Gamma-ray Bursts and the Black Holes They Make

Flying with Gerry Brown

Stony Brook, 26 November 2013 — RAMJW — A Tribute to Gerald E. Brown

- Plan for this talk:
  - Some memories and greetings
  - A quick brush-up on gamma-ray bursts
  - So *what* makes a gamma-ray burst? And *how*?
  - Where do we go next?

Greetings!

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“Tell me about Binary Stars”

How a young postdoc fell into Gerry’s Web, and liked it there...

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- A strange meeting in Princeton
- Then a classic trip to Caltech ....
- Eight papers with Gerry, with themes:
  - How do you make black holes?
  - What kind of black hole can make a gamma-ray burst?
  - How does a black hole make a gamma-ray burst?

Also with: Hans Bethe, Chang-Hwan Lee, Hyun-Kyu Lee, Garik Israelian, Gail McLaughlin, Joe Weingartner, Jerry Francischelli

Gamma-ray burst reminder

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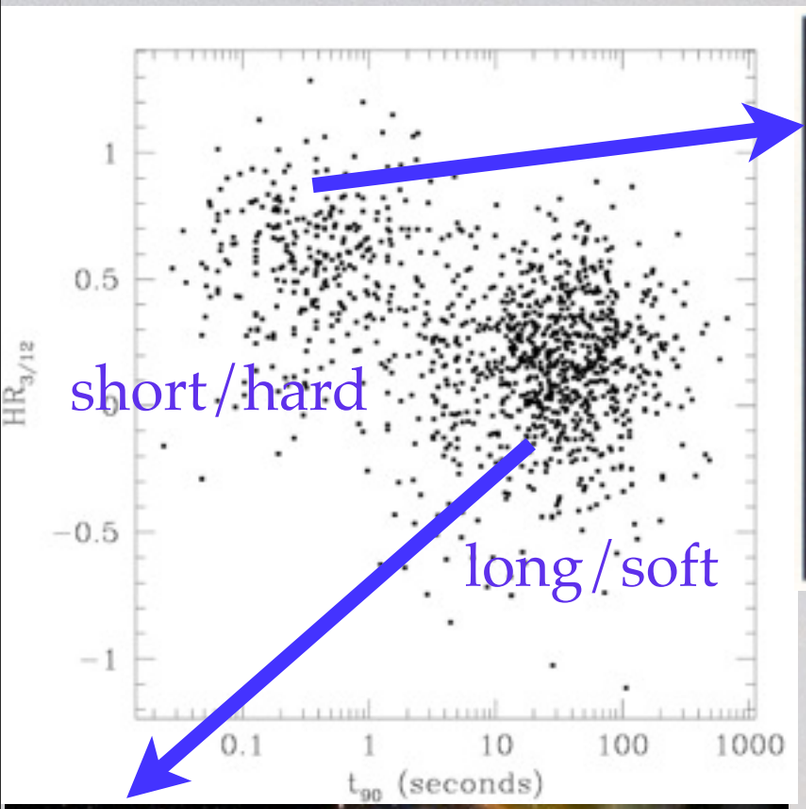
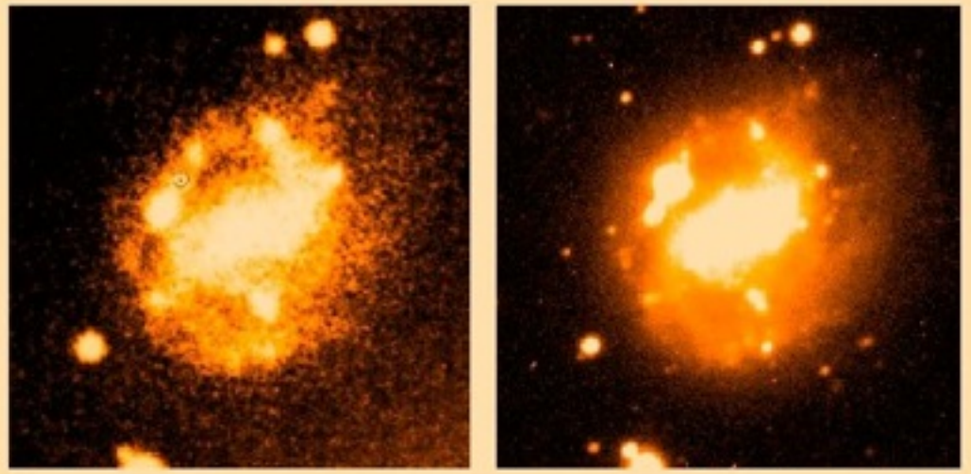
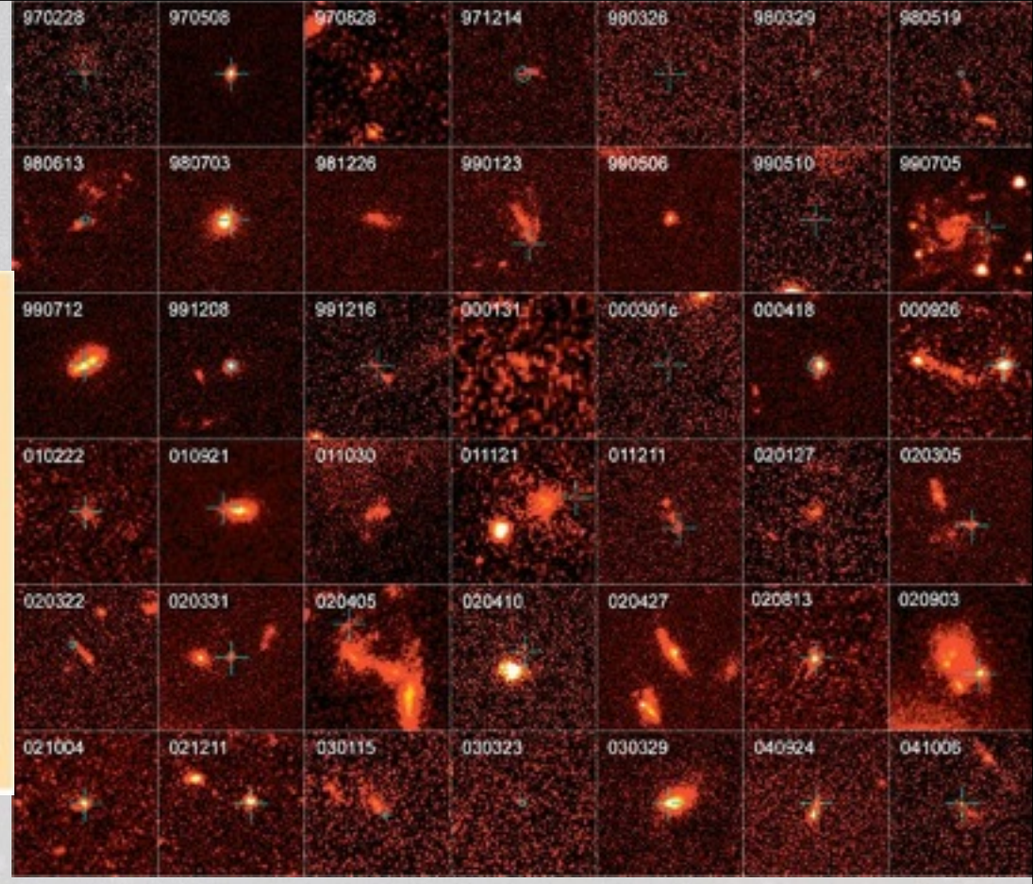


