The Antennae Galaxies: Archetype for Colliding Galaxies

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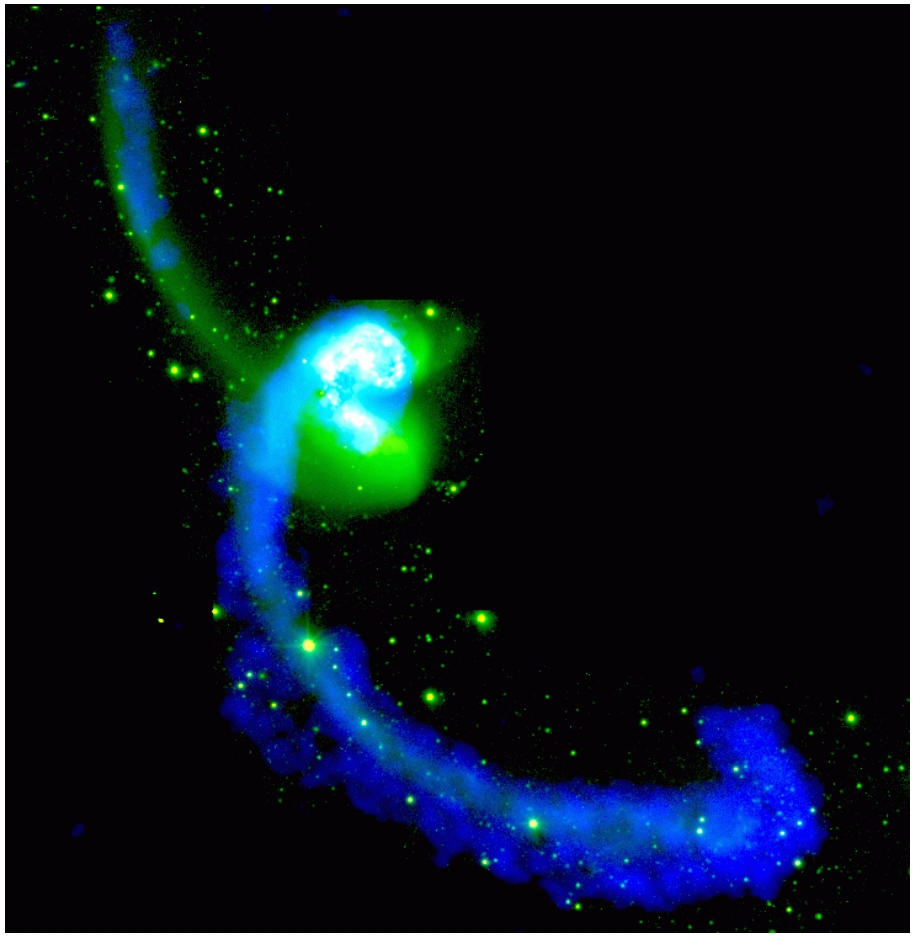
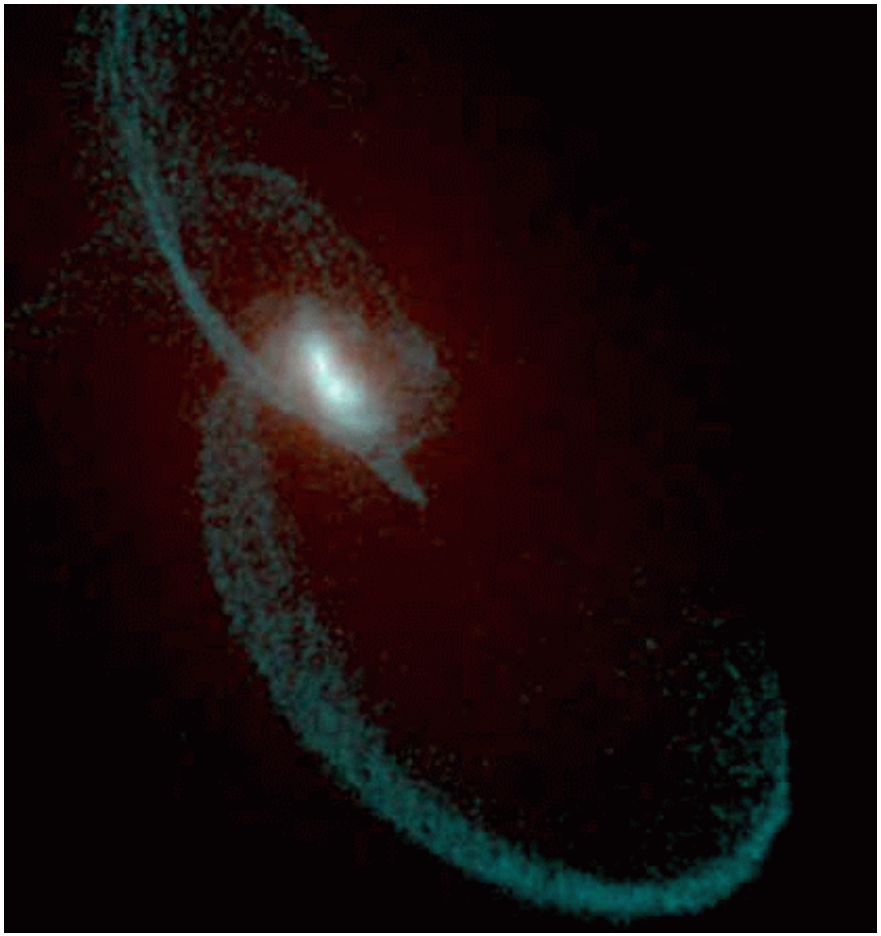
Punch line: We present a new model of the interacting galaxy NGC 4038/39 ("The Antennae"). This is the first realistic model which matches both the observed shape and motions of the tidal features.



