„Catastrophic Accretion“

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GRB observations

Gamma Ray Burst (GRB)

-first accidentally detected in the 70s

-0.1..1000s burst in hard ♑-rays

-divided in short (<2s) and long (>2s) bursts

-enormous energy-output <10^{54}erg

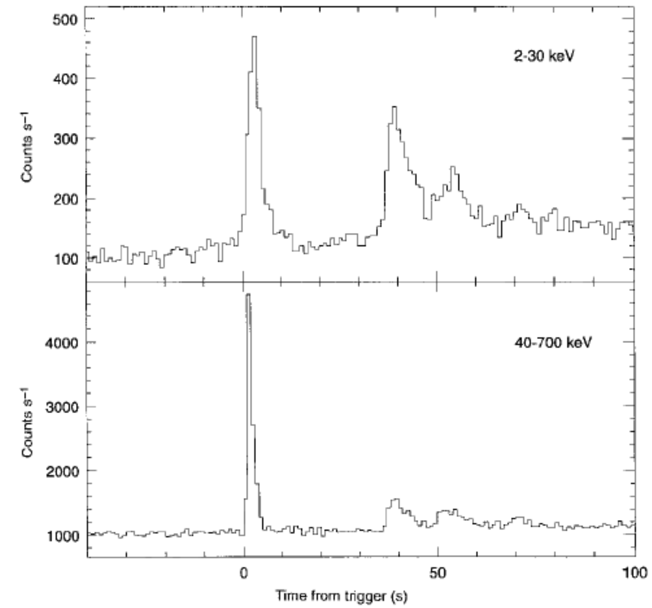
-ms-variations

→ GRBs linked to SN/BH creation

→ beaming assumed

→ inner engine r~100km (for ms-variations)

→ NS/BH as host system



from: Costa, et al, Nature 387,783

from: Paradijs, et al, Nature 386, 686

GRB optical afterglow (AG)

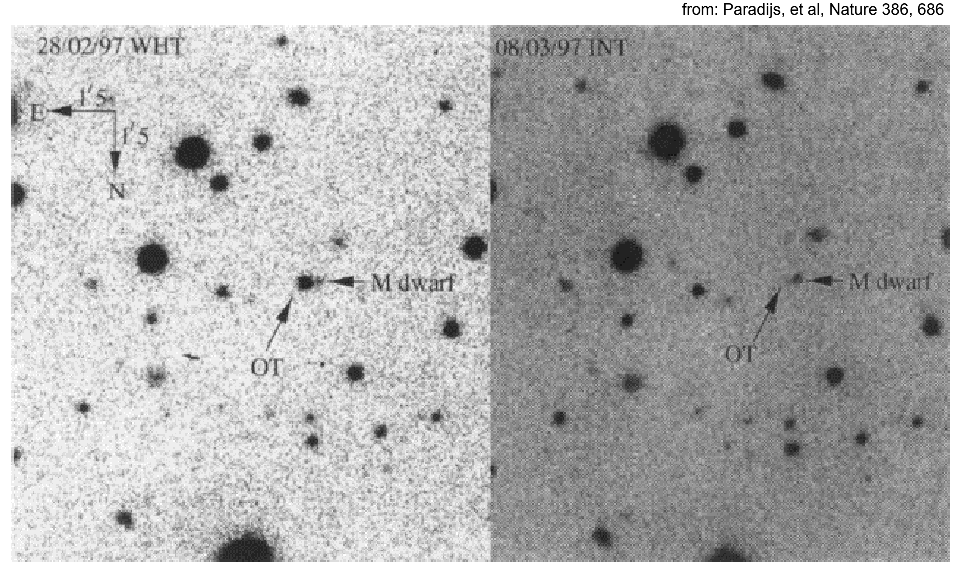
-power-law in luminosity and flux

$$f(\nu,t) \propto \nu^{-\alpha} t^{-\beta} \quad \alpha \approx 1,4 \quad \beta \approx 0,9$$

