Transients following white dwarfs merger

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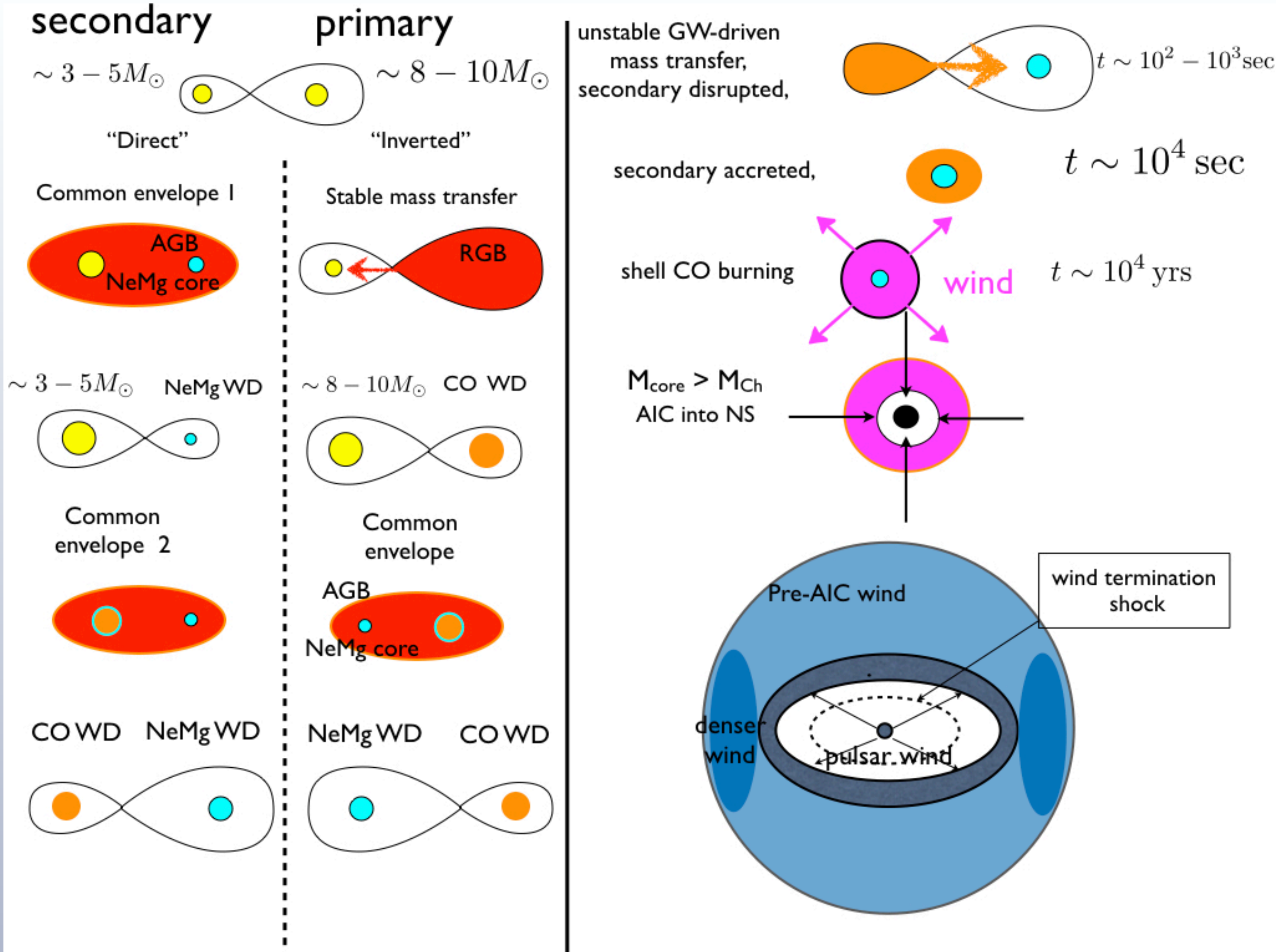
AT2018cow

- rise-time of ≤ 3 days & peak luminosity ~ 4×10^{44} erg s^{-1}
- small ejecta mass -> brighter and shorter SNe
  - light fast ejecta becomes transparent quickly
  - internal energy is not wasted on expansion
- The X-ray emission of initial power ~ 10^{43} erg s^{-1} had an extra component at t ≤ 15 days, peaking at ~ 40 keV
- Evolution of line profiles indicate anisotropy
- Similar optical and X-ray luminosities
- There is a clear change of properties of the emission at ~ 20 days, H & He lines appear
- There is an indication of the rising IR component at t ≥ 30 days
- There is bright radio emission t ≥ 80 day



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Stable mass transfer
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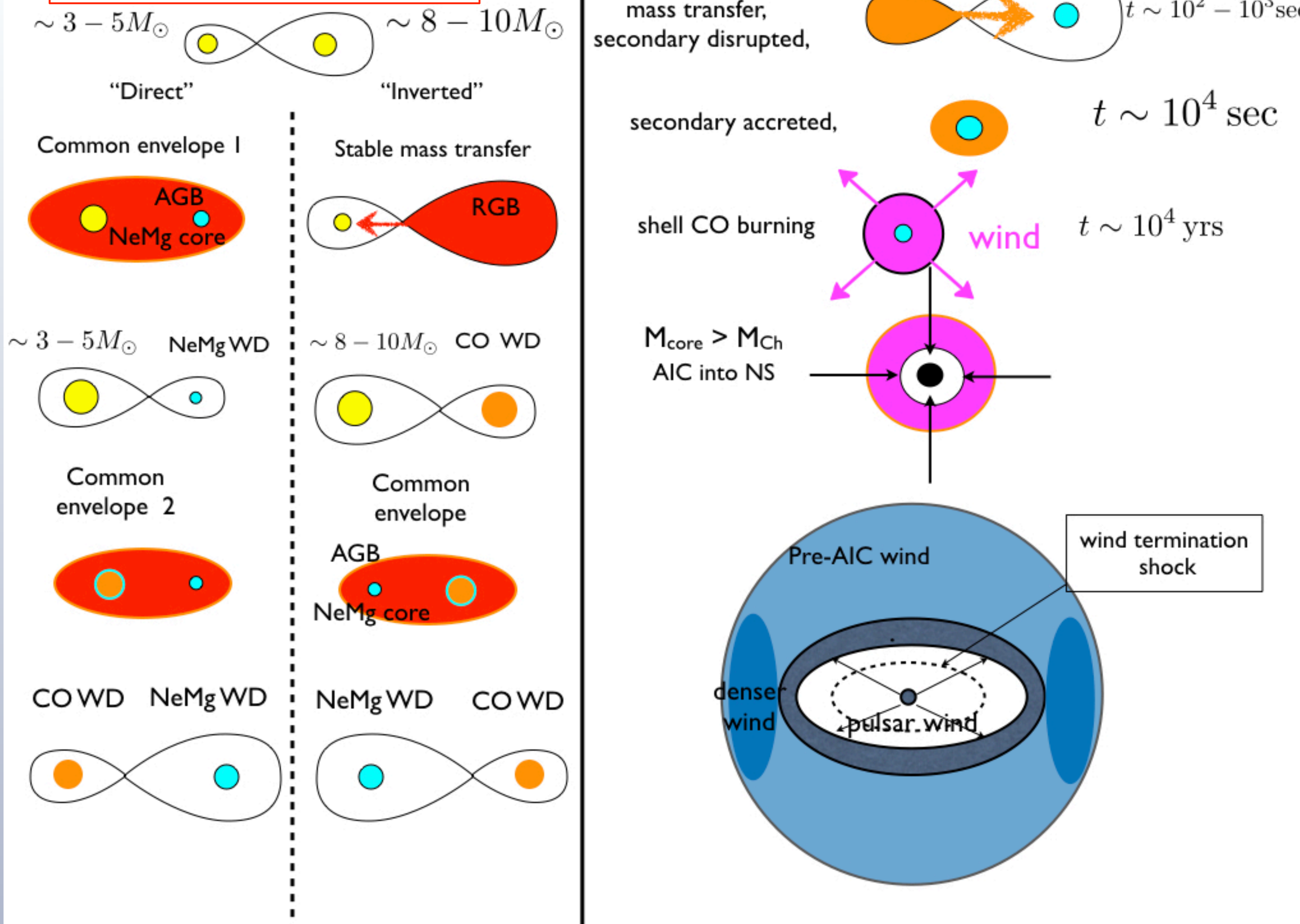
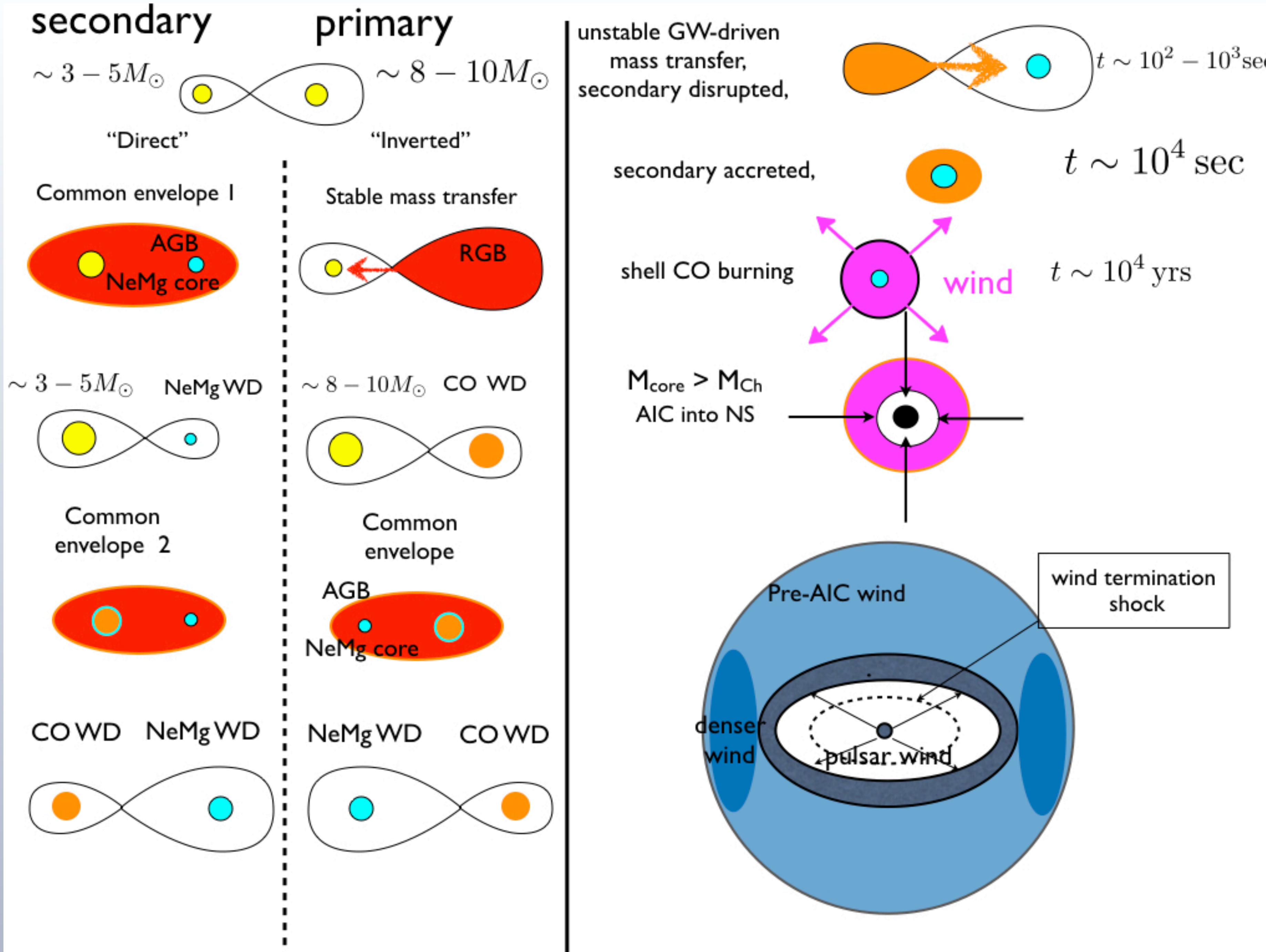
$t \sim 10^4$ yrs
$M_{core} > M_{Ch}$
AIC into NS
Pre-AIC wind
wind termination shock
denser wind
pulsar wind

