Collision dynamics in GRB internal shocks

And their implication for the production of multiple astrophysical messengers

Annika Rudolph, Anatoli Fedynitch, Jonas Heinze, Walter Winter
TeVPA, 27.08.2018

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

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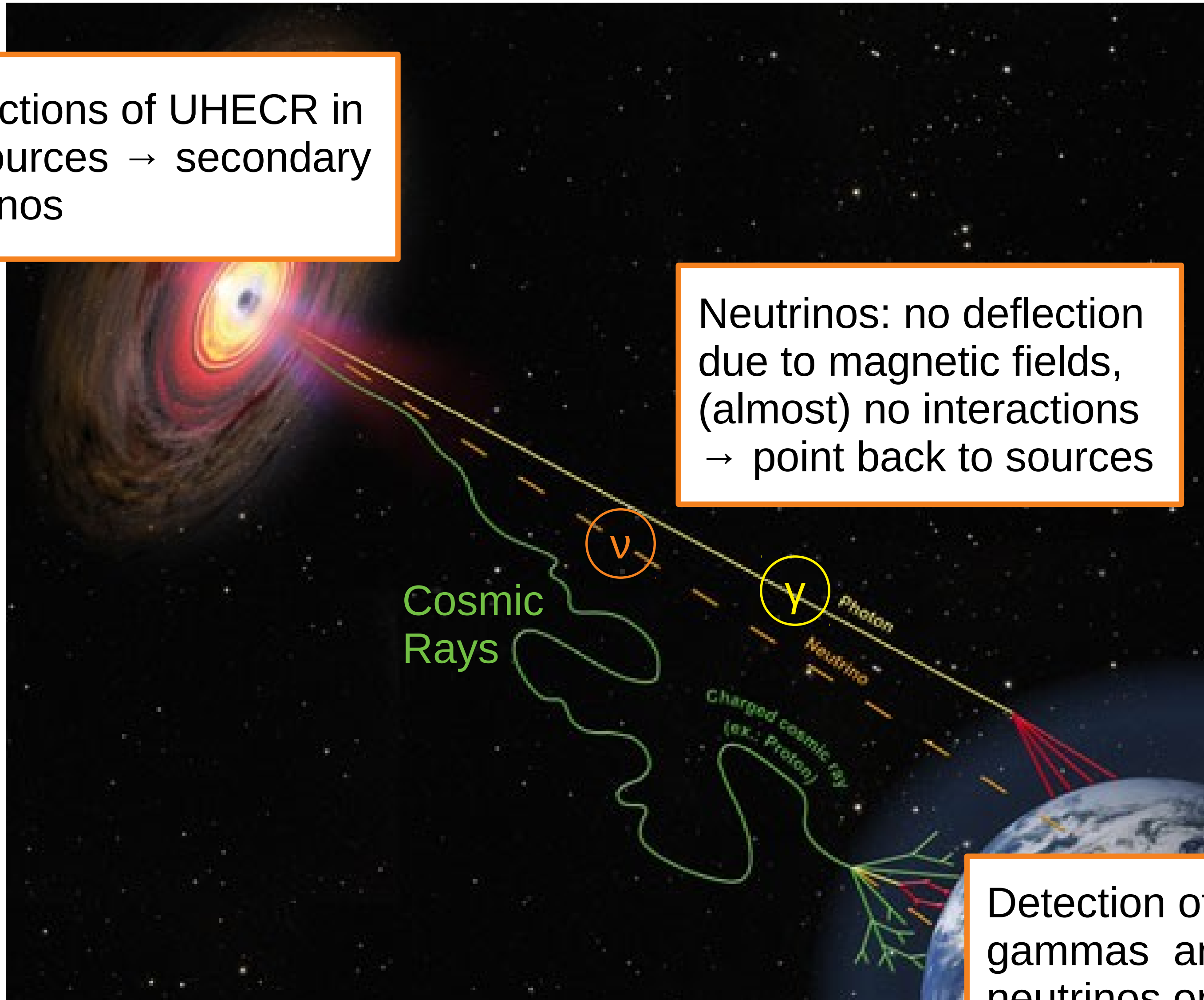
DESY

Common origin of UHECR and HE neutrinos

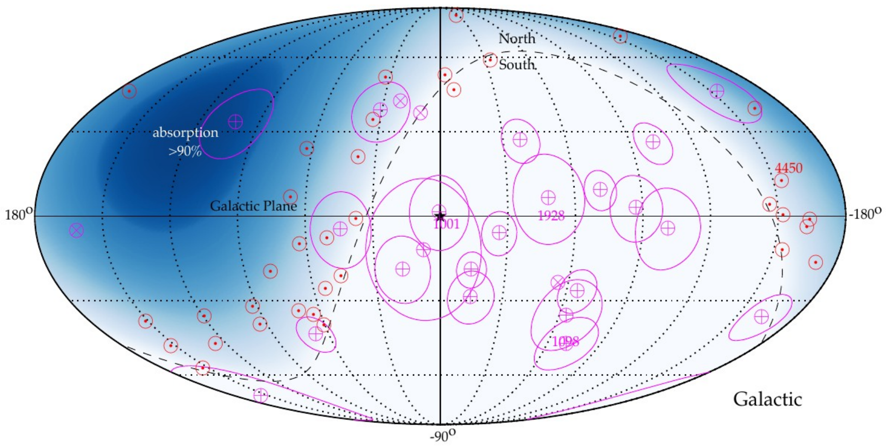
Interactions of UHECR in the sources → secondary neutrinos



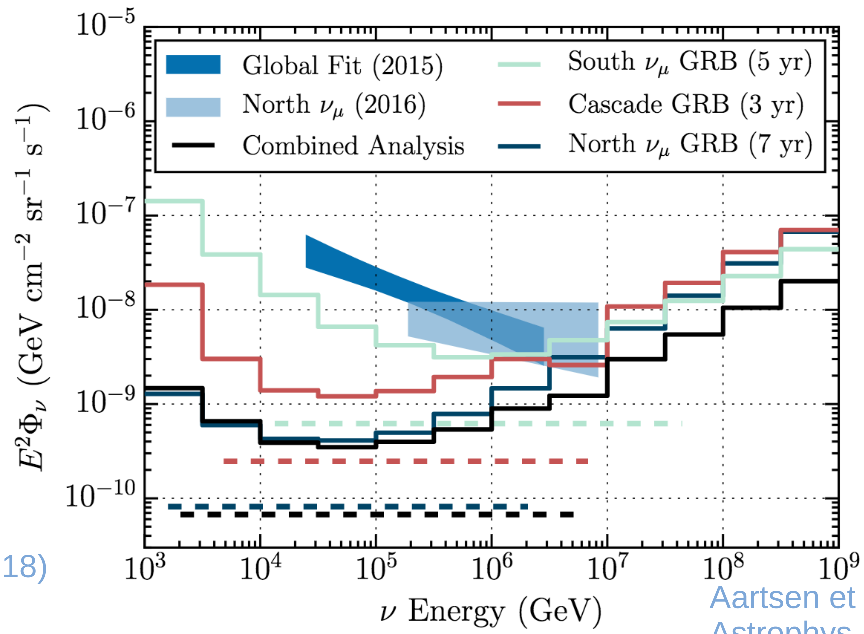
Neutrinos: no deflection due to magnetic fields, (almost) no interactions → point back to sources

