

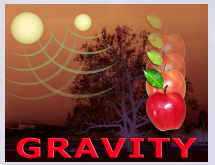
Science with GRAVITY

the NIR interferometric imager

Thibaut Paumard[1,2]

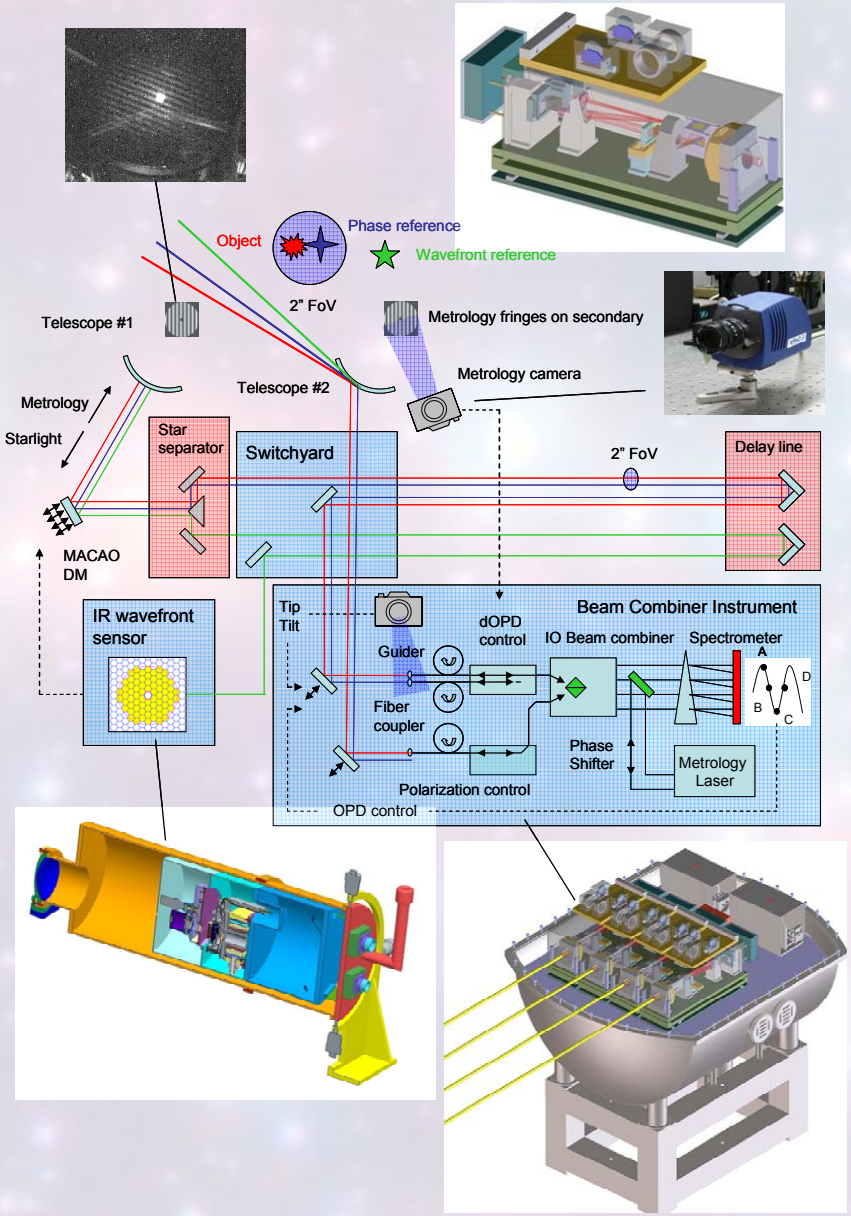
et al., for the GRAVITY consortium[1,2,3,4,5,6,7]

[1]LESIA (Observatoire de Paris/CNRS), [2]PHASE, [3]MPE, [4]University of Cologne, [5]MPIA, [6]LAOG, [7]SIM



Outline

Outline



GRAVITY, 2nd generation instrument for the VLTI

- H+K AO;
- fringe-tracker (+phase reference);
- extremely sensitive.

$\Rightarrow$ lock on 3 different sources!

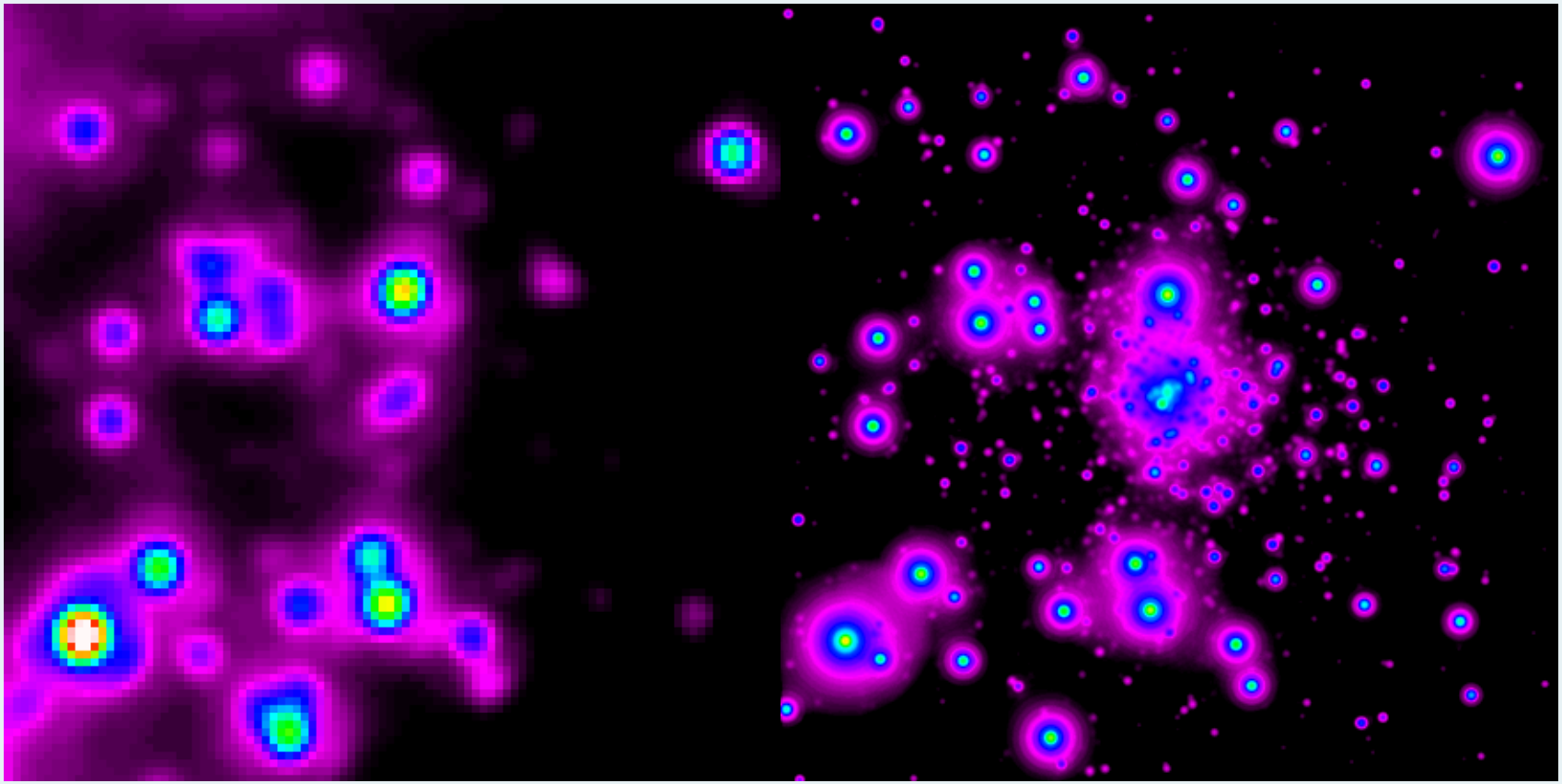
Operating modes

- AO: $K < 10$;
- Fringe-tracking: $K < 10$;
- Science: $K < 16$ (17);
- Baseline: 100m (UTs);
- K band, $R = 22$, 500 and 4000.

Outline

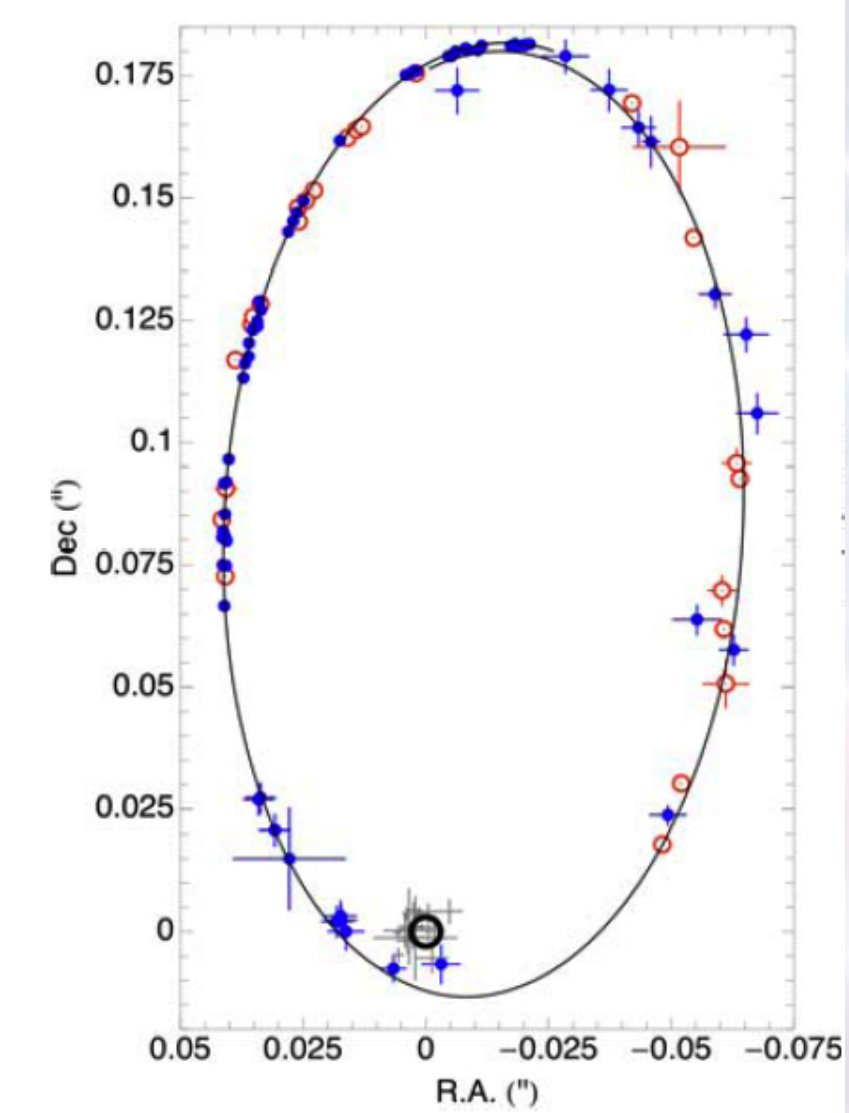
Overcome spatial crowding

Trippe et al. simulated field for E-ELT/MICADO (1” $\times$ 1”)



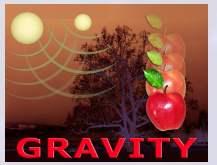
VLT (8 m) E-ELT (42 m)

The orbits of S stars are Keplerian

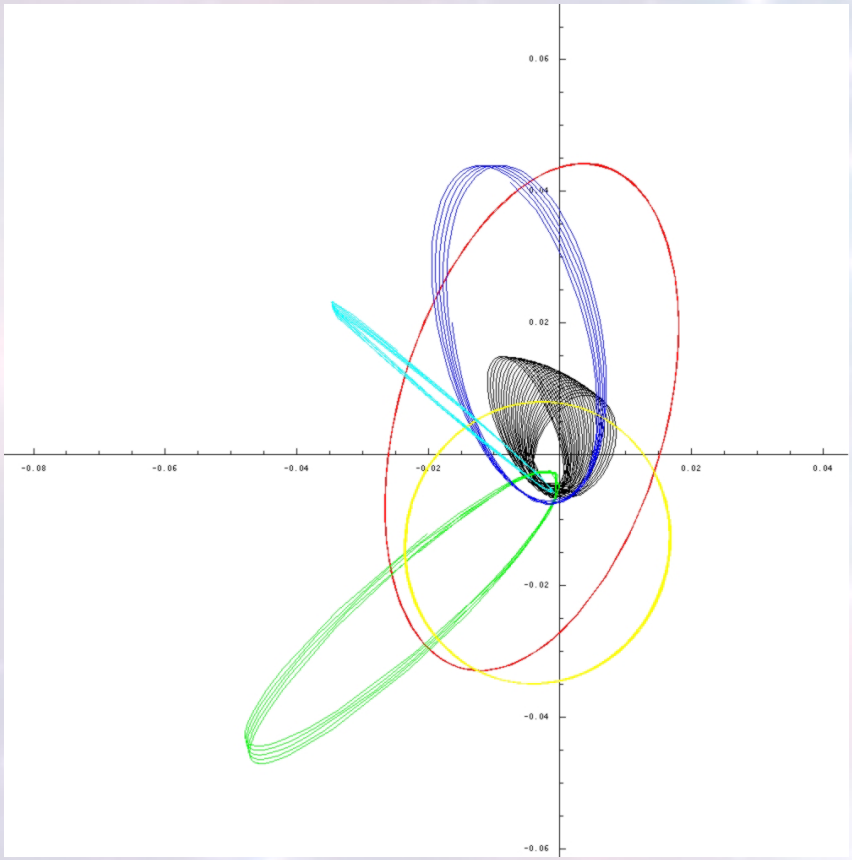


Fast precessing orbits

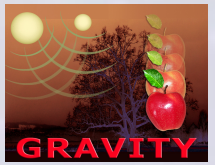
- At most 5% of the $\simeq 4\,10^6$ solar masses is extended,within the orbit of S2 (Mouawad et al. 2005);
- Is SgrA* still point like at the mas scale?
  - binary system?
  - contribution from a cluster of low-mass/intermediate mass BHs?
- Side questions: mass function and light/mass ratio of the cusp.



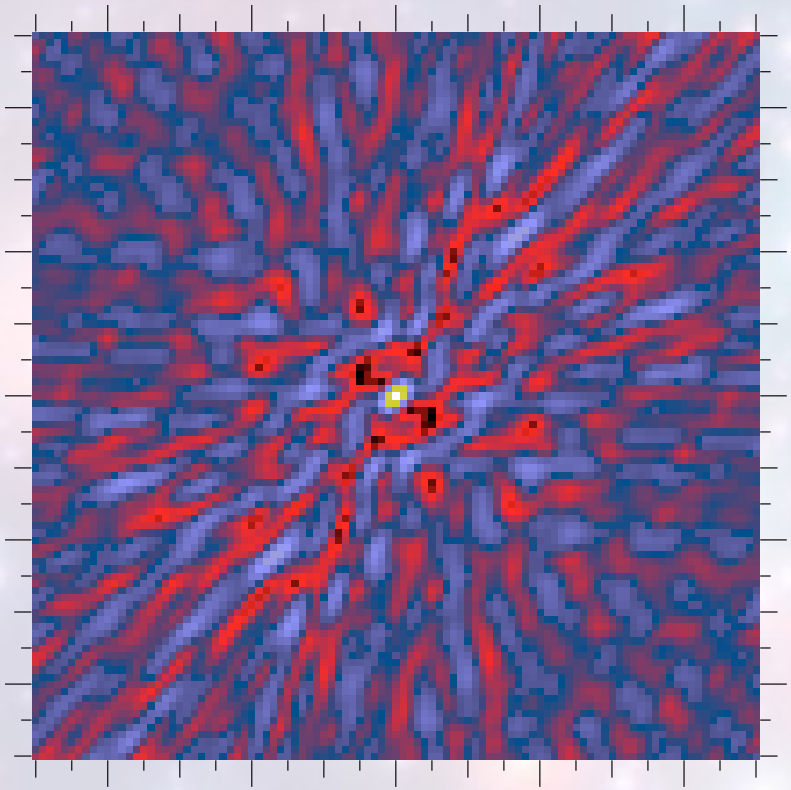
Down-sized S-cluster



- Short orbital periods ($\lesssim$ 1 yr);
- fast precession (validate GR);
- probe density profile closer to SgrA*;
- get the mass included within 100 R_S.



