Gamma Ray Bursts

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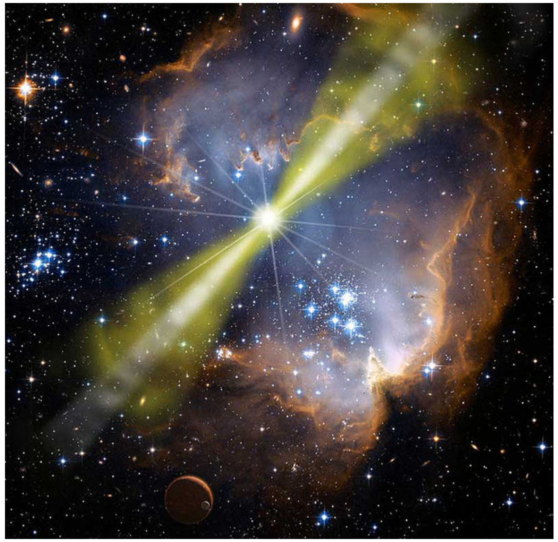
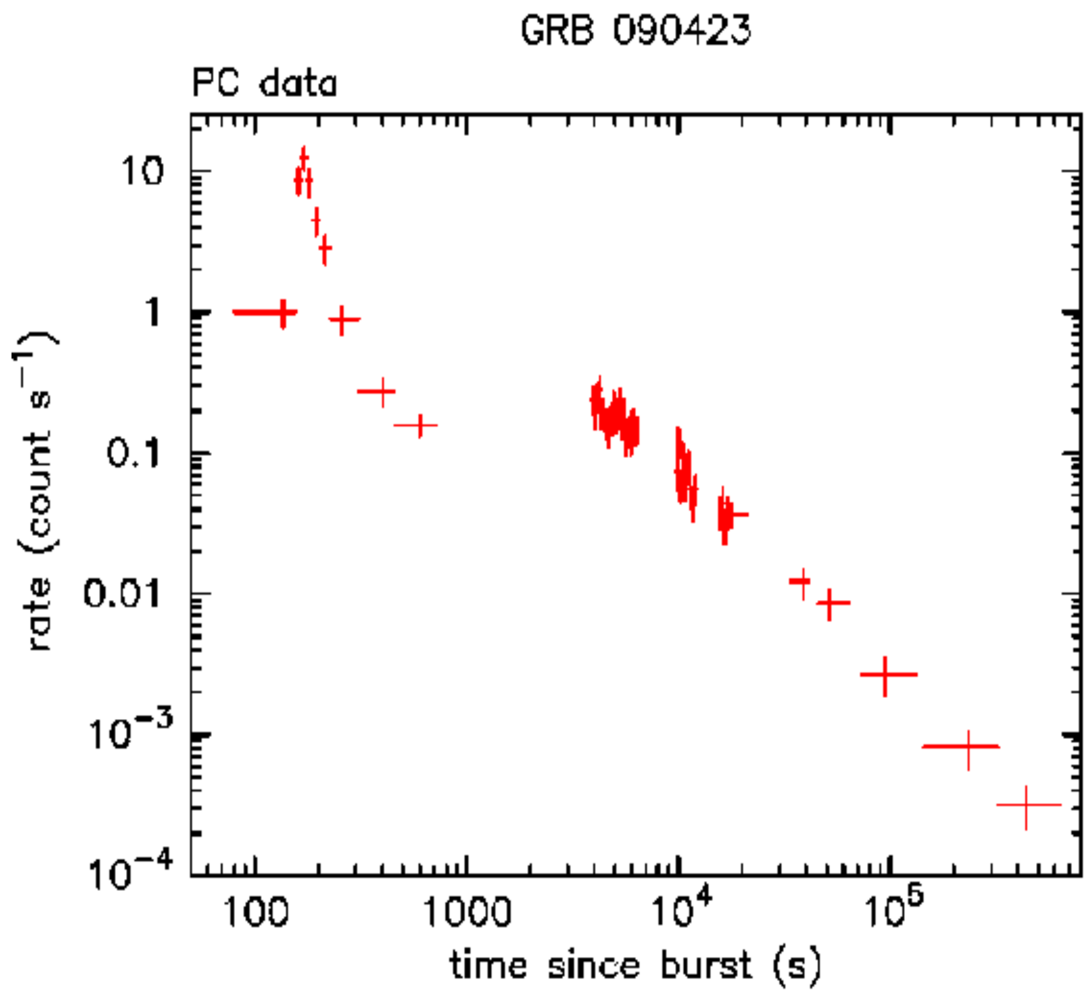
Wikipedia