S

- Initial binary ~ 5+8 M_{Sun}

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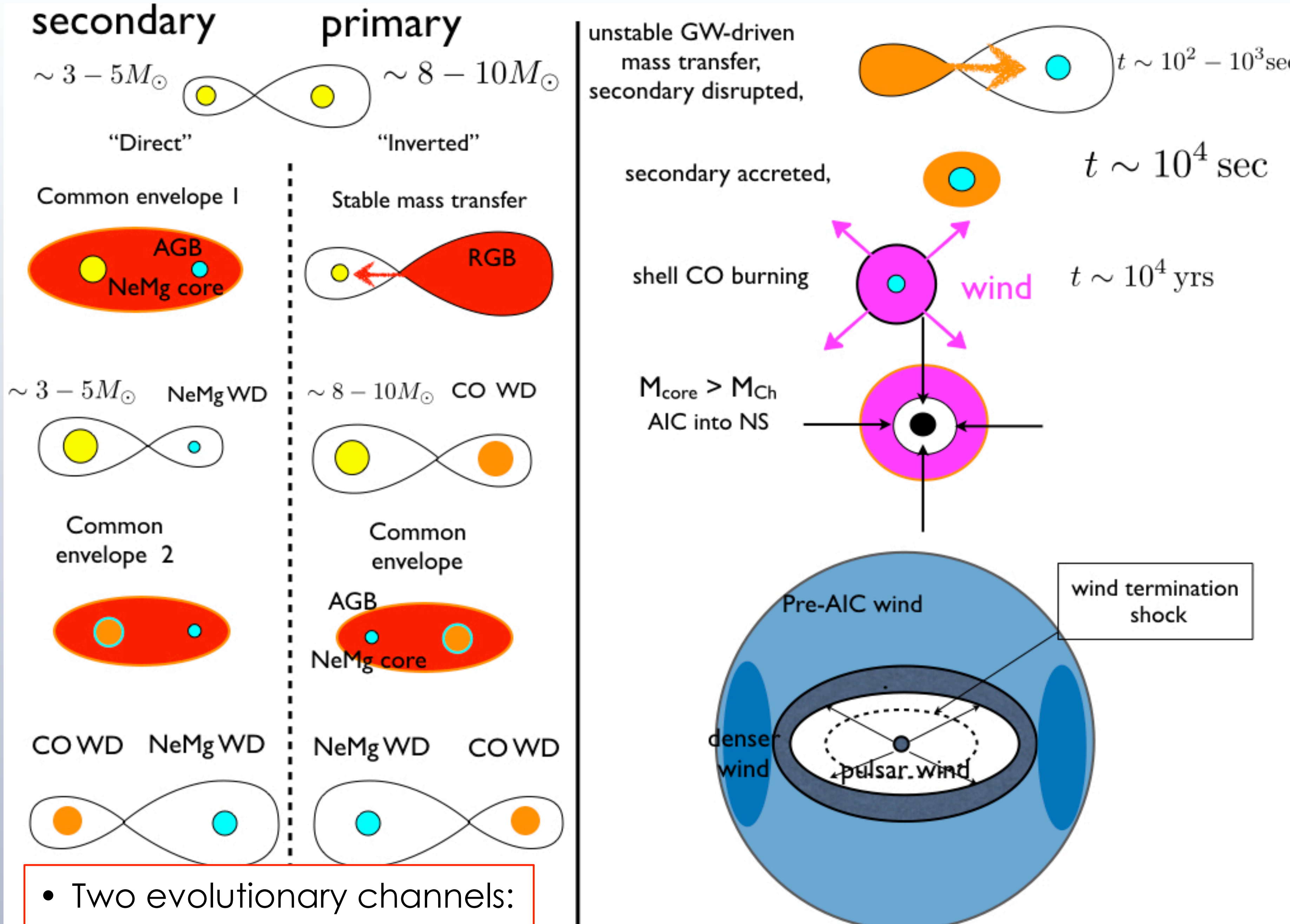
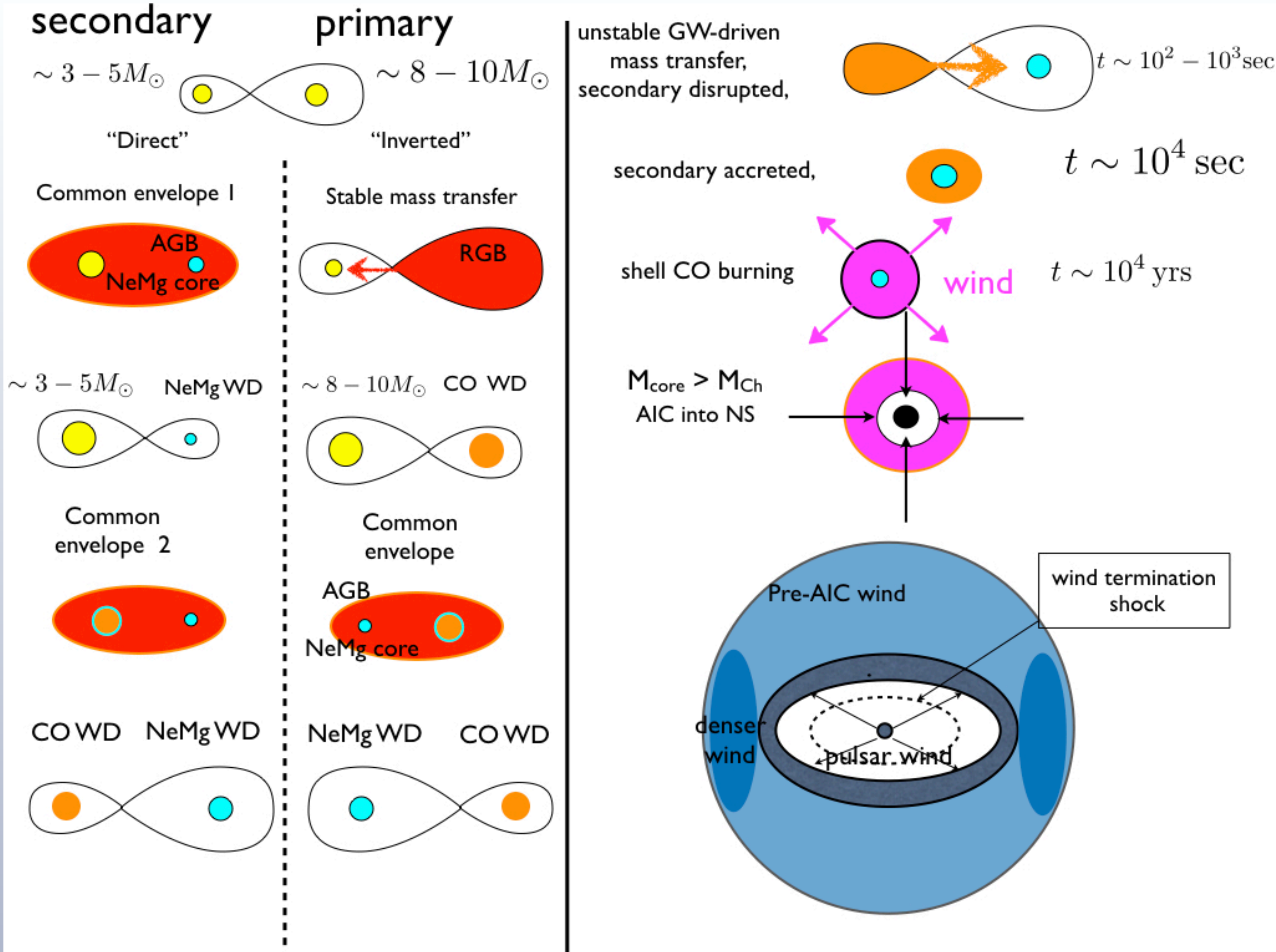


- Two evolutionary channels: ONeMg + CO WDs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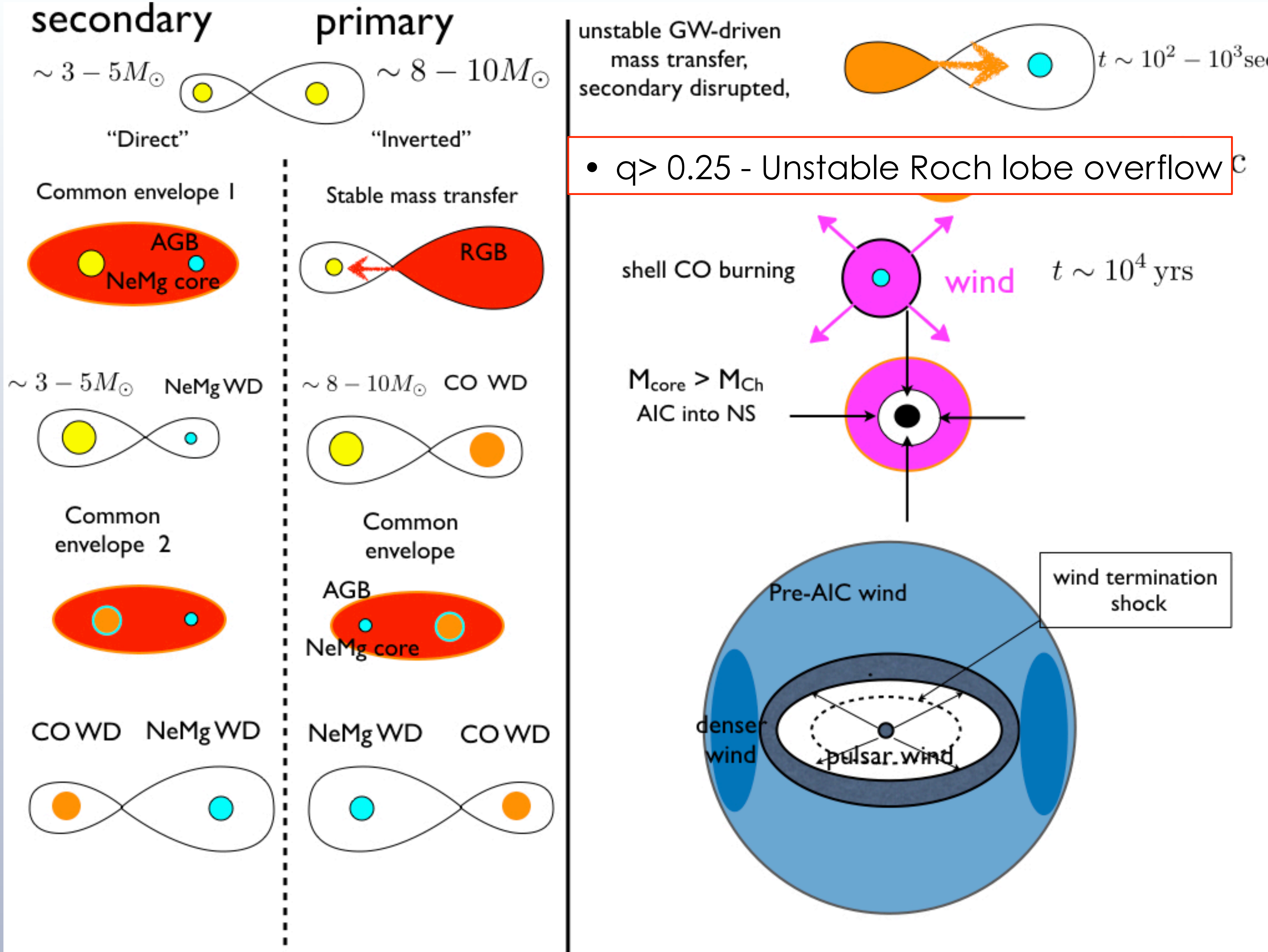
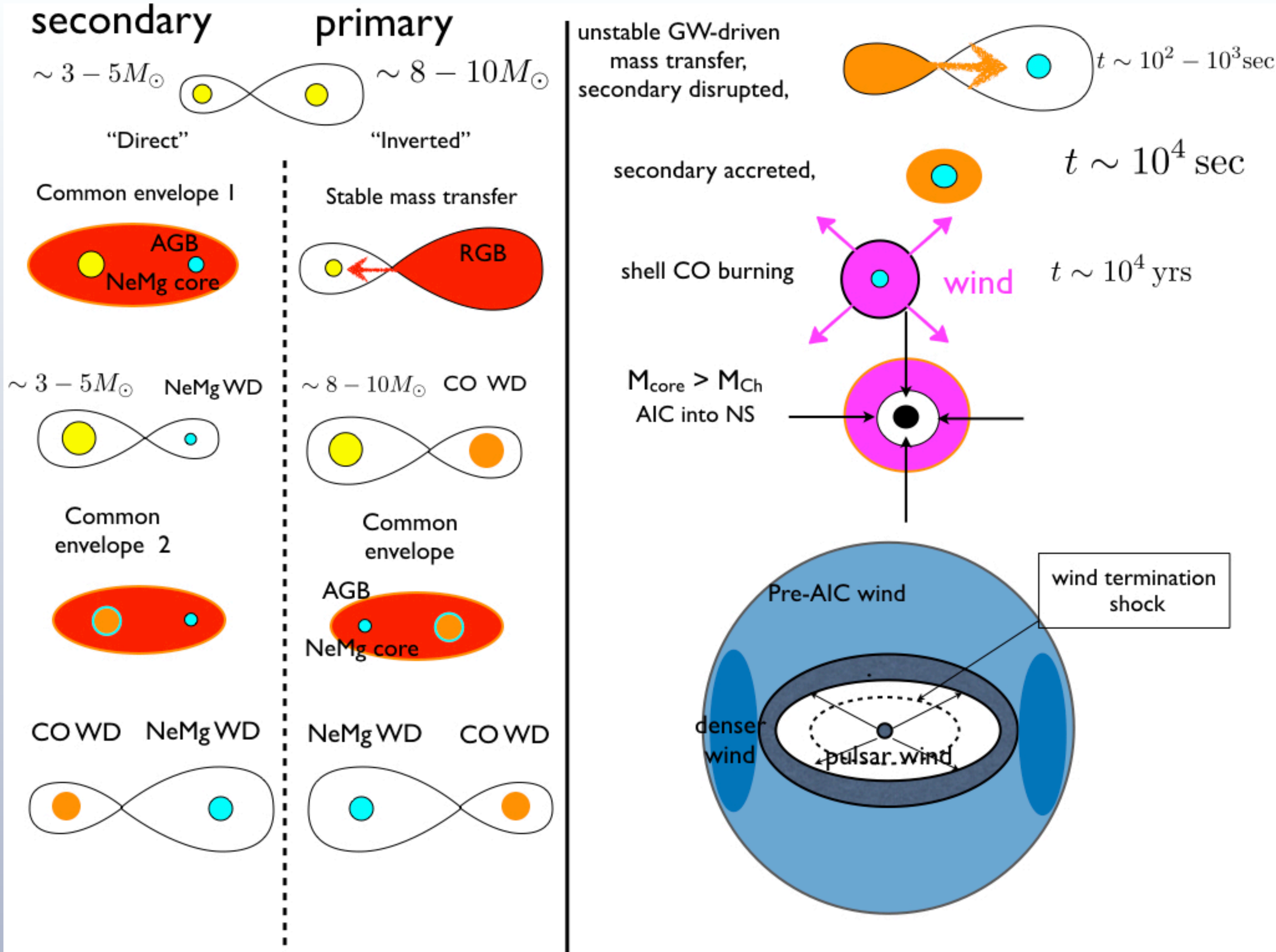


