feasibility of obtaining phase information using 3 point HBT

2 point correlation: $C_{12} = 1 + |V_{12}|^2$

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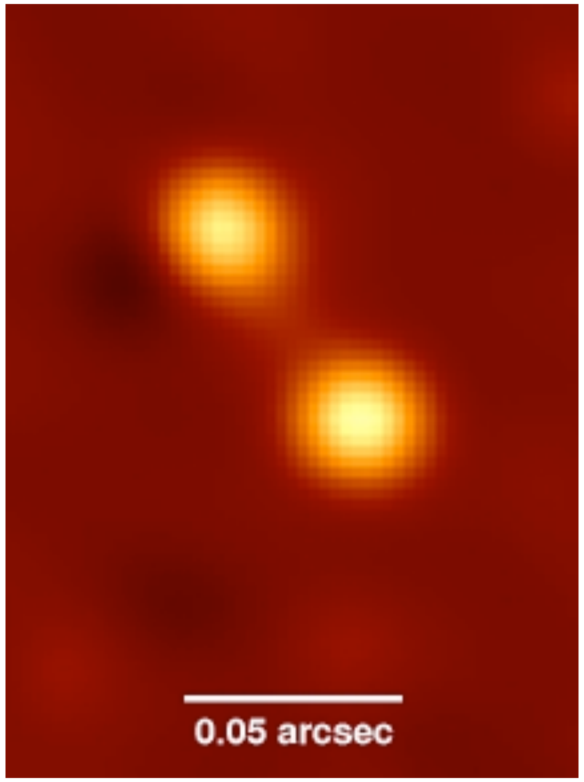
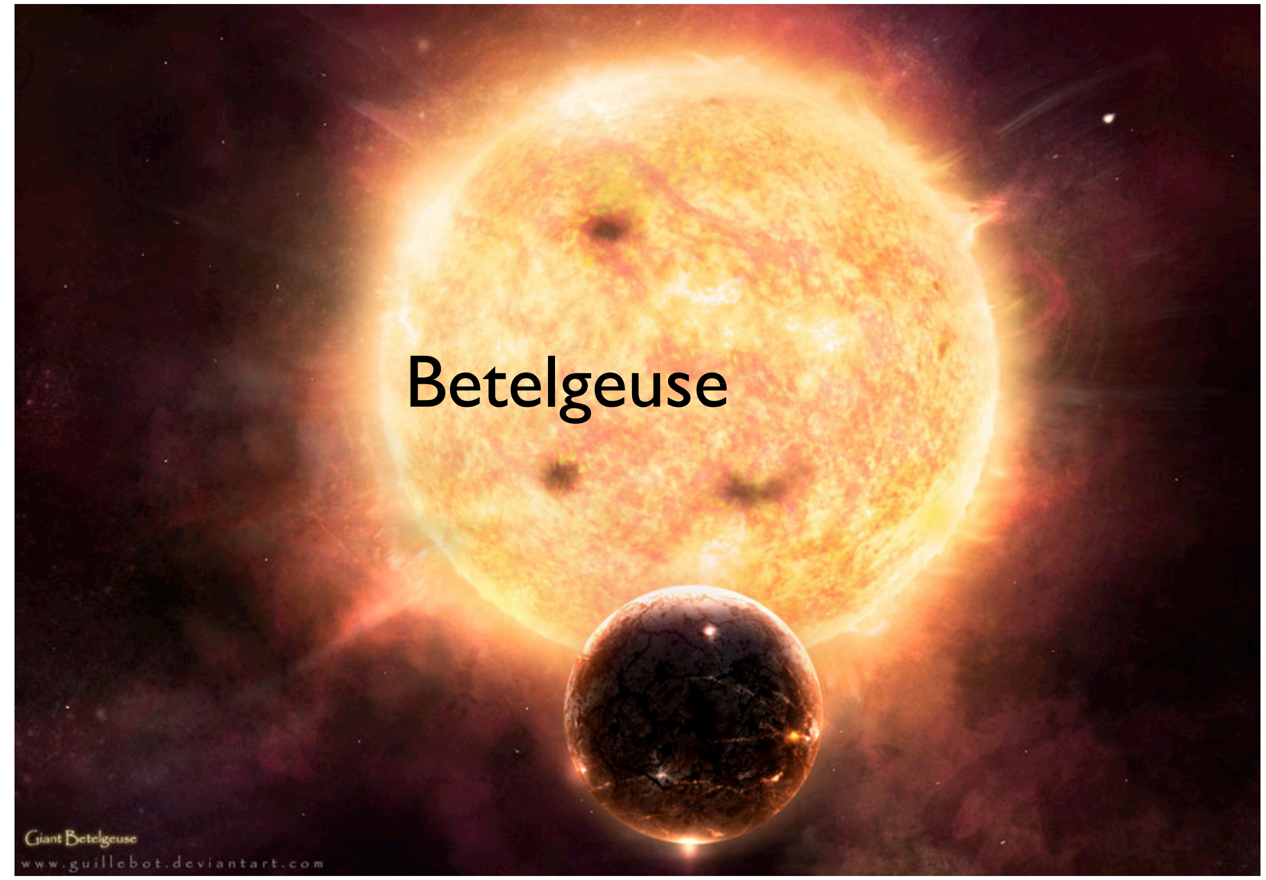
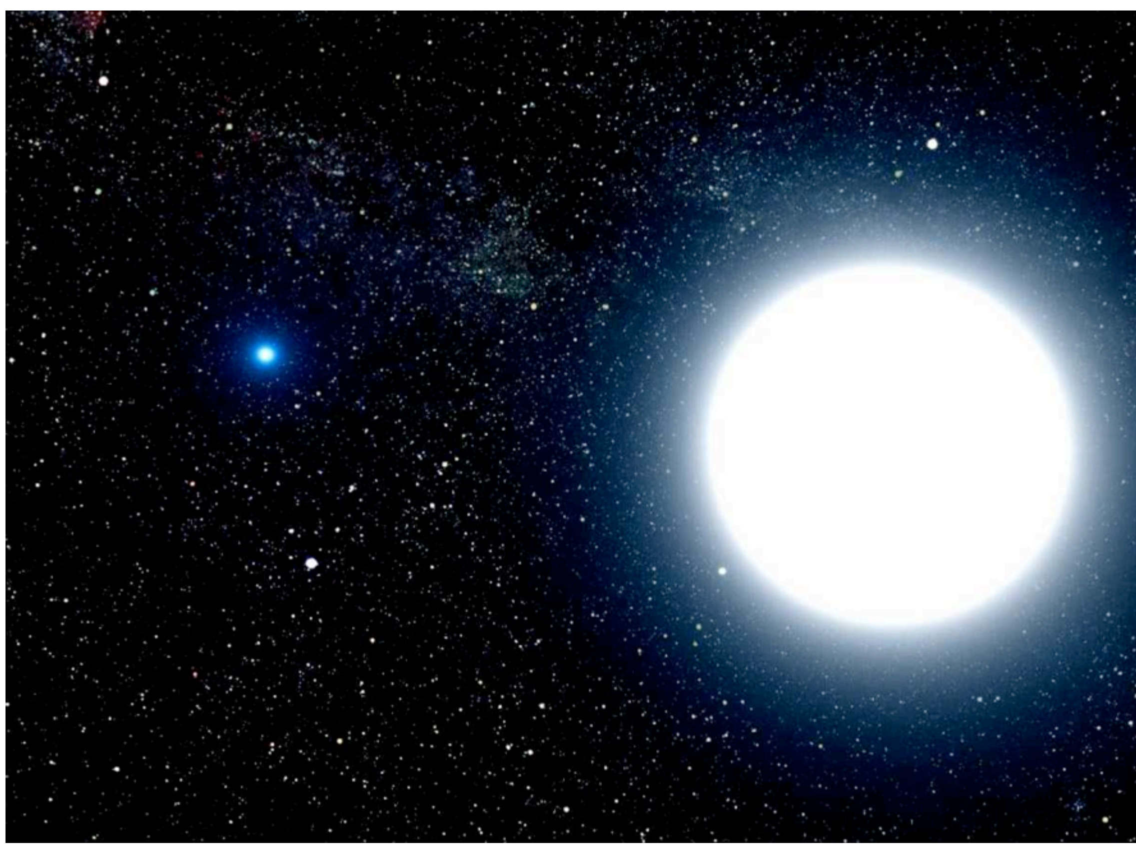
Feasibility of Observing Hanbury Brown and Twiss Phase, in prep.