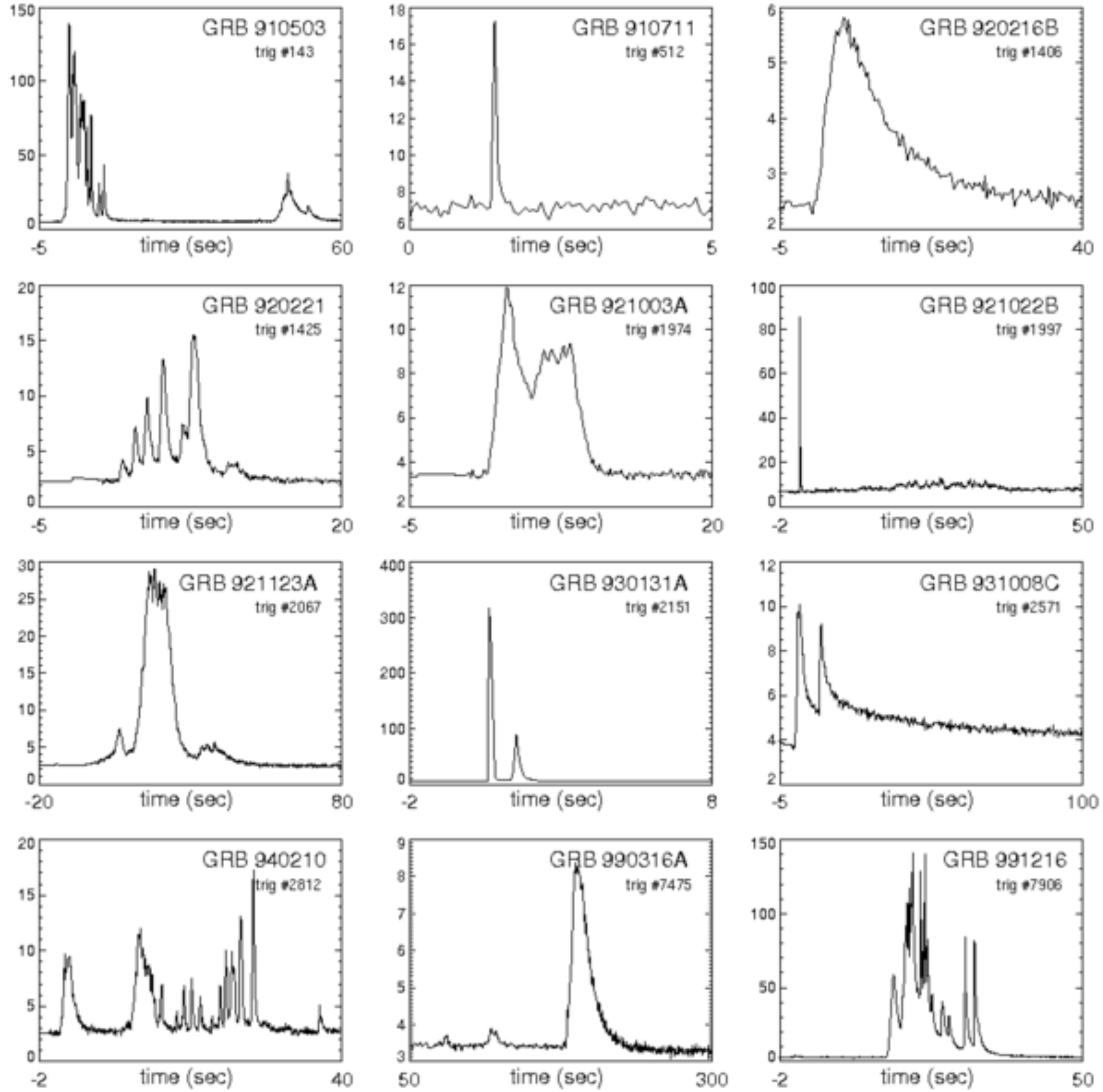


Gamma-ray bursts (GRBs) are flashes of gamma rays associated with extremely energetic explosions that have been observed in distant galaxies. They are the most luminous electro-magnetic events known to occur in the universe. Bursts can last from ten milliseconds to several minutes, although a typical burst lasts 20–40 seconds. The initial burst is usually followed by a longer-lived "afterglow" emitted at longer wavelengths (X-ray, ultraviolet, optical, infrared, micro and radio). Most observed GRBs are believed to consist of a narrow beam of intense radiation released during a supernova event, as a rapidly rotating, high-mass star collapses to form a neutron star, quark star, or black hole.

