The 30 Year Search for the Compact Object in SN 1987A

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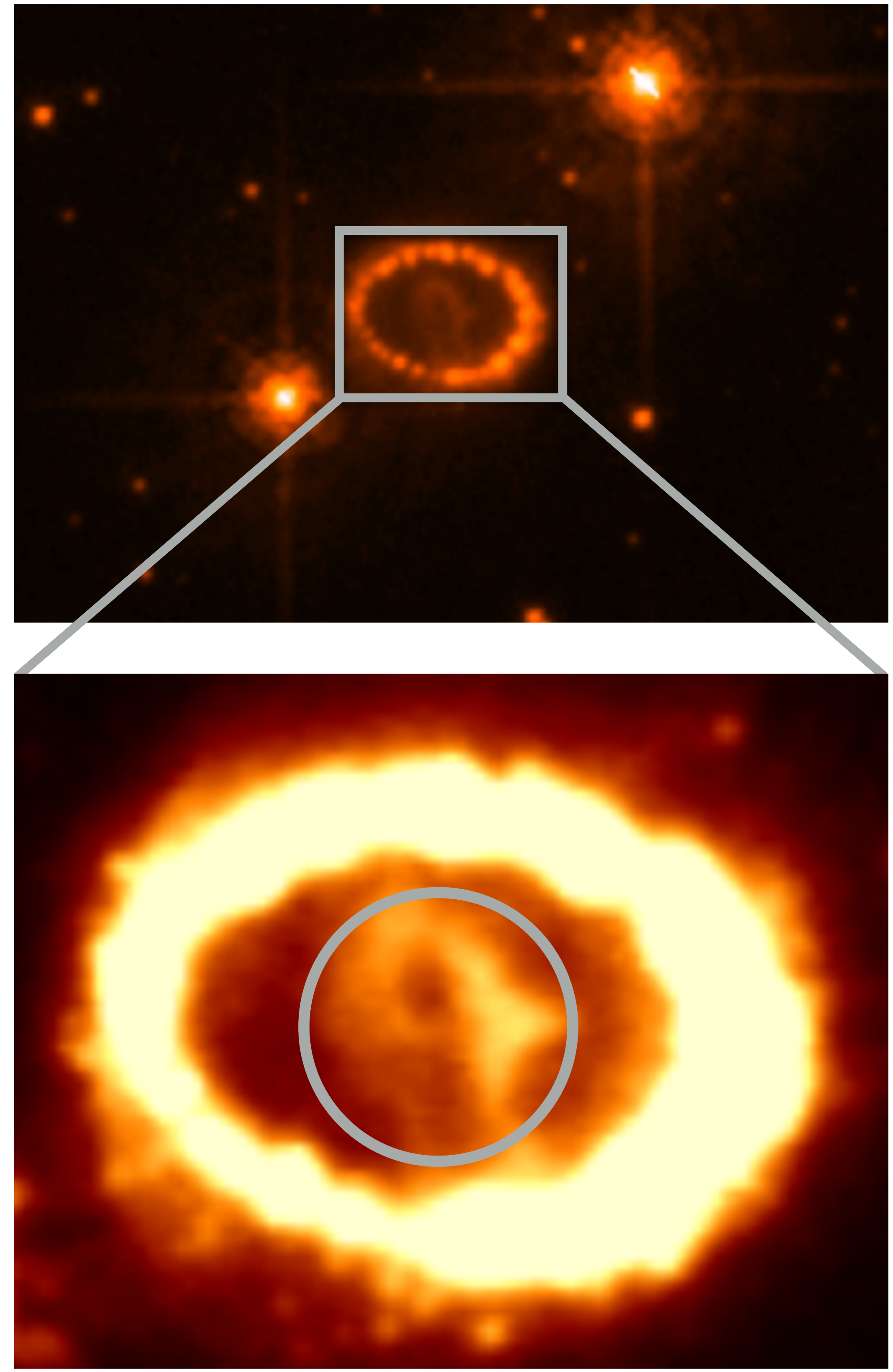
Image: NASA, ESA, and R. Kirshner (Harvard-Smithsonian Center for Astrophysics and Gordon and Betty Moore Foundation) and P. Challis (Harvard-Smithsonian Center for Astrophysics)

SN 1987A

- Closest since 1604
- Type II-pec, LMC 50 kpc



HST/WFC3 2018 *R*-band

SN 1987A

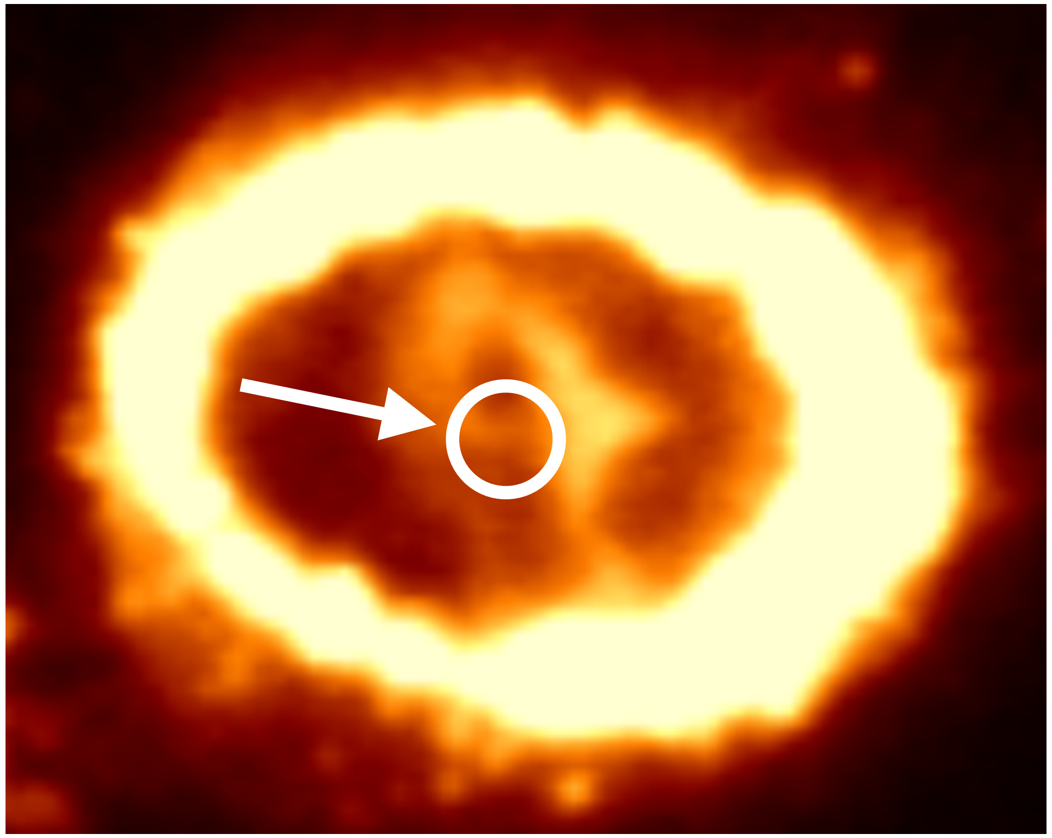
- Closest since 1604
- Type II-pec, LMC 50 kpc
- BSG (B3 Ia)
- Binary merger, 16+7 $M_\odot$??

Menon & Heger (2017)
Menon et al. (2018)

Anglo-Australian Observatory/David Malin

The Compact Object

- Not yet detected
- NS still possible
- New upper limits



HST/WFC3 2018 *R*-band

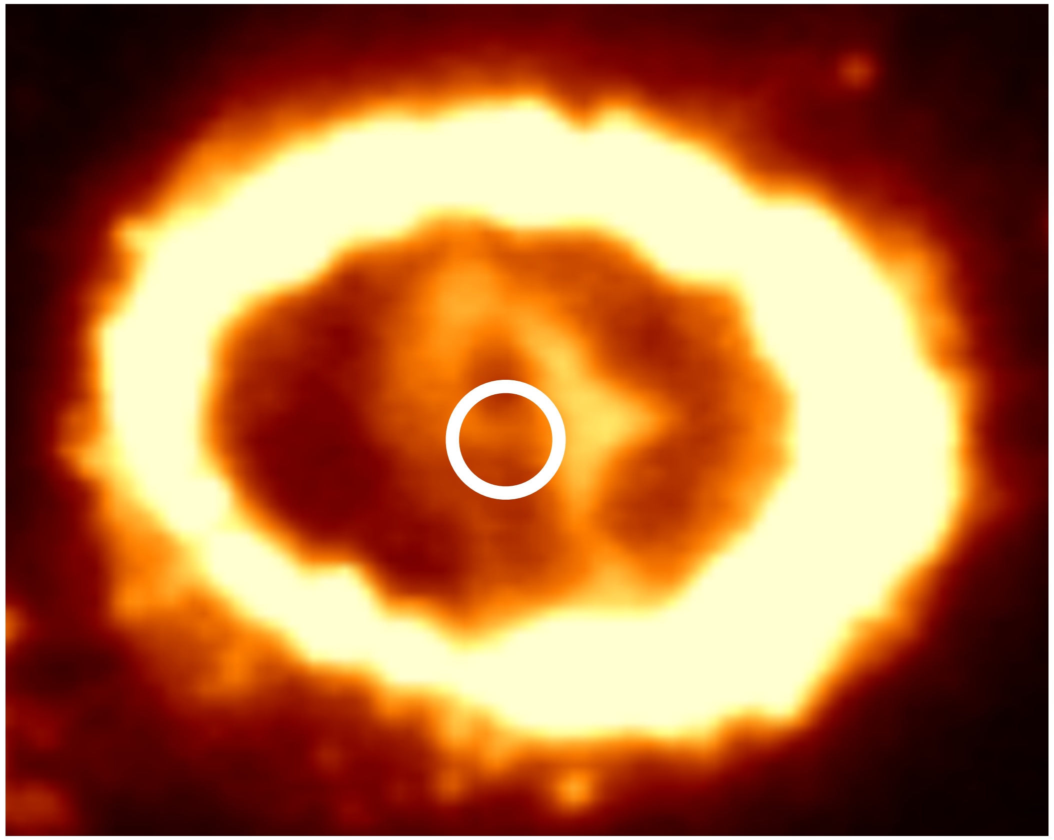
The 30 Year Search for the Compact Object in SN 1987A, Alp et al. (2018, ApJ, 864, 174)