Capella a and b

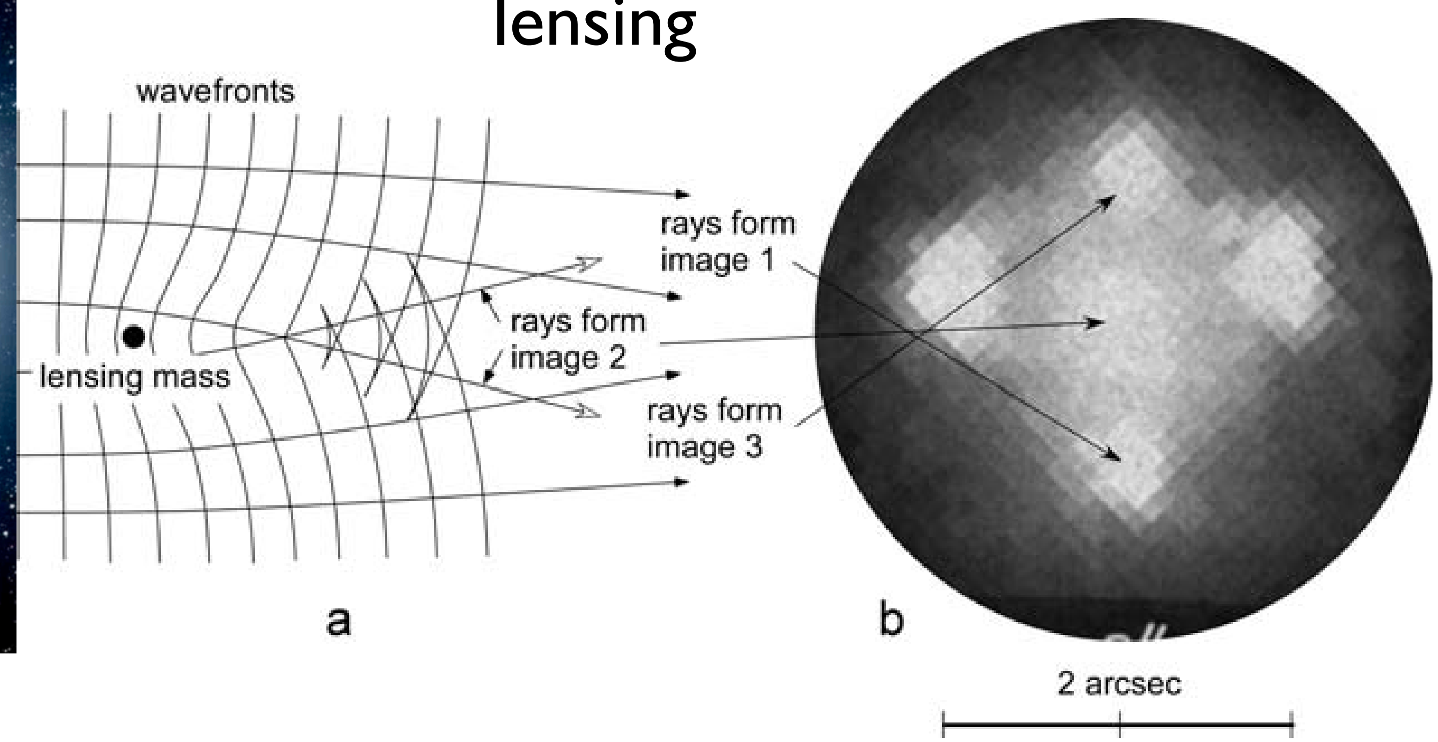




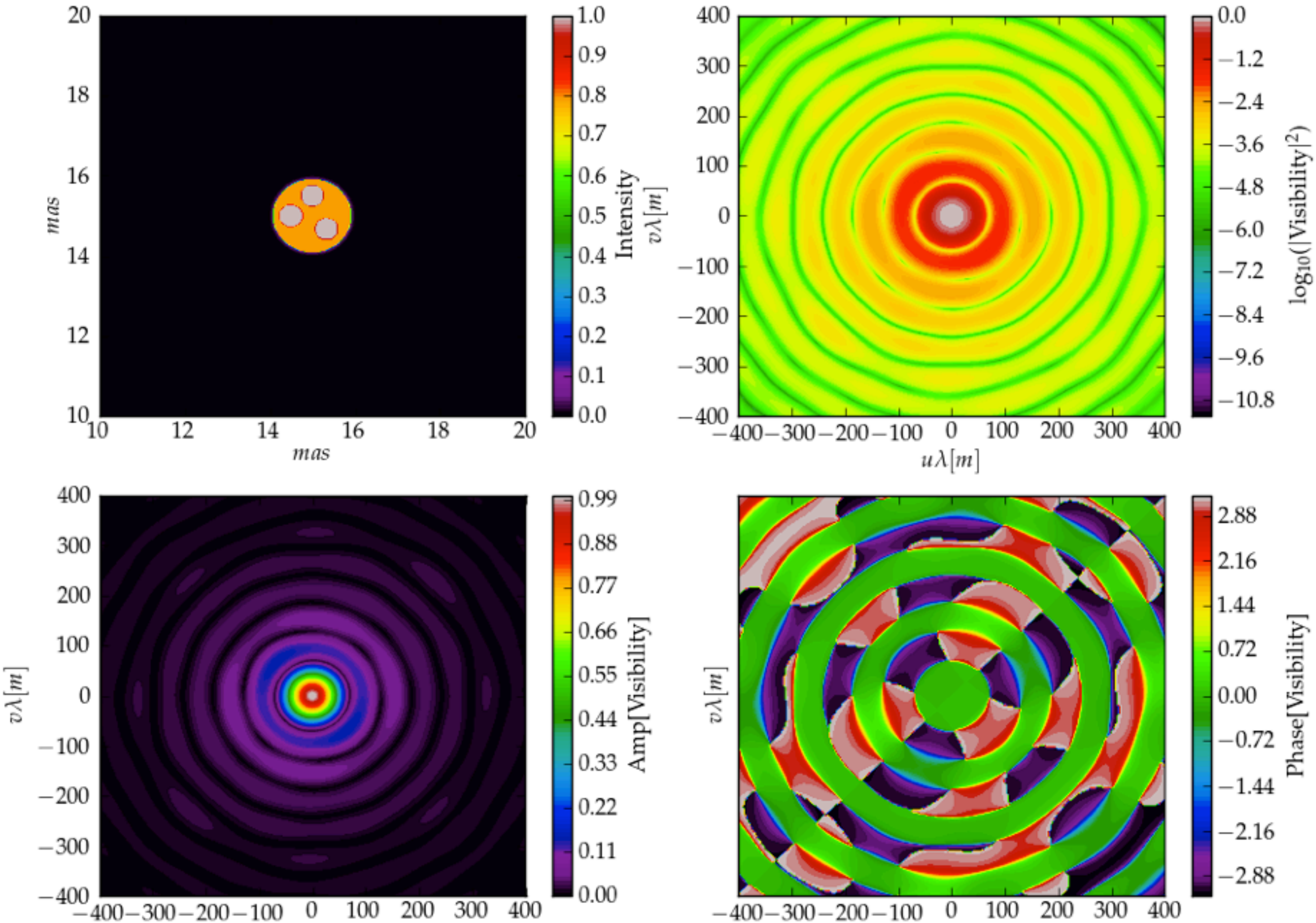
Sirius



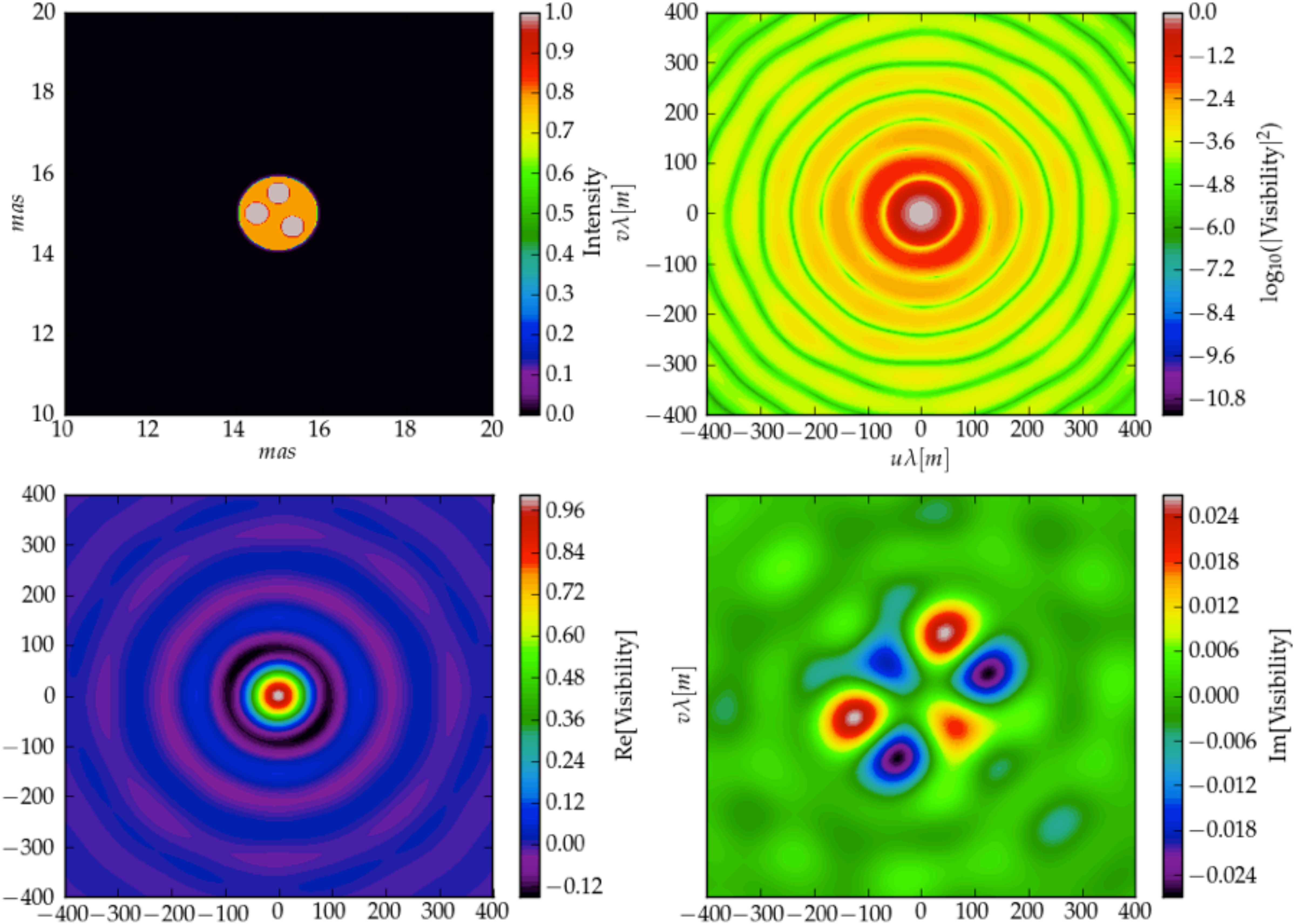
lensing



complex visibility of a structured, limbdarkened disk

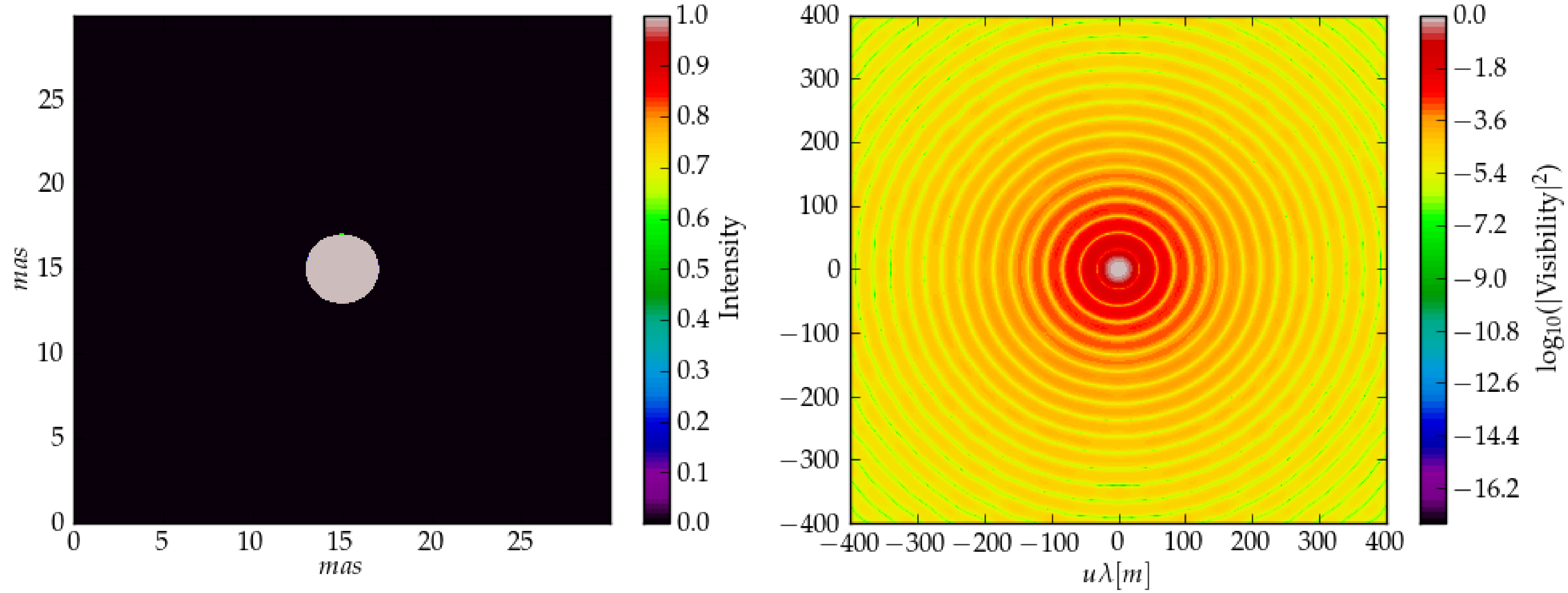


