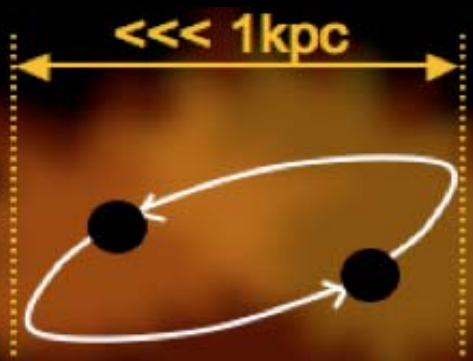
Taking a Radio Census of Binary Supermassive Black Holes

Stalling, inspirals, gravitational radiation, and SKA

Sarah Burke Spolaor

Swinburne University of Technology

CSIRO Astronomy and Space Sciences (ATNF)



< 200 parsecs

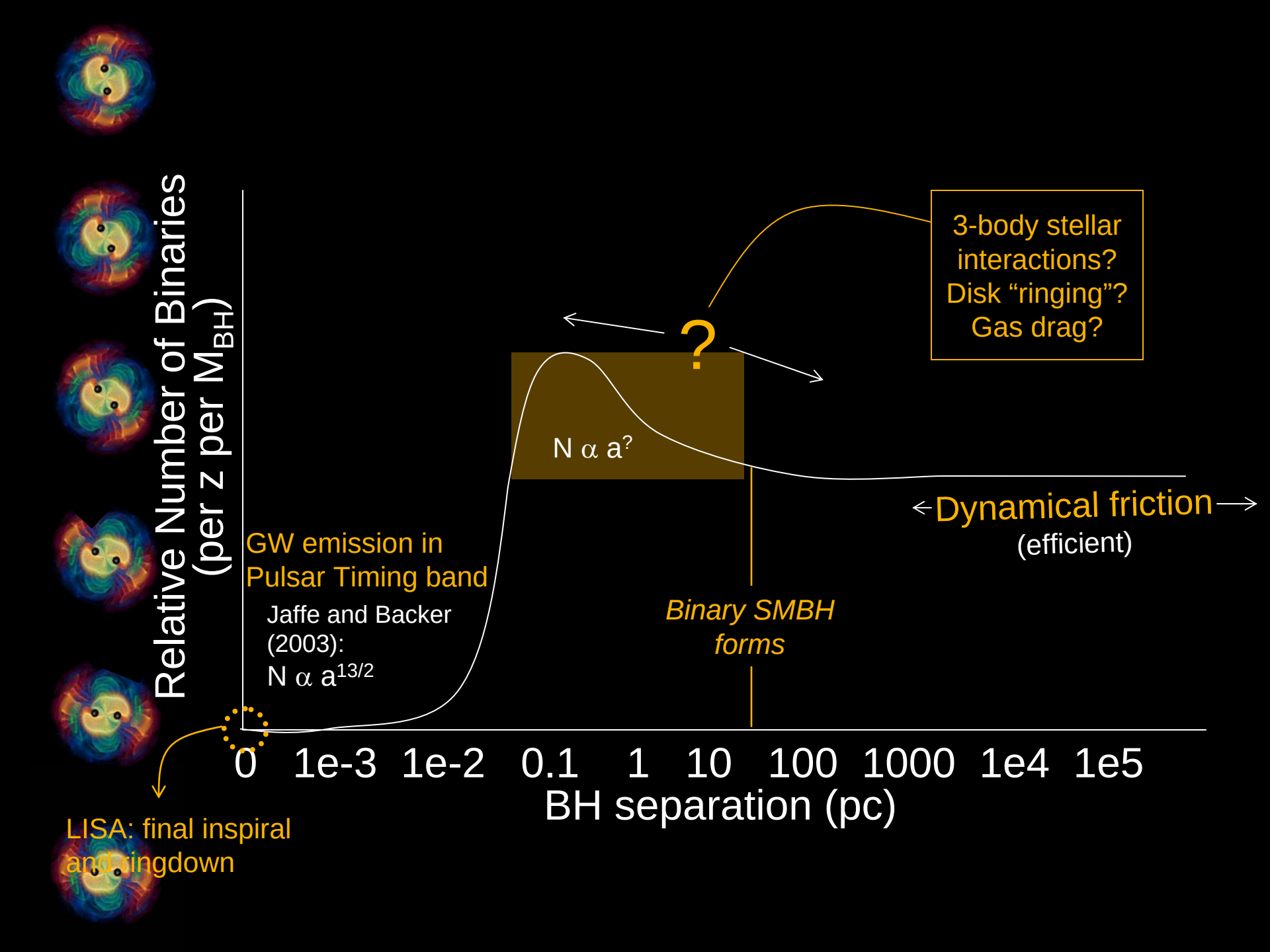
- → Shape inner galaxy
- → High velocity stars
- → Help mould fundamental relations with M_{BH}?

