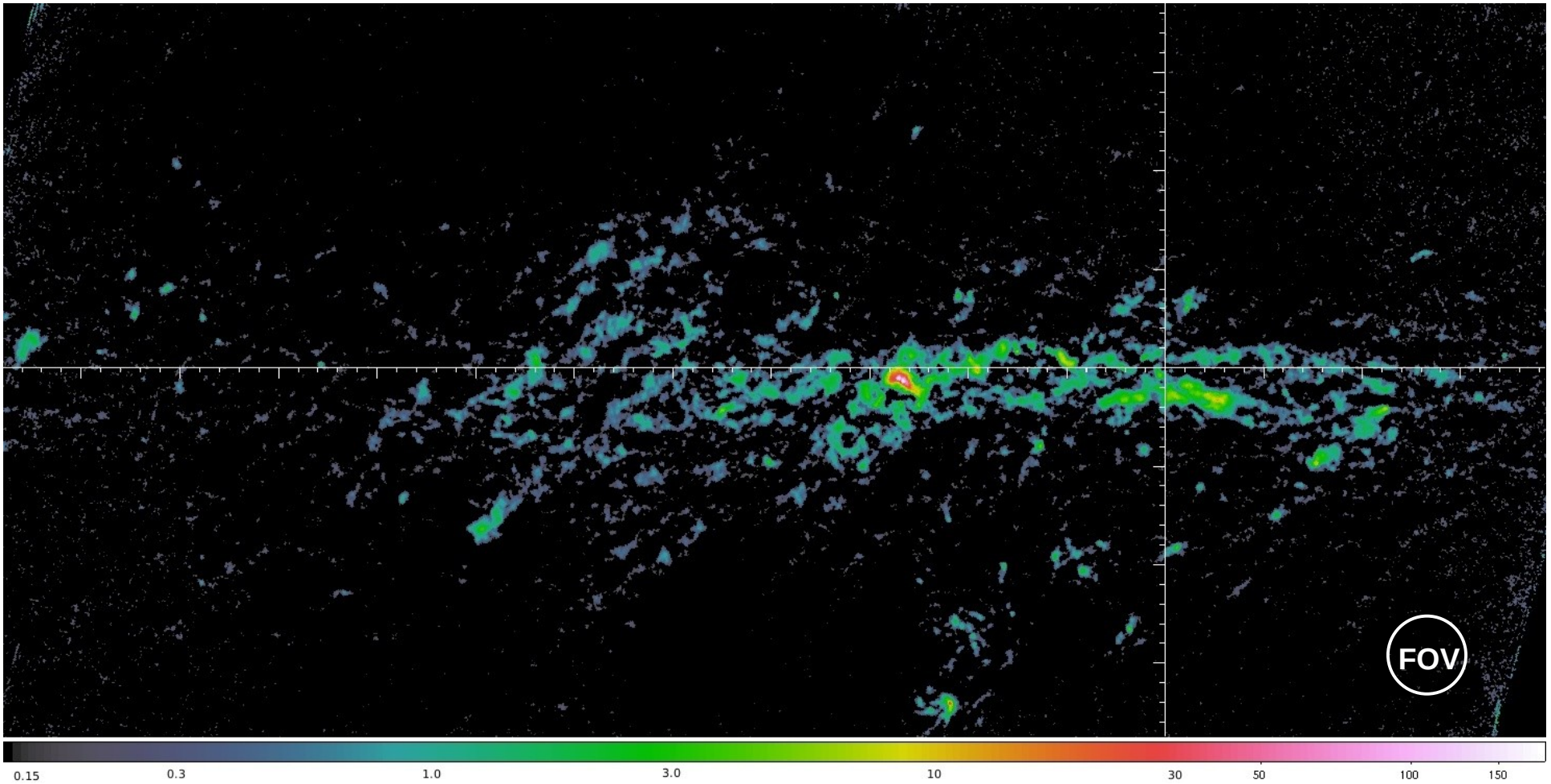
Scanning Strategies for Imaging Arrays

Attila Kovács
MPI for Radioastronomy



Max-Planck-Institut für Radioastronomie

Chopping

Differential Signals

Fast switching of detectors between source and blank sky.
Analyze difference signals.

E.g. 45” switching at 4 Hz for SHARC

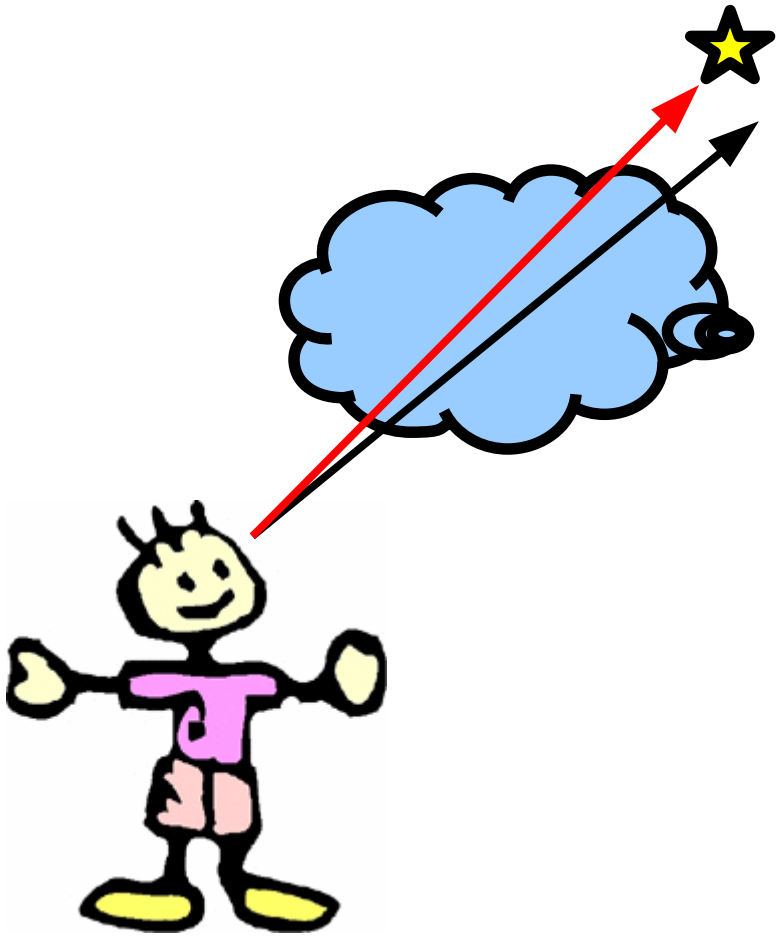
Problems

Differencing Noise
(2x observing time)

Insensitivity to Certain Spatial Components

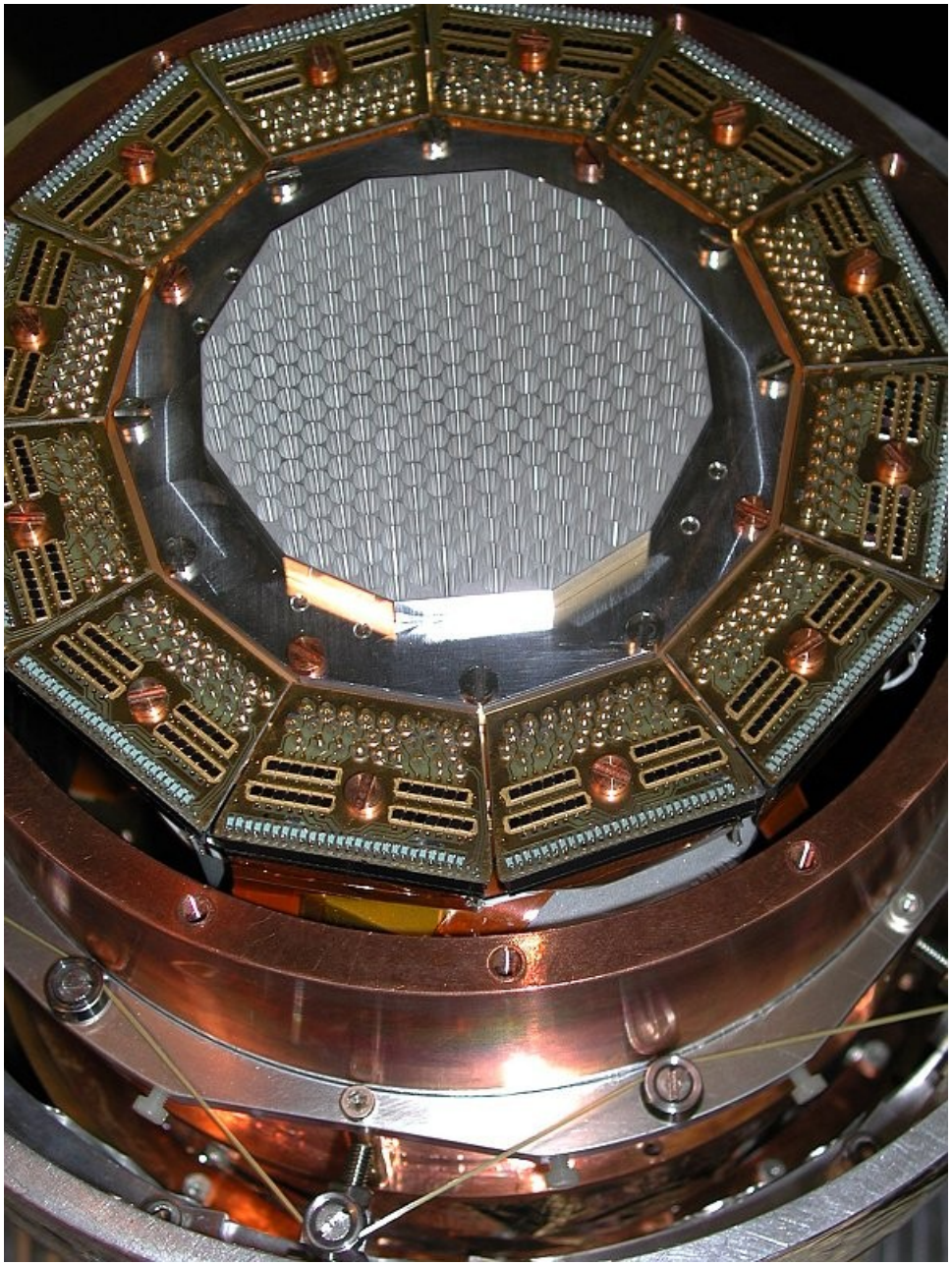
Duty Cycle

Striping
(Imperfect Sky Removal)

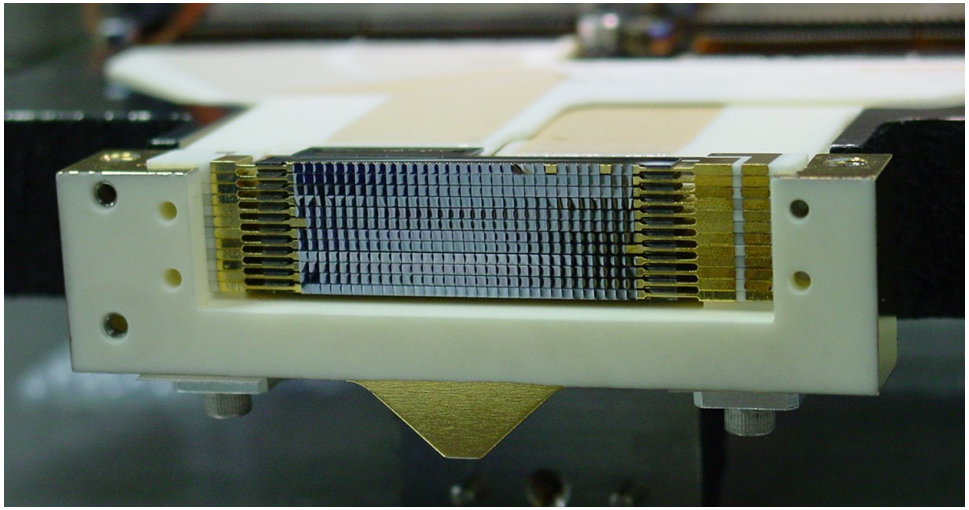


Large Arrays

LABOCA



SHARC-2



Poster on data reduction on Friday!

Observing Mode Wish List

Noise Resistance (esp. 1/f)

Large-Scale Sensitivity

Coverage

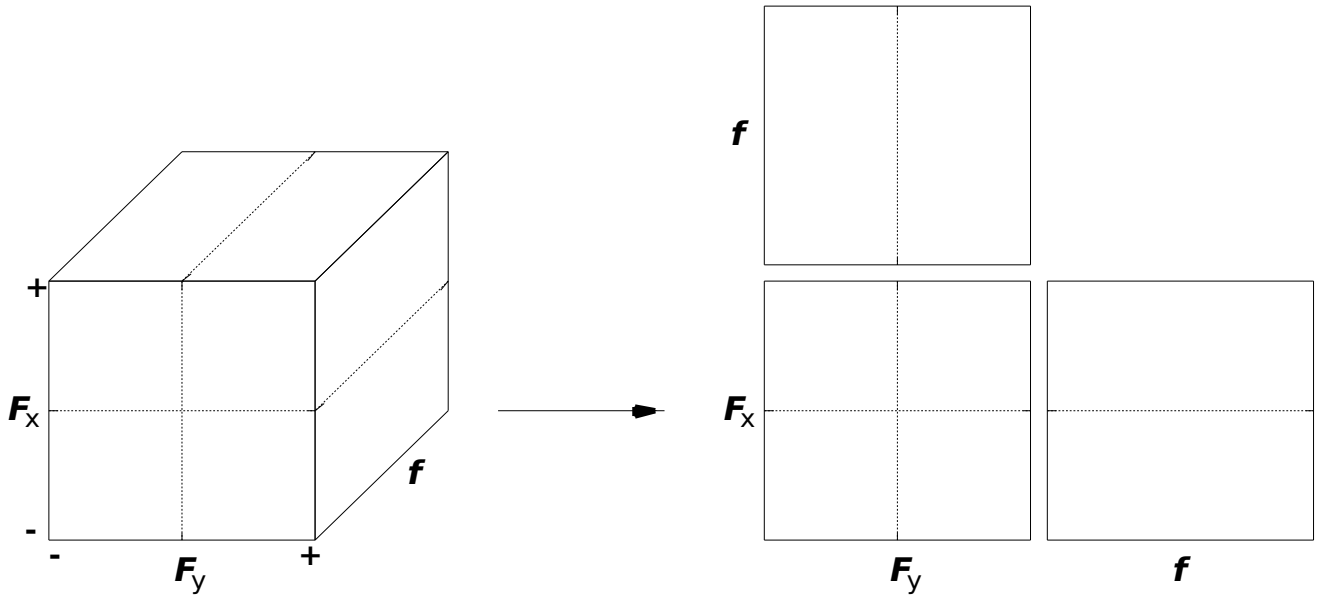
Dynamic Range

Feasibility of Implementation

Noise Resistance

Spectral Noise Locations

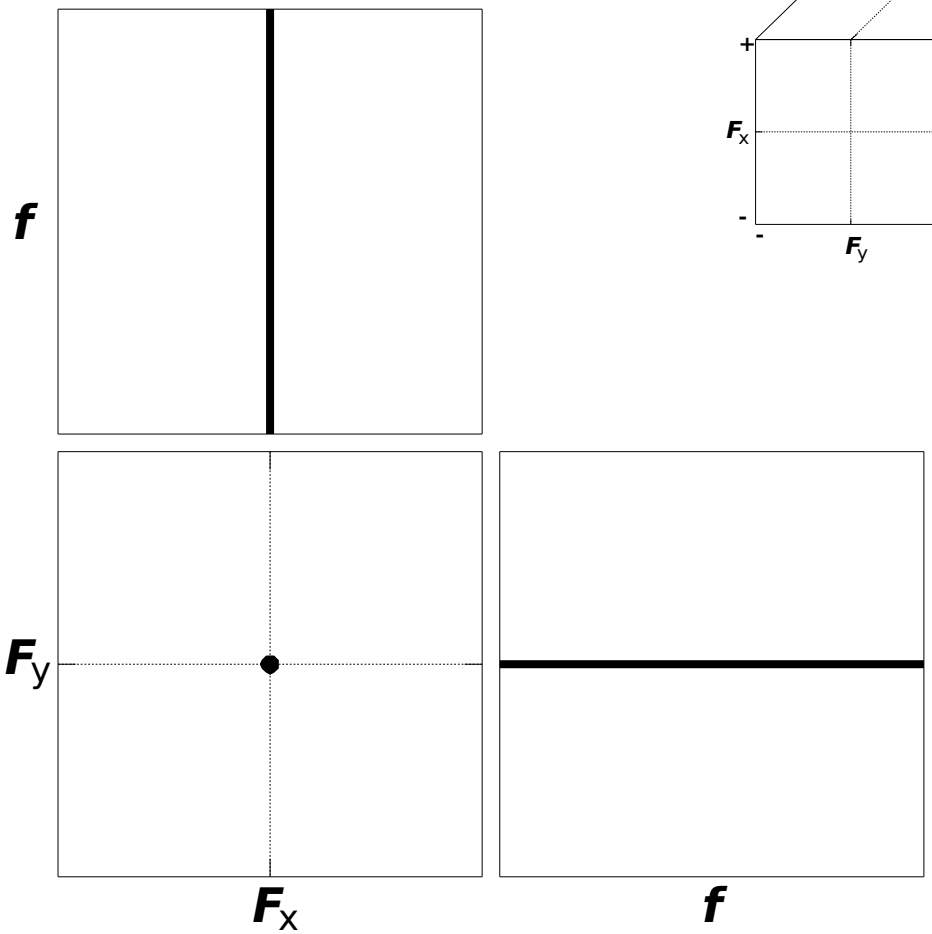
Stationary noise (in time and in space) is characterized by its power spectrum of independent components.

