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 10^{12} K (here the temperature means the average energy of electrons motion perpendicular to magnetic field lines).

Victorij Shvartsman

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

Basic formulae

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

$$v_{\rm turb} \sim 1.1\ (r/1{\rm pc})^{0.38} {\rm km\ s^{-1}},$$

Velocity of turbulent motions

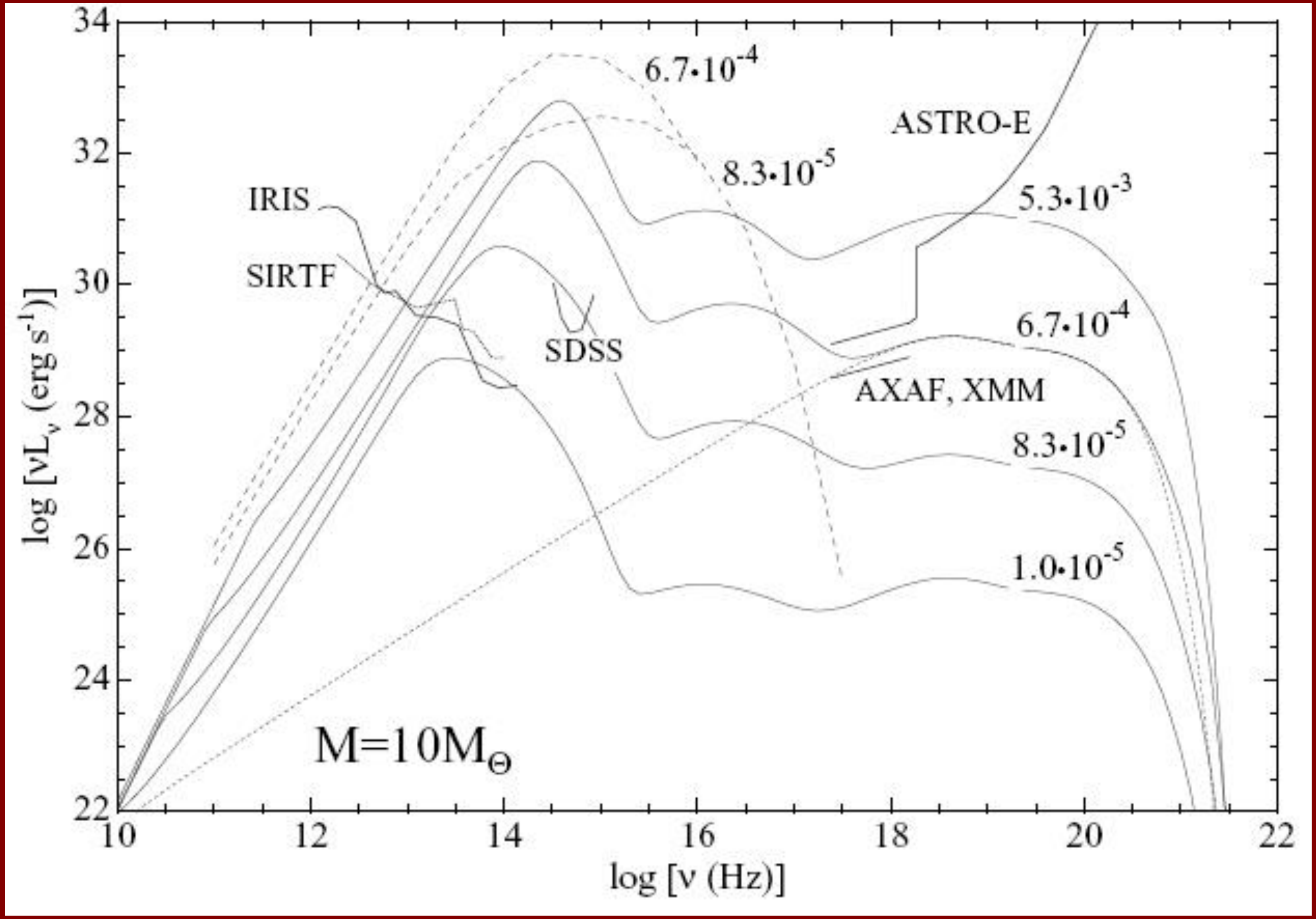
$$V \lesssim 52\ \left(r_g/r_o f_l{}^2\right)^{0.18} (M/M_\odot)^{0.14} {\rm km\ s^{-1}}$$

The critical velocity corresponding to an accretion disc formation.

(Fujita et al. 1998)

See also A&A 381, 1000 (2002)

Isolated accreting BHs

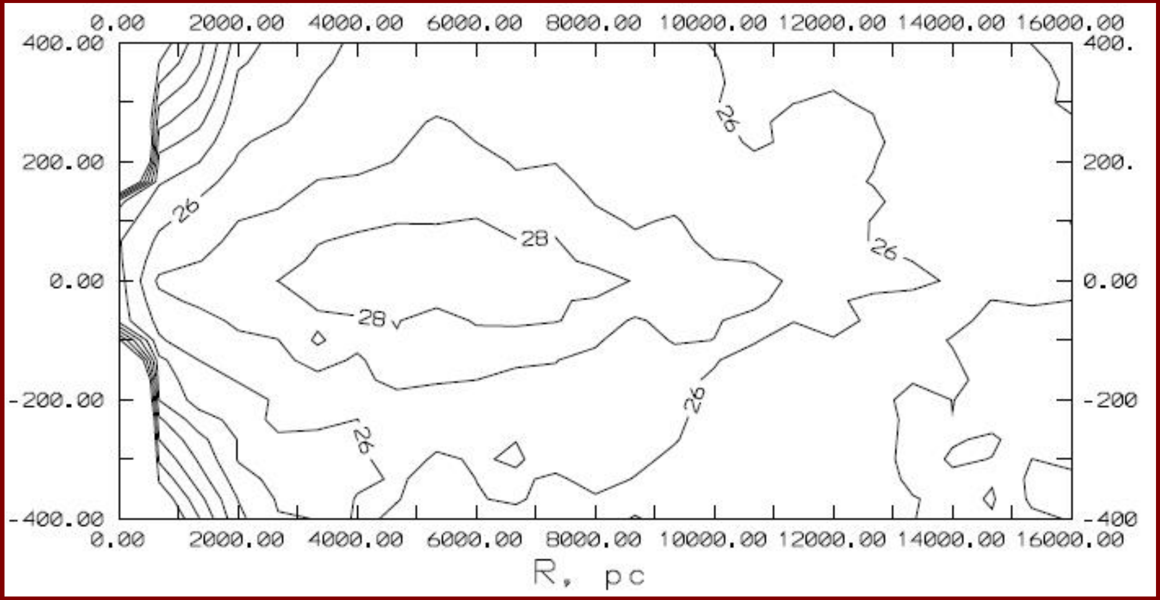


ADAF
10 solar masses

The objects mostly emit in X-rays or IR.

Fujita et al. **astro-ph/9712284**

The galactic population of accreting isolated BHs

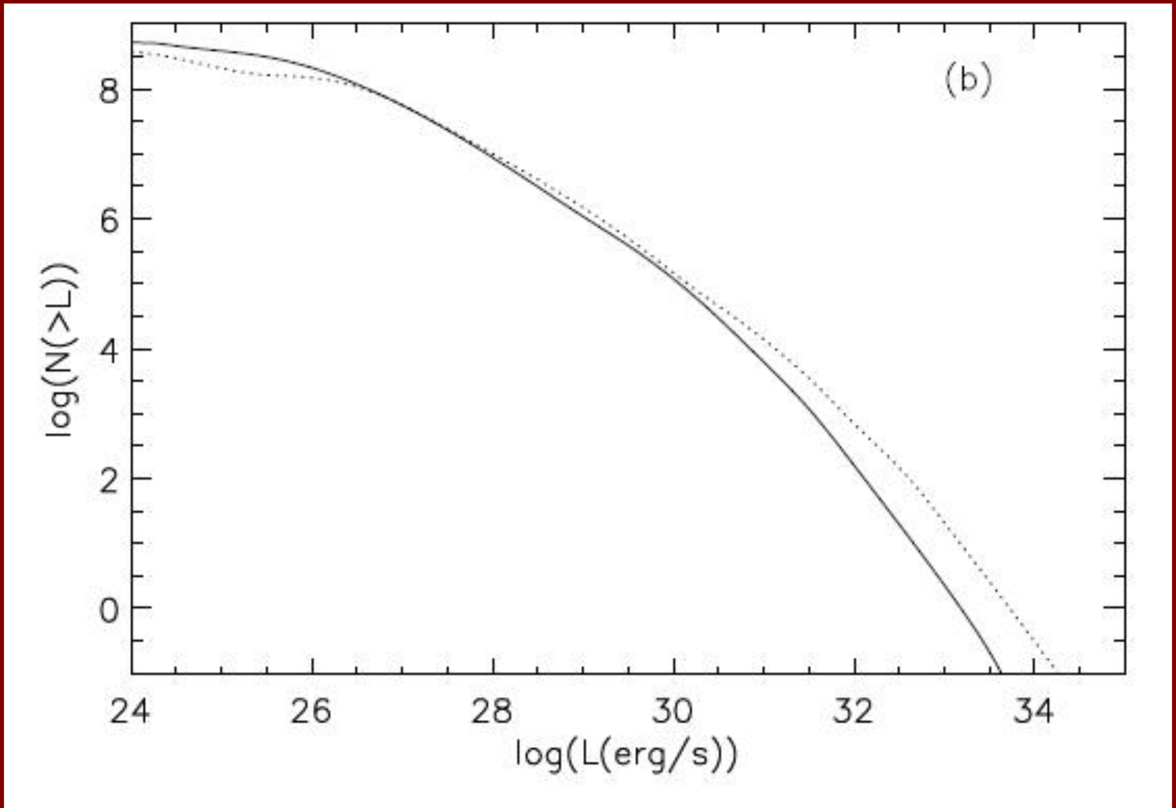


The luminosity distribution is mostly determined by the ISM distribution, then – by the galactic potential.

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.

astro-ph/9705236

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.

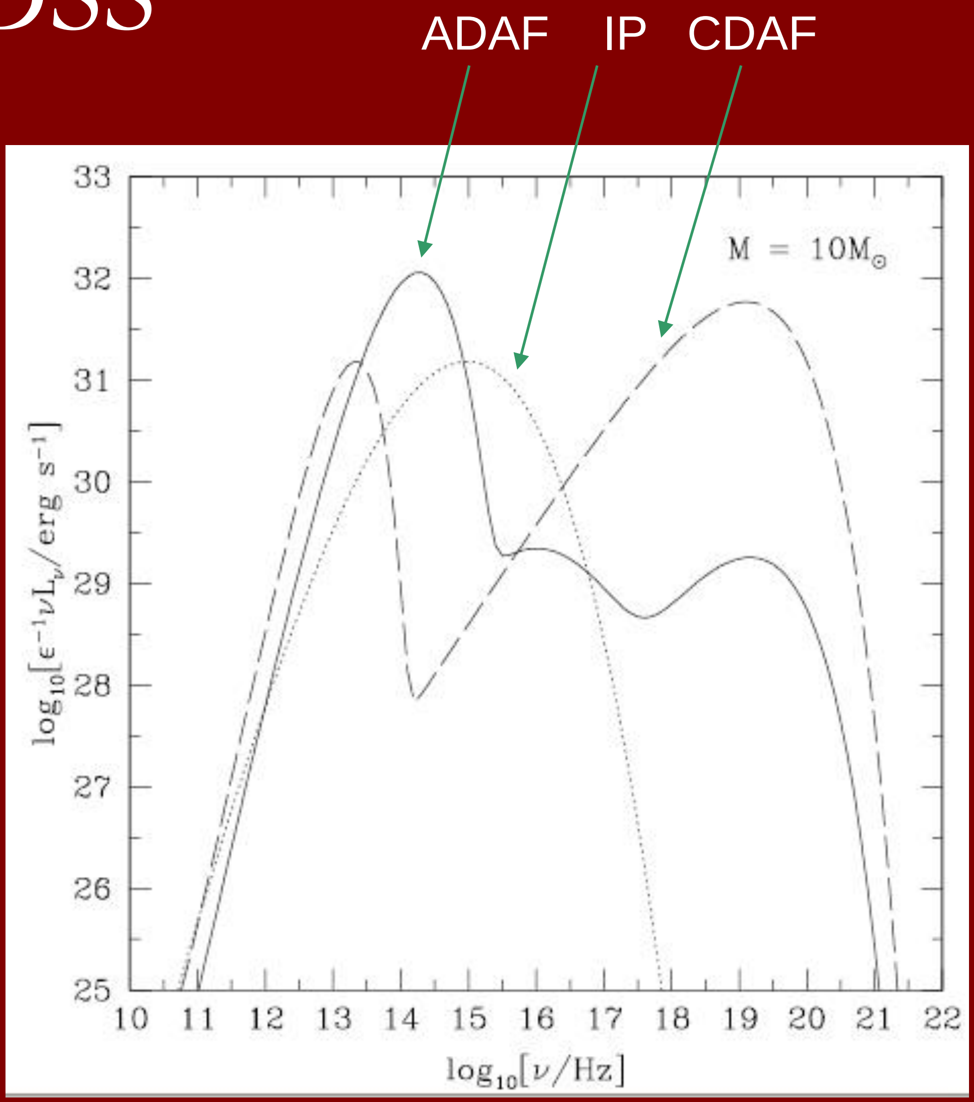
astro-ph/0109539

Digging in the SDSS

The idea is that the synchrotron 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 efficiency are poorly known



