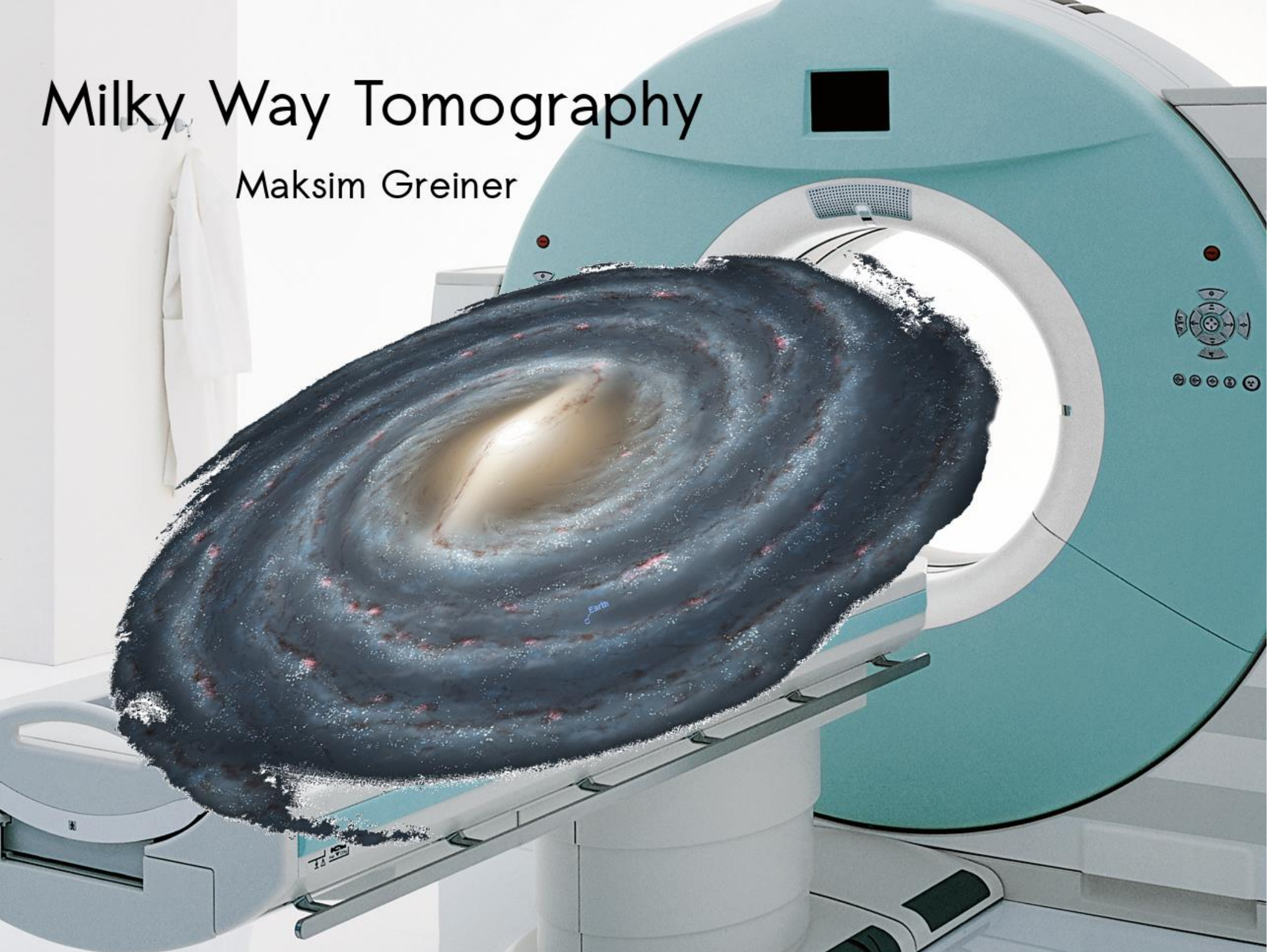
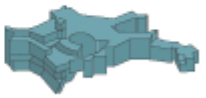
Milky Way Tomography

Maksim Greiner

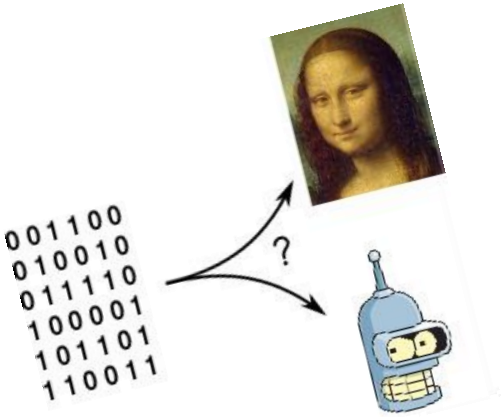


LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

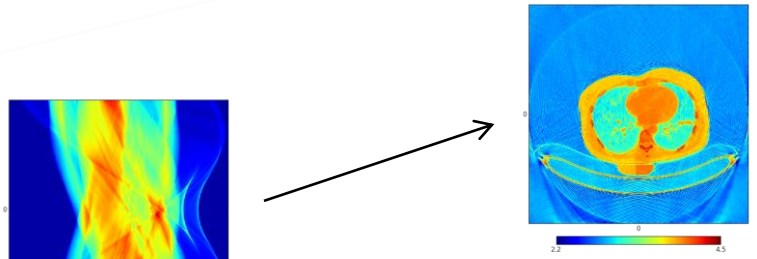
Max-Planck-Institut für Astrophysik



Turn data into images



X-Ray tomography in medicine



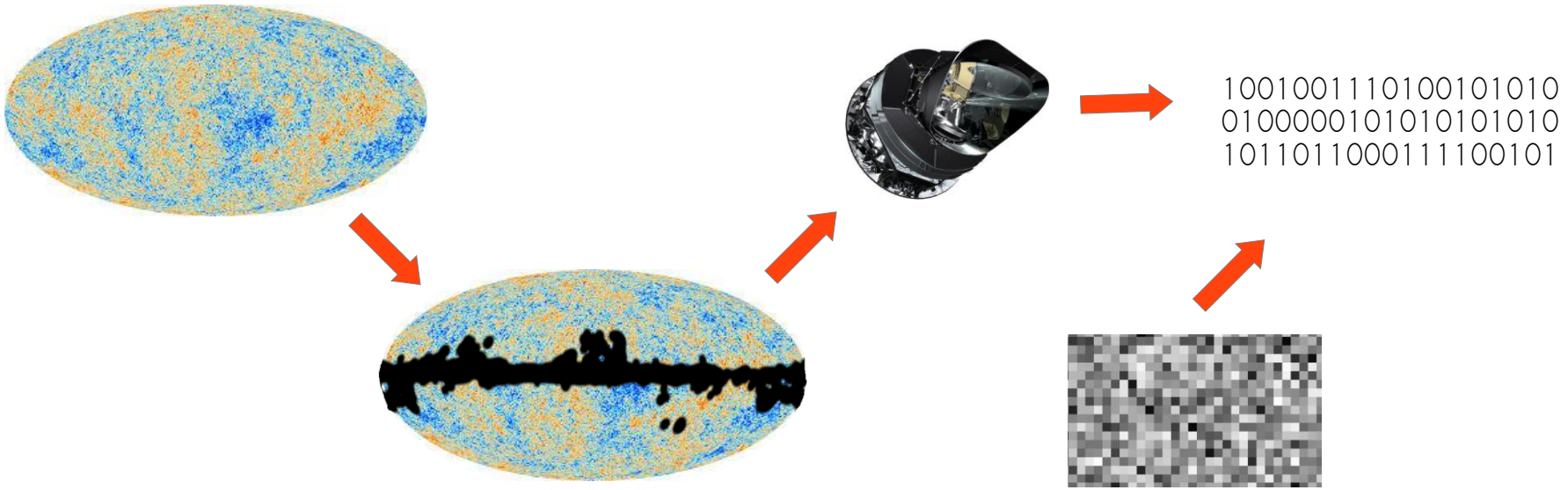
Tomography of the interstellar medium

What the SKA will enable

Turning data into images

the probability theory way of imaging

- we want to find an image
- data come from some sort of measurement
- measurement is usually noise influenced
- data set may not restrict all degrees of freedom of image



the probability theory way of imaging

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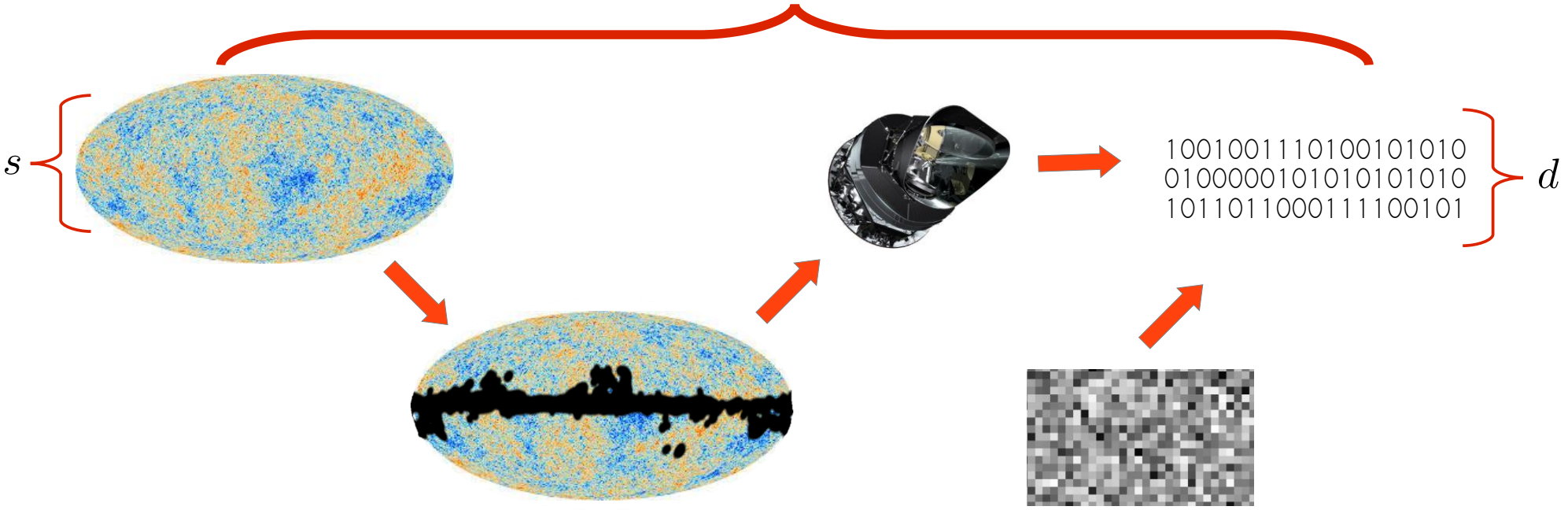
probabilistic forward model $\mathcal{P}(d|s)$



the probability theory way of imaging

$$\mathcal{P}(s|d) = \frac{\mathcal{P}(s)\mathcal{P}(s|d)}{\mathcal{P}(d)}$$

Since there is no unique solution we work with probabilities.

$\mathcal{P}(d|s)$ the forward model

$\mathcal{P}(s)$ our background information

$\mathcal{P}(s|d)$ our knowledge state having the data

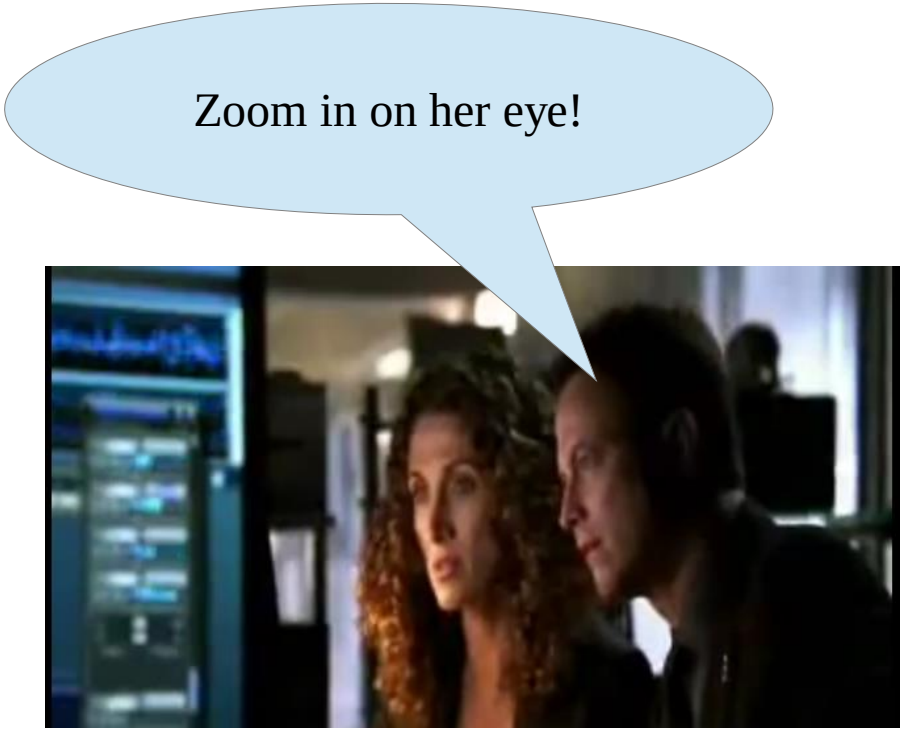
Get most likely value for *s* :
(or even better the mean)