Detection of UHECR, gammas and neutrinos on earth

Neutrino constraints on UHECR sources



Ahlers, Halzen,
Prog.Part.Nucl.Phys. 102 (2018)
73-88



Aartsen et al.
Astrophys. J,
843, 112 (2017)

Search for coincidence between IceCube neutrinos and high-energy photon detections constrain UHECR sources:

- Limits on the neutrino flux from AGNs

Aartsen et al, Astrophys. J,
835, 45 (2017)

- Lack of neutrinos from detected Gamma-Ray Bursts rule out the most simple GRB scenarios as sources of UHECR

Abbasi et al, Nature 484:
351-353 (2012)

What are Gamma-Ray Bursts?

GRB characteristics

- Luminosities:

  10^{49} - 10^{53} ergs / s

- Duration:

  0.1 – 100 s

- Progenitors:

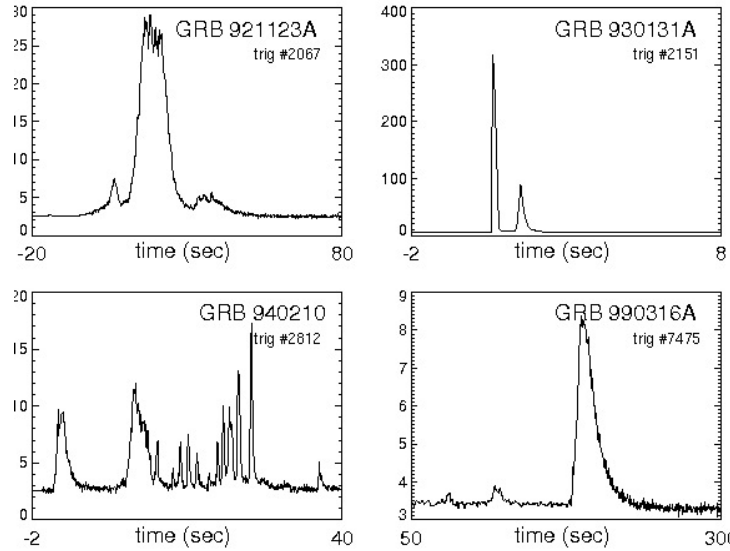
  sGRB (0.1 – 1 s) → Merger of 2 compact Objects

