X-ray binaries

KEY POINTS

- Brainstorming how to detect black holes
  - Can they be “imaged” directly?
  - Indirect methods
- The concept of accretion – black holes swallowing gas
- Mass transfer in close binaries – the first evidence for BHs

OBSERVED BLACK HOLE POPULATIONS

- STELLAR REMNANT:

$$3-30(?)\,M_{Sun} \quad \left(\sim 10^{7}(?)/\,\mathrm{galaxy}\right)$$

- SUPERMASSIVE:

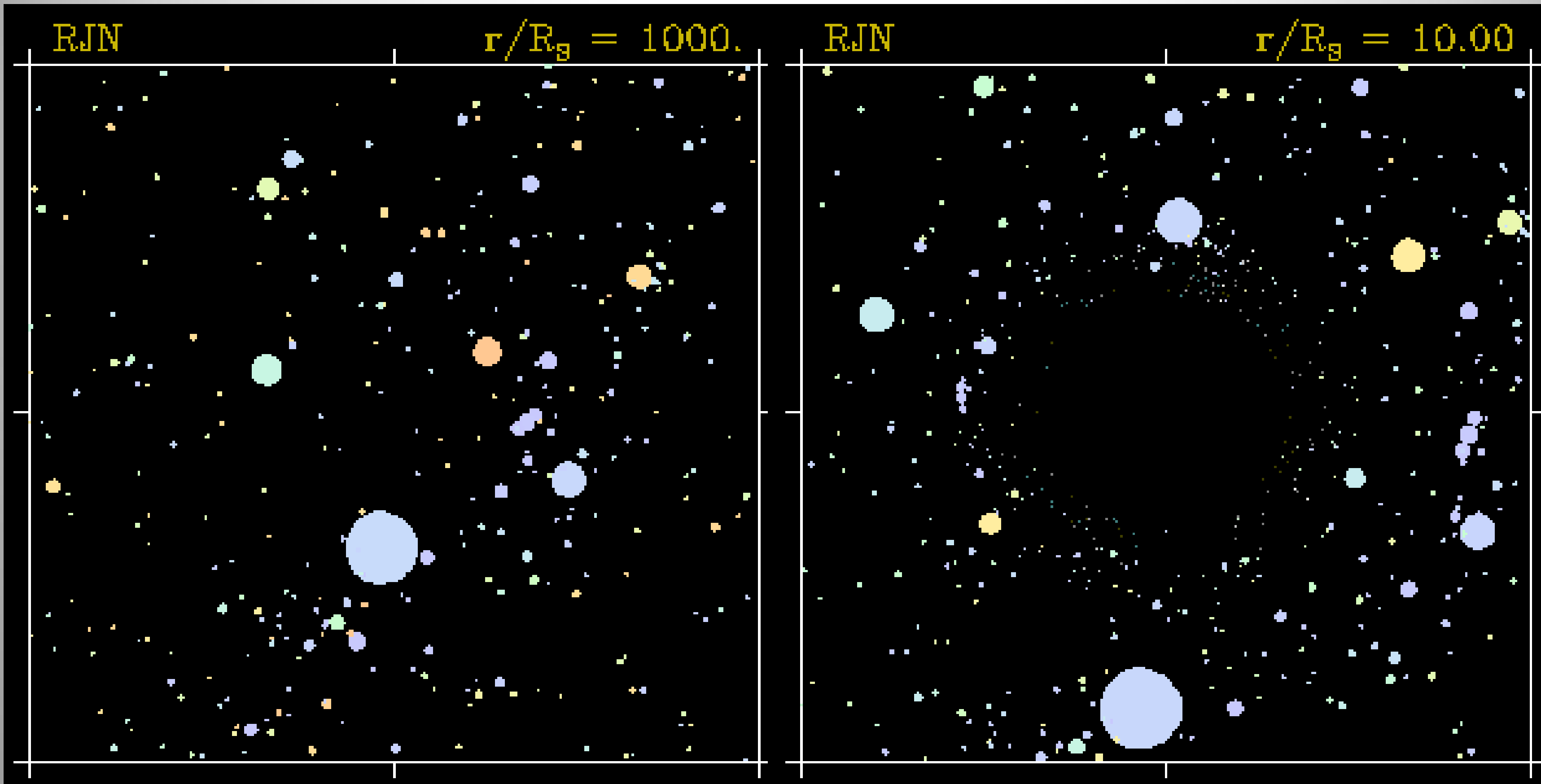
$$10^{6}->10^{9}\,M_{Sun} \quad \left(\sim 1-2/\,\mathrm{galaxy}\right)$$

- MINIHOLES? (e.g., Hawking evap.): no evidence
- MEDIUM MASS? $(10^{2-5}M_{Sun})$: abundance unknown

HOW DO WE KNOW?

