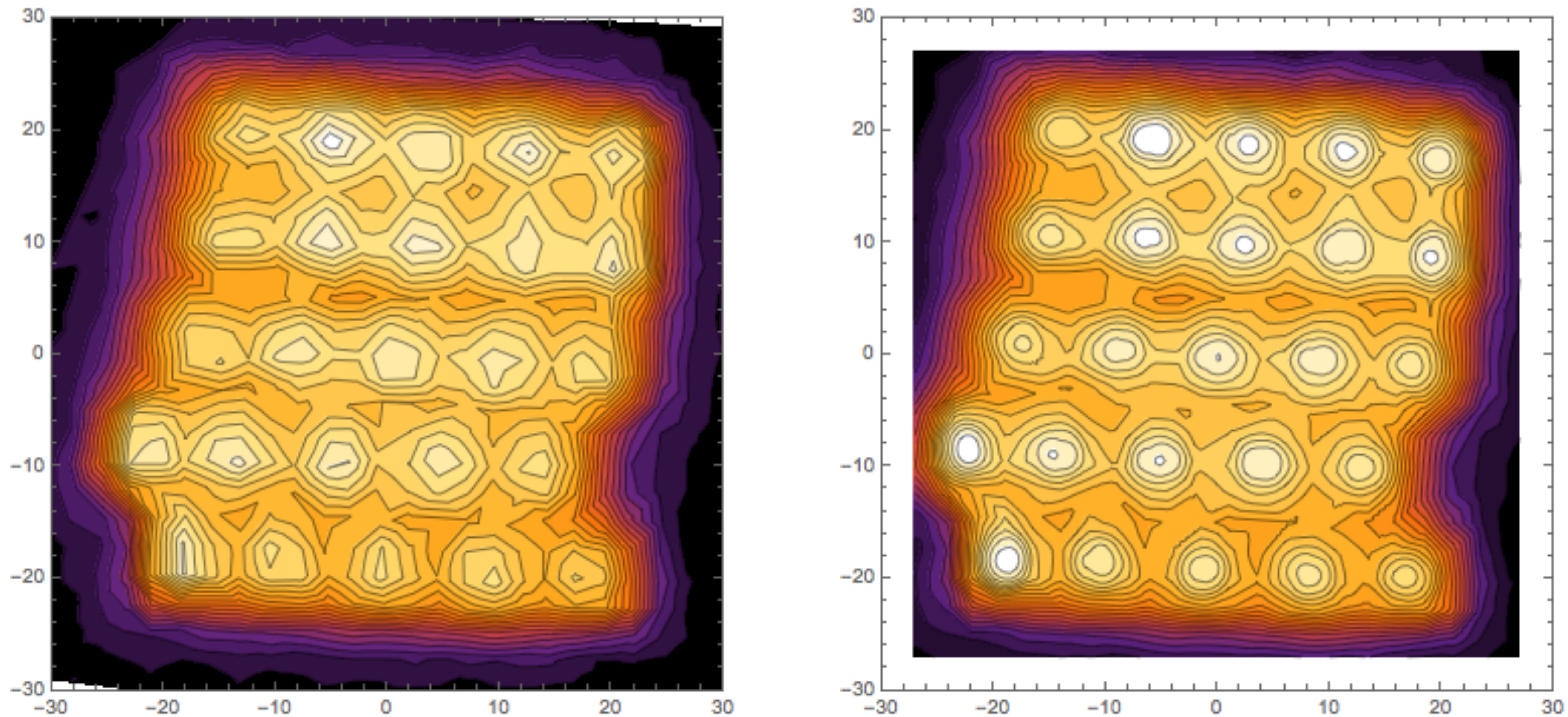
PACS_S Flux Calibration Concept

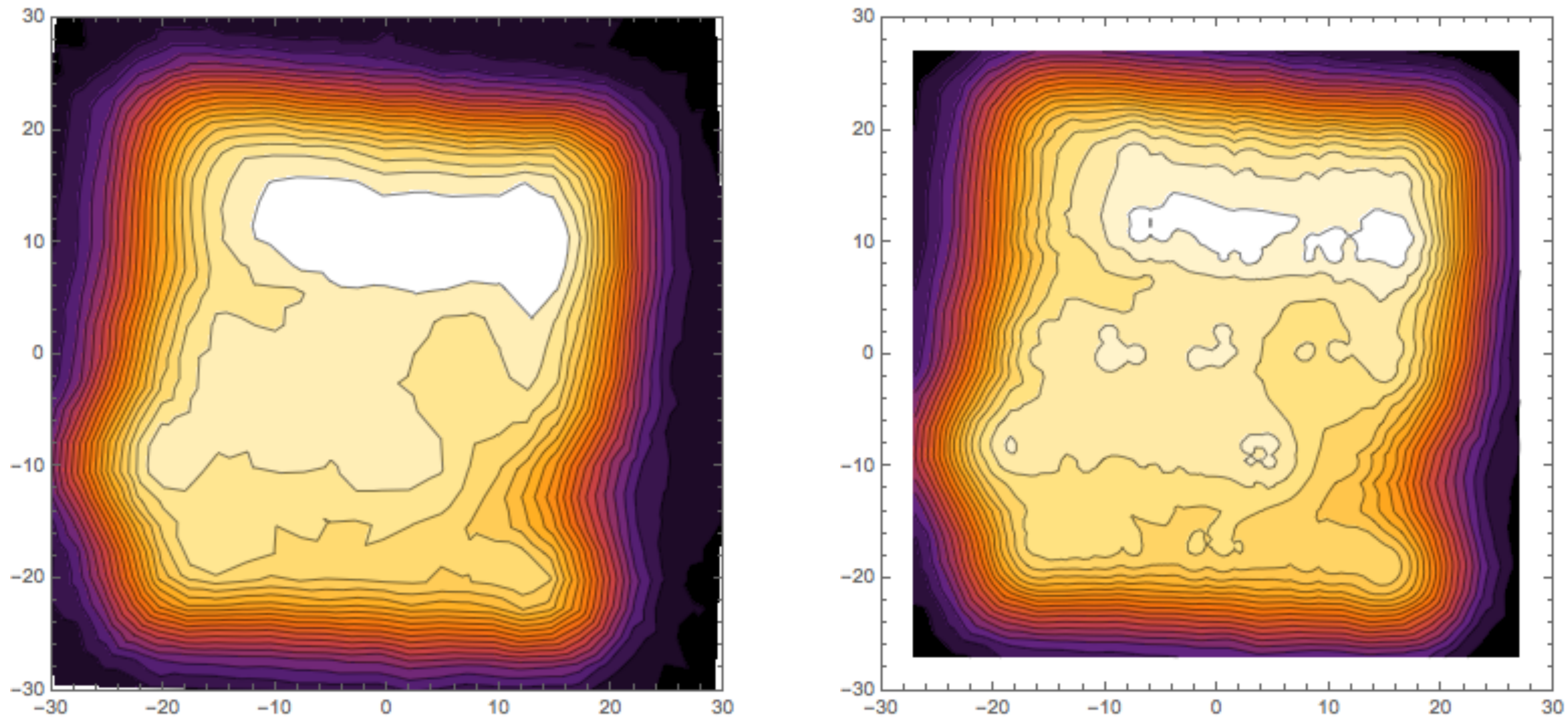
- Original concept: point source on central spaxel, sum of signals from all spaxels must add up to total flux of source
- At some point, replaced by (adopted) "point source correction" and 1x1 / 3x3 flux definition/correction. Should still be not too far from original idea
- But: Original concept implicitly assumes "flat" response, i.e., sum of spaxel signals independent of exact point source position on IFU.
  This is not fulfilled, particularly at short wavelengths!
  Affects non-central (point) sources <u>and drizzle</u>, but also (very) extended sources

"Flatness" of PACS IFU/Detector Response



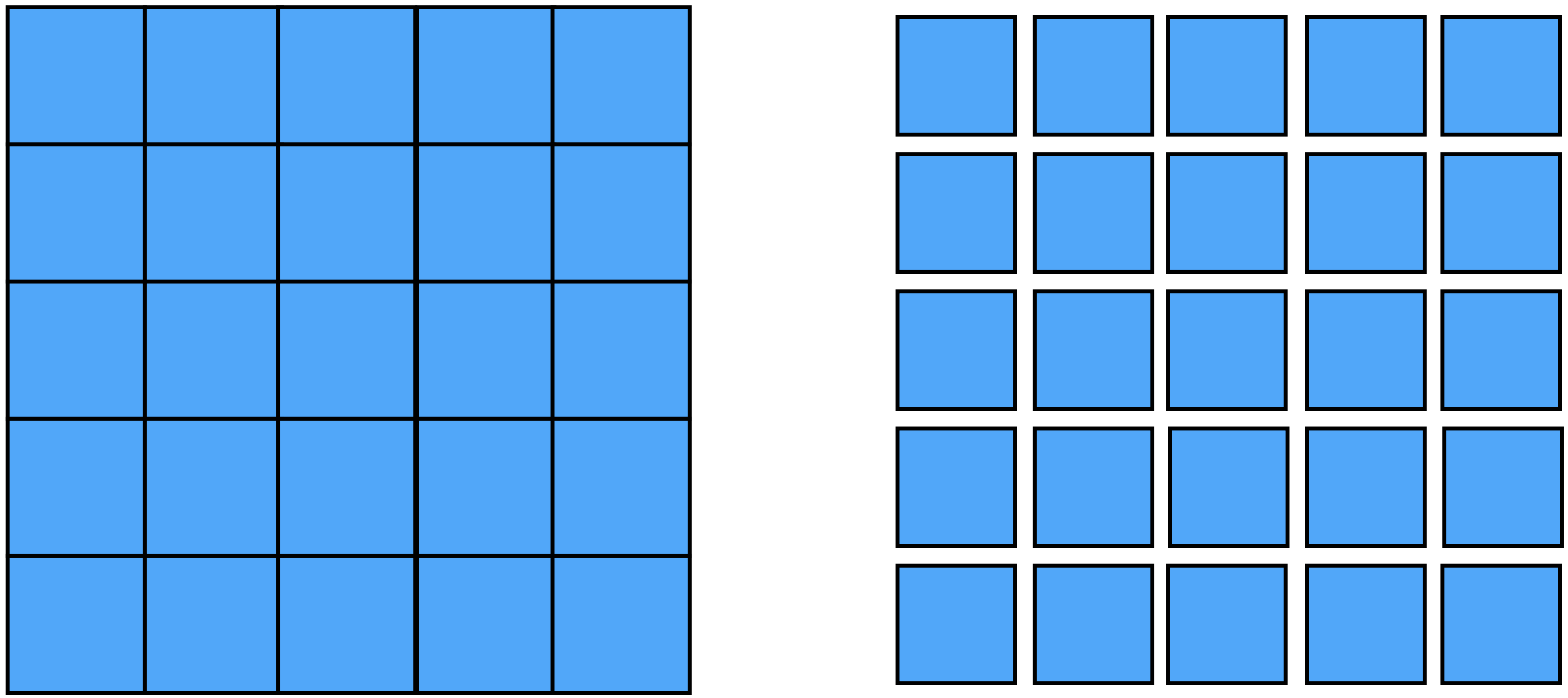
- Sum of all spaxels @ 62μm
- Left: Neptune "coarse" raster, right: "synthetic" beams

"Flatness" of PACS IFU/Detector Response



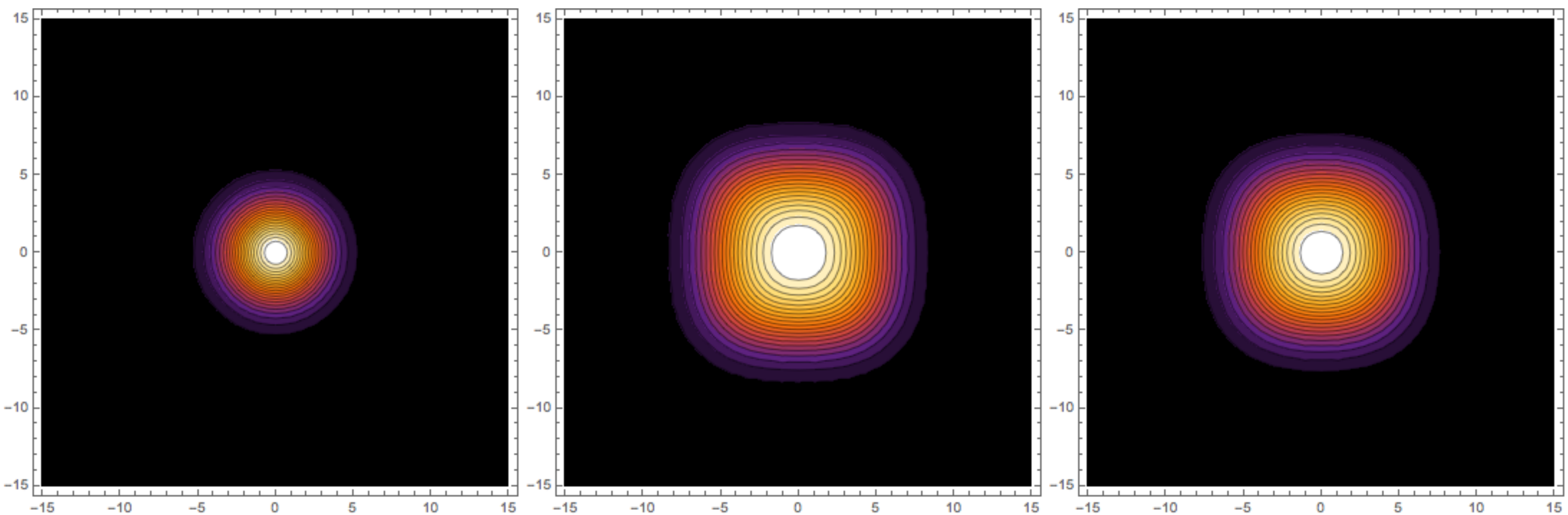
- Sum of all spaxels @ 145μm
- Left: Neptune "coarse" raster, right: "synthetic" beams

"Toy Model" of IFU/Detector Spatial Response



- Start with 9.4 arcsec (active) size & spacing
- Compare with 8 arcsec size, 9.4 arcsec spacing
- Telescope/optics PSF approximated by Gaussian, then convolved with "box" of size 9.4 or 8 arcsec, respectively