complex visibility of a structured, limbdarkened disk

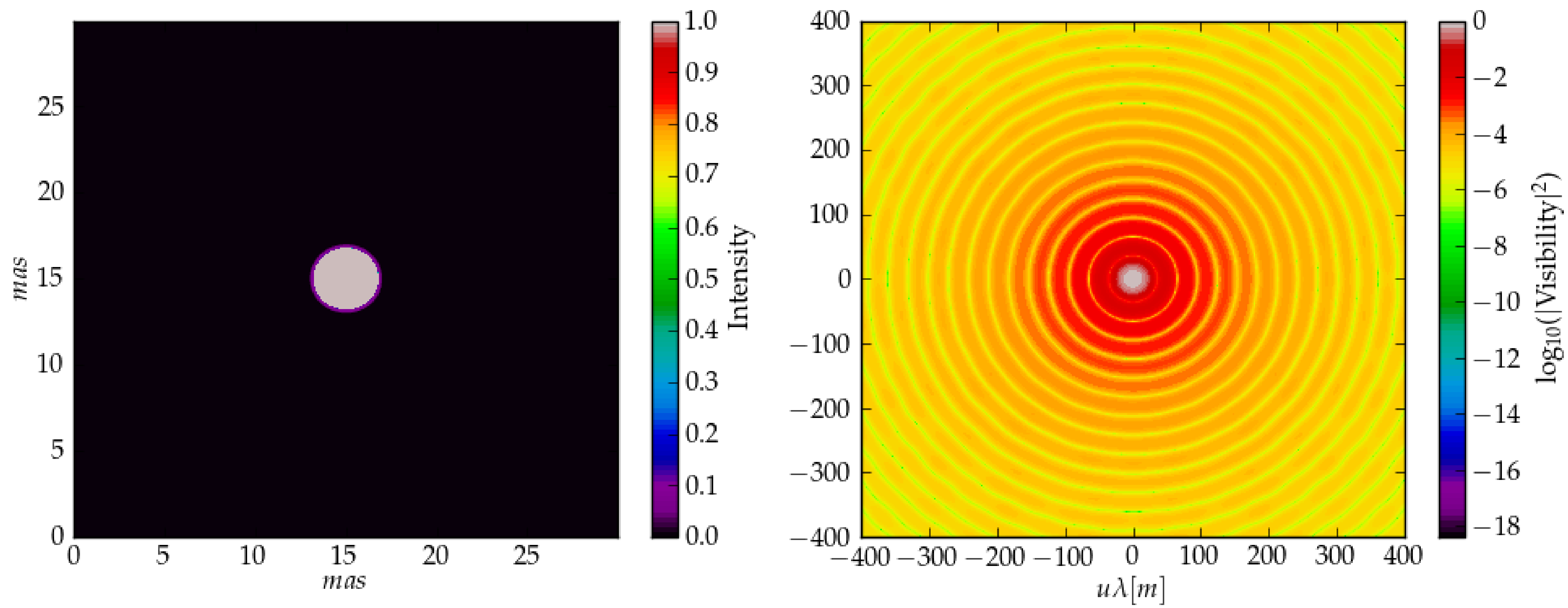


HBT simulations

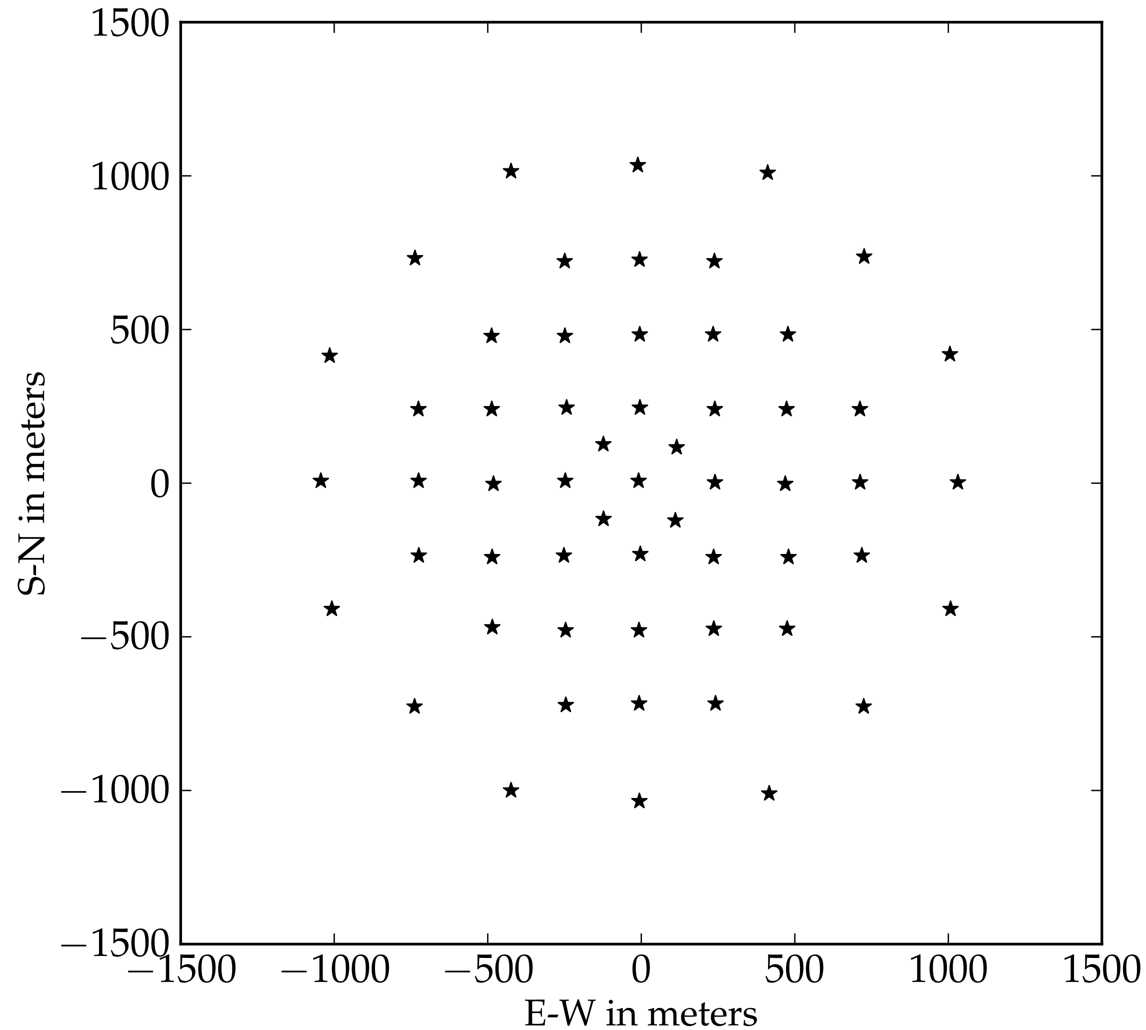
uniform disk



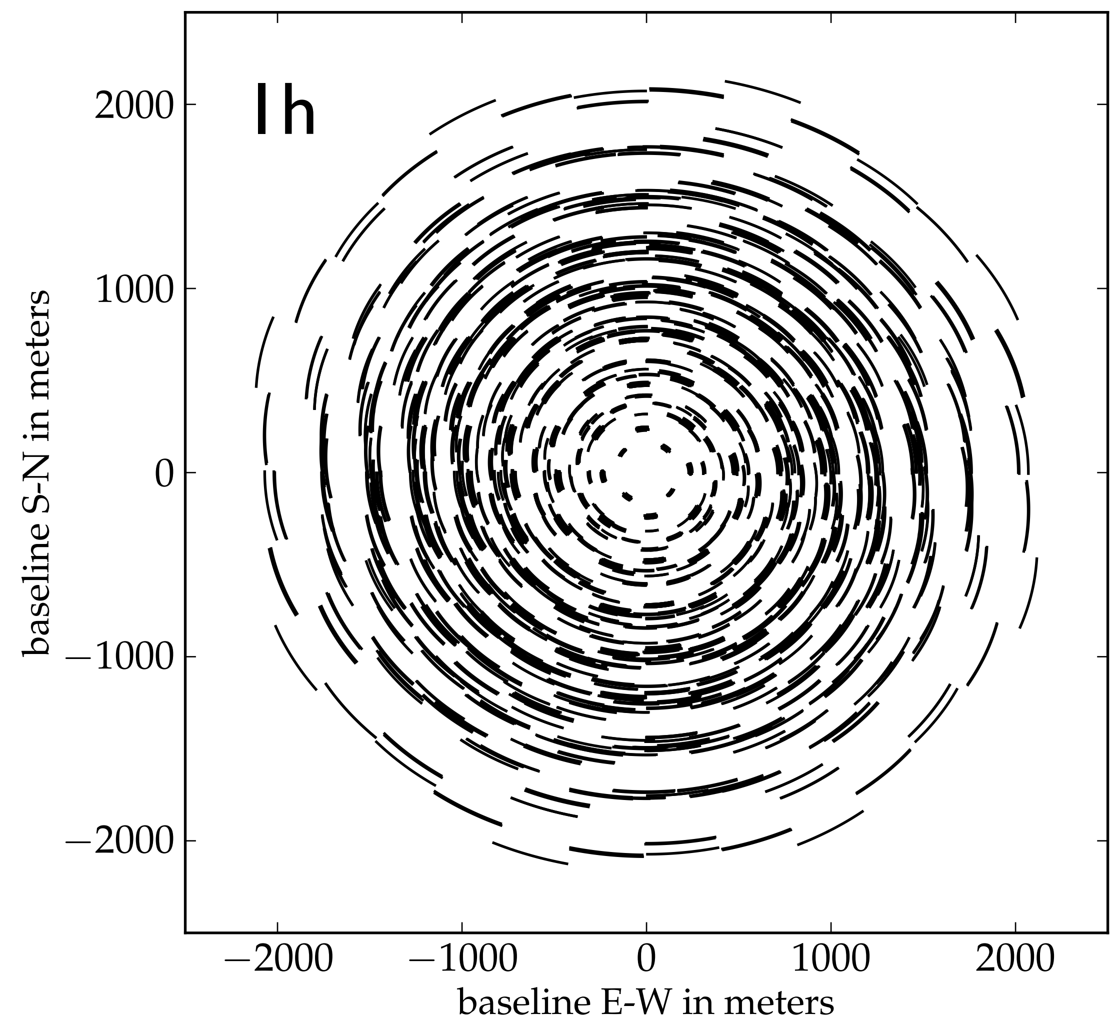
crudely limbdarkened disk



(u,v) coverage of one proposed CTA setup