HOW TO DETECT A BLACK HOLE

- Find "dark star" too massive to be a WD or NS
  - ...but how to tell?
- Detect light-bending effects
  - Microlensing, black hole "shadow"
- Anomalously high speeds of gas clouds or stars
  - ...mainly relevant for central BH in galaxies
- Accretion (swallowing) of gas
  - Heating of gas by strong gravity → X-rays, UV
  - ...but need a source of gas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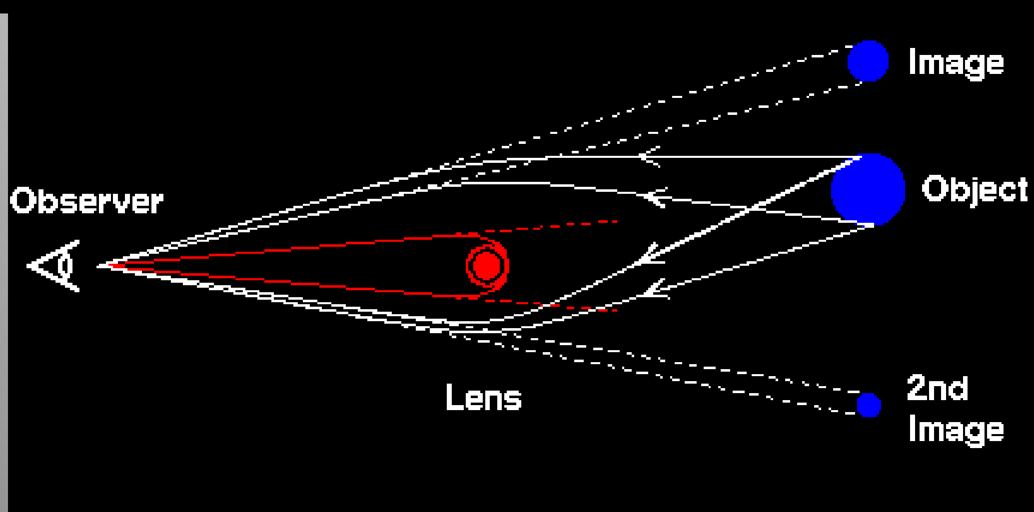
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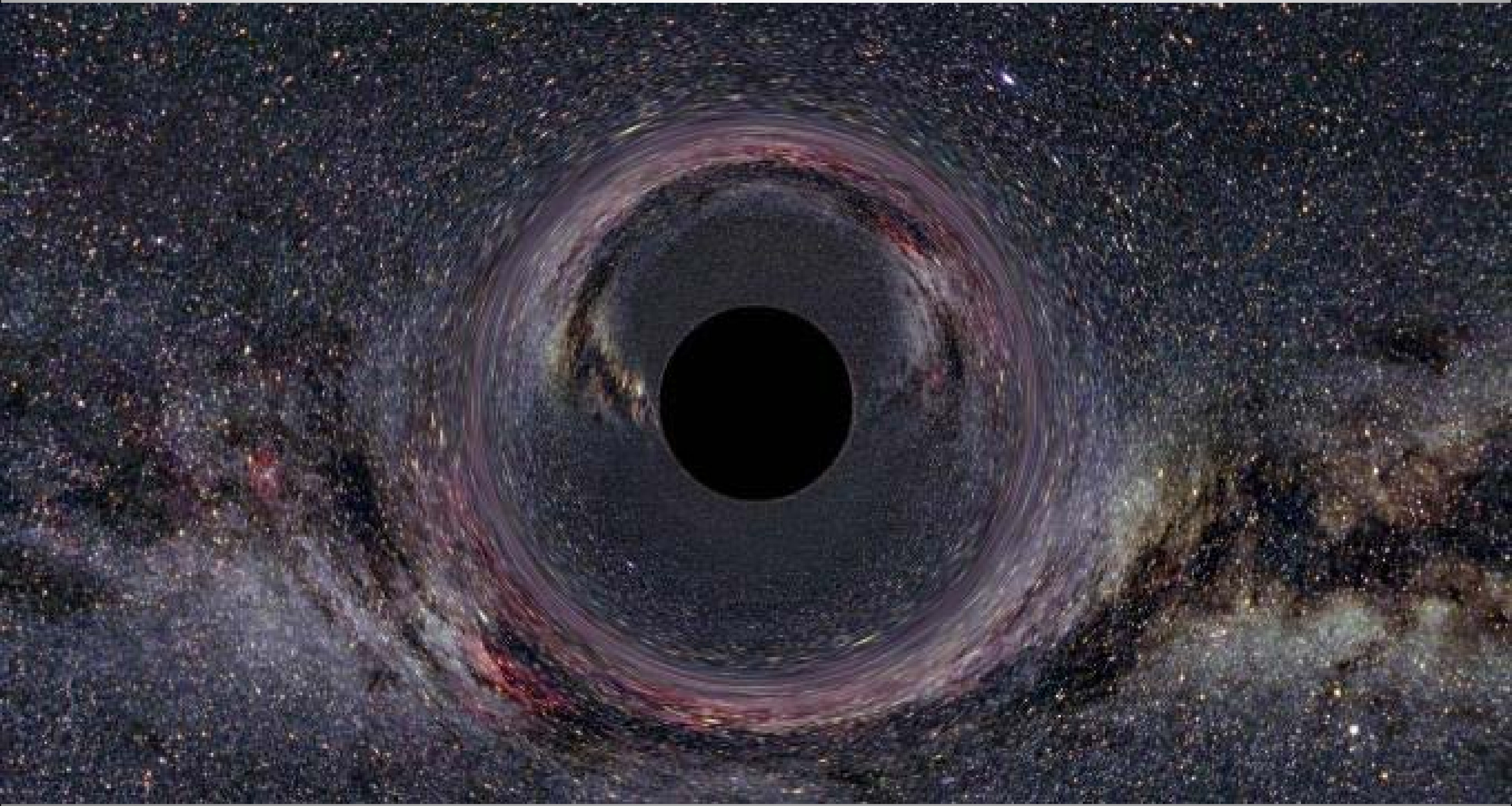
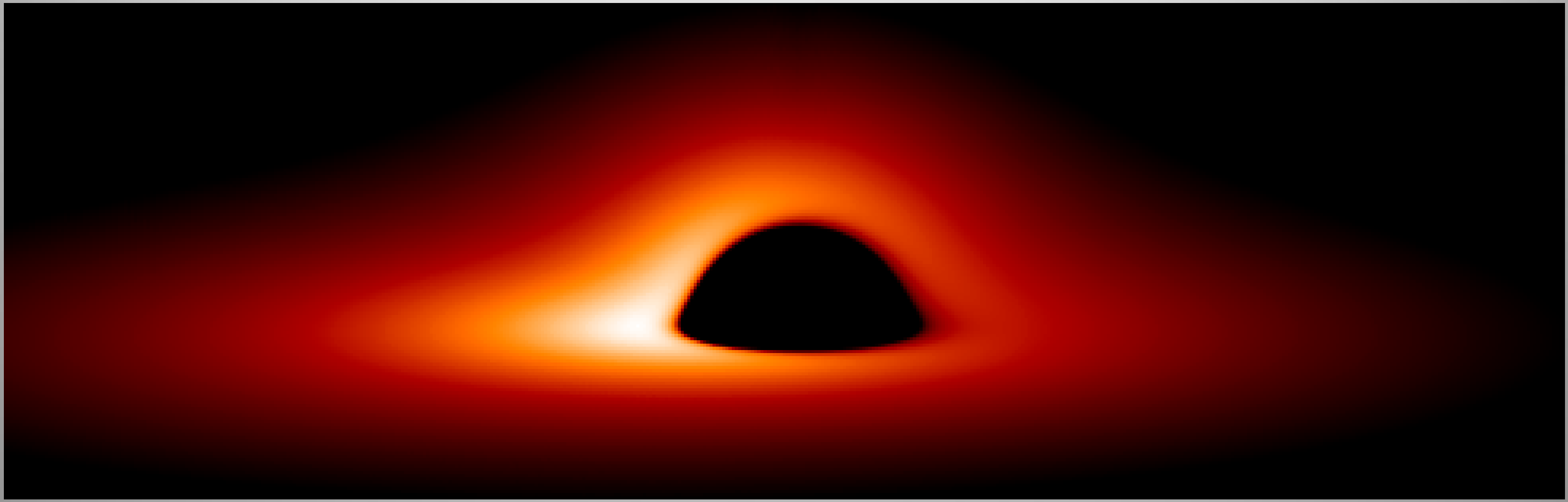


Courtesy Andrew Hamilton (CU)

CAN WE IMAGE BLACK HOLES?



