Quantum Astrometry

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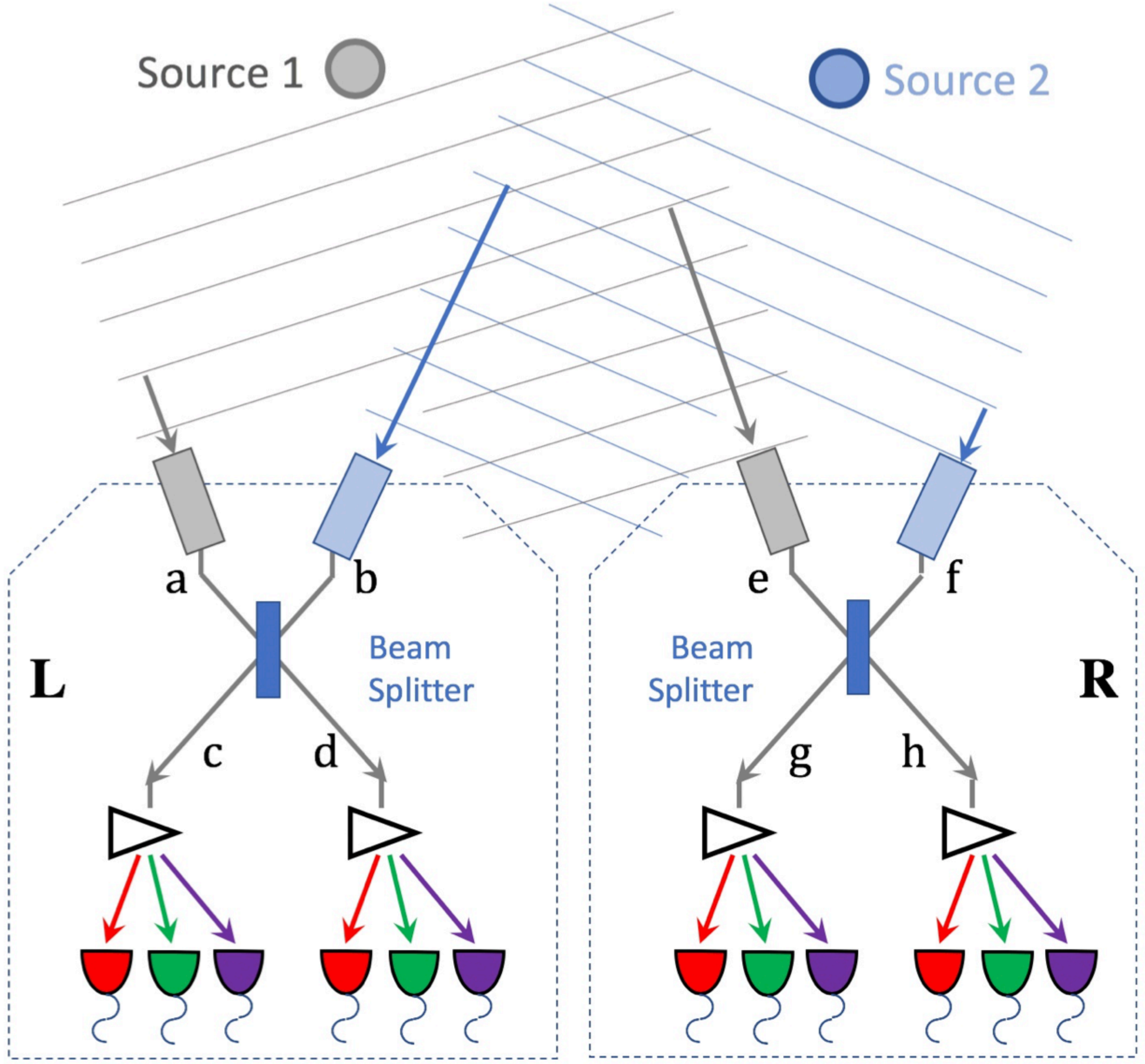
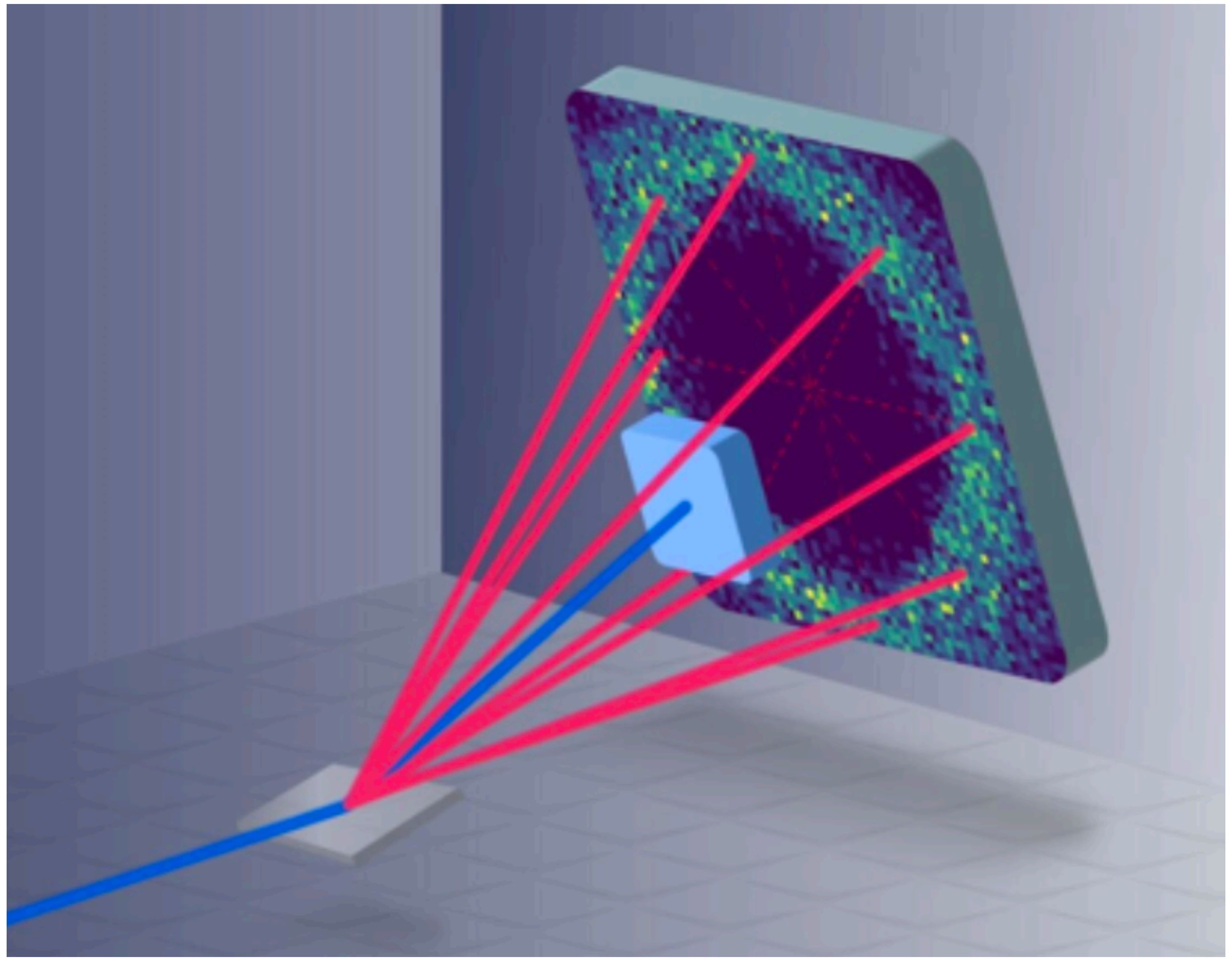


Quantum Astrometry
(Physics)



Quantum-enhanced Microscope
(NSLS-II)

THE ASTROPHYSICAL JOURNAL LETTERS, 875:L4 (52pp), 2019 April 10 https://doi.org/10.3847/2041-8213/ab0e85

First M87 Event Horizon Telescope Results. IV. Imaging the Central Supermassive Black Hole

The Event Horizon Telescope Collaboration
(See the end matter for the full list of authors.)