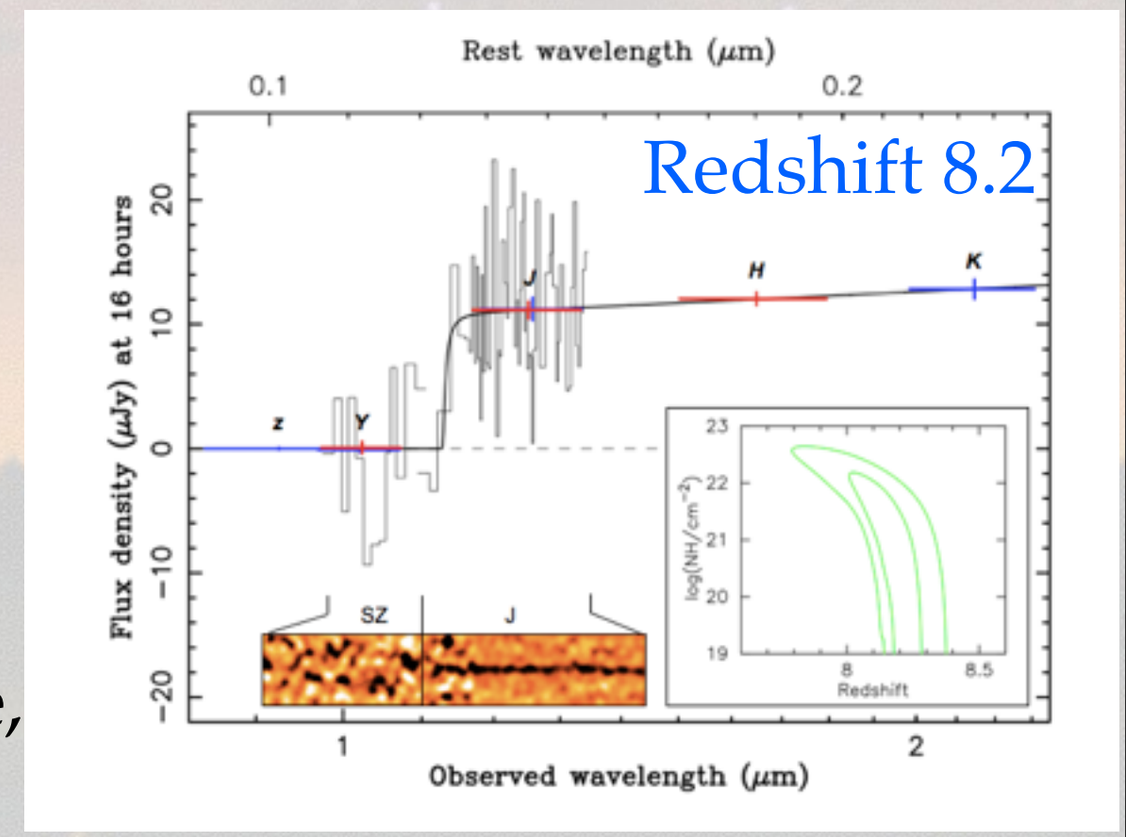
- 0.01-1000 s flashes of gamma rays
- $E_\gamma \lesssim 10^{44\text{-}45}$ J , $E_{tot} \lesssim 10^{45\text{-}46}$ J
- beamed, $f_{beam} \sim 0.01$
- ultra-relativistic, $\gamma \sim 30$ - 3000
- mechanism complex, overlap with supernovae
- emission of cosmic rays, neutrinos, gamma rays, gravity waves, ...

Long GRB reminder





- Associated with exploding massive stars
- Energy ~10x supernova, yet very different appearance
- Cosmology tool
- Redshift up to 9.4
- Universe 5% current age, 0.1% current volume



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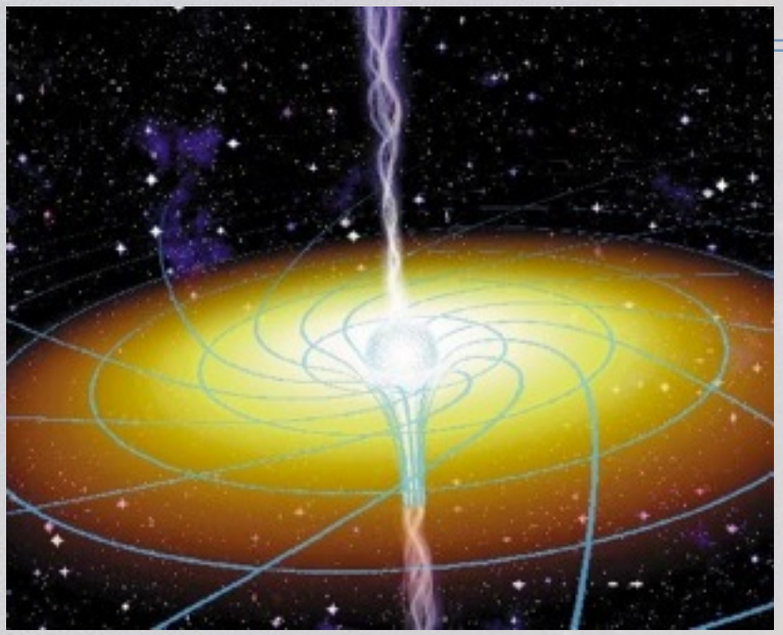
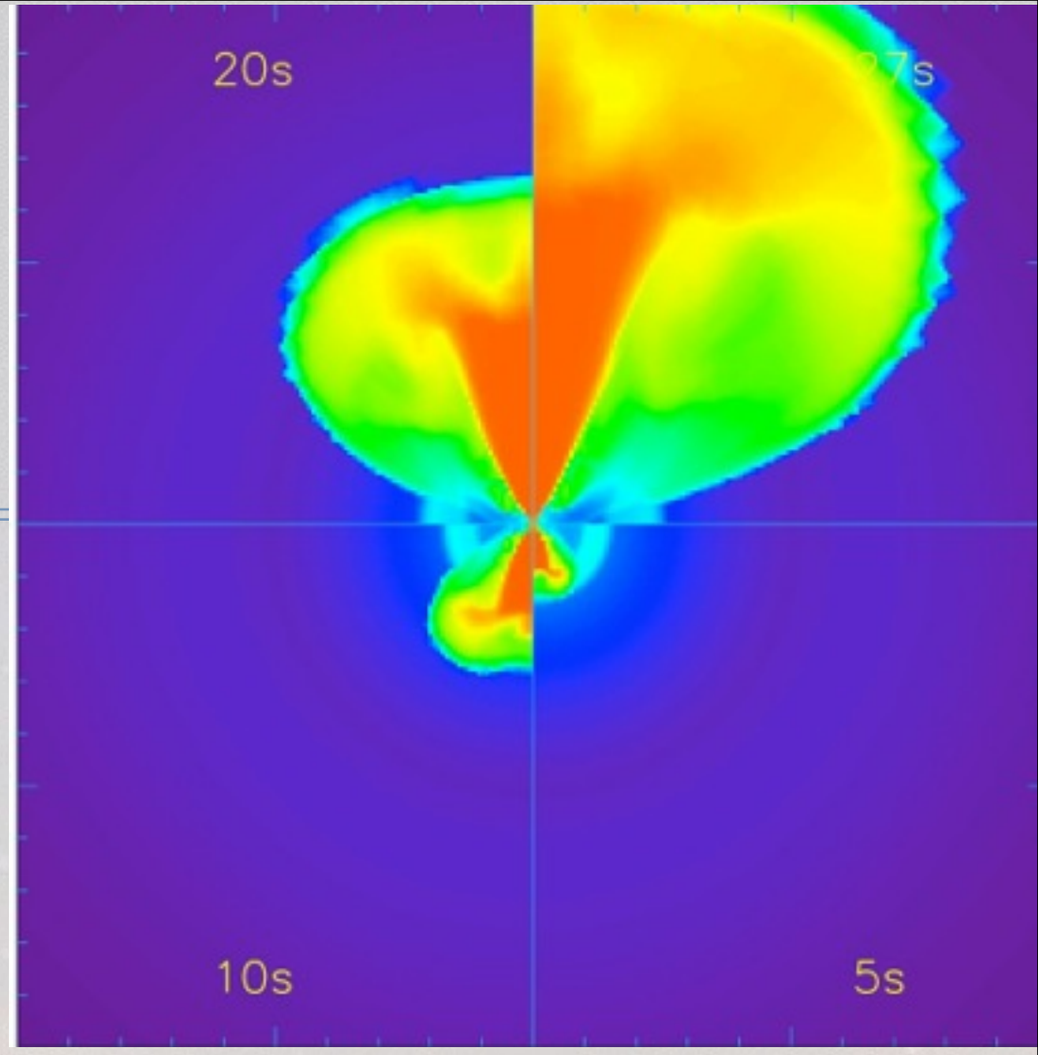
Distillation problem: Rotation

