Workshop on Perspectives on the Extragalactic Frontier:
from Astrophysics to Fundamental Physics

Tidal disruption events:
a possible source of UHECRs?

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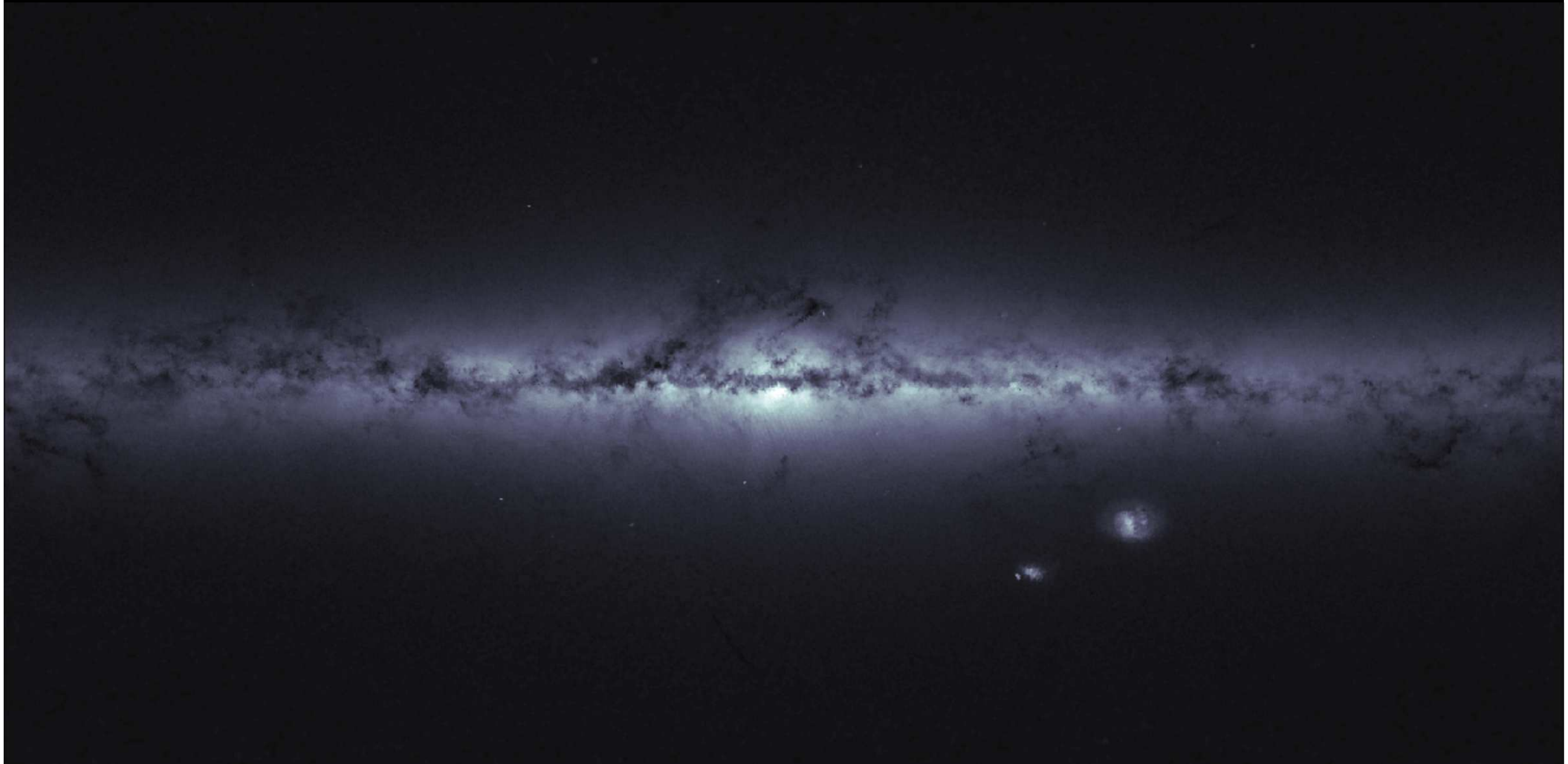
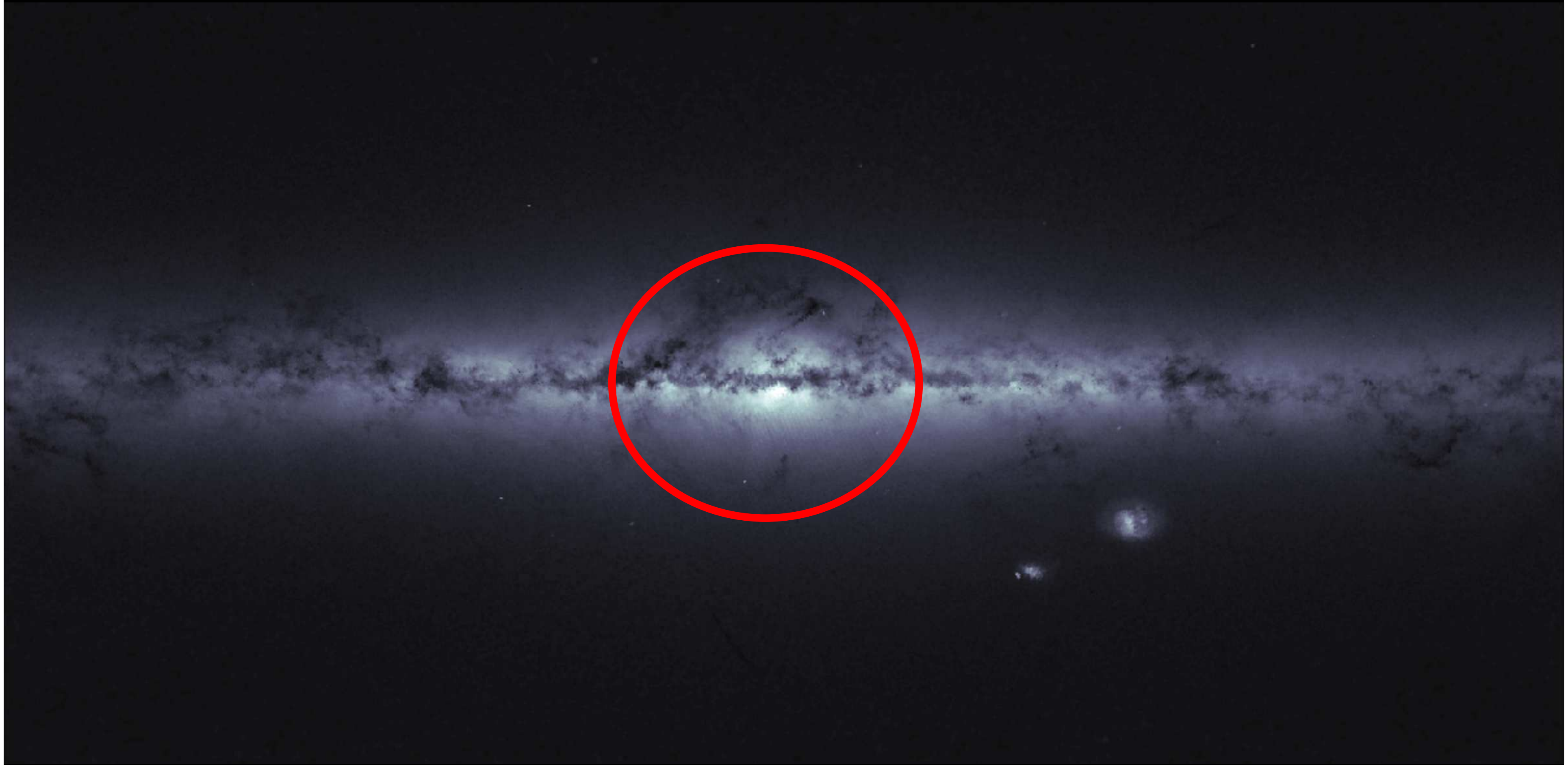
Trieste, May 3rd, 2016

What are tidal disruption events?

Where?

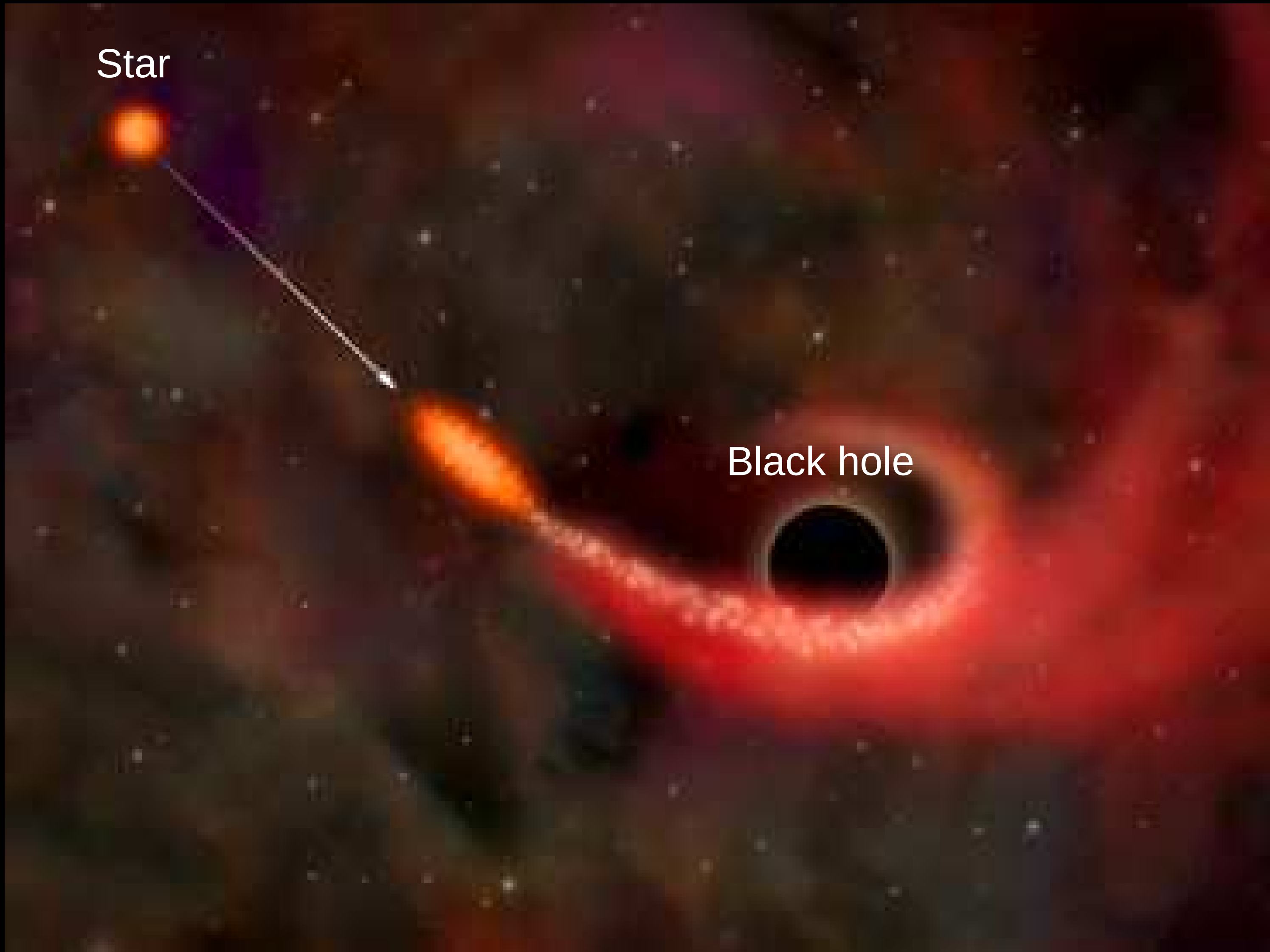


Where?



