

# Threats To Life From Outer Space<sup>+</sup>

Arnon Dar

La Thuile, Aosta Valley, March 9, 2002

Meteoritic Impacts

Supernova Explosions

Gamma Ray Bursts

Based on work in collaboration with

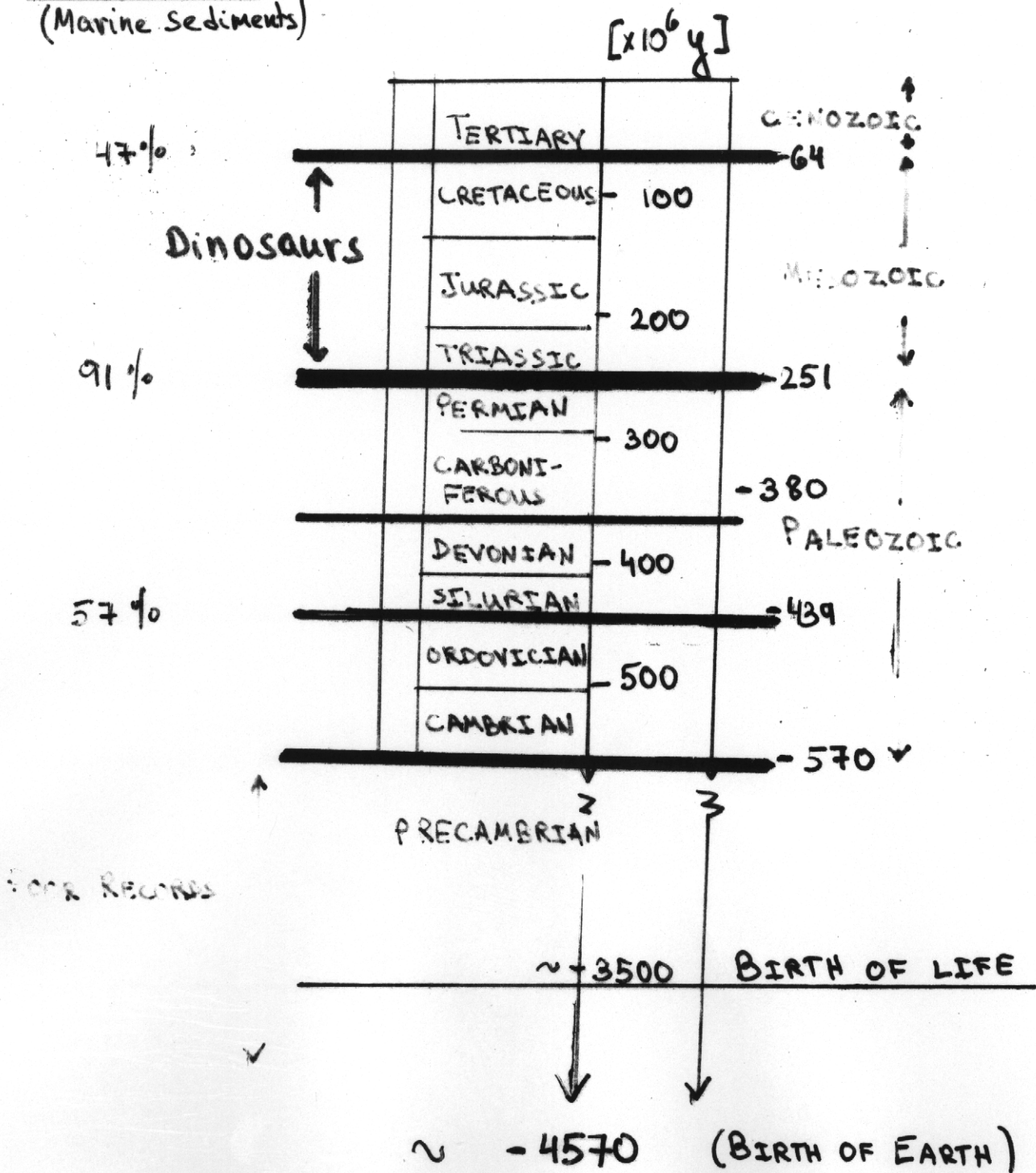
Ari Laor and Nir Shaviv PRL

Alvaro De-Rujula Astro-ph/

# EXTINCTIONS IN THE HISTORY OF LIFE

(FROM FOSSIL AND SEDIMENTS RECORDS)

Extinction  
(Marine Sediments)





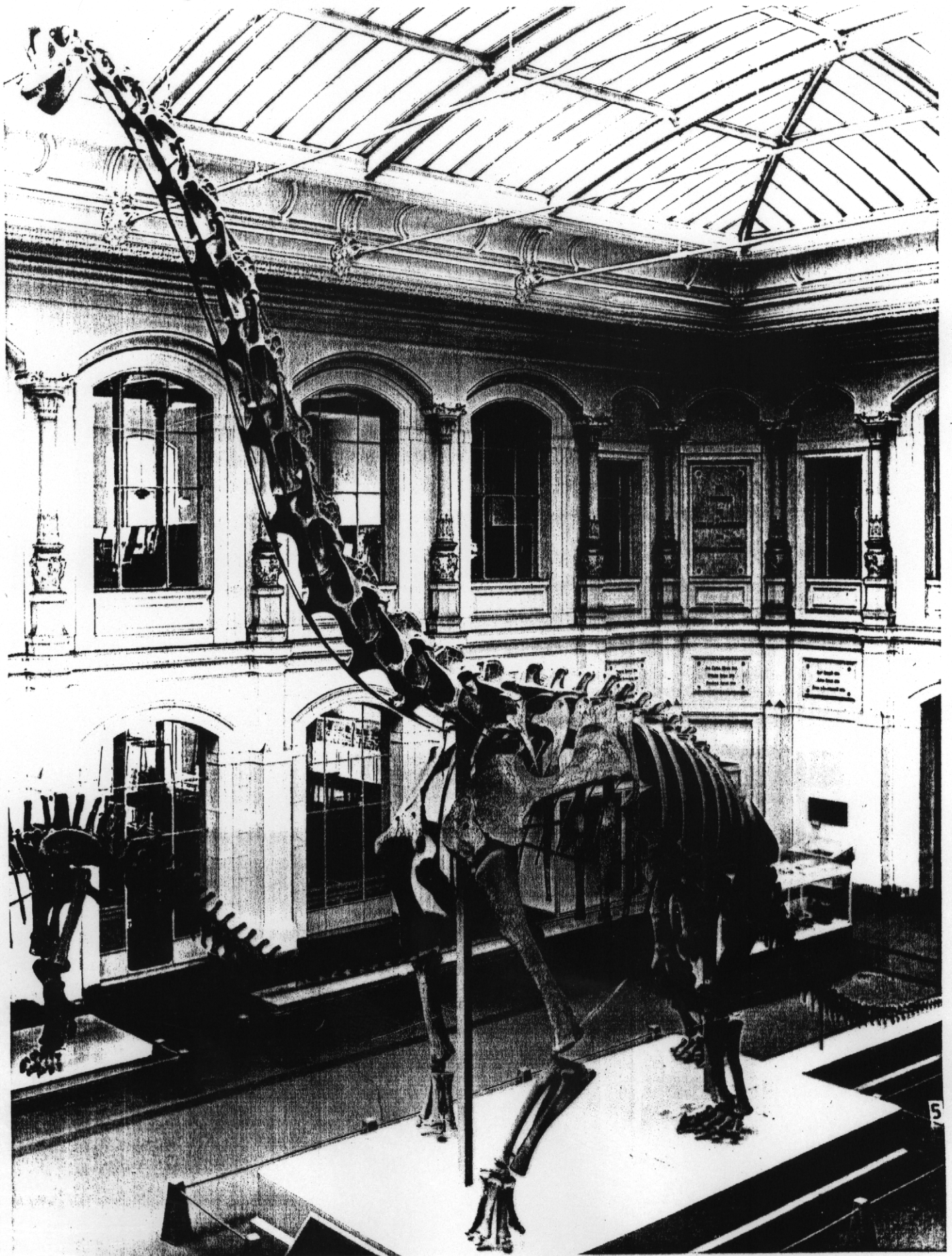
# The Accuracy of Geological Records

Deterioration due to:

