symmetry

MDPI

Article

Alternative Uses for Quantum Systems and Devices

Orchidea Maria Lecian

DICEA-Department of Civil, Constructional and Environmental Engineering, Faculty of Civil and Industrial Engineering, Sapienza University of Rome, Via Eudossiana, 18-00184 Rome, Italy; orchideamaria.lecian@uniroma1.it

Received: 31 January 2019; Accepted: 7 March 2019; Published: 2 April 2019

check for updates

Abstract: Quantum optical systems and devices were analyzed to verify theories both predicting new particles on flat spacetime, and for the verification of Planck-scale physics for cosmological investigation.

Keywords: quantum optical systems; astronomical and space-research instrumentation; instruments, apparatus, and components common to several branches of physics and astronomy; normal galaxies, extragalactic objects and systems; field theory; comparative planetology; properties of specific particles; quantum optics; fundamental astronomy

1. Introduction

The origin of galaxies can be testified [1] through semianalytic calculations for the growth of supermassive black holes to discriminate between seeding models and pertinent accretion modes according to the abundances and maximum masses of the formers.

Information about interstellar gas in high-redshift galaxies [2] is relevant in providing the tools for the numerical simulation of pressure and energy and verifying the behavior of their celestial bodies. The evolution of galactic structures and their compact objects in the vicinity of galaxy centers, as well as the refinements of General Relativity (GR)tests [3], can be achieved by accurately measuring the frequencies of the periapsis and Lense–Thirring precessions. By means of a single, linear interferometer [4], the evolution of a binary system can be followed as described by their leading-order quadrupole gravitational radiation by calculating the source rate (of gravitational radiation) and the observation range. For coalescing neutron-star binary systems, optimization of recycling frequency values can be calculated in the cases of the maximization of the detections rate or of the measurement precision. The signal-to-noise ratio is improved in longer-time observations. Signal and noise superpositions constitute probability volumes iff the likelihood ratio (i.e., the noise-to-signal ratio) has a single extremum that either is close to the physical state of the signal or its series converges close to the latter. Correlation coefficients and standard deviation should be accurate enough to compensate for the neglect of the first Post-Newtonian (PN) order in source modelization. The properties of galaxies and celestial bodies can also be accounted for by hypothesizing the existence of new particles and/or novel features of existing particles. Such analyses allow one to exploit the specificities of particles and of their aggregation states to further modelize the known characteristics of such bodies.

The studiedoptical quantum systems that rise by the quantum properties of particles, as well as those caused by the quantum-gravitational nature of spacetime and their interaction, allow one to also exploit such quantum properties for phenomena taking place at scales larger than the Planckian. Lab experiments aimed at verifying these descriptions, as well as observational surveys for astrophysical phenomena, are therefore affected by the quantum description of particles and spacetime in the resulting optical systems [5–8]. The role of possible modifications of the dispersion relations (such as those porposed in [9]) are therefore to be restricted to the analyzed length scales.

The quantum description of spacetime at scales larger than Planck length can give rise to phenomena ascribed to the semiclassical nature of the spacetime as well as its quantum properties, which affect the description of physical phenomena above the Planckian scale. The evidence for new physical phenomena at any scale larger than the Planckian can be described after the phenomenological description of effective quantum properties of spacetime in the solution to the gravitational-field equations.

The macroscopic appearance of the present universe as well as its matter content can therefore be completed with the quantum corrections to the associated optical systems, to which quantum-gravitational resulting corrections can also be applied.

For rapidly rotating stars, high angular resolution observations at near-IR regions and temperature-difference detection between the poles and the equator are possible through these techniques [10]. It is therefore possible to verify rotational instabilities by analysing the nature of emissions and their asymmetry, and the mass-loss rate, in order to measure the critical speed of the stellar wind(s)—by the brightness of the blobs, their size, and their morphology—at the poles (that characterizes and accompany these events).

A laser-based system was designed [11] that, with the calibration of interferometers, is able to compensate for dispersive technologies. The resulting device is suited for exoplanet detection by stellar spectroscopy and velocimetry.

Active Galatic Nuclei (AGN's) milliarcsecond-emission regions were shown to provide data for measuring the mass function of quasar black holes [12]. This is achieved by combining the phases observed in two identical telescopes to control the anisotropy of the UV emission (i.e., from interstellar medium). At these frequencies, an interferometer-based baseline can individuate the shape of the line-emitting region. The ratio of the total emission flux to that measured through a single instrument sets a lower bound to the size of the region. The continuum spectrum does differently correspond to the star background in the considered galaxy and/or continuum light scattered from the nucleus.

By combining three telescopes, it is possible to calculate the phase off-set for a baseline interferometer [13]. This techniques allows with the precision to resolve a pointlike source position of a celestial body such as an Earth-like planet within the Solar System.

The devices of very-long-baseline interferometry are equipped [14] to routine disk-based recording systems for Gbps data rates by both cm and mm networks. For this, receiver systems and coherence time improve both baseline and image/noise sensitivity for fiber-based communication networks and real-time networks in order to access the radio detection of microJy sky pixels to analyze needed sources, such that phase-referencing preparation should not be especially required before each self-calibration of the chosen target.

The Sagnac-Fabry-Pérot interferometer [15] is a device eligible both for the detection of gravitational waves and as an instrument for particle physics experiments.

The paper is organized as follows.

In Section 2, several models predicting new features for particles, fundamental-symmetry violations, and new particles are reviewed, and alternative verification experiments are proposed, for which at least some features of these models can be tested.

In Section 3, cosmological theories for Solar System planet and exoplanet formation are revised; the results of astrophysical experiments that are useful for the verification of such theories are outlined.

Concluding remarks about perspectives for the continuation of investigations are developed.

2. New-Particle Detection

The Berry geometrical phase is due to a nonrelativistic system, whose Hamiltonian $\mathcal{H}_\lambda \equiv \mathcal{H}_\lambda(\lambda_1, \lambda_2, ..., \lambda_n)$ depends continuously on a family of slowly changing parameters λ_i, $i = 1, ..., n$ [16]. In £ space dimensions, it determines a broken $O(3)$ symmetry, as the Hamiltonian $\mathcal{H}_\lambda$ does not commute with generators of an $O(3)$ symmetry [17–19].

Without following here the analyses of References [20,21], we report that, in curved spacetime, the wavefunction can be factorized as

$$\Phi(x) = e^{-i\Phi_G(x)}\varphi(x), \tag{1}$$

with $\Phi_G(x)$ being the gravitational part of the wavefunction,

$$\Phi_G(x) = -\frac{1}{4}\int_P^x dz^\sigma(\gamma_{\alpha\sigma,\beta}(z) - \gamma_{\beta\sigma,\alpha}(z))[(x^\alpha - z\alpha)k^\beta - (x^\beta - z\beta)k^\alpha] + \frac{1}{2}\int_P^x dz^\sigma \gamma_{\alpha\sigma}k^\sigma, \tag{2}$$

with plane-wave momentum k^α satisfying $k^\alpha k_\alpha = m_k^2$. This way, unless strong fine tunings are imposed on $\varphi(x)$ in Equation (1), there results broken $O(3)$ 3-dimensional space symmetry.

2.1. Weak Gravitational Fields

In the case of broken $O(3)$ space symmetry, the velocity-distribution function for velocities characterizing the wavepackets is constructed originating quantum states describing asymptotical ($-\infty$) KLSZ states. In the case of a weak gravitational field, the velocity distribution for particles [22] in the laboratory frame departs from that calculated on Minkowski flat spacetime as

$$f_v = \frac{1}{8\pi^3 det[(\varsigma_v)^2]} exp\left[-\frac{1}{2}(\vec{v} - \vec{v}_\odot)^T \varsigma_v^{-2}(\vec{v} - \vec{v}_\odot)\right] \tag{3}$$

with $\boldsymbol{\varsigma}_v \equiv diag[\varsigma_x, \varsigma_y, \varsigma_z]$ as the velocity dispersion tensor, which encodes the solution to the Einstein field equations (EFE')speculiarity through its metric tensor components. This situation gives rise to a velocity anisotropy:

$$\beta(\mathbf{r}) \equiv 1 - \frac{\varsigma_y^2 + \varsigma_z^2}{2\varsigma_x^2} \tag{4}$$

which can be detected by a ionization chamber able to recover the track parameters $(X, Y, Z, \theta, \phi, S)$.

For the detection of dark matter, given a weakly-interacting massive particle (WIMP)χ of mass m_χ, from parameter space (m_χ, ς_i) it is possible to evaluate the WIMP-nucleon cross section $\sigma_{W-nucleon}$.

In Reference [22], a model-independent cross section of dark matter on protons $\varsigma_{i,p}$ is found as $\varsigma_i \simeq 10^{-3} pb$ for scintillators targeted of CsI(Tl), ^{19} F [23,24], respectively.

