Double SMBHs and Double TDEs

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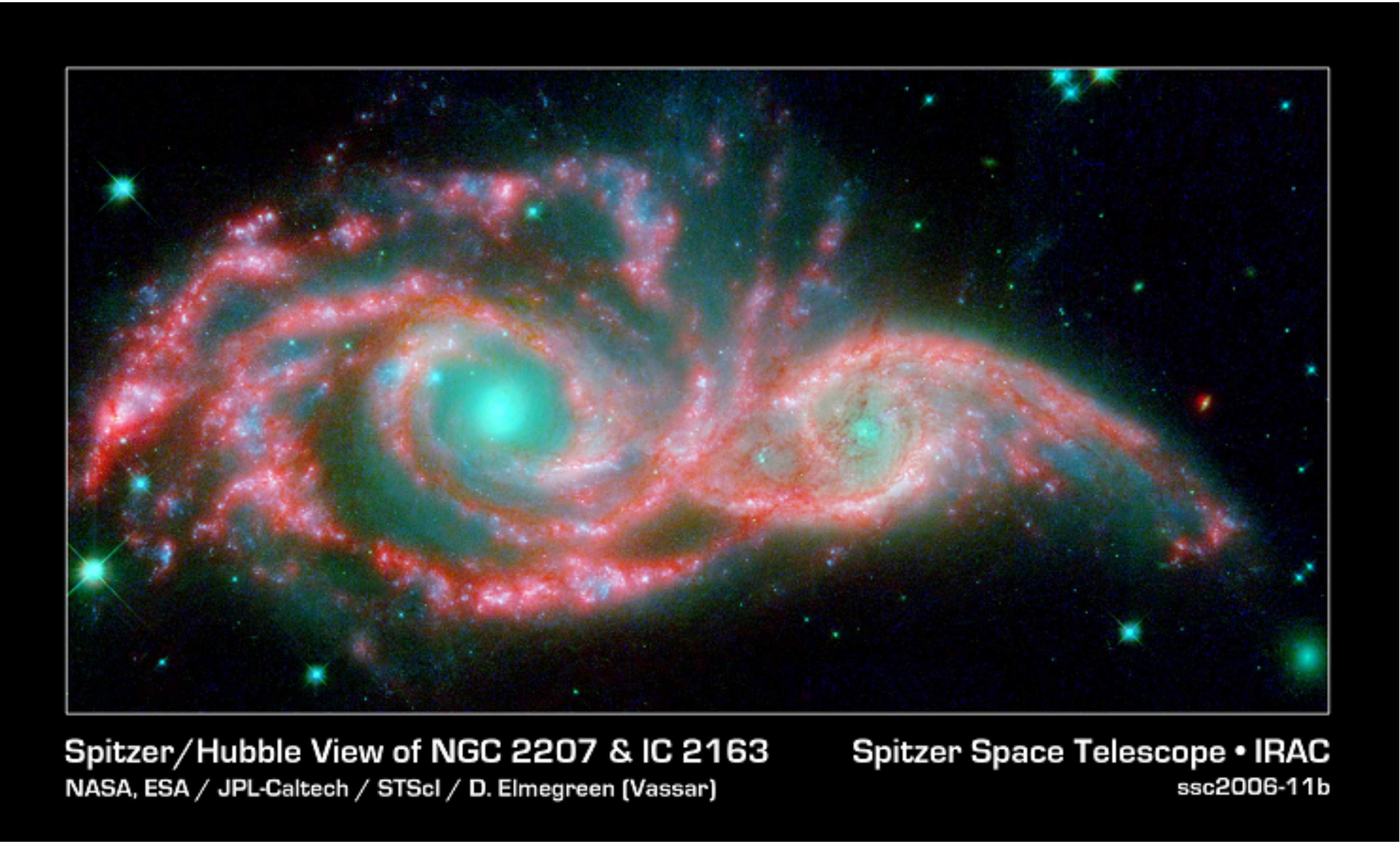
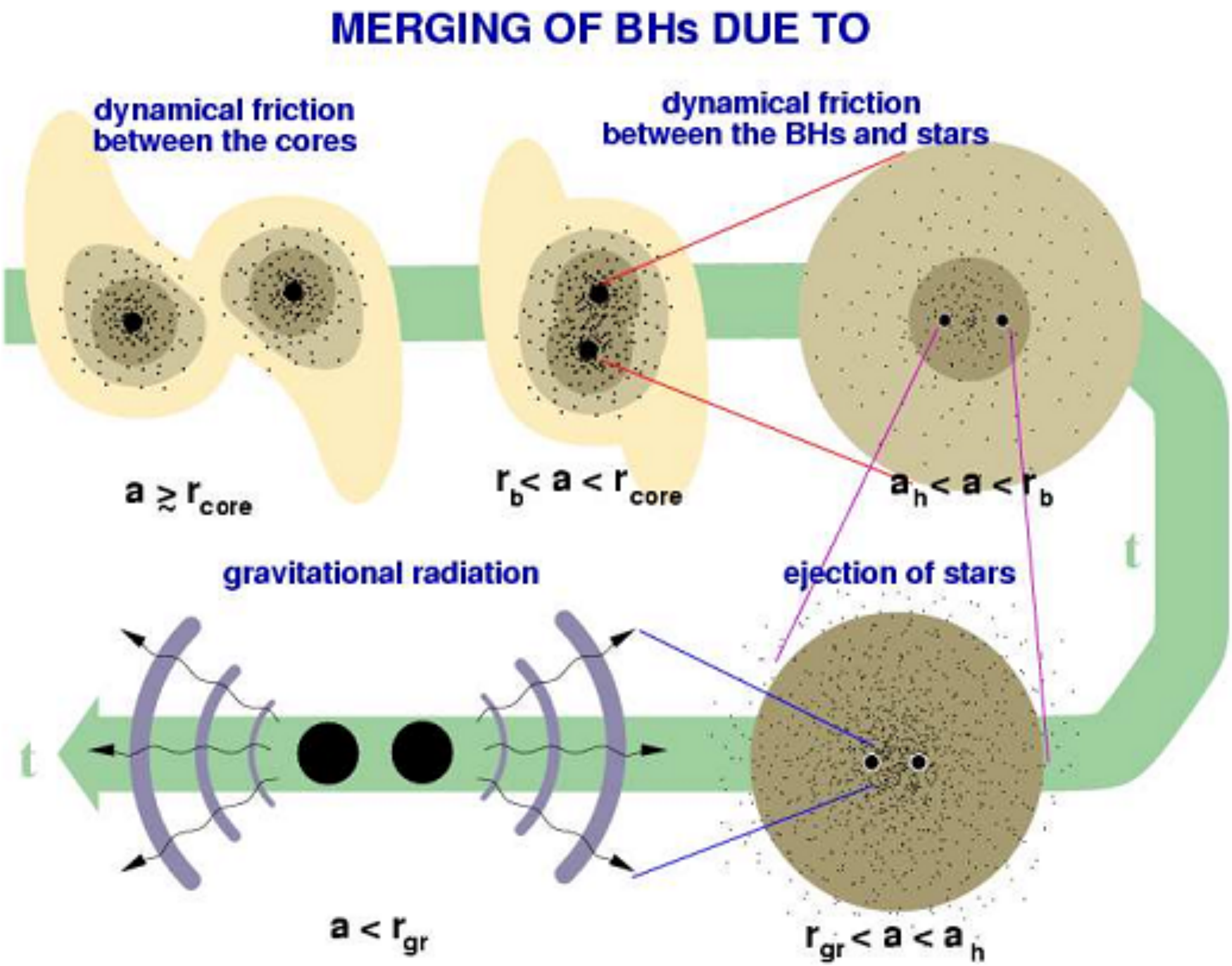
Outline

- Observational *evidences* of SMBHBs
- TDE rates from SMBHBs
- Double TDE rates from SMBHBs
- Conclusions and discussions

Observational *evidences* of SMBHBs



Observational *evidences* of SMBHBs

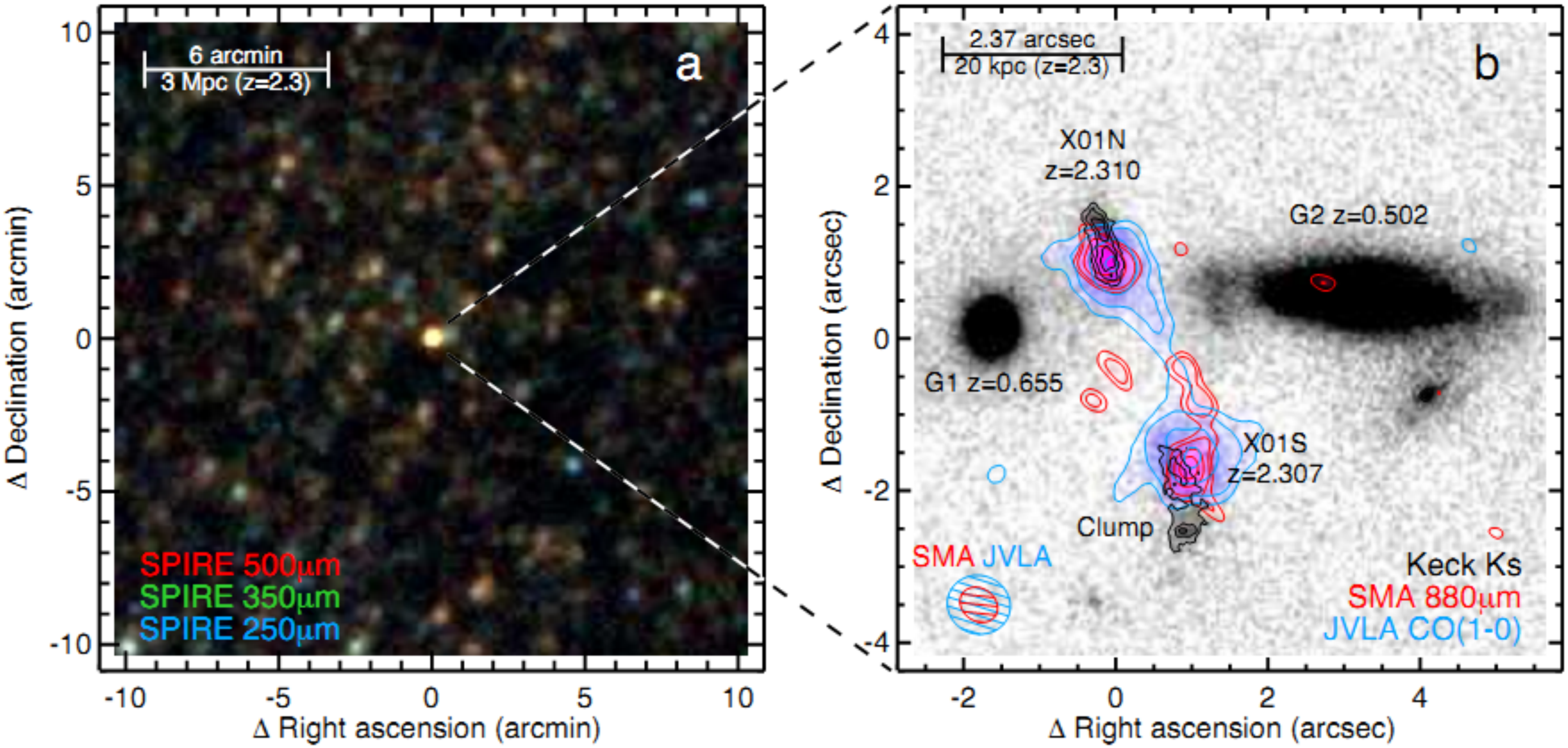


Observational *evidences* of SMBHBs

- QSO pairs in clusters of galaxies:~1kpc
- pairs of active galaxies, interacting galaxies:~0.1kpc, double-peaked narrow emission line
- SMBH pairs in *single* galaxies :~0.1kpc, heavily obscured
- spatially unresolved SMBHBs:~0.1pc, quasi-periodic signals , helical-patterns in jets, double-peaked broad lines … …
- post-merger candidates:~0.01pc, X-shaped radio sources, galaxies with central light deficits, double-double radio sources, recoiling SMBHs