• q> 0.25 - Unstable Roch lobe overflow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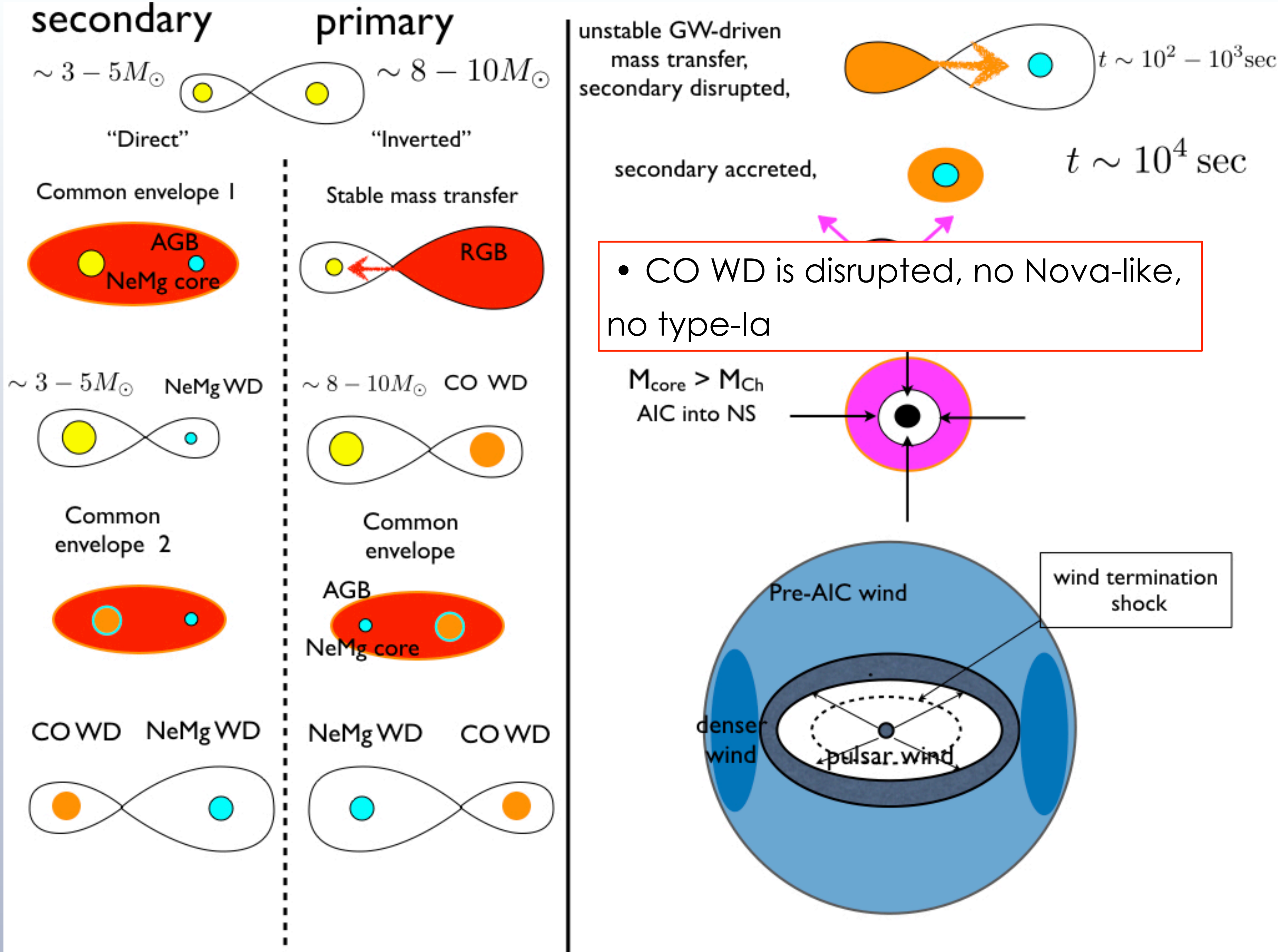
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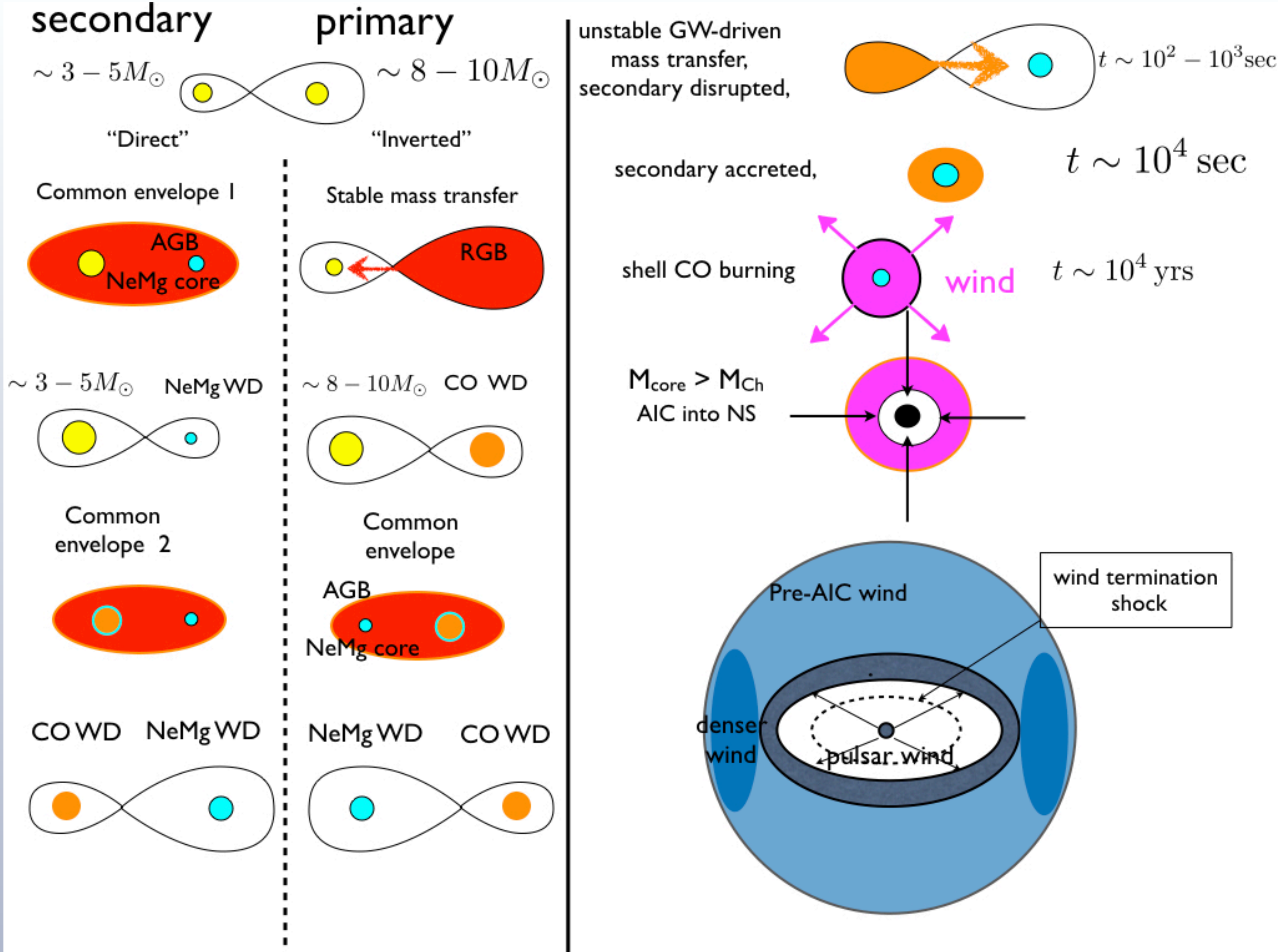
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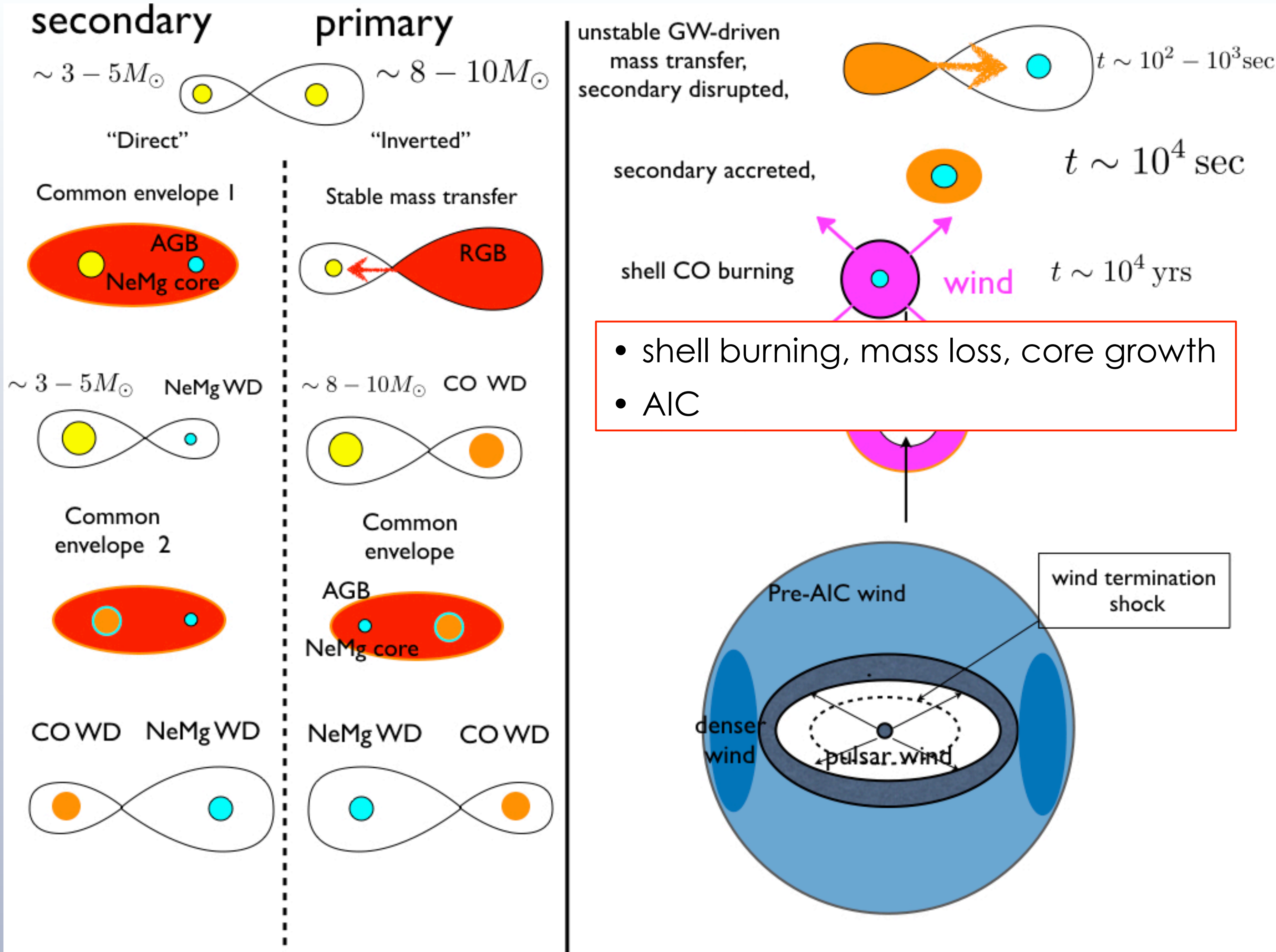
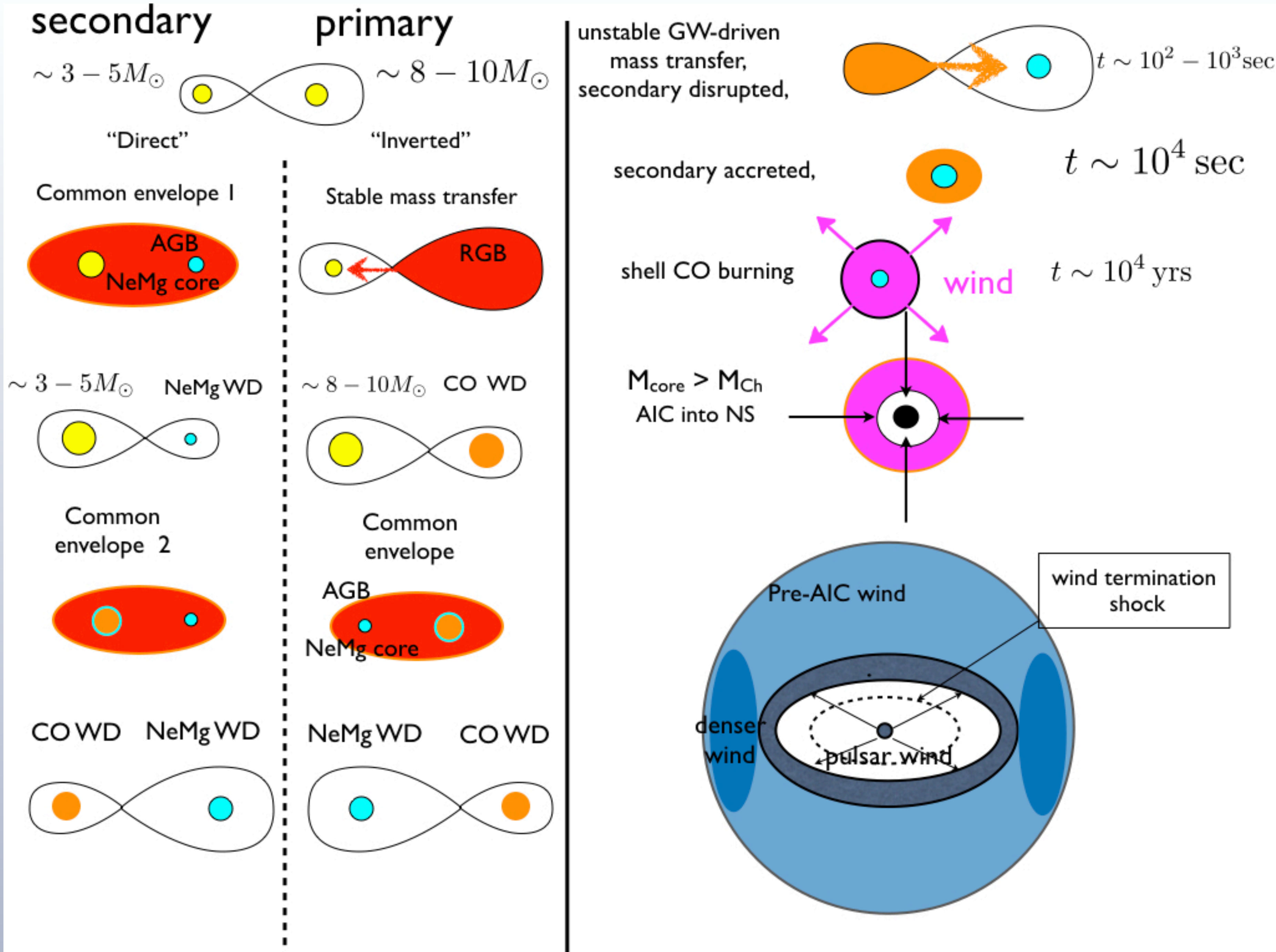


- shell burning, mass loss, core growth
- AIC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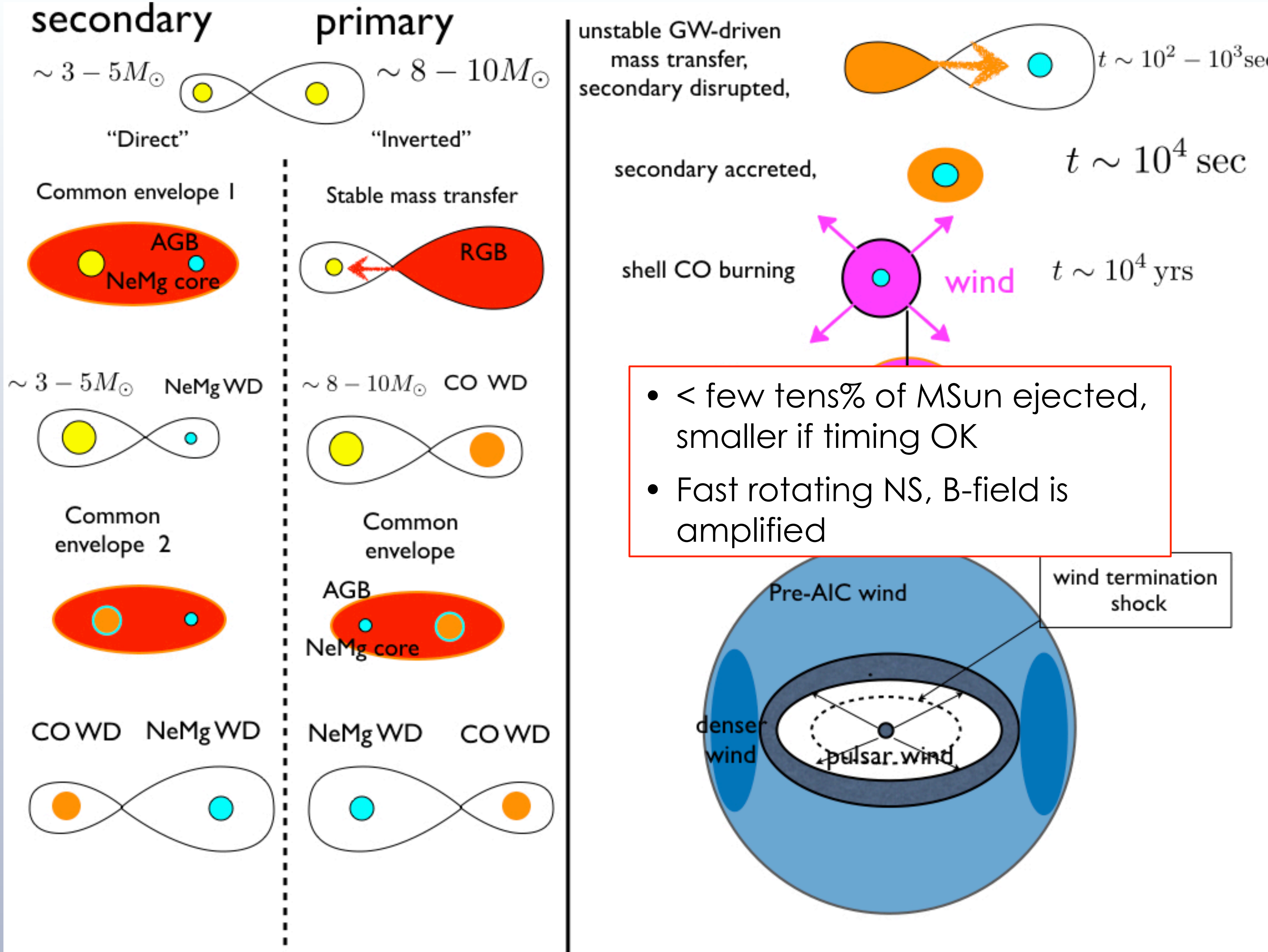
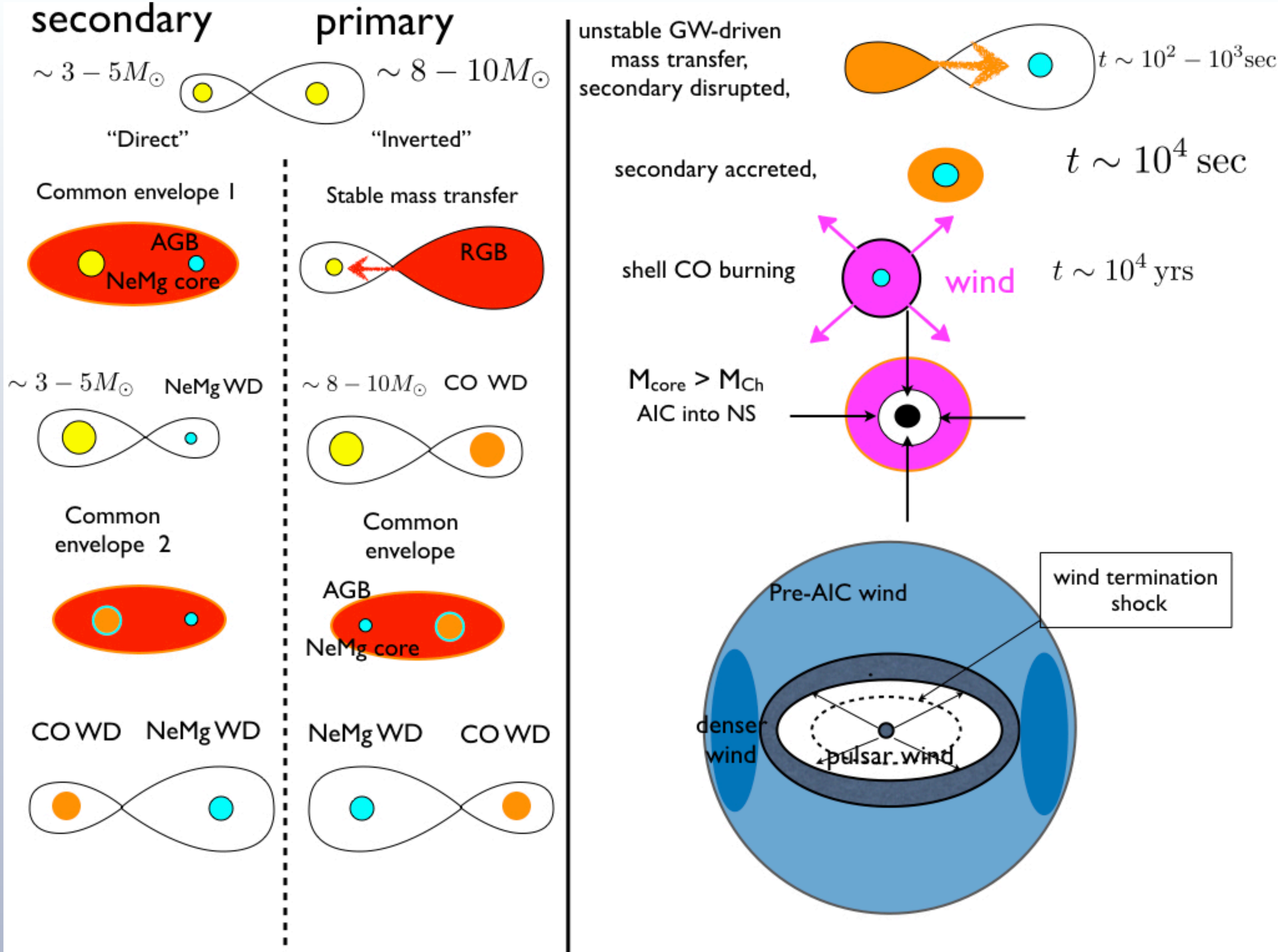