F targets were studied in Reference [25] for Earth-based experiments analyzing atmospheric-origin particles.

Detectors for anisotropic ultraenergetic cosmic rays of galactic origin are schematized in References [26–28]; the dark-matter-induced symmetry violations are examined in [29].

2.2. Fractional Charge

An instrument aimed at detecting fractional-charge particles is the rotor electrometer. It was designed as a Faraday container with an arbitrary high-impedance amplifier, endowed with copper pads, for which different charges reach the container walls at different velocities, such that the time of flight can be calculated, i.e., after a tuning the impedance suited for the charge to be detected [30,31].

For fractional quantum numbers, see also Reference [32].

2.3. Further Particles

Differently, the findings of References [33,34] can be compared. In Reference [34], the electric dipole moment of the electron and that of the neutron are evaluated as a constraint to CP violation arising from a broken $SU(3)$-symmetry, which can lead to theories characterized either by baryonic number N_b or leptonic number N_l violation.

Proton–proton collision outcomes are interests of study at the LHC facility, see, e.g., References [35,36], respectively.

This phenomenon can be compared with broken spacial $O(3)$ symmetry originating from a geometrical Berry phase Equation (1) on curved spacetime, and the remaining degrees of freedom can be used for further purposes. The difference can be confirmed by the individuation of sparticles whose mass dispersion relation Δm_{ij} for masses m_{ij} is given by

$$\frac{\Delta m_{jk}^2}{m_0^2} = \frac{\lambda_j \lambda_k^*}{\pi^2} \ln \frac{M_{Pl}}{M_G}, \tag{5}$$

where λ_i factorizes the (requested) coupling constant, m_0 is the mass of the common (standard-model) scalar (normalized to Planck mass M_{Pl}), and M_G is the mass for a (massive) gravitational mode.

Interacting Further Particles

After the breach of higher-dimensional structures [37–40], nonperturbative degrees of freedom give rise to Compton-length waves (particles) whose masses M_C are comparable with Planck mass M_{Pl}; they interact very weakly and gravitationally. In particular, masses M_C are of order $M_C \simeq R/M_{Pl}$, with R the lower bound on the compactification (energy) scale, and their gravitational interaction can modify ordinary Newtonian gravity.

A possibility was envisaged to verify the existence of particles such as those described by Equation (5) by cantilever detectors and/or silicon-based microelectromechanical systems [38–40]. In the following, alternative procedures are proposed for the sake of comparison with other theories and models.

2.4. Verifying New Particles by Alternative Experiments

Detectors for Earth-based experiments looking for WIMPs of mass m_W, $m_W 80 Gev$ scattering on smaller particles were proposed in Reference [41]; nevertheless, interaction signals happening in the Sun are considered as well.

The main differences between generic light scalars and axions were discussed in Reference [42] on the basis of P and T violations.The regions of the parameter space available for axions exclude, by electric dipole moment bounds, those for a Fifth-Force recognition as spin-dependent and mediated by an axion-like particle; nonetheless, for a generic scalar unaffected by CP violation, a Fifth-Force description is still possible.

The signal containing a spin-flipping effect calculated after the cross section of the absorption by a scanning Fabry-Pérot interferometer as a function of a 'relaxation time' can be 'cleaned' [43] in order to obtain the true description of the emission rate and the absorption one.

For a beam of electrons prepared for a Fabry-Pérot interferometer according to a required velocity distribution precision and (three-dimensional space) radial resolution, for Thomson scattering of laser electrons from an electron beam, Doppler-shifted wavelength of photons backscattered under 180 degrees, velocity distribution radially resolved in space, absolute electron energy, and the degree of space-charge compensation can be measured [44]. Measurement of longitudinal and transverse electron temperature is determined up to a lower bound for the ratio, respectively, and it has an upper bound (of $10/2$) for velocity distribution. It further reveals fractional space-charge compensation; moreover, it is suited for higher laser intensity, i.e., by appropriate placement and use of the cavity mirrors of a confocal resonator.

This technique provides, for the first time, nondestructive measurement of velocity distribution in an electron beam radially resolved in space. The results presented here comprise the direct measurement of the absolute electron energy and the degree of space-charge compensation in the electron beam. The determination of an upper bound of $10/2$ for the ratio of longitudinal-to-transverse electron temperature implies the first direct measurement of flattened velocity distribution.

Differently, it is also possible to look for new predicted particles by adapting previously proposed experiments and apparati for the required tasks.

Noise-minimization techniques involving changing mirror disposition for Michelson interferometers were reviewed in Reference [45].

For nonlinear interferometers [46], optical switching (for example, but not only, of mirrors) can be obtained via cross-phase modulation of a lossy (particle-beam) line, i.e., for a Sagnac interferometer.

The Sagnac effect can be explored by studying the role of spin-rotation coupling for circularly polarized light in order to testify on the photon-helicity coupling to rotation: for this, an analogous experiment of neutron interferometry can be performed [47]. The frequency shift and a constant optical phase shift for the prepared beam of neutrons can be tested by multiplying angular velocity Ω by the time of flight of a photon between two interferometers ends $\Delta t = l/c$ to obtain helicity-rotation phase shift $\Delta\Phi = 2\Omega l/c$ as the same phase shift predicted in the rotating frame at the detector.

The presence of different particles in the (Earth-based) lab system, such as those described for Equation (5), can be revealed by a different helicity-rotation phase shift $\tilde{\Delta}\Phi$.

Their gravitational and other kinds of interaction with neutrons in the prepared beam would modify neutron kinetic energy K_n. Indeed, velocities $\vec{v}$ correspond to the average of the wavepacket of the prepared neutron beam; should neutrons undergo interactions, their velocities after interaction(s) $\vec{v}' = \vec{v}_{n\ interact} \neq \vec{v}$ might be changed, i.e., in any case of inelastic scattering interaction(s). The helicity-rotation phase shift(s) can be measured by evaluating the requested time for end-to-end interferometer path covering, $\Delta\tilde{t}$, their velocities $\vec{v}_{n\ interact} \neq \vec{v}_{n\ \ i} \equiv c^2\vec{k}_i/\omega_i$ and their velocity distribution, being $\Phi \equiv \Phi(\vec{k})$ and $\Phi' \equiv \Phi(\vec{k}_{interact})$.

Differently, in the case of a weak gravitational field, the velocities of the new interacting particles (not prepared in the neutron beam) in the experiment environment would be further modified, e.g., such as established in Equation (3), for which different helicity-rotation phase shift(s) $\tilde{\Delta}\Phi\ ''$ would be detected.

The presence of different kinds of particles would be predictable in the case of different values for $\tilde{\Delta}\Phi\ ''$.

The effectiveness of a gravitational (but not necessarily only Berry) phase, such as the one in Equation (2), multiplying wavefunction Equation (1) (from which the neutron wavepacket is prepared), would lead to two different results, $\tilde{\Delta}\Phi_G\ '''$ and $\tilde{\Delta}\Phi\ '''$ for the measures of the helicity-rotation phase shift(s) according to whether the new particles interact gravitationally or not.

2.5. Semiclassical Descriptions

Analysis of a semiclassical regime for the quantum nature of gravity based on the notion of precausality was developed in Reference [48]. Among precausality requirements, the necessity to imply quantum modifications to matter fields rather than on the geometrical description of spacetime was also established for lab experiments in Minkowski spacetime. In curved spacetime, EFE nonlinearity plays a crucial role in determining the viability of a geometrical gravitational theory, and as far as quantum-gravity corrections to nongravitationally interacting high-energy matter fields are concerned [49].

Quantum optical corrections for Maxwell equations [5] are predicted for short-distance experiments, for which a Fock occupation space can be defined for the quantum optical system. Such corrections [50] can be framed within models interpreting the statistical correlations as the outcome of theories with local hidden variables.

An experiment with correlated light beams in coupled interferometers allows for semiclassical-limit analysis [51].

Among quantum (nonsemiclassical) effects, the production of Planck-sized black holes can be discerned in this way [52].

The modification of the thermodynamical properties of macroscopic materials [53] can, after these controls, be exploited to study the possibility of modified energy–momentum relations.

For low-energy matter fields, the phenomenon of gravitational decoherence can be investigated by studying a quantum system interacting with the external environment. This way, a modification to the quantum fields brought by the (Minkowski) lab gravitational field can be modeled as spacetime fluctuations of quantum-gravitational origin acting on the matter fields [54], as well as for experiments taking place in larger scales than Planck length.

Quantum-gravitational decoherence can, in this way, be differentiated from quantum decoherence by experiment settings including cold-ion traps [55].

The interpretation possibilities trapped-ion crystals and the generating functionals for self-interacting scalar fields [55,56] further be done for Reference [57] determining the corresponding two-point correlation function.

