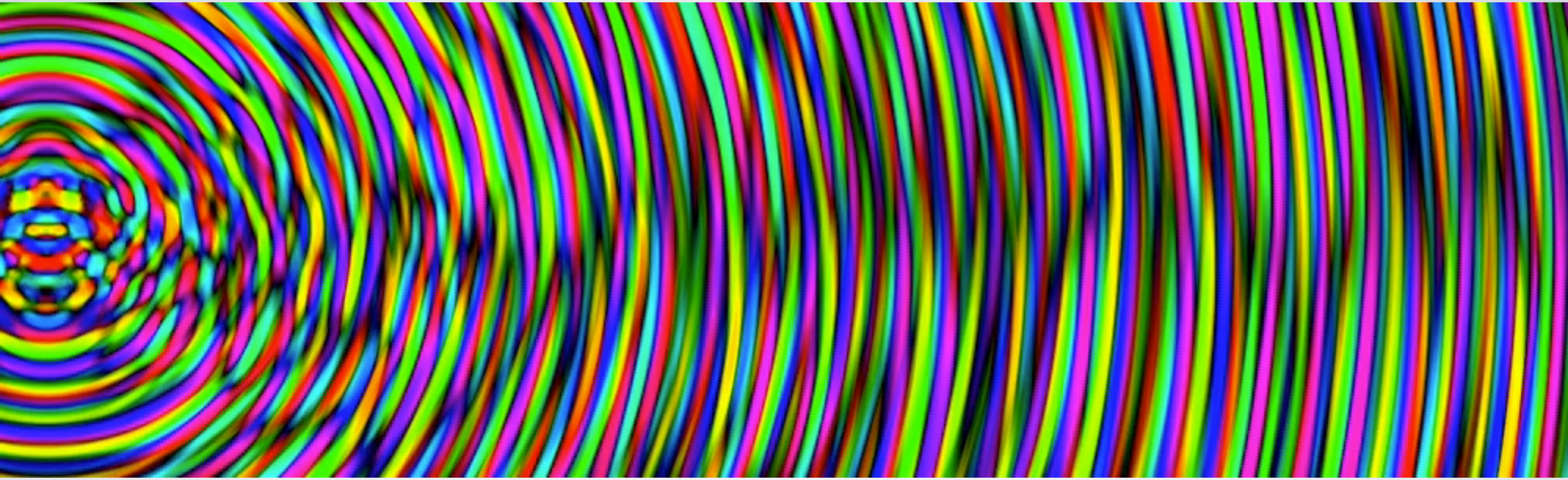
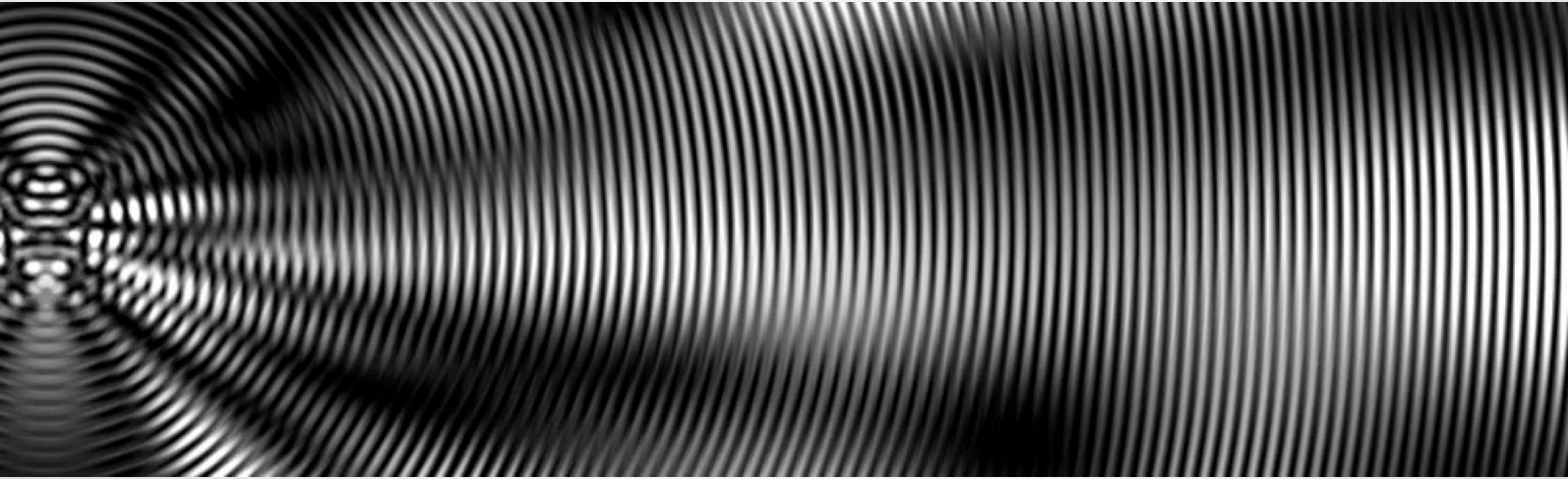
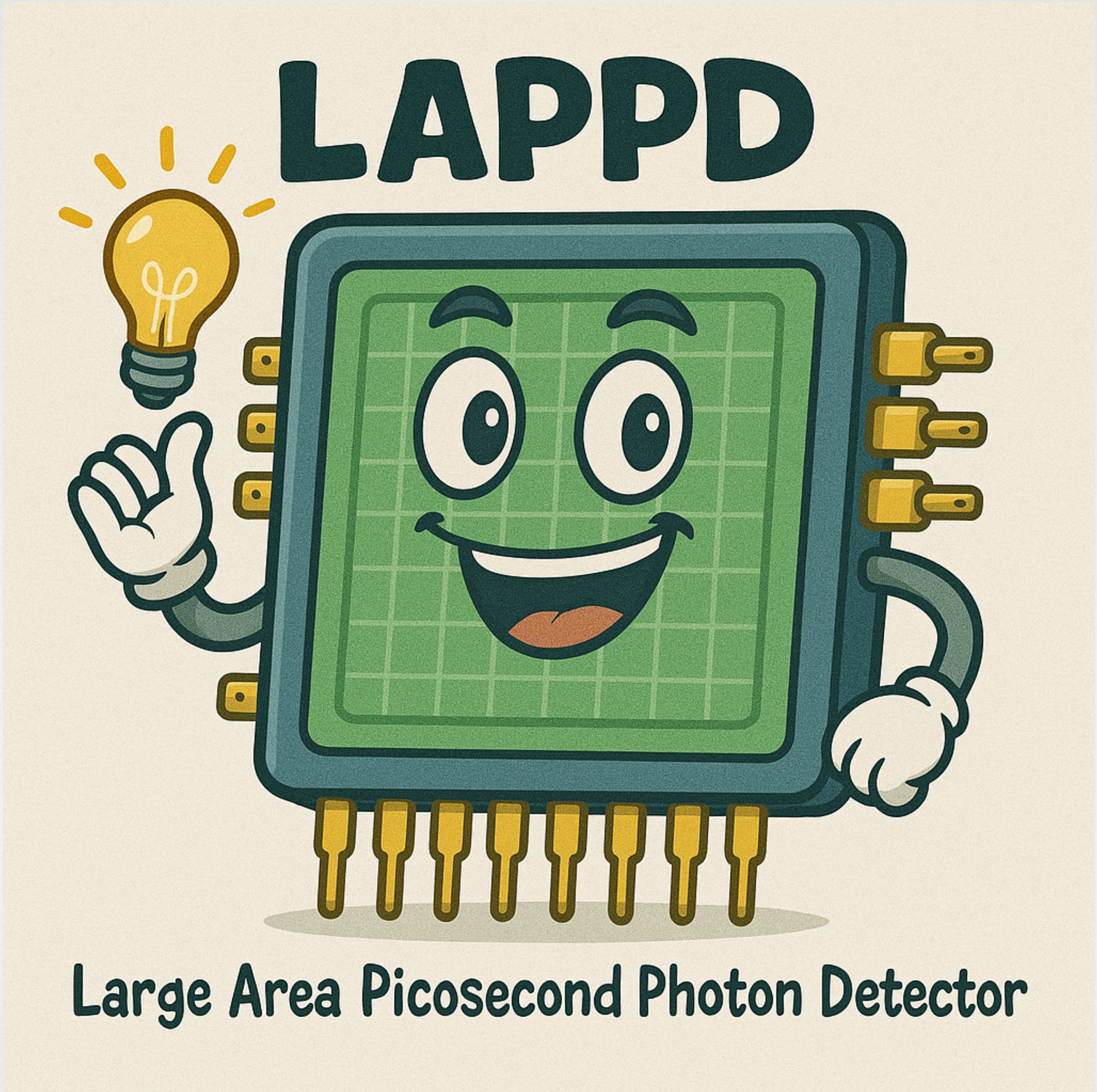
TRAILER