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	$\sim$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	5×10^7	7×10^{22}	.005	0
hot ISM	10	0.01	10^6	5×10^7	5×10^{13}	10^{-5}	0
GMC/cold, fast halo IMBH	2600	10^3	10^4	30	8×10^{30}	15	10
IMBH/disk pop/cold ISM	260	10^3	10^4	*	8×10^{33}	40	*
IMBH/disk pop/GMC	260	10^5	10^4	*	8×10^{37}	800	*
IMBH/disk pop/warm ISM	260	0.4	10^4	*	1×10^{27}	0.5	*

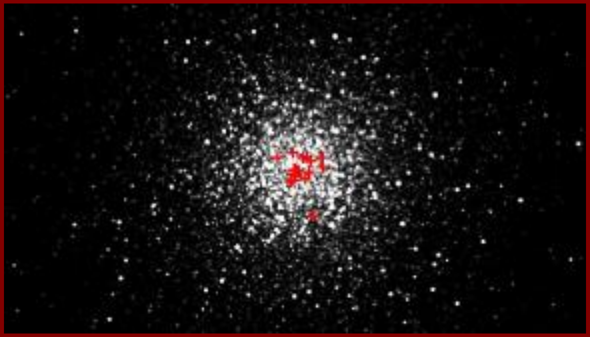
Maccarone astro-ph/0503097

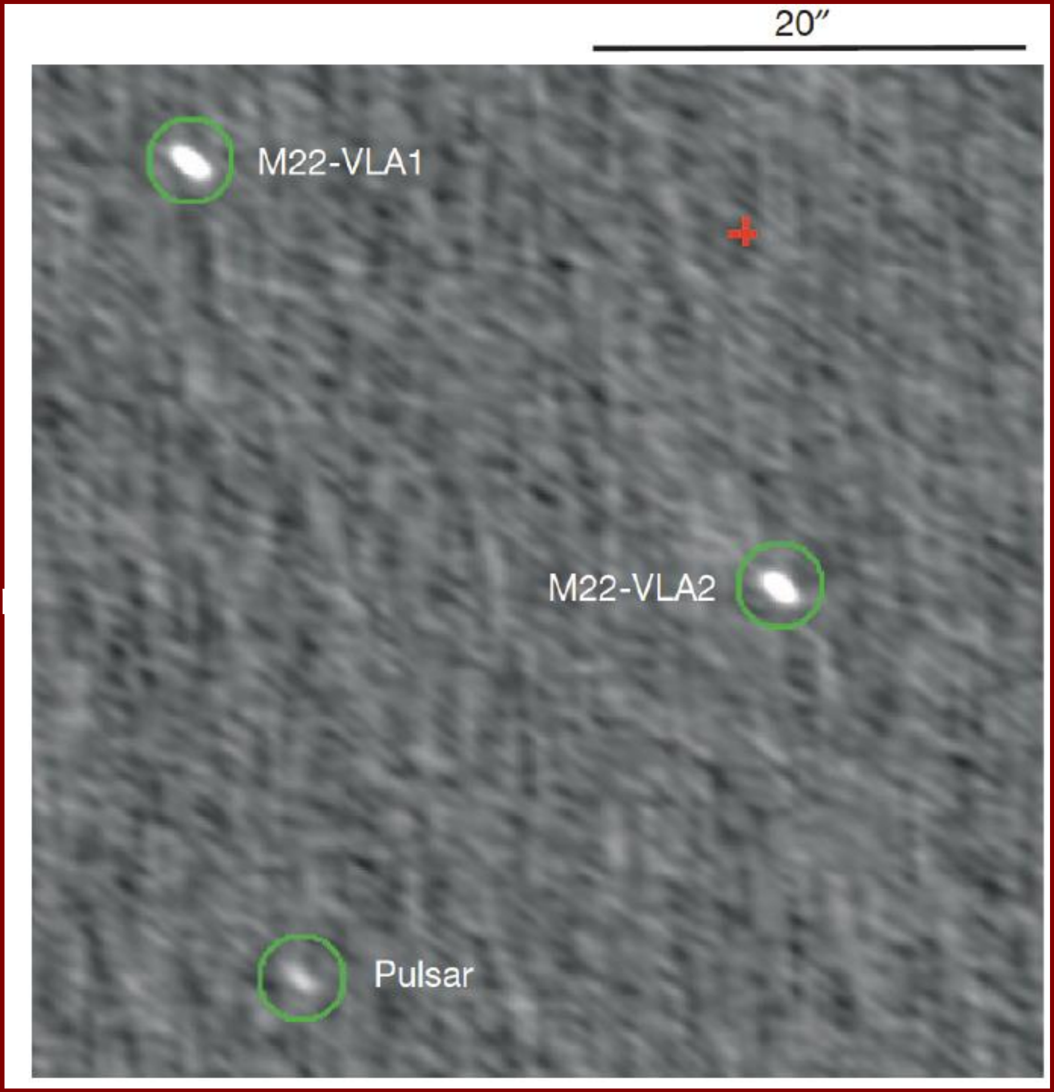
Two isolated BHs in a globular cluster?

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

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

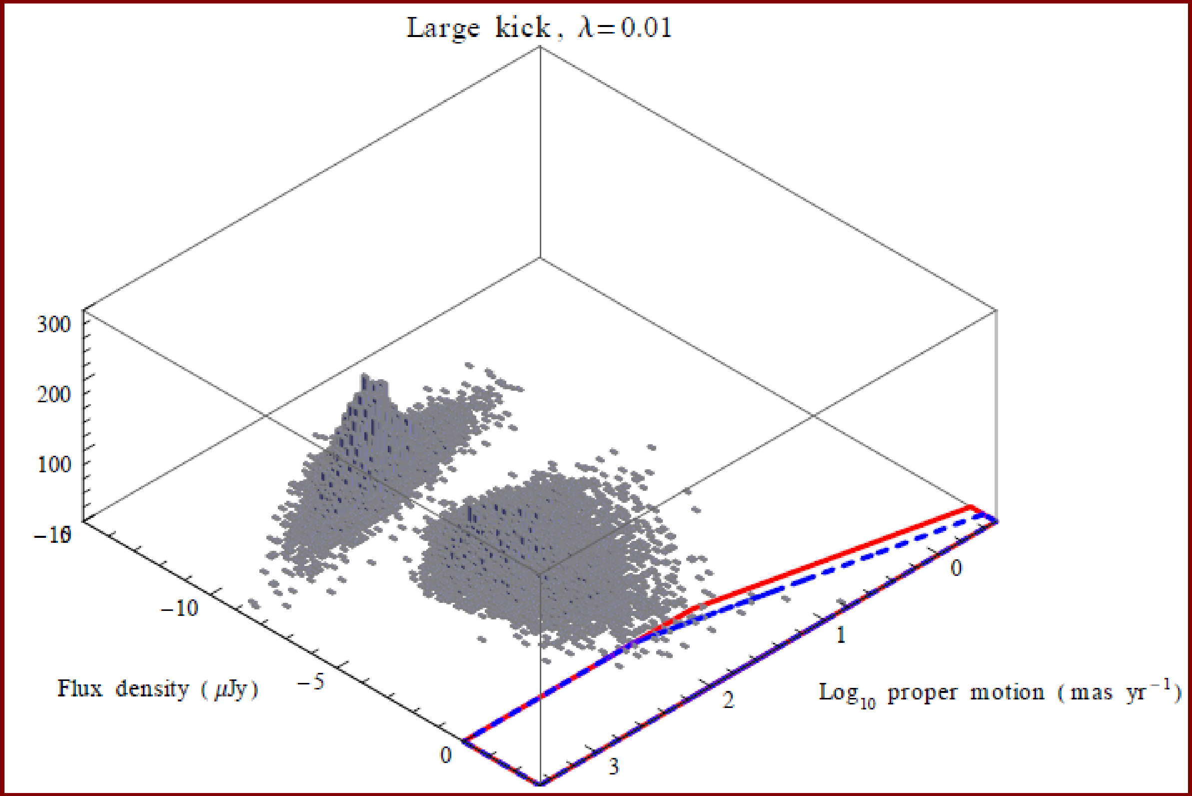
Numerical model for the cluster evolution and the number of BHs was calculated in the paper 1211.6608.





1210.0901

New calculations for radio IBHs



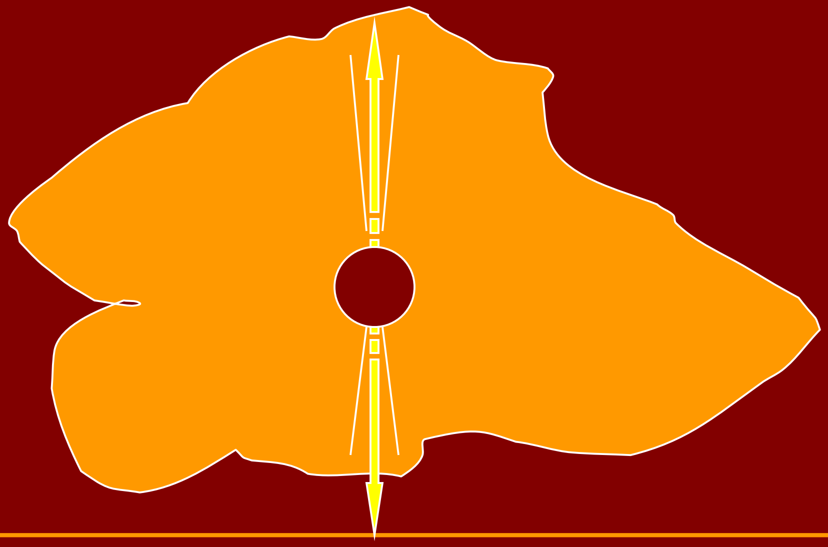
The authors calculate if IBHs can be detected by SKA and other future survey if the accrete from the ISM.
Different assumptions about initial velocitites and accretion efficiency are made.

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

1301.1341

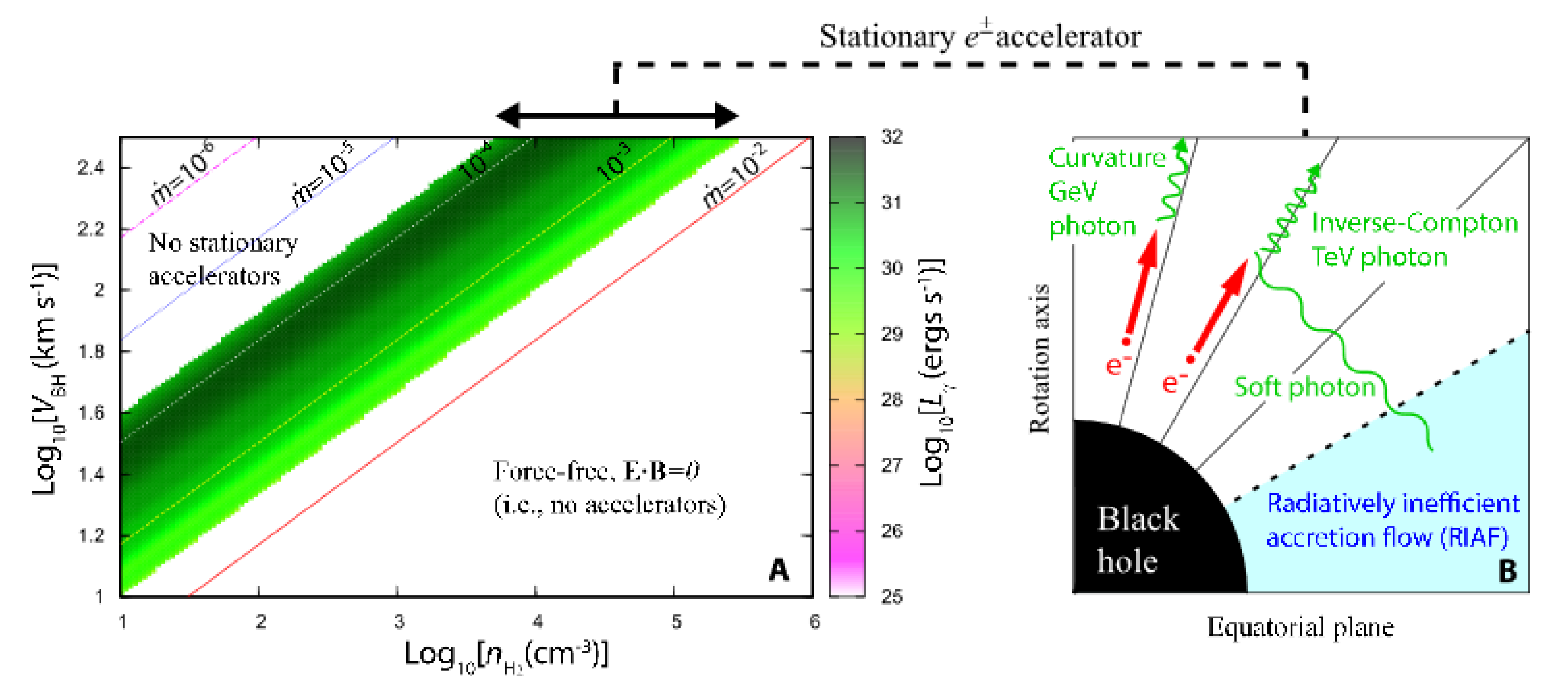
Electron-positron jets from isolated BHs

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.



