Quantum gravity constraints from electromagnetic domain

Fabrizio Fiore

Osservatorio Astronomico di Trieste

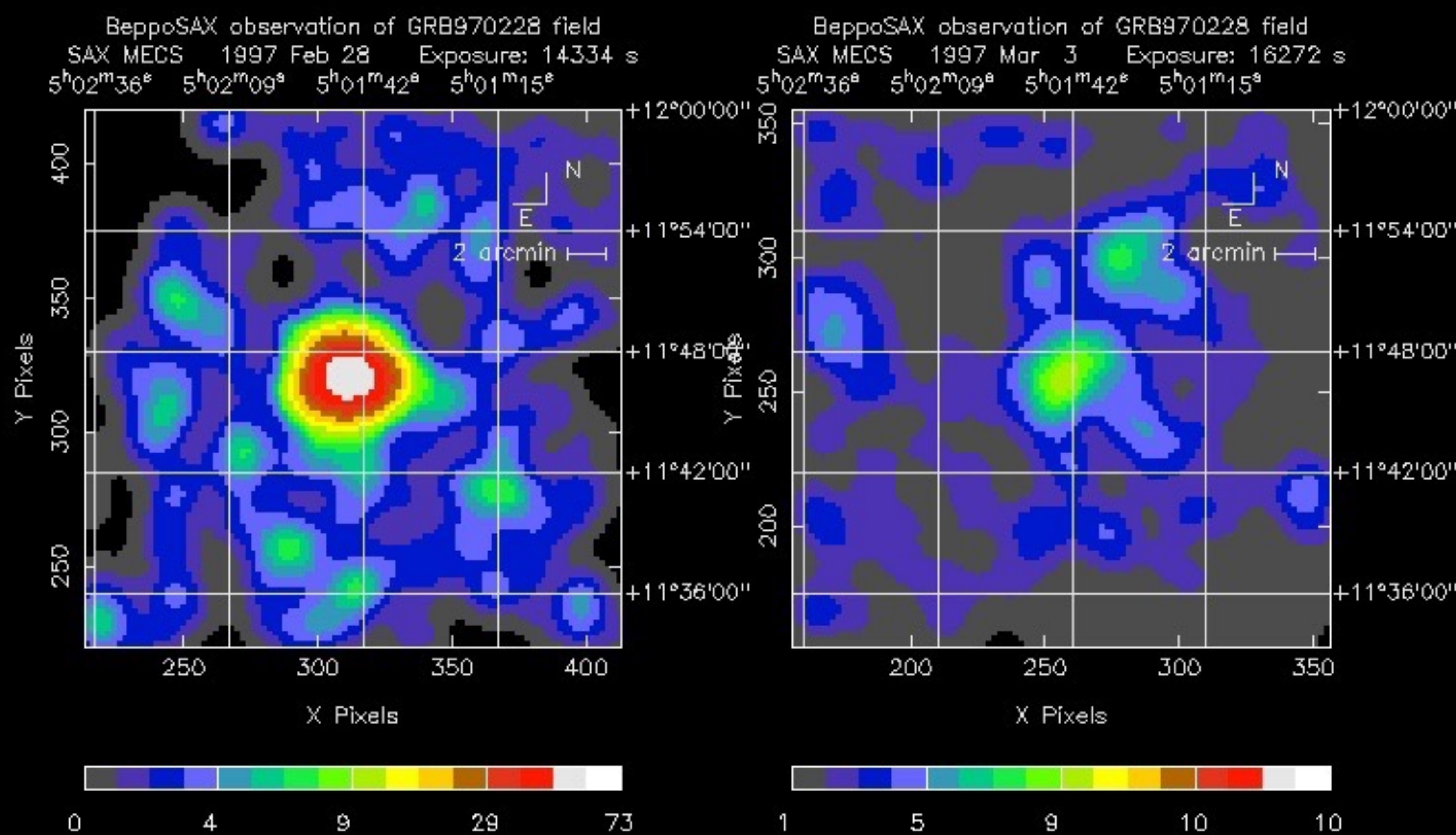
Outline

- QST probes: Gamma Ray Bursts
  - Fermi (GeV)
  - HERMES (Hard X-rays)
- QST probes: Quasars
  - HST
  - Ground based Adaptive Optic
  - GAIA

Gamma Ray Bursts

Gamma Ray Bursts

Gamma Ray Bursts



Gamma Ray Bursts

Gamma Ray Bursts

PROBING THE WARM INTERGALACTIC MEDIUM THROUGH ABSORPTION AGAINST GAMMA-RAY BURST X-RAY AFTERGLOWS

F. FIORE,[1] F. NICASTRO,[1,2] S. SAVAGLIO,[1] L. STELLA,[1] AND M. VIETRI[3]

Received 2000 June 16; accepted 2000 September 15; 2000 November 1

THE ASTROPHYSICAL JOURNAL, 544:L7–L10, 2000 November 20

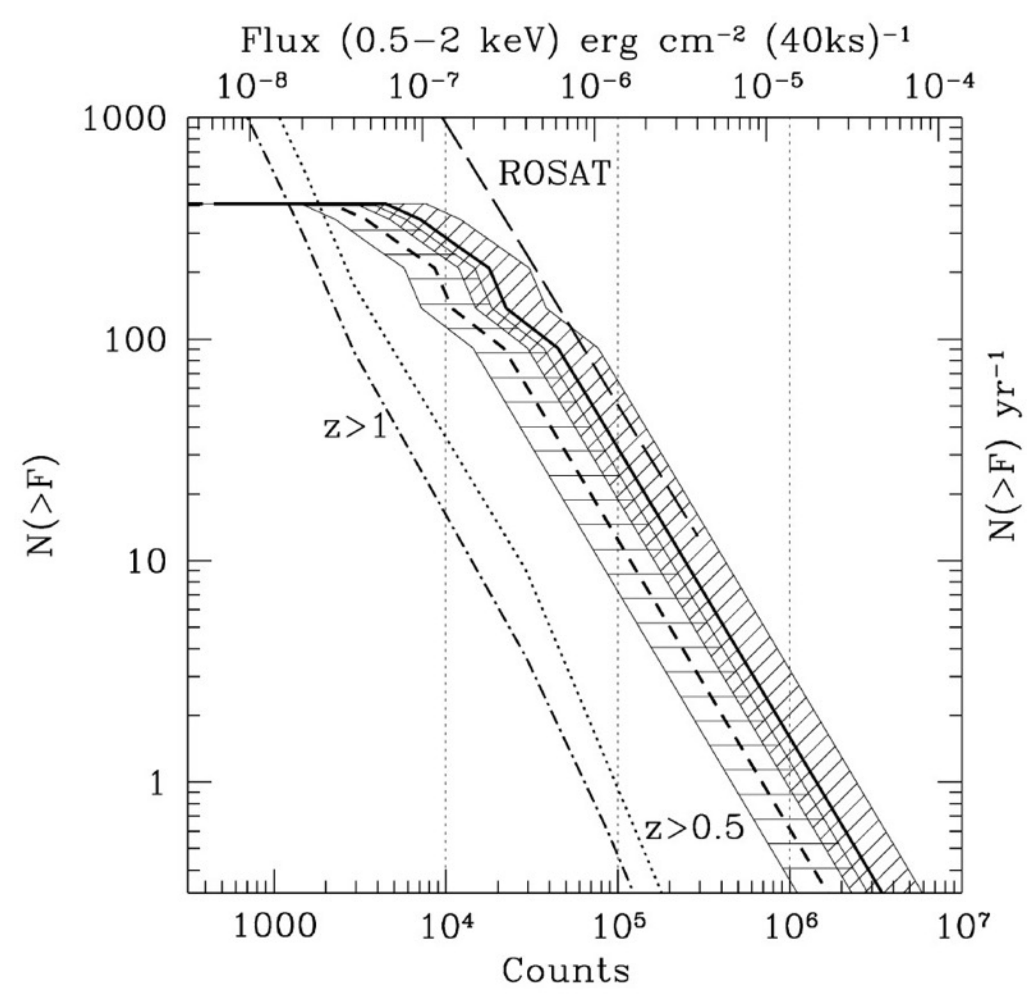
Gamma Ray Bursts

PROBING THE WARM INTERGALACTIC MEDIUM THROUGH ABSORPTION AGAINST GAMMA-RAY BURST X-RAY AFTERGLOWS

F. Fiore,[1] F. Nicastro,[1,2] S. Savaglio,[1] L. Stella,[1] and M. Vietri[3]

Received 2000 June 16; accepted 2000 September 15; 2000 November 1

The Astrophysical Journal, 544:L7–L10, 2000 November 20



Gamma Ray Bursts

Gamma Ray Bursts

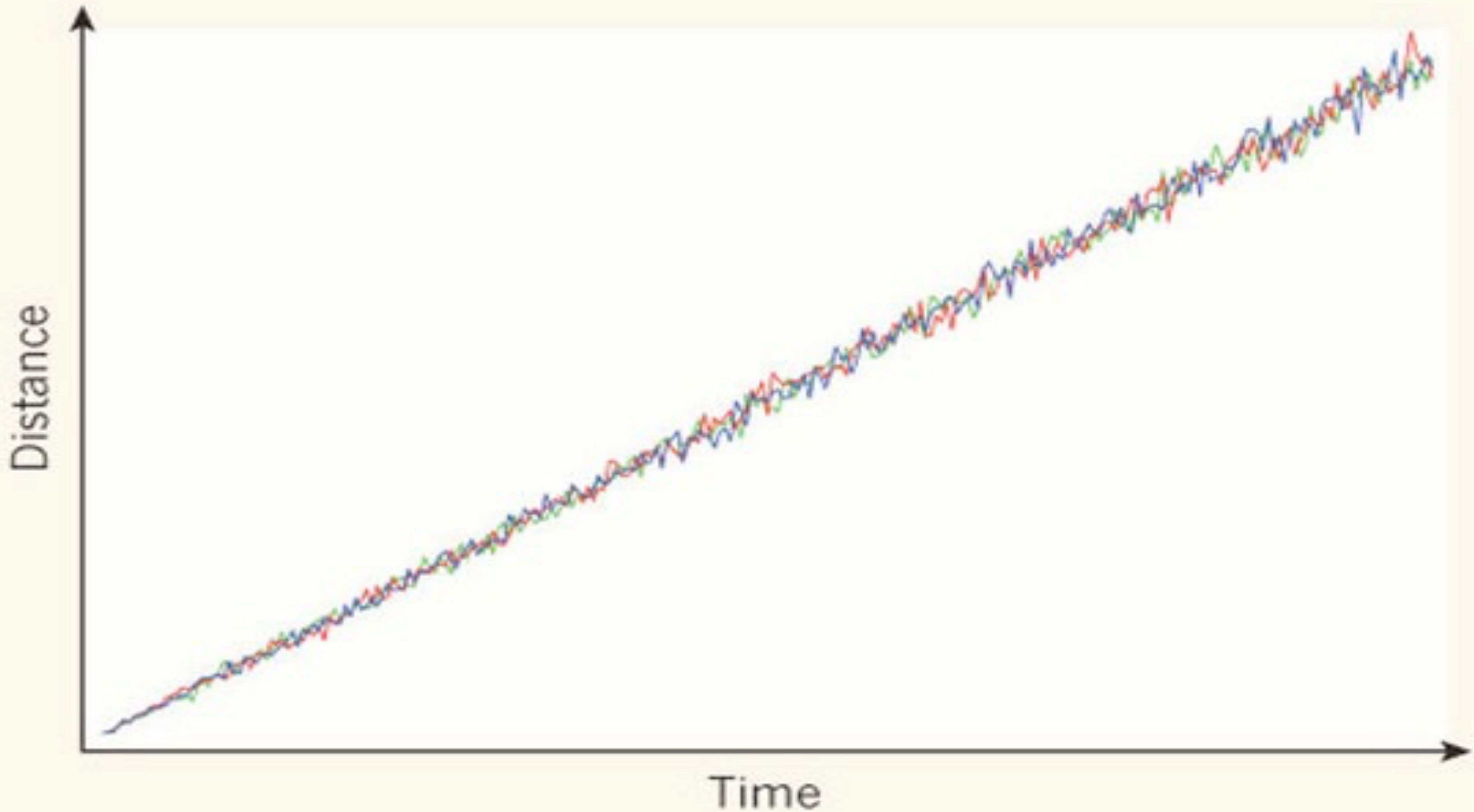
nature
International journal of science

Letter

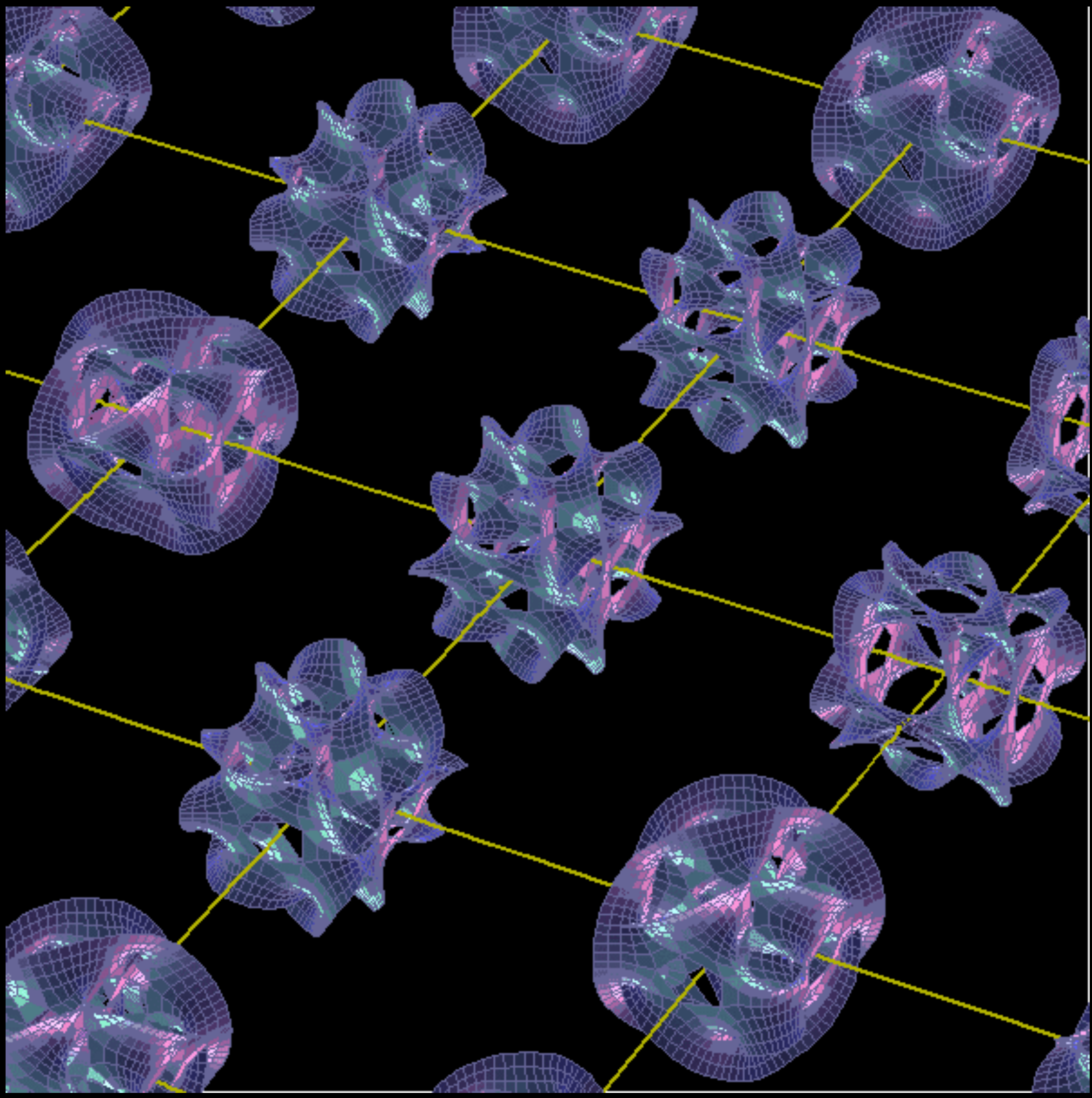
Tests of quantum gravity from observations of γ-ray bursts

G. Amelino-Camelia, John Ellis, N. E. Mavromatos, D. V. Nanopoulos & Subir Sarkar

Gamma Ray Bursts

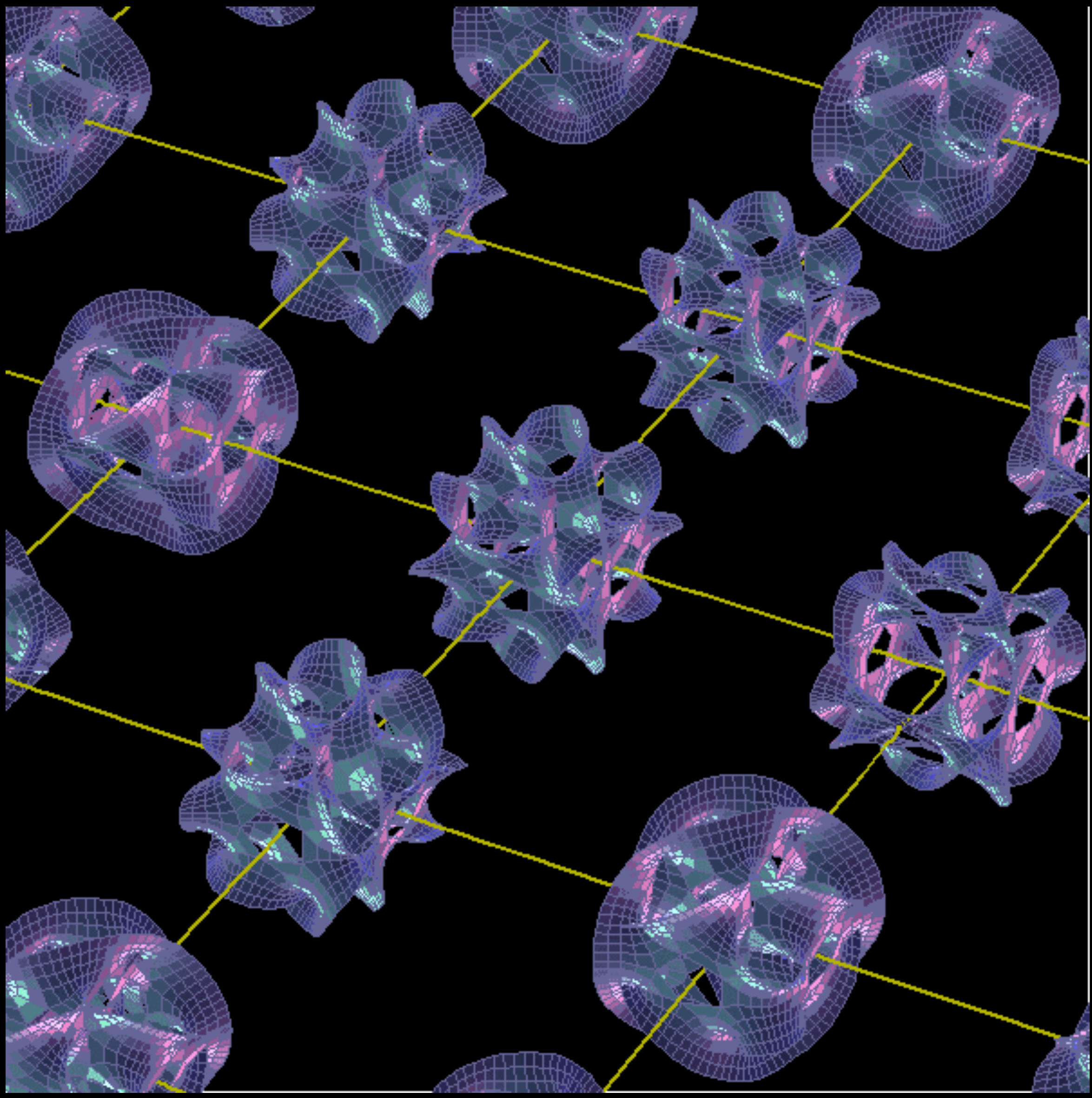


Space-time structure



Amelino-Camelia + 1998

Space-time structure



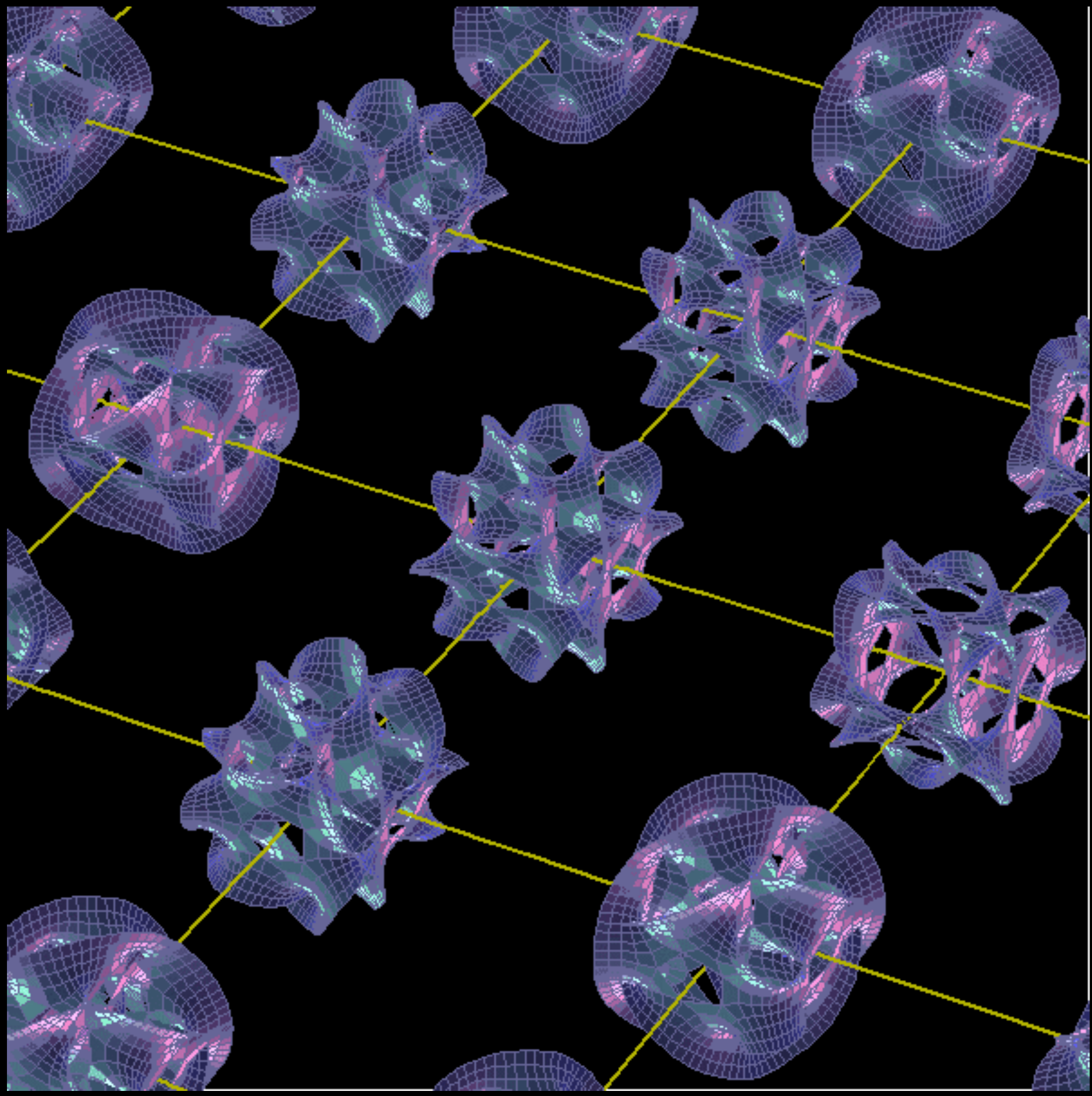
Amelino-Camelia + 1998

Space-time structure

Granular ST determines a dispersion relation:

$c^2p^2=E^2[1\pm(E/E_{QG})^{\alpha}]$

$E_{QG}=\eta 10^{19}$ GeV

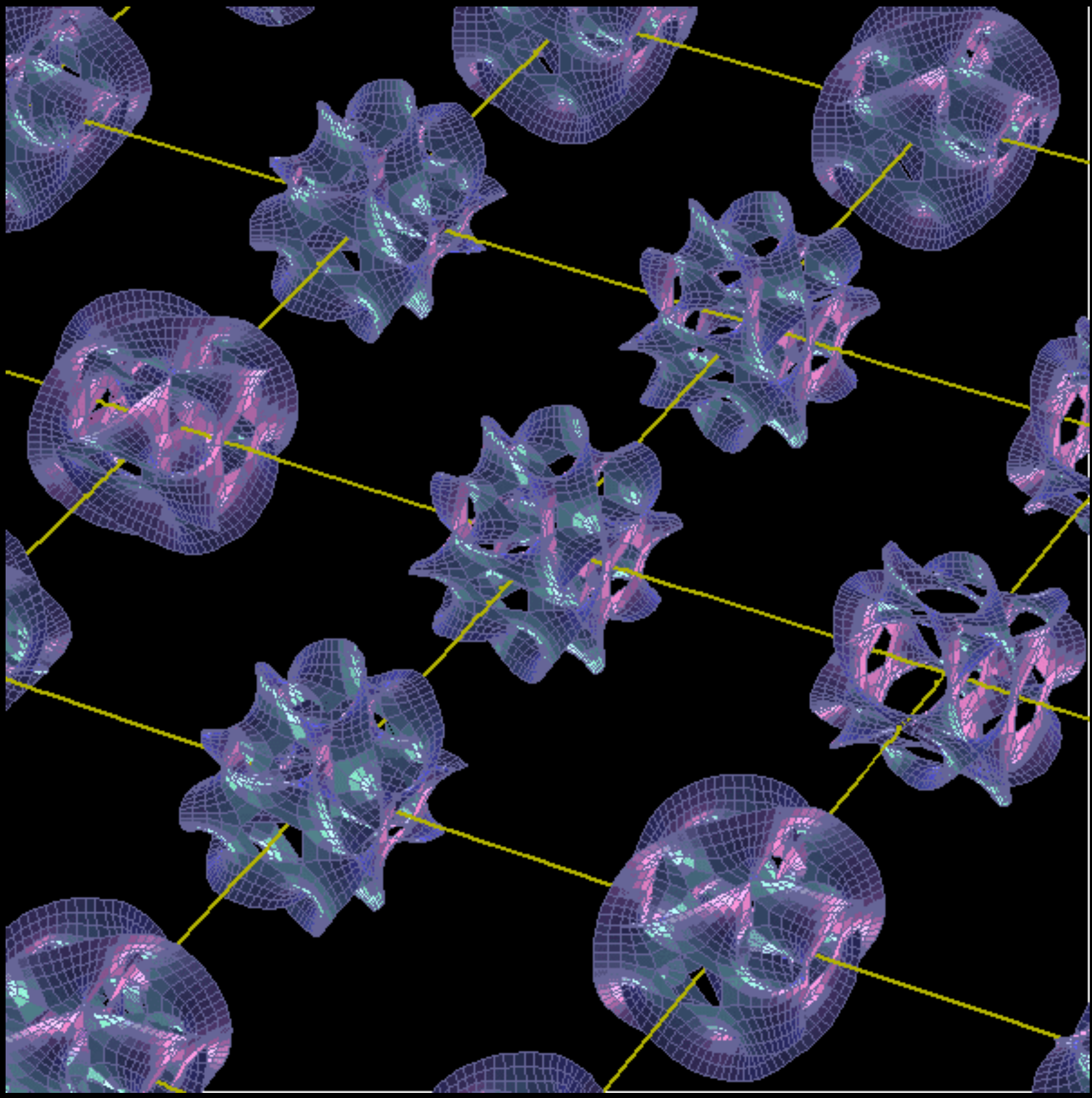


Amelino-Camelia + 1998

Space-time structure

Granular ST determines a dispersion relation:
$c^2p^2=E^2[1\pm(E/E_{QG})^\alpha]$
$E_{QG}=\eta 10^{19}$ GeV

$v=dE/dp=c[1\pm(E/E_{QG})^\alpha]$
$\Delta t \sim \pm(\Delta E/E_{QG})^\alpha \times D(z)/c$



Amelino-Camelia + 1998

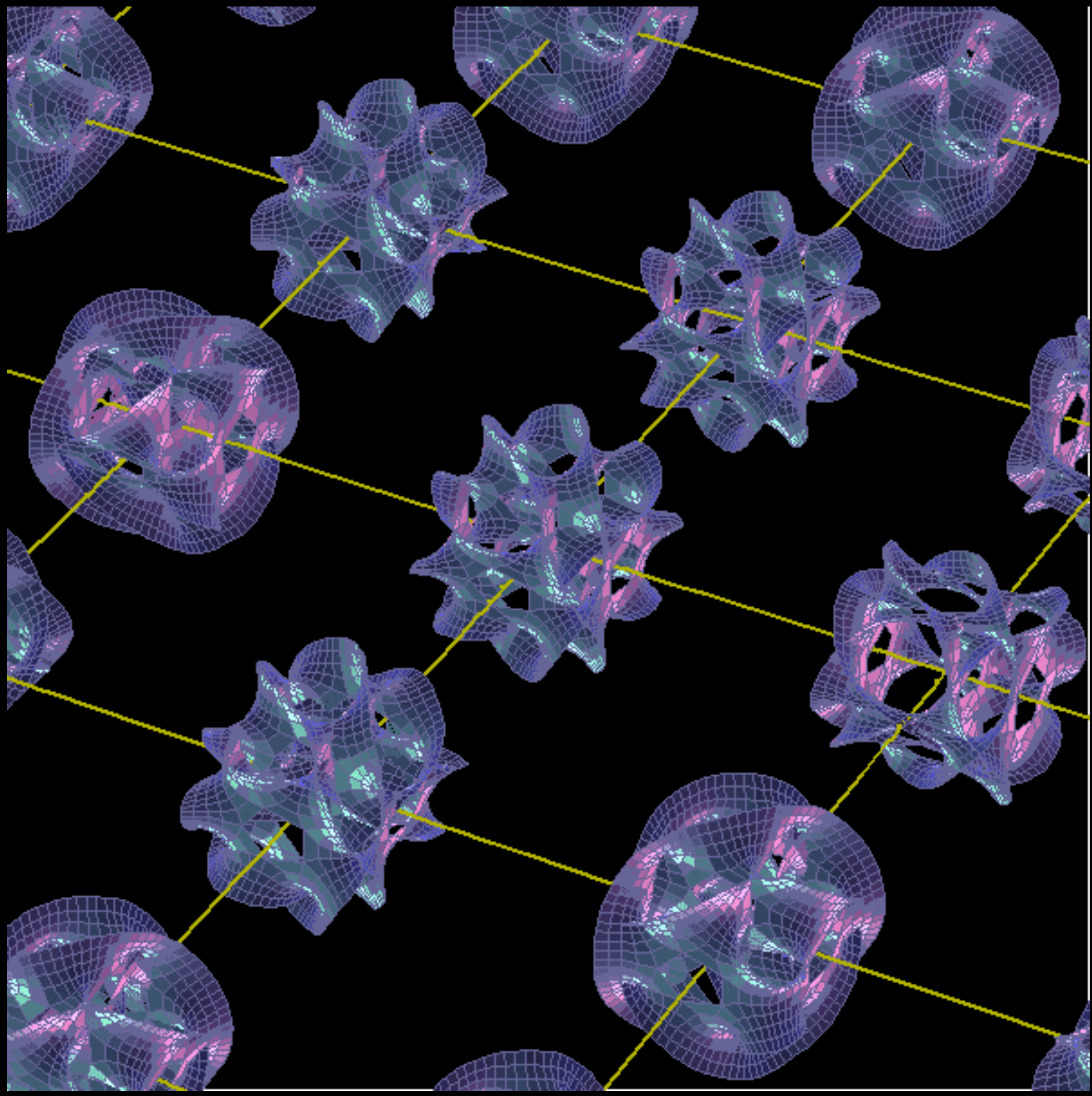
Space-time structure

Granular ST determines a dispersion relation:
$c^2p^2=E^2[1\pm(E/E_{QG})^{\alpha}]$
$E_{QG}=\eta 10^{19}$ GeV

