Revealing the High-Redshift Star Formation Rate (and more) with Gamma Ray Bursts

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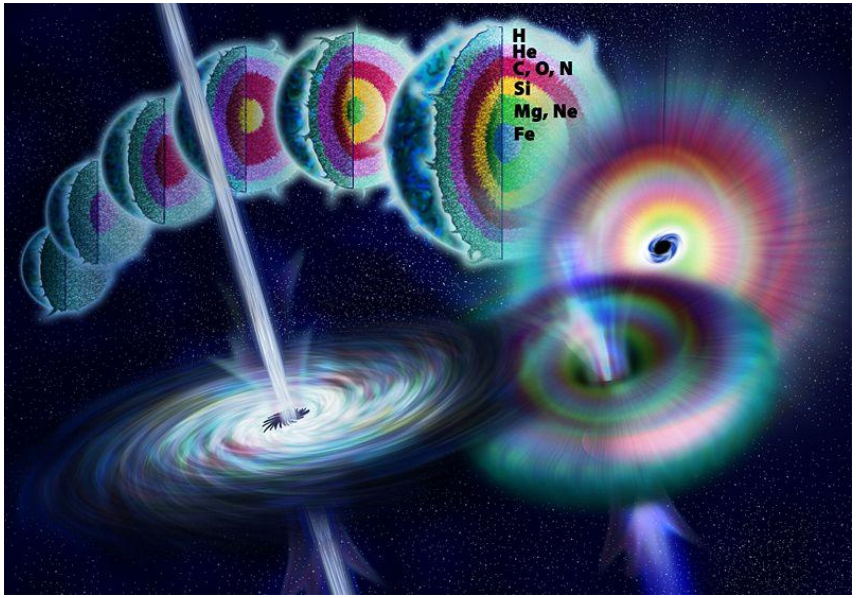
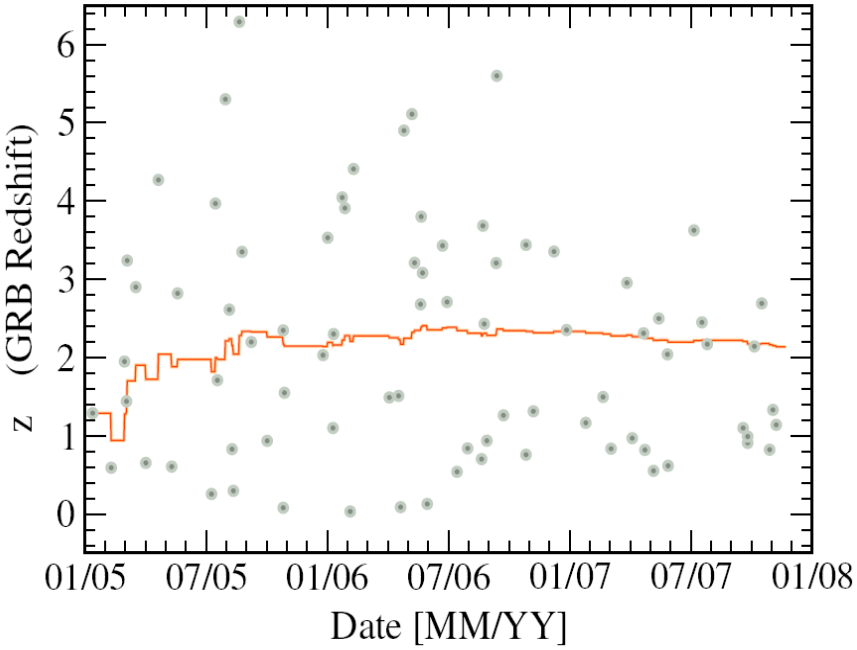
M. D. Kistler, H. Yüksel, J. F. Beacom & K. Z. Stanek ***Astrophys.J. 673 (2008) L119***
H. Yüksel & M. D. Kistler ***Phys. Rev. D 75, 083004 (2007)***

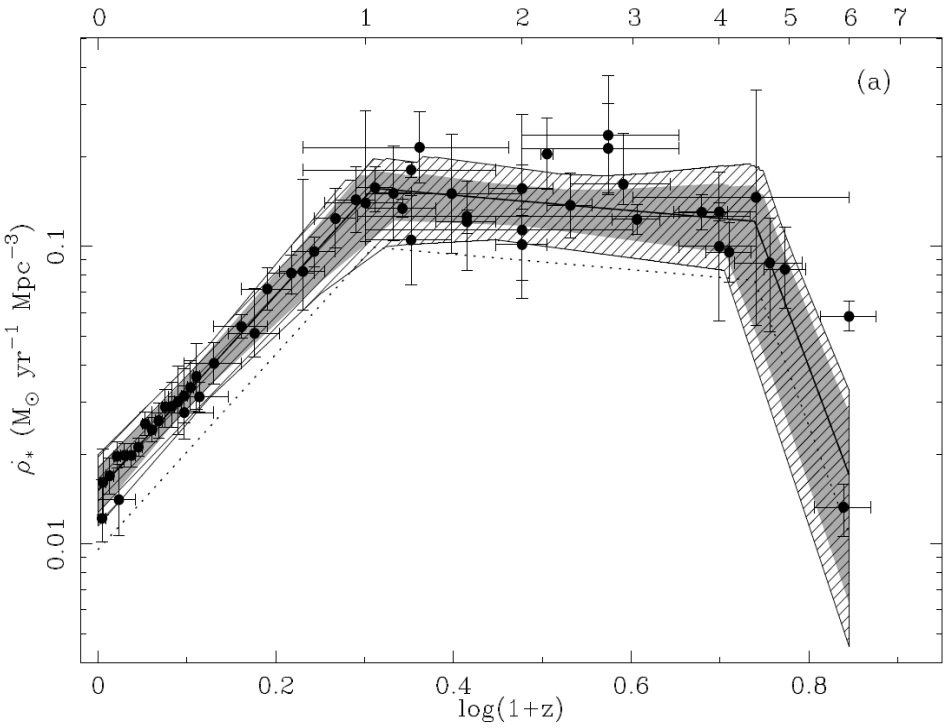
GRB Observations by Swift





- Association of GRBs with Supernovae:
  - Do their cosmic rate follow history of star formation?
  - Possible implications of enhanced GRB evolution compared to SFR
  - Can we probe high-z SFR with GRBs?