The "biggest" black holes (as seen from Earth)

- Center of the Milky Way
  - Mass: 4 million Suns
  - Distance: 25 thousand light-years
  - Size on sky: ~ grapefruit at distance of Moon
- Elliptical galaxy M87
  - Mass: 4 billion Suns
  - Distance: 50 million light-years
  - Size on sky: ~ orange at distance of Moon

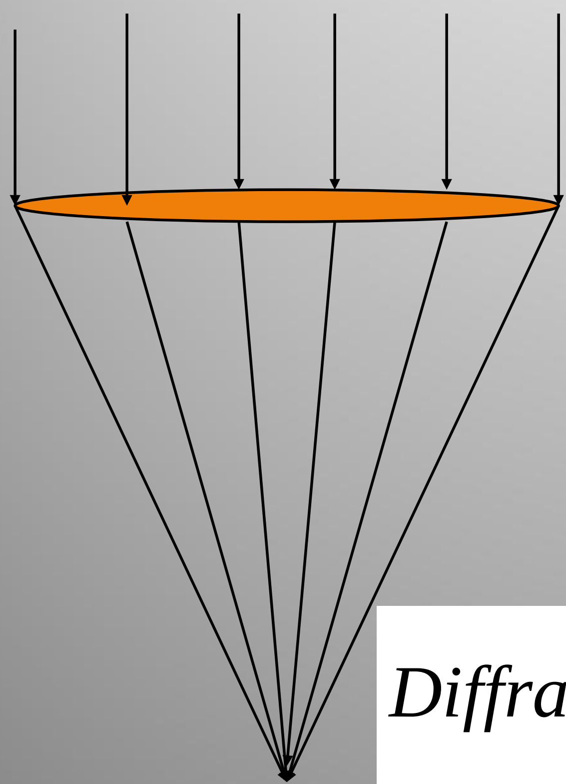
CAN WE IMAGE BLACK HOLES?

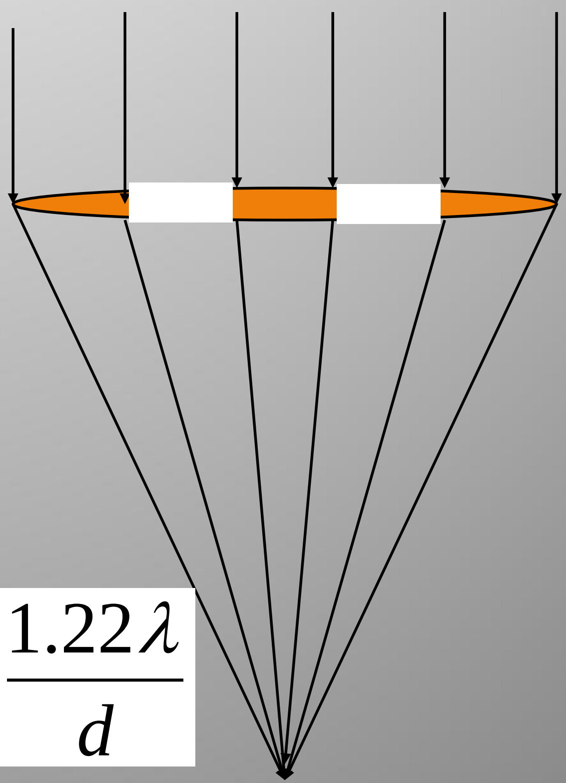
…probably soon!

- **HUBBLE: read newspaper @ 1 mile**
  - Optical/UV telescope in space
  - Falls short by 1000
- **VLBA: read newspaper in Colo. Springs**
  - Transcontinental radio telescope
  - Falls short by 1,000
- **EHT: read newspaper in New York**
  - Millimeter telescope array spanning Earth
  - Can just about do it!

Interferometery

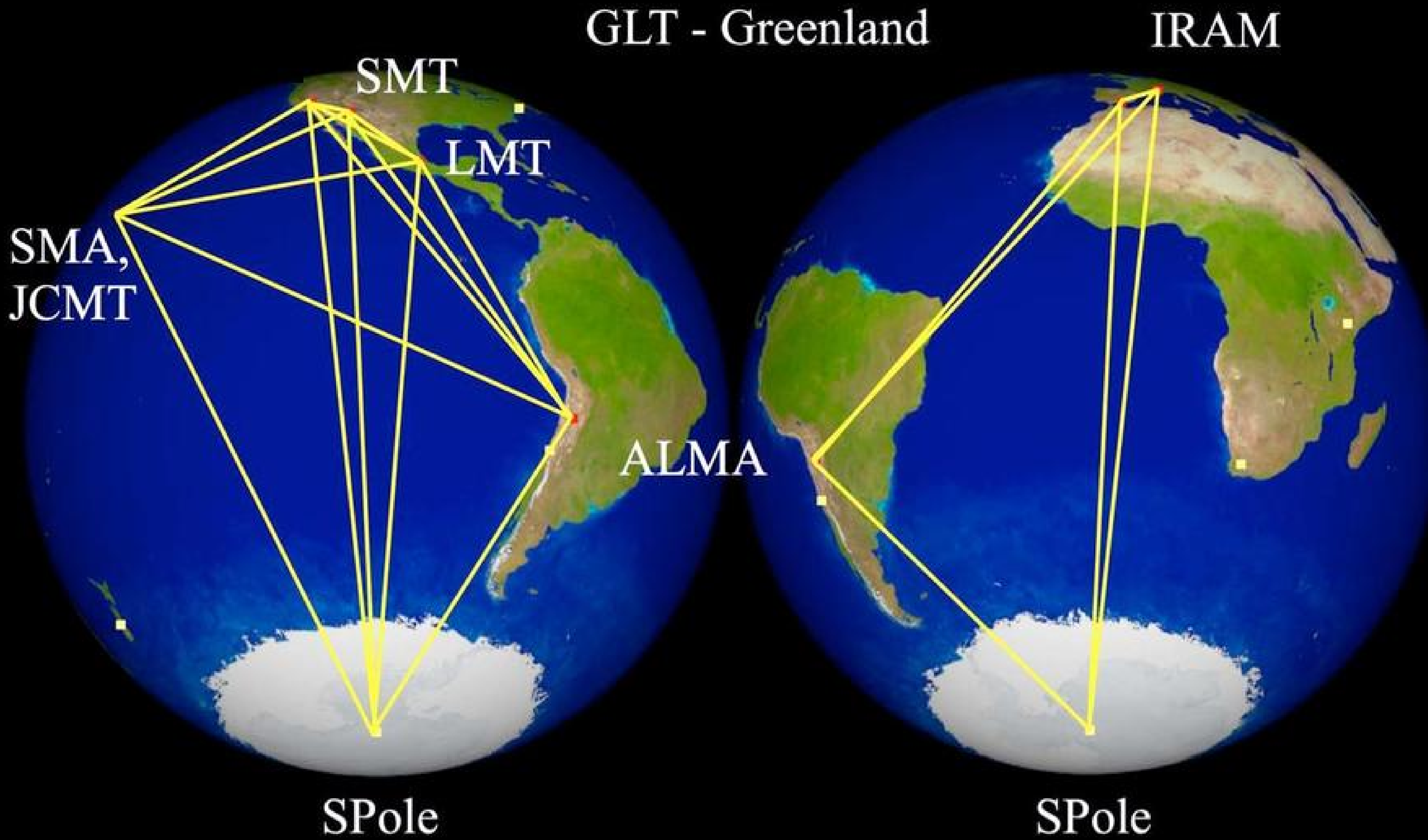
- Hard to do - but gives you the diffraction limit of a much larger aperture

