Can neutron star re-collapse? — A new perspective for the formation of SGRs/AXPs

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Outline

1. Motivation
2. Backgrounds of SGRs/AXPs
   - Observations
   - Models
   - Problems
3. Possible formation tracks in neutron star binaries
4. Summary
5. Future prospects

I. Motivation

Neutron star (NS) – Black hole (BH) connection

- AIC of white dwarf —— NS (Taam & van den Heuvel 1986)
- AIC of NS?

1. Connection with formation of BH?

Hyper-Eddington accretion required? (Ghosh et al. 1997)

Mass gap? (e.g. Ozel et al. 2010)

2. Other objects needed?

Possible objects: SGRs/AXPs

II. Backgrounds of SGRs/AXPs

Brief history

1. **1979.3.5, SGR 0526-66** (Mazets et al. 1999) : 50-150 keV, spike peaking at 10^{45} erg/s, 3min train, coherent 8s pulsations, flux decayed in a quasi-exponential manner
2. **1981, 1E 2259+586 (AXP):** soft energy spectrum 10^{35-36}erg/s, P_s=5-9s, no orbital Doppler shifts, no optical counterparts
3. **1986, naming of soft gamma-ray repeater**

Basic Facts:

(see Woods & Thompson 2006; Mereghetti 2008 for detailed reviews)

- Spin period: 5-12 s
- Secular and steady spin-down rate on timescale of 10^{3-5} yrs
- Constant X-ray luminosity 10^{34-36} ergs/s – 2-3 orders higher than spin-down luminosity (Mereghetti 2002)
- Differences: spectrum、spin period、X-ray variability

Standard model — Magnetar (Paczynski 1992; Duncan & Thompson 1992)

Background:

Magnetic field of quantum critical value — energy between Landau levels of electrons equals their rest mass

$$B_{QED} = \frac{m^2 c^3}{e\hbar} = 4.4 \times 10^{13} G$$

Beyond critical value, QED is needed!

Magnetar — highly magnetized NS (Paczynski 1992; Duncan & Thompson 1992)

Idea: magnetic dipole braking comes at the cost of rotational energy loss in the frame of classical electrodynamics

Requirements: very strong magnetic field $B \sim 10^{14-15}$ G (Duncan & Thompson 1992)

Origin: turbulent dynamo amplification of fossil fields (Thompson & Duncan 1993)

Physics: magnetic dipole radiation and/or a magnetically powered relativistic wind (Thompson & Duncan 1995, 1996; Thompson et al. 2002)

Alternative models:

1. Merger of two WDs — highly magnetized (10^8 G) WD (Morini et al. 1988; Paczynski 1990; Malheiro, Rueda & Ruffini 2012)

2. Accretion from residual disks (without high magnetic field)

a. NS with very low mass companion (Mereghetti & Stella 1995)

b. Debris disk of a disrupted massive companion (van Paradijs et al. 1995; Ghosh, Angellni & White 1997)

c. Fallback disk formed after SNe (Corbet et al. 1995; Chatterjee, Hernquist & Narayan 2000; Alpar 2001; Marsden et al. 2001)

3. Objects with more elementary matter

Quark star (Xu 2007; Horvath 2007); P star (Cea 2006)

Problems:

1. Strong magnetic field?

a. Estimation — magnetic dipole braking、classical electrodynamics

b. State of matter and radiation mechanism in strong magnetic field

c. Fermi observations — multipole field (Tong et al. 2012)

2. Super-strong magnetic field is not necessary and sufficient!

Detection of several SGRs/AXPs with relatively low B ($<B_{QED}$) (Rea et al. 2012, 2012); radio pulsars with high B ($>B_{QED}$) and SGR/AXP-like bursts (Manchester et al. 2005); Radio emission in AXPs (Camilo et al. 2006, 2007); PSR J1852+0400 - CCO (Halpern & Gotthelf 2010)

3. Accreting Objects? — 4U 2206+54 (Reig, Torrejon & Blay 2012)

Summary:

1. The nature and nurture of SGRs/AXPs are still the matters of debate…

2. The cause of exotic properties involves both internal nature and exterior environment!

Accreting SGRs/AXPs?

Softer spectra and less luminous flux without secular variation conflict with properties of canonical binaries

Accretion powered X-ray emission is supported (Baykal & Ogelman 1995; Mereghetti & Stella 1995)

Isolated object accreting from an accretion disk?