Super Massive Black Hole (SMBH) $(\sim 10^{5-10} M_{\odot})$

Tidal disruption events (TDE) occur when a star passes too close to a compact object that its field is able to overcome the stellar self-gravity and tear the star apart.



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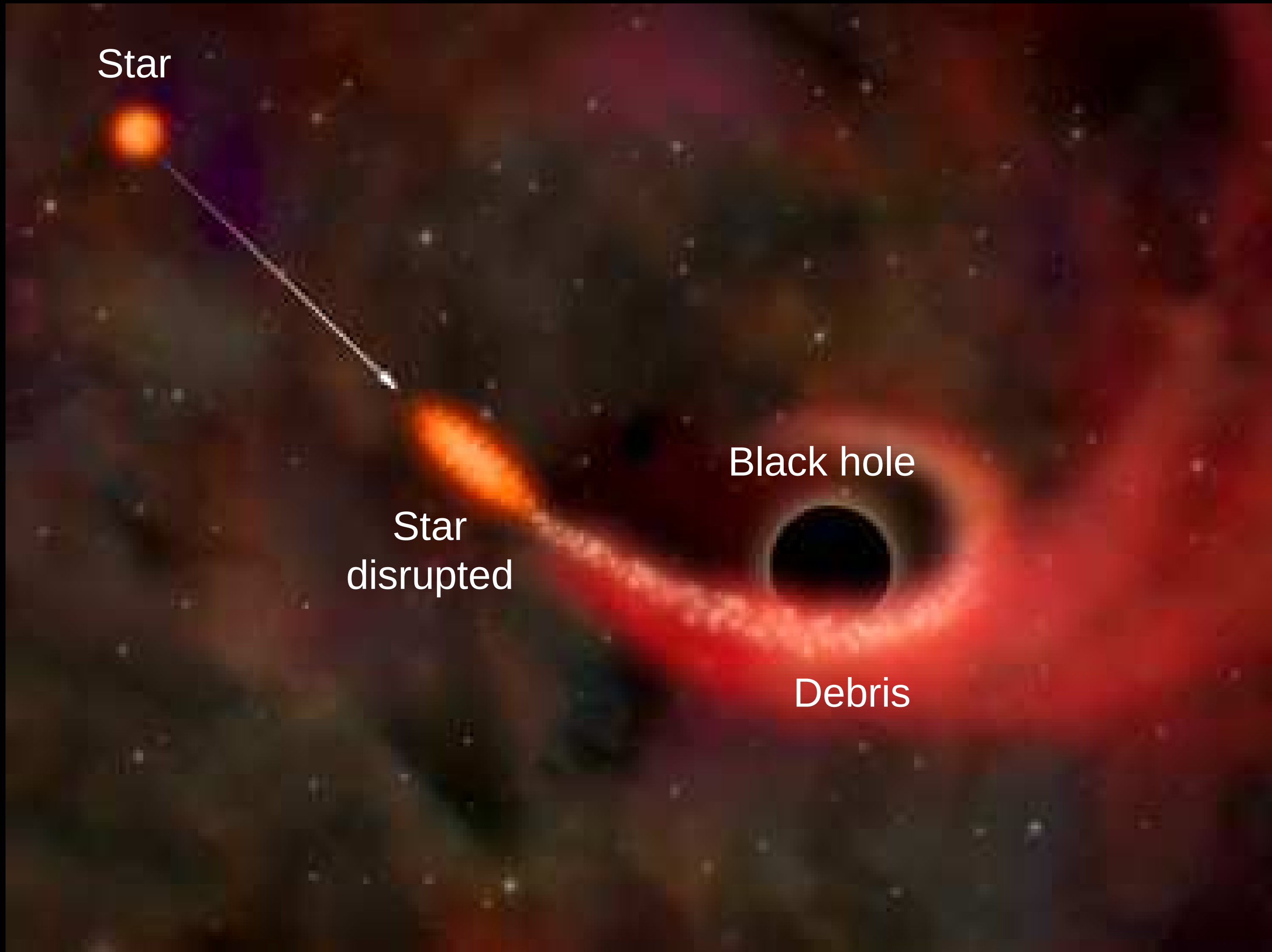
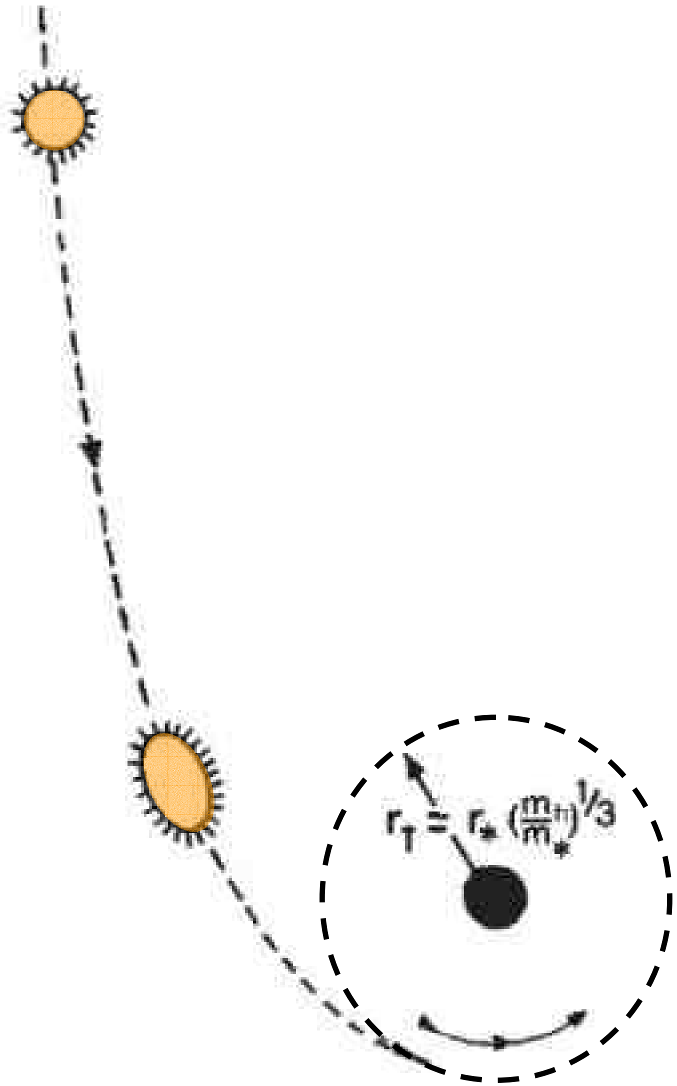




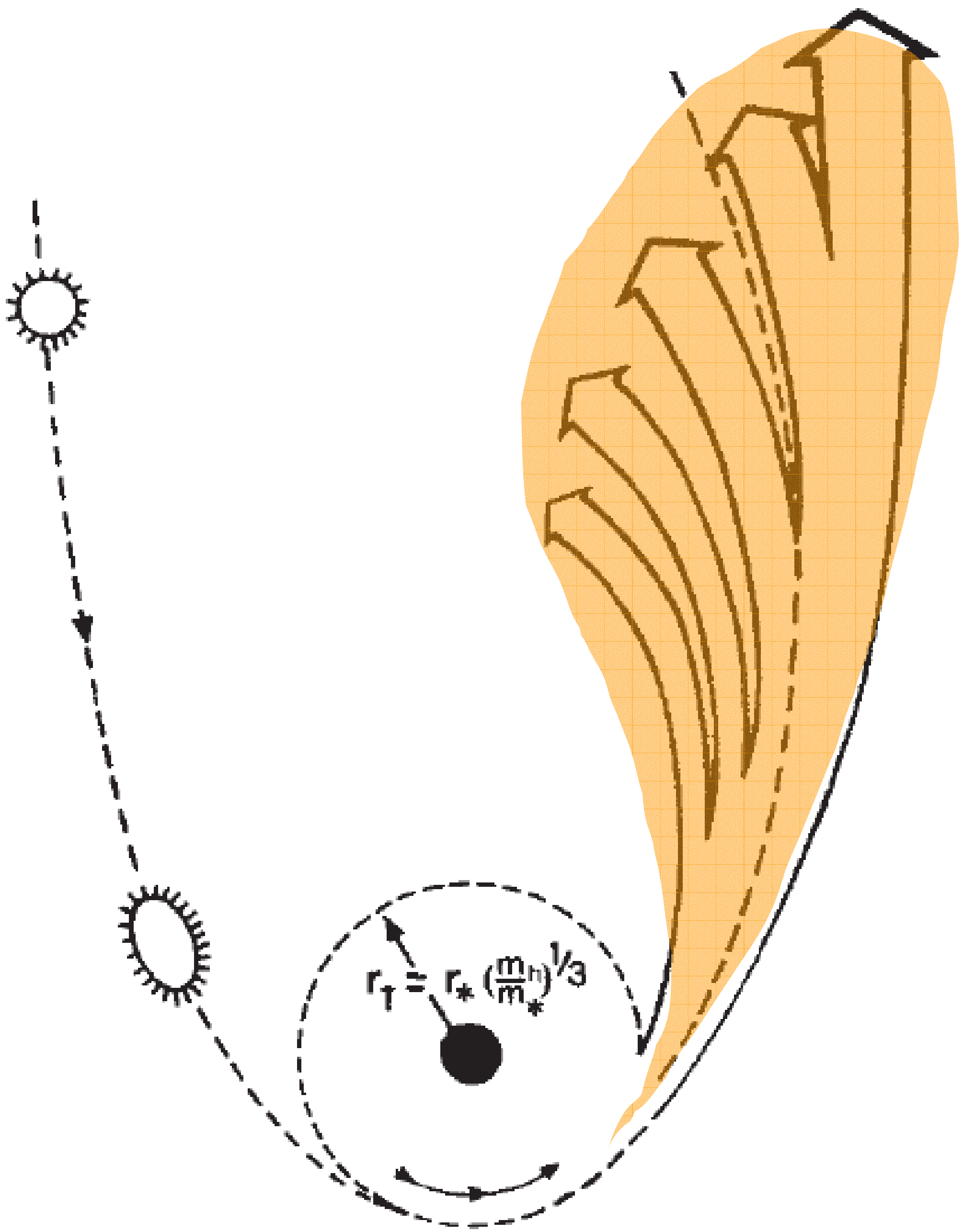
?

