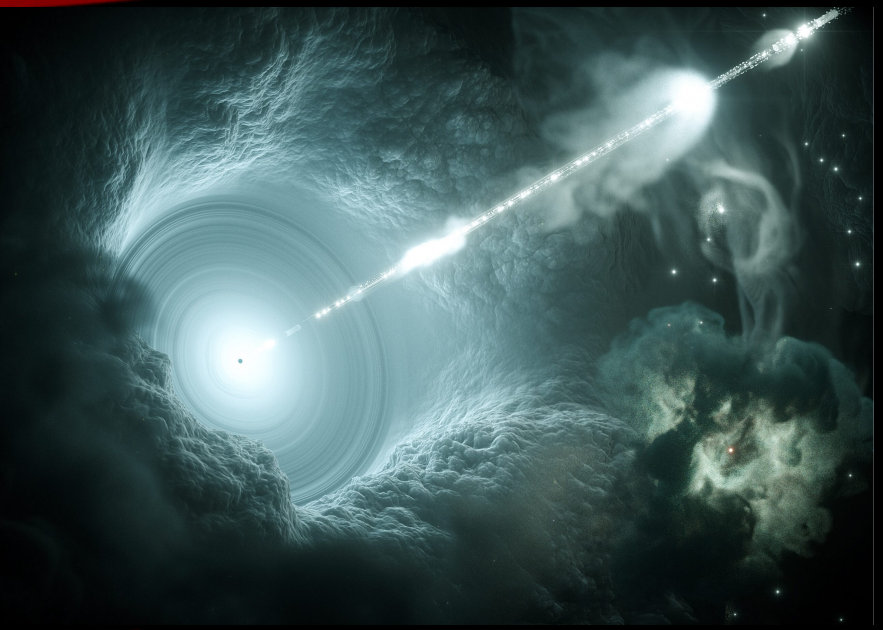

High Energy Astrophisics Across the Electromagnetic Spectrum

Elisa Prandini

Padova University

5 September 2022 - arQus School of Gamma-ray Astronomy and Statistics

SUMMARY

- The electromagnetic spectrum
  - Observational techniques
- Thermal and non-thermal Universe
- Blazars and their emission
  - Hands-on session on data and catalogs

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- **The electromagnetic spectrum**
  - **Observational techniques**
- Thermal and non-thermal Universe
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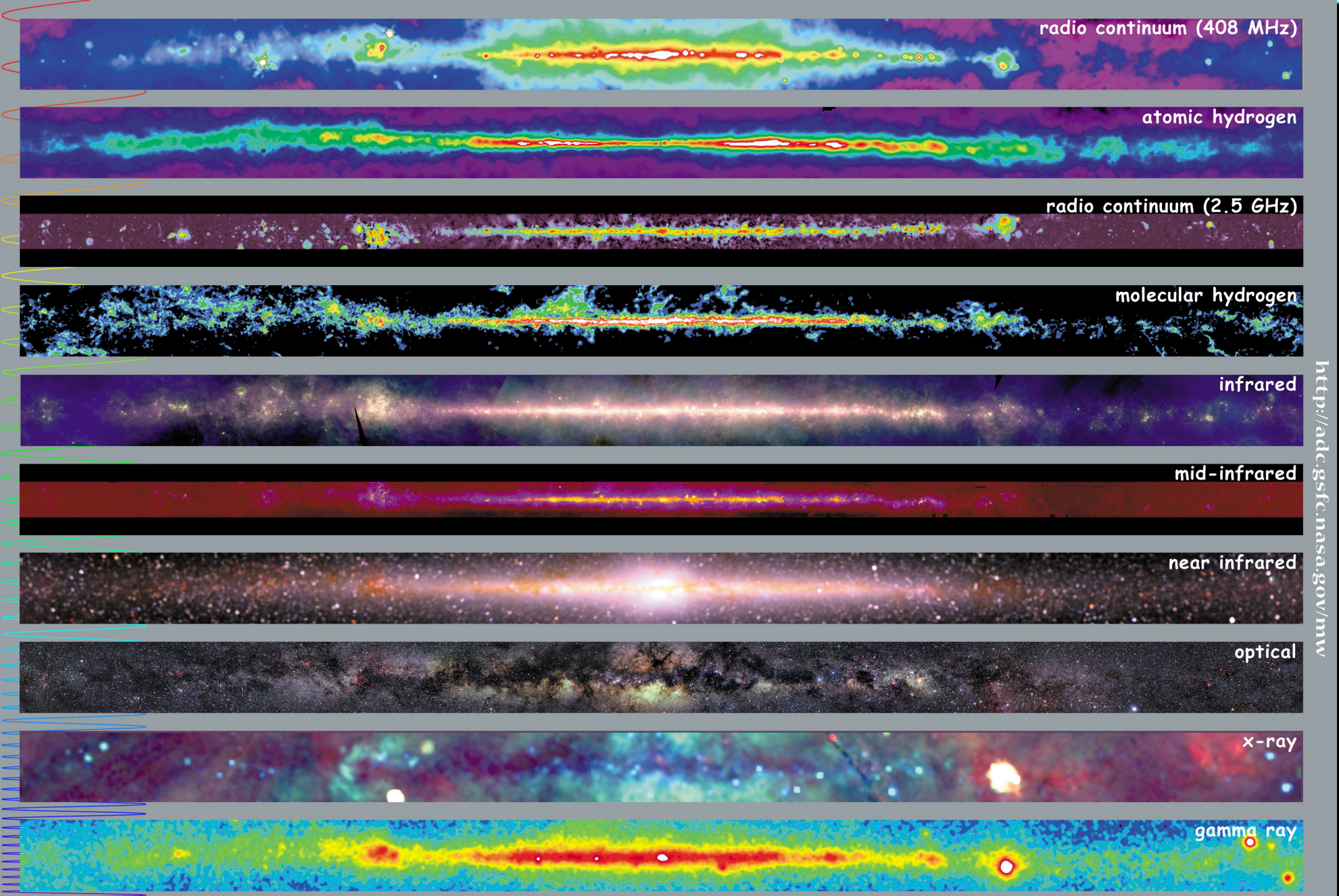
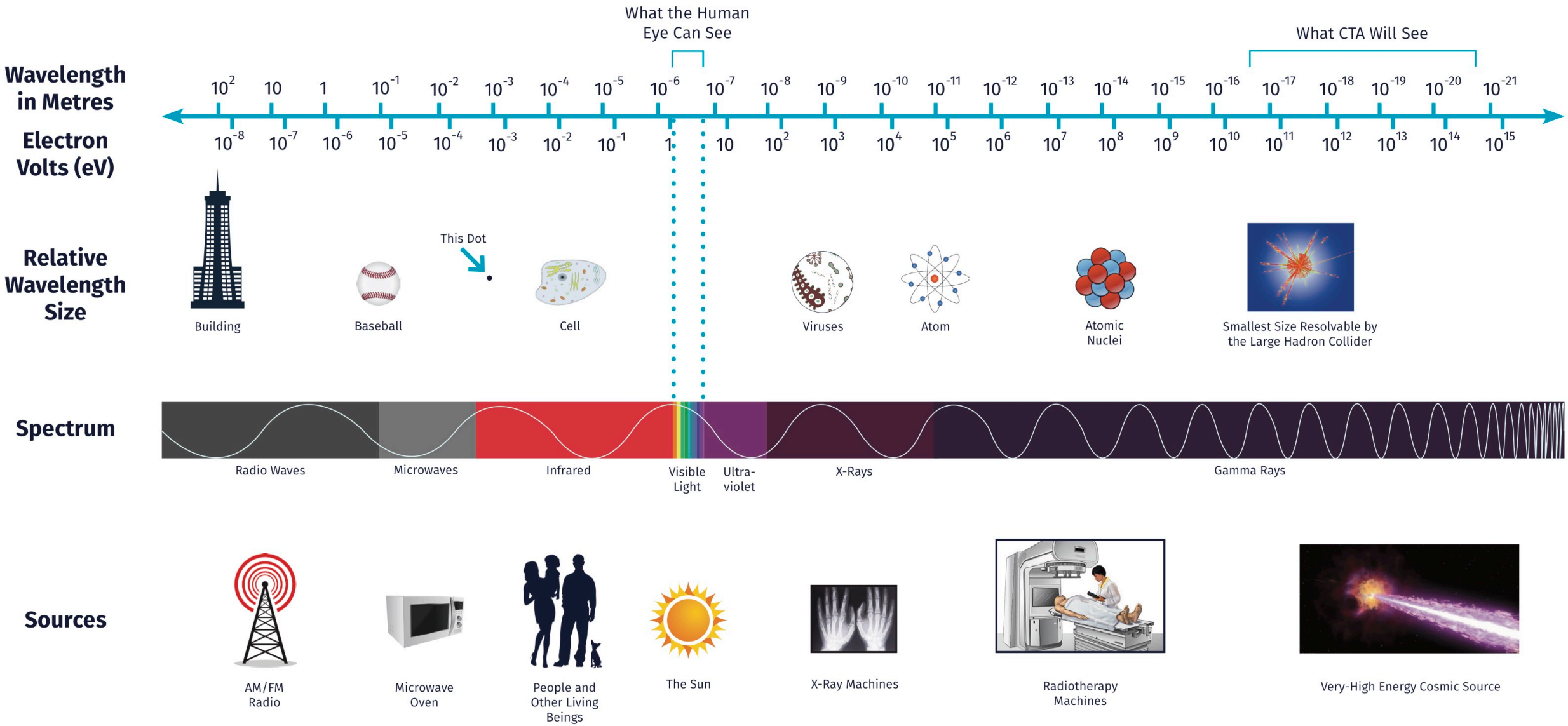
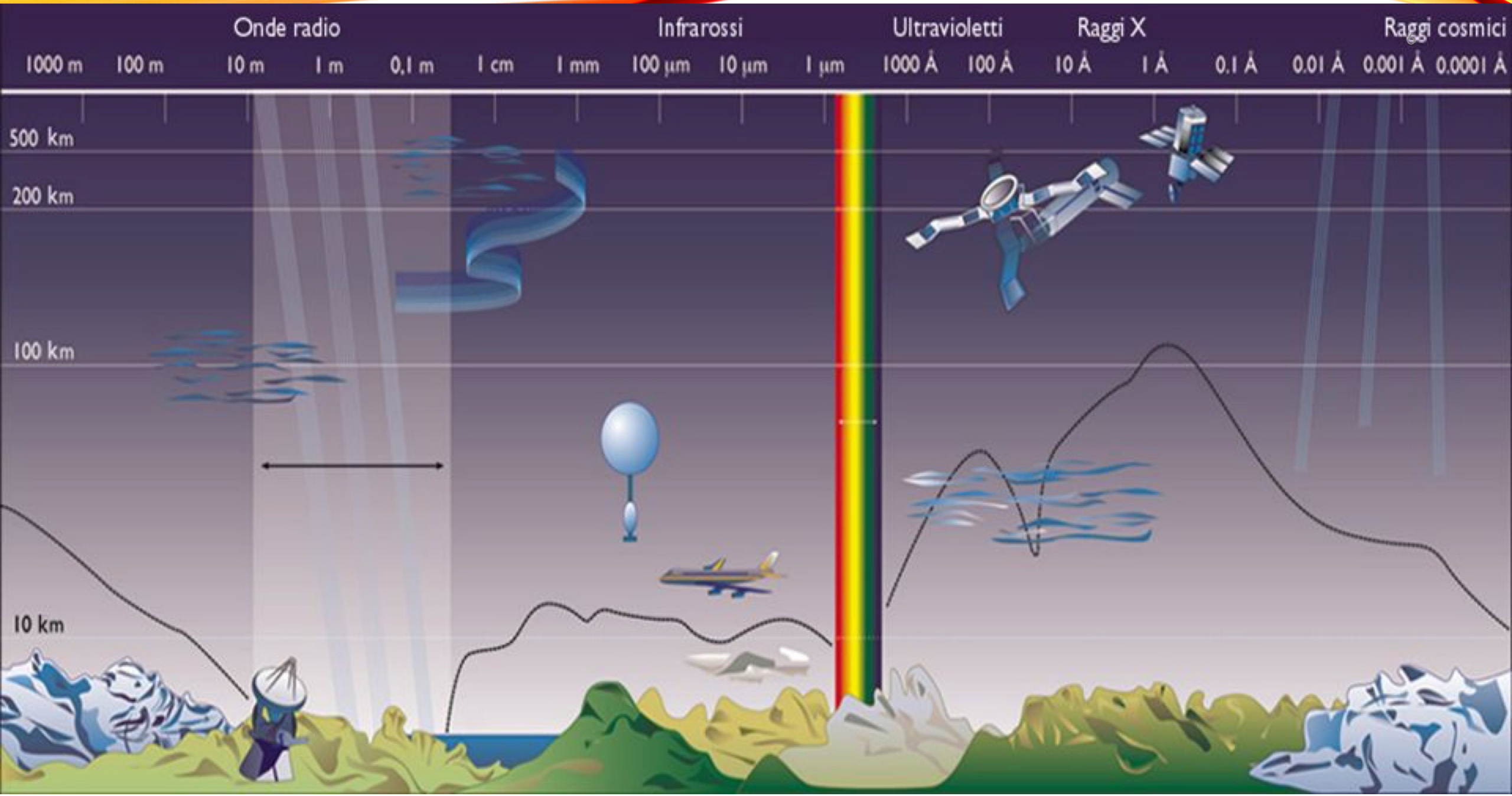
  - Hands-on session on data and catalogs



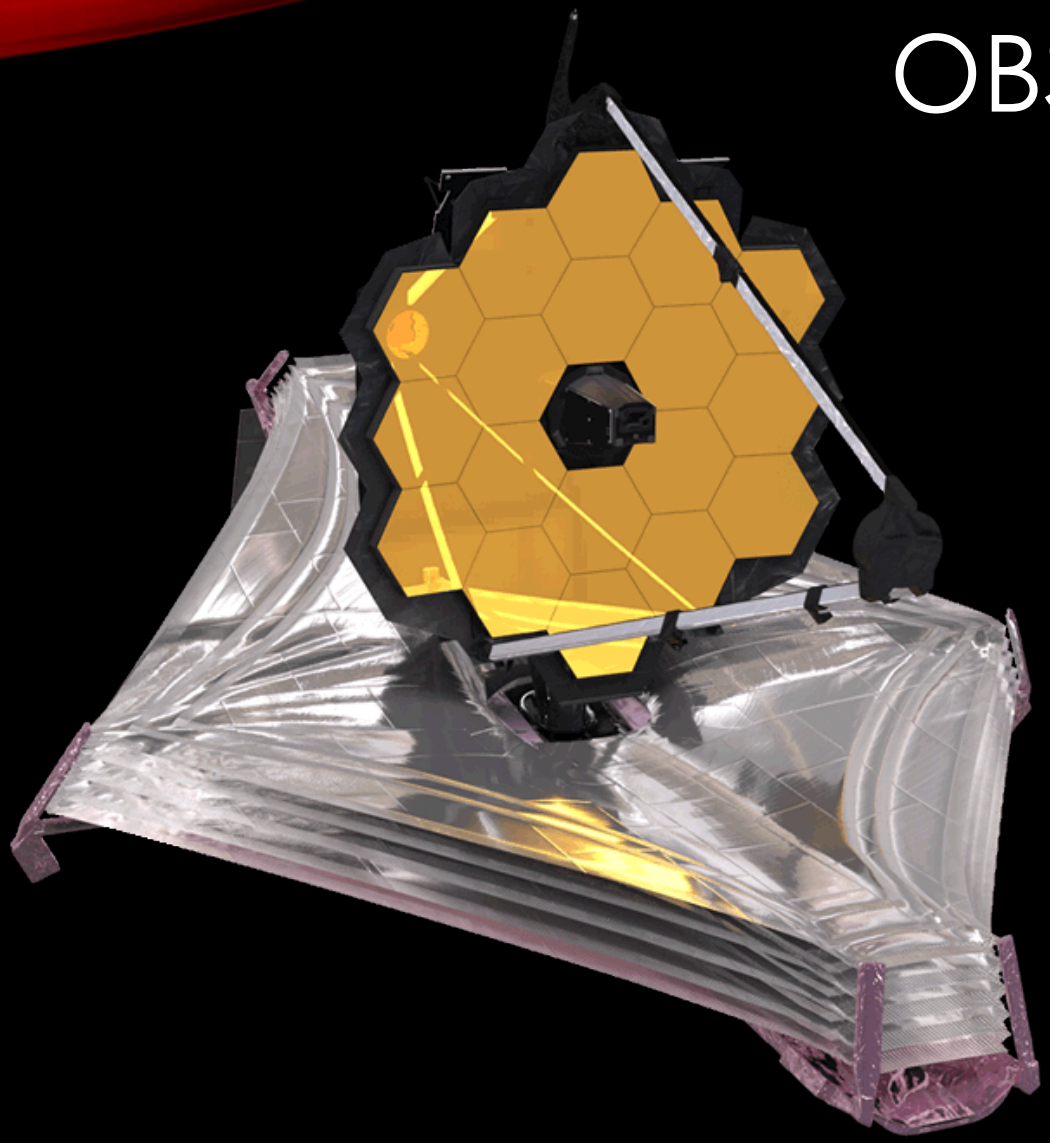
What do you see?