Re-collapse/re-explosion?

Coalescence or merger in NS binary

TZO (Thorne & Zytkow 1975, 1977)

Requirements:

- Closed system (orbital period < minimum critical period)
- Common envelope (CE) phase
- Energy deposit

III. Possible formation tracks in NS binaries

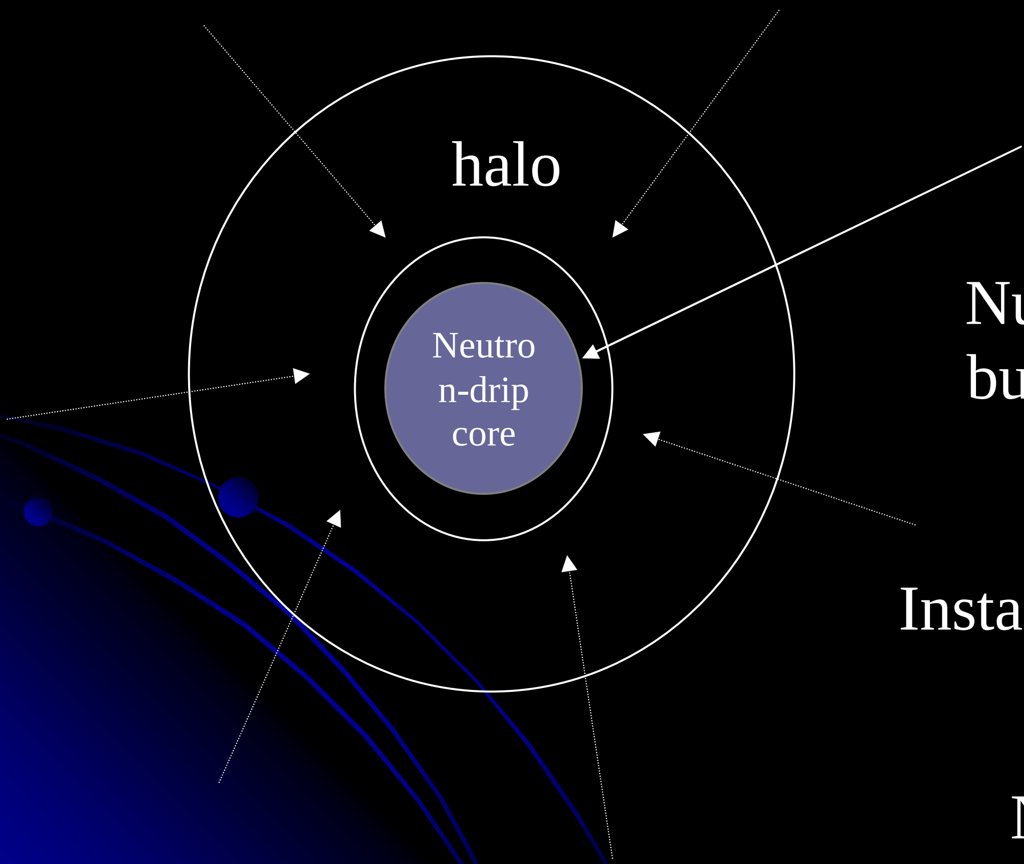
1. High mass NS binary systems

- Specialties
  - massive companion
  - Roche lobe over flow
  - super-Eddington rate
- Destinies
  - bipolar jet
  - close system
  - TZO

- TZO
  - Structure
    - convective envelope
    - radiative and isothermal halo
    - NS core
  - Categories
    - giant
      - < 9 solar mass
      - 5% gravitational energy + 95% nuclear energy
    - supergiant
      - >11.5 solar mass
      - 97% gravitational energy + 3% nuclear energy

Physics and Fate

Giant model: Inflowing envelope → (Inefficient convection) → Gravitational energy {X-ray luminosity; Thermal energy}



