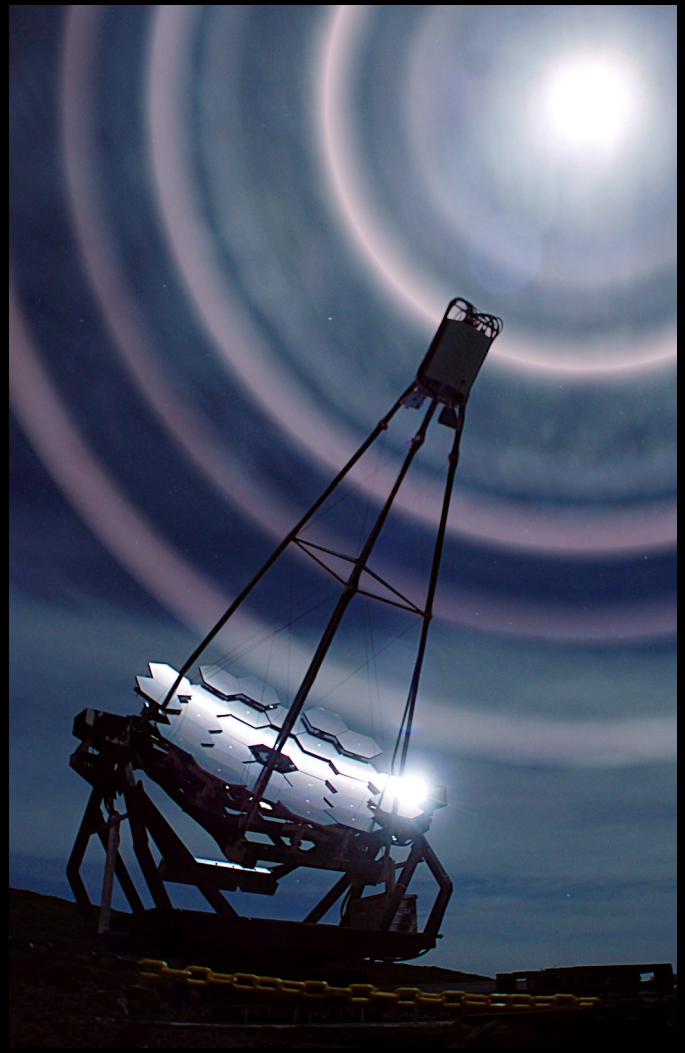

Credit: Jens Björn Buß (Jebuss) via Wikimedia Commons

Possibilities for High-Energy and Multi-Messenger SETI

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JUNE 23, 2025

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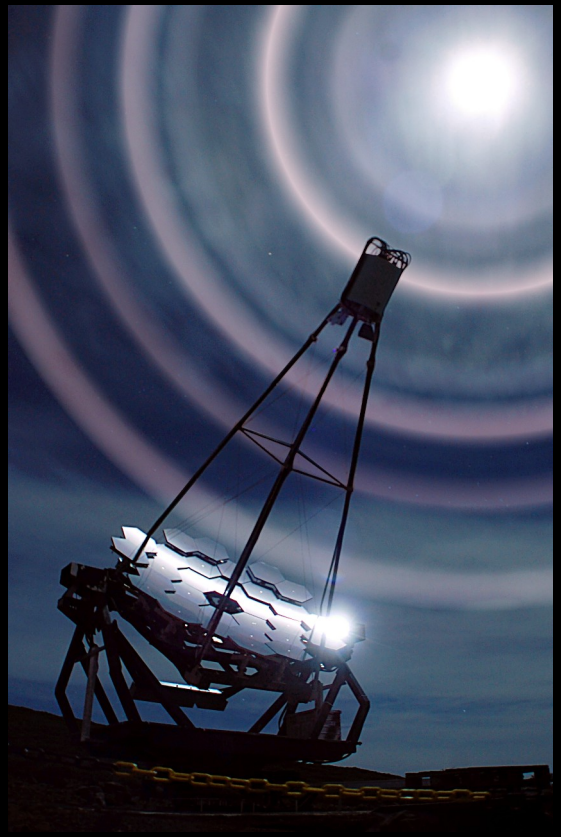
PREVIOUS HIGH-ENERGY/MULTIMESSENGER SETI WORKS