- \* Weather
- \* Geological Activity
- \* Continental Drifts
- \*

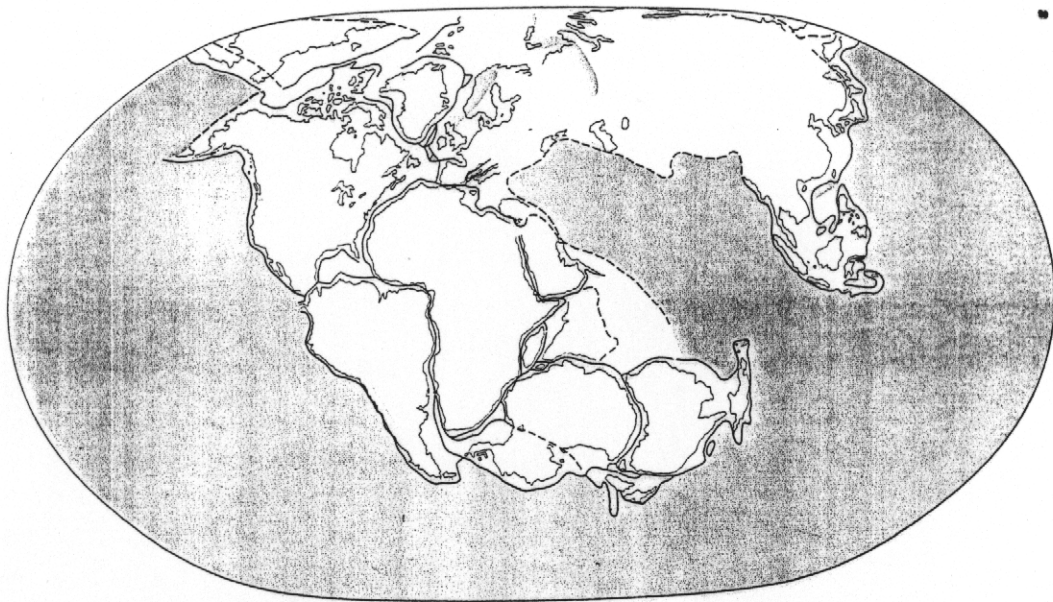
Timing Accuracy

ההרצ'ינולארי הנהגון היחיד שנמצא ולתור האחרון  
אמריקא באפריקא אלבא בקלין האפריקאית  
(נאלף בלעדי בתחילת המאה ה-19 עיטולאגיום גרמני)



# Continental Drift

היבשת לפני כ-200-240 מיליון שנה



יבשת אחת  
**PANGEA**

**200-240**  
**My**  
ago

Above *Triceratops*, a ceratopian ornithischian, was one of the last dinosaurs to appear at the very end of the Cretaceous Period. Note the large, parrot-like beak.

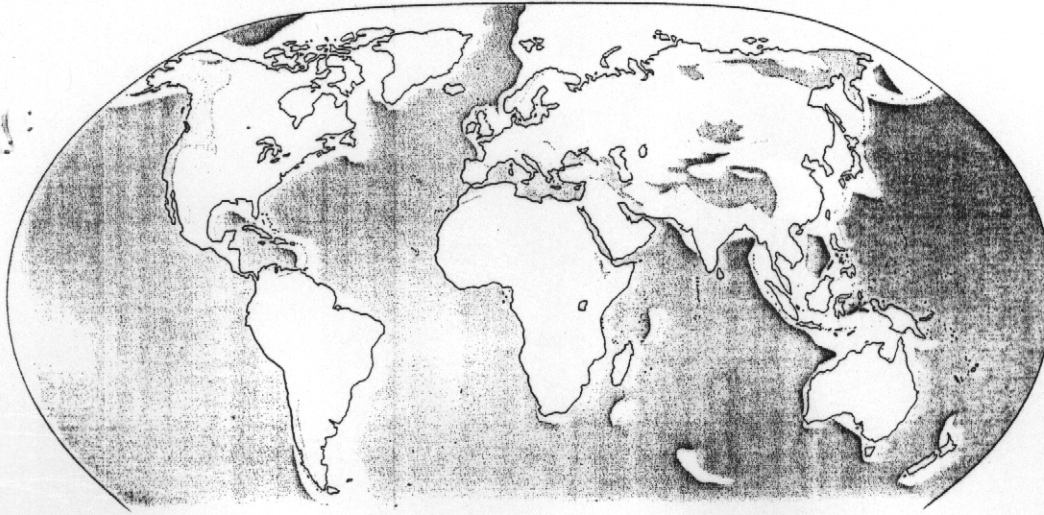
**Triassic Period**  
(240-200 myears ago)

Top left Continent positions in the Triassic show the existence of the supercontinent Pangea.

**Present Day**

Left Continental drift, made possible by tectonic plate movement, broke Pangea into the world we know today, and movement is continuing even now.

Today:



Vegetation     Tundra & ice  
 Mountain     Continental

היום



From the geological records:

- \* Mass Extinction
  - \* Gigantic Volcanic Eruptions
  - \* Global Climatic Change
  - \* Huge Sea Regression / Glaciation
- seem to be correlated in time!

**Why these 4 Catastrophes  
Are taking place  
Around the same Time?**

## Cosmic Mechanism?

May provide the answer to Fermi's famous question:

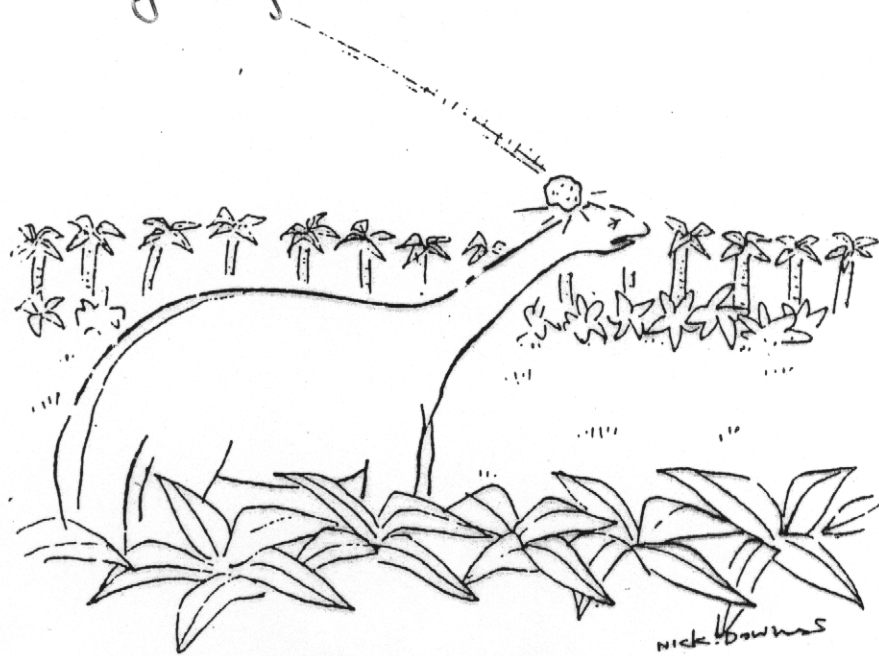
"Where Are They?"

(much more advanced civilizations)

# Meteoritic Extinction

L. Alvarez et al., Science 208, 1095 (1980)

- ① Meteoritic Impact ( $\sim 10^{12}$  tons Meteorite)
- ② Splash of Crustal Material High into the Atmosphere
- ③ Global Spread of Dust by Winds
- ④ Complete Obscuration of Sun Light
- ⑤ Extinction of Light-supported Life  
(photosynthesis supported life like plants, vegetation, ...)
- ⑥ Devastating Blow to the Food Chain
- ⑦ Extinction of Species.