Beams @ 62μm

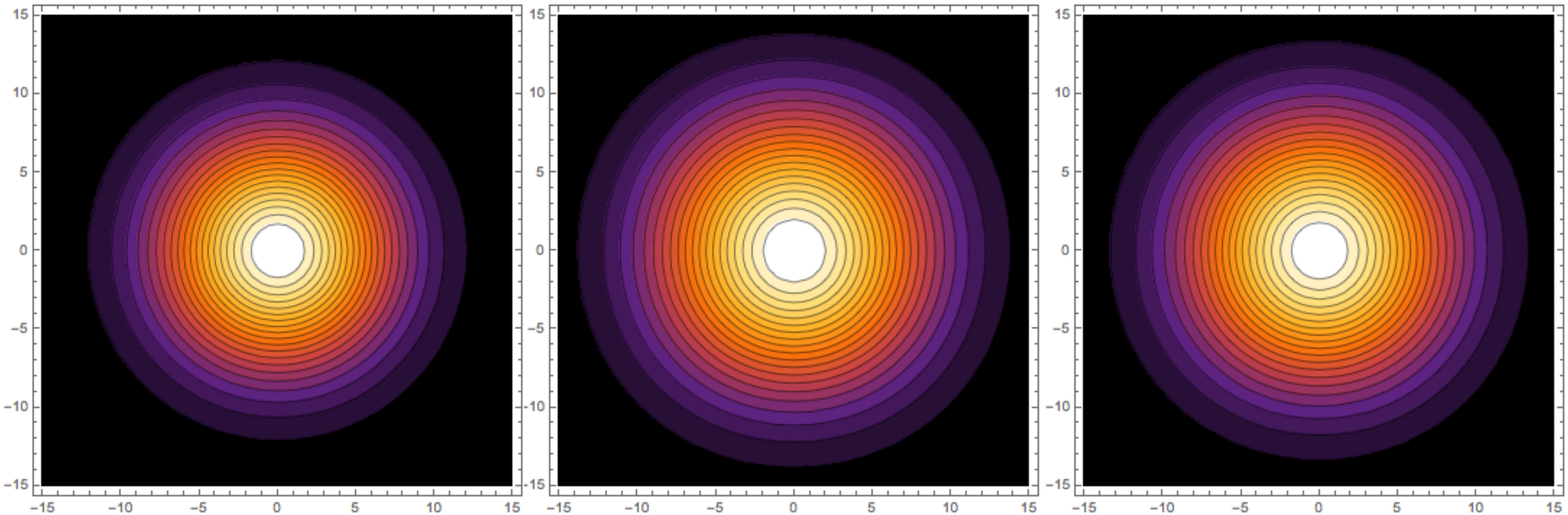


$e^{-(x^2+y^2)/w^2}$

Convolve[$e^{-(x^2+y^2)/w^2}$, UnitBox[x / 9.4, y / 9.4], {x, y}, {xx, yy}]

Convolve[$e^{-(x^2+y^2)/w^2}$, UnitBox[x / 8, y / 8], {x, y}, {xx, yy}]

Beams @ 145μm

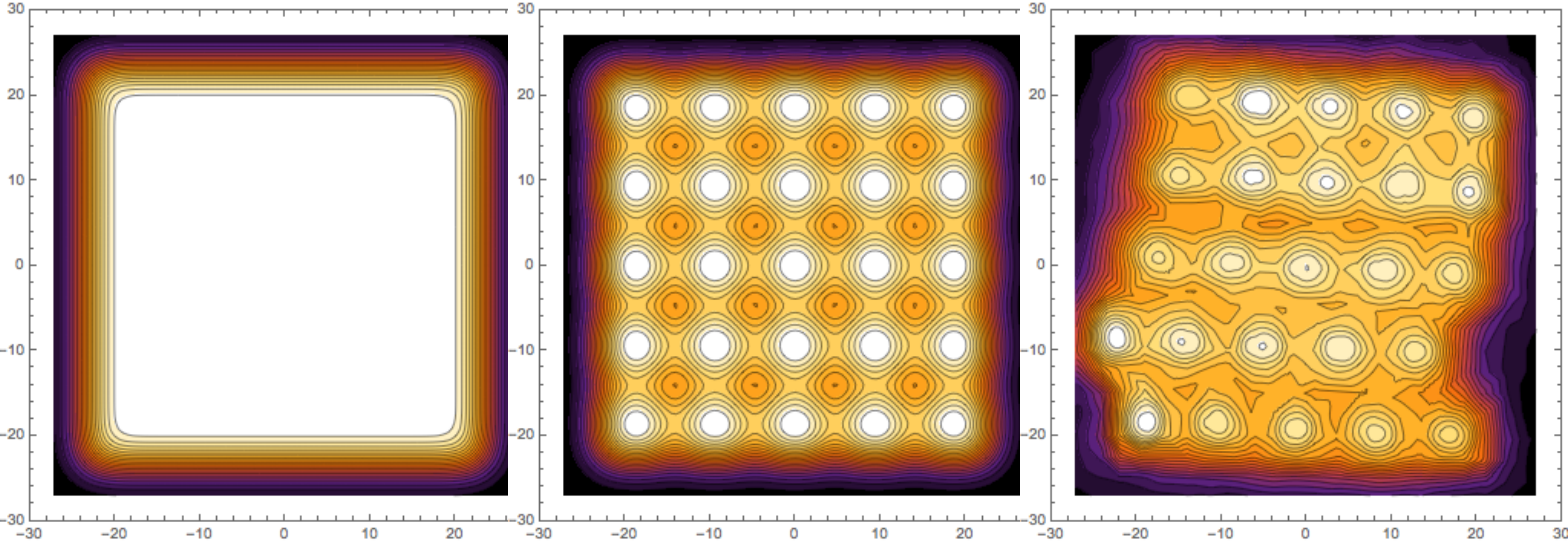


$e^{-(x^2+y^2)/(2.3*w)^2}$

Convolve[$e^{-(x^2+y^2)/(2.3*w)^2}$, UnitBox[x / 9.4, y / 9.4], {x, y}, {xx, yy}]

Convolve[$e^{-(x^2+y^2)/(2.3*w)^2}$, UnitBox[x / 8, y / 8], {x, y}, {xx, yy}]

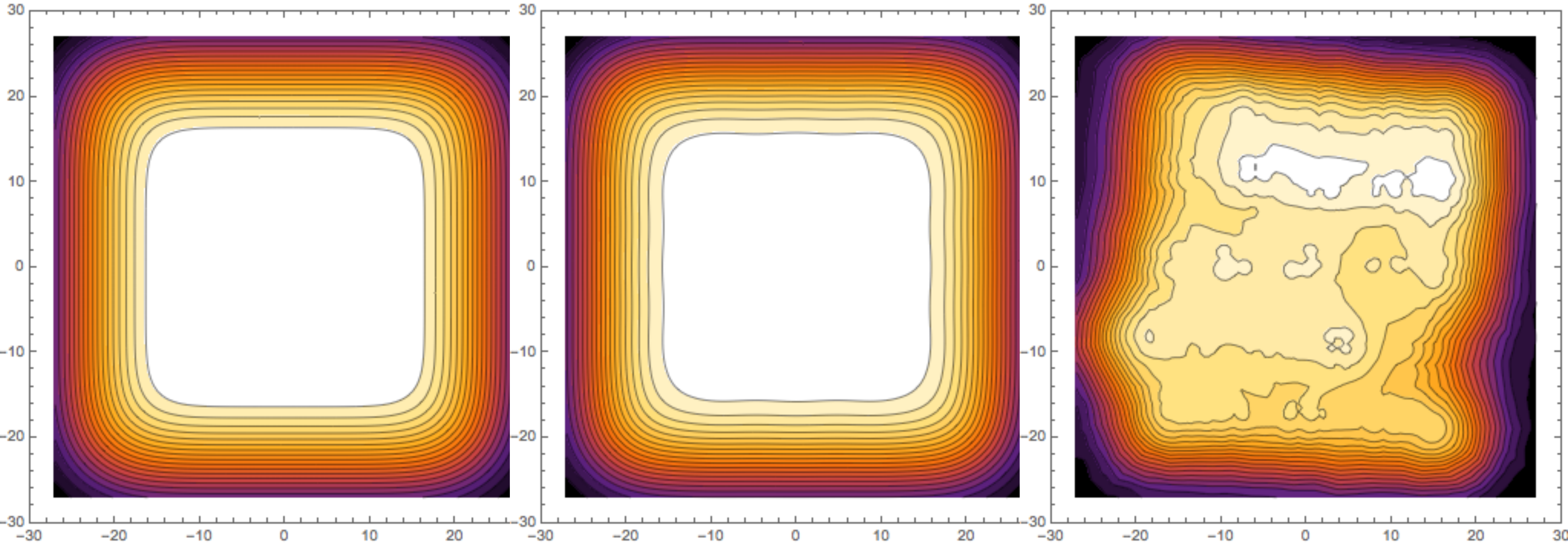
Sum of 25 Spaxels @ 62μm



9.4 arcsec active area | 8 arcsec active area | beam table

- Reduction of active area leads to comparable loss as observed in reality

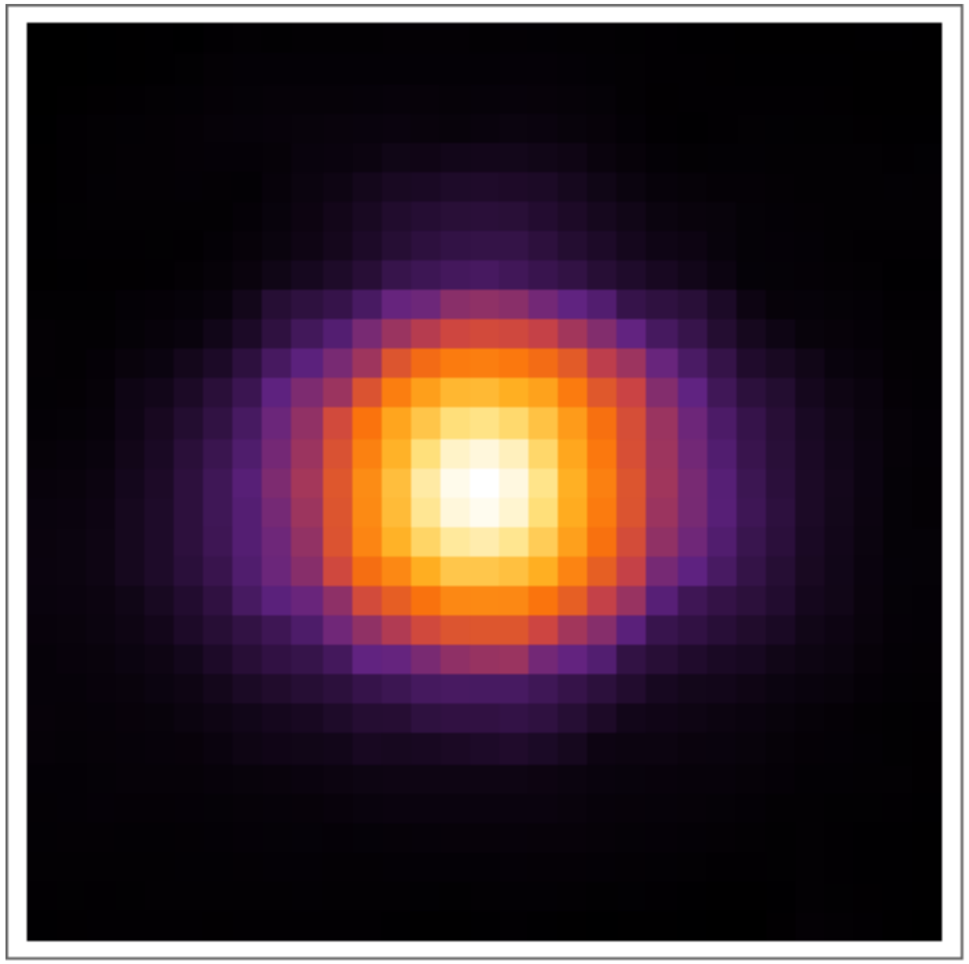
Sum of 25 Spaxels @ 145μm



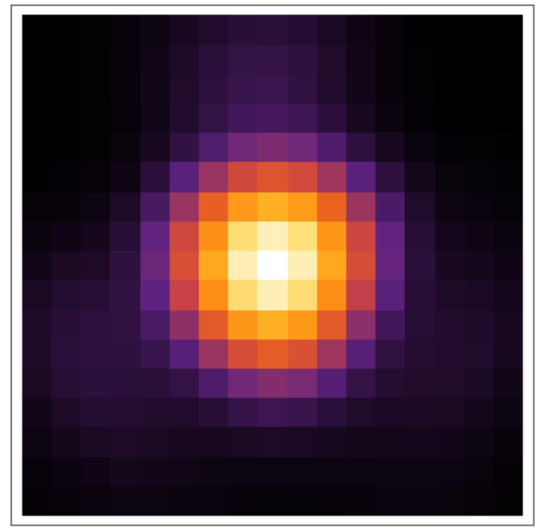
9.4 arcsec active area   8 arcsec active area   beam table

- (Some additional inhomogeneity in reality)

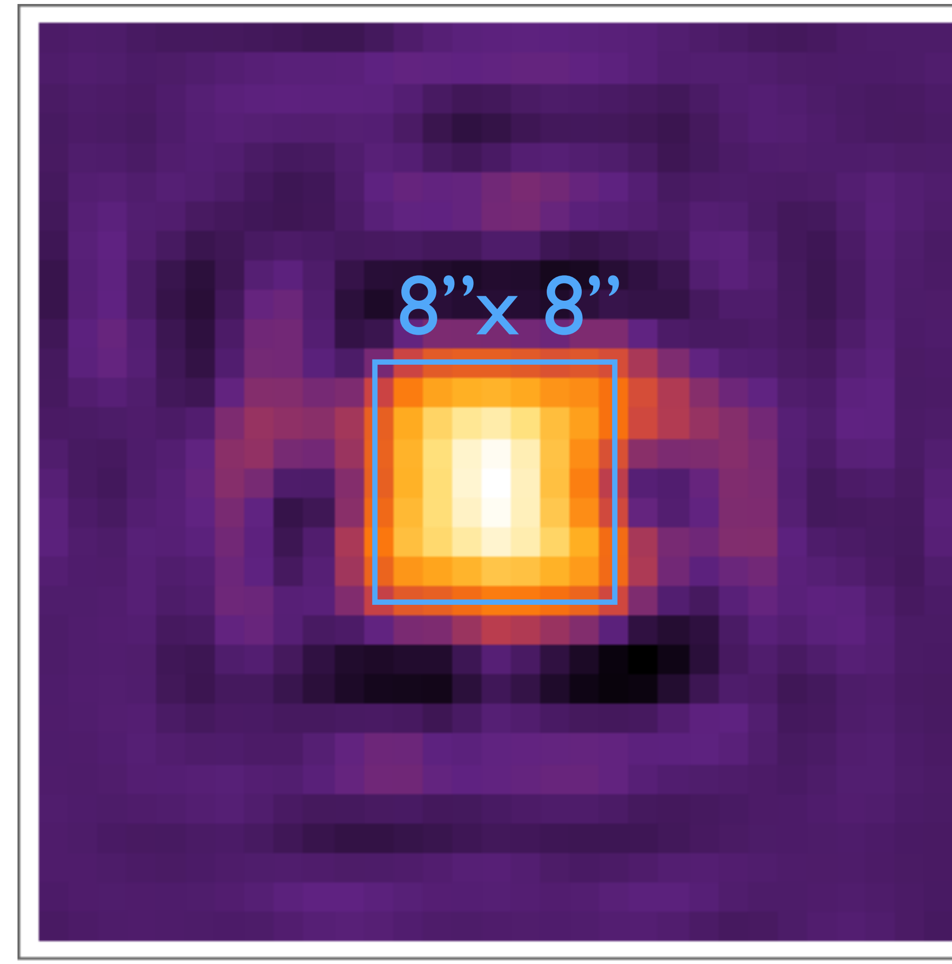
Deconvolve Spaxel 13 Beam with Photometer PSF