Observations



New Simulation

Historical Background: NGC 4038/39

- 1830's: Cataloged as entires 4038, 4039 in the New General Catalog (NGC).
- 1922: brief description by Perrine, `Notes on Four Interesting Nebulae': "Hook extending out from a Ring".
- 1923: first description in terms of "Antennae" by Duncan.
- 1940: first description in terms of tidal interaction by Holmberg.
- 1972: first referred to as "The Antennae" by Toomre & Toomre, who also present the first interaction model able to reproduce crossed tails.

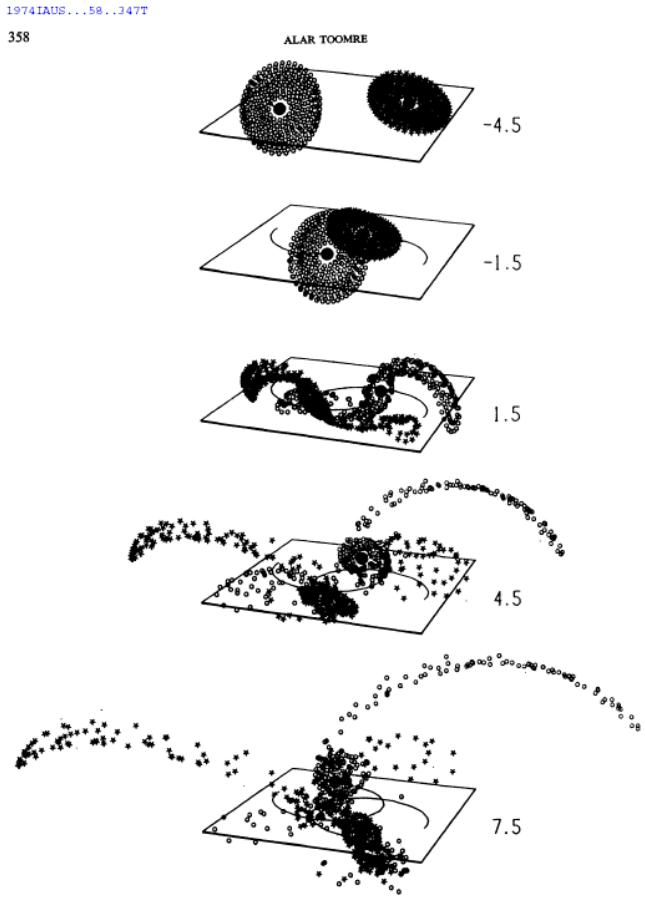


Fig. 9. Five views of the symmetric close encounter of two 60°-inclined disks of test particles presumed by TT (§VI.d) to caricature the recent history of NGC 4038/9. These views are equally spaced in time, with the instant 0 (not shown) meant to represent pericentre. The stereographic projection used here assumes a vantage point at a distance equal to 16 times that of the closest approach of the two central masses, or four times the edge length of the square that denotes their common orbit plane.

Ever since Toomre & Toomre (1972), The Antennae has been a key system for validating the once controversial idea that galaxies can and do merge

Challenges to Collisional Interpretation

- 1962, IAU 15, 194, Vorontsov-Velyaminov
  - Tails too long and thin to be tidal
- Refuted: 1978, Schweizer
  - Tails not as thin as you think