-non-thermal spectrum

-distinct colour

-observable for several days

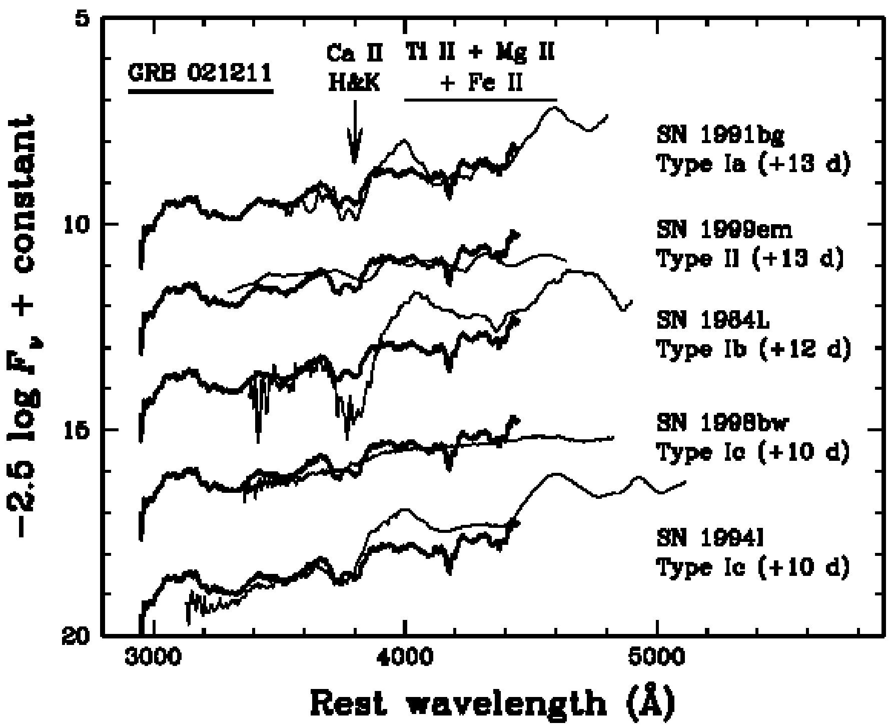


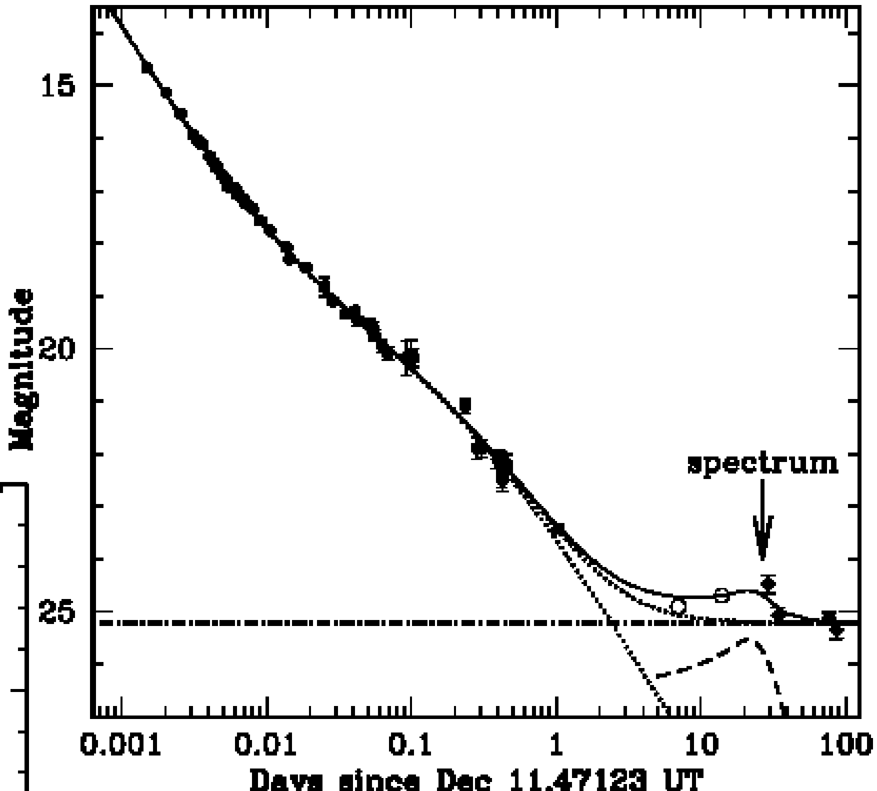
GRB observations

GRB-SN link:

-Re-brightening in the AG → SN bump

-Spectrum matches with SN spectra.





From: Della Valle, et al., A&A 406

"Hyper"-Accretion

Motivation:

-where does the energy for the powerful burst come from?

-about 1$M_\odot$ converted into photons of 10^{54} erg in about 1 second

-efficiency for $E_{grav} \rightarrow E_{phot}$ 5% for non-rotating BH
42% max. rotating BH
<10% for NS

→gravitational energy released

→fast accretion to compact object (rates of $M_\odot$/s)

→black hole or neutron star

Mechanisms:

radial fall of matter: -inefficient due to fast falling

accr. form disk: -poles cleared as path for jet
-balance of centrifugal force (angular momentum) and gravity
-slow, deep fall with high energy output

→ need rotation

Accretion-disk

Accretion to BH:

-relativistic potential has maximum at $3R_{schwarzschild}$

-at this radius perturbations move matter as fast into the BH as new matter arrives from the outer side

-$R_{schwarzschild}$ (event horizon) would be reached in $\sim 10^{-4}$s of free fall

→ no time to radiate away energy

-fast rotation slows the fall into the BH

→ more energy is transported away before the mass reaches event horizon

-cooling via neutrino emission (because hot disk is optically thick)

$$e+p \rightarrow n+v$$

$$e+n \rightarrow p+v'$$

$$e+e' \rightarrow v+v'$$

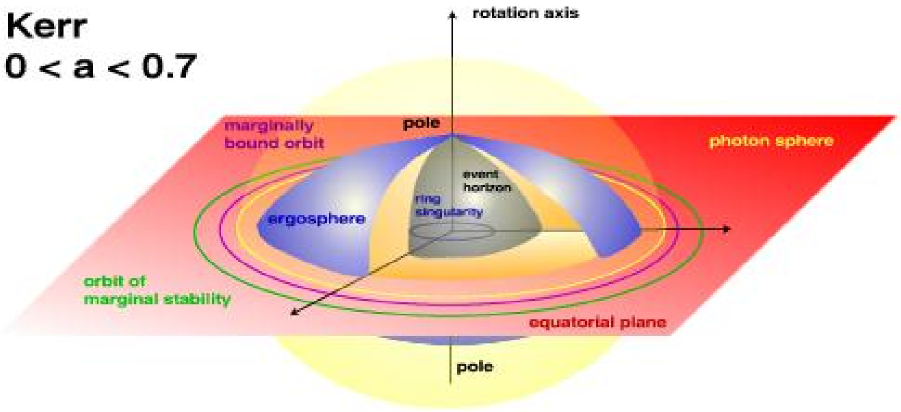
→ No photon emission

→ MeV Neutrinos

Accretion-disk

Blandford-Znajek-Mechanism:

- bring rotational energy from BH to the jet by magnetic coupling to the disk
- magnetic field topology transformed into torus by co-rotation with BH
- "gravimetric dynamo"