SFR → GRB Distribution

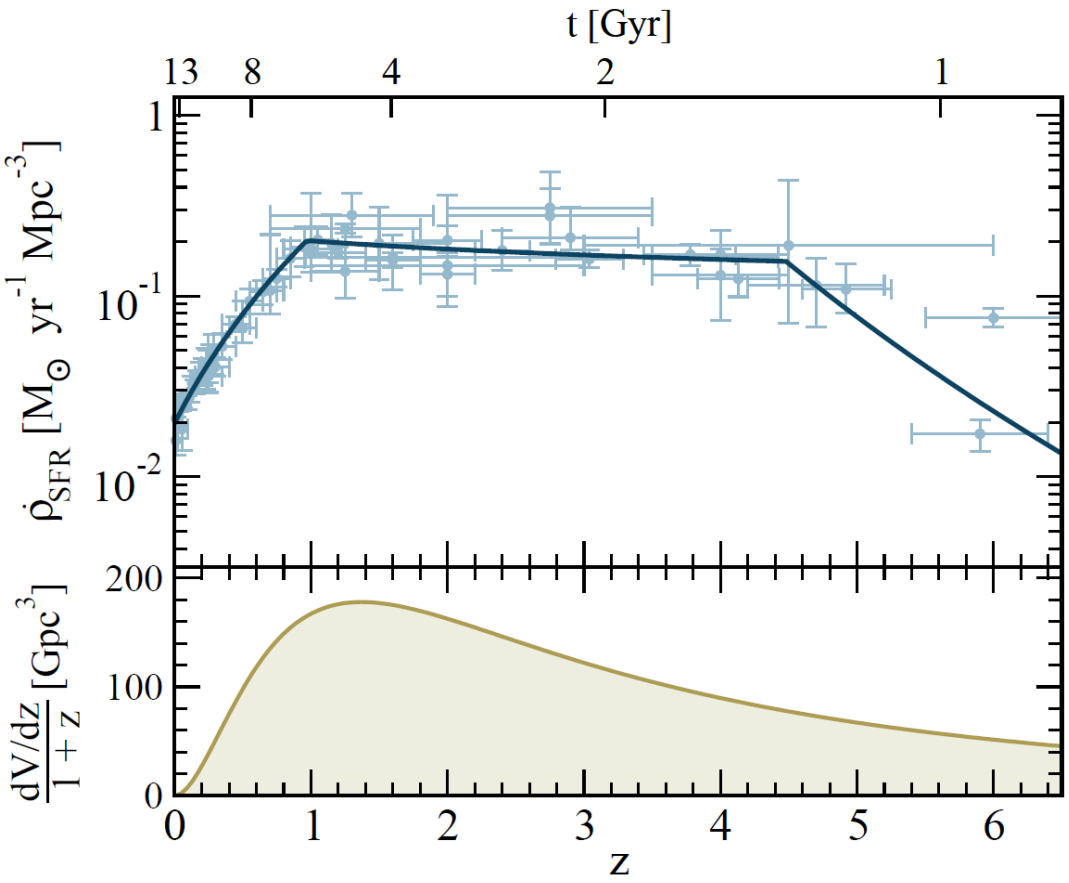


Hopkins & Beacom

$$\dot{n}_{\rm GRB}(z) = \mathcal{E}(z) \times \dot{\rho}_{\rm SF}(z)$$

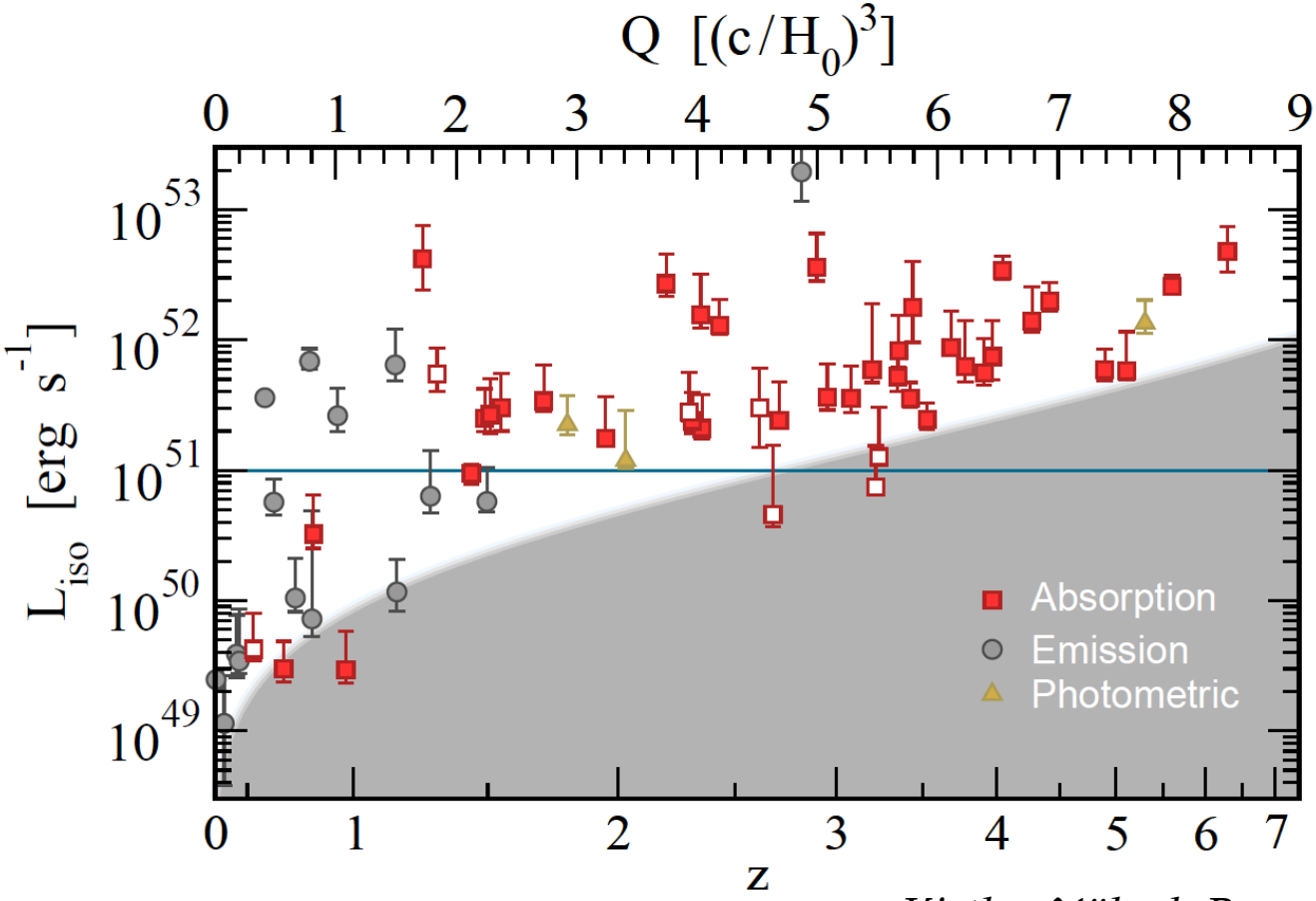
$$\frac{d\dot{N}}{dz} = F(z)\frac{\mathcal{E}(z)\,\dot{\rho}_{\rm SFH}(z)}{\langle f_{\rm beam}\rangle}\frac{dV/dz}{1+z}$$

