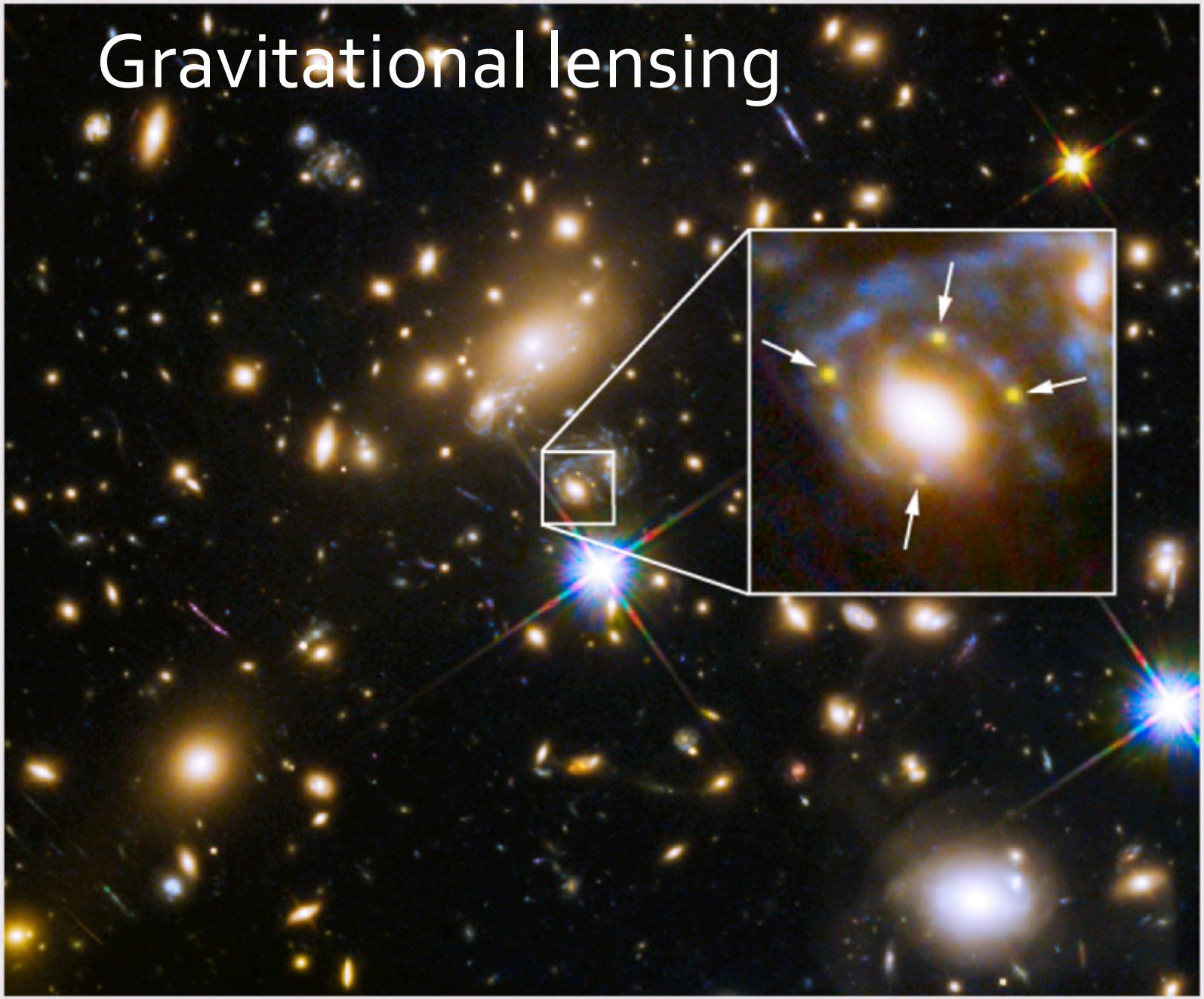