→ extraction of energy, reduction of BH rotation

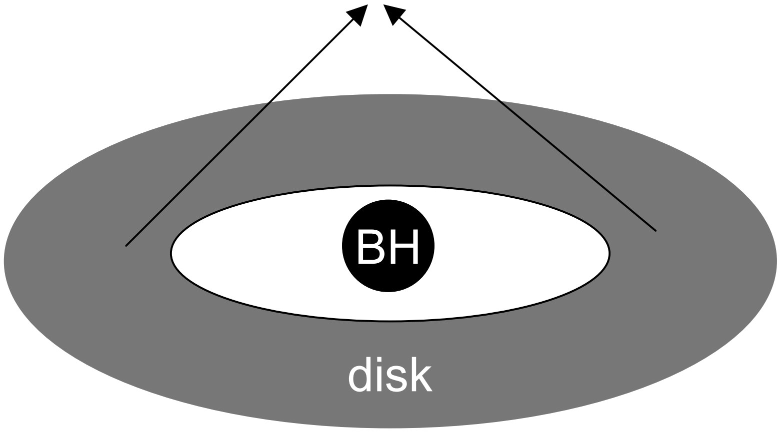
Jet formation

Neutrino-annihilation driven:

- Neutrino annihilation to inject energy from the disk to the jet.
- Neutrino flux must be high to overcome small cross-section.

v v’ → $e^+ e^-$ → ♑♑

→ Hydrodynamic gradient



The jet

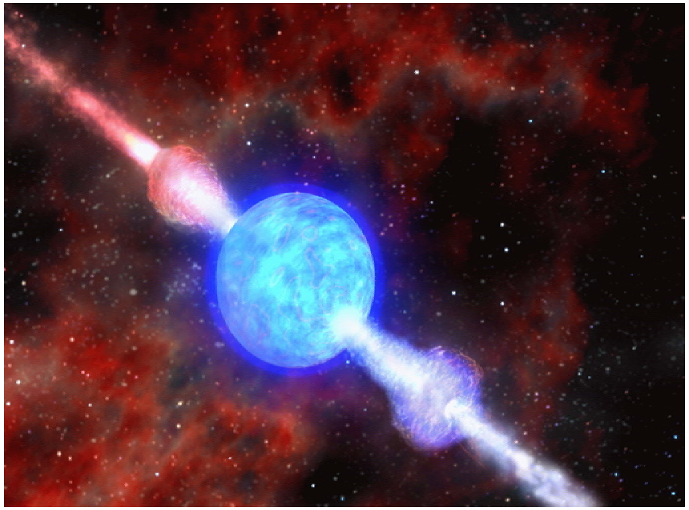
Idea of a jet:

- fast (relativistic ☝>100) stream of matter (p, e^-, n?)
- breaking out of the host system along it's rotational axis
- bound into cone by magnetic fields
- shocks in the jet by different flow velocities

→ GRB gamma photons

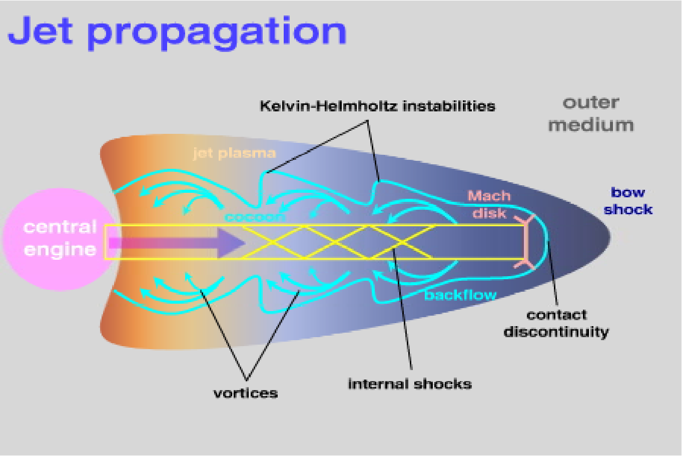
- hitting interstellar medium causing shocks in the jet

→ Afterglow



Physical processes in the jet to produce GRB:

- synchrotron radiation (electrons gyrating around magnetic field lines)
- bremsstrahlung (electrons de-/accelerated in internal shock fronts)
- inverse compton scattering (photons scattered to higher energies)



From accretion-disk to jet formation

Example: Collapsar model

Phase 1 (2s): "disk formation"

-matter in free fall

-angular momentum adds up

→ Accretion disk forms from the inside

→ simulation at 0.7s

Phase 2 (15s): "quasi steady state"

- mass transfer from disk to BH equals mass input from outside the disk
- accretion rate up to $1 M_\odot/s$ – $10\ M_\odot$ in total
- energy transfer to the poles by neutrino-annihilation and/or MHD

