Supermassive Black Holes
超大质量黑洞及其若干重大问题

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Institute of High Energy Physics 2024/09/12

Outline：

- Formation of SMBH
- Masses and Spins
- SMBH binaries and nano-Hz GWs
- Satellite BHs and observational consequences
- Opportunities in the era of JWST and VLTI

1、 Formation of SMBHs

3C 273: A STAR-LIKE OBJECT WITH LARGE RED-SHIFT

By Dr. M. SCHMIDT

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THE only objects seen on a 200-in. plate near the positions of the components of the radio source *3C* 273 reported by Hazard, Mackey and Shimmins in the preceding article are a star of about thirteenth magnitude and a faint wisp or jet. The jet has a width of 1″–2″ and extends away from the star in position angle 43°. It is not visible within 11″ from the star and ends abruptly at 20″ from the star. The position of the star, kindly furnished by Dr. T. A. Matthews, is R.A. 12h 26m 33·35s ± 0·04s, Decl. + 2° 19′ 42·0″ ± 0·5″ (1950), or 1″ east of component *B* of the radio source. The end of the jet is 1″ east of component *A*. The close correlation between the radio structure and the star with the jet is suggestive and intriguing.

Spectra of the star were taken with the prime-focus spectrograph at the 200-in. telescope with dispersions of 400 and 190 Å per mm. They show a number of broad emission features on a rather blue continuum. The most prominent features, which have widths around 50 Å, are, in order of strength, at 5632, 3239, 5792, 5032 Å. These and other weaker emission bands are listed in the first column of Table 1. For three faint bands with widths of 100–200 Å the total range of wave-length is indicated.

The only explanation found for the spectrum involves a considerable red-shift. A red-shift $\Delta\lambda/\lambda_0$ of 0·158 allows identification of four emission bands as Balmer lines, as indicated in Table 1. Their relative strengths are in agreement with this explanation. Other identifications based on the above red-shift involve the Mg II lines around 2798 Å, thus far only found in emission in the solar chromosphere, and a forbidden line of [O III] at 5007 Å. On this basis another [O III] line is expected at 4959 Å with a strength one-third of that of the line at 5007 Å. Its detectability in the spectrum would be marginal. A weak emission band suspected at 5705 Å, or 4927 Å reduced for red-shift, does not fit the wave-length. No explanation is offered for the three very wide emission bands.

It thus appears that six emission bands with widths around 50 Å can be explained with a red-shift of 0·158. The differences between the observed and the expected wave-lengths amount to 6 Å at the most and can be entirely understood in terms of the uncertainty of the measured wave-lengths. The present explanation is supported by observations of the infra-red spectrum communicated by Oke in a following article, and by the spectrum of another star-like object associated with the radio source *3C* 48 discussed by Greenstein and Matthews in another communication.

Table 1. Wave-lengths and Identifications

λ	$\lambda/1{\cdot}158$	λ_0	
3239	2797	2798	Mg II
4595	3968	3970	Hε
4753	4104	4102	Hδ
5032	4345	4340	Hγ
5200–5415	4490–4675		
5632	4864	4861	Hβ
5792	5002	5007	[O III]
6005–6190	5186–5345		
6400–6510	5527–5622		

The unprecedented identification of the spectrum of an apparently stellar object in terms of a large red-shift suggests either of the two following explanations.

(1) The stellar object is a star with a large gravitational red-shift. Its radius would then be of the order of 10 km. Preliminary considerations show that it would be extremely difficult, if not impossible, to account for the occurrence of permitted lines and a forbidden line with the same red-shift, and with widths of only 1 or 2 per cent of the wave-length.

(2) The stellar object is the nuclear region of a galaxy with a cosmological red-shift of 0·158, corresponding to an apparent velocity of 47,400 km/sec. The distance would be around 500 megaparsecs, and the diameter of the nuclear region would have to be less than 1 kiloparsec. This nuclear region would be about 100 times brighter optically than the luminous galaxies which have been identified with radio sources thus far. If the optical jet and component *A* of the radio source are associated with the galaxy, they would be at a distance of 50 kiloparsecs, implying a time-scale in excess of 10^5 years. The total energy radiated in the optical range at constant luminosity would be of the order of 10^{59} ergs.

Only the detection of an irrefutable proper motion or parallax would definitively establish *3C* 273 as an object within our Galaxy. At the present time, however, the explanation in terms of an extragalactic origin seems most direct and least objectionable.

I thank Dr. T. A. Matthews, who directed my attention to the radio source, and Drs. Greenstein and Oke for valuable discussions.

1943ApJ....97...28S

NUCLEAR EMISSION IN SPIRAL NEBULAE*

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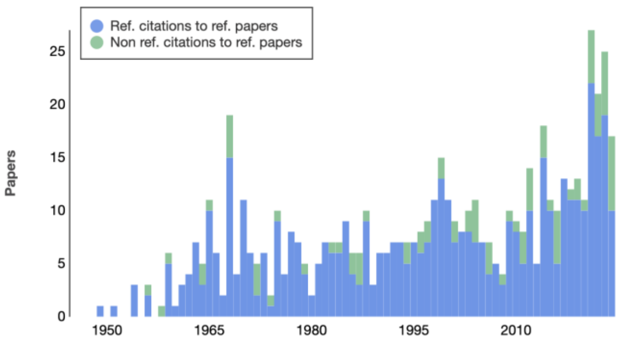
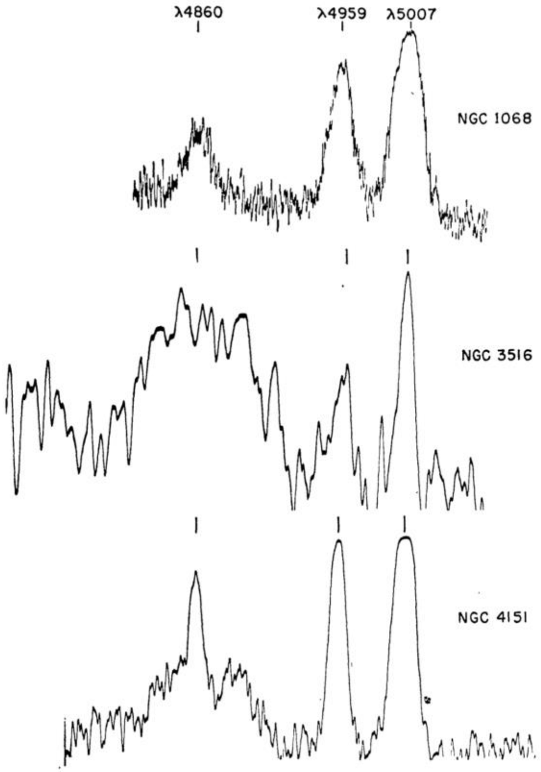
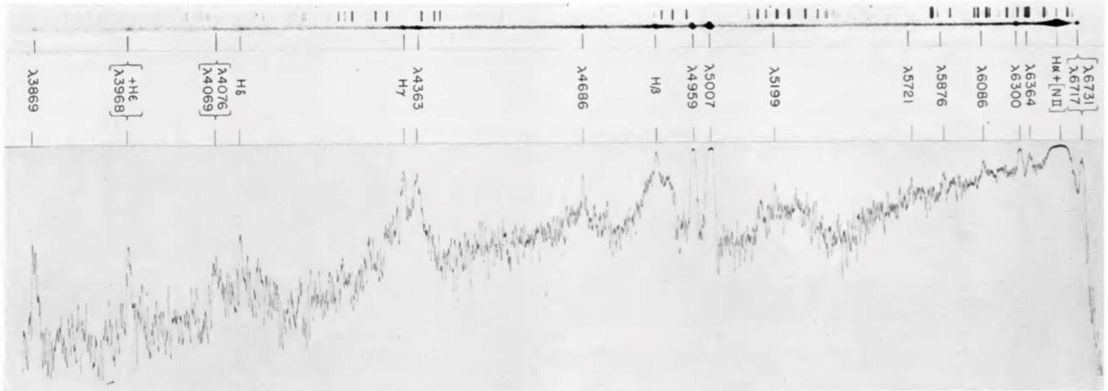
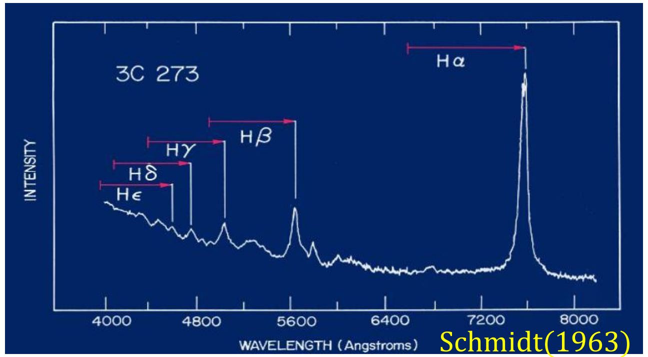
ABSTRACT

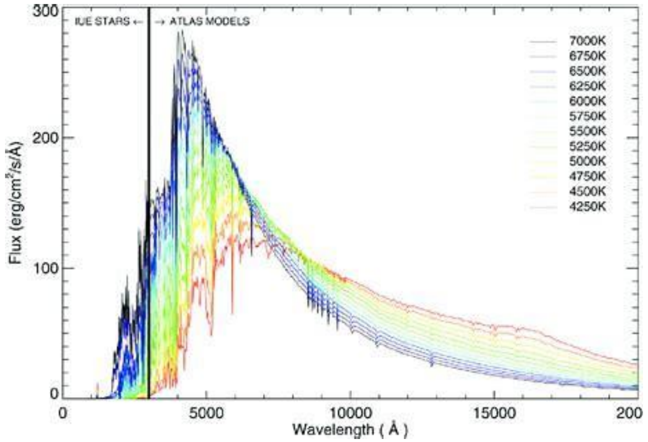
Spectrograms of dispersion 37–200 A/mm have been obtained of six extragalactic nebulae with high-excitation nuclear emission lines superposed on a normal G-type spectrum. All the stronger emission lines from λ 3727 to λ 6731 found in planetaries like NGC 7027 appear in the spectra of the two brightest spirals observed, NGC 1068 and NGC 4151.

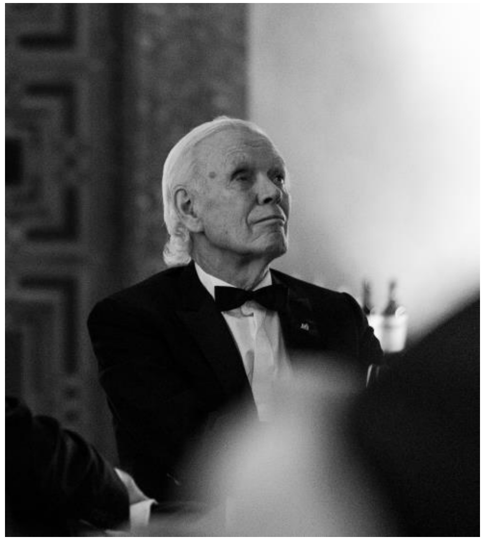












ESO director: 1975-1987

1959ApJ...130...38W

EMISSION NUCLEI IN GALAXIES

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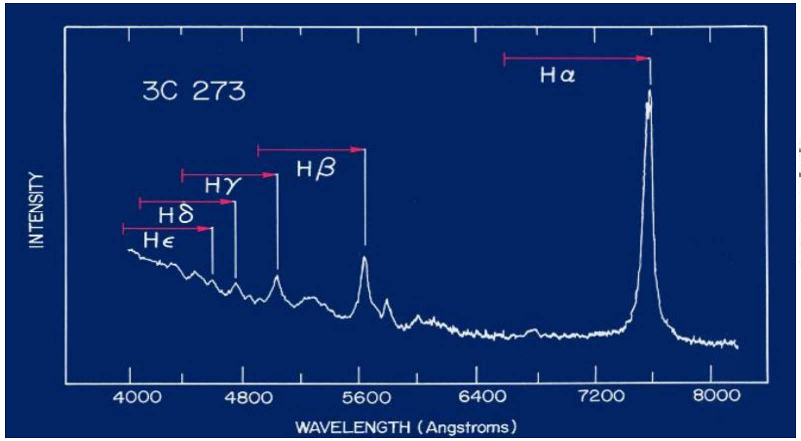
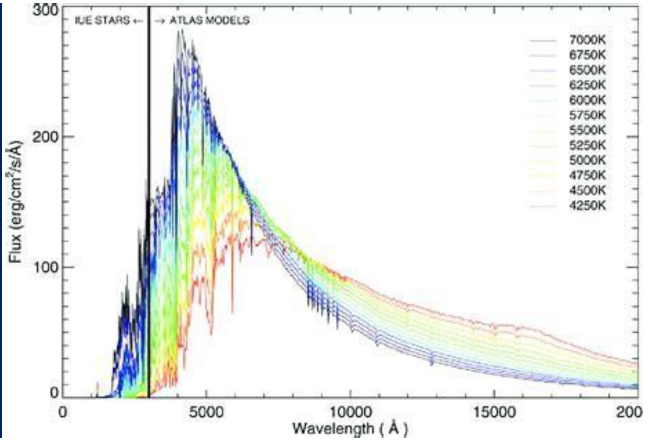
Received February 16, 1959

ABSTRACT

Some galaxies which show wide emission lines in the spectra of their nuclei are discussed. It is shown that, on statistical grounds, the nuclear emission must last for several times 10^8 years at least. The nuclei are extremely narrow, of the order of 100 parsecs, and, if a normal mass-to-light ratio applies, extremely massive. The width of the emission lines, which indicates velocities of a few thousand kilometers per second, is probably due to fast motions, circular or random, in the gravitational fields of the nuclei. The high star density in the nuclei may provide a source of excitation. In the nucleus of our own Galaxy the radio source Sagittarius gives evidence of strong magnetic fields and large amounts of relativistic particles. A mass of a few times 10^8 solar masses is needed to prevent disintegration of the source. The Andromeda Nebula has a nucleus with a somewhat smaller mass. The occurrence of dense nuclei may be a common characteristic of many galaxies.





FWHM(Hβ)：3000-10000km/s

T>10^8K

Fully ionized: no lines

Deep potential of heavy object:

motion-broadening

NOTES

ACCRETION OF INTERSTELLAR MATTER BY MASSIVE OBJECTS

Observations of quasi-stellar radio sources have indicated the existence in the Universe of extremely massive objects of relatively small size. The present note discusses the possible further growth in mass of a relatively massive object, by means of accretion of interstellar gas onto it, and the accompanying energy release. Although there is no evidence for (and possibly some evidence *against*) quasi-stellar radio sources occurring inside ordinary galaxies, for the sake of concreteness we consider the fate of an object of mass $M > 10^6$ (masses in solar units throughout) in an ordinary spiral galaxy somewhat like ours.

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Received May 7, 1964

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Доклады Академии наук СССР
1964. Том 158, № 4

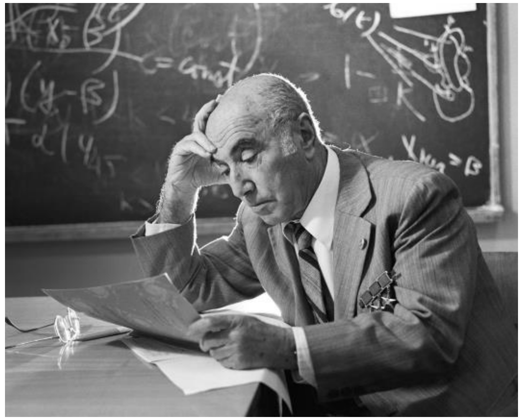
АСТРОНОМИЯ

Z′elDovich & Novikov

Академик Я. Б. ЗЕЛЬДОВИЧ, И. Д. НОВИКОВ

ОЦЕНКА МАССЫ СВЕРХЗВЕЗДЫ

Анализ наблюдательных данных о сверхзвездах типа 3С 273 показывает (1), что непрерывный спектр этих объектов в оптической области испускается центральным телом с размерами порядка $2 \cdot 10^{16}$ см, а эмиссионные линии возникают во внешней оболочке с размерами несколько парсек или больше. Генерация светового потока происходит, вероятно, в самой внутренней центральной области центрального тела, которую мы будем называть ядром. Окружающую ядро плазму назовем условно атмосферой. Для оценки массы сверхзвезды рассмотрим силы, действующие на плазму атмосферы. Предположим, что сила тяготения уравновешивается силой светового давления. Это предположение, некоторое обоснование которого будет дано ниже, приводит, как мы покажем, к значению массы сверхзвезды порядка $10^8 M_{\odot}$.



Energy source: supermassive black hole

GRAVITATIONAL COLLAPSE AND SPACE-TIME SINGULARITIES

Roger Penrose
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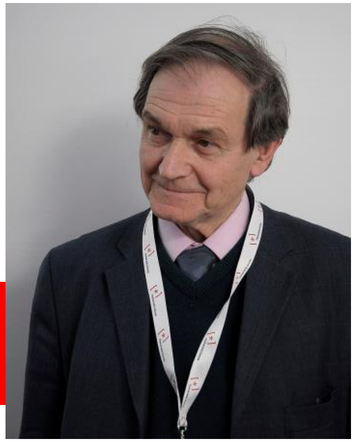
(Received 18 December 1964)



Wolf physics (1988)

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.

References

[1]F. Hoyle and W. A. Fowler, Monthly Notices Roy. Astron. Soc. 125, 169 (1963); F. Hoyle, W. A. Fowler, G. R. Burbidge, and E. M. Burbidge, Astrophys. J. 139, 909 (1964); W. A. Fowler, Rev. Mod. Phys. 36, 545 (1964); Ya. B. Zel'dovich and I. D. Novikov, Dokl. Akad. Nauk SSSR 155, 1033 (1964) [translation: Soviet Phys.—Doklady 9, 246 (1964)]; I. S. Shklovskiĭ and N. S. Kardashev, Dokl. Akad. Nauk SSSR 155, 1039 (1964) [translation: Soviet Phys.—Doklady 9, 252 (1964)]; Ya. B. Zel'dovich and M. A. Podurets, Dokl. Akad. Nauk SSSR 156, 57 (1964) [translation: Soviet Phys.—Doklady 9, 373 (1964)]. Also various articles in the Proceedings of the 1963 Dallas Conference on Gravitational Collapse (University of Chicago Press, Chicago, Illinois, 1964).

Galactic Nuclei as Collapsed Old Quasars

by

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Powerful emissions from the centres of nearby galaxies may represent dead quasars.

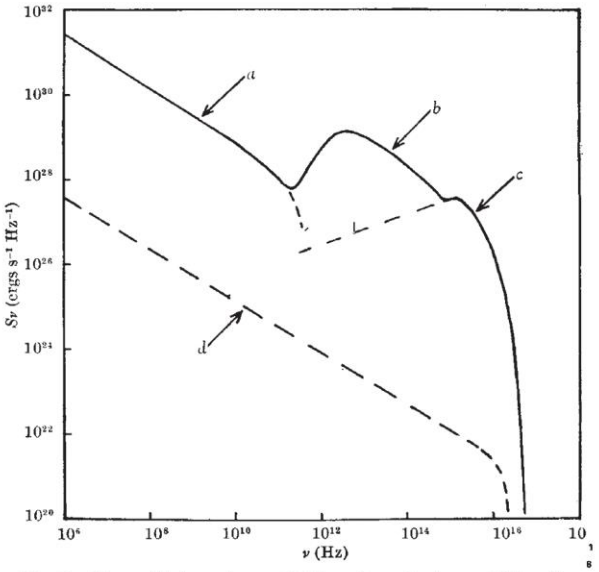


Fig. 1. The emitted spectrum of disk and synchrotron radiation for the standard model. The flux from Sagittarius *A* is weaker by a factor 100, indicating only 1 per cent efficiency of the proton synchrotron. *a*, Proton synchrotron; *b*, outer disk; *c*, central disk; *d*, electron synchrotron.

perature distributions. The total emission at frequency ν is given by

$$S_\nu = \int_0^\infty \frac{c}{4} u_\nu\,(T(r))\;4\pi r\mathrm{d}r \;=\; \frac{8\pi^2 h}{c^2}\int_0^\infty \frac{\nu^3\, r\mathrm{d}r}{\exp(h\nu/kT)-1}$$

Writing $x=h\nu/kT=h\nu r^{2a}(kA)$ we find

$$S_\nu = \frac{4\pi^2 h}{c^2}\left(\frac{kA}{h}\right)^a \int_0^\infty \frac{a\; x^{a-1}}{\mathrm{e}^x-1}\,\mathrm{d}x\;\nu^{3-a}$$

where
$$\int_0^\infty \frac{a\; x^{a-1}}{\mathrm{e}^x-1}\,\mathrm{d}x = a\,\Gamma(a)\zeta(a)$$

Thus for $a=8/3$ we have $S_\nu \propto \nu^{1/3}$

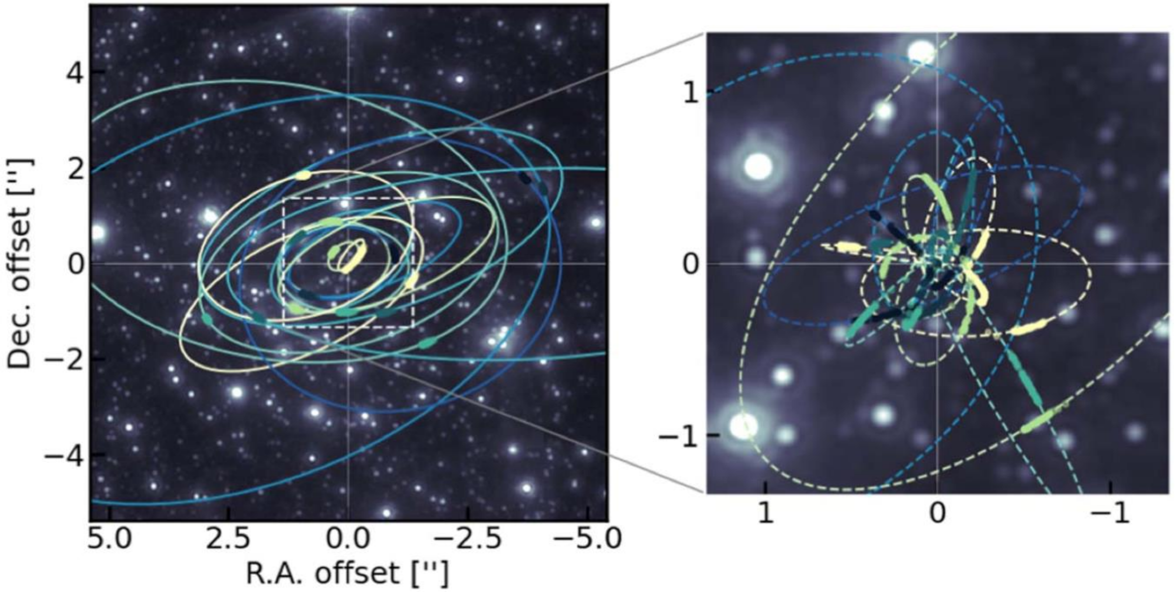
Galactic center：

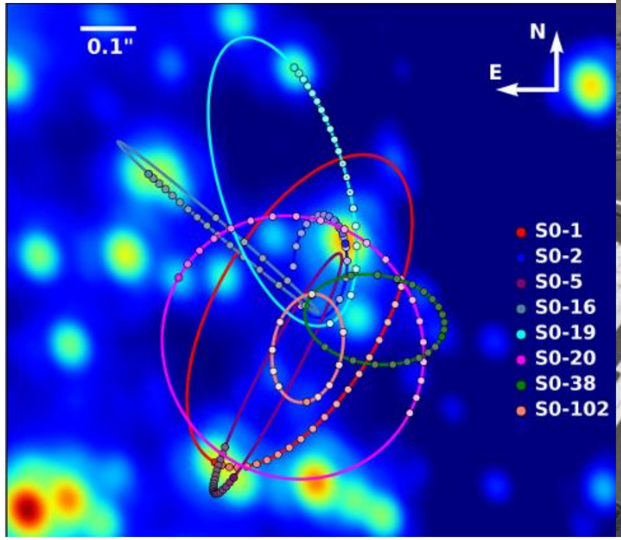
motivation

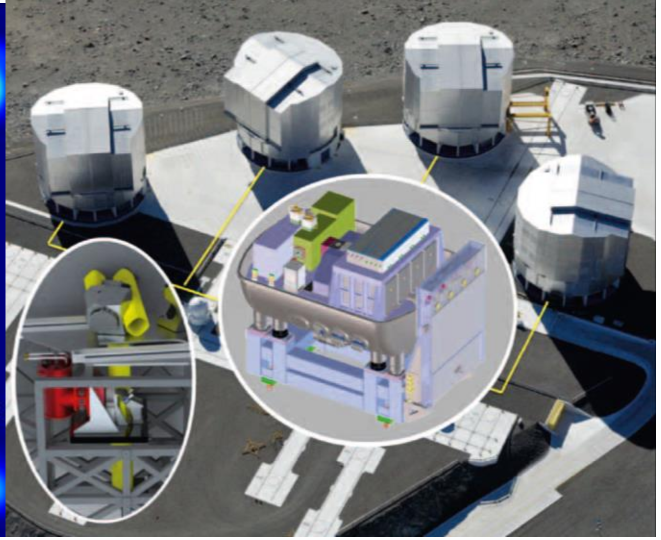

The Astrophysical Journal Letters, 932:L6 (29pp), 2022 June 10 https://doi.org/10.3847/2041-8213/ac68ef

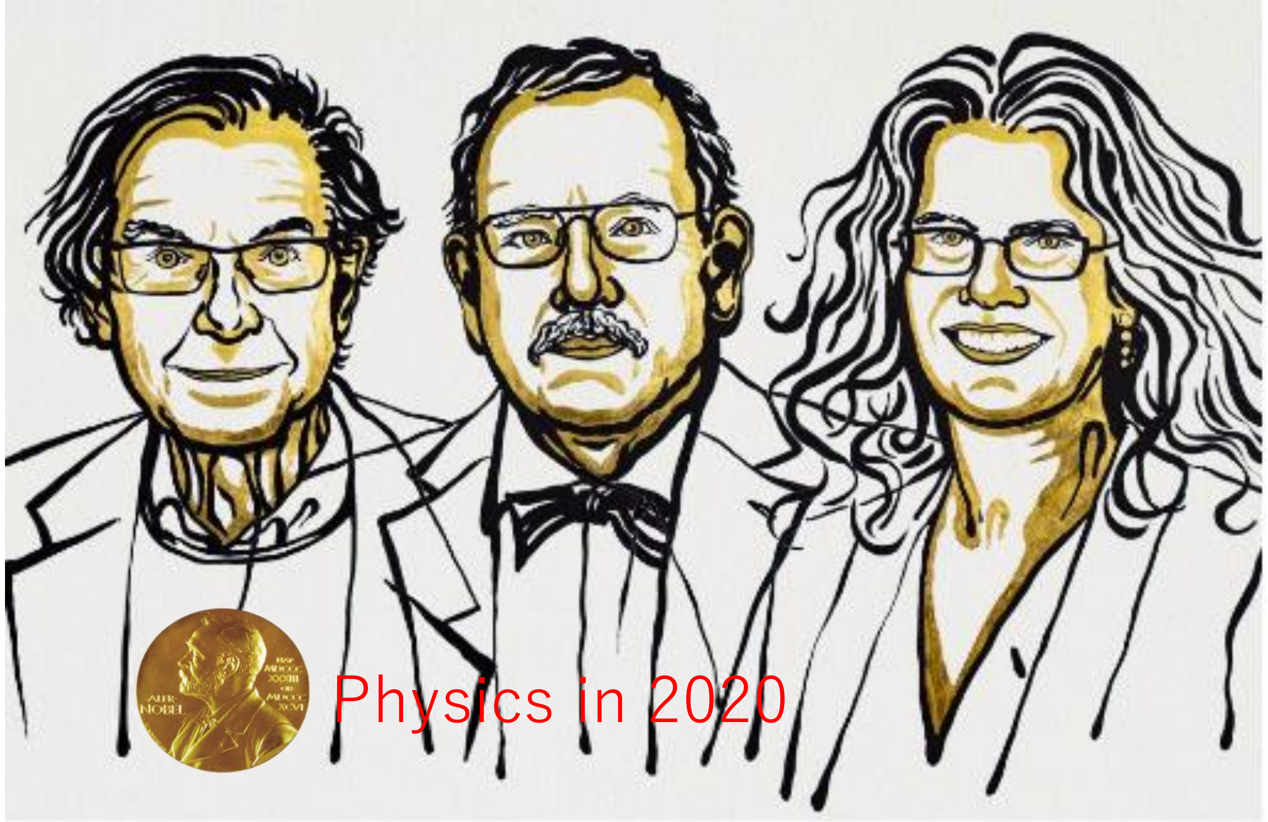
The Young Stars in the Galactic Center

Sebastiano D. von Fellenberg[1,2], Stefan Gillessen[2], Julia Stadler[3], Michi Bauböck[4], Reinhard Genzel[2,5], Tim de Zeeuw[2,6], Oliver Pfuhl[7], Pau Amaro Seoane[2,8,9,10], Antonia Drescher[2], Frank Eisenhauer[2], Maryam Habibi[2], Thomas Ott[2], Felix Widmann[2], and Alice Young[2]

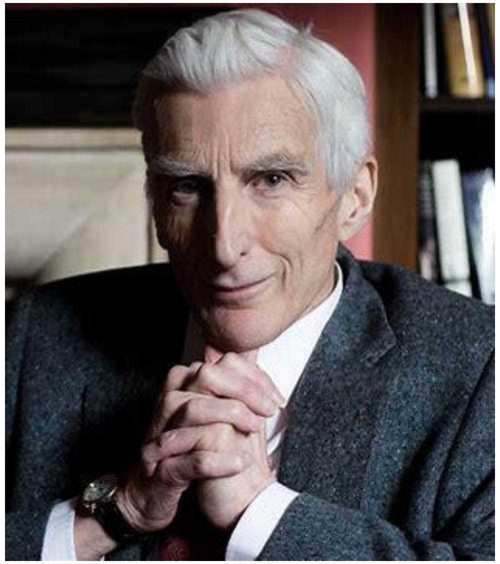








Formation of SMBHs?



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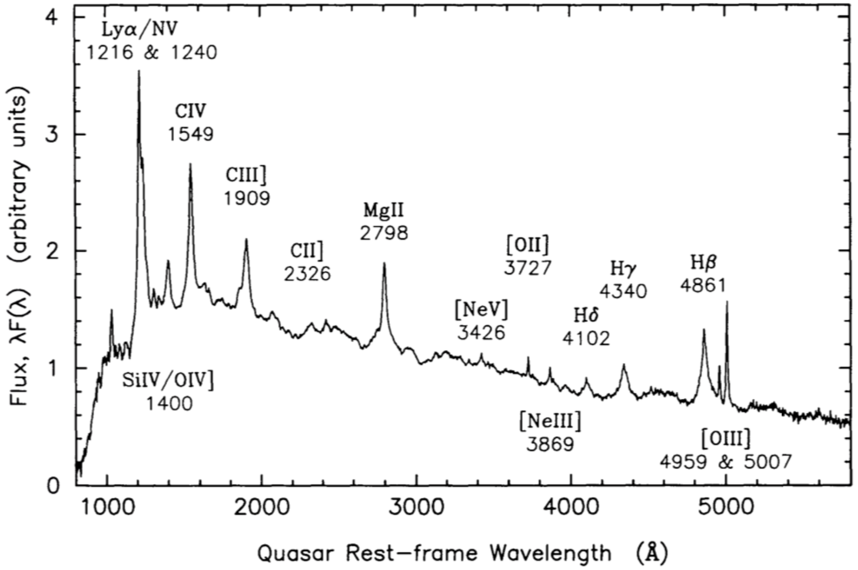

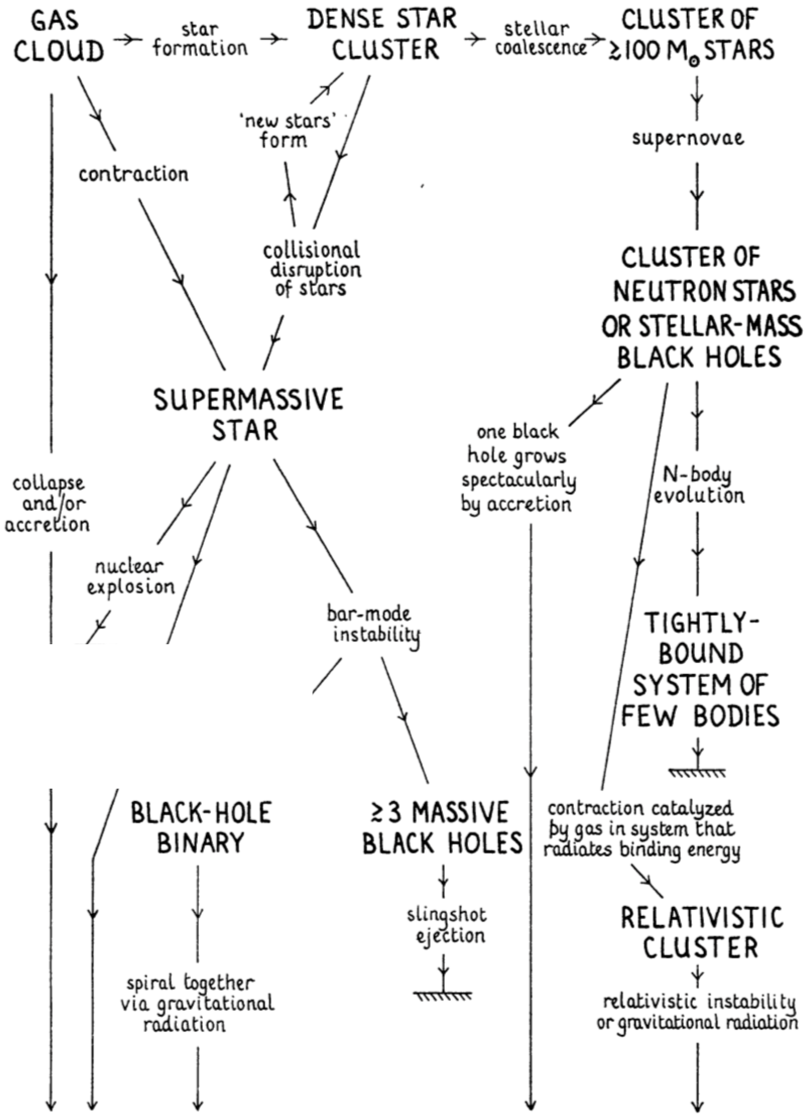

massive black hole

Ann. Rev. Astron. Astrophys. 1984. 22 : 471–506

BLACK HOLE MODELS FOR ACTIVE GALACTIC NUCLEI

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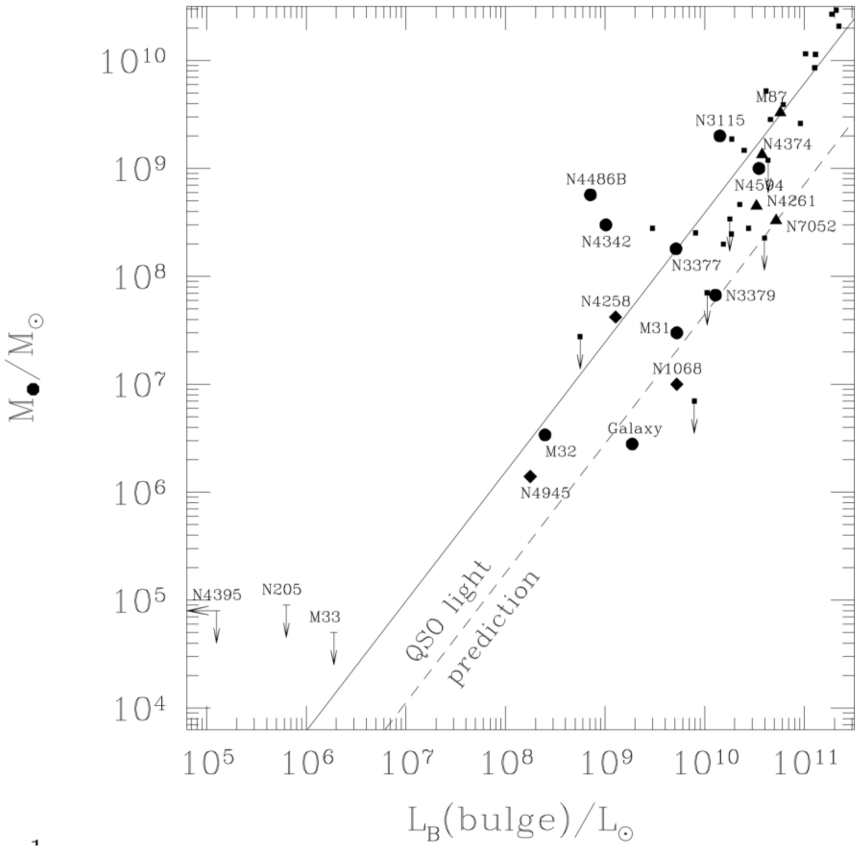
Quasars and galaxies: co-evolution

Richstone+1998



The Astrophysical Journal, 539:L9–L12, 2000 August 10

A FUNDAMENTAL RELATION BETWEEN SUPERMASSIVE BLACK HOLES AND THEIR HOST GALAXIES

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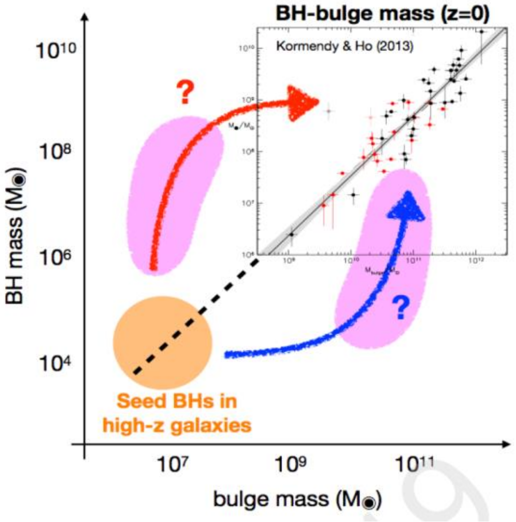
Received 2000 June 1; accepted 2000 June 29; published 2000 August 3

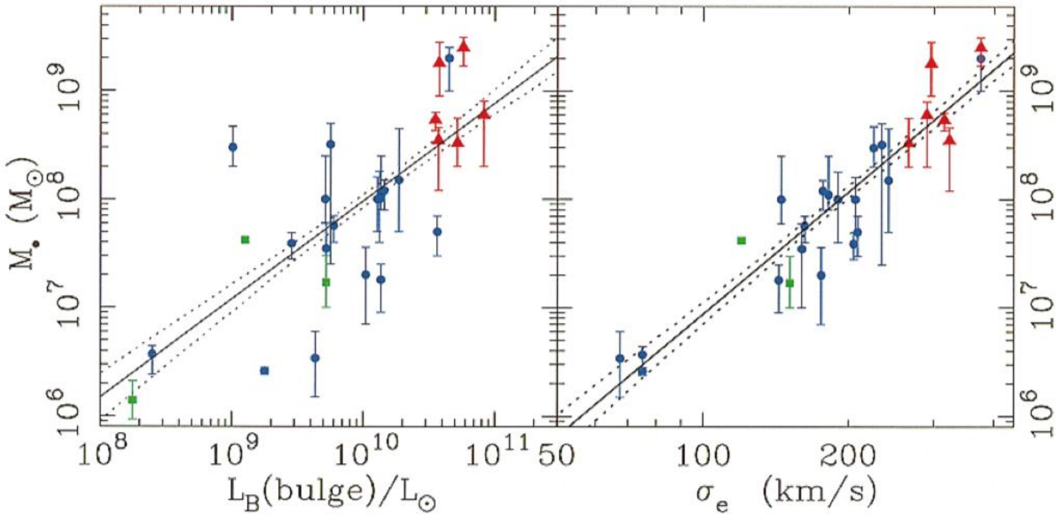


We thank Avi Loeb for an illuminating discussion, which served as a key motivation for this Letter, and W. Dehnen, C.

