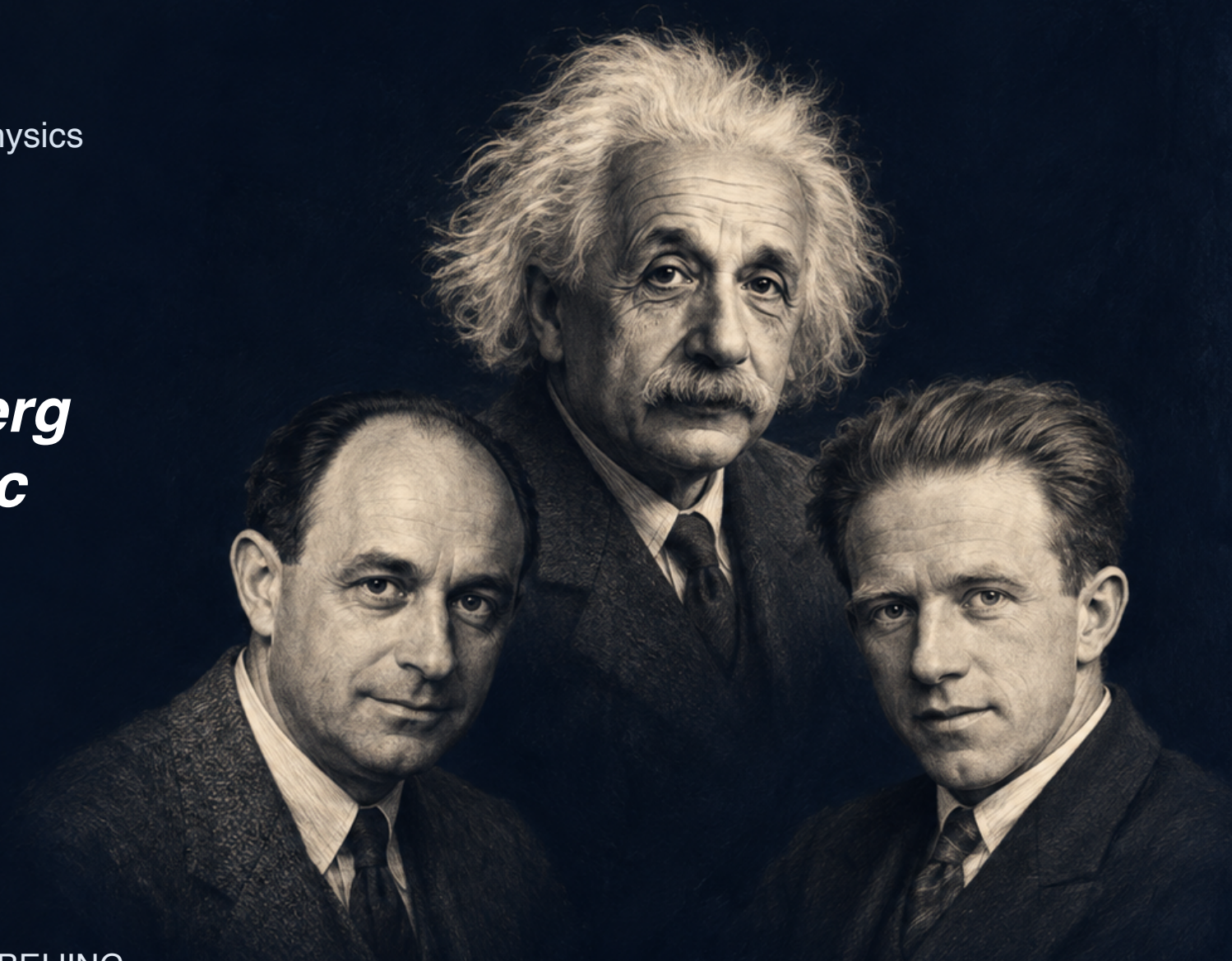
ICFP 2026

The International Conference on Fundamental Physics
from Quanta to Cosmos

Revisiting *"Einstein, Fermi, Heisenberg and the Birth of Relativistic Astrophysics"* in view of recent findings



Remo Ruffini

ICRA / ICRANet

24–26 OCTOBER 2026 · QIHU HOTEL, HUAIROU, BEIJING

HOST INSTITUTION: ITP-CAS · CO-ORGANIZERS: ICTP-AP, HIAS


Einstein, Fermi, Heisenberg
and the Birth of Relativistic Astrophysics
Remo Ruffini
University of Rome "la Sapienza"
and
International Center for Relativistic Astrophysics Network

Fermi, Heisenberg and Pauli at Como, 1927



E. Fermi, W. Heisenberg and W. Pauli (Como Conference, 1927).

CONTEXT

The photograph introduces Fermi's connections with the German quantum physics community.

The Preface suggests that Pauli, Heisenberg and Jordan may have influenced his changing research interests.

Quantum statistics, quantum field theory and weak interactions became central to his work.

Preface Fig. 1, p. vii (PDF p. 5); context: pp. vii–viii

Finzi and the history of the Rome school



Finzi, Bleuler, Ruffini, and Tauber.

CONTEXT

Finzi studied with Fermi and completed his thesis under Levi-Civita.

Long conversations with Finzi and Amaldi helped reconstruct the intellectual environment in Rome.

Personal testimony complements the published scientific record.

Preface Fig. 2, p. vii; photograph from the same book’s source material

Einstein, Oppenheimer and gravitational collapse



In a classic paper, Einstein objected to the possibility of an object not rotating to approach asymptotically, as postulated by Oppenheimer and Snyder, its Schwarzschild horizon [205]. Only recently it has been shown that the Einstein objections do not prevent the formation of a black hole (see our concluding remarks).

CONTEXT

Black-hole physics emerged from debates over gravitational collapse.

New observations of pulsars and X-ray binaries made strong gravity accessible.

Preface Fig. 4, p. xi (PDF p. 9); context: pp. x–xii

Fermi from Pisa to Rome



Young Enrico Fermi during the Pisa period (1918–1922).

CONTEXT

In 1926, Corbino created a chair of theoretical physics for Fermi in Rome.

Ruffini presents the unsuccessful 1925 Cagliari appointment as a possible turning point.

Fermi subsequently concentrated on quantum statistics, atomic models and beta decay.

Portrait: Chapter 1, Fig. 1, p. 3; discussion: Section 1.5, pp. 10–11

Fermi and the problem of stellar interiors

1.6 Fermi and the problem of stellar interiors

Except for his early work in Pisa, followed by the shock of the Cagliari affair, it is well known that in his research in Rome Fermi became extremely concrete and avoided speculation not supported by direct observational evidence. On one hand this gave the Rome school a sense of realism and an urgent quest for physical understanding. On the other hand this attitude kept Fermi and the Rome group out of that group of scientists who were able to approach the many consequences of Fermi-Dirac statistics for the final evolution of stars. It is appropriate here to attempt to justify this attitude by using Fermi's own words. Fermi was very knowledgeable about the physical status of atomic physics at the surface of stars but when it came to the analysis of their interiors, he would not enter into this topic to avoid having to "resort to very risky hypotheses." Let us follow this particular attitude in his 1930 lecture delivered in Trento:[9]

> *"...As can be seen even from these brief hints, the physical state of the surface of stars, at least of many stars, is relatively well known. If instead we want to say something about their interiors, we are forced to resort to very risky hypotheses. Therefore all the theories about the interior of stars are very uncertain, however, they agree on the fact that in the interior of stars the temperature must be very high; it has been estimated to be on the order of magnitude of tens of millions of degrees.*

Section 1.6, pp. 11–12 (PDF pp. 32–33); excerpt from p. 11

1.6 Fermi and the problem of stellar interiors
"If instead we want to say something about their interiors, we are forced to resort to very risky hypotheses."

