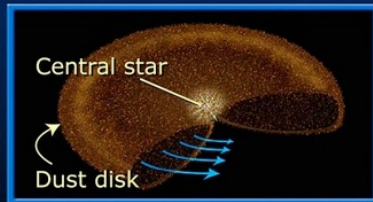


# Adventures in High Angular Resolution Astrophysics

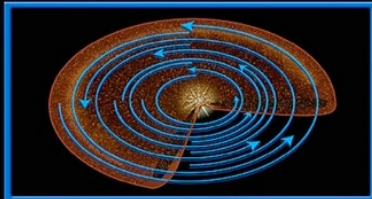
Mike Sitko

## TWO PLANET FORMATION SCENARIOS

### Accretion model



Orbiting dust grains accrete into "planetesimals" through nongravitational forces.



Planetesimals grow, moving in near-coplanar orbits, to form "planetary embryos."



Gas-giant planets accrete gas envelopes before disk gas disappears.



Gas-giant planets scatter or accrete remaining planetesimals and embryos.

### Gas-collapse model



A protoplanetary disk of gas and dust forms around a young star.



Gravitational disk instabilities form a clump of gas that becomes a self-gravitating planet.



Dust grains coagulate and sediment to the center of the protoplanet, forming a core.



The planet sweeps out a wide gap as it continues to feed on gas in the disk.

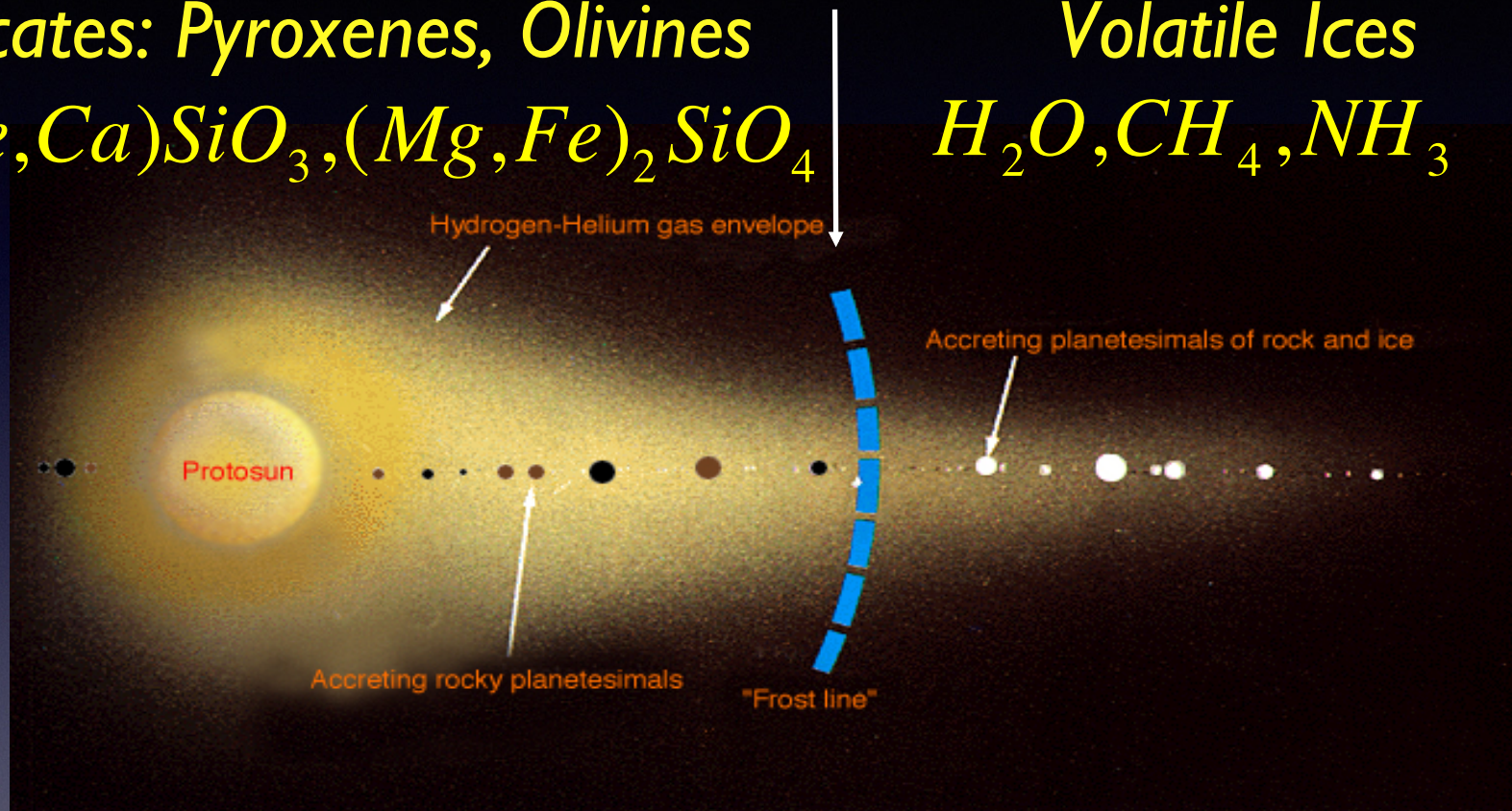
## How do planetary systems form & evolve?

1. Look at "baby" planetary systems
2. look at mature planetary systems

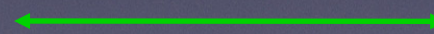
Beyond the “frost line” ice can condense, allowing more massive planets to form

