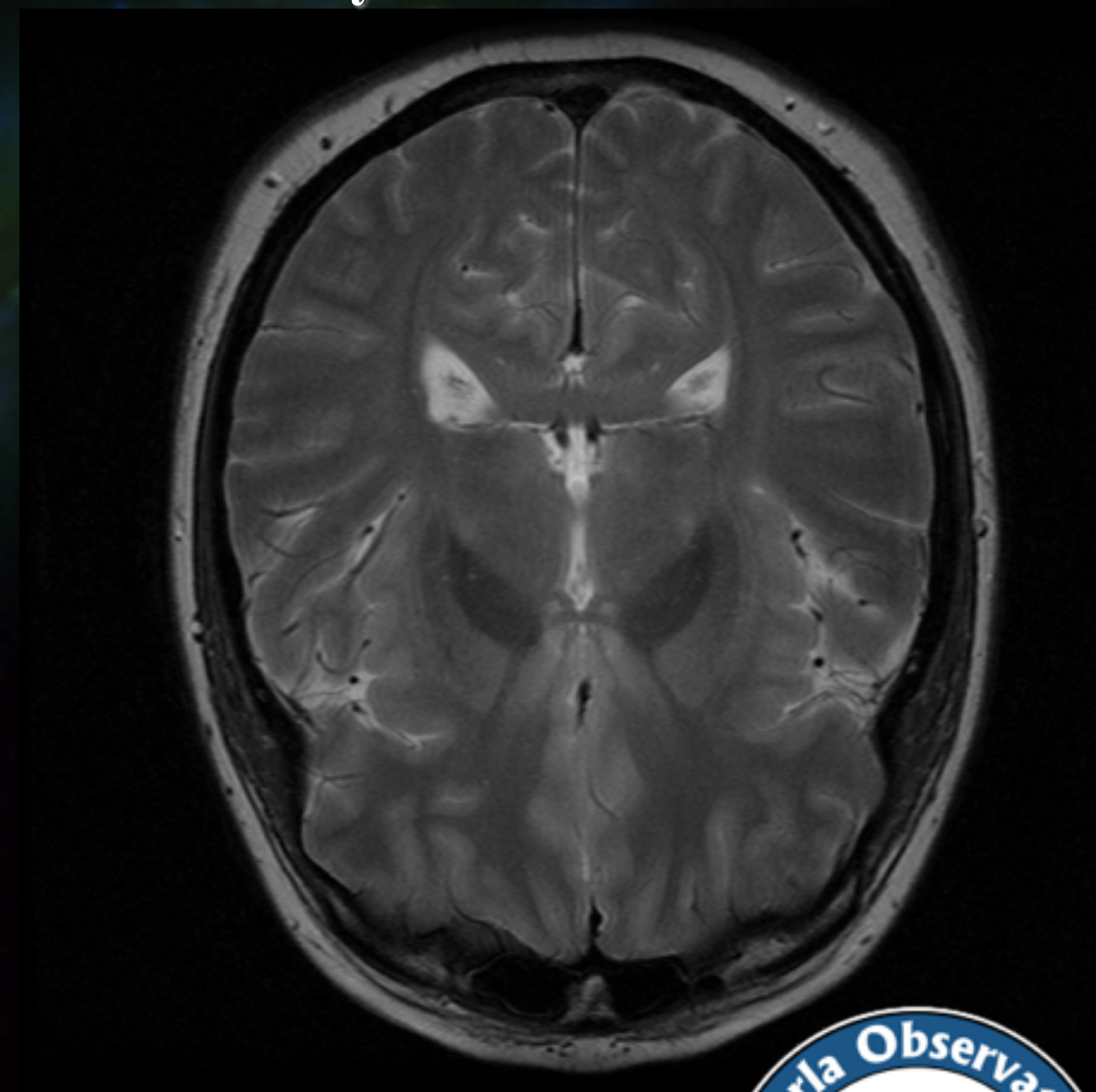
Signal and image processing

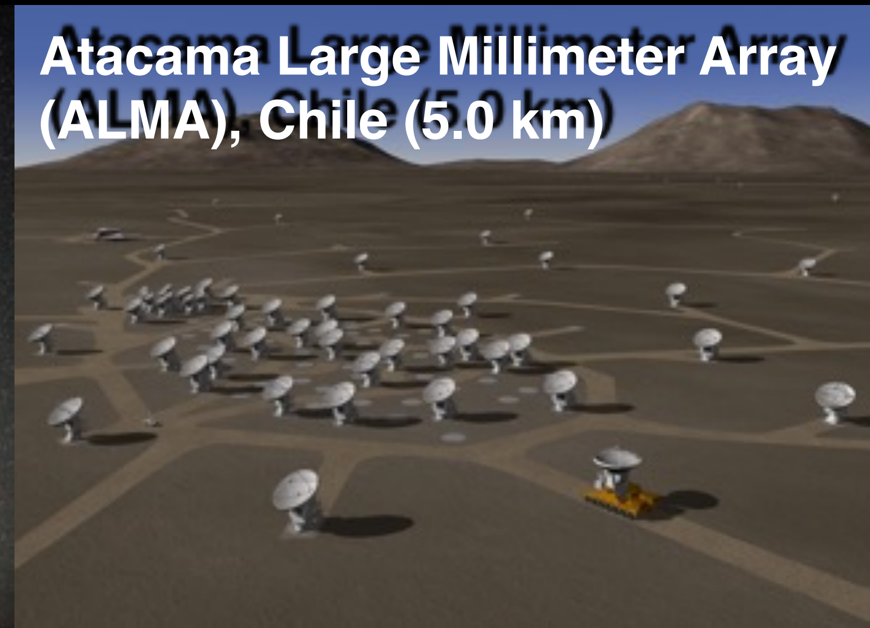
Seppo Mattila (sepmat@utu.fi)
Department of Physics and Astronomy

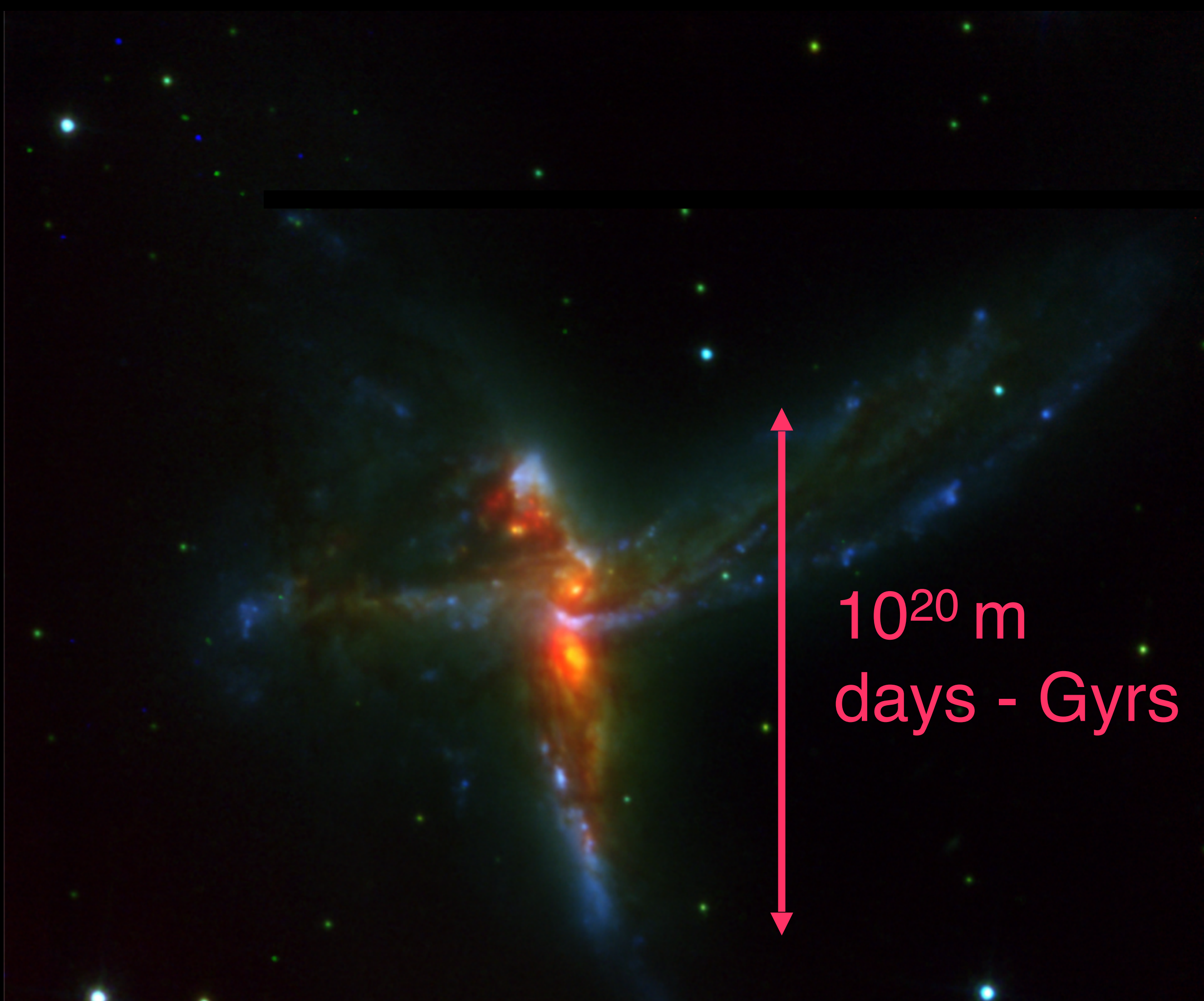


TYKS TURKU UNIVERSITY HOSPITAL

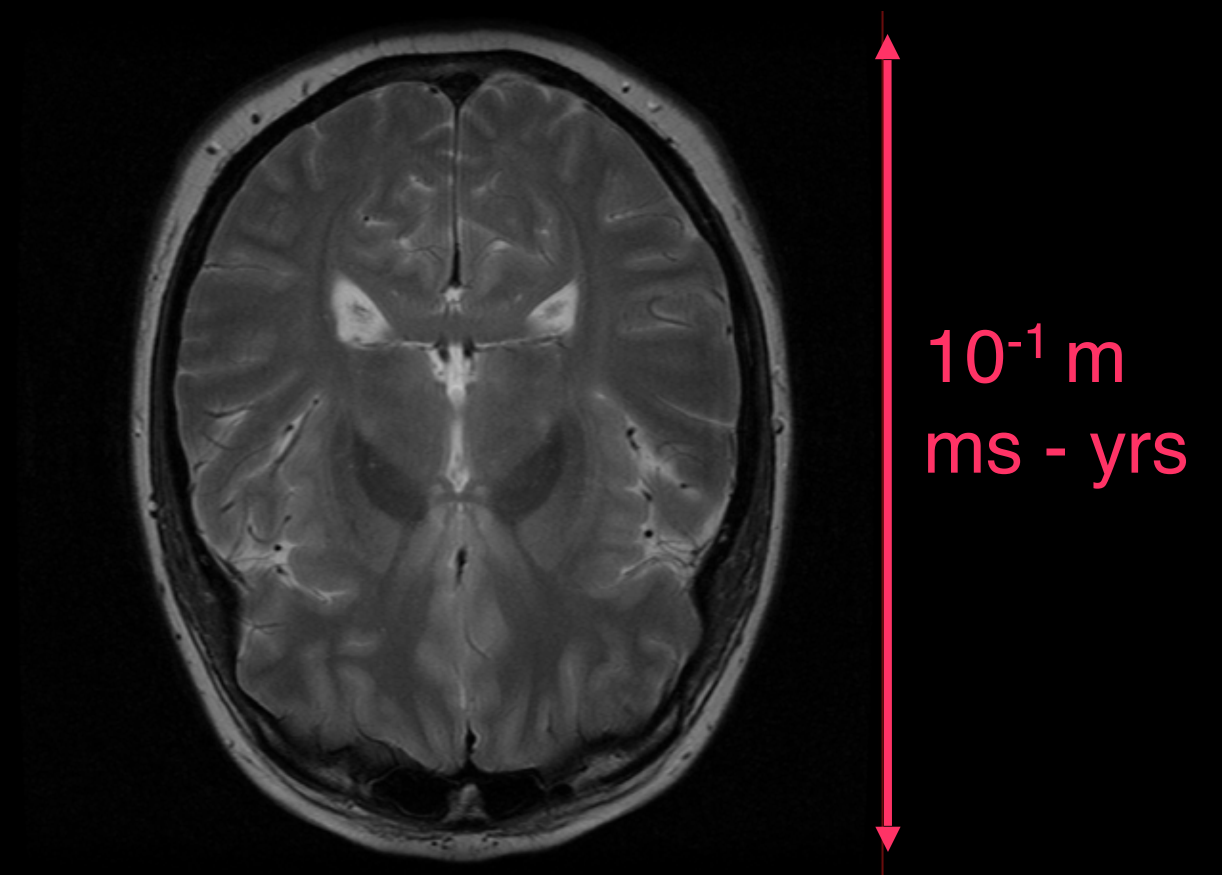
Turku PET Centre

Tuorla Observatory University of Turku





ESO VLT; NASA/ESA HST



3T MRI (AMI Centre, Aalto University)