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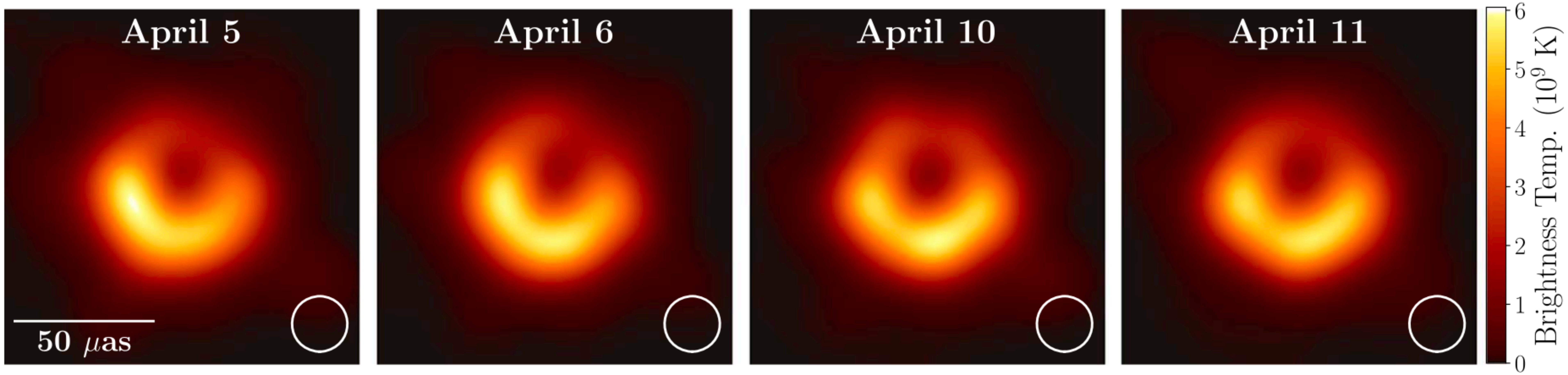
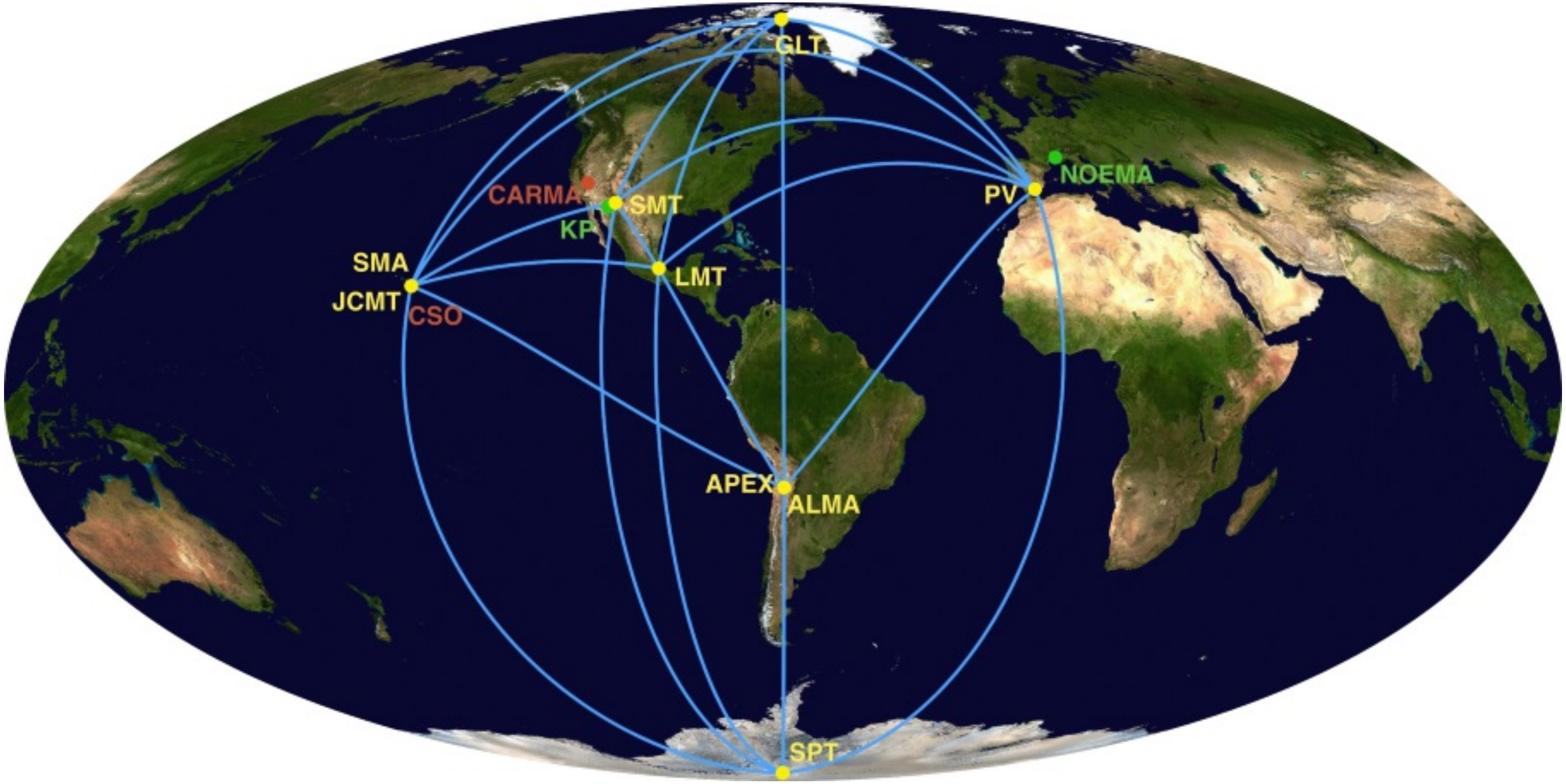


Figure 15. Averages of the three fiducial images of M87 for each of the four observed days after restoring each to an equivalent resolution, as in Figure 14. The indicated beam is 20 μas (i.e., that of DIFMAP, which is always the largest of the three individual beams).