Insulating layer: electron degenerate matter

Nuclear burning → (Neutrino runaway) → Release heat

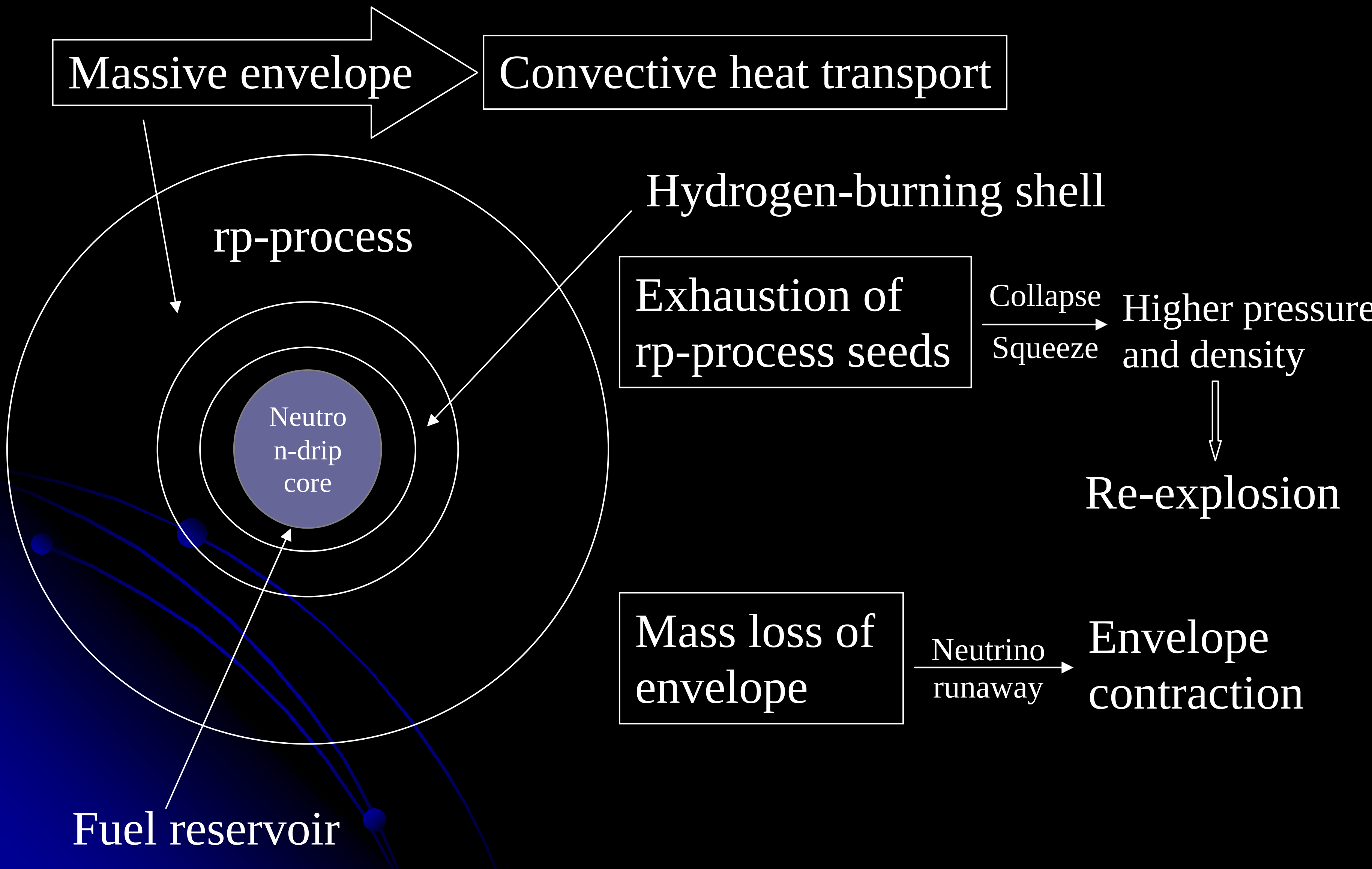
⇓

Instant and catastrophic contraction

⇓

NS + remnant disk
huge deposit thermal energy

Supergiant TZO model:



2. Low mass NS binary systems

Systems:
- <0.5 solar mass companion
- Ultra-short orbital period

Mechanisms:

Gravitational radiation → Orbital shrinkage

Tidal interaction →
- Expansion of radius
- Deposit of tidal energy

Orbital shrinkage + Expansion of radius ⇒ Components contact

Fate:
- Viscosity
- Frictional drag

⇒ Spiral-in and coalescence

Deposit of tidal energy + Spiral-in and coalescence → NS core accreting from disk

