



Istituto Nazionale di Astrofisica
Osservatorio astronomico di Brera



Universo in fiore
Corso Avanzato

La RadioAstronomia: dalle prime antenne a SKA

Anna Wolter

Anna.Wolter@brera.inaf.it

INAF-Osservatorio Astronomico di Brera

21 novembre 2012

Scaletta della lezione

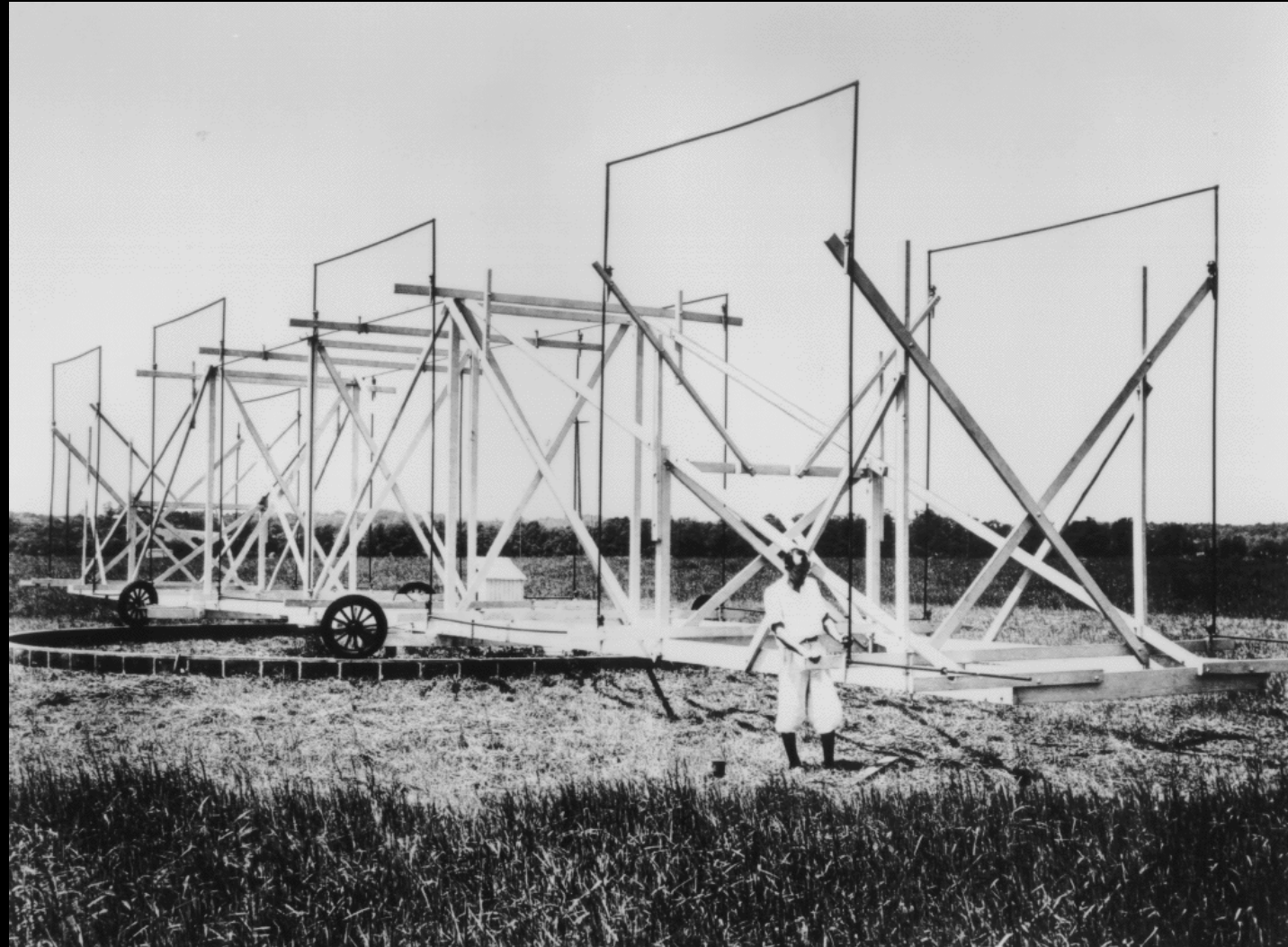
- i primi strumenti radio e la radiazione cosmica di fondo
- lo sviluppo delle schiere di antenne interferometriche
- sorgenti di onde radio
- dal magnetismo cosmico all'idrogeno primordiale con SKA

Primi strumenti e CMB

Marconi vince il premio Nobel nel 1909 per le
sue ricerche sulle onde radio



Onde radio dal cielo



La prima mappa del cielo radio

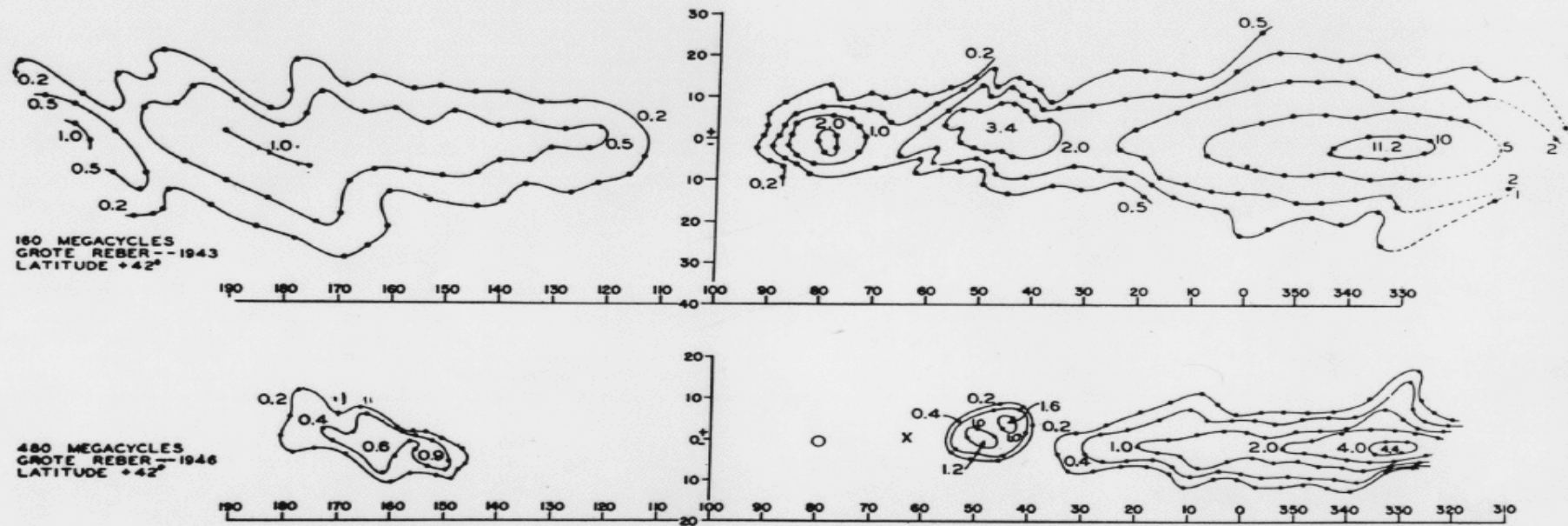
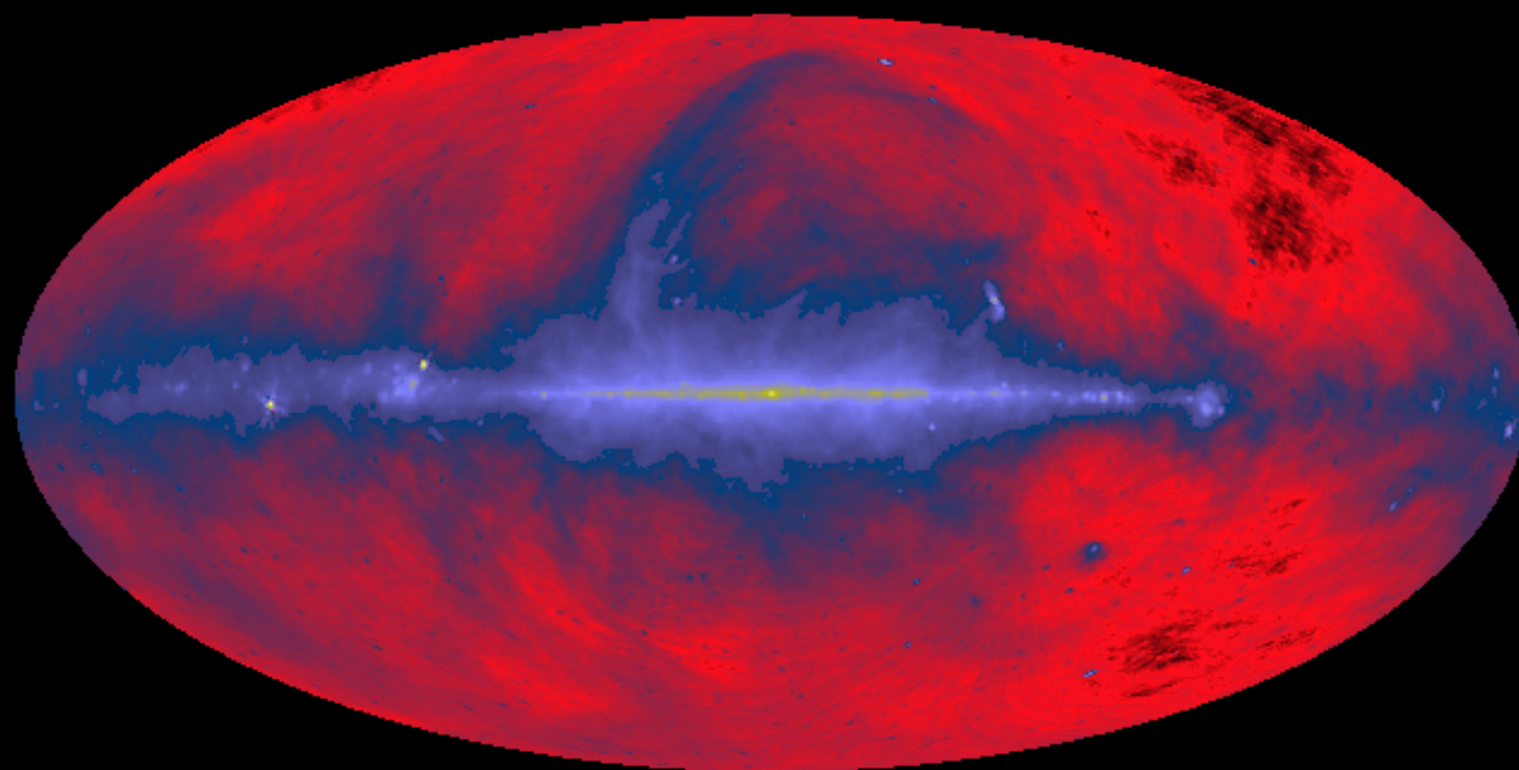
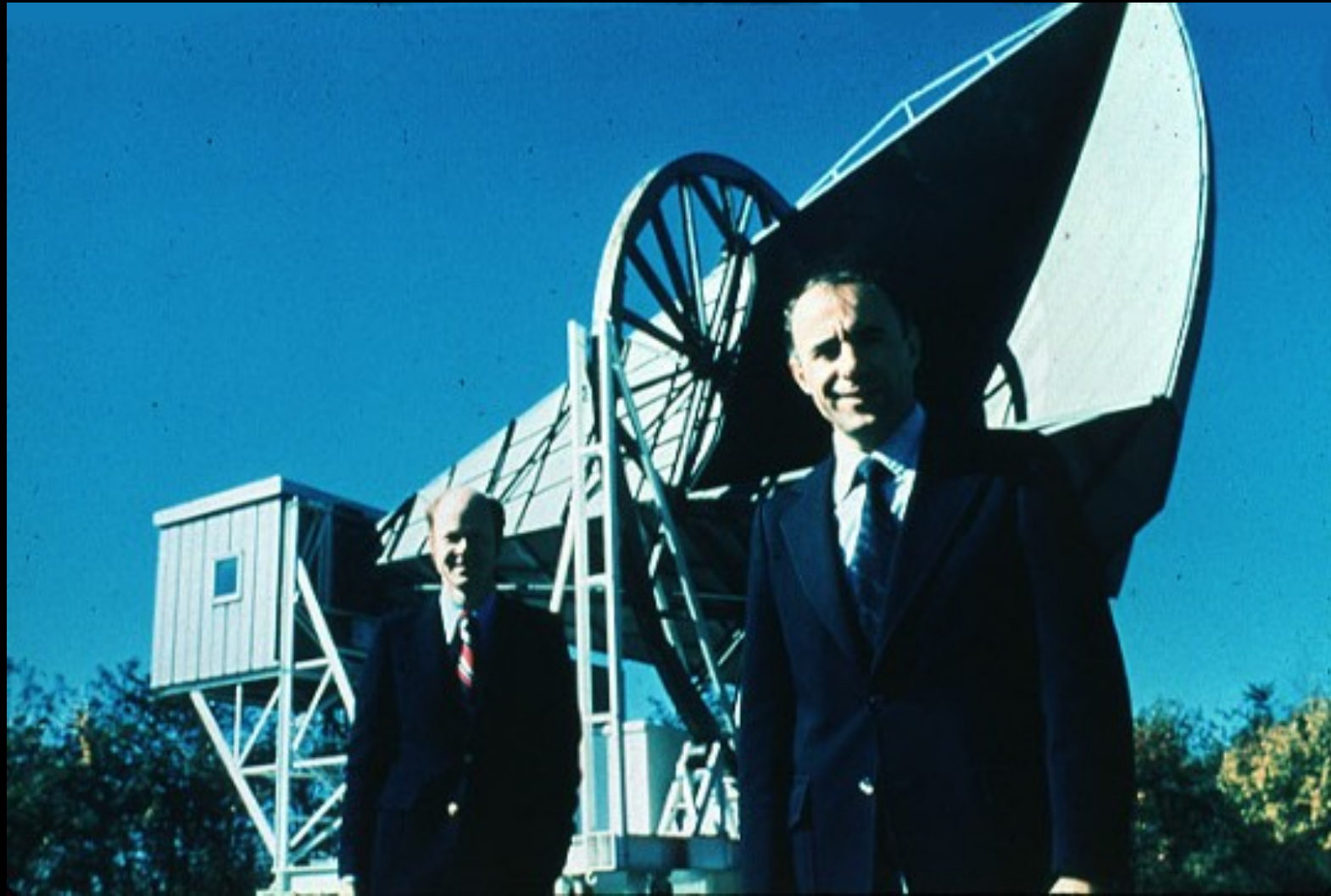


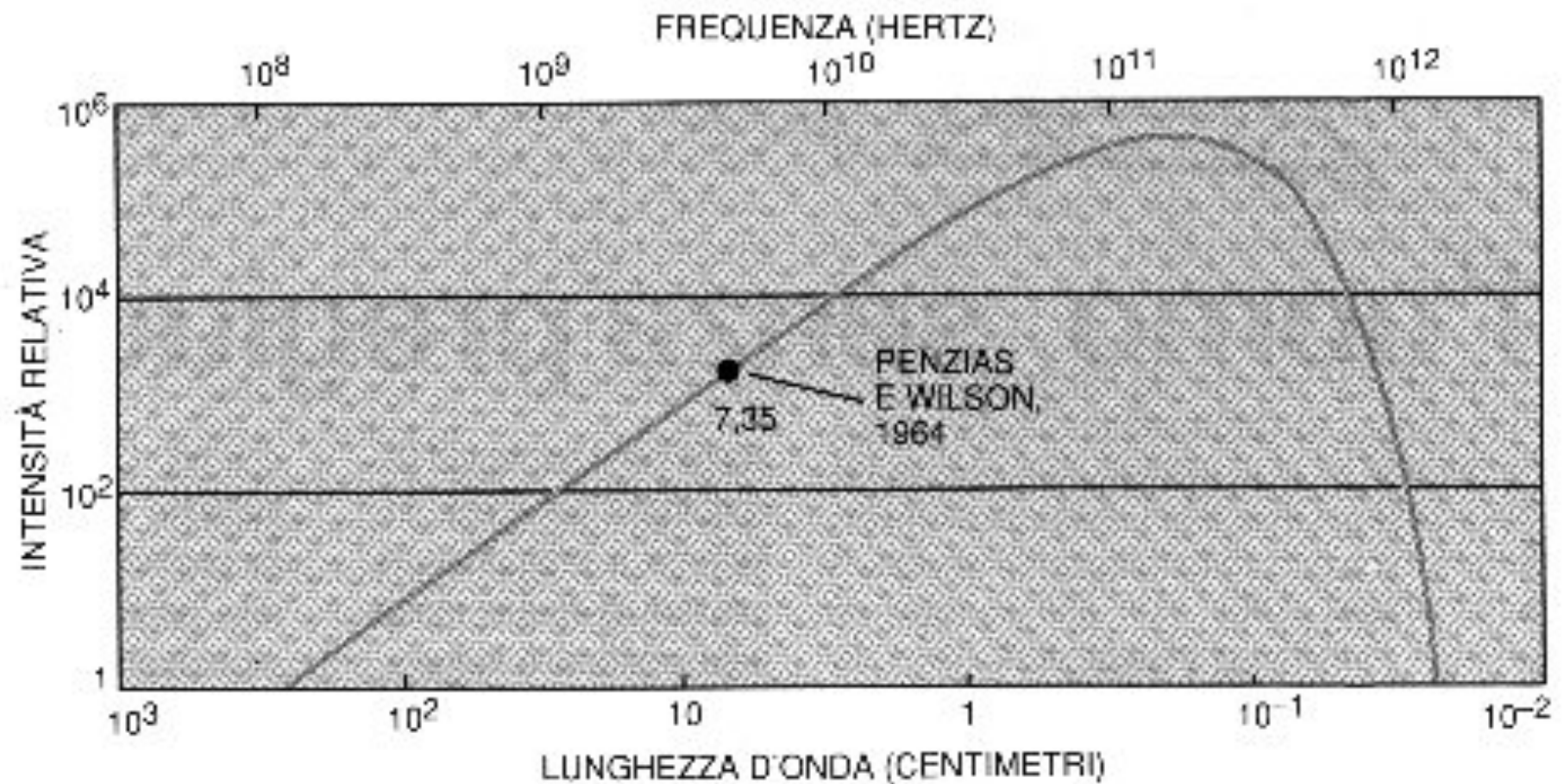
FIG. 7—Contours of constant intensity at 160 MHz and 480 MHz, taken at Wheaton, Illinois.