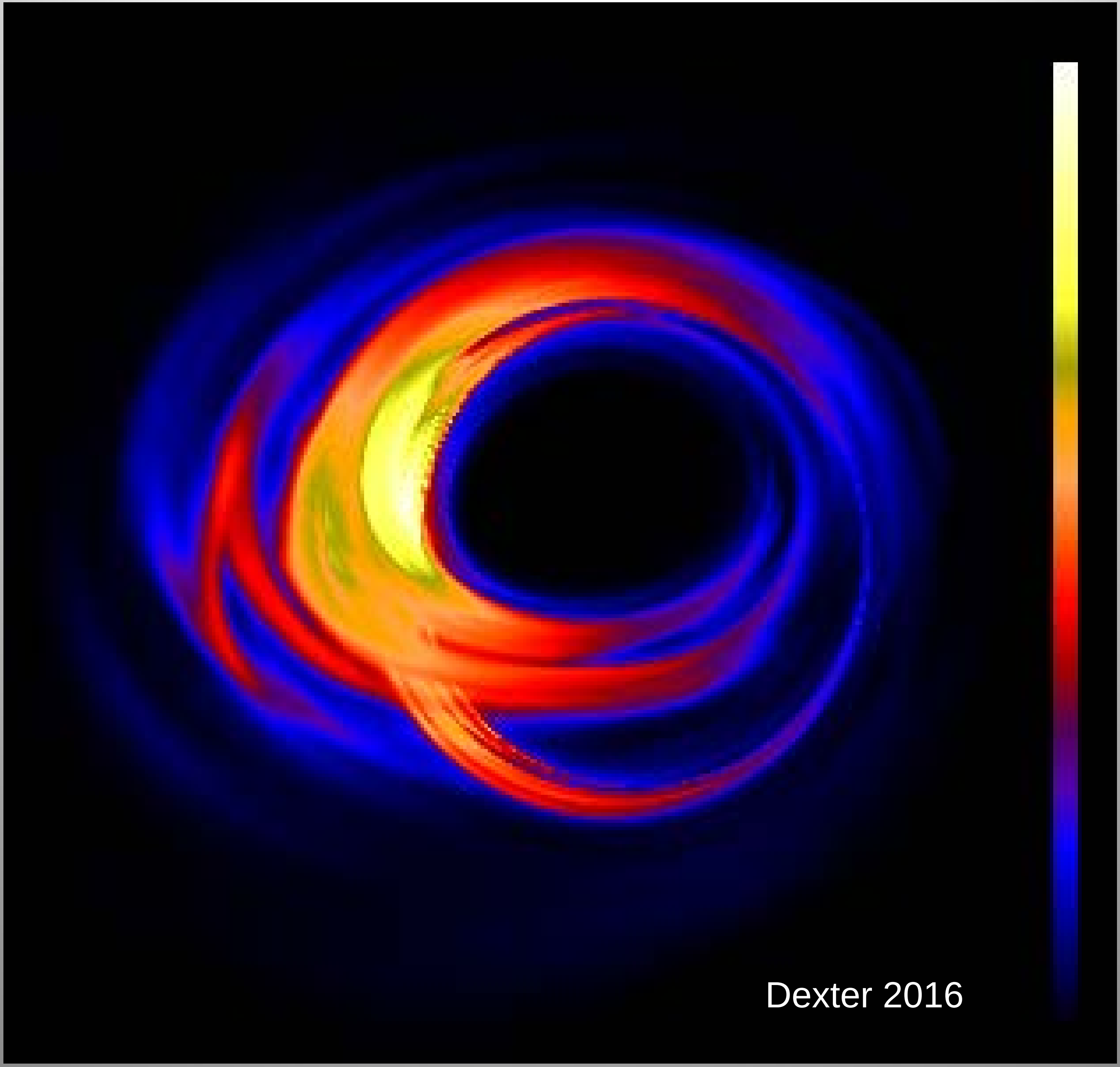




$$Diffraction\ Limit = \frac{1.22\lambda}{d}$$

Event Horizon Telescope 2017




Dexter 2016

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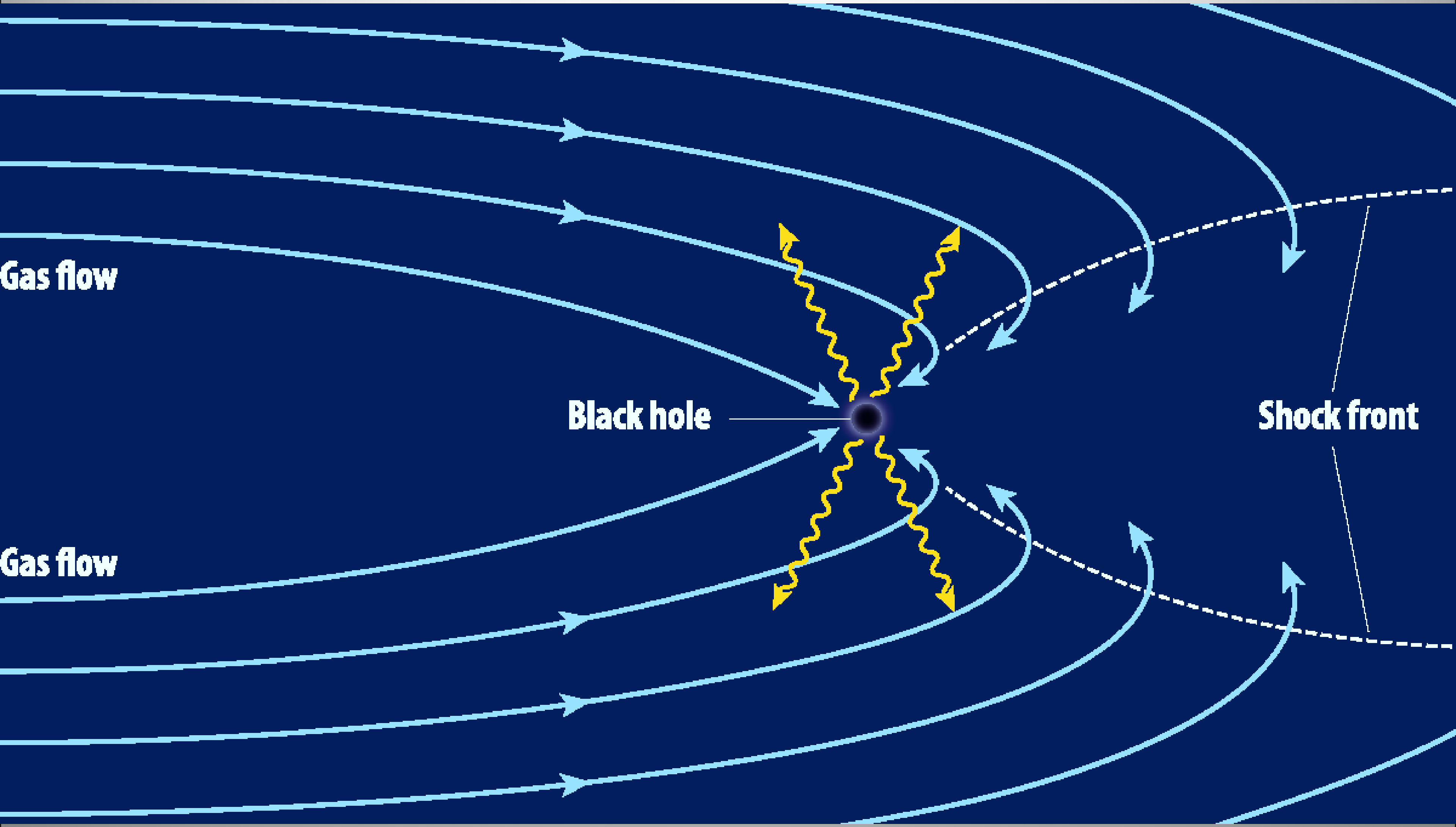
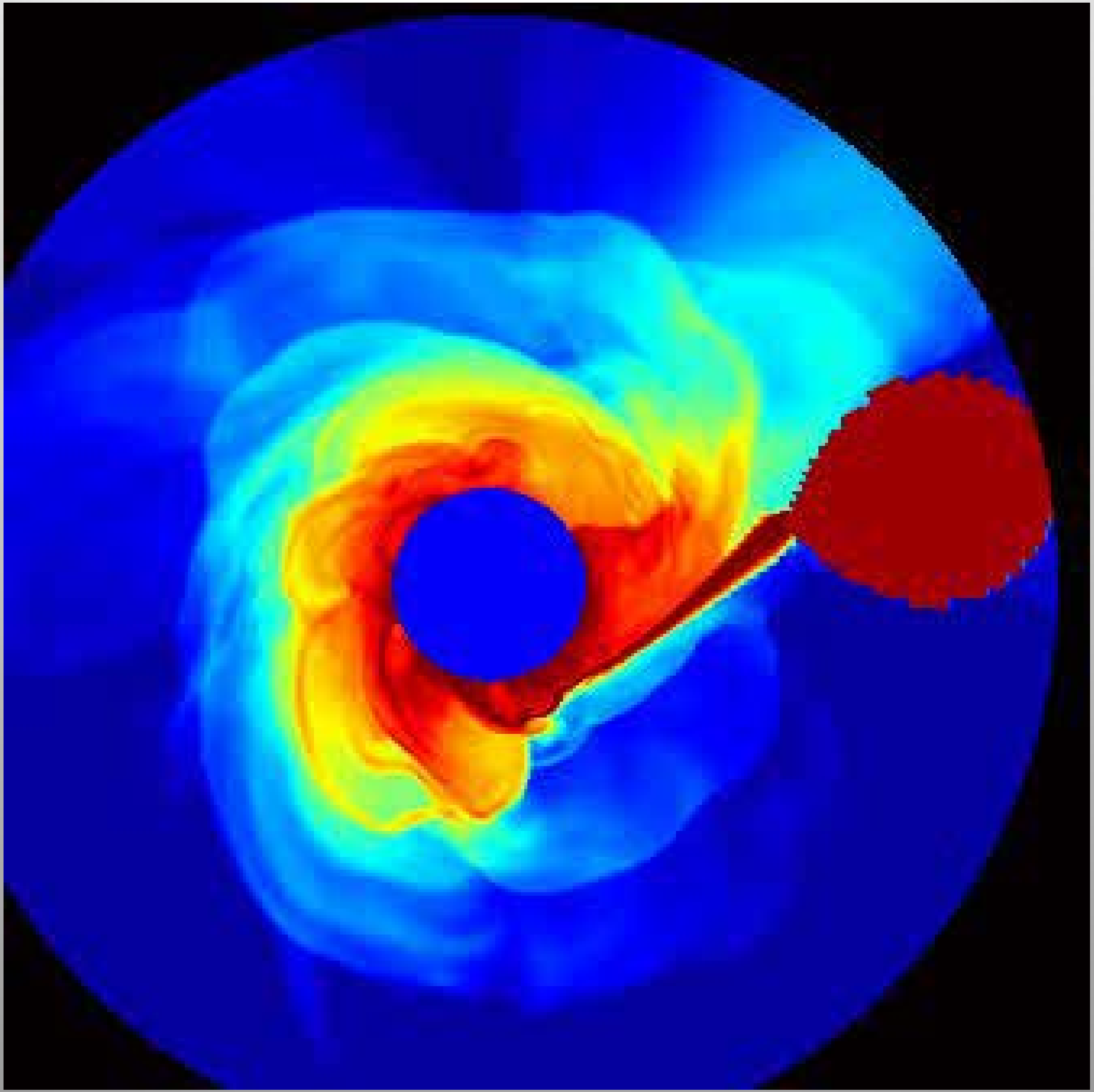

Gas flow
Gas flow
Black hole
Shock front



Simulation
by J. Blondin

Binaries: a better source of mass

Binary stars

Most stars in the Solar neighborhood are part of binaries (2/3)

Separations range from almost touching "contact binaries" to thousands of times Earth-Sun distance

