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後希格斯與普朗克粒子物理與宇宙學國際研討會
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Neutrinos from the centre of GRB

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Outline

- **Gamma-ray Burst**

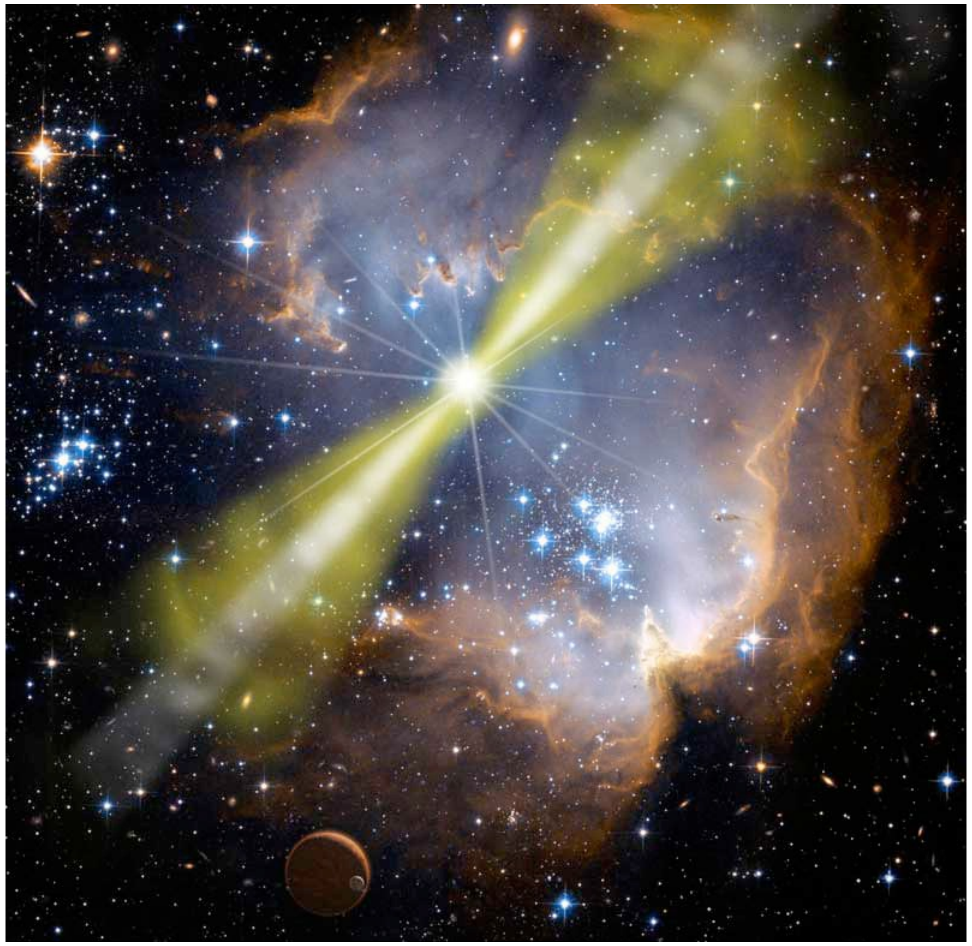
  & its central engine —— Neutrino-Dominated Accretion Flow

- **Global Neutrino Heating in the NDAF**

- **Diffuse Neutrino Background of GRB**

Gamma-ray Bursts (GRBs)

- **Gamma-ray Bursts —— Brightest Explosions Since the Big Bang**



- are extragalactic (isotropic distribution)
- release ~ 10^{47} - 10^{54} ergs in a few seconds

  (sun: 10^{33} erg/s; supernova: 10^{51} ergs/month)
- followed by a longer-lived “afterglow"

two populations of GRBs:

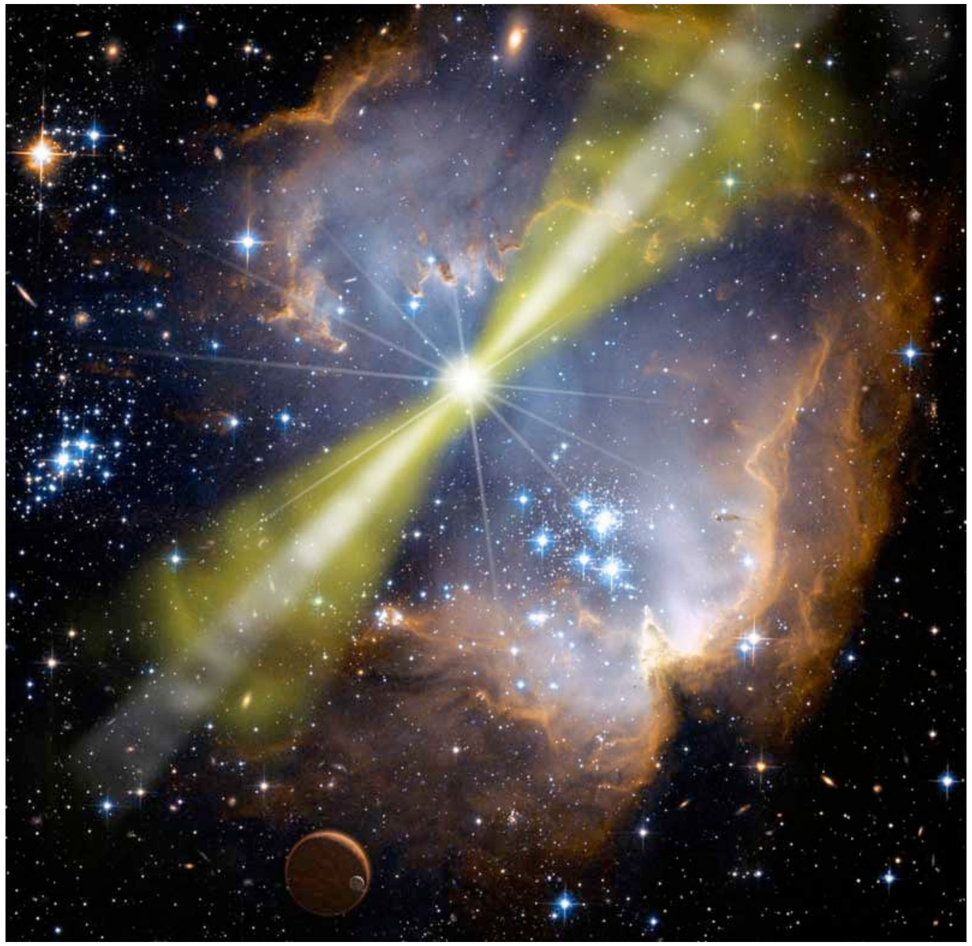
- Short Bursts (few milliseconds to 2 seconds)

  N*+N* or N*+BH merger
- Long Bursts (2 seconds to several minutes)

  core collapse of a hypernova

Central Engine

- the central engine should be able to drive an relativistic outflow with extremely high luminosity and energy