The correlation between quantum signals and interferometers was schematized in Reference [58] by setting the different theoretical interpretation of two-mode squeezed vacuum states and two independent squeezed states by considering the output states as influenced by the transmission coefficient of the beam splitter.

Quantum fluctuations of electrons in a storage ring can further be modeled as a Markov process for lattice-gauge theories [59].

Helium properties in several different aggregation states, by taking advantage of their features as macroscopic quantum states [60], have been exploited and proposed to be exploited for the detection of gravitational waves [61]. From a theoretical point of view, such experiments [62] allow to obtain hints about the topology of the Riemannian manifold generated as an EFE solution, not only in the weak-field limit. Applications for the determination of the mass of white dwarfs [63] and about the evolution of galaxy formation [63] have also been performed.

The experimental device, consisting of fiberoptic gyroscopes, allow establish a reliable offset with regard to the Earth-rotation effects [64]; the remaining noise can be studied as a quantum property of the aggregation state of the material [65].

Semiclassical Experiments

The modification of energy–momentum dispersion relations (as from analysis of its spectral decomposition) was proposed in the literature with the aim to propose properties of quantum spacetime foam and some of its semiclassical limits features.

In particular, it is possible to study the phenomenological implication of the foamy structure by investigating the properties of macroscopic materials with regard to their reflection and refraction specificities by comparing the atoms and molecules constituting the solid-state structure, either crystalline or amorphous. This is done by approximating the corresponding potential (wells) as black-hole-like potentials. In this case, the chosen interacting particle (photon) is small enough with regard to the potential wells and the Planck scale, but the experiment is conducted at length sizes larger than the Planck scale [7,8]. The overall gravitational regime of the lab system, however, is still Minkowskian, and there exists a valid paradigm to discriminate and calibrate interaction(s) between the system and the external environment.

Photon transit in a (macroscopic) block of diaelectric material is supposed to cause a (photon) momentum transfer; there exist appropriate temperatures at which a momentum change caused by the diffractive diaelectric index, for which the momentum transferred to the block can produce appreciable (position) reaction shift of the block as the photon exits the block. The diffractive diaelectric properties, caused by its solid-state structure, can be approximated to the effects of a lattice of (small-size) black holes, which can account for quantum-gravitational properties of the spacetime inside the block and, in particular, its foamy features. The described experiment [6] consists of letting a photon cross a block of diaelectric material of mass $\tilde{M}$ and volume $V_{\tilde{M}} = L_1 L_2 L_3$, whose refraction index n_{ref} can be evaluated after the absolute value of the Poynting vector, and whose center of mass should have moved of displacement ΔX_k at the exit of the photon after k double reflections, i.e.,

$$\Delta X_k = L_1 \frac{h\omega}{2\pi \tilde{M} c^2}(n - 1 + 2k) \tag{6}$$

with ω being the frequency of the photon. Any modification to the measured displacement has to be ascribed to quantum-gravitational phenomena, which can manifest in the modification of the photon energy, in the modification of the diffraction index of the diaelectric block, and/or after the spacetime foamy structure modifies the potential of the solid-state structure, photon energy, and their interaction.

3. Sky Investigations

3.1. 'Post-Keplerian' Objects

The values of spin and of the orientation of the massive black hole at the galactic center can be constrained by analyzing the motion of pulsars around it [66]. To do so, considering pulsar precession or any other quantities averaged on it have proven less efficient than considering the pulsar as a test particle moving in a Kerr metric. In the latter strategy at first PN order, no counterfilter has been theorized that is able to remove the Keplerian [67] 'noise' due to the other considered Newtonian 'material' in the galactic region. In Reference [68], S stars are considered for their almost Keplerian behavior from which perturbation due to a background Schwarzschild metric can be isolated; this way, the black-hole-spin-induced quadrupole moment can be measured under the description of redshift measurements distributed along the orbital path and more intensive at the pericenter. Under the assumption of a different background metric, the orbit of the star is influenced by the spin of the galactic black hole (BH) at PN order, as after analysis of photon-propagation delays, for which the geodesics path is governed by a Hamiltonian

$$H_{geod} = H_{Mink} + H_{Schw} + H_{FD} + H_q, \tag{7}$$

where flat spacetime Hamiltonian, the Schwarzschild Hamiltonian, the frame-dragging Hamiltonian, and the BH quadrupole moment have been defined, respectively: the Schwarzschild Hamiltonian is of the v^4 order, and both the frame-dragging Hamiltonian and the BH quadrupole moment one are of the v^6 order.

Further items of information can be obtained at the PN order for a star orbiting the galactic BH by a Keplerian nonprecessing orbit by simplifying the stellar Doppler shift as described by PN parameter β as $\beta \equiv \beta(r;a)$

$$\beta^2 = \frac{r_s}{r} - \frac{r_s}{2_a}, \tag{8}$$

with a being the orbital major semiaxis, and r_s the Schwarzschild radius of the BH. The periapse shift due to any kind of dark matter is negligible at this order.

The precession of a star orbiting the galactic BH can be expressed [69] as a function of astrometric deviation δ_x, as a function of galactic BH spin χ and a, $\delta_x \equiv \delta_x(\chi, a)$

$$\delta_x = \chi \frac{1}{a^{1/2}(1-e^2)^{3/2}} \tag{9}$$

For double-neutron-star binaries, orbital-period derivatives of orbital period $\dot{p}$ can acquire improvements by wide-bandwidth coherent-dispersion devices, as pointed out in References [70–72].

Appropriate controls from binary pulsar systems can [73] set upper and/or lower bounds on the parameters and/or the parameter space of theories whose low-energy limit admits a strong-field limit, different from GR, a different value for universal and/or a running Newton constant G, and on the energy density of the low-frequency (limit of) gravitational waves.

By studying the rate equation for the derivative of mass M growth of a large body, given as Ω, the Keplerian orbital frequency of the large body orbiting a star of mass M_* at orbital distance α and Σ_P the surface density of the field planetesimals, R the radius of the large body, [74,75]

$$\frac{dM}{dt} = \pi R^2 \Omega \Sigma_P F_G, \tag{10}$$

(References [76,77]), with F_G as the gravitational focusing factor.

The magnitude of Neptune's orbital expansion [78] has imposed a lower limit of about 5 AU; numerical results indicate the inclination distribution as sensitive to the rate of orbital evolution for giant planets, for which longer timescales of orbit evolution are correlated to higher inclinations.

For this, optical interferometers, infrared long-baseline and long-baseline (sub)millimeter interferometers, and high-sensitivity infrared observatories, are compared.

3.2. Verifying New Celestial Bodies by Alternative Experiments

3.2.1. Optical Interferometers

Optical interferometers are useful in the study of galaxies, celestial bodies in galaxies, and Newtonian and Keplerian material in and around them. Protoplanetary disks (i.e., around a star) can be analyzed for the information they carry for structure evolution [79] for the role of grains, dust, polycyclic aromatic hydrocarbons, and minerals. Extinction cross-section C_{exti} of a radiation field with solid (macroscopic) particles equals that for absorption C_{abs}, summed to that for scattering C_{sca}, and also equals the imaginary part of total electric polarizability α expressed as the sum of the latter, $\alpha_{j_{\hat{k}}}$, in the three direction of the semiaxes, i.e., $j = j_{\hat{x}}, j_{\hat{y}}, j_{\hat{z}}$, of the ellipsoid-shaped orbiting particle describing the grain, such as

$$C_{exti} = C_{abs} + C_{abs} = Im(\alpha) = Im\left[V(\epsilon_1 + i\epsilon_2 - \epsilon_m)\sum_{\varrho=1}^{\varrho=3}\frac{1}{(\epsilon_m + L_\varrho(\epsilon_1 + i\epsilon_2 - \epsilon_m))}\right] \tag{11}$$

with ϵ as the dielectric function, L_ϱ geometrical factors such that $\sum_{\varrho=1}^{\varrho=3} L_\varrho = 1$, and m the complex refractive index individuating (also) a mass, as solid materials are described by their own optical constants. The presence of different kinds of dust individuates different sizes for the formation of planets, as well as for their size (mass). The composition of dust and dust grains reveals structure age. Spectral analysis reveals the composition in brain minerals, dust, dust grains, different kinds of dust, and crystalline and amorphous material. Grain growth [80] can be individuated both by spectroscopy and by mm observation according to grain size.

Dust-temperature determination can be achieved by analysis of different vibrations of the lattices of heavy ions, and/or groups of ions having low bond energies, and/or when the signal-to-noise ratio is high.