sensitive to features on angular scale

$$\Delta\,\theta \sim \frac{\lambda}{b}$$

Achieved by radio interferometry

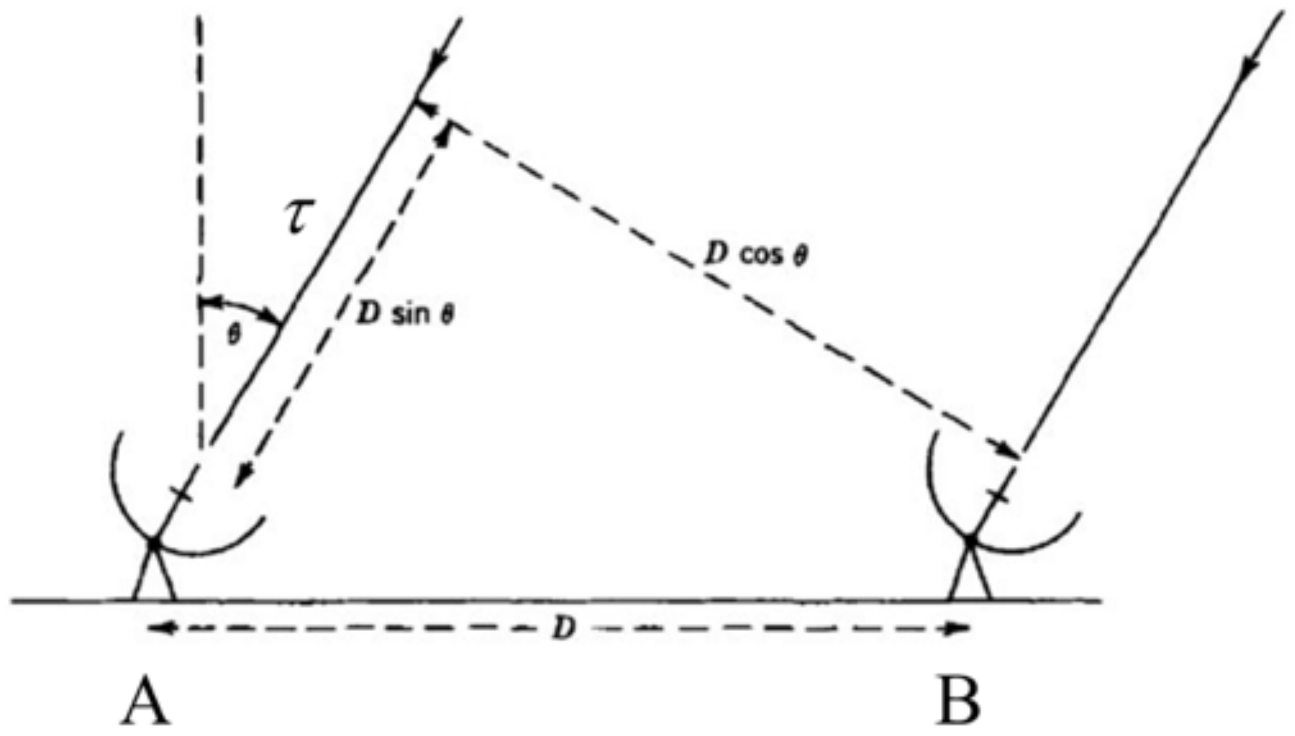


sensitive to features on angular scale

$$\Delta\,\theta \sim \frac{\lambda}{b}$$

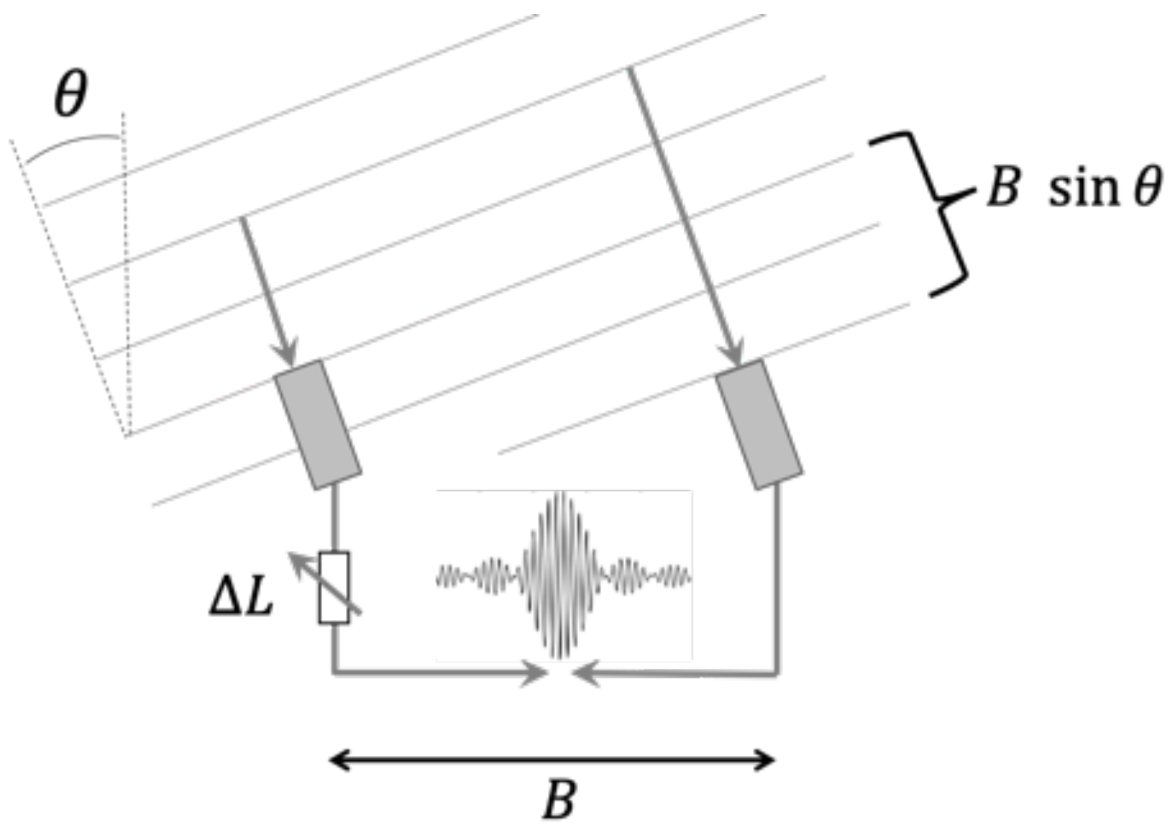
https://iopscience.iop.org/journal/2041-8205/page/Focus_on_EHT

Radio



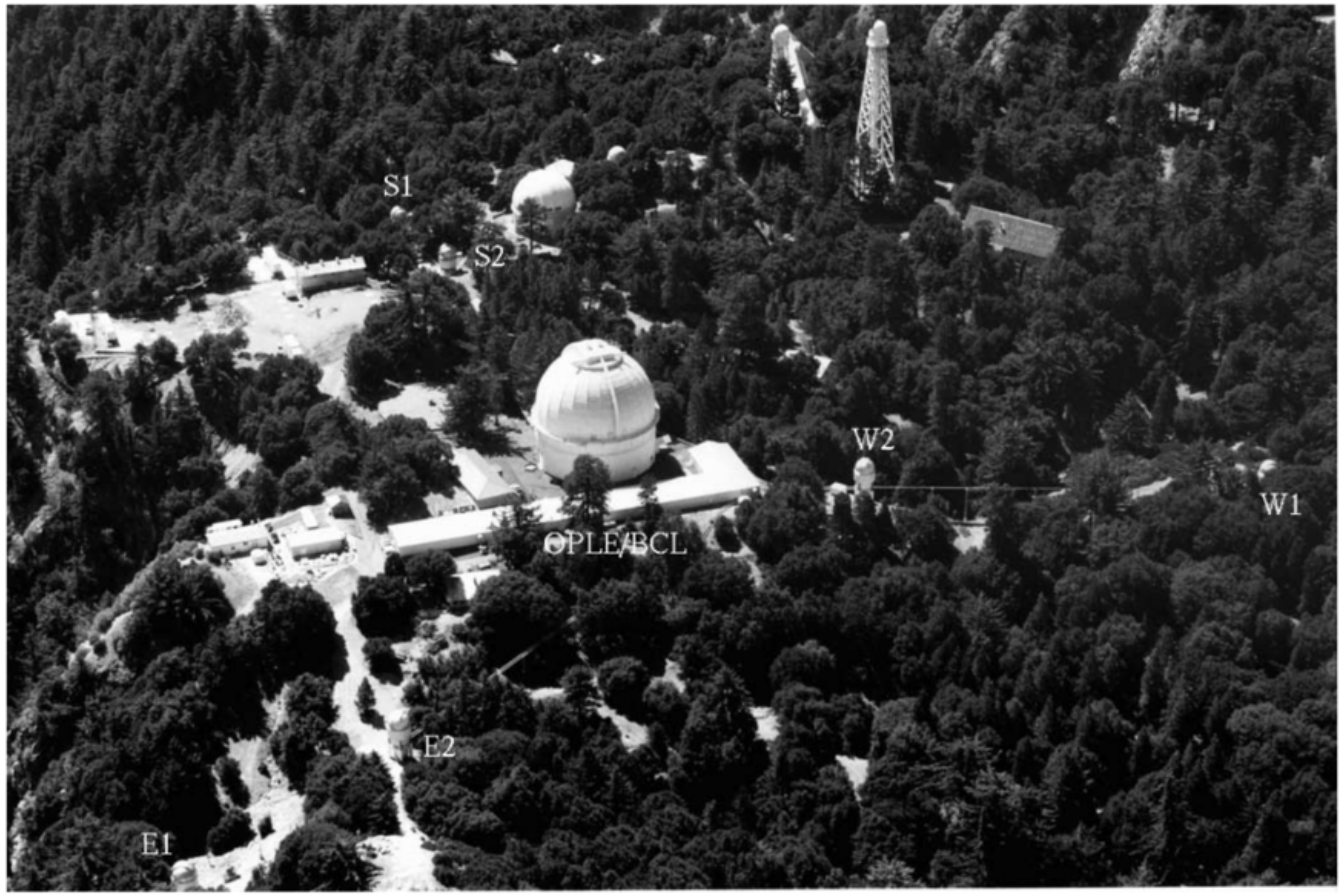
Can record entire waveform, over some band, separately at each receiver station and interfere later offline

Optical



Need to bring paths to common point in real time
Need path length compensated to better than c/bandwidth
Need path length stabilized to better than λ

CHARA (Center for High Angular Resolution Astronomy) Observatory
baselines up to 330m



Beam line path length control at CHARA

Question: How to get to longer baselines?