$v=dE/dp=c[1\pm(E/E_{QG})^{\alpha}]$
$\Delta t\sim\pm(\Delta E/E_{QG})^{\alpha}\times D(z)/c$

$$\Delta t = \eta_X \frac{E}{M_P} D(z) \pm \delta_X \frac{E}{M_P} D(z)$$

η=systematic δ=fuzziness



Amelino-Camelia + 1998

Space-time structure

Granular ST determines a dispersion relation:

$c^2p^2=E^2[1\pm(E/E_{QG})^\alpha]$

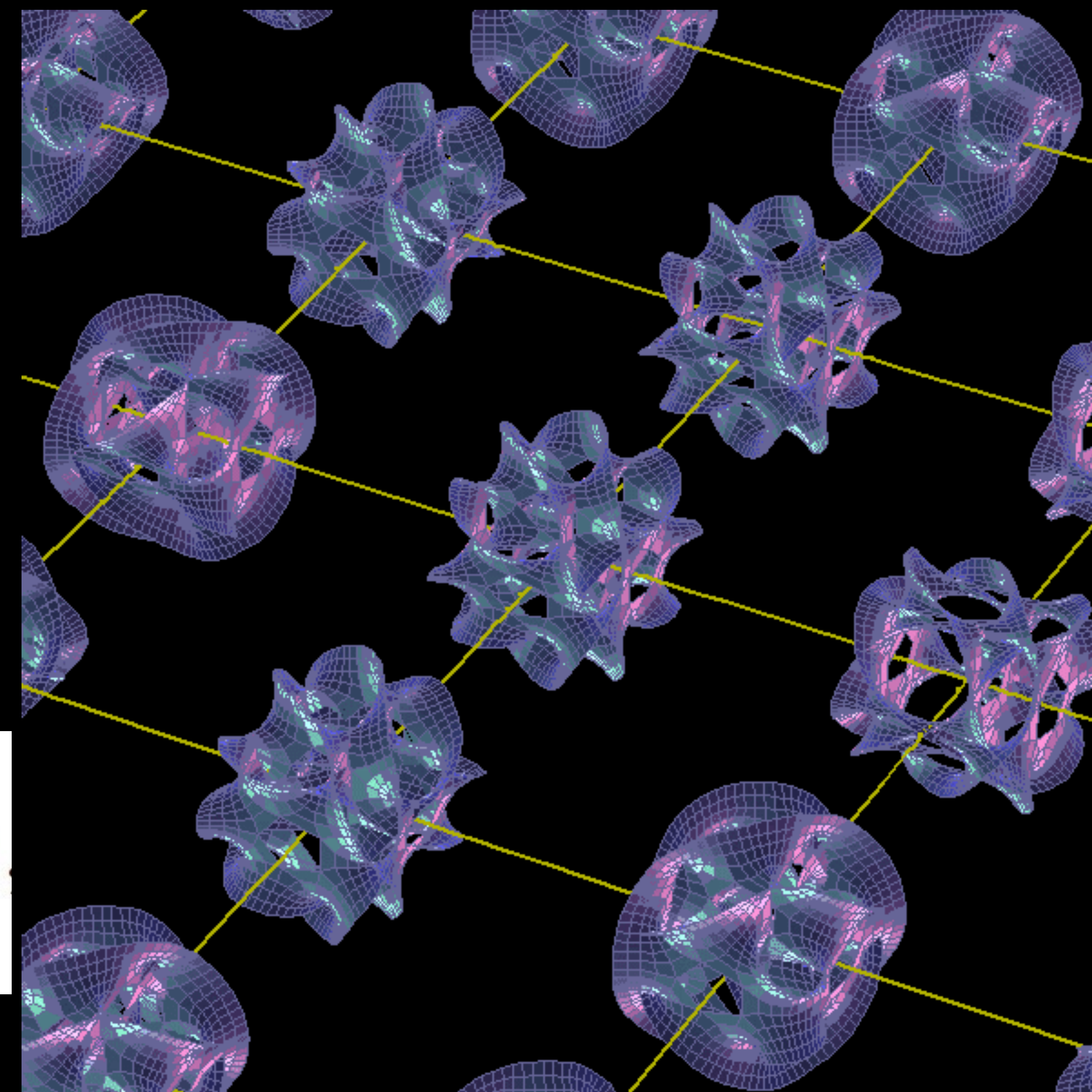
$E_{QG}=\eta 10^{19}$ GeV

$v=dE/dp=c[1\pm(E/E_{QG})^\alpha]$

$\Delta t\sim\pm(\Delta E/E_{QG})^\alpha\times D(z)/c$

$$\Delta t = \eta_X \frac{E}{M_P} D(z) \pm \delta_X \frac{E}{M_P} D(z)$$

η=systematic δ=fuzziness



Amelino-Camelia + 1998

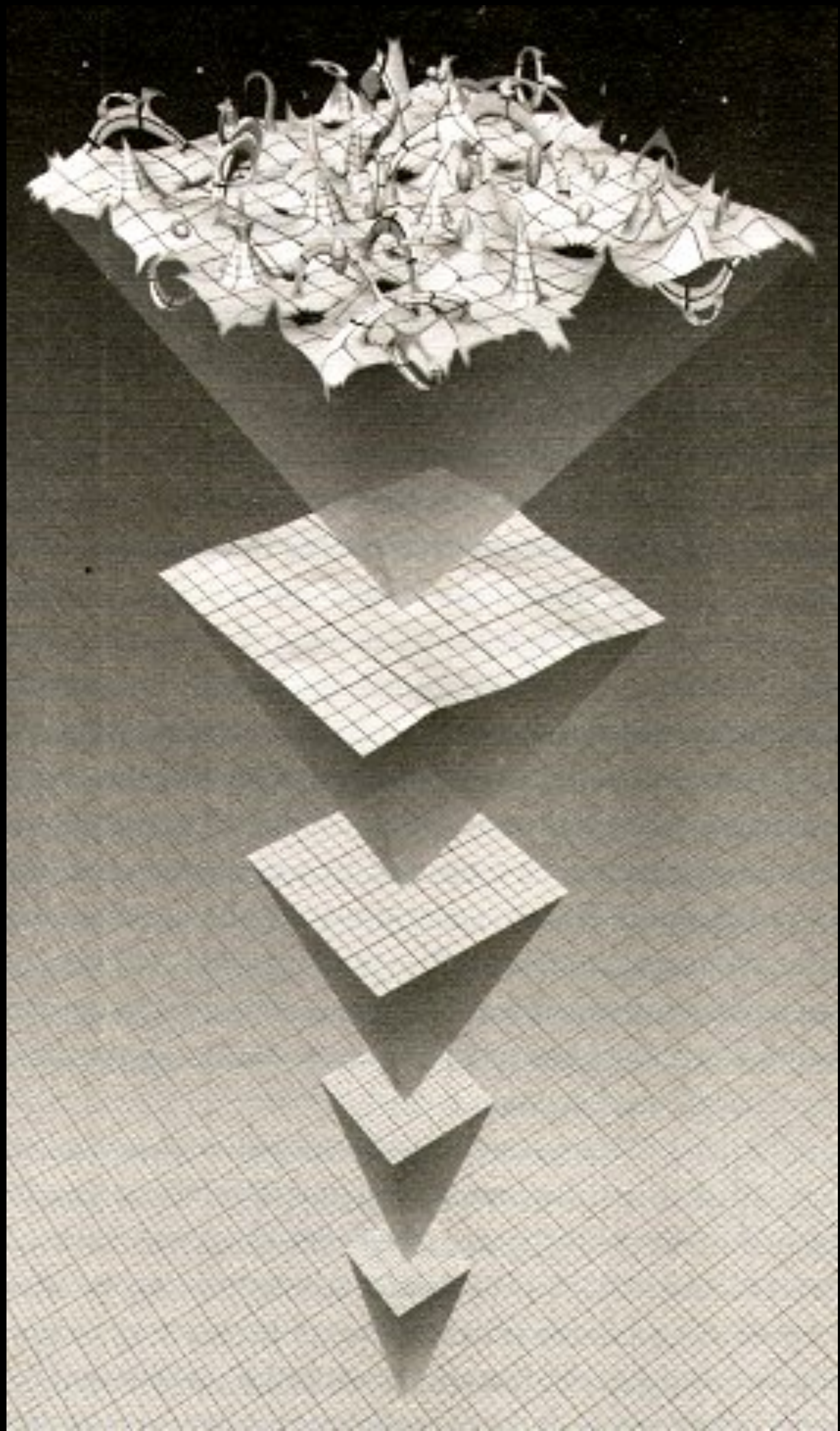
$\Delta t/\Delta E\sim$30ms/GeV$\sim$3μs/100keV $E_{QG}\sim E_{Planck}$, $\alpha=1$, $z\sim1$

Space-time structure

Not a single model

Many families of models

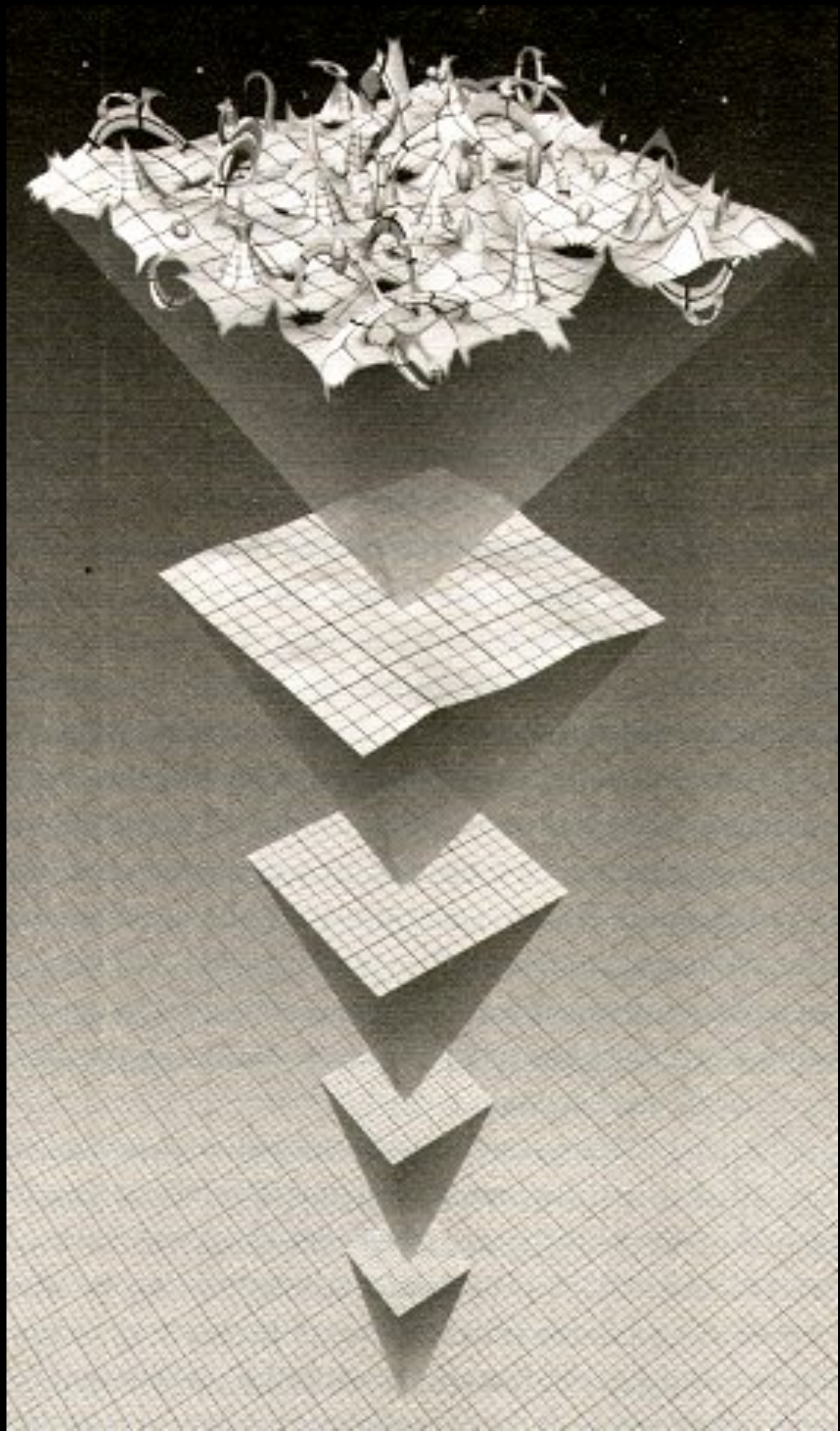
Fermi LAT GRBs



Abdo+2009

Fermi LAT GRBs

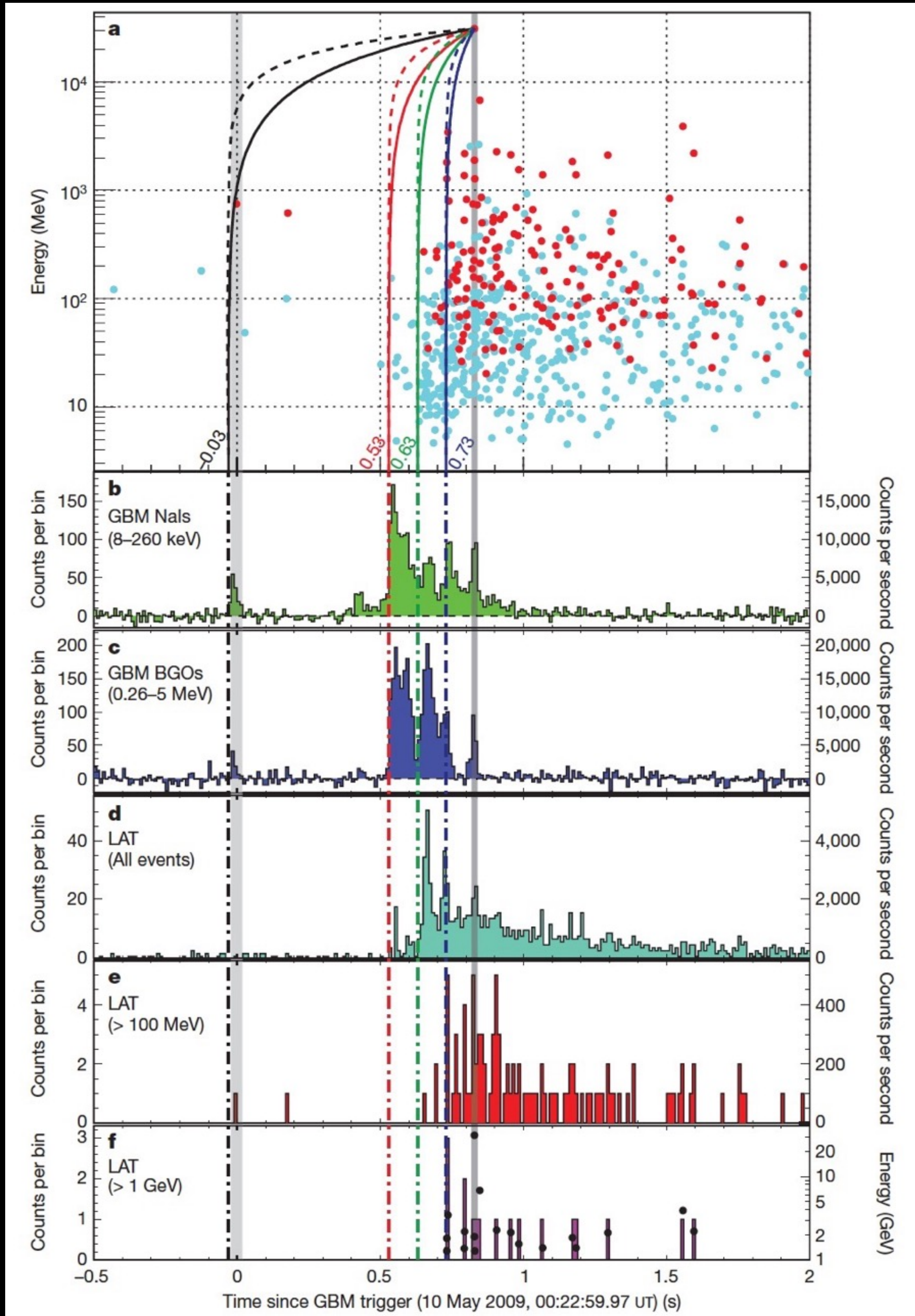
- Tests with Fermi:
  single photons
  rare events (1, or a few):
  GRB090510 z=0.9



Abdo+2009

Fermi LAT GRBs

- Tests with Fermi:
  single photons
  rare events (1, or a few):
  GRB090510 z=0.9



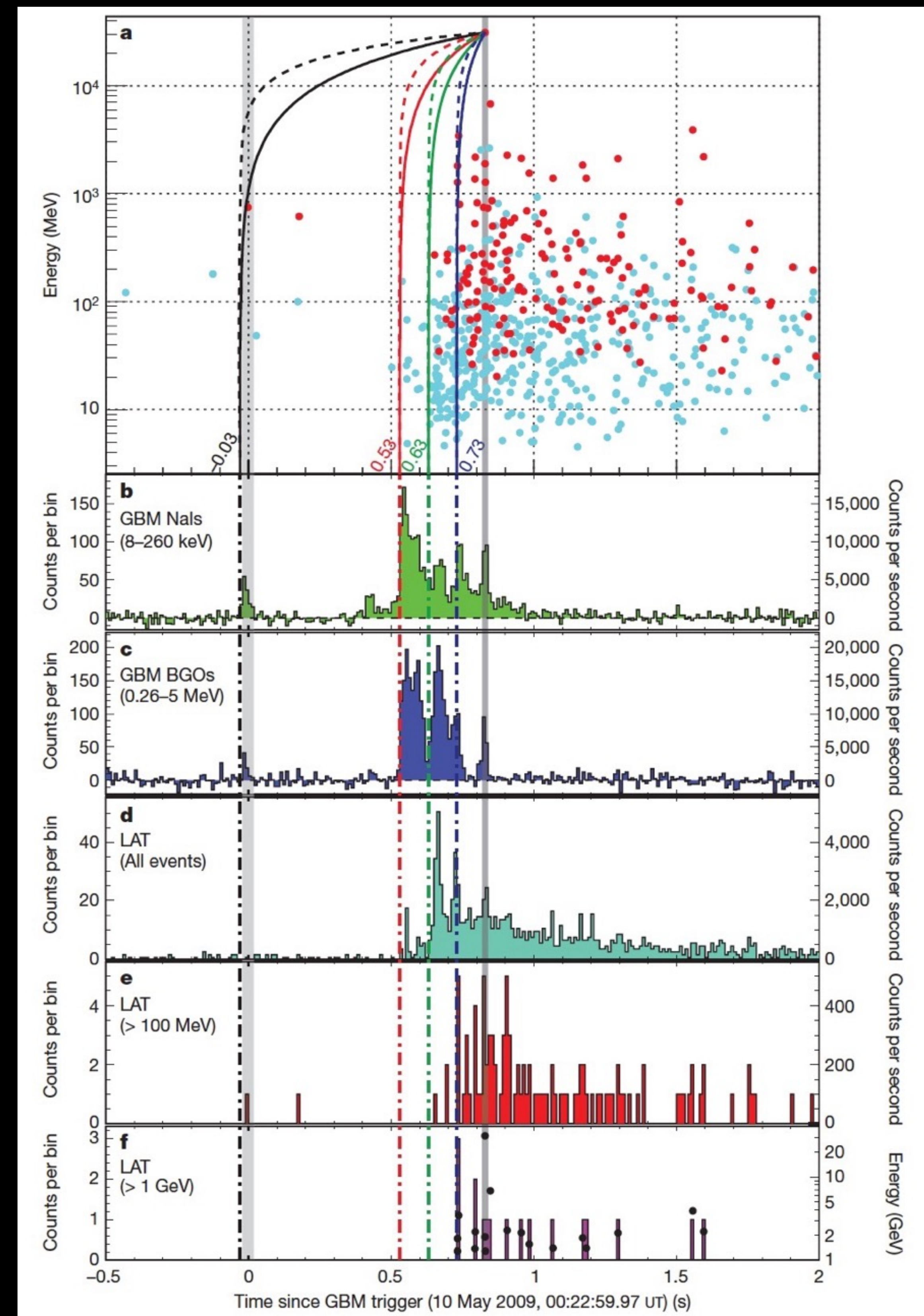
Abdo+2009

Fermi LAT GRBs

- Tests with Fermi:
  single photons
  rare events (1, or a few):
  GRB090510 z=0.9

- E_{obs}=29.9GeV, E_{em}=56.9GeV

Abdo+2009

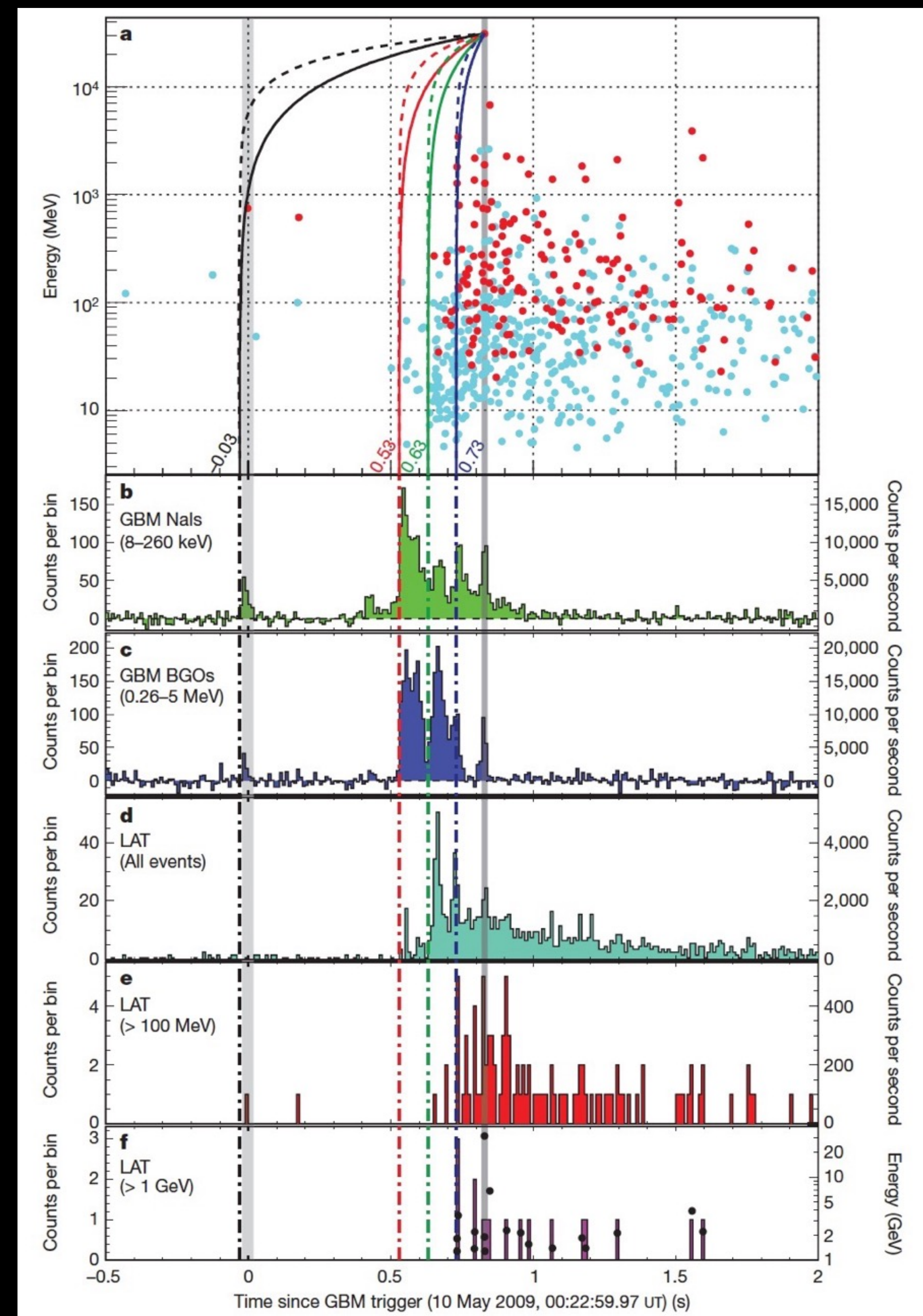


Fermi LAT GRBs

- Tests with Fermi:
  single photons
  rare events (1, or a few):
  GRB090510 z=0.9

- E_{obs}=29.9GeV, E_{em}=56.9GeV

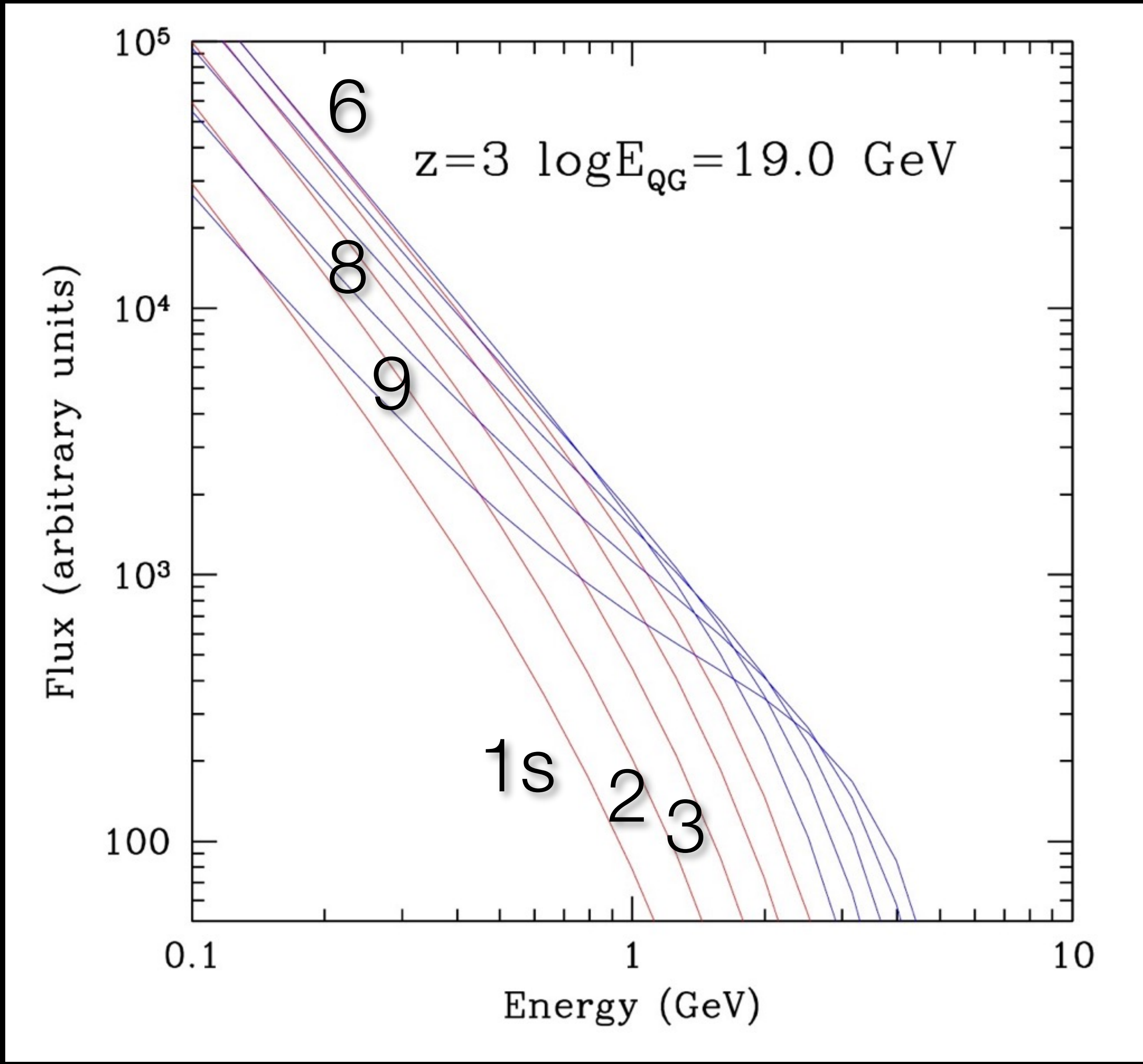
- $\Delta t/\Delta E \leq 1s/30GeV$, $E_{QG} \geq E_{Planck}$, $\alpha=1$



