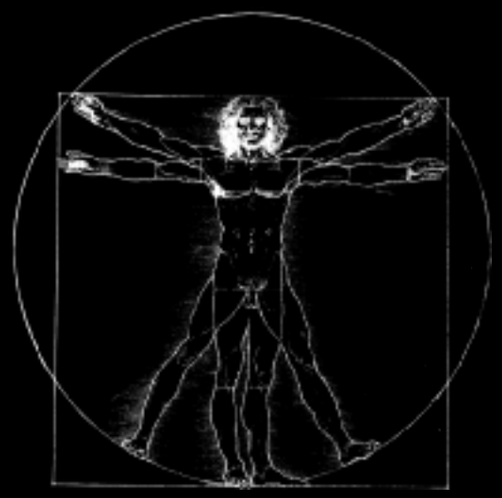
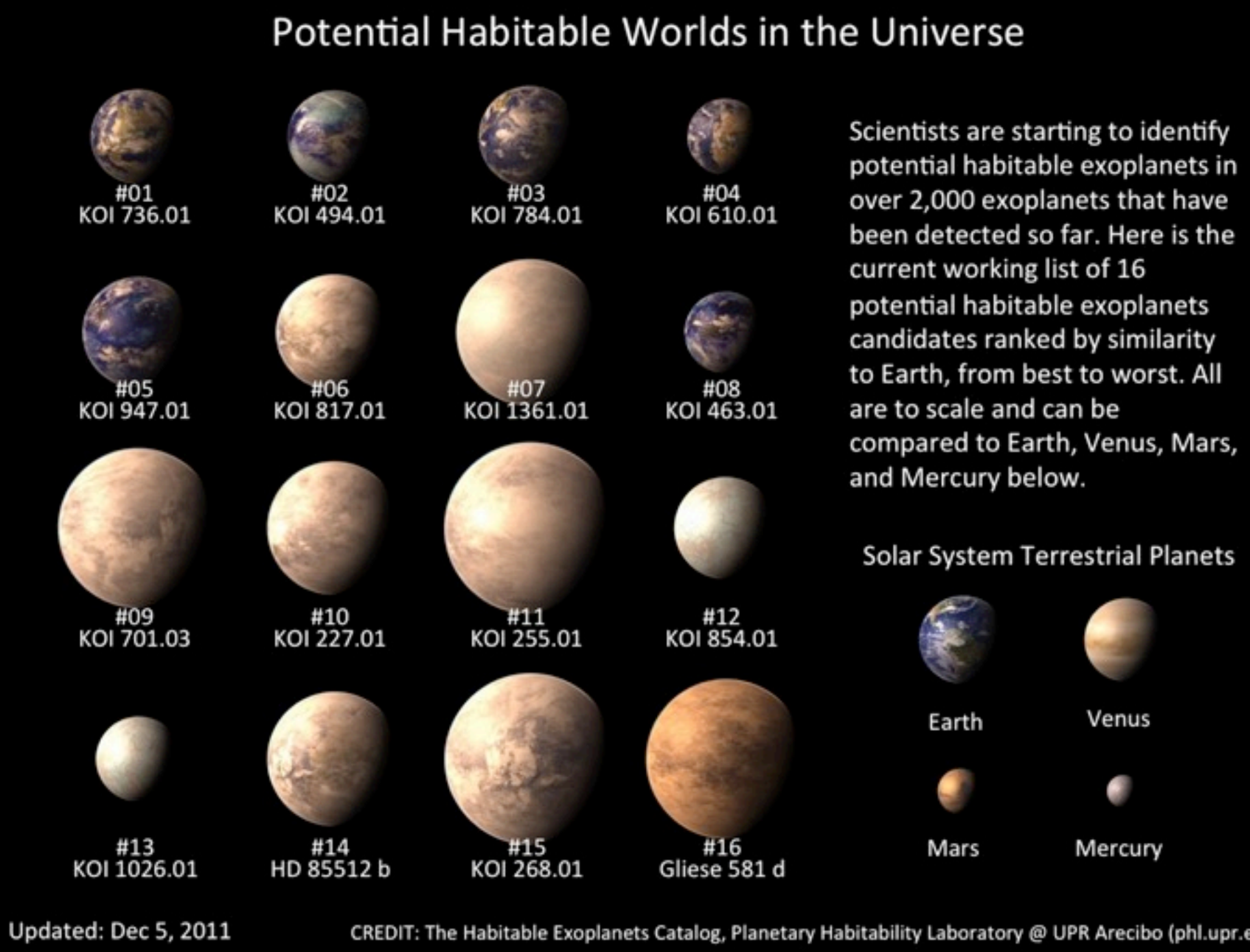
Advanced photonics for nulling techniques



Dr. Stefano Minardi

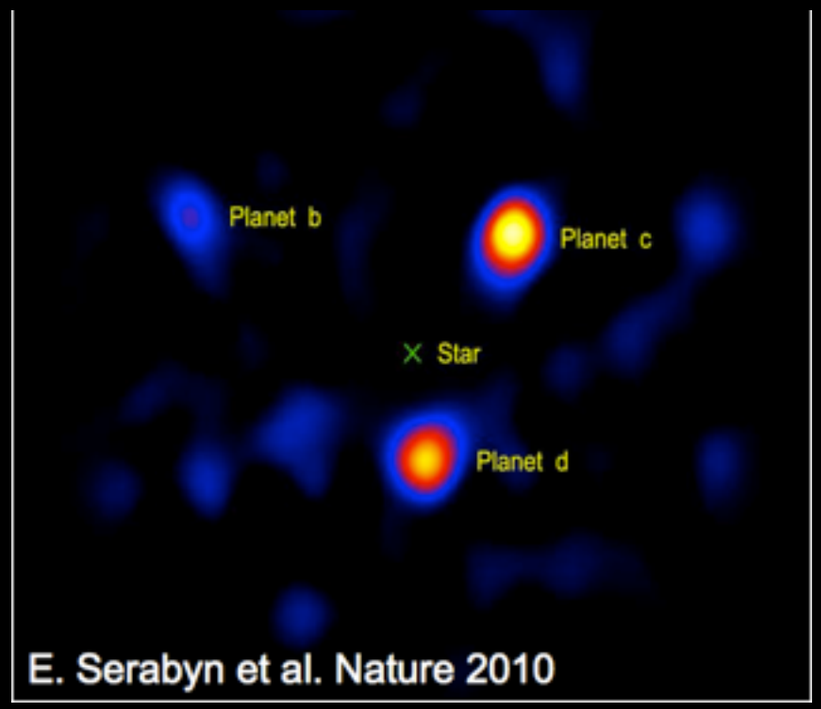
Friedrich Schiller University - Jena (D)

Detection of exoplanets



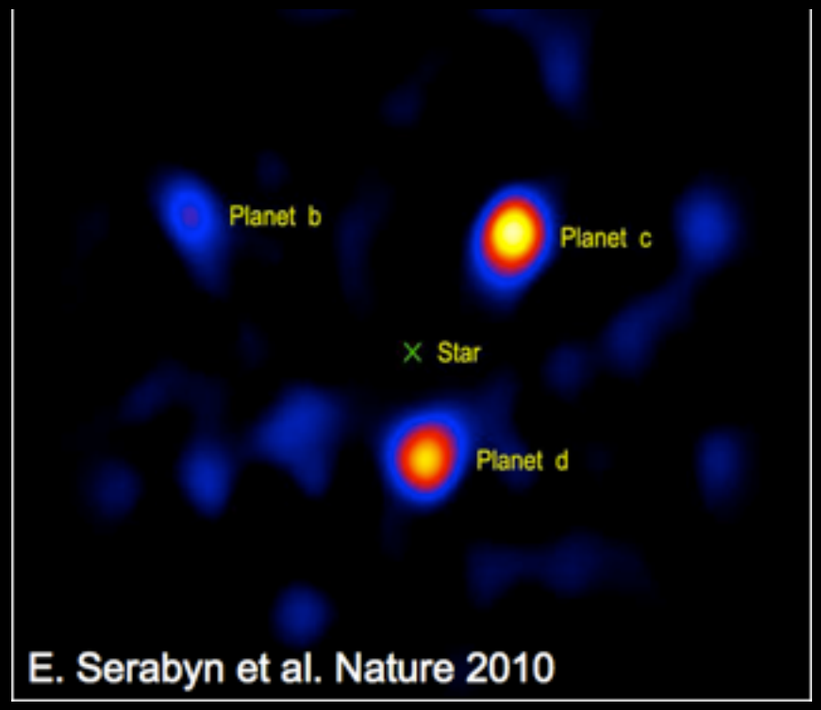
Problem: most of the known exoplanets are characterized by indirect detection techniques