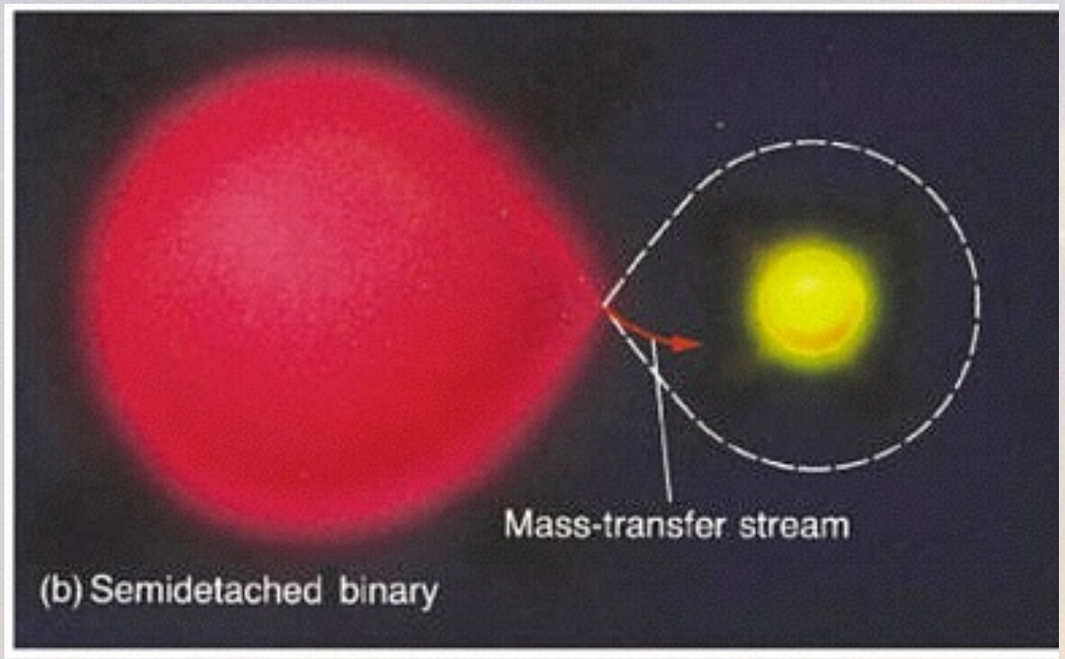




- With ~10x SN energy, you get non-relativ. explosion, v~0.1c
- Solution: beam energy into small fraction of mass.
- Result: ~1 Earth mass moving at γ=1000
- Requirements:
  - rapidly rotating star
  - beamed energy input

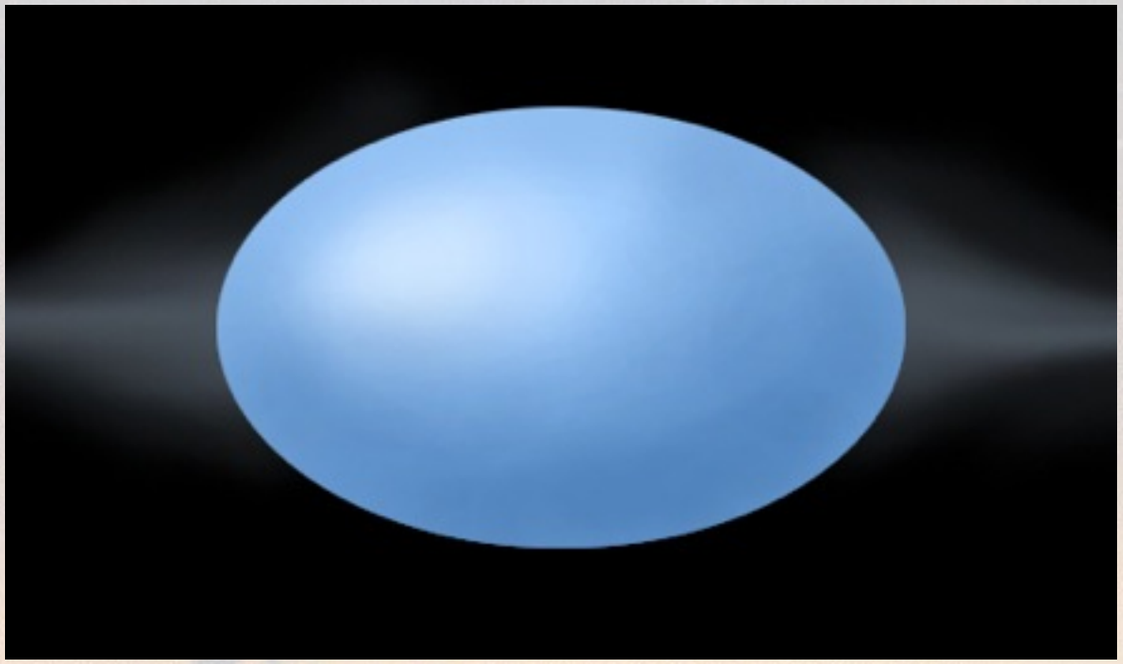
How to get fast-rotating stars?

