Intensity Interferometry:
Revealing the Universe's hidden details

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Introduction:
Beyond Traditional Telescopes

Optical and radio telescopes have been the cornerstones of astronomical observation, allowing scientists to explore distant galaxies, nebulae, and more.

However, there are limitations in terms of resolution when it comes to imaging small and distant celestial objects. The resolving power of a telescopes is constrained by its aperture size:

$$\frac{\text{aperture size}}{\text{wavelength}} \geq \frac{\text{distance}}{\text{object size}}$$

Practical and financial constraints limit the size of the apertures, thereby capping the resolution achievable.
This is where intensity interferometry or Hanbury-Brown-Twiss (HBT) interferometry could take over.

Interferometers at work

The technique was developed in the 1960s and subsequently tested by R. Hanbury Brown, J. Davis and L.R. Allen at the Narrabri Stellar Intensity Interferometer, situated near the town of Narrabri in Australia (left image). At the time, the detector technology available limited the resolution to approximately half a milliarcsecond.

Currently (2020s), however, there has been a resurgence of interest in this field, with numerous research groups implementing intensity interferometry on their telescopes. One notable set of telescopes used for this purpose are the MAGIC telescopes, located on the Canary Islands.

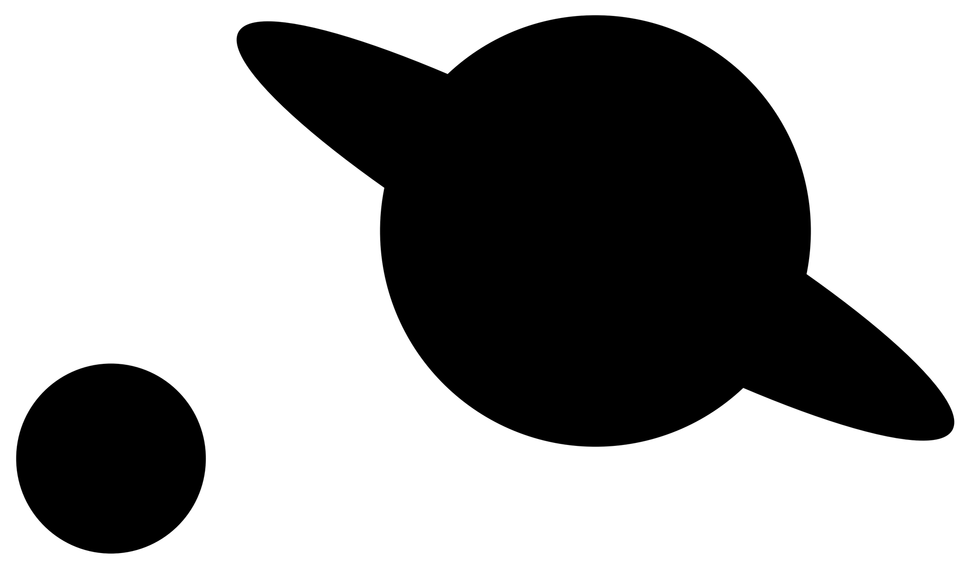
How it works:
All good things come in twos

Intensity interferometry exploits the second-order correlation function of the electromagnetic field to extract information about the source. Unlike amplitude interferometry, which relies on the phase information of the electric field, intensity interferometry measure the temporal correlation of the photon arrivals at two or more detectors.

The foundational principle is that photons emitted from a thermal source exhibit bunching behaviour, meaning they tend to arrive at detectors in correlated pairs. This effect is a manifestation of the Bose-Einstein statistic governing photons.

The degree of correlation between photon arrivals is directly related to the spatial coherence of the source. By varying the separation between the detectors and measuring the correlation, we can reconstruct the source's angular size.

Intensity interferometry is insensitive to atmospheric turbulence and optical imperfections, making it ideal to study faint and distant objects. It also requires less stringent path length matching compared to traditional interferometers.

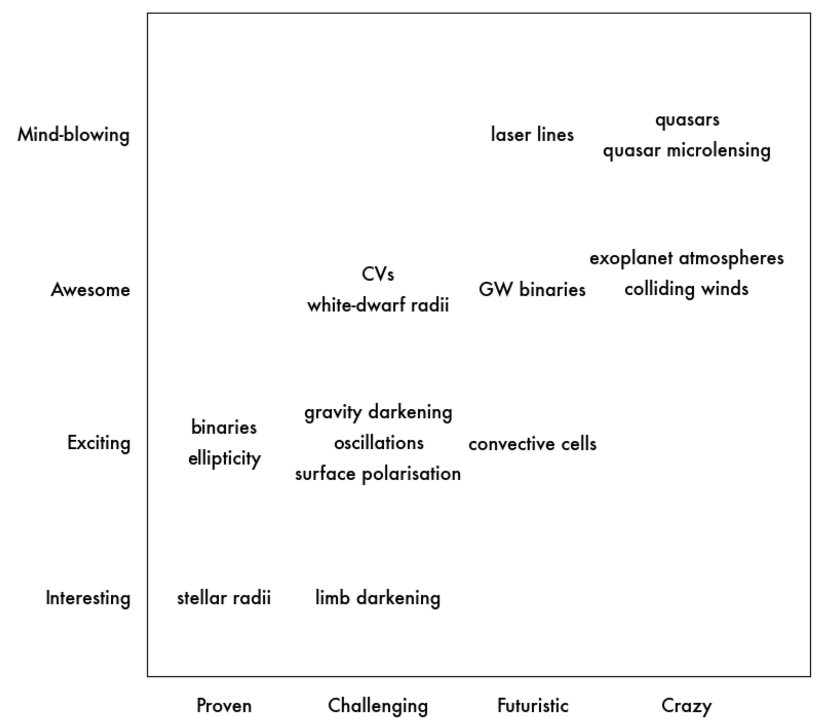


What is required:
The Need for Speed (and Sensitivity)

The price that one needs to pay instead of huge aperture sizes is exceptional timing precision and sensitivity. Photons arriving from even the largest stars, can be correlated over timescales of mere picoseconds (trillionth of a second).