Barkov et al. 1209.0293

IBHs in molecular clouds as TeV sources

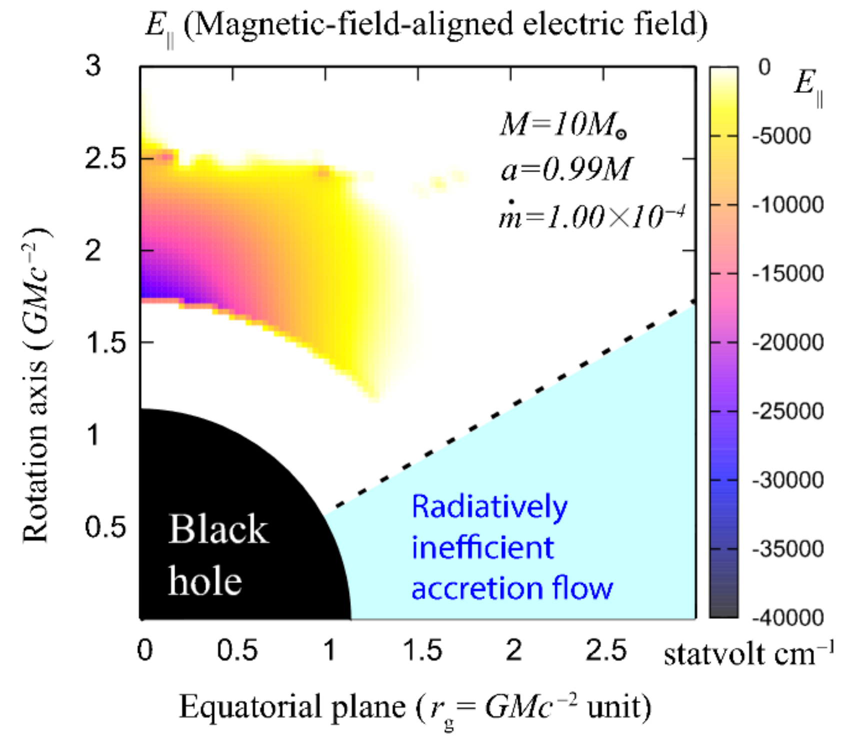


Rotation is important!

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

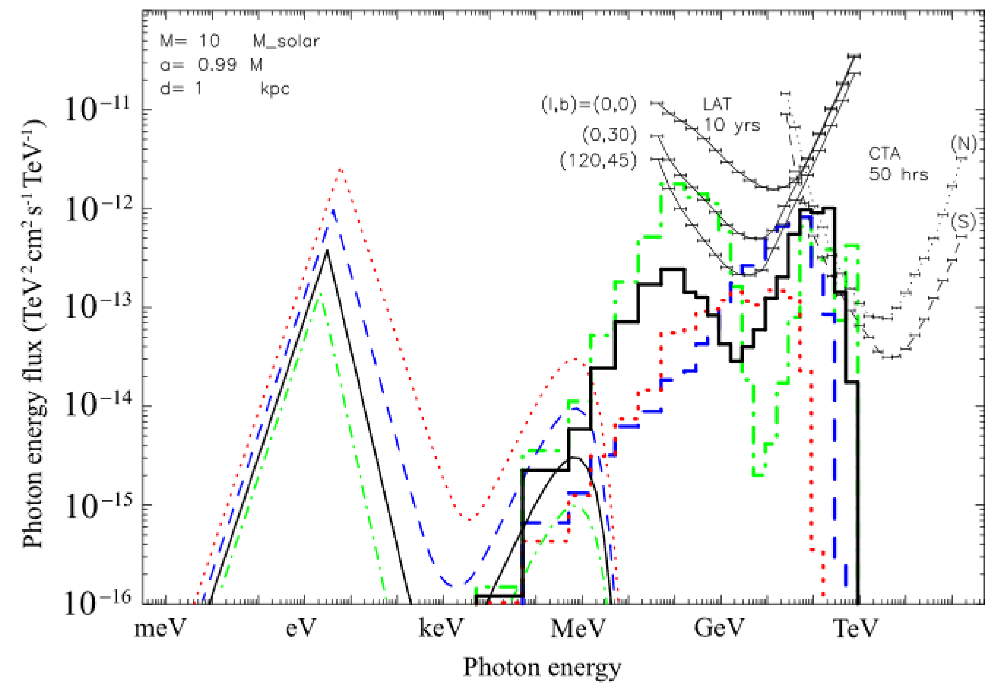
1808.03075

Particle acceleration by rotating IBHs



The red dotted, blue dashed, black solid, and green dash-dottedcurves correspond to the dimensionless accretion rate of $10^{-3.5}$, $10^{-3.75}$, 10^{-4}, and $10^{-4.25}$, respectively.

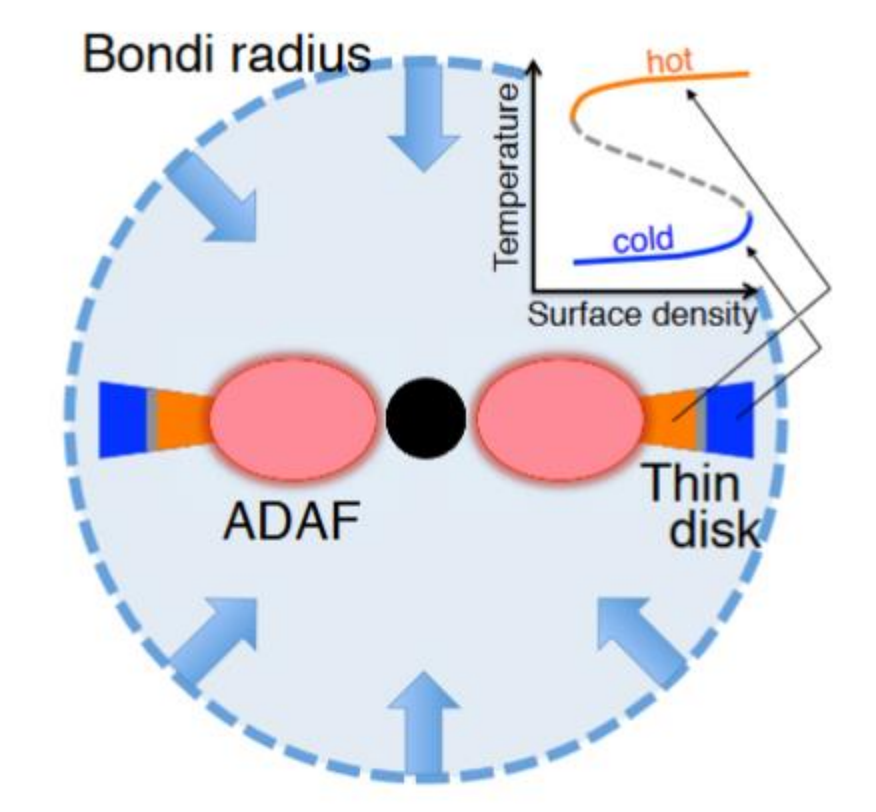
The distance is assumed to be 1 kpc.



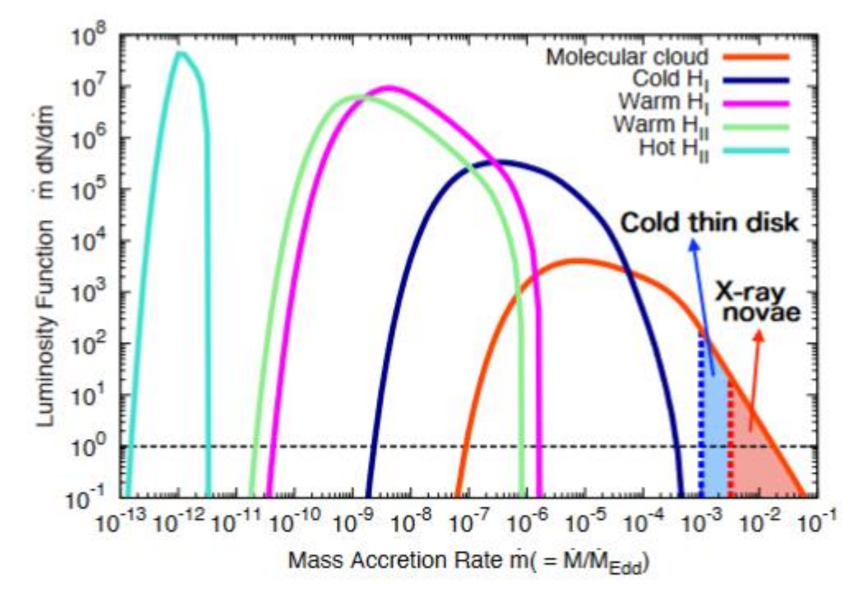
The thin curves on the left denote the input spectra of the ADAF. Such soft photons illuminate the accelerator in the polar funnel. The thick lines denote the spectra of the gamma-rays emitted from the accelerator.

1808.03075

X-ray nova and accreting 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.



Up to several event per year.
Then some of known X-ray nova
with unidentified companions,
can be due to isolated BHs.

1704.05047

Detailed study of AIBHs

$$\dot{M} = \lambda \cdot 4\pi \frac{(GM)^2 \rho}{(v^2 + c_s^2)^{3/2}}$$
$$\approx 3.7 \times 10^{15} \mathrm{g\ s^{-1}}$$
$$\cdot \left(\frac{\lambda}{0.1}\right) \left(\frac{M}{10\ \mathrm{M_\odot}}\right)^2 \left(\frac{\rho}{10^3\ \mathrm{cm^{-3}}\ m_p}\right) \left[\frac{v^2 + c_s^2}{(10\ \mathrm{km\ s^{-1}})^2}\right]^{-3/2}$$

$$\eta = \begin{cases} \eta_{\rm std}(\dot{M}/\dot{M}_{\rm th}) & (\text{when } \dot{M} < \dot{M}_{\rm th}) \\ \eta_{\rm std} & (\text{when } \dot{M}_{\rm th} < \dot{M} < 2\dot{M}_{\rm Edd}). \end{cases}$$

RIAF (radiatively-inefficient accretion flow). Below some threshold the luminosity is reduced.

$$L = \eta \dot{M} c^2$$
$$= 3.4 \times 10^{37} \mathrm{erg\ s^{-1}}$$
$$\cdot \eta\lambda \left(\frac{M}{10\ \mathrm{M_\odot}}\right)^2 \left(\frac{\rho}{10^3\ \mathrm{cm^{-3}}\ m_p}\right) \left[\frac{v^2 + c_s^2}{(10\ \mathrm{km\ s^{-1}})^2}\right]^{-3/2}$$

Most of AIBHs are in the RIAF state.

RIAF

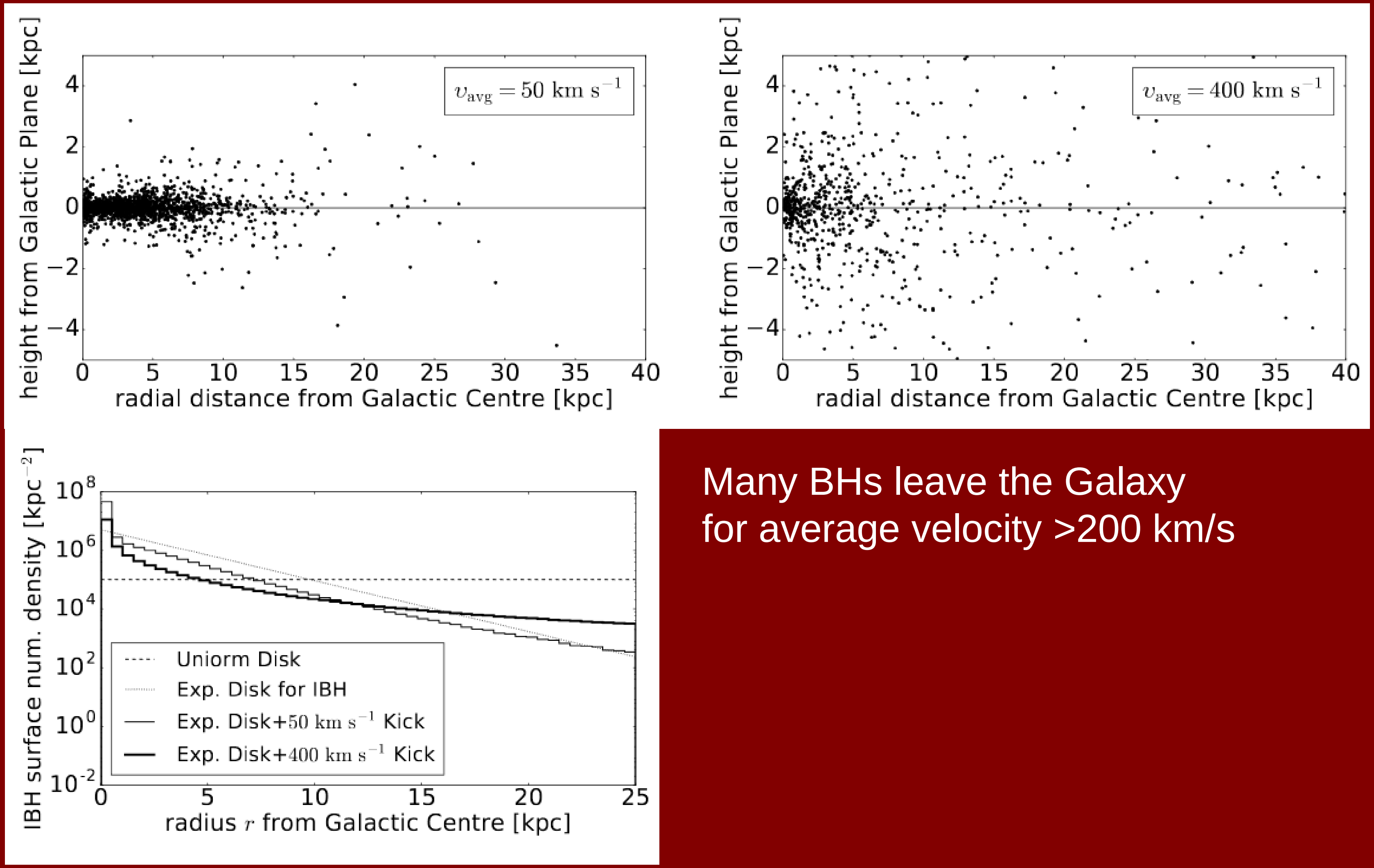
$$L = 9.0 \times 10^{32} \mathrm{erg\ s^{-1}}$$
$$\cdot \left(\frac{\lambda}{0.1}\right)^2 \left(\frac{M}{10\ \mathrm{M_\odot}}\right)^3 \left(\frac{\rho}{10^3\ \mathrm{cm^{-3}}\ m_p}\right)^2 \left[\frac{v^2 + c_s^2}{(10\ \mathrm{km\ s^{-1}})^2}\right]^{-3}$$