The course

tube.utu.fi/courses

Learning outcomes

After completing the course the students should be able to:

(1) Describe the principles behind some advanced astronomical imaging techniques and identify suitable topics in astrophysics that can be studies with them;

(2) Understand the physics behind some of the most important medical imaging modalities and describe their value in clinical applications;

(3) Identify and discuss the differences and similarities in the challenges faced when analyzing data in these two different disciplines;

(4) Describe the theoretical basis and suitability of several image/signal processing and analysis methods commonly used in astronomy and medical imaging;

(5) Identify suitable algorithms and apply them to astronomical and/or medical imaging datasets to enhance their scientific and/or clinical value;

(6) Produce a written course report

Teachers

Department of Physics and Astronomy

Seppo Mattila (sepmat@utu.fi)

Talvikki Hovatta

Kaj Wiik

Turku University Hospital

Jani Saunavaara (jani.saunavaara@tyks.fi)

Janika Paavola

Turku PET Centre

Lauri Nummenmaa

Virva Saunavaara

Mika Teräs

Jarno Teuho

Course programme

Monday 21.5

9:15-10:00 Introduction to the course (S. Mattila)

10:15-11:45 Basics of astronomical observations and data processing (S. Mattila)

11:45-12:00 computers and software (K. Wiik)

12-13 Lunch

13:00-13:45 Magnetic resonance imaging (MRI) basics (V. & J. Saunavaara)

13:45-14:15 Electroencephalography (EEG) basics (J. Paavola)

14:30-15:15 Positron emission tomography (PET) basics (M. Teräs)

15:15-16:00 PET application (L. Nummenmaa)

Monday 4.6.

Magnetic resonance imaging (MRI) (V. & J. Saunavaara, J. Paavola)

Thursday 7.6.

Radio interferometry (T. Hovatta & K. Wiik)

Monday 11.6.

Positron emission tomography (PET) (J. Teuho)

Thursday 14.6.

Astronomical signal and image processing (S. Mattila)

Practical sessions

- The whole day teaching sessions run typically between 10am and 4pm (with 1hr lunch break). The teachers will inform about the exact timing for each session, e.g.

Thursday 14.6. Astronomical signal and image processing

10:00 - 11:30 Lecture

11:45 - 12:30 Lecture/tutorial

12:30 - 13:30 Lunch

13:30 - 14:00 Tutorial continues

14:00 - 16:00 Hands-on work with data

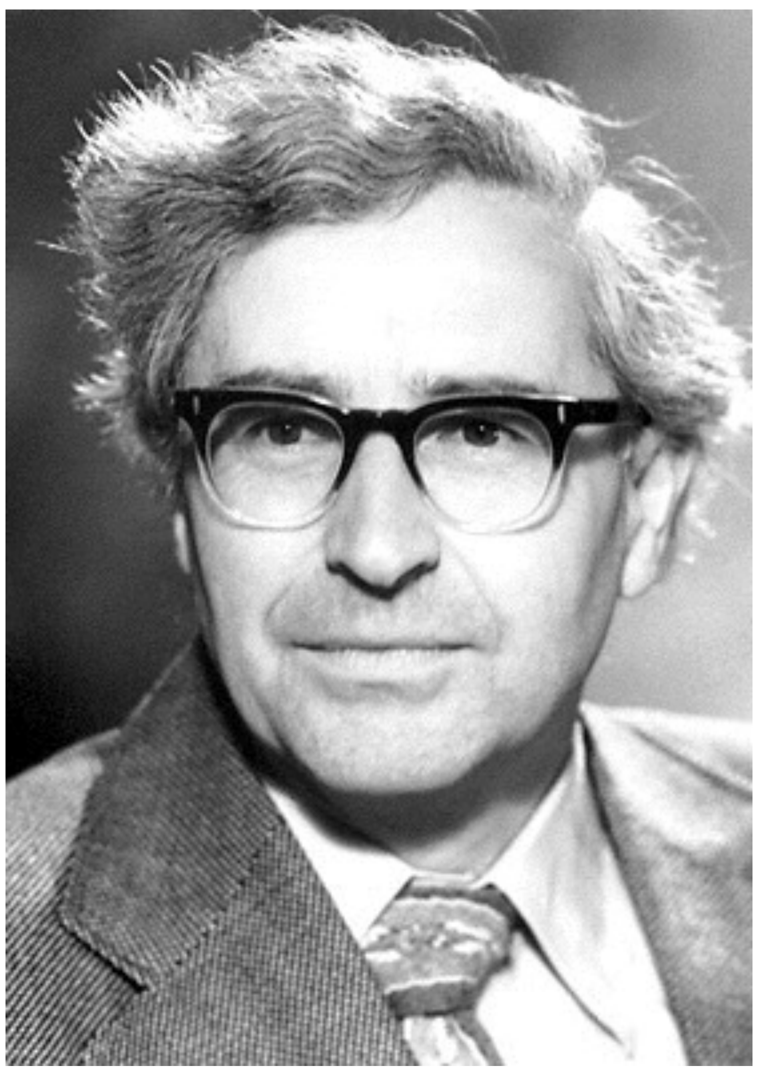
- All the four sessions are compulsory to attend in oder to pass the course + you need to report the practical work you have done in a course report.
- The grading will be based on the reports

Course report

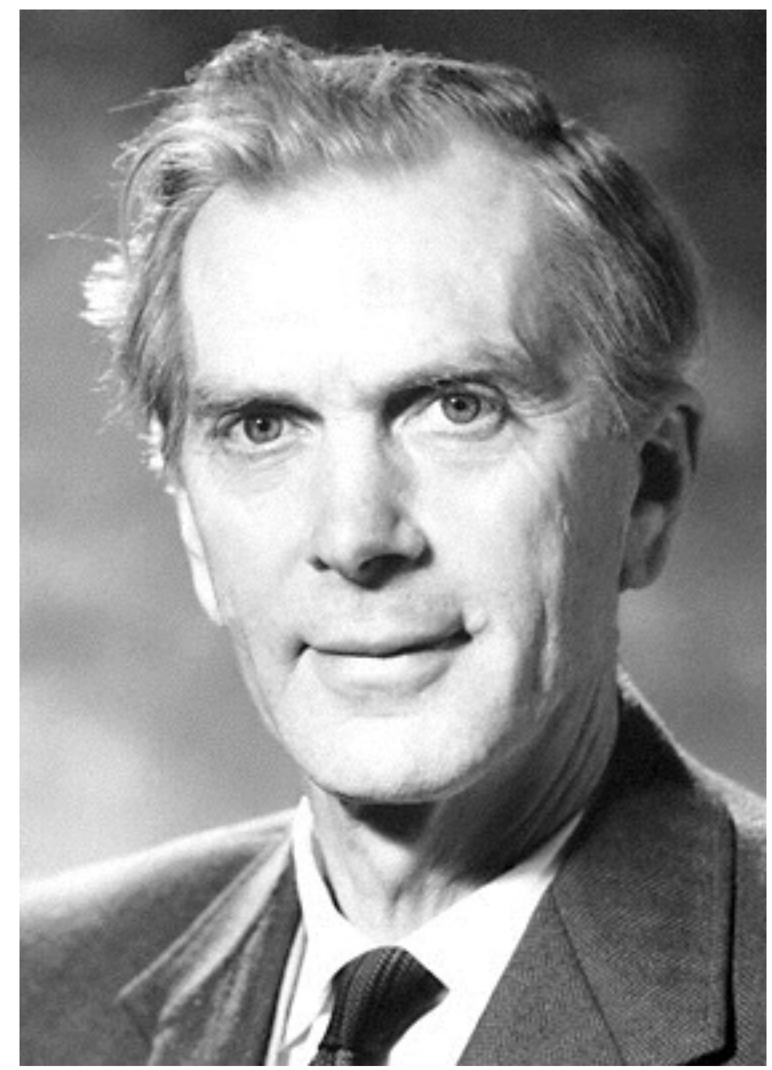
- The minimum length is 9 pages (12 pt font) of text (2 pages based on each of the four practical sessions + 0.5 page introduction + 0.5 page summary) + figures, tables, references
- For reporting the work done in each of the sessions please follow the advice of the teachers
- Keep in mind the learning outcomes (slide 4) when preparing your report
- For writing the report you can use any word processing software that you are familiar with. Please, save the report as PDF

Introduction

The Nobel prize in Physics 1974 was awarded “for their pioneering research in radio astrophysics: Ryle for his observations and inventions, in particular of the aperture synthesis technique, and Hewish for his decisive role in the discovery of pulsars”

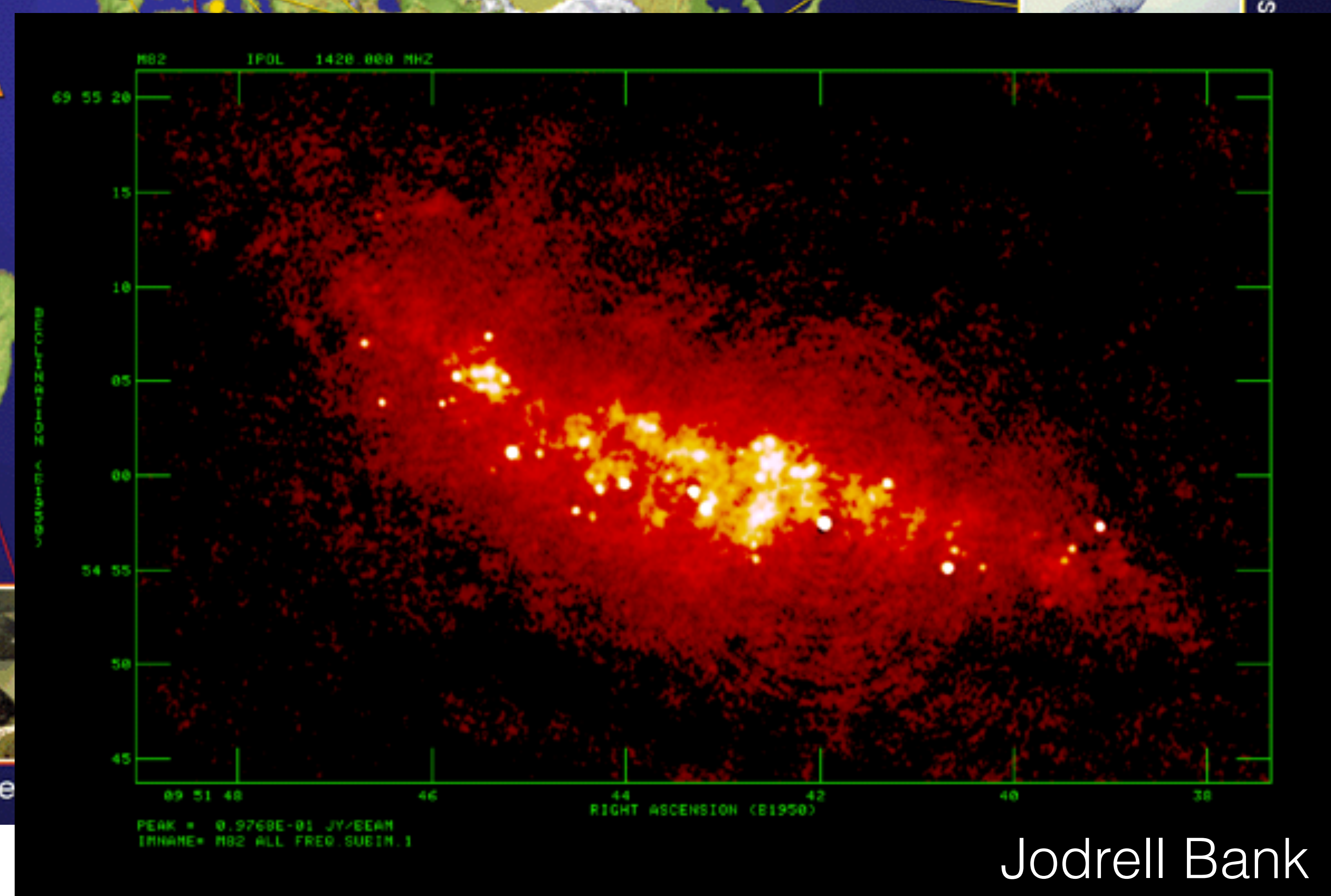


Antony Hewish (Cambridge)