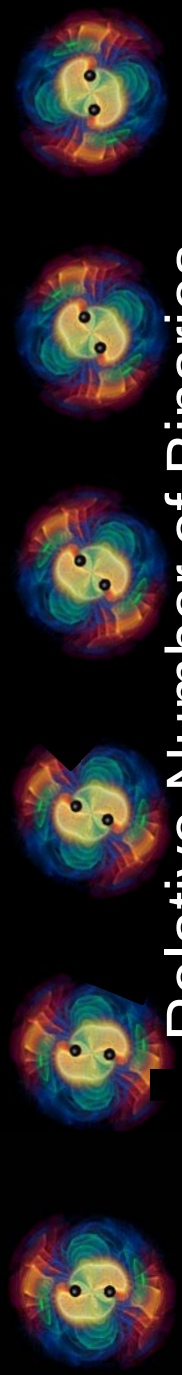
< 1 parsec

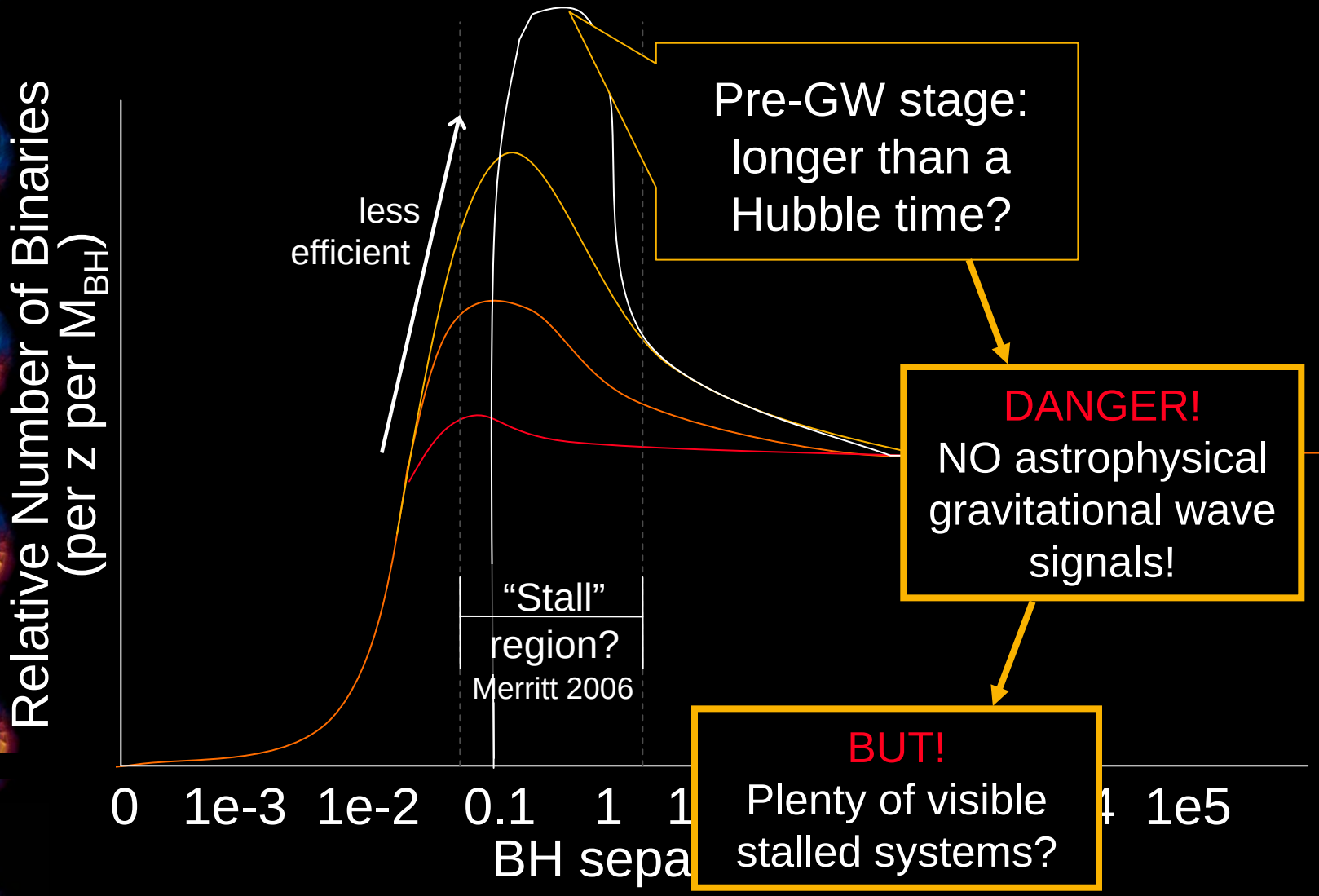
- → Gravitational waves: Pulsar timing arrays
- → $z < 2$
- → $M_{BH} > 10^6 M_\odot$