Standard

$$L = 3.4 \times 10^{35} \mathrm{erg\ s^{-1}}$$
$$\cdot \left(\frac{\lambda}{0.1}\right) \left(\frac{M}{10\ \mathrm{M_\odot}}\right)^2 \left(\frac{\rho}{10^3\ \mathrm{cm^{-3}}\ m_p}\right) \left[\frac{v^2 + c_s^2}{(10\ \mathrm{km\ s^{-1}})^2}\right]^{-3/2}$$

1801.04667

Spatial distribution

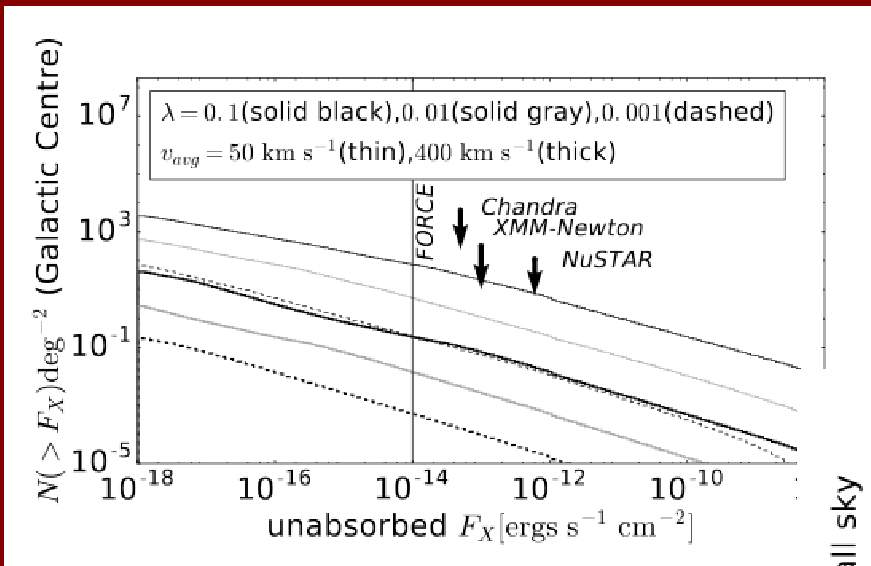


Many BHs leave the Galaxy
for average velocity >200 km/s

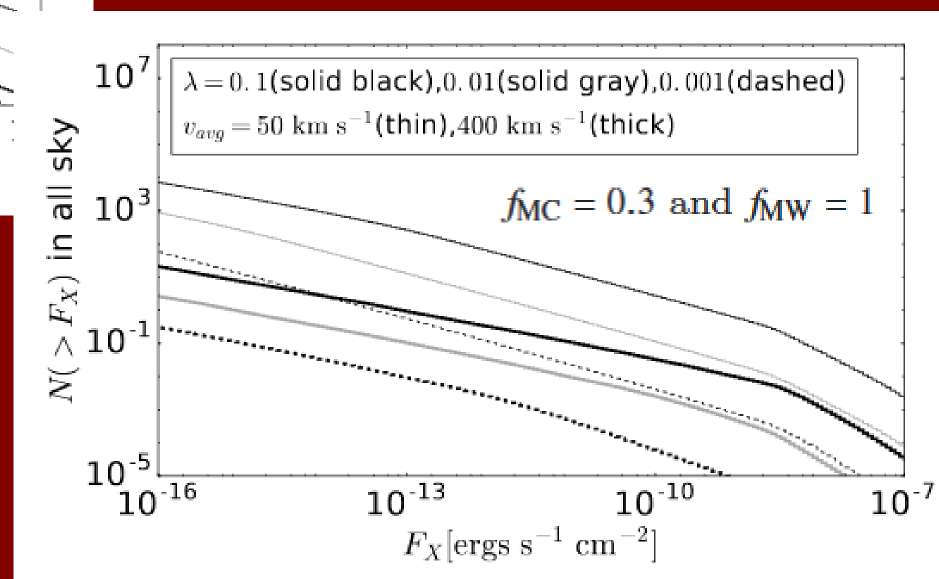
1801.04667

Observability

$dF_{\rm ph}/d\epsilon_{\rm ph} \propto \epsilon_{\rm ph}^{-\zeta}$ Power-law spectrum in the RIAF regime (hard state)



	$v_{\rm avg}$ [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



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

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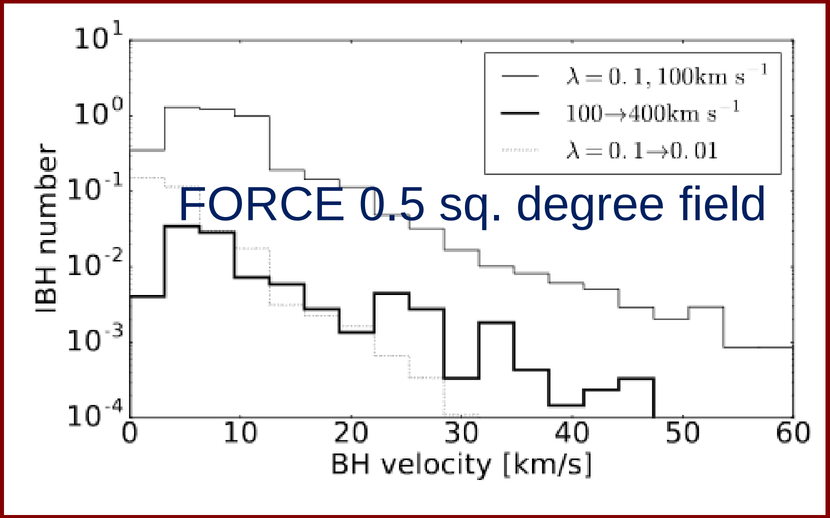
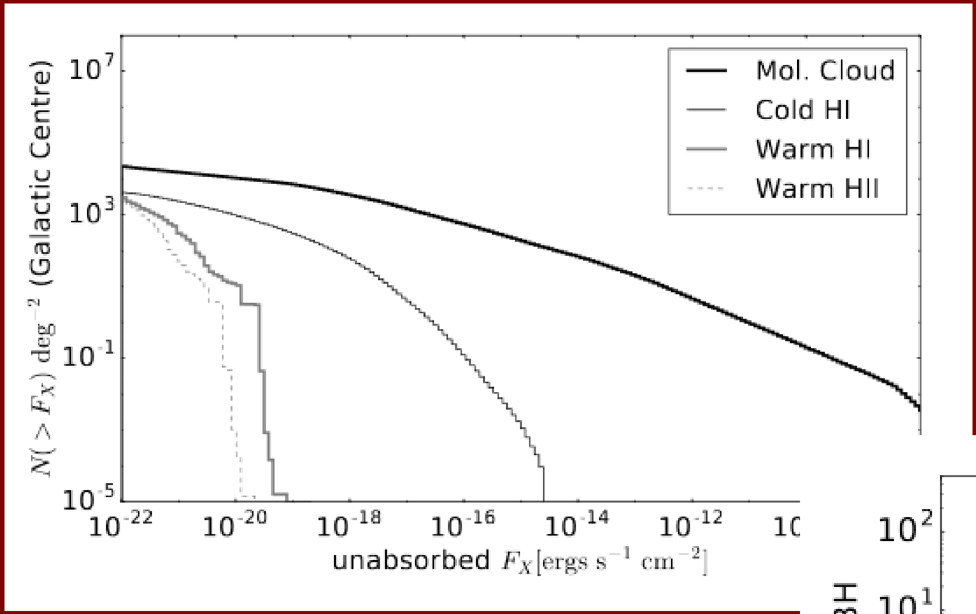
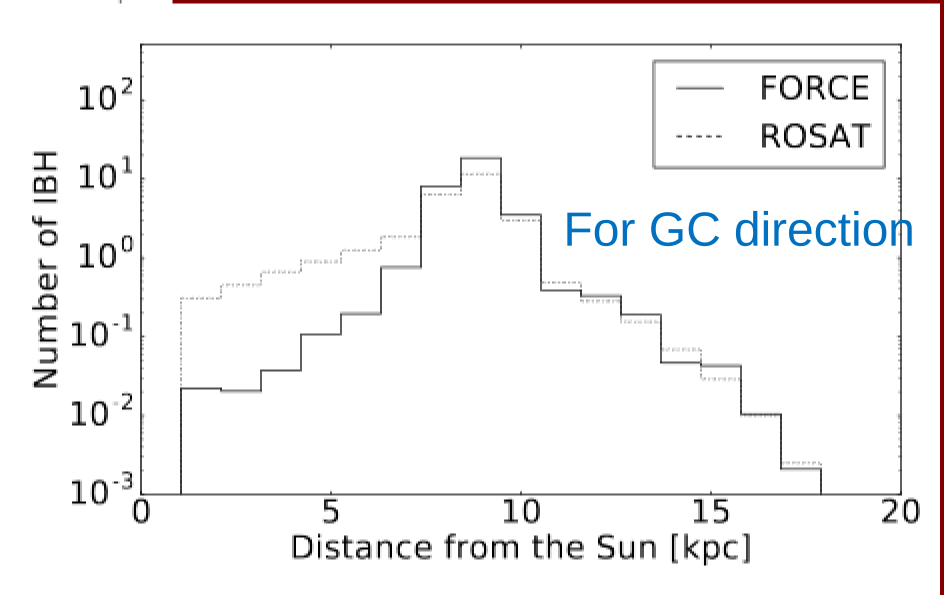
Properties of AIBHs





AIBHs from dense ISM regions contribute more.



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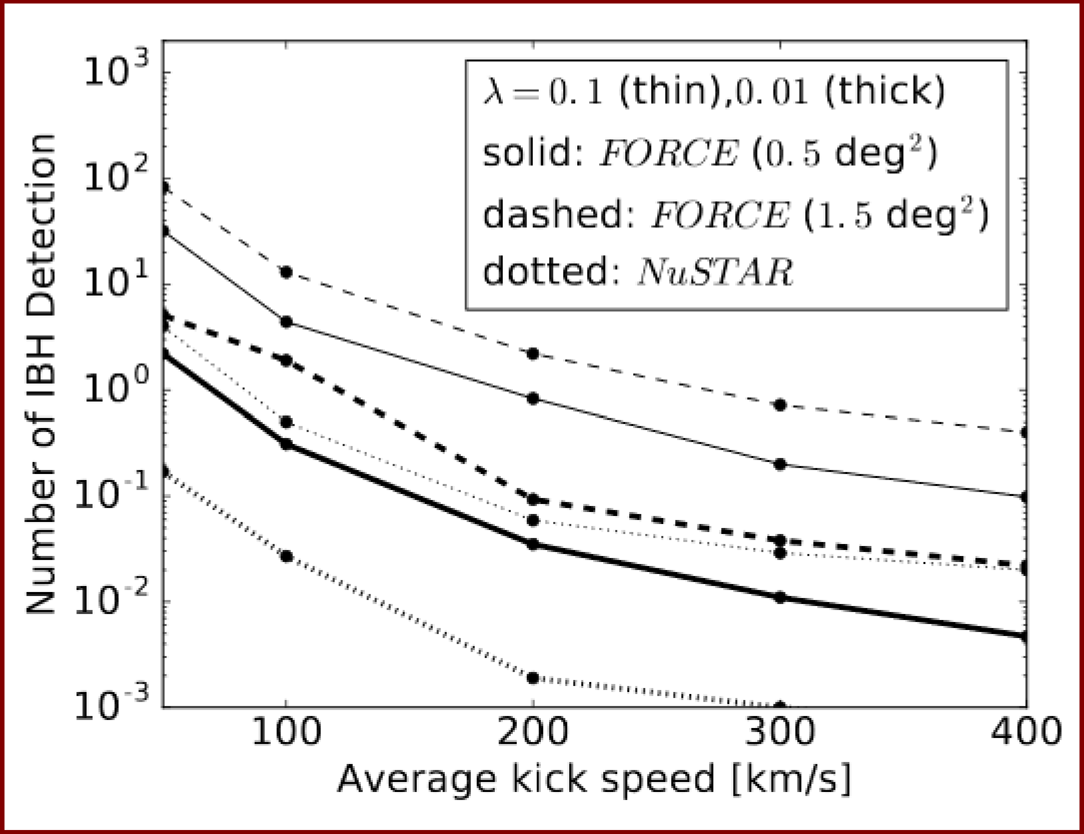
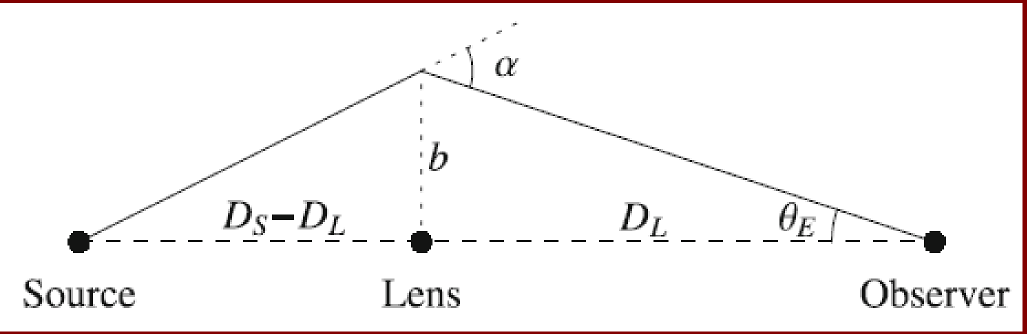
Deep survey towards the Galactic center



