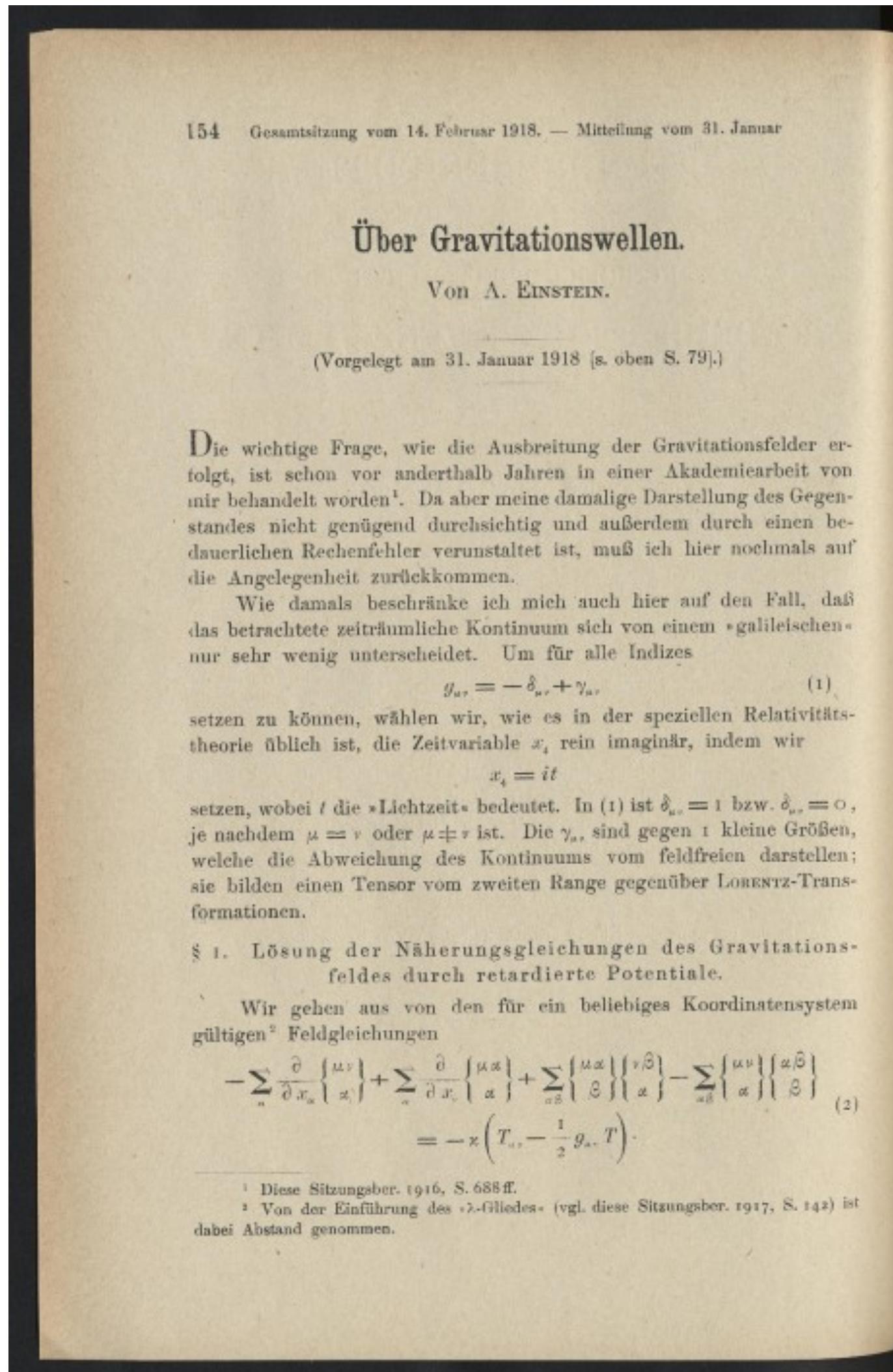
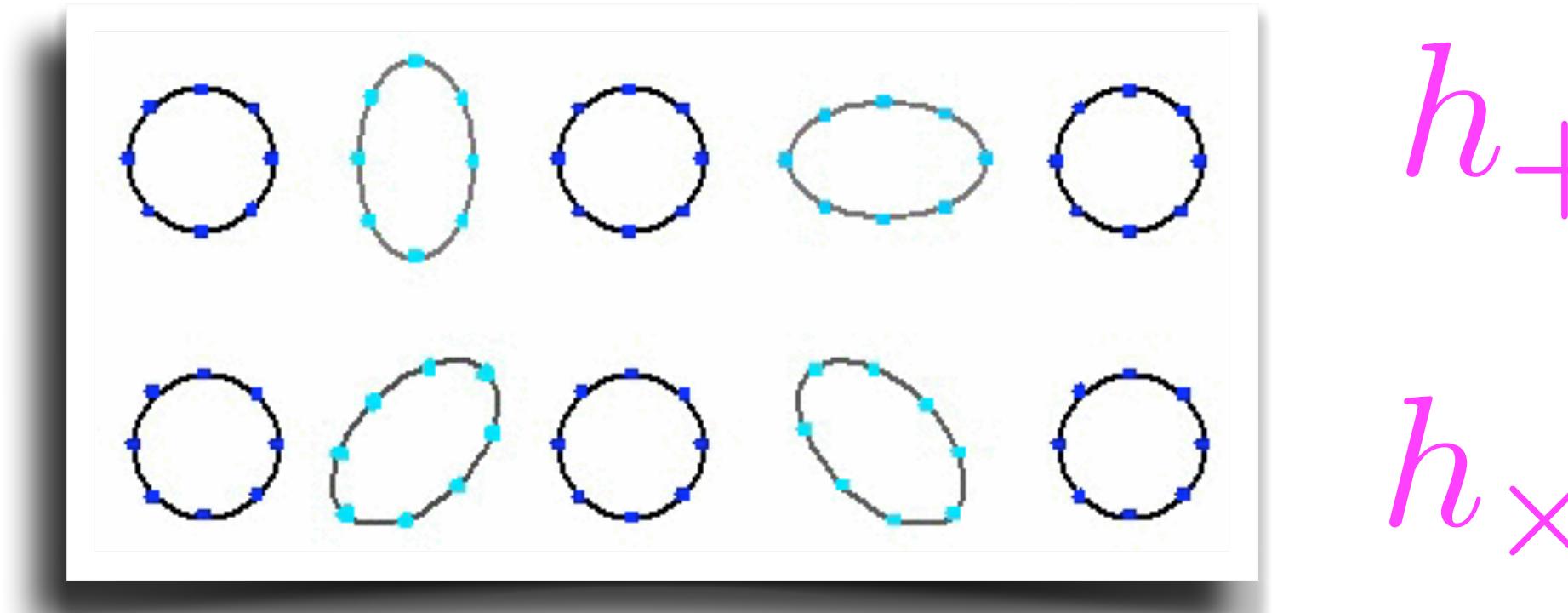