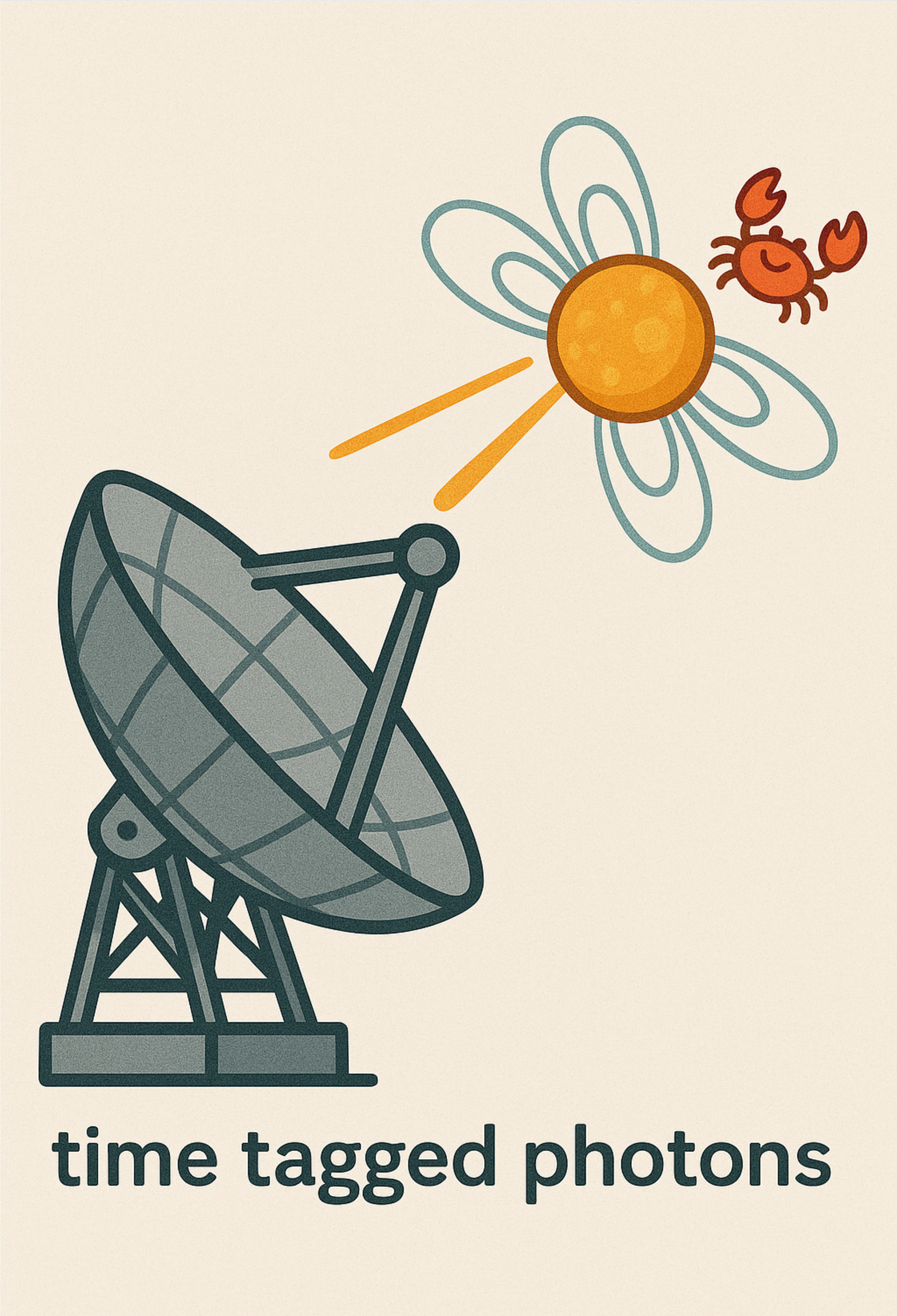


ADVERTISEMENT



Dr. Michael Minot
mjm@incomusa.com

CRAB APPEAL



"NANOCAM PROJECT"

heroic efforts of
Chris Stoughton
budget = $0
beg, borrow, steal

Andrew Sonnenschein
AS
borrowed Vikram Ravi from CalTech
borrowed PMT(s) from William Wester
borrowed Hale telescope from Shri Kulkarni