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

1801.04667

Gravitational microlensing - 1



Probability of microlensing is small.
For stars it is ~10^{-5} – 10^{-6} per year.

$$b = D_L \theta_E,$$

$$\alpha = b/D_L + b/(D_S - D_L).$$

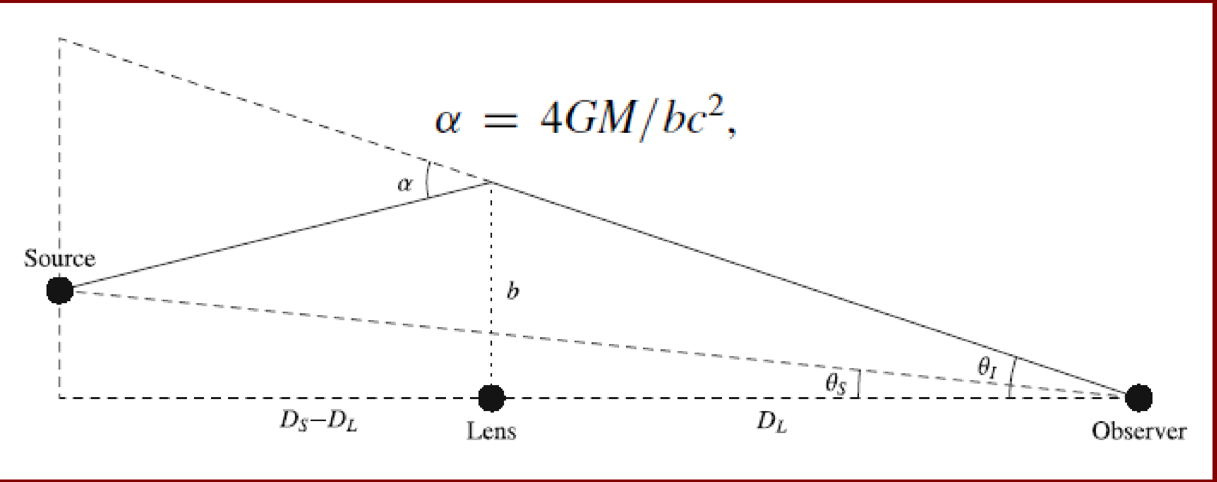
$$\theta_E = \sqrt{\kappa M \pi_{rel}}; \qquad \kappa \equiv \frac{4G}{c^2 \mathrm{AU}} \simeq 8.14 \frac{\mathrm{mas}}{M_\odot},$$

$$\pi_{rel} = \mathrm{AU}(D_L^{-1} - D_S^{-1})$$

$$\tau = \int dD_L \pi (D_L \theta_E)^2 n(D_L) \sim \frac{4\pi G M n}{c^2} D^2 = \frac{4\pi G \rho}{c^2} D^2 \sim \frac{G M_{tot}}{D c^2} \sim \frac{v^2}{c^2}$$

Andrew Gould (in Bozza et al. 2016)

Gravitational microlensing - 2



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

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

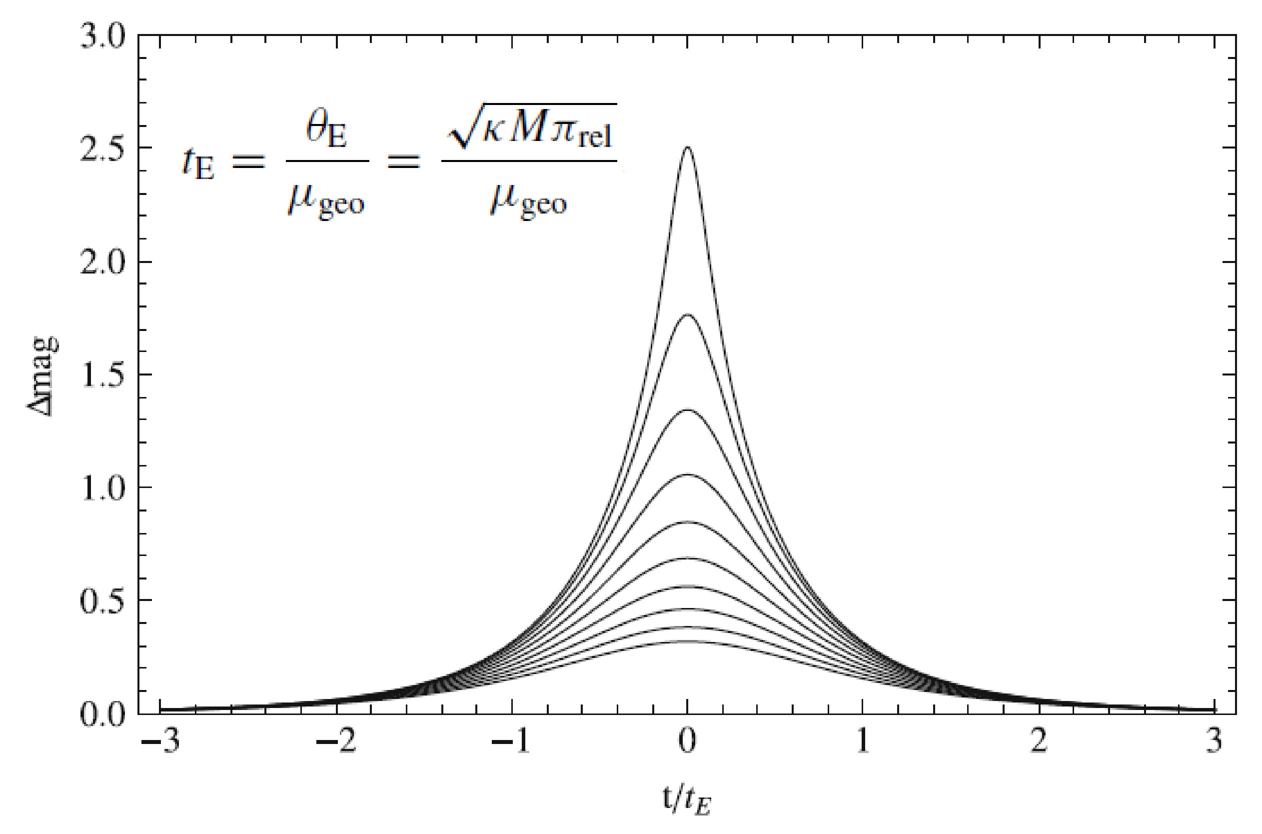
$$A_\pm = \pm\frac{u_\pm}{u}\frac{\partial u_\pm}{\partial u} = \frac{A \pm 1}{2}$$

$$u_\pm = \frac{u \pm \sqrt{u^2+4}}{2}; \qquad u \equiv \frac{\theta_S}{\theta_{\rm E}} \qquad u_\pm \equiv \frac{\theta_{I,\pm}}{\theta_{\rm E}}.$$

$$A = \frac{u^2+2}{u\sqrt{u^2+4}} = (1 - Q^{-2})^{-1/2}; \qquad Q \equiv 1 + \frac{u^2}{2},$$

Andrew Gould (in Bozza et al. 2016)

Light curves for point lenses

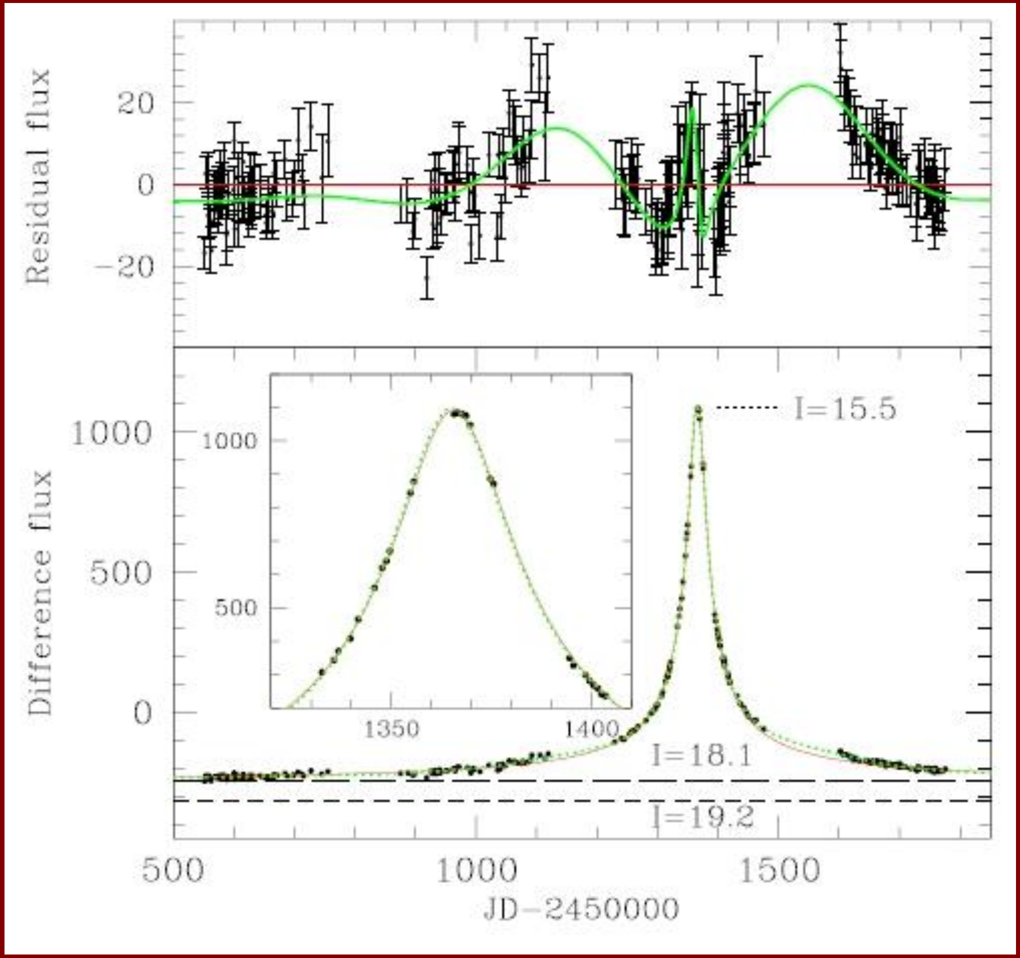


$$F(t) = f_s A(\mathbf{u}(t; t_0, u_0, t_E), \rho) + f_b;$$

$$\mathbf{u}(t; t_0, u_0, t_E) = (\tau(t), \beta) = \left(\frac{t - t_0}{t_E}, u_0\right).$$

Andrew Gould (in Bozza et al. 2016)

Microlensing and isolated BHs



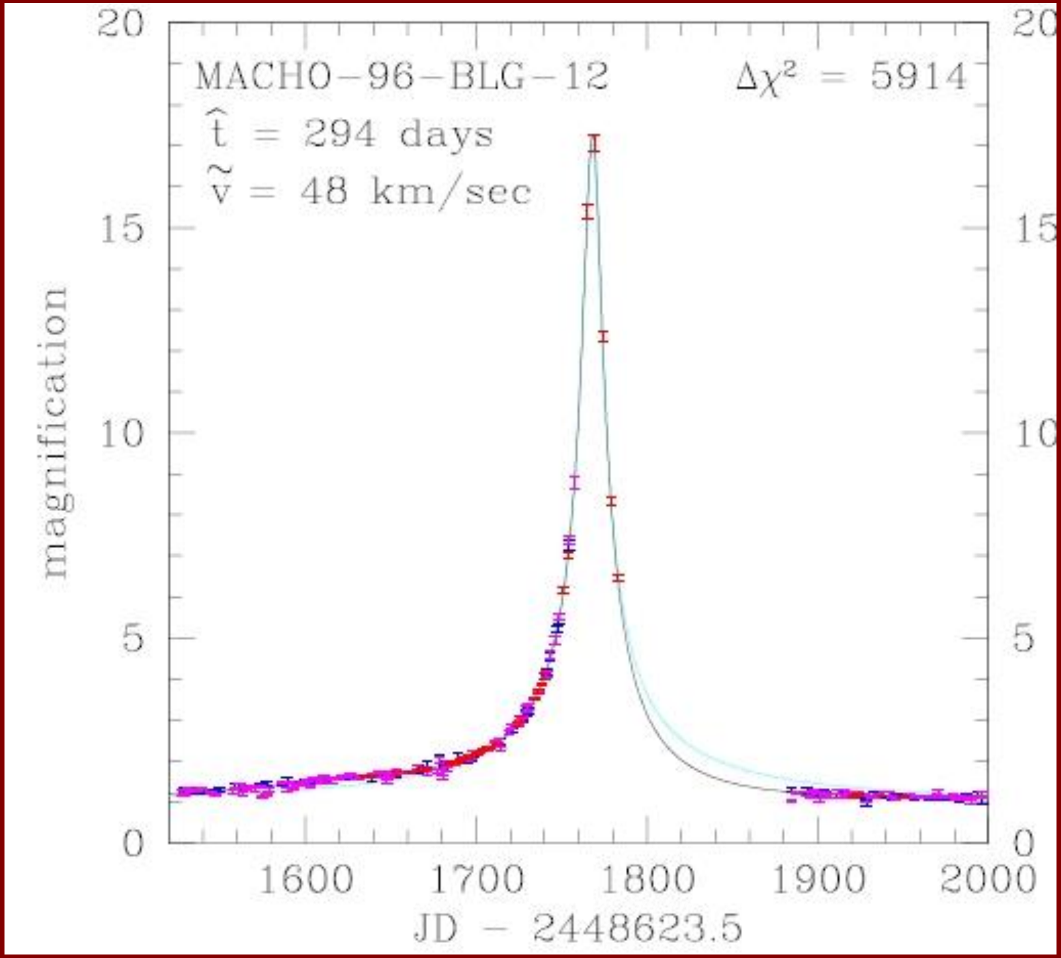
Event OGLE-1999-BUL-32

A very long event: 641 days.

