Gamma-Ray Binaries

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Overall information

- Binary systems that emit gamma-rays
  - Through outbursts (novae)
  - More continuously (Pulsar slowdown)
- Mid-2000 – New instruments
  - Fermi LAT (GeV) - Satellite
  - H.E.S.S - High Energy Spectroscopic System
- In Milky Way: ~101 +89/-52 objects [Estimated]

HE, 0.1–100 GeV VHE: >100 GeV

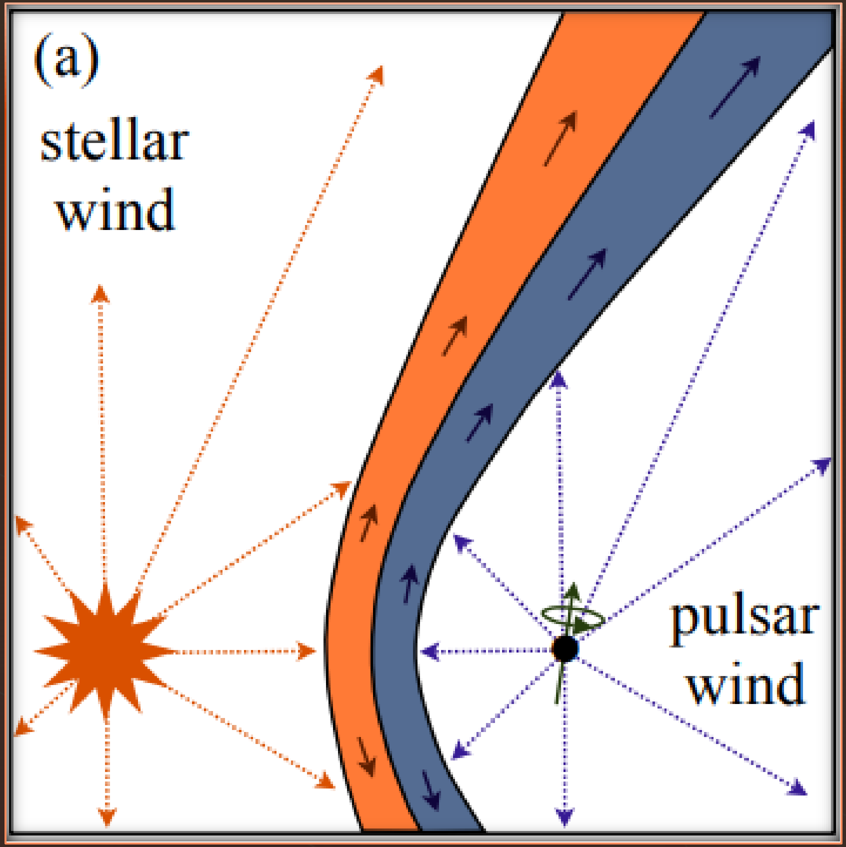
Table 1
Binary systems identified with sources of variable HE or VHE gamma-ray emission.

Name	Binary components		P_{orb} (d)	HE	VHE	Refs.[a]
(high-mass) gamma-ray binaries						
PSR B1259–63	pulsar	Be	1236.7	✓	✓	[12,13]
HESS J0632+057	?	Be	315		✓	[14,15]
LS I +61°303	?	Be	26.5	✓	✓	[16,17]
1FGL J1018.6–5856	?	O	16.6	✓	✓	[18,19]
LS 5039	?	O	3.9	✓	✓	[20,21]
(low-mass) gamma-ray binaries[b]						
XSS J12270–4859	pulsar	red dwarf	0.29	✓		[22,23]
PSR J1023+0038	pulsar	red dwarf	0.20	✓		[24]
2FGL J0523.3–2530	?	red dwarf	0.69	✓		[25,26]
PSR B1957+20	pulsar	brown dwarf	0.38	✓		[27]
PSR J0610–2100	pulsar	brown dwarf	0.29	✓		[28]
PSR J1311–3430	pulsar	brown dwarf	0.065	✓		[29,30]
microquasars (X-ray binaries)						
Cyg X-3	black hole?	Wolf–Rayet	0.20	✓		[31,32]
Cyg X-1	black hole	O	5.60	✓	?	[33,34]
novae						
V407 Cyg	white dwarf	red giant	14000?	✓		[35,36]
V1324 Sco	white dwarf	red dwarf	0.07?	✓		[37]
V959 Mon	white dwarf	red dwarf	0.30	✓		[37]
V339 Del	white dwarf	red dwarf	0.13?	✓		[37]
V1369 Cen	white dwarf	red dwarf	?	✓		[38]
colliding wind binary						
Eta Car	LBV	O/WR?	2014	✓		[39,40]