$$m = \arg\max \mathcal{P}(s|d)$$

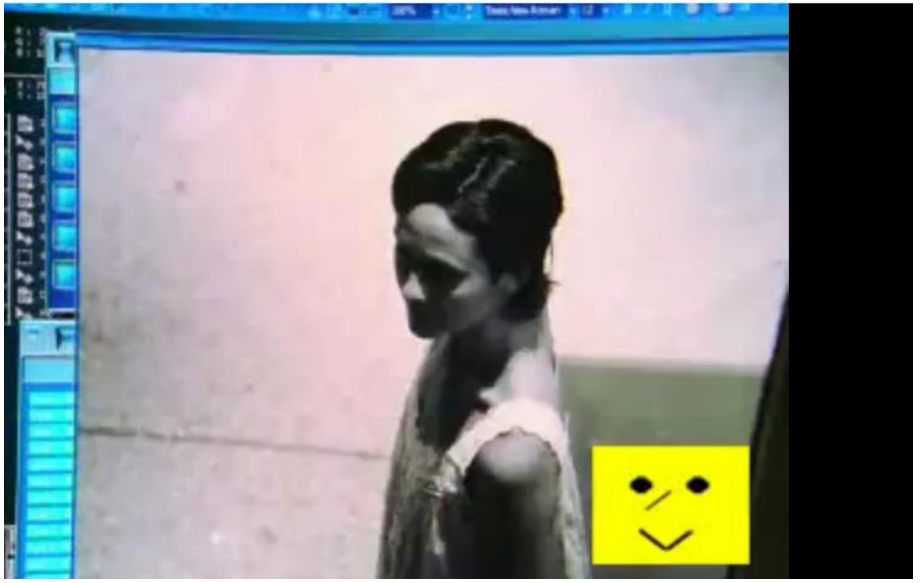
our map

The typical CSI scene

The typical CSI scene



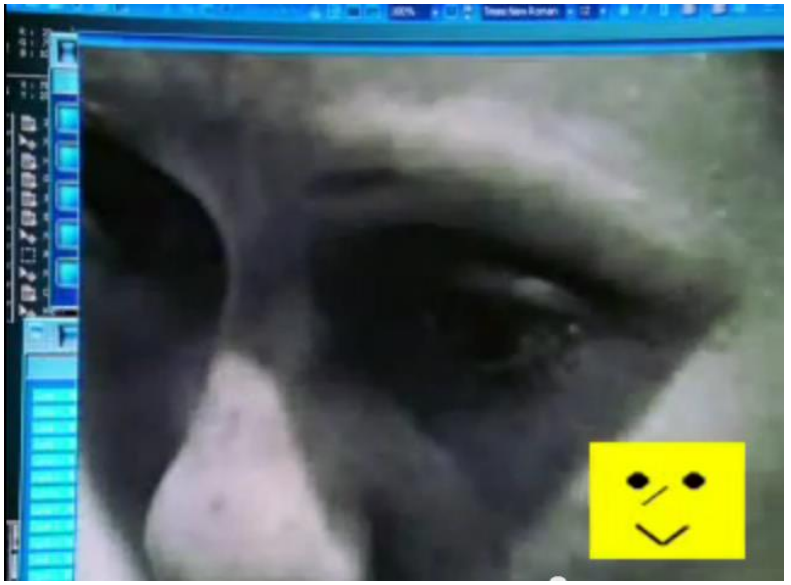
The typical CSI scene



The typical CSI scene

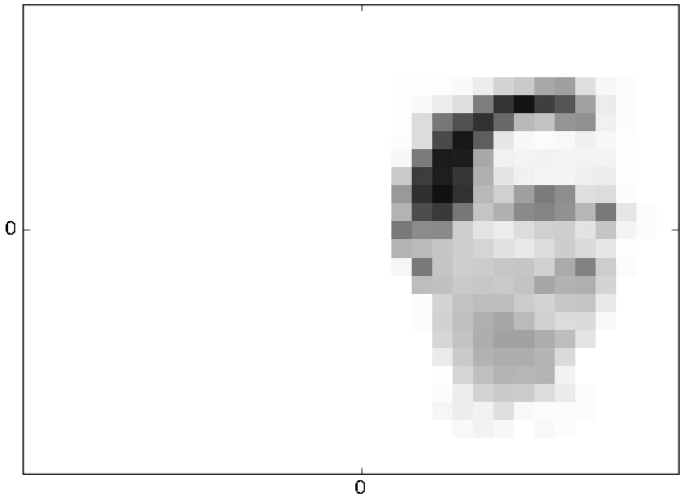
technology sounds

The typical CSI scene

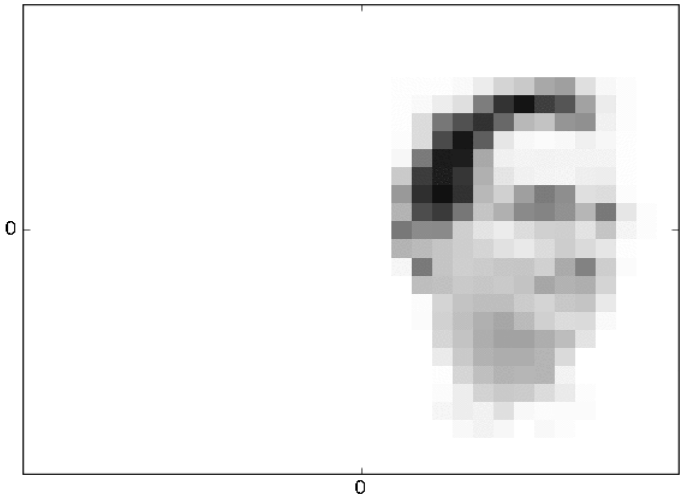


The typical CSI scene

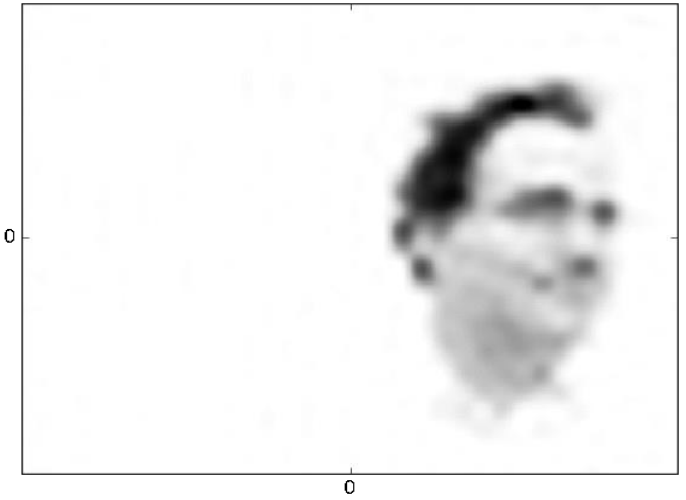
What is possible?



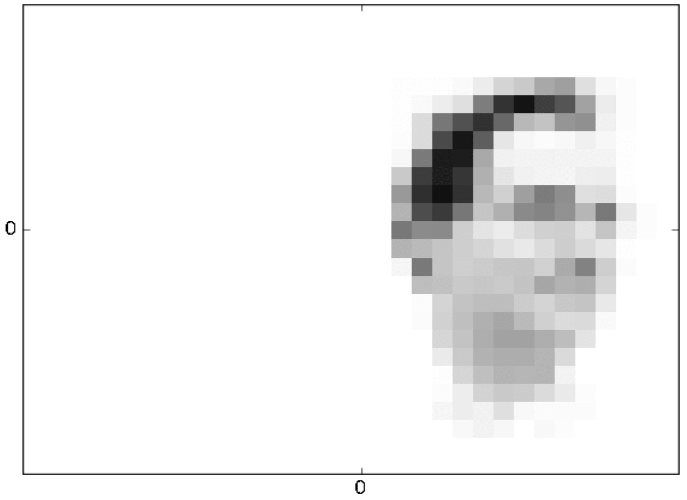
What is possible?



frame by frame filter

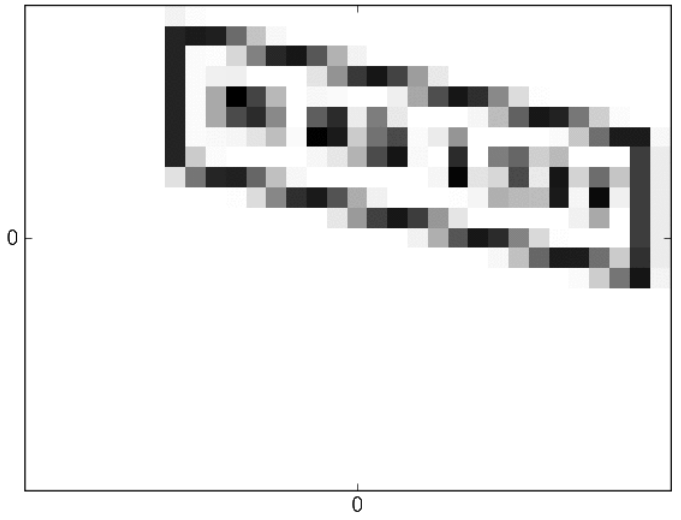


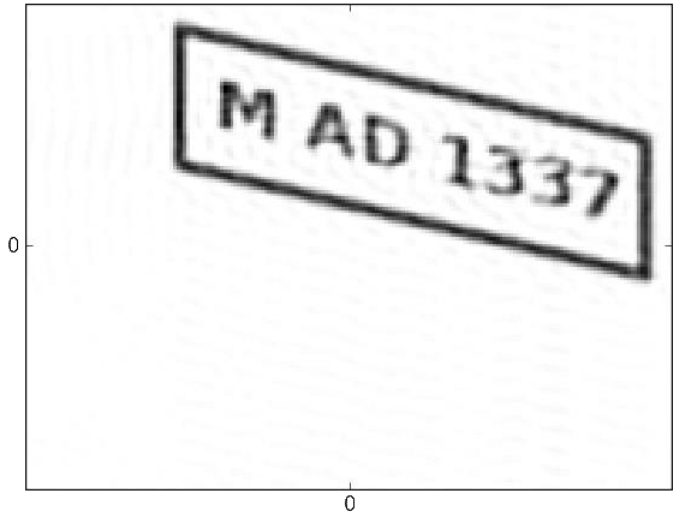
What is possible?



all frames combined

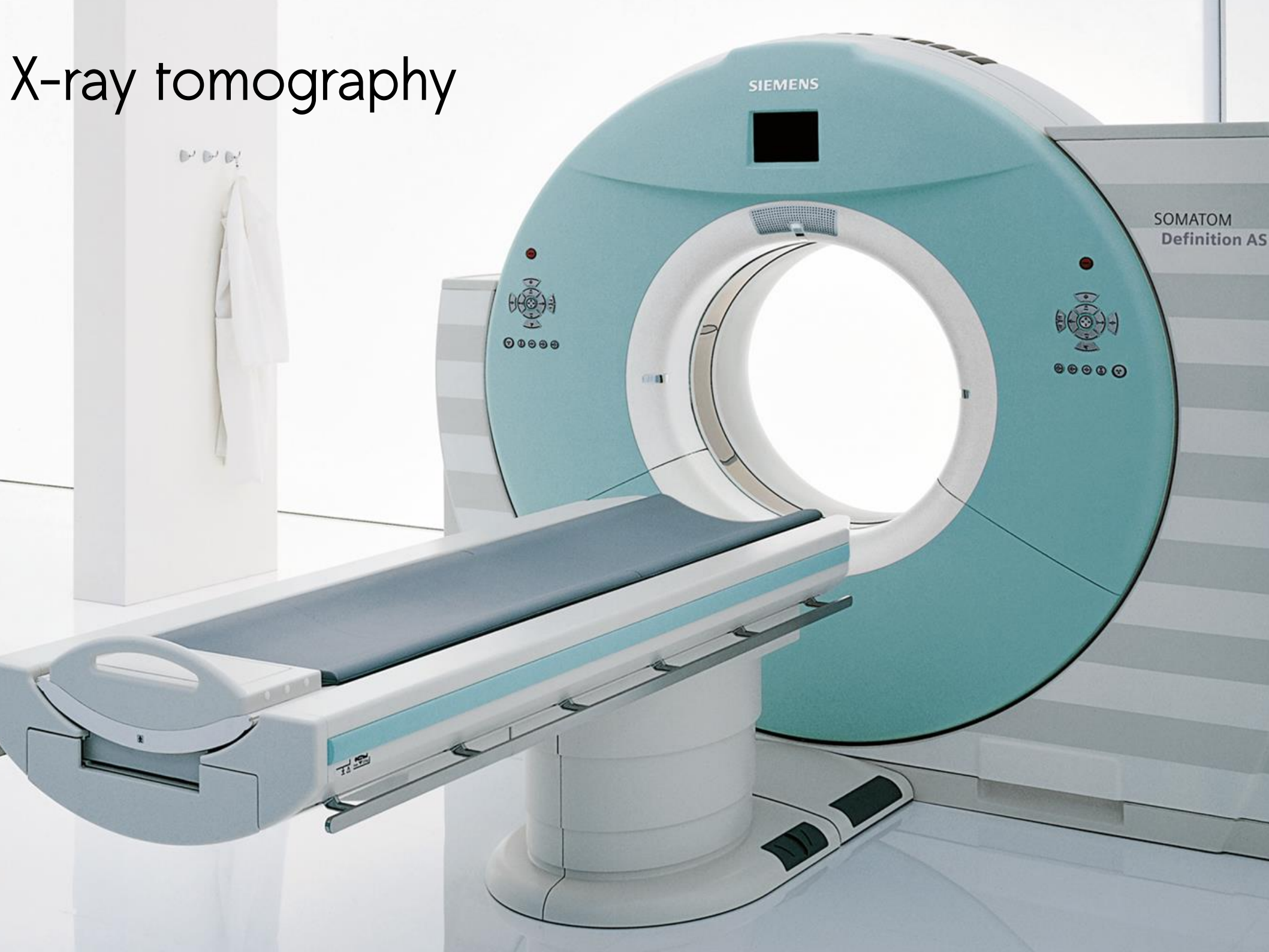
What is possible?
(more realistic)