- < few tens% of MSun ejected, smaller if timing OK
- Fast rotating NS, B-field is amplified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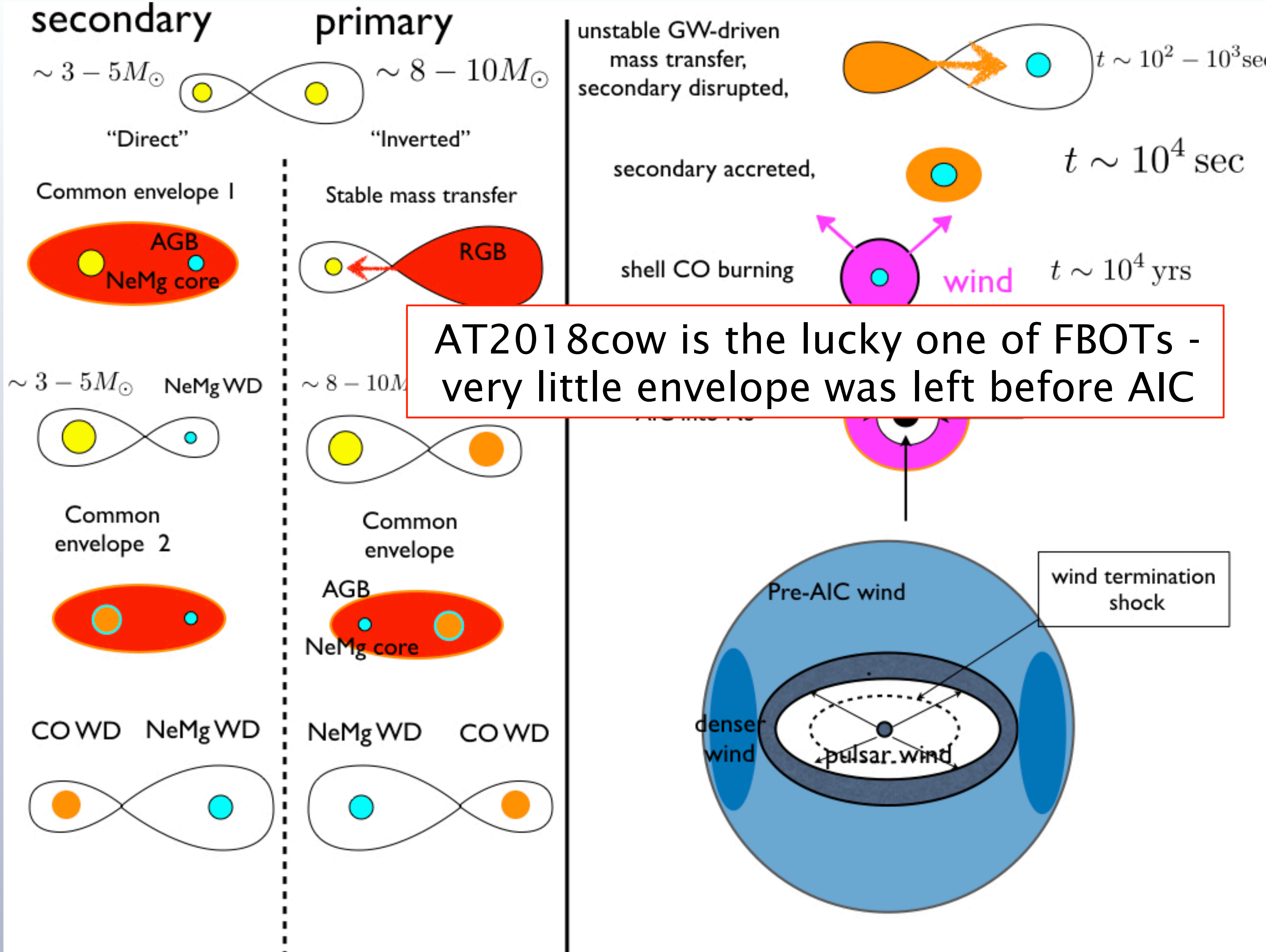
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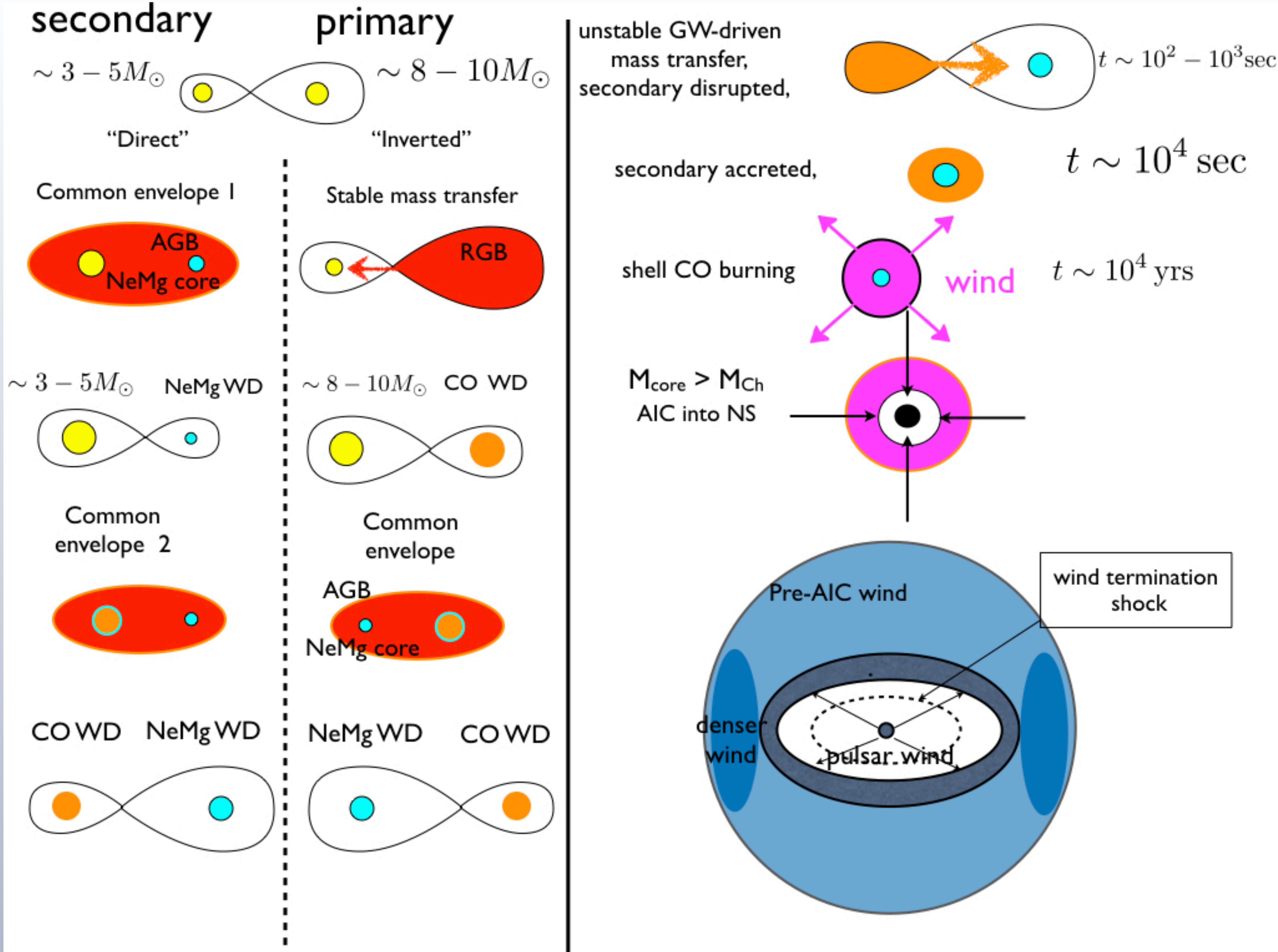
AT2018cow is the lucky one of FBOTs - very little envelope was left before AIC
Pre-AIC wind
wind termination shock
denser wind
pulsar wind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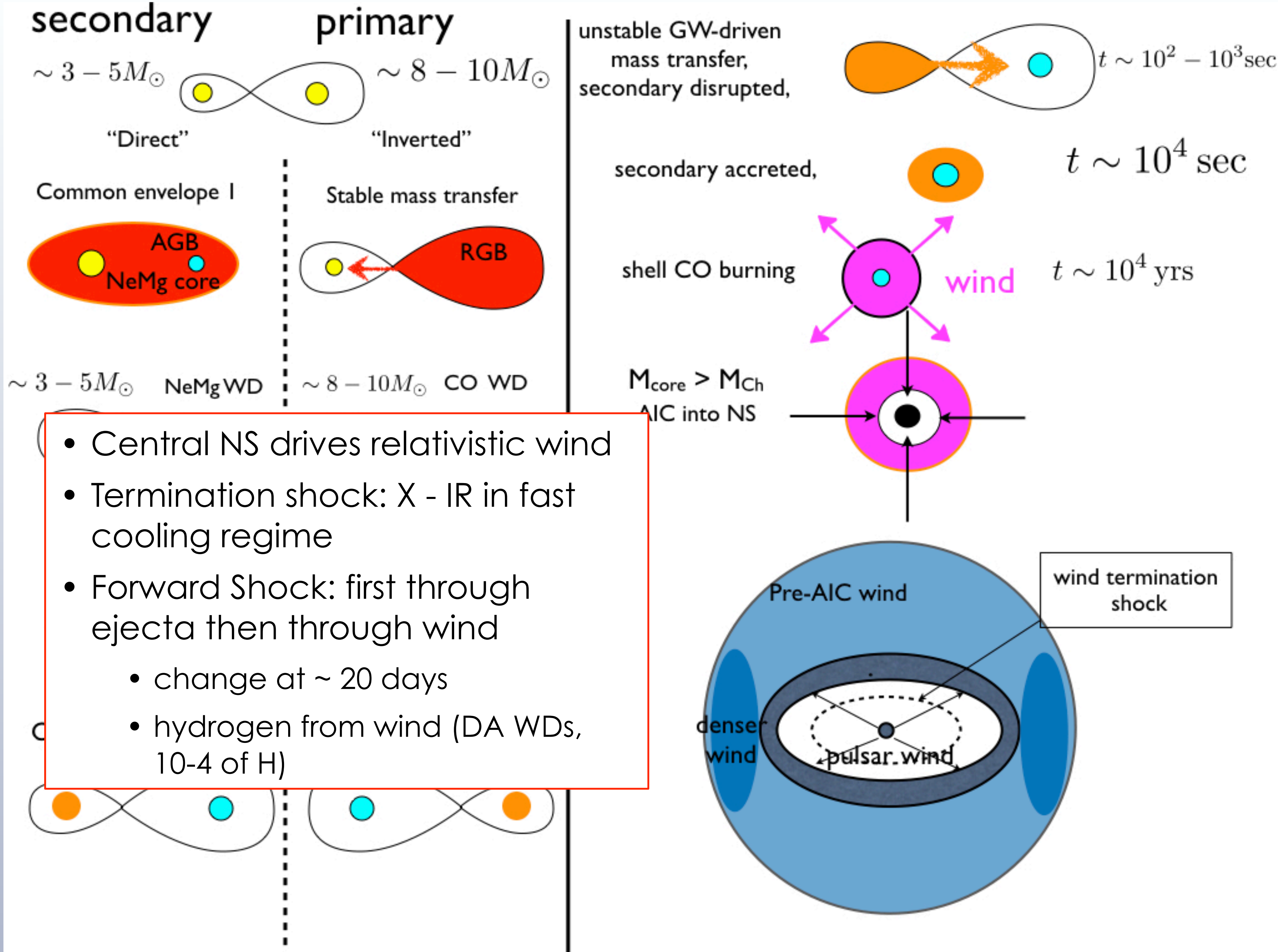
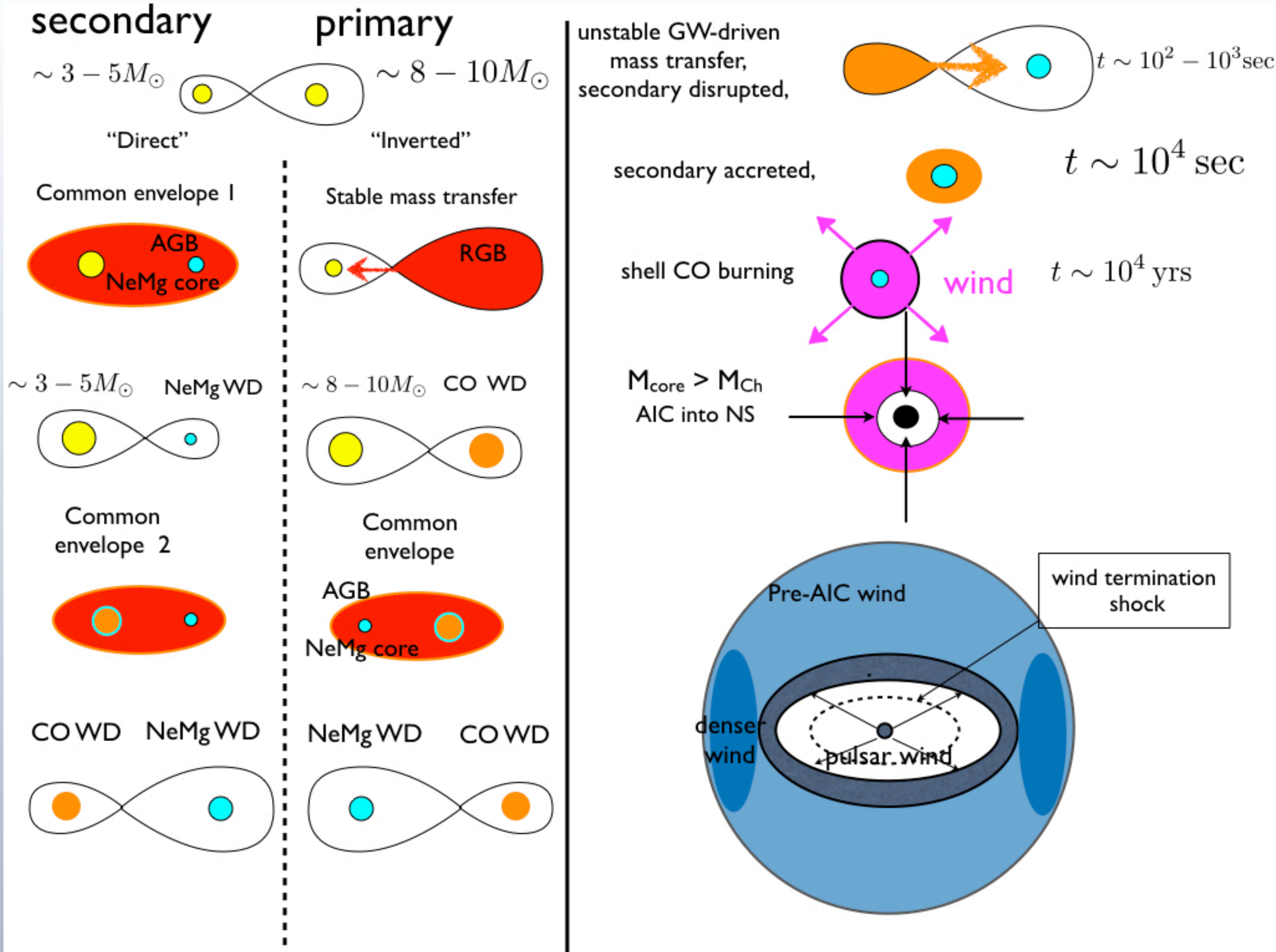