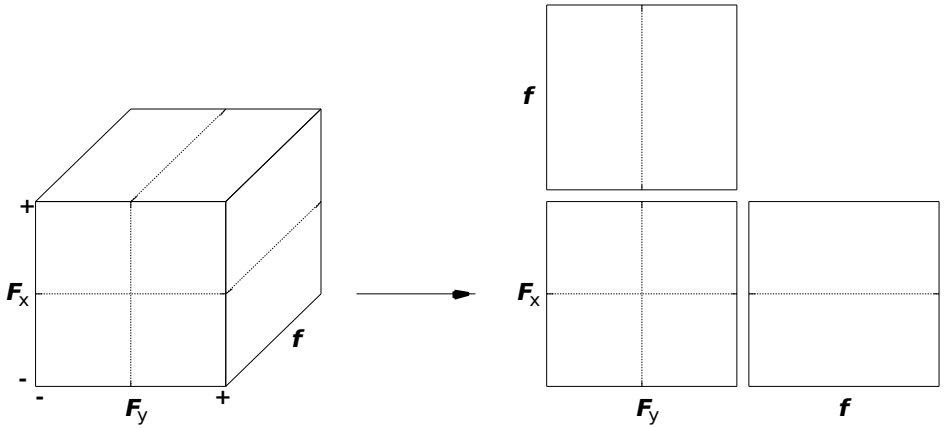


Projections of a spectral cube

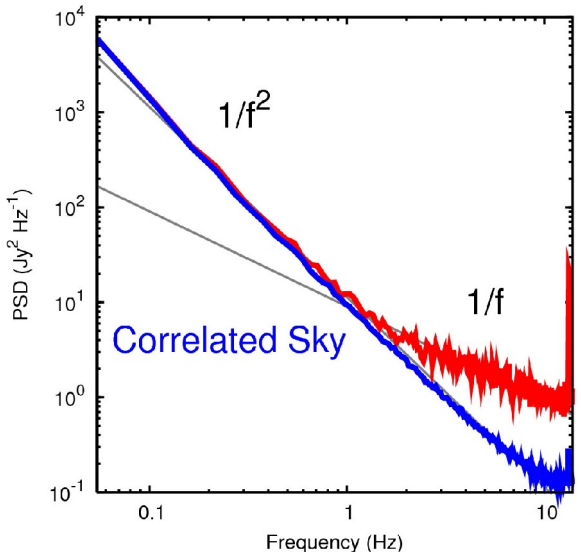
Noise Resistance

Spectral Noise Locations



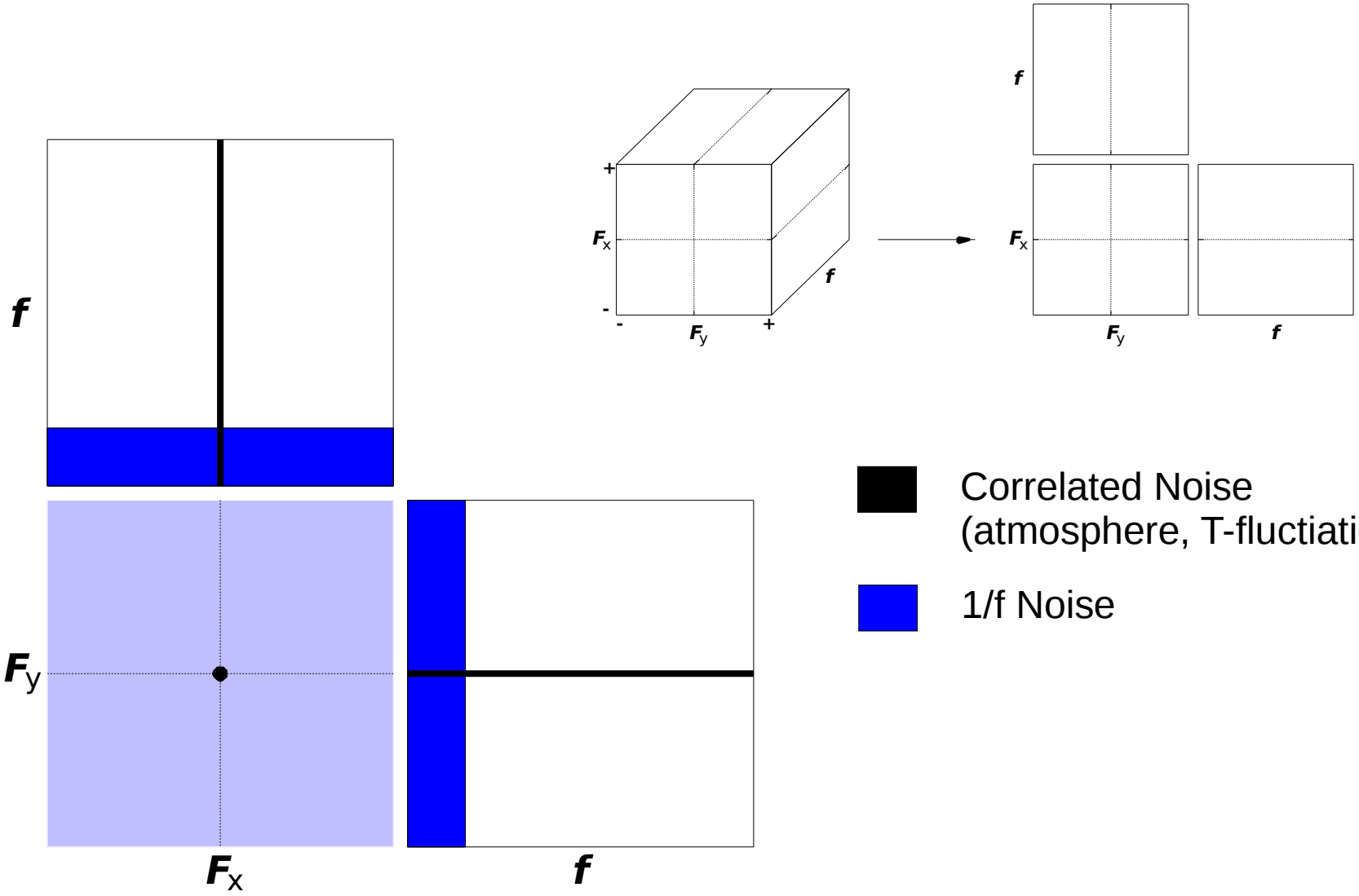


Correlated Noise
(atmosphere, T-fluctiation)



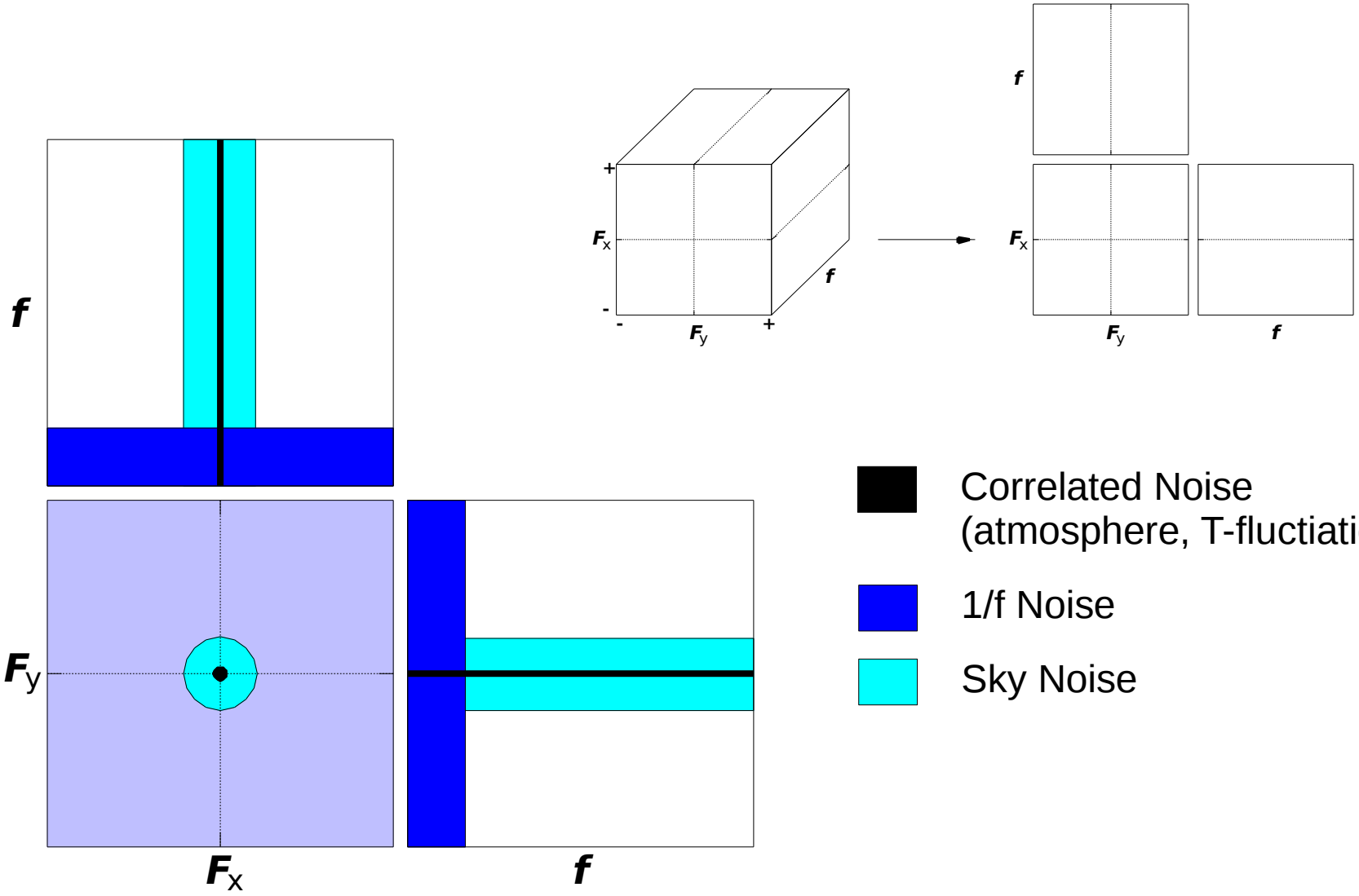
Noise Resistance

Spectral Noise Locations



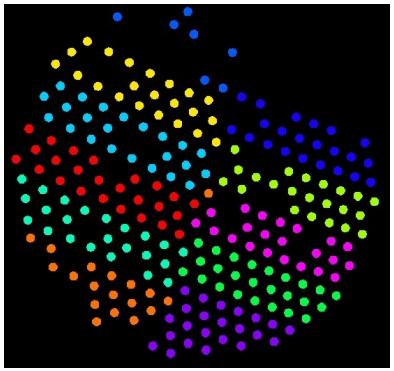
Noise Resistance

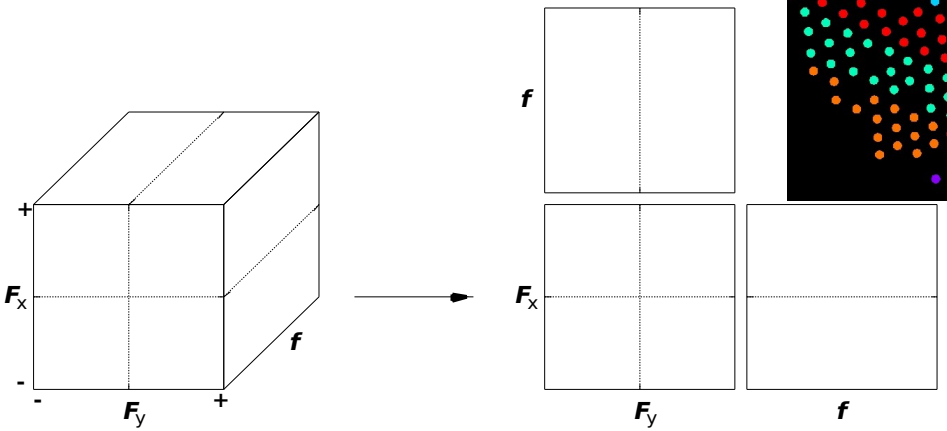
Spectral Noise Locations

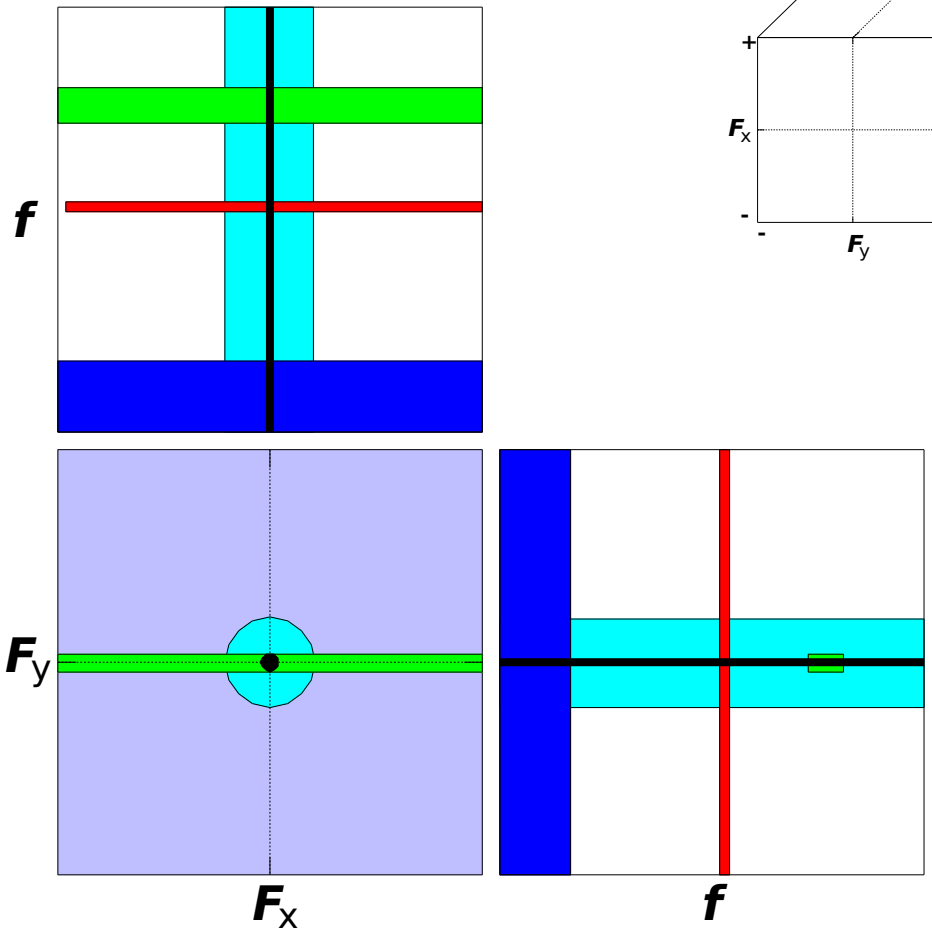


Noise Resistance

Spectral Noise Locations







Correlated Noise (atmosphere, T-fluctiation)

1/f Noise

Sky Noise

Narrow-band Resonance (isotropic)

Wide-band Resonance (oriented)

Noise Resistance

Strategies

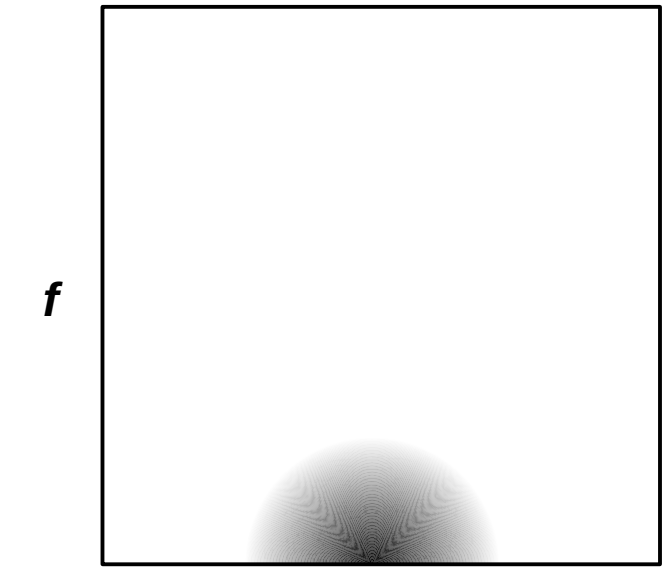
1/f Noise → Spread signals into the higher frequencies...