GALAXIES WITH LONG TAILS

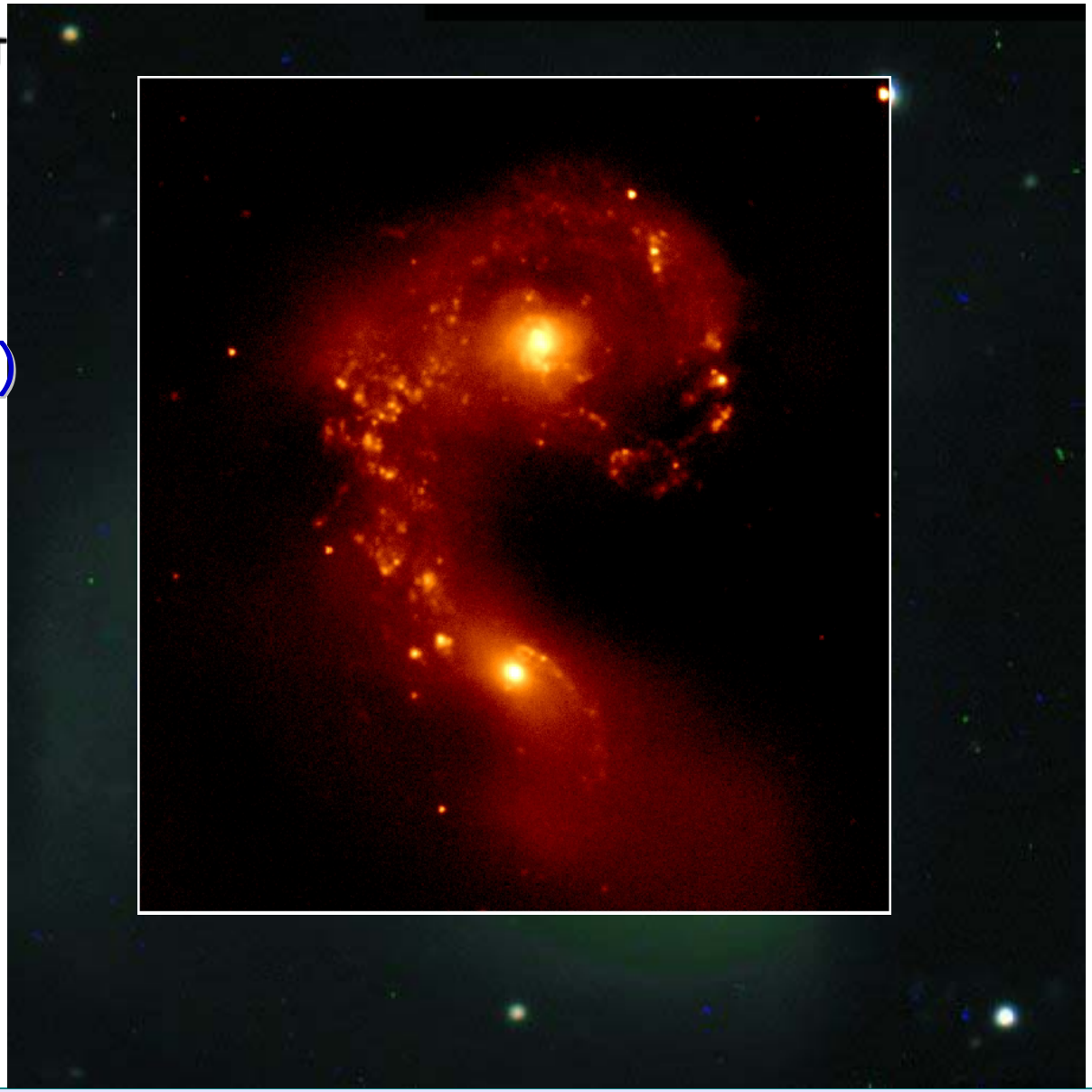
François Schweizer
Cerro Tololo Inter-American Observatory*

E. M. Berkhuijsen and R. Wielebinski (eds.), Structure and Properties of Nearby Galaxies, 279–286.

Figure 1. NGC 4038/9 on IIIa-J plates obtained with the CTIO 4-m telescope. North is at the top and east is at the left. (a) (left) Exposure of 50 minutes. (b) (right) Superposition print of two plates totalling 3.5 hours of exposure time. Note the dwarf stellar system near the tip of the southern tail.

Challenges to Collisional Interpretation

- 1976, 1977 Vorontsov-Velyaminov
  - Not two (obvious) progenitors
- Refuted: 1990, Stanford & Bushouse (use NIR to look through dust)