- record time of arrival of photons

$$\{t_1, t_2, t_3, t_4, t_5, \cdots\}$$

- calculate time interval between successive photons

$$\Delta_{i,j} \equiv t_j - t_i \quad \forall\, i, j$$

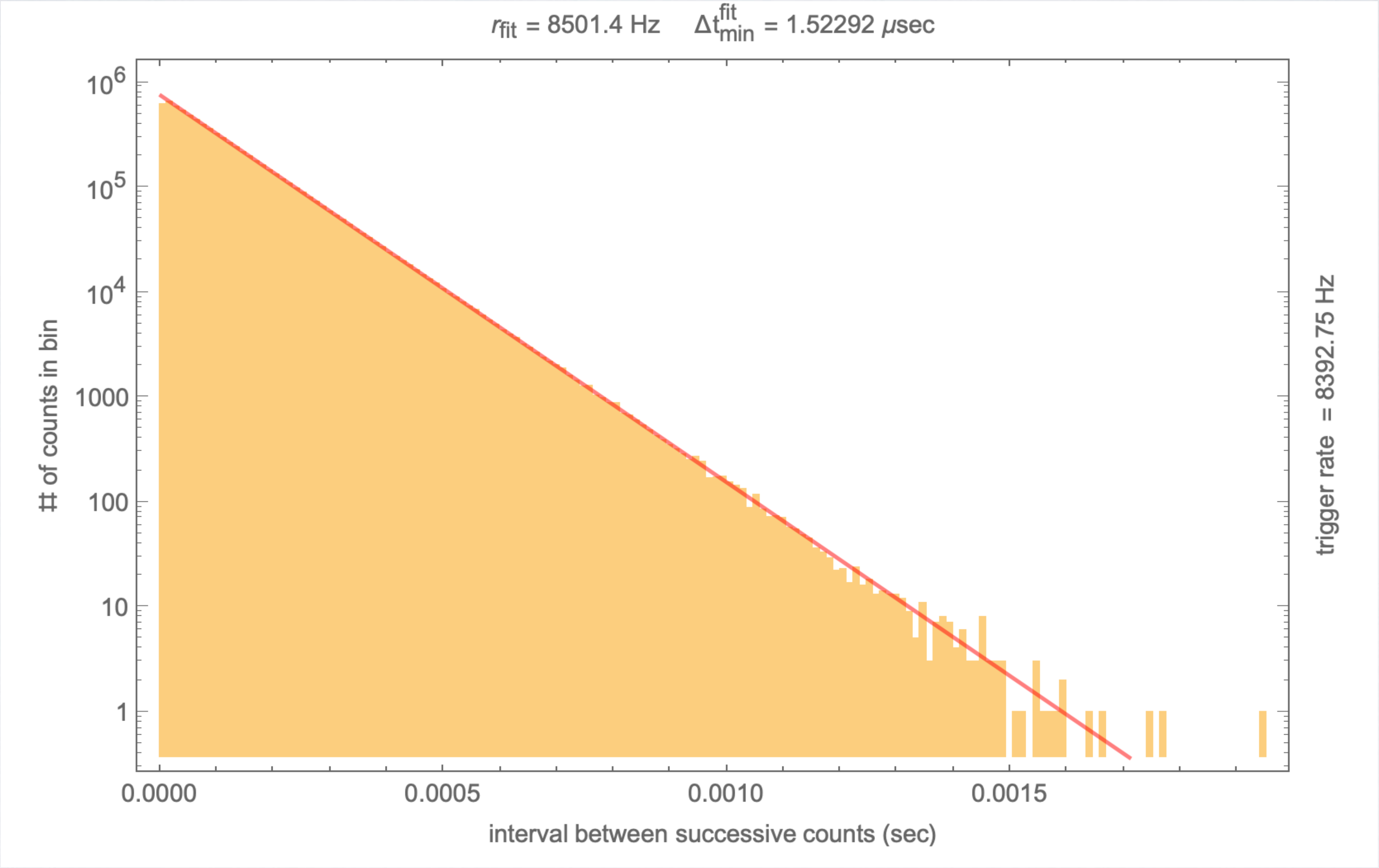
- plot histogram of $\Delta_{i,j}$ "*void probability function*"
- for Poisson arrival times

$$p[\Delta t]\, d\Delta t = f e^{-f\,\Delta t}\, d\Delta t \qquad f - \text{ photon rate}$$

- non-exponentiality = non-Poissoniality
- ? short timescale "sparking" in Crab optical emission ?

NANOCAM RESULTS

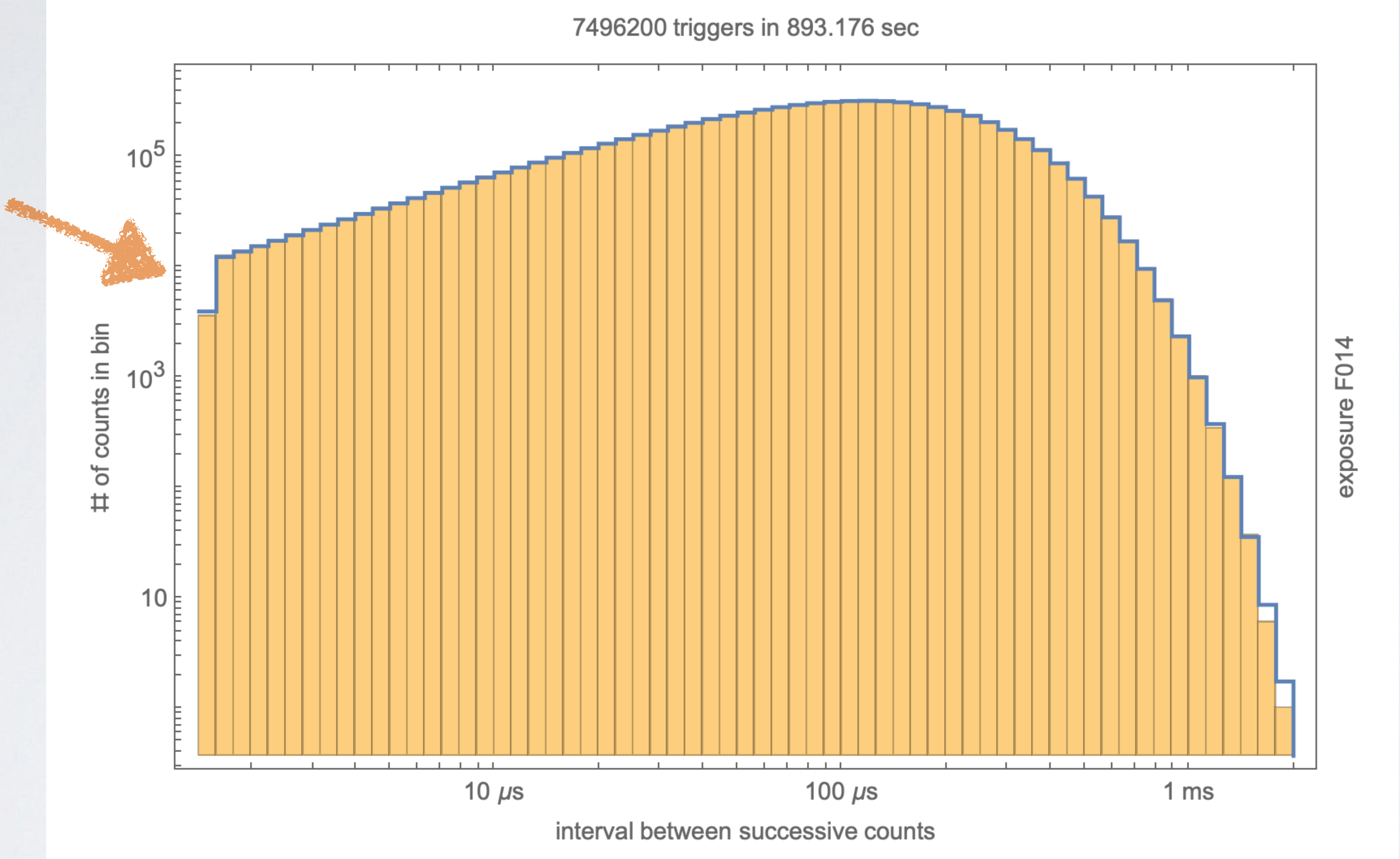
Empirically normal stars emit random (Poisson) photons