Abdo+2009

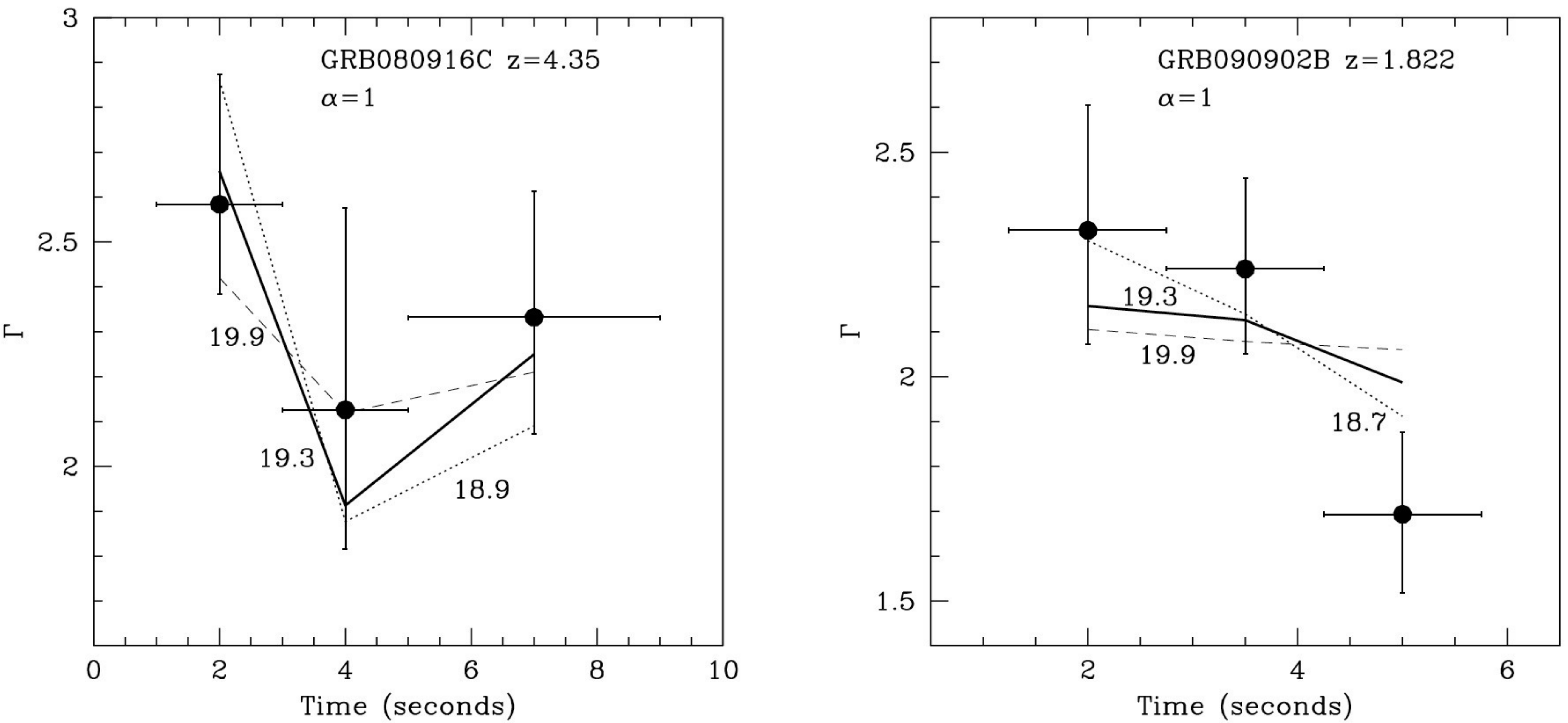
Fermi LAT GRBs

- Robust test: use full GRB information
- QST dispersion induced GRB spectral variations



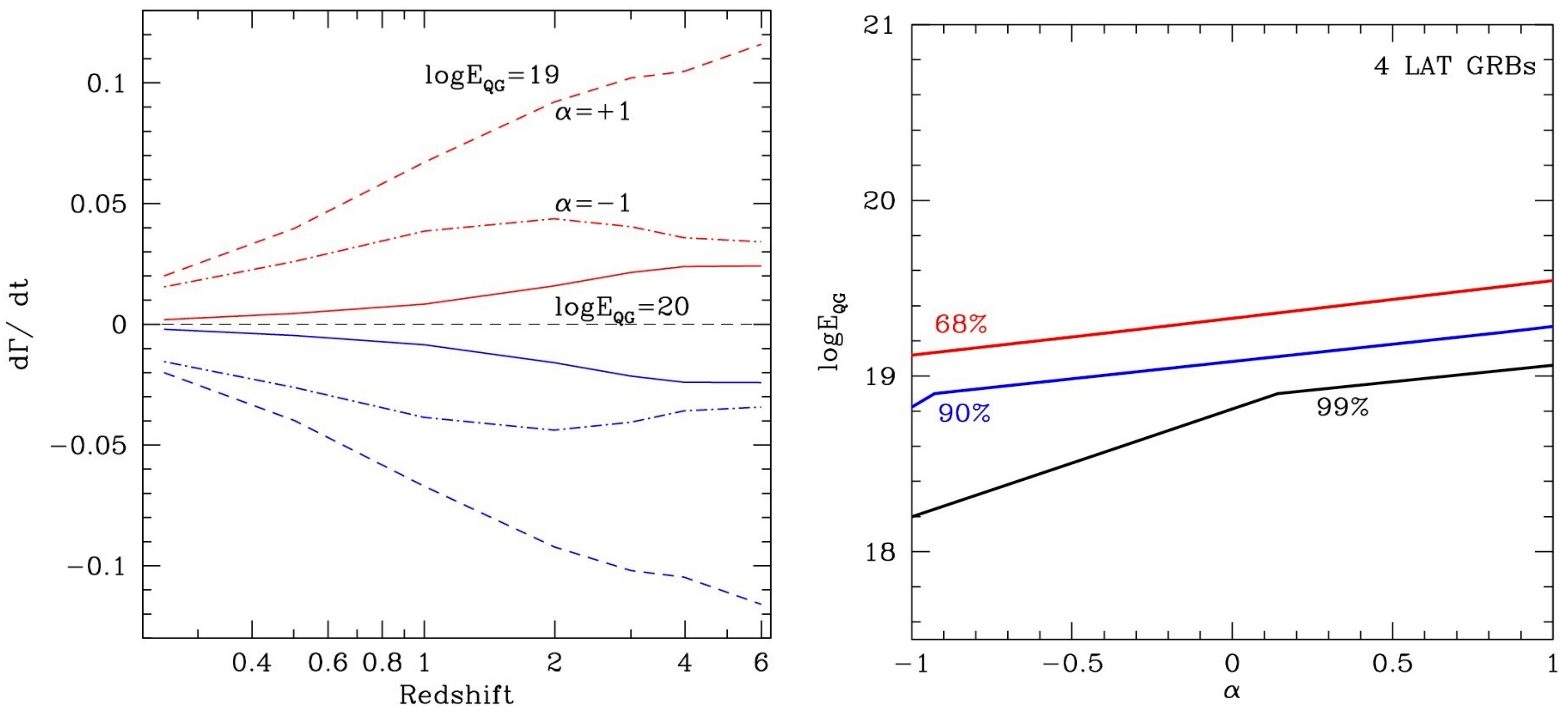
FF,GAC+2012 unpublished

Fermi LAT GRBs



FF,GAC+2012 unpublished

Fermi LAT GRBs



FF,GAC+2012 unpublished

Fermi LAT GRBs

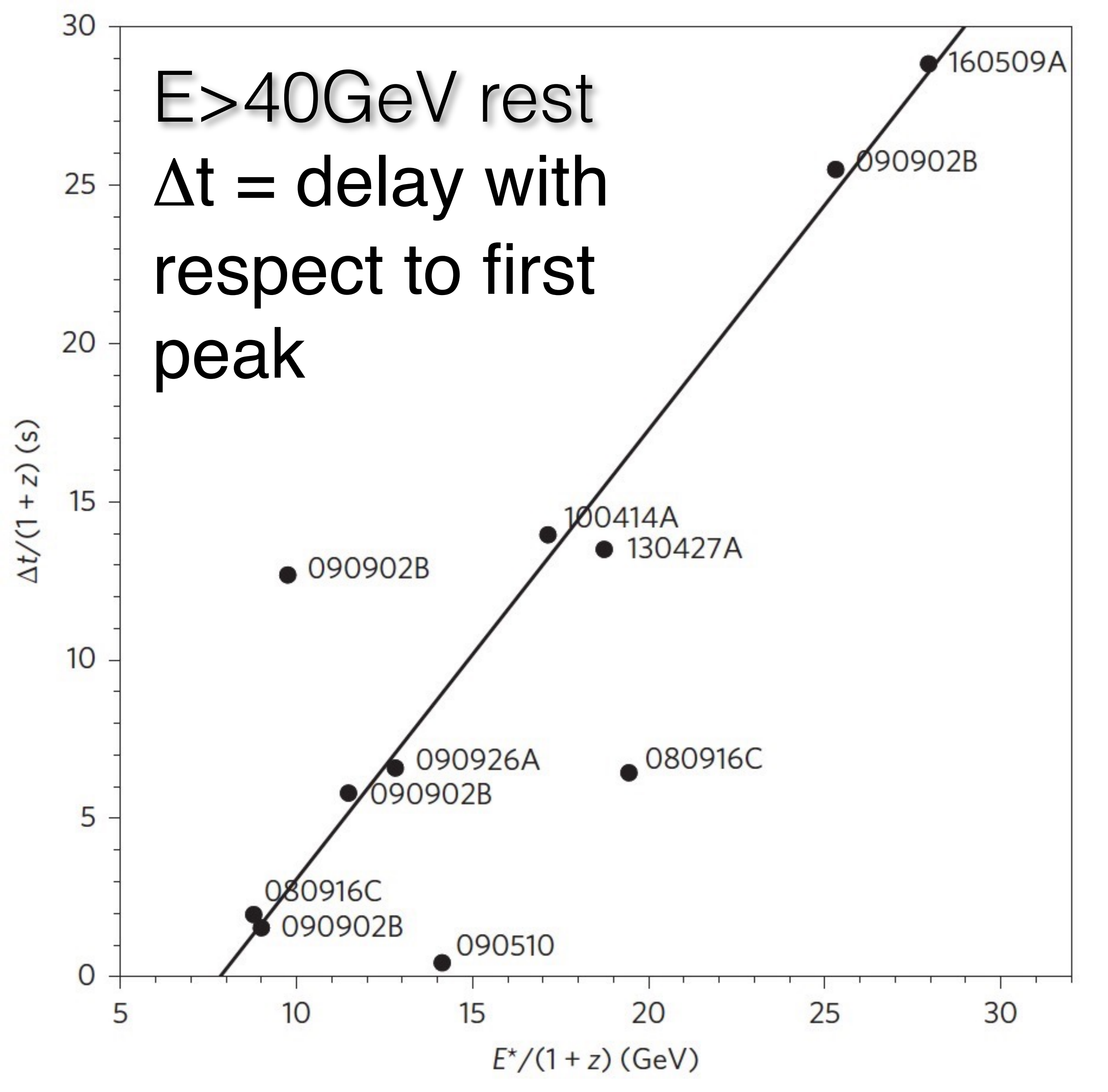
- Use all high-E photons

$$\Delta t = \eta_X \frac{E}{M_P} D(z) \pm \delta_X \frac{E}{M_P} D(z)$$

$$E^* \equiv E \frac{D(z)}{D(1)}$$

$$\Delta t = \eta_X D(1) \frac{E^*}{M_P} \pm \delta_X D(1) \frac{E^*}{M_P}$$

$$\eta_\gamma^{[pair]} \equiv \frac{M_P \Delta t_{pair}}{D(1) E^*_{pair}}$$



GAC,FF+ 2017

Fermi LAT GRBs

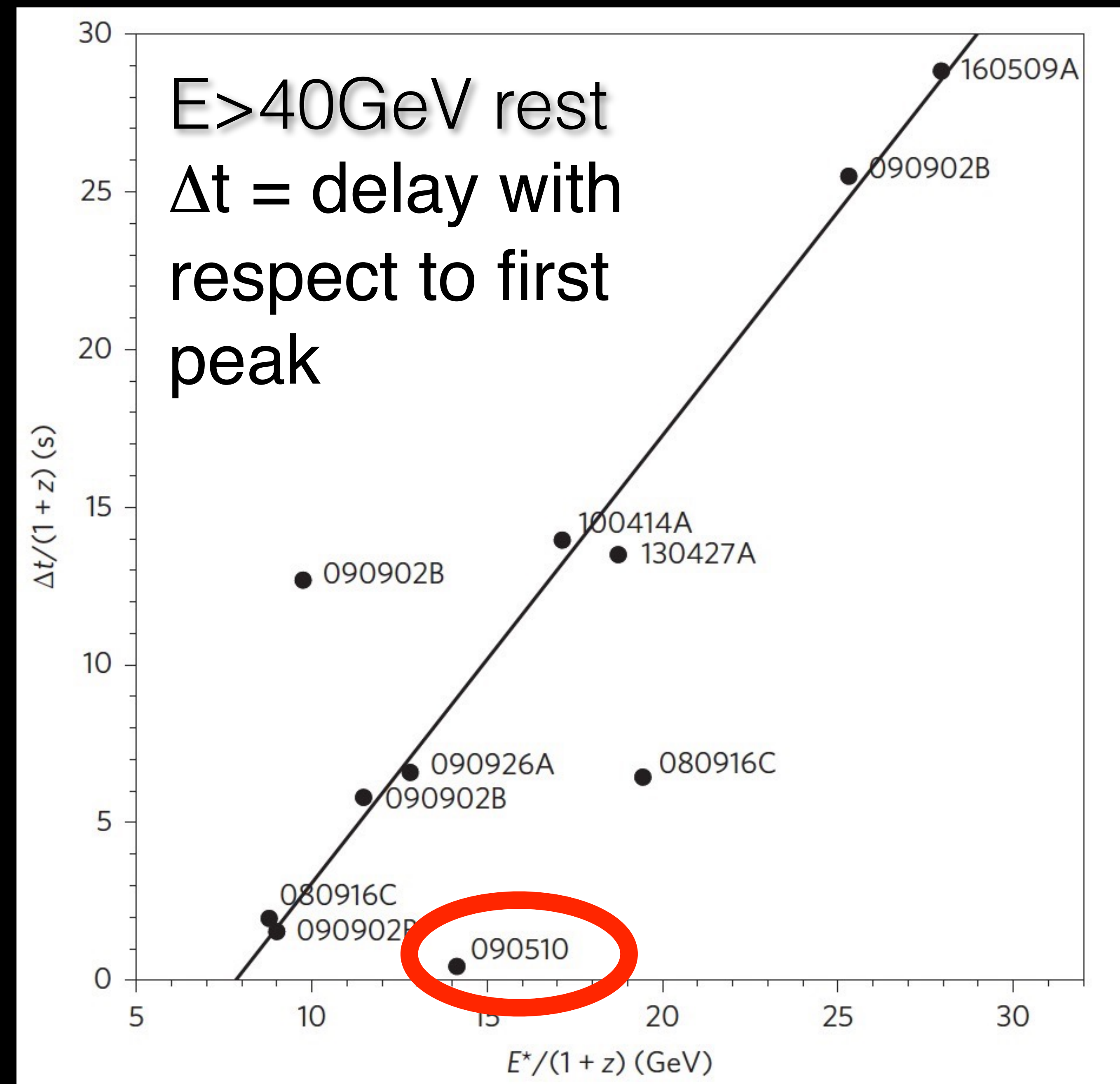
- Use all high-E photons

$$\Delta t = \eta_X \frac{E}{M_P} D(z) \pm \delta_X \frac{E}{M_P} D(z)$$

$$E^* \equiv E \frac{D(z)}{D(1)}$$

$$\Delta t = \eta_X D(1) \frac{E^*}{M_P} \pm \delta_X D(1) \frac{E^*}{M_P}$$

$$\eta_\gamma^{[pair]} \equiv \frac{M_P \Delta t_{pair}}{D(1) E^*_{pair}}$$



GAC,FF+ 2017

Fermi LAT GRBs

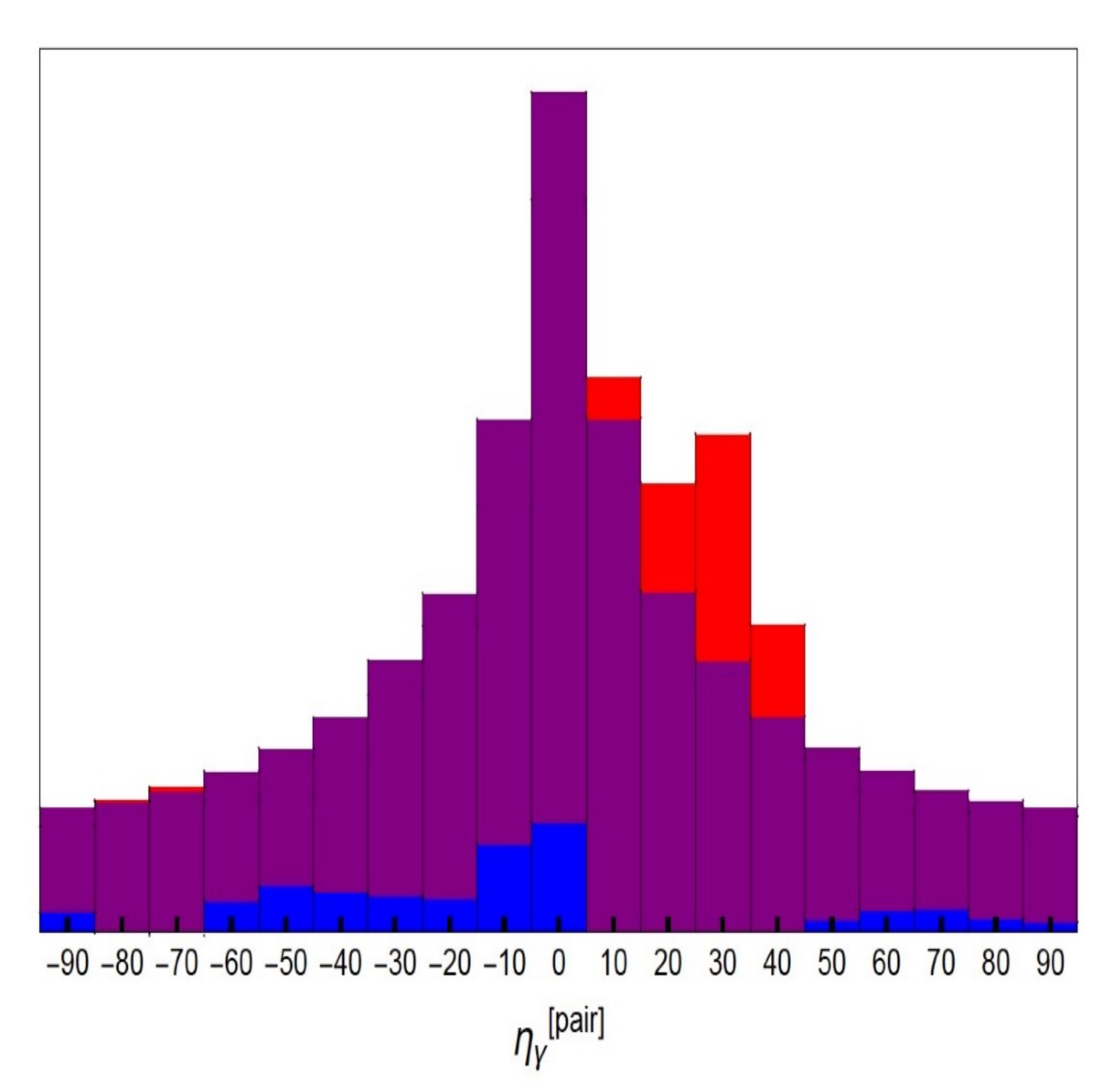
- Use all high-E photons

$$\Delta t = \eta_X \frac{E}{M_P} D(z) \pm \delta_X \frac{E}{M_P} D(z)$$

$$E^* \equiv E \frac{D(z)}{D(1)}$$

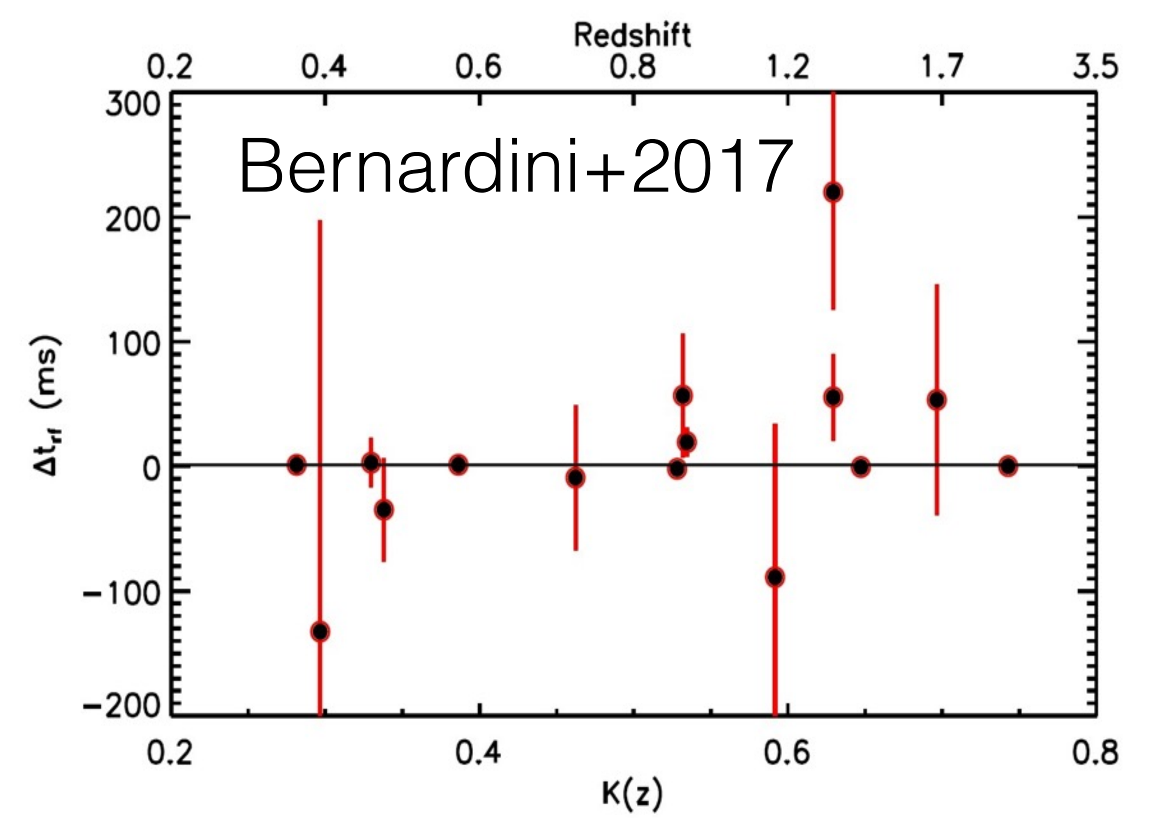
$$\Delta t = \eta_X D(1) \frac{E^*}{M_P} \pm \delta_X D(1) \frac{E^*}{M_P}$$

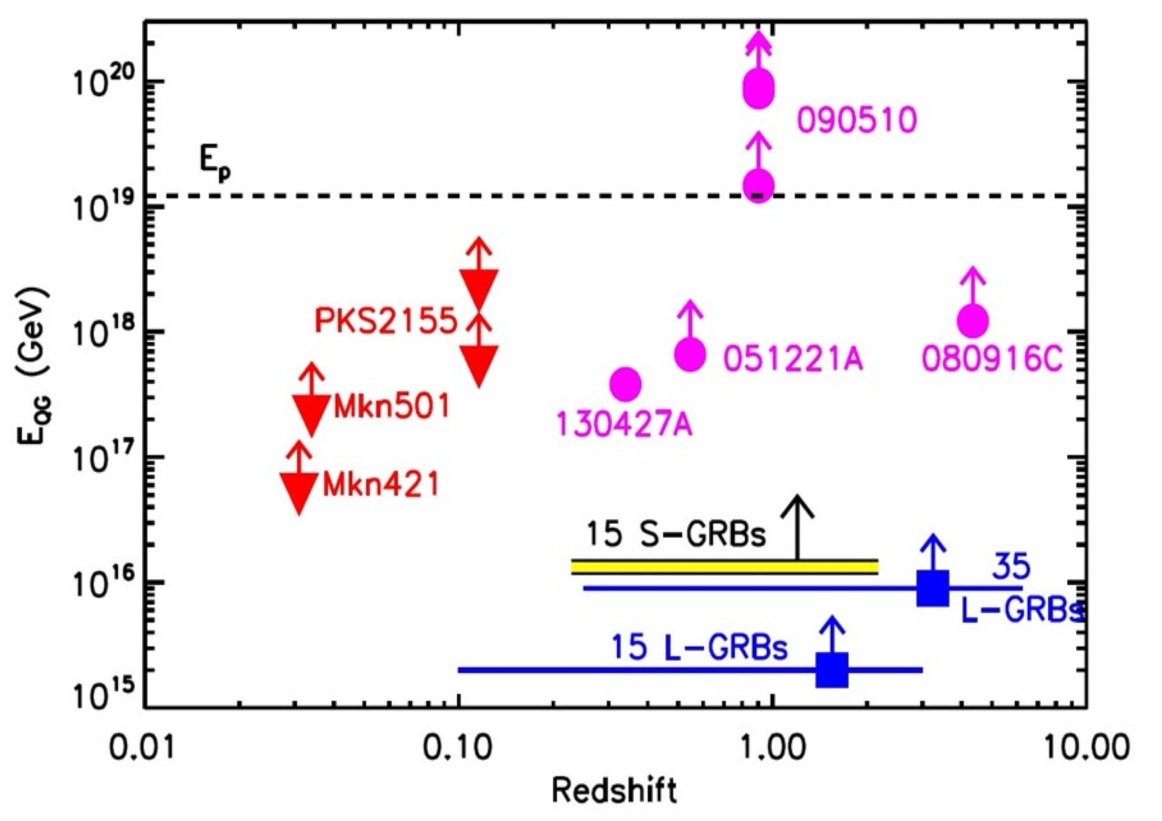
$$\eta_\gamma^{[pair]} \equiv \frac{M_P \Delta t_{pair}}{D(1) E^*_{pair}}$$



