40 Signs of Supermassive Black Hole Binaries

or, what I did last summer...

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Collaborators

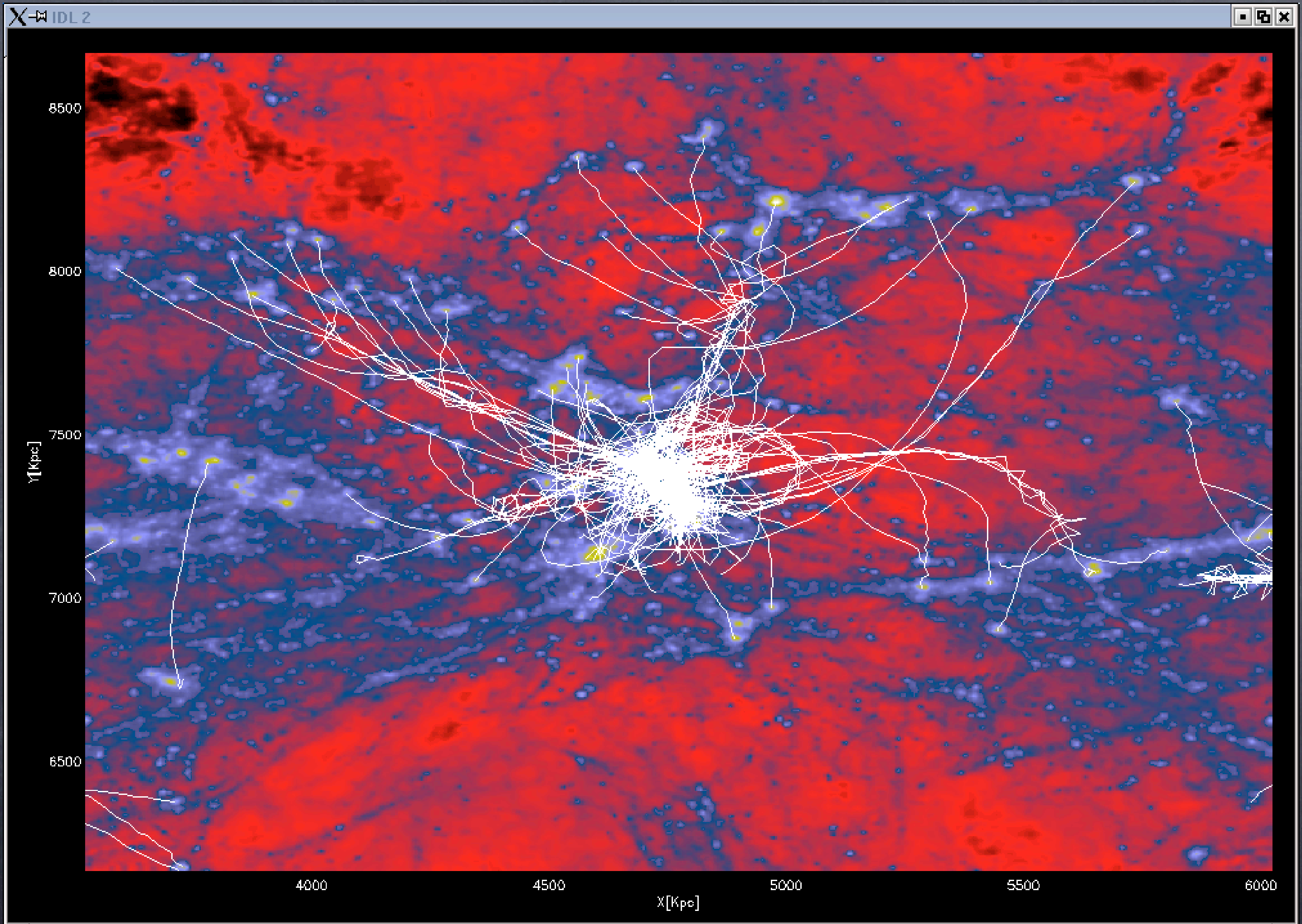
- Dr Kelly Holley-Bockelmann
- Tamara Bogdanovic
- Miroslav Micic
- Britton Smith
- assorted...

In the beginning...

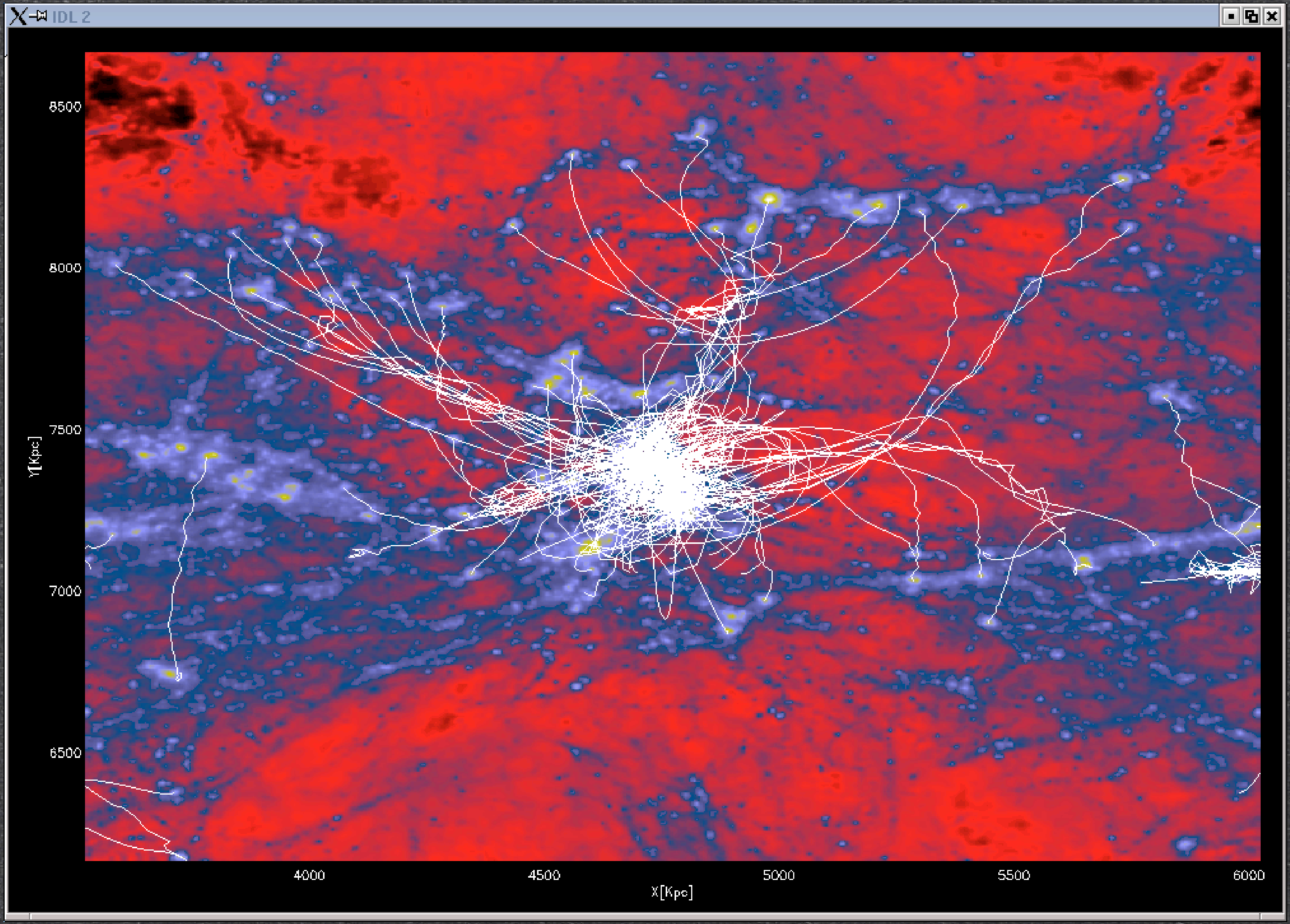
- use high resolution numerical sims to "tag" black hole formation and follow dynamical evolution
- effect of kicks (formation or merger)
- mock-up accretion history
  - "dry" pop III mergers
  - prompt accretion to SMBH

