The Rugged Landscape of the Core-Collapse Supernova Explosions

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Other work:

- Stellar mergers
- Global physical model for Cepheids
- Stellar dynamics (Kozai)
- Transient astronomy

Observational signatures of the ccSN explosion mechanism

- Core-collapse explosion mechanism poorly understood or perhaps unknown
- Initial properties of massive stars → explosion outcome: which stars explode and which do not?
    - Red supergiant problem (Kochanek et al. 2008, Smartt et al. 2009, 2015)
    - Mismatch in star-formation and SN rates (Horiuchi et al. 2011, 2014)
- What are the properties of the compact remnants?
    - Mass gap between neutron stars and black holes (Özel et al. 2010, Kreidberg et al. 2012)
    - Masses of double neutron stars (Özel et al. 2012, Pejcha et al. 2012)
- Understand the properties of the explosion (explosion energy, nickel mass): correlations, internal scatter, relation to progenitor properties

Predictions of the explosion mechanism
The critical neutrino luminosity

- **Neutrino mechanism**: stalled accretion shock revives when the neutrino luminosity from the proto-neutron star exceeds critical value L_{crit} (Burrows & Goshy 1993) ↔ antesonic condition (Pejcha & Thompson 2012)

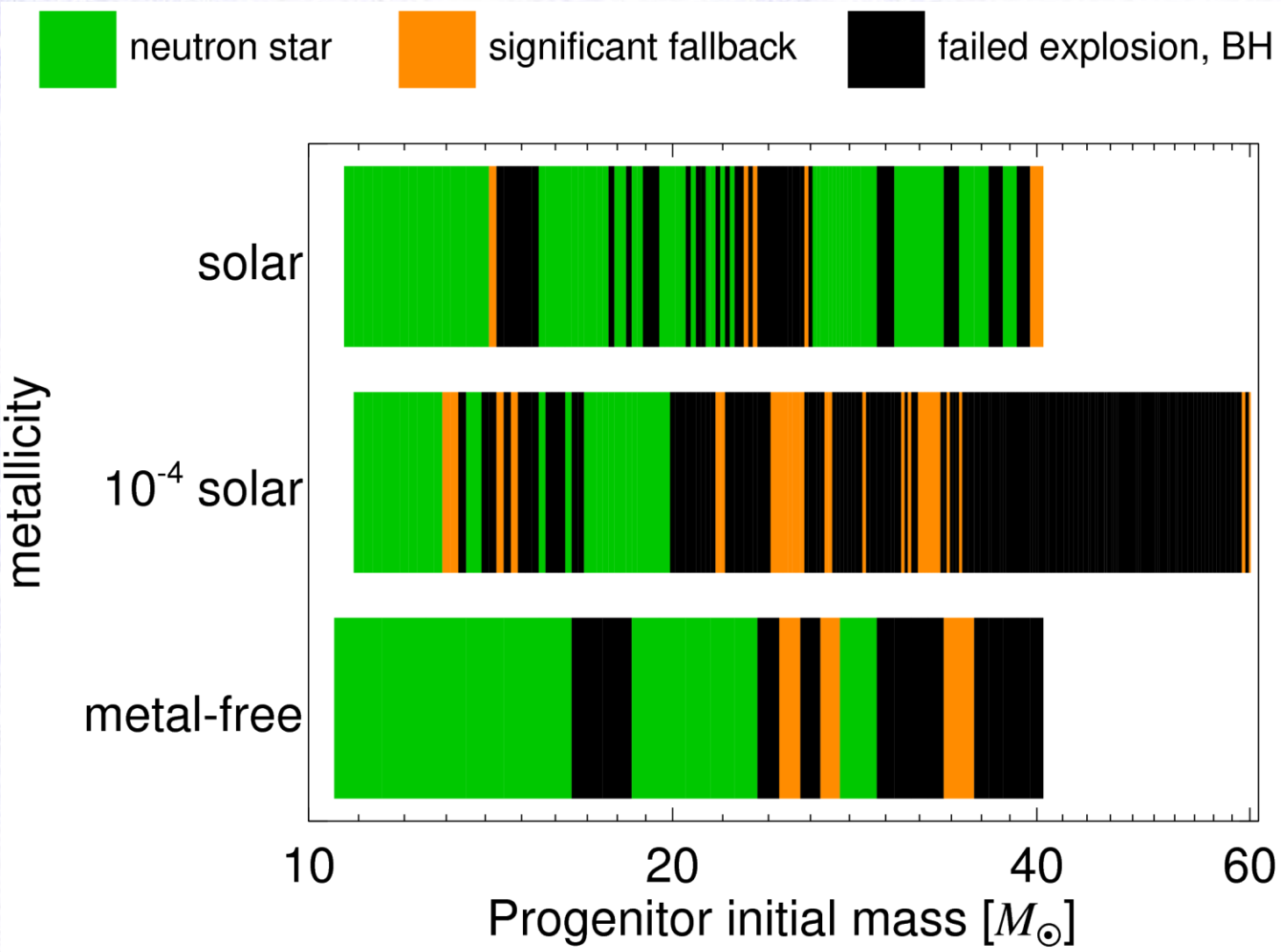
- Large **systematic uncertainties** L_{crit} due to (micro)physics, multidimensional effects