What the Human Eye Can See
What CTA Will See
Wavelength in Metres
Electron Volts (eV)
10^{2} 10 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12} 10^{-13} 10^{-14} 10^{-15} 10^{-16} 10^{-17} 10^{-18} 10^{-19} 10^{-20} 10^{-21}
10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15}
Relative Wavelength Size
This Dot
Building
Baseball
Cell
Viruses
Atom
Atomic Nuclei
Smallest Size Resolvable by the Large Hadron Collider
Spectrum
Radio Waves
Microwaves
Infrared
Visible Light
Ultra-violet
X-Rays
Gamma Rays
Sources
AM/FM Radio
Microwave Oven
People and Other Living Beings
The Sun
X-Ray Machines
Radiotherapy Machines
Very-High Energy Cosmic Source

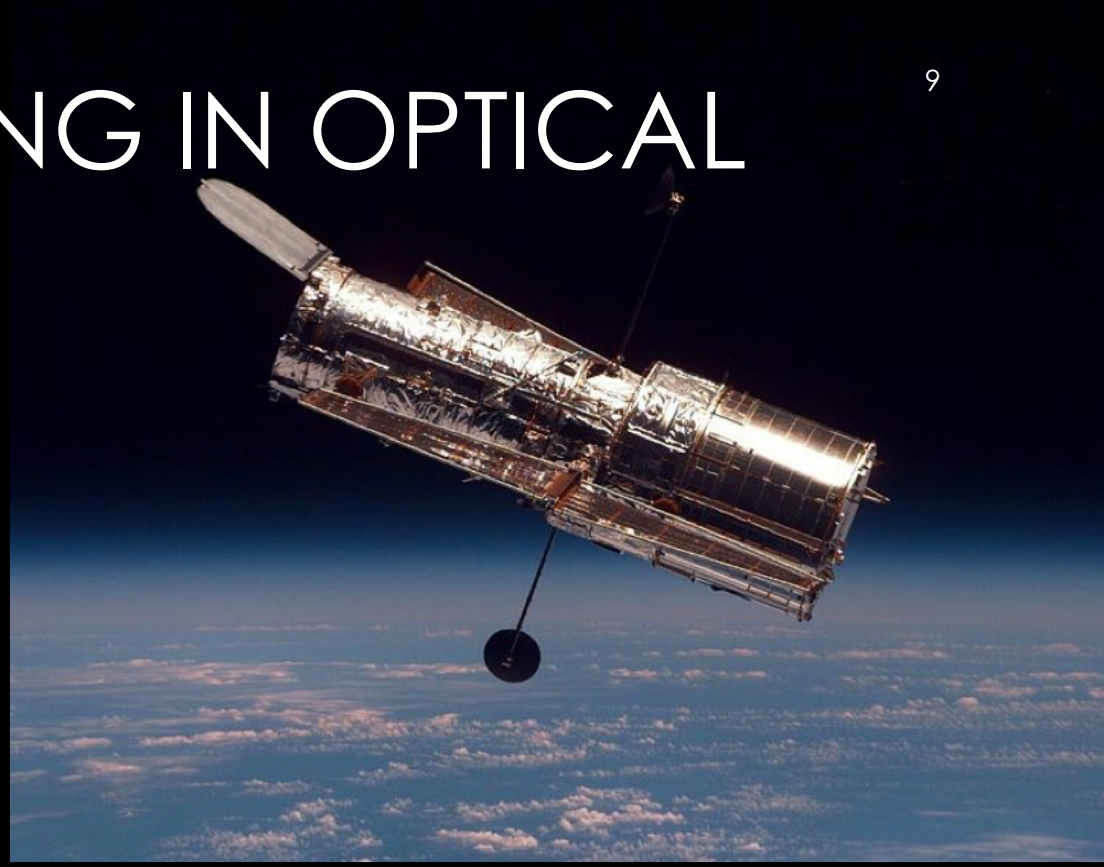

Onde radio
Infrarossi
Ultravioletti
Raggi X
Raggi cosmici
1000 m
100 m
10 m
1 m
0,1 m
1 cm
1 mm
100 µm
10 µm
1 µm
1000 Å
100 Å
10 Å
1 Å
0,1 Å
0.01 Å
0.001 Å
0.0001 Å
500 km
200 km
100 km
10 km

OBSERVING IN THE RADIO BAND

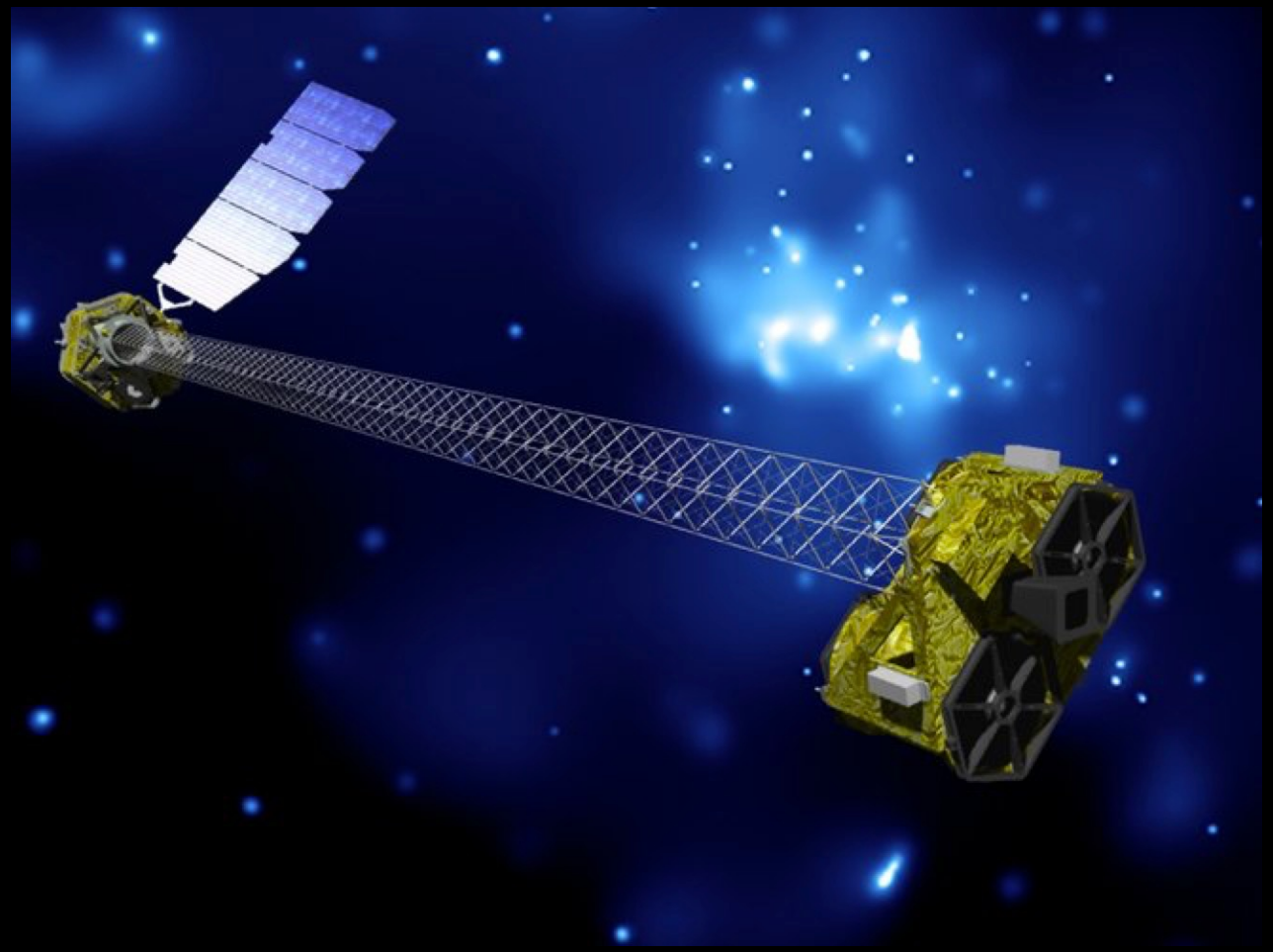
OBSERVING IN INFRARED

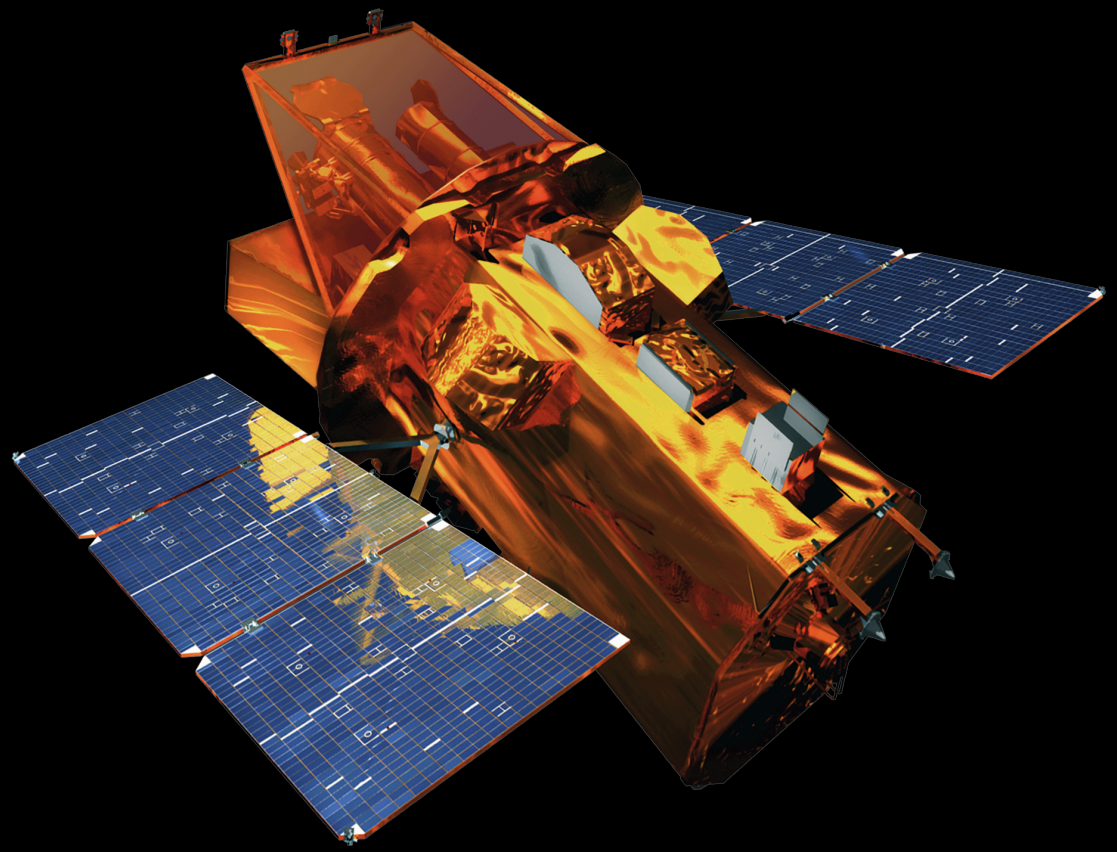


OBSERVING IN OPTICAL

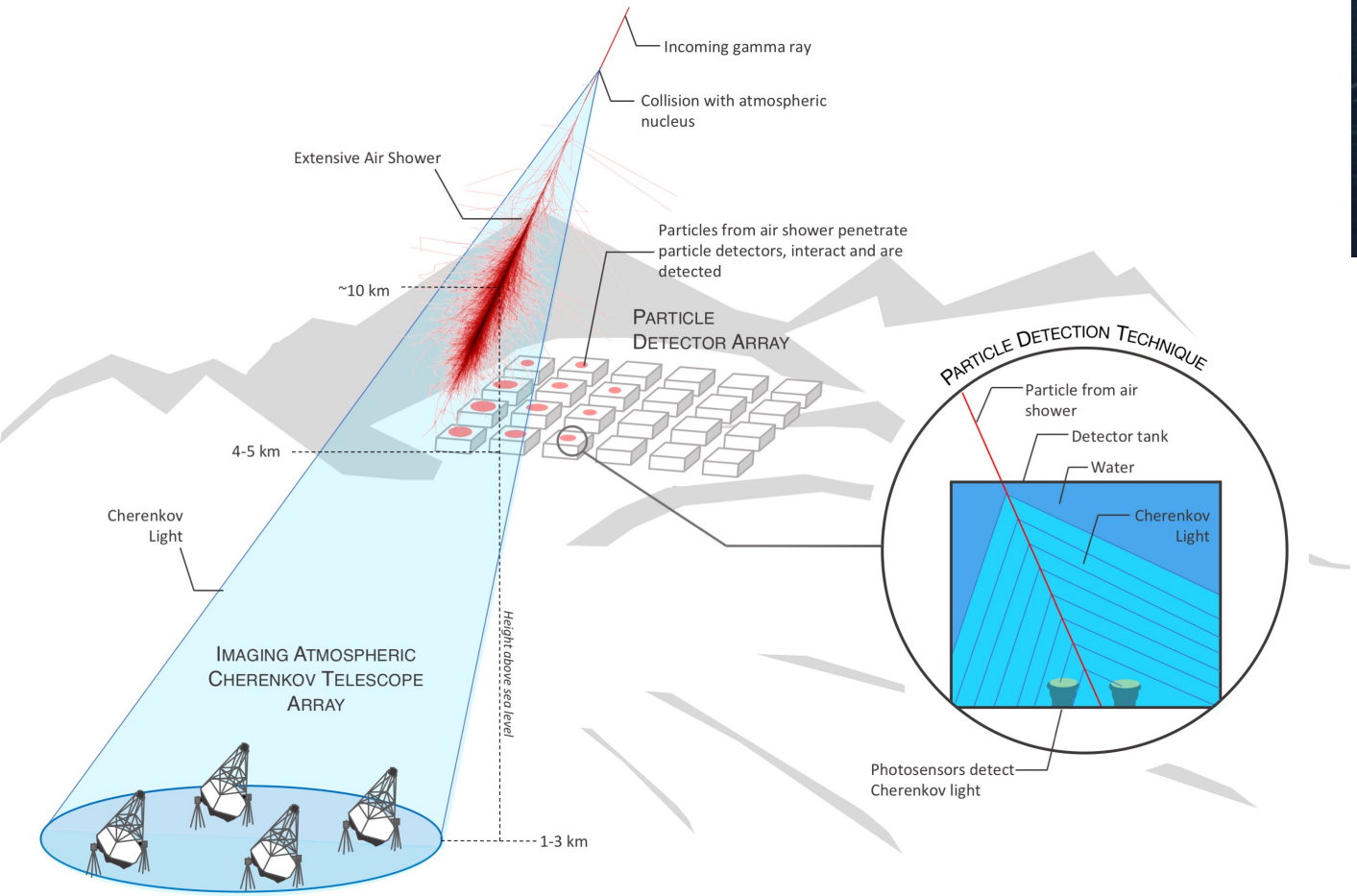


OBSERVING IN X-RAYS





OBSERVING IN GAMMA RAYS



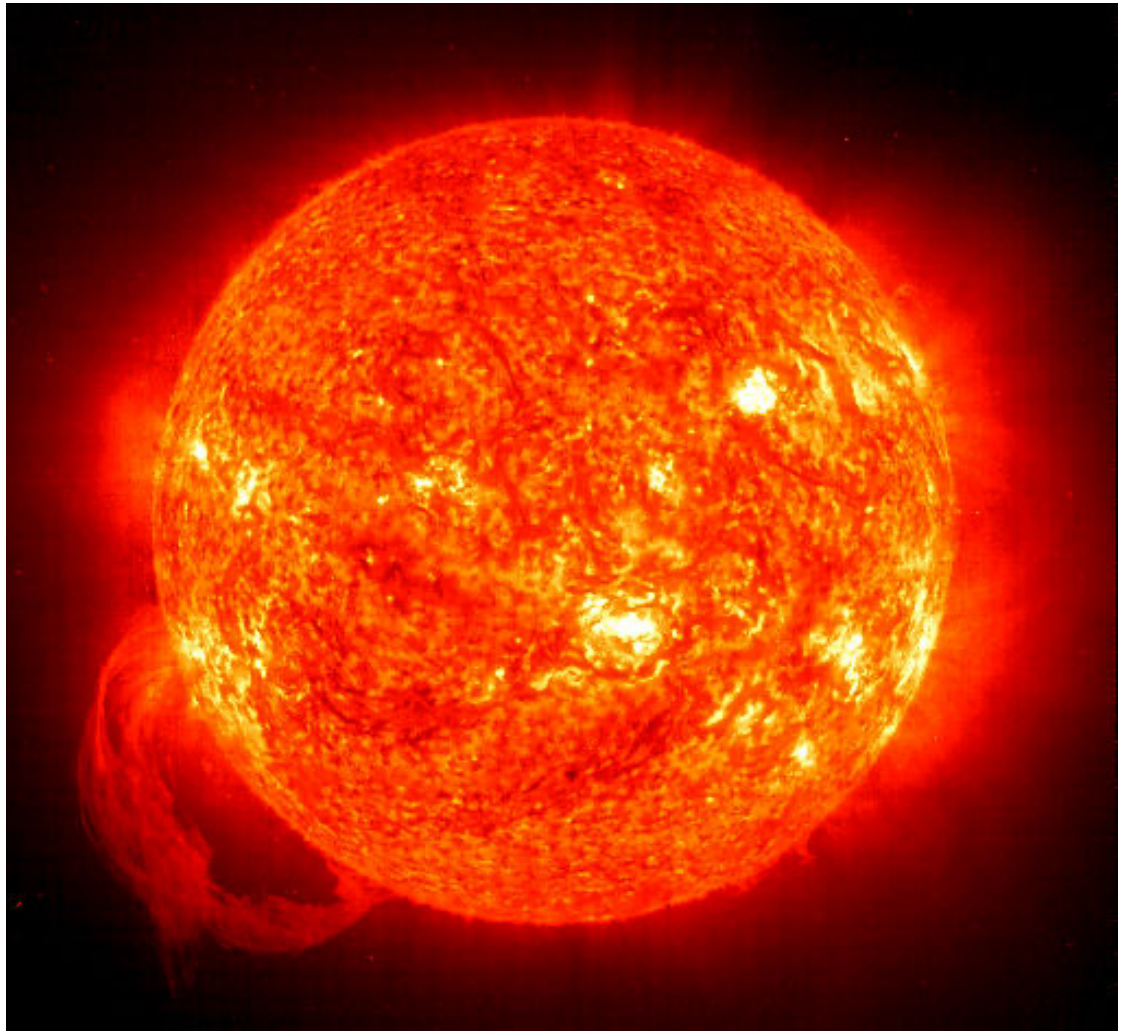
Shower image, 100 GeV γ-ray adapted from: F. Schmidt, J. Knapp, "CORSIKA Shower Images", 2005, https://www-zeuthen.desy.de/~jknapp/fs/showerimages.html