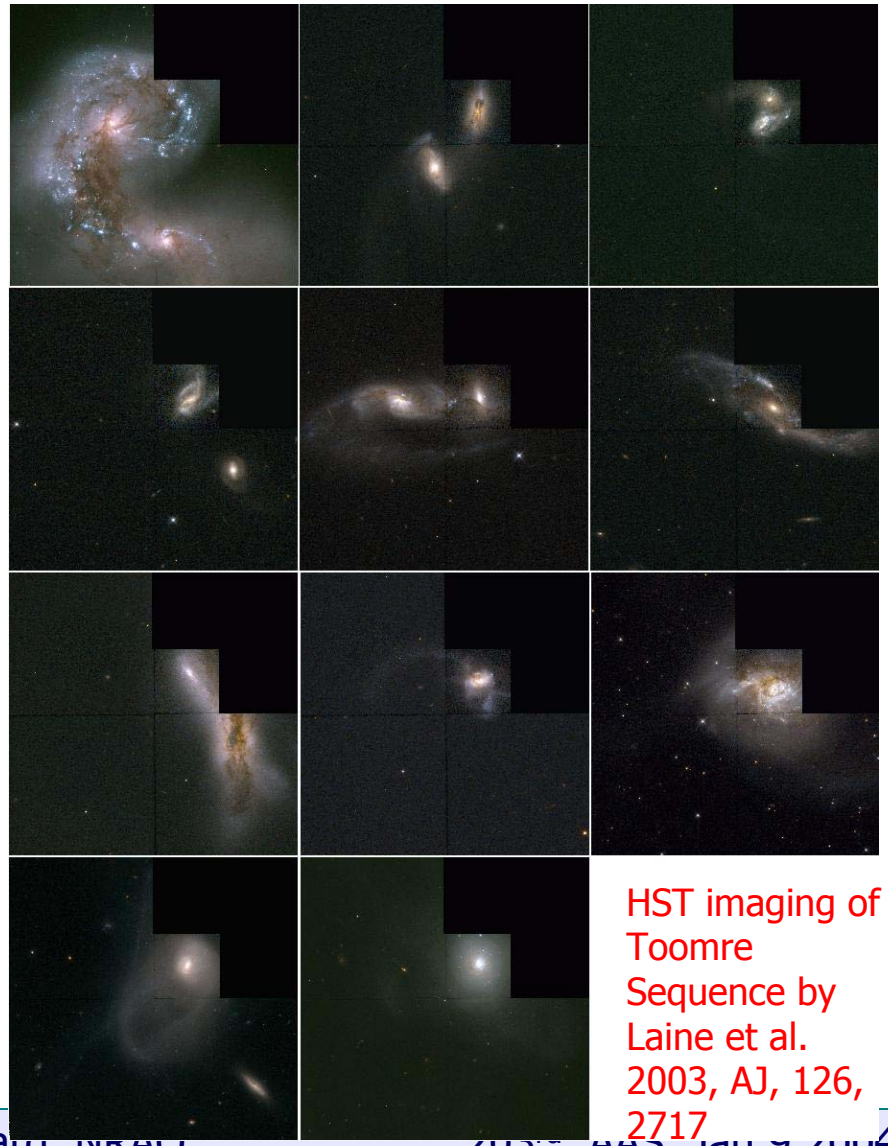


B. Brandt & WIRC team
(Cornell; APOD 2002-Apr-11)

NGC 4038/39 is the first member of "Toomre Sequence" of merging galaxies

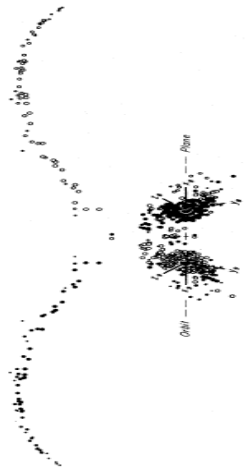
Toomre, 1977, *"Evolution of Galaxies & Stellar Populations"*, 401

- Suggestive sequence of peculiar galaxies representing the concept that two spiral galaxies could merge and evolve into an elliptical galaxies (The Toomre "Merger Hypothesis")
- Also closest member; may represent our best chance for understanding merging galaxies



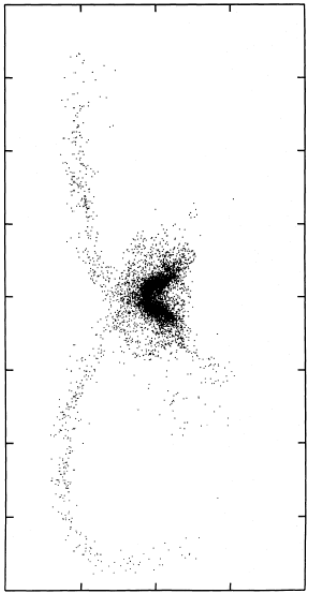
HST imaging of Toomre Sequence by Laine et al. 2003, AJ, 126, 2717

