

EXPLORATION OF ACTIVE PRIMORDIAL BODIES

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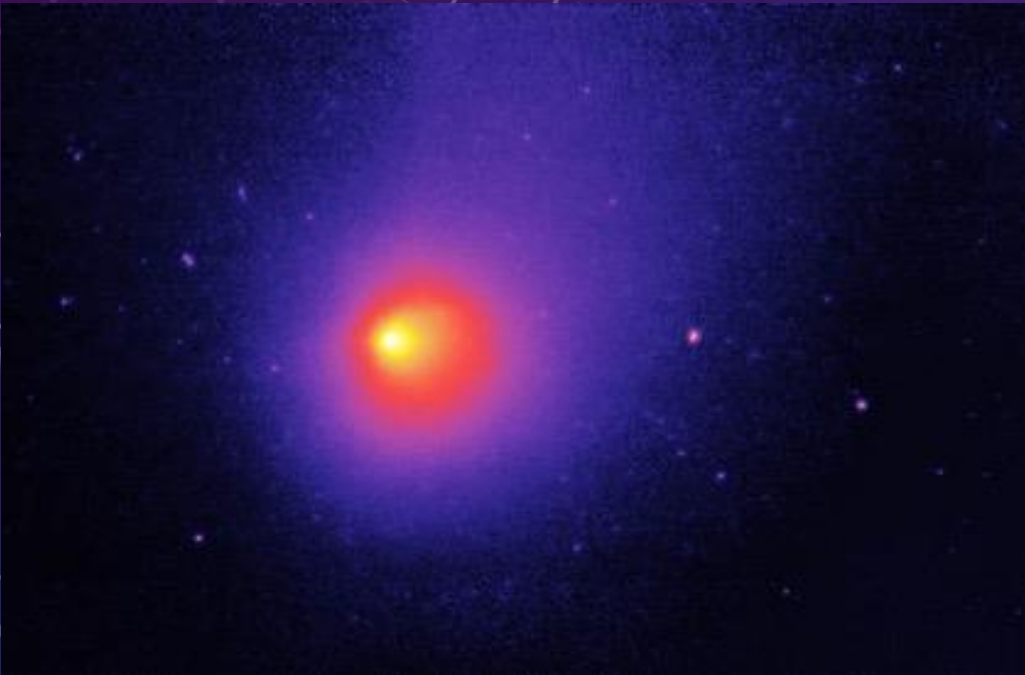
WHAT IS AN ACTIVE PRIMORDIAL BODY?

Properties

- Icy small bodies active at $R_h > 5\text{AU}$
- No significant exposure to the inner solar system

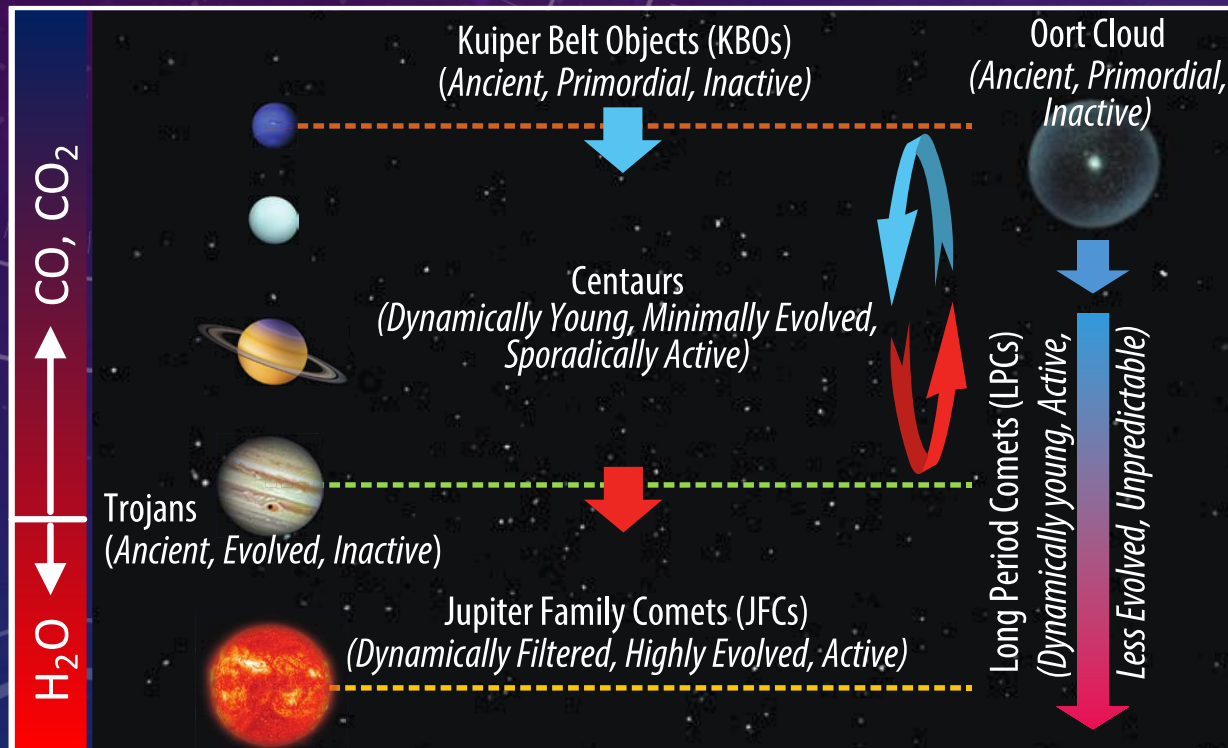
Examples

- Active Centaurs
- LPCs with $q > 5\text{AU}$
- Dynamically New LPCs



29P/Schwassmann-Wachmann 1

WHY DO THEY MATTER?