- Central NS drives relativistic wind
- Termination shock: X - IR in fast cooling regime
- Forward Shock: first through ejecta then through wind
  - change at ~ 20 days
  - hydrogen from wind (DA WDs, 10-4 of H)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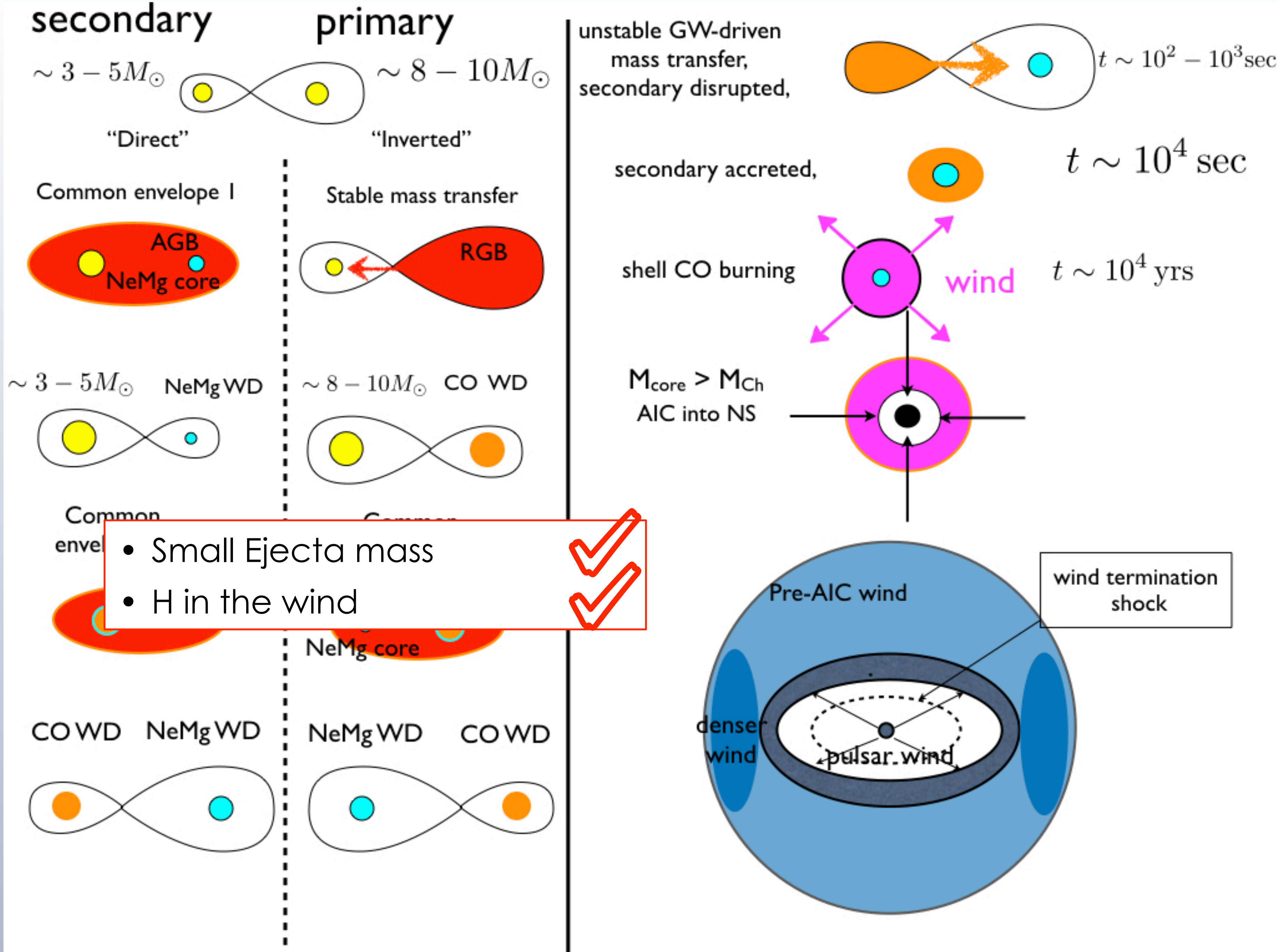

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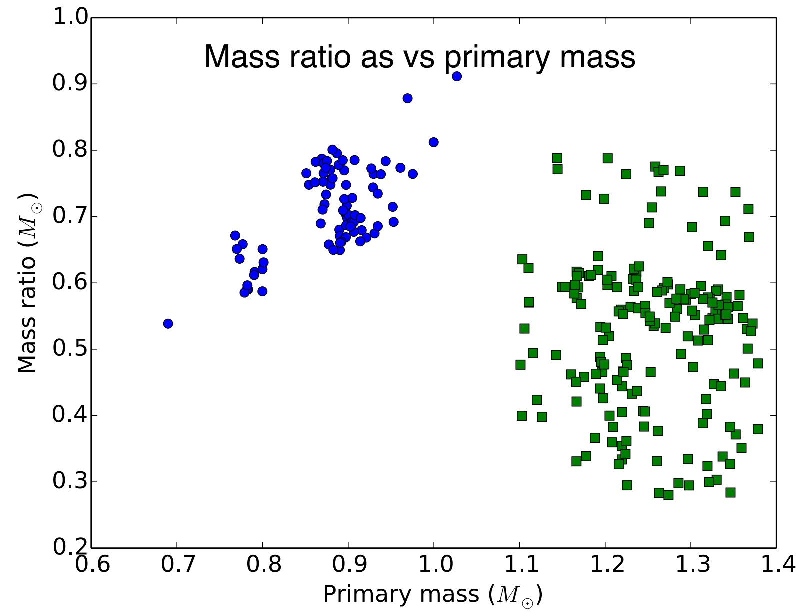
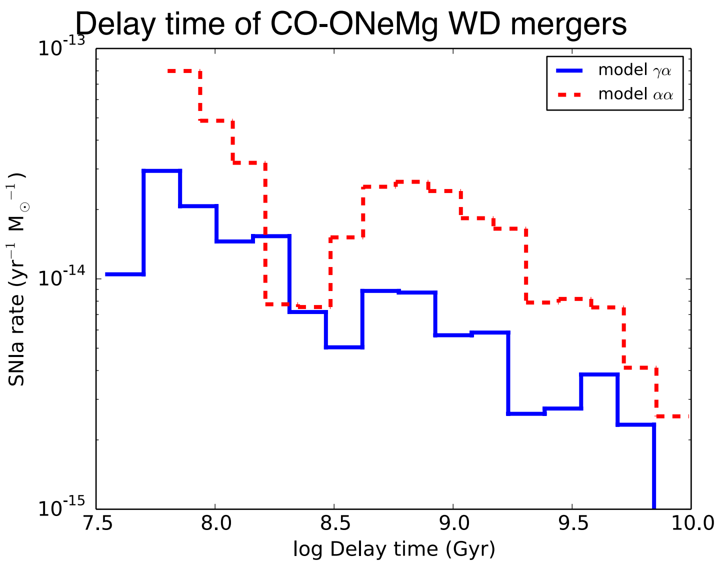
shock
denser
wind
pulsar wind
• Small Ejecta mass
• H in the wind

Population synthesis

- Initial binary ~ 5+8 M_{Sun}
- Two distinct evolutionary channel (direct and inverted)
- CO-ONeMg WD mergers rate ($q > 0.25$) ~ $5 \cdot 10^{-5}$ per Solar mass, consistent with the lower limit of the FBOT rate.
- Host galaxies: merger delays ~ 100 Myrs





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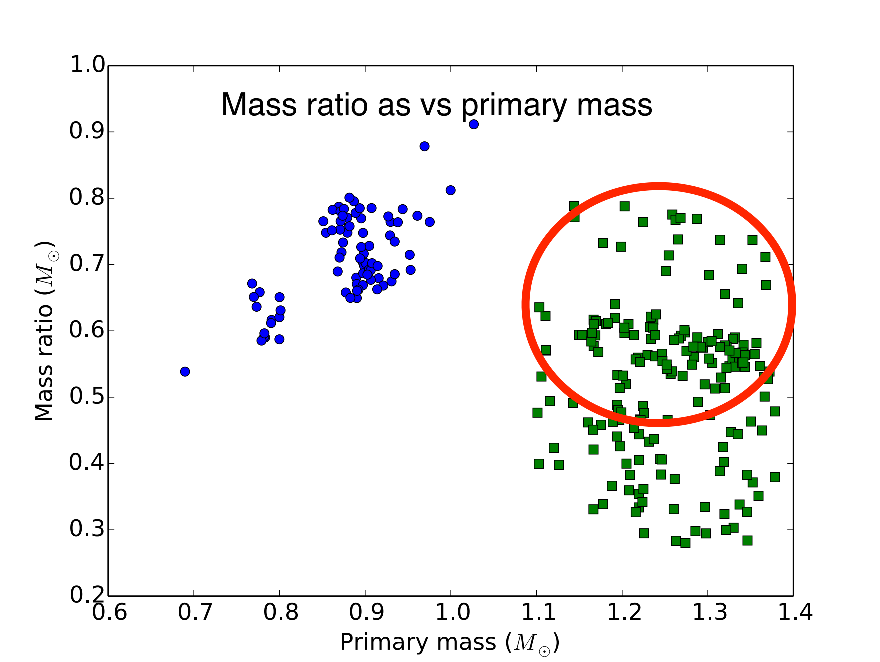

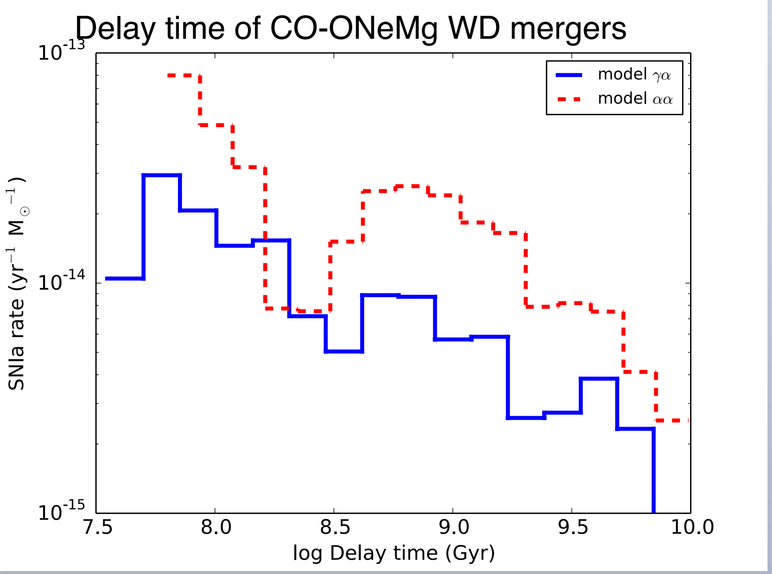

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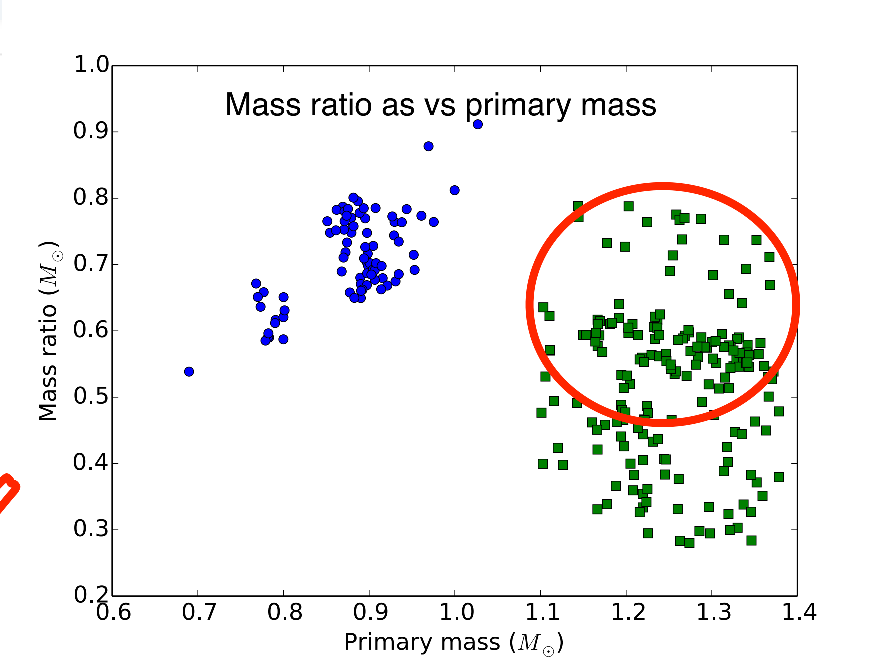