Central spaxel beam

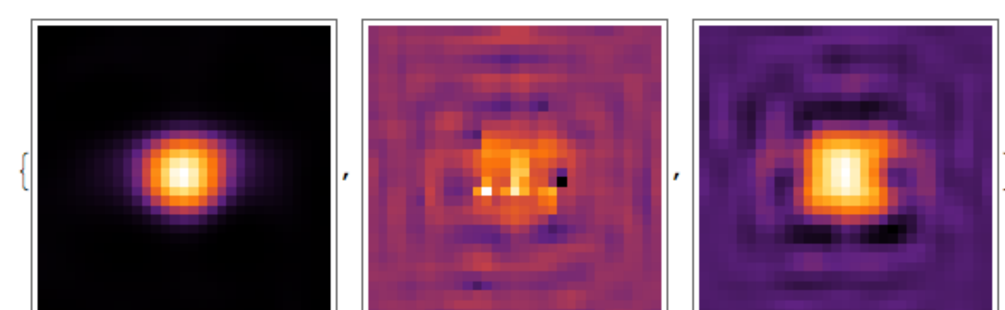


Blue photometer PSF



Deconvolved central spaxel

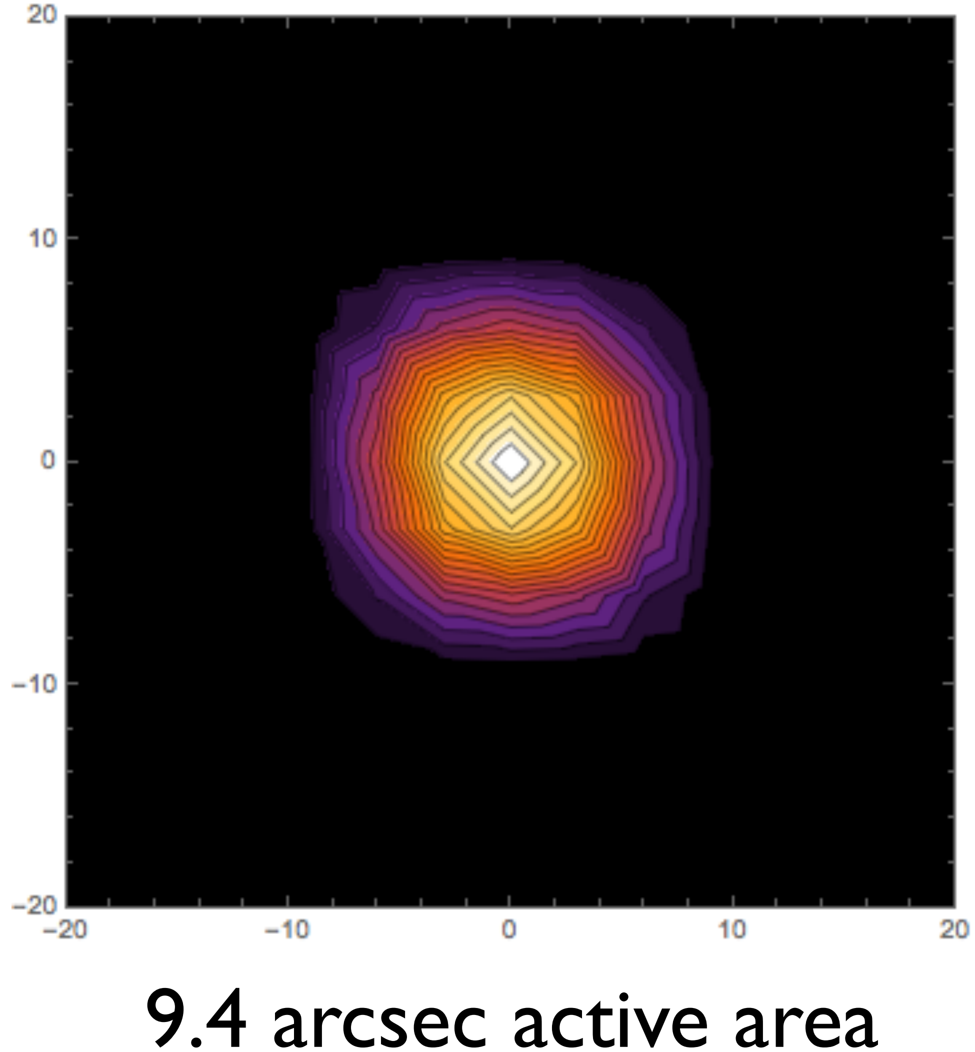
- Result of deconvolution depends on method/assumptions, but gives indication of reduced active area



Drizzle Experiment with "Toy Model" Beams

- Following the original flux calibration concept, the beams are normalized such that the sum of the signal from all 25 spaxels is 1 when the simulated point source falls on center of central spaxel, for both cases of active spaxel area
- The observations are simulated as a regular raster with 2.5 arcsec steps (y and z) and then drizzled on a 3 arcsec grid
- The drizzle normalization is set up to produce "flux per projected pixel" - aperture photometry by adding up values of projected pixels
- Then compare collected flux for both active areas

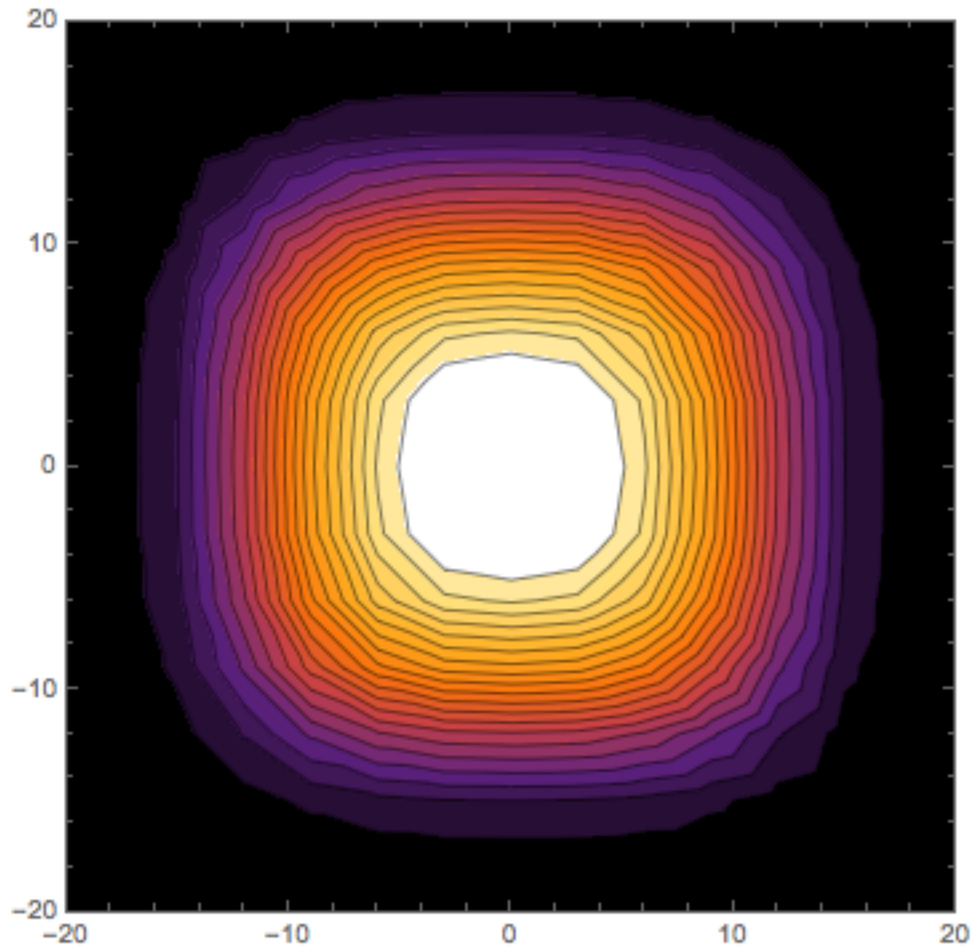
Drizzle @ 62μm: Point Source



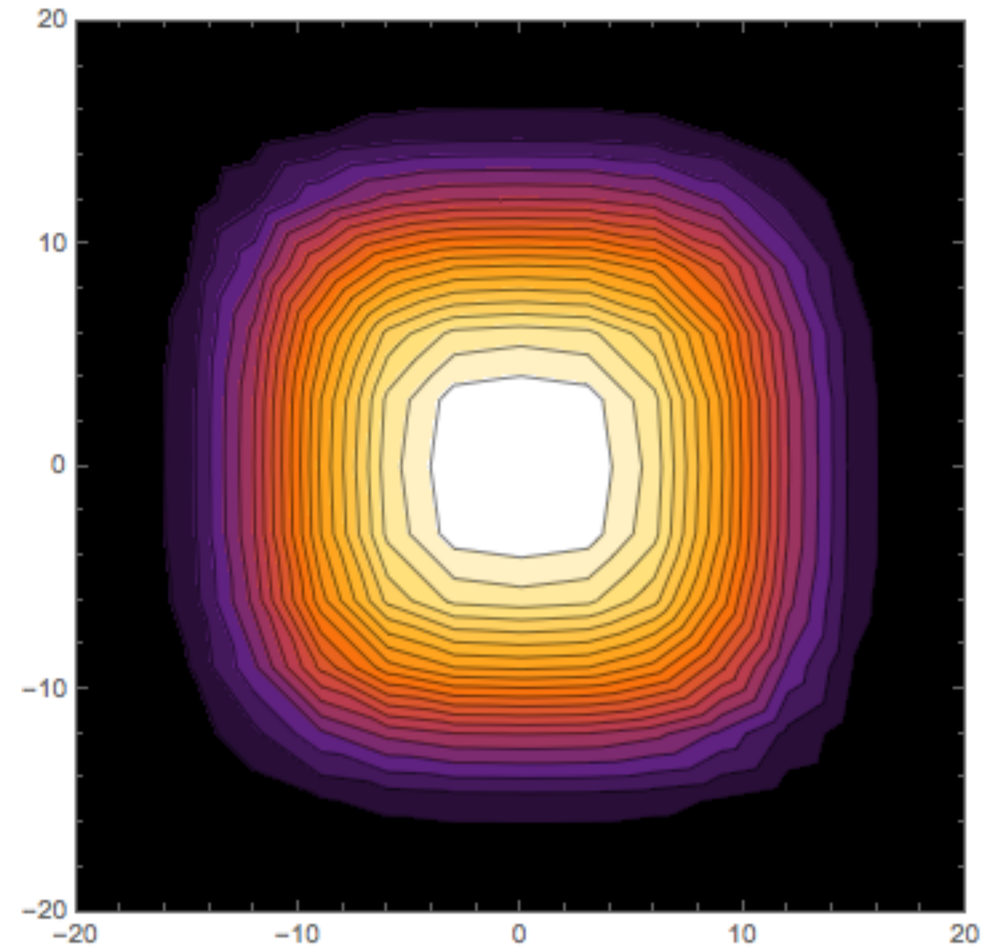

```
{Total[drizzle[[All, 3]]], Total[drizzle2[[All, 3]]], Total[drizzle2[[All, 3]]] / Total[drizzle[[All, 3]]]}
{1.0058267, 0.80344291, 0.7987886}
```

- While the sum of the flux from all spaxels, when the source is in the center, is 1 in both cases, the drizzle recovers only 80% for the smaller active area

Drizzle @ 62μm: Extended Source (20arcsec Square)