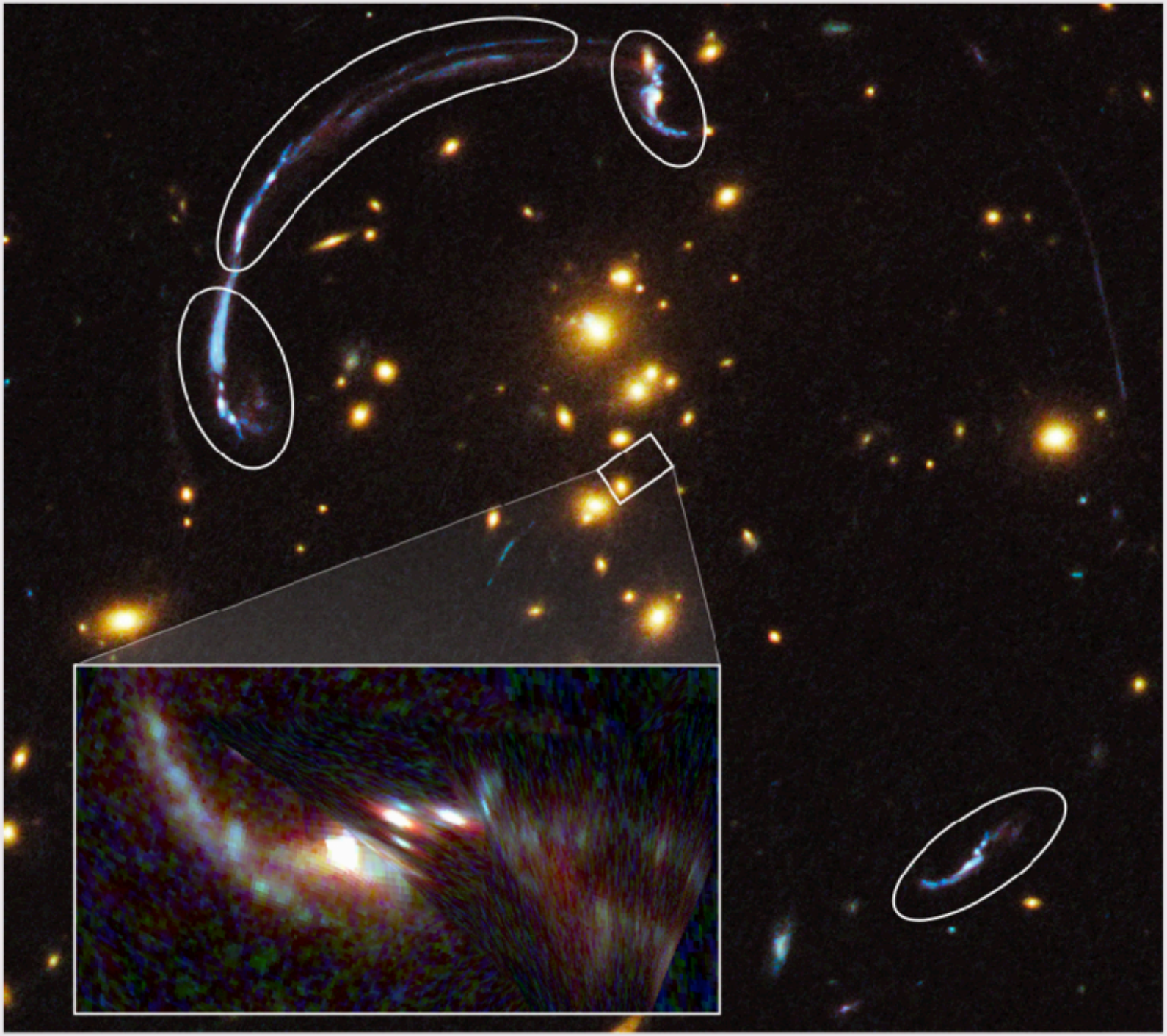
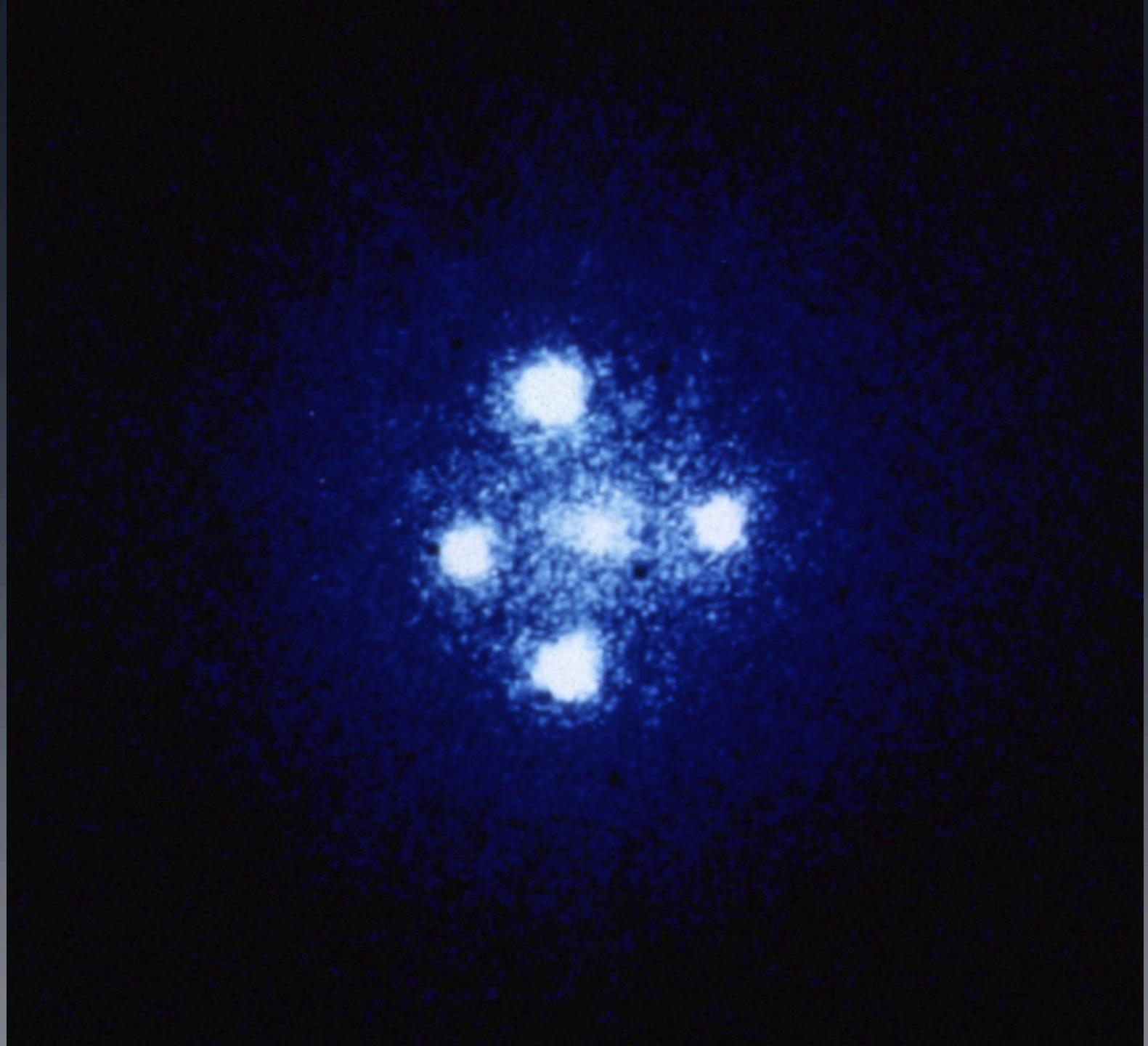