Modeling History

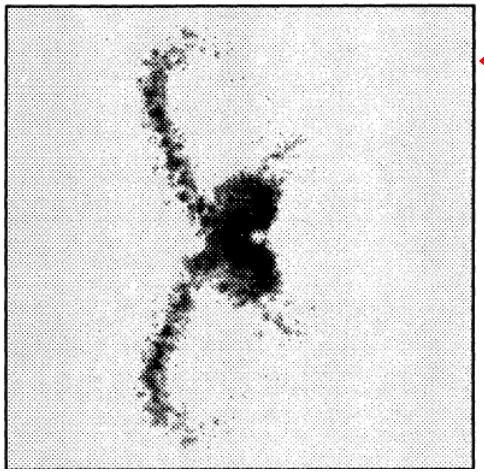


1972, Toomre & Toomre, test particles

Observations

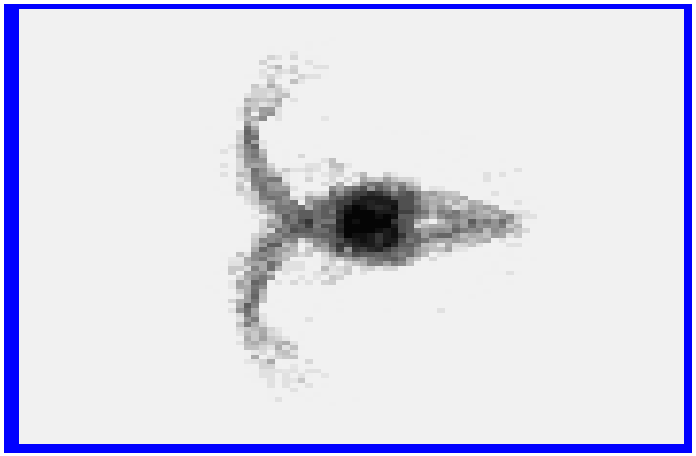


1988, Barnes, self-consistent

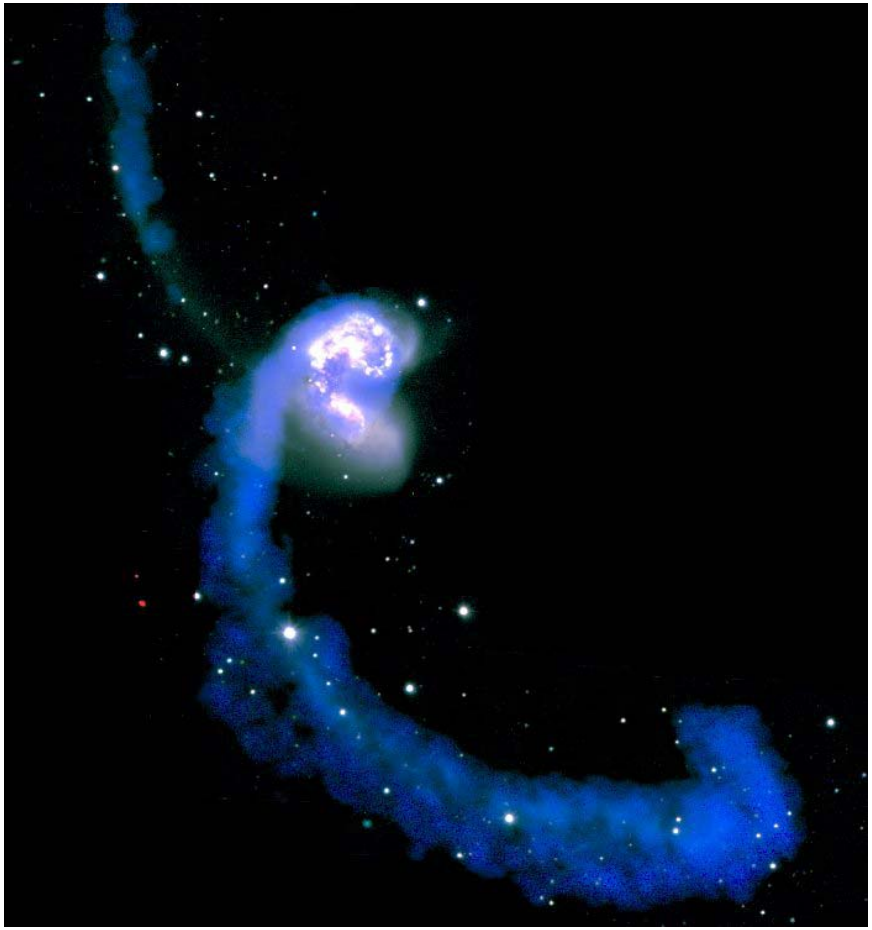


1993, Mihos et al.,
Self-consistent+gas dynamics

1996, Dubinski,
Self-consistent,
parabolic encounter



New modeling effort made possible by sensitive, high resolution observations of the cold atomic gas using the National Science Foundations Very Large Array (VLA) telescope



Blue=VLA HI Observations

Hibbard, van der Hulst, Barnes & Rich 2001, AJ, 122, 2969

Simulation

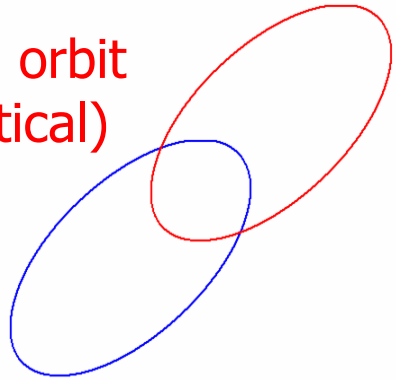
Blue=disk particles Red=halo particles

Our model is the first detailed match to the observed shape and motions of the tidal tails, using realistic galaxy models and starting conditions

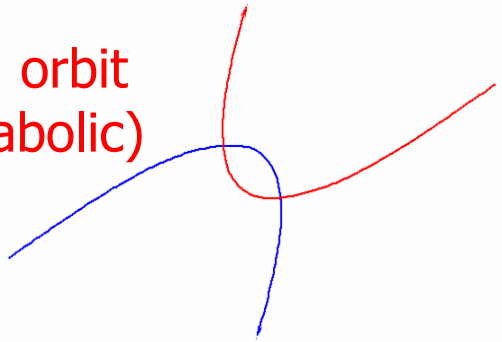
Yellow=HI data points (position and velocity)