9.4 arcsec active area

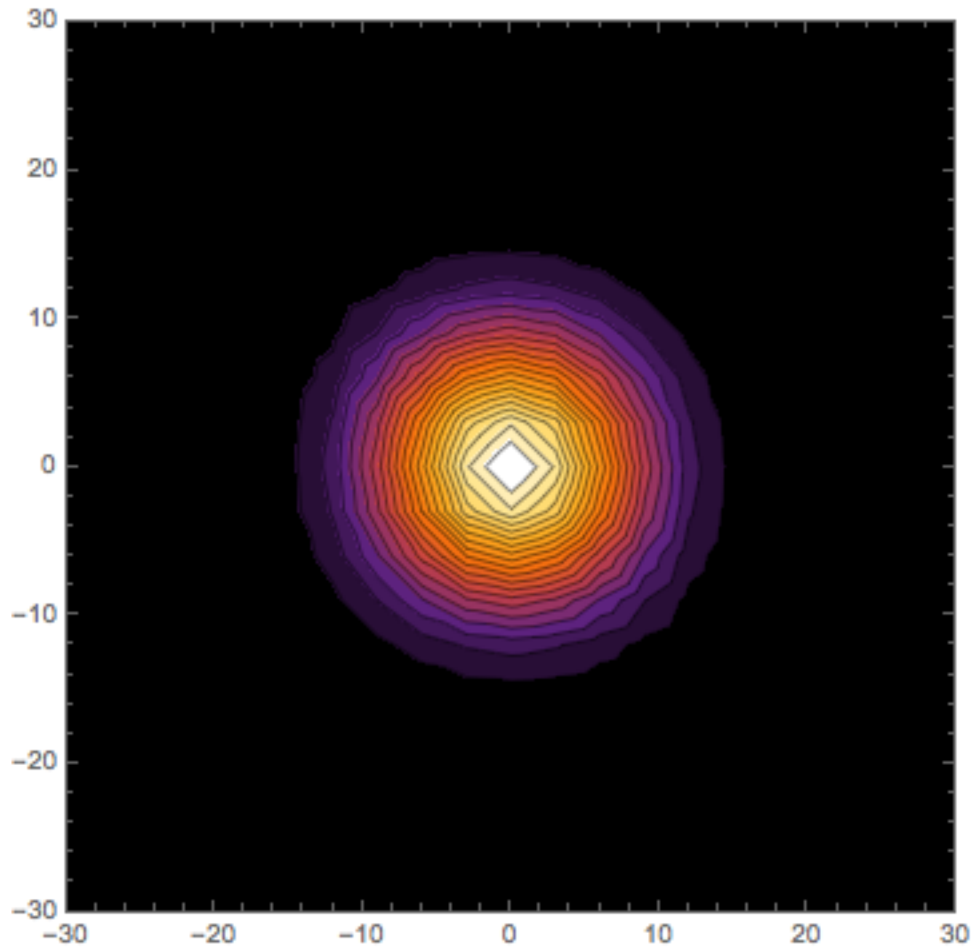


8 arcsec active area

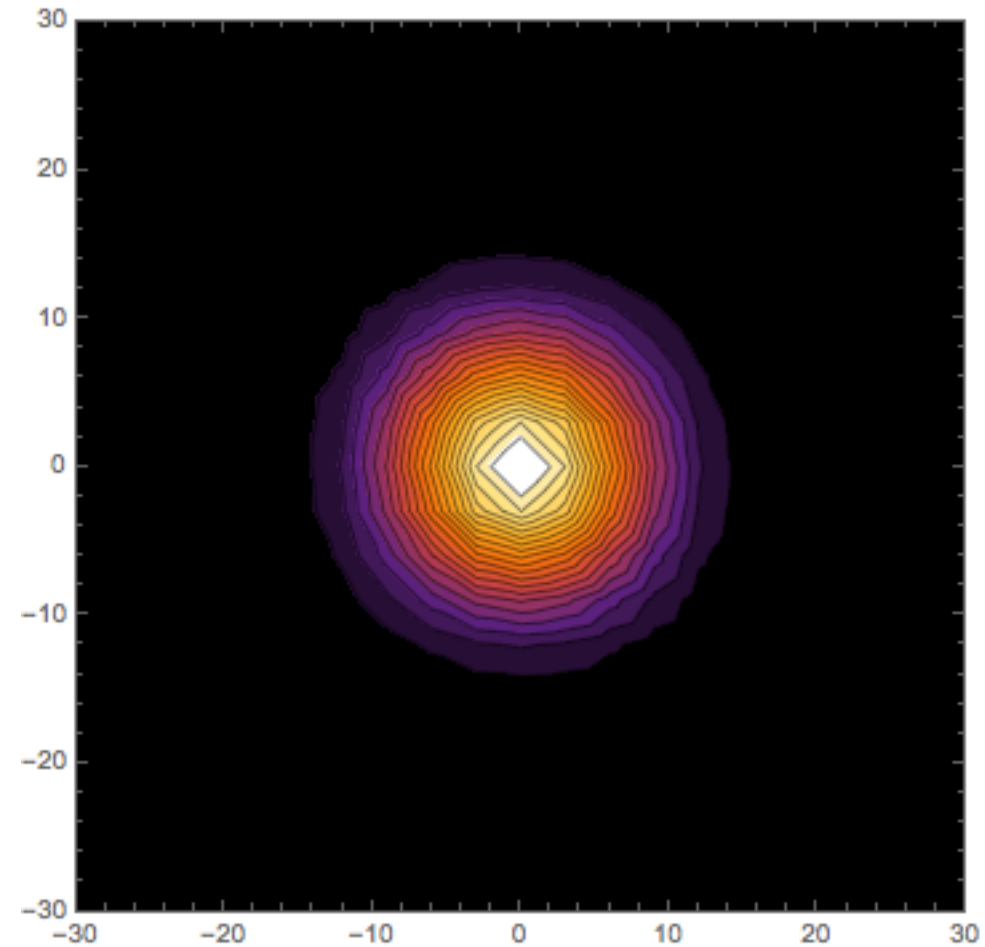
```
{Total[drizzle[[All, 3]]], Total[drizzle2[[All, 3]]], Total[drizzle2[[All, 3]]] / Total[drizzle[[All, 3]]]}
{1.0074262, 0.80627102, 0.80032762}
```

- With the smaller spaxel, the drizzle recovers 80% of the source flux
- Similarly, the central spaxel measures 80% of the surface brightness ($S[y,z]=1/9.4^2$, $\int S[y,z]\ Beam[y,z]\ dy\ dz$ over area >> beam width)

Drizzle @ 145μm: Point source



9.4 arcsec active area

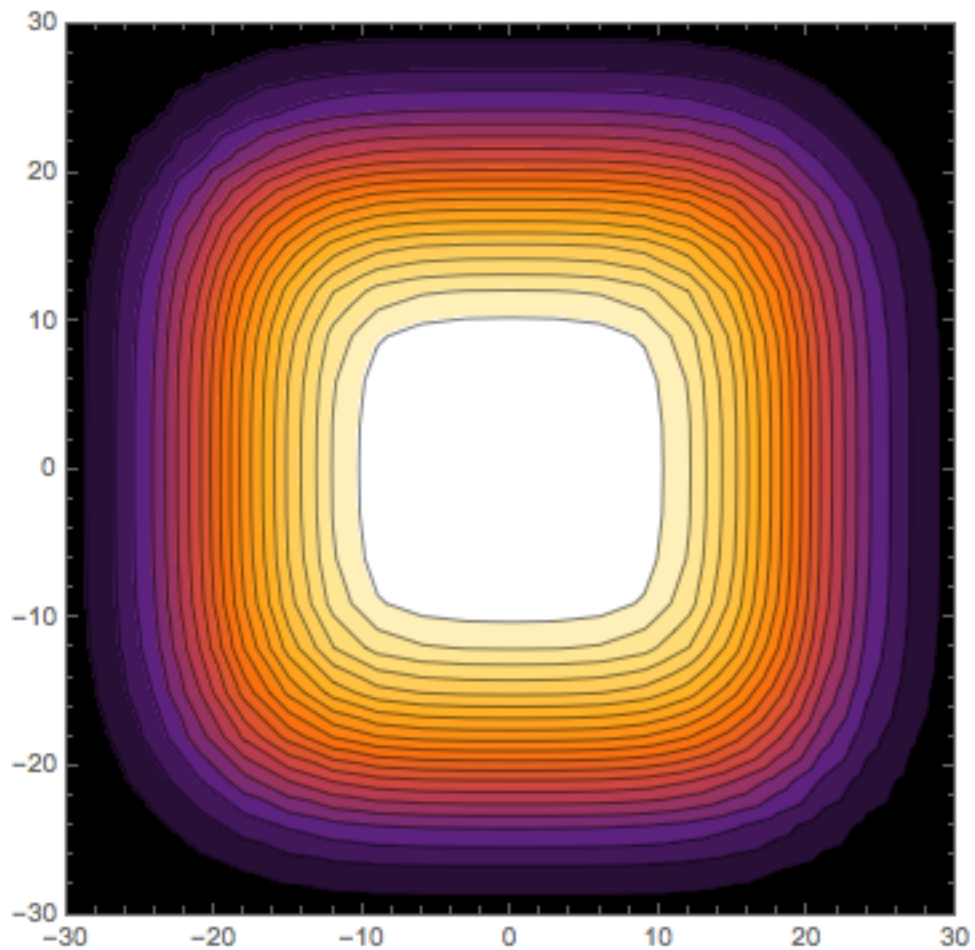


8 arcsec active area

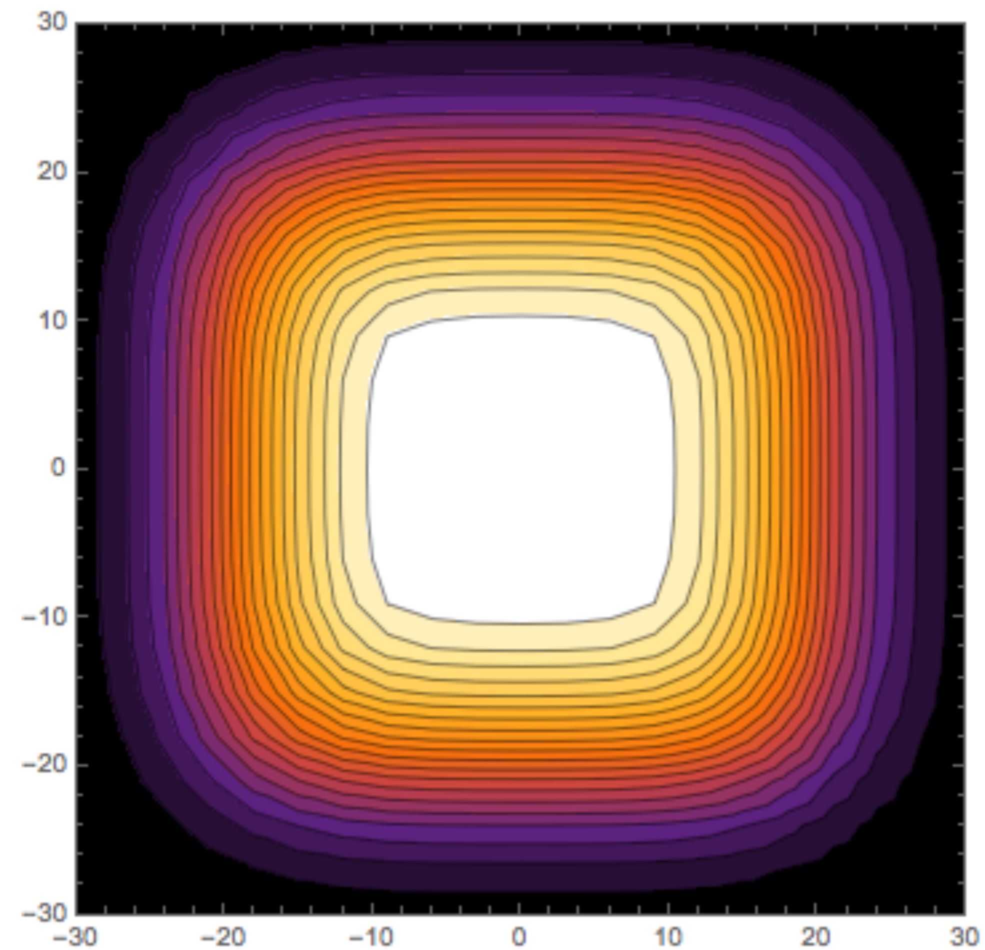
```
{Total[drizzle3[[All, 3]]], Total[drizzle4[[All, 3]]], Total[drizzle4[[All, 3]]] / Total[drizzle3[[All, 3]]]}
{1.0086299, 1.0053408, 0.99673904}
```

- Here, both cases recover the full flux, thanks to the larger telescope PSF

Drizzle @ 145μm: Extended Source (38arcsec Square)



9.4 arcsec active area



8 arcsec active area

```
{Total[drizzle3[[All, 3]]], Total[drizzle4[[All, 3]]], Total[drizzle4[[All, 3]]] / Total[drizzle3[[All, 3]]]}
{1.0008051, 0.99829375, 0.99749066}
```

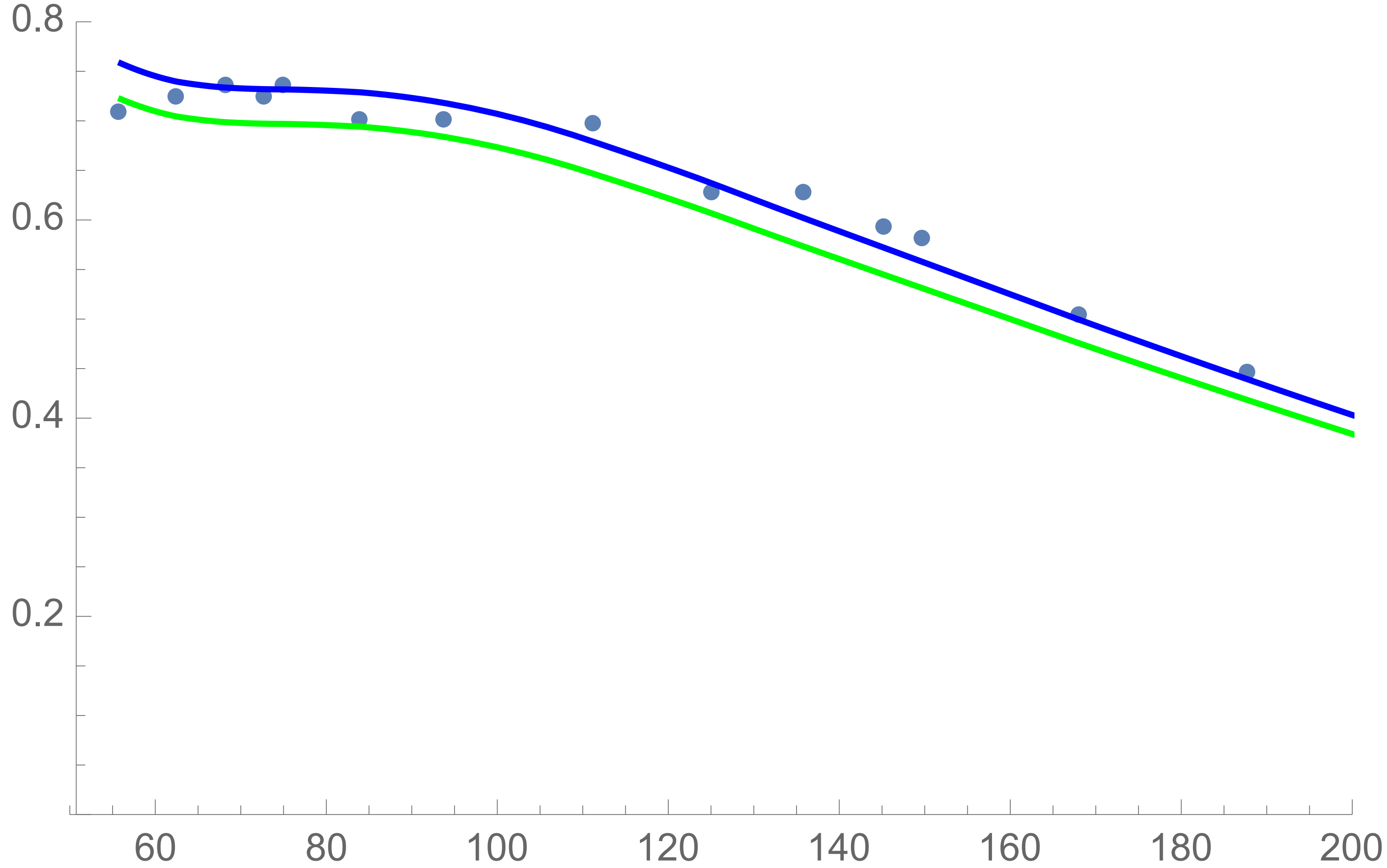
- The drizzle recovers the source flux
- Also, the central spaxel measures >99% of the surface brightness ($S[y,z]=1/9.4^2$, $\int S[y,z]\, Beam[y,z]\, dy\, dz$ over area >> beam width)

Way Forward

- The little experiment roughly reproduces Elena's findings
- To become more realistic, the experiment has to be repeated with the actual beams, which have to be normalized such, that the sum of all spaxels is 1 when a point source of flux 1 is observed at the peak position of the central spaxel.
  (This assumes that our present flux calibration is still consistent with the original concept!)
- Specific raster map observations + drizzle can then be simulated and analyzed for flux recovery
- Since source structure and raster positions enter into the flux recovery, no simple/universal correction factor!

