ELTE TTK

Fizikai Intézet

Az atomoktól a csillagokig

A fizika mindenkié

FIZIKAI NOBEL-DÍJ 2020.

Bejelentés 2020. október 6.

Roger Penrose

Reinhard Genzel

Andrea Ghez

for the discovery that black hole formation is a robust prediction of the general theory of relativity

for the discovery of a supermassive compact object at the centre of our galaxy

FIZIKAI NOBEL-DÍJ 2020.

Bejelentés 2020. október 6.

Roger Penrose

Reinhard Genzel

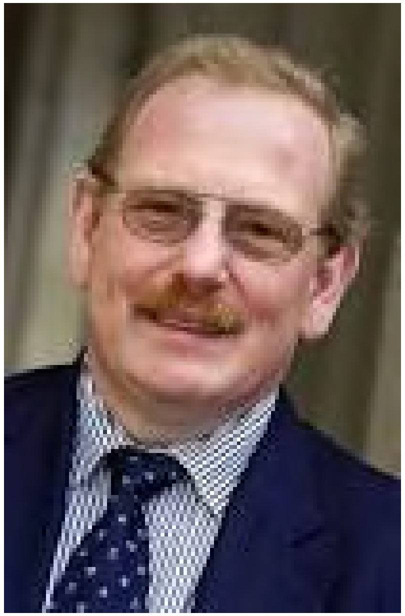
Andrea Ghez

annak felfedezéséért, hogy a fekete lyukak képződése az általános relativitáselmélet elkerülhetetlen következménye

a saját galaxisunk középpontjában található szupernehéz kompakt objektum felfedezéséért

FIZIKAI NOBEL-DÍJ 2020.

Bejelentés 2020. október 6.


Roger Penrose
(1931–)

Reinhard Genzel
(1952–)

Andrea Ghez
(1965–)

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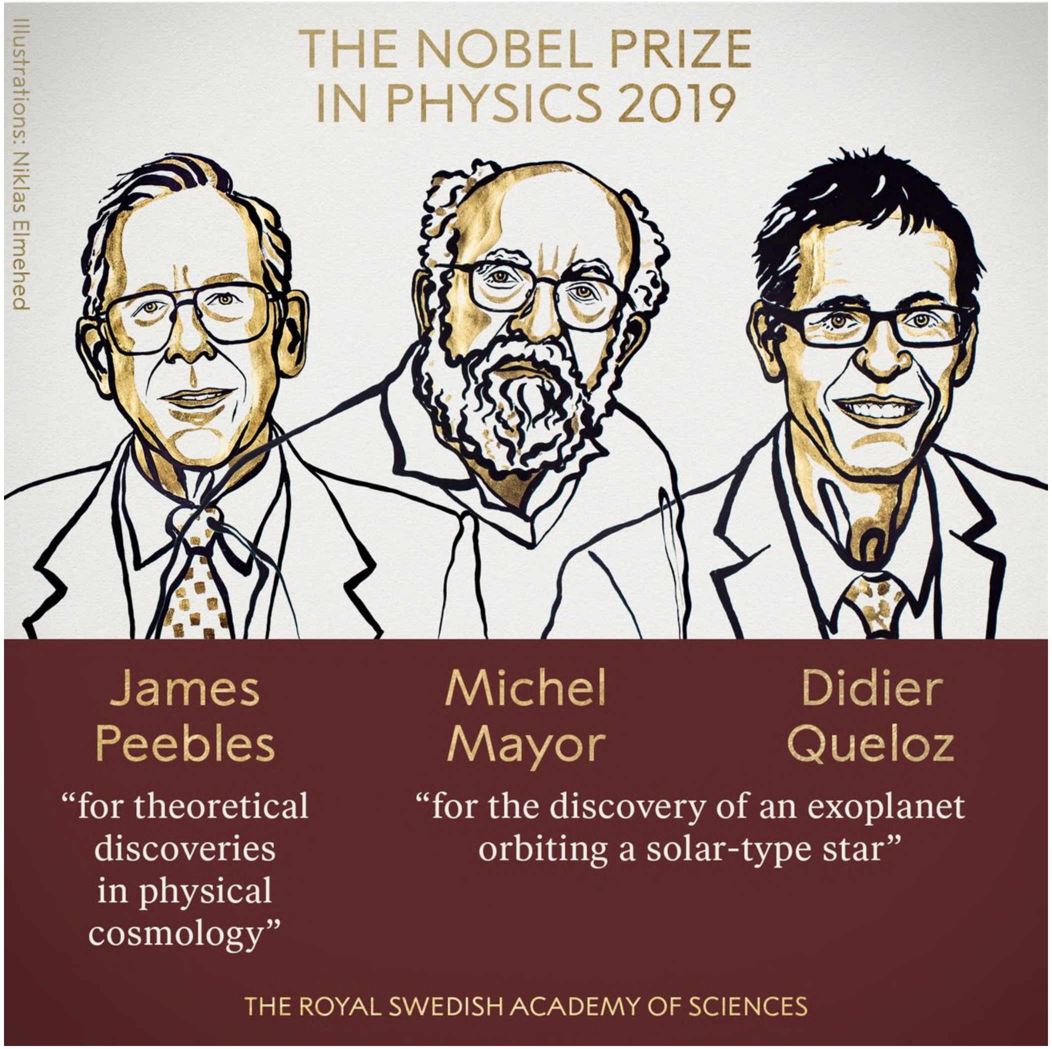
Bejelentés 2019. október 8.



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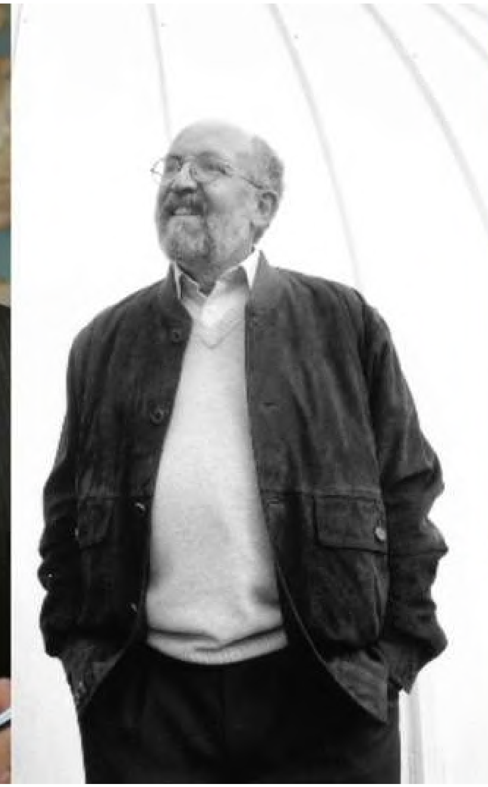
Bejelentés 2019. október 8.

James Peebles
(1935–)



Michel Mayor
(1946–)

Didier Queloz
(1966–)

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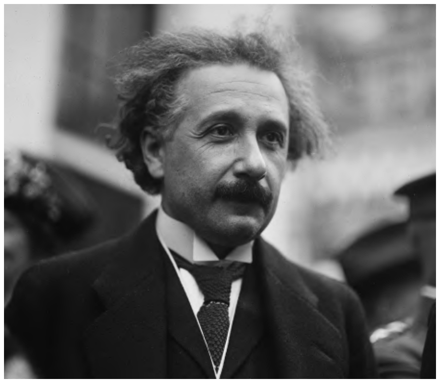
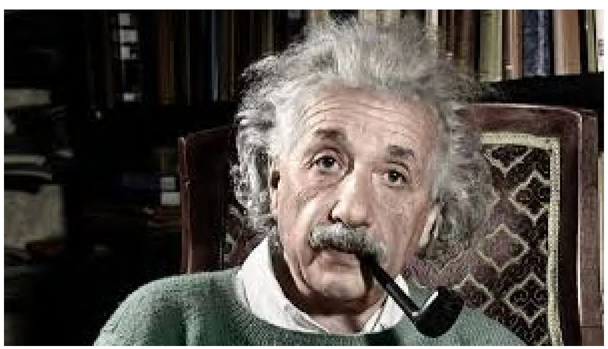
Általános relativitáselmélet



