Isolated BHs

Early works

«Halos around black holes» Soviet Astronomy – Astronom. Zhurn (1971)

In this paper accretion onto isolated BHs from the ISM was studied for different BH masses (including intermediate).

Dynamics of accretion, the role of turbulence, the role of magnetic fields in the ISM, spectrum.

Synchrotron radiation of magnetized plasma, which is heated during accretion up to 10¹² K (here the temperature means the average energy of electrons motion perpendicular to magnetic field lines).

(Development of this approach see in astro-ph/0403649)



Victorij Shvartsman

Basic formulae

(Fujita et al. 1998)

$$\begin{split} \dot{M} &\sim \pi r_{\rm cap}^2 \rho_{\rm gas} V \\ &\approx 7.4 \times 10^{13} \ {\rm g \ s^{-1}} \left(\frac{M}{M_{\odot}}\right)^2 \left(\frac{n_{\rm gas}}{10^2 \ {\rm cm^{-3}}}\right) \left(\frac{V}{10 \ {\rm km \ s^{-1}}}\right)^{-3} \\ &\approx 5.3 \times 10^{-4} \dot{M}_{\rm Edd} \left(\frac{M}{M_{\odot}}\right) \left(\frac{n_{\rm gas}}{10^2 \ {\rm cm^{-3}}}\right) \left(\frac{V}{10 \ {\rm km \ s^{-1}}}\right)^{-3} \end{split}$$

$$v_{\rm turb} \sim 1.1 \ (r/1 \ {\rm pc})^{0.38} \ {\rm km \ s^{-1}}, \quad \text{Velocity of turbulent motions} \end{split}$$

$$V \lesssim 52 \ \left(r_g/r_o f_l^2\right)^{0.18} (M/M_{\odot})^{0.14} \ {\rm km \ s^{-1}}$$
The critical velocity corresponding to an accretion disc formation.

See also A&A 381, 1000 (2002)

Isolated accreting BHs



ADAF 10 solar masses

The objects mostly emit in X-rays or IR.

Fujita et al. astro-ph/9712284

The galactic population of accreting isolated BHs



The luminosity distribution is mostly determined by the ISM distribution, then – by the galactic potential.

It is important that maxima of the ISM distribution and distribution of compact objects roughly coincide. This results in relatively sharp maximum in the luminosity distribution.

Searching in deep surveys



Agol, Kamionkowski (astro-ph/0109539) demonstrated that satellites like XMM or Chandra can discover about few dozens of such sources.

However, it is very difficult to identify isolated accreting BHs.

astro-ph/0109539

efficiency are poorly known

emission can appear in the optical range and in X-rays. Cross-correlation between SDSS and ROSAT data resulted in 57 candidates. Regime of accretion and its

Digging in the SDSS

The idea is that the synchrotron

ADAF IP CDAF



Chisholm et al. astro-ph/0205138

Radio emission from isolated BHs

 $L_{R} \sim L_{X}^{0.7}$

The task for LOFAR?

Phase/type	M_{BH}	n_H	T_{ISM}	N_{BH}	L_X	d_{radio}	N_{radio}
GMC Core	10	10^{5}	10^{4}	~ 1	5×10^{33}	12	~ 1
GMC/cold neutral	10	10^{3}	10^{4}	1.3×10^{6}	5×10^{29}	0.7	400
warm ISM	10	0.4	10^{4}	$5 imes 10^7$	7×10^{22}	.005	0
hot ISM	10	0.01	10^{6}	$5 imes 10^7$	5×10^{13}	10^{-5}	0
GMC/cold, fast halo IMBH	2600	10^{3}	10^{4}	30	$8 imes 10^{30}$	15	10
IMBH/disk pop/cold ISM	260	10^{3}	10^{4}	*	$8 imes 10^{33}$	40	*
IMBH/disk pop/GMC	260	10^{5}	10^{4}	*	$8 imes 10^{37}$	800	*
IMBH/disk pop/warm ISM	260	0.4	10^{4}	*	$1 imes 10^{27}$	0.5	*

Maccarone astro-ph/0503097

Two isolated BHs in a globular cluster?

eVLA observations showed two flat-spectrum sources without X-ray or/and optical identfications.

Most probably, they are accreting BHs. Probably, isolated.

Numerical model for the cluster evolution and the number of BHs was calculated in the paper 1211.6608.





More calculations for radio IBHs



The authors calculate if IBHs can be detected by SKA and other future survey if the accrete from the ISM. Different assumptions about initial velocitites and accretion efficiency are made.

SKA will be effective in discovering isolated accreting BHs due to their radio emission.

Calculations for SKA



~30 IBHs in SKA-1-mid ~700 IBHs in SKA-2

Better look at the Galactic center region



Electron-positron jets from isolated BHs

The magnetic flux, accumulated on the horizon of an IBH because of accretion of interstellar matter, allows the Blandford–Znajeck mechanism to be activated. So, electron–positron jets can be launched. Such jets are feasible electron accelerator which, in molecular clouds, allows electron energy to be boosted up to ~1 PeV. These sources can contribute both to the population of unidentified point-like sources and to the local cosmic-ray electron spectrum.