- Single star: core shrinks - spinup, but envelope expands - spindown
  - core-envelope exchange gives slow core
- Plus: Wind mass loss carries away angular momentum



Prevention 1: binary

- remove envelope
- short binary period forces rapid spin

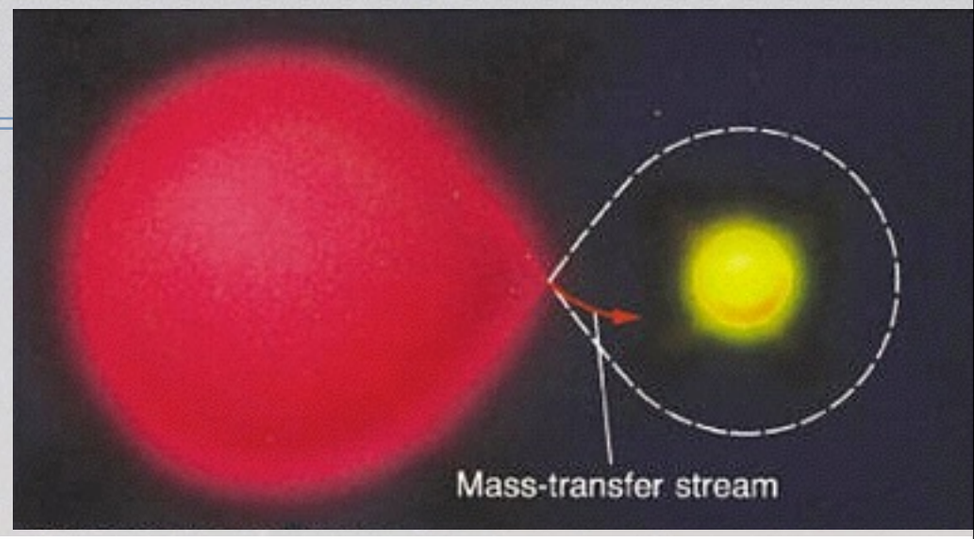


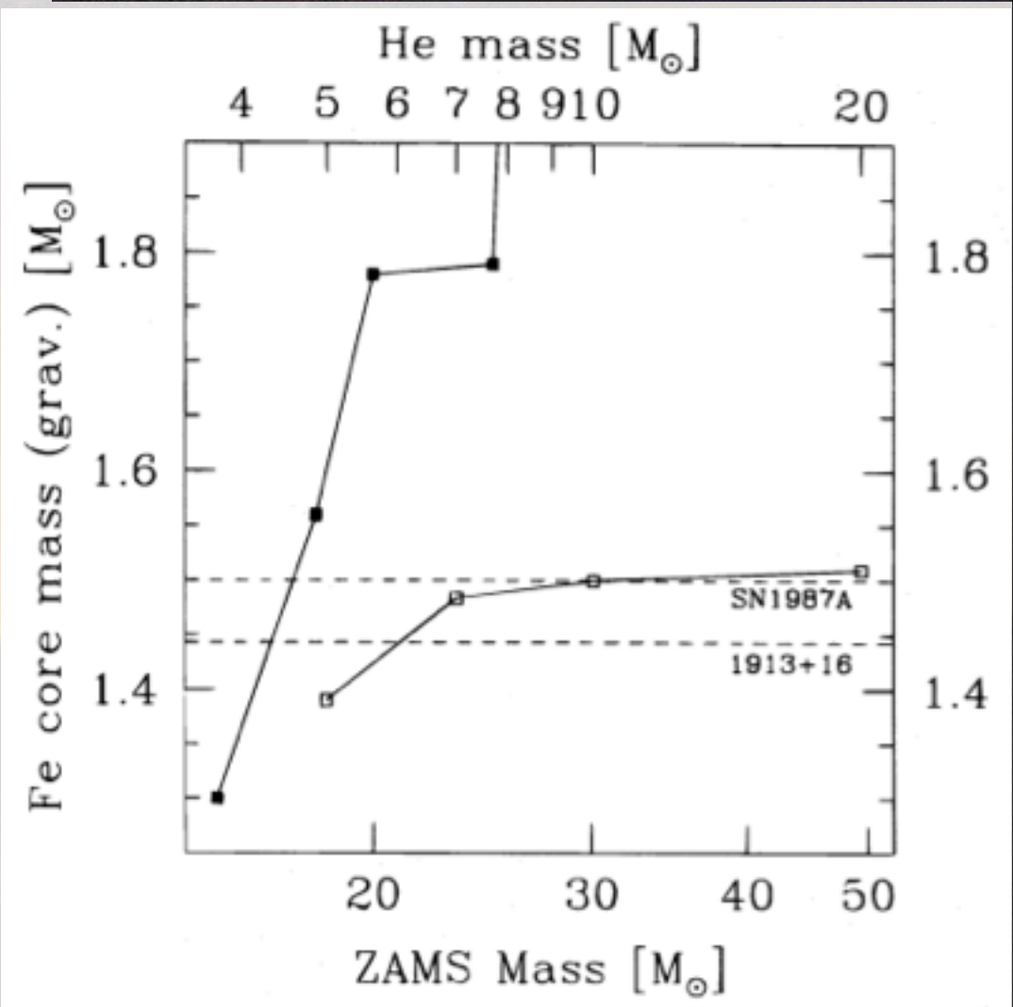
Prevention 2: fast rotation

- fast spin gives full mixing, prevents giant from forming
- only works if little wind loss

Black holes in binaries are different

- In binary, primary loses envelope
- Core evolves *differently!*
- Cannot derive BH mass limit from binary
- Later: effect reduced with better wind loss, especially at lower Z