Coalescence

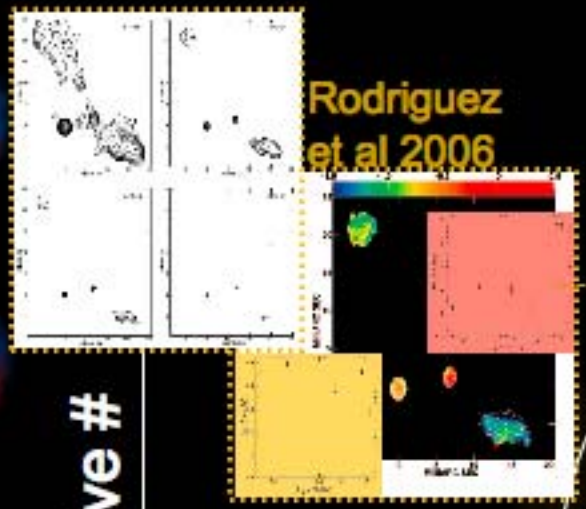
- → Gravitational waves: LISA
- → $M_{BH} < 10^7 M_\odot$


Relative Number of Binaries
(per z per M_{BH})
3-body stellar interactions?
Disk "ringing"?
Gas drag?
?
N α a?
Dynamical friction
(efficient)
GW emission in Pulsar Timing band
Jaffe and Backer (2003):
N α $a^{13/2}$
Binary SMBH forms
0 1e-3 1e-2 0.1 1 10 100 1000 1e4 1e5
BH separation (pc)
LISA: final inspiral and ringdown




Relative Number of Binaries
(per z per M_{BH})
less
efficient
"Stall"
region?
Merritt 2006
0
1e-3
1e-2
0.1
1
1e5
BH sepa
Pre-GW stage:
longer than a
Hubble time?
DANGER!
NO astrophysical
gravitational wave
signals!
BUT!
Plenty of visible
stalled systems?

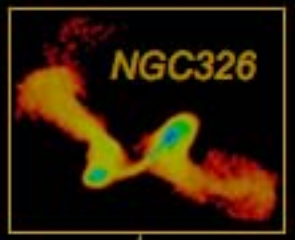
Known small-orbit systems



Rodriguez et al 2006

NGC6240

Komossa et al. 2003



NGC326

3C75

Owen et al. 1985

Relative #

?