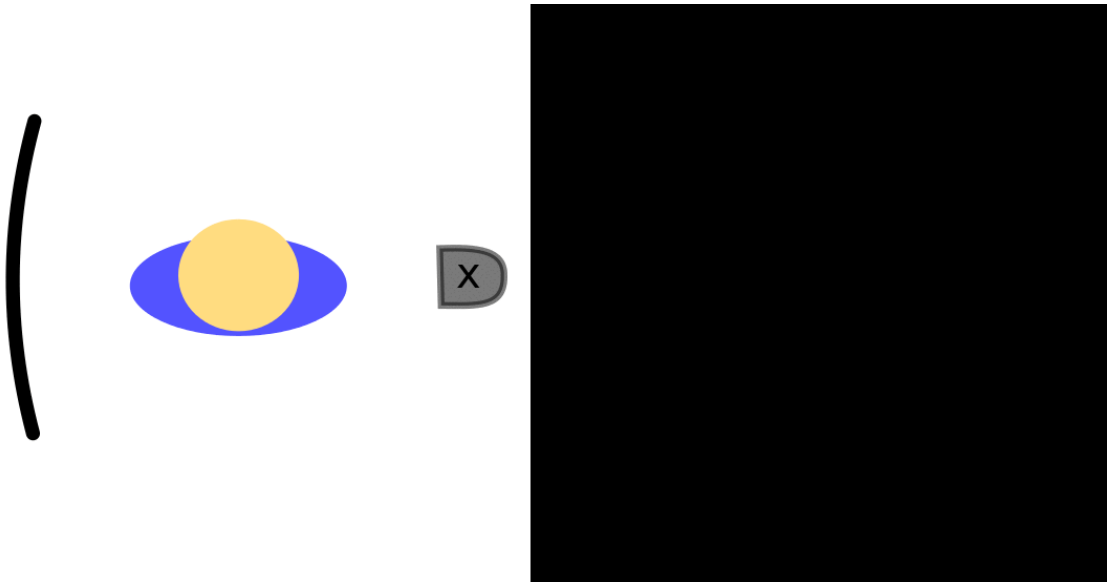


only 5 frames

X-ray tomography

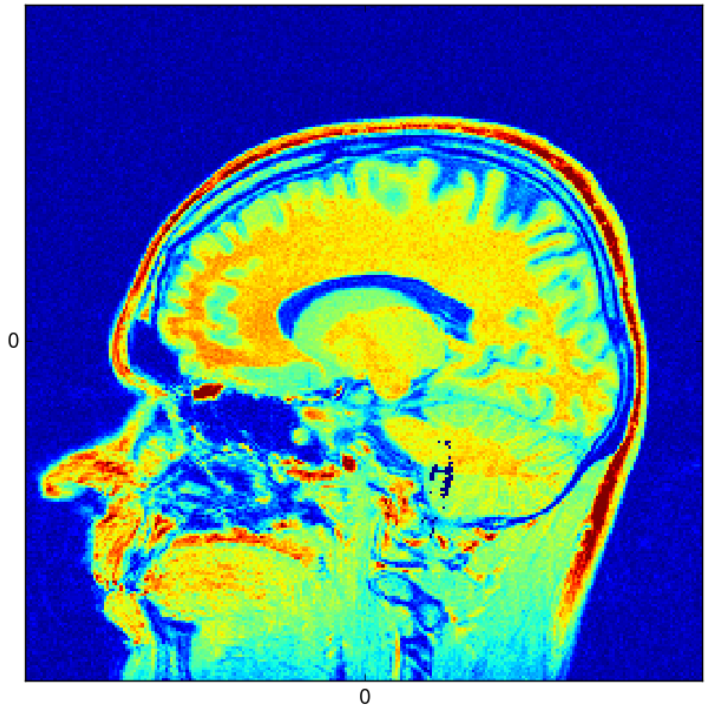


Tomography
X-ray CT

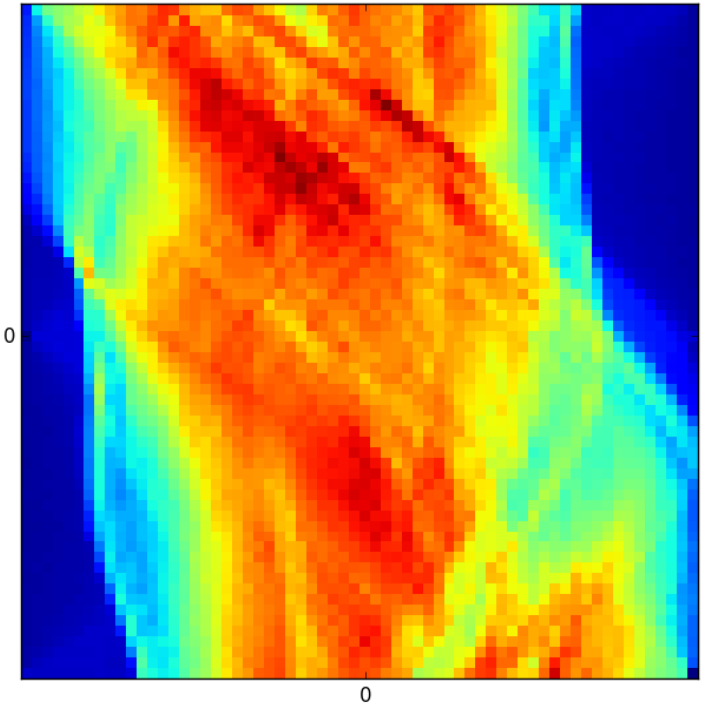


Tomography
X-ray CT

model



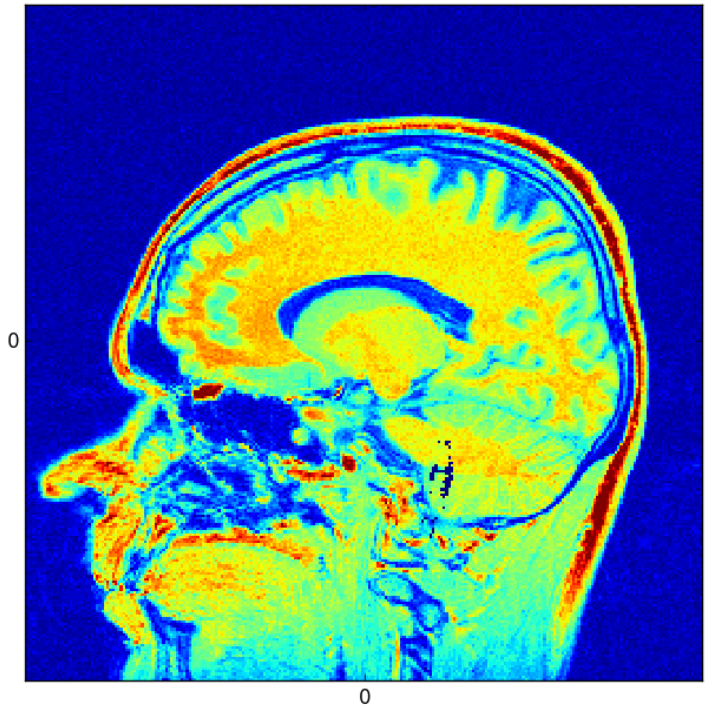
sinogram



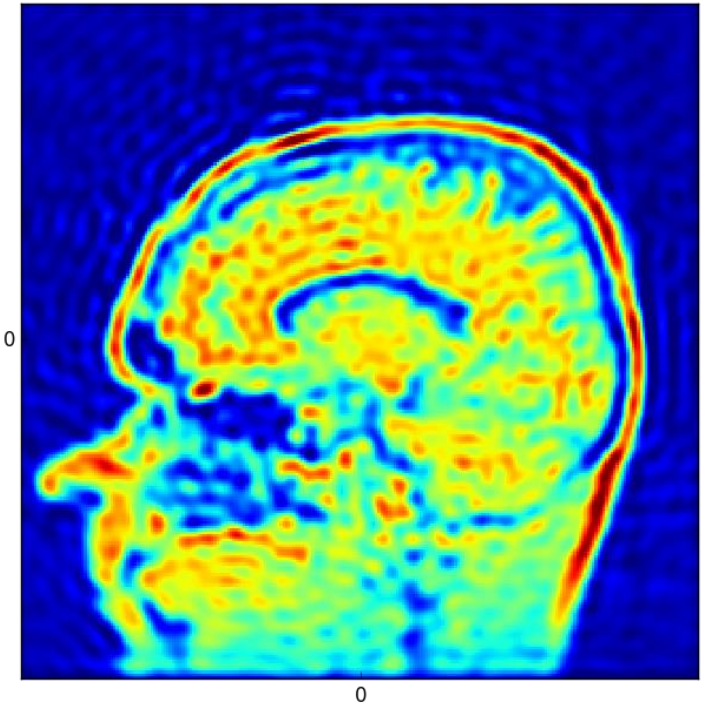
Tomography
X-ray CT

noise-free

model



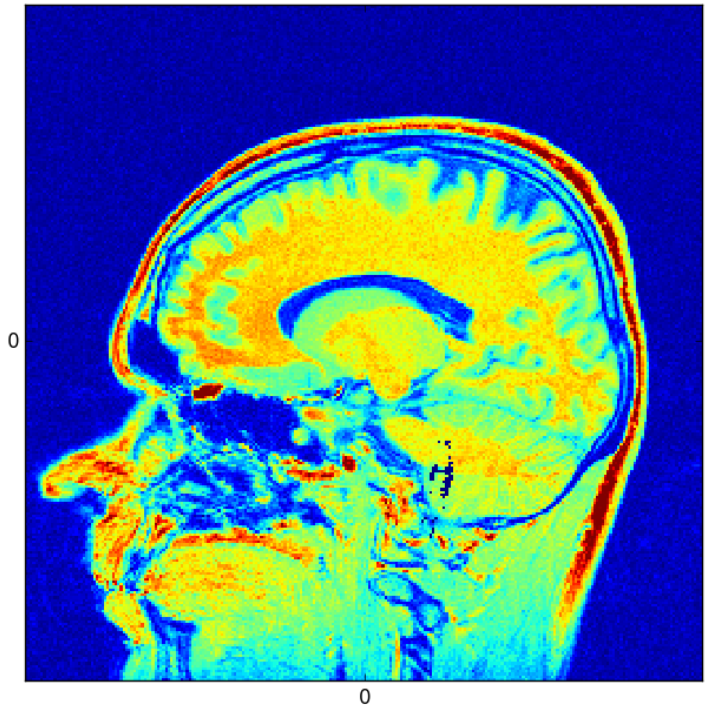
backprojection



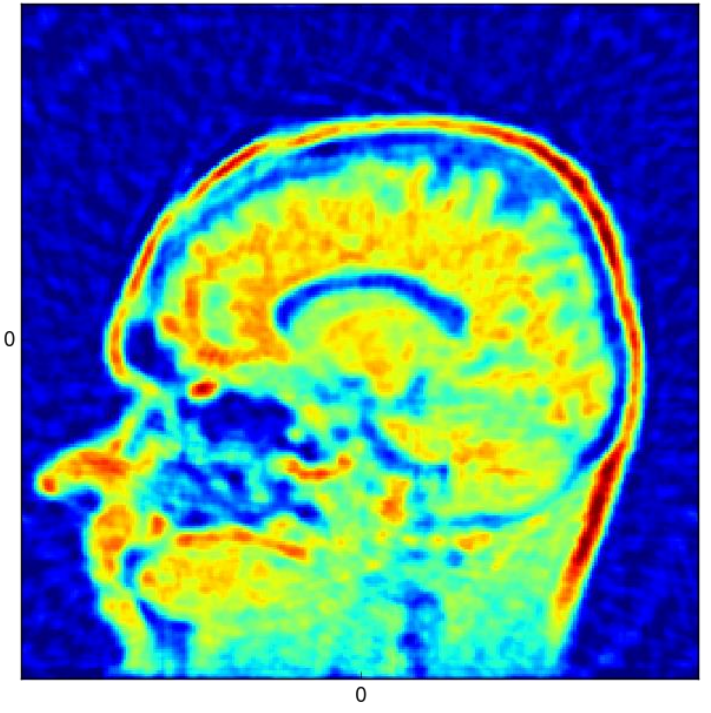
Tomography
X-ray CT

noise-free

model



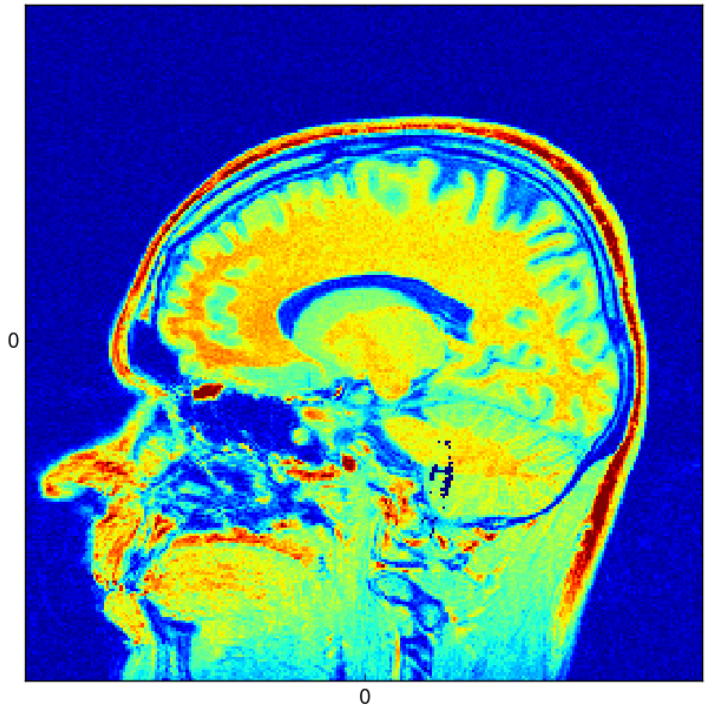
Wiener filter



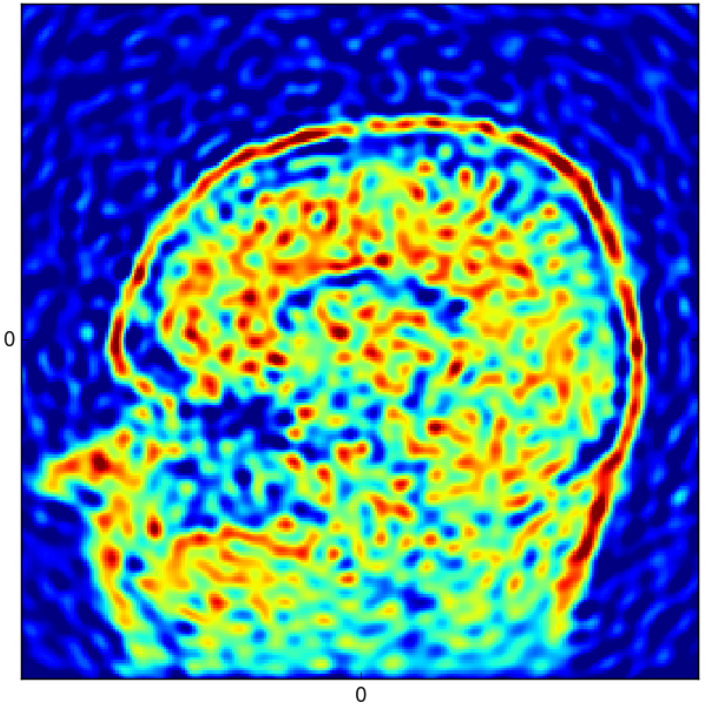
Tomography
X-ray CT

with noise

model



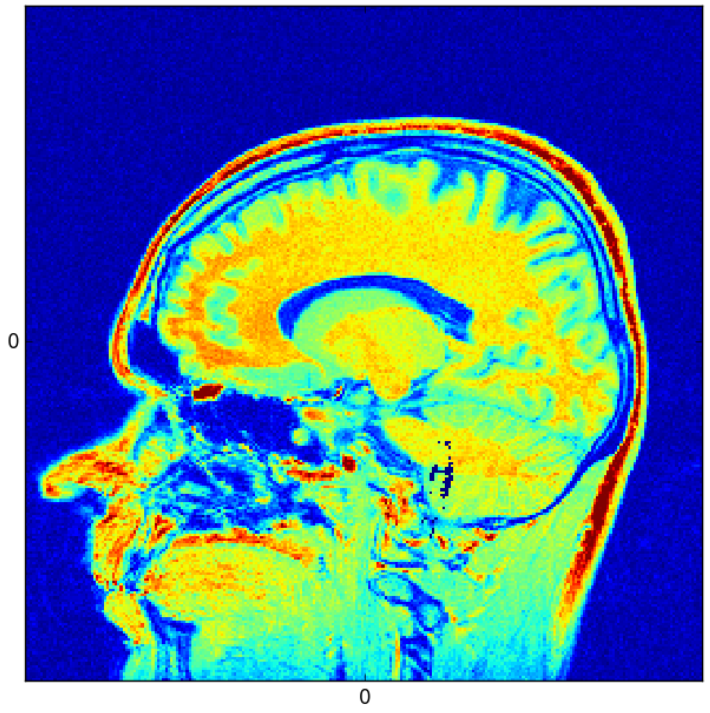
backprojection



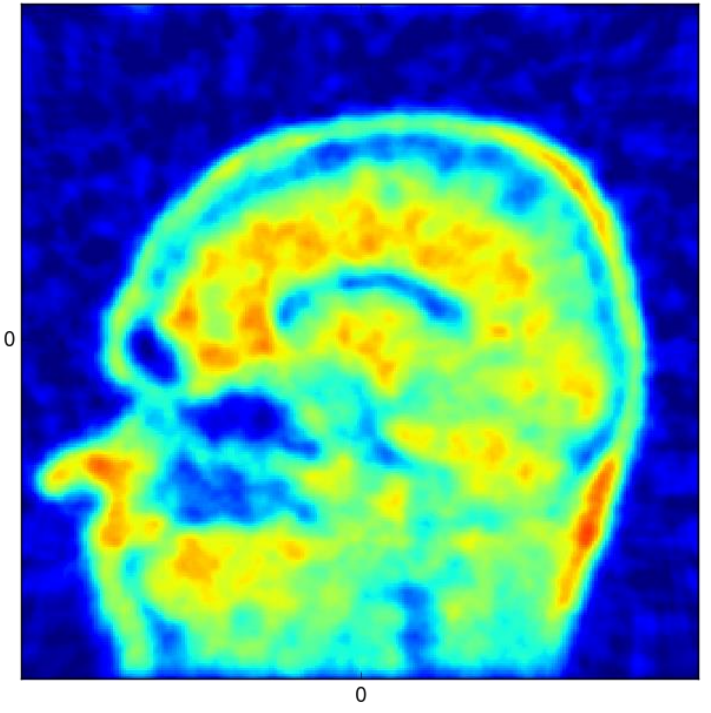
Tomography
X-ray CT

with noise

model



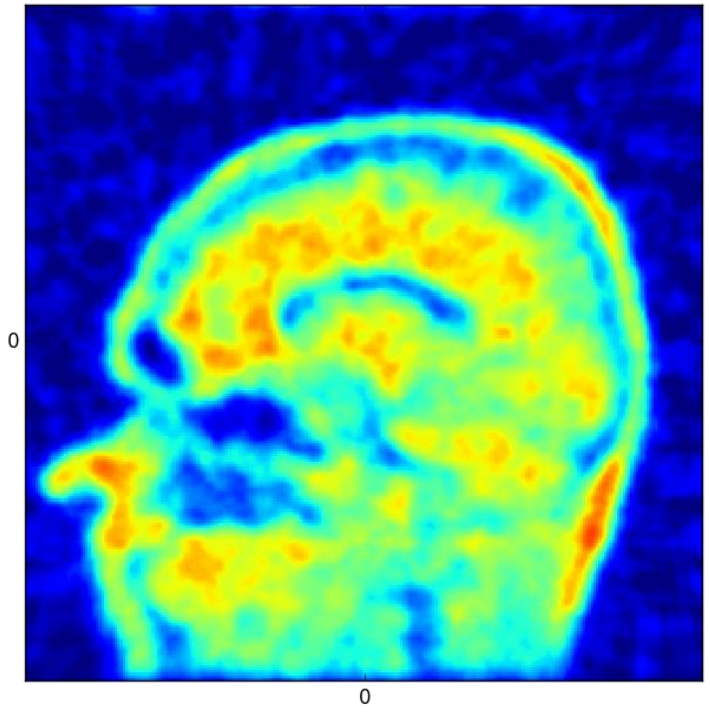
Wiener filter



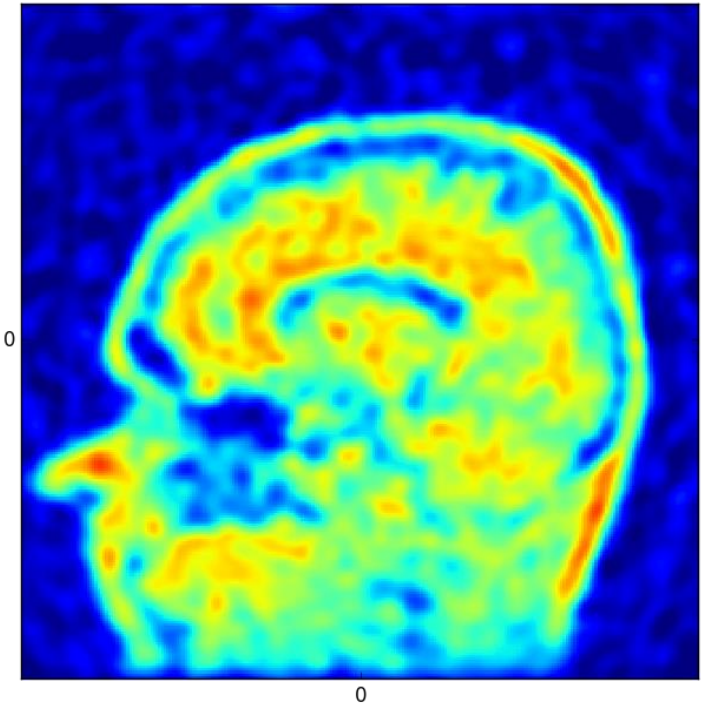
Tomography
X-ray CT

with noise

Wiener filter

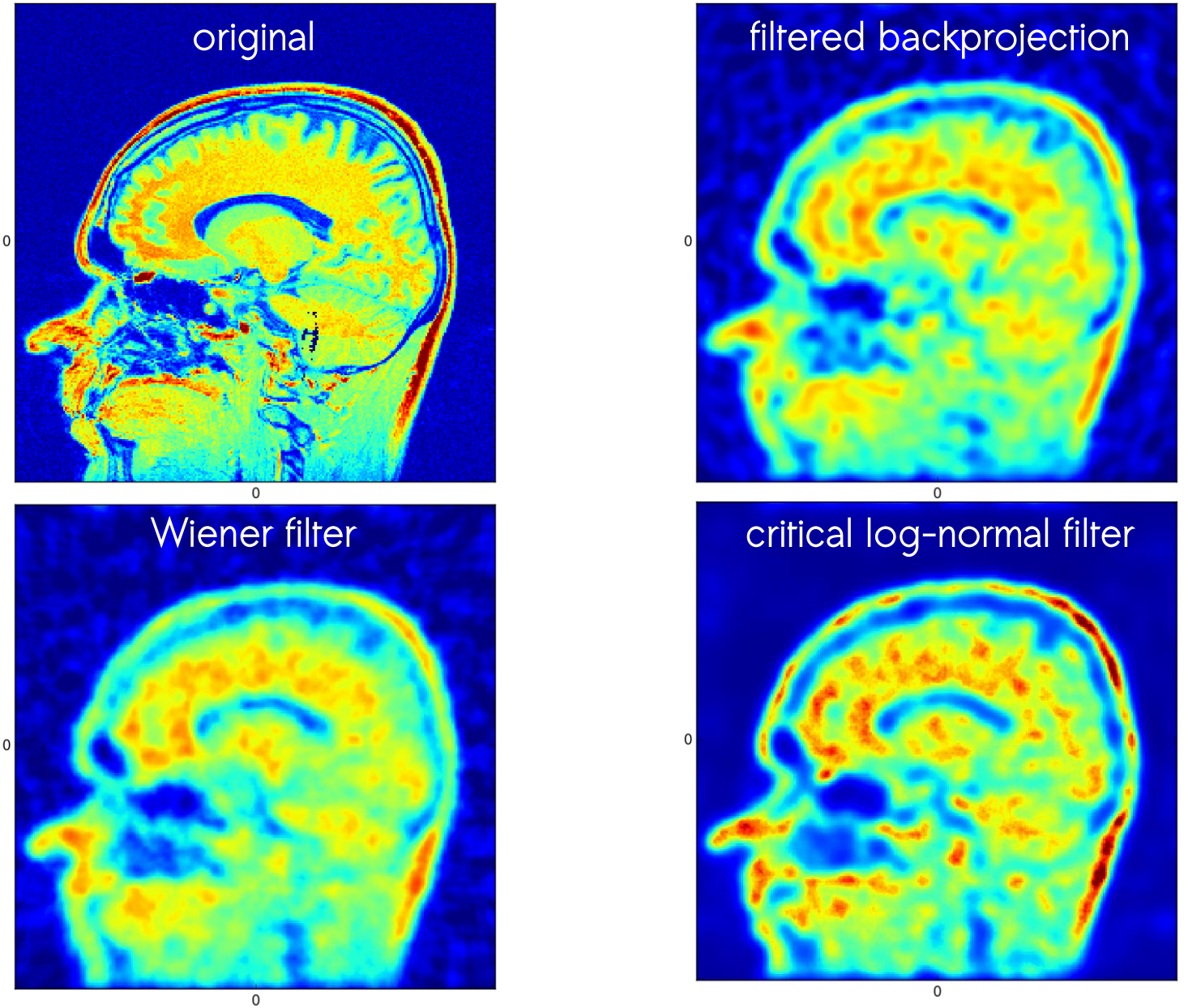


filtered backprojection



Tomography
X-ray CT

with noise



Tomography of the interstellar medium