Albert Einstein
1915

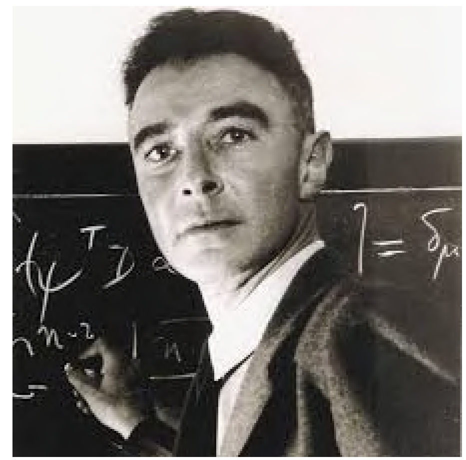


1939

???

a csillagok működésének megértése

az üzemanyagból kifogyott csillag gravitációs összeomlása



Robert Oppenheimer
1939

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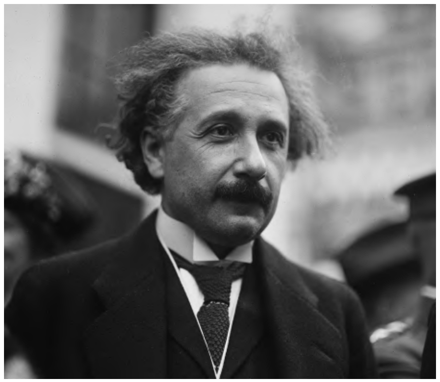
Általános relativitáselmélet



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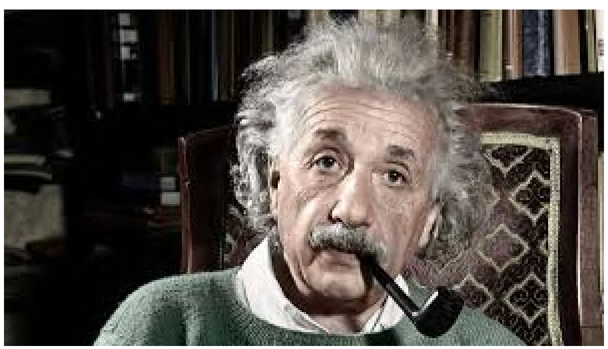
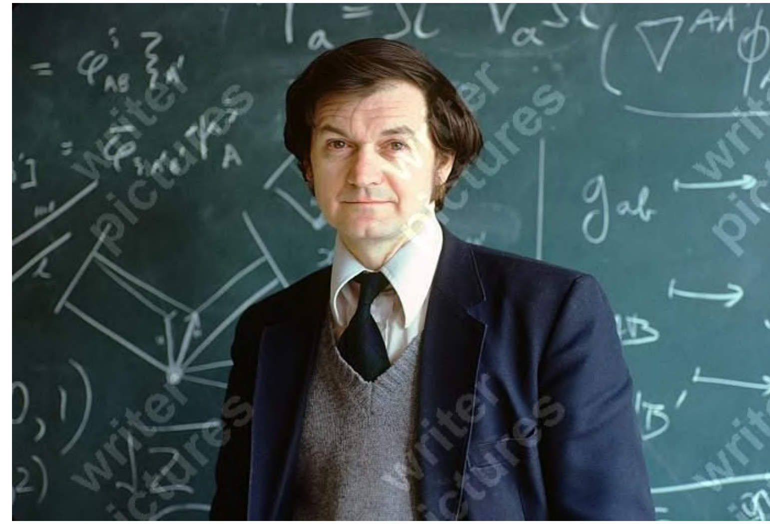
1915



1939

???



Roger Penrose
1965 január

Gravitational Collapse and
Space-Time Singularities
Physics Review Letters

FIZIKAI NOBEL-DÍJ 2020.

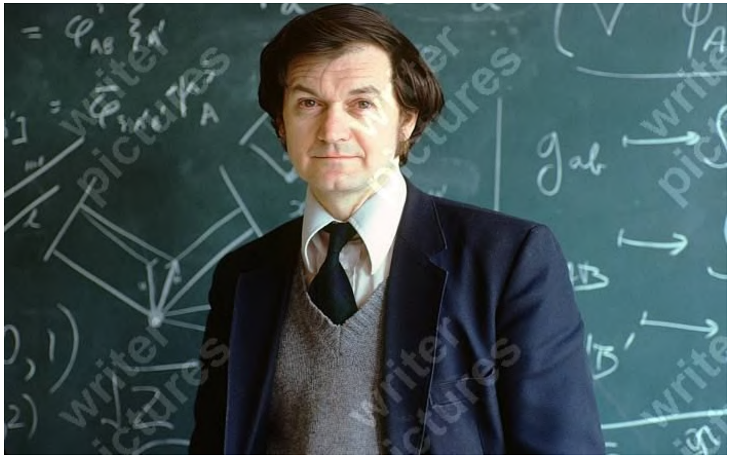
GRAVITATIONAL COLLAPSE AND SPACE-TIME SINGULARITIES

Roger Penrose
Department of Mathematics, Birkbeck College, London, England
(Received 18 December 1964)

The discovery of the quasistellar radio sources has stimulated renewed interest in the question of gravitational collapse. It has been suggested by some authors[1] that the enormous amounts of energy that these objects apparently emit may result from the collapse of a mass of the order of $(10^6\text{-}10^8)M_\odot$ to the neighborhood of its Schwarzschild radius, accompanied by a violent release of energy, possibly in the form of gravitational radiation. The detailed mathematical discussion of such situations is difficult since the full complexity of general relativity is required. Consequently, most exact calculations concerned with the implications of gravitational collapse have employed the simplifying assumption of spherical symmetry. Unfortunately, this precludes any detailed discussion of gravitational radiation—which requires at least a quadripole structure.

The general situation with regard to a spherically symmetrical body is well known.[2] For a sufficiently great mass, there is no final equilibrium state. When sufficient thermal energy has been radiated away, the body contracts and continues to contract until a physical singularity is encountered at $r=0$. As measured by local comoving observers, the body passes within its Schwarzschild radius $r=2m$. (The densities at which this happens need not be enormously high if the total mass is large enough.) To an outside observer the contraction to $r=2m$ appears to take an infinite time. Nevertheless, the existence of a singularity presents a serious problem for any complete discussion of the physics of the interior region.

The question has been raised as to whether this singularity is, in fact, simply a property of the high symmetry assumed. The matter collapses radially inwards to the single point at the center, so that a resulting space-time catastrophe there is perhaps not surprising. Could not the presence of perturbations which destroy the spherical symmetry alter the situation drastically? The recent rotating solution of Kerr[3] also possesses a physical singularity, but since a high degree of symmetry is still present (and the solution is algebraically special), it might again be argued that this is not representative of the general situation.[4] Collapse without assumptions of symmetry[5] will be discussed here.



Consider the time development of a Cauchy hypersurface C^3 representing an initial matter distribution. We may assume Einstein's field equations and suitable equations of state governing the matter. In fact, the only assumption made here about these equations of state will be the non-negative definiteness of Einstein's energy expression (with or without cosmological term). Suppose this matter distribution undergoes gravitational collapse in a way which, at first, qualitatively resembles the spherically symmetrical case. It will be shown that, after a certain critical condition has been fulfilled, deviations from spherical symmetry cannot prevent space-time singularities from arising. If, as seems justifiable, actual physical singularities in space-time are not to be permitted to occur, the conclusion would appear inescapable that inside such a collapsing object at least one of the following holds: (a) Negative local energy occurs.[6] (b) Einstein's equations are violated. (c) The space-time manifold is incomplete.[7] (d) The concept of space-time loses its meaning at very high curvatures—possibly because of quantum phenomena.[2] In fact (a), (b), (c), (d) are somewhat interrelated, the distinction being partly one of attitude of mind.

Before examining the asymmetrical case, consider a spherically symmetrical matter distribution of finite radius in C^3 which collapses symmetrically. The empty region surrounding the matter will, in this case, be a Schwarzschild field, and we can conveniently use the metric $ds^2=-2drdv+dv^2(1-2m/r)-r^2(d\theta^2+\sin^2\theta d\varphi^2)$, with an advanced time parameter v to describe it.[8] The situation is depicted in Fig. 1. Note that an exterior observer will always see matter outside $r=2m$, the collapse through $r=2m$ to the singularity at $r=0$ being invisible to him.

After the matter has contracted within $r=2m$, a spacelike sphere S^2 ($t=\text{const}$, $2m>r=\text{const}$) can be found in the empty region surrounding the matter. This sphere is an example of what will be called here a trapped surface—defined generally as a closed, spacelike, two-surface T^2 with the property that the two systems of null geodesics which meet T^2 orthogonally converge locally in future directions at T^2. Clearly trapped surfaces will still exist if the matter region has no sharp boundary or if spherical symmetry is dropped, provided that the deviations from the above situation are not too great. Indeed, the Kerr solutions with $m>a$ (angular momentum ma) all possess trapped surfaces, whereas those for which $m \leqslant a$ do not.[9] The argument will be to show that the existence of a trapped surface implies—irrespective of symmetry—that singularities necessarily develop.