Sir Martin Ryle (Cambridge)

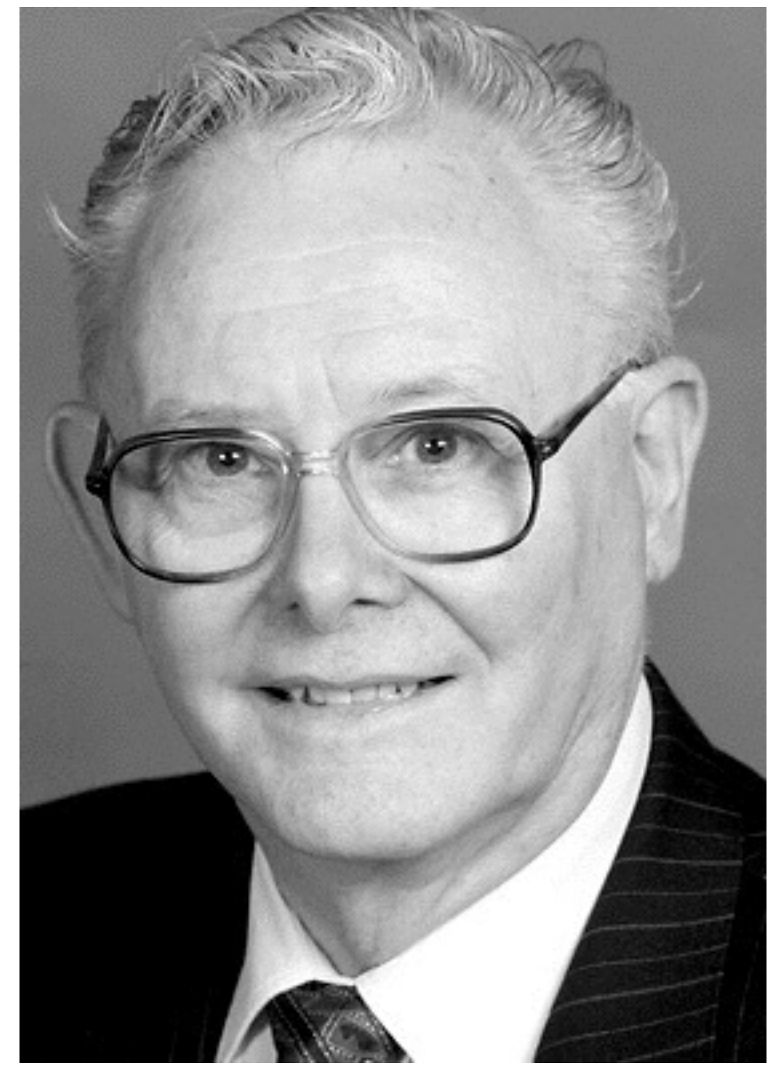
The Global VLBI - Array
Brewster
North Liberty
Hancock
Green Bank
Jodrell Lovell
Jodrell Mk2
Cambridge
Onsala 25m and 20m
Metsähovi
Los Alamos
Owens Valley
Pie Town
Mauna Kea
Kitt Peak
Urumqi
Shanghai
Westerbork
Medicina
Noto
EVN
VLBA
European VLBI Network (EVN)
Very Long Baseline Array (VLBA)
High Sensitivity Array (HSA)
Ft. Davis
St. Croix
V L A
Arecibo
Effelsberg
Yebes
Wettzell
Torun
Hartebeesthoek



Jodrell Bank

The Nobel prize in Physiology and Medicine 2003 was awarded "for their discoveries concerning magnetic resonance imaging"

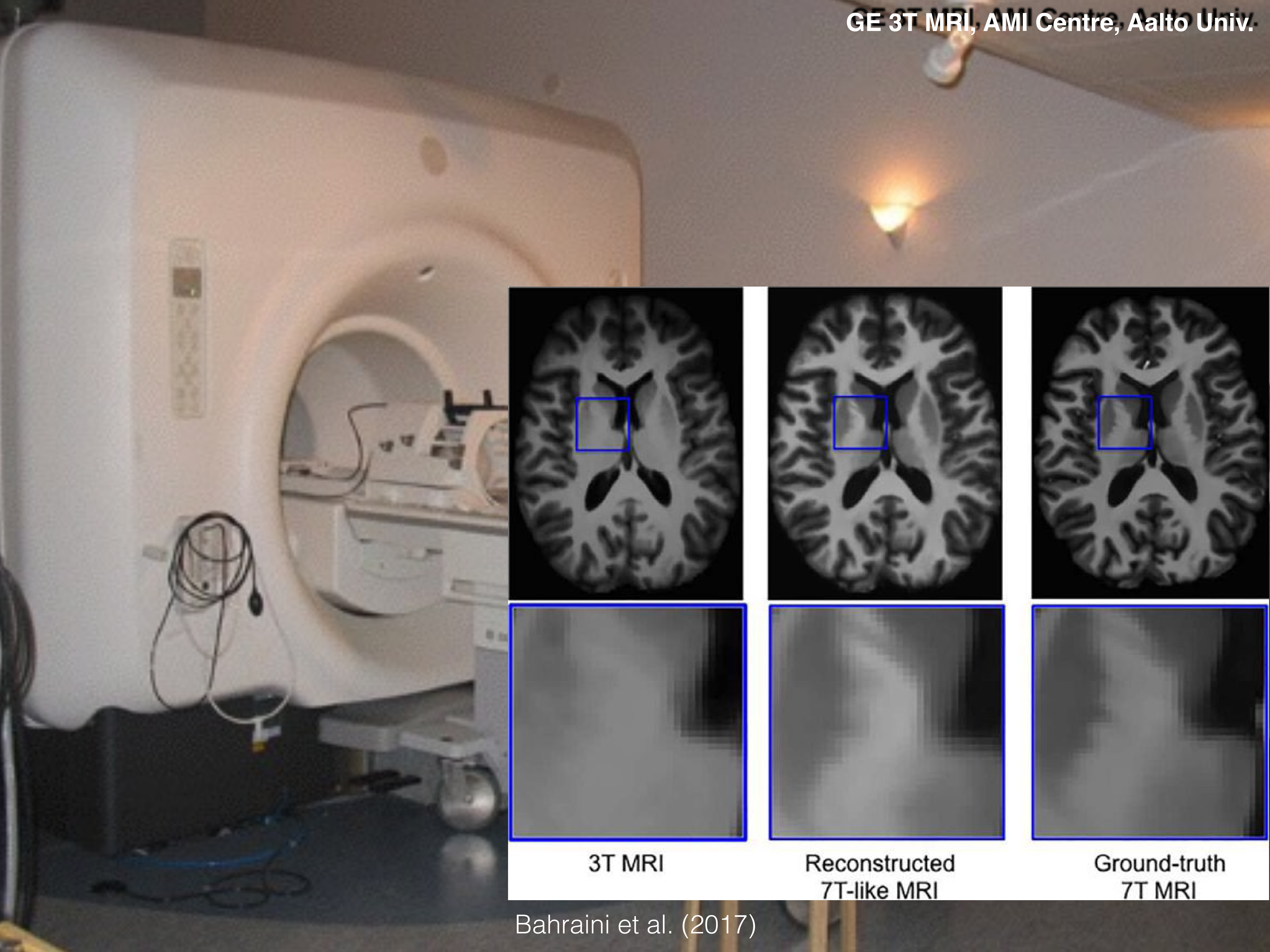
Paul Lauterbur (Illinois)



Sir Peter Mansfield (Nottingham)

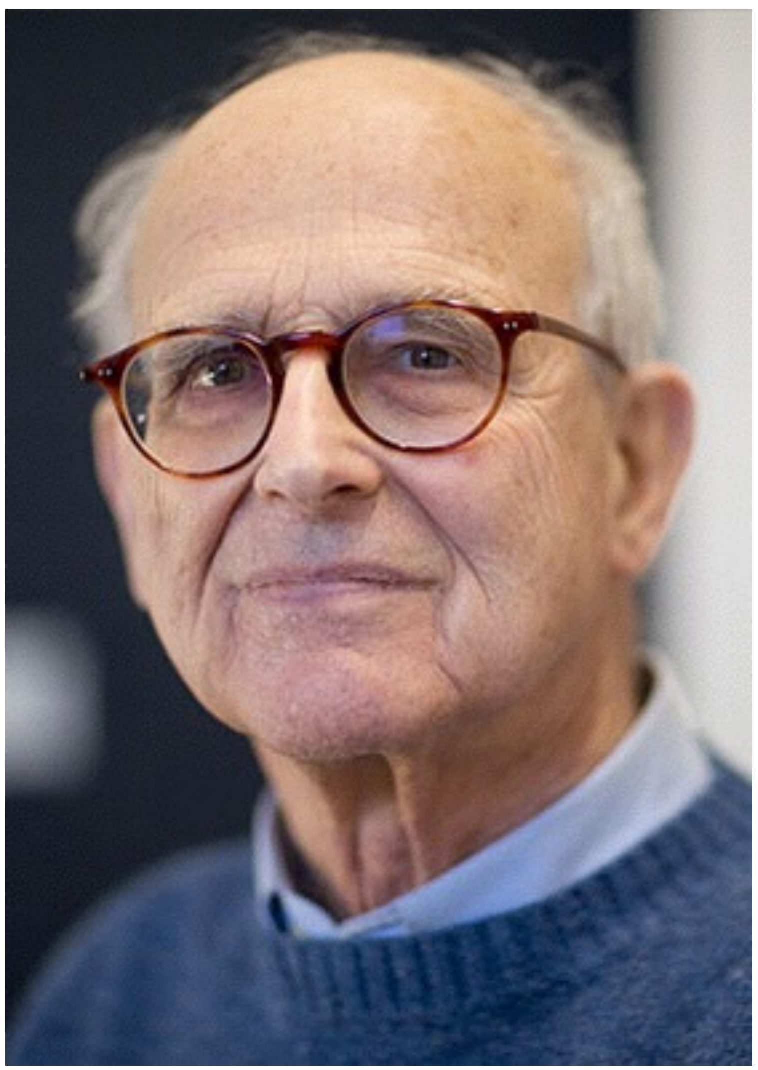

GE 3T MRI, AMI Centre, Aalto Univ.

GE 3T MRI, AMI Centre, Aalto Univ.

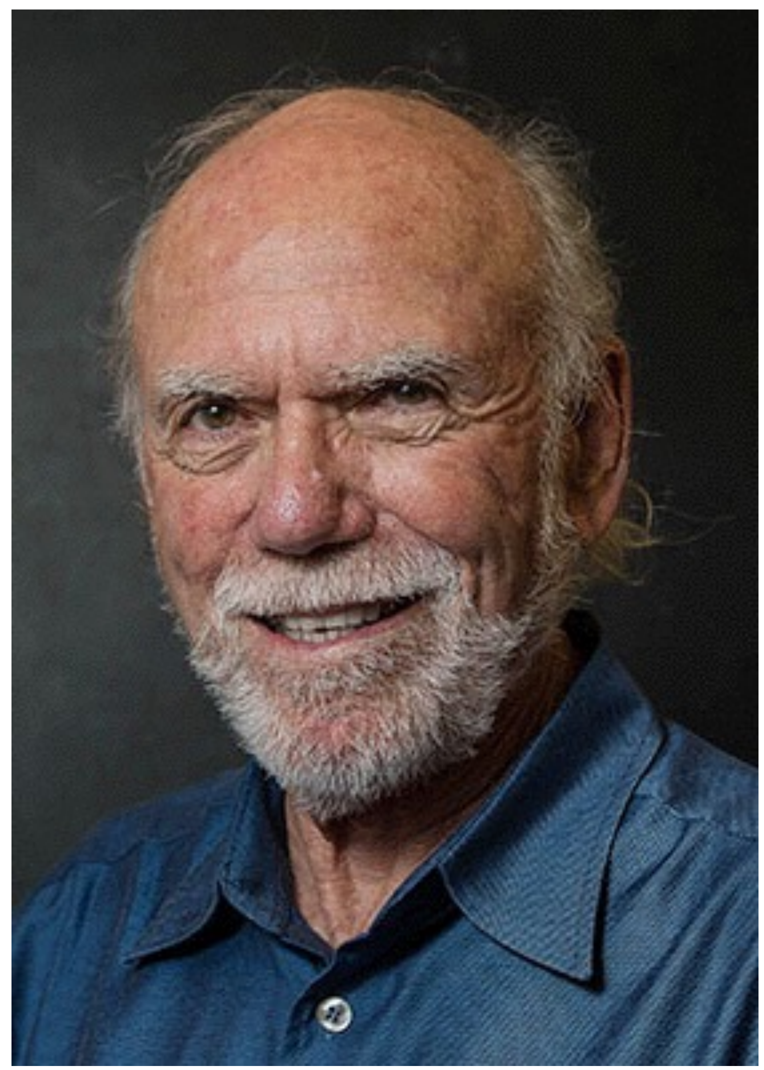


Bahraini et al. (2017)

The Nobel prize in Physics 2017 was awarded “for decisive contributions to the LIGO detector and the observation of gravitational waves.”