3.2.2. Transition Lines

Studying CO transition lines CO(3-2) or CO(2-1) at submillimetric (submm) scales allows one to infer the interaction properties between a BH and a spheroidal celestial body (of comparable features with regard to the former) [81], and helps shed light on the role of quasars and quasarlike objects in the evolution of galaxies. Galaxy emission lines were partially surveyed in Reference [82]. The same emission lines also provide information on star-disk size. An increased ratio among the lines might indicate [83] an increase of the temperature of the gas corresponding to the upper layers of the disks; higher angular resolution for scanning the dust region might indicate the presence of a warp; nevertheless, the variation of disk thinness is unlikely to be due to photoevaporation, grain growth, and binarity. Differently, the presence of a planet could be considered as responsible for warp shaping, the creation of an inner whole, and different angular resolutions for emission lines. Analysis of mm continuum can also detect azimuthal morphology. Emission-line analysis allows to control the spectral-energy distribution model, followed by the studied mechanism. CO (1-0) line observations have proven [84] effective in detecting galaxy-forming areas, and areas up to the optical range. The possibility of gravitational lensing for CO lines was discussed in Reference [85]. The detection of acoustic modes was discussed in Reference [86] as far as mirror suspensions are concerned.

3.2.3. Laser Interferometers

The use of sapphire crystals in laser interferometers was analyzed in Reference [87]. In restrictions due to the availability of the medium, which can be at least partially overcome by applying temperature gradient techniques, the interest in the detection of gravitational waves has been pointed out. Thermoelastic noise can be reduced [88] by changing the beam shape as a non-Gaussian mesa-shaped center-flat circular intensity profile by modifying the mirror shapes. This is necessary [89,90] to improve the techniques with center-flat mirrors and mesa-shaped beam optical cavities. Tests for the angular resolution [91] of a six-antenna millimeter radio interferometer that is able to detect, in a binary system of two stars with their each own disk, two different angular variables. Uniform probability distribution was chosen to impose a lower limit to the spectral index of one of the stars (Star A) as a function of the parameters of the other star (Star B), achieving a 99.7% (3 σ) confidence level, not only to determine different angular positions for two disks for Star A, but also to infer that they were not on the same plane by the nondetection in the scattered light images (within interstellar and galactic media) of the primary disk.

The emission from the target stars has mostly been modelled as thermal; nevertheless, other (and/or further) nonthermal mechanisms, i.e, in this case, free–free and gyrosynchrotron emissions, are eligible candidates to be supposed as a non-negligible fraction of the millimeter flux in the observations. The reached angular resolution enabled upper and lower bounds on disk-grain distribution (of Star A), and allowed for dust-deposit probability.

By the same device, it is possible to analyze [92] gaseous CO emission by the far quasar, its mass, density and temperature, and put lower bounds by comparing the CO line-flux ratios to those of a one-component large velocity gradient [93]. Excitation evaluation allows to evaluate on the quasar's gas and metallic enrichment. Dust emission and gas density at the given redshift allow to infer that not only was star formation possible at the observed time, but also rapid-growth black-hole formation at early cosmological times.

Appropriate continuum observations (at a millimeter scale) and the choice of molecular transitions allow to gain information about the core centers of stars and disks. Mm-continuum observations of two intermediate-mass star-forming regions up to high-mass star-forming regions, while the CN and CS molecular line shows chemical and physical effects [94] that cannot be confused with the opacity properties of celestial bodies. An increase of the dust opacity index and a decrease of the optical depth allows to hypothesize the presence of grains at the core and/or disk centers. The choice of opportune molecular-transition [95] lines allows to classify disk properties in star formation. To analyze continuum observations [96], the increase of the opacity index caused by an insufficient signal-to-noise ratio and UV coverage was proposed to ameliorate observations by increasing the baseline length. For proposals to refine the signal from line contamination (from bolometer data), see, e.g., Reference [97]. For a better opacity index, see Reference [98].

3.2.4. Baseline Interferometers

The detection-rate statistics of compact radio sources were analyzed for particular choices of sky pixelization [99]. For a single-baseline interferometer, they can be detected iff the most flux density coincides with that of a compact structure. Smaller, i.e., thinner, structures could be missed within this investigation pattern.

Arm-cavity-mirror mechanical modes of interferometric detectors might cause parametric instabilities. This instability can be dumped by adding a spring made of piezoelectric material with the task of dumping to the amplifier circuit attached to the detector material, and an extra resistor with the purpose of shunting, then linked to the ground of the circuit by electric wire [100]. The piezoelectric material has the anisotropic structure of Reference [101], such that strain-energy dissipation in the shunted piezoelectric material depends on the material's geometric shape.

Differently, this problem was proposed to be overcome by choosing a cooled silicon mass for the detector material [102].

As far as long-baseline interferometers are concerned, the dust-evaporation boundary region in young-stellar-object disks can be sufficiently resolved [103], such that the physics underlying grain formation can be schematized.

For a single-baseline Earth-based interferometer, differential astrometric observations are affected by stellar aberration in angular resolution [104]; variations of calibration terms among pixels of interest must be introduced to avoid correlations between calibration summands, and both azimuthal derivatives of the position-variable sky and equatorial angle, for which the former implies the lower bound for the accuracy of the velocity absolute value.

3.2.5. Redshift Role

At a redshift of $z = 6.419$, transition lines CO (6-5) and CO (7-6) indicate that the behavior of the interstellar gas allows for quick metal and dust enrichment; from the area of the molecular region and the brightness of the transition lines it is possible to infer [92] star and massive-BH formation can occur at the same cosmological epoch.

The stellar photosphere is suited for optical photometry in order to individuate emission regions by simple geometrical models for sources in the IR. By suitably expressing spectral-energy distribution for dust disks [105], upper and lower bounds for the dust-sublimation temperatures can be imposed after the calculation of the size of the region where the phenomenon takes place, whose radius can be parameterized as a square inverse function of dust temperature.

Calibration of source data and location ones can allow to Fourier-transform the (time) delay to the (event) rate domain, to which appropriate filters can be applied [106] to eliminate radio-frequency interference for early-cosmological investigation. By letting imaging scale as $O(Nlog(N))$, with N being the number of data samples, it is possible to individuate sources at redshifts $\tilde{z}$, $\tilde{z} = 7$ to $\tilde{z} = 11$ [107] to investigate the first epoch of star formation and of reionization. Therefore, weaker sources can also be detected.

Laser-photocathode uses [108] are advantageous in laser interferometry as a coherent transition radiation that can generate radiation is fully characterized by the square modulus of the Fourier transform. The energy spectrum emitted by transition radiation is uniform, such that, according to Reference [109], the frequency spectrum is only a(n exponential) function of the electron-beam form factor. For celestial bodies emitting in the IR spectrum, this is a consistent optimization criterion for system alignment.

4. Outlook

Planet formation can be individuated [110] by the spectral-energy distribution of the observed lines and in the spectrum in the continuum.

The distribution of major exoplanet axes is best accounted for nonlinear model fitting, for which the parameter space can be applied (Bayesian filters, described Markov chains).

Analysis of lines CO(1-0), CO(3-2) and CO(2-1) [111] can reveal the presence of large, massive, cold molecular clouds that exist with kinetic temperatures close to that of CMBtemperature (in the inner disks). Radial velocities and (position) offsets from the center of the star are measured, as well as the CO(3-2) spectrum in mm (wave) array-device observations.

By the same techniques and infrared observations [112,113], for CO (1-0) line observations, we can make numerical simulations [114] of the hydrodynamical properties of dust and gas morphology at the central region of ionizing stars, for which phenomena of star-formation account and compensate for the presence of nuclear gas according to star-formation rate.

Laser-frequency measurements [115] help calibrate frequency absolute and the long-term stability of a fiber Fabry-Pérot interferometer. For small temperatures, i.e., for a spectrum of 1–3 ms^{-1}, it is possible to characterize the Doppler radial velocity shifts at the 1 ms^{-1} of exoplanets.

Laser interferometers have proven efficient [116] in detecting particle interactions linearly in g, such as spin-gravity coupling, and P- and T-violating interactions from an astrophysical point of view. It may also apply to (integral-spin) dark-matter searches, as well as other kinds of investigations.

The existence of continuous spectra within the search for gravitational waves has led to the individuation of planets, for which several techniques have been set.

The needed hypotheses for for adding five parameters describing generic elliptical orbits, i.e., for eccentricities e, such that $e \simeq 0.8$ to computations for the computation of a monochromatic source, were analyzed in Reference [117] for a radio pulsar orbiting a planet, both for Earth-based detectors of gravitational waves as well as for interplanetary spacecrafts.

After pointing out spectral-analysis laser-frequency noise [118], time-delay-based interferometry is effective in comparing different optical paths. By numerically simulating different times of travel, it is possible to extract the spectrum signal of planets and other celestial bodies perturbing the gathered signal in spacecraft interferometry in the Solar System. By numerically simulating parameterized post-Newtonian (PPN) parameters β and γ for Solar System bodies for (geodesics) solutions to the variation of the metric, the opportune time is delayed.