**Silicates: Pyroxenes, Olivines**  
 $(Mg, Fe, Ca)SiO_3, (Mg, Fe)_2SiO_4$

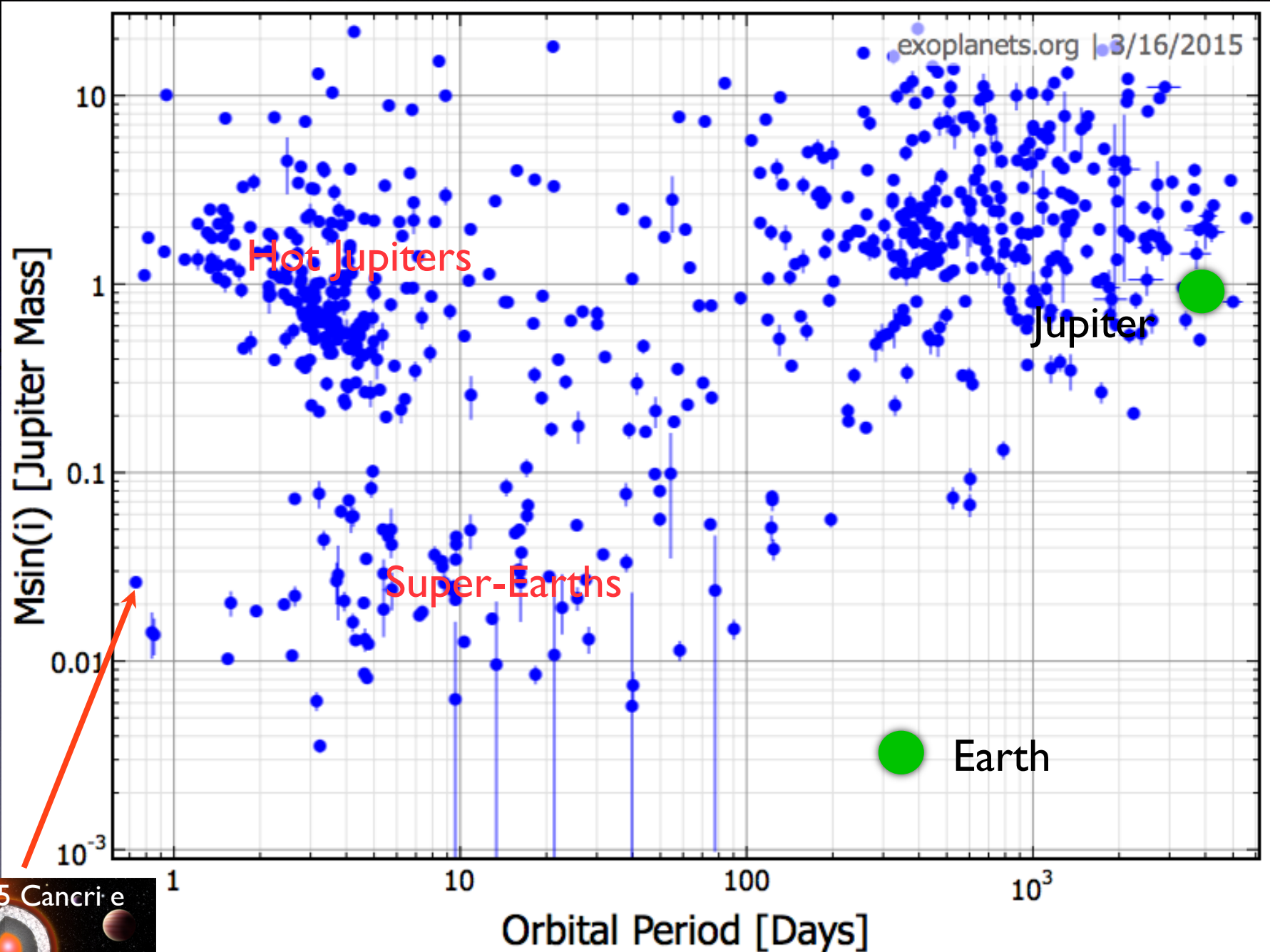
**Volatile Ices**  
 $H_2O, CH_4, NH_3$



Refractories  
(rock, metal)



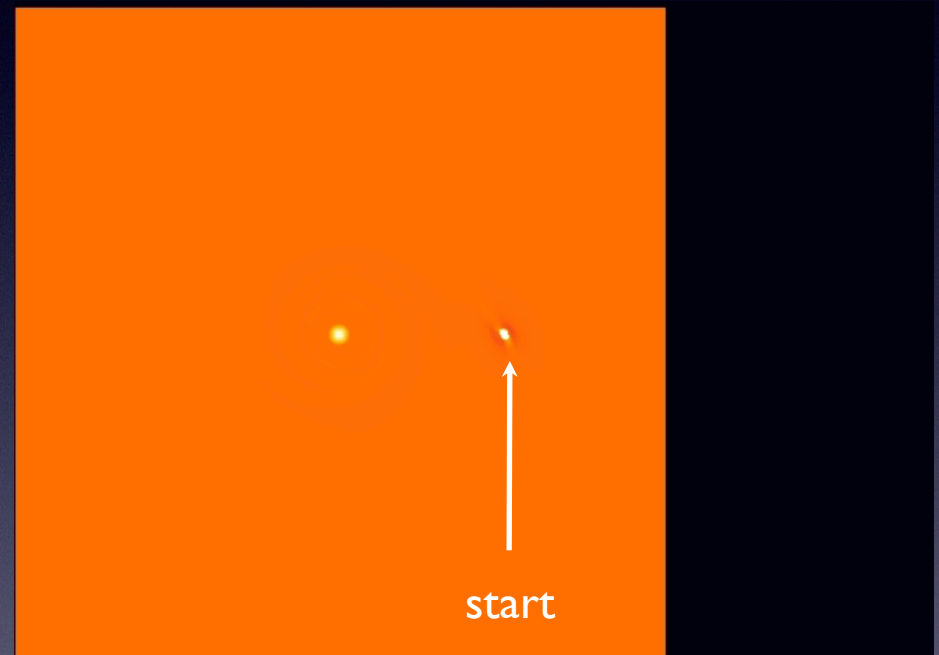
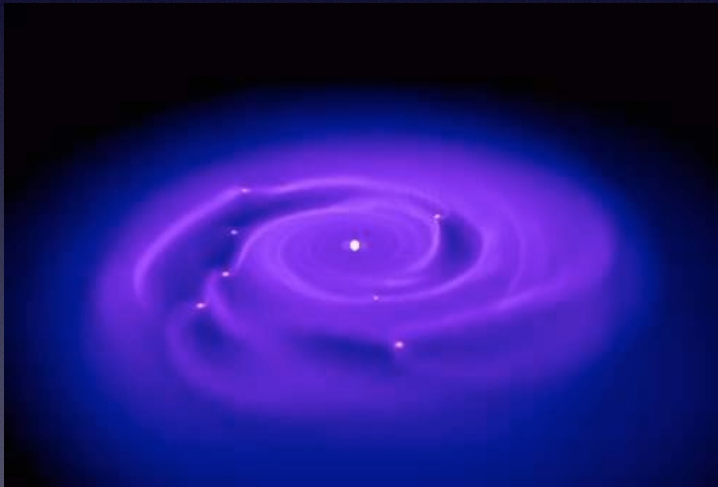
volatiles (ices  
& gas) and  
refractories



Okay, where did all the “Hot Jupiters” come from?