3. NS binaries in globular cluster (GC)

A. Encounter with single stars

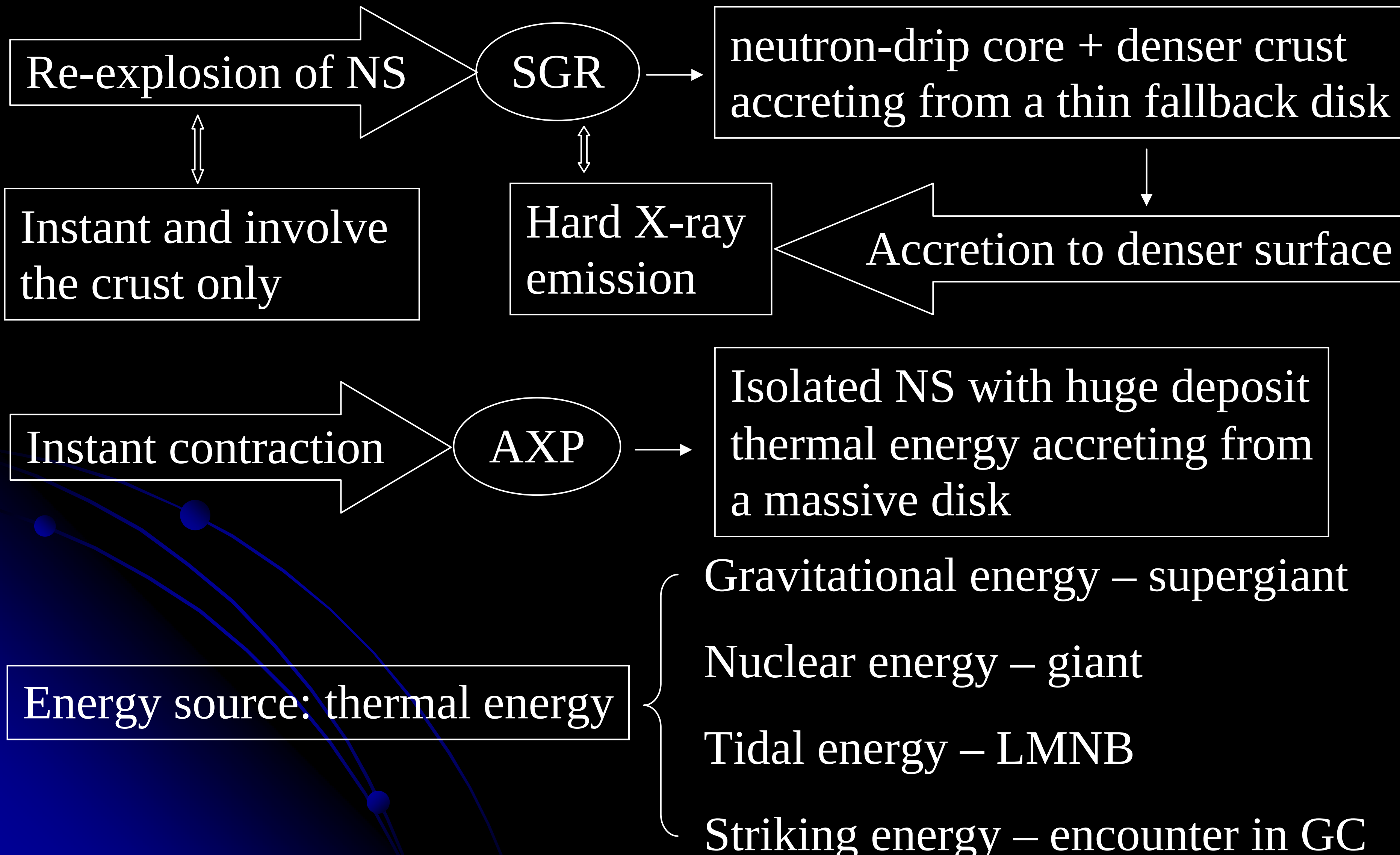
- Gravitational perturbation
- Catastrophic encounters → Rapid mass transfer

Direct collision → Instant and intense mass transfer / Deposit of striking energy → NS + disk