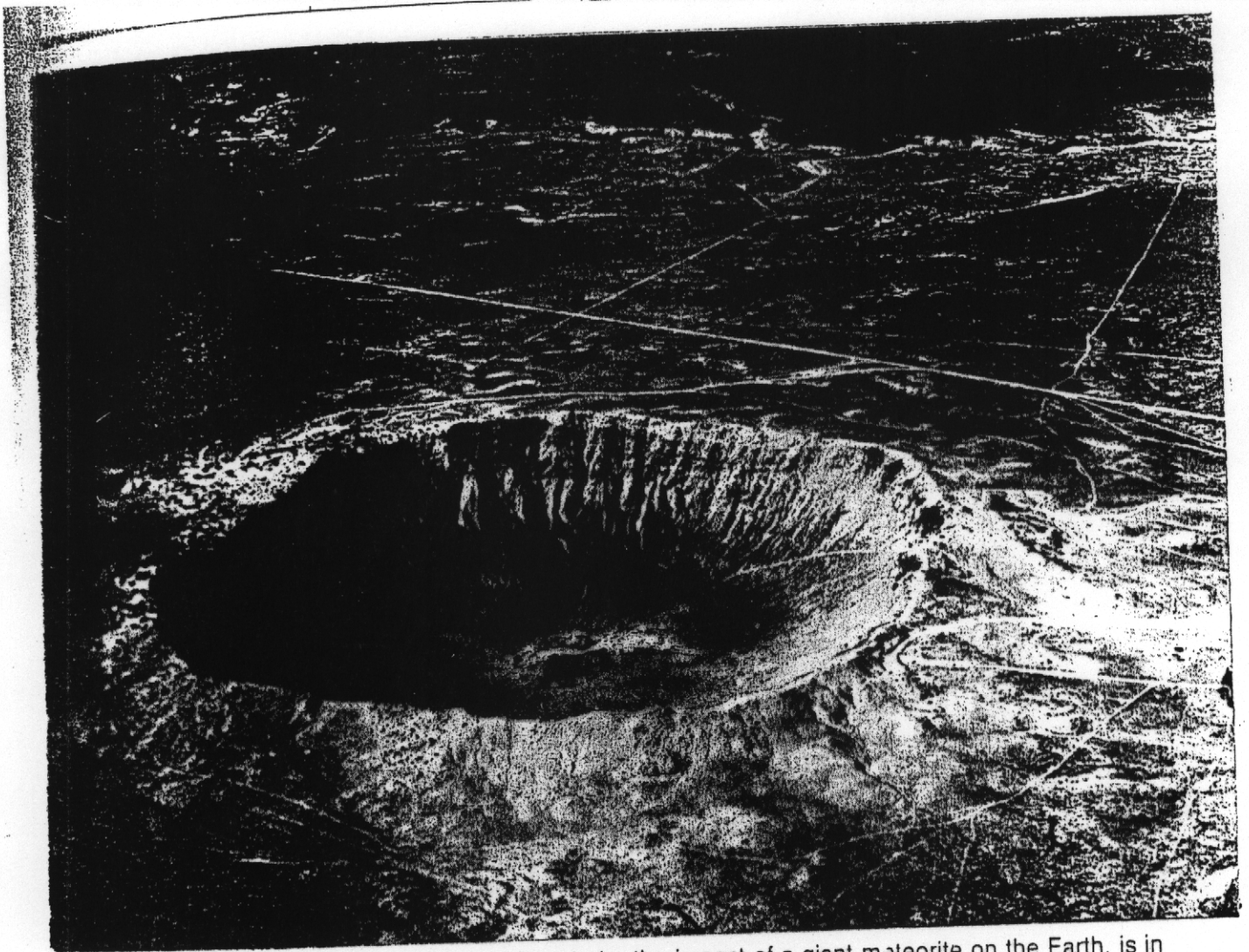
**MINOR EXTINCTION**

Evidence: The Iridium Anomaly ?  
Crater ? Chicxulub  
Quartz Grains, } ?  
Basaltic spherules }





**Highlands and maria.** Observed from lunar orbit, the highlands (above) appear a lot richer in large craters than the maria (below). This is explained by the fact that the maria solidified nearly a billion years after the highlands. The latter therefore underwent the intense meteoritic bombardment (which followed the accretion of the planetary bodies) of which traces are found throughout the Solar System from Mercury to the satellites of Saturn. During that period, certain giant impacts created the large circular basins which, when filled, formed the basaltic maria. Then and for more than three billion years, the highlands and maria underwent an identical, but less intense, bombardment and therefore display a similar density of small craters. (Apollos 17 and 16 photographs; NASA/NSSDC)



**The Meteor Crater.** The most famous crater made by the impact of a giant meteorite on the Earth, is in Arizona. With a diameter of 1.2 kilometres and 150 metres deep, it was formed about 40 000 years ago, and shows a marked similarity to lunar craters. It has been estimated that the size of the metallic meteorite responsible for the crater was of the order of 25 metres (that is a mass of 65 000 tonnes). However, because of the violence of the impact, only a very small fraction of this mass escaped destruction and could be recovered; this is the Canyon Diablo meteorite. Such an event only happens about once every 25 000 years on land above sea-level. The impact of the largest objects (of the order of 1 kilometre) only occurs about once every 100 million years. However, such events could have played an important role, in particular by throwing into the atmosphere hundreds of cubic kilometres of matter, which is nearly one hundred times more than the greatest volcanic eruptions. Such a quantity of dust encircling the whole Earth for many years would profoundly alter the climate by intercepting the light from the Sun. An event of this type could have been responsible for the disappearance of a large number of species at the end of the Cretaceous Period. (Yerkes Observatory)

meteorite

$D \sim 20 \text{ m}$

$m \sim 65\,000 \text{ tonnes}$

$E_{\text{kinetic}} \sim 5 \times 10^{23} \text{ erg}$   
 (T.N.T Equivalent 10 MT)

Crater Parameters

1.2 km (diameter)