Observations

ALMA	2014
VLT	2010–2014
HST	2009–2015
Chandra	2015

- Find maximum allowed flux
- Ejecta absorption
  UVOIR dust
  X-ray bound-free

  Connects the wavebands

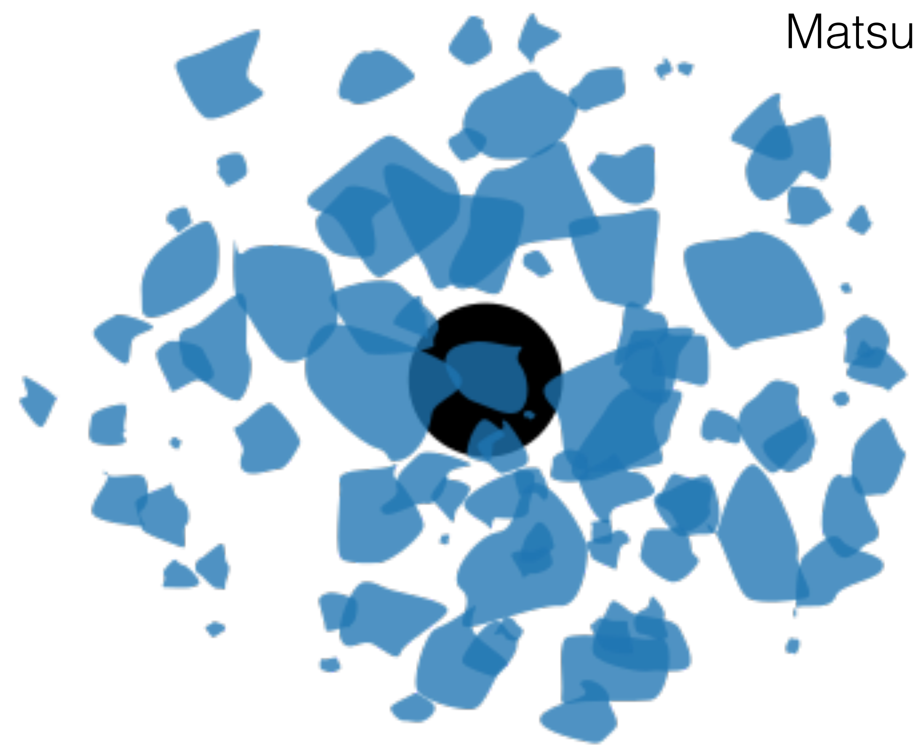


HST/WFC3 2018 *R*-band

UVOIR Dust Absorption

- Dust in opaque clumps
- Covering fraction 60%
- Re-emitted in thermal sub-mm/FIR
- Uncertainties:
  - Line of sight
  - Composition
  - Geometry

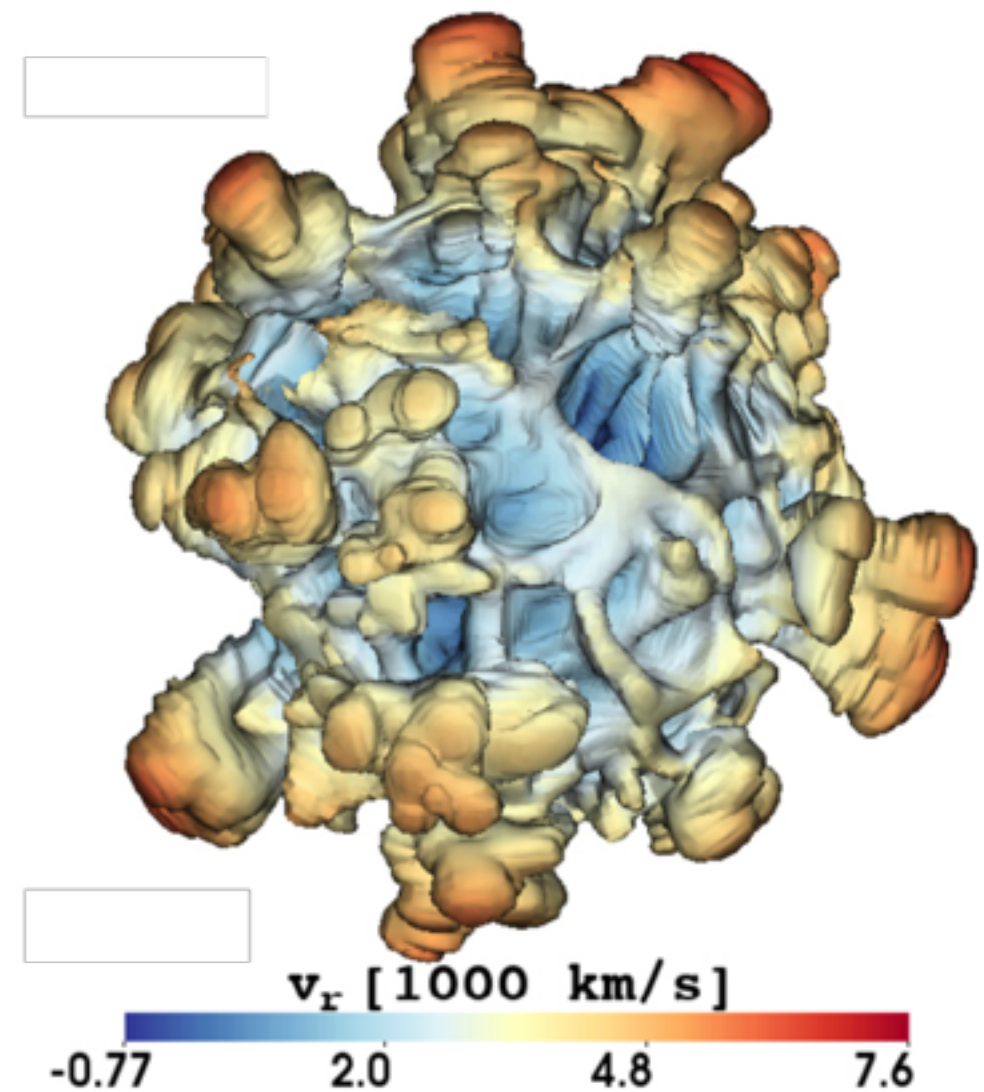
Bouchet et al. (1996)
Jerkstrand et al. (2011)
Matsuura et al. (2011)



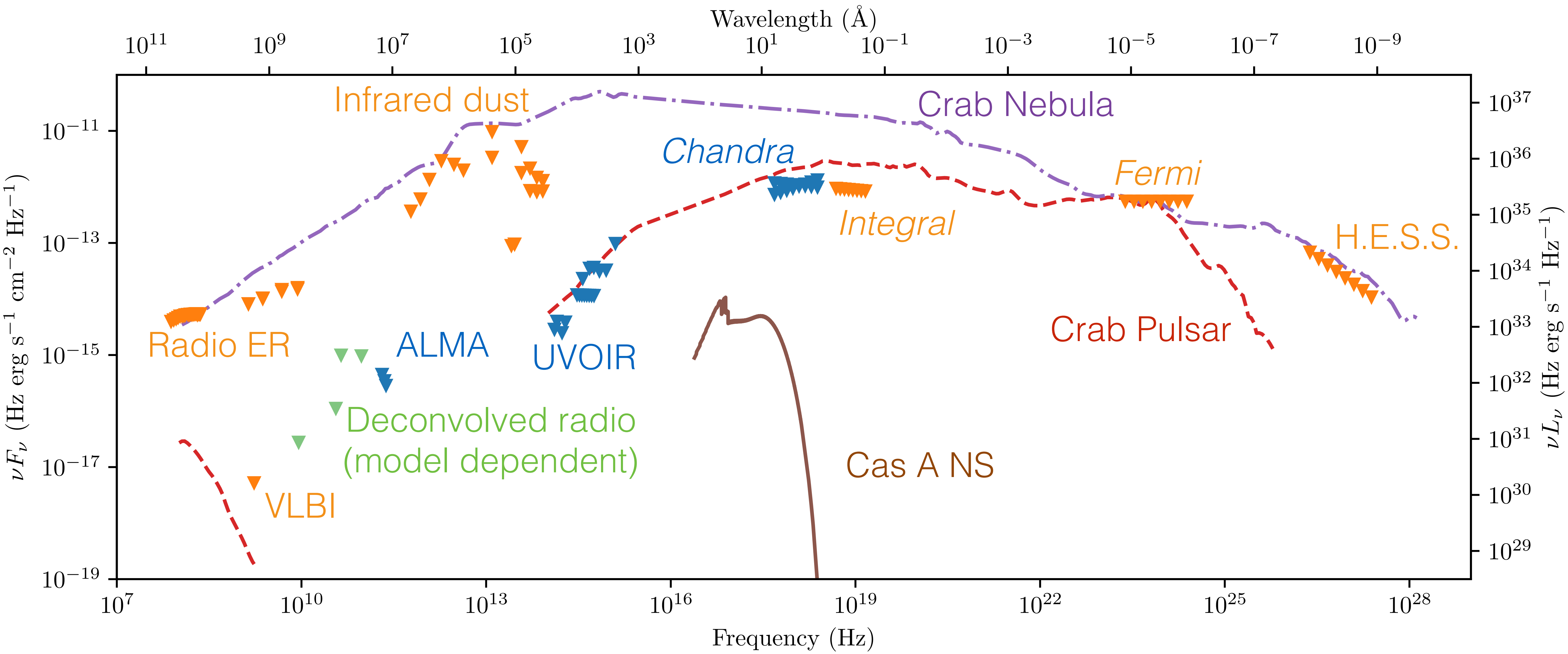
X-Ray Ejecta Absorption

Wongwathanarat et al.
(2013, 2015)

