Schwarzschild's orbit superposition method for disc galaxies

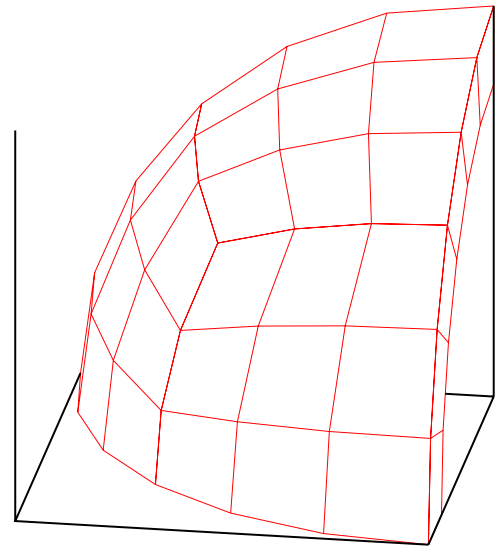
Eugene Vasiliev

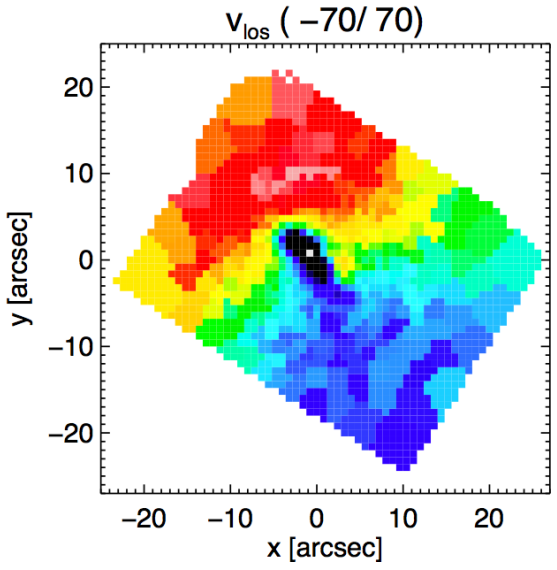
Lebedev Physical Institute

Gaia Challenge 2, Heidelberg, October 2014

Schwarzschild method in brief

- Take a trial potential $\Phi(\mathbf{r})$ and density $\rho(\mathbf{r})$;
- Compute a large number $N_{\rm orb}$ of orbits for many ($\sim 10^2$) dynamical times;
- For each orbit, store its contribution t_{oc} to each of $N_{\rm cons}$ constraints; (discretized density; LOSVD; etc.)
- Minimize the residual $\sum_c \left(\sum_o t_{oc} w_o - m_c\right)^2$, where m_c are the required values of constraints, and $w_o \geq 0$ are orbit weights to be found;
- If necessary, repeat for a different choice of trial potential Φ;
  find the one that best fits the data.





Schwarzschild method: pros and cons

+ Does not make (almost) any assumptions on the distribution function;
+ Provides information about orbital structure of the model;
+ Faster than N-body based techniques (M2M, iterative, ...);

$\pm$ Does not give an unique solution for DF?

– Discreteness effects ($N_{\mathrm{orb}} \sim 10^4, N_{\mathrm{cons}} \sim 10^3$) may obstruct fitting of high-quality data;
– Slow compared to more approximate methods (e.g. Jeans or torus modelling);