  lGRBs (10 – 100 s) → Collapse of massive stars

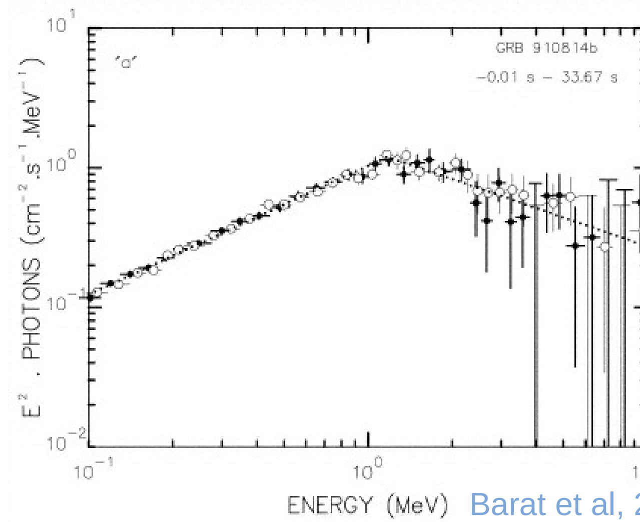
- Redshifts: 1-3

- Multiwavelength afterglow lasting up to months

Prompt emission

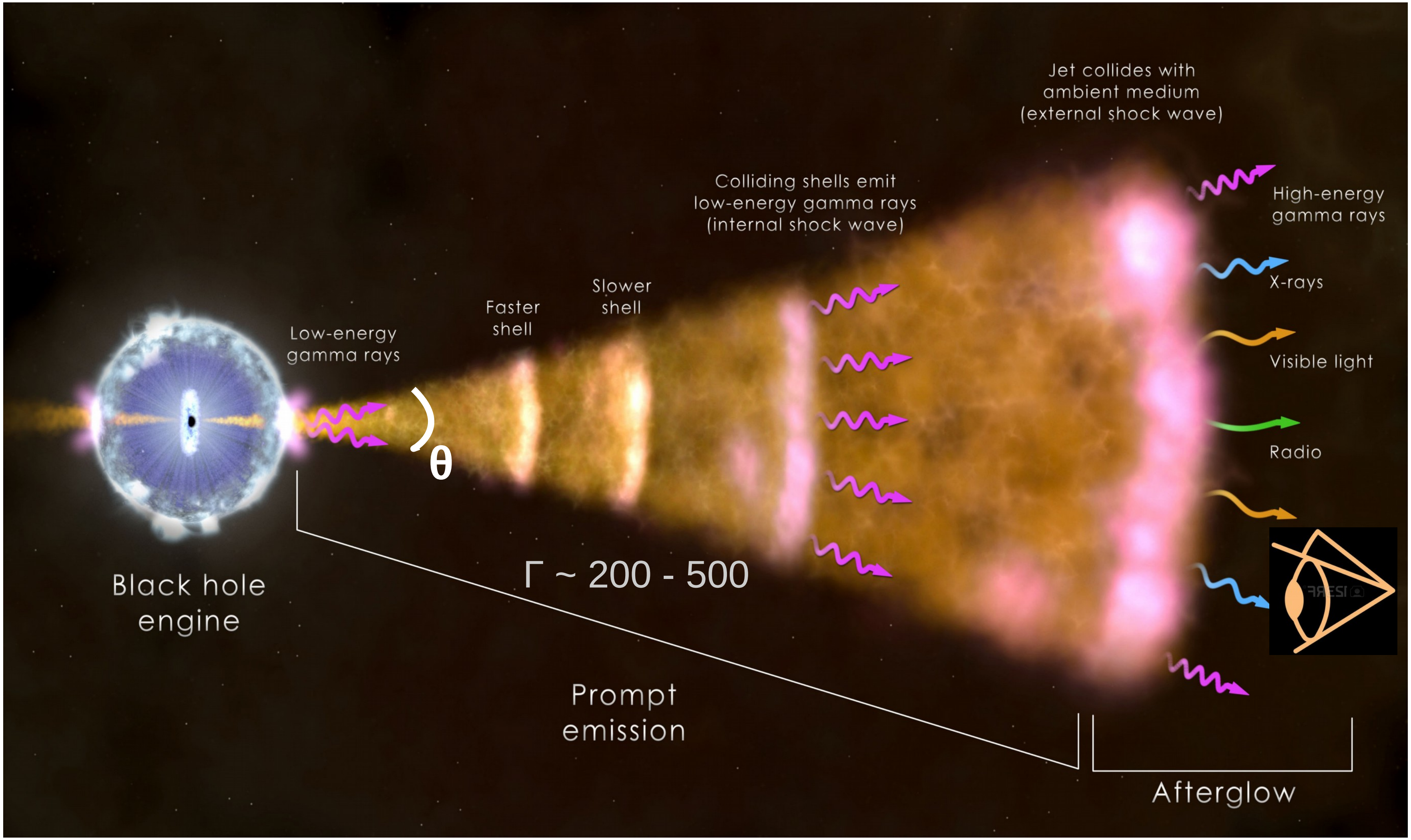


Daniel Perley



Barat et al, 2000, ApJ 538(1):152

Fireball-internal shock model

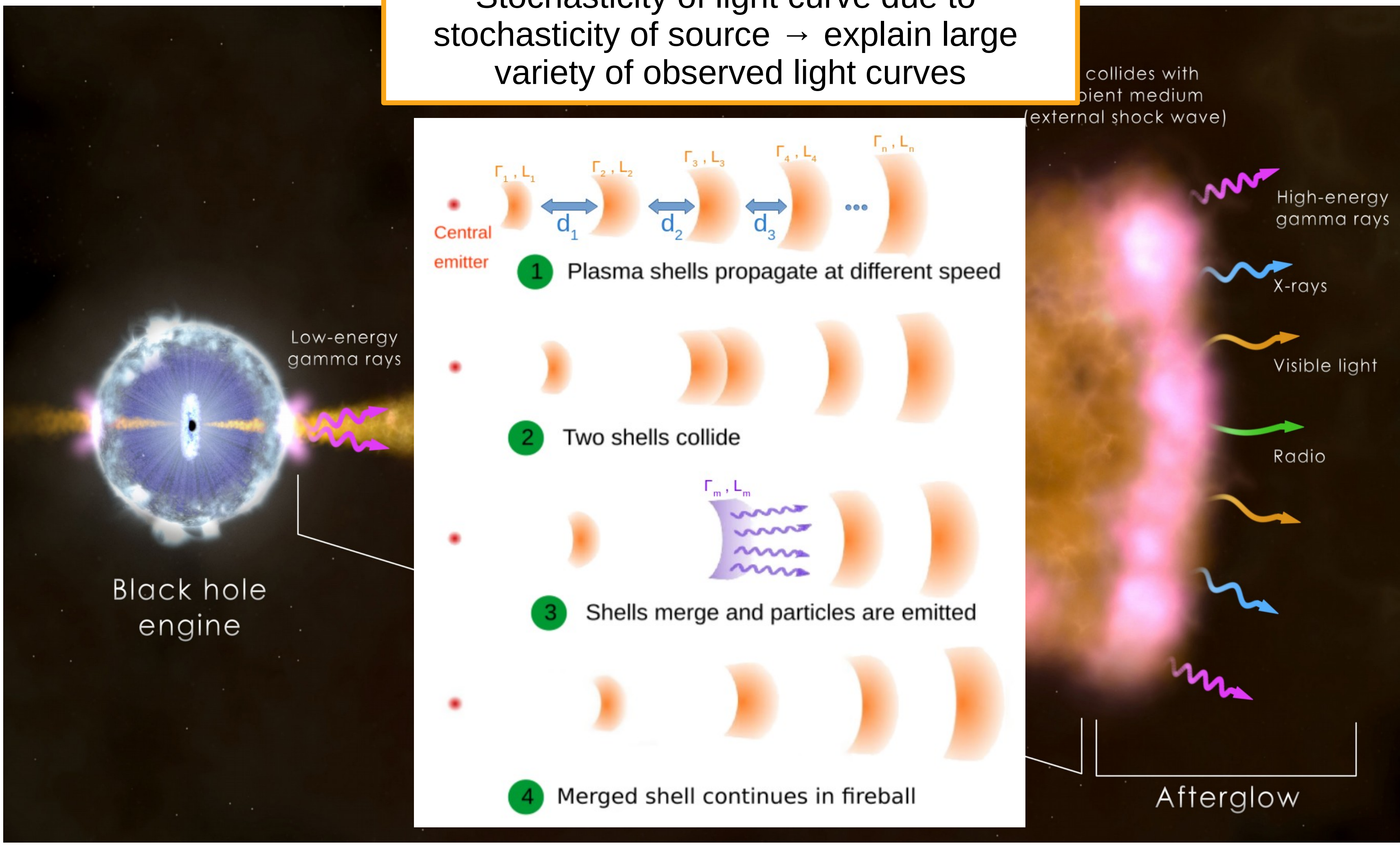


Source: NASA

Fireball-internal shock model

Multi-Collision model

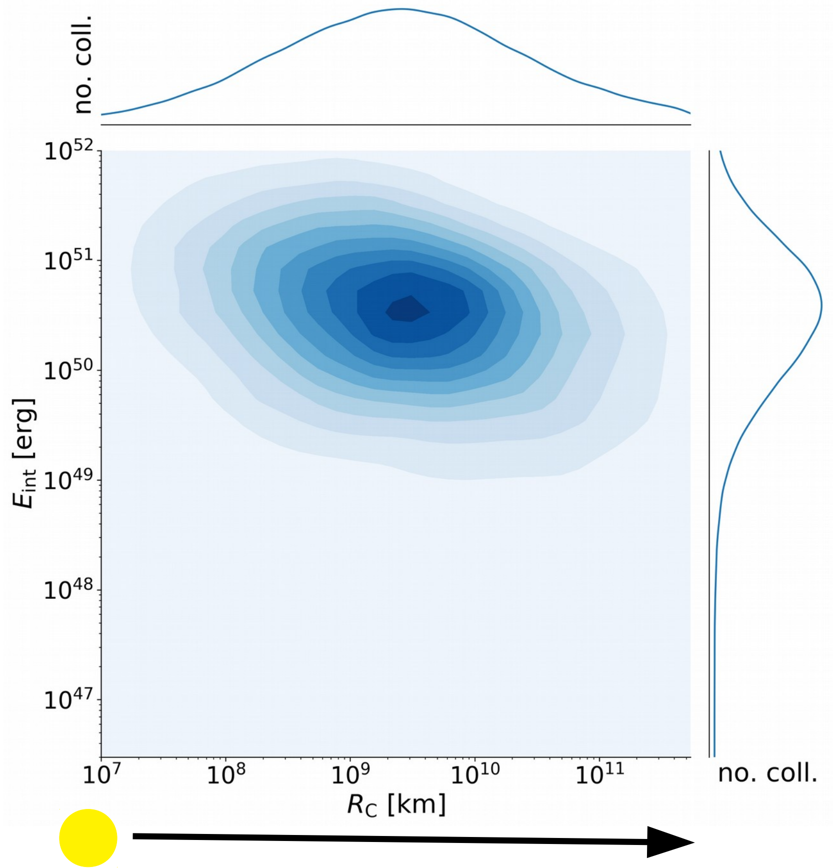
Stochasticity of light curve due to stochasticity of source → explain large variety of observed light curves



