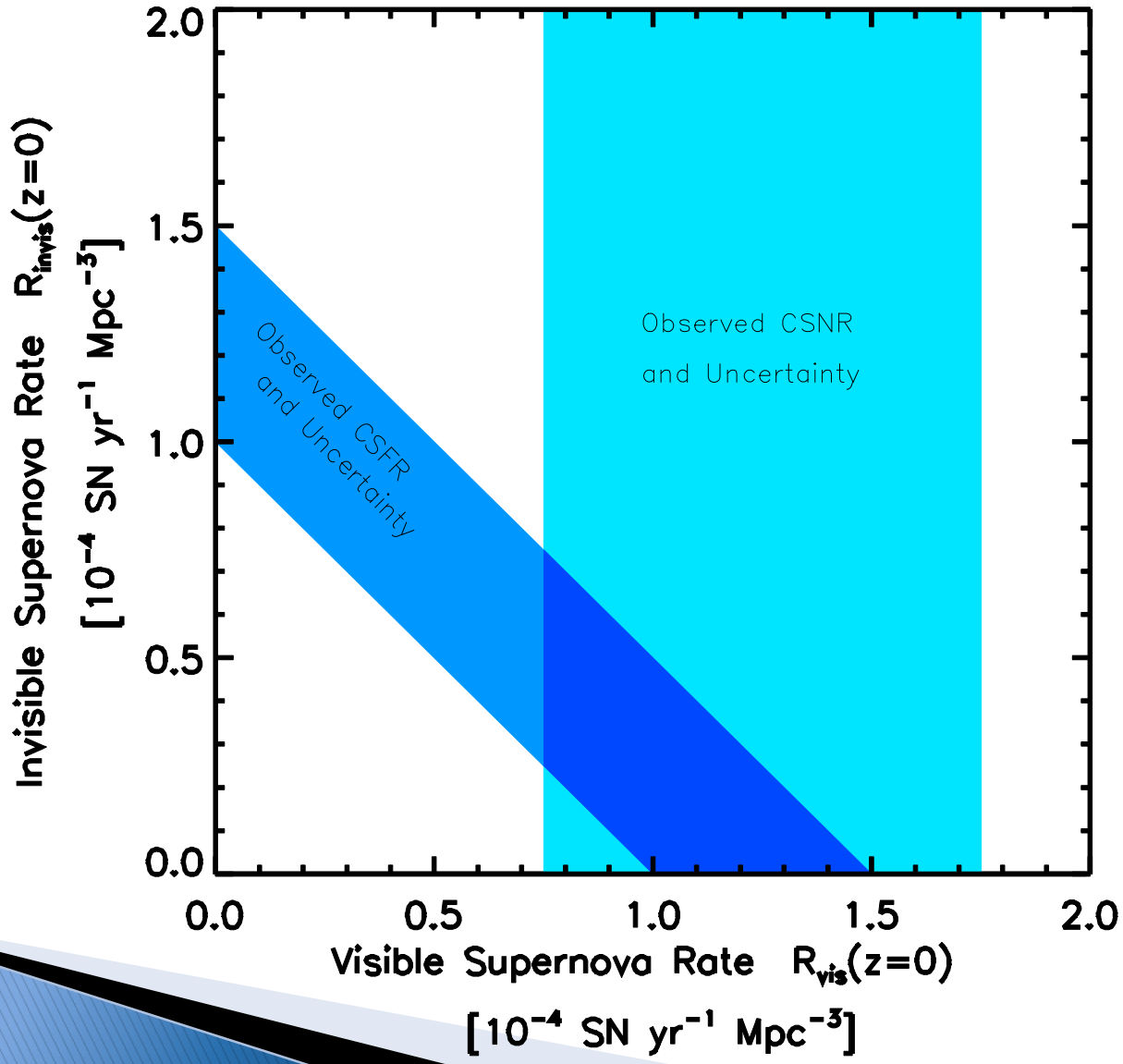

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