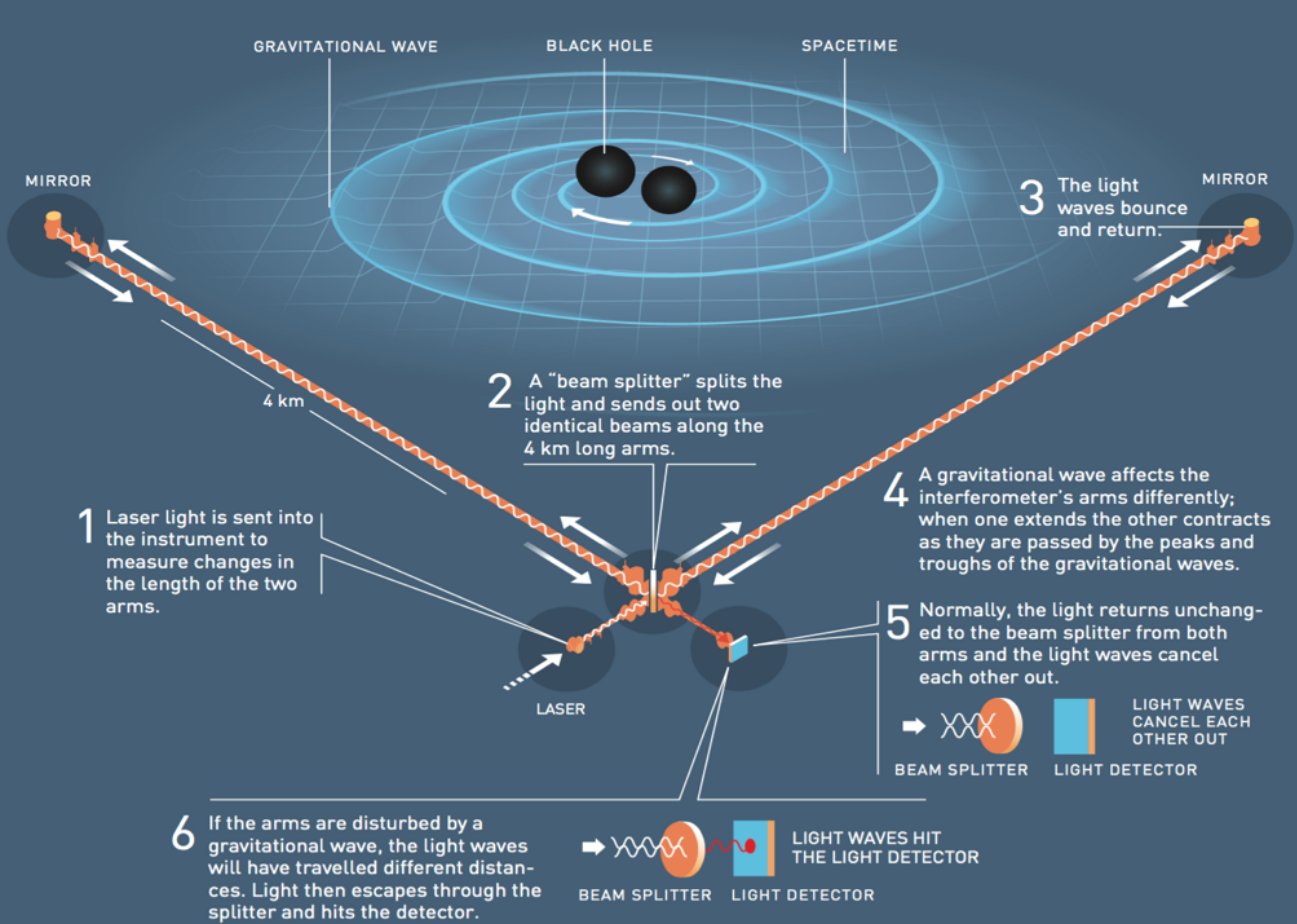
Rainer Weiss (MIT)



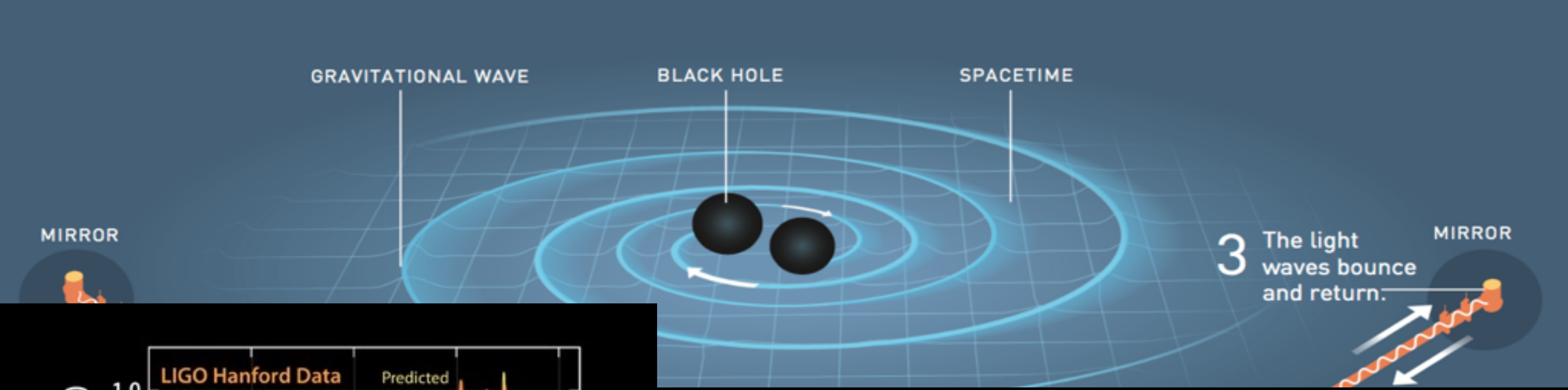
Barry Barish (Caltech)

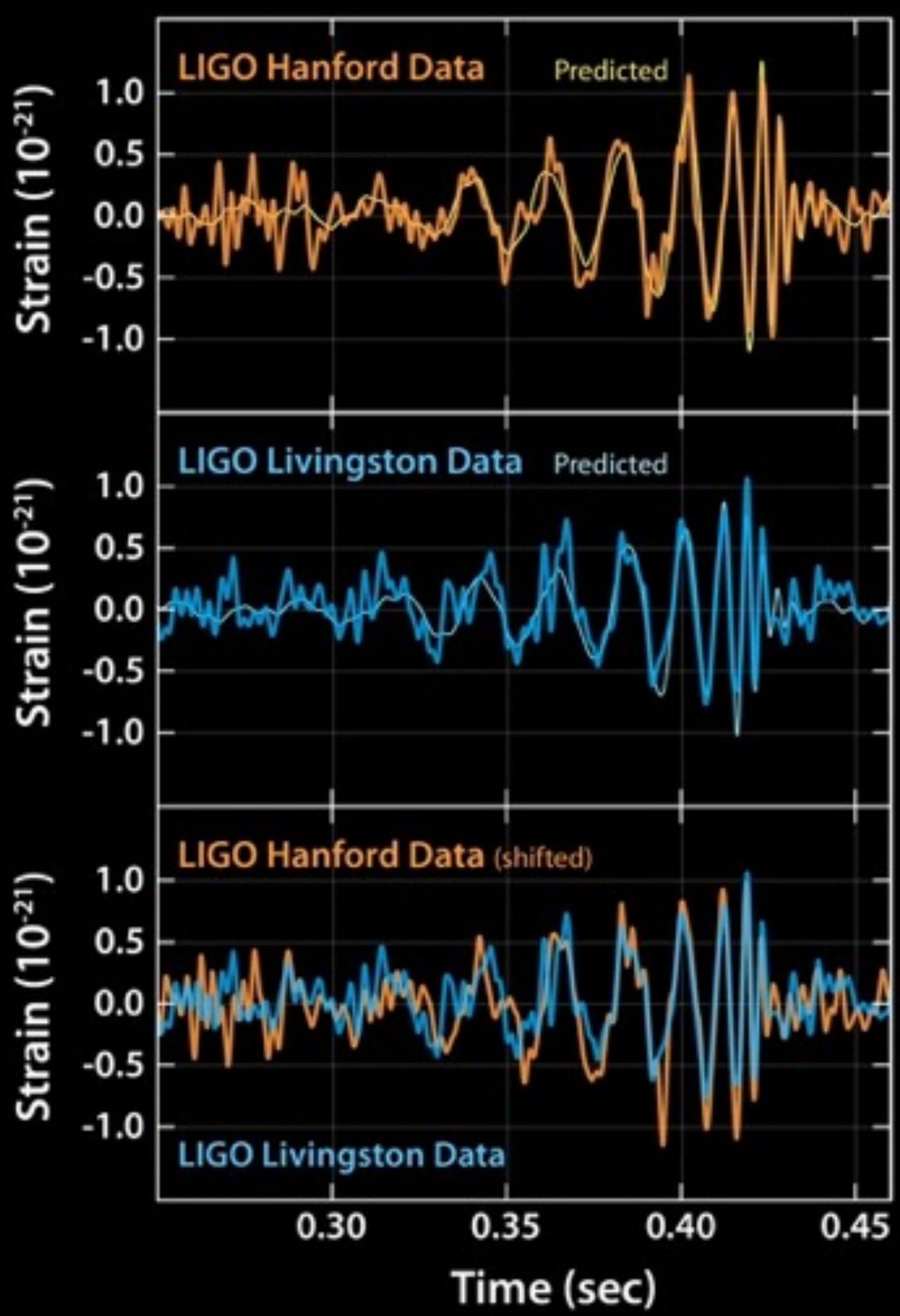
Kip Thorne (Caltech)

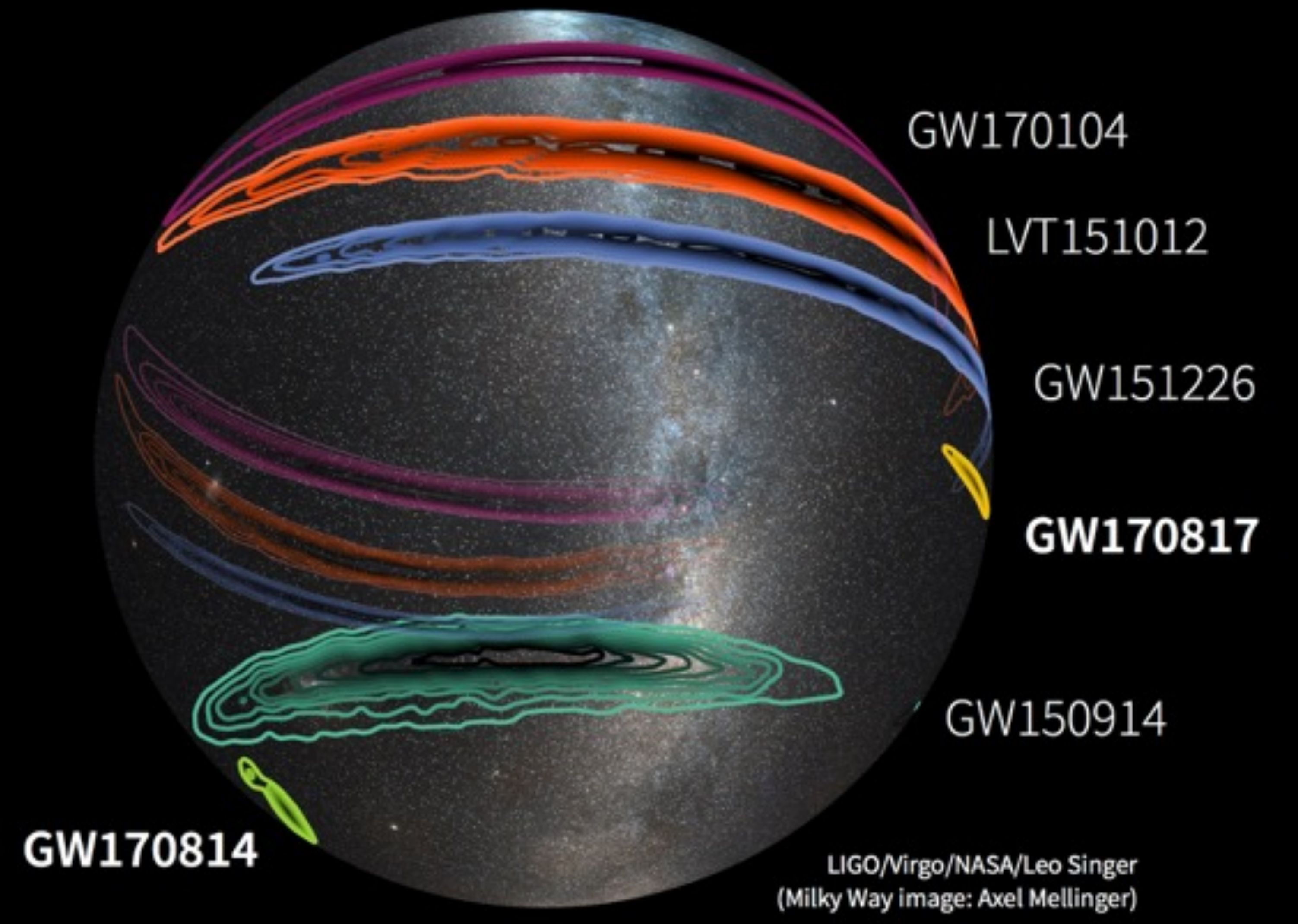
LIGO – A GIGANTIC INTERFEROMETER



LIGO – A GIGANTIC INTERFEROMETER







Astronomical and medical imaging
opportunities for interdisciplinary exchange of know-how ?