Direct planet-detection techniques

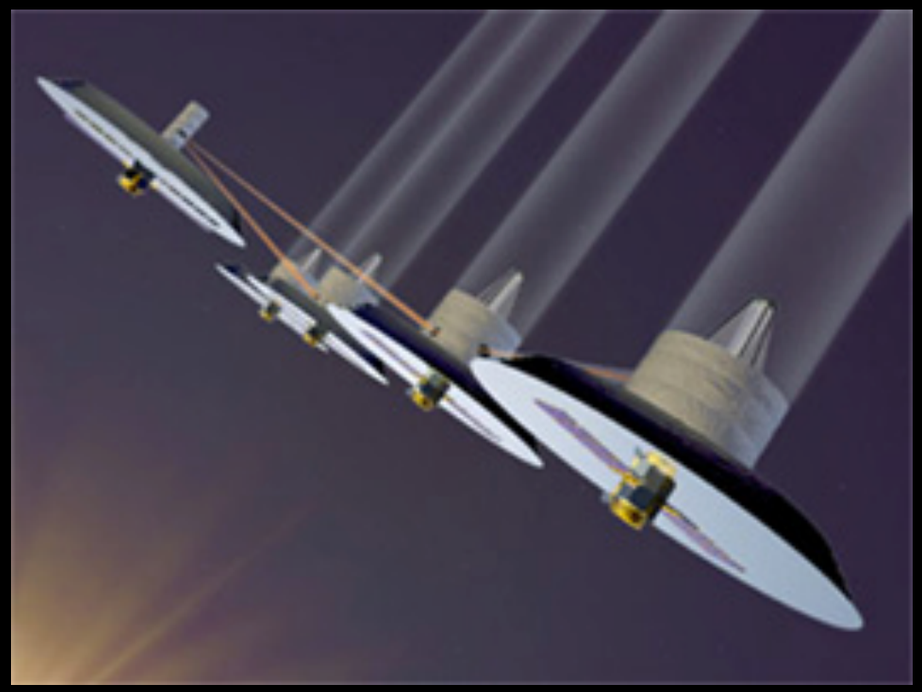


Stellar-coronagraphy

Direct planet-detection techniques

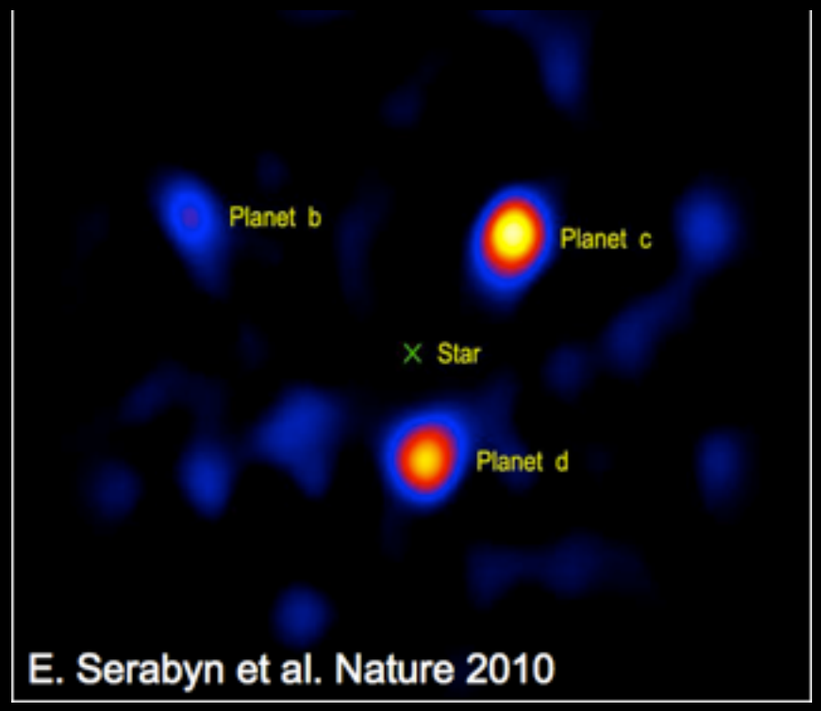


Stellar-coronagraphy

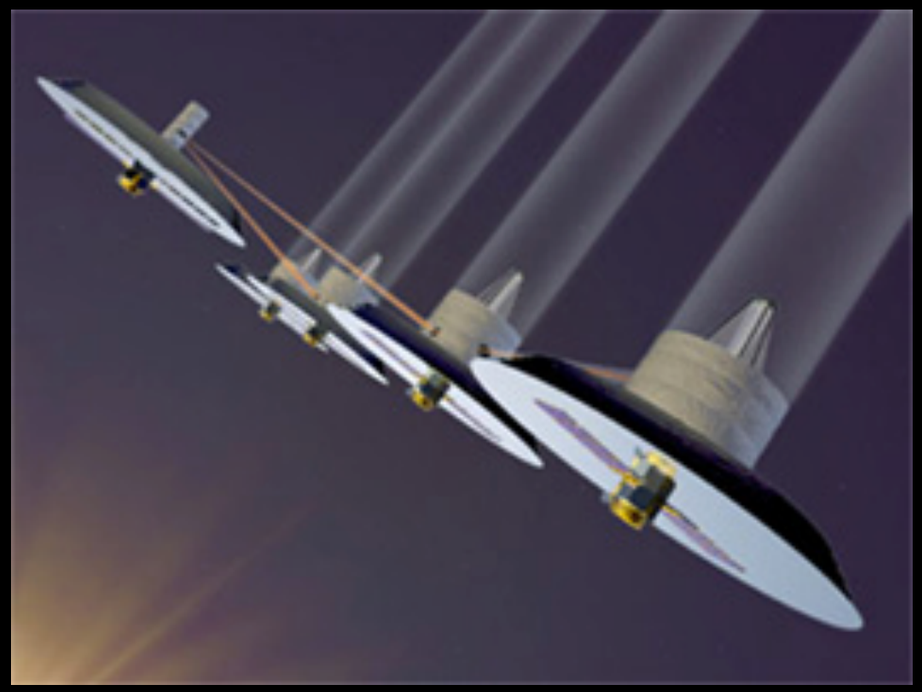


Nulling interferometry

Direct planet-detection techniques



Stellar-coronagraphy

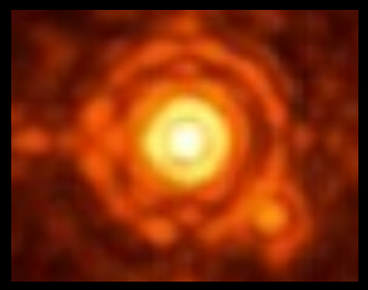


Nulling interferometry

In both cases, **stellar light is rejected**
and planet light transmitted

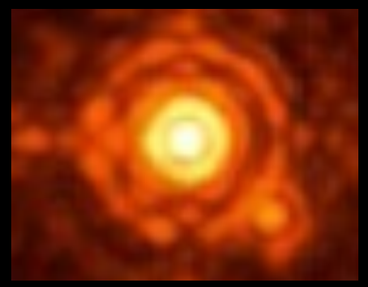
Photonics for stellar coronagraphy

Phase mask coronagraphs

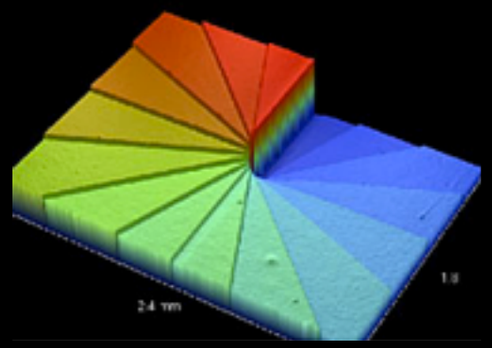


Beam with
Strehl>90%

Phase mask coronagraphs

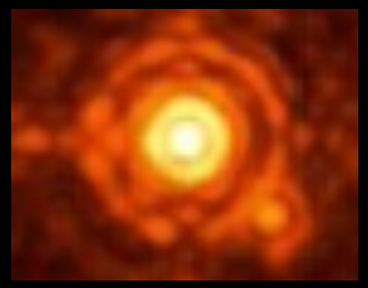


Beam with
Strehl>90%

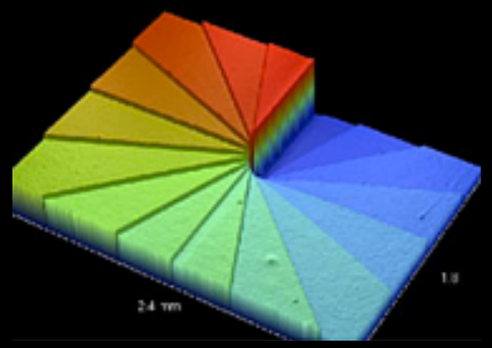


Phase mask
in image plane

Phase mask coronagraphs



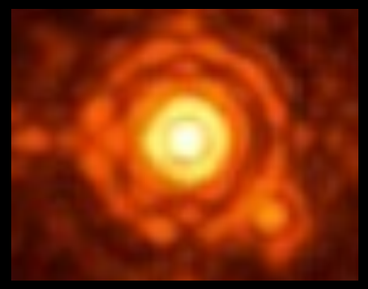
Beam with
Strehl>90%



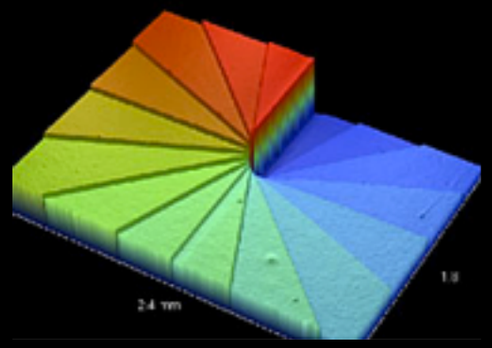
Phase mask
in image plane

Lens

Phase mask coronagraphs

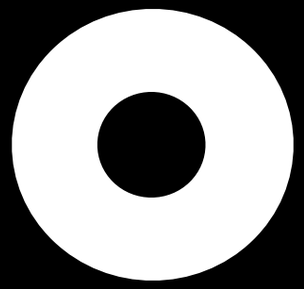


Beam with
Strehl>90%



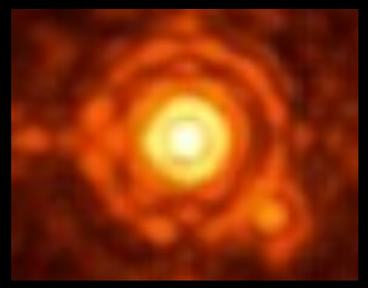
Phase mask
in image plane

Lens

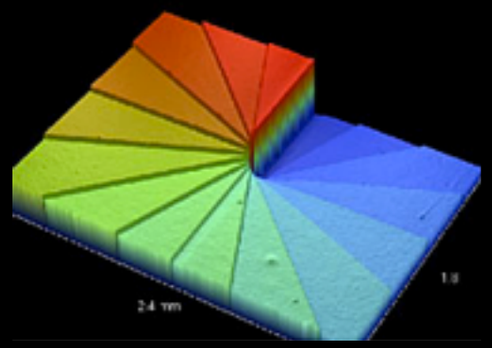


Scattered
star-light
in pupil plane

Phase mask coronagraphs

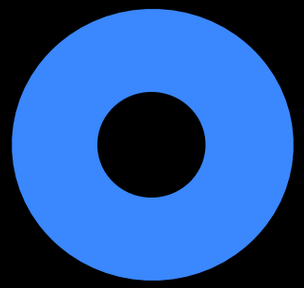


Beam with
Strehl>90%



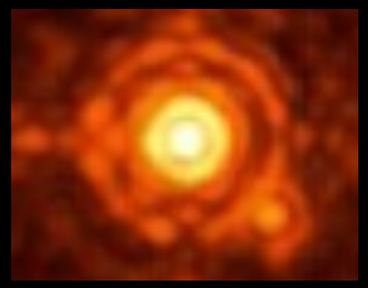
Phase mask
in image plane

Lens



Spatial
filtering of
scattered
star-light

Phase mask coronagraphs



Beam with
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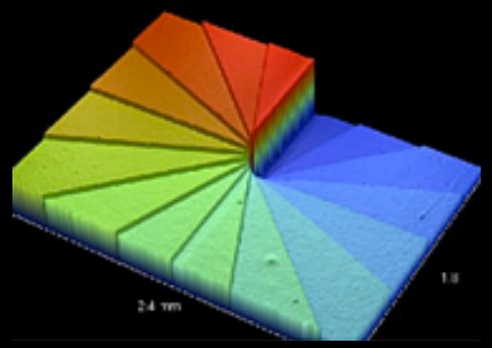
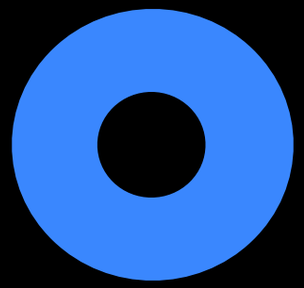


Phase mask
in image plane

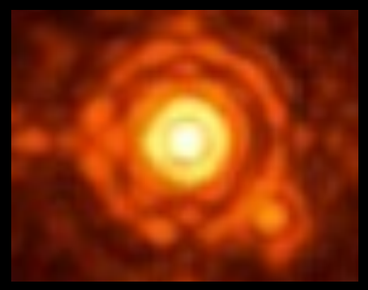
Lens



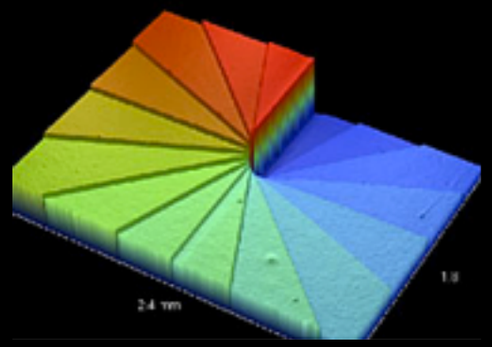
Spatial
filtering of
scattered
star-light

Lens

Phase mask coronagraphs

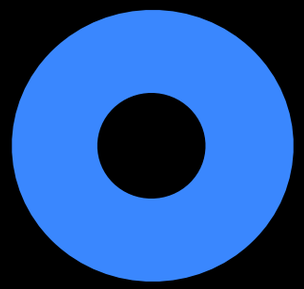


Beam with
Strehl>90%



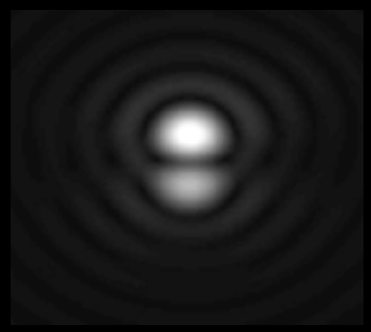
Phase mask
in image plane

Lens



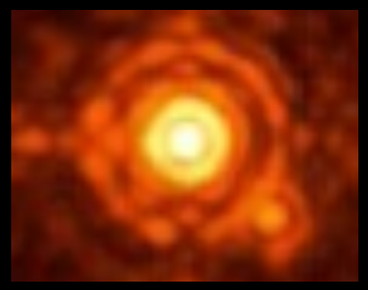
Spatial
filtering of
scattered
star-light

Lens

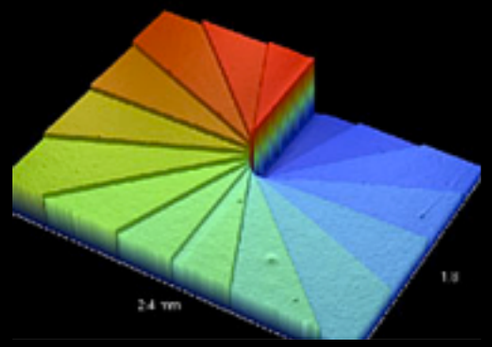


Filtered
Star image
with companion

Phase mask coronagraphs

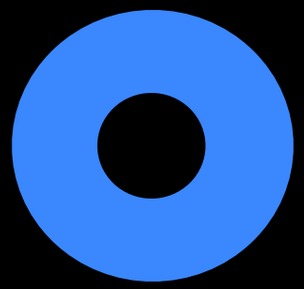


Beam with
Strehl>90%



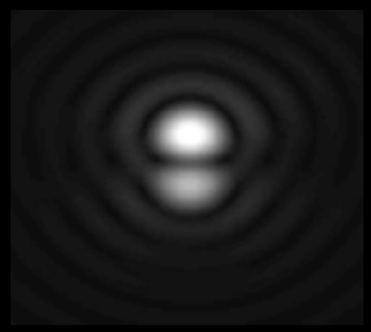
Phase mask
in image plane

Lens



Spatial
filtering of
scattered
star-light

Lens



Filtered
Star image
with companion

Types of phase mask coronagraphs:

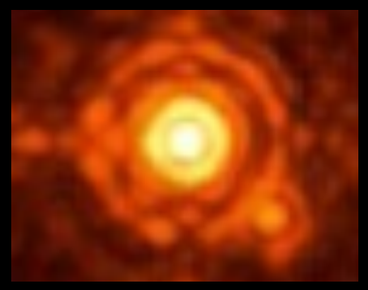
- Roddier nulling phase mask
[Roddier&Roddier PASP 109, 815 (1997)]

- Four quadrant phase mask
[Rouan et al. PASP 112, 1479 (2000)]

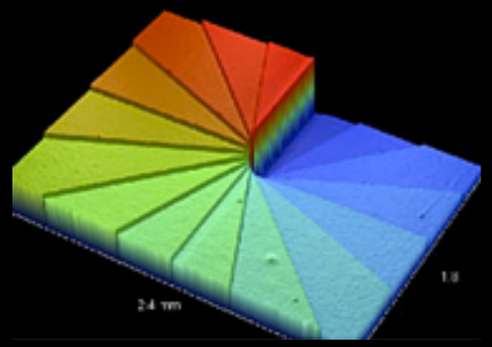
- Optical vortex mask (scalar)
[Foo et al. Opt. Lett. 30, 3308 (2005)]

- Optical vortex mask (vectorial)
[Mawet et al. Ap. J. 633, 1191 (2005)]

Phase mask coronagraphs

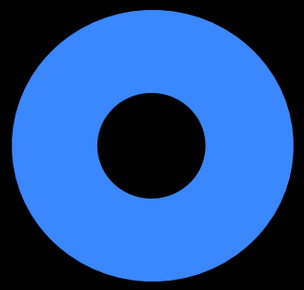


Beam with
Strehl>90%



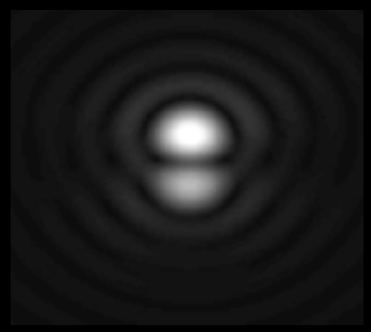
Phase mask
in image plane

Lens



Spatial
filtering of
scattered
star-light

Lens



Filtered
Star image
with companion

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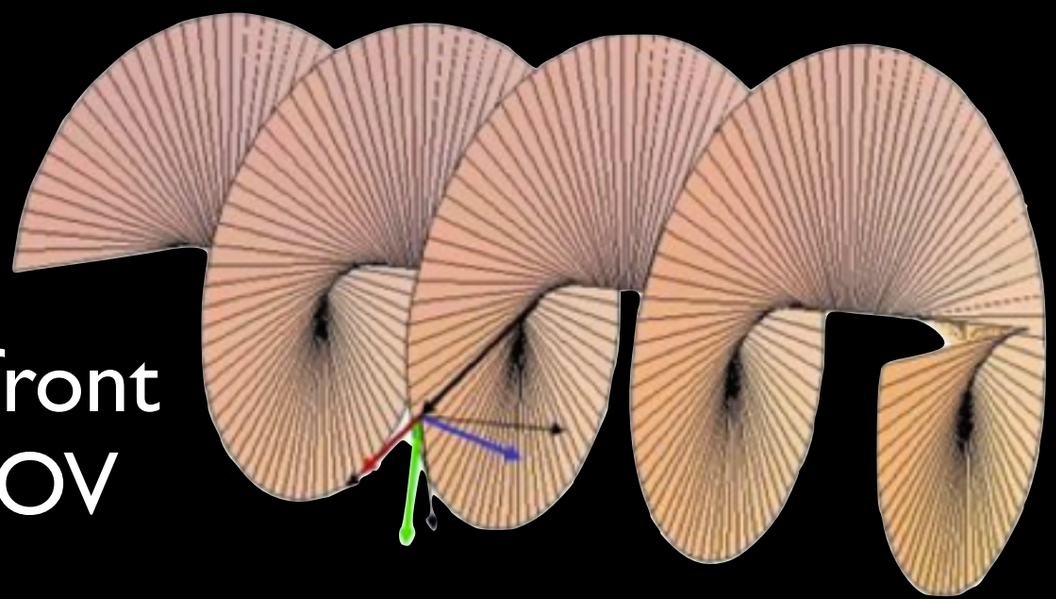
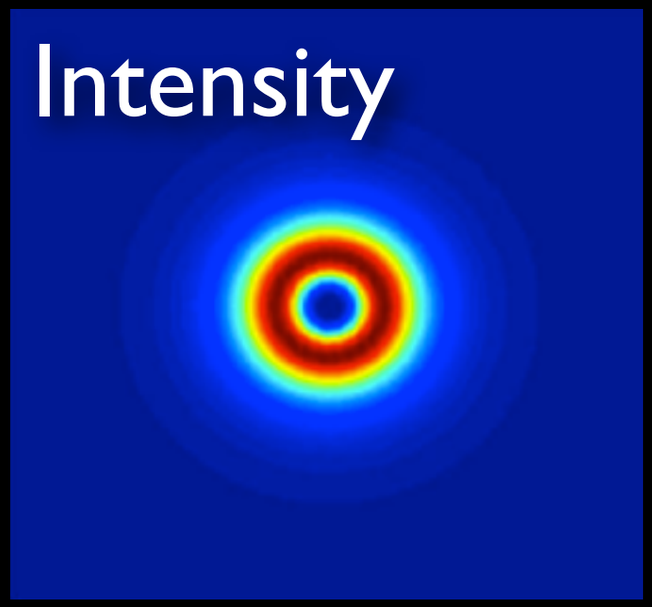
Large
discovery space