Within gravitational-wave observations, it is possible [119] to discover planets either orbiting compact binaries or passing close to them, with masses of around $\sim 2 \times 10^{30} g$, even at redshift $z \sim 1$. It is possible to resolve an inflation stochastic GW background in frequency range $f_{min} \sim 0.2$ Hz and $f_{max} \sim 1$ Hz. By gravitational-wave-detecting in space, at f_{min} or lower frequency $f \leq f_{min}$, it is possible to resolve extragalactic white-dwarf binaries, and, at higher frequencies, $f \geq f_{min}$, cosmological double neutron-star binaries and double black-hole binaries or black hole–neutron star binaries by assuming a nearly-flat noise spectrum.

Ultrashort-period exoplanets can be discovered [120] as weak sources of gravitational waves close to binary systems, according to the frequencies of emitted gravitational waves $f_{gr} > 10^{-4}$ Hz. By cumulative periastron shift, it is possible to express luminosity as a frequency function, as, usually, the ratio between the apparent luminosities of exoplanets and other celestial bodies to other binary systems reaching Earth-based detectors is widely resolved.

The atmosphere of extrasolar planets orbiting a star is possible by differential-phase measurements near the IR spectrum [121] by the brightness ratio of the planet and star.Indeed, after the possibility of angularly resolving the star, optimization of statistical tests for orbital and spectral parameters is possible. In case the planet's revolution time is not negligible, such optimization could, therefore, be lowered.

In particular, it is possible [122] to evaluate atmosphere cross section as a wavelength function, such as Rayleigh scattering and refraction, i.e., from 115 to 1000 nm, from UV O_2 absorption. As a result, it is possible to infer whether atmosphere for a given planet exists, and to establish the chemical elements or process that determine the planetary radius to near-IR refraction.

Microarcsecond resolution allows for astrometry measurements about the nuclei of active galaxies, and accretion disks of supermassive black holes and their the relativistic jets. Precision allows for the verification of stellar and galactic structure, as well as hypotheses about dark matter and cosmology back to star-formation times, small-scale investigations of quasar and AGN cores, and to investigate binary supermassive black holes.

At microarcsecond precision, the astrometric revelation of quasar parallaxes is rendered accessible [123], which allows to analytically investigate, at the cosmological scale, the parameter space possibly needed to describe dark energy. Indeed, a direct geometric measurement is free of astrophysical systematic effects. The particle-induced effects are summarizzed in [124–134].

By means of far-IR coherent interferometry, even close to quantum noise, it is possible for an interferometer to individuate an Earth-like planet. At high spectral resolution, precise measurements of atmospheric temperature and molecules, pressure, and composition are achievable.

Particle quantum properties and the quantum features of spacetime at Planckian lengths allow to investigate the semiclassical limit of quantum-gravitational expressions. Quantum optical systems resulting in aggregation states of matter allow to account for such quantum features for phenomena taking place at scales larger than the Planckian, for (lab) experiments, and for observational surveys taking place in the background (Minkowski) flat spacetime [5–8].

The paper was organized as follows.

In Section 1, the main motivations for the paper were presented.

In Section 2, theories predicting new features for experimentally known particles and new particles were recalled to specify which experiment systems could be useful for their verification.

In Section 3, experiment devices and techniques were recalled for the verification of fundamental features, such as planet and exoplanet formation and structure, of standard cosmology, were outlined.

In Section 4, brief remarks about perspective investigations were proposed.

Funding: This research received no external funding.

Conflicts of Interest: The author declare no conflict of interest.

References

1. Ricarte, A.; Natarajan, P. The observational signatures of supermassive black hole seeds. *arXiv* **2018**, arXiv:1809.01177.
2. Tamburello, V.; Capelo, P.R.; Mayer, L.; Bellovary, J.M.; Wadsley, J. Supermassive black hole pairs in clumpy galaxies at high redshift: delayed binary formation and concurrent mass growth. *Mon. Not. Roy. Astron. Soc.* **2017**, *464*, 2952–2962. [CrossRef]
3. Bender, P.L. Gravitational wave astronomy, relativity tests, and massive black holes. *IAU Symp.* **2010**, *261*, 240. [CrossRef]
4. Finn, L.S.; Chernoff, D.F. Observing binary inspiral in gravitational radiation: One interferometer. *Phys. Rev. D* **1993**, *47*, 2198. [CrossRef]
5. Faizal, M.; Momeni, D. Universality of short distance corrections to quantum optics. *arXiv* **2018**, arXiv:1811.01934.
6. Frisch, O.R. Take a photon. *Contemp. Phys.* **1965**, *7*, 45. [CrossRef]
7. Bekenstein, J.D. Is a tabletop search for Planck scale signals feasible. *Phys. Rev. D* **2012**, *86*, 124040. [CrossRef]
8. Bekenstein, J.D. Can quantum gravity be exposed in the laboratory? *Found. Phys.* **2014**, *44*, 452. [CrossRef]
9. Anandan, J.; Aharonov, Y. Geometry of quantum evolution. *Phys. Rev. Lett.* **1990**, *65*, 1697–1700. [CrossRef] [PubMed]
10. Van Boekel, R.; Kervella, P.; Scholler, M.; Herbst, T.; Brander, W.; de Koter, A.; Waters, L.B.F.M.; Hillier, D.J.; Paresce, F.; Lenzen, R.; et al. Direct measurement of the size and shape of the present-day stellar wind of eta carinae. *Astron. Astrophys.* **2003**, *410*, L37. [CrossRef]
11. Hajian, A.R.; Behr, B.B.; Cenko, A.T.; Olling, R.P.; Mozurkewich, D.; Armstrong, J.T.; Pohl, B.; Petrossian, S.; Knuth, K.H.; Hindsley, R.B. Initial results from the USNO dispersed Fourier transform spectrograph. *Astrophys. J.* **2007**, *661*, 616. [CrossRef]
12. Voit, G.M. On nulling interferometers and the line-emitting regions of agns. *Astrophys. J.* **1997**, *487*, L109. [CrossRef]
13. Danchi, W.C.; Rajagopal, J.; Kuchner, M.; Richardson, J.; Deming, D. The importance of phase in nulling interferometry and a three telescope closure-phase nulling interferometer concept. *Astrophys. J.* **2006**, *645*, 1554. [CrossRef]
14. Garrett, M.A. When you wish upon a star: Future developments in astronomical VLBI. *ASP Conf. Ser.* **2003**, *306*, 3.
15. Chen, Y.B. Sagnac interferometer as a speed meter type, quantum nondemolition gravitational wave detector. *Phys. Rev. D* **2003**, *67*, 122004. [CrossRef]
16. Thompson, R.; Papini, G. Berry's phase and gravitational wave. In Proceedings of the 5th Canadian Conference on General Relativity and Relativistic Astrophysics, University of Waterloo, Waterloo, ON, Canada, 13–15 May 1993; World Scientific Pub Co Inc.: Hackensack, NJ, USA, 1993.
17. Bruno, A.; Capolupo, A.; Kak, S.; Raimondo, G.; Vitiello, G. Berry-like phase and gauge field in quantum computing. In *Methods, Models, Simulations and Approaches Towards a General Theory of Change*; World Scientific: Singapore, 2012; pp. 83–94.