Interstellar medium

as dilute as vacuum made in a laboratory

but over light years of distances still an important component

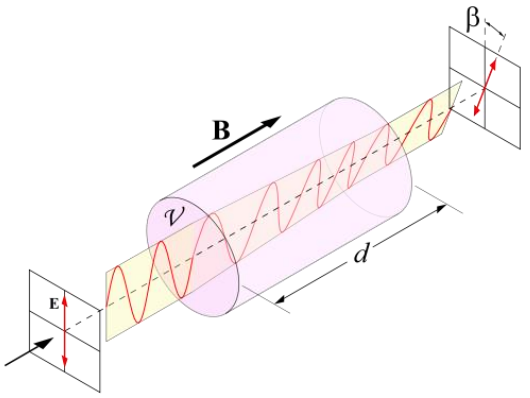
ionized part influences all electromagnetic radiation that reaches us

$\longrightarrow$ ionized part characterized by free electron density

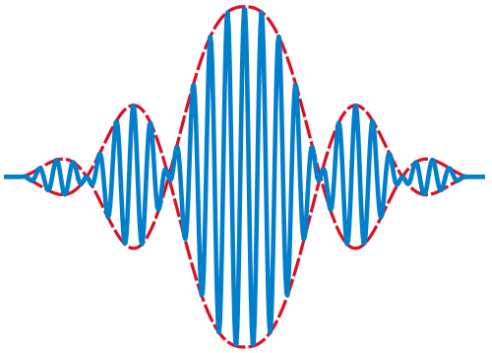
Interstellar free electrons

Influence on electromagnetic radiation

Faraday rotation

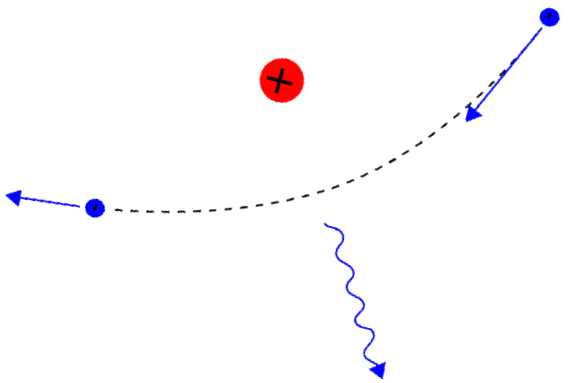


dispersion

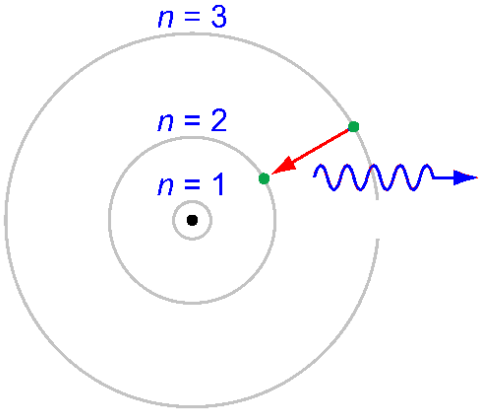


Emission of electromagnetic radiation

free free emission



H-alpha emission



Interstellar medium

as dilute as vacuum made in a laboratory

but over light years of distances still an important component

ionized part influences all electromagnetic radiation that reaches us

$\longrightarrow$ ionized part characterized by free electron density

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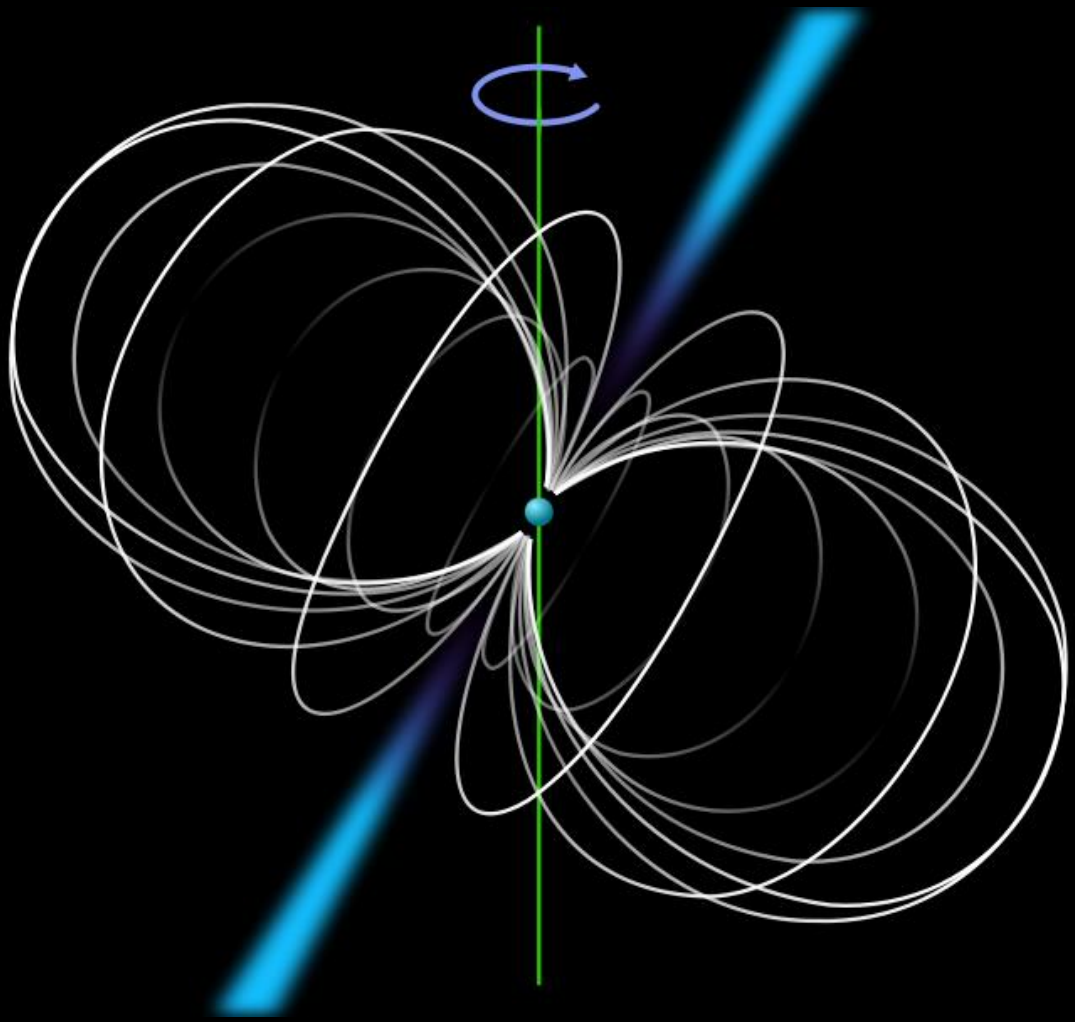
3D map of free electron density would be useful for