Astronomical vs. medical imaging instrumentation

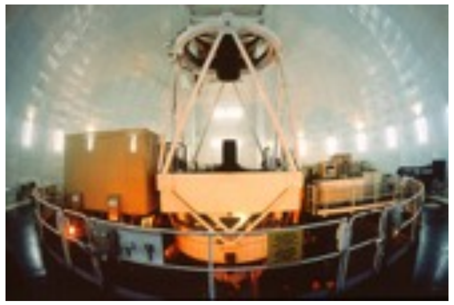
Astronomy

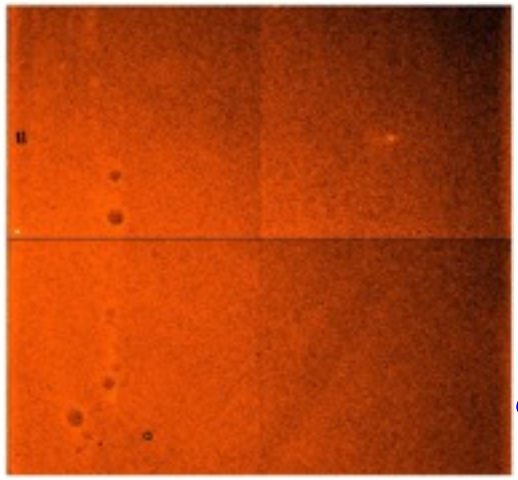
- Expensive one-off instruments using state-of-the-art technology
- Large international projects funded together by several countries
- For example the European Southern Observatory (ESO)
- Heavy competition for telescope time - time allocation committees rank proposals
- Determine which science will be done
- Most data are publicly available after 1 year from observation

Medicine

- Usually commercial instruments
- State-of-the-art instruments at more ‘affordable’ cost (from ~500 kEur for 1.5T scanners to >5 MEur for 7T scanners)
- Individual institutes/hospitals own their own instruments
- Freedom to decide which science will be done
- ‘Observer’ owns the data but data archives are in development !

Data reduction in astronomical imaging studies

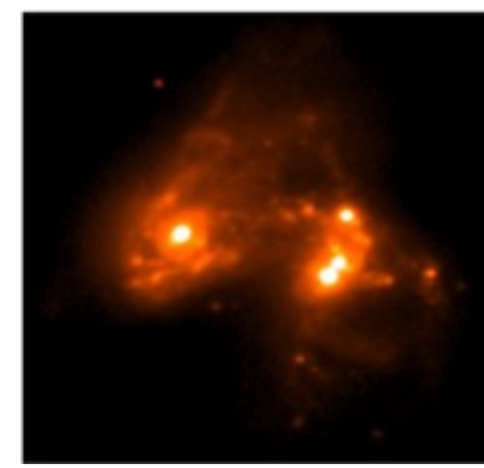




1024x1024

Sky subtraction & flat fielding

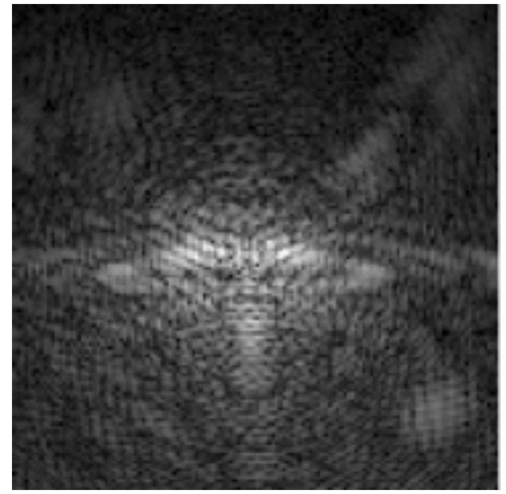
Aline & combine



- Use public and free packages (e.g. IRAF)
- Use pipelines (self-written or provided by the observatory)
- Reductions usually described in detail in the paper
  - Possible to exactly repeat
  - Calibration using stars available in the images

Data reduction in medical imaging studies

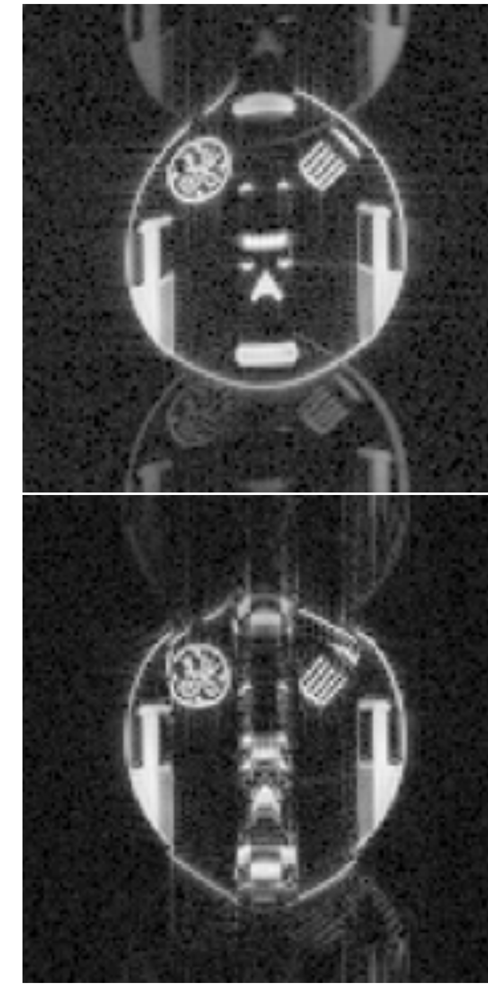
raw (k-space) MR image



128x128

IFT

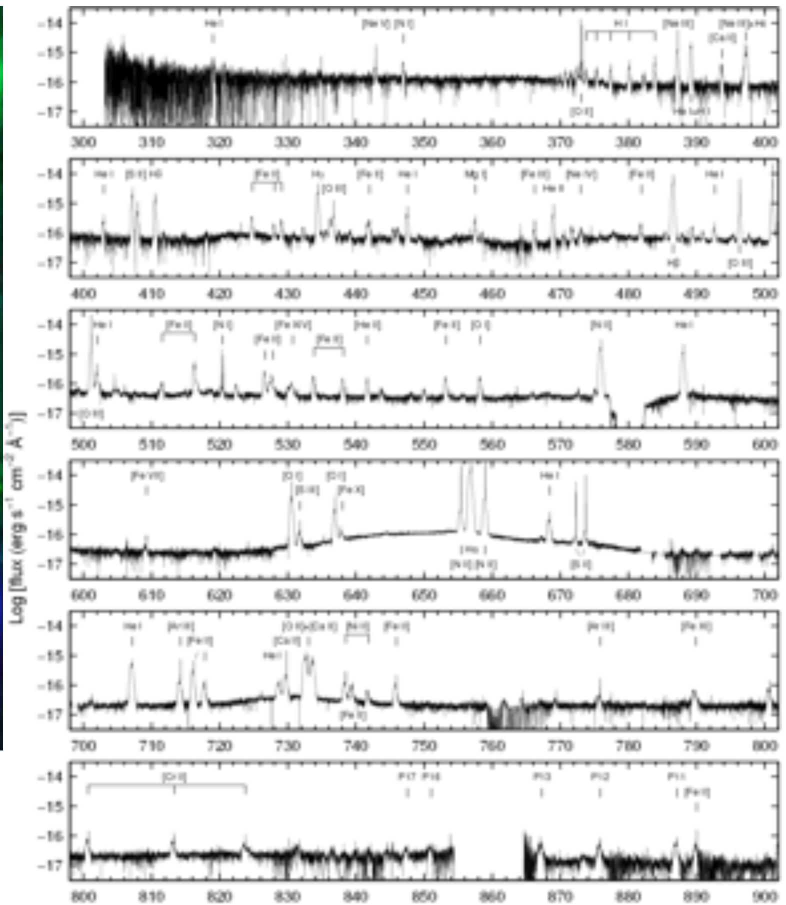
After reconstruction

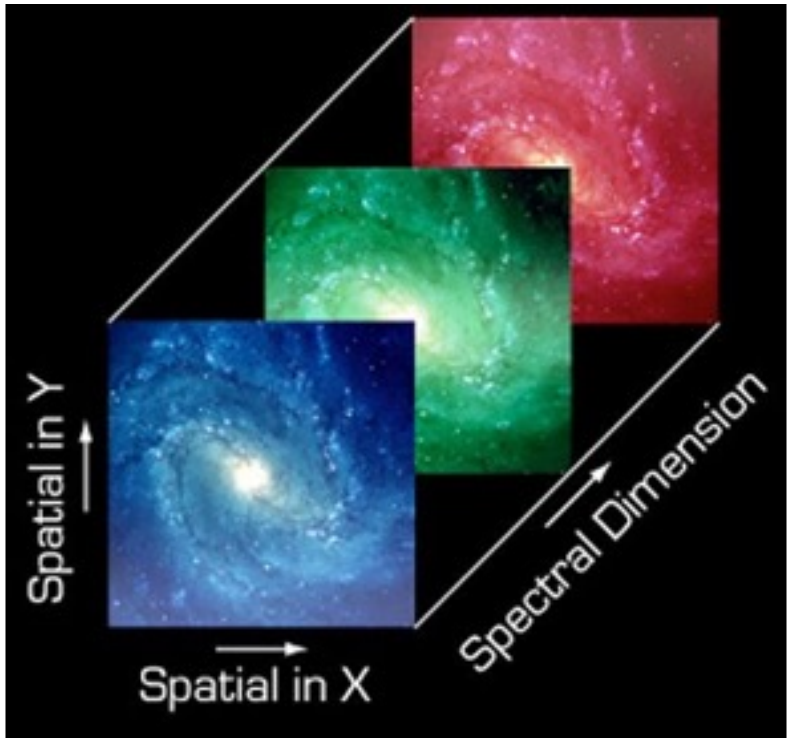


- Automatic but often 'hidden' data processing pipelines (required for the clinical use of the scanners)
- All details not always available to report in a paper, e.g., depend on the manufacturer of the imaging device
- Might be difficult to exactly repeat the data processing steps
- Calibration for medical imaging data using phantoms