← Dynamical friction →

Optical gal/QSO doubles; disturbed galactic structure

GW emission

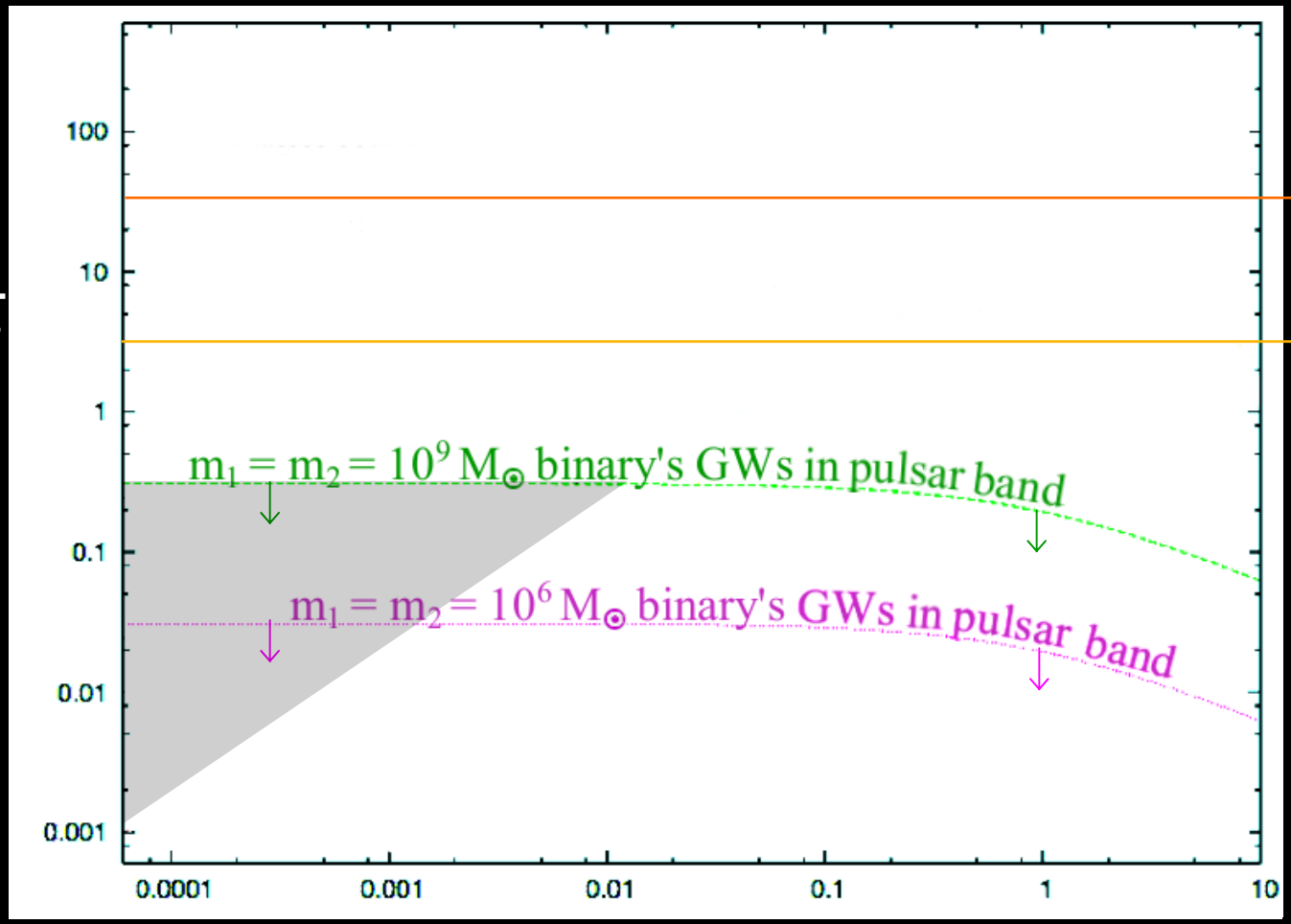
$N \propto a^{13/2}$

0 1e-3 1e-2 0.1 1 10 100 1000 1e4 1e5

BH semi-maj. axis

LISA: final inspiral and ringdown

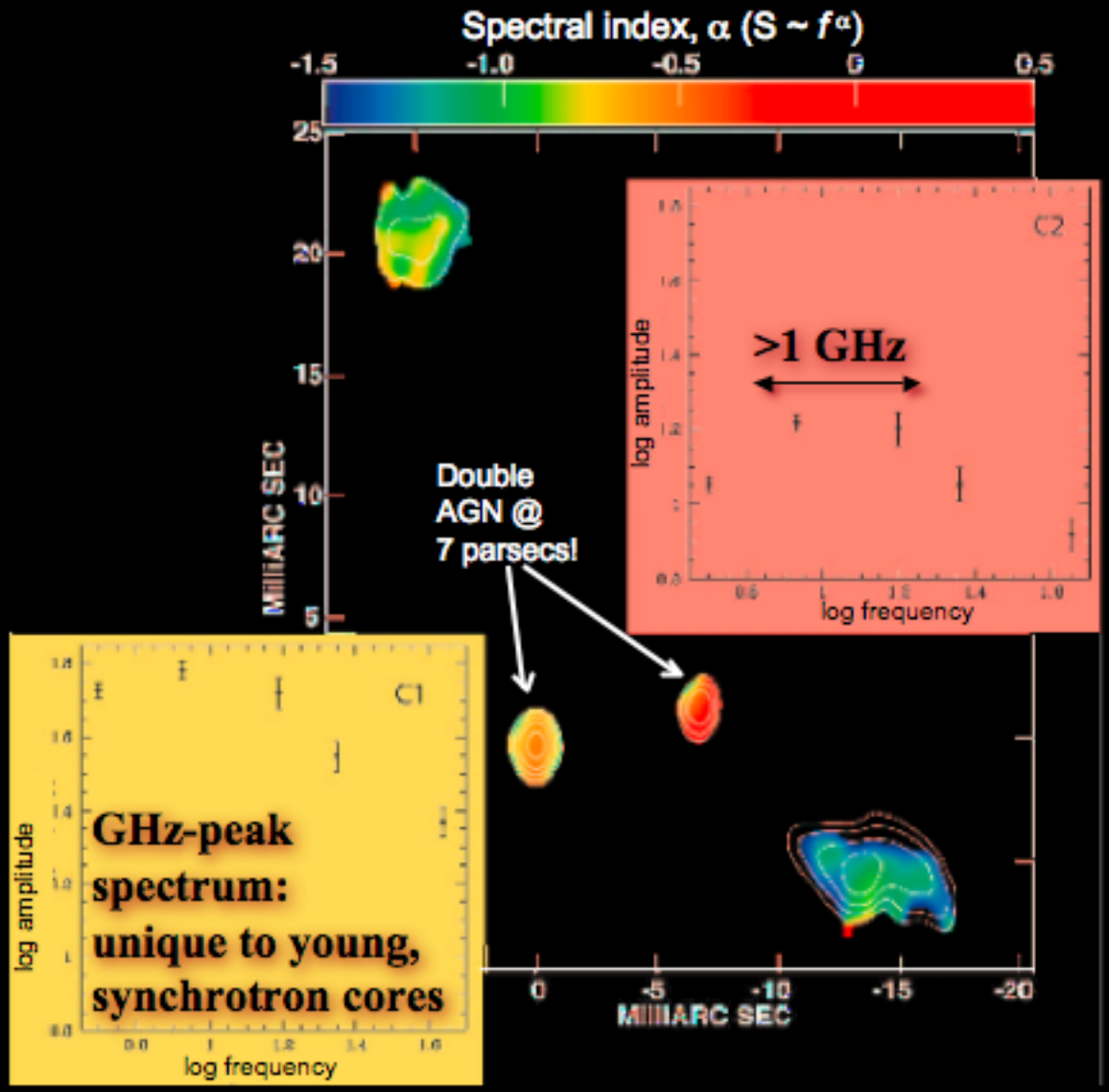
Long Baseline Interferometry



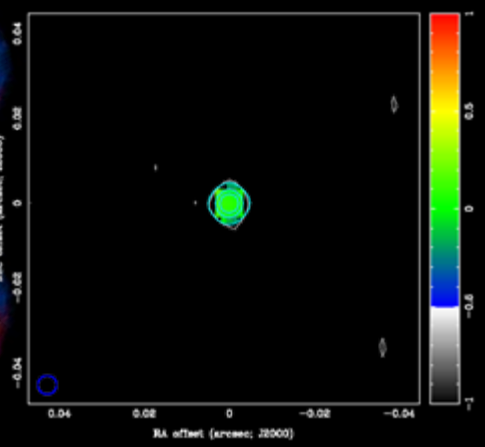
Radio spectral mapping

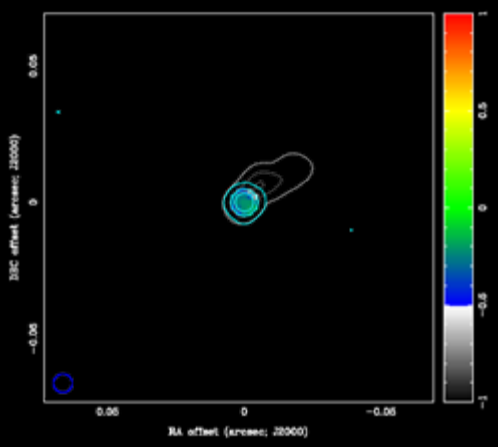
- ***Exploit*:**
  - **Radio active galactic nucleus ≈ black hole**
  - **Unique spectral energy distribution of compact radio nuclei --> (flat/peaking; α>-0.5 at GHz)**
  - **Sub-mas radio resolution**
- ***Do:***
  - **Spectral mapping at GHz frequencies**
  - **Search for multiple flat-spectrum components**
  - **At interesting scales & masses!**