Authors	Year	Journal	Medium	Idea
Abramowicz et al.	2020	*Nature* SR	GW	Planetary mass used as beacon orbiting Sgr A*
Berera & Calderón-Figueroa	2022	Phys. Rev. D	X	Pulsar-like signals from ETIs
Carstairs	2006	—	X, γ	Use of X-rays for quantum communications
Corbet	1997	JBIS	X	X-ray transients from XRBs as technosignature
Fischbach	2017	—	ν	Radioactive decay variations from new physics to detect ν
Harris	1986, 2002	ApSS, —	γ	Pionic signatures from antimatter starship engines
Hippke & Forgan	2017	—	X	Interstellar X-ray transmissions, including first search
Imara & Di Stefano	2018	ApJ	X	Possibility of megastructures around XRBs
Jackson	2018	—	GW	Graviational wave transmissions using black holes
Lacki	2015	—	ν	Planck-scale ν from particle accelerators
	2020	ApJ	X	X-ray transients from lensed XRBs
	2024	ApJ	γ, ν, GW	Limits on aggregate ETI emission
Learned et al.	1994, 2009	QJRAS, PhLet B	ν	Communication with ν
	2008	—	ν	Cepheid variability modulation by ETI ν beams
Lefebvre	1999	Ast. & Ap. Trans.	X	Sentient XRBs
Lentz	2024	—	EM, GW	Technosignatures from warp bubbles
Lingam & Loeb	2020	ApJ	(X)	Use of energetic phenomena to accelerate starships
Loeb	2024	RNAAS	EM	Hawking radiation from harnessed PBHs
Paksava	2010	NucPh A	GW	Cepheid variability modulation by ETI ν beams
Sellers	2022	—	GW	Gravitational waves from planetary-mass starships
Silagadze	2008	Acta Phys Pol B	ν	Muon ν beams for communication
Subotowicz	1979	Acta Astronaut.	ν	Communication with ν
Swain	2006	—	UHECRs	Mention of UHECRs as potential technosignature
Vidal	2011, 2024	JBIS	X	XRBs as optimum sites for ETIs
Vukotić, Ćirković, Filipović	2024	IOP Book	Multimessenger	Discussion of different messengers and bands for SETI
Whitmire	1980	ApSS	Isotopic	Radioactive isotopes in stars from dumped nuclear waste