"Black hole kills star and blasts 3.8 billion light-year beam at Earth" (UW press release on work of A.Levan)



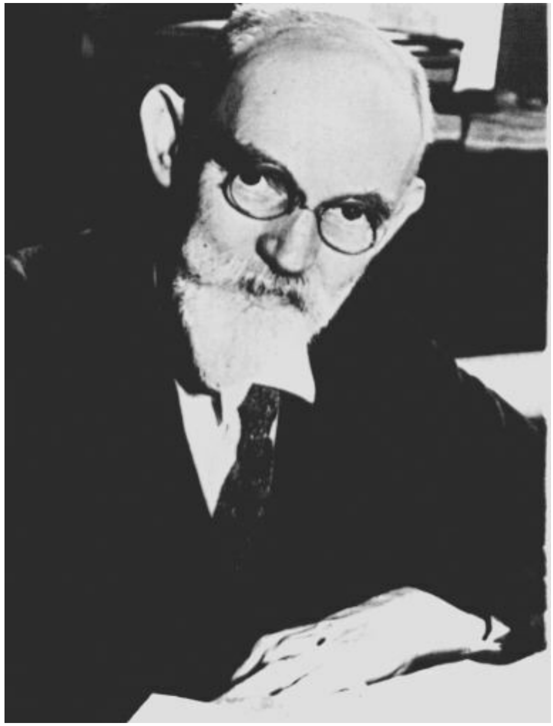
Light curves for some others



Our proposal

- Kinematics: our entry into the region illuminated by a continuous emitter
- No cataclysm required
- We demonstrate it in de Sitter space

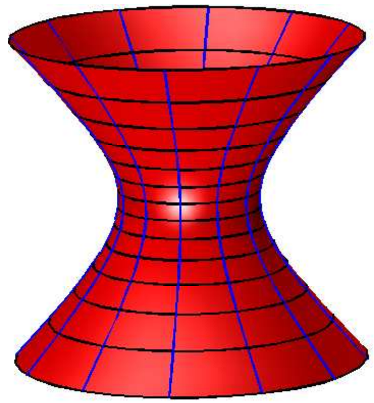
De Sitter space



- The hyperboloid $$-x_0^2 + \sum_{i=1}^{n} x_i^2 = \alpha^2$$

  in 5-dimensional Minkowski space

  $$ds^2 = -dx_0^2 + \sum_{i=1}^{n} dx_i^2.$$
- Ric = Λg, Λ = $3/\alpha^2$
- Picture from Moschella
- Let's scale metric so α=1
- The time-like/null geodesics are the intersections with 2-planes through 0 of slope >/= 45^o.

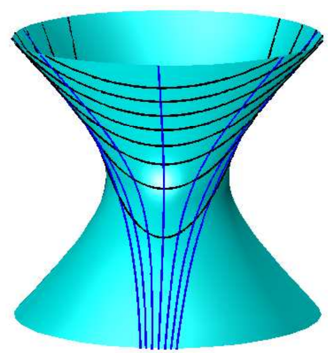


Anosov property

- Time-like geodesic flow on de Sitter space is Anosov (uniformly hyperbolic): there's a splitting of the tangent bundle to the space of unit time-like tangent vectors into the direct sum of the flow direction and bundles E^+, E^- such that all displacements in E^+ contract like e^{-t} in forwards proper time and similarly for E^- in backwards time.
- One proof: Jacobi equation $v'' = Mv = -R(u,v,u)$ for perpendicular displacement v to geodesic with unit tangent u. $\mathrm{Tr}\, M = -\mathrm{Ric}(u,u) = -\Lambda g(u,u) = \Lambda$. Rotational symmetry about u, so $v'' = \Lambda/3\ v$, and $v = v^+ e^{-t} + v^- e^t$.
- Another proof: unstable manifold W^- (integral submanifold of E^-) is given by the tangents to y=cst on $t=0$ in expanding flat slice coordinates (t,y):

  $x_0 = \sinh t + r^2/2\ e^t$, $x_1 = \cosh t - r^2/2\ e^t$,

  $x_j = e^t y_j$, where $r^2 = \Sigma y_j^2$ (for the geodesic $y=0$ at $t=0$).