parametric

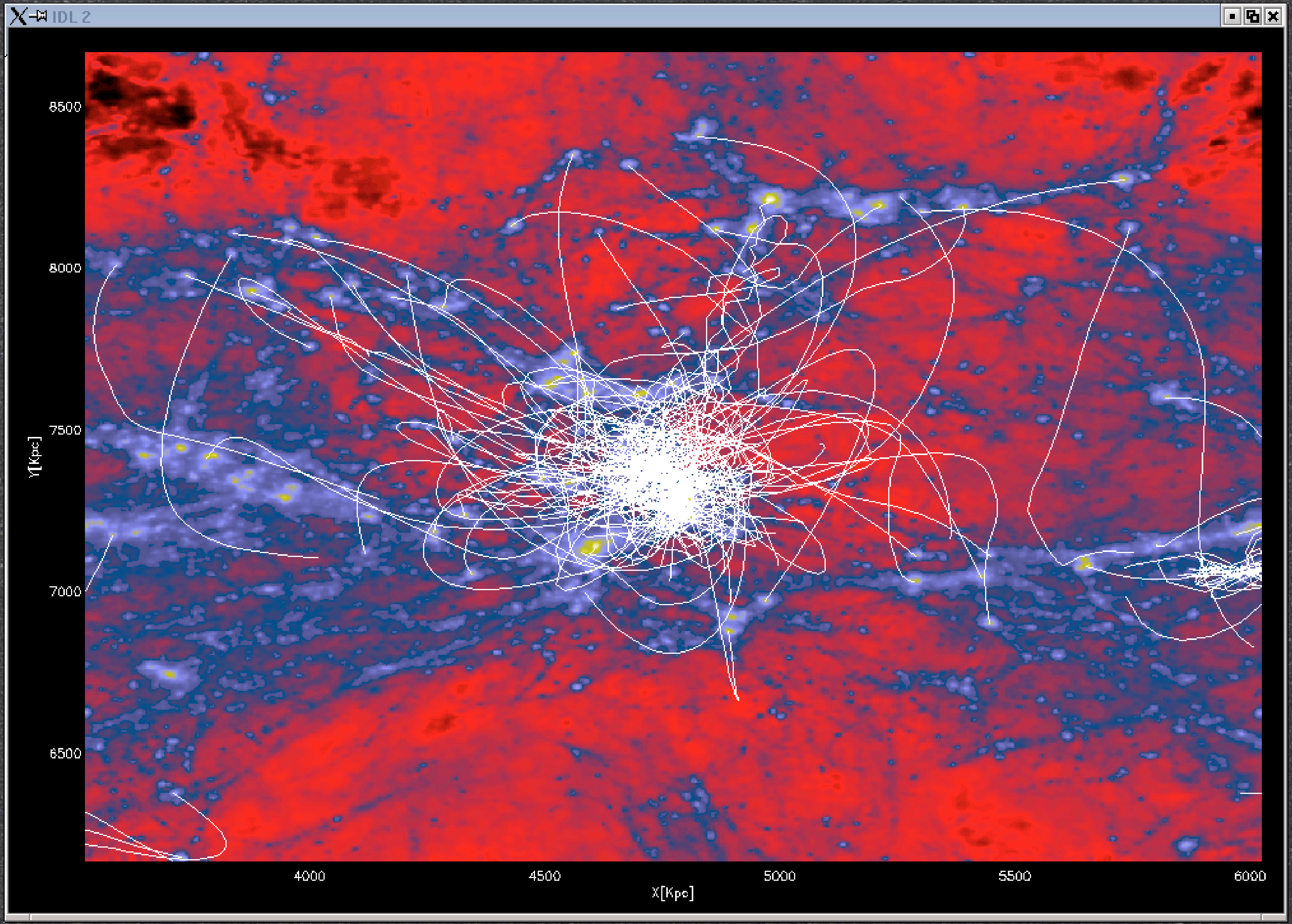
- choice of halo masses
- initial masses
- mass accretion histories
- offset in time from halo merger to BH merger
- explore dynamics in detail, trace baryons and possibilities of gas accretion