The existence of a singularity can never be inferred, however, without an assumption such as completeness for the manifold under consideration. It will be necessary, here, to suppose that the manifold M_+^4, which is the future time development of an initial Cauchy hypersurface C^3 (past boundary of the M_+^4 region), is in fact null complete into the future. The various assumptions are, more precisely, as follows: (i) M_+^4 is a nonsingular $(+---)$ Riemannian manifold for which the null half-cones form two separate systems ("past" and "future"). (ii) Every null geodesic in M_+^4 can be extended into the future to arbitrarily large affine parameter values (null completeness). (iii) Every timelike or null geodesic in M_+^4 can be extended

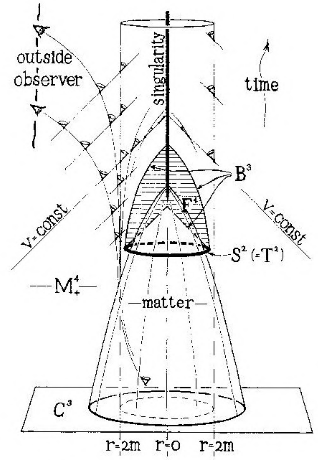


FIG. 1. Spherically symmetrical collapse (one space dimension surpressed). The diagram essentially also serves for the discussion of the asymmetrical case.

Penrose 1965

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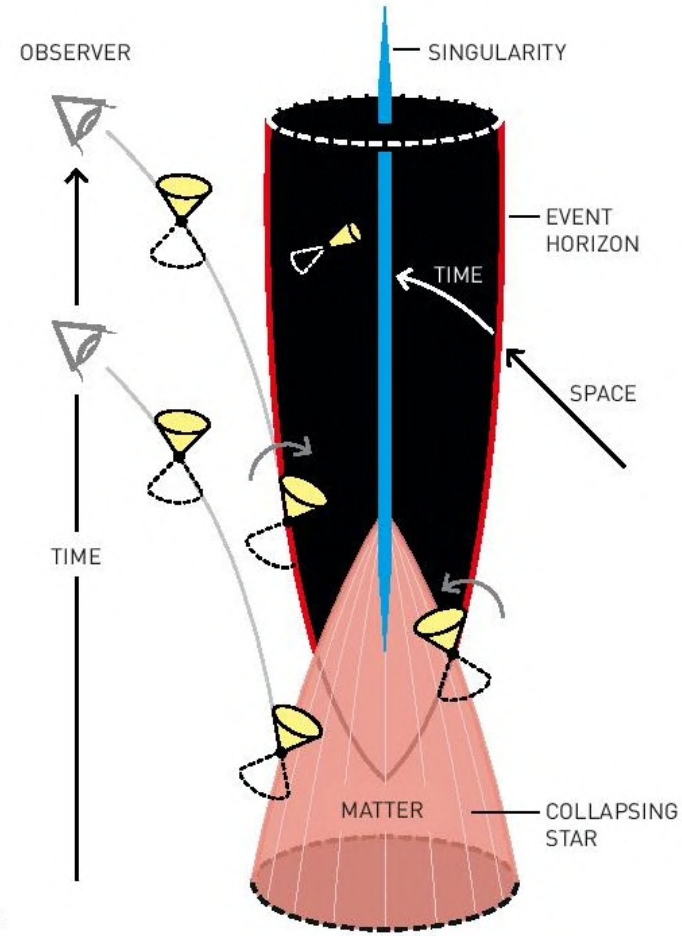

Nobel-bizottság 2020

VOLUME 14, NUMBER 3 PHYSICAL REVIEW LETTERS 18 JANUARY 1965

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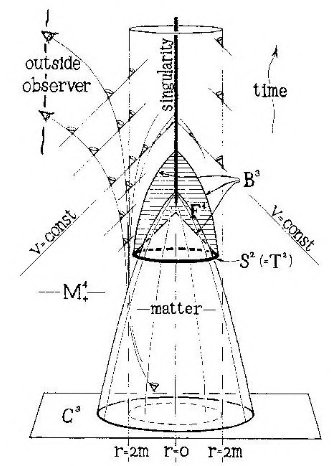

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Penrose 1965

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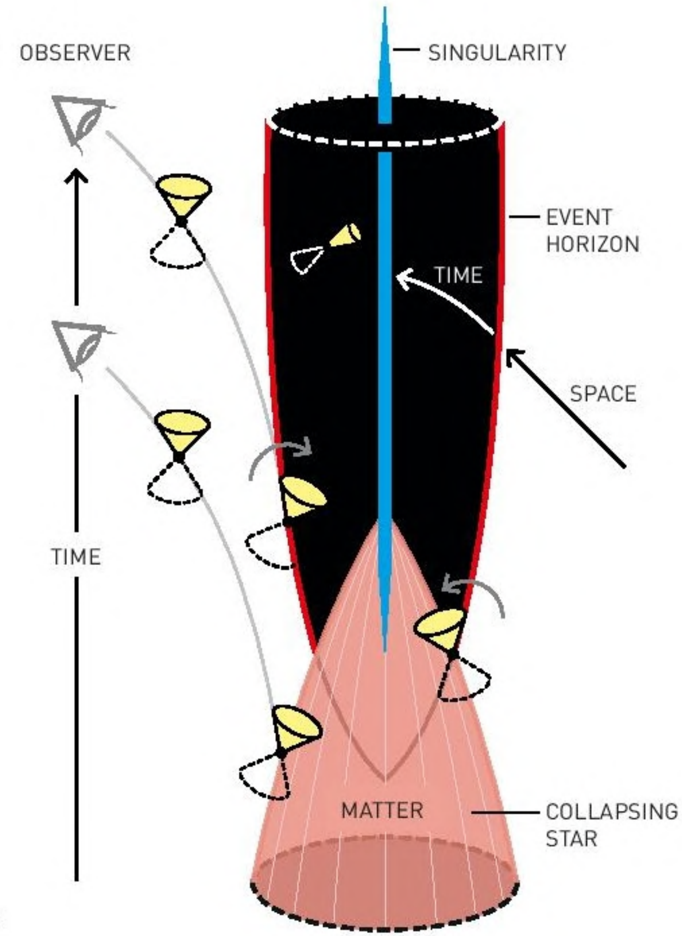

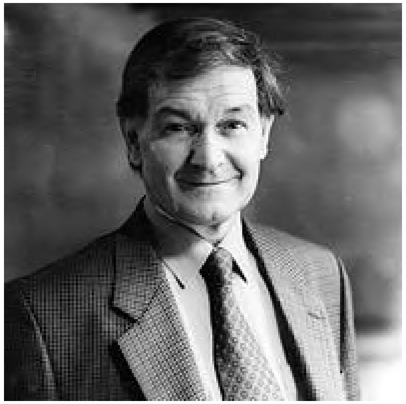

Roger Penrose

...deviations from spherical al symmetry cannot prevent space-time singularities from arising

...singularities necessary develop

Nobel-bizottság 2020

Penrose 1965

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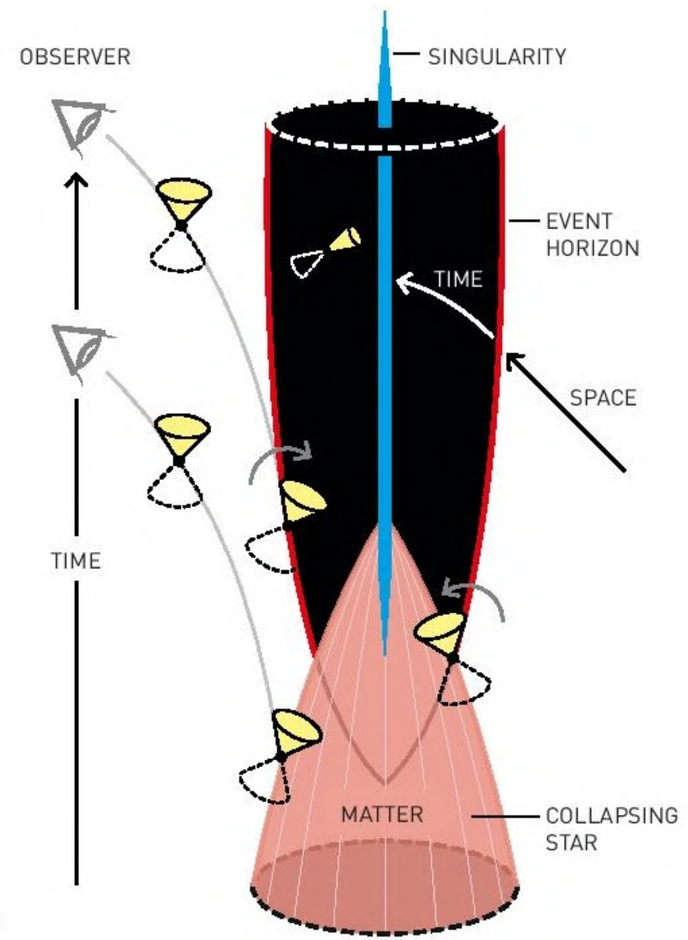