Volumetric Factor: Q(z)



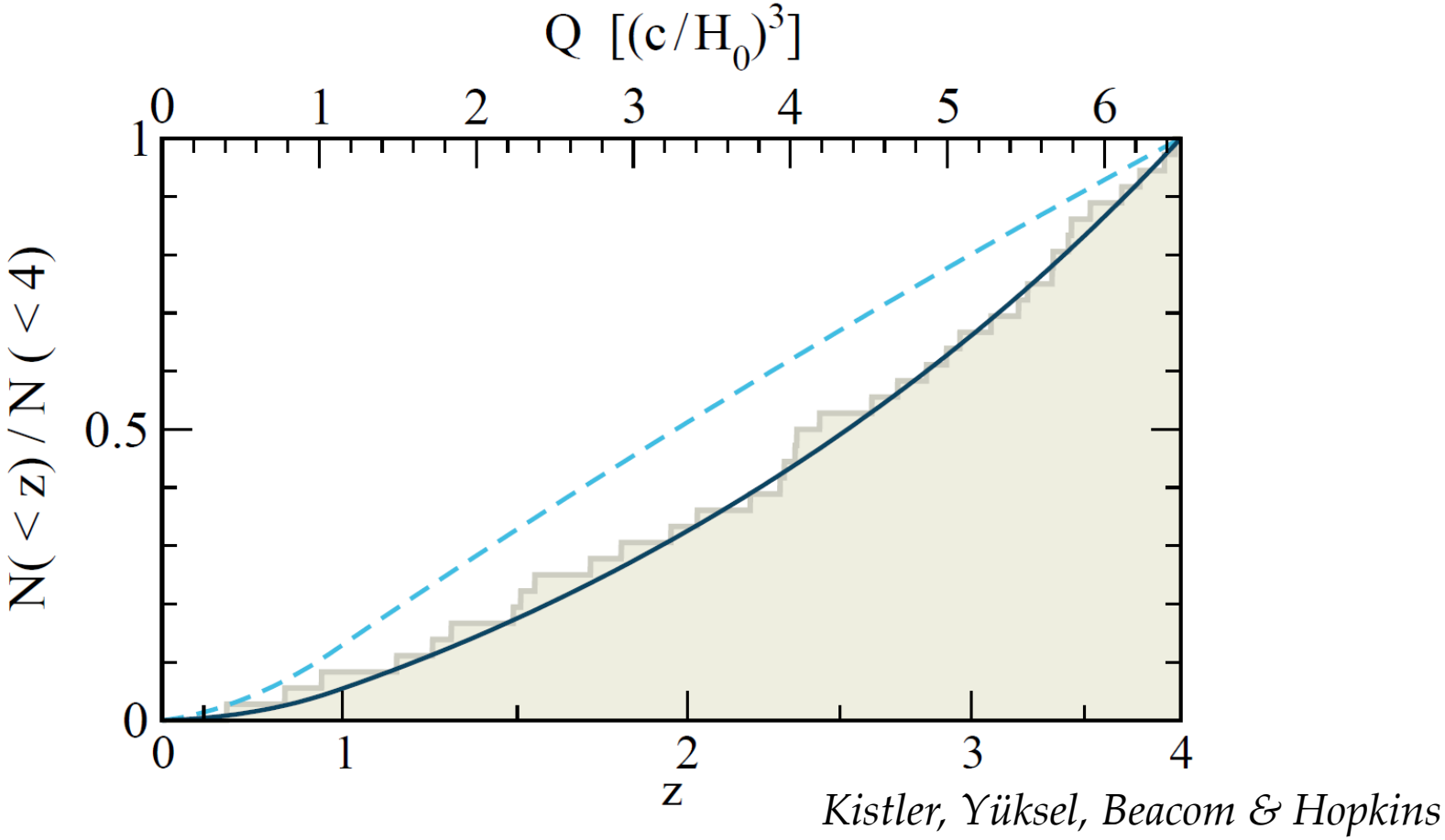
$$Q(z) = \int_0^z dz' \, \frac{dV/dz'}{1+z'} \qquad \frac{d\dot{N}}{dQ} = \frac{d\dot{N}/dz}{dQ/dz} = F(Q)\frac{\dot{n}_{\rm GRB}(Q)}{\langle f_{\rm beam}\rangle}$$