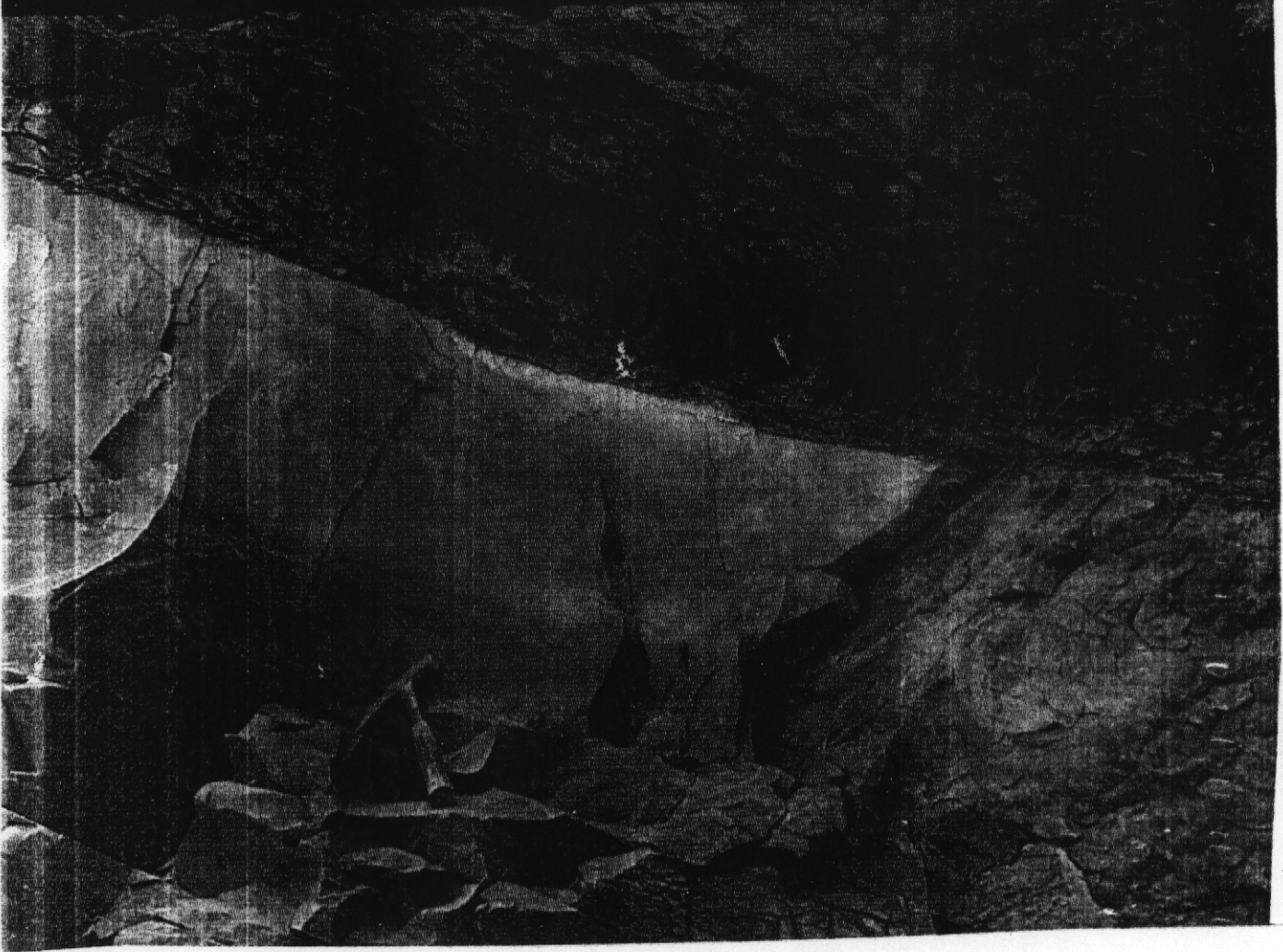
150 m (depth)

40000 y (age)



64 My

Des argiles noires marquent le passage d



The Cretaceous/Tertiary Boundary

Sediments :  $\sim 1 \text{ cm}$  in  $10^4 \text{ y}$

$1 \text{ m}$  in  $10^6 \text{ y}$

# Supernovae Extinctions?

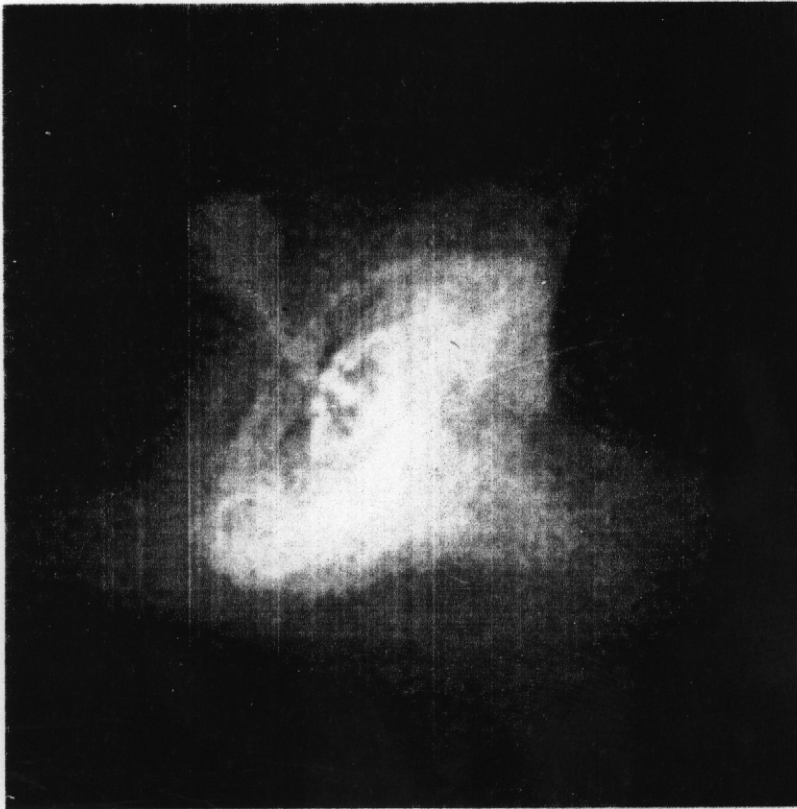
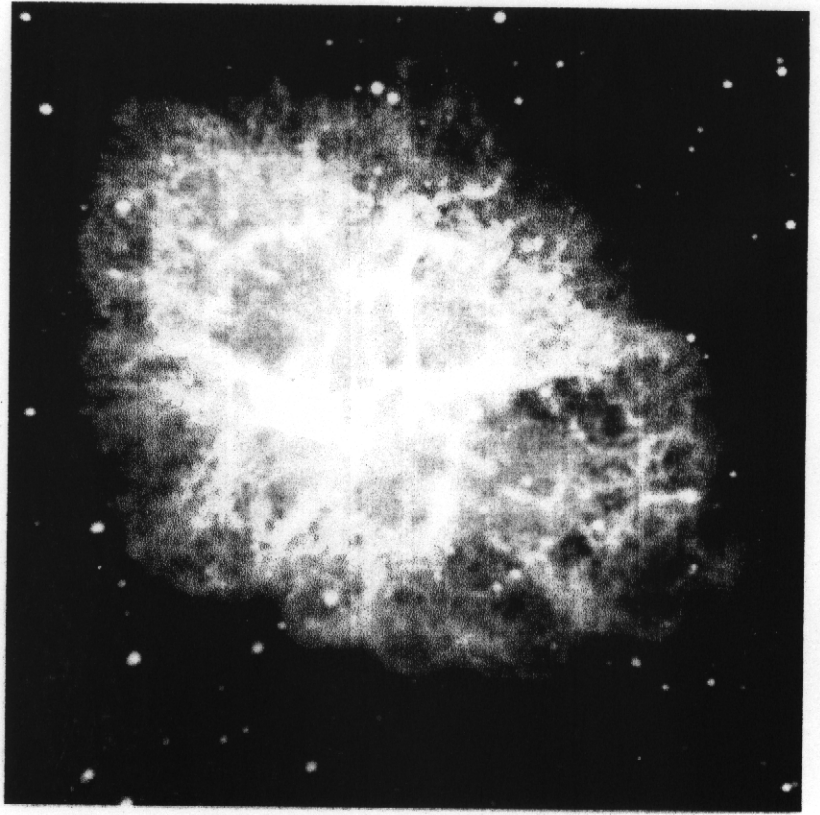
Cosmic Ray Bombardment  
From Nearby Supernovae

Light, Shock waves, etc  
have too small "killing range"

# CRAB NEBULA

(Palomar)

O  
P  
T  
I  
C  
A  
L



X  
R  
A  
Y

(Chandra)





# Supernova 1987A Rings



Hubble Space Telescope  
Wide Field Planetary Camera 2



SPACE  
TELESCOPE  
SCIENCE  
INSTITUTE

Neutrino Burst (s?)  $\Rightarrow$  Production of compact object  
~~Production of compact object~~  
**Black Hole ?**





## Atmospheric Production of $\mu$ 's by TeV Gamma Rays:

$$N_{\mu} [\text{ground level}] \approx 0.23 [\cos \theta_z]^2 (E_{\gamma} / \text{TeV})^{1.15}$$

$\Rightarrow$  A GRB At The Position Of Eta-Carinae  
that Points In our Direction Will  
Produce

$$\bar{F}_{\mu} \approx \frac{0.23 (\cos \theta_z^2) 100 E_{\gamma}}{4\pi (2.3 \text{ kpc})^2} \approx 5 \times 10^{10} \text{ cm}^{-2} \mu/s$$

HE Muons deposit  $\sim 2.5 \text{ MeV} \cdot \text{cm}^2/\text{g}$  in  
biological materials.  $5 \times 10^{10} \mu/s \text{ cm}^{-2}$   
deposit  $2 \times 10^5 \text{ erg} \cdot \text{g}^{-1}$ .