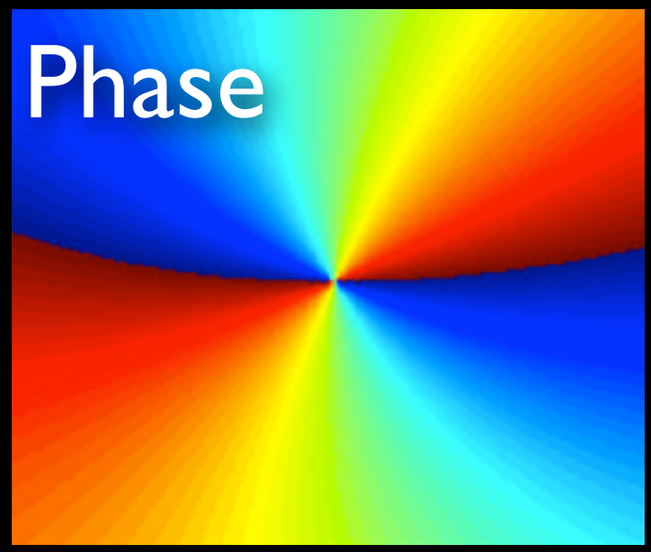
Optical Vortices

Phase front of an OV



E, B, k_{local}

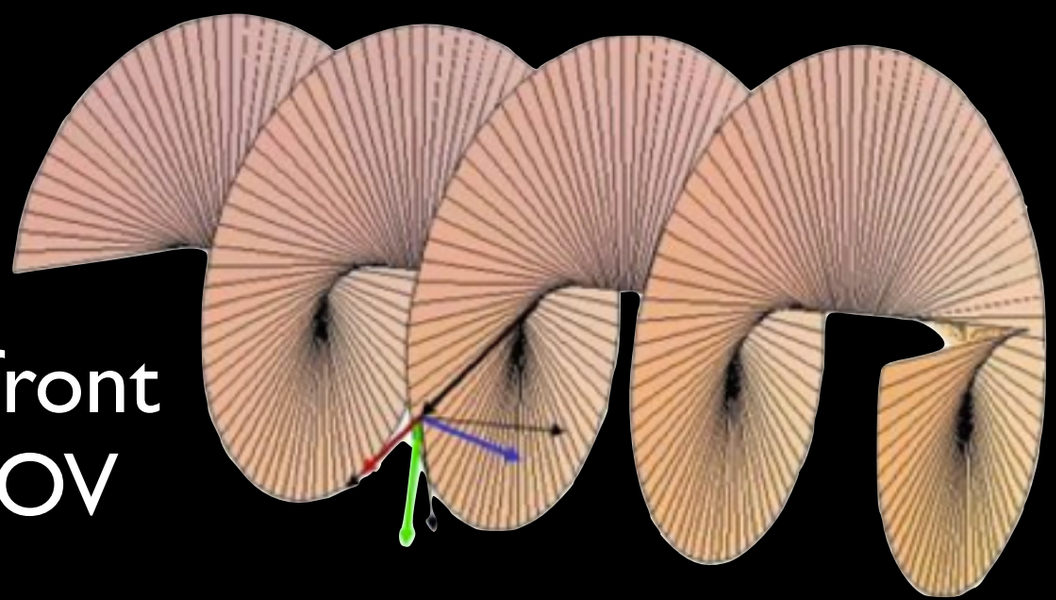




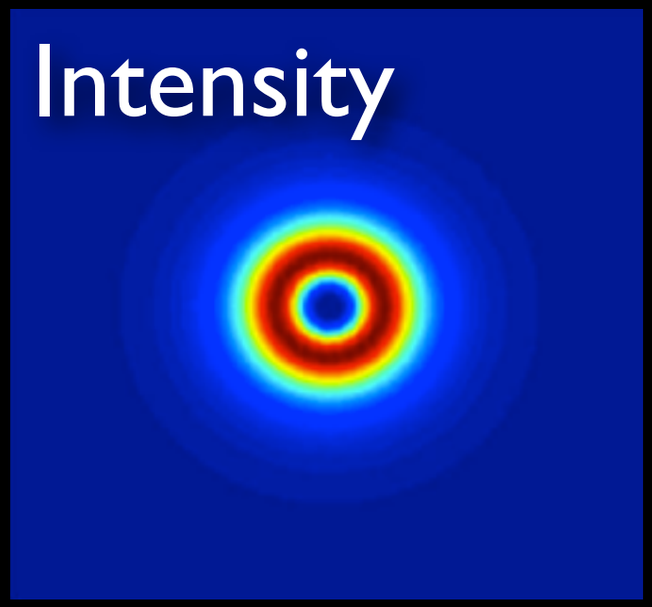
$$u(r,\theta,z) = A(r)e^{ikz}e^{im\theta}$$

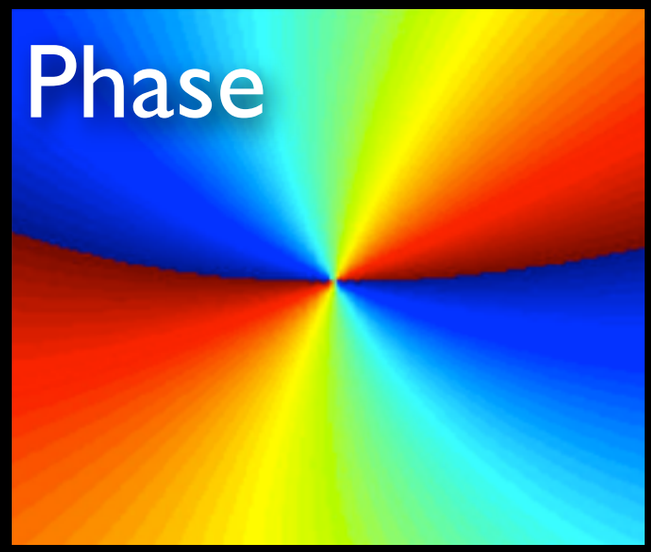
Optical Vortices

Phase front of an OV



E, B, k_{local}

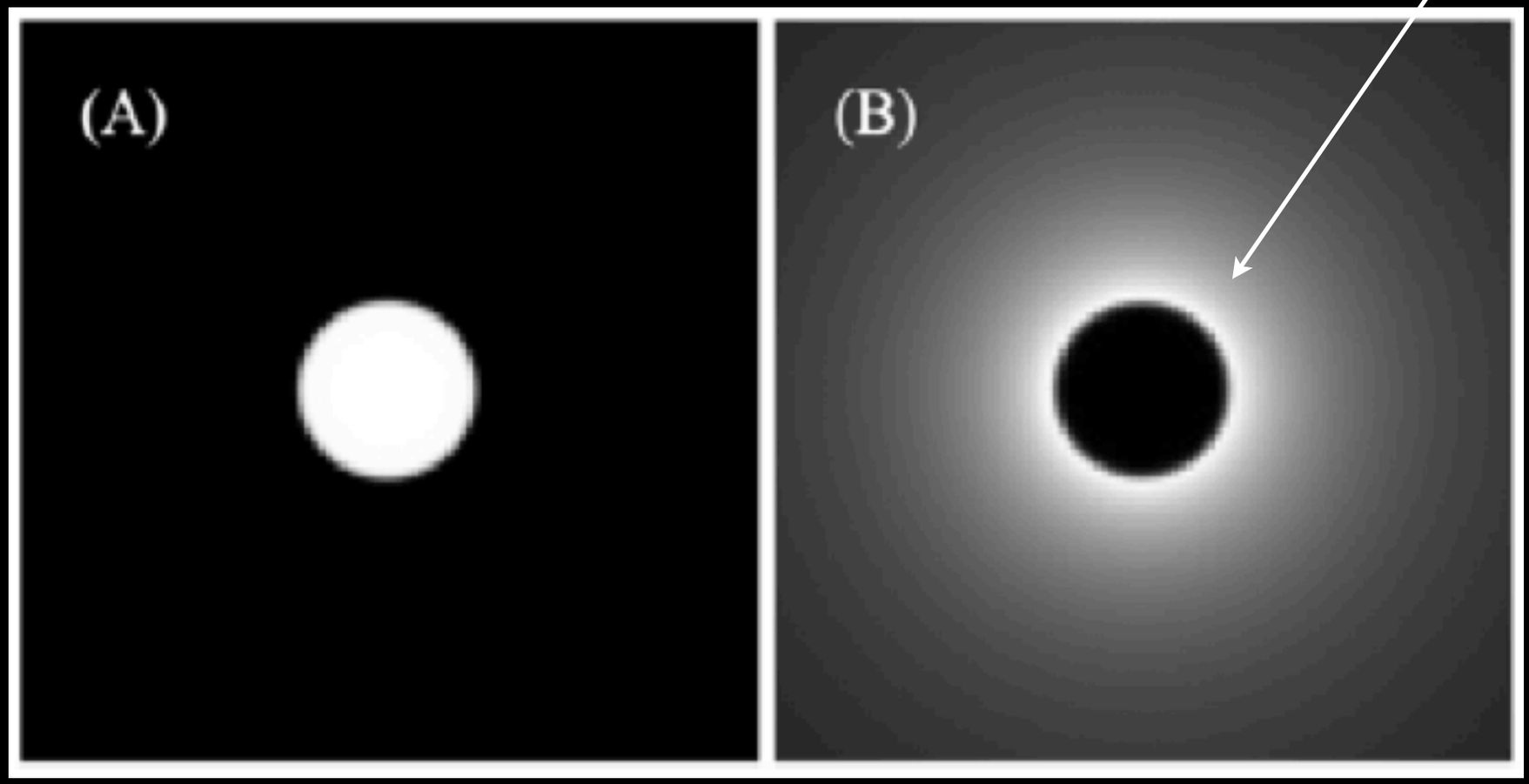




$$u(r,\theta,z) = A(r)e^{ikz}e^{im\theta}$$

Topological charge m

m=2 vortex coronagraph

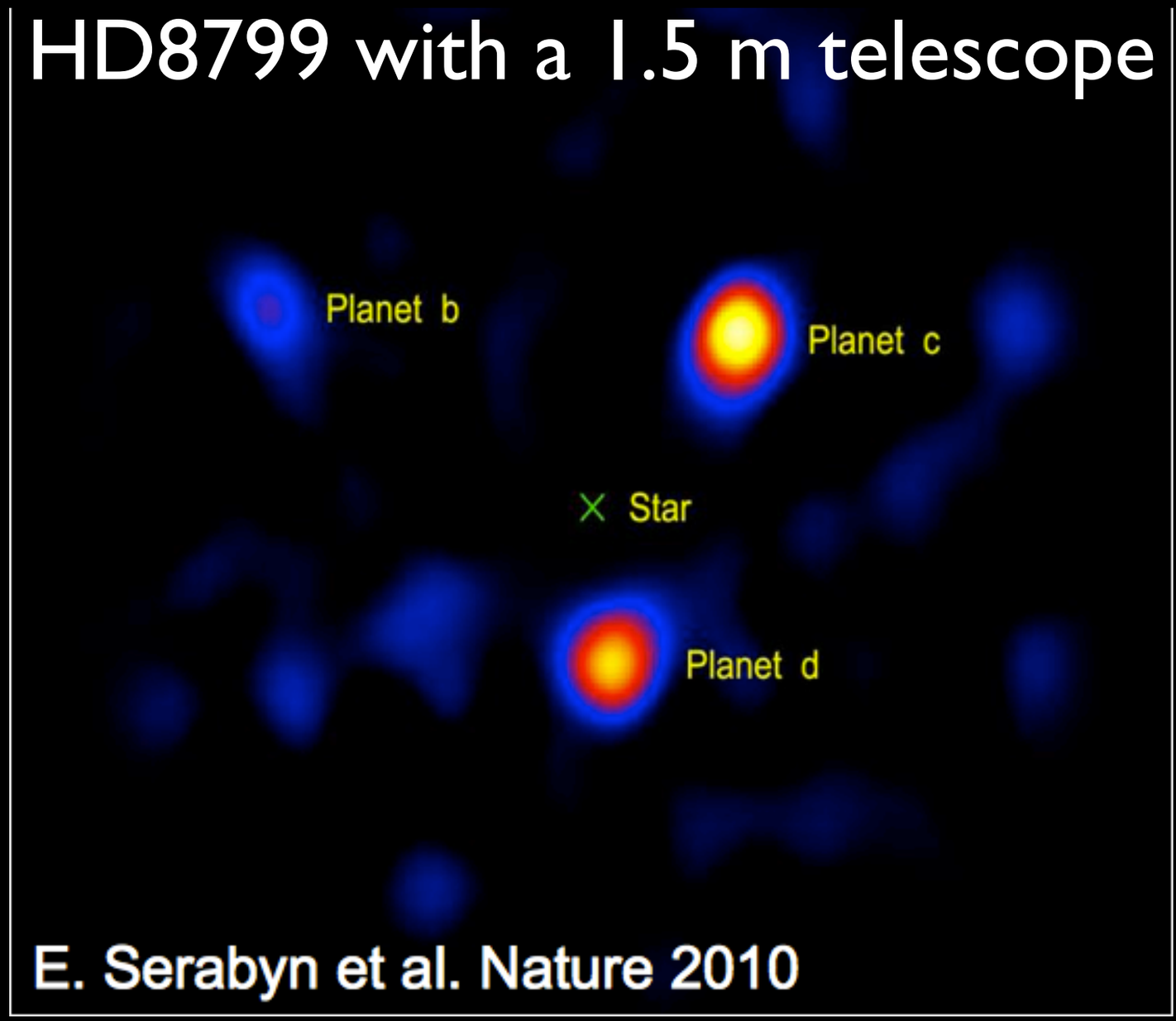


Input pupil Output pupil

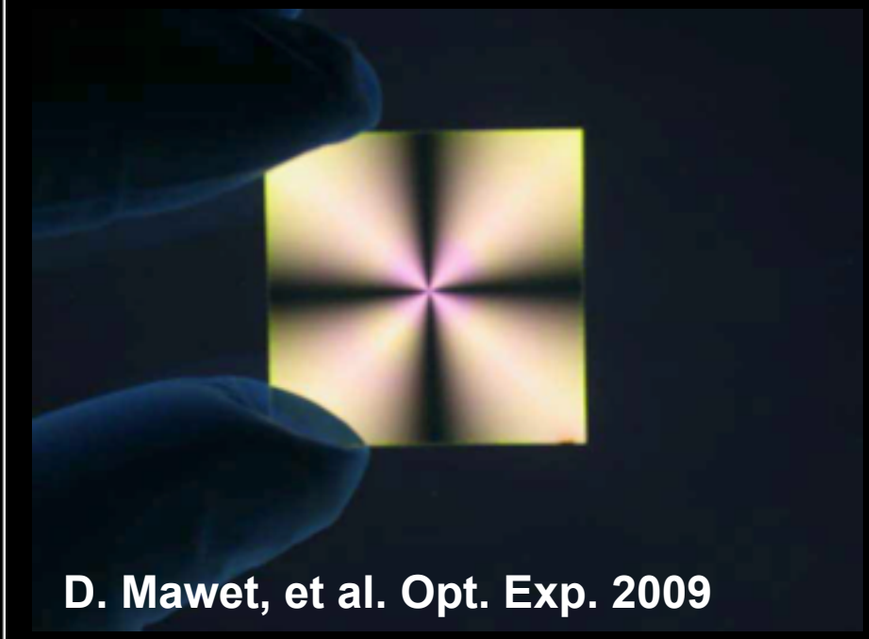
Reference: Mawet et al. ApJ 633, 1191 (2005)