GAC,FF+ 2017

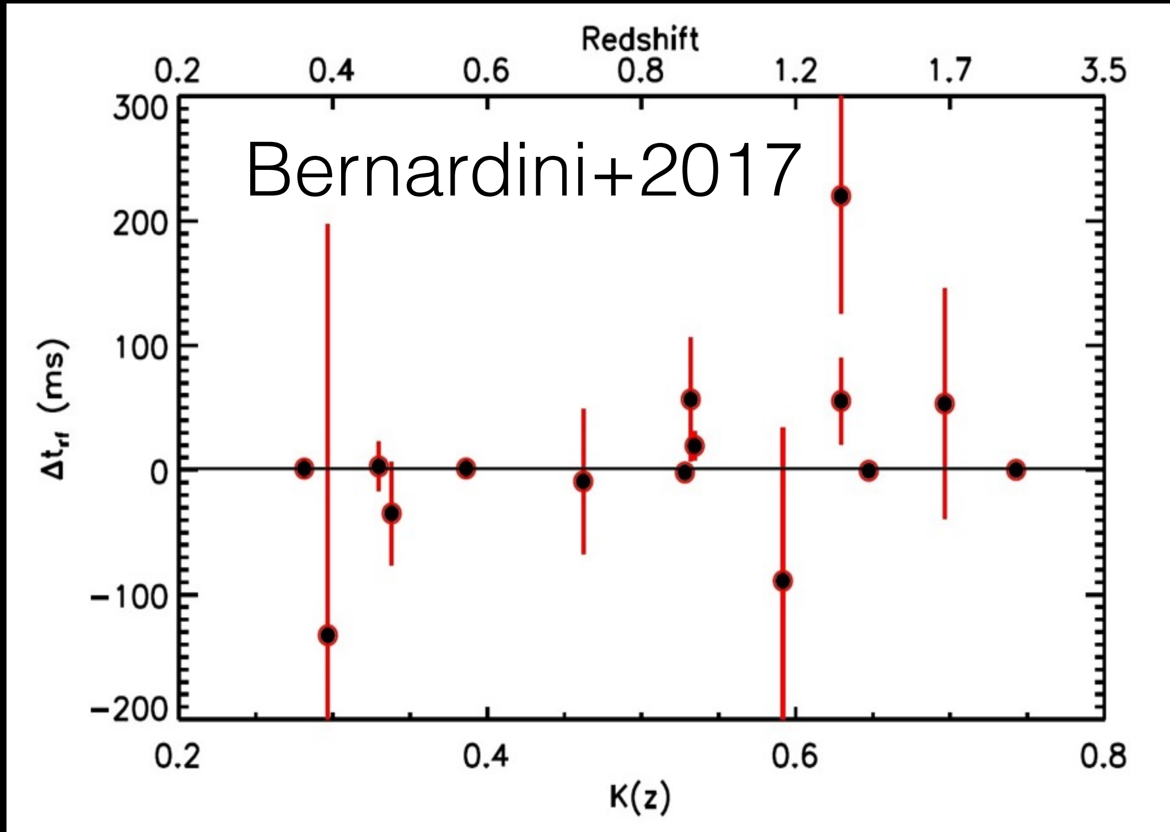
Hard X-rays GRBs

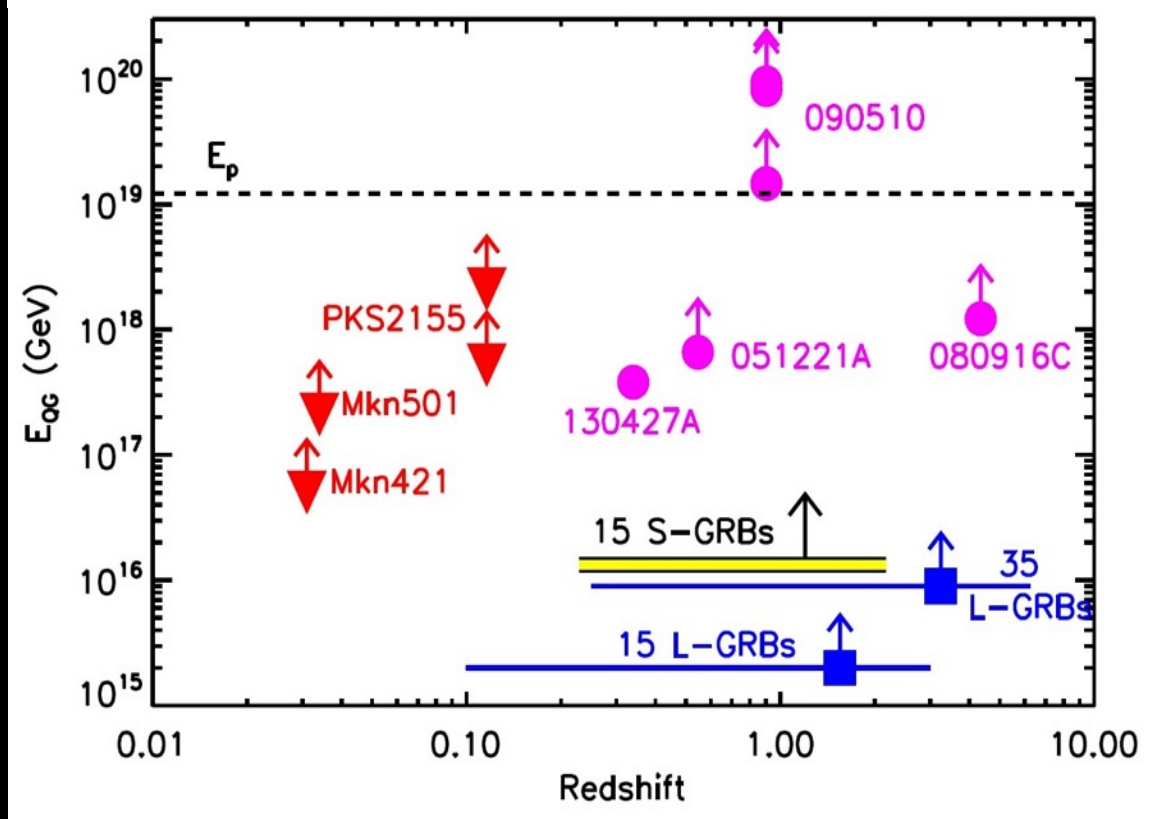




Hard X-rays GRBs

- Robust test:
  use full GRB information (CCF)
  thousands photons

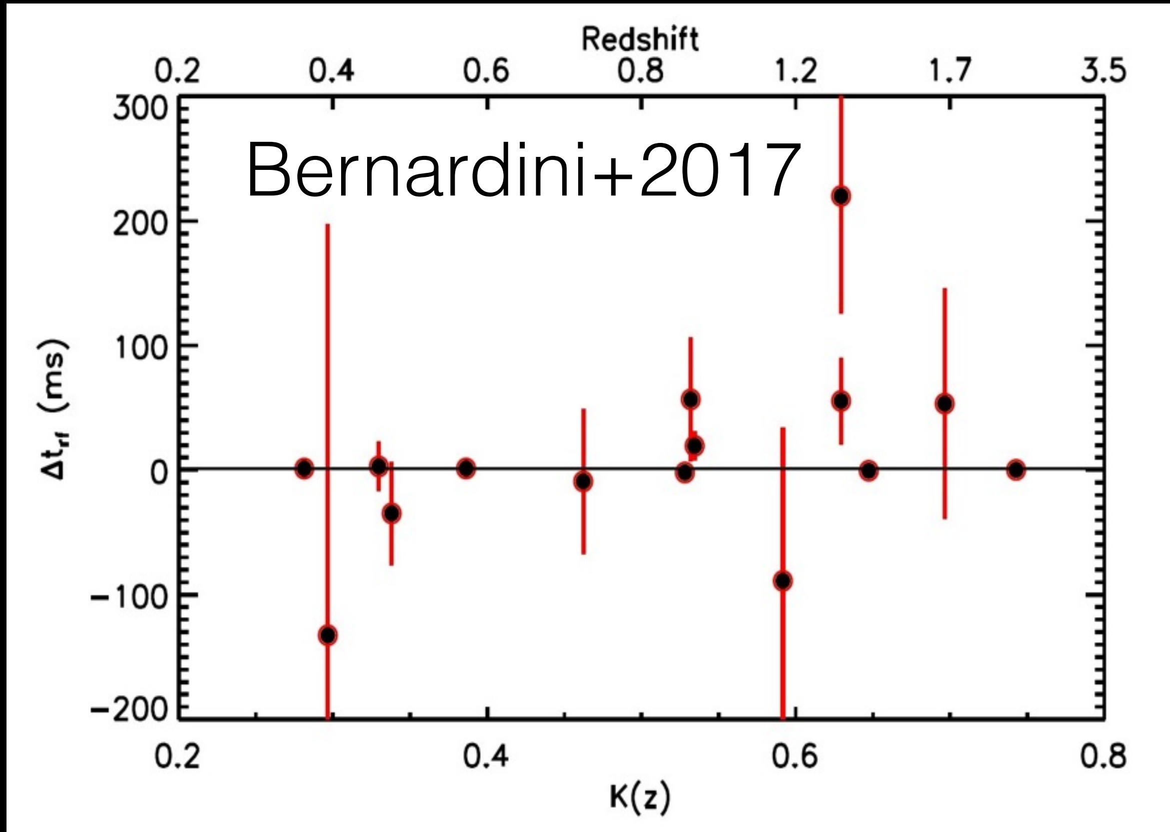


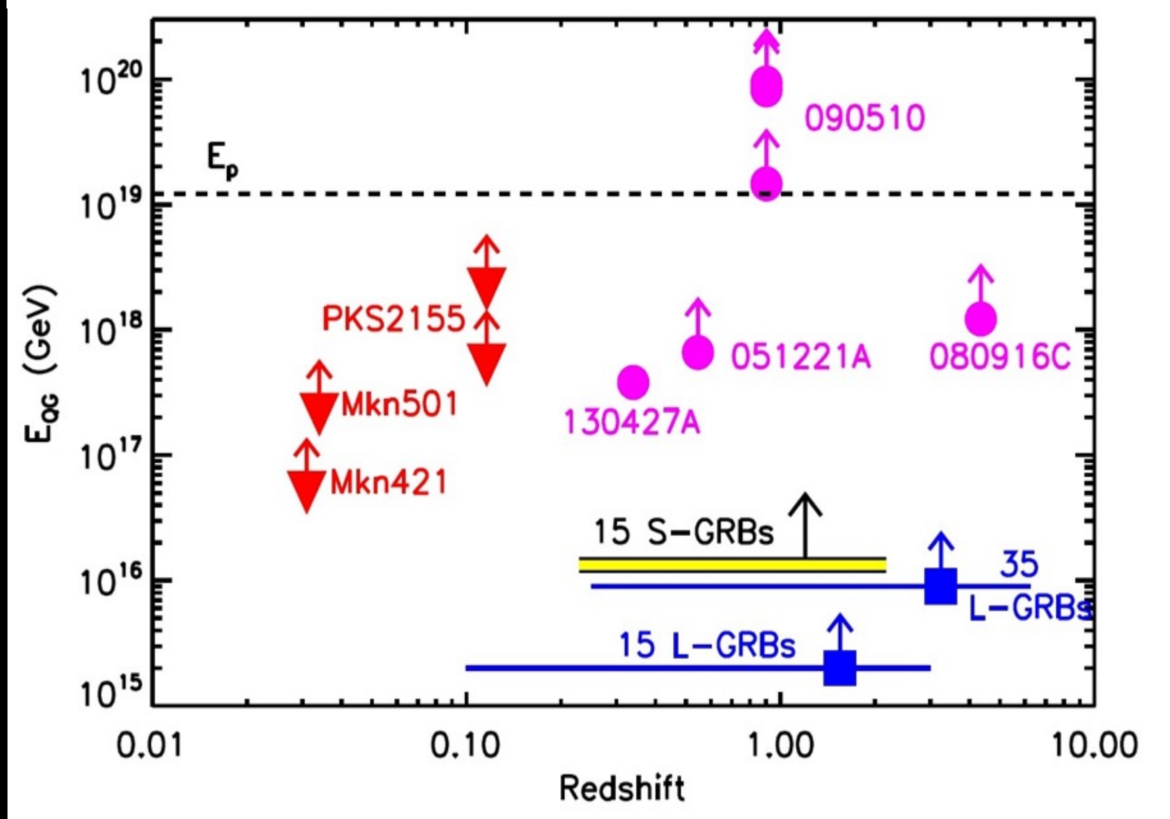


Hard X-rays GRBs

- Robust test:
  use full GRB information (CCF)
  thousands photons

- $\Delta t/\Delta E \sim 30\text{ms/GeV} \sim 3\mu\text{s}/100\text{keV}$
  $E_{QG} \sim E_{Planck}$, $\alpha=1$, $z\sim1$



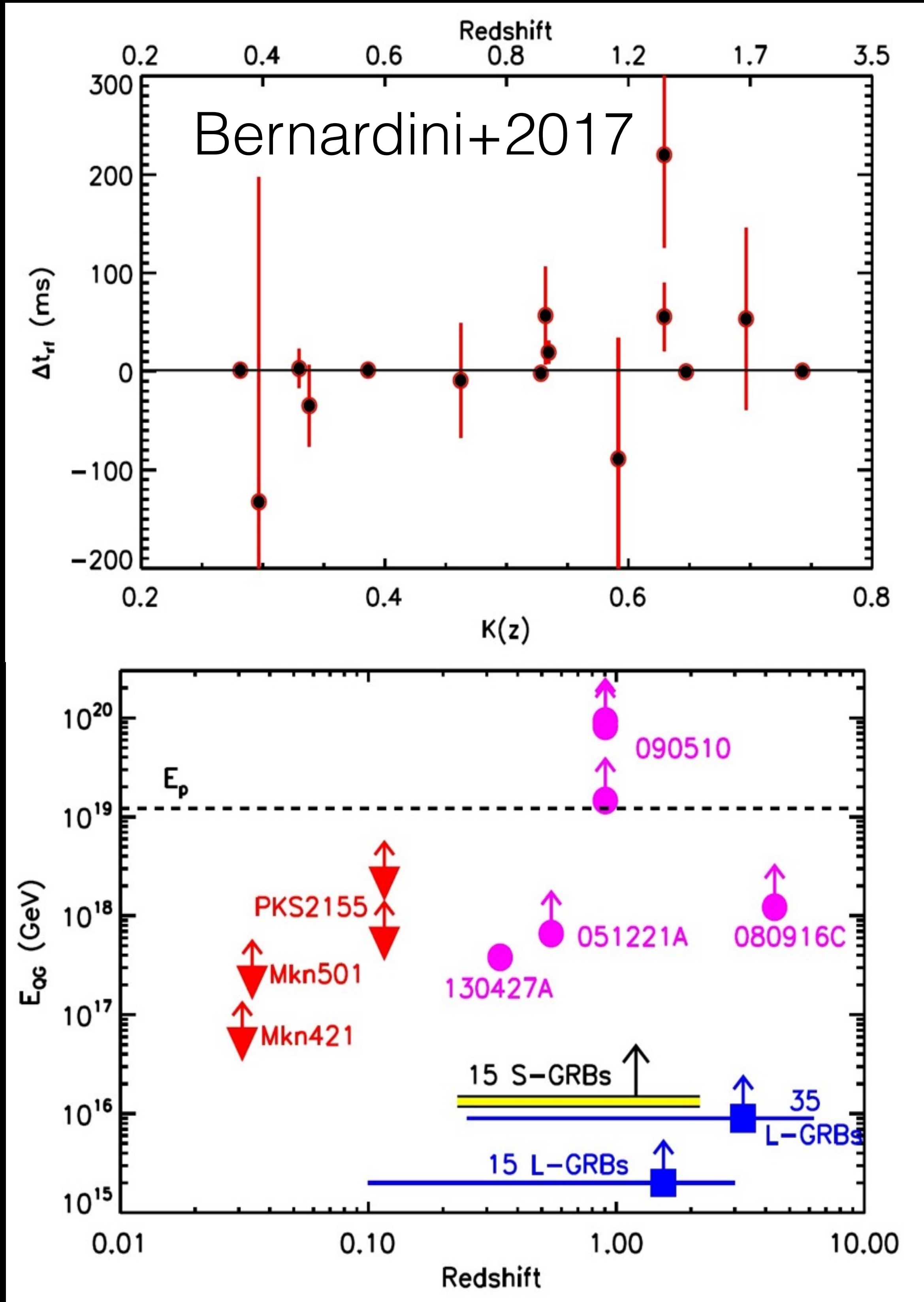


Hard X-rays GRBs

- Robust test:
  use full GRB information (CCF)
  thousands photons

- $\Delta t/\Delta E \sim 30ms/GeV\sim 3\mu$s/100keV
  $E_{QG} \sim E_{Planck}$, $\alpha=1$, $z\sim1$

- ~1ph/10μs, GRB with submm variability, detectors with um capability



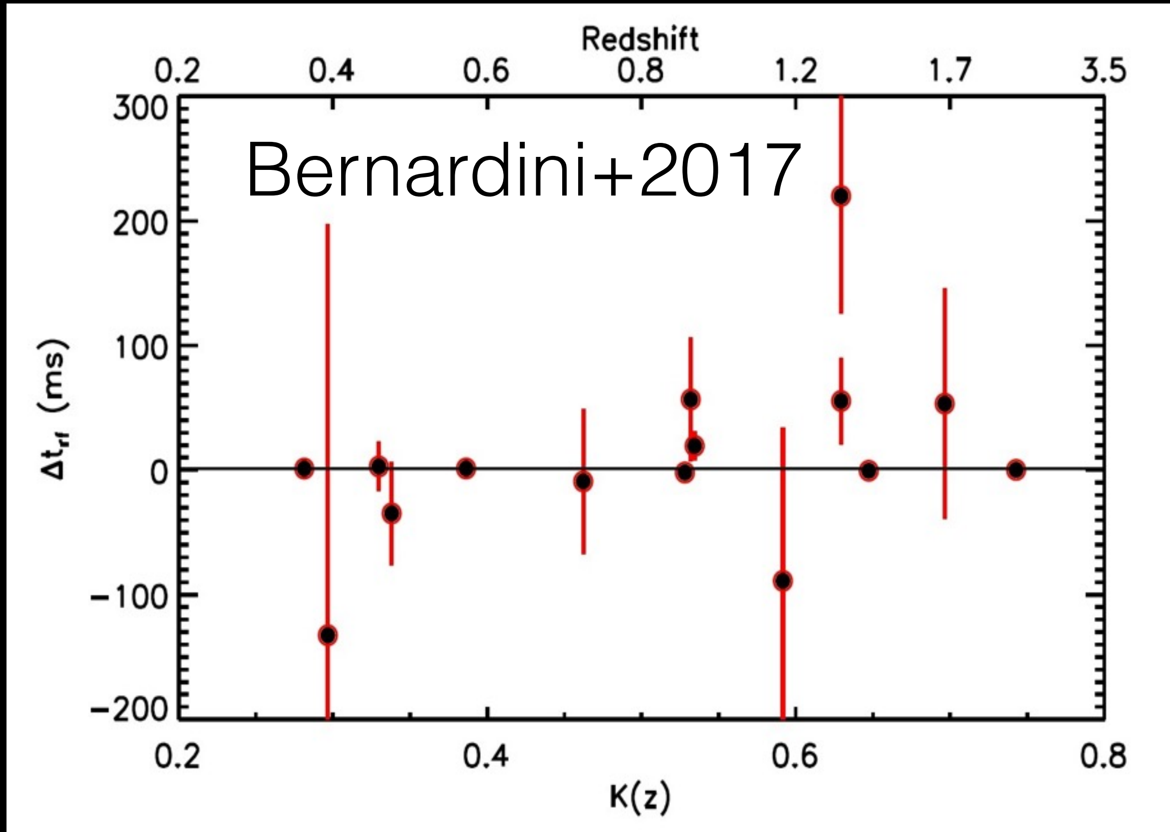
Hard X-rays GRBs

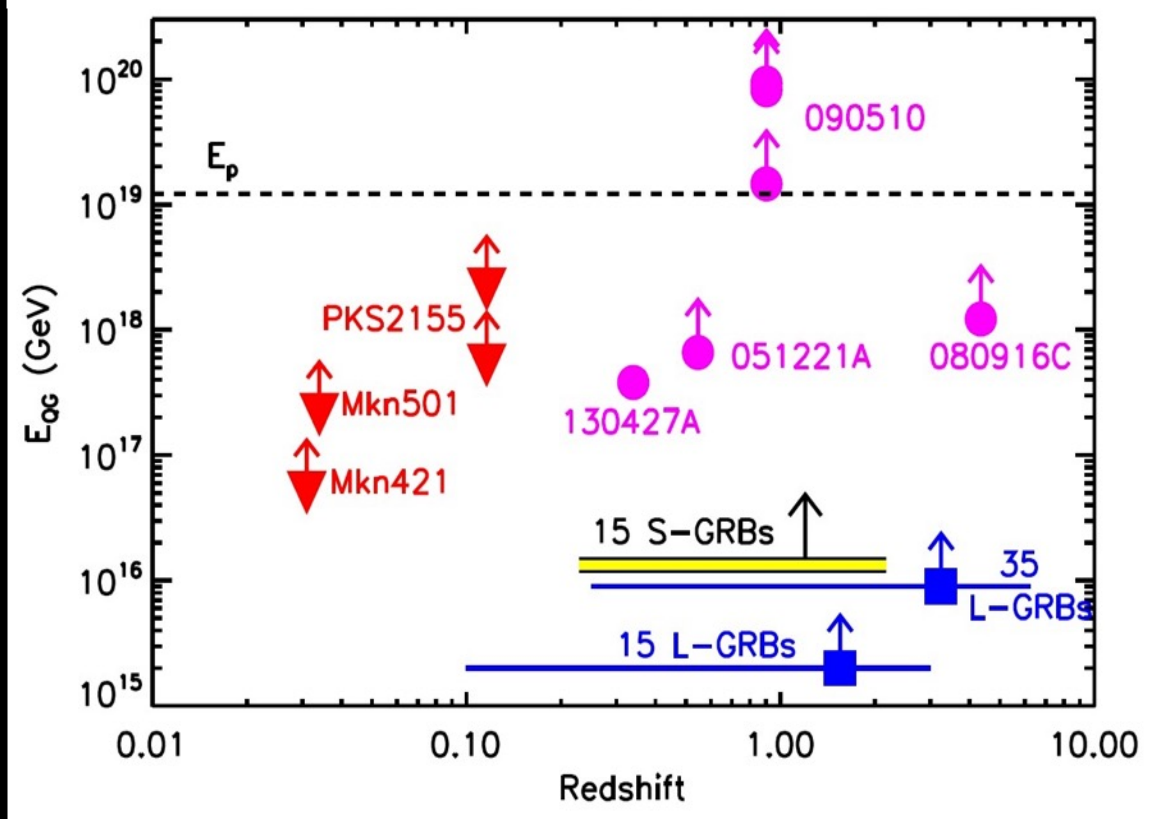
- Robust test:
  use full GRB information (CCF)
  thousands photons

- $\Delta t/\Delta E \sim 30ms/GeV\sim 3\mu$s/100keV
  $E_{QG} \sim E_{Planck}$, $\alpha=1$, $z\sim1$

- ~1ph/10μs, GRB with submm variability, detectors with um capability

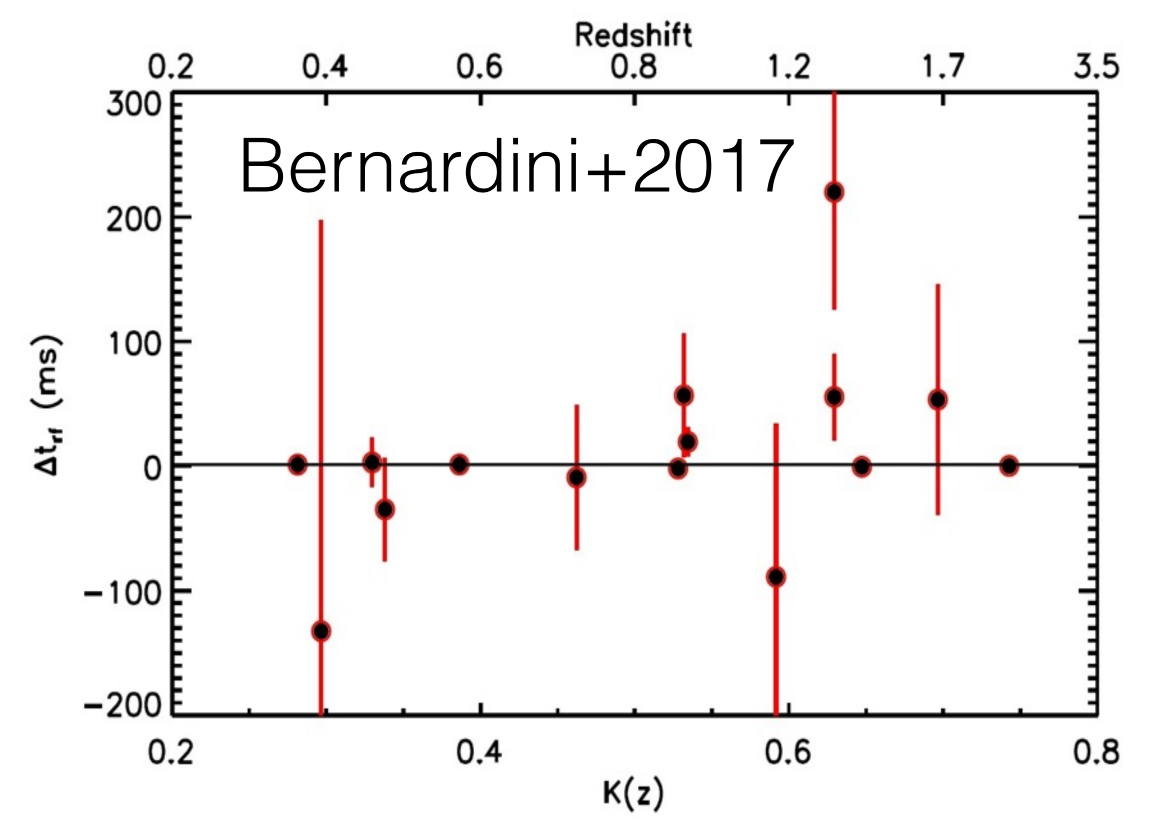
- $\Delta t/\Delta E$ must scale with $D(z)$ for a given E_{QG}

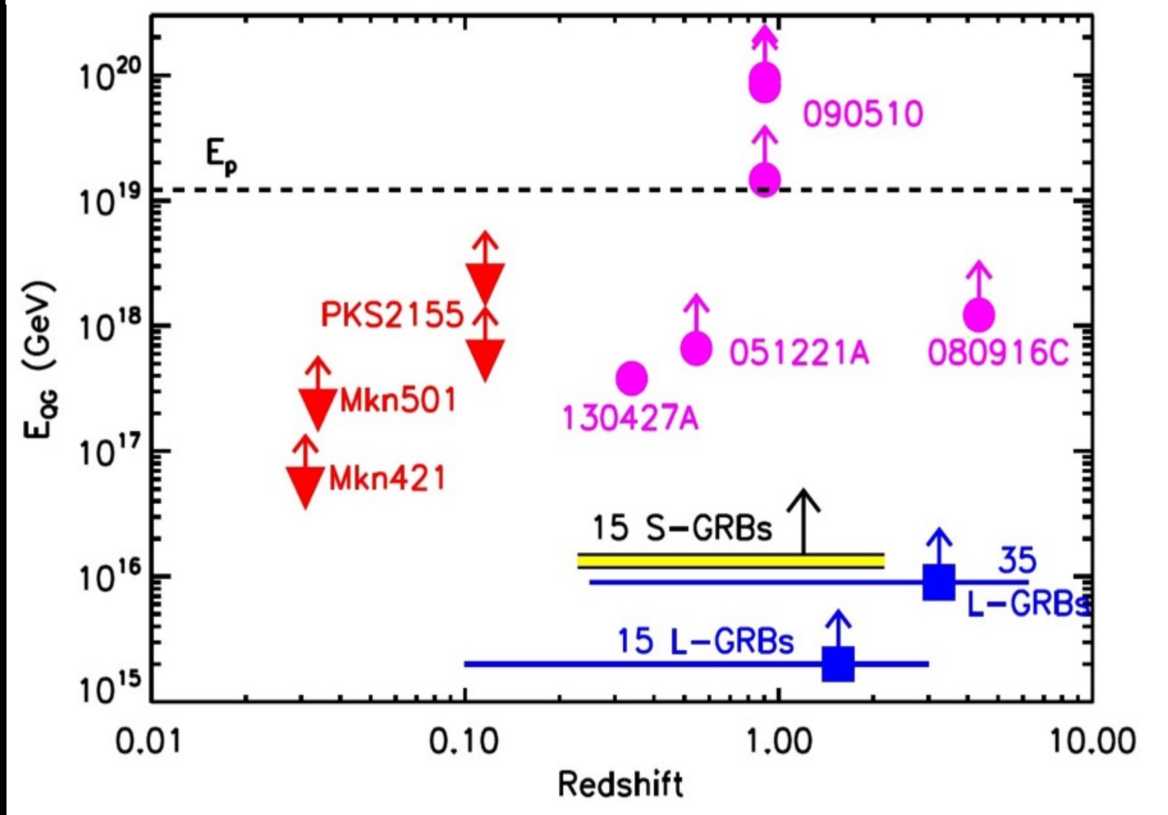




Hard X-rays GRBs

- Robust test:
  use full GRB information (CCF)
  thousands photons
- $\Delta t/\Delta E \sim 30ms/GeV \sim 3\mu s/100keV$
  $E_{QG} \sim E_{Planck}$, $\alpha=1$, $z\sim1$
- ~1ph/10μs, GRB with submm variability, detectors with um capability
- $\Delta t/\Delta E$ must scale with $D(z)$ for a given E_{QG}
- Tens/hundreds GRBs: ~10ph/cm^2/s
  —> Collecting area ~1m^2





Mission concept

Disruptive technologies: cheap, underperforming, but producing high impact. Distributed instrument, tens/hundreds of simple units

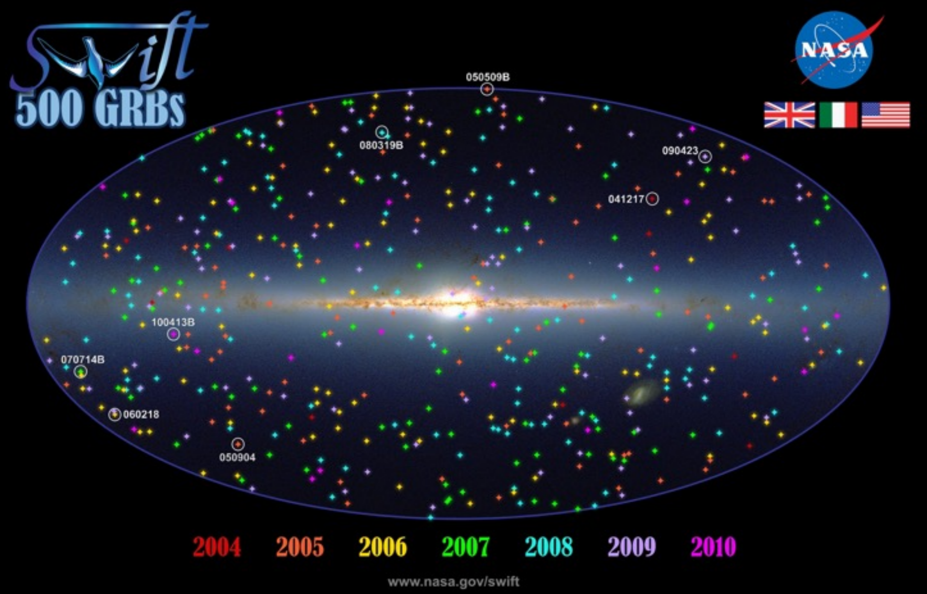
Mission concept

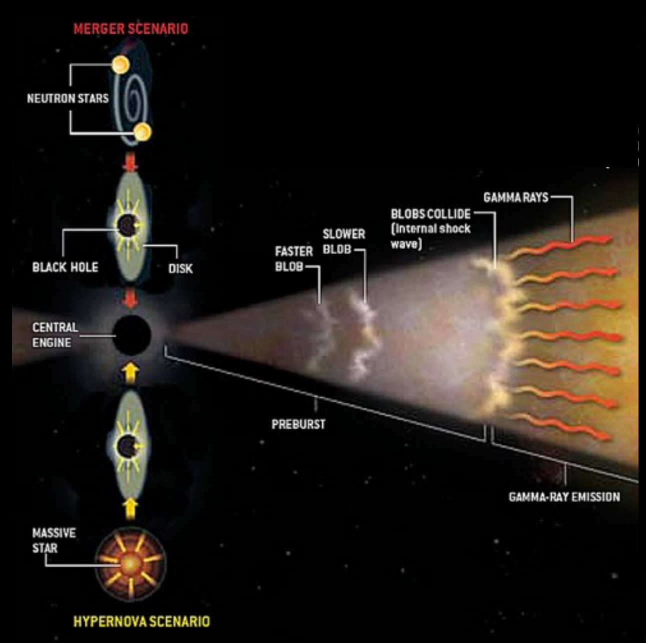
Disruptive technologies: cheap, underperforming, but producing high impact. Distributed instrument, tens/hundreds of simple units

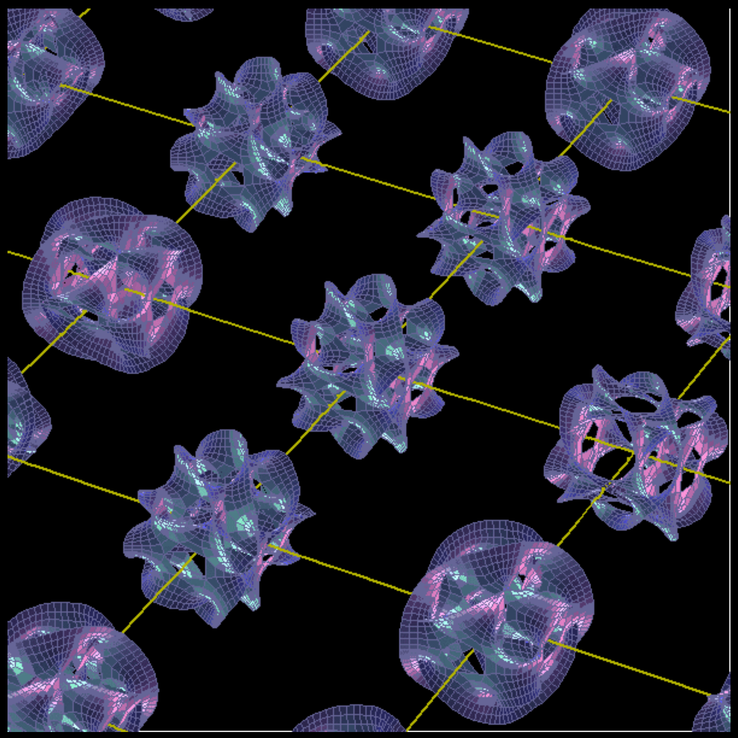
HERMES constellation of cubesat

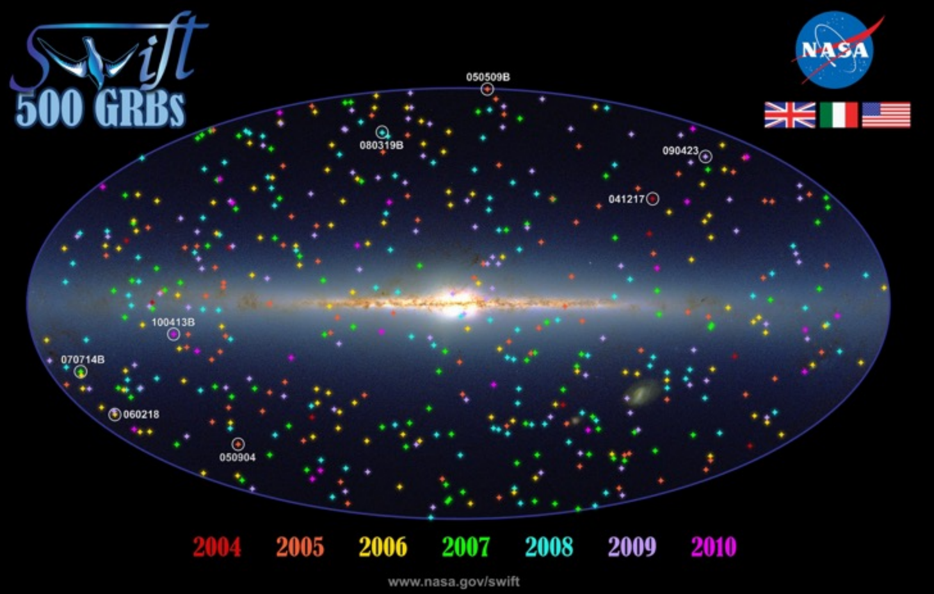
2016: ASI funds for detector R&D
2018: MIUR funds for pathfinder
(Progetti premiali 2015)