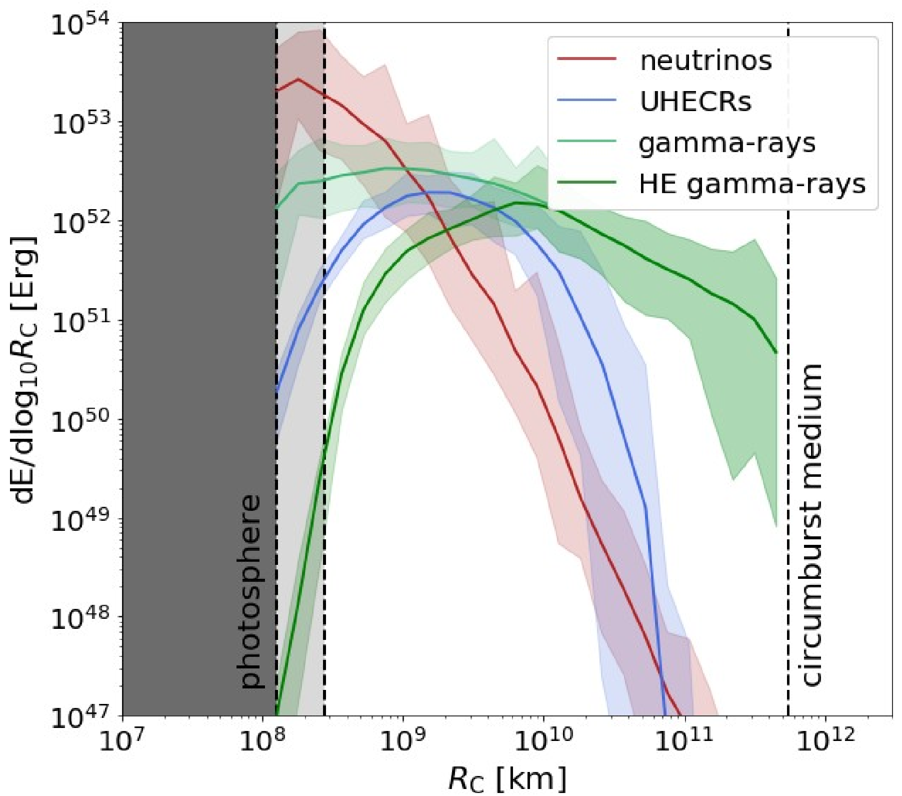
Source: NASA

Spatial resolution of fireball properties and particle production

Energy dissipation within the fireball



Energy in different particle species



See Bustamante, Heinze, Murase, Winter, Astrophys. J., 837, 33 (2017)

V_{shell} α R^2 → large collision radii = low densities (particles, photon fields, magnetic fields)

Spatial resolution of fireball properties and particle production

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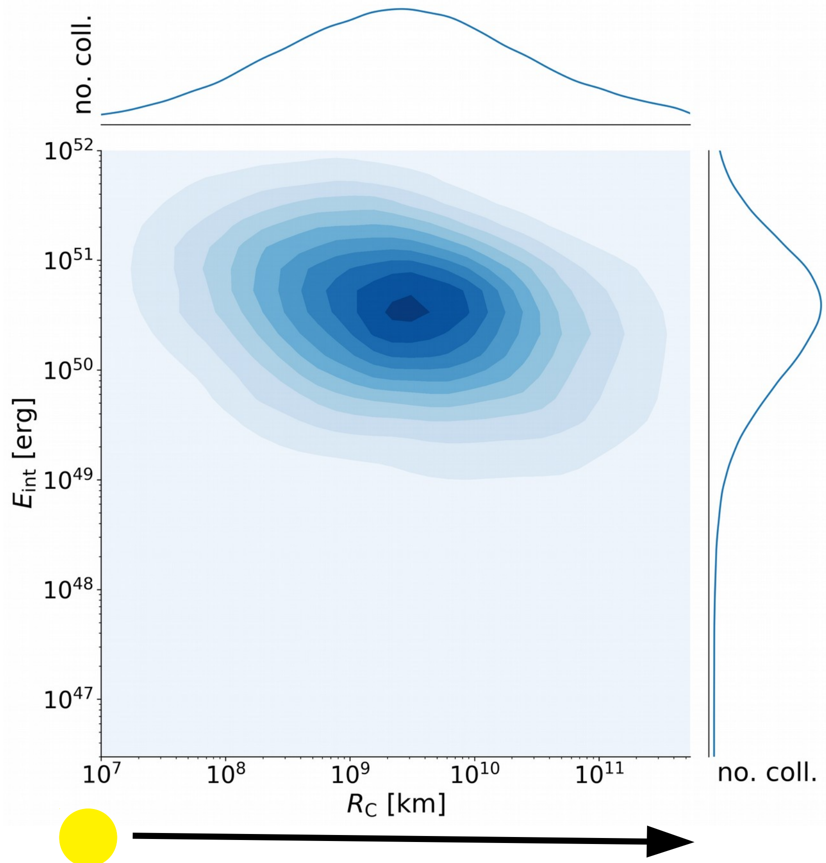
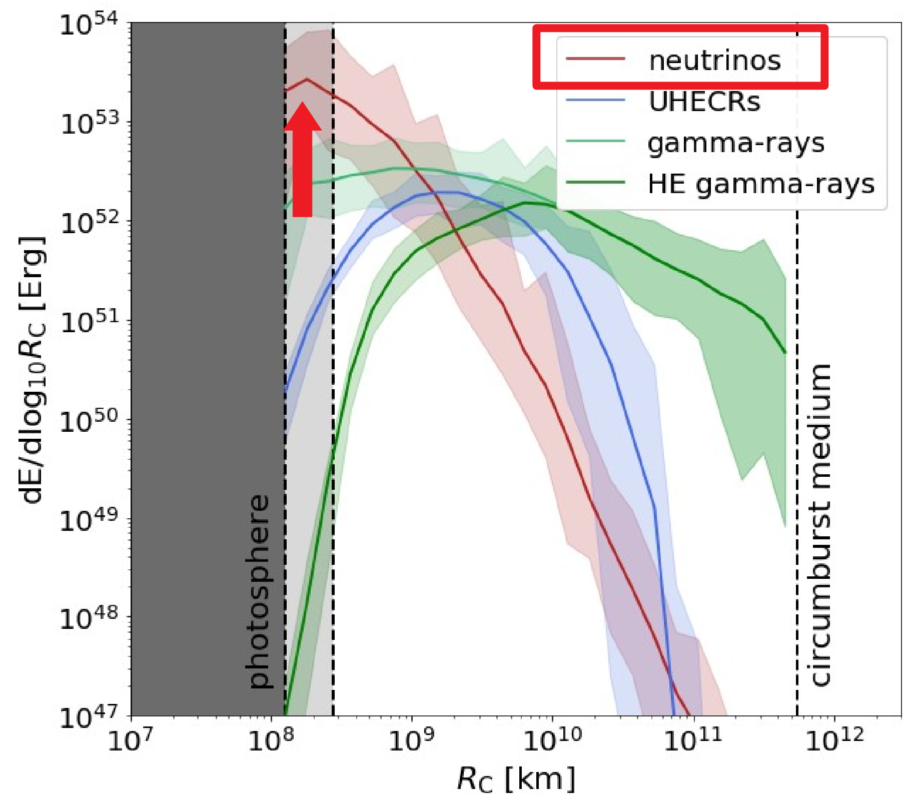