Faster Scanning

Generic Noise → Spread signals widely...

2-D Scanning
Random Source Crossings

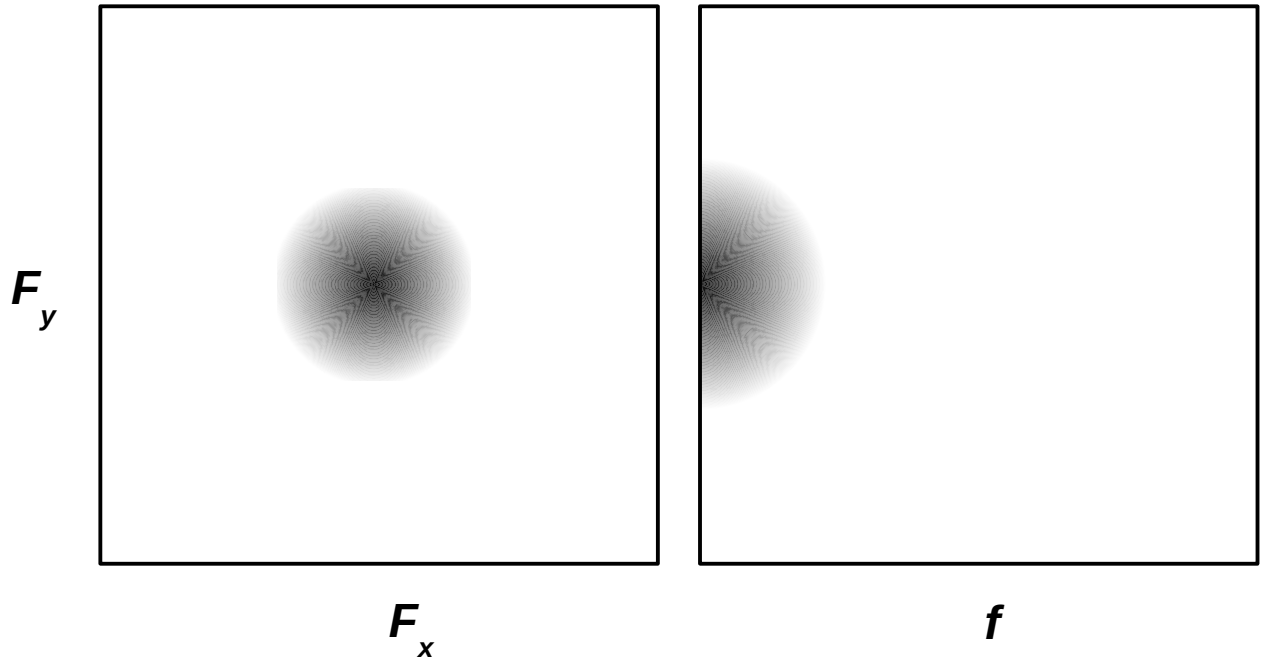
Sensitivity to Large Scales



Spectral Tapering
(convolution theorem)

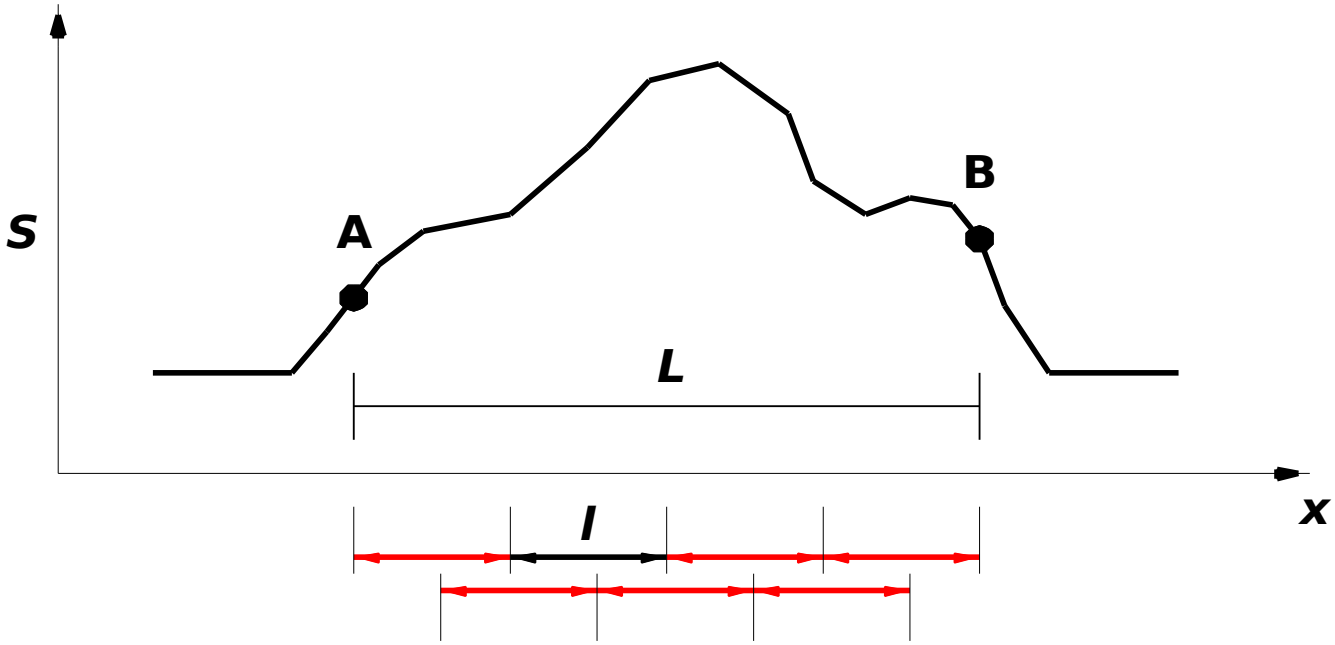
$S(x) \otimes P(x) \longrightarrow S(f) \times P(f)$

S: Source structure
P: Point source spectrum



Sensitivity to Large Scales

$$\sigma_L \approx \left(1 + \frac{L}{l}\right)^{1/2} \sigma_0$$



Scanning Wide

Dynamic Range

Ground-Based, High-Background Instrumentation

DOCTOR'S WARNING!
Avoid observing modes where changing of background can dwarf astronomical signals.

~~Secondary Movement~~

~~Calibrator Blades~~

Design Criteria

(1) Faster is Better!

(2) 2D Scanning.

(3) Random Source Crossings in Time-streams. (non-repeating patterns...)

(4) Wide Strokes matching the Largest Faint Structures.

---

(5) Scanning with Primary (for ground-based submm).

(6) Connected Patterns (settling time overheads).

(7) No Sharp Turns (acceleration overload).

What's Wrong with Staring?

Detector Noise Limited

$\sigma_{det} > \sigma_{bg}$

Dark Frame Calibration Time

=

On-Source Time

4 x overhead!!!

Space-based and airborne sub-mm and far-infrared instrumentation

Heavily Background Limited

$\sigma_{det} << \sigma_{bg}$

Dark Frame Calibration Time

<<

On-Source Time

small overhead

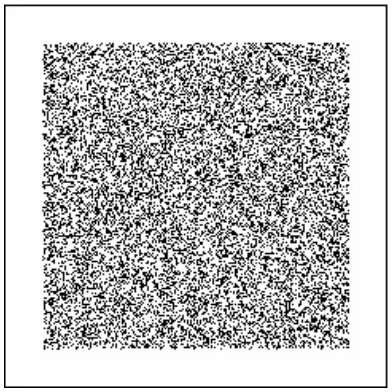
optical/IR cameras

Ground-based sub-mm cameras

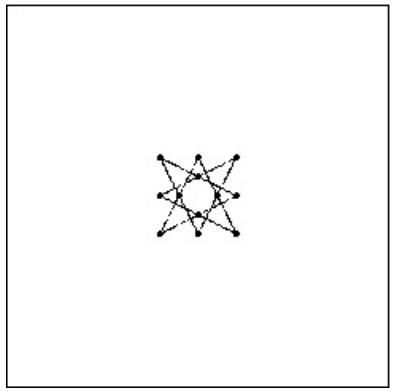
Simulations

Pattern Gallery

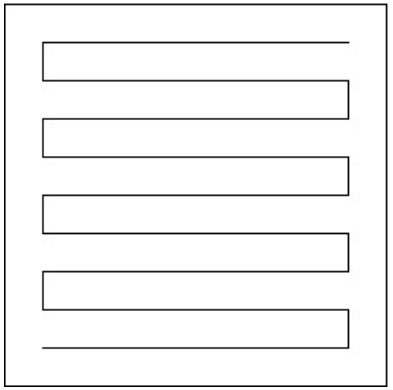
random



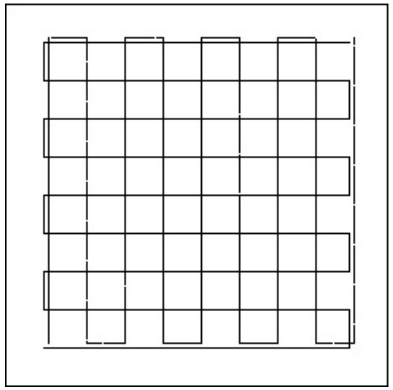
DREAM



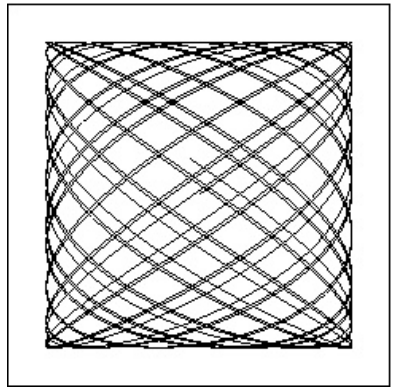
OTF



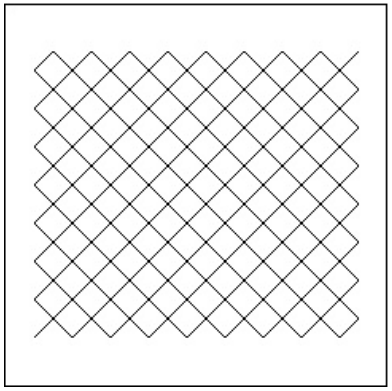
OTF (cross-linked)



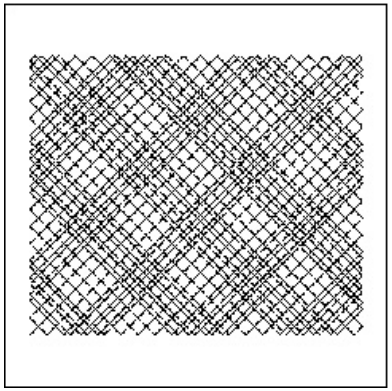
Lissajous



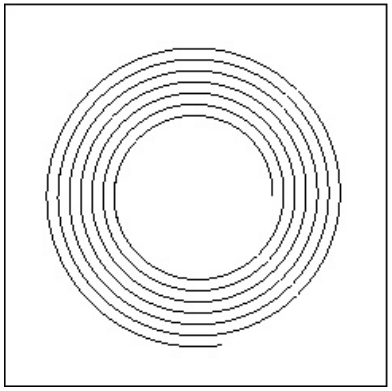
Billiard (closed)



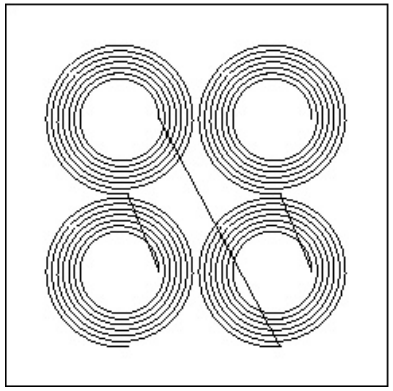
Billiard (open)



spiral



raster-spiral

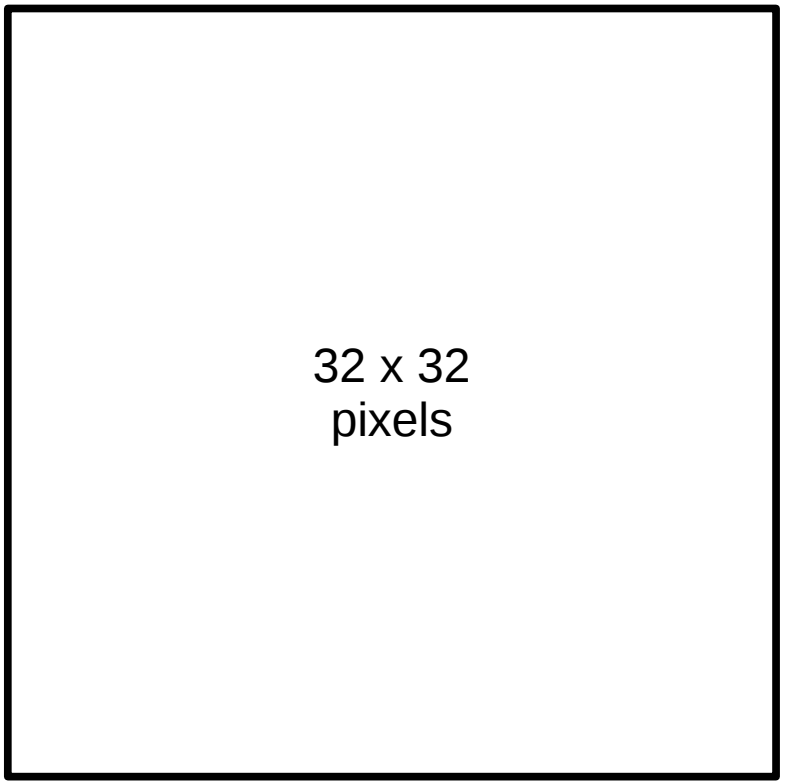


... and other patterns...