- 3D neutrino-driven SN simulations
- Photoelectric absorption $\tau \sim 20$ at 2 keV
- $\tau \sim 1$ in 2066

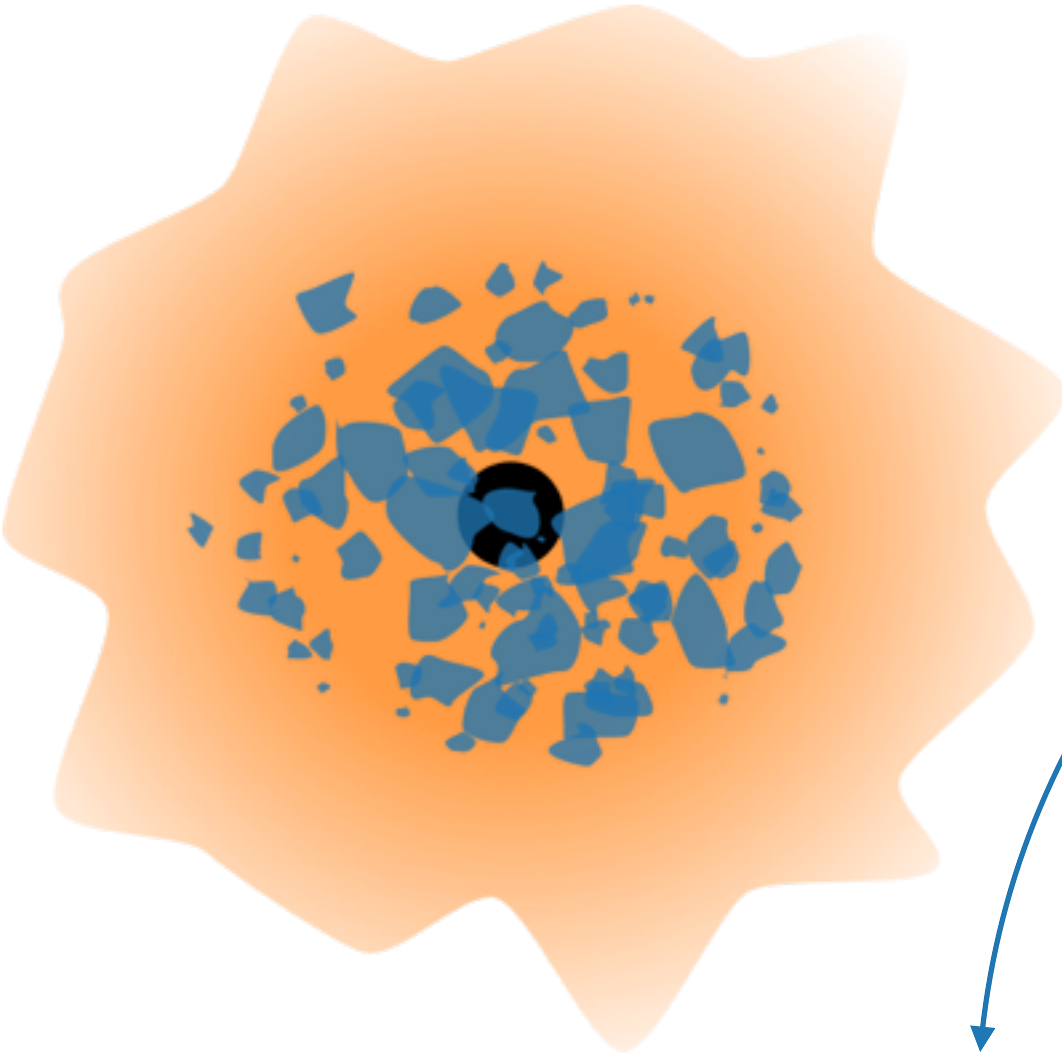


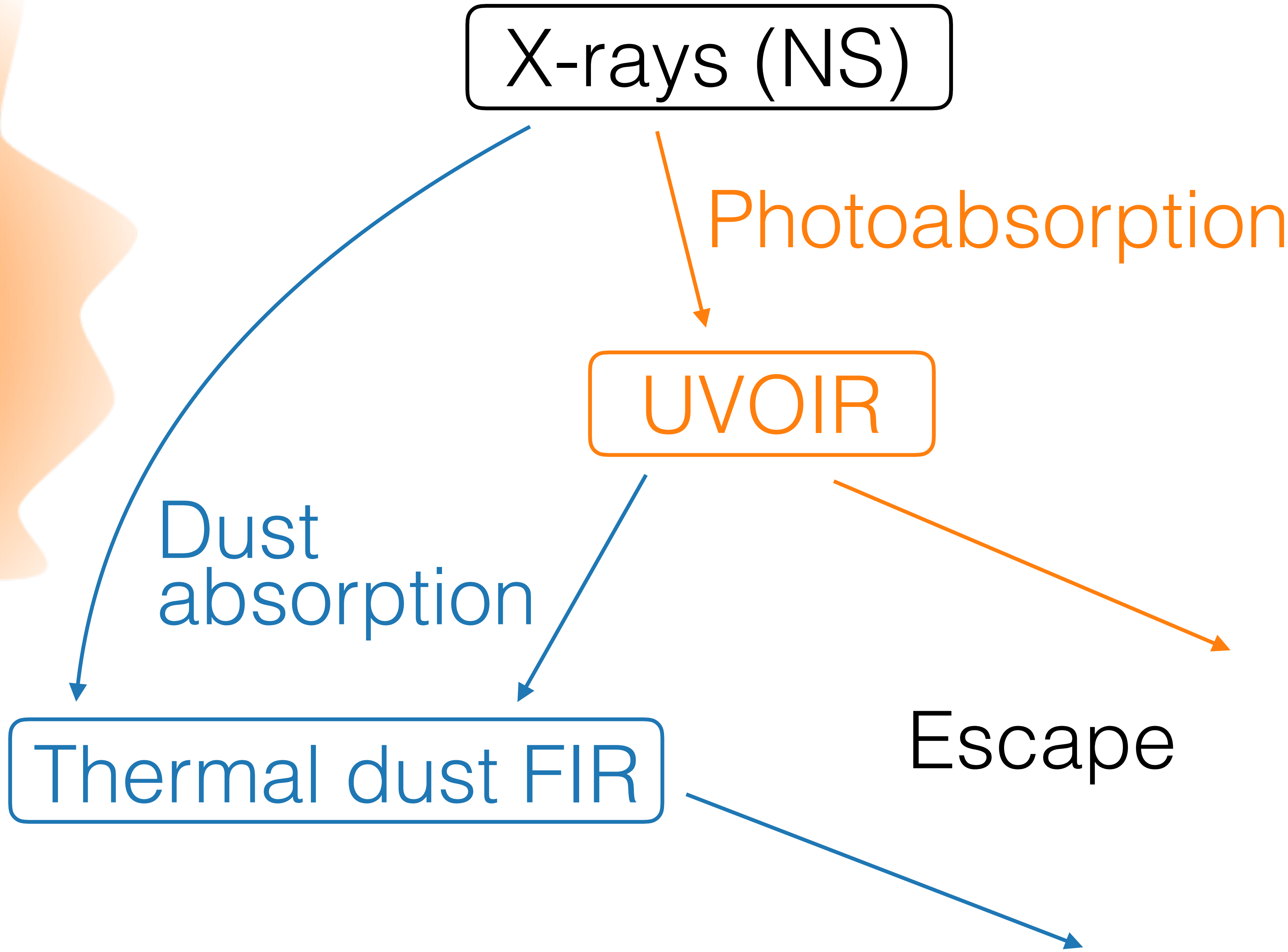
X-ray Absorption in Young Supernova Remnants
Alp et al. (2018, ApJ, 864, 175)



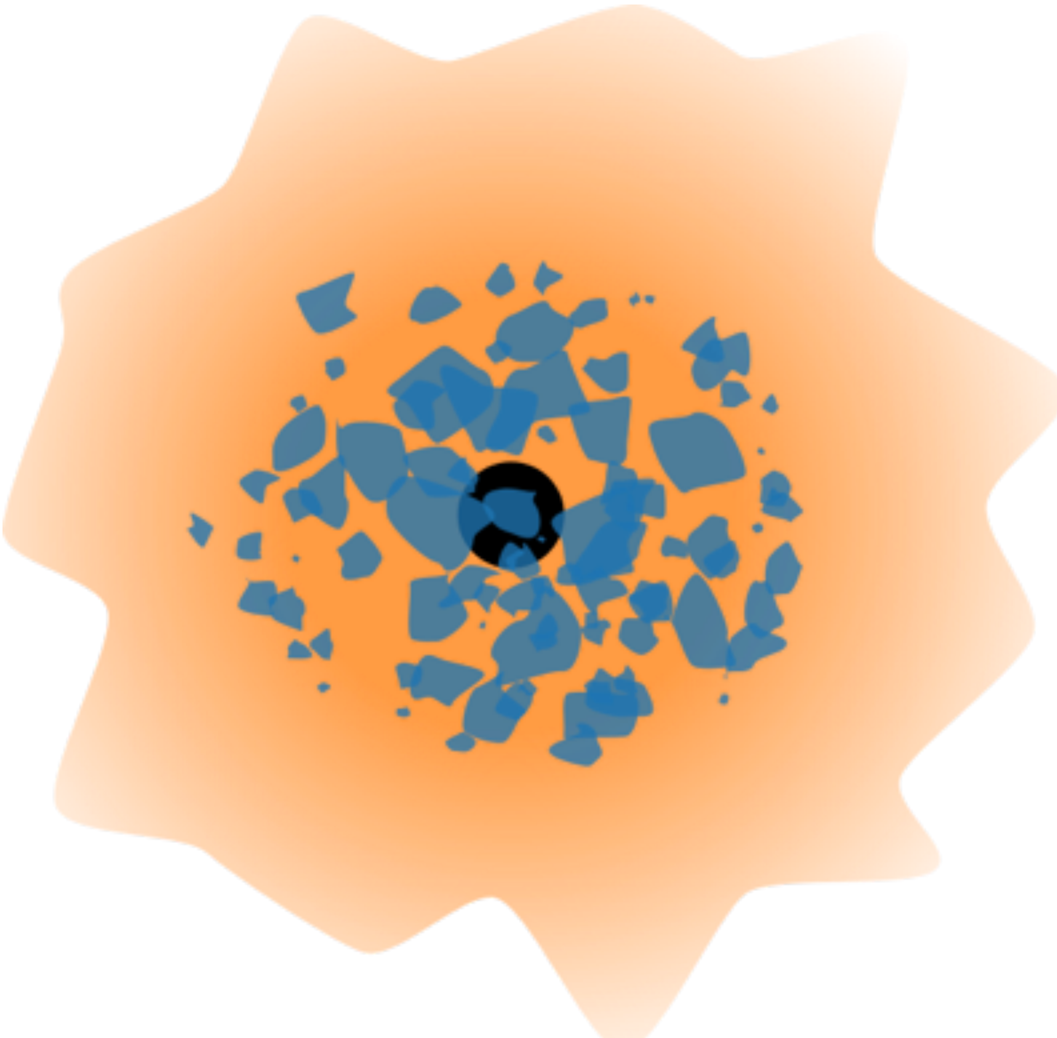
- Construct a physical model
- Combine limits to constrain physical models:
  - Surface emission (temperature)
  - Accretion
  - Pulsar wind activity