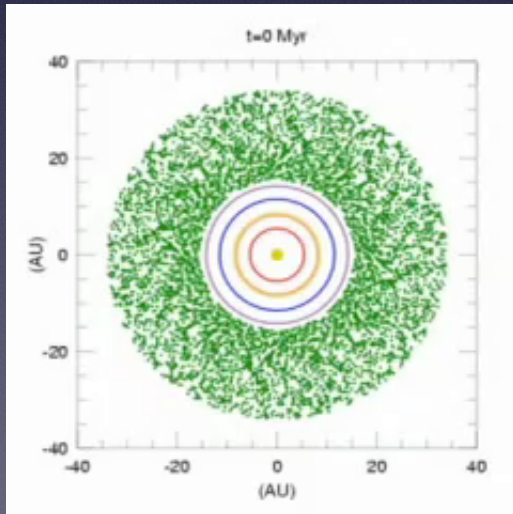
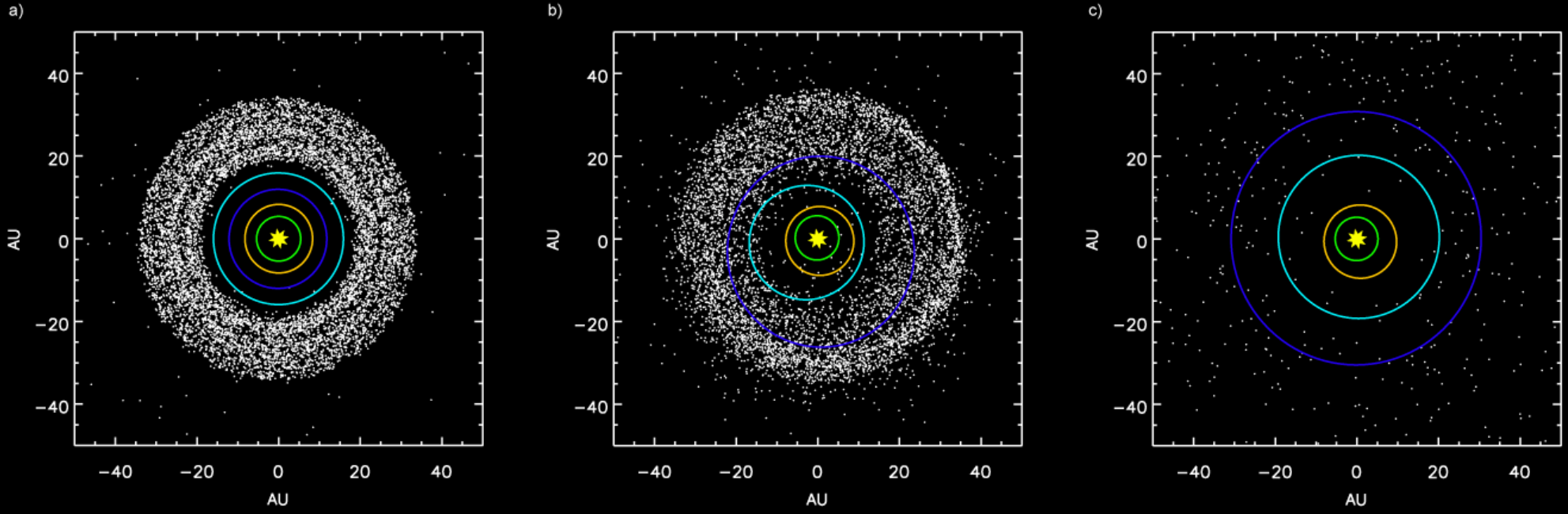
Cannot form inside the snow/frost line