Distance from engine

Energy in different particle species



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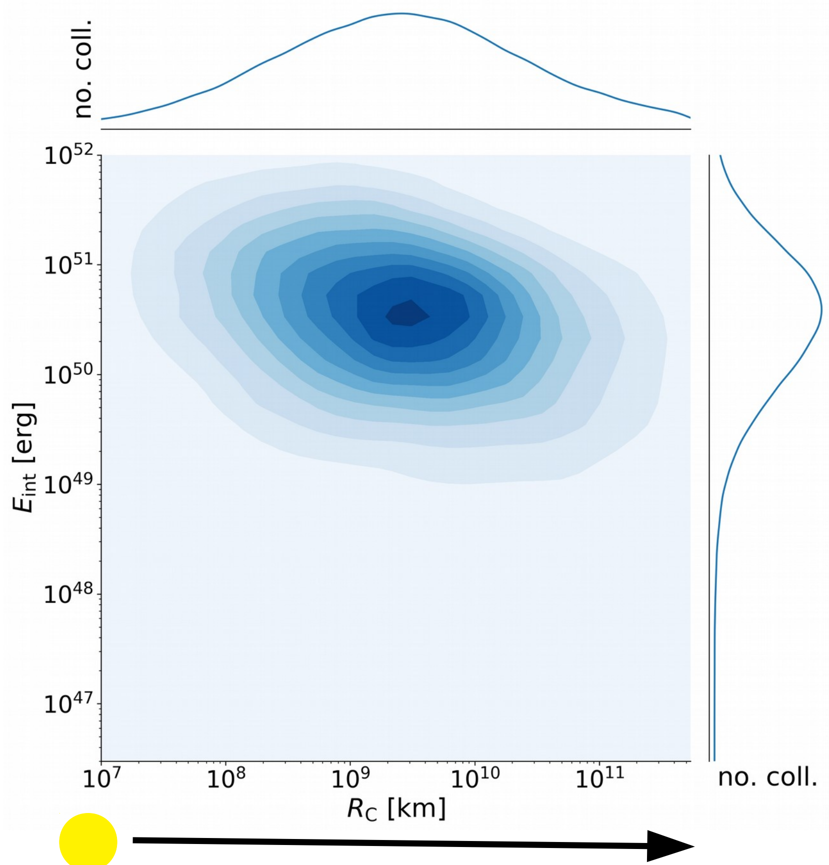

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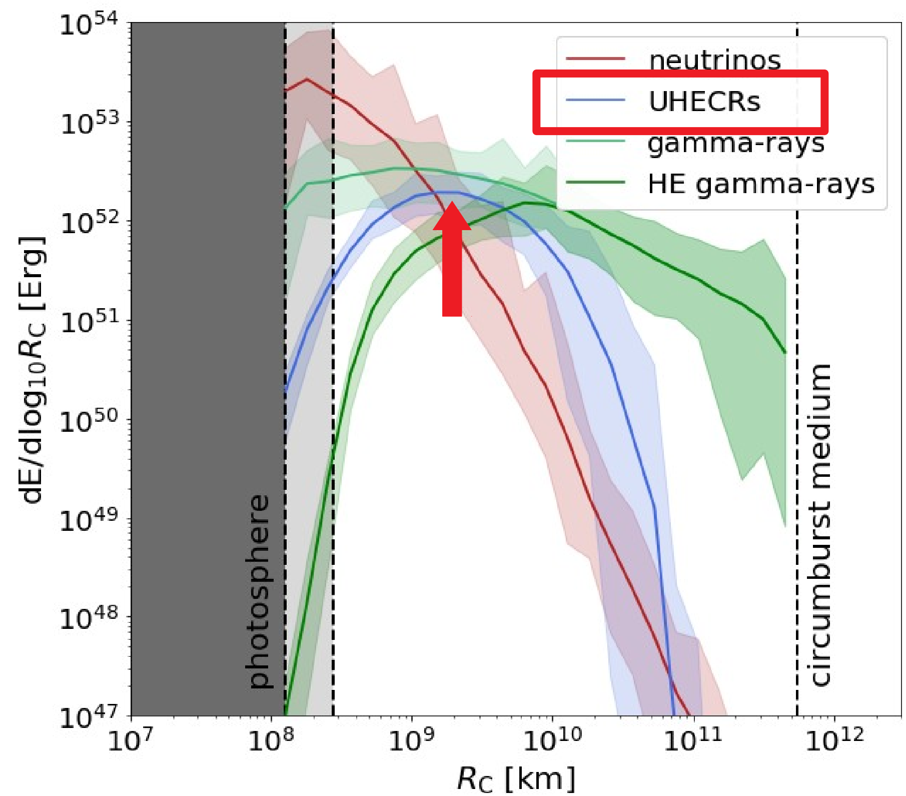