Assumption:

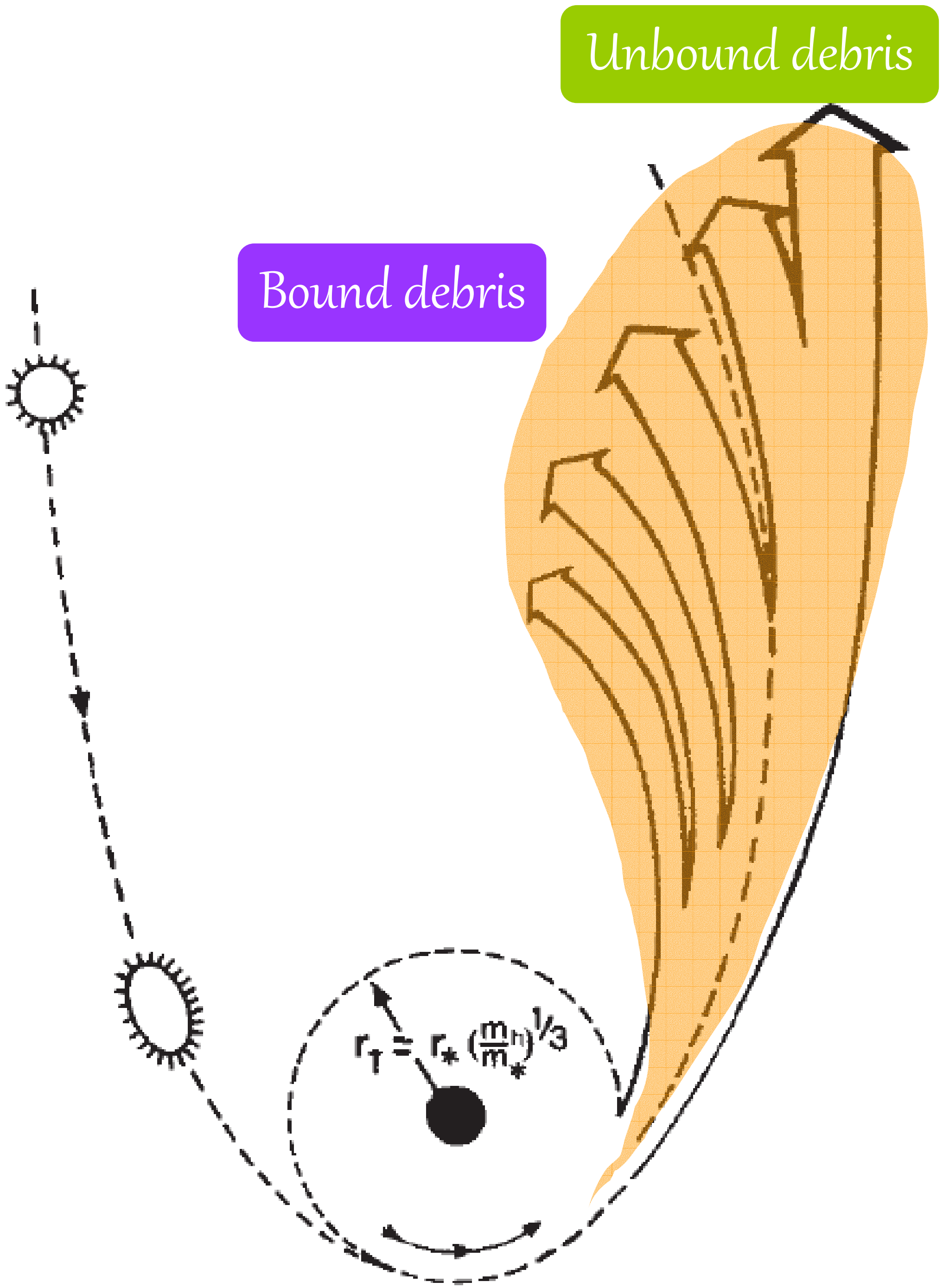
star is totally disrupted in a single flyby.

Stream of debris

What happens to the debris?

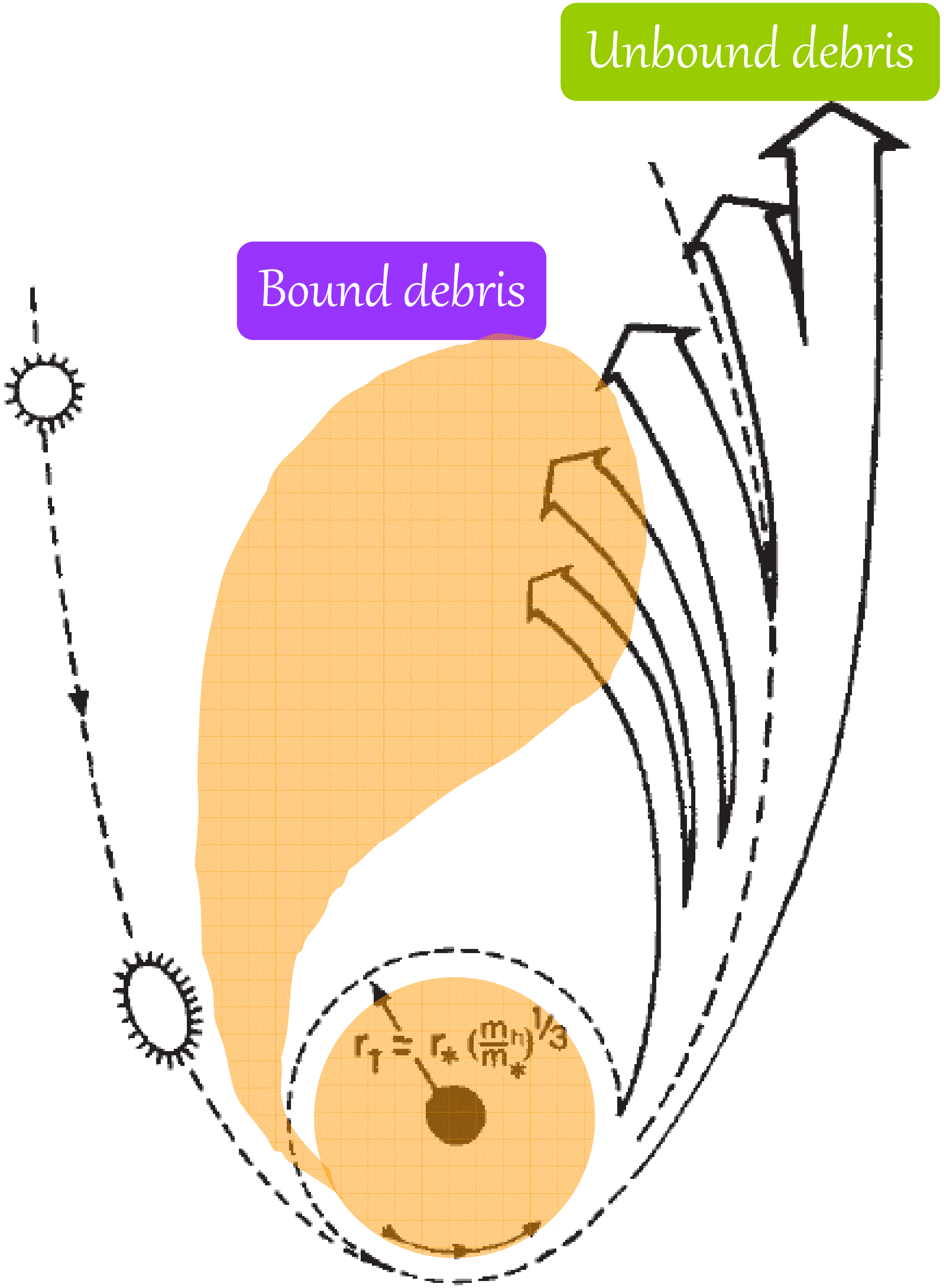


Debris is spread over a range of energies



Debris is spread over a range of energies

~ 50%	~ 50%



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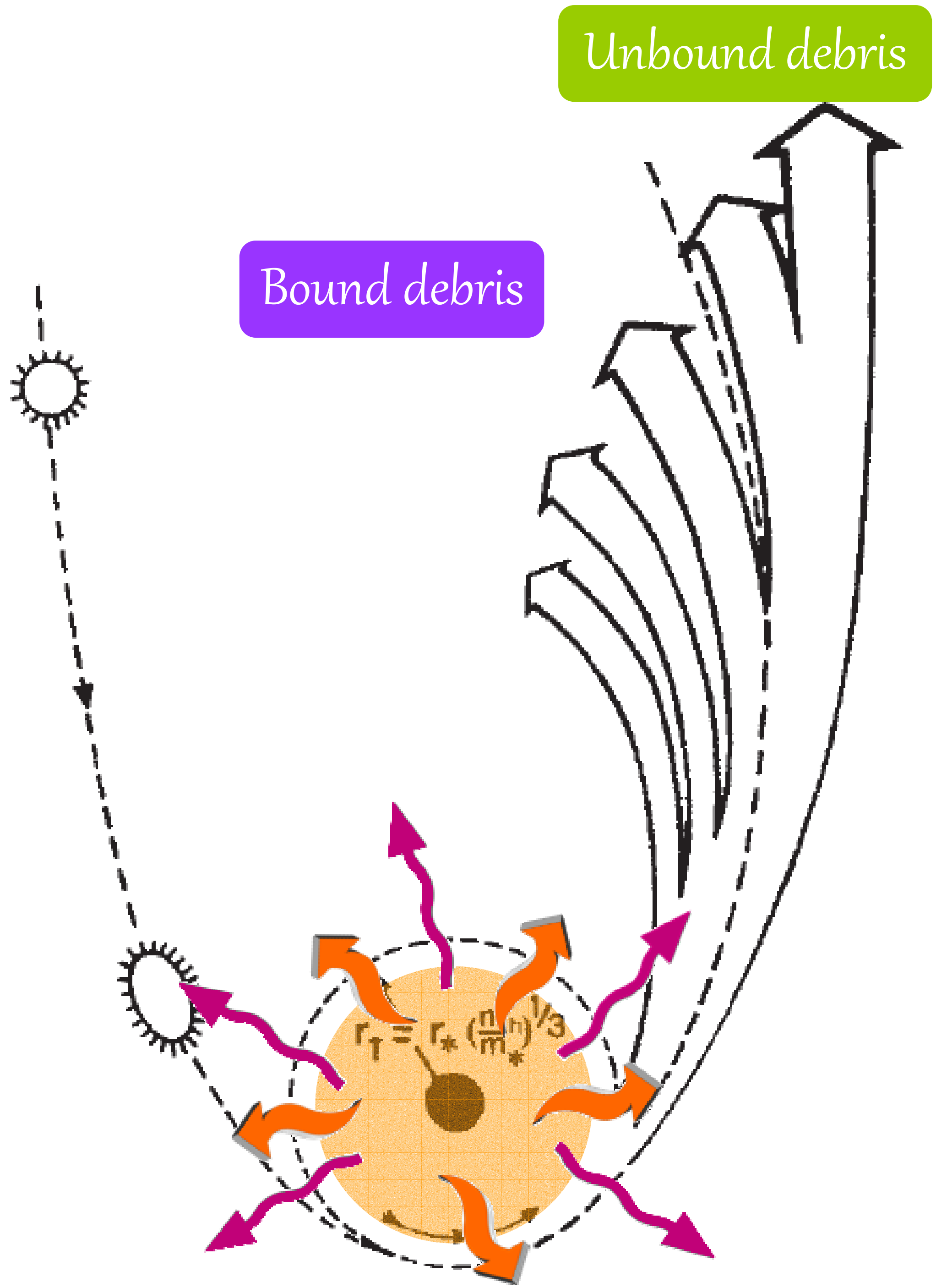
Bound debris circularizes to form an accretion disc