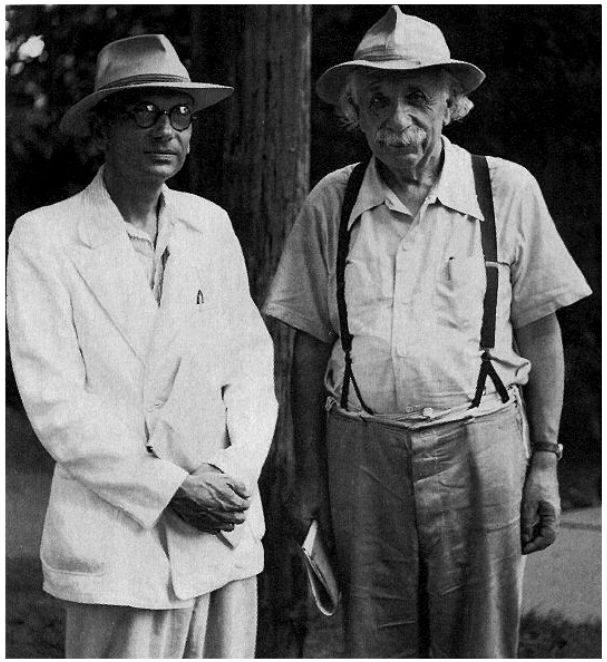
CONTEXT

Fermi contrasted observable surfaces with less directly testable stellar interiors.

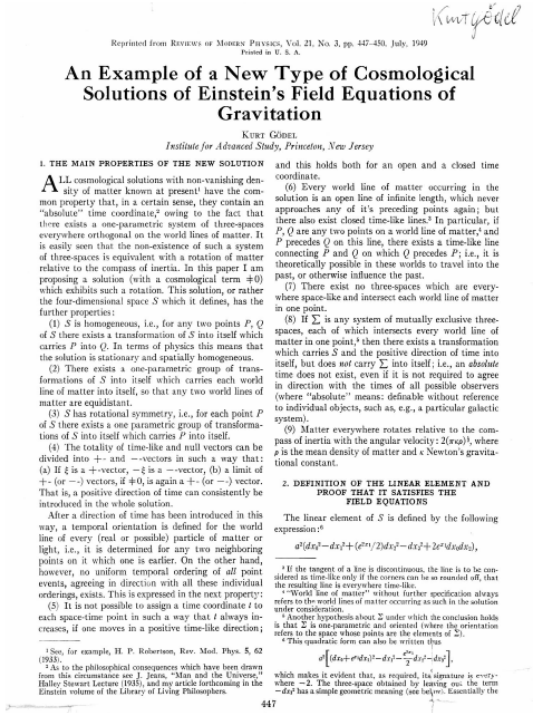
His caution limited the Rome group's engagement with stellar endpoints.

Fermi–Dirac statistics later underpinned white-dwarf and neutron-star theory.

Gödel, Einstein and relativistic cosmology



(a)



Reprinted from Reviews of Modern Physics, Vol. 21, No. 3, pp. 447-450, July, 1949
Printed in U. S. A.

An Example of a New Type of Cosmological Solutions of Einstein's Field Equations of Gravitation

Kurt Gödel
Institute for Advanced Study, Princeton, New Jersey

1. THE MAIN PROPERTIES OF THE NEW SOLUTION

ALL cosmological solutions with non-vanishing density of matter known at present[1] have the common property that, in a certain sense, they contain an "absolute" time coordinate,[2] owing to the fact that there exists a one-parametric system of three-spaces everywhere orthogonal on the world lines of matter. It is easily seen that the non-existence of such a system of three-spaces is equivalent with a rotation of matter relative to the compass of inertia. In this paper I am proposing a solution (with a cosmological term $+0$) which exhibits such a rotation. This solution, or rather the four-dimensional space S which it defines, has the further properties:

(1) S is homogeneous, i.e., for any two points P, Q of S there exists a transformation of S into itself which carries P into Q. In terms of physics this means that the solution is stationary and spatially homogeneous.

(2) There exists a one-parametric group of transformations of S into itself which carries each world line of matter into itself, so that any two world lines of matter are equidistant.

(3) S has rotational symmetry, i.e., for each point P of S there exists a one parametric group of transformations of S into itself which carries P into itself.

(4) The totality of time-like and null vectors can be divided into $+$- and $-$-vectors in such a way that: (a) If ξ is a $+$-vector, $-\xi$ is a $-$-vector, (b) a limit of $+$- (or $-$-) vectors, if $\neq 0$, is again a $+$- (or $-$-) vector. That is, a positive direction of time can consistently be introduced in the whole solution.

After a direction of time has been introduced in this way, a temporal orientation is defined for the world line of every (real or possible) particle of matter or light, i.e., it is determined for any two neighboring points on it which one is earlier. On the other hand, however, no uniform temporal ordering of *all* point events, agreeing in direction with all these individual orderings, exists. This is expressed in the next property:

(5) It is not possible to assign a time coordinate t to each space-time point in such a way that t always increases, if one moves in a positive time-like direction; and this holds both for an open and a closed time coordinate.

(6) Every world line of matter occurring in the solution is an open line of infinite length, which never approaches any of it's preceding points again; but there also exist closed time-like lines.[3] In particular, if P, Q are any two points on a world line of matter,[4] and P precedes Q on this line, there exists a time-like line connecting P and Q on which Q precedes P; i.e., it is theoretically possible in these worlds to travel into the past, or otherwise influence the past.

(7) There exist no three-spaces which are everywhere space-like and intersect each world line of matter in one point.

(8) If $\sum$ is any system of mutually exclusive three-spaces, each of which intersects every world line of matter in one point,[5] then there exists a transformation which carries S and the positive direction of time into itself, but does *not* carry $\sum$ into itself; i.e., an *absolute* time does not exist, even if it is not required to agree in direction with the times of all possible observers (where "absolute" means: definable without reference to individual objects, such as, e.g., a particular galactic system).

(9) Matter everywhere rotates relative to the compass of inertia with the angular velocity: $2(\pi\kappa\rho)^{\frac{1}{2}}$, where ρ is the mean density of matter and κ Newton's gravitational constant.