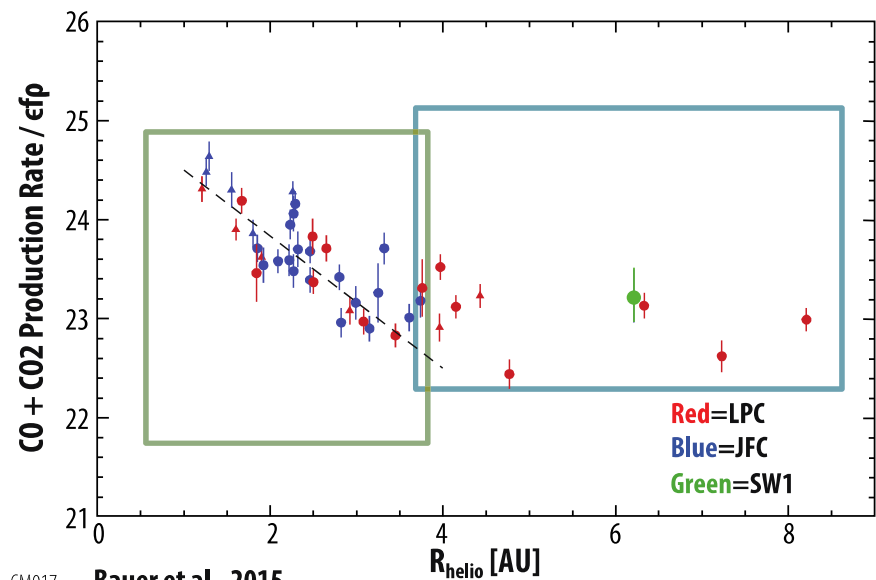
Activity

- Not driven by water sublimation
- Source mechanism(s) not understood

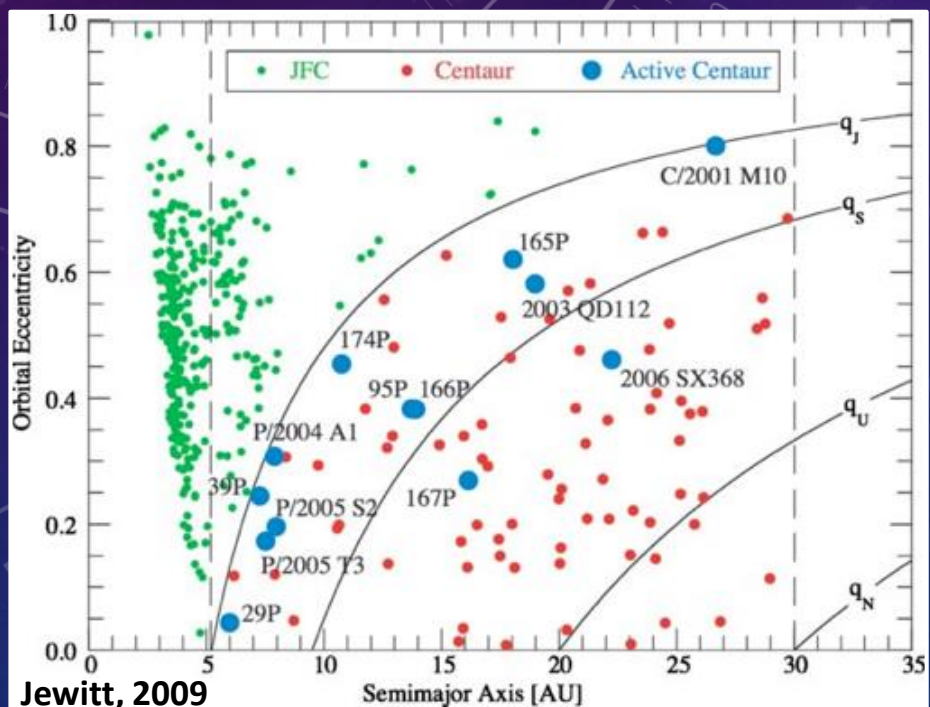
Physical State

- Minimal physical evolution
- (Centraurs) Parent population of the JFCs

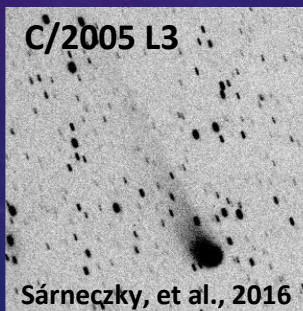
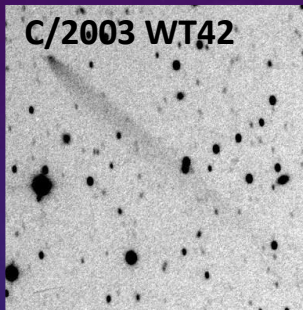
ACTIVITY PATTERNS