Physical Model





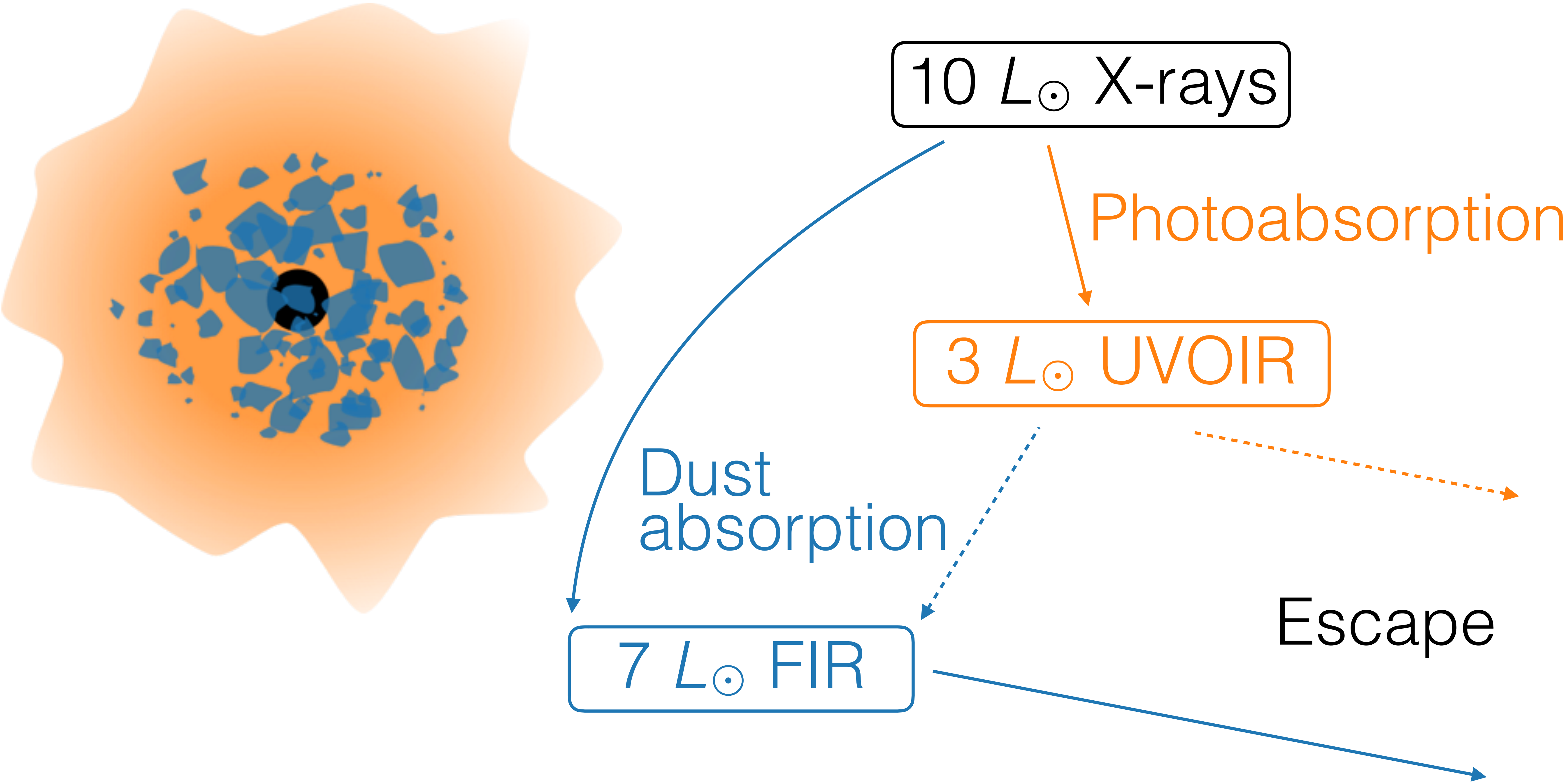
Thermal Surface Emission



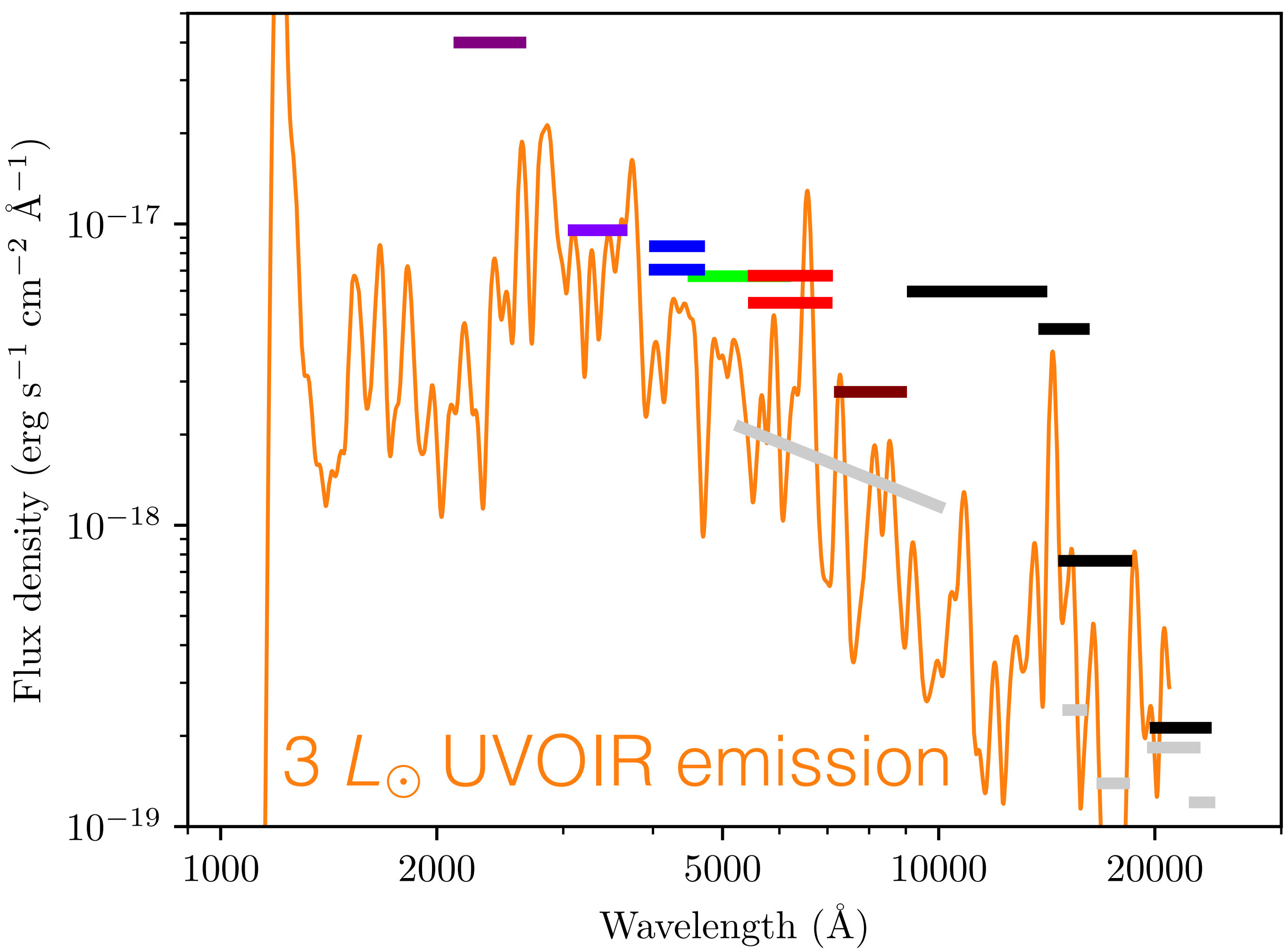
10 $L_\odot$ X-rays

NS temperature of 3 MK →
10 $L_\odot$ soft X-rays

Thermal Surface Emission



UVOIR Limits

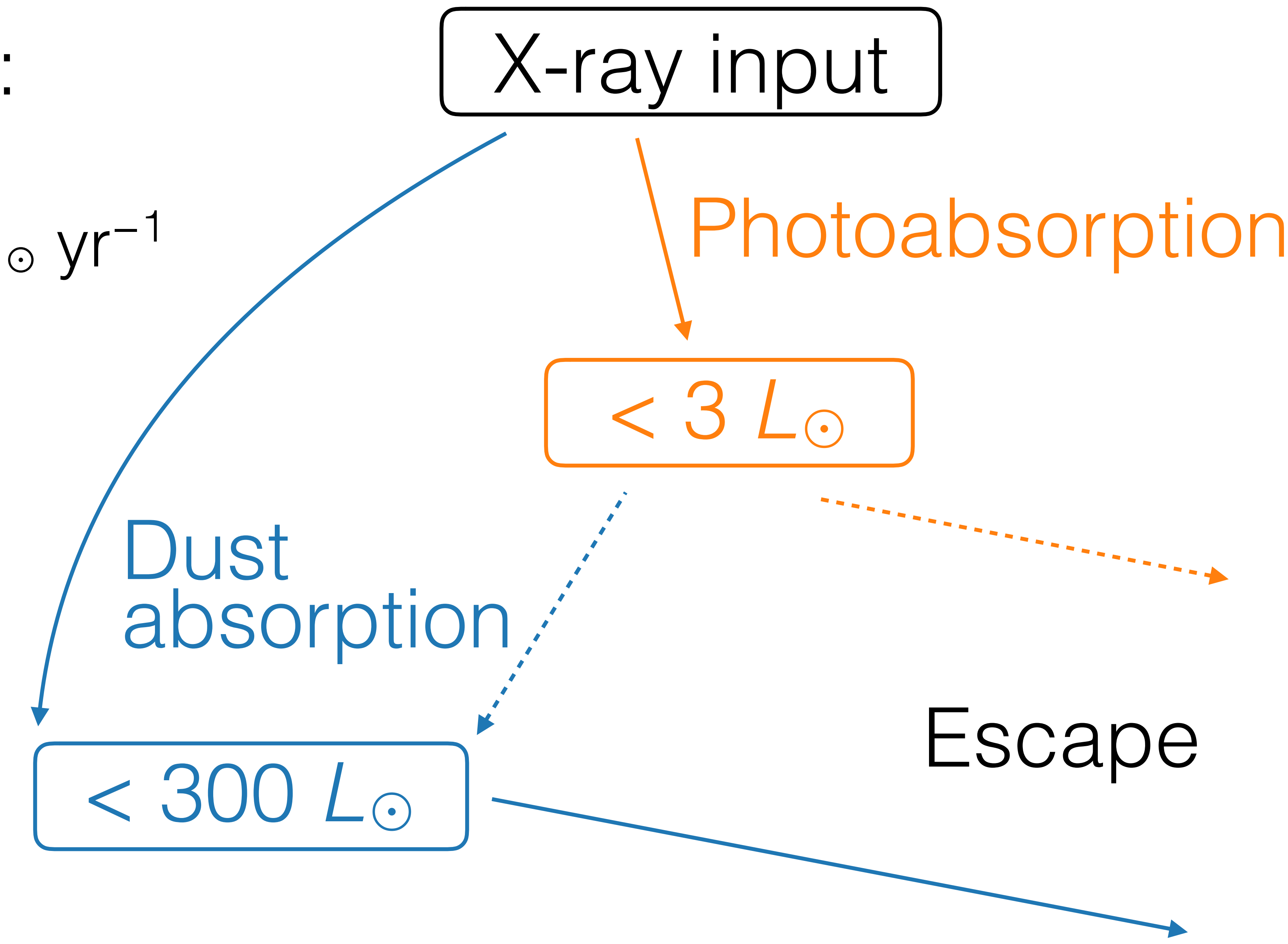


Model spectrum from Jerkstrand et al. (2011)

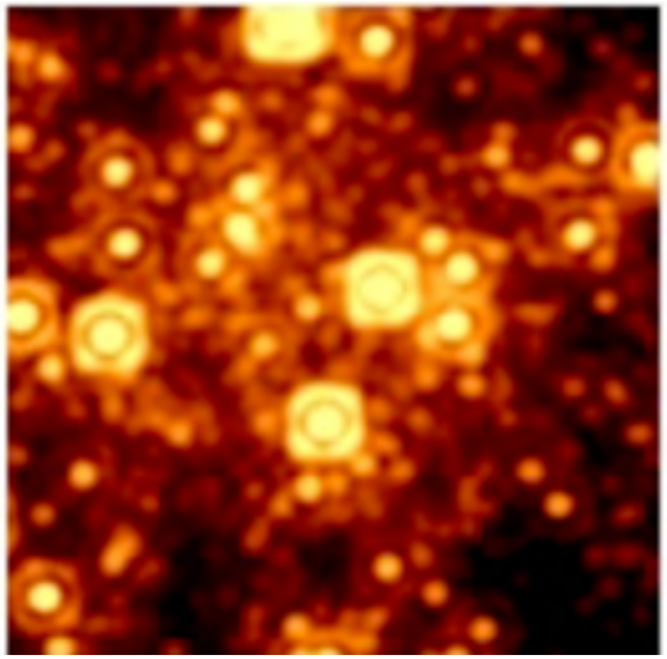
The prediction is marginally consistent with data, possibly indicating that the NS is dust-obscured (given the high prior and conservative limits).