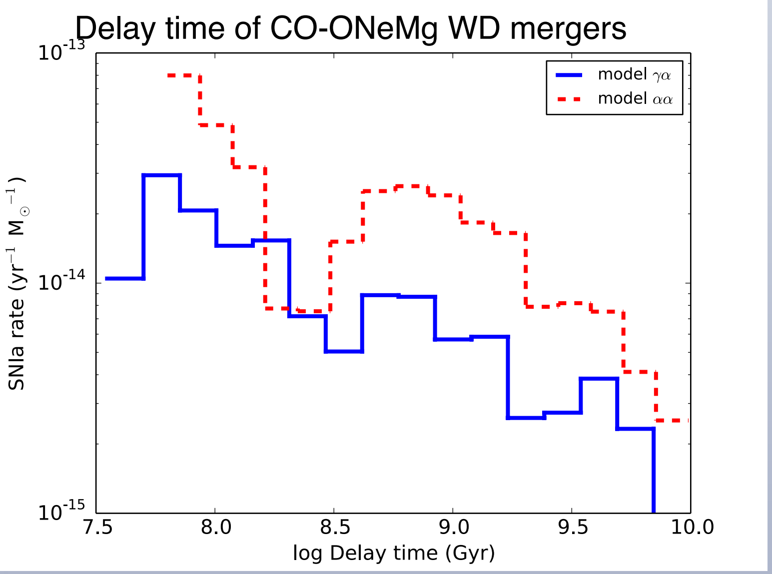

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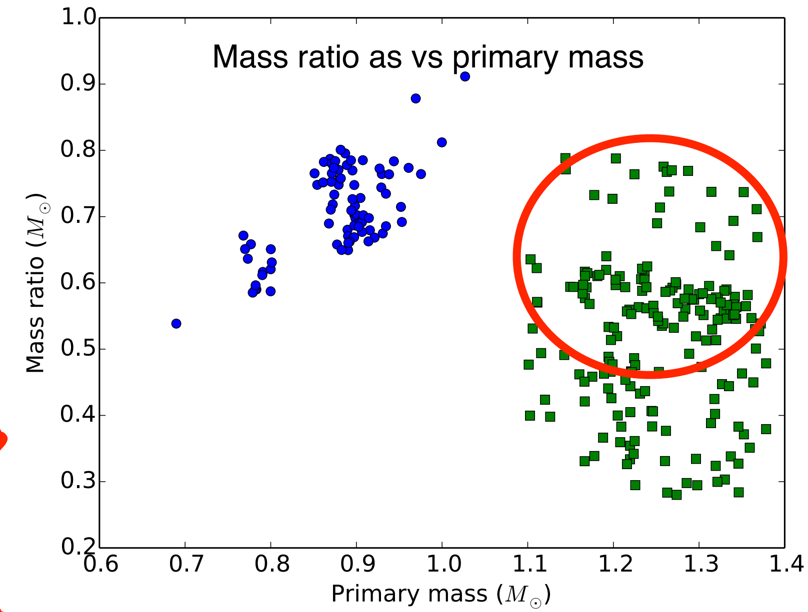

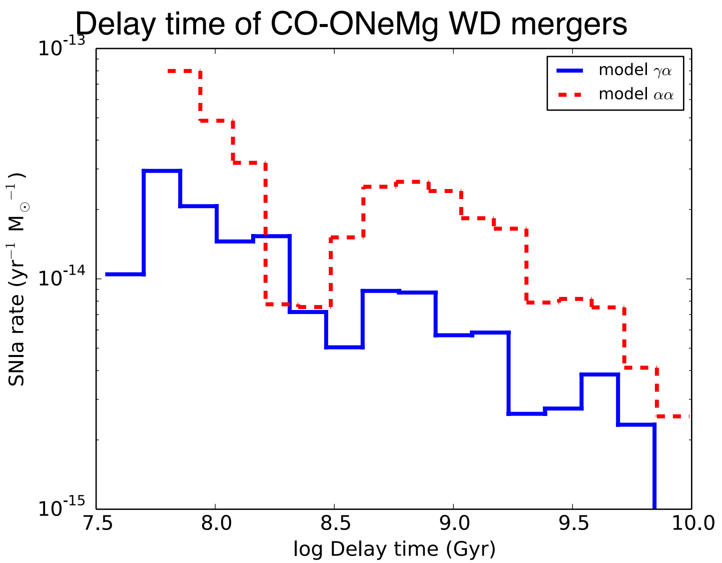

Wind and ejecta

- Minimal bounce-off mass: 10^{-2} MSun
- Ejecta velocity from proto-NS of 30 km: ~ 0.25 c
- Optical transparency: few days
- Ejecta-wind interaction: slow down in ~ 30 days
- Blackbody radius $R_{bb} \sim 8 \times 10^{14}$ cm - wind-driven cavity expands to these scales on time scales of few days

- Similar X-ray and optical luminosities: expected in the fast cooling

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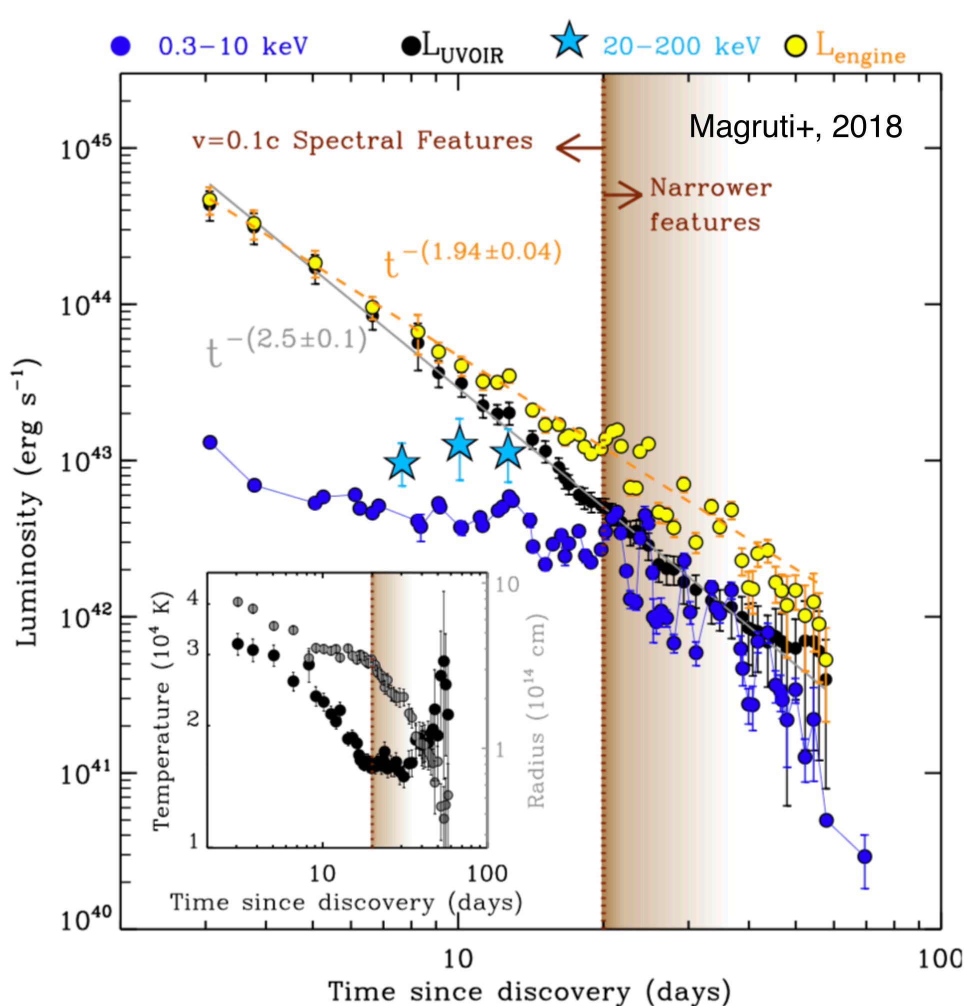

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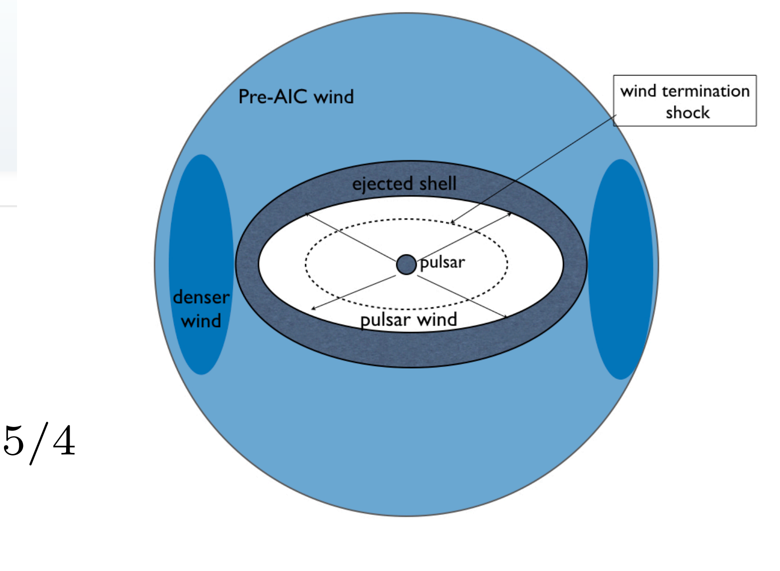


- PWN dynamics inside ejecta

$$\frac{L_w}{4\pi R^2 c} = \rho_{ej}\left(\partial_t R - \frac{R}{t}\right)^2$$

$$\rho_{ej} = \frac{3}{4\pi}\frac{M_{ej}}{(V_{ej,0}t_{ej})^3}$$

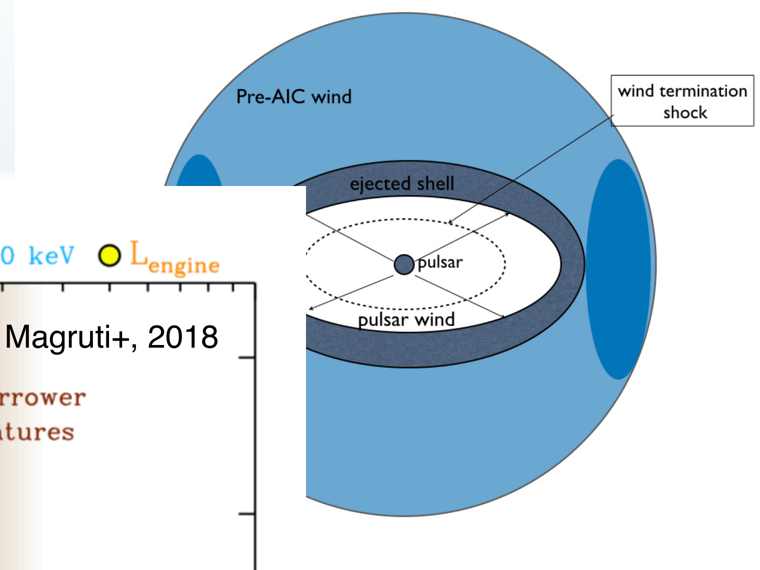
$$R_{PWN} \propto t^{5/4}$$

- Breaks out into the wind when ejecta slows down, ~ a month
- **Optical emission: forward shock from the NS-driven wind**
- Radiation dominated forward shock

$$T_{FS} \approx \left(\frac{cL_{w,0}M_{ej}}{\sigma_{SB}^2 V_{ej,0}^3 t^5}\right)^{1/8} = 4\times 10^4 t_d^{-5/8}\mathrm{K}$$

- Anisotropy: $L_w \propto \sin^2\theta$

NS wind-ejecta



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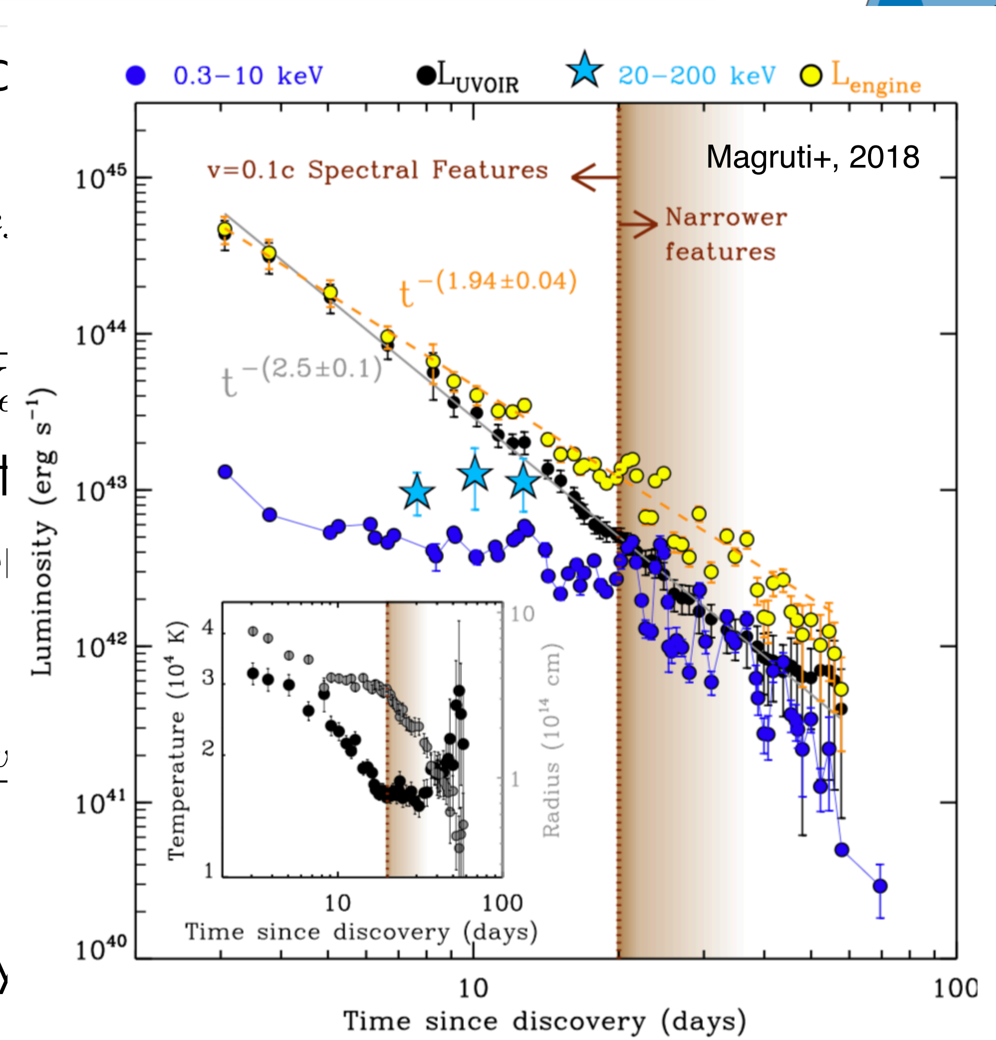
$$\rho_{ej} = \frac{3}{4\pi} \frac{}{(V_{\epsilon}}$$