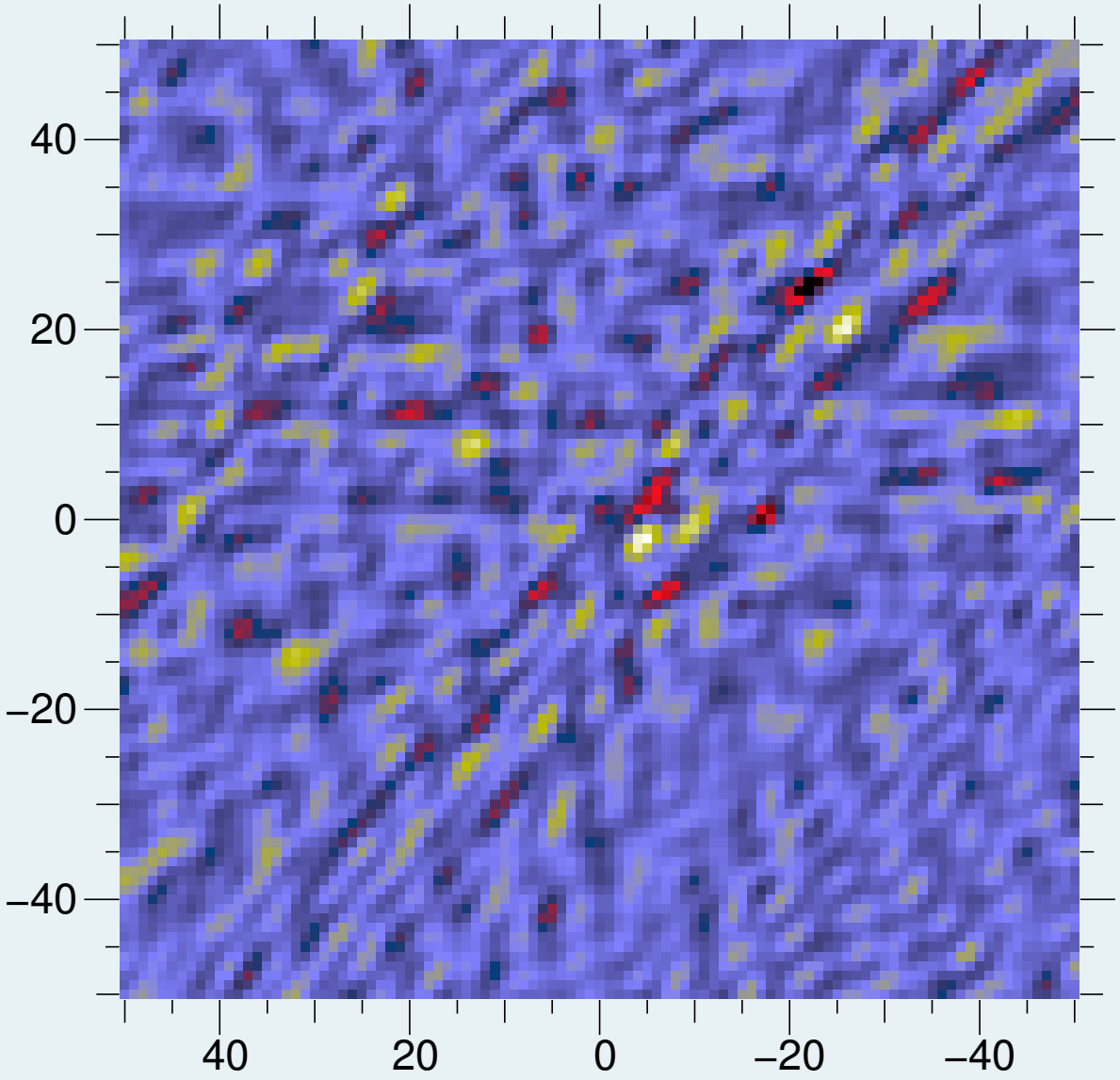
PSF: 3 (V, φ) sets, K-band, 4 UTs



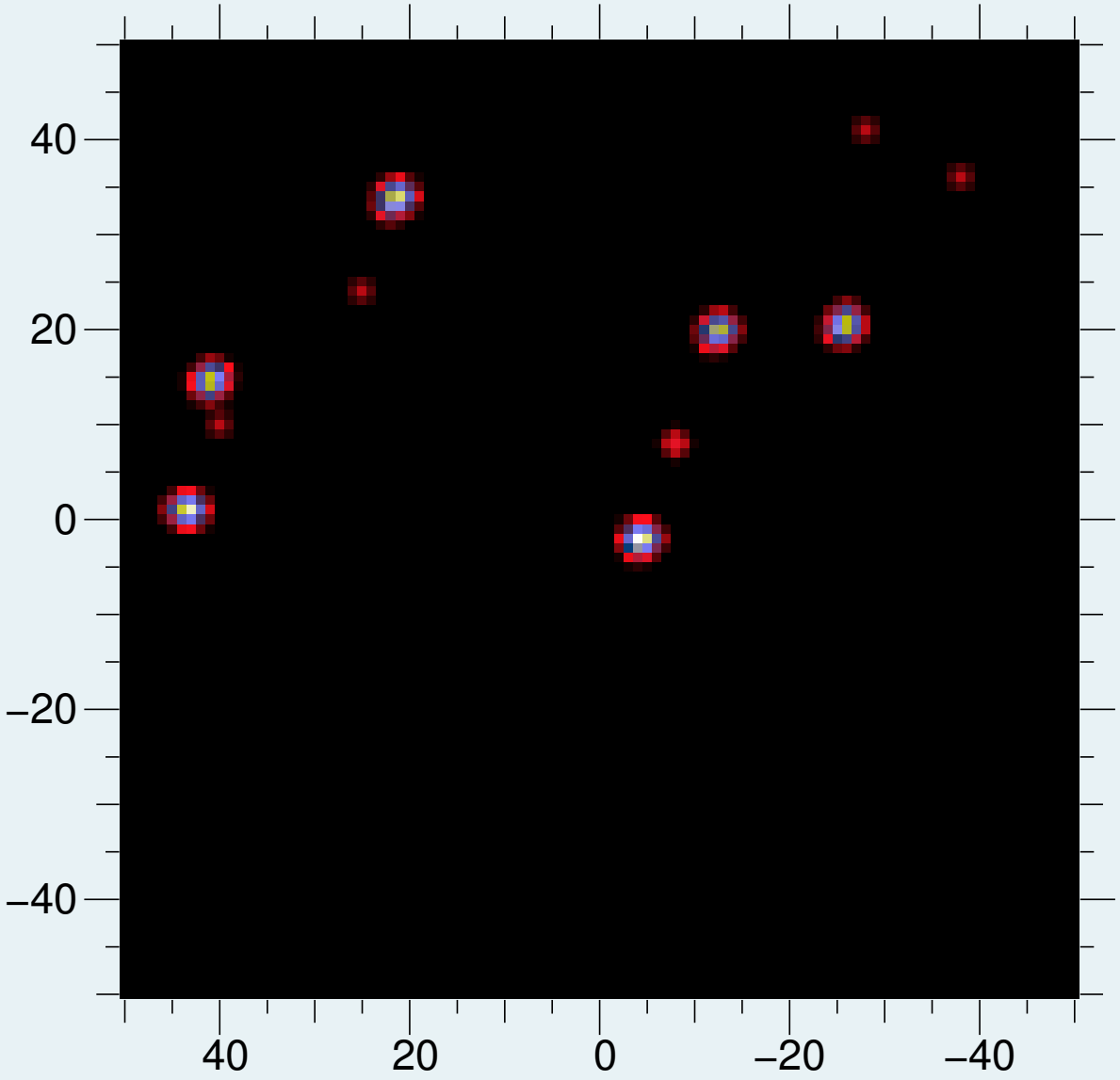
Assumed constraints:

- 3 hours per obs.;
- 5 sp. elmnts from 2.0 to 2.4 microns;
- dynamic range: $\simeq$ 1 mag;
- error on visibility: 1%;
- error on phase: 2°.

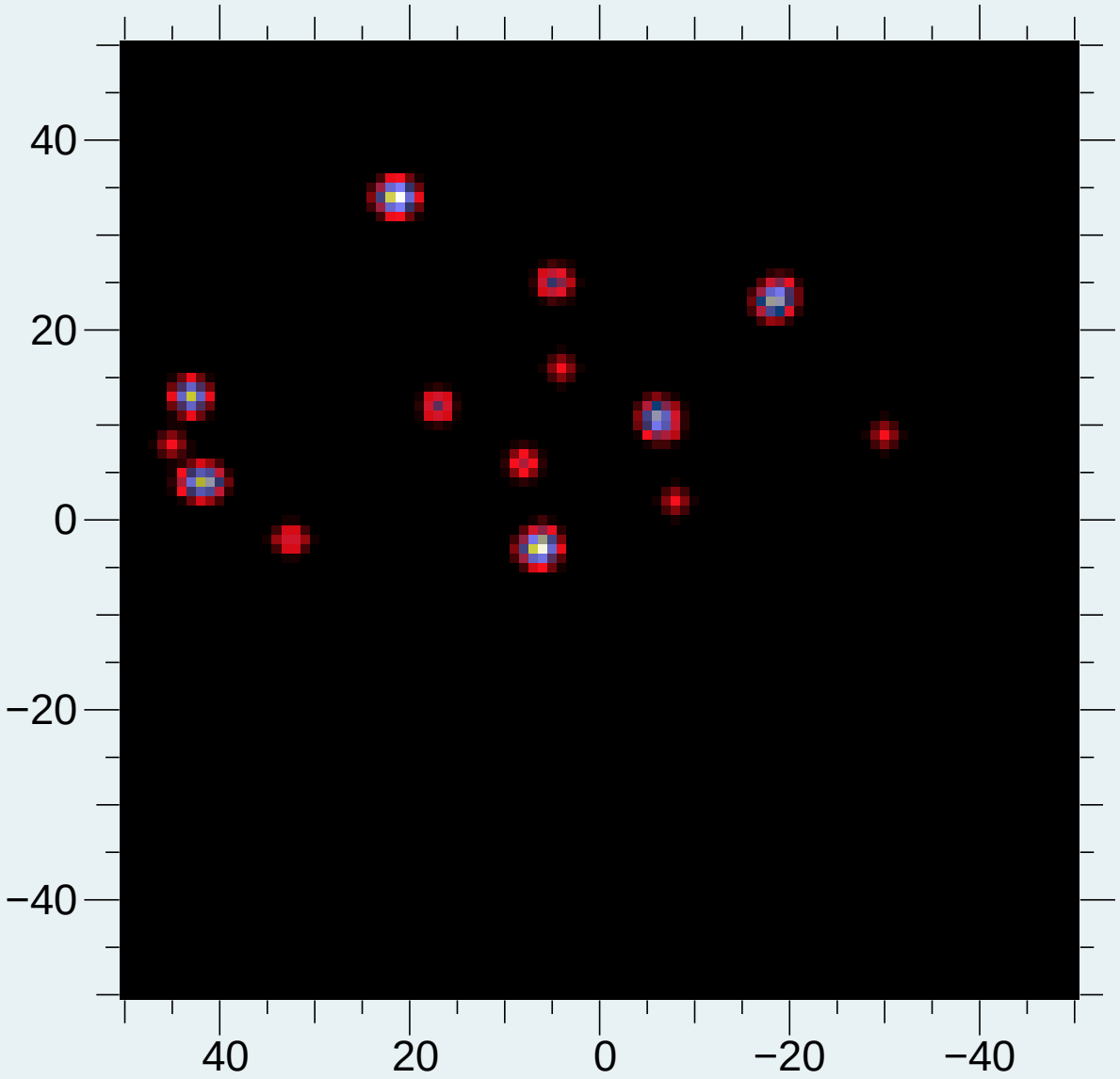
Synthesised image 6 stars, $m_K \simeq 18$–19



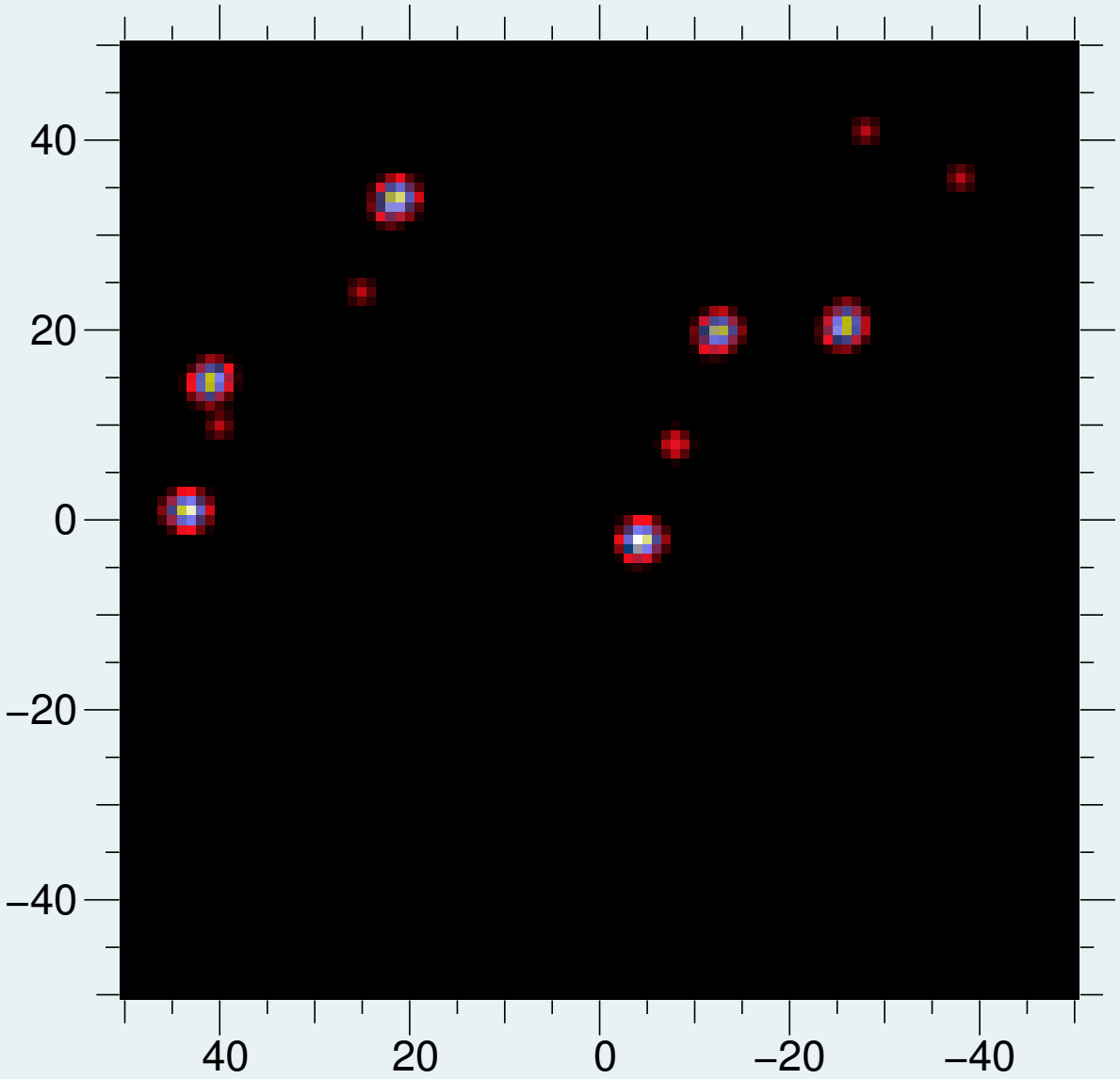
Synthesised image cleaned 6 stars, $m_K \simeq 18$–19