Detectors must be incredibly fast to distinguish these near-simultaneous arrivals and accurately measure the correlation function.

Furthermore, only a tiny fraction of photons arriving at the telescopes will have originated from the target star, the rest coming from noise. Detecting faint correlations amidst the noise requires highly sensitive detectors capable of registering even individual photons.

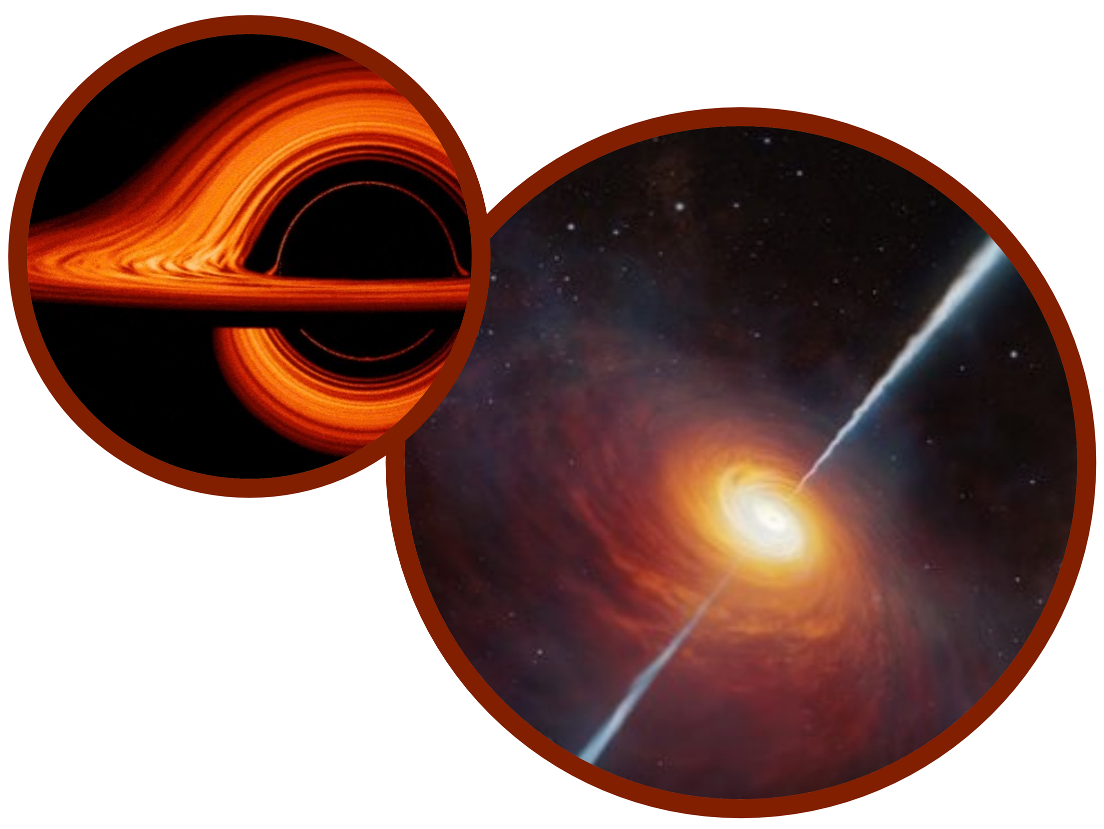


Proposed Targets

To date, intensity interferometry has been employed primarily for the measurement of angular diameters and oblateness in stars.
However, the proposed targets encompass a diverse range of celestial objects, some of which are are highlighted and categorised in the top plot.
It highlights a progression from established studies like stellar radii, to more ambitious targets, like imaging accretion disks associated with black holes and quasars (see bottom images).

Prospectives:
Expanding the boundaries of Space Observations

Although challenging, intensity interferometry has the potential to achieve unprecedented resolution, enabling the measurement of angular diameters of stars, study of accretion disks around black holes, protoplanetary disks, quasars and even exoplanets. By overcoming the limitations of traditional telescopes, intensity interferometry could be the next great leap in astronomical observation.



Further Readings:

First Measurements of Angular Diameters of stars:
R. Hanbury Brown, J. Davis, and L. R. Allen, The Angular Diameters of 32 Stars, Monthly Notices of the Royal Astronomical Society 167, 121 (1974)

Most Recent Measurements with VERITAS telescopes:
A. Acharyya et al., An Angular Diameter Measurement of β UMa via Stellar Intensity Interferometry with the VERITAS Observatory, arXiv:2401.01853

Most Recent Performance Paper of the MAGIC-SII:
MAGIC Collaboration, Performance and first measurements of the MAGIC Stellar Intensity Interferometer, Monthly Notices of the Royal Astronomical Society ***529****, 4387 (2024)*

Future Prospects of Intensity Interferometry Workshop 2024:
Perimeter Institute for Theoretical Physics, Canada, https://events.perimeterinstitute.ca/event/347/overview