Formed further out & migrated - planet-disk drag

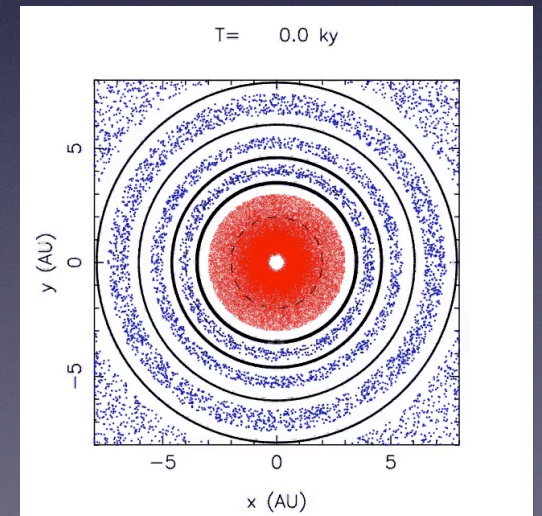


A nice “little” (8 MB) of one example,  
by Phil Armitage, U Colorado

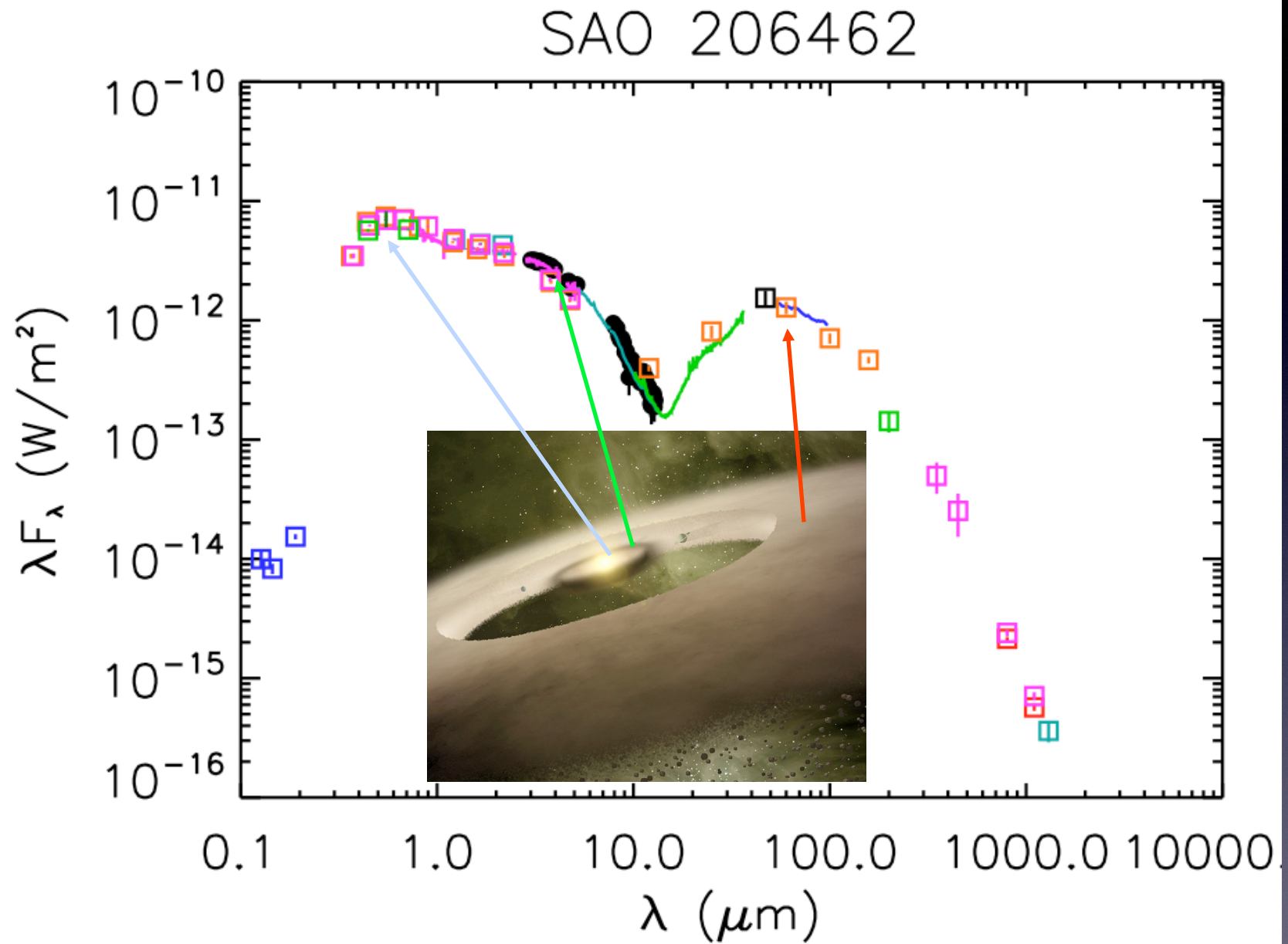
# Also, planetary migration



“Nice Model”  
“Grand Tack”