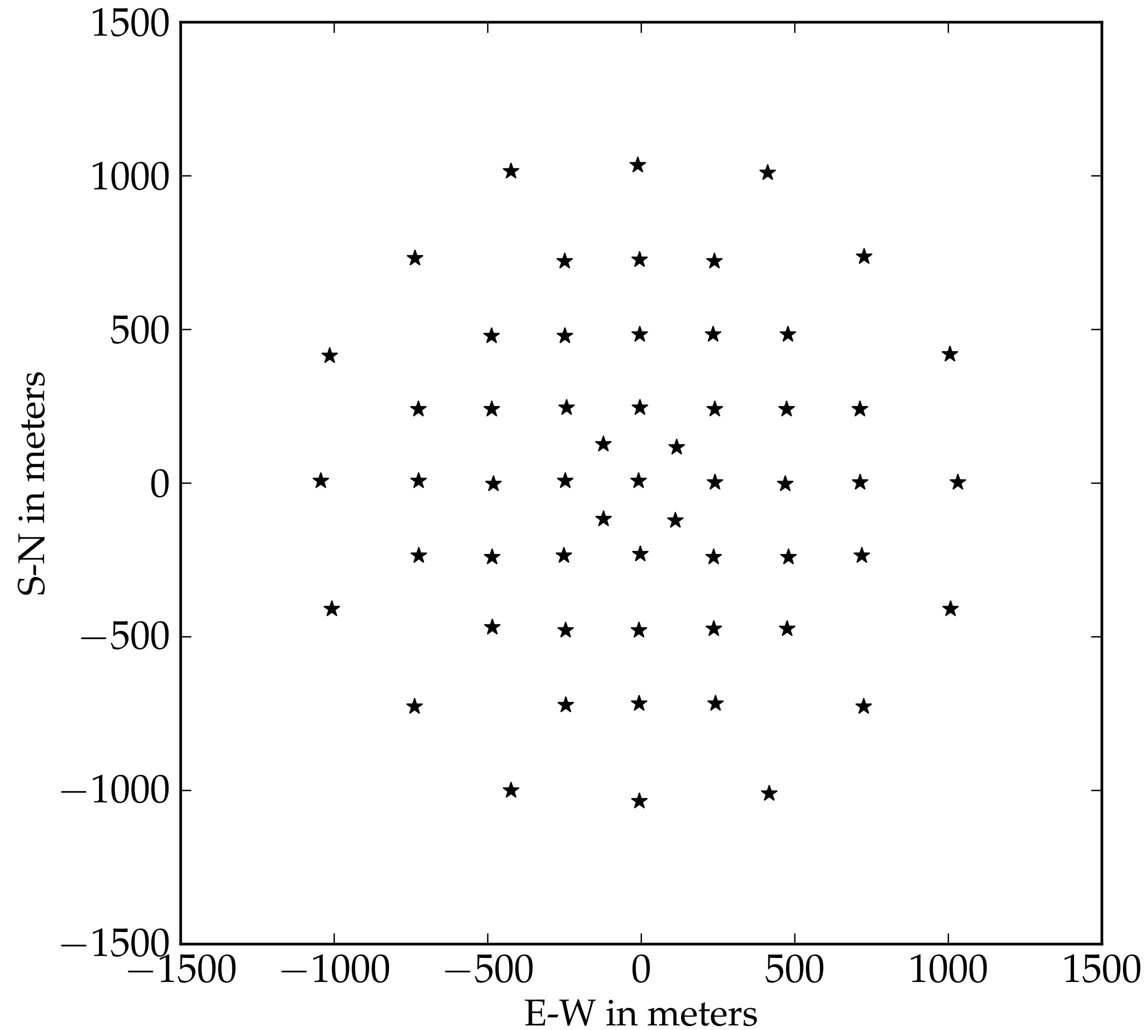


Zurich (47°8' latitude)



Capella: declination 45°

(u,v) coverage of one proposed CTA setup



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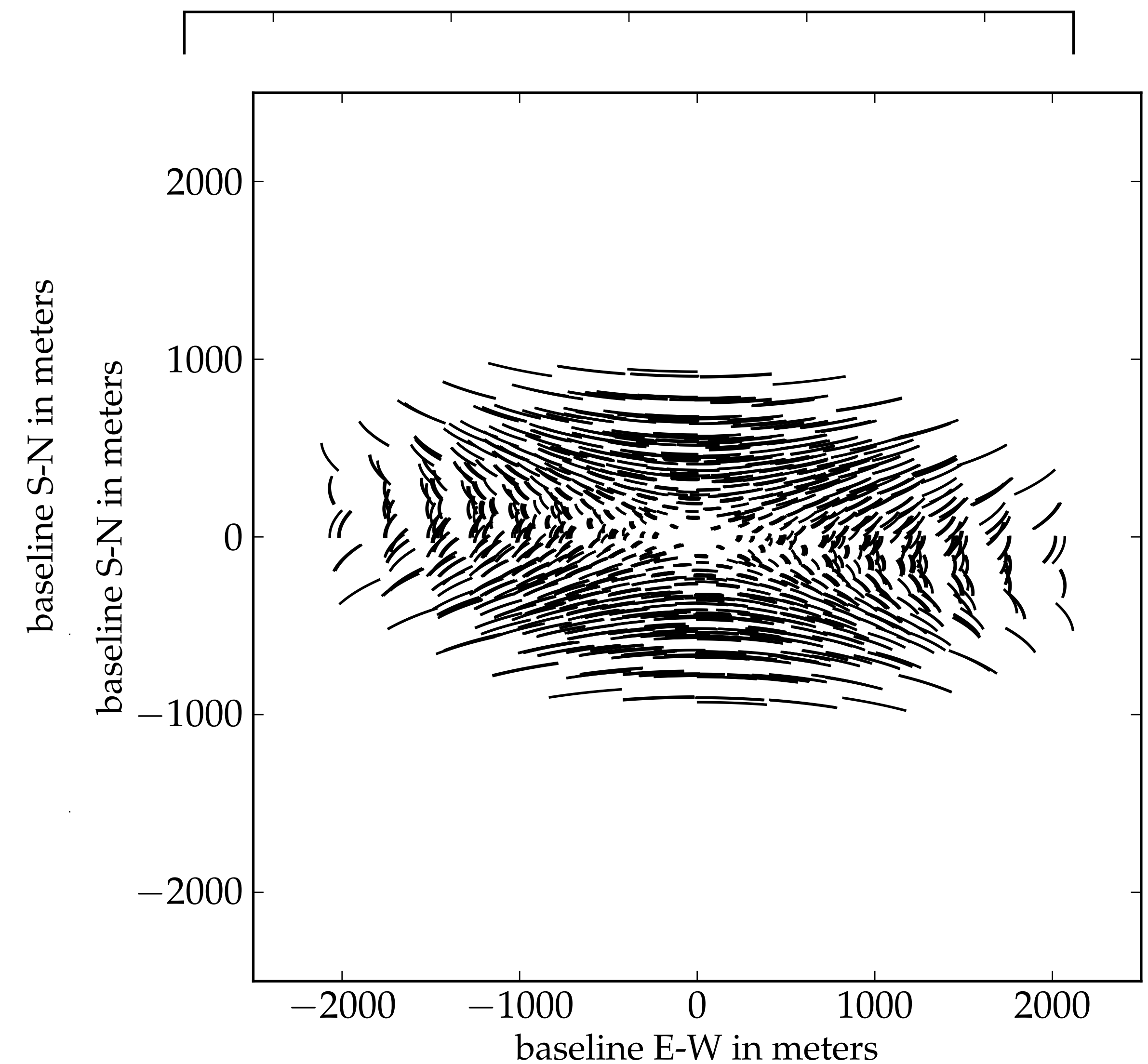
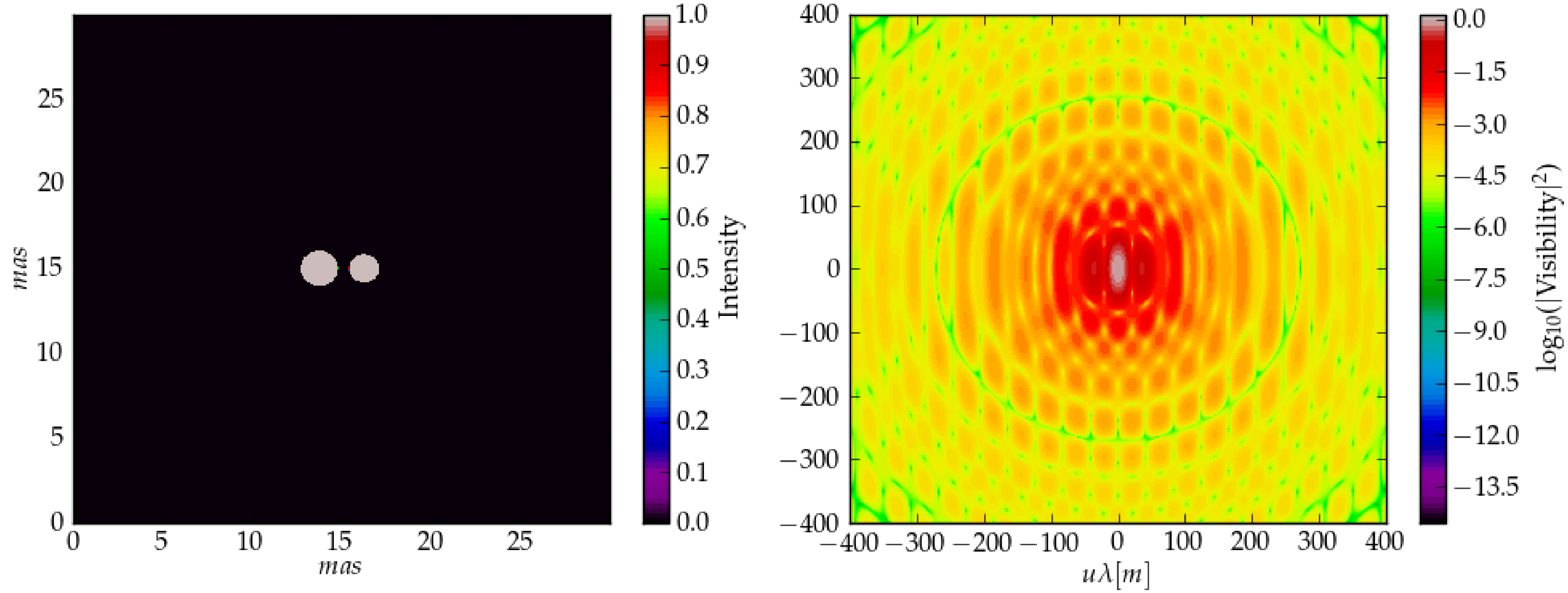