# Gravitational waves - 1918



Transverse and traceless  
 Speed of light  
 Two polarizations  
 Carry energy and momentum  
 “Deform” macroscopical objects



$$\bar{h}_{ij}(t, r) = \frac{2G}{c^4 r} \ddot{I}_{ij}(t - r)$$

$$G = (6.67408 \pm 0.00031) \times 10^{-20} \text{ km}^3 / (\text{kg s}^2)$$

$$c = 299792.458 \text{ km/s}$$

Measurable sources: extreme astrophysical events,  
 black hole or neutron star binaries

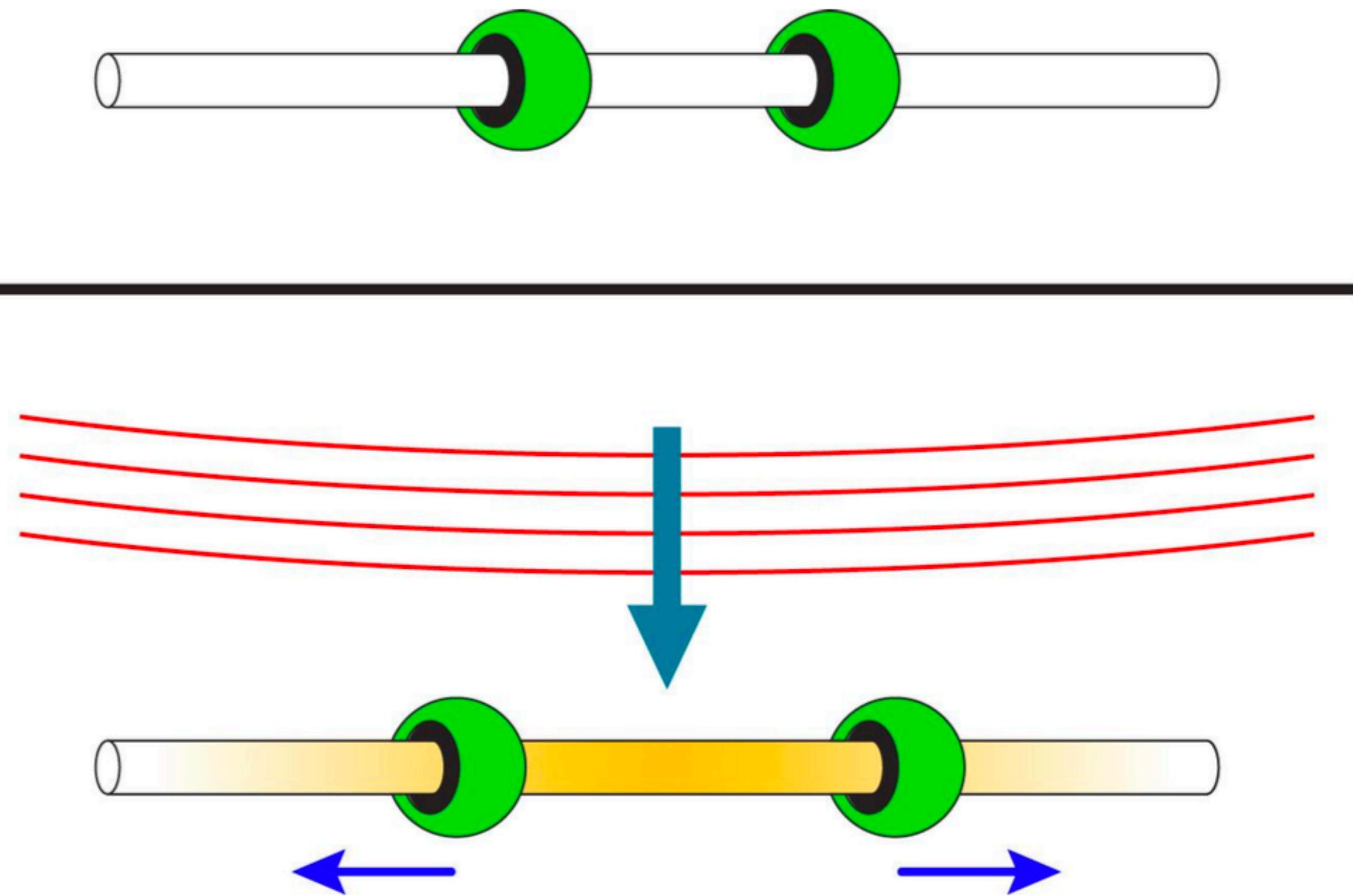
$$\frac{2GM}{c^2 R} \approx 1$$

# Gravitational waves: A theoretical challenge

Major contributions to radiation theory [E.T.Newmann]

1. J. Goldberg, PR 99, 1873-83 (1955)
2. F. Pirani, (1956), Bull. Acad. Polo. Sci., III, 5, p. 143 (Introduced Petrov Classification of Algebra of the Weyl tensor.)
3. R. Sachs, P.G. Bergmann; 1958, Phys. Rev. 112, p. 674 (linear theory, definition of multipoles)
4. A. Trautman, King's College Notes; Lectures on General Relativity, 1958, eventually revised and published in "Lectures on General Relativity" Vol.1, Prentice Hall, 1965 (Sommerfeld radiation conditions applied to GR, very influential set of notes.) and recently republished as a "golden oldie" in the GRG Journal.
5. R. Penrose, Ann. Phys., 1960, 10, p. 171. (Major exposition of Spinor Calculus and GR)