Longer-Baseline Telescopes Using Quantum Repeaters

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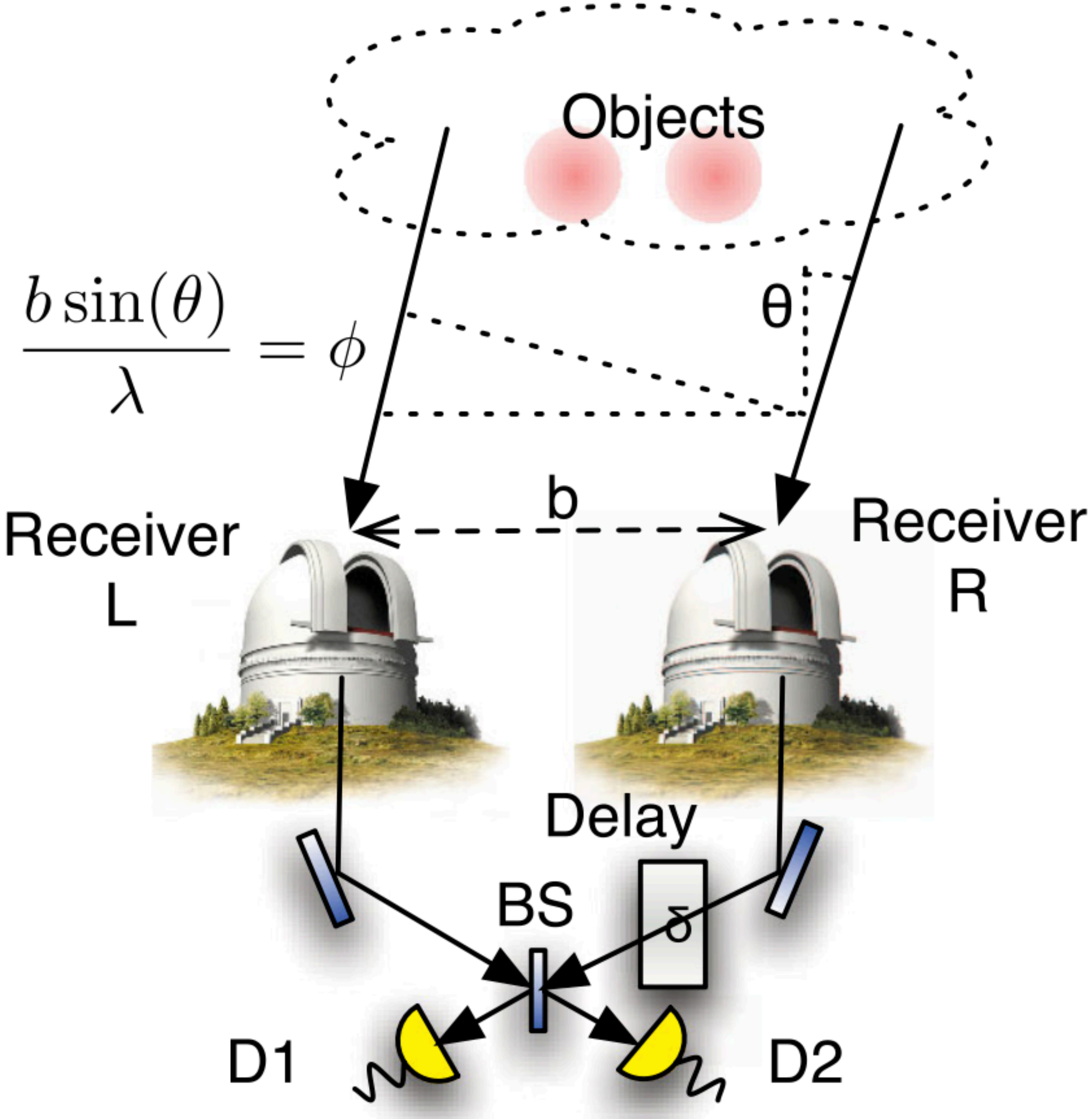
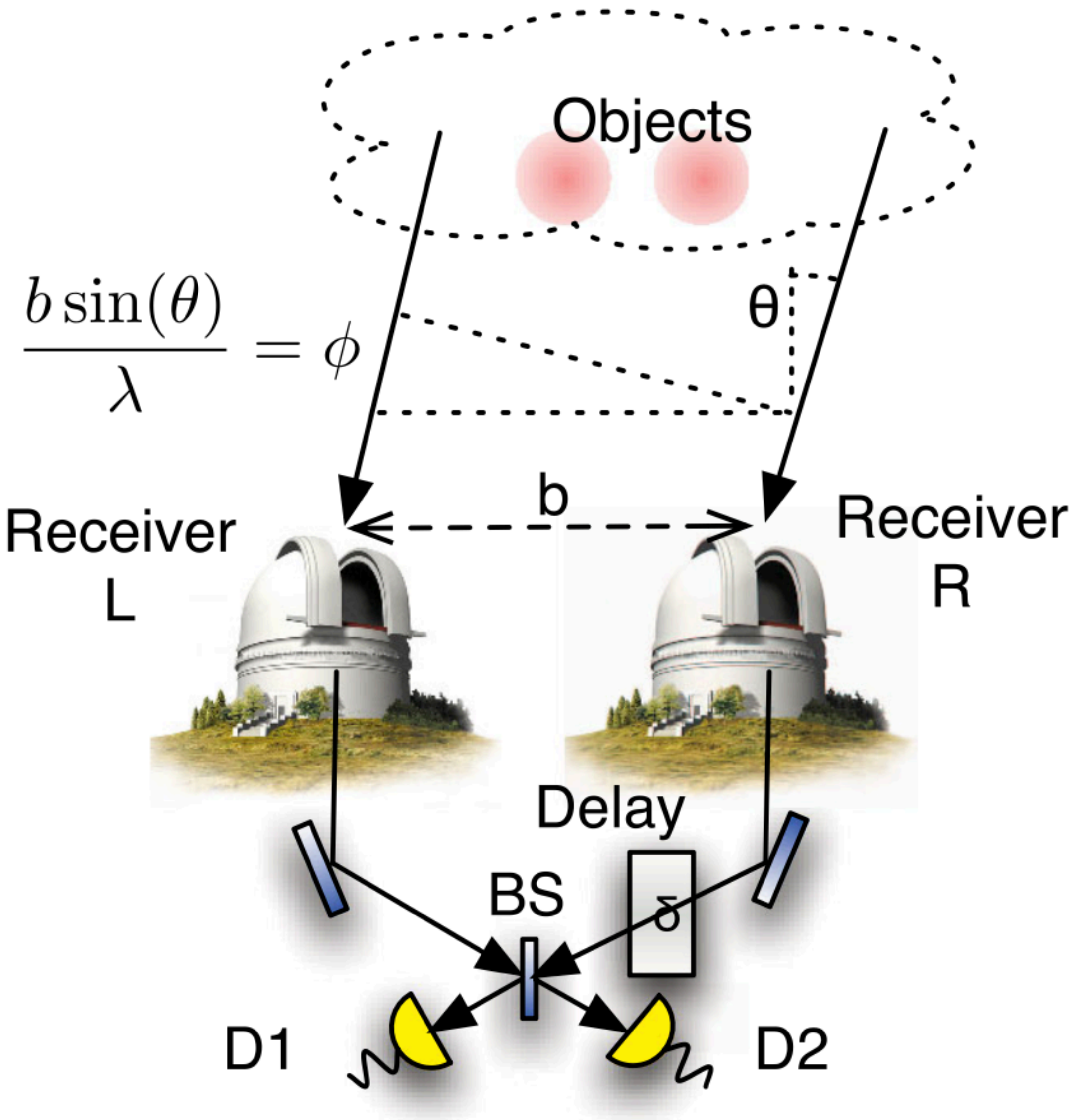
(Received 25 October 2011; revised manuscript received 22 May 2012; published 16 August 2012)