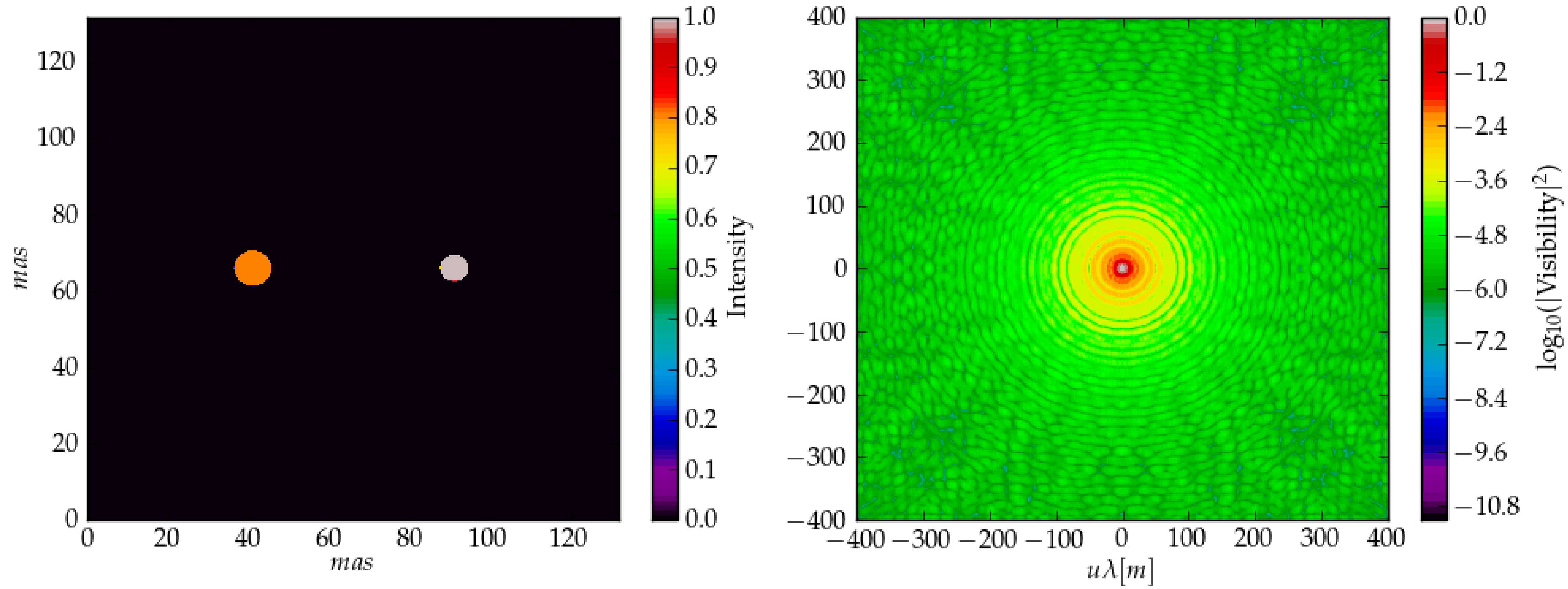
Sirius at -16°

more HBT simulations

close binary (separations of the order of mas)



Capella a and b separation around 50mas



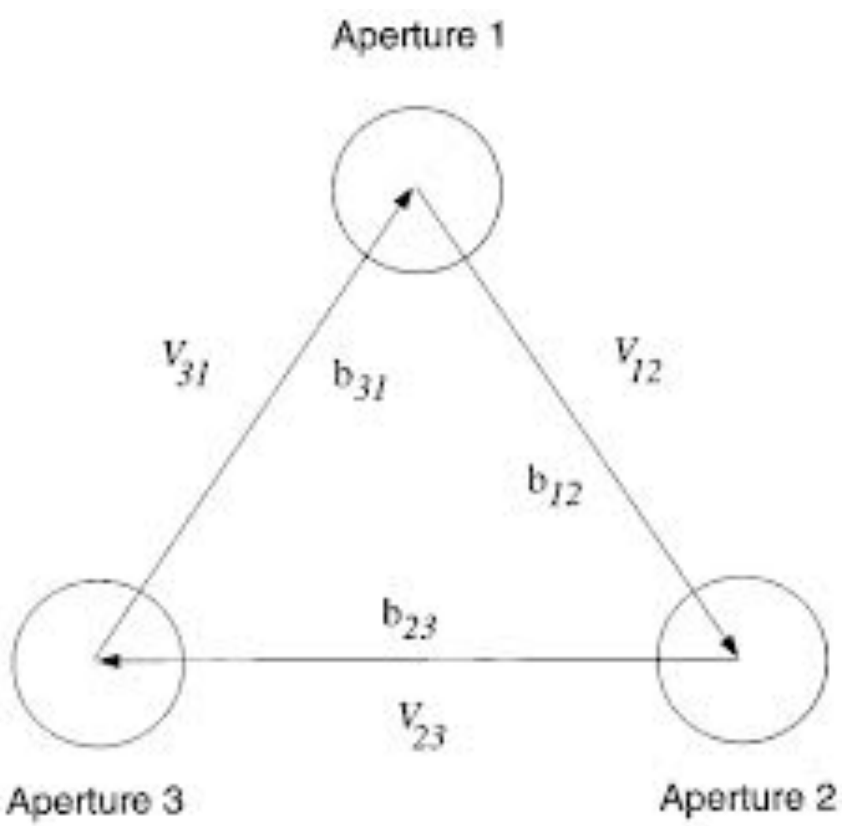
3 point correlation

3 point correlation function:

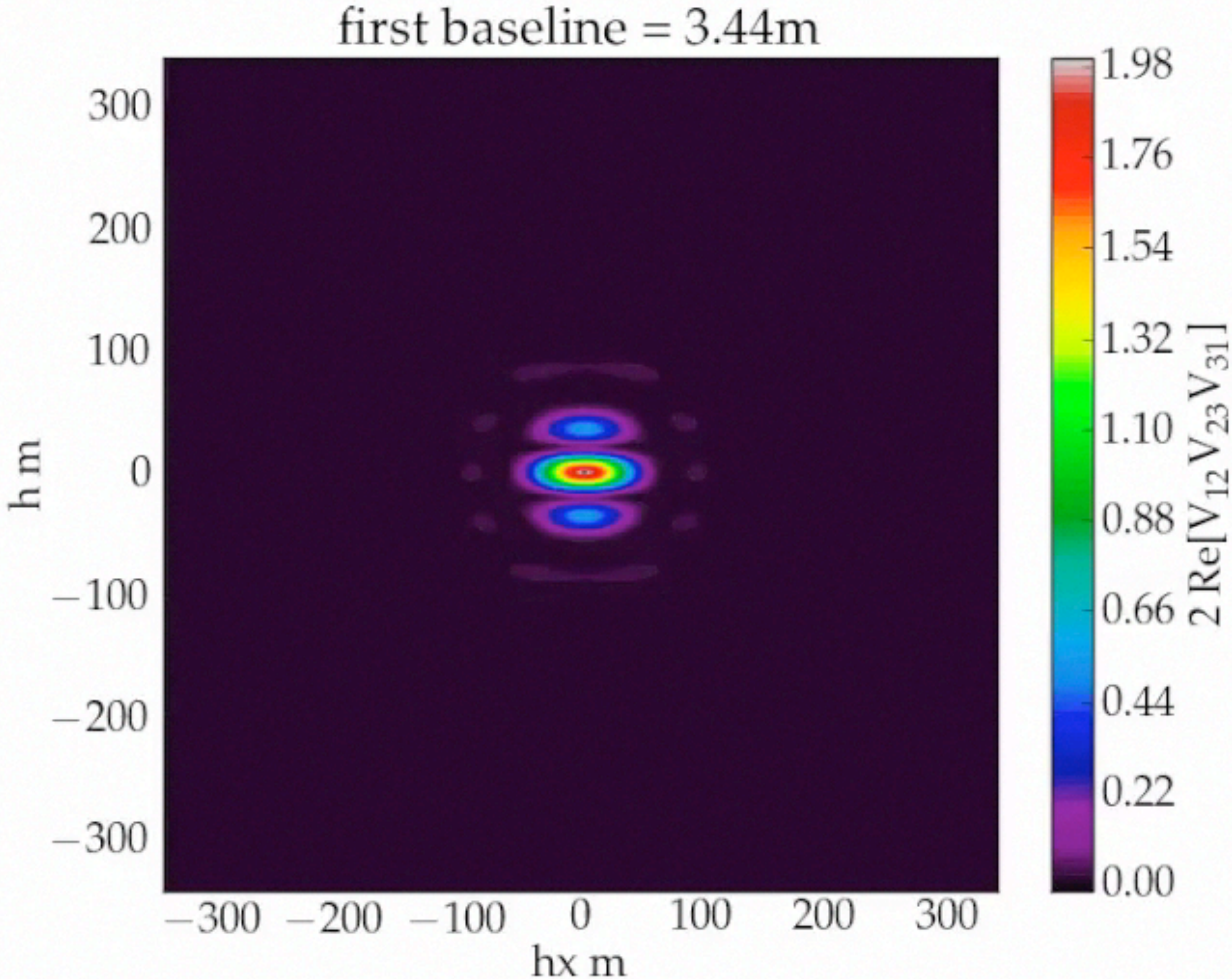
$$C_{123} = 1 + |V_{12}|^2 + |V_{23}|^2 + |V_{31}|^2 + 2Re[V_{12}V_{23}V_{31}]$$

bispectrum:

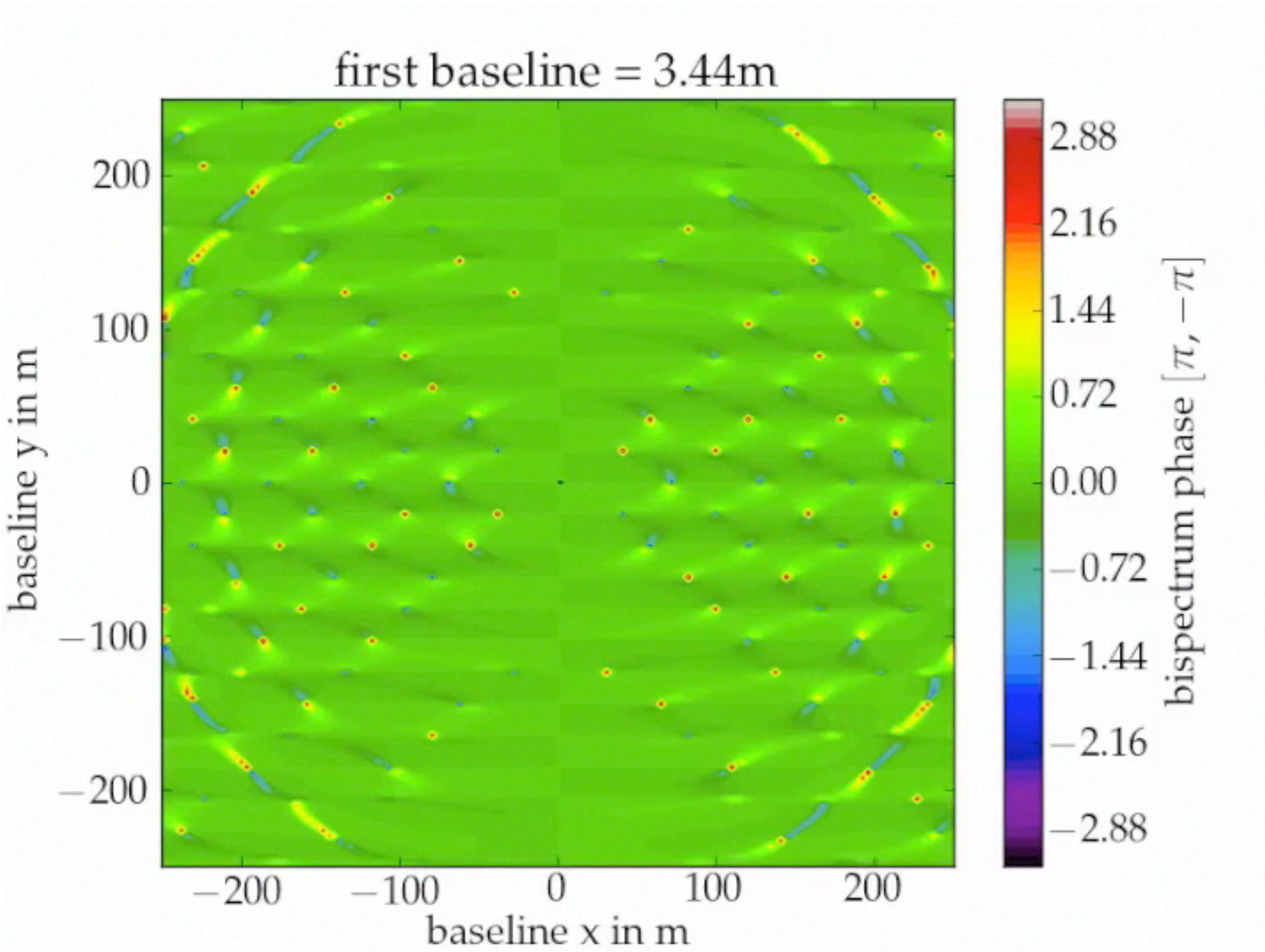
$$V_{12}V_{23}V_{31} = |V_{12}||V_{23}||V_{31}|e^{i(\phi_{12}+(\phi_2-\phi_1)+\phi_{23}+(\phi_3-\phi_2)+\phi_{31}+(\phi_1-\phi_3))}$$
$$= |V_{12}||V_{23}||V_{31}|e^{i(\phi_{12}+\phi_{23}+\phi_{31})}$$



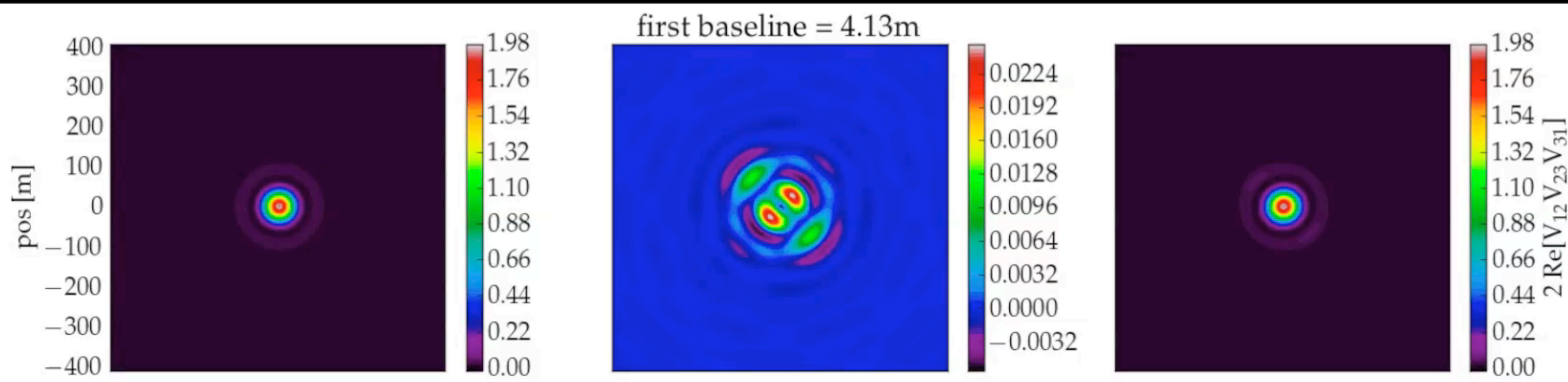
3 point correlation for a close binary



theoretical bispectrum phase in a close binary



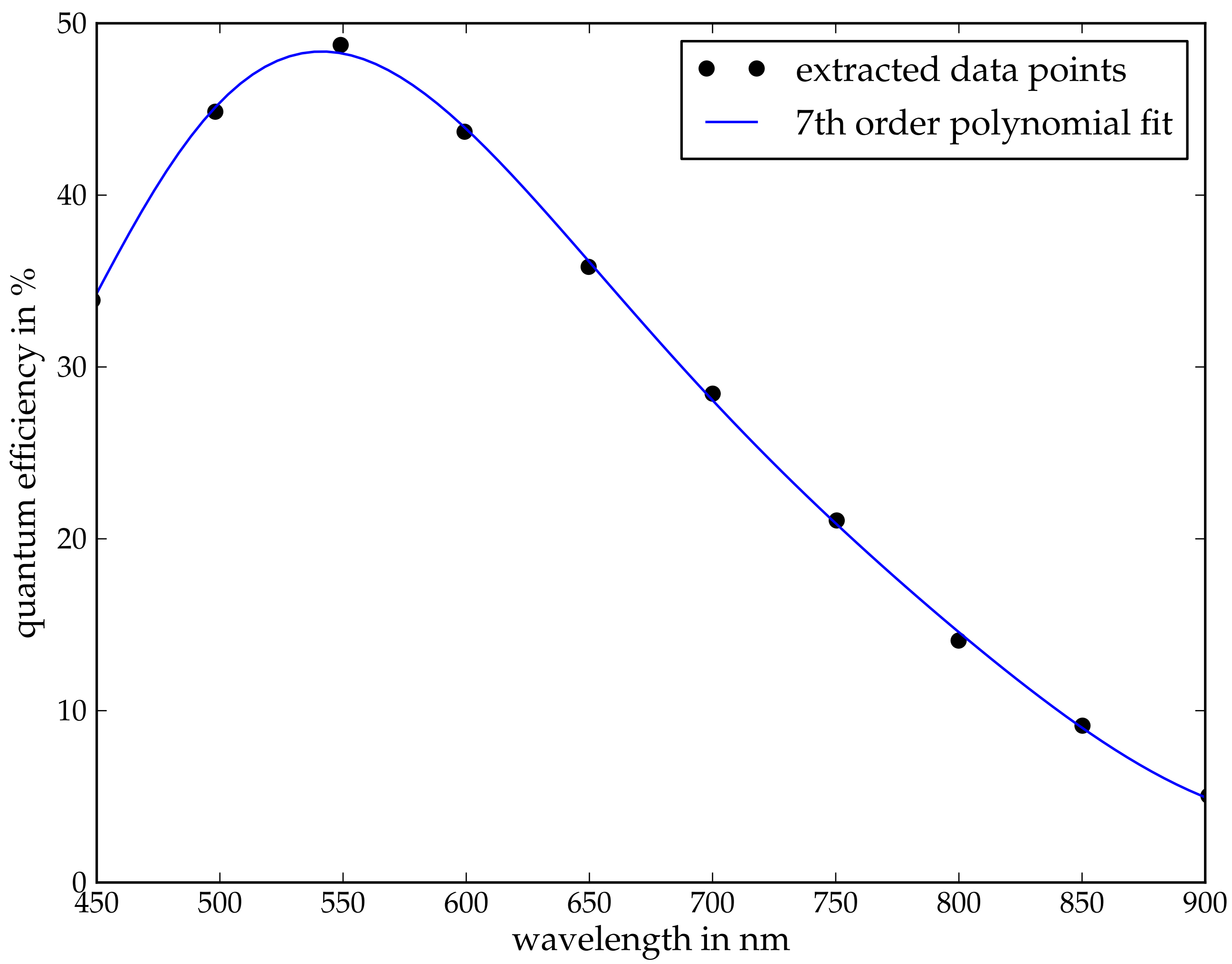
a comparison



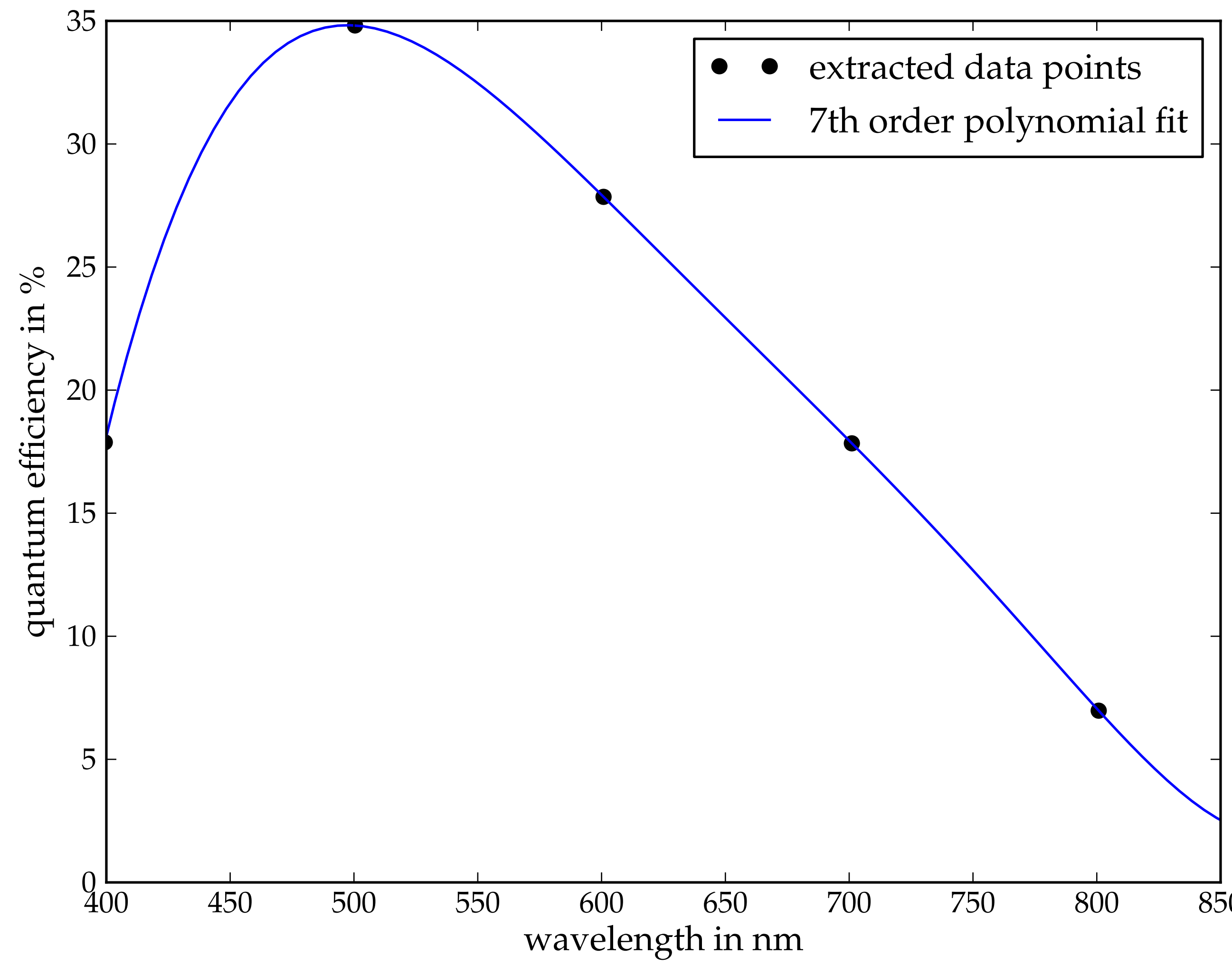
find the code and examples

www.physik.uzh.ch/~tina/3HBT

use two off the shelf single photon avalanche diode counters



Picoquant PDM series



IDQuantique ID100

detector	max efficiency	wavelength of max efficiency	time resolution Δt	dead time
Picoquant PDM series	49 %	550 nm	50 ps	80 ns
IDQuantique ID100 series	35 %	500 nm	40 ps	45 ns