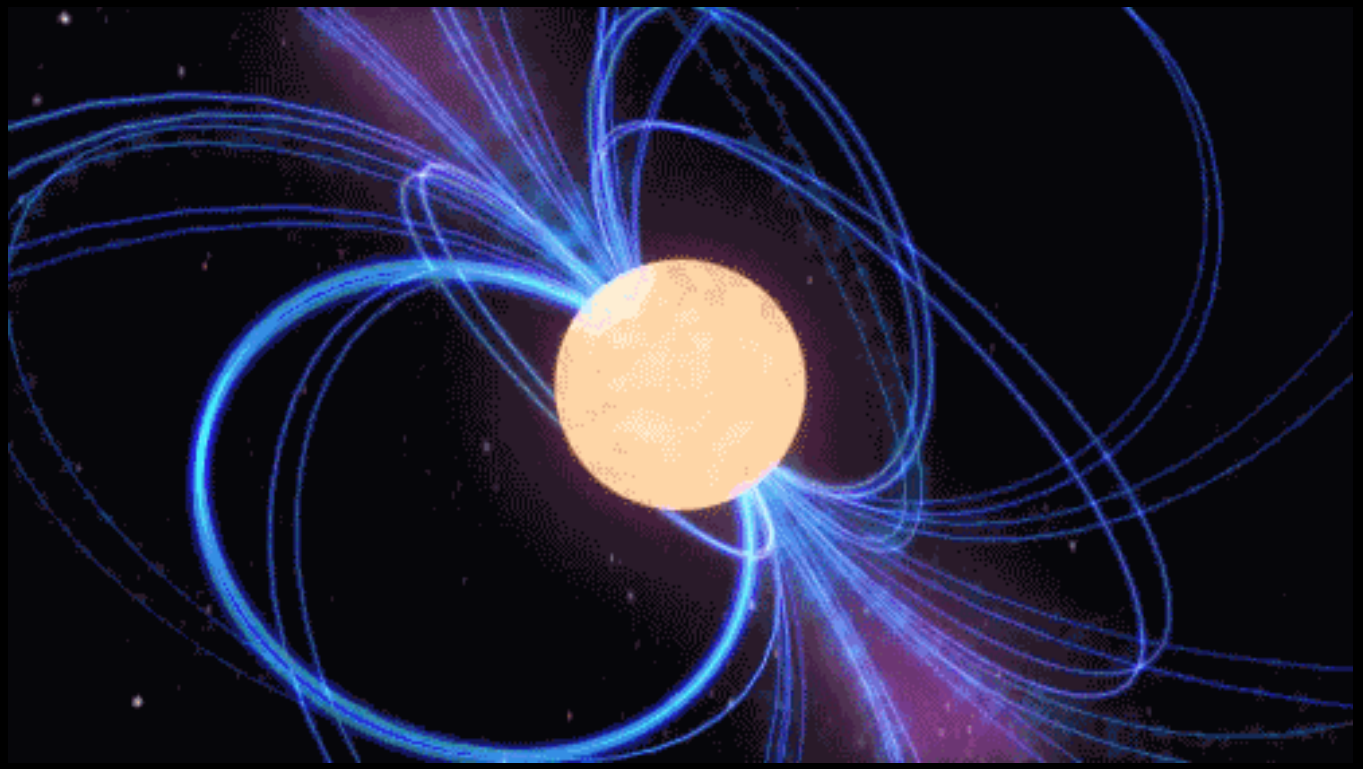
- understanding the structure and evolution of the Milky Way
- estimating the distance of pulsars
- learning the distribution of magnetic fields in the Milky Way
- and even cosmic magnetic fields...

When big stars die
- the birth of a neutron star -

The cool kind of neutron star
- a pulsar -



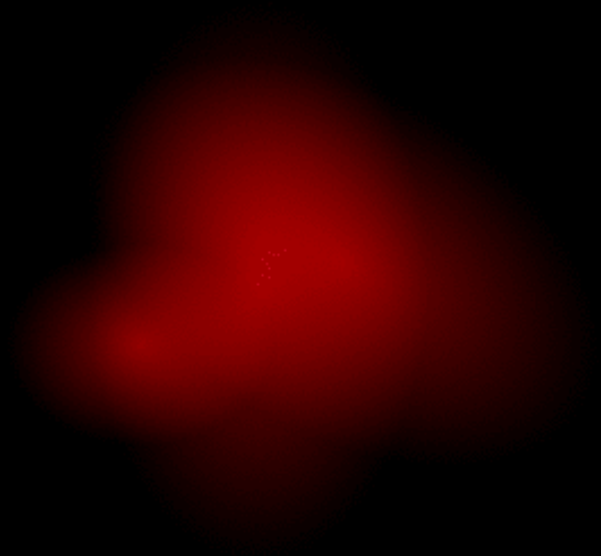
The cool kind of neutron star
- a pulsar -

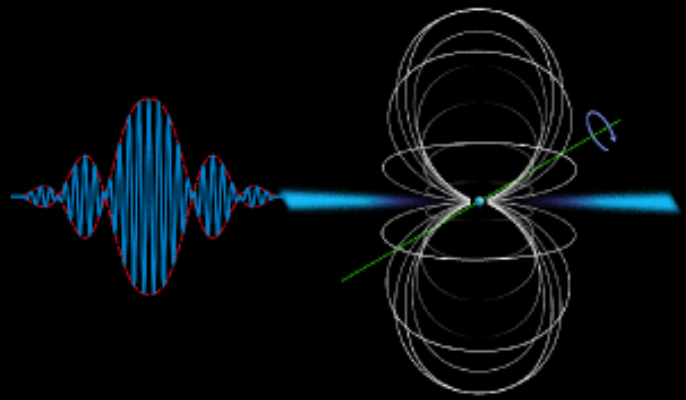


The cool kind of neutron star
- a pulsar -

Crab Pulsar taken at 800nm (slow motion)

Pulsars and tomography
- whats the connection? -

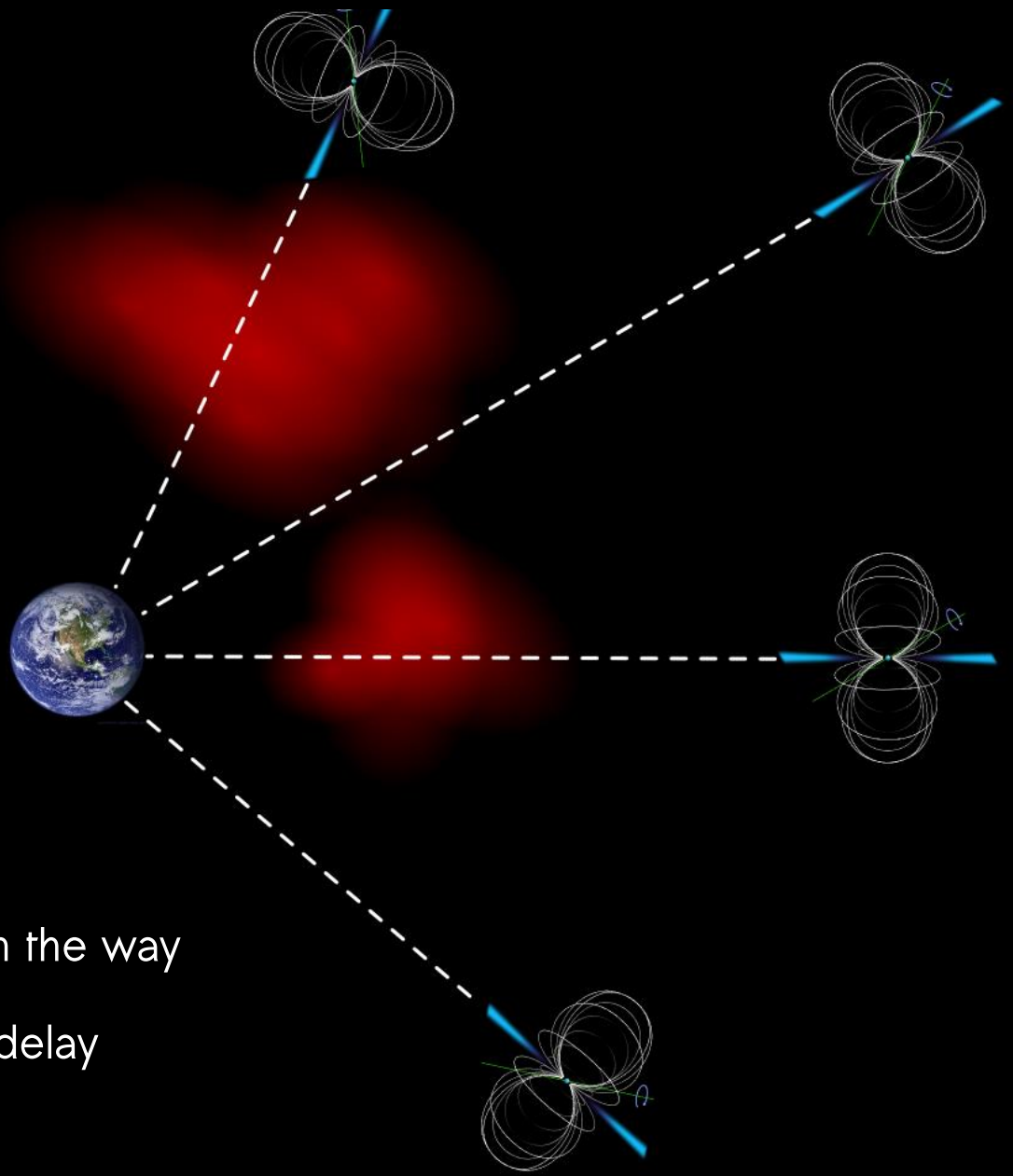




ionized cloud elongates wave packet

⟶ time delay between different frequencies

Pulsars and tomography
- whats the connection? -



more ionized gas in the way

⟶ bigger time delay

Pulsars and tomography
- whats the connection? -

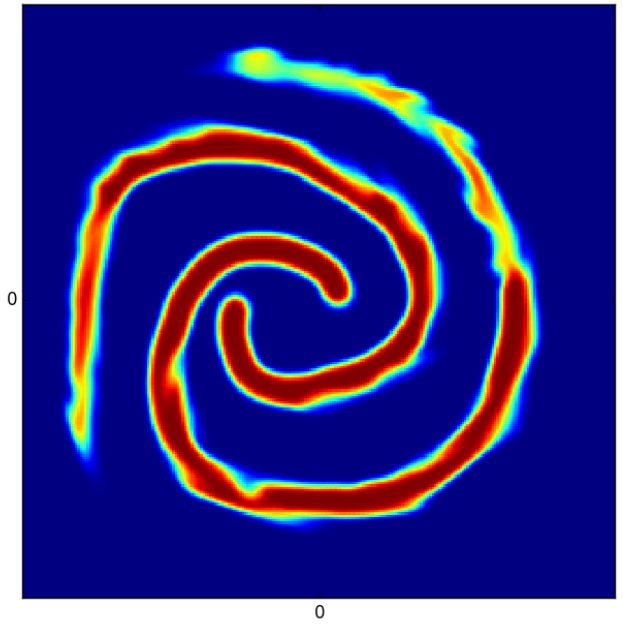
different frequencies emitted by pulsars arrive at different times

the time delay is proportional to the amount of ionized gas on the line of sight

same principle as X-ray tomography (but with static sources)

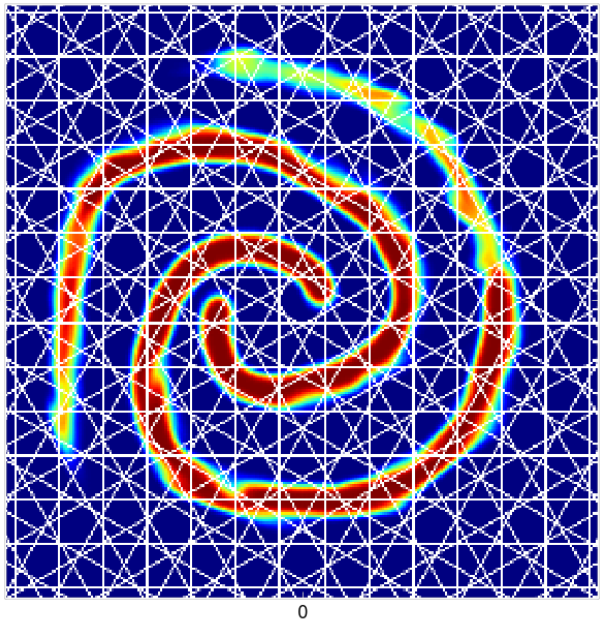
$\longrightarrow$ use information theory to derive a 3D map of the interstellar medium