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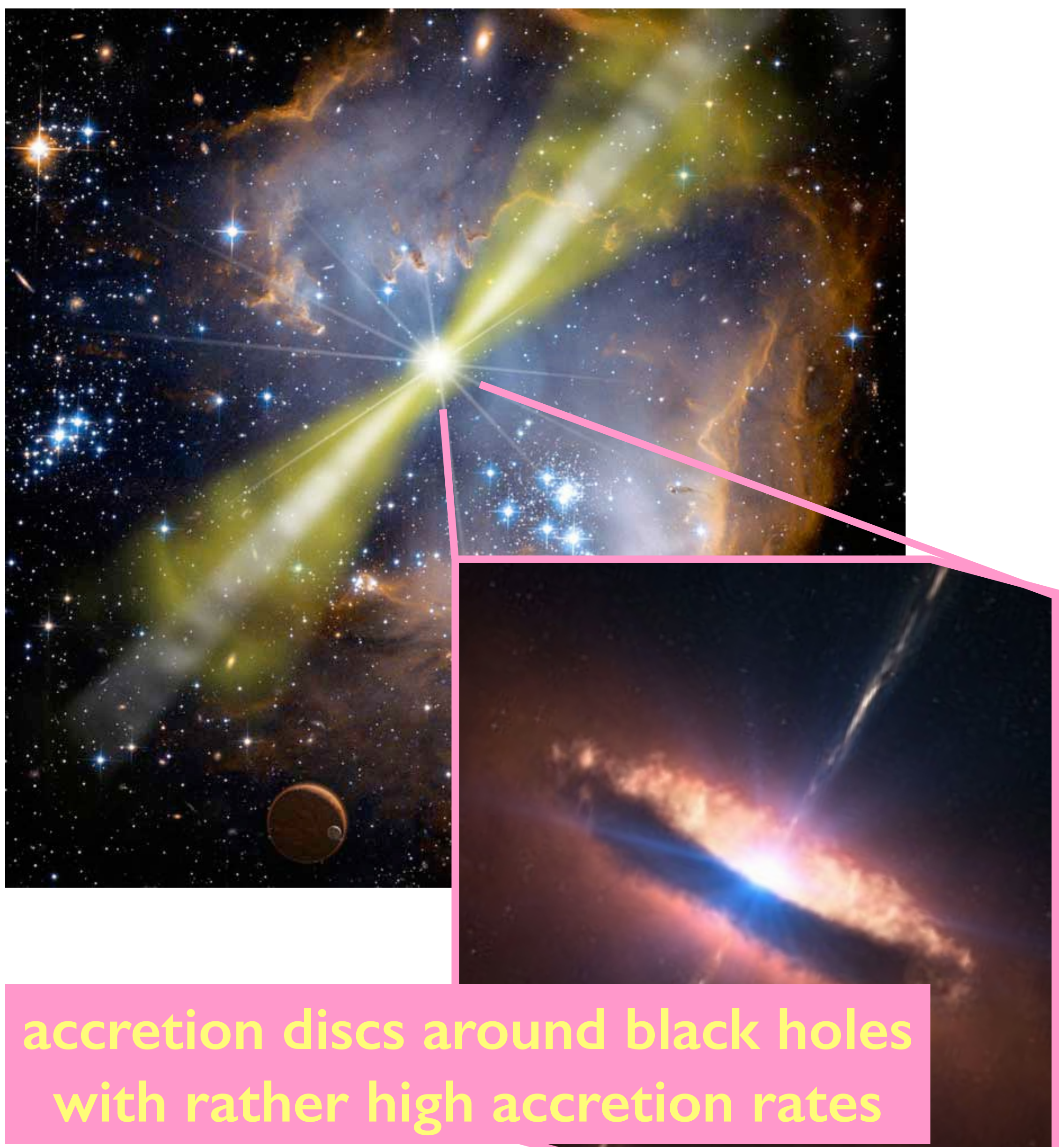

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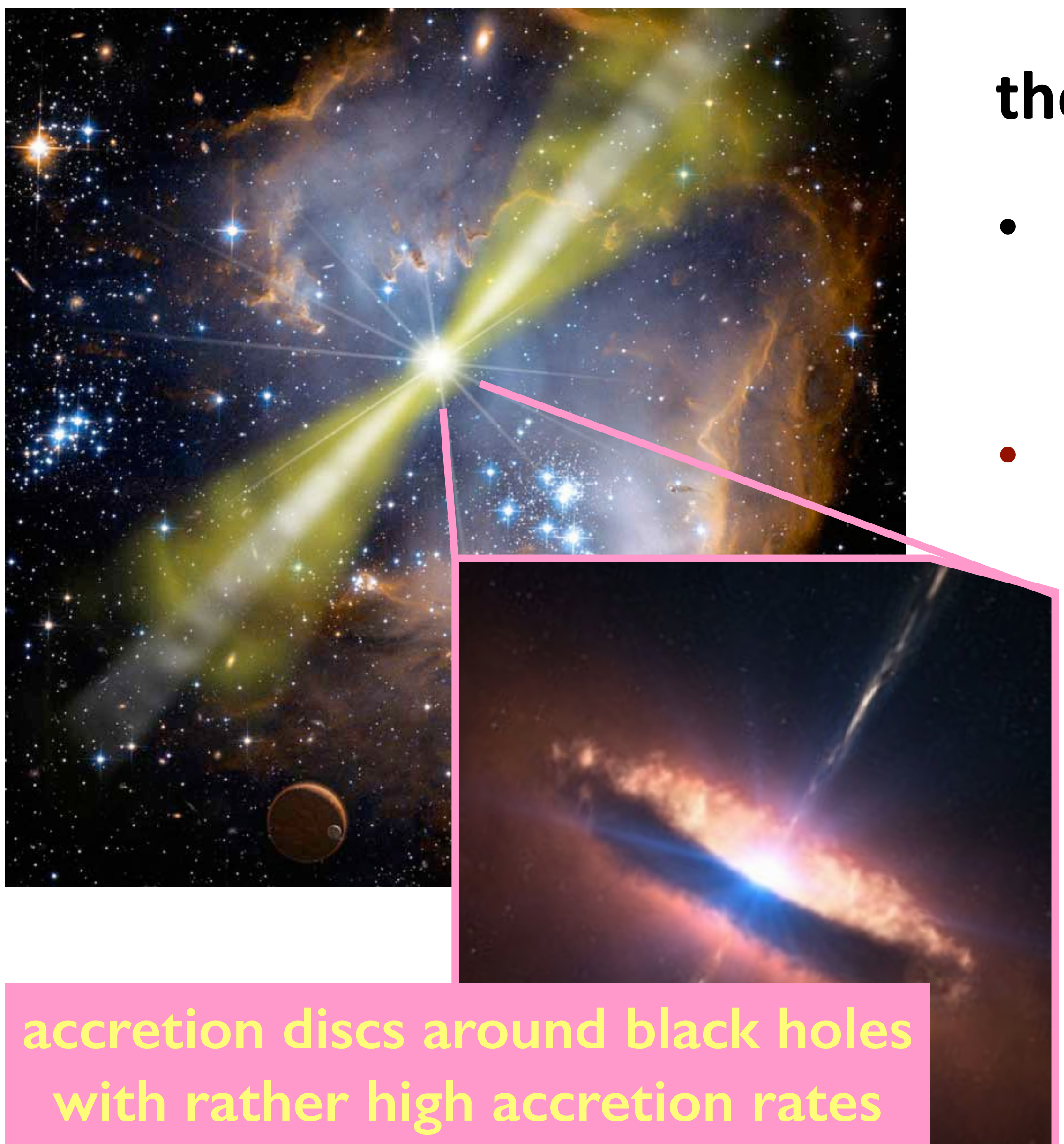

the driving mechanism:

- Magneto-driven jet (BZ/BP process, MHD process)
- Neutrino-driven jet (neutrino annihilation)