I. COMMUNICATION



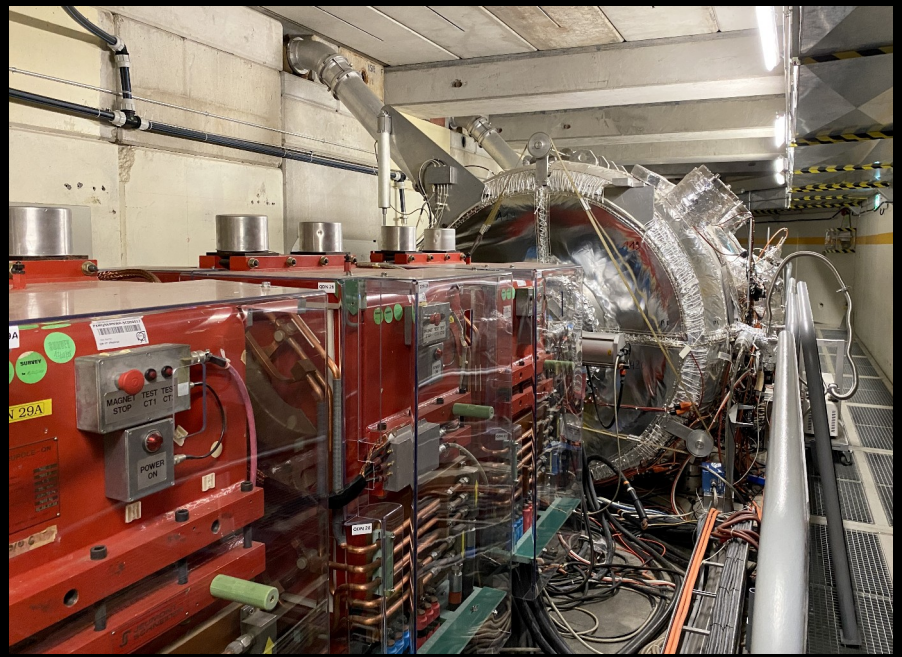
Credit: NASA

Credit: Jens Björn Buß (Jebuss) via Wikimedia Commons

Some works have suggested ETIs would deliberately use high-energy or non-photonic messengers to send messages

- At higher energies, diffraction less severe – tighter beams
- Can modulate existing high-energy phenomena like XRBs to generate bright signal
- Neutrinos and GWs are penetrative

II. INDUSTRY

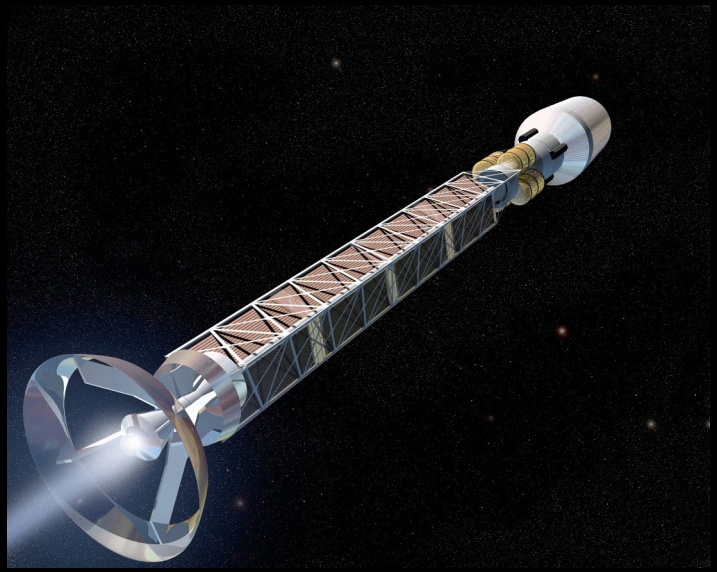


These forms of radiation could be byproducts of large-scale industries

- Byproducts of reactor usage
  - Pionic radiation from antimatter
  - Neutrinos from nuclear reactors
  - Hard to detect
- Particle accelerator experiments
- Neutrinos to heat stellar interiors

Credit: Mramoeba via Wikimedia Commons [Antimatter Factory, CERN]