Simple toy model

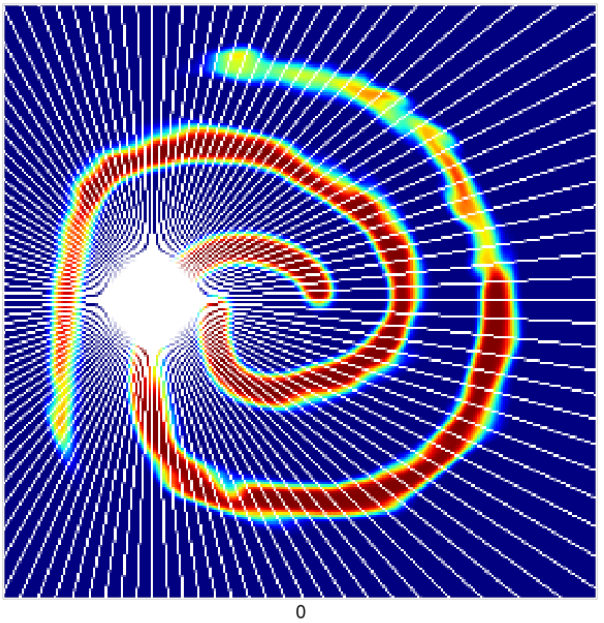


Simple toy model

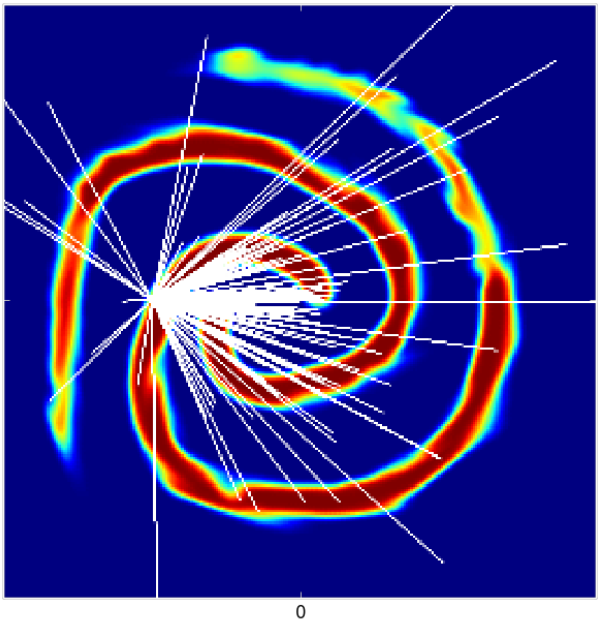
CT scan pattern

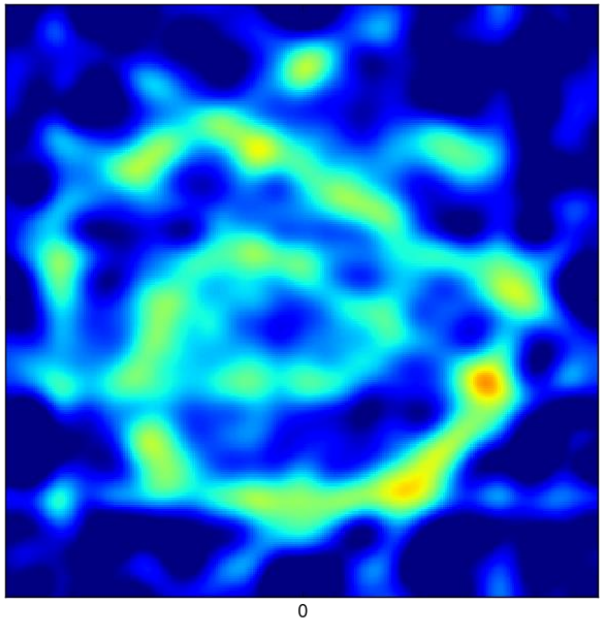


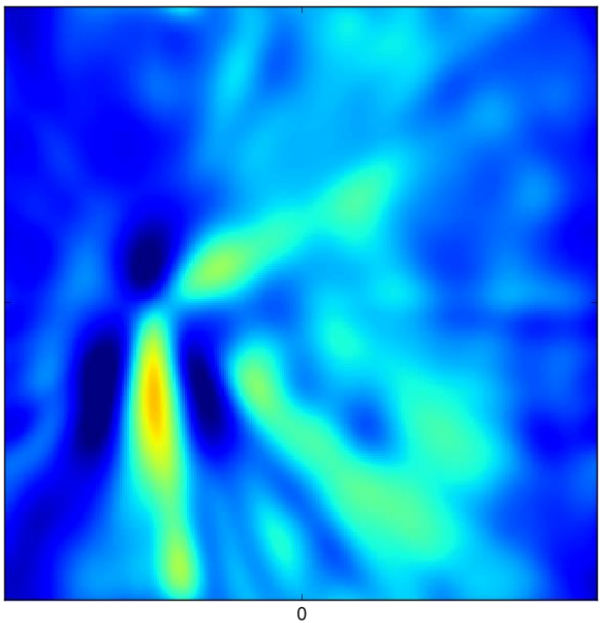
all sky map

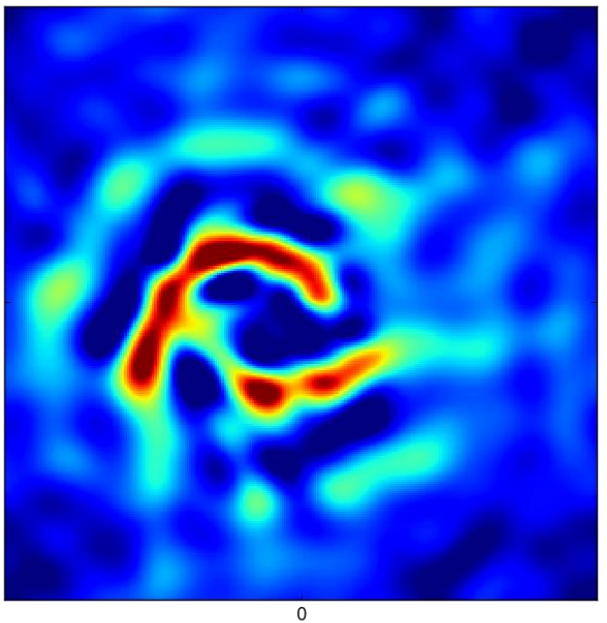


pulsar pattern

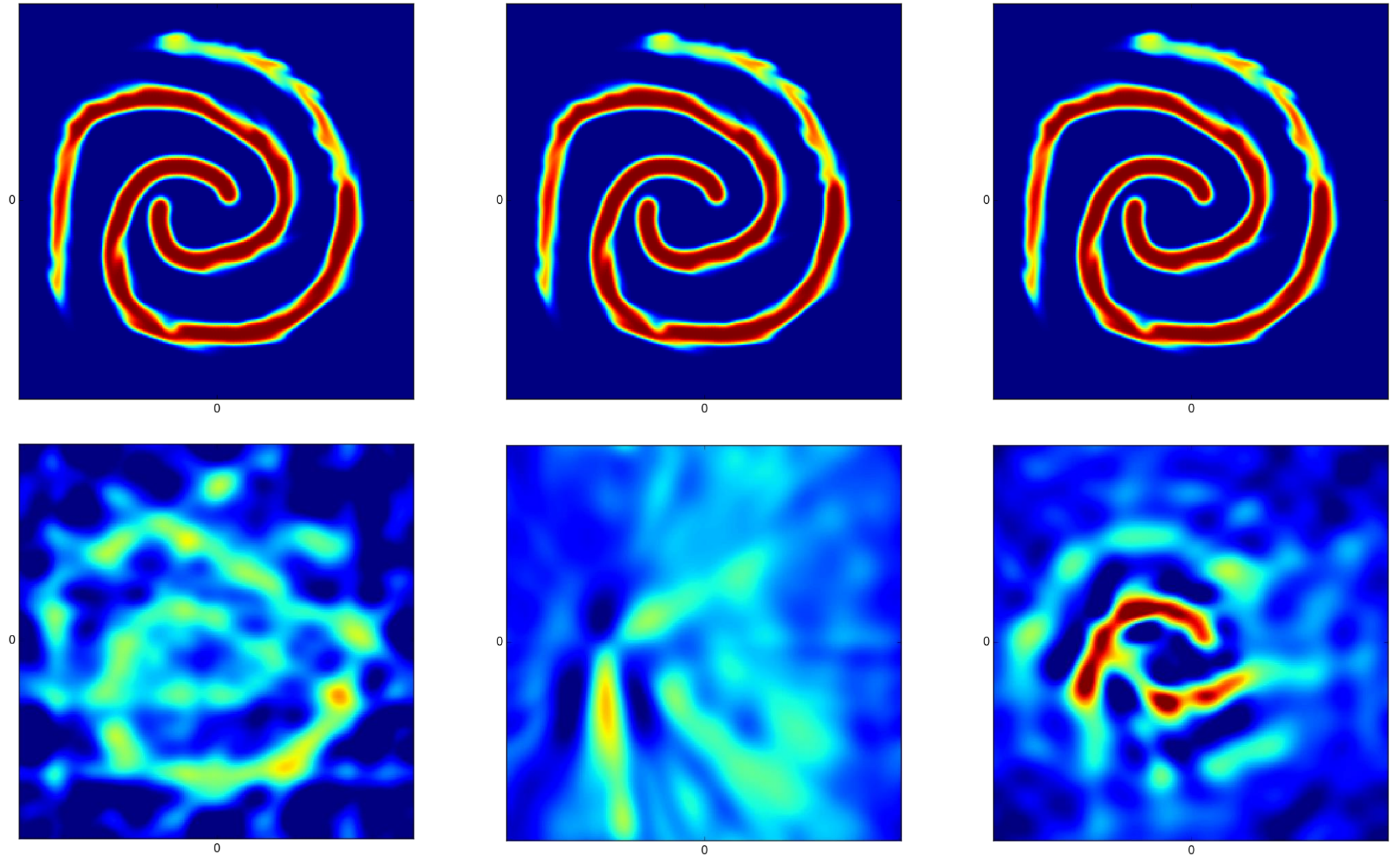








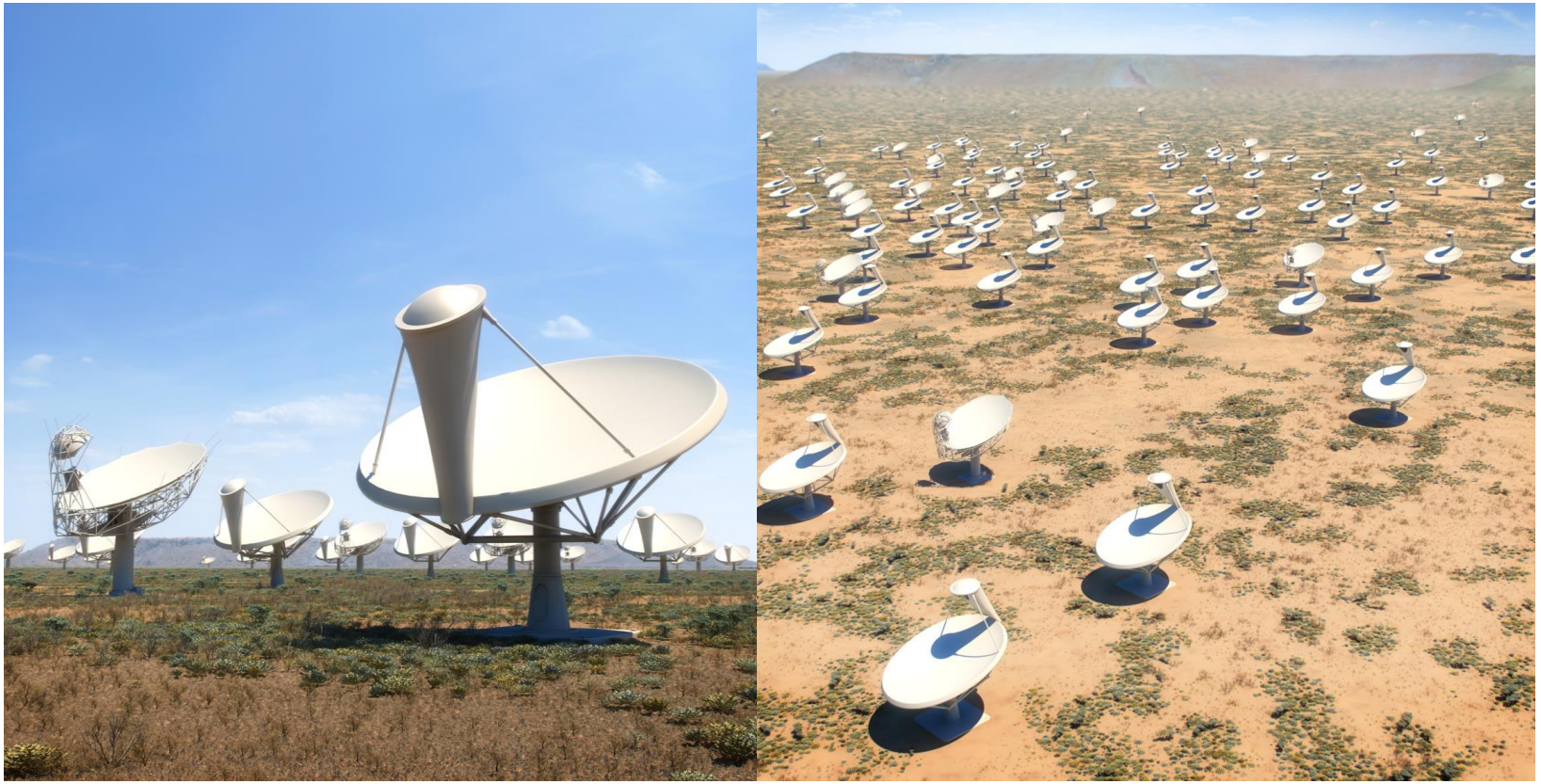
Simple toy model



What will the SKA enable?