Not to scale

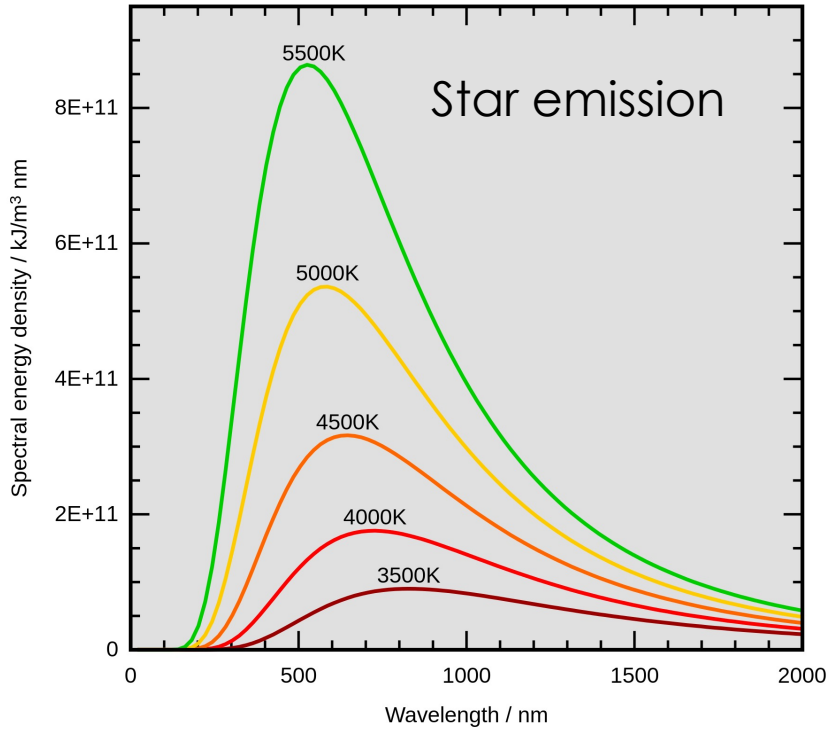
SUMMARY

- The electromagnetic spectrum
  - Observational techniques
- **Thermal and non-thermal Universe**
- Blazars and their emission
  - Hands-on session

THERMAL PROCESSES

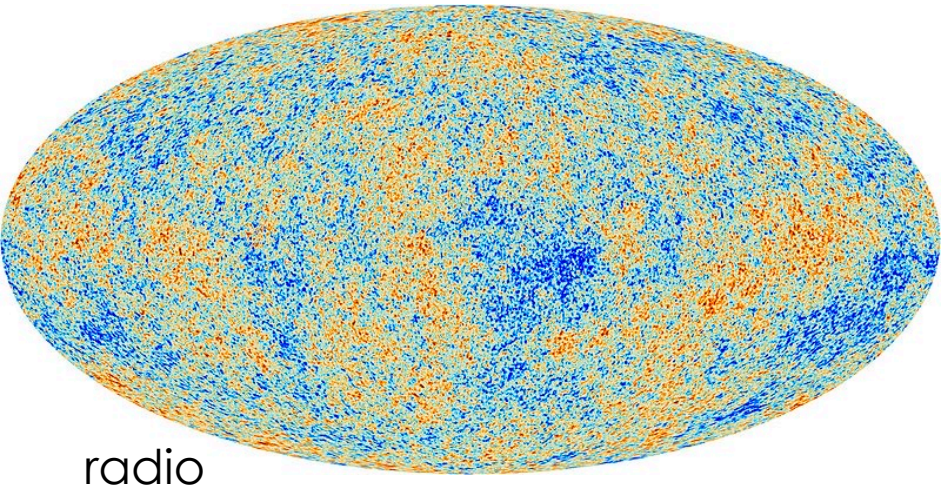


- Equilibrium
- Temperature



What is the coldest thermal emission that you know?

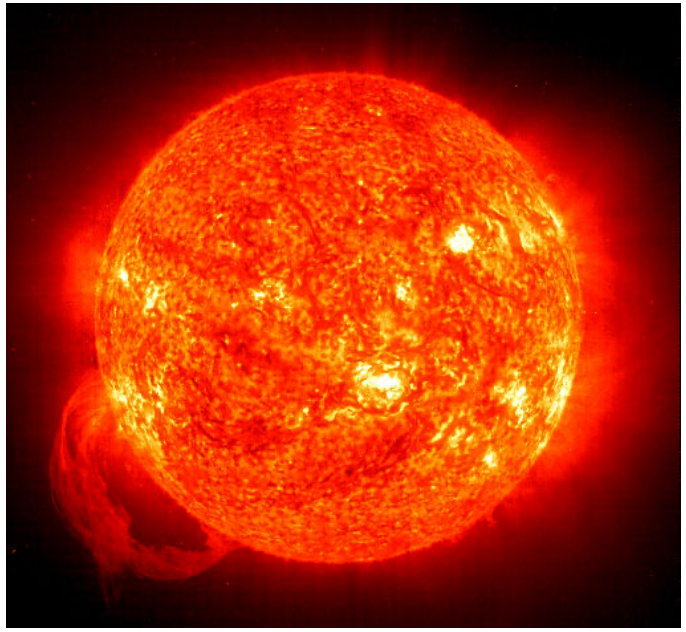
THERMAL RADIATION



radio

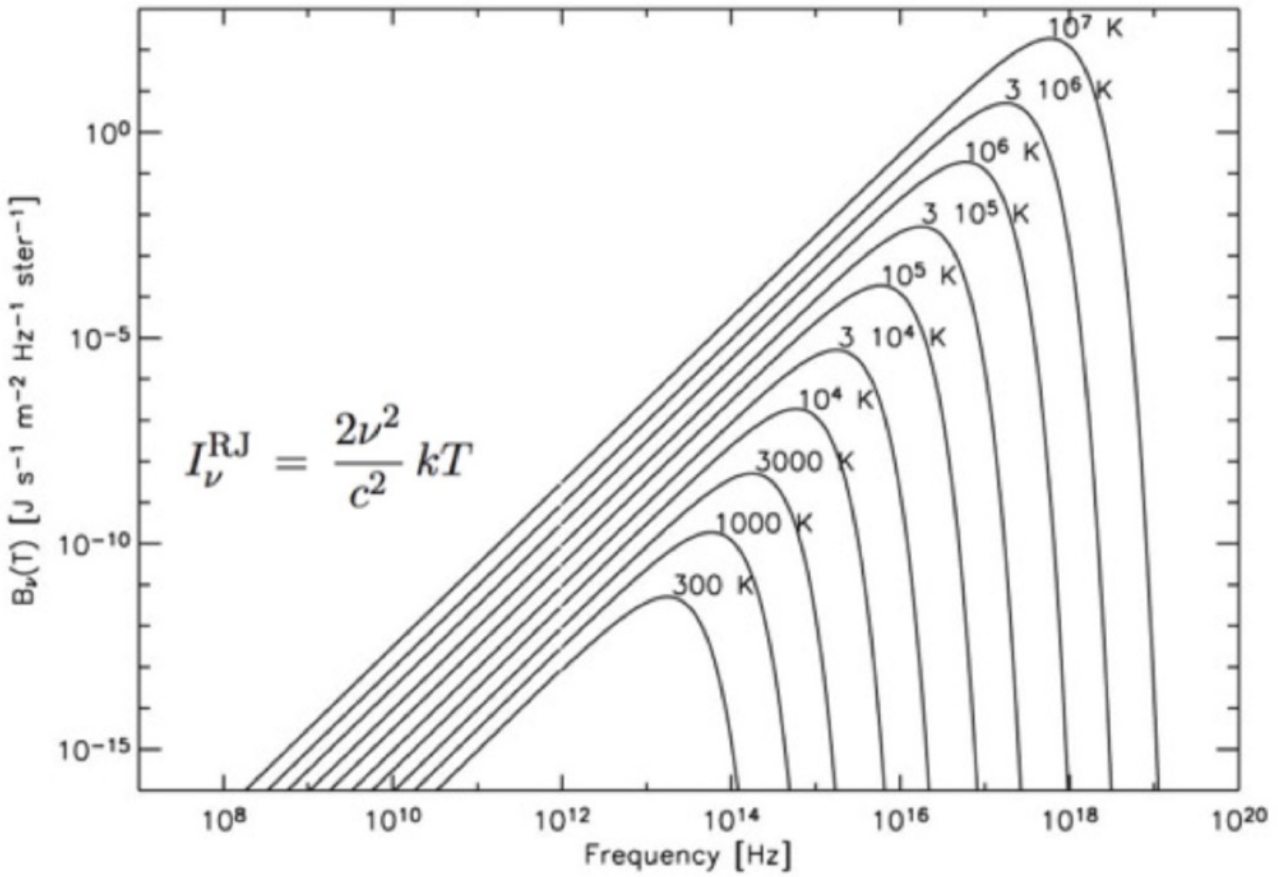
infrared

optical



X rays

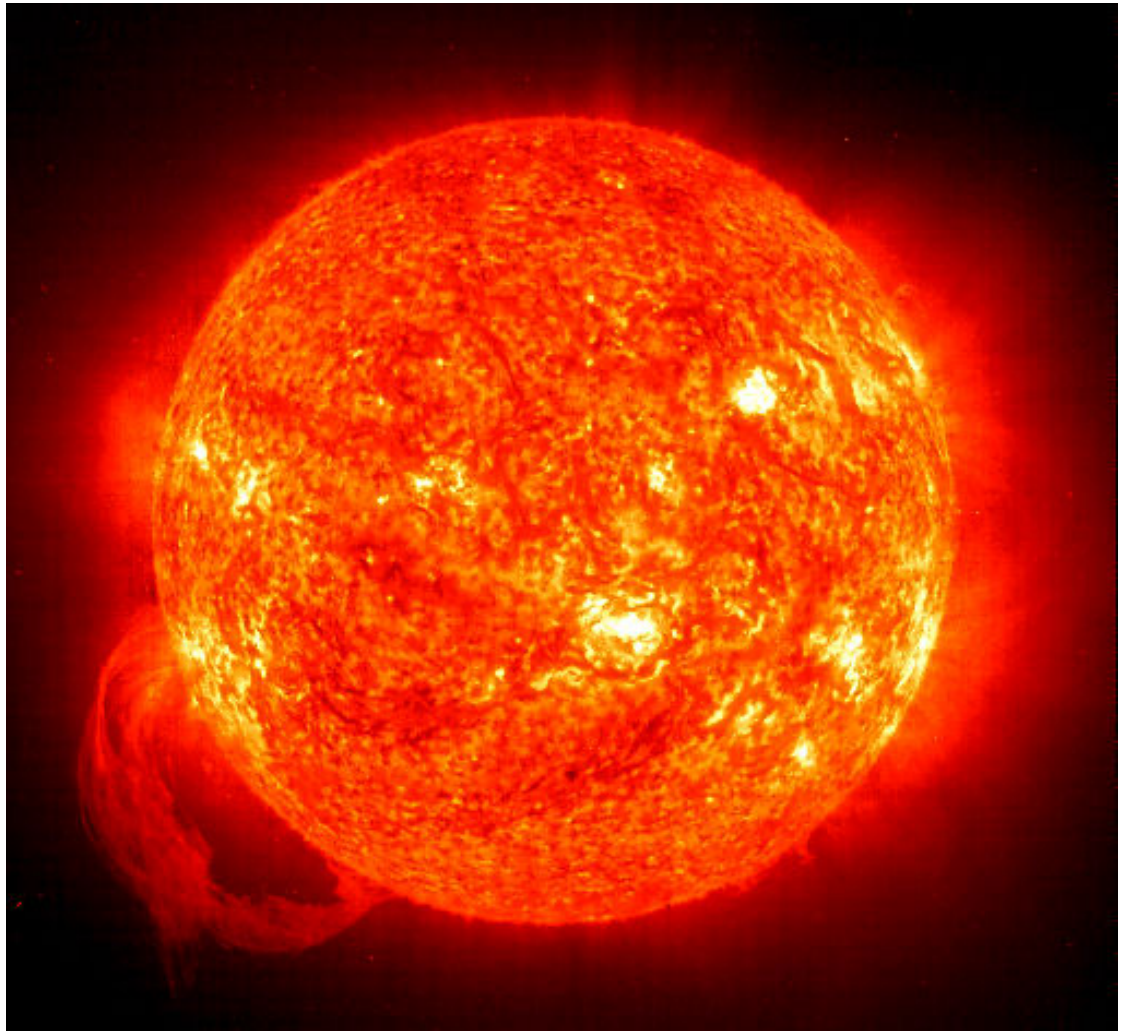
THERMAL EMISSION MEANS BLACK BODY SPECTRUM



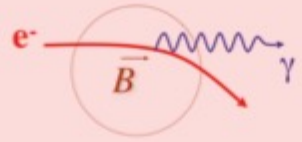
μm IR optical UV X-ray

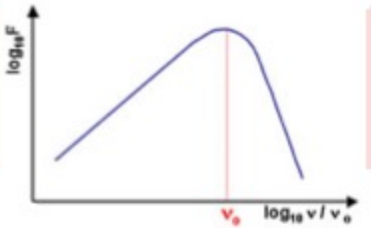

Radio
Microwave
Infrared
UV
X-Ray
Gamma Ray
Radio
60,000 nm
600 K
Infrared
1200-800 nm (10-3.6 um)
4,500 K
Optical
450-750 nm
6,000 K
Ultraviolet
400-200 nm
10,000 K
X-ray
100-10 nm
10,000,000 K
Multiwavelength Whirlpool Galaxy
COLD GAS: Radio waves reveal regions of gas cool enough for CO_2 molecules to exist.
COOL STARS: Infrared shows smaller cool red stars that make up most of the galaxy.
SOLAR STARS: Optical light comes from stars around the size of the Sun.
HOT STARS: Ultraviolet shows the larger hot blue stars that are less frequent in galaxies.
HOT GAS: X-rays are emitted from the hottest regions of gas where atoms are ionized.
COOL LOW ENERGY RADIATION
VISIBLE LIGHT
HOT HIGH ENERGY RADIATION