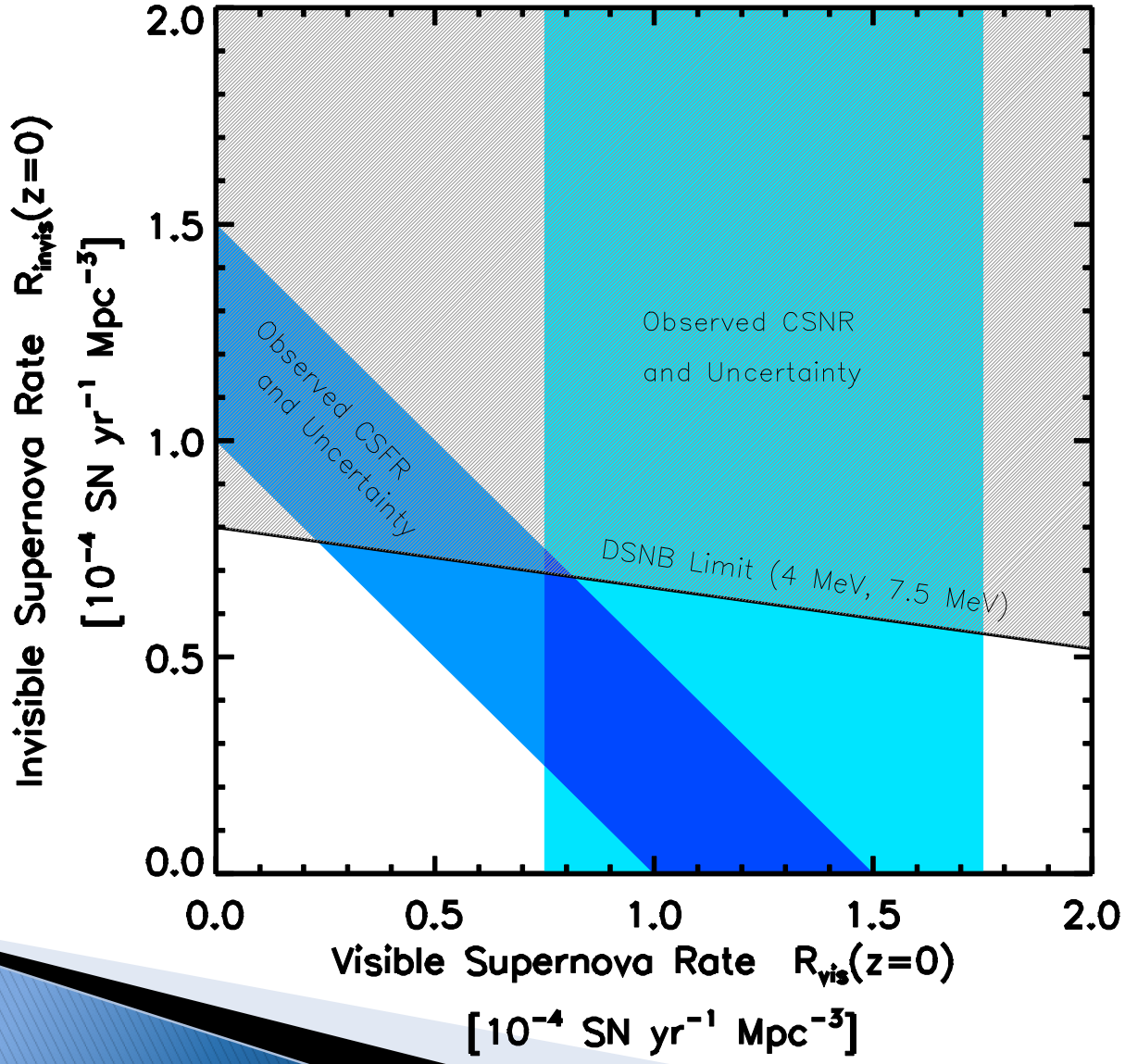

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