Observational *evidences* of SMBHBs

Spatially resolved SMBHBs



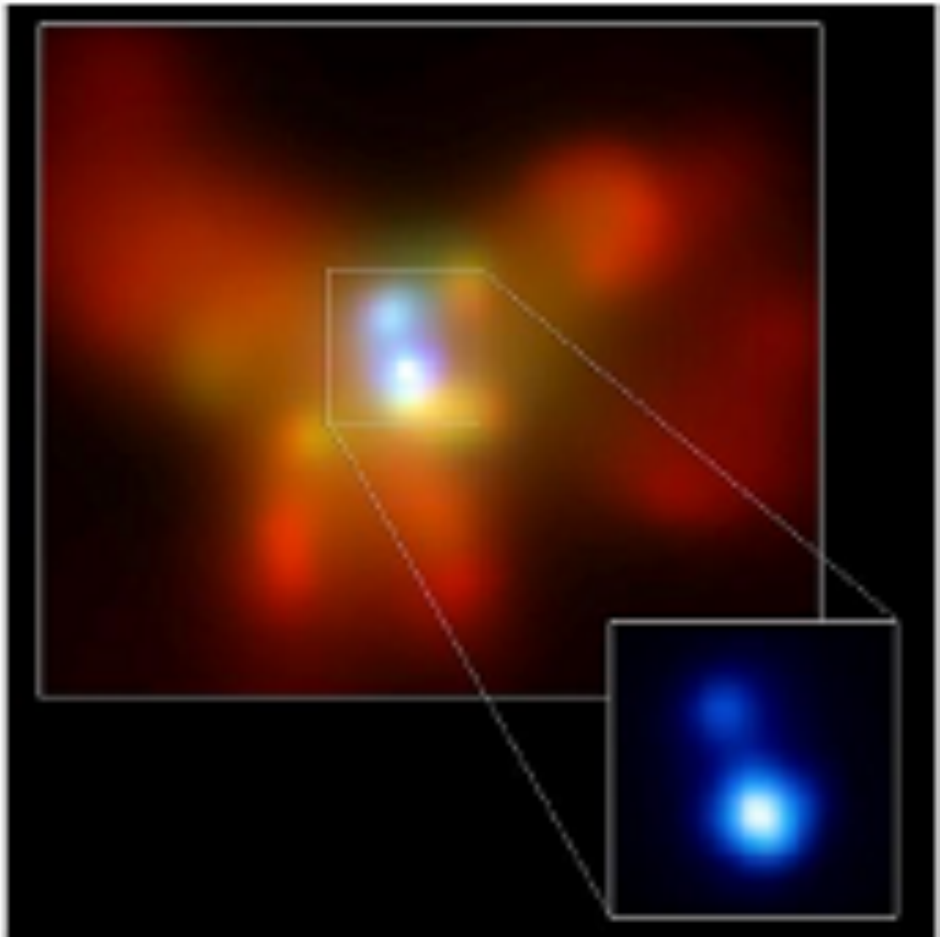
HXMM01:~19kpc

Fu, H et al., 2013, Nature

Observational *evidences* of SMBHBs

Dual AGNs

NGC 6240:~700pc



Komossa, et al., 2003, ApJL

Observational *evidences* of SMBHBs

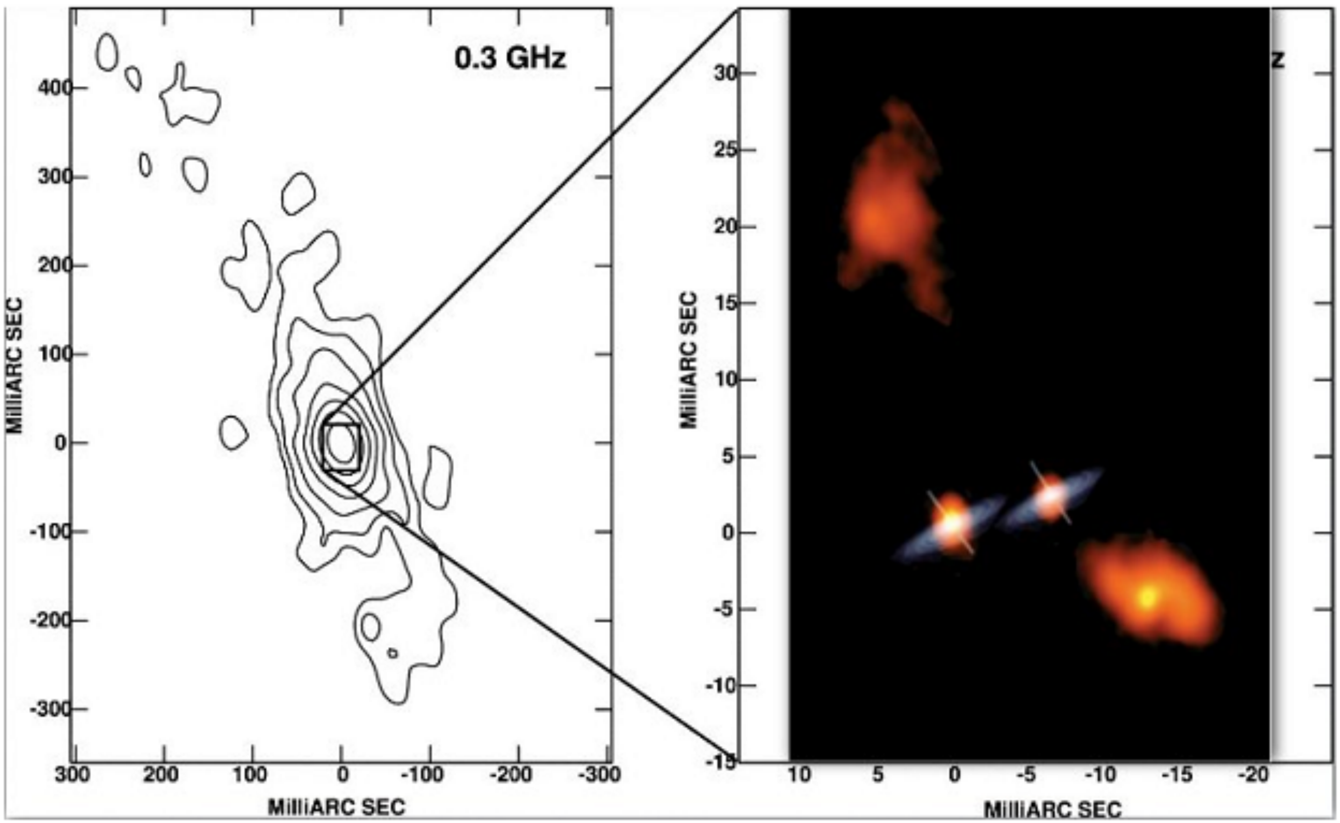
NGC3393

Chandra NGC 3393:
~ 135pc

Fabbiano 2011

Observational *evidences* of SMBHBs

RADIO GALAXY（E）： 0402+379/4C +37.11

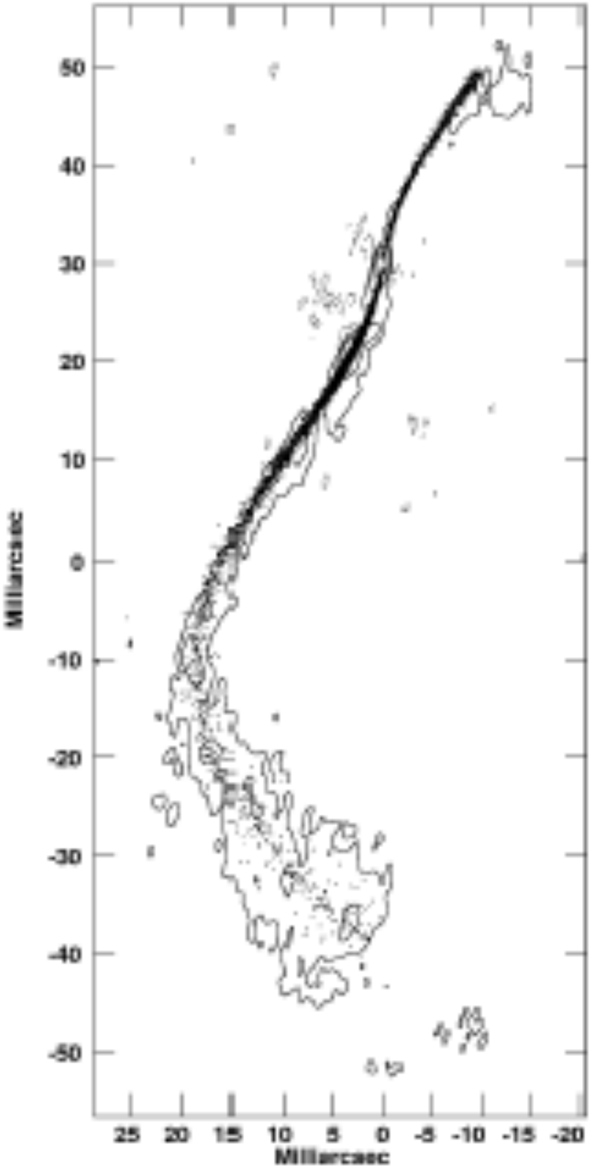


0402+379 (z=0.055):~7pc (projected) Rodriguez 2006

Observational *evidences* of SMBHBs

MORPHOLOGY OF GALAXIES