Check: "Canonical" PS Correction vs. Central/5x5

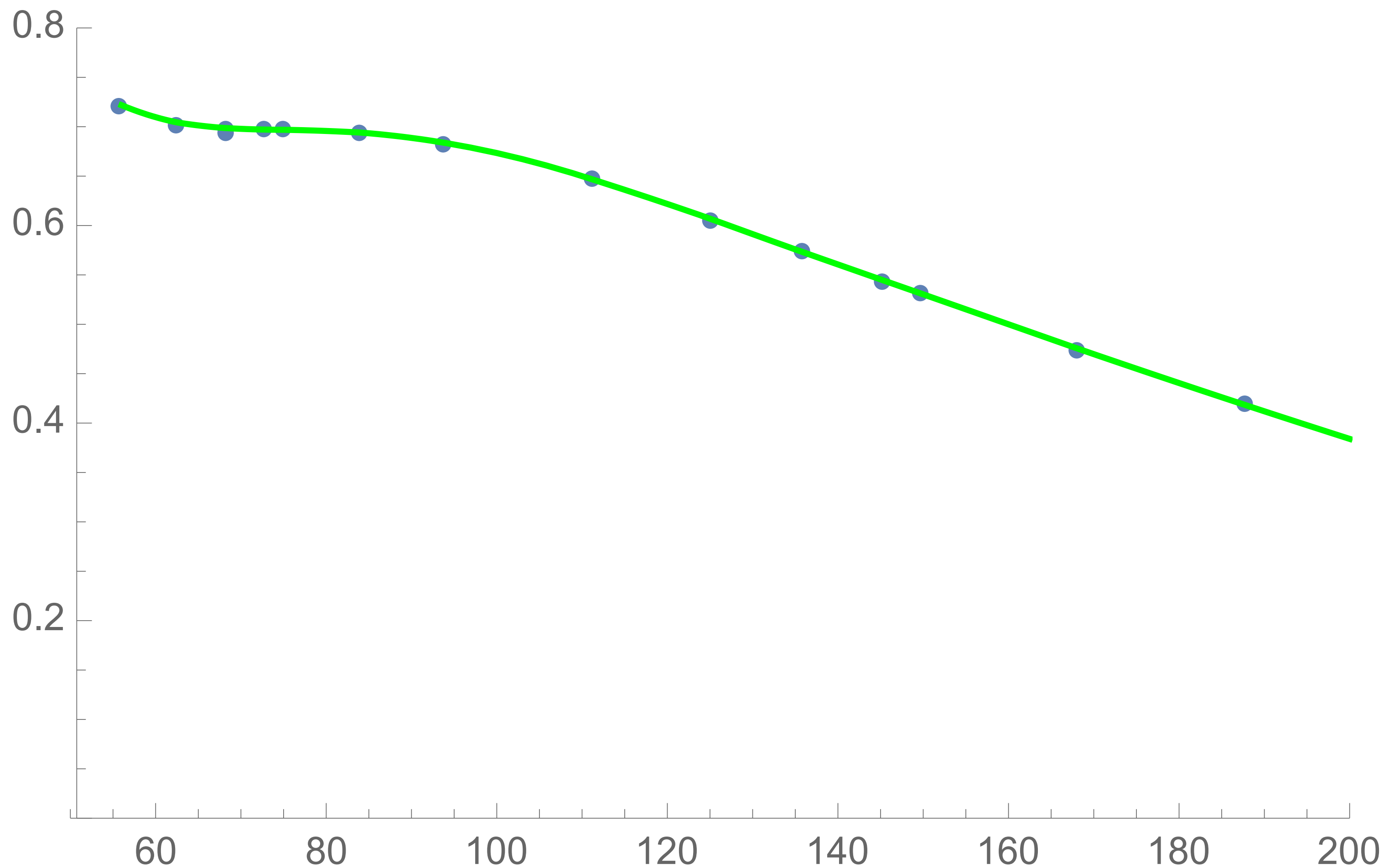
```
Show[ListPlot[pointsourcecorralt, PlotRange → {{50, 200}, {0, 0.8}}],
 Plot[pointsourcecorr[x] * 1.05, {x, 56, 200}, PlotStyle → Blue],
 Plot[pointsourcecorr[x], {x, 56, 200}, PlotStyle → Green]]
```



- ~5% Difference, little wavelength dependance
- "Toy Model" beams show similar effect: smaller active area increases ratio central/5x5

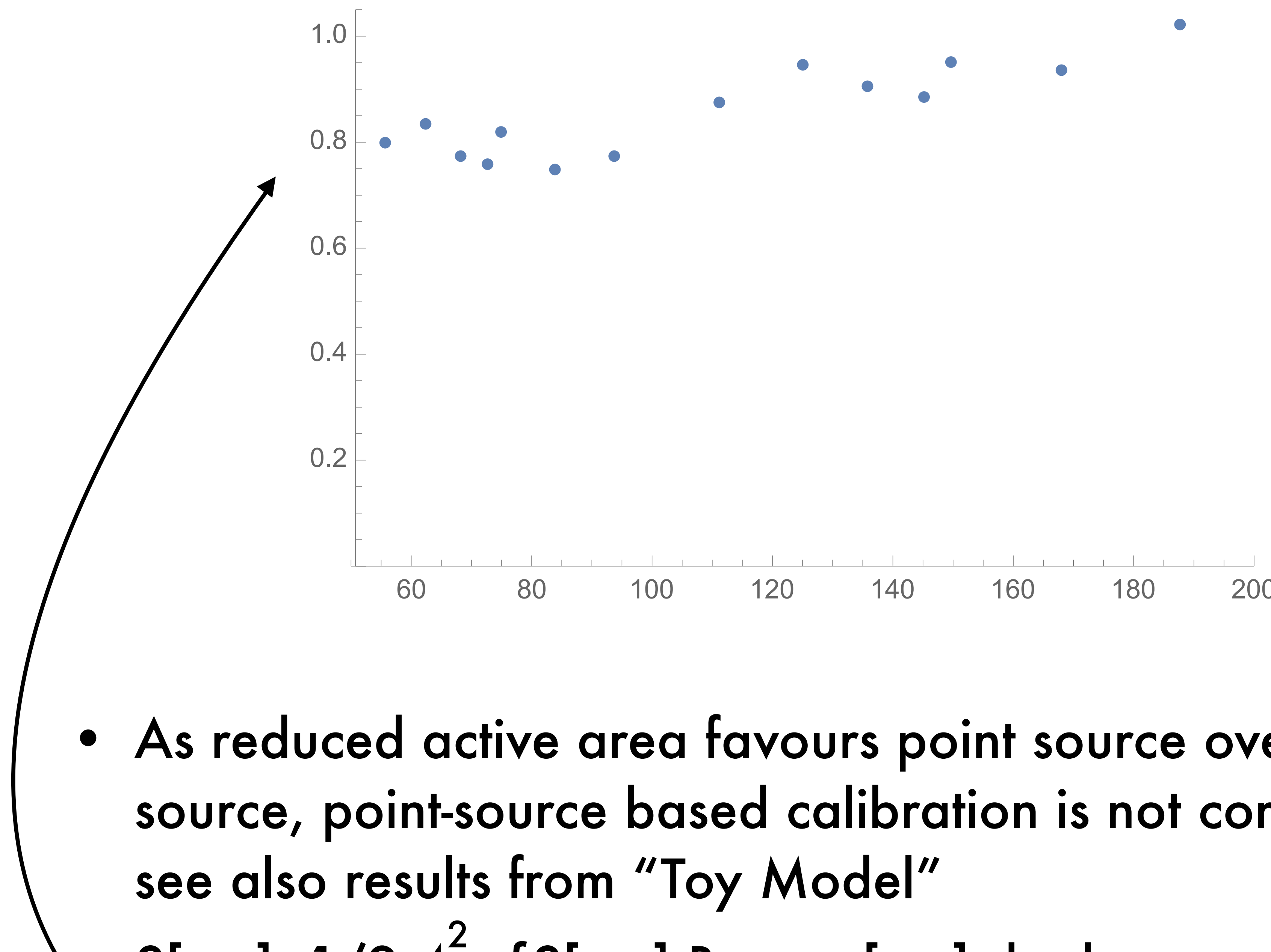
Update: Beams Renormalized to "Canonical" PS Correction

```
Show[ListPlot[pointsourcecorralt, PlotRange → {{50, 200}, {0, 0.8}}],
 Plot[pointsourcecorr[x], {x, 56, 200}, PlotStyle → Green]]
```



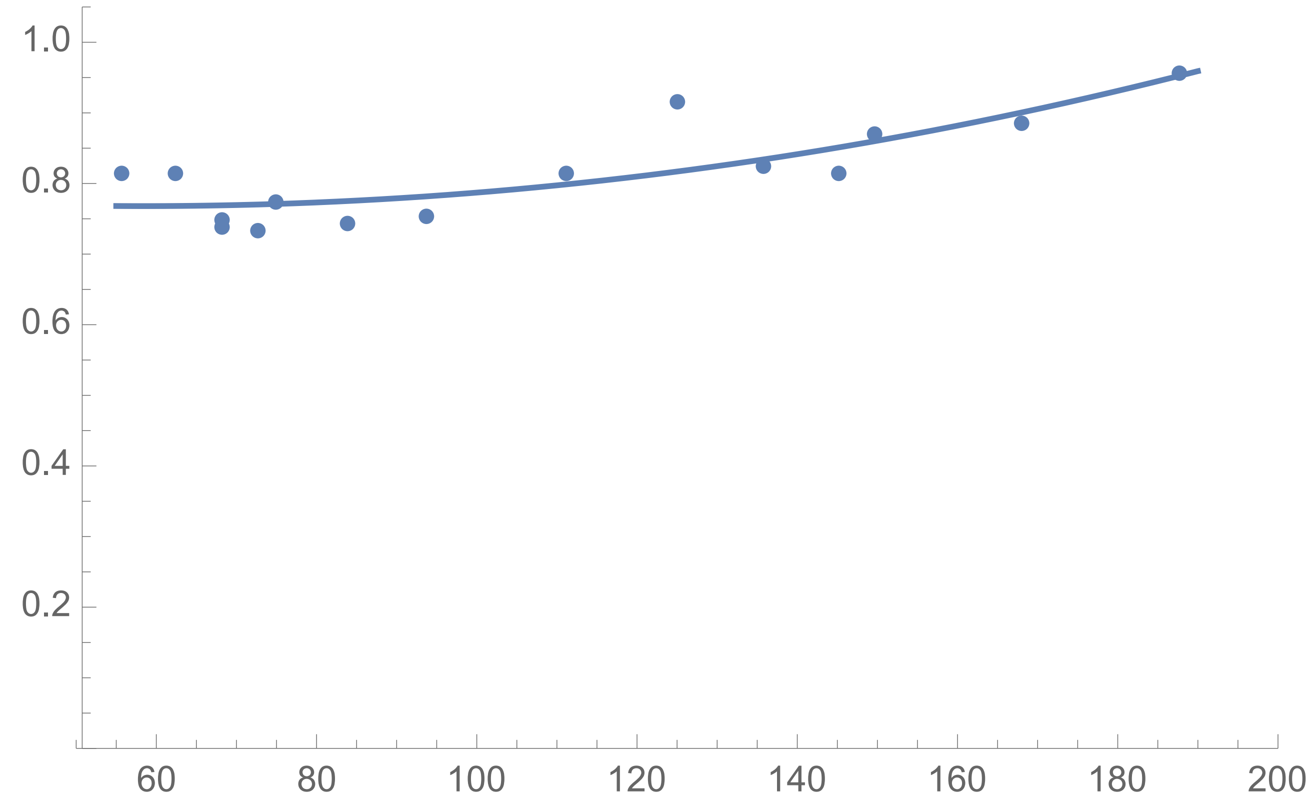
- Peak of central spaxel beam (dots) adjusted to PSC (line)
- All other beams adjusted by same factor

Extended Source Surface Brightness Correction



- As reduced active area favours point source over (flat) extended source, point-source based calibration is not correct for such sources - see also results from "Toy Model"
- $S[y,z]=1/9.4^2$, $\int S[y,z]\ Beam_{13}[y,z]\ dy\ dz$ over area >> beam width
  - nominal spaxels should collect/detect 1Jy from this surface brightness
- Beams are normalized by $\sum$ 25 beams[0,0], as for drizzle

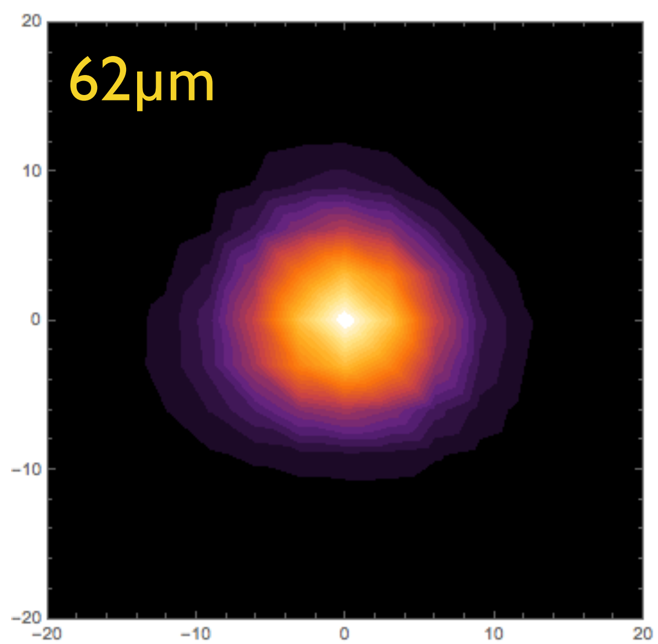
Updated Extended Source Surface Brightness Correction