- Breaks out ... vn, ~ a month
- **Optical e... riven wind**
- Radiation

$$T_{FS} \approx \left(\frac{cL_w}{\sigma_{SB}^2} \right.$$

- Anisotropy

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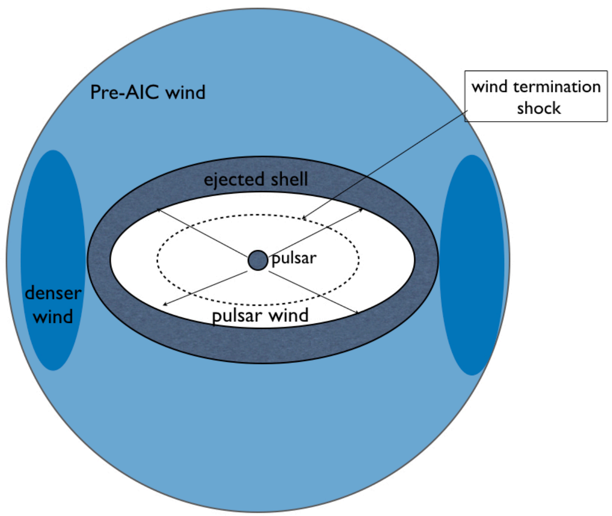

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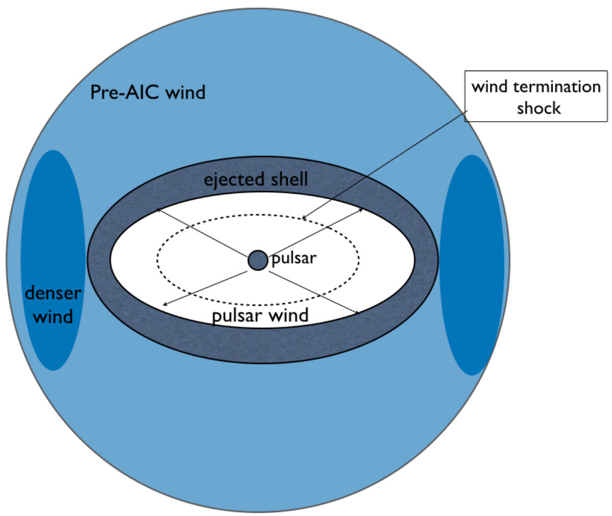

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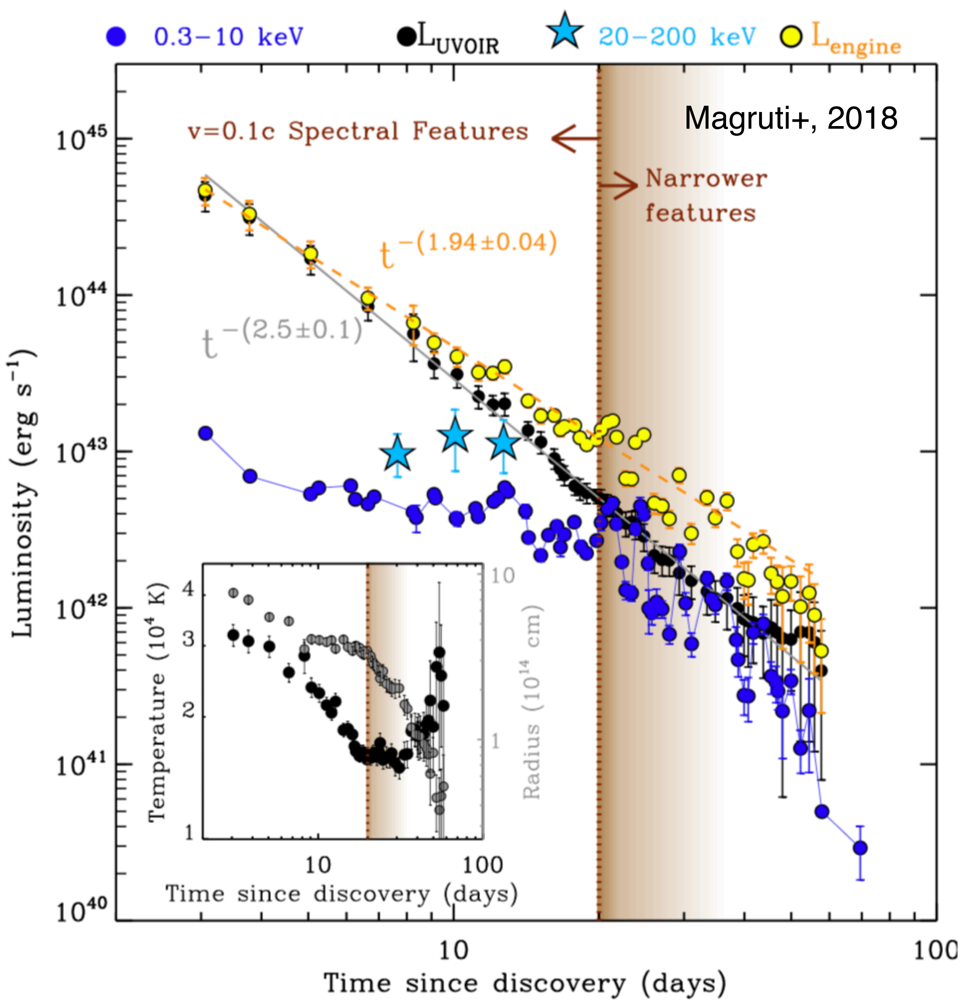

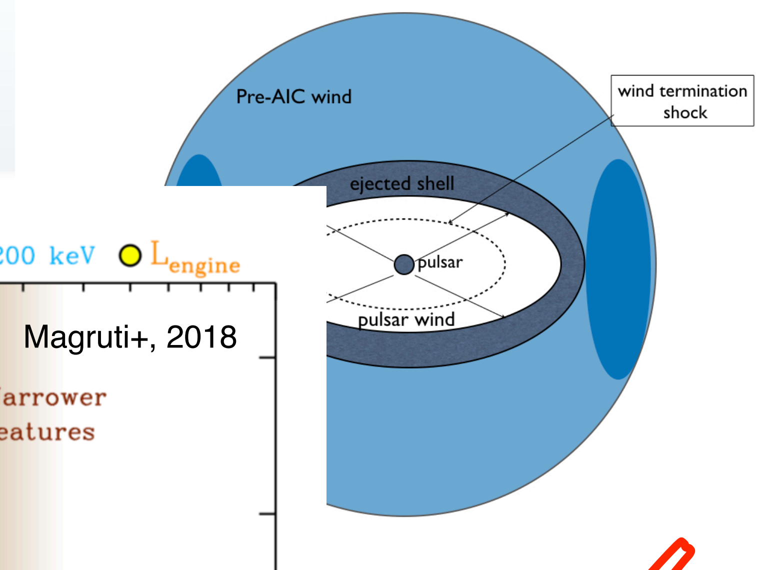

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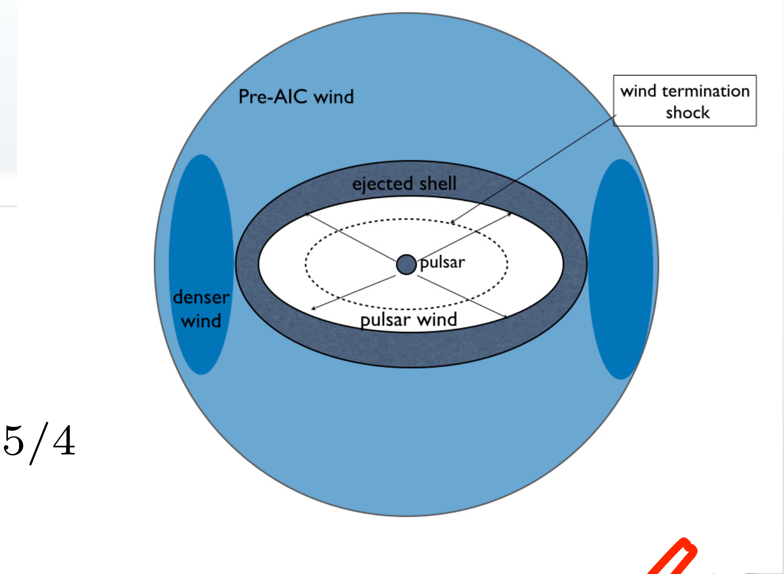

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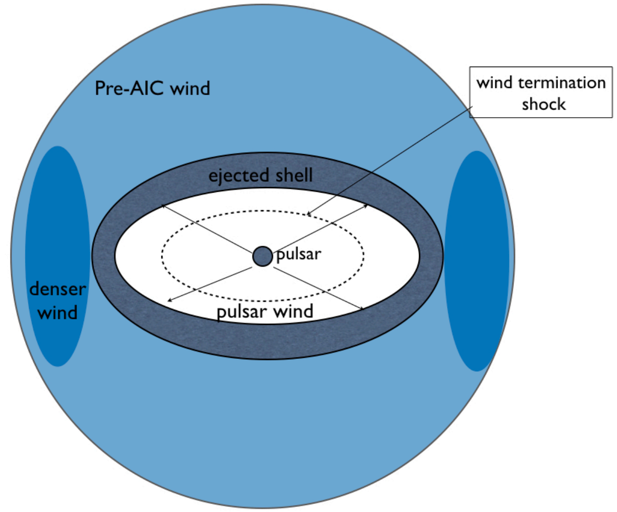

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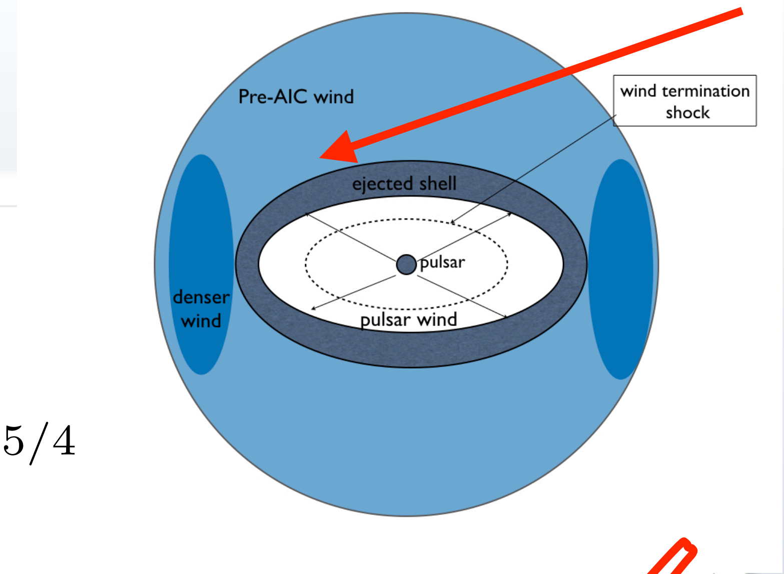

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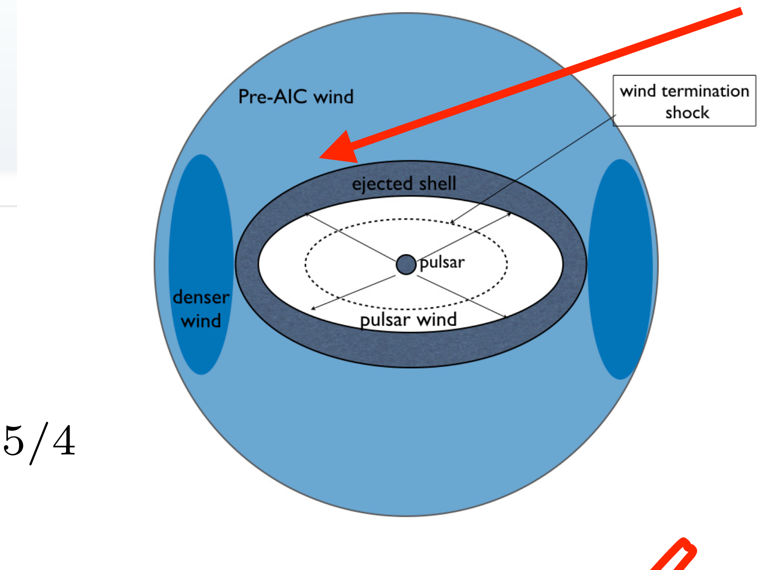

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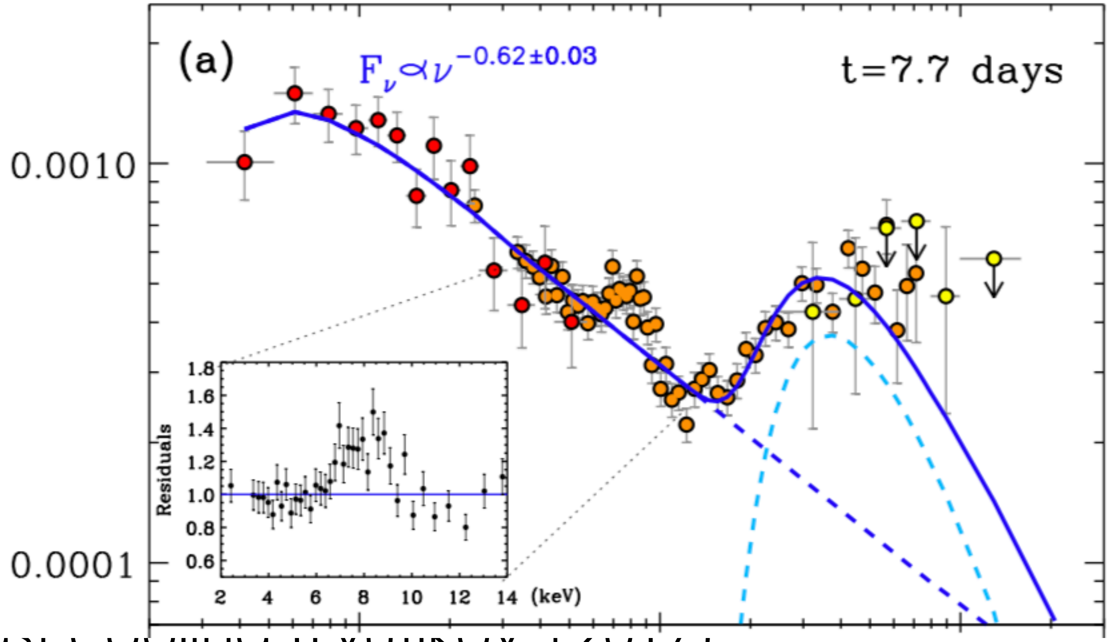

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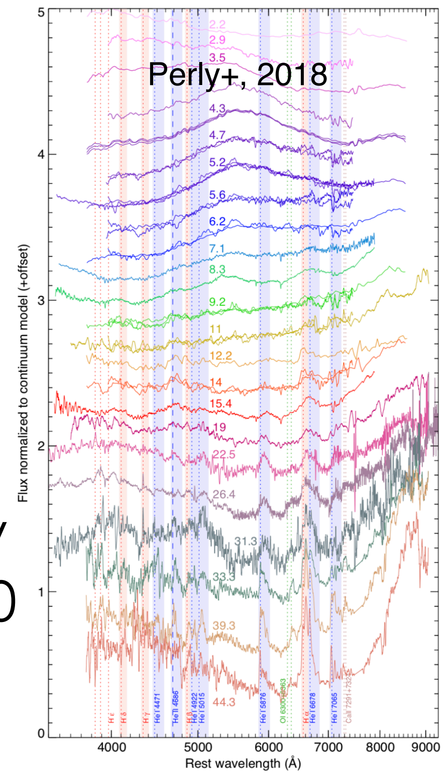