black body source

number density for photons:

$$n(E)dE = \frac{8\pi}{(hc)^3} \frac{E^2 dE}{\exp\left[E/k_B T\right] - 1}$$

in terms of bandwidth:

$$n(\lambda)\Delta\lambda = \frac{8\pi}{\lambda^4} \frac{\Delta\lambda}{\exp\left[hc/\lambda k_B T\right] - 1}$$

in the small angle approximation the solid angle Ω is around $\pi(\theta/2)^2$

coherence time: $\Delta\tau \sim 1/\Delta\nu = \lambda^2/c\Delta\lambda$

$$r\Delta\tau = n(\lambda)\frac{Ac\Omega}{4\pi}\Delta\tau = \frac{2Ac\Omega}{\lambda^4} \frac{\Delta\lambda}{\exp\left[hc/\lambda k_B T\right] - 1}\Delta\tau = \frac{2A\Omega}{\lambda^2(\exp\left[hc/\lambda k_B T\right] - 1)}$$

approximate rates using a black body toy model

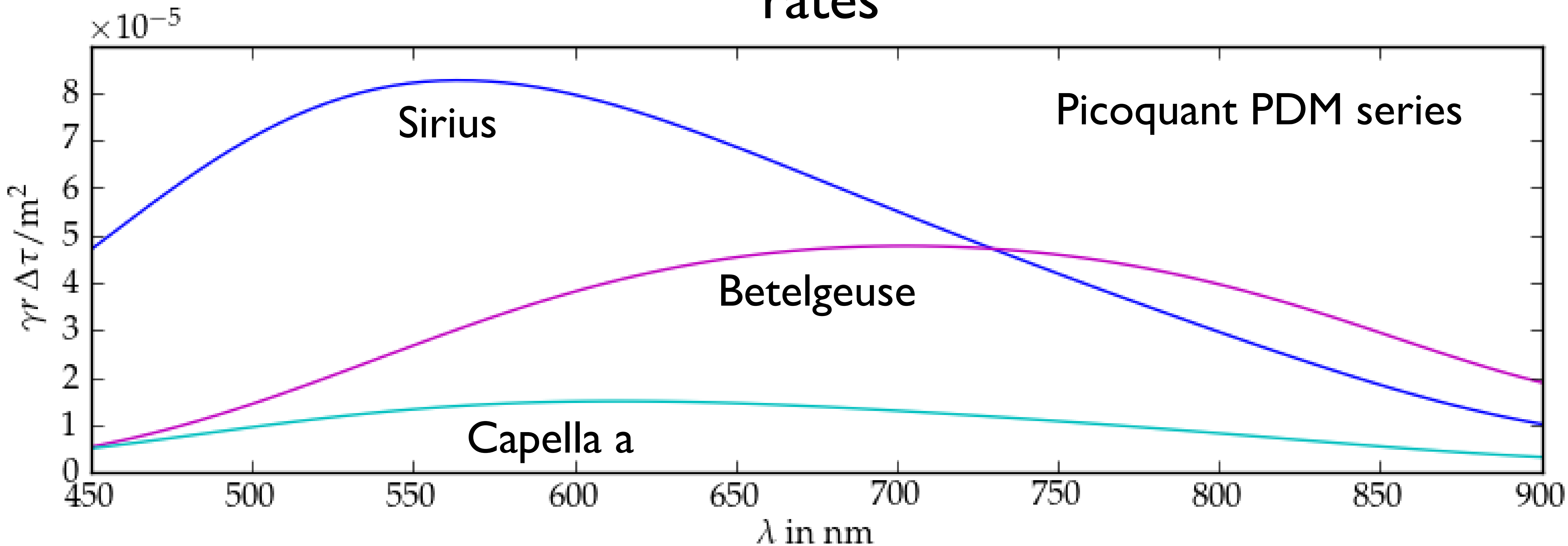
let r be the average count rate of one detector, so in one coherence time:

$$\gamma r \Delta\tau = \frac{\gamma A \Omega}{\lambda^2 (\exp[hc/\lambda k_B T] - 1)}$$

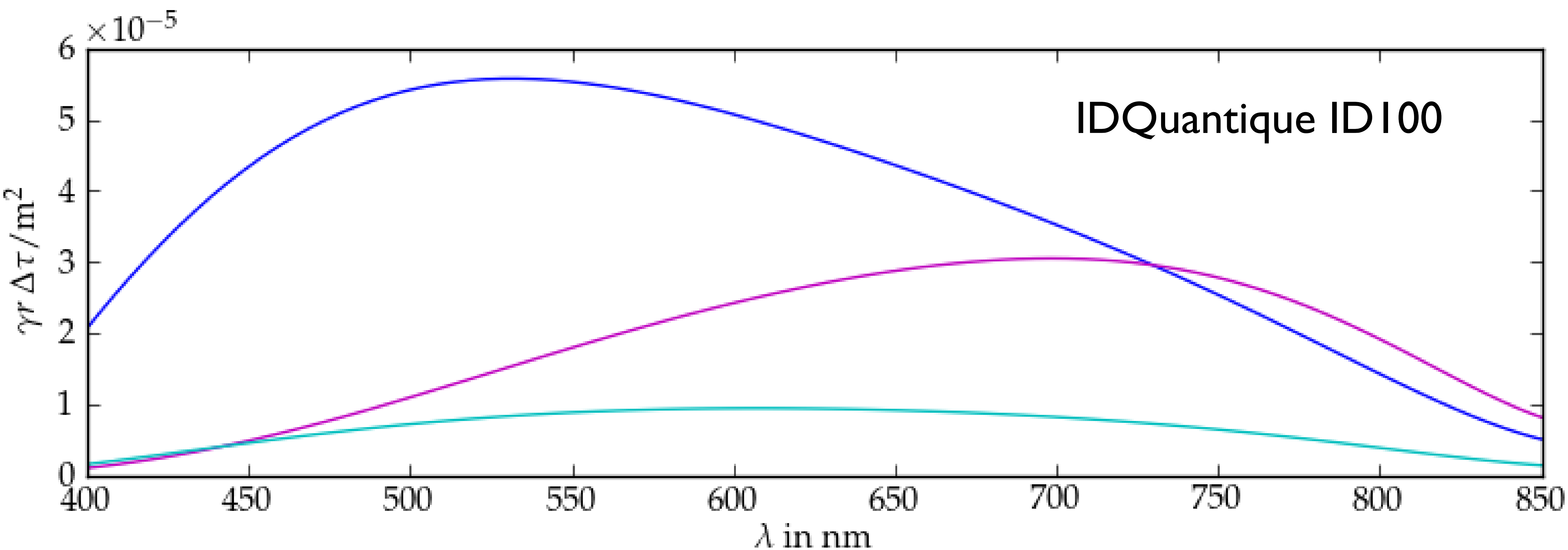
in the following we'll look at:

source	temperature [K]	diameter [arcsec]
Sirius	9940	.006
Betelgeuse	3500	.04
Capella a	5700	.003
Capella b	4940	.004

rates



$\times 10^{-5}$
Picoquant PDM series
Sirius
Betelgeuse
Capella a
$\gamma r\, \Delta\tau / \mathrm{m}^2$
0
1
2
3
4
5
6
7
8
450
500
550
600
650
700
750
800
850
900
λ in nm



$\times 10^{-5}$
IDQuantique ID100
$\gamma r\, \Delta\tau / \mathrm{m}^2$
0
1
2
3
4
5
6
400
450
500
550
600
650
700
750
800
850
λ in nm

signal to noise ratio and observation times

2 point correlation: $C_{12} = 1 + |V_{12}|^2$

$$SNR \sim \frac{r^2 \Delta\tau \Delta t}{r \Delta t} = r\Delta\tau$$

the signal to noise ratio for an integration time:

$$SNR(\Delta t) = |V_{12}|^2 \gamma r \Delta\tau$$

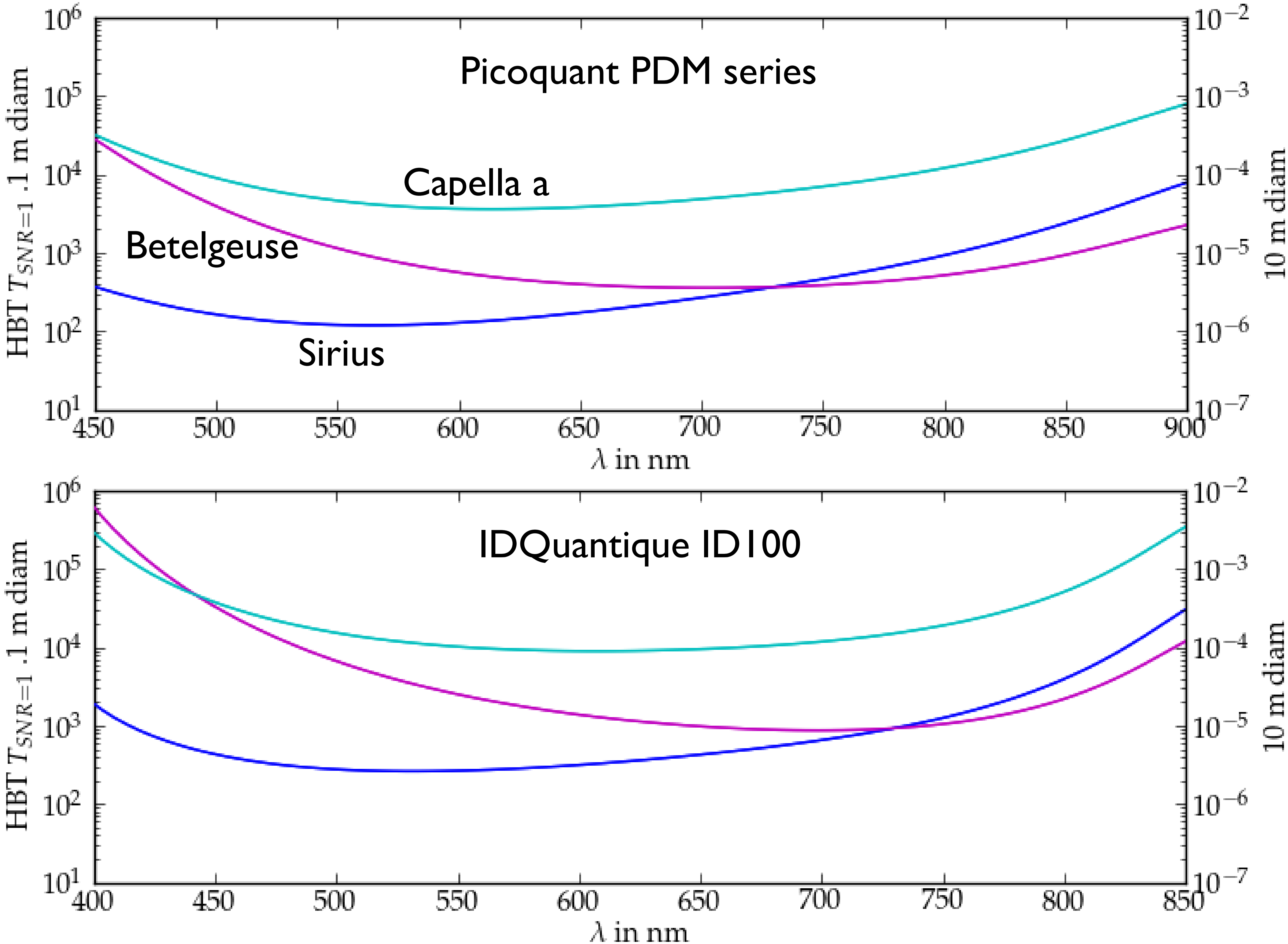
$$SNR = SNR(\Delta t)\sqrt{T_{\rm obs}/\Delta t}$$