2. DEFINITION OF THE LINEAR ELEMENT AND PROOF THAT IT SATISFIES THE FIELD EQUATIONS

The linear element of S is defined by the following expression:[6]

$$a^2[(dx^0)^2-dx_1^2+(e^{x_1}/2)dx_2^2-dx_3^2+2e^{x_1}dx_2dx_3],$$

[1] See, for example, H. P. Robertson, Rev. Mod. Phys. 5, 62 (1933).
[2] As to the philosophical consequences which have been drawn from this circumstance see J. Jeans, "Man and the Universe," Halley Stewart Lecture (1935), and my article forthcoming in the Einstein volume of the Library of Living Philosophers.
[3] If the tangent of a line is discontinuous, the line is to be considered as time-like only if the corners can be so rounded off, that the resulting line is everywhere time-like.
[4] "World line of matter" without further specification always refers to the world lines of matter occurring as such in the solution under consideration.
[5] Another hypothesis about $\sum$ under which the conclusion holds is that $\sum$ is one-parametric and oriented (where the orientation refers to the space whose points are the elements of $\sum$).
[6] This quadratic form can also be written thus

$$a^2\left[(dx_0+e^{x_1}dx_2)^2-dx_1^2-\frac{e^{2x_1}}{2}dx_2^2-dx_3^2\right],$$

which makes it evident that, as required, its signature is $+---$, where -2. The three-space obtained by leaving out the term $-dx_3^2$ has a simple geometric meaning (see below). Essentially the

(b)

Kurt Gödel and Albert Einstein (1954), together with an original reprint of the classic paper dedicated by Gödel to Einstein in honor of his seventieth birthday. The copy was autographed to me by Kurt Gödel in 1974 and is now at the ICRANet Center in Pescara.

CONTEXT

The figure pairs a 1954 photograph with an autographed offprint of Gödel's paper.

The surrounding discussion turns to Friedmann cosmology and the Soviet-Russian school.

This provides the cosmological setting for the Fermi–Turkevich calculation.

The Fermi–Turkevich nucleosynthesis calculation

2.5 The Fermi and Turkevich paper

As I already mentioned the Fermi-Turkevich paper was never published by the authors in a scientific journal and their results were only reproduced later in the review article "Theory of Origin and Relative Abundance Distribution of the Elements" by Alpher and Herman [158].[9] This article had the significant footnote "We are indebted to Drs. E. Fermi and A. Turkevich for their cooperation and communication of unpublished results. The authors take the responsibility for the correctness of this transcription and interpretation of their work."

The basic assumptions in the Fermi-Turkevich work were:

1) the initially radiation dominated Friedman cosmological model, following Gamow;
2) the complete and detailed values for the reaction rates expressed in their Table XII (see below);
3) the techniques of numerical integration of the rate equations by electronic machines.

2.5 The Fermi and Turkevich paper
"The Fermi-Turkevich paper was never published by the authors in a scientific journal and their results were only reproduced later in the review article 'Theory of Origin and Relative Abundance Distribution of the Elements' by Alpher and Herman [158]."

CONTEXT

A radiation-dominated Friedmann universe sets the cosmological background.

Detailed reaction rates and numerical integration give the abundance evolution.

Section 2.5, p. 61 (PDF p. 82); original section excerpt

Reaction rates as inputs to cosmic evolution

TABLE XII. Reaction rates. [The quantities a_1 and a_2 are defined in Eq. (130), T_8 is the temperature in units of 10^8 °K, $T_8 = 152t^{-1/2}$ from Eq. (100), and $q_0 = 10^{21}$ sec.$^{3/2}$ cm^{-3}.]

No.	Reaction	Specific reaction rates	Term in rate equations, $\mathcal{R}'$ [See Eq. (132)]
1	$N=H+e^-$	10^{-3} sec.$^{-1}$	$10^{-3}x_N$
2	$N+H=D+h\nu$	6.6×10^{-20} sec.$^{-1}$	$6.6\times10^{-20}q_0x_Nx_Ht^{-3/2}$
3	$N+D=T+h\nu$	2.0×10^{-22} sec.$^{-1}$	$2.0\times10^{-22}q_0x_Nx_Dt^{-3/2}$
4	$N+D=N+N+H$	Negligible (see reaction 18)	0
5	$N+He^3=He^4+h\nu$	10^{-21} sec.$^{-1}$ (estimated)	$10^{-21}q_0x_Nx_{He^3}t^{-3/2}$
6	$N+He^3=T+H$	1.5×10^{-15} sec.$^{-1}$	$1.5\times10^{-15}q_0x_Nx_{He^3}t^{-3/2}$
7	$H+H=D+e^+$	$a_1=2\times10^{-39}$; $a_2=3.16$	$7.0\times10^{-41}q_0(x_H)^2t^{-7/6}10^{-0.592t^{1/6}}$
8	$H+D=He^3+h\nu$	$a_1=8.6\times10^{-21}$; $a_2=3.48$	$3.0\times10^{-22}q_0x_Hx_Dt^{-7/6}10^{-0.652t^{1/6}}$
9	$H+D=H+H+N$	Negligible (see reaction 18)	0
10	$H+T=He^4+h\nu$	$a_1=1.5\times10^{-19}$; $a_2=3.62$	$5.3\times10^{-21}q_0x_Hx_Tt^{-7/6}10^{-0.678t^{1/6}}$
11	$H+T=He^3+N$	$1.5\times10^{-15}\times10^{-36.8/T_8}$ sec.$^{-1}$	$1.5\times10^{-15}q_0x_Hx_Tt^{-3/2}10^{-0.242t^{1/2}}$
12	$D+D=He^4+h\nu$	$a_1=3.07\times10^{-19}$; $a_2=3.99$	$1.08\times10^{-20}q_0(x_D)^2t^{-7/6}10^{-0.747t^{1/6}}$
13	$D+D=He^3+N$	$a_1=3.0\times10^{-15}$; $a_2=3.99$	$1.1\times10^{-16}q_0(x_D)^2t^{-7/6}10^{-0.747t^{1/6}}$
14	$D+D=H+T$	$a_1=3.0\times10^{-15}$; $a_2=3.99$	$1.1\times10^{-16}q_0(x_D)^2t^{-7/6}10^{-0.747t^{1/6}}$
15	$D+T=He^4+N$	$a_1=5.0\times10^{-13}$; $a_2=4.24$	$1.8\times10^{-14}q_0x_Dx_Tt^{-7/6}10^{-0.794t^{1/6}}$
16	$D+He^3=He^4+H$	$a_1=1.5\times10^{-12}$; $a_2=6.72$	$5.3\times10^{-14}q_0x_Dx_{He^3}t^{-7/6}10^{-1.259t^{1/6}}$
17	$D+He^4=Li^6+h\nu$	$a_1=1.4\times10^{-21}$; $a_2=6.96$	$4.9\times10^{-23}q_0x_Dx_{He^4}t^{-7/6}10^{-1.304t^{1/6}}$
18[a]	$D+h\nu=H+N$	$5.9\times10^{12}T_8^{3/2}10^{-110/T_8}$ sec.$^{-1}$	$1.1\times10^{+16}x_Dt^{-3/4}10^{-0.723t^{1/2}}$
19	$T=He^3+e^-$	1.8×10^{-9} sec.$^{-1}$	$1.8\times10^{-9}x_T$
20	$T+T=He^4+N+N$	$a_1=2.6\times10^{-13}$; $a_2=4.57$	$9.1\times10^{-15}q_0(x_T)^2t^{-7/6}10^{-0.856t^{1/6}}$
21	$T+T=He^6+h\nu$	$a_1=2.6\times10^{-19}$; $a_2=4.57$	$9.1\times10^{-21}q_0(x_T)^2t^{-7/6}10^{-0.856t^{1/6}}$
22	$T+He^3=He^4+N+H$	$a_1=1.5\times10^{-12}$; $a_2=7.24$	$5.3\times10^{-14}q_0x_Tx_{He^3}t^{-7/6}10^{-1.356t^{1/6}}$
23	$T+He^3=He^4+D$	$a_1=1.0\times10^{-13}$; $a_2=7.24$	$3.5\times10^{-15}q_0x_Tx_{He^3}t^{-7/6}10^{-1.356t^{1/6}}$
24	$T+He^3=Li^6+h\nu$	$a_1=3.1\times10^{-18}$; $a_2=7.24$	$1.1\times10^{-19}q_0x_Tx_{He^3}t^{-7/6}10^{-1.356t^{1/6}}$
25	$T+He^4=Li^7+h\nu$	$a_1=5.5\times10^{-19}$; $a_2=7.56$	$1.9\times10^{-20}q_0x_Tx_{He^4}t^{-7/6}10^{-1.416t^{1/6}}$
26	$He^3+He^3=Be^6+h\nu$	$a_1=1.4\times10^{-17}$; $a_0=11.49$	$4.9\times10^{-19}q_0(x_{He^3})^2t^{-7/6}10^{-2.151t^{1/6}}$
27	$He^3+He^3=He^4+H+H$	$a_1=1.4\times10^{-11}$; $a_2=11.49$	$4.9\times10^{-13}q_0(x_{He^3})^2t^{-7/6}10^{-2.151t^{1/6}}$
28	$He^3+He^4=Be^7+h\nu$	$a_1=1.7\times10^{-19}$; $a_2=12.01$	$6.0\times10^{-21}q_0x_{He^3}x_{He^4}t^{-7/6}10^{-2.250t^{1/6}}$