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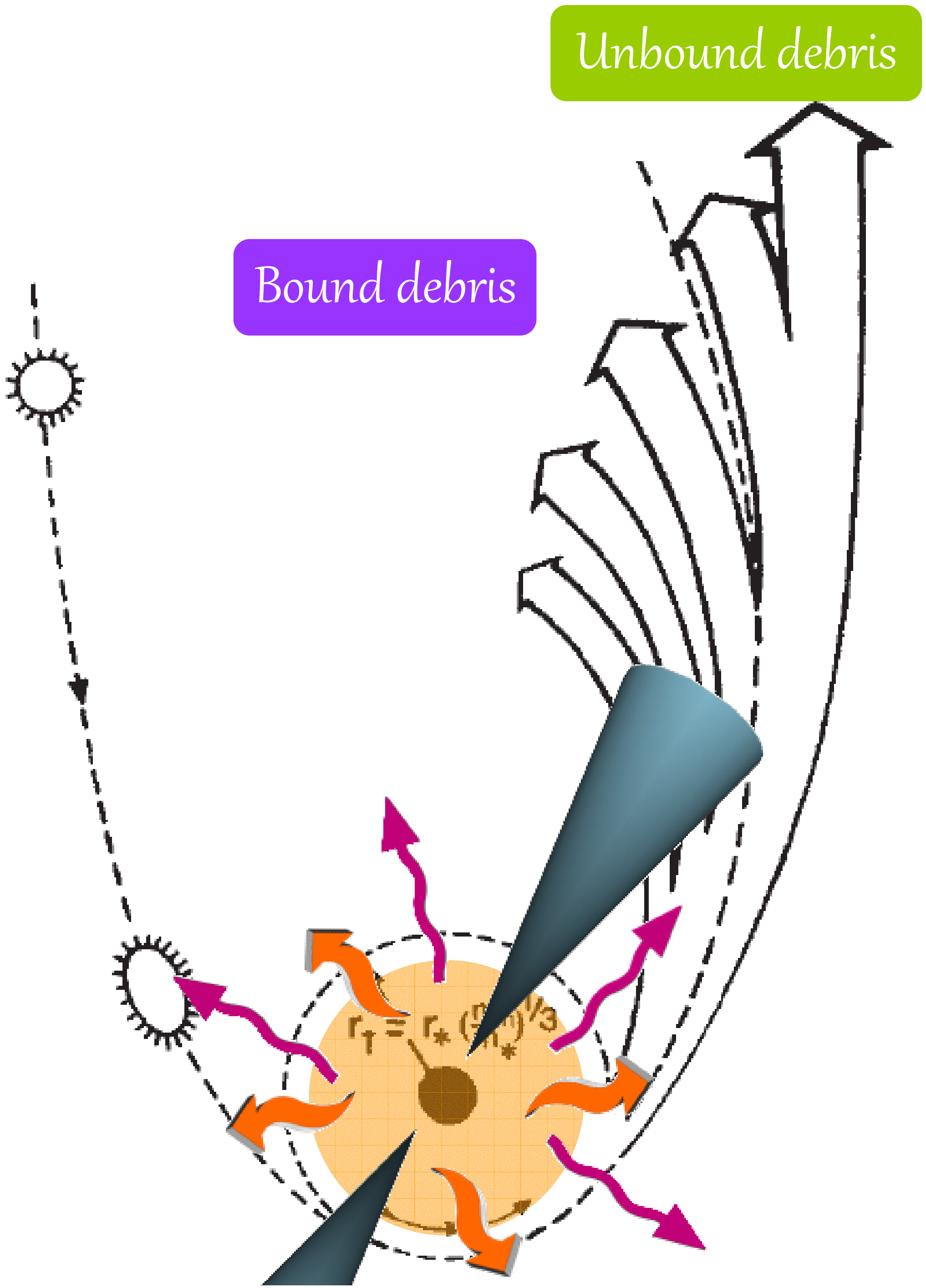
Debris accretes viscously: thermal flare in UV/soft X-ray



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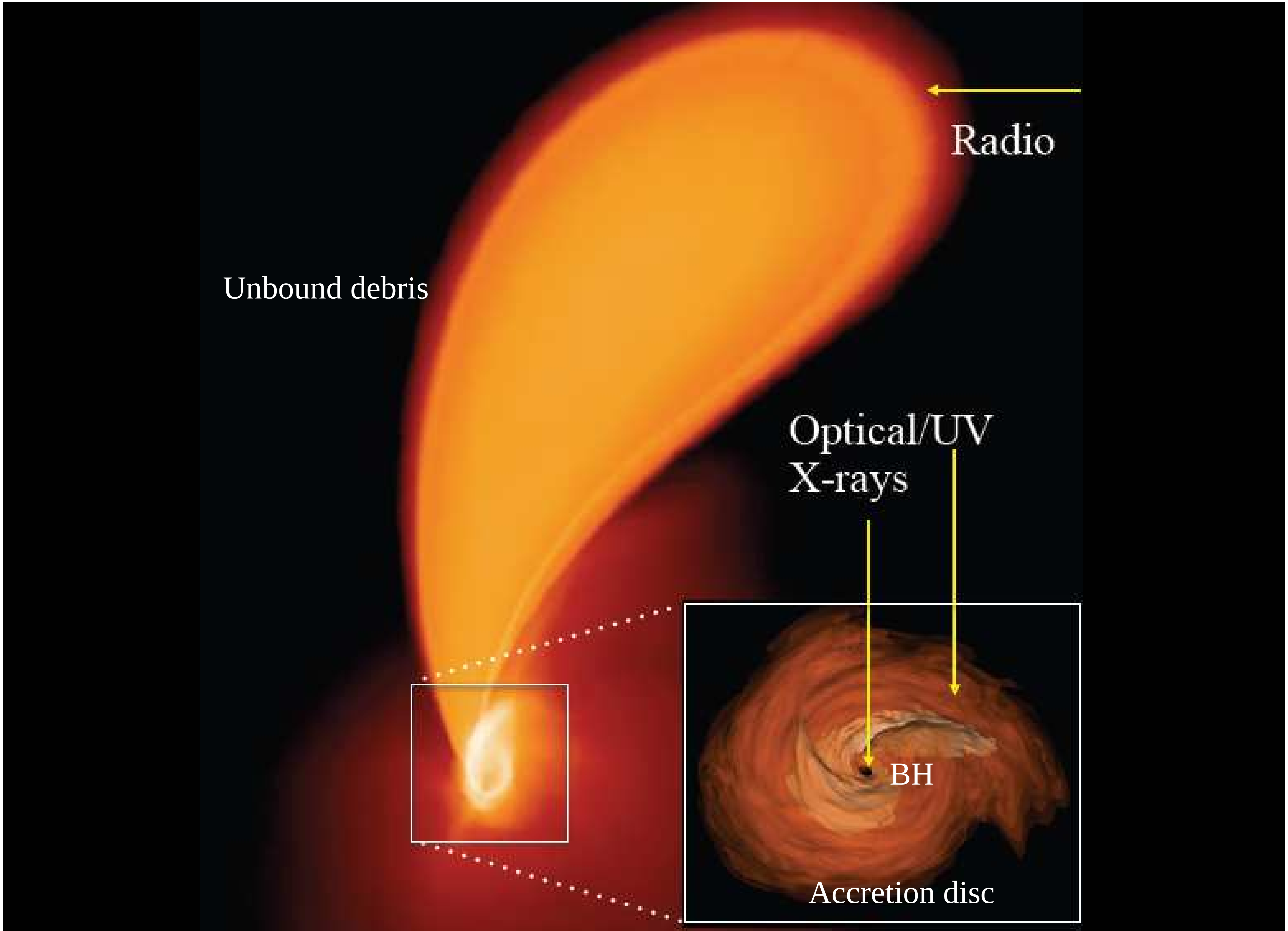
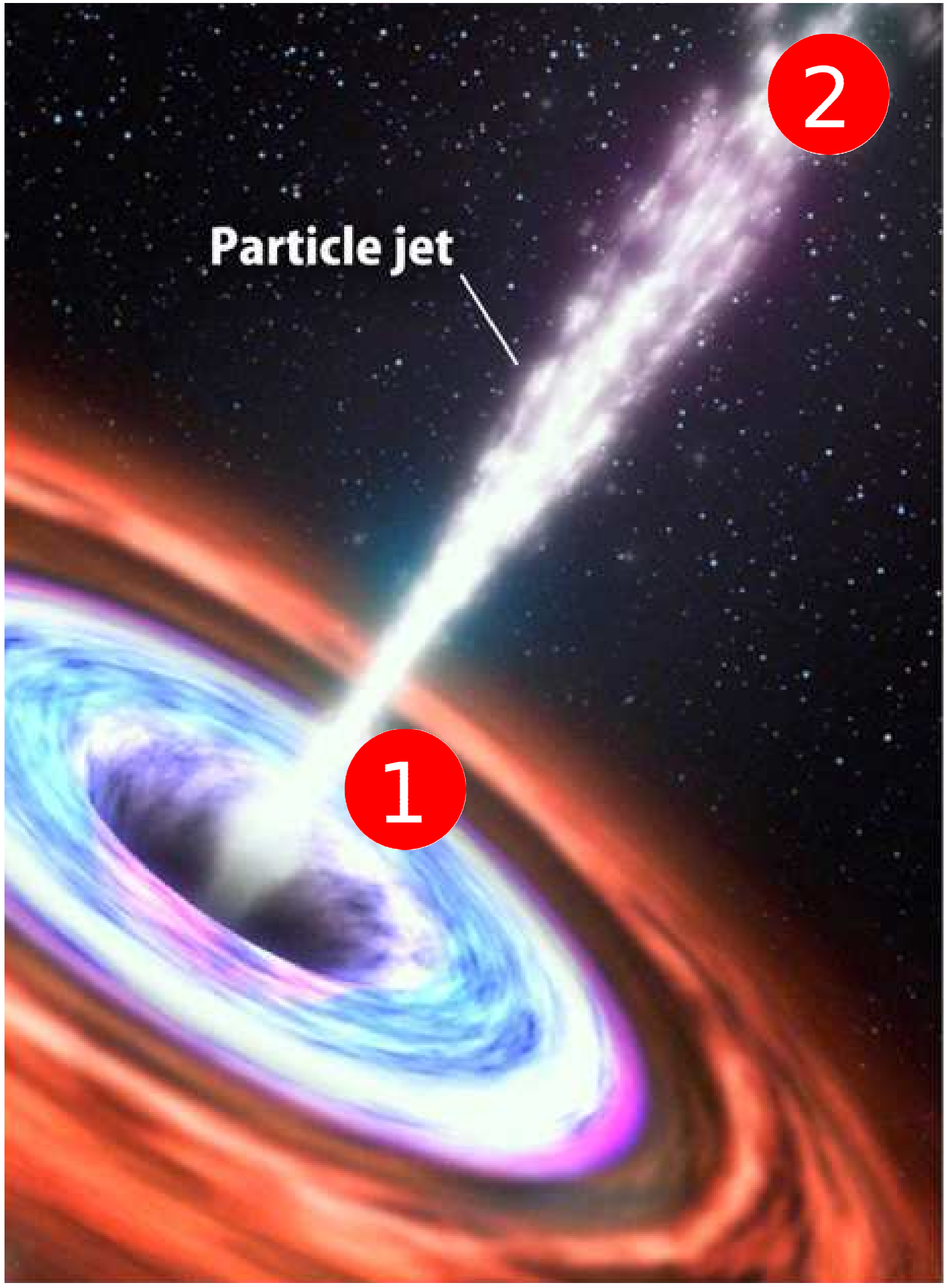
Relativistic jet and radio signal