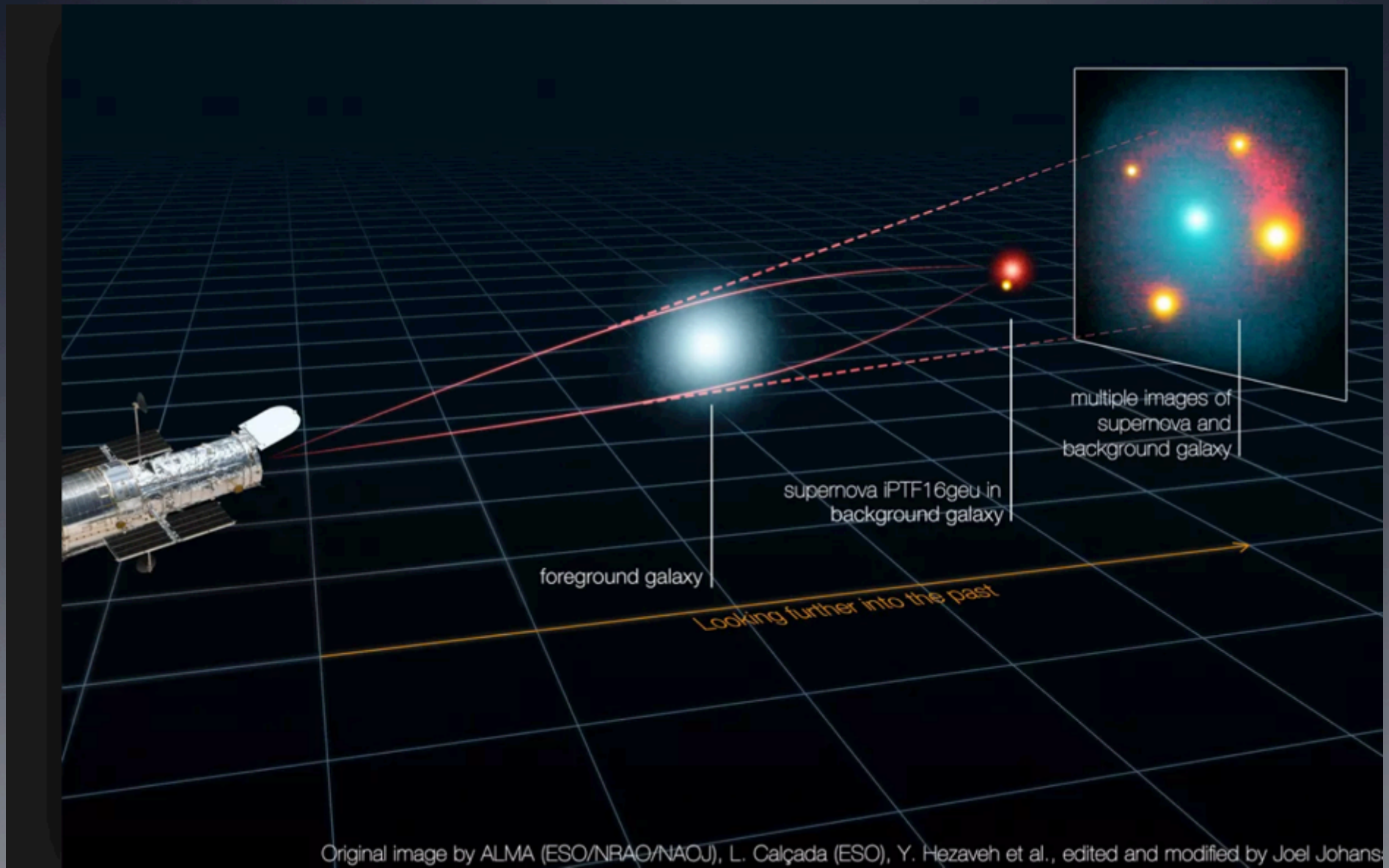