$2 \times 10^5 \text{ erg} \cdot \text{g}^{-1} \approx$  Lethal Dose For humans

Lethal Dosage  $\approx 2 \times 10^4 \text{ erg} \cdot \text{g}^{-1}$

(the whole body dose from penetrating  
ionizing radiation resulting in 50%  
mortality)

Additional killers: Radioactivation of  
the atmosphere and the ground by the  
HE muons.

THE GRB Great Debate

1967 - 1973 →

Man Made Or Cosmic Phenomena  
 (A-Bombs, H-Bombs)

Klebesadel et al. ApJ, 182 L85 (1973)

1973 - 1991 →

Nearby Or Cosmological

$D \approx 3 \times 10^{22}$  cm  
 $E \approx 10^{40} \Delta\Omega$  erg  
 $E \approx (1+z) 10^{-5} D^2 \Delta\Omega T$   
 obs:  $10^{-5}$  erg  $\cdot$  s $^{-1}$   $\cdot$  cm $^{-2}$ ;  $\sim 10$  s

$D \sim 10^{28}$  cm  
 $E \approx 10^{52} \Delta\Omega$  erg !!!

Meegan et al. (BATSE/CGRO) Nature 355, 143 (1992)

1991 - 1997 →

Galactic Halo Or Cosmological

n- $\star$  quakes,  
 n- $\star$  phase transitions

ns-ns mergers  
 ns-BH mergers  
 Accretion Induced Collapse  
 Core Collapse  $\rightarrow$  BH

Djorkovski et al (keck) Nature 387, 876 (1997)

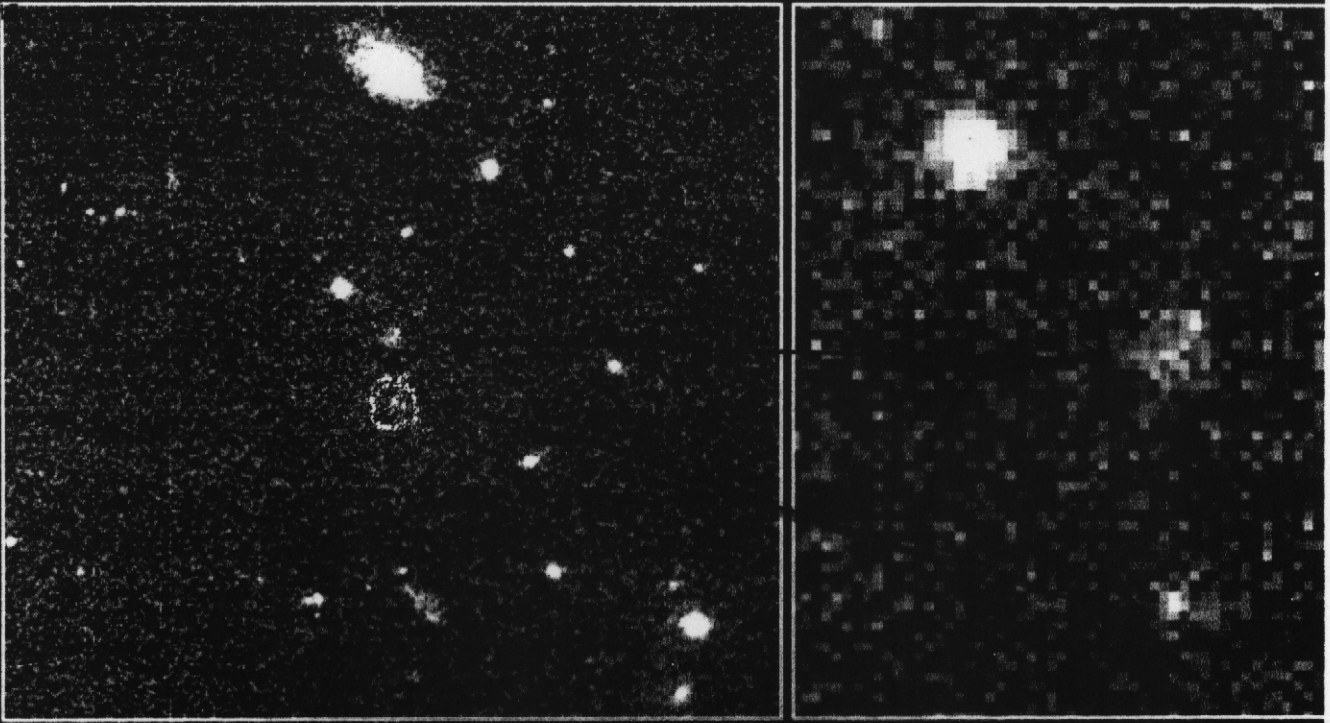
1997 - ? →

Relativistic Fireballs Or Superluminal Jets  
 (e.g. Rees+..., Paczynski+...) (e.g. Shaviv+Dar)

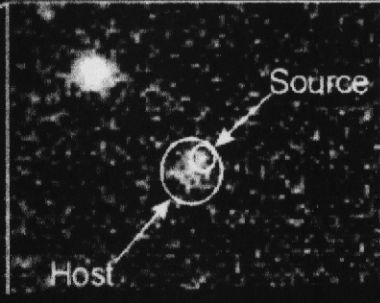
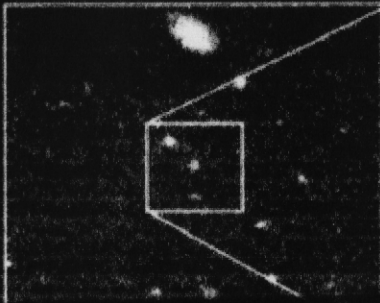


September 16 1997

02/00 13:19

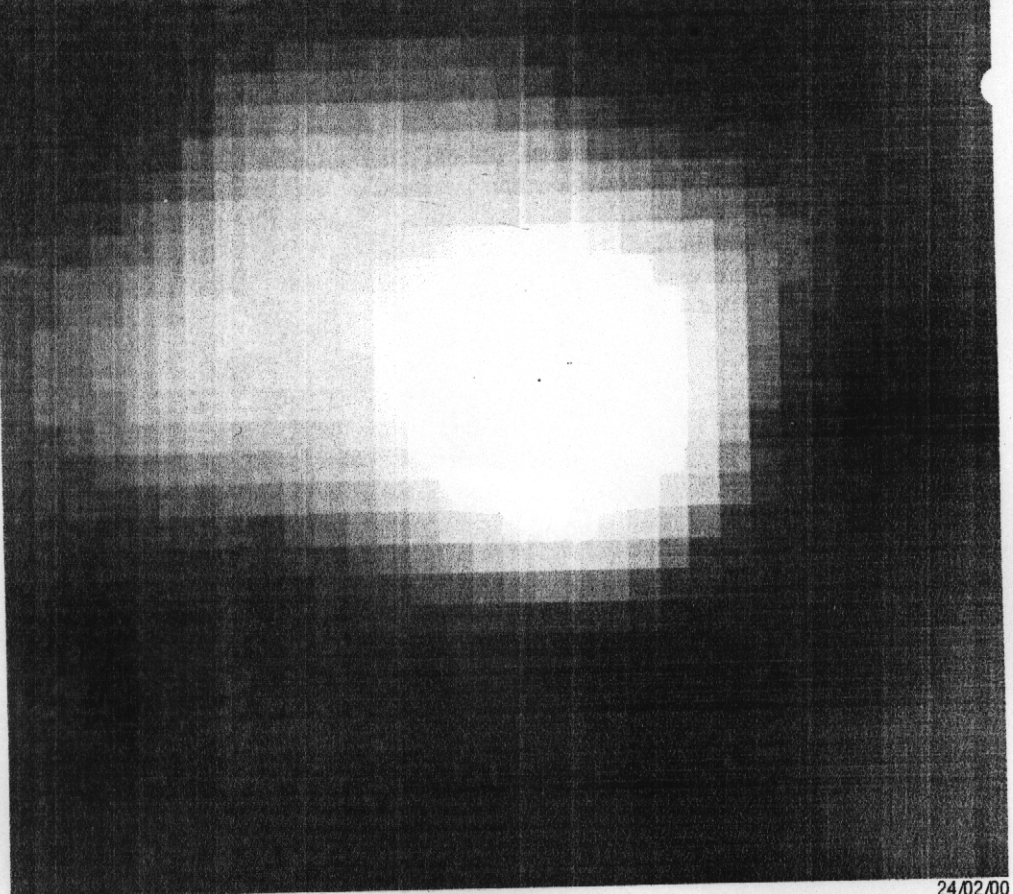


**Gamma Ray  
Burst  
GRB 970228**



PRC97-30 • ST Sci OF

GRB 970228  
 March 26, 1997  
 $z = 0.69$   
 $D \approx 10^{28}$  cm  
 $10 \times 10^9$  LY!