- So most pairs of geodesics separate exponentially in both forward and backward time.

Null geodesics between time-like geodesics in de Sitter space

- Seems not to have been treated fully (despite de Sitter, Weyl, fashion in the 1950-60s…)
- Given a receiver geodesic r (wlog y=0) and an emitter geodesic e, there is a (future-preserving) isometry M such that e = Mr. Parametrise them by their proper times t_r=t and t_e=u, then the set of pairs (t,u) with a future-pointing null geodesic from e to r is given by:

  $-(a \sinh u + b \cosh u) \sinh t + (c \sinh u + d \cosh u) \cosh t = 1$

  with $a \sinh u + b \cosh u < \sinh t$,

  where [a b \\ c d] is the top block of M. Constraints

  $(ab-cd)^2 \leq (a^2-c^2-1)(b^2-d^2+1)$, both factors non-negative and a≥1.
- Can write in terms of T = exp t, U = exp u, as

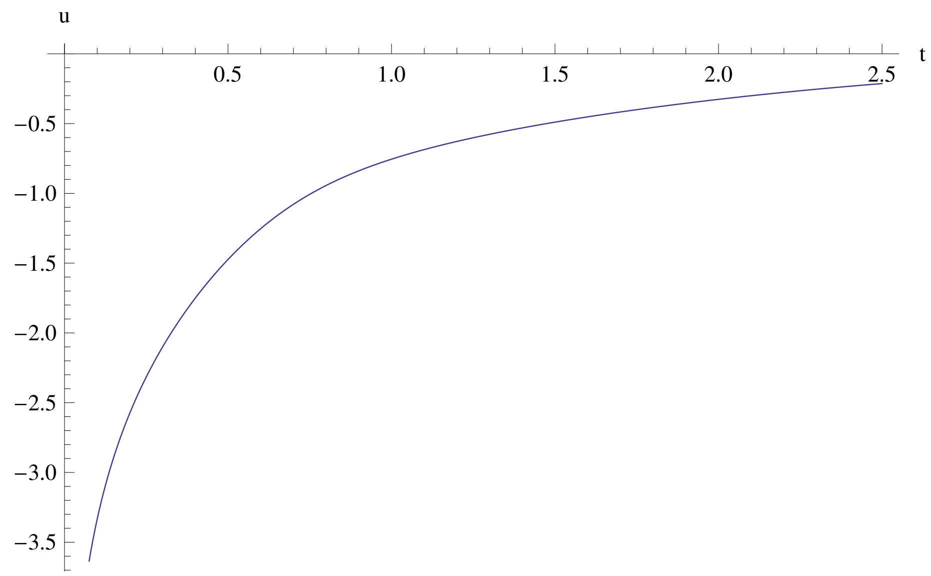
  $-ATU+BT/U+CU/T-D/TU=2$,

  with A,B,C,D≥0 a linear transformation of a,b,c,d. Causal solution

  $T=(U+\mathrm{sqrt}[BD+(1-BC-AD)U^2+ACU^4])/(B-AU^2)$ for $U<\mathrm{sqrt}[B/A]$

General features

- There is a first t* (T^2=D/B) after which e becomes visible to r (u starts at -∞) [when we enter π(W^-(e))] and a last u* (U^2=B/A) from which emissions can be seen by r (as t ➔+∞).
- u(t) monotone increasing
- Exceptionally, D=0, t*=-∞ (backward asymptotic) or A=0, u*=∞ (forward asymptotic) or B=0, t*=+∞, u*=-∞ (past-asymptotic to antipodal).
- Weyl did not like t* finite and declared that no emitters follow such geodesics: BIG MISTAKE in our opinion!



u as a function of t, with origin shifted to (t*,u*), for a sample emitter geodesic

Red/blue-shift

- Redshift z defined by $1+z = dt/du = U/T\ dT/dU$
- $\omega_r/\omega_e = 1/(1+z) = du/dt$
- z goes from -1 (infinitely blue) to $+\infty$ (infinitely red) as t goes from t^* to $+\infty$.
- $1+z \sim t-t^*$ as t decreases to t^*.
- $z>0$ for all but a bounded interval of t. Time of passage through $z=0$ is defined by $(UT)^2=D/A$.
- Blueshift period $t_B = \frac{1}{2}\log\frac{1+\sqrt{AD}+\sqrt{1+2\sqrt{AD}+AD-BC}}{\sqrt{AD}}$
- Exceptionally z goes from 0 to ∞ (backward asymptotic) or -1 to 0 (forward asymptotic), or jumps across 0 (intersecting geodesics).