on timescales much longer than HBT photon bunching

NANOCAM RESULTS

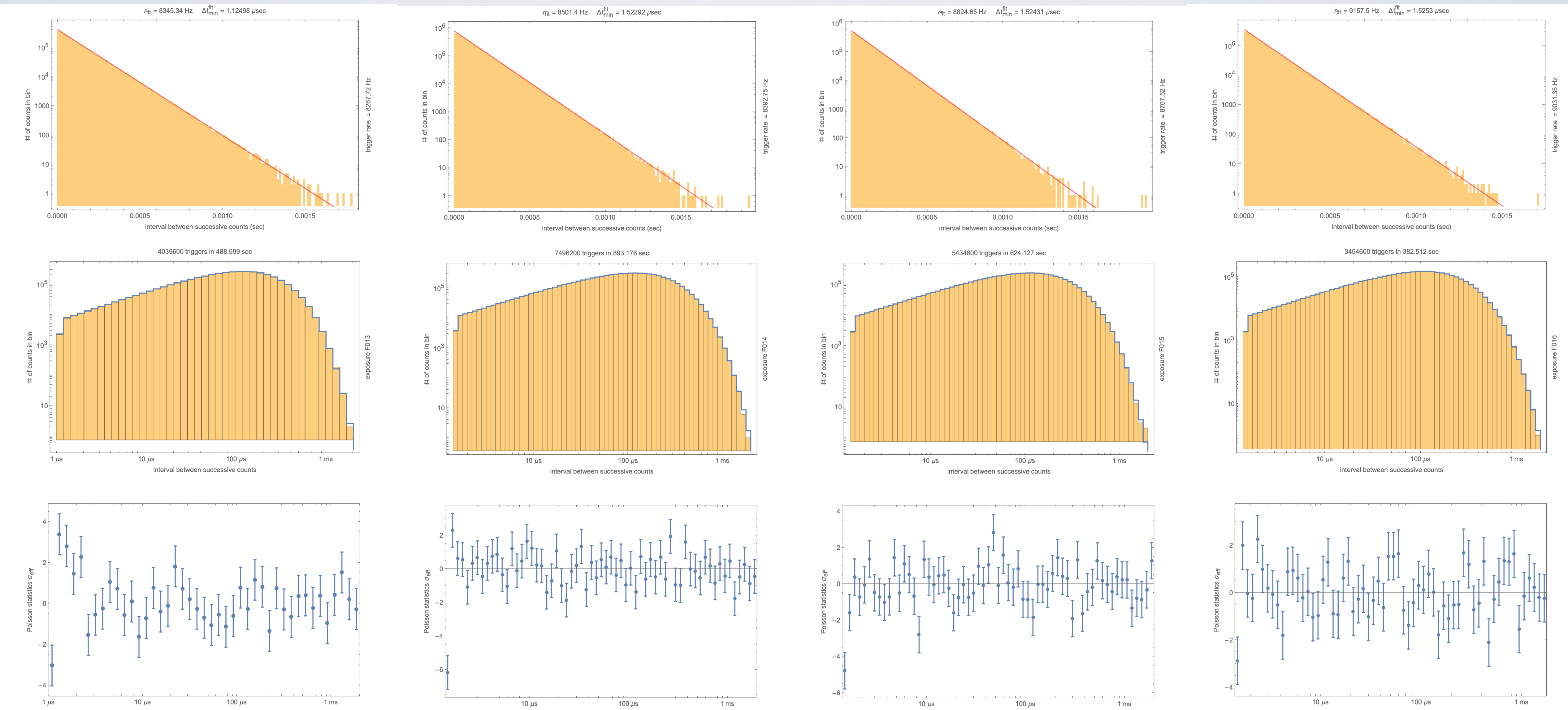
Empirically normal stars emit random (Poisson) photons



on timescales much longer than HBT photon bunching

CRAB APPEAL

randomly chosen guide stars near Crab



Crab? please look for yourself!

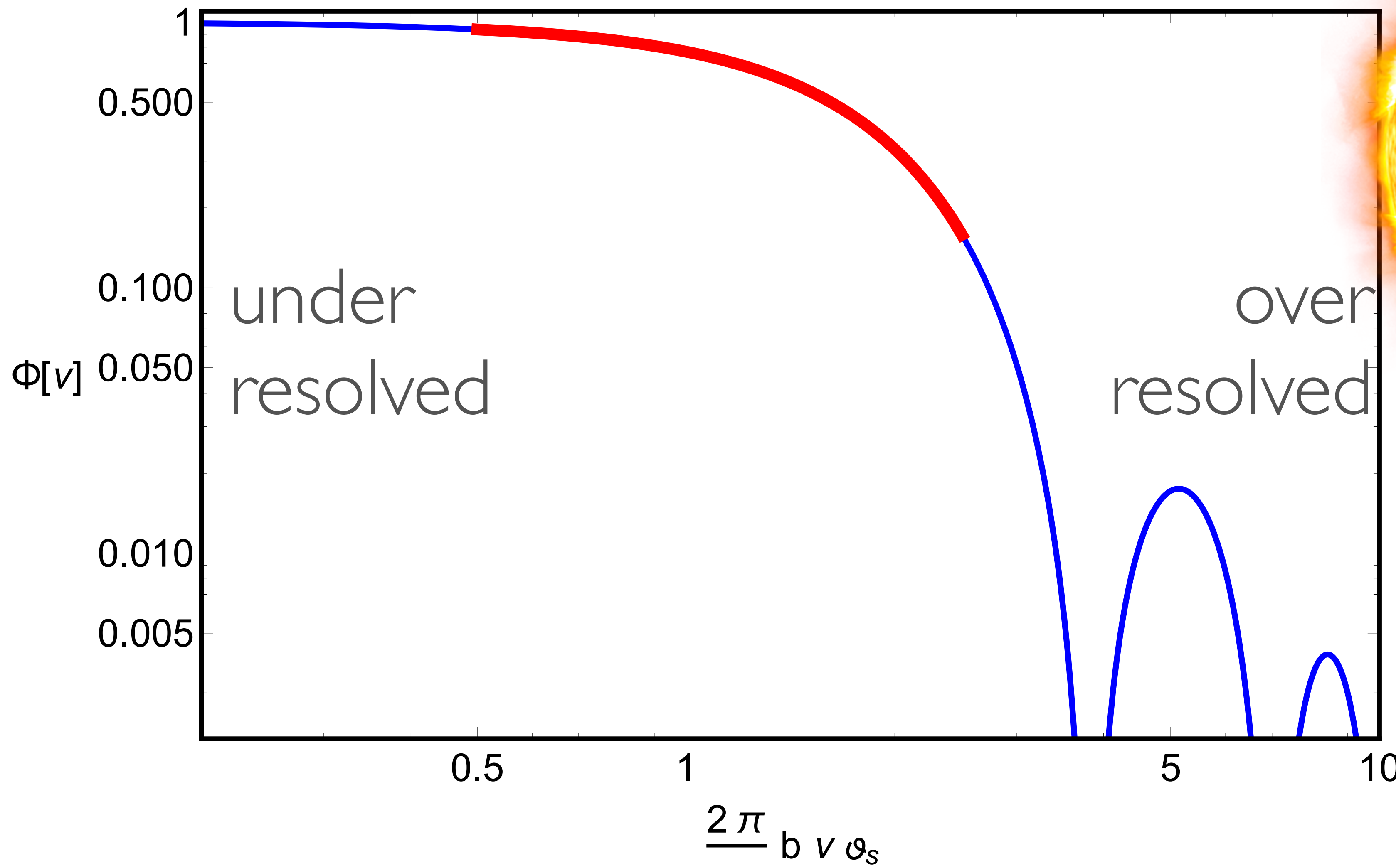
Intensity Interferometry Image Reconstruction II Holography