CM017 Bauer et al., 2015



Jewitt, 2009

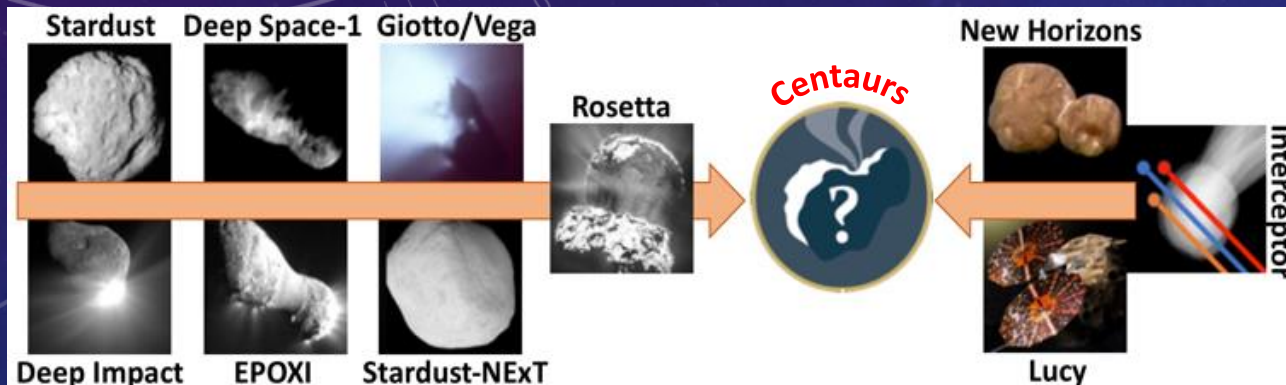
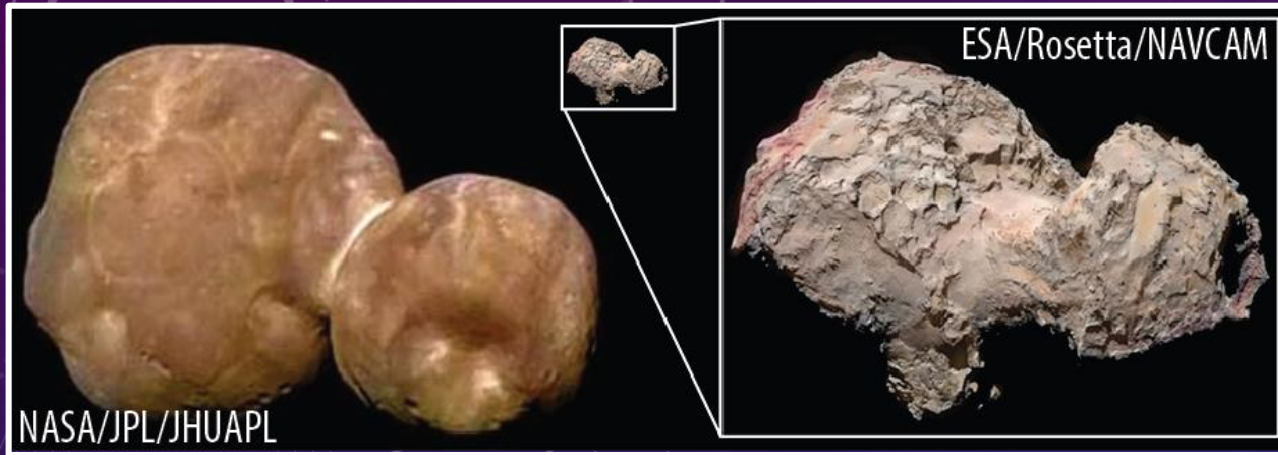


Sárneczky, et al., 2016

- Direct gas production detected for only a few objects
- ~20% of Centaurs active w/perihelion dependence
- LPCs do not display consistent behavior with R_H
- Suspected Sources of CO, CO₂ and CH₄ are hyper-volatile
- Outbursts do not track with R_H (Amorphous Ice?)

PHYSICAL EVOLUTION

- Water sublimation rapidly erodes objects within the JFC region
- Evolutionary signature of outer solar system activity is unknown
- Active Centaurs are physically intermediate between TNOs and JFCs
- APBs offer physical connection between mission targets