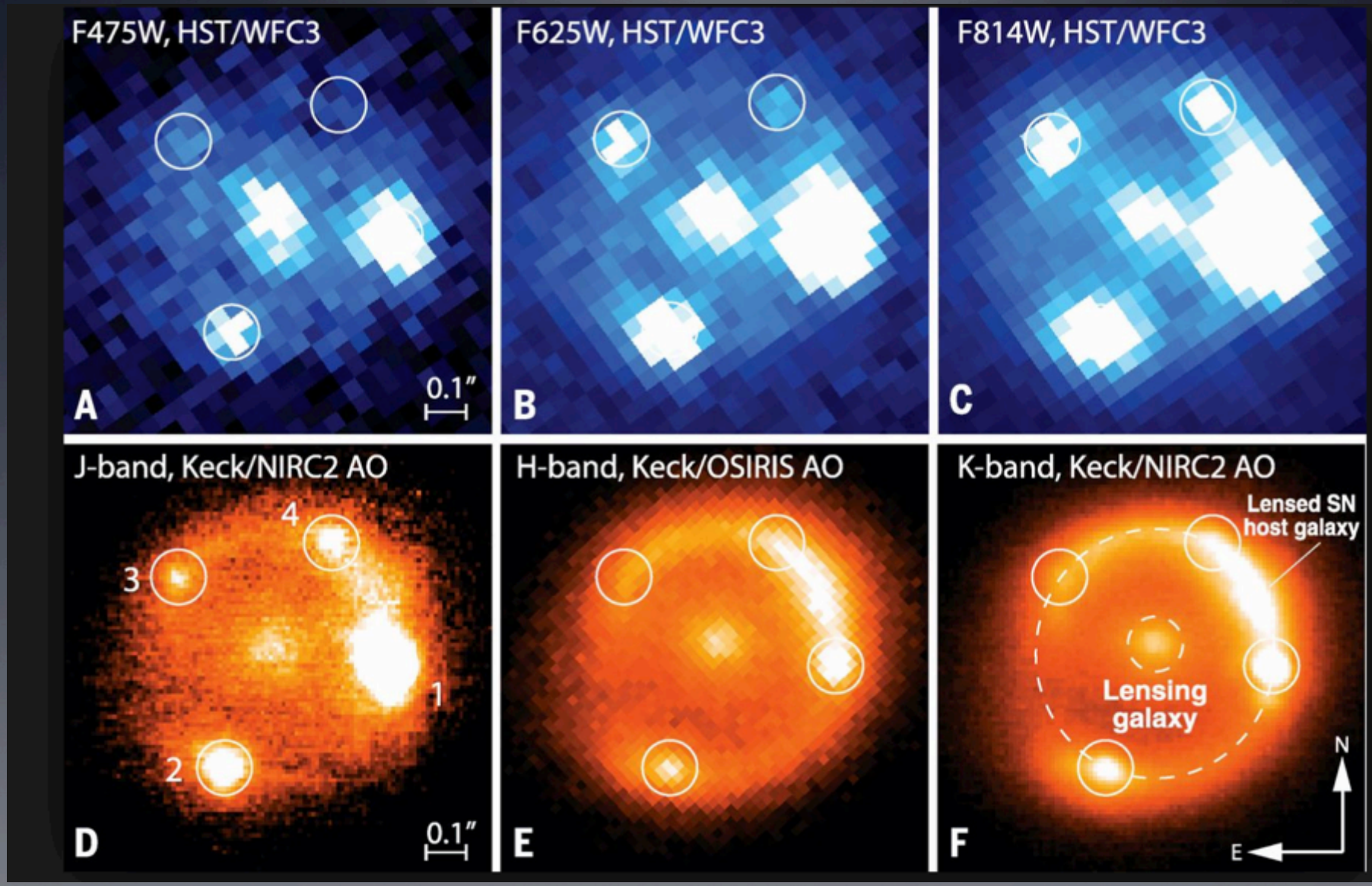
Gravitational lensing