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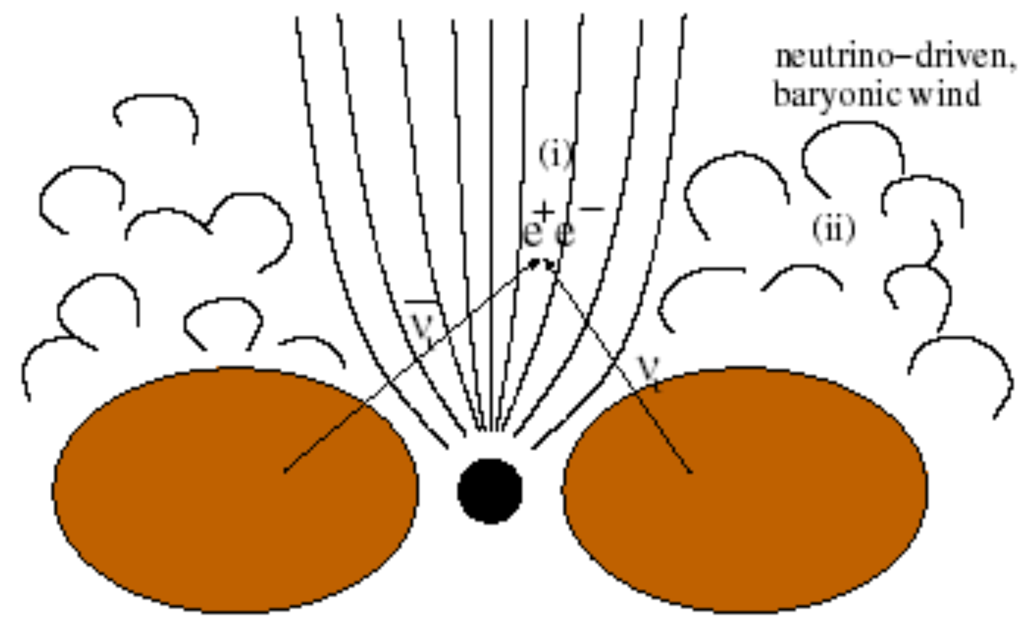
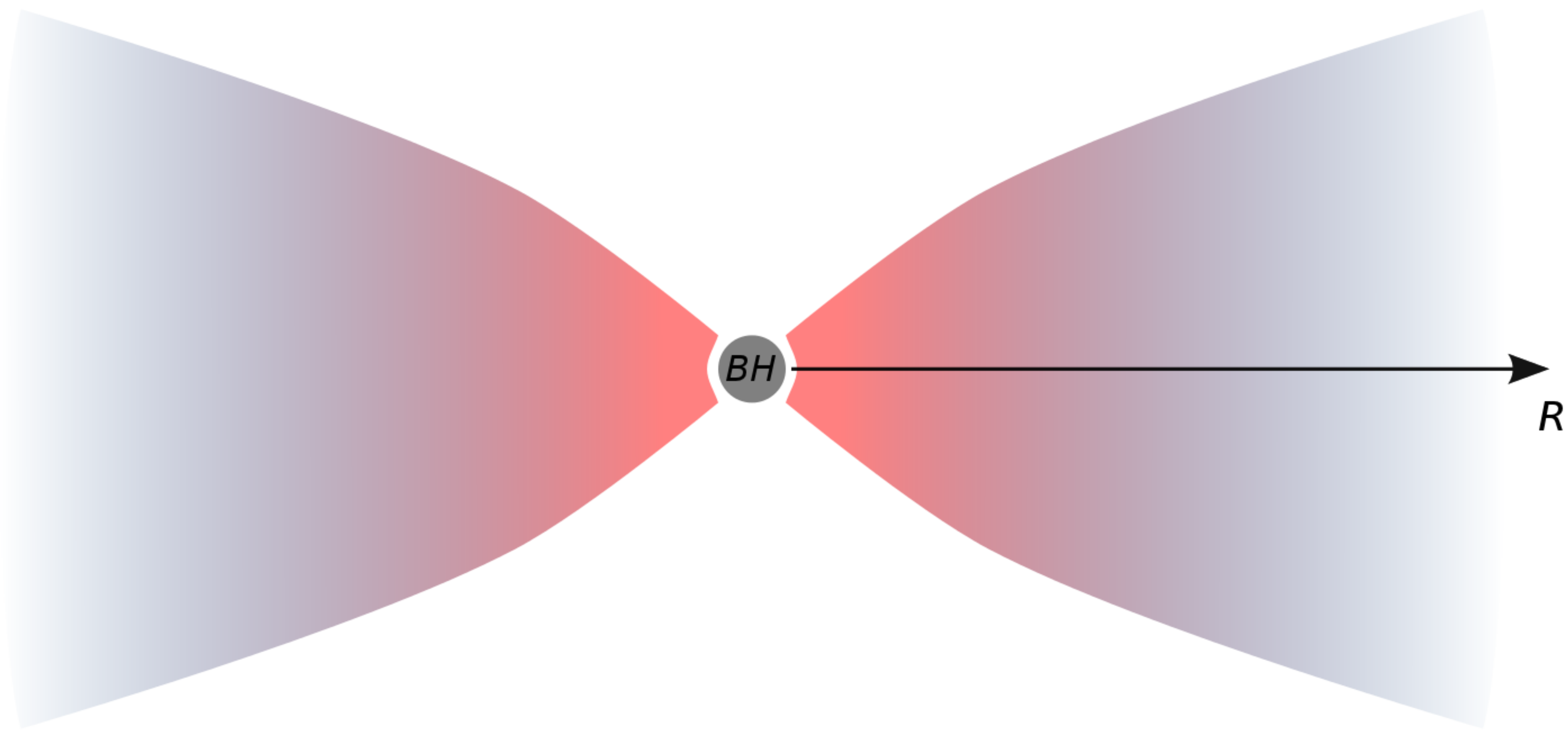


Neutrino-Dominated Accretion Flow

- a rather **hot and dense** hyper-accretion flow (optically thick)



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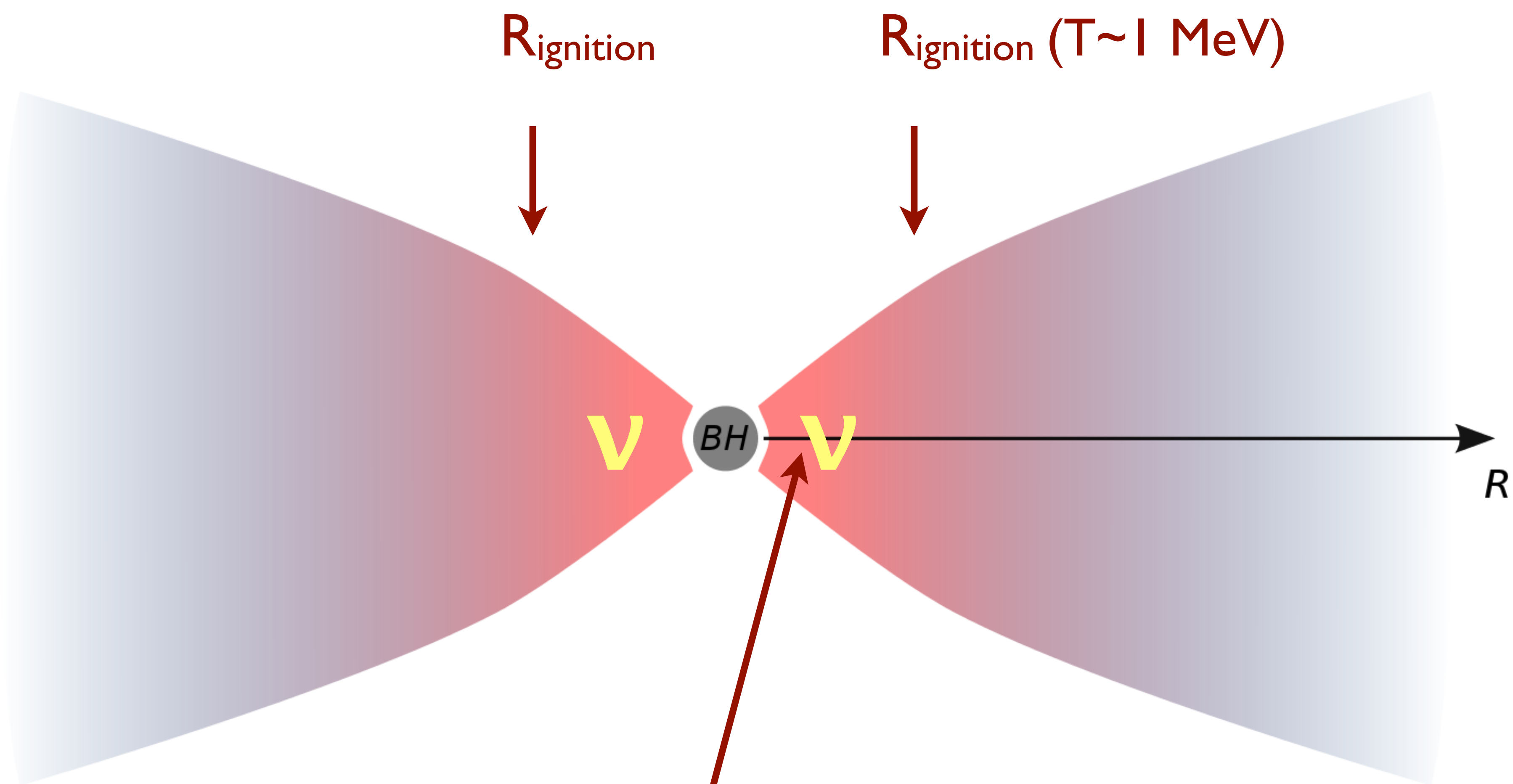

pair capture of electron & positron (URCA process)