The Astrophysical Journal, 539:L13–L16, 2000 August 10

A RELATIONSHIP BETWEEN NUCLEAR BLACK HOLE MASS AND GALAXY VELOCITY DISPERSION

Karl Gebhardt,[1,2] Ralf Bender,[3] Gary Bower,[4] Alan Dressler,[5] S. M. Faber,[2] Alexei V. Filippenko,[6] Richard Green,[4] Carl Grillmair,[7] Luis C. Ho,[5] John Kormendy,[8] Tod R. Lauer,[4] John Magorrian,[9] Jason Pinkney,[10] Douglas Richstone,[10] and Scott Tremaine[11]
Received 2000 June 2; accepted 2000 June 29; published 2000 August 3



We thank Avi Loeb for suggesting that we examine the correlation between black hole mass and velocity dispersion.

Soltan Argument

Mon. Not. R. astr. Soc. (1982) **200**, 115–122

Masses of quasars

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Received 1981 October 18; in original form 1981 August 19

$$\rho_{\mathrm{QR}} = \int_0^\infty \int_0^\infty L\Phi(L|z)\,\mathrm{d}L\,\frac{\mathrm{d}t}{\mathrm{d}z}\,\mathrm{d}z$$

Mon. Not. R. Astron. Soc. (1992) **259**, 421–424

Remnants of the quasars

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Accepted 1992 May 19. Received 1992 May 11; in original form 1992 February 3

ABSTRACT
Assuming a standard black hole accretion model for quasars, we estimate the present total mass density, ρ_{BH}, of quasar remnants using recent observations of quasar populations and of typical quasar spectra over a wide wavelength range. We find $\rho_{\mathrm{BH}} \gtrsim (1.4\text{–}2.2)\times 10^5\ \mathrm{M}_\odot\ \mathrm{Mpc}^{-3}$ for a quasar radiative efficiency of 0.1. This is an upward revision by a factor of 3.0–4.6 from a decade-old estimate by Sołtan. A typical bright galaxy is thus expected to contain a central black hole of $\gtrsim 10^7\ h^{-3}\ \mathrm{M}_\odot$. Furthermore, we expect that $\gtrsim 50$ per cent of ρ_{BH} is contributed by objects of mass $\gtrsim 10^8\ h^{-2}\ \mathrm{M}_\odot$ and $\gtrsim 10$ per cent by those more massive than about $6\times 10^8\ h^{-2}\ \mathrm{M}_\odot$.

Mon. Not. R. Astron. Soc. **335**, 965–976 (2002)

Observational constraints on growth of massive black holes

Qingjuan Yu★ and Scott Tremaine★
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Conclusion:
SMBH from accretion

Article

A small and vigorous black hole in the early Universe

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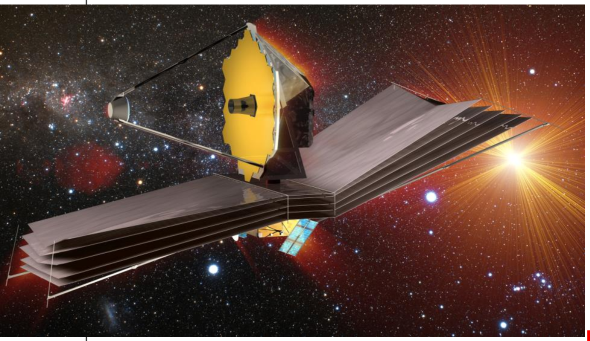
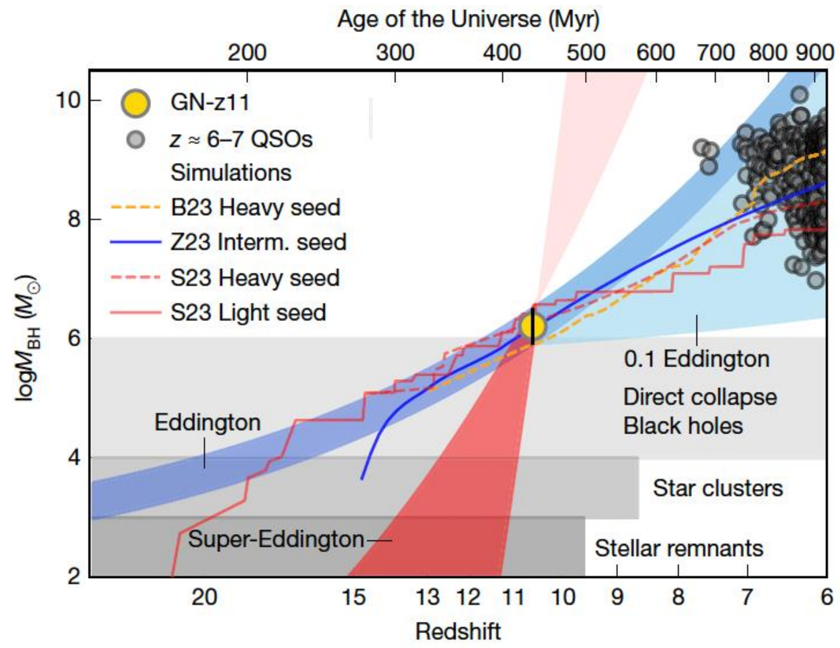
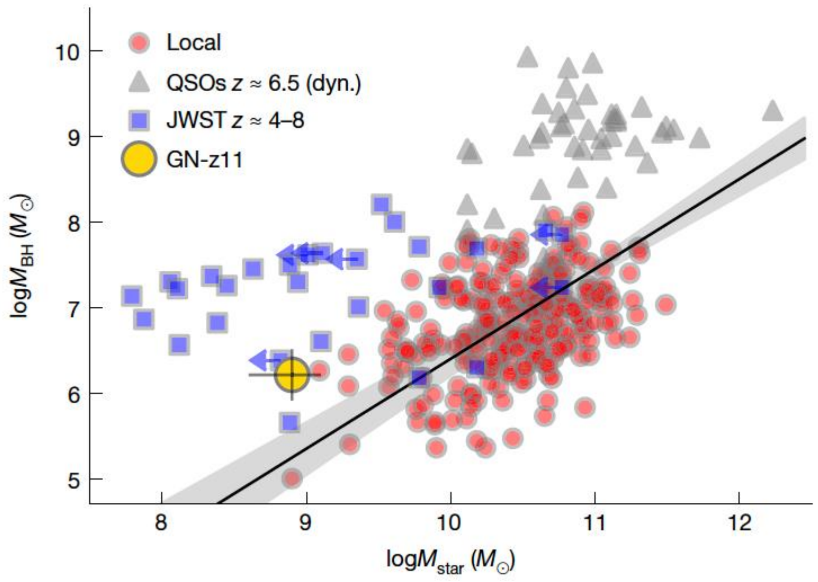
Several theories have been proposed to describe the formation of black hole seeds in the early Universe and to explain the emergence of very massive black holes observed in the first thousand million years after the Big Bang[1–3]. Models consider different seeding and accretion scenarios[4–7], which require the detection and characterization of black holes in the first few hundred million years after the Big Bang to be validated. Here we present an extensive analysis of the JWST-NIRSpec spectrum of GN-z11, an exceptionally luminous galaxy at $z = 10.6$, revealing the detection of the [NeIV]λ2423 and CII*λ1335 transitions (typical of active galactic nuclei), as well as semi-forbidden nebular lines tracing gas densities higher than 10^9 cm^{-3}, typical of the broad line region of active galactic nuclei. These spectral features indicate that GN-z11 hosts an accreting black hole. The spectrum also reveals a deep and blueshifted CIVλ1549 absorption trough, tracing an outflow with velocity 800–1,000 km s^{-1}, probably driven by the active galactic nucleus. Assuming local virial relations, we derive a black hole mass of $\log(M_{BH}/M_{\odot}) = 6.2 \pm 0.3$, accreting at about five times the Eddington rate. These properties are consistent with both heavy seeds scenarios and scenarios considering intermediate and light seeds experiencing episodic super-Eddington phases. Our finding explains the high luminosity of GN-z11 and can also provide an explanation for its exceptionally high nitrogen abundance.



Super-Eddington BHs !





Article

A dynamical measure of the black hole mass in a quasar 11 billion years ago

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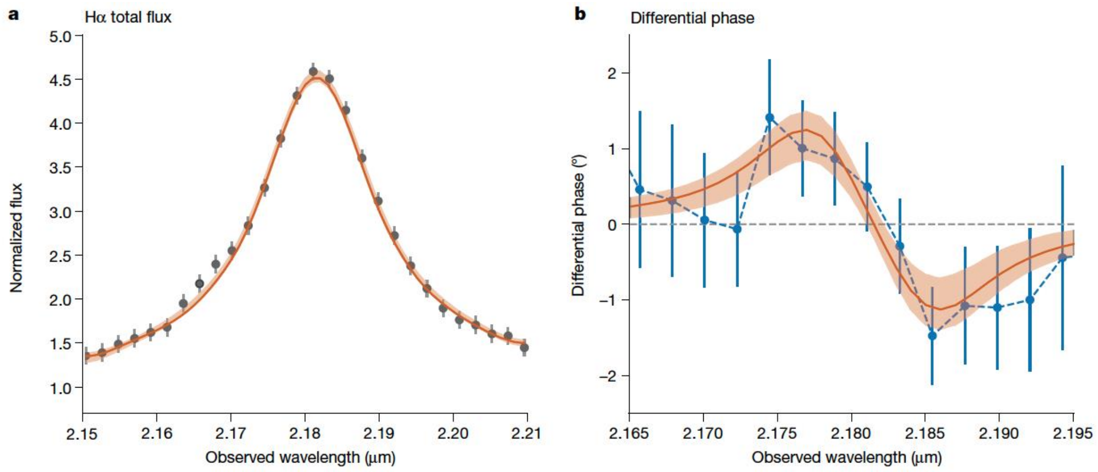
Tight relationships exist in the local Universe between the central stellar properties of galaxies and the mass of their supermassive black hole (SMBH)[1–3]. These suggest that galaxies and black holes co-evolve, with the main regulation mechanism being energetic feedback from accretion onto the black hole during its quasar phase[4–6]. A crucial question is how the relationship between black holes and galaxies evolves with time; a key epoch to examine this relationship is at the peaks of star formation and black hole growth 8–12 billion years ago (redshifts 1–3)[7]. Here we report a dynamical measurement of the mass of the black hole in a luminous quasar at a redshift of 2, with a look back in time of 11 billion years, by spatially resolving the broad-line region (BLR). We detect a 40-μas (0.31-pc) spatial offset between the red and blue photocentres of the Hα line that traces the velocity gradient of a rotating BLR. The flux and differential phase spectra are well reproduced by a thick, moderately inclined disk of gas clouds within the sphere of influence of a central black hole with a mass of 3.2×10^8 solar masses. Molecular gas data reveal a dynamical mass for the host galaxy of 6×10^{11} solar masses, which indicates an undermassive black hole accreting at a super-Eddington rate. This suggests a host galaxy that grew faster than the SMBH, indicating a delay between galaxy and black hole formation for some systems.

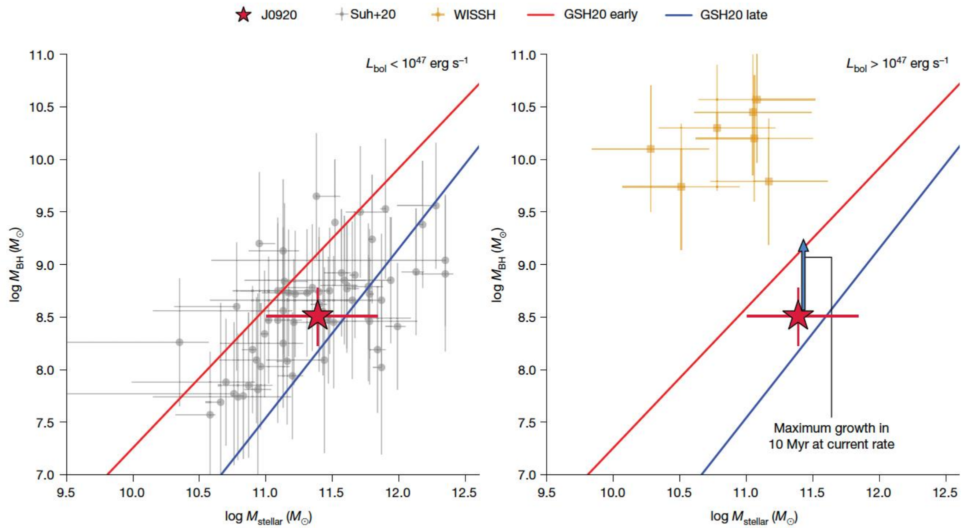
SDSS J0920

z=2.3

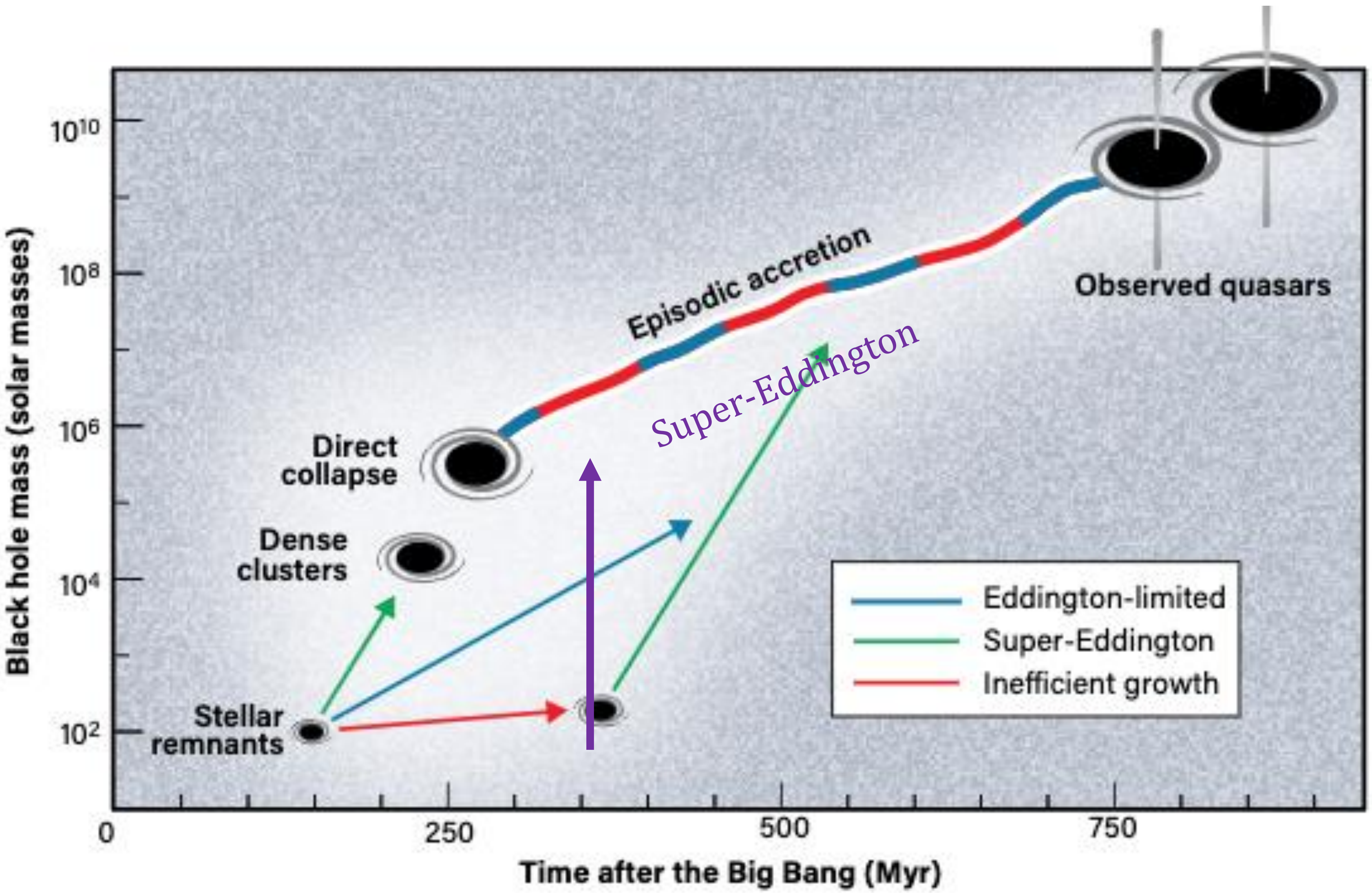
Super-Eddington BHs！

超爱黑洞！

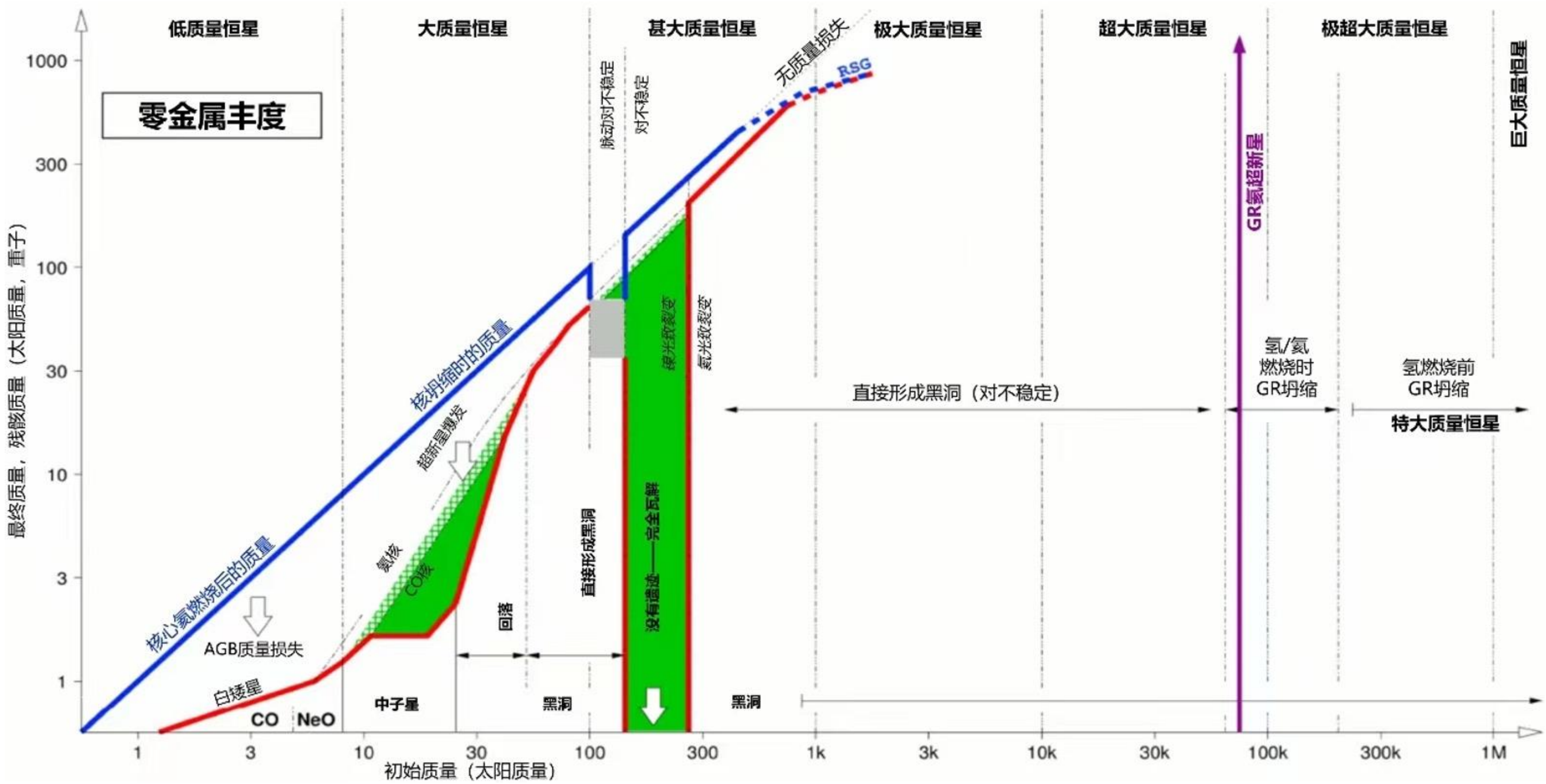




重种子黑洞 ->超Eddington吸积->超大质量黑洞



How to form seed BHs？



Physics Reports 1054 (2024) 1–68

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Physics Reports

journal homepage: www.elsevier.com/locate/physrep

Observational evidence for primordial black holes: A positivist perspective

B.J. Carr [a], S. Clesse [b], J. García-Bellido [c], M.R.S. Hawkins [d], F. Kühnel [e,*]

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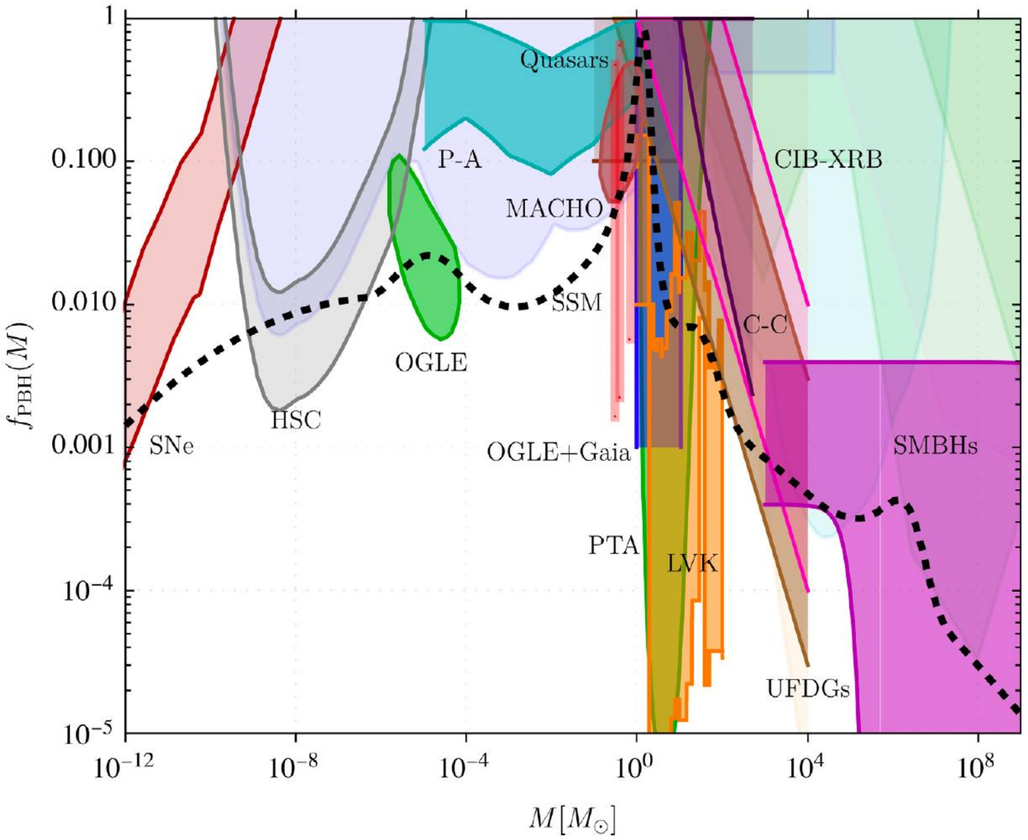
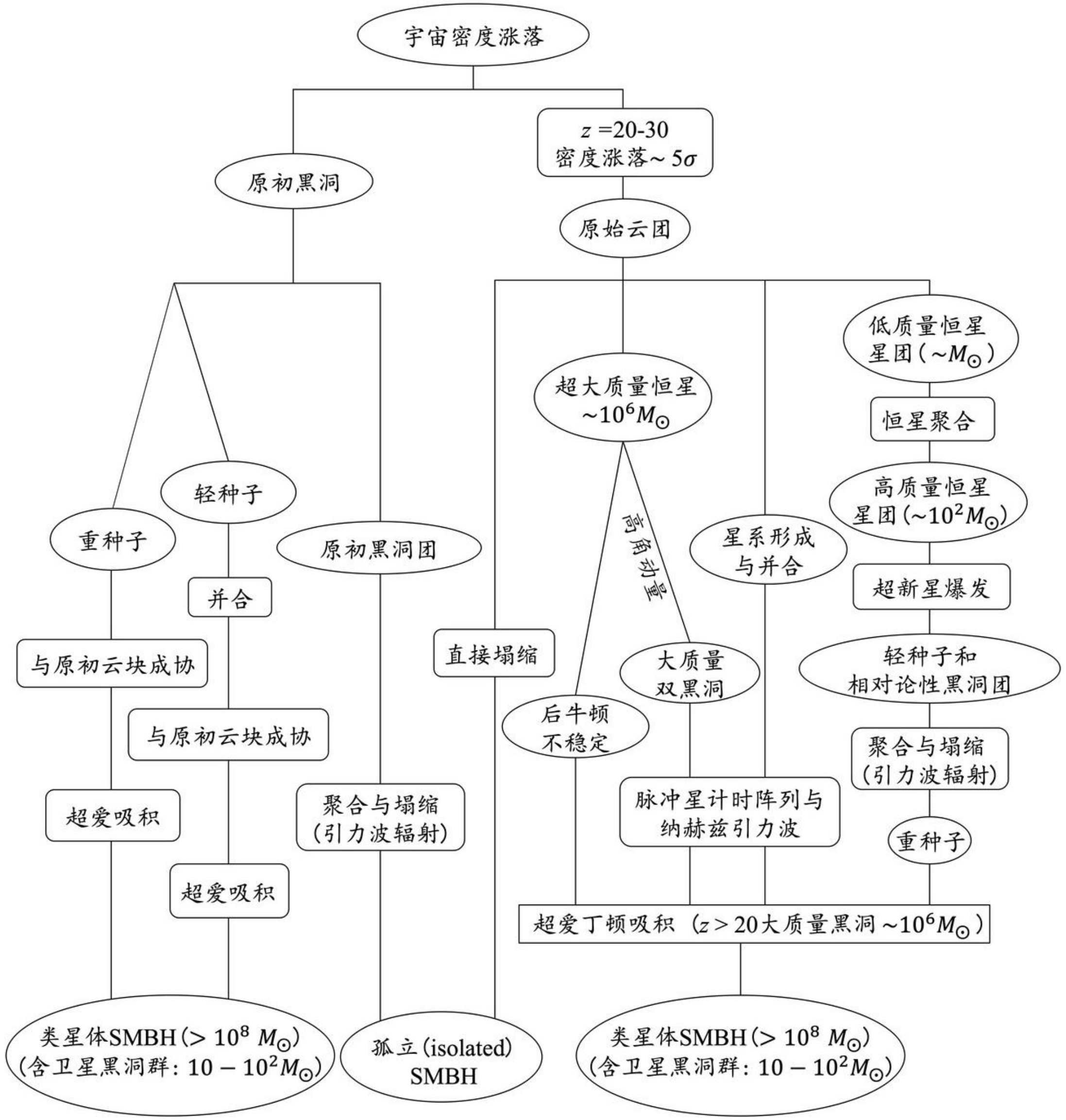
[d] Department of Physics and Astronomy, University of Edinburgh, United Kingdom
[e] Max Planck Institute for Physics, Germany

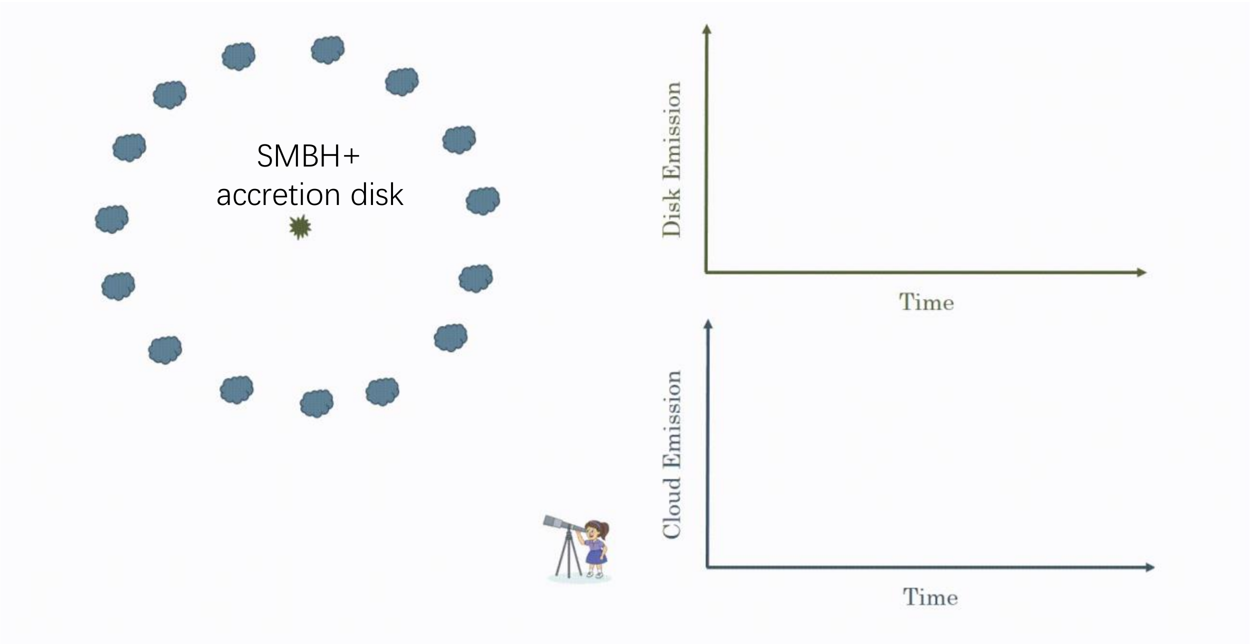


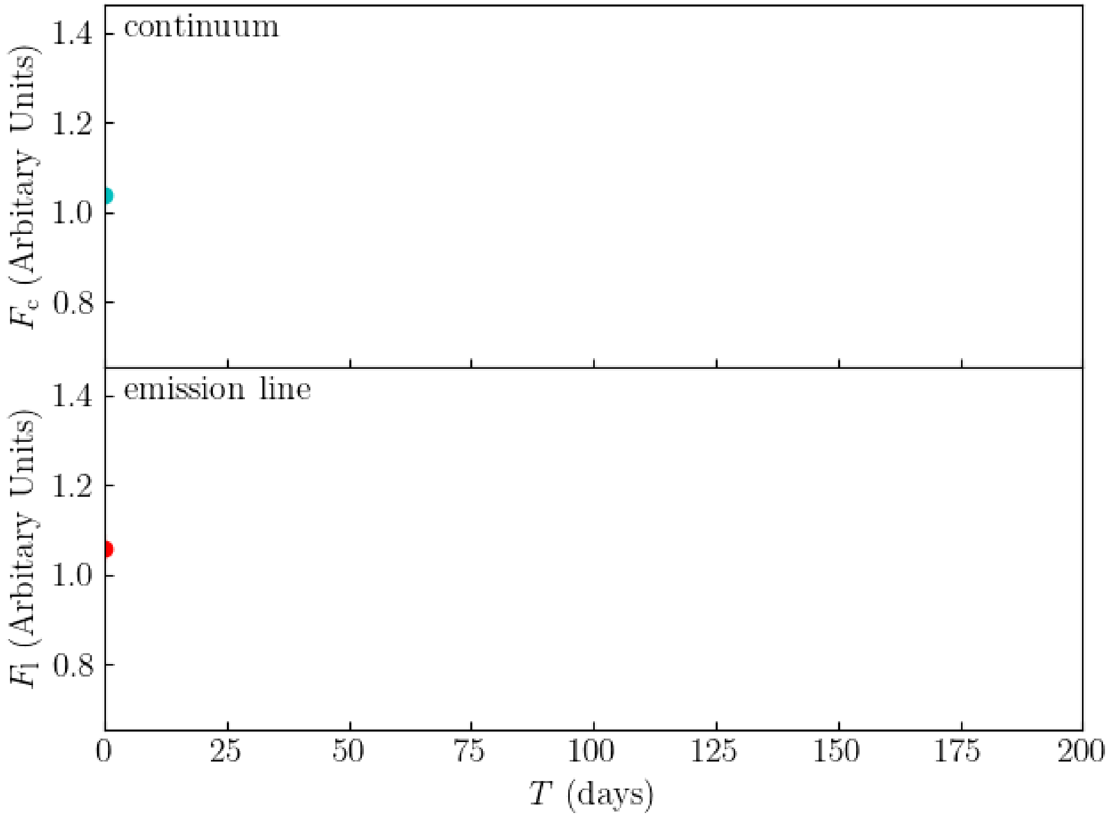
超大质量黑洞形成与演化全景图

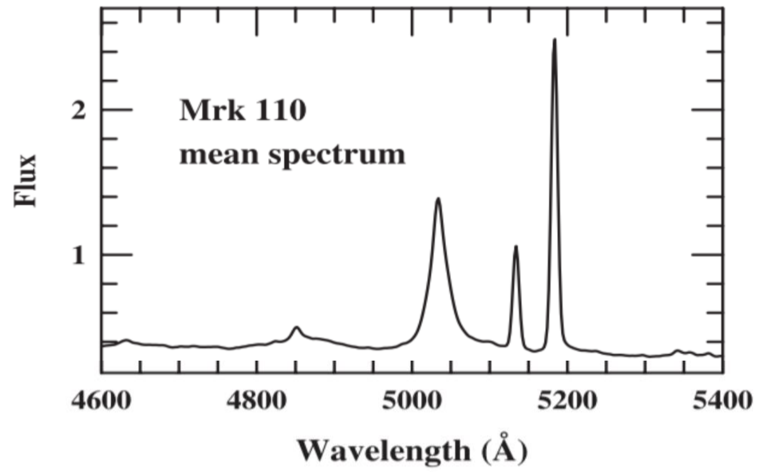


2、 Masses and spins

Classical tool: reverberation mapping

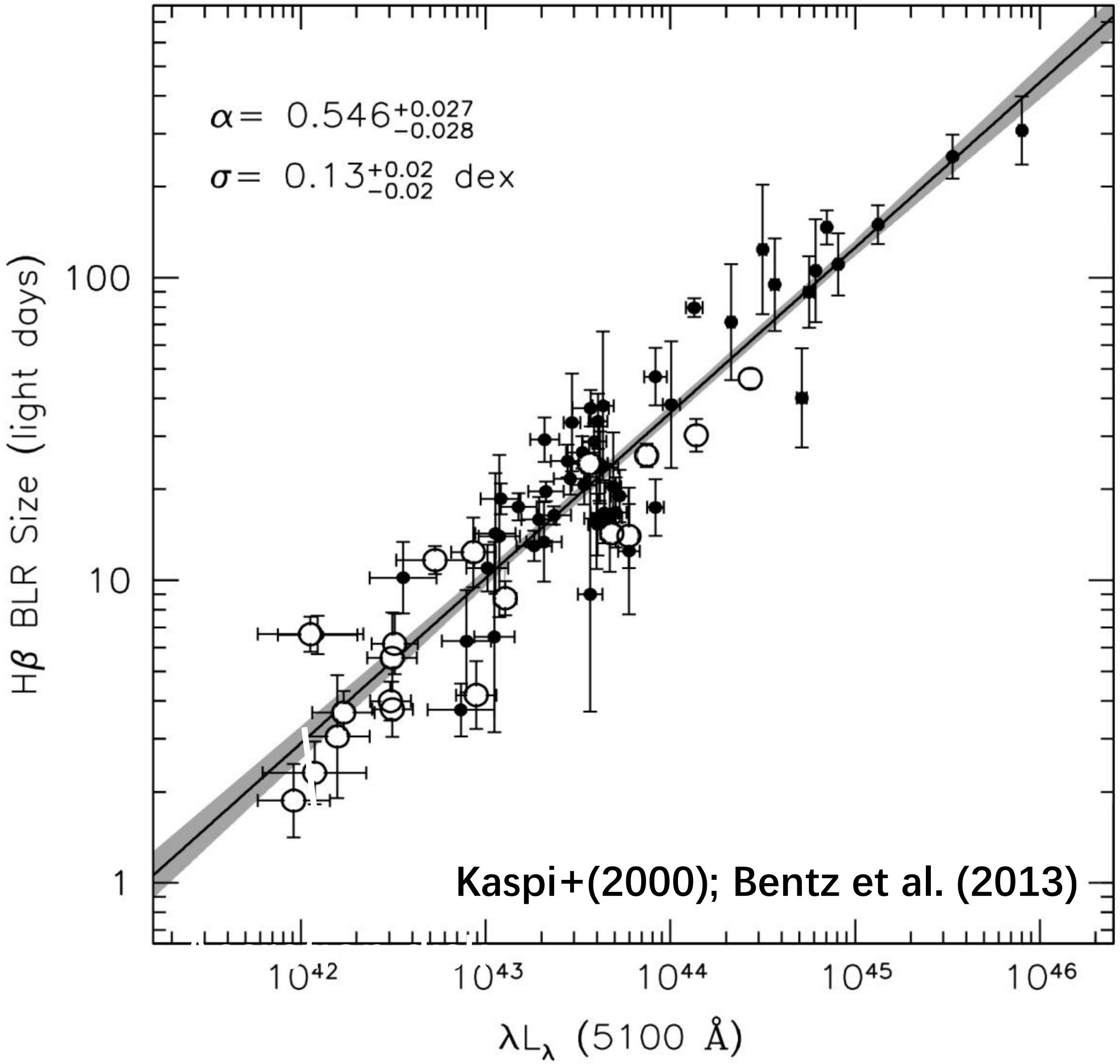






$$M_\bullet = f_{\rm BLR}\frac{V_{\rm FWHM}^2 R_{\rm BLR}}{G}$$

Broad-line region: *R*-*L* relation

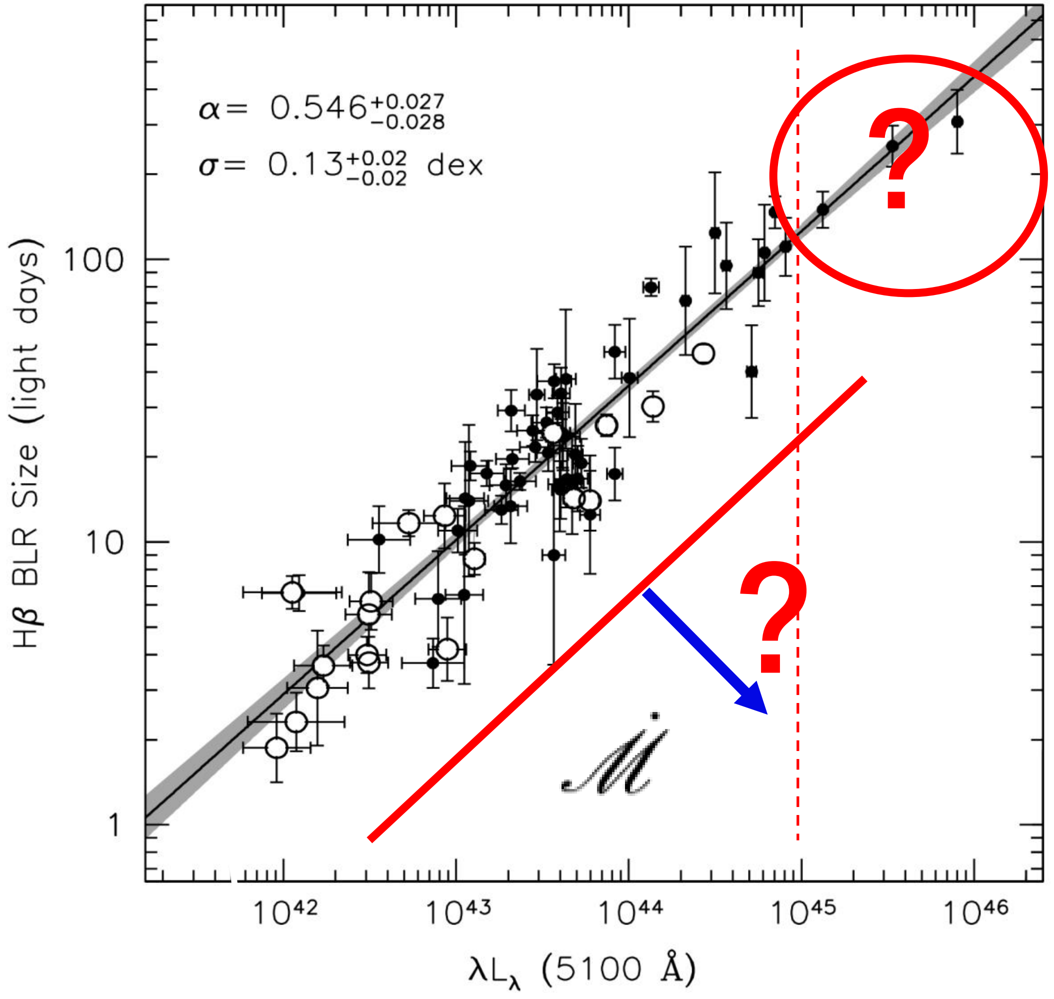


The empirical relation:

widely used for SMBH masses

from single epoch spectra

BLR: *R*-*L* scaling relations



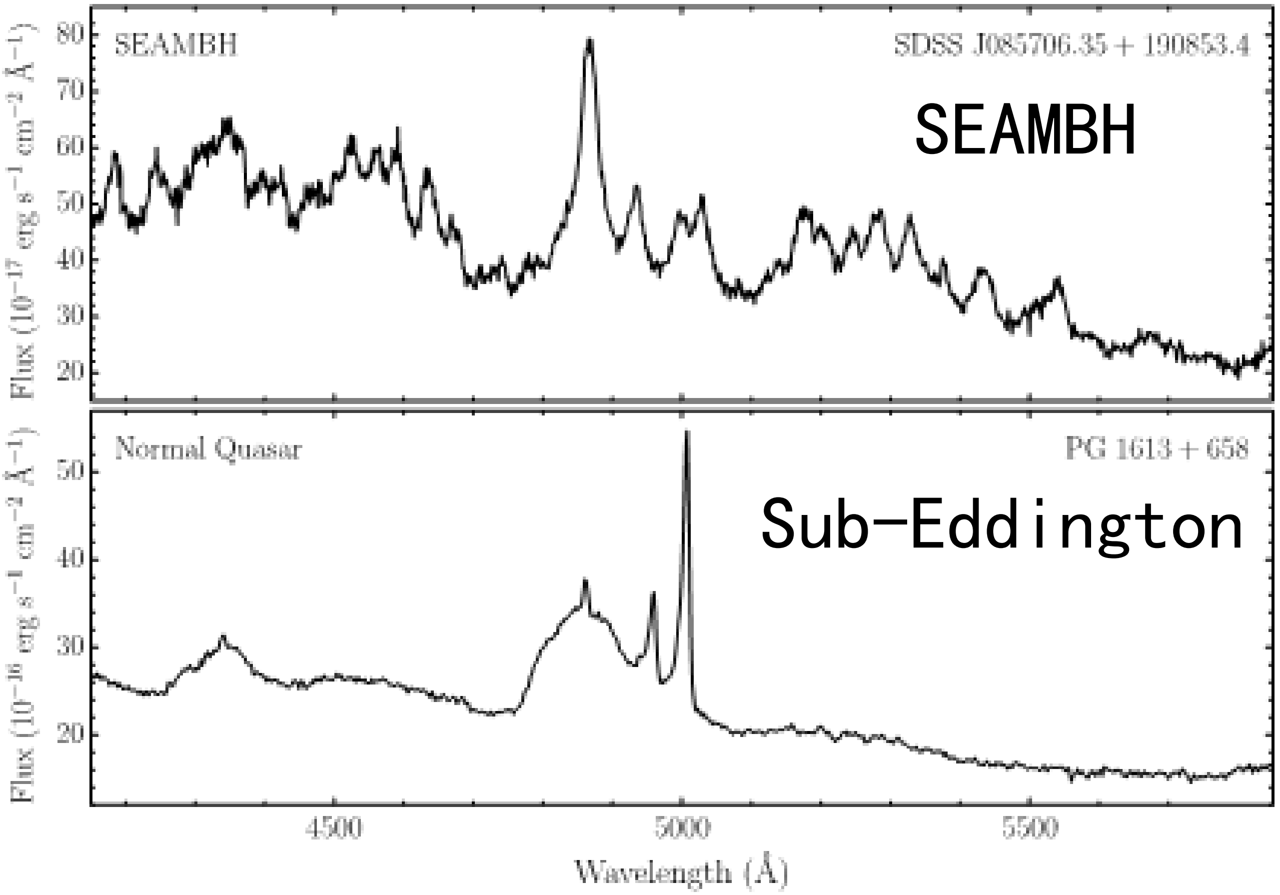
Questions:

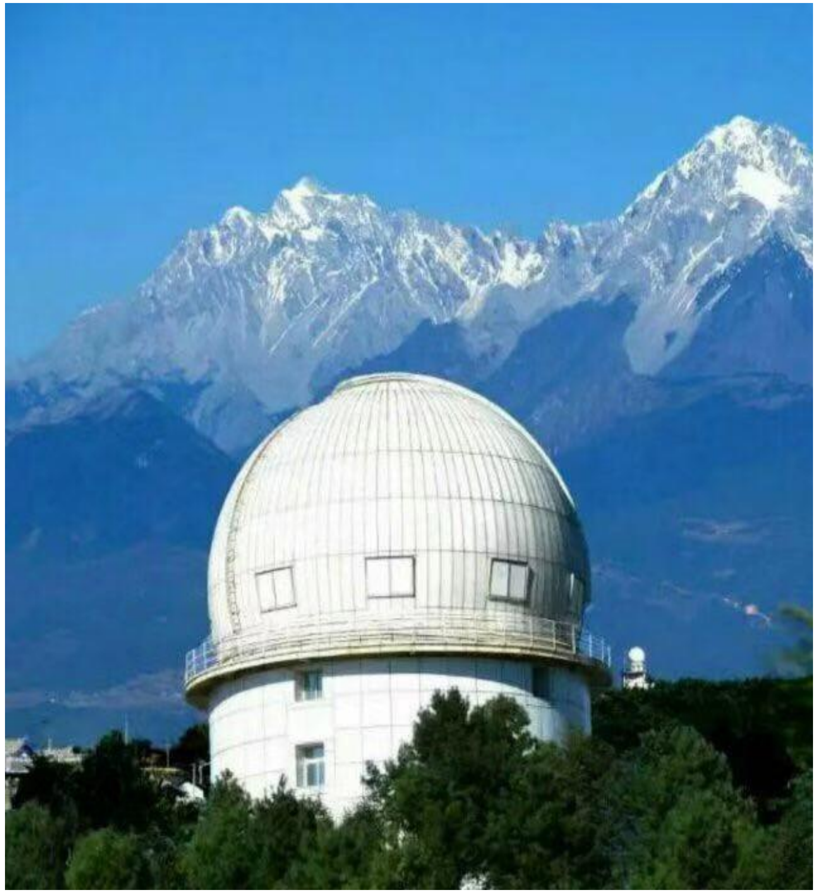
- Luminous quasars?
- Accretion rates?
- SMBH numbers: binary?

Kaspi+(2000); Bentz et al. (2013)

Lijiang2.4m & CAHA2.2m: SEAMBH2012

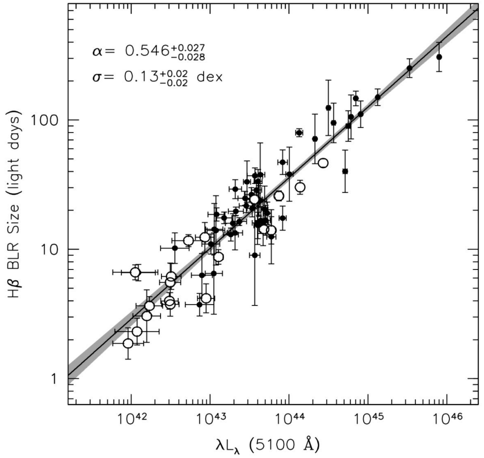
(super-Eddington accreting massive black holes)

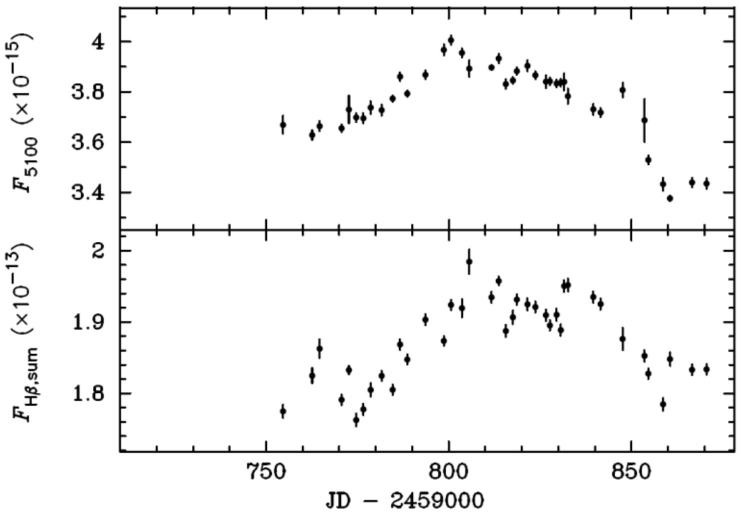




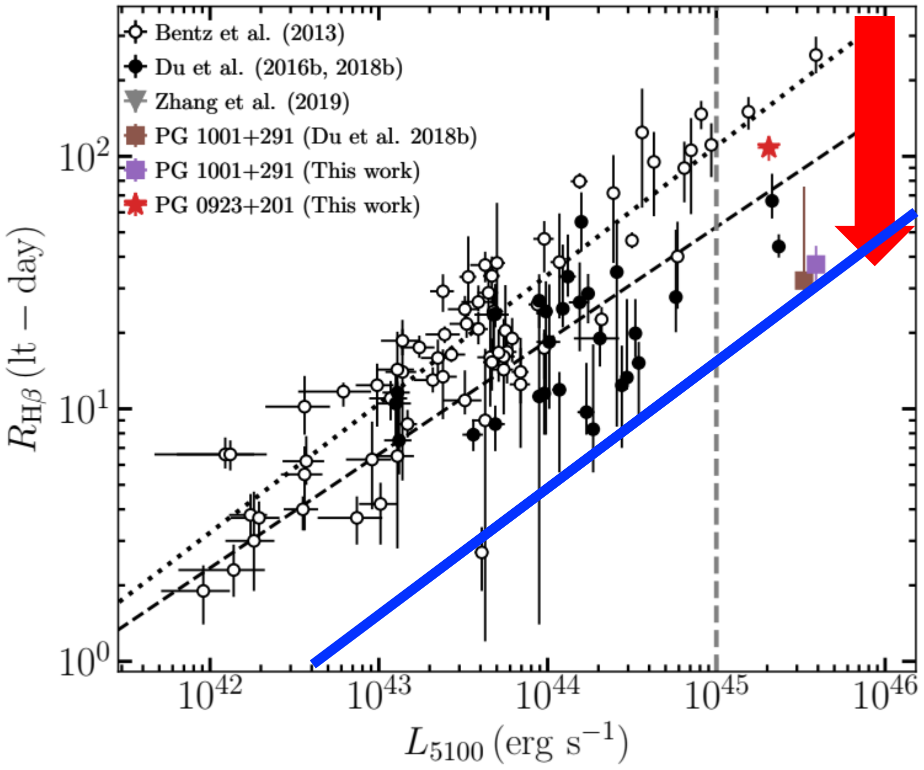
For fast growth of seed black holes to SMBH

Broken R-L relation → New Relation



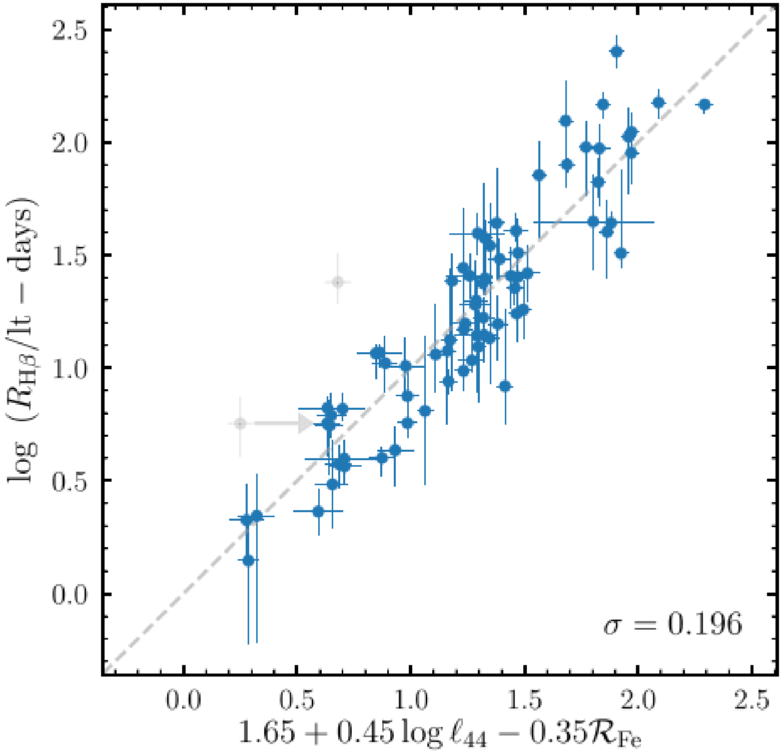


预计51天延迟；但短于10天



Li et al. 2021，Du et al. (2014;2015;2016;2018a)

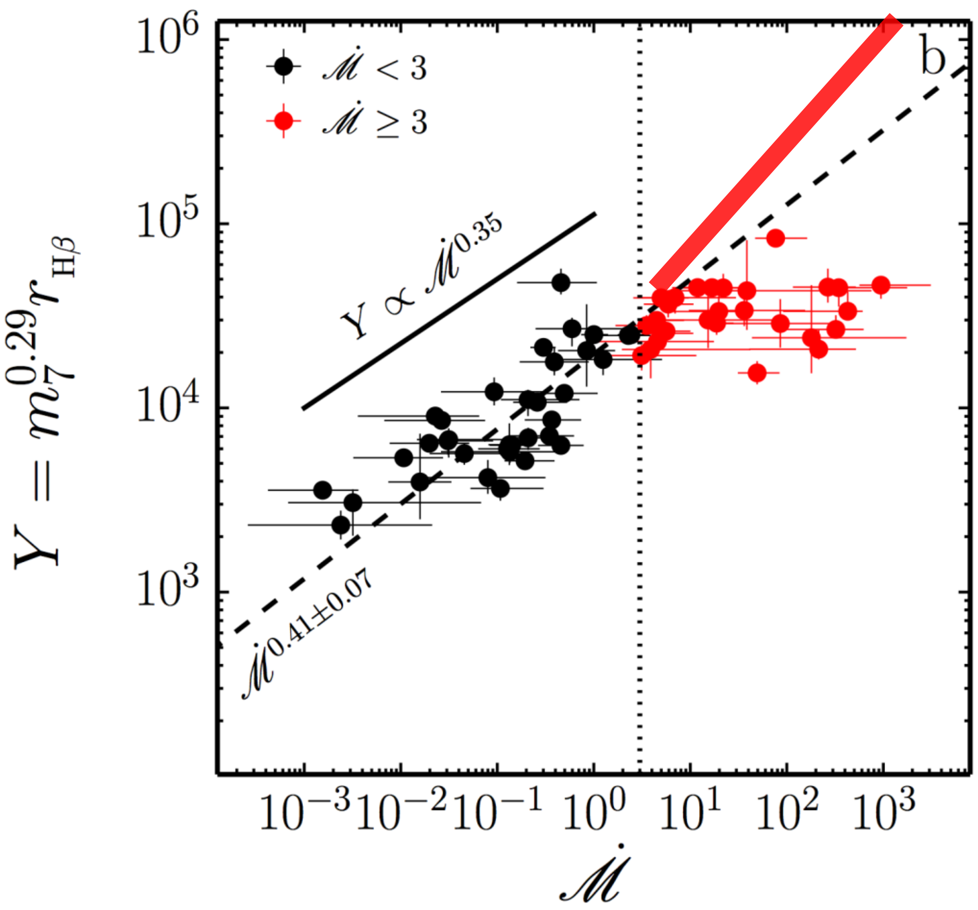
Highest rates：$2000L_{\rm Edd}/c^2$



Du & Wang (2019)

One order

Radiated luminosity: Saturated (Du et al. 2015b)



✔经典模型: 标准烛光

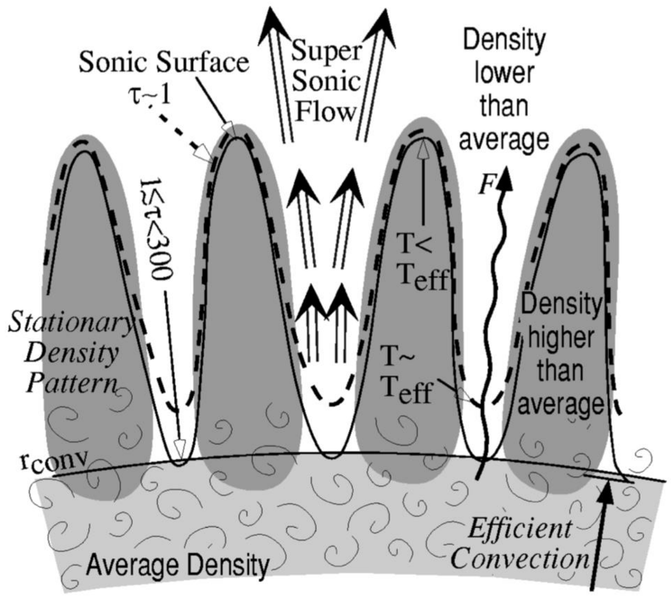
(Abramowicz et al. 1988;
Wang et al. 2013)

✗ photon bubble 模型

(Begelman 2000)

✗ 有MHD数值模拟结果

(CfA; Primceton)
(Jiang et al. 2014;
Sadowski & Narayan 2015)



η Carine (Shaviv2000)

Super-Eddington implication: SMBH formation

Heavy seed BHs: super-Eddington accretion

$$\dot{\mathscr{M}} = \dot{M}_\bullet / \dot{M}_{\rm Edd} \sim 10^3 \qquad M_\bullet = M_{\rm seed} \exp\left(\frac{1-\epsilon}{\epsilon}\frac{\dot{\mathscr{M}}\, t}{t_{\rm Salp}}\right)$$

Mon. Not. R. Astron. Soc. **314**, L17–L20 (2000)

Narrow-line Seyfert 1 galaxies and the evolution of galaxies and active galaxies

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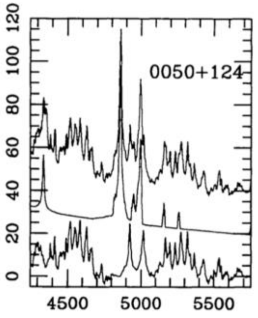
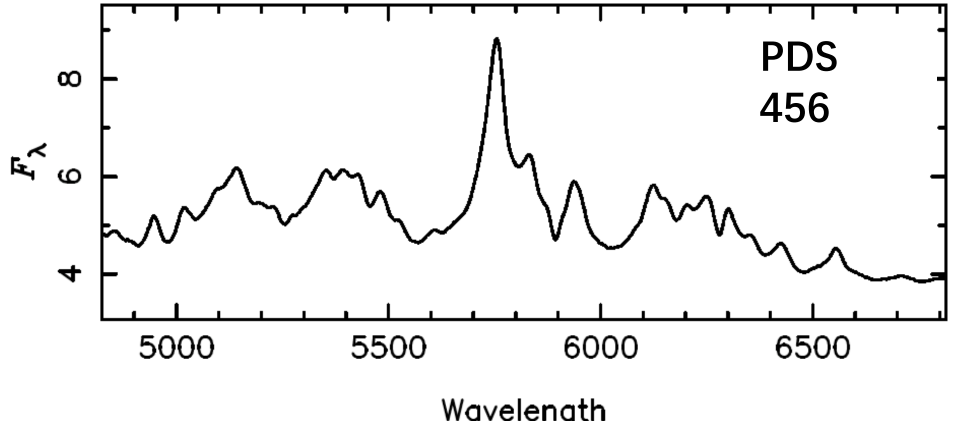


I Zw1

ABSTRACT
Narrow Line Seyfert 1 galaxies (NLS1s) are intriguing owing to their continuum as well as emission-line properties. The observed peculiar properties of the NLS1s are believed to be as a result of an accretion rate close to the Eddington limit. As a consequence of this, for a given luminosity, NLS1s have smaller black hole (BH) masses compared with normal Seyfert galaxies. Here we argue that NLS1s might be Seyfert galaxies in their early stage of evolution and as such may be low-redshift, low-luminosity analogues of high-redshift quasars. We propose that NLS1s may reside in rejuvenated, gas-rich galaxies. We also argue in favour of collisional ionization for production of Fe II in active galactic nuclei.

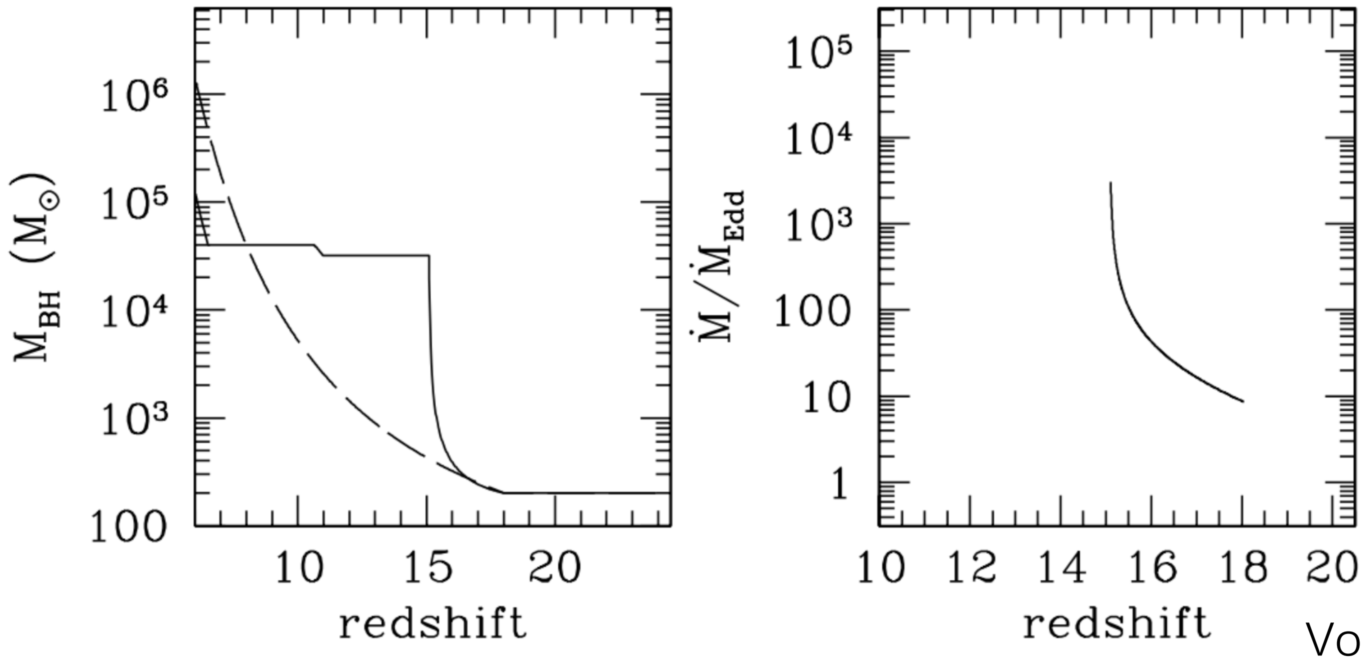
Key words: galaxies: active – galaxies: evolution – quasars: general – galaxies: Seyfert.



BH growth

- timescale: $$t_\bullet = 0.13\,(1-\eta)^{-1}\left(\frac{\delta_{10}}{0.35}\right)^{-1}\left(\frac{\dot{\mathscr{M}}}{10}\right)^{-1}\ \mathrm{Gyr.}$$

z ~ 7： 0.8Gyr



Volonteri & Rees (2005)

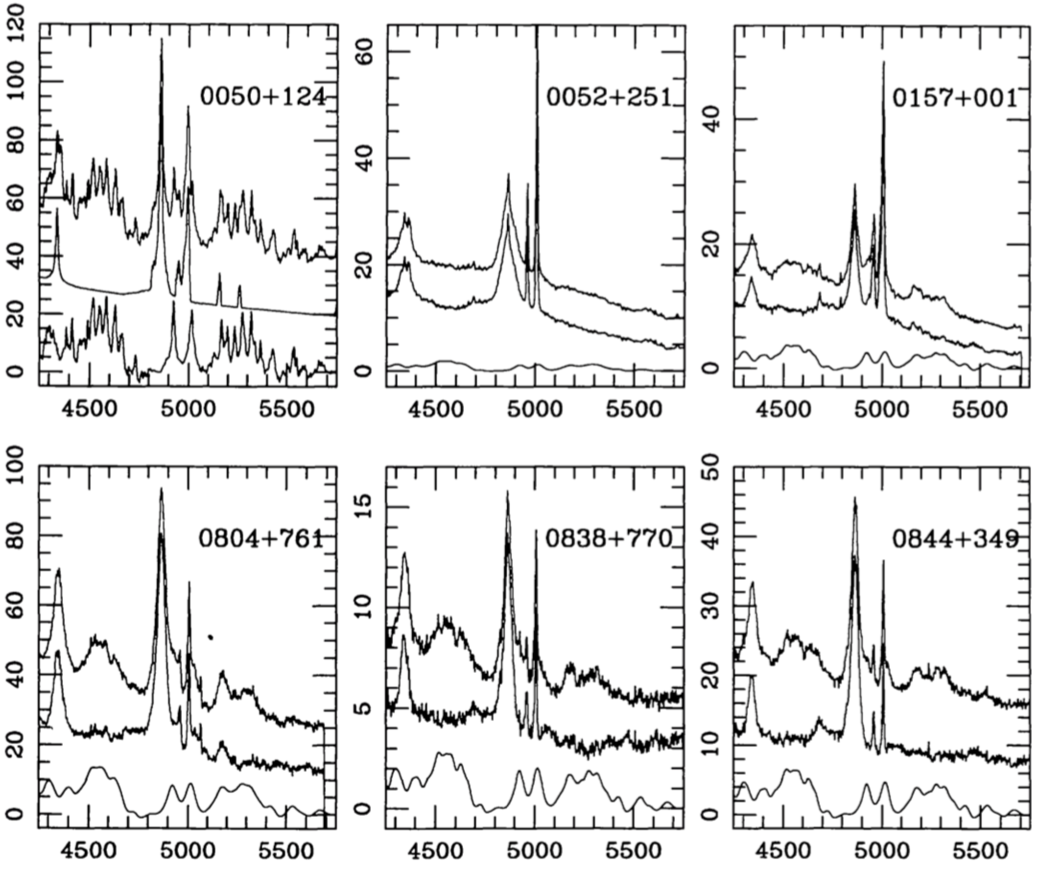
Strong Fe!

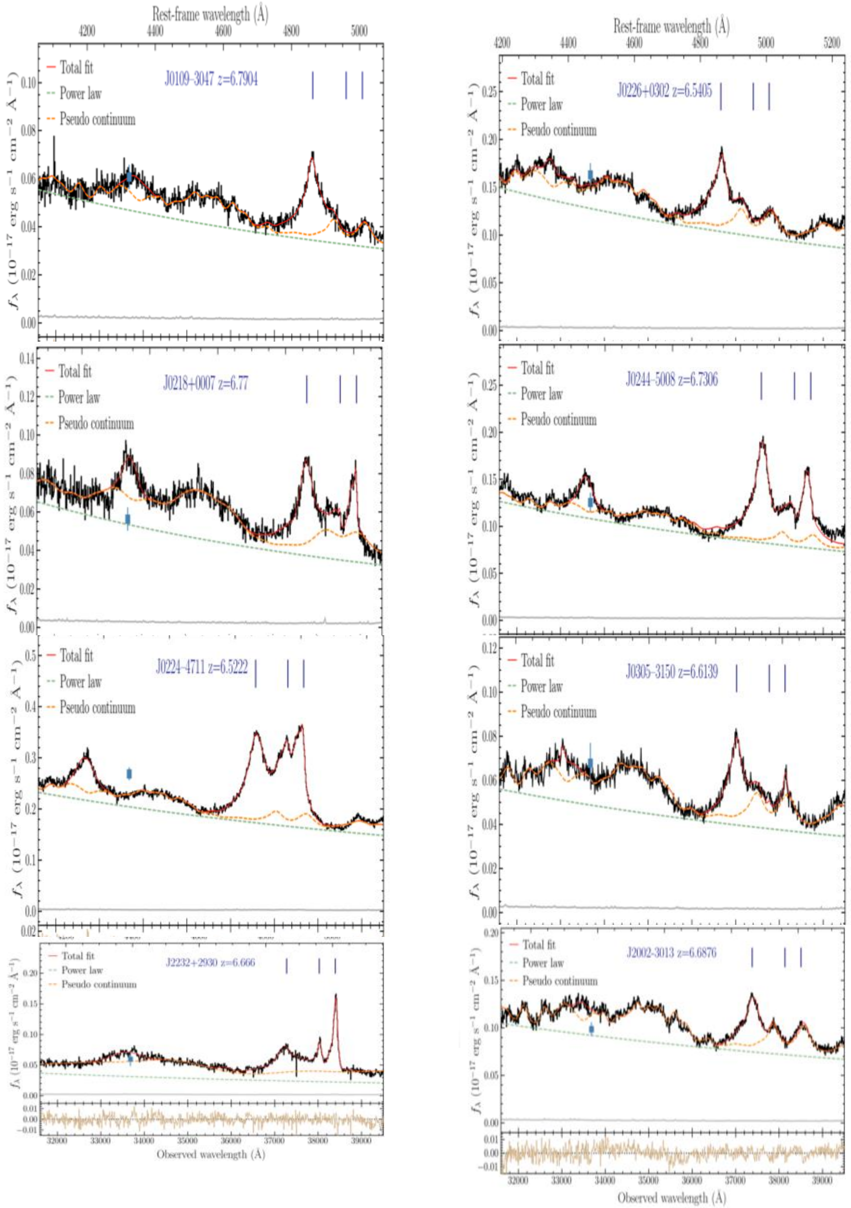
JWST results（Yang+2023）

JOURNAL SUPPLEMENT SERIES, 80:109–135, 1992 May

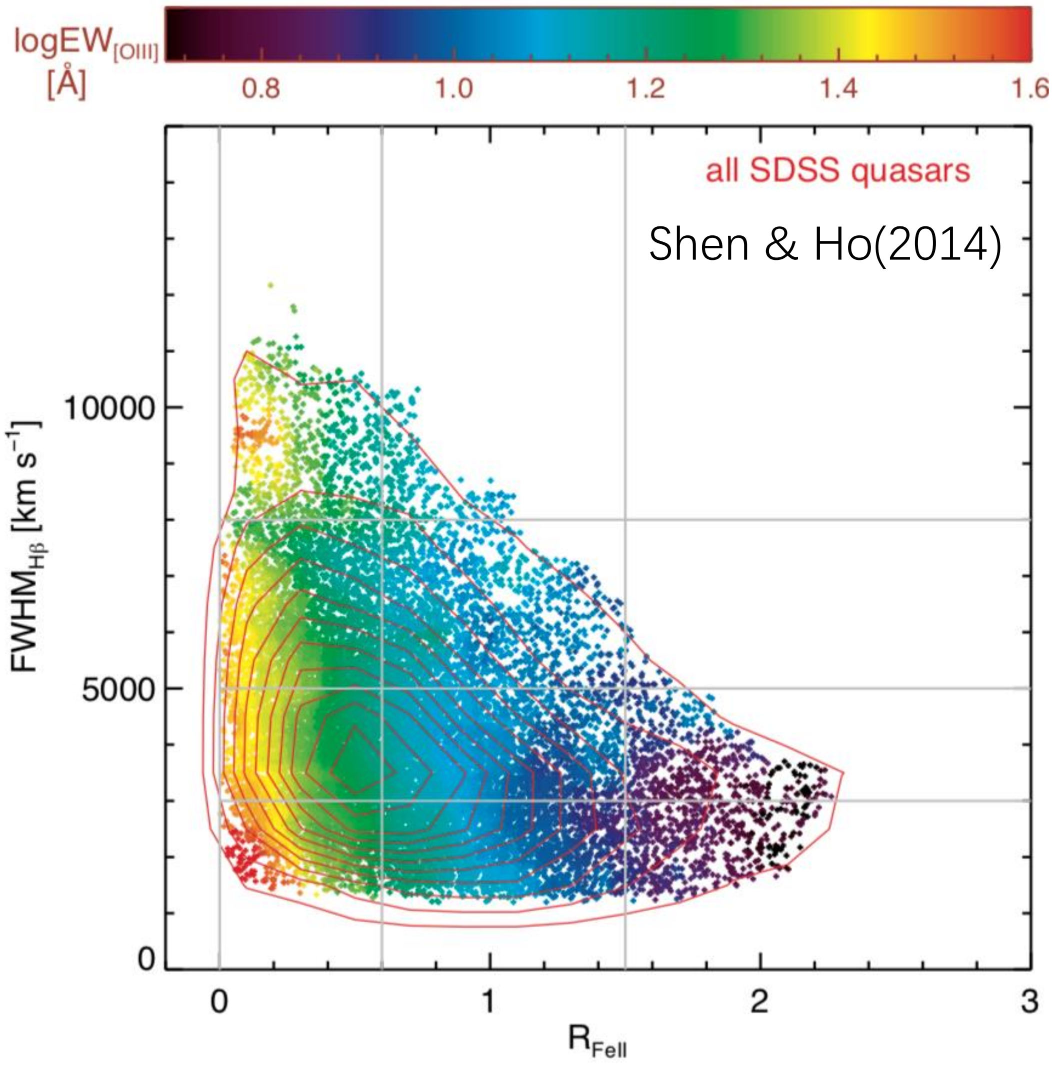
THE EMISSION-LINE PROPERTIES OF LOW-REDSHIFT QUASI-STELLAR OBJECTS

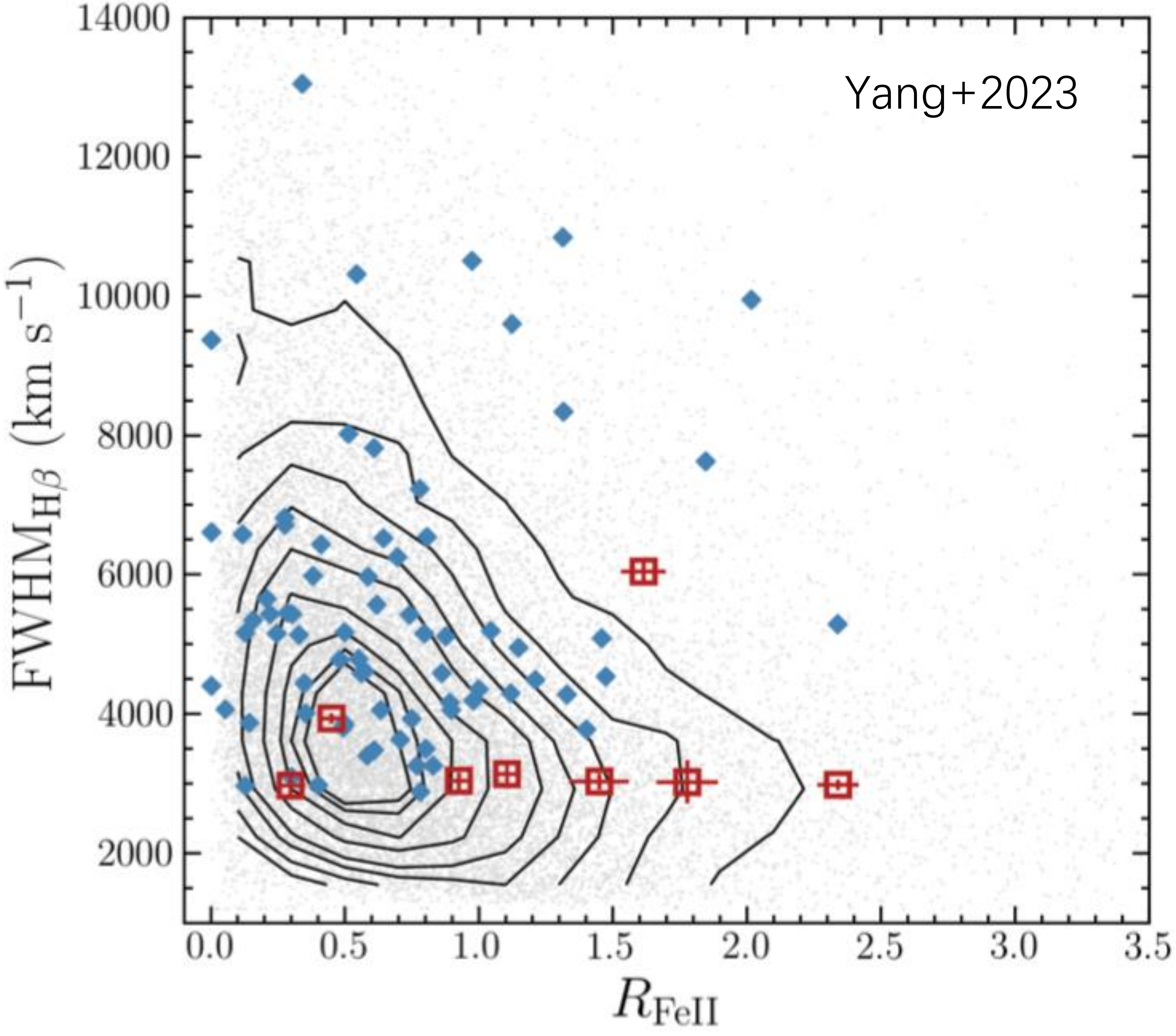
TODD A. BOROSON AND RICHARD F. GREEN
Kitt Peak National Observatory, National Optical Astronomy Observatories,[1] P.O. Box 26732, Tucson, AZ 85726
Received 1991 August 2; accepted 1991 October 14