[a] The photon concentration is included in the constant.

TABLE XII. Reaction rates. [The quantities a_1 and a_2 are defined in Eq. (130); T_8 is the temperature in units of 10^8 °K, $T_8 = 152t^{-1/2}$ from Eq. (100), and $q_0 = 10^{21}$ sec.$^{3/2}$ cm^{-3}.]

CONTEXT

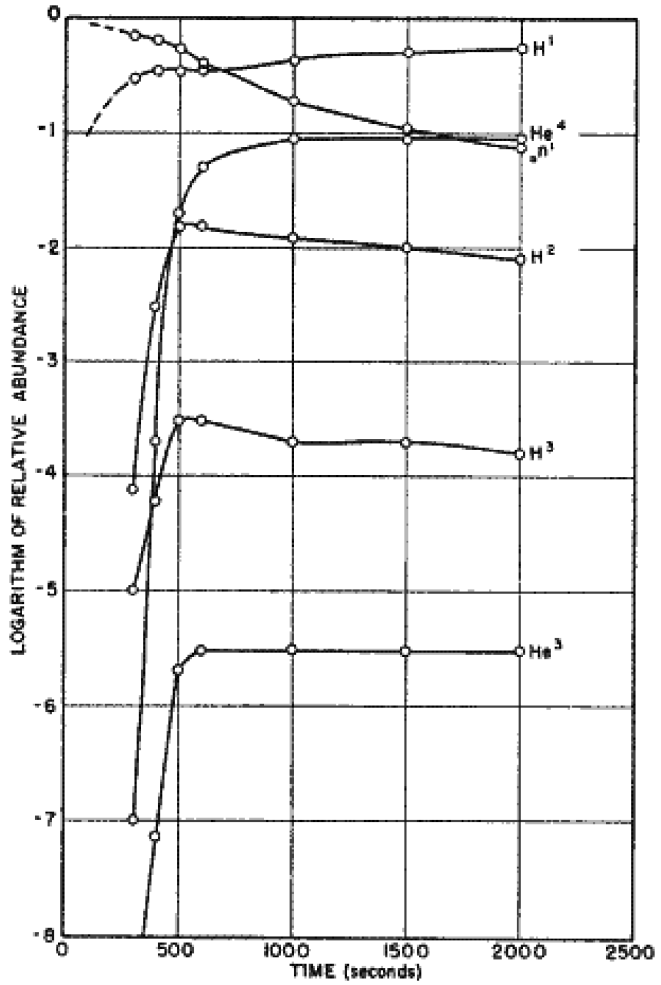
The table lists nuclear reactions, their rates and their terms in the evolution equations.

Reactions involving hydrogen, deuterium, tritium and helium determine the light-element network.

The reaction network is evolved within a specified expanding-universe model.

Table XII, p. 62 (PDF p. 83); context: p. 61

Non-equilibrium production of the light elements



Relative abundance of the very light elements as a function of time according to the non-equilibrium formulation of Fermi and Turkevich (unpublished). The nucleon concentration was taken to be 10^{21} cm^{-3} at t = 1 sec in an expanding universe dominated by radiation. The relative abundances are the ratios of the number of nuclei of a given species in a volume V to the total number of nucleons in that volume. Since both quantities vary with the universal expansion in the same way the effect of the expansion is not evident. (Fig. 20 of the paper "Theory of Origin and Relative Abundance Distribution of the Elements" by R.A. Alpher and R.C. Herman, Rev. Mod. Phys. 22, 153 (1950)).