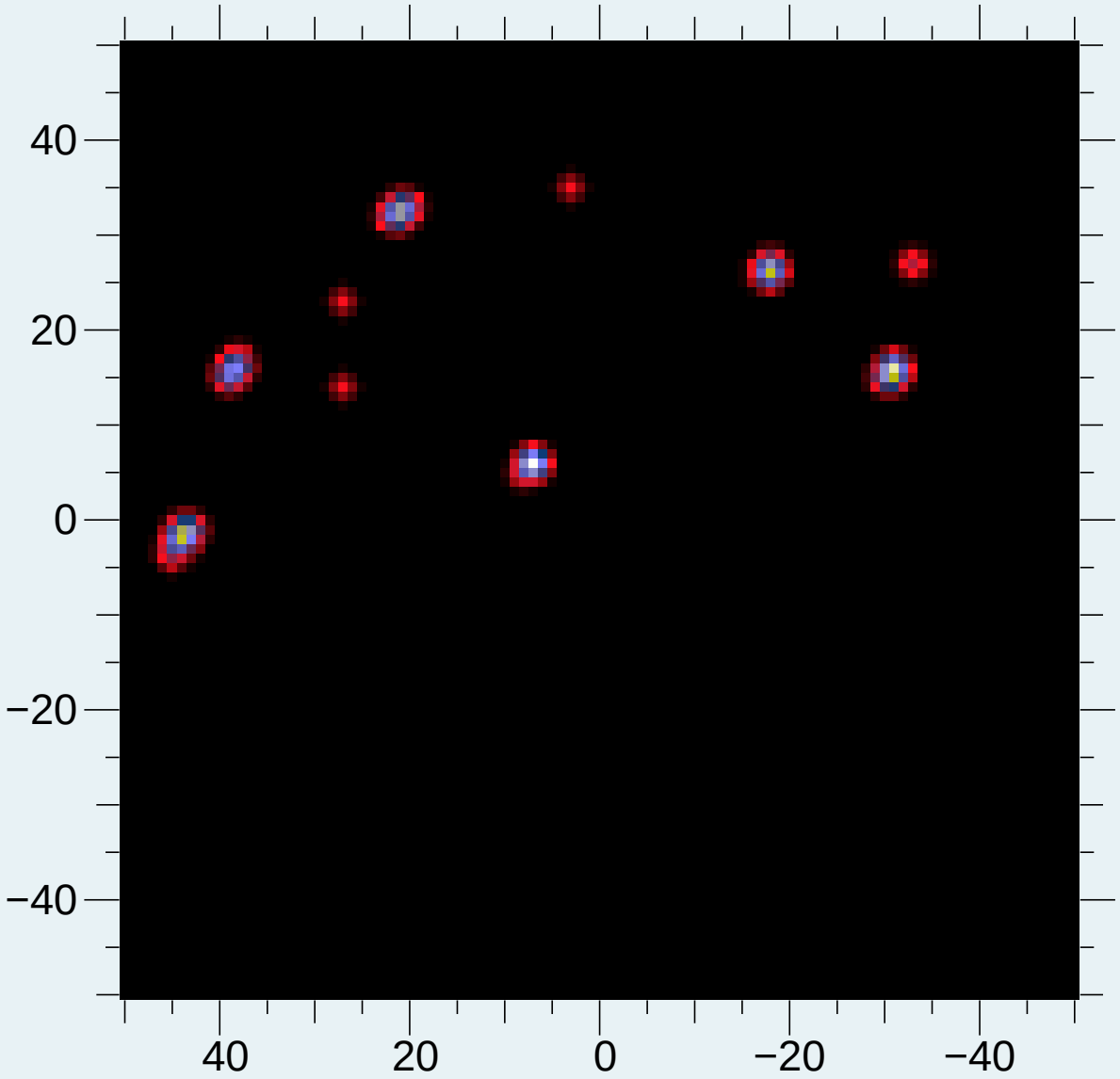
3 months proper motion: May (2 (V, φ) sets)



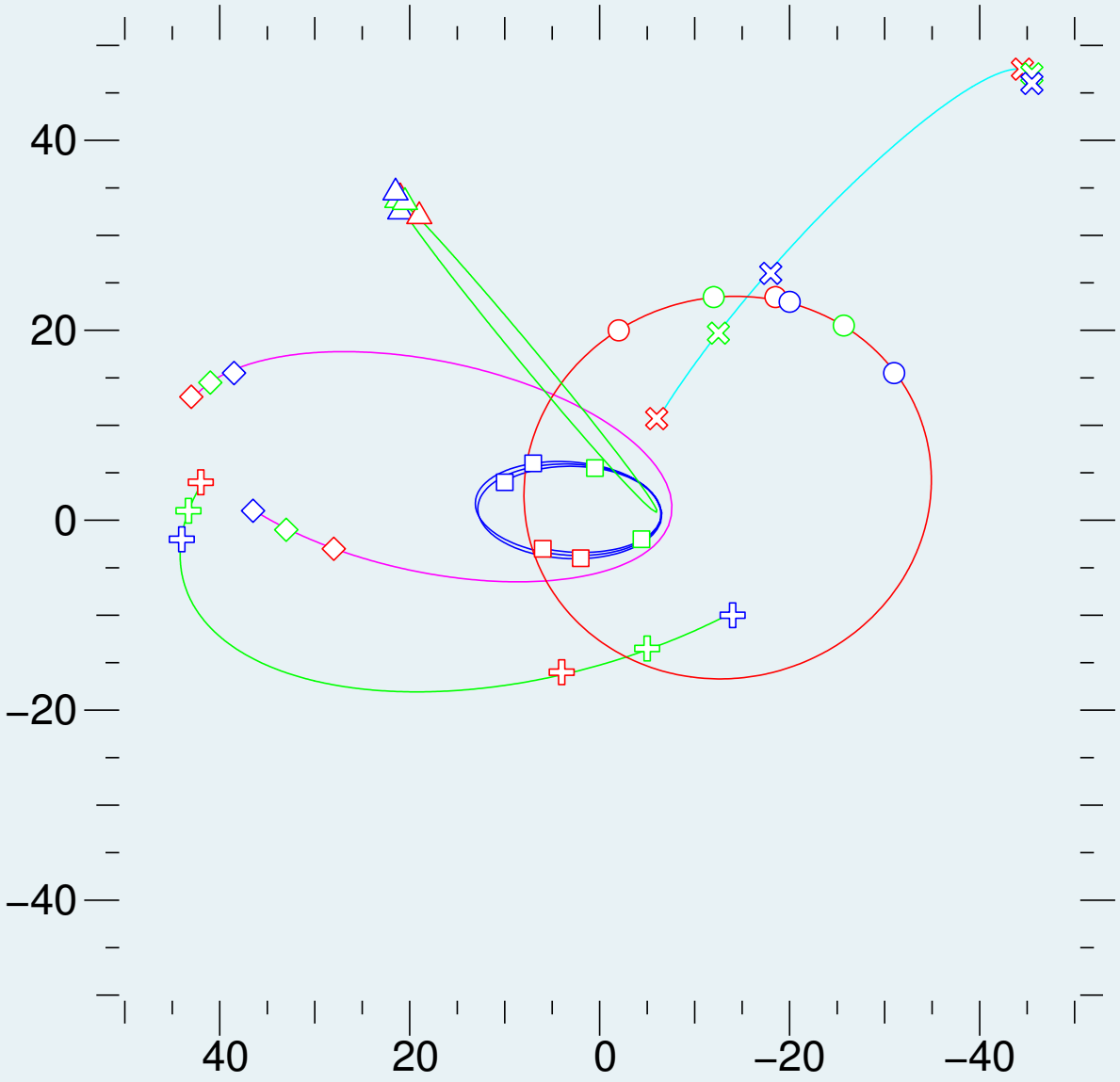
3 months proper motion: June (3 (V, φ) sets)



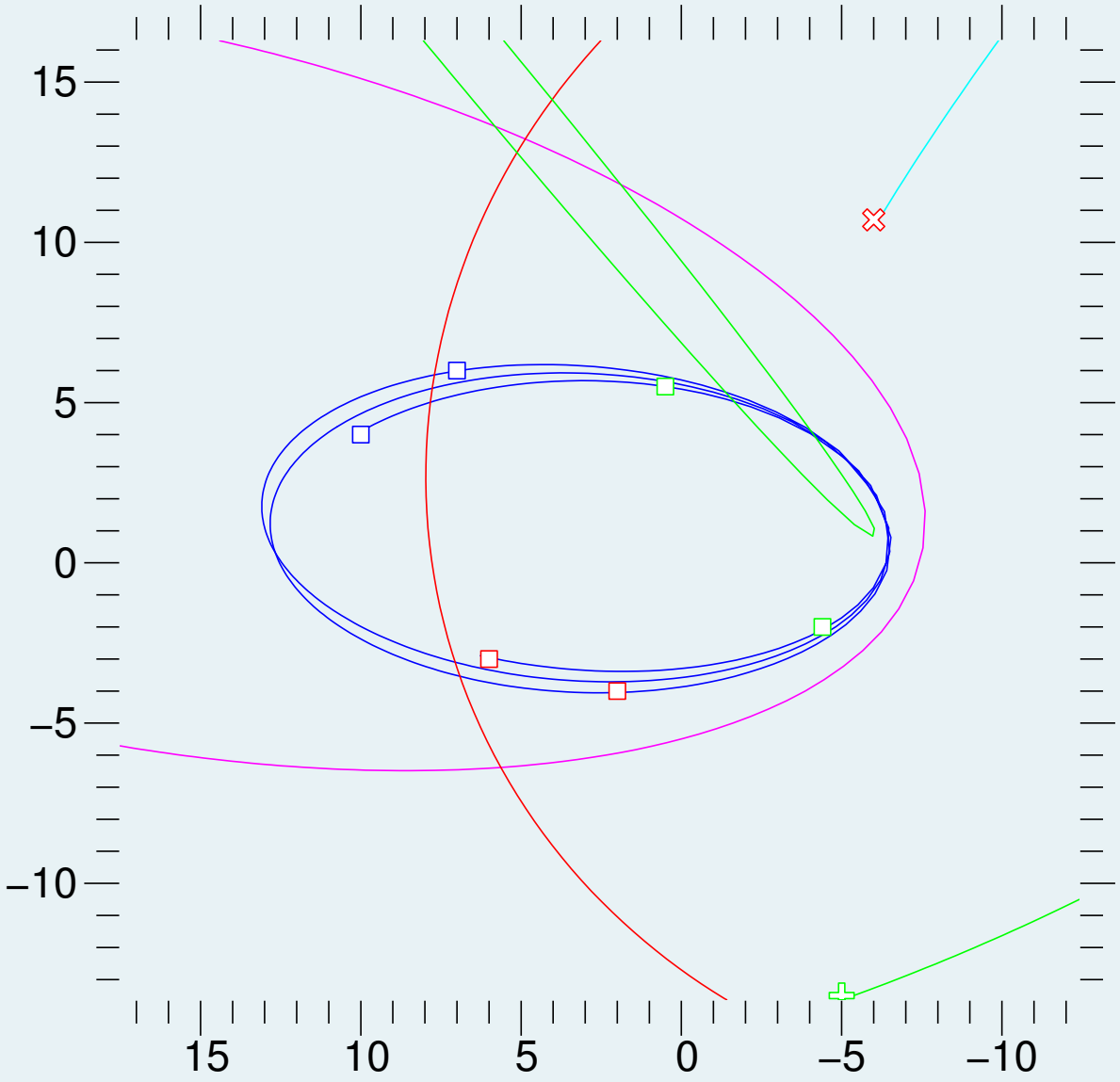
3 months proper motion: July (2 (V, φ) sets)



2 seasons proper motion

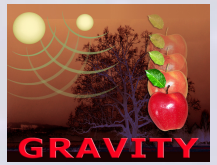


2 seasons proper motion



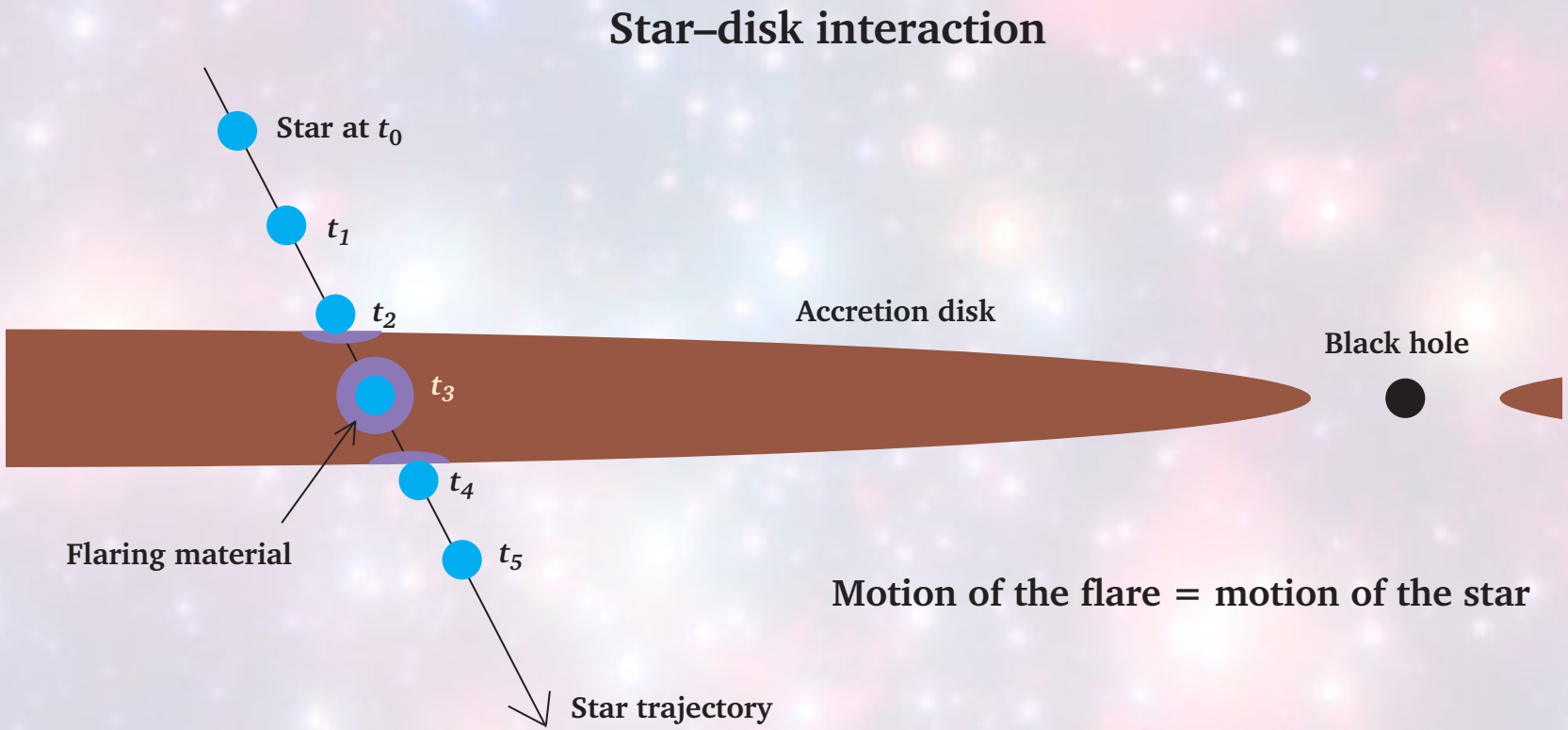
Detect new stars on tight orbits

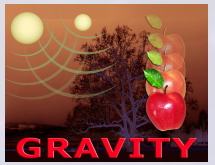
- Detect relativistic effects;
- Detect dark matter cusp;
- Discriminate smooth DM vs. discrete DM.