Majority are far enough apart that the stars evolve independently

Mass transfer binaries

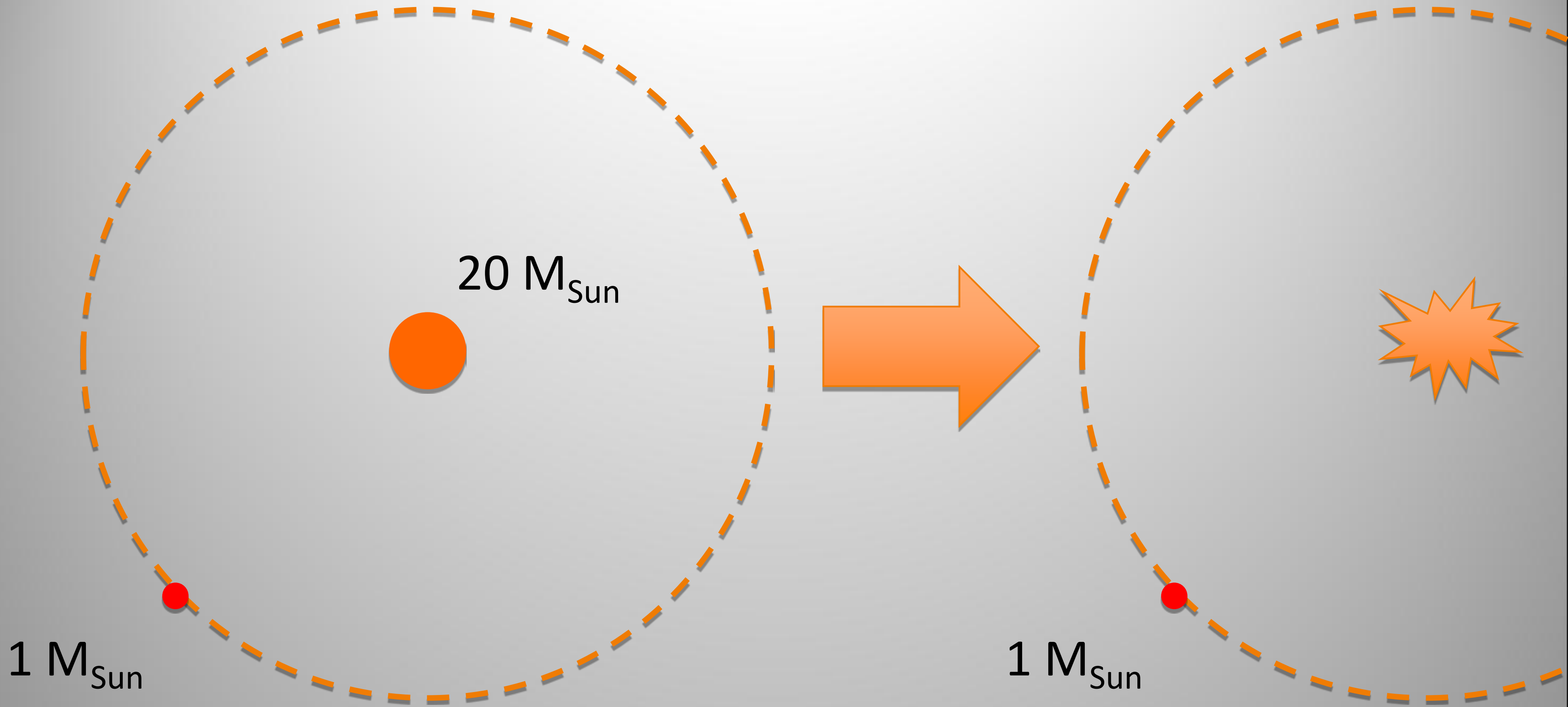
- **Some** binaries close enough to transfer mass both before and after formation of NS or BH
- This mass transfer is **crucia**l to setting up a black hole for detection

Mass transfer binaries require a BH or NS to form in orbit with a normal star

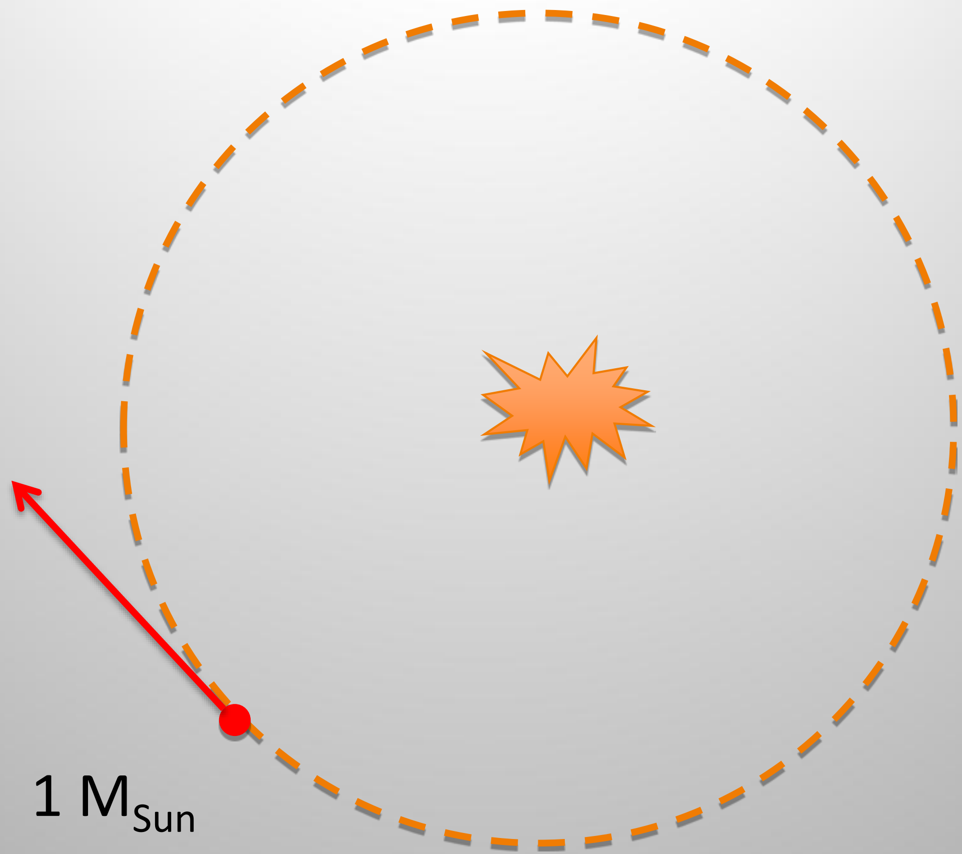
BH or NS should form from the *more massive* star in the binary (which collapses first)

This is a problem: the supernova explosion required to create the BH or NS should disrupt the binary

