Between dynamical friction and gravitational waves:

Eccentricity in (super)massive sources

Constanze Roedig

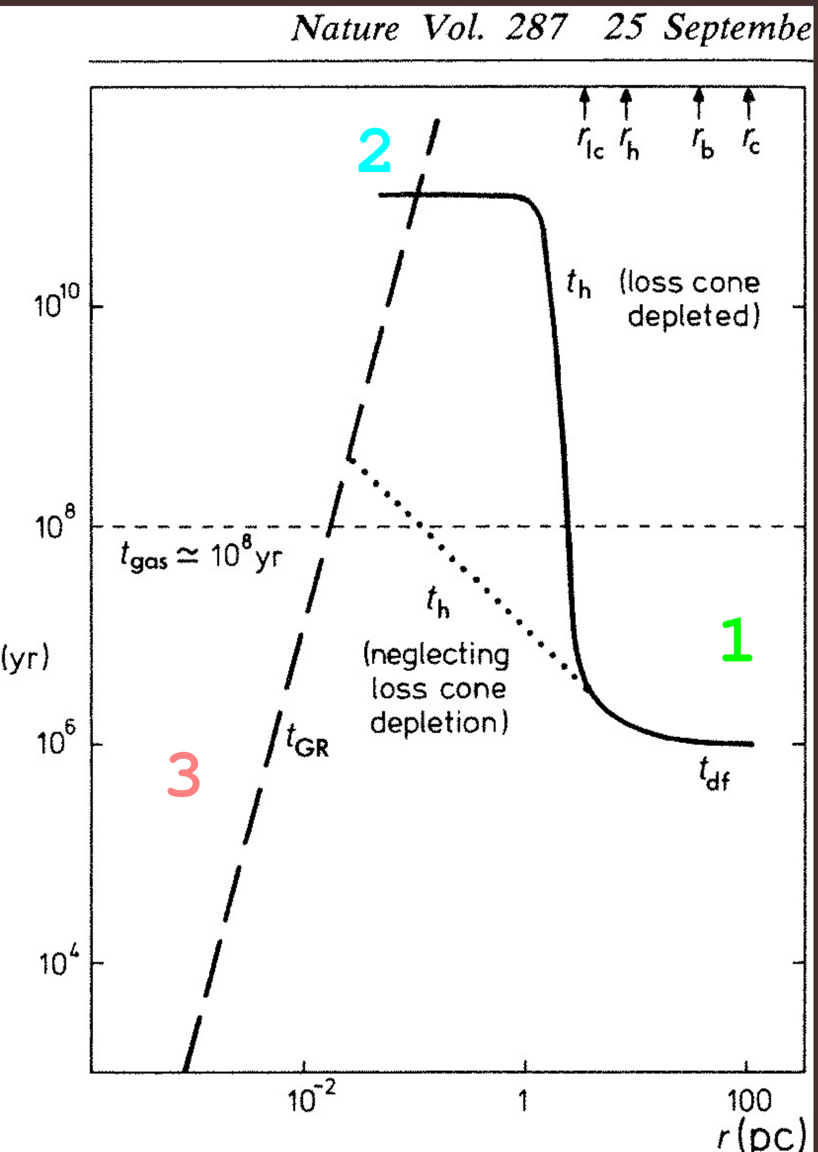
with:

Alberto Sesana, Massimo Dotti & Jorge Cuadra

Outline:

- Context and set-up:
  - Massive & Supermassive BHB on sub-pc scale
- Key results (stars & gas):
  - Environment causes high eccentricities
- Impact on possible observations:
  - Distribution of e in (ELISA/NGO || PTA)
  - EM counterparts ?!

the merger paradigm

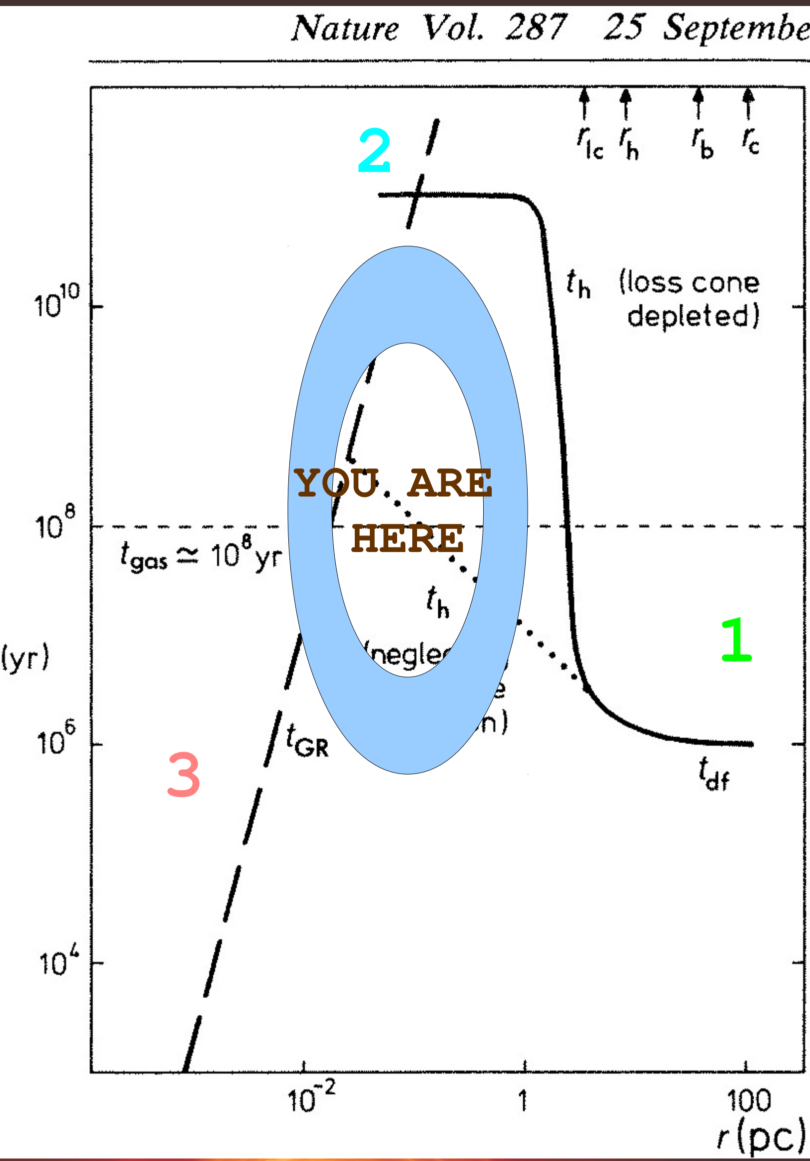


- dynamical friction regime
- binary hardening
  by interaction with gas and/or stars
- emission of GWs
  inspiral/merger/ringdown

[Begelman, Blandford, Rees 1980]

Constanze Rödig
Albert Einstein Institut für Gravitationsphysik

the merger paradigm



- dynamical friction
- binary hardening

Variability
Decoupling

PTA

- emission of GWs

Fossil gas
GW–Recoil

ELISA

[Begelman, Blandford, Rees 1980]

