(The Formation of) Stars and Planets

AIP
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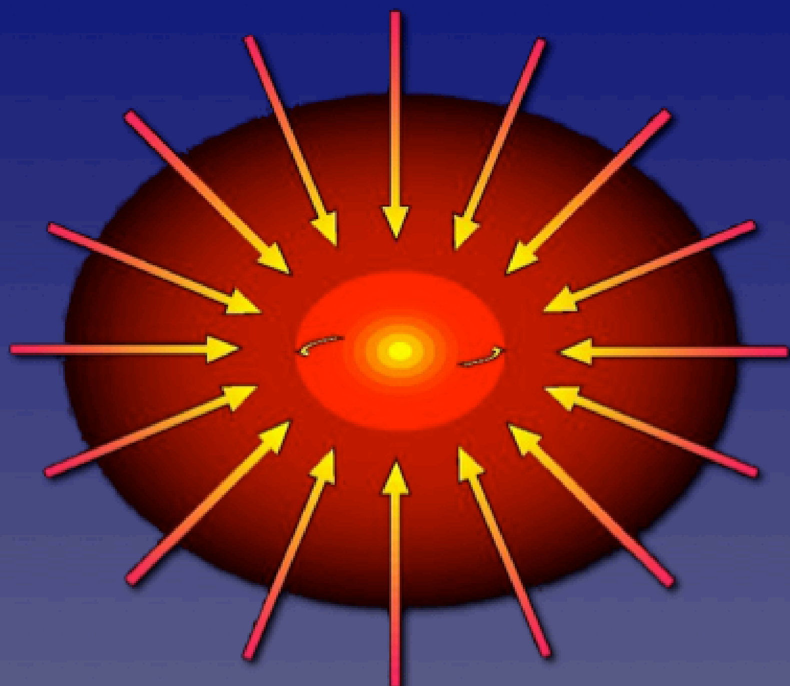
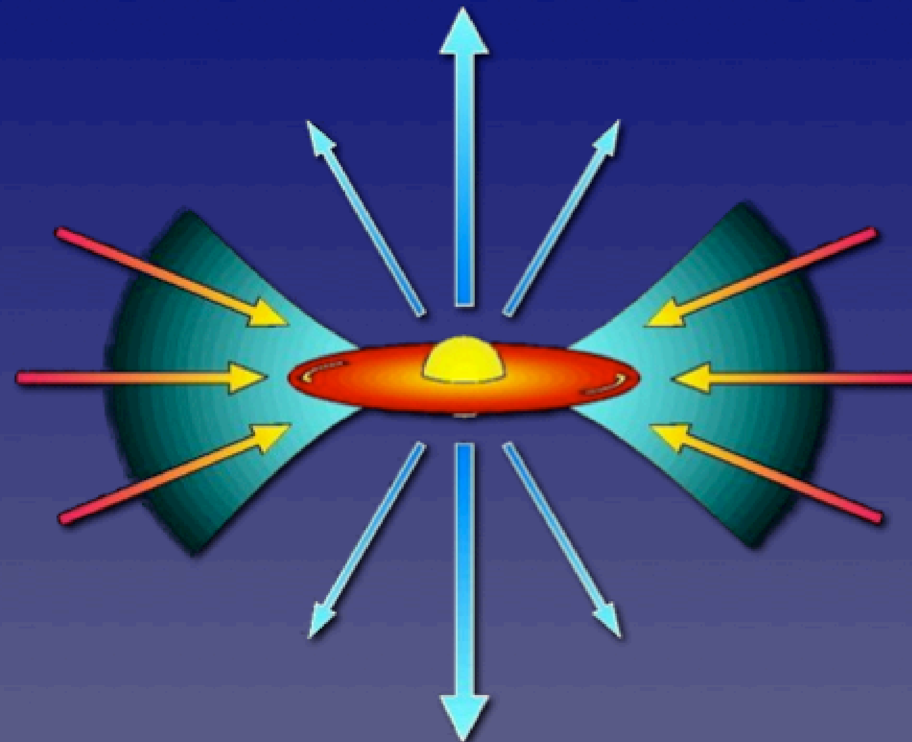
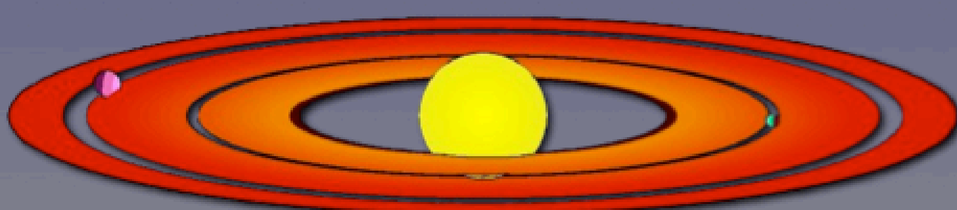
The isolated star formation paradigm