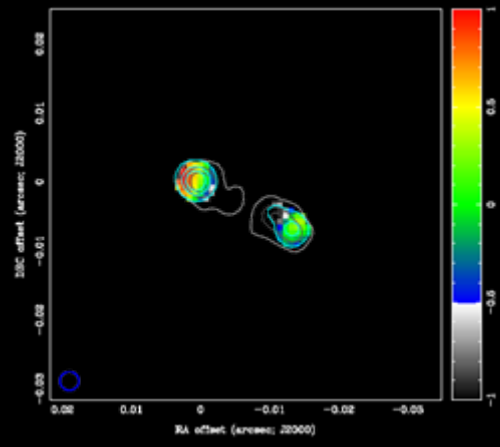
0402+379
Rodriguez et al. 2006



Our search



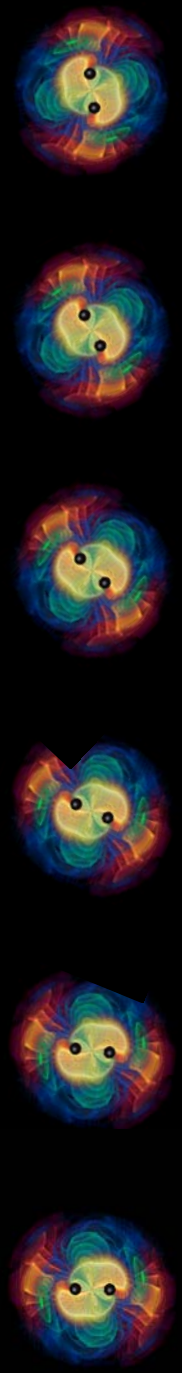


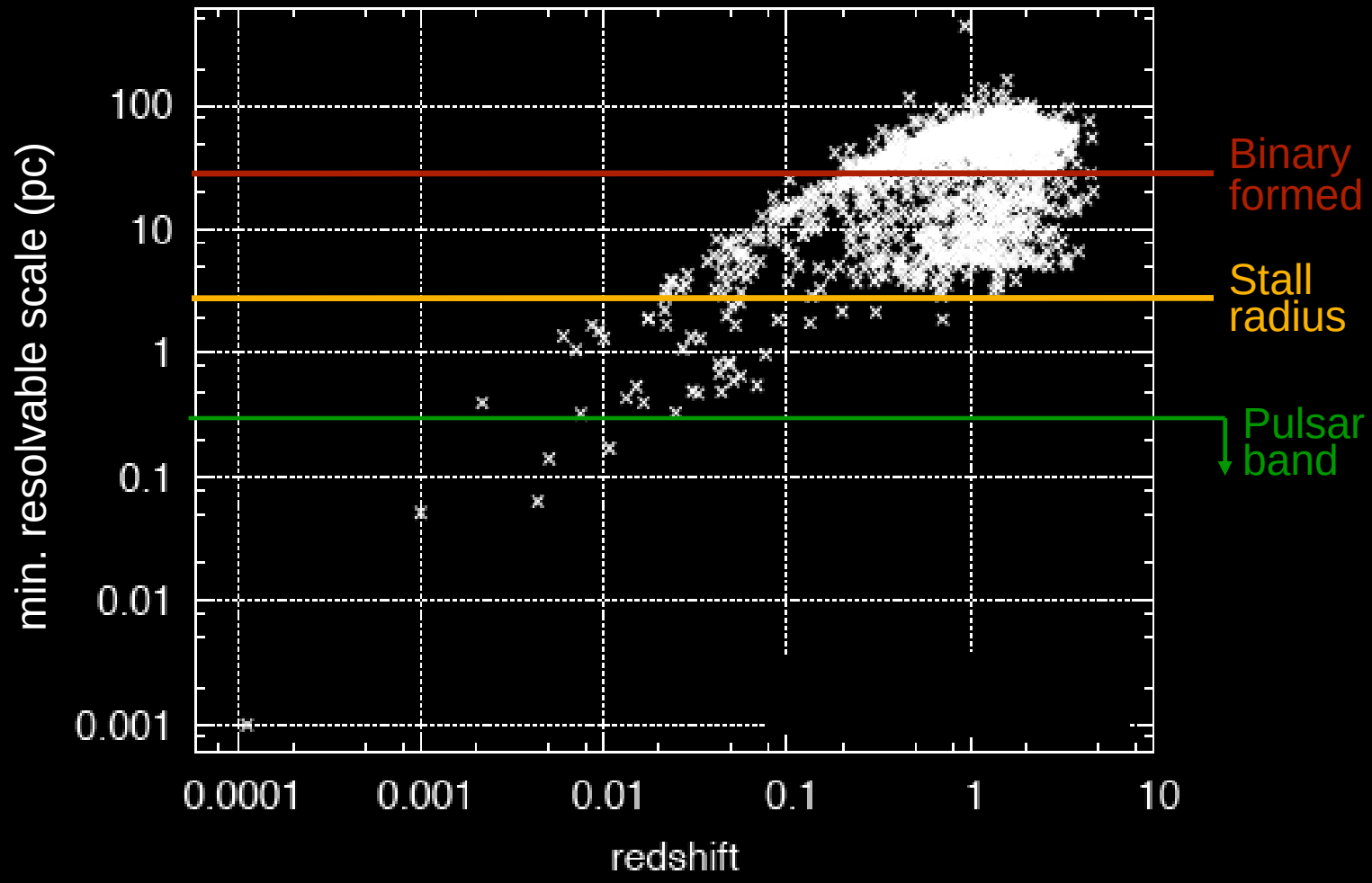


- **>10^5 hrs archival VLBA data (Petrov et al.)**
- **2, 5, 8, 15, 24, up to 43 GHz**
- **3982 spectral images for 3114 active galactic nuclei (drawn from ~6000)**