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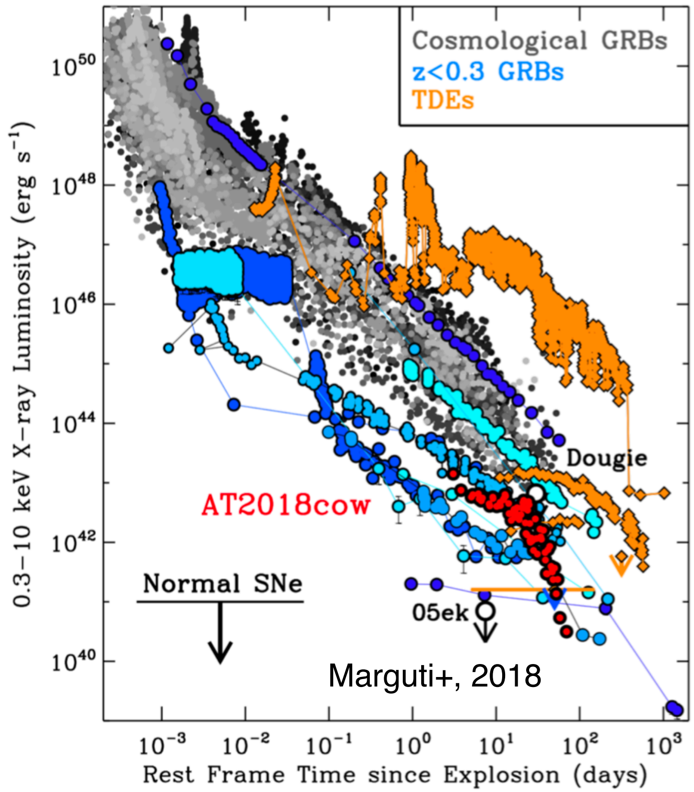

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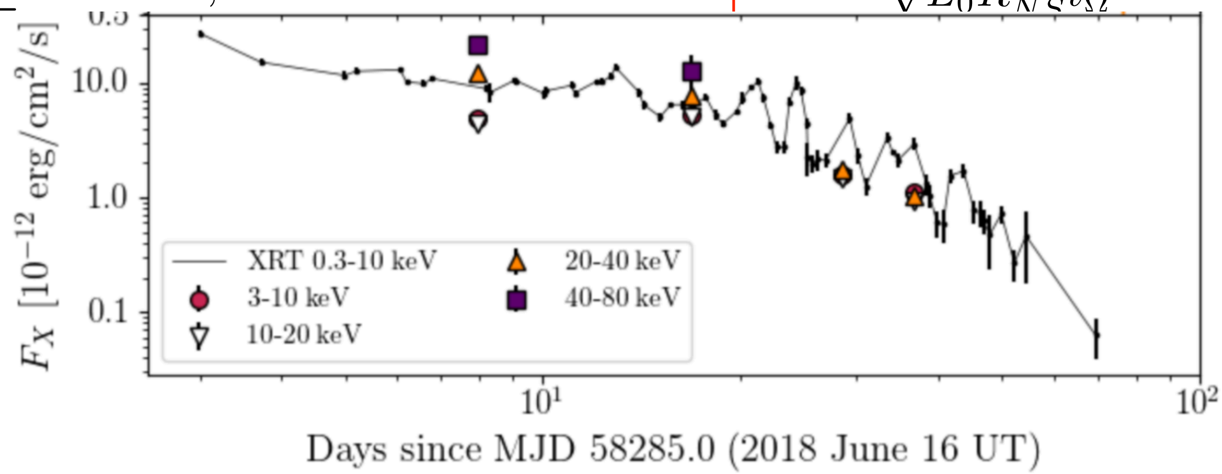

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IR

- Ejecta contributes a lot to free-free absorption

$$\tau_{ff,ej} = 2 \times 10^{20} \nu_{GHz}^{-4.2} T_4^{-2.7} t_d^{-10}$$

- Thin for

$$\nu_{GHz} > 7 \times 10^4 t_d^{-2.4}$$

- High frequencies, 341 and 230 GHz, are transparent all along, while lower frequency, 34 GHz traces expanding τ = 1 surface.
- In radio and far IR ejecta thick until the shock breakout from the ejecta, ~ month

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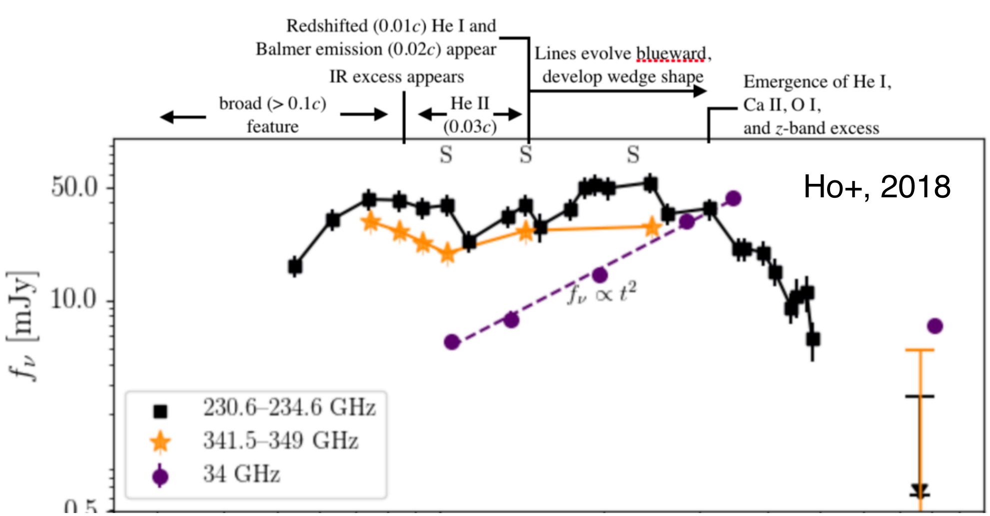

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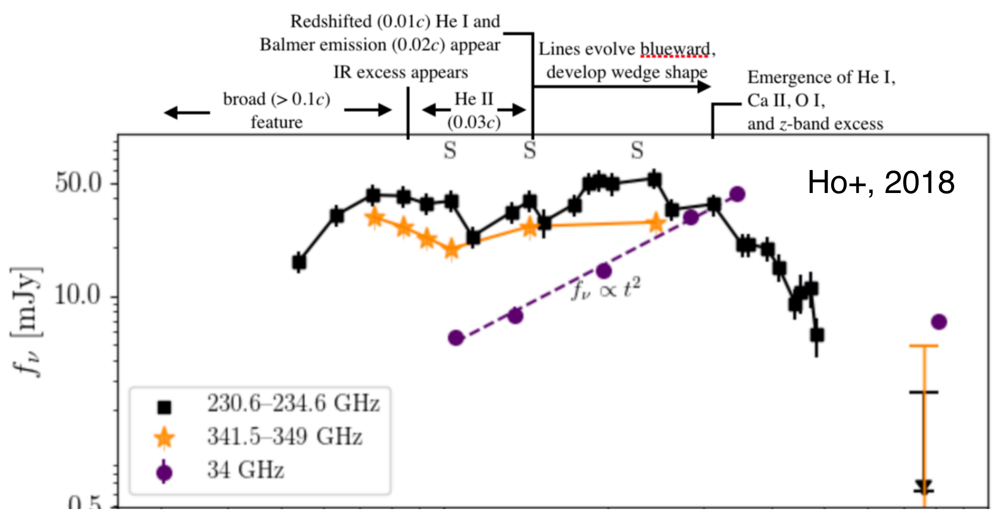

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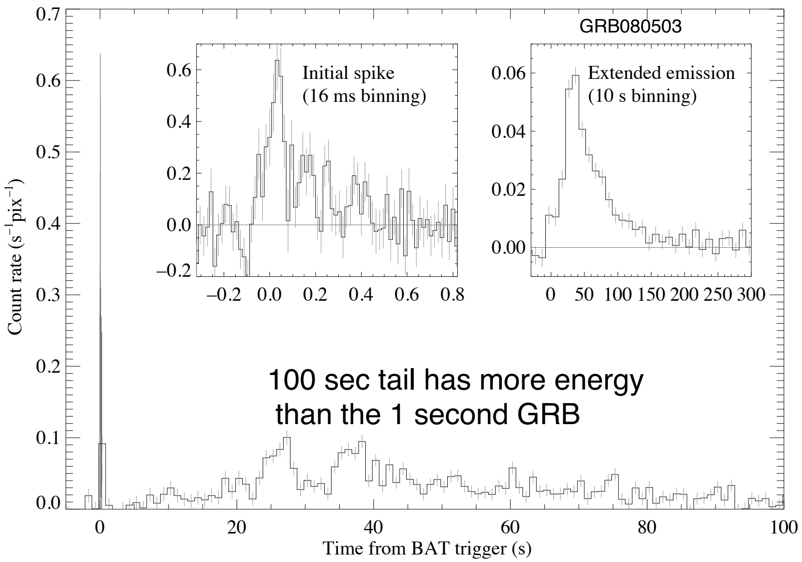
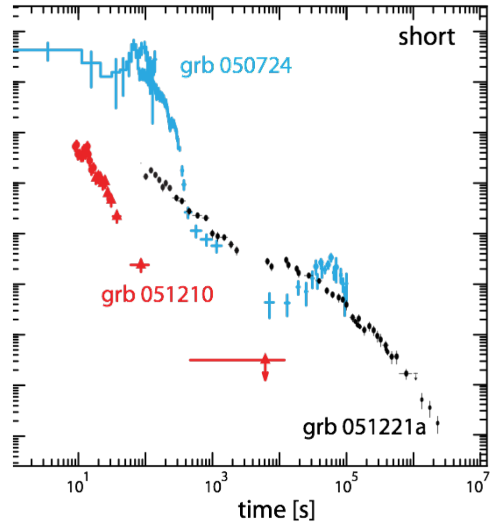
Connection to Short GRBs: there are problems with NS+NS scenario, not seen in GW170817





Active stage of NS-NS merger takes 10-100 msec, then collapse into BH. Very little mass is ejected.

Many short GRBs have long 100 sec tails, energetically comparable/dominant to the prompt spike.

Many GRBs have late time flares, 10^5 sec

Would be good to have an active object remaining, but $M_{tot} > 2.5\ M_{Sun}$

AIC of merged WDs: bounce-off may produce a short GRB (Lyutikov & Toonen 2017)

Scenario

- Initial binary ~ 5+8 M_{Sun}
- 1.3 M_{Sun} ONeMg WD + q> 0.25 another WD
- Unstable Roch lobe overflow - CO WD is disrupted on few orbital time scales - tens of seconds
- high accretion rate - material not expelled in Nova-like events
- C-detonation does not happen - avoids SN Ia
- Shell burning, wind mass-loss
- ONeMG reaches super-Ch. mass, goes AIC
  - < few tens% of MSun ejected, smaller if timing OK
  - Newly formed fast rotating NS, B-field is amplified (not too extreme)
- Central power NS drives relativistic wind
- Termination shock: X - IR in fast cooling regime
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AT2018cow is the lucky one of FBOTs - very little envelope was left

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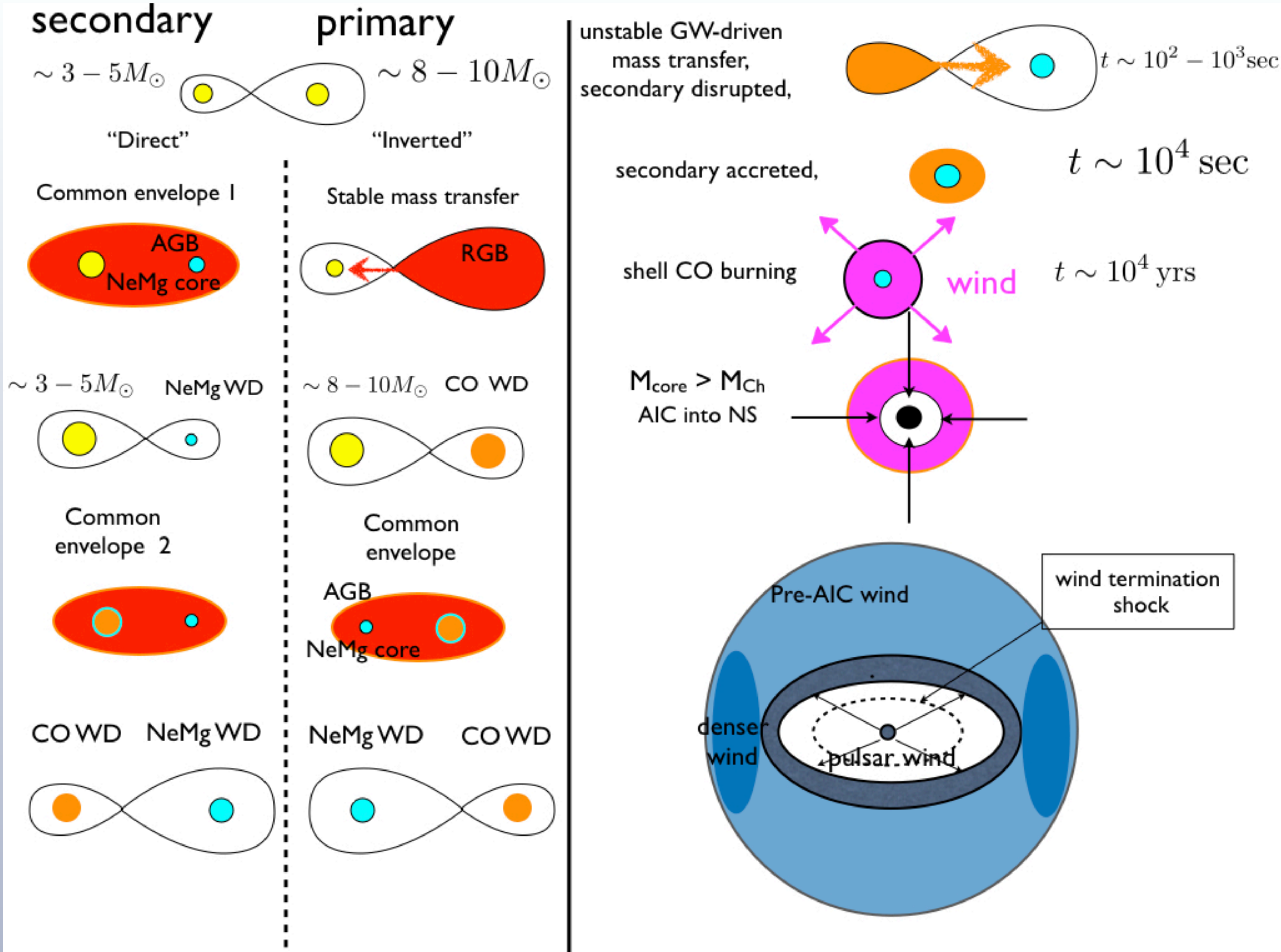
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"Direct"
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Common envelope I
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unstable GW-driven mass transfer, secondary disrupted,
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shell CO burning
wind
$t \sim 10^4$ yrs
$M_{core} > M_{Ch}$
AIC into NS
Pre-AIC wind
wind termination shock
denser wind
pulsar wind

Lyutikov & Nelson, in prep

WD-WD mergers and AIC as short GRB engine

- Rates:
  - WD-WD mergers ~ 1 per 100-1000 yr per Galaxy, ~ SN Ia (and other SN)
  - Short GRBs ~ 1 per 10^5 yr per Galaxy, so 0.1-1% needed
  - Super-Ch. mass: 10% of total mergers, so 1-10% of Super-Ch. mergers needed
- So, we need a narrow, very special channel to produce a GRB from WD-WD mergers