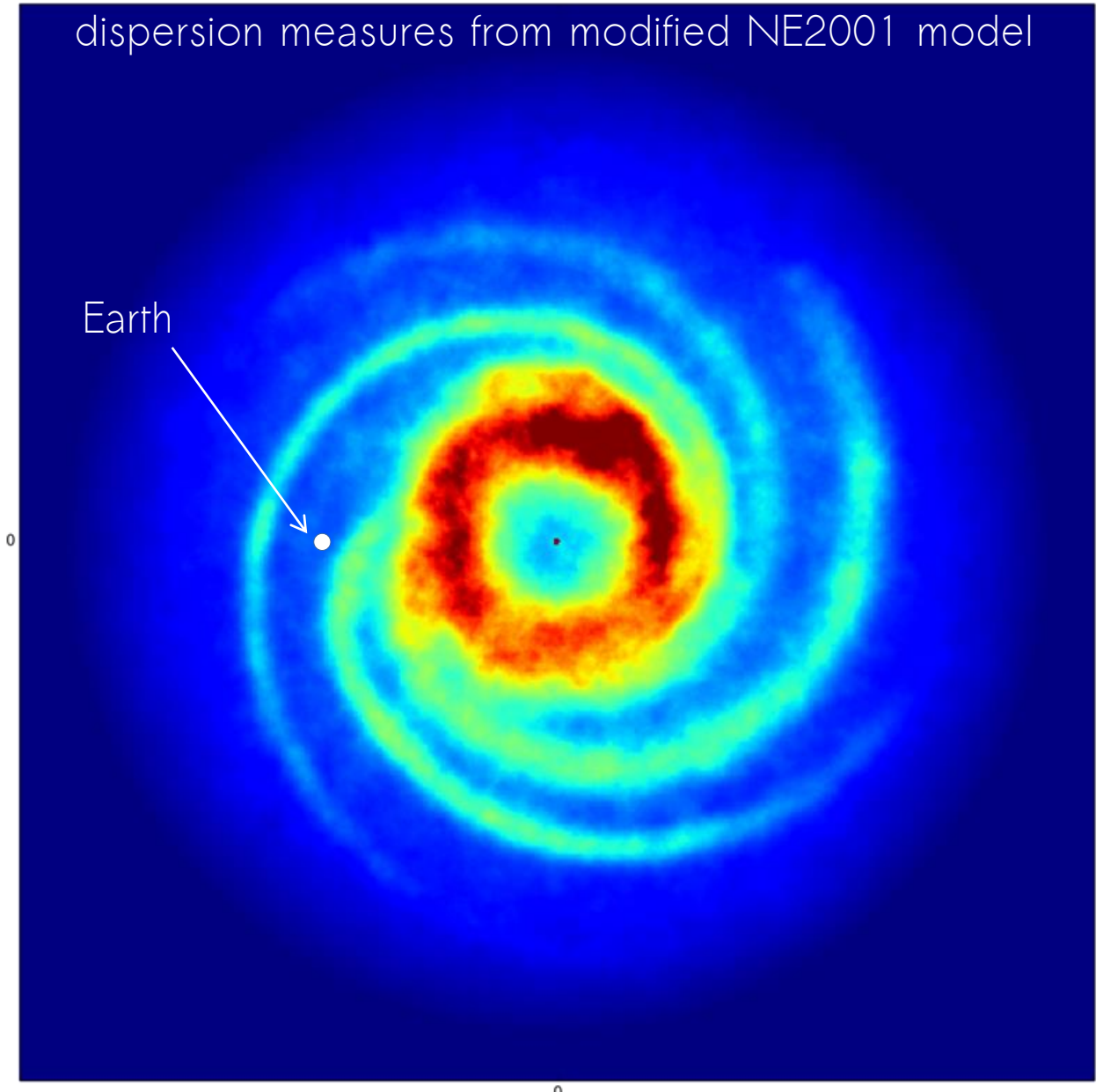
The Square Kilometer Array (SKA)

The SKA people hope to find ~ 10000 pulsars with distance uncertainties below 20%



Simulated SKA data

simulated pulsar population and SKA observation
(using PsrPopPy)



Simulated SKA data

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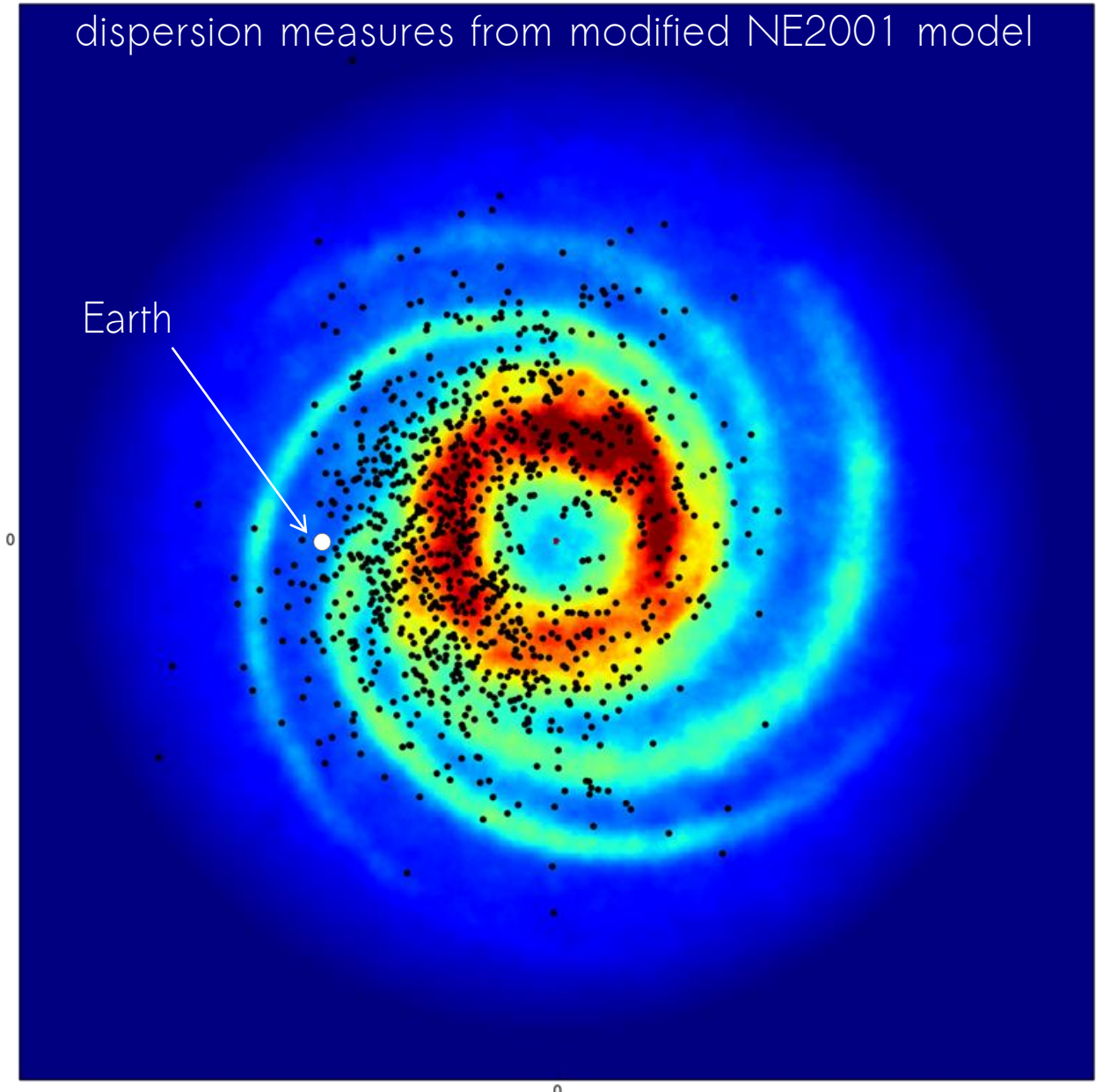
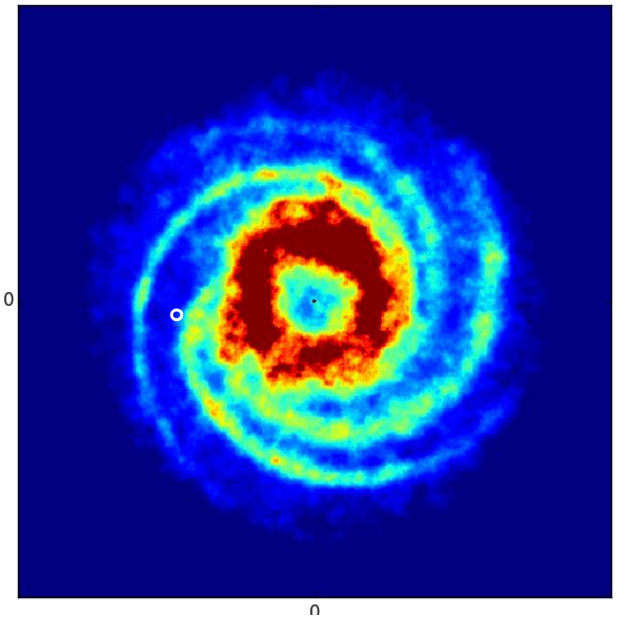
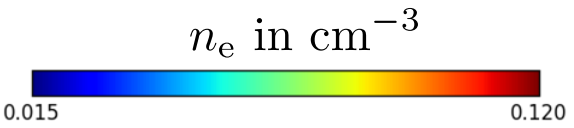
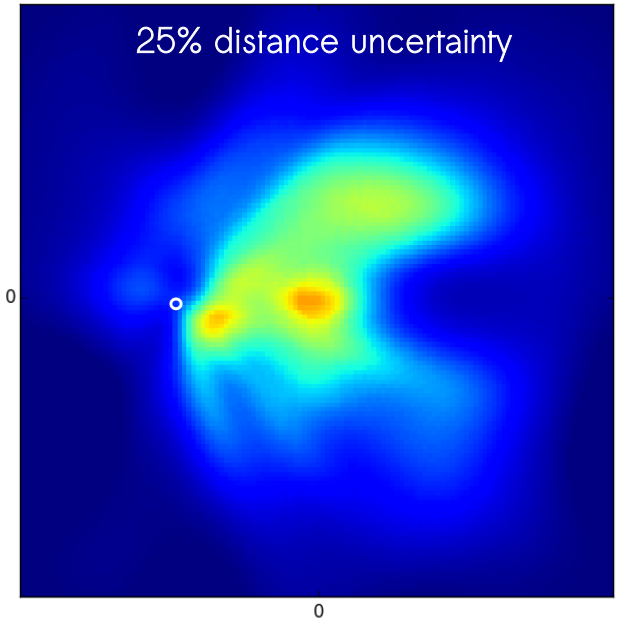