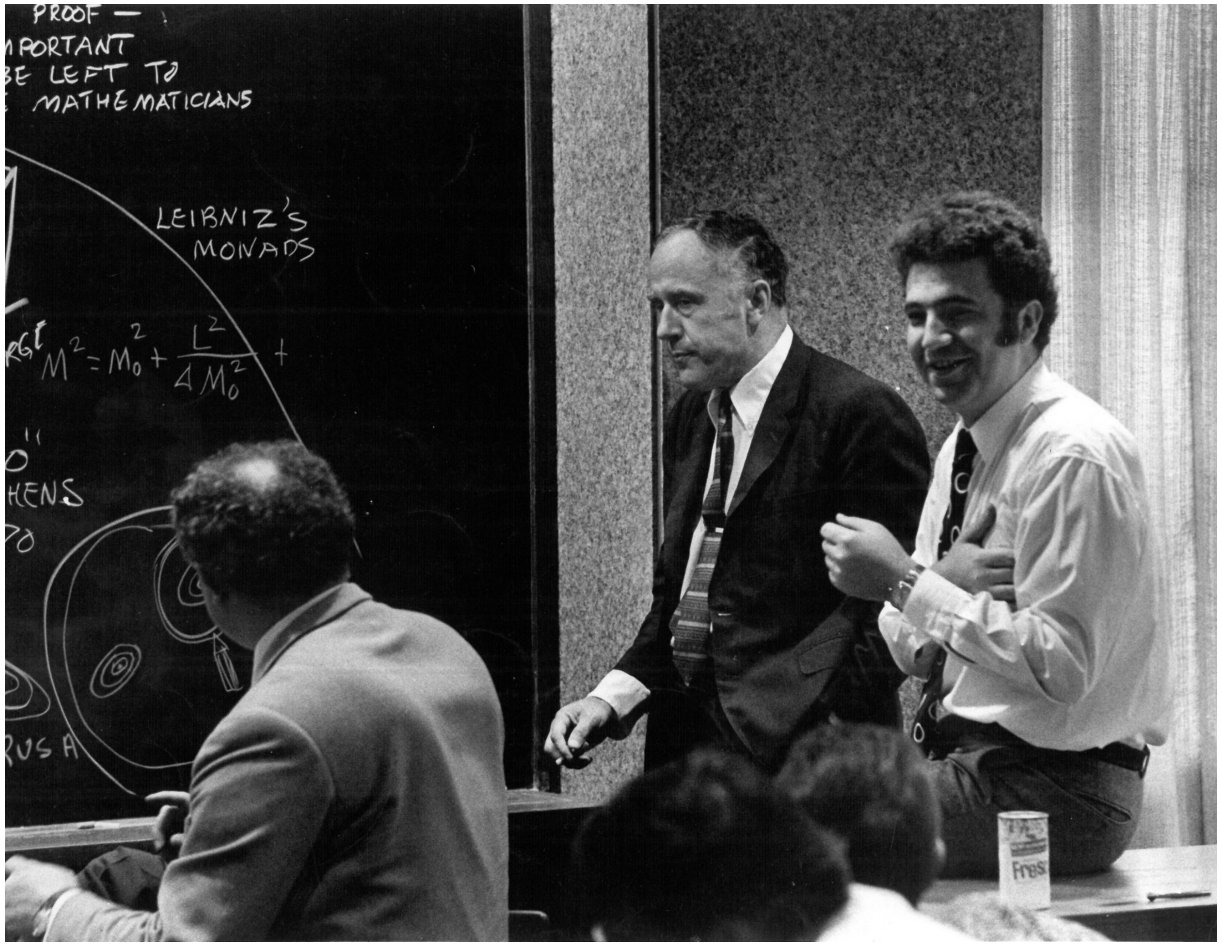
CONTEXT

The curves track light-element abundances over time.

Mass-5 and mass-8 gaps restrict the formation of heavier elements.

Chapter 2, Fig. 13, p. 63 (PDF p. 84); context: pp. 64–65

Relativistic astrophysics at Princeton



Johnny Wheeler, Remo Ruffini and collaborators at Princeton in 1970.

CONTEXT

Numerical methods addressed stellar endpoints and gravitational radiation.

Space observations connected theoretical models with astrophysical data.

Wheeler urged the group to pursue black holes beyond neutron stars.

Christodoulou’s thesis defense at Princeton



Demetri Christodoulou being addressed by Eugene Wigner at his Ph.D. thesis defense at Princeton in 1971, with David Wilkinson, Johnny Wheeler and Remo Ruffini looking on.

CONTEXT

The photograph records Christodoulou’s doctoral defense in 1971.

Students, postdocs and senior physicists formed a productive research community.

Black-hole physics included reversible and irreversible processes.

Chapter 3, Fig. 9, p. 88 (PDF p. 109); context: pp. 86, 90

Ruffini and Wheeler: the physics of black holes



Remo Ruffini and Johnny Wheeler at Princeton around 1970.

CONTEXT

Their work examined the ergosphere and physical processes for black-hole energy conversion.

Binary systems offered a possible route to observing black holes.

The emphasis shifted toward physical processes with astrophysical consequences.

A collaboration spanning several decades



Demetri Christodoulou, Johnny Wheeler and Remo Ruffini in Princeton around 2003. In the background one sees the phrase “Raffiniert ist der Herrgott, aber boshaft ist er nicht” (Subtle is the Lord, but malicious he is not) written in charcoal from the fireplace by Einstein and later carved into the marble mantle.

CONTEXT

The photograph around 2003 reconnects the collaborators of early black-hole physics.

Einstein’s inscription links the scene to the tradition of relativity research.

Chapter 3, Fig. 11, p. 89 (PDF p. 110); context: Section 3.7

Salam, Zhou Enlai and international collaboration



Abdus Salam and Chou En-Lai. (Quoted in section 3.11)

CONTEXT

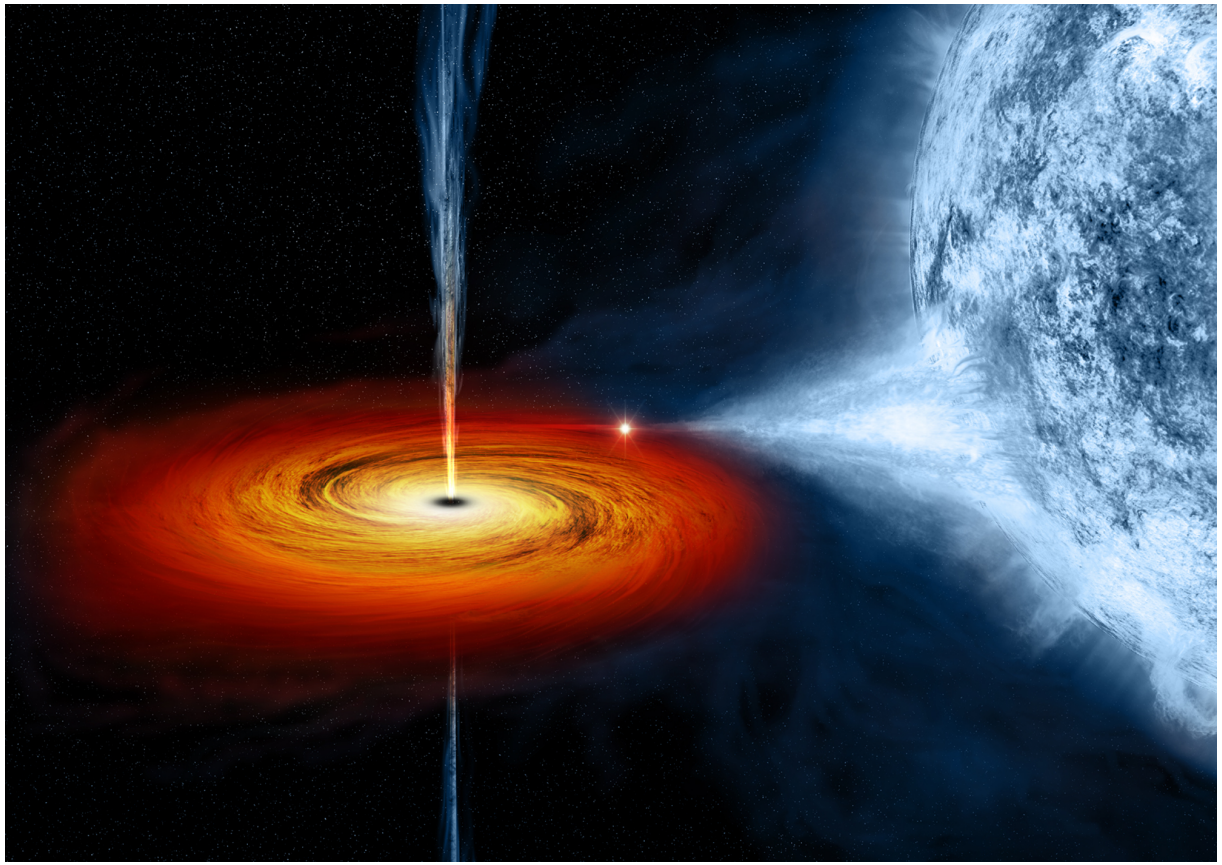
Salam and Ruffini helped organize physics teaching for researchers from developing countries.

The book recalls Salam’s role in introducing Ruffini to the Chinese scientific community.

Shanghai hosted the Third Marcel Grossmann Meeting in 1982. Zhou Peiyuan helped support the meeting and international participation.

Chapter 3, Fig. 16, p. 109 (PDF p. 130); related text: pp. 96–98

Cygnus X-1: identifying a black hole



Artist’s illustration of Cygnus X-1: a stellar-mass black hole accreting material from a massive companion star.