# “Pre-Transitional Disks”

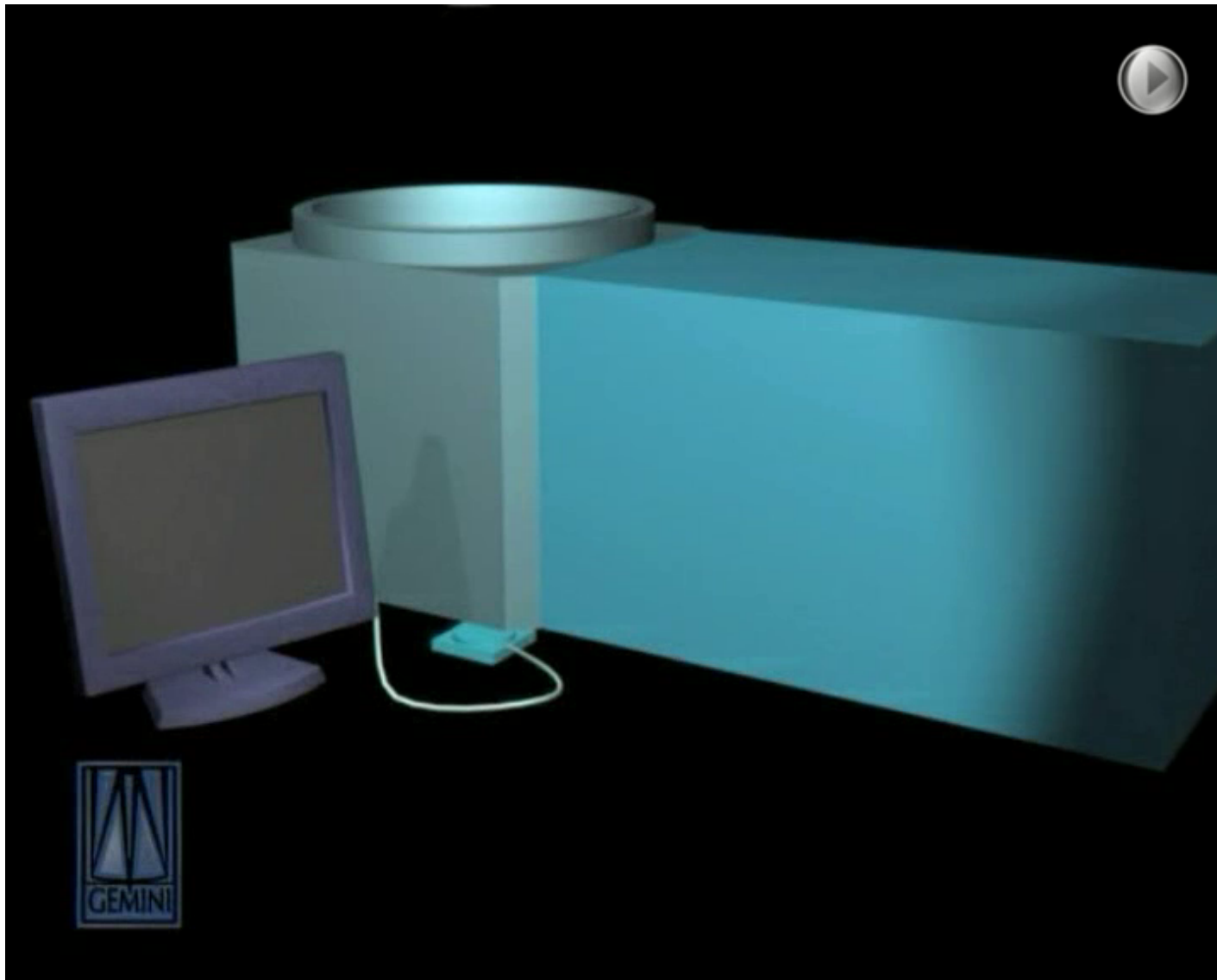


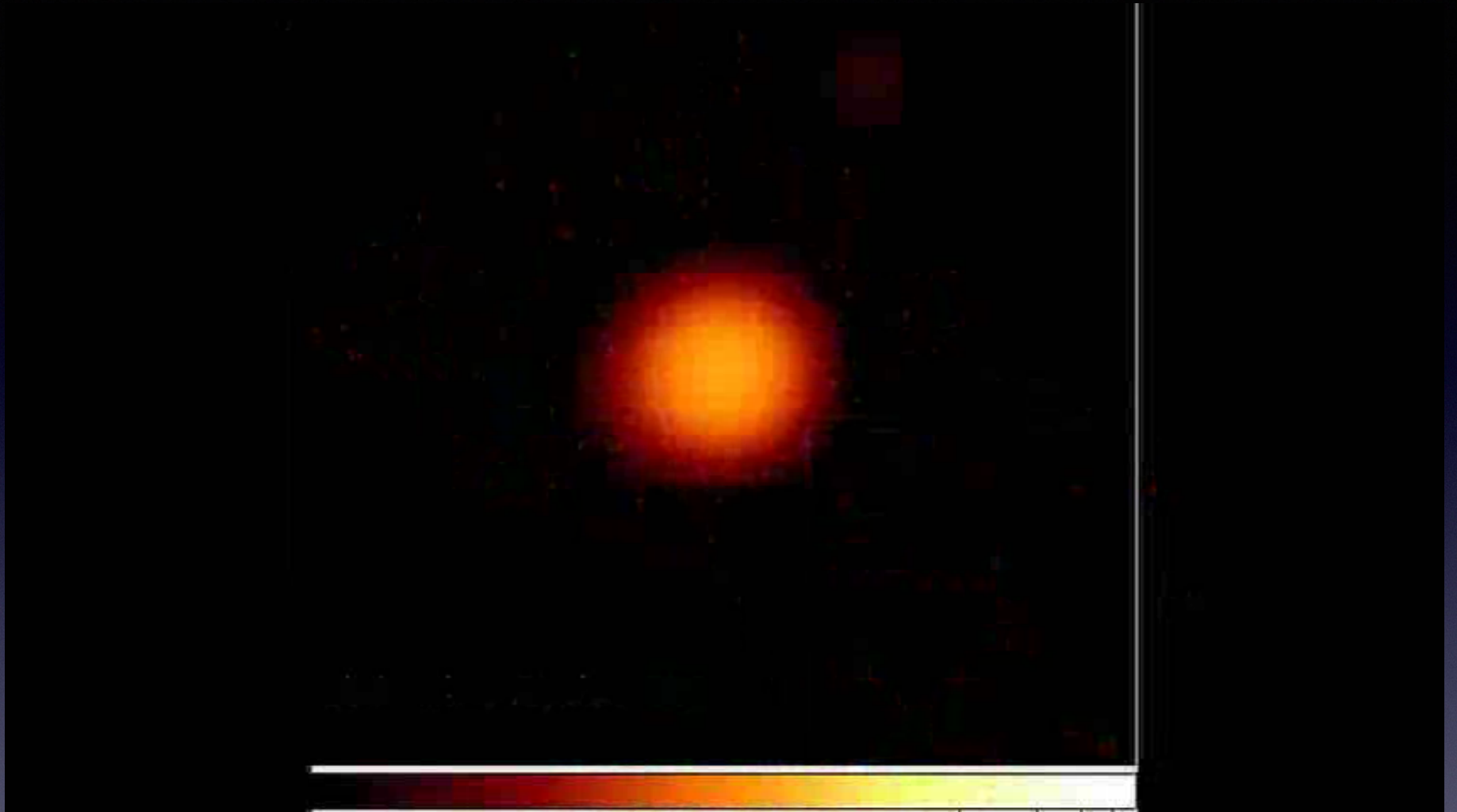
# High Angular Resolution Astrophysics:

- Direct Imaging
- Interferometry



# Adaptive Optics





In actual operation....