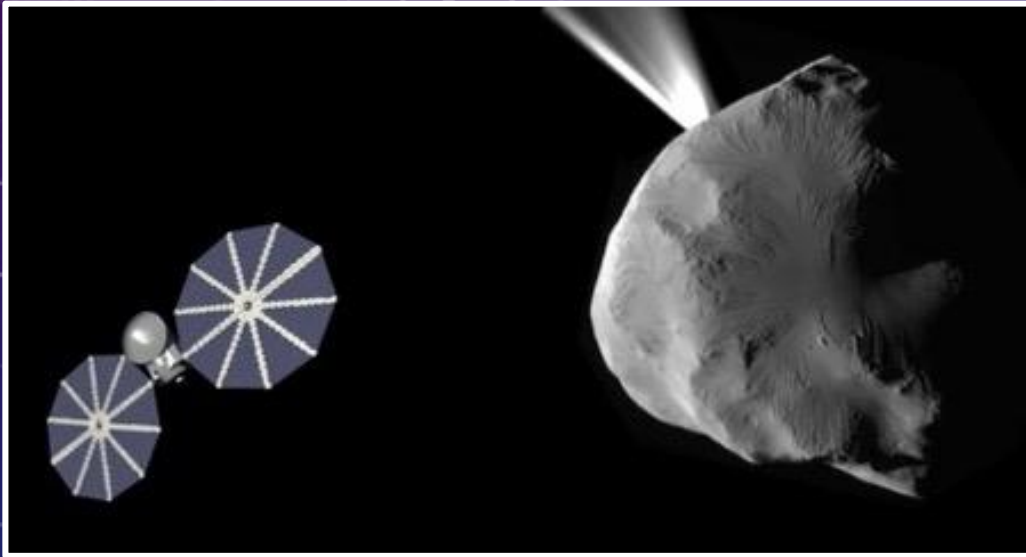


A DECADE OF DISCOVERY

Much has been learned since the last survey

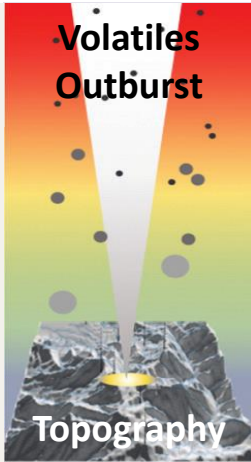
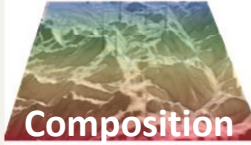
- The majority of ABPs have been identified since 2010 (now over 200)
- The patterns of heliocentric activity dependence of APBs are being revealed
- Ring systems have been discovered around Centaurs (Chiron, Chariklo)
- We have orbited a JFC *and* flown by a progenitor TNO
- An orbital resonance linking Centaurs to JFCs has been identified

AN EXPLORATION IMPERATIVE

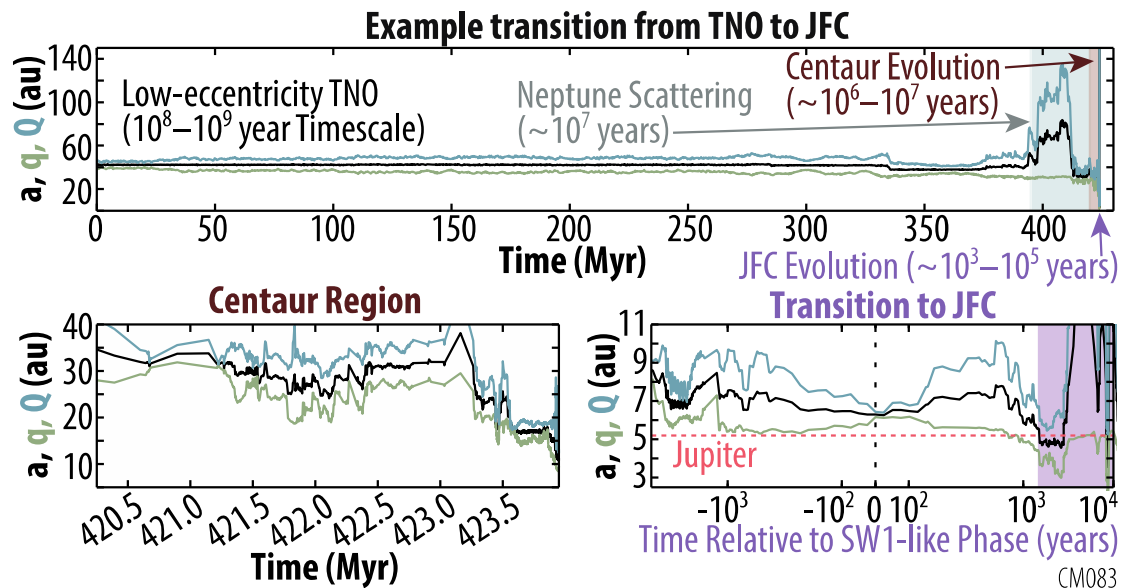


- Active primordial bodies are the keys to many locks
- They connect previous and future mission targets
- They are the most pristine objects accessible to spacecraft
- They provide sampling of volatiles
- They are an evolutionary bridge
- *The most scientifically valuable targets are accessible now.*