→ GRB start

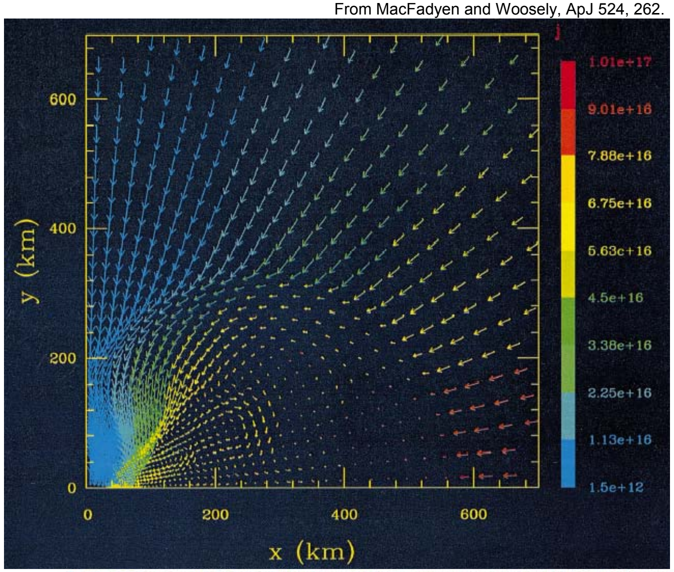
→ simulation at 7.5s

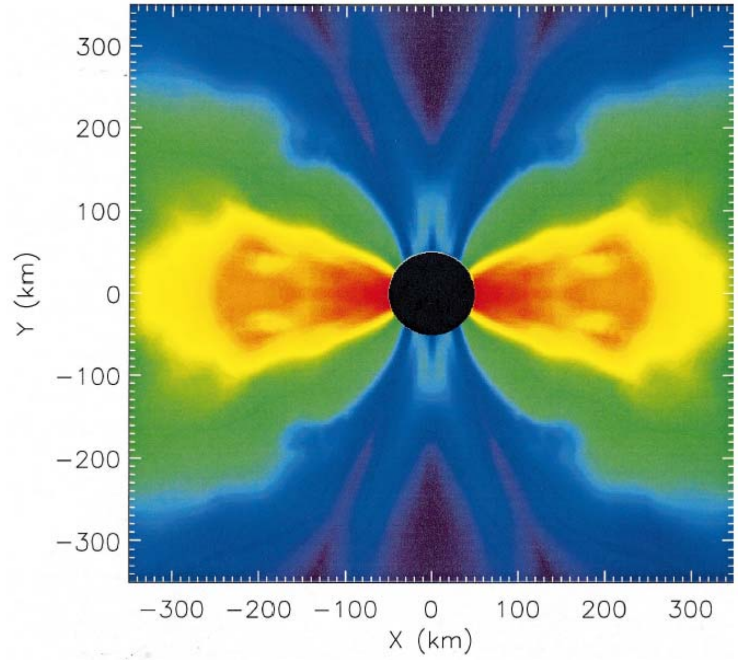
parallel: "explosion"

-energy deposition along rot. axis of BH

→ jet formation

From MacFadyen and Woosely, ApJ 524, 262.





The stage for long bursts

Statistics:

-1 SN/galaxy in 100 years

-1 GRB/galaxy in 100.000 years

→ not every SN (not even every Type Ib/c) triggers a GRB

Requirements for GRB progenitor:

→ star must form black hole (initial mass ~20$M_\odot$)

→ star must have lost is H-envelope (otherwise breakout-time to long)

→ rotation must form disk prior to outburst

The stage for long bursts

Single star as host system:

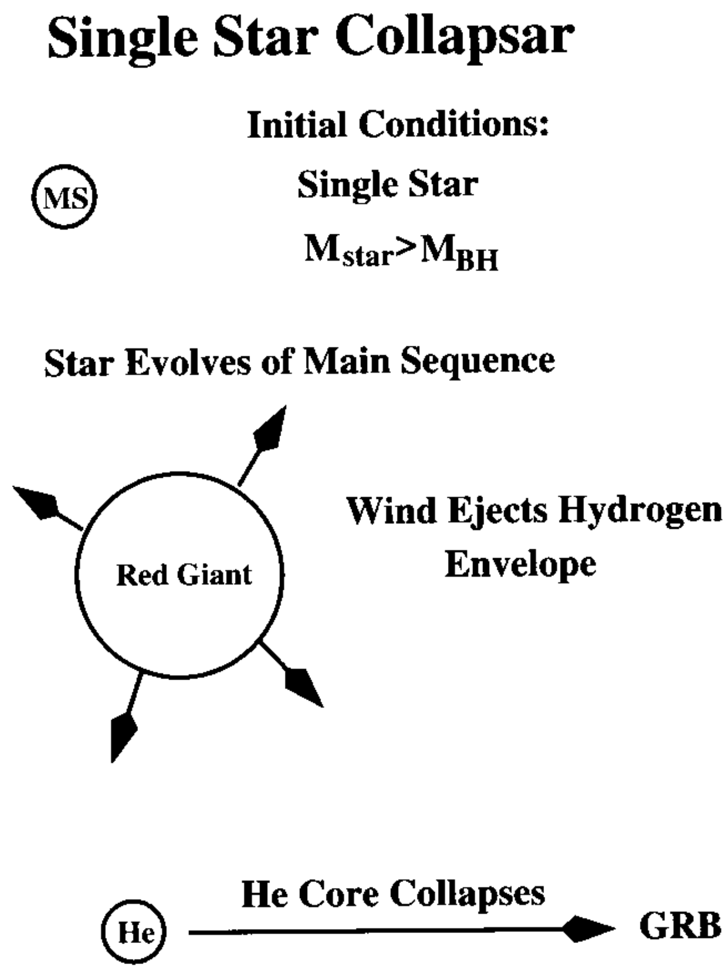
ok: star must form black hole (initial mass ~20M$_\odot$)

ok: no H envelope

no: rapid rotation

When H envelope is blown away in a wind this will take angular momentum out of the system.

→ Think about binary system.