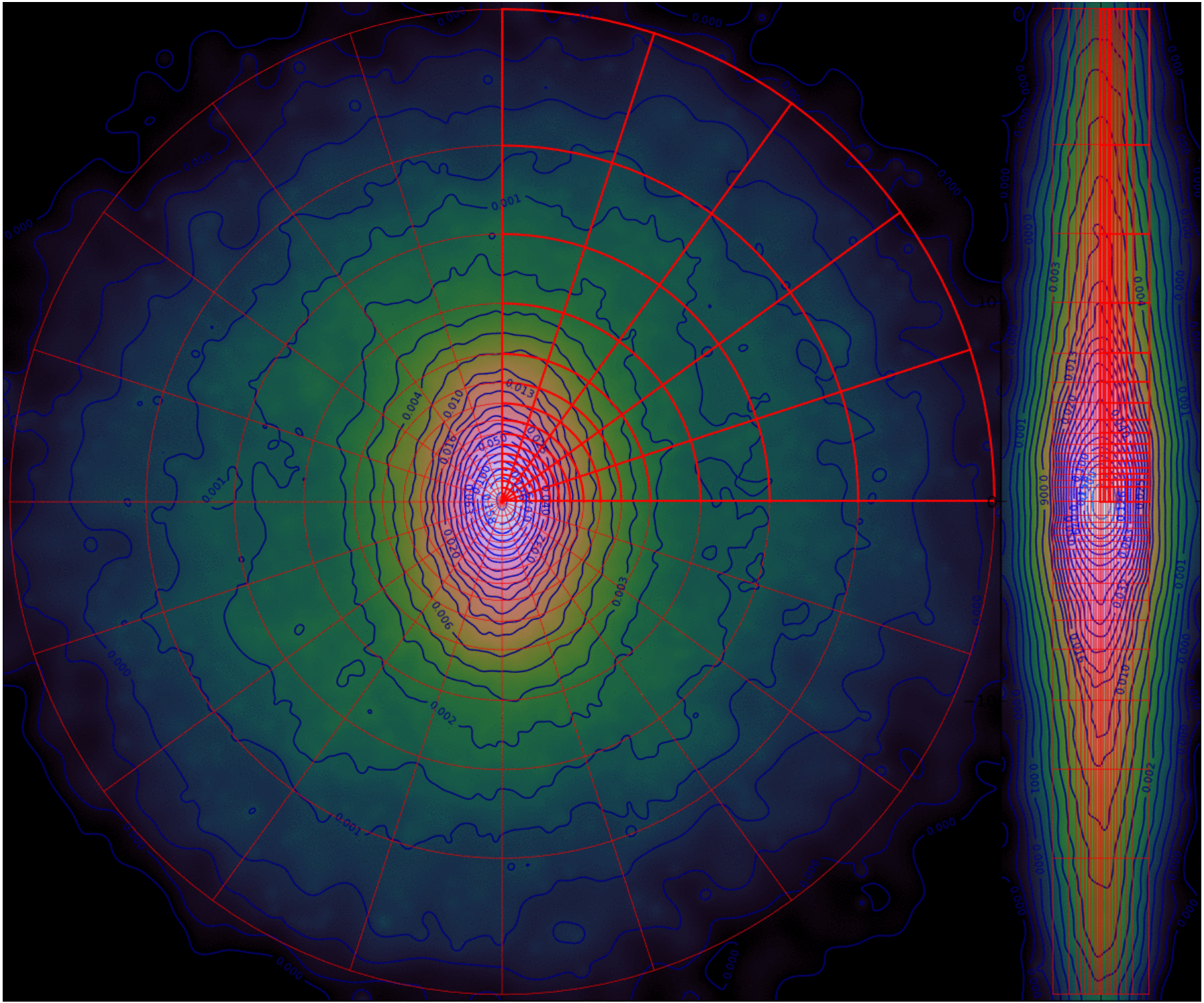
SMILE – an implementation of Schwarzschild method

- A flexible choice of potential model: many analytical profiles or several general-purpose approximations: spherical-harmonic spline or basis-set expansion for elliptical galaxies, cylindrical spline for disc galaxies.
- Powerful orbit analysis tools (frequency map, chaos detection).
- Multi-component models with arbitrary geometry (e.g. triaxial).
- GUI with integrated visualization and scriptable console versions.

\+ Theorist's tool (e.g. creating initial conditions or analyzing orbital structure of N-body simulations).

– No support for observational constraints yet.

\+ Publicly available at `http://td.lpi.ru/~eugvas/smile/`
Vasiliev(MNRAS,2013); Vasiliev&Athanassoula (in prep.)