CONTEXT

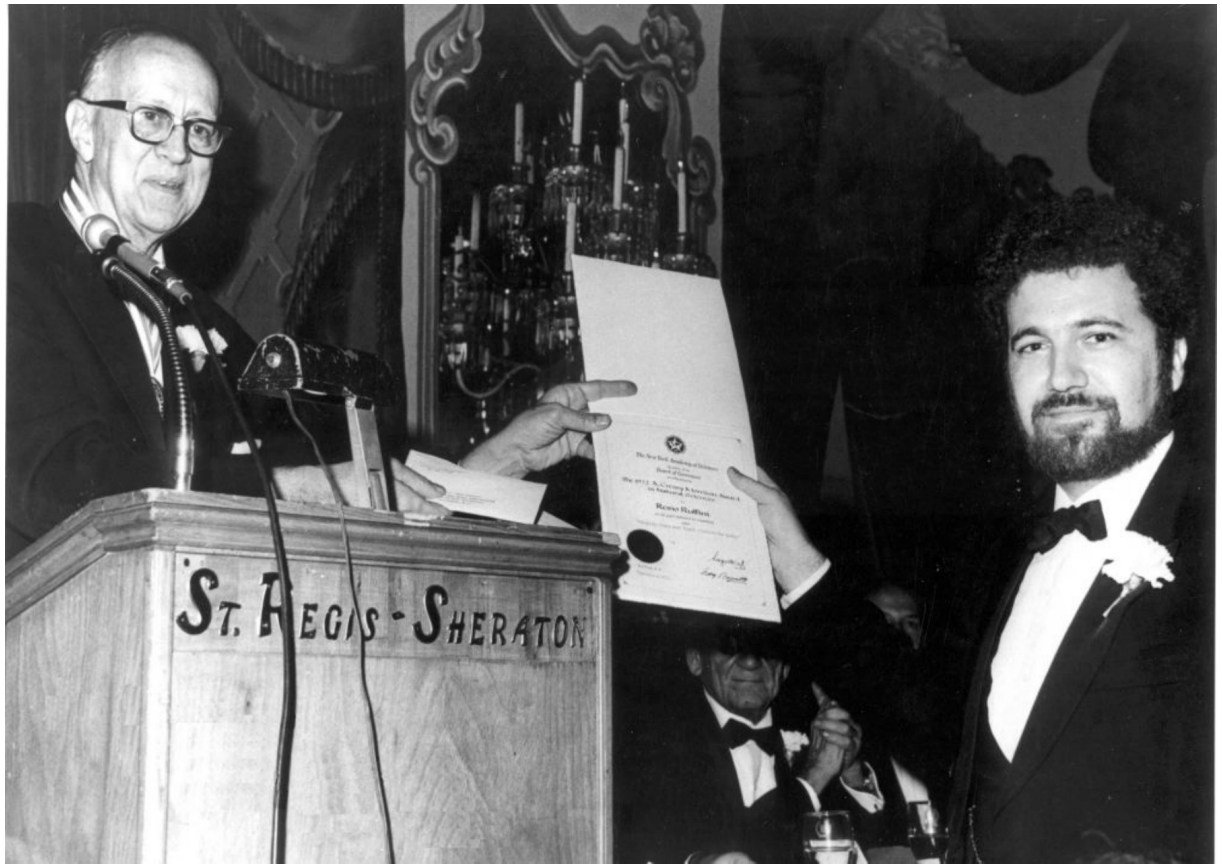
Rapid X-ray variability locates the emission in a very compact region.

Optical orbital measurements reveal a massive unseen companion.

A compact mass above neutron-star limits supports a black-hole interpretation.

Context: Section 3.8, pp. 91–92. Illustration: NASA/CXC/M. Weiss.

Ruffini’s Cressy Morrison Award, 1972



Remo Ruffini receiving the Cressy Morrison Award from the New York Academy of Sciences in 1972.

CONTEXT

At Les Houches in 1972, Ruffini returned to neutron-star equilibrium using gravitational Thomas–Fermi equations.

The surrounding section connects compact-star limits and X-ray binaries to the identification of a black-hole candidate.

Chapter 3, Fig. 12, p. 91 (PDF p. 112); related discussion: pp. 91–92.

Giacconi receives the Nobel Prize, 2002



Riccardo Giacconi receiving the Nobel Prize in 2002. (Quoted in section 3.8)

CONTEXT

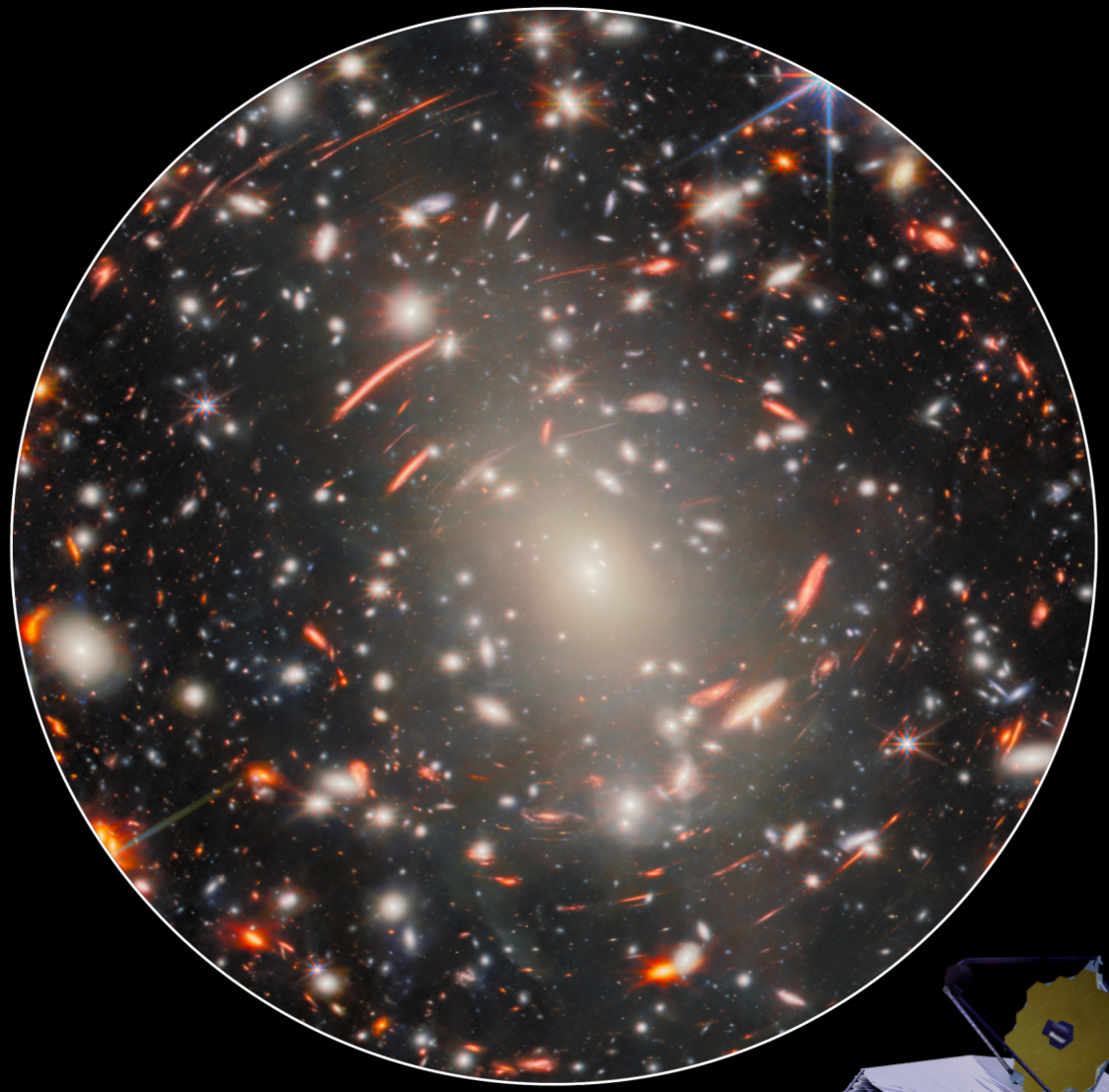
The prize recognized pioneering work that led to the discovery of cosmic X-ray sources.