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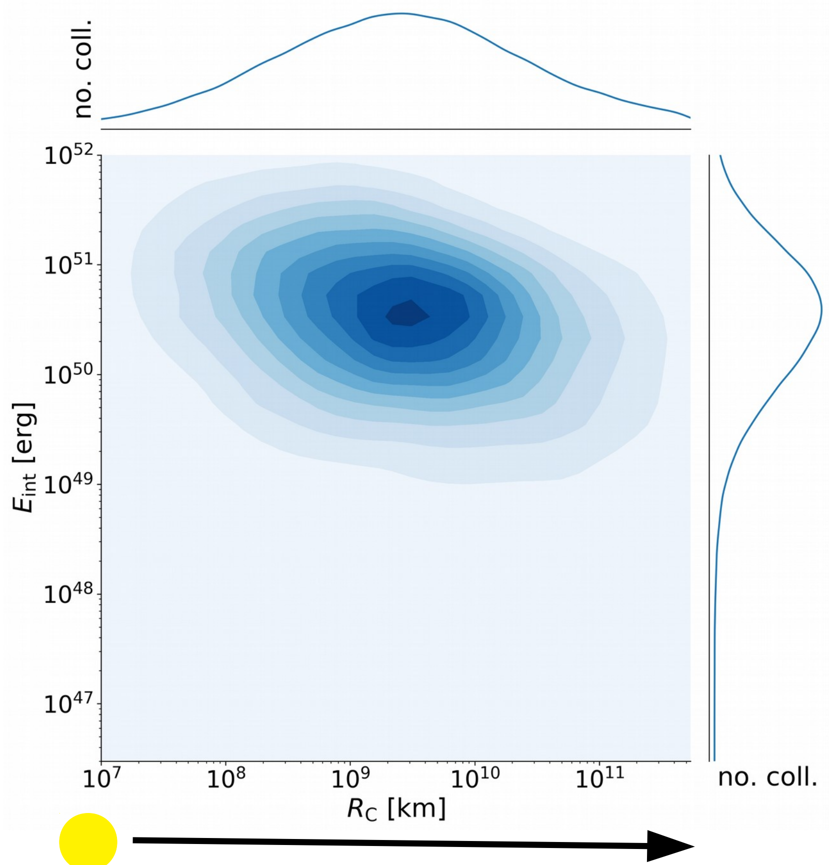

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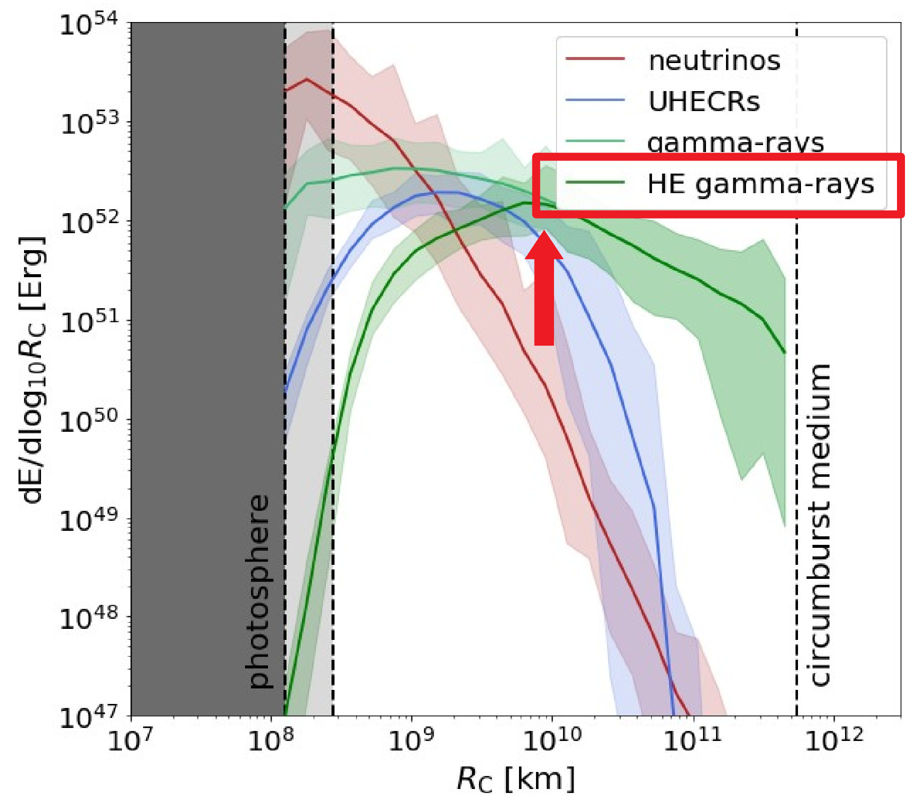

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Alternative collision models

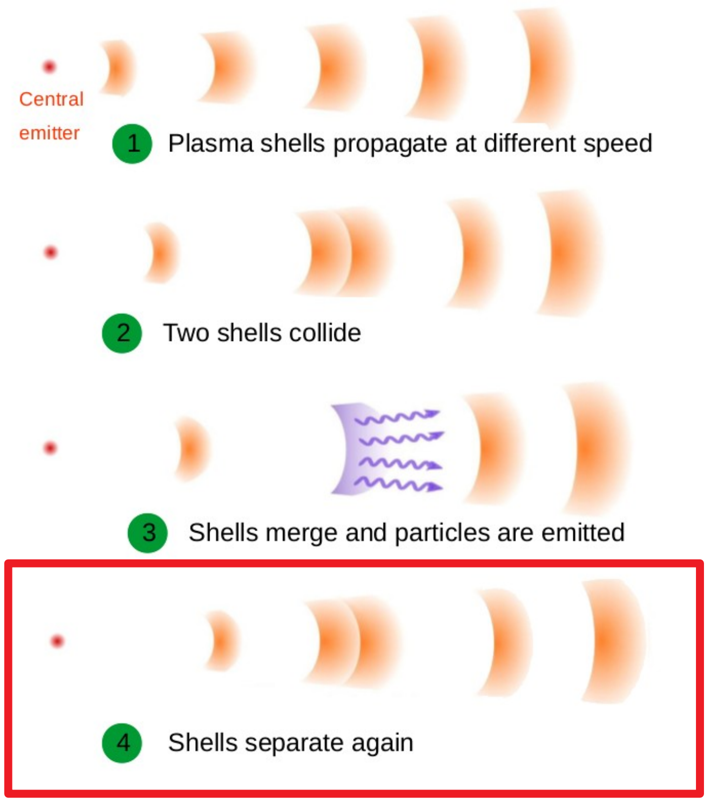
Ultraefficient shock scenario

Kobayashi, S. & Sari R. 2001, Astrophys. J., 551, 934 (KS'01)