# Subaru High Contrast Instrumentation

Strategic  
Exploration of  
Exoplanets and  
Disks with  
Subaru

Subaru – 8.2 m telescope

AO 188

Classical Lyot Coronagraph

HiCIAO – NIR Science camera

Direct Imaging

Simultaneous Differential Imaging

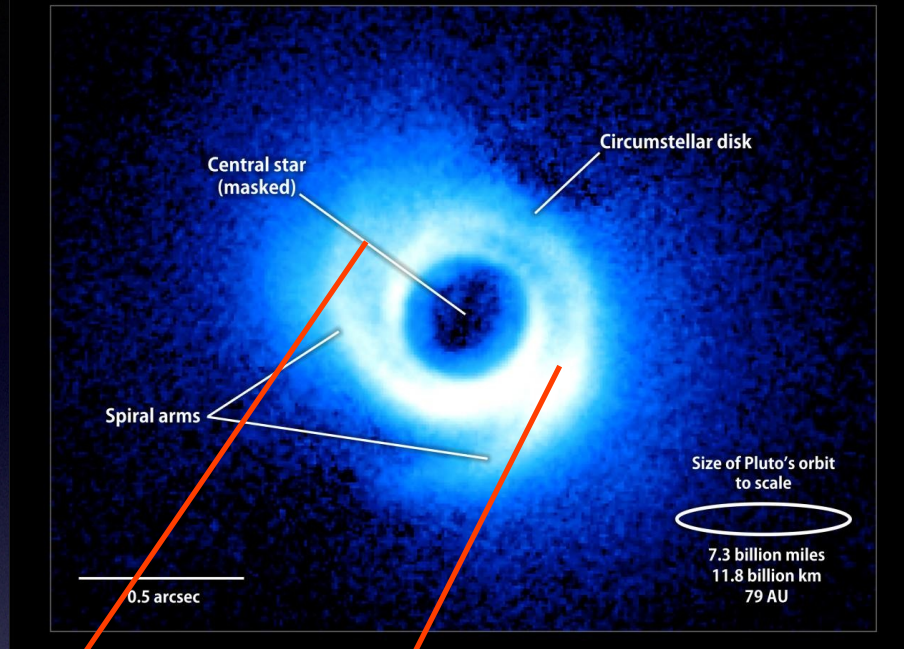
Polarization Differential Imaging

Modes can be combined

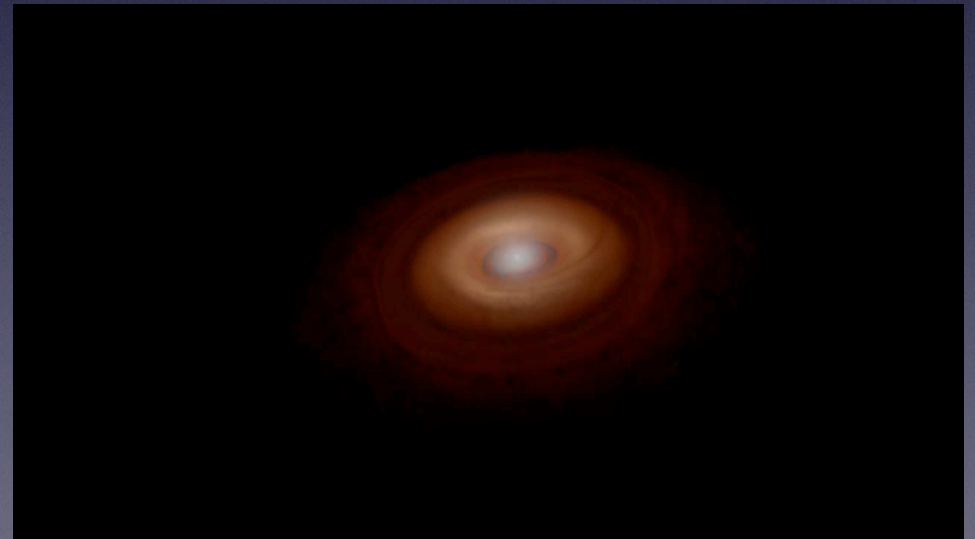


# SAO 206462

Spiral features revealed in SAO 206462's dust disk



from Muto et al.2012,  
ApJL, 748, L22



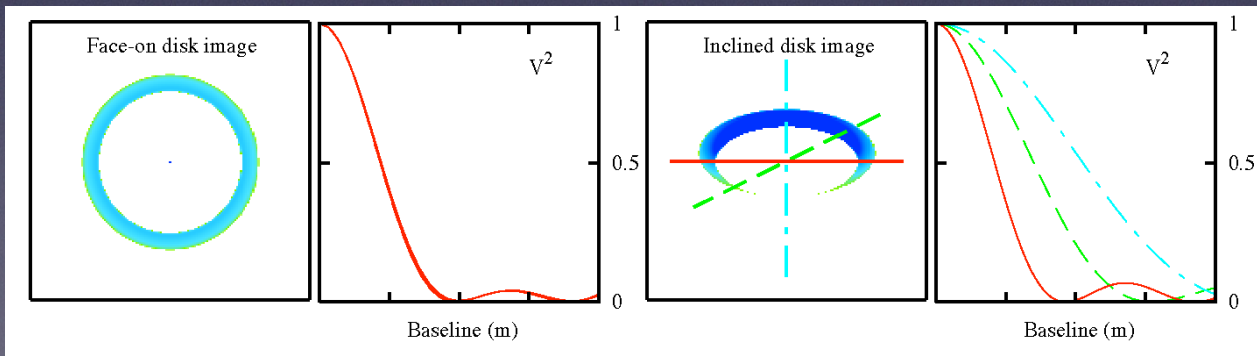
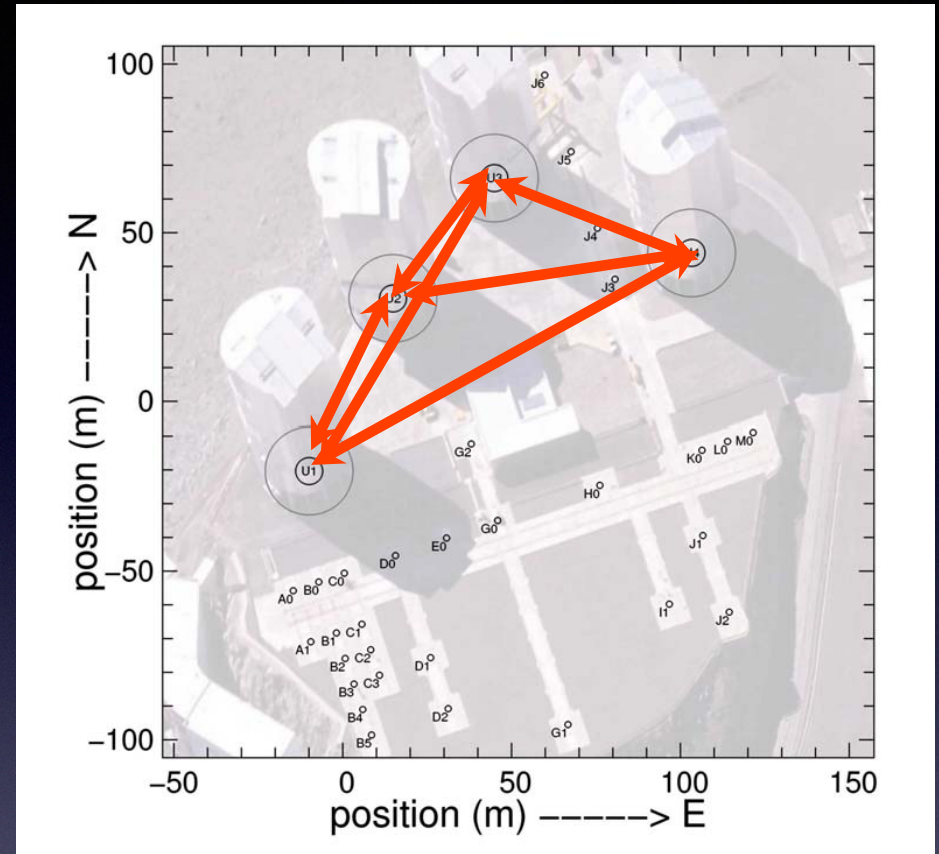
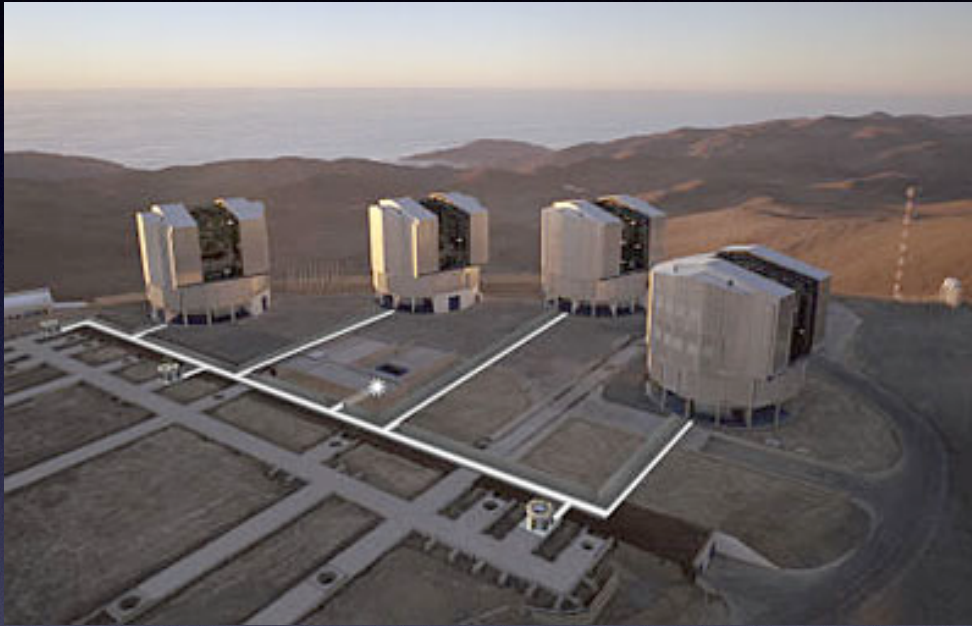
# This is what we see