SMILE²

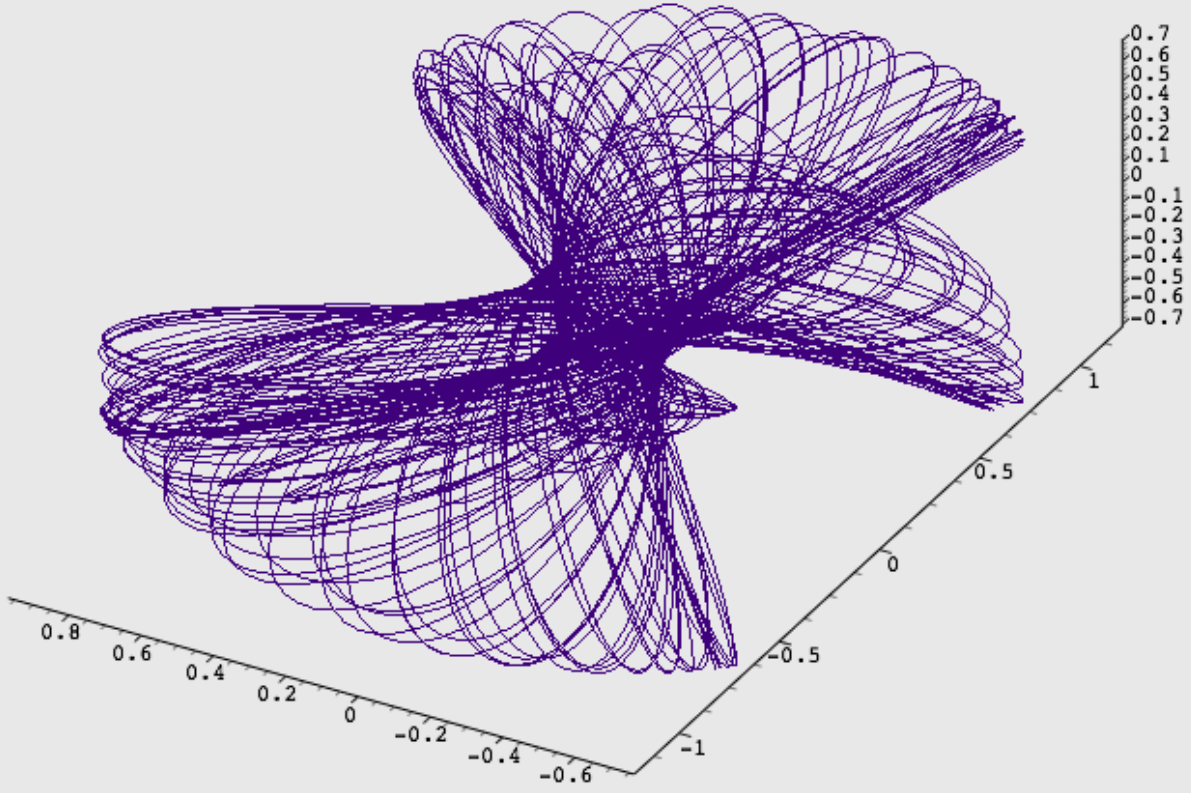
Orbit | Potential | Poincare section | Frequencies | Lyapunov number | Frequency map | Schwarzschild model

Orbit/plot type

- 2d projection
- 3d orbit - line
- 3d orbit - mesh
- r_peri
- Lperi²
- L²
- ΔE(t)
- L(t)

Import

Export



Potential | Orbit integration

	0th component
Potential type	Spline
# radial coefs	15
# angular coefs	6
Density model	Dehnen
total mass	1
axis ratio y/x (q)	0.8
axis ratio z/x (p)	0.5
scale radius	1
cusp exponent	1
BH mass	0

X	0.736678	Vx	0.226182
Y	0.62036	Vy	0.334224
Z	0.264139	Vz	-0.0231498
E	-0.5	Torb	12.0512

Random IC | Start

show 1 'th part out of 1

save settings on exit | Print

(2,1,-2) thin orbit
Ifx=1.0313976
Ify=1.3189997
Ifz=1.6908722
FreqDiff=0.000139
Inertia=0.74,0.477,0.321
Lz=-0.00107±0.116, Lx=-0.000483±0.0828
E=-0.5, deltaE=1.05e-06