Sgr A* has flares

3 models



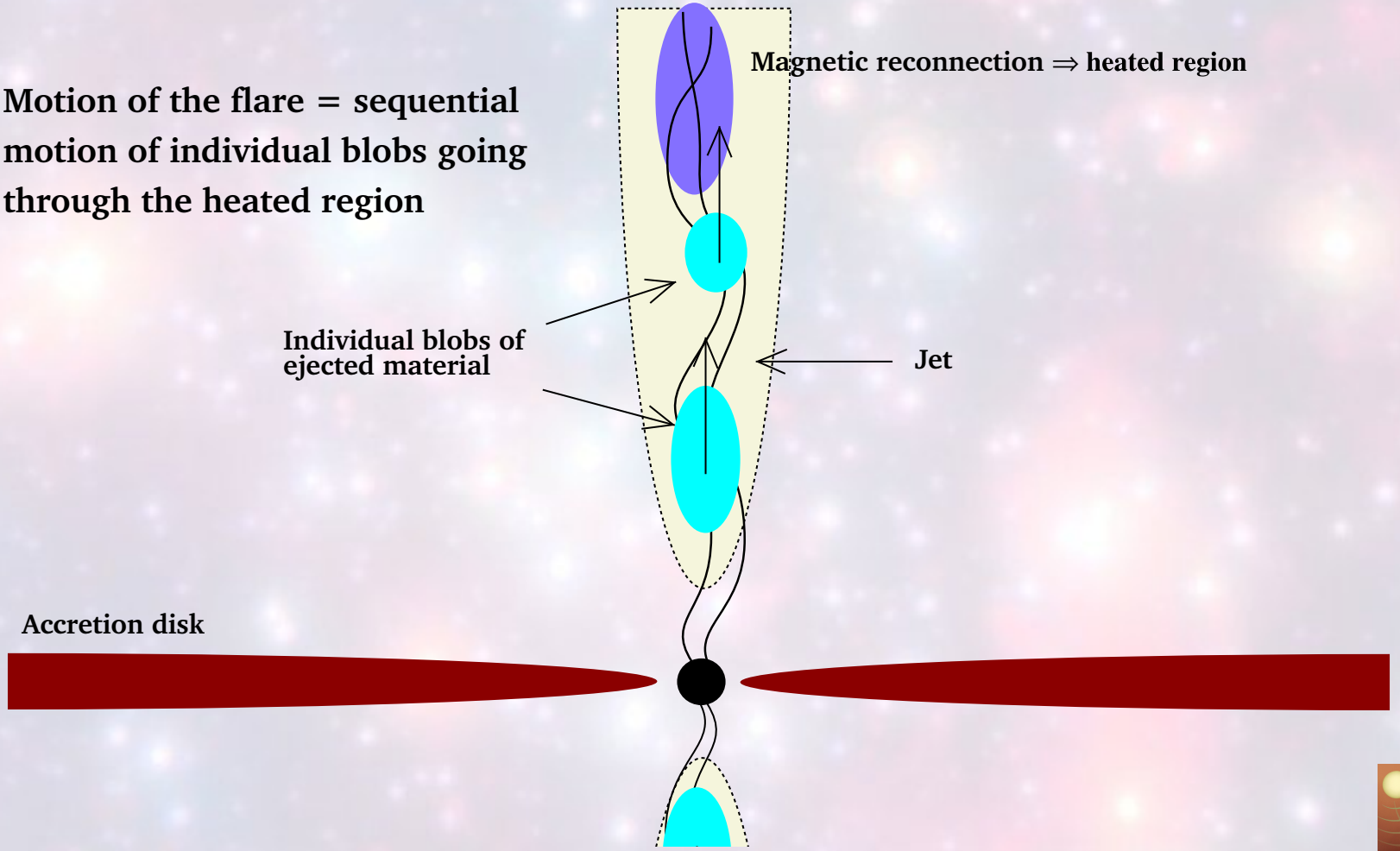


Nayakshin et al. (2004)

3 models

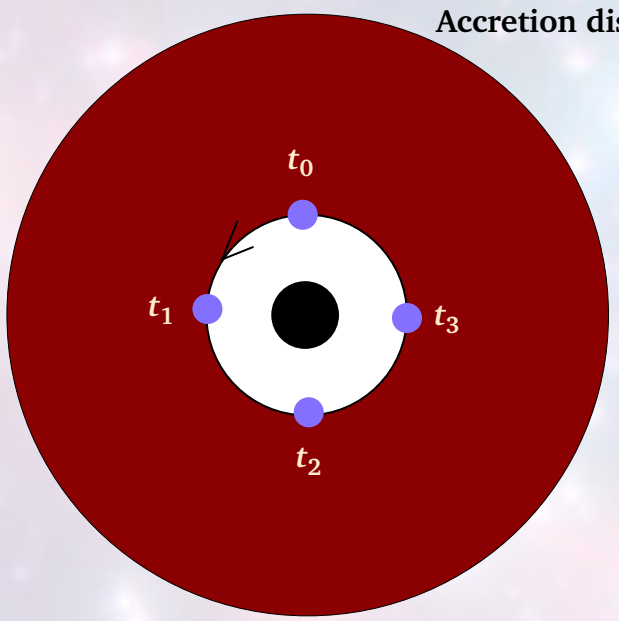
Magnetic reconnection in a jet

Motion of the flare = sequential motion of individual blobs going through the heated region

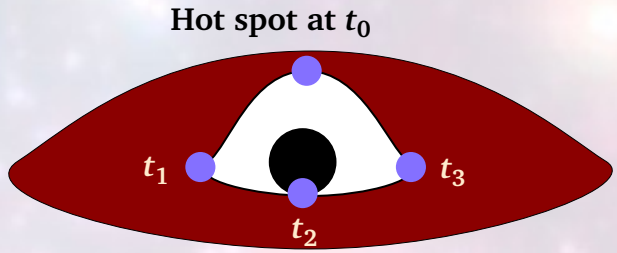


3 models

Hot spot on the last stable orbit



Last stable orbit seen from above



Last stable orbit seen at high inclination

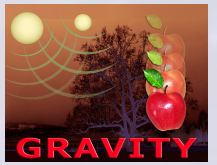
Motion of the flare =
orbital motion of the clump

on average = 0

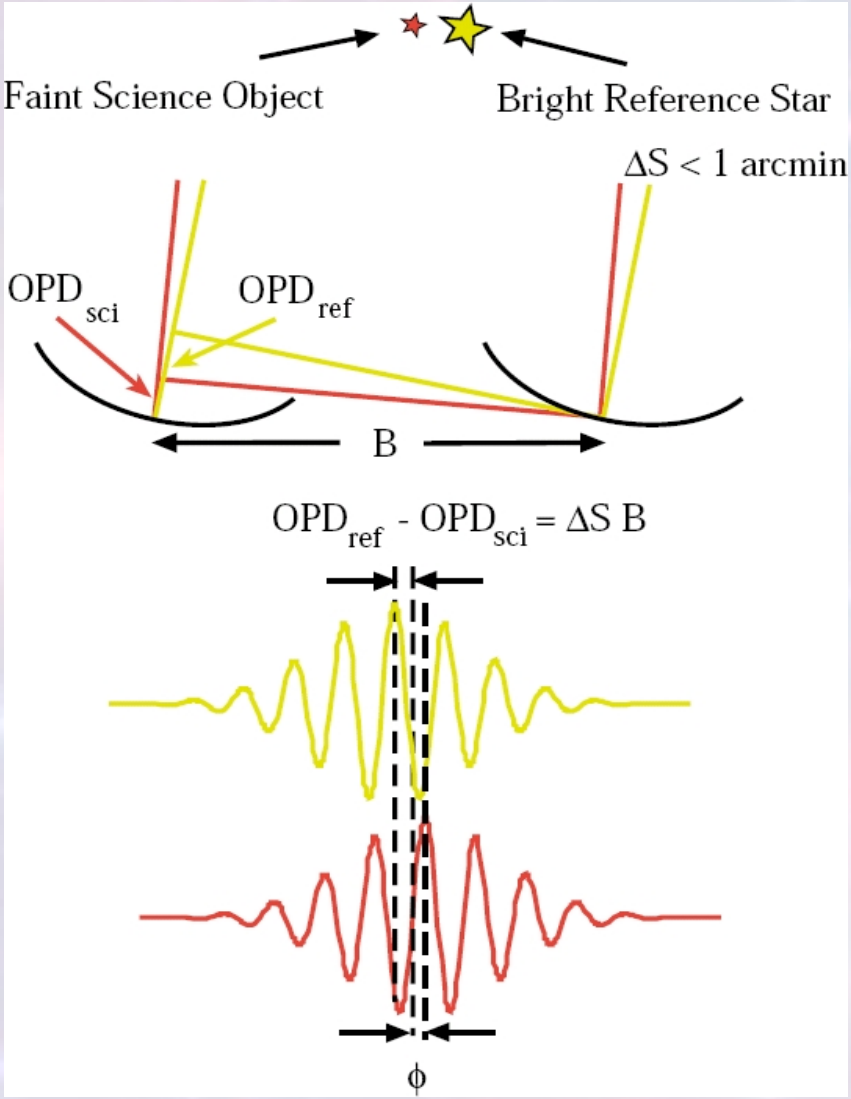
3 models

Whatever the nature of flares

- Flare emission comes from matter;
- Near SgrA*, matter moves at relativistic velocities;
- $c = 10\mu\mathrm{as/min}$
- $R_S = 10\mu\mathrm{as}$



Imaging @ 1 mas, astrometry @ 10 μas

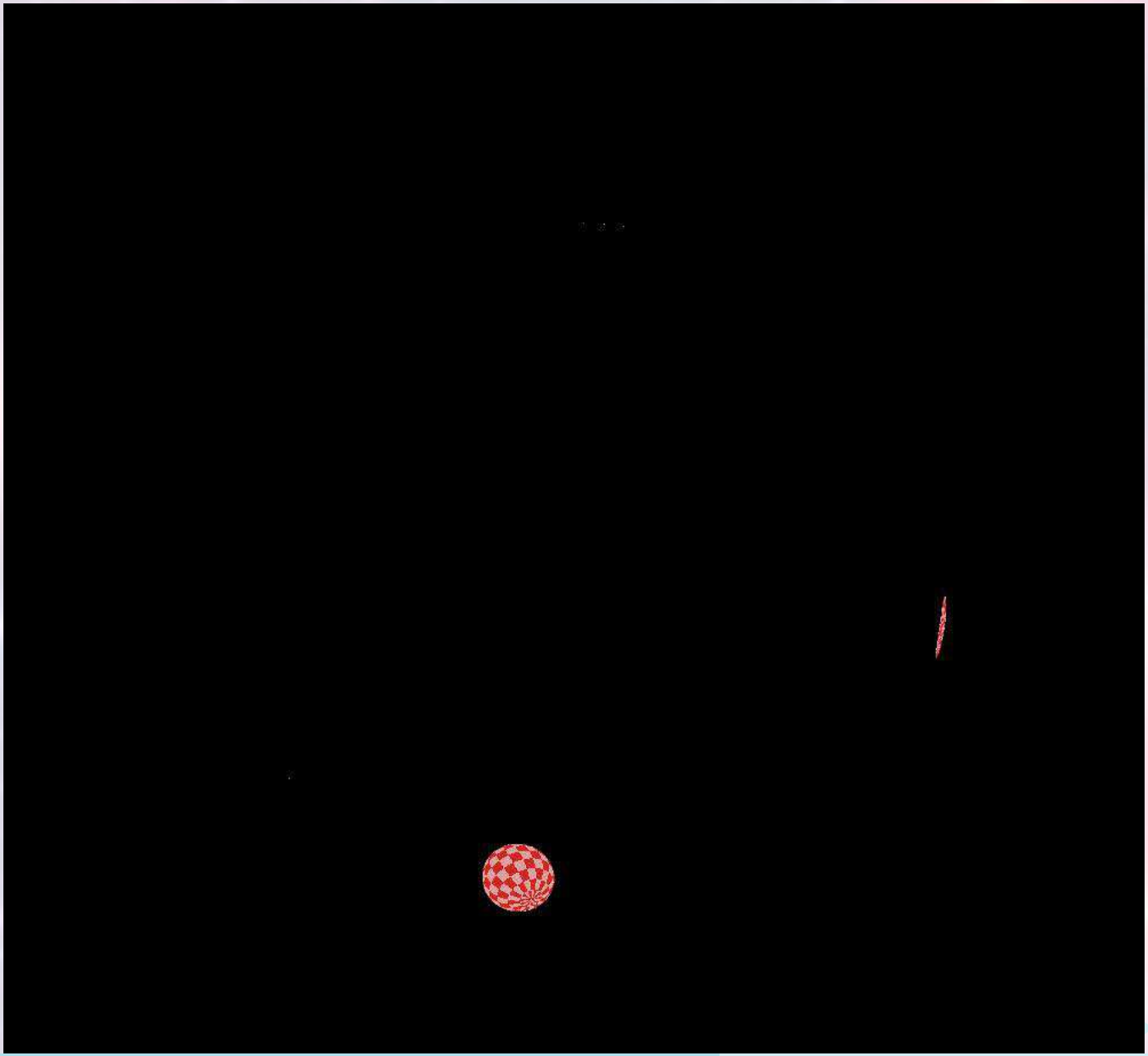


(Glindemann & Lévêque 2000)

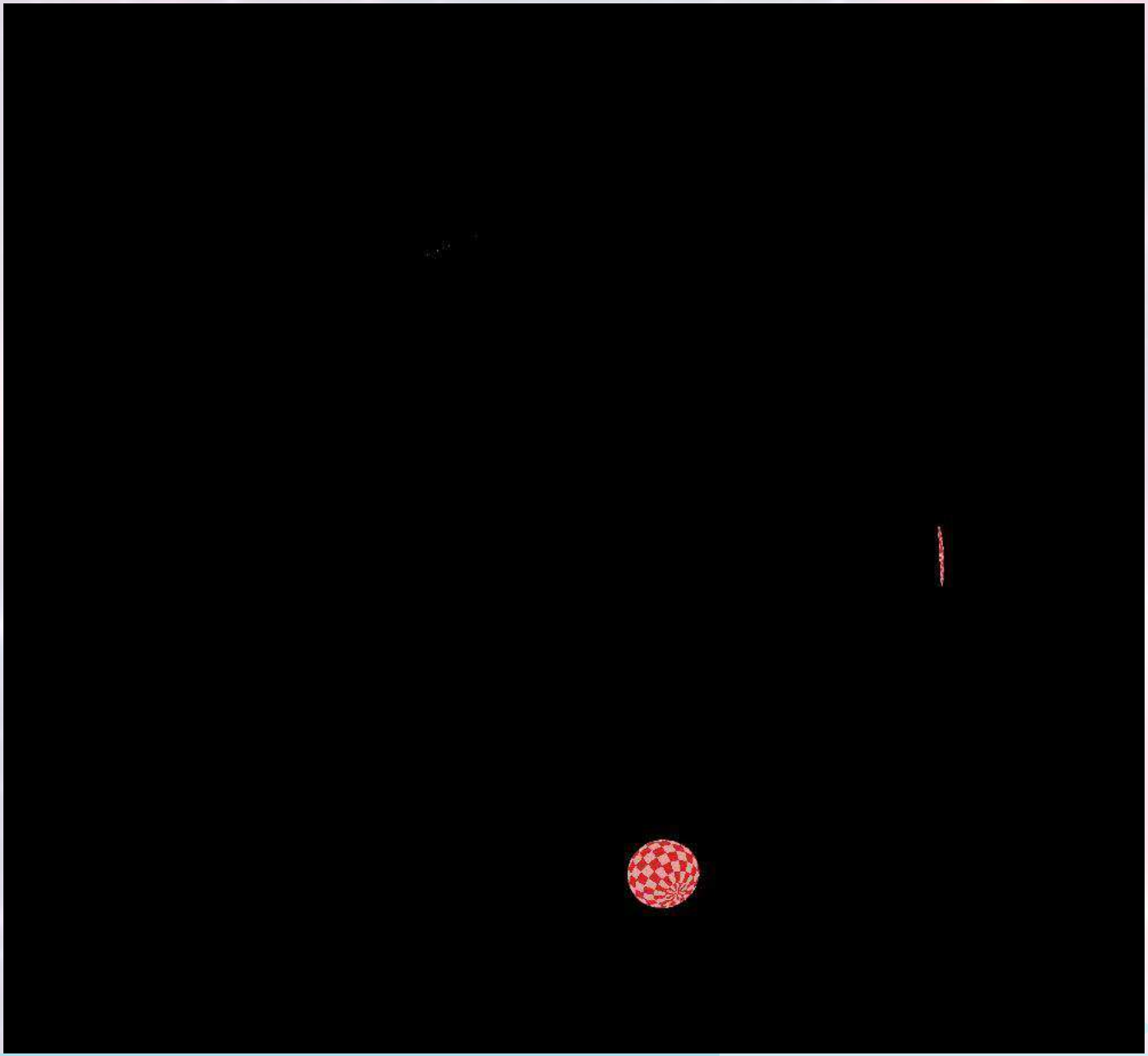
- $B = 100$-m baseline;
- reference–science objects distance: $\Theta = 1.2''$;

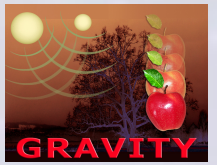
$\Rightarrow$ $\sigma_\Theta = 1\ R_S = 10\ \mu$as accuracy in $t = 65$ s integration time!