Submitted to MNRAS;

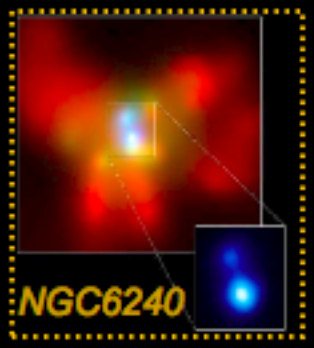
"A Radio Census of Binary Supermassive Black Holes", Burke-Spolaor 2010



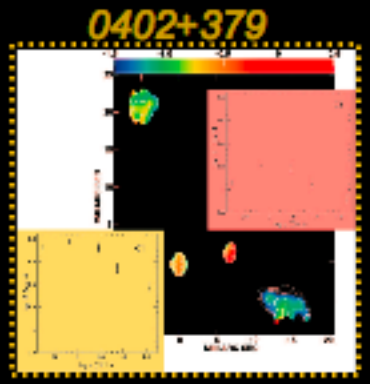

min. resolvable scale (pc)
100
10
1
0.1
0.01
0.001
0.0001
0.001
0.01
0.1
1
10
redshift
Binary formed
Stall radius
Pulsar band

Results

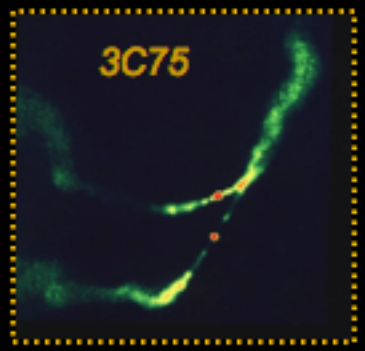
- **ONE binary out of 3114!** (Rodriguez source)
- **0.03% radio AGN visible as binary**
- **$0.15 < t_{inspiral} < 1.5$ Gyr** (no stalling!)
- **Caveat:**
  - **Covariance with probability of radio ignition of second black hole: P_{radio}**



$F_1 \approx 1.5F_2$



$F_1 \approx 4F_2$



$F_1 \approx F_2$

The way forward?

Survey many sources!

- **To find another:**
  - **~3,000**
- **To detect ~10:**
  - **~30,000**
- **To break P_{radio} - $t_{inspiral}$ degeneracy:**
  - **~45,000 (and find no more)**
- **To have far higher success rate:**
  - **Have sensitivity << 40 mJy**

Method Requirements

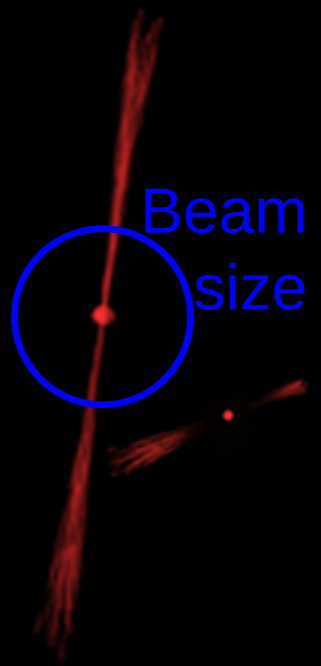
1. ★ **Multi-frequency GHz**

2. ★ **Long enough baselines**

3. **Image/flux fidelity**
   - → ★ ***u, v*** **coverage**
   - → **Calibration/variability**

