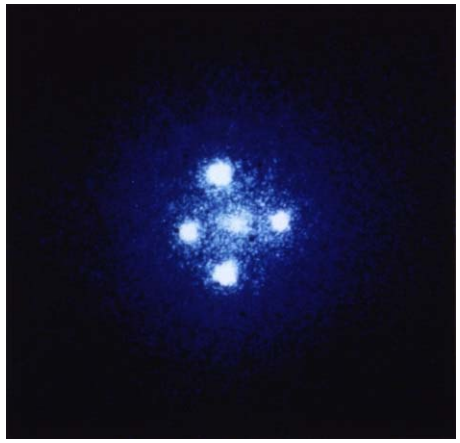
LIGO

Is the Gravitational interaction with Dark Matter the same as with Protonic Matter? Testing the Strong Equivalence Principle in its Darker Corners



Einstein's Cross
Courtesy of NASA, ESA and STScI

Sydney Meshkov[1], Jennifer Siegal-Gaskins[2], Stan Whitcomb[1]

GWADW: Takayama

26 May 2014

[1] LIGO Laboratory/Caltech

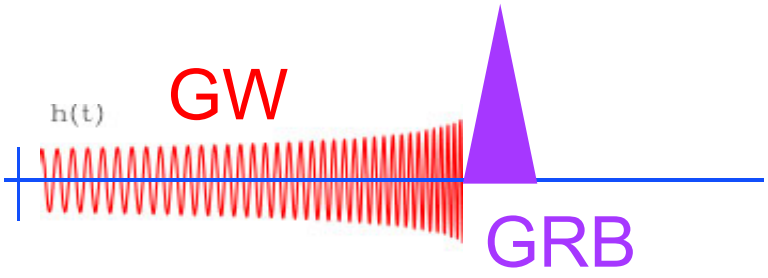
[2] Division of Physics Mathematics and Astronomy, Caltech

LIGO-G1400542-v1

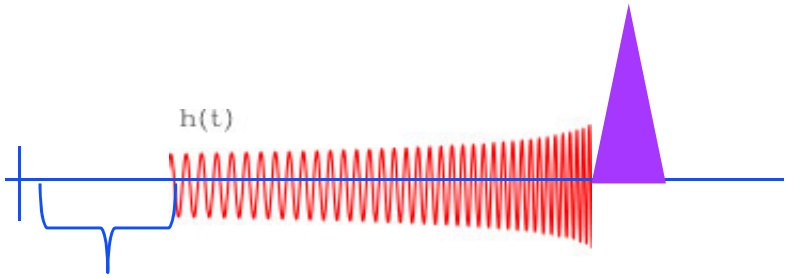
Question: Can GWs Tell us Anything about Gravity from Dark Matter

- Many different types of gravitational interaction with ordinary matter and Dark matter
  - » Different types of ordinary matter with ordinary matter?
    - – Tested via Eötvös experiments with high precision
  - » Different types of ordinary matter with Dark matter?
    - – Tested via Eötvös experiments with moderate precision
  - » Dark matter with Dark matter?
  - » Electromagnetic energy with ordinary matter?
    - – Tested with bending of “starlight” to moderate precision
  - » Electromagnetic energy with Dark matter?
  - » Gravitational wave energy with ordinary matter?
  - » Gravitational wave energy with Dark matter?
- Can be seen as a test of the Equivalence Principle
  - » Many different ways to express EP, but all relate to equality of gravitational interactions

Candidate Test: Use Strong Gravitational Lensing of a Gamma Ray Burst Source



- Two images of the same GRB and associated GW signal
- Same GRB seen at different times due to gravitational interaction with lensing galaxy