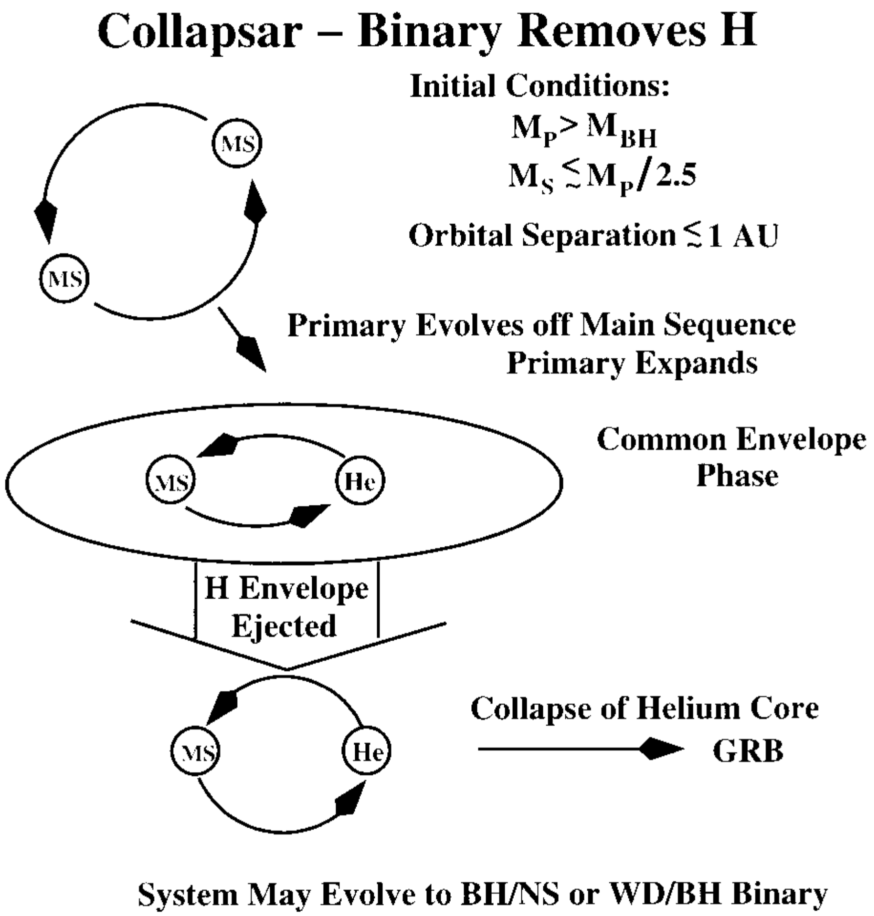
The stage for long bursts

Binary system as host system:

- hydrogen is lost in common envelope phase.
- some angular momentum of the star is lost, but ang. momentum of system remains.

Calculations involving magnetic shear flows show that rotation is still not fast enough to produce a collapsar disk.

→ Binary system in same stage of evolution (by Fryer 99)

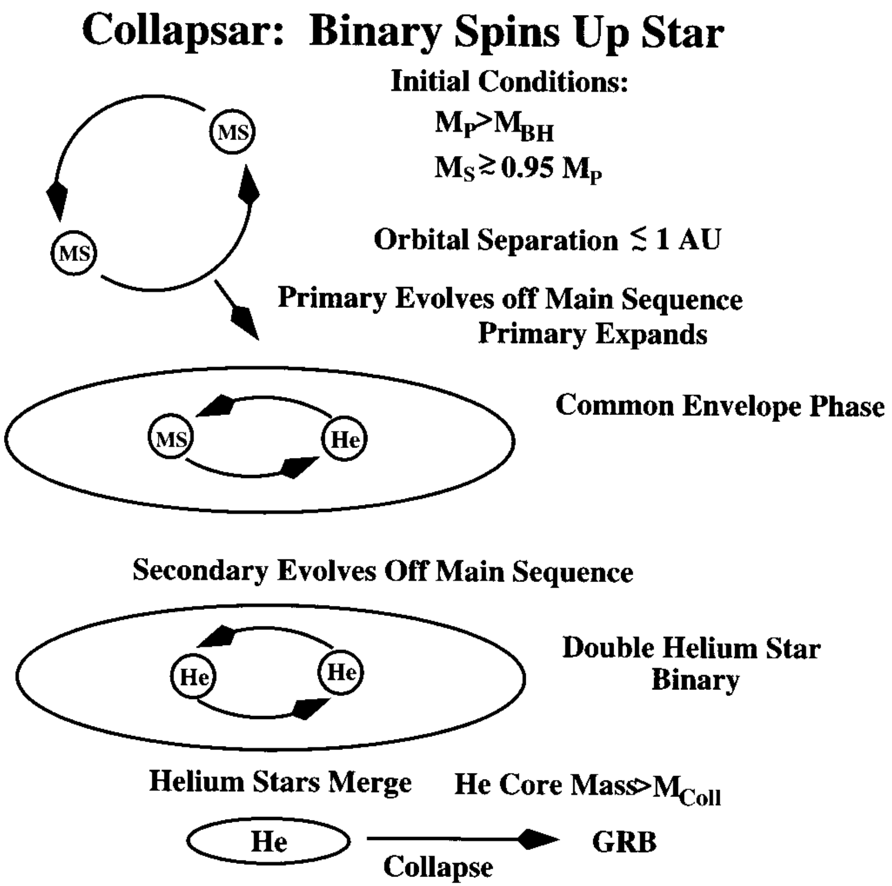


The stage for long bursts

Binary system with both stars in same stage of evolution:

- core merger spins up the central mass and produces a disk upon collapse.
- this scenario is a rare case, can it explain the number of observed GRB?