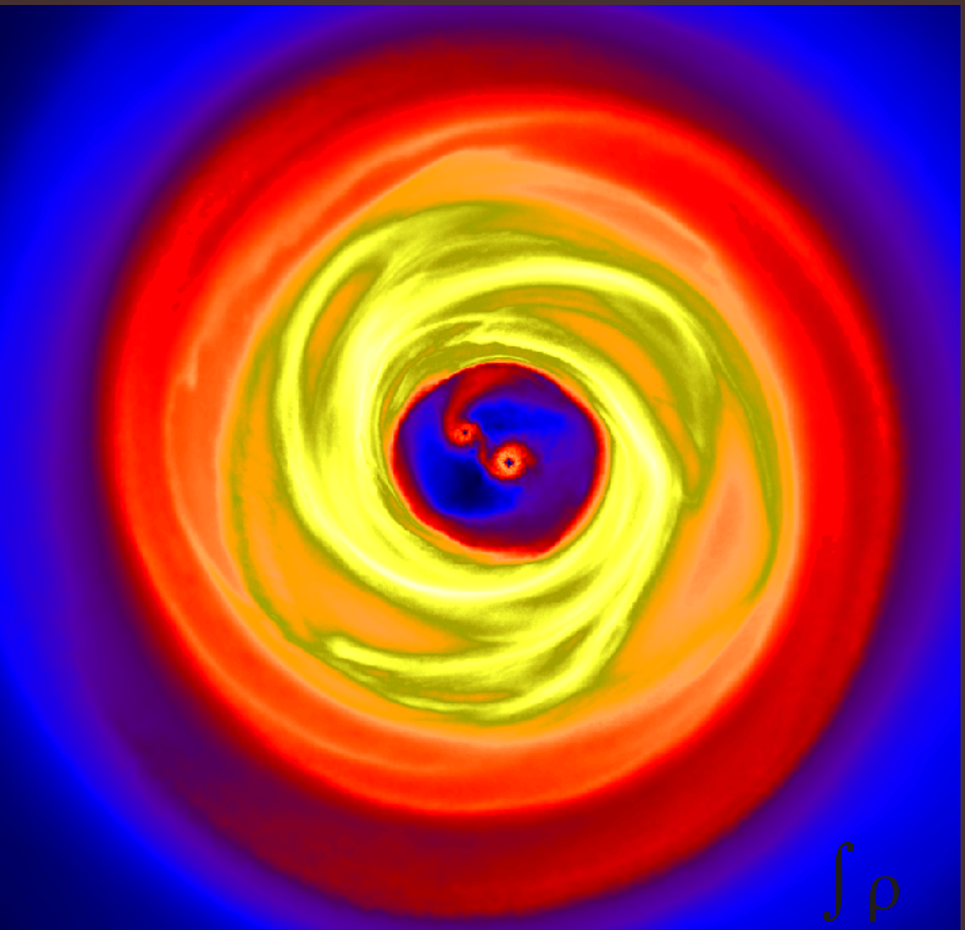
Constanze Rödig
Albert Einstein Institut für Gravitationsphysik

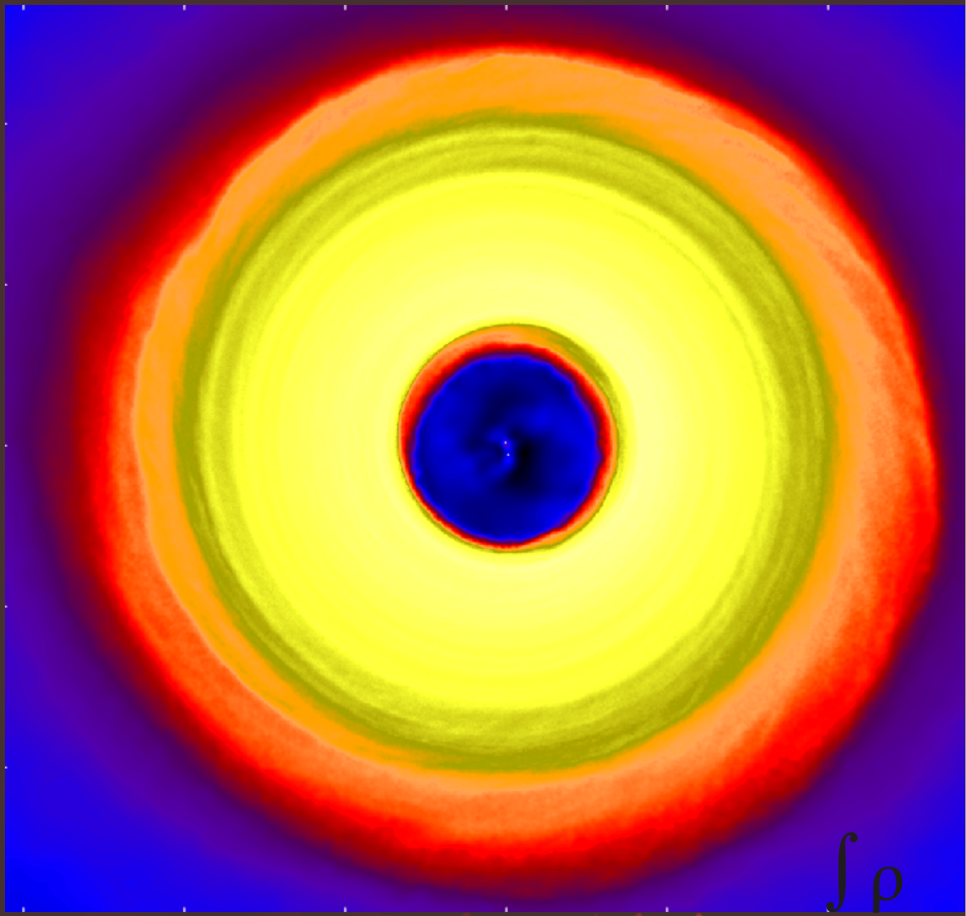
Massive vs *Supermassive*

at a~0.05pc

- BHB dyn. coupled to environ
- M_{BH}/M_d >0.1
- Ecc growing/saturating
- Not ovservable in GW, EM(?)

- BHB only marginally coupled
- M_{BH}/M_d <<0.1
- Ecc & Binary shrinking
- Observable with PTA + EM (?)