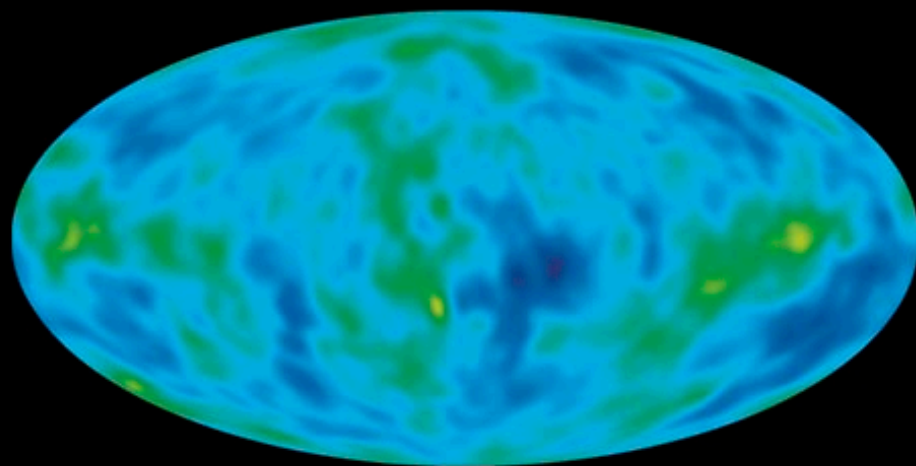
La scoperta della radiazione di fondo



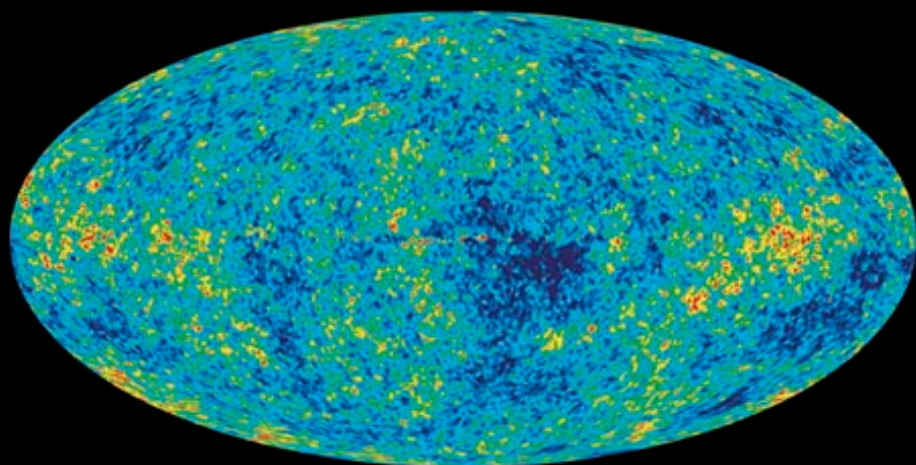
Alpher, Herman e Gamow nel 1948 prevedono l'eco del Big Bang.
Penzias e Wilson osservano un "rumore" nel 1964
Premio Nobel nel 1978



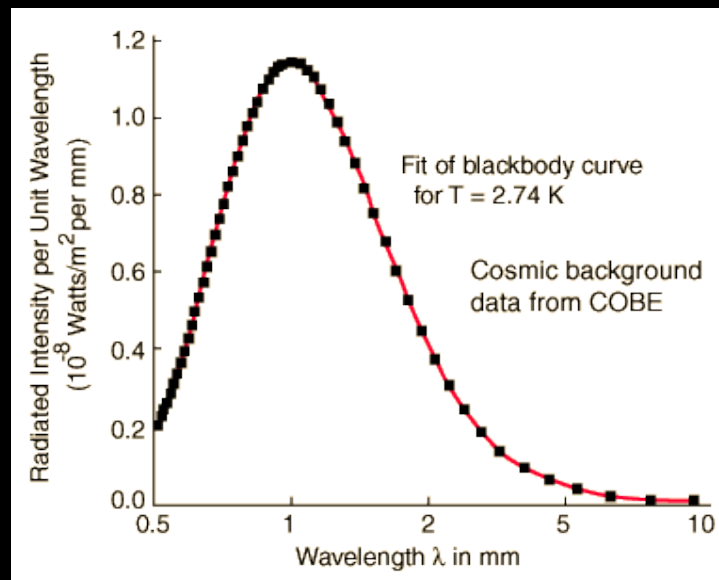
Misura delle fluttuazioni di temperatura della radiazione fossile di fondo $T = 2.725 \text{ K}$



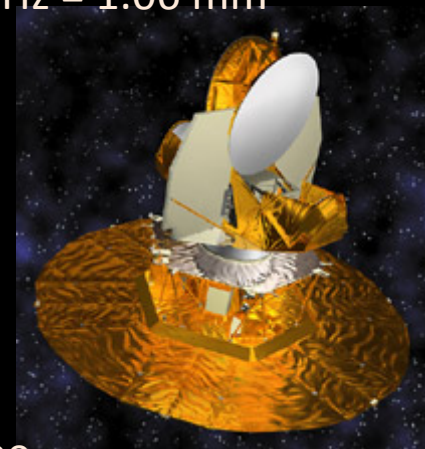
COBE



WMAP

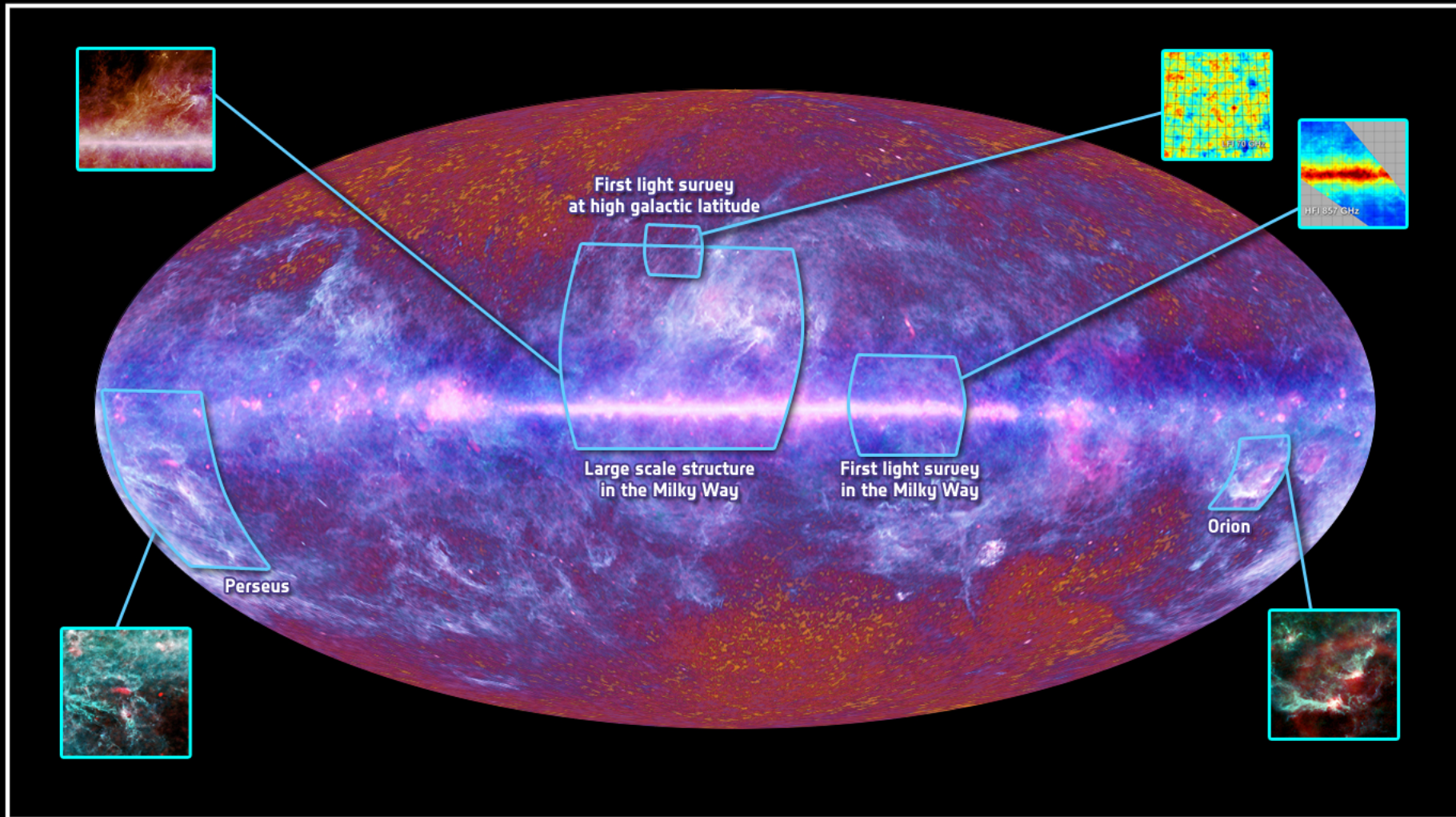


Picco a 283 GHz = 1.06 mm



Disuniformità di $T = 1/100000$

Misura delle fluttuazioni di temperatura della radiazione fossile di fondo $T = 2.725 \text{ K}$



The Planck one-year all-sky survey



(c) ESA, HFI and LFI consortia, July 2010



Los Alamos

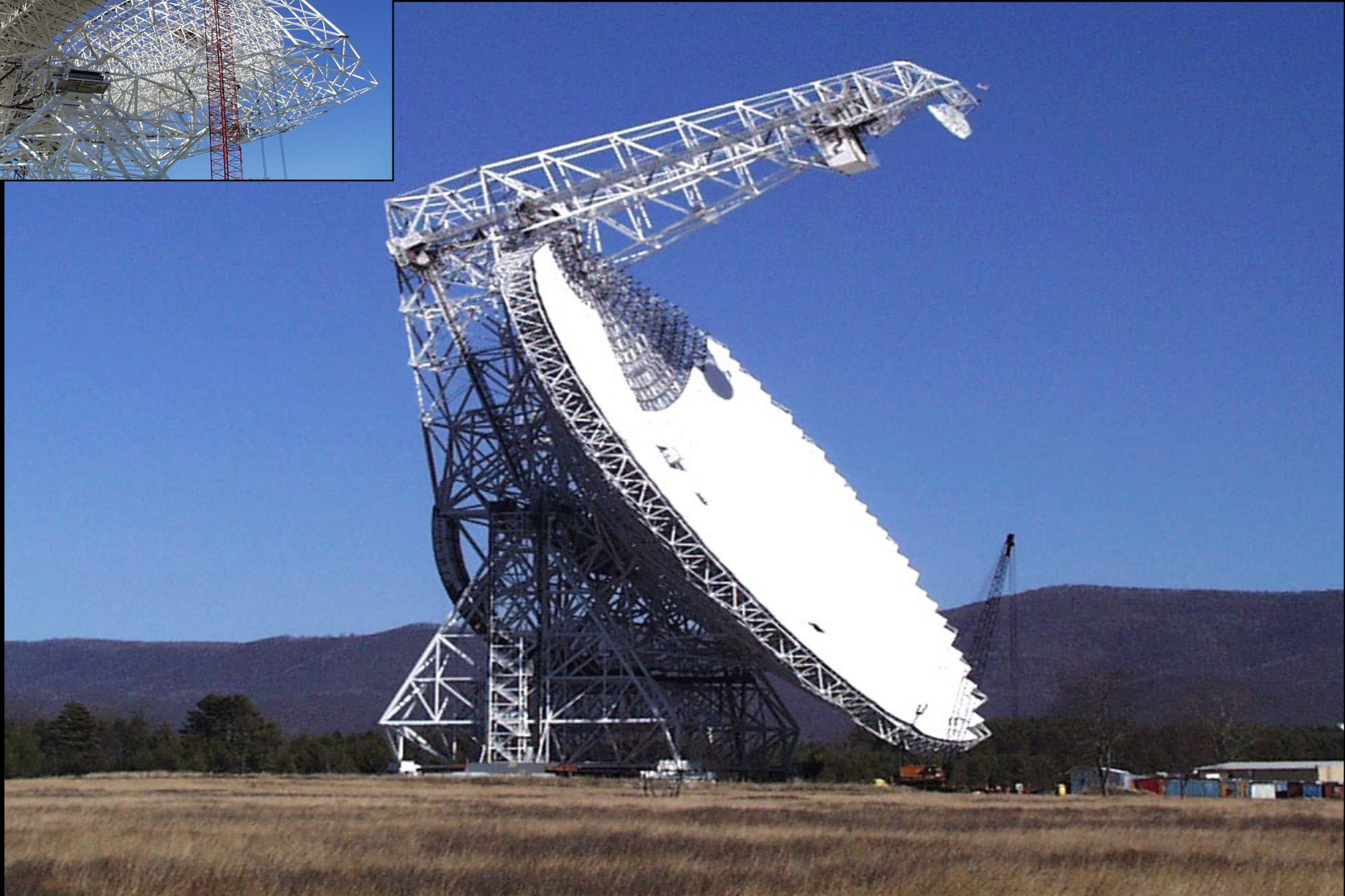


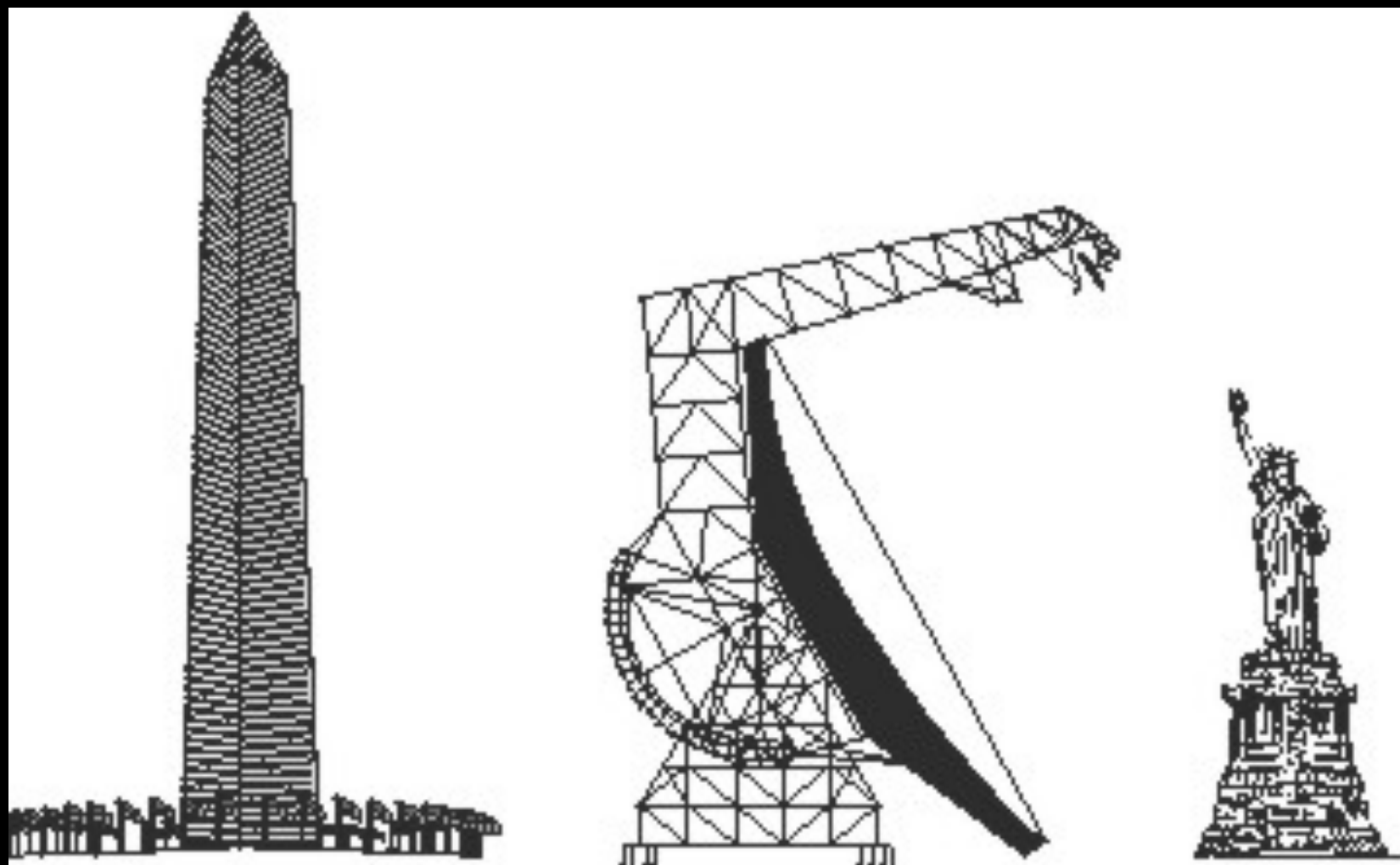
Mauna Kea

Radiotelescopio di PARKES



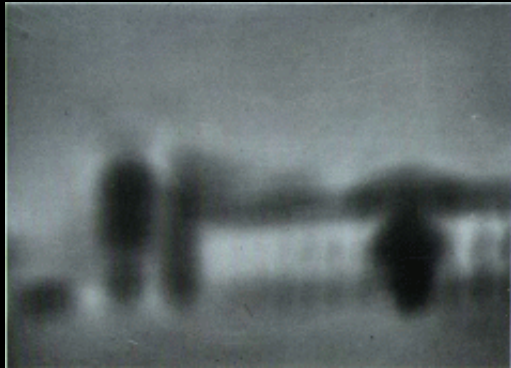
Green Bank







Risoluzione del Telescopio Radio



D=30 m; risoluzione = 30'



D=80 m risoluzione = 10'



D=1600 m risoluzione = 23''

$$r = \frac{1,22\lambda}{D} \text{ [rad]}$$

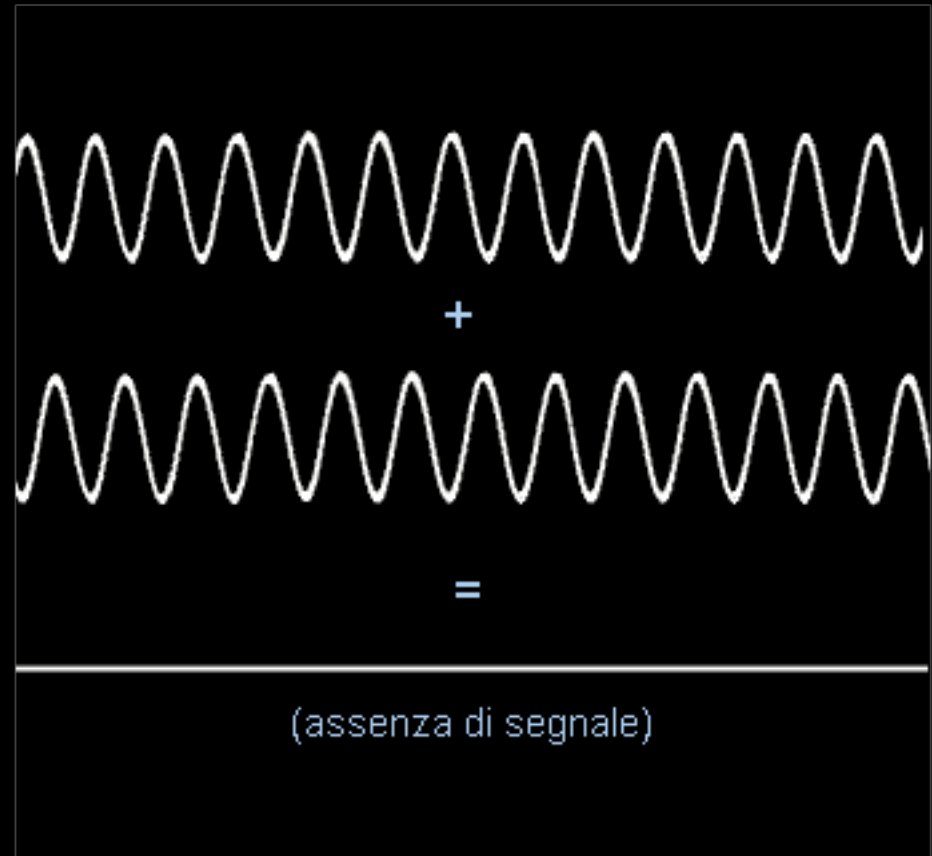
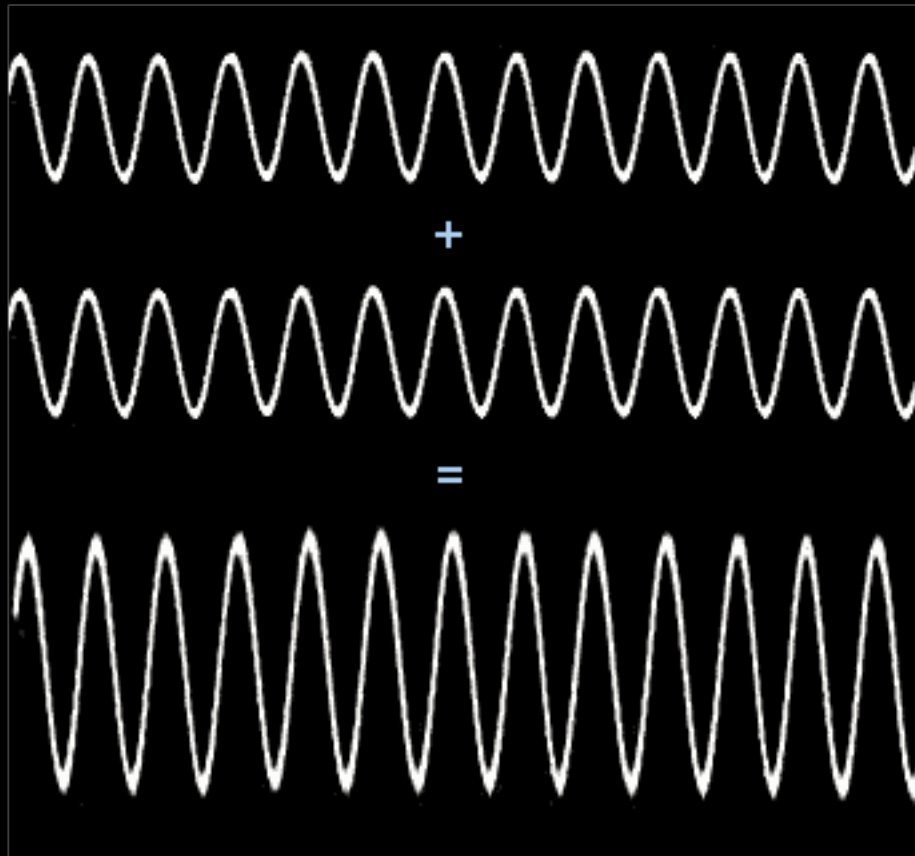
$\lambda = 20 \text{ cm}$

I radiotelescopi sono miopi !!