Krolik +, 2016

Where can UHECRs be produced?

Jets



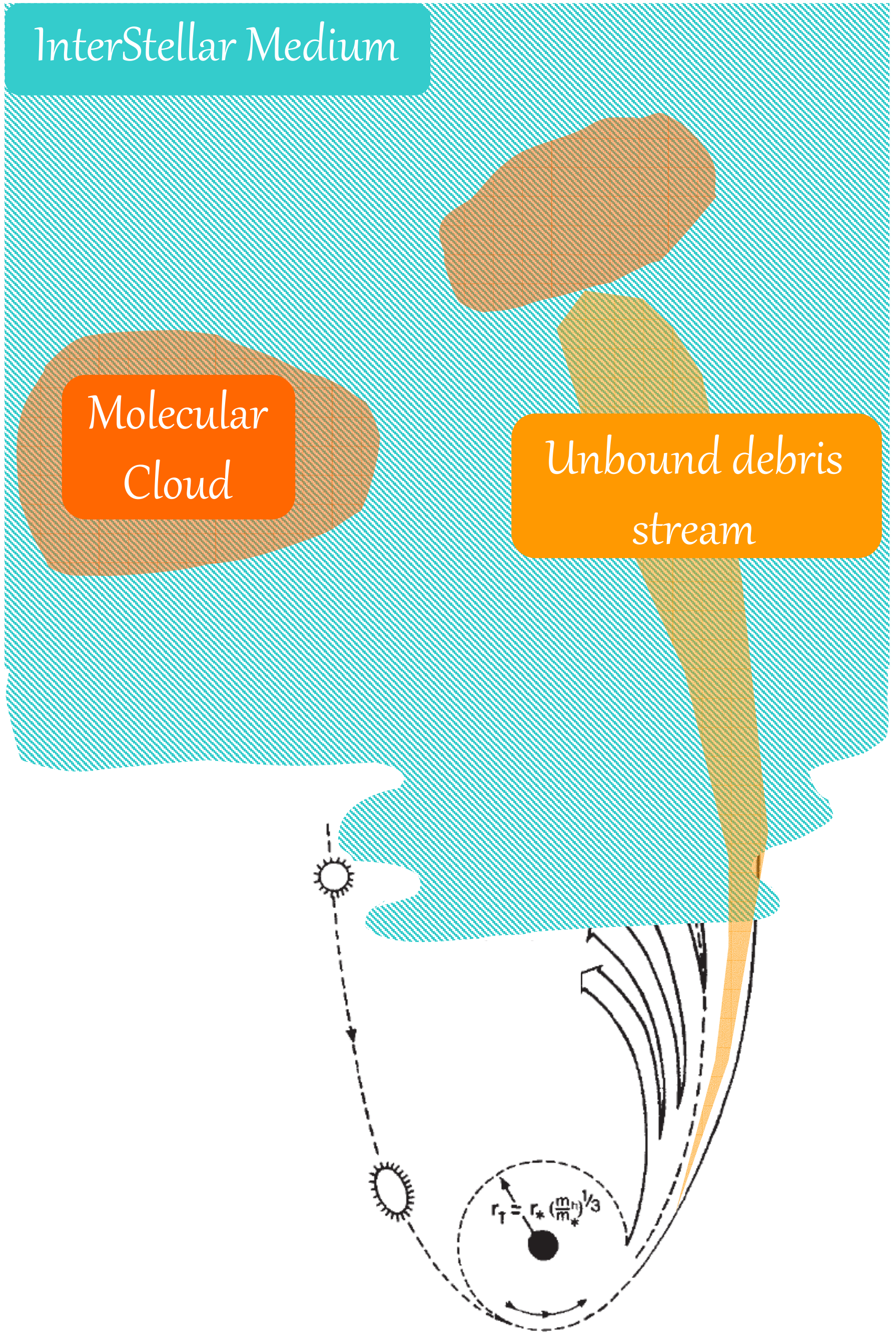
1 At relatively short distances from the engine, internal dissipation shocks within the jets accelerate particles and produce X-ray emission.

2 At larger distances, outflows interacts with the surrounding matter, which slows it down and produces radio emission.

$10^{19\text{-}20}$ *eV CRs*

(Farrar & Piran, 2014, arXiv: 1411.0704)

Unbound debris – molecular cloud collision



Strong shock into the MC: CRs produced

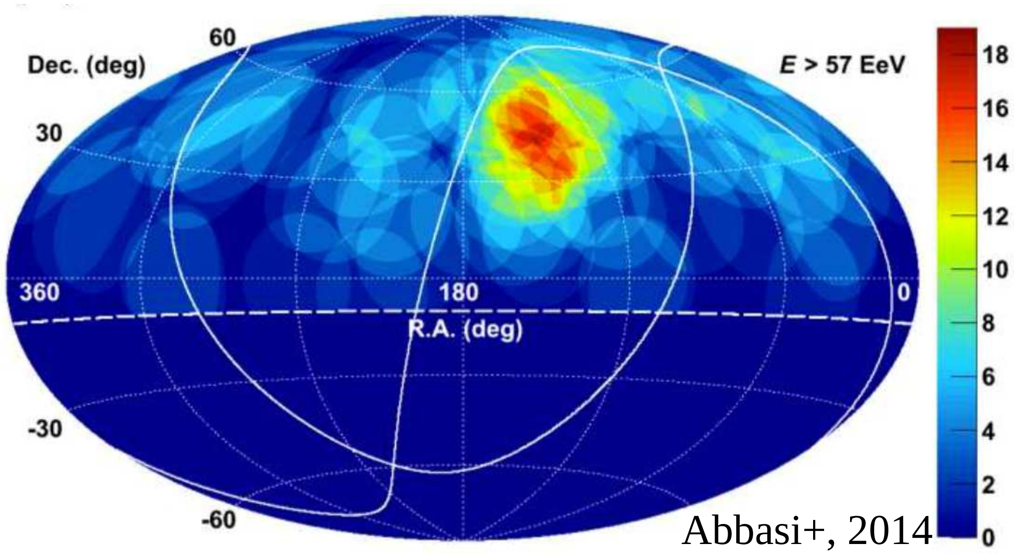
CRs then collide with non-relativistic protons in the MC: π^0 and γ-rays ($0.1 - 10^5$ GeV) produced

$\sim 10^2$ y after TDE

10^{15} eV CRs

(Chen+, 2015, arXiv: 1512.06124)

Can TDEs explain hot spots?



Model TDE with 5 parameters:

- BH mass
- distance from Earth
- fraction of star's rest-mass energy converted in UHECRs
- fraction of jetted TDEs
- beaming fraction

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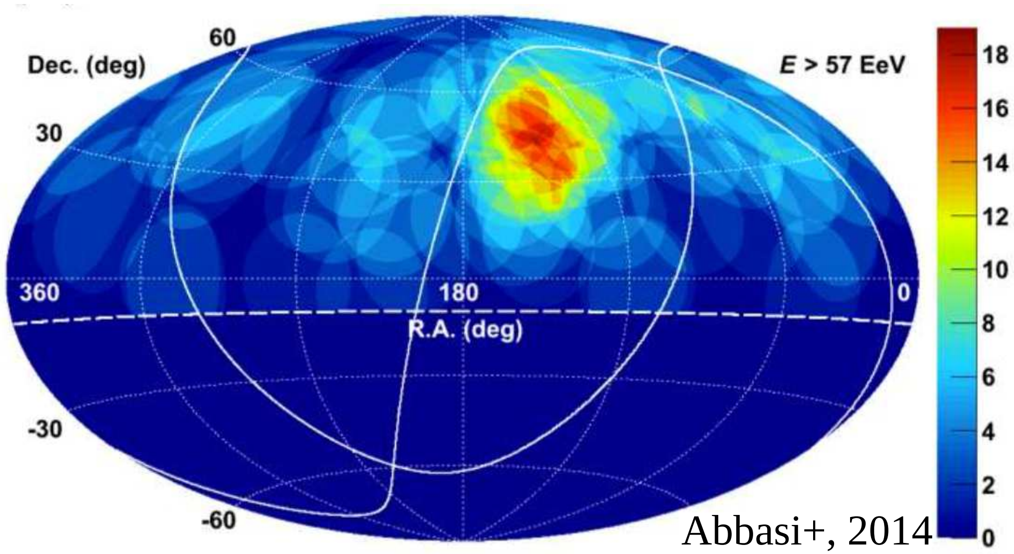
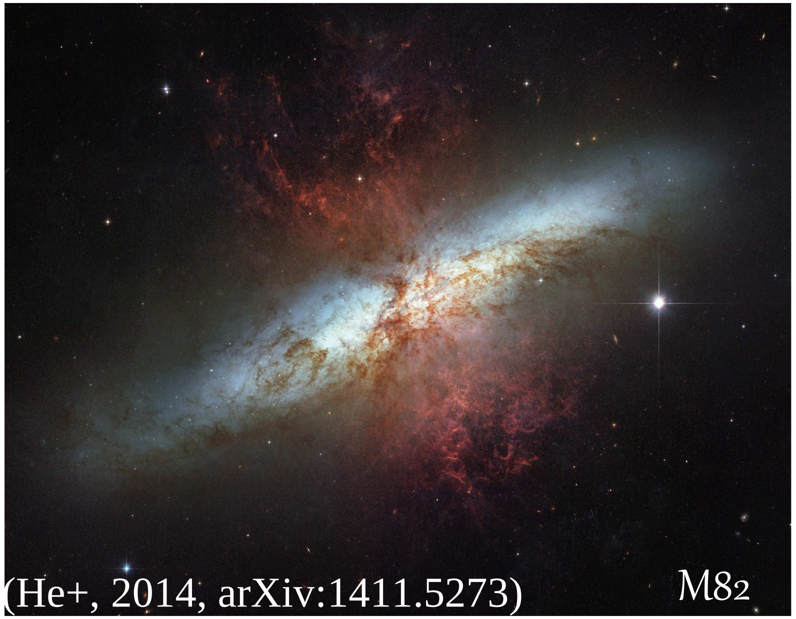