$$p + e^- \rightarrow n + \nu_e, \quad n + e^+ \rightarrow p + \bar{\nu}_e$$

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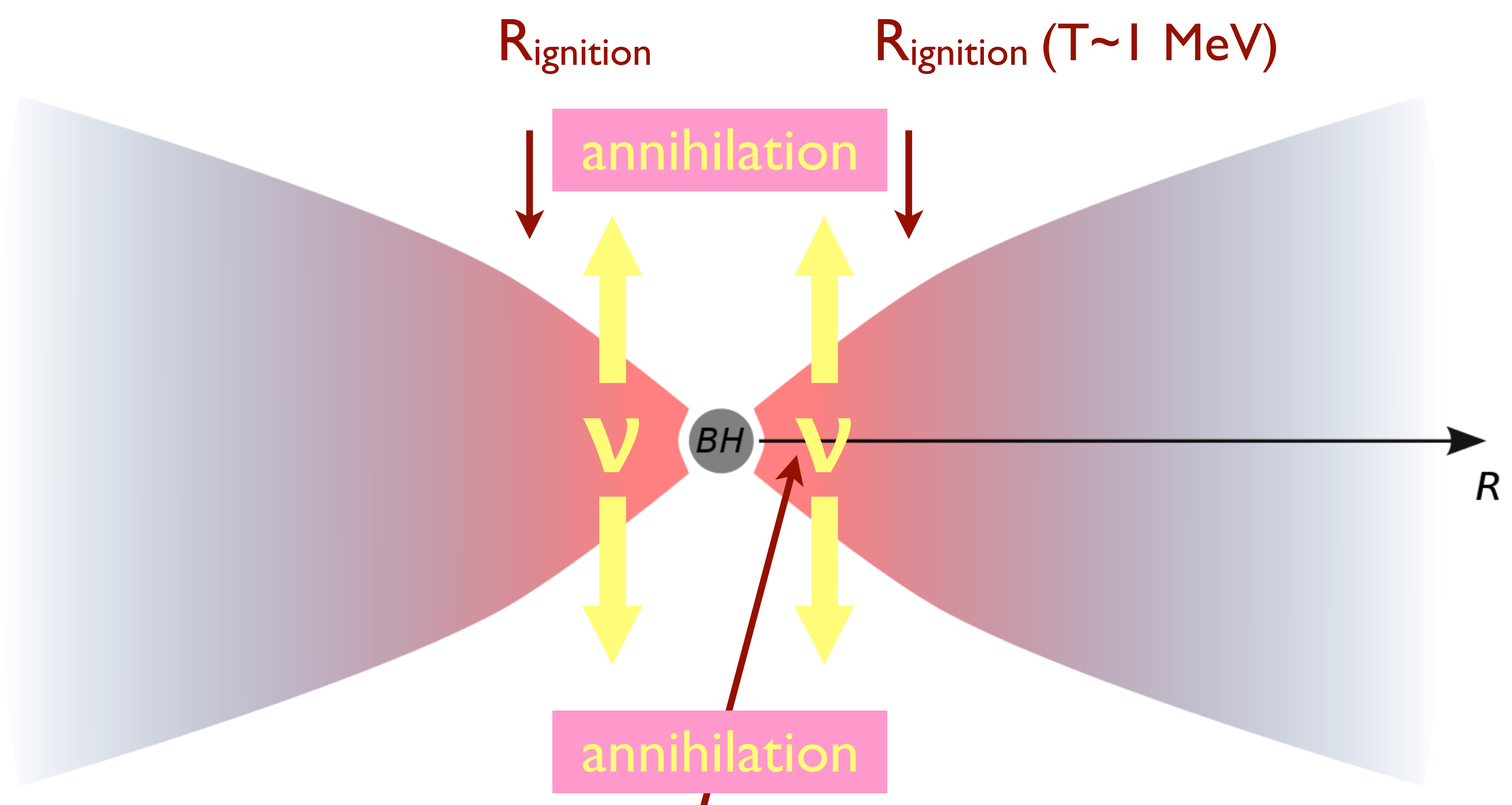

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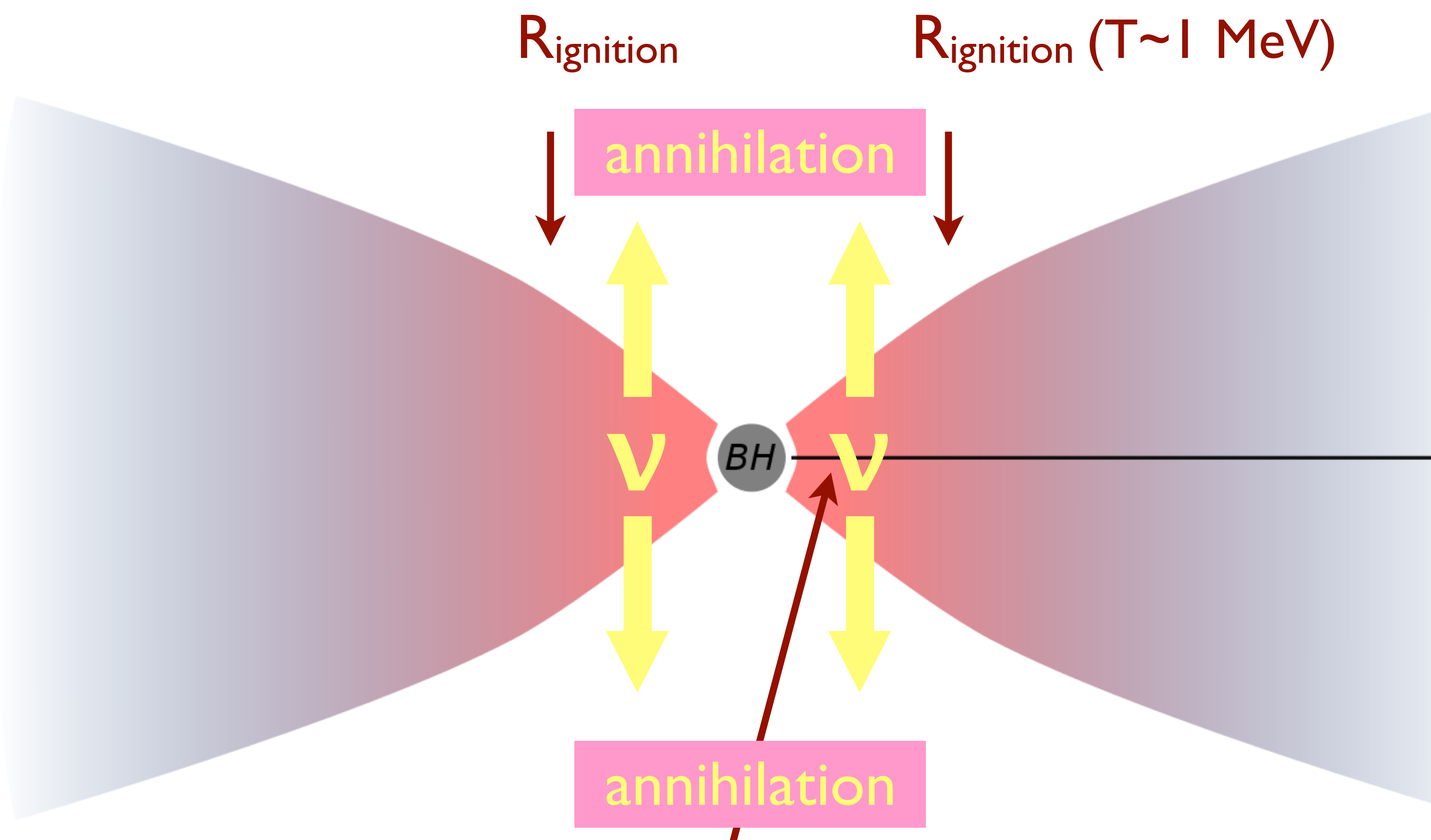

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- consider an NDAF with

$$M_{BH} = 3\ M_{sun}$$
$$\dot{M} = 1\ M_{sun} s^{-1}$$

- released potential energy
  ~ 10^{54} erg/s
- total neutrino luminosity
  L_ν ~ 10^{54} erg/s (90%)
- energy for neutrino-driven jet
  $L_{\nu\nu}$ ~ 10^{52} erg/s (1%)

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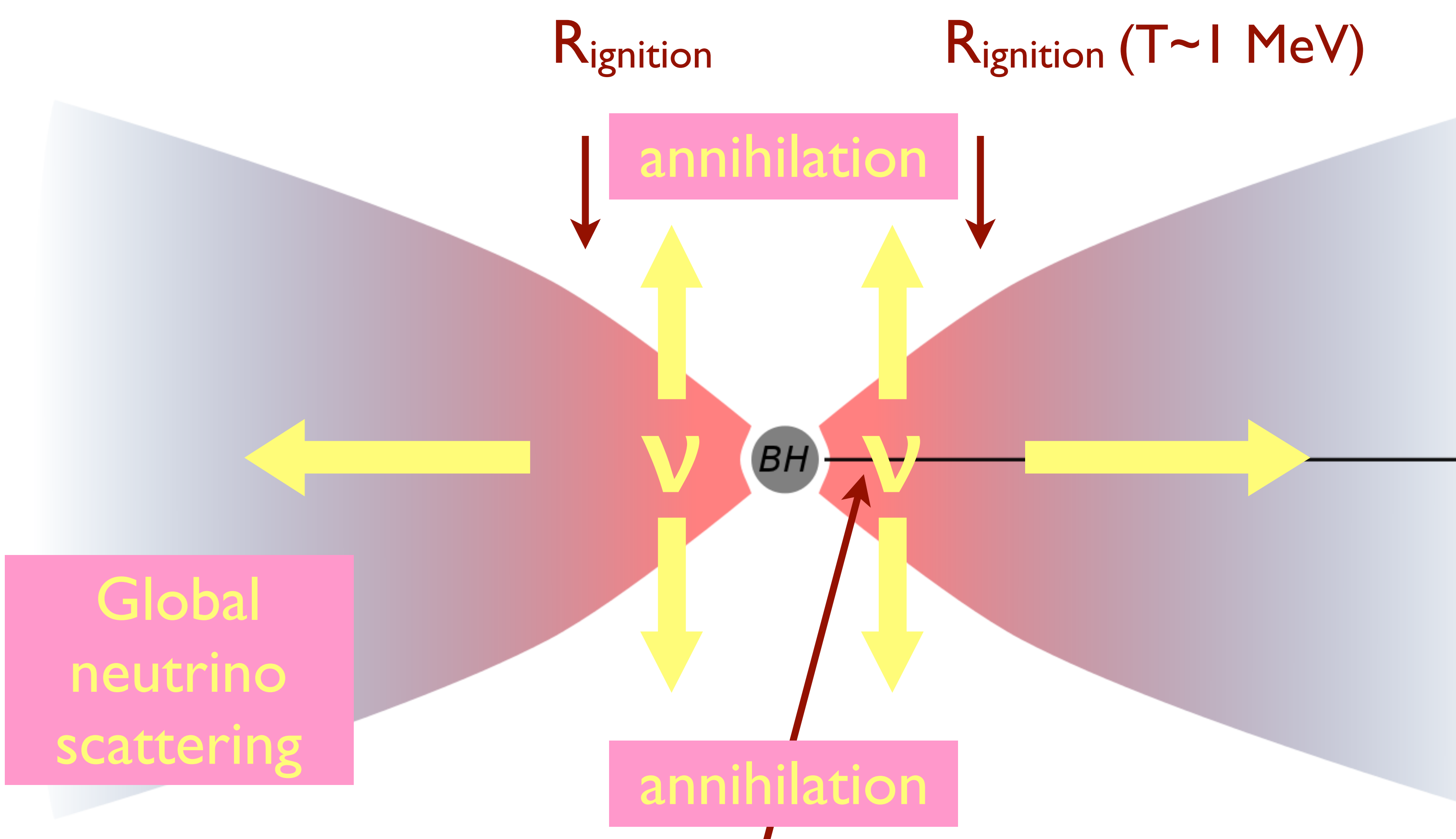