# Quasar Jet + Lobes (Radio Images)

3C175 = B0710+118



- Quasar at  $z=0.768$
- Overall linear size  $212/h$  kpc (Hubble constant  $H = 100h$  km/s/Mpc)
- Double lobes with prominent hot spots
- Narrow jet, no counterjet (Doppler hidden?)
- Jet brightens and bends as it enters its lobe
- VLA 4.9 GHz image at 0.35 arcsec resolution

$\sim 1.06$  Mly

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See also Deep VLA Imaging of Twelve Extended 3CR Quasars, by Alan H. Bridle, David H. Hough, Colin J. Lonsdale, Jack O. Burns and Robert A. Laing, *The Astronomical Journal*, **108**, 766-820 (1994). Also related abstract from AAS Meeting #183.

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← Go back to:

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  - NRAO VLA Home Page
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- 

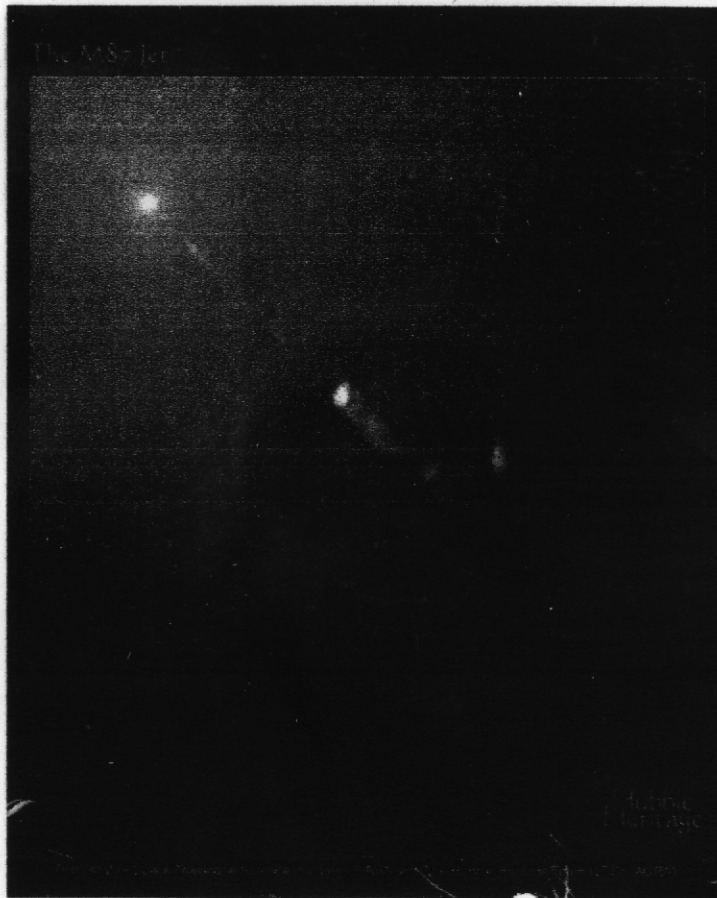
Last updated: 20 March 1996, 15:00 EST

# SUPERLUMINAL MOTIONS

## Extragalactic

What is the nature of  
One-sided moving jets ?

Owen & Birretta (1999)



## Galactic

Discovery of two-  
sided moving jets

Mirabel & Rodriguez (1994)





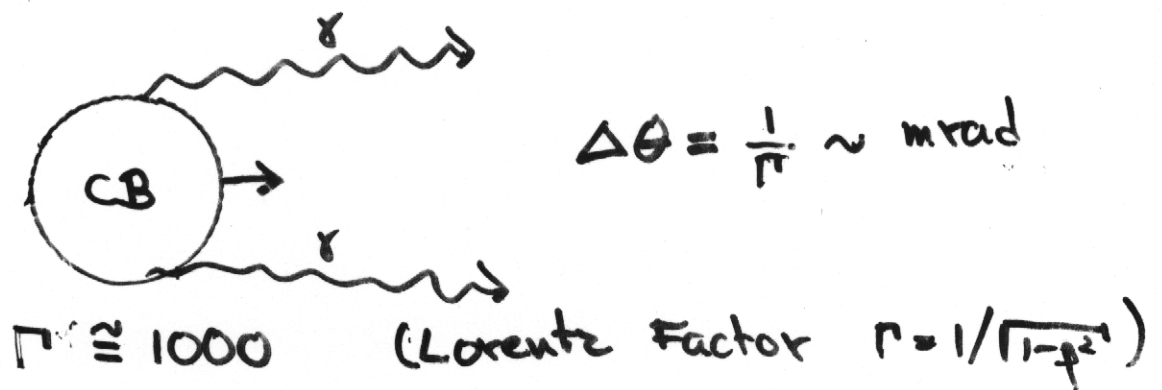
# Extinction By GRBs

1. By Jetted  $\gamma$ -Rays :

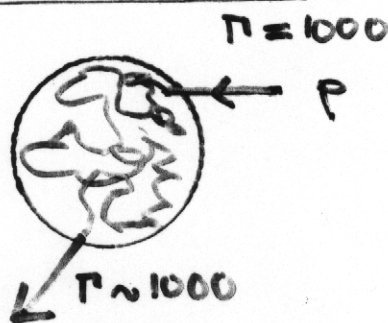
MeV  $\gamma$ -Rays

TeV  $\gamma$ -Rays ?

2. By Jetted Cosmic Rays:  $E_p \sim 1000 \text{ TeV}$

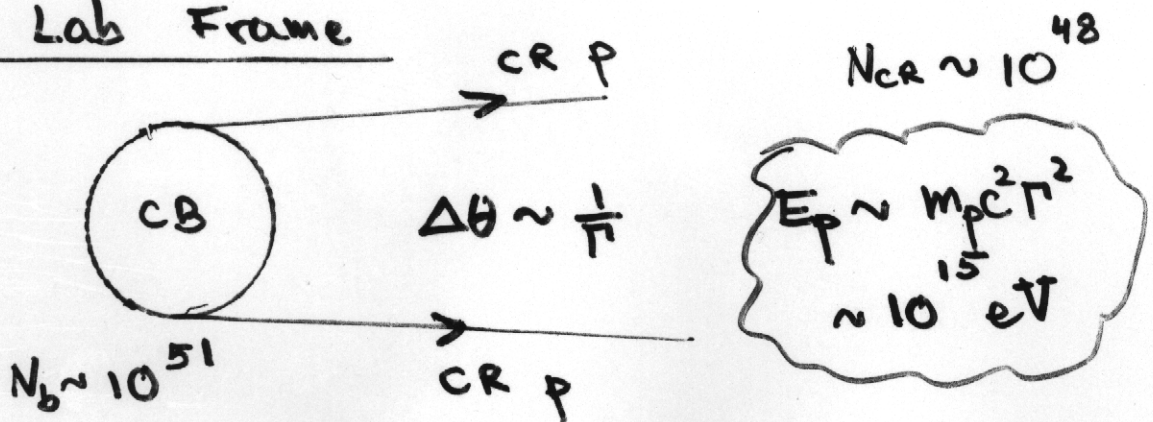


In CB rest frame :