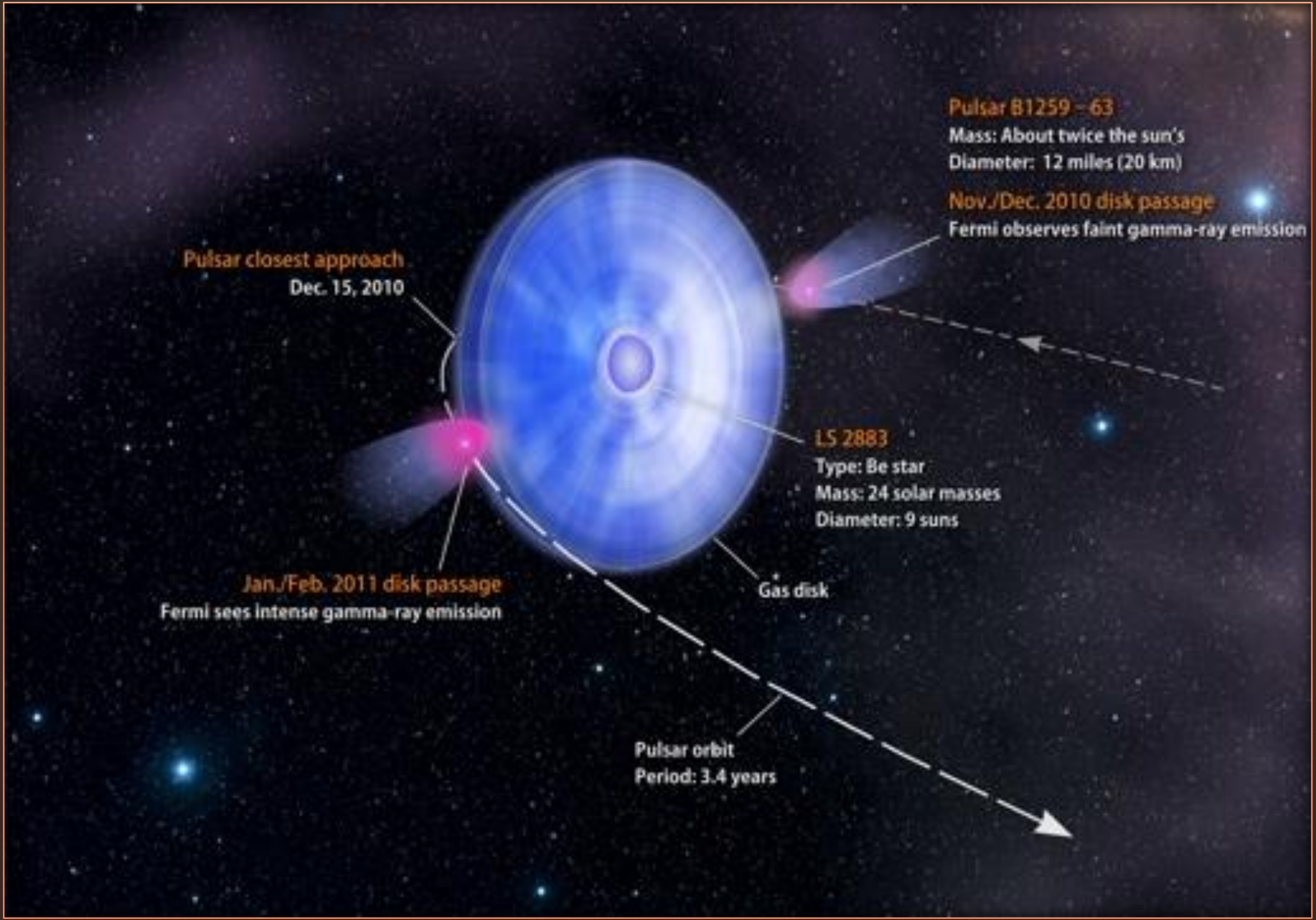
[a] I only give one or two recent references as entry points to the HE/VHE literature.
[b] Not including another >50 *Fermi*-LAT pulsars in binaries.