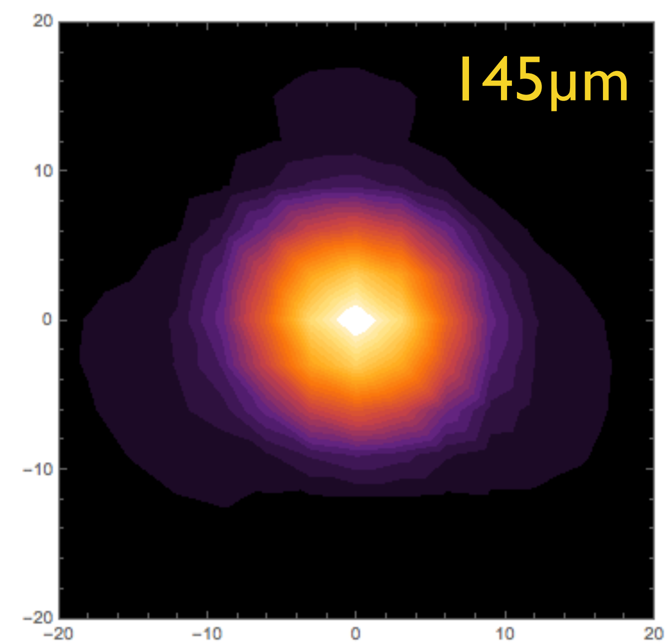


- Same as previous, but with renormalized beams, such that central spaxel beam peak matches "canonical" PSC (which is 1x1 to total) Line: 2nd order fit $0.80566001 - 0.0012896054\,\lambda + 0.000011037955\,\lambda^2$
- $S[y,z]=1/9.4^2$, $\int S[y,z]\, Beam_{13}[y,z]\, dy\, dz$ over area >> beam width
  - nominal spaxels should collect/detect 1Jy from this surface brightness

Drizzle Experiment with Actual ("Synthetic") Beams

- Create raster observation: 13x13 pointings, $\Delta y = \Delta z$ = 2.5″, 3″ grid (as before), but with point source coupling defined by actual beams, normalized by ∑(25 beams[y=0, z=0])





	62µm	145µm
Total [drizzle]	0.86462894	0.95300724
	0.89193382	**1.0536027**
Central beam [0,0] / ∑(25 beams [0,0])	0.7239	0.5914

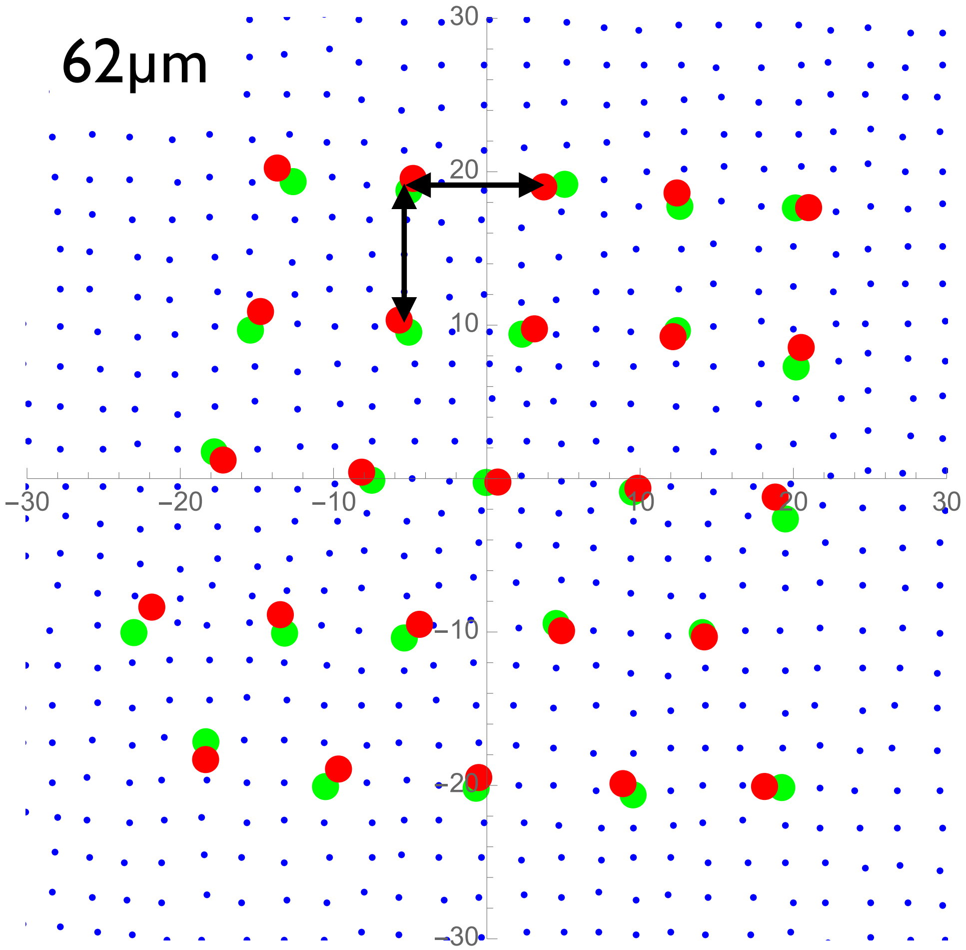
(Appendix: Drizzle Code)

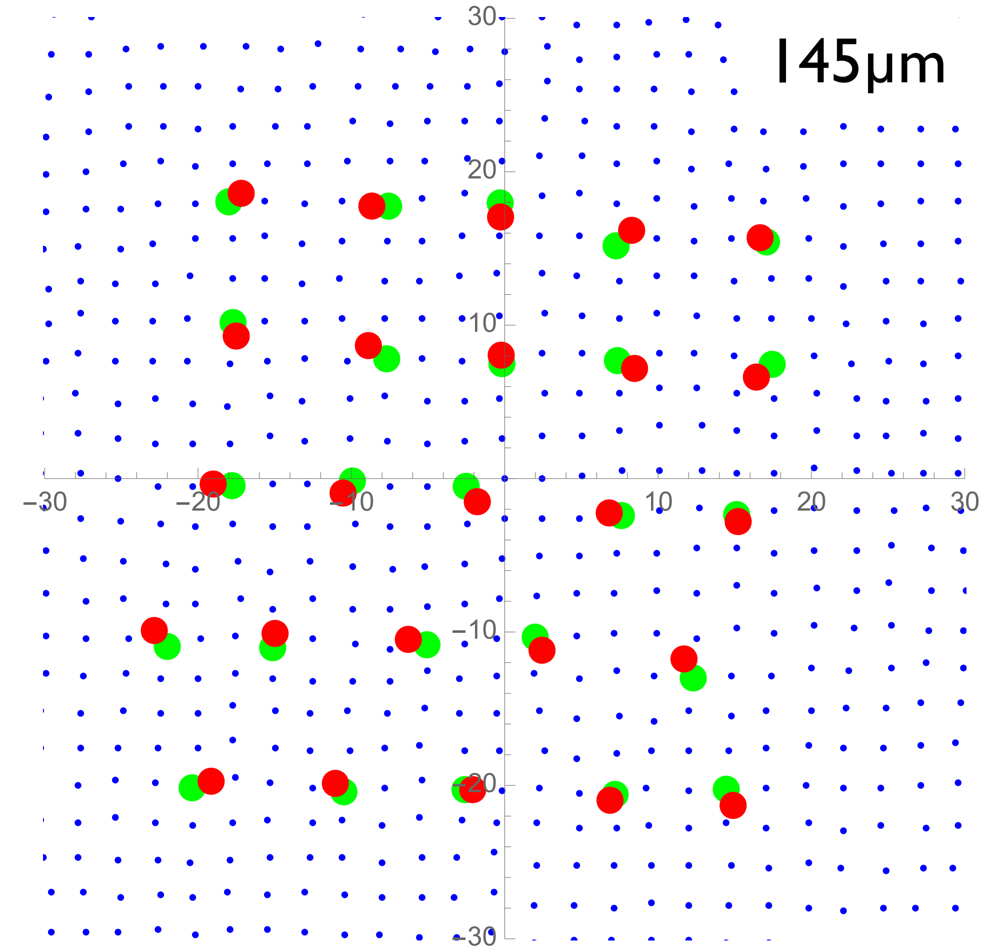
```
Δx = 3; Δy = 3;
arearatio = Δx * Δy / 9.4^2
```

← **9.255 @62μm / 8.94 @145μm, but we decided to stick to 9.4**

```
0.10185604

minx = Min[data[[All, 1]]]; minx = Δx * Floor[(minx - 2 Δx) / Δx]
maxx = Max[data[[All, 1]]]; maxx = maxx + 2 Δx

-42

43.71099

miny = Min[data[[All, 2]]]; miny = Δy * Floor[(miny - 2 Δy) / Δy]
maxy = Max[data[[All, 2]]]; maxy = maxy + 2 Δy

-42

40.980668

mm = Ceiling[(maxx - minx) / Δx] + 1
nn = Ceiling[(maxy - miny) / Δy] + 1

30

29

psfa = Table[0, {m, mm}, {n, nn}, {p, 4}]; Dimensions[psfa]

{30, 29, 4}

For[i = 1, i ≤ mm, i ++, For[k = 1, k ≤ nn, k ++, psfa[[i, k, 1]] = minx + (i - 1) Δx; psfa[[i, k, 2]] = miny + (k - 1) Δy ]]

For[ind = 1, ind ≤ lines, ind ++,
 xp = data[[ind, 1]]; yp = data[[ind, 2]]; sig = data[[ind, 3]];
 left = Floor[(xp - minx) / Δx] + 1; right = left + 1; down = Floor[(yp - miny) / Δy] + 1; up = down + 1;
 xr = minx + left * Δx; xl = xr - Δx; yu = miny + down * Δy; yd = yu - Δy;
 psfa[[left, up, 3]] += sig * (xr - xp) * (yp - yd);
 psfa[[right, up, 3]] += sig * (xp - xl) * (yp - yd);
 psfa[[left, down, 3]] += sig * (xr - xp) * (yu - yp);
 psfa[[right, down, 3]] += sig * (xp - xl) * (yu - yp);
 psfa[[left, up, 4]] += (xr - xp) * (yp - yd);
 psfa[[right, up, 4]] += (xp - xl) * (yp - yd);
 psfa[[left, down, 4]] += (xr - xp) * (yu - yp);
 psfa[[right, down, 4]] += (xp - xl) * (yu - yp)]

For[i = 1, i ≤ mm, i ++, For[k = 1, k ≤ nn, k ++, psfa[[i, k, 3]] = If[psfa[[i, k, 4]] > 0, arearatio * psfa[[i, k, 3]] / psfa[[i, k, 4]], 0 ]]]
```

Spaxel Area/Size






```
dy62={9.2499229, 9.4208102, 9.1056975, 8.6901102,
     9.349345, 9.2685438, 9.0736414, 8.4164956,
     9.0201117, 9.1524262, 8.8300055, 9.0998935,
     8.3856346, 9.0575605, 8.7996251, 9.0446952,
     8.6391126, 8.6749727, 8.548594, 8.8281851}

dz62={9.743448, 9.936582, 9.9915084, 10.065054,
     10.046297, 9.1765313, 9.2731417, 9.1886285,
     9.2514622, 9.5505081, 9.7523916, 9.8755798,
     10.044179, 9.9038444, 9.7439418, 9.0626664,
     9.4562224, 9.2378611, 9.2122242, 9.3212746}
```

```
dy145={8.1133194, 8.9119137, 8.9168976, 8.1580631,
     9.2156355, 8.624318,8.7478855, 7.9219209,
     8.4631066, 8.6498899, 8.739031, 8.4596571,
     8.016429, 8.708396, 8.6439164, 8.6667989,
     8.4076867, 8.5651656,8.3748771, 8.4927014}

dz145={9.5485981, 9.7671648, 9.7532537, 9.7462263,
     9.775588, 8.9465795, 8.9312104, 8.9696967,
     9.1271324, 9.5359798, 9.4049758, 9.4154418,
     9.5411065, 9.6170673, 9.6458597, 9.0793132,
     9.0004107, 9.0091555,9.0838499, 9.3030159}
```

More Typical Drizzle Experiment

- Raster observation:
  5x5 pointings, Δy=14.5″, Δz=16″, 3″ drizzle grid (blue)
  3x3 pointings, Δy=22″, Δz=24″, 4″ drizzle grid (red)