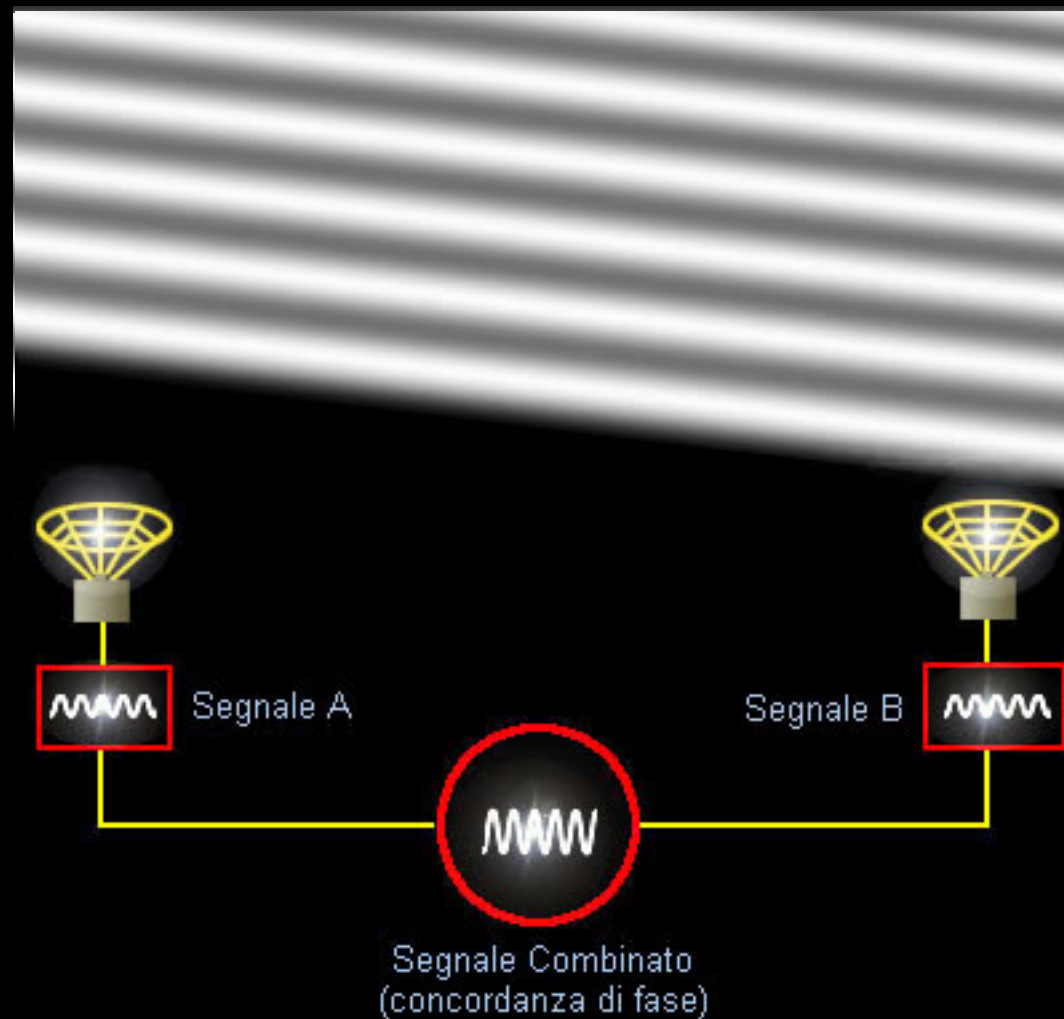
COME SI PUÒ MIGLIORARE?

L'interferometria

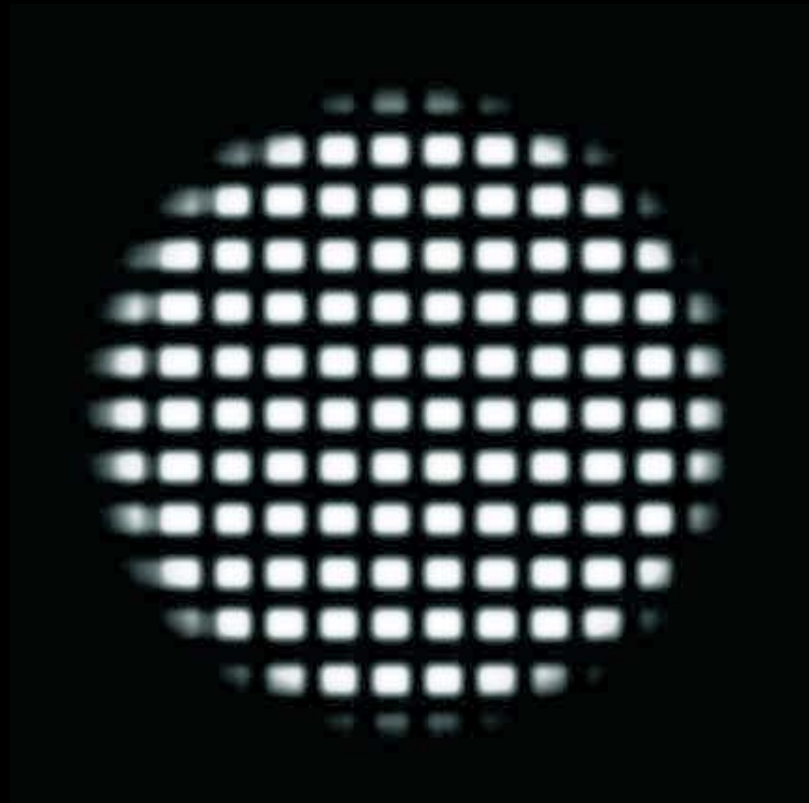
Produrre frange di interferenza



Schema di interferometro



Effetto dell'interferometro



Per migliorare la risoluzione i segnali vengono combinati così da ottenere un potere risolutivo pari ad un unico rivelatore di diametro corrispondente alla massima distanza tra le antenne



Image courtesy of NRAO/AUI

VLA





Westerbork



ATCA
Narrabri



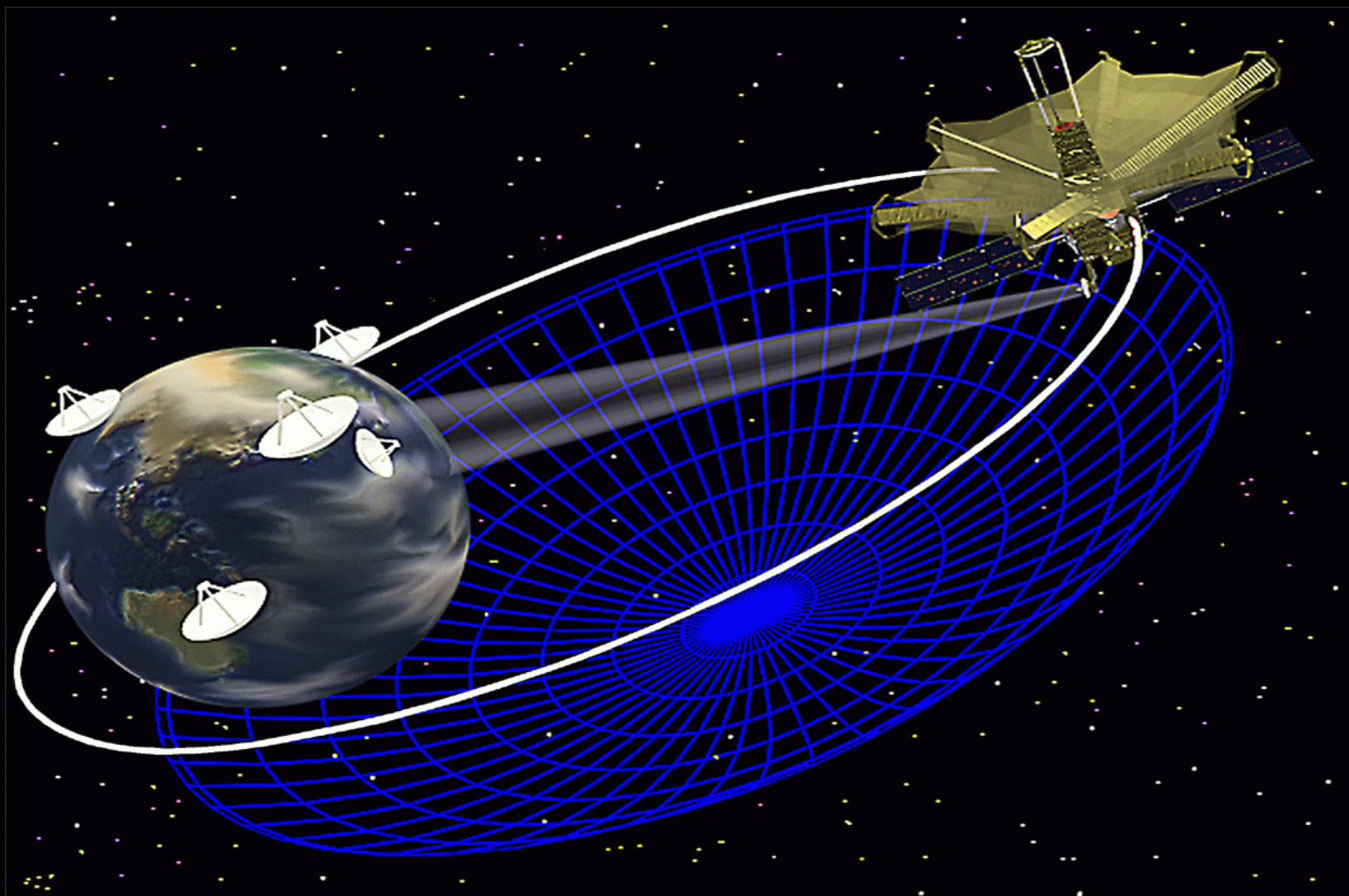
NMA Giappone

National Astronomical Observatory
of Japan, Nobeyama Radio
Observatory



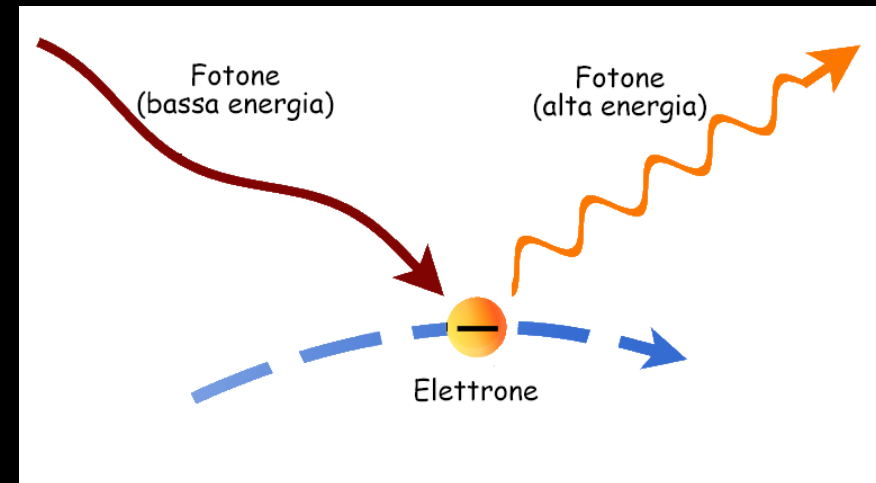
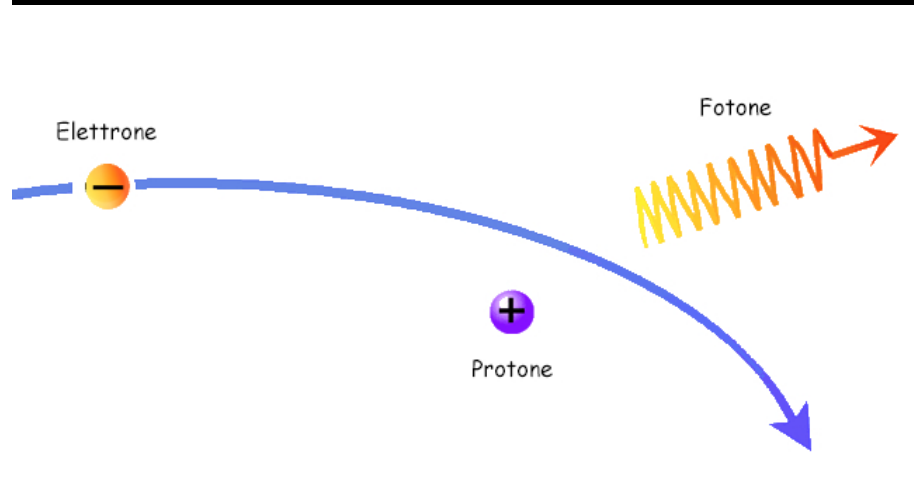


HALCA (1997-2003): apogeo a 21,400 km e perigeo a 560 km
RADIOASTRON (2011-): 390,000 – 10,000 km @1.35–6.0, 18.0 e 92.0 cm



Sorgenti di onde radio

Come vengono prodotte onde radio

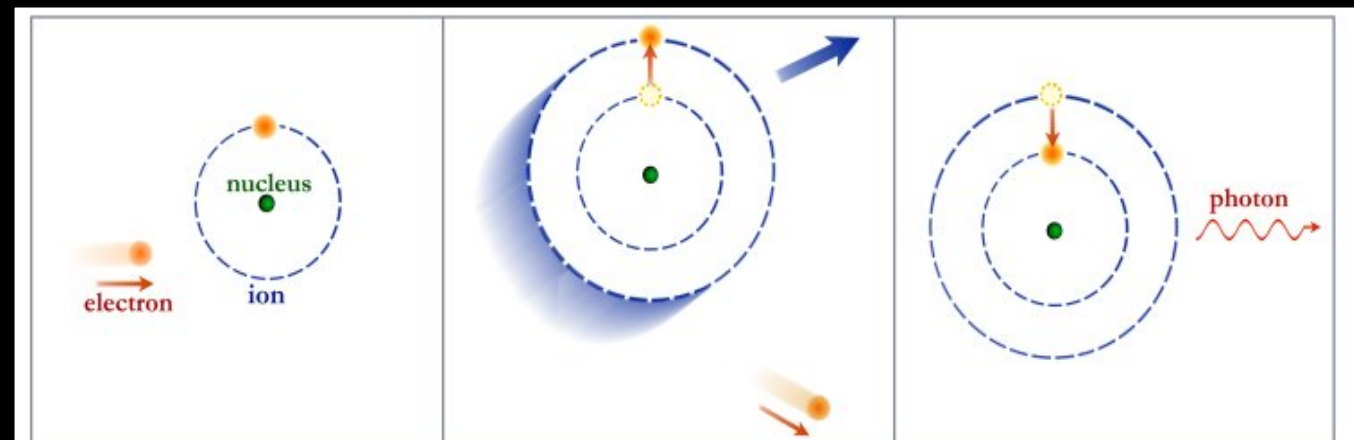


Bremsstrahlung (radiazione di frenamento)

Effetto Compton

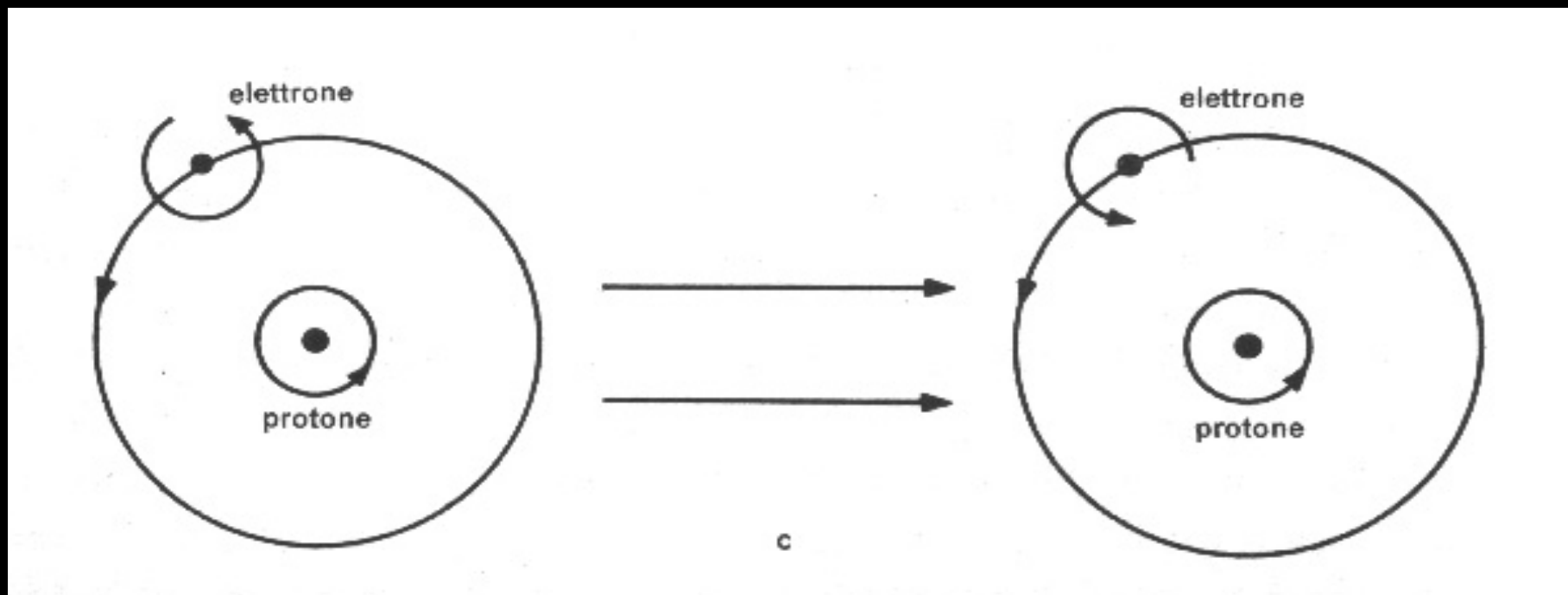
Se l'energia è sufficiente l'atomo viene **IONIZZATO**