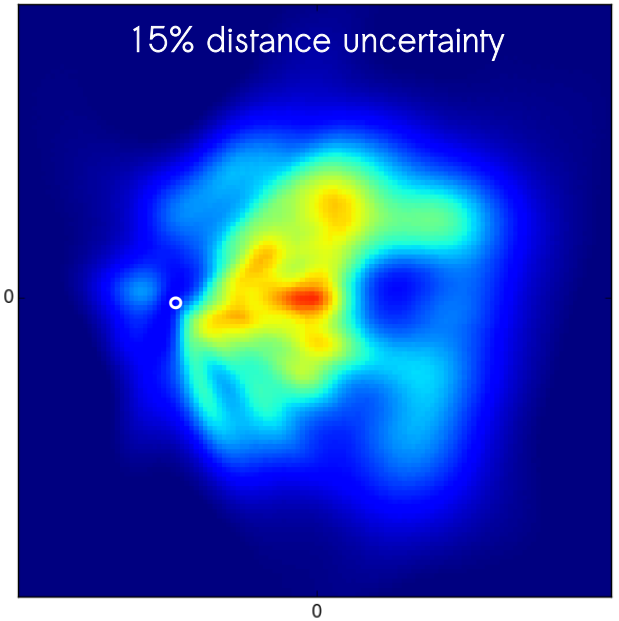
Simulated SKA data

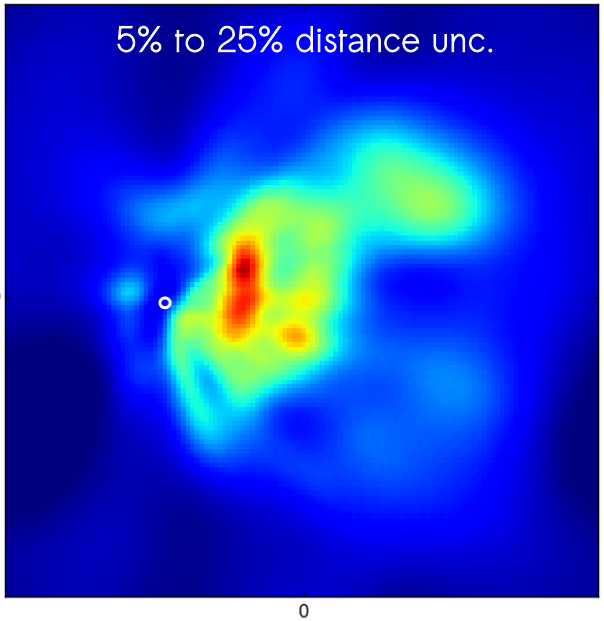
- 10000 pulsars -







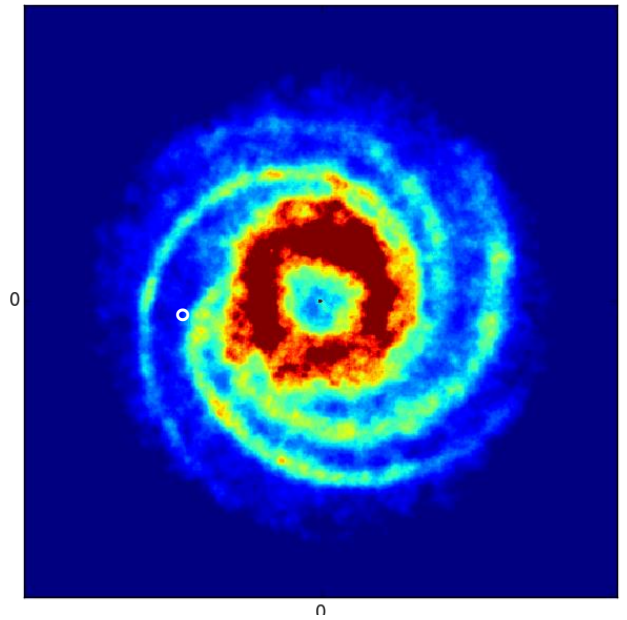


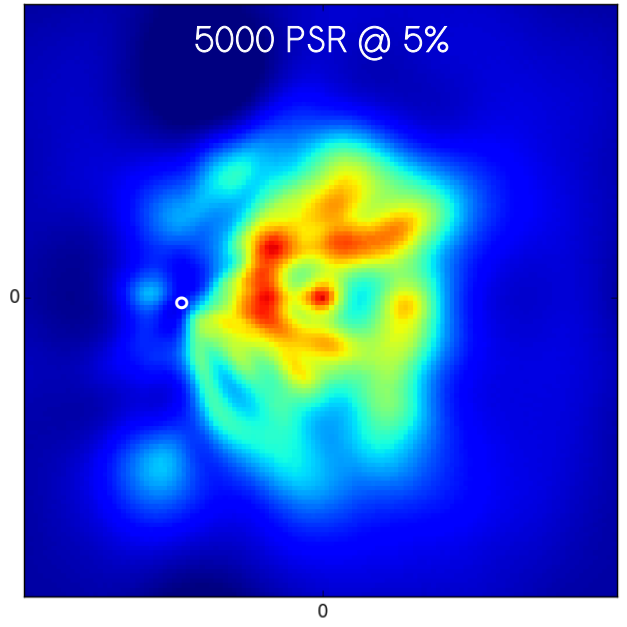


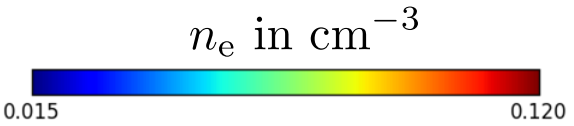
Simulated SKA data

- wish for low distance uncertainties -

If we could go to 5% distance uncertainty, reconstruction would improve strongly

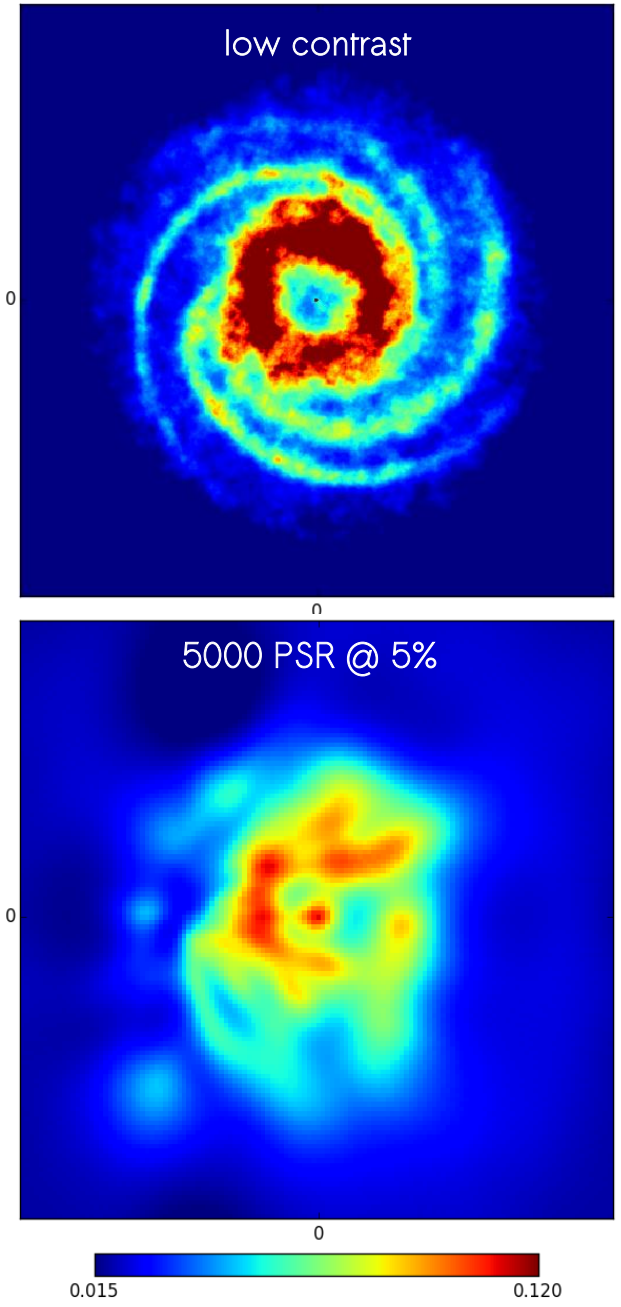


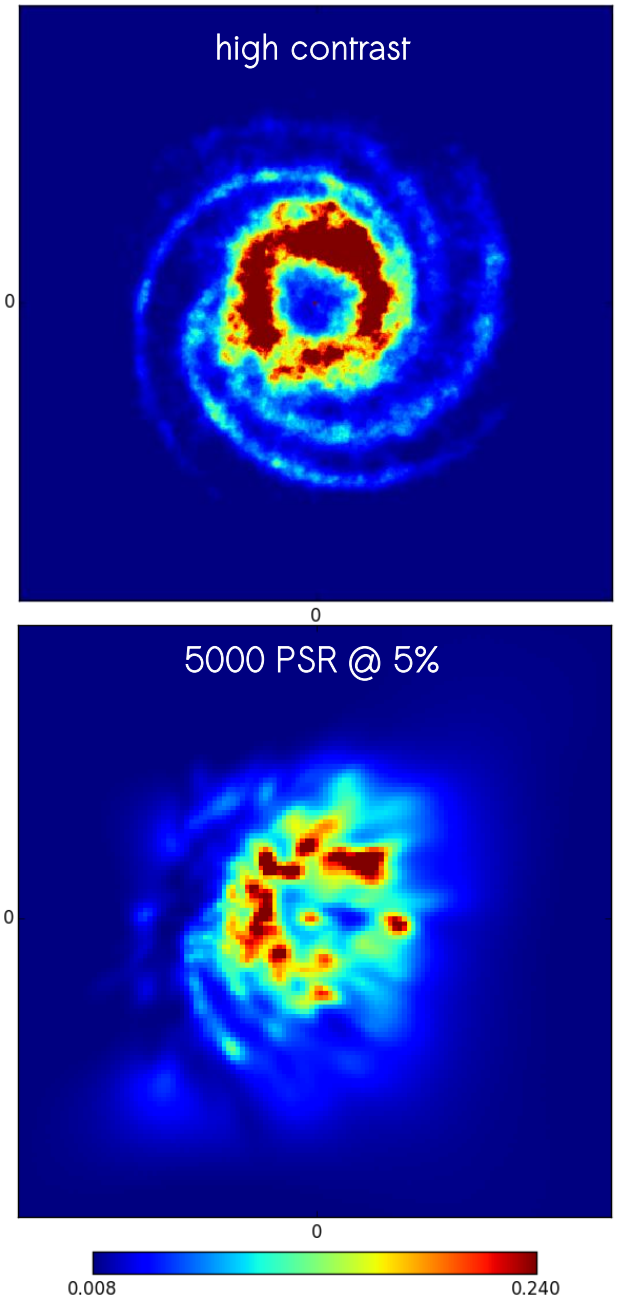




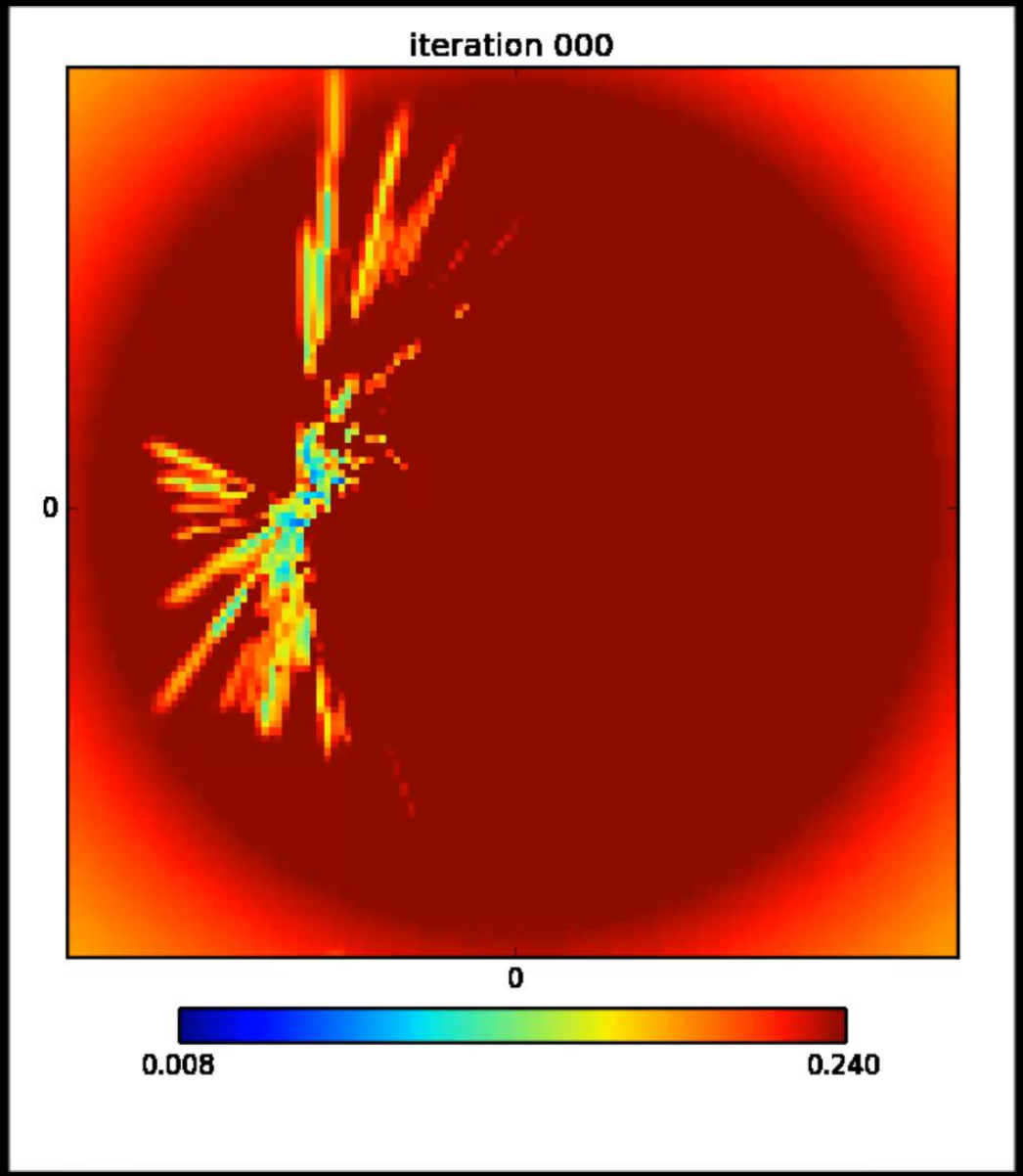
Simulated SKA data

- wish for low distance uncertainties & high contrast -

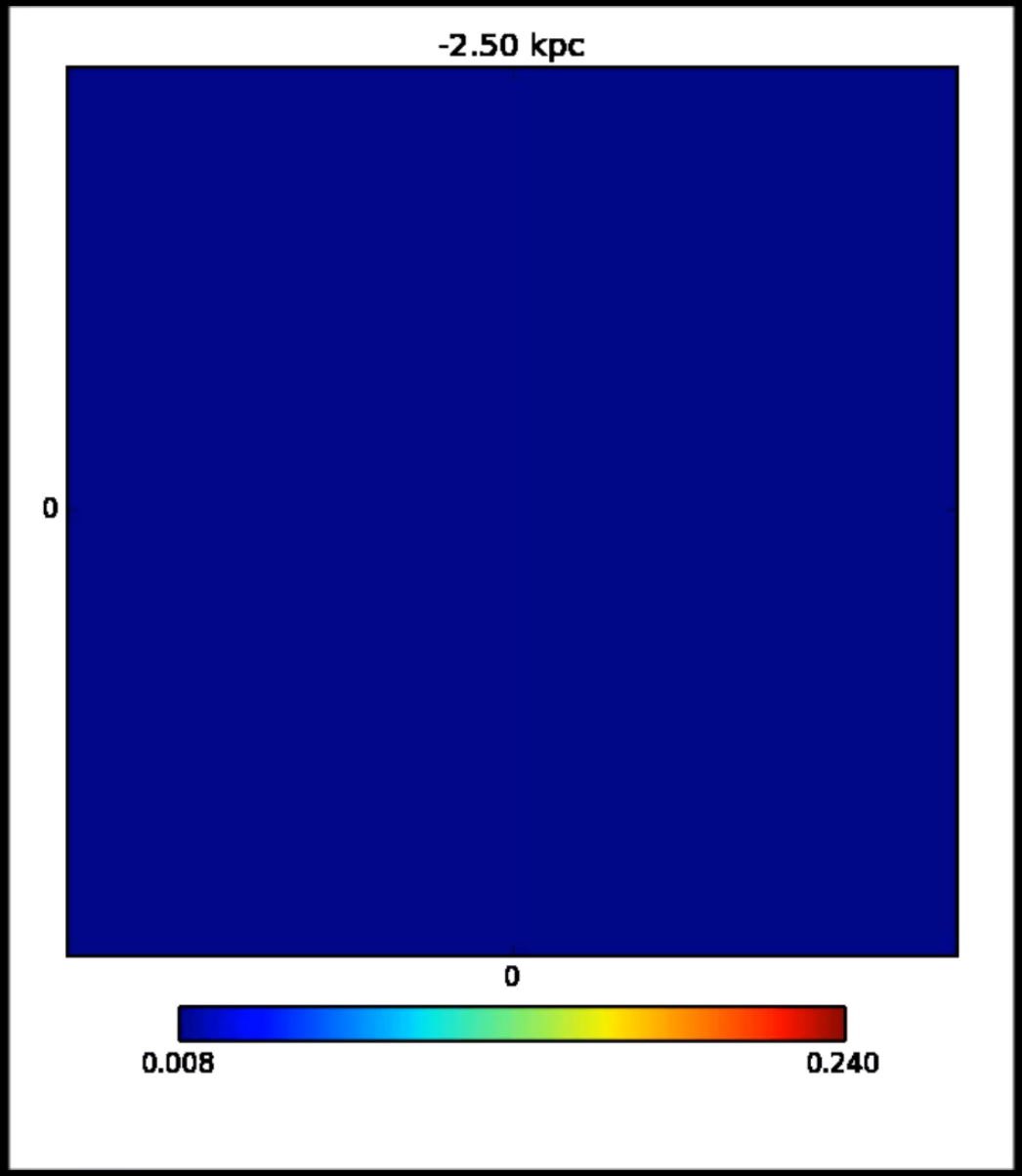




power spectrum iteration



3D movie



Conclusions

data to images

knowledge about measurement process +
prior information (e.g. correlation structure)
$\longrightarrow$ map (most likely image)

X-Ray tomography

Wiener filter only slightly better than filtered backprojection
log-normal critical filter better

tomography of free electron density

tomography: line-integrals to image
pulsar radiation $\longrightarrow$ line-integrals through n_e

SKA

10^4 lines of sight
tomography of n_e promising