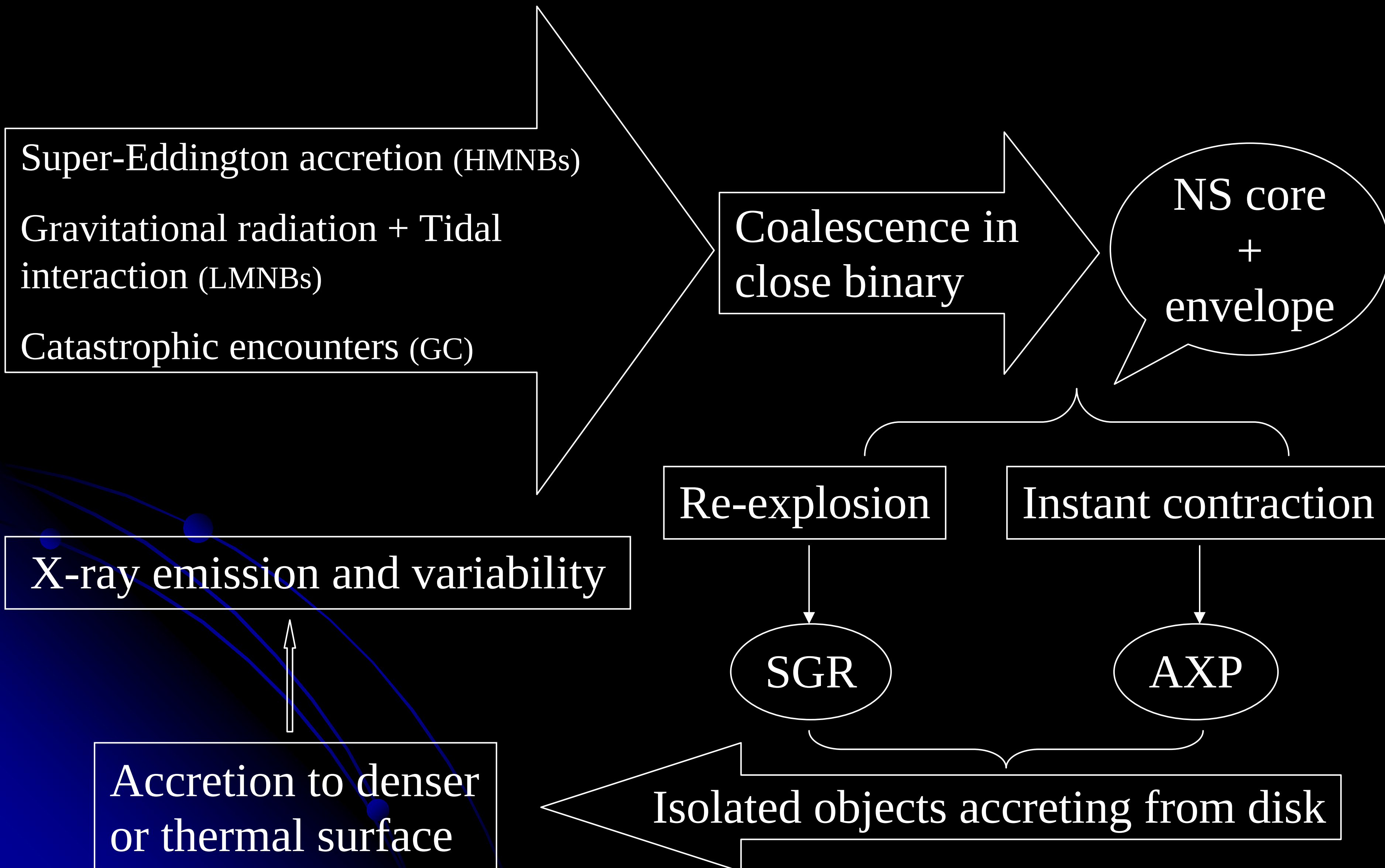
B. Re-collapse of newborn NS

Newborn NS → (Large asymmetric kick velocity) → Embedded in a main sequence star → TZO

Nature and nurture of SGR/AXP



IV. Summary


Super-Eddington accretion (HMNBs)
Gravitational radiation + Tidal interaction (LMNBs)
Catastrophic encounters (GC)
Coalescence in close binary
NS core + envelope
Re-explosion
Instant contraction
SGR
AXP
Isolated objects accreting from disk
Accretion to denser or thermal surface
X-ray emission and variability

V. Future prospects – searching for supports

- Theoretical supports: population synthesis for numerical calculation?
- Observations supports?

Thanks for your attention!
Comments are welcome!