18. Pachos, J.; Zanardi, P.; Rasseti, M. NonAbelian Berry connections for quantum computation. *Phys. Rev. A* **2000**, *61*, 010305. [CrossRef]
19. Berry, M.V. Quantal phase factors accompanying adiabatic changes. *Proc. R. Soc. Lond.* **1984**, *A392*, 45–57. [CrossRef]
20. Hinterbichler, K. Theoretical aspects of massive gravity. *Rev. Mod. Phys.* **2012**, *84*, 671–710. [CrossRef]
21. Visser, M. Mass for the graviton. *Gen. Rel. Grav.* **1998**, *30*, 1717. [CrossRef]
22. Billard, J.; Mayet, F.; Grignon, C.; Santos, D. Directional detection of dark matter with MIMAC: WIM identification and track reconstruction. *J. Phys. Conf. Ser.* **2001**, *309*, 012015. [CrossRef]
23. Lee, H.S.; Bhang, H.C.; Choi, J.H.; Dao, H.; Hahn, I.S.; Hwang, M.J.; Jung, S.W.; Kang, W.G.; Kim, D.W.; Kim, H.J.; et al. Limits on WIMP-nucleon cross section with CsI(Tl) crystal detectors. *arXiv* **2007**, arXiv:0704.0423.
24. Archambault, S.; Aubin, F.; Auger, M.; Behke, E.; Beltran, B.; Clark, K.; Dai, X.; Davour, A.; Farine, J.; Faust, R.; et al. Dark matter spin-dependent limits for WIMP interactions on F-19 by PICASSO. *Phys. Lett. B* **2009**, *682*, 185. [CrossRef]
25. Goodman, J.A.; Ellsworth, A.S.; Ito, J.R.; MacFall, J.R.; Siohan, F.; Streitmatter, R.E.; Tonwar, S.C.; Vishwanath, R.; Yodh, G.B. Composition of primary cosmic rays above 10^{13}ev from the study of time distributions of energetic hadrons near air shower cores. *AIP Conf. Proc.* **1979**, *49*, 1.
26. Ficthel, C.E.; Linsley, J. High-energy and ultrahigh-energy cosmic rays. *Astrophys. J.* **1986**, *300*, 474. [CrossRef]
27. Alexandrov, A.; Asada, T.; Puonaura, A.; Consiglio, L.; D'Ambrosio, N.; De Lellis, G.; Di Crescenzo, A.; Di Marco, N.; Di Vacri, M.L.; Furuya, S.; et al. Intrinsic neutron background of nuclear emulsions for directional Dark Matter searches. *Astropart. Phys.* **2016**, *80*, 16. [CrossRef]
28. SuperCDMS Collaboration. The SuperCDMS Experiment. *arXiv* **2005**, arXiv:astro-ph/0502435.
29. Carroll, S.M.; Mantry, S.; Ramsey-Musolf, M.J.; Stubbs, C.W. Dark-matter-induced weak equivalence principle violation. *Phys. Rev. Lett.* **2009**, *103*, 011301. [CrossRef]
30. Price, J.C.; Innes, W.R.; Klein, S.; Perl, M.L. The rotor electrometer: A new instrument for bulk matter quark search experiments. *Rev. Sci. Instrum.* **1986**, *57*, 2691. [CrossRef]
31. Innes, W.R.; Perl, M.L.; Price, J.C. A rotor electrometer for fractional charge searches. In Proceedings of the 4th International Conference on Muon Spin Rotation, Relaxation and Resonance, Uppsala, Sweden, 23–27 June 1986; pp. 1–2.
32. Mathai, V.; Wilkin, G. Fractional quantum numbers via complex orbifolds. *arXiv* **2018**, arXiv:1811.11748.
33. Sparnaay, M.J. Measurements of attractive forces between flat plates. *Physica* **1958**, *24*, 751. [CrossRef]
34. Dimopoulos, S.; Hall, L.J. Electric dipole moments as a test of supersymmetric unification. *Phys. Lett. B* **1995**, *344*, 185. [CrossRef]
35. Evans, L.; Bryant, P. LHC Machine. Available online: https://iopscience.iop.org/article/10.1088/1748-0221/3/08/S08001/pdf (accessed on 27 March 2019).
36. Aad, G.; Brad Abbott, B.; Abdallah, J.; Khalek, S.A.; Abdinov, O.; Aben, R.; Abi, B.; Abolins, M.; AbouZeid, O.; Abramowicz, H.; et al. Measurement of the $t\bar{t}$ production cross-section as a function of jet multiplicity and jet transverse momentum in 7 TeV proton-proton collisions with the ATLAS detector. *JHEP* **2015**, *1501*, 020. [CrossRef]
37. Antoniadis, I.; Dimopoulos, S.; Dvali, G.R. Millimeter range forces in superstring theories with weak scale compactification. *Nucl. Phys. B* **1998**, *516*, 70. [CrossRef]
38. Price, J.C. *International Symposium on Experimental Gravitational Physics*; Michelson, P.F., Ed.; World Scientific: Singapore, 1988; pp. 436–439.
39. Kapitulnik, A.; Kenny, T. *NSF Proposal 1997*; National Science Foundation: Alexandria, VA, USA, 1997.
40. Weld, D.M.; Xia, J.; Cabrera, B.; Kapitulnik, A. A new apparatus for detecting micron-scale deviations from newtonian gravity. *Phys. Rev. D* **2008**, *77*, 062006. [CrossRef]
41. Gould, A. Cosmological density of WIMPs from solar and terrestrial annihilations. *Astrophys. J.* **1992**, *388*, 338–344. [CrossRef]
42. Mantry, S.; Pitschmann, M.; Ramsey-Musolf, M.J. Differences between axions and generic light scalars in laboratory experiments. *arXiv* **2014**, arXiv:1411.2162.
43. Gibbs, H.M.; Hull, R.J. Spin-exchange cross sections for Rb-87- Rb-87 and Rb-87- Cs-133 collisions. *Phys. Rev.* **1967**, *153*, 132. [CrossRef]

44. Habfast, C.; Poth, H.; Seligmann, B.; Wolf, A.; Berger, J.; Blatt, P.; Hauck, P.; Meyer, W.; Neumann, R. Measurementof laser light thomson scattered from a cooling electron beam. *Appl. Phys. B* **1987**, *44*, 87. [CrossRef]
45. Biscardi, R.; Ramirez, G.; Williams, G.P.; Zimba, C. Effects of rf sidebands on spectral reproducibility for infrared synchrotron radiation. *Rev. Sci. Instrum.* **1995**, *66*, 1856. [CrossRef]
46. D'Ariano, G.M.; Kumar, P. A quantum mechanical study of optical regenerators based on nonlinear loop mirrors. *IEEE Photonics Tech. Lett.* **1998**, *10*, 699. [CrossRef]
47. Mashhoon, B.; Neutze, R.; Hannam, M.; Stedman, G.E. Observable frequency shifts via spin rotation coupling. *Phys. Lett. A* **1998**, *249*, 161. [CrossRef]
48. Di Casola, E.; Liberati, S.; Sonego, S. Between quantum and classical gravity: Is there a mesoscopic spacetime? *Found. Phys.* **2015**, *45*, 171. [CrossRef]
49. Di Casola, E.; Liberati, S.; Sonego, S. Nonequivalence of equivalence principles. *Am. J. Phys.* **2015**, *83*, 39. [CrossRef]
50. Freedman, S.J.; Clauser, J.F. Experimental test of local hidden-variable theories. *Phys. Rev. Lett.* **1972**, *28*, 938. [CrossRef]
51. Ruo Berchera, I.; Degiovanni, I.P.; Olivares, S.; Genovese, M. Quantum light in coupled interferometers for quantum gravity tests. *Phys. Rev. Lett.* **2013**, *110*, 213601. [CrossRef] [PubMed]
52. Nicolini, P.; Mureika, J.; Spallucci, E.; Winstanley, E.; Bleicher, M. Production and evaporation of Planck scale black holes at the LHC. In Proceedings of the MG13 Meeting on General Relativity Stockholm University, Stockholm, Sweden, 1–7 July 2012.
53. Castellanos, E. Planck scale physics and Bogoliubov spaces in a Bose-Einstein condensate. *EPL* **2013**, *103*, 40004. [CrossRef]
54. Bassi, A.; Grossardt, A.; Ulbricht, H. Gravitational decoherence. *Class. Quant. Grav.* **2017**, *34*, 193002. [CrossRef]
55. Cirac, J.I.; Zoller, P. Quantum computations with cold trapped ions. *Phys. Rev. Lett.* **1995**, *74*, 4091. [CrossRef]
56. Bermudez, A.; Aarts, G.; Mueller, M. Quantum sensors for the generating functional of interacting quantum field theories *Phys. Rev. X* **2017**, *7*, 041012. [CrossRef]
57. De Ramo'n, J.; Garay, L.J.; Marti'n-Marti'nez, E. Direct measurement of the two-point function in quantum fields. *Phys. Rev. D* **2018**, *98*, 105011. [CrossRef]
58. Ruo-Berchera, I.; Degiovanni, I.P.; Olivares, S.; Samantaray, N.; Traina, P.; Genovese, M. One- and two-mode squeezed light in correlated interferometry. *Phys. Rev. A* **2015**, *92*, 053821. [CrossRef]
59. Jowett, J.M. Dynamics of electrons in storage rings including nonlinear damping and quantum excitation effects. *Conf. Proc. C* **1984**, *830811*, 283.
60. Froewis, F.; Sekatski, P.; Duer, W.; Gisin, N.; Sangouard, N. Macroscopic quantum states: Measures, fragility and implementations. *Rev. Mod. Phys.* **2018**, *90*, 025004. [CrossRef]
61. Singh, S.; De Lorenzo, L.A.; Pikovski, I.; Schwab, K.C. Detecting continuous gravitational waves with superfluid ^{4}He. *New J. Phys.* **2017**, *19*, 073023. [CrossRef]
62. Zloshchastiev, K.G. Acoustic phase lenses in superfluid He as models of composite space-times in general relativity: Classical and quantum properties with provision for spatial topology. *Acta Phys. Polon. B* **1999**, *30*, 897–905.
63. Yang, Y.; Zabludoff, A.I.; Dave, R.; Eisenstein, D.J.; Pinto, P.A.; Katz, N.; Weinberg, D.H.; Barton, E.J. Probing galaxy formation with he II cooling lines. *Astrophys. J.* **2006**, *640*, 539. [CrossRef]
64. Tajmar, M.; Plesescu, F.; Seifert, B. Anomalousfiber optic gyroscope signals observed above spinning rings at low temperature. *J. Phys. Conf. Ser.* **2009**, *150*, 032101. [CrossRef]
65. Tajmar, M.; Plesescu, F. Fiber-optic-gyroscope measurements close to rotating liquid helium. *AIP Conf. Proc.* **2010**, *1208*, 220. [CrossRef]
66. Zhang, F.; Saha, P. Probing the spinning of the massive black hole in the Galactic Center via pulsar timing: A full relativistic treatment. *Astrophys. J.* **2017**, *849*, 33. [CrossRef]
67. Barausse, E.; Cardoso, V.; Pani, P. Can environmental effects spoil precision gravitational-wave astrophysics? *Phys. Rev. D* **2014**, *89*, 104059. [CrossRef]
68. Angelil, R.; Saha, P.; Merritt, D. Towards relativistic orbit fitting of Galactic center stars and pulsars. *Astrophys. J.* **2010**, *720*, 1303. [CrossRef]