Micic, Abel & Sigurdsson '06



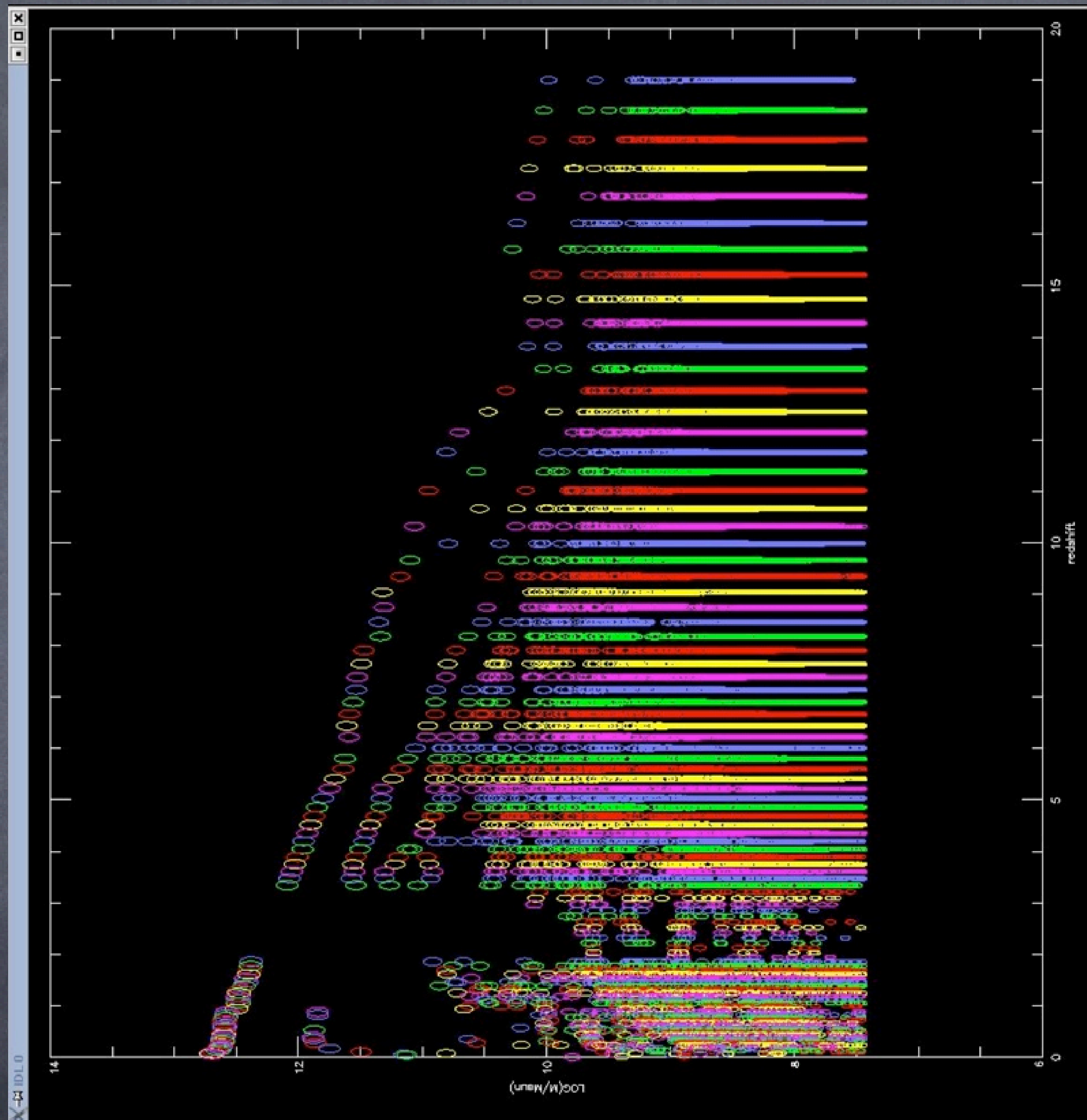
Trajectories of presumptive IMBH formed in mini-halos at z=8.16, through to z=1, with the assumption that the IMBH receive natal kicks with characteristic velocities of about 75 km/s. Most IMBH still reach the dominant halo, but many are decoupled from their parent mini-halos and their density profile is much flatter.



Trajectories of IMBH from z=8.16 to z=1 under the assumption that the IMBH received "maximal" natal kicks of about 200 km/sec. The IMBH now decouple from their parent mini-halos; many fail to reach the local dominant halo, and their density profile is very flat.

Merger trees

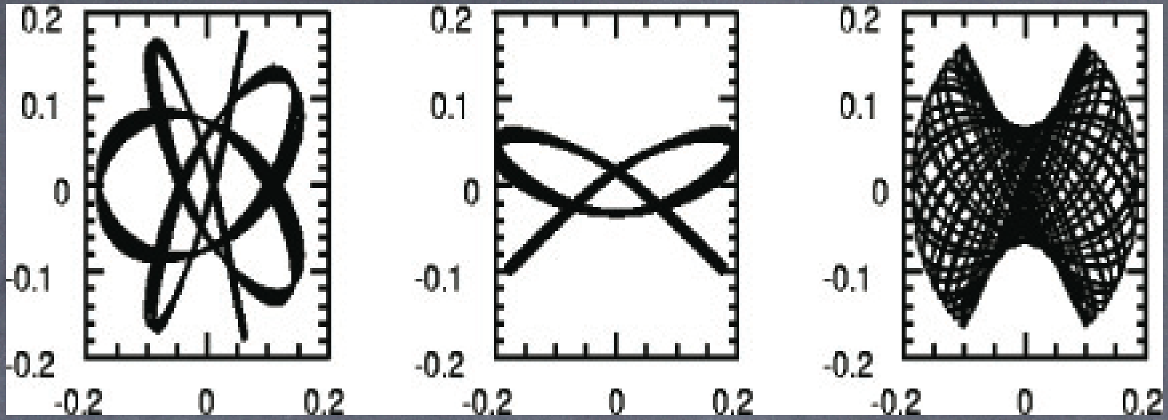
- look at masses, mass ratios
- redshift history
- host galaxy
- LISA signals
- where and what failed to merge



Merger Tree: from z=20-0; halo masses

Late history

- low mass BH from $z > 6$ can get stuck
- if halos are triaxial then some fraction explores inner kpc on ~ 100 dynamical time scales. Dynamical friction can then become effective, maybe.
- Look at stages of dynamical mergers, leverage off existing results



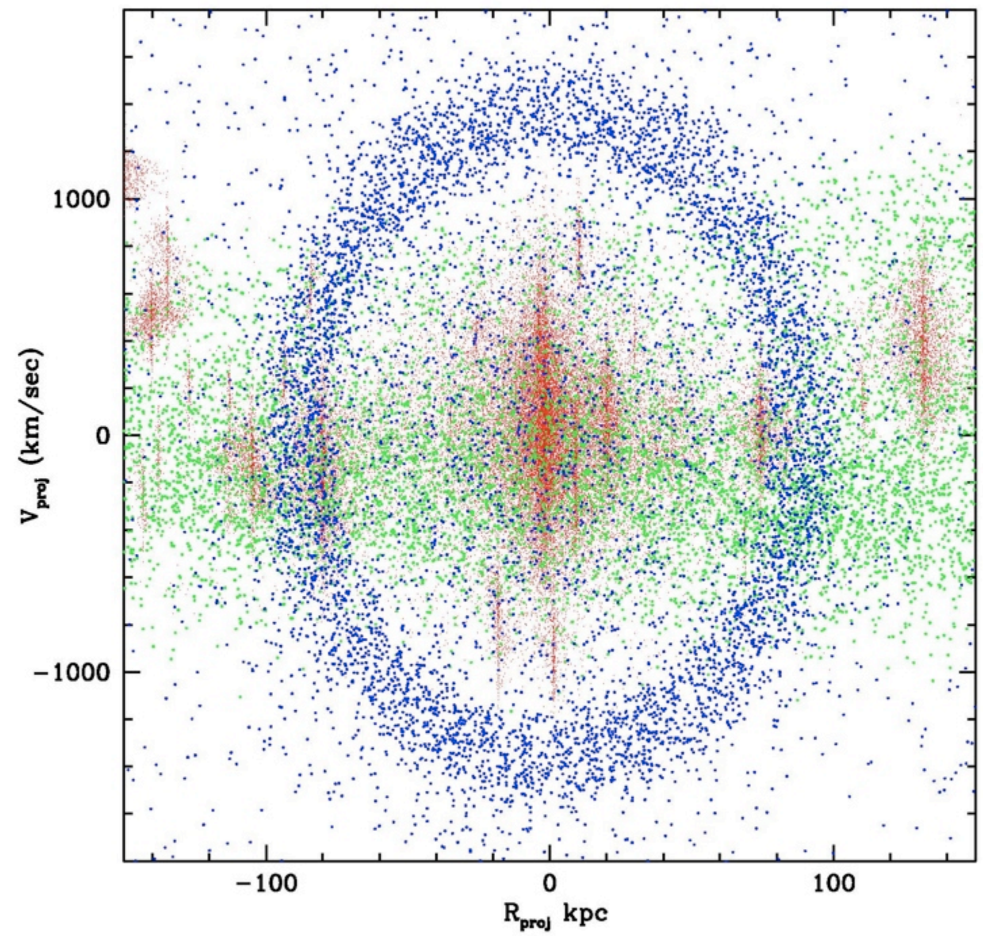
Boxes and boxlets in a triaxial potential
including centrephilic and centrephobic orbits
Flow to centre depends on fraction of centrephilic
and chaotic orbits