Abbasi+, 2014



Model TDE with 5 parameters:

- BH mass
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Conditions on efficiency of the mechanism that produces TDEs:

- time between events less than magnetic-dispersion time;
- growth of SMBH by TDEs is slower than its growth by accretion at Eddington limit.

TDEs can account for hot spot flux

(Pfeffer+, 2015, arXiv: 1512.04959)

Thank you for the attention!

Swift J1644

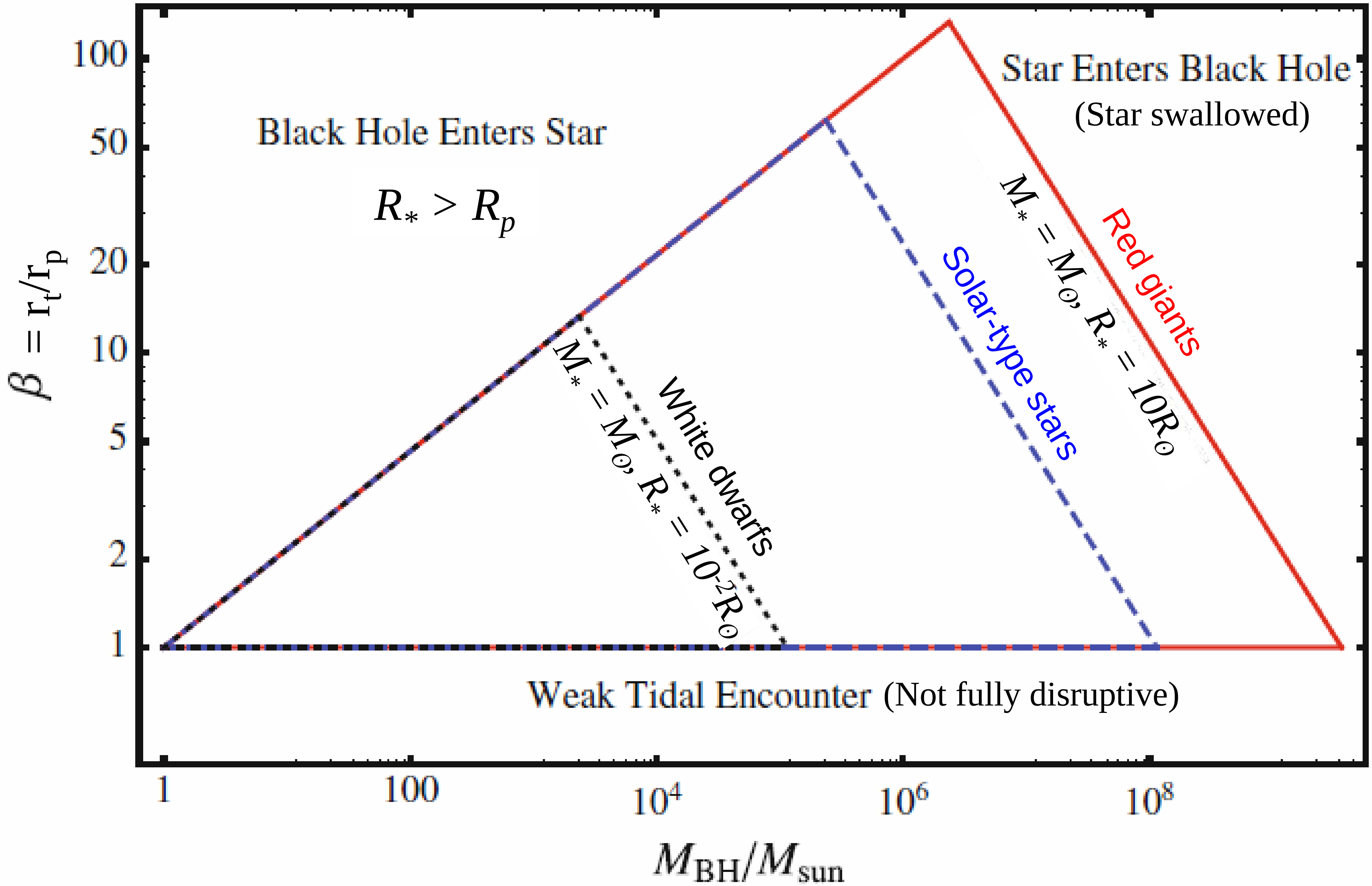
BR slightly larger than 10^{17} G cm

TA hot spot (2014)

After 5 years of operation
Circle of radius 20°
Right ascension 146°.7
Declination 43°.2
72 UHECRs (19 in hot spot)

Parameter space of tidal disruption

Only a star within its respective triangle can be tidally disrupted



This is Not What We Expected TDEs to Look Like

Event	M_{BH} ($10^6 M_\odot$)	L_{peak} (10^{43} erg s^{-1})	E_{tot} (10^{51} erg)	T_{BB} (@ ~peak) (10^4 K)	R_{BB} (@ ~peak) (10^{15} cm)	Line Width (10^3 km s^{-1})	Host Type
SDSS J0748		n/a	n/a			10.0 ± 0.5 (He II)	?
PS-10jh	4^{+4}_{-2}	$\gtrsim 22$	$\gtrsim 2.1$	$\gtrsim 3$	$\gtrsim 0.6$	5.4 ± 1.5 (He II -22d)	E+A
PS-11af	8 ± 2	8.5 ± 0.2	0.41 ± 0.01	1.91 ± 0.08	0.95	No features	?
SDSS TDE2	$35.52^{+55.31}_{-25.80}$	4.1 ± 0.2 (g-band)	?	$1.82^{+0.07}_{-0.06}$	0.72	3.4 ± 1.1 (Hα)	E+A
PTF09ge	$5.65^{+3.02}_{-0.98}$	5.7	n/a	$2.19^{+0.33}_{-0.24}$	$0.59^{+0.16}_{-0.12}$	10.1 ± 0.7 (He II -19d)	E+A
PTF09axc	$2.69^{+0.66}_{-0.64}$	1.9	n/a	$1.19^{+0.32}_{-0.17}$	$1.14^{+0.41}_{-0.43}$	11.9 ± 0.2 (Hα 7d)	E+A
PTF09djl	$3.57^{+9.97}_{-2.96}$	12.2	n/a	$2.67^{+0.69}_{-0.43}$	$0.58^{+0.41}_{-0.21}$	6.5 ± 0.4 (Hα 2-62d)	E+A
ASASSN-14ae	$2.45^{+1.55}_{-0.74}$	8.2 ± 0.5	0.17	2.2 ± 0.1	$0.7 \pm .0.03$	3.6 ± 0.2 (Hα)	E+A

But from accretion expect $L_{peak} \sim 10^{47} \left(M_{BH,6}\right)^{-3/2}$ erg s^{-1}

But $0.1 M_\odot c^2 \sim 10^{53}$ erg

But from accretion expect $T_{eff} \sim 10^5$ K (reprocessing material?)

But $R_T \sim 7 \cdot 10^{12} R_*^{-1/3} M_{BH,6}^{1/3} M_*^{-1/3}$ cm (reprocessing material?)

But at R_T: $v \sim 4 \cdot 10^4 M_{BH,6}^{1/3}$ km s^{-1}

I. Arcavi, TDE school, 2015

E+A galaxies

Classification of Post-Starburst and Post-Star-Forming galaxies

Passive galaxies dominating rich clusters, whose star formation history has probably been perturbed by their interaction with the hostile environment.

Classification depending on spectral optical features

Post-starburst galaxies

Objects where star formation activity has been abruptly truncated after a strong burst episode, are generally indicated as

E+A or k+a (and a+k) galaxies,

and are characterized by strong Balmer absorption lines with no emission.

Post-star-forming galaxies

Galaxies with normal star formation activity brusquely truncated without a starburst event are characterized by moderate Balmer absorption lines.

Conditions on sources of UHECRs

Hillas criterion

CR confined during acceleration

$$R_L = \varepsilon/qB < R$$

$$BR \gtrsim 3 \times 10^{17}\,\Gamma^{-1}\,Z^{-1}\,E_{20}\ \mathrm{Gauss\,cm}$$

Total bolometric luminosity

$$L_{\rm bol} \approx \frac{1}{6} c\,\Gamma^4\,(BR)^2 \gtrsim 10^{45}\,\Gamma^2\,(E_{20}/Z)^2\ \mathrm{erg/s}$$

Density of sources

$$n_{\rm src} \approx 3 \times 10^{-9} \frac{\dot{E}_{44}}{\epsilon_{UCR}\,\Gamma^2\,(E_{20}/Z)^2}\ \mathrm{Mpc}^{-3}$$

Source density lower limit

$$n_{\rm min} = 2 \times 10^{-5}\ (7 \times 10^{-4})\ \mathrm{Mpc}^{-3}$$

Papers

Tidal disruption jets as the source of ultra-high energy cosmic rays

(Farrar & Piran, 2014)

Ultra-high-energy-cosmic-ray hot spots from tidal disruption events

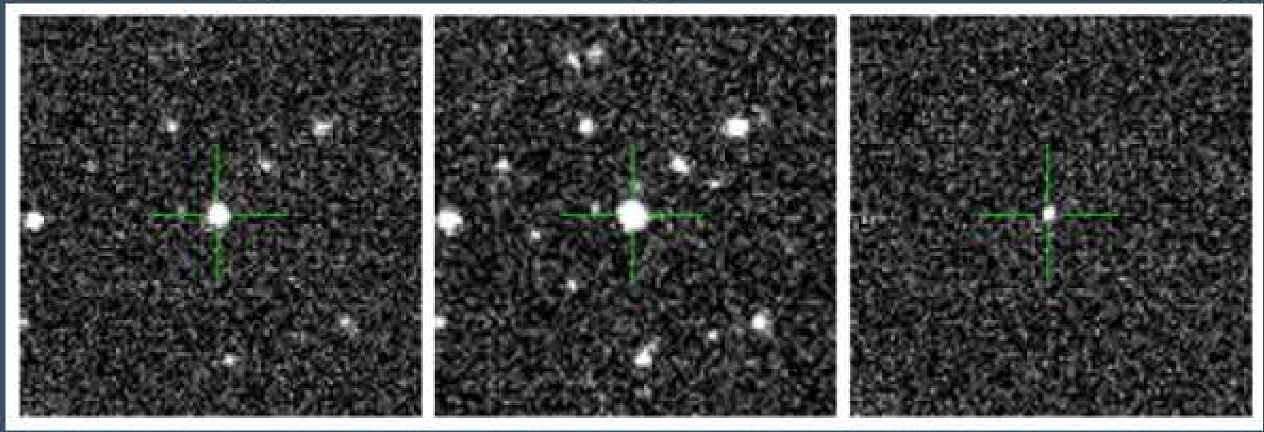
(Pfeffer +, 2015)

The Gamma-Ray Afterglows of Tidal Disruption Events

(Chen+, 2015)

How is a TDE discovered?