Mass estimate for the lense >4 M_0

Mao et al. astro-ph/0108312

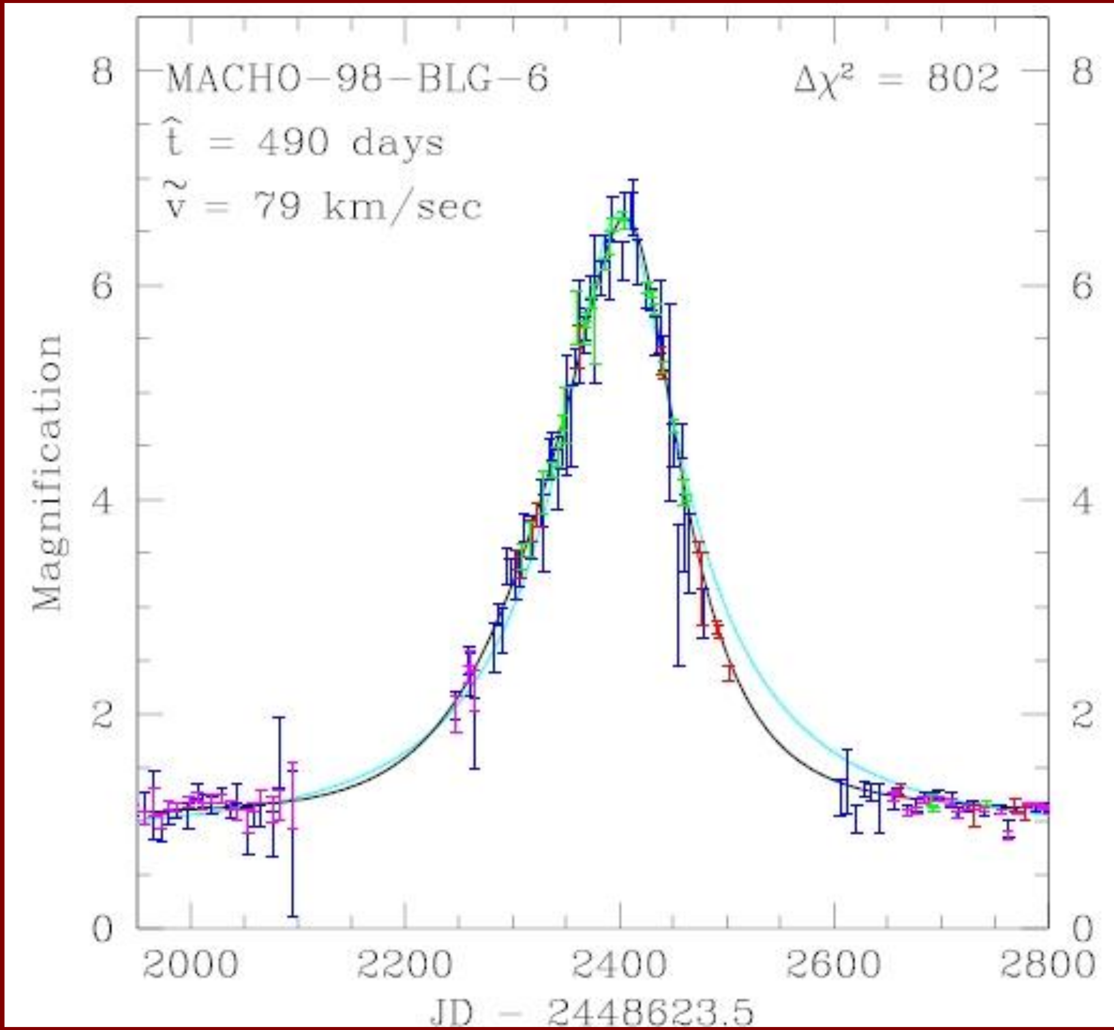
Microlensing – the MACHO project



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

Bennet et al. astro-ph/0109467

Again MACHO!

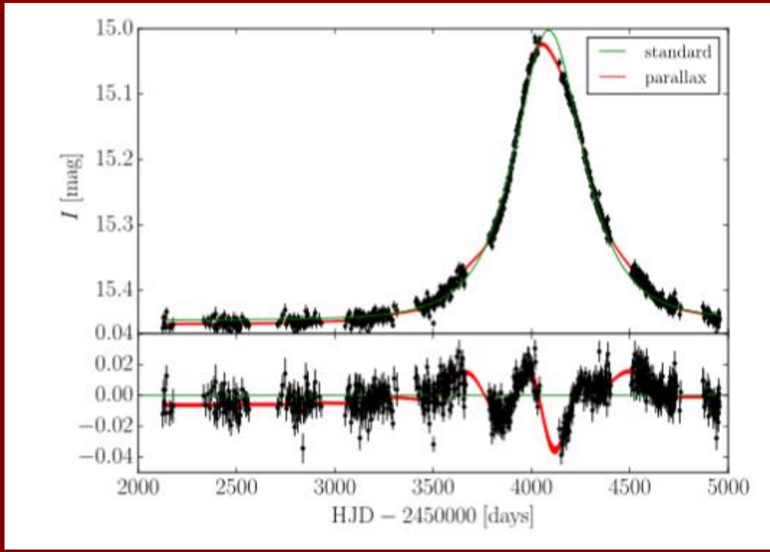


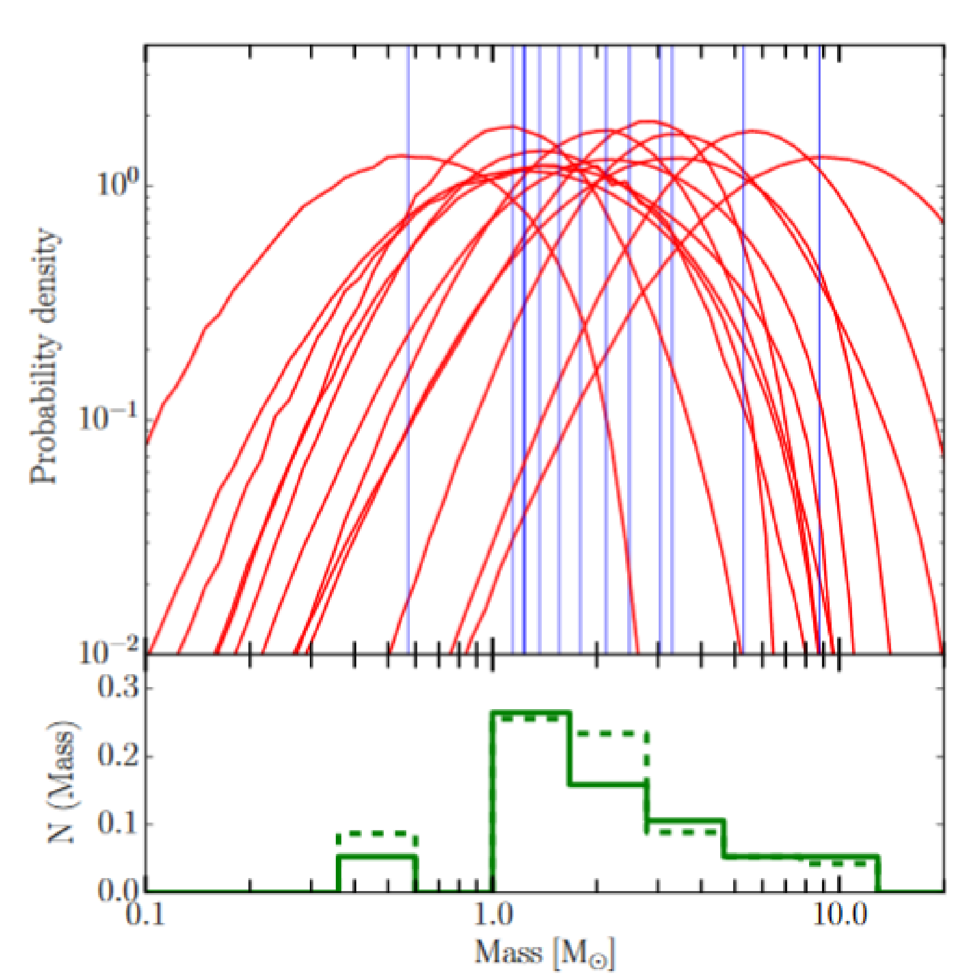
MACHO-98-BLG-6
3-13 solar masses.

Bennet et al. astro-ph/0109467

More examples

OGLE-III data



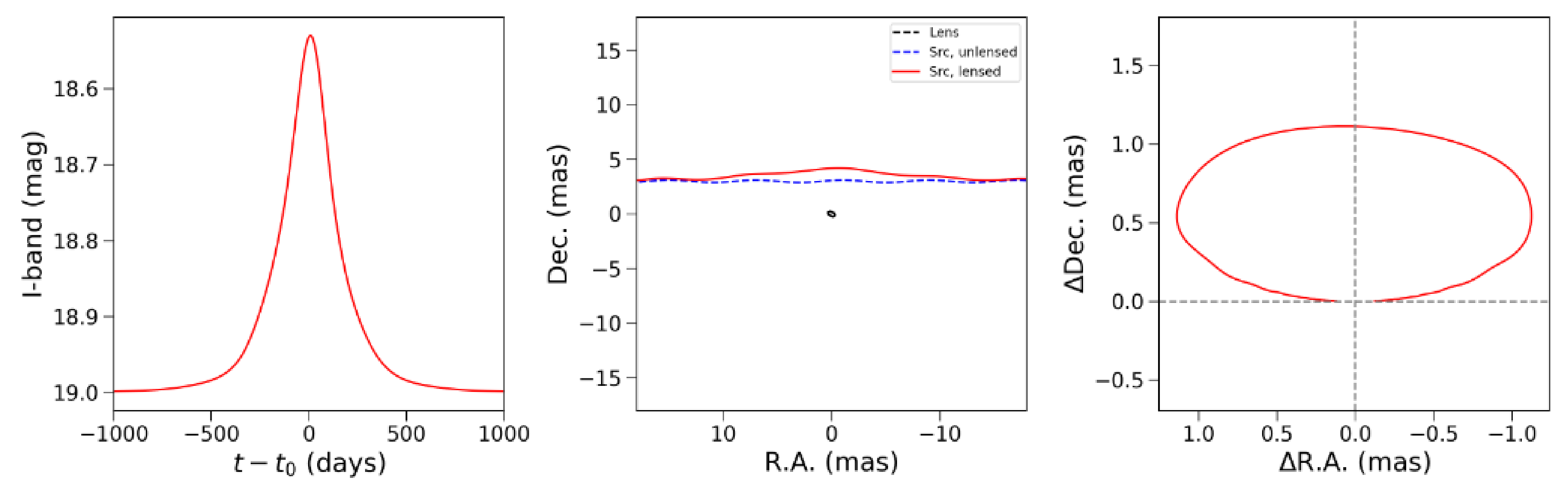


OGLE3-ULENS-PAR-02
8.7 solar masses at 1.8 kpc

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

1509.04899, see also 1601.02830

Photometric and astrometric

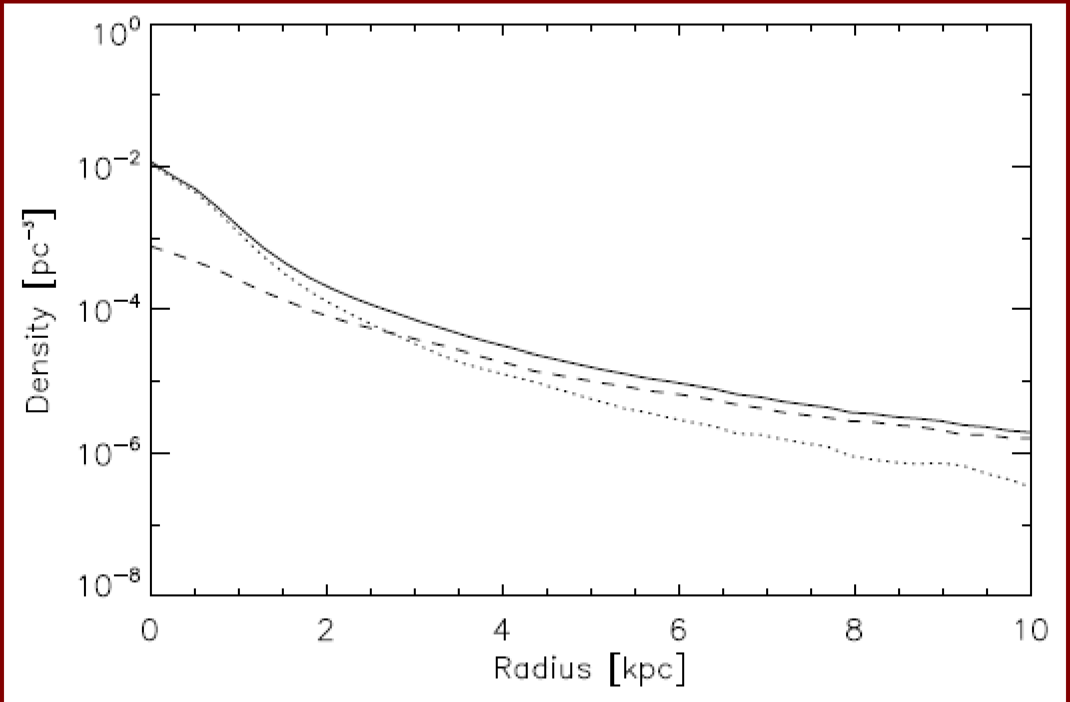


Photometry and astrometry for a black hole at 3 kpc
lensing a background star at 6 kpc with a relative proper motion of 8 mas yr^{-1}.