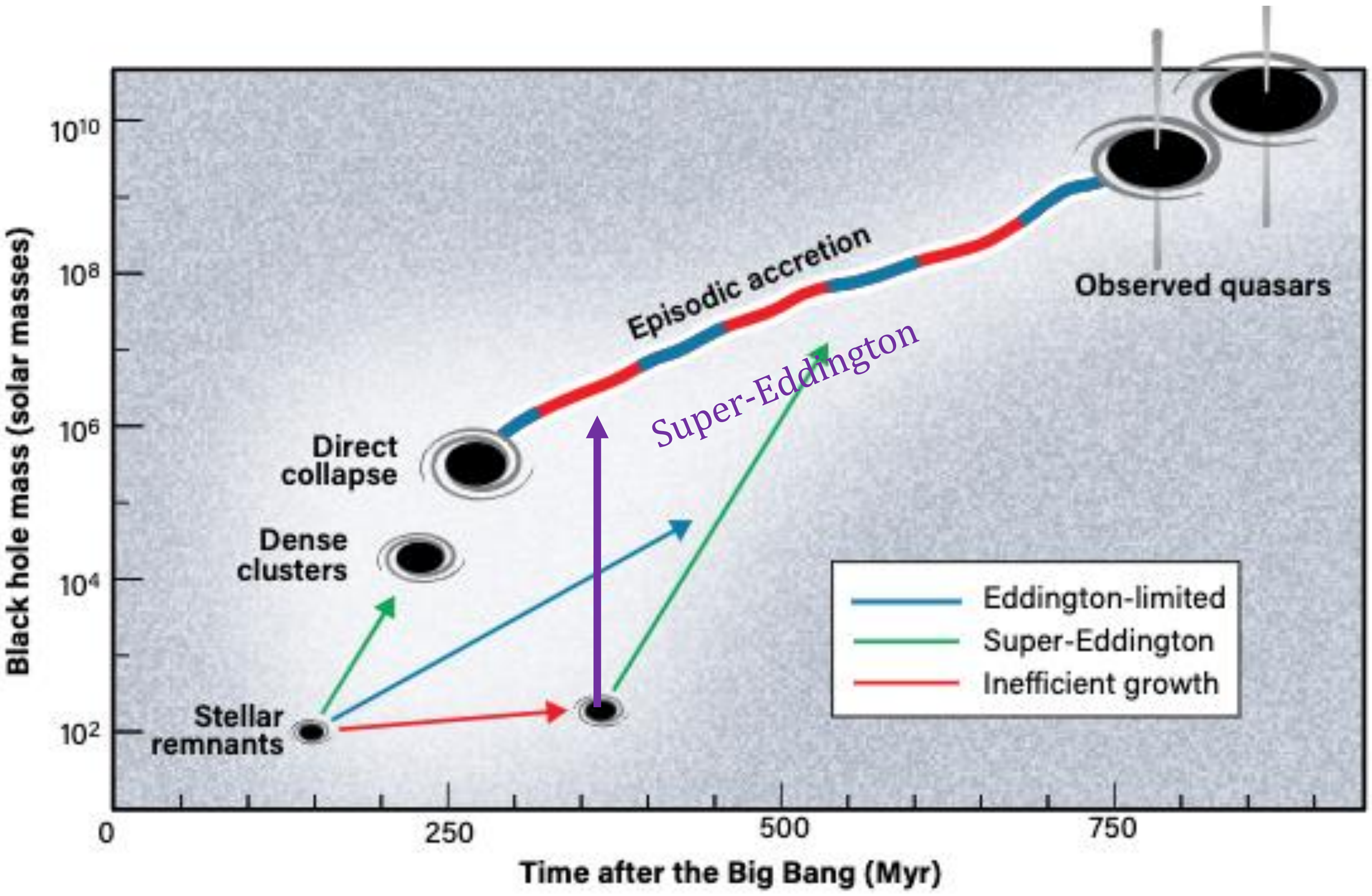


JSWT and SDSS quasars





Heavy seed ->Super-Eddington->SMBH



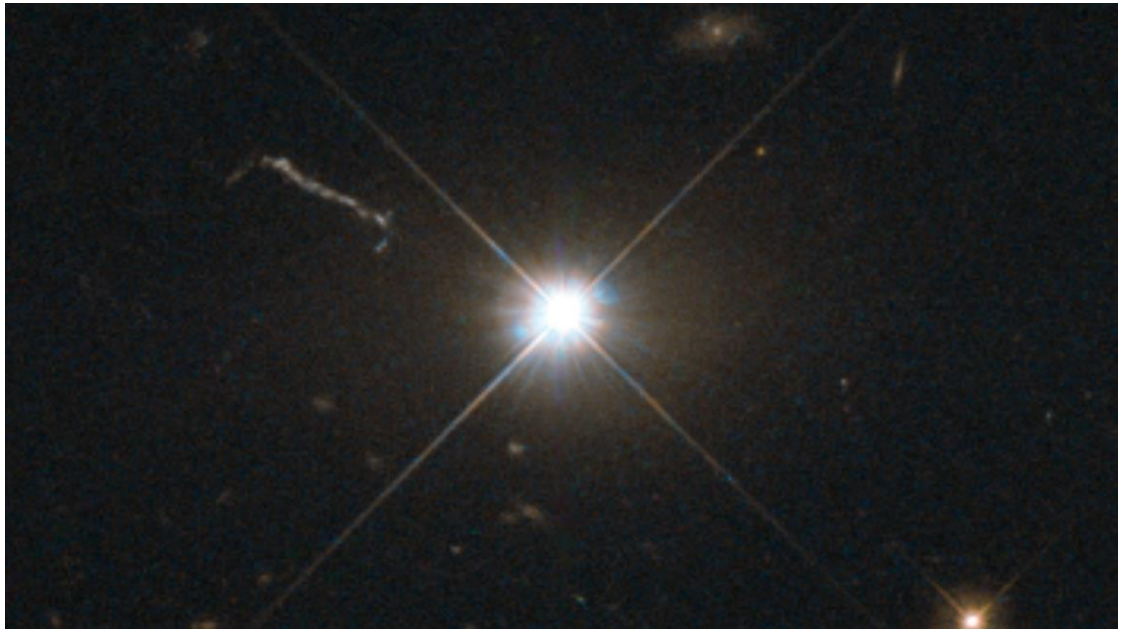
3C 273: breakthrough

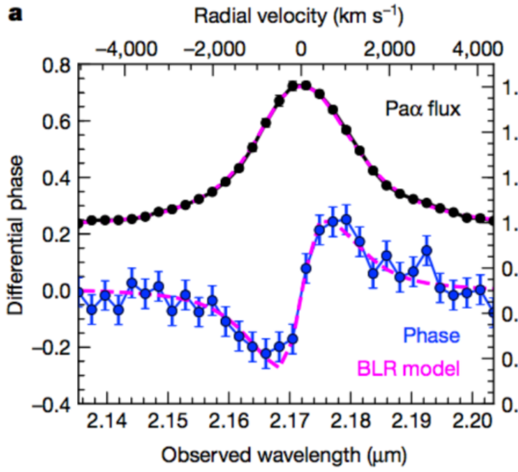
LETTER 2018, Nature, 563, 567

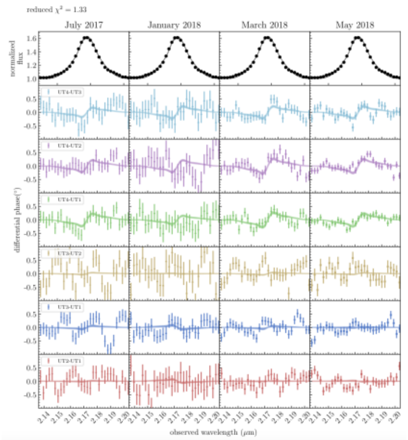
https://doi.org/10.1038/s41586-018-0731-9

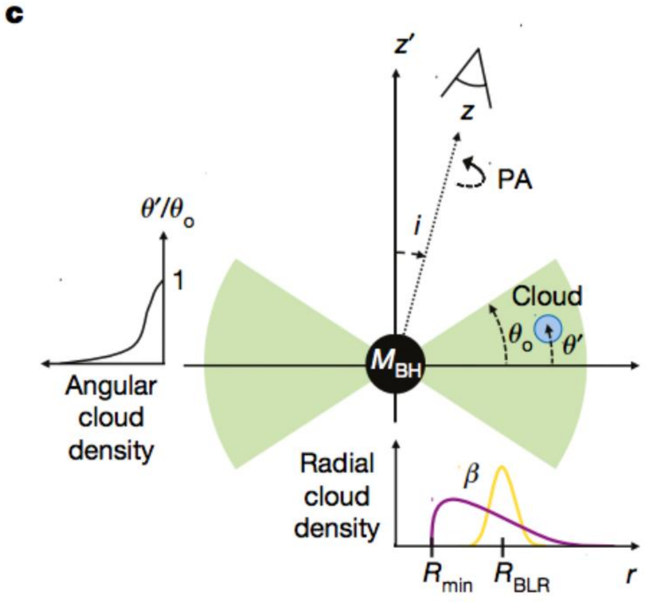
Spatially resolved rotation of the broad-line region of a quasar at sub-parsec scale

GRAVITY Collaboration*









SMBH masses:

$$(2.6 \pm 1.1) \times 10^8 M_\odot$$

Interferometry Era: GRAVITY/VLTI

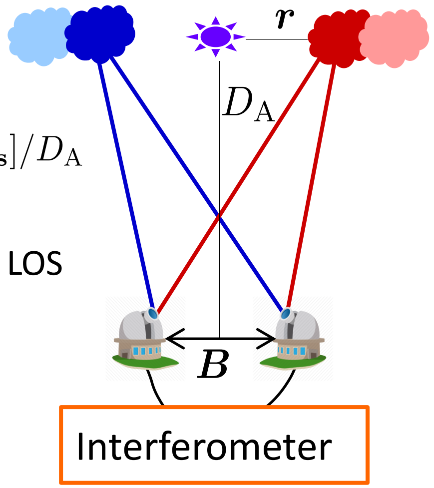
SA/GRAVITY

$$\phi_*(\lambda, \lambda_r) = -2\pi \boldsymbol{B} \cdot [\boldsymbol{\epsilon}(\lambda) - \boldsymbol{\epsilon}(\lambda_r)]/\lambda$$

$$\boldsymbol{\epsilon}(\lambda) = \bar{\boldsymbol{\alpha}}(\lambda) \sim [\boldsymbol{r} - (\boldsymbol{r} \cdot \boldsymbol{n}_{\rm obs})\boldsymbol{n}_{\rm obs}]/D_{\rm A}$$

Angular size Perpendicular to LOS

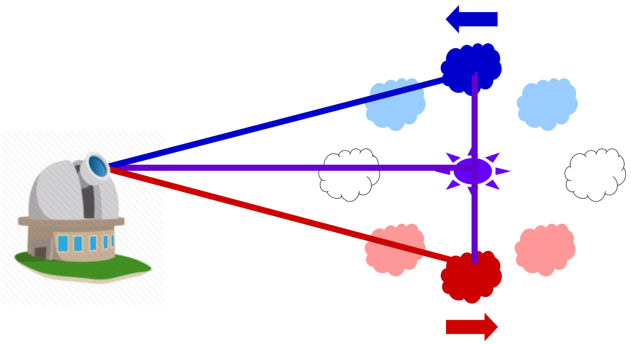
Assuming $D_{\rm A} \rightarrow R_{\rm BLR}$ and $M_\bullet$



RM

$$c\tau_{\rm lag} = r - \boldsymbol{r} \cdot \boldsymbol{n}_{\rm obs}$$

BLR size Parallel to LOS



SARM = SpectroAstrometry + Reverberation Mapping

$$\underbrace{\text{SpectroAstrometry}}_{\downarrow\ \Delta\theta} + \underbrace{\text{Reverberation Mapping}}_{\downarrow\ \Delta R} \;\Rightarrow\; D = \frac{\Delta R}{\Delta \theta}$$

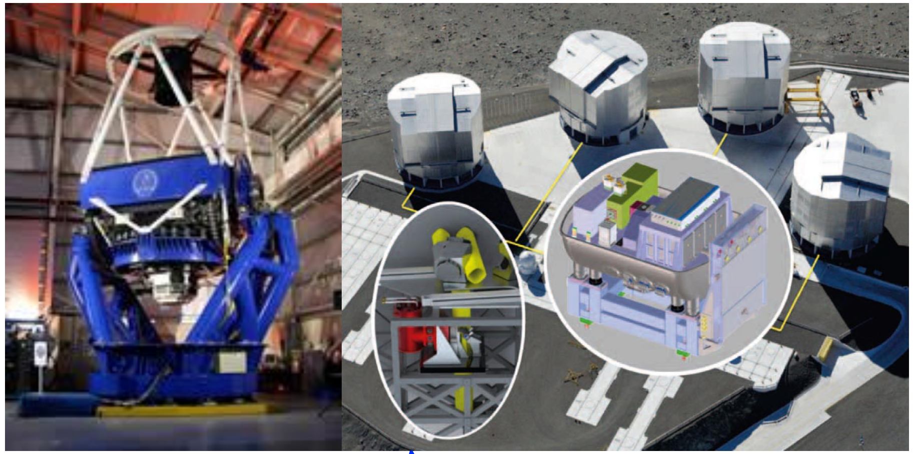
- SARM analysis
  - Precision SMBH masses
  - Geometric distances of quasars
  - High-quality 2D transfer functions: SMBH binaries

SARM : SpectroAstrometry + Reverberation Mapping

nature astronomy
LETTERS
https://doi.org/10.1038/s41550-019-0979-5

A parallax distance to 3C 273 through spectroastrometry and reverberation mapping

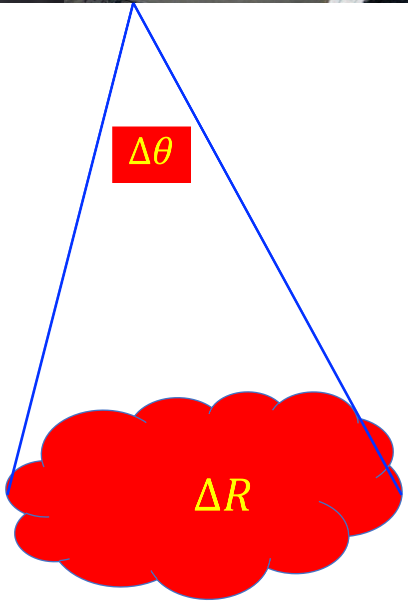
Jian-Min Wang[1,2,3]*, Yu-Yang Songsheng[1,4], Yan-Rong Li[1], Pu Du[1] and Zhi-Xiang Zhang[5]



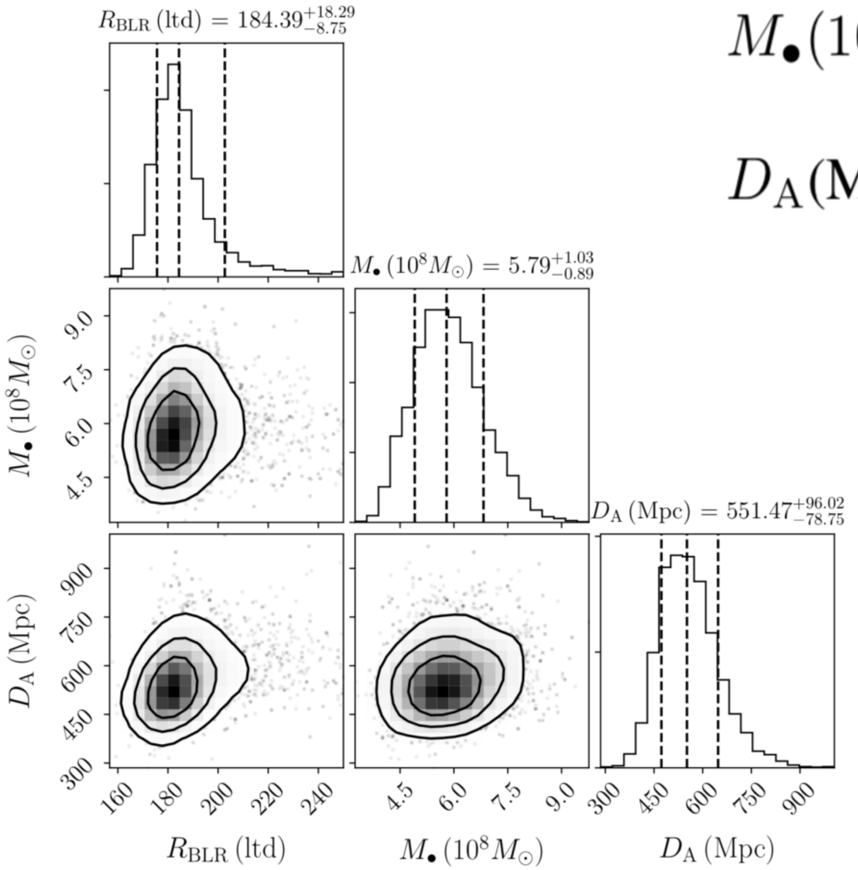
Cosmic distances and masses

$$d = \frac{\Delta R}{\Delta\theta}; \qquad M_{\rm BH}$$

2m Telescope data ≡ VLTI data. !



Cosmic distances of quasars： SARM results



$M_\bullet(10^8 M_\odot)$ $5.78^{+1.11}_{-0.88}$

$D_{\rm A}$(Mpc) $551.50^{+97.31}_{-78.71}$

$H_0 = 71.5^{+11.9}_{-10.6}\,{\rm km\,s^{-1}\,Mpc^{-1}}$

$\frac{\Delta D}{D} \sim 15\%$

Purely geometric measurements, independent of：

- 👍 extinction/reddening
- 👍 standardization
- 👍 cosmic ladders (Cepheids, SNIa)
- 👍 examinations of systematic errors

SARM is expected to expand sample

A&A 654, A85 (2021)
https://doi.org/10.1051/0004-6361/202141426

2nd SARM results

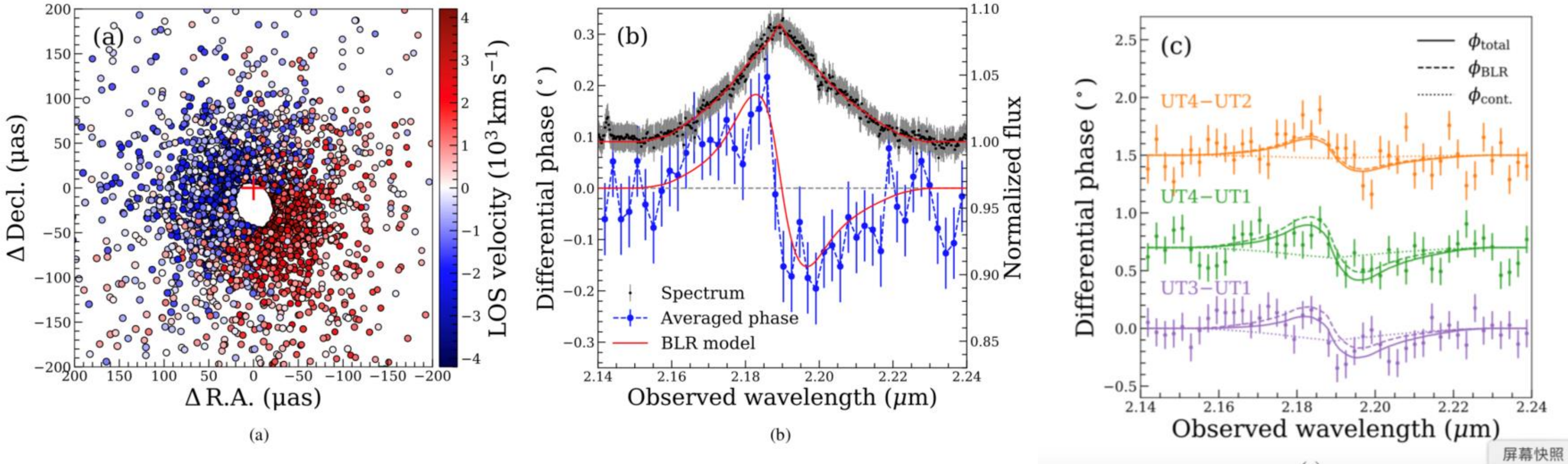
Astronomy & Astrophysics

A geometric distance to the supermassive black Hole of NGC 3783

GRAVITY Collaboration:★ A. Amorim[15,17], M. Bauböck[1], M. C. Bentz[23], W. Brandner[18], M. Bolzer[1], Y. Clénet[2], R. Davies[1], P. T. de Zeeuw[1,13], J. Dexter[20,1], A. Drescher[1,22], A. Eckart[3,14], F. Eisenhauer[1], N. M. Förster Schreiber[1], P. J. V. Garcia[11,16,17], R. Genzel[1,4], S. Gillessen[1], D. Gratadour[2,21], S. Hönig[5], D. Kaltenbrunner[1], M. Kishimoto[6], S. Lacour[2,12], D. Lutz[1], F. Millour[7], H. Netzer[8], C. A. Onken[21], T. Ott[1], T. Paumard[2], K. Perraut[9], G. Perrin[2], P. O. Petrucci[9], O. Pfuhl[12], M. A. Prieto[19], D. Rouan[2], J. Shangguan[1], T. Shimizu[1], J. Stadler[1], A. Sternberg[8,10], O. Straub[1], C. Straubmeier[3], R. Street[24], E. Sturm[1], L. J. Tacconi[1], K. R. W. Tristram[11], P. Vermot[2], S. von Fellenberg[1], F. Widmann[1], and J. Woillez[12]

(Affiliations can be found after the references)

Received 29 May 2021 / Accepted 24 July 2021



(a) (b) (c)

$$\frac{\Delta D}{D} \sim 30\%$$

SARM in collaboration

A&A 643, A154 (2020)
https://doi.org/10.1051/0004-6361/202039067

Astronomy & Astrophysics

The spatially resolved broad line region of IRAS 09149−6206

GRAVITY Collaboration: A. Amorim[19,21], M. Bauböck[1], W. Brandner[22], Y. Clénet[2], R. Davies[1], P. T. de Zeeuw[1,17], J. Dexter[24,1], A. Eckart[3,18], F. Eisenhauer[1], N. M. Förster Schreiber[1], F. Gao[1], P. J. V. Garcia[15,20,21], R. Genzel[1,4], S. Gillessen[1], D. Gratadour[2,25], S. Hönig[5], M. Kishimoto[6], S. Lacour[2,16], D. Lutz[1], F. Millour[7], H. Netzer[8], T. Ott[1], T. Paumard[2], K. Perraut[12], G. Perrin[2], B. M. Peterson[9,10,11], P. O. Petrucci[12], O. Pfuhl[16], M. A. Prieto[23], D. Rouan[2], J. Shangguan[1,⋆], T. Shimizu[1], M. Schartmann[1], J. Stadler[1], A. Sternberg[8,14], O. Straub[1], C. Straubmeier[3], E. Sturm[1], L. J. Tacconi[1], K. R. W. Tristram[15], P. Vermot[2], S. von Fellenberg[1], I. Waisberg[13], F. Widmann[1], and J. Woillez[16]

A&A, 684, A167 (2024)
https://doi.org/10.1051/0004-6361/202348167

Astronomy & Astrophysics

The size-luminosity relation of local active galactic nuclei from interferometric observations of the broad-line region⋆

GRAVITY Collaboration: A. Amorim[1,2], G. Bourdarot[3], W. Brandner[4], Y. Cao[3], Y. Clénet[5], R. Davies[3], P. T. de Zeeuw[6], J. Dexter[3,7], A. Drescher[3], A. Eckart[8,9], F. Eisenhauer[3], M. Fabricius[3], H. Feuchtgruber[3], N. M. Förster Schreiber[3], P. J. V. Garcia[2,10,11], R. Genzel[3,12], S. Gillessen[3], D. Gratadour[5,13], S. Hönig[14], M. Kishimoto[15], S. Lacour[5,16], D. Lutz[3], F. Millour[17], H. Netzer[18], T. Ott[3], T. Paumard[5], K. Perraut[19], G. Perrin[5], B. M. Peterson[22,⋆⋆], P. O. Petrucci[19], O. Pfuhl[16], M. A. Prieto[20], S. Rabien[3], D. Rouan[5], D. J. D. Santos[3], J. Shangguan[3], T. Shimizu[3], A. Sternberg[18,21], C. Straubmeier[8], E. Sturm[3], L. J. Tacconi[3], K. R. W. Tristram[10], F. Widmann[3], and J. Woillez[16]

Table 1. Physical properties of our four new targets and the three targets that were already observed by GRAVITY.

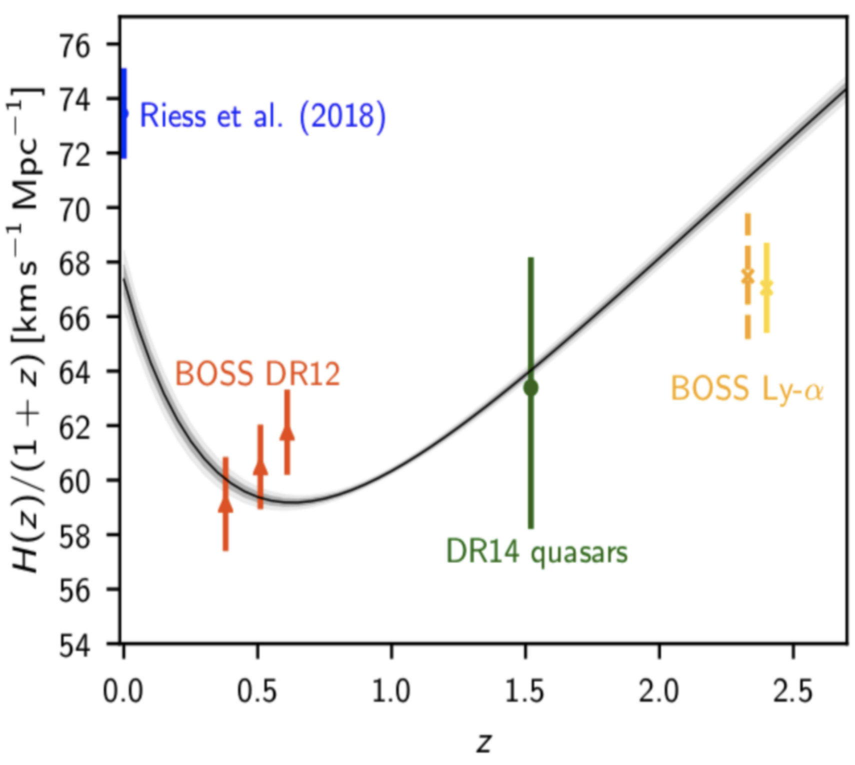
Object (1)	RA (J2000) (2)	Dec (J2000) (3)	z (4)	$\log \lambda L_\lambda$ (5100 Å) (erg s^{-1}) (5)	Ref. (6)	σ_* (km s^{-1}) (7)	Ref. (8)	D_A (Mpc) (9)
Mrk 509	20:44:09.738	−10:43:24.54	0.0344	44.19	1	182	8	144
PDS 456	17:28:19.796	−14:15:55.87	0.185	46.30	2	182$^{(1)}$	This work	657
Mrk 1239	09:52:19.102	−01:36:43.46	0.020	44.40$^{(2)}$	3	~250$^{(3)}$	9	86
IC 4329A	13:49:19.266	−30:18:33.97	0.016	43.51	4	~225	9	69
3C 273	12:29:06.700	+02:03:08.60	0.158	45.90	1	210	10	582
NGC 3783	11:39:01.762	−37:44:19.21	0.0097	43.02	6	95	11	42
IRAS 09149-6206	09:16:09.39	−62:19:29.90	0.0573	44.92d	5,7	250$^{(4)}$	7	236

The Astrophysical Journal Supplement Series, 253:57 (15pp), 2021 April https://doi.org/10.3847/1538-4365/abe539

Geometric Distances of Quasars Measured by Spectroastrometry and Reverberation Mapping: Monte Carlo Simulations

Yu-Yang Songsheng[1,2], Yan-Rong Li[1], Pu Du[1], and Jian-Min Wang[1,2,3]
[1] Key Laboratory for Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, 19B Yuquan Road, Beijing 100049, People's Republic of China; wangjm@ihep.ac.cn
[2] University of Chinese Academy of Sciences, 19A Yuquan Road, Beijing 100049, People's Republic of China
[3] National Astronomical Observatories of China, Chinese Academy of Sciences, 20A Datun Road, Beijing 100020, People's Republic of China
Received 2020 November 25; revised 2021 January 28; accepted 2021 February 9; published 2021 April 13

- 100 AGNs: 2-3%



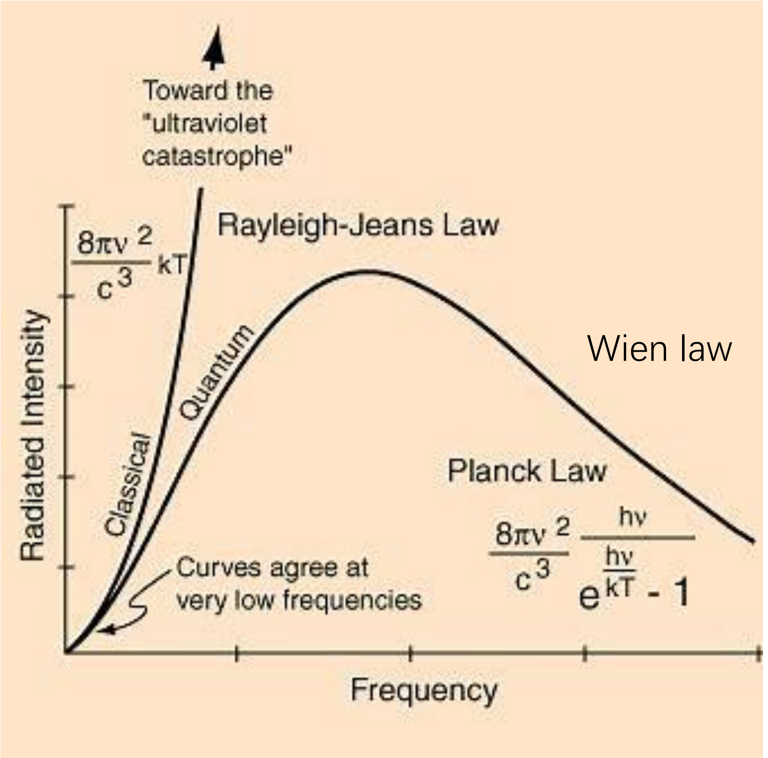
Big question：Cosmic dynamics

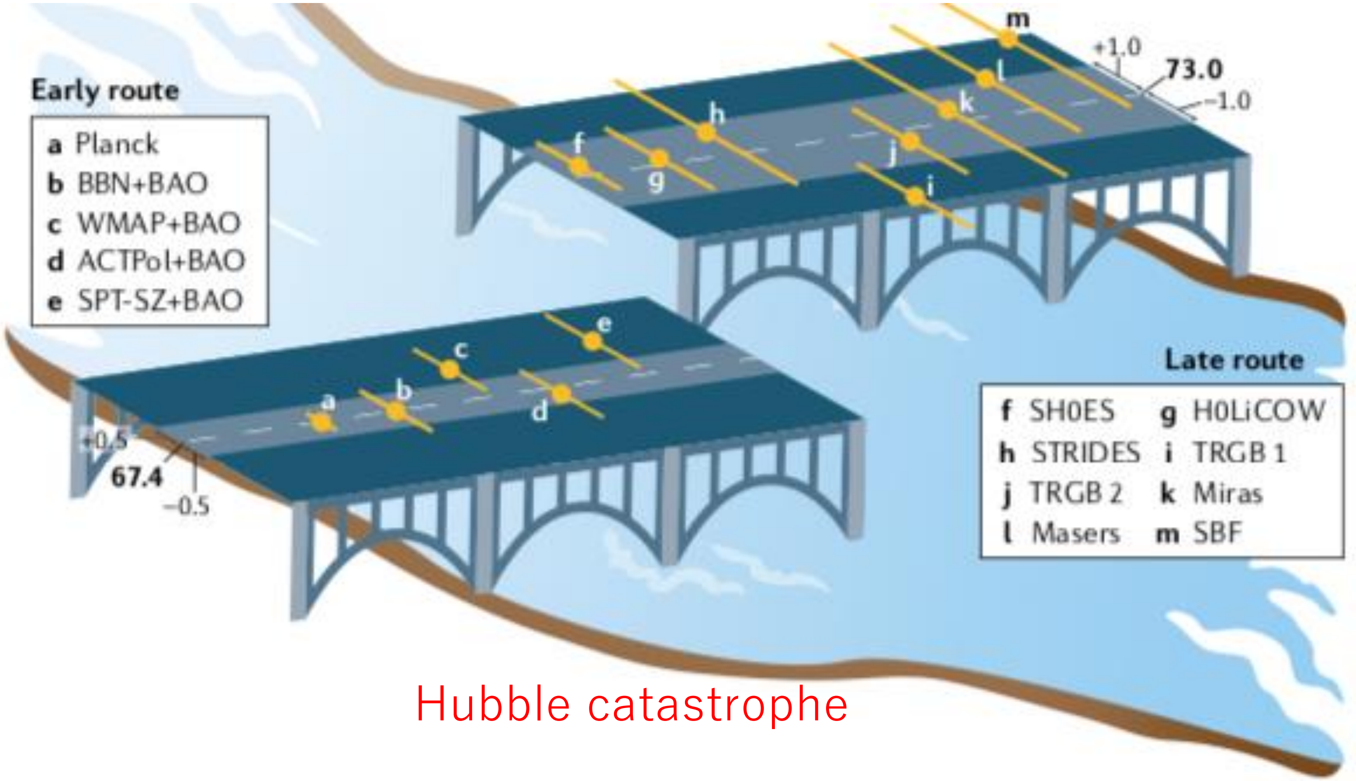
"quantum born"

Max Planck

"new physics born?"