What is your favourite?

http://www.submm.caltech.edu/~sharc/scanning/

Simulations

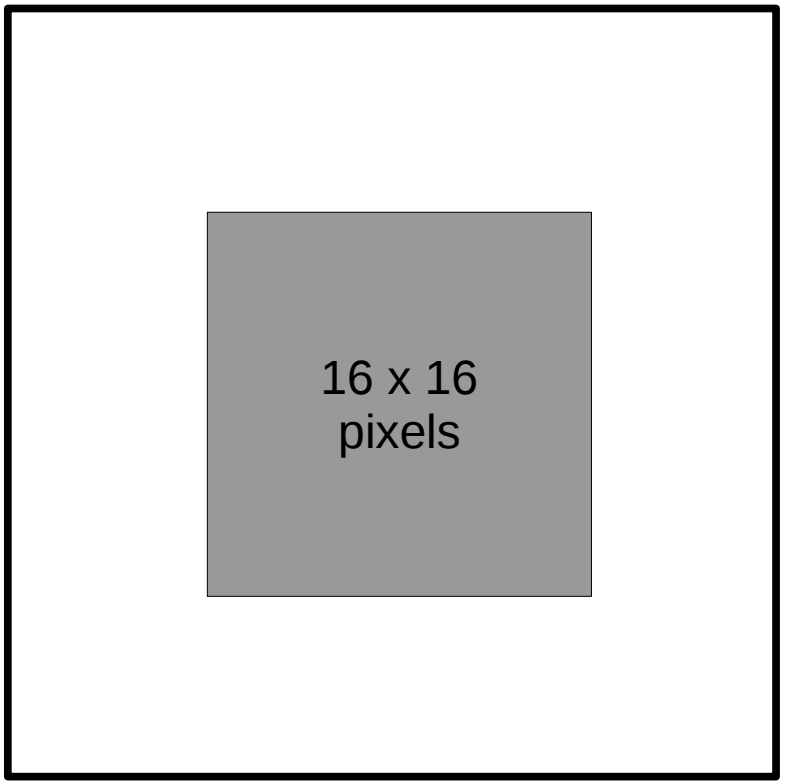


http://www.submm.caltech.edu/~sharc/scanning/

Simulations

Size

Aim to cover same area



“Speed”

1 pixel/frame average scanning speed

(1 position/frame)

Spectral Moments

$$m_i = \left\langle f^i \hat{P}_{f,\mathbf{F}} \right\rangle = \frac{\sum_f \sum_{\mathbf{F}} f^i \hat{P}_{f,\mathbf{F}}}{\sum_f \sum_{\mathbf{F}} f^i}$$

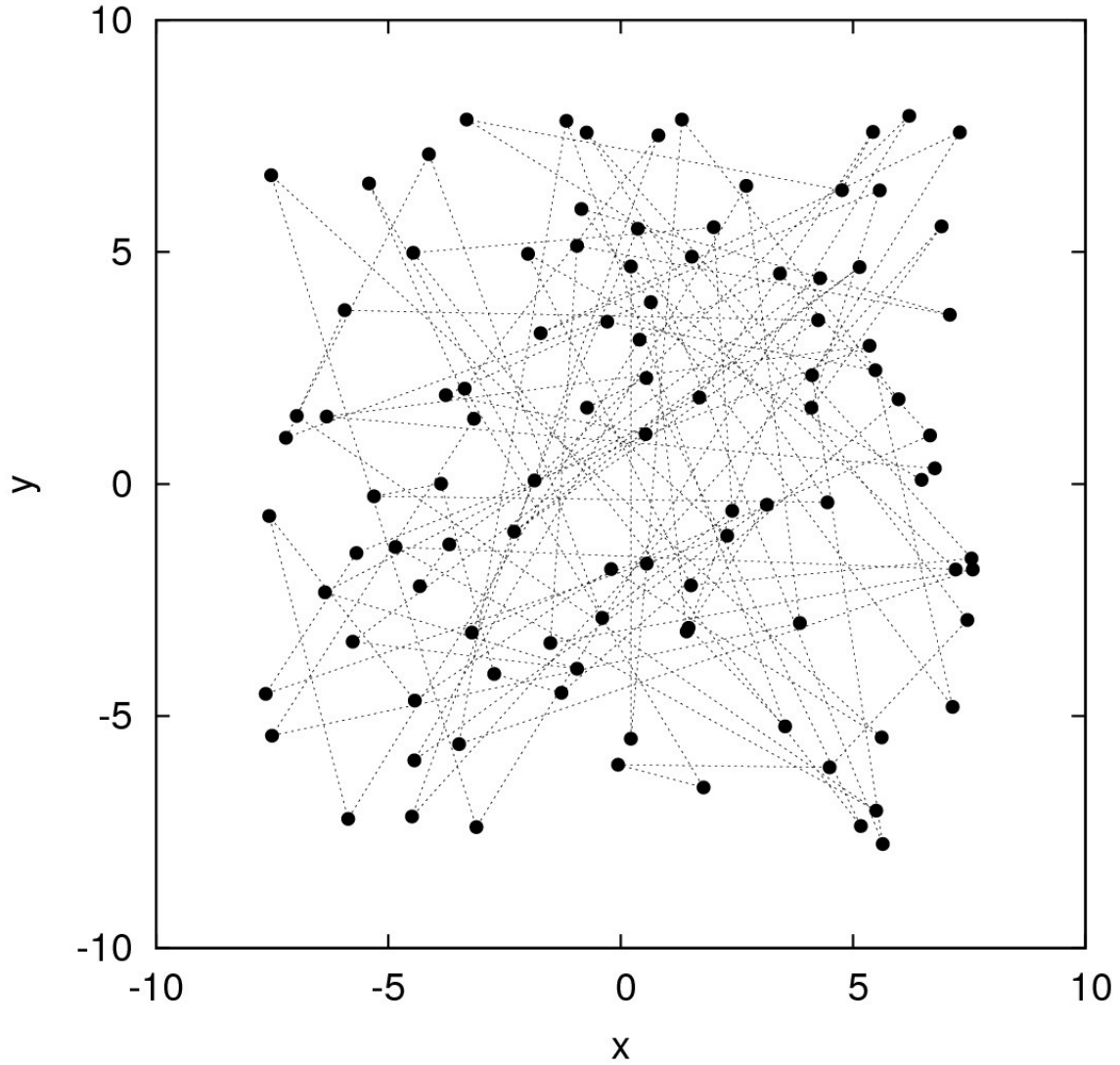
m_0: The fraction of phase space volume occupied by a point source observed with the pattern.

m_1: Resistance against canonical 1/f noise (electronics)

m_2: Resistance against $1/f^2$ noise (atmopshere + temperature fluctuations)

m_1,m_2: Also large-scale sensitivity indicators...