Little room left for:

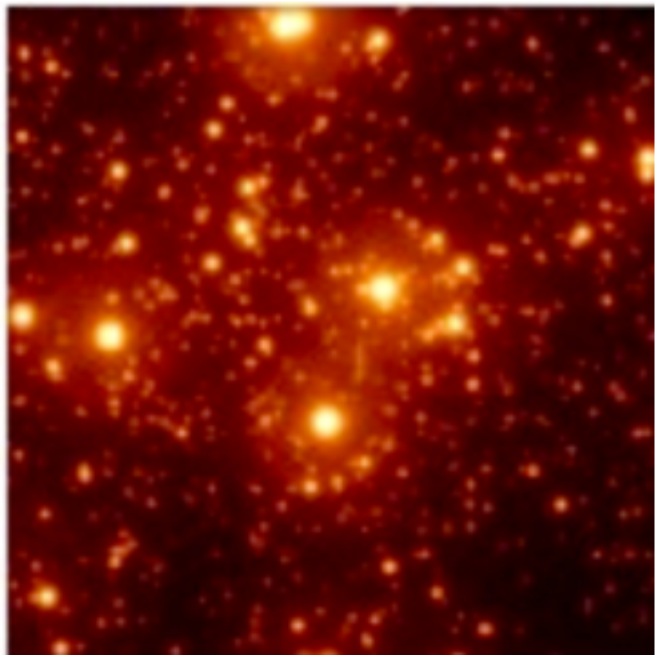
- Accretion rate: $< 2 \times 10^{-11}\, \eta^{-1}\, M_\odot\, \mathrm{yr}^{-1}$
- Pulsar: $B < 10^{14}\, P^2$ G s^{-2}



Future Observations



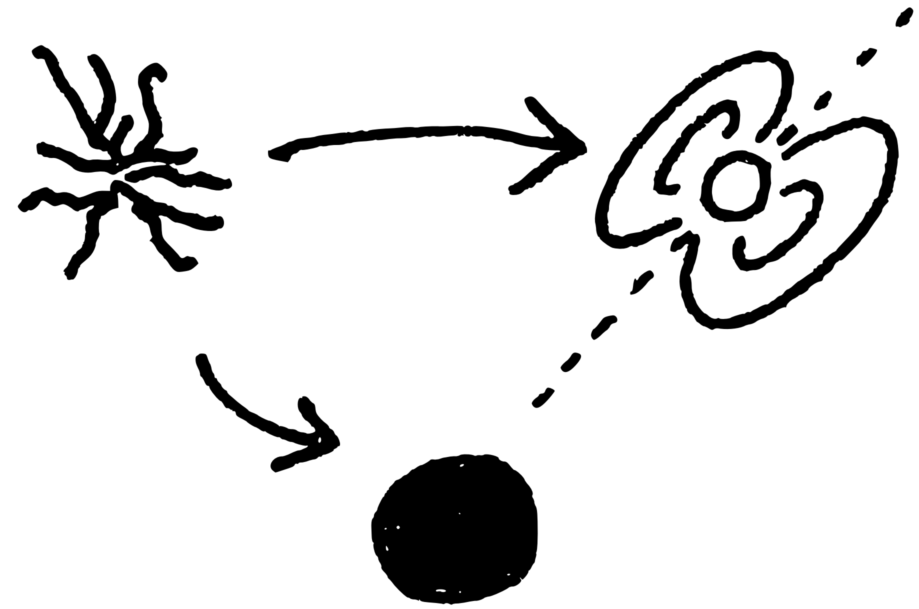
HST 200 mas



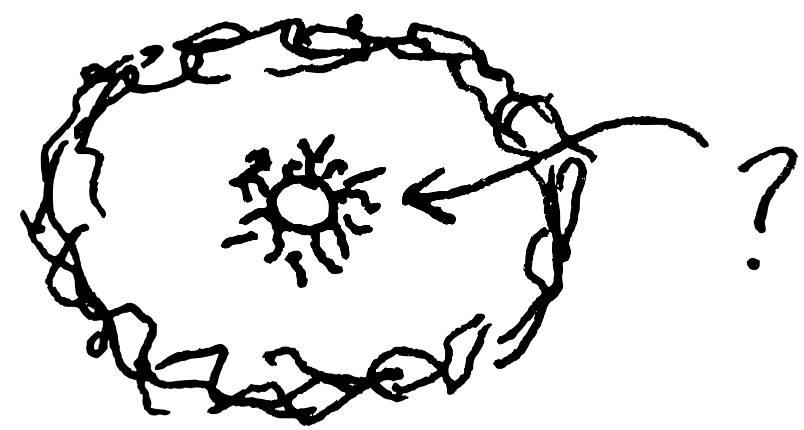
GMT 20 mas

Giant Magellan Telescope
2018 Science Book

- ELTs should either detect a NS or require dust
- ALMA (sub-mm) dust observations