- Parameterize systematic uncertainties by **modifying explosion threshold** consistently for all progenitors
- Apply to 1D time-evolution with GR1D + custom L_{crit} calculation of **400 progenitors** and 3 equations of state

- Outcomes: **successful supernova** (neutron star), **fallback supernova** (explosion energy insufficient to unbind the star), **collapse to black hole** (no supernova)
- Observables: NS and BH **masses, explosion energy, nickel mass**

What is the range of outcomes of the neutrino mechanism?
Can the neutrino mechanism explain the observed properties of supernovae?

Which stars explode?



Woosley et al.(2002) progenitors

one parameterization

Similar results: O'Connor & Ott (2011), Ugliano et al. (2012), Ertl et al. (2015), Nakamura et al. (2014), Muller et al. (2016)

Global model of Type II-Plateau SNe

- Complete self-consistent hierarchical phenomenological model of light curves and expansion velocities -> all covariances and uncertainties exposed
- Training set:
  - 26 well-observed nearby supernovae in 24 host galaxies
  - ~6300 magnitude measurements in 21 photometric bands from 0.19 to 2.2 μm
  - ~230 expansion velocity measurements
  - 391 free parameters

Global parameters:

Magnitude zeropoint

Reddening law

SED evolutionary sequence

$$m_i(t) = \overline{M}_i + \mu_j + \mathscr{R}_i E(B-V) - 2.5\Pi(t) - 2.5\Theta_i(t)$$

Individual parameters:

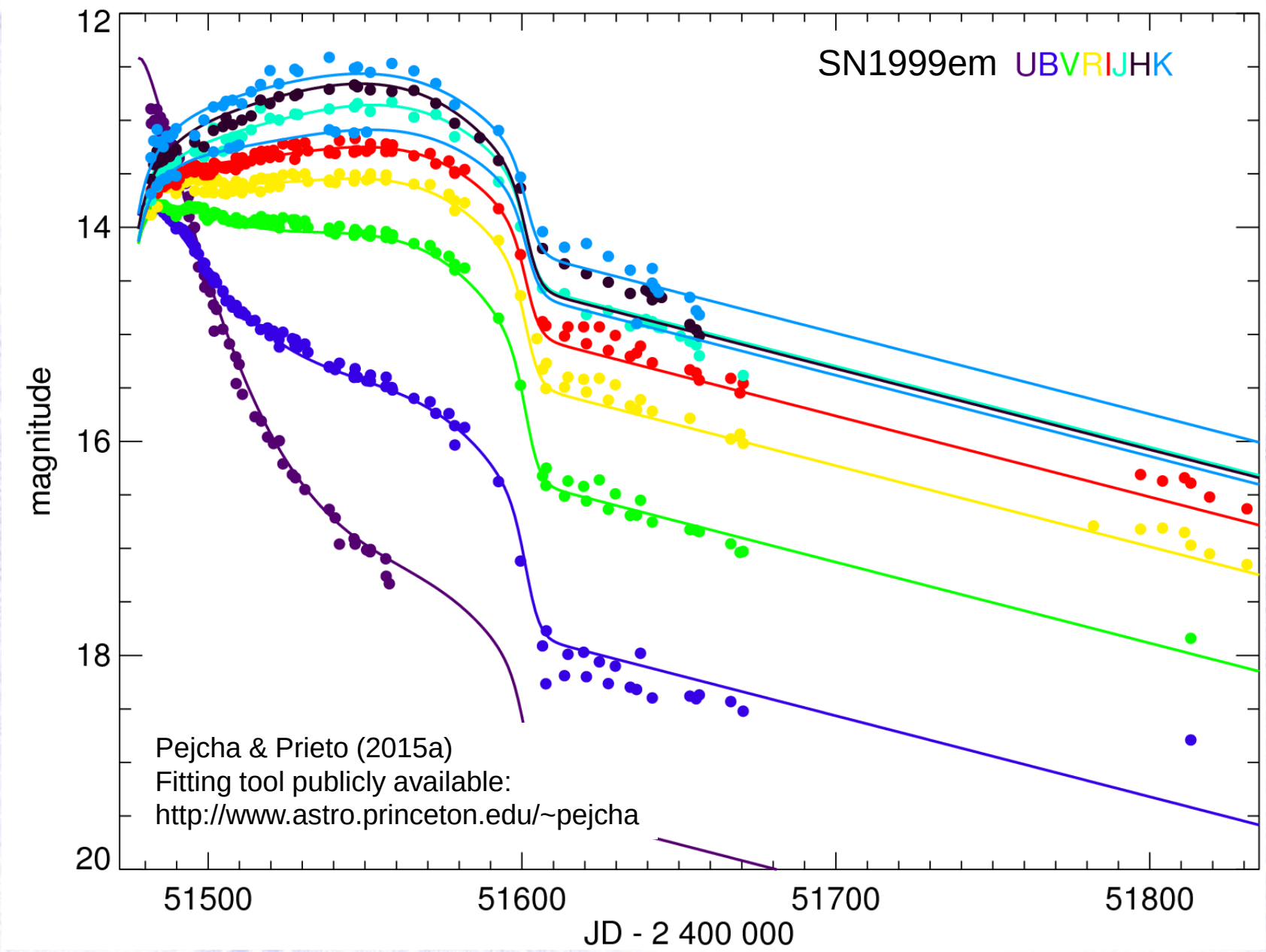
Distance modulus

Reddening