Atomo eccitato



Come vengono prodotte onde radio

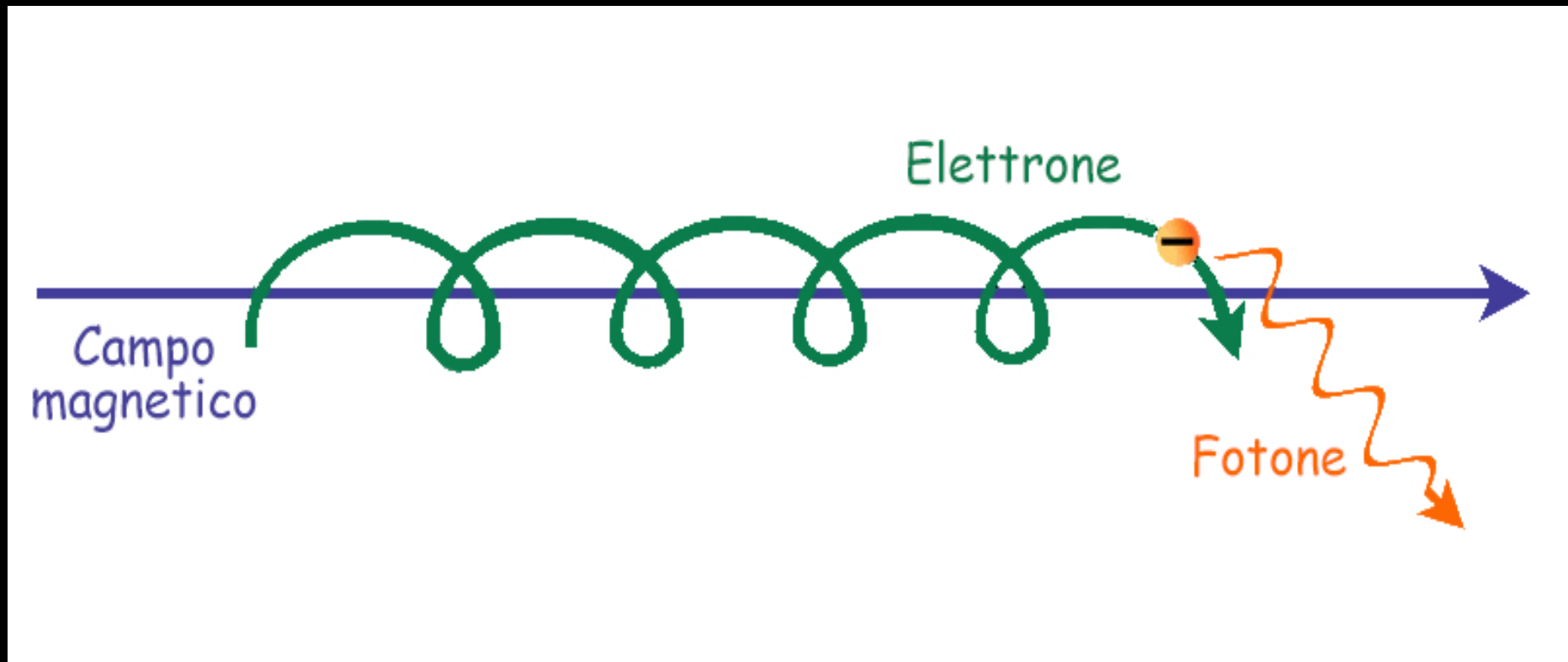
Inversione di spin



Produce una RIGA di emissione a 21 cm

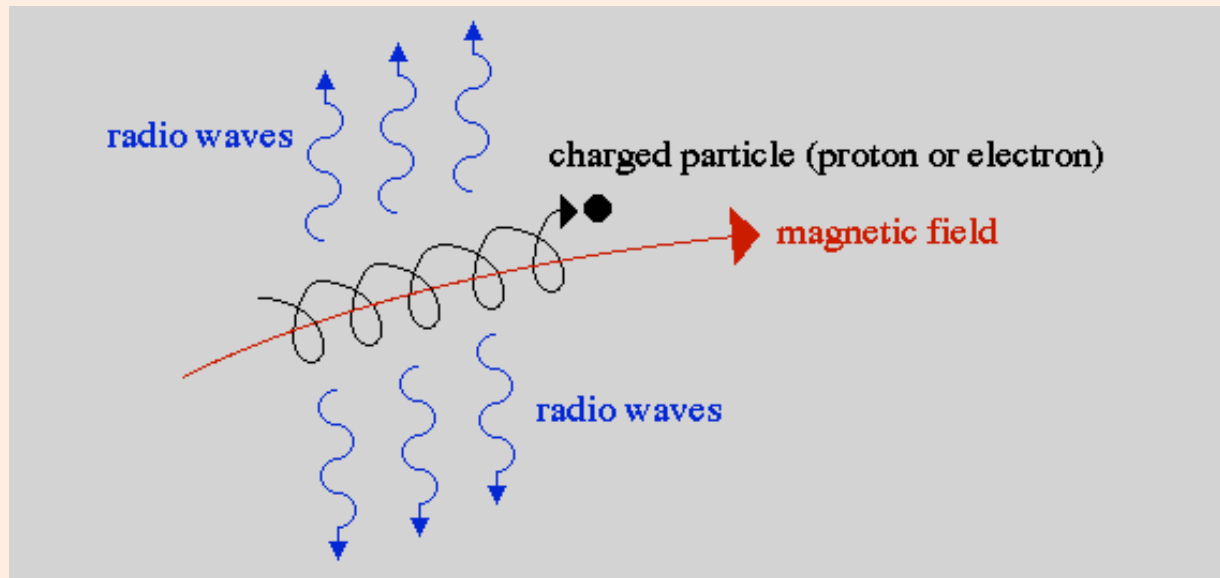
Come vengono prodotte onde radio

Radiazione di sincrotrone



Indica la presenza di campo magnetico

Synchrotron Radiation



$$\frac{dE}{dt} = 1.6 \times 10^{-15} \gamma^2 H^2$$

(erg s⁻¹ if H in G)

$$\nu_s \approx 4.2 \gamma^2 H$$

(MHz if H in G)

RADIO : $H = 10^{-6}$ G $\gamma > 1000$

Ensemble of particles with
power-law energy distribution : $N(E)dE = N_0 E^{-\delta} dE$

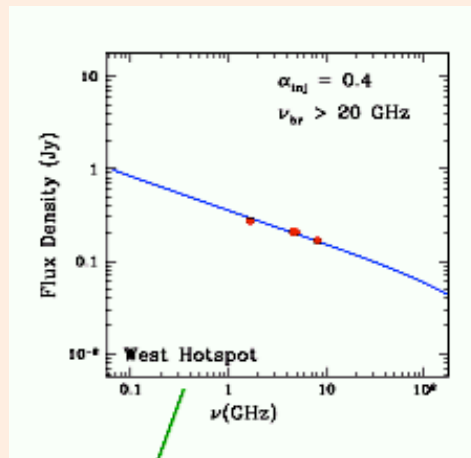
Radio diagnostics:

1 - Spectrum → age of radiating particles

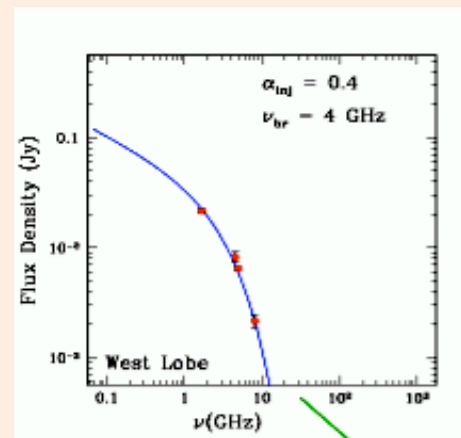
Emissivity of Ensemble of Electrons :

$$\underline{\varepsilon}(\underline{\nu}) \propto \underline{N}_0 H_{\perp}^{1+\alpha} \underline{\nu}^{-\alpha}$$

$$\alpha = \frac{\delta - 1}{2}$$

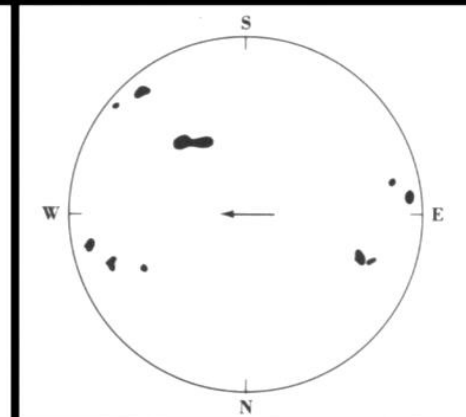
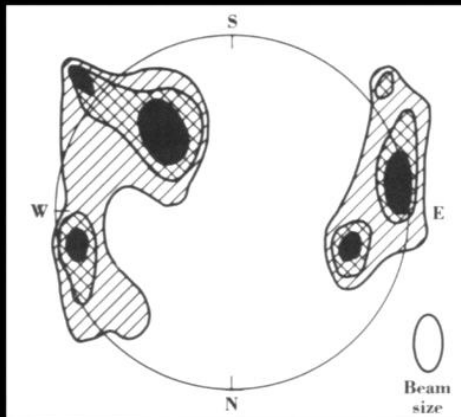
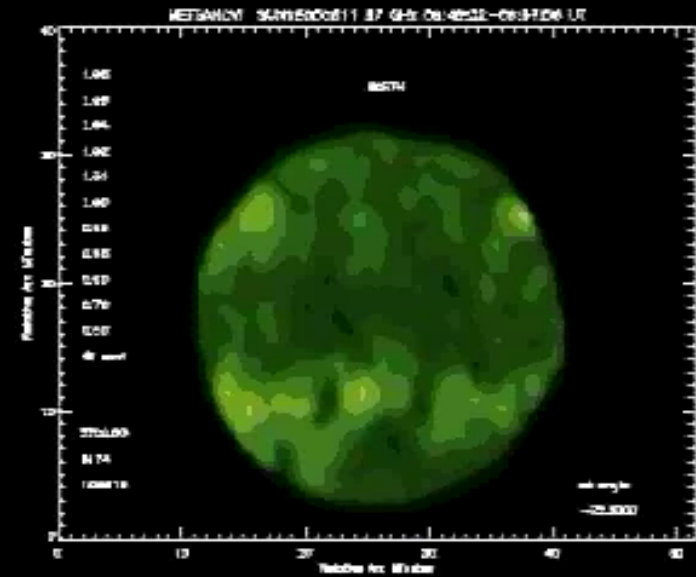
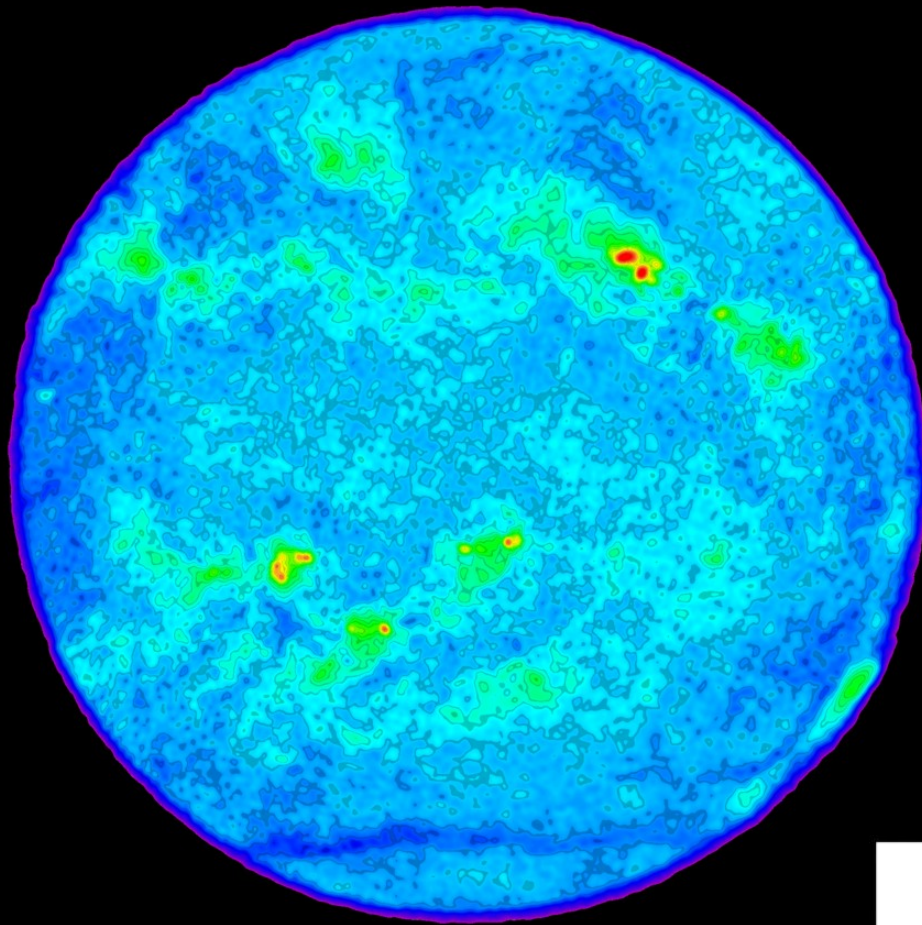


Original spectrum



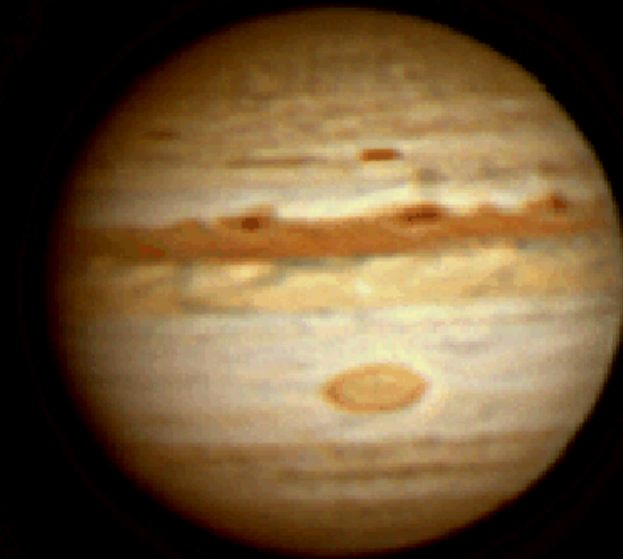
Aged spectrum

Sorgenti radio nella nostra Galassia

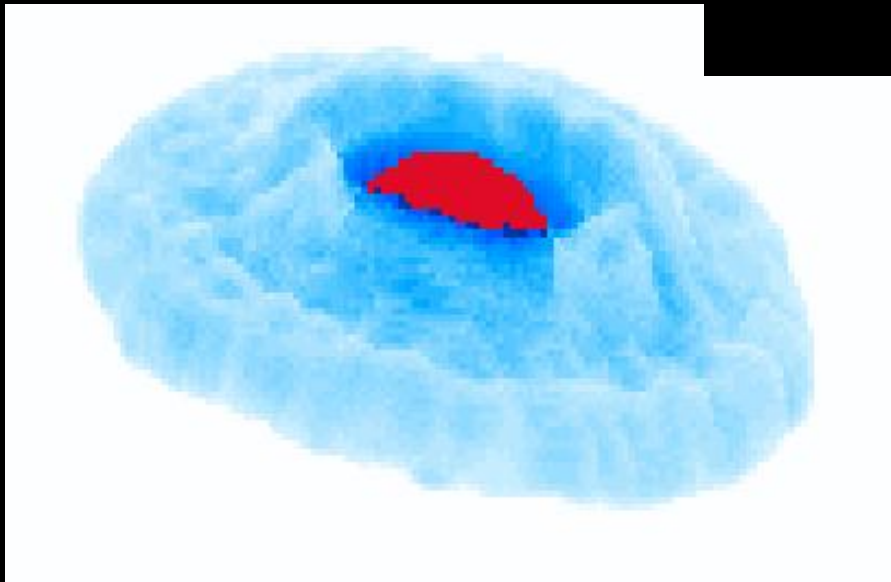


Giove:

In ottico

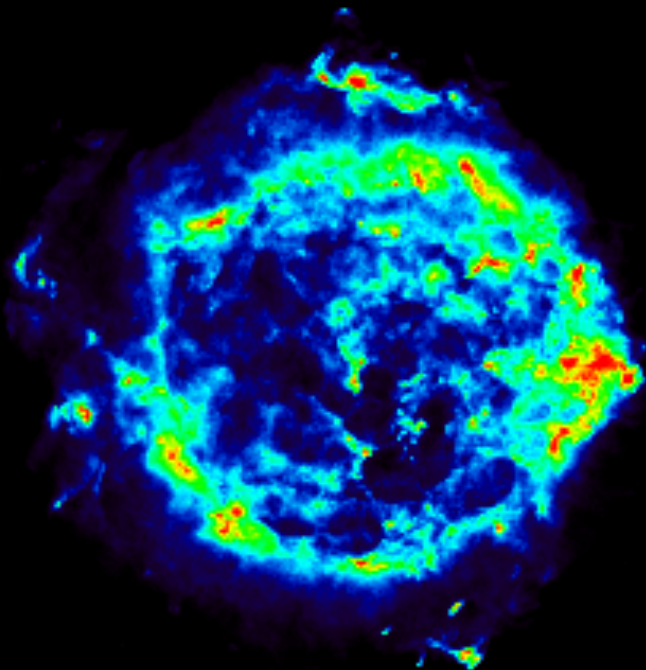


Jupiter - Nordic Optical Telescope

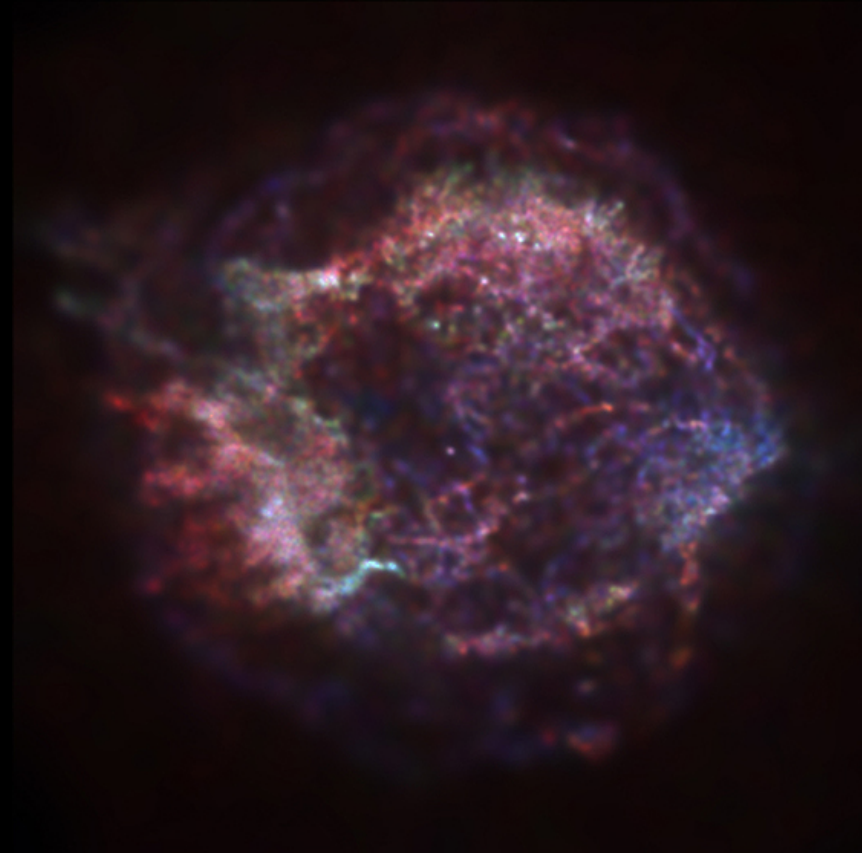


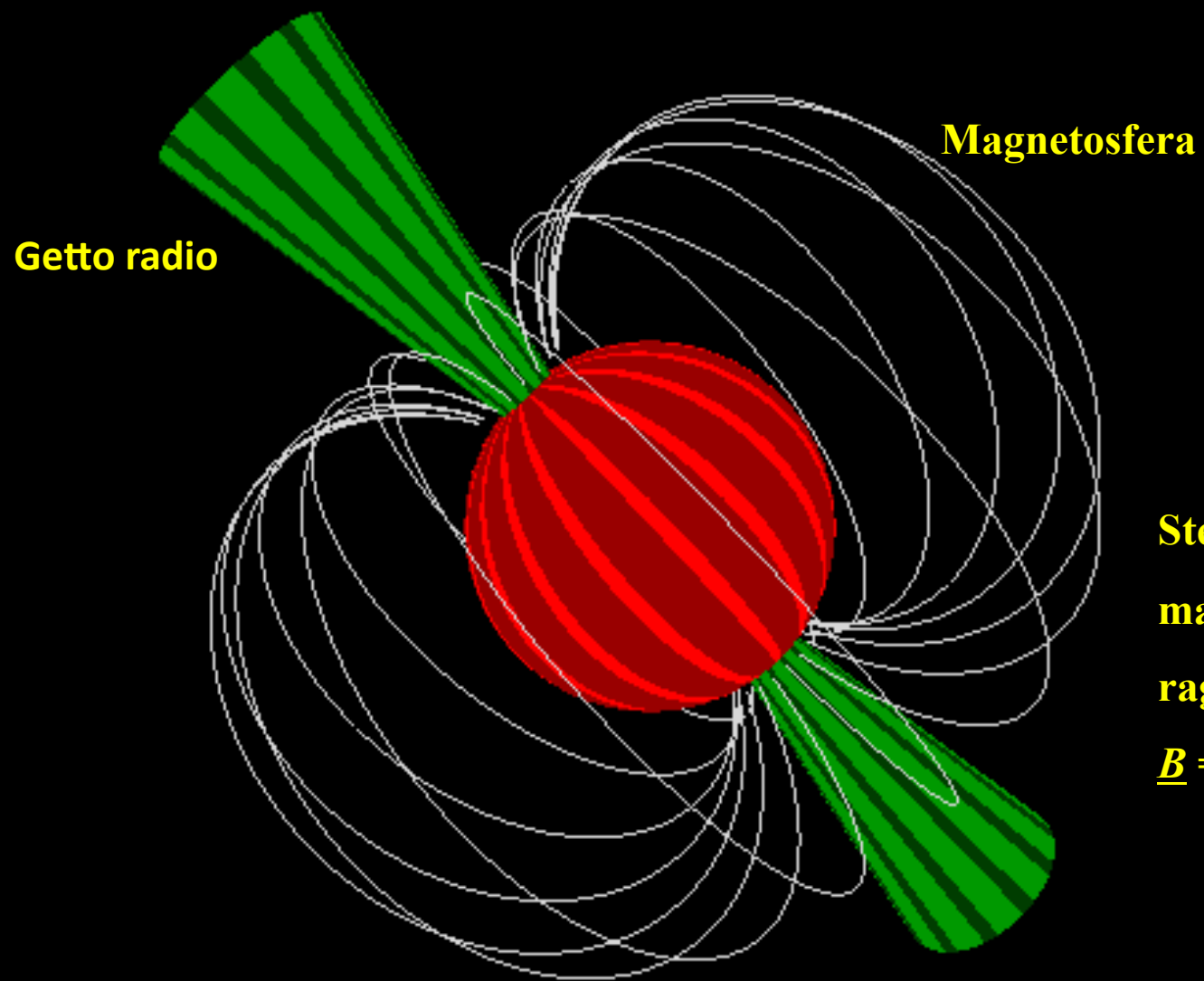
In radio

Il resto di supernova Cassiopea A visto da Einstein/ROSAT e da Chandra



Nella banda radio





Stella di Neutroni

massa = 1.4 M sol

raggio = 10 km

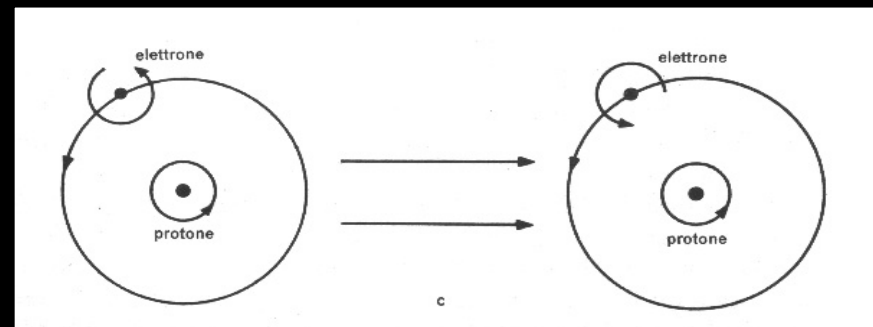
$\underline{B} = 10^8 - 10^{13} \text{ G}$