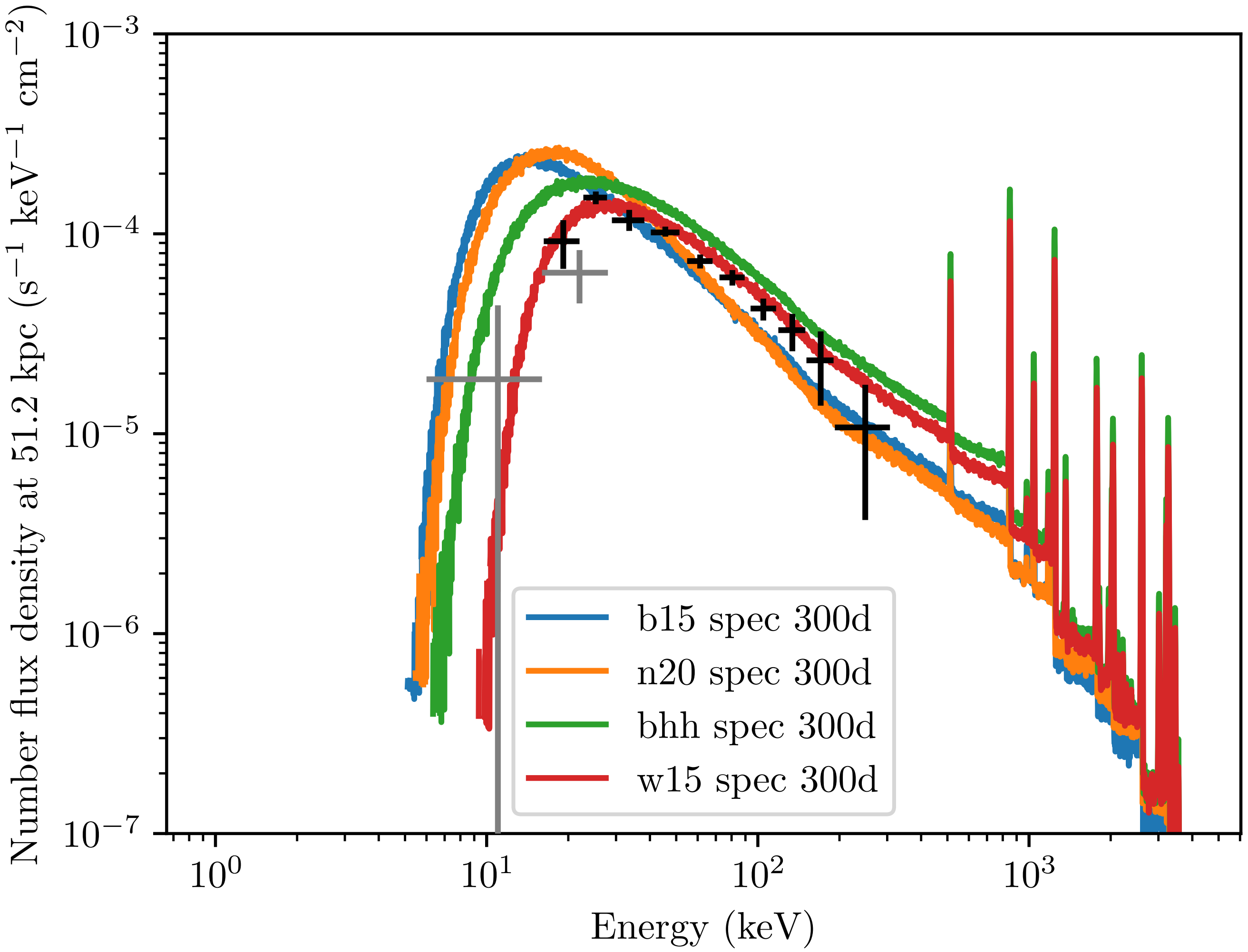


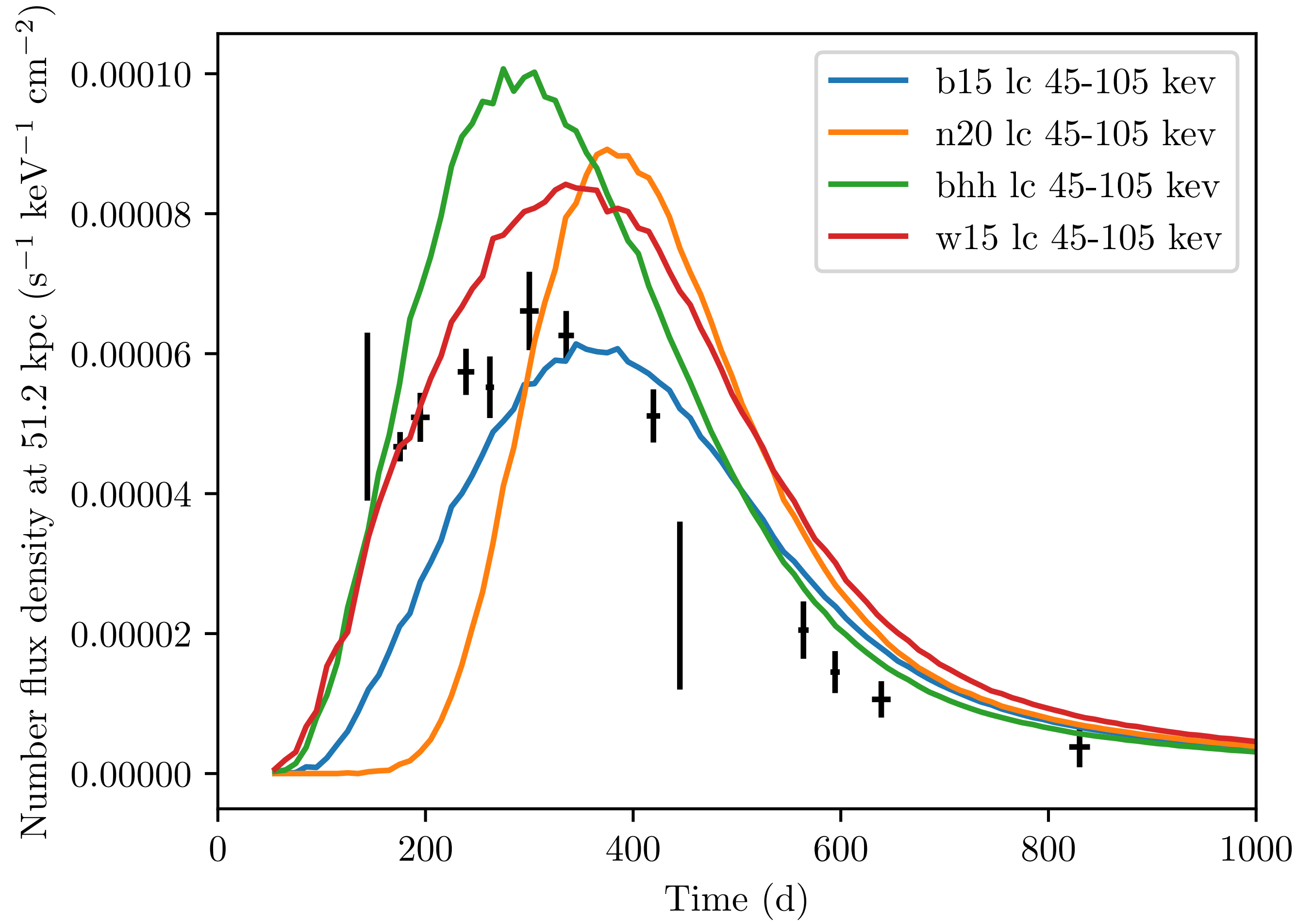
- NS possible, but not much parameter space left
- Dust properties are the largest uncertainties
- Future sub-mm and UVOIR observations will be important



KTH VETENSKAP OCH KONST

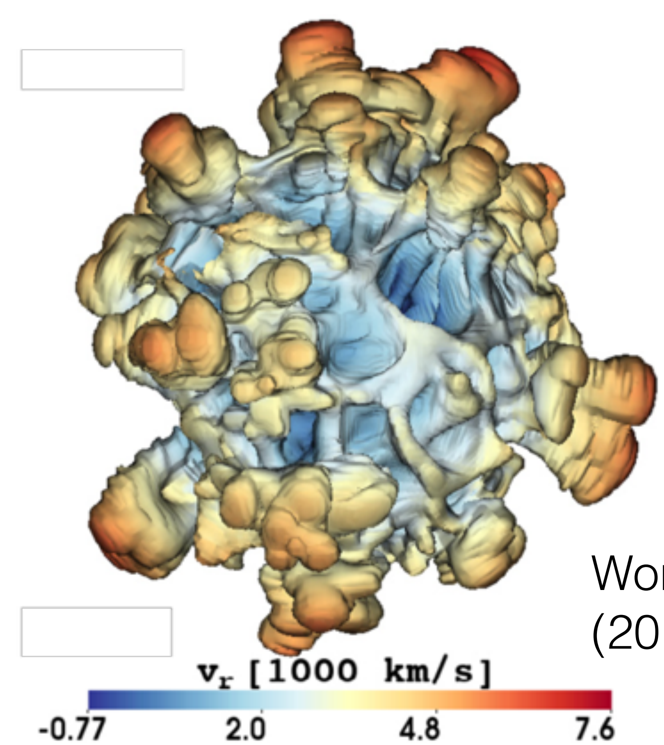
Oskar Klein centre





3D Neutrino-Driven SN Simulations vs. Reality, Alp et al. (in prep.)