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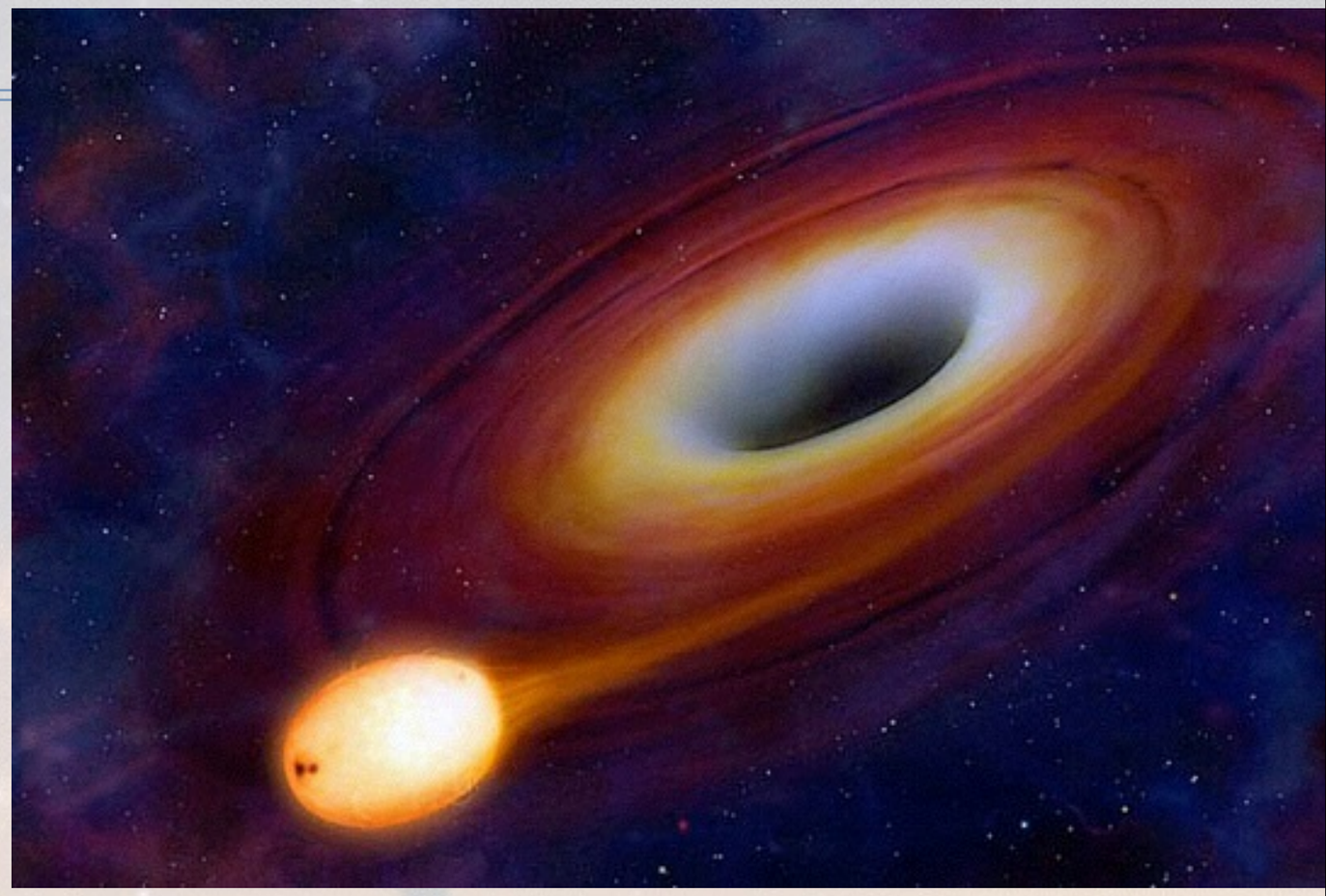
Brown, Weingartner, RW

Black-hole novae: Natural GRBs

- BH in short binary
- So fast-spinning He star made this black hole
- Exactly what a GRB needs!
- Still a good model, some spin predictions confirmed



Brown et al. 2000:
model calculations, explain strange S, Si excess in some BH binaries
Lee et al. 2002:
more extensive calculations, for whole population
Carried further by a.o. Moreno-Mendez, Lee

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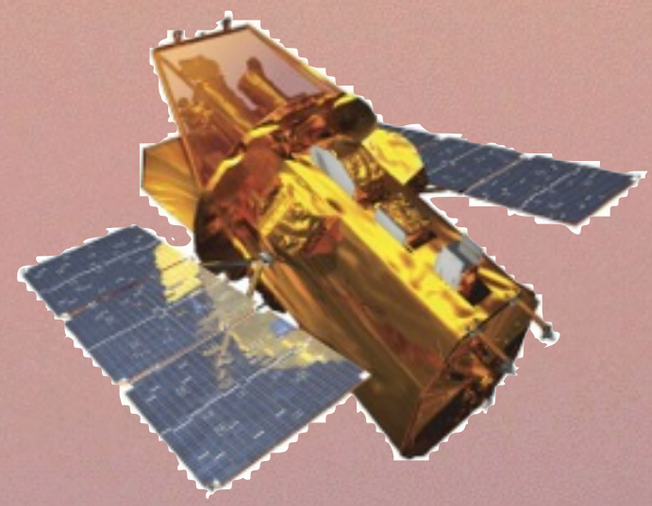
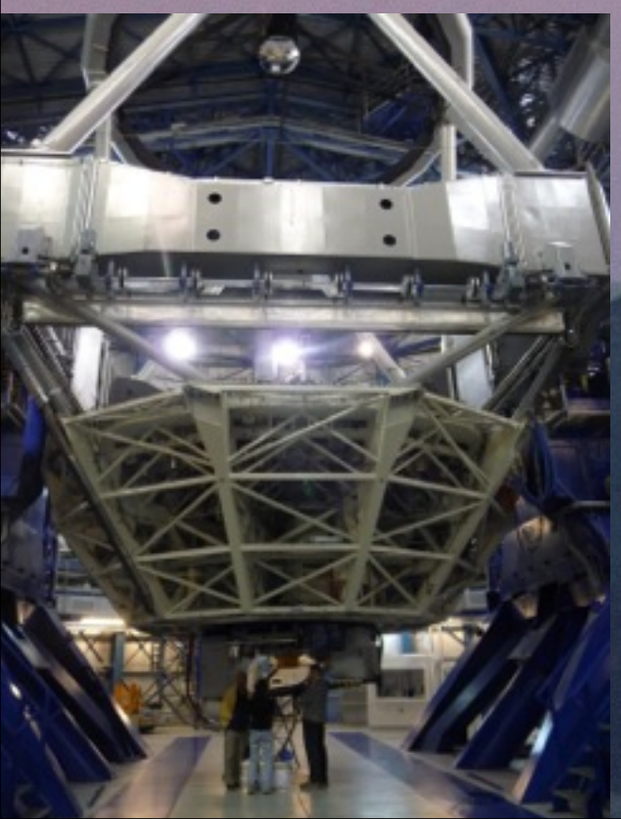
Test: winds and heavier elements

- Strongly reduced stellar winds needed to save the star from slowing down
- This can be done by reducing heavy (A>2) element content of stars, but by a lot: wind strength scales as $Z^{0.5}$
- Programme: very fast followup of GRBs, to use the spectra taken when the GRB is bright to establish Z (and z, to confuse you ...)