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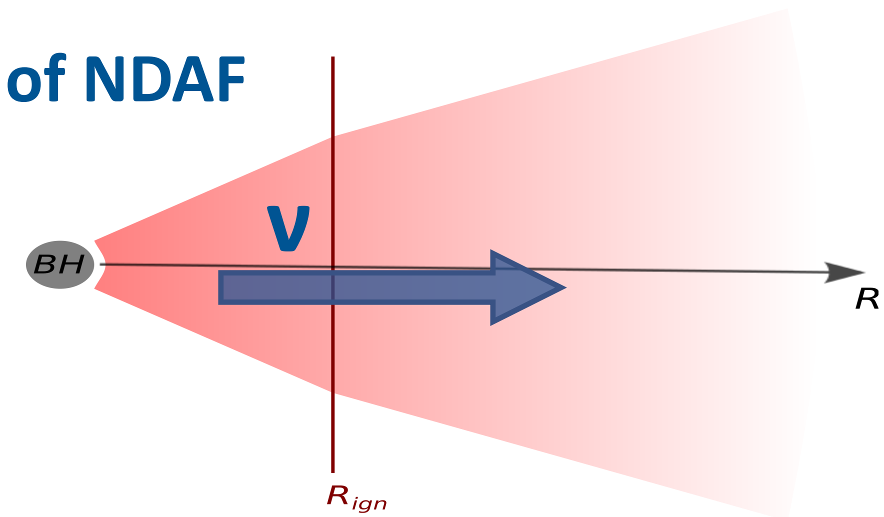
Global Neutrino Scattering in NDAF

- **Why "global neutrino scattering" ? (Motivation)**
  - **plenty of neutrinos are produced in the region of NDAF (URCA process)**
  - **the hot disk transparent to neutrinos**



possible effects to the to accretion flow

SL and F. Yuan, MNRAS 431, 2362 (2013)

- **Energy exchange — heat the disk**

  If the global heating is important, the temperature of the gas may be higher than Virial temperature (internal energy = potential energy). Subsequently, accretion will be stopped.

- **Momentum exchange — neutrino wind**

  Neutrino may exert radiation pressure on the gas and blow them away thus again the accretion may stop.

Global Neutrino Scattering in NDAF

- neutrino absorption by nucleons $\nu_e + n \to e^- + p, \quad \bar{\nu}_e + p \to e^+ + n$

$$\boxed{\sigma_{\nu n}(E_\nu) \simeq \sigma_{\bar{\nu} p}(E_{\bar{\nu}}) \approx 9.85 \times 10^{-44} E^2_{\nu(\bar{\nu})}\ \mathrm{cm}^2}$$

- neutrino-electron elastic scattering $\nu + e^-, e^+ \to \nu + e^-, e^+$

$$\sigma_{\nu e}(E_\nu) \approx 5.57 \times 10^{-44} \left(1 + \frac{\eta_e}{4}\right) \frac{k_{\mathrm{B}} T}{m_e c^2} E_\nu\ \mathrm{cm}^2$$

$$\sigma_{\bar{\nu} e}(E_{\bar{\nu}}) \approx 2.33 \times 10^{-44} \left(1 + \frac{\eta_e}{4}\right) \frac{k_{\mathrm{B}} T}{m_e c^2} E_{\bar{\nu}}\ \mathrm{cm}^2$$

inner NDAF

- neutrino-baryon elastic scattering $\nu + p, n, \mathrm{He} \to \nu + p, n, \mathrm{He}$

$$\sigma_p(E_\nu) \approx 2.04 \times 10^{-44} E^2_\nu\ \mathrm{cm}^2$$

$$\sigma_n(E_\nu) \approx 2.46 \times 10^{-44} E^2_\nu\ \mathrm{cm}^2$$

$$\sigma_\alpha(E_\nu) \approx 7.55 \times 10^{-46} E^2_\nu\ \mathrm{cm}^2$$

outer ADAF

- neutrino annihilation $\nu + \bar{\nu} \to e^- + e^+$

Global Neutrino Scattering in NDAF

- The received neutrino (antineutrino) spectrum at **r**

$$F^{in}_{\nu(\bar{\nu})}(E_{\nu(\bar{\nu})}, r) = \int_{R_s}^{r} e^{-\tau_{\nu(\bar{\nu})}} \frac{1}{4\pi r^2} \frac{\mathrm{d}L_{\nu(\bar{\nu})}(E_{\nu(\bar{\nu})}, r')}{\mathrm{d}r'} \mathrm{d}r'$$

$$F^{out}_{\nu(\bar{\nu})}(E_{\nu(\bar{\nu})}, r) = \int_{r}^{r_{out}} \frac{e^{-\tau_{\nu(\bar{\nu})}}}{4\pi r H(r')} \ln\sqrt{\frac{r'+r}{r'-r}} \frac{\mathrm{d}L_{\nu(\bar{\nu})}(E_{\nu(\bar{\nu})}, r')}{\mathrm{d}r'} \mathrm{d}r'$$

- $\tau_{\nu(\bar{\nu})} = \int_{r'}^{r} (\sigma n)_{\nu(\bar{\nu})} \mathrm{d}r''$ neutrino (antineutrino) optical depth from r' to r