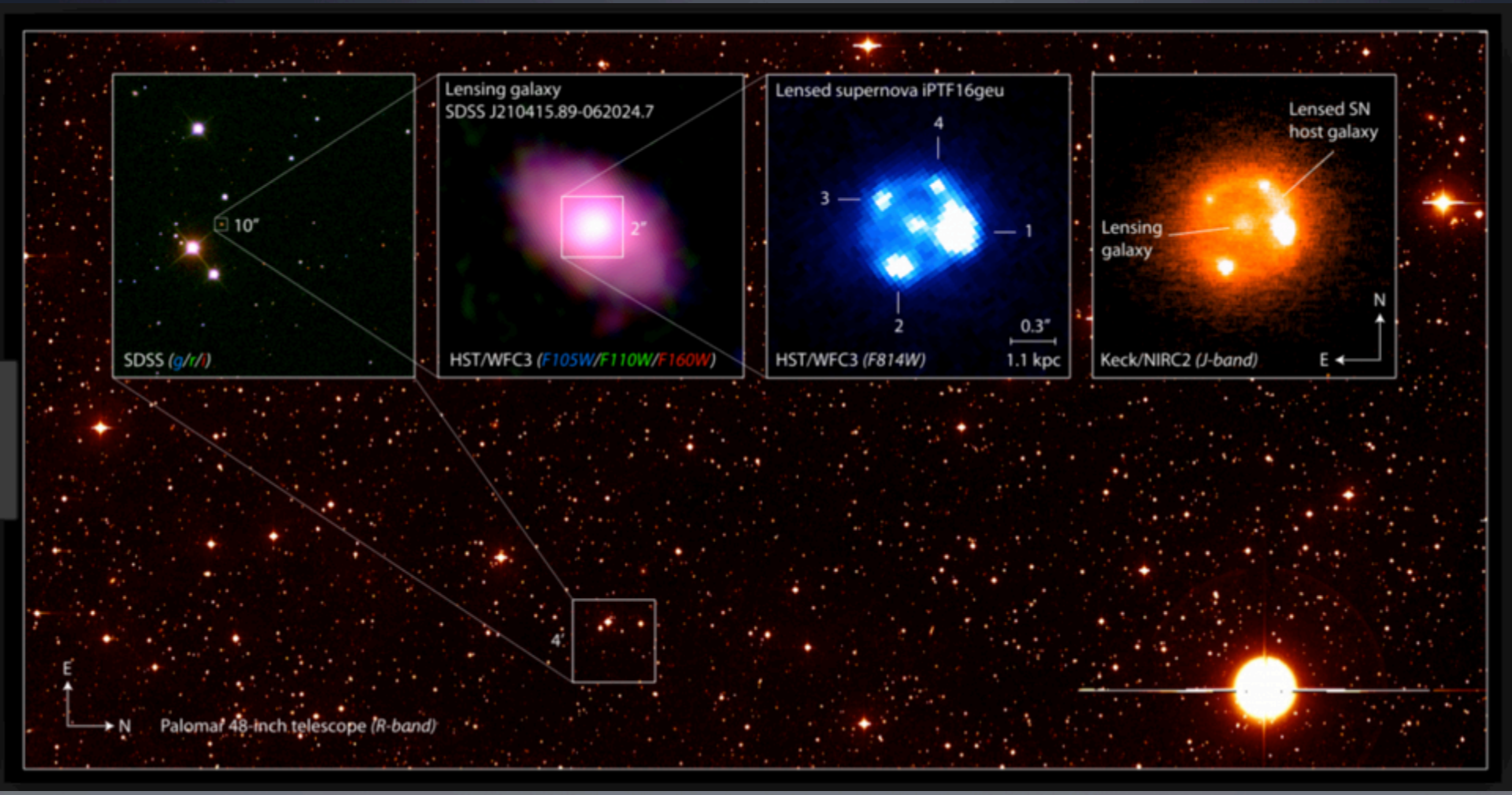


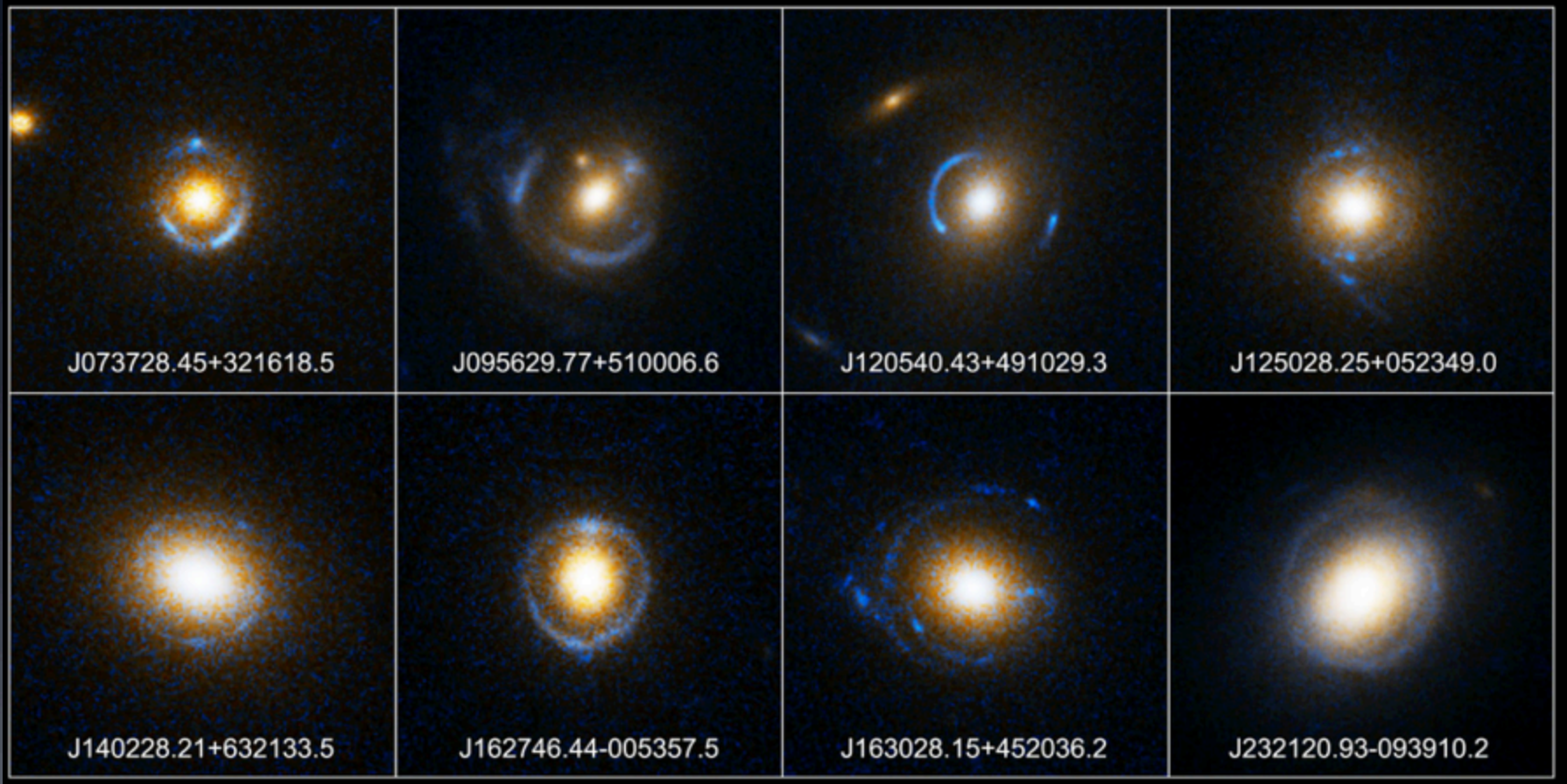





multiple images of
supernova and
background galaxy
supernova iPTF16geu in
background galaxy
foreground galaxy
Looking further into the past
Original image by ALMA (ESO/NRAO/NAOJ), L. Calçada (ESO), Y. Hezaveh et al., edited and modified by Joel Johans


F475W, HST/WFC3
F625W, HST/WFC3
F814W, HST/WFC3
A
0.1″
B
C
J-band, Keck/NIRC2 AO
H-band, Keck/OSIRIS AO
K-band, Keck/NIRC2 AO
4
3
1
2
Lensed SN
host galaxy
Lensing
galaxy
N
E
D
0.1″
E
F


Lensing galaxy
SDSS J210415.89-062024.7
Lensed supernova iPTF16geu
Lensed SN
host galaxy
Lensing
galaxy
10″
2″
4
3
1
2
0.3″
1.1 kpc
N
E
SDSS (g/r/i)
HST/WFC3 (F105W/F110W/F160W)
HST/WFC3 (F814W)
Keck/NIRC2 (J-band)
4′
E
N
Palomar 48-inch telescope (R-band)