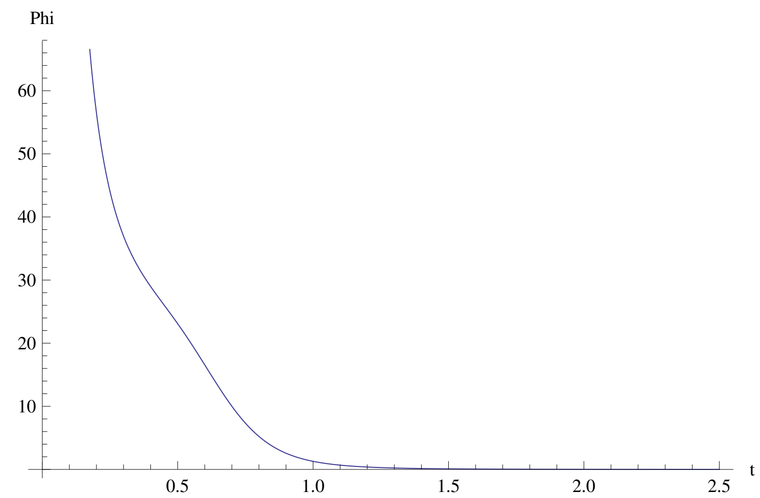
Received Flux

- The received flux $\Phi = P/((1+z)\rho)^2$, where P is the emitter power per unit solid angle and the “corrected luminosity distance” ρ accounts for geometric expansion of the bundle of rays.
- In de Sitter space, ρ is given by change in affine parameter along the null geodesic scaled to equal elapsed time in emitter frame initially. Thus

  $\rho = 1-(C/T-AT)U.$
- ρ starts at 1 (de Sitter radius) at t*: large apparent distance is offset by Lorentz transformation of isotropic emission into a narrow forward beam (angle 2(1+z)).

  $d\rho/dU = (AD-BC)/\mathrm{sqrt}[BD]$ at U=0,

  and ρ goes to +∞ with t.
- Hence if P=cst, Φ starts infinite and its integral over t diverges because $\Phi \sim P/(t-t^*)^2$



For a real emitter

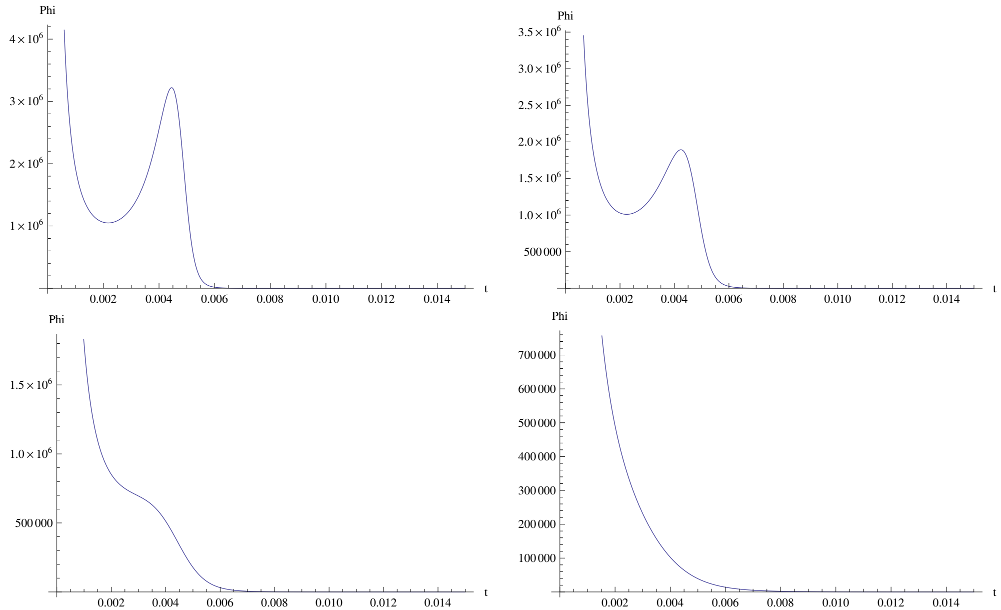
- Emitter power P is not constant, probably has a start date, may go through a supernova phase and is probably an integrable function of emitter time u
- So Φ doesn't really start infinite, nor have infinite integral, but still can have a large initial peak
- Received energy per unit area from time t* to t is

$$\int_{-\infty}^{u(t)} \frac{DP(u)}{T\rho^3}(e^{-u} + \frac{T}{D} - \frac{Ce^u}{D})\, du$$