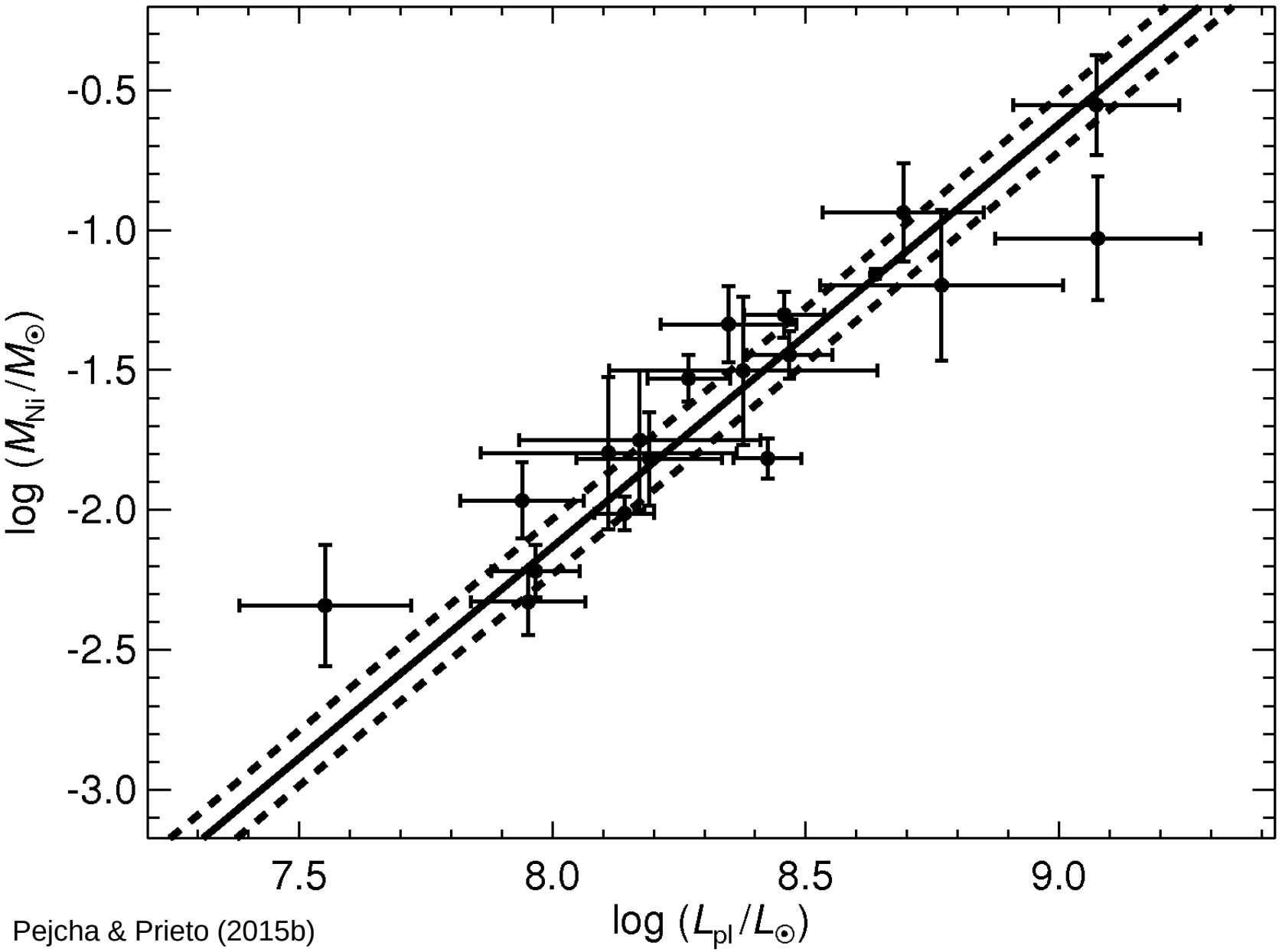
Radius evolution (wavelength independent) from velocities