New image Old image Difference image



The TDE PTF09axc

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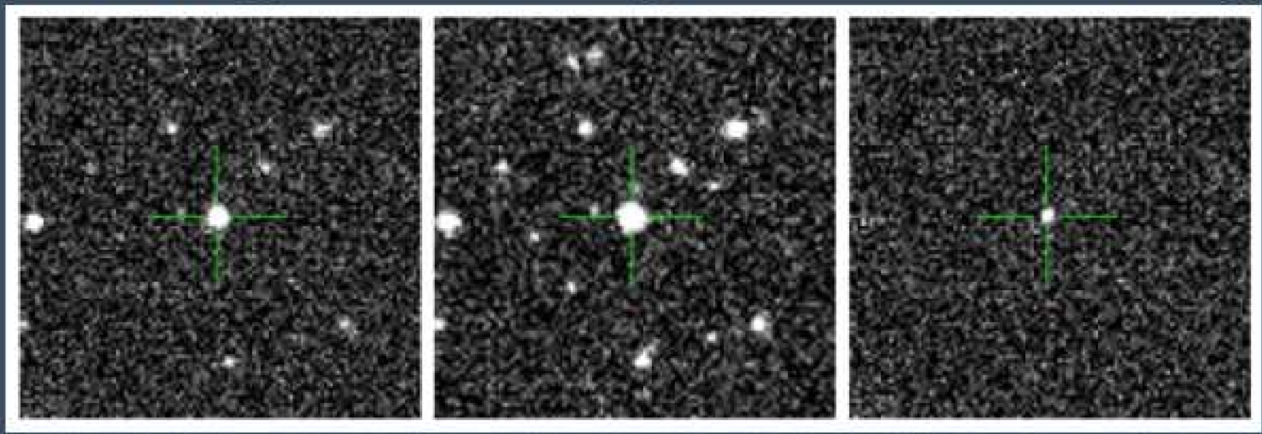

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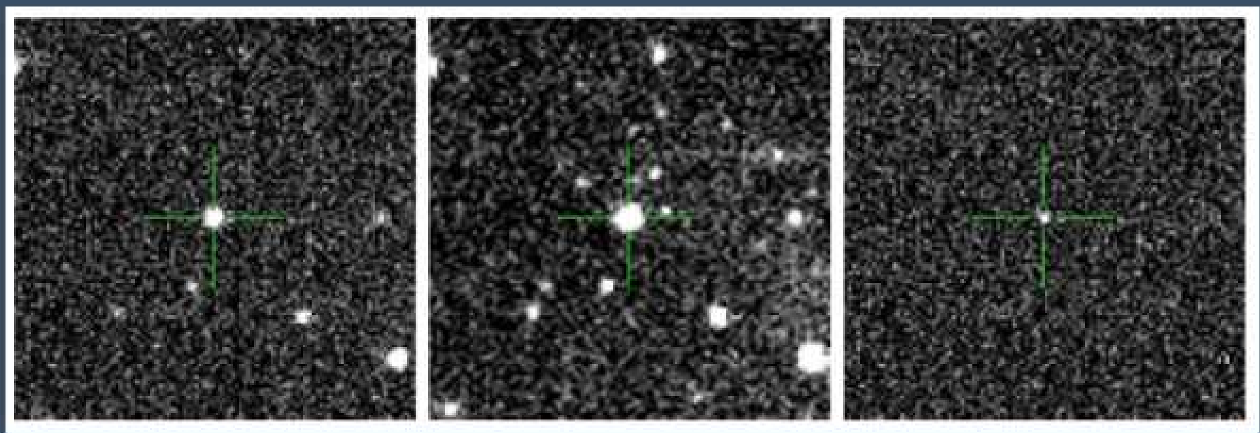

An AGN

I. Arcavi, TDE school, 2015

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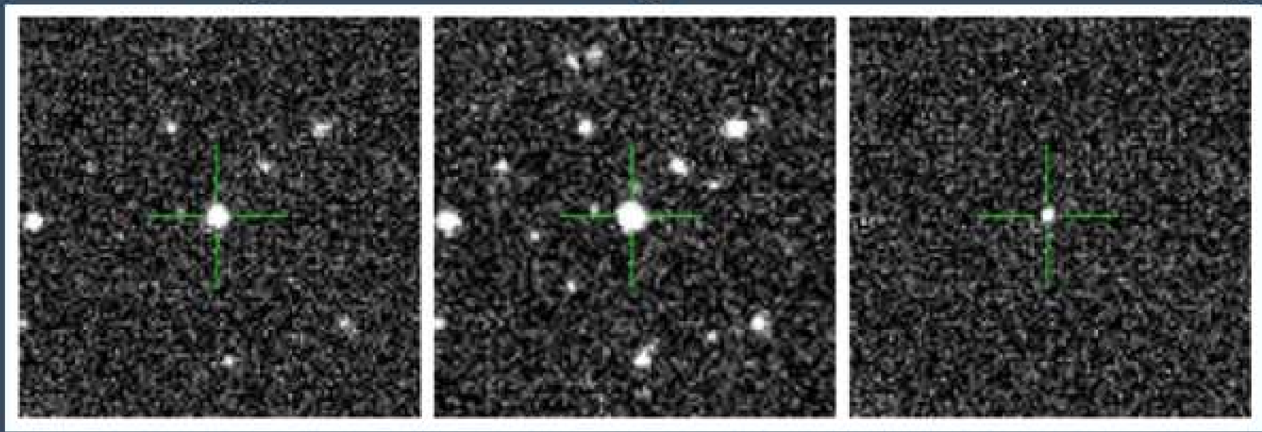

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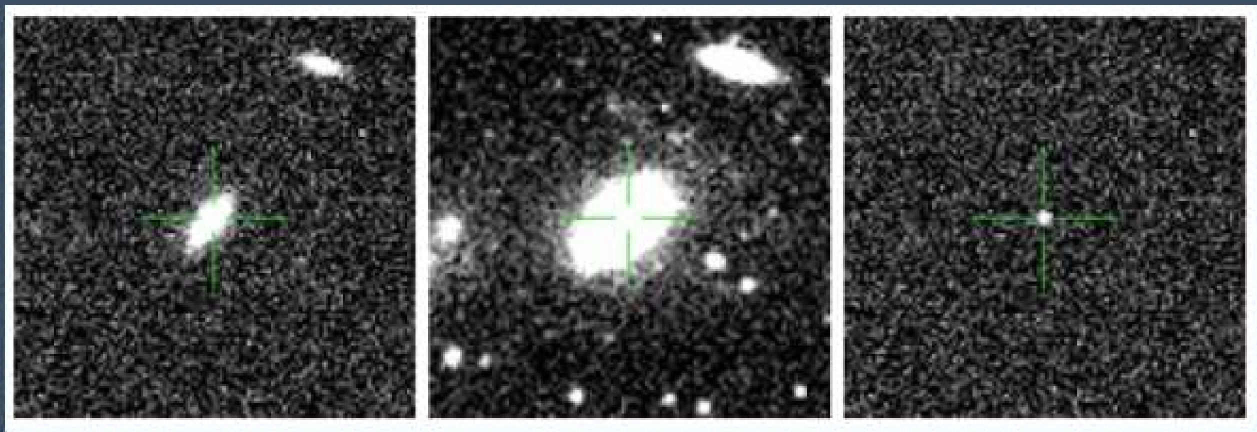

A Type Ia SN

I. Arcavi, TDE school, 2015

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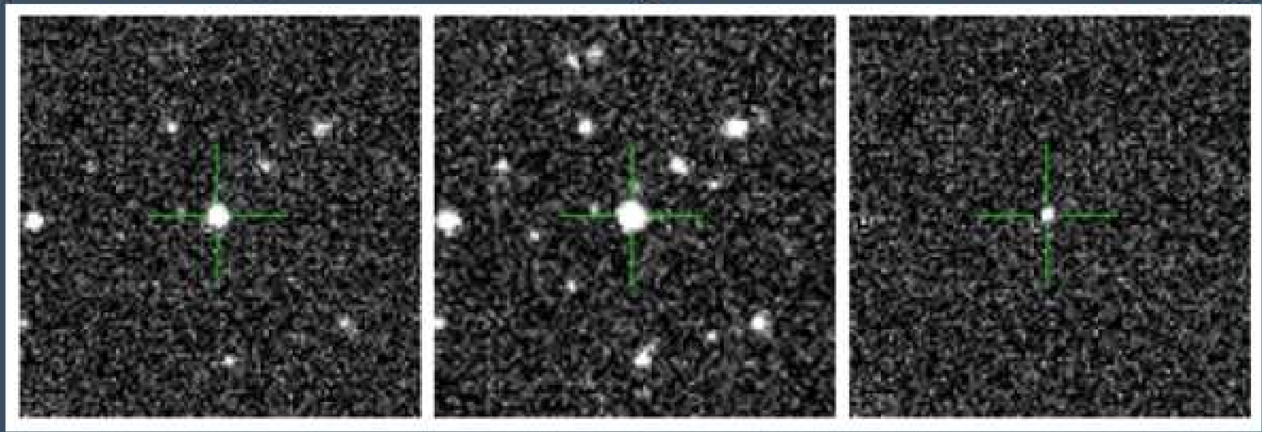
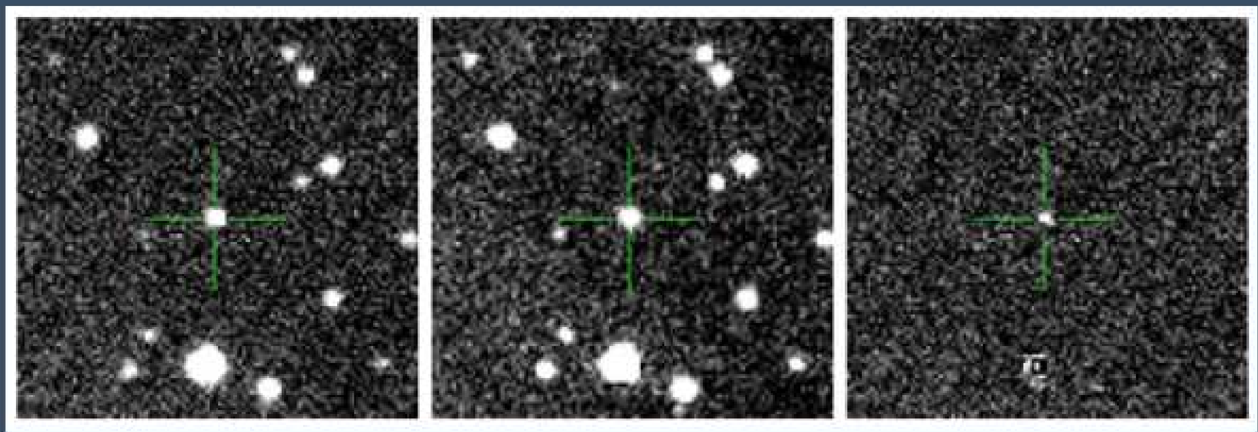