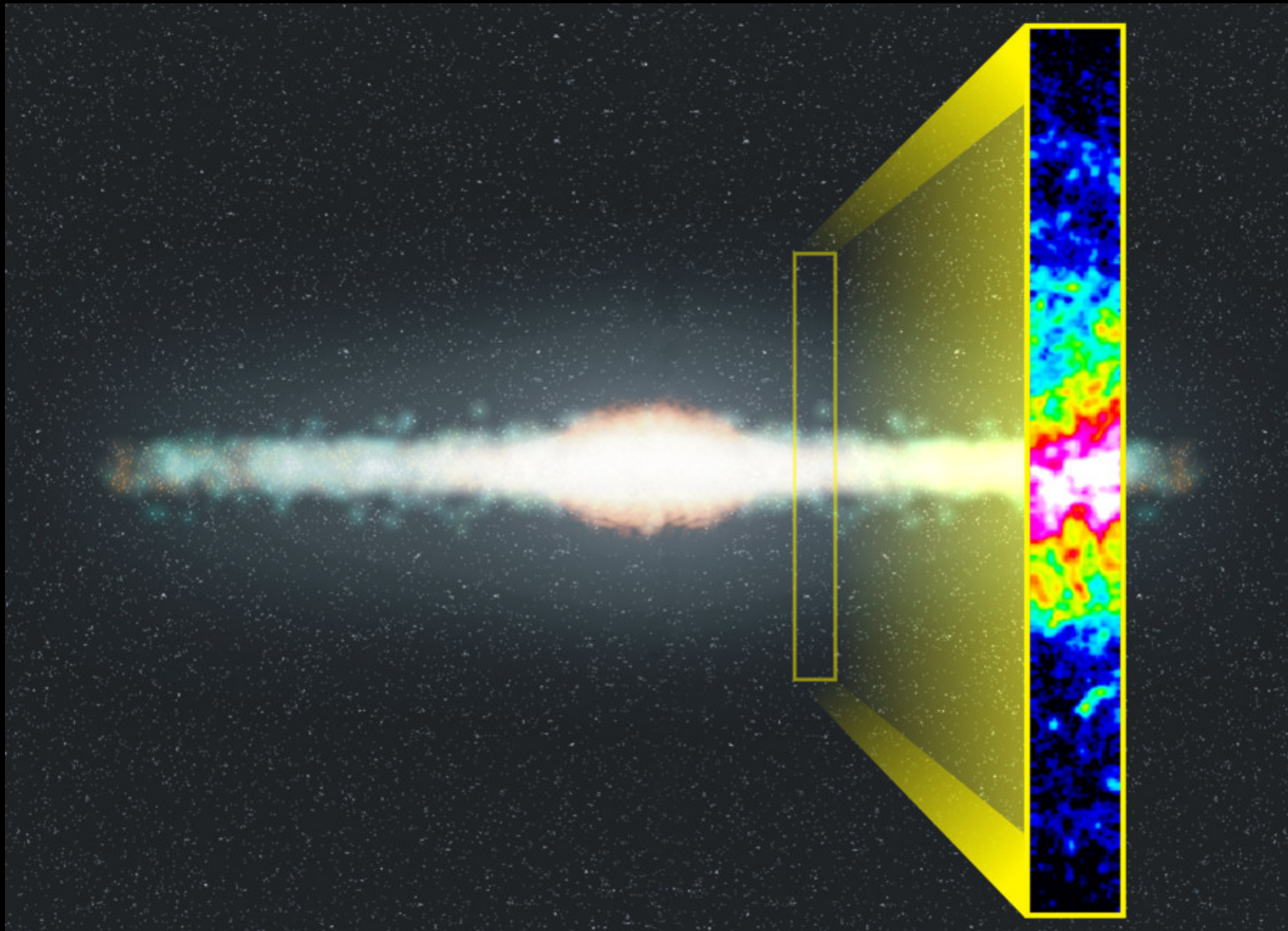
Schema di pulsar

Sorgenti di emissione radio

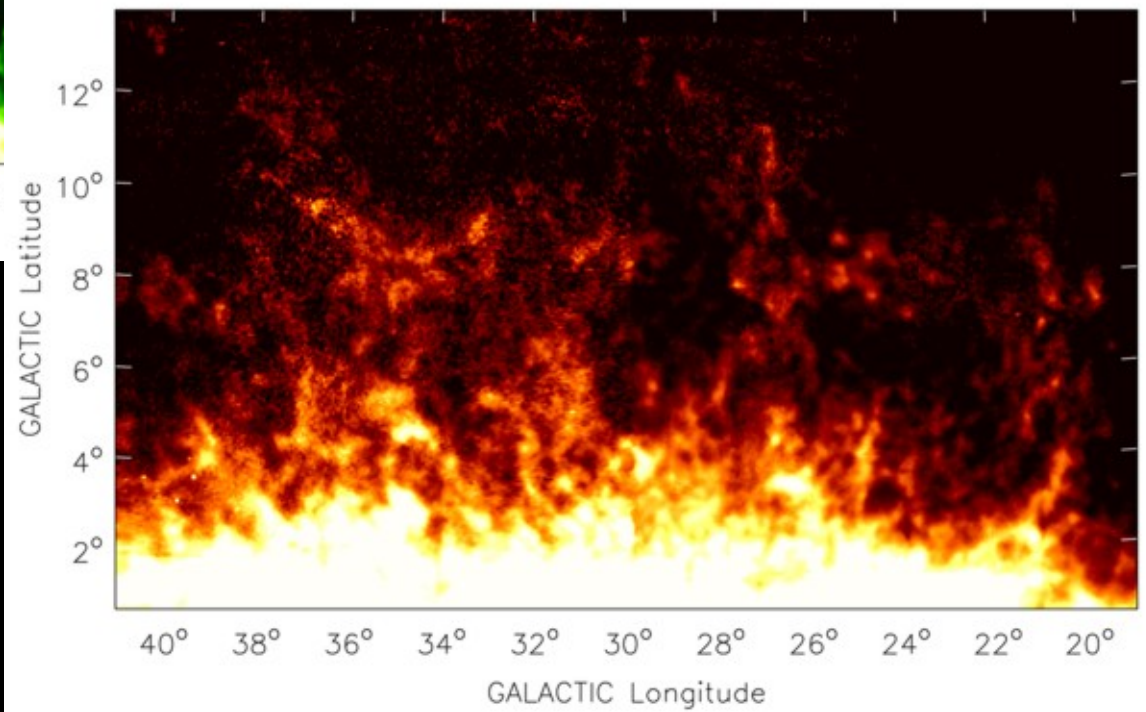
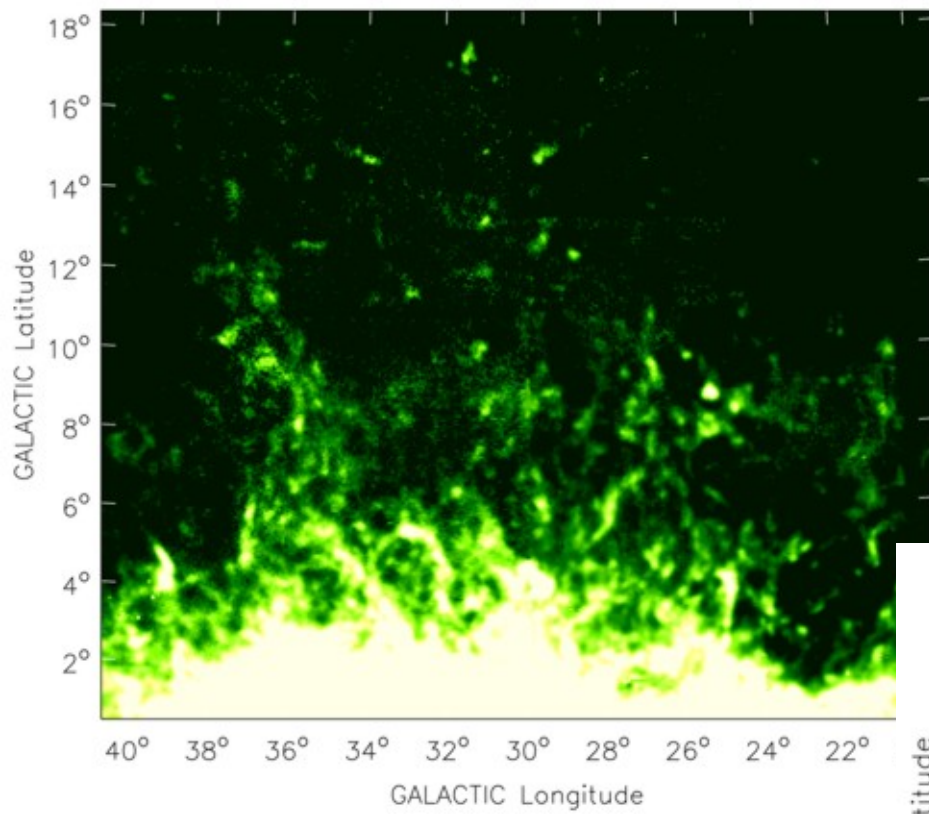
Galassie normali

- Il gas “freddo”, in particolare l'idrogeno **ATOMICO** (l'elemento più abbondante nel cosmo), produce emissione radio alla frequenza di 21 cm (inversione di spin): si vede una **RIGA** di emissione in radio