6. R. Sachs, Proc. Roy. Soc., 1961, 264, p. 309 (Introduced optical parameters, shear, divergence, twist, asymptotic structure of curvature tensor)
7. F. Pirani, 1961, King's College Notes; published in "Lectures on General Relativity", Vol.1, Prentice Hall, 1965 (Introduce the Petrov Classification of Weyl tensors)
8. J. Goldberg, R. Sachs, (1962), Acta Physica Polonica, Vol. XII, p12 (The Goldberg-Sachs Theorem; Princ. Null Vectors of Algebraically Special Metrics)
9. H. Bondi, M. van der Burg, A. Metzner, 1962, Proc. Roy. Soc. 269, p.21, (Introduction of null coordinates, asymptotic solutions of Einstein equations, mass loss Theorem, BMS group)
10. R. Sachs, Proc. Roy. Soc., 1962, 270, p. 103 (Generalized Bondi work, elucidated the BMS group)
11. E. Newman, R. Penrose, JMP, 1962, 3, p.566 (systematic use of tetrad calculus and spinor analysis, Goldberg-Sachs Theorem, Peeling)
12. E. Newman and T. Unti, 1962, JMP, 3, p. 892 (Asymptotic Integration of the Einstein Eqs, the BMS group)
13. I. Robinson and A. Trautman, 1962, Proc. Roy. Soc. 265 p.463, (Integrated most of the Einstein Eqs. for twist-free algebraically special metrics)
14. R. Penrose, 1963, Phys.Rev.Ltrs, 10, p. 66, (Introduced Null Infinity and Conformal Compactification of Space-Time)