Filling the loss-cone

- Triaxiality fills loss cones efficiently (cf Ostriker et al)
- possible role in EMRI
- Binary stars for SMBH interaction (cf Miller)
- SMBHB loss cone filling
- Combine with F-P diffusion and dyn fric

Hypervelocity stars

- Small % of IC* may be ejected from SMBHB mergers in ellipticals.
- High Z, younger population
- Kinematic signature
- Maybe PNe and colour signature...



Holley-Bockelmann et al '06

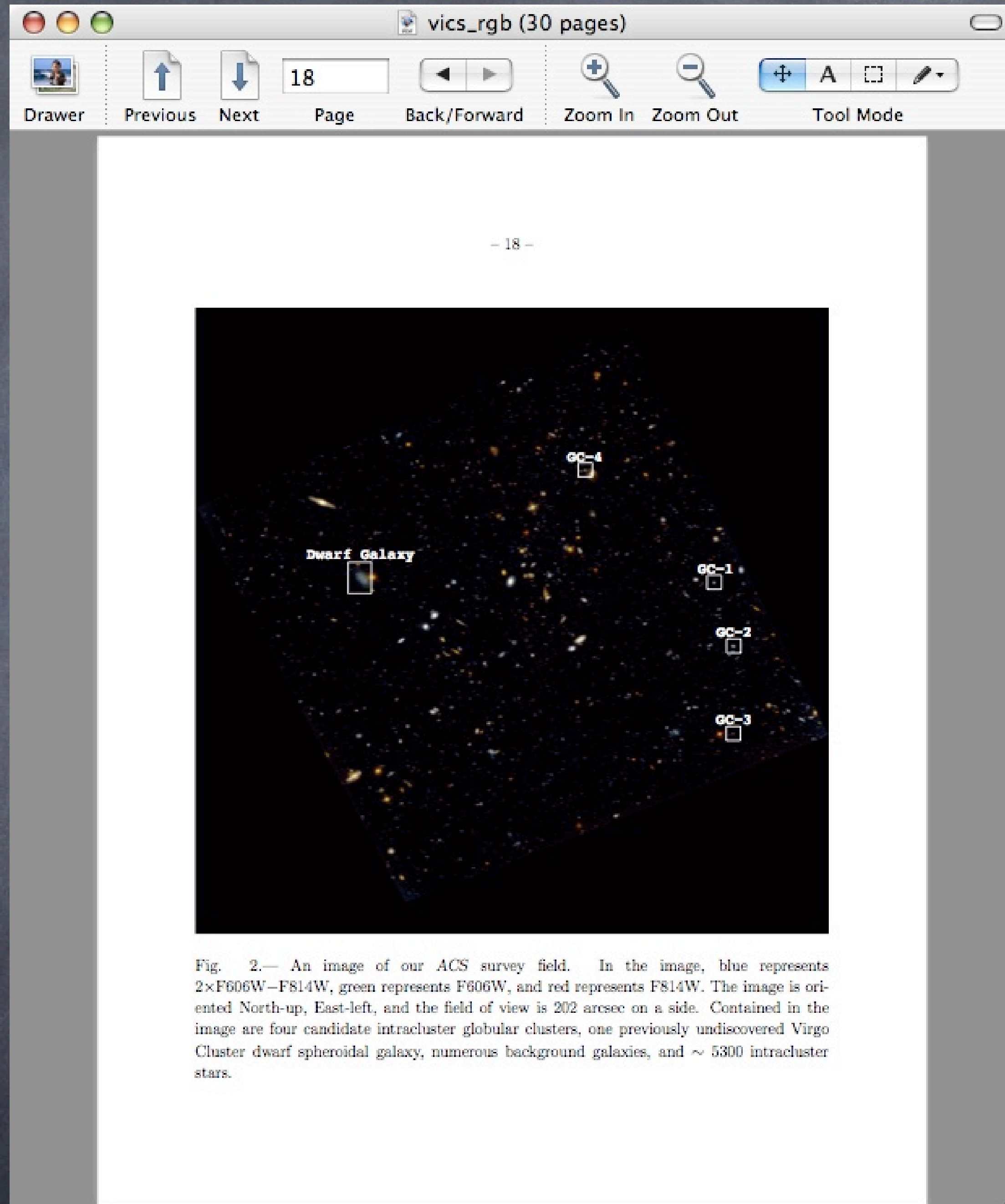


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Fig. 2.— An image of our *ACS* survey field. In the image, blue represents 2×F606W−F814W, green represents F606W, and red represents F814W. The image is oriented North-up, East-left, and the field of view is 202 arcsec on a side. Contained in the image are four candidate intracluster globular clusters, one previously undiscovered Virgo Cluster dwarf spheroidal galaxy, numerous background galaxies, and $\sim$ 5300 intracluster stars.

VICS ACS field in Virgo

E-M signature

- Look at binaries in last few million years before merger
- Assume primary is accreting gas
- Look at interaction
- Luminosity profile
- spectroscopic signature - smoking gun?