Blue regime eccentricity e ~>0.5

- Generic feature

  in gaseous disc and stellar environment

- Timescales vary (stars)

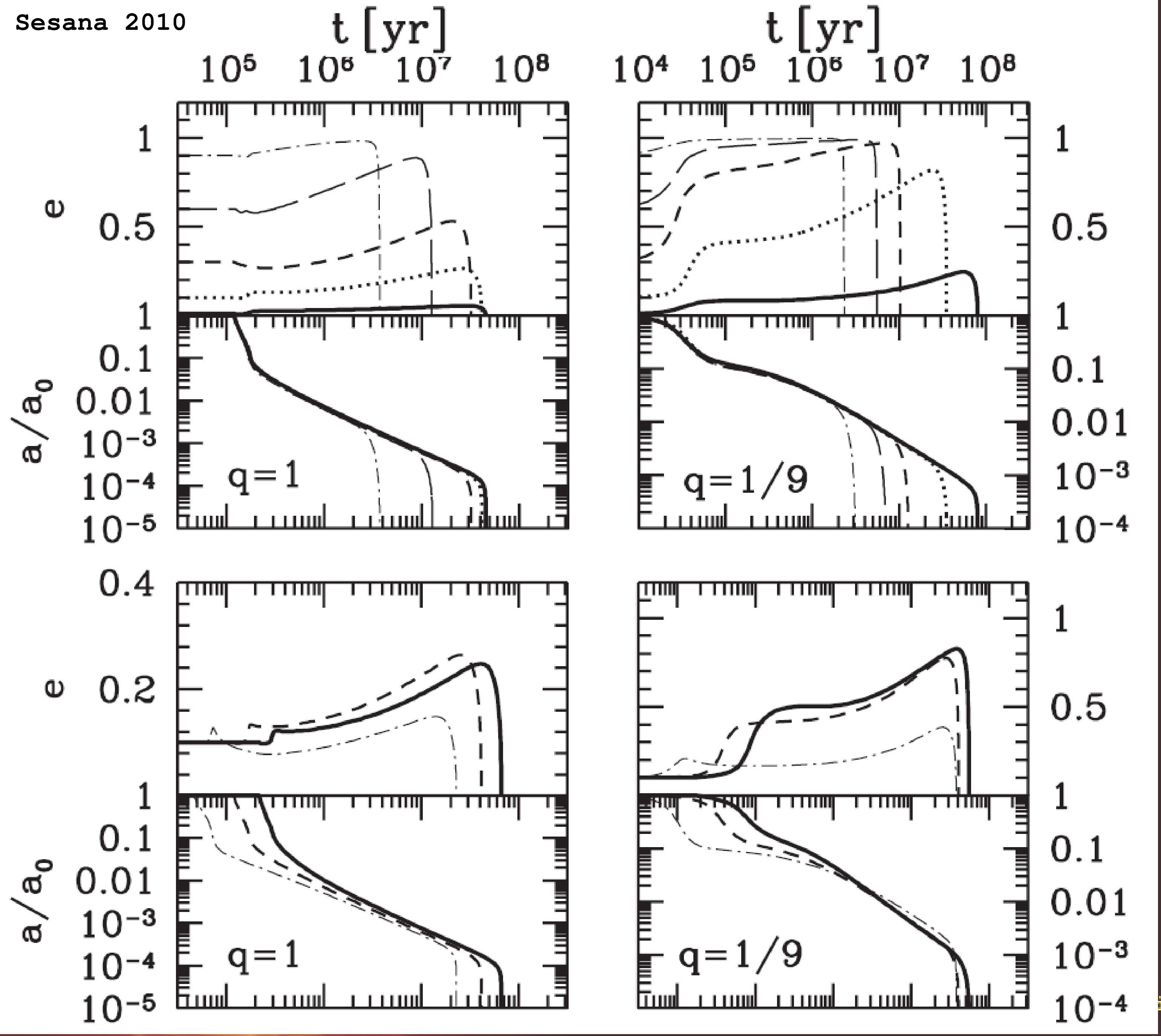
  more unequal mass : higher e

  steeper cusps evolve faster

- Wide binaries (1pc > a > 0.01pc) are most probably eccentric

Constanze Rödig
Albert Einstein Institut für Gravitationsphysik

Stellar environment: e grows



M= 10^6

cusp slope Γ= 1.5

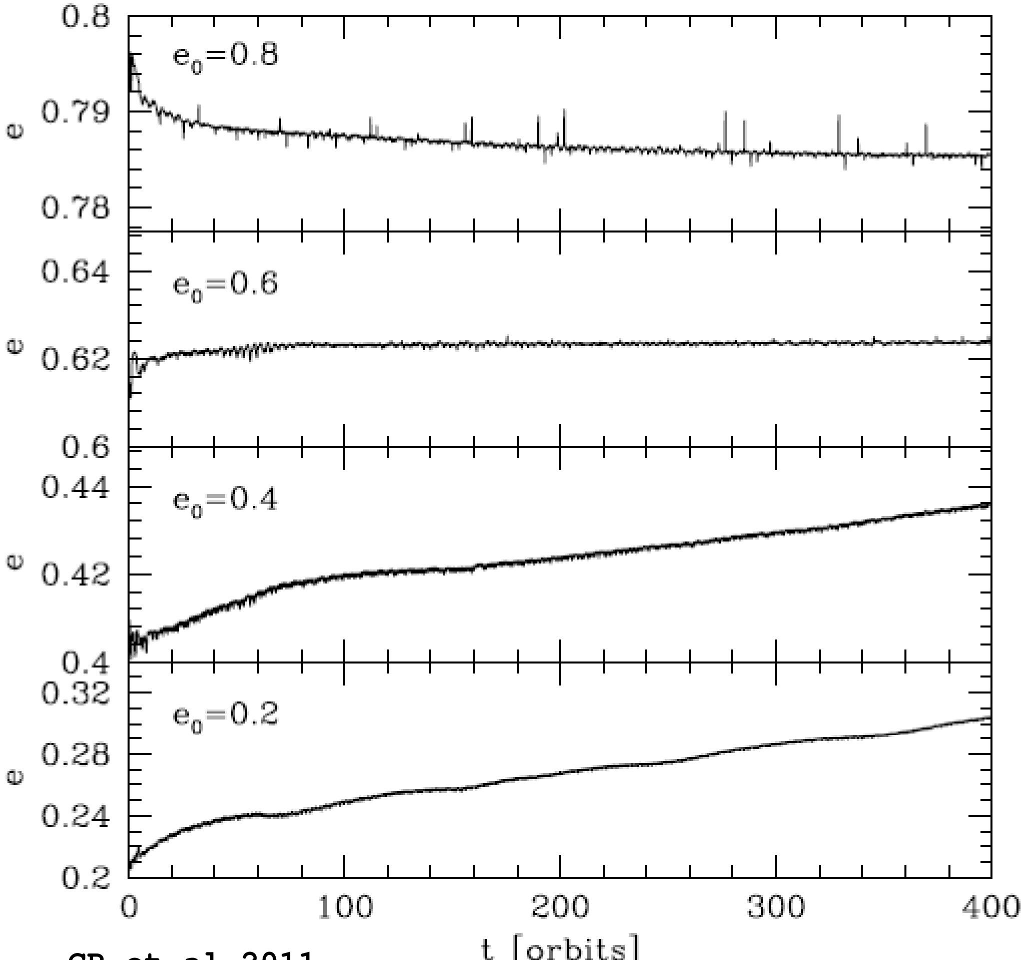
vary:
-initial e

M= 10^6

initial e =0.1

vary:
-cusp slope Γ

Gaseous disc environment:



CR et al 2011

Prograde discs:

- Self-gravitating disc
- Geometrically thin
- Massratio BHB q=1/3

- Saturating e ~ 0.6

Constanze Rödig
Albert Einstein Institut für Gravitationsphysik

Implications for GW Observations

- Supermassive sources: **PTA**

  somewhere between blue and pink regime

- Massive sources: **ELISA/NGO**

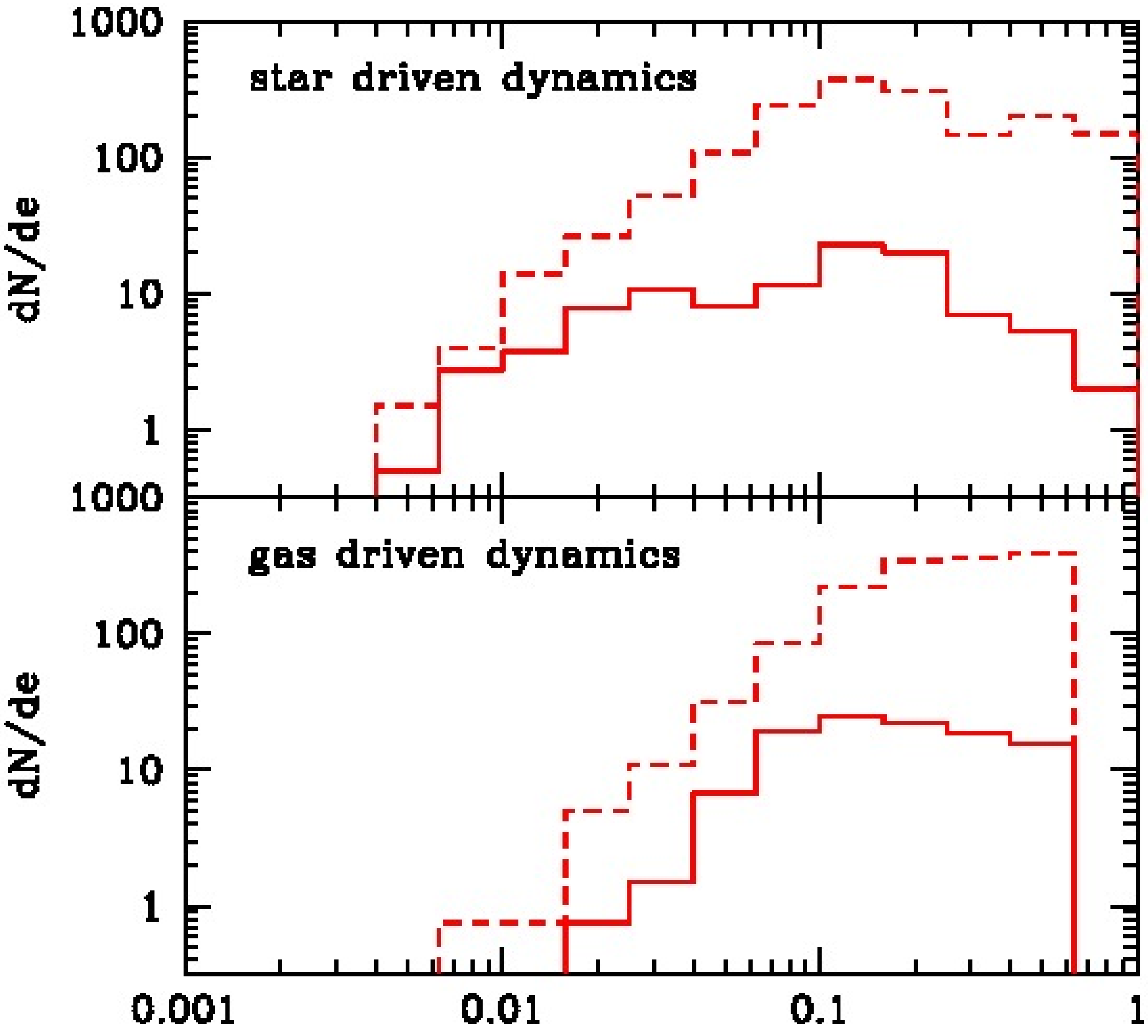
  at the end of pink (=GW) regime

  → requires translation & thus assumptions about migration/hardening time-scales

- Based on MBH cosmic evolution model starting from light seeds

Expected e distribution in PTA-window

"Inefficient" is dashed



Roedig & Sesana 2011

- Stars efficient:

  $p(e_0) \propto e$

- Stars inefficient:

  $e_0 = 0$

Use e > 0 in templates

- Gas efficient:

  ß-disc: $\alpha = 0.3$, m=1

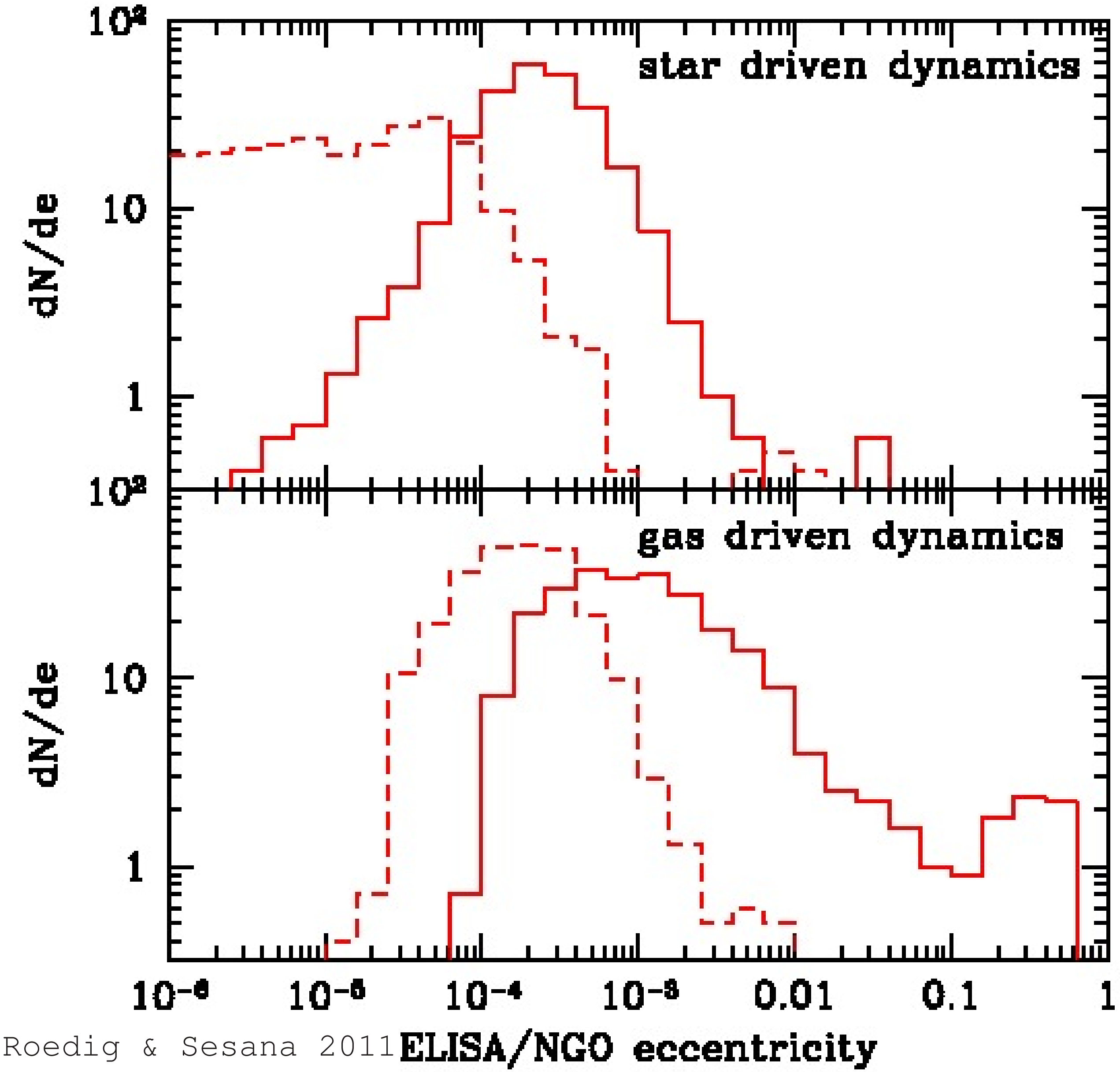
- Gas inefficient:

  ß-disc: $\alpha = 0.1$, m =0.1

Constanze Rödig
Albert Einstein Institut für Gravitationsphysik

Expected e distribution in ELISA-window

"Inefficient" is dashed



Roedig & Sesana 2011

Stars efficient:

$p(e_0) \alpha$ e

Stars inefficient:

$e_0 = 0$

dN/de pairwise distinc

Environment memory not completely lost

Gas efficient:

ß-disc: $\alpha = 0.3$, m=1

Gas inefficient:

ß-disc: $\alpha = 0.1$, m = 0.1

Constanze Rödig
Albert Einstein Institut für Gravitationsphysik

Implications for EM Observations

- Supermassive sources: **PTA**

  large fraction still coupled to environment

  short orbital period ~ years

  ➡ periodicity studies + spectral lines

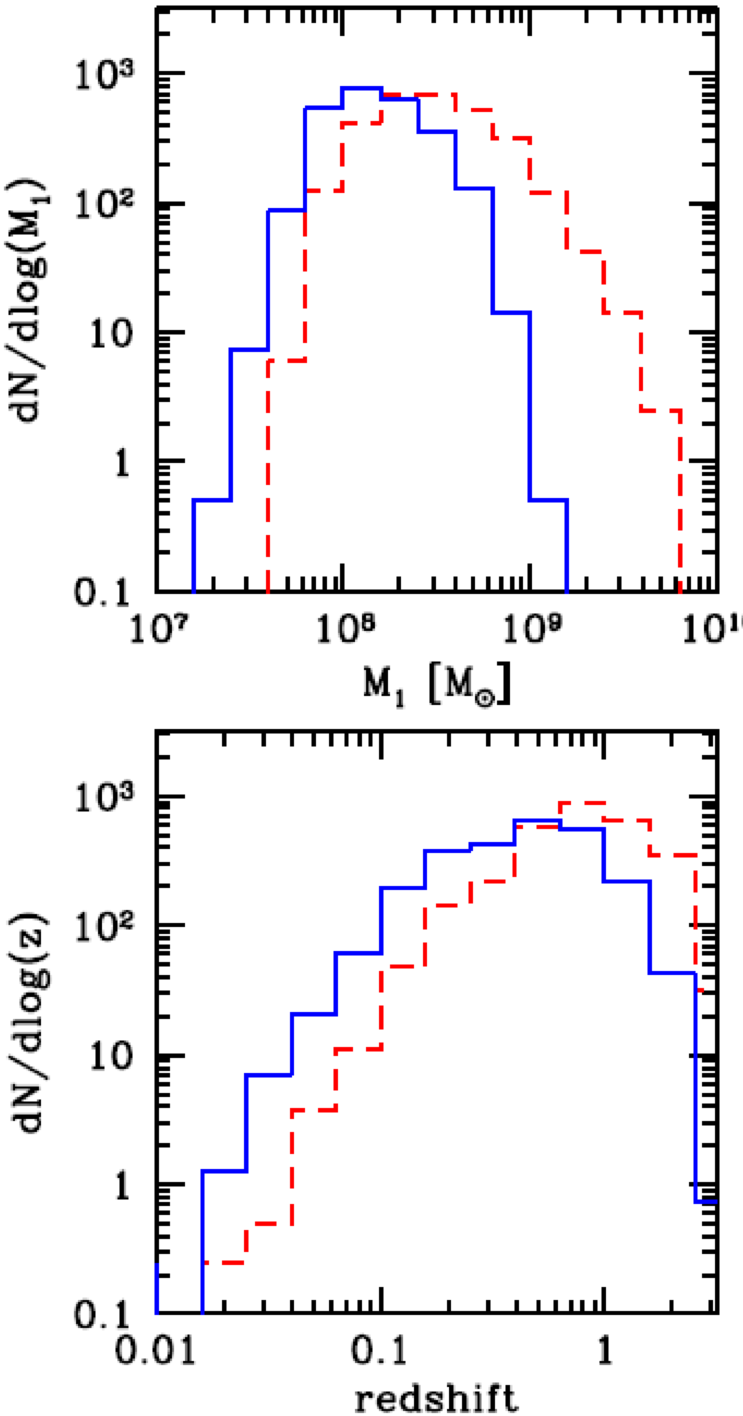
- Massive sources: **ELISA/NGO**

  long orbital periods ~ 100 years

  less luminous

  ➡ ??? spectroscopy maybe ???

Constanze Rödig
Albert Einstein Institut für Gravitationsphysik



Sesana, CR, Reynolds, Dotti 2011

The chance of EM + GW: PTA

For periodicity AND/OR clear spectra:

BHB must still be coupled to its environment

Distribution of PTA sources:

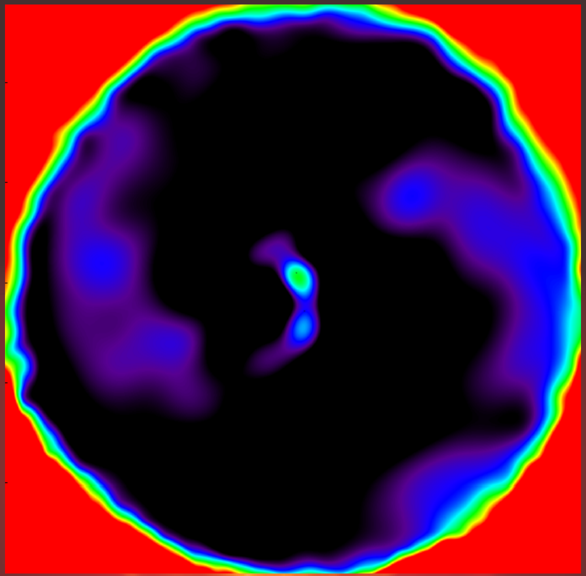
- coupled to disc
- decoupled already

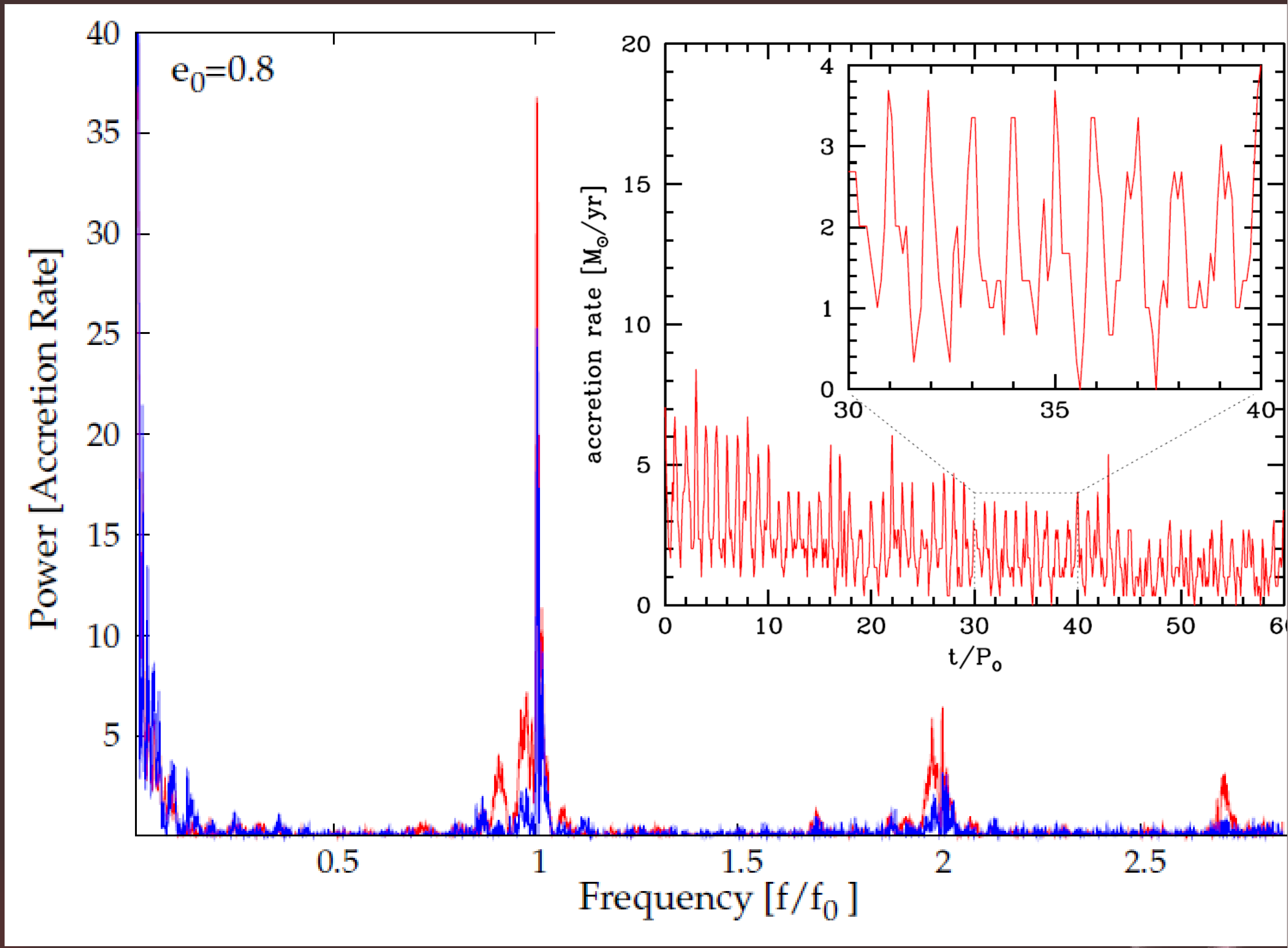
EM observations PTA: Periodic source

Amplitude modulation up to (x 3)

Refill of MiniDiscs on orbital timescale

Significant modulation of accretion rate only for high e:



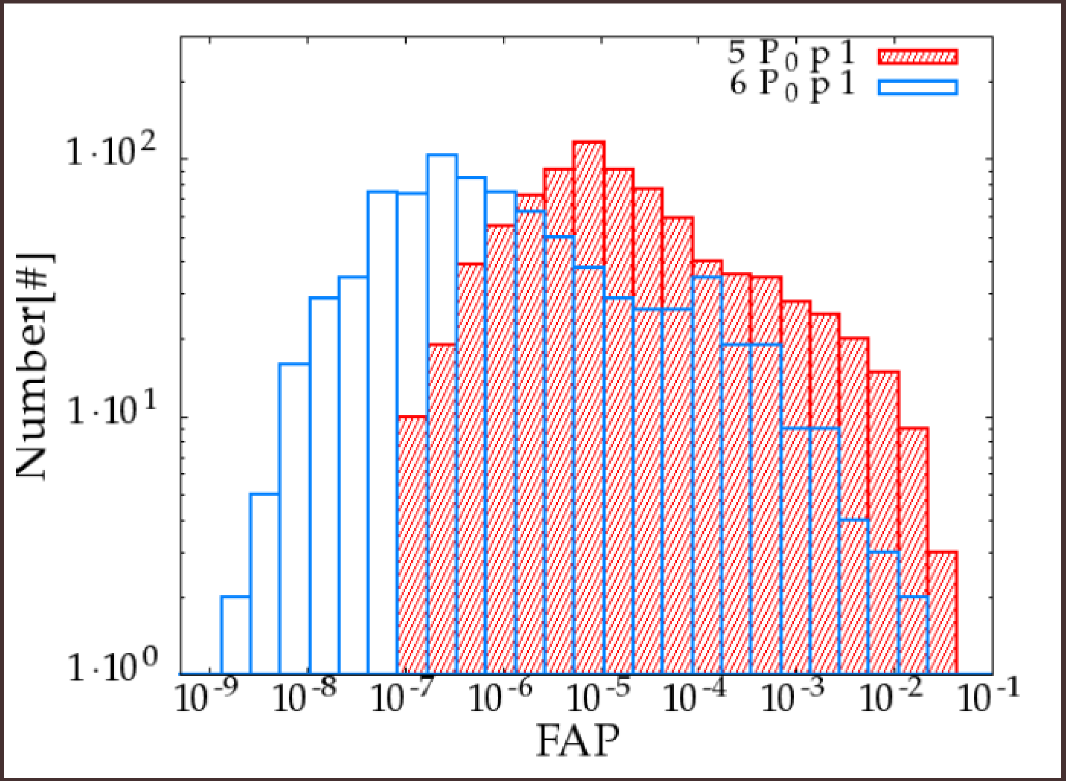


CR et al & Sesana et al 2011

Constanze Rödig
Albert Einstein Institut für Gravitationsphysik

EM observations: Identification

Sesana, CR, Reynolds, Dotti 2011



(I) Periodic source

Amplitude modulation (x3)

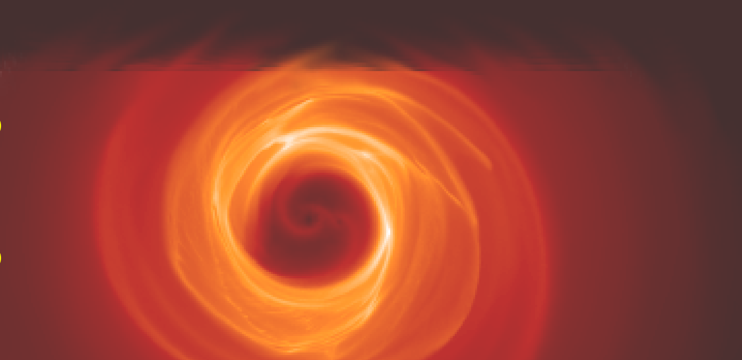
Possible emission mechanisms depending on MiniDisc size:

- .Instant accretion (Bondi tpye)
- .Optical/UV BLR
- .Upscattering (X-ray)
- .Hot-spots (X-ray)

False Alarm Probability in AllskySurvey (~ **MAXI**):

- 5 orbits with 55 pointings
- 6 orbits with 66 pointings
-

Problem: **Poor flux sensitivity**



Constanze Rödig
Albert Einstein Institut für Gravitationsphysik

EM observations: (II) Spectral Lines

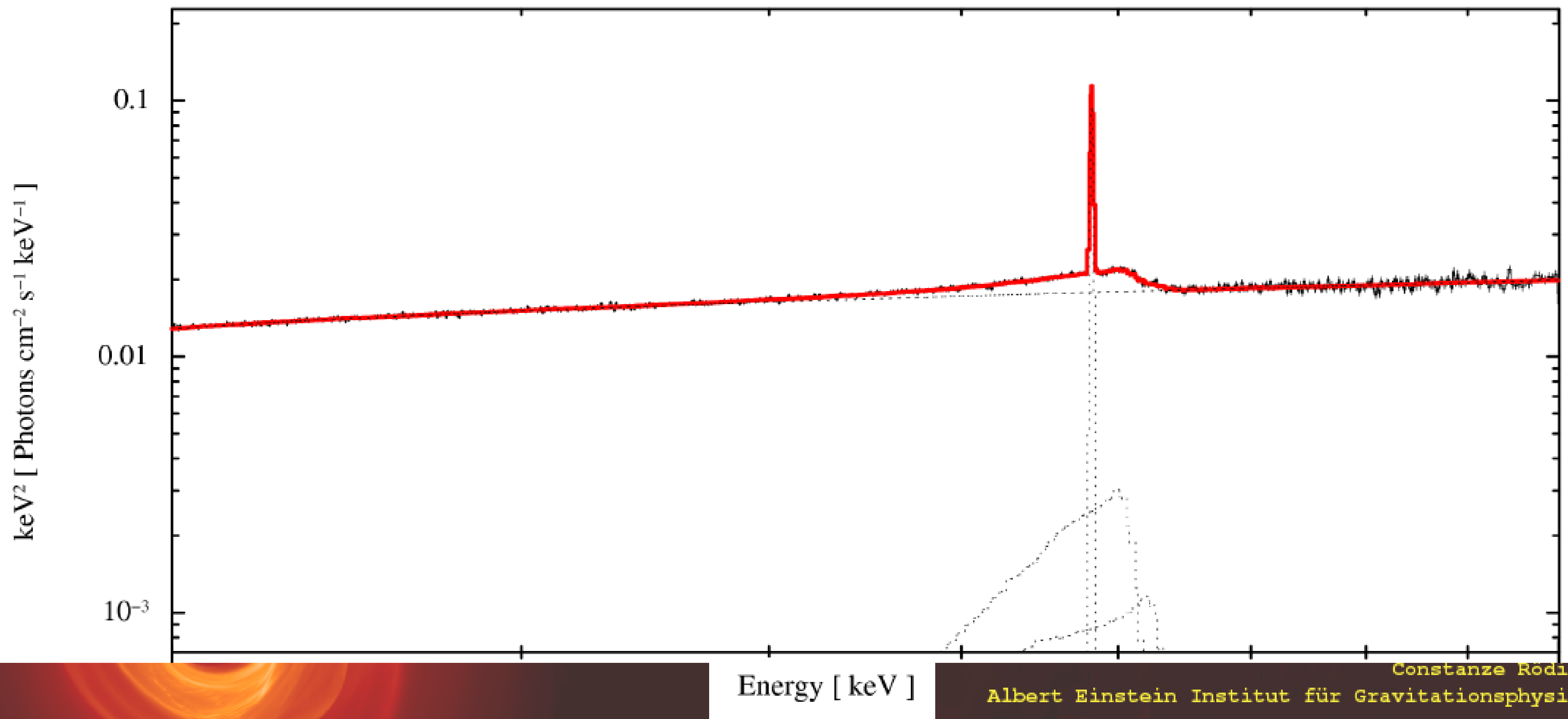
X-ray:

Relativistic double Fe K α

Resolvable from the 2 Minidiscs

(assuming ATHENA-like mission)

Sesana, CR, Reynolds, Dotti



Conclusions

- MBHB eccentricity grows to high values during hardening stage for wide range of parameters (stars & gas)
- eccentricity impacts observations:

  EM: Periodicity & Spectral Lines

  ELISA: Distributions of residual ecc differ for gas vs stars

  PTA: ecc > 0.1 for majority of sources

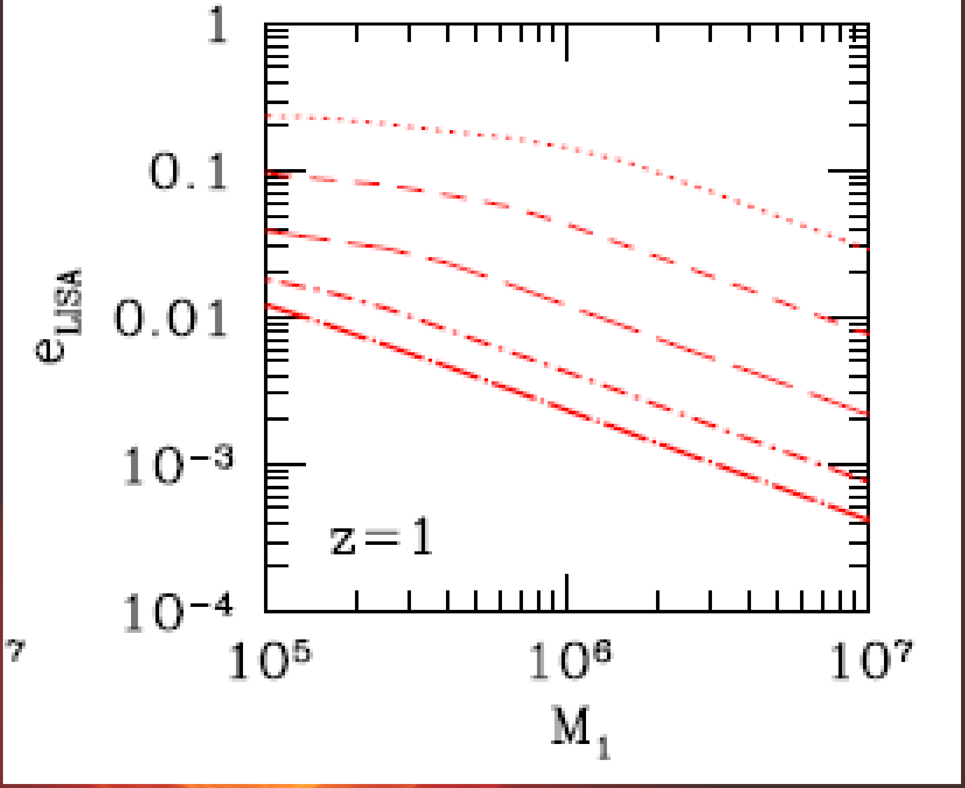
Thank you for your attention!