IIA. TRANSPORT

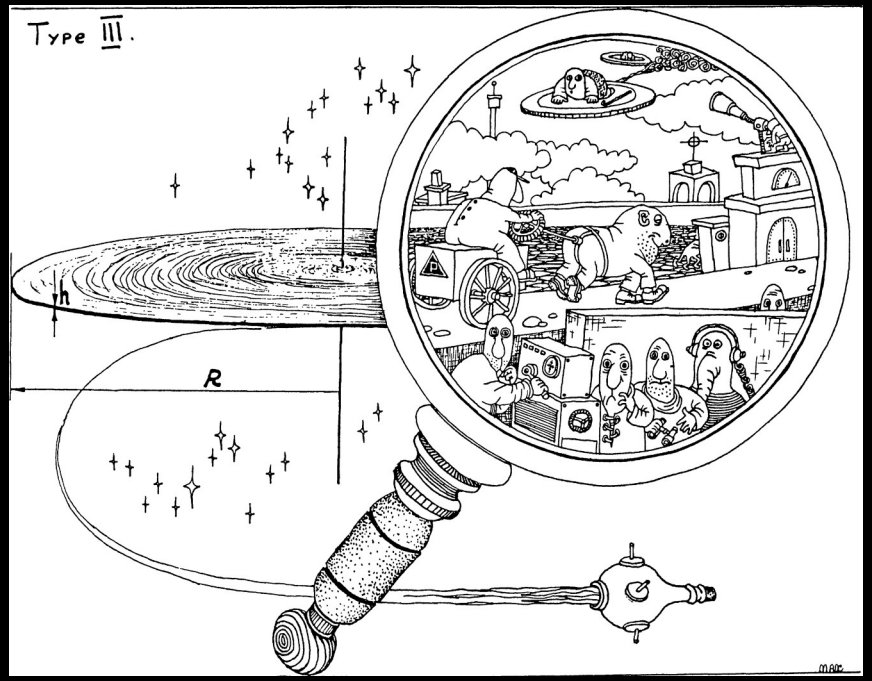


High-energy phenomena can accompany interstellar travel

- Pionic radiation from antimatter rockets
- Phenomena to accelerate sails
- Relativistic fragments in atmosphere appears like UHECRs
  - cf. Relativistic dust hypothesis
- General relativistic signatures

Credit: NASA/MSFC via Wikimedia Commons

III. HABITAT



Credit: I. Maximov, in Kardashev (1985)

ETIs might be drawn to high-energy phenomena as places to work and live

- Immense energy gradients
  - Especially around XRBs
  - "Stellivore" hypothesis
- In extreme limit of speculation, life indigineous to these environments – nuclear life

THE KARDASHEV SCALE

TYPE I
Planetary

TYPE II
Stellar

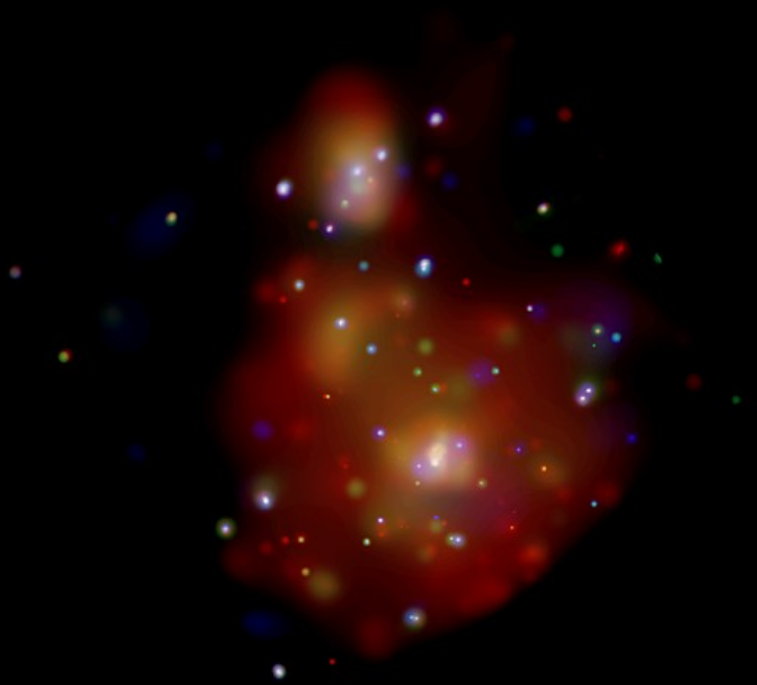
TYPE III
Galactic

A measure of power usage by ETIs (originally for communications)

Canonically, $K = 0.1 \log_{10} (P / 1\ MW)$

Credit: Type I – ESA/Hubble; Type II – Danielle Futselaar, SETI International; Type III – ESA/Hubble & NASA/D. Milisavljevic (Purdue University)

POPULATIONS AS TECHNOSIGNATURES



Credit: NASA/CXC/SAO/R.DiStefano et al.