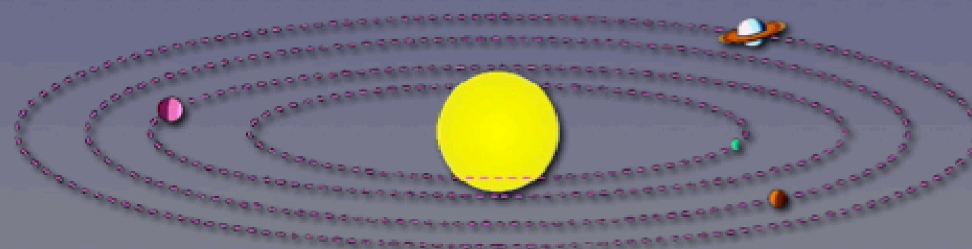
Class 0:
10^4 yrs; 10-10^4 AU; 10-300 K



Class I-II:
$10^{5\text{-}6}$ yrs; 1-1000 AU; 100-3000 K



Class II-III:
$10^{6\text{-}7}$ yrs; 1-100 AU; 100-5000 K



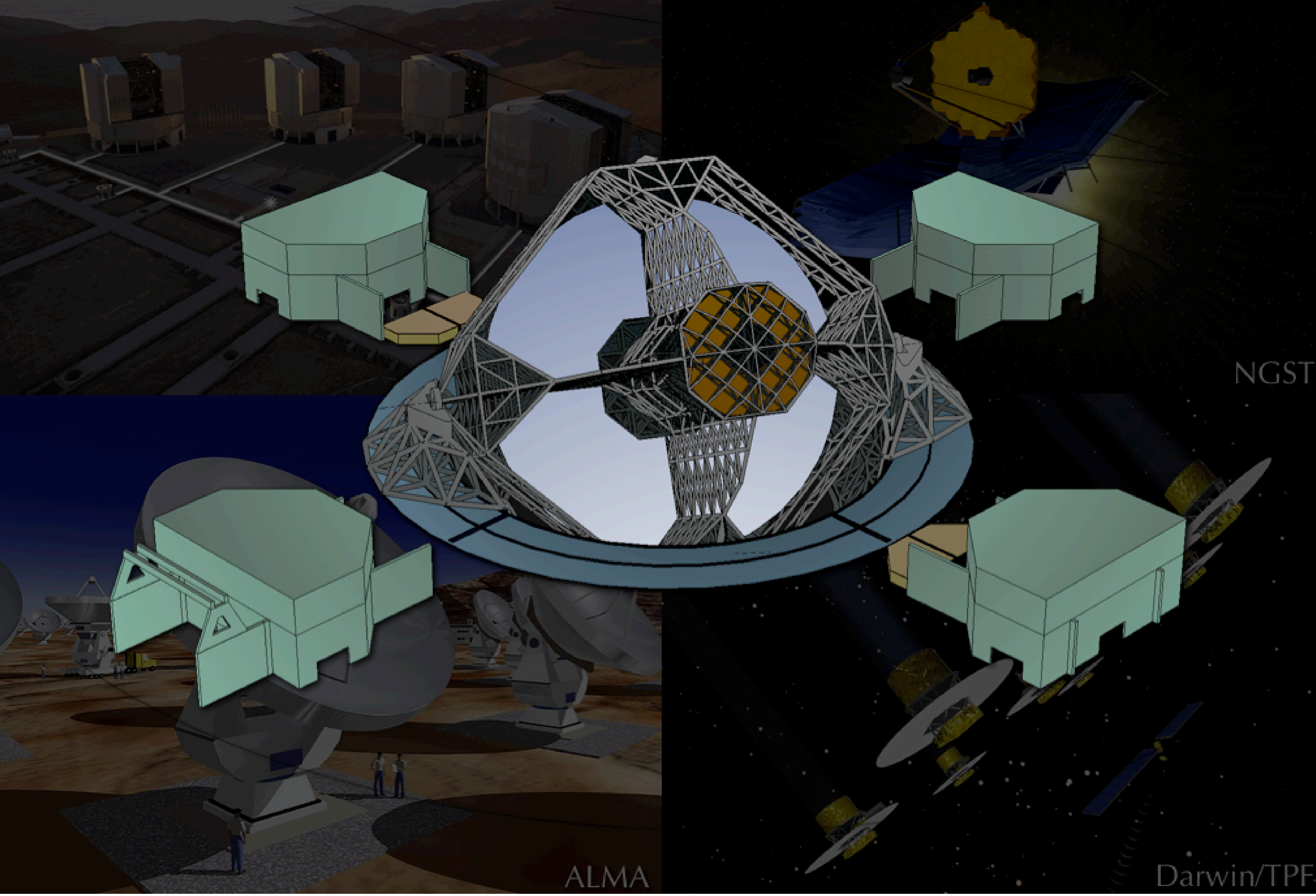
Class IV:
$10^{7\text{-}9}$ yrs; 1-100 AU; 100-5000 K