Starting point and pace through SED evolution

A global model of light curves and expansion velocities



What are the properties of the explosions?



Pejcha & Prieto (2015b)

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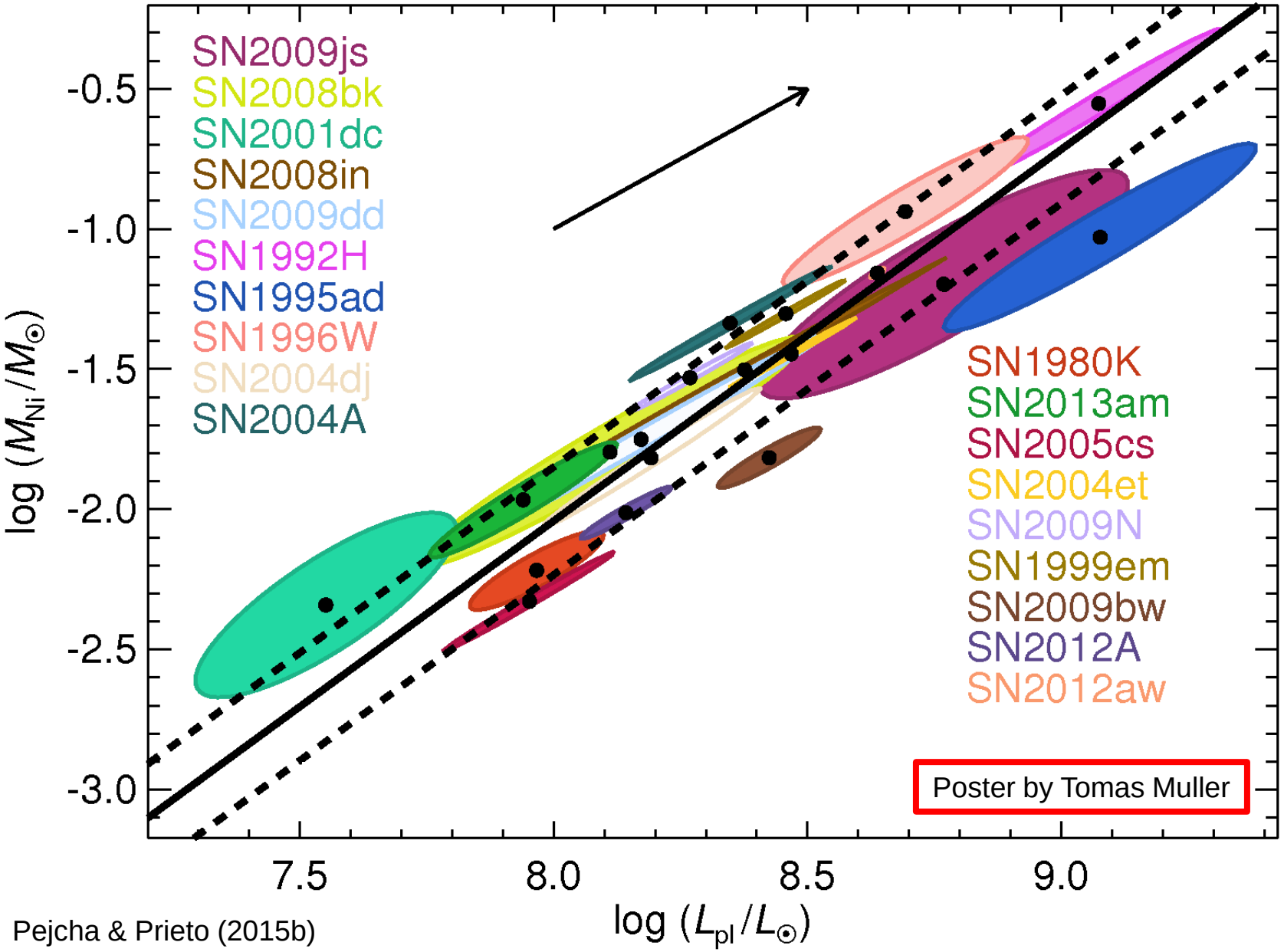