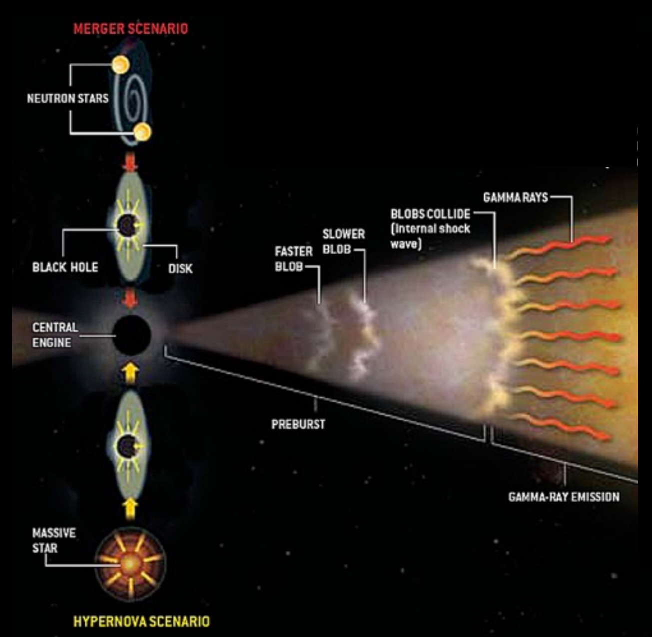
2017 progetti premiali 2016 proposal
2018 H2020 Space proposal

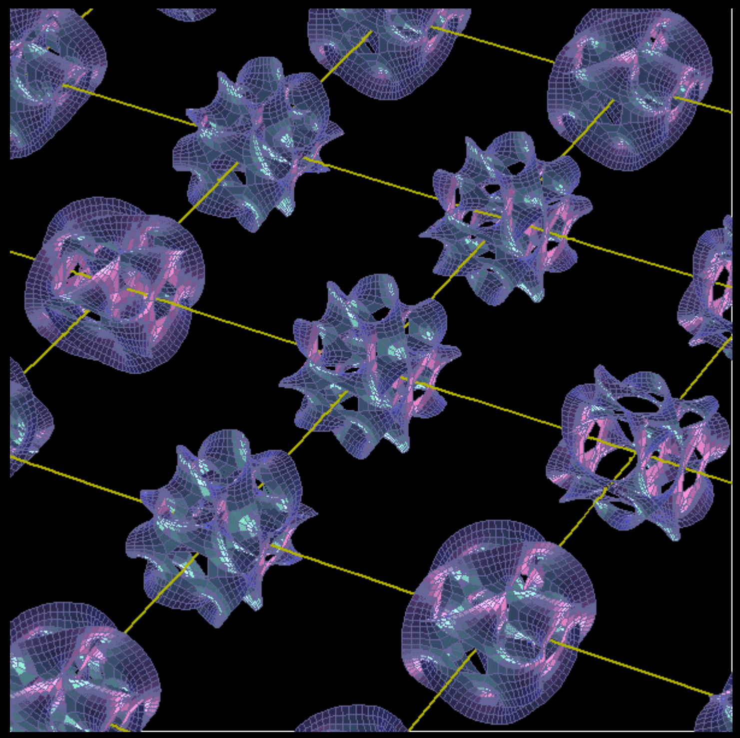

Swift
500 GRBs
050509B
080319B
090423
041217
100413B
070714B
060218
050904
2004 2005 2006 2007 2008 2009 2010
www.nasa.gov/swift


MERGER SCENARIO
NEUTRON STARS
BLACK HOLE
DISK
CENTRAL ENGINE
MASSIVE STAR
HYPERNOVA SCENARIO
FASTER BLOB
SLOWER BLOB
BLOBS COLLIDE (internal shock wave)
GAMMA RAYS
PREBURST
GAMMA-RAY EMISSION

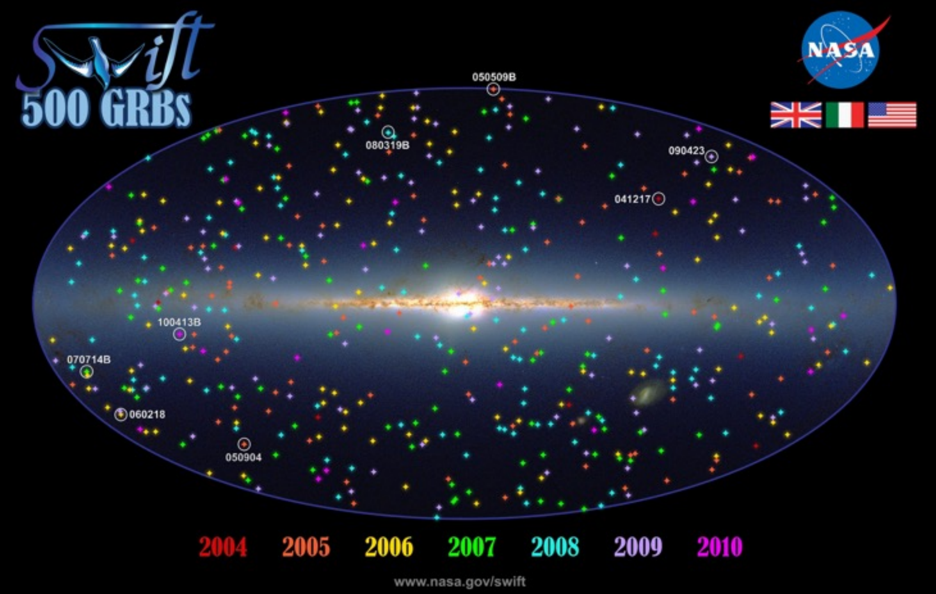


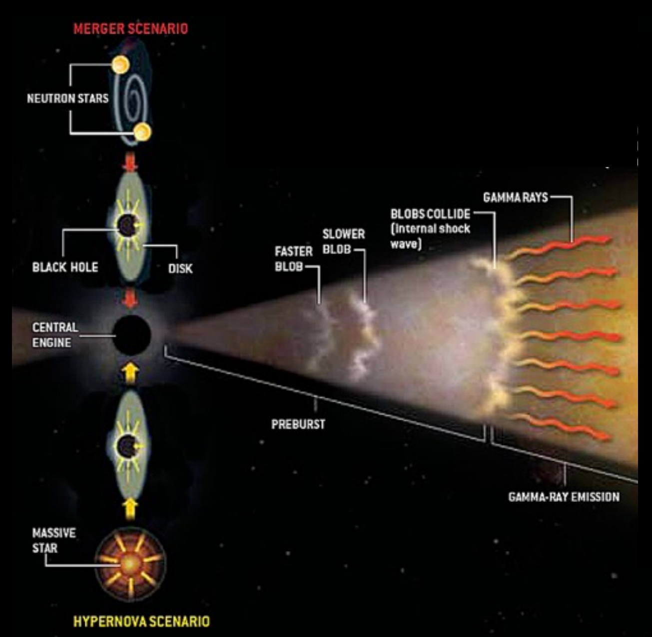

Swift
500 GRBs
050509B
080319B
090423
041217
100413B
070714B
060218
050904
2004 2005 2006 2007 2008 2009 2010
www.nasa.gov/swift

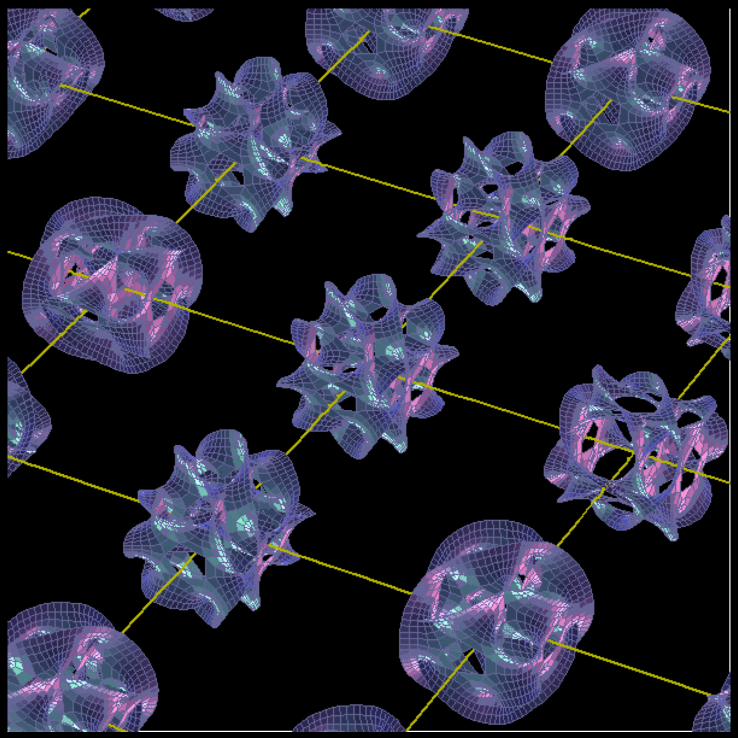

MERGER SCENARIO
NEUTRON STARS
BLACK HOLE
DISK
CENTRAL ENGINE
FASTER BLOB
SLOWER BLOB
BLOBS COLLIDE (internal shock wave)
GAMMA RAYS
PREBURST
GAMMA-RAY EMISSION
MASSIVE STAR
HYPERNOVA SCENARIO



How to *promptly* localise a GRB *prompt* event? (in particular those associated to a GW events)

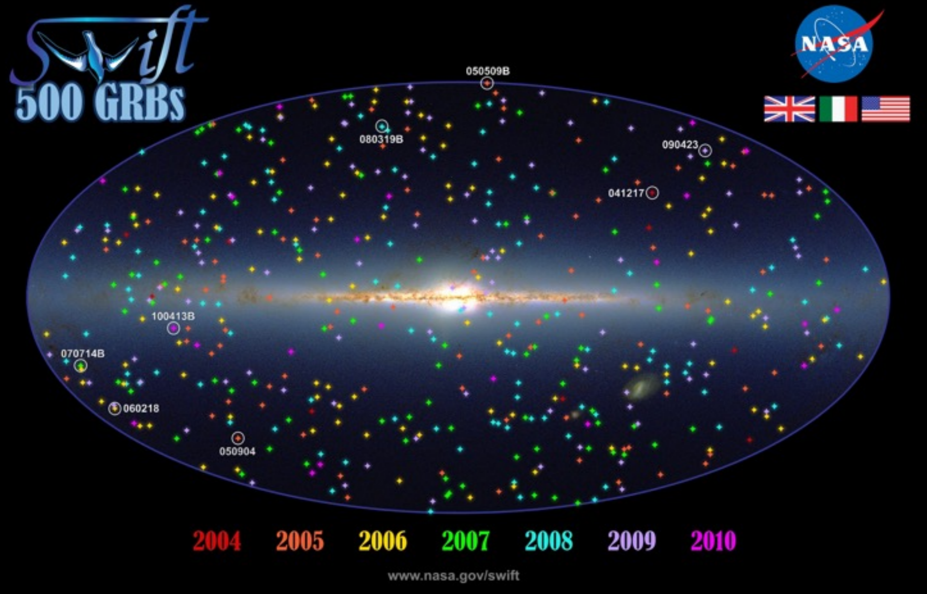


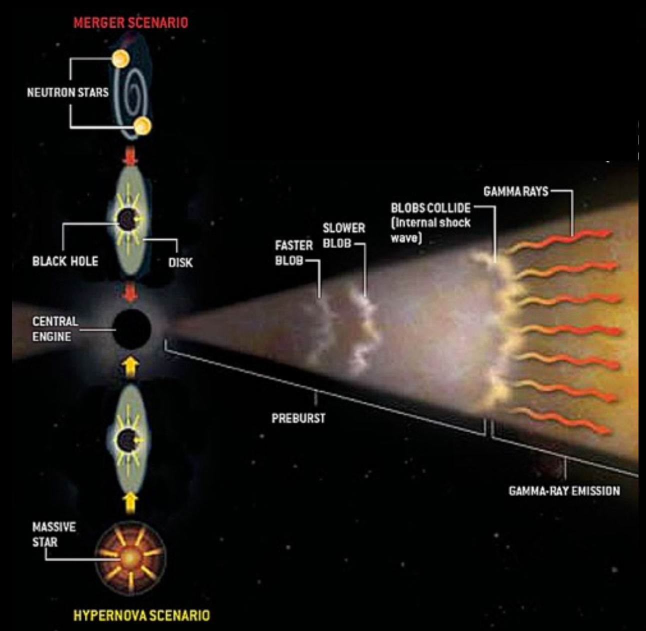


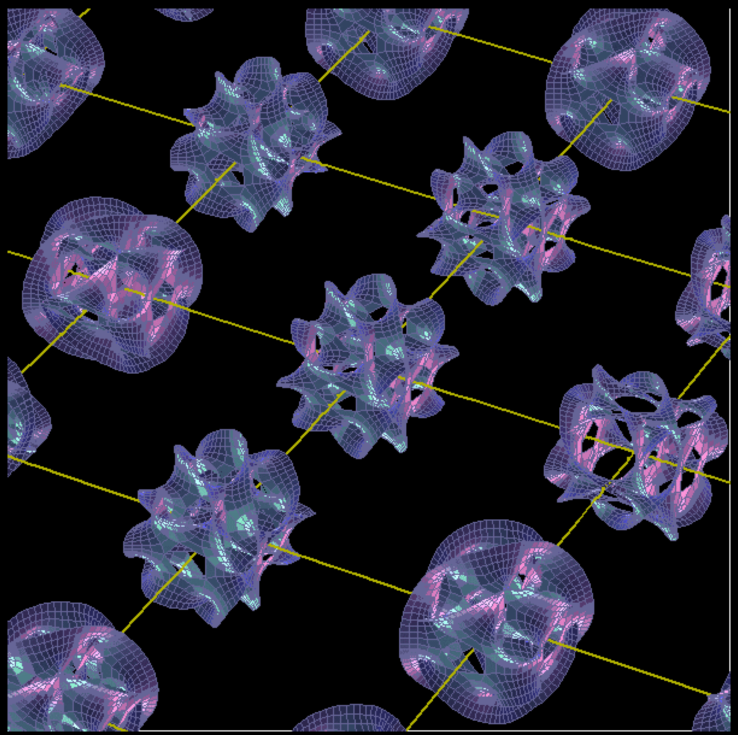


How to *promptly* localise a GRB *prompt* event? (in particular those associated to a GW events)

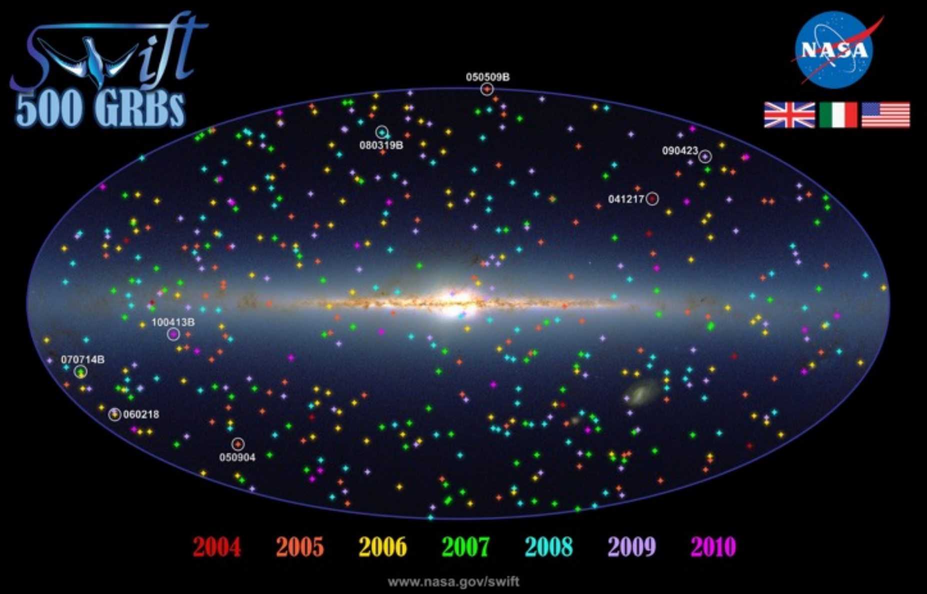
How to construct a GRB engine?



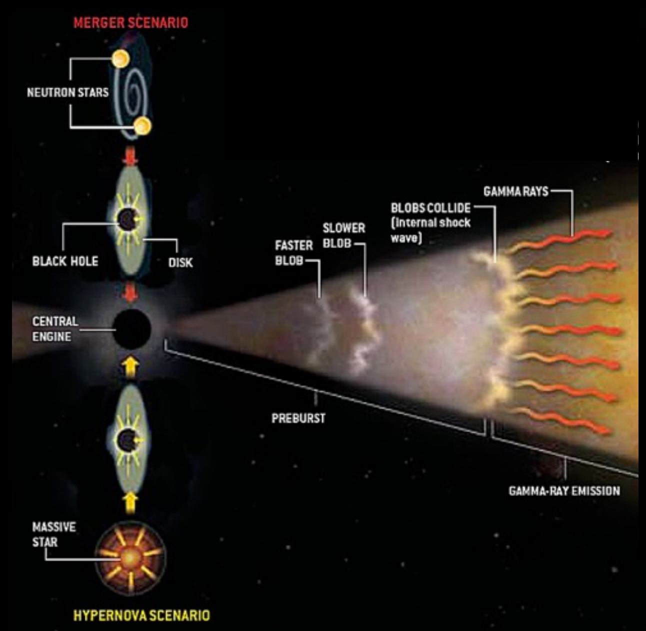




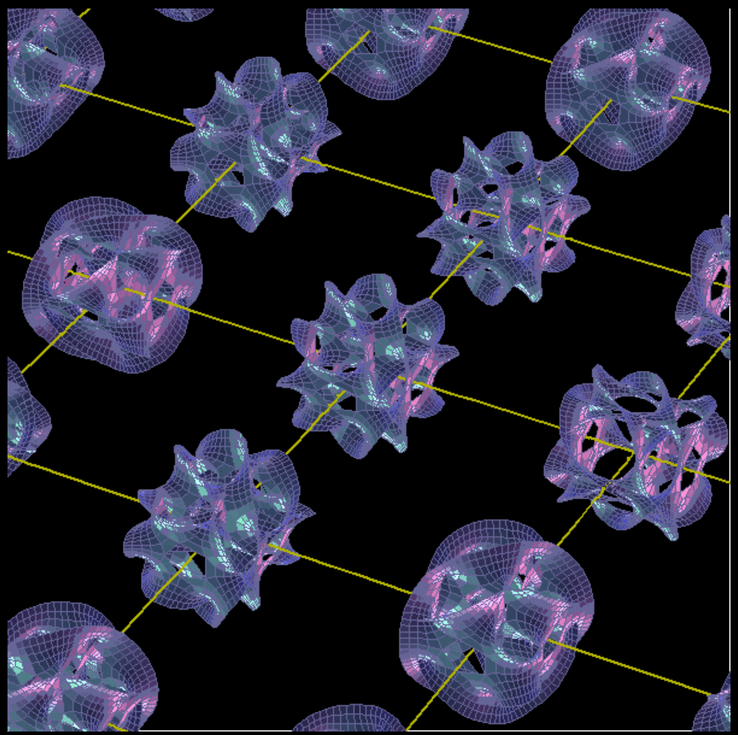
How to *promptly* localise a GRB *prompt* event? (in particular those associated to a GW events)



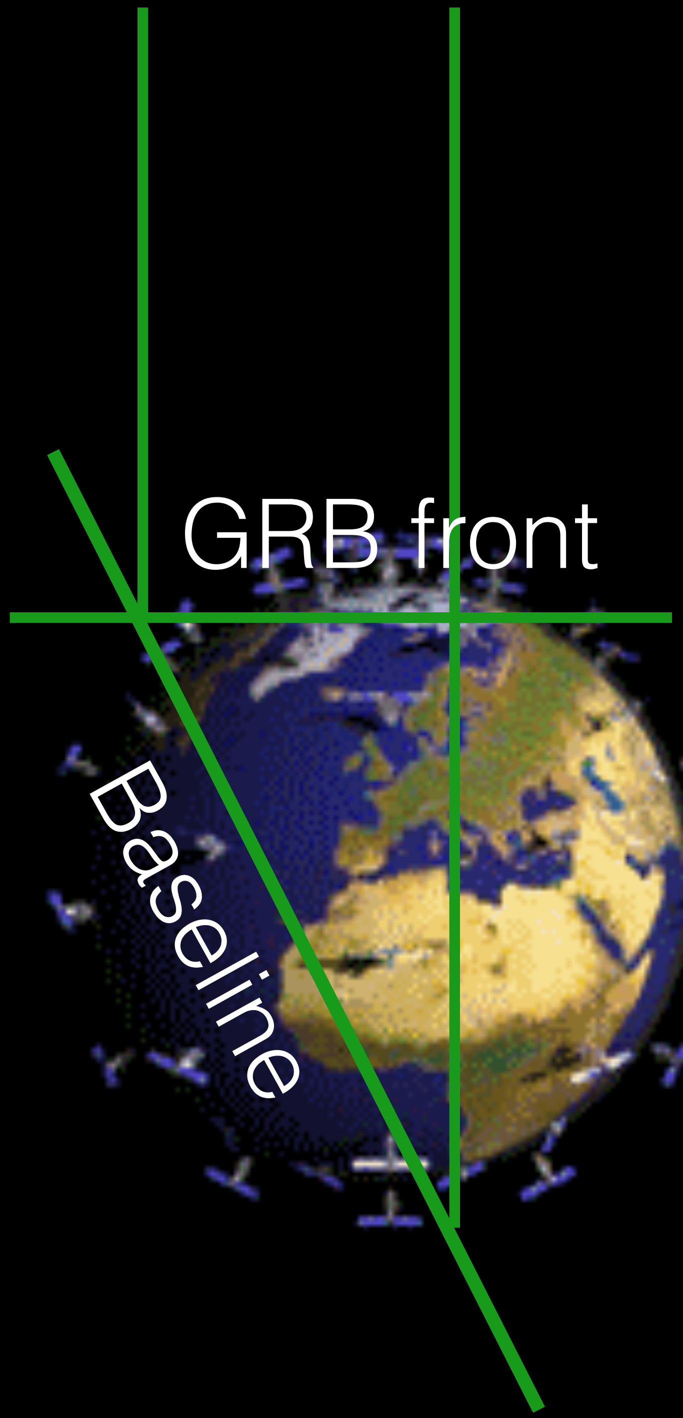
How to construct a GRB engine?



Which is the ultimate granular structure of space-time?



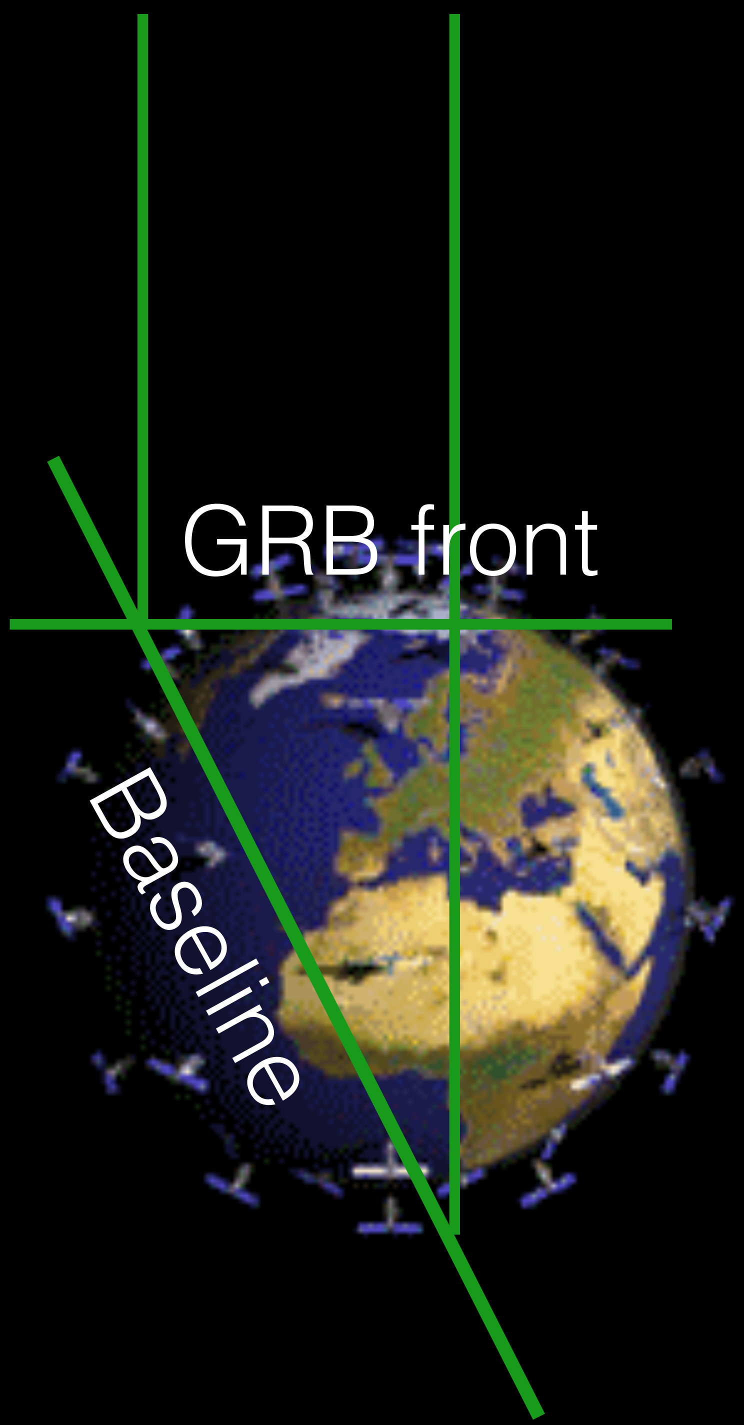
Experiment concept



Experiment concept

1. Measure GRB positions through delays between photons arrival times:

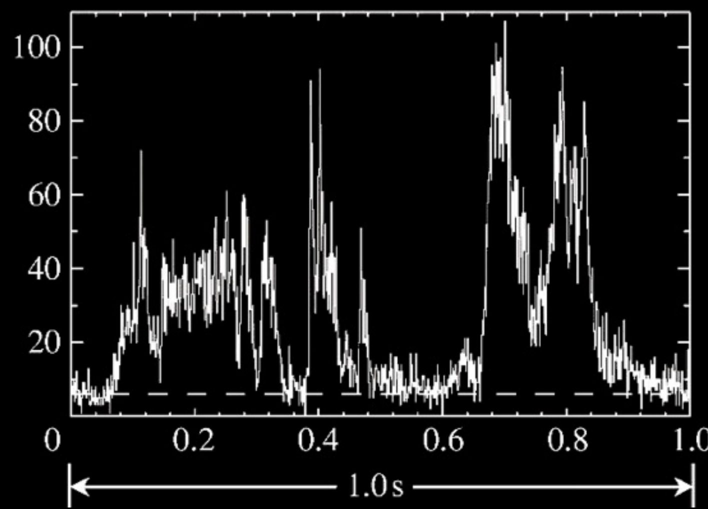
$\sigma_{Pos} = \sigma_{CCF} \times c \,/\, \langle B \rangle \,/\, (N \times (N - 1 - 2)^{1/2}$



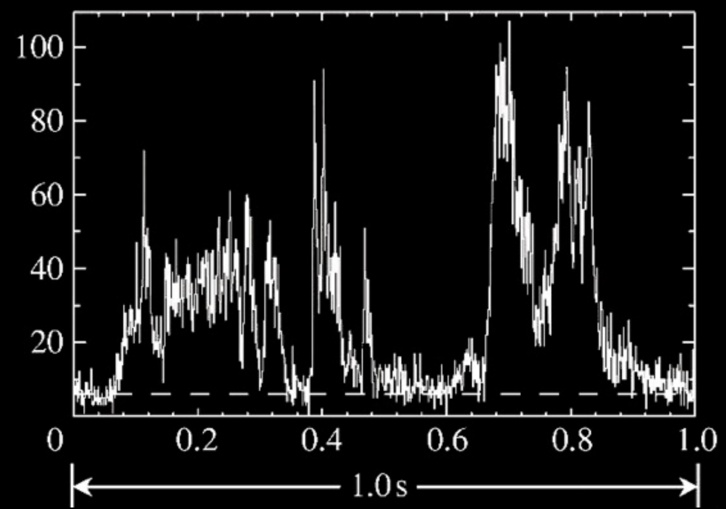
Experiment concept

1. Measure GRB positions through delays between photons arrival times:

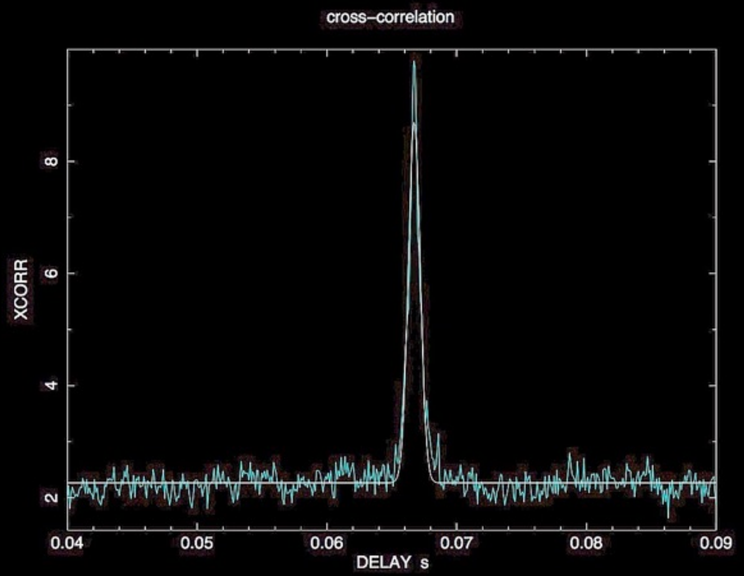
$\sigma_{Pos} = \sigma_{CCF}$ x c / <B> / (Nx(N –1– 2)$^{1/2}$