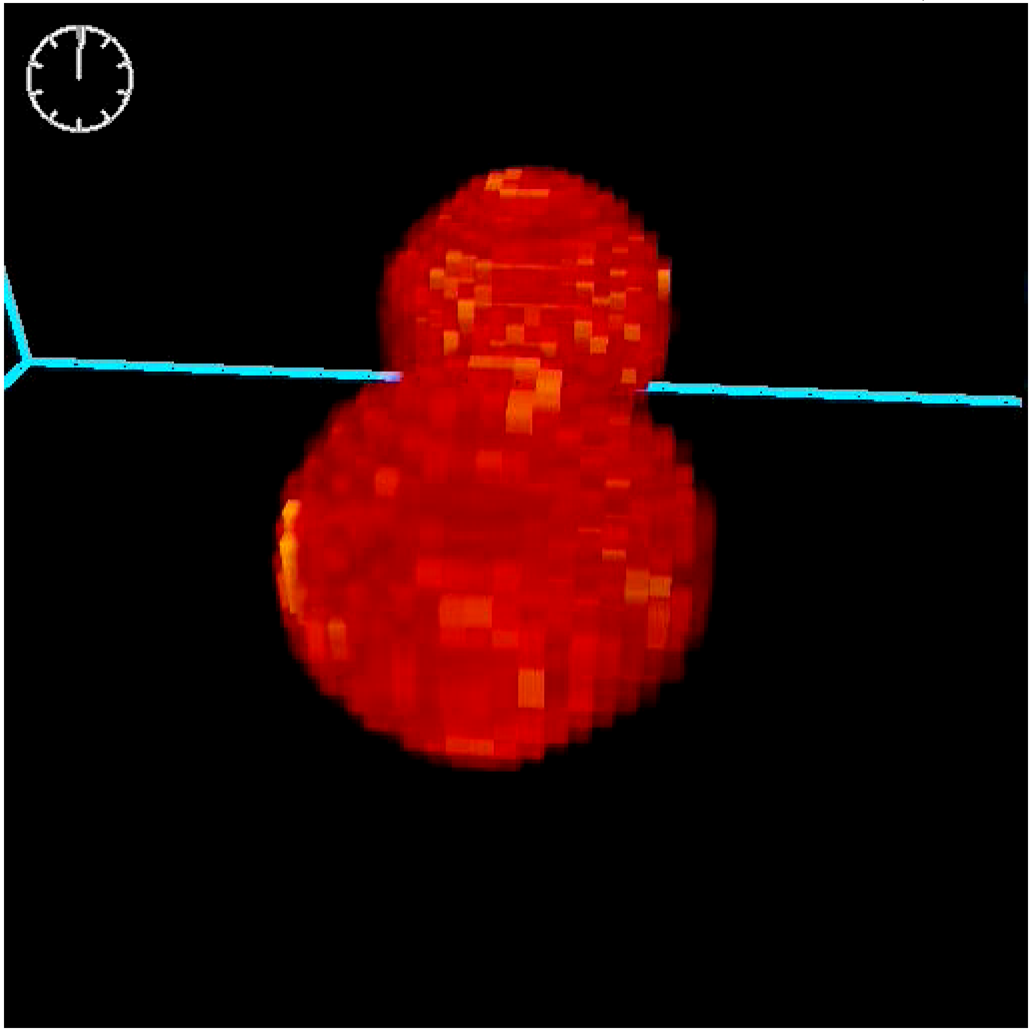
Alternative: Binary system with BH



Computational models…

From: Janka et al., MPA website.

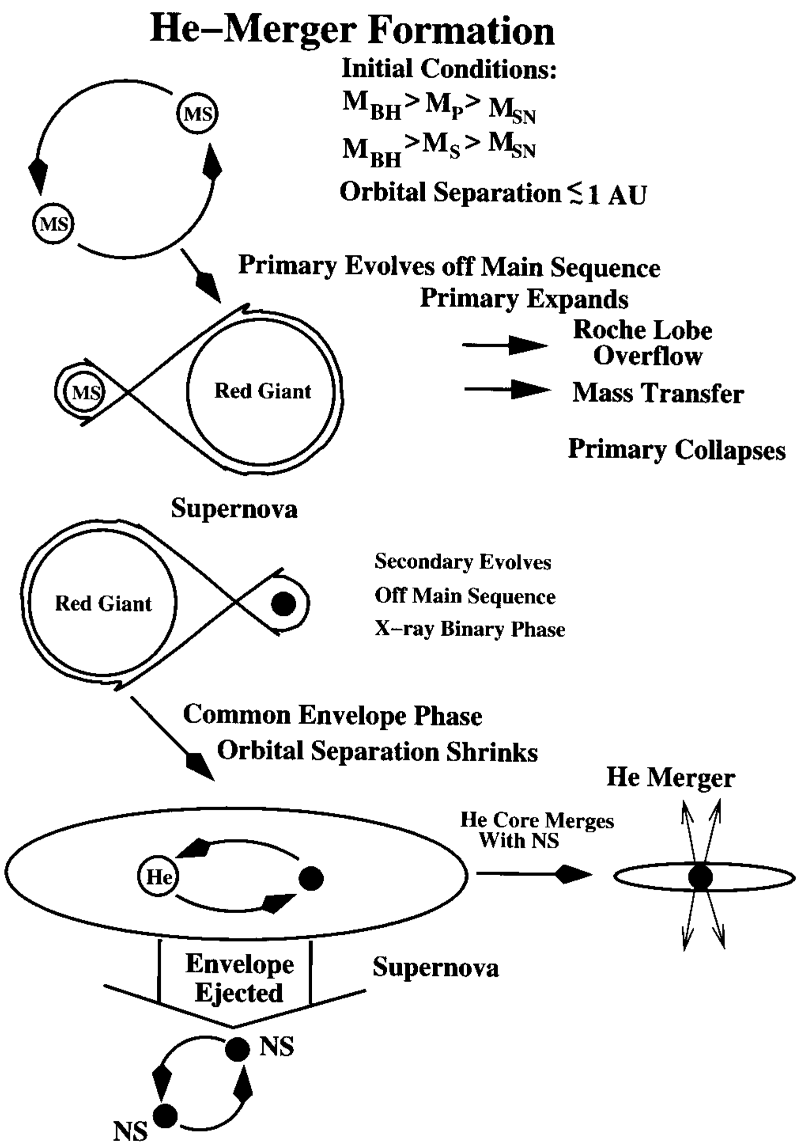
Binary system merging in fractions of a second, heating up – leading to BH creation.