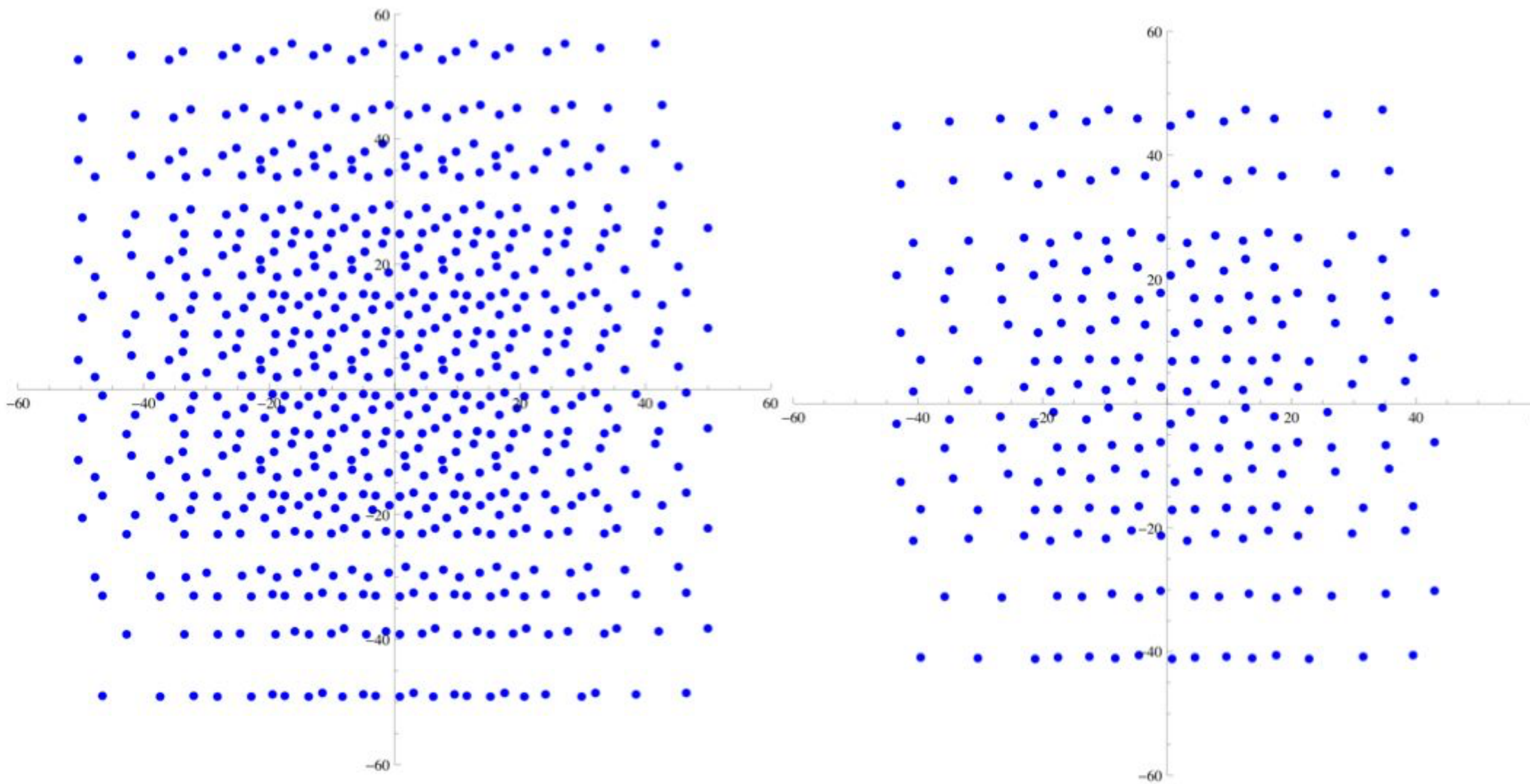
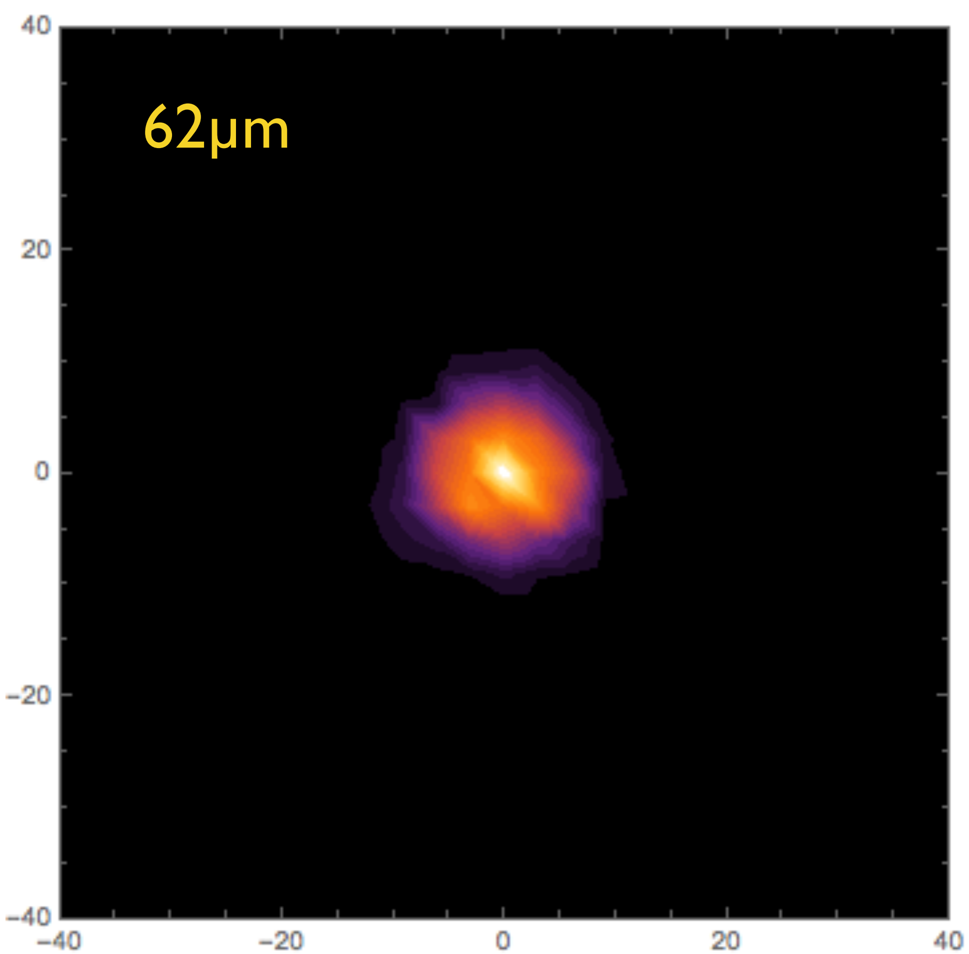


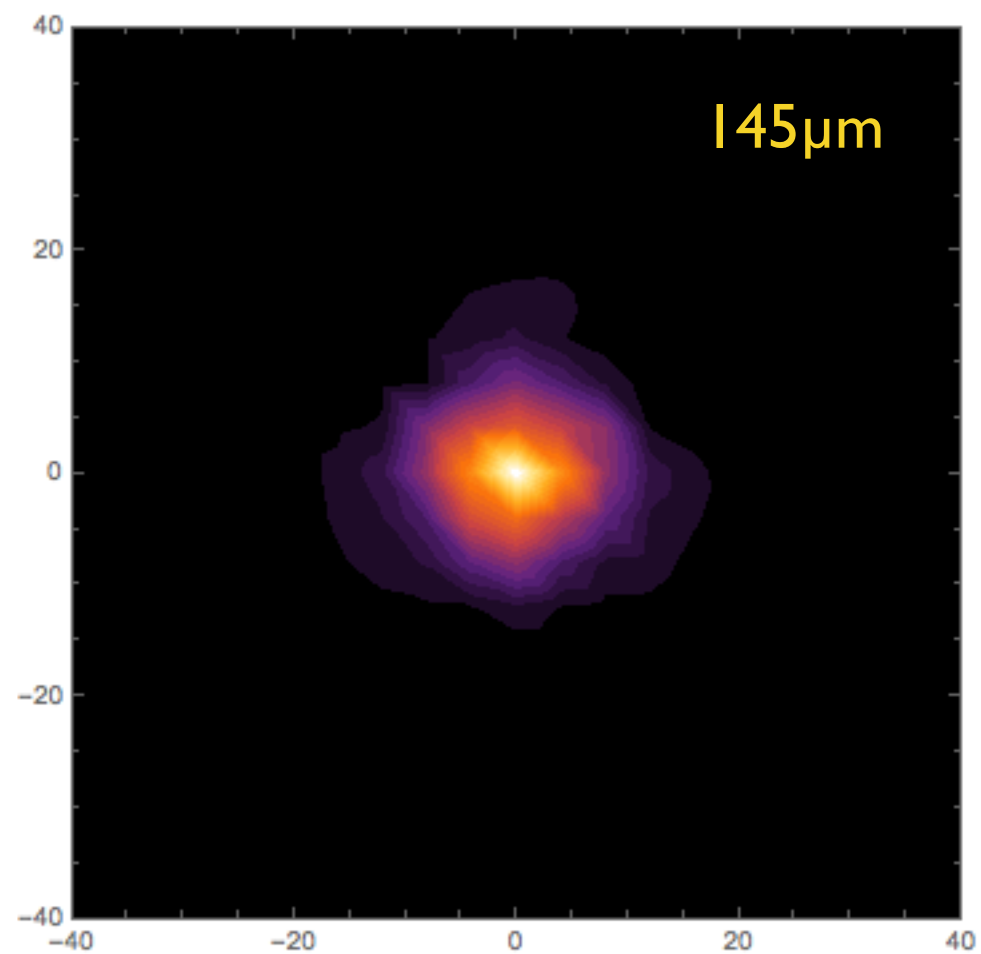
Figure 6.2. Spatial sampling by all PACS spaxels when using a 5x5 raster with step size 14.5"/16" for the blue (left) and a 3x3 raster with step size 22"/24" for the red (right)

(PACS Observer's Manual)

More Typical Drizzle Experiment

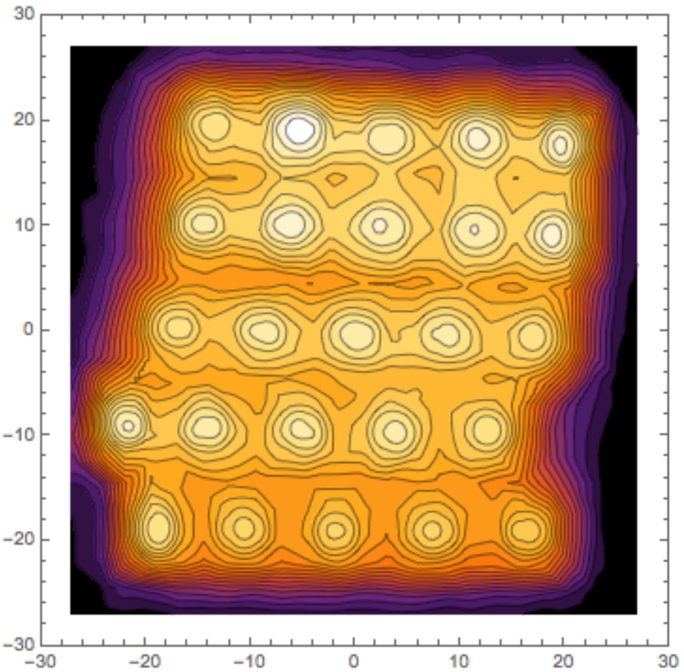
- Raster observation: as recommended by PACS OM, renormalized beams (as before), 9.4” spaxel size



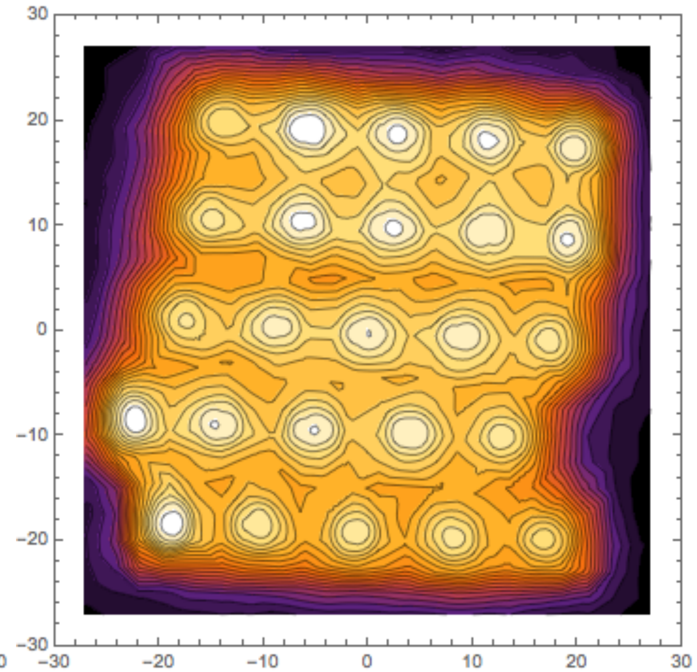


Total [drizzle] **0.75546747** **0.85487137**

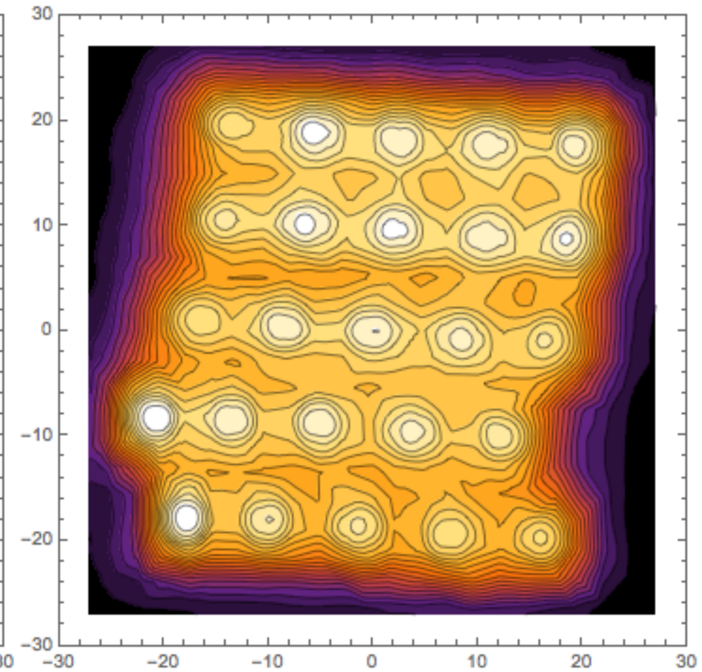
"Flatness" of PACS IFU/Blue Detector Response