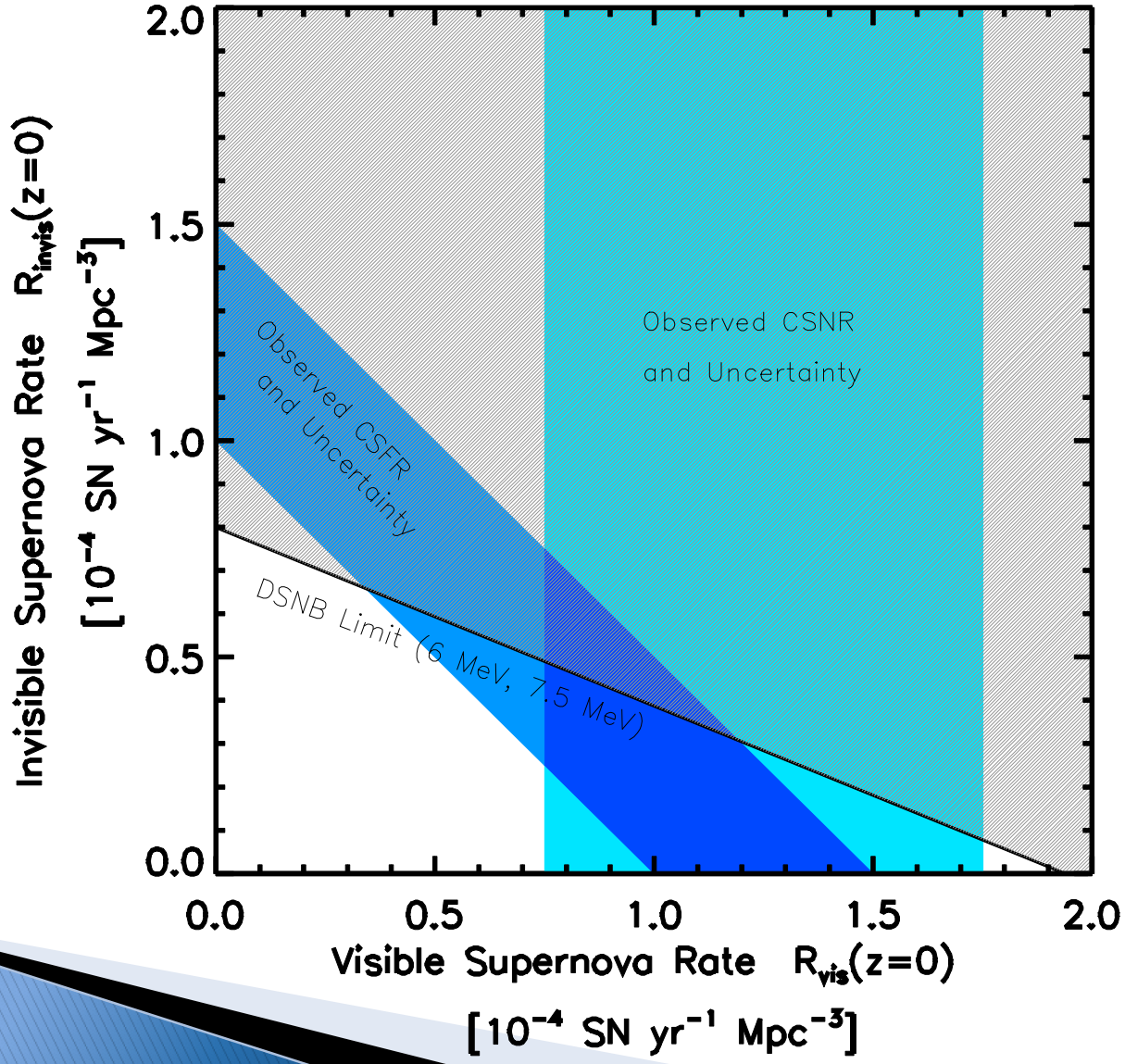

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