Random

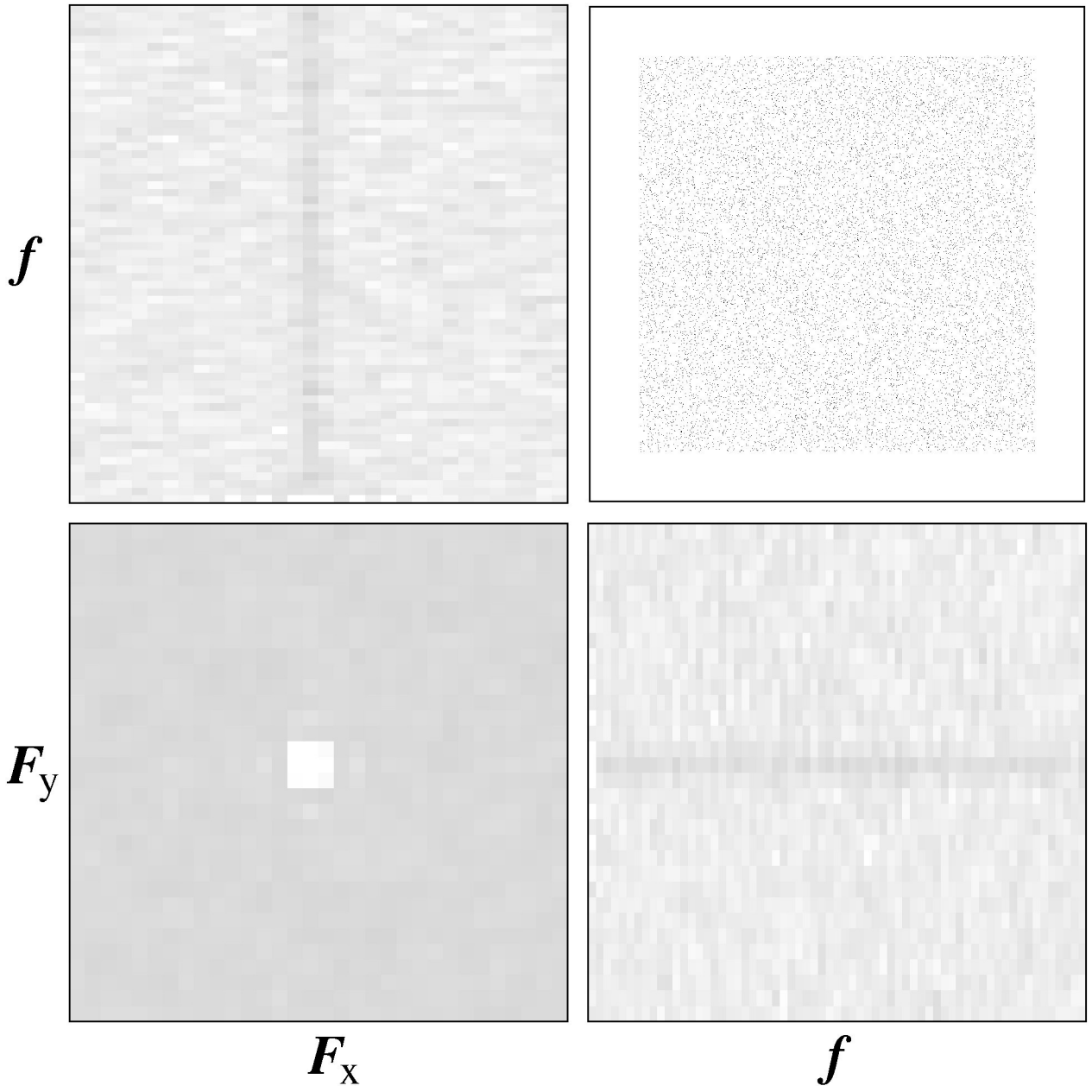


Random

$m_0 = 1.000$

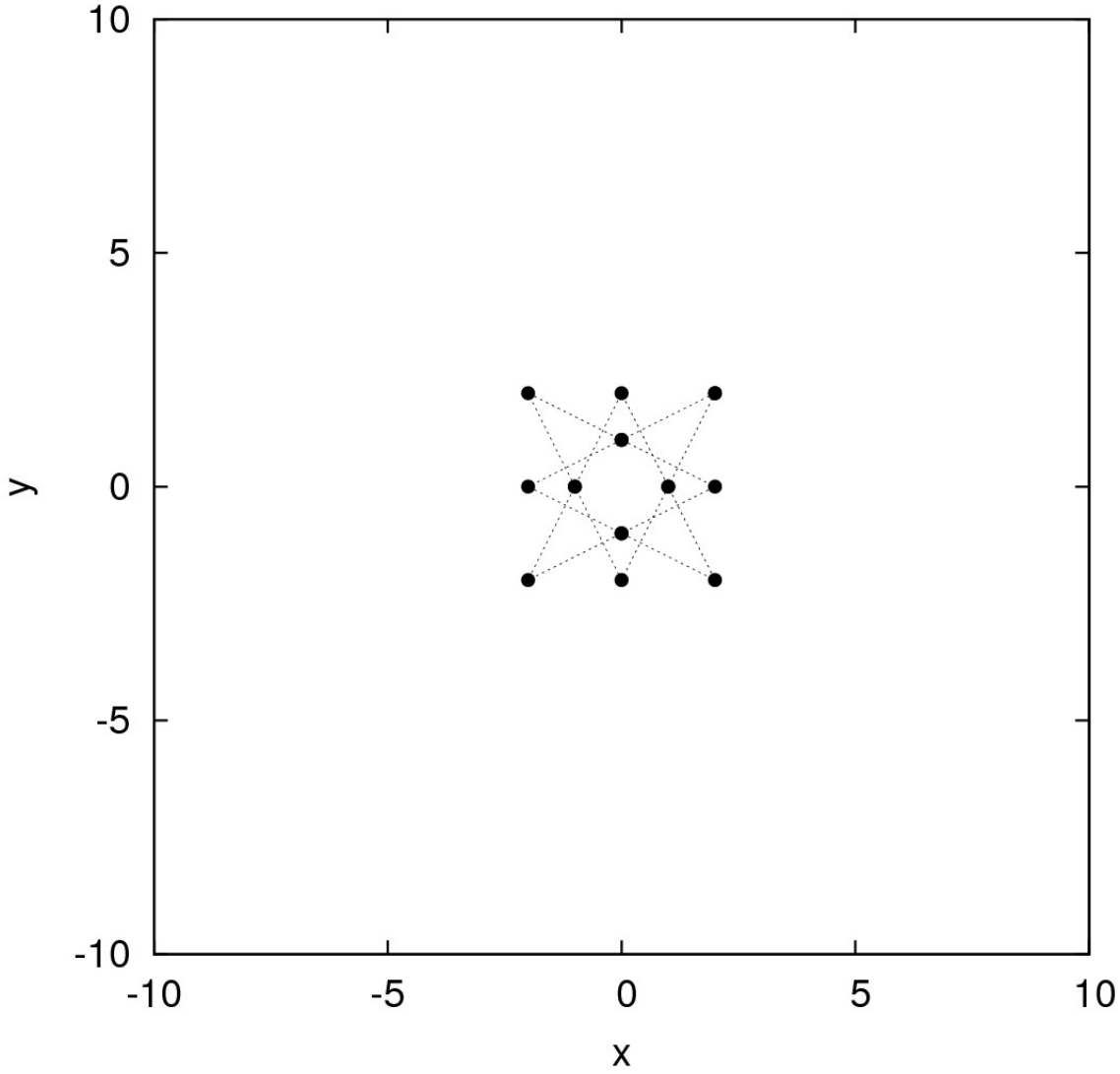
$m_1 = 1.000$

$m_2 = 1.000$



DREAM

Dutch Real-Time Acquisition Mode



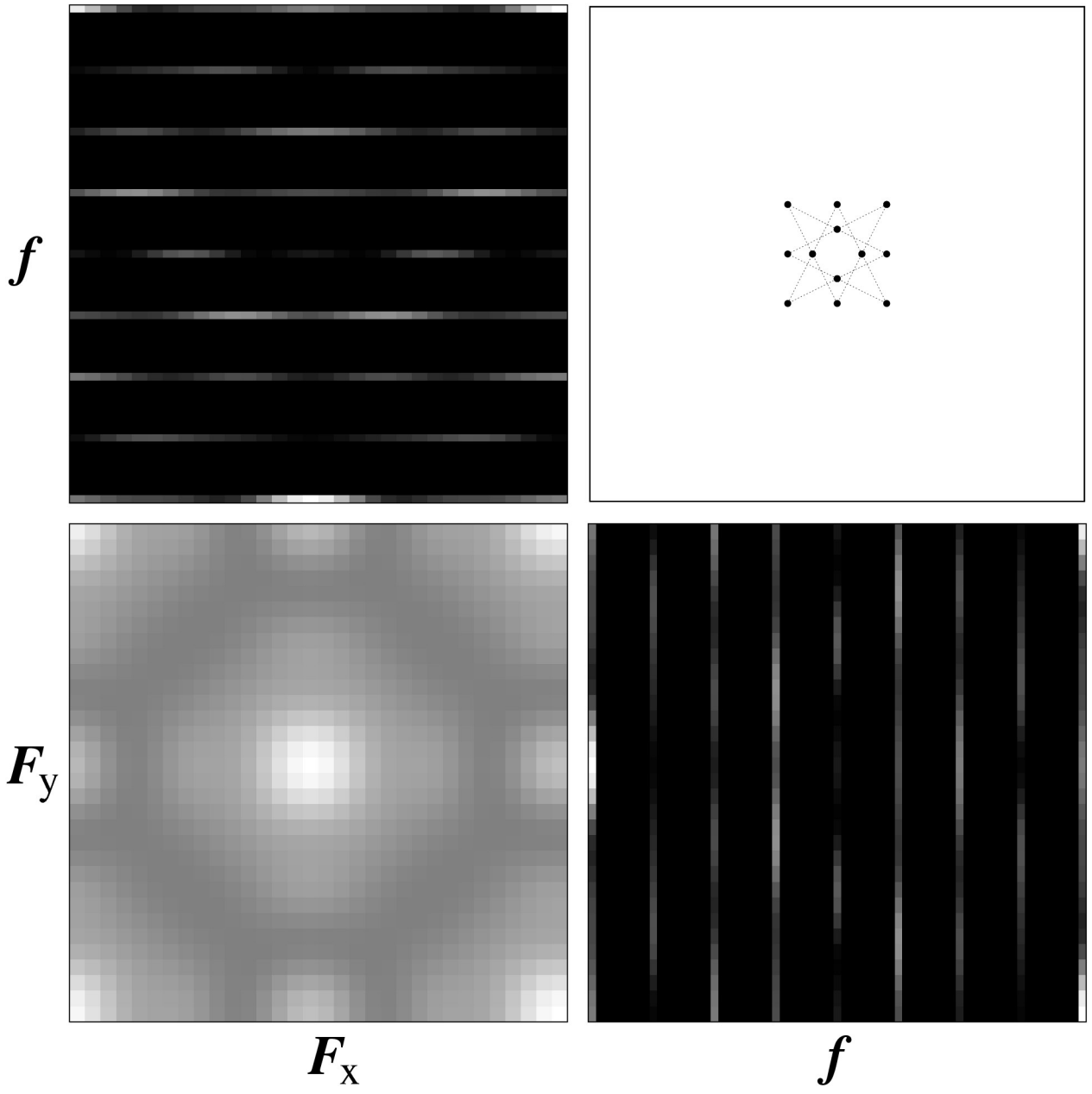
DREAM

Dutch Real-Time Acquisition Mode

$m_0 = 0.0018$

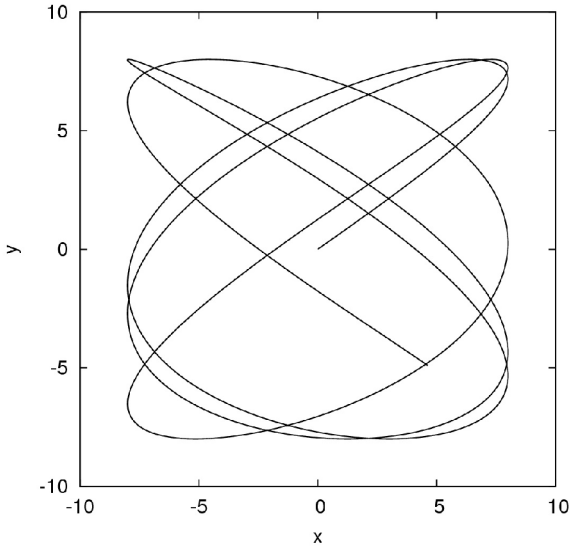
$m_1 = 0.0018$

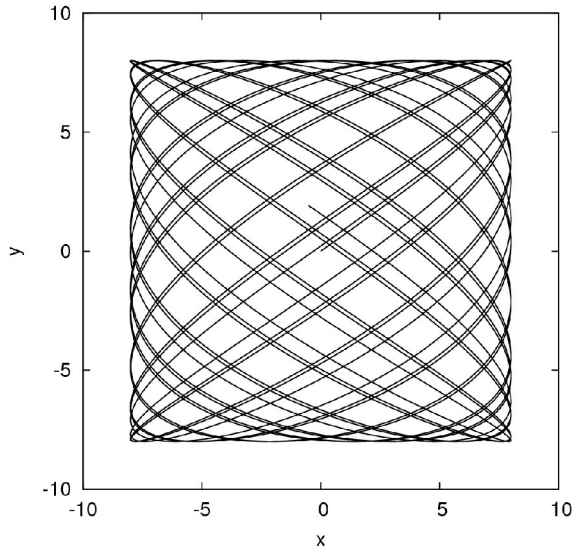
$m_2 = 0.0019$



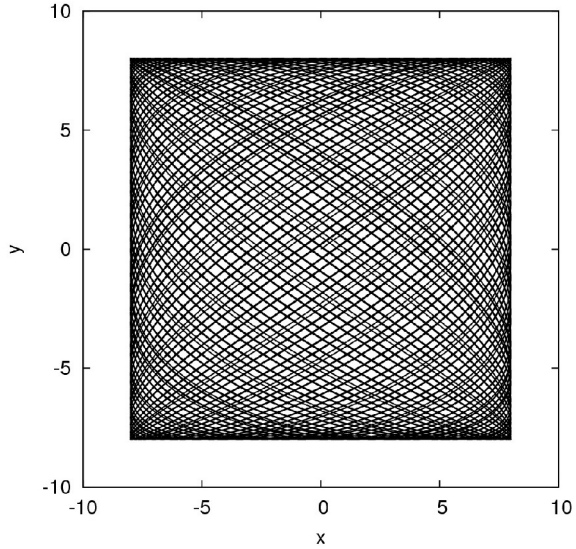
Lissajous

Used for SHARC-2 FoV mapping since 2003.





Irrational x and y frequencies lead to non-repeating, open patterns



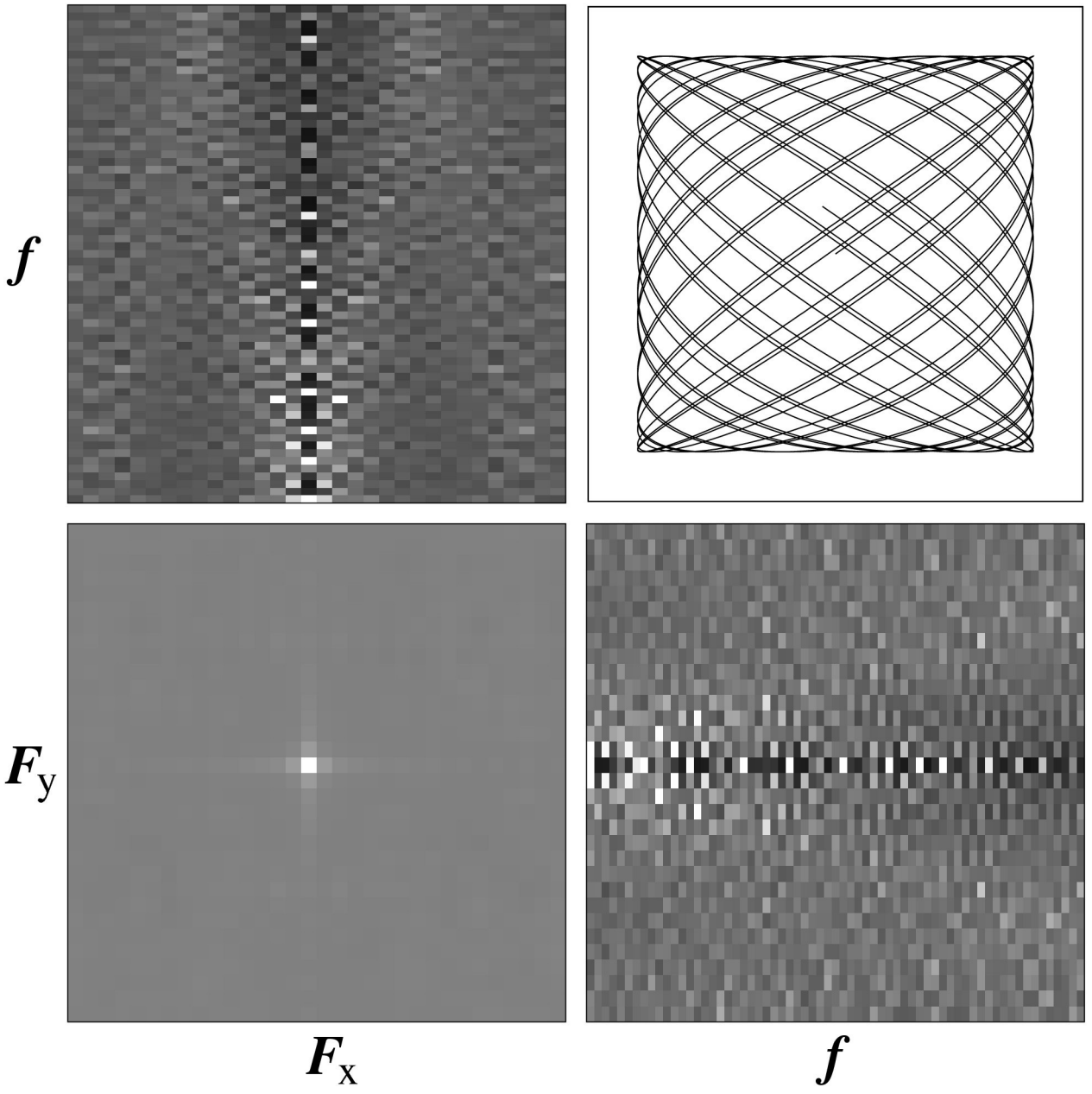
Edge-heavy coverage

Lissajous

$m_0 = 0.129$

$m_1 = 0.126$

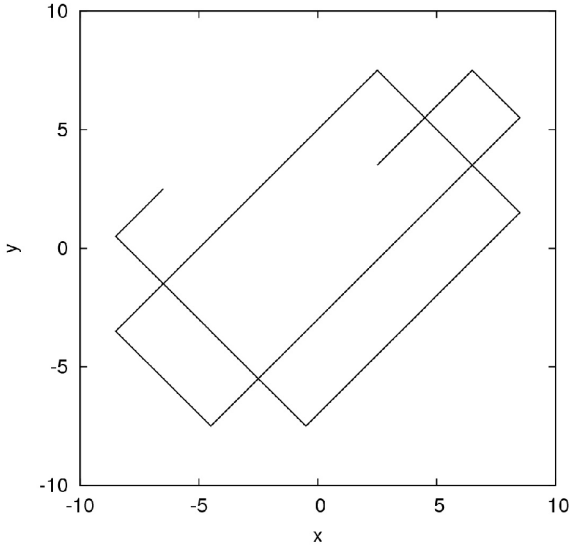
$m_2 = 0.125$

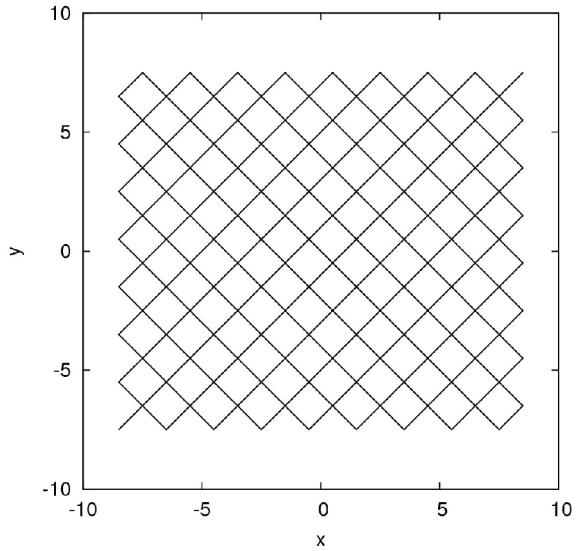


Billiard Scan

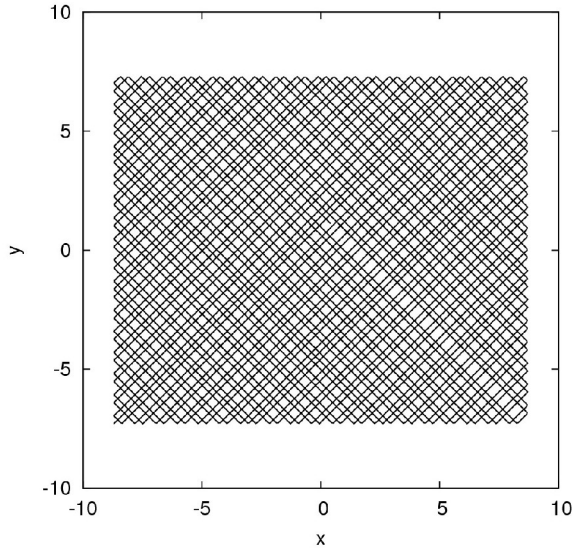
a.k.a. 'PONG' and 'box-scan'

Used for SHARC-2 large-field mapping since 2003 (Borys & Dowell).





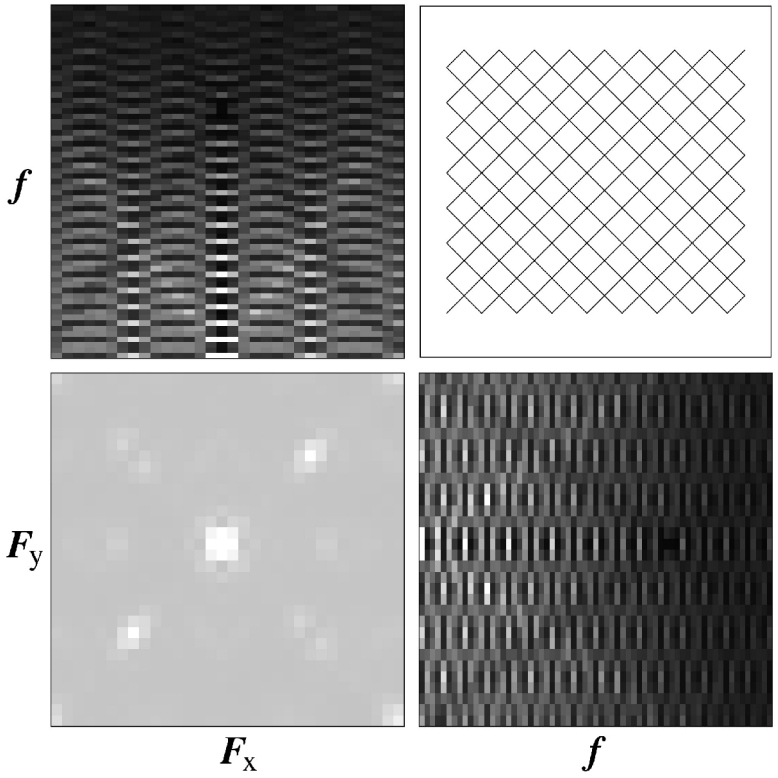
Rational x and y frequencies lead to closed patterns

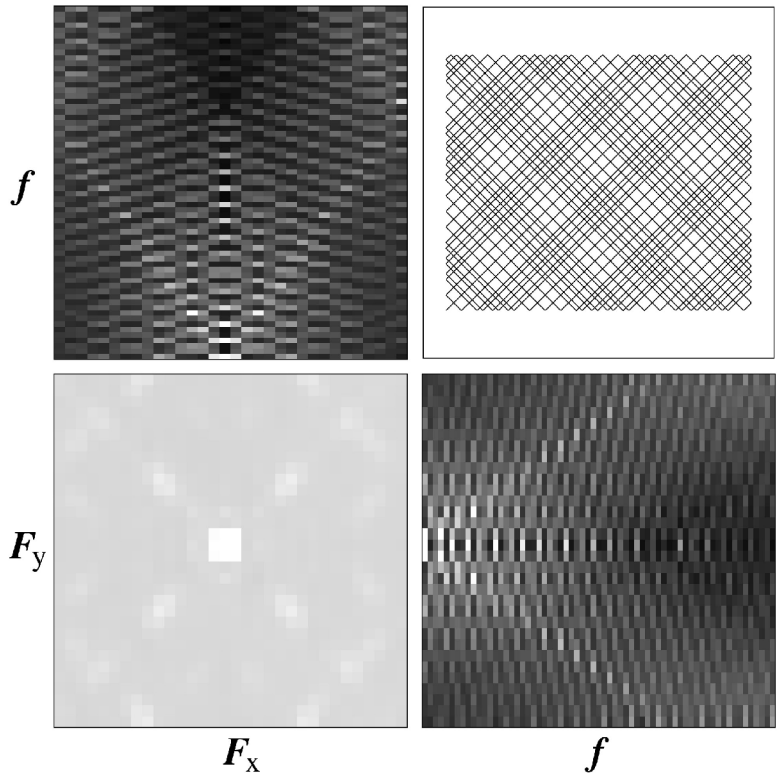


Irrational x and y frequencies lead to non-repeating, open patterns

Billiard Scan (closed)

a.k.a. 'PONG' and 'box-scan'