Rotating blob movie

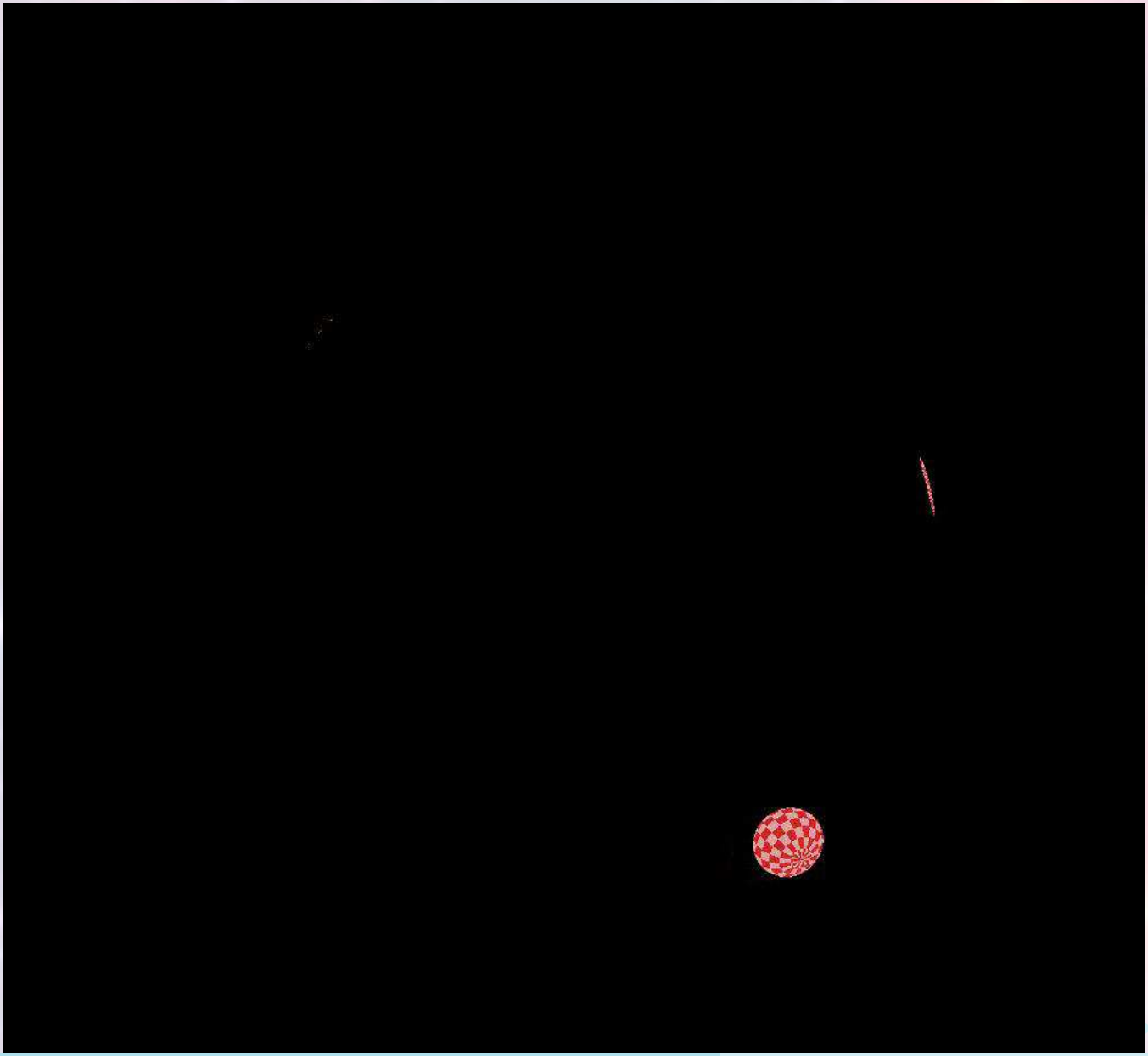


Rotating blob movie

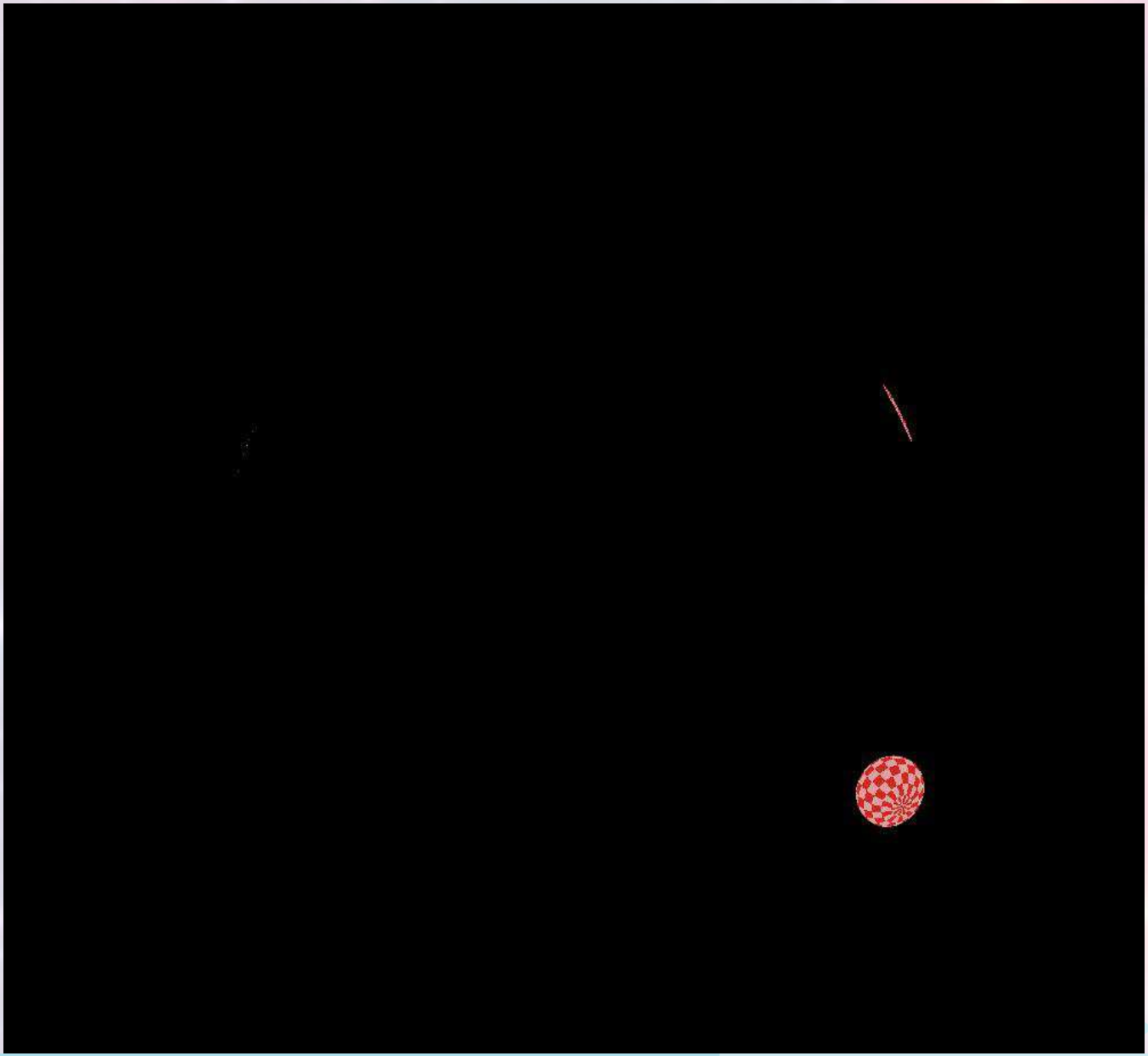




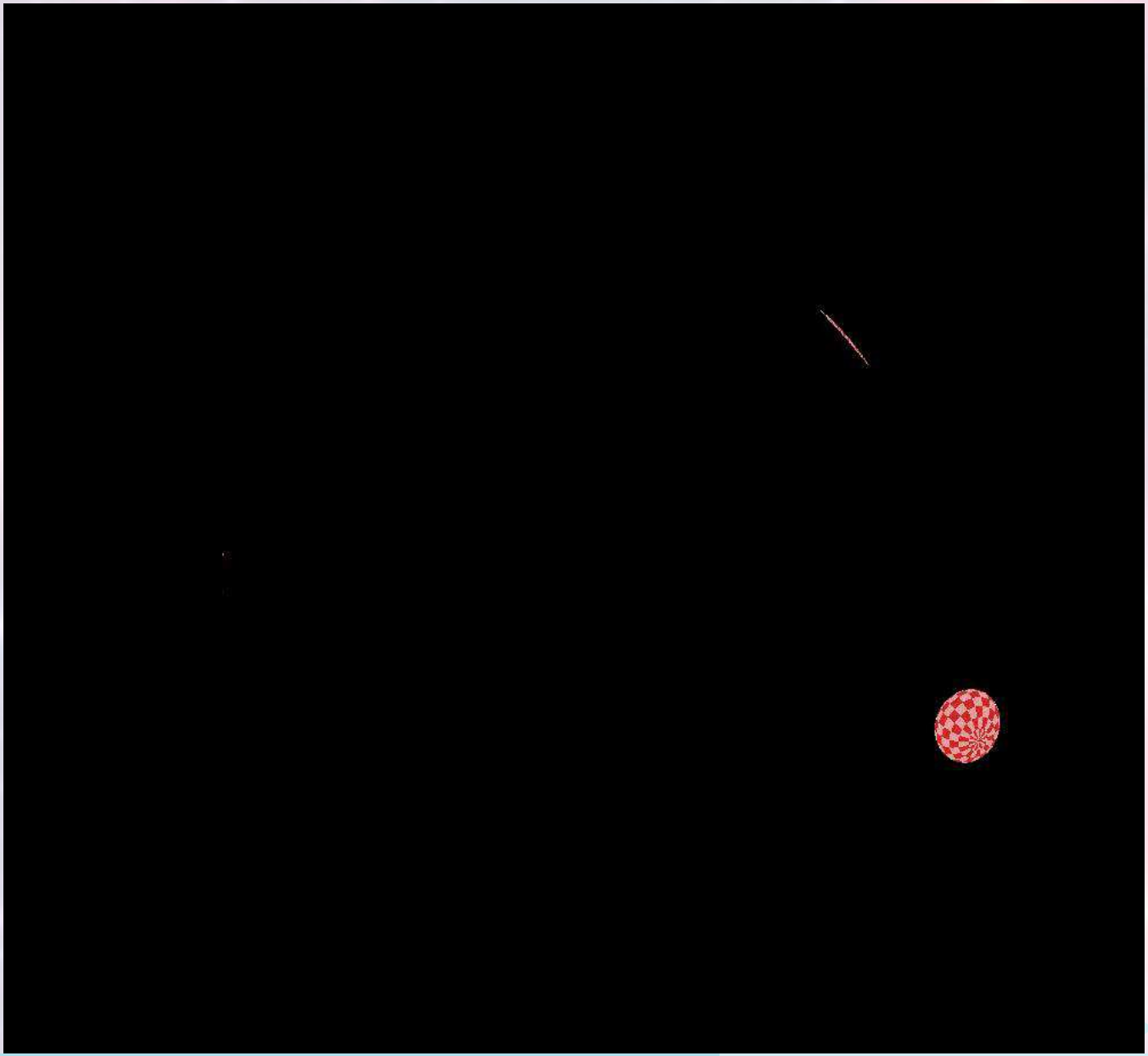
Rotating blob movie



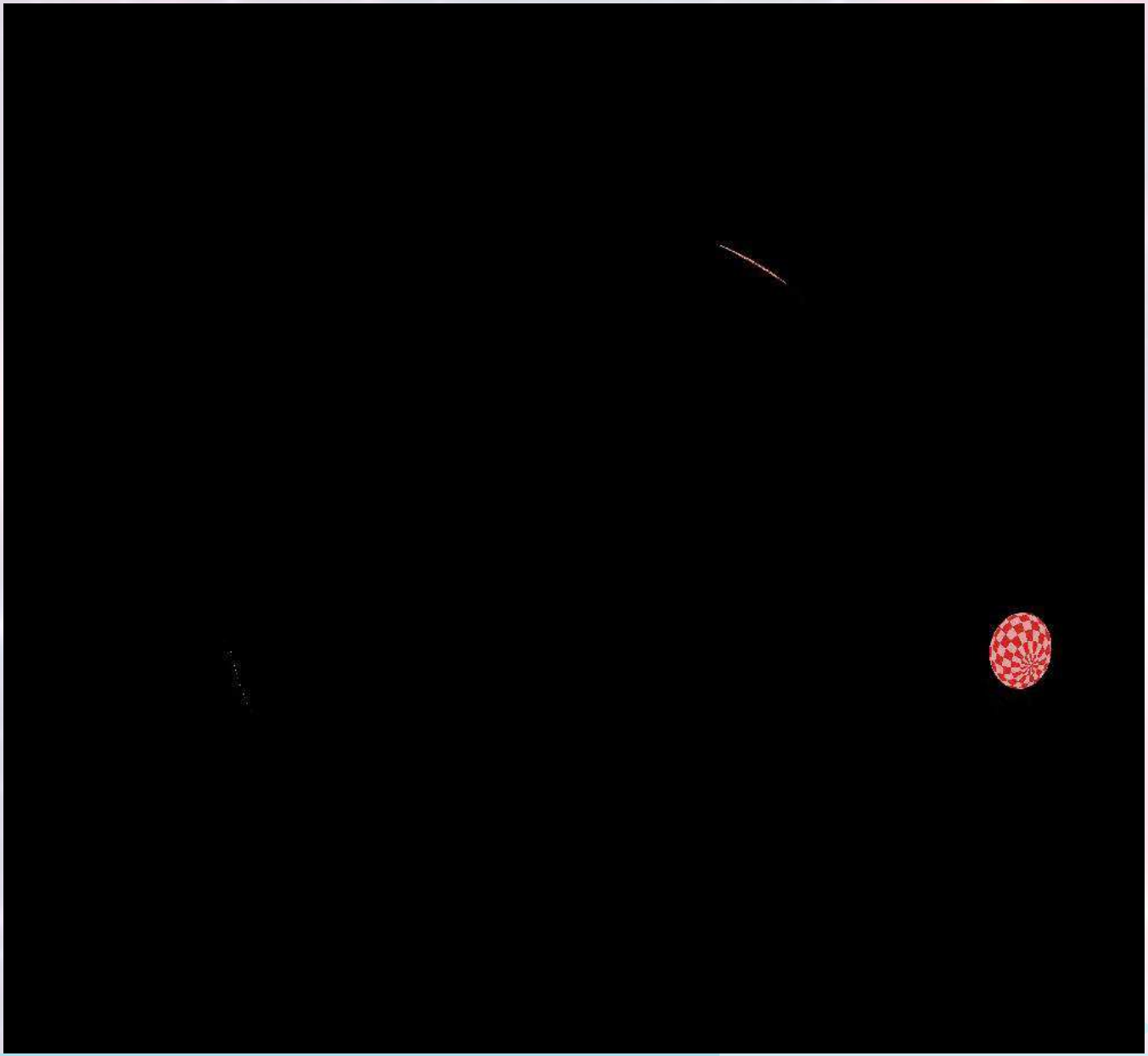
Rotating blob movie

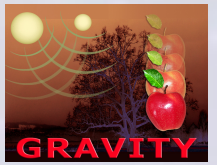


Rotating blob movie

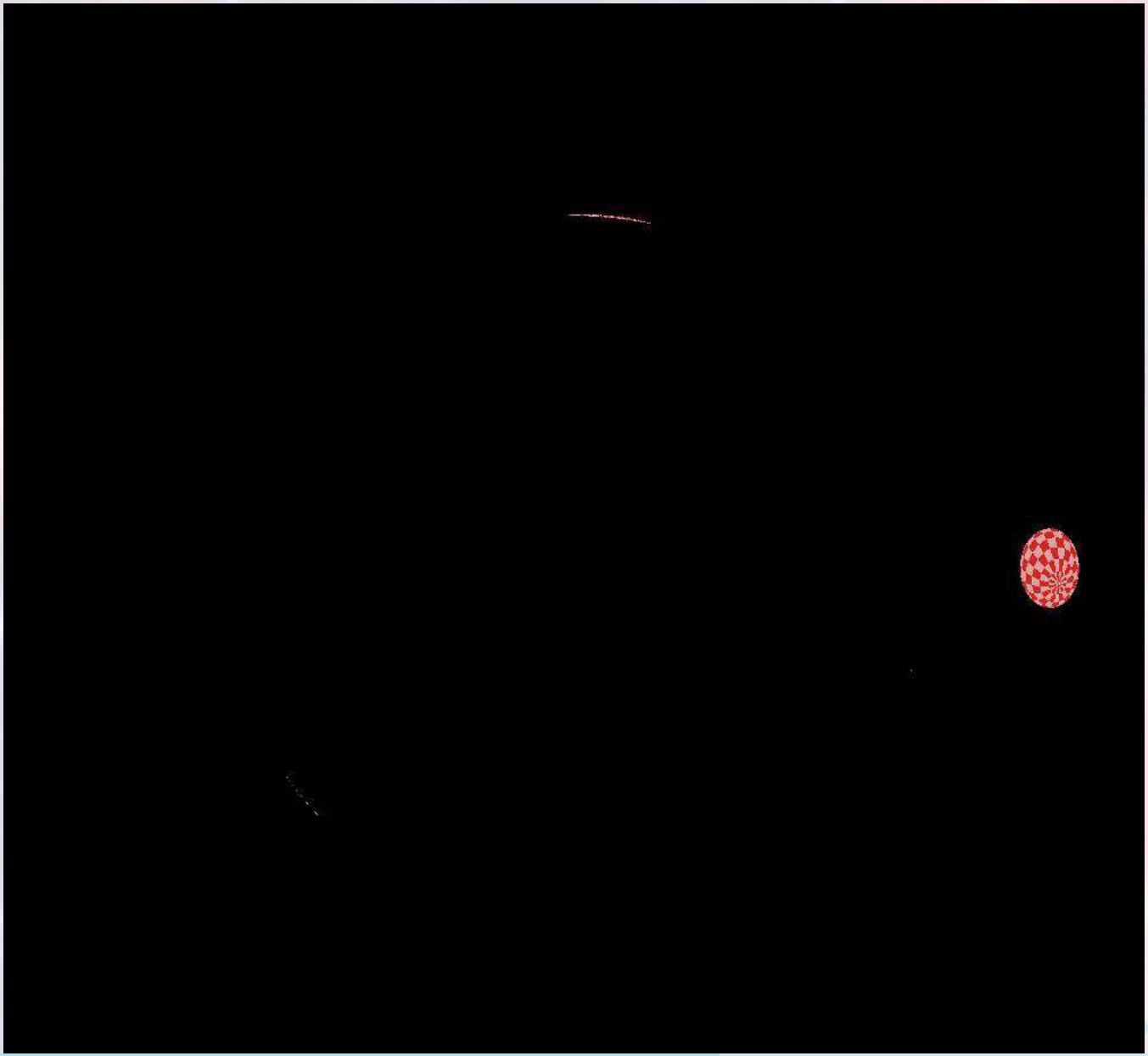


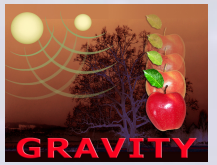
Rotating blob movie





Rotating blob movie

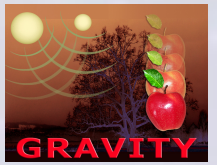




Rotating blob movie

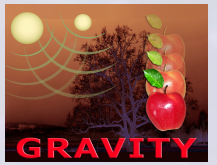
Rotating blob movie

Rotating blob movie

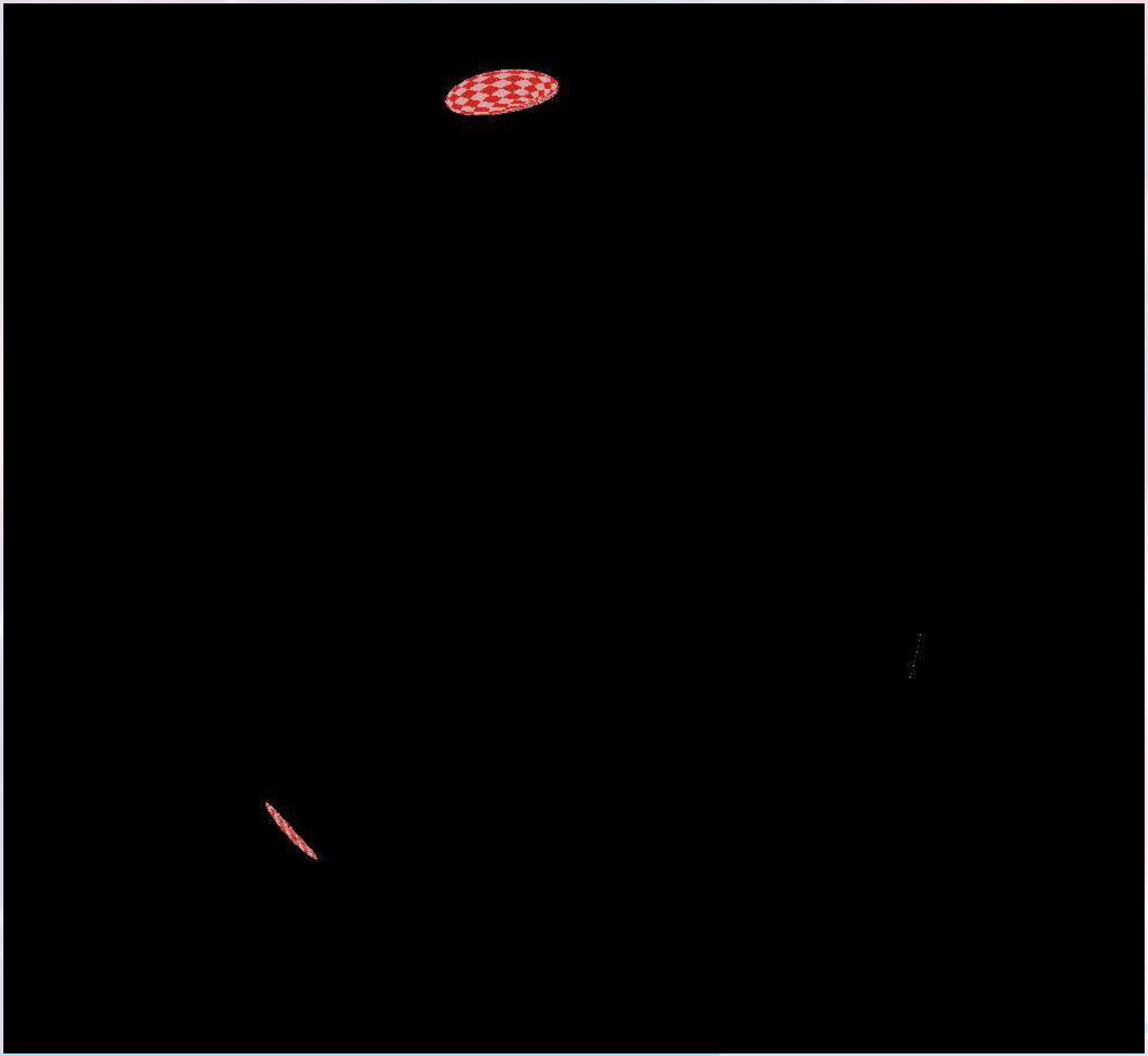


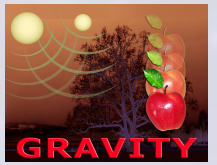
Rotating blob movie

Rotating blob movie



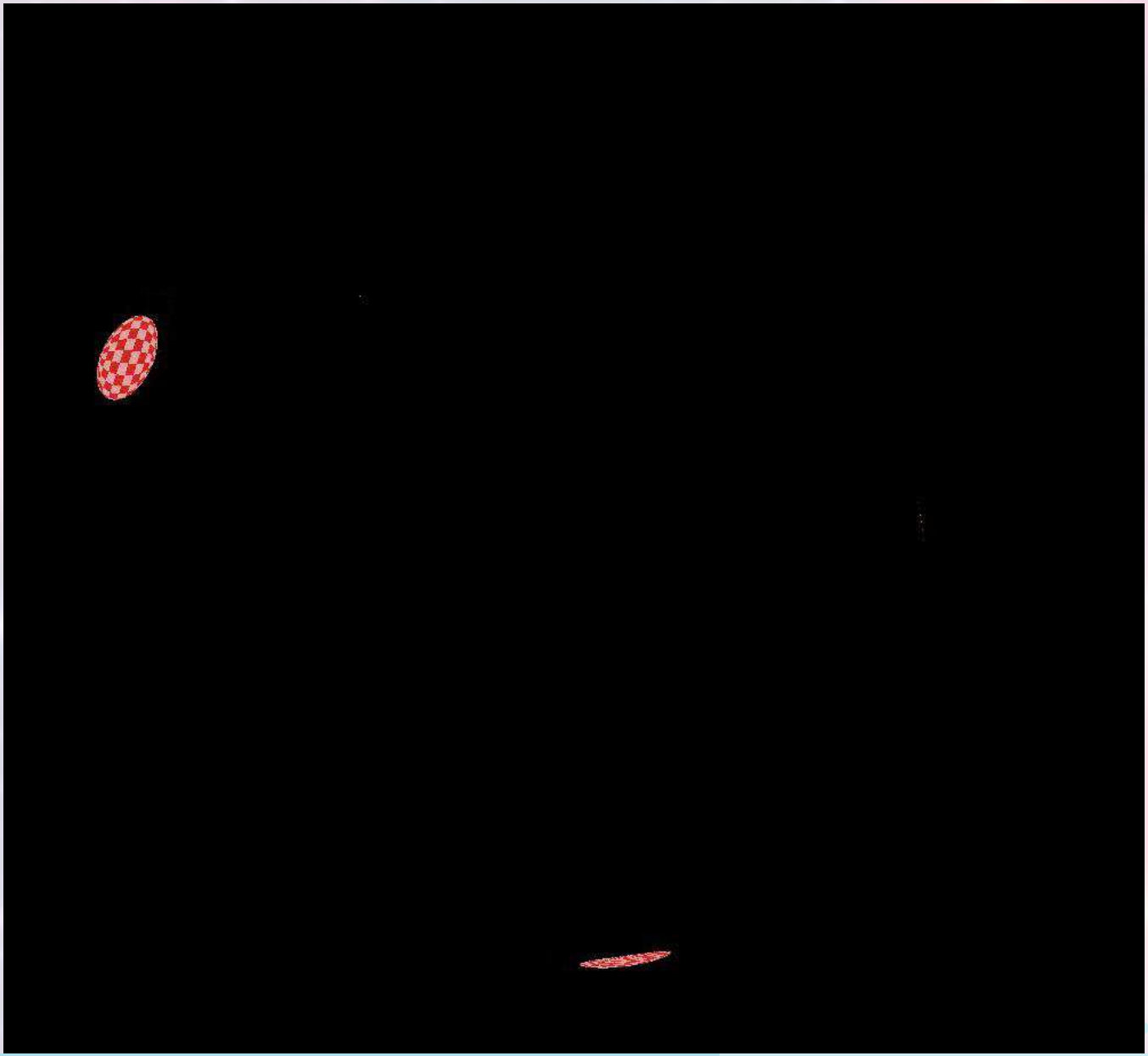
Rotating blob movie





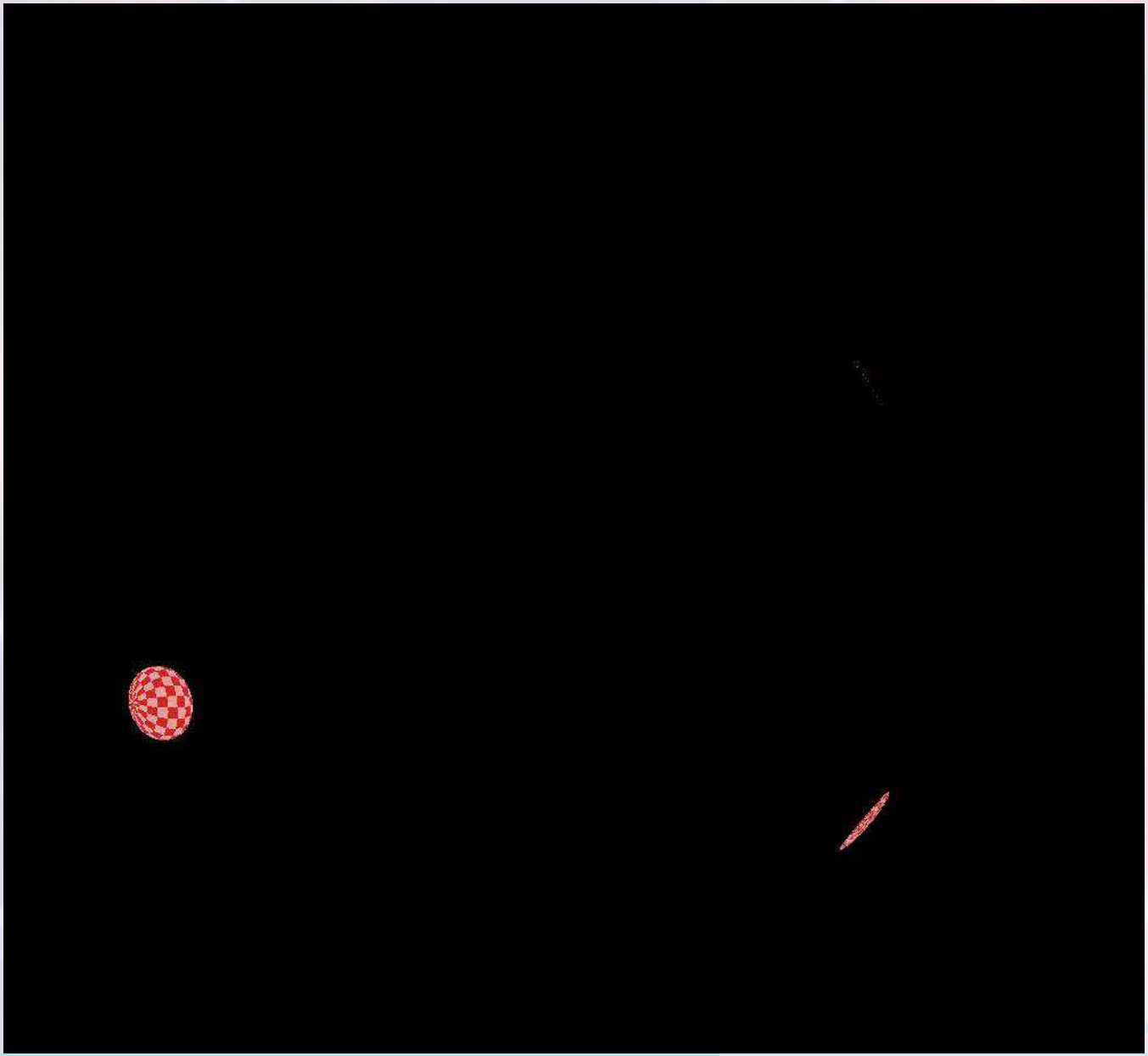
Rotating blob movie

Rotating blob movie

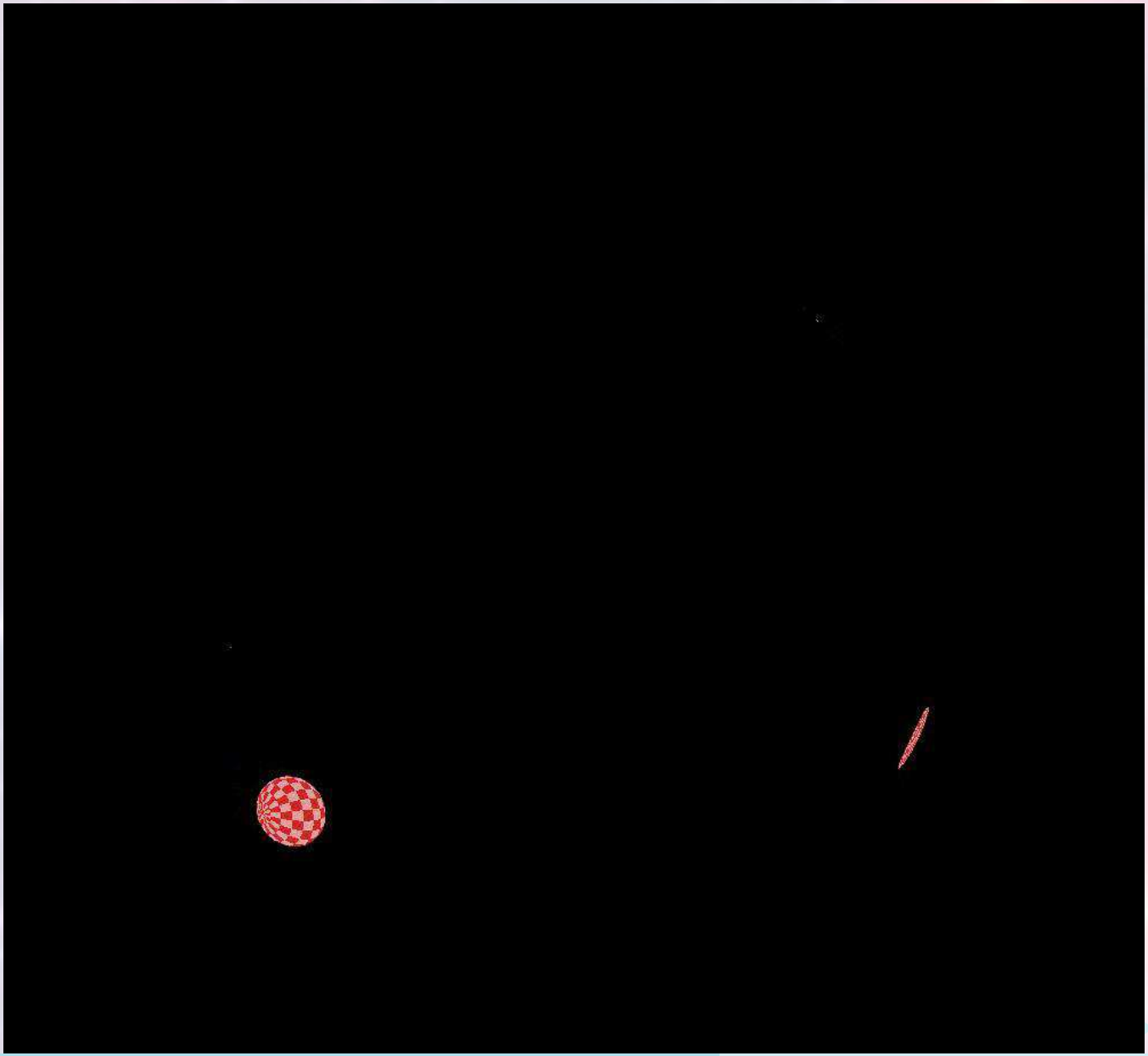