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.

1904.01773

Probabilities of lensing

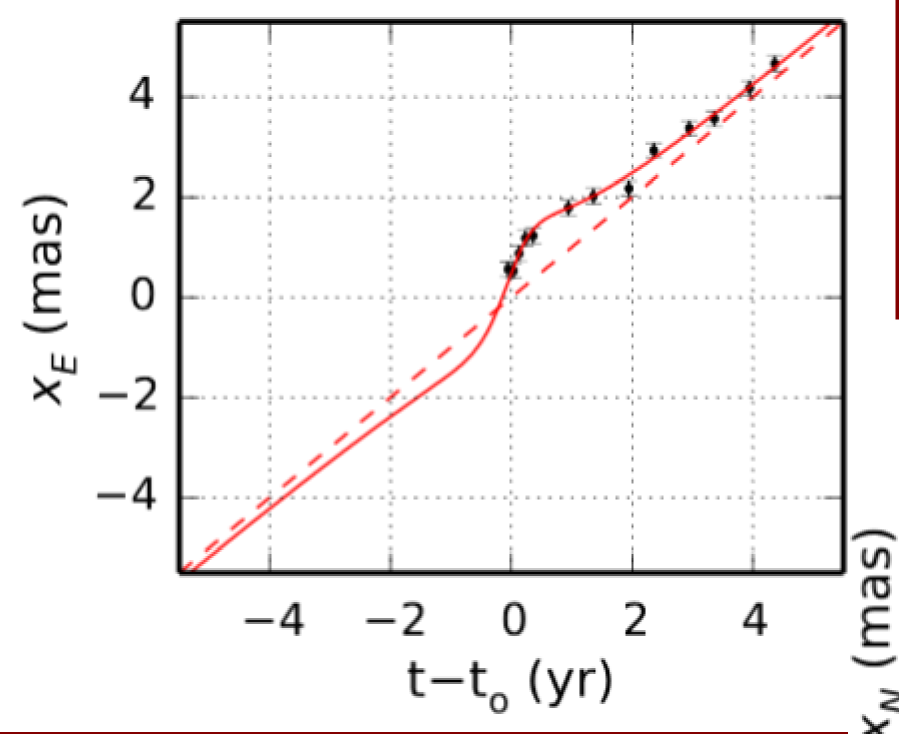


30-40% of events with >100 days are due to black holes

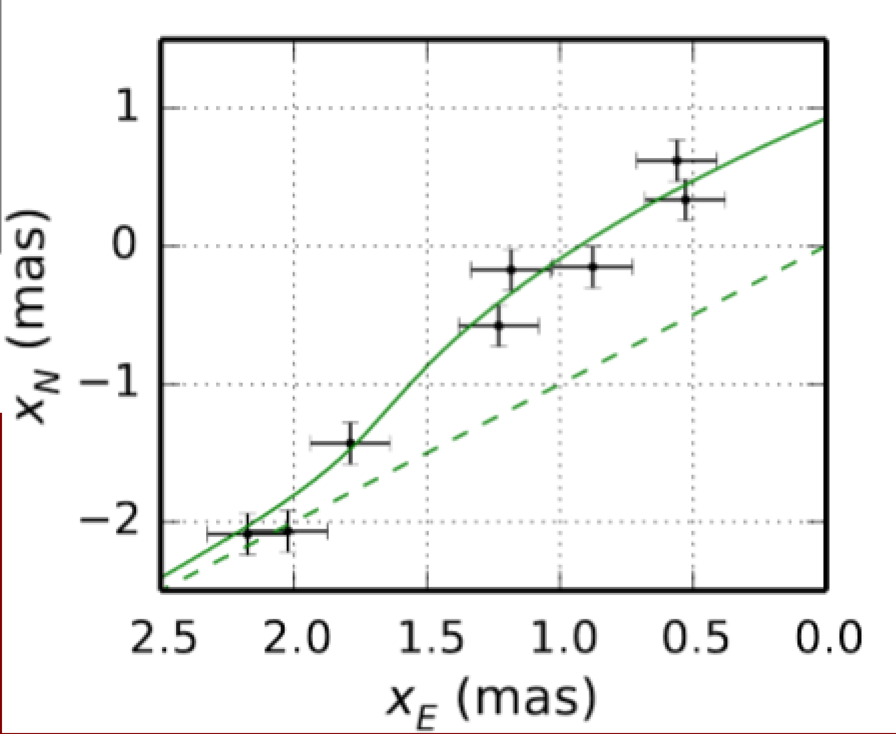
l.o.s. (l, b)	Γ_{star} $[10^{-5}\ \mathrm{star}^{-1}\ \mathrm{yr}^{-1}]$	$\langle t_E \rangle_{star}$ [days]	Γ_{NS} $[10^{-6}\ \mathrm{star}^{-1}\ \mathrm{yr}^{-1}]$	$\langle t_E \rangle_{NS}$ [days]	Γ_{BH} $[10^{-6}\ \mathrm{star}^{-1}\ \mathrm{yr}^{-1}]$	$\langle t_E \rangle_{BH}$ [days]
$(0°, 0°)$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

1009.0005

Astrometric microlensing and BHs



A simulation of the 2D astrometric shift due a 10 solar masses BH at 4 kpc microlensing a background source at 8 kpc with a relative proper motion of 7 mas/yr and impact parameter u_0=0.5.



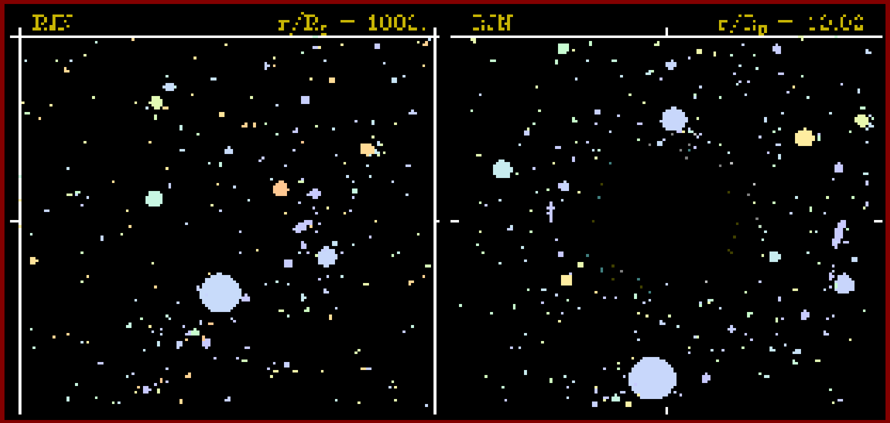
Also Gaia can contribute.

1607.08284

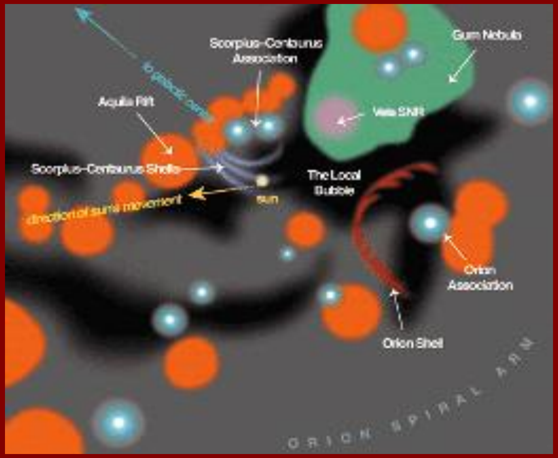
Black holes around us

- 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



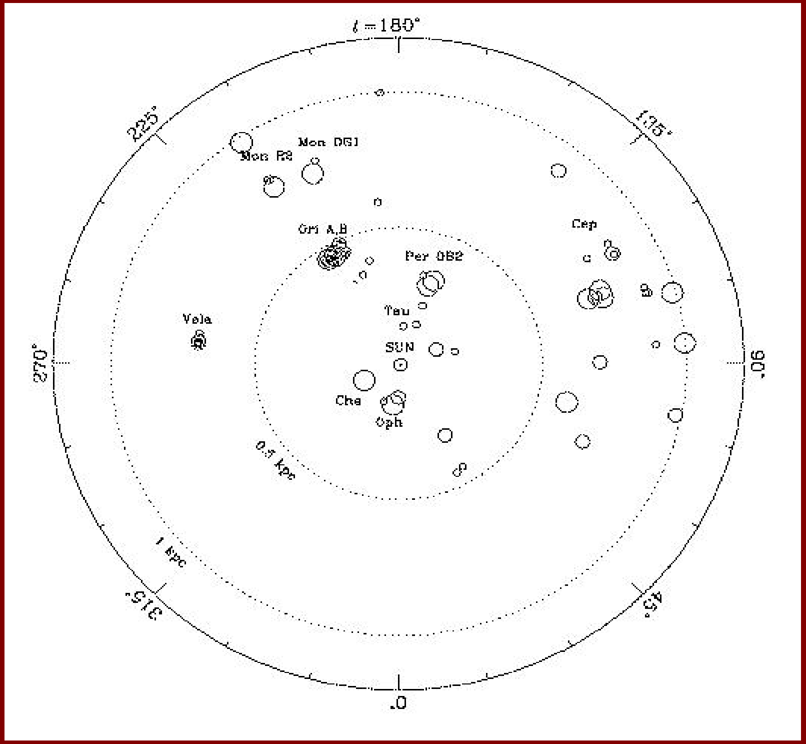
The Solar proximity

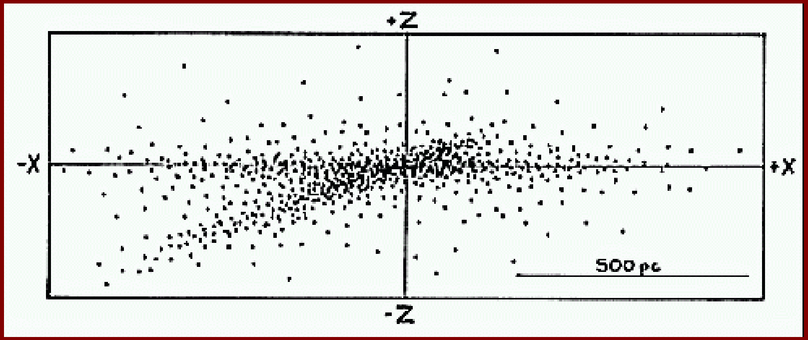


- The solar vicinity is not just an average "standard" region
- The Gould Belt
- R=300-500 pc
- Age: 30-50 mill. years
- 20-30 SN in a Myr (Grenier 2000)
- The Local Bubble
- Up 6 SN in several Myrs

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 ~20º
- 2/3 of massive stars in 600 pc from the Sun belong to the Belt