The vectorial vortex coronagraph

HD8799 with a 1.5 m telescope



E. Serabyn et al. Nature 2010



D. Mawet, et al. Opt. Exp. 2009

The vectorial vortex coronagraph

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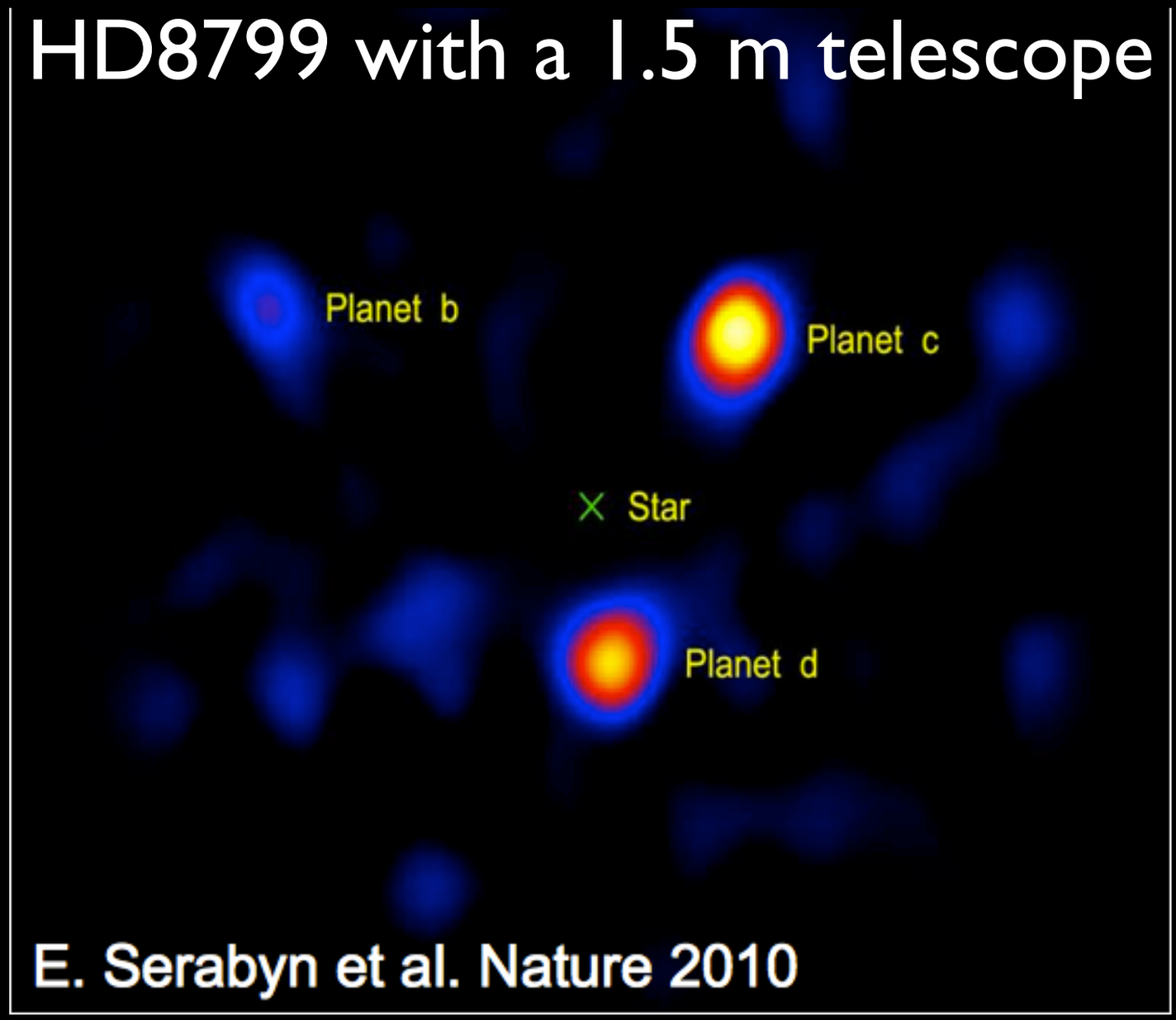
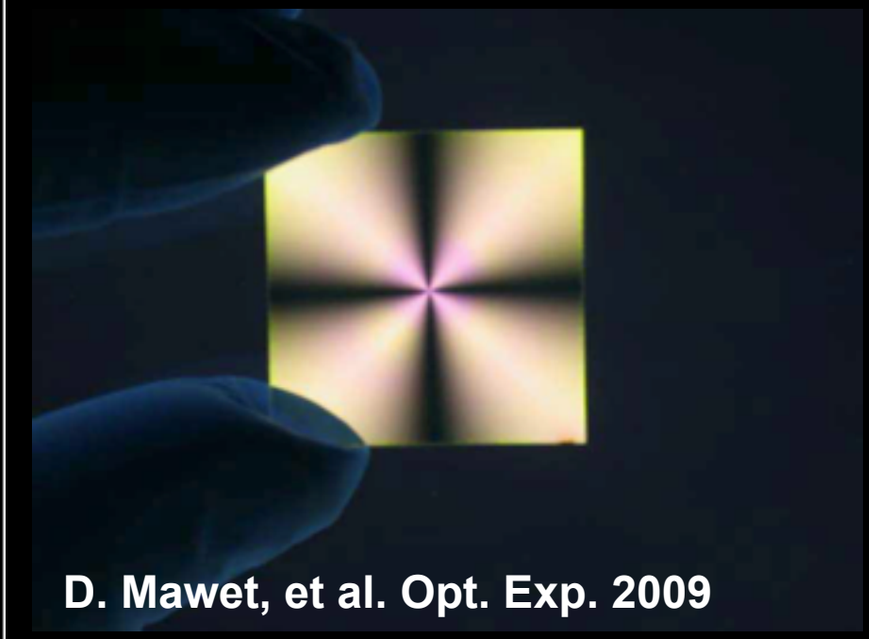


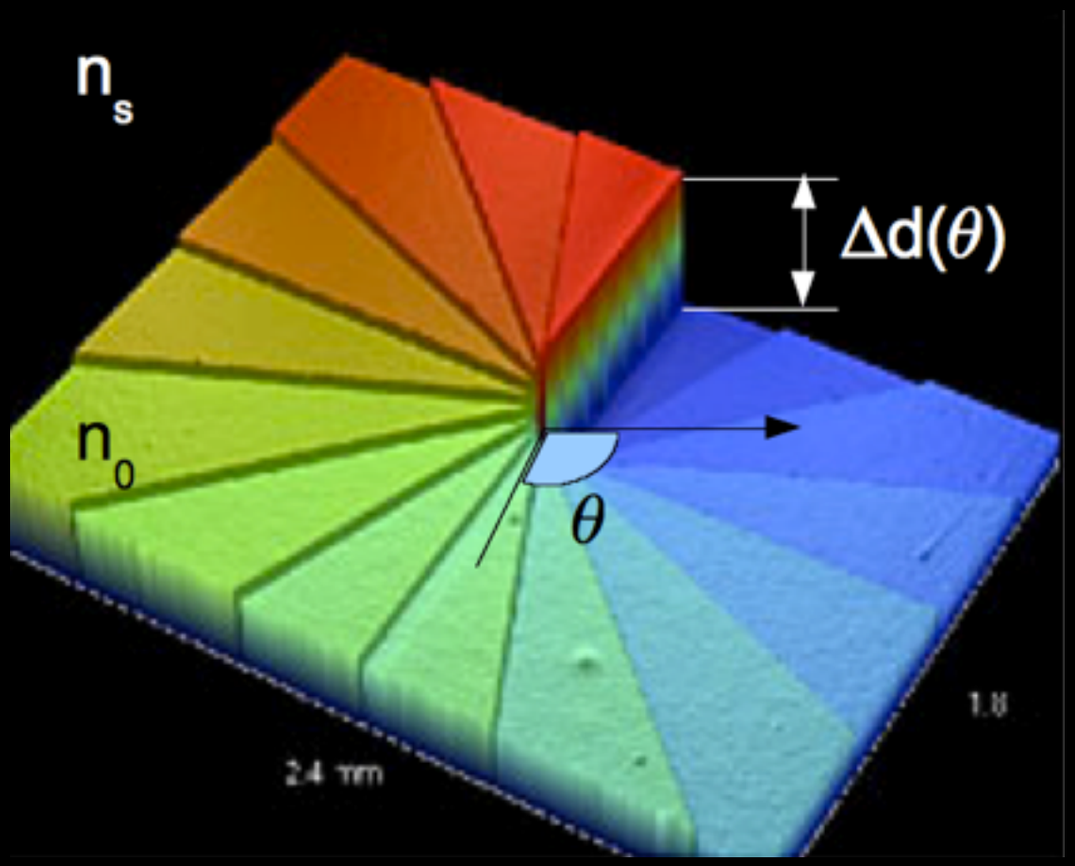


Demonstrated BB attenuation of 2×10^{-3} (in lab)

Focal plane AO may be difficult to implement due to vectorial nature

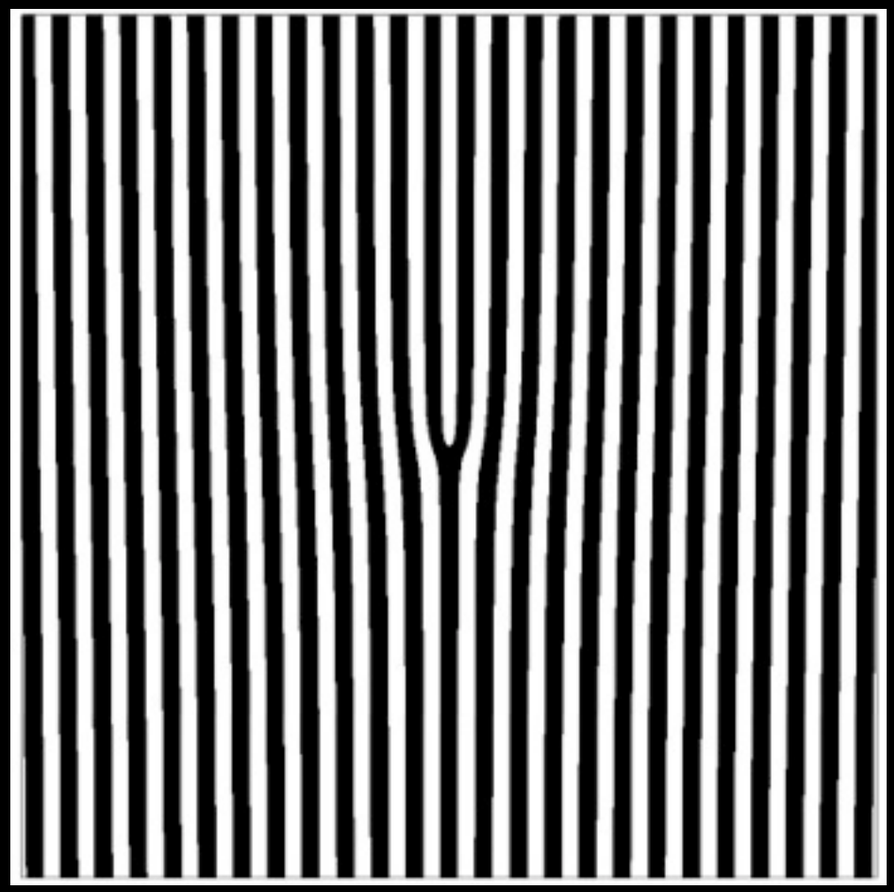
The scalar vortex generation

Corkscrew phase plate



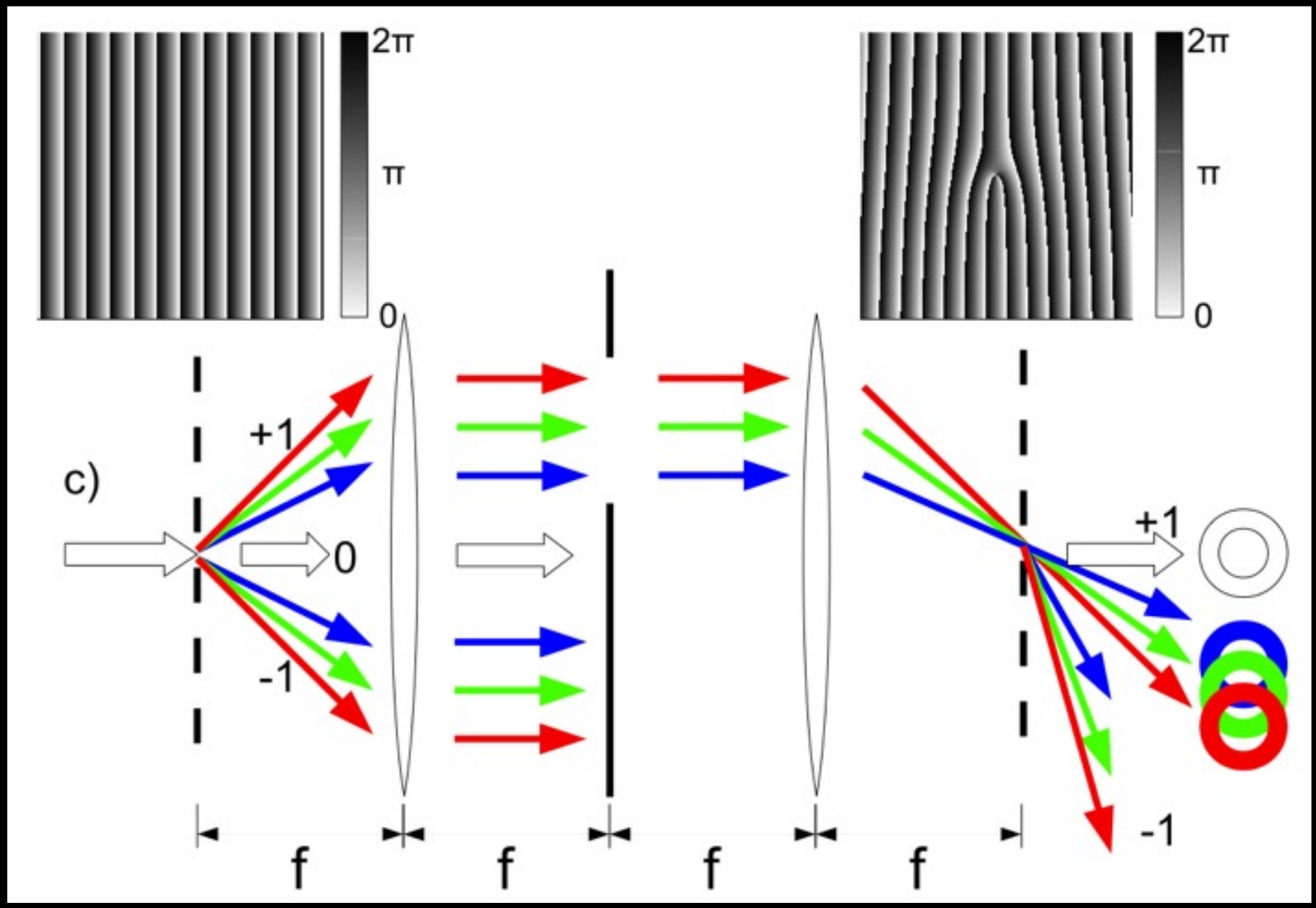
Highly Chromatic
Output: mixture of vortices