Adams Riess

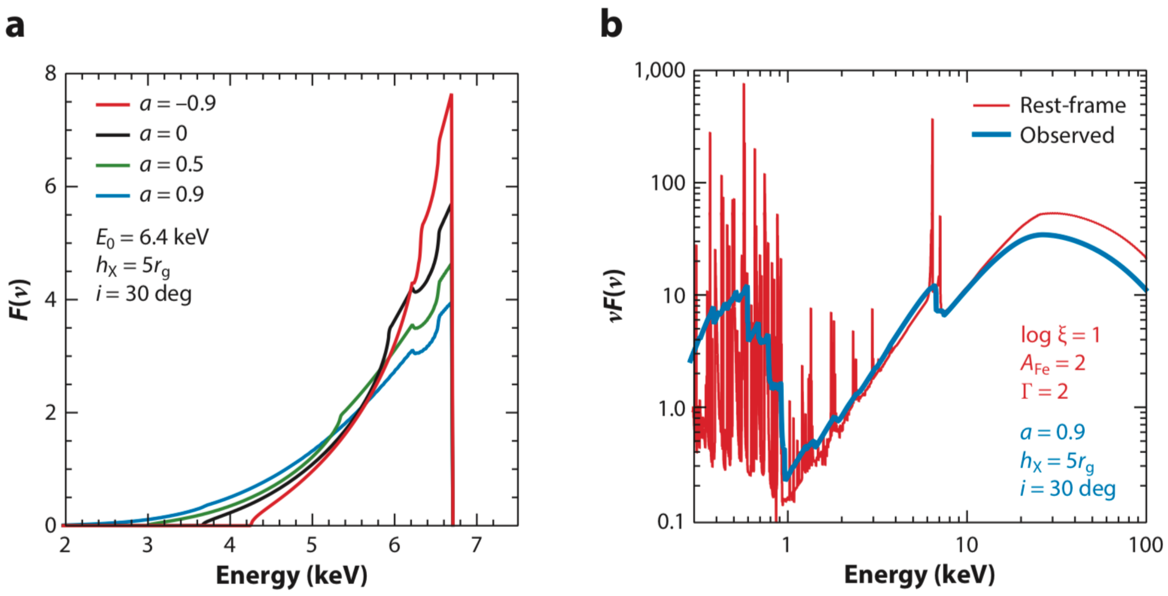


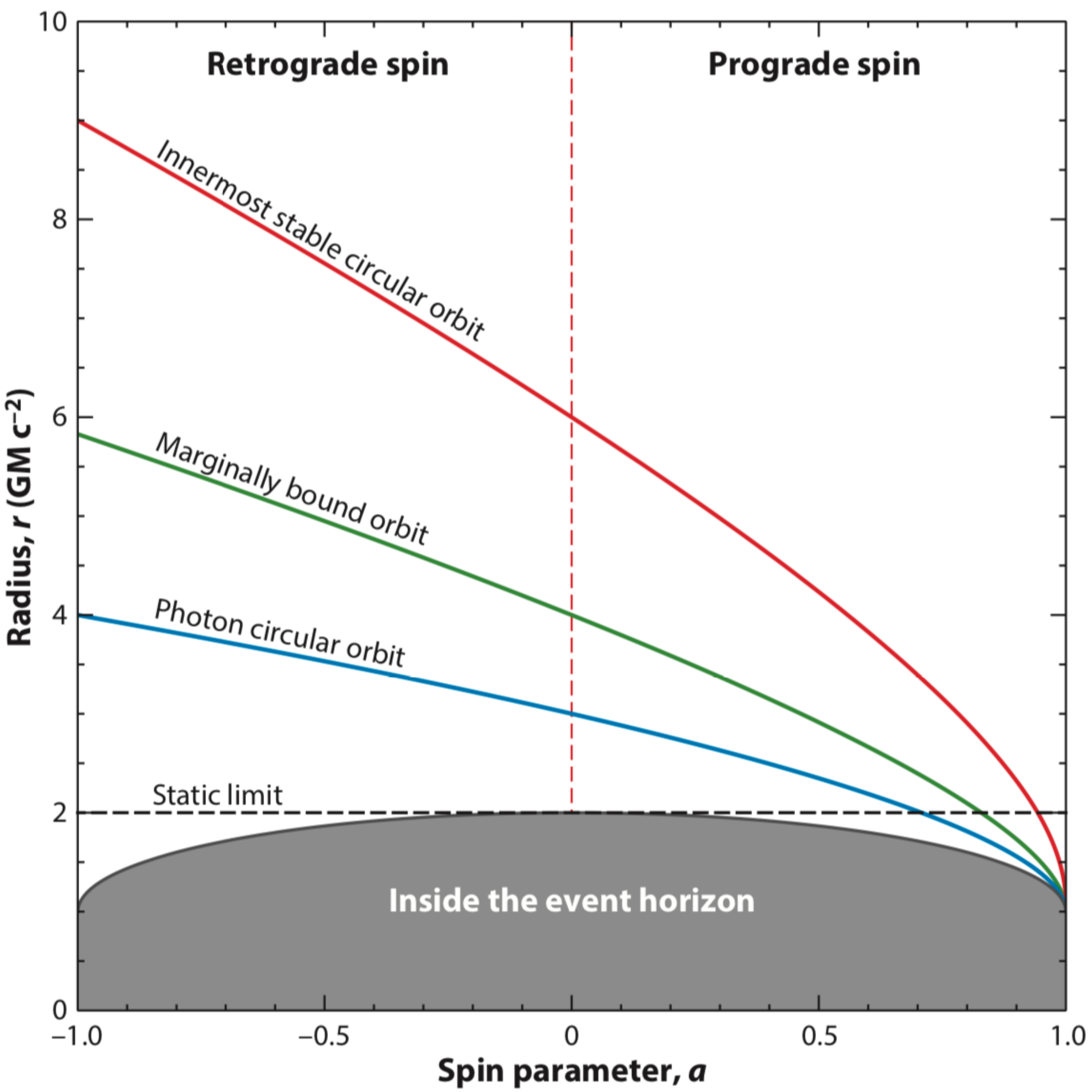


Hubble catastrophe

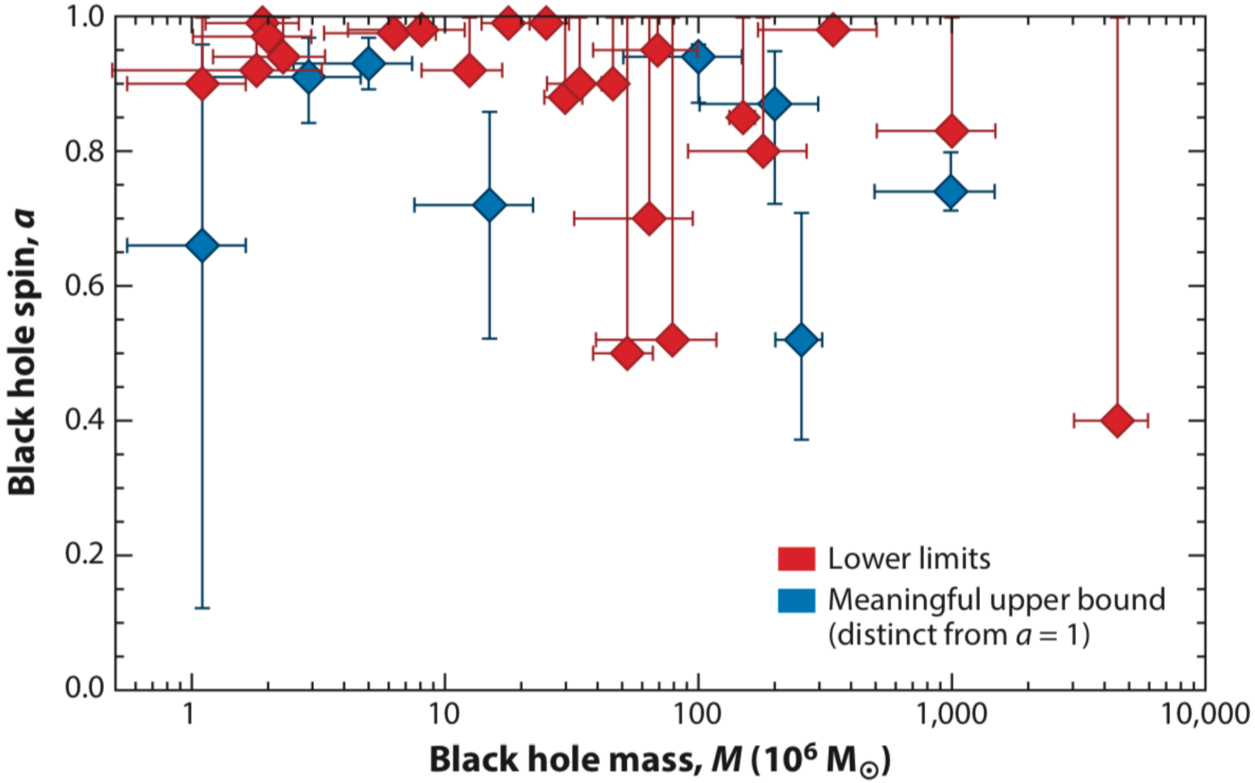
BH spins: X-rays
(Reynolds 2021)

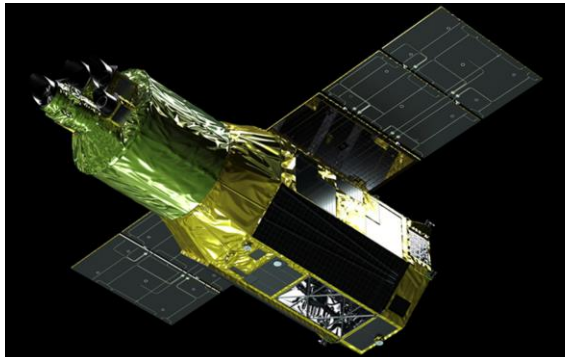
Spins: history of accretion





Results:





Hitomi → XRISM

(2016)

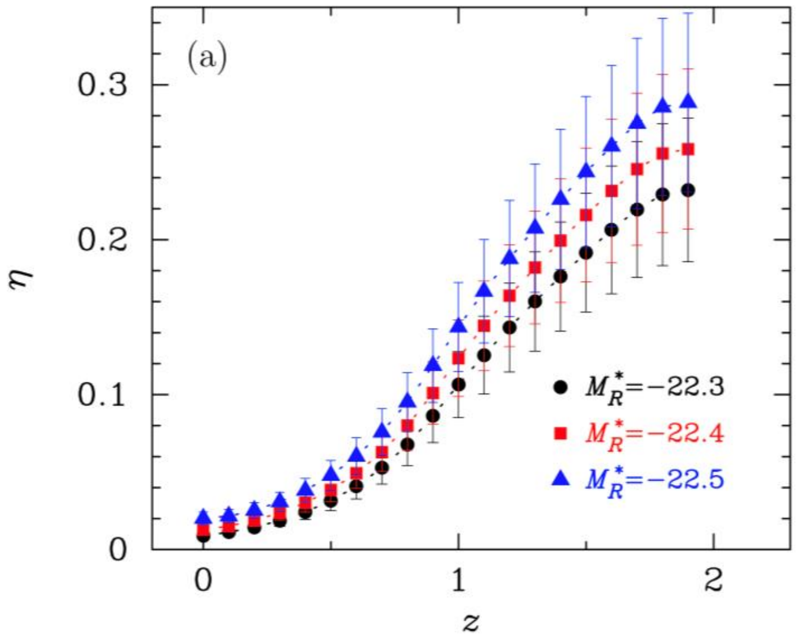
X-ray Imaging and Spectroscopy Mission

The Astrophysical Journal, 697:L141–L144, 2009 June 1 doi:10.1088/0004-637X/697/2/L141

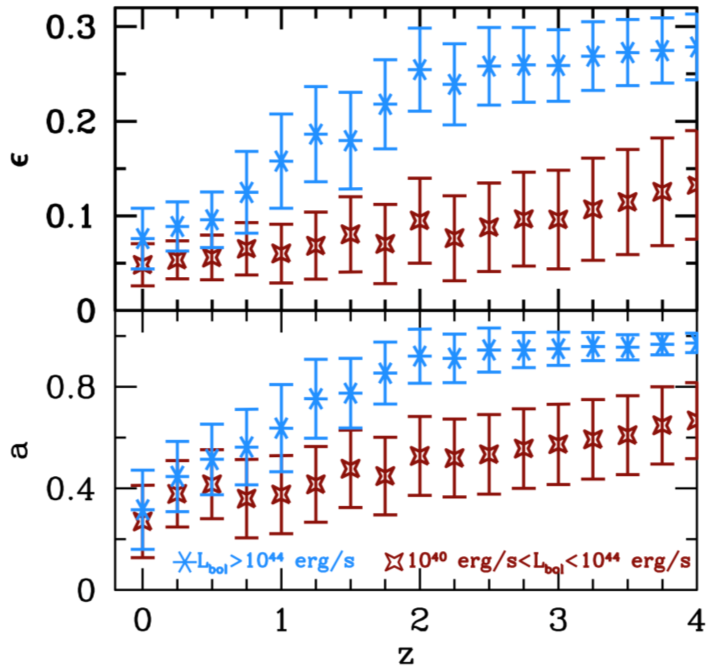
EPISODIC RANDOM ACCRETION AND THE COSMOLOGICAL EVOLUTION OF SUPERMASSIVE BLACK HOLE SPINS

Jian-Min Wang[1,2], Chen Hu[1], Yan-Rong Li[1], Yan-Mei Chen[1], Andrew R. King[3], Alessandro Marconi[4], Luis C. Ho[5], Chang-Shuo Yan[1], Rüdiger Staubert[6], and Shu Zhang[1]

Cosmic evolution of spins: $$\eta^{-1} = 1 + \frac{c^2}{\dot{U}}\left(\frac{dt}{dz}\right)^{-1}\frac{d}{dz}\left(\frac{\rho_\bullet^{\rm qso}}{\delta}\right).$$

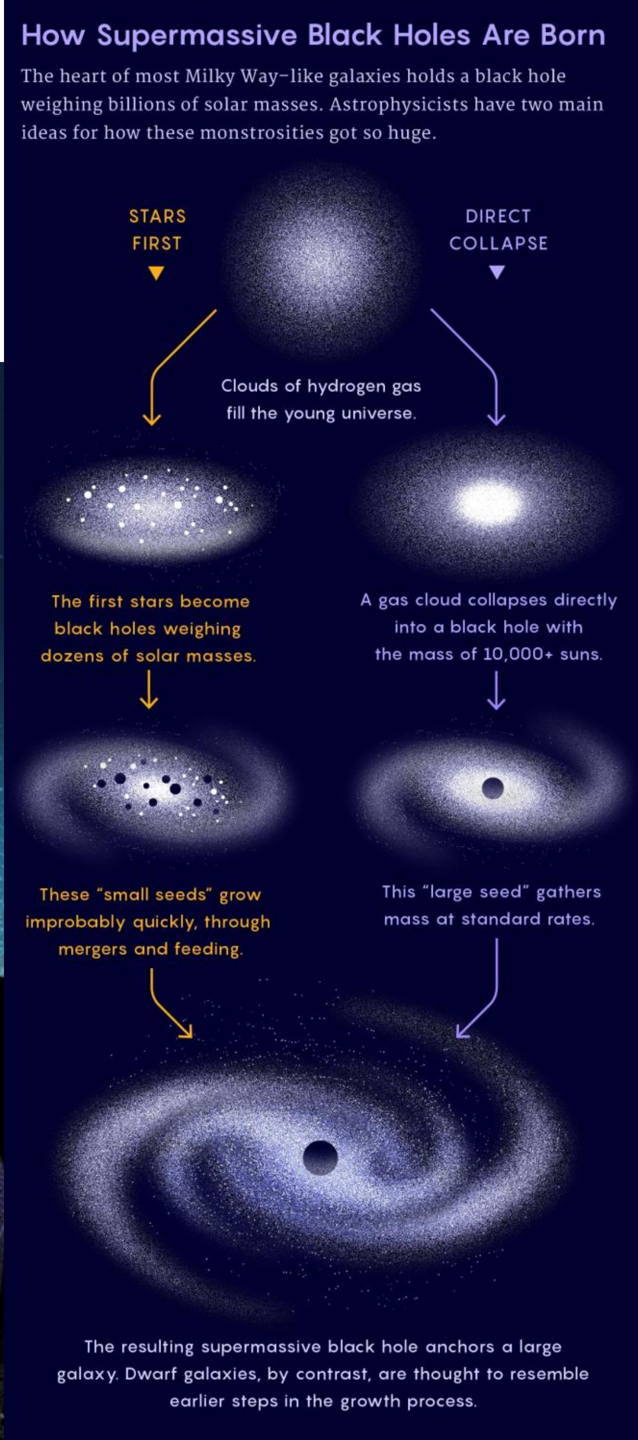


Wang+2009



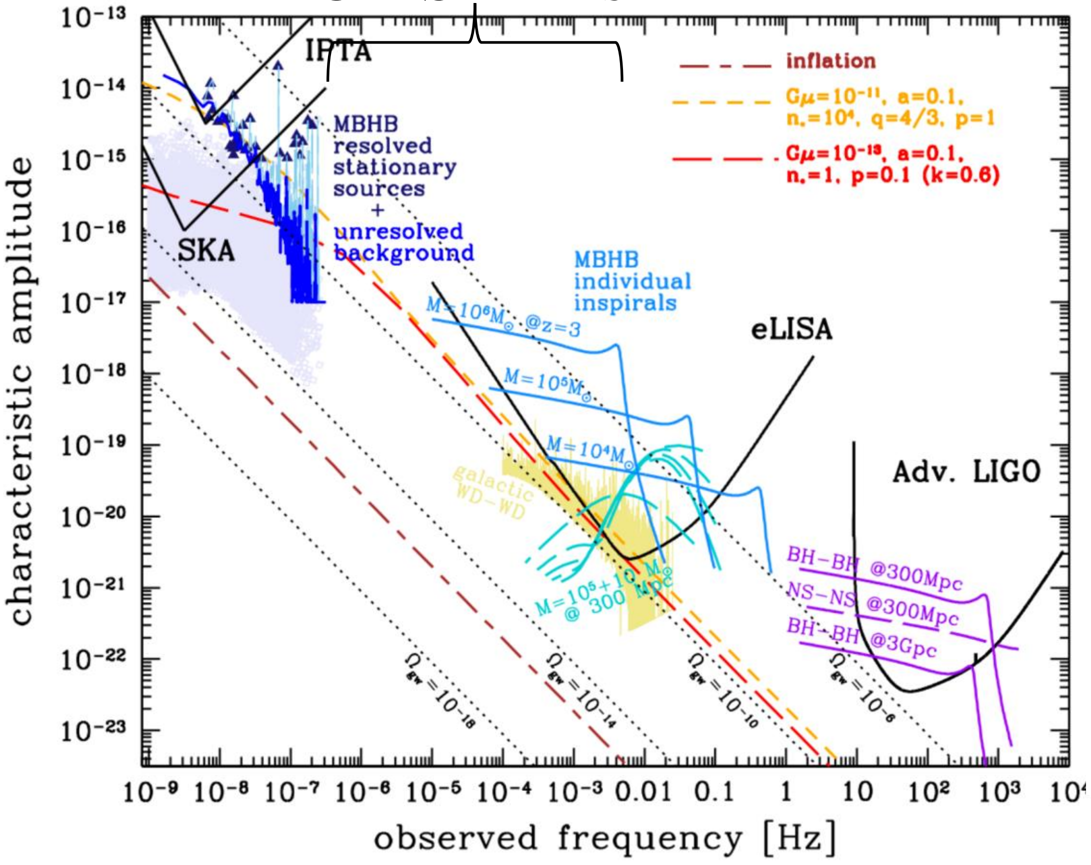
Volonteri+2013

3、SMBH binaries and nano-Hz GWs

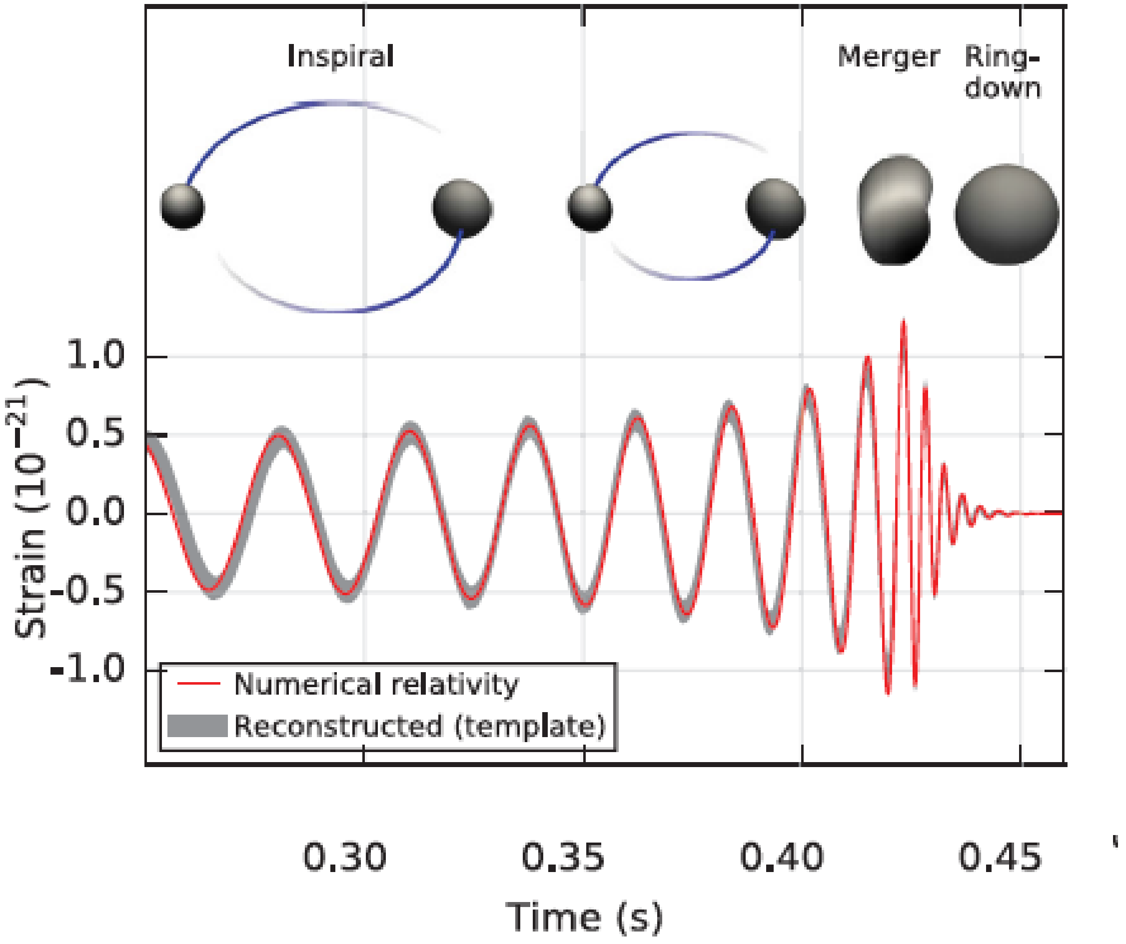


SMBH binaries： orbital parameters？

CB-SMBHs



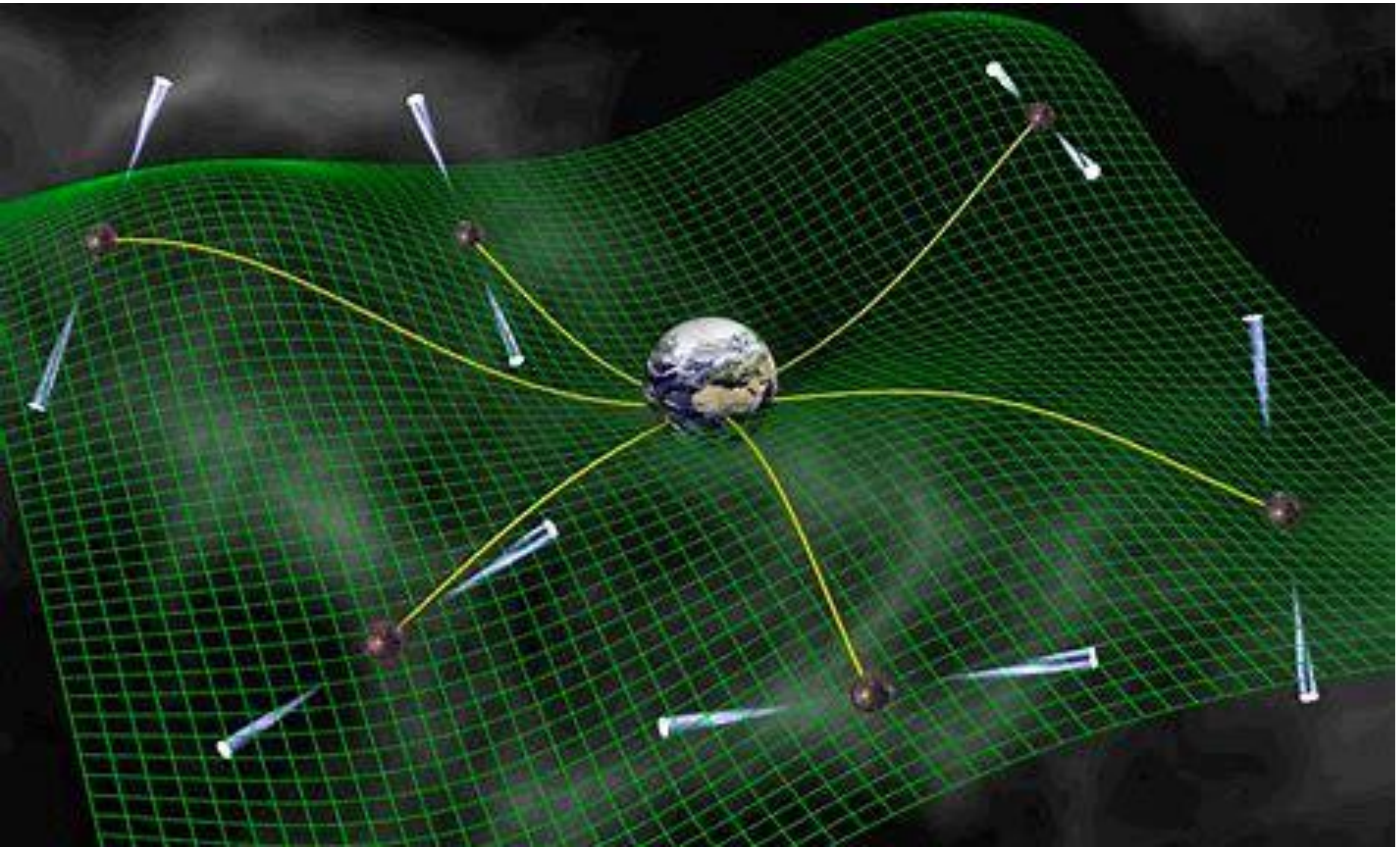
LIGO: 100Hz-GWs

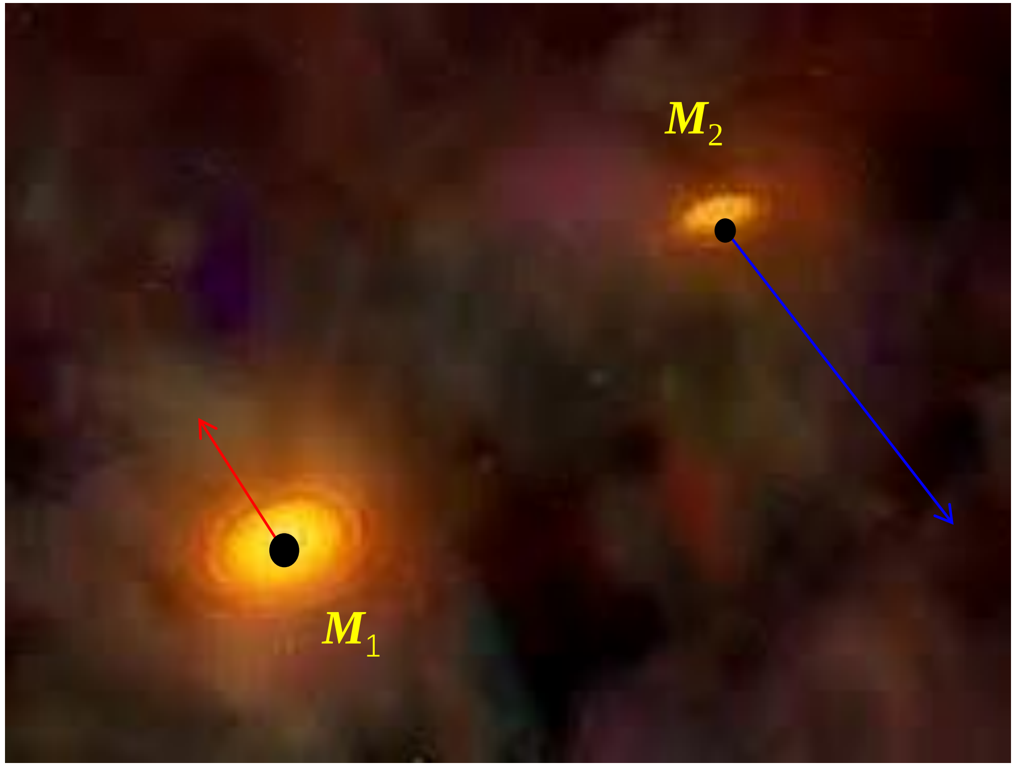


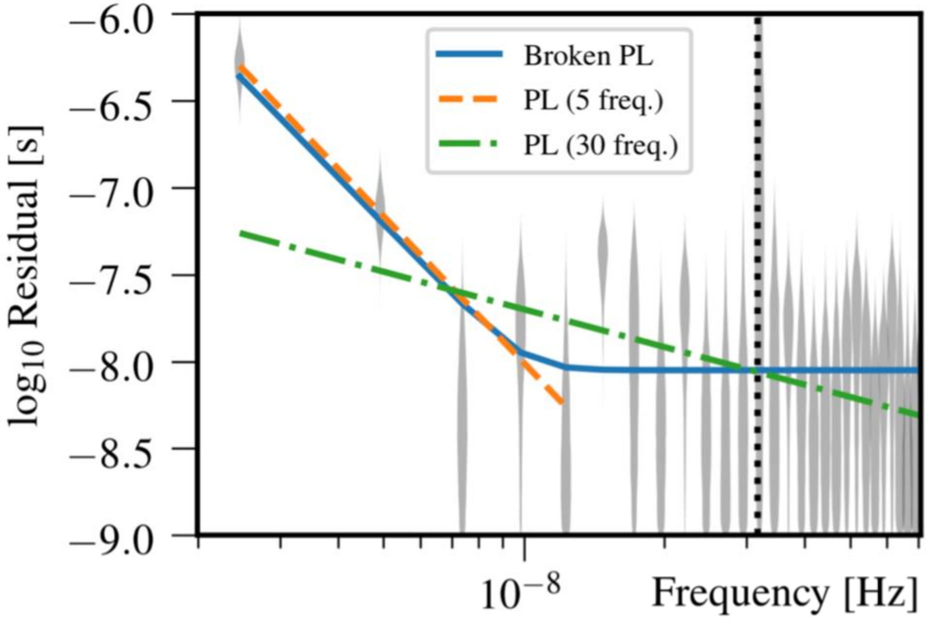
Period ～ 10-100yrs： entire waveform possible， chirping impossible

PTA：CB-SMBHs for GWs

(Songsheng+2021)







Arzoumanian+2009.04496

THE ASTROPHYSICAL JOURNAL, 862:171 (10pp), 2018 August 1 https://doi.org/10.3847/1538-4357/aacdfa

CrossMark

Kinematic Signatures of Reverberation Mapping of Close Binaries of Supermassive Black Holes in Active Galactic Nuclei

Jian-Min Wang[1,2,3], Yu-Yang Songsheng[1,2], Yan-Rong Li[1], and Zhe Yu[1,2]

For binary BLRs

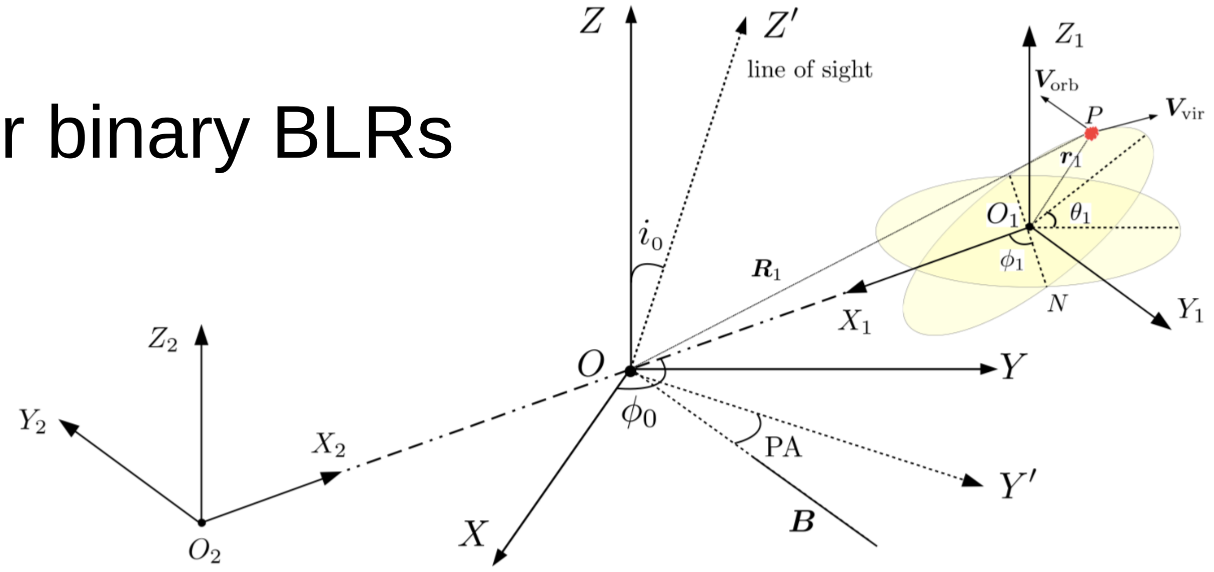
Blandford & McKee(1982):

2D-transfer functions of

a single BLR

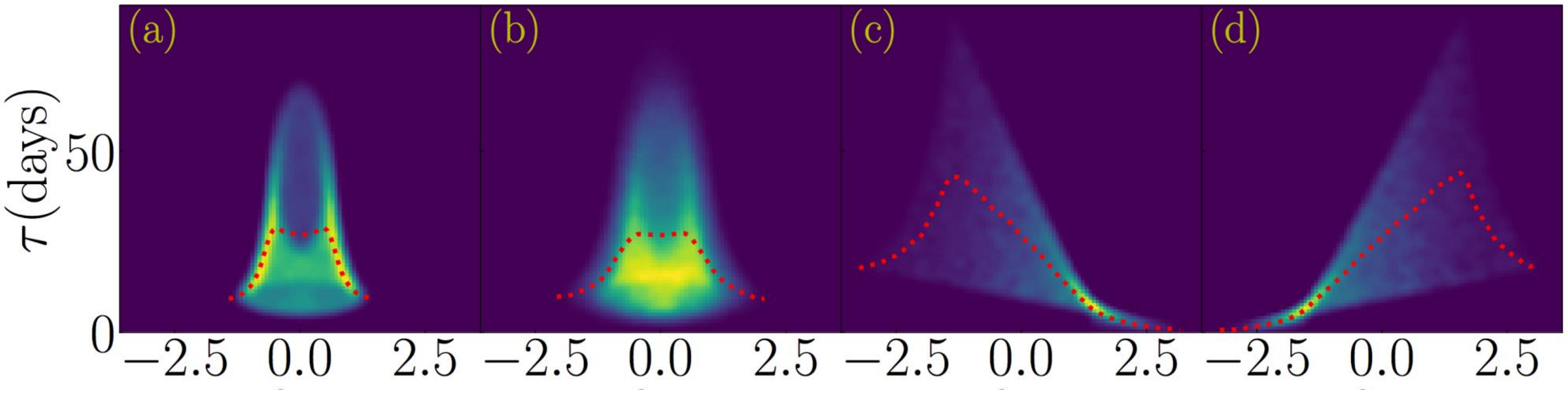
$$\Psi(v,\, t) = \frac{1}{2\pi}\mathscr{F}^{-1}\left[\frac{\tilde{L}_{\ell}(v,\, \omega)}{\tilde{L}_{\rm c}(v,\, \omega)}\right],$$

$$\tilde{L}_{\ell,{\rm c}} = \mathscr{F}[L_{\ell,{\rm c}}(v,\, t)],$$

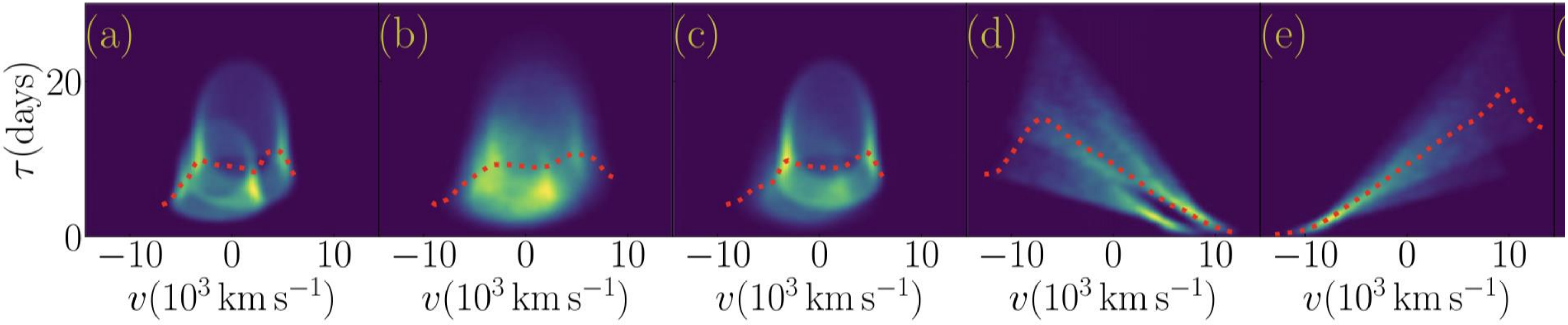


$$\Psi_{\rm tot}(v,\, t) = \frac{\Psi_1(v,\, t)}{1 + \Gamma_0} + \frac{\Psi_2(v,\, t)}{1 + \Gamma_0^{-1}},$$

Songsheng+(2020); Kovacevic+(2020)