La nostra galassia



La nostra galassia

M31 - Andromeda

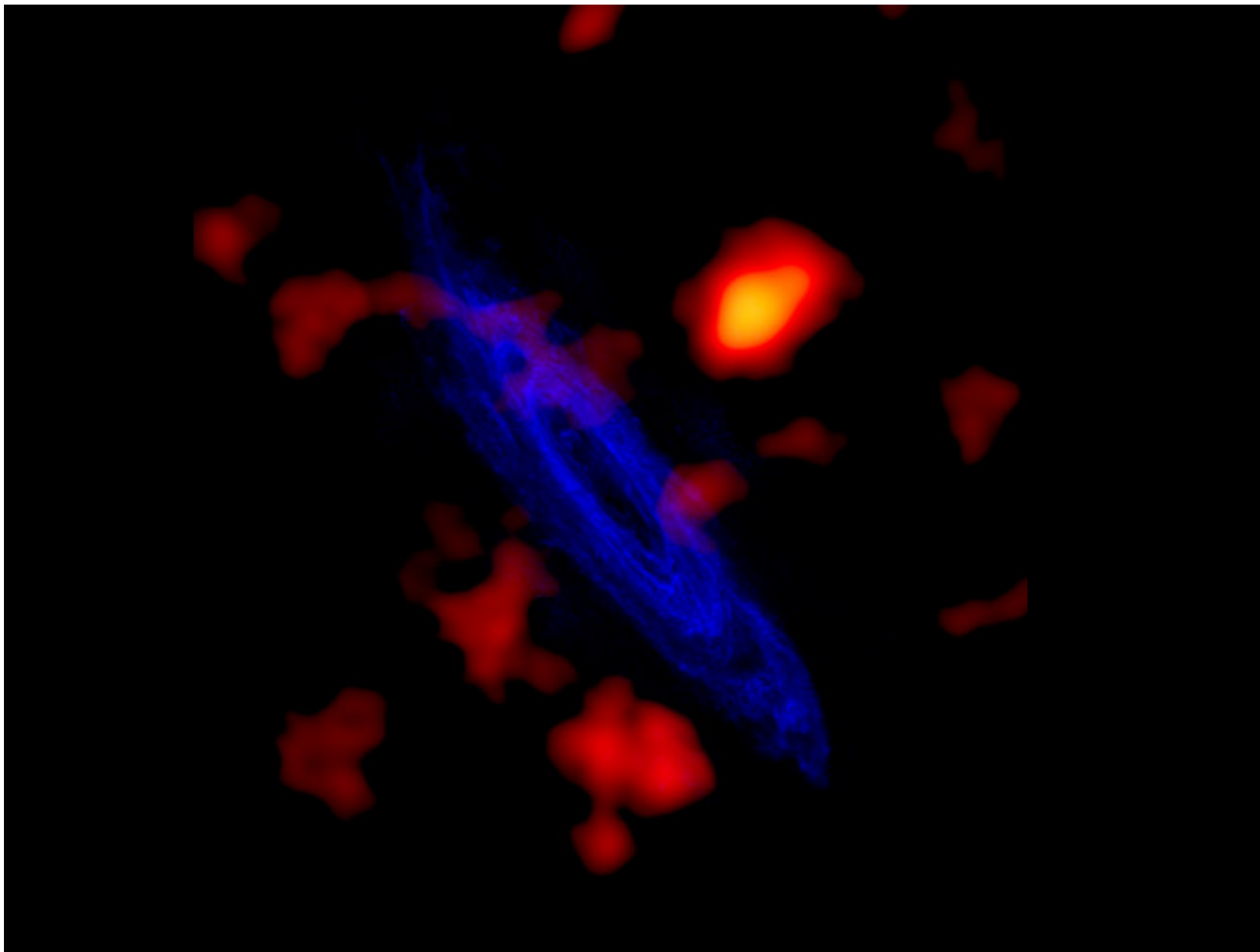


M31



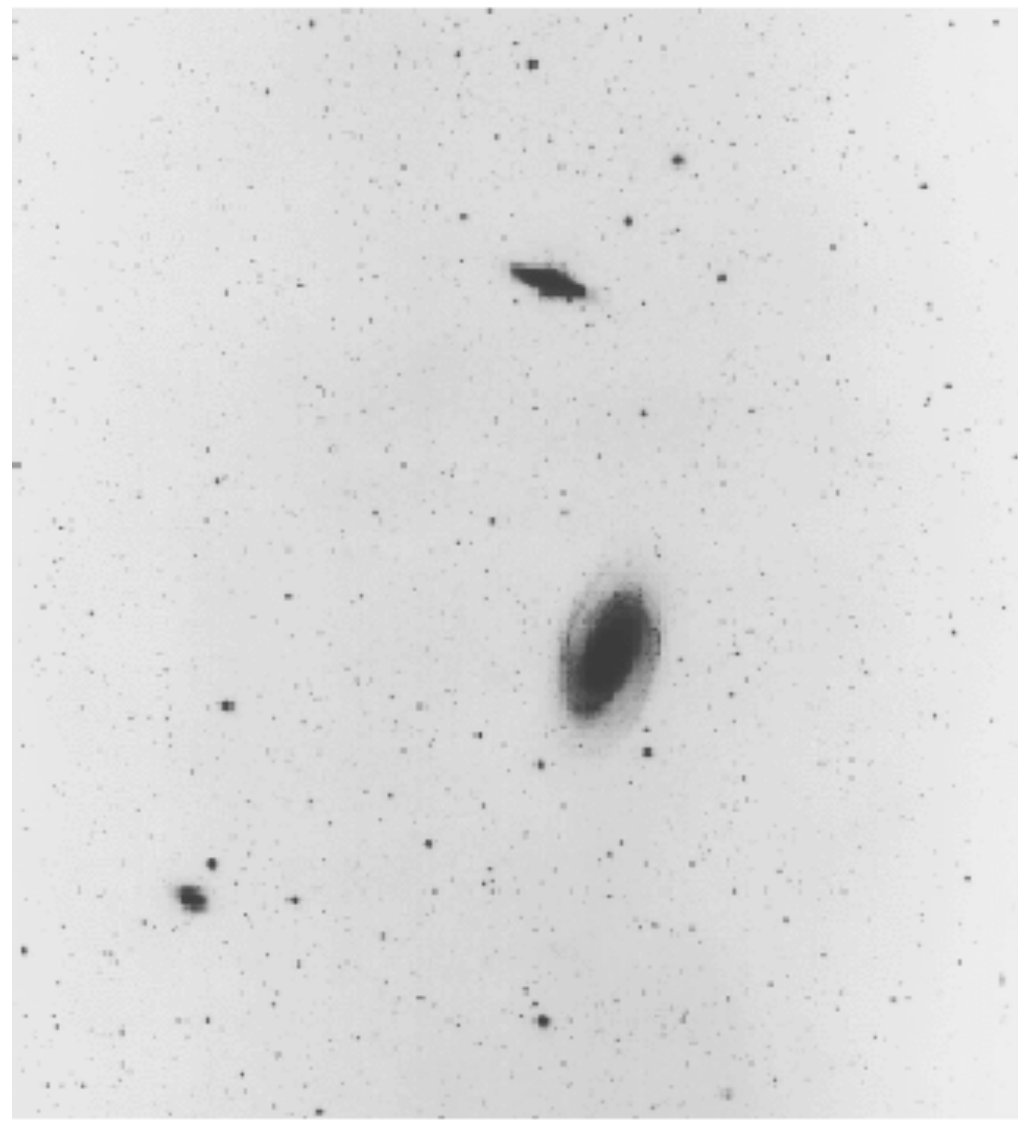
1
40,000 LY



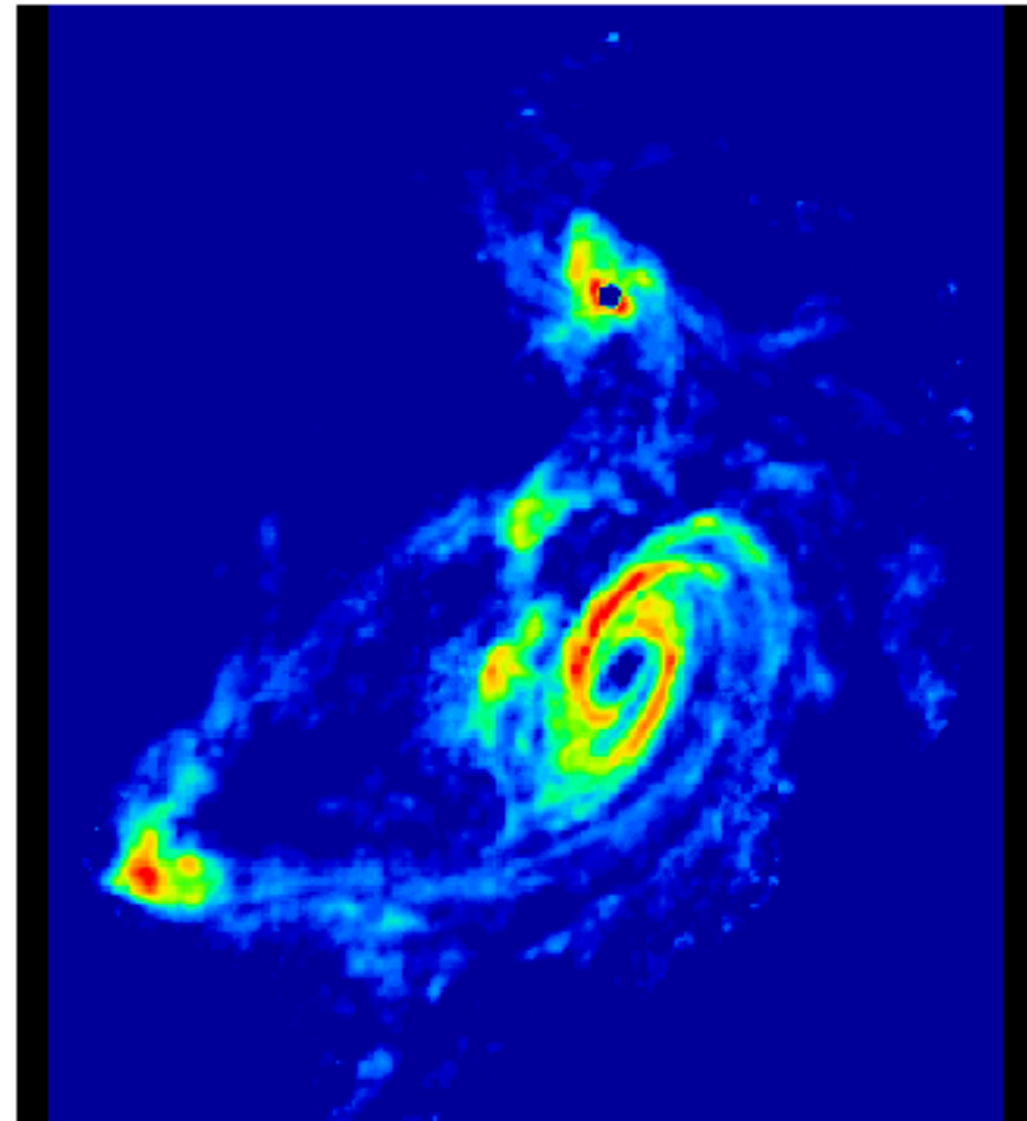


TIDAL INTERACTIONS IN M81 GROUP

Stellar Light Distribution

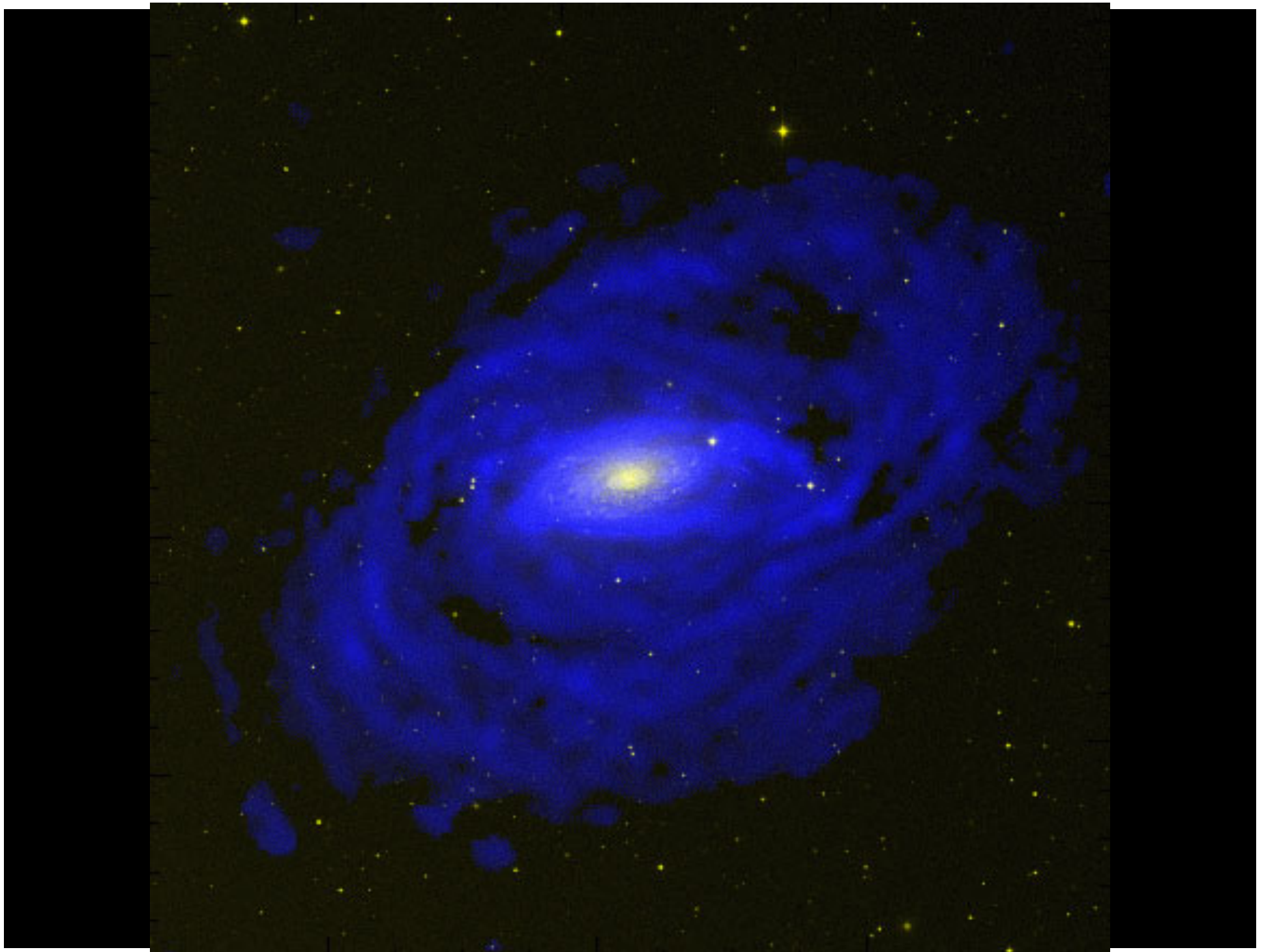


21cm HI Distribution

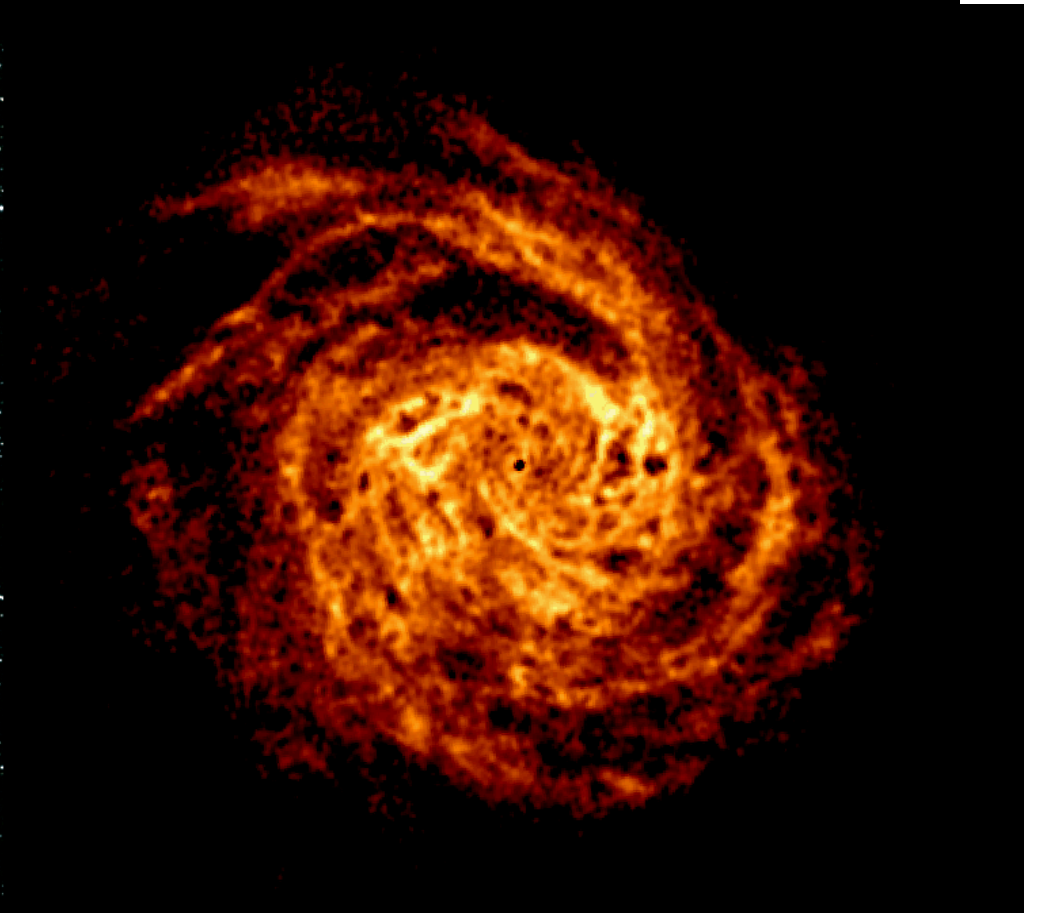


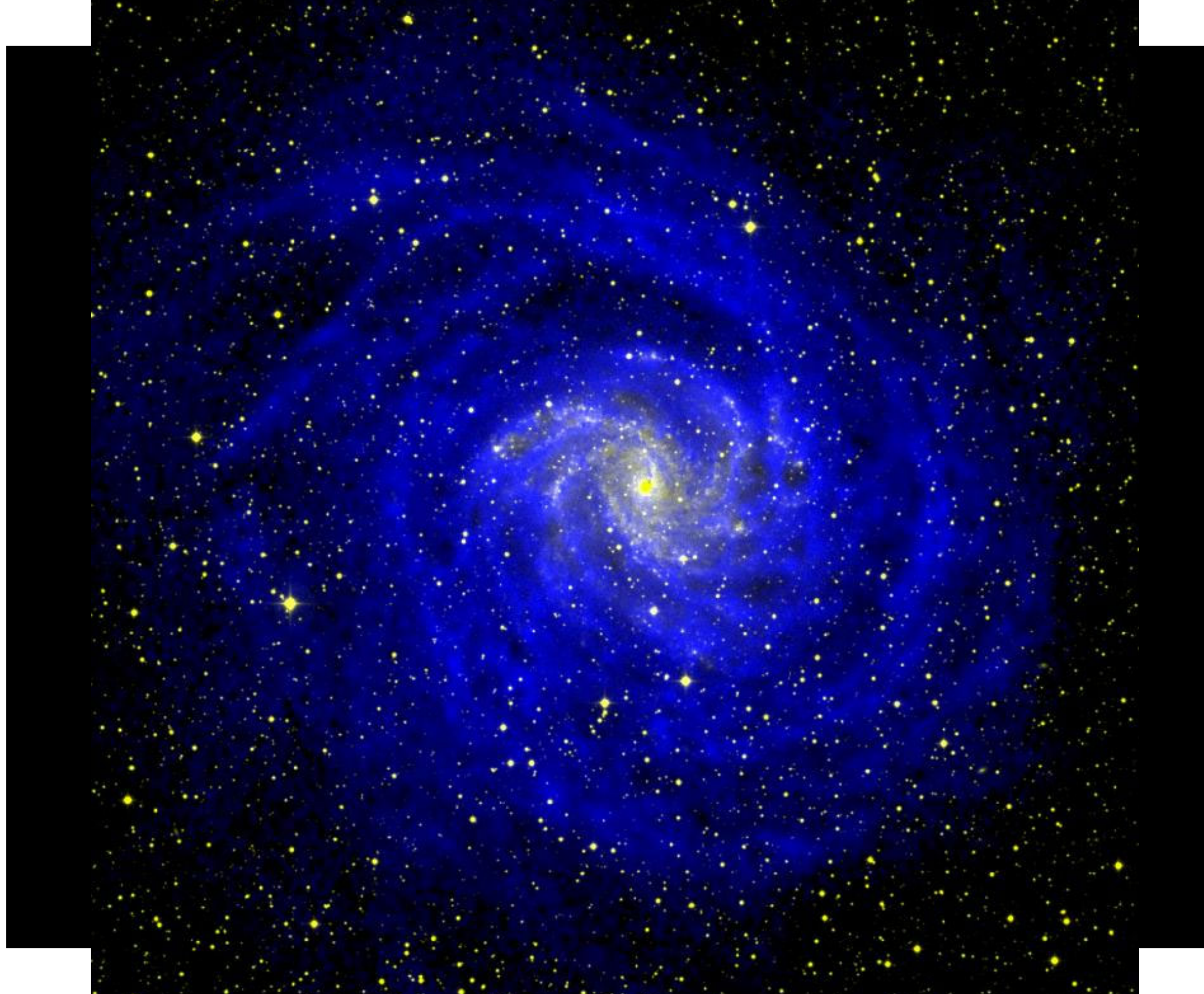
NGC 5055



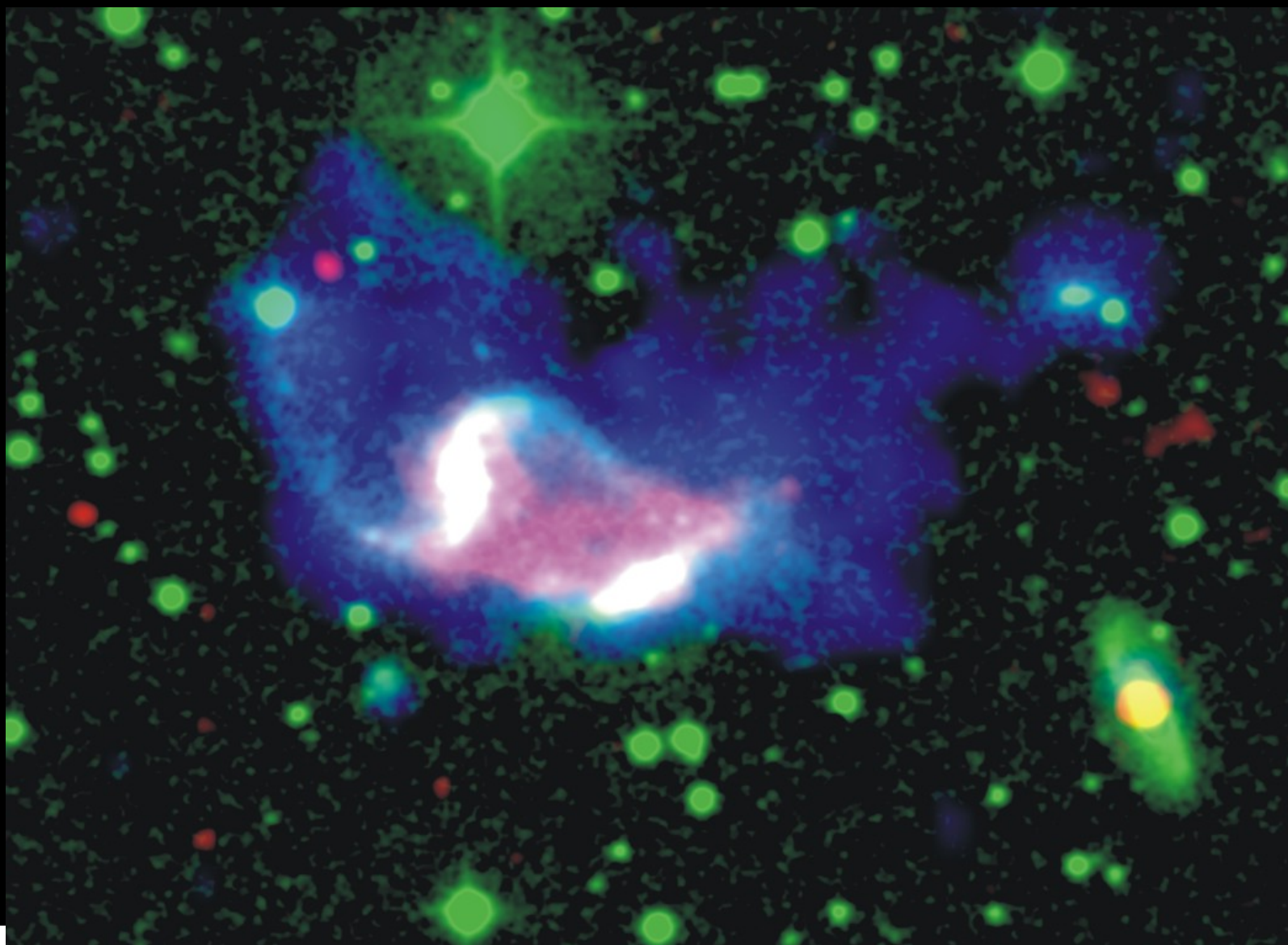


NGC 6946

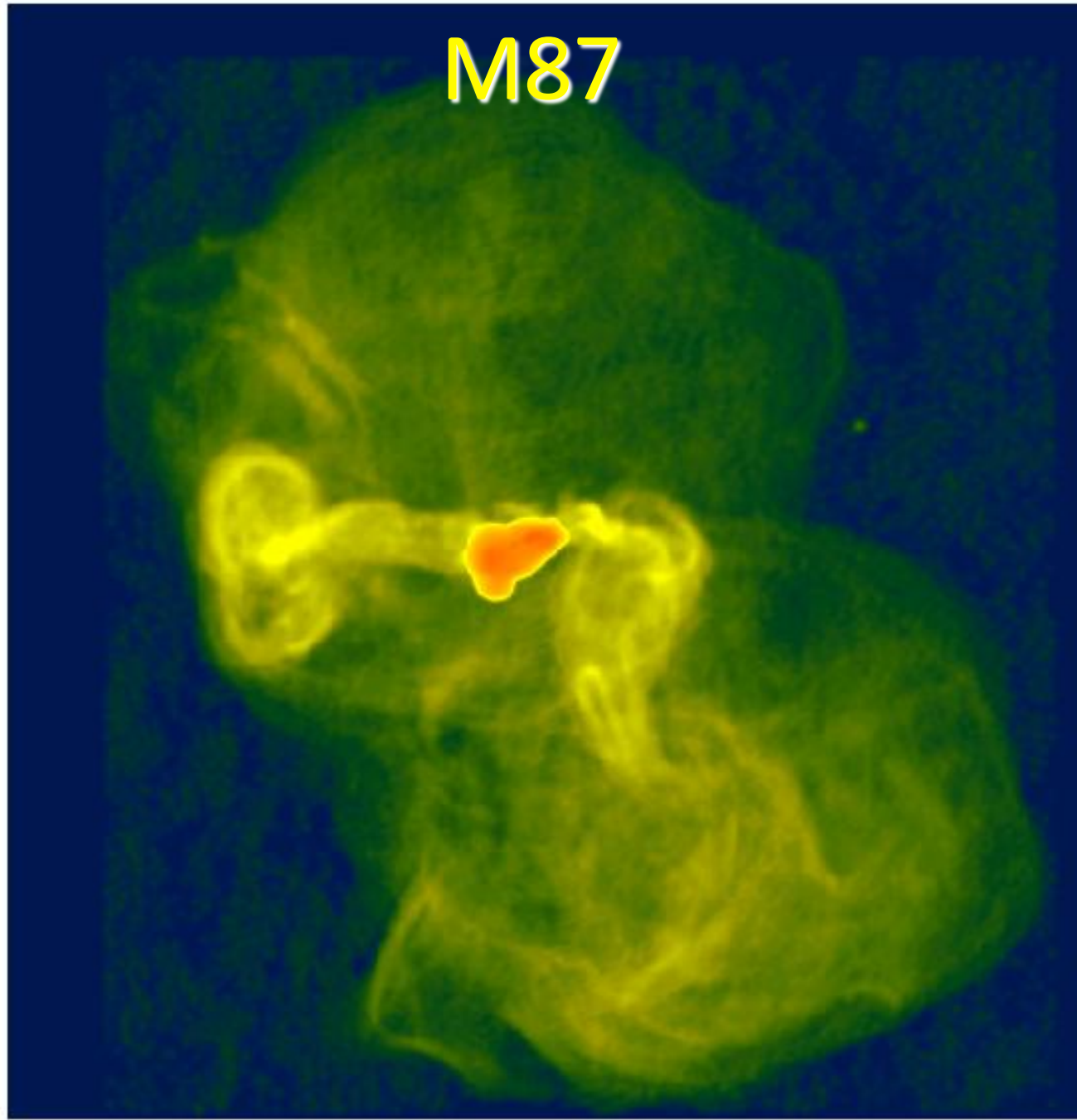




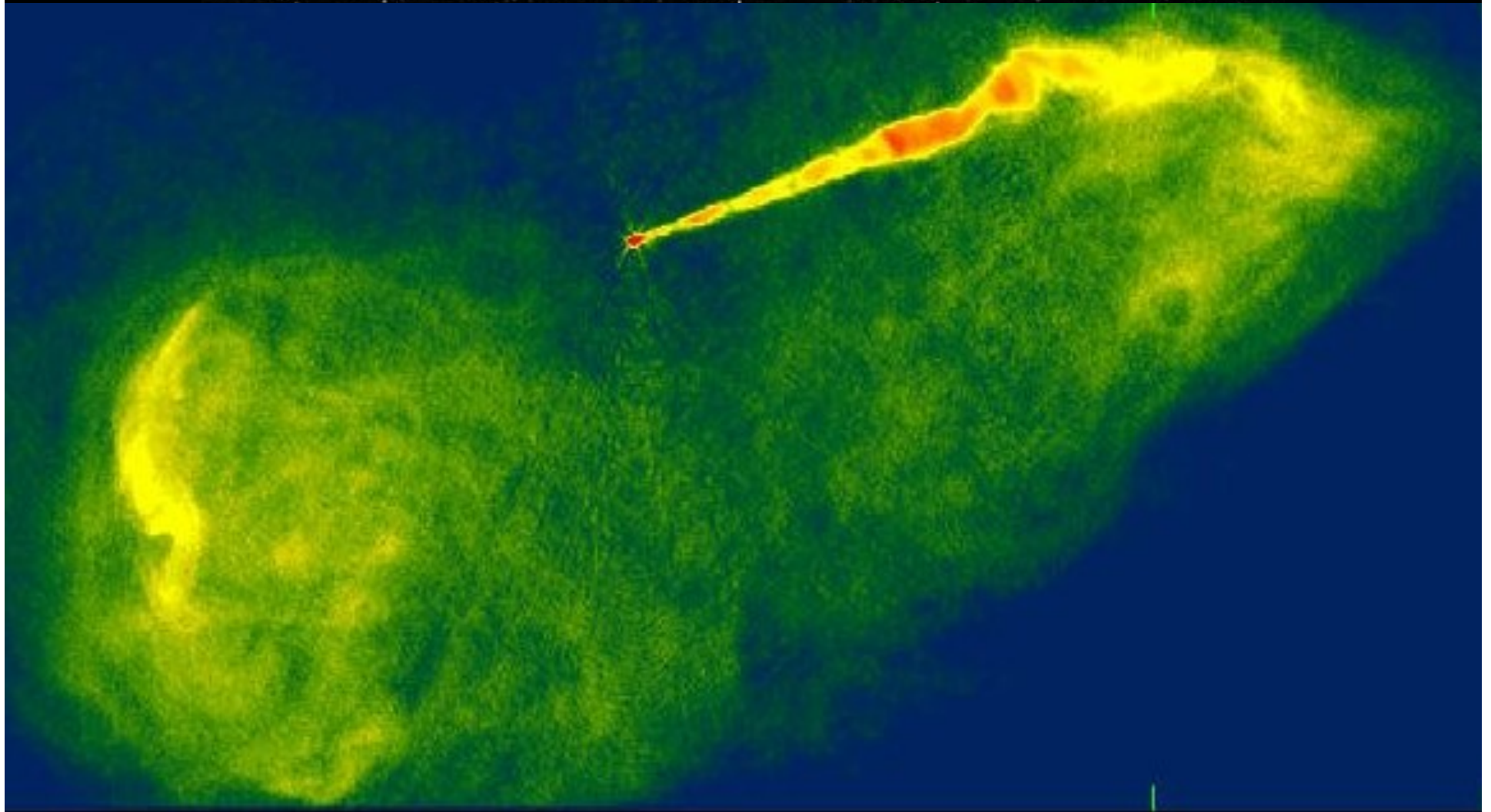
UGC 813



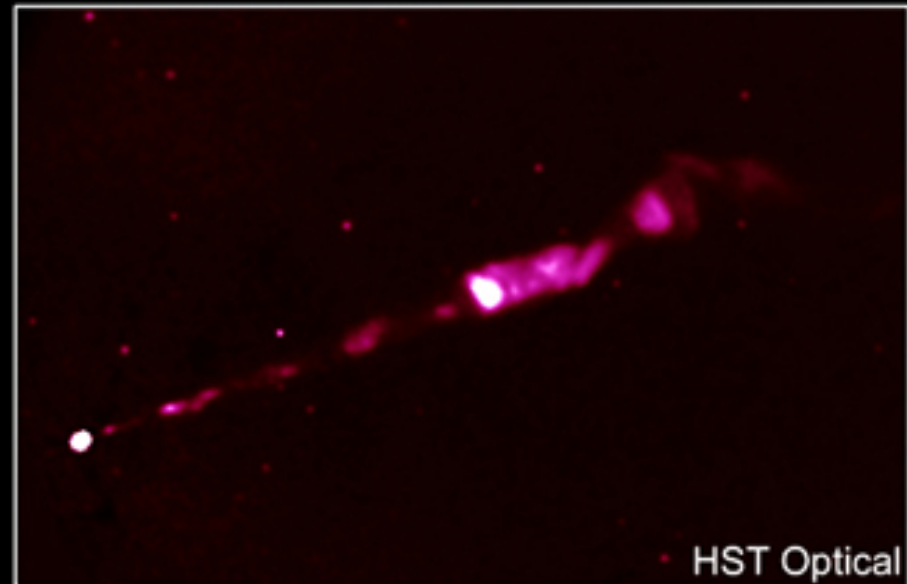
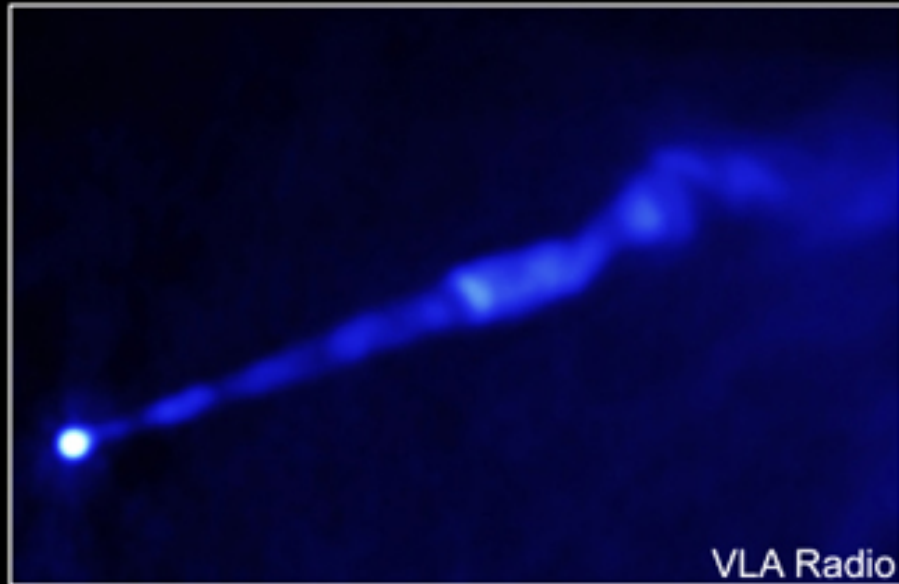
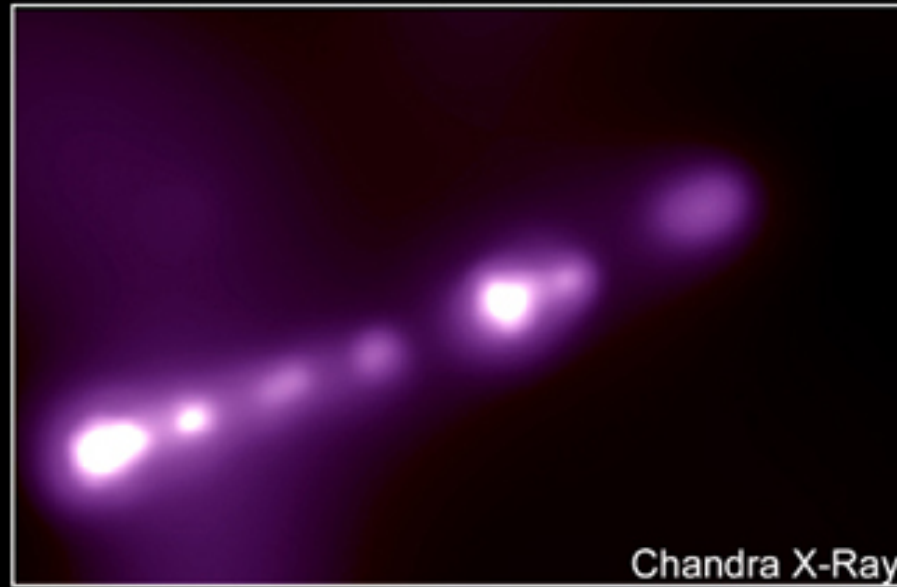
M87



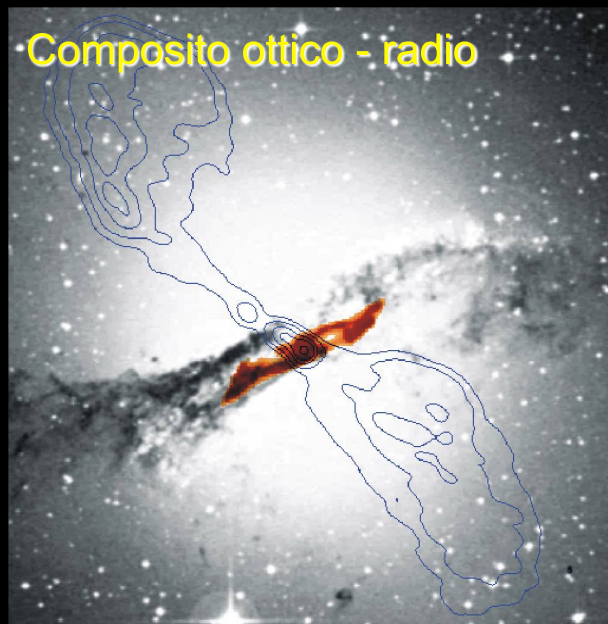
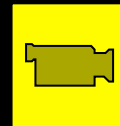
M87



M87

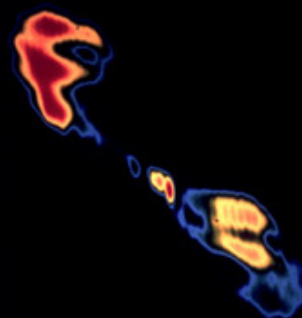


NGC 5128 = Centauro A

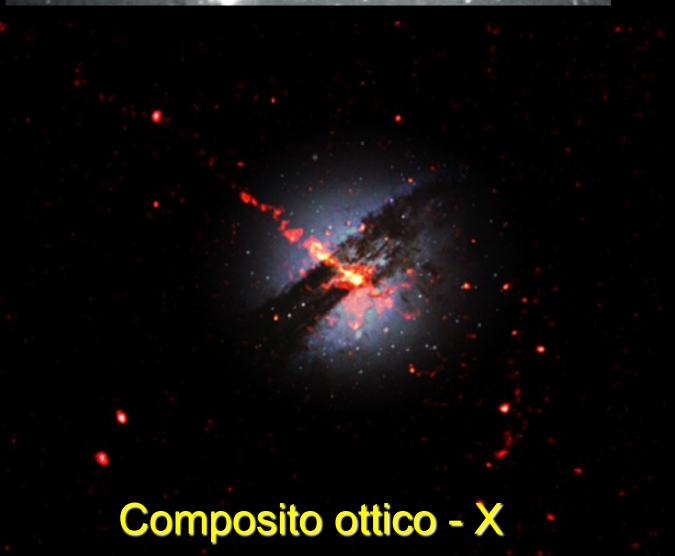


(11 Mpc)

Emissione radio

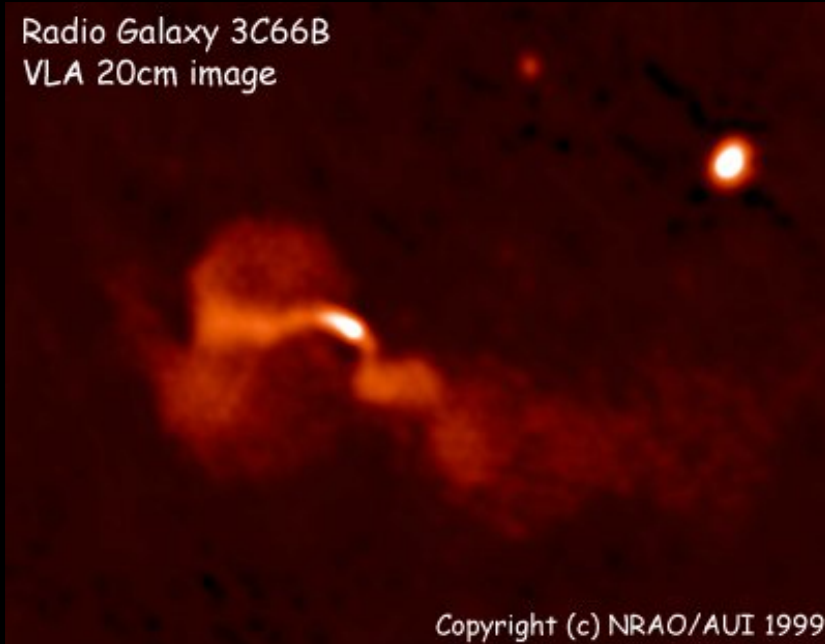


Composito ottico - X



3C66B = B0220+427

Radio Galaxy 3C66B
VLA 20cm image



Copyright (c) NRAO/AUI 1999

Radiogalassia (FR I)
distante 65 Mpc ($z = 0.0125$)

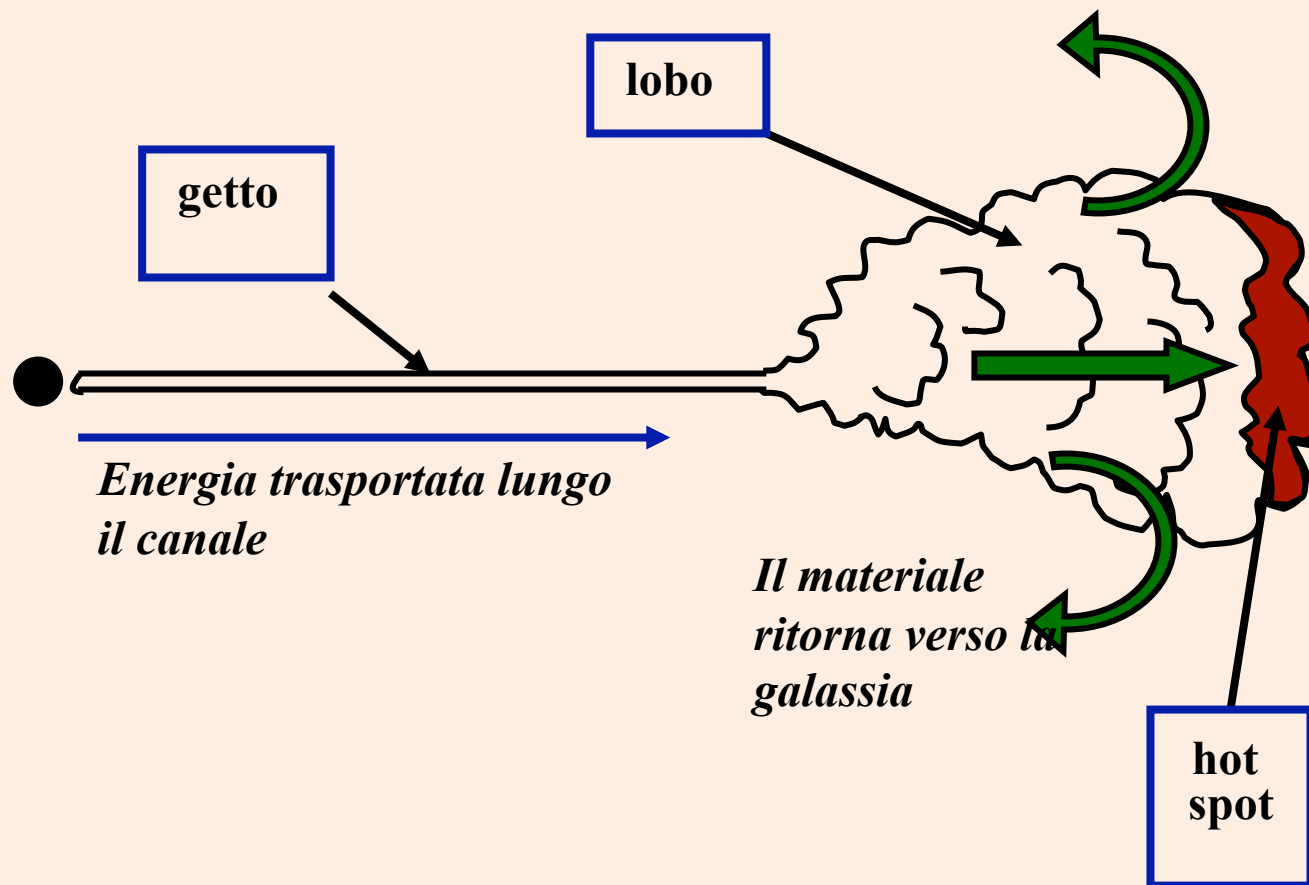
Getti e piume si estendono fino a
140 kpc dalla galassia
(40.000 anni luce)



Radio Galaxy 3C66B Radio/optical superposition
Copyright (c) NRAO/AUI 1999

Getti Relativistici

... fasci focalizzati di gas ionizzato



PKS2356-61 ($z = 0.1$)



Quasar in
una
galassia
ellittica

IN CONCLUSION:

What is learned from radio emission (cont)

-Relativistic particles:

energy
number density
age

- Magnetic fields :

intensity
profile
structure - power spectrum
degree of ordering

[tratto da Luigina Feretti]

SKA

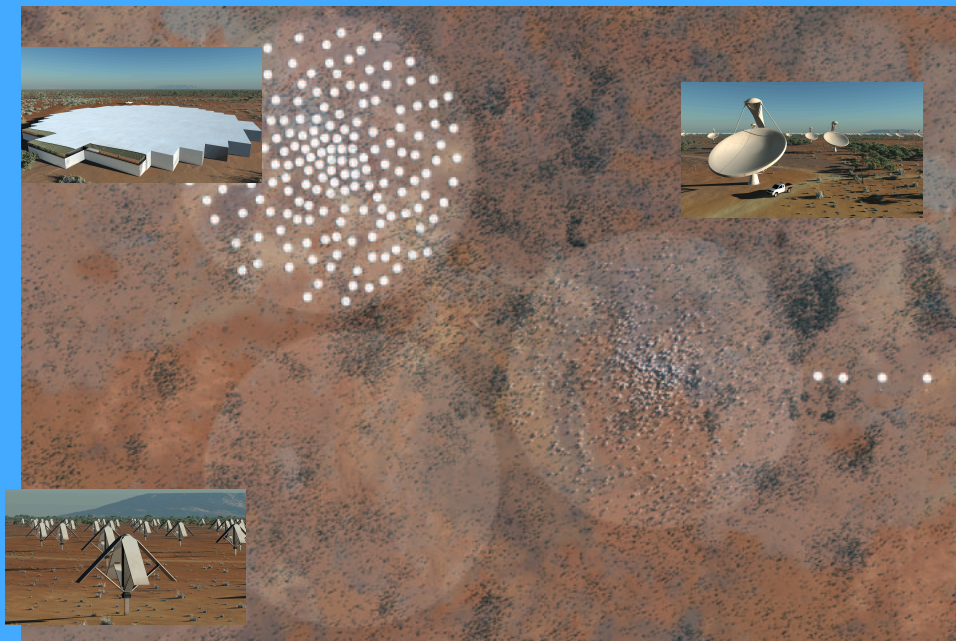
An aerial photograph of the Square Kilometre Array (SKA) in a vast, arid desert landscape. The terrain is reddish-brown with sparse green shrubs. Numerous white, parabolic radio telescope dishes are scattered across the landscape, some in the foreground and many more in the distance, creating a sense of scale. In the far background, a range of low mountains is visible under a clear sky. A blue banner with white text is overlaid on the lower portion of the image.

+ The Square Kilometre Array

Exploring the Universe with the world's largest radio telescope

Lo SKA

- Il “telescopio per l'idrogeno”
(galassie distanti)
- 1 sq km di area di raccolta
- Estensione 3000 km
- [67 organizzazioni da 20 paesi]



Timeline

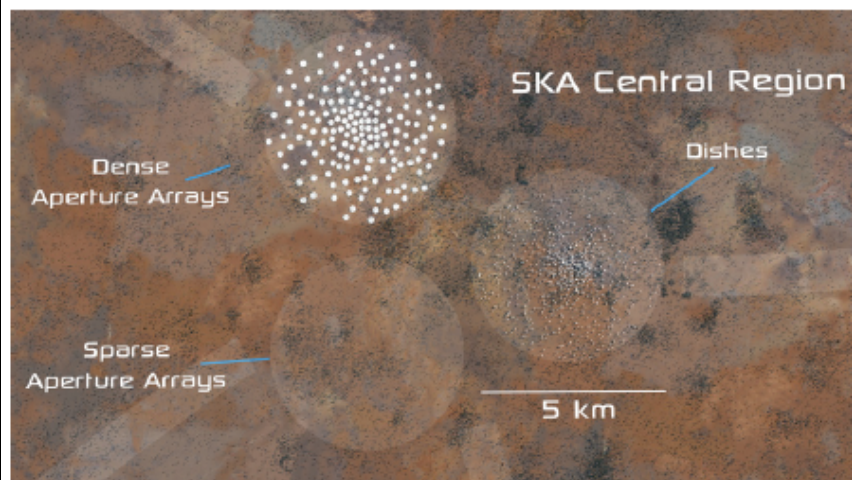
- 1991 Concetto
- 2008-2012 Sviluppo del progetto. (1500MEur?)
- 2012 Decisione sul sito: Sud Africa E Australia/NZ
- 2013-2015 Progetto tecnico dettagliato
- 2016 Costruzione (fase 1)
- 2019 Prima scienza
- 2023 Fine della costruzione e commissioning.
- 2024 Operatività completa.

http://www.skatelescope.org/wp-content/uploads/2011/03/SKAOfficialAnimation_2010_with-swinburnelogo.mov

Tecnologia

- Enormi volumi di dati
- Collegamento tra siti geograficamente lontani
- Disposizione delle antenne: più dense al centro.
- Tre tipi di antenne, copertura di frequenza da 70 MHz a 10 GHz.