Fork hologram



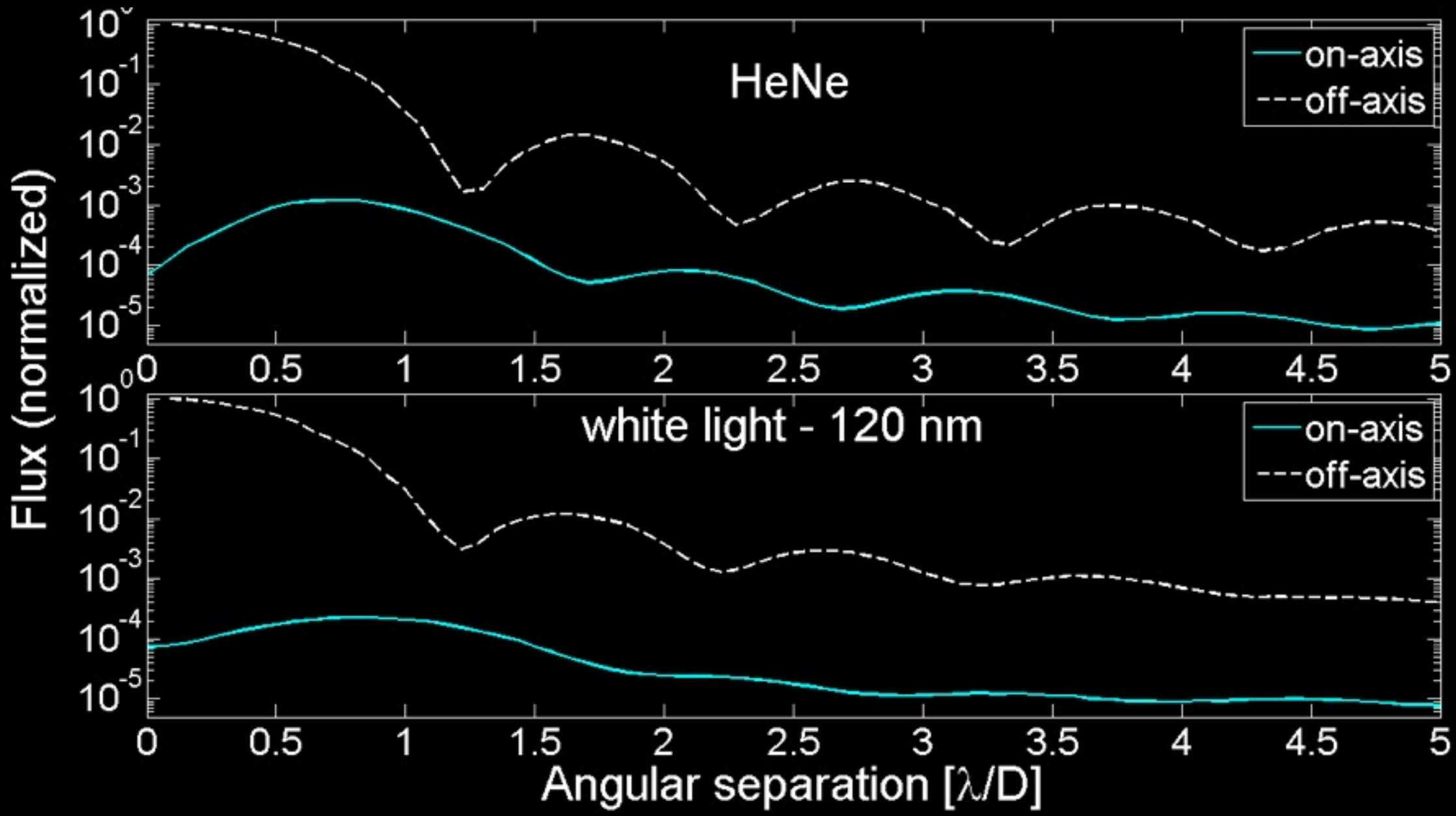
Highly Chromatic
Output: angularly dispersed vortices

Broadband scalar vortex generation



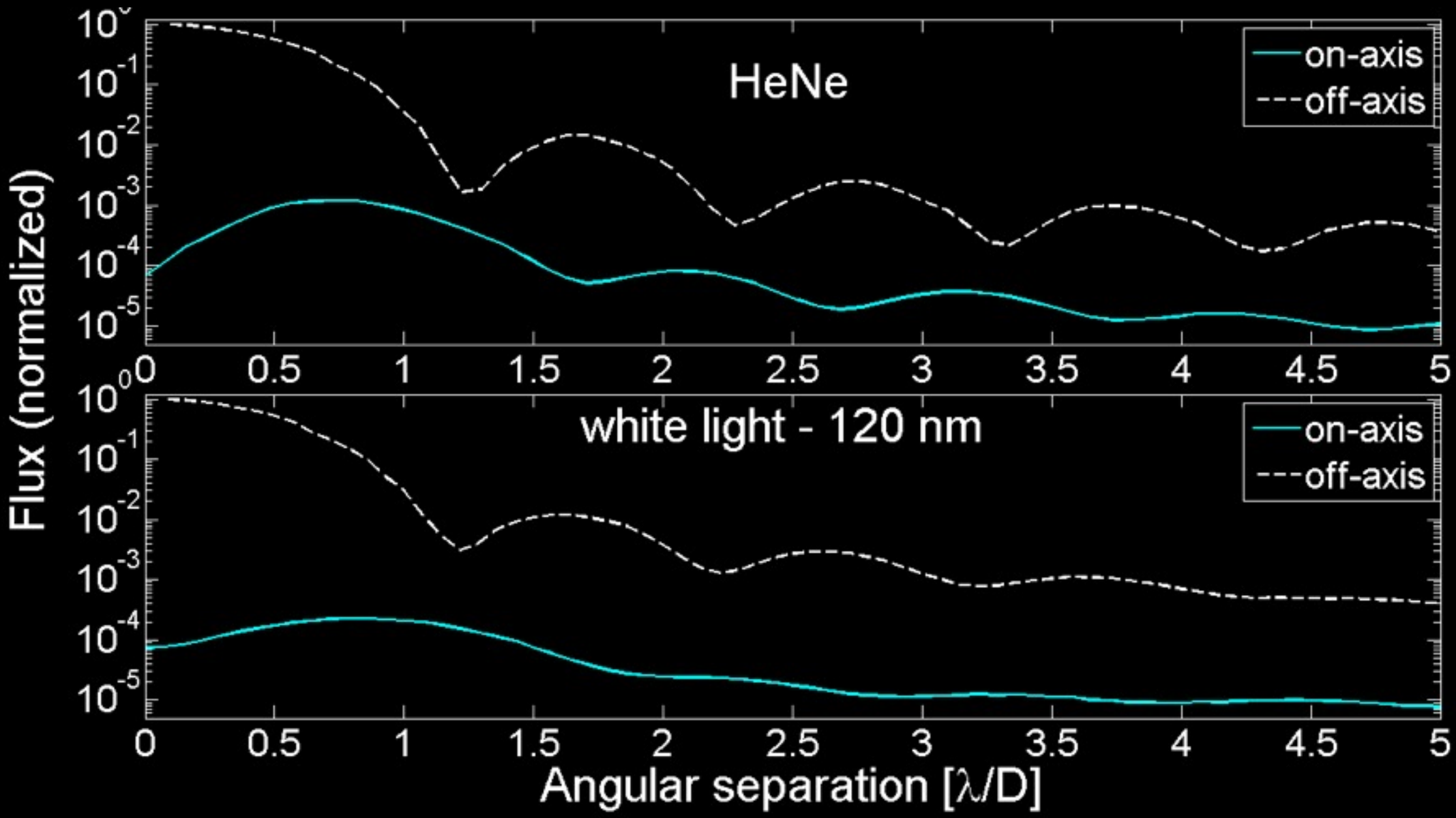
Same method as for the excitation of vortices nested in femtosecond pulses [see Opt. Lett. 29, 1942 (2004)]

Peak-to-peak contrast



Errmann, Minardi, Pertsch MNRAS 435, 565 (2013)

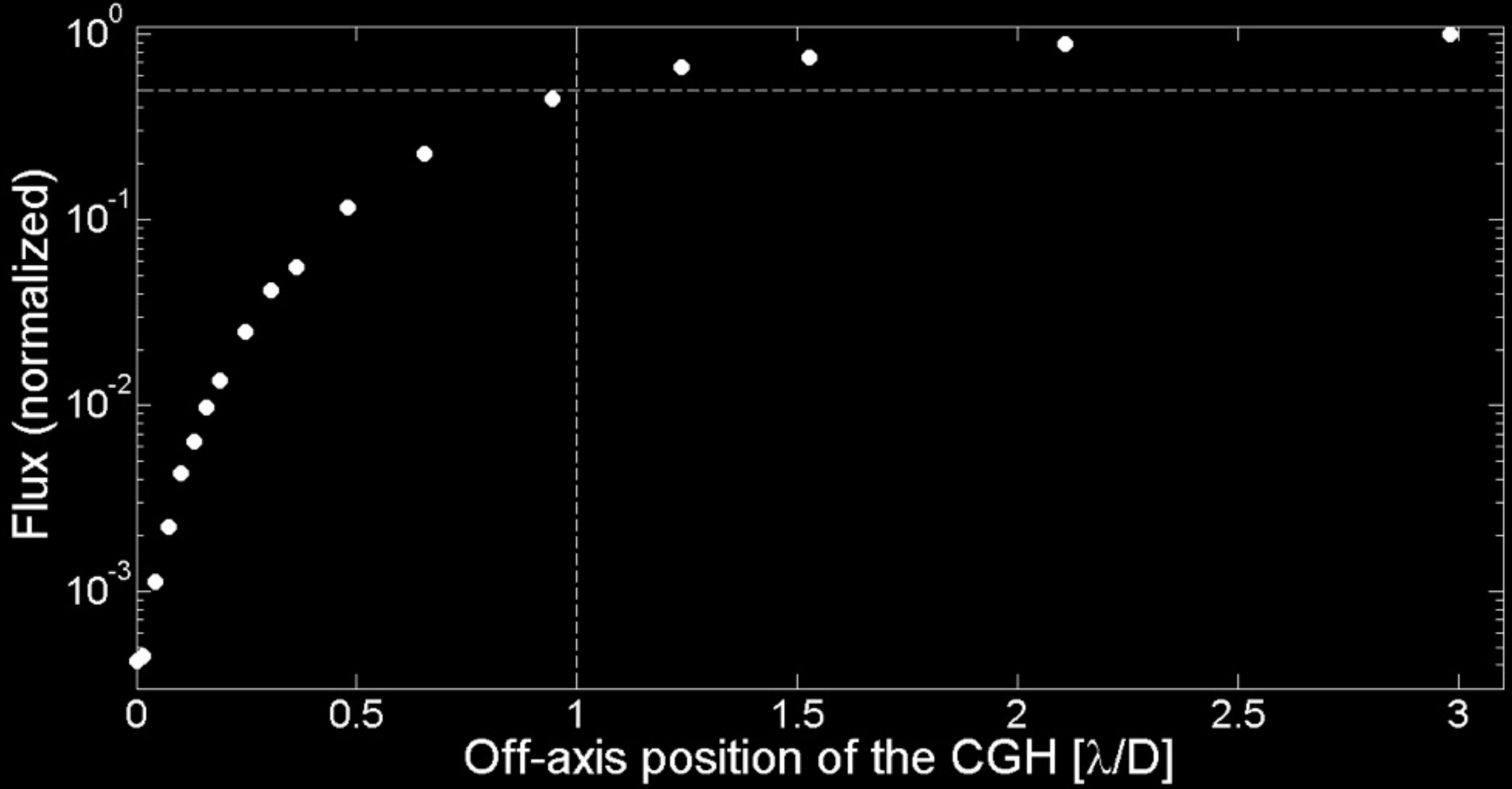
Peak-to-peak contrast



Raw attenuation $3 \cdot 10^{-4}$ over 120 nm at 650 nm

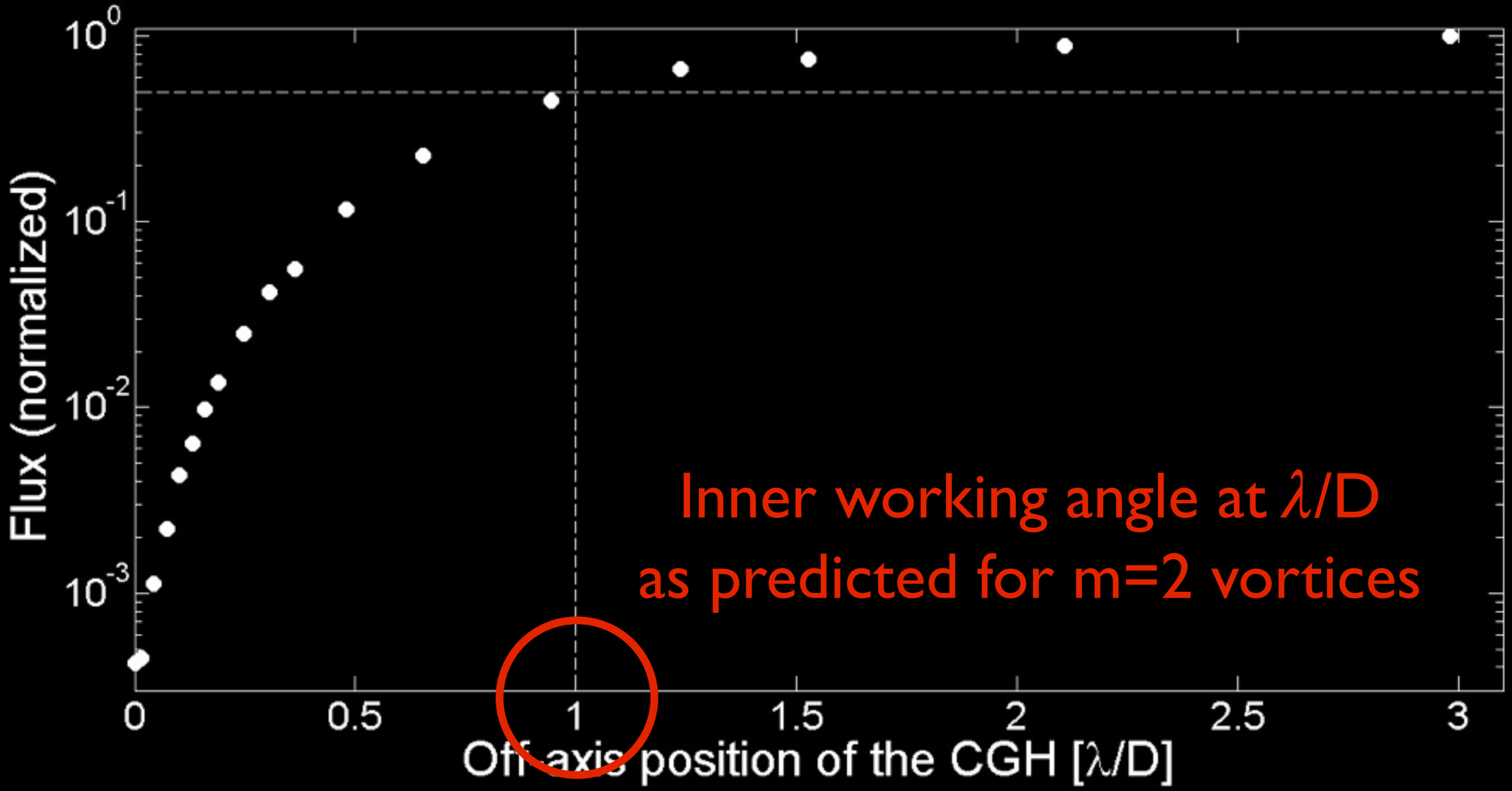
Errmann, Minardi, Pertsch MNRAS 435, 565 (2013)

Inner working angle



Errmann, Minardi, Pertsch MNRAS 435, 565 (2013)