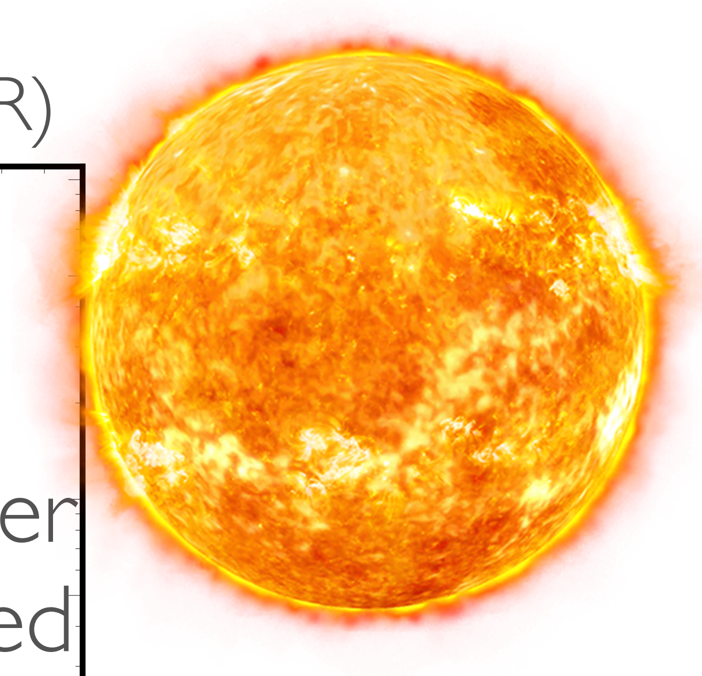
Stellar Intensity Interferometry Workshop
Fraunhofer Society / Research Campus
Waischenfeld, Germany
2025-10-17

Albert Stebbins
Fermilab

COHERENCE FUNCTION

(UNIFORM BRIGHTNESS DISK E.G. STAR)





- b transverse baseline
- ν frequency
- ϑ_s angular radius of disk
- Φ coherence function $\in[0,1]$

Coherence / Correlation Function

$$\Phi[\vec{\ell}, \nu] \to w_\Phi[\Delta\hat{\mathbf{n}}, \nu]$$

- For intensity interferometry there is a linear relation between $\Phi \propto I_\nu[\hat{\mathbf{n}}_1]\, I_\nu[\hat{\mathbf{n}}_2]$ so the observable is **not** linear in I_ν nor localized in $\hat{\mathbf{n}}$.
- Rather

$$\Phi[\vec{\ell}, \nu] = |\phi[\vec{\ell}, \nu]|^2 = \frac{\left(\int d^2\hat{\mathbf{n}}_1\, e^{-i\,\vec{\ell}\cdot\hat{\mathbf{n}}_1} B_1[\hat{\mathbf{n}}_1, \nu]\, I_\nu[\hat{\mathbf{n}}_1]\right)\left(\int d^2\hat{\mathbf{n}}_2\, e^{+i\,\vec{\ell}\cdot\hat{\mathbf{n}}_2} B_2[\hat{\mathbf{n}}_2, \nu]\, I_\nu[\hat{\mathbf{n}}_2]\right)}{\left(\int d^2\hat{\mathbf{n}}_1\, B_1[\hat{\mathbf{n}}_1, \nu]\, I_\nu[\hat{\mathbf{n}}]\right)\left(\int d^2\hat{\mathbf{n}}_2\, B_2[\hat{\mathbf{n}}_2, \nu]\, I_\nu[\hat{\mathbf{n}}]\right)}$$

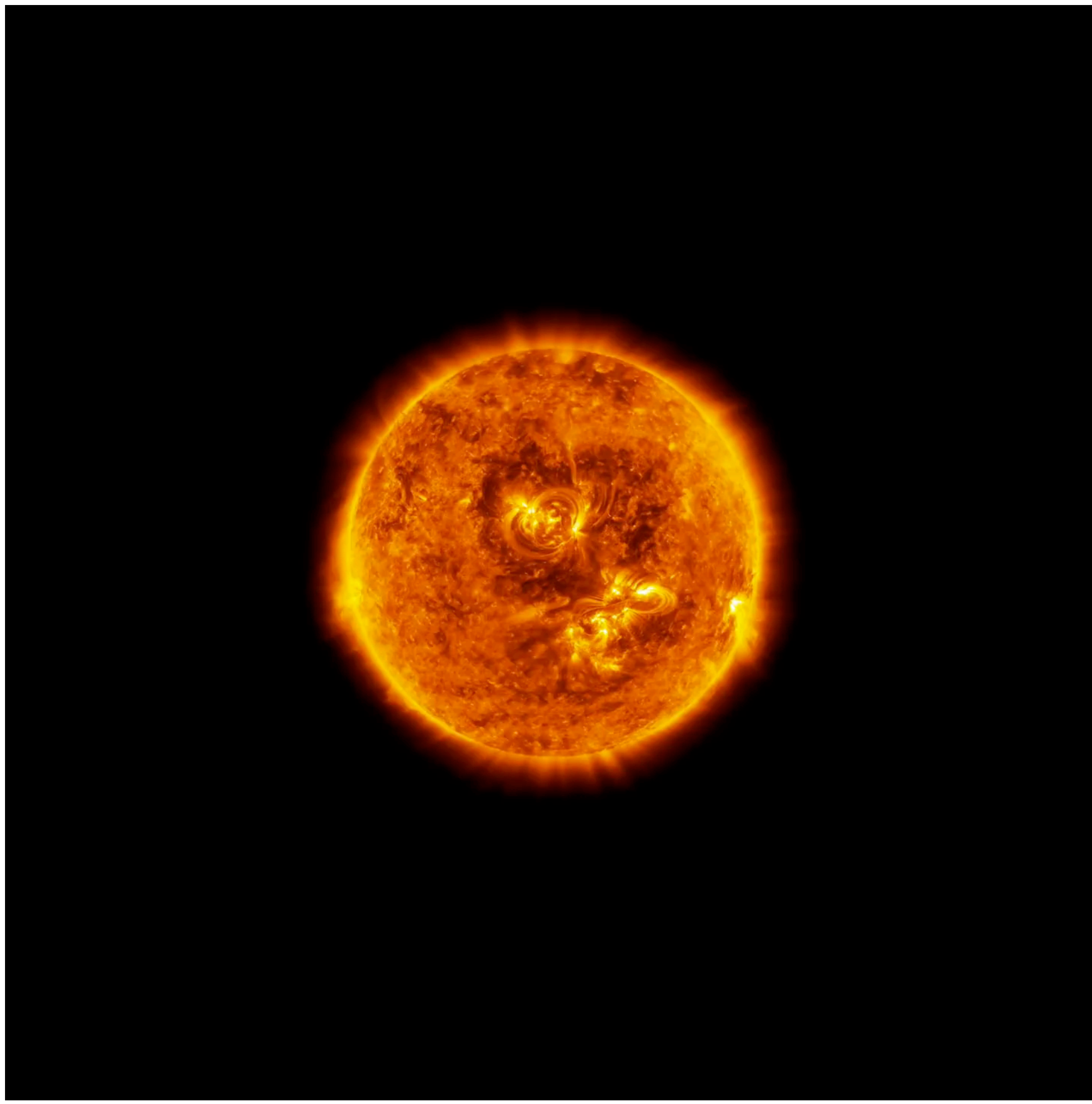
- One could take the **image space** to be the normalized intensity spatial power spectra: $|\phi[\vec{\ell}, \nu]|^2$.
  - power spectrum **misses half the information**: $|\phi[\vec{\ell}, \nu]|$ but not $\arg[\phi[\vec{\ell}, \nu]|]$.
- However it is **suggested** to instead use the **coherence correlation function**, which is the Fourier transform of the power spectrum,, as the image space