Here's why …



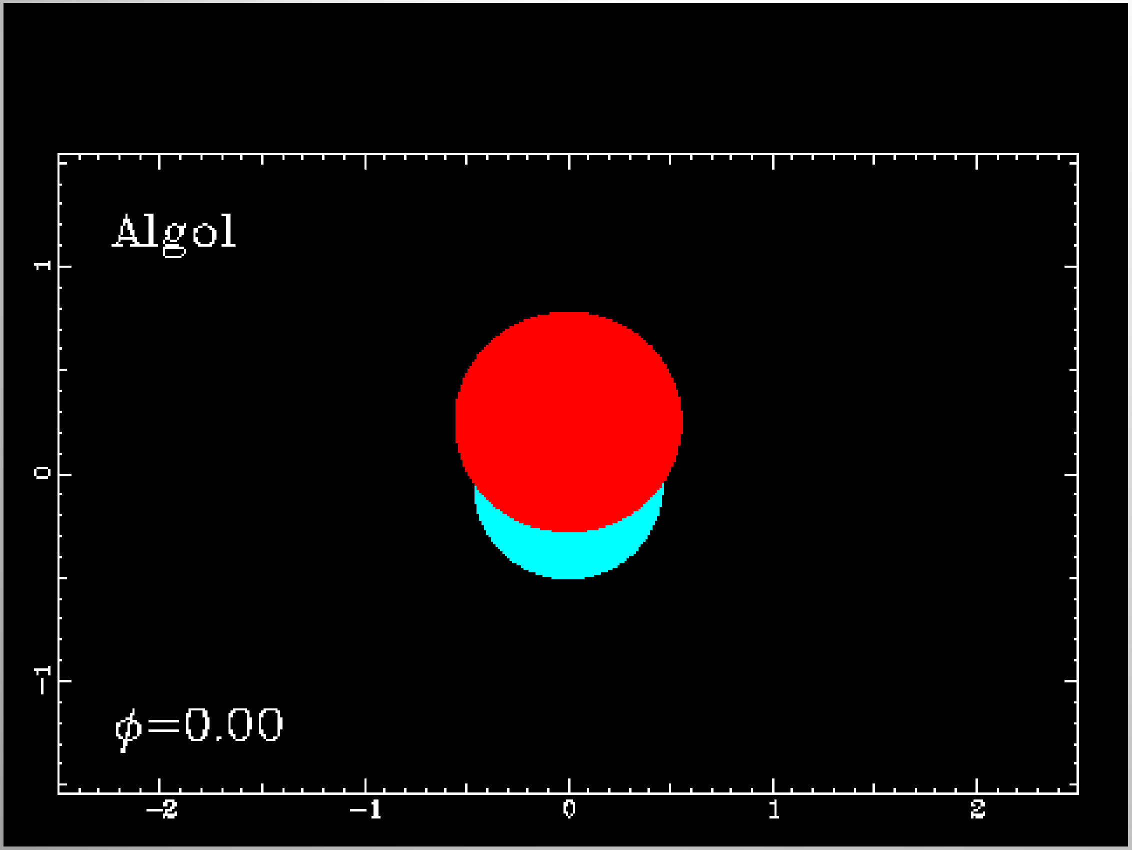
Suppose a supernova destroys a 20 Solar mass star in a binary system with a low mass star. What happens to the low mass star?



Gravity felt by the low mass star reduced suddenly as the supernova ejecta passes by the orbit. Binary is typically unbound: star flies off into space…

Resolution: stars in binary are (were) close enough together that mass can be exchanged between them as they evolve: no longer evolve as two isolated objects

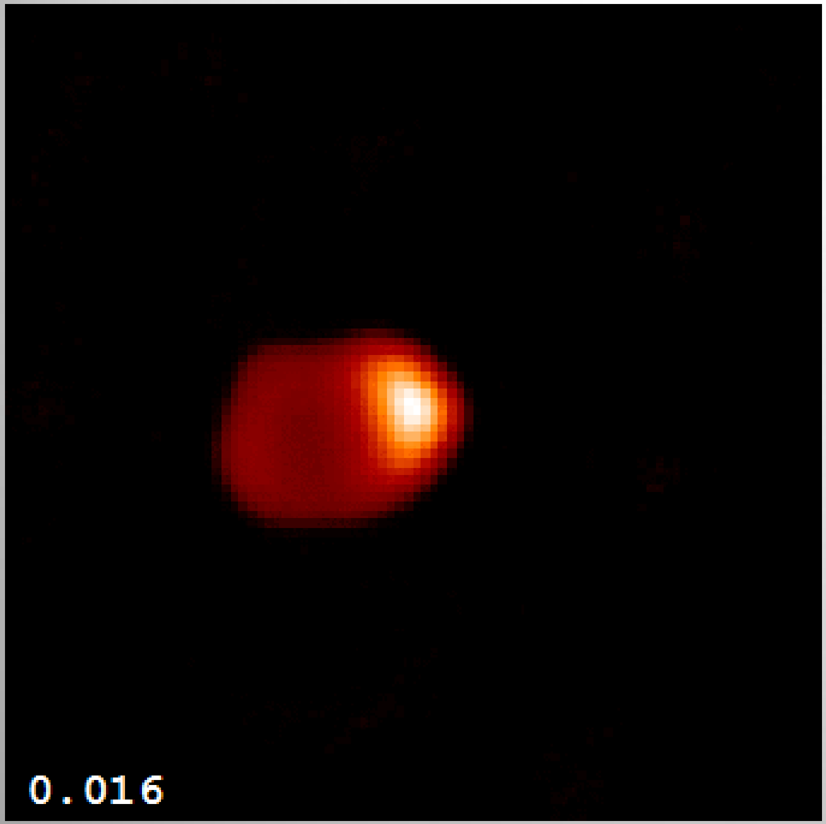
The crucial clue …



Algol

Massive blue star on the main sequence (fusing hydrogen in its core)

…in orbit with a less massive red star that is on its way to becoming a red giant