GRB Luminosity Distribution



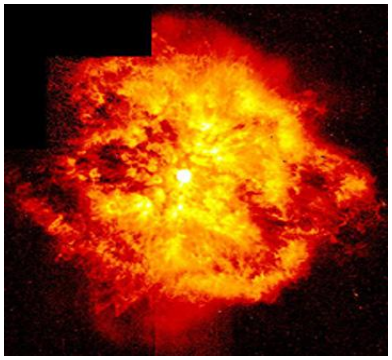
Kistler, Yüksel, Beacom & Hopkins

Cumulative Distribution of GRBs



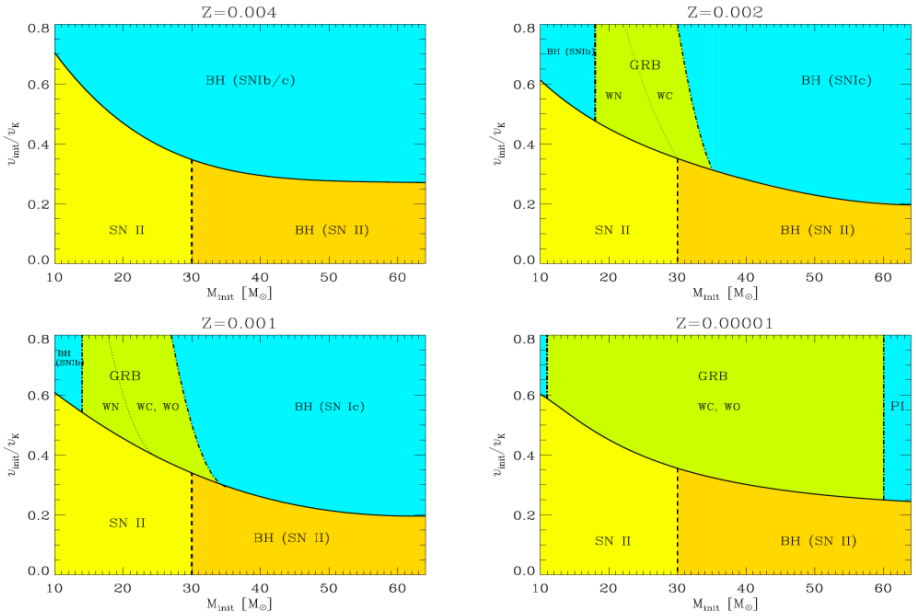
Additional evolution of $\mathbf{(1+z)^{1.5}}$ over just SFR is favored

Why Additional Evolution?

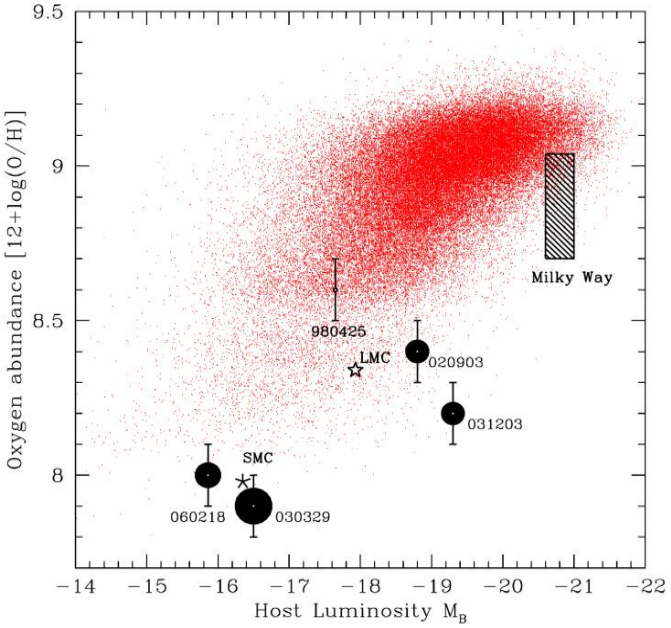


Collapsar model requires rapidly rotating star, lacking H/He envelope, which is satisfied by a metal-poor progenitor

Host galaxy studies indicate GRBs mostly occur in metal poor, underluminous, star forming regions



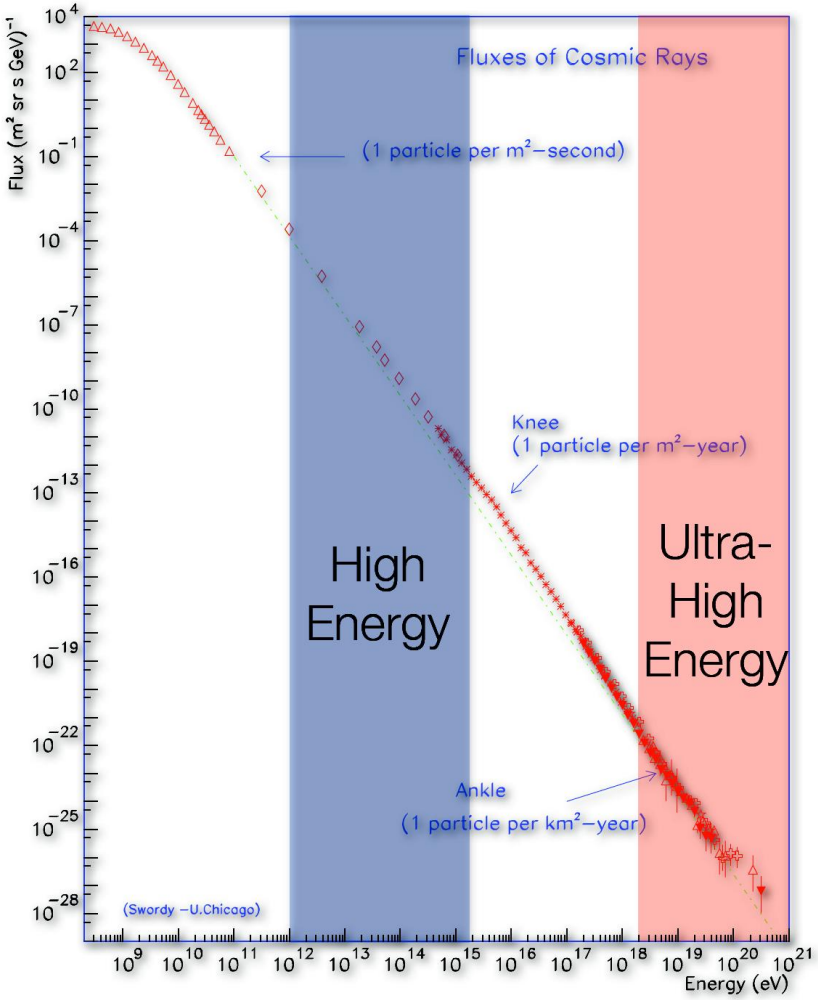
Yoon, Langer &Norman



Stanek et. al.