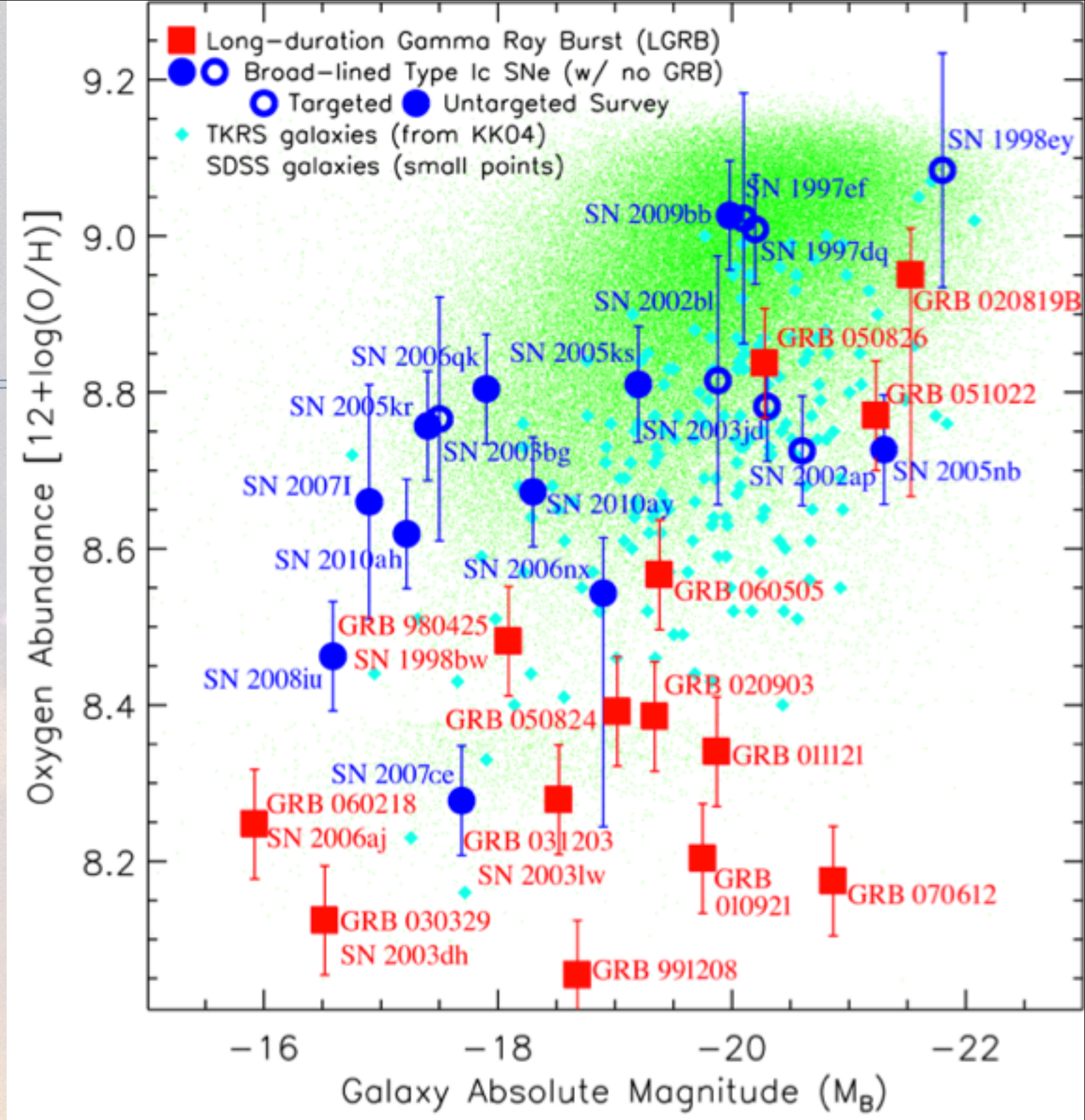
The ESO VLT/Xshooter programme





Evidence: ‘metallicity’

- GRBs favour metal-poor sites
- However, up to 0.5 solar seen
- Favours some binaries in mix



Graham & Fruchter 2013

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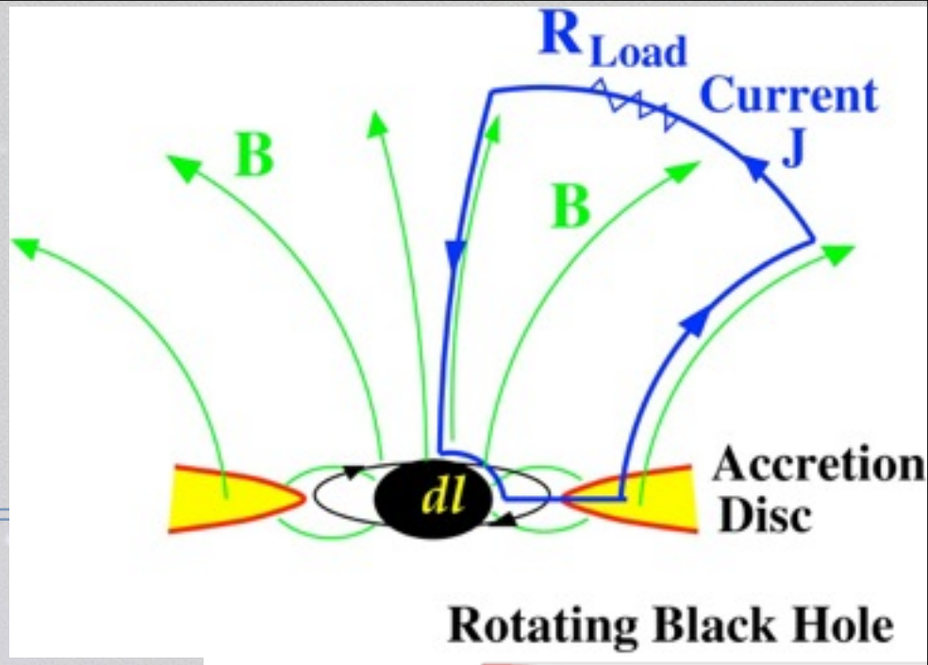
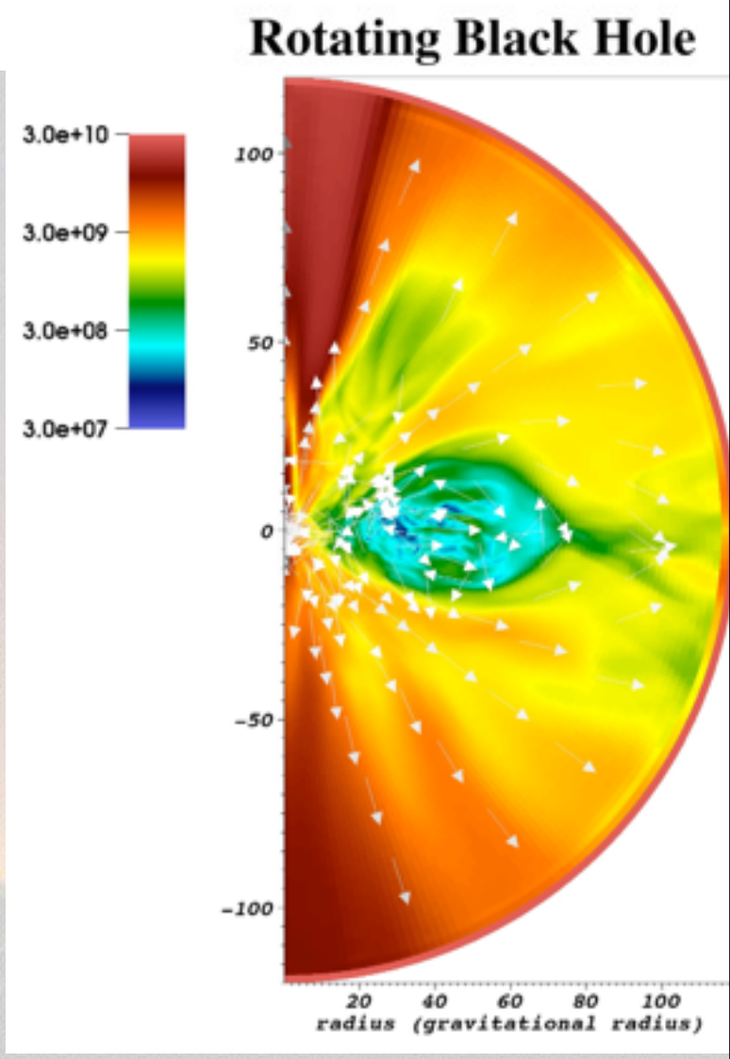
The engine: Must it be a BH?