PARAMETER / SPECIFICATION

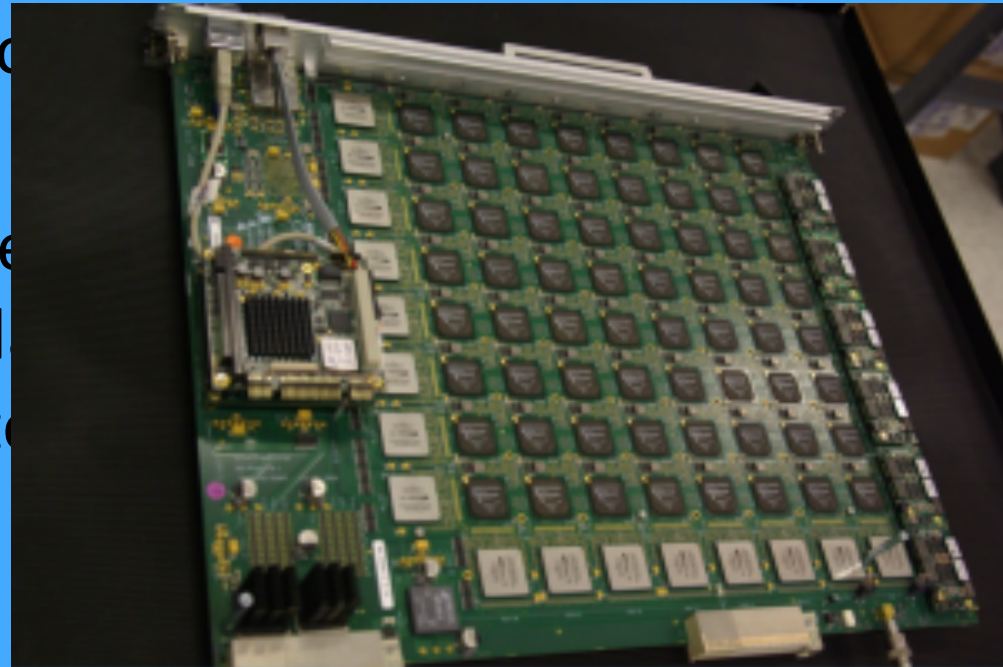
- FREQUENCY RANGE 70 MHz TO 10 GHz
- FIELD-OF-VIEW 200 SQ DEG [70 - 300 MHz]
1-200 SQ DEG [0.3 - 1 GHz]
1 SQ DEG MAXIMUM [1 -10 GHz]
- ANGULAR RESOLUTION <0.1 ARCSECOND
- SPECTRAL CHANNELS 16 384 PER BAND PER BASELINE
- SYNTHESISED IMAGE DYNAMIC RANGE >1 000 000
- IMAGING PROCESSOR COMPUTER 10^{17} OPERATIONS/SECOND
- FINAL PROCESSED DATA OUTPUT 10 GB/SECOND

Software

- Richiede una capacità del processore di 100 petaflops/sec, ~ 50 volte più potente del più potente super computer nel 2010; l'equivalente di circa un miliardo di PC. (in tempo reale)
- Servono nuove tecniche di analisi dati
- Mezzi e supporti per archivi

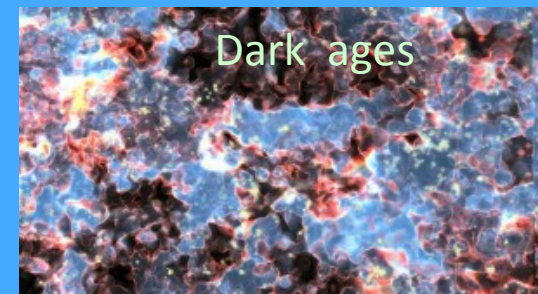
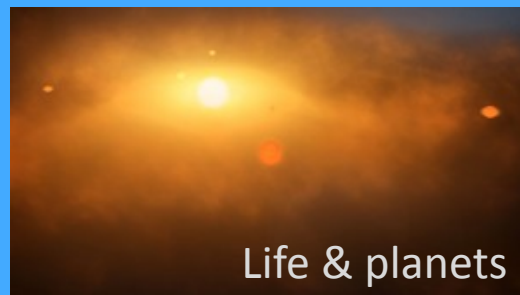
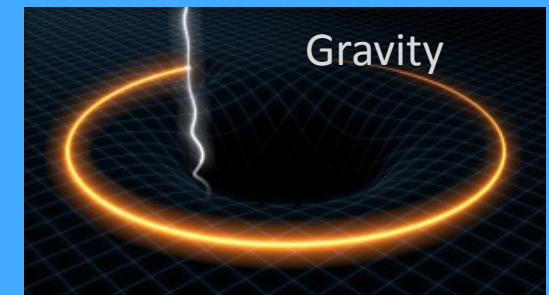
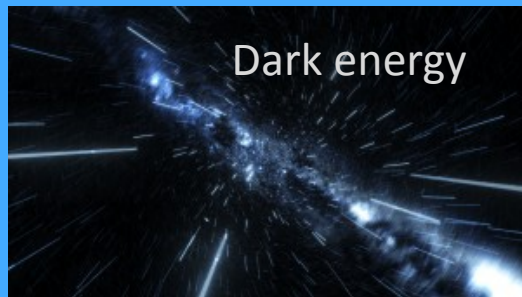
Trasporto del segnale

- ~ 160 Gigabits/sec di data saranno trasmessi da ogni antenna a un processore centrale: **dieci volte** il traffico attuale di Internet! Con le schiere (aperture array) si arriva a m Internet di oggi!
- Fibre ottiche per: trasmissione dati da connessione all'est



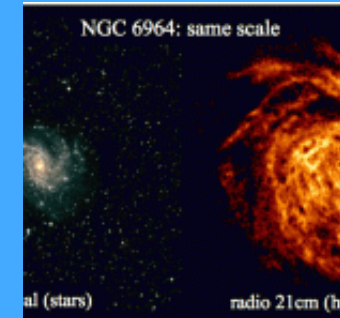
Scienza

- Cinque progetti fondamentali



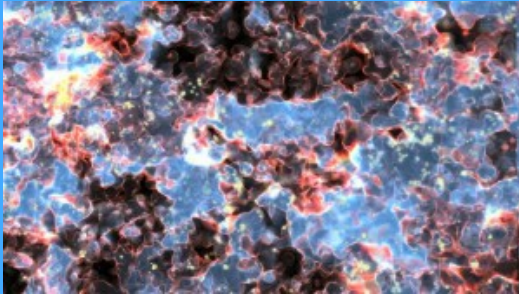
- Progetto flessibile

Evoluzione cosmologia e Energia Oscura

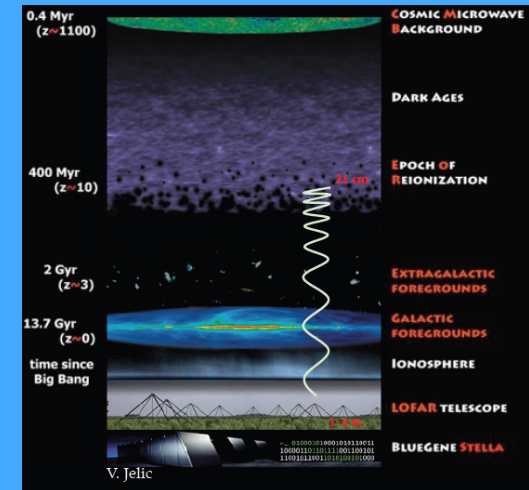


- Emissione a 21 cm: traccia la distribuzione di massa e la sua evoluzione cosmologica
- Componente barionica primaria dell'Universo
- Formazione & evoluzione delle galassie
- “Billion Galaxy Survey”
- Energia oscura attraverso le distorsioni della distribuzione dei redshift e le lenti gravitazionali
- Distribuzione di HI ad alto redshift per evidenziare l'acquisizione di gas in diverse epoche cosmiche

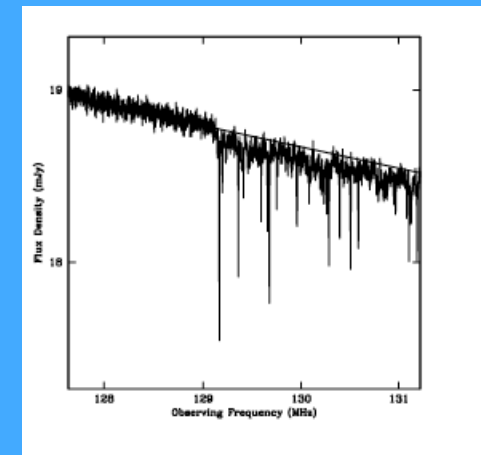
Le età oscure: i primi BHs & stelle



- Osservazioni “tomografiche” dell’emissione di HI durante l’Epoca di Re-ionizzazione (da materiale neutro a grumi ionizzati): mappe 3D
- 21-cm forest (modeste sovradensità di HI in “controluce” di sorgenti radio brillanti – fino a $z > 8$)



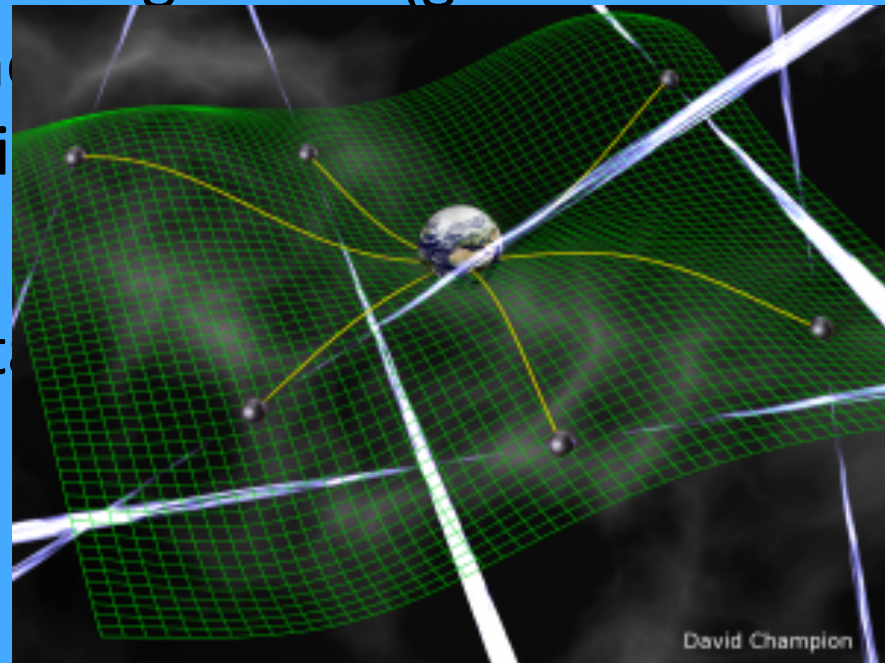
Carilli+02
 $z=10$ 100 hr SKA



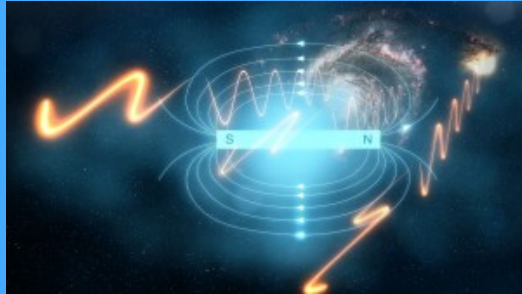
Test di gravità in campi forti (pulsars & BHs)



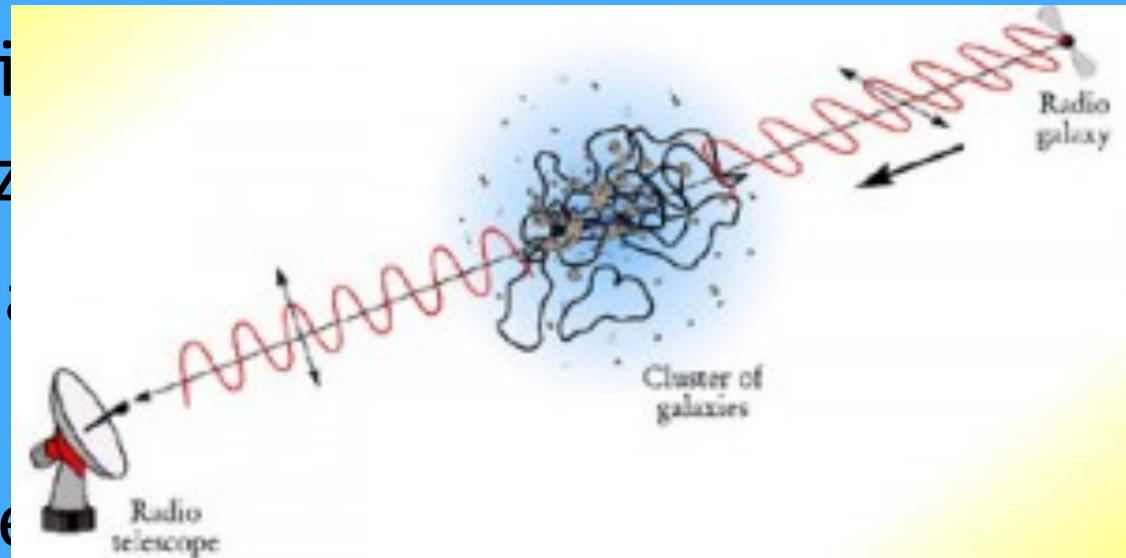
- Einstein aveva ragione sulla gravità? (gravità e quanto-meccanica fanno sul Universo con campi piccole?)
- Test: una pulsar in orbita
- Pulsar Timing Array



Origine e evoluzione del magnetismo cosmico

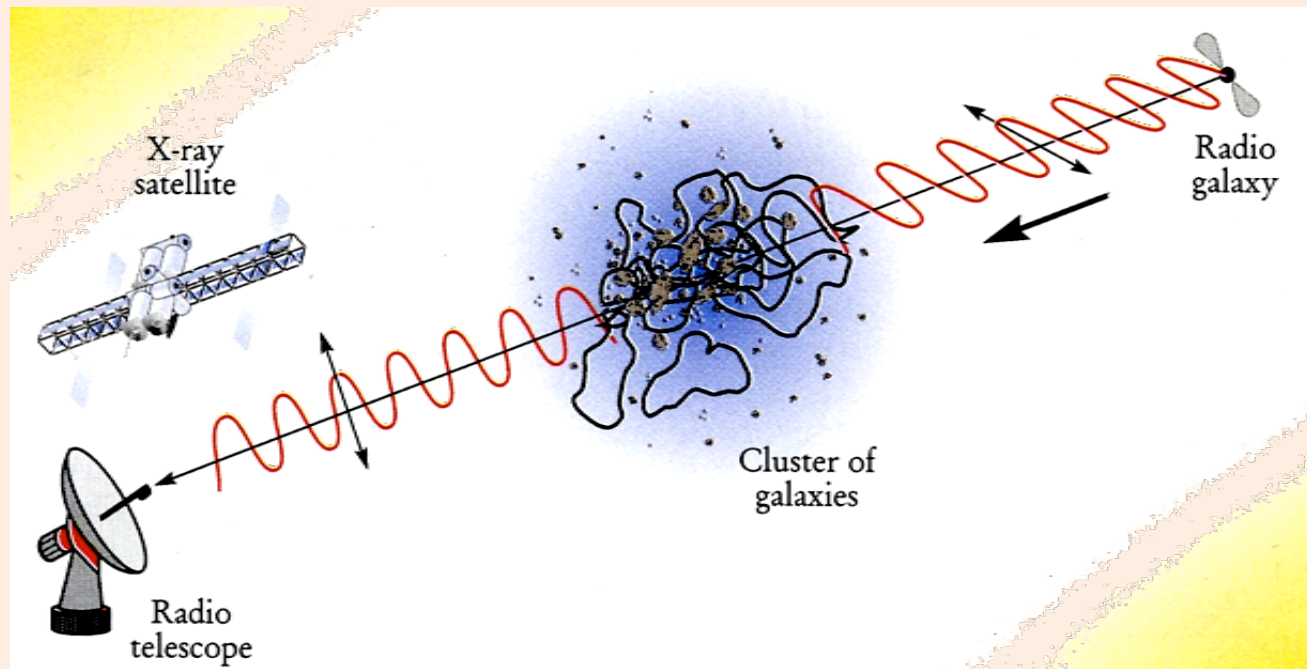


- Campi magnetici di ordini grandezze
- Mappa – 3D magnetica intensità
- Altre galassie (e)
- Origine del campo B – evoluzione



Radio diagnostics:

Rotation Measure $\rightarrow$ H along the line of sight



A linearly polarized wave traveling from a radio source through a magnetized medium experiences a phase shift of the left versus right circularly polarized components, leading to a rotation of the position angle of the linear polarization, as the square of the observing wavelength:

$$\Delta\theta \propto \mathbf{RM} \lambda^2 \quad \text{with}$$

$$RM \propto \int_0^L n_e B_{\parallel} dl$$

La culla della vita – ricerca di esopianeti

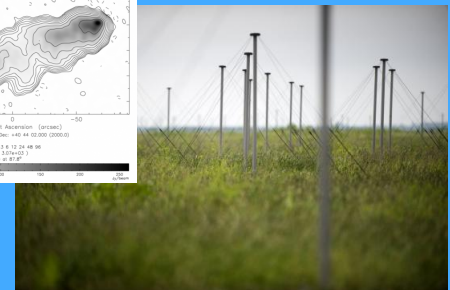
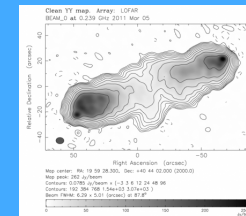


SKA Organization

- **7 member states + Italy** (Australia: Department of Innovation, Industry, Science and Research Canada: National Research Council China: National Astronomical Observatories, Chinese Academy of Sciences Italy: National Institute for Astrophysics New Zealand: Ministry of Economic Development Republic of South Africa: National Research Foundation The Netherlands: Netherlands Organisation for Scientific Research United Kingdom: Science and Technology Facilities Council)
- a not-for-profit company; headquarters in Manchester, UK: to formalise relationships between the international partners and centralise the leadership of the project.
- Board of Directors
- At this time a big re-organization of panels responsibilities etc. is underway

PathFinders

- Antenne singole
 - Arecibo ALFALFA (HI mass function) [Giovannelli et al 2005]
 - GMRT HI absorption at $z \sim 3$ [Kanekar et al 2008]
 - WSRT HI emission at $z \sim 0.2$ [Verheijen et al 2007]
- Schiere di antenne
 - eEVN (electronic European VLBI Network)
 - e-MERLIN
 - EVLA
 - LOFAR [pulsar, HI searches, EoR]



Precursors

- Australian

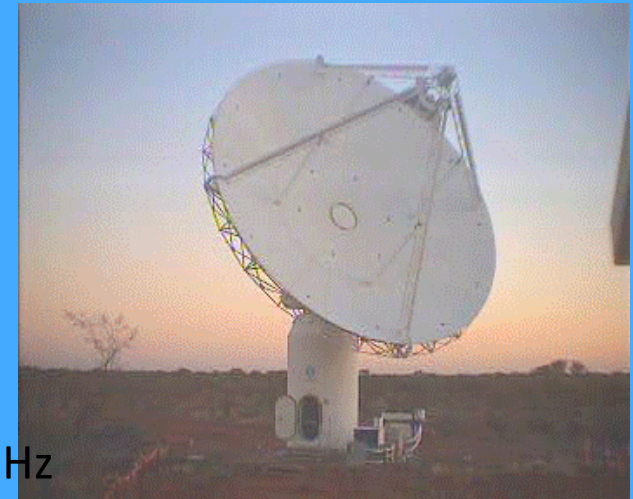
- ASKAP (Australian SKA Pathfinder)
(36 ant 12 m diameter manufactured)

- MWA (Murchison Widefield Array) 80 - 300 MHz

Int.l collab: US, Australia, New Zealand and India. Feb 2012 init constr.

<http://www.atnf.csiro.au/projects/askap/>

<http://www.mwatelescope.org/index.html>



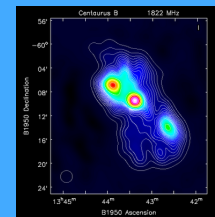
- South African

- MeerKAT (KAT-7 1.2 - 1.95 GHz)

- 64+7 antennas: 0.58 – 14.5 GHz/20km baseline

<http://www.ska.ac.za/meerkat/index.php>

<http://www.ska.ac.za/meerkat/kat7.php>





The Square Kilometre Array