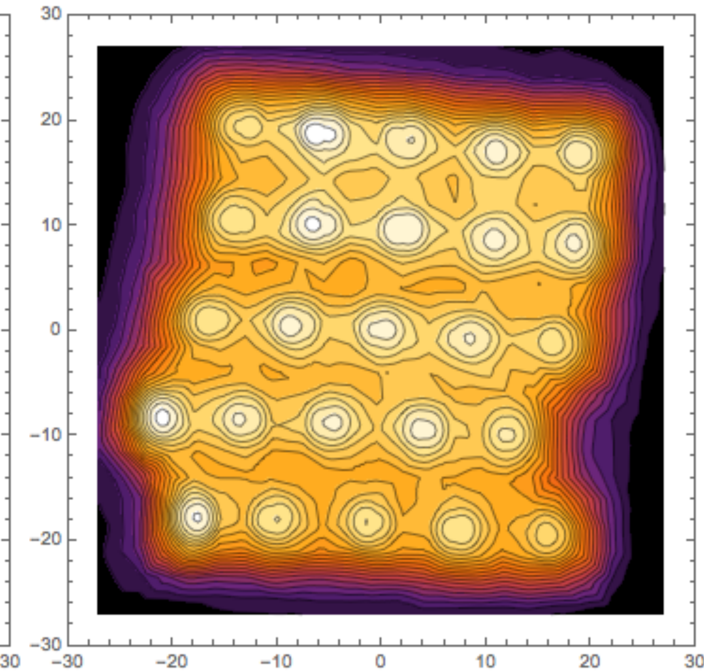
55



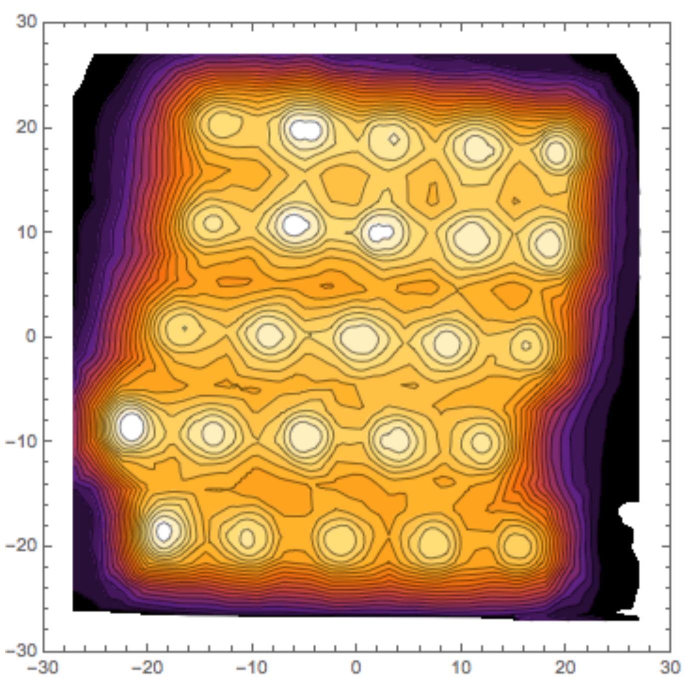
62



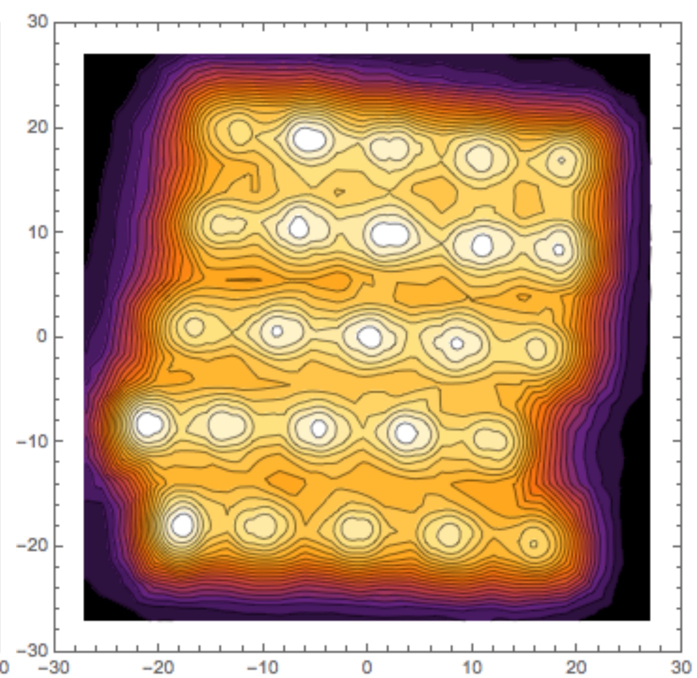
68



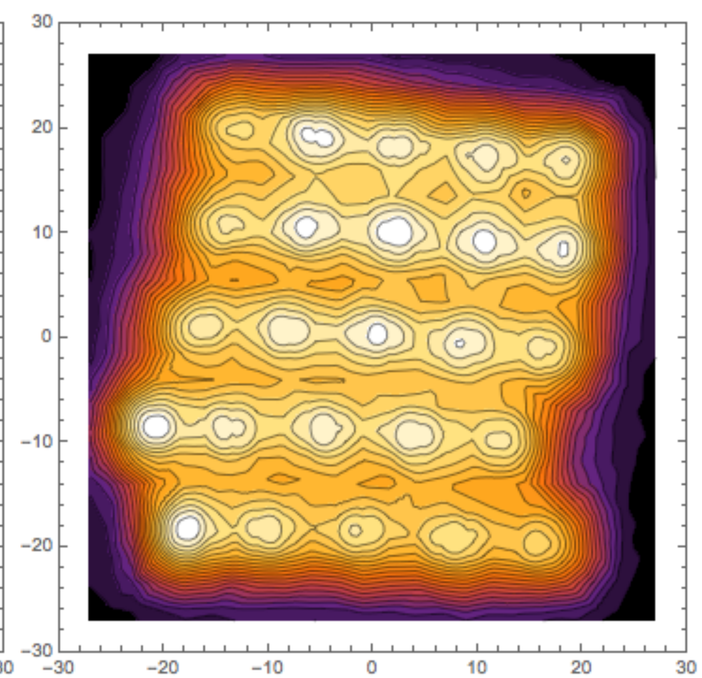
73



75



84



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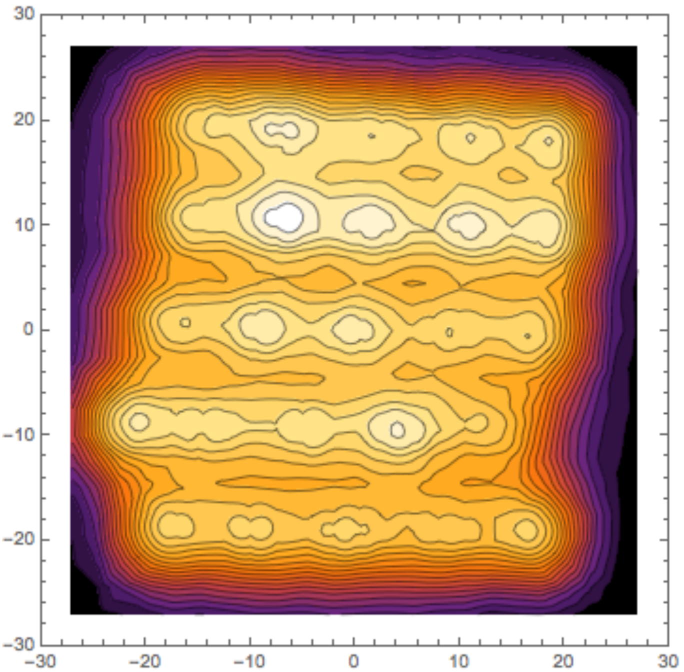
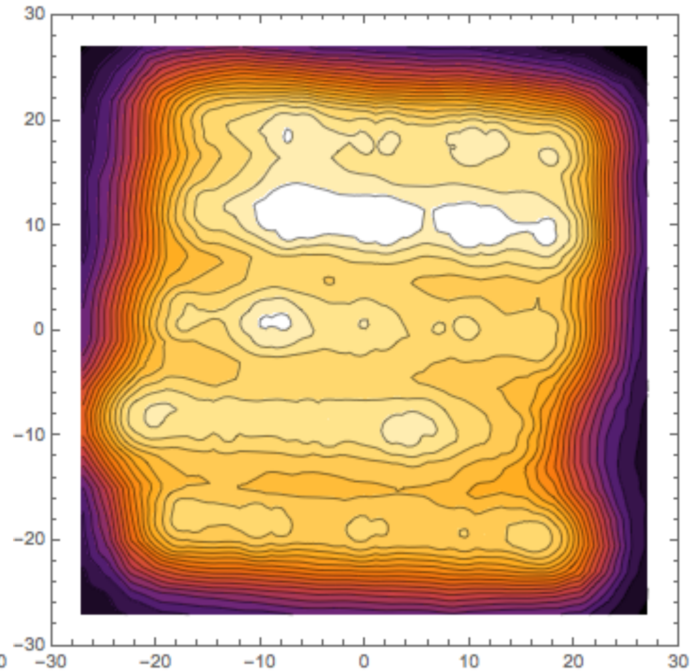
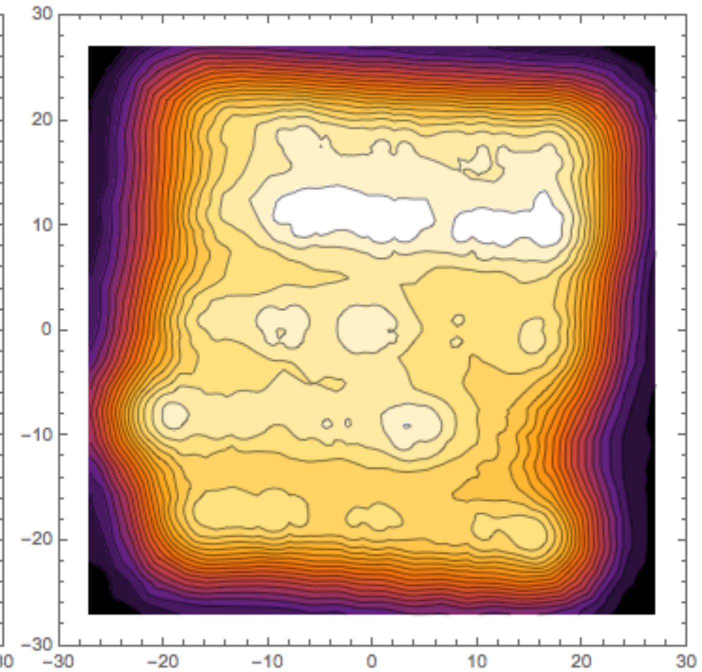
"Flatness" of PACS IFU/Red Detector Response



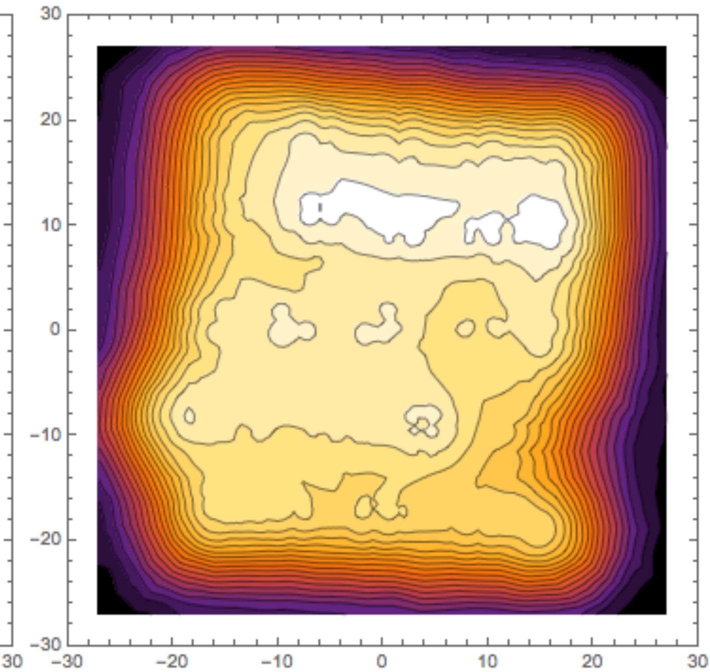
110



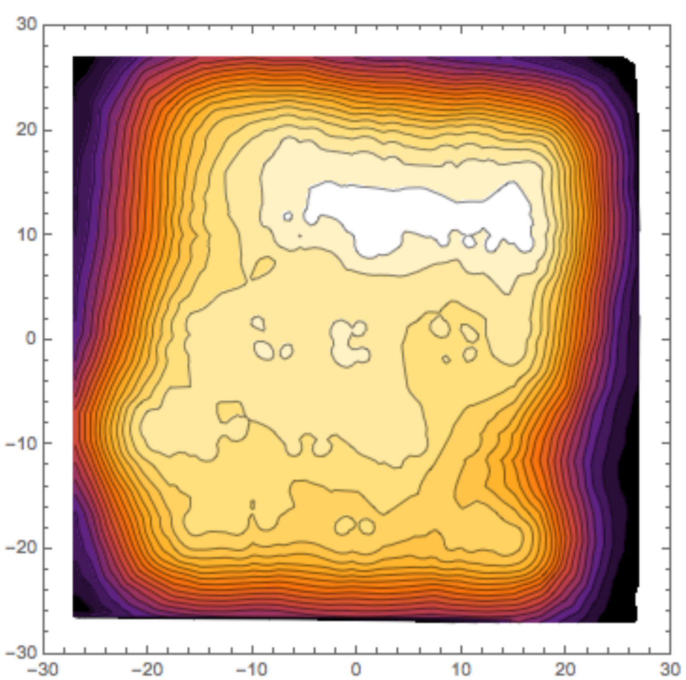
125



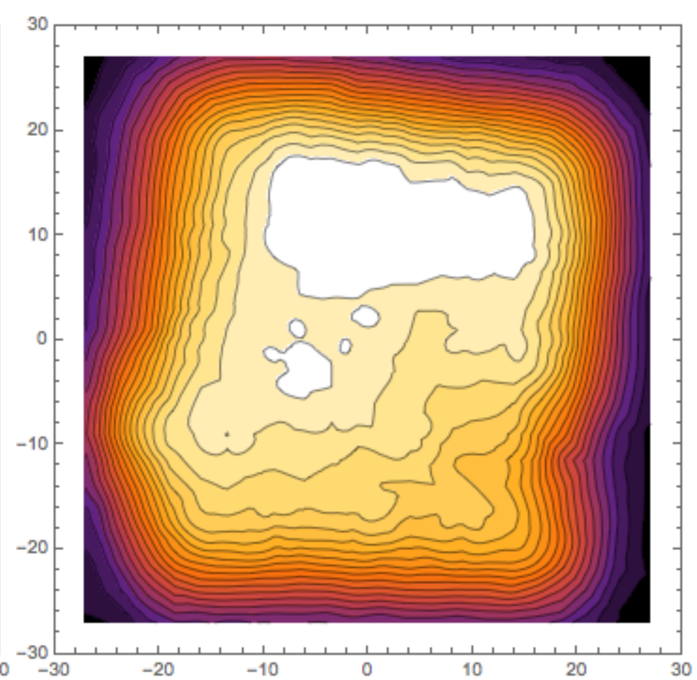
136



145



150



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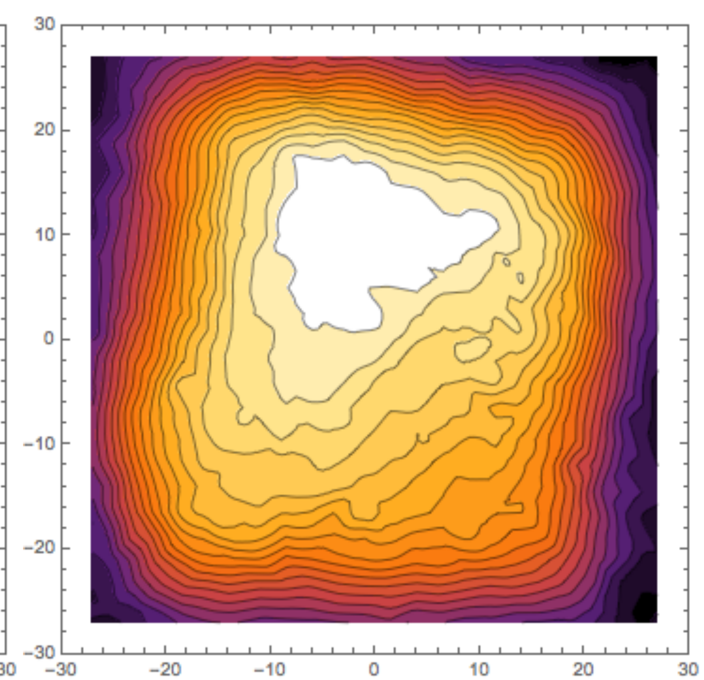

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Increasing gradient of point source/ extended source response (???)