- BH can swallow material on spin axis
- Clear channel can then let the jet out
- Magnetic powering ('Blandford-Znajek') helps
- However, highly magnetic neutron star not excluded, if you could make them spinning fast
- Intrinsic problem: the engine region is hidden

Lee (H.-K.), Brown, Wijers, 2000a,b

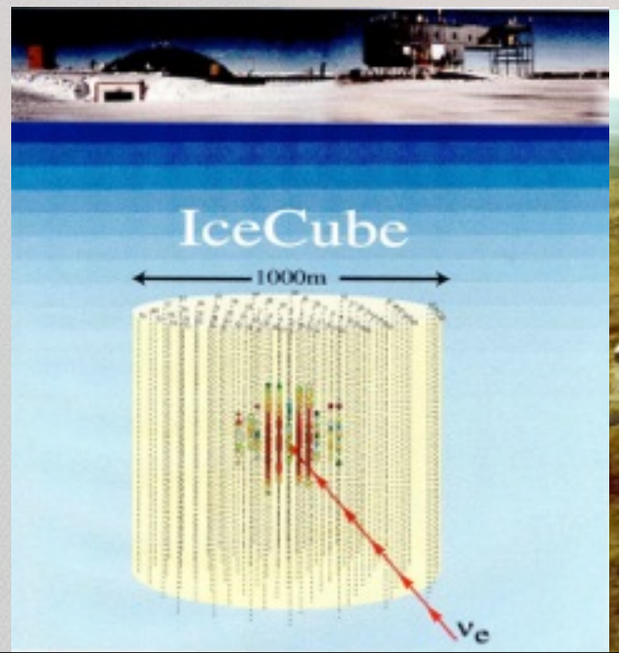




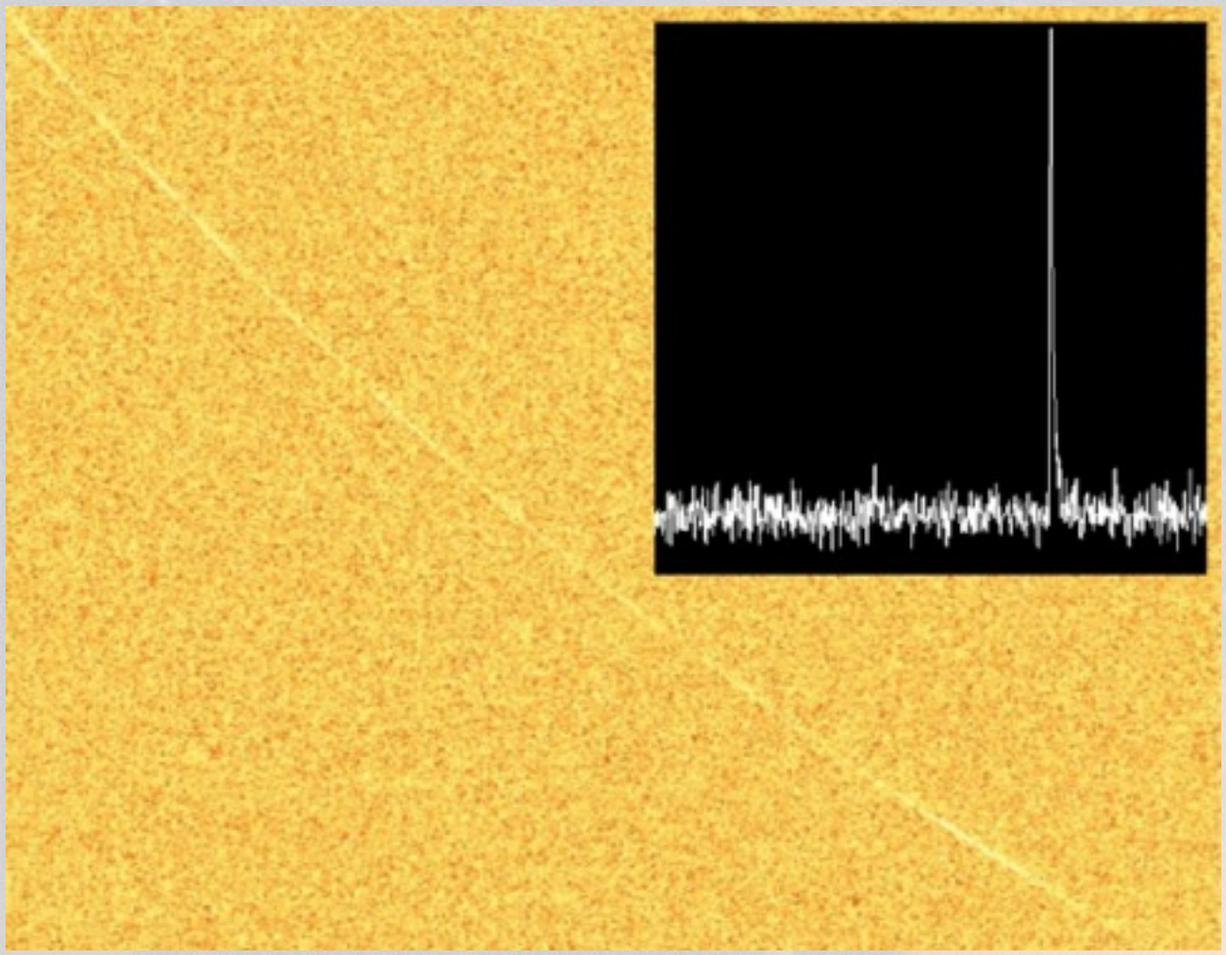
Markoff et al.

How to see the central engine? Astroparticle physics!