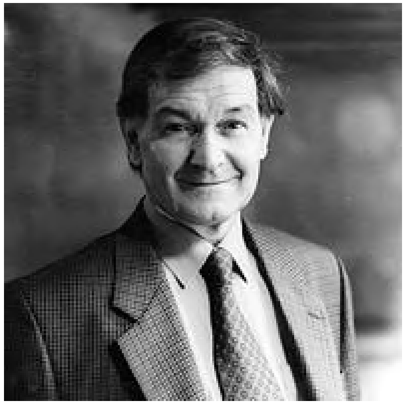

Roger Penrose

Stephen Hawking
(1942–2018)

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Penrose 1965

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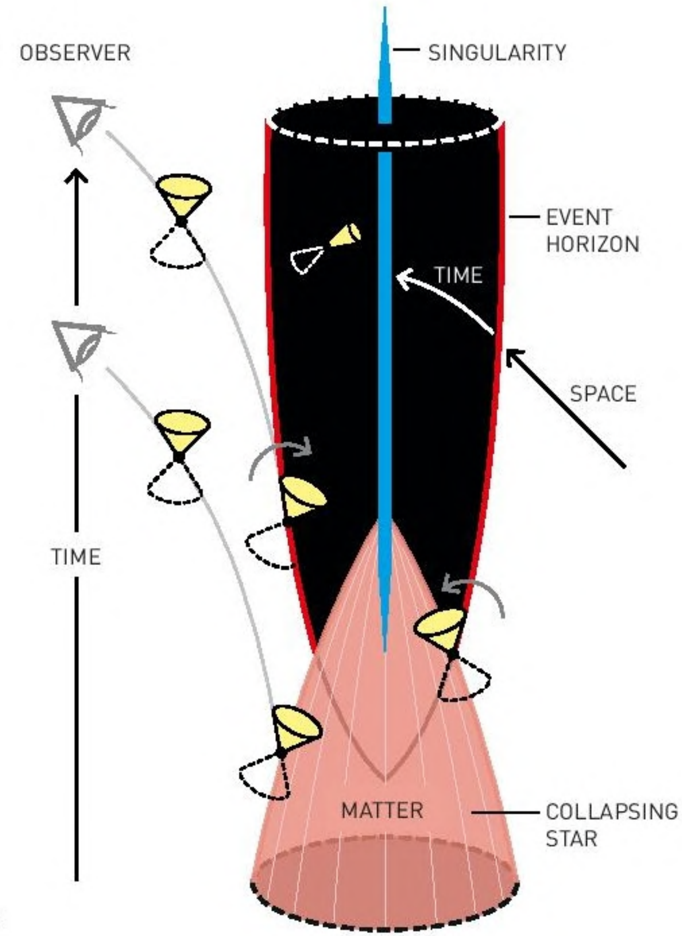

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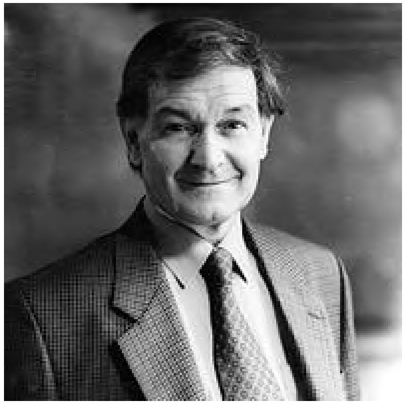

Roger Penrose

Stephen Hawking
(1942–2018)

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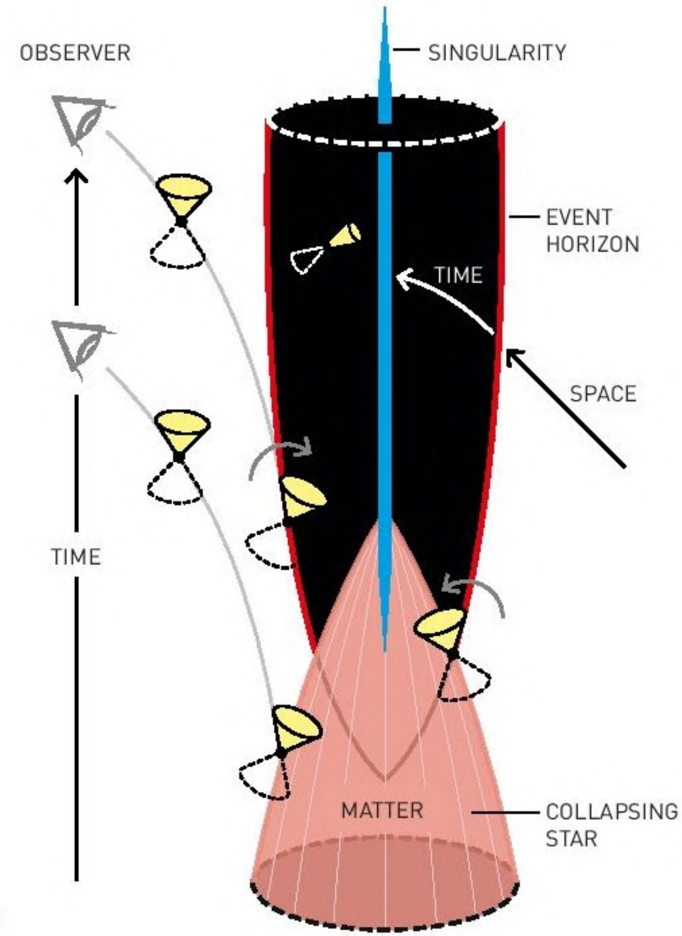

...deviations from spherical al symmetry cannot prevent space-time singularities from arising

...singularities necessary develop

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Penrose 1965

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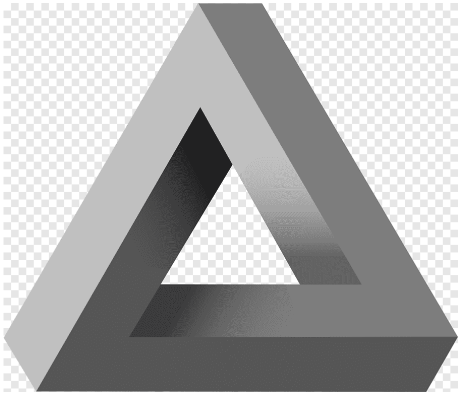
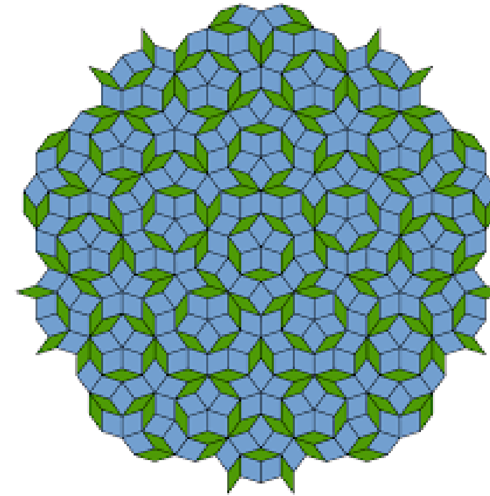
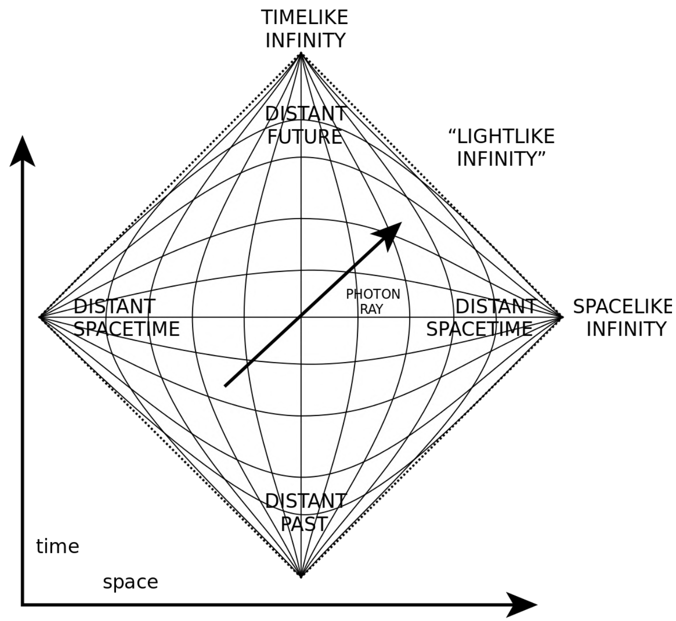
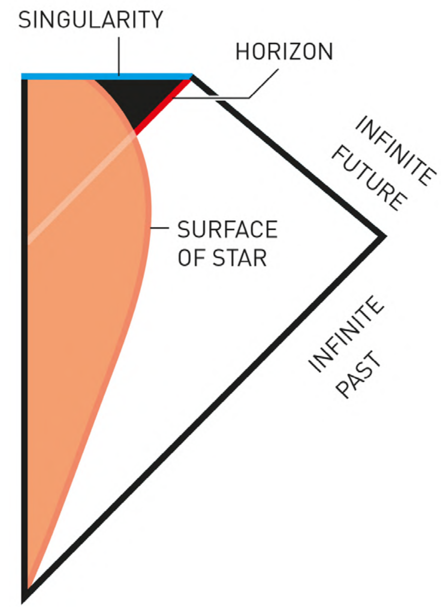