- If interstellar coordination is possible, some galaxies may have anomalous populations of objects
  - e.g. Too many or too few XRBs in a galaxy
- Can look for "wrong" discrete sources within galaxies, or at collective glow of all sources

COLLECTIVE EMISSION AS TECHNOSIGNATURE CONSTRAINT

M82

9×10^{-12} erg cm^{-2} s^{-1}

$< 3 \times 10^{-5}$ L_{sun} star^{-1}

M81

$< 2 \times 10^{-12}$ erg cm^{-2} s^{-1}

$< 10^{-5}$ L_{sun} star^{-1}

The sum of all ETI broadcasts cannot outshine the galaxy itself!

There are a lot of things galaxies with ETIs could do but don't

Credit: Fermi-LAT via Aladin

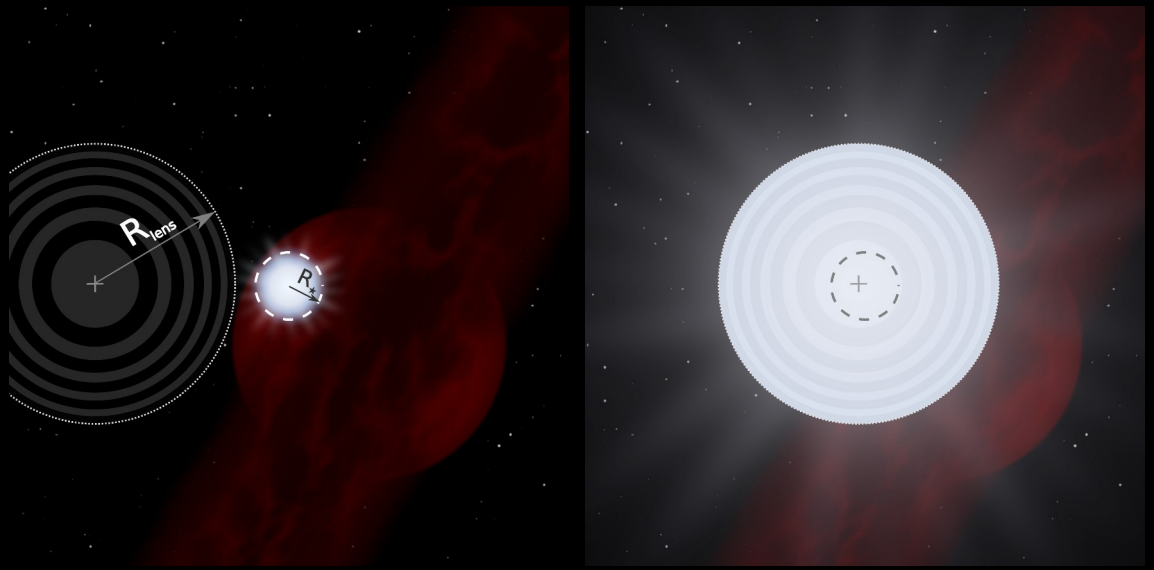
ABSENCE AS A TECHNOSIGNATURE

Missing high-energy phenomena might signify tampering

- Energy collection from Dyson swarms around XRBs?
- High-energy phenomena inhibited for “habitability” reasons?
- Suppression of flares around M dwarfs?