NON-THERMAL PROCESSES

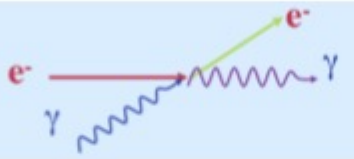


- Synchron radiation

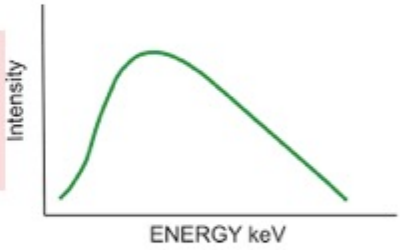




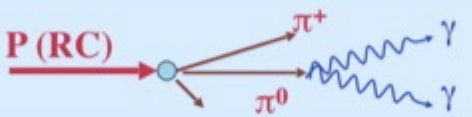
- Inverse Compton



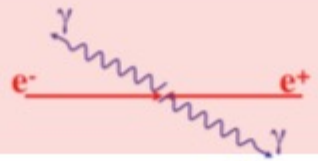
- Bresstrahlung

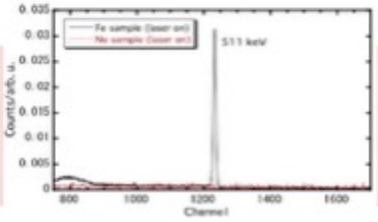


- Particle collision

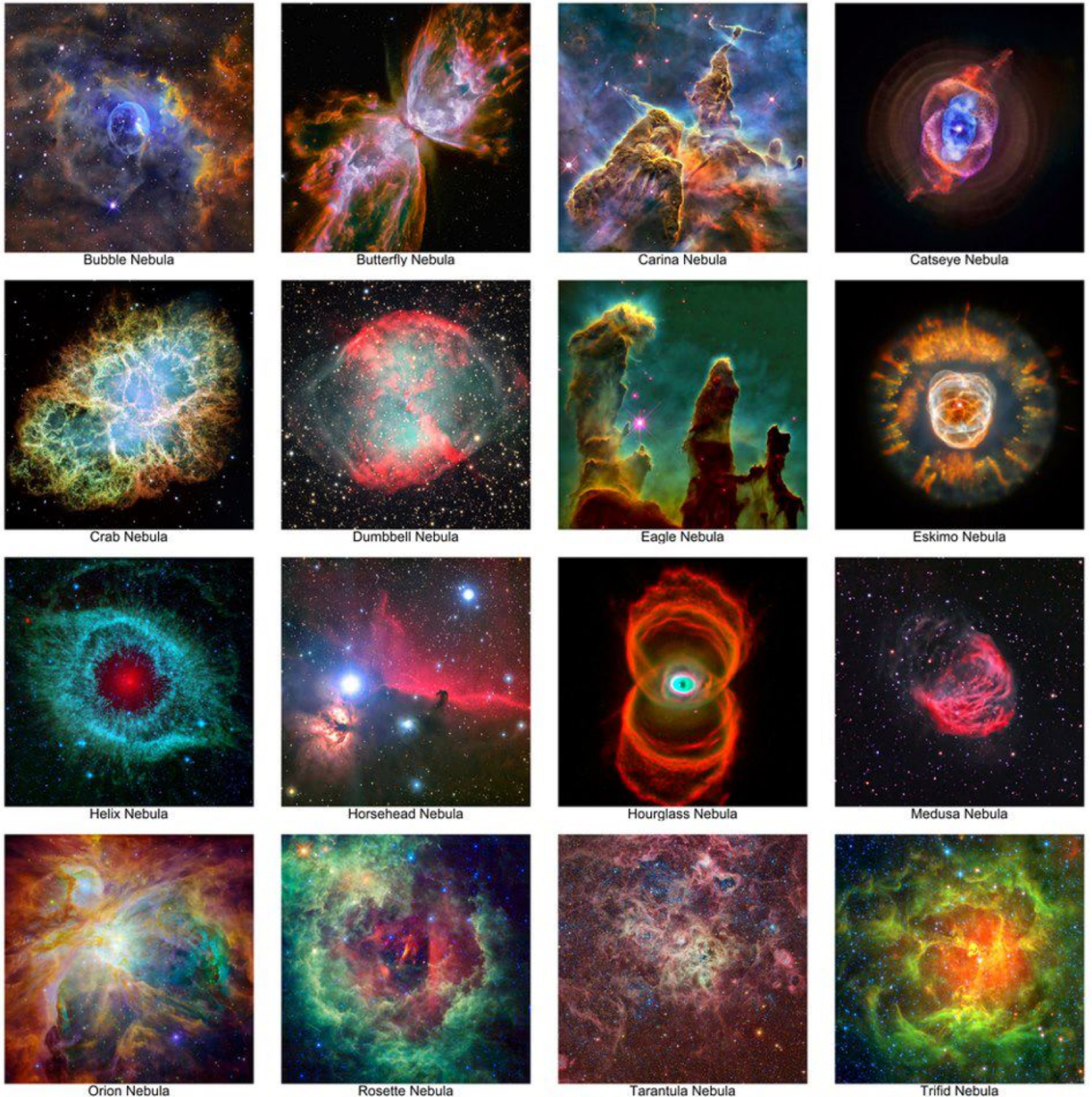


- Annihilation

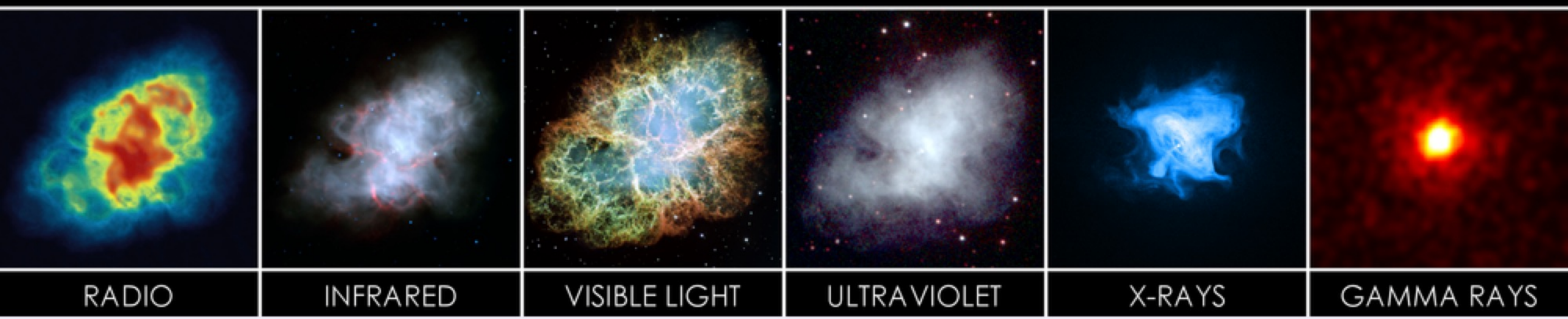




NON THERMAL EMISSION IN OUR GALAXY: NEBULAE



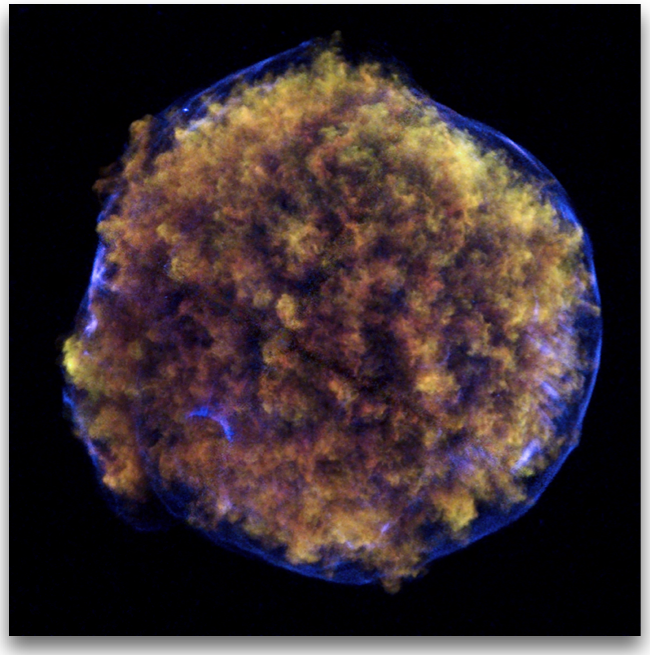
COMBINING PIECES TOGETHER



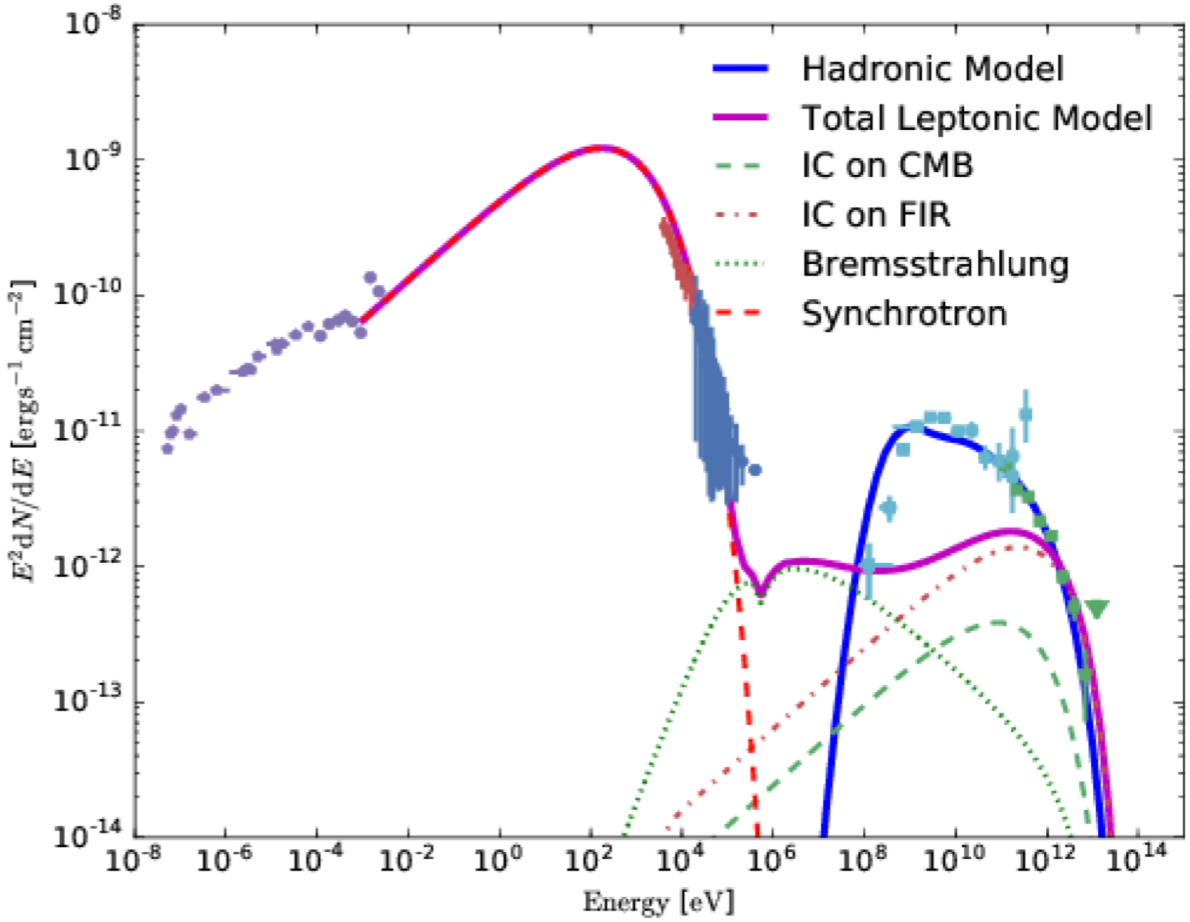
The crab nebula in radio, infrared, visible, ultraviolet, x-ray and gamma-ray wavelengths.

Sources: Radio: NRAO/AUI and M. Bietenholz, J.M. Uson, T.J. Cornwell; Infrared: NASA/JPL-Caltech/R. Gehrz (University of Minnesota); Visible: NASA, ESA, J. Hester and A.Loll (Arizona State University); Ultraviolet: NASA/Swift/E. Hoversten, PSU, X-ray: NASA/CXC/SAO/F. Seward et al.; Gamma: NASA/DOE/Fermi LAT/R. Buehler

EMISSION FROM A SUPERNOVA REMNANT

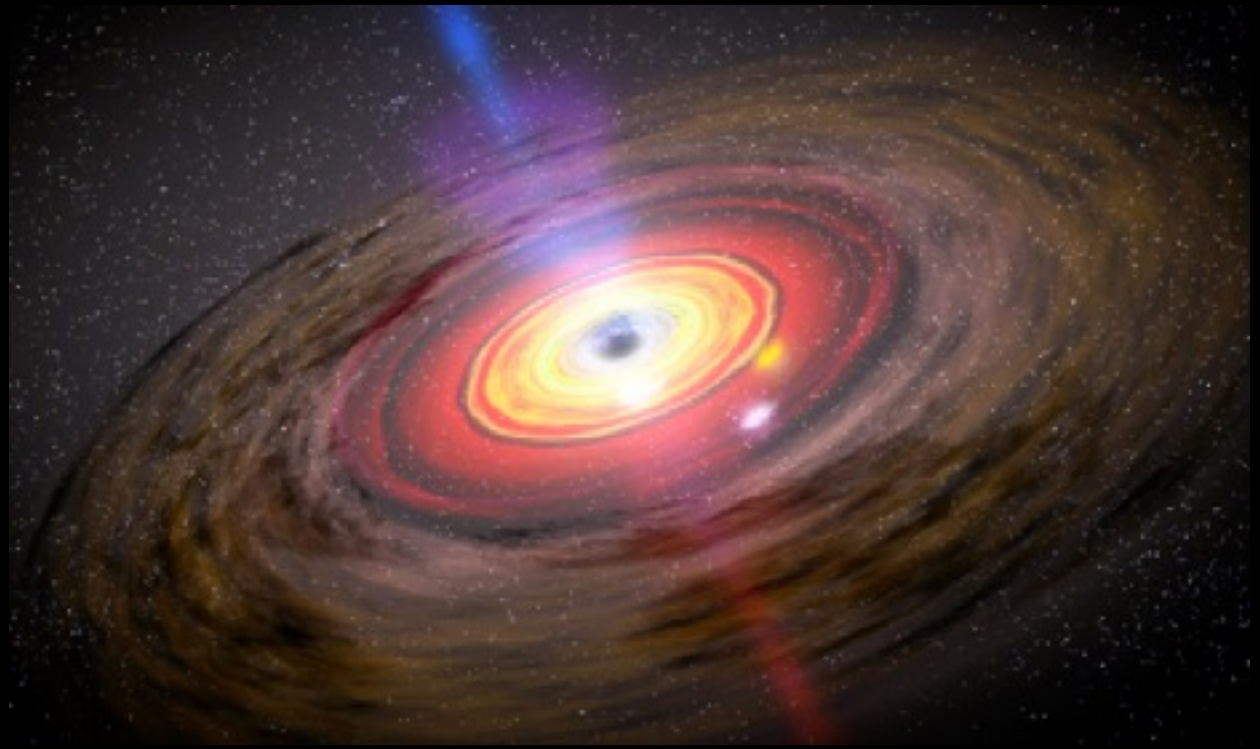


- Non-thermal emission at all wavelenghts dominate!



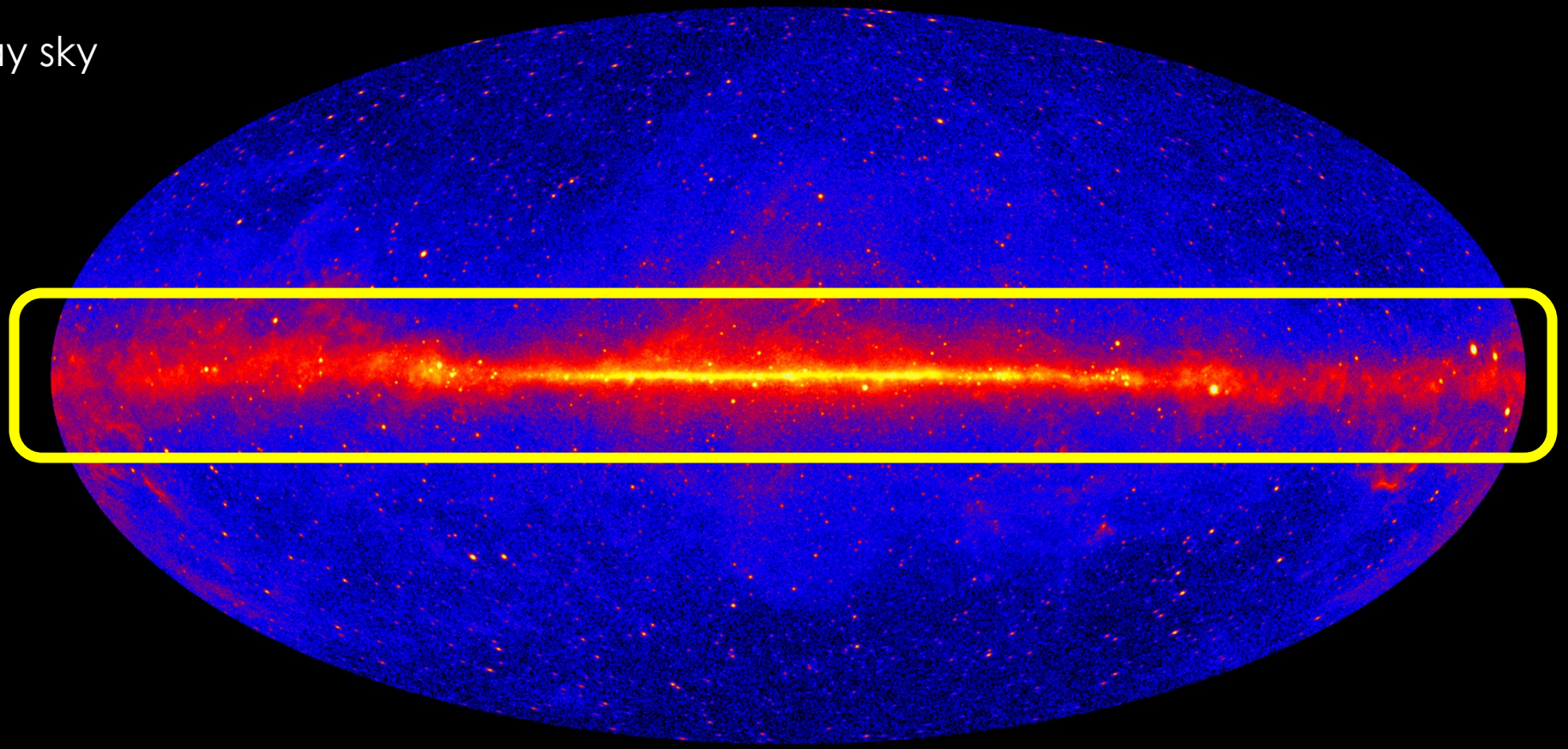
STUDY OF NON-THERMAL UNIVERSE

- **Extreme accelerators**
  - Characterization
  - Test physics in extreme conditions
  - Multimessenger connection: origin of cosmic rays
- **Search for anomalies from the standard model**
  - Search for dark matter
  - Evidence of axion-like particles



GALACTIC AND EXTRAGALACTIC OBJECTS

Gamma ray sky



Fermi LAT 12 years map

THE EXTRAGALACTIC, NON THERMAL SKY

- **Gamma ray survey: Fermi LAT**
- How many sources do we know?
  - Fermi Catalog → ~6000 sources (https://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermilpsc.html)
- Which sources?
  - **Blazars** dominate the extragalactic gamma ray sky!