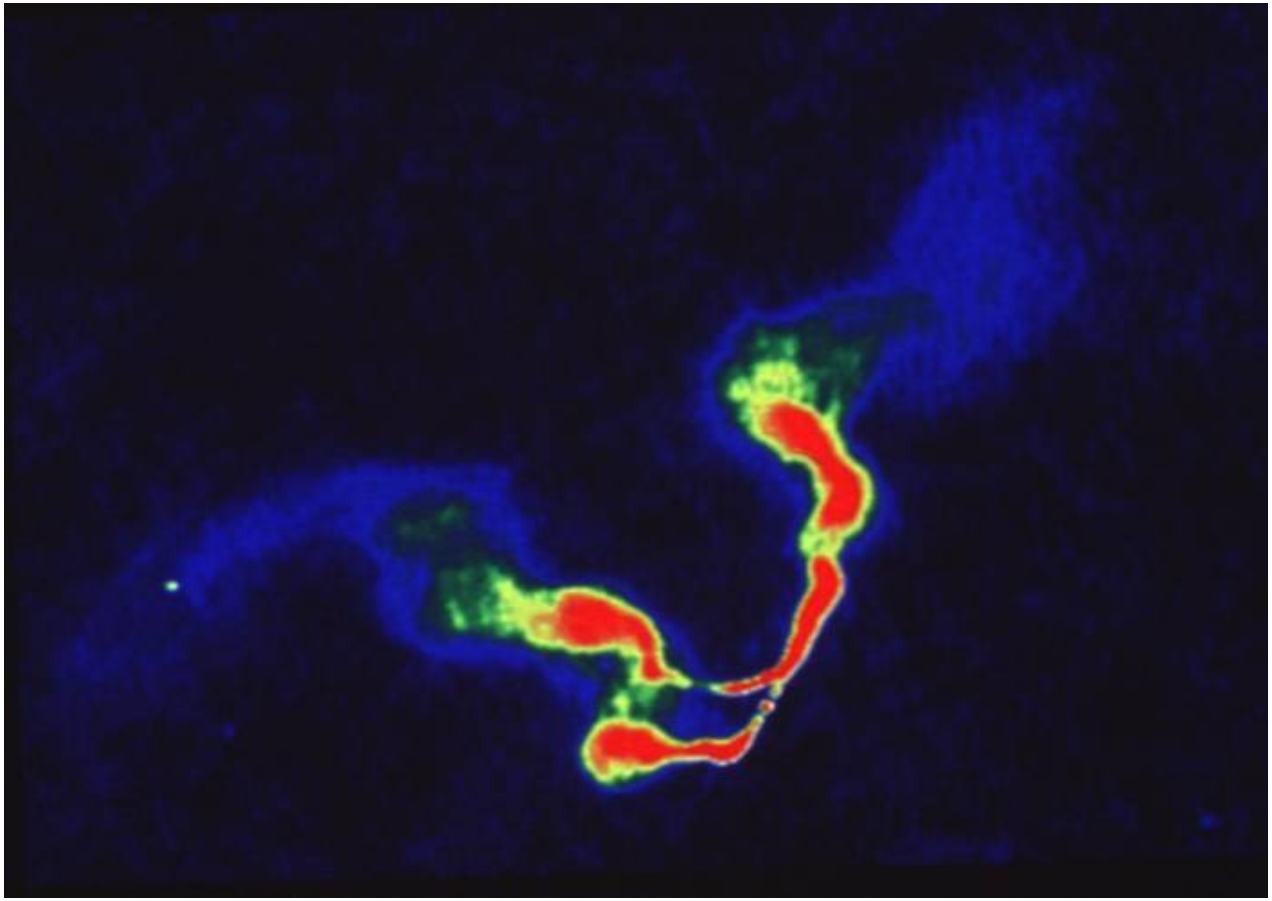
4C12.50



Begelman et al , 1980, Nature

Observational *evidences* of SMBHBs

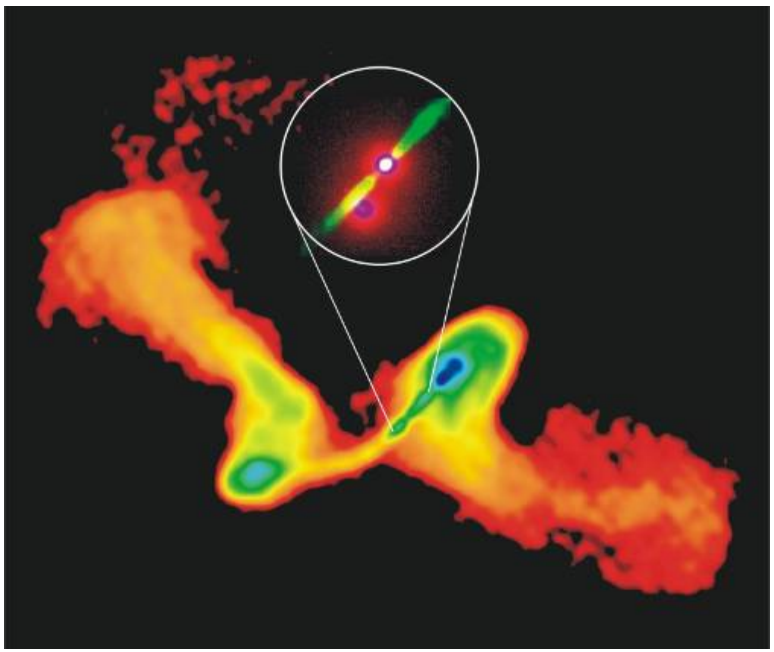
MORPHOLOGY OF GALAXIES: X-SHAPE

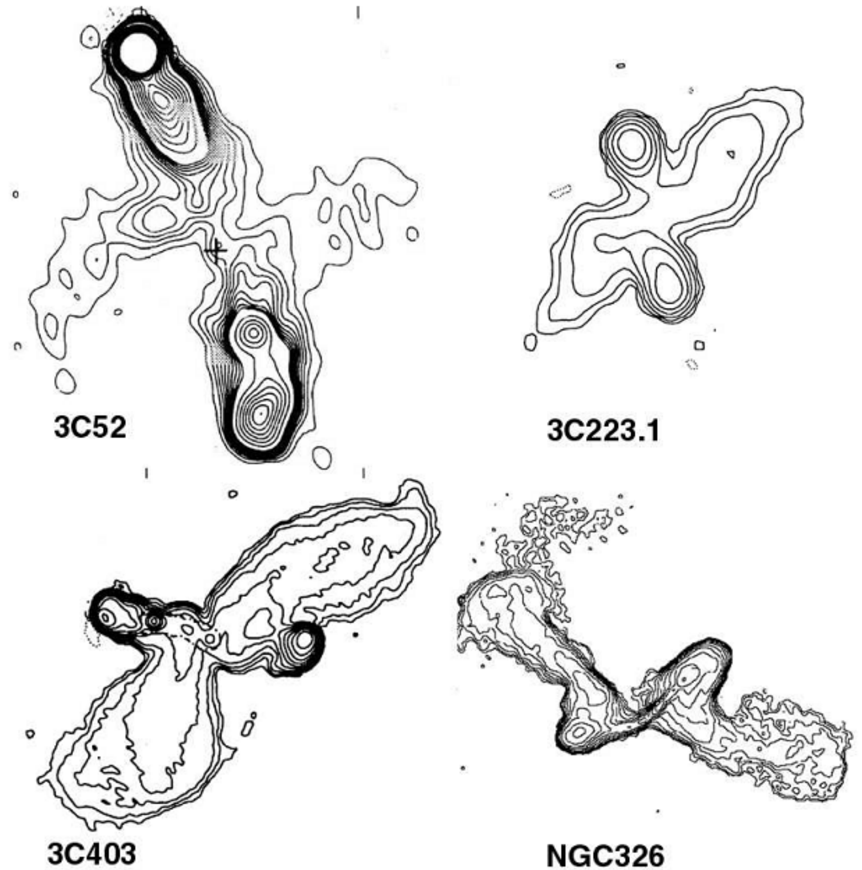


Komossa, et al., 2003, ApJL

Observational *evidences* of SMBHBs

DOUBLE-DOUBLE RADIO GALAXIES

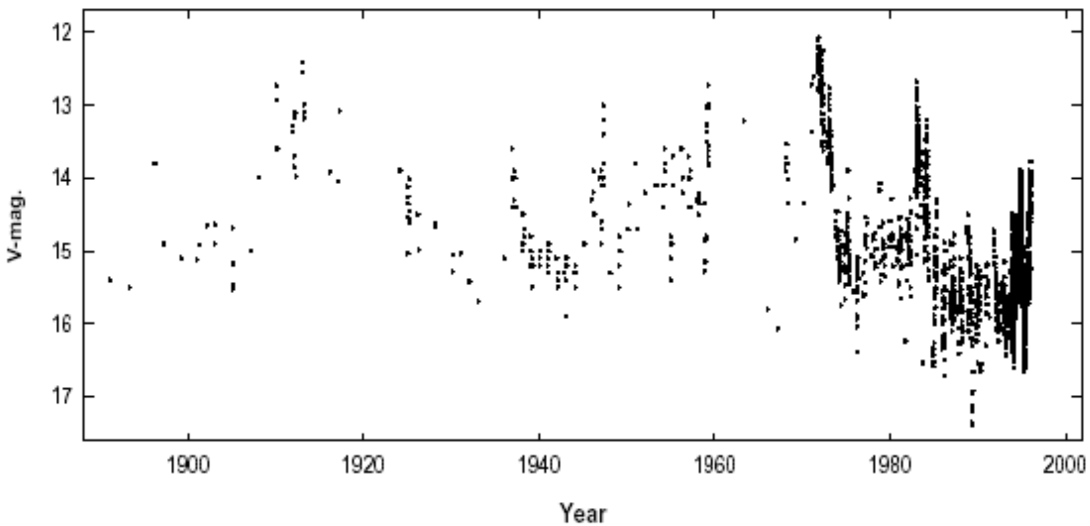


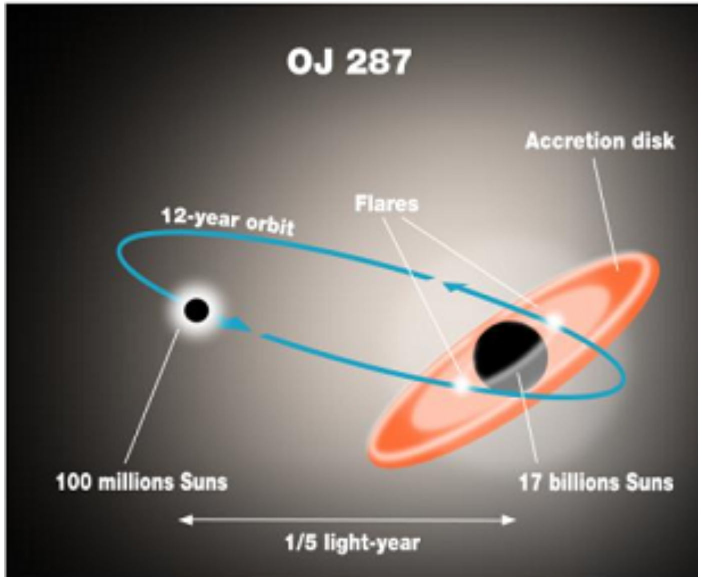


Merritt& Ekers, 2002; Liu 2004

Observational *evidences* of SMBHBs

PERIODIC/QUASI-PERIODIC LIGHT CURVE



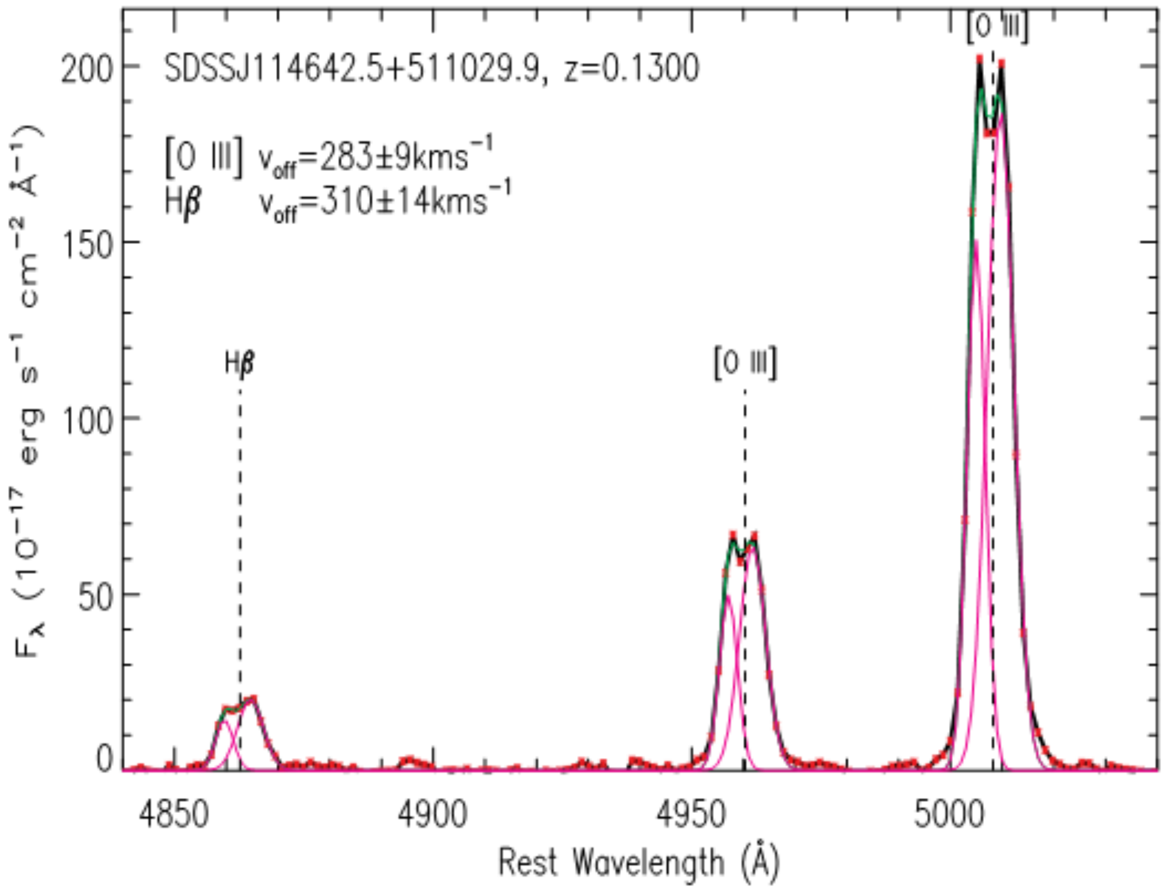


BL Lac object OJ287: p=11.86 yr (Sillapaa et al. 1988)