AN EXPLORATION IMPERATIVE

Question:	Goal:	Exploration Objective:	
What physical mechanisms drive activity and evolution of ice-rich planetesimals beyond 5 au?	Understand how presolar processes are recorded in the materials of primitive bodies	Measure the relative composition and isotopic signature of escaping volatiles	 Volatiles Outburst Topography
		Map the distribution, local environment and energy balance of active regions on APB surfaces	
	Probe accretion and formative processes in the solar nebula	Identify the features and morphology of real-time physical modification of APB nuclei	 Composition
		Investigate early stage evolutionary processes associated with Centaur transition through the gateway region	
	Determine the effect and timing of secondary processes on the evolution of primitive bodies	Explore the mechanisms, compositional distinctiveness, and energetics of outbursts	 Temperature Interior
		Probe the interior structures of the near-subsurface and deep interior of APBs	
		Compare the activity patterns and evolution of APBs in different dynamical classes	

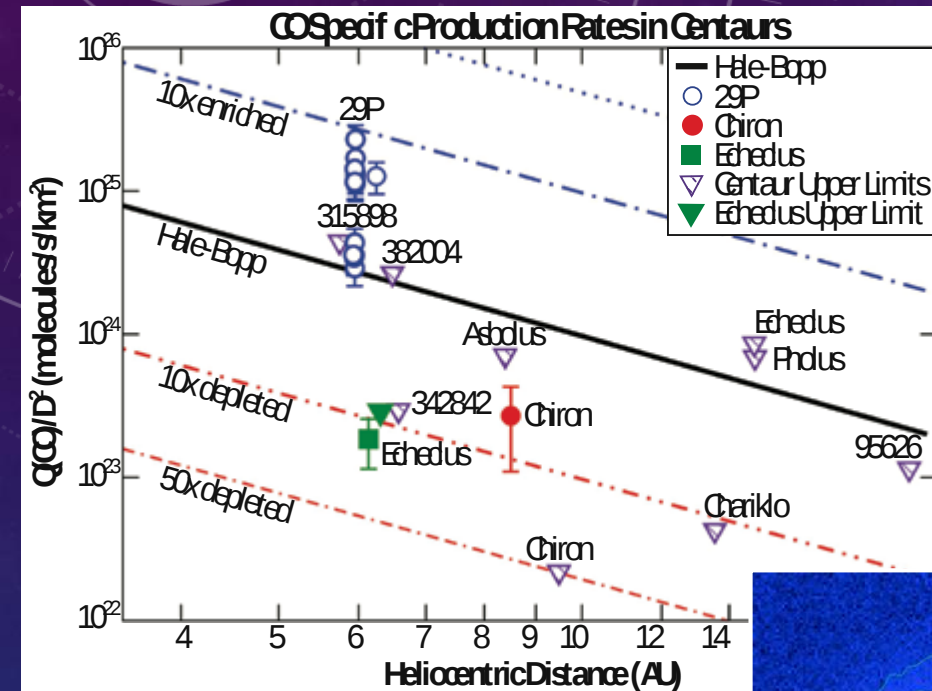
THE ORBITAL GATEWAY



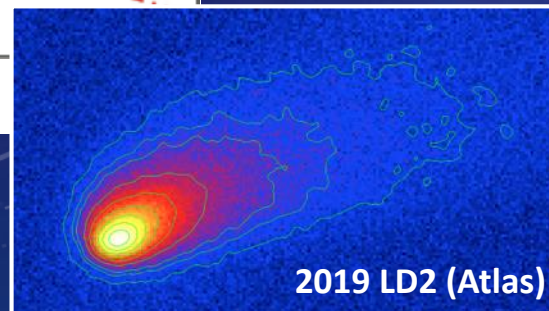
- The Active Centaurs are the most accessible of the APBs
- Sarid et al. (2019) Reported the on and orbital resonance through which 70% of future JFCs pass
- ‘Gateway’ APBs are embryonic comets

THE PRIME CANDIDATES

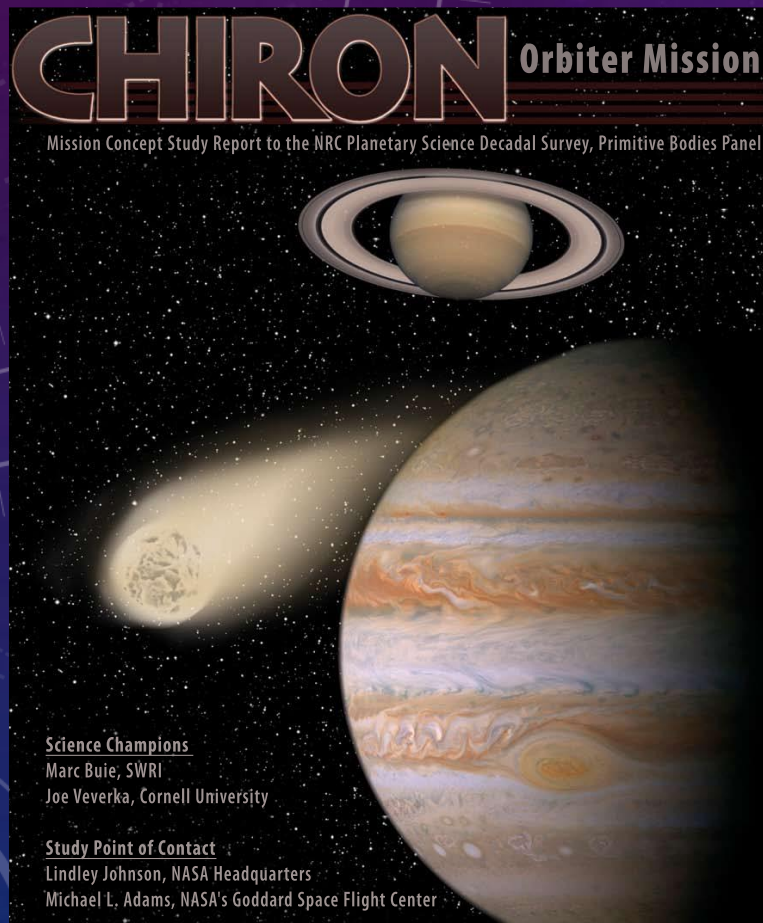
- There are 3 outbursting ABPs where CO production has been detected
- One candidate has a 'ring' system
- A recently discovered object is in *current transition to the JFCs*
- All are accessible with missions in the Discovery/New Frontiers class