$$|0\rangle_L |1\rangle_R + e^{i\phi} |1\rangle_L |0\rangle_R,$$



PRL 109, 070503 (2012) PHYSICAL REVIEW LETTERS week ending 17 AUGUST 2012

Longer-Baseline Telescopes Using Quantum Repeaters

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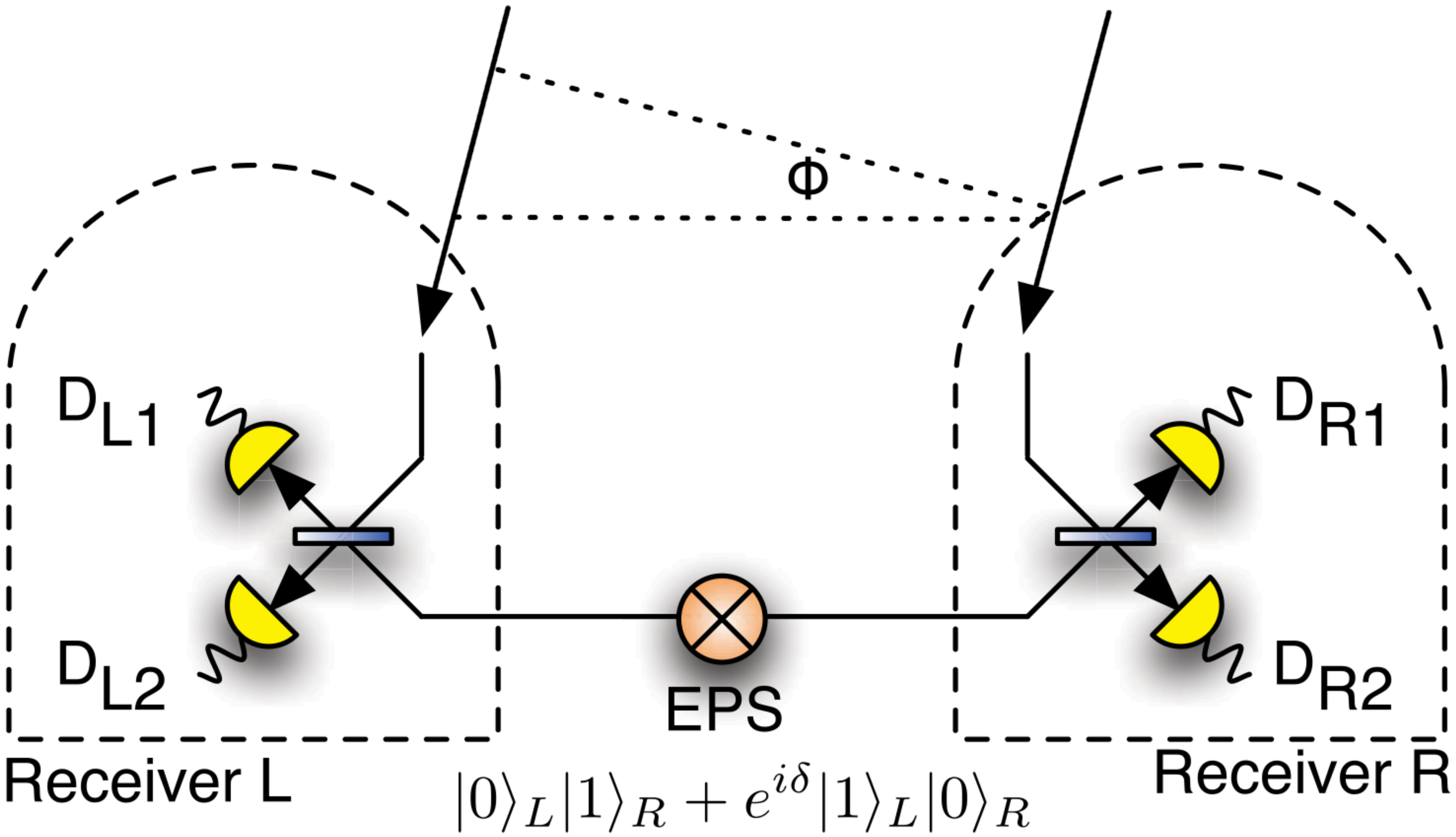

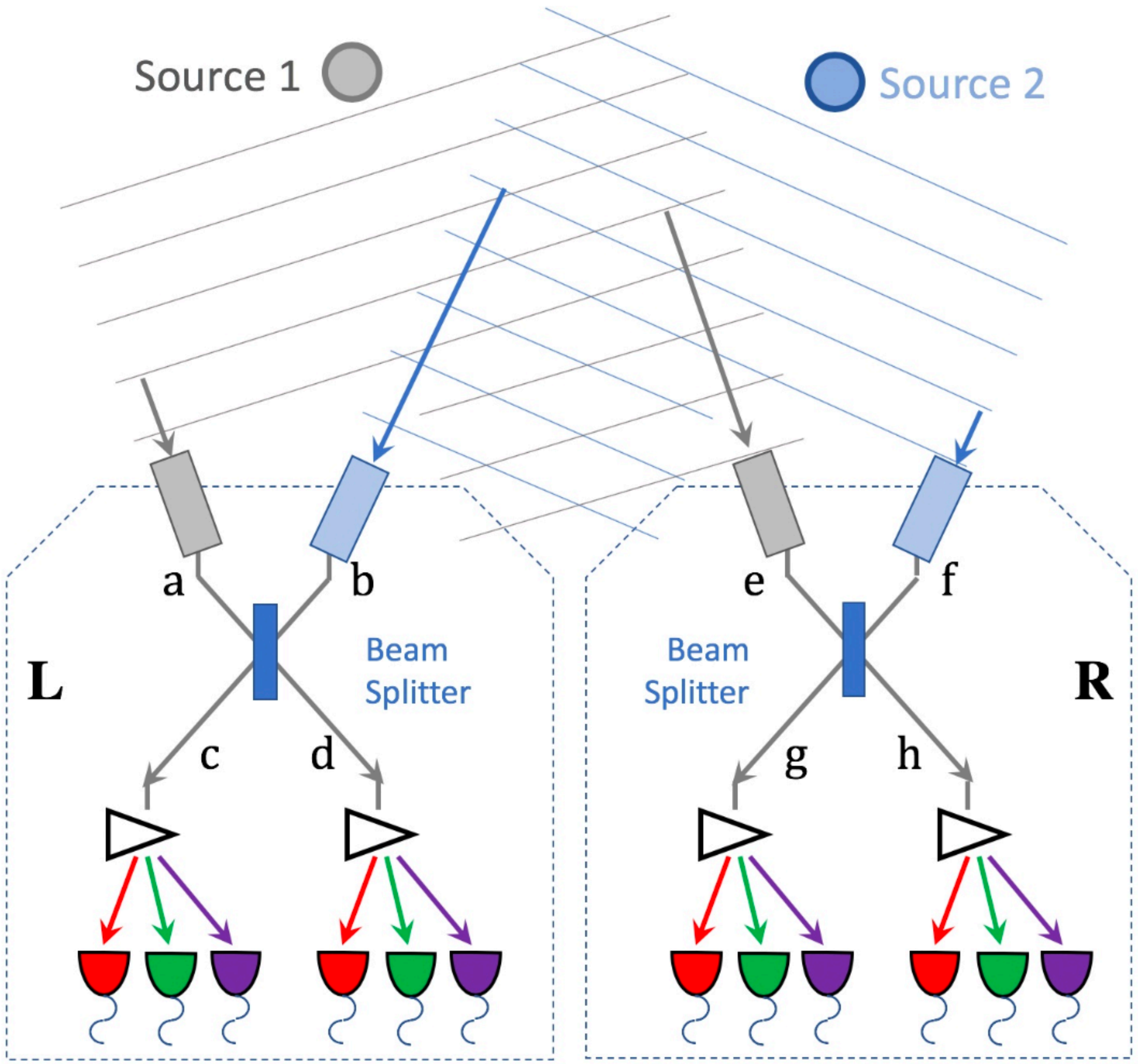

FIG. 3.— The two-photon, two source amplitude interferometer. Source 1 sends a photon which arrives as a plane wave at both input single-mode channels "a" and "e". The path length difference leads to a phase offset of δ_1, and the photon is in an entangled state $|0\rangle_L|1\rangle_R + e^{i\delta_1}|1\rangle_L|0\rangle_R$ between the two observatories **L** and **R** (we recommend references Gulbahar (2020); Tan et al. (1991); Hardy (1994); van Enk (2005); Morin et al. (2013); Lvovsky et al. (2001) for details of the mode and path entanglement phenomena of photons). At the same time a photon from Source 2 enters channels "b" and "f" with a phase difference δ_2 and in an entangled state $|0\rangle_L|1\rangle_R + e^{i\delta_2}|1\rangle_L|0\rangle_R$. (The photon collection at each station can be in two separate telescopes, as shown, or in one, as long as the two sources can be imaged separately.) These are then interfered using the beam splitters in the two stations as shown. If the two photons are close enough together in both time and frequency, then due to quantum mechanical interference the pattern of coincidences between measurements at "c" and "d" in **L** and "g" and "h" in **R** will be sensitive to the *difference* in phase differences $(\delta_1 - \delta_2)$; and this in turn will be sensitive to the relative opening angle between the two sources. No optical connection path is needed between the two stations; and the measurement can be carried out in many spectroscopic bins simultaneously, as suggested by the arrays of detectors at each output.