$m_0 = 0.091$

$m_1 = 0.068$

$m_2 = 0.058$

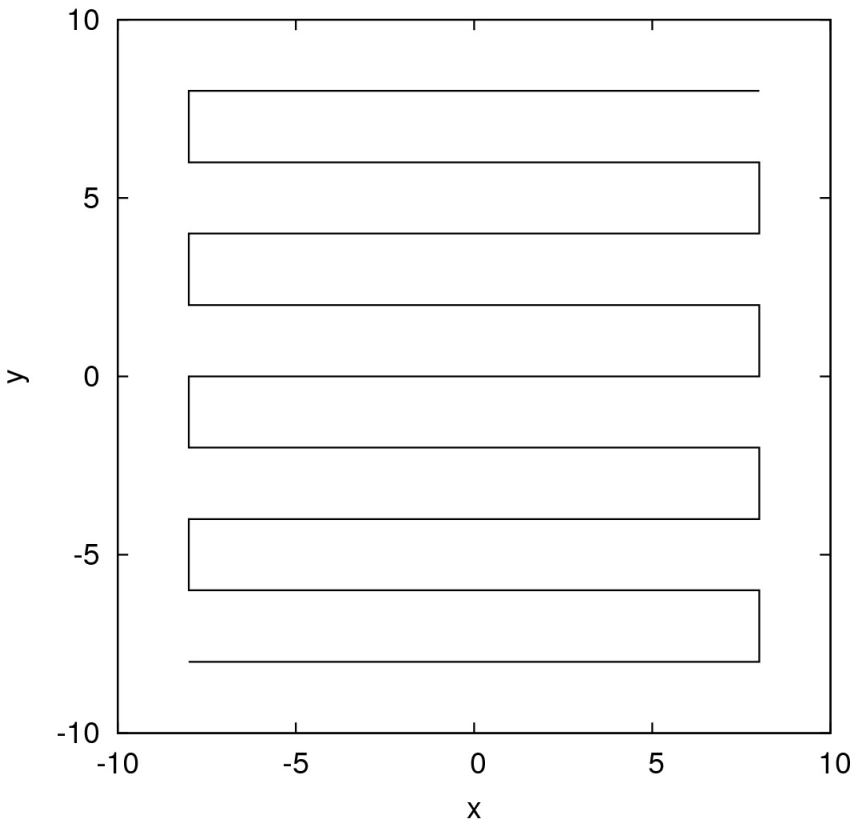
$m_0 = 0.097$

$m_1 = 0.089$

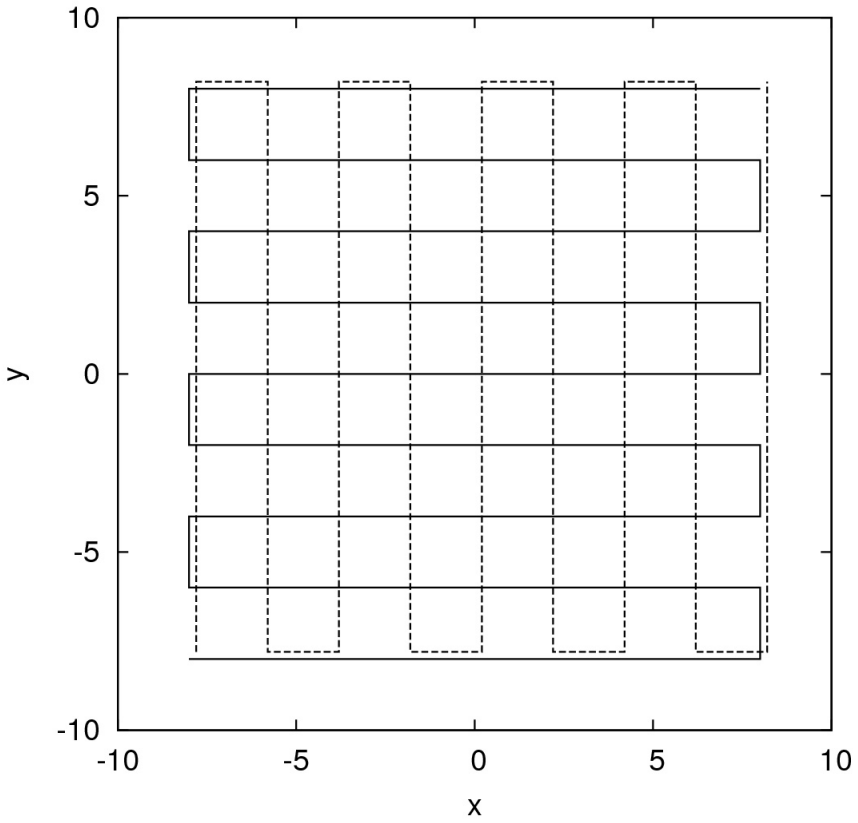
$m_2 = 0.086$

On-The-Fly (OTF) Scanning

a.k.a. 'Serpentine' or 'Raster Scan'



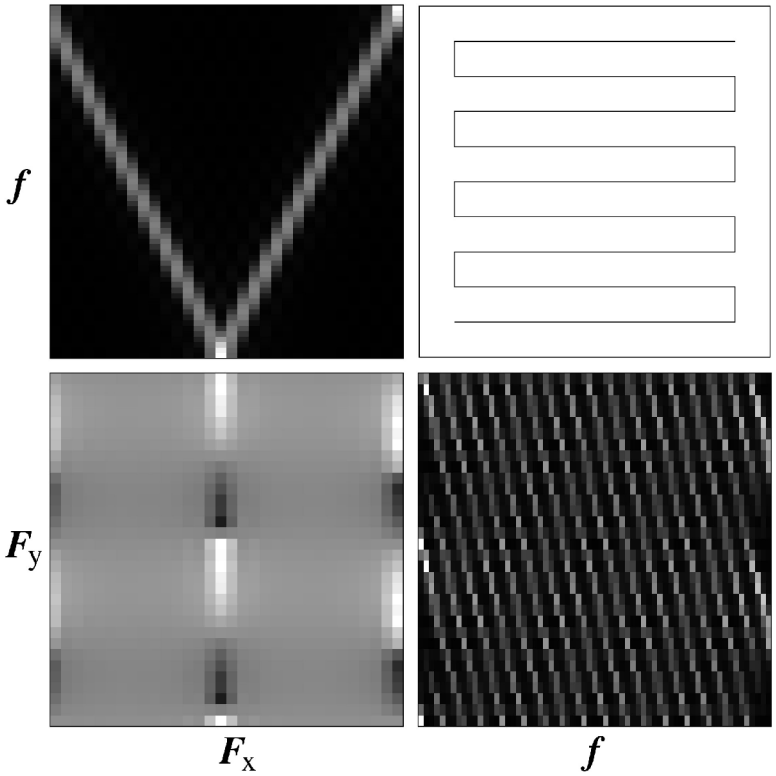
Directional Sensitivity
to Large Scales...

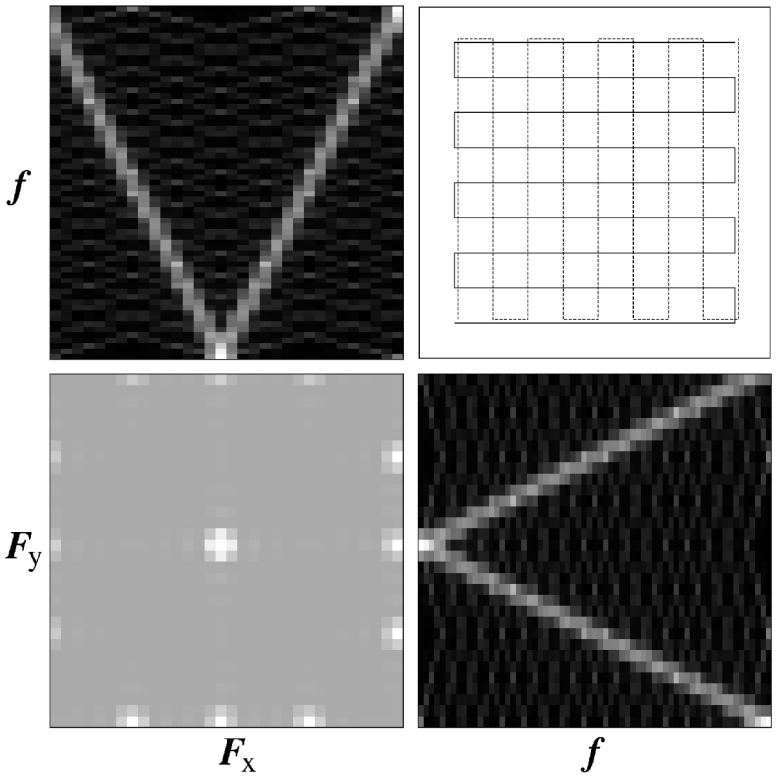


Cross-linked at 90 deg
for better large scale sensitivity
in both directions

On-The-Fly (OTF) Scanning

a.k.a. 'Serpentine' or 'Raster Scan'





$m_0 = 0.018$

$m_1 = 0.018$

$m_2 = 0.018$

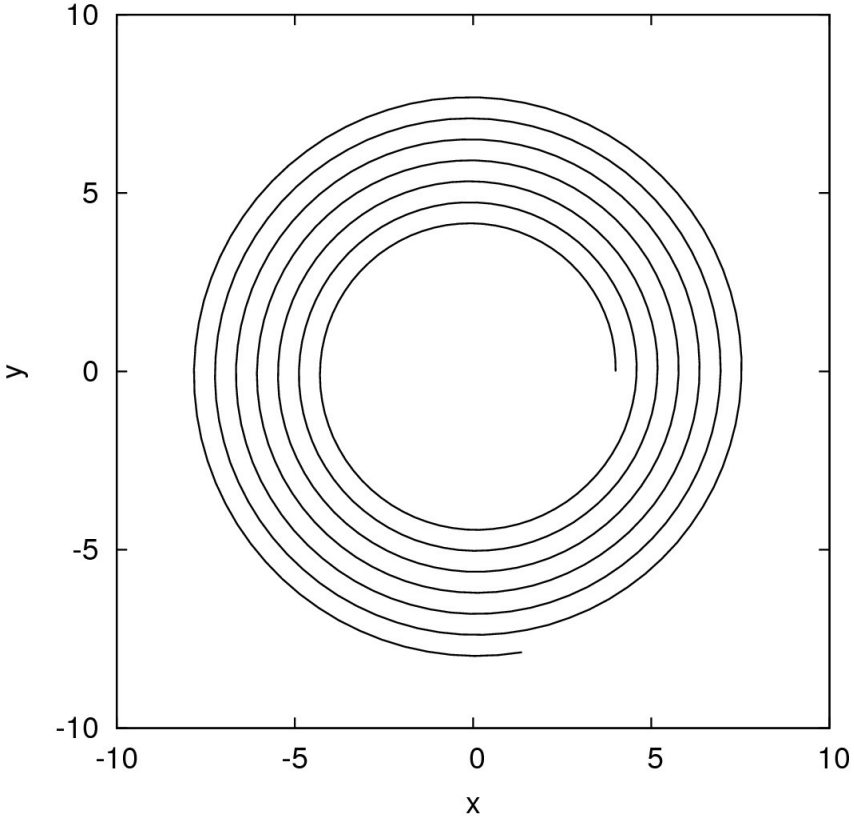
$m_0 = 0.035$

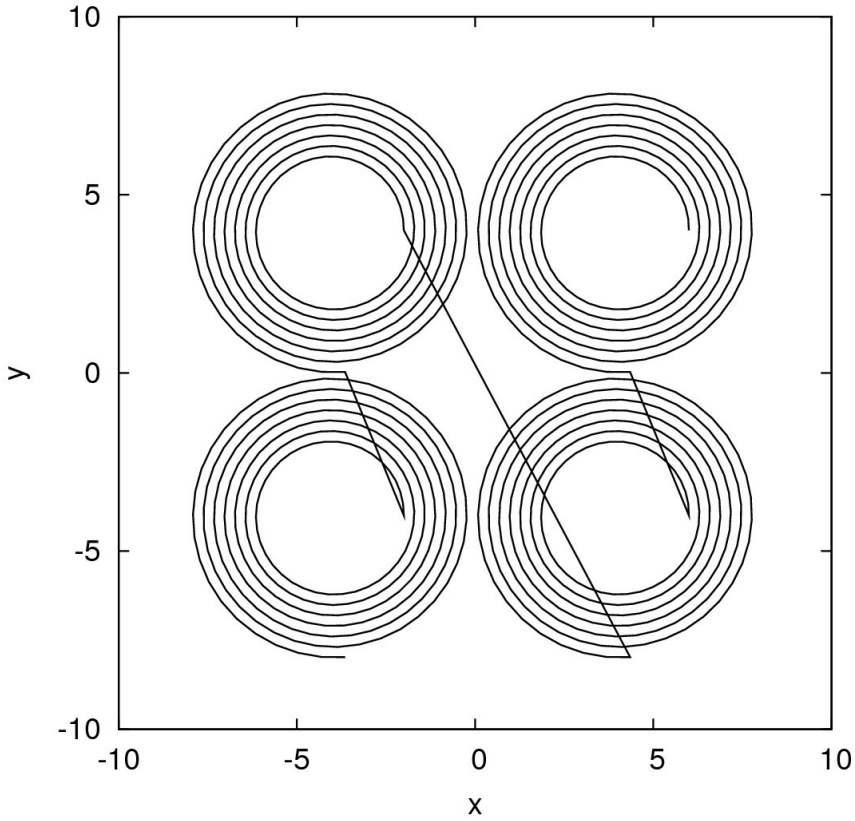
$m_1 = 0.035$

$m_2 = 0.035$

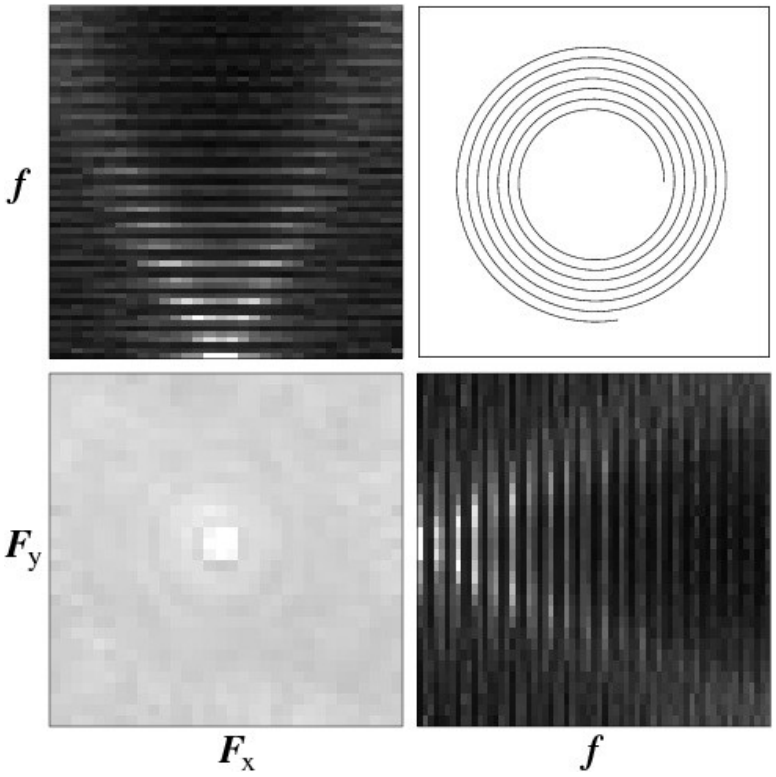
Archimedian Spirals

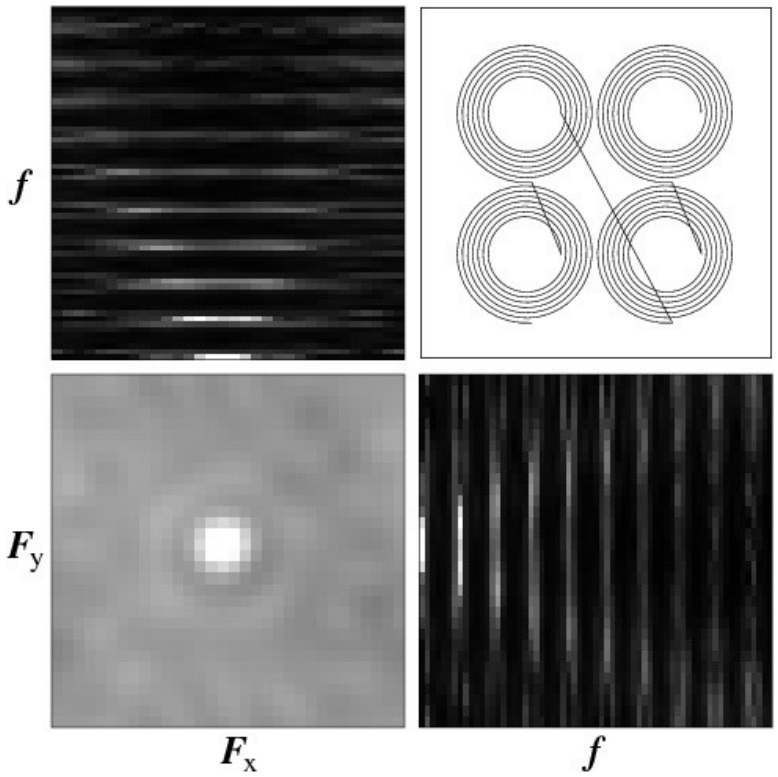
Used at the APEX telescope in Chile for *LABOCA* Mapping





Archimedian Spirals





$m_0 = 0.061$

$m_1 = 0.056$

$m_2 = 0.054$

$m_0 = 0.080$

$m_1 = 0.073$

$m_2 = 0.070$

Score Card

Pattern	Geometric Paramters	Moments m_0	m_1	m_2	l_c	Comments
random	a, b	1.000	1.000	1.000	a, b	discrete, unfeasible(?)
Lissajous	$A_x, A_y, \omega_y/\omega_x$	0.129	0.126	0.125	$2A_x, 2A_y$	smooth
billiard (open)	a, b, θ	0.097	0.089	0.086	a, b	
billiard (closed)	(see above)	0.091	0.068	0.058	a, b	
rotating OTF	$L, \Delta, \delta\Theta$	0.088	0.085	0.084	L	requires several angles 0–90°
raster of spirals	$\Delta_{\rm ras}, r_0, r_{\rm max}$	0.080	0.073	0.070	$2r_{\rm max}$	
spiral	$r_0, r_{\rm max}$	0.061	0.056	0.054	$2r_{\rm max}$	smooth
crossed OTF (90°)	L, Δ	0.035	0.035	0.035	L	
chop	d	0.030	0.030	0.045	d	discrete, (oriented), secondary
OTF	L, Δ	0.018	0.018	0.018	Δ, L	strongly oriented
DREAM		0.018	0.018	0.019	4 pixels	discrete, secondary
stare		n/a	0.000	0.000	FOV	up to 4× integration time