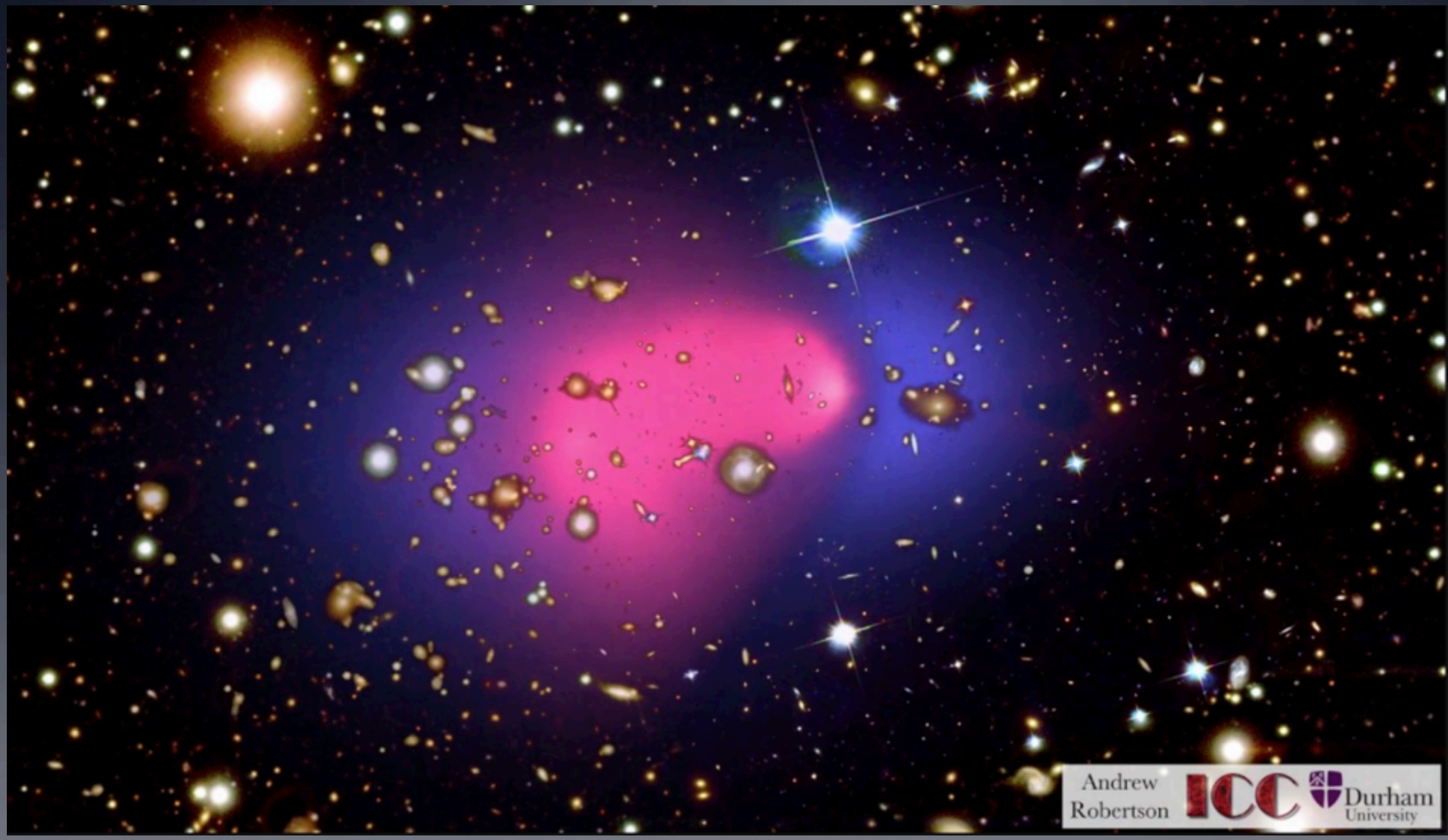


Einstein Ring Gravitational Lenses

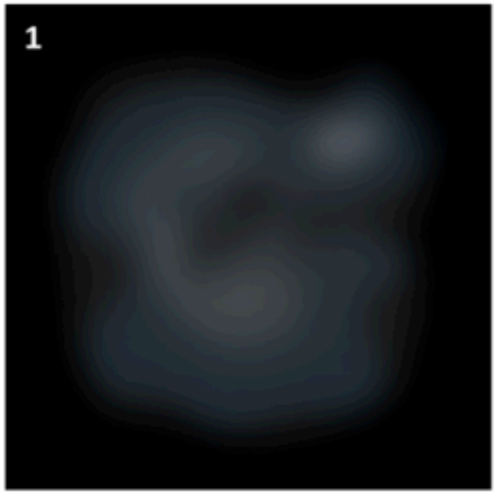
Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, A. Bolton (Harvard-Smithsonian CfA), and the SLACS Team

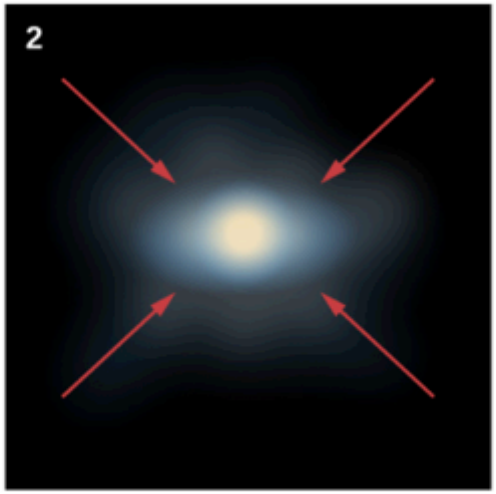
STScI-PRC05-32


Andrew
Robertson
ICC
Durham
University

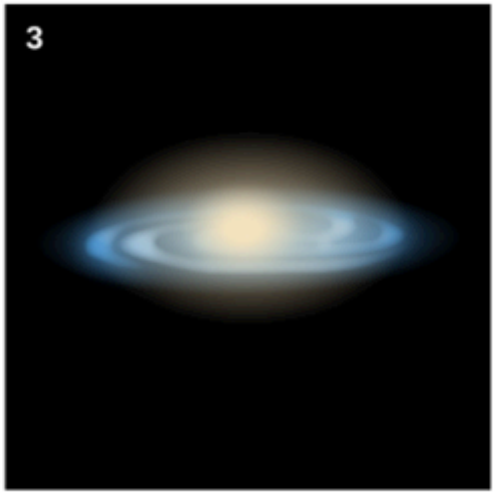
Rapid Collapse



Primordial hydrogen cloud.

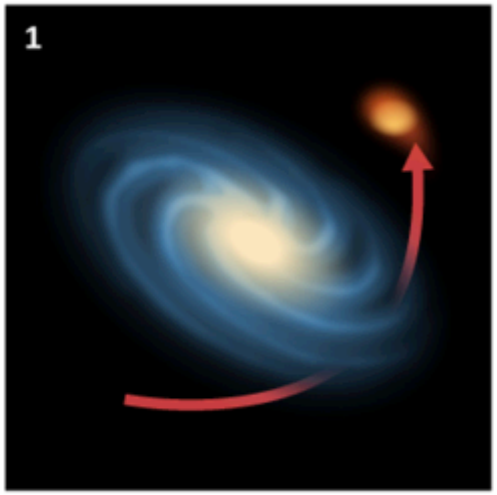


Cloud collapses under gravity.

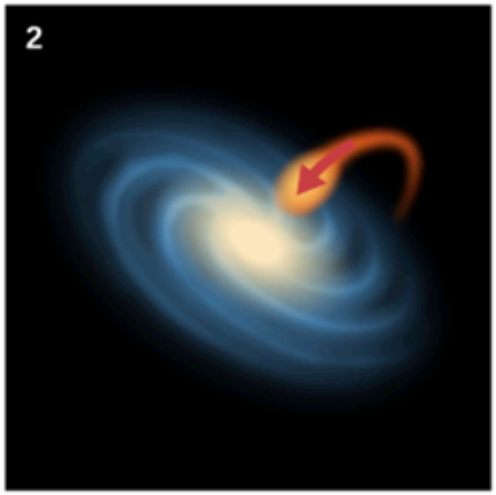


Large bulge of ancient stars dominates galaxy.