Archiving data: astronomical and medical imaging

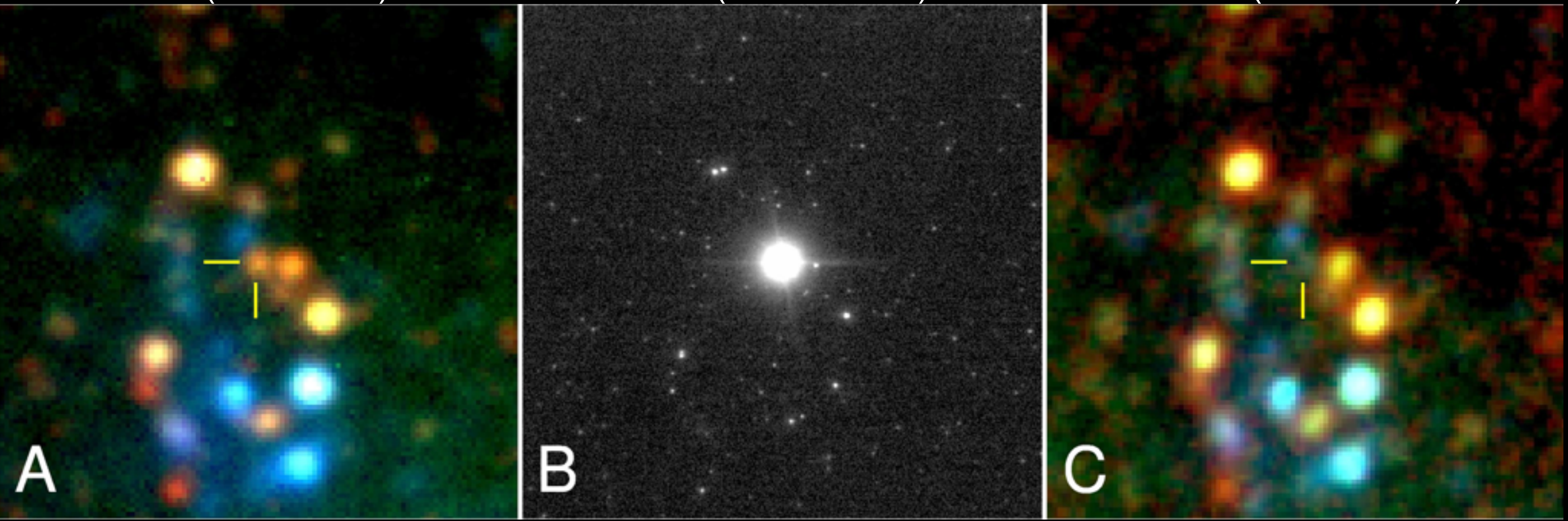
- International observatories responsible for storing and distributing the raw data (and more advanced data products), e.g., the ESO and HST Science Archives
- Astronomical data become available for the whole international research community typically one year from the date of observation
- Turku Clinical Research Centre building a data archive (incl. medical imaging data) to be used by researchers within the Hospital District of Southwest Finland
- Data archives open completely new opportunities for research (examples from astronomy!) - virtual observatories the digital future for astronomy !





Example of research based on archival data witnessing a stellar explosion in real time

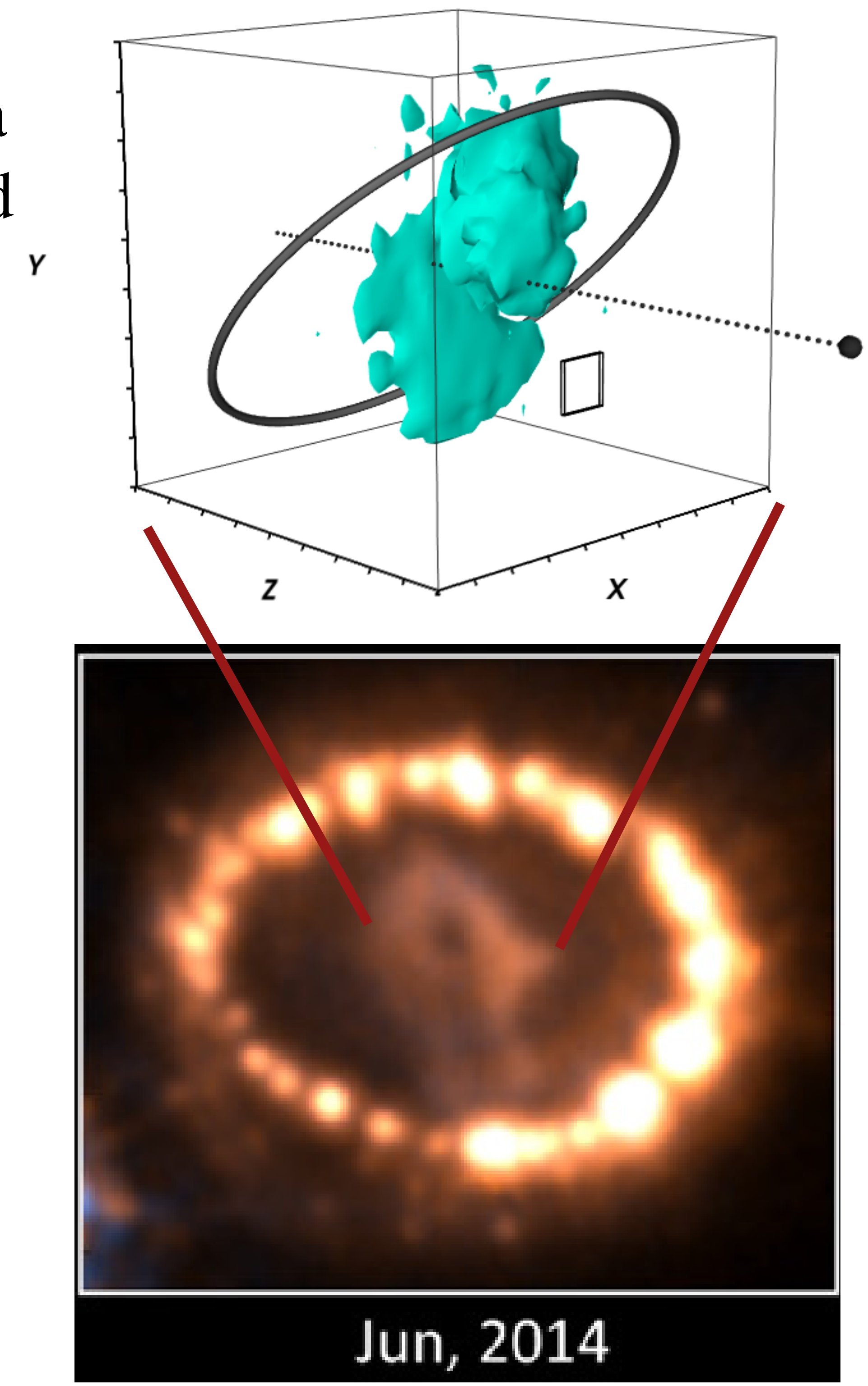
ESO VLT (archival) ESO VLT (new data) ESO NTT (new data)

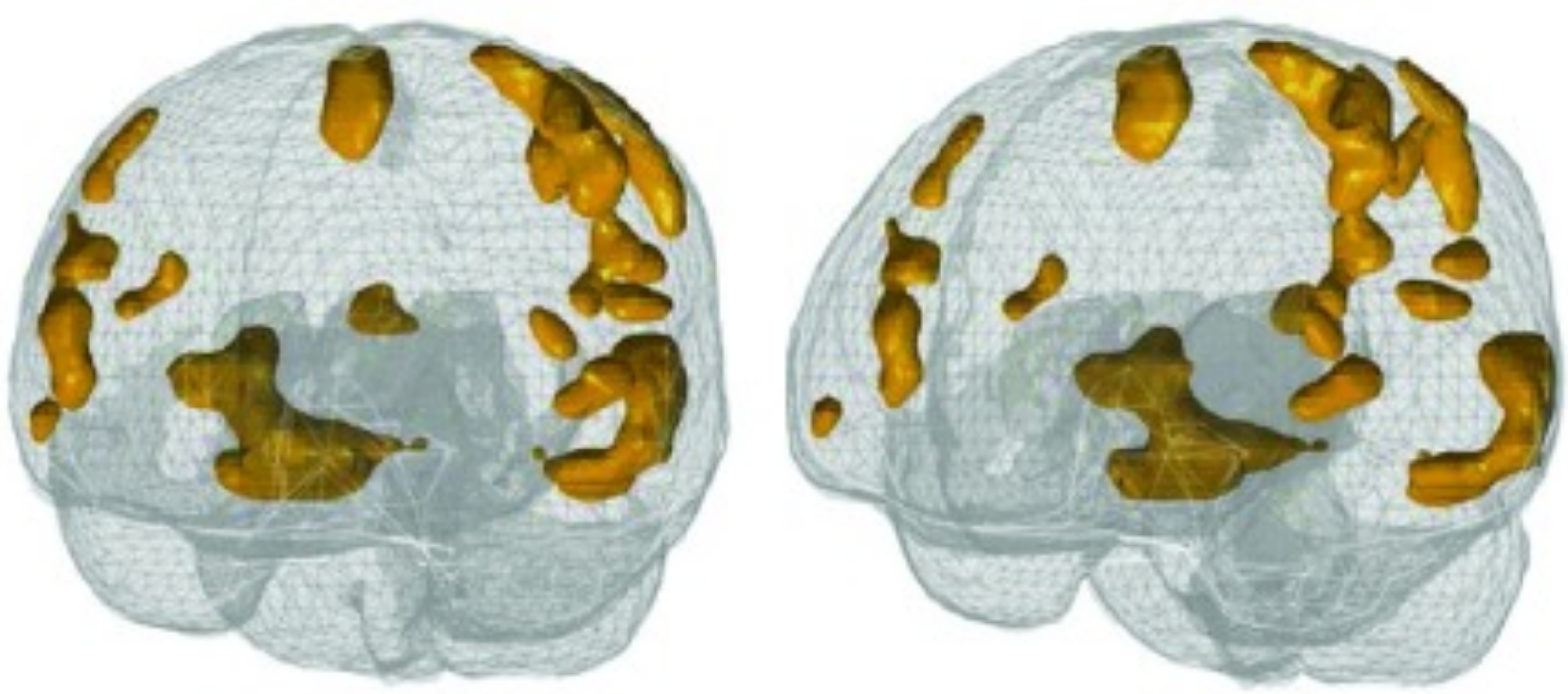


Mattila+2010

3D visualisation: astronomical and medical imaging

- In medical imaging 3 dimensional information (x, y, z) often available and sophisticated tools already exist for the analysis and visualisation of data cubes
- In astronomical imaging a new generation of instruments with integral field units now provide data also in 3D (x, y, λ) and new tools are being developed

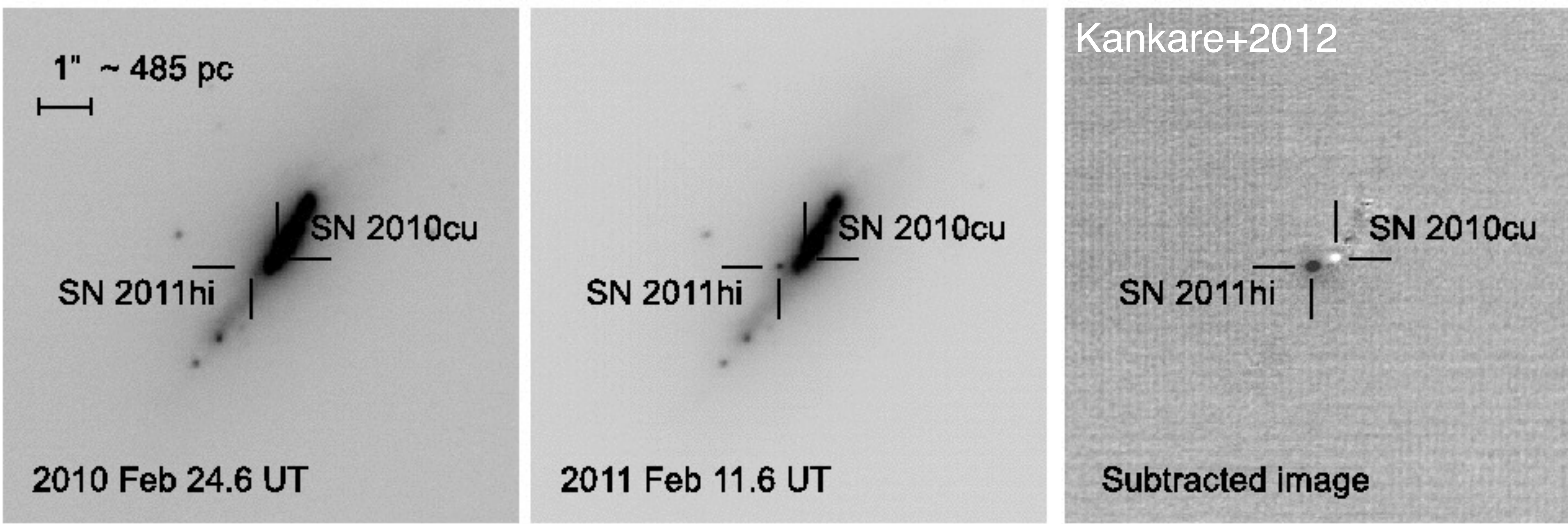




Functional magnetic resonance imaging (fMRI)