+



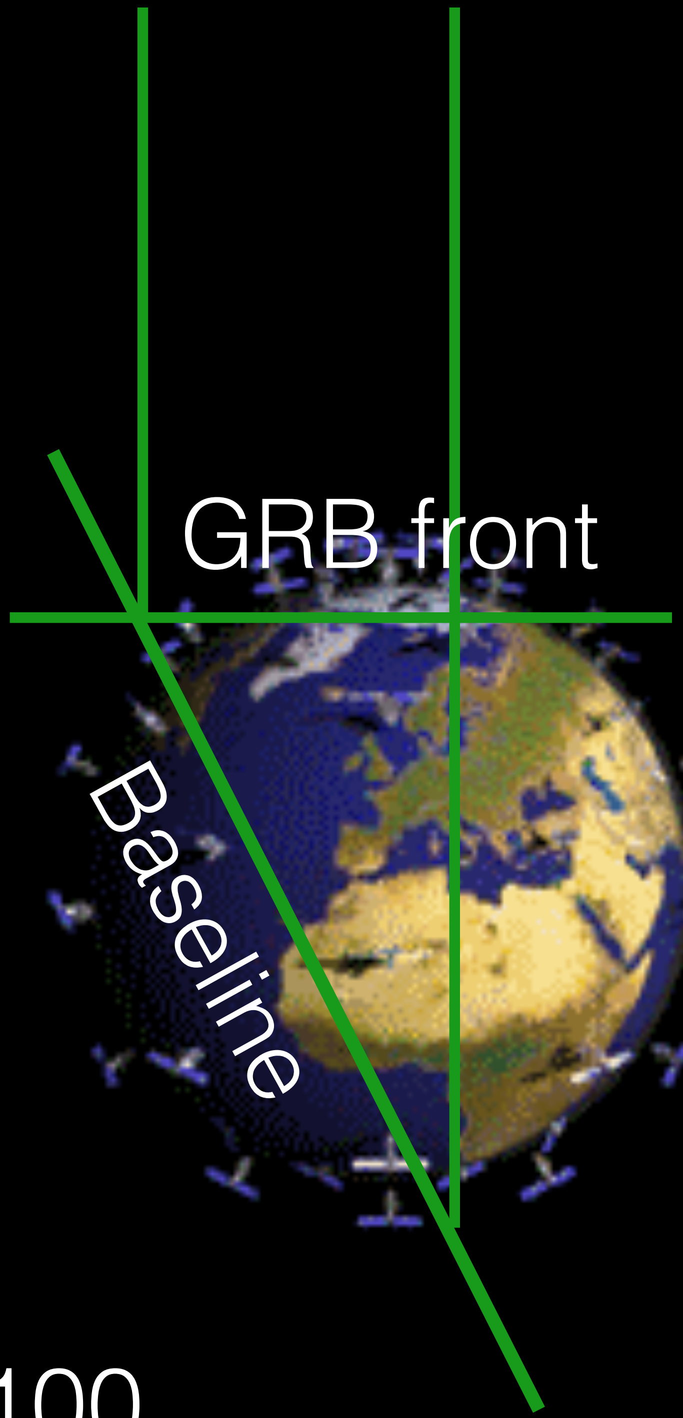
=



σ_{CCF}~10μs

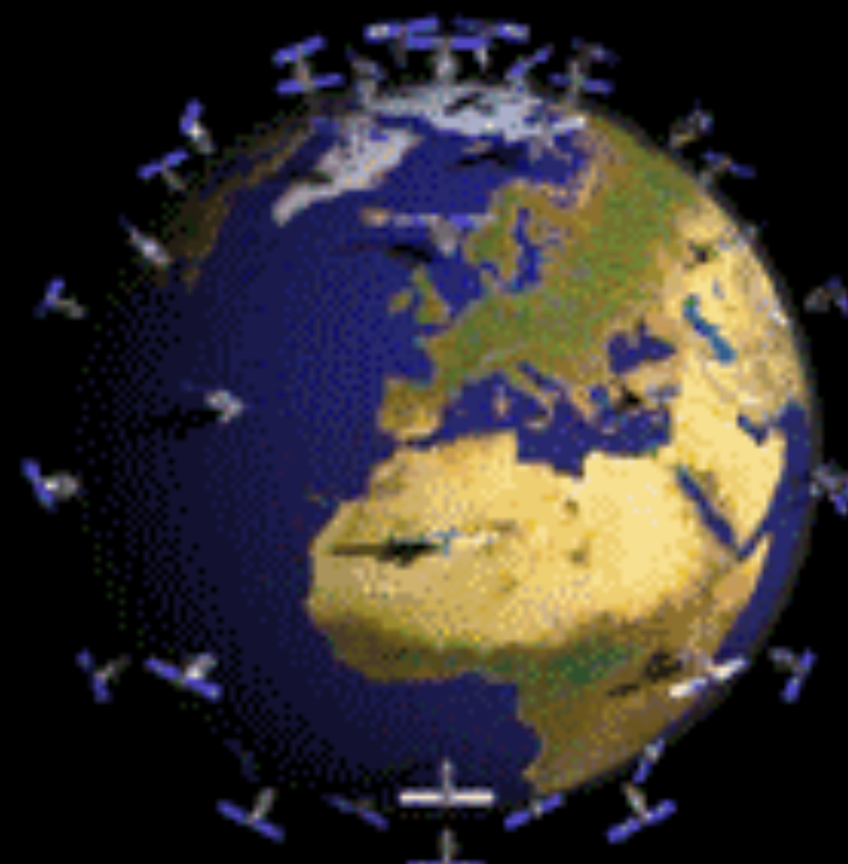
σ_{Pos}~10arcsec

if <B>~7000km, N~100



Experiment concept

Experiment concept



Experiment concept

2. Add the signal from different units

Total collecting area 50-100cm^2 x 100-200 = 1m^2

Experiment concept

2. Add the signal from different units

Total collecting area 50-100cm^2 x 100-200 = 1m^2

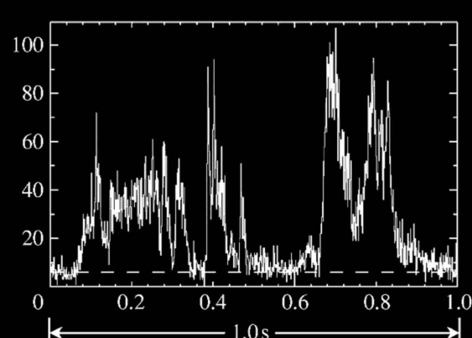
Transient fine (μs-ms) temporal structure

Experiment concept

2. Add the signal from different units

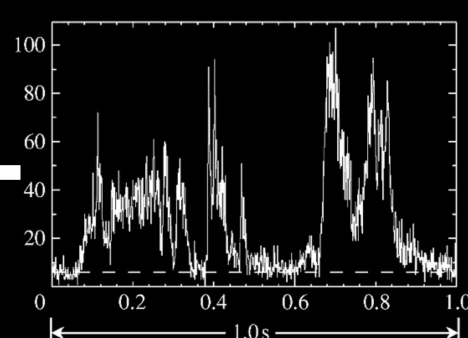
Total collecting area 50-100cm^2 x 100-200 = 1m^2

Transient fine (μs-ms) temporal structure



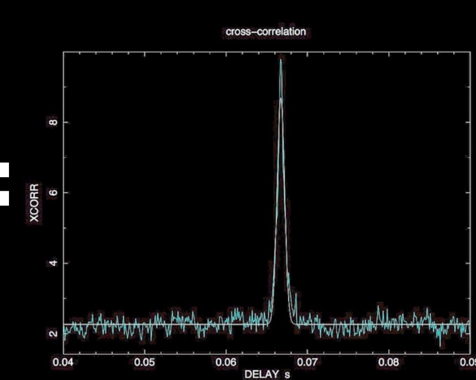
E_{low}

+



E_{high}

=

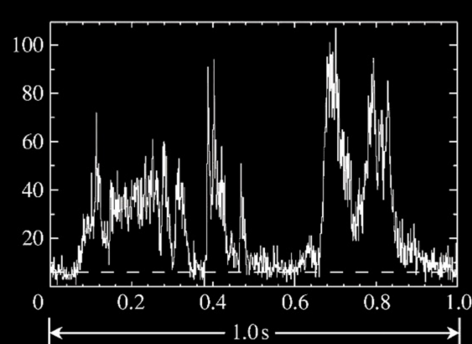


Experiment concept

2. Add the signal from different units

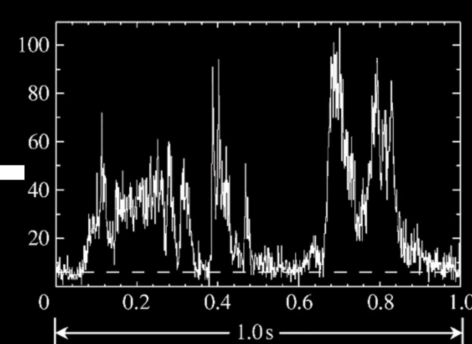
Total collecting area 50-100cm^2 x 100-200 = 1m^2

Transient fine (μs-ms) temporal structure



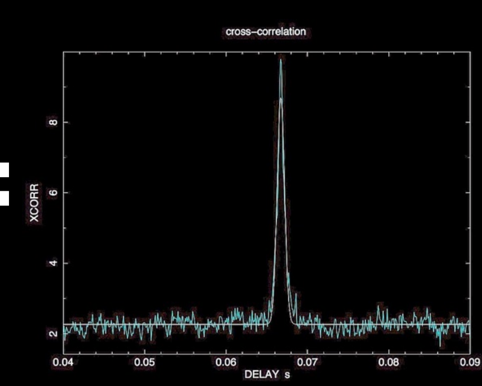
E_{low}

+



E_{high}

=



$\Delta t/\Delta E \sim 3\mu s/100keV$ $E_{QG} \sim E_{Planck}$, $\alpha=1$, $z \sim 1$

Spacecraft

Spacecraft

3U minimum, simplest basic configuration
$\leq 100cm^2$ detector

Spacecraft

3U minimum, simplest basic configuration
$\leq 100 cm^2$ detector

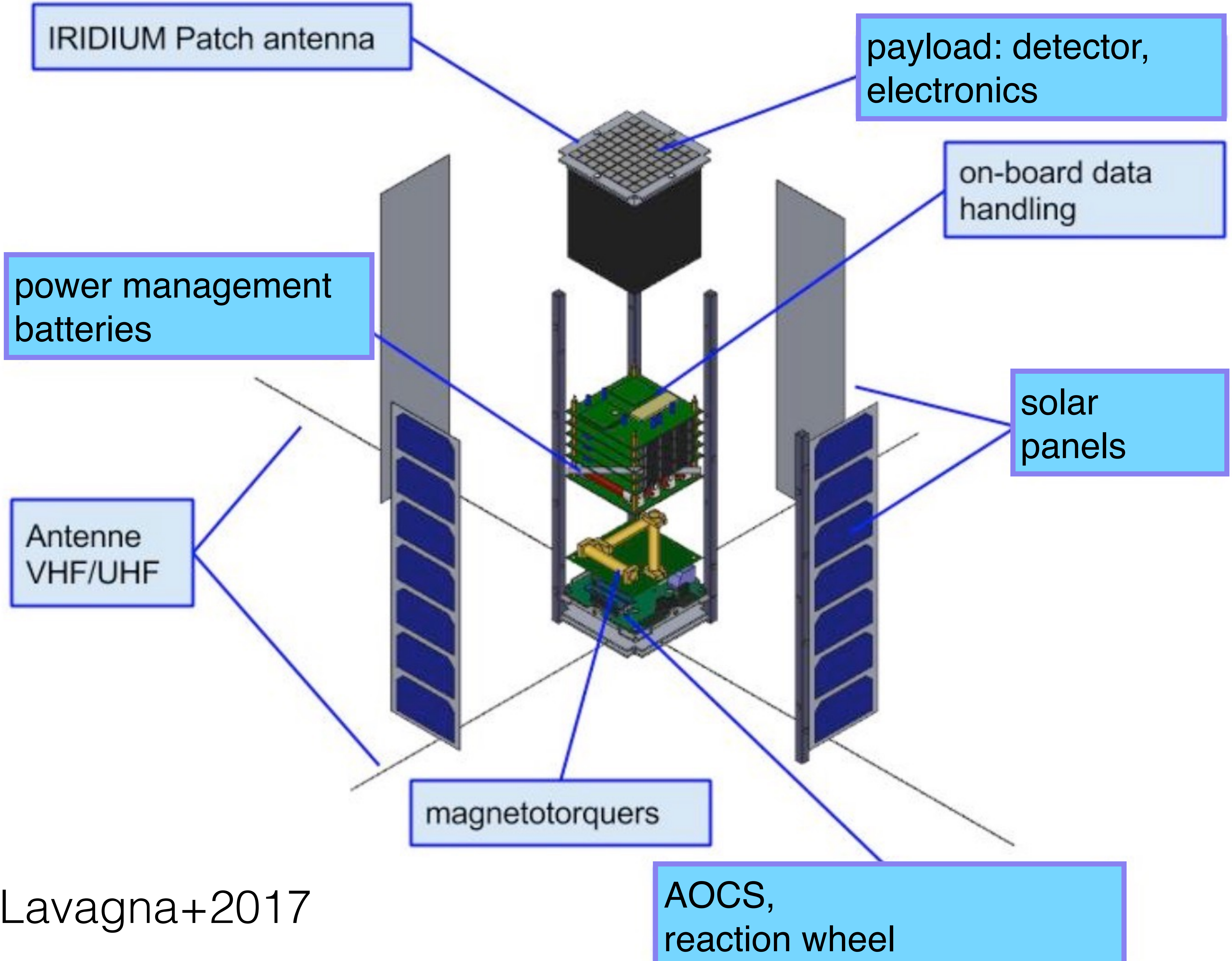
6U more performing configuration
$\leq 200 cm^2$ detector, more accurate GPS, more accurate AOCS

Spacecraft

3U minimum, simplest basic configuration
$\leq 100 cm^2$ detector

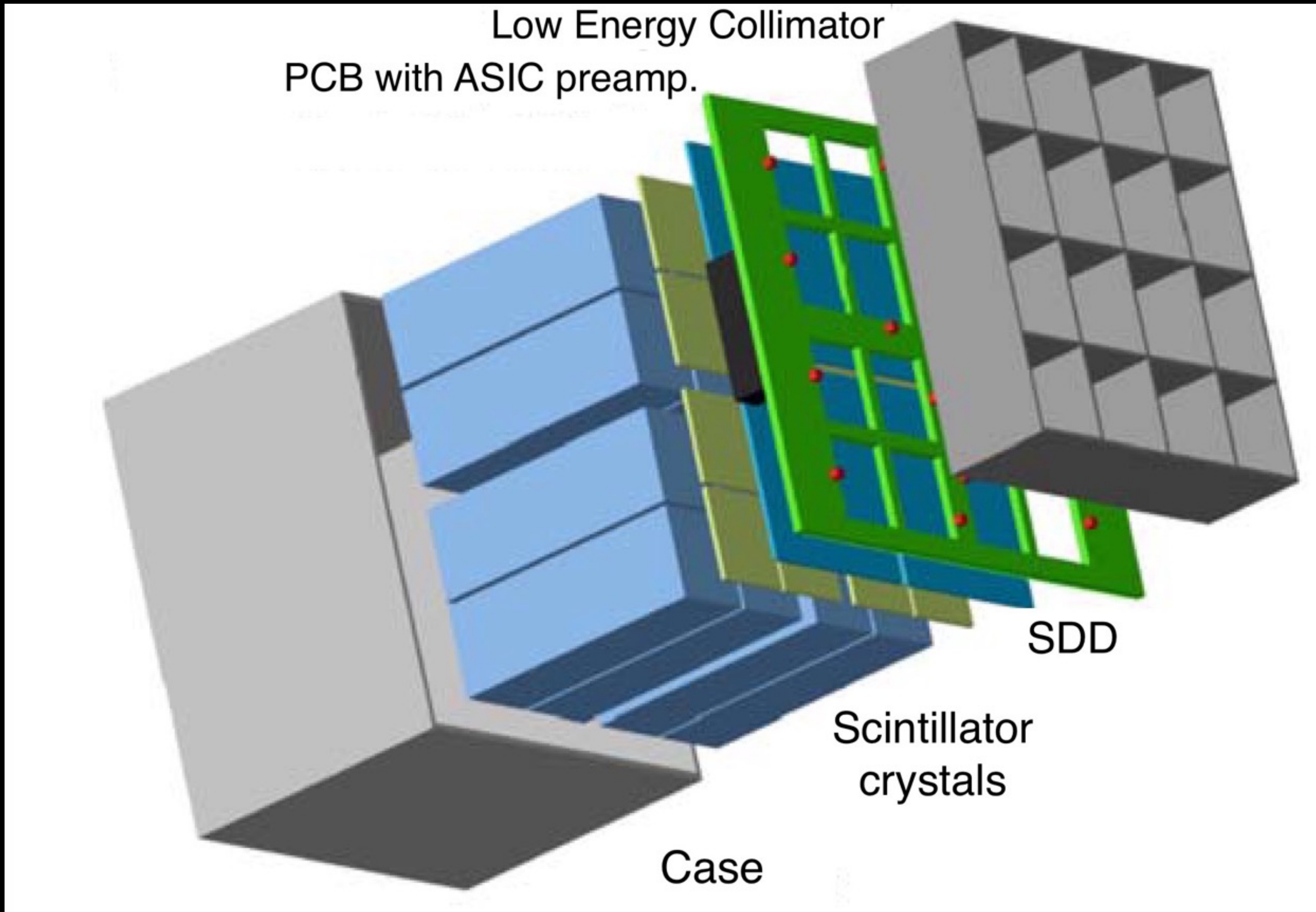
6U more performing configuration
$\leq 200 cm^2$ detector, more accurate GPS, more accurate AOCS

…



Lavagna+2017

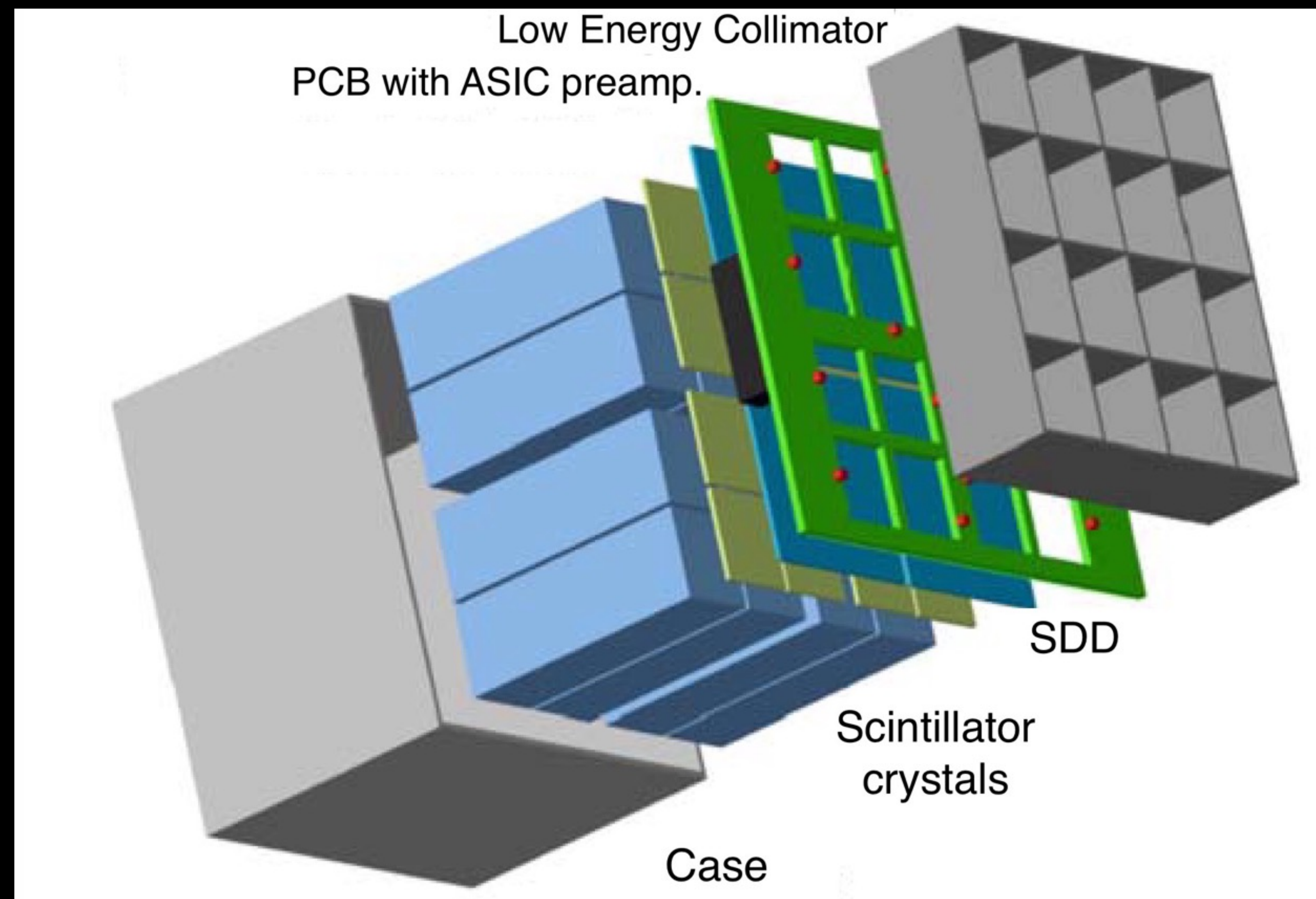
Payload



Labanti+2017

Payload

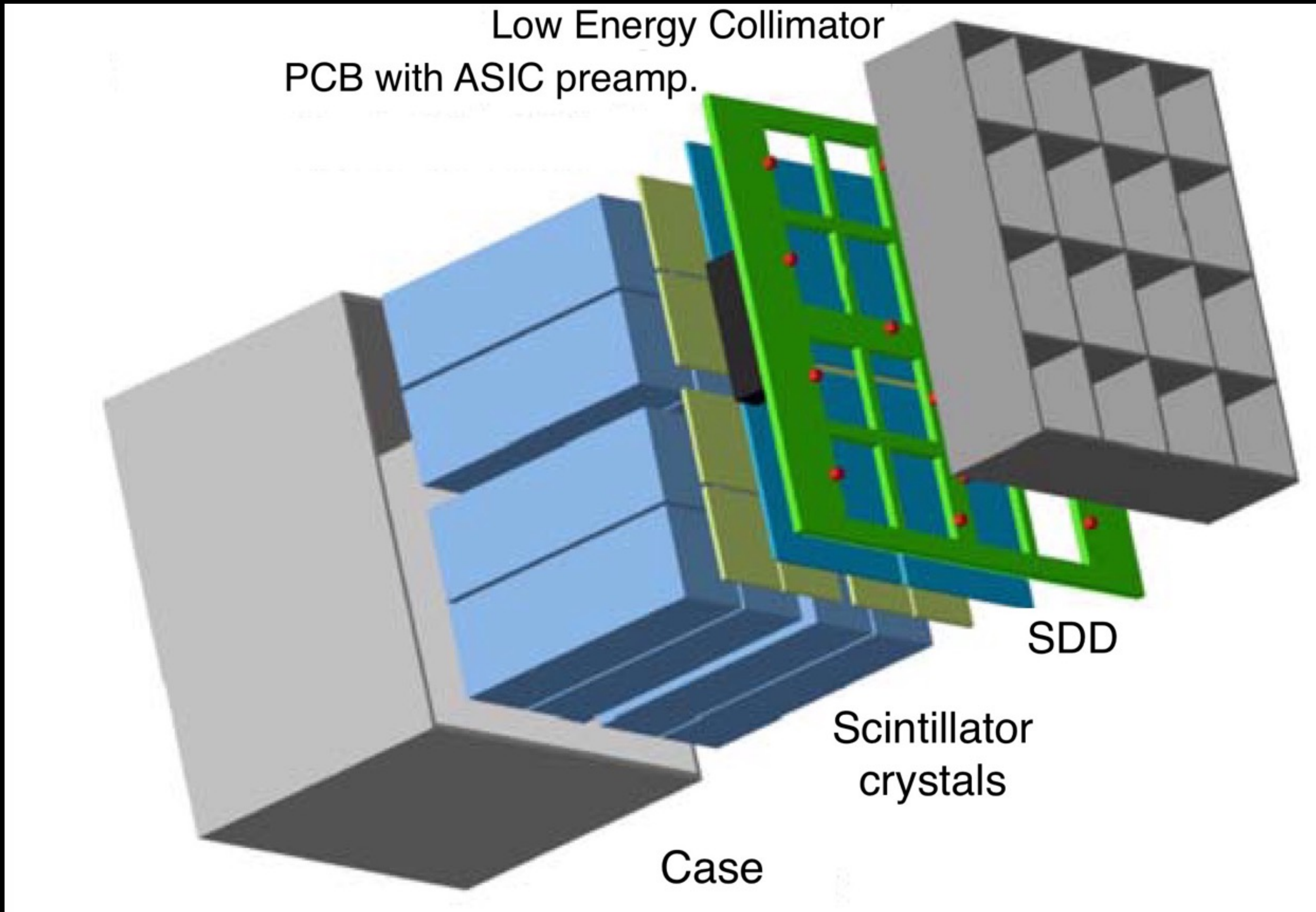
- Scintillator cristal (CsI, GAGG, BGO, etc.) Photo detector, SDD



Labanti+2017

Payload

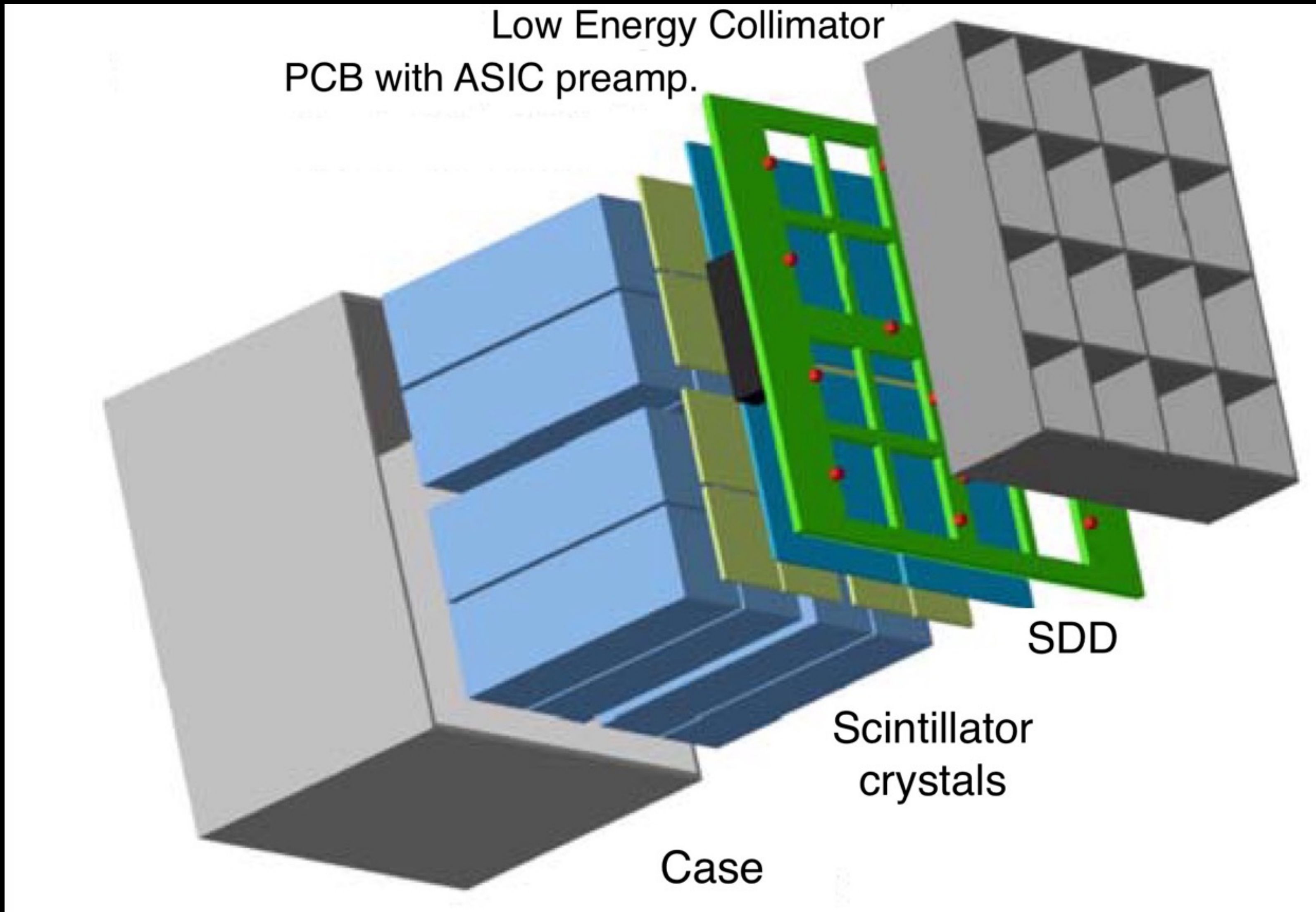
- Scintillator cristal (CsI, GAGG, BGO, etc.) Photo detector, SDD
- 5-300 keV (3-1000 keV)