A single BLR



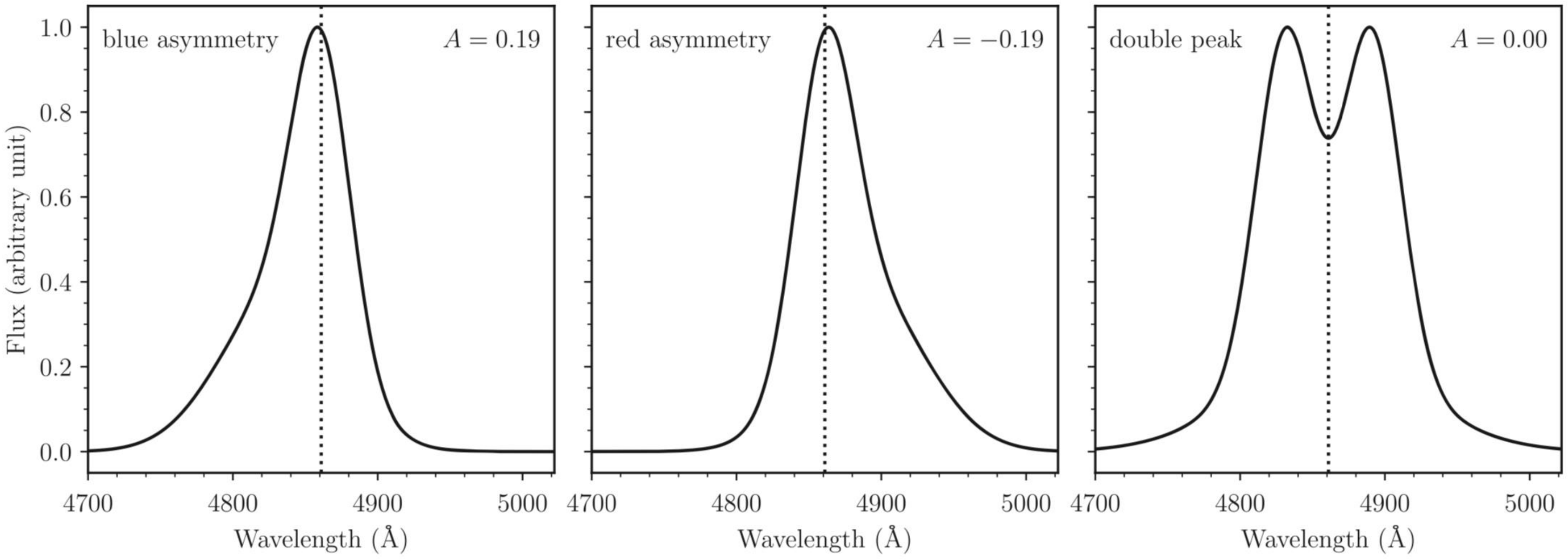
RM: 2D transfer functions

（Wang+2018；Songsheng+2019; Kovacevic+2019）

Offsets are due to orbital motion

Wyoming IR Observatory 2.3m: MAHA since 2017

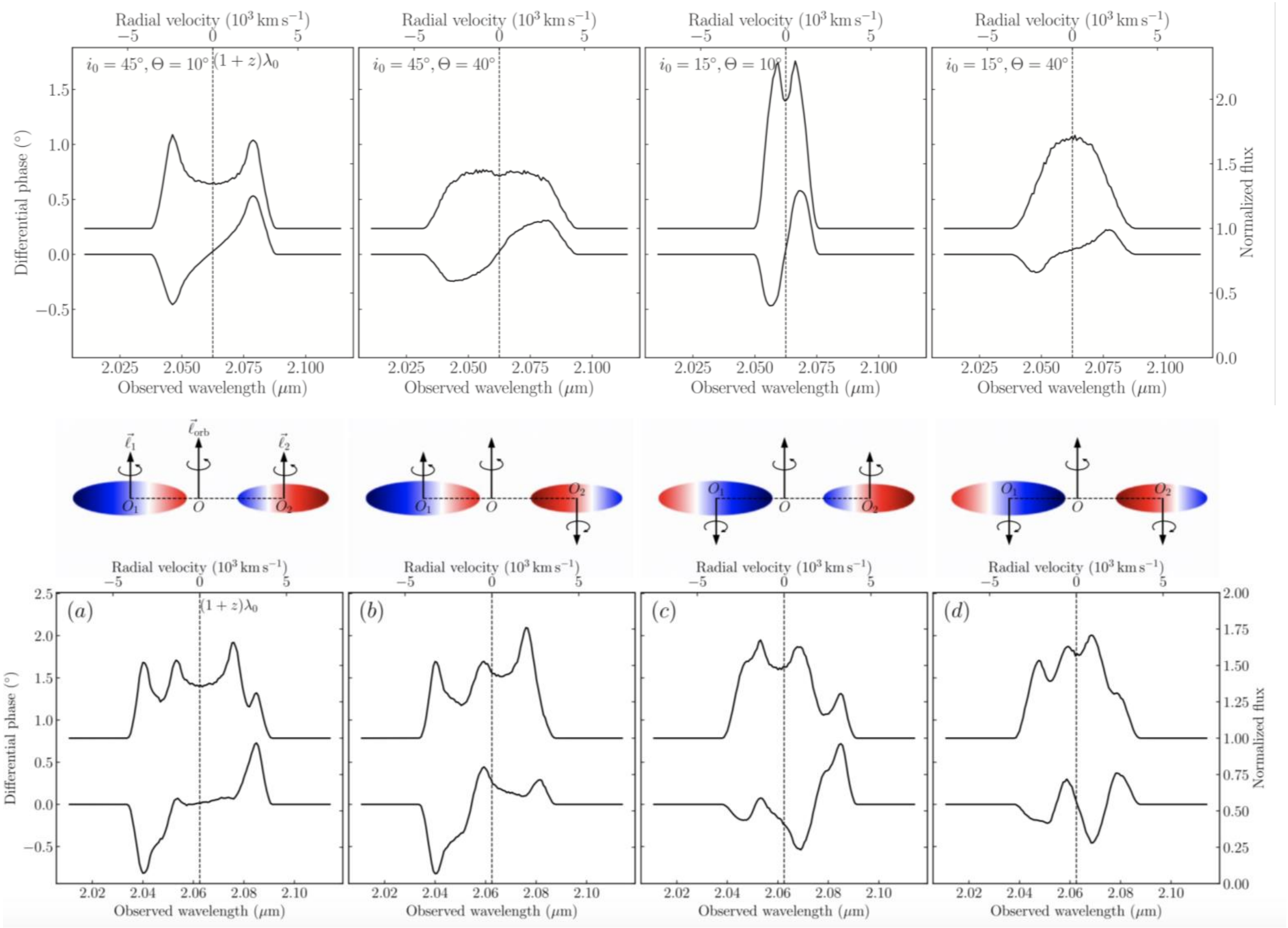
(Monitoring AGNs with Hβ Asymmetry)

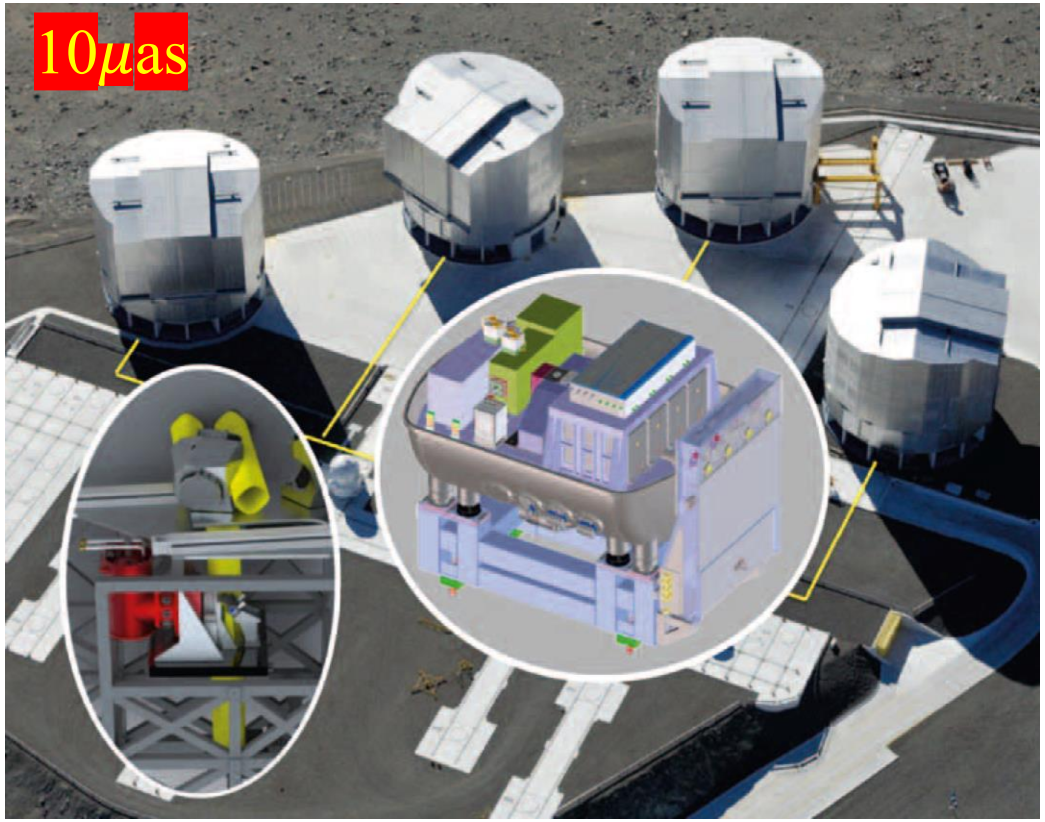


For SMBH binaries

Sample: ~100 AGNs

Signals: GRAVITY/VLTI (Songsheng+2019, Kovacevic+2020)

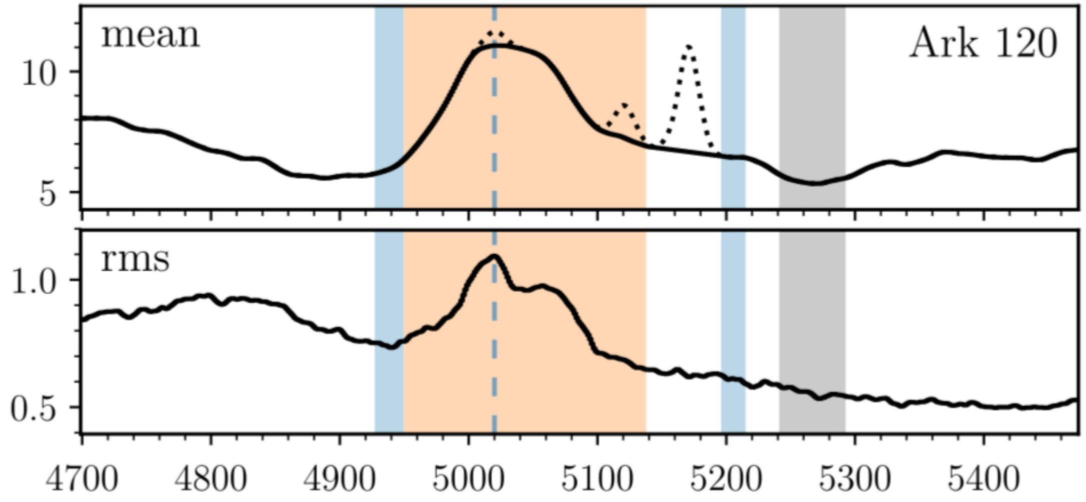


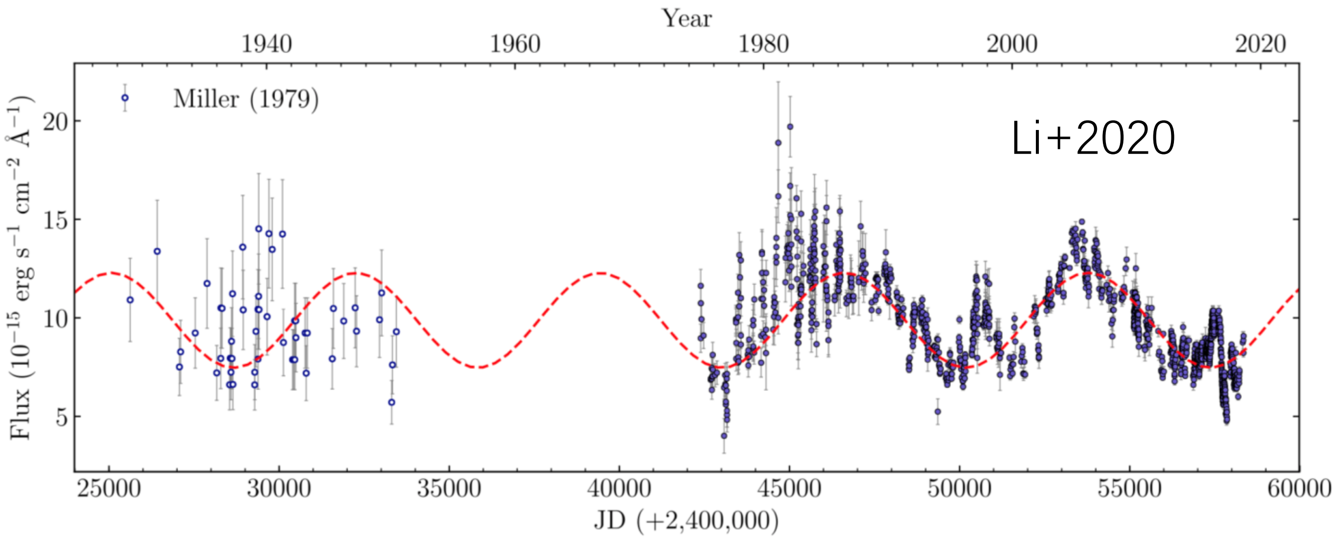


More complicated signals see Kovacevic+2020

VLTI (25hours): Akn 120

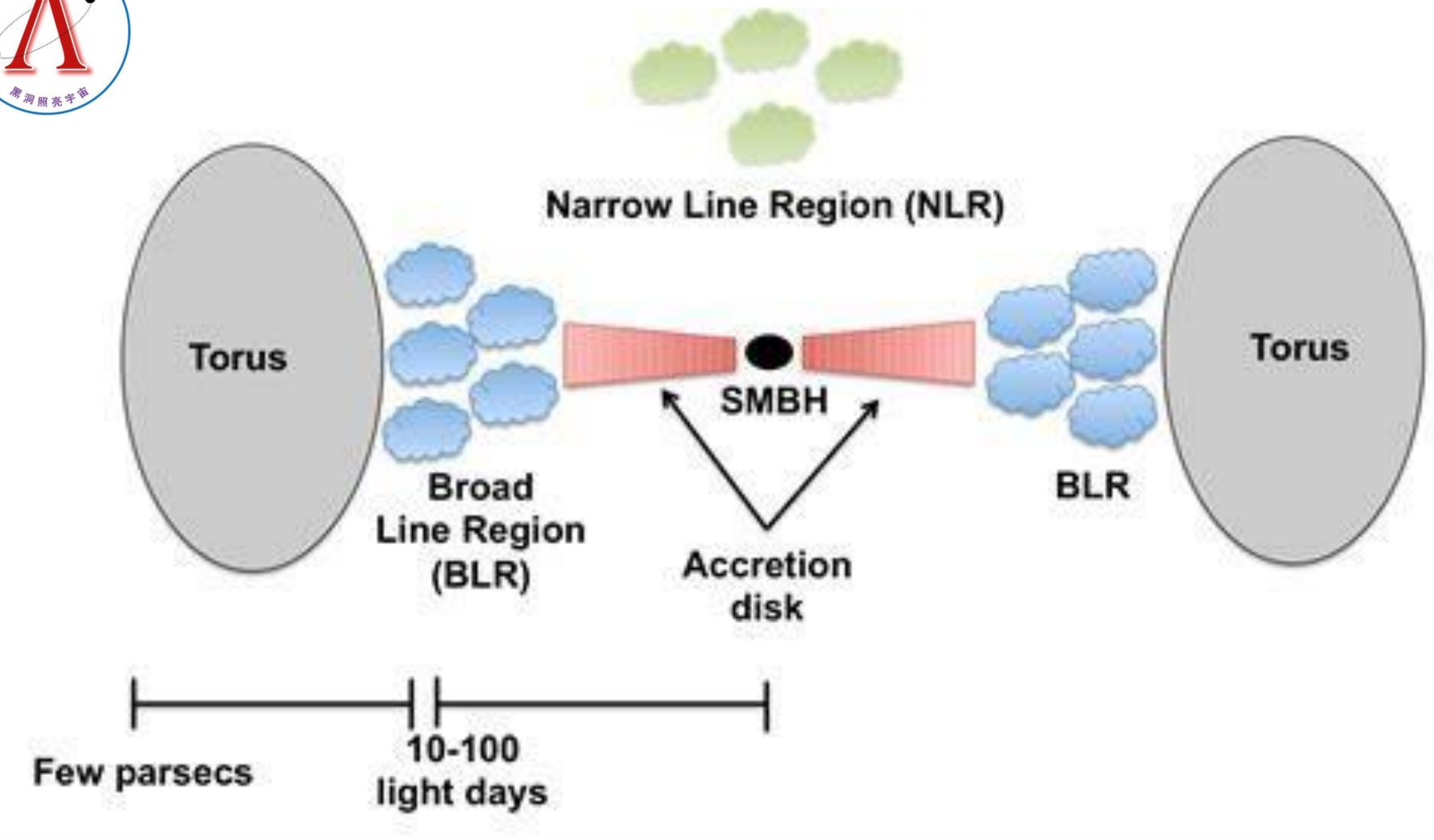
Joint the Largest Telescopes

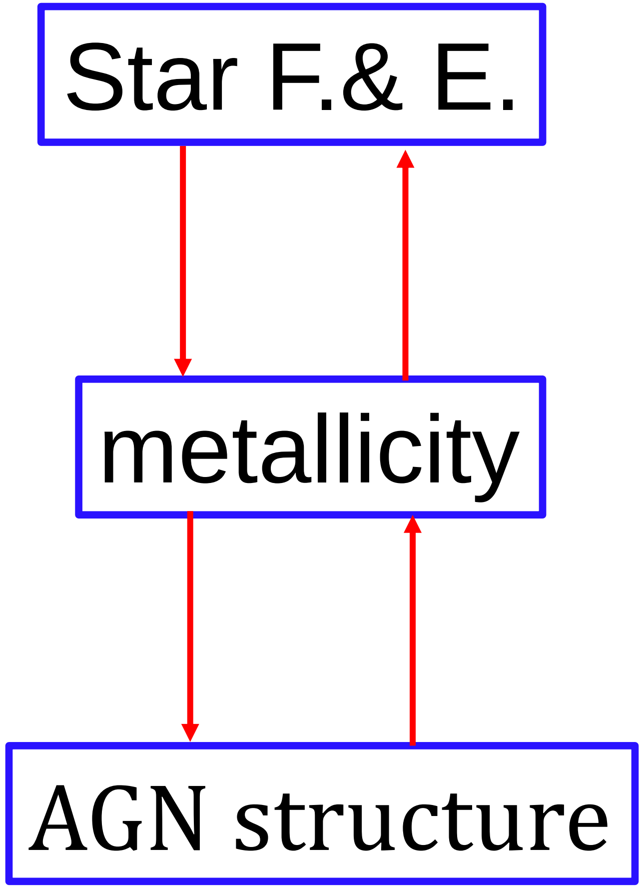




4、Satellite BHs of SMBH: observational consequences

Formation of AGN structure





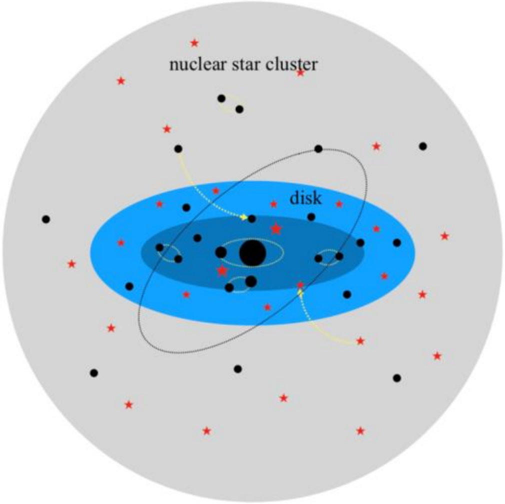
Observations of variations：lines and continuum

THE ASTROPHYSICAL JOURNAL, 409:592–603, 1993 June 1

STAR TRAPPING AND METALLICITY ENRICHMENT IN QUASARS AND ACTIVE GALACTIC NUCLEI[1]

PAWEŁ ARTYMOWICZ,[2,3] D. N. C. LIN,[2,4] AND E. JOSEPH WAMPLER[5]

Received 1992 August 3; accepted 1992 December 7



Metal-rich BLR:：stars inside accretion disks？

THE ASTROPHYSICAL JOURNAL, 521:502–508, 1999 August 20

THE FORMATION AND MERGER OF COMPACT OBJECTS IN THE CENTRAL ENGINE OF ACTIVE GALACTIC NUCLEI AND QUASARS: GAMMA-RAY BURST AND GRAVITATIONAL RADIATION

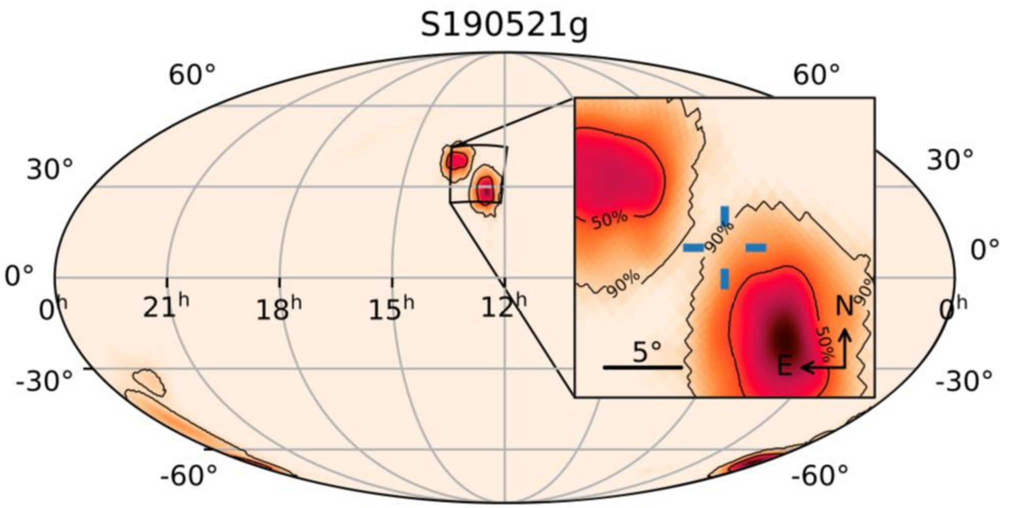
K. S. CHENG
Physics Department, University of Hong Kong, Hong Kong, People's Republic of China

AND

JIAN-MIN WANG
Astronomy Department, Beijing Normal University, Beijing 100875; Astronomy Department, Nanjing University, Nanjing 210008; and Chinese Academy of Sciences-Peking University Joint Beijing Astrophysical Center (CAS-PKU.BAC), Beijing 100871, People's Republic of China
Received 1998 October 7; accepted 1999 April 1

Prediction：GRB、Compact objects and GWs

预言21年后观测：初步证据



LIGO detection of GW 190521

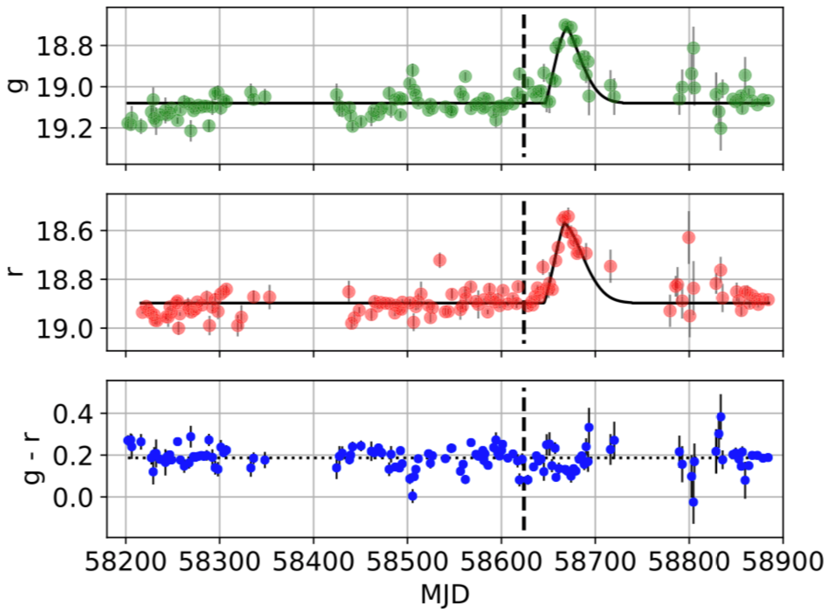
PHYSICAL REVIEW LETTERS **124,** 251102 (2020)

Editors' Suggestion   Featured in Physics

Candidate Electromagnetic Counterpart to the Binary Black Hole Merger Gravitational-Wave Event S190521g*

M. J. Graham,[1,†] K. E. S. Ford,[2,3,4] B. McKernan,[2,3,4] N. P. Ross,[5] D. Stern,[6] K. Burdge,[1] M. Coughlin,[7,8] S. G. Djorgovski,[1] A. J. Drake,[1] D. Duev,[1] M. Kasliwal,[1] A. A. Mahabal,[1] S. van Velzen,[9,10] J. Belecki,[11] E. C. Bellm,[12] R. Burruss,[11] S. B. Cenko,[13,14] V. Cunningham,[9] G. Helou,[15] S. R. Kulkarni,[1] F. J. Masci,[15] T. Prince,[1] D. Reiley,[11] H. Rodriguez,[11] B. Rusholme,[15] R. M. Smith,[11] and M. T. Soumagnac[16,17]

ZTF detection of quasar flare
J124942.3 + 344929 at z = 0.438 (Graham+2019)



AGN accretion disks： compact objects

The Astrophysical Journal, 937:61 (12pp), 2022 October 1 https://doi.org/10.3847/1538-4357/ac8163

OPEN ACCESS

CrossMark

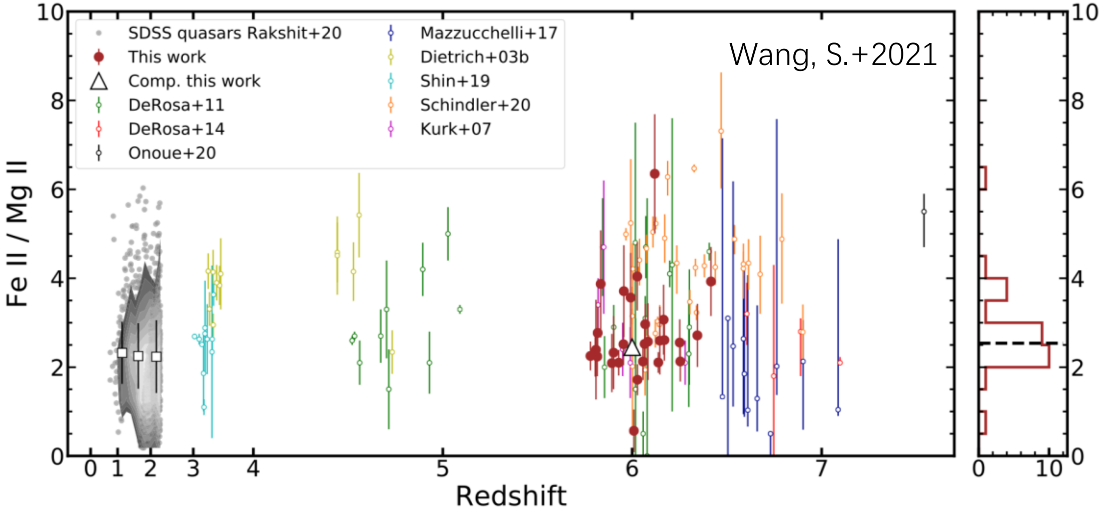
Potential Signature of Population III Pair-instability Supernova Ejecta in the BLR Gas of the Most Distant Quasar at $z = 7.54$*

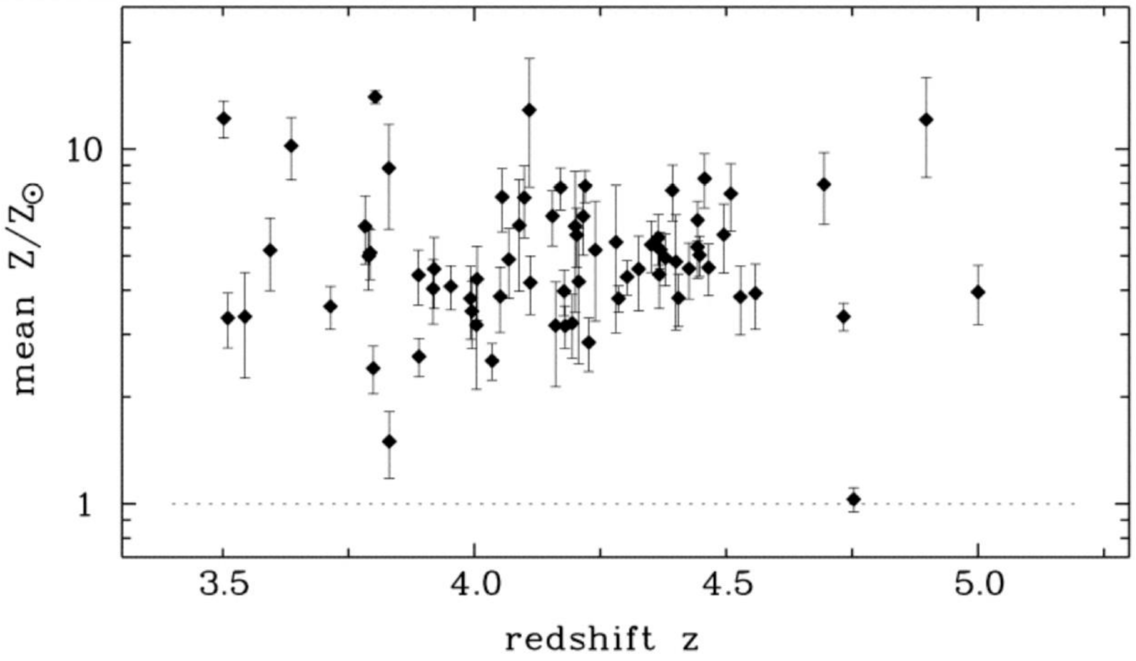
Yuzuru Yoshii[1,2], Hiroaki Sameshima[1], Takuji Tsujimoto[3], Toshikazu Shigeyama[4], Timothy C. Beers[5], and Bruce A. Peterson[6]

[1] Institute of Astronomy, School of Science, The University of Tokyo, 2-21-1 Osawa, Mitaka, Tokyo 181-0015, Japan; yoshii@ioa.s.u-tokyo.ac.jp
[2] Steward Observatory, University of Arizona, 933 North Cherry Avenue, Room N204, Tucson, AZ 85721-0065, USA
[3] National Astronomical Observatory of Japan, Mitaka-shi, Tokyo 181-8588, Japan
[4] Research Center for the Early universe, Graduate School of Science, University of Tokyo, Bunkyo-ku, Tokyo 113-0033, Japan
[5] Department of Physics and JINA Center for the Evolution of the Elements (JINA-CEE), University of Notre Dame, Notre Dame, IN 46556, USA
[6] Mount Stromlo Observatory, Research School of Astronomy and Astrophysics, Australian National University, Weston Creek P.O., ACT 2611, Australia
Received 2021 August 13; revised 2022 July 12; accepted 2022 July 13; published 2022 September 28

z=7.54, cosmic age： 0.7Gyr;　Fe abund.： 20 solar

Cosmic evolution of abundance?





Star formation and evolution：

- AGN structure
- Metallicity
- Compact objects
- Gravitational waves

Self-gravitating disk: AGN structure? (2009–)

The Astrophysical Journal, 746:137 (27pp), 2012 February 20 doi:10.1088/0004-637X/746/2/137

STAR FORMATION IN SELF-GRAVITATING DISKS IN ACTIVE GALACTIC NUCLEI. II. EPISODIC FORMATION OF BROAD-LINE REGIONS

The Astrophysical Journal, 739:3 (11pp), 2011 September 20 doi:10.1088/0004-637X/739/1/3

STAR FORMATION IN SELF-GRAVITATING DISKS IN ACTIVE GALACTIC NUCLEI. I. METALLICITY GRADIENTS IN BROAD-LINE REGIONS

The Astrophysical Journal Letters, 719:L148–L152, 2010 August 20 doi:10.1088/2041-8205/719/2/L148

ACCRETION DISKS IN ACTIVE GALACTIC NUCLEI: GAS SUPPLY DRIVEN BY STAR FORMATION

The Astrophysical Journal, 701:L7–L11, 2009 August 10 doi:10.1088/0004-637X/701/1/L7

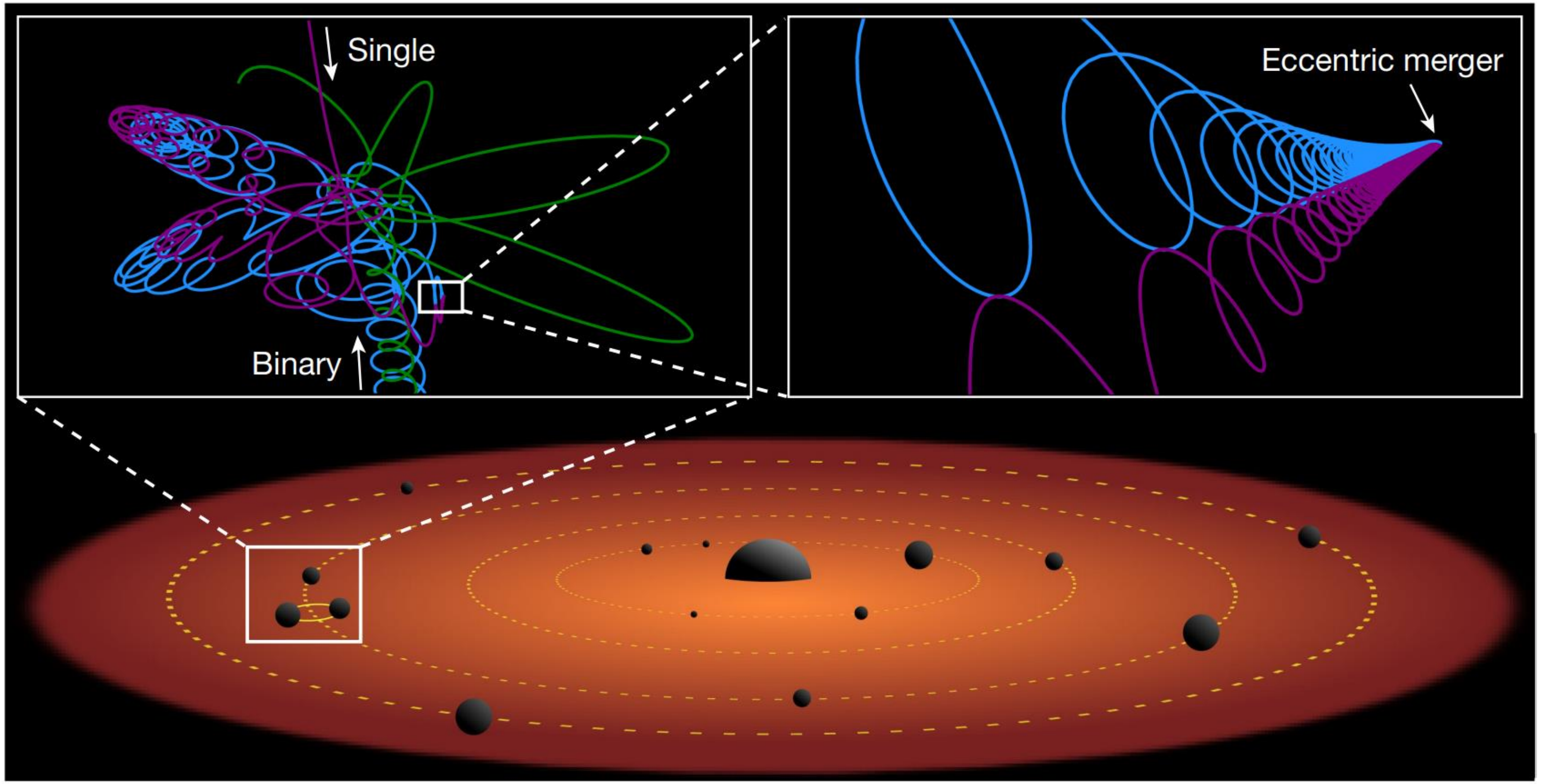
EVOLUTION OF GASEOUS DISK VISCOSITY DRIVEN BY SUPERNOVA EXPLOSIONS IN STAR-FORMING GALAXIES AT HIGH REDSHIFT

The Astrophysical Journal, 954:84 (33pp), 2023 September 1 https://doi.org/10.3847/1538-4357/acdf48

CrossMark

Star Formation in Self-gravitating Disks in Active Galactic Nuclei. III. Efficient Production of Iron and Infrared Spectral Energy Distributions

◆ Graham et al (2022)： 9 others（LIGO/Virgo during O3）.

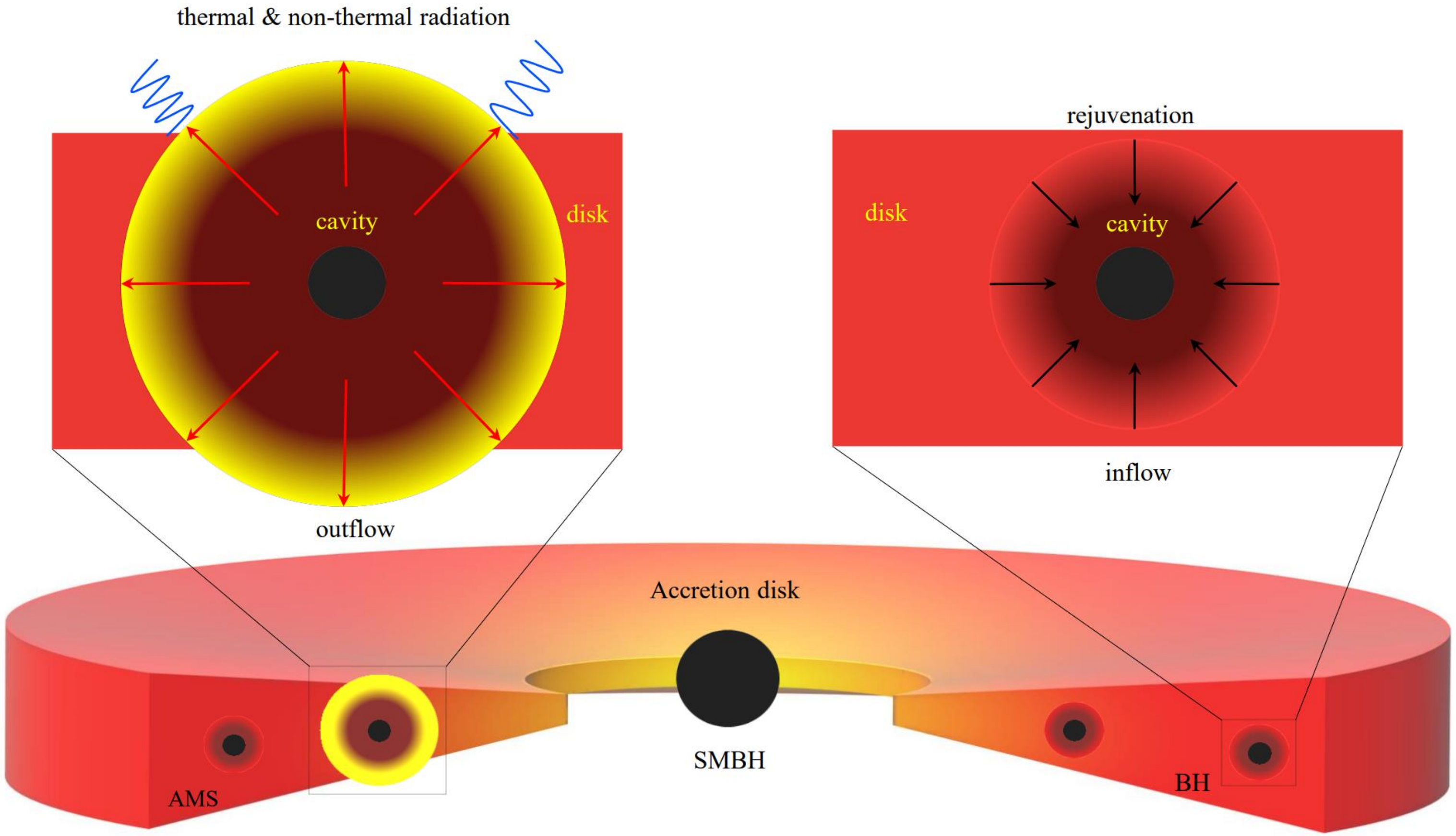


Samsing+(2022)

sMBHs: Observational consequences?