High-mass gamma-ray binaries

- Powered by pulsar rotation
  - Pulsar's slow down (~ 8*10^35 erg/s)
  - Powers the relativistic wind and **radiation**
    - Wind produces a shock front in binary system's case
    - This in turn radiates gamma-rays with the wind of secondary (Inverse Compton)
  - Charged particles + magnetic field in poles
  - Synchrotron radiation
- With Be-star [Balmer emission lines with usually B-type stars]
  - High rotation around axis -> Forms a material disk
  - Pulsar moves through -> Produces gamma-rays (not pulsed)



Pulsar + BE-star



Low-mass gamma-ray binaries

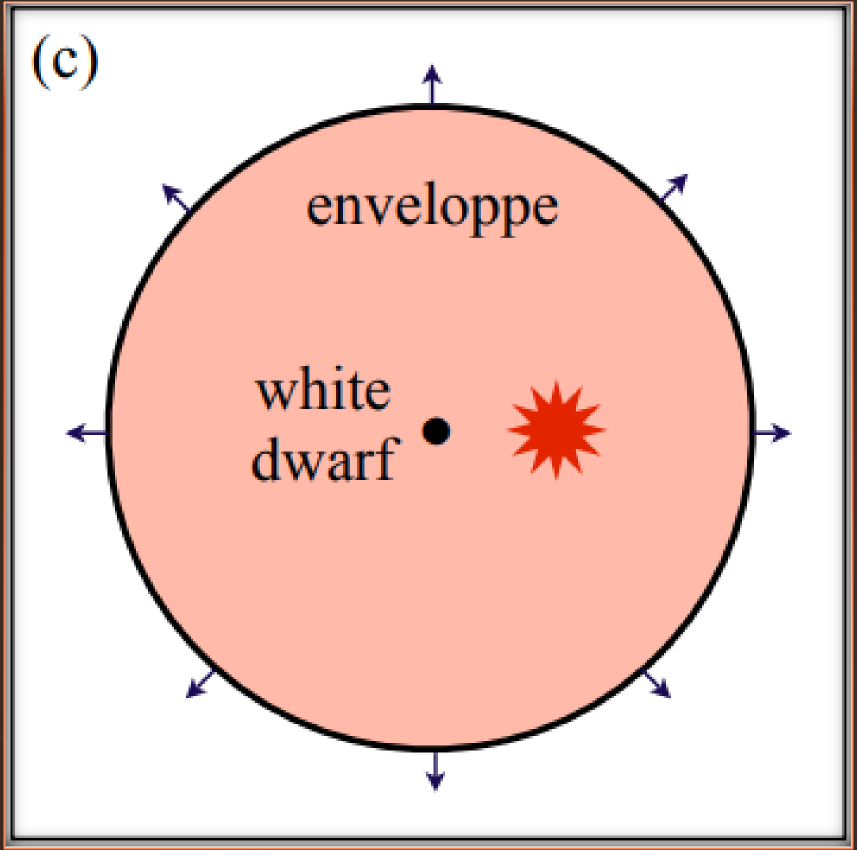
- Gamma-rays dominate spectral energy distribution (XSS J12270–4859)
- [2014] 55/161 out of ANY gamma-ray pulsars are binary [Fermi-LAT]
  - Millisecond pulsars
  - Spun back by the matter flow from donor star
- Inverse Compton gamma-ray emission from active accretion disk when hit by the pulsar wind

Microquasars

- Like Active Galactic Nuclei – sized down
- Synchrotron emission from jets -> Evidence of TeV scale energies
- Massive donor -> Accretion disk + corona -> Majorly x-ray seen
- ~ 1-10 % of all high energy radiation is in gamma-rays
- Only seen when radio emission also seen (jets)
  - Binary's spectral state
  - Originate **farther** from the jet base -> No pair production et cetera

Novae

- Lower energy (1-10 MeV) gamma-rays expected
- 100 MeV gamma-rays also detected
  - High velocity ejecta -> Shock front outside the binary separation
  - Interaction with Interstellar matter -> Radiation
  - Also affected by the companion star
- Seeing the gamma-rays:
  - Gives ways to study shock fronts/sweeping of matter outside of supernovae



Wind driven gamma-ray binaries

- Not always present
  - Eta Car -> 0.2% of winds energy within gamma-rays
  - Similar binaries do not seem to show any caused by winds
  - Small shock front/radiative losses
- Could be used to estimate:
  - Maximum accretion energy
  - Magnetic fields
  - How much wind energy -> Non-thermal energy in shocks

Conclusion on former slides

- Gamma-ray binaries combine multiple groups of high-energy astrophysics
  - Magnetized outflows
  - Shock-fronts and winds
  - Novae and conceptual similarities to supernovae
- Mainly in HE-range
  - Cherenkov Telescope Array for VHE
  - In LE-range – noise by the hot coronae/radioactive decay