69. Waisberg, I.; Dexter, J.; Gillessen, S.; Pfuhl, O.; Eisenhauer, F.; Plewa, P.M.; Baubock, M.; Jimenez-Rosales, A.; Habibi, M.; Ott, T.; et al. What stellar orbit is needed to measure the spin of the Galactic centre black hole from astrometric data? *Mon. Not. R. Astron. Soc.* **2018**, *476*, 3600. [CrossRef]
70. Stairs, I.H. Testing general relativity with pulsar timing. *arXiv* **2003**, arXiv:astro-ph/0307536.
71. Jodrell Bank Observatory Pulsar Group. *COBRA: Pulsar Documentation*; Jodrell Bank Observatory Pulsar Group: Lower Withington, UK, 2001.
72. Swinburne Pulsar Group, The Caltech, Parkes, Swinburne Recorder Mk II. 2002. Available online: http://astronomy.swin.edu.au/pulsar/ (accessed on 27 November 2002).
73. Taylor, J.H. Pulsar timing and relativistic gravity. *Philos. Trans. R. Soc. Lond. Ser. A* **1992**, *341*, 117–134. [CrossRef]
74. Yagi, K.; Stein, L.C. Black hole based tests of general relativity. *Class. Quant. Grav.* **2016**, *33*, 054001. [CrossRef]
75. Wolf, S.; Malbet, F.; Alexander, R.; Berger, J.-P.; Creech-Eakman, M.; Duchene, G.; Dutrey, A.; Mordasini, C.; Pantin, E.; Pont, F.; et al. Circumstellar disks and planets. Science cases for next-generation optical/infrared long-baseline interferometers. *Astron. Astrophys. Rev.* **2012**, *20*, 52. [CrossRef]
76. Safronov, V.S. *Evolution of the Protoplanetary Cloud and Formation of the Earth and the Planets*; Serie: NASA technical translation, F-677; Program for Scientific Translations: Jerusalem, Israel, 1972.
77. Armitage, P.A. *Astrophysics of Planet Formation*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2010.
78. Malhotra, R. The origin of pluto's orbit: Implications for the solar system beyond neptune. *Astron. J.* **1995**, *110*, 420. [CrossRef]
79. Henning, T.; Meeus, G. Dust processing and mineralogy in protoplanetary accretion disks. *arXiv* **2009**, arXiv:0911.1010.
80. Brauer, F.; Dullemond, C.P.; Henning, T. Coagulation, fragmentation and radial motion of solid particles in protoplanetary disks. *Astron. Astrophys.* **2008**, *480*, 859. [CrossRef]
81. Coppin, K.; Swinbank, A.M.; Neri, R.; Cox, P.; Alexander, D.M.; Smail, I.; Page, M.J.; Stevens, J.A.; Knudsen, K.K.; Ivson, R.J.; et al. Testing the evolutionary link between submillimetre galaxies and quasars: CO observations of QSOs at z 2. *Mon. Not. R. Astron. Soc.* **2008**, *389*, 45. [CrossRef]
82. Hippelein, H.; Maier, C.; Meisenheimer, K.; Wolf, C.; Fried, J.W.; von Kuhlmann, B.; Kummel, M.; Phelps, S.; Roser, H.-J. Star forming rates between z = 0.25 and z = 1.2 from the CADIS emission line survey. *Astron. Astrophys.* **2003**, *402*, 65. [CrossRef]
83. Hughes, A.M.; Andrews, S.A.; Espaillat, C.; Wilner, D.J.; Calvet, N.; D'Alessio, P.; Qi, C.; Williams, J.P.; Hogerheijde, M.R. A spatially resolved inner hole in the disk around GM aurigae. *Astrophys. J.* **2008**, *698*, 131. [CrossRef]
84. Lisenfeld, U.; Braine, J.; Duc, P.A.; Brinks, E.; Charmandaris, V.; Leon, S. Molecular and ionized gas in the tidal tail in Stephan's Quintet. *Astron. Astrophys.* **2004**, *426*, 471. [CrossRef]
85. Downes, D.; Solomon, P.M. Molecular gas and dust at Z = 2.6 in smm j14011+0252: a strongly lensed, ultraluminous galaxy, not a huge, massive disk. *Astrophys. J.* **2003**, *582*, 37. [CrossRef]
86. Braccini, S.; Casciano, C.; Coredo, F.; Frasconi, F.; Gregori, G.P.; Majorana, E.; Paparo, G.; Passaquieti, R.; Puppo, P.; Rapagnani, P.; et al. Monitoring the acoustic emission of the blades of the mirror suspension for a gravitational wave interferometer. *Phys. Lett. A* **2002**, **301**, 389. [CrossRef]
87. Barish, B.C.; Camp, J.; Kells, W.P.; Sanders, G.H.; Whitcomb, S.E.; Zhang, L.; Zhu, R.-Y.; Deng, P.; Xu, J.; Zhou, G.; et al. Development of large size sapphire crystals for laserinterferometer gravitational-wave observatory. *IEEE Trans. Nucl. Sci.* **2002**, *49*, 1233. [CrossRef]
88. D'Ambrosio, E.; O'Shaughnessy, R.W.; Strigin, S.; Thorne, K.S.; Vyatchanin, S. Reducing thermoelastic noise in gravitational-wave interferometers by flattening the light beams. *arXiv* **2004**, arXiv:gr-qc/0409075.
89. D'Ambrosio, E.; O'Shaughnessy, R.; Thorne, K. LIGO Report Number G000223-00-D. Available online: http://admdbsrv.ligo.caltech.edu/dcc/ (accessed on 16 August 2000).
90. Braginsky, V.; D'Ambrosio, E.; O'Shaughnessy, R.; Strigin, S.; Thorne, K.; Vyatchanin, S. LIGO Report Number T030009-00-R. Available online: https://dcc.ligo.org/public/0027/T030009/000/T030009-00.pdf (accessed on 23 January 2003).
91. Duchene, G.; Menard, F.; Stapelfeldt, K.; Duvert, G. A layered edge-on circumstellar disk around HK Tau B. *Astron. Astrophys.* **2003**, *400*, 559–565. [CrossRef]