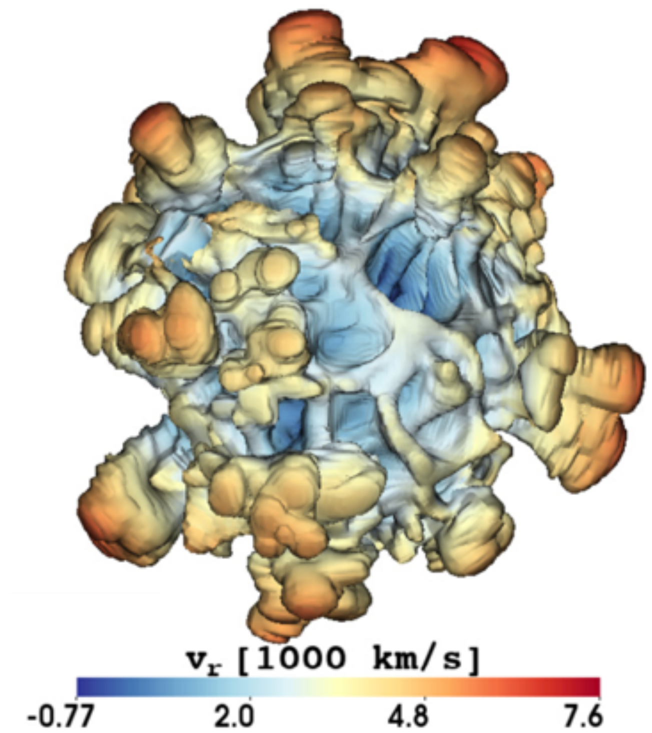
PRELIMINARY



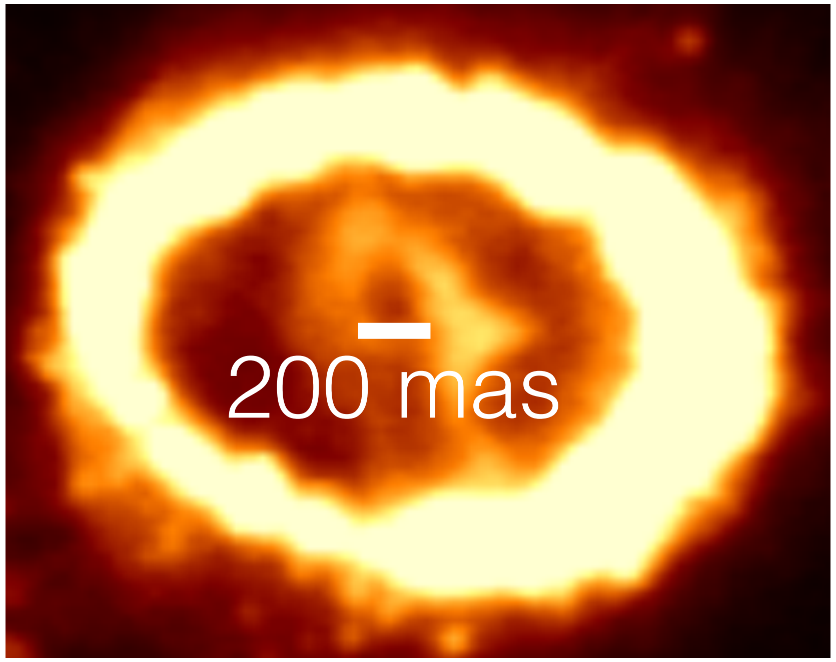
Wongwathanarat et al. (2013, 2015)

X-Ray Ejecta Absorption

Wongwathanarat et al.
(2013, 2015)

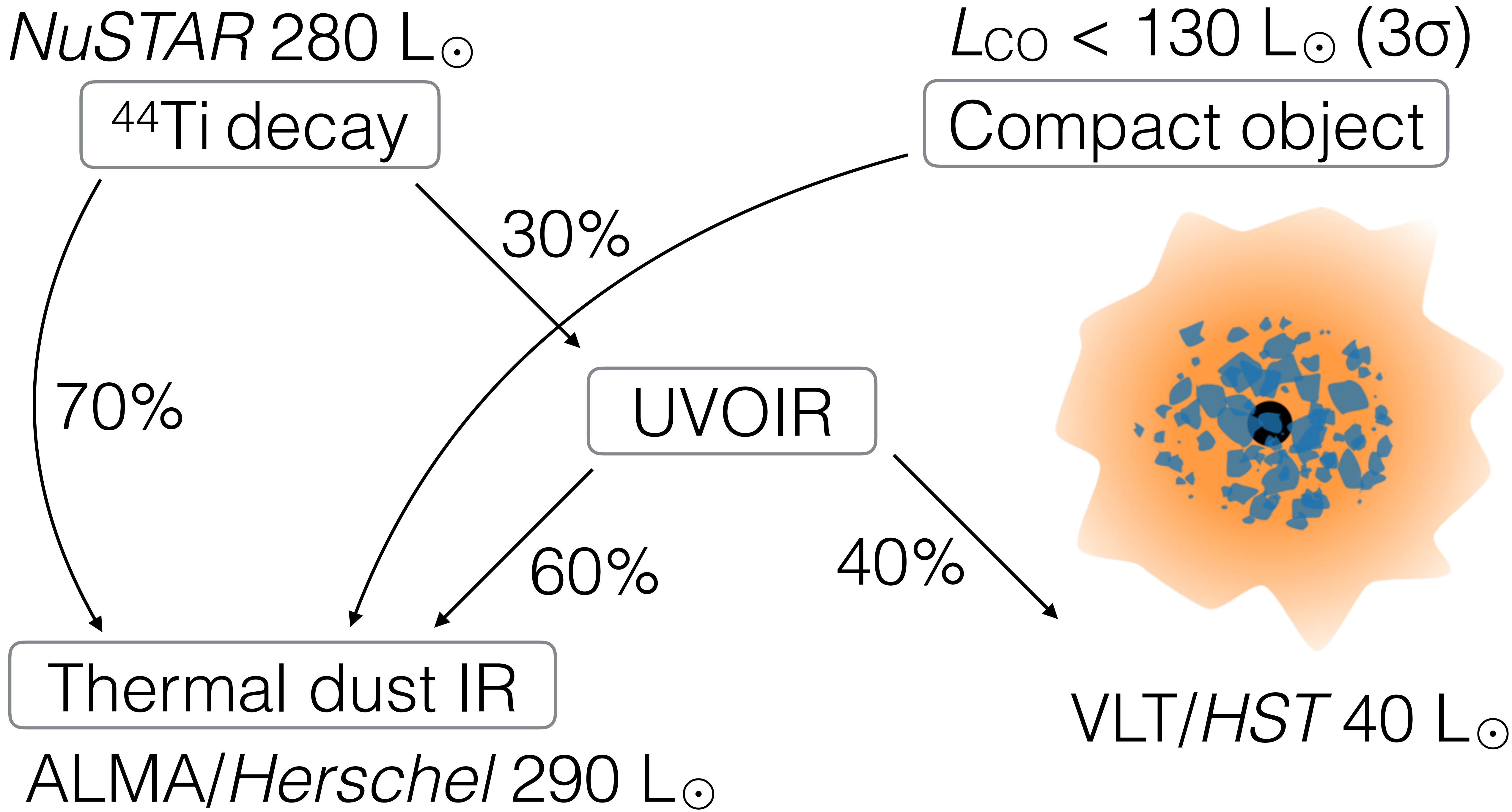


- 3D neutrino-driven SN simulations
- Photoelectric absorption τ ~ 20 at 2 keV
- Typical length ~10 mas



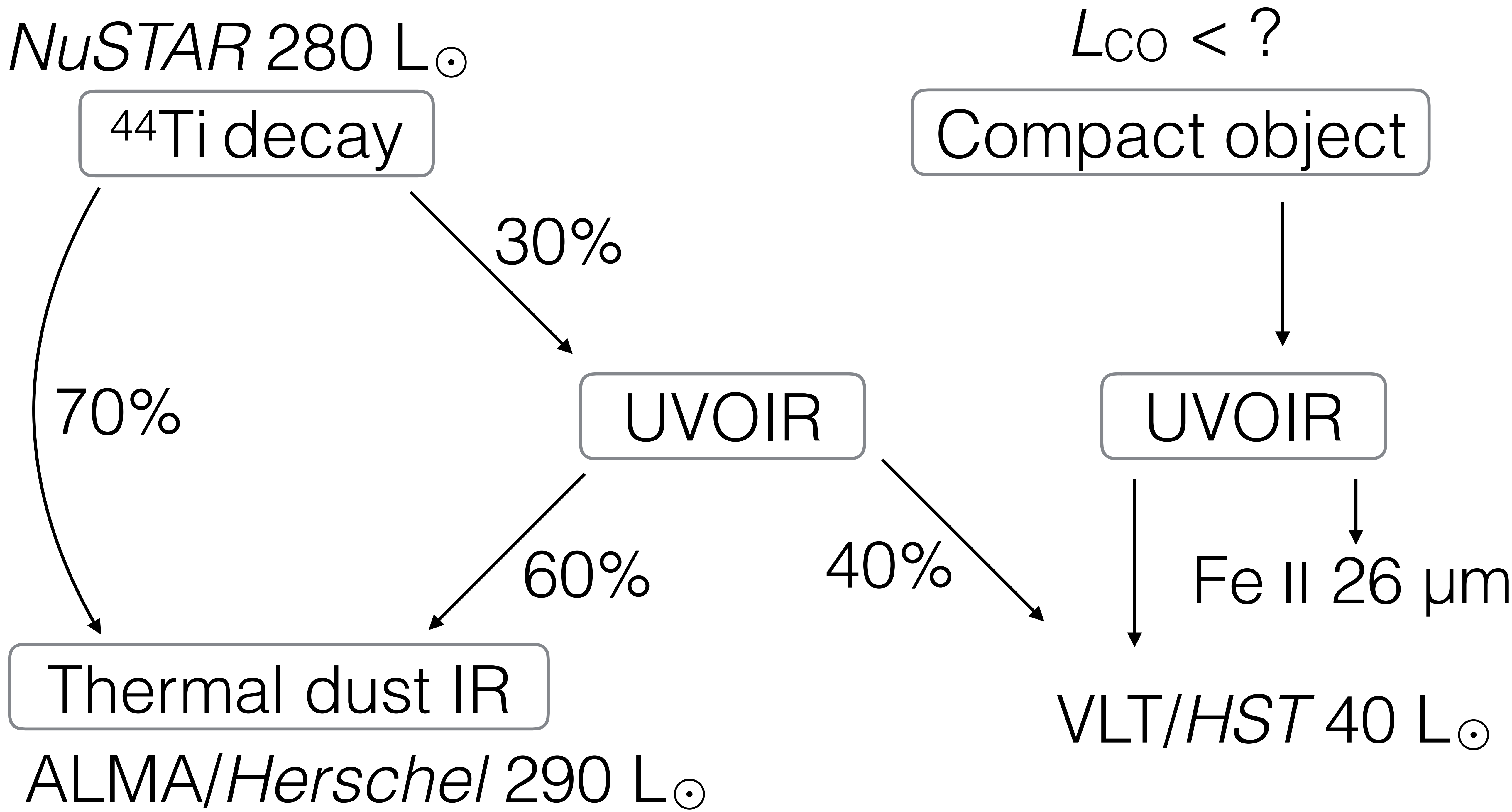
X-ray Absorption in Young Supernova Remnants, Alp et al. (ApJ, 2018)