# Inner Disk Structure from Interferometry

## Very Large Telescope Interferometer - VLTI

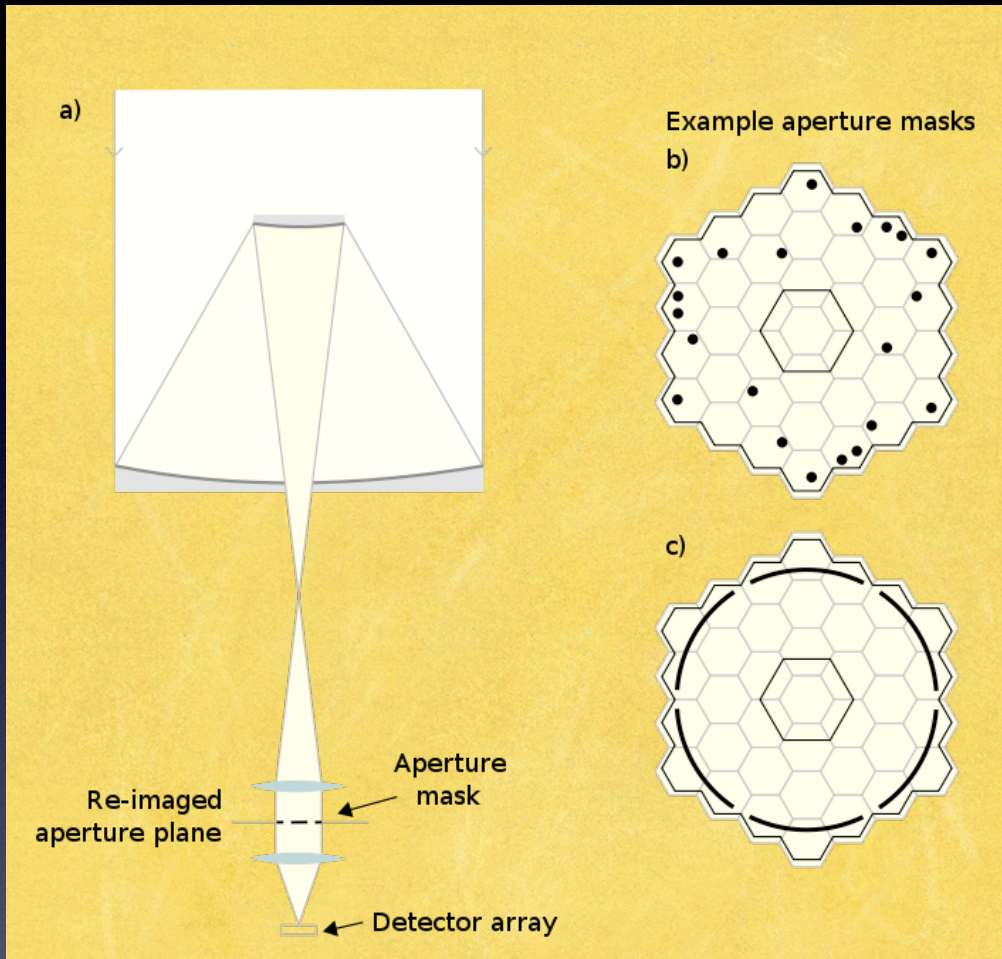
Largest baseline 130 m.



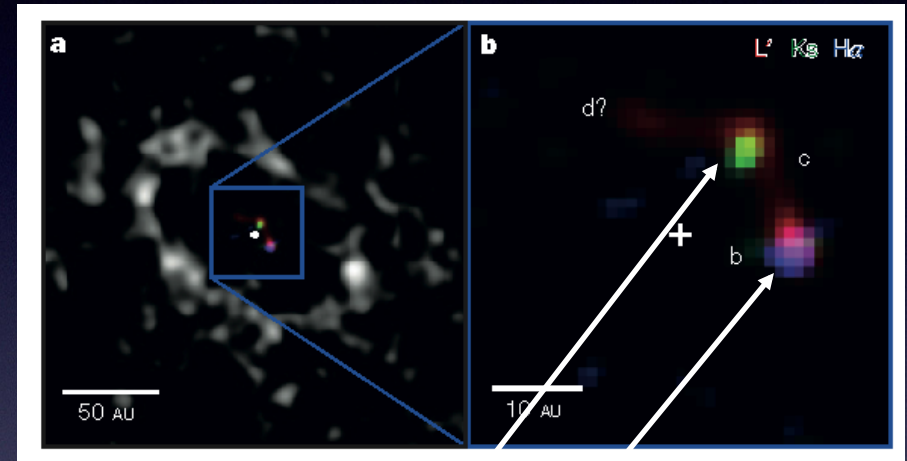
Spatial resolution  
- a few milli-arcsec

<http://www.youtube.com/watch?v=u5GzsdwdnVWM>

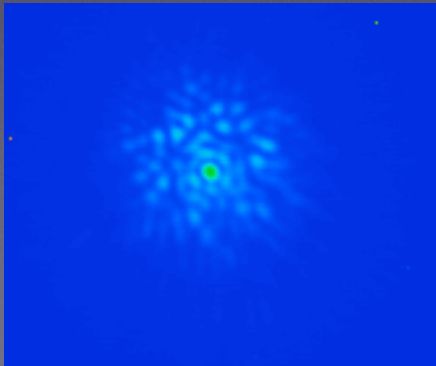
# Non-Redundant Sparse Aperture Mask Interferometry