Table 5. LAT 4FGL-DR3 Source Classes

Description	Identified		Associated	
	Designator	Number	Designator	Number
Galactic center	GC	1	···	···
Young pulsars, identified by pulsations	PSR	135	···	···
Young pulsars, no pulsations seen in LAT yet	···	···	psr	2
Millisecond pulsars, identified by pulsations	MSP	120	···	···
Millisecond pulsars, no pulsations seen in LAT yet	···	···	msp	35
Pulsar wind nebula	PWN	11	pwn	8
Supernova remnant	SNR	24	snr	19
Supernova remnant / Pulsar wind nebula	SPP	0	spp	114
Globular cluster	GLC	0	glc	35
Star-forming region	SFR	3	sfr	2
High-mass binary	HMB	8	hmb	3
Low-mass binary	LMB	2	lmb	6
Binary	BIN	1	bin	6
Nova	NOV	4	nov	0
BL Lac type of blazar	BLL	22	bll	1435
FSRQ type of blazar	FSRQ	44	fsrq	750
Radio galaxy	RDG	6	rdg	39
Nonblazar active galaxy	AGN	1	agn	8
Steep spectrum radio quasar	SSRQ	0	ssrq	2
Compact steep spectrum radio source	CSS	0	css	5
Blazar candidate of uncertain type	BCU	1	bcu	1491
Narrow-line Seyfert 1	NLSY1	4	nlsy1	4
Seyfert galaxy	SEY	0	sey	2
Starburst galaxy	SBG	0	sbg	8
Normal galaxy (or part)	GAL	2	gal	4
Unknown	UNK	0	unk	134
Total	···	389	···	4112
Unassociated	···	···	···	2157

SUMMARY

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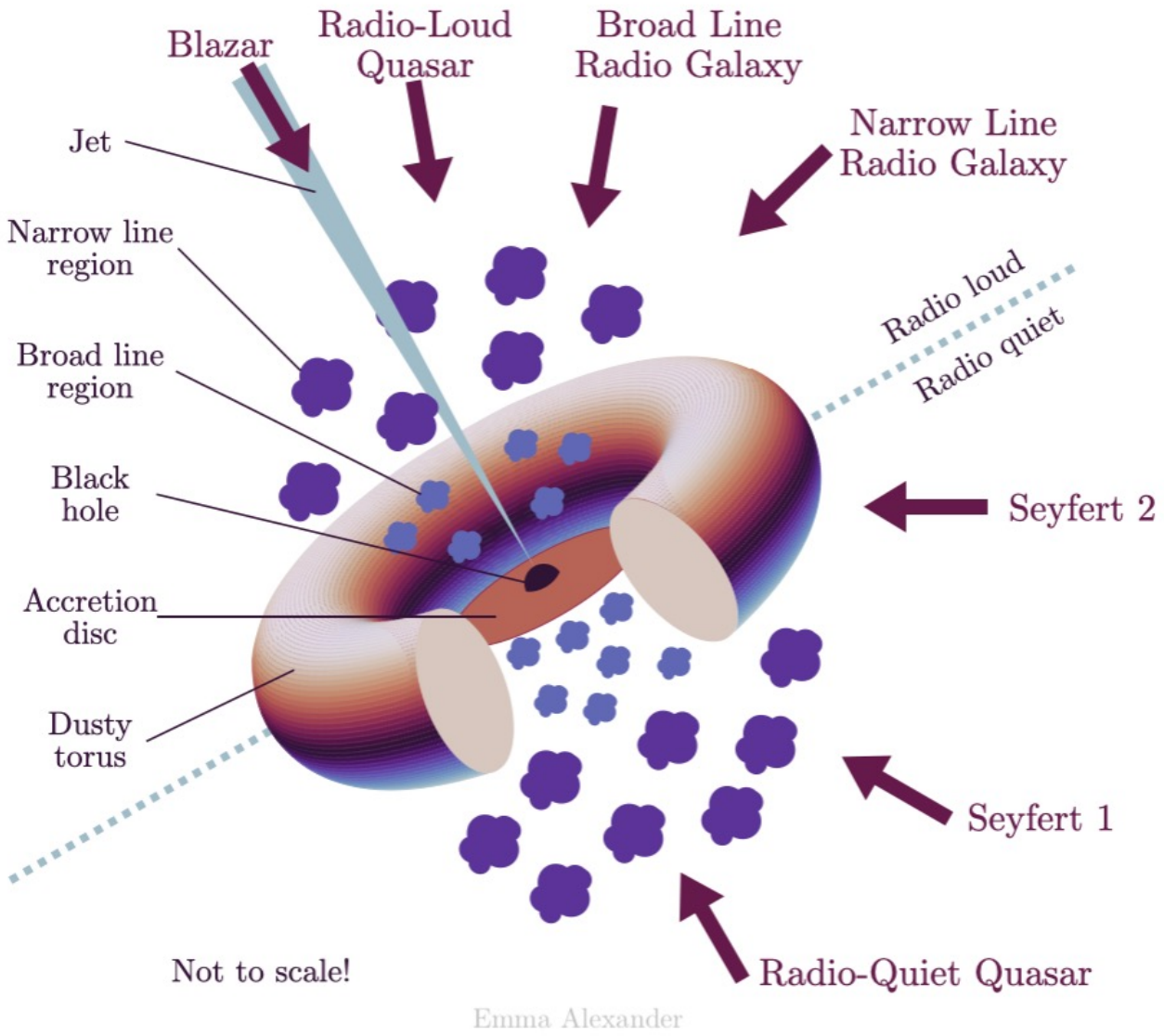
- **Blazars and their emission**

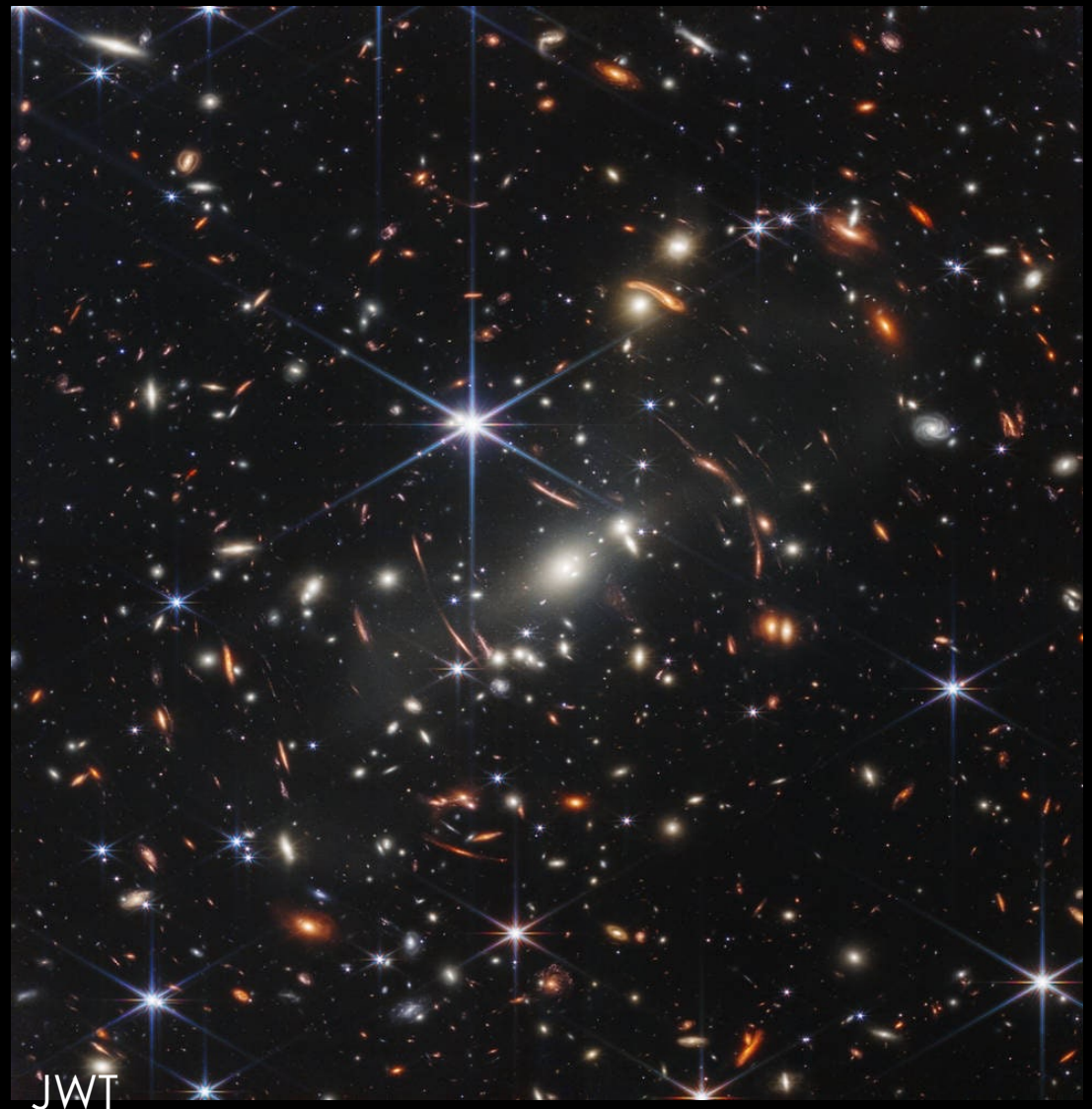
JETTED ACTIVE GALACTIC NUCLEI



- Central, **supermassive black hole**
- Energy from *accretion*
- Jet of ultra relativistic particles

- 1% of all galaxies
- 10% jetted

JETTED ACTIVE GALACTIC NUCLEI

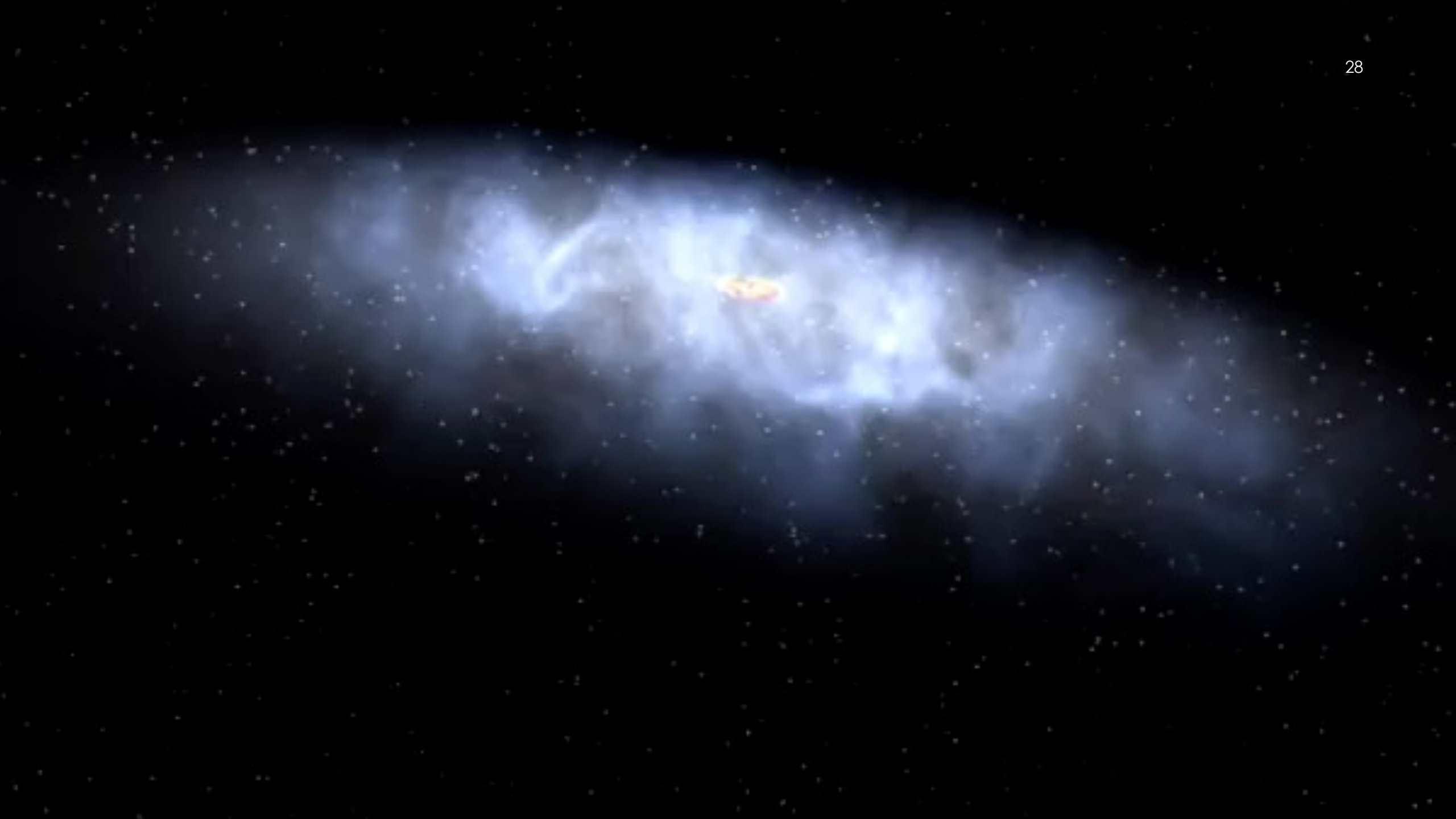


- Central, **supermassive black hole**
- Energy from *accretion*
- Jet of ultra relativistic particles

- 1% of all galaxies → **~10^{11} galaxies**
- 10% jetted
- **~5000 jetted galaxies detected**

JETTED-AGNS: EXAMPLES

Why??



WHY DO WE STUDY THESE OBJECTS?

- Most extreme particle accelerator available
- Test **physics** in energy regimes not available on Earth
- Test **propagation** of gamma rays

PARTICLES IN THE JET

- Acceleration + collimation
- Magnetic field

- Which kind of emission?
- Which energy band?