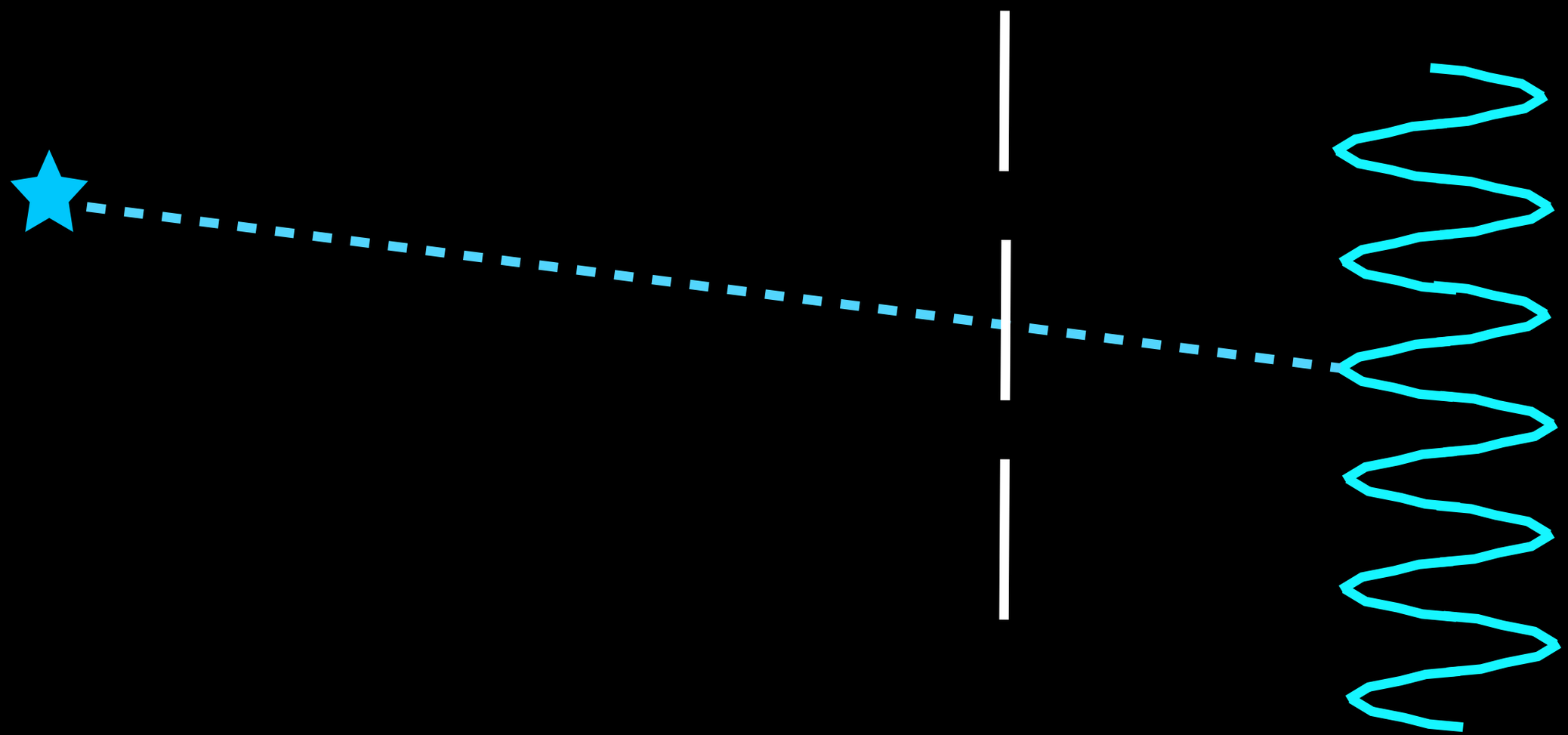
Inner working angle



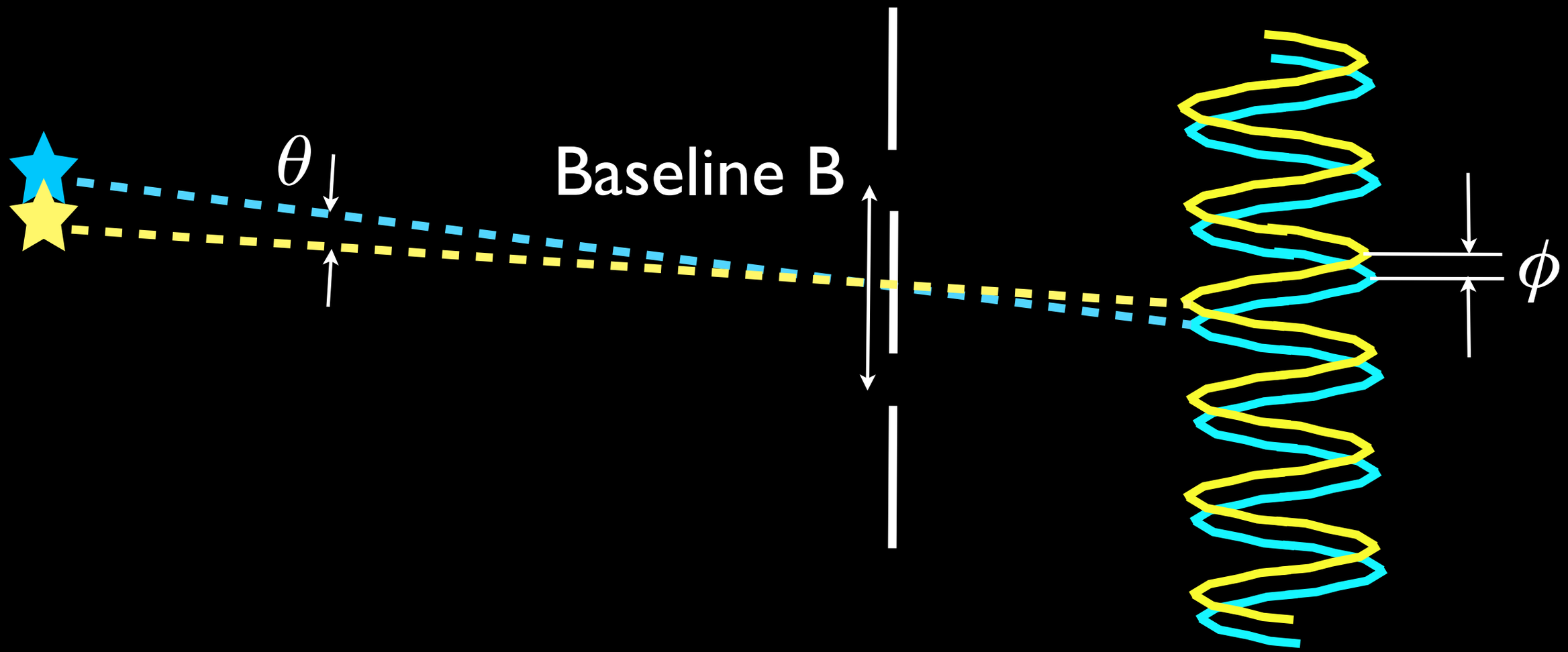
Errmann, Minardi, Pertsch MNRAS 435, 565 (2013)

Photonics for nulling interferometry

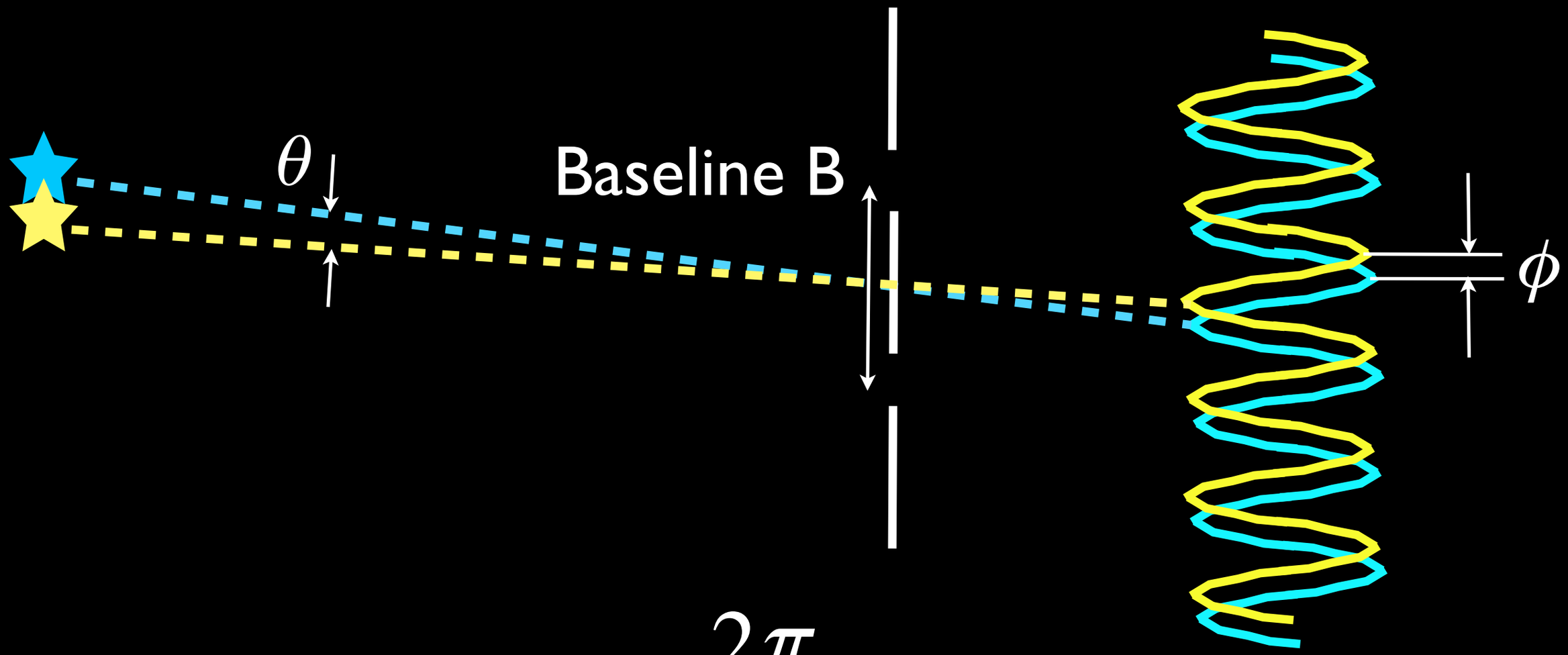
Principles of interferometry



Principles of interferometry



Principles of interferometry



$$\phi \simeq \frac{2\pi}{\lambda} B\theta$$

Phase shift of fringes proportional to angular separation of point sources

Principles of nulling interferometry

Let's imagine that the separation of the planet is such that the maxima of the companion (planet) correspond to the minima of the star (planet fringes out of phase respect to star fringes)...

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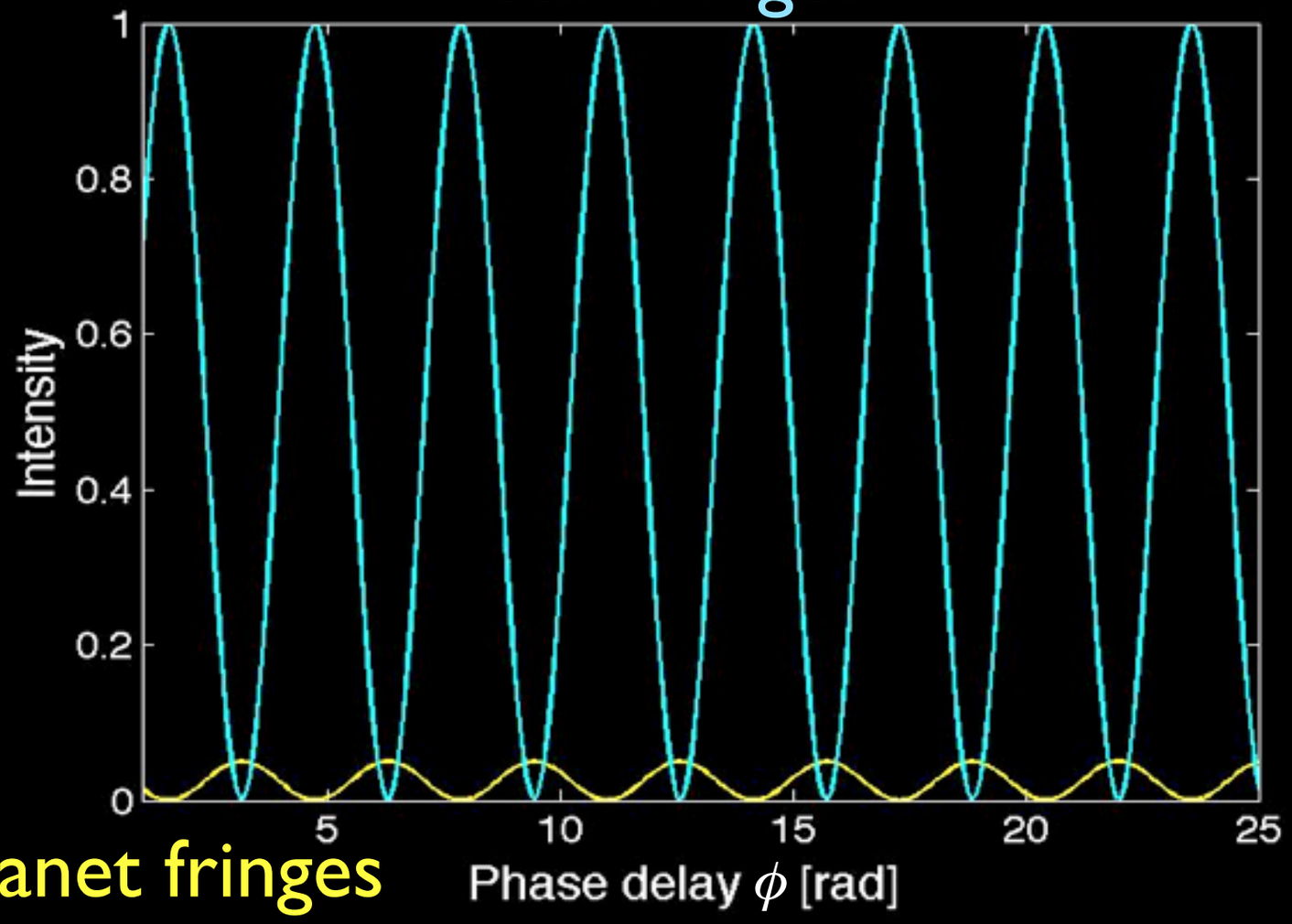
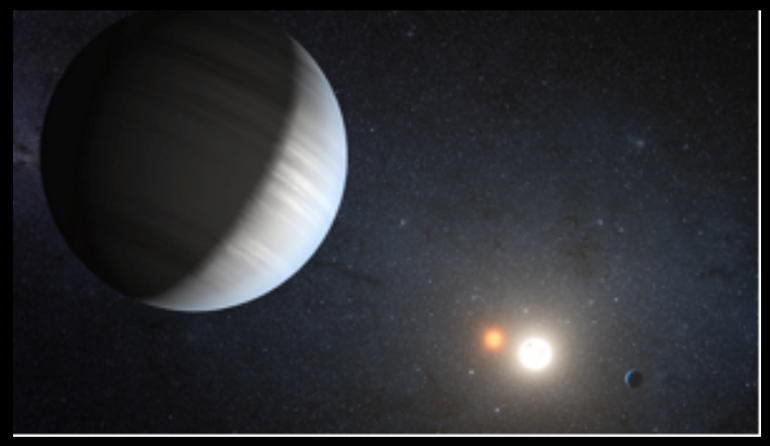
Star fringes