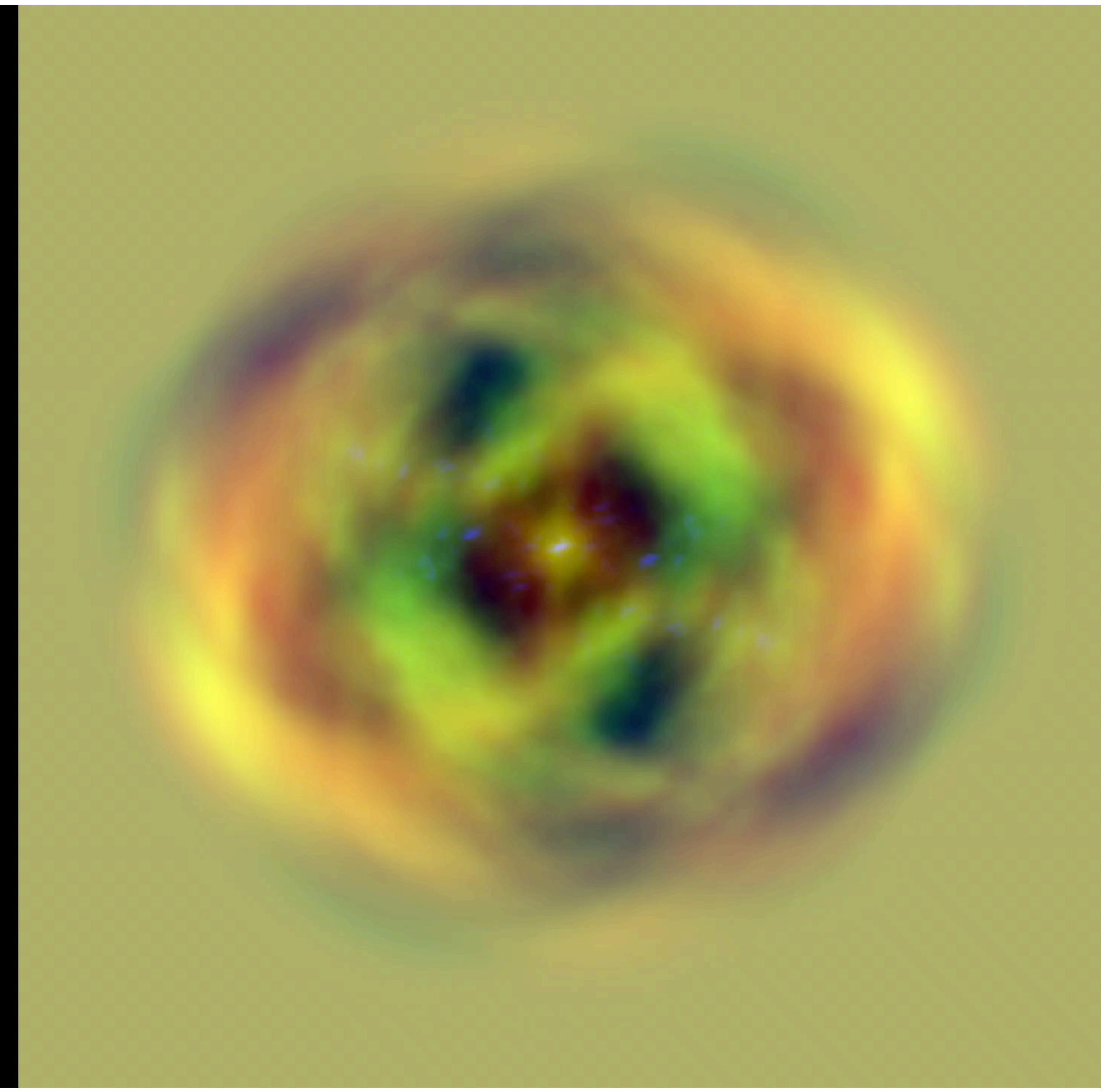
$$w_\Phi[\Delta\hat{\mathbf{n}}, \nu] \equiv \frac{\int d^2\vec{\ell}\, e^{i\,\vec{\ell}\cdot\vec{\Delta\theta}}\, \Phi[\vec{\ell}, \nu]}{\int d^2\vec{\ell}\, \Phi[\vec{\ell}, \nu]} = \frac{\int d^2\hat{\mathbf{n}}\, B_1[\hat{\mathbf{n}}, \nu]\, B_2[\hat{\mathbf{n}} + \Delta\hat{\mathbf{n}}, \nu]\, I_\nu[\hat{\mathbf{n}}]\, I_\nu[\hat{\mathbf{n}} + \Delta\hat{\mathbf{n}}]}{\int d^2\hat{\mathbf{n}}\, B_1[\hat{\mathbf{n}}, \nu]\, B_2[\hat{\mathbf{n}}, \nu]\, I_\nu[\hat{\mathbf{n}}]^2}$$

  with properties
    - $w_\Phi[\Delta\hat{\mathbf{n}}, \nu]$ contains **all** the information from intensity interferometry
    - $0 \le w_\Phi \le 1$
    - $w_\Phi[\mathbf{0}, \nu] = 1$
    - $w_\Phi[\Delta\hat{\mathbf{n}}, \nu]$ invariant under $\Delta\hat{\mathbf{n}} \to -\Delta\hat{\mathbf{n}}$ and $I_\nu \to -I_\nu$
    - if the support, $|\hat{\mathbf{n}}_1 - \hat{\mathbf{n}}_2|$, of I_ν is compact then so is the support of $w_\Phi[\Delta\hat{\mathbf{n}}, \nu]$
- No attempt to reconstruct $I_\nu[\hat{\mathbf{n}}]$