## Sticky bead argument (Bondi/Feynmann - Chapel Hill)



# GRAVITATIONAL WAVES: PIONEERING THEIR DETECTION

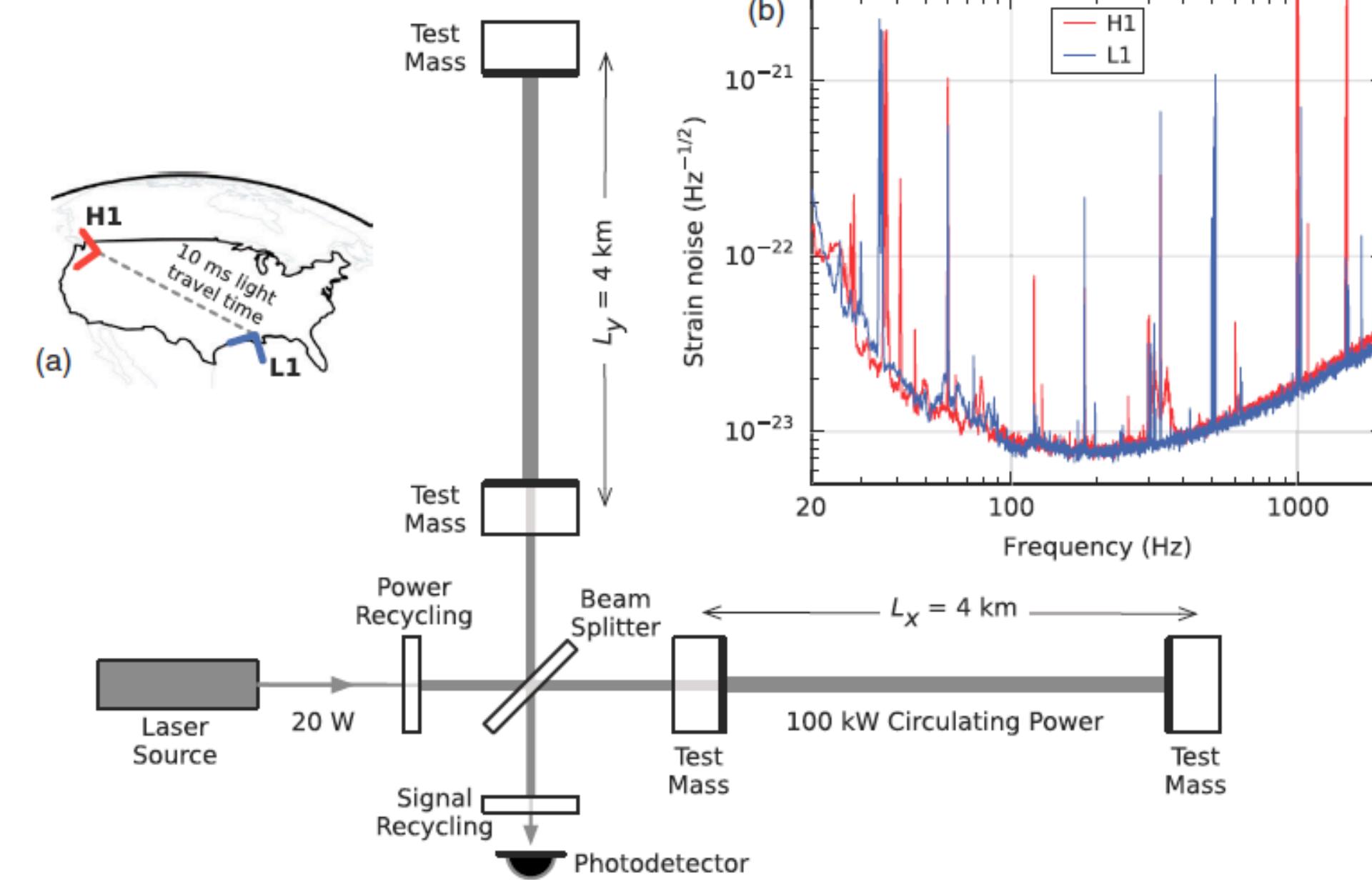
Joseph Weber (1919-2000)