92. Bertoldi, F.; Cox, P.; Neri, R.; Carilli, C.L.; Walter, F.; Omont, A.; Beelen, A.; Henkel, C.; Fan, X.; Strauss, M.A.; et al. High-excitation CO in a quasar host galaxy at z = 6.42. *Astron. Astrophys.* **2003**, *409*, L47. [CrossRef]
93. Mao, R.Q.; Henkel, C.; Schulz, A.; Zielinsky, M.; Mauersberger, R.; Stoerzer, H.; Wilson, T.L.; Gensheimer, P. Dense gas in nearby galaxies. XIII. CO submillimeter line emission from the starburst galaxy M 82. *Astron. Astrophys.* **2000**, *358*, 433.
94. Beuther, H.; Schilke, P.; Wyrowski, F. High-spatial-resolution CN and CS observation of two regions of massive star formation. *Astrophys. J.* **2004**, *615*, 832. [CrossRef]
95. Yorke, H.W.; Sonnhalter, C. On the Formation of Massive Stars. *ApJ* **2002**, *569*, 846. [CrossRef]
96. Kumar, M.S.N.; Fernandes, A.J.L.; Hunter, T.R.; Davis, C.J.; Kurtz, S. A massive disk/envelope in shocked H_2 emission around an UCHII region. *Astron. Astrophys.* **2003**, *412*, 175. [CrossRef]
97. Gueth, F.; Bachiller, R.; Tafalla, M. Dust emission from young outflows: The case of L 1157. *Astron. Astrophys.* **2003**, *401*, L5. [CrossRef]
98. Hogerheijde, M.R.; Sandell, G. Testing Envelope Models of Young Stellar Objects with Submillimeter Continuum and Molecular-Line Observations. *ApJ* **2000**, *534*, 880. [CrossRef]
99. Porcas, R.W.; Alef, W.; Ghosh, T.; Salter, C.J.; Garrington, S.T. Compact structure in first survey sources. In Proceedings of the 7th European VLBI Network Symposium on New Developments in VLBI Science and Technology and EVN Users Meeting, Toledo, Spain, 12–15 October 2004.
100. Gras, S.; Fritschel, P.; Barsotti, L.; Evans, M. Resonant dampers for parametric instabilities in gravitational wave detectors. *Phys. Rev. D* **2015**, *92*, 082001. [CrossRef]
101. Hagood, N.; von Flotow, A. Damping of structural vibrations with piezoelectric materials and passive electrical networks. *J. Sound Vib.* **1991**, *146*, 243. [CrossRef]
102. Zhang, J.; Zhao, C.; Ju, L.; Blair, D. Study of parametric instability in gravitational wave detectors with silicon test masses. *Class. Quant. Grav.* **2017**, *34*, 055006. [CrossRef]
103. Tannirkulam, A.K.; Harries, T.J.; Monnier, J.D. The inner rim of YSO disks: Effects of dust grain evolution. *Astrophys. J.* **2007**, *661*, 374. [CrossRef]
104. Turyshev, S.G. Relativistic stellar aberration for the space interferometry mission (2). *arXiv* **2002**, arXiv:gr-qc/0205062.
105. Akeson, R.L.; Boden, A.F.; Monnier, J.D.; Millan-Gabet, R.; Beichman, C.; Beletic, J.; Hartmann, L.; Hillenbrand, L.; Koresko, C.; Sargent, A.; et al. Keck interferometer observations of classical and weak line T tauri stars. *Astrophys. J.* **2005**, *635*, 1173. [CrossRef]
106. Parsons, A.R.; Backer, D.C. Calibration of low-frequency, wide-field radio interferometers using delay/delay-rate filtering. *Astron. J.* **2009**, *138*, 219. [CrossRef]
107. Bradley, R.; Backer, D.; Parsons, A.; Parashare, C.; Gugliucci, N.E. *A Precision Array to Probe the Epoch of Reionization*; Bulletin of the American Astronomical Society: New York, NY, USA, 2005; p. 1216.
108. Nozawa, I.; Gohdo, M.; Kan, K.; Kondoh, T.; Ogata, A.; Yang, J.; Yoshida, Y. *Bunch Length Measurement of Femtosecond Electron Beam by Monitoring Coherent Transition Radiation*; JACoW: Geneva, Switzerland, 2015. [CrossRef]
109. Frank, I.M.; Ginzburg, V.L. Radiation of a Uniformly Moving Electron Due to Its Transition from One Medium to Another. *J. Phys.* **1945**, *9*, 353.
110. Orellana, M.; Cieza, L.A.; Schreiber, M.R.; Merin, B.; Brown, J.M.; Pellizza, L.J.; Romero, G.A. Transition disks: 4 candidates for ongoing giant planet formation in Ophiuchus (Research Note). *Astron. Astrophys.* **2012**, *539*, A41. [CrossRef]
111. Loinard, L.; Allen, R.J. Cold massive molecular clouds in the inner disk of m31. *arXiv* **1998**, arXiv:astro-ph/9801164.
112. Unwin, S.C.; Shao, M.; Tanner, A.M.; Allen, R.J.; Beichman, C.A.; Boboltz, D.; Catanzarite, J.H.; Chaboyer, B.C.; Ciardi, D.R.; Edberg, S.J.; et al. Taking the measure of the universe: Precision astrometry with SIM PlanetQuest. *Publ. Astron. Soc. Pac.* **2008**, *120*, 38. [CrossRef]
113. Lloyd, J.P. Habitable Planet Detection and Characterization with Far Infrared Coherent Interferometry. *arXiv* **2011**, arXiv:1104.4112.
114. Sheth, K.; Regan, M.W.; Vogel, S.N.; Teuben, P.J. Molecular gas, dust and star formation in the barred spiral ngc 5383. *Astrophys. J.* **2000**, *532*, 221. [CrossRef]

115. Jennings, J.; Halverson, S.; Terrien, R.; Mahadevan, S.; Ycas, G.; Diddams, S.A. Frequency stability characterization of a broadband fiber Fabry-Pérot interferometer. *Opt. Express* **2017**, *25*, 15599. [CrossRef]
116. Stadnik, Y. *Manifestations of Dark Matter and Variations of the Fundamental Constants of Nature in Atoms and Astrophysical Phenomena*; Springer: Cham, Switzerland, 2017.
117. Dhurandhar, S.V.; Vecchio, A. Searching for continuous gravitational wave sources in binary systems. *Phys. Rev. D* **2001**, *63*, 122001. [CrossRef]
118. Wang, G.; Ni, W.T. Orbit optimization for ASTROD-GW and its time delay interferometry with two arms using CGC ephemeris. *Chin. Phys. B* **2013**, *22*, 049501. [CrossRef]
119. Seto, N. Detecting planets around compact binaries with gravitational wave detectors in space. *Astrophys. J.* **2008**, *677*, L55. [CrossRef]
120. Cunha, J.V.; Silva, F.E.; Lima, J.A.S. Gravitational waves from ultra short period exoplanets. *Mon. Not. R. Astron. Soc.* **2018**, *480*, L28. [CrossRef]
121. Joergens, V.; Quirrenbach, A. Modeling of closure phase measurements with amber/vlti—towards characterization of exoplanetary atmospheres. *Proc. SPIE Int. Soc. Opt. Eng.* **2004**, *5491*, 551. [CrossRef]
122. Betremieux, Y.; Kaltenegger, L. Transmission spectrum of earth as a transiting exoplanet from the ultraviolet to the near-infrared. *Astrophys. J.* **2013**, *772*, L31. [CrossRef]
123. Ding, F.; Croft, R.A.C. Future dark energy constraints from measurements of quasar parallax: Gaia, SIM and beyond. *Mon. Not. R. Astron. Soc.* **2009**, *397*, 1739. [CrossRef]
124. Papini, G. Zitterbewegung and gravitational Berry phase. *Phys. Lett. A* **2012**, *376*, 1287. [CrossRef]
125. Winterflood, J.; Blair, D.G.; Notcutt, M.; Schilling, R. Position control system for suspended masses in laser interferometer gravitational wave detectors. *Rev. Sci. Instrum.* **1995**, *66*, 2763. [CrossRef]
126. Fujimoto, R. X-Ray Spectroscopic Observations of Intermediate Polars and Mass Determination of White Dwarfs. Ph.D. Thesis, Tokyo University, Tokyo, Japan, 1998.
127. Hees, A.; Do, T.; Ghez, A.M.; Martinez, G.D.; Naoz, S.; Becklin, E.E.; Boehle, A.; Chappel, S.; Chu, D.; Dehghanfar, A.; et al. Testing General Relativity with stellar orbits around the supermassive black hole in our Galactic center. *Phys. Rev. Lett.* **2017**, *118*, 211101. [CrossRef] [PubMed]
128. Weinberg, N.N.; Milosavljevic, M.; Ghez, A.M. Stellar dynamics at the galactic center with a thirty meter telescope. *Astrophys. J.* **2005**, *622*, 878. [CrossRef]
129. Psaltis, D. Testing general relativity with the event horizon telescope. *arXiv* **2018**, arXiv:1806.09740.
130. Zucker, S.; Alexander, T.; Gillessen, S.; Eisenhauer, F.; Genzel, R. Probing post-newtonian gravity near the galactic black hole with stellar doppler measurements. *Astrophys. J.* **2006**, *639*, L21. [CrossRef]
131. Barnes, P.D., Jr.; Caldwell, D.; DaSilva, A. Low background underground facilities for the direct detection of dark matter. In Proceedings of the 1990 Summer Study on High Energy Physics, Snowmass, CO, USA, 25 June–13 July 1990.
132. Giacomelli, G. High-energy astrophysics: Status of observations at large underground detectors. In Proceedings of the 2nd International Workshop on Theoretical and Phenomenological Aspects of Underground Physics, Toledo, Spain, 9–13 September 1991.
133. Giacomelli, G. High-energy underground physics and astrophysics. *Nucl. Phys. (Proc. Suppl.)* **1993**, *33*, 57–76. [CrossRef]
134. Beier, E.W.; Frank, E.D.; Frati, W.; Kim, S.B.; Mann, A.K.; Newcomer, F.M.; Van Berg, R.; Zhang, W.; Hirata, K.S.; Inoue, K.; et al. Survey of atmospheric neutrino data and implications for neutrino mass and mixing. *Phys. Lett. B* **1992**, *283*, 446. [CrossRef]