4. ★ **Need many sources**

5. ★ **Few mJy sensitivity**



★ Possible SKA design issue

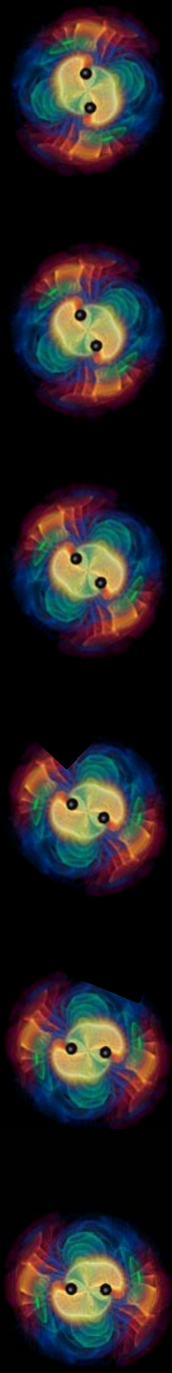
★ SKA wins over VLBA

SKA Baselines

ν, GHz	λ, cm	θ_{3000km}, mas	linear res at any z, D_{3000km}	Minimum baseline to resolve a_{stall} At z < 0.1	At z < 0.2	At z < 0.3
1	21	20	< 170 pc	>> Earth	>>>Earth	Moon-ish
2	15	10	< 85 pc	> Earth	>>Earth	>>Earth
5	6	4	< 35 pc	7,360 km	>Earth	> Earth
8	3.7	2.5	< 20 pc	4,600 km	8,250 km	Too big
10	3	2	< 15 pc	3680 km	6,600 km	9,000 km
20	1.5	1	< 9 pc	1840 km	3,300 km	4,470 km
40	0.7	0.5	< 4 pc	920 km	1,650 km	2,230 km

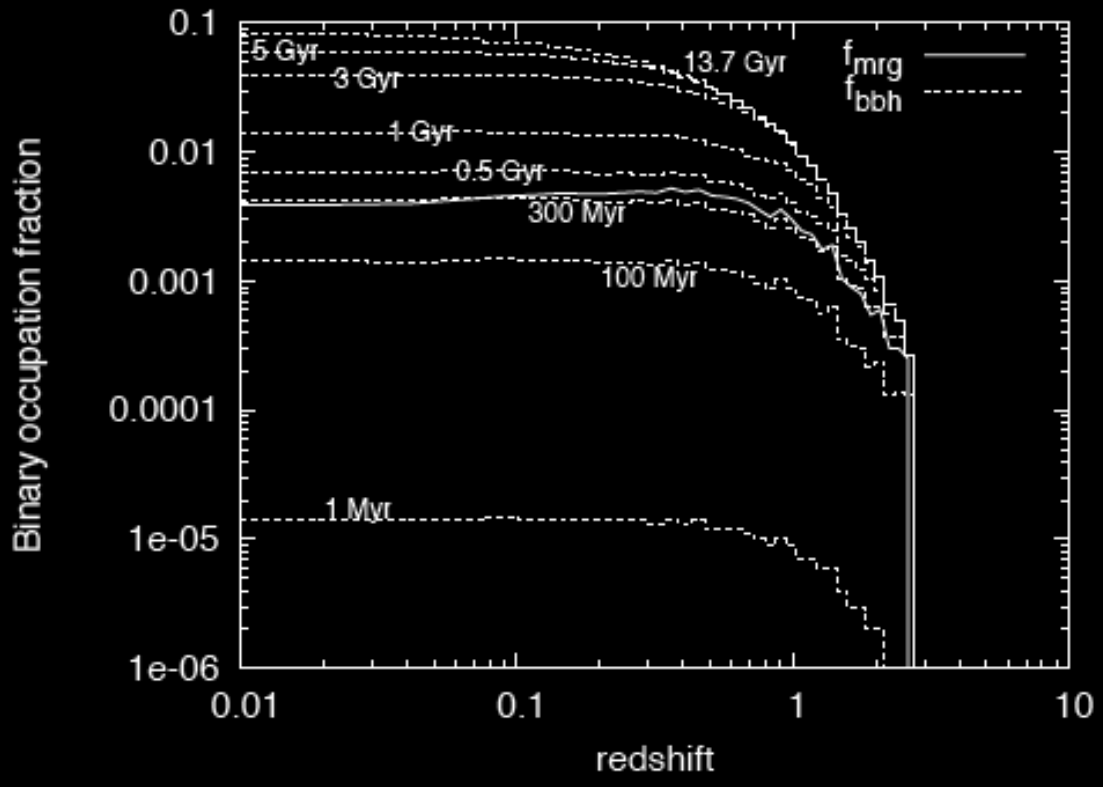
Conclusions

- **Only direct way to find/probe small-orbit supermassive black hole binaries**
  - **Relevance: gravitational waves, galaxy formation, post-merger dynamical processes**
- **<0.03% of radio AGN exhibit binaries**
- **No evidence for widespread stalling**
  - **$0.15 < t_{insp} < 1.5$ Gyr**
- **Need more sources, long baselines, adequate sensitivity, multi-frequency >GHz coverage**
  - **SKA will tell all! (?)**



(END)

Merger rate predictions



How long can the inspiral last before a positive detection?

Millennium Database: Springel et al. (2005)