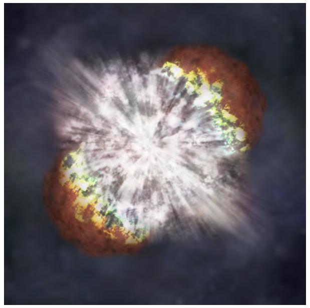


PENROSE

FIZIKAI NOBEL-DÍJ 2020.

De hol vannak a fekete lyukak?

kis tömegűek



szupernóva-
maradványok

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De hol vannak a fekete lyukak?

kis tömegűek

szupernóva-
maradványok

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De hol vannak a fekete lyukak?

kis tömegűek

szupernóva-
maradványok

szupernehéz tömegűek

galaxisok magjában

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De hol vannak a fekete lyukak?

kis tömegűek

szupernóva-
maradványok

közepes tömegűek

felfedezés: 2020

???

szupernehéz tömegűek

galaxisok magjában

FIZIKAI NOBEL-DÍJ 2020.

De hol vannak a fekete lyukak?

kis tömegűek

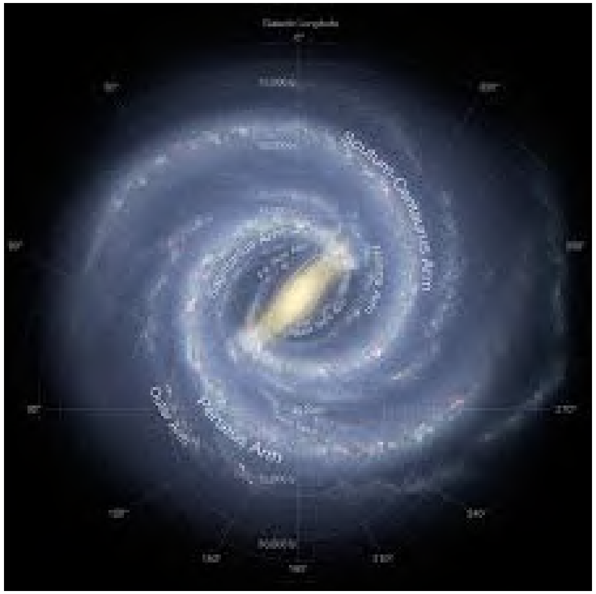
szupernóva-
maradványok

közepes tömegűek

felfedezés: 2020

???

szupernehéz tömegűek



ez a mi galaxisunk

Van-e a közepén
szupernehéz fekete lyuk?

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szupernehéz tömegűek

a Galaxis középpontját porfelhők takarják

ezért IR-ben nézik (2,2 μm)

Nap

ez a mi galaxisunk

Van-e a közepén szupernehéz fekete lyuk?

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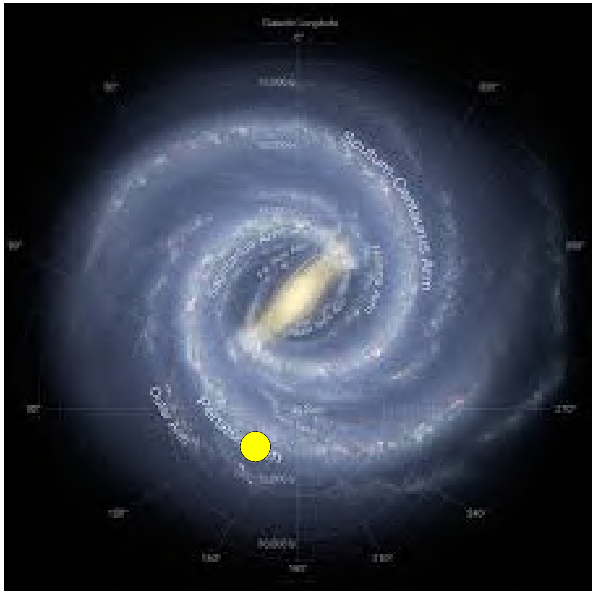
óriástávcsövek

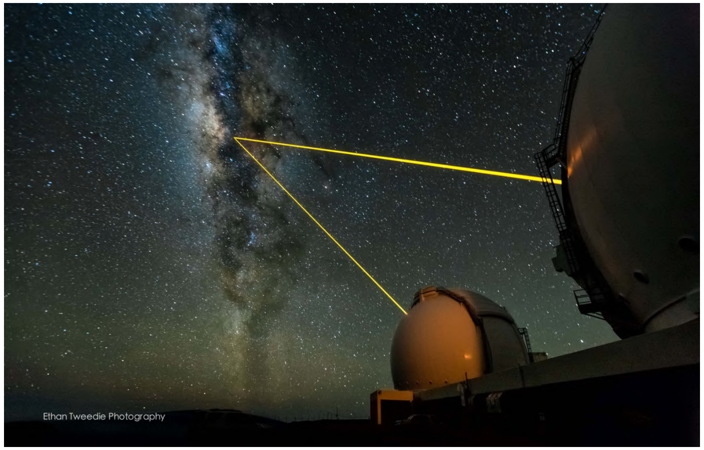
VLT

Very Large Telescope

Chile



1990–2000-es évek



Keck Telescope

Hawaii

Fizikai Nobel-díj 2020.

óriástávcsövek

VLT

Very Large Telescope

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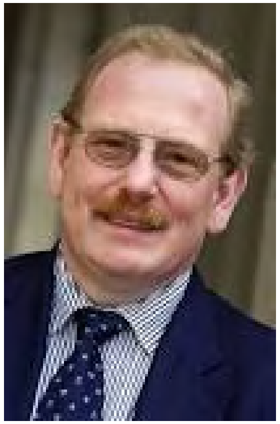
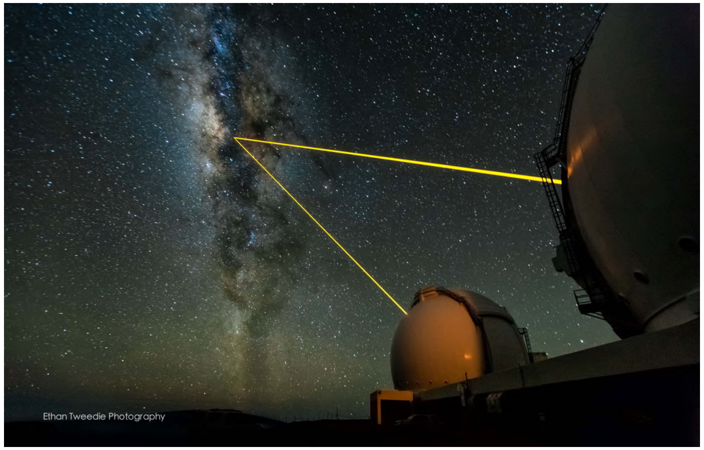


Reinhard Genzel

Max Planck Institute

1990–2000-es évek



Keck Telescope

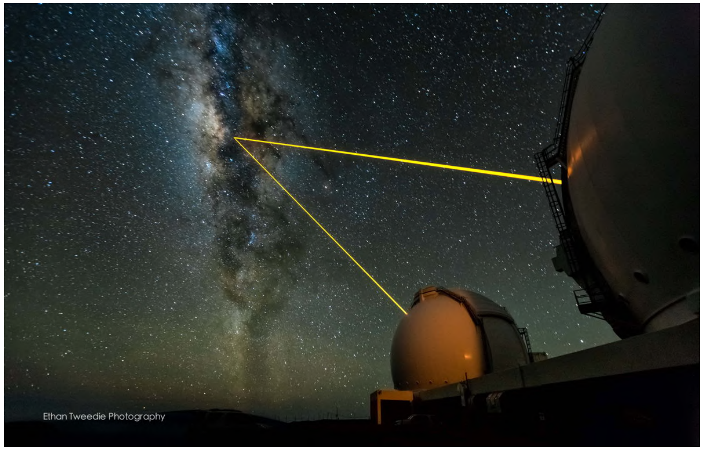
Hawaii

Andrea Ghez

UCLA

FIZIKAI NOBEL-DÍJ 2020.