Labanti+2017

Payload

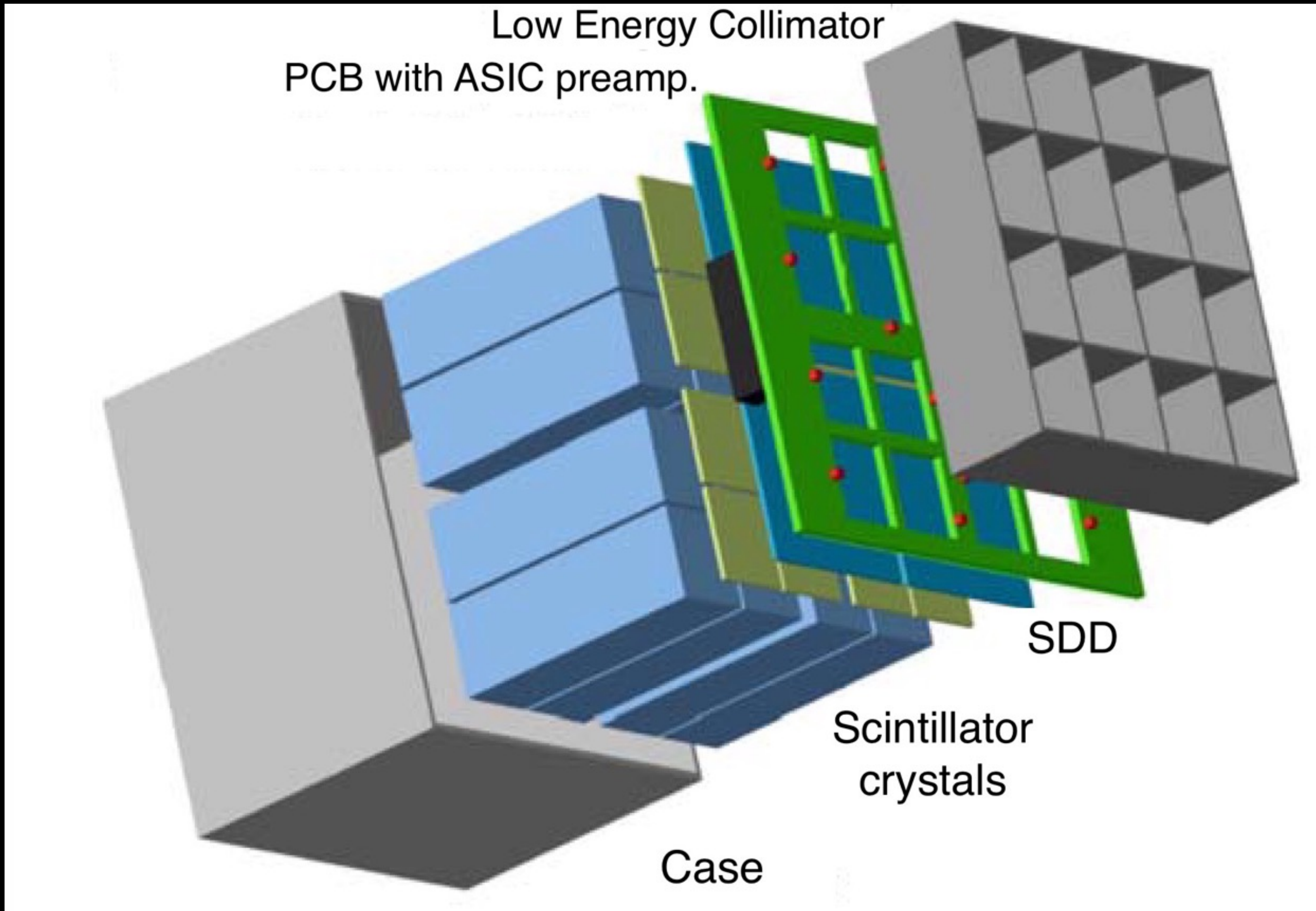
- Scintillator cristal (CsI, GAGG, BGO, etc.) Photo detector, SDD
- 5-300 keV (3-1000 keV)
- ~60 cm^2 coll. area



Labanti+2017

Payload

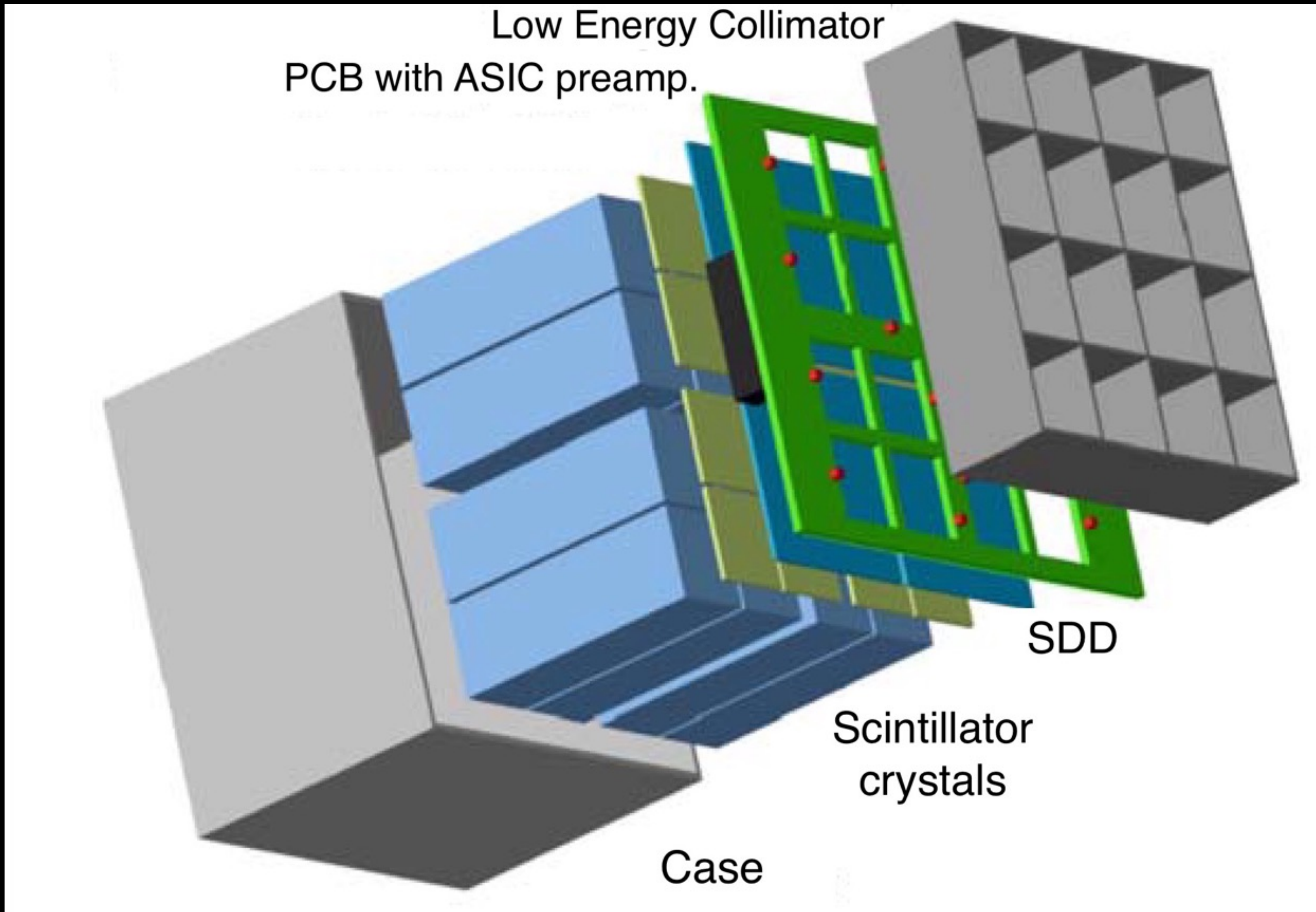
- Scintillator cristal (CsI, GAGG, BGO, etc.) Photo detector, SDD
- 5-300 keV (3-1000 keV)
- ~60 cm^2 coll. area
- a few st FOV



Labanti+2017

Payload

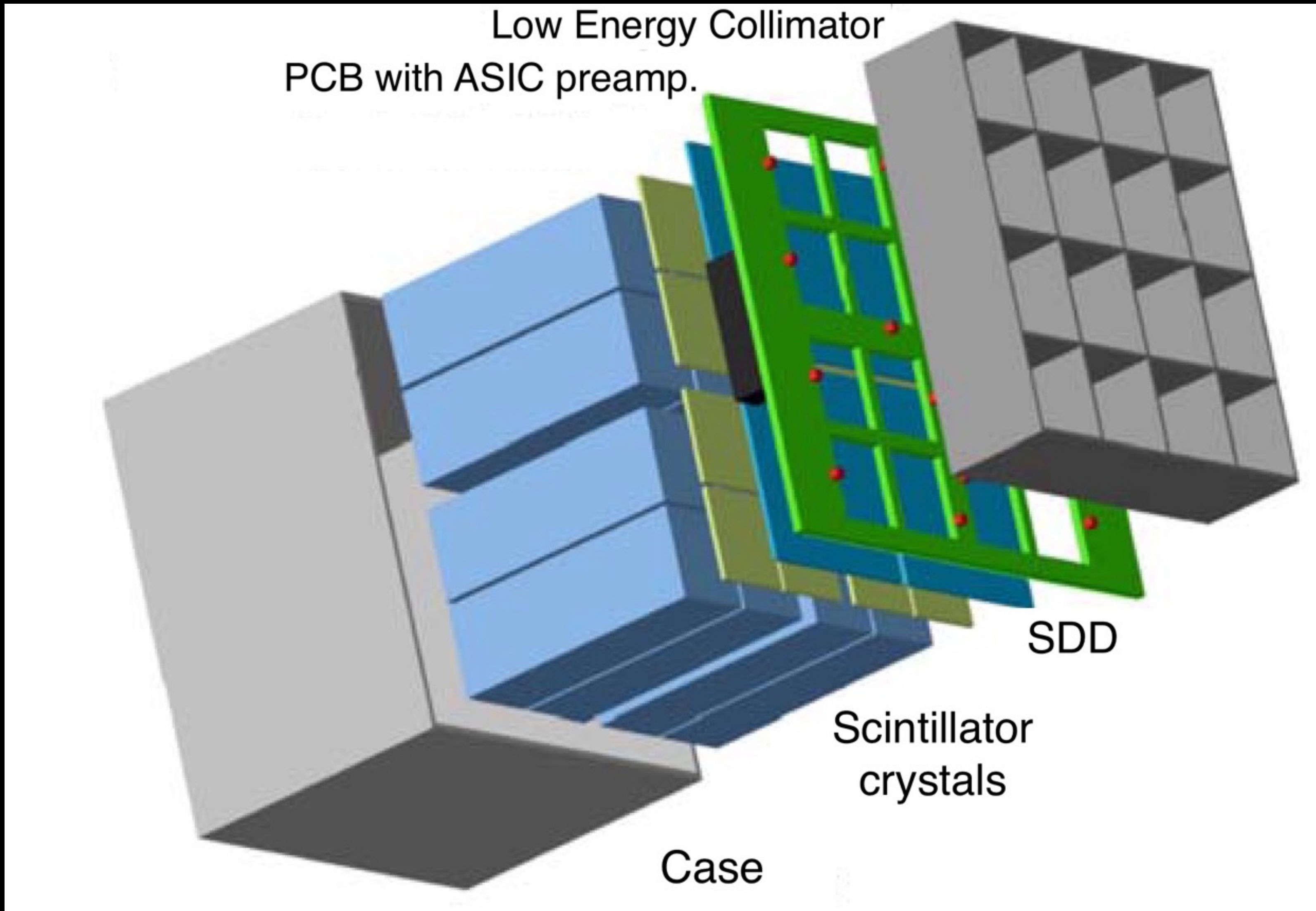
- Scintillator cristal (CsI, GAGG, BGO, etc.) Photo detector, SDD
- 5-300 keV (3-1000 keV)
- ~60 cm^2 coll. area
- a few st FOV
- Temporal res. 10-100 nsec



Labanti+2017

Payload

- Scintillator cristal (CsI, GAGG, BGO, etc.) Photo detector, SDD
- 5-300 keV (3-1000 keV)
- ~60 cm^2 coll. area
- a few st FOV
- Temporal res. 10-100 nsec
- ~1.8kg



Labanti+2017

Why HERMES now

Why HERMES now

Why HERMES now

Breakthrough scientific case:
- EM of GWE

Why HERMES now

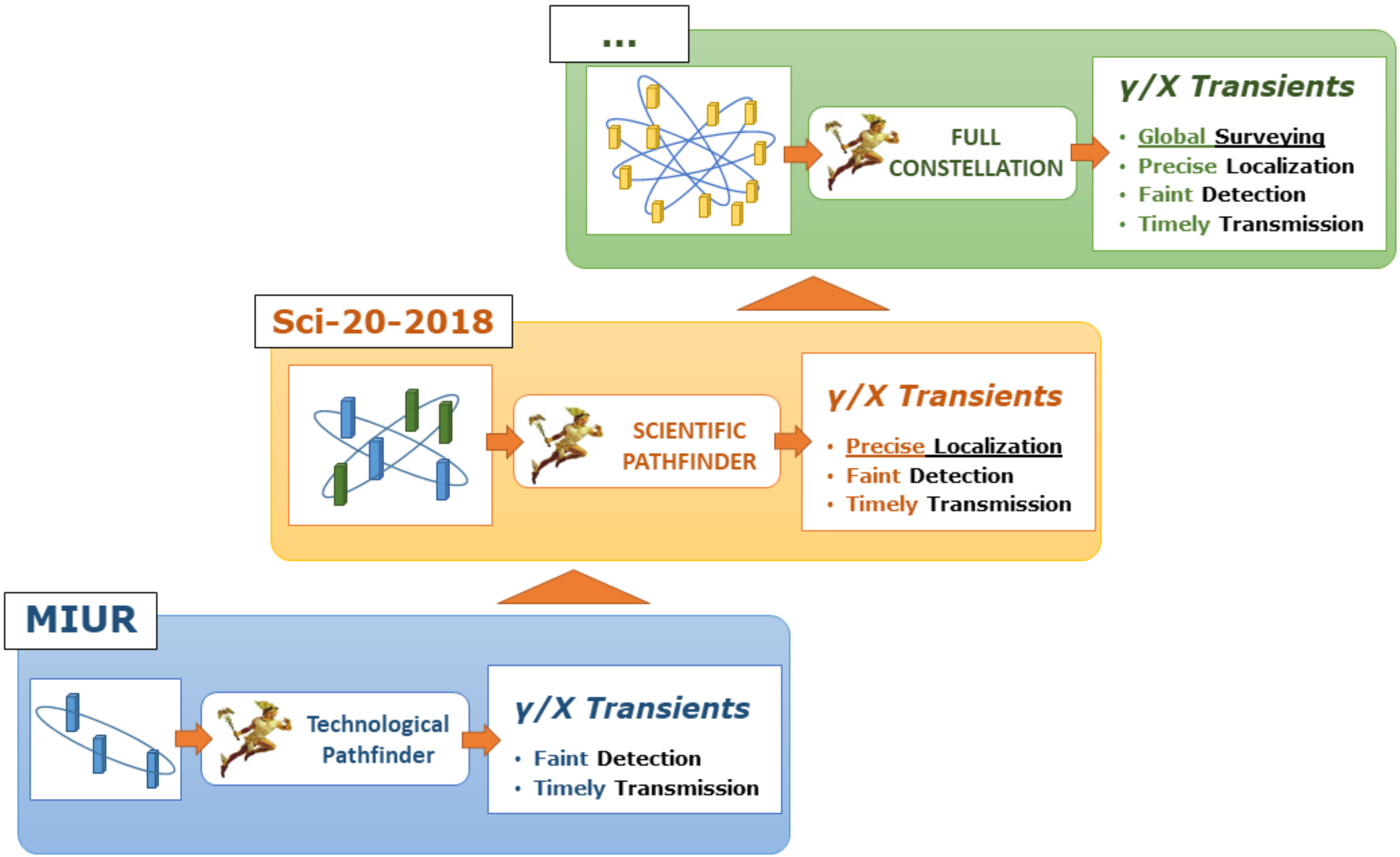
Breakthrough scientific case:

- EM of GWE

Modularity:

- Avoid single point failures, improve hardware
- Pathfinder

Why HERMES now



Why HERMES now

Breakthrough scientific case:

- EM of GWE

Modularity:

- Avoid single point failures, improve hardware
- Pathfinder

Why HERMES now

Breakthrough scientific case:

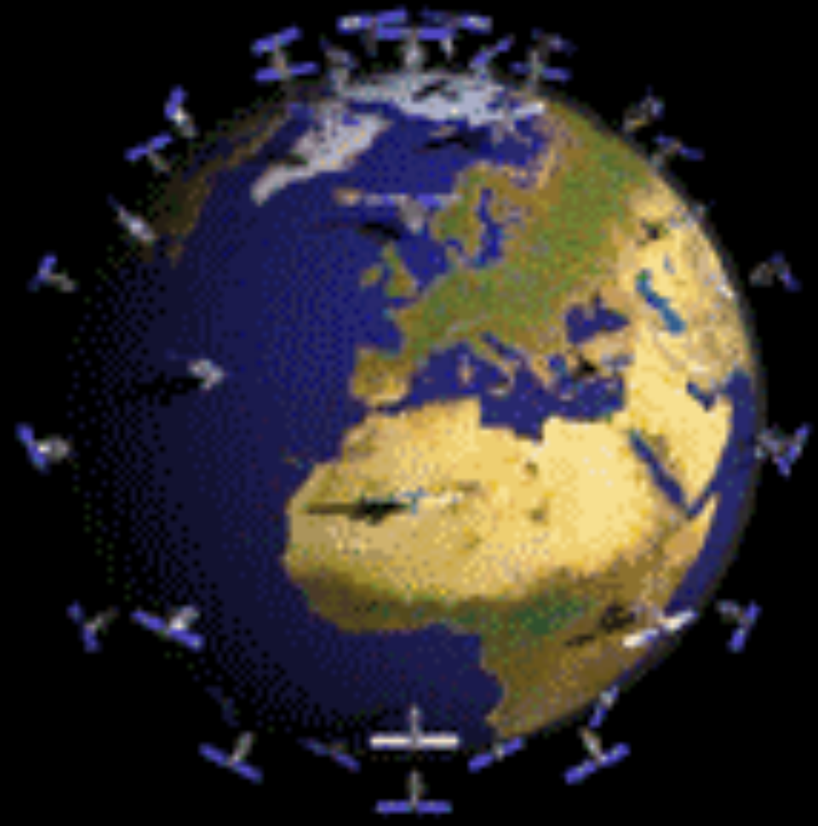
- EM of GWE

Modularity:

- Avoid single point failures, improve hardware
- Pathfinder

Open μsec - msec window:

- Accurate positions
- QG tests



Why HERMES now

Breakthrough scientific case:

- EM of GWE

Modularity:

- Avoid single point failures, improve hardware
- Pathfinder

Open μsec - msec window:

- Accurate positions
- QG tests

Limited cost and quick development

- COTS + in-house components
- Trend in cost reduction of manufacturing and launching QS

Programmatics

Progetto Premiale 2015

- KO May 2018
- PDR T0+9
- CDR+QR T0+15 QM—> PFM1
- AR T0+24 —> PFM2+PFM3
- Launch mid 2020 (VegaC maiden flight or Vega)

QST with Quasars

- In general models have both systematic and non-systematic effects. Some models do not have systematic in-vacuo dispersion but still have “fuzziness” (non-systematic effects).
- Time cannot be measured with uncertainty $< t_{Planck} \sim 5.4\times10^{-44}$ s —> Fuzzy distances
- From fuzzy distances to phase shifts: QST scenarios predict a degradation of the diffraction images of distant sources (GAC+ 1999,2001,2003, Ragazzoni+ 2003, Ng+2003, Steinbring 2007, Tamburini+ 2011)
- The first naïve approach prompted tests using HST observations of distant QSOs: Phase shift of light propagated over long distance

QST with QSOs

Use of diffraction as interferometry effect by a telescope dish of diameter D. An error on the phase of a wave-front translate in an error ΔL on the distance of the light source. This will translate in an apparent angular shift Δθ.

Ragazzoni+2003

Phase shifts cause a drop of the Strehl ratio: image peak/diffration spike of unaberrated telescope

$$S \approx \exp\left[-\left(\Delta\theta \frac{D}{\lambda}\right)^2\right]$$

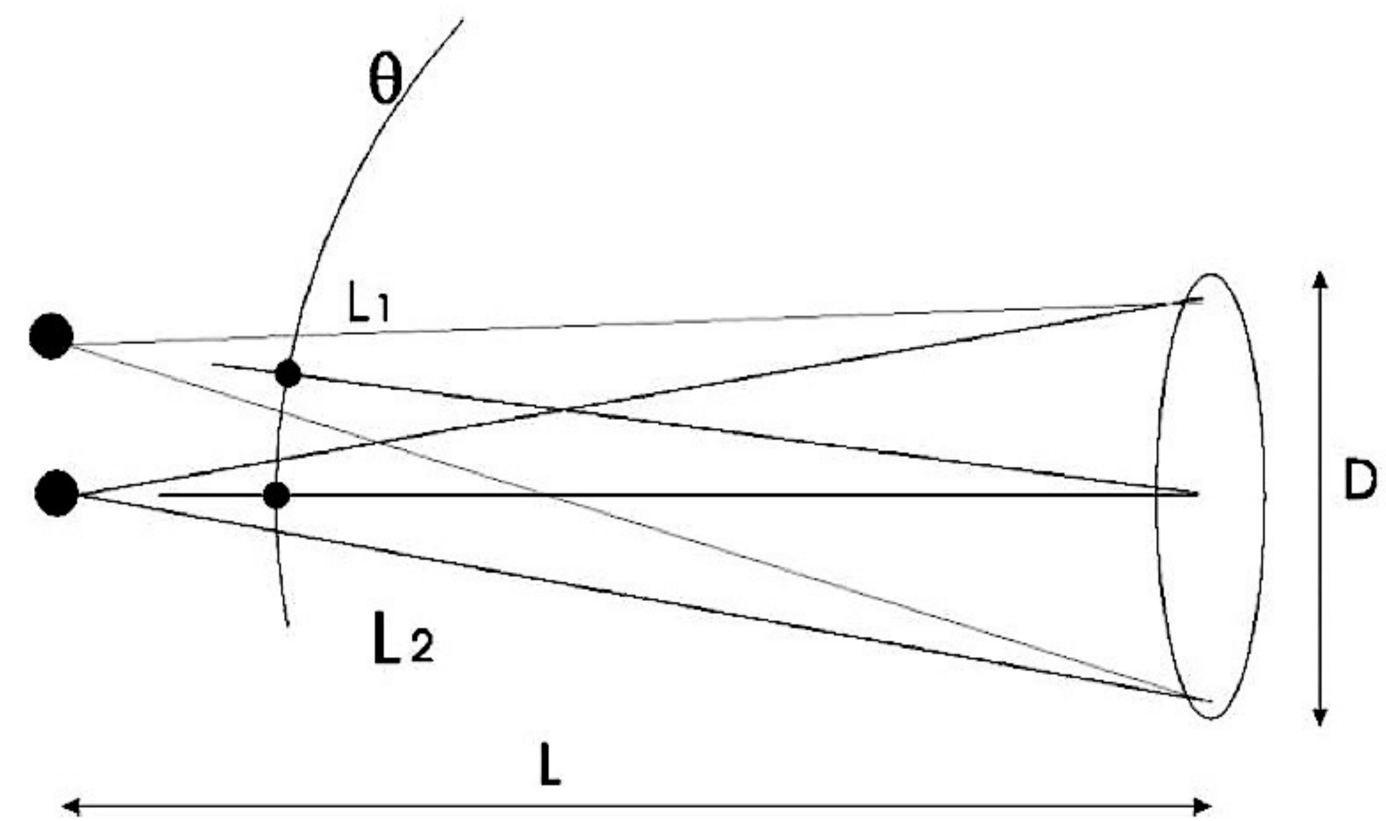
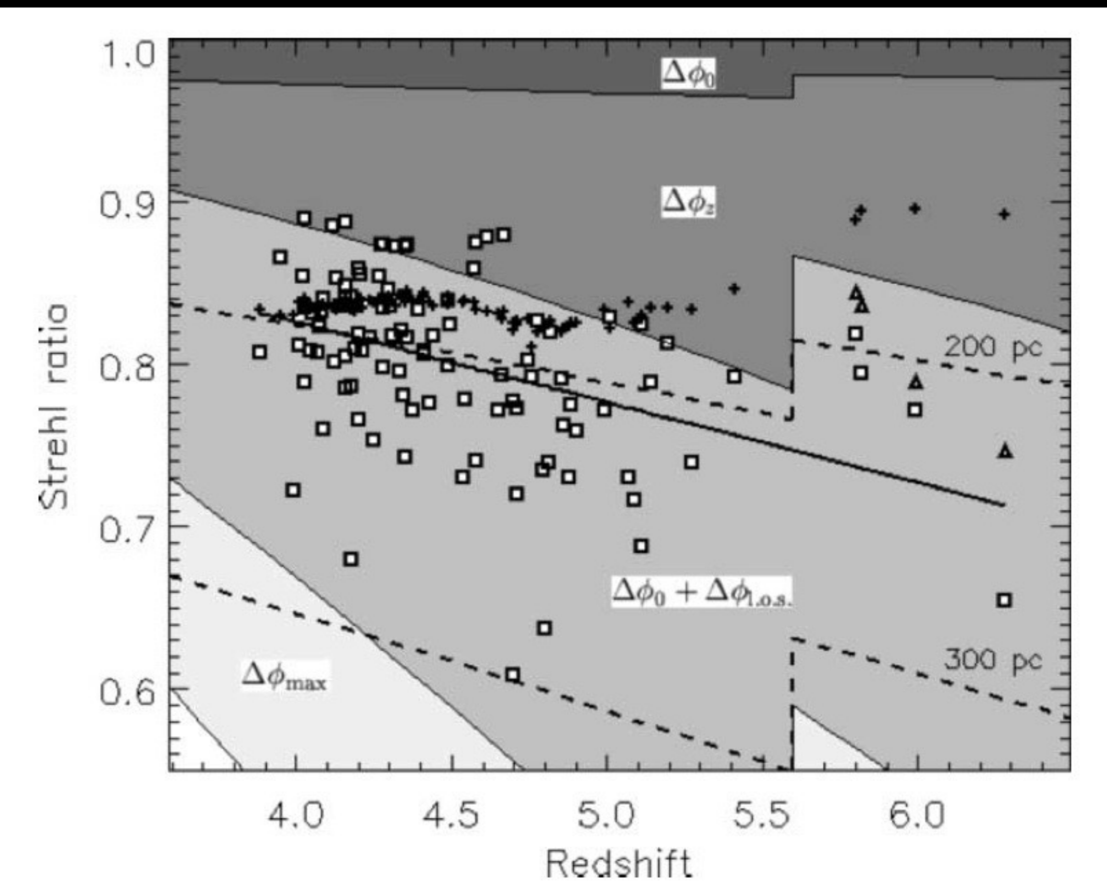
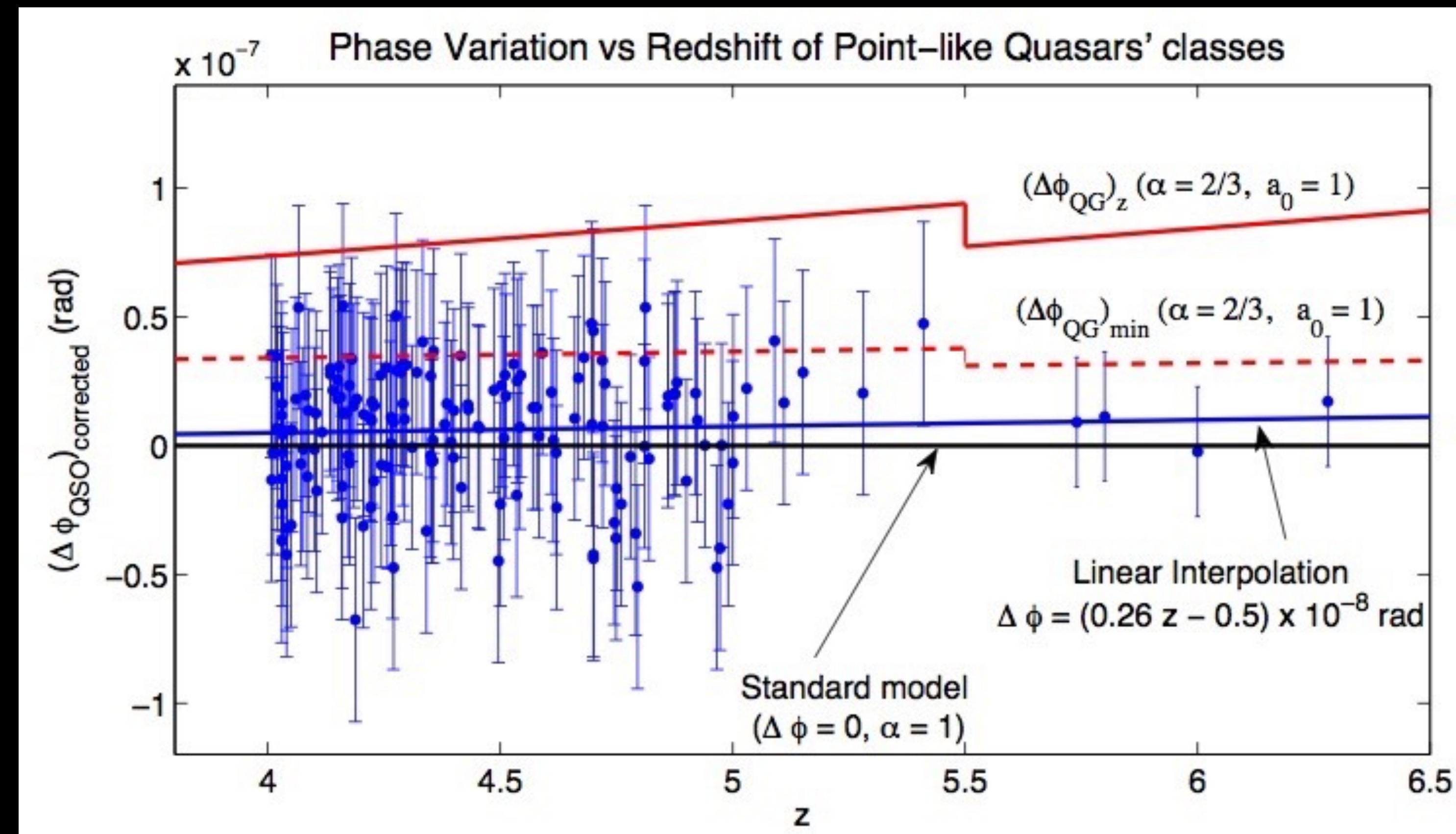


FIG. 1.—Observation of a light source at a distance L from the center of the telescope aperture. The distances between the source and two extremity positions on the aperture are denoted by L_1 and L_2. A variation in L_1 and L_2 will result in an apparent displacement $\Delta\theta$ in the location of the source .