- Global neutrino heating rate

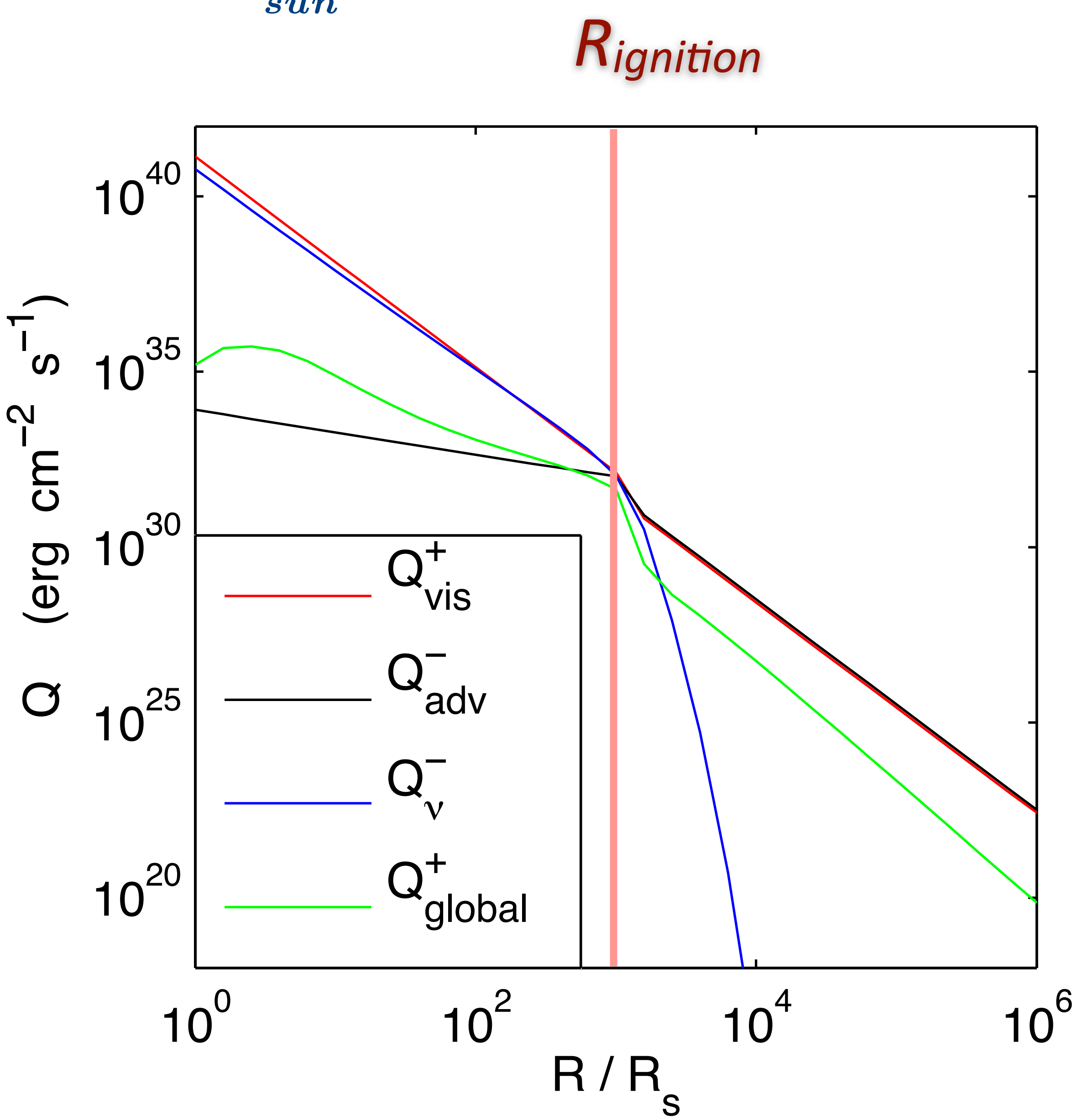
$$\begin{aligned} \dot{q}_{global} &= \int_0^{\infty} \left[F^{in}_{\nu}(E_\nu, r) + F^{out}_{\nu}(E_\nu, r)\right] \left(\sigma_{\nu n}(E_\nu) n_n E_\nu + \sigma_{\nu e}(E_\nu)(n_{e^-} + n_{e^+})\theta E_\nu\right) \mathrm{d}E_\nu \\ &+ \int_{Q+m_e c^2}^{\infty} \left[F^{in}_{\bar{\nu}}(E_{\bar{\nu}}, r) + F^{out}_{\bar{\nu}}(E_{\bar{\nu}}, r)\right] \left(\sigma_{\bar{\nu} p}(E_{\bar{\nu}}) n_p E_{\bar{\nu}} + \sigma_{\bar{\nu} e}(E_{\bar{\nu}})(n_{e^-} + n_{e^+})\theta E_{\bar{\nu}}\right) \mathrm{d}E_{\bar{\nu}} \end{aligned}$$

$$\theta \equiv (E^{in}_\nu - E^{out}_\nu)/E^{in}_\nu \simeq 1/2 - 2k_{\mathrm{B}}T/E_\nu$$

the average neutrino energy loss rate in neutrino-electron scattering

Global Neutrino Scattering in NDAF

$\dot{M} = 1\ M_{sun}\ \mathrm{s}^{-1}$



- around the 'ignition' radius, the global neutrino heating rate global becomes comparable to the viscous heating rate and can not be neglected
- preliminary results of our 2D simulation confirm that in the NDAF with relative high accretion rate, the temperature around the 'ignition' radius significantly rises

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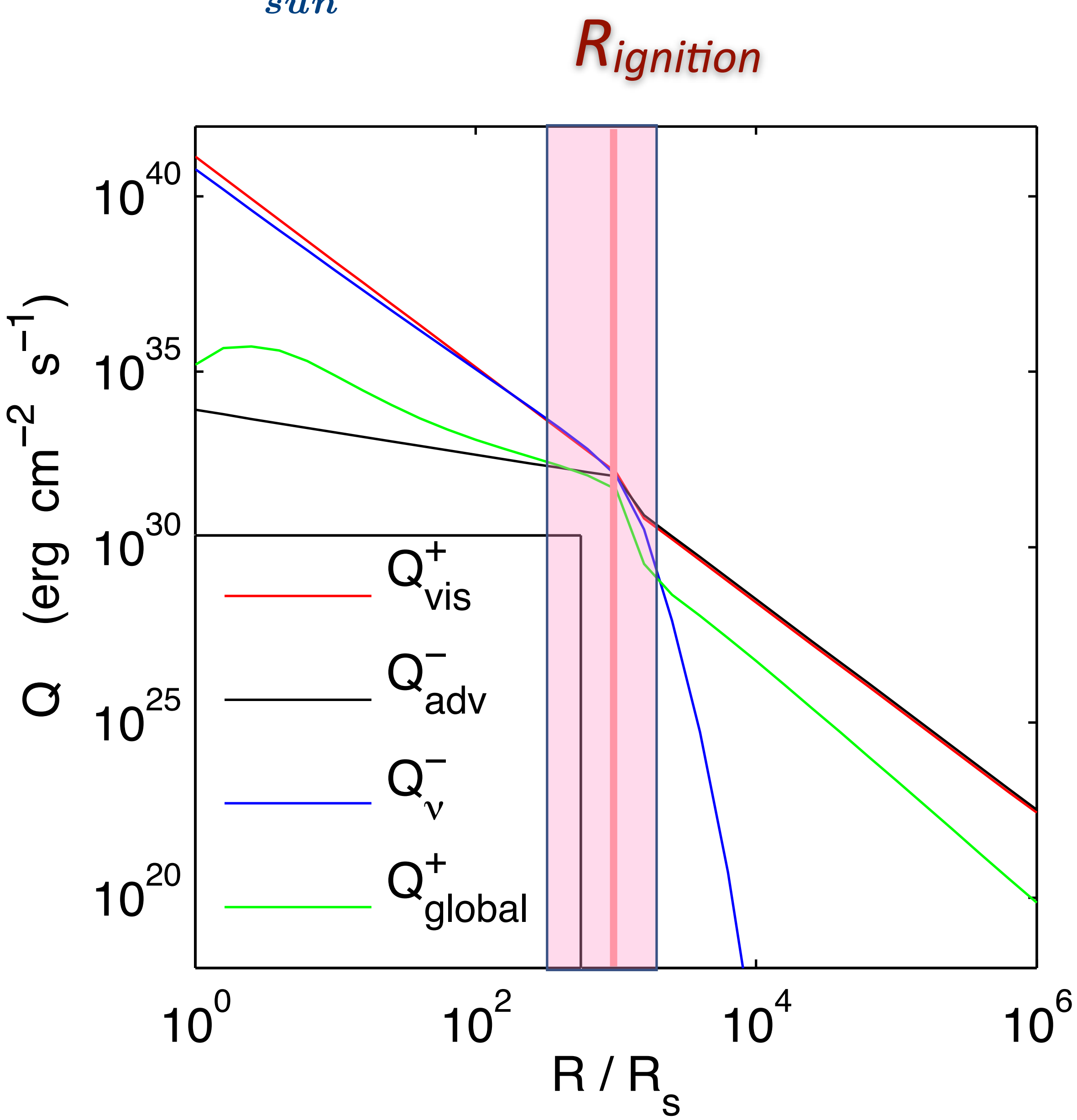