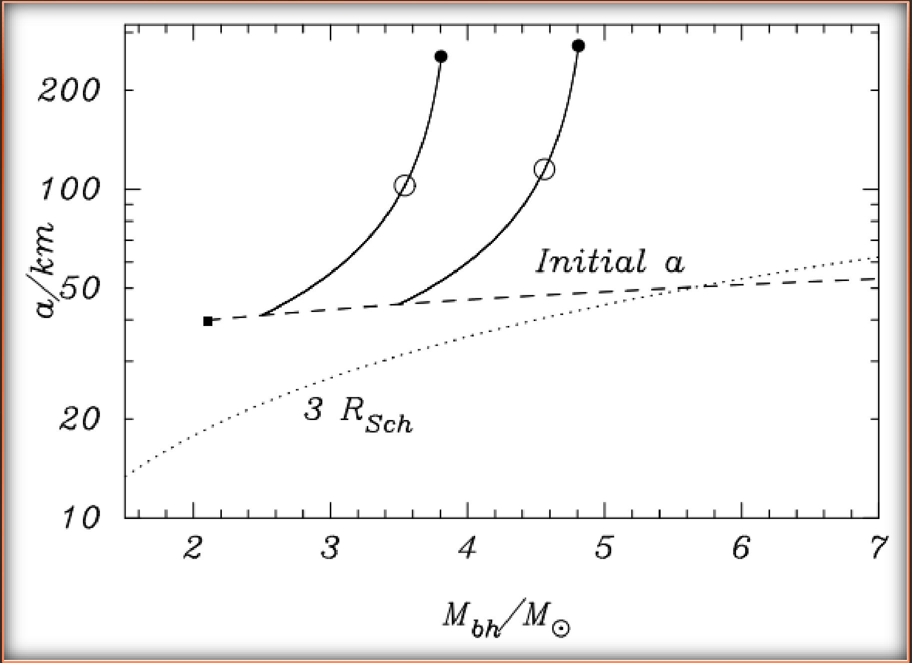
Theoretical example from 1998 (NS + BH)

- Standard system formed -> Matter exchange -> Supernova
  - Close binary of neutron star and black hole forms
  - Accretion rate highly super-Eddington (1 Sun mass/year)
- Gravitational waves -> Separation shrinks -> Neutron star fills Roche lobe
  - Mass transfer driven by gravitational waves
  - Stops the collision
  - Neutrons travel rapidly – no decay, no mass loss
  - Accretion flow does not form a disk (angular momentum to orbits)
- Assuming that:
  - Roche lobe stays filled || No rotation for black hole nor neutron star
  - The required mass transfer-rate is then:
  - The constant kappa = 4.1*10^17 cm*g^(1/3)

$$\dot{m} = \frac{32G^3}{5\kappa^4 c^5} \frac{m^{16/3}}{q^{2/3}(q+1)^{1/3}(q-2/3)}.$$

Continuing

- Right mass proportions: 1.4 and 2.1 solar masses (donor/primary)
- Separation a > 3*Schwarzschild radius (assume rotation, so laxed)
- Disk may form when separation has increased
- Gravitational energy of matter falling in – not enough for gamma-rays
  - Assume rotation (Kerr blackhole) + strong magnetic field
  - Magnetic field locked into disk -> Rotation energy taken from the black hole
  - Radiation emerges from the black hole's rotation axis
- Absorbed if baryons present
  - Before accretion disk – very little
  - Tidal heating of neutron star (forced to corotate) -> Wind which diminishes in time



$$L \approx 10^{50} \left(\frac{\mu M}{3\ M_\odot}\right)^2 \left(\frac{B}{10^{15}\ \mathrm{G}}\right)^2 \ \mathrm{ergs\ s^{-1}}.$$

Energy of radiation taken from rotational energy of BH

In conclusion

- Short bursts
  - Merging of two neutron stars
  - Unstable mass transfer between neutron star and black hole
  - 1 out of 10-20 bursts are short
- During accretion like x-ray binaries (former classes)
- Neutron star ends its life when its mass drops to a lower limit
  - R~33km, M=0.1 solar masses, L~10^(50)ergs/s, L_neutrino ~ 10^(51) ergs/s
  - Enriches space with elements (Thorium)
- Whole process is quick

References

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- Simon F. Portegies Zwart "Gamma-Ray Binaries: Stable Mass Transfer from a Neutron Star to a Black Hole" in The Astrophysical Journal (503:L53-L56) 1998
- https://fermi.gsfc.nasa.gov/science/eteu/binaries/