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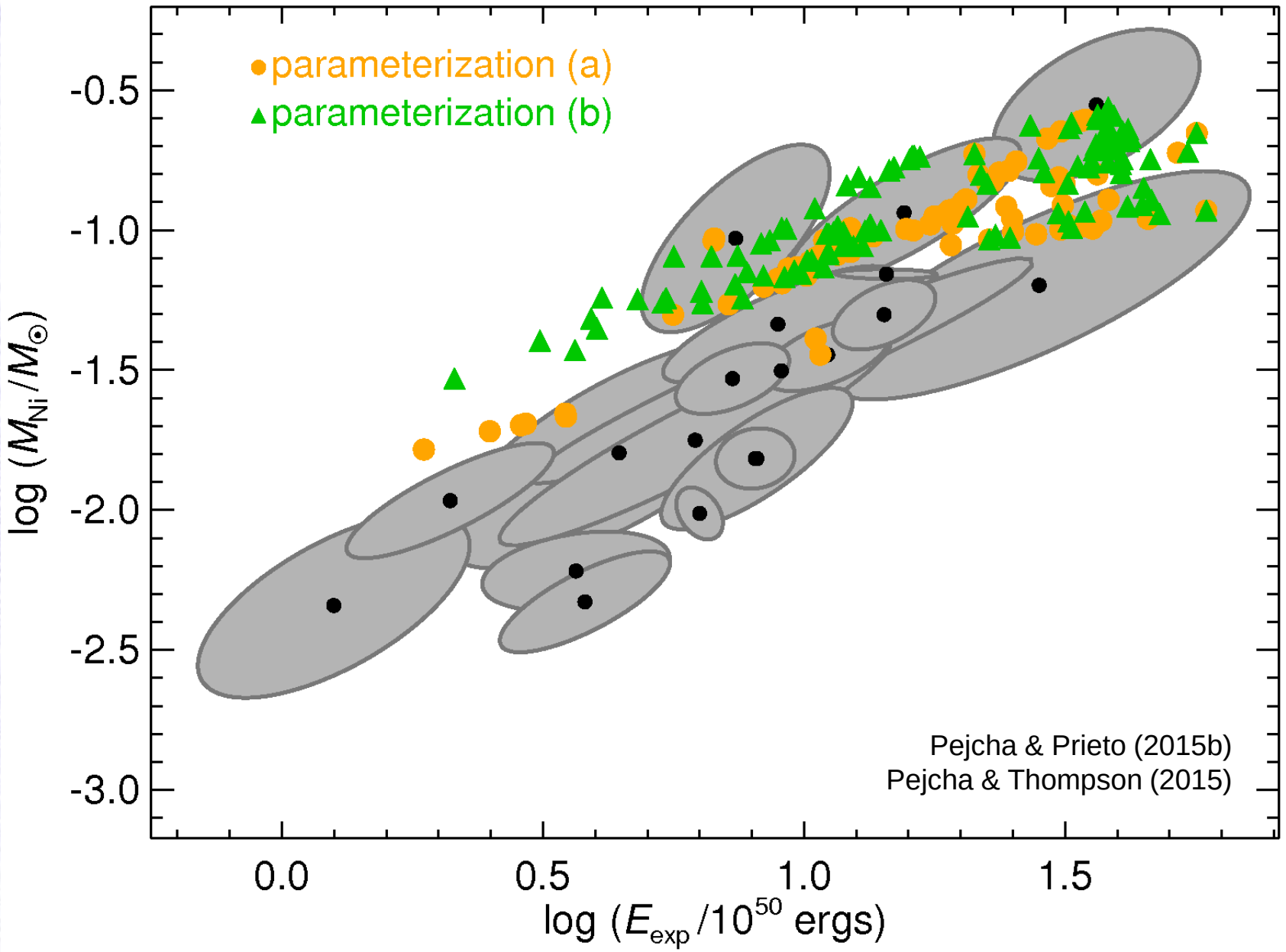
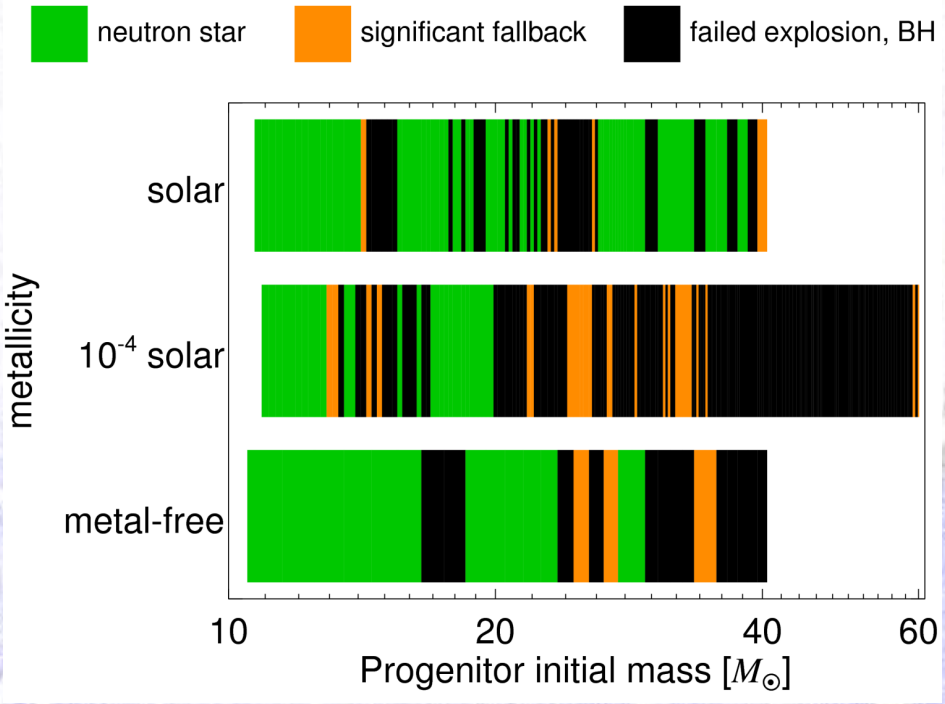


Conclusions

- L^{crit} convolved with progenitor structure gives testable predictions for fraction of remnant masses, explosion energies, nickel masses
- Successful and failed explosions intertwined in a complex non-monotonic pattern (Pejcha & Thompson 2012, 2015)
- A new method to determine parameters of type II-Plateau supernovae taking into account all statistical uncertainties reveals diversity of supernovae



- Type II-Plateau SN explosions are not described by a single physical parameter or a simple one-dimensional trajectory through the parameter space, but instead reflect the diversity of the core and surface properties of their progenitors (Pejcha & Prieto 2015a,b)
- Future work: global model of light curves and velocities based on physical evolution of bolometric luminosity, radius, effective temperature