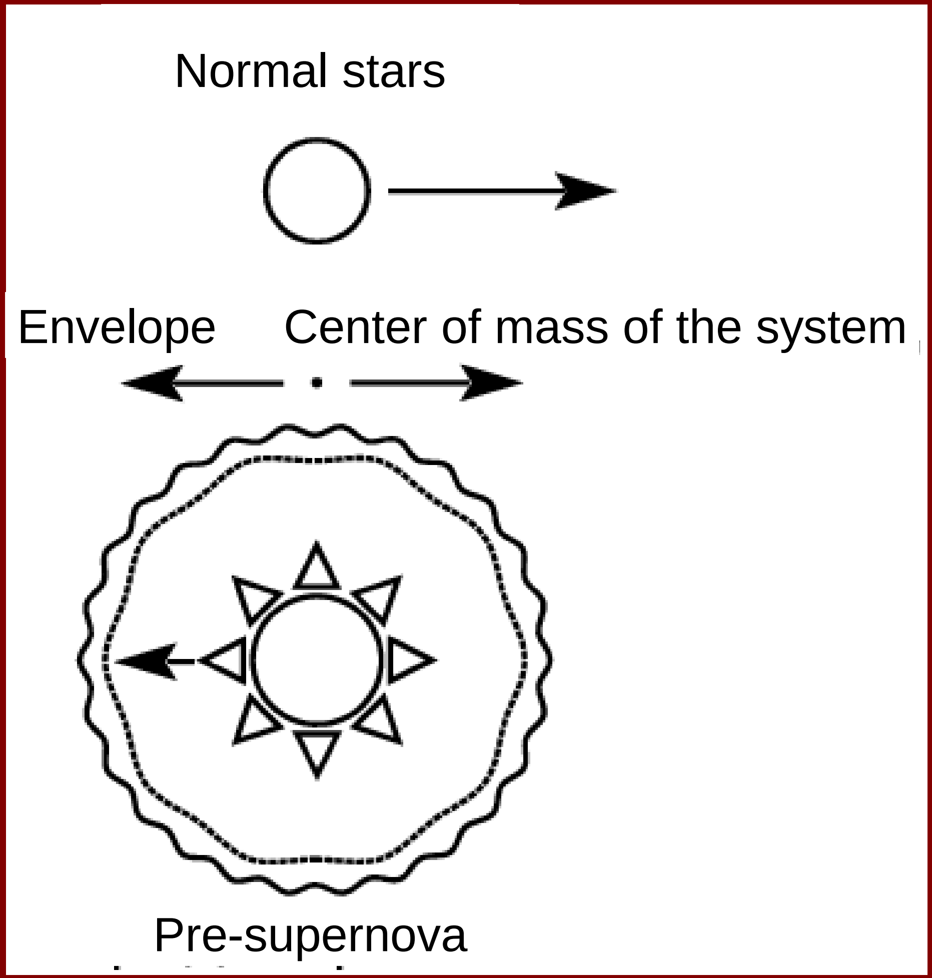
Close-by BHs and runaway stars

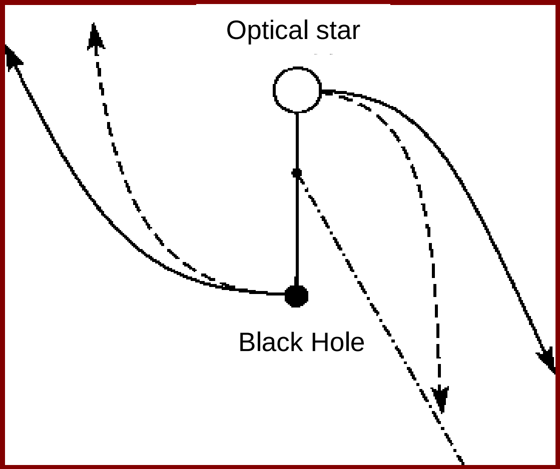
- 56 runaway stars inside 750 pc (Hoogerwerf et al. 2001)
- Four of them have $M > 30\ M_{solar}$

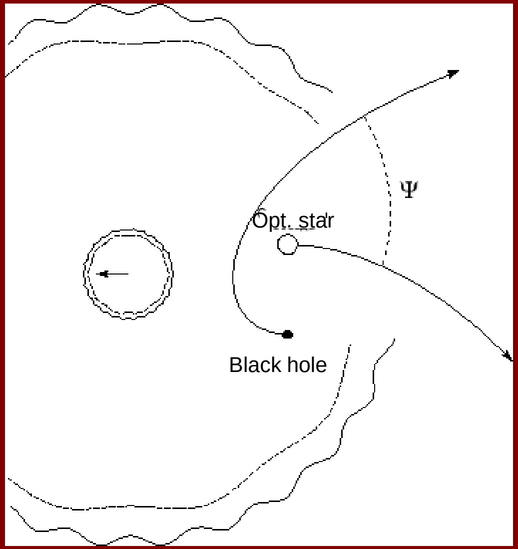
Star	Mass	Velocity km/s	Age, Myr
ξ Per	33	65	1
HD 64760	25-35	31	6
ς Pup	67	62	2
λ Cep	40-65	74	4.5

Prokhorov, Popov (2002) [astro-ph/0511224]

SN explosion in a binary

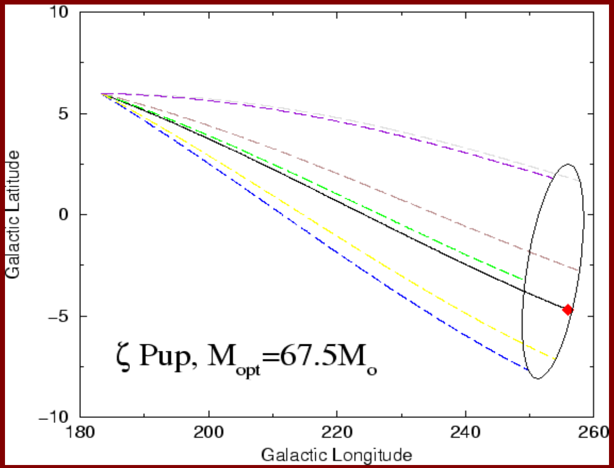


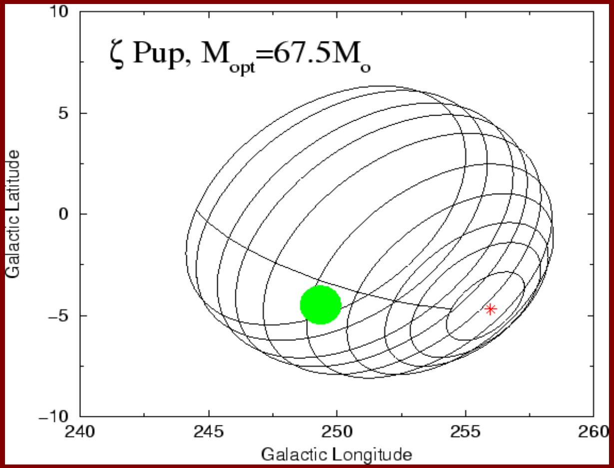




ς Pup

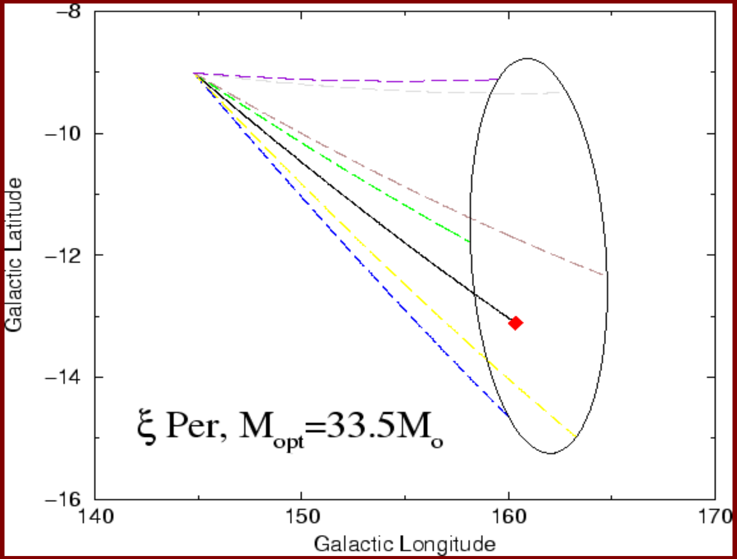
- Distance: 404-519 pc
- Velocity: 33-58 km/s
- Error box: 12º x 12º
- N_{EGRET}: 1

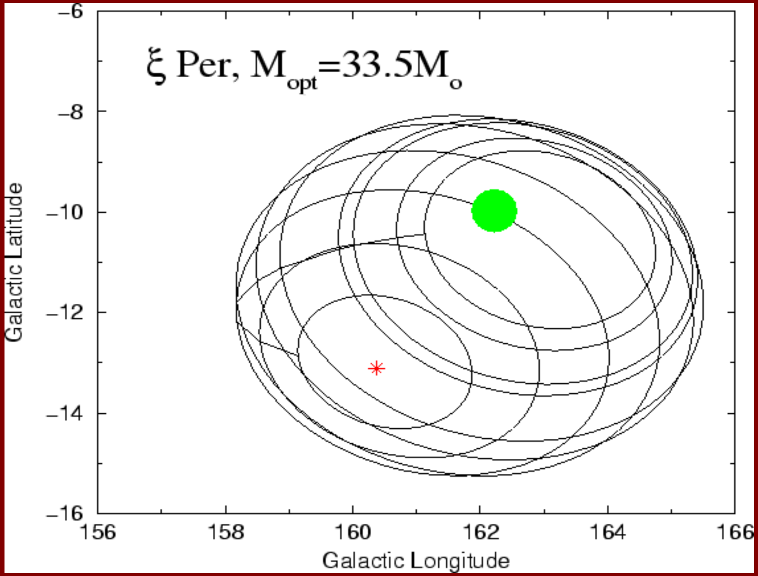




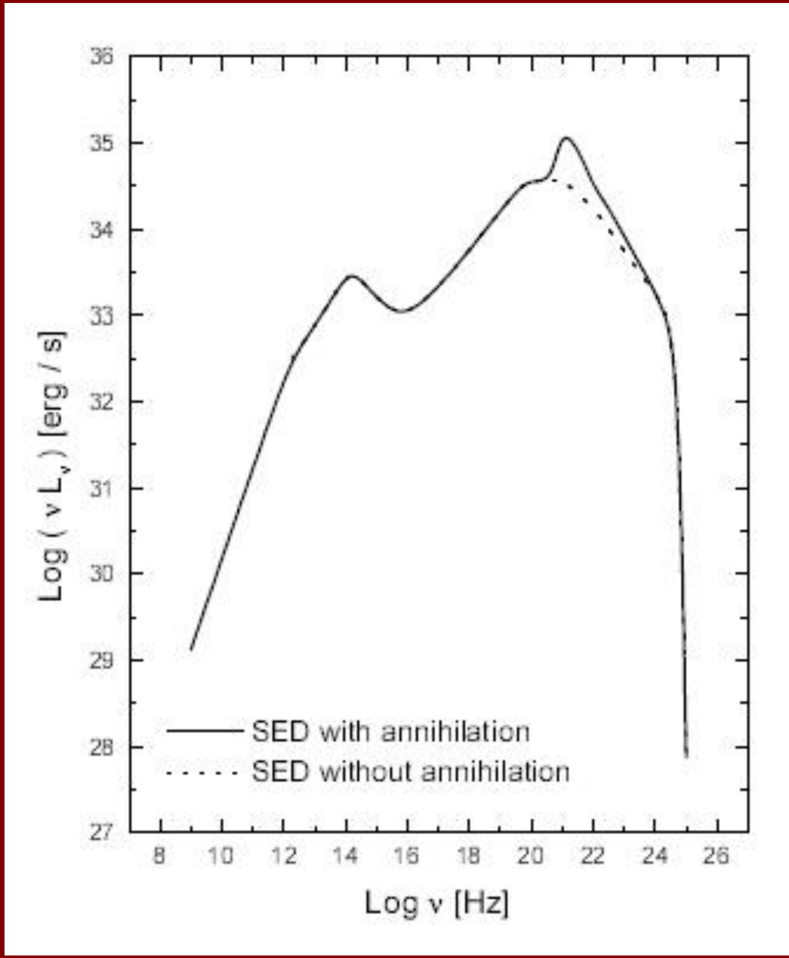
ξ Per

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





Gamma-ray emission from isolated BHs



Kerr-Newman isolated BH.

Magnetosphere. B ~ 10^{11} Гс

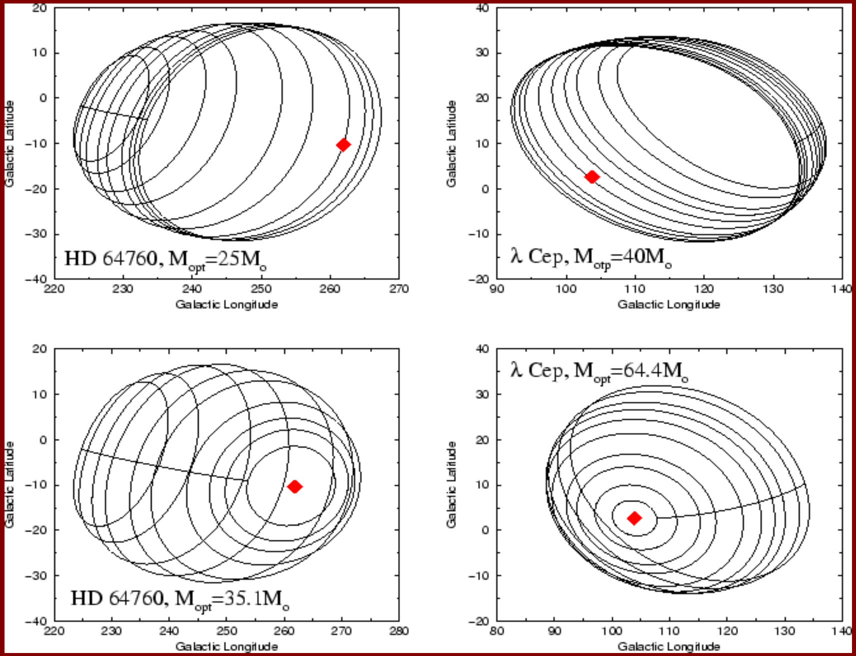
Jets.

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 (40-50º)
- 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)