One photon from Source 1 arrives at **a** and **e**

$$|0\rangle_L|1\rangle_R + e^{i\delta 1}|1\rangle_L|0\rangle_R$$

Another photon from Source 2 arrives at **b** and **f**

$$|0\rangle_L|1\rangle_R + e^{i\delta 2}|1\rangle_L|0\rangle_R$$

(path entanglement)

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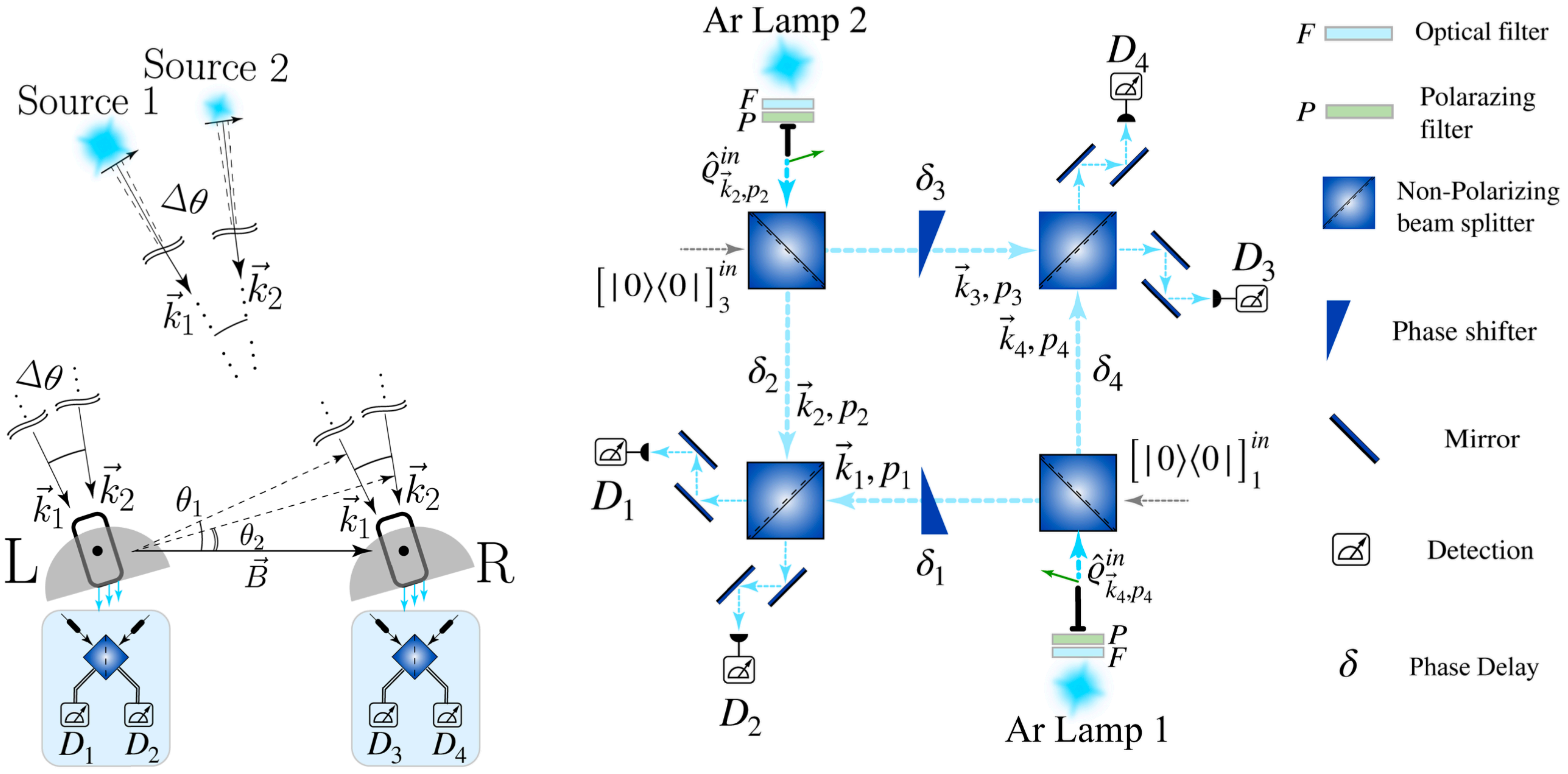
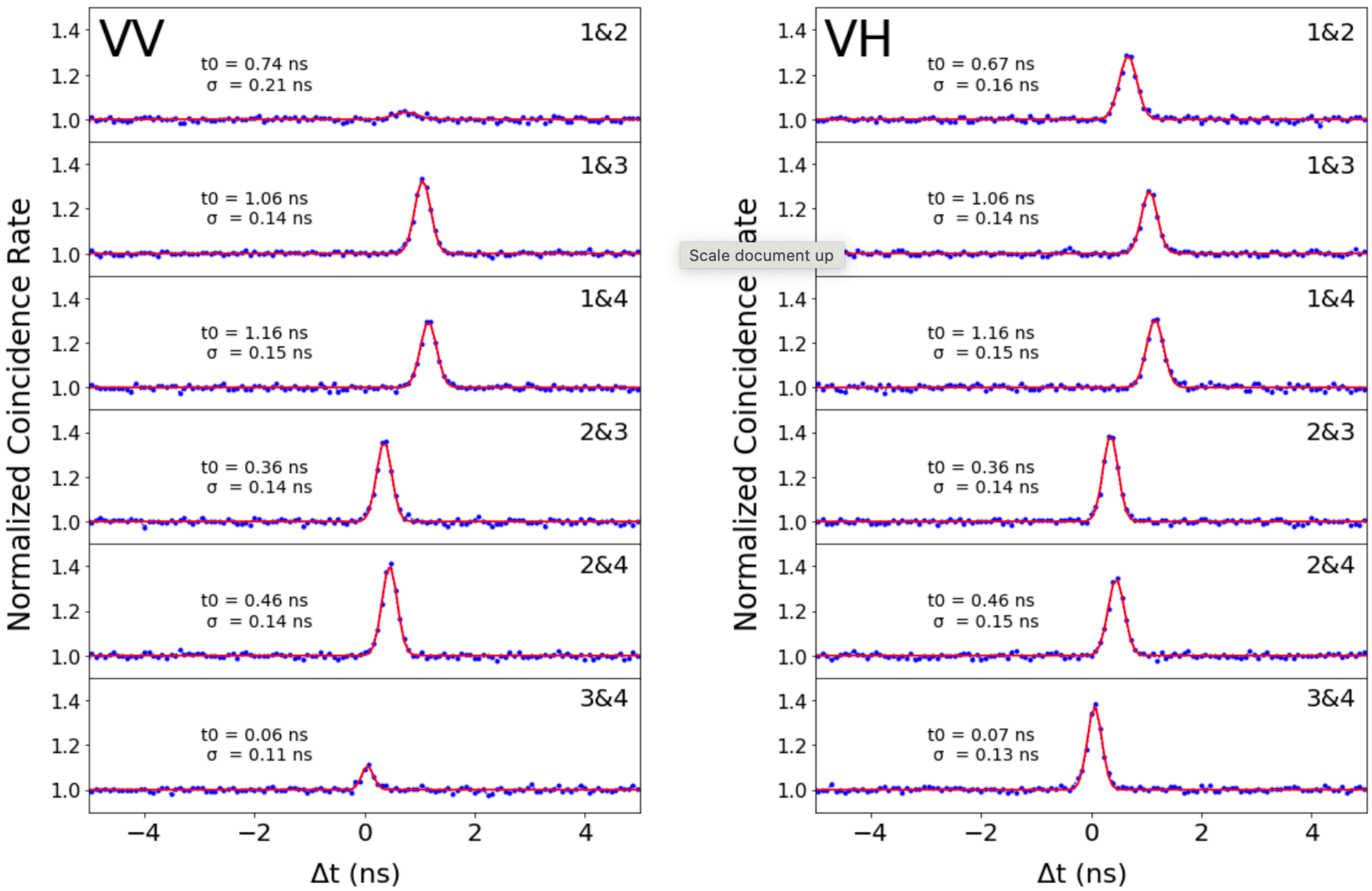
Optics EXPRESS