óriástávcsövek



adaptív optika

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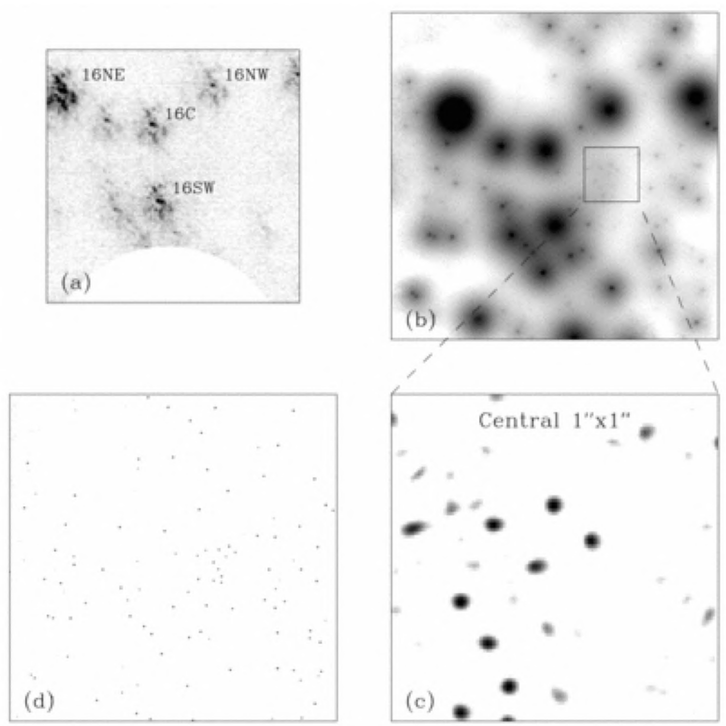

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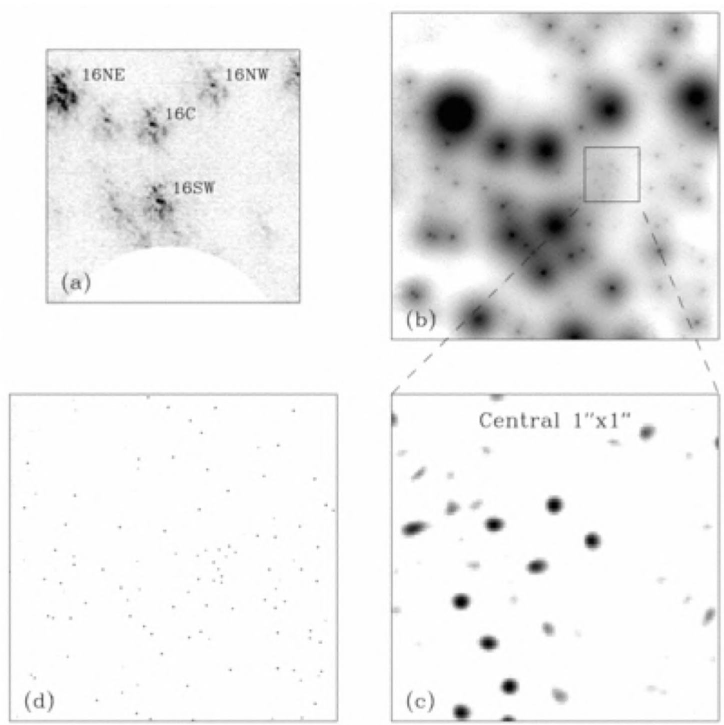

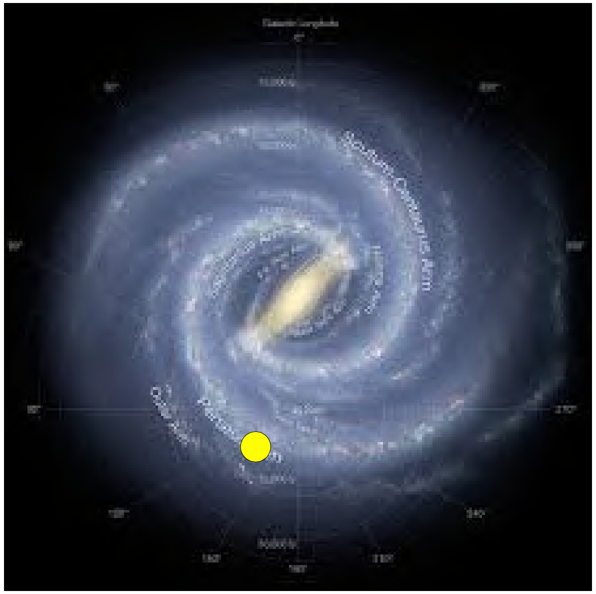

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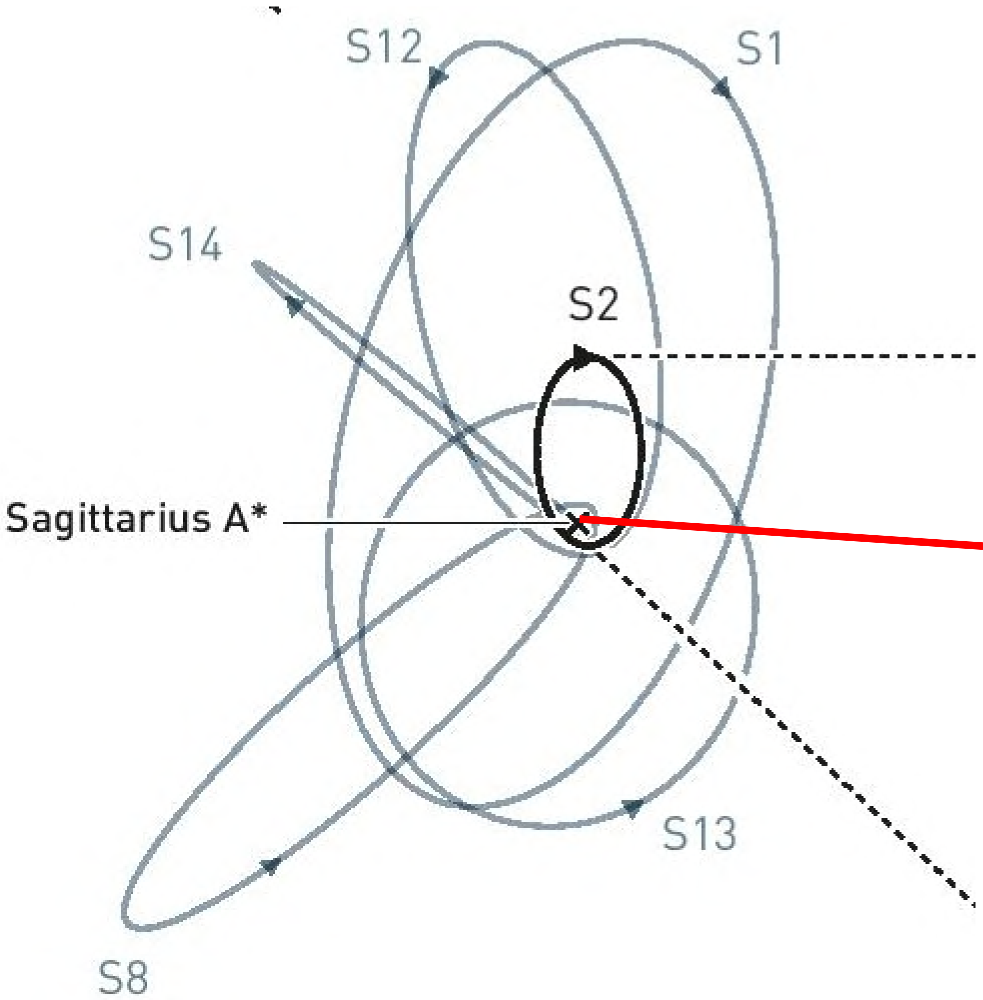