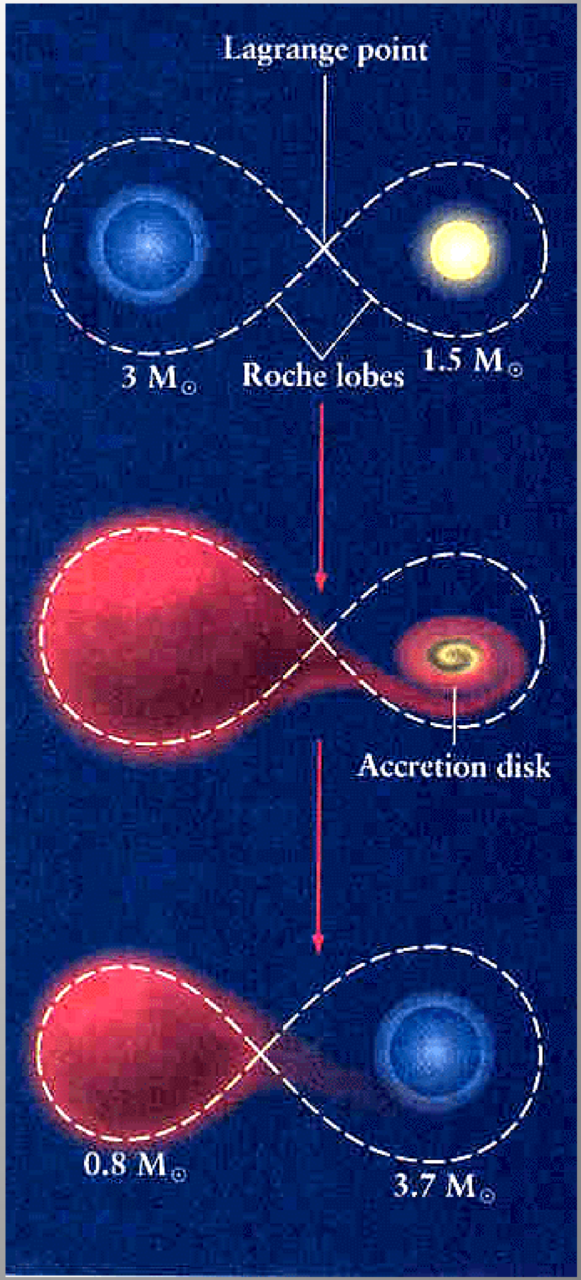
Algol

…as imaged by the CHARA optical interferometer

Paradox: more massive stars have *shorter* life times, so why is the massive star still on the main sequence while the less massive companion is already becoming a red giant?

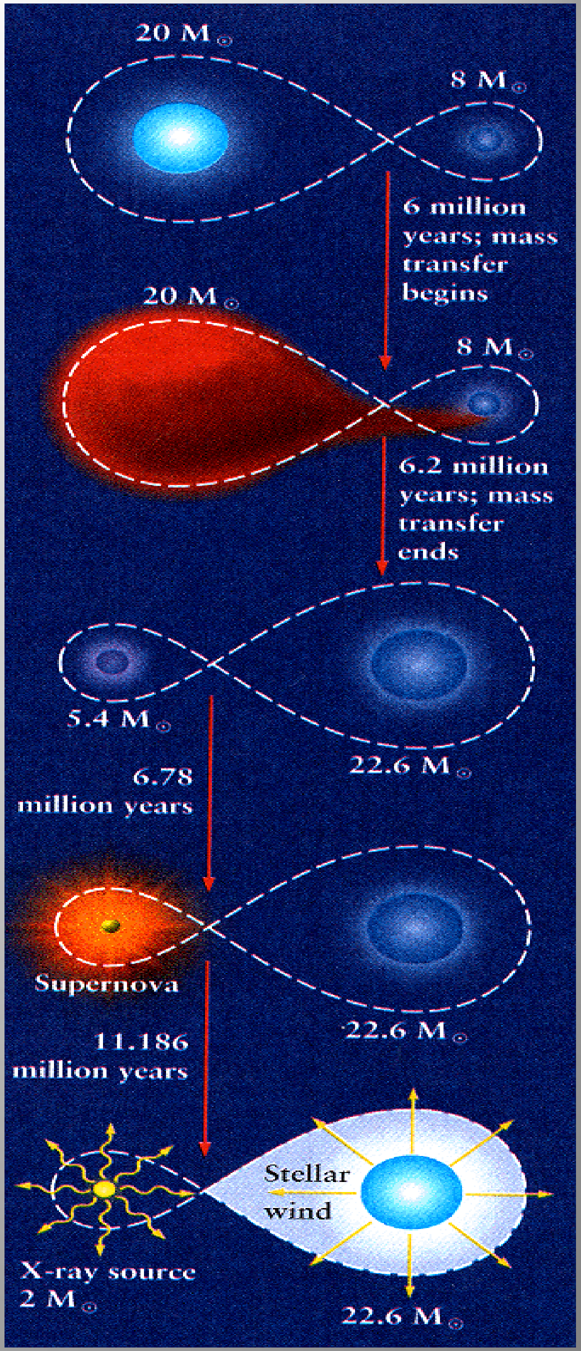
The "Algol Paradox" resolved

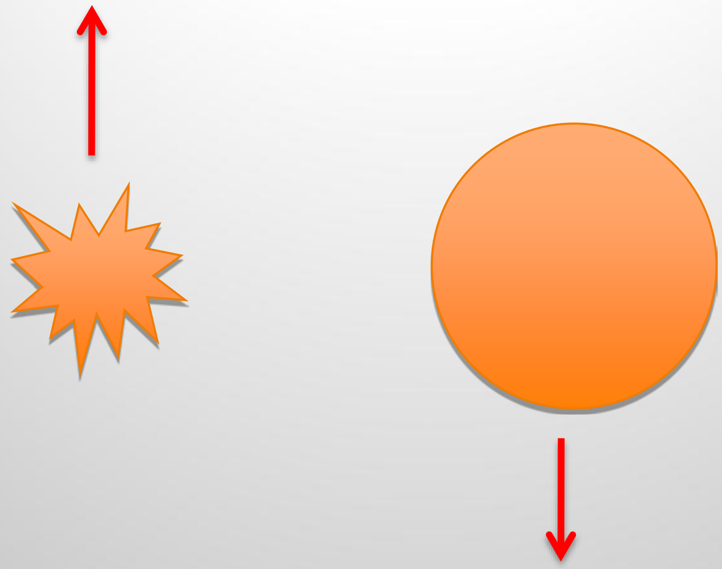
- Roche lobe = "sphere" of influence
  - actually teardrop shaped
- Matter flows across Lagrange point



ALGOLS CAN EVOLVE INTO X-RAY BINARIES

- **Crucial that mass ratio flips**
  - otherwise stars can fly apart
- **Compact star either NS or BH**
  - depends on mass of precursor
- **Two modes of mass transfer**
  - stellar wind: star smaller than Roche lobe
  - "Roche lobe overflow": star swells to fill Roche lobe





How much mass transfer is “enough”?

The star that explodes as a supernova has to be *less massive* at the time of explosion – to keep the binary from being disrupted

Two roles for mass transfer in binaries:

1. Typically need mass transfer to *form* a close binary with a normal star in orbit about a compact object (a neutron star or black hole)

2. Need further mass transfer *on to* the compact object to produce observable X-ray emission via *accretion*