The book links Uhuru and the identification of Cygnus X-1 to the growth of black-hole astrophysics.

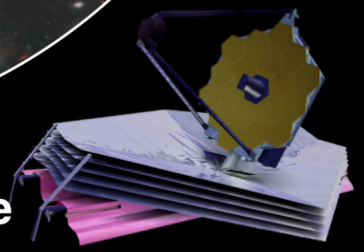
Chapter 3, Fig. 13, p. 107 (PDF p. 128); related discussion: Section 3.8.

Images of our Universe

In its infancy with black holes dark matter dominated

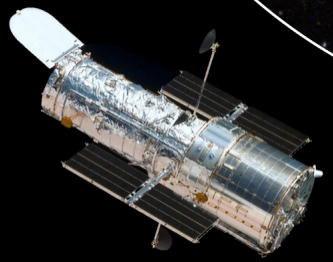


James Web Space Telescope



Approaching the death by black holes baryonic matter dominated





Hubble Space Telescope

Orbital distances of space observatories and gravitational-wave missions

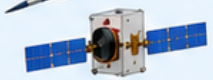
Low Earth Orbit (LEO)

~ 200 – 600 km

X-ray / gamma-ray telescopes



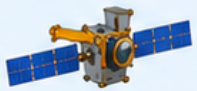
Giacconi rocket (1962)
~225 km (suborbital)



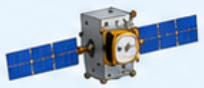
Uhuru (1970)
~520 – 560 km



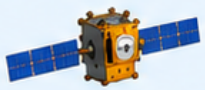
BeppoSAX (1996)
~600 km



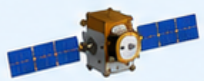
Swift (2004)
~600 km



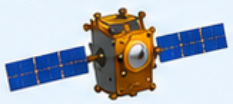
Fermi (2008)
~565 km



HXMT (2017)
~550 km



GECAM (2020)
~600 km

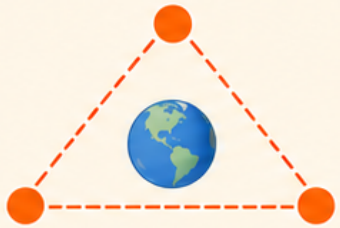


Einstein Probe (2024)
~600 km

TianQin (planned)

~ 93,600 km altitude

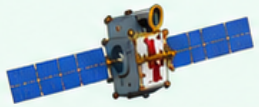
(geocentric orbit radius: 100,000 km)
Arm length: 173,000 km



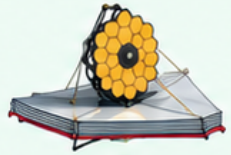
Missions around the Sun–Earth L2 point

~ 1,500,000 km from Earth

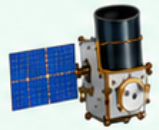
Infrared / X-ray telescopes



eROSITA / Spektr-RG (2019)



JWST (2021)



Euclid (2023)



Nancy Grace Roman
(2026, en route)



Ariel (planned, 2031)