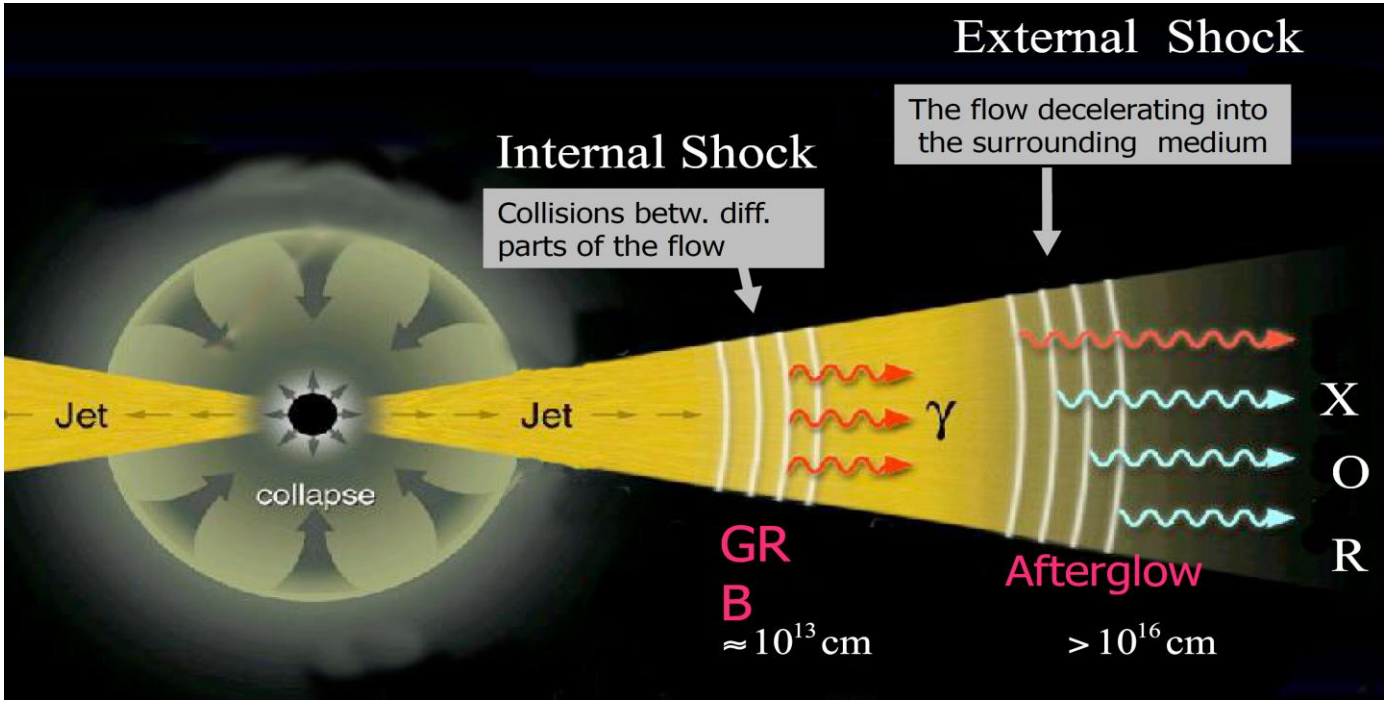
Ultra High Energy Cosmic Rays

- What is their origin?
- What is the acceleration mechanism?
- Where does the energy come from?
- Nearby sources?
- Sources can not be too far either! (due to photopion production)