The stage for long bursts

Binary system with black hole:

very small margin for total ang. momentum



The stage for SHORT bursts

Neutron-star merger (idea of Paczynski 1986)

binary NS ꝏ BH(2,5$M_{\bullet}$) + disk(0,1..0,2$M_{\bullet}$)

Accretion rate 🕔 1$M_{\bullet}$/s

■luminosity 🕔 10^{53} erg/s

Neutron-star merging with black-hole (idea of Paczynski 1991)

BH + NS ꝏ BH(3$M_{\bullet}$) + disk(0,5$M_{\bullet}$)

Accretion rate 🕔 1..10$M_{\bullet}$/s

■ luminosity 🕔 10^{53}.. 10^{54}erg/s

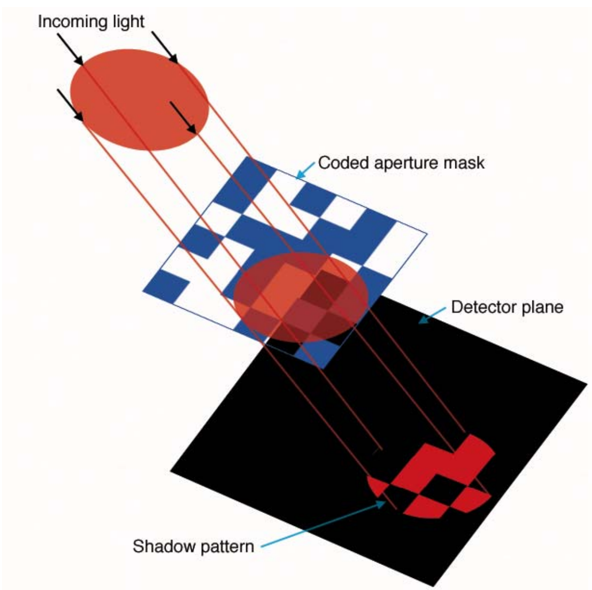
Experimental outlook…

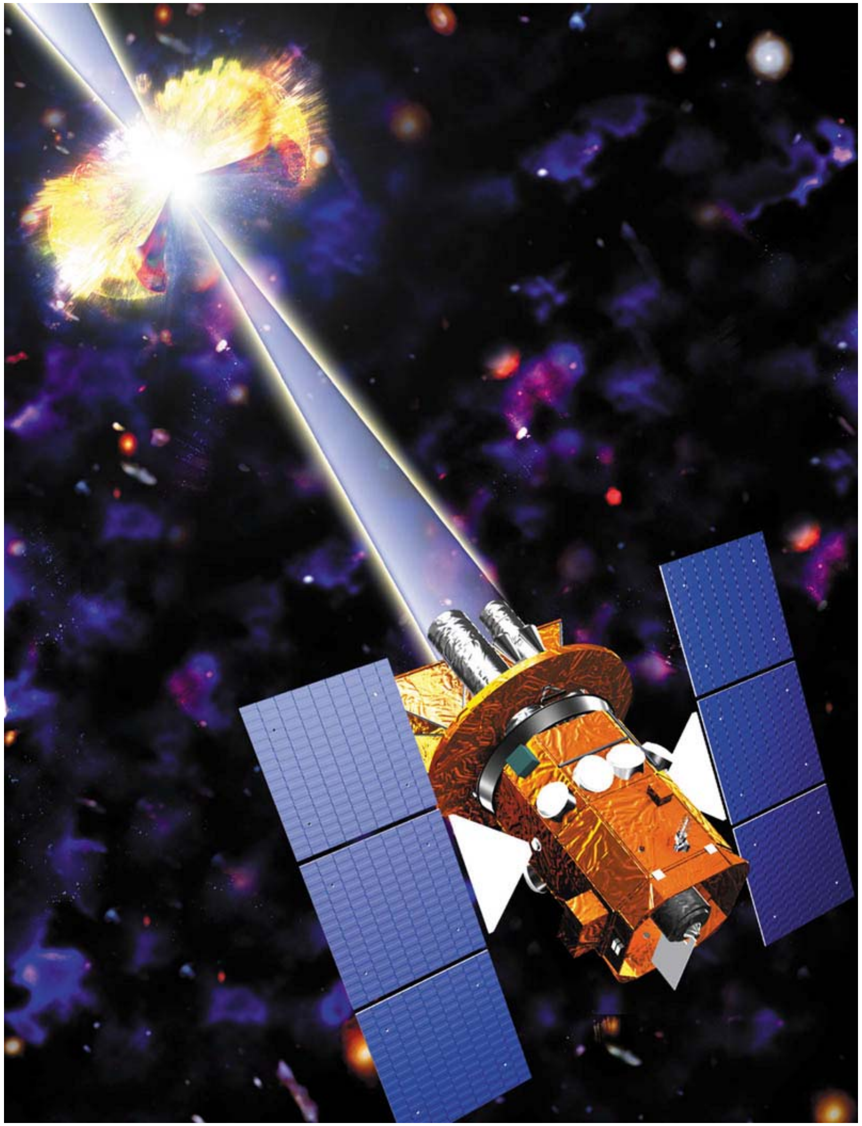
Swift

- to observe high energy emissions with coded mask
- automatically detect GRBs by sudden rise in count rate and alert astronomers at numerous experiments