Space-based gravitational wave detectors

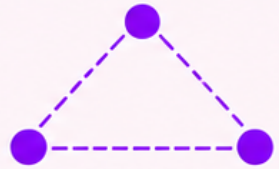
~ 50 million km from Earth

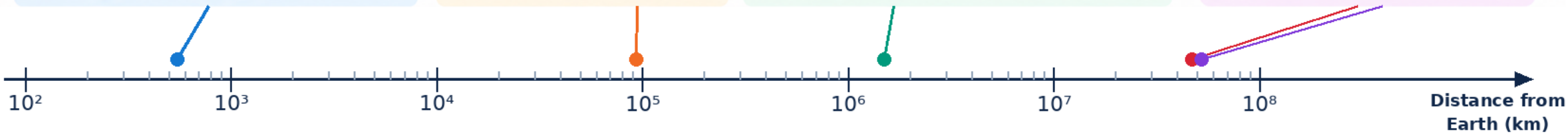
Sun-orbiting constellations

LISA (ESA, planned 2030s)
Arm length: 2,500,000 km



Taiji (planned 2030s)
Arm length: 3,000,000 km





Low Earth orbit
200–600 km

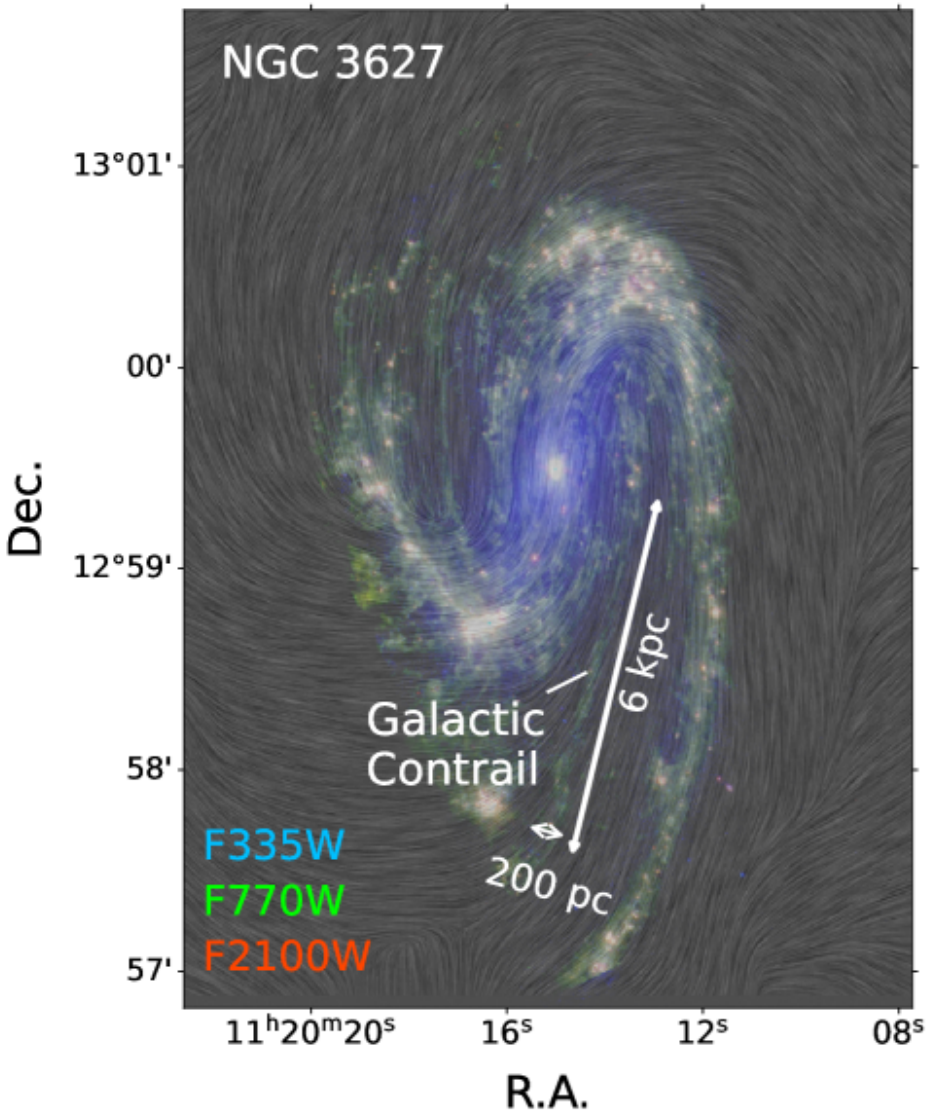
High Earth orbit
TianQin: ~93,600 km

Around L2
~1.5 × 10^6 km

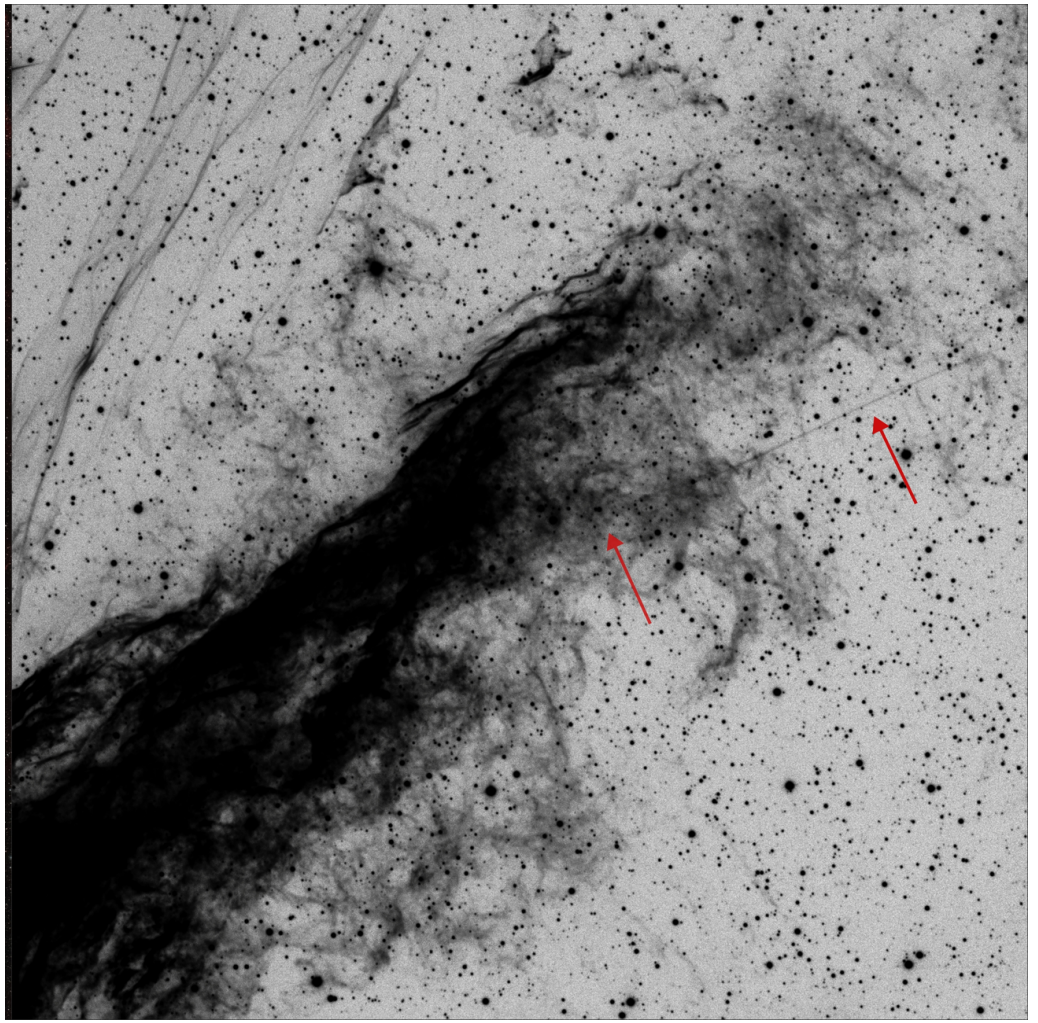
Heliocentric missions
~5 × 10^7 km from Earth

Little Red Dots (LRD)



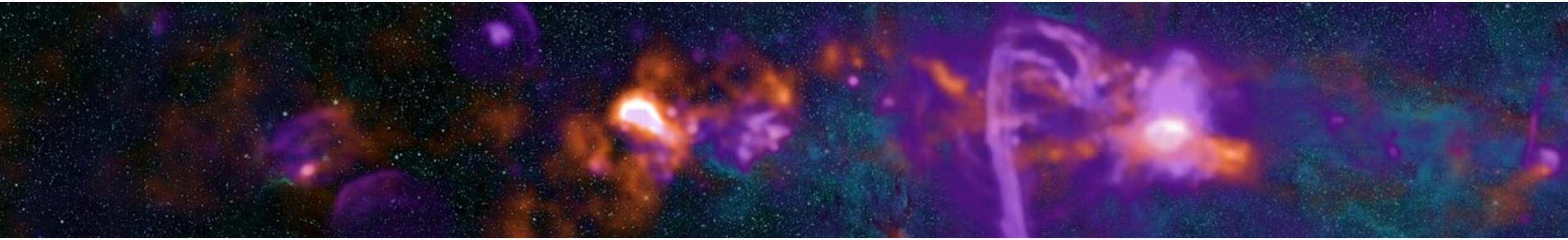


A 6 kpc × 200 pc "galactic contrail": gas focused behind a massive black hole crossing the disc · Zhao & Li 2025



A razor-thin trail across the Veil — the wake of a fast compact object · Martínez-Delgado et al. 2026

Islands of Electromagnetic Tranquility in Our Galactic core and Little Red Dots that Shelter Molecules and Prebiotic Chemistry



Milky Way core
Sagittarius A* has mass 4×10^6 M$\odot$ and accretes weakly. The Central Molecular Zone holds about 6×10^7 M$\odot$ of gas at 50–200 K. The absence of strong UV or X-ray fields preserves fragile molecules, including nitriles such as in G+0.693−0.027, which are precursors to RNA nucleotides.

Little Red Dots
LRDs are 30–200 pc systems at high redshift with central black holes of a few million solar masses. Their size is comparable to the Milky Way's inner 100 pc. They contain cold dust with temperatures 100–1000 K, and no X-ray emission is detected,.

Region	Radius (pc)	$M_{\rm BH}$	$T_{\rm dust}$ (K)	Environment
Milky Way CMZ	~ 200	$4 \times 10^6\, M_\odot$	12–35	molecule rich, low radiation
Little Red Dot	30–200	10^6–$10^7\, M_\odot$	100–1000	X-ray undetected
Quasar Core	1–1000	10^8–$10^9\, M_\odot$	1000–1500	strong UV/X-ray, dusty torus