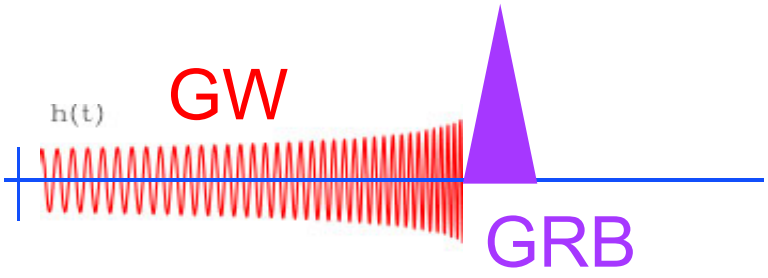
Δt ~ 100 days

Lensing is mainly due to Dark matter halo which contains ~90% of total mass

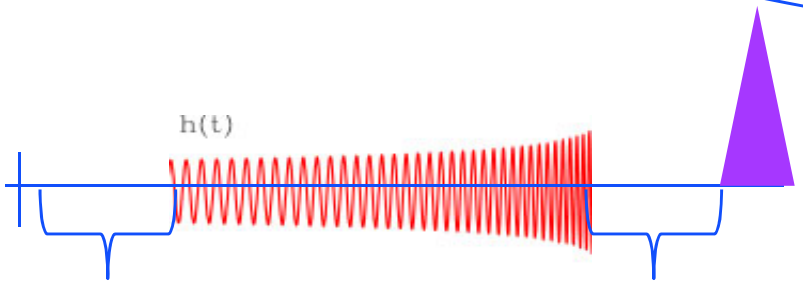
Galaxy Image Credit: NASA and The Hubble Heritage Team (STScI/AURA)

(Assume GRBs are due to NS-NS or NS-BH mergers)

Candidate: Use Strong Gravitational Lensing of a Gamma Ray Burst Source



- If gravitational interaction of Dark matter is different for EM energy and GW energy, then pathlengths for EM and GW will differ



Δt ~ 100 days δt to ~1 s

Tests equality of gravitational interaction to $\delta t/\Delta t \sim 10^{-7}$

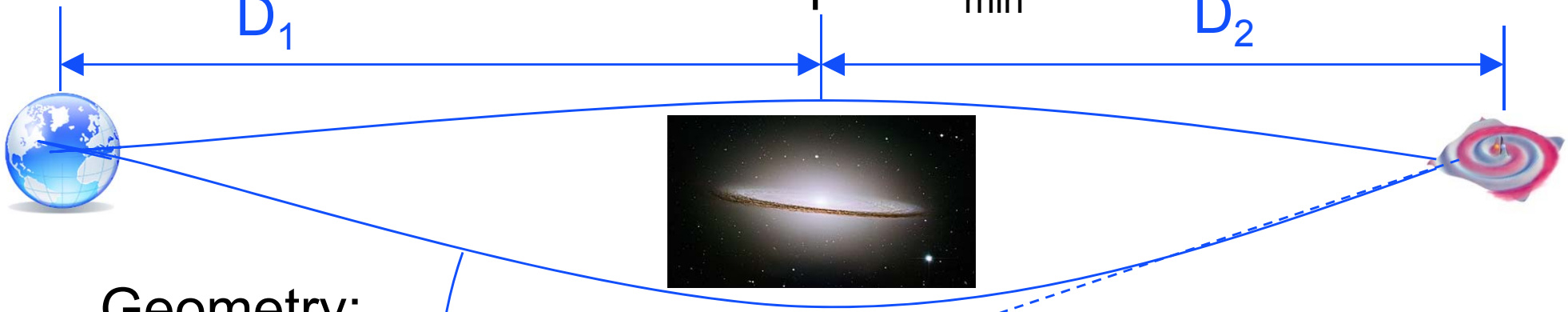
Galaxy Image Credit: NASA and The Hubble Heritage Team (STScI/AURA)

(Assume GRBs are due to NS-NS or NS-BH mergers)

MINIMUM Distance to Source

$M \sim 10^{12}\ M_\odot$

$R \sim 20\ \text{kpc} \sim b_{min}$



Geometry:

$\Delta\varphi \sim b/2D_1$

$\sim b/2D_2$

(assumes galaxy about half-way)

Lensing:

$\Delta\varphi \sim 2R_S/b$

$R_S = 2GM/c^2$

~ 0.1 pc

Solve for $D = D_1 + D_2$:

$D \sim b_{min}^2/2R_S$

~ 2 Gpc

Requires third generation detectors (ET or equivalent)

LIGO

How Realistic is This?

- Must have GW detection capability
  - » ET range for NS-NS ~ 10 Gpc (z~ 1.4)
  - » Sky coverage ~1, likely to catch both instances
  - » Estimated BNS rate 10^3-10^7 per year (confusion issues?)
  - » Must have localization capability to ~few degrees, uncertain
- Must have GRB detection capability
  - » Have to be in beaming angle (10%?)
  - » Range for short GRBs? (need some improvement, now ~1 Gpc)
  - » Localization needed to ~ few degrees
  - » Chance of catching both ~ (sky coverage)^2 ~ 10% (?)
- Must have a lensed GRB
  - » Fraction of lensed quasars (typical z ~1-2), small but not tiny (10^{-3}?)
  - » Possibility of 1-10 lensed events per year in the ET era ?
- Quite likely that ET can do this test