Wierzos, Womack, & Sarid, 2017

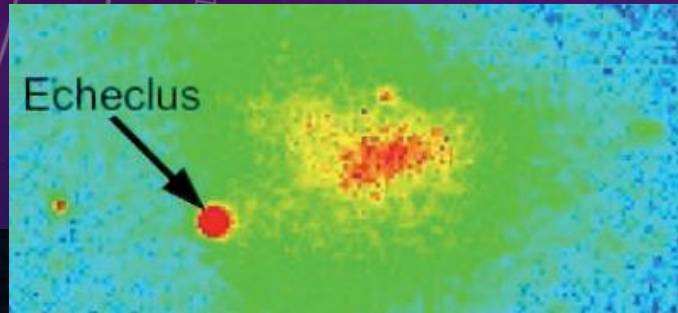


95P/CHIRON

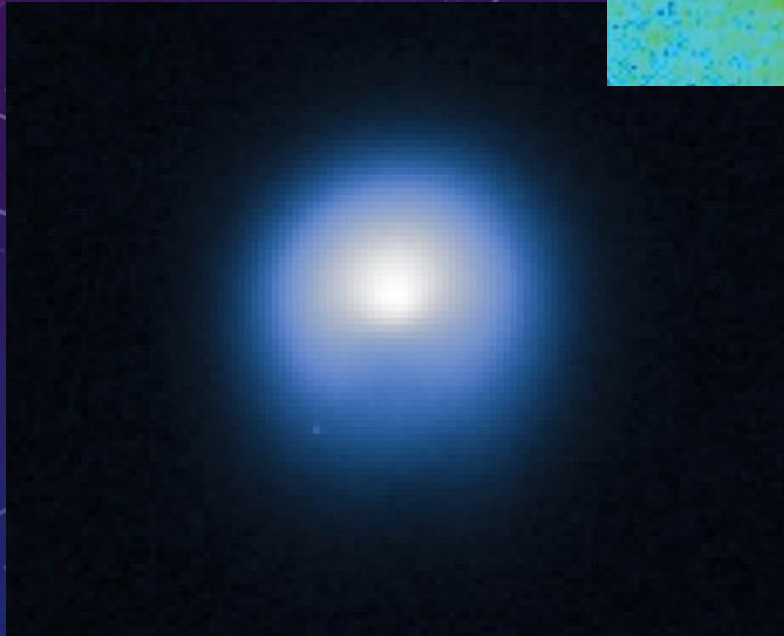


- Chiron was the first object identified with the Centaur group
- It is the largest of the candidate objects
- It has a ring/shroud of debris
- Is consistently active further than any where CO is measured
- It has experienced outbursts in the past
- Study of an orbital mission in 2013 survey-New Frontiers option