Planet fringes



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- 100% light of planet observed!
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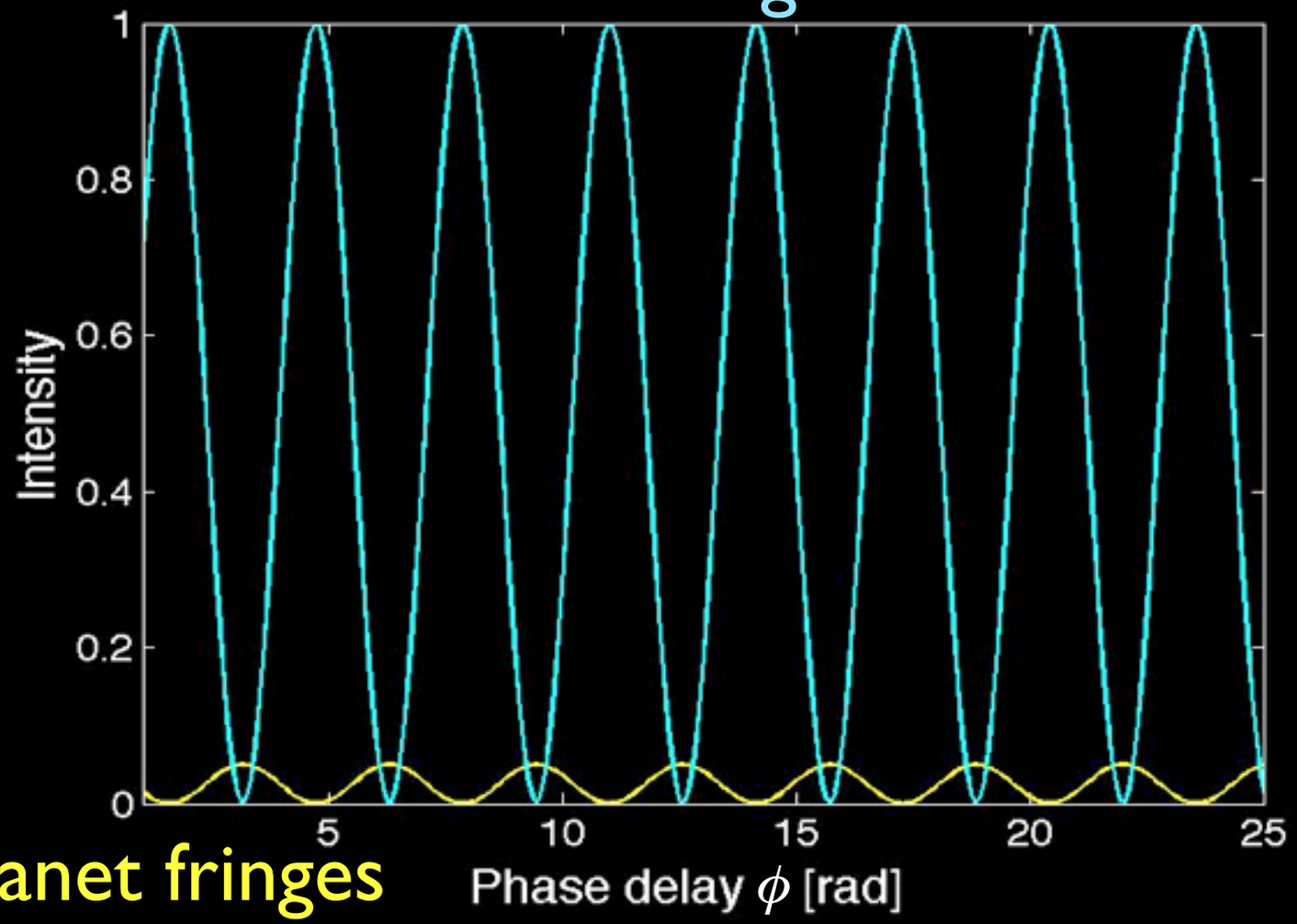

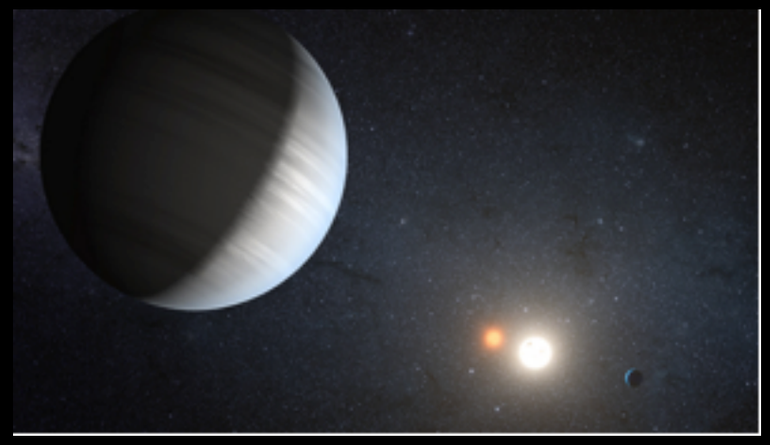

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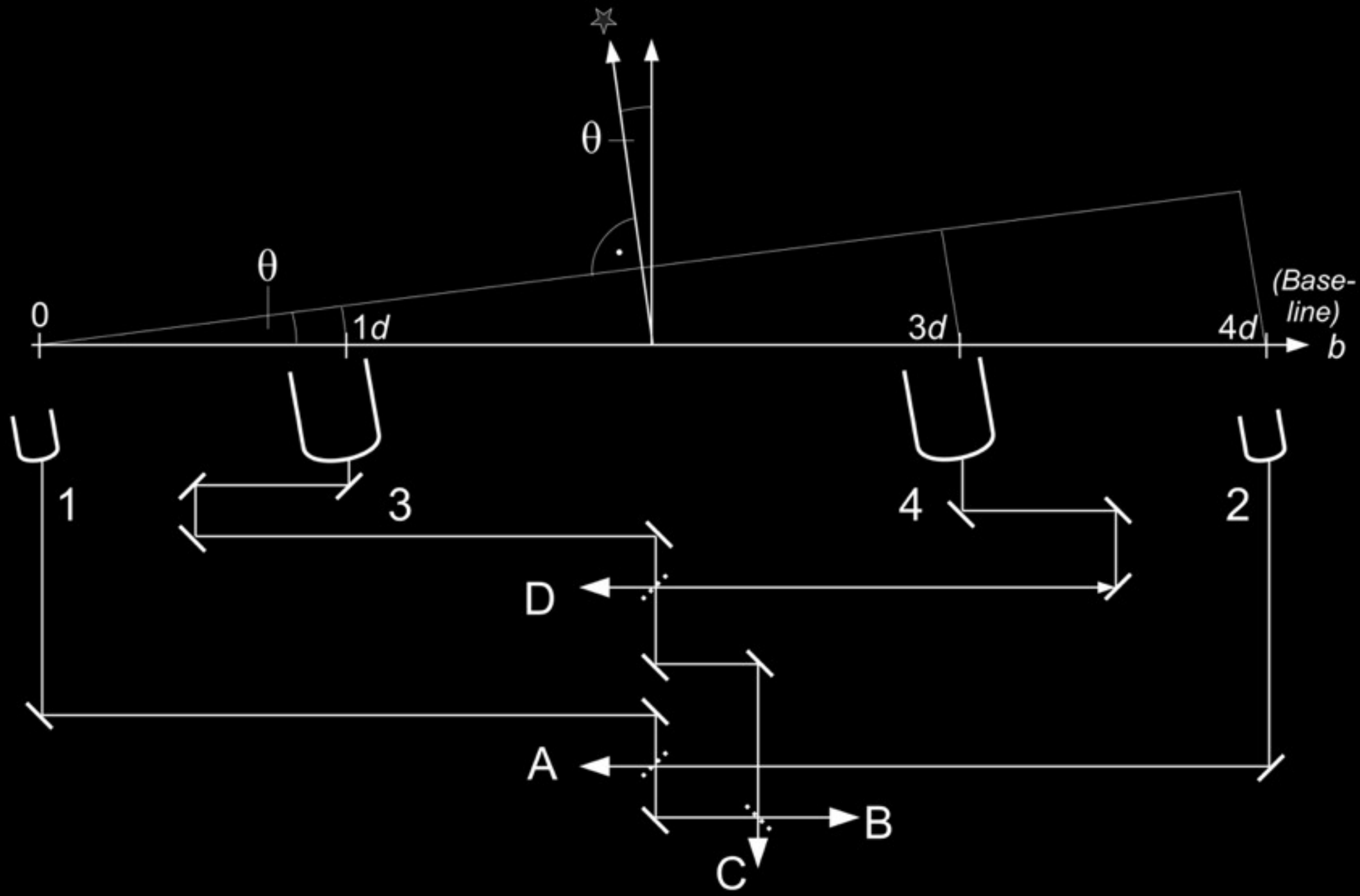
Nulling is the equivalent of coronagraphy for the interferometry technique

Reference: Bracewell 1978

Multiple telescope nulling



Reference: Angel&Wolf ApJ 475,373 (1997)

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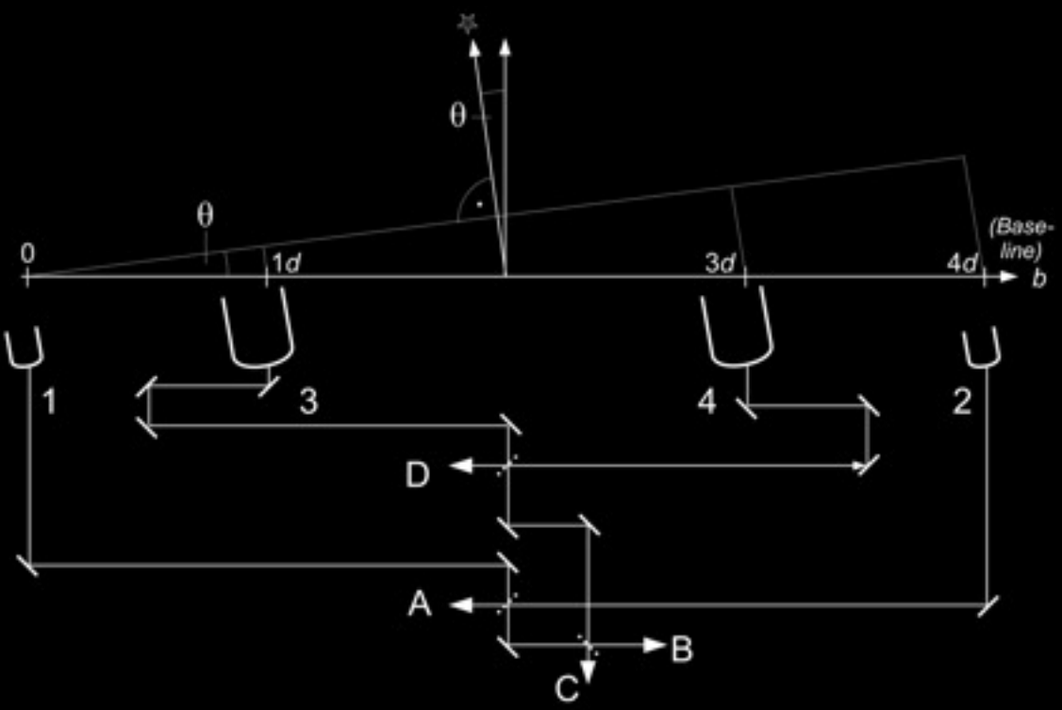

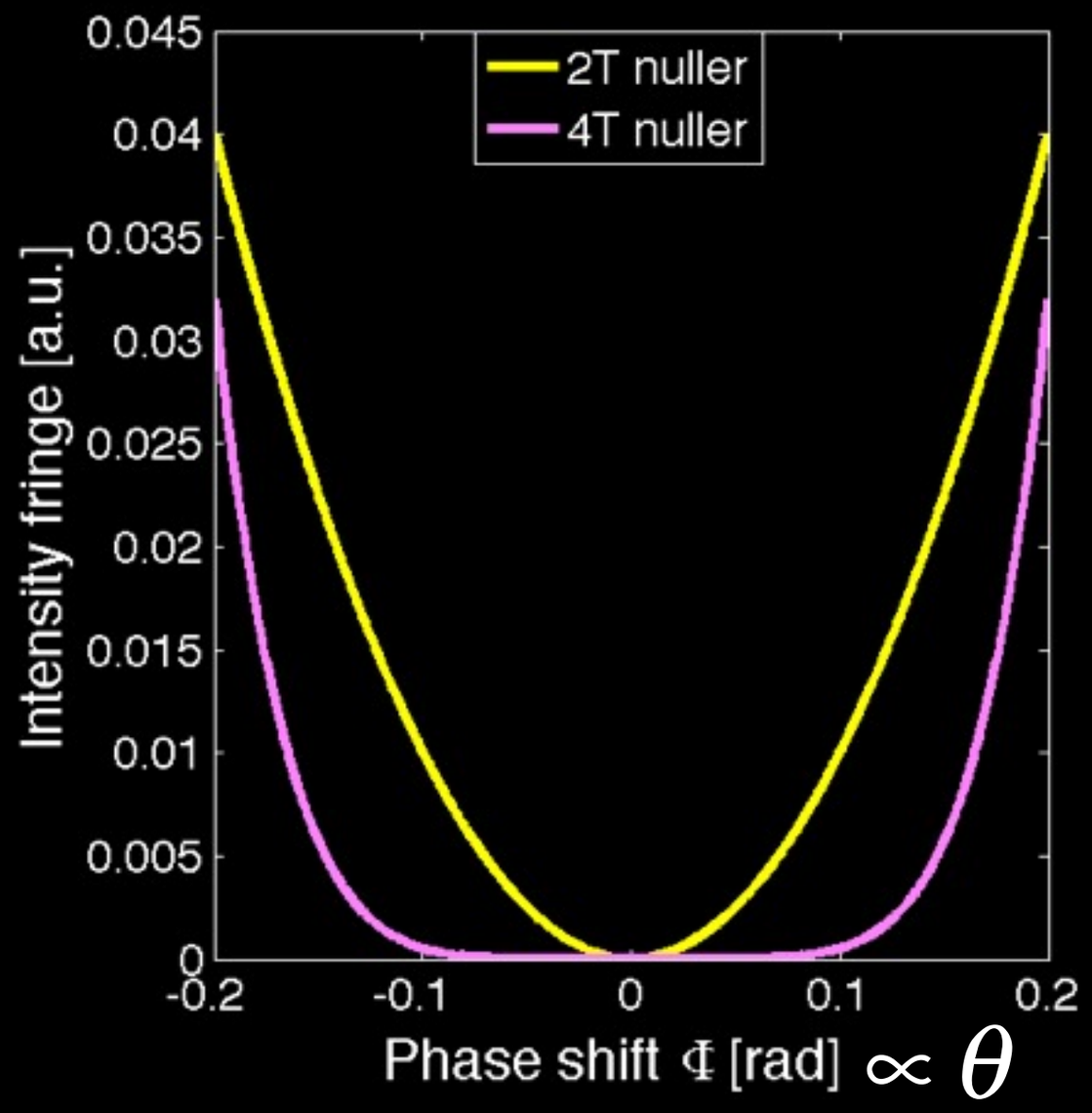

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Integrated optics 4T nuller

Motivation: modal filtering is expected to yield deep nulls

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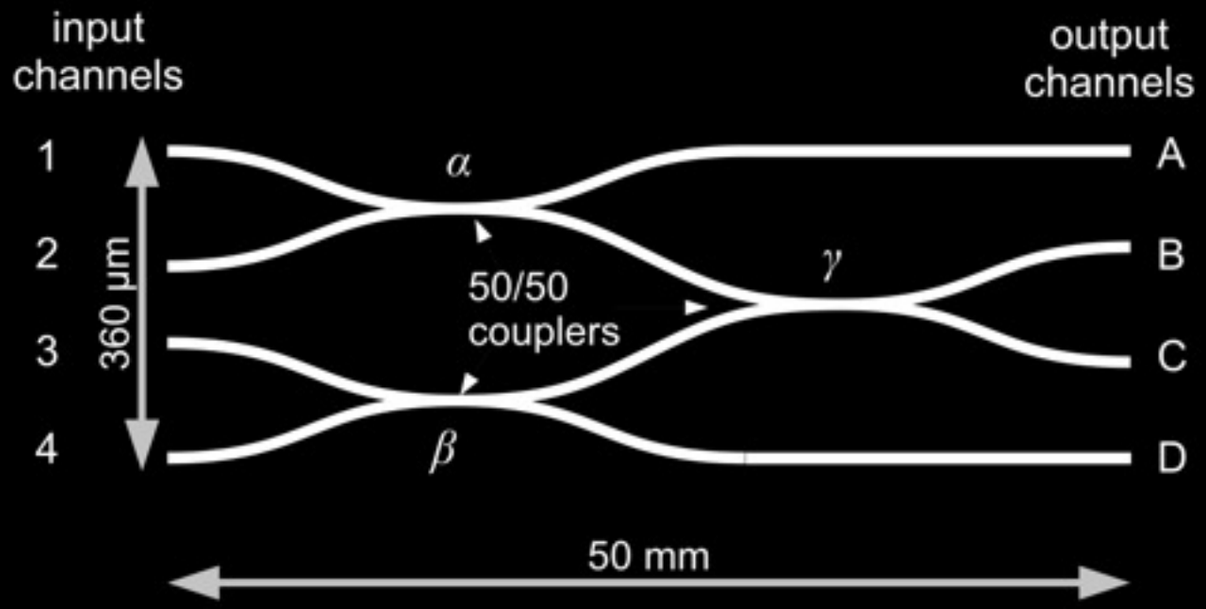