-imaging in UV

-observation data is immediately public



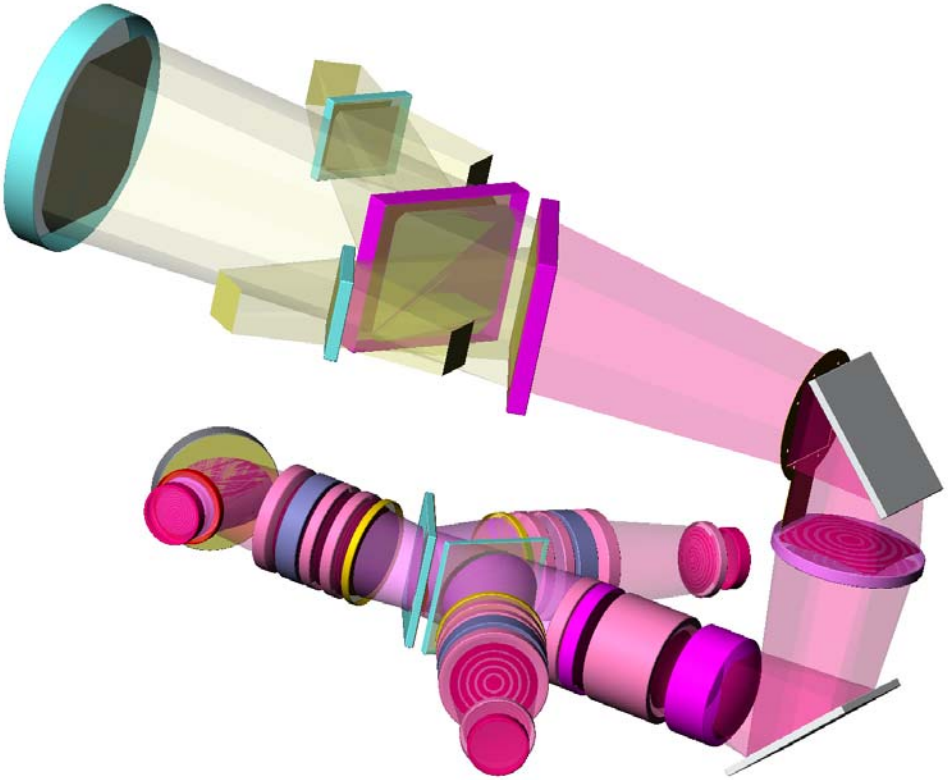


Experimental outlook…

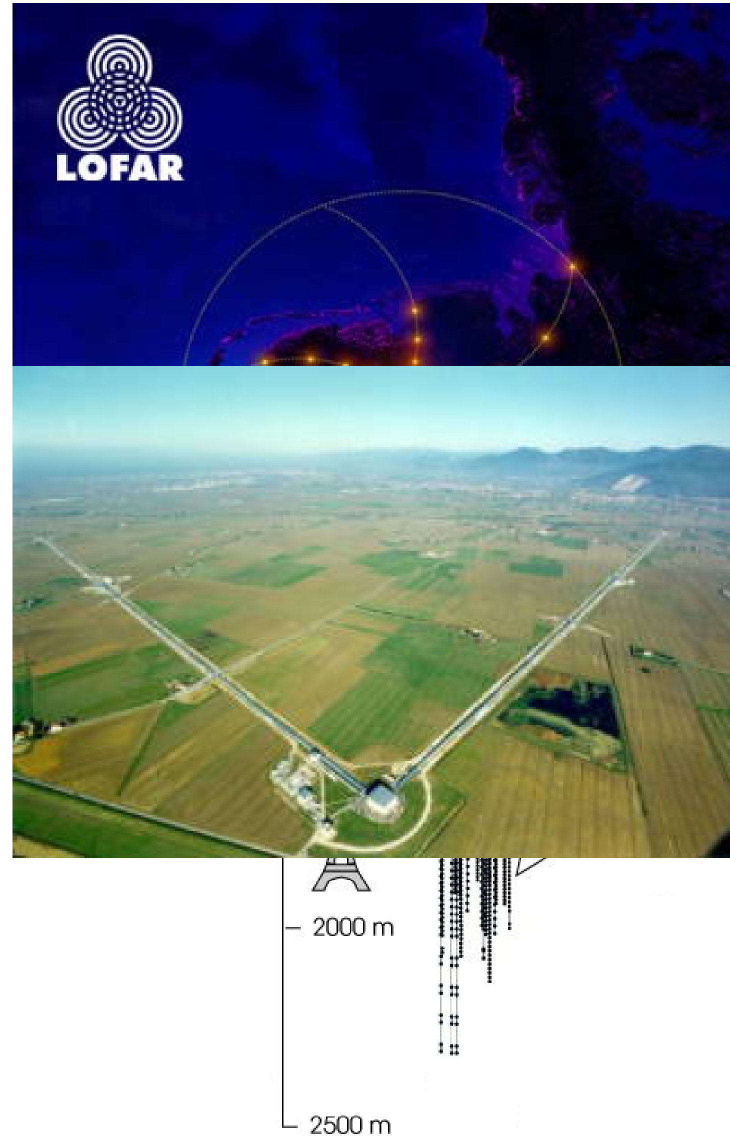
Grond

- imaging in 7 bands from optical to IR
- fast follow-up of AGs to learn about AG properties automatically detect the redshift of bursts to enable quick observations with sensitive spectrographs
- make a redshift statistic to use GRBs for cosmology
- first instrument to measure AG colors simultaneously in one instrument

- technically challenging because of thermal and optical issues



Experimental outlook…



LOFAR

- distributed radio telescope for the MHz-Band
- computationally challenge is the combination of >1000 antennas spread over Europe to aperture synthesis (data rate: TB/s)

→ could receive radio-photons from GRB inner engine

Gravitational Waves (Virgo)

- Michelson-style interferometer with km of baseline

→ might detect gravitational waves caused by accretion, merger, BH spinup

Neutrino Detectors (Icecube)

- Cherenkov-light from Neutrino-Mass interaction
- very small cross-section, therefor 1km³ of antartic ice with PMTs.

→ detect GeV, TeV neutrinos from GRB jet

Further reading…

Institute Library:

- Fryer, C. L., “Stellar Collapse”, Kluwer Academic Publishers, 2004

ADS or arxiv.org:

-Popham, R., “Hyperaccreting black holes and gamma-ray bursts”, ApJ 518, 356

-Narayan, R. “Accretion models of gamma-ray bursts!, ApJ 557, 949

-Fryer, C.L., “Binary merger progenitors for gamma-ray bursts and hypernovae”, astro-ph/0412024

Have a nice weekend!