NGC 5548: < pc? (Li, Wang & Ho + 2016)

Observational *evidences* of SMBHBs

DOUBLE PEAKS

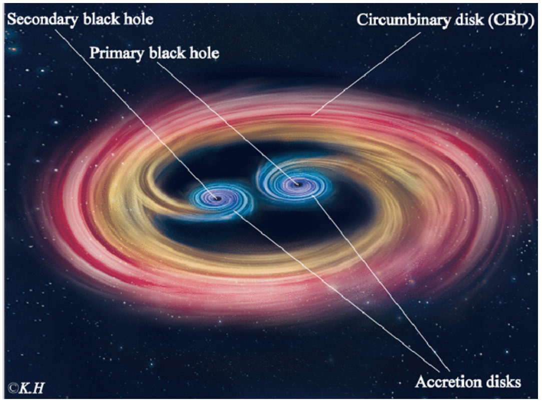


Liu X. et al.2010

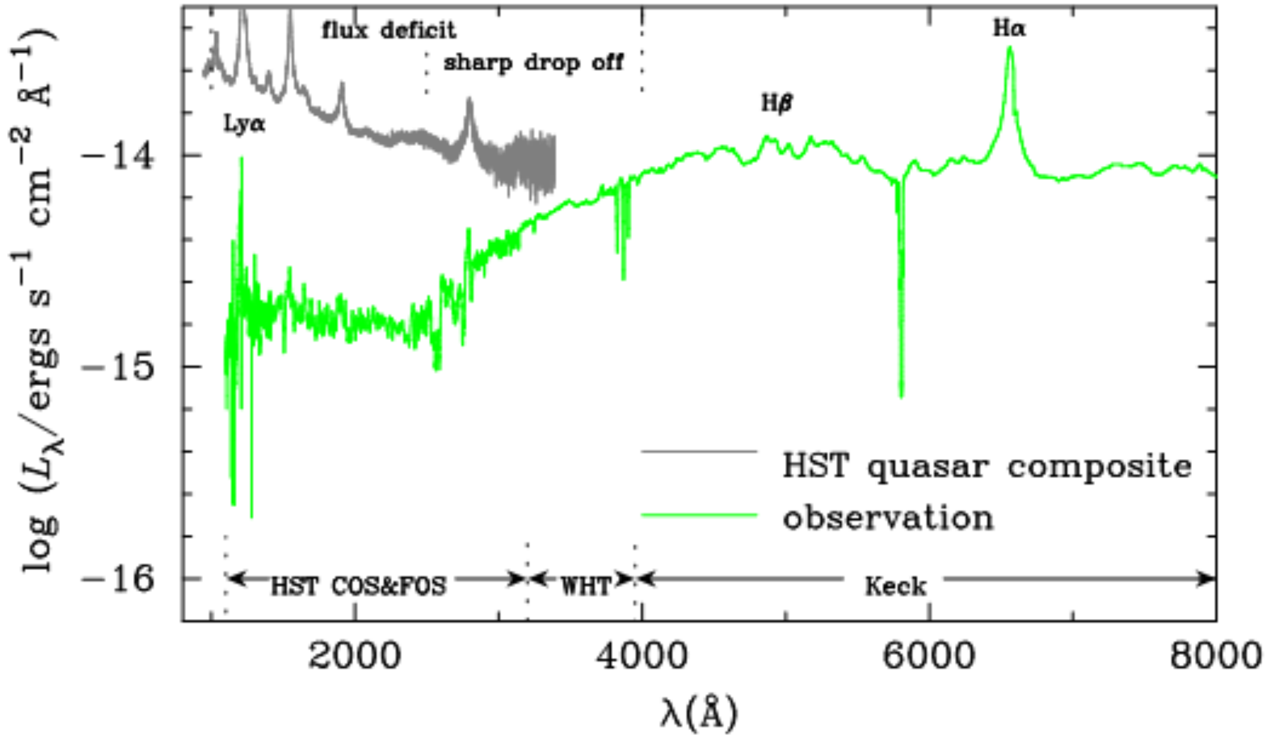
Zhou + 2004, Wang + 2009, Liu + 2010, Smith + 2010