174P/Echeclus



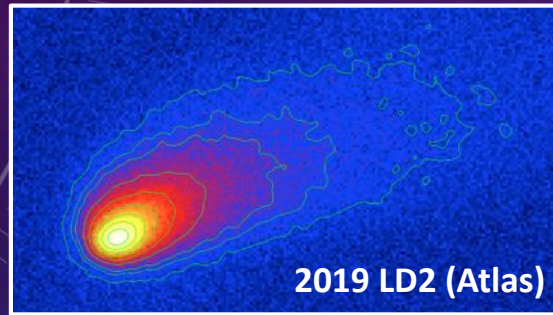
Rousselot, 2008



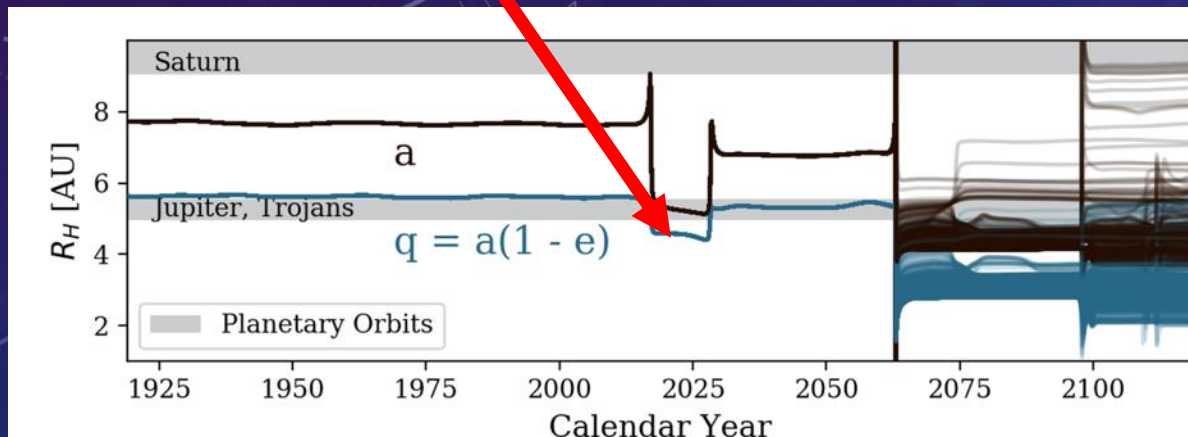
Kareta, 2020

- Experiences periodic large outbursts
- Major outburst in 2005 produced a separate object
- Quiescently active near perihelion
- Most eccentric orbit of the best candidates
- Chiron orbiter study compared accessibility. An Echeclus orbiter is a stretch for New Frontiers.

2019 LD2 (ATLAS)



Current orbit



Kareta et al., 2020

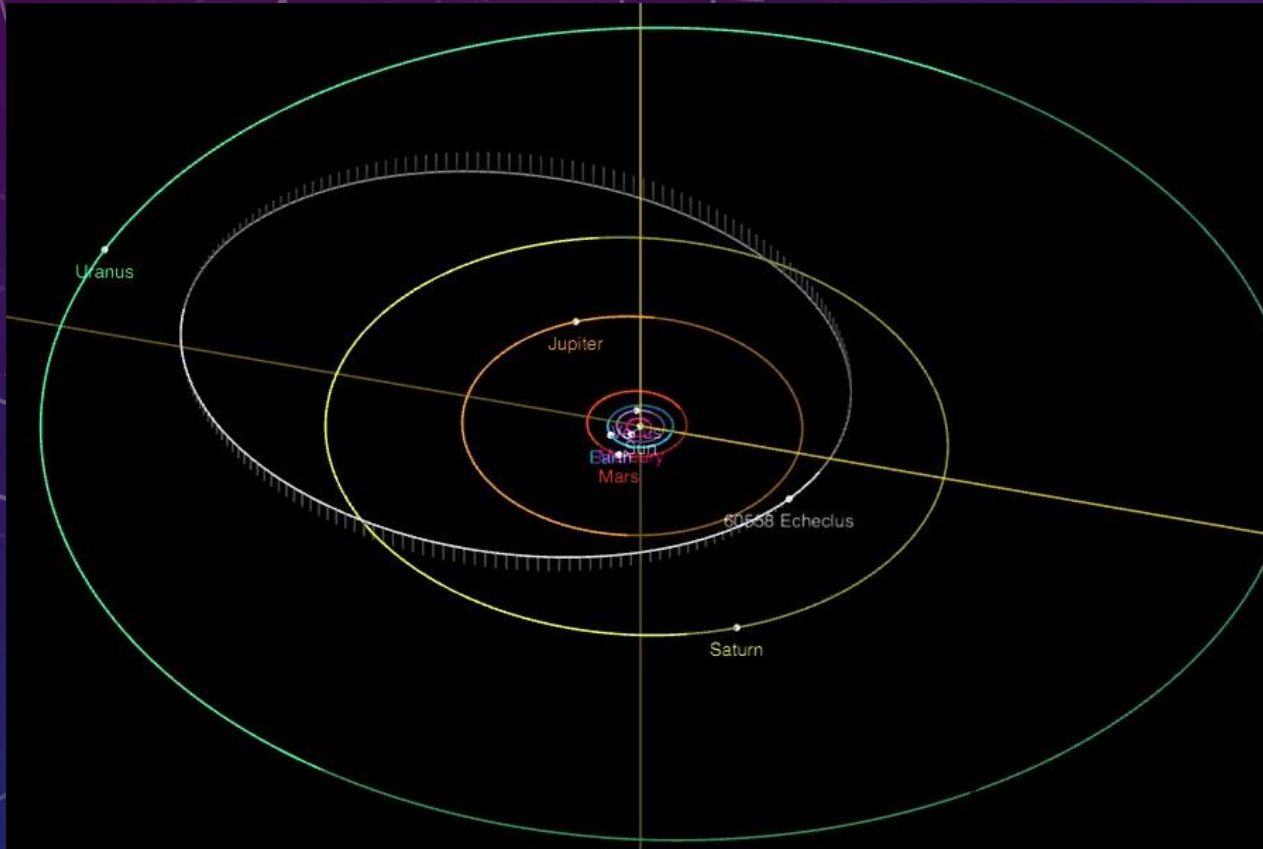
- Recent APB discovery
- Near co-orbital with Jupiter
- Rapidly developing orbit: Jupiter encounters in 2027 and 2063
- >90% chance of entering JFC population (~40% $q < 3$ AU)
- Ideal candidate for study of transition
- Activity patterns not well studied
- Possible sample return option