Case I - obscured



Jerkstrand et al. (2011), Boggs et al. (2015)
Matsuura et al. (2015), Dwek & Arendt (2015)

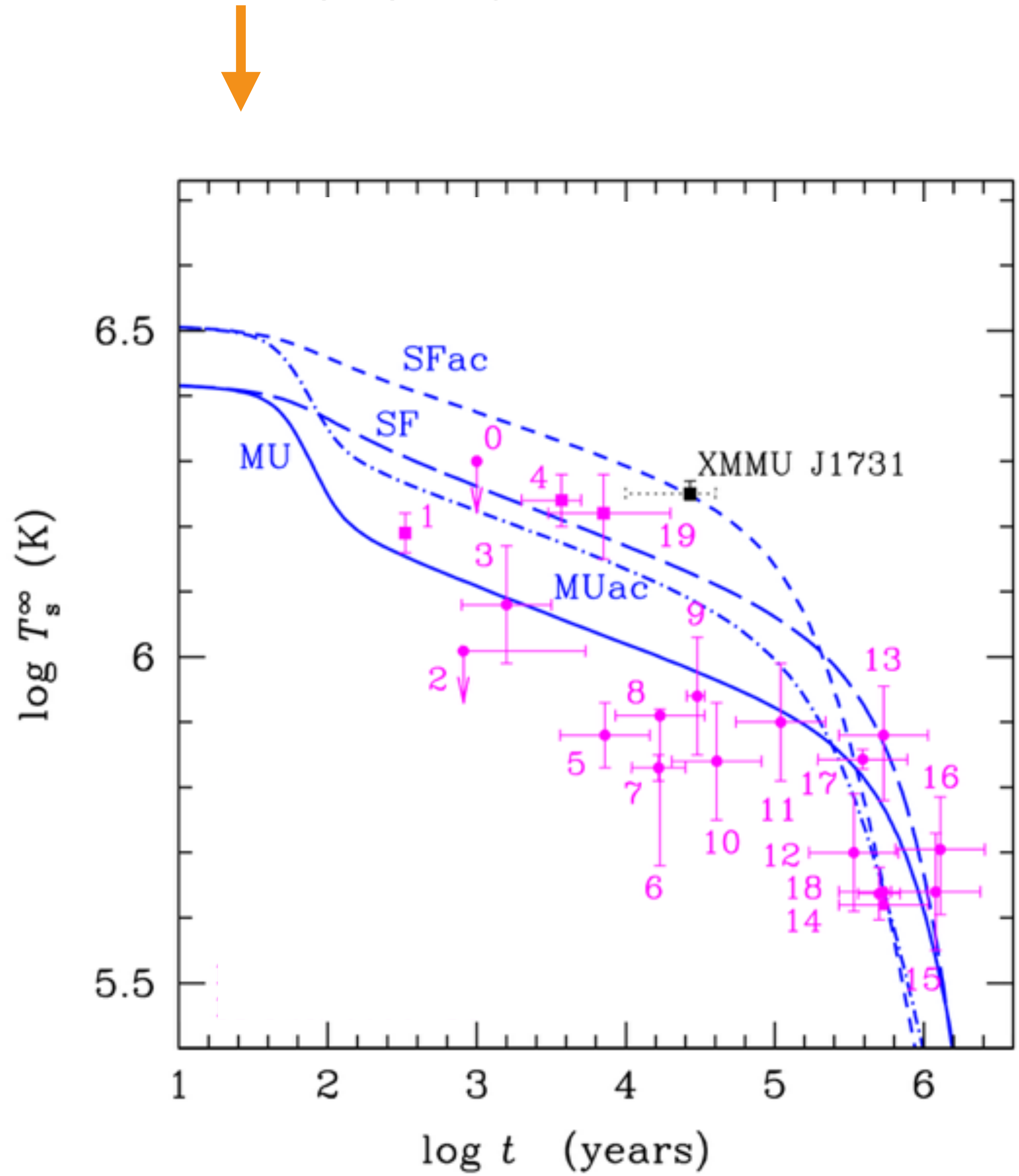
Case II - not obscured



Jerkstrand et al. (2011), Boggs et al. (2015)
Matsuura et al. (2015), Dwek & Arendt (2015)

Thermal Emission

Bolometric	~ 7 MK
X-rays	~ 8 MK
Theory	< 4 MK



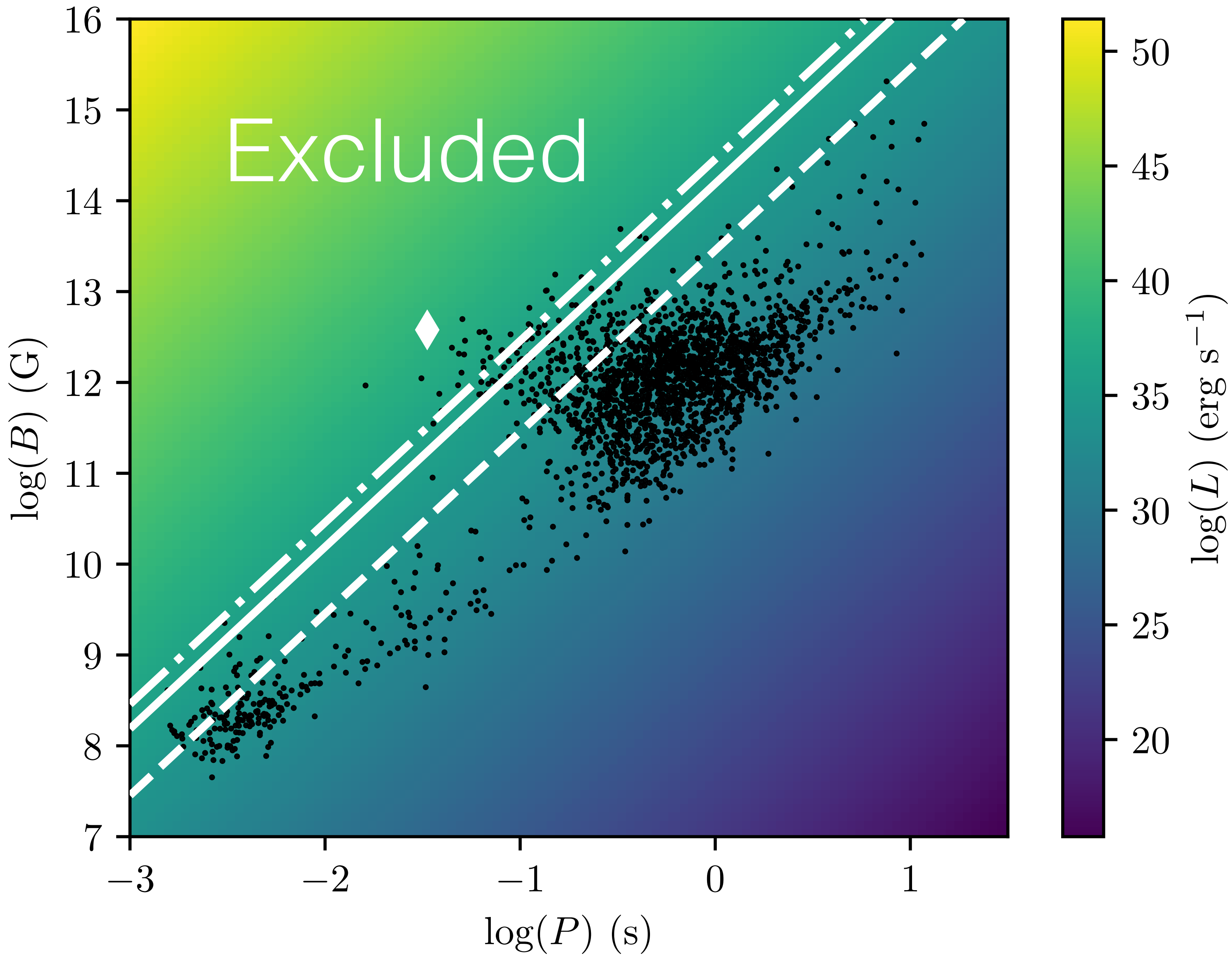
Klochkov et al. (2015)

Pulsar Activity

Rotating dipole in vacuum

$$\dot{E} \propto \frac{B^2}{P^4}$$

$B < 10^{14}\, P^2$ G s^{-2}



Manchester et al. (2005)