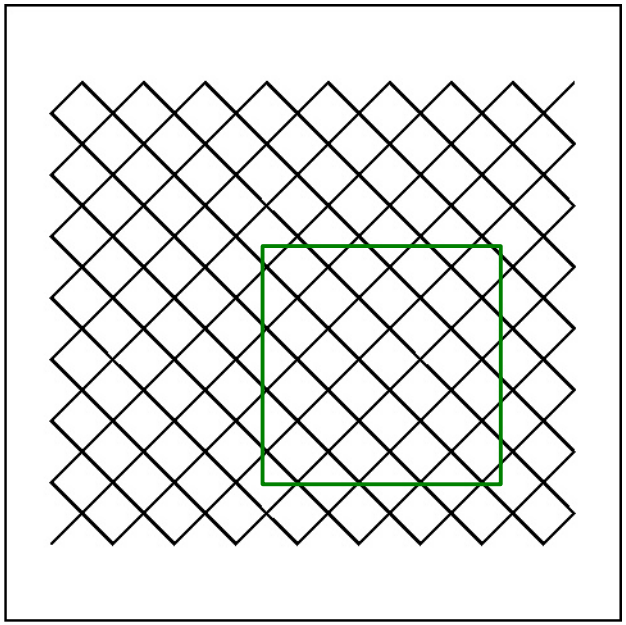
Score Card

Pattern	Geometric Paramters	Moments m_0	m_1	m_2	l_c	Comments
random	a, b	1.000	1.000	1.000	a, b	discrete, unfeasible(?)
Lissajous	$A_x, A_y, \omega_y/\omega_x$	0.129	0.126	0.125	$2A_x, 2A_y$	smooth
billiard (open)	a, b, θ	0.097	0.089	0.086	a, b	
billiard (closed)	(see above)	0.091	0.068	0.058	a, b	
rotating OTF	$L, \Delta, \delta\Theta$	0.088	0.085	0.084	L	requires several angles 0–90°
raster of spirals	$\Delta_{\mathrm{ras}}, r_0, r_{\max}$	0.080	0.073	0.070	$2r_{\max}$	
spiral	$r_0, r_{\max}$	0.061	0.056	0.054	$2r_{\max}$	smooth
crossed OTF (90°)	L, Δ	0.035	0.035	0.035	L	
chop	d	0.030	0.030	0.045	d	discrete, (oriented), secondary
OTF	L, Δ	0.018	0.018	0.018	Δ, L	strongly oriented
DREAM		0.018	0.018	0.019	4 pixels	discrete, secondary
stare		n/a	0.000	0.000	FOV	up to 4× integration time

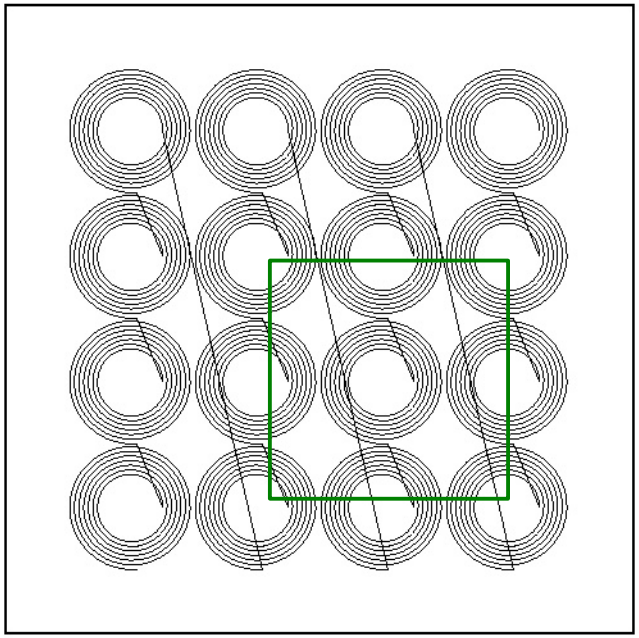
Large Fields

What's the best strategies for fields > FoV?

All at once...



Little by little...



Large Fields

What's the best strategies for fields > FoV?

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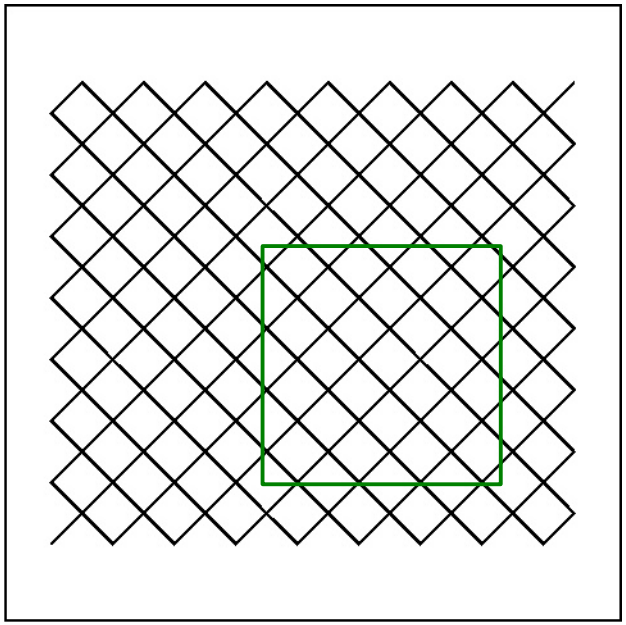
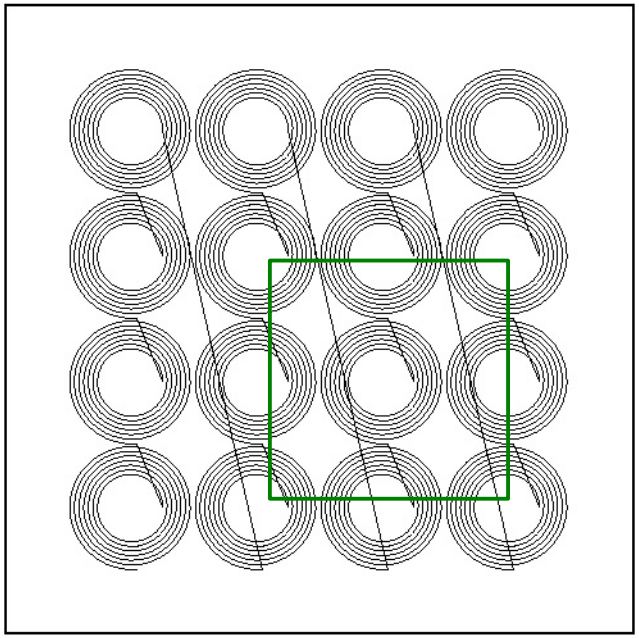


Little by little...



The answer does not depend on field size.
It depends entirely on the pattern chosen!!!

Conclusions

I. Recipes for Designing Better Patterns

II. Rankings:

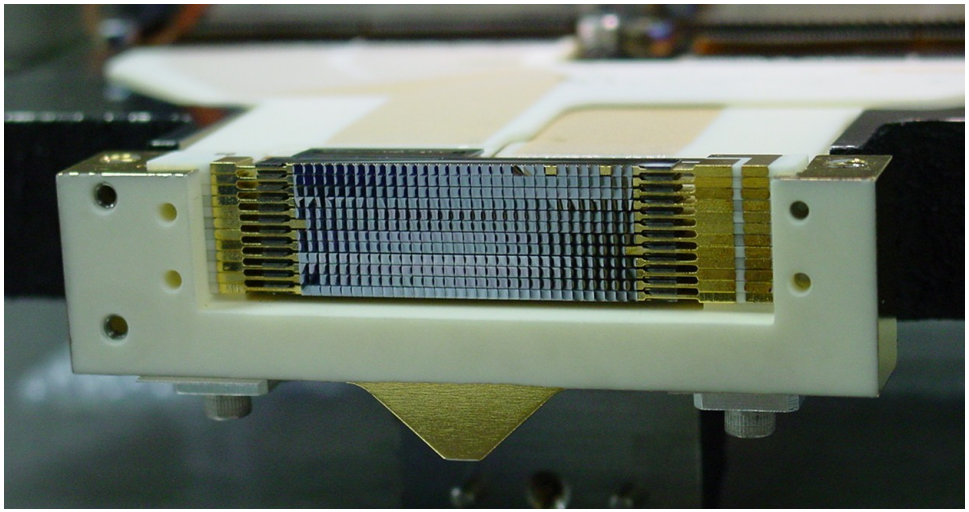
(1) Random
(2) Lissajous, Billiard, Spirals
(3) Cross-Linked OTF

III. Evaluate you own pattern at

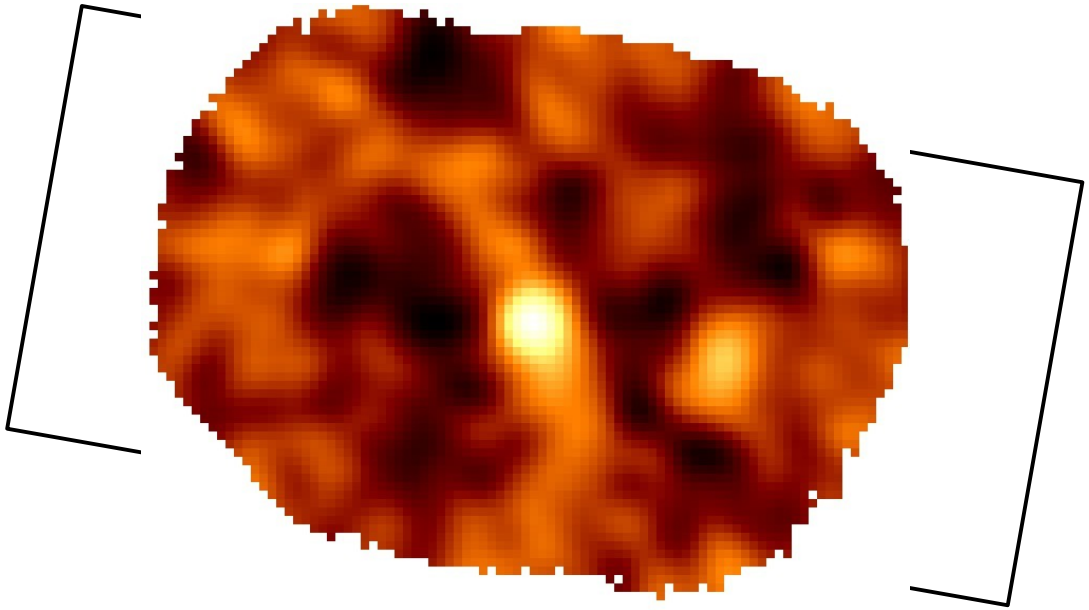
http://www.submm.caltech.edu/~sharc/scanning