Credit: NASA

TRANSIENTS AS TECHNOSIGNATURES

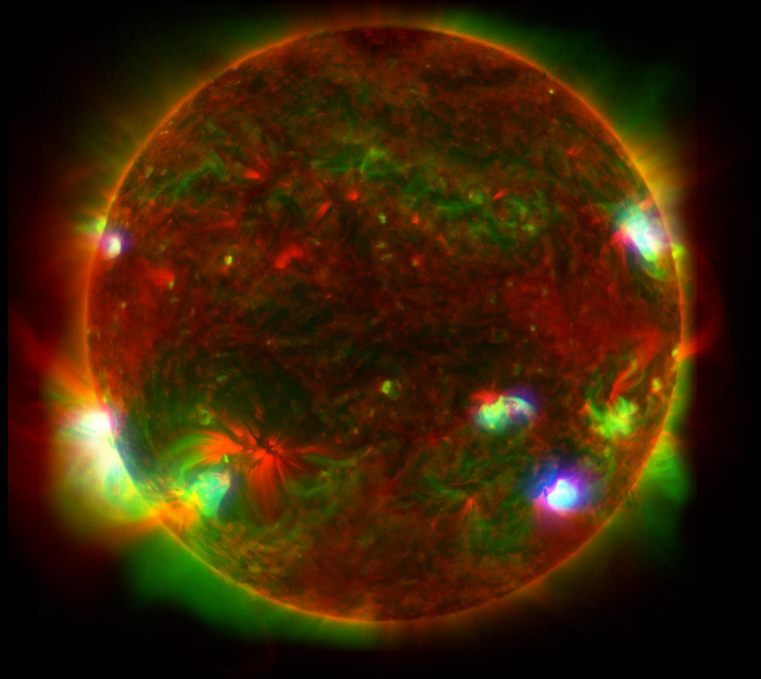


Many putative technosignatures would resemble unusual high-energy transients

- X-ray bursts from material dropped onto (or lensed) neutron stars
- Unusual central engines of particle accelerators ($\Gamma \gg 1000$)

Credit: Lacki, personal collection (modified version of Lacki 2020)

SOLAR SYSTEM INSTRUMENTS



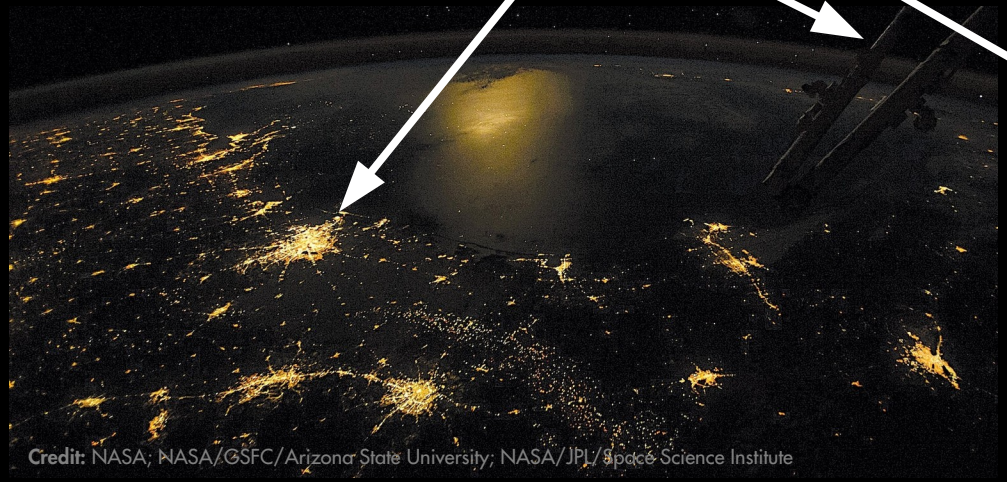
Credit: NASA Jet Propulsion Laboratory

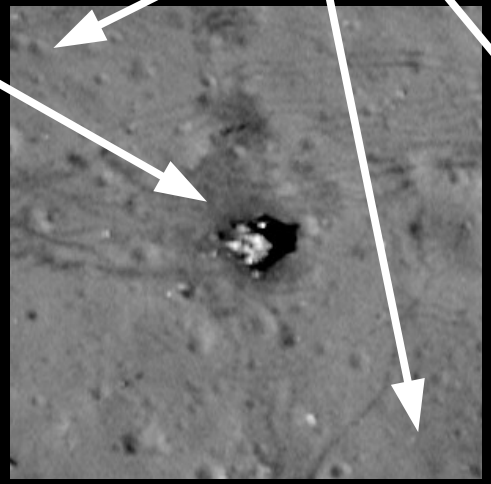
- Heliospheric and interplanetary probes have high-energy instruments
  - IPN localizes GRBs
  - Gamma-ray, X-ray telescopes
- Solar neutrino observatories can detect distant phenomena
  - SN 1987A
- Possibility of Solar System technology