Detecting time-variability: astronomical and medical imaging

- Detection and study of stellar explosions (supernovae) by repeated imaging of galaxies
  - SN detection by precise image alignment, matching of the point spread functions (PSFs), intensity and background levels followed by image subtraction
- Functional MRI to map brain activity by detecting changes in associated blood flow
  - Analyse the data by statistical voxel by voxel comparison to a model (stimulus ⊗ Hemodynamic Response Function)



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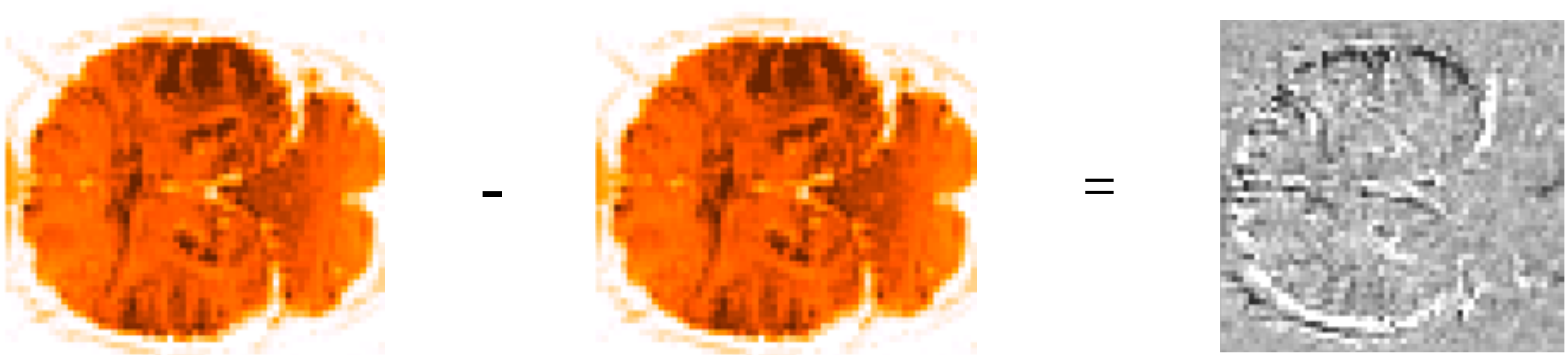
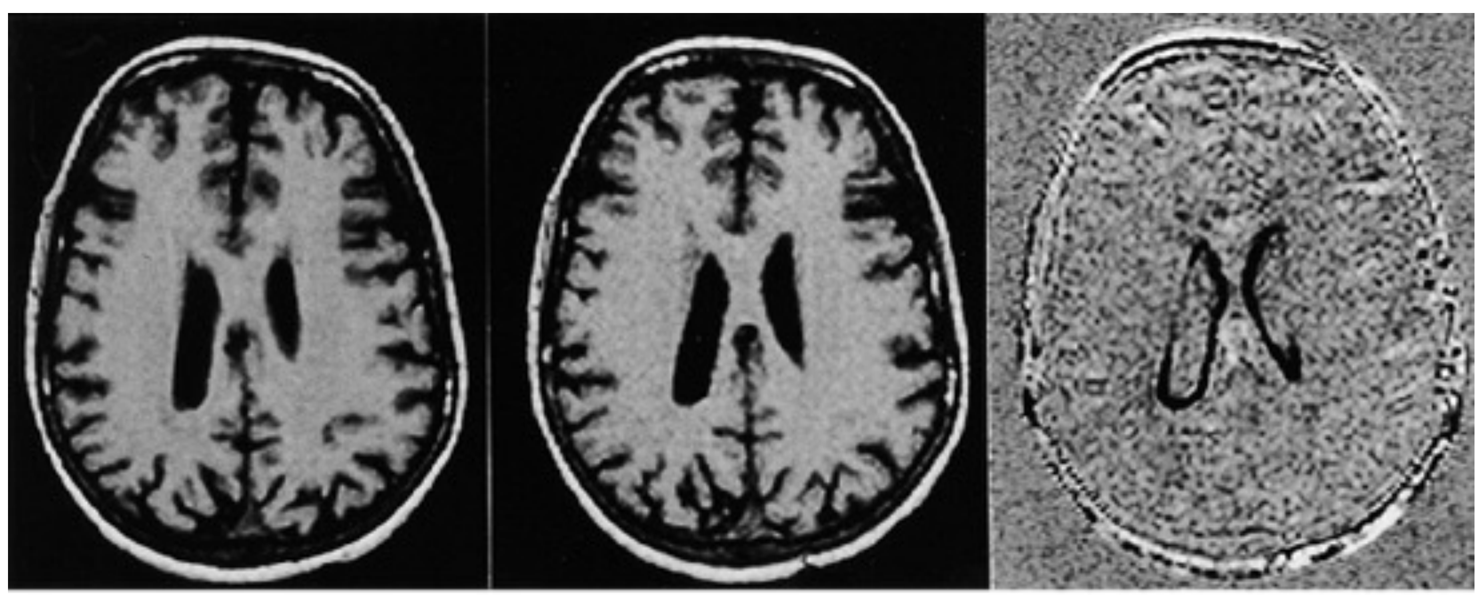


Detecting time-variability: astronomical and medical imaging

- Can monitor volumetric changes, e.g., loss of tissue in Alzheimer's
- Accurately register new and reference images (natural landmarks etc.)
- Normalise image intensities
- Apply image subtraction between the new and the reference image to reveal any tiny volumetric changes between the two images

Reference new +6 months subtracted



(a) (b) (c)

Bradley et al. 2002, British J. of Radiology, 75, 506


Sep, 1994
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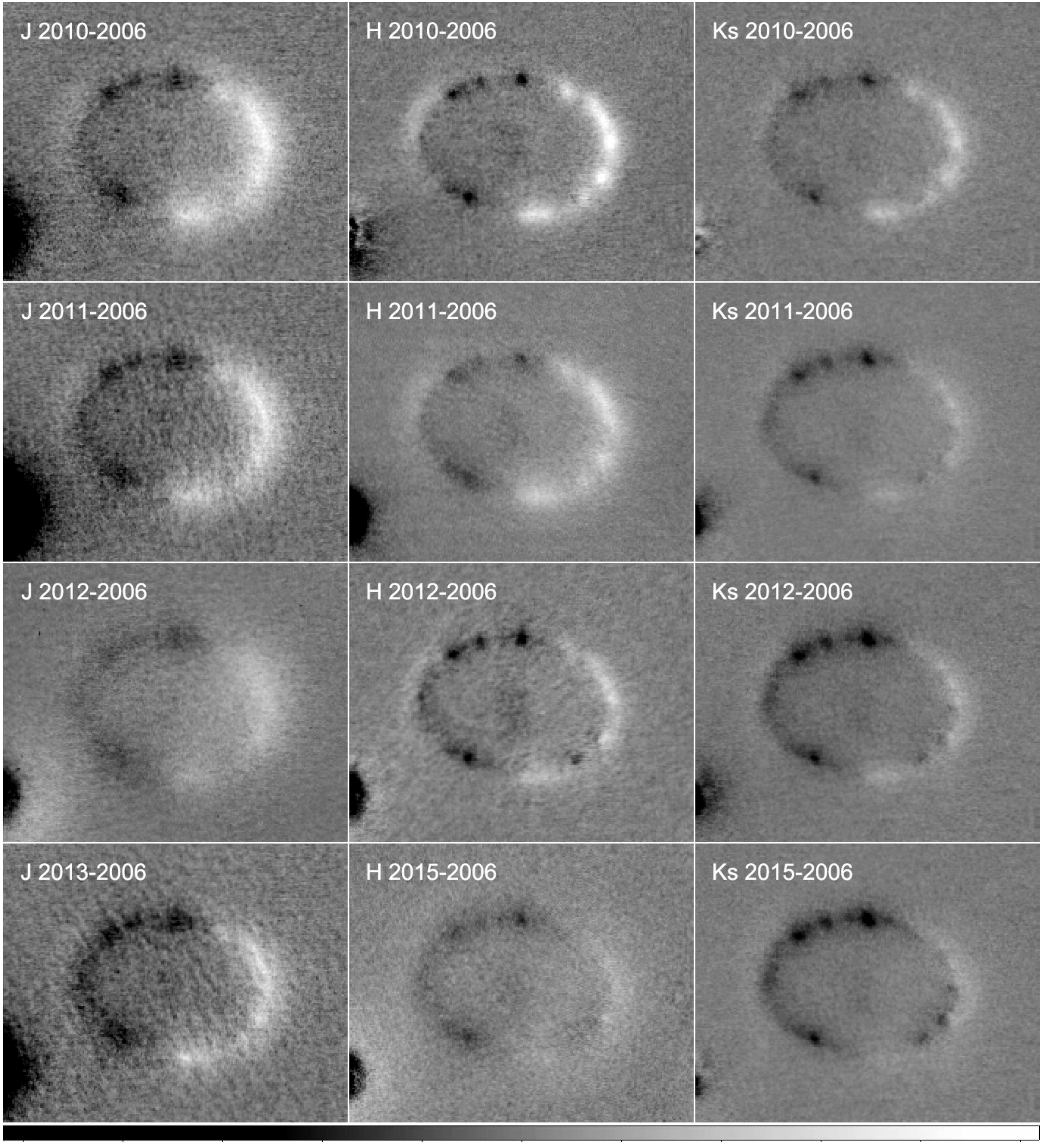
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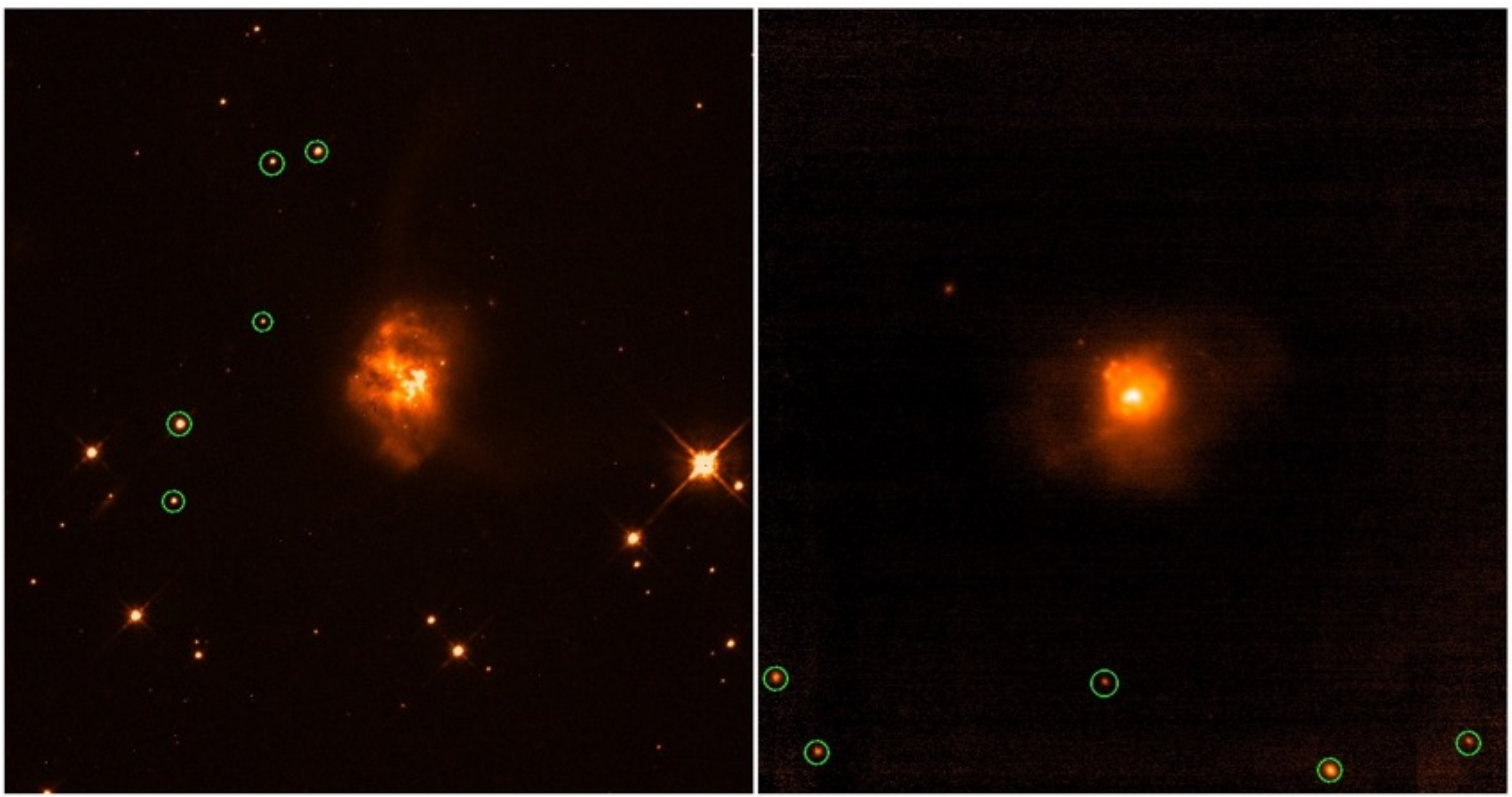
Ahola (2018)