Method

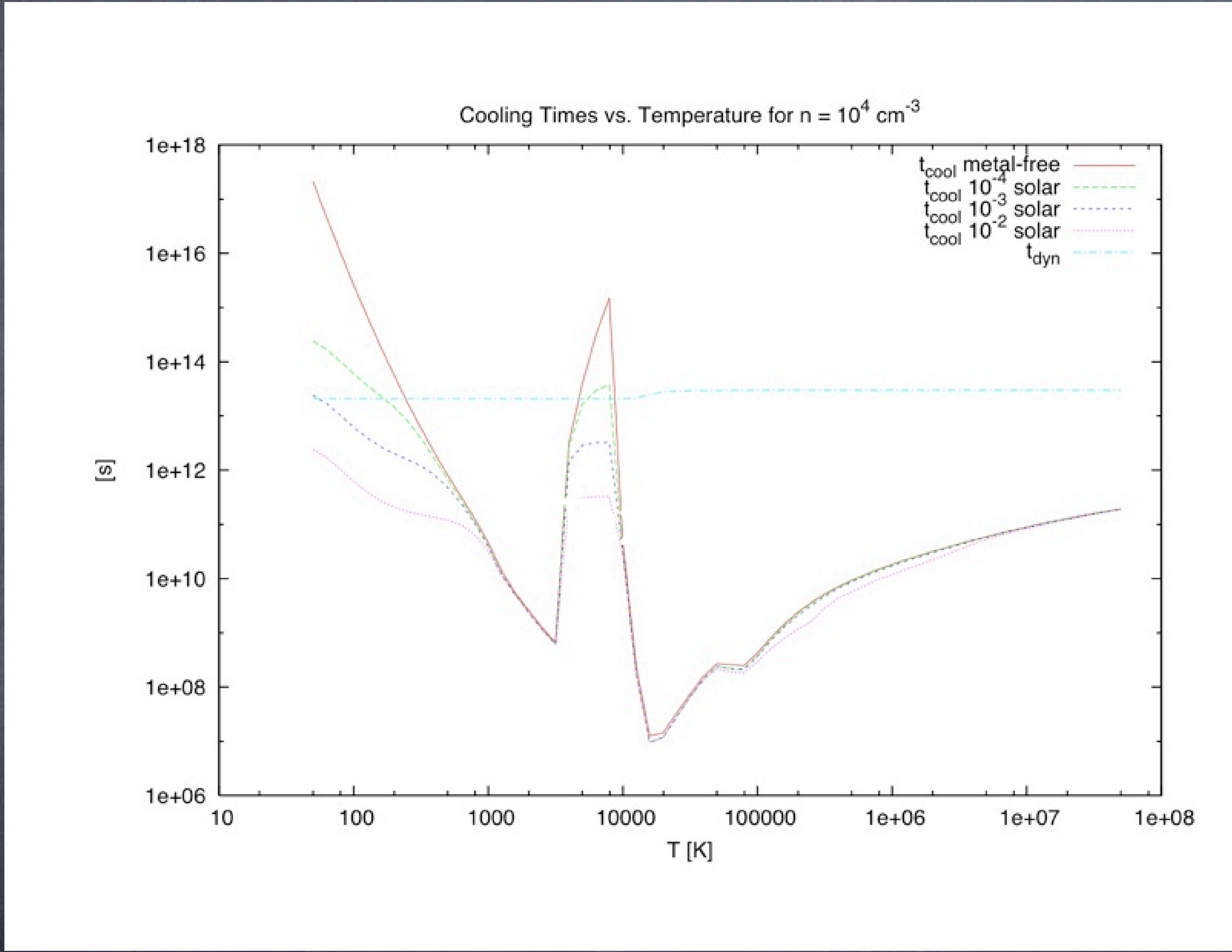
- Gadget
- Paczynski-Wiita potential (extend to pseudo-Kerr maybe)
- High res disk (~ 100,000 particles)
- Truncate inner disk and mimic accretion
- Optics

Madness

- Relativistic viewing, arbitary inclination, currently 2-D disk geometry, extend to 3-D
- cLoop code for cooling (Smith)
  - full Z, non-solar Z, BB or H/He
  - 10-10,000,000 K
  - external radiation sources
  - effective opacity (for $\tau >> 1$)
- Not full radiative transfer code!

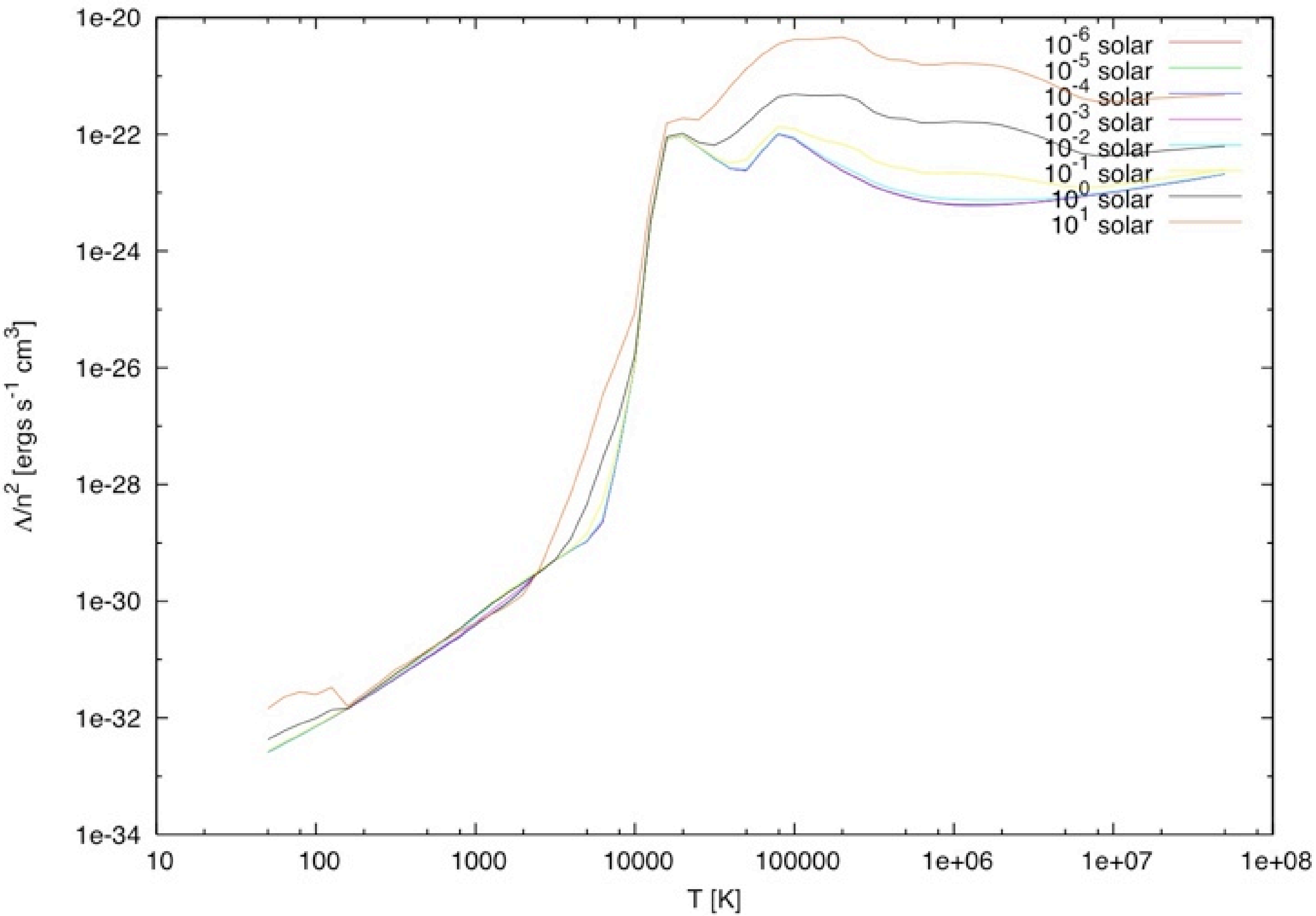
Motive

- Initial conditions: masses, mass ratio, a, e, inclination
- Central illumination and local cooling
- Look at Hα
- L_X vs L_{bol} and x-ray spectral shape
- Quantify LISA sources and what they look like now, infer high z?