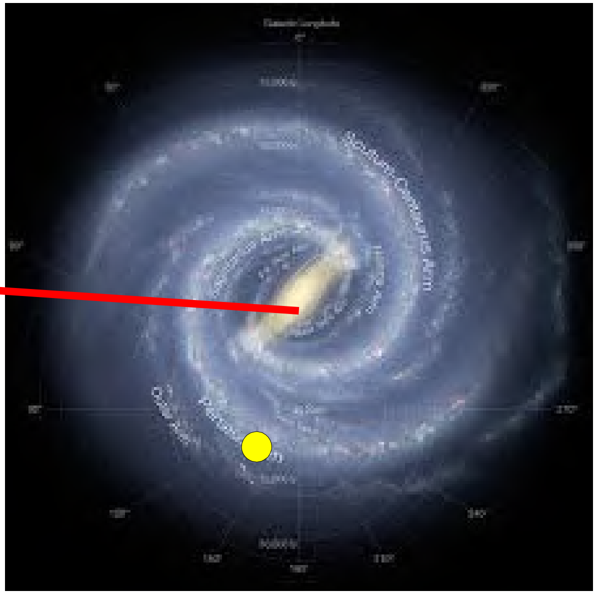

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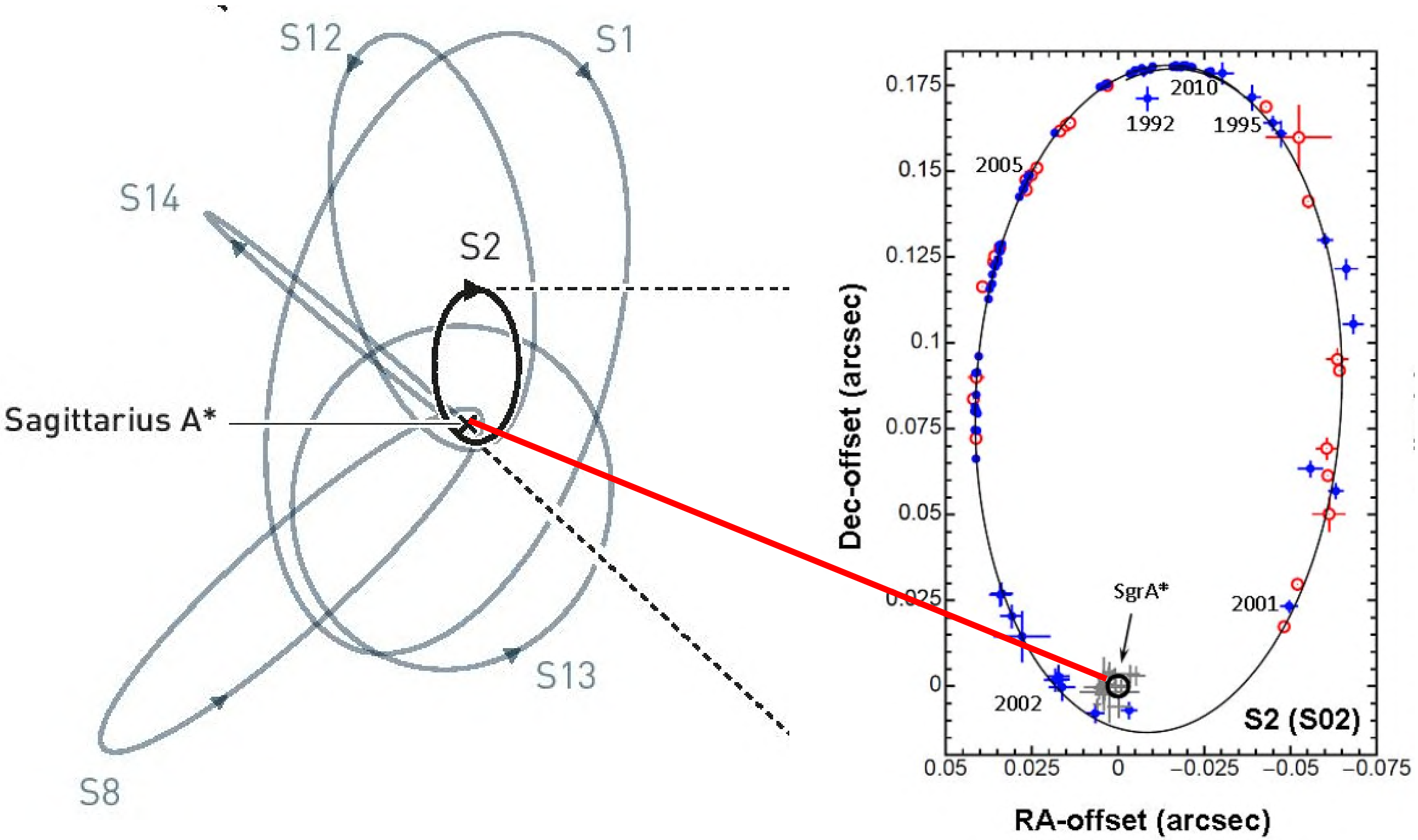