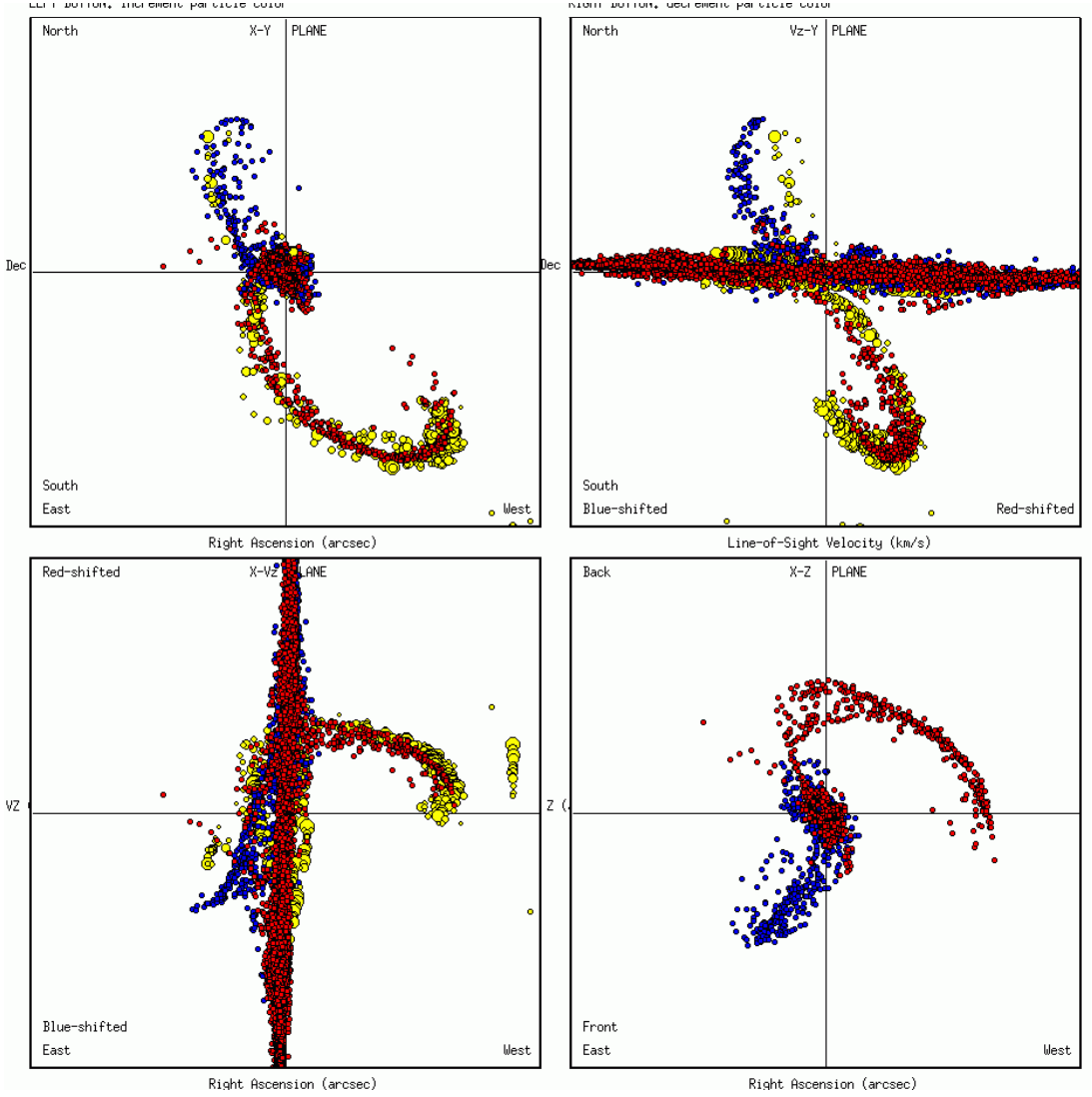
Red & Blue=simulation data points

e=0.5 orbit (elliptical)



e=1 orbit (parabolic)