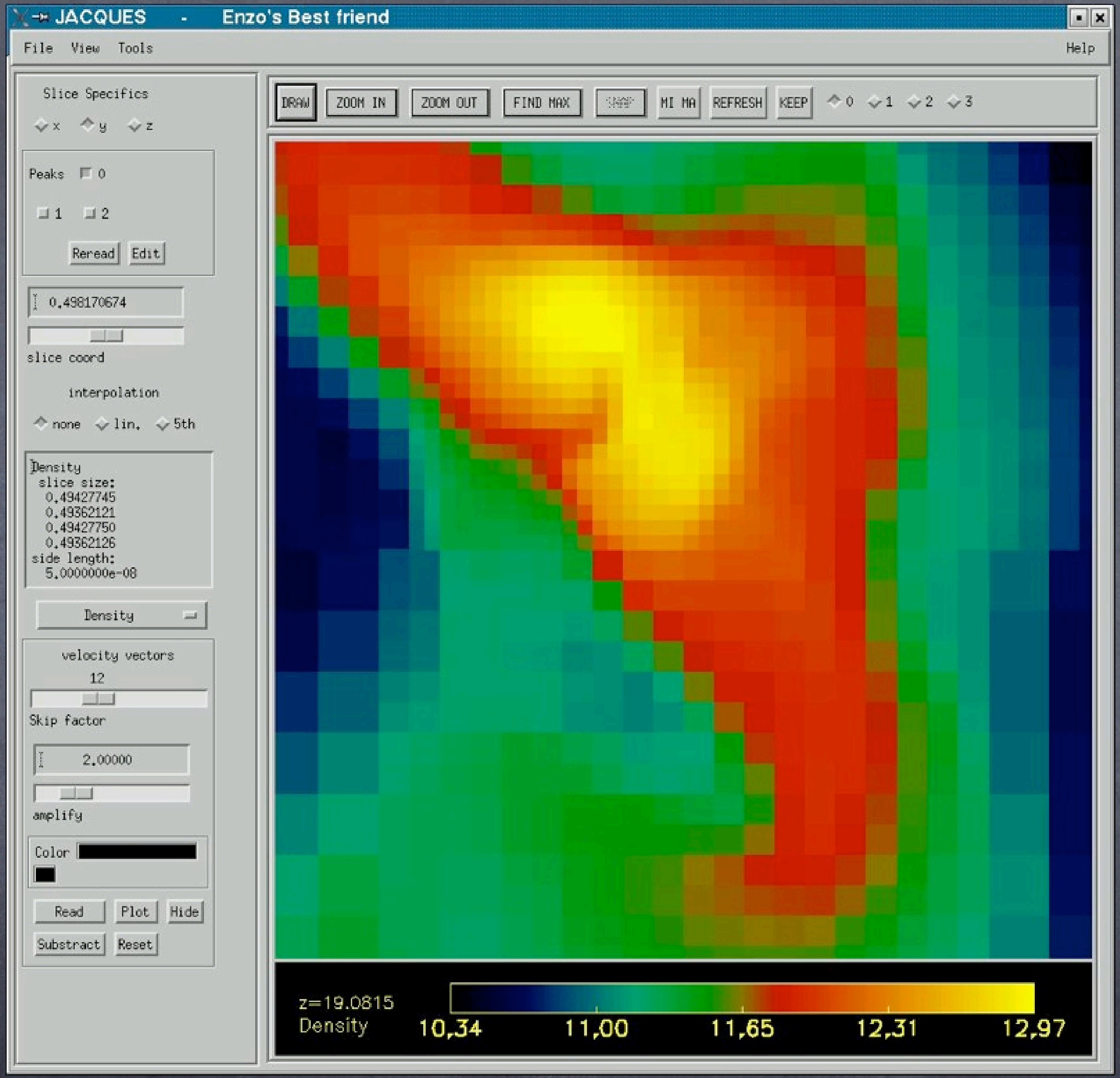


B. Smith (thesis)

Smith, Sigurdsson & Abel '06



1e-20
1e-22
1e-24
1e-26
1e-28
1e-30
1e-32
1e-34
10
100
1000
10000
100000
1e+06
1e+07
1e+08
T [K]
Λ/n^2 [ergs s^-1 cm^3]
10^-6 solar
10^-5 solar
10^-4 solar
10^-3 solar
10^-2 solar
10^-1 solar
10^0 solar
10^1 solar