Motivation: Problems in the standard merging shell scenario

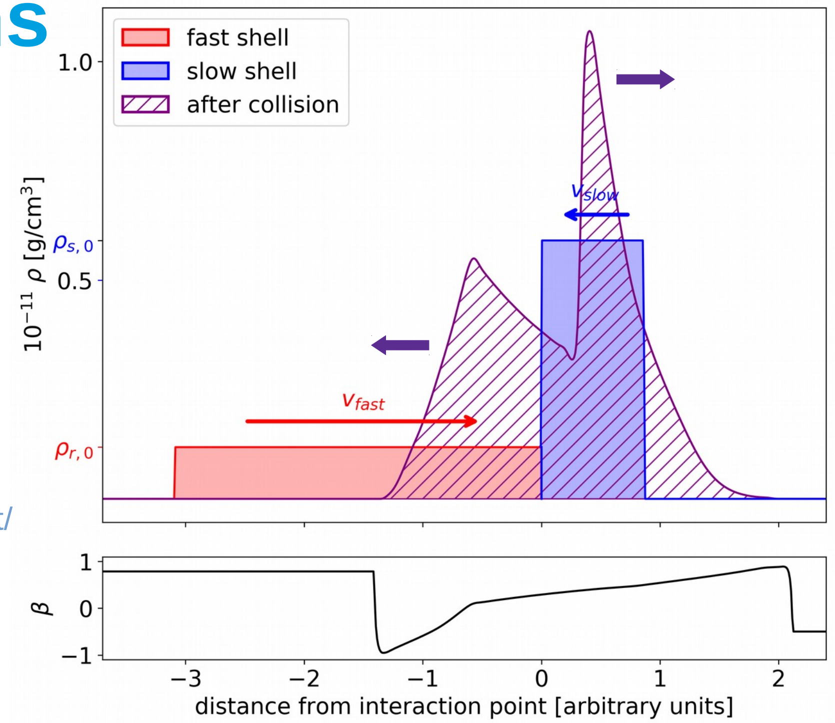
1. Low efficiency in converting fireball kinetic energy into radiation
→ bright afterglow / photospheric emission? (not compatible with observations)

2. High variability in the light curve requires highly variable central source



Possible solution: alternative collision dynamics (ultraefficient shock scenario)
→ intrinsically solves both problems

Analysing ultraefficient shocks with hydrodynamic simulations



Each collision is a hydrodynamic process

Kino et al, Astrophys. J. 611: 1021-1032 (2004)

→ Set up 1D RHD simulation to analyse collision process with PLUTO

http://plutocode.ph.unito.it/

Results:

1. Ultraefficient shock scenario realistic for shells with **comparable masses** and **high spread in Lorentz factor**

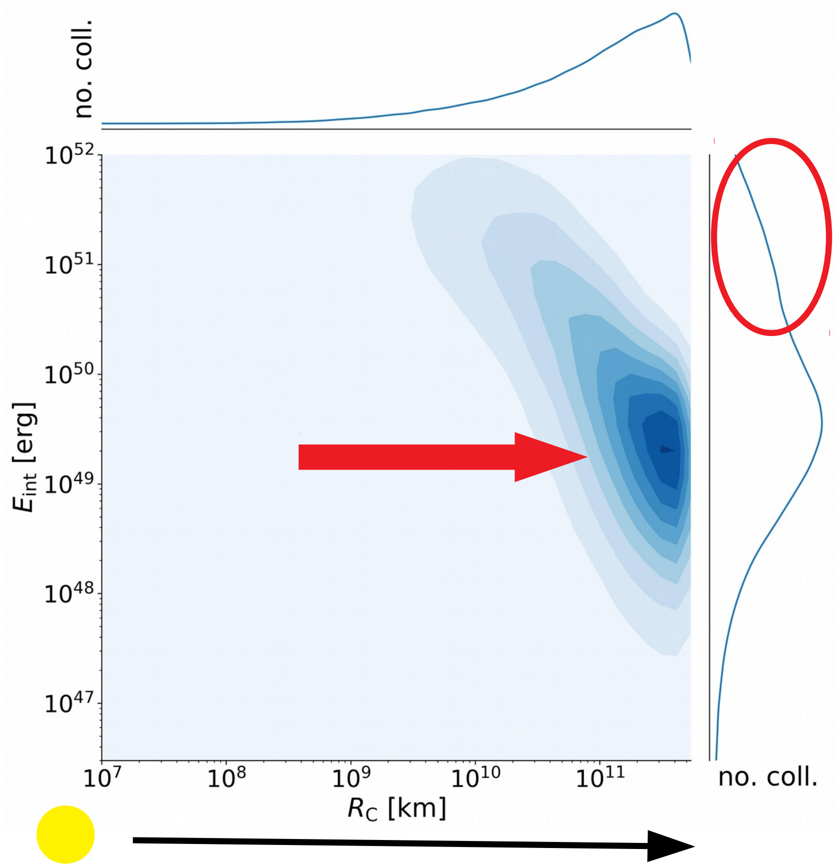
2. Non-thermal energy dissipation decrease the probability for ultraeff. shocks