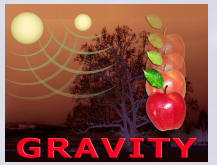
Rotating blob movie

Rotating blob movie



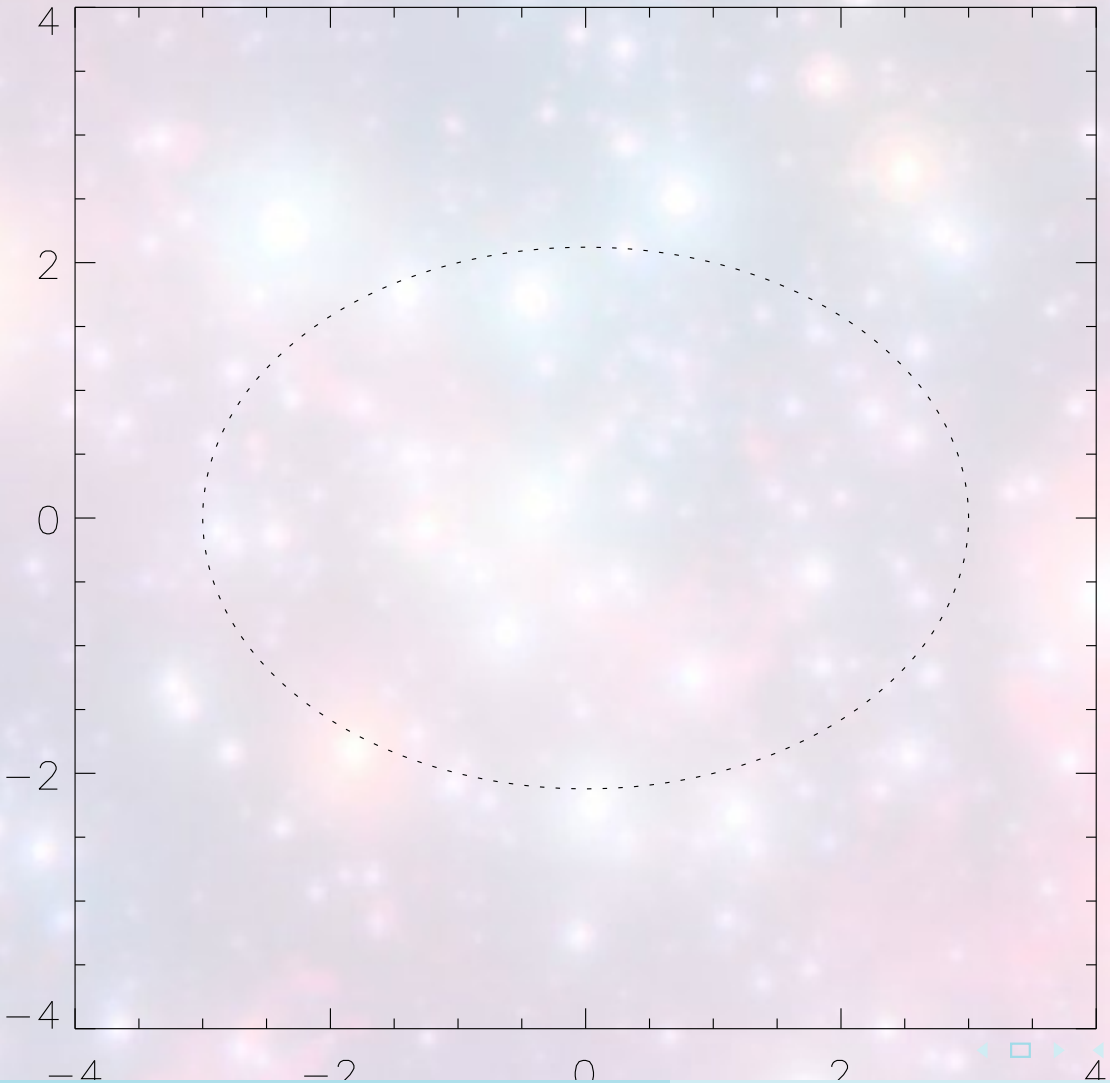
Rotating blob movie



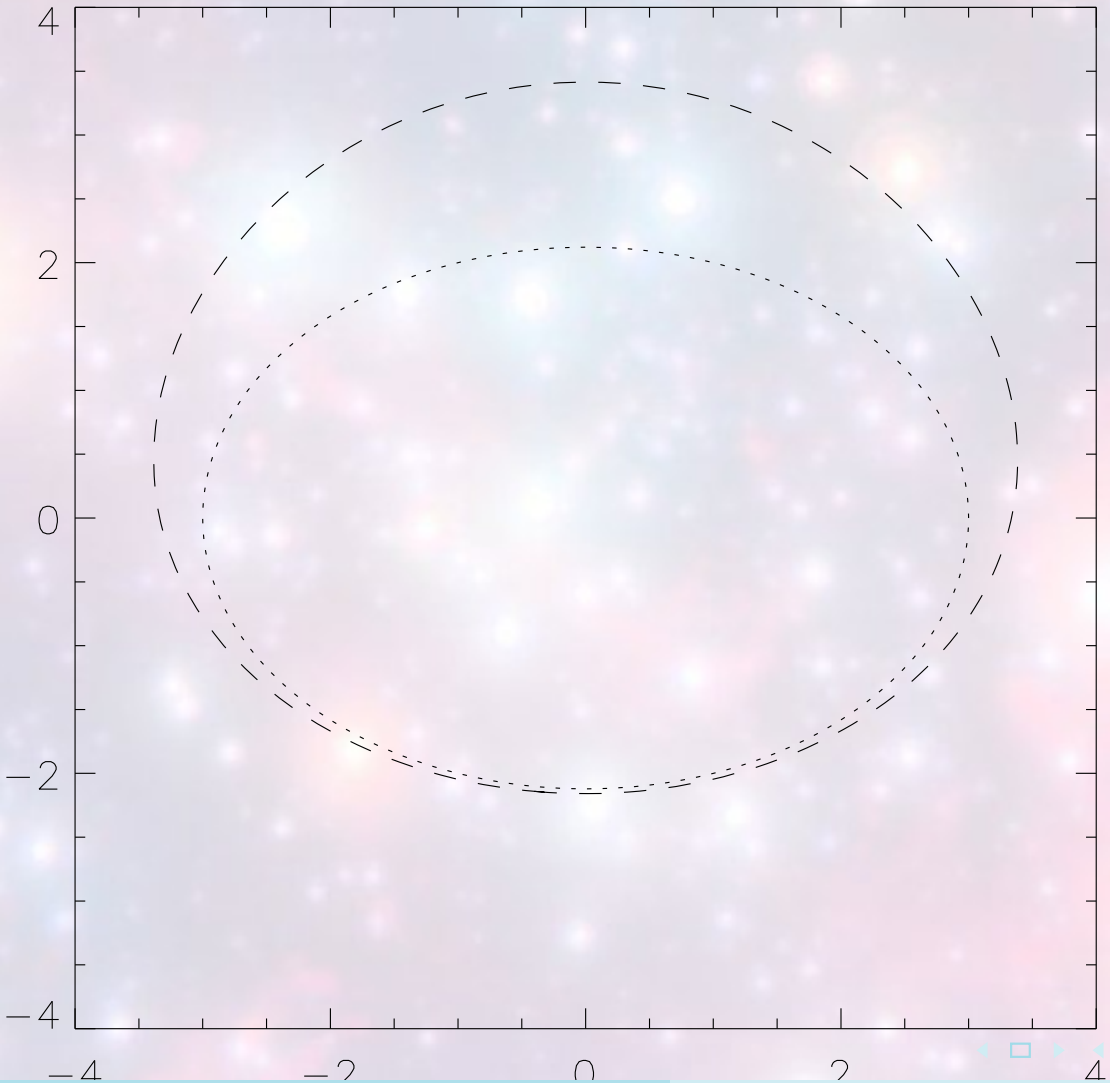


Rotating blob movie

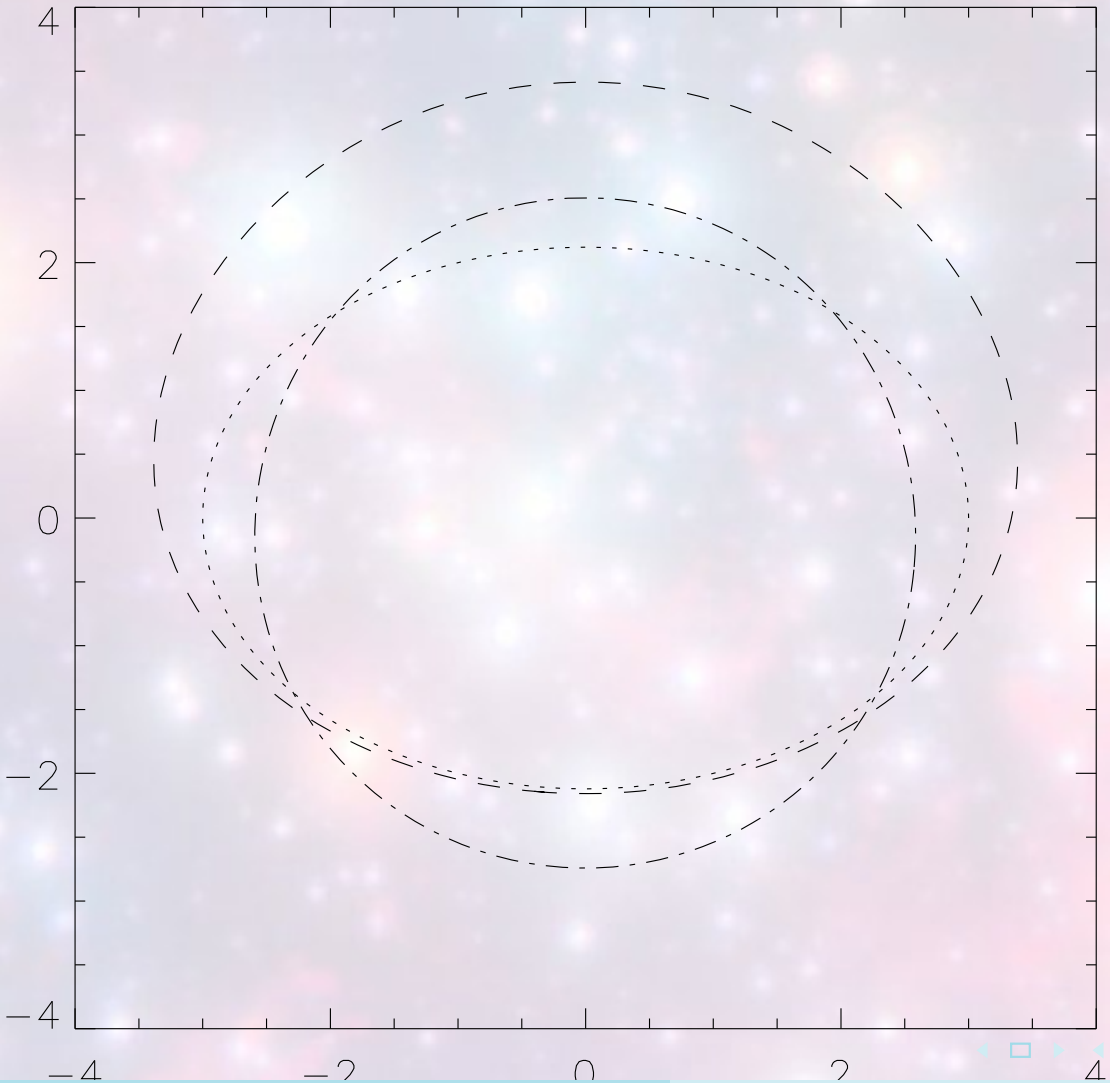
Astrometric model



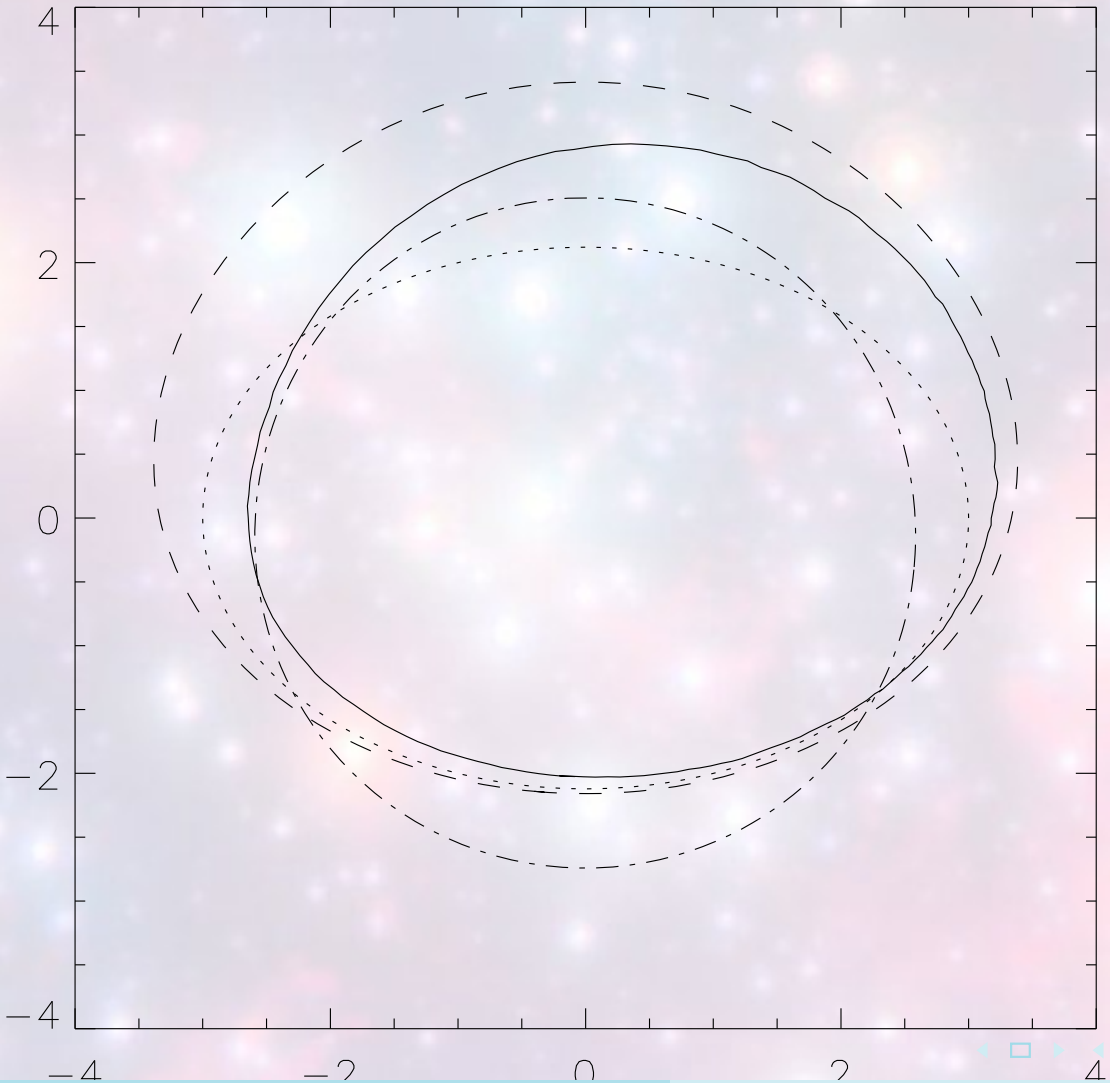
Astrometric model



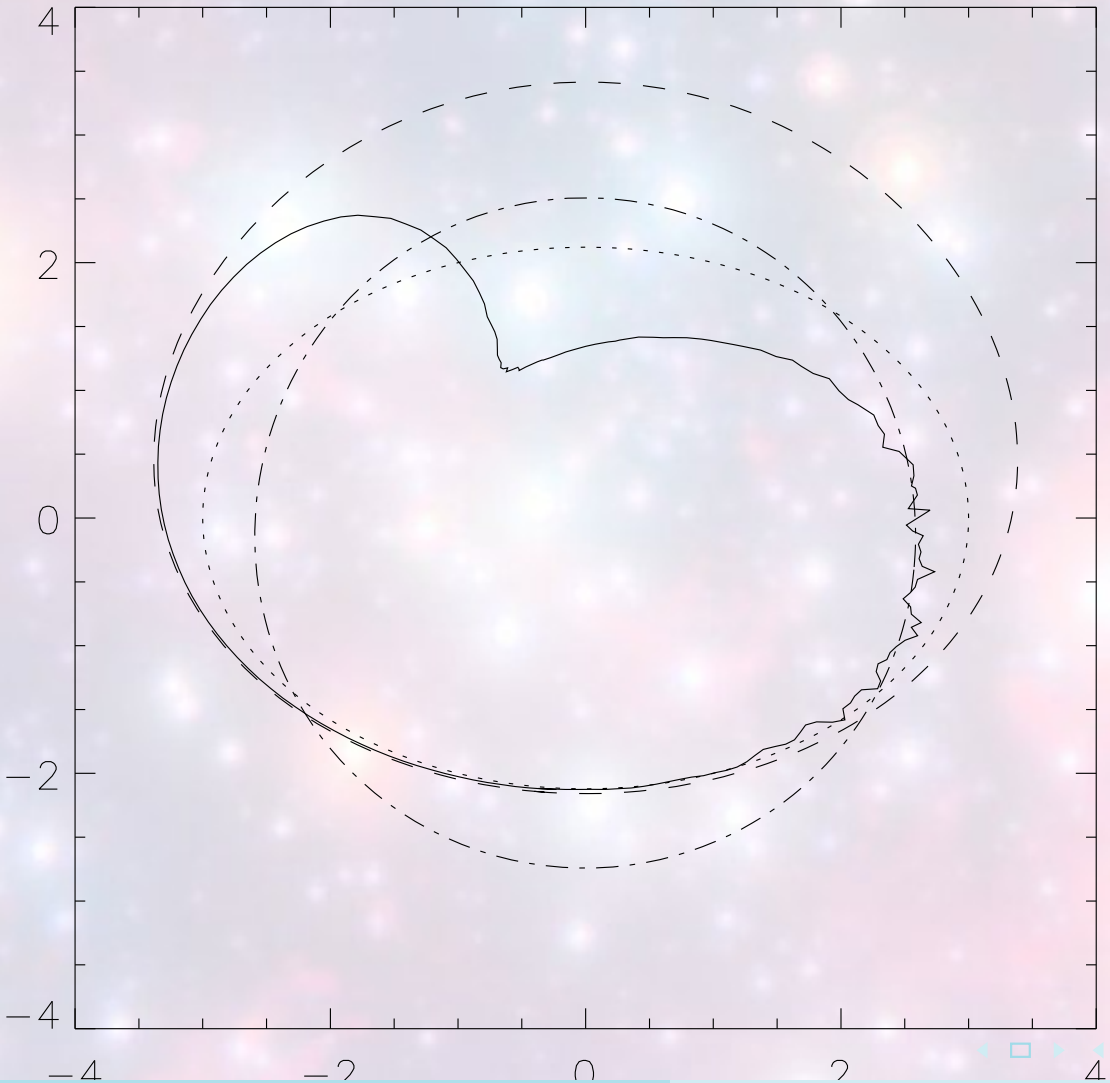
Astrometric model



Astrometric model



Astrometric model



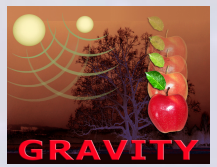
Astrometry of flares

A flare model

- Orbiting spot;
- On Last Stable Orbit;
- Shredded by tidal forces.

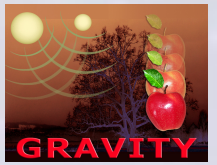
Whatever the model, 10μas is the right scale

- $c = 10\mu\mathrm{as/min}$
- $R_\mathrm{S} = 10\mu\mathrm{as}$



Unique calibration needs

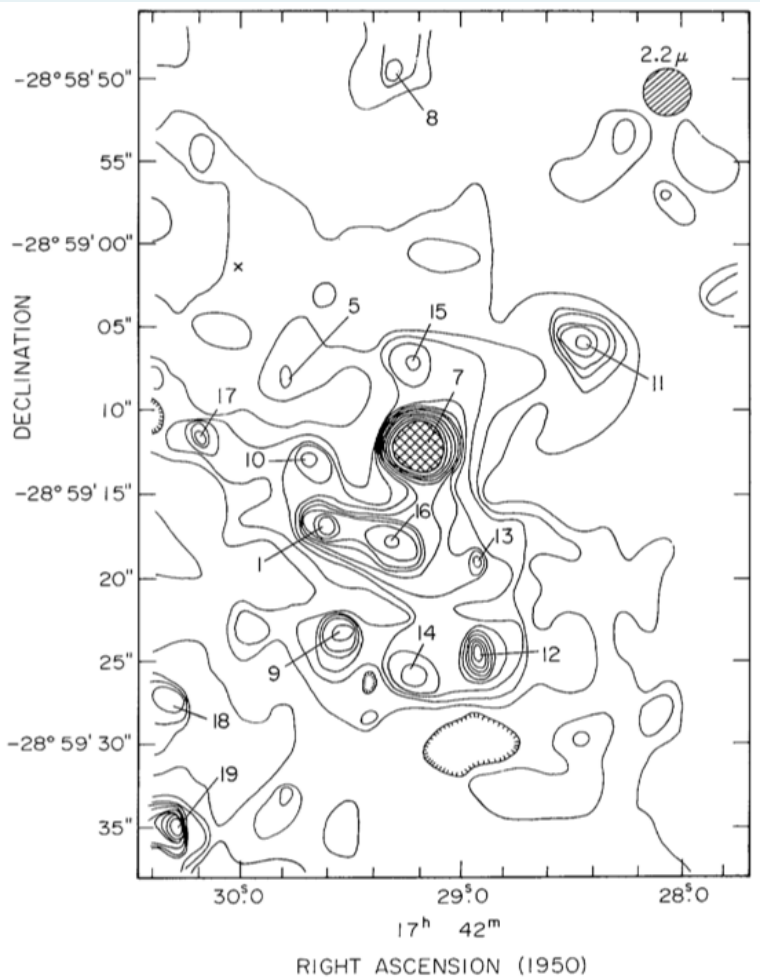
- To calibrate visibilities:
  - Point like stars at $K < 10$, all over the (Paranal) sky: check that they are really point-like (e.g. not astrometric binaries), measure distance to help constrain apparent size;