The TDE PTF09axc



A variable star

I. Arcavi, TDE school, 2015

How is a TDE discovered?

I. Arcavi, TDE school, 2015

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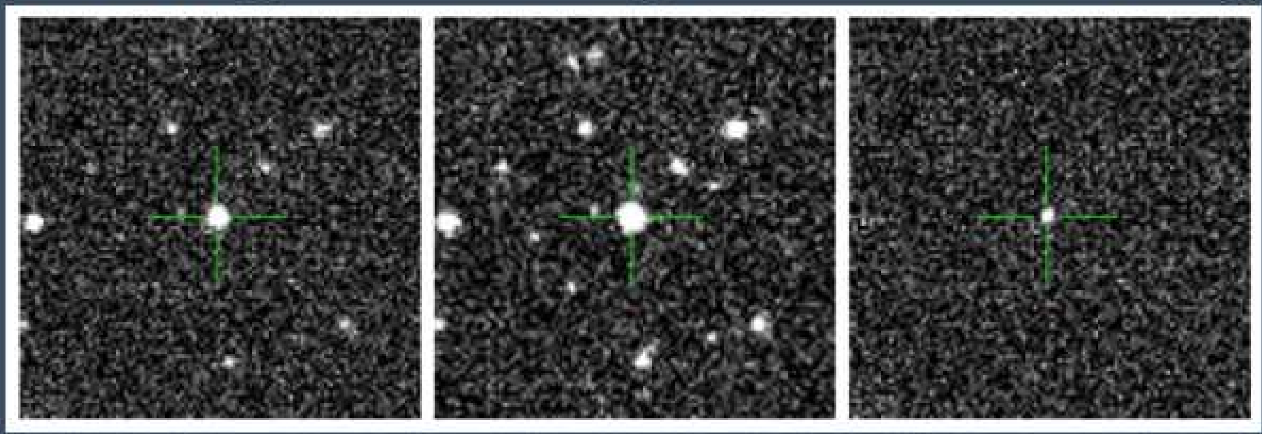
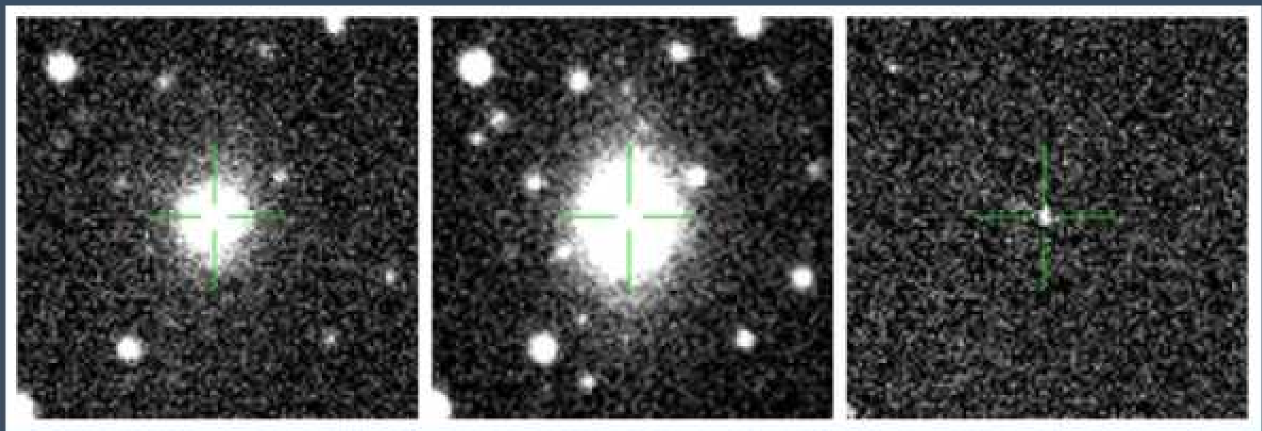


The TDE PTF09axc



An artifact (not real)

I. Arcavi, TDE school, 2015

How is a TDE discovered?

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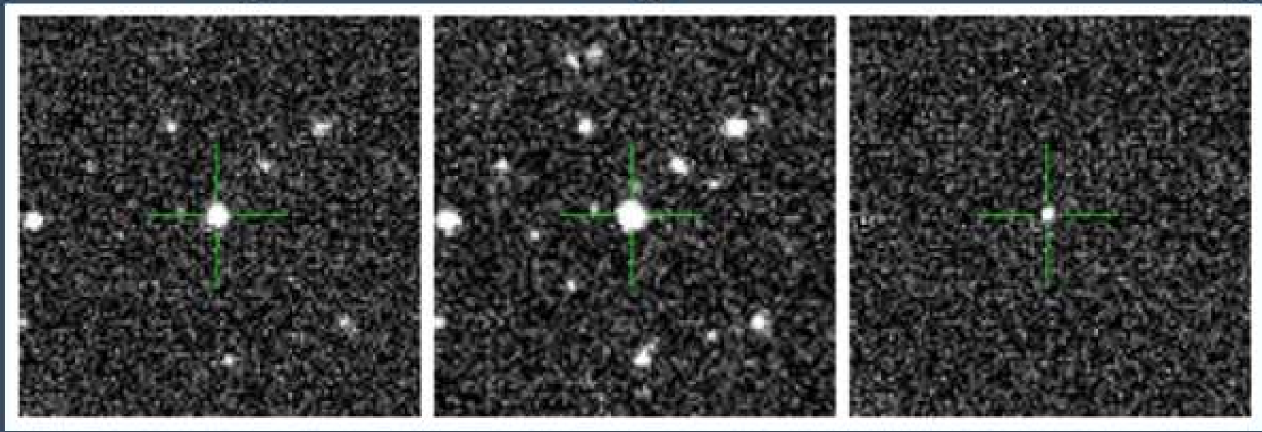


The TDE PTF09axc

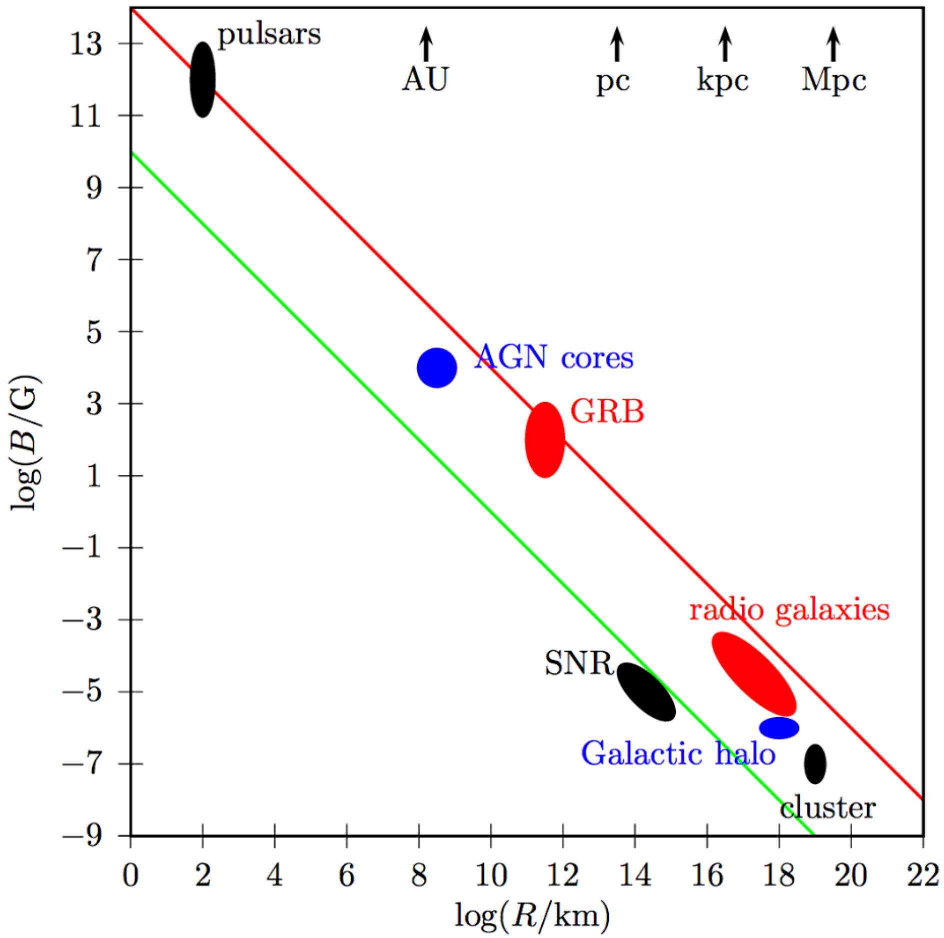
Finding TDEs is hard:

- Galaxy centers are difficult to subtract correctly
- Many contaminants (AGN, SNe in galaxy centers)

Consequences:

- Miss a lot of TDEs

Hillas criterion



If the particle escapes from the region where it was being accelerated, it will be unable to gain more energy. This gives a limit on its max. energy:

$$\varepsilon_{max} = qBR$$

This is obtained asking that the Larmor radius doesn't exceed the size of the acceleration region:

$$R_L = \varepsilon/qB < R$$

Geometrical criterion known as Hillas criterion

Sources above:

Red line: Accelerate protons up to 10^{21} eV

Green line: Accelerate iron up to 10^{20} eV