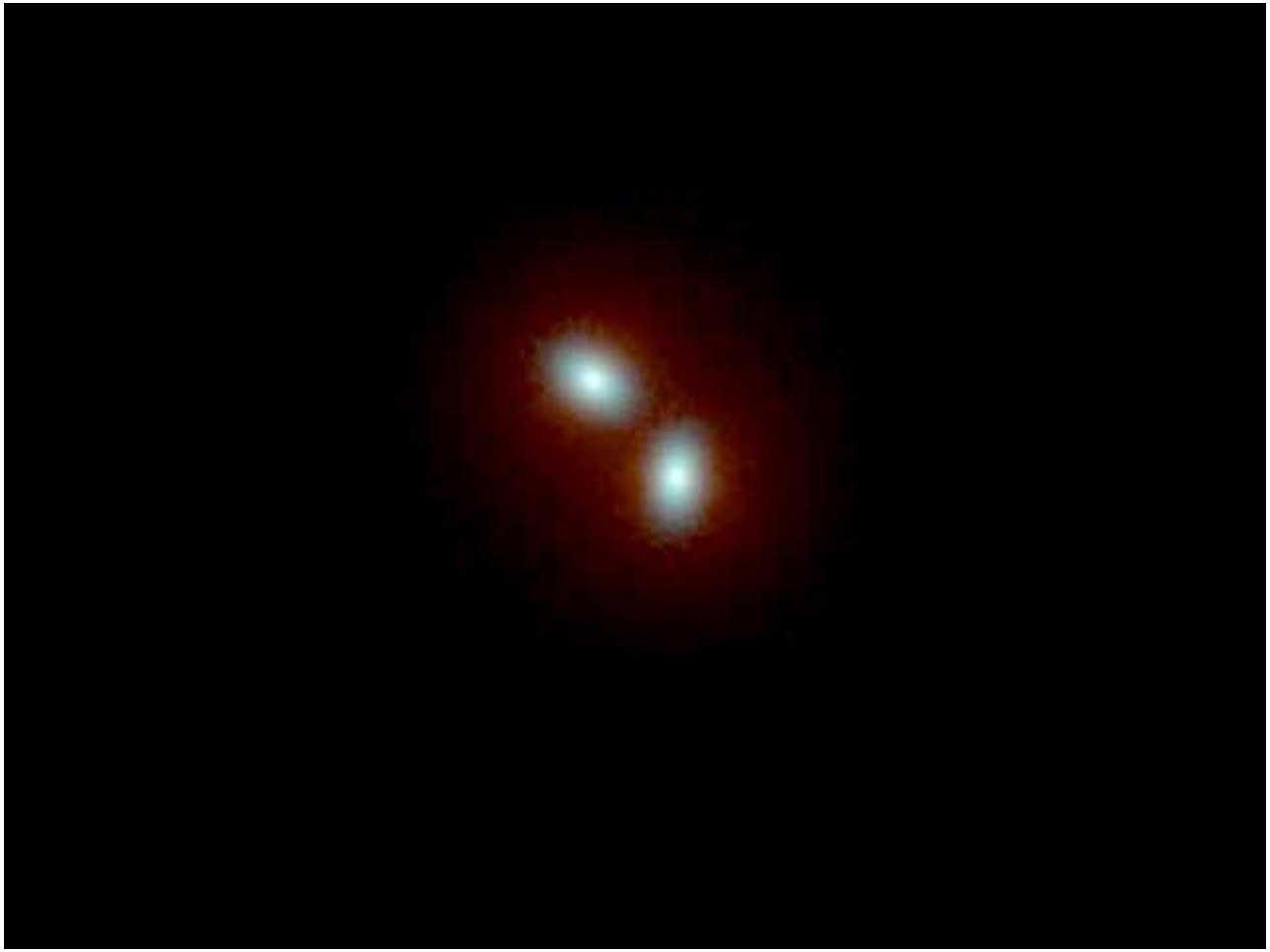




Time Evolution

http://www.ifa.hawaii.edu/~barnes/pressrel/antfacts/

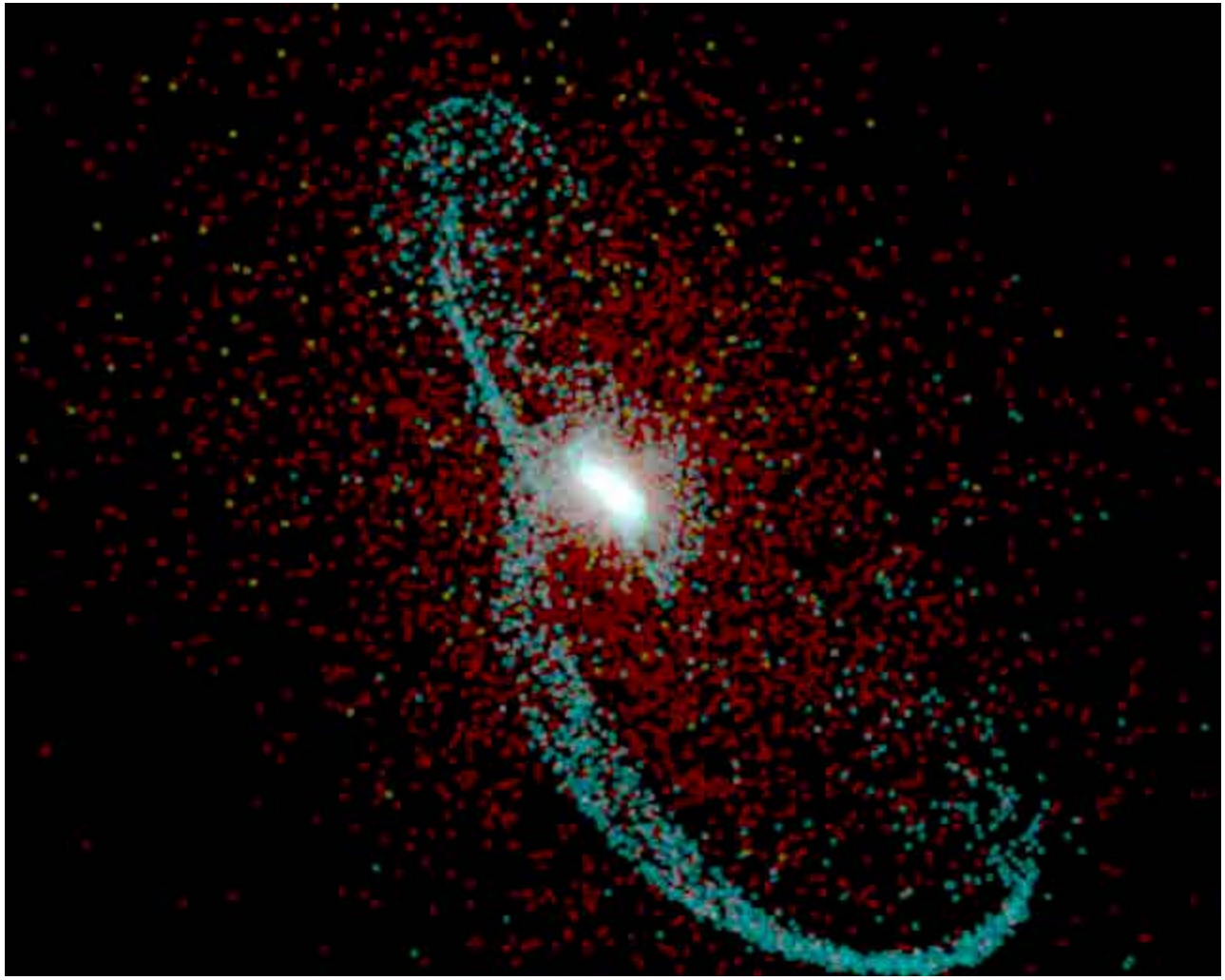
1 million particle simulation of best fitting parameters