COHERENCE VARIATIONS

SUBTRACT TEMPORAL MEAN





$I_\nu[\hat{\mathbf{n}}]$

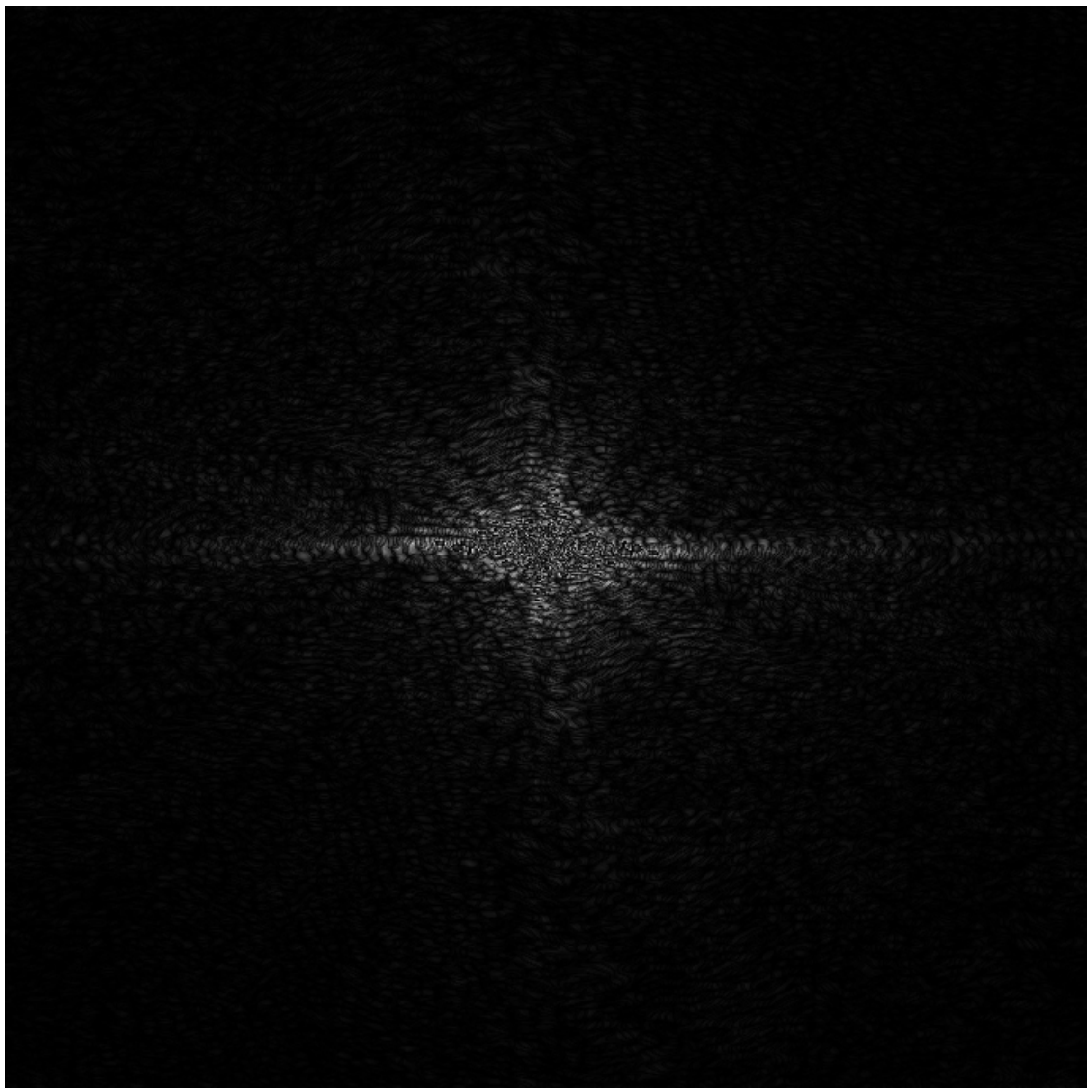
$w_\Phi[\Delta\hat{\mathbf{n}}, \nu] - \overline{w_\Phi[\Delta\hat{\mathbf{n}}, \nu]}$