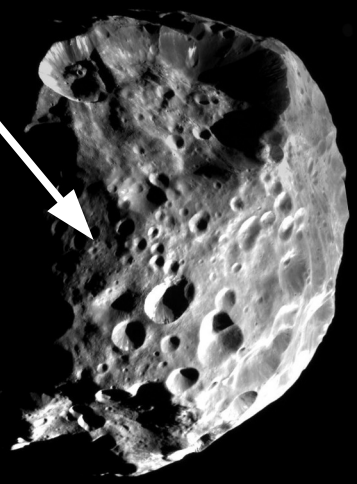
THE FERMI* PARADOX

Human technosignatures

No (obvious) alien technosignatures



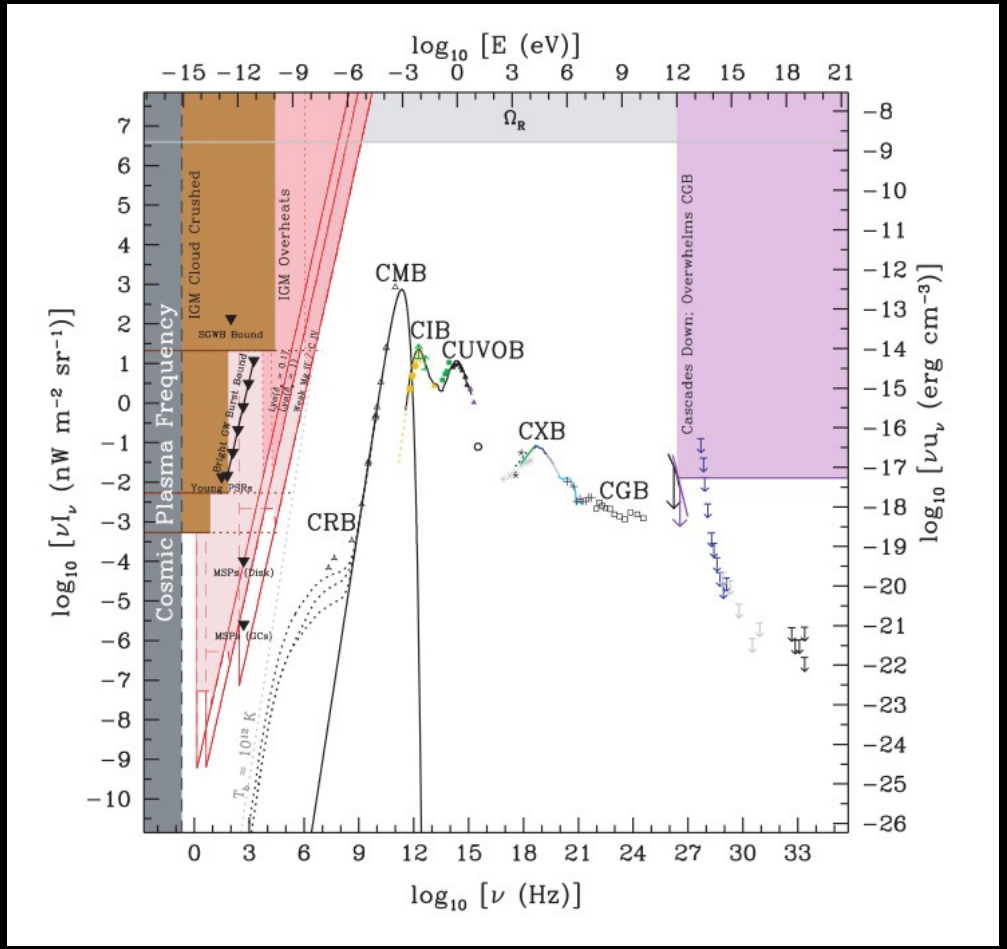




No obvious artifacts or settlements anywhere in the Solar System

Yet it would take <100 million years to spread across the galaxy – just 1% of the Galaxy's history

THE GREAT SILENCE: HIGH ENERGY EDITION



Credit: Lacki (2010)