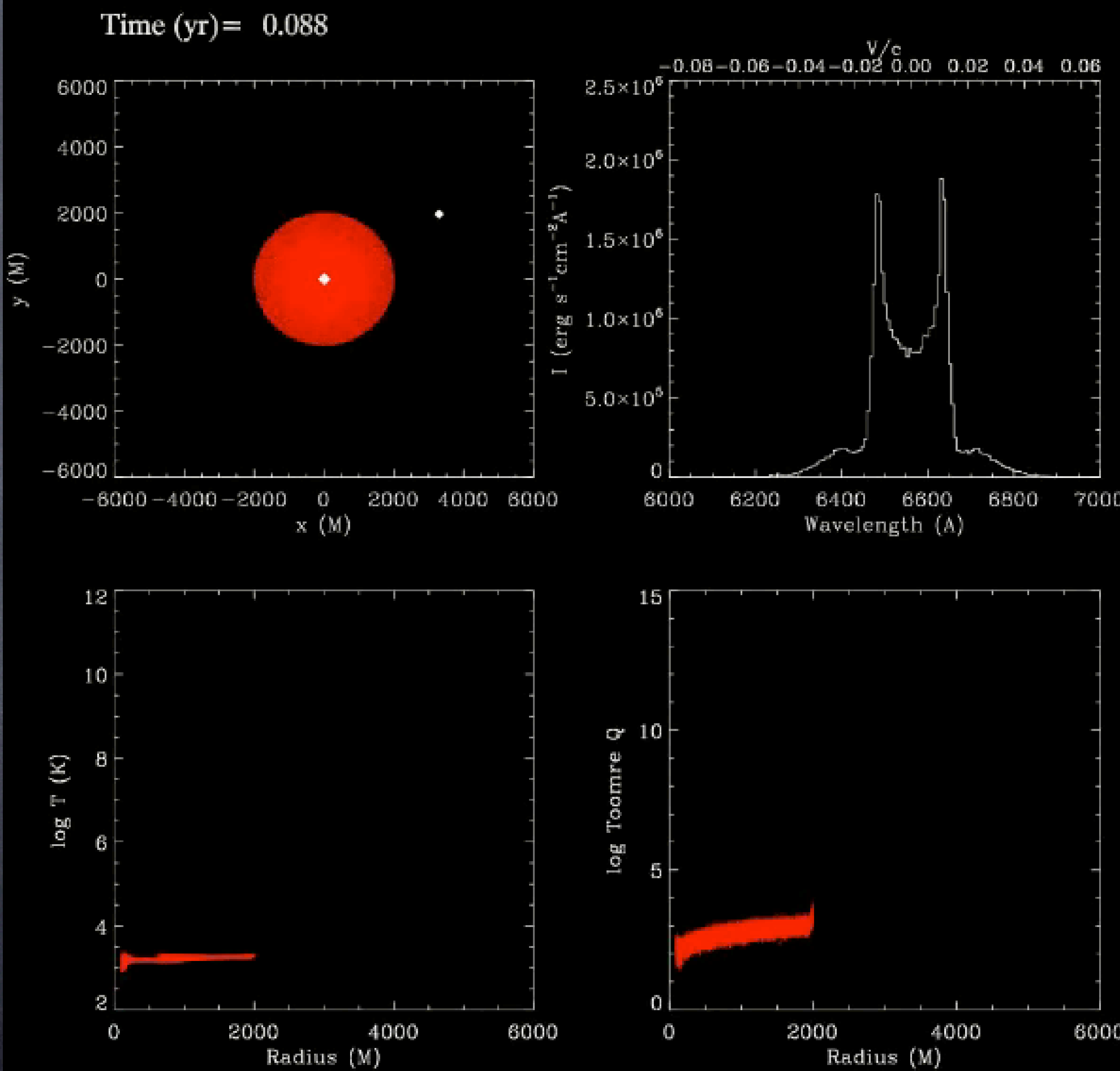


2nd star

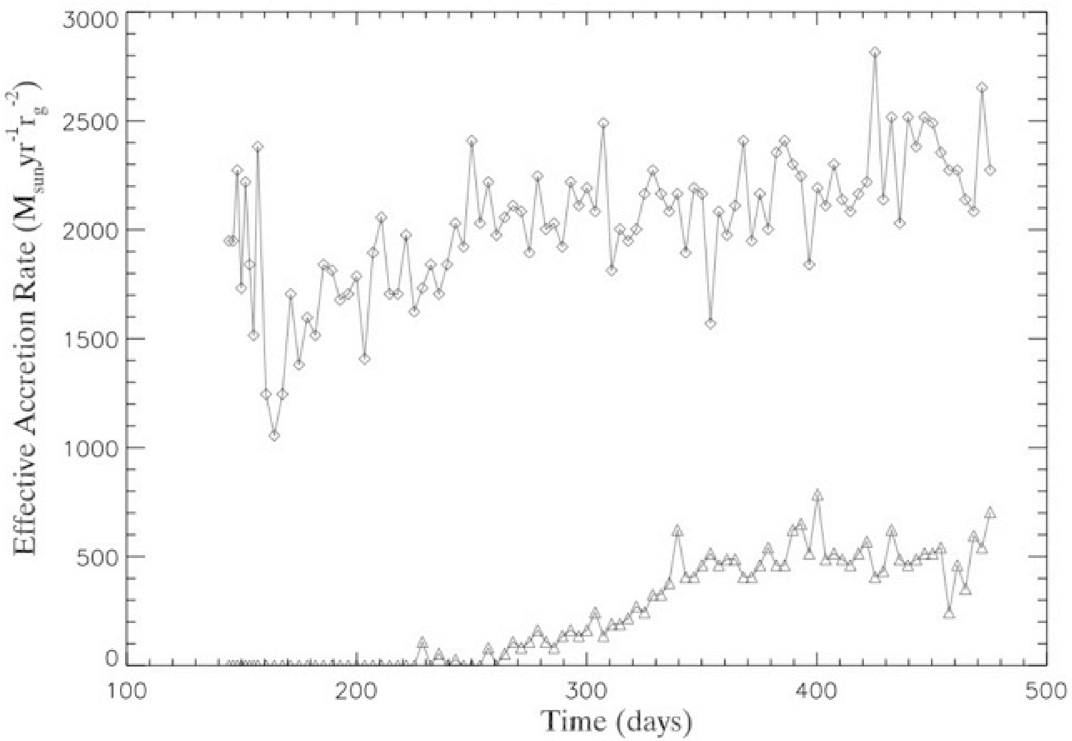
transition from Pop III to Pop II

SMBHB interaction

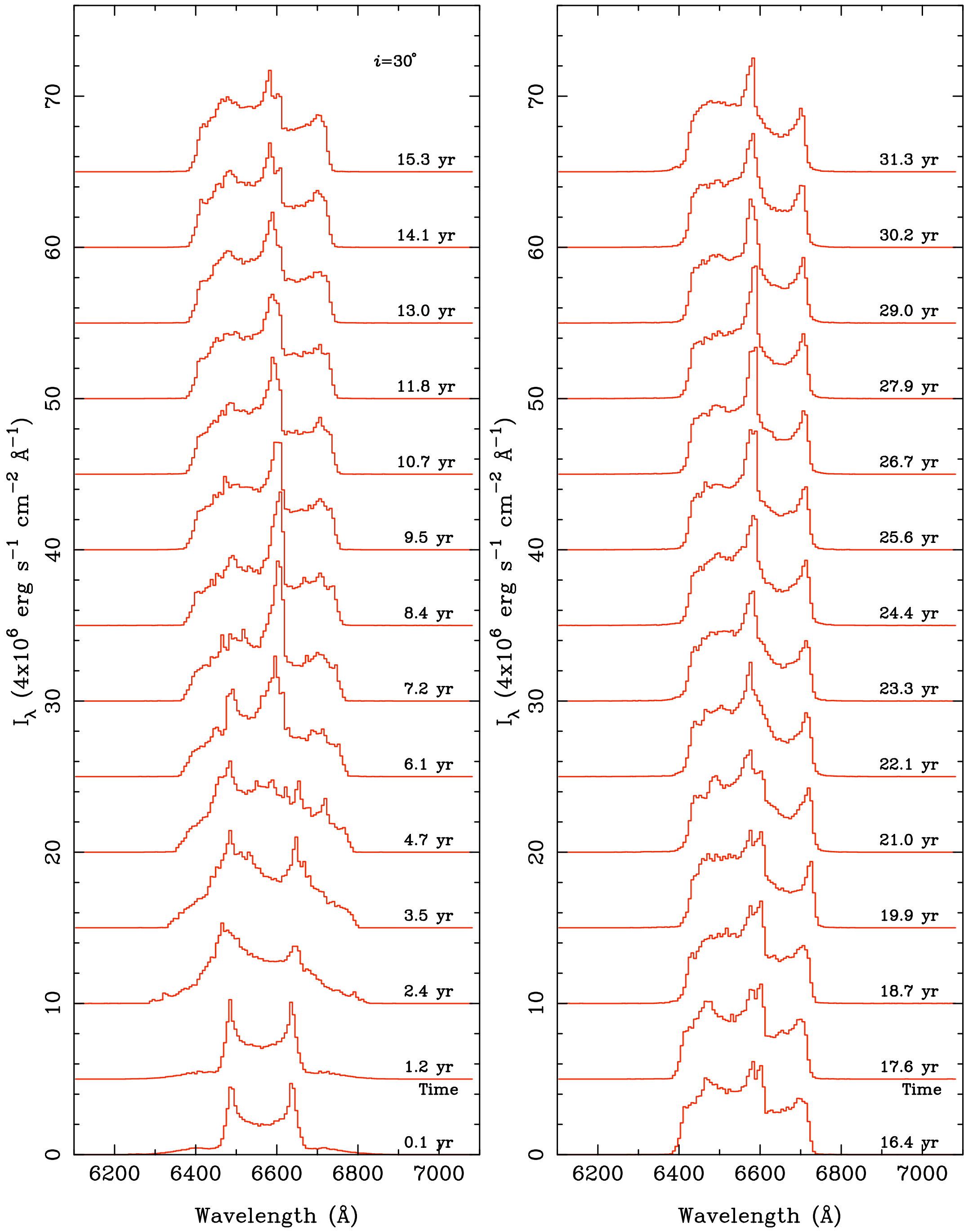
- Initial:
    - High mass, primary gas only, coplanar, high eccentricity
    - pro & retrograde, exploring q
- out-of-plane next
- quasi-circular needs refined I.C.s
- Very finest in SPH simulations!