Constanze Rödig
Albert Einstein Institut für Gravitationsphysik

Impact on GW observations: LISA

$$e_{\mathrm{LISA}} \propto M^{-0.73} q_{\mathrm{s}}^{-1.2}$$

CR, Dotti, Sesana, Cuadra, Colpi (2011)



- Model assumptions:

  Ecc @ Decoupling =0.6

  SS-disc with alpha=0.3

- Formula holds for:

  1 > q > 0.01

Not sensitive to details of the disc!

Constanze Rödig
Albert Einstein Institut für Gravitationsphysik

Residual ecc in LISA band NOT sensitive to disc details

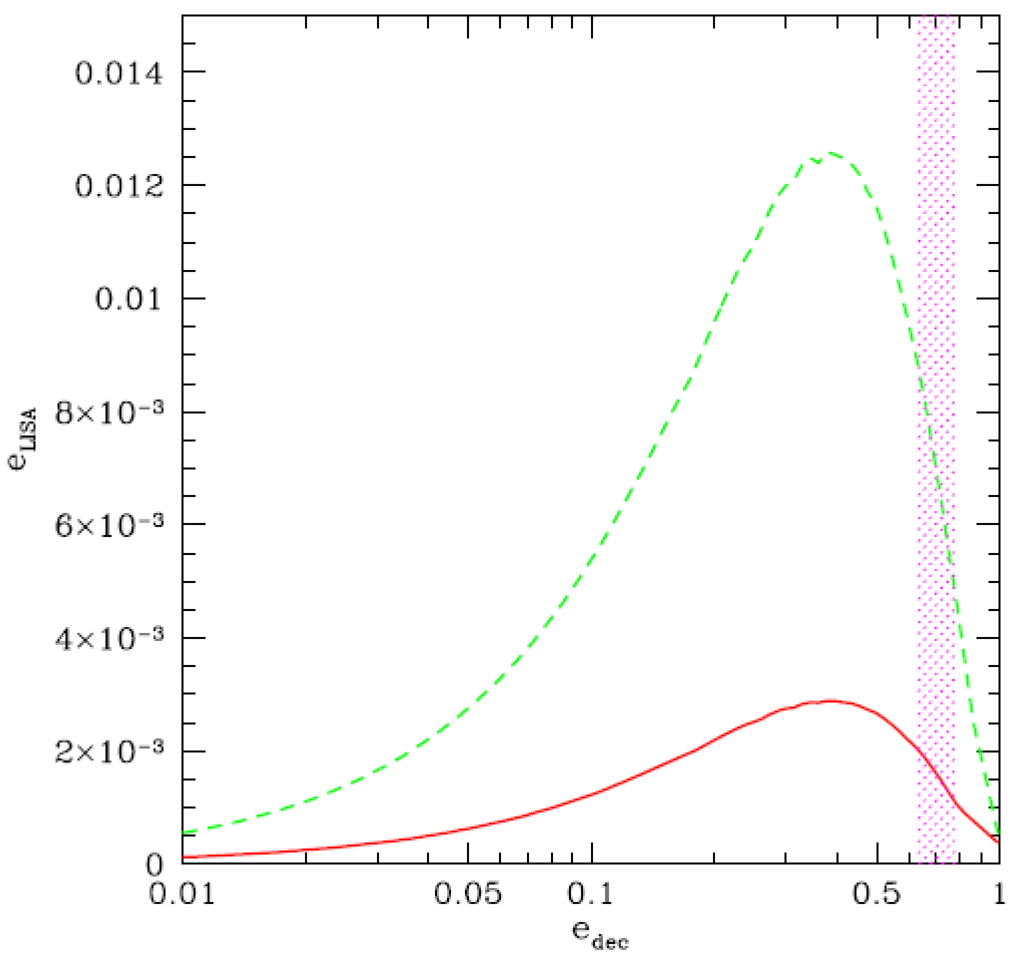


Figure 6. Residual eccentricity $e_{\rm LISA}$ as a function of $e_{\rm dec}$. Red–solid curve refers to $q = 1/3$, green–dashed curve to $q = 0.1$. In the figure the mass of the primary BH black hole is $M_1 = 2.6 \times 10^6$ M$_\odot$ and the redshift of the binary is $z = 1$. The shaded vertical stripe brackets the

- High ecc(gas):

  earlier decoupling

  faster circularization

  second era of

  gas-interaction ??

- Low mass, close-by, unequal mass MBHB likely to have **significant e**

Constanze Rödig
Albert Einstein Institut für Gravitationsphysik

Why is there a limiting value of the eccentricty?

- Over-Density excited by secondary BH

  → Torque on BH
  → ecc grows

  Size of cavity depends on ecc (Arymowicz &Lubow94)

- Torques less & less efficient

Constanze Rödig
t Einstein Institut für Gravitationsphysik

What happens to the eccentricity ?

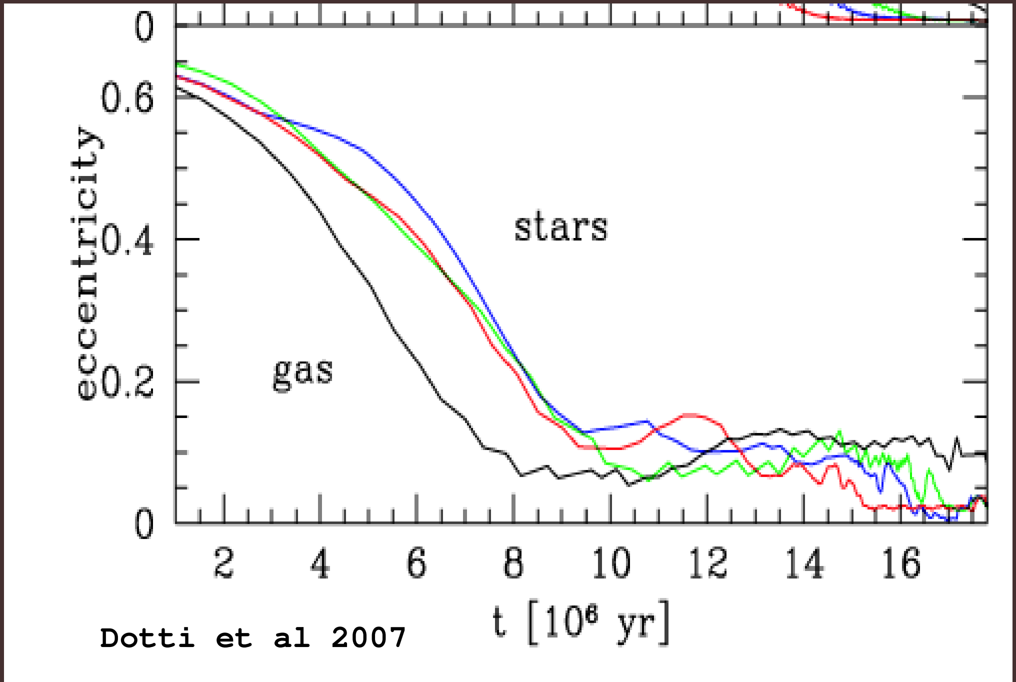
- At large scales:

  (dyn friction regime)

  both stars AND

  gas result in:

  e <~ 0.1



Semi-major-axis a ~ 10 pc

Constanze Rödig
Albert Einstein Institut für Gravitationsphysik