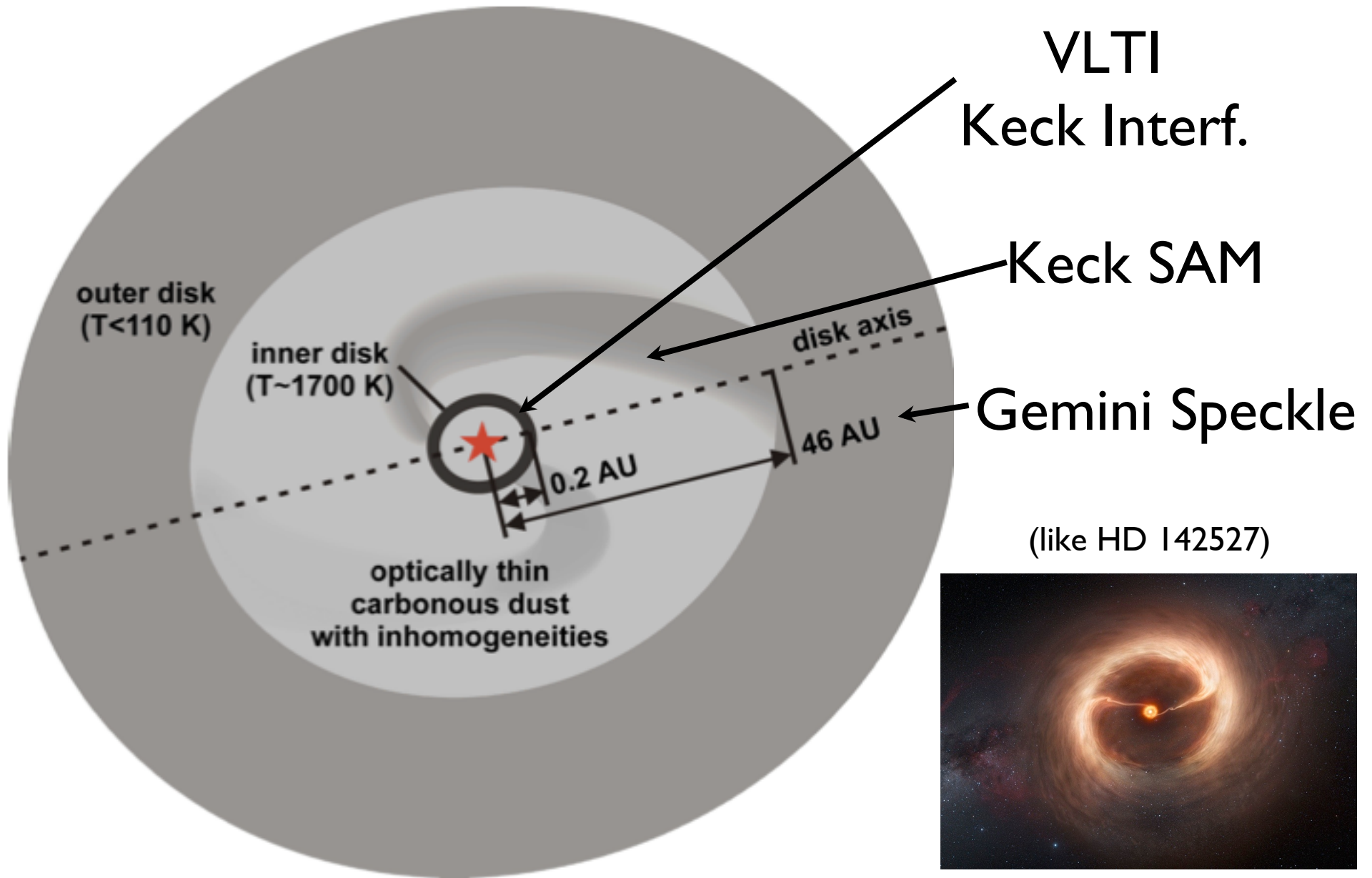
Sallum & Follette 2015



Protoplanets in a disk



# VI247 Ori, a Gapped Pre-Transitional Disk

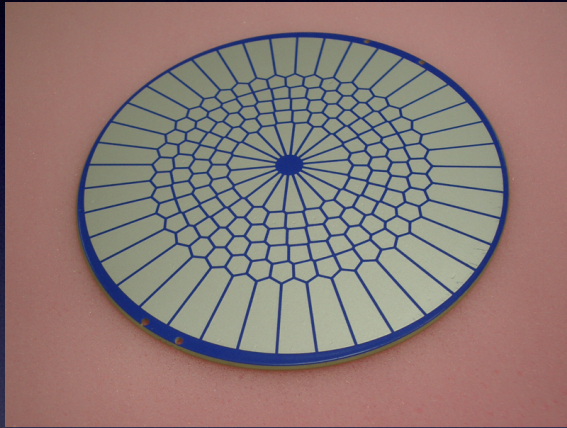


from Kraus et al. 2013, *ApJ*, 768, 80

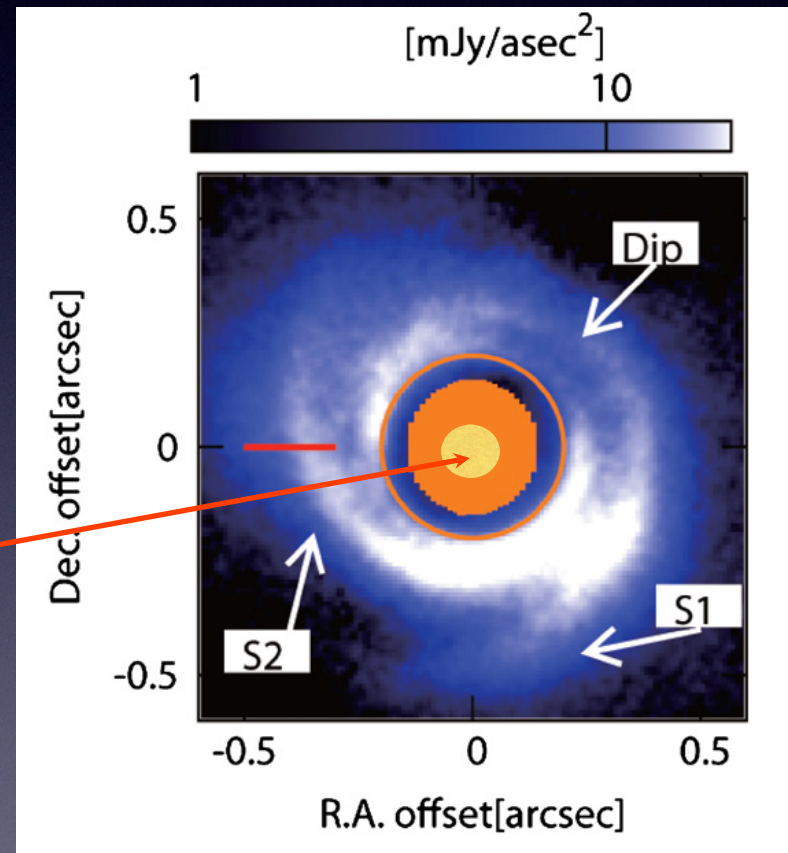


# The New Reality!

## “Extreme Adaptive Optics”

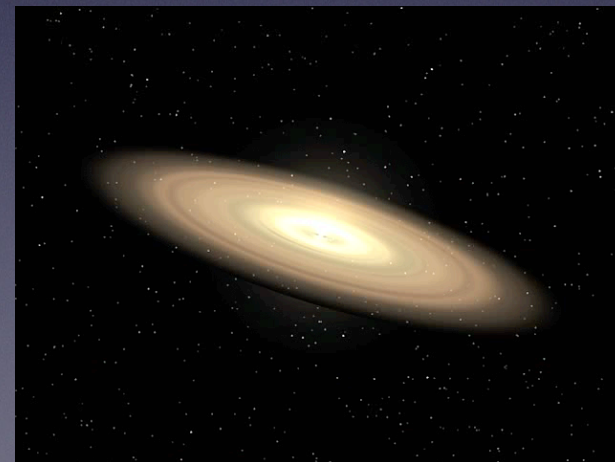
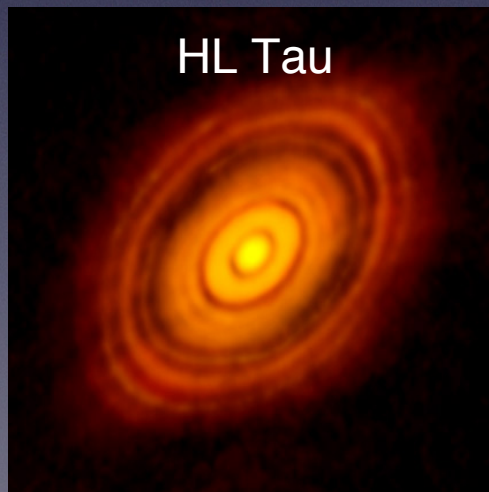


Subaru Telescope  
SCE<sub>x</sub>AO  
Apodized Spot



Also SPHERE (VLT), GPI (Gemini)

# Atacama Large Millimeter/submillimeter Array (ALMA)



# Large Binocular Telescope Mt. Graham, Arizona



Expected spatial resolution  $\sim 0.01$  arcsec