General Relativity and Gravitational Waves  
(Interscience Publishers, NY, 1961)

$$\frac{\delta L}{L} \approx h_{ij} n^i n^j$$

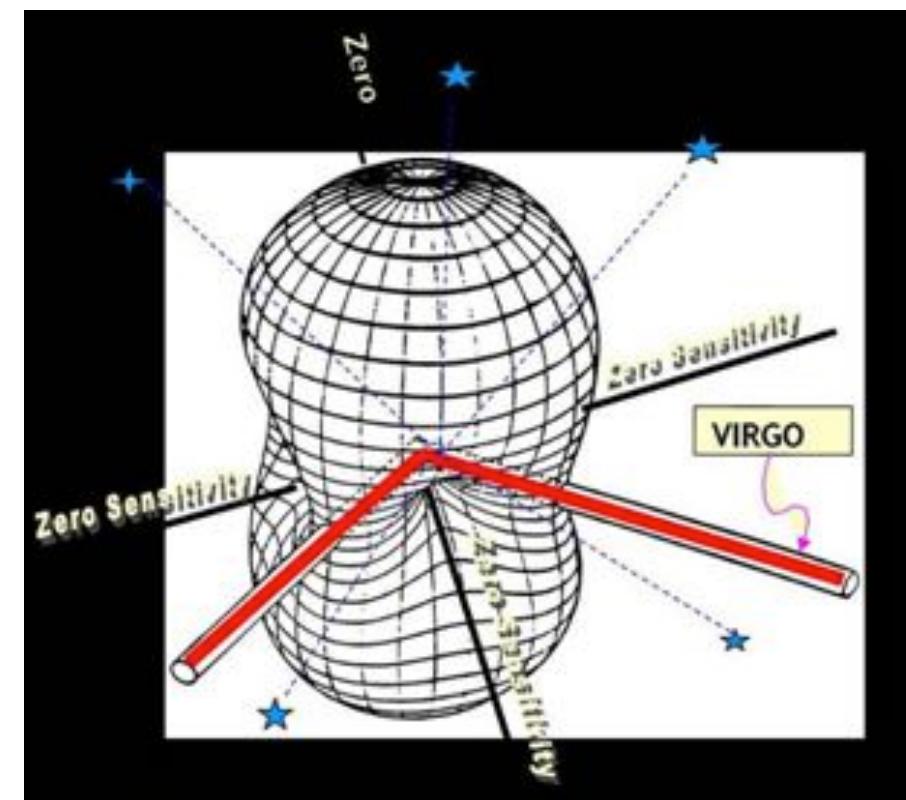


# LIGO/Virgo interferometers



$$h = \frac{\Delta L}{L} \approx 10^{-21}$$

O3: April 1st 2019-  
KAGRA will join soon



# THE GRAVITATIONAL-WAVE SPECTRUM

Much like electromagnetic waves, gravitational waves are emitted by many different objects over a wide range of frequencies. Terrestrial interferometers such as the Laser Interferometer Gravitational-Wave Observatory (LIGO) and Virgo are sensitive to only a subset of those frequencies, which limits their ability to ‘see’ certain cosmic phenomena. They won’t detect collisions of supermassive black holes found in the hearts of galaxies, for example. But space-based interferometers and other approaches for picking up gravitational waves could extend physicists’ reach.