3. In complete fireball simulation (const mass outflow), only ~10 % of the collisions

→ **Ultraefficient shock scenario only possible under very specific conditions**

Fireball properties in the ultraefficient shock scenario

Energy dissipation within the fireball



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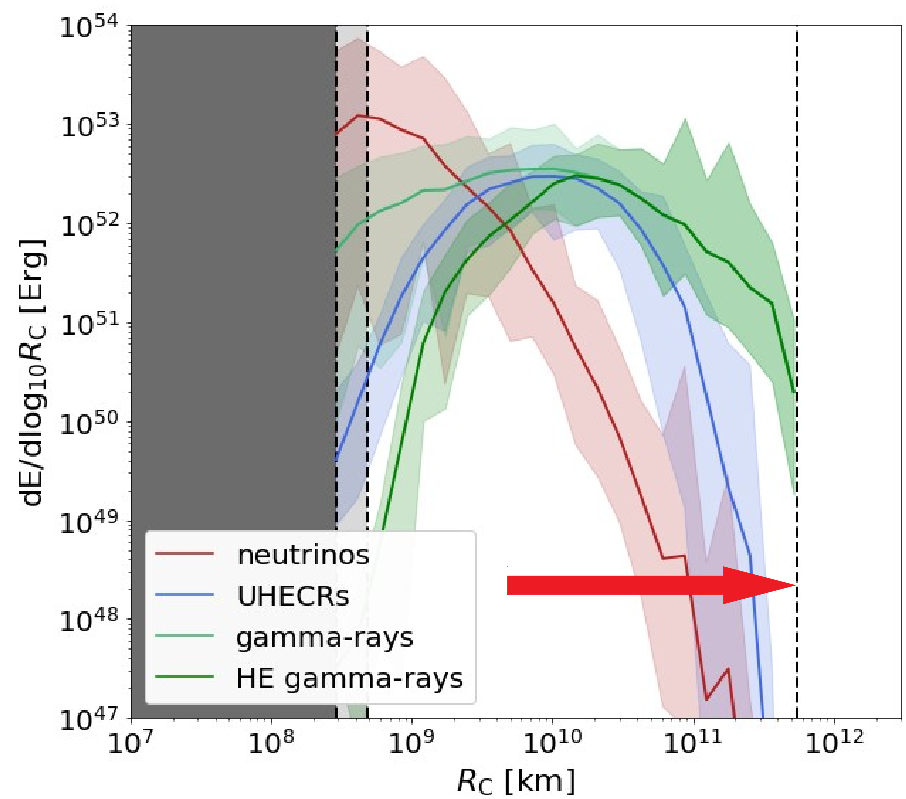
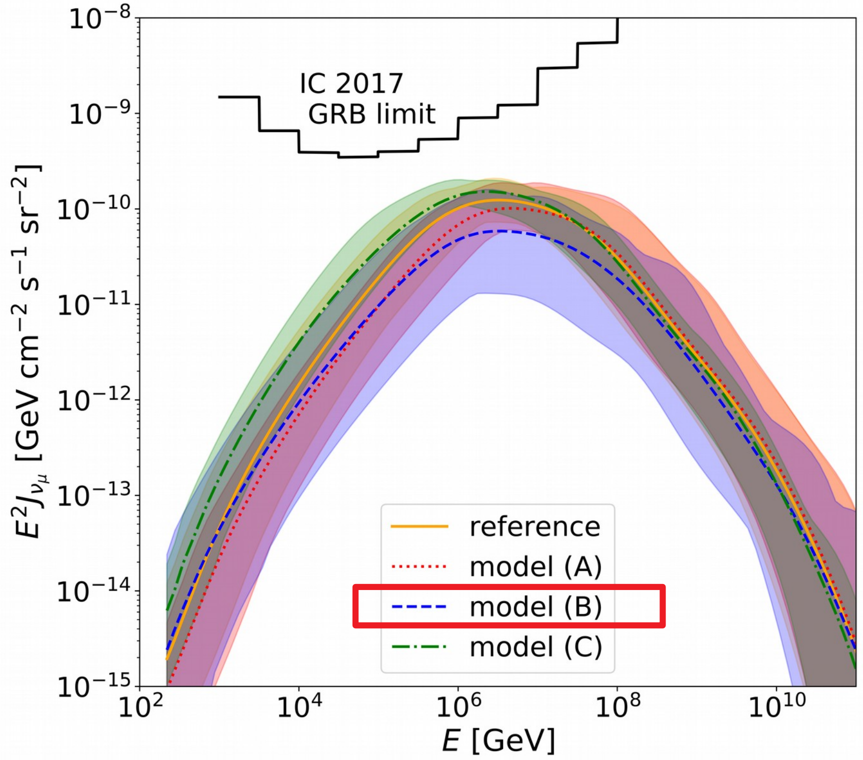


Impact on observables

For the same luminosity, light curve variability and duration

1) Neutrino Flux : Slightly reduced in ultraefficient shock scenario (model B)

2) Light curve : Few collisions with high energies dominate the light curve → more structure



	$N_{\mathrm{Shell,ini}}$	Efficiency [%]	$E_{\gamma,\mathrm{vis}}/E_{\gamma,\mathrm{tot}}$	$E_{\mathrm{p}}/E_{\gamma}$	E_{ν}/E_{γ}
Std.	1000	17.87	0.75	0.55	2.16
Ultraeff.	125	36	0.95	0.57	1.34

Summary and conclusion

Multi-Collision model

- Allows to identify production regions of different particle species

Ultraefficient shock scenario

- Intrinsically high efficiency and less source variability required
- Neutrino Fluxes comparable, light curves slightly different

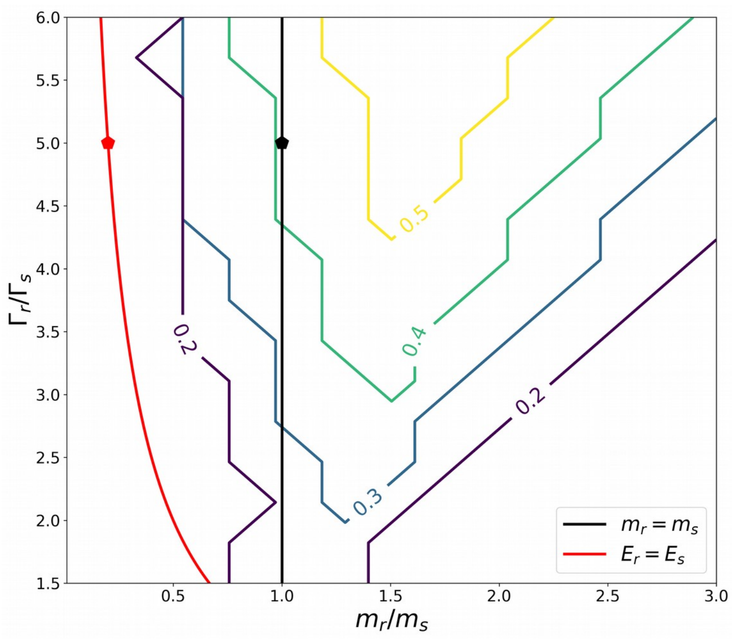
Hydrodynamic simulations

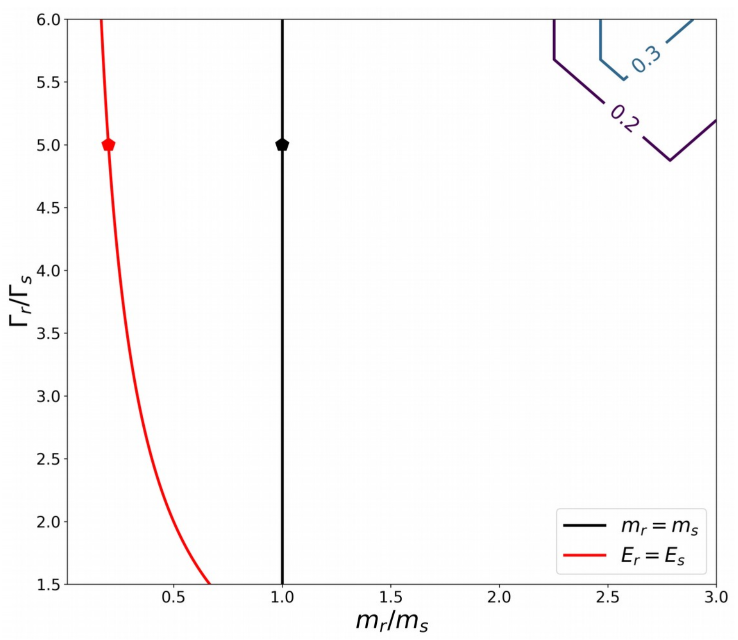
- Validation of collision process model
- Standard merging-shell scenario is usually a good approximation
- Ultraefficient shock scenario only applicable under very specific conditions

Backup

Impact of energy dissipation / 2-shell parameter space

No energy dissipation in PLUTO	50% of Eint into non-thermal particles





Fireball evolution (constant power outflow)