QST with QSOs



Steinbring 2007



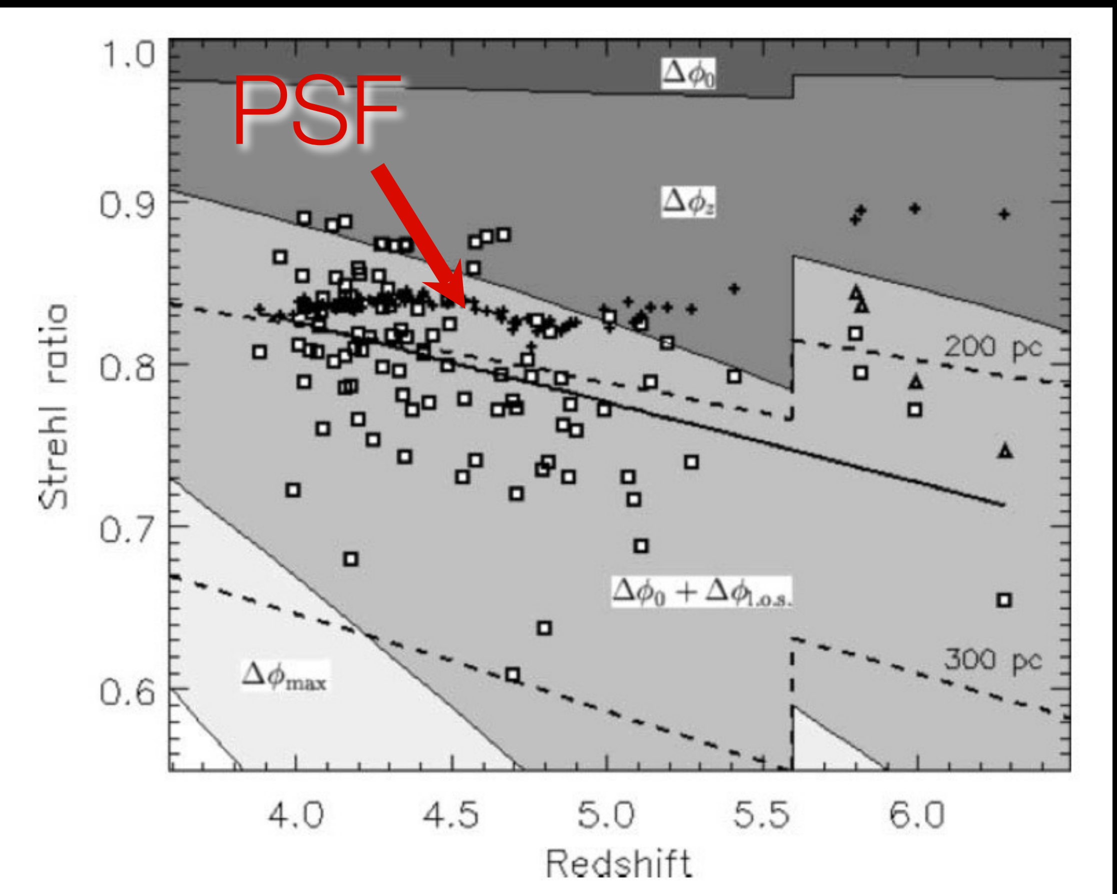
Tamburini+ 2011

$$\Delta\phi \approx \frac{\lambda}{D}\sqrt{-ln(S)} \qquad \Delta\phi = 2\pi a\left(\frac{l_P}{\lambda}\right)^{\alpha}\left(\frac{L}{\lambda}\right)^{1-\alpha} = 2\pi a\,\frac{l_P^{\alpha}L^{1-\alpha}}{\lambda}$$

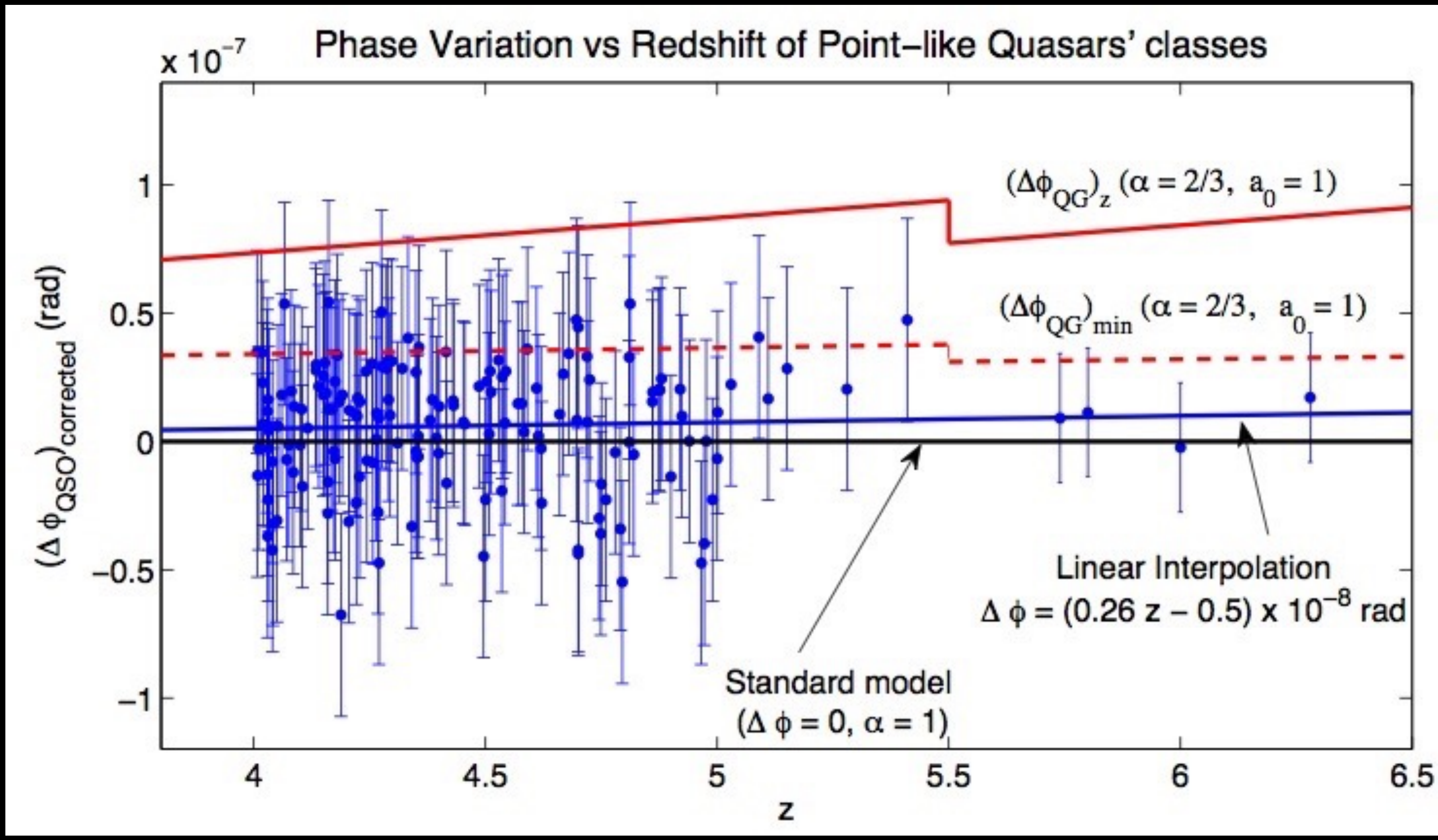
Ng+2003

$$\Delta\phi(z)_{QSO} = \Delta\phi_{ab} + \Delta\phi(z)_{size} + \Delta\phi(z)_{QG} + \Delta\phi(z)_{lens}$$

QST with QSOs



Steinbring 2007



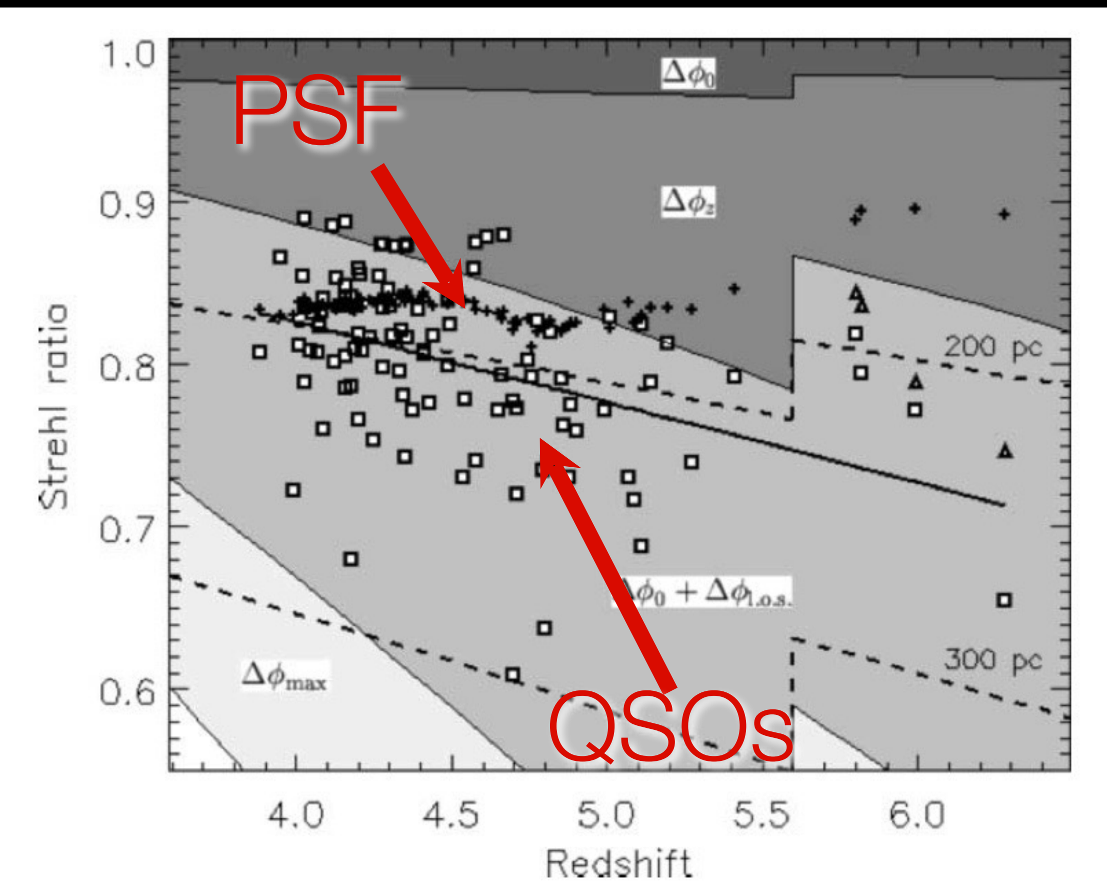
Tamburini+ 2011

$$\Delta\phi \approx \frac{\lambda}{D}\sqrt{-ln(S)} \qquad \Delta\phi = 2\pi a\left(\frac{l_P}{\lambda}\right)^{\alpha}\left(\frac{L}{\lambda}\right)^{1-\alpha} = 2\pi a\,\frac{l_P^{\alpha}L^{1-\alpha}}{\lambda}$$

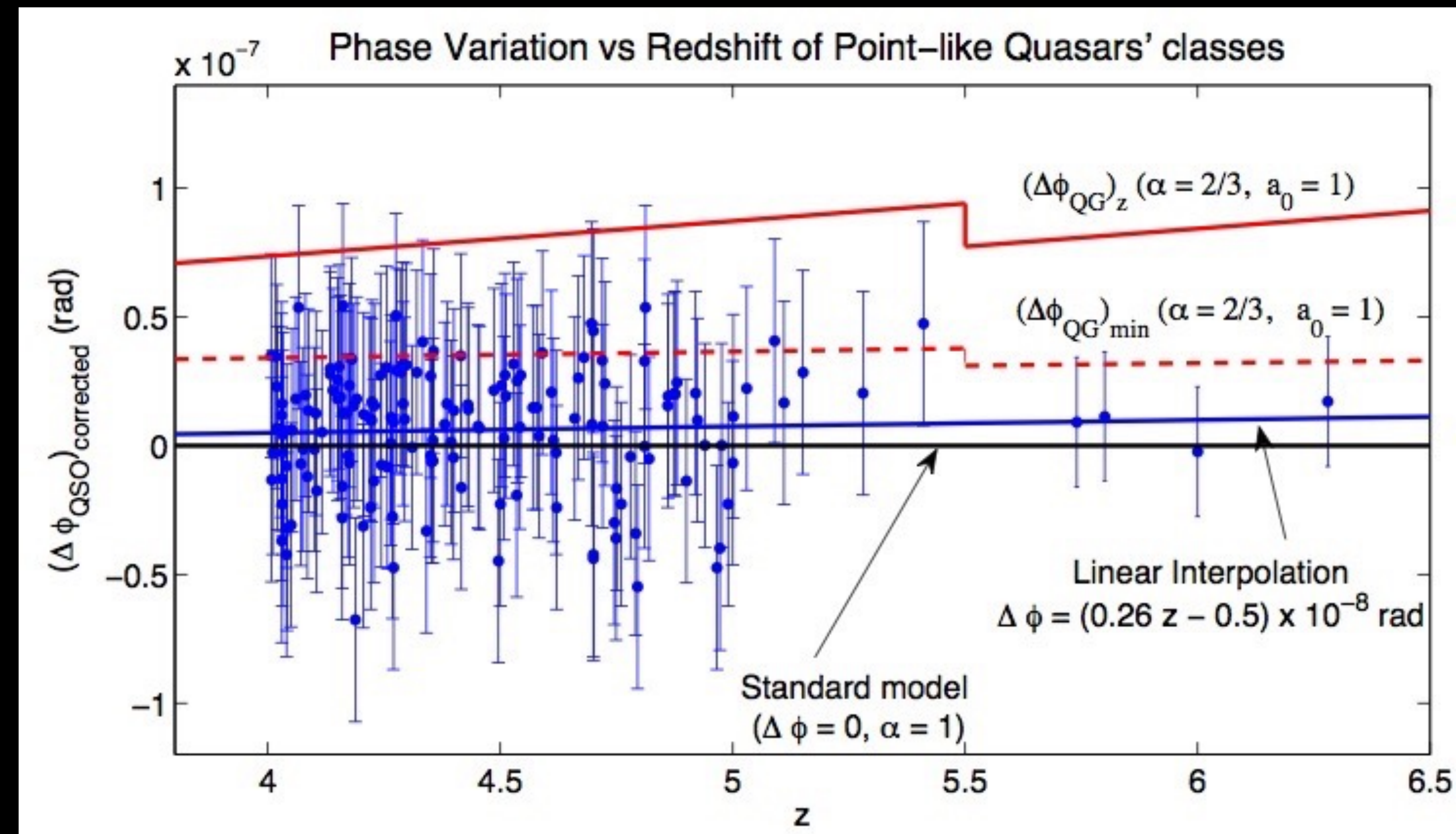
Ng+2003

$$\Delta\phi(z)_{\mathrm{QSO}} = \Delta\phi_{\mathrm{ab}} + \Delta\phi(z)_{\mathrm{size}} + \Delta\phi(z)_{\mathrm{QG}} + \Delta\phi(z)_{\mathrm{lens}}$$

QST with QSOs



Steinbring 2007



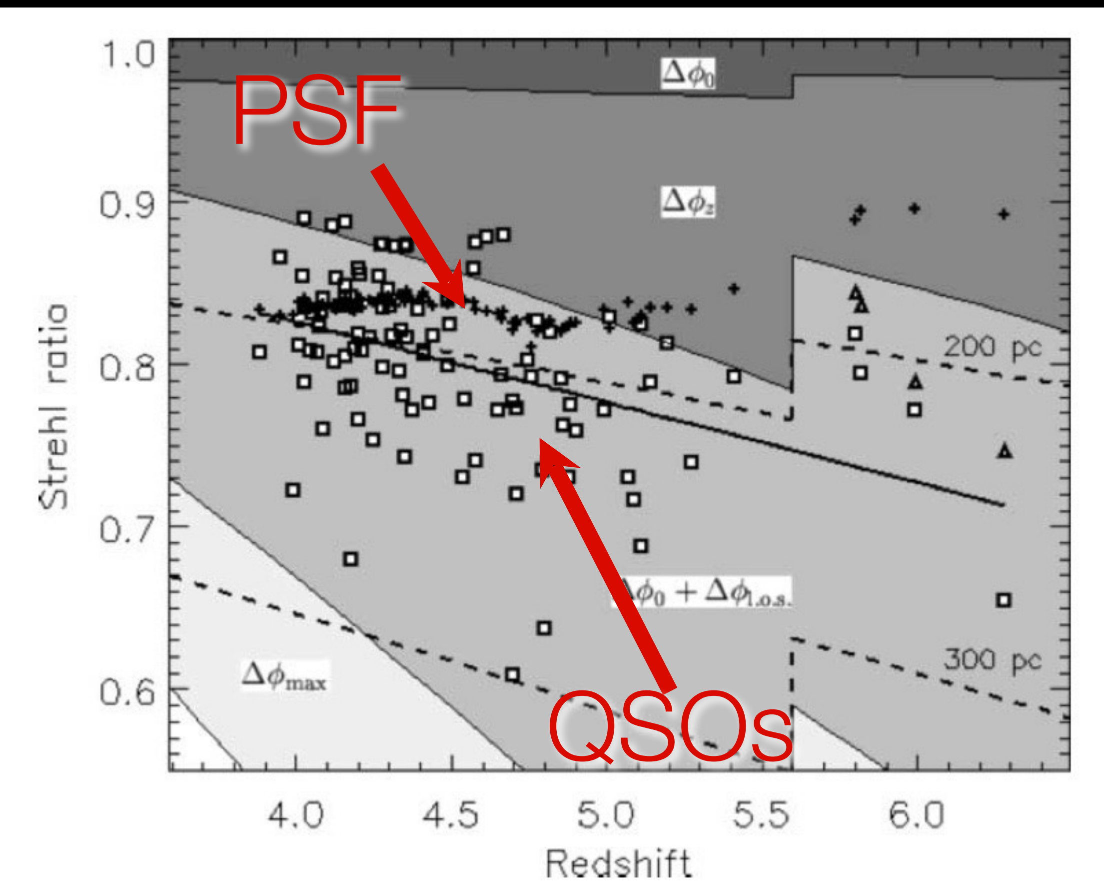
Tamburini+ 2011

$$\Delta\phi \approx \frac{\lambda}{D}\sqrt{-ln(S)} \qquad \Delta\phi = 2\pi a\left(\frac{l_P}{\lambda}\right)^{\alpha}\left(\frac{L}{\lambda}\right)^{1-\alpha} = 2\pi a\,\frac{l_P^{\alpha}L^{1-\alpha}}{\lambda}$$

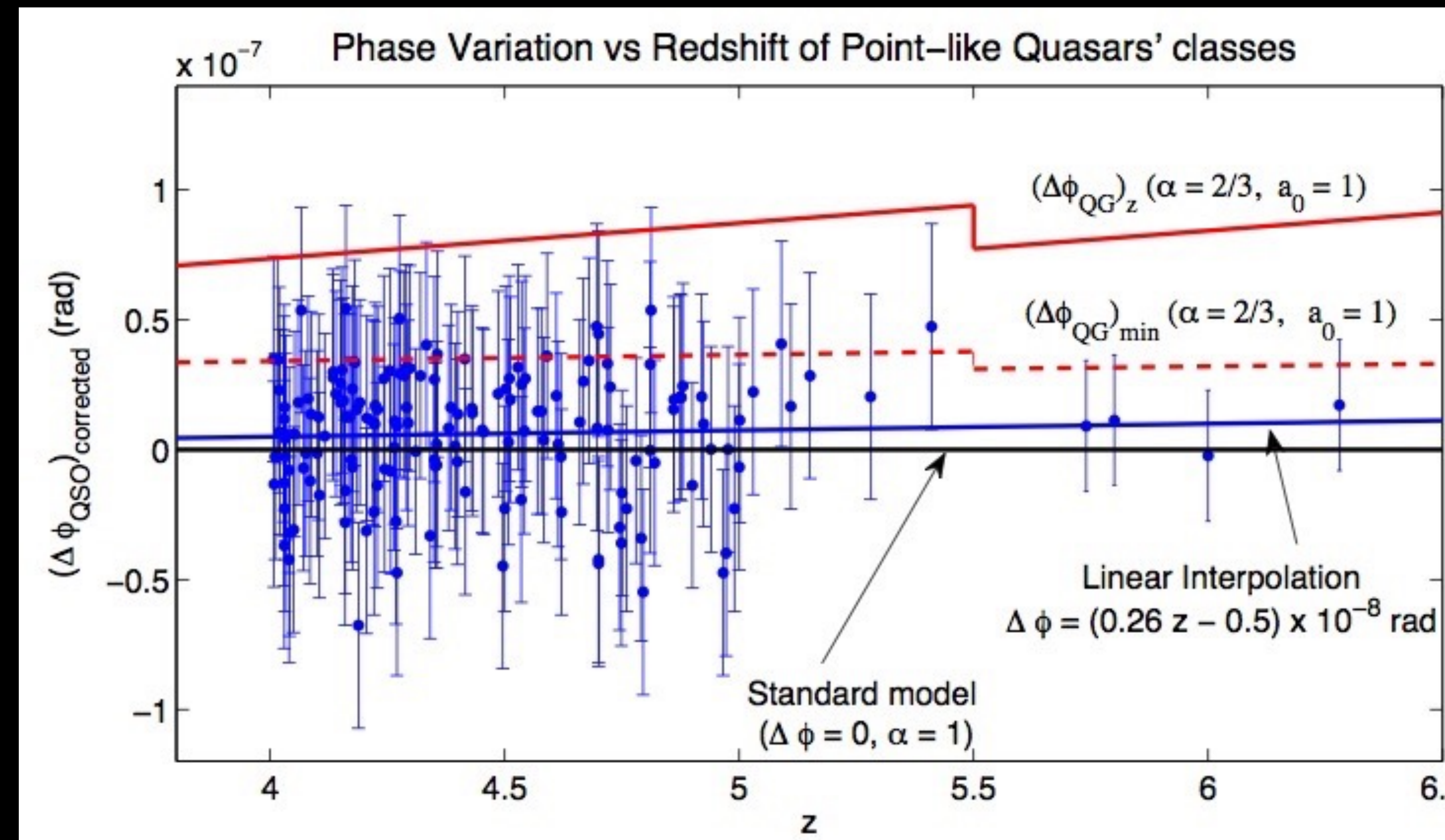
Ng+2003

$$\Delta\phi(z)_{\rm QSO} = \Delta\phi_{\rm ab} + \Delta\phi(z)_{\rm size} + \Delta\phi(z)_{\rm QG} + \Delta\phi(z)_{\rm lens}$$

QST with QSOs



Steinbring 2007



Tamburini+ 2011

$$\Delta\phi \approx \frac{\lambda}{D}\sqrt{-ln(S)} \qquad \Delta\phi = 2\pi a\left(\frac{l_P}{\lambda}\right)^{\alpha}\left(\frac{L}{\lambda}\right)^{1-\alpha} = 2\pi a\frac{l_P^{\alpha}L^{1-\alpha}}{\lambda}$$

Ng+2003

$$\Delta\phi(z)_{\rm QSO} = \Delta\phi_{\rm ab} + \Delta\phi(z)_{\rm size} + \Delta\phi(z)_{\rm QG} + \Delta\phi(z)_{\rm lens}$$

QST with Quasars

$\Delta\phi(\lambda,D,S)=\lambda/\Delta\sqrt{}\ln(S)$

QST with Quasars

$$\Delta\phi(\lambda, D, S) = \lambda / \Delta\sqrt{\ln(S)}$$

$\Delta\phi(0.75, 2.4, 0.83) = 1.5 \cdot 10^{-7}$ rad (HST I band)

QST with Quasars

$$\Delta\phi(\lambda, D, S) = \lambda / \Delta\sqrt{\ln(S)}$$

$\Delta\phi(0.75, 2.4, 0.83) = 1.5 \cdot 10^{-7}$rad (HST I band)

$\Delta\phi(2.2, 8.2, 0.6) = 1.9 \cdot 10^{-7}$rad (LBT K) present observations

$\Delta\phi(1.2, 8.2, 0.5) = 1.2 \cdot 10^{-7}$rad (LBT J) feasible right now

QST with Quasars

$$\Delta\phi(\lambda,D,S)=\lambda/\Delta\sqrt{\ln(S)}$$

$\Delta\phi(0.75,2.4,0.83)=1.5\cdot10^{-7}$rad (HST I band)

$\Delta\phi(2.2,8.2,0.6)=1.9\cdot10^{-7}$rad (LBT K) present observations

$\Delta\phi(1.2,8.2,0.5)=1.2\cdot10^{-7}$rad (LBT J) feasible right now

$\Delta\phi(0.75,8.2,0.4)=8\cdot10^{-8}$ rad LBT SHARK and forerunner, I band, 2014-2020

QST with Quasars

$$\Delta\phi(\lambda,D,S)=\lambda/\Delta\sqrt{\ln(S)}$$

$\Delta\phi(0.75,2.4,0.83)=1.5\cdot10^{-7}$rad (HST I band)

$\Delta\phi(2.2,8.2,0.6)=1.9\cdot10^{-7}$rad (LBT K) present observations

$\Delta\phi(1.2,8.2,0.5)=1.2\cdot10^{-7}$rad (LBT J) feasible right now

$\Delta\phi(0.75,8.2,0.4)=8\cdot10^{-8}$ rad LBT SHARK and forerunner, I band, 2014-2020

$\Delta\phi(0.75,23,0.4)=3\cdot10^{-8}$ rad LIVE, LBT Interferometer visible extension, I band, >2020)

QST with Quasars

$$\Delta\phi(\lambda,D,S)=\lambda/\Delta\sqrt{\ln(S)}$$

$\Delta\phi(0.75,2.4,0.83)=1.5\cdot10^{-7}$rad (HST I band)

$\Delta\phi(2.2,8.2,0.6)=1.9\cdot10^{-7}$rad (LBT K) present observations

$\Delta\phi(1.2,8.2,0.5)=1.2\cdot10^{-7}$rad (LBT J) feasible right now

$\Delta\phi(0.75,8.2,0.4)=8\cdot10^{-8}$ rad LBT SHARK and forerunner, I band, 2014-2020

$\Delta\phi(0.75,23,0.4)=3\cdot10^{-8}$ rad LIVE, LBT Interferometer visible extension, I band, >2020)

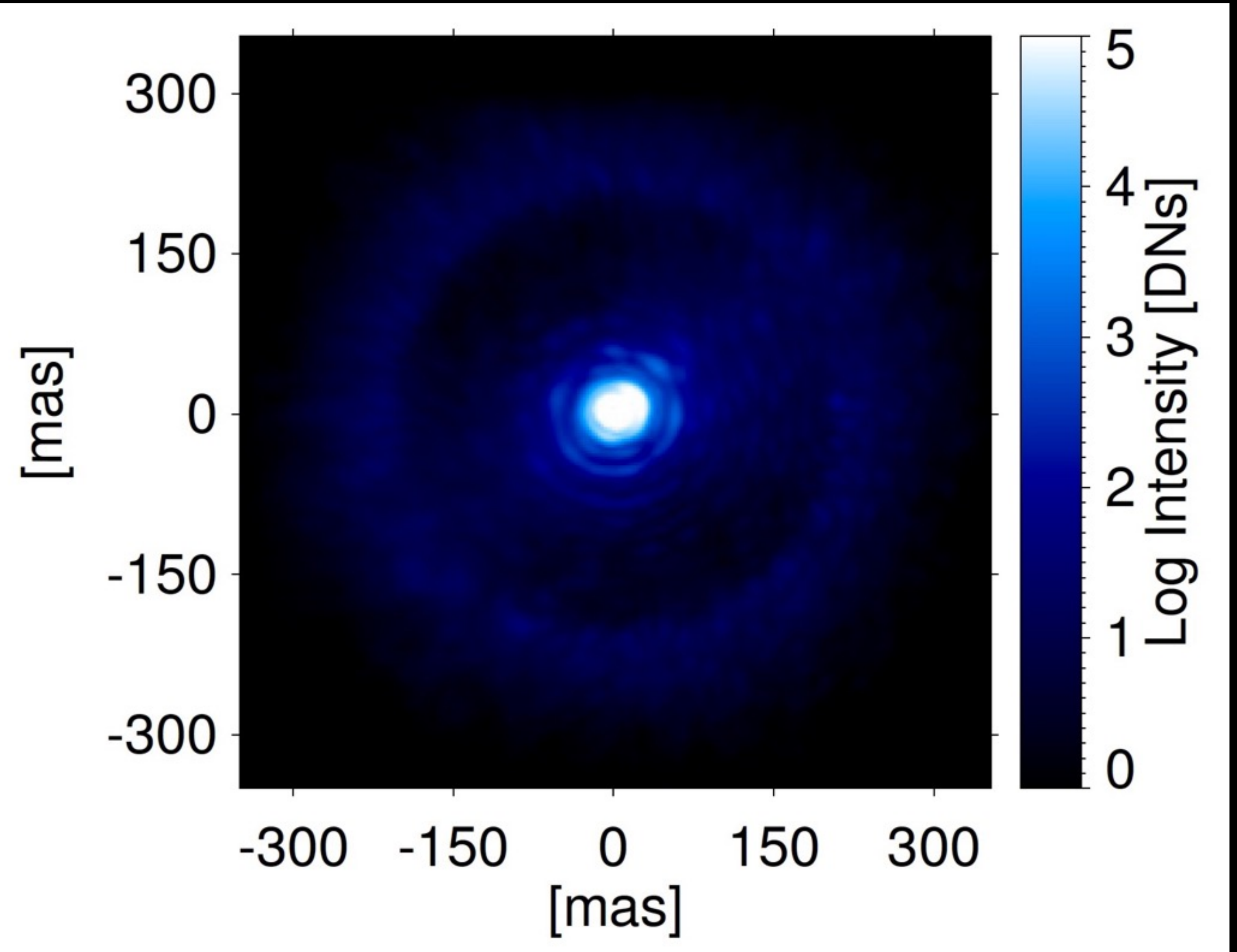
$\Delta\phi(1.2,40,0.7)=3\cdot10^{-8}$ rad E-ELT Y/J, Mikado, ~2025)

Why LBT?

- The best adaptive optic system so far on 8m class telescope!
- Extremely good Strehl ratio at NIR wavelengths (>0.9)
- Good Strehl ratio at optical wavelength (0.4-0.5)
- Binocular telescope, 23m baseline.

Why LBT?

SHARK-Forerunner, I band
PSF~17mas
Pedichini+2017



- The best adaptive optic system so far on 8m class telescope!
- Extremely good Strehl ratio at NIR wavelengths (>0.9)
- Good Strehl ratio at optical wavelength (0.4-0.5)
- Binocular telescope, 23m baseline.

Summary

- Start of Quantum Space Time Phenomenology
- GeV observations of GRB
- Multimessenger approach
- Robust approach requires use of full GRB information and analysis of hundreds events
- —> Hard X-ray observations of GRB (CCF)
- Quasars as probes of fuzzy QST

Summary

Not a single model
Many families of models

Summary

Not a single model
Many families of models

Roles of QST phenomenology:

Summary

Not a single model
Many families of models

Roles of QST phenomenology:

1. *Prune* the intricate bunch of branches, freeing the most promising trunks

Summary

Not a single model
Many families of models

Roles of QST phenomenology:

1. *Prune* the intricate bunch of branches, freeing the most promising trunks

2. *Guide* further theoretical developments

Summary

Not a single model
Many families of models

Roles of QST phenomenology:

1. *Prune* the intricate bunch of branches, freeing the most promising trunks
2. *Guide* further theoretical developments

Thanks!