- Large if ρ decreases to a small value before going to +∞
- This favours the region of short blueshift period BC >> AD.

Two-parameter family

- By isometries, we can reduce the generic case to a=cosh ϕ, b=c=0, d=cos θ.
- Then A=D=(a-d)/2 and B=C=(a+d)/2
- And shift origin of t to t* for the plots



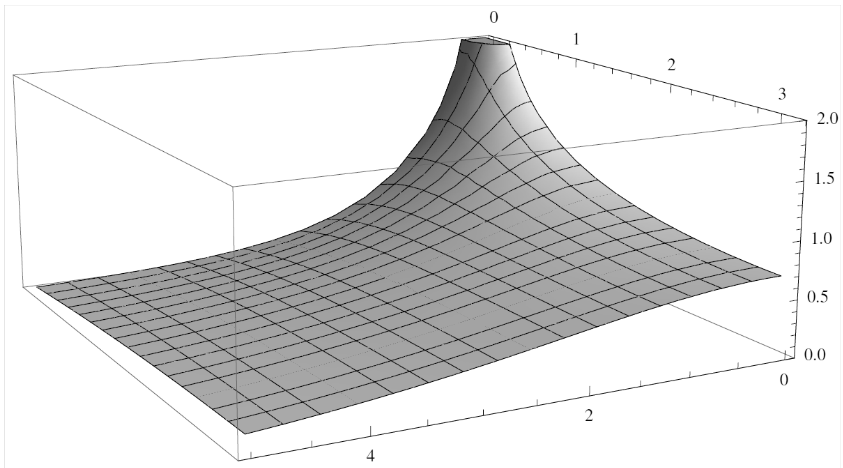


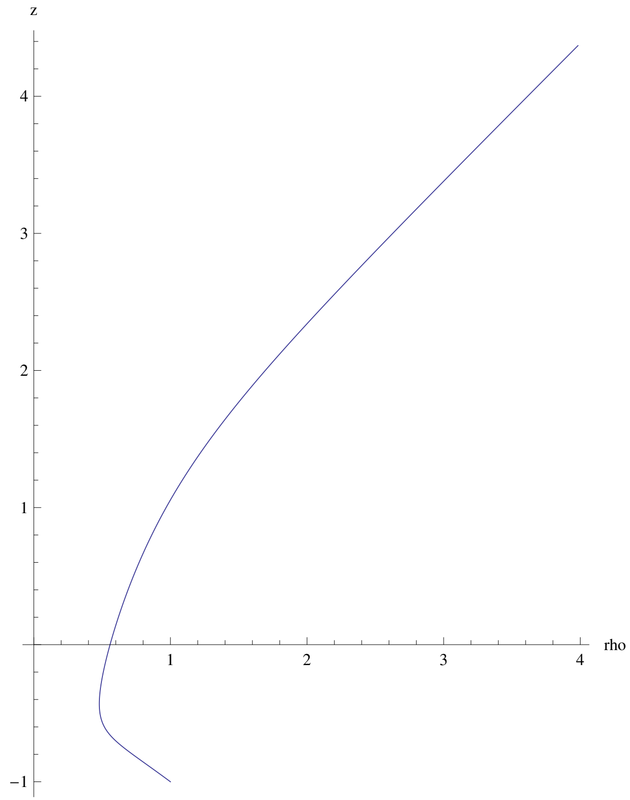
Figure 5: Blueshift period (vertical) as a function of θ (top axis) and ϕ (bottom axis)