Complex Images

~~spherical cows~~

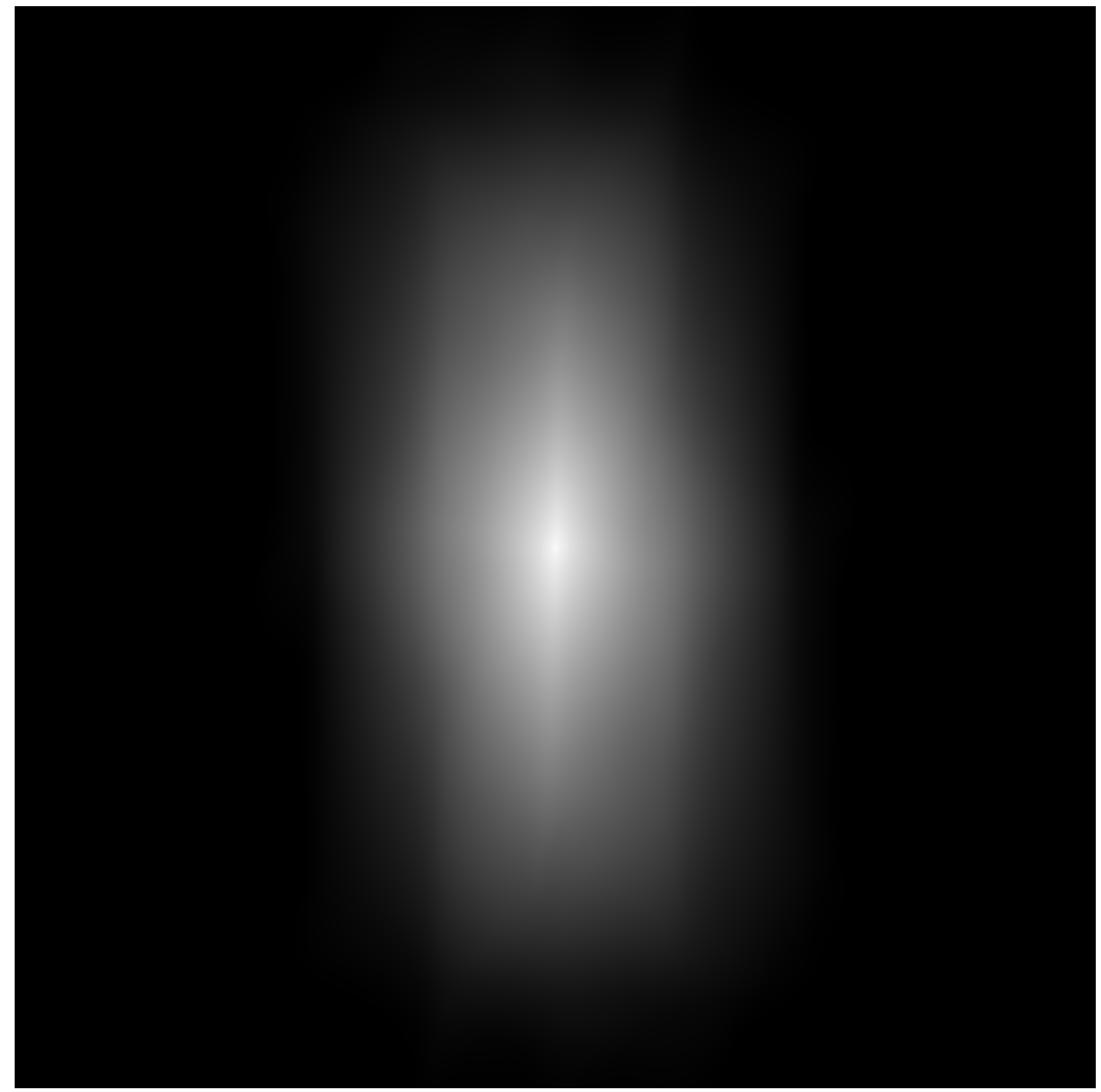
Visibility & Correlation Function

$\phi[\overrightarrow{\ell}, \nu]$



visibility

$w_{\Phi}[\Delta\hat{\mathbf{n}}, \nu]$



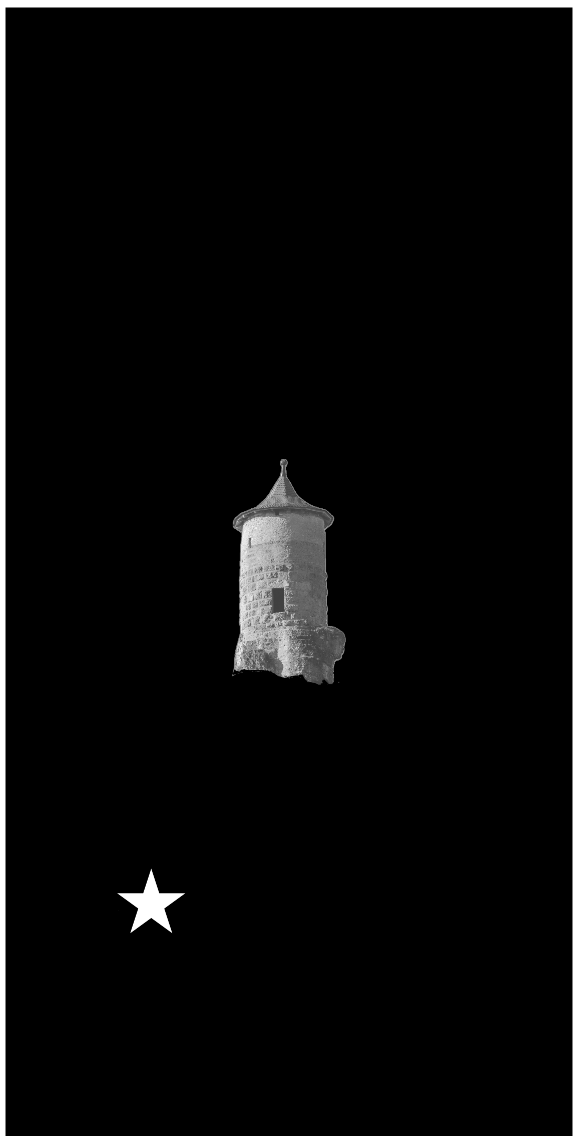
correlation function

Holographic Phase Recovery

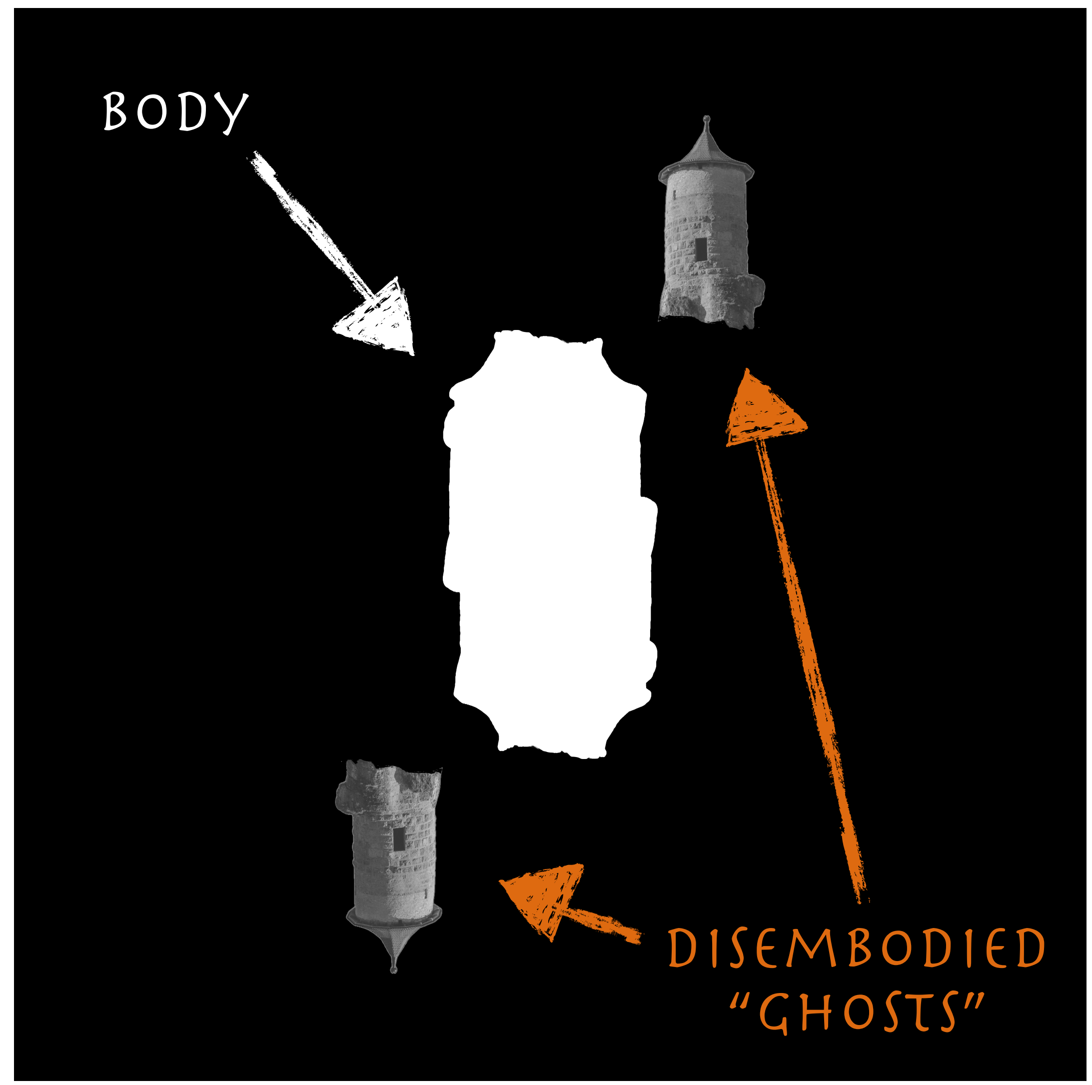
idea from Paul Stankus

If there is a close small bright star

then the star-object correlation function contains all of the phase information



$I_\nu[\hat{\mathbf{n}}, \nu]$



$w_\Phi[\Delta\hat{\mathbf{n}}, \nu]$

Is Holographic Phase Recovery Practical?

- Not sure.

- Seems to require more uv coverage than is likely to be available in practice.

- Perhaps partial holography might be possible?

Stankus Ideas

- Holography requires a nearby unresolved source - which may be rare.

- Can one modify the optics to allow a distant star to illuminate both sensors.

- One would have to do this in equivalent way for all the telescopes — this could be challenging!

Holographic methods in need of further study!

Thank you all for this great meeting!