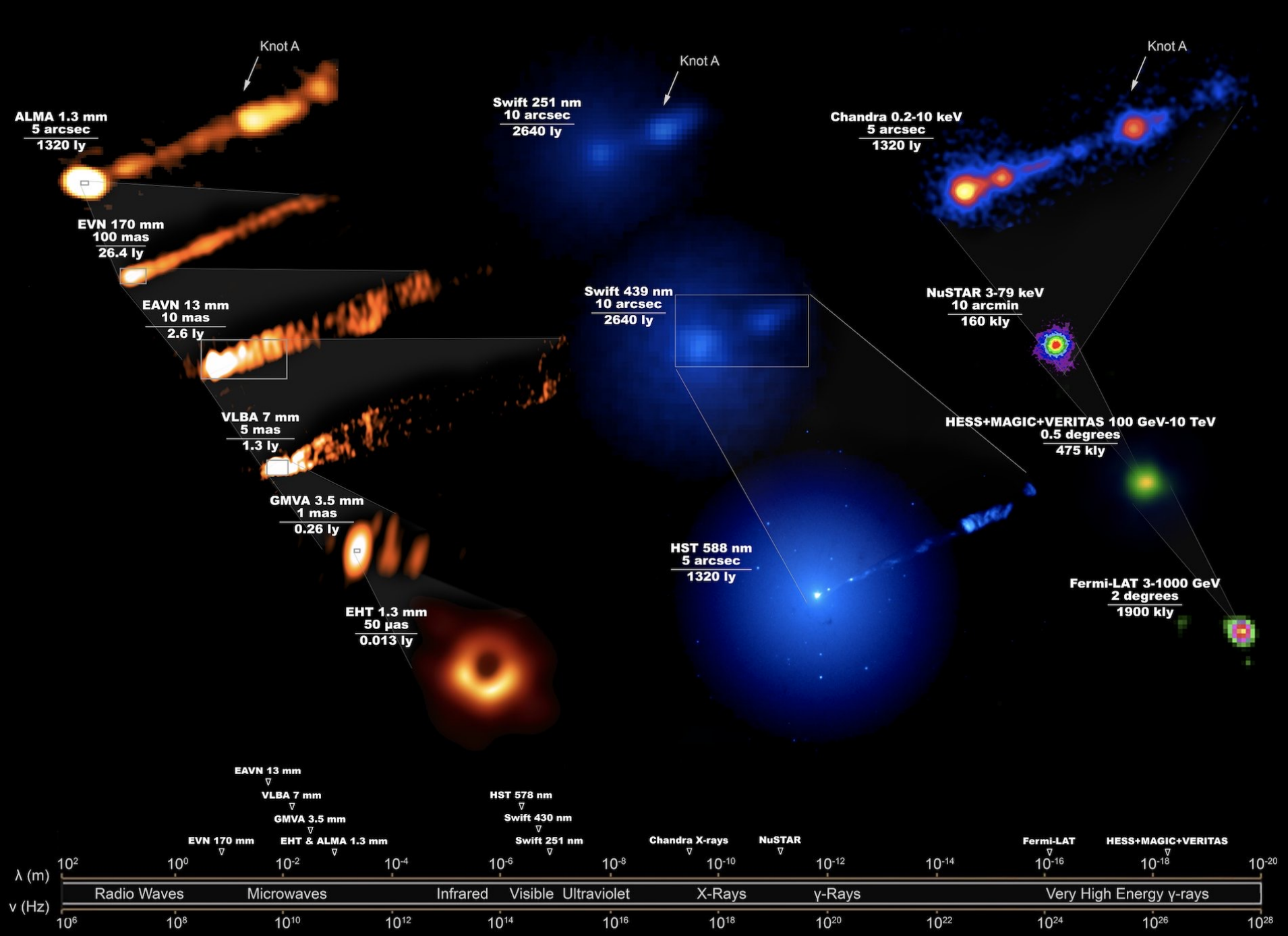
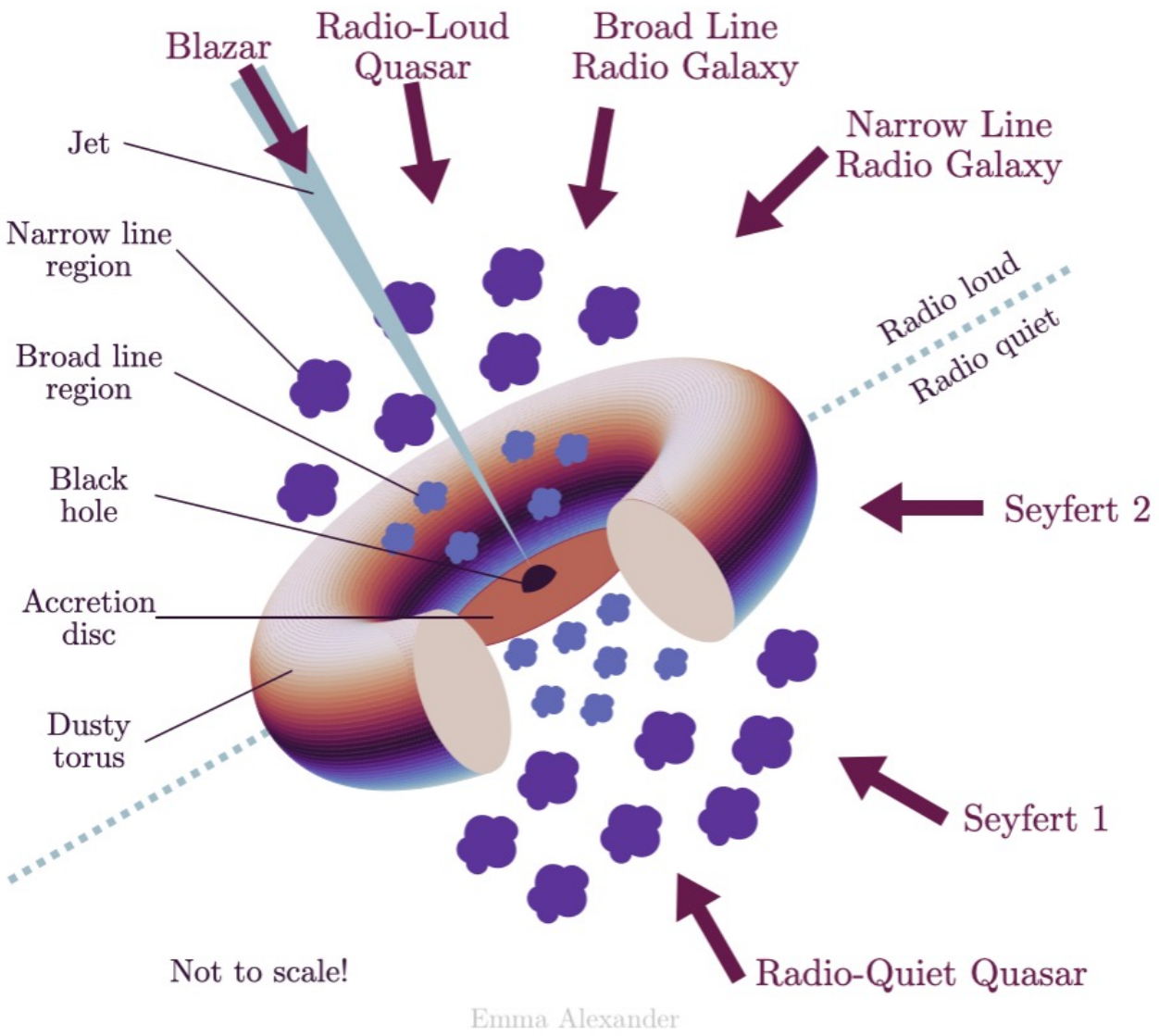


Image Credit: The EHT Multi-wavelength Science Working Group; the EHT Collaboration; ALMA (ESO/NAOJ/NRAO); the EVN; the EAVN Collaboration; VLBA (NRAO); the GMVA; the Hubble Space Telescope; the Neil Gehrels Swift Observatory; the Chandra X-ray Observatory; the Nuclear Spectroscopic Telescope Array; the Fermi-LAT Collaboration; the H.E.S.S collaboration; the MAGIC collaboration; the VERITAS collaboration; NASA and ESA. Composition by J. C. Algaba

On large scales, the emission is a superposition of many contributions

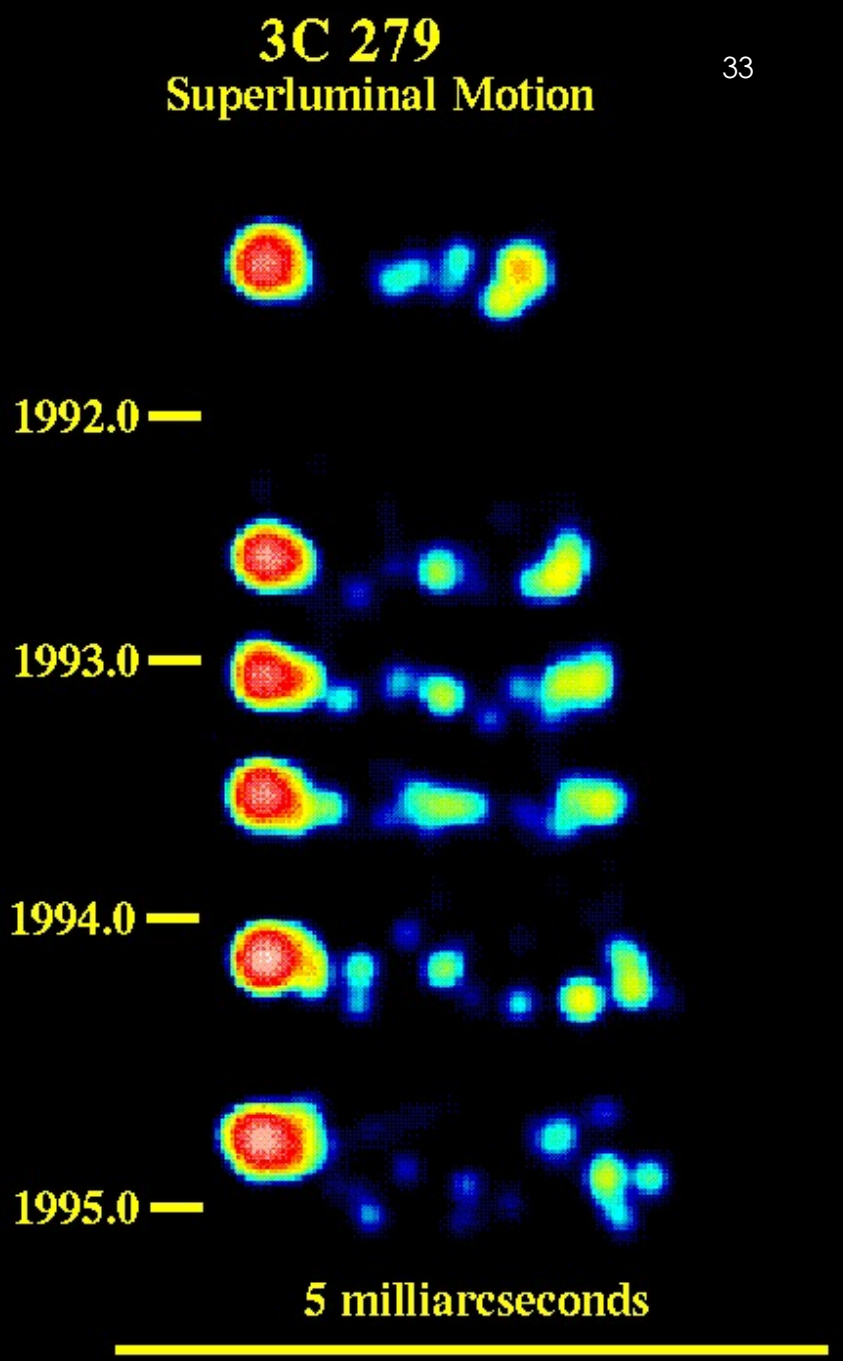
→ Models are very complex!

LOOKING FOR THE EASIEST CASE….

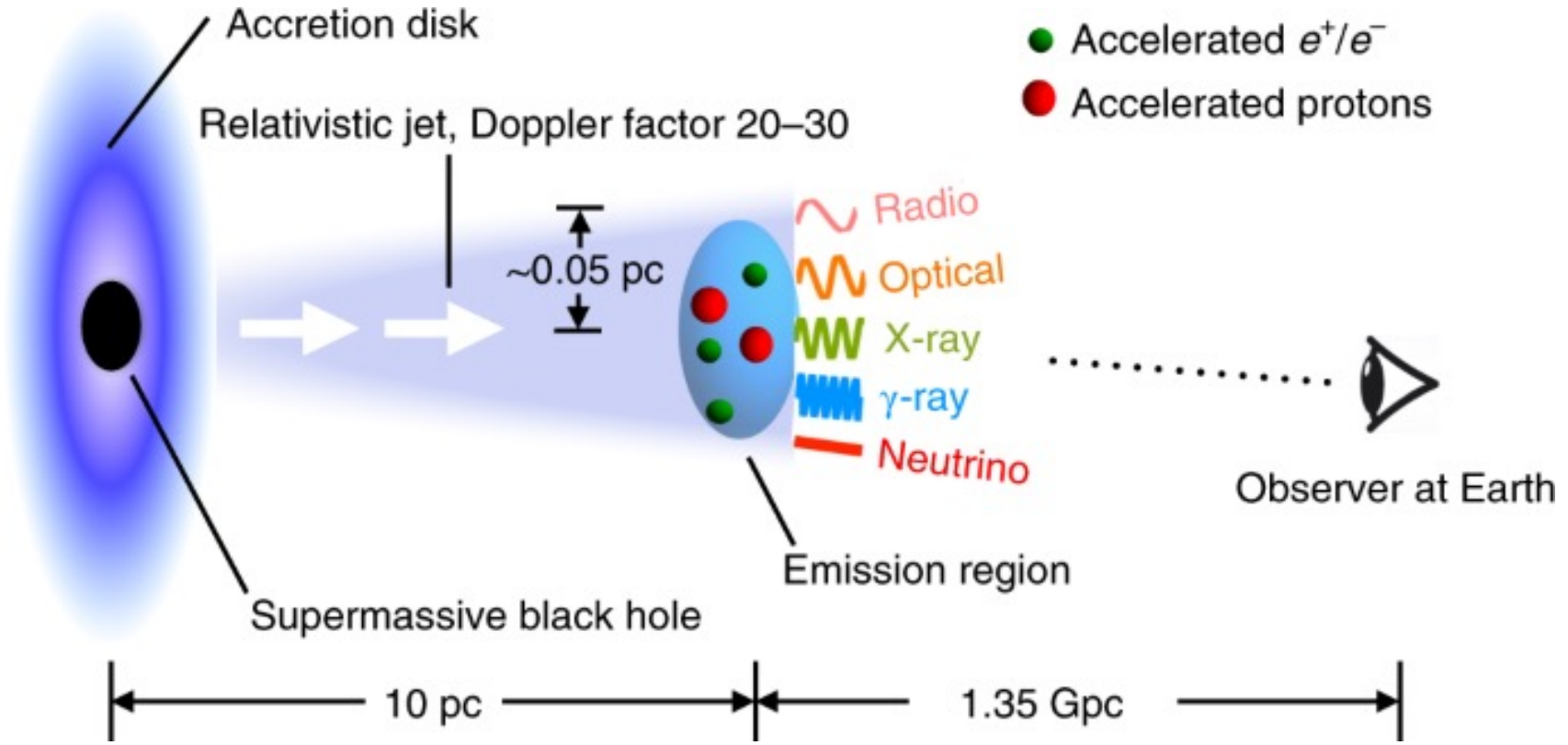


RELATIVISTIC BOOST

- Time is contracted
- Luminosity is highly enhanced
- Explaination of superluminal motion detected in some blazars (example: 3C 279)
- **From a blazar you see almost only the jet!**