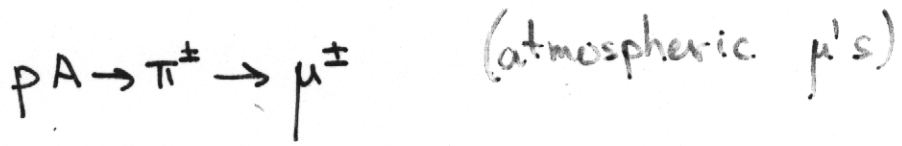
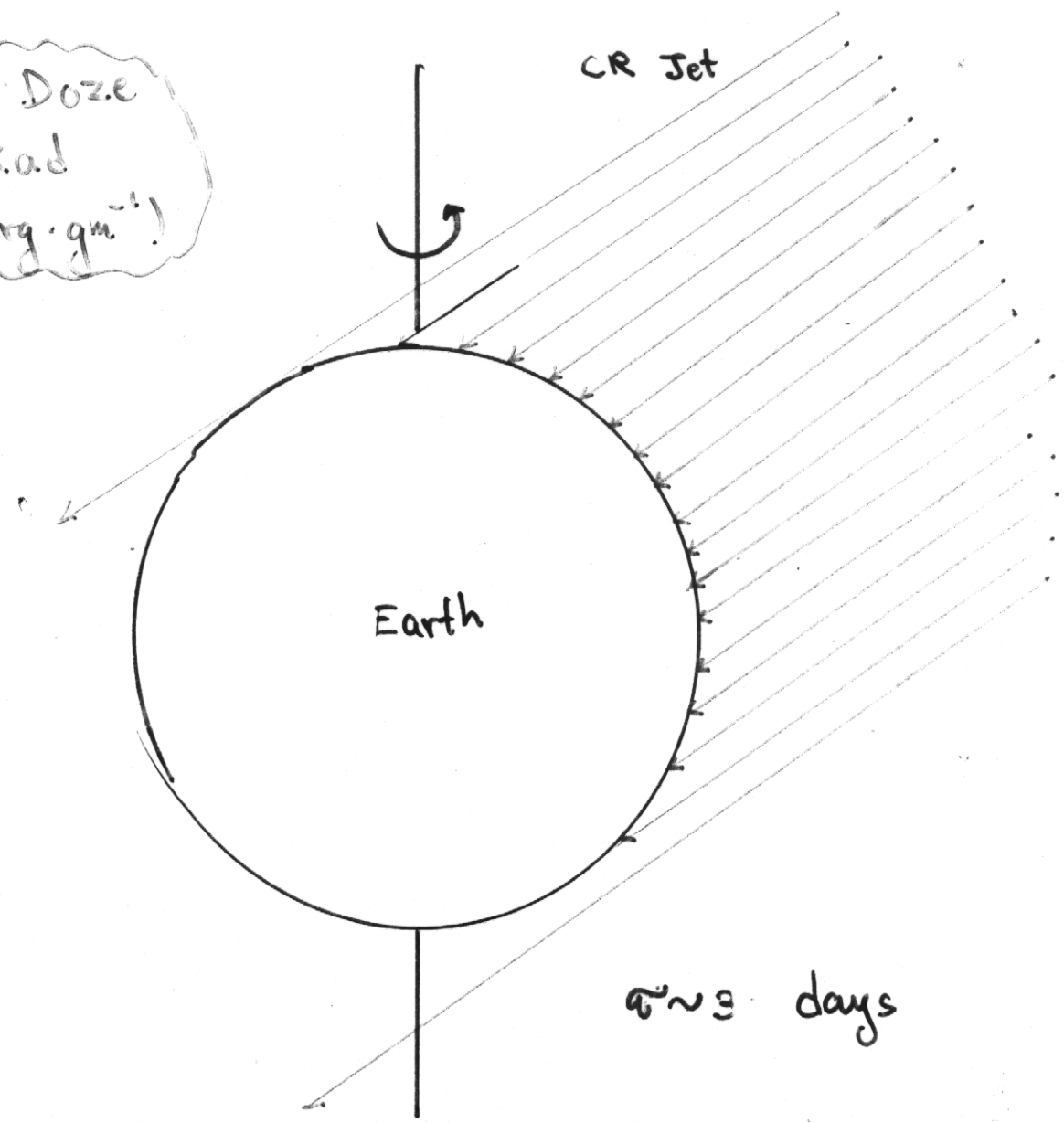
Incident ISM Particle  
Isotropized By Magnetic  
Deflection and Emerge  
with  $\sim$  same  $\Gamma$

In Lab Frame



# Mass Extinctions By CR Jets From GRBs

LD = Lethal Dose  
 250 Rad  
 (Rad =  $10^2 \text{ erg} \cdot \text{gm}^{-1}$ )



$I_\mu (D < \dots) \sim 10^{12} \text{ cm}^{-2}$   
 $\Delta t \sim 3 \text{ days}$

$\Delta E \sim 100 \text{ LD} !!!$

Radioactivation of the Environment  
 Destruction of the Ozone Layer

Frequency  $\sim 1/10^8 \text{ y}$



# The Life Threat From Eta Carinae and From Galactic GRBs\*

Arnon Dar

International School of Space Science  
L'Aquila, Italy August 29 - September 7

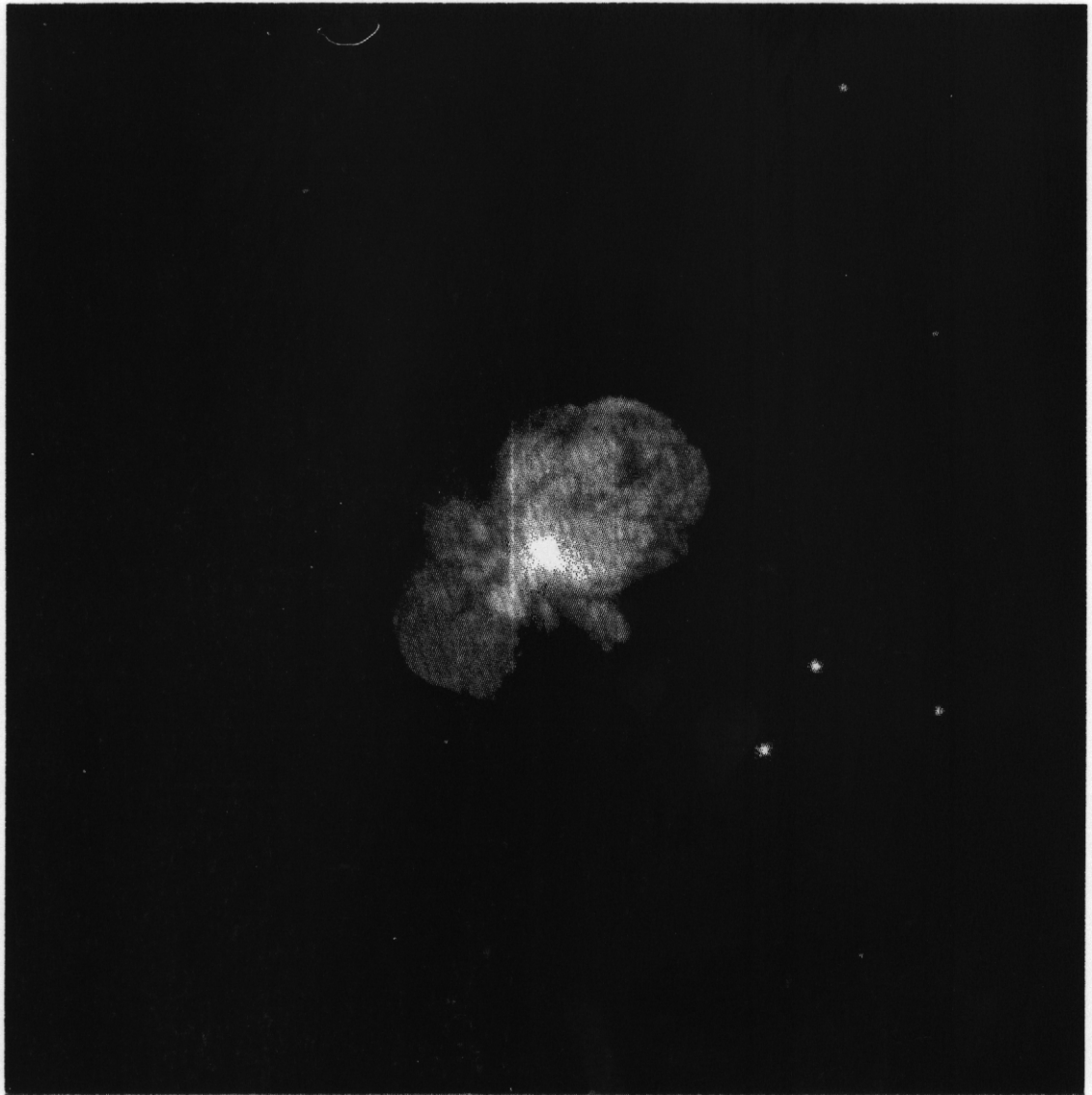
\* Based on collaboration with Alvaro De Rúgula