necessary observation time:

$$T_{\rm obs}(SNR) = \frac{SNR^2}{|V_{12}|^4}\Delta t \left[\frac{\gamma A \Omega}{\lambda^2(\exp[hc/\lambda k_B T] - 1)}\right]^{-2}$$

we are now talking about geometric means of the collection area of two telescopes and their photon counters' efficiencies.

HBT observation times for SNR = 1



signal to noise ratio and observation times for 3 point correlation

the signal to noise ratio for an integration time:

$$SNR_3(\Delta t) \sim V_{123}(\gamma r \Delta\tau)^{3/2}(\Delta\tau/\Delta t)^{1/2}$$

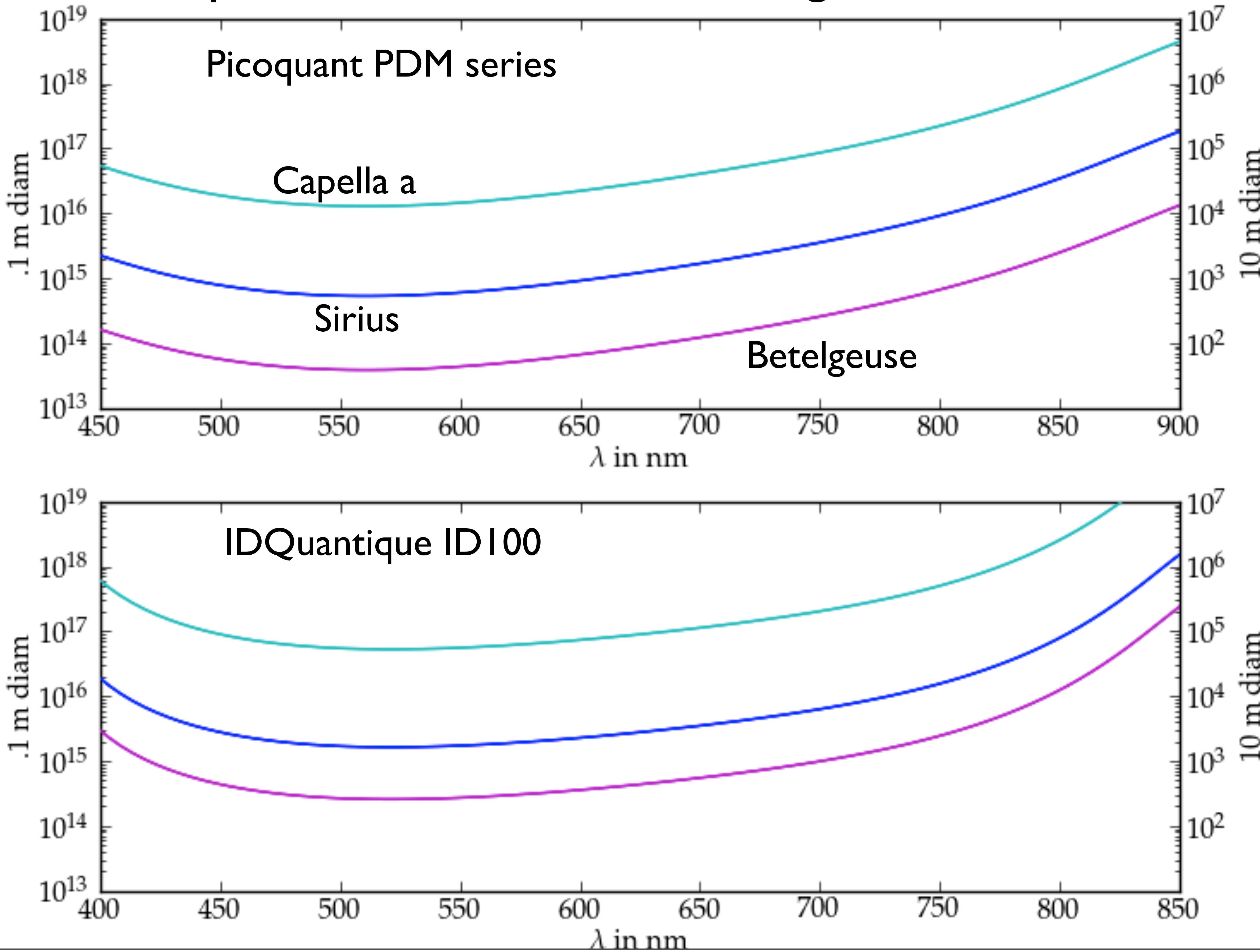
where: $V_{123} :\sim \mathrm{Re}[V_{12}V_{23}V_{31}]$

necessary observation time:

$$T_{\mathrm{obs}}(SNR) = \frac{SNR^2}{V_{123}^2}\frac{\Delta t^2}{\Delta\tau}\left[\frac{\gamma A\Omega}{\lambda^2(\exp[hc/\lambda k_B T]-1)}\right]^{-3}$$

this is where bandwidth comes in to haunt us.

3 point observation times change to V_{123}=.001



take home

SNR for standard HBT is independent of bandwidth
3 point HBT measurements will depend on bandwidth

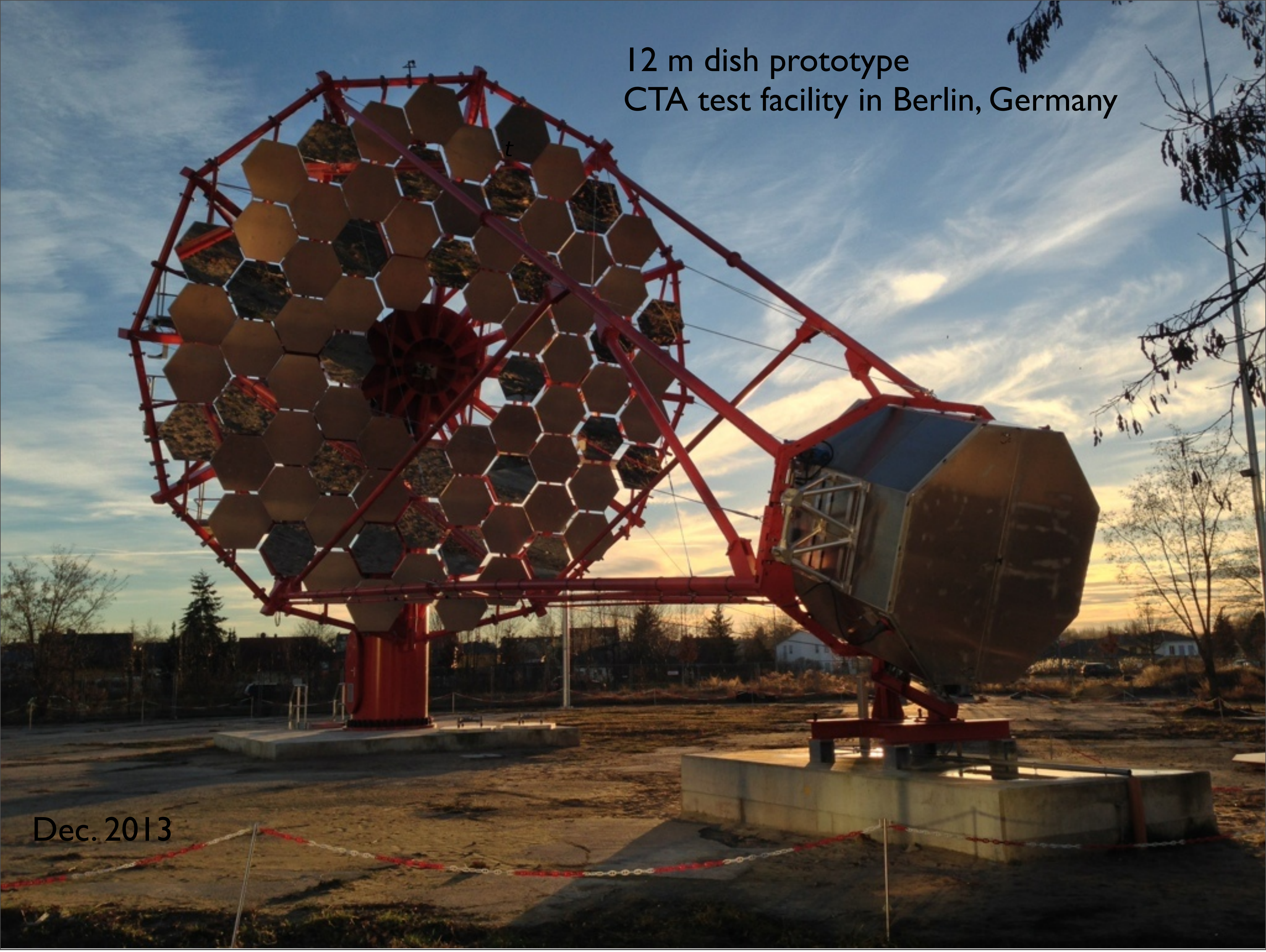
observation times for 2 point correlation go with γA^{-2} ,

for 3 point correlation with γA^{-3}

Capella and Betelgeuse HBT can be done with amateur telescopes!
Telescopes of a few meters diameter could even do 3 point correlation for Betelgeuse recovering phase information and thus the structure in the atmosphere

larger telescopes could measure 3 point correlation for various types of astrophysical sources

since we're not point like - will the features be washed out?
what about large scale features?


12 m dish prototype
CTA test facility in Berlin, Germany
Dec. 2013