29P/SCHWASSMANN-WACHMANN 1



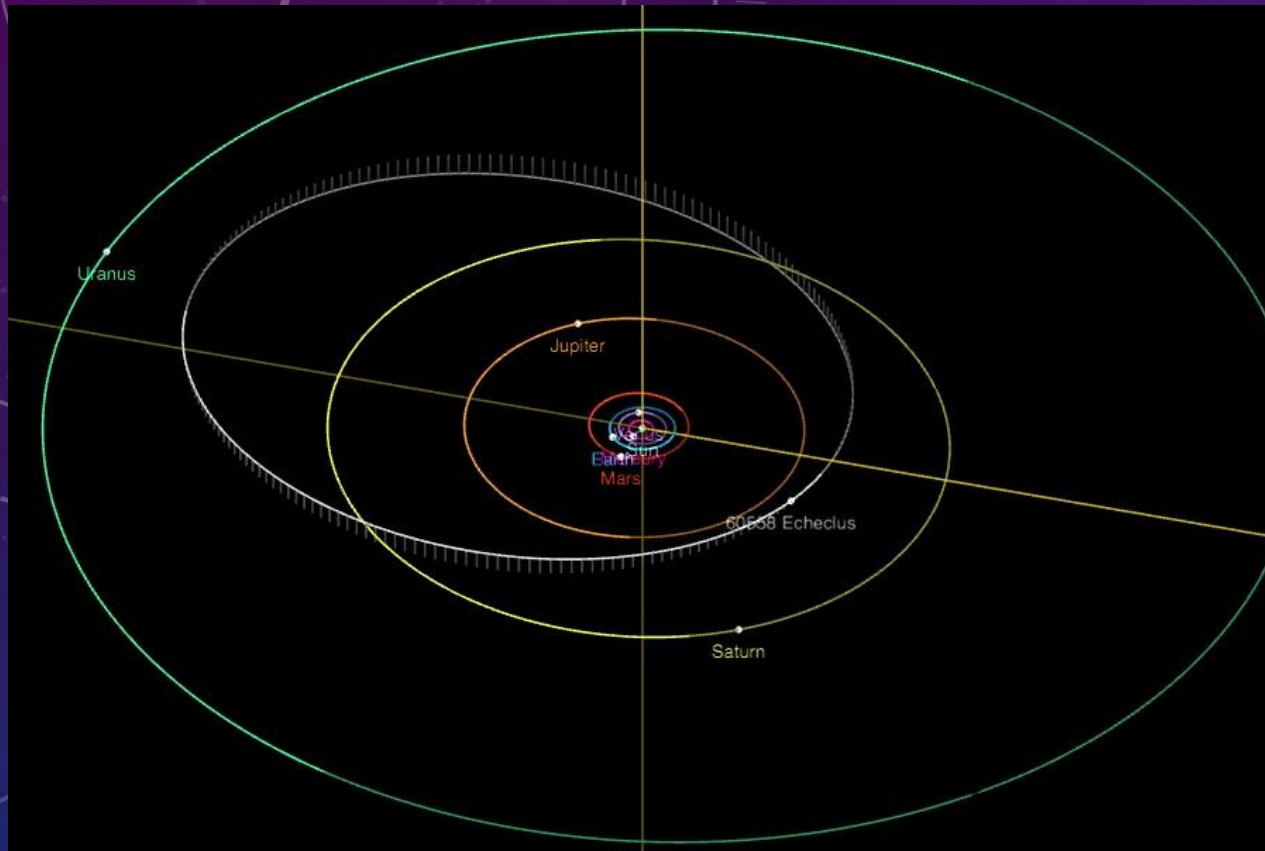
- First active object discovered with an orbit beyond Jupiter (1927)
- Continuously active for 90+ years
- Highest CO production of any Centaur
- Experiences ~7 outbursts per year
- Low eccentricity/inclination orbit
- Gateway orbit resident with 70% likelihood of becoming a JFC

MISSION CHALLENGES



- Orbital encounters are require assist or advanced propulsion
- Orbital periods and assist phasing opportunities are widely spaced
- Debris clearing from active bodies is slow-Dangerous for a flyby
- Potential for sporadic activity makes orbit preferable
- Cruise phases are *long* (>10 yr) for orbital encounters

TIME IS OF THE ESSENCE



- The best candidates are near most favorable mission configuration
- 29P and 2019 LD2 are phased with Jupiter for assist in the late 2030s
- Chiron and Echeclus orbit within Saturn in the 2040s through 2050s
- If these opportunities are missed, 29P, Echeclus, and Chiron are not available until after 2100.
- 2019 LD2 becomes a JFC in 2063

THE WINDOW IS ALREADY OPEN



- Two mission concepts were proposed (to 29P and Chiron) in the 2019 Discovery call...*however*
- The Discovery window closes soon
- Proposal through launch adds 10-20 years to cruise phase
- New Frontiers concept development must begin in the next 2 rounds