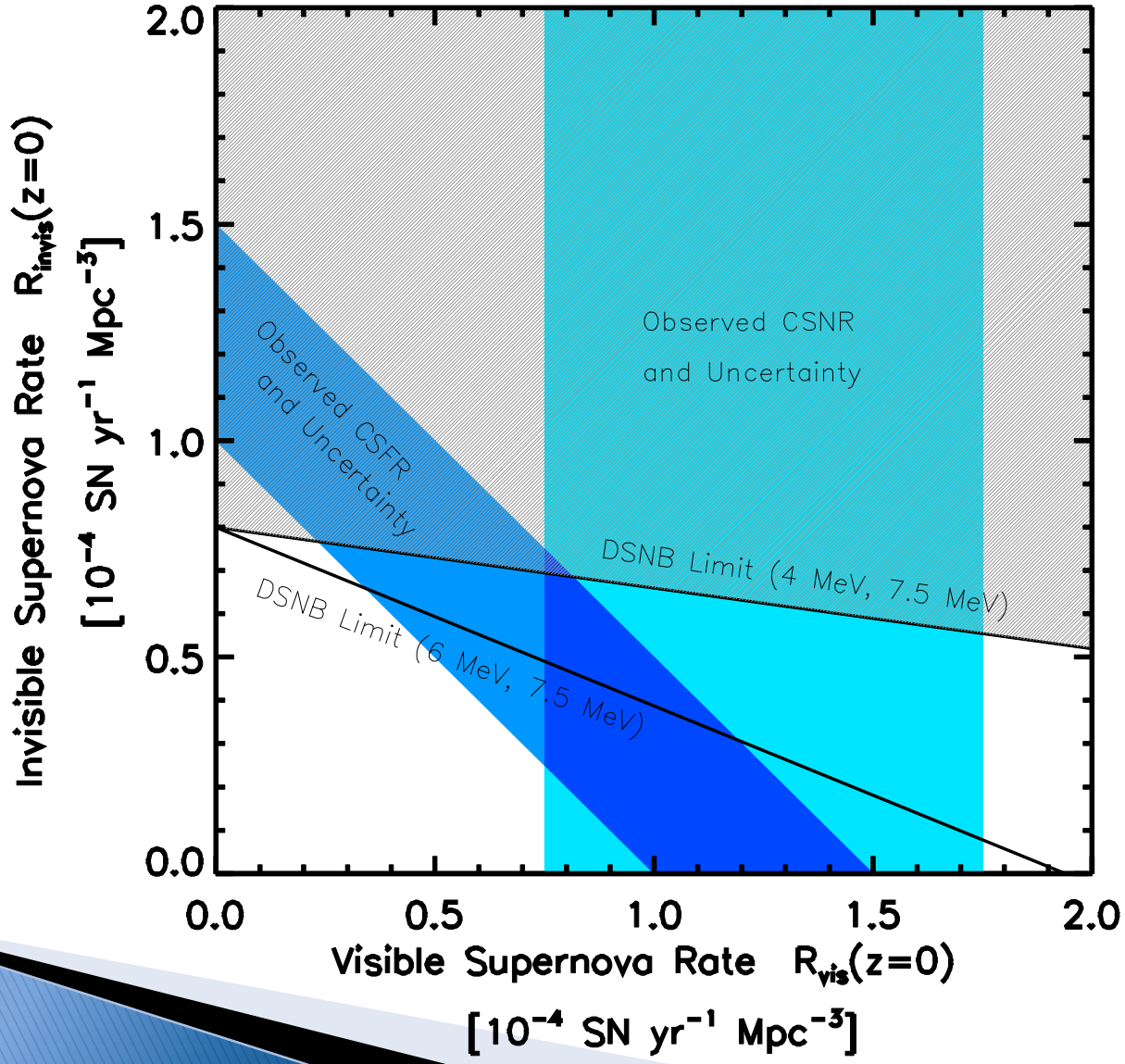

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