ETA CARINAE

The Most Luminous Object In Our Galaxy

$$L \approx 10^7 L_{\odot}$$

$$D \approx 7500 \text{ LY}$$



⇒ Eta Carinae is Nearing  
its Hypernova/Supernova  
Death.

Will Produce GRB  
At 2 kpc !



# GRBs of known z

Table I - Gamma-ray bursts of known redshift

GRB	z	D <sub>L</sub>	F <sub>γ</sub>	E <sub>γ</sub>	R[HG]
970228	0.695	4.55	1.1	0.22	25.2
970508	0.835	5.70	0.32	0.07	25.7
970828	0.957	6.74	9.6	2.06	24.5
971214	3.418	32.0	0.94	2.11	25.6
980425	.0085	.039	0.44	8.1E-6	14.3
980613	1.096	7.98	0.17	0.61	24.0
980703	0.966	6.82	2.26	1.05	22.6
990123	1.600	12.7	26.8	19.80	23.9
990510	1.619	12.9	6.55	5.00	28.5
990712	0.434	2.55	6.5	0.53	21.8
991208	0.70	4.64	10.0	1.51	24.4
991216	1.020	7.30	19.4	5.35	24.8
000131	4.500	44.4	4.2	11.60	27.8
000301c	2.040	17.2	0.41	0.46	28.0
000418	1.119	8.18	2.0	0.82	23.9
000926	2.066	17.4	2.20	10.54	25.6
010222	1.474	11.5	12.0	7.80	25.9

Comments: z: Redshift. D<sub>L</sub>: Luminosity distance in Gpc, for  $\Omega_m = 0.3$ ,  $\Omega_\Lambda = 0.7$  and  $H_0 = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}$ . F<sub>γ</sub>: BATSE  $\gamma$ -ray fluences in units of  $10^{-5} \text{ erg cm}^{-2}$ . E<sub>γ</sub>: (Equivalent spherical) energy in units of  $10^{53}$  ergs corrected for galactic extinction. R[HG]: R-magnitude of the host galaxy, except for GRB 990510, for which the V-magnitude is given.

GRB 990123 AT A DISTANCE OF  
ETA CARINAE :  $D \cong 2.3 \text{ kpc}$

$$F_\gamma = \frac{E_\gamma}{4\pi D^2} \cong \frac{2 \times 10^{54} \text{ erg}}{4\pi (2.3 \text{ kpc})^2} \cong 3 \times 10^9 \text{ erg/cm}^2$$

$F_\gamma = 3 \times 10^9 \text{ erg/km}^2 \cong 1 \text{ kiloton TNT/km}^2$  !  
(In the hemisphere facing Eta Carinae)

# Will the GRB From the Hypernova Death of Eta Carinae Point in Our Direction?

There are  $\sim 3$  Large Blue Variable stars like Eta Carinae in our Galaxy. Their life time is  $\sim 1$  My. If they were able to cause mass extinction, the rate of mass extinction would have been once in  $\sim 300\,000$  y.

The observed rate of mass extinction in the geological records is once in  $\sim 100$  My

$\Rightarrow$  Beaming angle  $< 6^\circ$

The most probable direction of a GRB is along the polar axis.

Based on the radial velocities, proper motion and the projected shape of its equatorial debris disk:

Davidson and Humphrey 1997, ARA&A:

The tilt angle of the polar axis of Eta Carinae relative to our line of sight:  $57^\circ \pm 10^\circ$ !

## TeV $\gamma$ -Rays From GRBs

Four large ground-based gamma ray detectors have reported detections of TeV  $\gamma$ -rays in directional and temporal coincidence of with some GRBs detected by BATSE:

The Tibet air shower array  
HEGRA-AIROBICC Cherenkov array  
Milagro water-Cherenkov detector  
GRANDE muon detector

The estimated total GRB energy in TeV photons in each case has been found to be 2 orders of magnitude larger than in sub MeV photons!

Note: TeV photons from distant GRBs are strongly absorbed in the intergalactic space by  $\gamma + \gamma \rightarrow e^+ + e^-$  on the IR background radiation!

⇒ Most GRBs May Be Obscured From Us In TeV  $\gamma$ -Rays But not Galactic GRBs like the one that may be produced by the hypernova death of Eta Carinae



## Temporal Coincidence Of Catastrophes

The passage of a highly relativistic beam with a relativistic mass  $E/c^2 \sim 10^{-3} M_{\odot}$  through the Oort cloud and the asteroid belt

produces a perturbation that may put comets/meteorites ~~to~~ on a collision course with Earth. The bombardment of Earth with a barrage of comets (meteorites) will last typically ~~over~~ during a time period of the order of the free fall time from the Oort cloud to the sun:

$$t_{\text{fall}} = \pi \left[ \frac{R_0^3}{8GM_{\odot}} \right]^{1/2} \approx 1.7 \text{ My}$$

for  $R_0 \sim 50000 \text{ AU}$ .

The bombardment of Earth during 1-2 My after the GRB could have triggered the huge volcanic eruptions over 1-2 My around the K/T and P/T boundaries that created the Deccan traps in India and the Siberian basalt floods. The injection of dirt and volcanic ash into the atmosphere could have blocked light and induce glaciation and sea regression.

# The Rate of GRB Mass Extinctions

$$\dot{N}_{\text{GRB}} \approx 10^3 \text{ y}^{-1} \quad \text{Observed}$$

$$\Sigma_{\text{Galaxy}} (R < 25) \approx 2 \times 10^5 \text{ deg}^{-2} \quad (\text{HST, Casertano 2001})$$

$$\Rightarrow 1.2 \times 10^{-7} \text{ y}^{-1} \text{ GRBs} / L_{\text{MW}} \text{ that} \\ \text{point in our direction}$$

but

$$\text{star formation rate} \sim (1+z)^3 \\ \text{GRBs} \langle 1+z \rangle \sim 2.1$$

$$\Rightarrow 1.3 \times 10^{-2} \text{ y}^{-1} \text{ or once in } 70 \text{ My} \\ \text{point in our direction in a MW-like galaxy}$$



Pistol Nebula and Massive Star HST • NICMOS  
PRC97-33 • ST Sci OPO • D. Figer (UCLA) and NASA

תמונה באינפרא אדום  
 ברחוק של "צופיות האקצנה"  
 ליד מרכז הגלקסיה (ברחוק  
 25000) . הכוכב במרכז ותאורה  
 בעוצמתה  $L \sim 10^7 L_{\odot}$  !  
 $M \sim 200 M_{\odot}$



The last view seen by a dinosaur?