Often things are much messier

Visible: Hester et al. 1996, AJ / HST+WFPC-2

Infrared: McCaughrean & Andersen 2002, A&A / VLT+ISAAC

ELTs in the 2010-2020 context



ELTs: requirements, advantages, and caveats

- Should be excellent in near-IR and mid-IR
  - Crucial for star/planet formation and characterisation
- Large collecting area yields high sensitivity
  - For imaging and low-res spectroscopy, NGST is similar or better at 1-2μm and much better at 5-30μm
- Large telescope diameter yields high resolution
  - Order of magnitude better than VLT/NGST, similar to VLTI; requires extreme AO performance
- Single telescope yields filled *u,v*-plane imaging
  - Vital for complex sources, crowded regions
- MCAO yields wide field-of-view
  - Essential to boost AΩ product for surveys and clusters

Scaling relations for telescope sensitivity

Background limited case:

$$\frac{S}{N} \propto \frac{D}{\theta} \times \sqrt{\frac{\eta}{B}} \qquad \text{Speed} \propto \frac{D^2}{\theta^2} \times \frac{\eta}{B}$$

Detector limited case:

$$\frac{S}{N} \propto D^2 \times \eta \qquad \text{Speed} \propto D^4 \times \eta^2$$

- D Telescope diameter
- θ Delivered image size
- B Background
- η System throughput

After Matt Mountain (2003)

Some fiducial numbers

- Scale VLT at 2μm to 50 metre diameter telescope
- Seeing-limited case (300 mas FWHM):
  - Spatial resolution: 50AU at Taurus-Auriga; 150AU at Orion; 1500AU at inner galaxy; 15000AU at LMC
  - Sensitivity: 3σ, 1hr point source limit K_s=23.0
    Equivalent to 1M_{Jup} at 1Myr at Orion (500pc)
- AO case (10 mas FWHM, with 50% of point source flux in diffraction-limited core, 50% in halo):
  - Spatial resolution: 1.5AU at Taurus-Auriga; 5AU at Orion; 50AU at inner galaxy; 500AU at LMC
  - Sensitivity: 3σ, 1hr point source limit K_s=26.0
    Equivalent to 1M_{Jup} at 1Myr at M16 (2kpc)

ELT "killer apps" for exoplanet research?

- Direct imaging of exoplanetary systems
  - Around single stars or binaries; in habitable zones; hot planets around young stars; terrestrial planets with 100m?
- Spectroscopy of exoplanets
  - Chemistry; weather; rotation; biogenic tracers; extend RV surveys over much greater volumes, ages, environments
- Exoplanets in unusual places
  - Population II stars (clue to formation mechanism); white dwarfs (survivors of stellar evolution); free-floating objects (microlensed true planets and/or sub brown dwarfs)
- Planets in the making: circumstellar disks
  - Gaps; timescale for gas dissipation; dust agglomeration; ice processing; location of giant planet formation

ELT "killer apps" in star formation?

- Cores and protostars
  - Extinction mapping to arcsec scales; structure, chemistry, kinematics of cores; tracing infall
- Jets and outflows
  - Delineating jet formation zone; detailed time-lapse studies of time-variable outflow and interaction with medium
- Stellar/substellar IMF and the impact of environment
  - Trace IMF across Milky Way (to $1M_{Jup}$ at Orion; HBL everywhere); LMC; nearby galaxies; confusion-limited
- Formation and impact of massive stars
  - Through disks or collisions?; effects of wind-wind, wind-cloud, wind-ISM, ionising interactions

Other "local" ELT "killer apps"?

- High spatial resolution studies of planets, moons, asteroids, KBOs/TNOs, and comets
  - Imaging the solar system (10km at Mars, 75km at Saturn, >300km at Pluto); surface and atmospheric changes: weather, vulcanism, atmospheric freeze-out; D/H ratio and mix of ice species for TNOs
- Mass function of black holes and neutron stars
  - Radial velocity curves for BH/disk and companion
- Physics of neutron stars
  - Visible light variability; millisec resolution at V=26
- Follow-up microlensing sources
  - Cold white dwarfs; brown dwarfs

The keys to an effective ELT science case

- For a general-purpose observatory, must identify vital, complementary role in major themes
  - E.g. "Origins" theme driving NGST and ALMA; search for terrestrial planets driving Eddington, Kepler, Darwin, TPF
- Must identify "killer applications" that use unique combination of ELT capabilities
  - Deep, high spatial near/mid-IR resolution imaging of complex regions; medium- to high-resolution spectroscopy of extremely faint sources, with either MOS or IFU
- Conversely, must identify lower limit to capabilities (e.g. aperture) which can deliver the "killer apps"
- Reasonable upper limit for large projects (1Msec?)