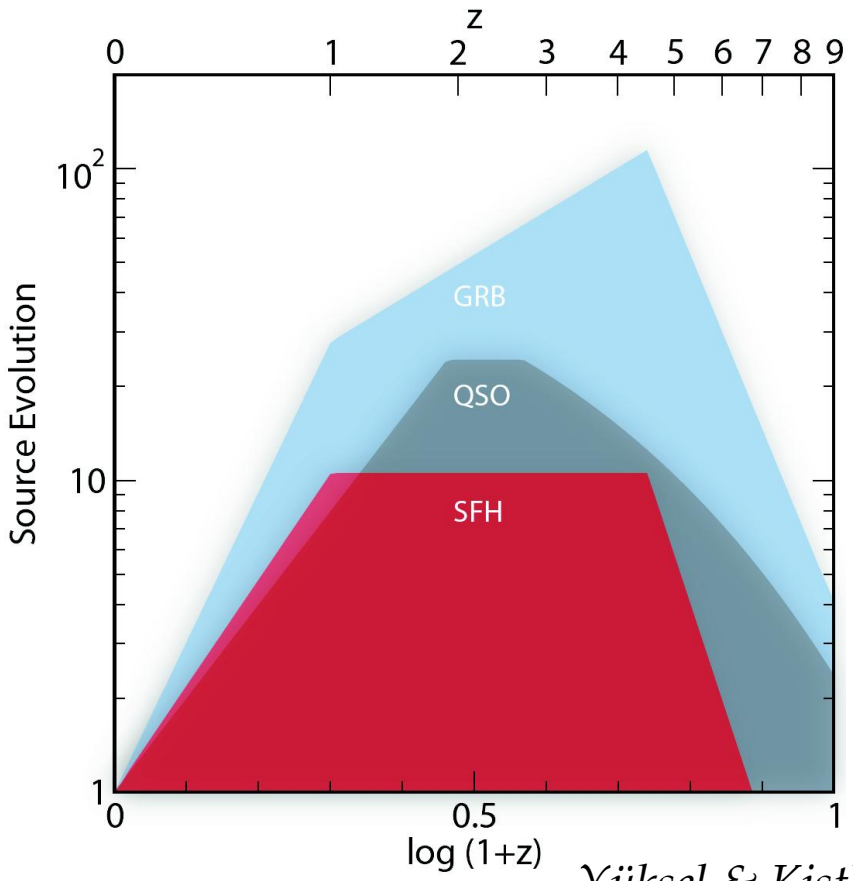


UHECR and GRBs

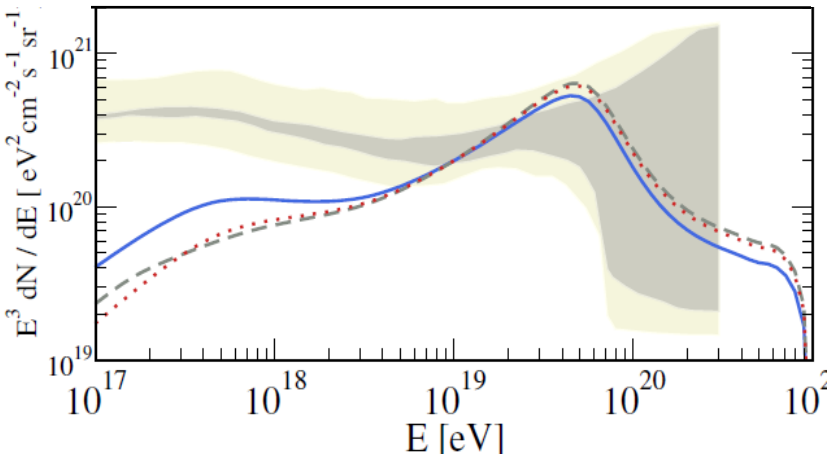
- GRBs need to accelerate UHECR above $>10^{20}$ eV and produce flux large enough to explain observations



Cosmic Ray Source Evolution

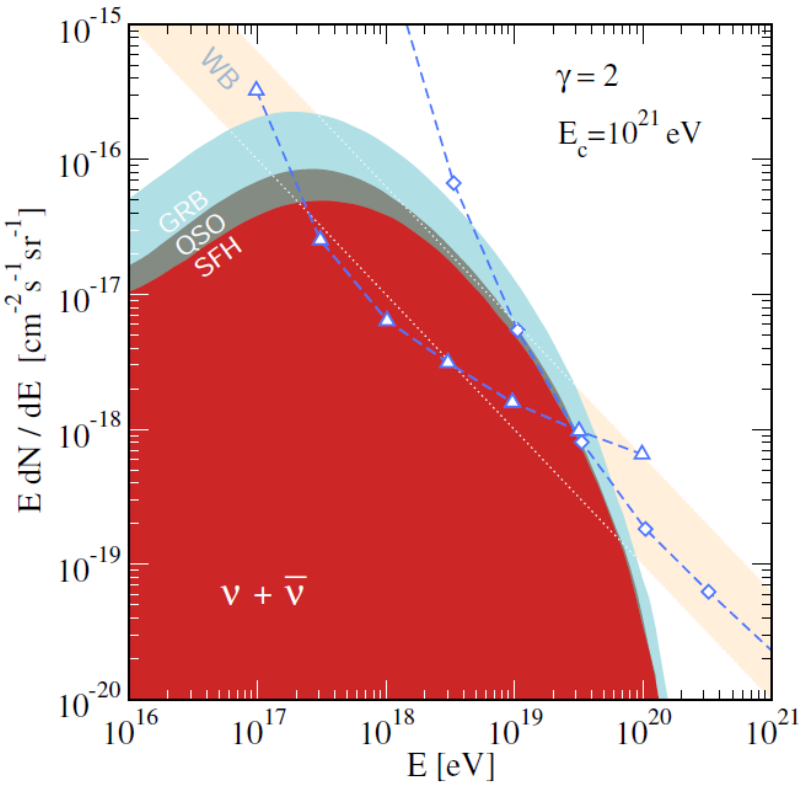


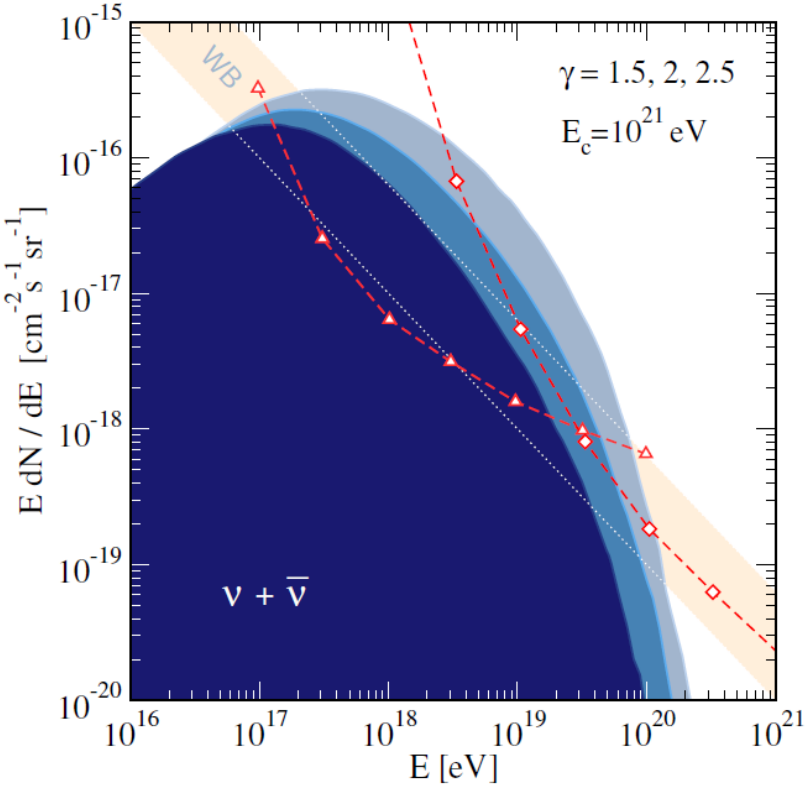
Yüksel & Kistler



$$\mathcal{W}_{\rm GRB}(z) \propto \begin{cases} (1+z)^{4.8} & : \ z < 1 \\ (1+z)^{1.4} & : \ 1 < z < 4.5 \\ (1+z)^{-5.6} & : \ 4.5 < z, \end{cases}$$