Observational *evidences* of SMBHBs

SED OF SMBHBS



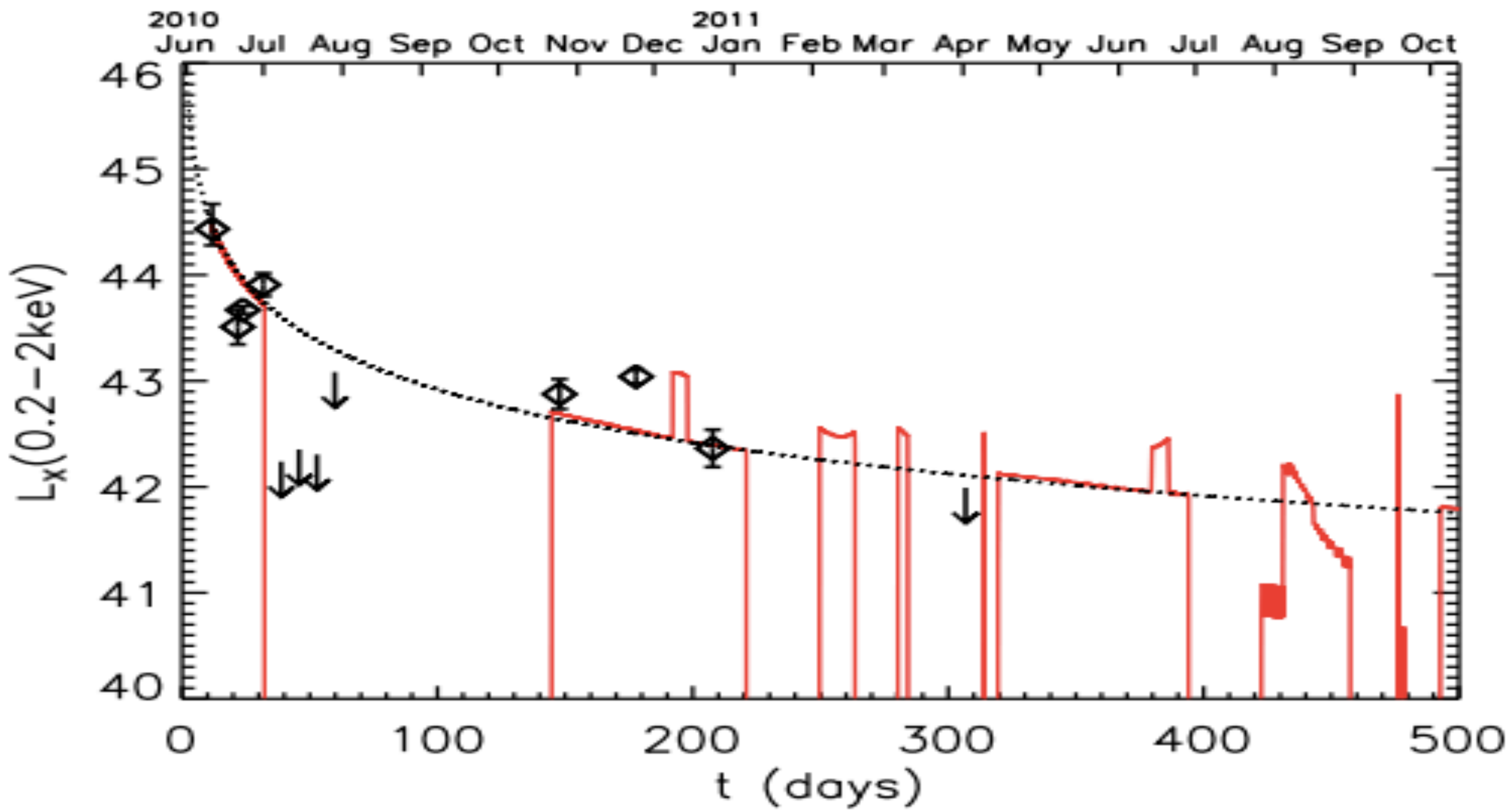
Hayasaki 2009



Yan et al. 2015, ApJ

Observational *evidences* of SMBHBs

NON-PERIODIC LIGHT CURVE

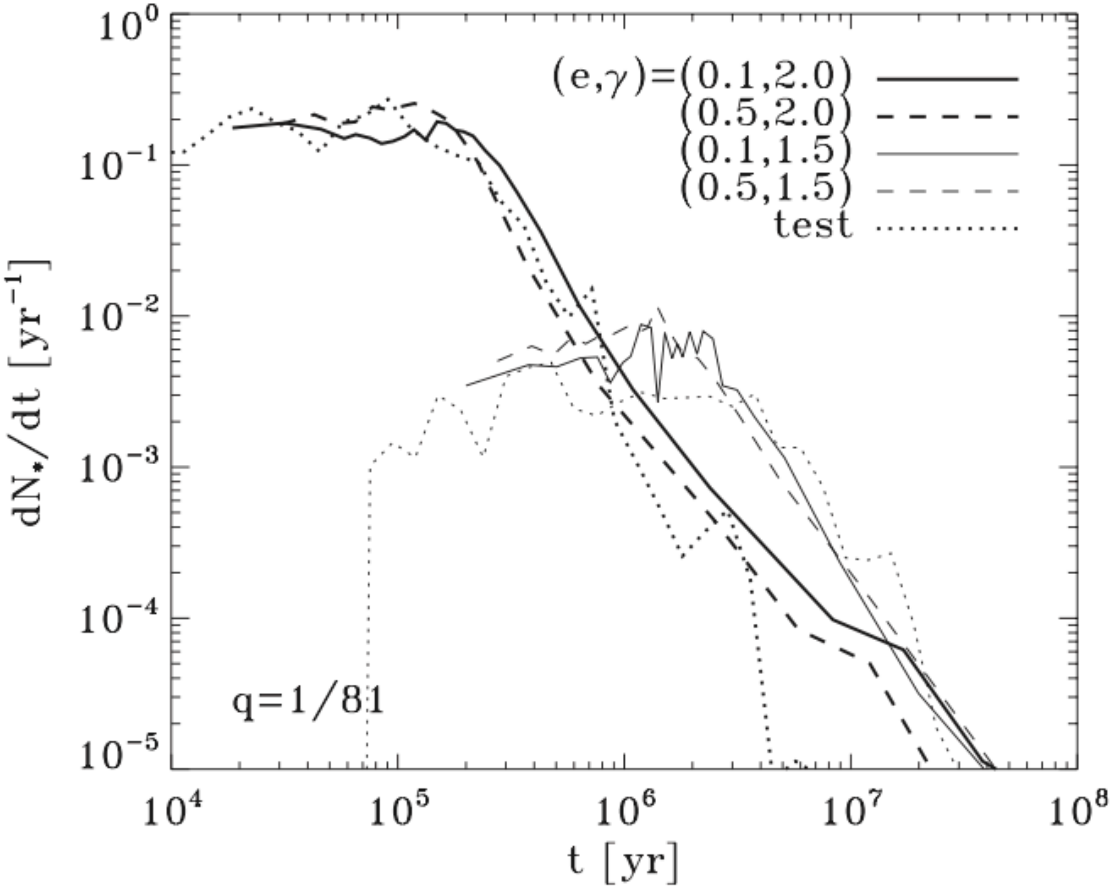


SDSS J120136.02+300305.5

Liu et al. 2014

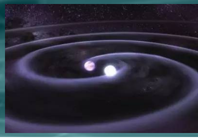
TDE rates from SMBHBs

Enhanced TDE rates from SMBHBs



Chen, X. +, 2008, 2009, 2011; Liu, F.K. & Chen, X. 2013;
Li, S., Liu, F.K. +2017

TDE rates from SMBHB

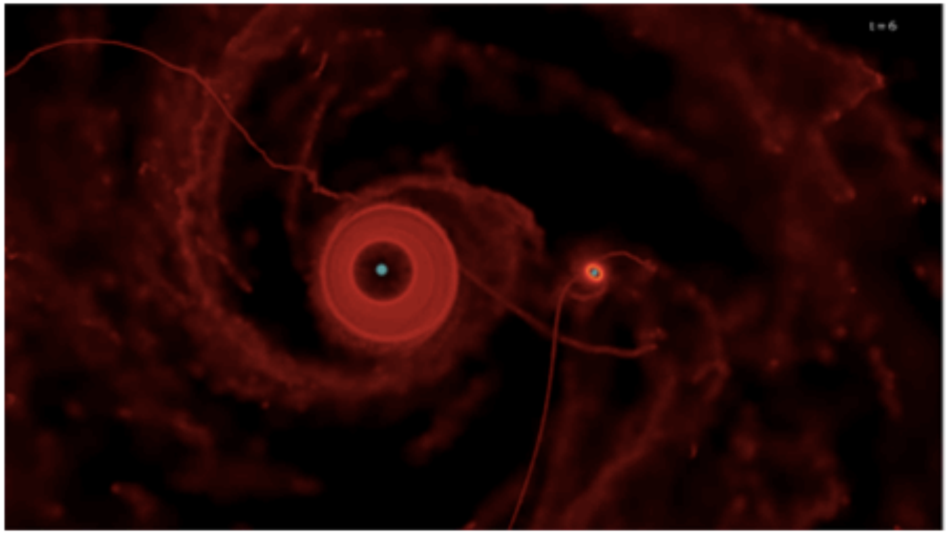


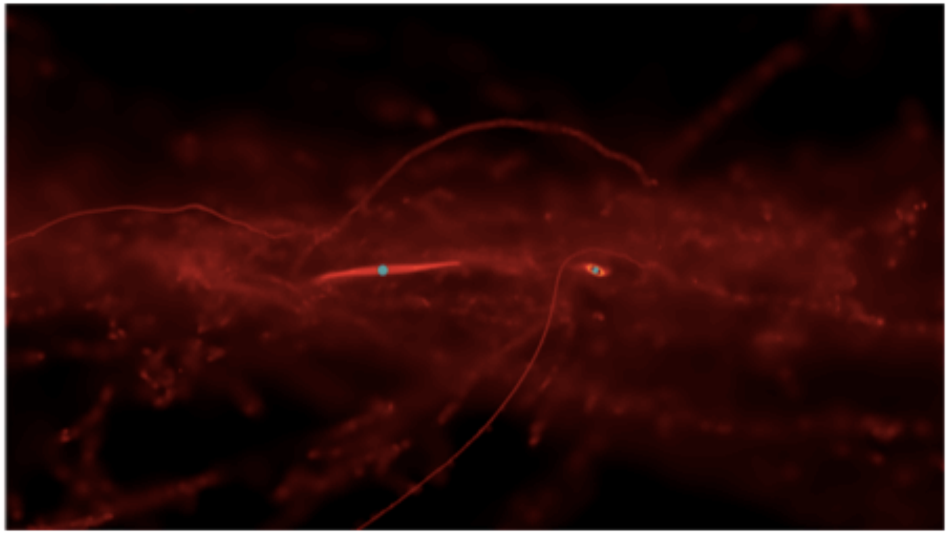
“A tidal disruption event in the nearby ultra-luminous infrared galaxy F01004-2237”

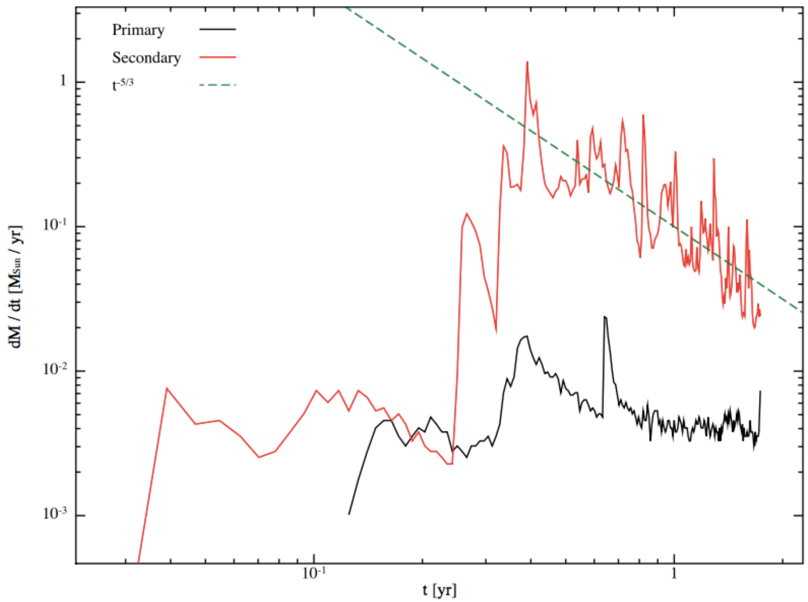
Tadhunter, C. + 2017, Nature Astron.

- TDE event rate is about 10^{-1} /yr/galaxy
- The concentrated nuclear star formation close to the central SMBHs
- The formation of SMBH binary

TDE rates from SMBHBs







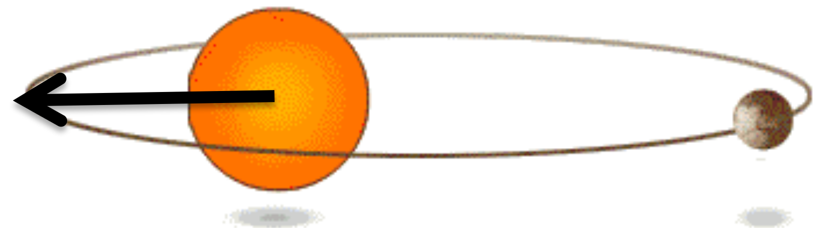
Evolution of the fallback debris

from TDEs

Coughlin, E.R. + 2017, MNRAS

Double TDE rates from SMBHBs

Lidov-Kozai Mechanism



Orbital parameters: a, e

Dynamic parameters: E, J

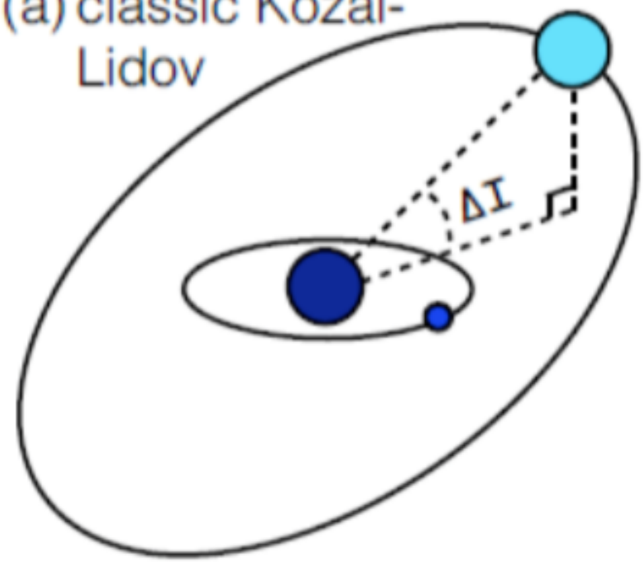
$$E = -\frac{GM}{2a}, \quad J = \frac{\sqrt{1-e^2}}{\sqrt{GMa}}$$

Runge-Lenz vector:

$$\vec{e} = \frac{1}{GM}\vec{p}\times(\vec{r}\times\vec{p}) - \frac{\vec{r}}{r} = \overrightarrow{const}$$

Double TDE rates from SMBHBs

Hierarchical triple systems:



two objects orbit each other in a relatively tight inner binary while the third object is on a much wider orbit.

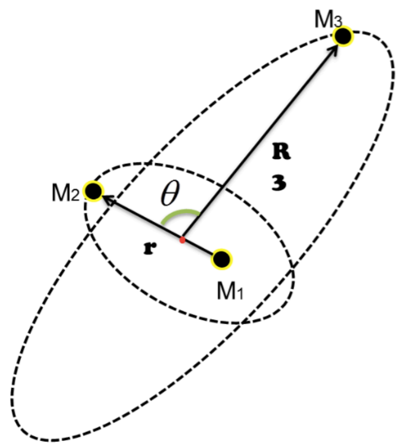
$$\frac{dE}{dt} = \frac{da}{dt} = 0, \quad \frac{d\vec{J}}{dt} \neq \vec{0}$$

$$\frac{d\vec{e}}{dt} \neq \vec{0}$$

[e.g.] Naoz,S. 2016, ARAA,54,441

Double TDE rates from SMBHBs

Hamiltonian of a triple system



$$\mathcal{H} = \frac{1}{2}m_1\dot{r}_1^2 + \frac{1}{2}m_2\dot{r}_2^2 + \frac{1}{2}m_3\dot{r}_3^2 - \frac{m_1m_2}{r} - \frac{m_1m_3}{|r_1 - r_3|} - \frac{m_2m_3}{|r_2 - r_3|}$$

$$= -\frac{Gm_1m_2}{2a_1} - \frac{Gm_3(m_1+m_2)}{2a_2}$$

$$-\frac{G}{a_2}\sum_{l=2}^{\infty}\left(\frac{a_1}{a_2}\right)^l M_l \left(\frac{|\mathbf{r}|}{a_1}\right)^l \left(\frac{a_2}{|\mathbf{R}|}\right)^{l+1} P_l(\cos\theta)$$