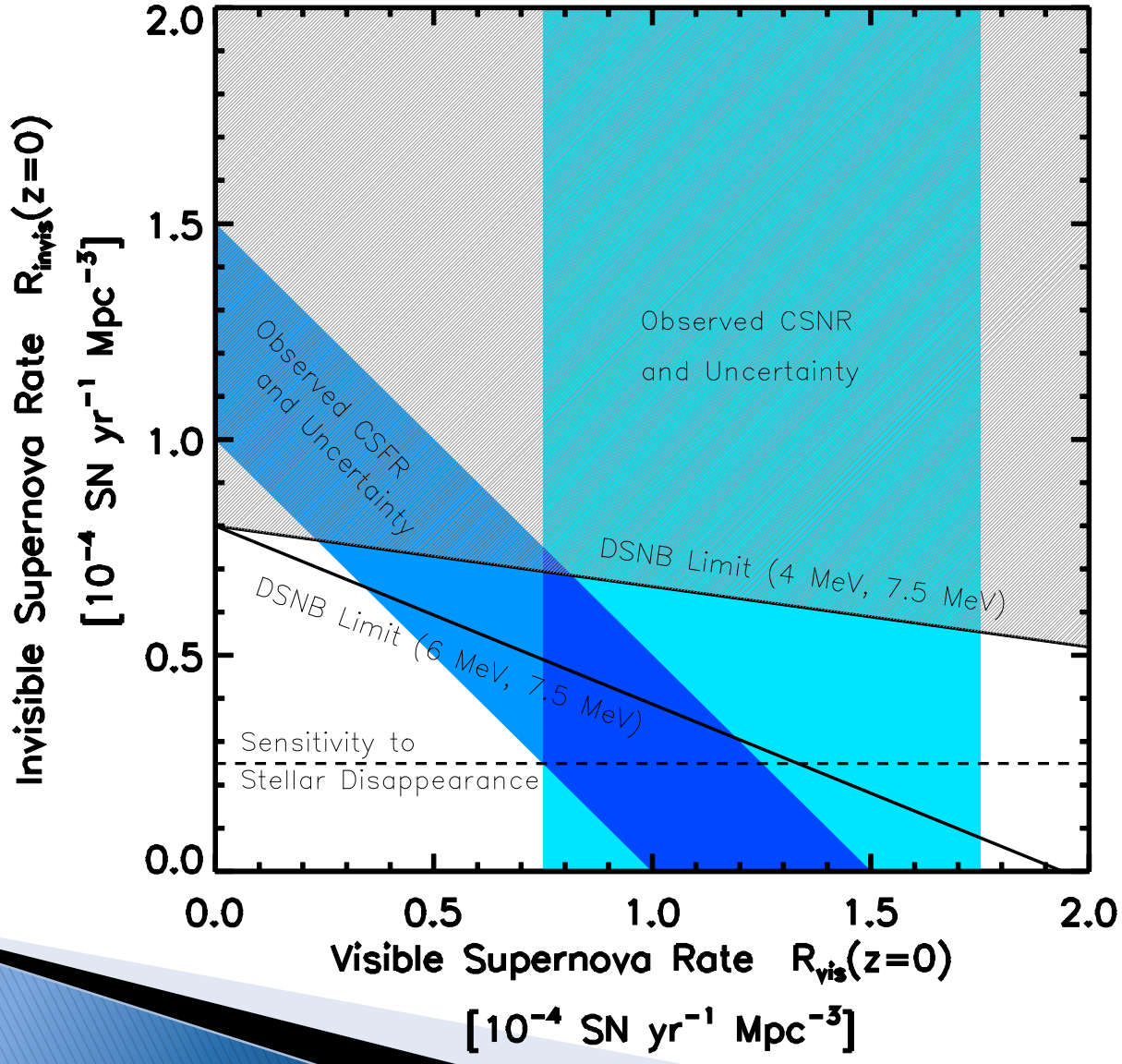

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