Accretion-modified Stars (AMS) 统一名词

Wang et al. 2021, ApJL911, L14



AMS演化

巨超爱丁顿吸积

↓

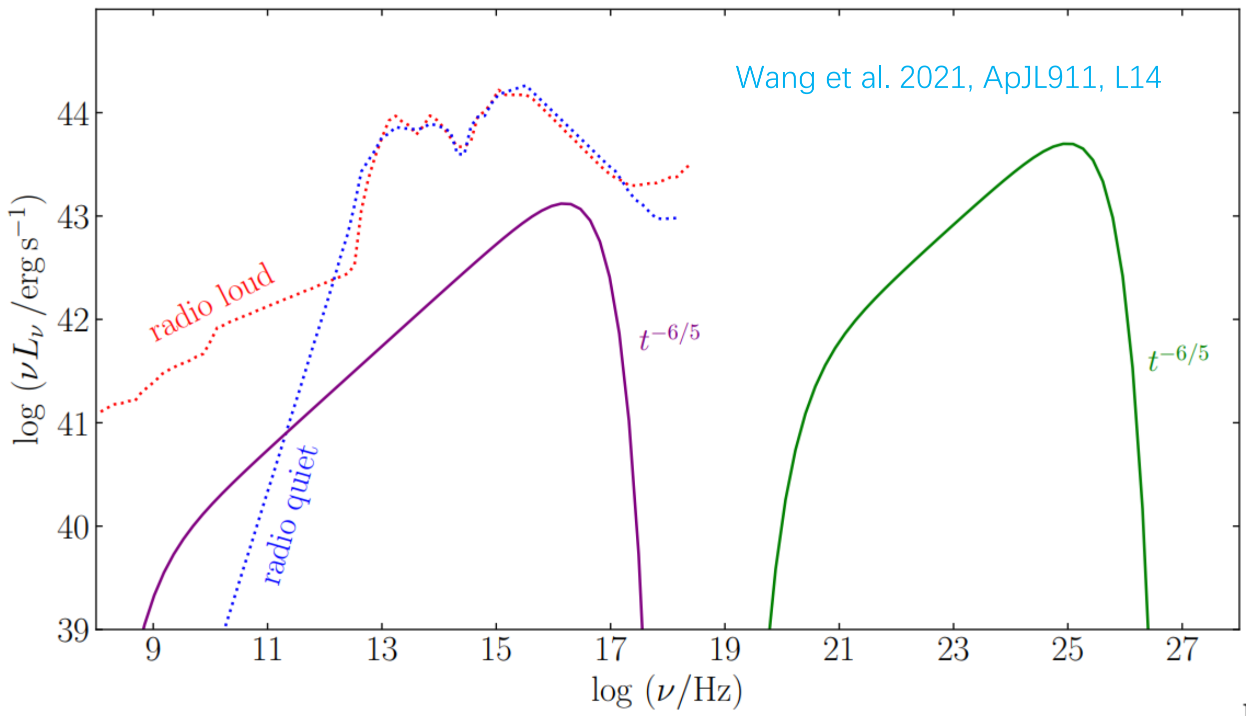
Bondi 爆炸

↓

AMS复活

$$\dot{m}_{\rm Bon} = \frac{\dot{M}_{\rm Bon}}{\dot{M}_{\rm Edd}} \approx \begin{cases} 8.9 \times 10^8\, m_1(\alpha_{0.1}M_8)^{-2/5}\dot{\mathscr{M}}^{1/10} r_4^{-3/4} & \text{(for corotation)}, \\ 5.1\, m_1(\alpha_{0.1}M_8)^{-7/10}\dot{\mathscr{M}}^{11/20} r_4^{-3/8} & \text{(for counter rotation)} \end{cases}$$

$$t_{\rm rej} = \frac{R_{\rm exp}}{c_s} = 268.9\, \alpha_{0.1}^{3/10} M_8^{11/20} \dot{\mathscr{M}}^{-13/40} r_4^{21/16} E_{52}^{1/4}\,{\rm yr}.$$



Bondi explosion SED

观测特征

激波加速电子

↓

相对论Lorentz因子$\gamma\sim10^5$

同步辐射 | 外Compton散射 (EIC)

$\nu_{\rm syn}^{\rm max} \approx 0.17\, B_0 \gamma_{\rm max,5}^2\ \rm keV$

$\nu_{\rm IC}^{\rm max} \approx \gamma_{\rm max}^2 \nu_{\rm UV} \approx 41.7\, \gamma_{\rm max,5}^2 \nu_{15}^{\rm UV}\ \rm GeV$

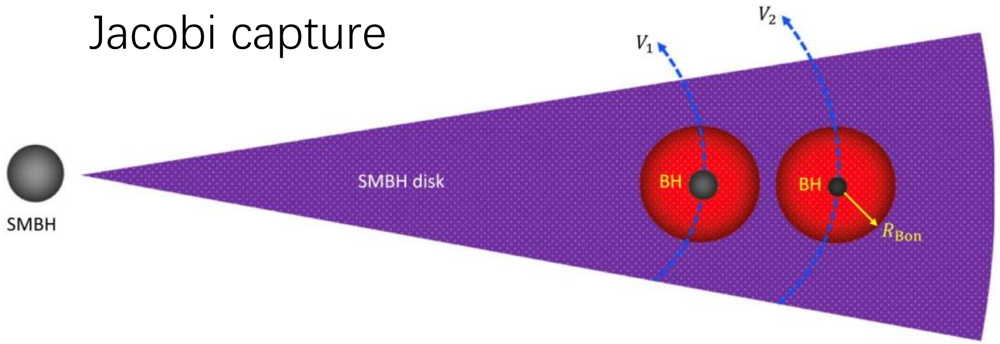
- Bondi吸积率 $\sim10^9 L_{\rm Edd}/c^2$.
- 吸积时标：$t_{\rm a}\sim10^5 m_1 {\rm s}$.
- 强大外流: 10倍超新星.
- Bondi爆炸：从射电宁静到中等射电强跃变.
- EIC: 峰值≈40 GeV *Fermi*-LAT可以探测.

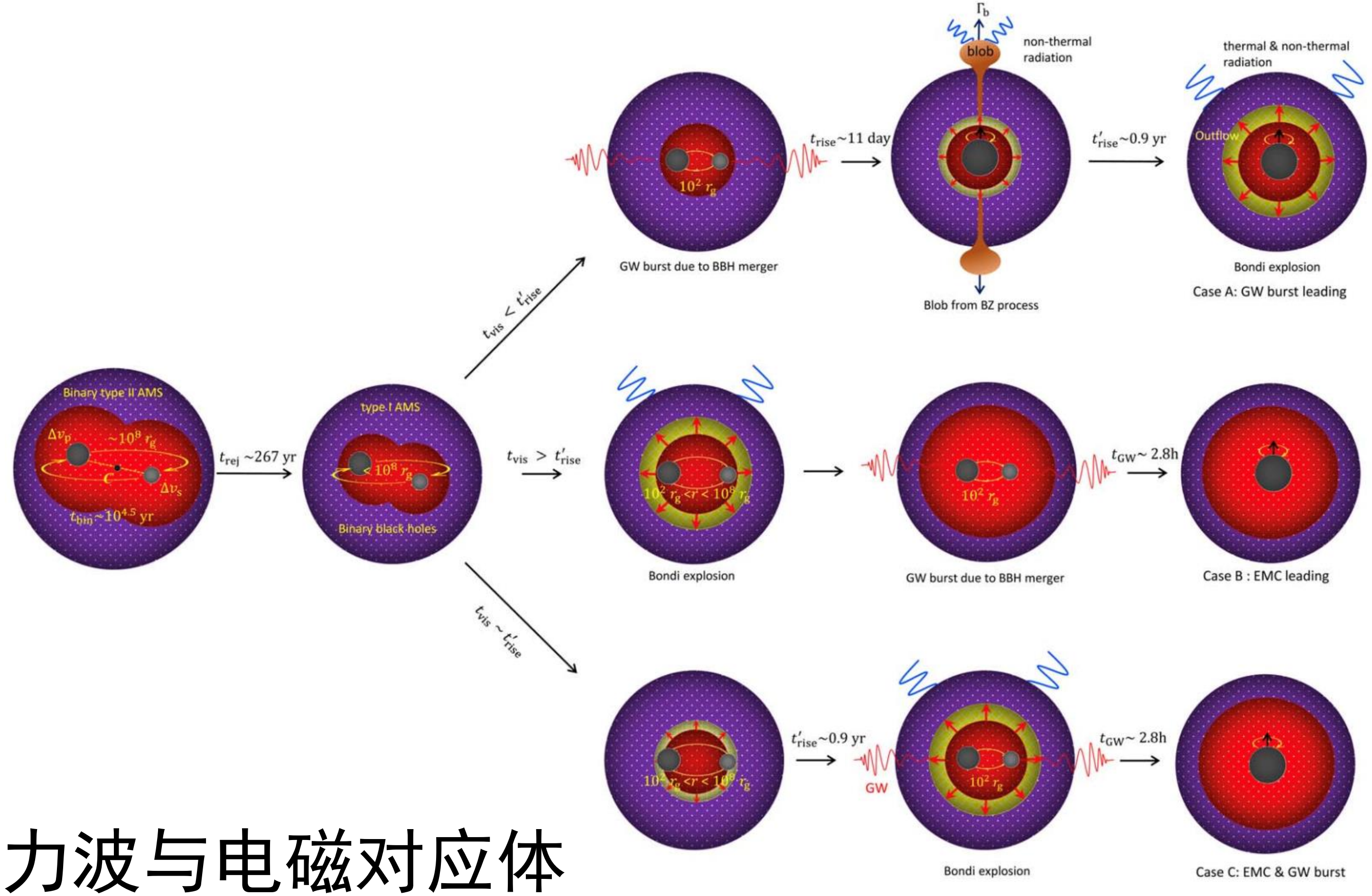
The Astrophysical Journal Letters, 916:L17 (11pp), 2021 August 1 https://doi.org/10.3847/2041-8213/ac0b46

Accretion-modified Stars in Accretion Disks of Active Galactic Nuclei: Gravitational-wave Bursts and Electromagnetic Counterparts from Merging Stellar Black Hole Binaries

Jian-Min Wang[1,2,3], Jun-Rong Liu[1,2], Luis C. Ho[4,5], Yan-Rong Li[1], and Pu Du[1]

Jacobi capture



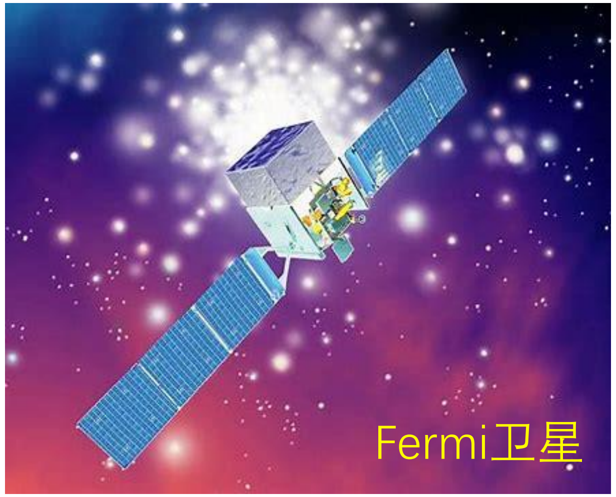


AMS: radio、γ-rays

slow transients

Merger rates: a few per year

LIGO: 10^2Hz GWs

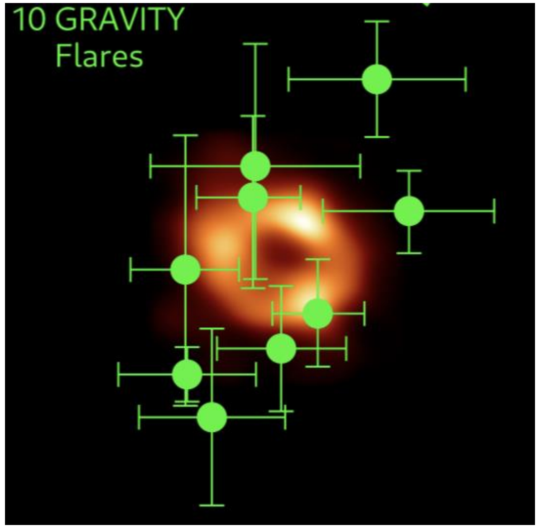


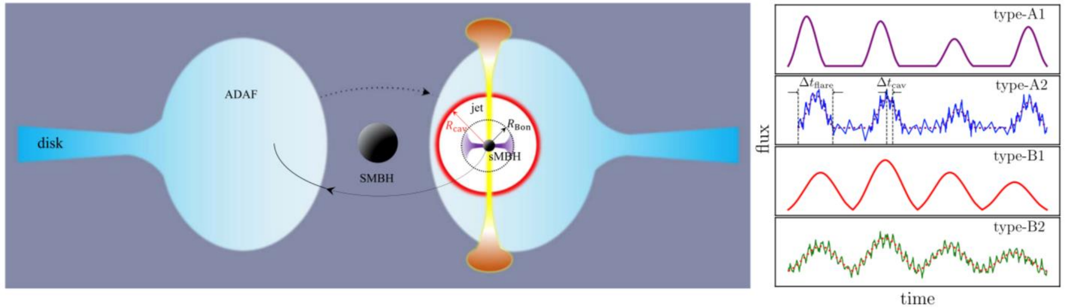
引力波与电磁对应体

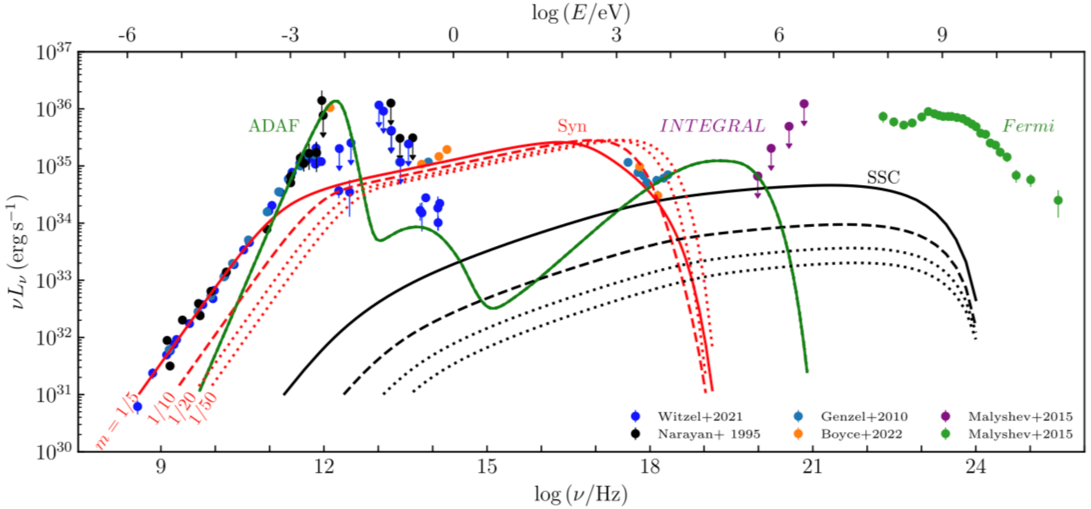
The Astrophysical Journal Letters, 958:L40 (13pp), 2023 December 1 https://doi.org/10.3847/2041-8213/ad0bd9

Accretion-modified Stars in Accretion Disks of Active Galactic Nuclei: The Low-luminosity Cases and an Application to Sgr A*

Jian-Min Wang[1,2,3], Jun-Rong Liu[1,4], Yan-Rong Li[1], Yu-Yang Songsheng[1], Ye-Fei Yuan[5], and Luis C. Ho[6,7]







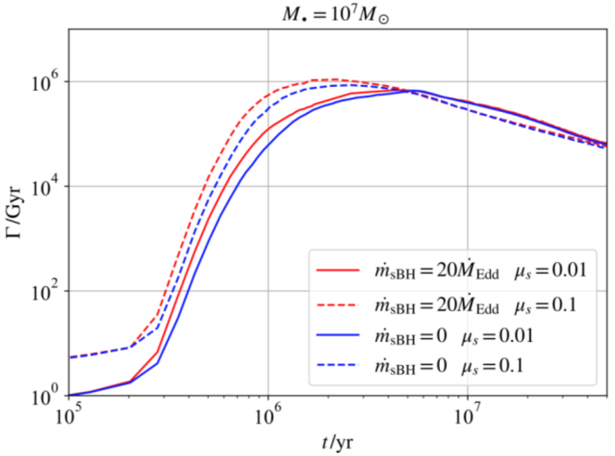
Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

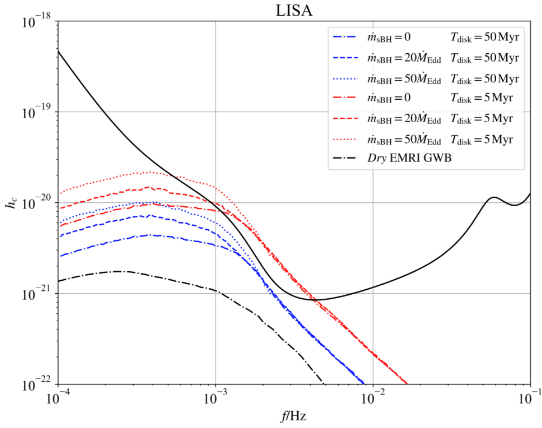
MNRAS **520,** 4502–4516 (2023) https://doi.org/10.1093/mnras/stad422
Advance Access publication 2023 February 7

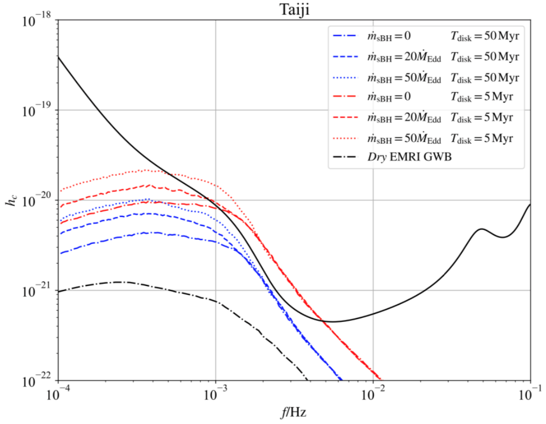
Accretion-modified stellar-mass black hole distribution and milli-Hz gravitational wave backgrounds from galaxy centre

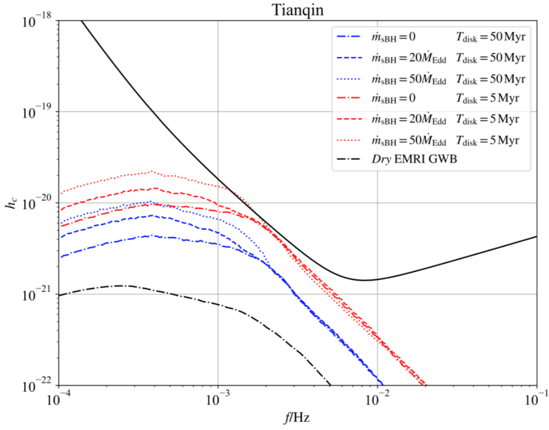
Mengye Wang,[1] Yiqiu Ma[2★] and Qingwen Wu[1★]

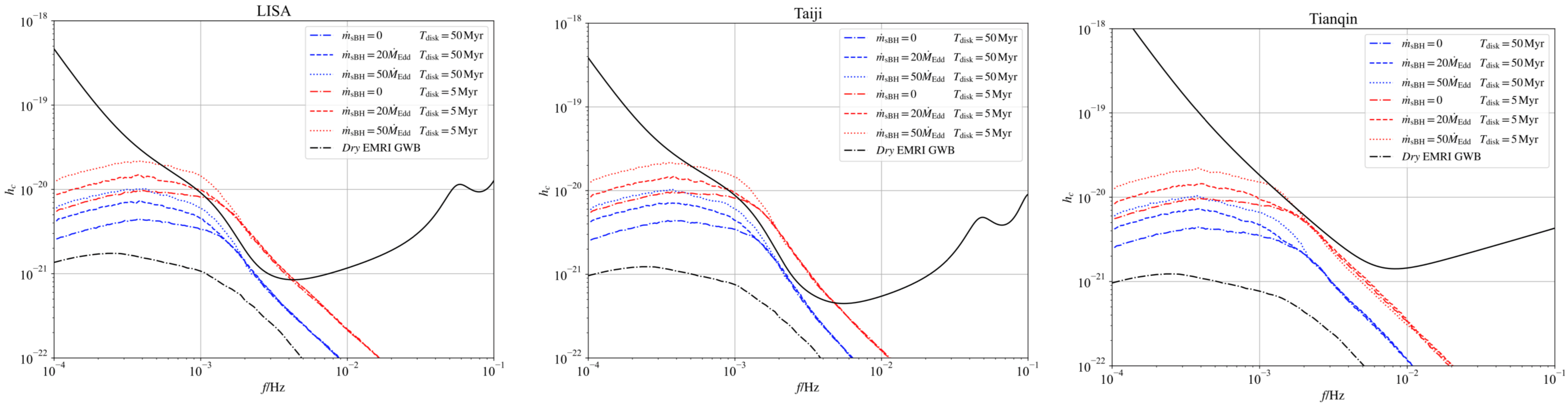
$$\frac{\partial f(E, J, m)}{\partial t} + \nabla \cdot [f(E, J, m)\boldsymbol{v}] = \text{collision terms},$$







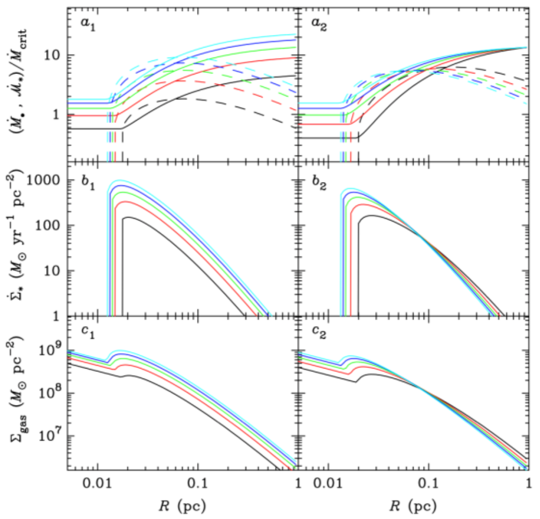


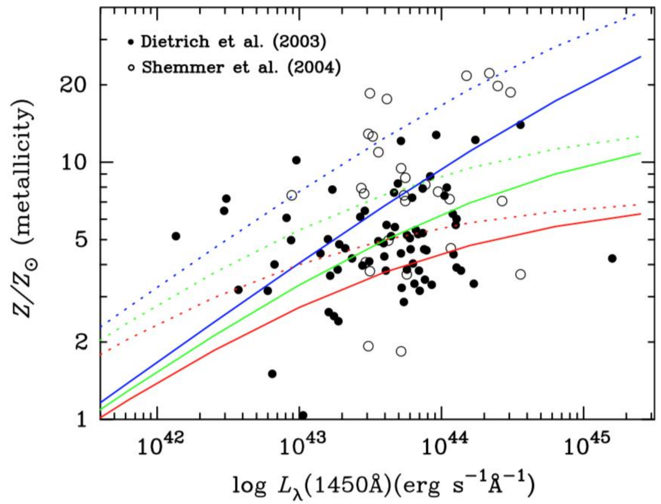

LISA
Taiji
Tianqin
$\dot{m}_{\rm sBH}=0$ $T_{\rm disk}=50\,{\rm Myr}$
$\dot{m}_{\rm sBH}=20\dot{M}_{\rm Edd}$ $T_{\rm disk}=50\,{\rm Myr}$
$\dot{m}_{\rm sBH}=50\dot{M}_{\rm Edd}$ $T_{\rm disk}=50\,{\rm Myr}$
$\dot{m}_{\rm sBH}=0$ $T_{\rm disk}=5\,{\rm Myr}$
$\dot{m}_{\rm sBH}=20\dot{M}_{\rm Edd}$ $T_{\rm disk}=5\,{\rm Myr}$
$\dot{m}_{\rm sBH}=50\dot{M}_{\rm Edd}$ $T_{\rm disk}=5\,{\rm Myr}$
Dry EMRI GWB
h_c
f/Hz

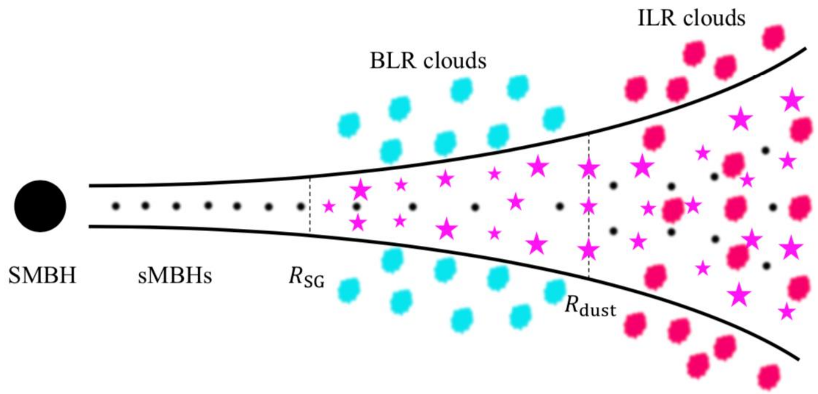
The Astrophysical Journal, 954:84 (33pp), 2023 September 1 https://doi.org/10.3847/1538-4357/acdf48

Star Formation in Self-gravitating Disks in Active Galactic Nuclei. III. Efficient Production of Iron and Infrared Spectral Energy Distributions

Jian-Min Wang[1,2,3], Shuo Zhai[1,4], Yan-Rong Li[1], Yu-Yang Songsheng[1], Luis C. Ho[5,6], Yong-Jie Chen[1,4], Jun-Rong Liu[1,4], Pu Du[1], and Ye-Fei Yuan[7]







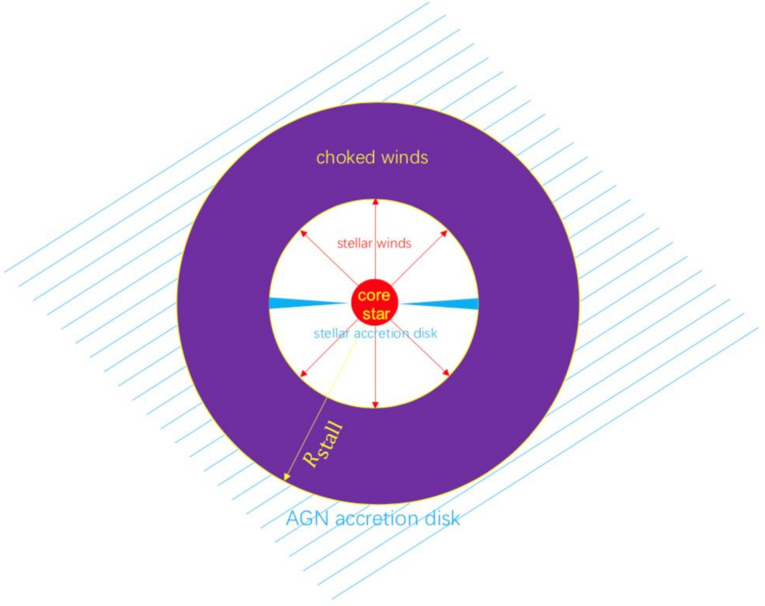
Evolution of stellar population?

Mass function

$$\frac{\partial}{\partial t}\Psi(m_*, t) + \frac{\partial}{\partial m_*}[\dot{m}_*\Psi(m_*, t)] = -\dot{\mathcal{R}}_{\rm SN}(m_*, t) + \dot{\mathcal{S}}_{\rm AD}(m_*, t),$$

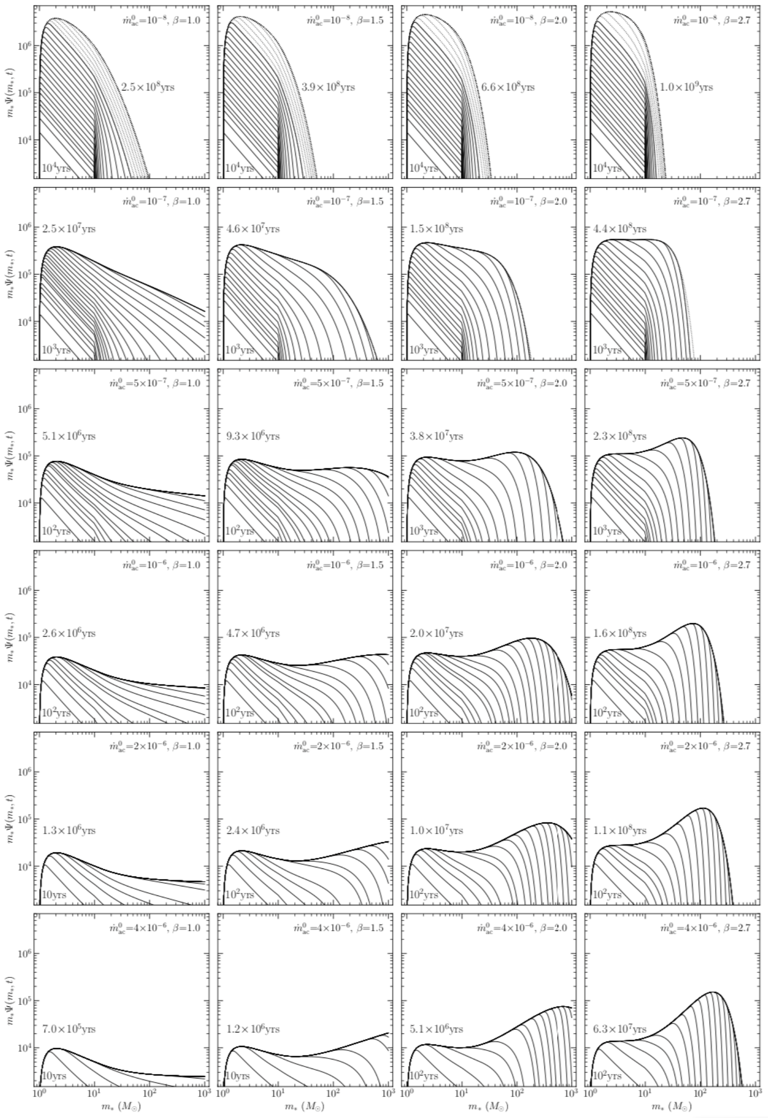
$$\dot{m}_* = \dot{m}_{\rm ac} - \dot{m}_{\rm W}$$

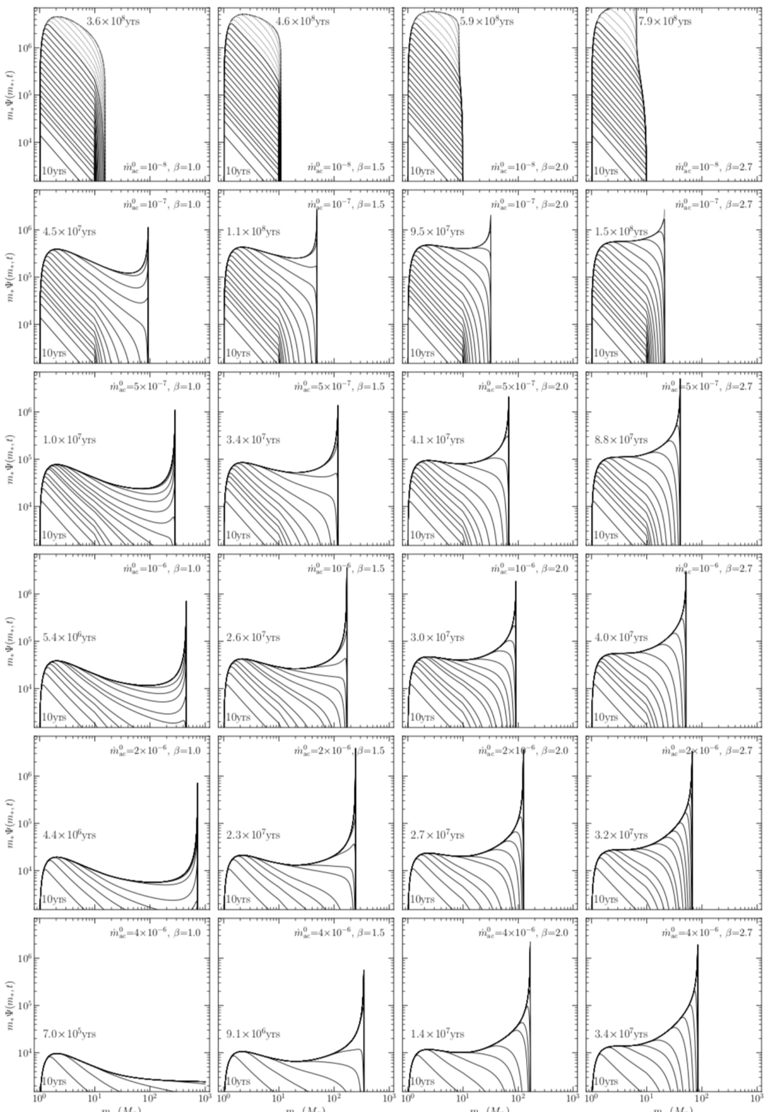
Stars： accretion and stellar winds



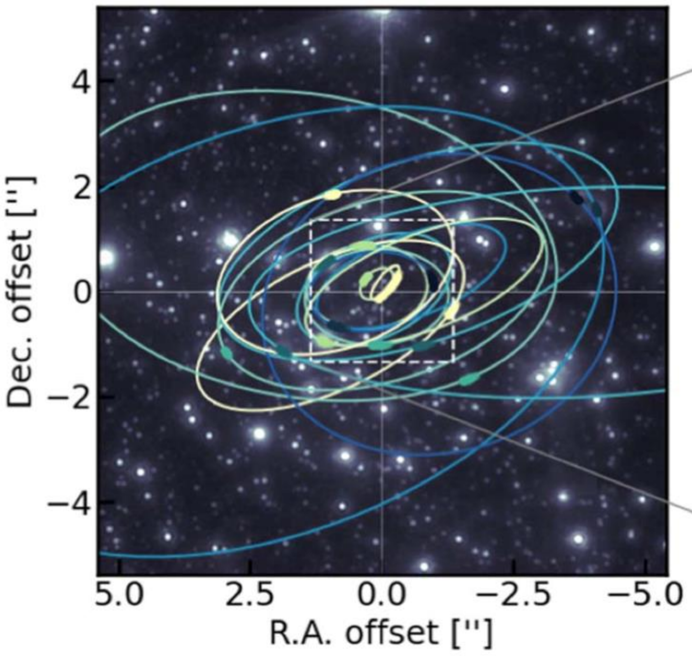
Mass function: pile-up

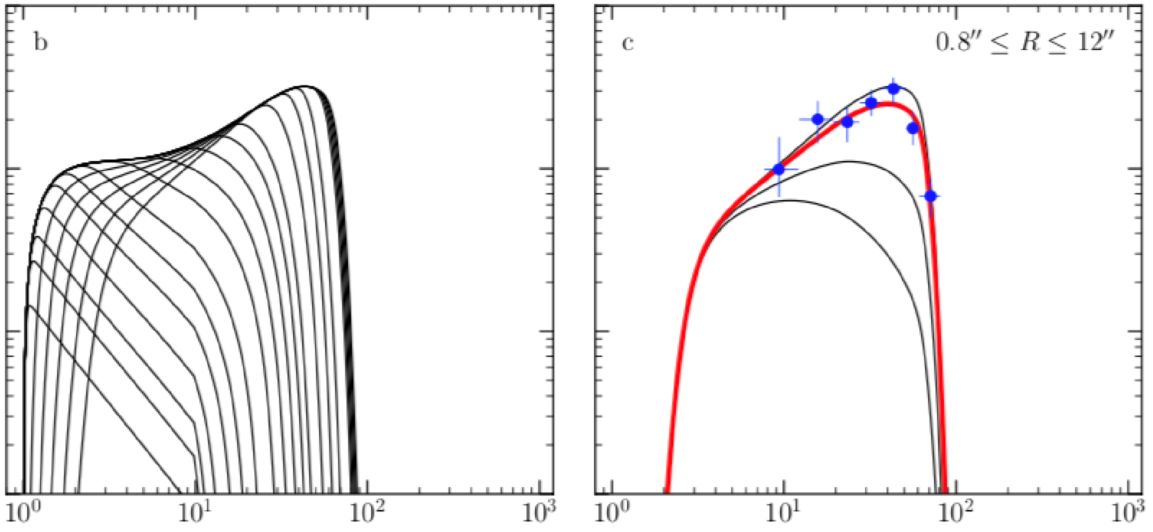
$$\dot{m}_* = \dot{m}_{\rm ac} - \dot{m}_{\rm w}$$