The inverse Compton emission of these locally generated cosmic rays may explain the variety of gamma-ray spectra detected from nearby molecular clouds.



IBHs in molecular clouds as TeV sources



Rotation is important!

The black holes rotational energy is electromagnetically extracted via the Blandford-Znajek process.



gamma-rays emitted from the accelerator.

1808.03075

Photon energy

X-ray nova and accreting isolated BHs



Up to several event per year. Then some of known X-ray nova with unidentified companions, can be due to isolated BHs. Around accreting isolated BHs in molecular clouds it is possible to have conditions (hydrogen-ionization disk instability) necessary for X-ray nova appearance.



Detailed study of AIBHs

$$\begin{split} \dot{M} &= \lambda \cdot 4\pi \frac{(GM)^2 \rho}{(v^2 + c_s^2)^{3/2}} \\ \approx 3.7 \times 10^{15} \text{g s}^{-1} \\ &\cdot \left(\frac{\lambda}{0.1}\right) \left(\frac{M}{10 \text{ M}_{\odot}}\right)^2 \left(\frac{\rho}{10^3 \text{ cm}^{-3} m_p}\right) \left[\frac{v^2 + c_s^2}{(10 \text{ km s}^{-1})^2}\right]^{-3/2} \\ \eta &= \begin{cases} \eta_{\text{std}}(\dot{M}/\dot{M}_{\text{th}}) & (\text{when } \dot{M} < \dot{M}_{\text{th}}) \\ \eta_{\text{std}} & (\text{when } \dot{M}_{\text{th}} < \dot{M} < 2\dot{M}_{\text{Edd}}). \end{cases} \\ &\text{RIAF (radiatively-inefficient accretion flow)} \\ &\text{Below some threshold the luminosity} \\ \text{is reduced.} \end{cases} \\ &L &= \eta \dot{M} c^2 \\ &= 3.4 \times 10^{37} \text{erg s}^{-1} \\ &\cdot \eta \lambda \left(\frac{M}{10 \text{ M}_{\odot}}\right)^2 \left(\frac{\rho}{10^3 \text{ cm}^{-3} m_p}\right) \left[\frac{v^2 + c_s^2}{(10 \text{ km s}^{-1})^2}\right]^{-3/2} \end{cases} \\ &\text{Most of AlBHs} \\ \text{are in the RIAF state.} \end{cases} \\ &L &= 9.0 \times 10^{32} \text{erg s}^{-1} \\ &\cdot \left(\frac{\lambda}{0.1}\right)^2 \left(\frac{M}{10 \text{ M}_{\odot}}\right)^3 \left(\frac{\rho}{10^3 \text{ cm}^{-3} m_p}\right)^2 \left[\frac{v^2 + c_s^2}{(10 \text{ km s}^{-1})^2}\right]^{-3} \end{split} \\ &L &= 3.4 \times 10^{35} \text{erg s}^{-1} \\ &\text{Standard} \\ &\cdot \left(\frac{\lambda}{0.1}\right) \left(\frac{M}{10 \text{ M}_{\odot}}\right)^2 \left(\frac{v^2 + c_s^2}{(10 \text{ km s}^{-1})^2}\right]^{-3/2} \end{split}$$

Spatial distribution



Observability

 $dF_{\rm ph}/d\epsilon_{\rm ph} \propto \epsilon_{\rm ph}^{-\zeta}$

Power-law spectrum in the RIAF regime (hard state)



The authors focus on harder X-ray emission than in ROSAT case

	$v_{ m avg}$ [km s ⁻¹]						
	50	100	200	300	400		
bulge	0.018	1.4×10^{-3}	0.067	3.7×10^{-3}	9.1×10^{-3}		
disc	32	4.5	0.79	0.19	0.086		





Deep survey towards the Galactic center



FORCE is a japanies project, if approved – then to be launched in mid 2020s.

Perspectives for JWST and Millimetron



1905.04923

Different spectra are for different accretion rates: from 10⁻¹⁰ up to 10⁻⁴ of Eddington

Orion cloud distance



Gravitational microlensing - 1



Andrew Gould (in Bozza et al. 2016)

Gravitational microlensing - 2



$$(\theta_I - \theta_S)D_S = \alpha(D_S - D_L)$$

$$\theta_I(\theta_I - \theta_S) = \frac{4GM\pi_{\rm rel}}{c^2 {\rm AU}} \equiv \theta_{\rm E}^2.$$

 $\frac{u^2}{2}$,

$$A_{\pm} = \pm \frac{u_{\pm}}{u} \frac{\partial u_{\pm}}{\partial u} = \frac{A \pm 1}{2}$$

$$u_{\pm} = \frac{u \pm \sqrt{u^2 + 4}}{2}; \qquad u \equiv \frac{\theta_S}{\theta_E} \qquad u_{\pm} \equiv \frac{\theta_{I,\pm}}{\theta_E}.$$
$$A = \frac{u^2 + 2}{u\sqrt{u^2 + 4}} = (1 - Q^{-2})^{-1/2}; \qquad Q \equiv 0$$

Andrew Gould (in Bozza et al. 2016)

Light curves for point lenses



$$t_{\mathrm{E}}) = (\tau(t), \beta) = \left(\frac{t - t_0}{t_{\mathrm{E}}}, u_0\right).$$

Andrew Gould (in Bozza et al. 2016)

Microlensing and isolated BHs



Event OGLE-1999-BUL-32

A very long event: 641 days.