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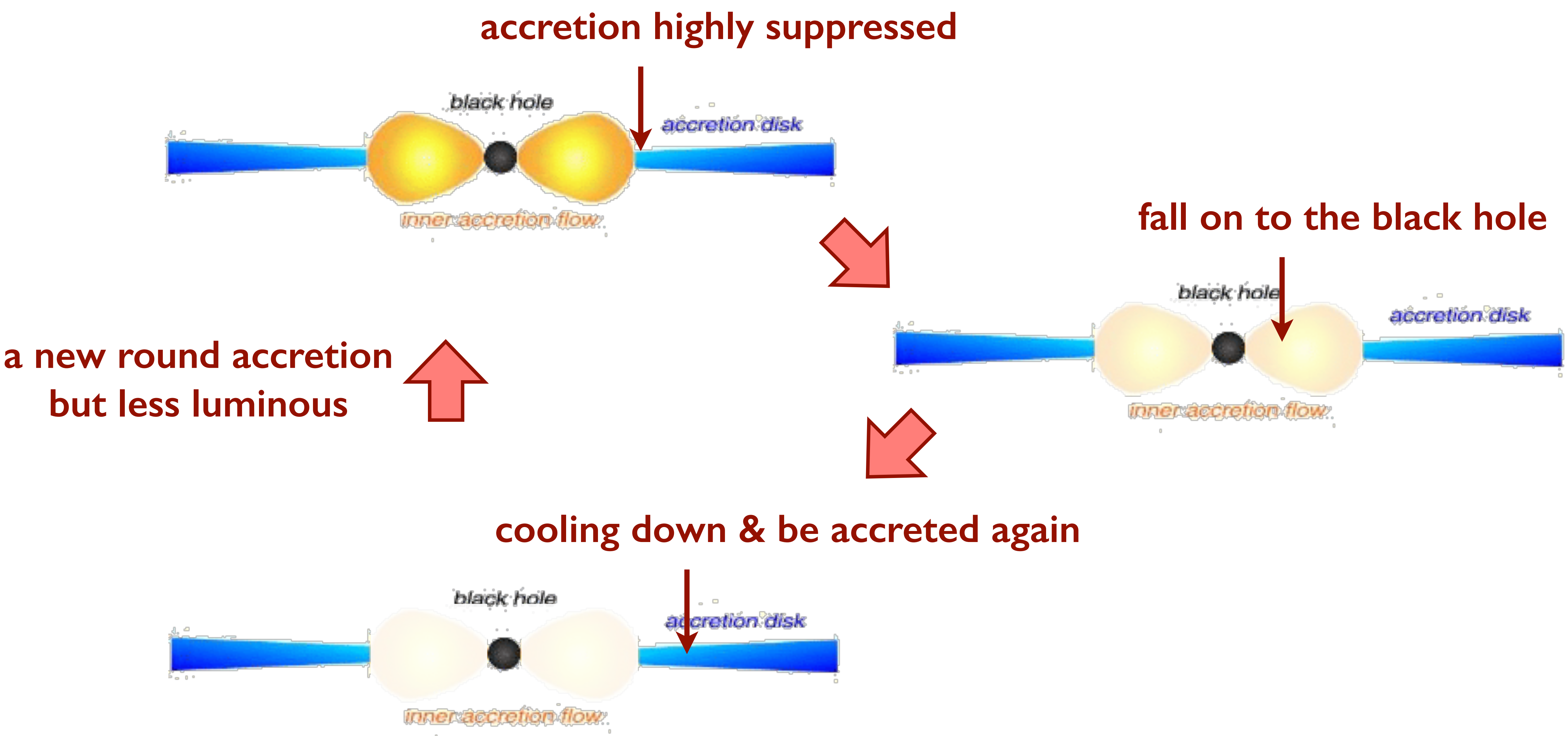
Global Neutrino Scattering in NDAF

- If some region of the NDAF do be heated higher than its Virial temperature



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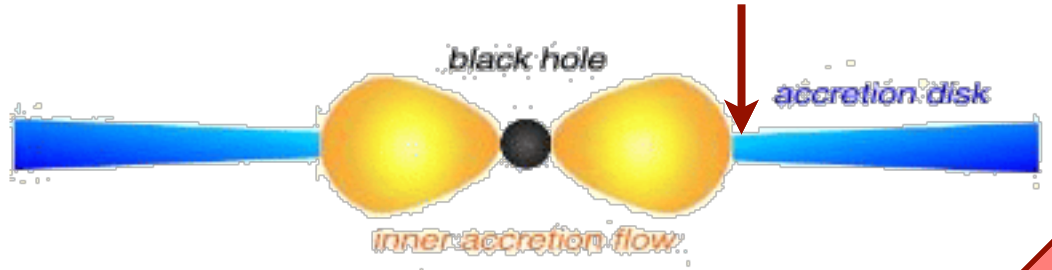
accretion highly suppressed



fall on to the black hole

a new round accretion
but less luminous

cooling down & be accreted again

- The black hole activity will oscillate between an active and an inactive phase.

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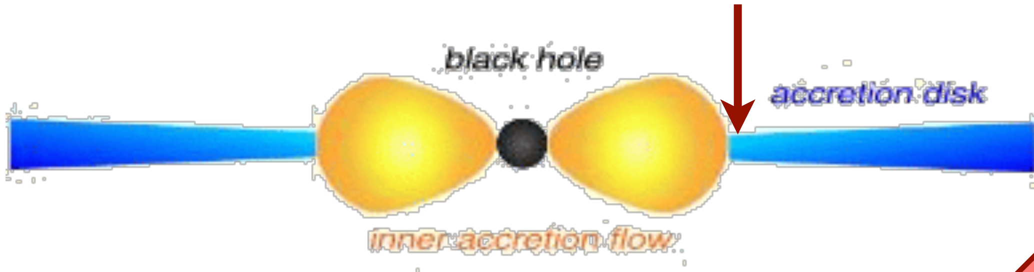

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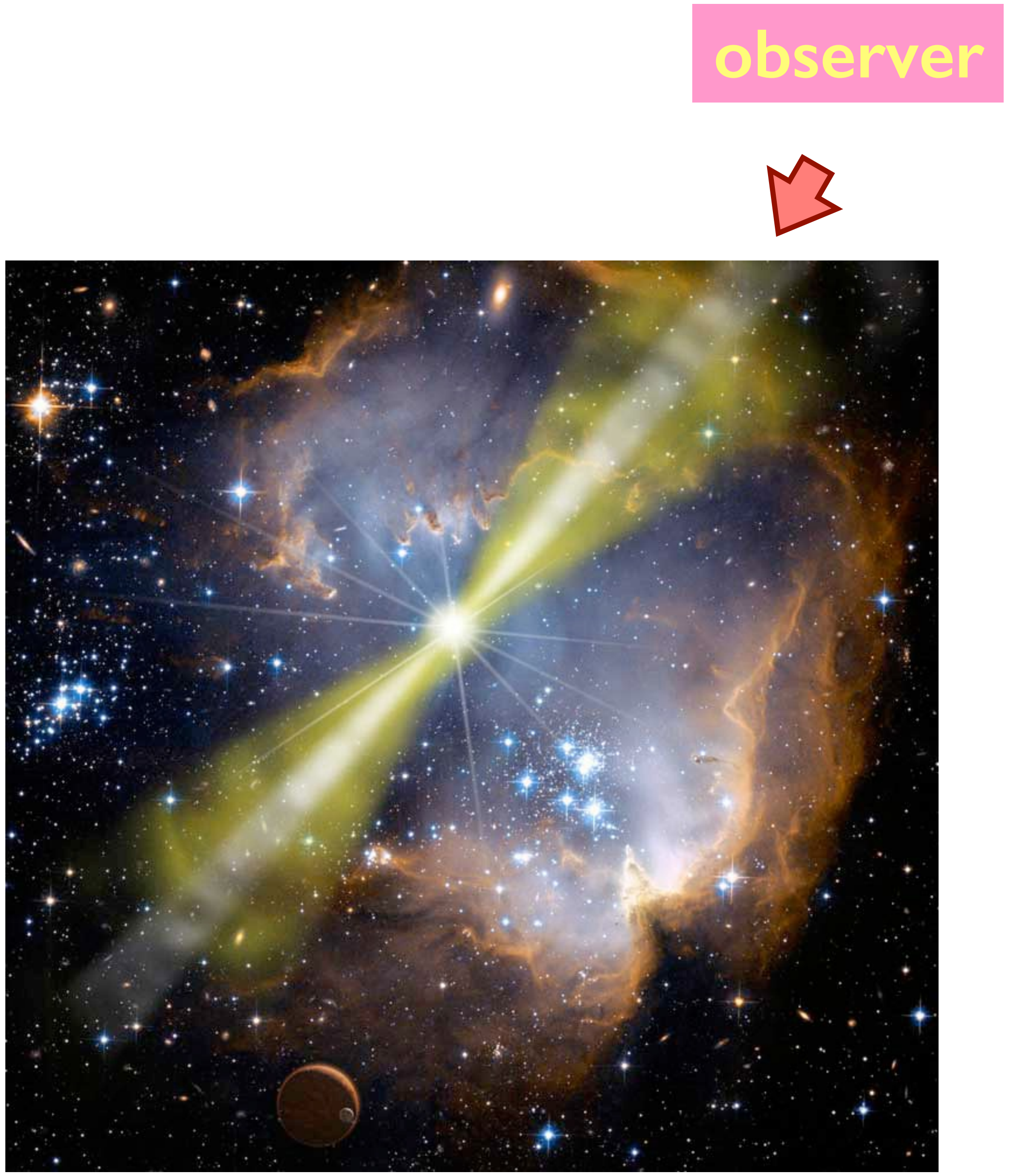
simulation including time variation needed

See directly to the central engine ?