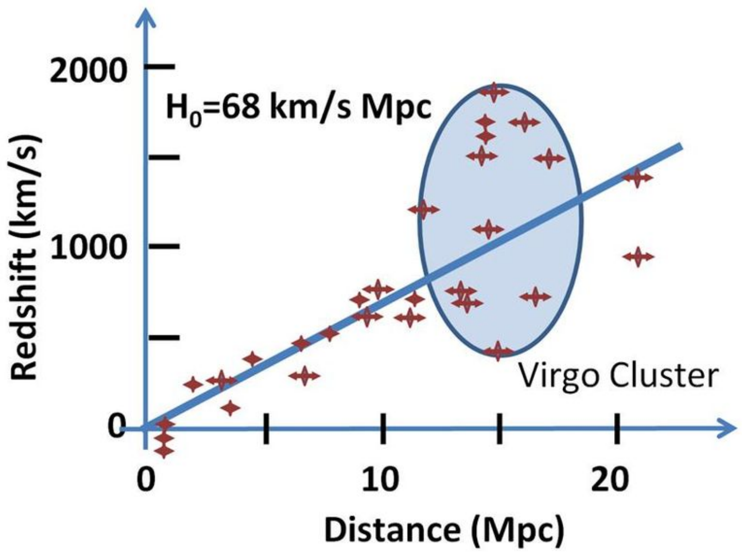
What about claims to measure redshift of gamma ray bursts?

- Perhaps an artefact of intervening dust?

Hubble plot

- z v ρ
- Note z ~ ρ as t ➔ +∞.
- All emitters for which the blueshift period was in our distant past line up along this asymptote.
- So an asymptotic Lemaitre-Hubble law, with H=1/de Sitter radius.





Beyond de Sitter

- Anosov systems are structurally stable, so all small perturbations of the metric have close time-like behaviour.
- But does not apply to null geodesics.
- Still, expect gamma ray bursts from same mechanism (our entry into region illuminated by emitter), and asymptotic Lemaitre-Hubble law with H = Lyapunov exponent
- For example, Schwarzschild - de Sitter metric

  $ds^2 = -Q(r)dt^2 + Q(r)^{-1}dr^2 + r^2 d\Omega^2$ with

  $Q(r) = 1 - 2M/r - r^2/a^2 > 0$ in $r_b<r<r_c$

  satisfies $Ric = \Lambda g$ and extends beyond $r=r_c$ to submanifold

  $X^2 - T^2 = k^{-2}Q(r)$ of R^5 with

  $ds^2 = -dT^2 + dX^2 + b(r)dr^2 + r^2 d\Omega^2$,

  $k = (r_c^3 - Ma^2)/a^2 r_c^2 \approx 1/a$, $b(r) = (1-k^{-2}Q'(r)^2)/Q(r) \approx 1$

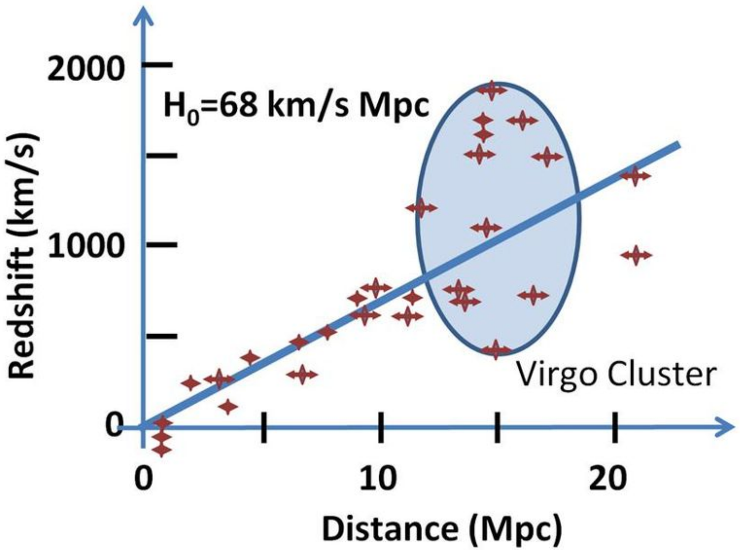
  which is a small perturbation for M small, $r>(Ma^2)^{1/3}$.