Mass estimate for the lense $>4 M_0$

Mao et al. astro-ph/0108312

Microlensing – the MACHO project



MACHO-96-BLG-6 3-16 solar masses.

Bennet et al. astro-ph/0109467

Again MACHO!



MACHO-98-BLG-6 3-13 solar masses.

Bennet et al. astro-ph/0109467

More examples

OGLE-III data



OGLE3-ULENS-PAR-02 8.7 solar masses at 1.8 kpc

Altogether 13 candidates for WD, NS, or BH lensing.



1509.04899, see also 1601.02830

Gaia helps to estimate mass of lenses



Photometric and astrometric



Photometry and astrometry for a black hole at 3 kpc

lensing a background star at 6 kpc with a relative proper motion of 8 mas yr^{-1} .

Left: Photometric light-curve.

Center: Astrometry of the lens and source, with parallax, as would be seen on the sky. Right: Astrometry of the lensed source after the propermotion is removed.

Probabilities of lensing



30-40% of events with >100 days are due to black holes

1.o.s.	Γ_{star}	$\langle t_E \rangle_{star}$	Γ_{NS}	$\langle t_E \rangle_{NS}$	Γ_{BH}	$\langle t_E \rangle_{BH}$
(l, b)	[10 ⁻⁵ star ⁻¹ yr ⁻¹]	[days]	$[10^{-6} \text{star}^{-1} \text{yr}^{-1}]$	[days]	[10 ⁻⁶ star ⁻¹ yr ⁻¹]	[days]
$(0^{\circ}, 0^{\circ})$	2.67	16	1.47	25	0.38	67
(1°, -3°.9)	0.52	20	0.40	28	0.10	77

Population synthesis of isolated BHs and NSs to predict microlensing events



1912.045106 see also1706.04204

Astrometric microlensing and BHs



Black holes around us

- Black holes are formed from very massive stars
- It is very difficult to see an isolated black hole:
 - Microlensing
 - Accretion
 -?
- It is very improtant to have even a very approximate idea where to serach.
 Let us look at our neighbouhood....

There should be about several tens of million isolated BHs in the Galaxy



The Solar proximity





The solar vicinity is not just an average "standard" region

- The Gould Belt
- R=300-500 pc
- Age: 30-50 mill. years
- 20-30 SN in a Myr (Grenier 2000)
- The Local Bubble
- Up 6 SN in several Myrs

The Gould Belt

- Poppel (1997)
- R=300 500 pc
- The age is about 30-50 million years
- A disc-like structure with a center 100-150 pc from the Sun
- Inclined respect to the galactic plane by ~20°
- 2/3 of massive stars in 600 pc from the Sun belong to the Belt





Close-by BHs and runaway stars

56 runaway stars inside 750 pc	Star	Mass	Velocit y km/s	Age, Myr
(Hoogerwerf et al. 2001)	ξ Per	33	65	1
 Four of them have M > 30 M_{solar} 	HD 64760	25-35	31	6
Joidi	ς Pup	67	62	2
	λ Сер	40-65	74	4.5

38

SN explosion in a binary





ς Pup

- Distance: 404-519 pc
- Velocity: 33-58 km/s
- Error box: 12° x 12°
- N_{EGRET}: 1



ξ Per

- Distance: 537-611 pc
- Velocity: 19-70 km/s
- Error box: 7° x 7°
- N_{EGRET}: 1



Gamma-ray emission from isolated BHs



Kerr-Newman isolated BH.

Magnetosphere. B ~ 10^{11} C

Jets.

See details about this theory in Punsly 1998, 1999.

astro-ph/0007464, 0007465 – application to EGRET sources

Runaway BHs

- Approximate positions of young close-by BHs can be estimated basing on data on massive runaway stars
- For two cases we obtained relatively small error boxes
- For HD 64760 and for λ Cep we obtained very large error boxes (40-50°)
- Several EGRET sources inside



Resume

- 1. Accreting stellar mass isolated BHs
- They should be! And the number is huge!
- But sources are very weak.
- Electron-positron jets and/or radio sources
- Problems with identification, if there are no data in several wavelengths
- 2. Microlensing on isolated stellar mass BHs
- There are several good candidates
- But it is necessary to find the black hole ITSELF!
- 3. Exotic emission mechanisms
- As all other exotics: interesting, but not very probable
- If it works, then GLAST will show us isolated BHs
- 4. Runaway stars
- A rare case to make even rough estimates of parameters
- Error-boxes too large for any band except gamma-rays
- All hope on the exotic mechanisms (Torres et al. astro-ph/0007465)