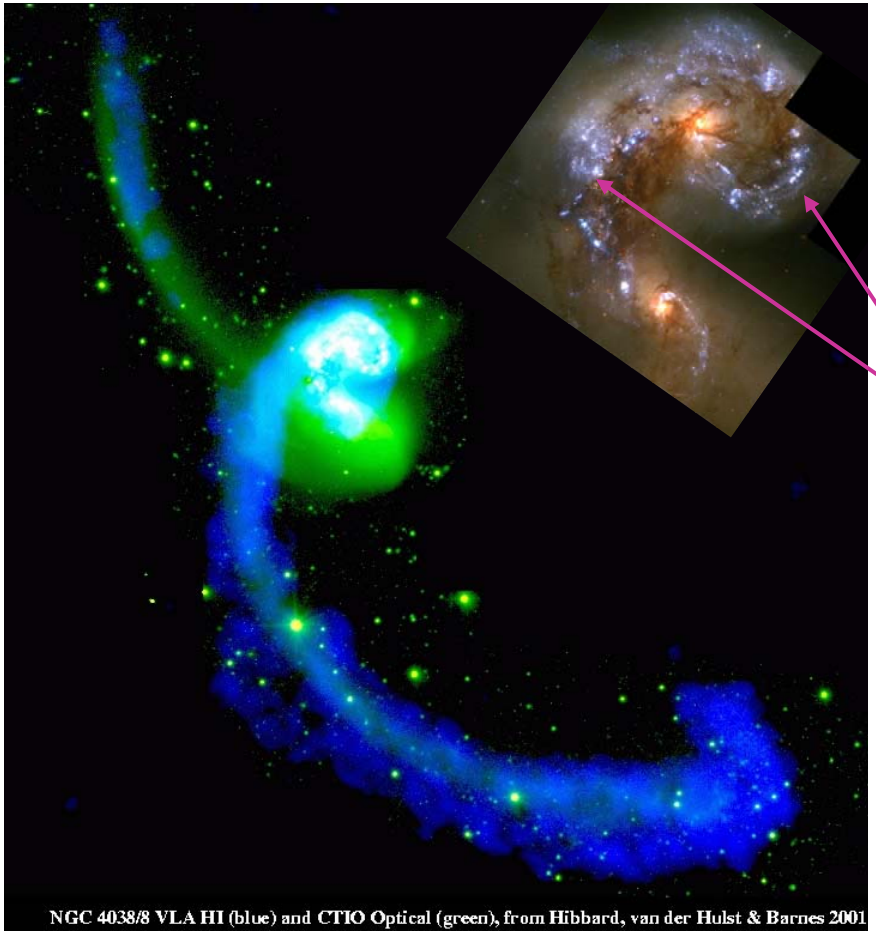
System made first pass ~220 Myr ago; will merge in ~40 Myr

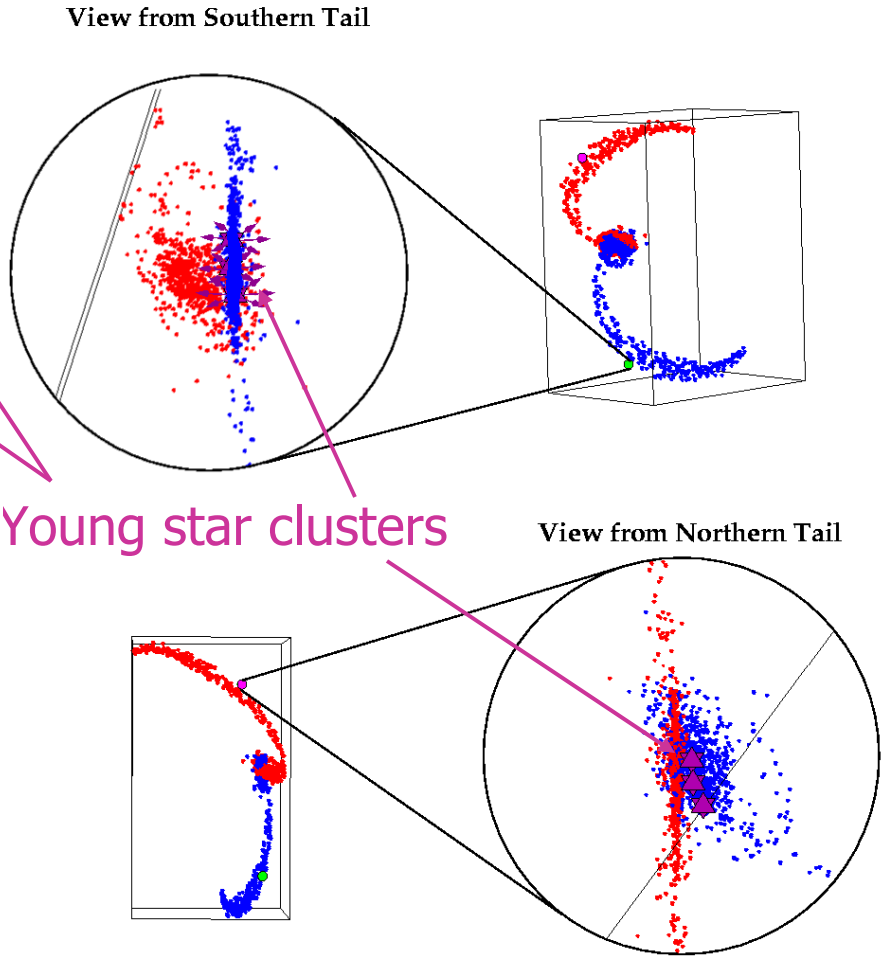
3-dimensional structure of The Antennae

http://www.ifa.hawaii.edu/~barnes/pressrel/antfacts/



3-dimensional structure of The Antennae may help explain some outstanding puzzels





Our new model is an important step towards increasing our understanding of this merger archetype

- First model which matches both the observed shape and motions of The Antennae tidal features in detail.
- Parabolic orbit much more plausible starting condition
- Time evolution can be compared to data from star clusters/populations/element enrichment
- 3-d structure can help us understand some outstanding puzzels