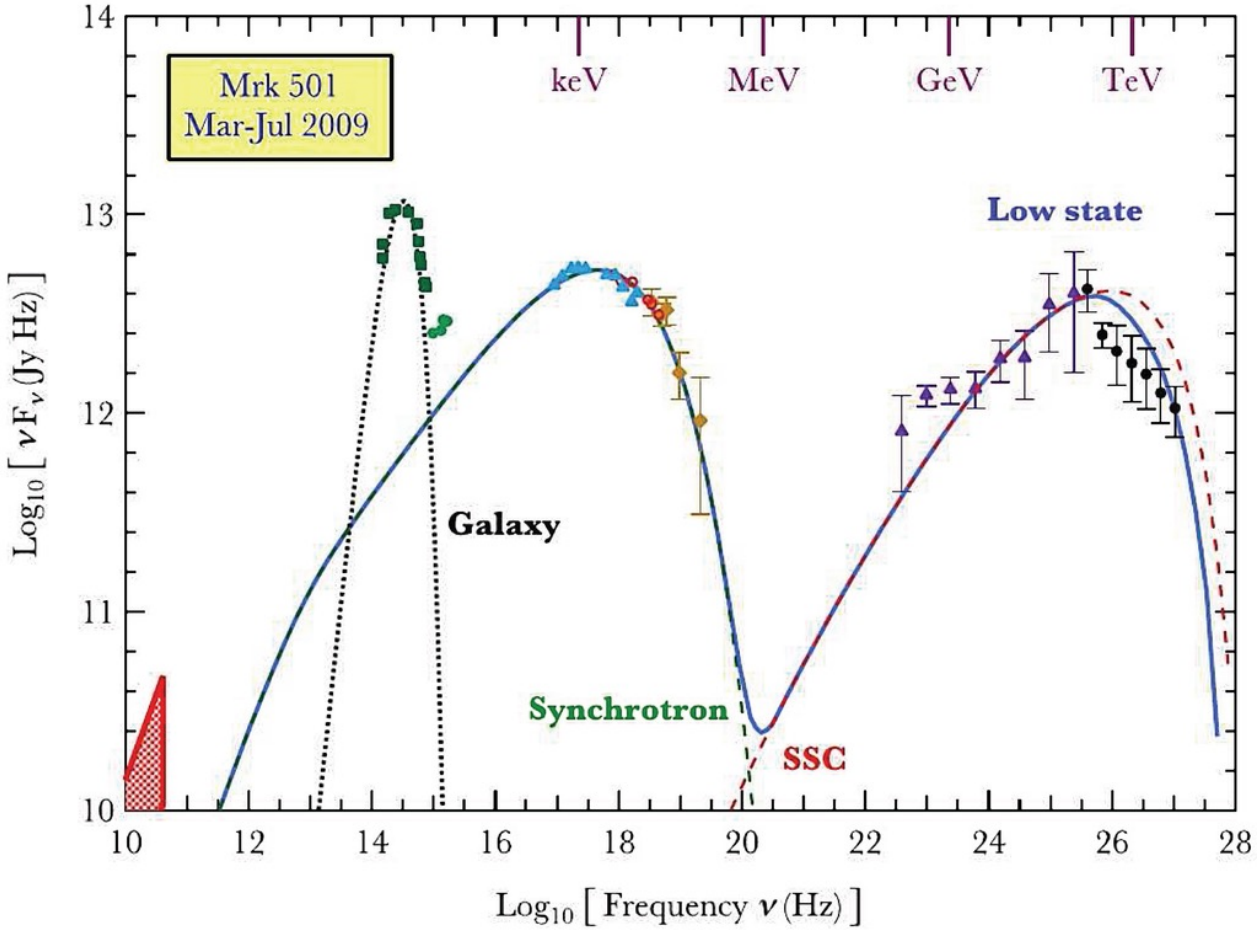
PHYSICS PROCESSES IN A BLAZAR'S JET



STANDARD SCENARIO: TWO MAIN MECHANISMS

- **Syncrotron emission**: from radio to X rays

- **Inverse Compton emission**: from X-rays to gamma rays

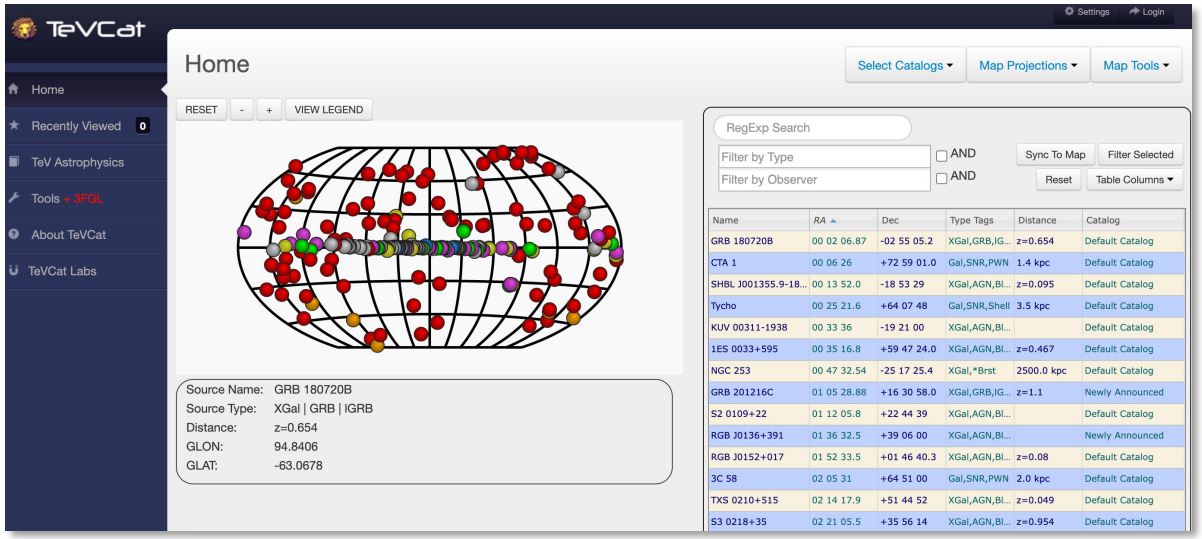


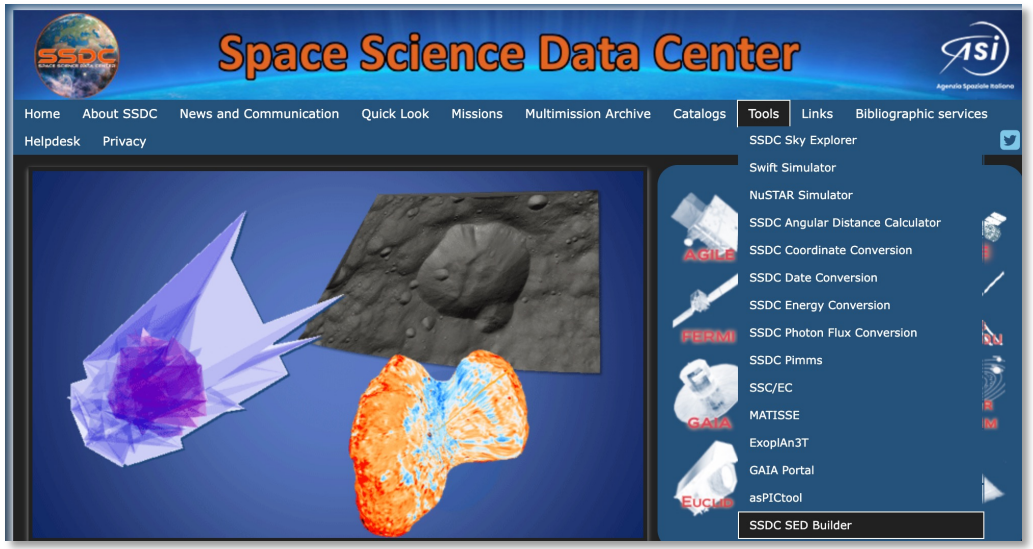
LET'S SEE SOME OF THE MOST ENERGETIC BLAZARS

- Mkn 501
- 3C 66A
- 3C 279

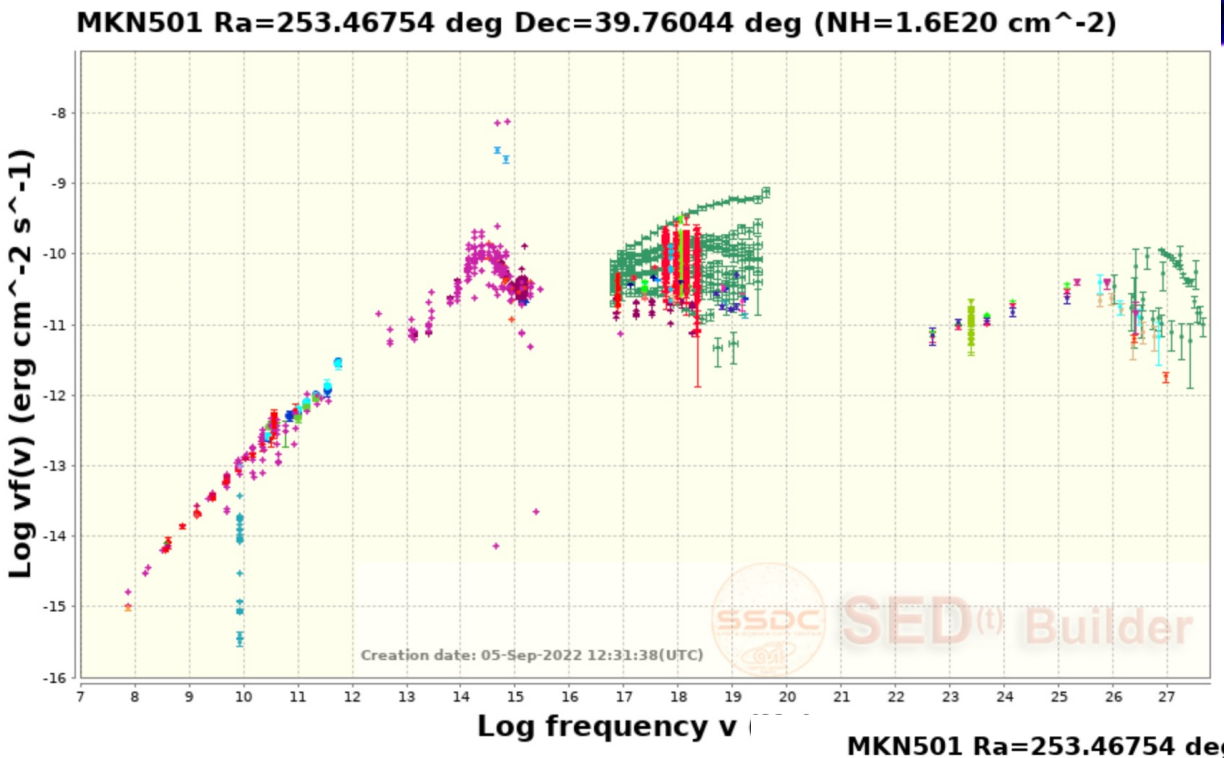
1. Search for the redshift of these blazars (http://tevcat2.uchicago.edu/)

2. Build the spectral energy distribution (https://tools.ssdc.asi.it/SED/)

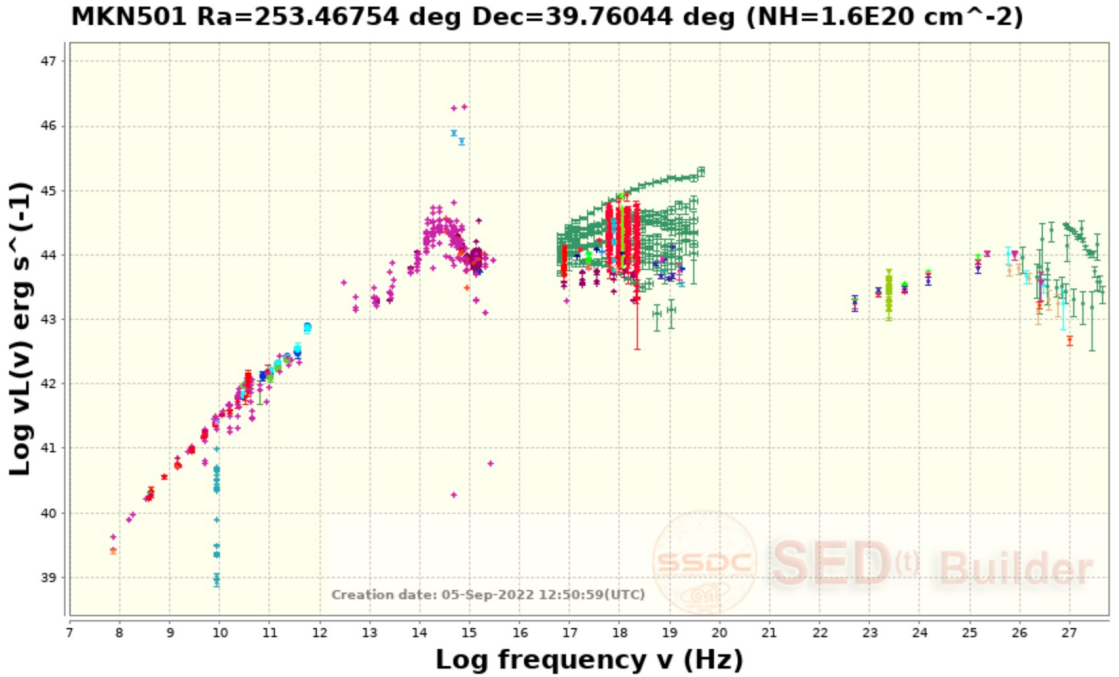


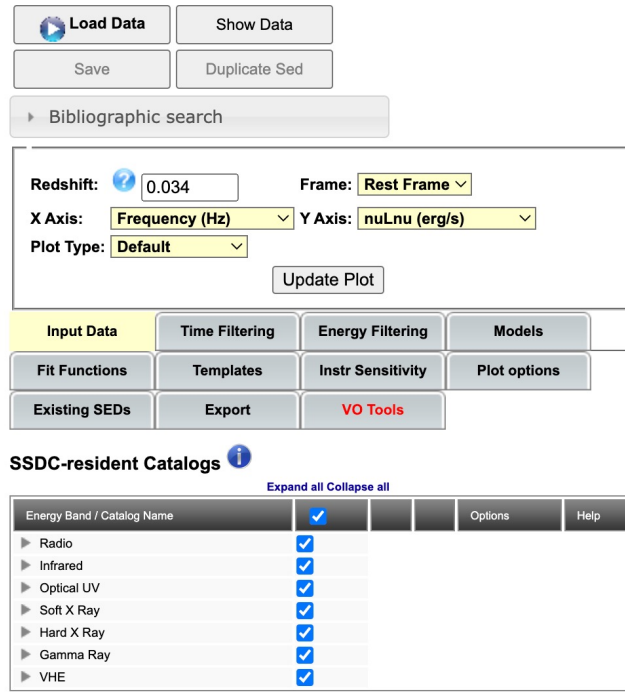


MKN 501

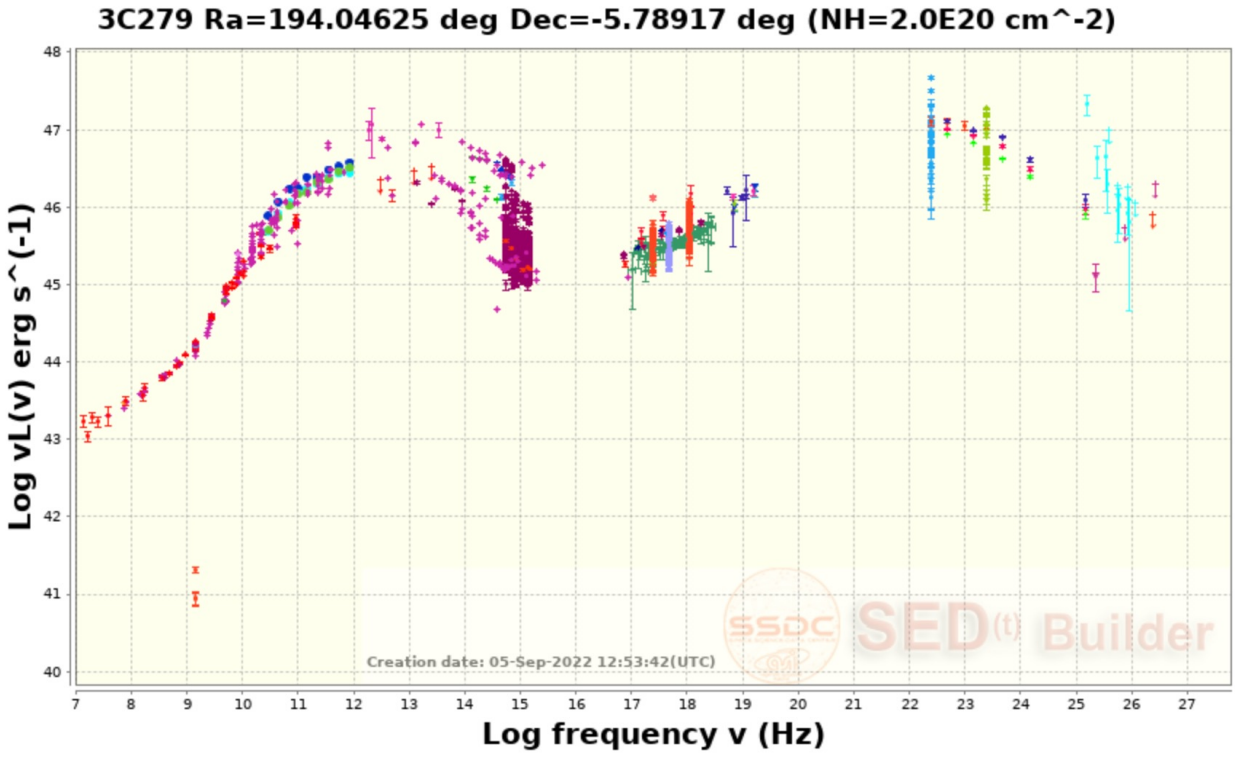


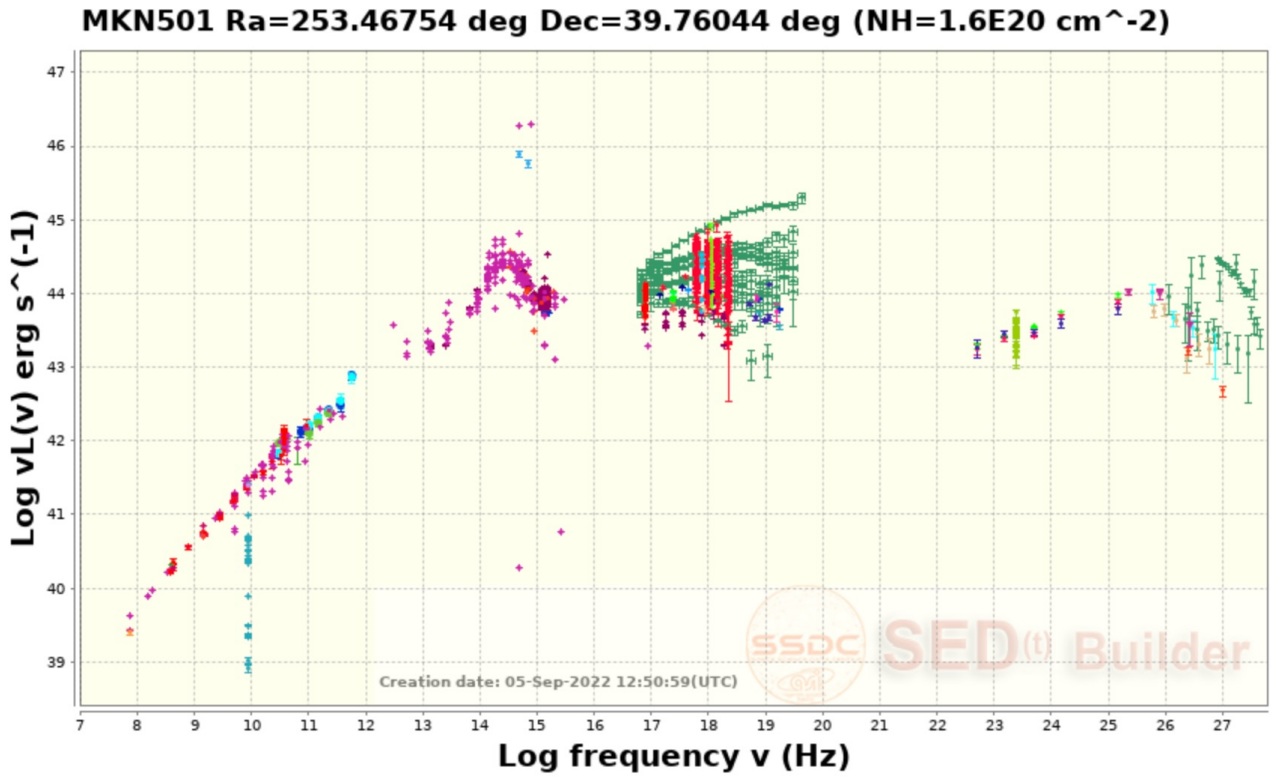
Compare source emission → correct for redshift