Towards quantum telescopes: demonstration of a two-photon interferometer for precision astrometry



(a) SNSV scheme

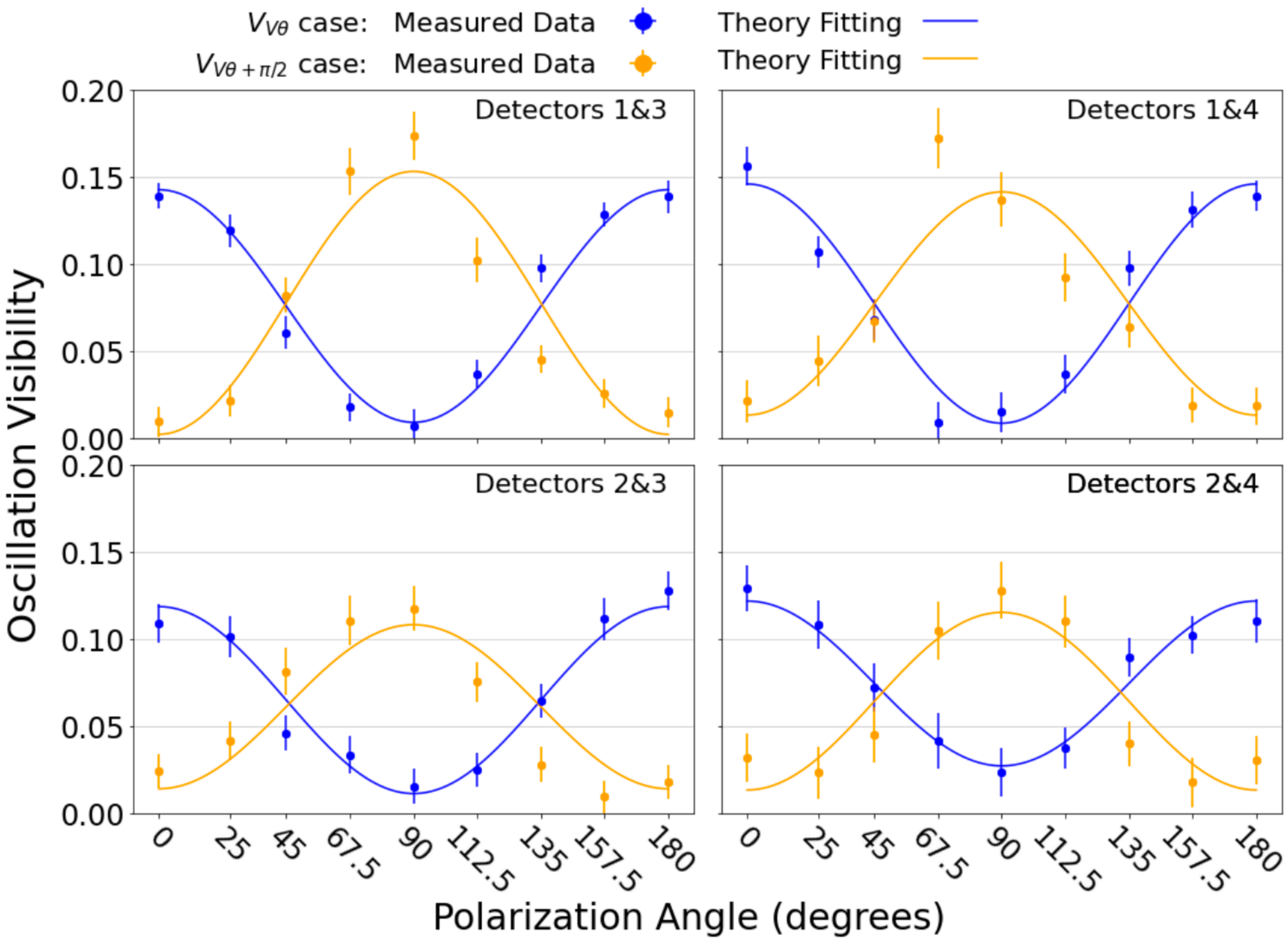
(b) Tabletop implementation



(a) VV

(b) VH

HBT peaks ✓

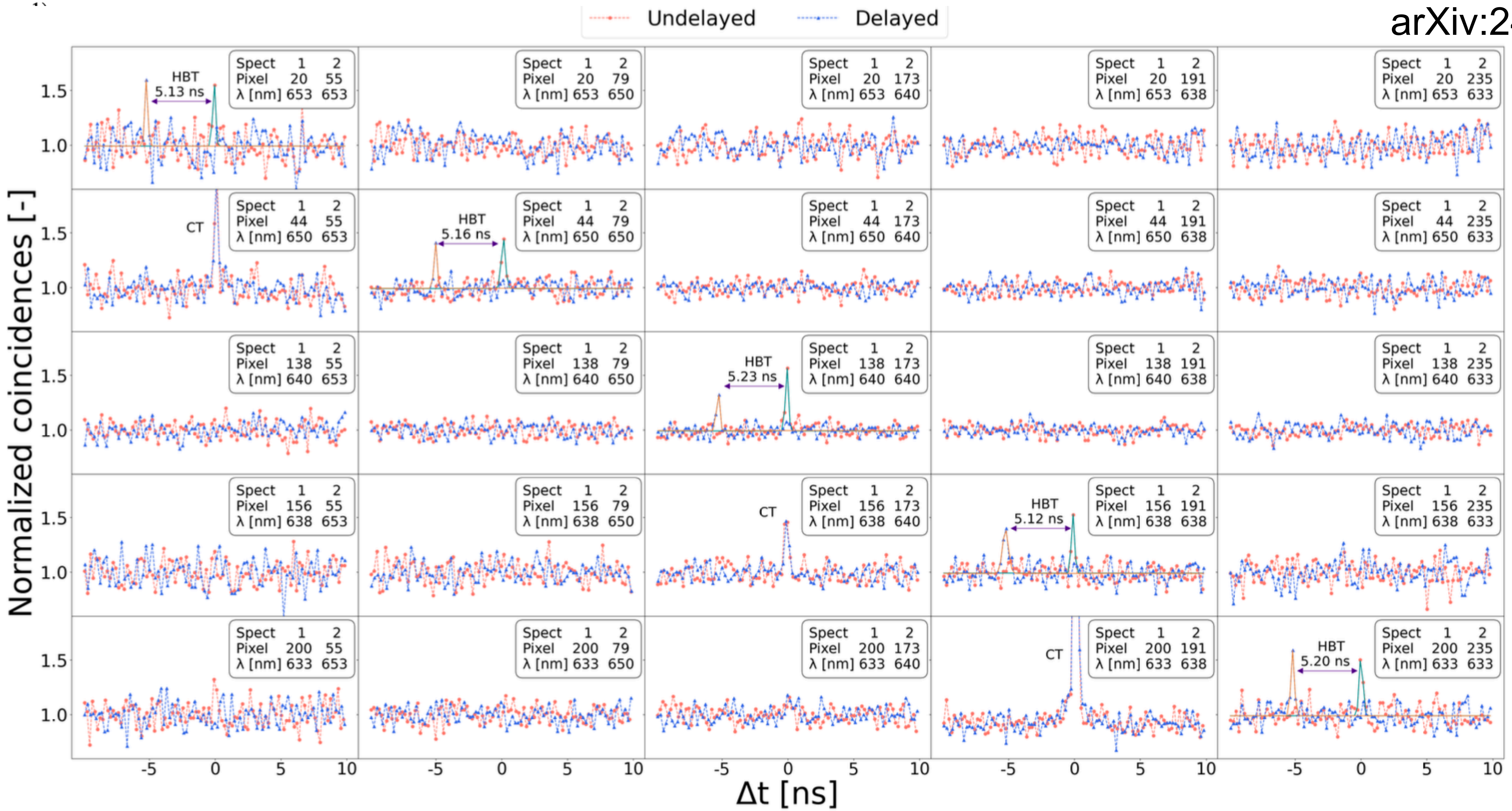

$V_{V\theta}$ case: Measured Data
Theory Fitting
$V_{V\theta+\pi/2}$ case: Measured Data
Theory Fitting
Detectors 1&3
Detectors 1&4
Detectors 2&3
Detectors 2&4
Oscillation Visibility
0.00
0.05
0.10
0.15
0.20
0
25
45
67.5
90
112.5
135
157.5
180
Polarization Angle (degrees)