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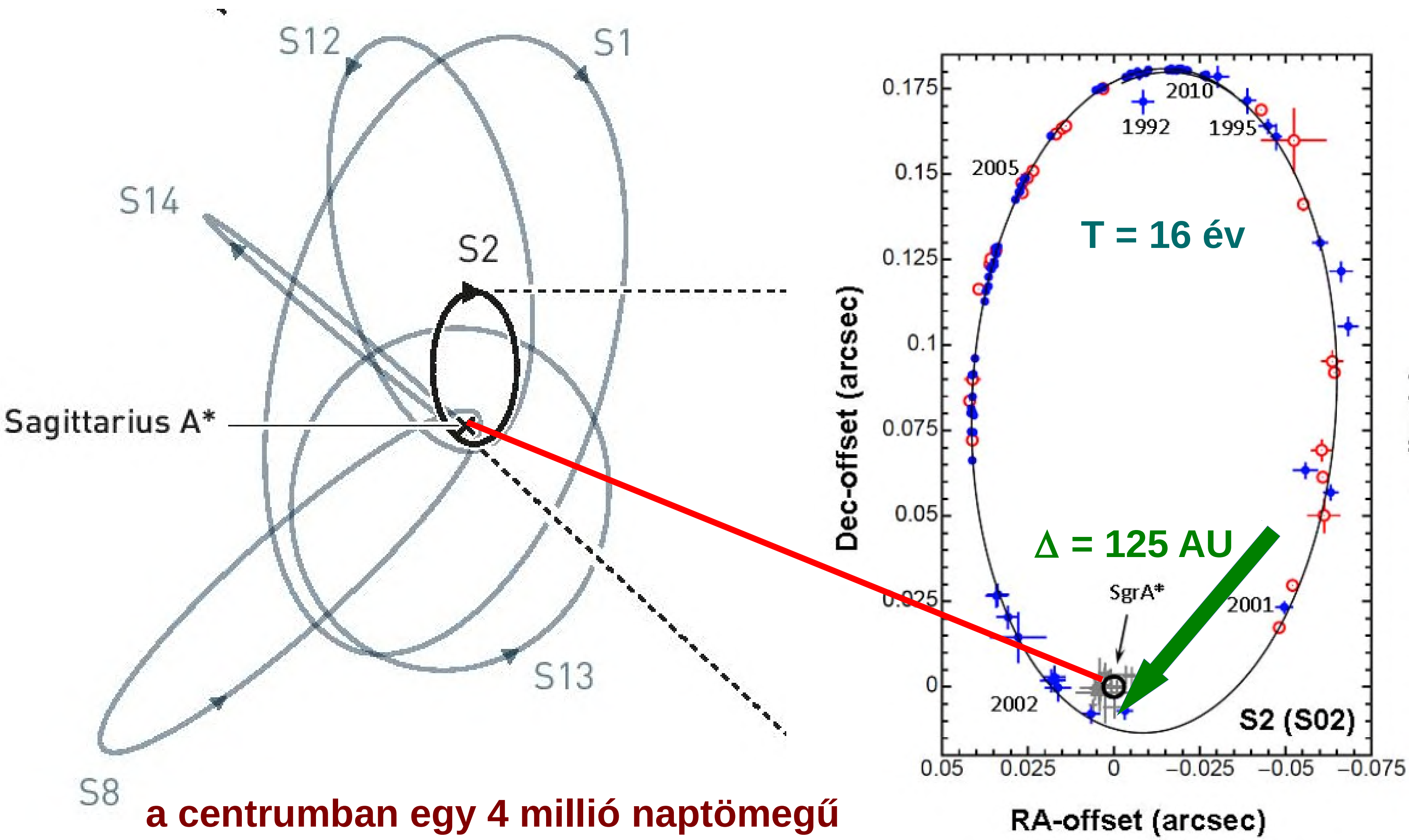
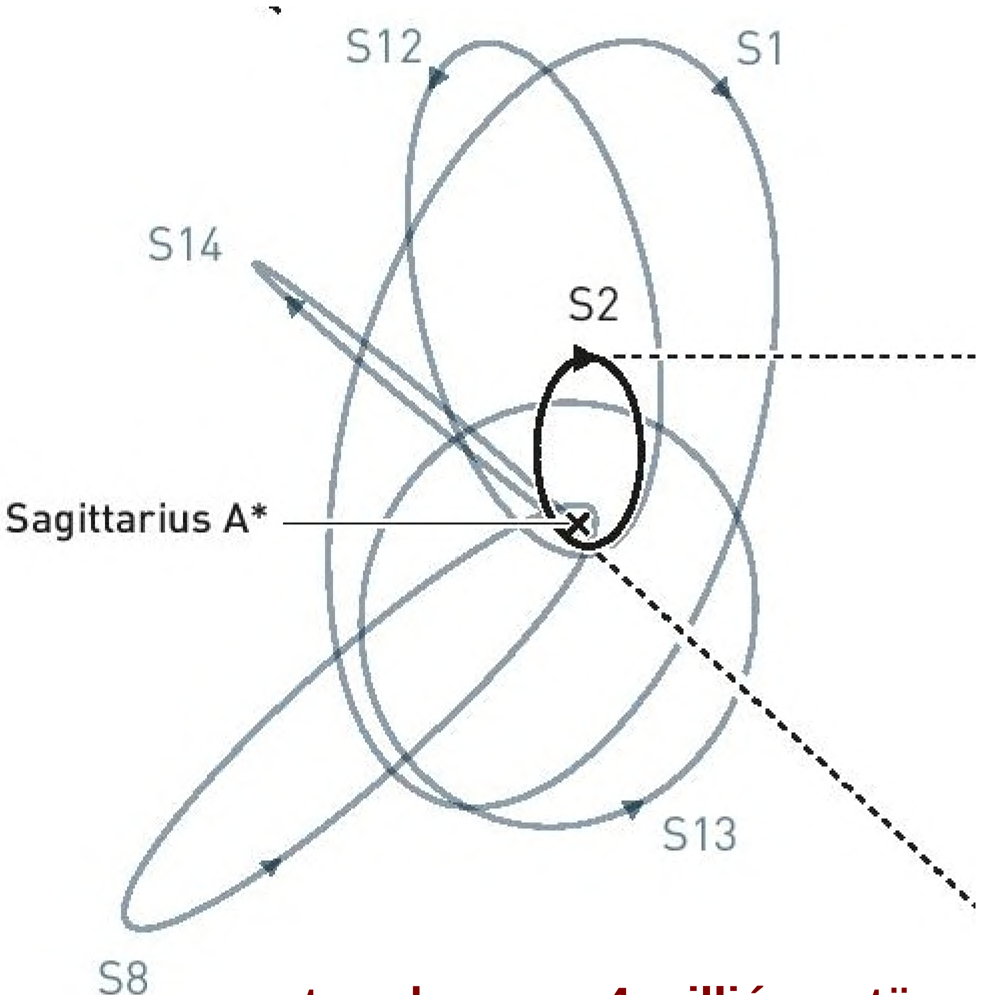
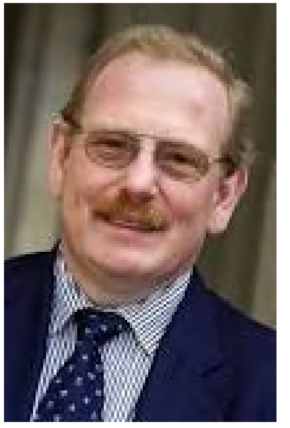


a centrumban egy 4 millió naptömegű kompakt objektum van

R_S = 0,8 AU

FIZIKAI NOBEL-DÍJ 2020.





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Nobel-díj 2020

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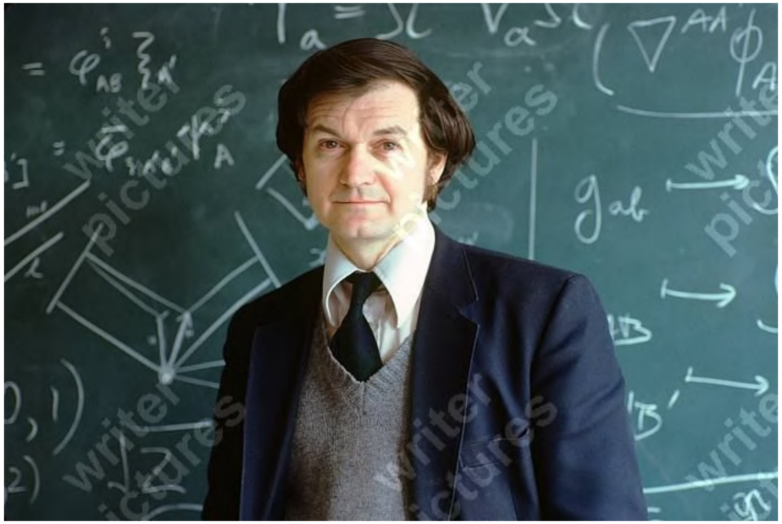
FIZIKAI NOBEL-DÍJ 2020.

Roger Penrose



a fekete lyukak létezése az általános relativitáselmélet elkerülhetetlen következménye

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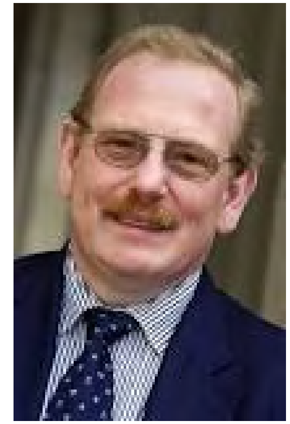

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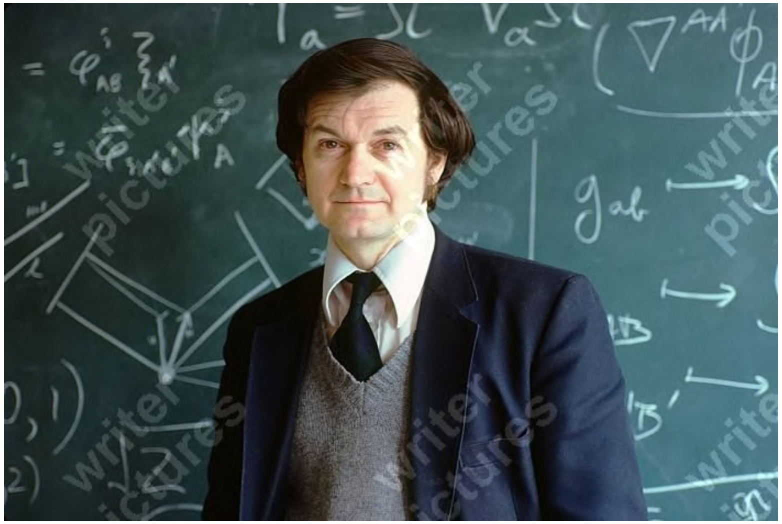

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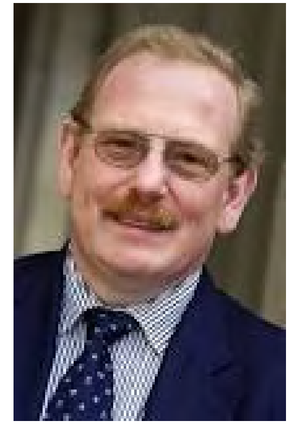

Reinhard
Genzel

Max Planck
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az általános relativitáselmélet
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Fizikai Intézet

Az atomoktól a csillagokig

A fizika mindenkié