$$= \mathcal{H}_1 + \mathcal{H}_2 + \Phi$$

Harrington, R+, 1968, AJ

Liu, Lai, Yuan∗, 2015, PRD

Double TDE rates from SMBHBs

Equations of motion in vector form

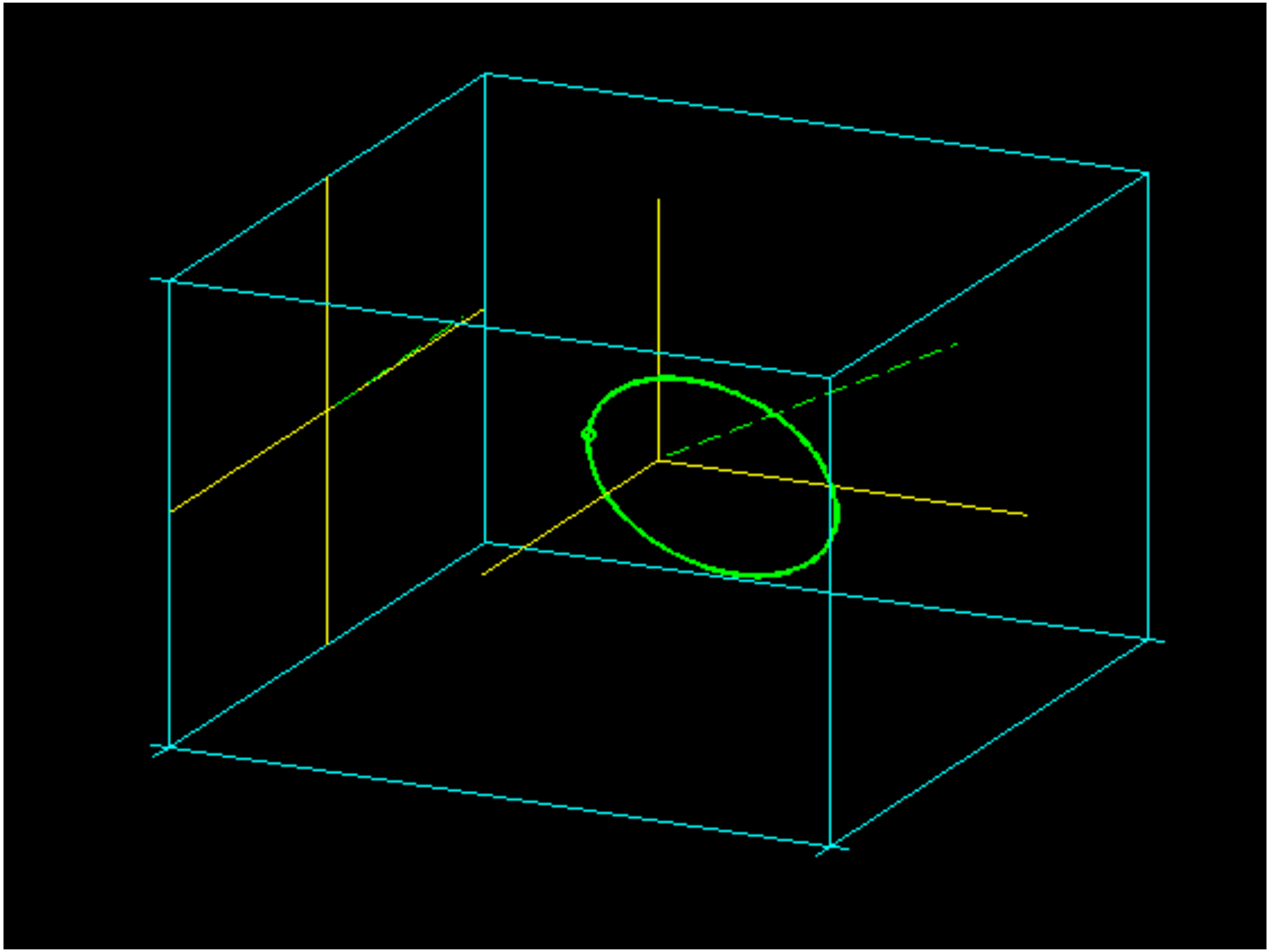
$$[j_i, j_j] = \frac{1}{\sqrt{GMa}} \varepsilon_{ijk} j_k$$
$$[e_i, e_j] = \frac{1}{\sqrt{GMa}} \varepsilon_{ijk} j_k$$
$$[j_i, e_j] = \frac{1}{\sqrt{GMa}} \varepsilon_{ijk} e_k$$

$$\frac{dF}{dt} = [F, \mathcal{H}(\mathbf{j}, \mathbf{e})] = [F, \mathbf{j}]\nabla_{\mathbf{j}}\mathcal{H} + [F, \mathbf{e}]\nabla_{\mathbf{e}}\mathcal{H}$$

$$\frac{d\mathbf{j}_1}{dt} = \frac{3}{4\,t_K}\left[(\mathbf{j}_1 \cdot \hat{\mathbf{n}}_2)\,\mathbf{j}_1 \times \hat{\mathbf{n}}_2 - 5(\mathbf{e}_1 \cdot \hat{\mathbf{n}}_2)\,\mathbf{e}_1 \times \hat{\mathbf{n}}_2\right]$$
$$\frac{d\mathbf{e}_1}{dt} = \frac{3}{4\,t_K}\left[(\mathbf{j}_1 \cdot \hat{\mathbf{n}}_2)\,\mathbf{e}_1 \times \hat{\mathbf{n}}_2 + 2\,\mathbf{j}_1 \times \mathbf{e}_1 - 5(\mathbf{e}_1 \cdot \hat{\mathbf{n}}_2)\mathbf{j}_1 \times \hat{\mathbf{n}}_2\right]$$
$$\frac{d\mathbf{j}_2}{dt} = \frac{3}{4t_K}\frac{L_1}{L_2}\left[(\mathbf{j}_1 \cdot \hat{\mathbf{n}}_2)\,\hat{\mathbf{n}}_2 \times \mathbf{j}_1 - 5(\mathbf{e}_1 \cdot \hat{\mathbf{n}}_2)\,\hat{\mathbf{n}}_2 \times \mathbf{e}_1\right]$$
$$\frac{d\mathbf{e}_2}{dt} = \frac{3}{4t_K\sqrt{1-e_2^2}}\frac{L_1}{L_2}\Bigg[(\mathbf{j}_1 \cdot \hat{\mathbf{n}}_2)\,\mathbf{e}_2 \times \mathbf{j}_1 - 5(\mathbf{e}_1 \cdot \hat{\mathbf{n}}_2)\mathbf{e}_2 \times \mathbf{e}_1 - \left[\frac{1}{2} - 3e_1^2 + \frac{25}{2}(\mathbf{e}_1 \cdot \hat{\mathbf{n}}_2)^2 - \frac{5}{2}(\mathbf{j}_1 \cdot \hat{\mathbf{n}}_2)^2\right]\hat{\mathbf{n}}_2 \times \mathbf{e}_2\Bigg]$$