Visibility

Multifrequency-resolved Hanbury Brown–Twiss Effect

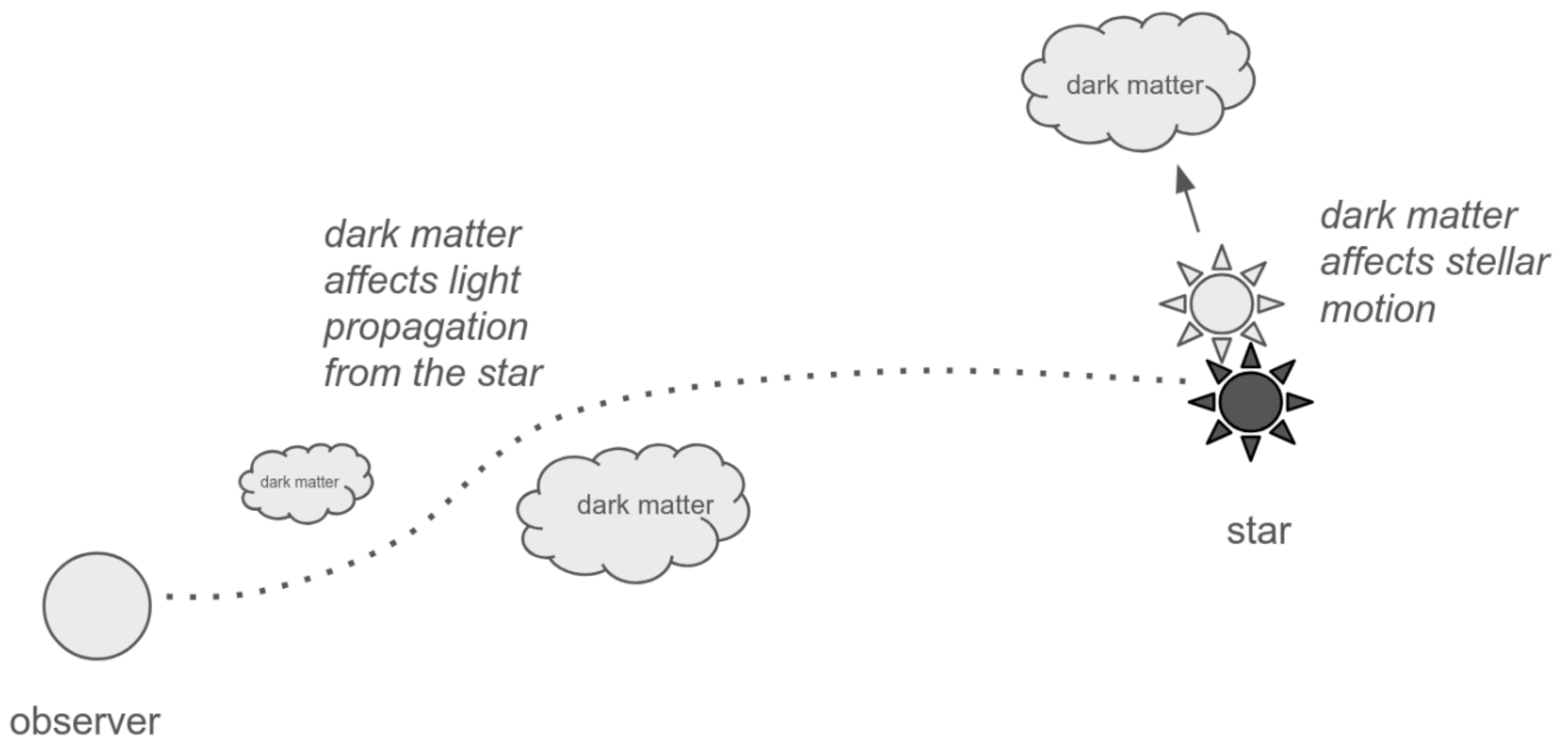
Joseph Ferrantini,[1,a)] Jesse Crawford,[1,a)] Sergei Kulkov,[2,a)] Jakub Jirsa,[2,3] Aaron Mueninghoff,[4] Lucas Lawrence,[1] Stephen Vintskevich,[5] Tommaso Milanese,[6] Samuel Burri,[6] Ermanno Bernasconi,[6] Claudio Bruschini,[6] Michal Marcisovsky,[2] Peter Svihra,[2] Andrei Nomerotski,[2,7] Paul Stankus,[1] Edoardo Charbon,[6] and Raphael A. Abrahao[1,b)]

arXiv:2406.13959

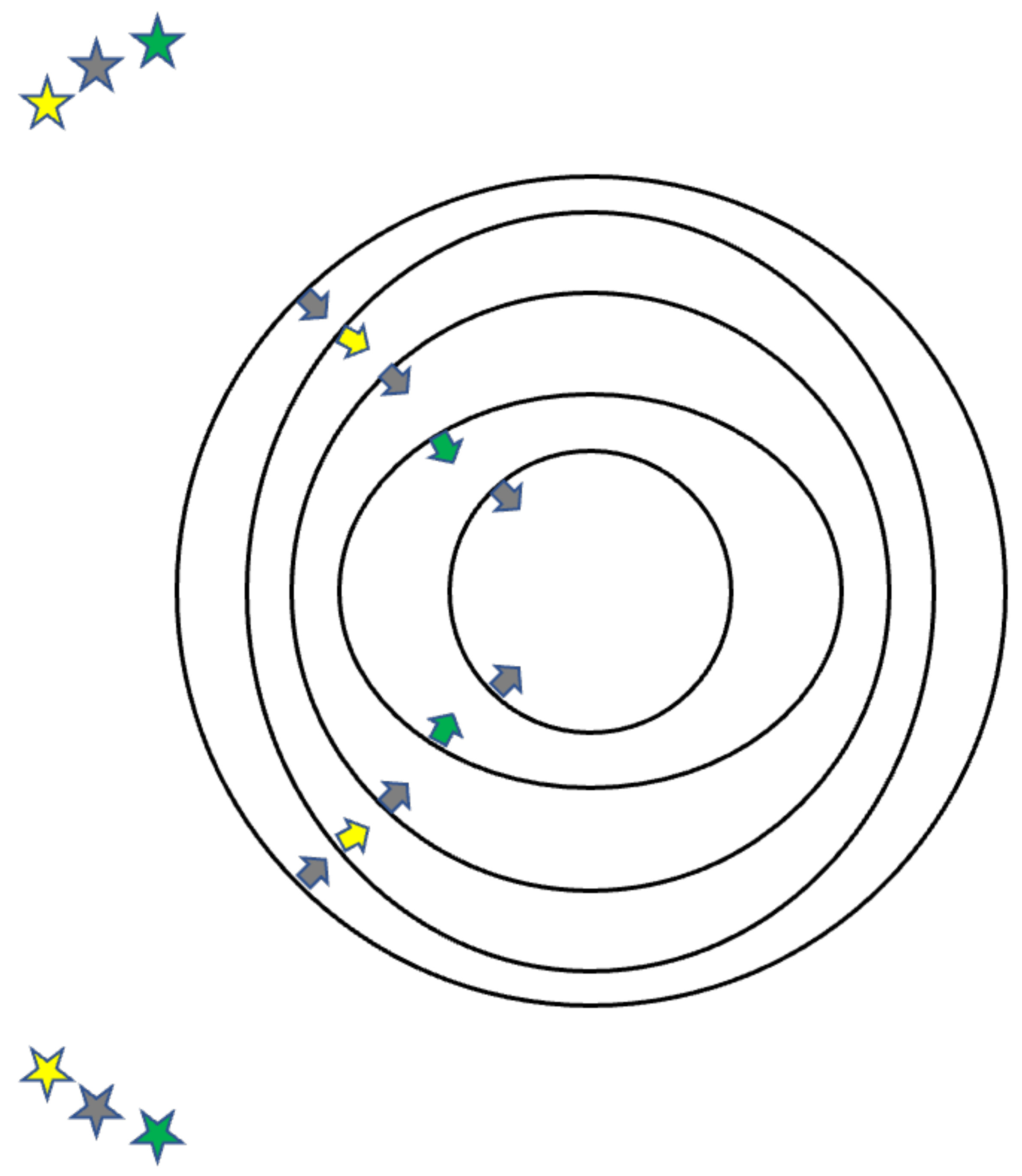


Implications for Astrophysics and Cosmology

✓ Dark Matter



✓ Gravitational Waves



✓ Hubble Constant

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