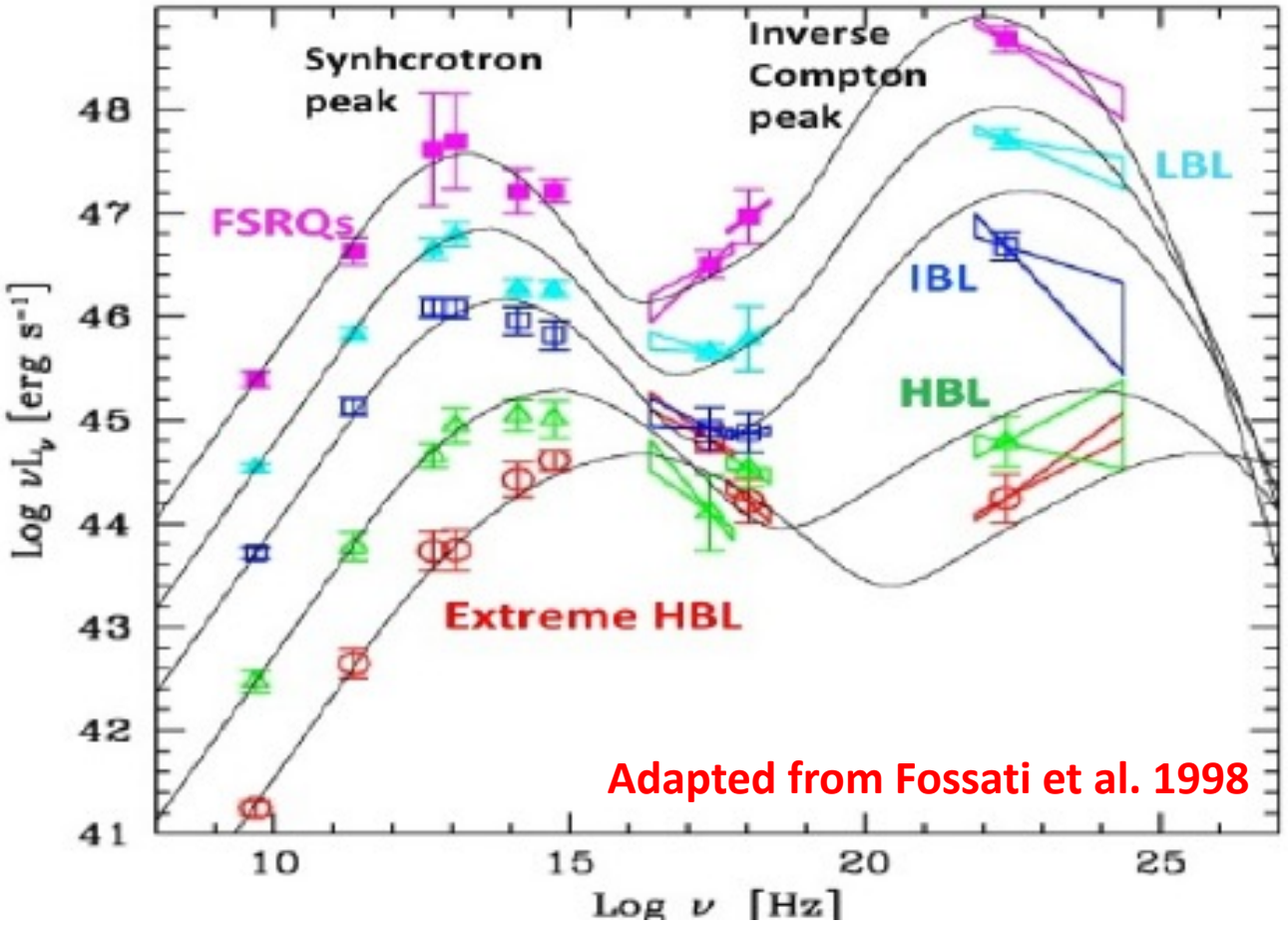


COMPARISON


3C279 Ra=194.04625 deg Dec=-5.78917 deg (NH=2.0E20 cm^-2)
Log vL(v) erg s^(-1)
Log frequency v (Hz)
Creation date: 05-Sep-2022 12:53:42(UTC)
SSDC SED Builder


MKN501 Ra=253.46754 deg Dec=39.76044 deg (NH=1.6E20 cm^-2)
Log vL(v) erg s^(-1)
Log frequency v (Hz)
Creation date: 05-Sep-2022 12:50:59(UTC)
SSDC SED Builder

THE BLAZAR SEQUENCE



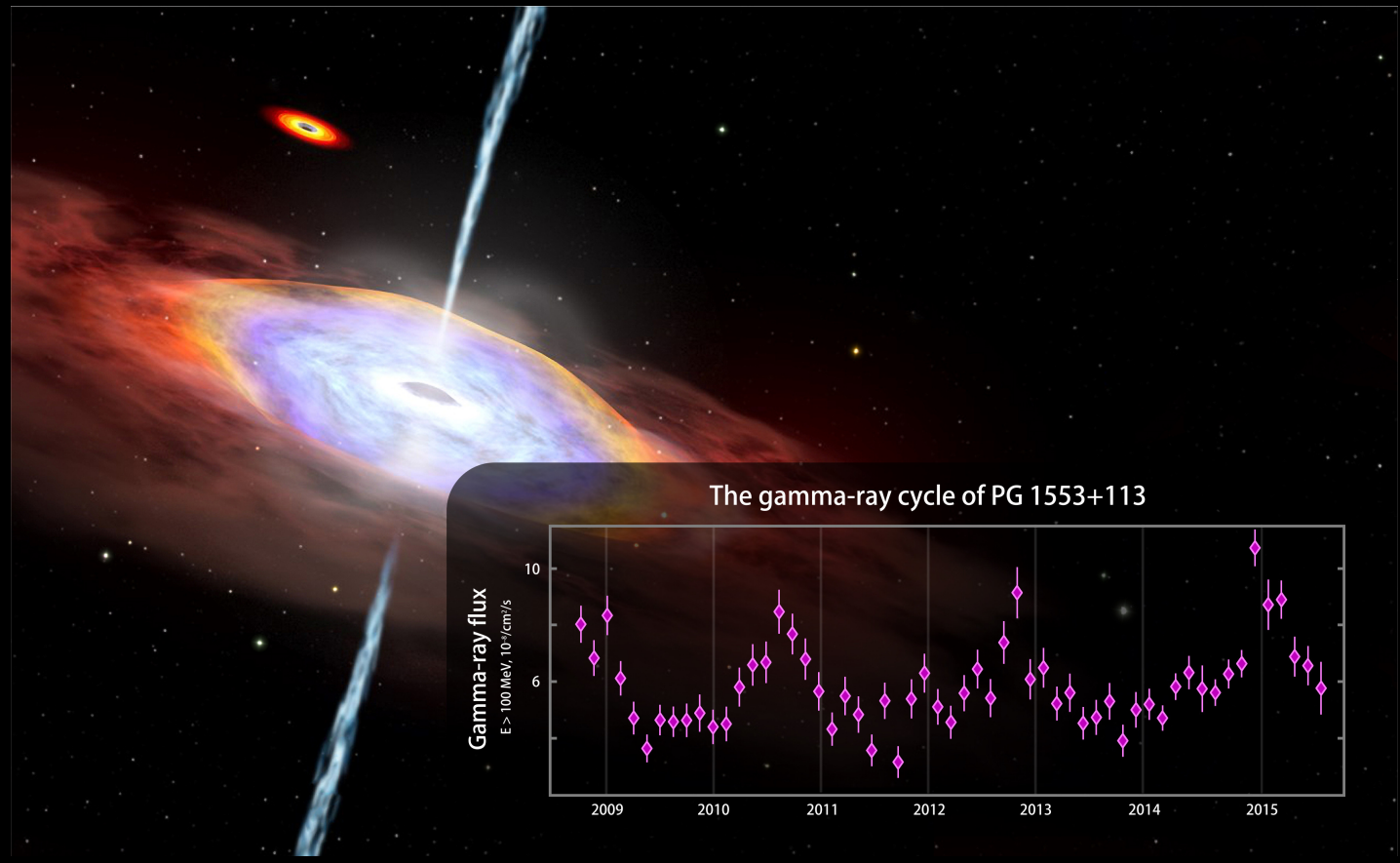
- SED **brightness anti-correlates with the peak position**
- TeV detections are in line with the blazar sequence

GAMMA RAYS TO THE HIGHEST ENERGIES

- http://tevcat2.uchicago.edu/
- **How many blazars** detected in this energy band?
- Which is the **most distant?**
- Which was **detected first?**

MY FAVOURITE SOURCE: PG 1553+113

- Uncertain redshift
- HBL
- Periodic emission in Fermi-LAT (gamma rays)
- MWL emission?



LET'S HAVE A LOOK AT THE MOST FAMOUS BLAZAR OF THE SKY: **TXS 0506+056**

- Build the SED (from ssdc website)
- Find it in TeVCaT

HISTORY OF A MILESTONE

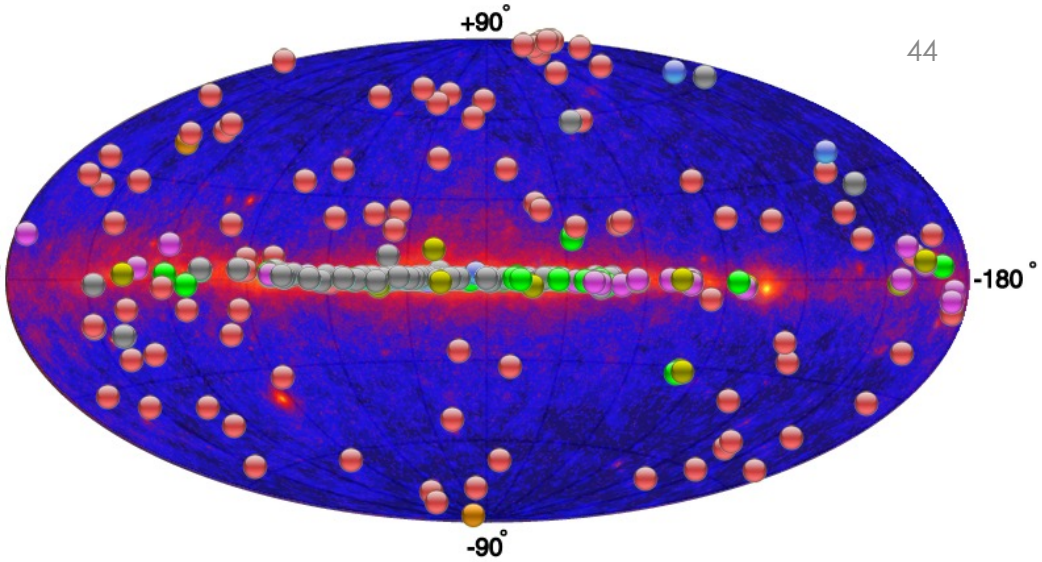
- The 22nd September 2017, a high energy, astrophysical neutrino was detected by IceCube

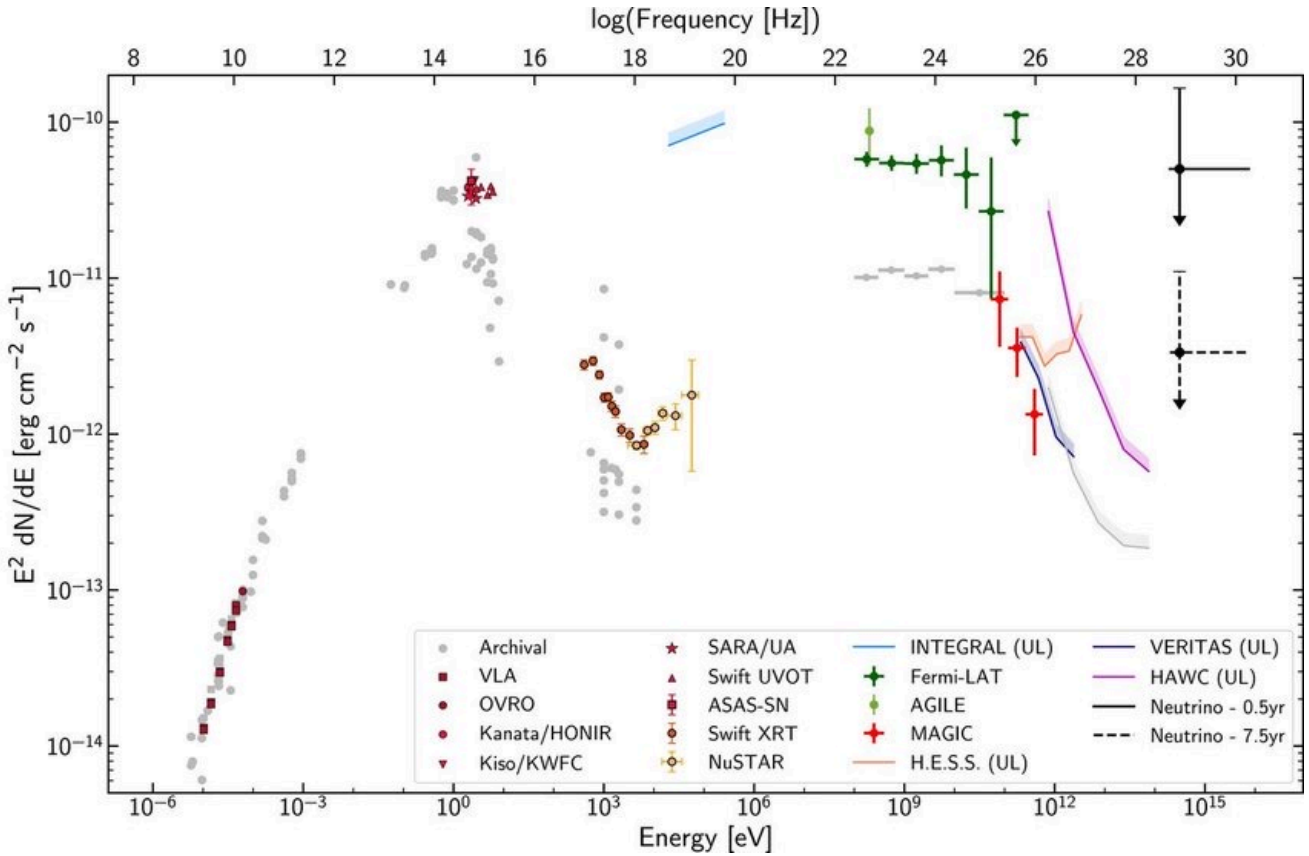
- Gamma-ray observations (Fermi-LAT & MAGIC) + observation at other bands have revealed that it was coming from a blazar

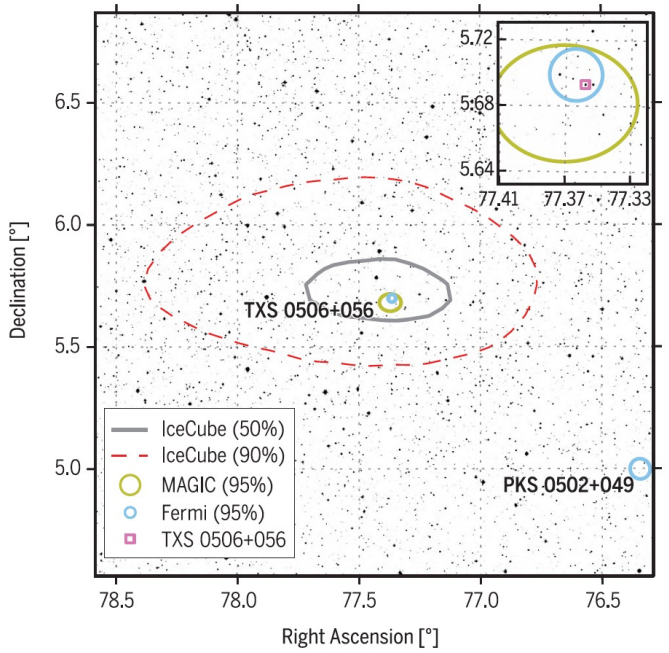
- For the first time the astrophysical source of high-energy neutrinos was detected!

- **Blazars are cosmic ray accelerators!**

THE NEUTRINO BLAZAR







The search continues…

Thank you!