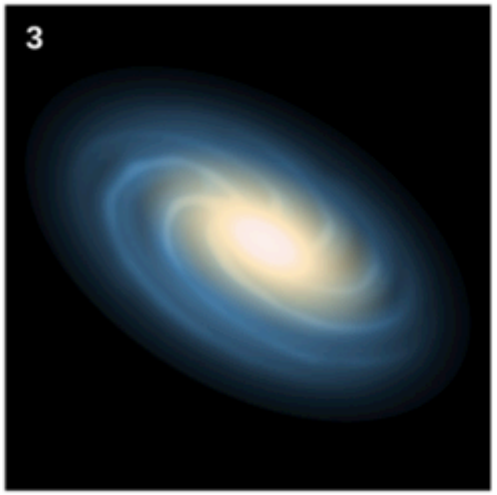
Environmental Effects



Disk galaxy and companion.



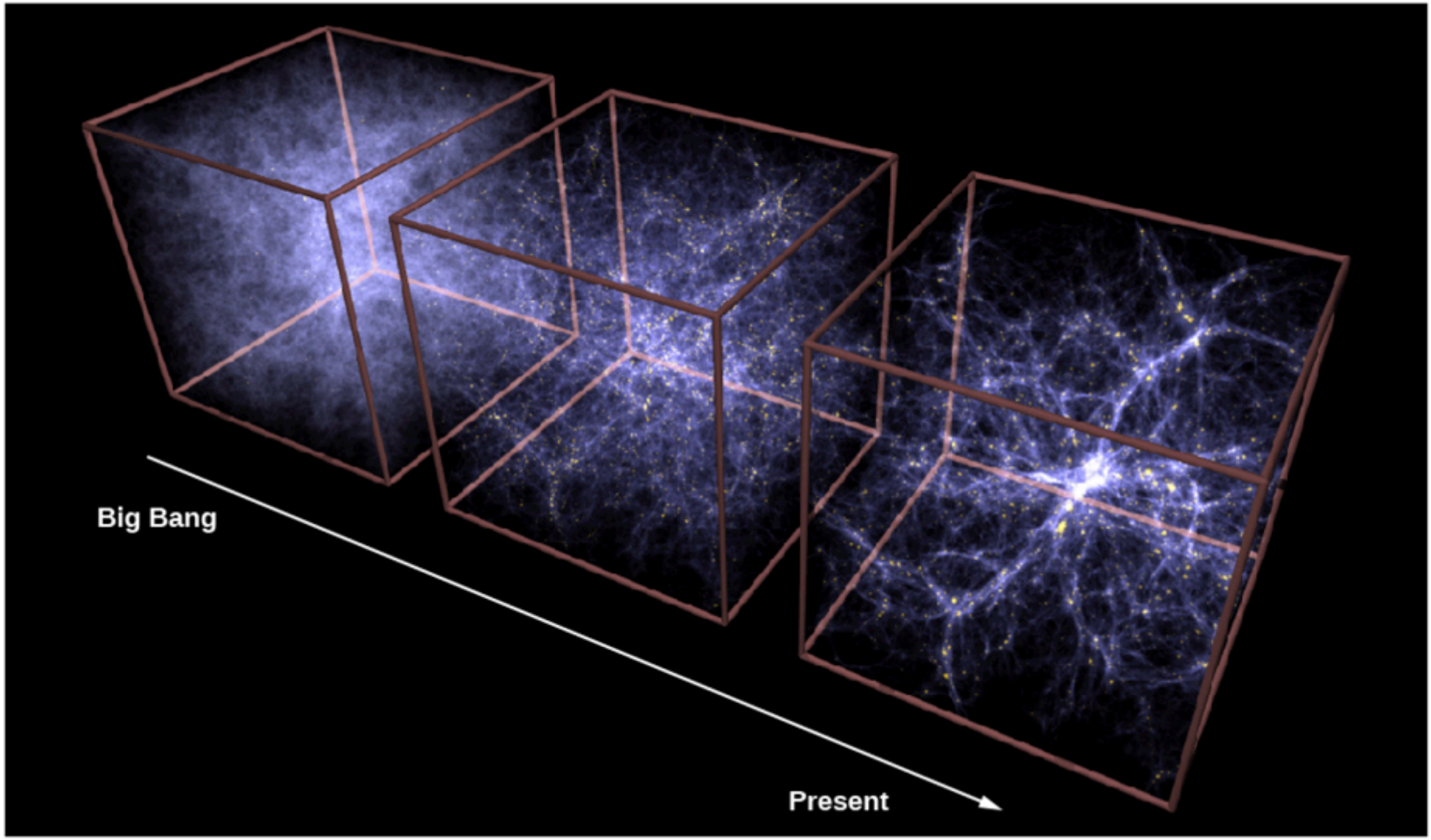
Smaller galaxy falls into disk galaxy.



Bulge inflates with addition of young stars and gas.

Galaxy keywordss

- **Elliptical galaxy: ellipse, no star formation**
- **Irregular galaxy: no pattern, merger**
- **Spiral galaxy:**
- **Redshift: lines shifted to longer wavelength from expansion of universe**
- **Distance ladder: steps to calculate distance**
- **Galaxy evolution: changes in galaxies over cosmic time**
- **Local group: small cluster of galaxies, including Milky Way**
- **Starburst: galaxy with a burst of star formation, often a result of collisions**
- **Quasar and AGN: accreting supermassive black holes**


Big Bang
Present