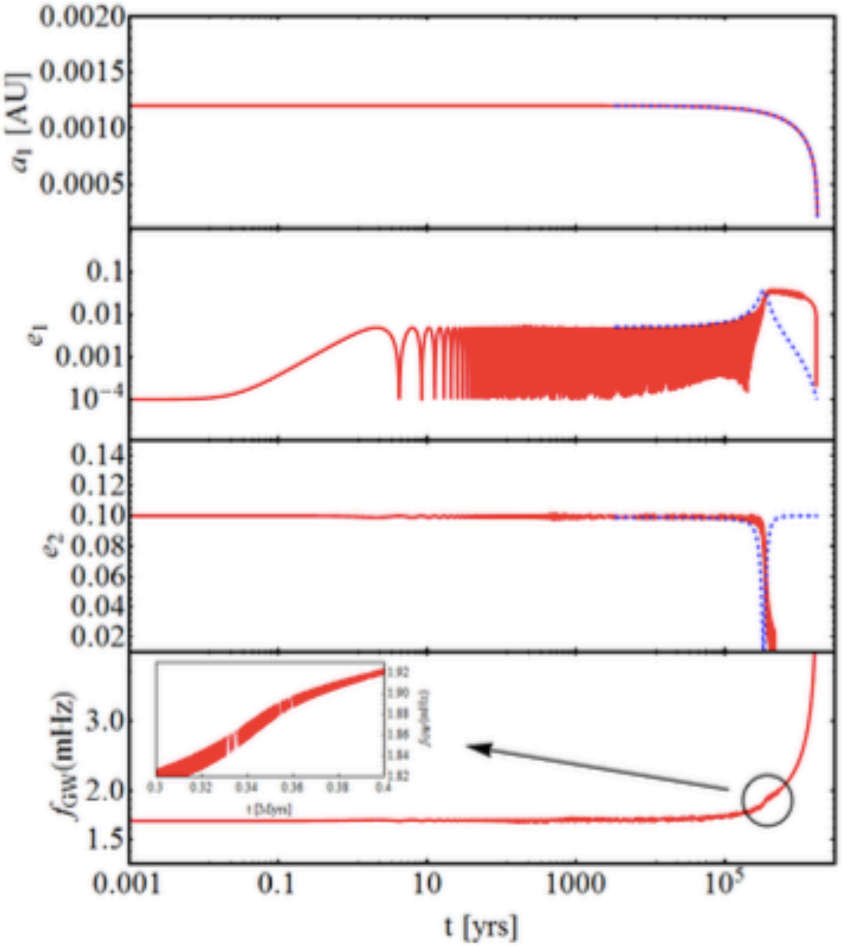
Tremaine+, arXiv:1309.0544

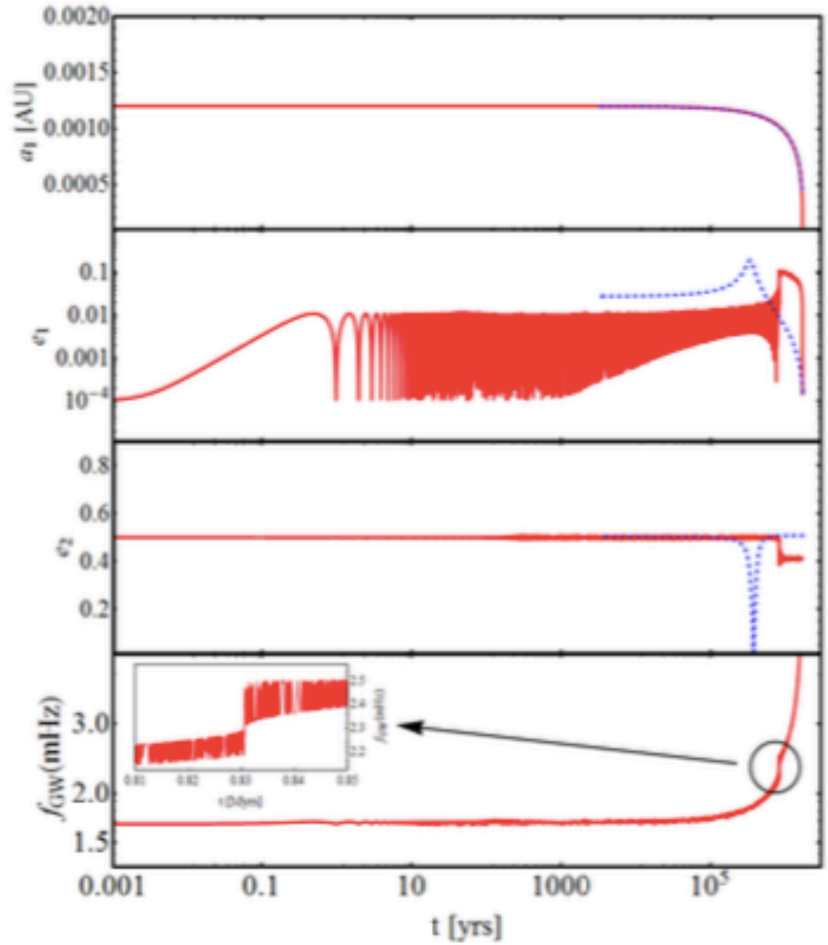
Double TDE rates from SMBHBs



https://www.cfa.harvard.edu/research/ta/kozai-lidov-mechanism

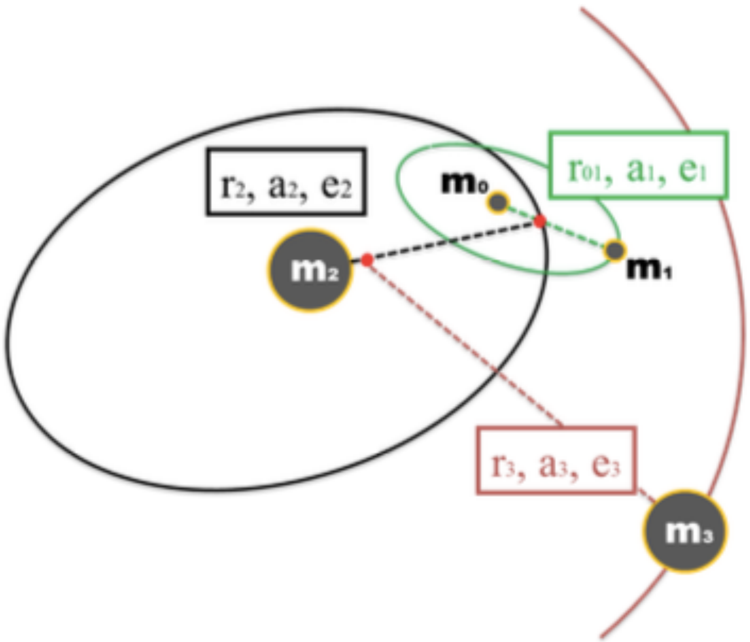
Double TDE rates from SMBHBs

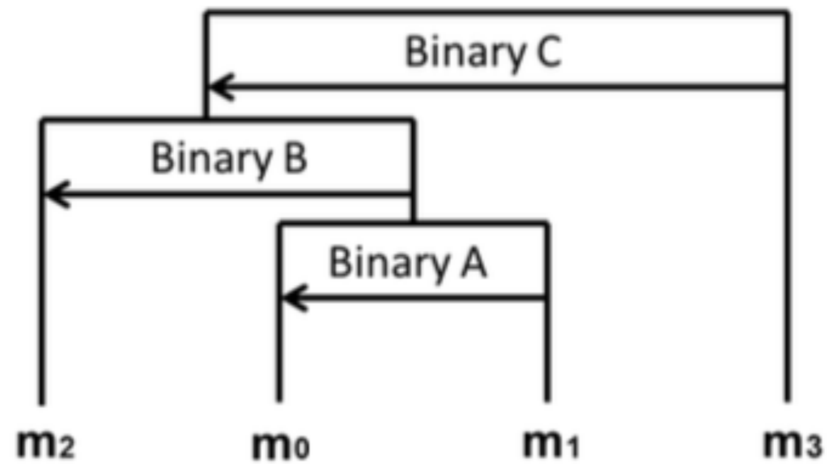




Liu, Lai, Yuan∗, 2015, PRD

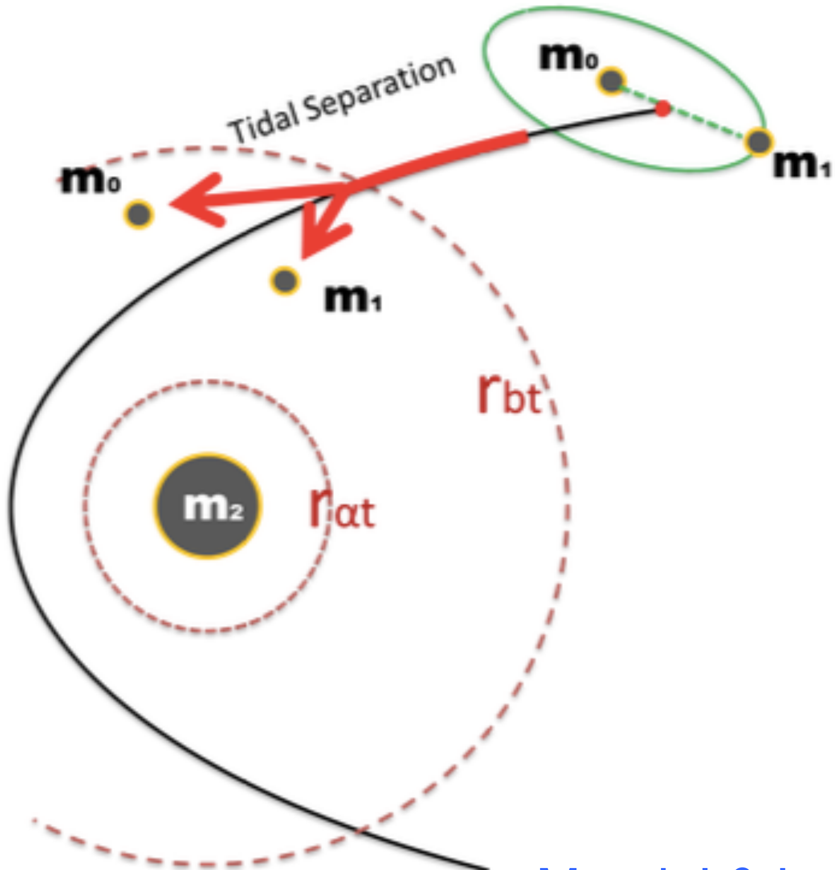
Double TDE rates from SMBHBs





Double TDE rates from SMBHBs

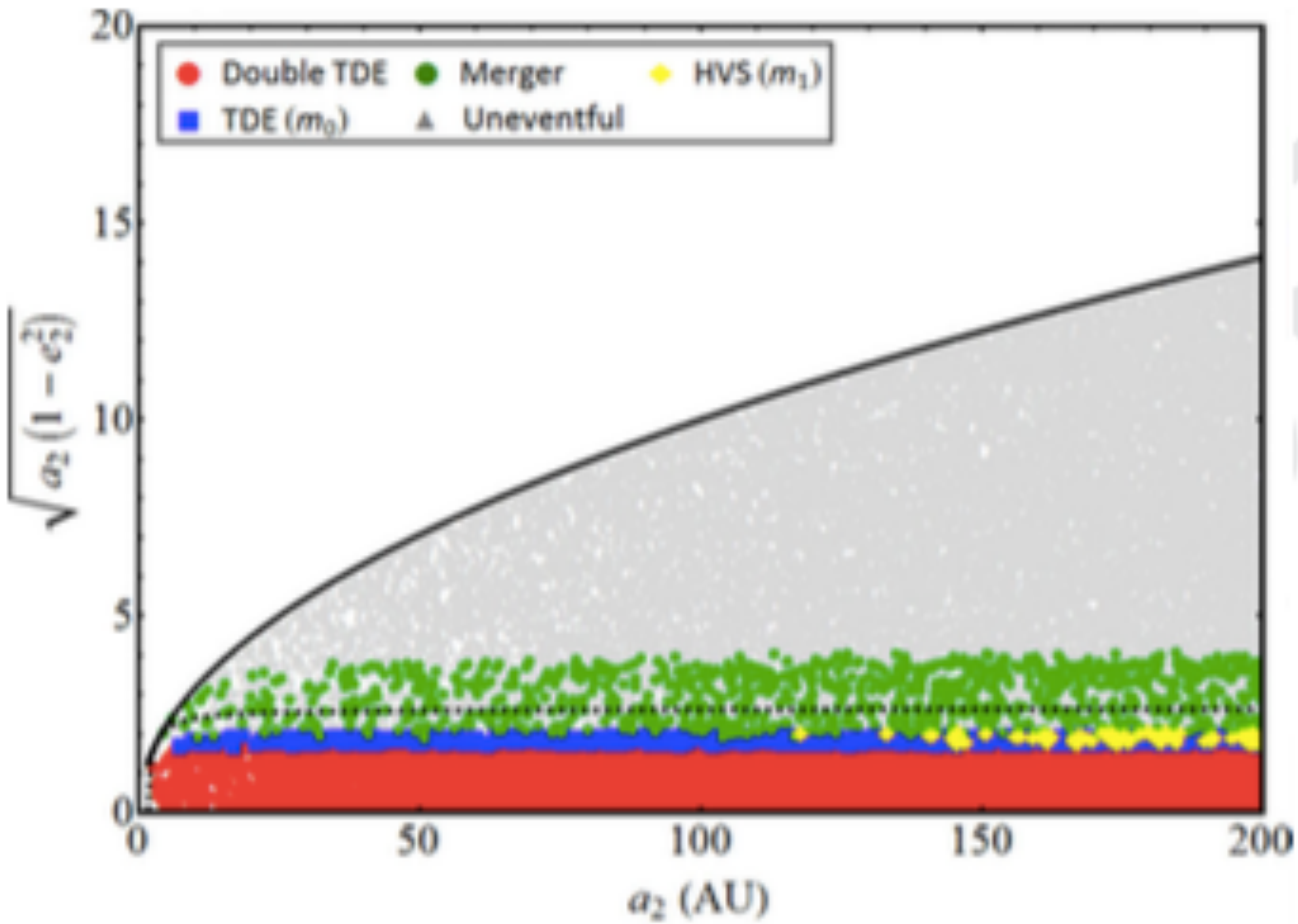
TIDAL BREAK-UP OF BINARIES



$$r_{bt} \sim a_1 \left(\frac{m_2}{m_0 + m_1} \right)^{1/3},$$

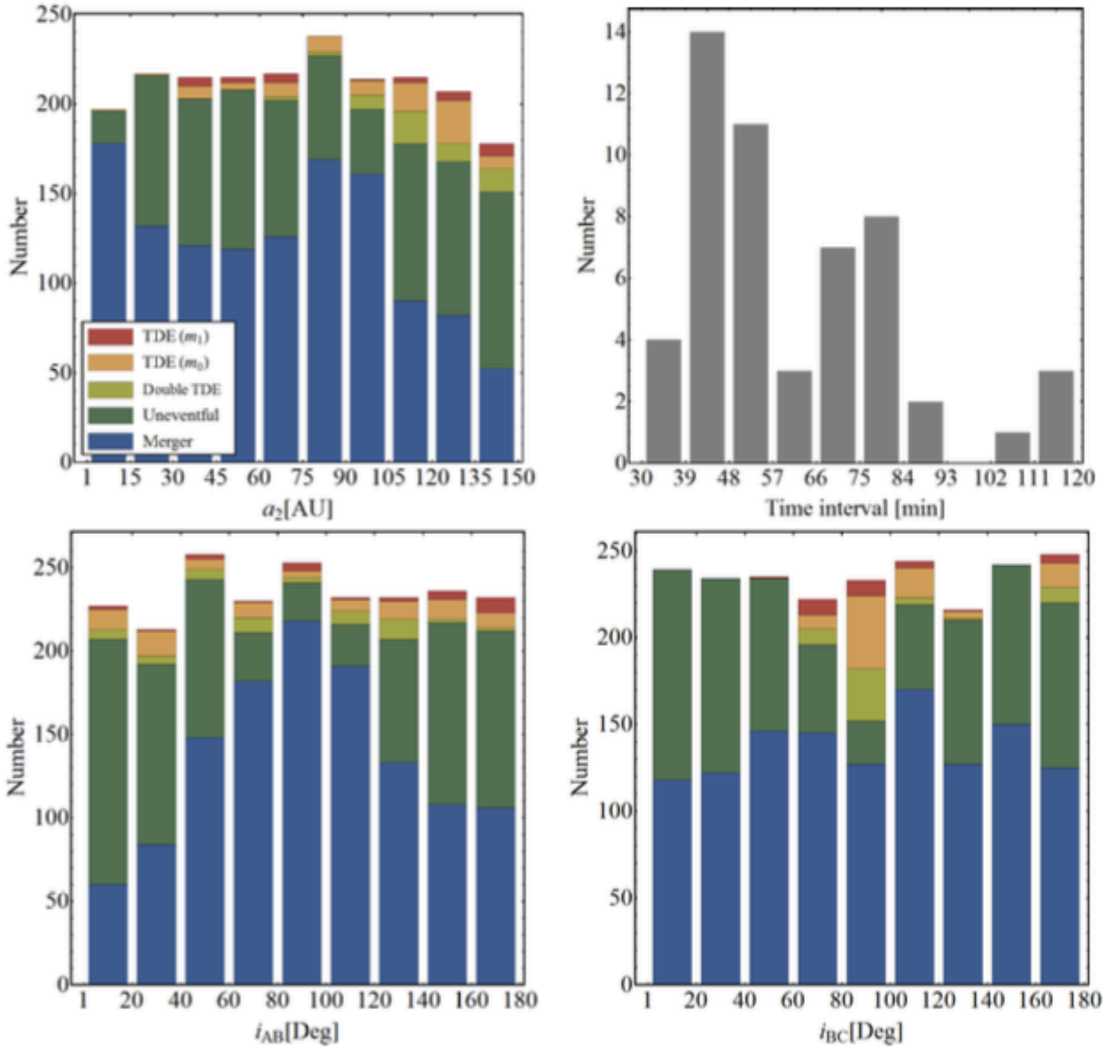
Mandel & Levin, 2015, ApJL, 805,4
Liu, Wang, Yuan∗, 2017, MNRAS, 466,3376