  - Point-like stars of $K < 16$, at less than 2'' from $K < 10$;
- To translate phases into arcseconds, need to measure the astrometric baseline:
  - Well known binaries all over the sky.



Outline

Active Galactic Nuclei

Becklin & Neugebauer 1975, 0.1pc aperture

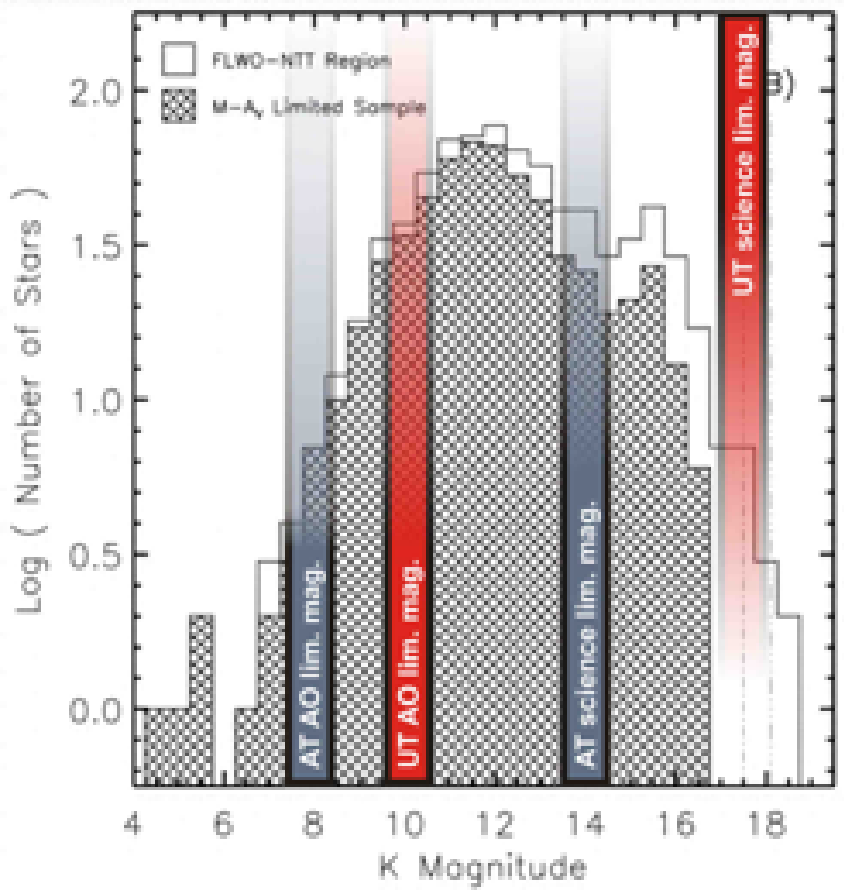


Same resolution up to 20 Mpc

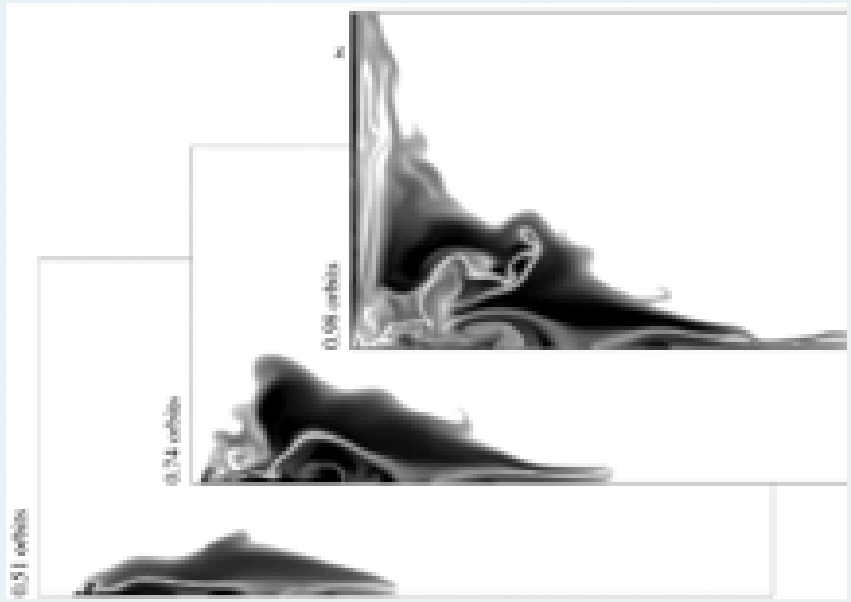
- Probe central 100 pc at any redshift;
- 11 pc res. in quasar PDS456 ($z = 0.184$);
- 0.1 pc within 20 Mpc (Circinus, Cen A);
- Velocity gradient in BLR $\Rightarrow$ rotation, size, BH mass.

Stellar-scale accreting systems

KLF of Orion Trapezium cluster



Muench et al. 2002

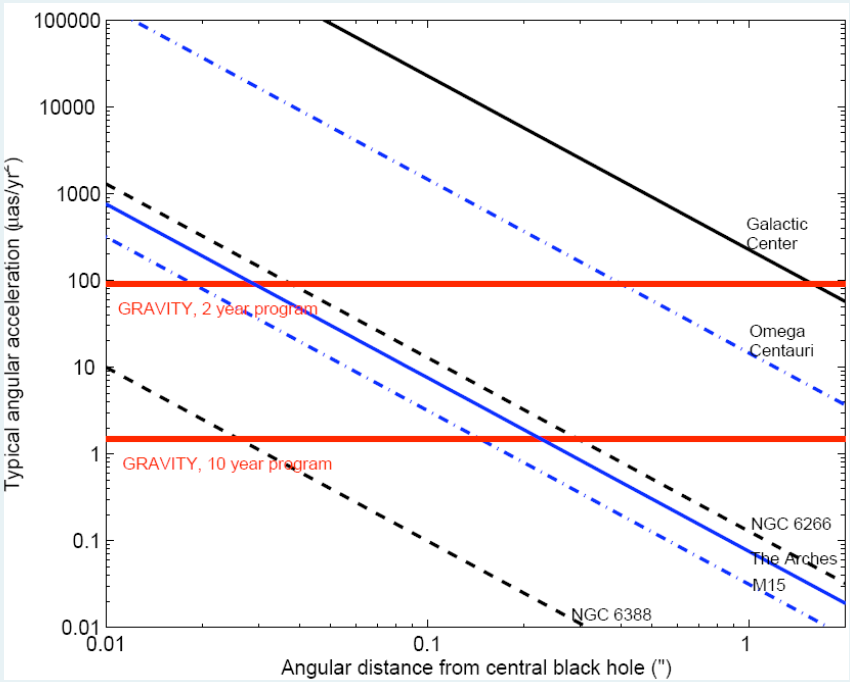


Turner et al. 1999, $\simeq$ 30 mas at 150 pc

- Protostellar and systems
- Microquasars;
- Structure of disk;
- Evolution of jet

Complex stellar system

Detect acceleration of stars orbiting BHs in globular clusters



Astrometric determination of masses

- Intermediate mass black holes:
  - GCIRS 13E;
  - Globular clusters;
- Companions in binary stars;
- Exoplanets:
  - Photocentre wobble due to orbital motion;
  - Photocentre displacement due to transit.

Outline

GRAVITY: general purpose imager + exceptional astrometry

- First light: November 2015!
- Optimised for top-level GC science:
  - Dynamics of stars at $\simeq 1000 R_S$;
  - Proper motion of material at few R_S;
- High-dynamics spectro-imaging at K-band:
  - Spatial resolution: few mas;
  - Spectral resolution: up to 4000;
  - Very sensitive;
- 10μas astrometry within minutes!

$\Rightarrow$ General purpose instrument:

- (A)GNs imaging + dynamics;
- Spectro-imaging of protoplanetary disks & jets, microquasars;
- Astrometric masses: black holes, brown dwarfs, exoplanets...
- <insert favorite interferometric case here>