gamma-ray, X-ray, ultraviolet, optical, infrared, microwave and radio, neutrino

- the jet acceleration mechanism

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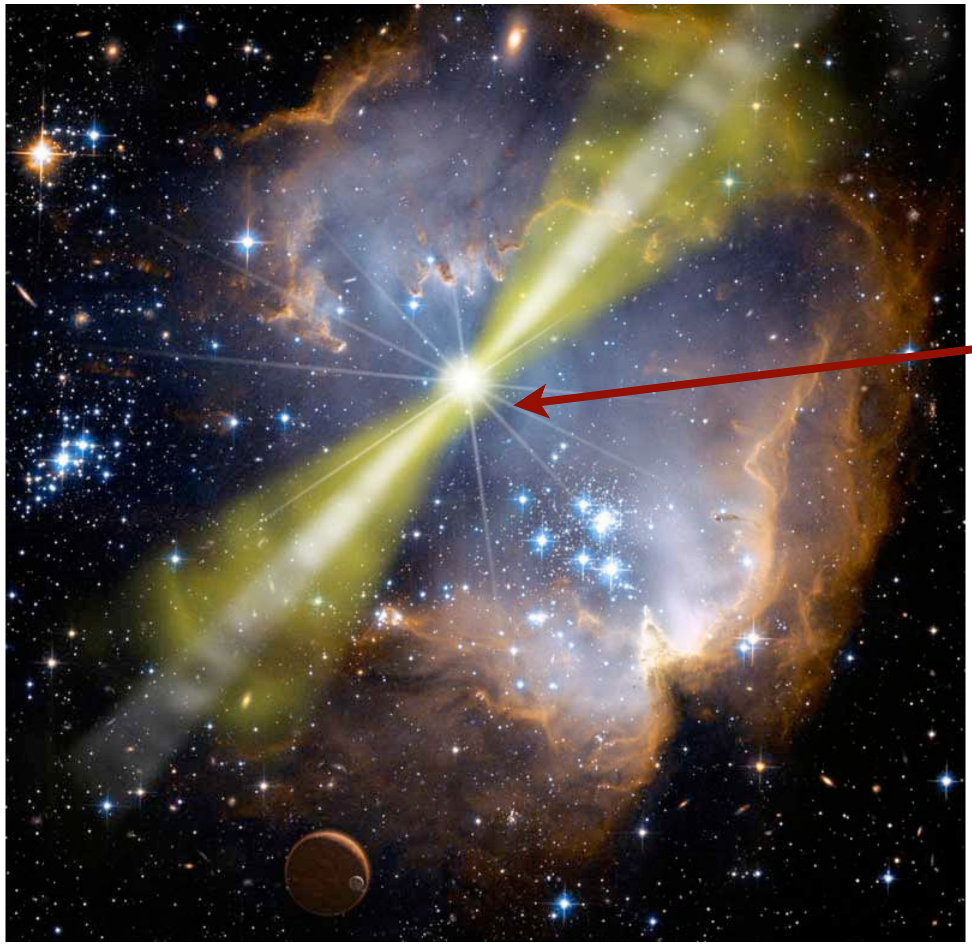
observer

gamma-ray, X-ray, ultraviolet, optical, infrared, microwave and radio, neutrino



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neutrino, gravitational wave

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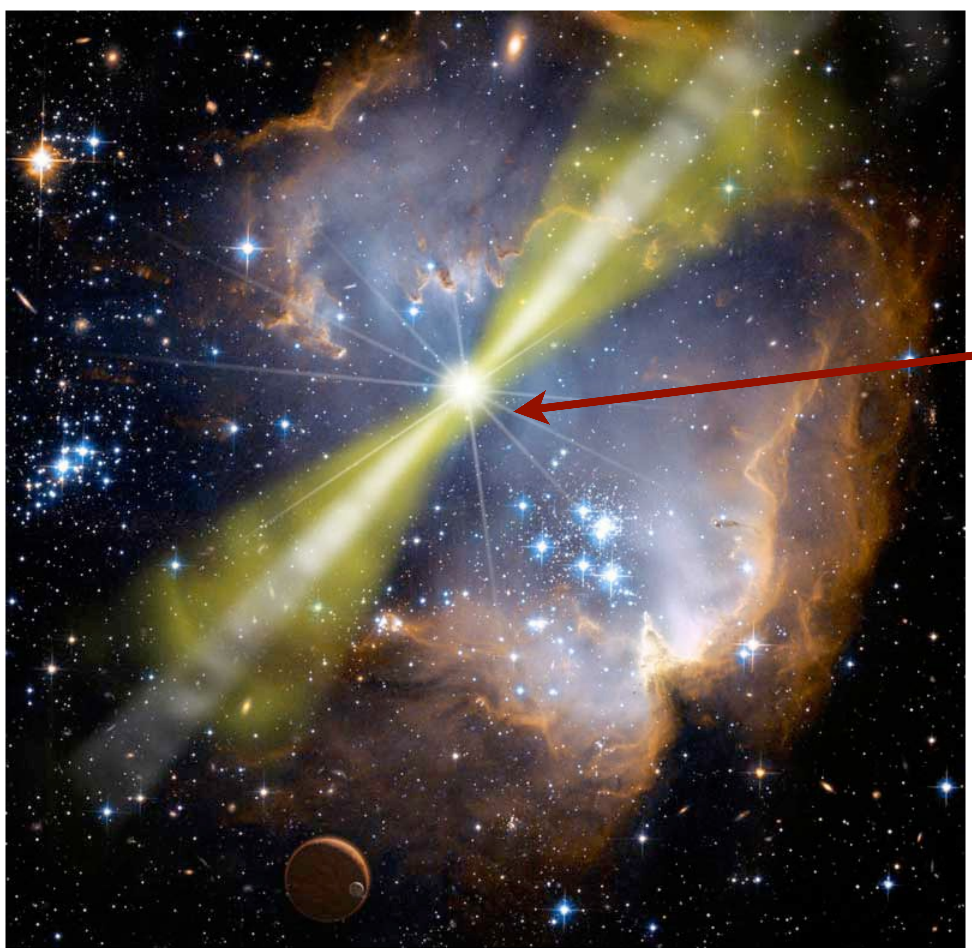

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Diffuse neutrino background

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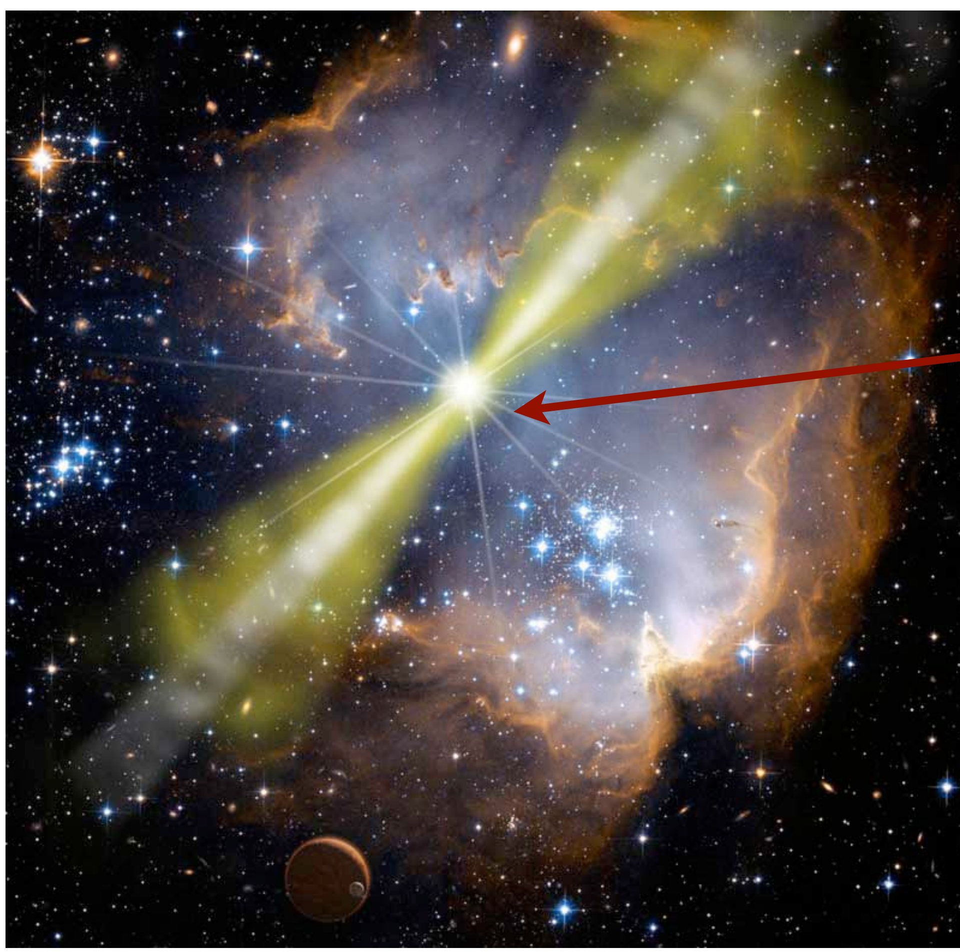

- the jet acceleration mechanism

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Diffuse neutrino background

- the type of central engine
- information on the star formation


Thanks