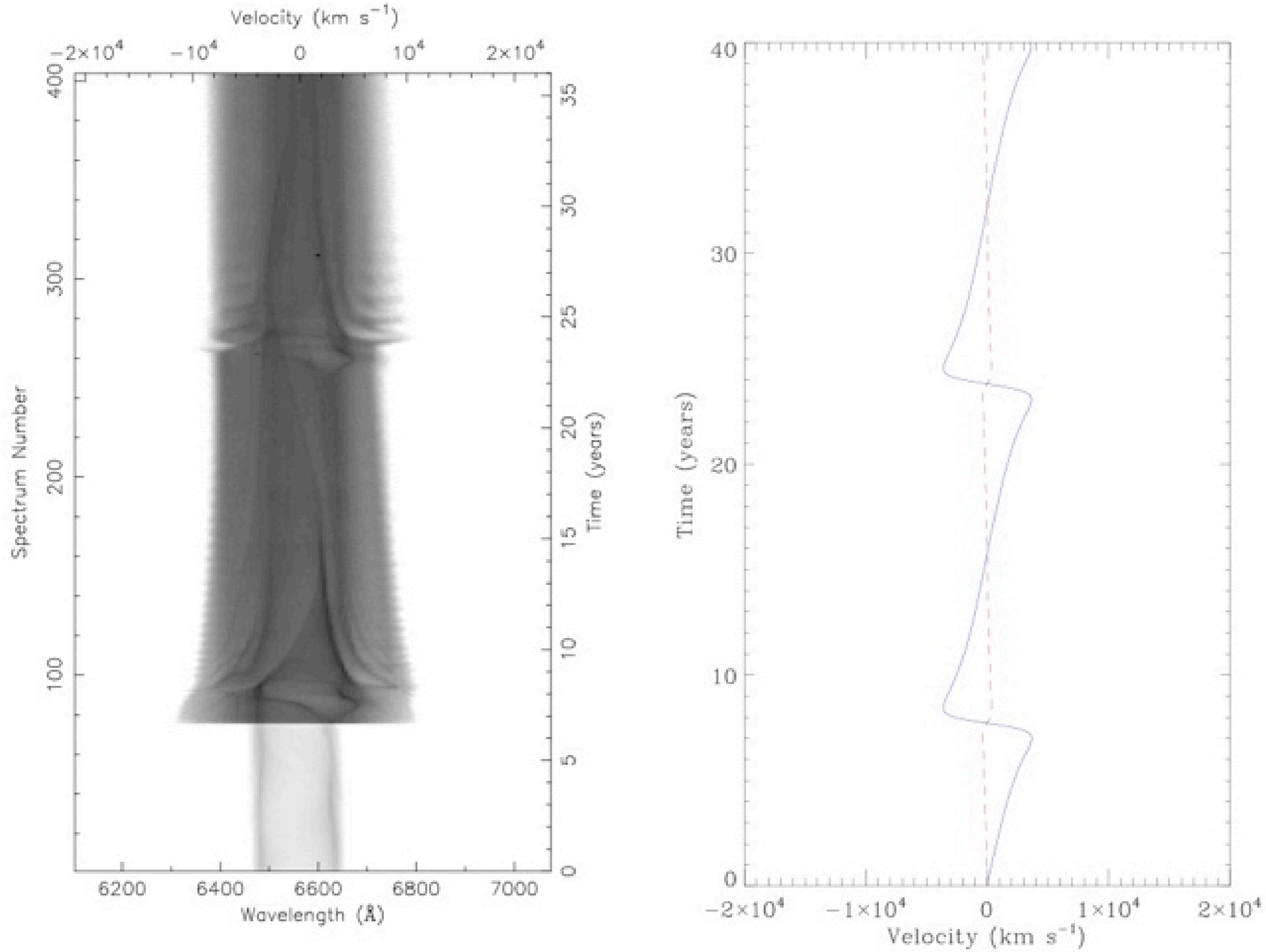
Time (yr)= 0.088
y (M)
x (M)
V/c
I (erg s^{-1}cm^{-2}A^{-1})
Wavelength (A)
log T (K)
Radius (M)
log Toomre Q
Radius (M)



Accretion rate on primary and secondary



i=30°
15.3 yr
14.1 yr
13.0 yr
11.8 yr
10.7 yr
9.5 yr
8.4 yr
7.2 yr
6.1 yr
4.7 yr
3.5 yr
2.4 yr
1.2 yr
Time
0.1 yr
31.3 yr
30.2 yr
29.0 yr
27.9 yr
26.7 yr
25.6 yr
24.4 yr
23.3 yr
22.1 yr
21.0 yr
19.9 yr
18.7 yr
17.6 yr
Time
16.4 yr
Iλ (4x10^6 erg s^-1 cm^-2 Å^-1)
Wavelength (Å)



Trailed of two orbits
showing me spectrogram an velocity
and orbital structure

Preliminary Results

- Clear Hα signature, but viewing geometry matters.
  - Look for in synoptic sky surveys
  - followup to confirm
- Correlate spectra with x-ray and bolometric signature
- Periodic x-ray flaring (eccentricity sensitive?)
- x-ray hardness variation

Conclusions

- More simulations...
- explore parameter space
- compare with observations, possible current candidate local AGNS
- OJ287 anyone? ;-)
- Tie it all together...

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