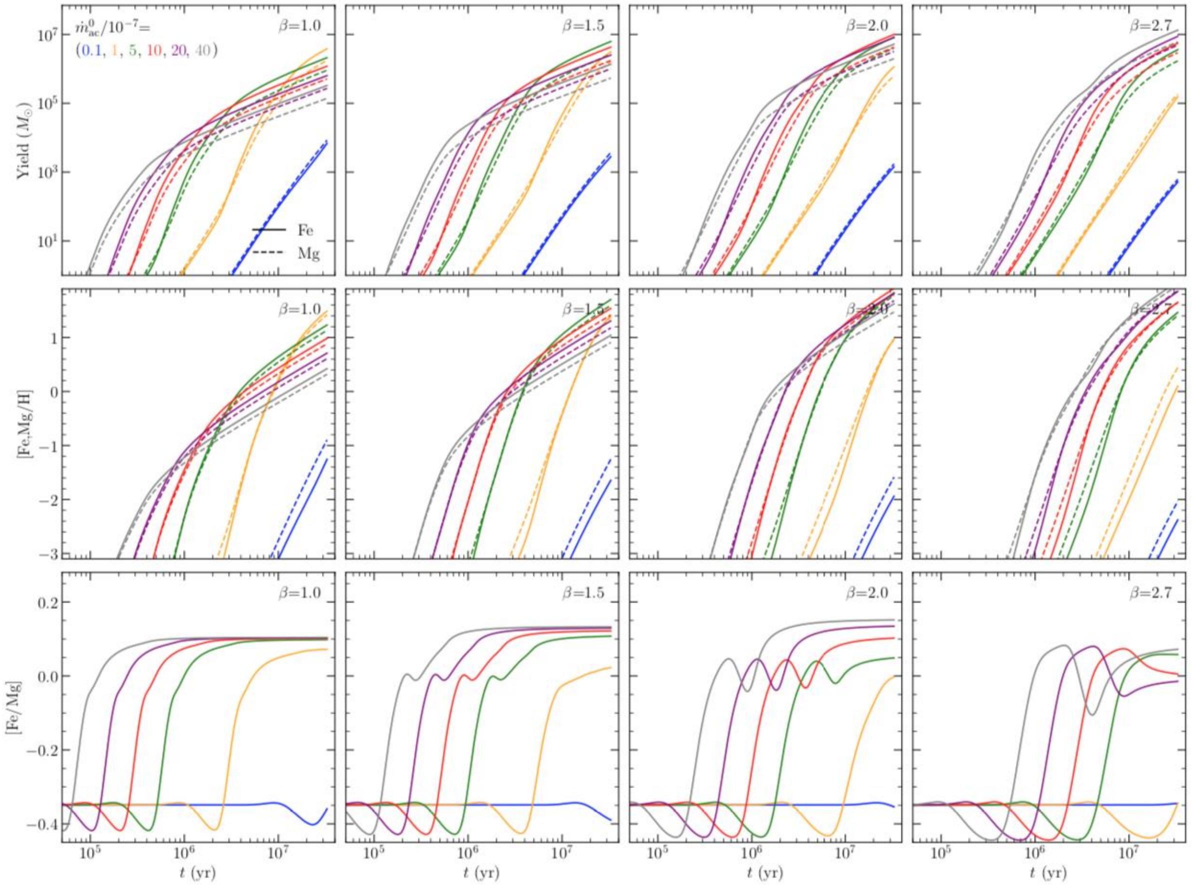


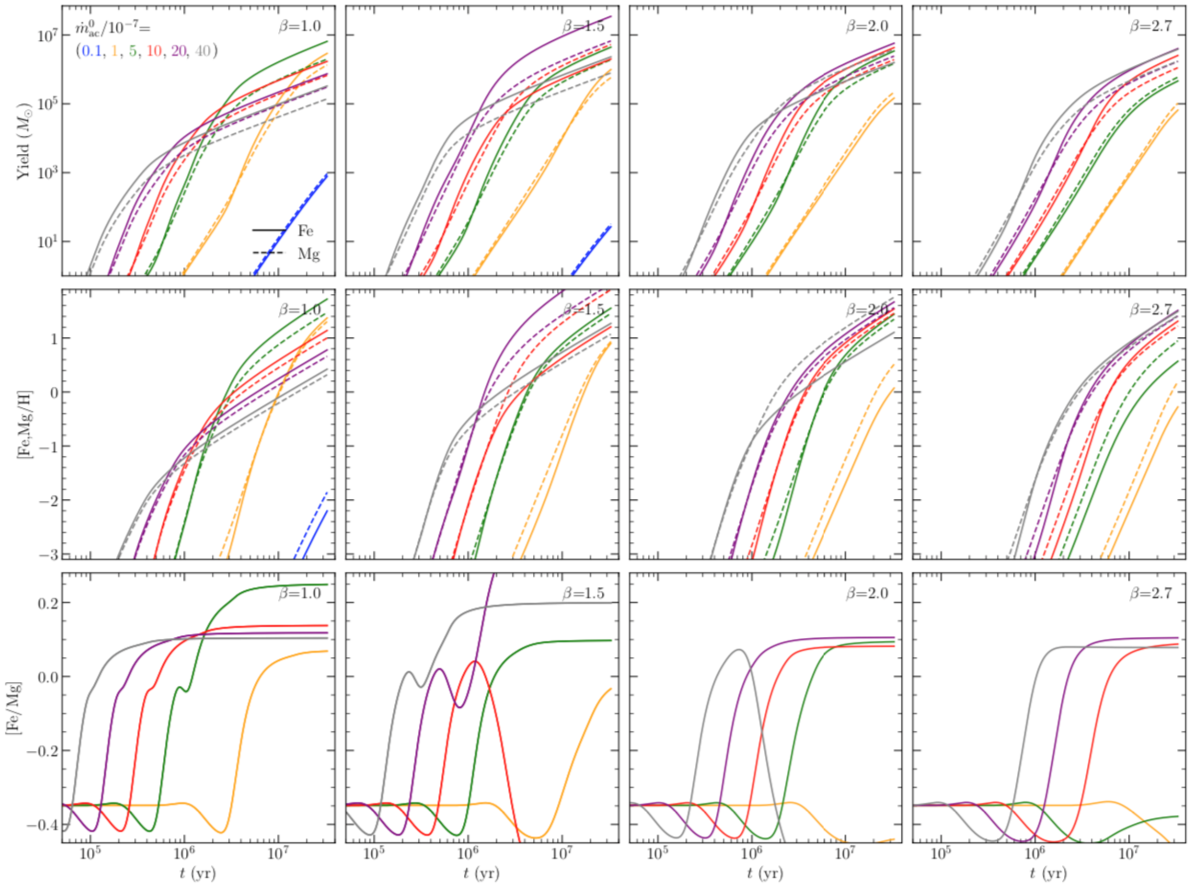
Galactic center：young massive stellar disk





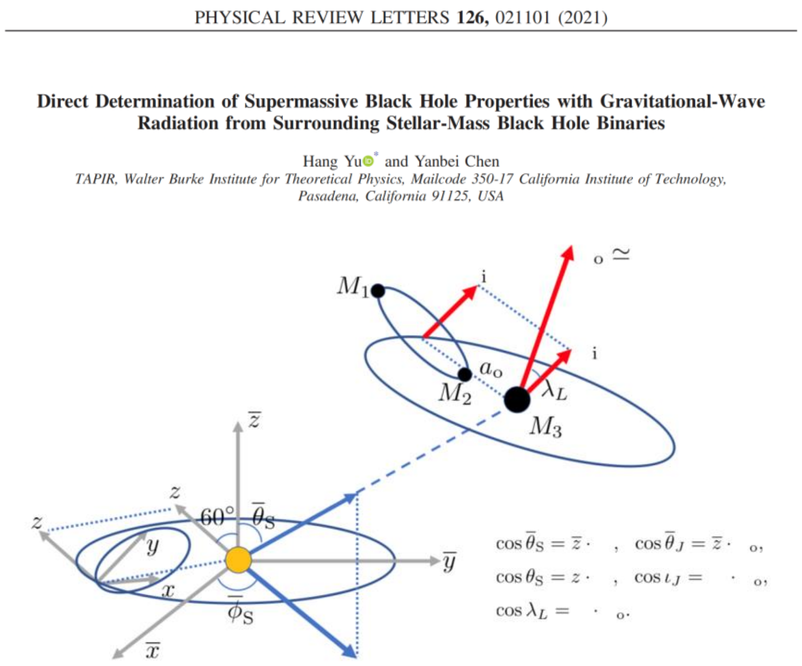
Iron abundance





Problems：Form. & Evo of Stars and Radiation

- Massive stars in AGN disks: element yields and compact objects
- Interaction between stars and the disk
- Binaries: compact-compact, star-comp, merger, TDE
- Accretion-modified stars:
  - ➢What is star？
  - ➢Outflow-driven cavity
- AMS feedback: AGN structure formation
- GWs: LIGO、LISA、PTA

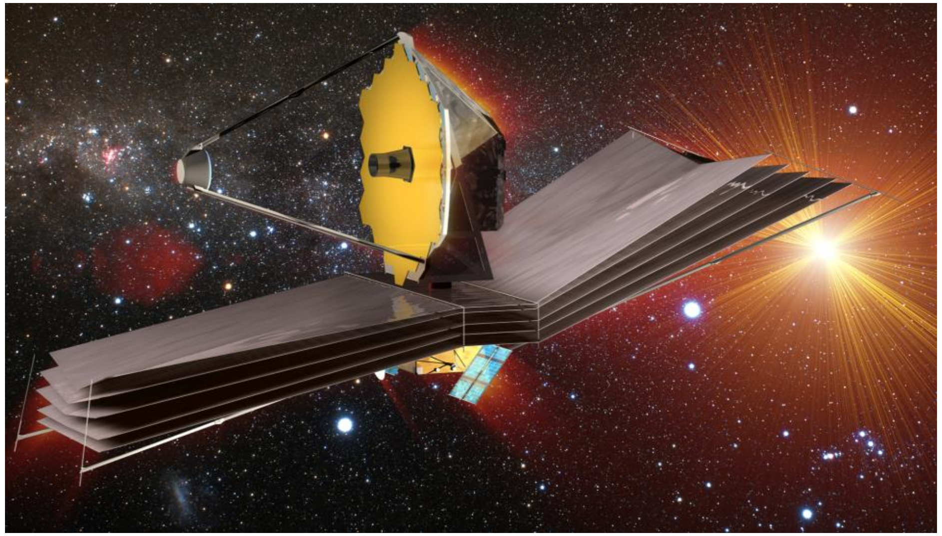

PHYSICAL REVIEW LETTERS 126, 021101 (2021)

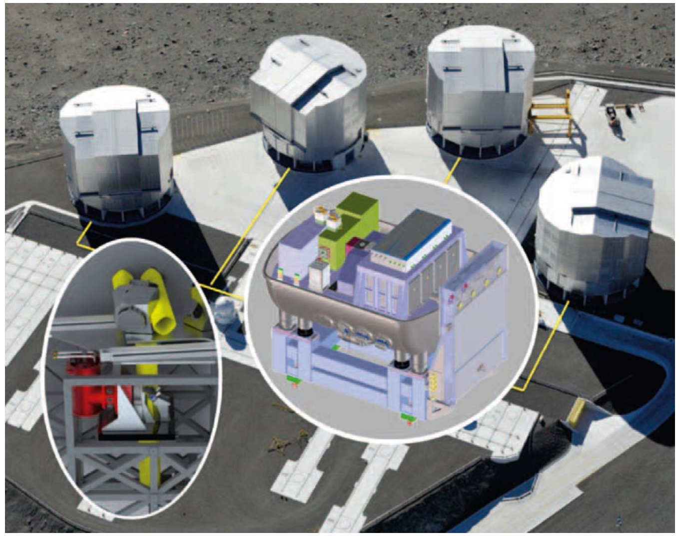
Direct Determination of Supermassive Black Hole Properties with Gravitational-Wave Radiation from Surrounding Stellar-Mass Black Hole Binaries

Hang Yu and Yanbei Chen

TAPIR, Walter Burke Institute for Theoretical Physics, Mailcode 350-17 California Institute of Technology, Pasadena, California 91125, USA

5、 Opportunities of JWST & VLTI Era





早期宇宙中：小红点

Article

A population of red candidate massive galaxies ~600 Myr after the Big Bang

https://doi.org/10.1038/s41586-023-05786-2

Received: 25 July 2022

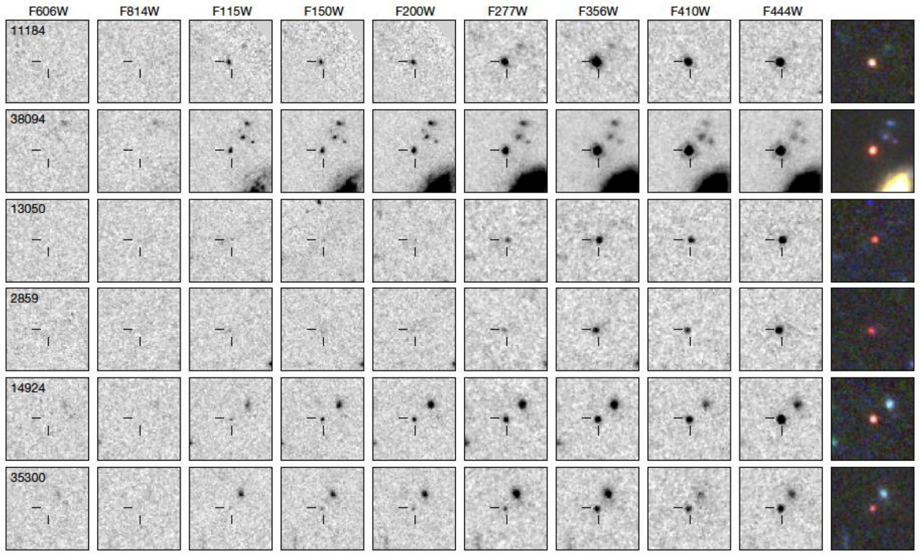
Accepted: 2 February 2023

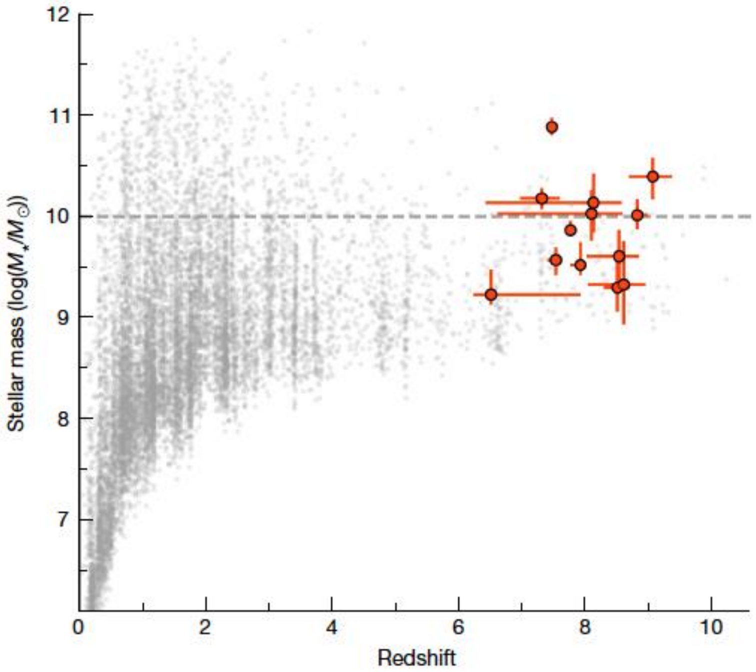
Published online: 22 February 2023

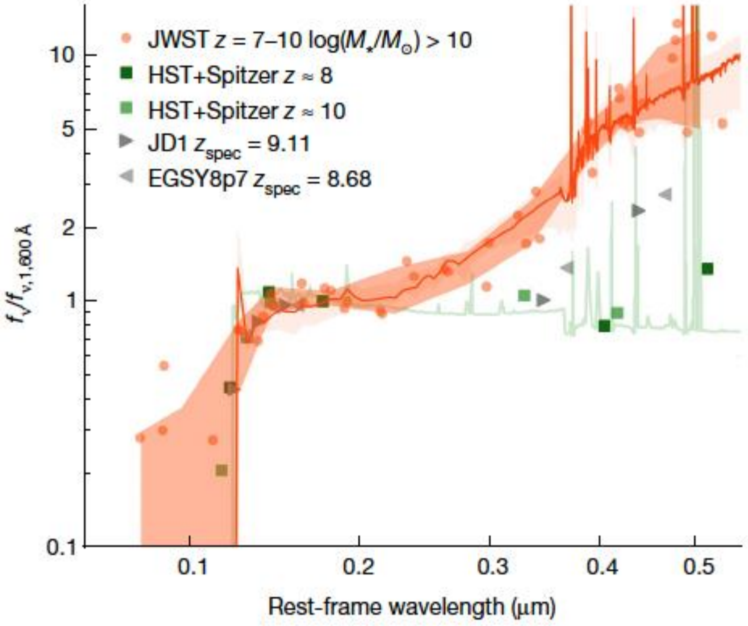
Check for updates

Ivo Labbé[1]✉, Pieter van Dokkum[2], Erica Nelson[3], Rachel Bezanson[4], Katherine A. Suess[5,6], Joel Leja[7,8,9], Gabriel Brammer[10], Katherine Whitaker[10,11], Elijah Mathews[7,8,9], Mauro Stefanon[12,13] & Bingjie Wang[7,8,9]

Galaxies with stellar masses as high as roughly 10^{11} solar masses have been identified[1–3] out to redshifts z of roughly 6, around 1 billion years after the Big Bang. It has been difficult to find massive galaxies at even earlier times, as the Balmer break region, which is needed for accurate mass estimates, is redshifted to wavelengths beyond 2.5 μm. Here we make use of the 1–5 μm coverage of the James Webb Space Telescope early release observations to search for intrinsically red galaxies in the first roughly 750 million years of cosmic history. In the survey area, we find six candidate massive galaxies (stellar mass more than 10^{10} solar masses) at $7.4 \le z \le 9.1$, 500–700 Myr after the Big Bang, including one galaxy with a possible stellar mass of roughly 10^{11} solar masses. If verified with spectroscopy, the stellar mass density in massive galaxies would be much higher than anticipated from previous studies on the basis of rest-frame ultraviolet-selected samples.







Draft version June 14, 2023
Typeset using LaTeX twocolumn style in AASTeX63

UNCOVER: Candidate Red Active Galactic Nuclei at $3 < z < 7$ with JWST and ALMA

Ivo Labbe,[1] Jenny E. Greene,[2] Rachel Bezanson,[3] Seiji Fujimoto,[4,*] Lukas J. Furtak,[5] Andy D. Goulding,[2] Jorryt Matthee,[6] Rohan P. Naidu,[7,8,†] Pascal A. Oesch,[9,10] Hakim Atek,[11] Gabriel Brammer,[10] Iryna Chemerynska,[11] Dan Coe,[12,13,14] Sam E. Cutler,[15] Pratika Dayal,[16] Robert Feldmann,[17] Marijn Franx,[18] Karl Glazebrook,[1] Joel Leja,[19,20,21] Michael Maseda,[22] Danilo Marchesini,[23] Themiya Nanayakkara,[1] Erica J. Nelson,[24] Richard Pan,[23] Casey Papovich,[25,26] Sedona H. Price,[3] Katherine A. Suess,[27,28] Bingjie Wang (王冰洁),[19,20,21] John R. Weaver,[15] Katherine E. Whitaker,[15,10] Christina C. Williams,[29,30] and Adi Zitrin[5]

The Astrophysical Journal, 964:39 (18pp), 2024 March 20 https://doi.org/10.3847/1538-4357/ad1e5f

UNCOVER Spectroscopy Confirms the Surprising Ubiquity of Active Galactic Nuclei in Red Sources at $z > 5$

Jenny E. Greene[1], Ivo Labbe[2], Andy D. Goulding[1], Lukas J. Furtak[3], Iryna Chemerynska[4], Vasily Kokorev[5], Pratika Dayal[5], Marta Volonteri[4], Christina C. Williams[6,7], Bingjie Wang (王冰洁)[8,9,10], David J. Setton[1,31], Adam J. Burgasser[11], Rachel Bezanson[12], Hakim Atek[4], Gabriel Brammer[13], Sam E. Cutler[14], Robert Feldmann[15], Seiji Fujimoto[16,32], Karl Glazebrook[17], Anna de Graaff[18], Gourav Khullar[12], Joel Leja[8,9,10], Danilo Marchesini[19], Michael V. Maseda[20], Jorryt Matthee[21,22], Tim B. Miller[23,24], Rohan P. Naidu[25,33], Themiya Nanayakkara[17], Pascal A. Oesch[13,26], Richard Pan[19], Casey Papovich[27,28], Sedona H. Price[12], Pieter van Dokkum[29], John R. Weaver[14], Katherine E. Whitaker[14,30], and Adi Zitrin[3]

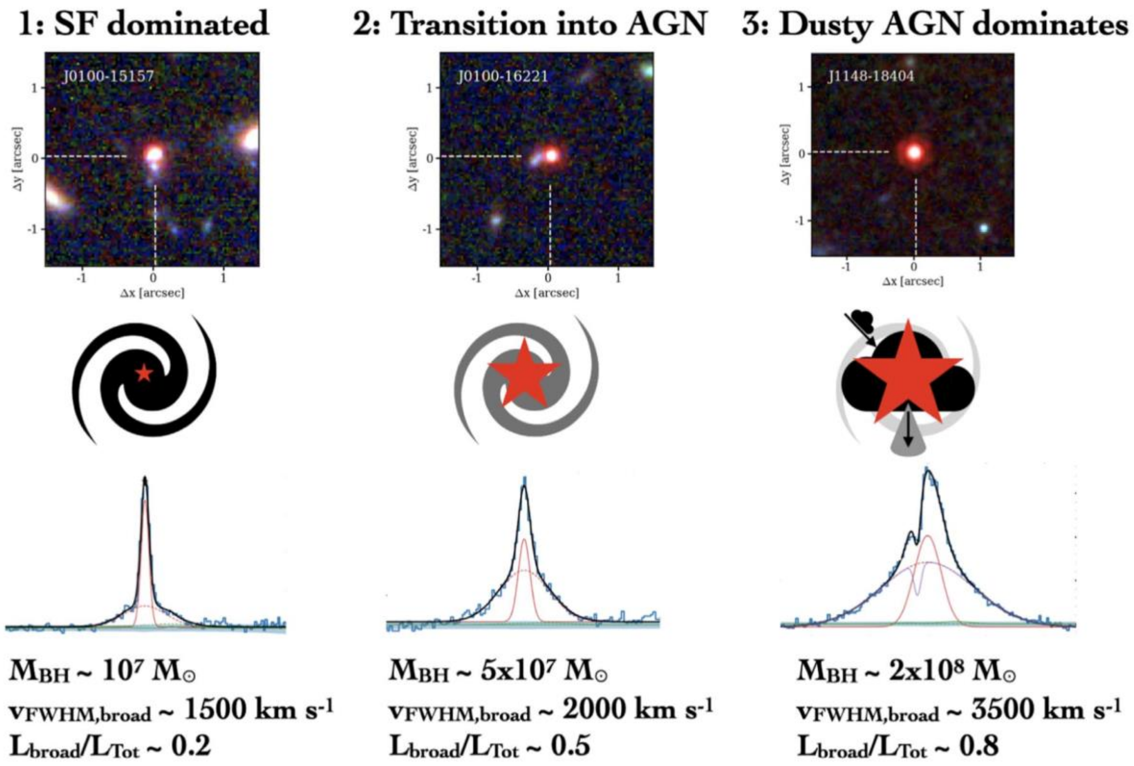
The Astrophysical Journal, 963:129 (28pp), 2024 March 10 https://doi.org/10.3847/1538-4357/ad2345

Little Red Dots: An Abundant Population of Faint Active Galactic Nuclei at $z \sim 5$ Revealed by the EIGER and FRESCO JWST Surveys

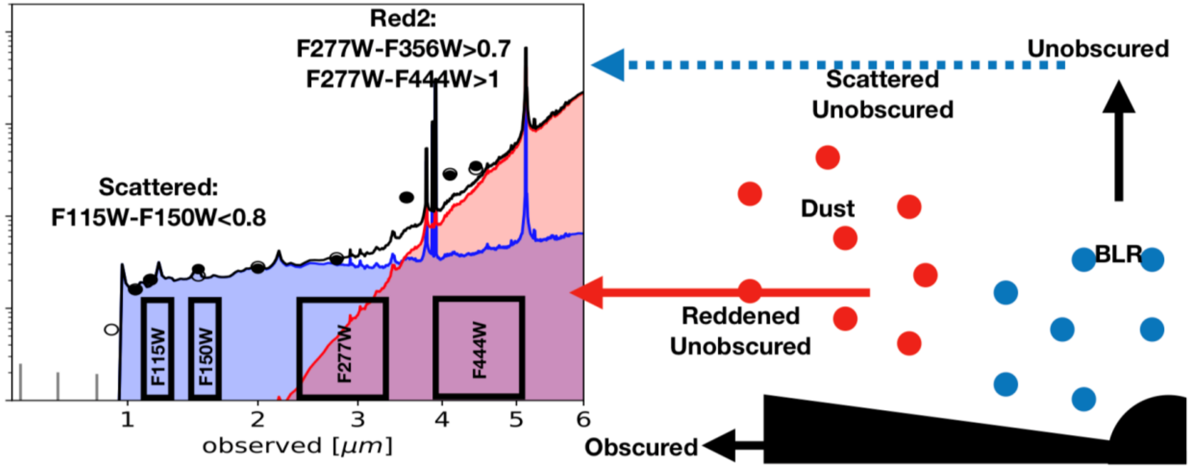
Jorryt Matthee[1,2], Rohan P. Naidu[3,23], Gabriel Brammer[4], John Chisholm[5], Anna-Christina Eilers[3], Andy Goulding[6], Jenny Greene[6], Daichi Kashino[7,8], Ivo Labbe[9], Simon J. Lilly[1], Ruari Mackenzie[1], Pascal A. Oesch[4,10], Andrea Weibel[10], Stijn Wuyts[11], Mengyuan Xiao[10], Rongmon Bordoloi[12], Rychard Bouwens[13], Pieter van Dokkum[14], Garth Illingworth[15], Ivan Kramarenko[10], Michael V. Maseda[16], Charlotte Mason[4,17], Romain A. Meyer[10,18], Erica J. Nelson[19], Naveen A. Reddy[20], Irene Shivaei[21,22], Robert A. Simcoe[3], and Minghao Yue[3]

- Density：100-500 times quasar LF
- SED：V-shaped

Early phase of Universe：various stages



Matthee+2024



Labbe+2023/4

Mon. Not. R. astr. Soc. (1985) **213,** 841–856

Warmers: the missing link between Starburst and Seyfert galaxies

Roberto Terlevich *Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, East Sussex BN27 1RP*

Jorge Melnick *Universidad de Chile, Santiago, Chile*

Accepted 1984 December 2. Received 1984 November 23; in original form 1984 August 22

Mon. Not. R. astr. Soc. (1992) **255,** 713–728

The starburst model for active galactic nuclei: the broad-line region as supernova remnants evolving in a high-density medium

Roberto Terlevich,[1] Guillermo Tenorio-Tagle,[2] Jose Franco[3] and Jorge Melnick[4]

[1] *Royal Greenwich Observatory, Madingley Road, Cambridge, CB3 0EZ*
[2] *Instituto de Astrofísica de Canarias, 38200 La Laguna, Tenerife, Spain*
[3] *Instituto de Astronomía UNAM, Apartado Postal 70-264, 04510 México D. F., México*
[4] *European Southern Observatory, Casilla 19001, Santiago, Chile*

Mon. Not. R. Astron. Soc. **272,** 198–212 (1995)

The starburst model for active galactic nuclei – II. The nature of the lag

R. Terlevich,[1] G. Tenorio-Tagle,[2] M. Różyczka,[3] J. Franco[4] and J. Melnick[5]

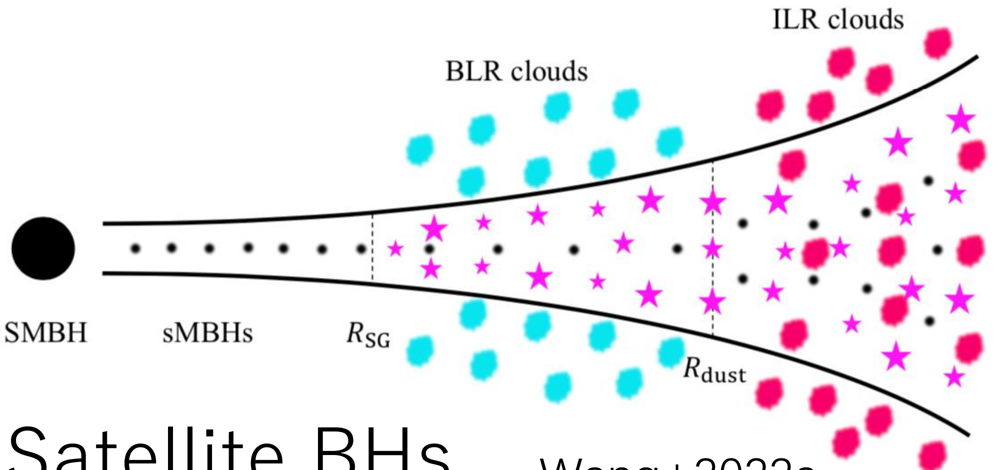
[1] *Royal Greenwich Observatory, Madingley Road, Cambridge CB3 0EZ*
[2] *Instituto de Astrofísica de Canarias, 38200 La Laguna, Tenerife, Spain*
[3] *Warsaw University Observatory, Al. Ujazdowskie 4, Pl-00478 Warszawa, Poland*
[4] *Instituto de Astronomía UNAM, Apartado Postal 70-264, 04510 México DG, México*
[5] *European Southern Observatory, Casilla 19001, Santiago, Chile*

Forthcoming silent revolution: GWs

- SMBH accretion disk： changed

  stars/compact objects

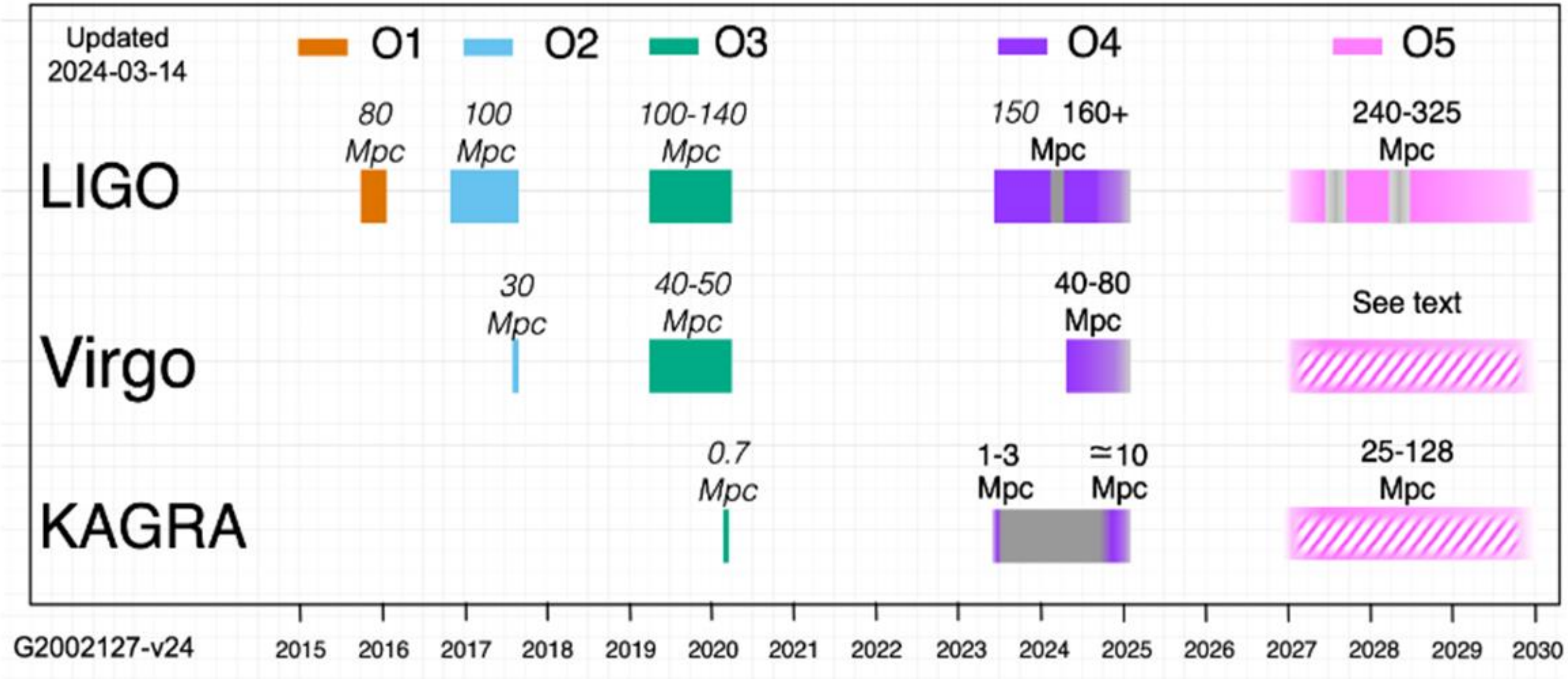
- Starburst: new roles?



Satellite BHs

Wang+2023a

LIGO观测计划


Updated
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O5
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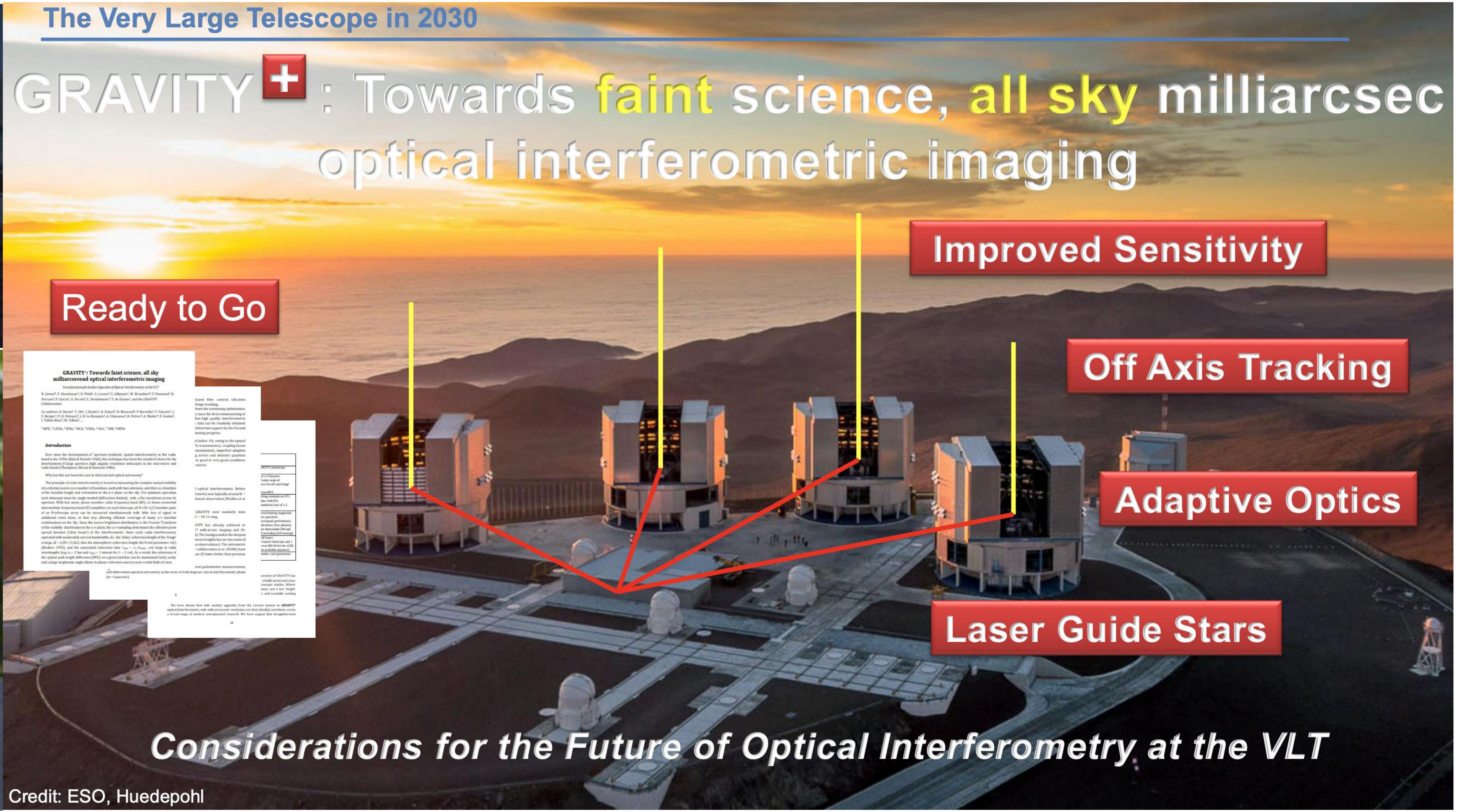
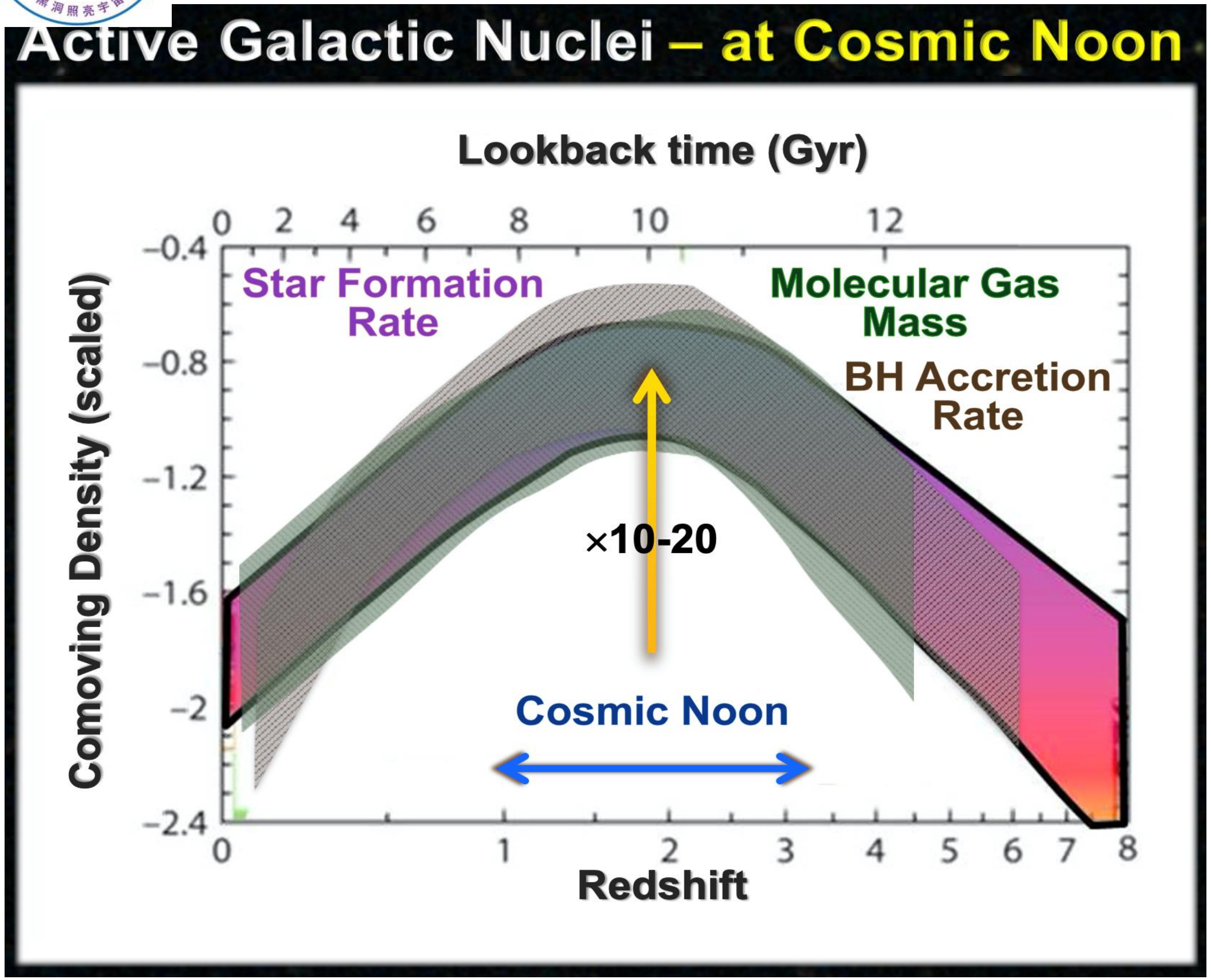
In future 5-yrs：GRAVITY+ (300-500 quasars)





GRAVITY+ core sciences ：

- z=2-3 SMBH
- Cosmic distances：

  expansion history/dark energy
- SMBH binaries: nano-Hz GWs

GRAVITY+科学白皮书
https://www.mpe.mpg.de/7480772/GRAVITYplus_WhitePaper.pdf

Remaks：

●SMBH：SEABHs；seed: stellar or primordial BHs？

●SARM：quasar as probe of Universe

●SMBH binaries：PTA observations

●AGN structure formation：

stellar evolution in dense environment

●LIGO GWs：AGN SED and variations