Lissajous

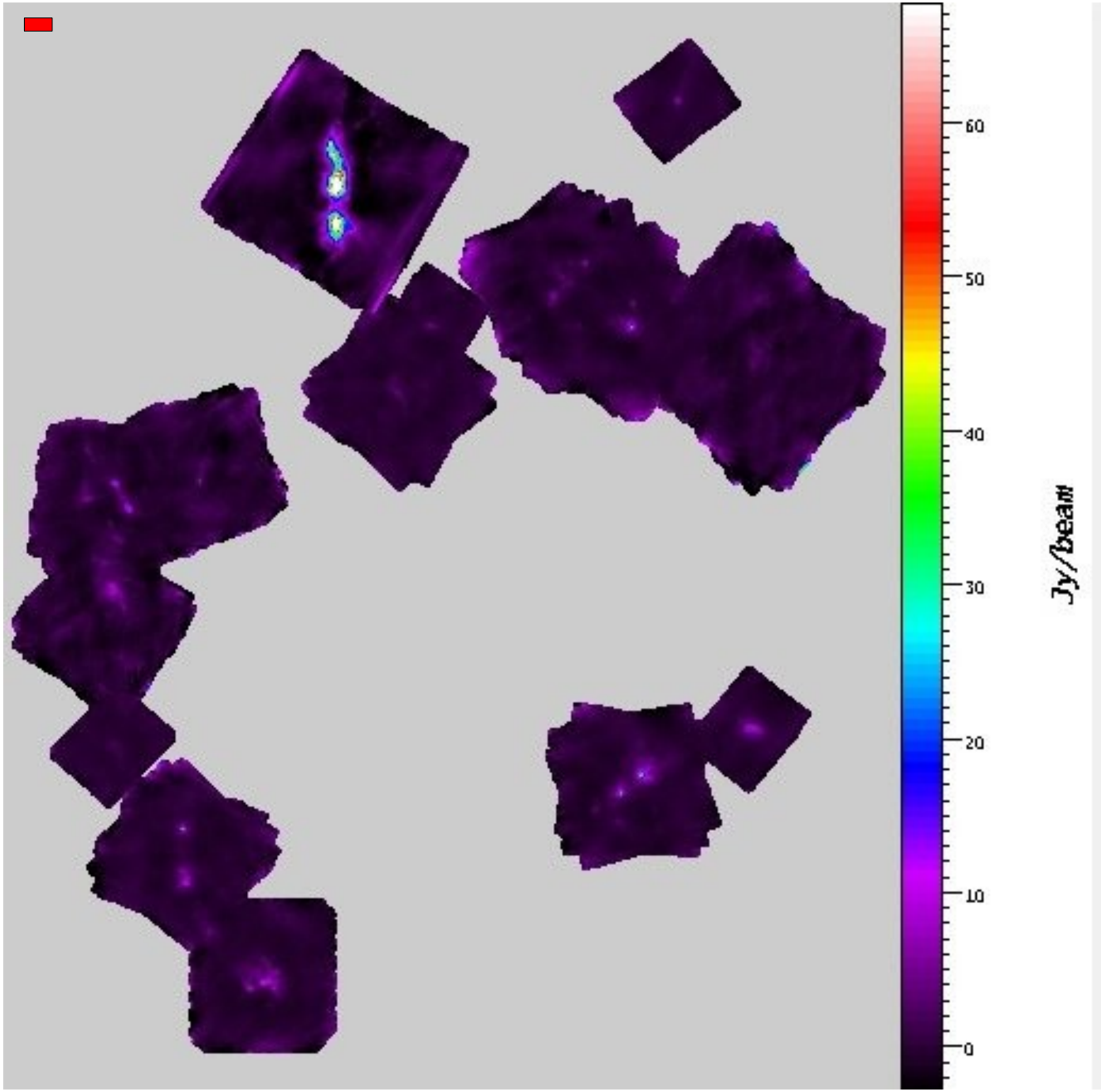
SHARC-2



SMM J163631.47 +405546.9



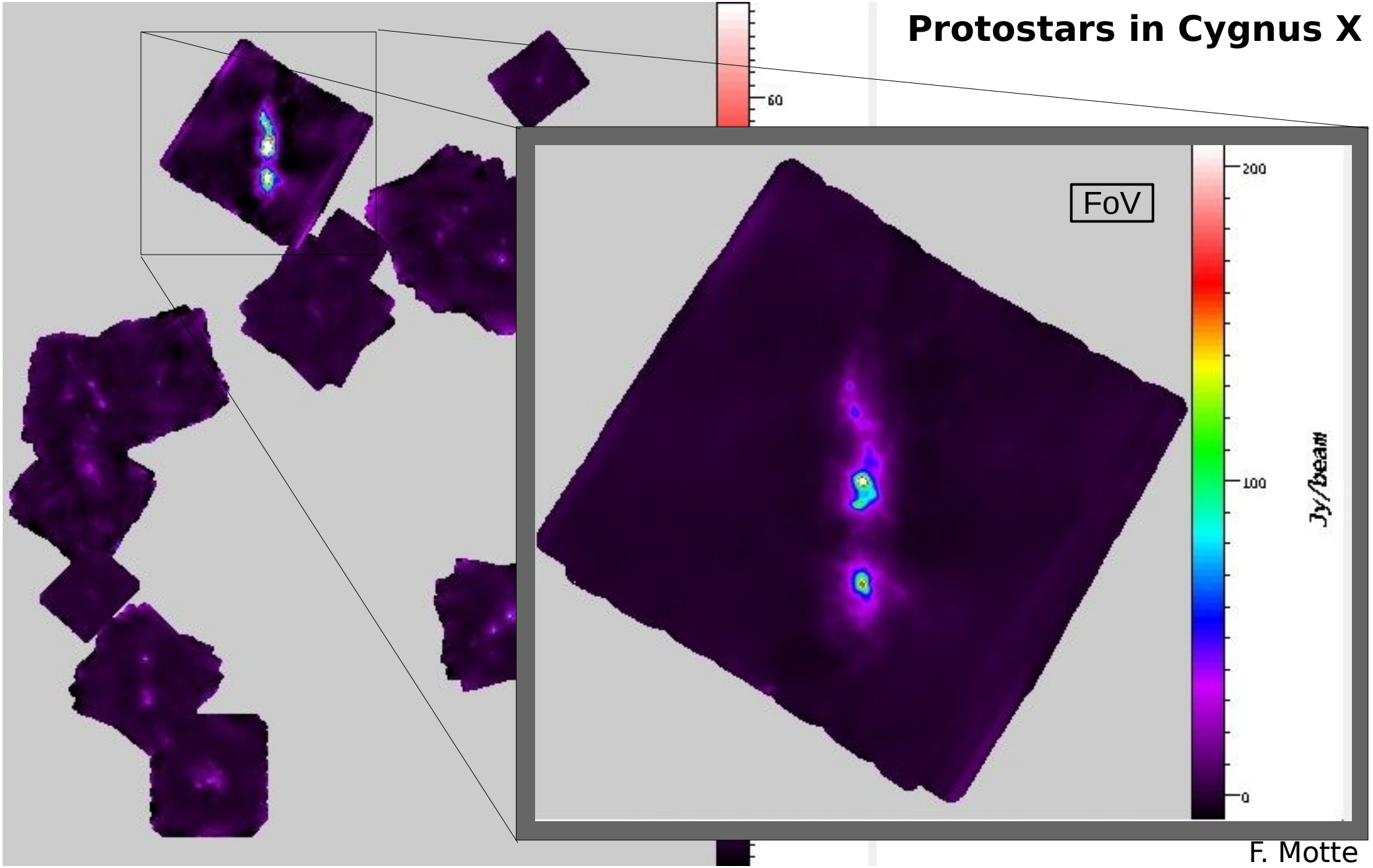
Billiard



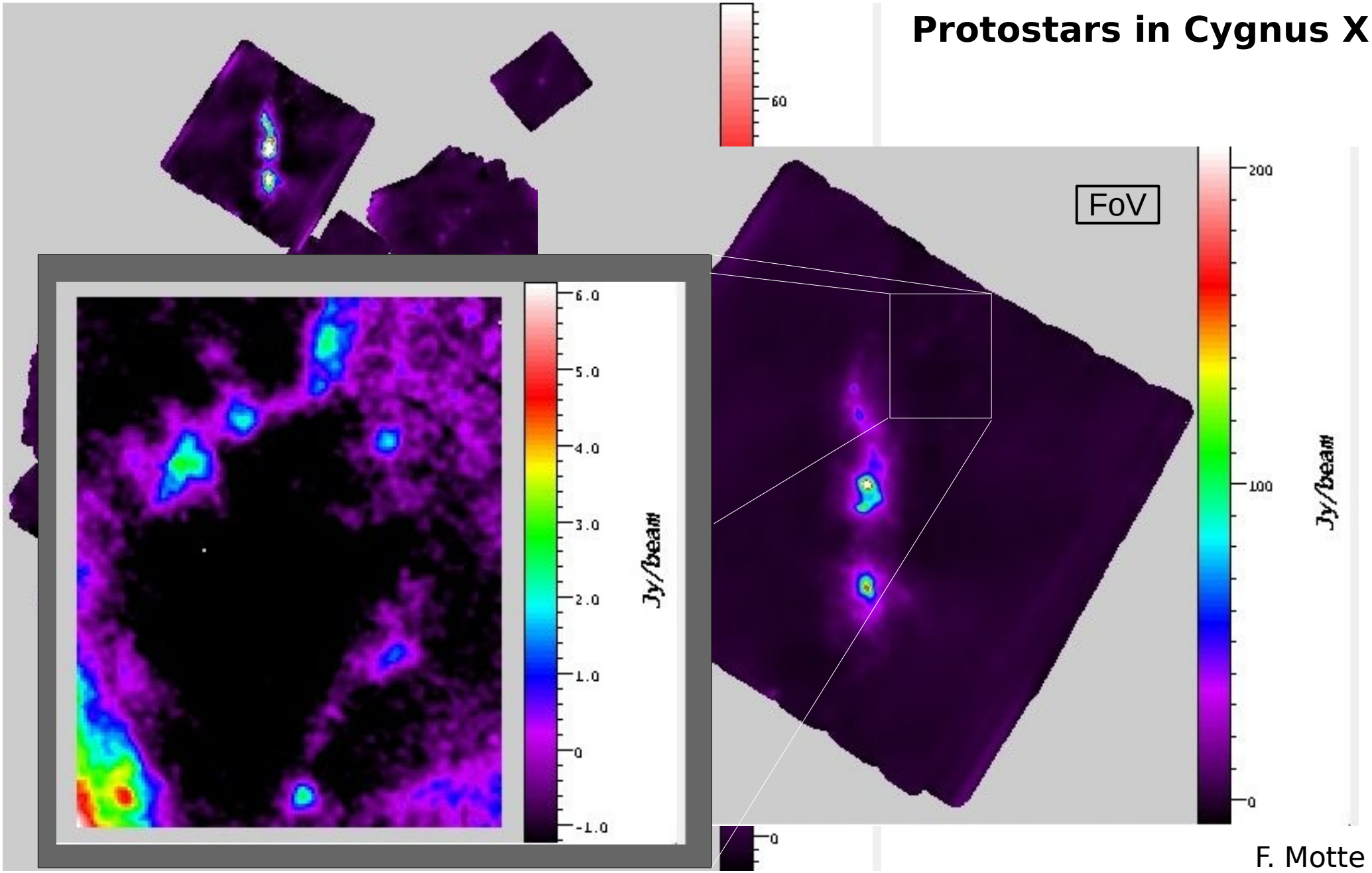
Protostars in Cygnus X

F. Motte

Billiard

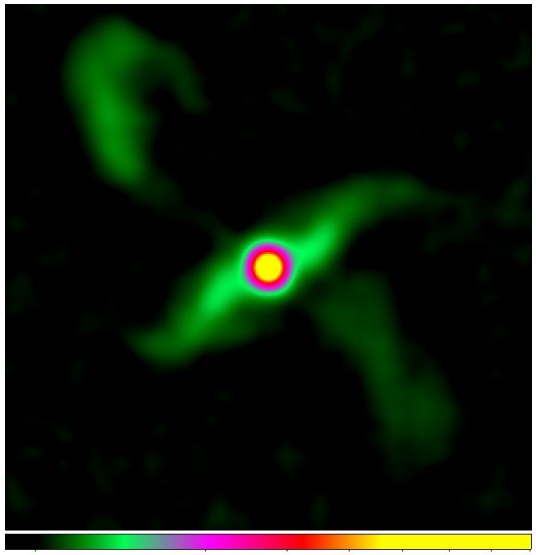


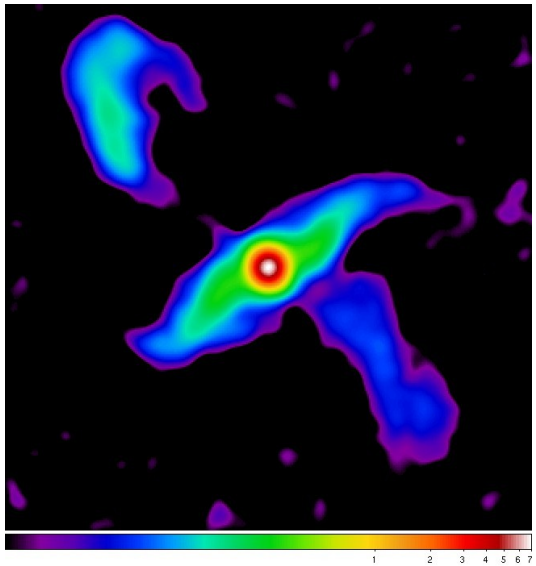
Billiard


Protostars in Cygnus X
FoV
60
6.0
5.0
4.0
3.0
2.0
1.0
0
-1.0
Jy/beam
200
100
0
Jy/beam
0
F. Motte

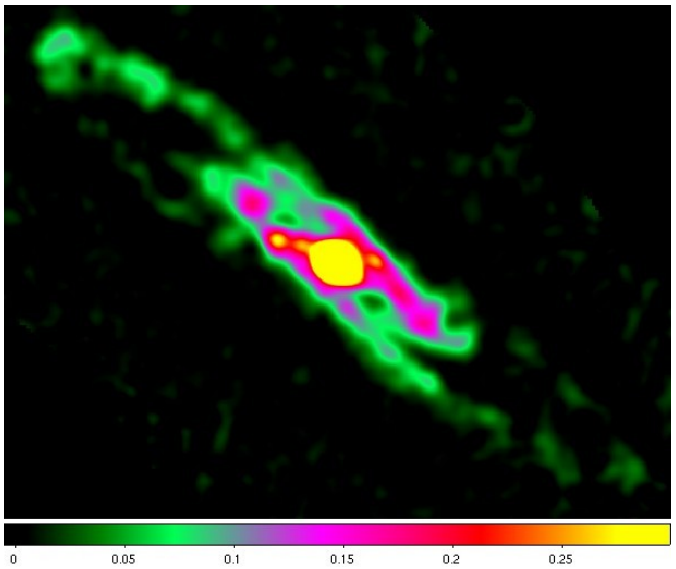
Raster of Spirals

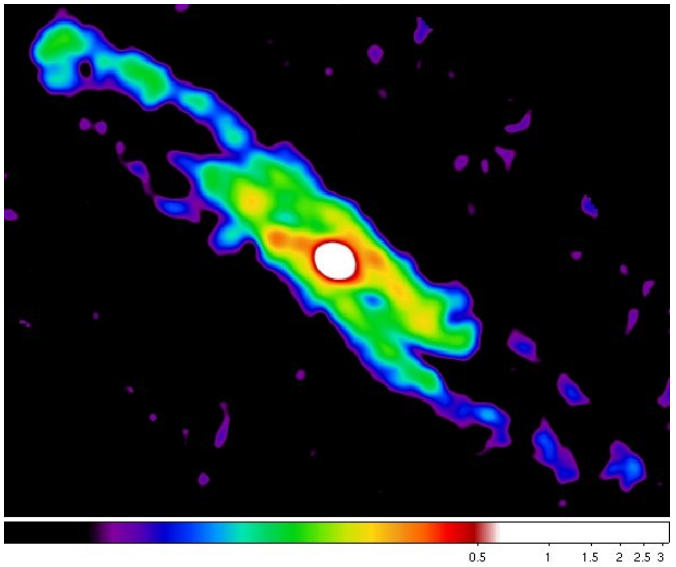
Centaurus A



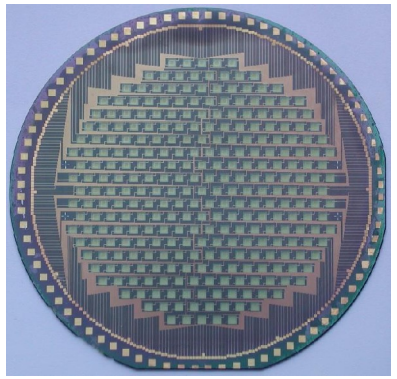


NGC 253

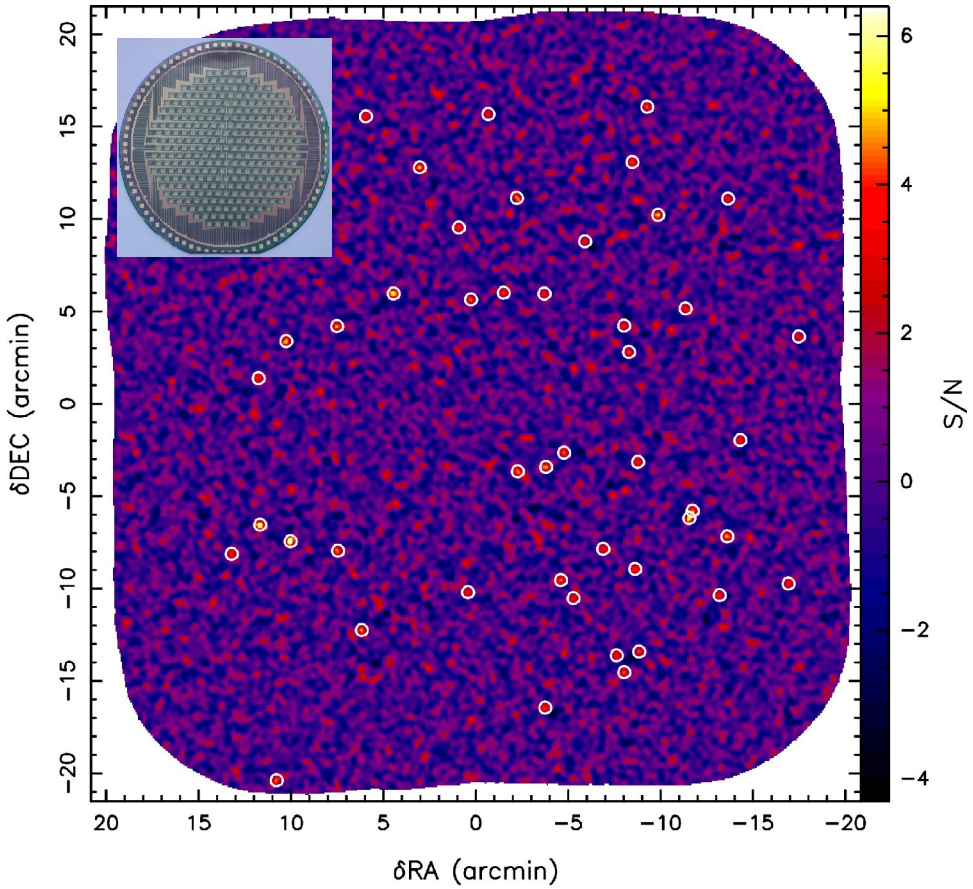


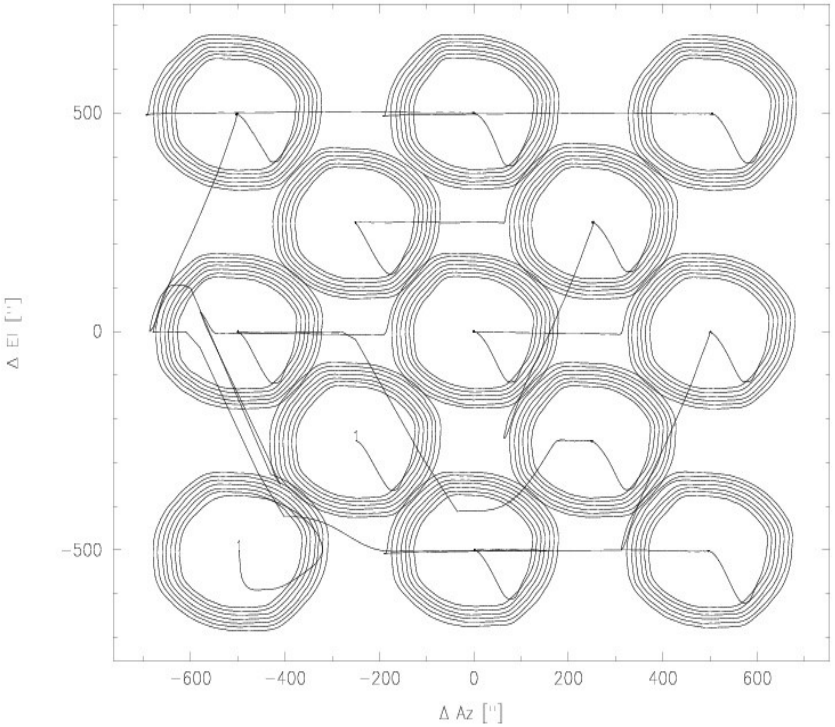


LABOCA



Raster of Spirals





Cross-Linked OTF

The Galactic Centre Region by LABOCA from the *ATLASGAL* survey