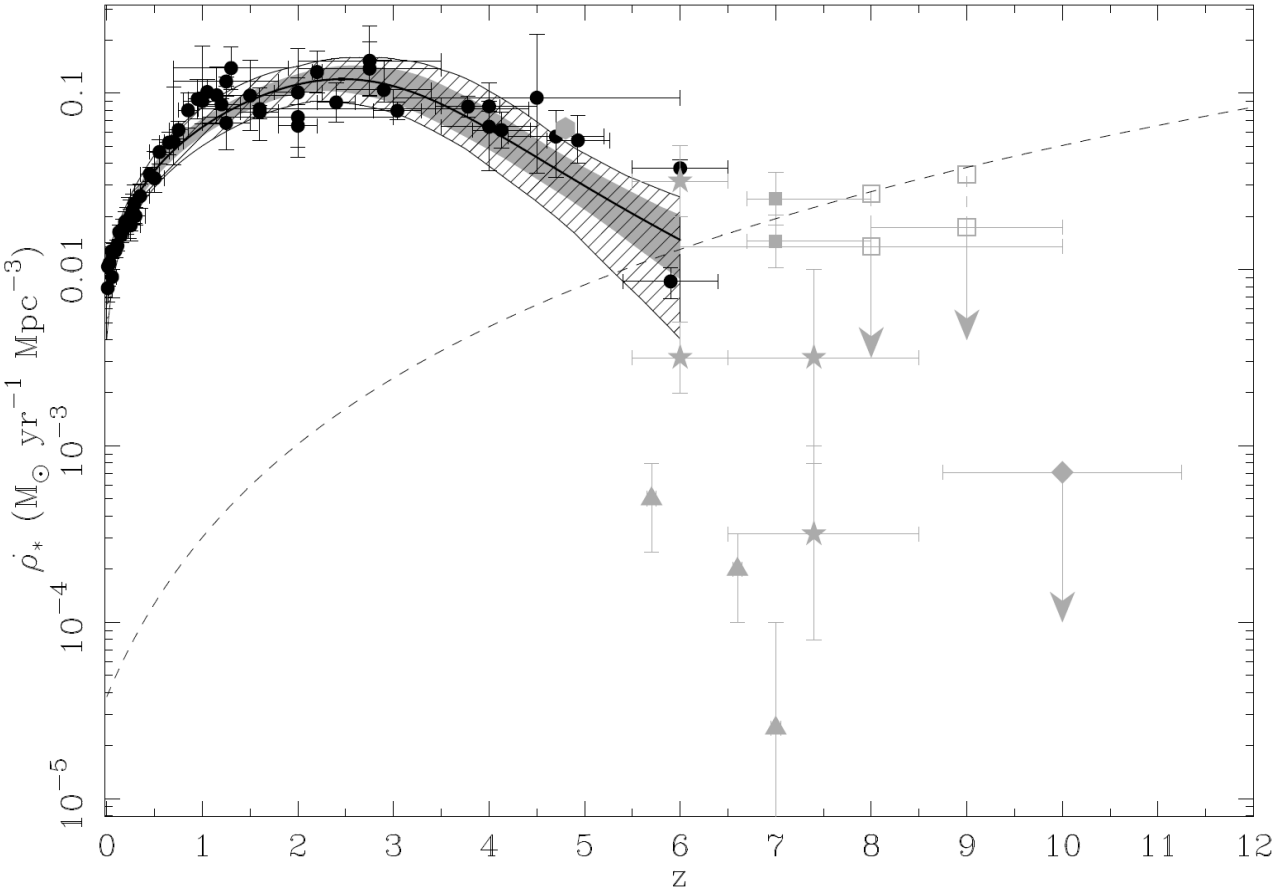
Testing CR Injection & Source Evolution with Neutrinos





Yüksel & Kistler

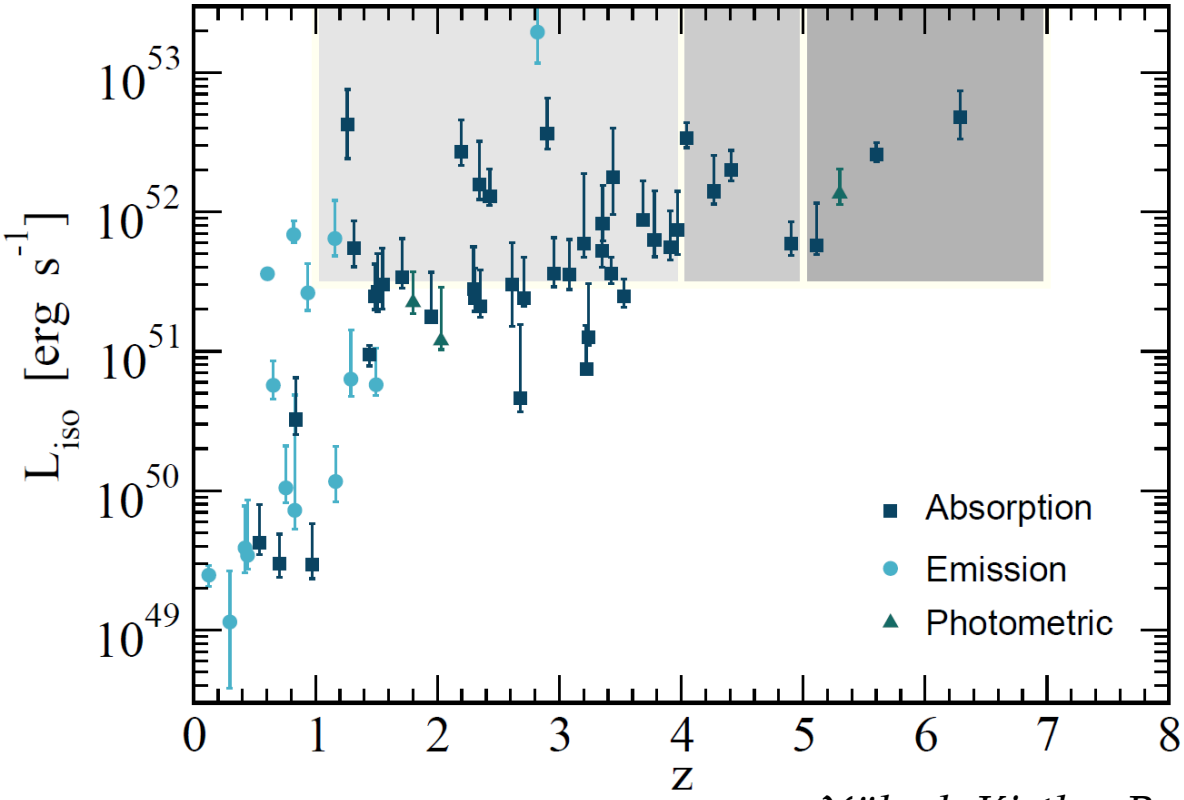
What About SFR at High-z?