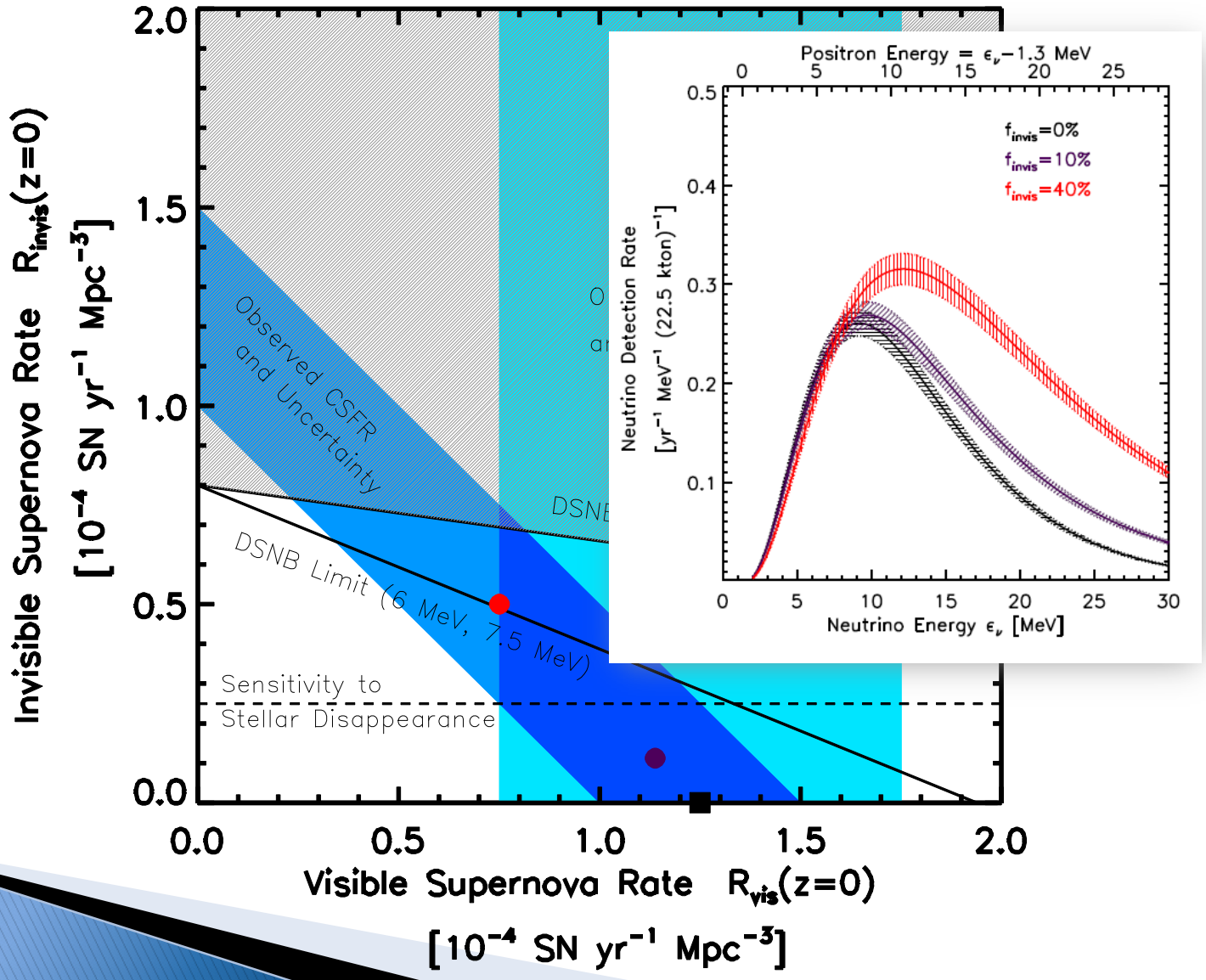

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