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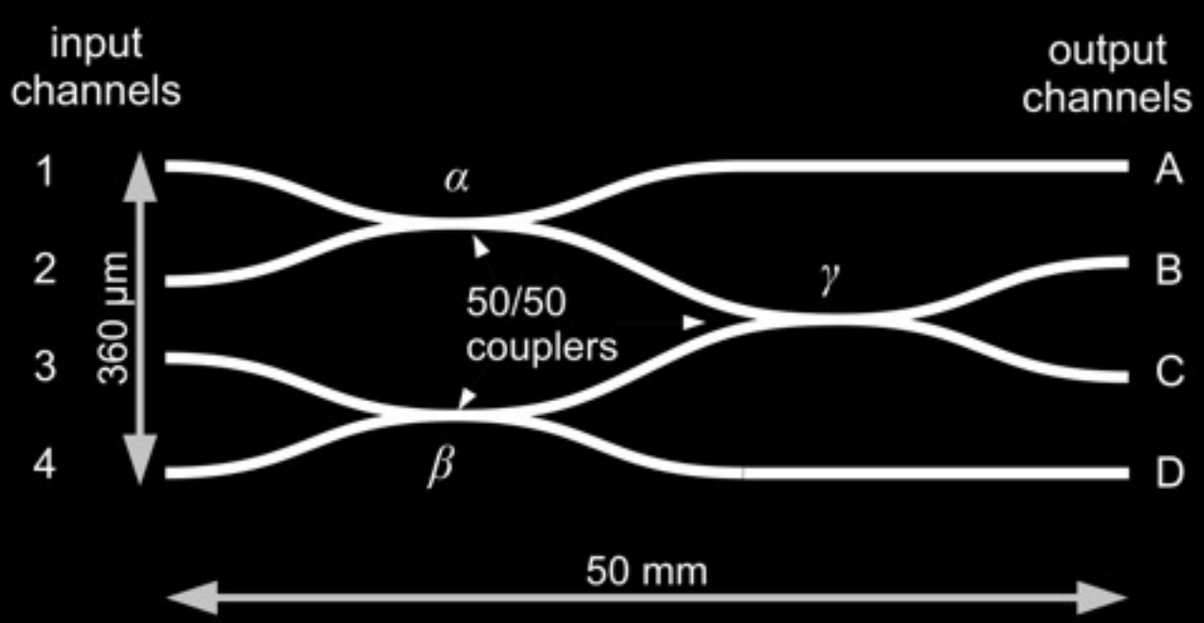

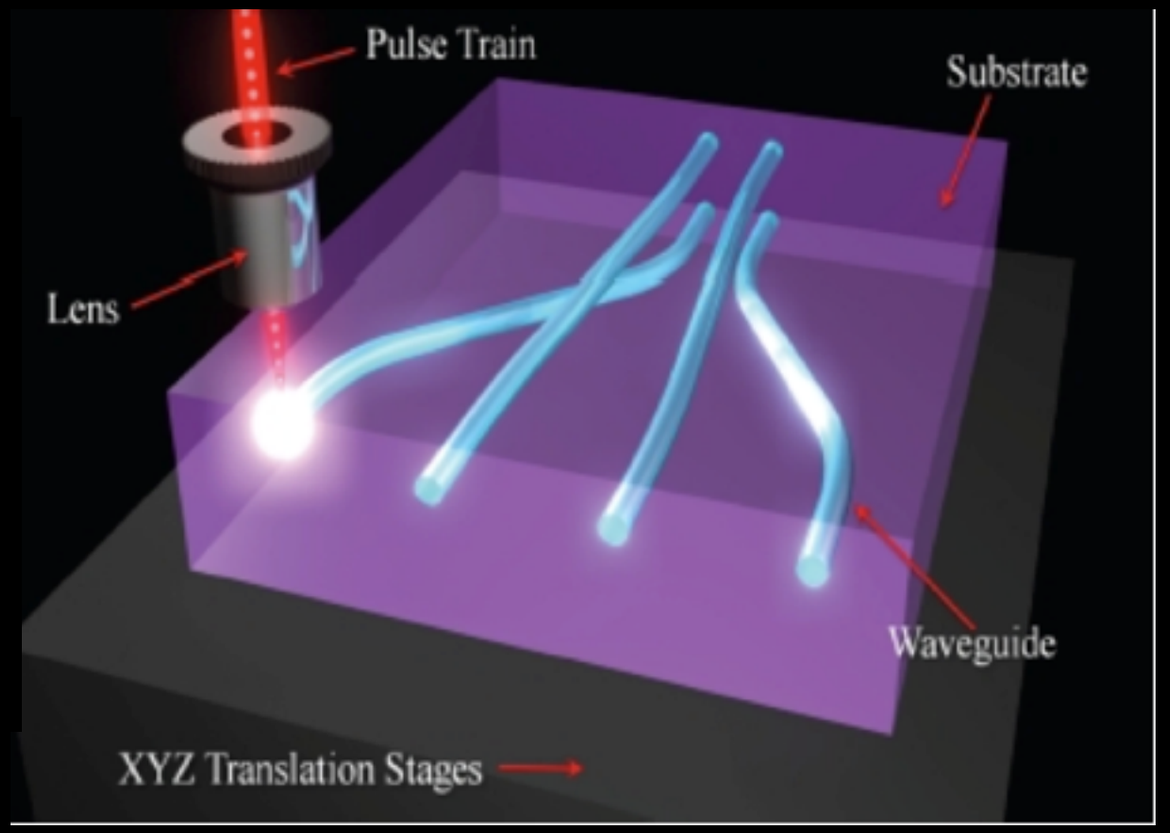

1) ~100 fs laser pulses are tightly focused in a transparent material.

2) The laser induces a permanent modification of the material with variation of refractive index.

3) Positive variations of the refractive index are suitable for waveguide writing.

Test of the IO 4T nuller

- Proof-of-principle experiments in monochromatic light (633 nm)
- Simulation of angular transmission through phase modulation

Errmann, Minardi, Labadie et al. SPIE 9146-77 (2014)

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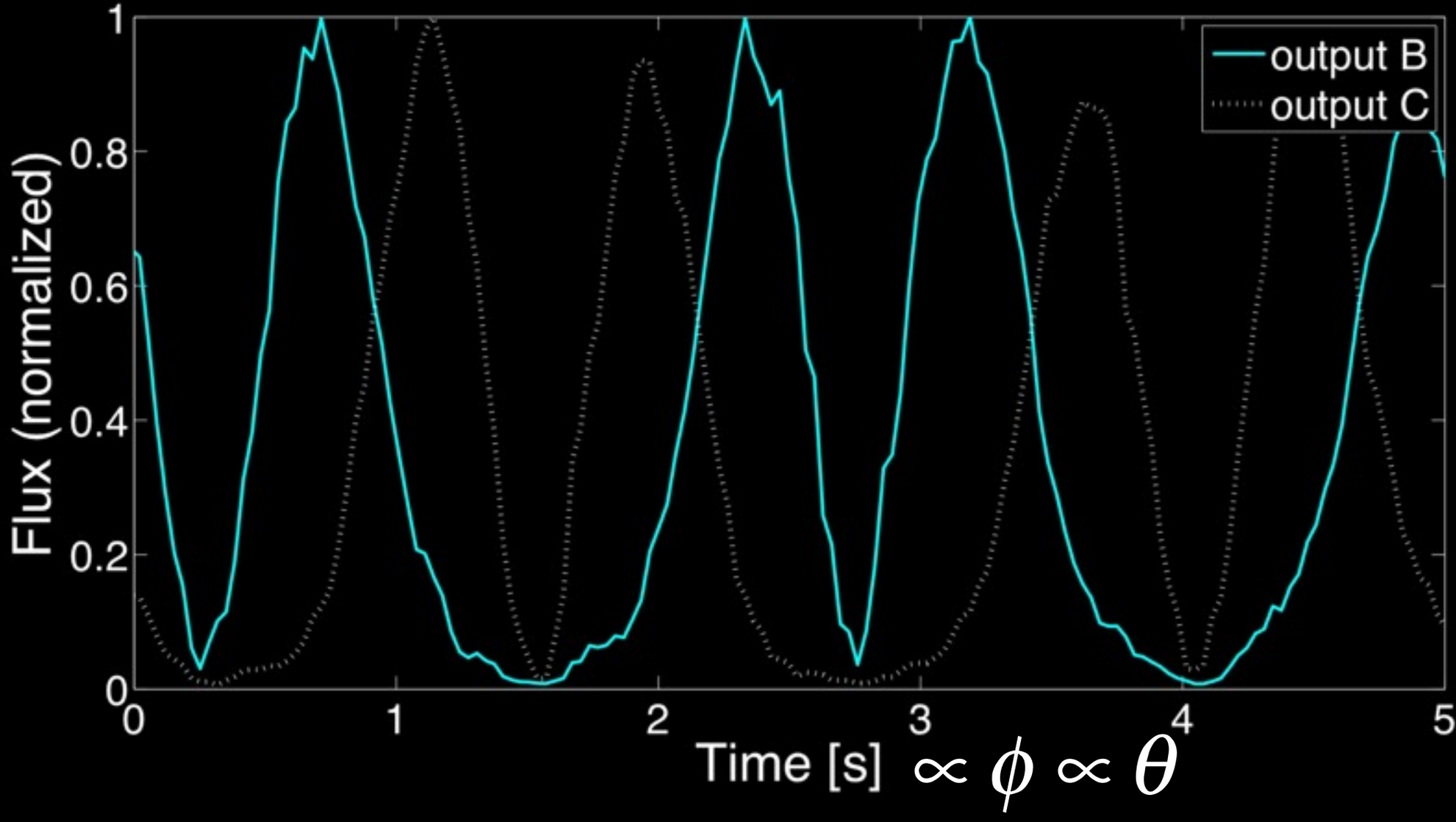

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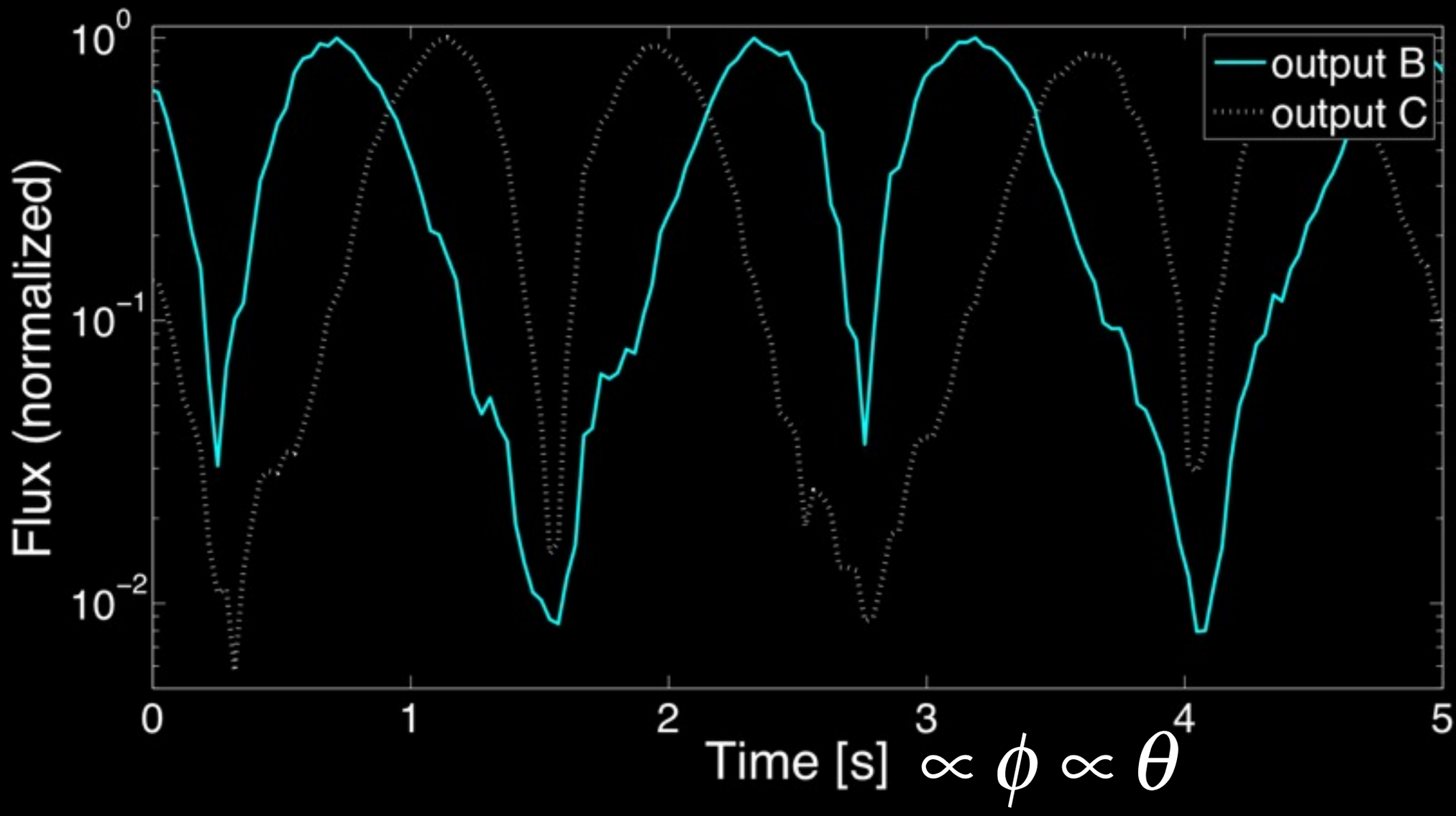

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Conclusions/Outlook

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Coronagraphy:

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