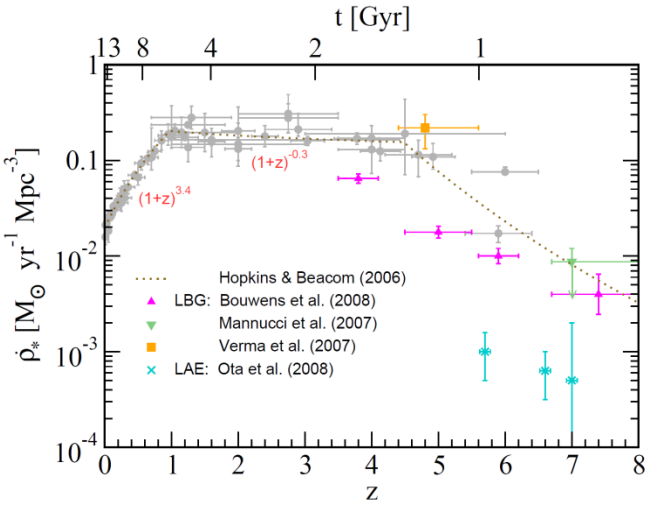


Hopkins

The GRB Technique

$$\langle \dot{\rho}_* \rangle_{z_1-z_2} = \frac{\mathcal{N}^{obs}_{z_1-z_2}}{\mathcal{N}^{obs}_{1-4}} \frac{\int_1^4 dz \, \frac{dV/dz}{1+z} \dot{\rho}_*(z) \, (1+z)^\alpha}{\int_{z_1}^{z_2} dz \, \frac{dV/dz}{1+z} (1+z)^\alpha}$$





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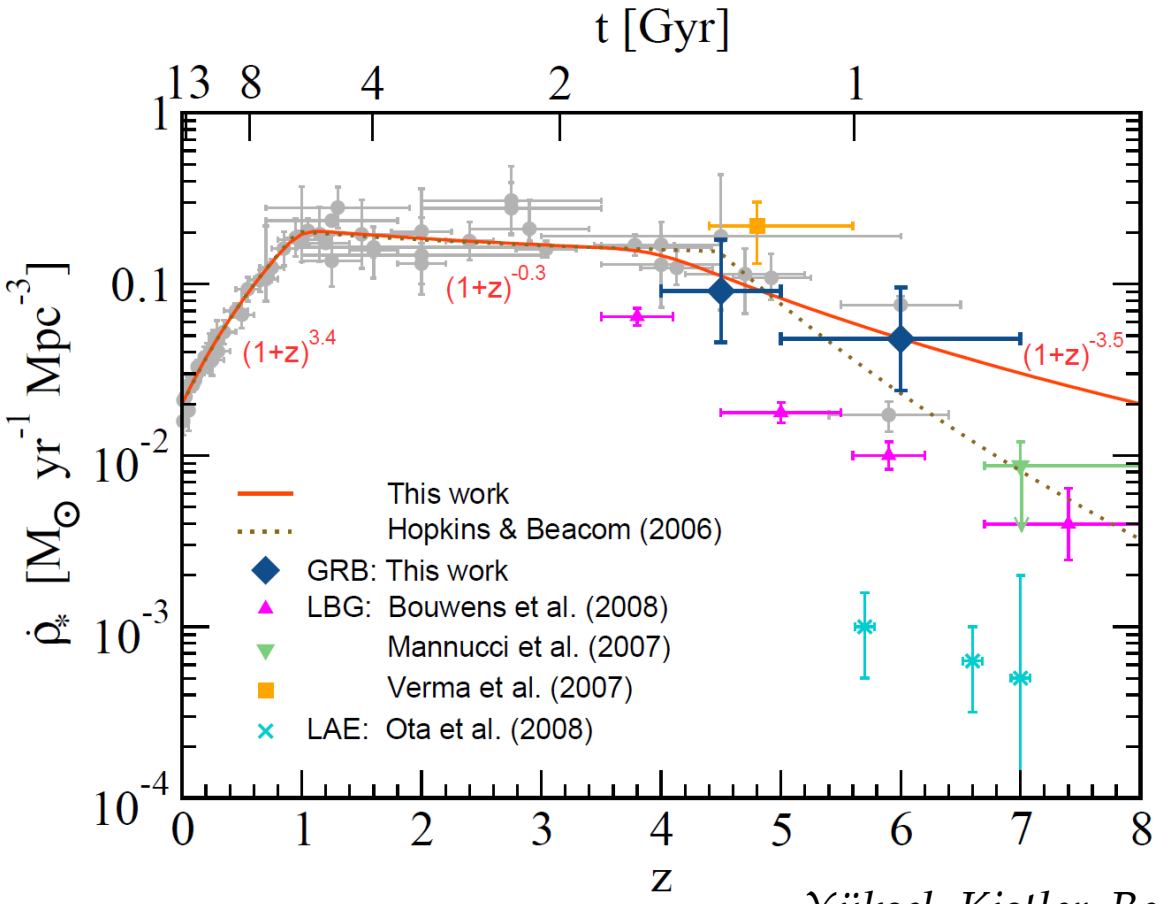
GRB Inferred High-z SFR Rate



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Conclusions

- Observed GRB distribution suggests their rate evolve faster than SFR:
  - Preference for low metallicity?
  - Interesting implications for GRB produced cosmological backgrounds (e.g., GZK neutrinos)

- Number of GRBs observed beyond z ~ 4 shows that SFR at high-z cannot be too low:
  - Reionizing the Universe through Stars
  - Impact of multiple injections of highly asymmetric relativistic ejecta by GRBs (enrichment of IGM & GRB Feedback?)