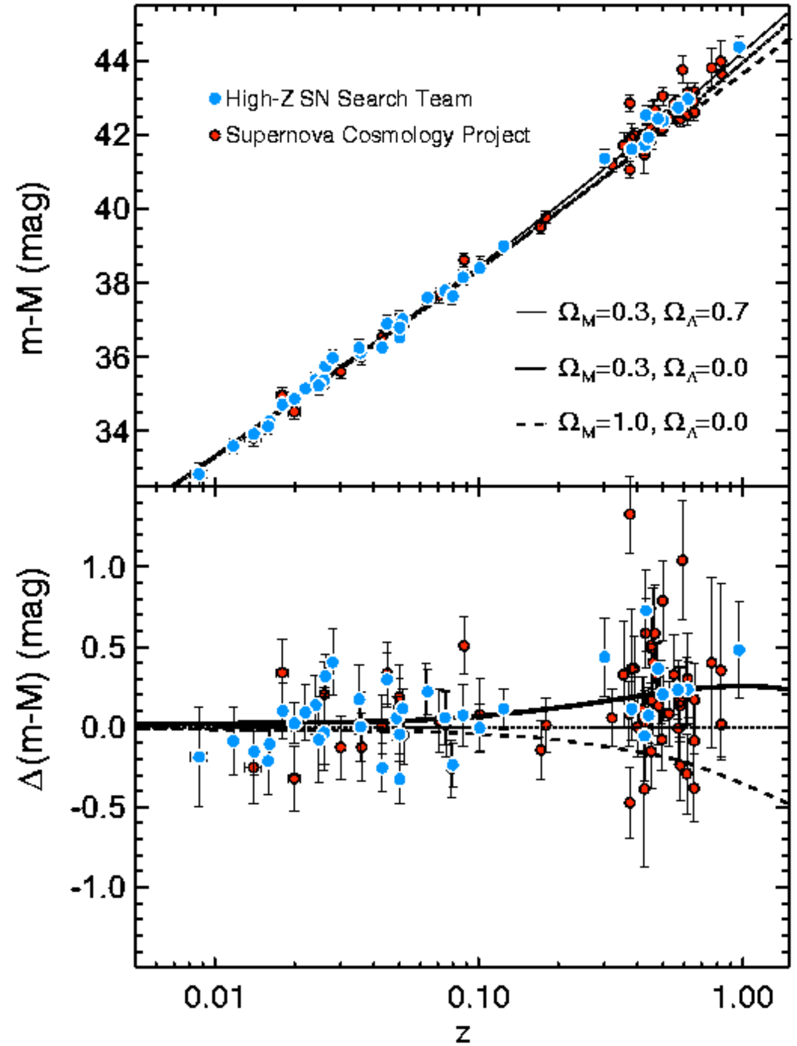
Conclusion

- We propose gamma ray bursts are a kinematic effect: our entry into the union of the forward light-cones of a continuous emitter. No cataclysm required.
- Also Lemaitre-Hubble law does not require big bang
- Can we revise cosmology further?

  Explain the cosmic microwave background, the proportions of light elements, dark sky at night?

Observations





Standard Interpretation

- Friedmann-Lemaitre-Robertson-Walker universe
- $ds^2 = -dt^2 + S(t)^2\, dr^2$ and cosmic flow r=cst, where dr^2 is Euclidean, spherical or hyperbolic (k=0,+1,-1).
- Then $1+z = S(t_r)/S(t_e)$ and $\rho = S(t_r) \int dt/S(t)$ (for k=0)
- e.g. $S(t) = e^{Ht}$ implies $z = H\rho$.
- $S(t) = t^{\alpha}$, $\alpha=⅔$ (matter), ½ (radiation) implies $(1-(1-\alpha)\rho)^{\alpha} = (1+z)^{\alpha-1}$.
- Can infer S from z v. ρ via $S^{-1}(1/(1+z)) = t_r - \int_0^{\rho} d\rho/(1+z)$; big bang $S(t^*)=0$ iff integral is finite.
- Extrapolating back from observations and Friedmann eqn for S implies there is $t^* \approx -13.7$ billion years with $S(t^*)=0$.

$$H^2 \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2} + \frac{\Lambda}{3},$$

- Even if allow deviation from homogeneous space, Penrose-Hawking singularity theorems prove backward null and time-like geodesic incompleteness under "trapping surface" conditions.

But

- FLRW too simplistic (cosmic time)
- Penrose-Hawking singularity theorems do not say **all** null and timelike geodesics are incomplete
- Could Hubble's law arise instead from statistical assumptions about inhomogeneous distribution of matter and chaotic trajectories? Perhaps via some ergodic theory about accumulation of redshift along null geodesics.
- As a simple starting point to ensure hyperbolicity, we included positive cosmological constant.
- And hit on an explanation of gamma ray bursts (as well as Hubble's law).