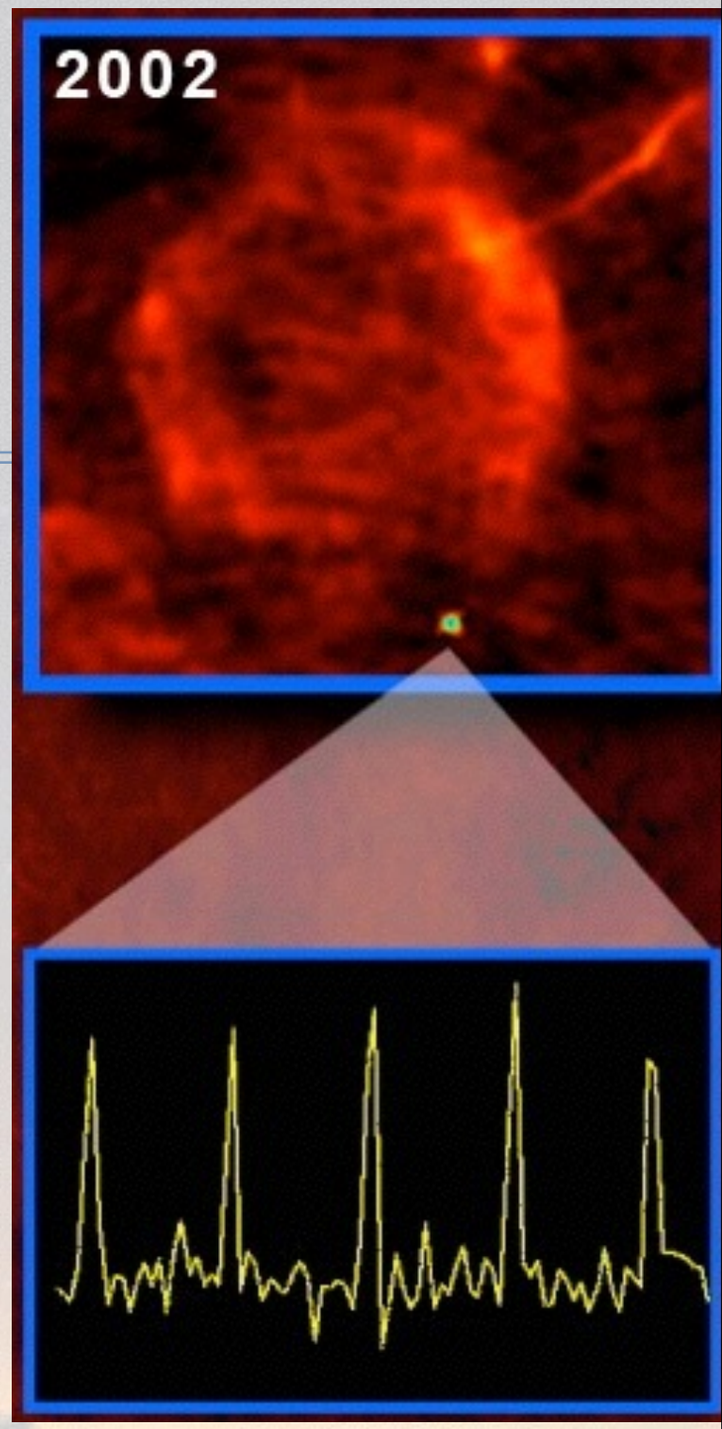
- The engine and inner outflow make:
  - photons
  - neutrinos
  - gravity waves
  - cosmic rays



And while we are at it: What other monsters?



‘Fast radio bursts’:
millisecond radio pulses, Gpc away
(Lorimer et al. 2007, Thornton et al. 2013)



‘Galactic centre burper’:
Burst every 77.102min, if anything
(Hyman et al. 2005, Spreeuw et al. 2009)

Monster Searcher: LOFAR

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Conclusions

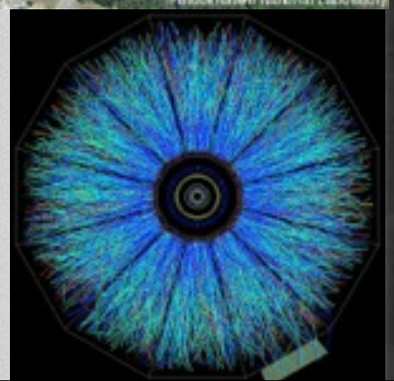
- Binary black hole models for gamma-ray bursts are alive and well, continue to be interesting research line
- Gamma-ray burst progenitors are being slowly elucidated, and at the same time used to unveil cosmic history
- The intrinsic GRB mechanism remains a tough problem, but calculations are now getting beyond sketches and schematics
- There are even weirder explosions out there

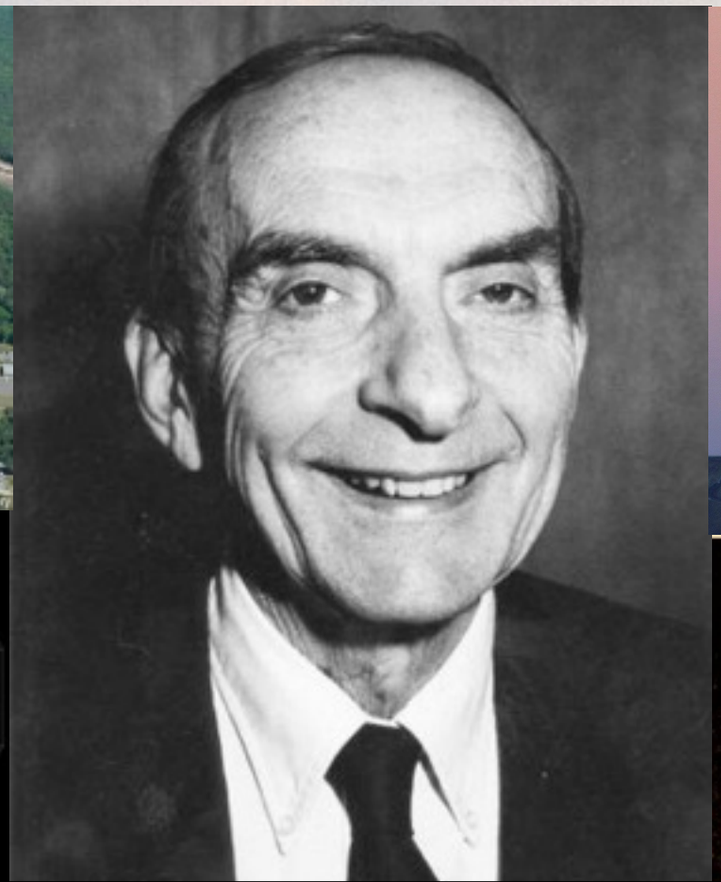
Take-home questions

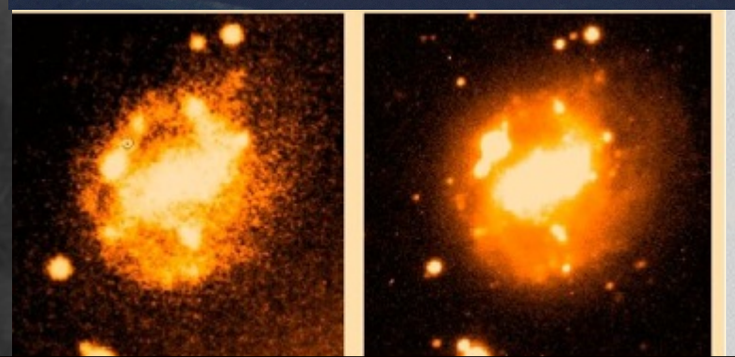
- How fast must a black hole really spin to make a gamma-ray burst?
- What if it spins more slowly? Could it make a weird supernova?
- What is the connection between supernovae and gamma-ray bursts? Very different mechanisms from similar starting point. Can you mix them? What do you get then?
- What are these Fast Radio Bursts? Where is the real limit of what Mother Nature can throw at us?

Physics & Astrophysics
Gerry's Congenial Genius

- 'Two sciences divided by the same laws of nature'
- Gerry knew the differences, but did not care; he just used the good bits of both







Os homini sublime dedit caelumque videre
Iussit et erectos ad sidera tollere vultus

Humanity was given uplifted eyes,
To regard the stars and ponder the skies

(Ovidius, Metamorphoses, book I: creation)