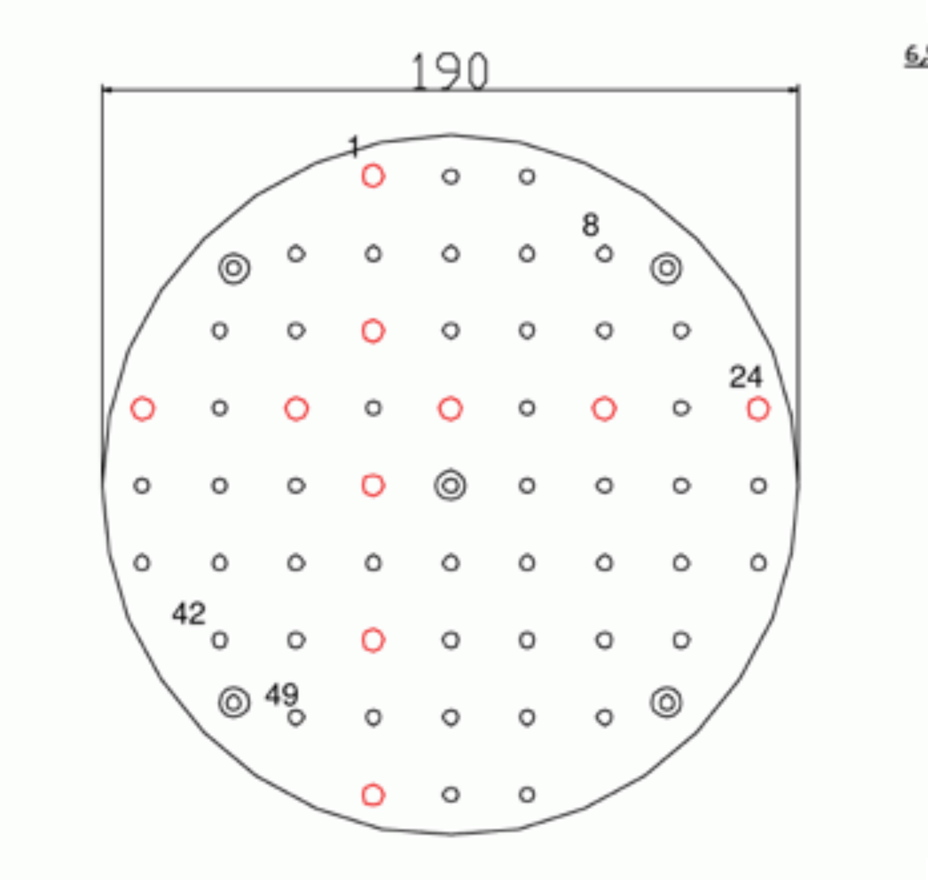
Data quality control: astronomical and medical imaging

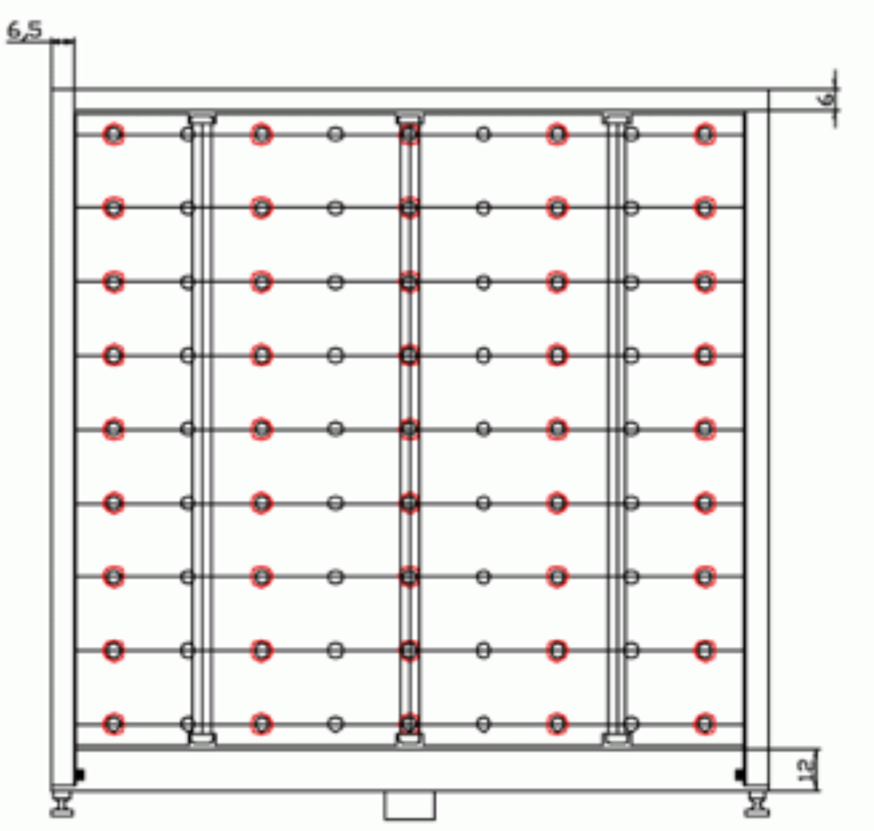
- In astronomy can usually identify several point sources (stars) common to the images
- Can derive precise geometric transformations, match point spread functions and signal levels between the images - importance for calibration and data quality control
- In medical imaging can use test objects (phantoms) to provide reference structures (similar to stars in astronomy) in the imaging volume to allow precise mapping of geometric distortions, uniformity and stability of the signal

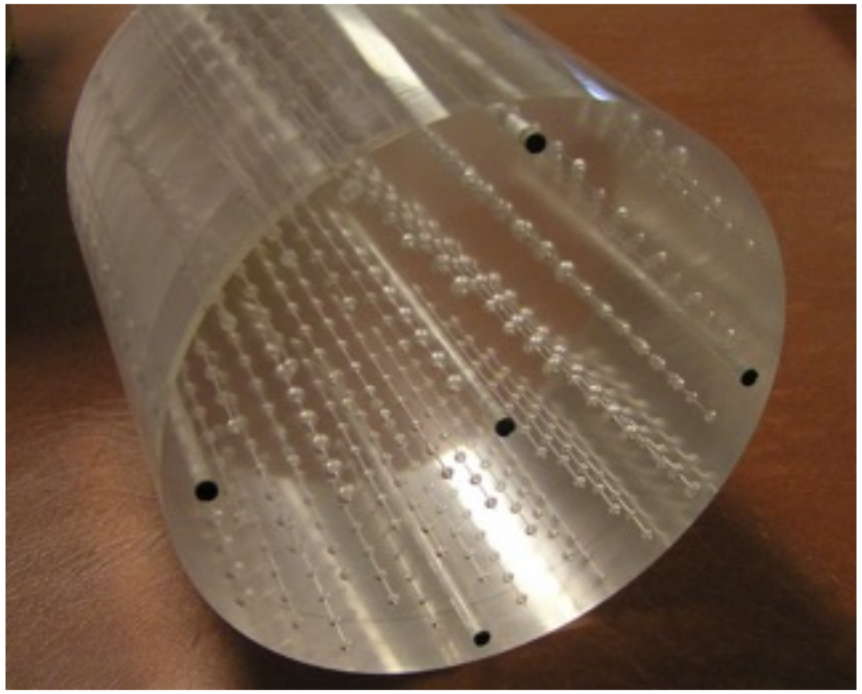


Phantom-based evaluation of geometric distortions in MRI

- In magnetic resonance imaging (MRI) test objects (phantoms) widely used for the data quality control a bit similar to calibration data in astronomy
- However, phantoms with suitable grid structures not commonly available
- A phantom prototype with a suitable grid structure for different imaging modes
  - ~500 spheres of 4-6 mm diameter over the head coil imaging volume
  - Spheres connected by 0.7 mm capillaries
  - Provide ~60 'point sources' (0.7mm – 6mm) per axial slice surrounded by a circle



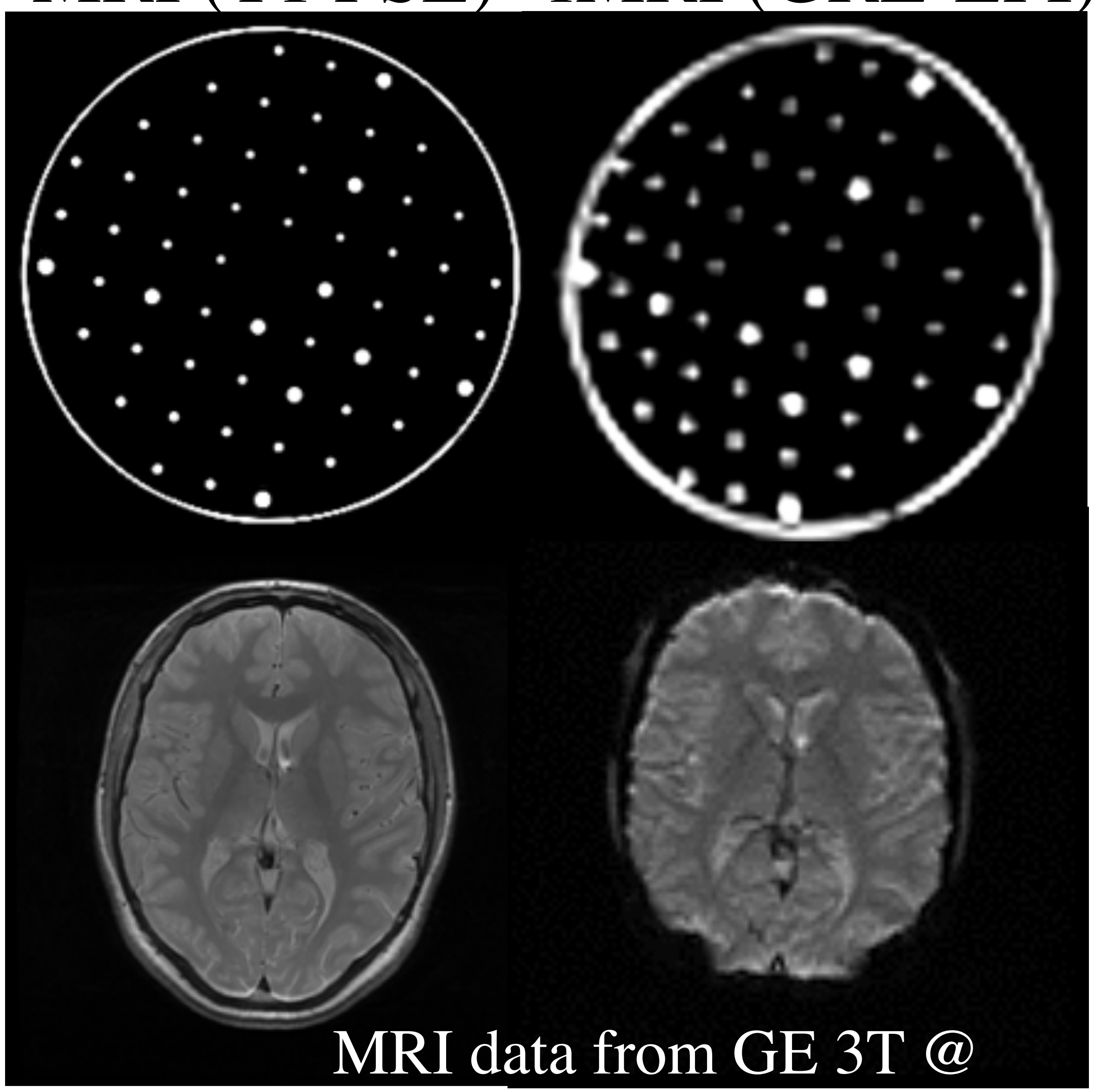




Mattila et al. 2007, MRM

- The structures well detected in both MRI and functional MRI sequences
  - Quantitative info on image geometry and point spread function

MRI (T1 FSE)   fMRI (GRE-EPI)



Mattila et al. 2007, MRM

Thank you

2.6m Nordic Optical Telescope
La Palma, Spain (2.4 km)