Double TDE rates from SMBHBs



Liu, Wang, Yuan∗, 2017, MNRAS, 466,3376

Double TDE rates from SMBHBs

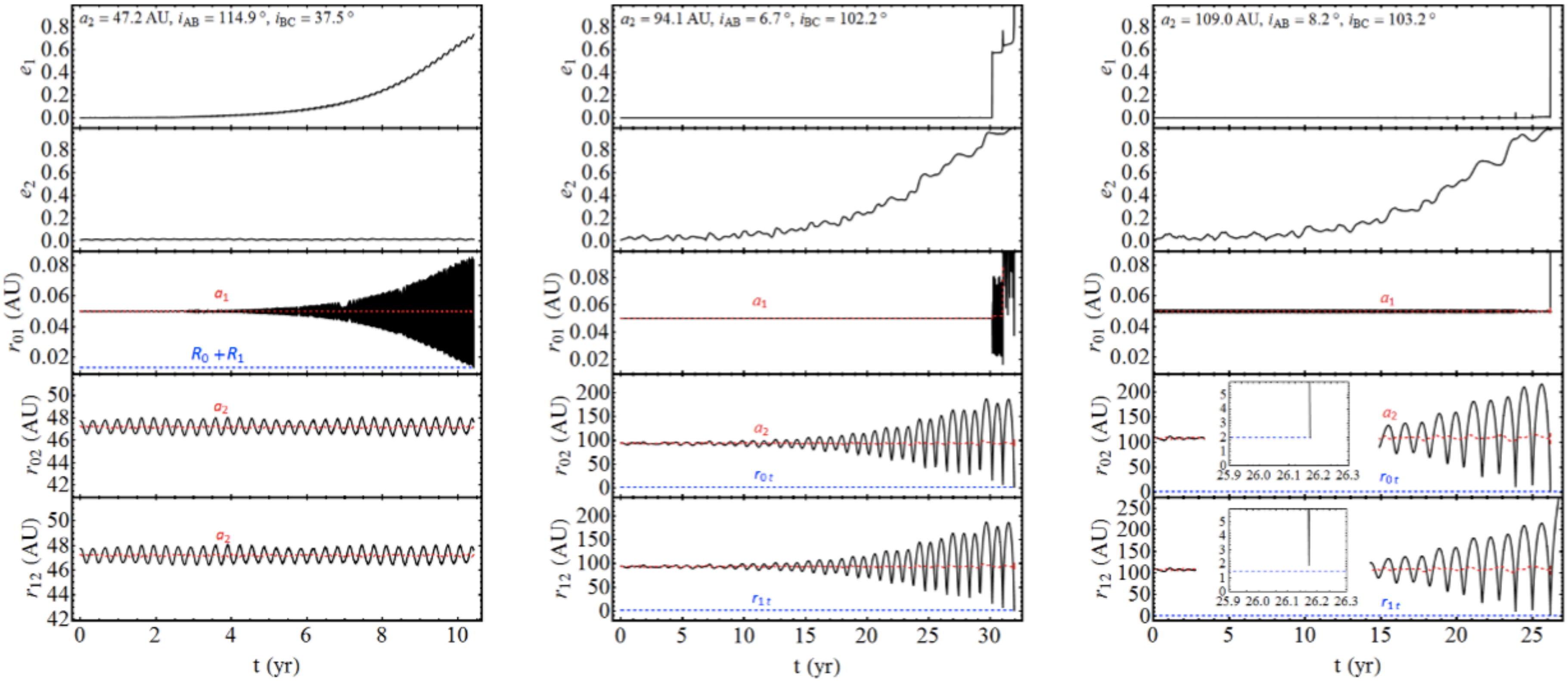


Final distributions of different endings of the stellar binaries

$m_0 = 2M_\odot$, $m_1 = 1M_\odot$, $m_2 = m_3 = 10^6 M_\odot$, $a_1 = 0.05AU$, $a_3 = 400AU$
$e_{1,0} = e_{2,0} = e_{3,0} = 0.001$

Liu, Wang, Yuan*, 2017, MNRAS, 466,3376

Double TDE rates from SMBHBs



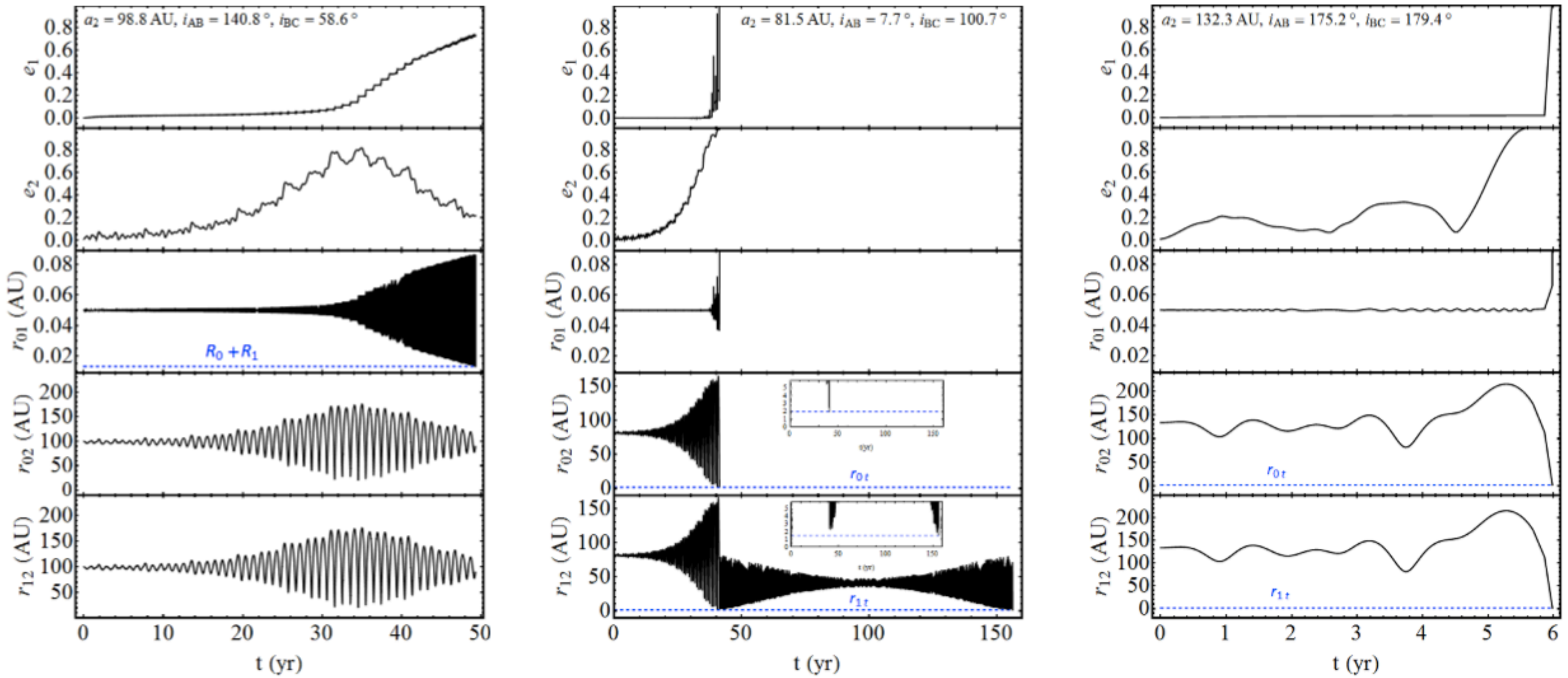
Merging

Double TDE

single TDE

Liu, Wang, Yuan*, 2017, MNRAS, 466,3376

Double TDE rates from SMBHBs



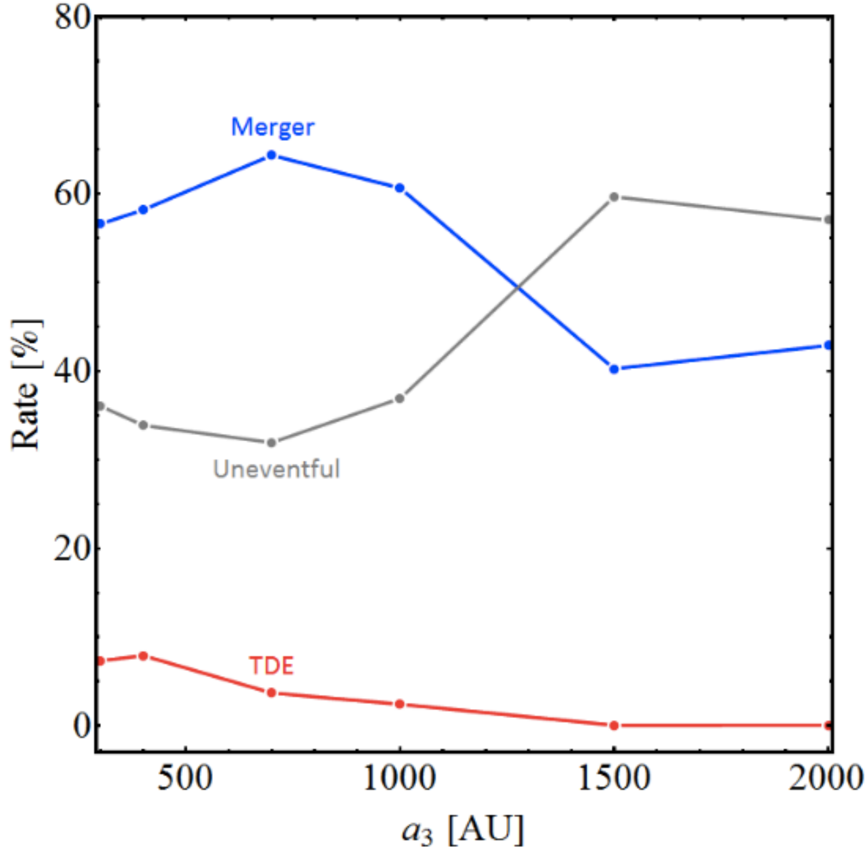
Merging

single TDE

Double TDE

Liu, Wang, Yuan∗, 2017, MNRAS, 466,3376

Double TDE rates from SMBHBs



Rates of the stellar mergers, TDEs and uneventful events as a function of different semi-major axis of the SMBH binary.

Liu, Wang, Yuan∗, 2017, MNRAS, 466,3376

Conclusions and discussions

- Evolution of the stellar binary varies a lot through LK oscillations or the chaotic interactions
- Increasing the formation of merging compact binaries
- Increase of the TDE & DTDE rates from SMBHBs

THANKS !